MONASH University

The Universe is My Laboratory

Christopher Henschke

Master of Arts

This document is submitted in partial fulfilment of Doctorate of Philosophy at Monash University in 2017

Faculty of Art Design & Architecture

Department of Design

Abstract

This exegesis documents research and studio practice that conceptually and materially investigates the relationships between contemporary art and experimental particle physics. This practice-based research focuses upon my cross-disciplinary collaborations with particle physicists working at the European Organisation for Nuclear Physics (CERN) undertaken between 2013 and 2016 as part of the art@CMS collaboration program at CERN. The studio research led to the production and exhibition of a series of artworks that demonstrate critical and exploratory engagement with the philosophical, epistemological, and material aspects of particle physics, and collaboration with the physicists and the apparatuses used in their research.

The theoretical and philosophical aspects and implications of quantum physics, and how this relates to experimental particle physics, will be presented. Issues arising between theory and experimentation – in terms of observation, measurement and interpretation – are discussed, along with resultant philosophical and ontological insights and implications. This inquiry into the philosophy of particle physics has been framed largely through the epistemology of quantum physicist Niels Bohr. Based on Bohr's insights, I present an analysis of the phenomena of entanglement, as an intersection between physics and philosophy. Complementing these investigations, I examine how other twentieth century and contemporary artists, ranging from Marcel Duchamp and Robert Rauschenberg to Joan Brassil and Ryoji Ikeda, have worked with science and technology. I critique aspects of cross-disciplinary practices and art–science residency programs, regarding the forms and durations of such programs and how this influences the artworks produced.

Based upon my research practice, I argue that I have been able to gain an understanding of conceptual and material parameters of experimental physics. Through collaboration with particle physicists at their research laboratories, I have produced six main art projects that engage with particle physics experiments, in order to explore our relationships with fundamental aspects of physical reality. Three of these projects incorporate digital audio and visual media, and data from physics experiments: *Edge of the Observable*, *Nature of the Apparatus*, and *Song of the Muons*. The other three are sculptural and installation projects which use particle physics apparatuses, including in situ works at CERN: *Potential Objects*, *Activated Objects*, and *Song of the Phenomena*. I argue that my collaboration has led to an in-depth engagement with particle physics; through which I have found shared traits between art practice and high-energy physics, namely that they are both experimental material cultures. Through my interactions with both physicists and apparatuses, I have produced artworks which are interdisciplinary epistemic things, and which express the material agency of subatomic phenomena as a form of entity realism. I argue that these works manifest and question the limits of, and relationships between, art, science, and the subatomic and macroscopic universe.

Declaration of originality

This thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

[redacted]

Christopher Henschke
August 2017

Acknowledgements

I would like to express my thanks and gratitude to my supervisors, Vince Dziekan, Mark Guglielmetti, and Mark Boland. I would also like to thank Michael Hoch and Wolfgang Adam from the Compact Muon Solenoid experiment at CERN, and Mick Storr for connecting me with CMS, and express my appreciation for being involved in the "art@CMS" collaboration program. This inspiring and compelling experience provided me with many key aspects of my research and practice. I also greatly thank my parents Jurgen and Pamela, and my brother Dr Adam Henschke, as well as my friends. Most of all I would like to thank Donna Kendrigan, whose love and essential support gave me the energy with which to undertake and complete this candidature.

Dr Campbell Aitken of Express Editing Writing and Research provided professional editing services in accordance with the Institute of Professional Editors' *Guidelines for editing research theses*. Dr Ashley Crawford also assisted with editing, which was much appreciated.

This research was supported by an Australian Government Australian Postgraduate Award (APA) Scholarship.

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List of acronyms and abbreviations

ANAT	Australian Network for Art and Technology
API	Advanced Programming Interface
ATLAS	A Toroidal LHC ApparatuS
CERN	Conseil Européen pour la Recherche Nucléaire (European Council for Nuclear Research)
CMS	Compact Muon Solenoid
CRT	cathode ray tube
DESY	Deutsches Elektronishes Synchrotron
E.A.T.	Experiments in Art and Technology
ERNIE	Electronic Random Number Indicating Equipment
HD	High-definition video (usually 1920 pixels wide by 1080 pixels high)
Hz	Hertz
ICHEP	International Conference on High Energy Physics
ISEA	International Symposium on Electronic Art
FAPP	for all practical purposes
IEEE	Institute of Electrical and Electronics Engineers
KIT	Karlsruhe Institute of Technology
LEP	Large Electron Positron collider
LHC	Large Hadron Collider
LIGO	Laser Interferometer Gravitational-Wave Observatory
LINAC	Linear Accelerator
MIDI	Musical Instrument Digital Interface
MOMA	the Museum of Modern Art, New York
NHM	Natural History Museum, Vienna
PCM	Pulse-code Modulation
PSI	Paul Scherrer Institute
RGB	red-green-blue
SPS	Super Proton Synchrotron
SPDC	spontaneous parametric down conversion
STEM	Science Technology Engineering and Mathematics
XFEL	Free Electron Laser experiment
ZHdK	Zurich University of the Arts
ZKM	Zentrum fur Kunst und Medientechnologie

Introduction

This practice-led research project arose from my experiences at the Australian Synchrotron, where I undertook artist residencies in 2007 and 2010. The Australian Synchrotron is a circular particle accelerator, 216 metres in circumference, which accelerates subatomic particles to almost the speed of light. The energy produced by the accelerator is used to probe matter at the atomic scale. During my residencies in this laboratory, I realised I had interrelated questions regarding fundamental aspects of particle physics, in terms of theory and experiment, and another, deeper question about the reality of the subatomic realm. I concluded my residencies, but these questions remained unanswered.

Following these experiences, I pondered how scientists can objectively observe and measure fundamental aspects of nature through instruments that were developed according to the very theories they were testing. This raised a question: how do such complex relationships between theory and experiment actually work in scientific practice, whilst maintaining objectivity? Moreover, the sheer scale and complexity of such experiments seemed overwhelming to me (and indeed some of the scientists). These ideas were reflected in a text I read at the time by philosopher Jürgen Habermas, entitled 'Die Neue-Unubersichlichkeit',[1] which translates literally to as 'the new unsurveyability'.[2] This led me to wonder if it were possible at all to meaningfully engage with such science whilst being a non-expert; was it possible to push through the initial state of being overwhelmed by such a seemingly unsurveyable site to reach a deeper level of engagement? This was a key issue: how can an outsider, such as an artist, interact with such science? This issue has wider implications, considering the accelerating pace of social and environmental change driven by scientific research.[3]

Another source of inspiration and inquiry came in the form of an equation printed on a t-shirt, which I found in the gift shop of a high-energy physics laboratory (see plate 17). This equation is the "Standard Model Lagrangian", a condensed version of the "Standard Model" equation that accurately describes and predicts almost all known physical phenomena in the universe (as described in Section 2.6). The high-energy physics laboratory I refer to is CERN, the Conseil Européen pour la Recherche Nucléaire (European Organisation for Nuclear Research) (as described in Section 2.3 and Chapter 4). Such a collision of the fundamental with the everyday seemed at once profound yet absurd, sublime and ridiculous (or was it ridiculous to think it is ridiculous?) This led me to question what happens when these worlds collide, and what can be revealed about

[1] Habermas, Jürgen. "The New Obscurity: the Crisis of the Welfare State and the Exhaustion of Utopian Energies." *Philosophy Social Criticism* 11, no. 2 (1986): 1-18.

[2] Habermas stated that the 'technical accomplishments [of contemporary science] … inherently have conflicting consequences … the more complex these systems become, the greater becomes the probability of dysfunctional secondary effects', such as a 'helplessness [which] more and more replaces attempts to find orientation determined by and directed toward the future.' This was evident when I took a group of art students on a field trip to the synchrotron. One student lamented that it just made them feel even smaller and dumber than they were before! Although this was not the result I had hoped for, (inspiration, not exhaustion, was the goal of the excursion), it did resonate with my own initial feelings of being overwhelmed and powerless.

[3] Although this research was focused on my personal interactions with science, it is part of a larger cross-disciplinary engagement. In the concluding chapter, I address the theme why fostering engagement with science is important. As Carl Sagan stated: 'we live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology. This is a recipe for disaster' (Sagan, Carl. "Why We Need To Understand Science." *Mercury* 22, no. 2 (1993): 52).

the relationships between the human and subatomic realms through this collision? And what is created in the collisions of art and high-energy physics?

Outline of argument and exegesis

Through the research and practice detailed in this exegesis, I explore the connections and tensions between art practice and experimental particle physics. My form of research is explicitly qualitative, although it is situated in a highly quantitative research domain. Working with such 'oppositional values'[4] is itself a key aspect of cross-disciplinary practice, which I discuss in Chapters 3 and 4. I argue that the greater the artist's engagement in such cross-disciplinary art–science projects, the more fruitful the outcomes are, in terms of the breadth and depth of the practices that develop and the artworks produced. For this to occur, one must establish a nuanced understanding of, and engagement with, both the art and the science involved. This is essentially my overarching argument: in order to critically engage with science, one needs to do this on its own terms, which I believe is possible to a degree without being a scientist. This can be undertaken through an awareness of the philosophical and epistemological aspects and implications of theoretical physics, as is presented in Chapter 1. Through using a material-cultural framework, one can gain insights into the social and material parameters of practices in experimental physics – this is presented in Chapter 2. Furthermore, art practice provides means of interaction with such parameters; this is discussed in Chapters 3 and 4.

In Chapter 1, I present an overview of the theoretical aspects of the subatomic realm, through a detailed examination of the developments in quantum physics that have led to the current state of particle physics. I introduce the hypothetico-deductive method as used in empirical science, and how this relates to the subatomic realm, where the notions of objectivity derived from classical physics do not apply. This leads to the conflict between realists and antirealists, in terms of the meanings ascribed to the theories of quantum physics. This debate, which is ongoing in science, is discussed throughout Chapter 1. I explore the quantum revolutions of the early twentieth century, and the ways in which the leading scientists of the time developed disparate approaches to grapple with and understand the counterintuitive subatomic world, from Heisenberg's uncertainty principle to Bohr's concepts of complementarity and phenomena. I then examine the "measurement problem" – how to measure quantum properties with classical devices, and where the quantum and macroscopic realms meet. This leads to a discussion of the theories and phenomena of entanglement and decoherence.

In Chapter 2, I examine the material and social aspects of experimental particle physics. As a counter to the theory-centric orientations discussed in Chapter 1, in this chapter I provide an overview of experimentalism in particle physics, and how this mode of scientific practice proposes a different way of understanding observation and measurement. I examine the genealogical development of detectors used in high-energy physics, and how they can be seen as hermetic worlds, social entities, and epistemic things or knowledge objects. I then look at experiments as scientific models and the nature of information and data that come from such experiments.

[4] Ox, Jack, and Richard Lowenberg. "SARC (Scientists/Artists Research Collaborations)." SEAD: White Papers, 2012. Accessed April 28, 2015. https://seadnetwork.files.wordpress.com/2012/11/ox_final3.pdf, p 156.

In Chapter 3, I undertake a fundamental shift from the practices of science itself, to art practices that engage with aspects of science and technology. I commence with an overview of art and science collaboration, and define types of cross-disciplinary practice, namely interdisciplinarity and transdisciplinarity. I examine aspects of experientialism in art practice, then provide an overview of key twentieth-century artists who have used science and technology. I move on to contemporary art which engages with energy, particles, laboratories, and finally high-energy physics.

In Chapter 4, I describe my own art practice working with particle physics, namely through the art@CMS collaboration at CERN. I discuss my experiences, and present six main projects. Three of these incorporate digital audio and visual media, and data from experiments. The other three are material sculptural installations and interventions. As manifested in these works, my research and practice move from scientific concepts, through objects and data from experiments, to collaborating with the physicists and finally engaging directly with devices used in particle physics.

Chapter 5 is the conclusion, where I summarise my research, experiences, and the projects I have produced. I argue that my practice is interdisciplinary, and engages deeply with concepts and materials found in particle physics. Also, I argue that my practice is itself ultimately an experiment with art and science, and the works produced are 'epistemic things'.[5]

A series of colour plates, which documents my studio practice and artworks I have produced and exhibited, follows Chapter 5.

The Appendix contains selected conference and exhibition programs, and articles and catalogue essays by curators and reviewers, which are evidence of the engagement with my practice and artworks by members of the international contemporary arts and particle physics communities.

The *Intermezzo* is essentially a self-contained section, although it is placed between Chapter 2 and Chapter 3, between the science and the art. It is a case study regarding an intersection between physics and philosophy. I examine the writings of philosopher Karen Barad and physicist Anton Zeilinger regarding the phenomena of entanglement. This is pertinent to my overall research into how we understand subatomic phenomena, as I frame my inquiry into the philosophy of particle physics largely through the epistemology of quantum physicist Niels Bohr. Both Zeilinger and Barad also refer to Bohr on their interpretations of entanglement phenomena. I was initially inspired by the experimental metaphysics of Barad, and it was through her writing that I began my research on Bohr. Although I find the contemporary materialist philosophy of Barad insightful, I believe her view is flawed. I explain my position using the insights of Anton Zeilinger, which supports the primacy of materiality, from which knowledge emerges through an interplay with human subjects.

My critical interstitial regarding Barad vs Zeilinger in the Intermezzo also reveals why I have taken a path that is closer to the science-based material agency of physicist and sociologist Andrew Pickering,[6] as described in

[5] Knorr Cetina, Karin. "Objectual practice." In *The Practice Turn in Contemporary Theory*, edited by Karin Knorr Cetina, Theodore R. Schatzki, and Eike Von Savigny, 184-197, London: Routledge, 2001., p.191

[6] Pickering, Andrew. "The Mangle of Practice: Agency and Emergence in the Sociology of Science." *American Journal of Sociology* 99, no. 3 (1993): 559-589, p. 568

Section 2.4, than the “new materialism” of Barad.[7] I believe to get to the heart of the matter that lies within the Large Hadron Collider experiment (LHC), one must be able to stand up to the scrutiny of scientists, in order to meaningfully and critically engage with them. Through such engagement, I believe cross-disciplinary heuristics and “creoles” can be developed, which, in a way, make short-circuits between the disciplines, and can lead to a ‘deep coupling’[8] of art and science. In this way, my research and practice is itself an interdisciplinary experiment. In this experiment, I investigated the following questions:

- What are the key philosophical and epistemological issues and insights that arise through the scientific understanding and exploration of the subatomic?
- How can art practices and artworks engage with and manifest such concepts, practices and problems as found in experimental particle physics?
- How does one develop cross-disciplinary practice in art / science collaboration?

[7] This is also why I have rejected the more ‘vitalist’ metaphysical variations of new materialism, such as is found in Jane Bennett’s *Vibrant Matter: A Political Ecology of Things* (Duke University Press, 2009). She poetically invokes the energy calling to her from some objects in a gutter, but I want to work with forms of active matter that are experimentally measurable, and explore the agency of such empirically energetic matter, via the apparatuses of science, and through this, explore the nature of science itself.

[8] Malina, Roger. “Welcoming Uncertainty: The Strong Case for Coupling the Contemporary Arts to Science and Technology.” In *Artists-in-Labs Networking in the Margins* edited by Scott, Jill, and Zürcher Hochschule Der Künste, 15-23. Wien: Springer Verlag, 2006, p.17

Chapter 1 – A Universe of Theories

This chapter presents an overview of the theoretical aspects of particle physics. Although I devote many pages to a study of the development of quantum theory, it is important to present the history and philosophy underpinning particle physics, as it helps in understanding how and why it developed the way it did, and its philosophical and ontological implications. This presentation of history and philosophy informs contemporary practice in experimental particle physics, as discussed in Chapter 2. Furthermore, this research allowed me to engage in meaningful and critical discussion with particle physicists, the results of which I present in Chapter 4. To clarify, quantum physics is generally (but not explicitly) of a theoretical nature, and particle physics generally incorporates this into large experiments, such as the Large Hadron Collider (LHC) experiment at CERN (discussed in Chapter 2).

The scientific and epistemic factors discussed in this chapter represent the viewpoints of key figures such as Bohr, Heisenberg, Einstein and Schrodinger; although they have informed my practice and viewpoint, they are not indicative of my own stance, which I discuss in Chapter 5. Throughout Chapter 1 I identify major events in the formation of contemporary particle physics. The chapter headings are devices that guide the reader to focus on key concepts, but also encourage the unpacking of such concepts. As philosopher of science Paul Feyerabend argues, seemingly straightforward 'terms such as "experiment" and "observation" cover complex processes containing many strands.'[9] In discussing the inspirations and uncertainties that are found in both the development and content of this science, the form and flow of the writing itself reflects such uncertainties and inspirations. These discoveries and concepts are addressed in a form that is both historical and thematic, via a criss-crossing path through the 'garden of physics.'[10]

1.1. The nature of science

In this section I discuss the nature of empirical science, as developed by major twentieth-century philosophers of science. This is to demonstrate that, although scientific research, particularly physics, adheres to a rigorous framework known as the hypothetico-deductive method, it contains aspects that are not as rigorous and systematic as they may seem. I address aspects of epistemology and discuss how different views respond to the relationship between science and nature.

The epistemology of contemporary science, or what is understood as being valid scientific knowledge, is a combination of mathematics, logic-based reasoning, and empirical inquiry based upon observation of natural phenomena.[11] These systems of scientific logic and empiricism were largely brought together and formalised

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[9] Feyerabend, Paul. *Against Method*, Third ed. (Verso, 2010), p.xxv

[10] Aaserud, Finn and JL Heilbron. *Love, Literature and the Quantum Atom: Niels Bohr's 1913 Trilogy Revisited*. Oxford: Oxford University Press, 2013, p.105

This term is taken from one scientist's response to Bohr's initial model of the atom (discussed in Section 1.2): 'He did not stumble over a hidden feature in the landscape of nature, but built hothouses and ha-ha's in the garden of physics.' And in this sense it is a good metaphor, as I too construct forms that magnify certain aspects of particle physics, whilst overlooking others.

[11] Although the origins of the scientific method date back to antiquity, eighteenth-century philosophers Immanuel Kant, John Locke and David Hume are key figures who developed the logical and empirical methods used in science, and Francis Bacon advocated the use of technology to 'twist the lion's tail' of nature in order to understand it (Hacking, Ian. *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press, 1983, p.149).

in the twentieth century. The epistemological framework behind contemporary scientific research is generally the hypothetico-deductive method, developed by philosopher of science Karl Popper, most directly in his 1934 book *The Logic of Scientific Discovery*. Popper implemented a system for undertaking scientific research that adhered to principles of logical and empirical testing, which can be summarised as follows: 'scientists frame conjectures and test their logical consequences. A proposition is scientific if and only if it is falsifiable.'[12] Any theory must in principle be testable through experiment; in other words, to be a scientifically valid theory, a conjecture or hypothesis must be able to be proven wrong or false.[13] This proposition deems that if a theory cannot be tested by physical experiments, it is metaphysics, which is 'not meaningless or useless', but is not science.[14] According to Popper, a theory is never completely right or true, it is only ever temporarily validated by experiment, and may be overthrown by future experiments.[15]

In order to understand such epistemology, one can look at how scientific activity engages with nature – in other words, asking what is the 'relation between a theory and the world'?[16] On this question, realists and empiricists have opposing viewpoints. A realist may say that science endeavours to give us a 'picture … of the world [that] is a true one, faithful in its details, and the entities postulated in science really exist.'[17] In contrast, as Popper advocated, an empiricist would say that science seeks only to 'correctly describe what is *observable* [my italics].'[18] Antirealism is an extreme form of empiricism, essentially consisting of not believing that any reality can be ascribed beyond observation (discussed in Section 1.3). In general, an empiricist such as Popper would say that 'only observation can give us knowledge concerning facts.'[19] However, as is discussed in Sections 1.5 to 1.7), neither the concept nor method of observation in particle physics is as straightforward as they are on the scale of macroscopic or everyday objects. On the subatomic scale, the very notion of objectivity central to empirical science is brought into question.

Objectivity has been a cornerstone of science since the seventeenth century. In that era, Isaac Newton formalised observations of the motion of objects into 'powerful techniques of logical and mathematical manipulation.'[20] In essence, Newton's laws of motion are mathematical models or analogies, which, given initial states of objects, can allow the determination of later states. Objectivity is maintained, as such states exist independently of the scientist's measurements. For example, if the position and velocity of a moving object at a certain time are known, precise calculations can be made of the object's future positions and velocities. Furthermore, the act of observing such an object has no effect upon it. This is known as classical physics, and is considered objective, as it describes aspects of the physical world without requiring reference

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[12] Feyerabend, *Against Method*, p.ix.

[13] There is a fundamental difference between validation and falsification – a theory does not have to be initially validated or proven true by experiment to be deemed scientific, but it must be shown that it is falsifiable i.e. that it is possible to devise and / or conduct experiments that can potentially disprove the theory, to prove that it is false.

[14] Ibid., p. ix. It should be noted that Popper was suspicious of the logical positivist Vienna School, although he was associated with them. I do not examine science and positivism, but instead focus upon the realism–antirealism debate.

[15] Popper, Karl. "Selections from The Logic of Scientific Discovery." In *The Philosophy of Science*, edited by Richard Boyd, Philip Gasper, and J.D. Trout, 99-119. Cambridge: MIT Press, 1993, p.101

[16] Van Fraassen, Bas C. *The Scientific Image.* Oxford University Press, 1980, p.vii

[17] Ibid., p.7

[18] Ibid., p.4

[19] Popper, "Selections from The Logic of Scientific Discovery", p.114

[20] Kuhn, Thomas S. *The Structure of Scientific Revolutions*, 3rd ed. The University of Chicago Press, 1996, p.183

to the scientist.[21] This system is also one in which the relation between cause and effect is determined by the initial conditions. However, the notion of causality, which is fundamental to classical physics, becomes problematic when dealing with particle physics (as discussed in Section 1.3).

Rhetorically asking 'what are the rules of scientific method?' and 'can there be a theory of such rules, a methodology?',[22] Popper advocated for what he called the 'empirical method'[23] as the means of ensuring the practice of science itself remained scientific. Depending on which theory best addressed the empirical observations, using hypothesis and deduction, scientists are free to change theoretical perspectives, but should remain within the epistemological framework of the empirical method.[24] Popper ultimately believed in 'a unity of science … [in which] all the sciences should employ the same methods.'[25] However, looking at the way science developed throughout history, Albert Einstein stated that 'the facts of experience do not permit … [the scientist to] be too much restricted, in the construction of [their] conceptual world, by the adherence to an epistemological system.'[26] Popper in fact refers to Einstein, stating that 'there is no logical path' in the development of a new theory,[27] yet Popper argues that 'the act of conceiving or inventing a theory … is irrelevant to the analysis of scientific knowledge.'[28]

Physicist and philosopher (and student of Popper's)[29] Paul Feyerabend disagreed with Popper's view, stating 'the *history* of a science becomes an inseparable part of the science itself.'[30] In his critique of the empirical method, *Against Method*,[31] Feyerabend stands against a singular epistemological framework. He states that, although it is 'possible to create a tradition [or scientific method] that is held together by strict rules,'[32] and, somewhat understatedly, acknowledges that this 'is also successful to some extent'[33] he questions whether it is 'desirable to support such a tradition to the exclusion of everything else.'[34] From his detailed analysis of key events in the development of science, Feyerabend reaches the conclusion that 'the only principle that does not inhibit progress [within scientific research] is: anything goes.'[35] Unpacking this 'notorious aphorism'[36] reveals Feyerabend's own artistic and Dadaist tendencies – he states that scientists should invent and contemplate theories in 'a relaxed and "artistic" fashion' in ways that are 'forbidden by methodological rules.'[37] As Feyerabend states, 'a Dadaist is prepared to initiate joyful experiments even in those domains

[21] Heisenberg, Werner. *Physics and Philosophy: The Revolution in Modern Science.* London: Allen & Unwin, 1958), p.55
[22] Popper, "Selections from The Logic of Scientific Discovery", p.101
[23] Ibid.
[24] Thomas Kuhn further developed the way theories change within an epistemological system, coining the term paradigms' to describe the theories or world views held by competing groups of scientists. Kuhn also developed the concept of 'incommeasurability' between theories, stating that any one theory can become so specific, communication between such groups can become impossible.
[25] Hacking, *Representing and Intervening,* p.5
[26] Feyerabend, *Against Method*, p.xiv
[27] Popper, in yd, Gasper & Trout, *The Philosophy of Science*, p.100
[28] Ibid., p.99
[29] Interestingly, another student of Popper's, George Soros, applied one of Popper's theories to economics and became a billionaire.
[30] Feyerabend, *Against Method,* p.14
This insight I found to be a key factor in my own interactions with physics and physicists (as discussed in Chapter 4).
[31] The title of the book was inspired by, and "in analogy to" Susan Sontag's seminal essay *Against Interpretation*. Feyerabend, *Against Method,* p.xi.
[32] Feyerabend, *Against Method*, p.3.
[33] Ibid.
[34] Ibid. This is a rejection of "scientism", the belief that only scientific knowledge is factual.
[35] Ibid., p.7
[36] As Ian Hacking states, this term will forever haunt Feyerabend, although Feyerabend himself defended it as 'the terrified exclamation of a rationalist who takes a closer look at history' (ibid., p. xii)
[37] Ibid., p.150

where change and experimentation seem to be out of the question' (Dadaism is discussed in Section 3.3).[38] This may seem at odds with the precise and objective methods used in particle physics, as is discussed below and in Chapter 2, but, as will be seen in Chapter 4, provided an impetus for my own practice in working within such a domain.[39]

In summary, science is a method of hypothetico-deductive reasoning based upon logical analysis of experiments performed in such a way that objectivity is maintained. However, some practitioners of science, including Einstein and Feyerabend, believe that science itself does not develop logically, and indeed question whether it should.

1.2. Quantum revolutions

Feyerabend's epistemic driver, that *anything goes*, provides a conceptual framework through which to consider the formation of particle physics, which is full of chance, complexity, and is as colourful as the characters involved. In this section I examine the work of key players in the quantum revolution, namely Heisenberg, Schrodinger, and Bohr. I also explore how developments in quantum theory challenged fundamental notions regarding objectivity and causality.

The quantum revolution in physics began in 1900 with Max Planck's discovery that energy is ultimately 'composed of a very definite number of equal finite packages.'[40] This seemingly simple yet radical insight, that physical reality was ultimately comprised of discrete units, was brought about by an act of desperation on Planck's part.[41] This breakthrough 'represented a fundamental unraveling of the structure of classical physics,' which assumed that energy, and thus nature, was continuous.[42] Building upon this breakthrough, the Danish physicist Niels Bohr developed one of the first models of the structure of the atom in 1913, based upon a conceptual model of a structure comprised of electrons in fixed quantised orbits around a central nucleus. However, Bohr's model contained parameters that could not be measured or observed, and was ultimately rejected, in part due to such unfalsifiable components.[43]

In 1925 Werner Heisenberg developed a system called quantum mechanics. Put simply, quantum mechanics is a series of reductive mathematical models that predict the behaviours of subatomic entities. Heisenberg described this system as being based on relations between quantities produced by such entities that can be 'observed in principle.'[44] He stressed that theories of the subatomic should only deal with observable or measurable quantities, and not unobservable ones as described in Bohr's original theory.[45] Heisenberg's empiricist reasoning, which accords with Popper's epistemology, is reflected in the attitude of his colleagues,

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[38] Ibid., p.xiv

[39] In fact, this principle made a deep and lasting impression upon me when I first discovered it during a history and philosophy of science elective (part of my undergraduate degree in science, which I terminated soon after, in search of a more expressive engagement with the physical universe).

[40] Baggott, J.E. *The Quantum Story: a History in 40 Moments.* Oxford: Oxford University Press, 2011, p.15

[41] This was to find a resolution to a huge discrepancy between the theory of the time and experimental observations, which was dramatically called 'the ultraviolet catastrophe.'

[42] Ibid., p.16

[43] It is interesting to note that almost a century later, there are still pro-Heisenberg jokes going around about this – one senior scientist at CERN said to me: 'Bohr's model kneels!'

[44] Fine, A. "The Natural Ontological Attitude." In *The Philosophy of Science*, edited by Richard Boyd, Philip Gasper, and J.D. Trout, 261-277. Cambridge: MIT Press, 1993, p.267

[45] Baggott, *The Quantum Story*, pp.46-47

such as Max Born, who wrote that 'we must require that they [the theories] involve only observable quantities such as energies, frequencies of light, intensities and phases'[46] and indeed only mathematical 'symbols as referred to [these] measurable quantities.'[47] Such empirical concepts informed my own processes in working with properties that can be measured by detectors *and* perceived by humans, as will be discussed in Chapter 4.

The relations between the measurable quantities described above can be accurately calculated by the deceptively simple mathematical apparatus of Heisenberg's matrix mechanics. In short, Heisenberg replaced the Newtonian parameters describing the motion of macroscopic objects with 'analogous' calculations between matrices. This entails that classical physics' equations for the positions and velocities of electrons or other particles – in other words, actual physical properties – are replaced by equations for the frequencies and amplitudes of harmonic oscillators, which are abstract mathematical forms.[48] But what does this analogy mean in terms of the actual physical nature of the subatomic objects? This question 'deeply alarmed' Heisenberg[49] when he initiated his own quantum mechanics revolution, which is known, rather poetically, as the Night of the Heligoland.[50]

Almost a century later, there remain myriad competing interpretations regarding such revolutions and the nature of the subatomic universe. This is in part due to the fact that we cannot directly perceive such phenomena, as they are mediated by the apparatuses used in physics experiments. As stated in Section 1.1, a realist scientist believes that theories are ultimately able to paint a true picture of reality, and thereby engages in 'identifying a reality underlying the formulas of the theory and thereby explaining the predictive success of the formulas as approximately true descriptions of this reality.'[51] At the other extreme, an instrumentalist sees theories simply as tools to assist in producing accurate predictions, or correlations with the data from measuring instruments, but such theories do not represent any kind of physical reality. In general, an antirealist will '*accept* a theory (accept it as empirically adequate)' as opposed to a realist who will '*believe* the theory (believe it to be true).'[52] Heisenberg took an antirealist stance in terms of the relationship between quantum theory and the subatomic realm. He believed quantum mechanics, which he also called 'matrix

[46] Kragh, Helge. *Niels Bohr and the Quantum Atom: The Bohr Model of Atomic Structure 1913-1925*. Oxford: Oxford University Press, 2012, p.353

[47] Ibid., p.314

[48] Heisenberg, *Physics and Philosophy*, p.41

[49] Baggott, *The Quantum Story*, p.48.

[50] The actual events on the Night of the Heligoland of Heisenberg's breakthrough are quite dramatic and chaotic, in keeping with Feyerabend. Heisenberg made his discovery whilst on the island of Heligoland off the coast of Germany, whilst trying to escape from bad hayfever and too much Bohr. On the night of his breakthrough, he was so excited he could not sleep, so whilst inventing quantum mechanics, he was climbing around on rocks and learning Goethe's poems by heart. 'At first I was deeply shaken . . . I was so excited that I could not think of sleep. So I left the house . . . and awaited the sunrise on top of a rock' (Pais, Abraham. *Niels Bohr's times: in physics, philosophy, and polity*. Oxford: Oxford University Press, 1991, p.275). The island of Heligoland features awe-inspiring pillars of red rock jutting out into the wild North Sea. Whilst Heisenberg sat atop these rocks, gazing into the ocean below, thinking about the nature of matter and energy and relationships between position, velocity, frequency and amplitude, the waves of the ocean swirled around the rocks in energetic dynamics, suggesting structures below the surface of the sea. This is a poetic relation apparently overlooked by scientific historians. As the light of the morning sun dawned upon Heisenberg, so did enlightenment. He recounted 'I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy at the thought that I had to probe this wealth of mathematical structures nature had so generously spread out before me.' (Baggot, *The Quantum Story,* p.48)

[51] Fine, "The Natural Ontological Attitude", p.268

[52] Van Fraassen, Bas. "To Save the Phenomena." In *The Philosophy of Science*, edited by Richard Boyd, Philip Gasper and J.D. Trout, 187-194. Cambridge: MIT Press, 1993, p.193

mechanics', was completely abstract and only served as a mathematical calculation tool, and was not a model representing aspects of nature.

In summary, Max Planck posited that energy is ultimately composed of discrete units or quanta. Bohr developed this concept into a model of the atom, which he took to be a real description of nature but which could not be falsified. Heisenberg developed an abstract mathematical tool, quantum mechanics, which perfectly agreed with experimental observations, yet he believed it did not represent an underlying reality of nature, as is discussed below.

1.3. Uncertainties

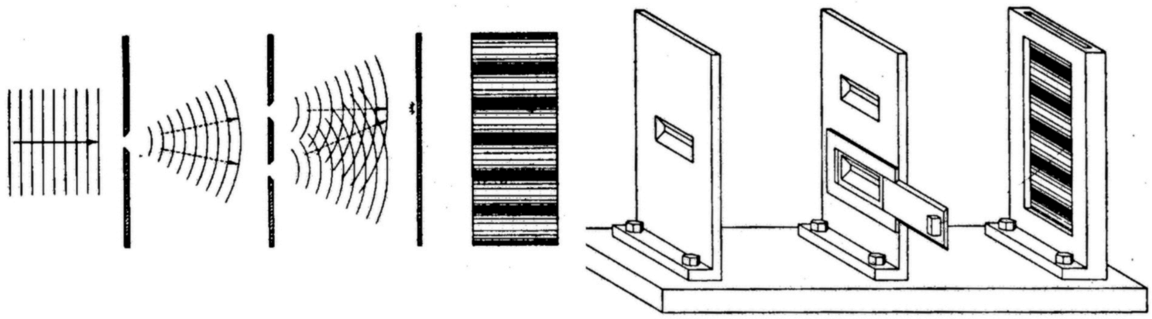

Fig. 3 Fig. 4

Figure 1. Niels Bohr, *Untitled,* 1949.

In this section, I discuss the development of Heisenberg's uncertainty principle. As this underpins much of contemporary particle physics, it is important to examine both its development and its epistemological implications, and how it informs the ongoing debate between scientific realists and antirealists.

When analysed in a macroscopic or classical framework, subatomic phenomena display contradictory qualities. This has led to many physicists, including Heisenberg, to take such an antirealist stance as described above. The wave-particle duality paradox is such an example; a subatomic particle, or a photon of light, exhibits both wave-like and particle-like properties (see fig. 1), yet as Heisenberg states, such qualities are 'mutually exclusive, because a certain thing cannot at the same time be a particle (i.e. a substance confined to a very small volume) and a wave (i.e. a field spread out over a large space)'.[53] Such seemingly paradoxical experimental outcomes are supported by the mathematical restrictions of matrix mechanics, in that it does not allow properties such as position and momentum to be simultaneously calculated. A more precise

[53] Heisenberg, *Physics and Philosophy*, p.50

calculation, or alternately a more precise measurement of one variable means a loss of precision of the other variable. From this, Heisenberg developed his uncertainty principle.[54]

One of the greatest advances in quantum physics, which also produced one of its greatest conundrums, was to use wave functions, denoted by ψ, as mathematical tools to calculate the temporal probability of the paths and positions of subatomic particles. This equation, developed by the physicist Erwin Schrödinger, signals another revolutionary moment in particle physics, that of the unpredictability of individual particle events. As physicist Richard Feynman stated:

> Where did we get that [equation] from? Nowhere. It's not possible to derive it from anything you know. It came out of the mind of Schrödinger, invented in his struggle to find an understanding of the experimental observations of the real world.[55]

Feynman went on to note, 'the only information available from [this equation] concerns the probabilities of certain outcomes, [thus] causality and determinism are abandoned.'[56] A key outcome of this equation, backed up by countless experiments (including my own – see Section 4.6), is the quantum jump, which describes the randomness associated with changes of energy of subatomic entities.[57] It is impossible to predict specific future events based upon knowledge of current events; both theory and experiment reveal that there is no link between cause and effect in terms of individual particle events.[58] Thus, the concept of causality, central to classical physics, is rendered meaningless in the subatomic realm.

Einstein, an avowed realist, did not like this implication of quantum physics, which he summed up in his famous edict 'God does not play dice with the world.'[59] Schrödinger – another realist –also disagreed with Heisenberg. Schrödinger wrote that 'because of the lack of *Anschaulichkeit* (visualisability)[60] [of Heisenberg's theory], I felt deterred by it, if not to say repelled.'[61] Heisenberg had this to say in response: 'the more I think about the physical portion of the Schrödinger theory, the more repulsive I find it … What Schrödinger writes

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[54] An illustration of the uncertainty principle, using an imagined experimental setup, is as follows: If I wish to measure the position of an electron with an energised photon of light, the photon's energy will jolt the electron and change its momentum. This means I can get a measurement of the electron's position at the instant of interaction, but at the cost of affecting its momentum and not being able to know that value accurately. Conversely, if I want to get an accurate measure of the momentum of the electron, I have to use a photon of very low energy, which disallows a clear indication of its position. Thus increased certainty about one aspect of the electron comes at the cost of less certainty about its other attributes. This has been formalised by equations such as $\Delta p \, \Delta q \geq \hbar/2$, and $\Delta E \, \Delta t \geq \hbar/2$, where Δq is the change or imprecision in position, Δp is the change or imprecision in momentum, ΔE and Δt are changes in the energy of such a system, and $\hbar$ = Planck's constant, 6.626×10^{-34} joule-seconds. These equations express 'reciprocal limitations (the bigger Δp the smaller Δq, etc.) on the accuracies with which, in a given experiment, the various variables are knowable' (Pais, *Niels Bohr's Times*, p.306). Although Planck's constant is such a small number, this uncertainty only relates to very small entities, but on this scale, 'quantum mechanics places a fundamental limit on the precision with which both position and momentum can be jointly determined in any laboratory experiment' (Baggott, *The Quantum Story,* p.91). The above equation is very simple, as it only deals with a solitary particle, however, with more particles and forces such equations become very complex very quickly. This experiment is Heisenberg's famous microscope thought experiment, which shows how the uncertainty relation works, but which Niels Bohr criticised as badly constructed, as it gets mixed up with the observer effect.

[55] http://www.feynmanlectures.caltech.edu/III_16.html

[56] Baggott, *The Quantum Story,* p.75

[57] This is a largely misused term in popular culture. As opposed to a great conceptual leap, it literally describes the lowest possible change of energy a subatomic state can undergo. Thus, a quantum jump means almost no change of energy. However, Heisenberg did use it to describe changes in the mind of the observer – 'since through the observation our knowledge of the system has changed discontinuously, its mathematical representation also has undergone the discontinuous change and we speak of a quantum jump' (Heisenberg, *Physics and Philosophy*, p.54).

[58] Statistically, it is another story – quantum theory is amazingly precise when a mass of events has been measured.

[59] Einstein actually wrote, in a letter to colleague Max Born in 1926 about quantum mechanics, that 'I, at any rate, am convinced that He does not throw dice.' Clark, Ronald. *Einstein: The Life and Times*. New York: World Publishing Company, 1971, p.414

[60] This term originates from Kant; visualisability being a property of objects, it also relates to our intuition of such objects.

[61] Baggott, *The Quantum Story,* p.67

about the visualisability of his theory "is … probably not quite right", in other words, it's crap.'[62] In the middle ground between Heisenberg and Schrodinger, Niels Bohr was increasingly concerned by the 'hopeless paradoxes' Heisenberg's theory seemed to be producing.[63] He lamented that 'the [abstract] mathematical scheme does not help. I …? want to understand how nature actually avoids contradictions.'[64] Moreover, Bohr found that one of the fundamental assumptions of Heisenberg's uncertainty principle rested on shaky philosophical ground. In his thought experiment involving the measurement of an electron (described above), Heisenberg presumed that the photon actually disturbs the electron. This is in fact a separate issue, known as the 'observer effect,'[65] where, on the subatomic scale, photons of light have momentum and energy comparable to the particles they are interacting with, thus 'the measurement *necessarily* disturbs the object.'[66] Furthermore, this reveals an ontological belief of Heisenberg's that contradicts his antirealist view of the quantum realm. However, Heisenberg was not initially concerned by the philosophical implications of his theories, stating that 'success justified the means.'[67] It is evident that his 'philosophical rationale [was] added after the fact.'[68] Conversely, for Bohr, 'what is at stake … in the challenge posed by quantum physics is nothing less than how we can account for the fact that science works.'[69] In other words, this was an issue of realism and antirealism. At stake are the implications for the epistemology of science and our understanding of the fundamental nature of the universe.

In summary, Heisenberg's uncertainty principle and Schrodinger's wave equation describe paradoxical and probabilistic aspects of subatomic phenomena, both of which impact on our understanding of the reality underlying such phenomena. The philosophical and ontological implications of quantum physics were paramount in understanding and directing the theories forming at the time.

1.4. Complementarity

In this section I provide an overview of Niels Bohr's nuanced philosophical insights into – and epistemological stance on – quantum physics. This is known as the Copenhagen Interpretation, although it is often confused with Heisenberg's theories described above It is important to note that the Copenhagen Interpretation is still the standard view of quantum physics.[70]

Niels Bohr founded the Institute of Theoretical Physics in Copenhagen in 1920, where many of the breakthroughs in quantum theory were made; regular visitors to the Institute included Schrödinger and Heisenberg. Bohr had a wide range of interests: he knew Goethe's poems off by heart, was a proficient illustrator (see figure 1), and was attentive to developments in contemporary art and music.[71] He was

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[62] Ibid.

[63] Pais, *Niels Bohr's times*, p.302

[64] Ibid.

[65] This also produces an uncertainty in measurement of quantum phenomena, but leads to confusion with the uncertainty principle. See https://www.quora.com/Why-do-people-mix-up-the-observer-effect-and-the-uncertainty-principle

[66] Barad, Karen Michelle. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press, 2007, p.107

[67] Kragh, *Niels Bohr and the Quantum Atom,* p.321

[68] Ibid., p.353

[69] Barad, *Meeting the Universe Halfway,* p.143

[70] This is corroborated by Sujeevan Sivasundaram and Kristian Hvidtfelt Nielsen, "Surveying the Attitudes of Physicists Concerning Foundational Issues of Quantum Mechanics." (2016). Accessed January 8, 2017. https://arxiv.org/abs/1612.00676.

[71] This demonstrates that C.P. Snow was incorrect when he said that scientists were culturally ignorant (discussed in Chapter 3).

impressed 'that [in paintings] an object could be several things, could change, could be seen as a face, a limb and a fruitbowl.'[72] He was arguably influenced by the philosophy of his friend Harald Hoffding,[73] as well as that of Immanuel Kant.[74] Hoffding gave Bohr 'the conviction that [although] no single system of thought could cover any extensive domain of experience … every serious thinker can contribute something unique to the world picture.'[75] Kant developed a world picture derived from experience,[76] and defined the 'limitation of all empirical knowledge to objects of possible experience.'[77] Based upon this, he drew a distinction between noumena and phenomena; that is, between our understanding of external objects as mediated by our perceptions, and the objects in themselves: 'phenomena are objects of possible experience, while noumena are things in themselves, forever outside the domain of possible experience.'[78] Kant states 'As appearances, they [the perceived phenomena] cannot exist in themselves, but only in us… We know nothing but our mode of perceiving them. Appearances … are called phenomena… In the empirical employment of our understanding things will be known only as they appear.'[79] Bohr took the distinction between phenomena and noumena further still — unlike Kantian noumena, where macroscopic objects may be outside our complete understanding but which are still conceivable in principle, 'there is nothing we can say or, in the first place, think about [quantum objects] except as manifest in the effects of their interactions with measuring instruments upon those instruments.'[80] In other words, 'quantum objects do not appear to allow us to form any conception of them and their behavior. They are literally unthinkable.'[81] Buoyed by such concepts, Bohr was determined and unrelenting in his quest to resolve the apparent paradox of the wave–particle duality and develop a consistent theory of the quantum realm.[82] As Heisenberg later described:

> Bohr realized that an inconsistency is … much worse than a paradox because inconsistency means that you just talk nonsense – that you do not know what you are talking about. A paradox may be very disagreeable but you can still make it work. An inconsistency can never be made to work.[83]

In the macroscopic world, as in classical physics, waves and particles are different things. Yet in order to gain a complete picture of a subatomic entity, it is necessary to measure wave and particle properties as macroscopic behaviours of quantum objects. An example that illustrates this is the double slit experiment.

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[72] Miller, Arthur. "Visualization Lost and Regained: The Genesis of the Quantum Theory 1913-1927." In *On Aesthetics in Science*, edited by Judith Wechsler, 73-101. Boston: Birkhäuser, 1988, p.76

[73] Aaserud and Heilbron, *Love, Literature, and the Quantum Atom*, p.105

[74] Historians disagree as to the degree of influence Kant's writings had on Bohr [i.e. Pais, p.424 vs Aaeserud and Heilbron, p.105]. David Kaiser wrote a paper explicitly on what he argued was Kant's implicit effect upon Bohr, as shown through 'deep parallels' between their philosophies (Kaiser, David. "More Roots Of Complementarity: Kantian Aspects And Influences." *Studies in History and Philosophy of Science* 23, no. 2 (1992): 213-39)

[75] Ibid., p.106

[76] Kant developed other important concepts, such as his notion of the 'mathematical sublime', which deals with scale, and the 'dynamic sublime', which deals with the might and power of nature, and our limited abilities to intuitively grasp or aesthetically measure such states, yet we can grasp the concept that we cannot grasp it. Unfortunately, an in-depth discussion of the sublime is out of the scope of this exegesis.

[77] Kaiser, "More Roots Of Complementarity", p. 218.

[78] Ibid.

[79] Kant, Immanuel. *Critique of Pure Reason.* New York: Prometheus Books, 1990. pp.158-160

[80] Plotnitsky, Arkady. *Epistemology and probability: Bohr, Heisenberg, Schrodinger, and the nature of quantum-theoretical thinking.* New York: Springer, 2010, p. 7

[81] Ibid., p.9

[82] Biographical accounts tell of how Bohr drove Schrödinger so hard he fell ill, yet Bohr kept questioning him by his sick bed (Pais, p.299); he even made Heisenberg cry when he found an error in his paper. This was no mean feat (although maybe mean), for Heisenberg was a big man and anecdotally only liked three things – drinking, fighting and physics (Pais, p.308)

[83] Kragh, *Niels Bohr and the Quantum Atom*, pp.366-367. This statement led me to realise that, in working with such concepts as described here, I also had to remain consistent and meaningful as much as possible, and avoid the 'talk nonsense' trap (hence the density of this chapter). The use of this stance in art/science collaboration will be discussed in detail in Chapter 3.

This is comprised of a source of photons of light (or particles such as electrons), a solid plate with one or two open slits, and a detector (usually a light-sensitive screen). Depending on the setup, namely, whether one or two slits are open between the source and the detector, the photons (or electrons) display particle-like or wave-like properties. However, it is not possible to detect both at once – the variations of the experimental setup are mutually exclusive.[84] Bohr used the term 'complementarity' to describe this situation.[85] As he stated, 'the very nature of the quantum theory forces us to regard [the particle and wave behaviours] as complementary but exclusive features of the description … [they are] complementary pictures of the phenomena.'[86] In subtle distinction to Heisenberg's uncertainty principle, Bohr provided an ontological insight into the nature of these phenomena, and their relation to the unobservable subatomic entities underlying them, which he called the principle of indeterminacy. Complementary behaviours are not simultaneously determinate in this way; 'Bohr's complementarity surpasses the mere distinction [between phenomena and unobservables], and shares Kant's actual mechanism for guaranteeing the objective reality of our judgments.'[87] That is, it is not just that we cannot measure both values at once, it is that they cannot simultaneously exist. Bohr realised that '"wave" and "particle" are classical descriptions that refer to different *phenomena*, not to independent physical objects … [and that] it is impossible to observe particle and wave behaviours simultaneously because mutually exclusive experimental arrangements are required.'[88]

1.5. Phenomena

Bohr's insights into the relationship between phenomena and apparatus have played a key role in contemporary philosophy, informing contemporary philosophers such as Karen Barad. This relationship also influenced how I approached the phenomena produced in the Large Hadron Collider, and works I developed from my exploration of them, as I discuss in Chapter 4. Central to Bohr's investigation was the nature of measurement practices, or in other words, the nature of quantum physics experiments. As stated above, Bohr's investigation was informed by his practical and material expertise.

Bohr uses the term 'phenomenon' in a way that builds upon the Kantian sense of the term, as something we can observe or measure. Bohr developed his understanding of phenomena in a way that explicitly addressed the issue that we can only indirectly know about the subatomic or quantum realm via the technologies with which we observe it. Fundamental to this issue is the relationship between the objects of investigation and the apparatus used to observe or measure them. For Bohr, the interaction between object and apparatus 'forms an inseparable part of the phenomenon.'[89] Bohr said 'An independent reality in the ordinary [that is, classical]

[84] There are additional factors at play in this experiment, which I shall not go into in this general overview, such as the interference effects between particles, even between one particle and itself, and the way a particle behaves depending on whether one or both slits are open, as if it knows what sort of experiment is being conducted, and behaves accordingly.

[85] The term 'complementarity' was initially coined by the philosopher William James in 1891, 'to denote a quality of consciousness in schizophrenics' (Pais, *Niels Bohr's times*, p.424)

[86] Pais, *Niels Bohr's times*, p.315

[87] Kaiser, "More Roots Of Complementarity", p.214. It is out of the scope of this exegesis to delve deeper into this connection.

[88] Barad, *Meeting the Universe Halfway,* p.198

[89] Barad, *Meeting the Universe Halfway,* p.119

physical sense can … neither be ascribed to the phenomena nor to the agencies of observation.'[90] He realised that, although the phenomena under investigation may be subatomic, we are:

> … constrained by our inability to construct experimental apparatus in anything other than classical or macroscopic forms, [thus] we are denied an insight into the 'true' quantum world. What we get instead is the quantum world as reflected in the mirrors of our classical apparatus.[91]

Thus, for example, the behaviour exhibited by electrons is constrained by the types of experiments undertaken. Due to the fact that they are made with macroscopic devices, or 'apparatus of "classical" dimensions', the effects of such experiments are 'substantial enough to be observed and recorded in the laboratory, perhaps in the form of an exposed photographic plate, or in the deflection of a pointer in a voltmeter, or the observation of a track in a cloud chamber.'[92] Unlike in the macroscopic world, where we can ask definite questions about what things *are*, in the subatomic realm, Bohr stated that one should ask: 'Does the electron (or any other object) *behave* like a particle or like a wave? That question is answerable, but only if one specifies the experimental arrangement by means of which "one looks" at the electron.'[93] Bohr also realised that classical experiments and descriptions are all we have with which to interpret and understand the quantum realm, which includes such things as models and diagrams used to explain concepts.[94] Bohr also stated one must have 'an emphasis on the proper use of words,'[95] – even language must be used carefully in describing experiments.[96]

Bohr stressed (and was stressed about) the fundamental importance of finding a new form of objectivity in physics, which, as described above, had been lost in classical terms, due to the death of causality and end of the separation between the objects of investigation and the scientist. Bohr realised that objectivity can only be achieved by precisely specifying the agencies of observation (i.e. the specific experimental setup), including the role of the observer. In a sense, the language used to describe the experiment is itself is a part of the experiment, and must also be precisely defined.[97]

1.6. Measurement

In this section I discuss the problem of the measurement of quantum systems – the 'measurement problem'. I give detailed descriptions of specific measuring devices, and elaborate upon issues regarding them, as they played a major role in informing my practice (discussed in Chapter 4).

As stated above, it is not possible to directly observe subatomic phenomena — experimental apparatus is required as an intermediary (this is also discussed in Chapter 2). This raises a range of issues regarding the nature and limits of scientific research, specifically in regard to the quantum realm. As Bohr stated (in an understated way), this is a problem 'of a peculiar nature,'[98] as it brings the realm of the subatomic into

[90] Pais, *Niels Bohr's times*, p.314
[91] Baggott, *The Quantum Story,* p.97
[92] Ibid., p.96
[93] Pais, *Niels Bohr's times*, p.314
[94] Ibid., pp.428–429. One example is the precisely detailed and rendered 'clock in the box experiment' drawing of 1949. It is noteworthy that a diagram can be a physics experiment.
[95] Ibid., p.315
[96] A statement that informed my attempts at careful and precise descriptions of these key concepts.
[97] This leads inexorably to a kind of 'circle of hermeneutics', which is in a sense an analogy of the (and is in itself a form of a) measurement problem.
[98] Ibid.

collision with the everyday world. This poses a question that has fundamentally guided my research from the outset, which can be stated as follows: Where does the quantum world end and the macroscopic world begin? In order to address this, I shall describe the nature of, and the problem with, measurement of quantum phenomena.

In Bohr's own words, 'the concept of observation is in itself so far arbitrary as it depends upon which objects are included in the system to be observed.'[99] Such an ambiguity regarding the distinction between the classical and quantum realms can be illustrated as follows. An apparatus used to detect quantum phenomena, say a voltmeter, can itself be understood in quantum mechanical terms, and thus should be treated as such. In order to measure its quantum properties, another piece of classical apparatus is required, which can also be treated quantum mechanically, and so on. In Heisenberg's later writings, informed by Bohr, he reflects upon this issue, stating:

> Since the measuring device has been constructed by the observer, what we observe is not nature, in itself, but nature exposed to our method of questioning. … In this way quantum theory reminds us, as Bohr has put it, of the old wisdom that when searching for harmony in life one must never forget that in the drama of existence we are ourselves both players and spectators.[100]

This statement implies the demise of classical physics' notion of objectivity, and also an awareness of the agential connection between humanity and the universe. Perhaps inspired by Bohr's insistence upon precise use of words, Heisenberg points out that:

> the measuring device deserves this name only if it is in close contact with the rest of the world, if there is an interaction between the device and the observer… If the measuring device would be isolated from the rest of the world, it would be neither a measuring device nor could it be described in the terms of classical physics.[101]

Contemporary physicist David Wallace pushes the measurement problem to its (il)logical conclusion:

> In physics … we include the measurement device as part of a larger quantum system … conceptually speaking, this…just pushes the problem back: in order to interpret that larger quantum system we need to recourse to a primitive [i.e. classical] notion of measurement of *that system*. And if we try to model that process of measurement too, we need another third primitive notion of measurement and so on ad infinitum.[102]

However, Wallace escapes from such infinite regress with a pinch of pragmatism: 'As a practical matter,' he states, 'the process is not infinite: it terminates when the measurements we are interested in are of macroscopically large quantities.'[103]

A common example of such a measurement device is the Geiger–Muller tube, or Geiger counter, used to detect subatomic particle emissions, usually from radioactive decay of atomic nuclei. Although a Geiger counter is simple, it is ultimately a quantum measurement apparatus.[104] As is written in the back of a standard physics textbook, there is:

[99] Ibid., p.314

[100] Heisenberg, *Physics and Philosophy,* pp.56-57

[101] Ibid., p.56

[102] Wallace, *Quantum Theory According to the Everett Interpretation*. Oxford: Oxford University Press, 2012, p.20

[103] Ibid.

[104] Basically, a Geiger counter works by creating a state of high voltage potential between two electrodes in a tube of gas. When a particle enters the tube, it charges or ionises some atoms in the gas, which are then attracted to the electrodes, and a momentary circuit is made, discharging the voltage potential. Thus even a quantum level increase in the voltage will trigger a discharge that is 'classically' measurable. An application of this is in detecting invisible emissions from radioactive materials, and is characterised by a random or stochastic clicking sound each time a particle is detected.

> no prescription … for where to introduce the break between the quantum and classical systems ... one is apparently free to introduce the break at any point of the chain with the same result… [thus] the Geiger counter could be regarded either as a classical or as a quantum system, depending on where the break was introduced.[105]

The quantum system of a radioactive atom becomes coupled with the classical system of the measurement device. This is described probabilistically by Schrödinger's wave function: when a particle is detected and a measurement is made, the wave function 'collapses' into an actual event registered by the apparatus. However, until this measurement event occurs, the device itself can be seen as part of the quantum system, and can be described quantum mechanically, in what is called a 'superposition' of states.[106] Such a superposition implies that multiple states, such as the probability of a particles' position or energy, exist simultaneously until a measurement is made.[107] For example, when not observed or measured, an electron can be in two places at once, or an atom can 'borrow' energy to do quantum tunnelling tricks. Such seemingly impossible behaviours have given rise to a wide variety of interpretations in terms of their macroscopic meaning. These include Popper's anti-uncertainty experiment (he was a realist, after all!)[108] and David Bohm's pilot wave causality, which invokes hidden variables that are (probably) unfalsifiable; via Von Neumann's anthropocentric analysis, in which the consciousness of the observer collapses the wave function (thus meaning the universe had to wait until we came along to observe it before it became physical); and Everitt's 'manyworlds' multiverse, the most radical realist interpretation of all, where everything goes![109]

The problems that arise from the lack of a clear division between the quantum and macroscopic worlds are illustrated by an infamous thought experiment by Erwin Schrödinger. In a 1935 paper, he described the now-iconic Schrödinger's Cat paradox.[110] The experimental setup has a cat in a box with a Geiger counter and a radioactive source, which puts the contents of the box into a quantum state. According to the Copenhagen Interpretation, the cat in the box is in a superposition of alive and dead states, and is thus simultaneously alive and dead. Such an outcome goes obviously against our notions and experiences of macroscopic reality, and

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[105] Geroch, Robert. *Geometrical Quantum Mechanics: 1974 Lecture Notes*. Montreal: Minkowski Institute Press, 2013, pp.120–121

[106] A superposition of two waves is simply an addition of the phases of each wave. For example, if two sound waves are in phase, the volume will be doubled, but if they are out of phase, they will cancel each other out and it will be silent.

[107] Such superpositions mathematically occupy points in an abstract space of possibility called Hilbert Space. The difficulty associated with understanding Hilbert Space can be summed up by David Hilbert's admonition of a student who dropped out of his maths class to become a poet, apparently stating 'I knew he wasn't creative enough'. I produced a physics-poster artwork inspired by Hilbert's abstract inversions, which was surreptitiously exhibited in a hallway at CERN, as is discussed in Chapter 4.

[108] Perhaps surprisingly, Popper was ultimately a realist. In the 1980s, he devised a variation on the classic double slit experiment, to see whether measurement collapses the wave function, in a way which sought to disprove Heisenberg's uncertainty principle and demonstrate that a particle has precise position and momentum, as Einstein believed. I find it poetic that Popper's experiment which is now known as the Popper effect, which – although falsifiable – seems to provide evidence both for and against his position. The scientists who undertook this experiment in 1999 wrote, inconclusively: 'The results of our experiment agree with [the Copenhagen Interpretation of] quantum mechanics and Popper's prediction too.' Yoon-Ho Kim and Yanhua Shih, "Experimental Realization of Popper's Experiment: Violation of the Uncertainty Principle?" *Foundations of Physics* 29, no. 12 (1999), p. 1858

[109] It is unfortunately out of the scope of this exegesis to delve too deeply into the more esoteric realms of quantum interpretation. However, Everett's multiverse interpretation postulates that every quantum event literally splits the universe in two, so that everything that can happen does happen in one of the branches. This is much like Borges' classic tale 'The Garden of Forking Paths', which, written in 1941, spookily pre-empted Everett by a decade. Personally, I shy away from Everett, as madness lies down that path! Yet it is taken seriously by many physicists and philosophers, not to mention a multitude of speculative fiction writers, although it is totally unfalsifiable (at least in this universe).

[110] The experimental setup is as follows: An apparatus is contained in a box, comprising a Geiger counter with a radioactive sample, poison gas, and a cat. If the counter detects a particle emission, and discharges the voltage in the Geiger-Muller tube, this activates a relay switch which releases a hammer that shatters a small flask of hydrocyanic acid, which then kills the cat. Schrödinger concluded the description as follows: 'If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay would have poisoned it. The ψ-function of the entire system would express this by having in it the living and the dead cat (pardon the expression) mixed or smeared out in equal parts.' Trimmer, John D. "The Present Situation in Quantum Mechanics: A Translation of Schrödinger's *Cat Paradox* paper." *Proceedings of the American Philosophical Society* (1980): 323-338.

presents a 'picture [that is] indeed blurred: it is meaningless to speculate on whether it is really alive or dead until the box is opened, and we look.'[111] With this provocative thought experiment, Schrödinger illustrated the inability of quantum theory to determine the break between the quantum and classical systems. In a sense, he was trying to understand the physical meaning of his own equation, which (as mentioned in Section 1.3) was invented in his attempt to understand the quantum world.[112] Schrödinger's cat has since become the quintessential emblem or signature of quantum physics,[113] with countless references to it, ranging from serious debate to pop culture[114] and to the playful and absurd.[115]

1.7. Entanglement

In what can be seen as a last-ditch effort to demonstrate conceptual flaws in quantum mechanics, Einstein, Podolski, and Rosen put together a thought experiment in 1935 that pitches quantum mechanics against some fundamental tenets of macroscopically observed reality. Their argument basically states that physical reality exists independently of humans and measurement, and that actions upon one object cannot instantaneously affect another object at great distances, in line with the laws of relativity; this is known as 'local realism'. In support of their argument, Schrödinger wrote a paper that included the following discussion:

> When two [quantum] systems, … enter into temporary physical interaction … [and] after a time of mutual influence the systems separate again, they can no longer be described in the same way as before, … by endowing each of them with a [state] of its own. [This effect is] the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought. By the interaction the two representatives [the quantum states] have become entangled.[116]

As Schrödinger states, the phenomenon he called 'entanglement' is *the* characteristic trait of quantum mechanics (much more than his popularly celebrated cat paradox). In entanglement, both particles share quantum qualities, and when they are separated, one could measure, say, the position of one and momentum of the other, and thus know both, proving quantum mechanics wrong. But according to quantum mechanics, when one of these particles is measured, the other instantaneously takes on the same properties, seemingly as if it 'knows' the measurement made on the other, even if the particles are separated by a great distance. But Einstein's theory of relativity forbids any form of communication faster than the speed of light, thus such instantaneous change of states made from measuring entangled particles would seem to allow the transmission of information in a manner that violates the laws of relativity. Einstein called this posited effect 'spooky action at a distance.'[117]

In 1964, the theoretical physicist John Bell rediscovered the argument, and mathematically demonstrated that

[111] Baggott, *The Quantum Story,* p.157

[112] Referring to quantum mechanics in general, or maybe his infamous cat, Schrödinger is supposed to have said 'I don't like it, and I'm sorry I ever had anything to do with it.' John Gribbin, *In Search of Schrödinger's Cat.* London: Black Swan, 1984, p.v

[113] A recent ground-breaking quantum entanglement experiment by Anton Zeilinger essentially teleported an image of a cat, which was chosen 'in honour' of Schrodinger's experiment. See https://www.scientificamerican.com/article/entangled-photons-make-a-picture-from-a-paradox/

[114] For endless variations, see http://knowyourmeme.com/memes/schrodinger-s-cat

[115] It is because of this cat that I became first interested in quantum physics, through a playful description of the experiment in Douglas Adams' book *Dirk Gently's Holistic Detective Agency* (London: Heinemann, 1987), which involves psychics attempting to ascertain whether the cat was dead without opening the box. This idea has been mentioned in serious books on the subject, as such psychic activity is ultimately a form of observation and would collapse the wave function.

[116] Trimmer, "The Present Situation in Quantum Mechanics", p.v

[117] Clark, *Einstein, the Life and Times*, p.414

quantum theory was incompatible with the assumptions of local realism, which is known as Bell's inequality.[118] Entanglement experiments were undertaken to test Bell's idea, and to the shock of some, including Bell, it was found that the 'results clearly exclude local realism.'[119] Quantum mechanics wins the argument. However, the specific states of such features are completely random, in accordance with Schrödinger's probability equation. Intriguingly, this is good news for Einstein, as it is precisely this 'randomness of the individual quantum event, of the measurement result, that keeps entanglement from violating the impossibility of signalling faster than light.'[120] Quantum particles may appear to communicate instantaneously, but their messages are totally random; thus it is impossible to 'influence what is being sent ... to communicate some new information to someone else.'[121] Such quantum systems are thus non-local, but are also 'free' from being usable in a way that would go against Einstein's theory of relativity. The random roll of the dice preserves relativity.

Furthermore, neither of the two entangled photons actually carries specific polarisation until one is measured. Individual photons normally carry polarisation, but when they are entangled, they lose this state. This subtle and experimentally verified fact means that our relationship with physical reality goes against the notion that such qualities exist independently of measurement. Thus, the entanglement experiment supports Bohr's philosophical stance. Quantum states are simply representations of the knowledge we have of specific physical situations or experimental setups.

1.8. Decoherence

The question 'where does the quantum world end?' so-far remains unanswered. Another proposal, put forward by the mathematician John Von Neumann, was of a kind of chain of linkages between quantum and macroscopic systems. Known as Von Neumann chains, this is a mathematical formalisation that enables the modelling of measuring devices such as the Geiger counter setup mentioned above.[122] However, as I have been personally warned, one should not take such a mathematical model literally,[123] raising again the issue of whether one should interpret such theories in a material or macroscopic sense.

Historically, the question of realism was swept under the quantum carpet after the 1930s. The Copenhagen Interpretation became standard, and antirealism reigned. It became taboo to even talk about realism or observability; 'it was absolutely impossible at that time to discuss these ideas with colleagues, or even to present them in a publication.'[124] Such views could only be communicated through 'underground physics newsletters' in the 'quantum subcultures' that developed during the 1970s.[125] One example was the hand-

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[118] Zeilinger, A. *Dance of the Photons: from Einstein to Quantum Teleportation* 1st ed. New York: Farrar, Straus and Giroux, 2010, p. 136

[119] Ibid., p.137

[120] Ibid., p.222

[121] Ibid., p.154

[122] However, such mathematical models can become unyieldingly complex when applied to actual experimental arrangements: 'the theory becomes a veritable monster … while its relation to experience is more obscure than ever' (Feyerabend, *Against Method*, p.44, footnote 25).

[123] When I met Anton Zeilinger in Vienna (as discussed in Chapter 4), I asked him about the reality of Von Neumann chains, and he replied 'I don't believe in them.' This simple and outright refutation clarified a key issue for me, as I had been working on an area of research that used such chains to link matter, observation and knowledge, inspired by a paper that seemed to be based on solid physics, but which was ultimately inconsistent.

[124] Zeh, Heinz Dieter. "Roots and Fruits of Decoherence." Séminare Poincare 1 (2005):115-129, p.117. Accessed April 16, 2016. http://www.bourbaphy.fr/zeh.pdf

[125] See Kaiser, *How the hippies saved physics*, Chapter 6.

printed *Epistemological Letters* newsletter, which featured research by Heinz Dieter Zeh and John Bell. Zeh proposed a different way to approach the question of where and how the 'quantum cut' occurs; this became known as decoherence theory.

According to Zeh, the universe itself is a quantum system, with its own Schrödinger wave function, but within this, depending on the amount of interaction or interference between its components, things will display more or less classical behaviours. A scientist observing a quantum system such as an atomic nucleus is basically 'part of a much bigger "nucleus" ([or quantum] system): the quantum universe.'[126] As Zeh states, 'Macroscopic objects are never found in energy eigenstates [quantum superpositions], … therefore, [according to Bohr] it was … concluded that "quantum theory is not made for macroscopic objects" or even the universe.'[127] Basically, Zeh's solution of the quantum/macroscopic divide, and the measurement problem, is that it is all quantum; we cannot look at the system (in this case the universe) from the outside (see Section 1.6). As opposed to a wave function collapse, decoherence is a kind of 'irreversible entanglement.'[128] Zeh says:

> the most important fruit of decoherence (that is, of a universal entanglement) is the fact that no classical concepts are required any more on a fundamental level … [and no] need for a fundamental concept of 'observables' (which would assume certain values only upon measurement).[129]

Such a viewpoint implies the end of classical physics, even on a macroscopic scale, except (perhaps ironically) for practical purposes. It also implies the demise of Heisenberg's antirealism, as this is a realist view. The universe itself *is* a quantum system, but if there is enough interference between its parts, decoherence occurs and the quantum state will very quickly decohere into what appears as a macroscopic or classical form.[130] This 'at least suggests, a solution to the measurement problem'[131] and solves the Schrödinger's cat paradox, as the environmental effects upon such a large and complex object as a cat would cause it to decohere into a form that appears classical almost instantaneously 'for all practical purposes.'[132] Thus, according to decoherence theory, there is *no* pre-determined cut between the quantum and macroscopic domains. The apparent transition depends on scales, energies and the ultimately unavoidable environmental influences, which, in a Bohrian sense, depend on the types of 'conjugate' measurements.[133]

A survey conducted in 2016 found that decoherence is physicists' favoured solution to the measurement problem. [134] This may point to a shift away from the antirealist attitudes prevalent in the twentieth century; however, the same survey found that the majority of physicists stated that the Copenhagen Interpretation was their preferred version of quantum mechanics. It seems there is no pre-defined hard-edged cut between the quantum and macroscopic realms, although traditional quantum mechanics 'requires us to idealise measurements as having infinitely sharp boundaries.'[135] However, there is a catch. As Zeh himself pointed out,

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[126] Zeh, "Roots and Fruits of Decoherence", p.118
[127] Ibid.,
[128] Ibid., p. 123. This is where such concepts begin to get tricky (to say the least), and too complex to fully unfold in this exegesis.
[129] Ibid., pp. 118–119
[130] Zeh has calculated the decoherence of small macroscopic systems such as a speck of dust to be in the region of picoseconds.
[131] Schlosshauer, Maximilian. "Decoherence, the Measurement Problem, and Interpretations of Quantum Mechanics." *Reviews of Modern Physics* 76, no. 4 (2004): 1267-1305. Accessed May 19 2017. https://arxiv.org/abs/quant-ph/0312059v4.
[132] This term, also known as FAPP, was a favourite of John Bell, and belies an experimentalist edge.
[133] Zeh, "Roots and Fruits of Decoherence", p.119
[134] Sujeevan Sivasundaram and Kristian Hvidtfelt Nielsen, "Surveying the Attitudes of Physicists", 2016.
[135] Wallace, *The Emergent Multiverse,* p.17

'Feynman said "the concept of a universal wave function has serious conceptual difficulties. This is so since this function must contain amplitudes for all possible worlds depending on all quantum-mechanical possibilities …"'[136] Such a universal wave function would be so complex[137] as to be practically incalculable,[138] and would require an observer outside the universe itself. Thus this concept is unfalsifiable.

There is (at least) one more twist in the tale regarding quantum measurement: the concept itself may itself be fundamentally flawed. I conclude this discussion with John Bell, and his radical empirical article, perhaps inspired by Feyerabend and Sontag, which is provocatively titled *Against Measurement*:

> The first charge against 'measurement', in the fundamental axioms of quantum mechanics, is that it anchors there the shifty split of the world into 'system' and 'apparatus'. A second charge is that the word comes loaded with meaning from everyday life, meaning which is entirely inappropriate in the quantum context. … in fact the word has had such a damaging effect on the discussion, that I think it should now be banned altogether in quantum mechanics. I think it would be good to replace the word 'measurement', … by the word 'experiment'. For the latter word is altogether less misleading.[139]

In refuting the notion of an outside observer objectively measuring a quantum system, Bell asked:

> What exactly qualifies some physical systems to play the role of 'measurer'? Was the wavefunction of the world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer, for some better qualified system ... with a PhD?[140]

1.9. Conclusion

As Feyerabend stated, 'the history [and thus the current state] of science will be as complex, chaotic, full of mistakes and entertaining as the ideas it contains.'[141] This statement is echoed in this chapter, and has indeed informed my method of presenting the history and ideas discussed in this exegesis. The path taken over this chapter has been one of chaos and colour, amidst struggles to keep consistency in a dynamically changing landscape. In a way, we have come full circle. Starting out with Popper's grand unifying epistemology, we have gone from a kind of certainty about uncertainty, through attempts to find a logic and consistency in applying the Copenhagen framework of antirealism, bringing confusion about cats and where the quantum/classical divide exists, to entanglement within and with the universe itself, and finally coming to a position, from a realist viewpoint, that states there is no divide between the quantum and macroscopic, which is, however, unfalsifiable.[142] And, although we are now surrounded by the technologies spawned by quantum revolutions,[143] there is still uncertainty surrounding the implications of quantum theory,[144] the debate between the realist and antirealist schools is ongoing, and the spirit of Einstein lingers.[145]

To conclude, this chapter has presented some insights into the key concepts found in the theories surrounding particle physics, through an unfolding of their historical, philosophical and epistemological parameters. The

[136] Zeh, "Roots and Fruits of Decoherence", p.13
[137] Even the idea of this makes the 'Neumannian nightmare' of Von Neumann chains pale in comparison (Feyerabend, *Against Method*, p.44, footnote 25).
[138] The pro-decoherence physicist Maximillian Schlosshauer asked whether they should 'dare to postulate this total state'. Schlosshauer, *Decoherence*, p.8.
[139] Bell, 'Against measurement', *Physics World*, 3, no. 8 (1990): 33
[140] Ibid.
[141] Ibid.
[142] It is also evident from this journey that such solutions seem to create yet more problems.
[143] Such technologies range from atom bombs to iPhones. They are discussed more in Chapter 2.
[144] See Sivasundaram and Hvidtfelt Nielsen, "Surveying the Attitudes of Physicists".
[145] In fact, after a visit to CERN, a well-dressed yet evidently eccentric elderly lady on the train told me that 'the spirit of Einstein is watching you!'

key concepts to take from this are as follows: the unobservability and unknowability of quantum objects; the uncertainty regarding quantum properties such as position and momentum; the relationship between phenomena and apparatus; entanglement, the nature of quantum properties; the measurement problem and the division between quantum and macroscopic realms; and decoherence, the interaction between quantum systems and their environment. Essentially, in this chapter I have described the science which suggests that a fundamental division between the subatomic and macroscopic regions of the material universe exists, and yet shown that the division between these realms is ill-defined; it is shaped by the phenomena produced and the apparatuses used to observe, measure or indeed create such phenomena.

Upon reflection, this chapter might be seen as an overly theory-laden account of reality.[146] Another way to gain insights into the universe as seen through the processes and devices of particle physics is from the perspective of the experimenters, and indeed from the point of view of the apparatuses themselves. This perspective is taken up in Chapter 2.

[146] Hacking, *Representing and Intervening,* p.173

Chapter 2 – The Universe and the Laboratory

In this chapter I examine the experimental and material aspects of particle physics. As described in the concluding remarks of Section 1.9, particle physics is a theory-laden field. Feyerabend 'denounces it [the concept of science being theory-laden] but not because he thinks some [scientific] statements are theory free. Theory is everywhere.'[1] This raises questions about the relationships between theory and experiment. As is discussed in this chapter, for those working in experimental physics, 'the issue is not whether theory entered, but which theory and how it intruded.'[2]

In Chapter 1, discussion regarding experiments and measurement was restricted to the use of experiments as empirical means of validating hypotheses. I detailed how the Copenhagen Interpretation of quantum physics is underwritten by an anti-realist stance, charging that the theories of quantum physics do not provide a meaningful picture of the underlying reality. As subatomic entities cannot be directly observed, and the theories framing the experiments give rise to paradoxical interpretations of the measurements, these interpretations (theories) create anomalies in the representation and formations of realism. In this chapter I observe science from the other side, so to speak – from the side of the experiments. I examine the material aspects of particle physics experiments, and through this examination explore other aspects of particle physics, such as the social and cultural parameters.

Laboratories are sites of knowledge production, in the form of the results of scientific experiments, yet they are also sites of practice and culture. As physicist-cum-science-sociologist Andrew Pickering states, such a culture can be seen in 'a broad sense, to denote the "made things" of science …[such as] skills and social relations, machines and instruments, as well as scientific facts and theories.'[3] In this chapter I embrace such an encompassing view of these dimensions of science. Aside from providing a counterpoint to theory-centrism, this chapter provides a cultural and material framework in which to view the concepts explored in Chapter 1. As in Chapter 1, I take a genealogical approach to the structure of this chapter, in part to engage with the overwhelming complexity of contemporary laboratory experiments through the material histories of the devices. I discuss the social and agential aspects of such devices in Section 2.4, and analyse their material epistemicity in Section 2.5. Although particle physics largely relies on mathematics, I do not engage directly with it but instead explore its relations with experiments through the use of models, data and information.

2.1. Experimenting

In this section I shift from quantum physics to particle physics, from theory to experiment, in reflection of the developments that occurred in particle physics over the latter part of the twentieth century.[4] As outlined in Chapter 1, the leading theoretical physicists of the twentieth century held either realist or antirealist interpretations of the material nature underlying their theories. Was an electron, for example, a

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[1] Hacking, *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press, 1983, p.173

[2] Galison, Peter. *Image and logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press, 1997, p.328

[3] Pickering, Andrew. *The Mangle of Practice: Time, Agency, and Science*. Chicago: University of Chicago Press, 1995, p.3

[4] This overview parallels the discussion of experiments in art practice in Section 3.2.

theoretical model of some entity which only produced secondary effects within measuring devices? As the theories and models changed, and the scientists argued over their interpretations, their understanding of the particles in question changed, but did the particles change? In *The Scientific Image*, the antirealist Van Fraassen asked 'whose electron did Millikan observe; Lorentz's, Rutherford's, Bohr's, or Schrödinger's?'[5] The experimental physicist and philosopher Ian Hacking's realist reply was that the scientists 'were all talking about electrons. They [just] had different theories about electrons.'[6] Through both theory and experiment, the image or representation of such a hypothetical entity comes more into focus, through more precise experiments involving the determination of physical variables such as mass and charge.[7] Nonetheless, at least for an experimenter, the reality of such an entity is made concrete when you can use it (described below). This shift from the empirical antirealism of the Copenhagen Interpretation is revealed in poetic exclamations such as this:

> Entities, states and processes described by correct theories really do exist. Protons, photons, fields of force are as real as toe-nails, turbines, eddies in a stream and volcanoes… interactions of small particle physics are as real as falling in love.[8]

A champion of experimentalism in science, Hacking, stated 'Don't just peer, interfere!'[9] This proclamation, perhaps his own kind of radical empirical principle, signals a material turn from the theoretical to the physical in particle physics. A key to this shift is the recognition of the material and practical impacts of experimental science upon epistemology. In this sense, one gains knowledge of the physical attributes of subatomic particles by *using* them. Familiarity with the electron, for example, produced a shift from it being a theoretical to a physical entity, its manipulability giving 'added credence to its reality.'[10] Electrons are now commonly used as tools, in experiments ranging from desk-sized electron microscopes to the three-kilometre long Free Electron Laser experiment (XFEL) at the Deutsches Elektronishes Synchrotron (DESY) in Hamburg, Germany (discussed in Chapter 4). Hacking described the material underpinnings of such a transition: 'By the time that we can use the electron to manipulate other parts of nature in a systematic way, the electron has ceased to be something hypothetical, something inferred. It has ceased to be theoretical and has become experimental.'[11]

According to Hacking, some of the breakthroughs in particle physics came 'not from the theory but … from a keen ability to get nature to behave in new ways.'[12] His response to the debate in question is as follows: 'Realism and anti-realism scurry about, trying to latch onto something in the nature of representation that will vanquish the other ... That is why I turn from representing to intervening.'[13] Hacking's position within the epistemological debate regarding scientific realism is known as entity realism. From Hacking's experimentally centred point of view, there are 'two distinctions: between theories and entities, and between two kinds of

[5] Van Fraassen, *The Scientific Image,* p. 214. Milikan was the first to measure the charge of a single electron, and for it won the Nobel Prize in 1923.
[6] Hacking, *Representing and Intervening,* p.81
[7] Ibid., p.83
[8] Ibid., p.21
[9] Ibid., p.189
[10] Galison, *Image and Logic,* p.427
[11] Hacking, *Representing and Intervening,* p.262
[12] Ibid., p.158
[13] Ibid., p.145

unobservable entities: experimental entities and theoretical entities.'[14] Entity realism posits that if you can experimentally, materially intervene or interact with unobservable entities, via scientific apparatuses, they are real. Theoretical entities, however, are not considered real until they can be physically manipulated through specific experimental setups, in accordance with Bohr.

Peter Galison, a historian of physics, analysed particle physics in a way that supports Bohr's apparatus–phenomena relations (as discussed in Sections 1.4 and 1.5), but which also engages with entity realism as described by Hacking. Galison states 'experimental physicists confront nature through instruments, their daily work largely determined by the character of the apparatus.'[15] Galison provides a detailed material history that runs in parallel to the developments described in Chapter 1, regarding the manifestation and measurement of subatomic phenomena, in essence from the point of view of the apparatuses themselves. A brief overview of this history provides another path into the realm of particle physics, and addresses the question of what an experiment is. As Galison states, 'The genealogy of these instruments helps to explain how they became certified as legitimate keys to the domain of the subvisible … a history – refracted through specific material objects' of the experimental devices.[16] Such a genealogy is outlined below.

Around the time Planck made the first quantum breakthrough, the Scottish scientist Charles Wilson was building the first 'cloud chambers', spherical pressurised glass vessels containing supersaturated vapours. He originally wanted to study cloud formations on location in the Scottish Highlands, in the naturalist tradition of nineteenth-century scientists, but something kept interfering with the process, causing condensation tracks in even the cleanest of glass vessels (which he painstakingly hand-blew). He tried to get the 'damn spots' out of his chambers,[17] but soon realised they were produced from cosmic particles interacting with the gases in the supposedly hermetically sealed apparatuses. Wilson developed his cloud chambers into particle observation devices, which created mini vapour trails when particles were 'injected' into them from early cathode ray tube (CRT)-based linear accelerators.[18] The tracks were photographed and the images analysed to work out what sort of particles might have created the various visual forms.

Radically reworking the concept behind the linear accelerator was Ernest Lawrence, who invented the cyclotron, the first circular particle accelerator, in 1934. It was composed of two D-shaped electromagnets around a circular vacuum chamber; the magnetic fields oscillate, causing charged particles to spiral from the middle to the outer edge, accelerating on the way. His first cyclotron cost 25 dollars to make and could fit in the palm of his hand. In the 1950s Donald Glaser brought cloud chamber and cyclotron technologies together in the form of the first bubble chambers,[19] where particles are accelerated into detector chambers, for which

[14] Miller, Boaz. "What Is Hacking's Argument for Entity Realism?" *Synthese* 193, no. 3 (2016): 991-1006, p.994

[15] Galison, *Image and Logic,* p.315

[16] Ibid., p.5

[17] One is tempted to make a comparison with another famous Scot and her 'damned spot', Lady Macbeth (Shakespeare, *Macbeth*, Act 5, Scene 1)

[18] Particle accelerators and televisions have a common ancestry: the cathode ray tube (CRT) was invented in 1897 by German physicist Karl Braun. After harnessing the particles accelerating within the CRT, American inventor Allen B. Du Mont developed one of the first modern television sets in 1932. At the same time, English physicists Cockcroft and Walton were building linear accelerators, shooting particles down an evacuated tube eight feet long. Australian physicist Mark Oliphant improved on their accelerator design, devising the first synchrotron in 1950. Robin Fox's *CRT: Homage to Leon Theremin (2012)* manifests this connection, as is discussed in Chapter 3.

[19] The inspiration for this invention has been (erroneously) claimed to have occurred as Glaser gazed into a glass of beer!

he was awarded a Nobel Prize in Physics in 1960. Due to a variety of external forces, such as the Manhattan Project and abundant post-WWII and Cold War scientific funding,[20] these apparatuses significantly increased in size and energy. The development of high-pressure vessels and high-energy accelerators signaled 'a transition in the character [of experimental particle physics] between 1939 and 1959,' which went from 'individuals in little labs [to] gigantism.'[21] This is an example of the material genealogy of particle detector apparatuses — how simple devices develop into highly complex ones. Examples such as this provided a way for me to comprehend aspects of contemporary particle physics experiments historically, which I found very useful when undertaking my research practice at the Large Hadron Collider (discussed in Chapter 4).

To summarise, examining particle physics from an experimentalist's point of view reveals different aspects of the science, a different way to understand subatomic nature. In counter to theory-centrism, a material understanding of subatomic entities brings a practice-based entity realism to such particles – electrons *are* real because you can do things with them, such as smash them together in accelerators. Also, in laboratories 'there is a momentum and motivation to experimentation that is not enslaved to theory… Experimenters do their work to explore new domains of phenomena.'[22] Such statements refute the dominance of theory in the laboratory – as Hacking stated, 'experimentation has a life of its own.'[23]

2.2. Observation

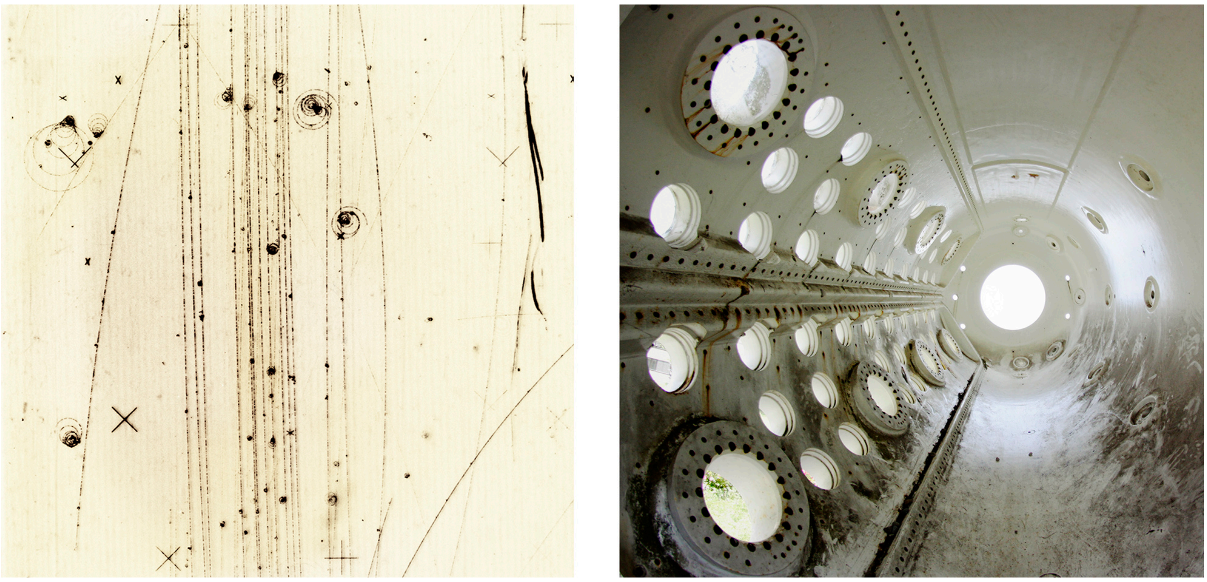

Figure 2. Chris Henschke, "Gargamelle particles and chamber", 2014

As described in Chapter 1, it is not possible to directly observe subatomic phenomena, only their secondary effects produced in apparatuses. Such an indirect or mediated mode of observation is now commonplace – 'the things that are "seen" in 20th Century science can seldom be observed with the unaided human senses.'[24]

[20] It is unfortunately out of the scope of this exegesis to discuss the global political and military pressures acting on physics at this time; it is also unavoidable, but seems remiss, to relegate such things as the Manhattan Project and the development of nuclear weapons to a footnote. However, nuclear physics – the study of atoms – is different to particle physics, which is the study of the *sub*atomic.

[21] Galison, *Image and Logic,* p.315.

[22] Ibid., p.8.

[23] Hacking, *Representing and Intervening*, p.150.

[24] Ibid., p.168.

Scientists now 'speak of "observing" what we would naively suppose to be unobservable,'[25] which illustrates a shift in the importance of the issue regarding observation, described in Chapter 1. Such indirect or technologically enhanced observation occurs at both the largest and smallest scales, ranging from the depths of the cosmos to the subatomic universe. Practically speaking, this means that the observing scientist is 'now located inside a complex system of hardware and software,'[26] which is Bohr's 'agencies of observation' – the apparatuses used in particle physics. Hacking asks, 'why should a philosopher care how [an observation device] works? Because it is one way to find out about the real world.'[27] Such devices, and what they reveal of the subatomic world, and our relation to it, are discussed in detail in this section.

Concurrent to the debates about realism and antirealism, there were disputes in the world of experimental particle physics over the nature and use of images produced in the experiments. The conflict between representation and abstraction was rendered manifest in the forms of the experiments themselves. As Galison argued, 'we can follow two broad classes of detection devices that link the microscopic world with the world of our senses. One class – the image-making devices – produces the pictures, while the other – the logic devices – produces counts.'[28] These two main types of devices are discussed below.

The bubble chambers of the mid-twentieth century produced countless photographic images of fine trails of the particles' paths, analogous to the way that jets leave trails in the sky (see fig. 2). It is important to note, however, that these tracks are secondary effects, the particles themselves being completely invisible, requiring extensive analysis to find important visual signatures. The term 'golden event'[29] was used to describe a perfectly captured photographic image of a rare or important particle produced in such a setup. These images came with 'the promise of the homomorphic representation, the ability to mimic nature through nature's own inscription.'[30]

Regarding the mimetic qualities inherent in photographs, a way of describing the photographic process in relation to experimental physics is as follows:

> a mechanical reproduction in the making of which man plays no part. … between the originating object and its reproduction there intervenes only the instrumentality of a nonliving agent. … an image of the world is formed automatically, without the creative intervention of man.[31]

This gives such images an ontological connection with the objects they represent: the photograph 'shares, by virtue of the very process of its becoming, the being of the model of which it is the reproduction; it is the model.'[32] Such images have an indexical correspondence with what they represent. Photographs are indexical in that they 'correspond to reality by their contiguity with the depicted object at the moment of their production.'[33] As semiotician Winfried Nöth stated, 'photos are characterized by … indexicality in general, namely: "The index asserts nothing; it only says 'There!' It takes hold of our eyes, as it were, and forcibly

[25] Ibid., p.183.
[26] Galison, *Image and Logic,* p.430
[27] Hacking, *Representing and Intervening*, p.186
[28] Galison, *Image and Logic,* p.4
[29] Ibid. p.25
[30] Ibid., p.426
[31] Bazin, Andre, The Ontology of the Photographic Image (translated by Hugh Gary)." *Film Quarterly* 13, no. 4 (1960): 4., p.7
[32] Ibid., p.8
[33] Ibid.

directs them to a particular object, and there it stops."'[34] This is also true in regard to photographs of particle phenomena when examined by scientists or 'scanners'. Bubble chamber images in the mid twentieth century were analysed by 'scanners' (trained non-physicists), who looked for particular features that might signify unique particle interactions. Literally millions of images were examined this way, usually in darkened rooms containing 'scanning tables'. Many of the scanners were women,[35] and it is perhaps ironic that the scanning table system used at CERN was called MILADY.[36]

Other experimental detector designs from the 1950s and 1960s are not only notable for their novelty but also for their failures – as Hacking observed, 'most experiments don't work most of the time,'[37]. As the interfaces between the realm of the human subjects and the subatomic objects, experiments themselves may live, they may be changed and mutate in an ad hoc manner, and if unsuccessful they may die.[38] One unique mode of experimentation, which had a short lifespan, was the sonic spark chamber. This was developed at CERN by experimentalist Georges Charpak[39] in the early 1960s. The sonic spark gap chamber utilised the acoustic phenomena produced in detectors. Charpak developed a method that used an array of transducer probes (microphones)[40] to locate the sound of the sparks produced from collisions.[41]

However, the unique mimetic forms of representation described above, and idiosyncratic methods used to create them, often by 'individuals in little labs'[42] such as Glaser's small teams, were challenged by Luis Alvarez, one of the key scientists involved in the Manhattan Project. Alvarez's regimented experiences and regulated methods steered the science towards an analytical logical system that built up mathematical models from multiple experiments. He established the 'big-science approach to particle-physics … that came increasingly to dominate the field' from the 1960s onwards.[43] As newer types of experiments and electronic detectors were developed, the visual knowledge attained from the golden events were superseded by the numerical and statistical analysis Alvarez championed. However, 'no individual click of a Geiger–Muller counter could serve

[34] Ibid. This is a semiotic relationship, but a study of semiotics is out of the scope of this exegesis.

[35] It should be noted there was a dearth of official recognition of the role women took in such laborious activities, which can be illustrated by this peculiar paragraph in the 1973 CERN Courier (which also throws in a somewhat surprising reference to contemporary art of the time (that also refutes C.P.Snow's edict)): 'Mechanical gadgets are intrinsically fascinating – witness the popular appeal of the kinetic art of Swiss sculptor Jean Tinguely – and physicists with an engineering bent, a flair for computing and unbridled ingenuity found the challenge of constructing scanning machines irresistible. Given the dearth of female physicists in labs at the time and the fact that most scanners were "girls", computer-aided data analysis often gave rise to computer-aided dating. Many a romance began in the purlieu of a scanning room, sometimes blossoming into a lifelong relationship, sometimes ending in heartbreak. There must be several senior readers who can confirm this!' Sourced from http://cerncourier.com/cws/article/cern/65041

[36] As will be mentioned in Chapter 4, I undertook a short 'scan' of some bubble-chamber film from CERN, which itself took hours. I turned the forms I collected into a short animation homage, called *Bubbles for the Ladies.*

[37] Hacking, *Representing and Intervening,* p.230

[38] One attempt by Glaser was to capture particle tracks in solid form within a liquid polymer – 'the "total fantasy" was to create a "solid Christmas tree of tracks" … this try was an utter failure, resulting in much brown liquid and no tracks' (Galison, *Image and Logic,* p.325). This desired effect is reminiscent of the 'Lichtenberg trees', lightning-like structures that form in acrylic blocks when high-energy particles pass through them. This was an experiment I attempted to undertake at the Australian Synchrotron as part of my research project, but a few hours before the experiment was due to take place, I was stricken with a terrible disease.

[39] Charpak later developed the wire chamber, a kind of multi-wire Geiger counter, for which he was awarded the Nobel Prize in Physics in 1992.

[40] Wenzel, W.A. "Recent Developments in Spark Chambers." *IEEE Transactions on Nuclear Science* 13, no. 3 (1966): 34-45, p.38.

[41] This innovation informed my project Song of the Muons, which is described in Chapter 4.

[42] See footnote 20.

[43] Pickering, Andrew. "New Ontologies." In *The Mangle in Practice: Science, Society, and Becoming,* edited by Andrew Pickering, and Keith Guzik, 1-14. Durham: Duke University Press, 2008, p.570.

as evidence; the electronic devices could persuade only by *accumulating*.'[44] Galison sums up the tension that developed between the 'image and logic traditions':

> Images [captured in bubble chambers] are presented, and defended, as mimetic – they purport to preserve the forms of things as they occur in the world. … Against this mimetic tradition … [is] the 'logic tradition' which has used electronic counters coupled in electronic logic circuits… to make statistical arguments for the existence of a particle or effect. The clash of image and logic traditions [is the clash of the] golden event versus statistical demonstration, the objectivity of passive registration versus the persuasiveness of experimental control, vision versus numbers, and photography versus electronics.[45]

A parallel can be drawn between Schrödinger vs Heisenberg, and Glaser vs Alvarez – in other words, between those who sought visualisability and those who only counted on the mathematics. It is also interesting that Bohr's epistemology frames this, particularly his insight into phenomena and apparatuses. An experiment designed to produce images will do so, and one designed to produce numerical data gets numbers. Arguably, both forms are needed to gain the fullest possible understanding of the various aspects of the phenomena in question. Such experiments are therefore complementary, as defined by Bohr: both types of experiment are needed to gain the fullest possible understanding of the phenomena, yet the types of experiments are mutually exclusive, in that one experiment cannot measure both types of properties.[46]

To summarise, observation in particle physics is mediated by the apparatus used and the types of experiments undertaken. This concurs with Bohr's concept of phenomena (see Section 1.6), the relation between the subatomic entities and the apparatuses used to measure or observe them, and his theory of complementarity (see Section 1.5), in that different aspects of a phenomenon are revealed through different experimental setups. Also, golden events were challenged by the statistical and numeric methods of multiple observations; these are brought together in contemporary hybrid detector experiments. From the above discussion, I conclude that experimental observation is an interplay of matter and meaning, an interplay which develops dynamically in time, in line with the development of the apparatuses of observation, the detectors. This conclusion raises questions, discussed in Sections 2.3 to 2.5, as to the nature and delineation of such apparatuses.

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[44] Galison, *Image and Logic,* p.437

[45] Galison, *Image and Logic*, pp. 19–25

[46] As discussed in footnote 99 of Chapter 1, Karl Popper tried to devise an experiment to measure two properties. Also, more recent experiments, such as the quantum eraser, seek to measure complementary properties with the one apparatus, leading to some surprising results, which are discussed in the *Intermezzo*.

2.3. Detectors

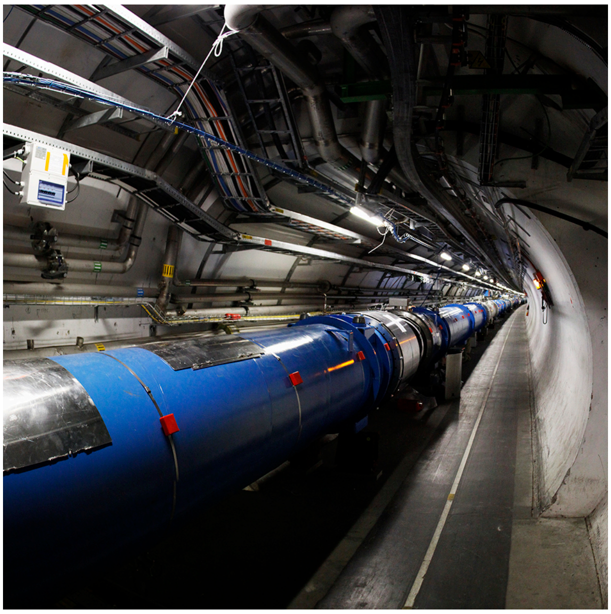

Figure 3. Chris Henschke, “LHC tunnel”, 2013.

The Large Hadron Collider (LHC) at CERN near Geneva, Switzerland, is the largest scientific experiment in the world. The LHC is a circular device 27 kilometres in circumference (see fig. 3), which accelerates subatomic particles to almost the speed of light, then smashes them together, releasing trillions of electron-volts of energy.[47] The particles collide in gargantuan detectors, such as the Compact Muon Solenoid (CMS), a 12,000-ton five-storey-high device, situated 100 metres underground on the French-Swiss border, which is capable of recording up to a million collision events every second in three dimensions, using 100 million individual detector components. Data from the detector is used to reconstruct collision events, revealing fundamental aspects of the invisible world that could not otherwise be known.

The once-competing logic and mimetic experimental methods, described in Section 2.2, have been brought together in contemporary subatomic physics experiments. The devices involved represent a shift from the pure to the hybrid experiment. Heralding a renaissance in subatomic imaging, contemporary particle physics experiments using the LHC combine image and logic-based analysis, in what Galison called a transition from ‘the modern to the postmodern laboratory.’[48] Detectors in these devices are ‘high-tech bricolages’ of both bubble chamber and electronic logic devices.[49] These hybrid detectors contain the historical epistemology of experimental particle physics, in which events are ‘produced by electronics, fished by a computational net out of the ocean of microphysical debris’[50] through what are called golden channels, a term that is a nod to the golden events of the bubble chamber era. However, unlike the singular indexical image, golden channels can be comprised of literally millions of separate data channels that comprise contemporary detectors. These are

[47] This may sound like a lot of energy, but on a macroscopic scale it actually isn’t – a mosquito flying across a room has about a trillion electron-volts of energy. And yet, although this may now not sound like a lot of energy, if it is focused upon one subatomic particle of the aforementioned mosquito, it is tremendous! Such seemingly contradictory viewpoints show the dramatic changes in magnitude when shifting different points of view, especially between the macroscopic and subatomic.

[48] Galison, *Image and Logic*, p. 553

[49] Ibid., p. 550

[50] Ibid., p. 551

reconstructed into three-dimensional digital models or representations of the collision events, known as signatures. [51] Like bubble chamber tracks, these signatures are only secondary; the actual particles are ultimately inferred and probabilistic, due to various factors, from their extremely short lifetime to noise in the system (see Section 2.7), but also because of Heisenberg's uncertainty principle.[52] The signatures are constructed through an almost unimaginably complex process that begins in the hardware of the detectors themselves, which filter high-energy events from countless other collisions. These are sent through various levels of automated signal processing and data analysis, and a subset of these selected events are further analysed by computers and finally the physicists, in a complex intertwining of data, models and theory, using literally over a million lines of computer code.[53]

Such signatures are not mimetic or homomorphic in the way golden events are, but they are produced in a way that scientists see as being objective, in that they are 'formed automatically, without the [scientists'] creative intervention.'[54] Yet they have a different ontological connection with the objects they represent to that of photographs (described above); they are a hybrid of image and numbers, being and knowledge. As ethnographer Arpita Roy stated, the 'characteristic patterns of decay formed by particles subsequent to collisions, such as a Higgs boson decaying into two energetic photons, are termed signatures and constitute the chief unit of discovery in [contemporary] particle physics.'[55] I agree with Roy in that such signatures are unique as they are both things and signs of such things, bringing together physical forms and knowledge in a 'coalescence of the human and the material.'[56] Roy stated that 'the signal is real … not because it is materially present in a collision…[but] because the physicist recognizes or receives it.'[57] In other words, such signatures are a combination of matter and meaning; they are ontological and epistemological.

There are very complex technical parameters all along the chain of processes that occurs in the detector between the actual particle collisions to the reconstructed event that appears on a computer screen. A fundamental aspect of the complexity is due to the high-energy nature of the experiment itself, in line with Einstein's seminal equation $e=mc^2$, which literally describes the equivalence of mass and energy; such collisions produce intense energy. This occurs when the particles travel as close to the speed of light as possible (which is the purpose of a particle accelerator), and collide. In this process their mass becomes energy, which produces other types of matter. Rarely, they may be in the form of theorised high-energy particles for which the physicists are searching, but usually lots of other particles are produced, which are considered 'junk',[58] as they have previously been discovered (possibly by the MILADY ladies), classified, and

[51] A variation on such hybrid detectors, which uniquely manifests Glazer's idea of capturing tracks in a solid volume, is the time-projection chamber, such as the ALICE experiment at CERN, which Galison described poetically as 'an image falling through space'.

[52] Such inference means that entities like the Higgs are still rare enough not to be real in Hacking's sense, but they are statistically very highly probable, of a degree of over the 5 Sigma standard, meaning that if the Higgs didn't exist, there is a 0.0000003% chance that the detector data would randomly show that it did.

[53] This brings to mind both Habermas' concept of the 'neue-unubersichlichkeit' or unsurveyability of the overall system (as mentioned in the Preface), and in contrast, the notion of the 'superorganism' (as discussed in Section 2.4).

[54] Bazin, "The Ontology of the Photographic Image", p.7

[55] Roy, Arpita. "Ethnography and Theory of the Signature in Physics." *Cultural Anthropology* 29, no. 3 (2014): 479-502, pp.479-480

[56] Ibid., p.485

[57] Ibid., p.485

[58] I found a specific instance of such 'junk' events unique and compelling, and used it in an artwork, *Edge of the Observable*, discussed in Chapter 4.

filed away. As Galison stated, once 'you have seen one anti-muon-neutrino you have seen them all.'[59] Due to this junk, the half-a-billion collisions that occur every second create a tremendous amount of noise in the detectors, which has to be removed from the signals, data and subsequent reconstructions, and this is not a straightforward or easy task (data and information is discussed in Section 2.7).

As an example, experimental research using the CMS detector proved the existence of the theorised Higgs boson, a fundamental particle so ephemeral and short-lived (in the order of femtoseconds) it is called a 'resonance [which is] indicative of a previously unknown particle.'[60] In conducting such research the scientists are 'bump-hunting', as it is colloquially called – looking for unexpected peaks in the data. A bump, such as the one that signalled the Higgs boson, 'is the peak around which a cluster of events coheres', which 'gives meaning to the aforementioned signatures';[61] 'these bumps became more than the sign of a resonance, they became signs of a new particle in nature'.[62]

2.4. Hermetic worlds

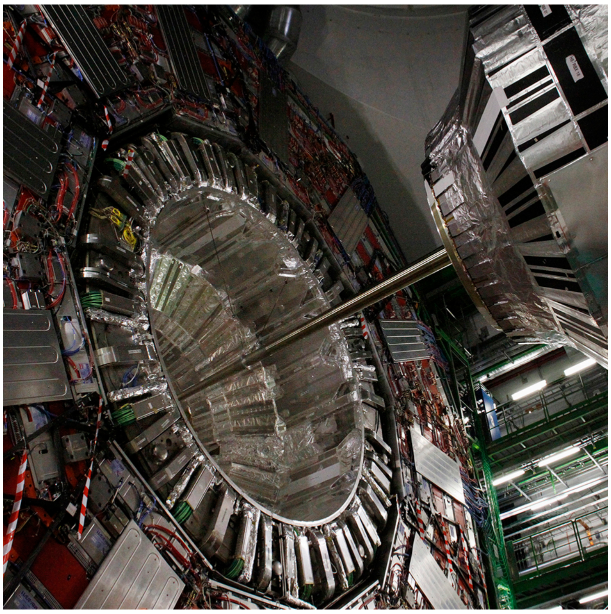

Figure 4. Chris Henschke, "CMS detector", 2015.

A detector such as a CMS is more than just the sum of its technologies and the objects that comprise its material dimensions (see fig. 4). These 'megalithic machines'[63] are both material and social microcosms, and the fact that they are known as 'hermetic detectors'[64] belies a poetic dimension to the technical terminology; as in Borges' story of 'The Zahir', both the human and electronic eyes are focused inwards upon one point.[65] As Galison stated, 'each detector is a world in itself',[66] comprising both the devices and the groups

[59] Galison, *Image and Logic,* p.20
[60] Baggot, J.E. *The Quantum Story: a History in 40 Moments.* Oxford: Oxford University Press, 2011, p.269
[61] Roy, "Ethnography and Theory of the Signature in Physics", p.491
[62] Galison, *Image and Logic,* p.426
[63] Ibid., p.688
[64] Frass, William. "Particle Detectors." Lecture, Particle Physics, Oxford: Oxford University, Michaelmas 2009. Accessed 18 July 2017. http://www2.physics.ox.ac.uk/sites/default/files/Detectors.pdf, p. 23.
[65] Borges, Jorge Luis. *Labyrinths: Selected Stories and Other Writings*. London: Penguin Books, 2000, pp. 189-197.
[66] Galison, *Image and Logic,* p.688

of scientists who design, construct, and operate them. Almost four thousand scientists, engineers and technicians operate the CMS. Sociologist Karin Knorr Cetina used the term 'superorganisms'[67] to describe such combinations of detector and scientists. Knorr Cetina pointed out that the detector is 'never like a robot that simply performs all tasks… [but] more like a three-dimensional mosaic of working bits and pieces, including human interfaces.'[68]

In addition to the physical energies used in the experiments, the practice of high-energy physics involves huge amounts of human intellectual and social energy. The environments of high-energy physics facilities are 'marked by a constant humming of the experiment.'[69] This does not just relate to the mechanical hum of the machines, but the hum of communication between the scientists, and indeed, between the people and the detector itself. Knorr Cetina described this as 'a sort of consciousness, an uninterrupted hum of self-knowledge.'[70] Such a hum speaks of the highly complex feedback mechanisms within the device, between the millions of components in the detector, between the detector and the scientists, and among the scientists themselves. Ultimately, the detectors are the interfaces between the scientists and the fleeting forms of subatomic nature they are seeking – 'physicist and nature meet in the detector, where knowledge and passion are one.'[71]

From the view of the scientists themselves, these 'massive instruments are physiological beings, with behavioral states and idiosyncrasies.'[72] Although the description of a detector as a physiological being 'is clearly fictional,' Knorr Cetina, who has undertaken field research at CERN, stated:

> At the same time, [describing a detector as a being] is an expression of the very real ways of handling the instrument, of the kind of responses one gets from it, of the sort of relationship when the instrument is completed and running, of the type of thing *not* expressed by the technical vocabulary, which is *also* present.[73]

Scientists have even expressed love for their machines:[74] upon entering the detector cavern at CMS, I overheard one scientist (somewhat self-mockingly, in a Gollum-like tone) call it 'my precious!' Working with such apparatuses can produce strong emotional bonds. Having 'the opportunity to know the apparatus ... made part of it and suffered through its failures ... is an integral part of knowing how to create phenomena.'[75] Such emotional ties are thus an integral and necessary part of the research, and belie a deeper engagement than the stereotype of the cold and disconnected scientist suggests. As Ian Hacking stated:

> Noting and reporting readings of dials – Oxford philosophy's picture of experiment – is nothing. Another kind of observation is what counts: the uncanny ability to pick out what is odd, wrong instructive or distorted in the antics of one's equipment. The experimenter is not the 'observer' of traditional philosophy of science, but rather the alert and observant person.[76]

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[67] The term "hive mind" is also used to describe such large-scale scientific collaborations, however in keeping within a material framework I shy away from this term and its Cartesian undertones.
[68] Knorr Cetina, Karin. *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge: Harvard University Press, 1999, p.130
[69] Ibid., p.173
[70] Ibid., p.178
[71] Traweek, Sharon. *Beamtimes and Lifetimes*. Cambridge: Harvard University Press, 1992, p.17
[72] Knorr Cetina, *Epistemic Cultures,* p.114
[73] Ibid., p.250
[74] Ibid., p.122
I have also heard of physicists speaking of "detector fetishes".
[75] Hacking, *Representing and Intervening,* p.230
[76] Hacking, *Representing and Intervening,* p.230

The bonds with devices are due to the combination of intellectual and emotional energy the scientists put into them, which in turn increases the scientist's identification with their devices. 'Detectors are distinctive and serve as the "signature" of the group. … Their conception and development, their maintenance, their performance … are the stuff of frustration, hope, heartbreak and triumph for research groups.'[77]

Nevertheless, it should be noted that these apparatuses ultimately function without such subjective human and social parameters. As Roy stated, 'once a technology is instituted, it *functions* independently of the scientist or engineer, whose presence becomes extraneous and is required simply for maintenance, safety and repairs.'[78] Although personal and emotive factors are part of the scientific process in the day-to-day reality of developing and running such experiments, they are not part of the objective output as dispassionately presented in scientific reports. As prescribed by Bohr (amongst many others), such reports are in a sense the essence of science; they include precise and accurate descriptions of the experimental setup as well as the data that was produced, in order that the experiment can be analysed or repeated.[79] Overall, objectivity requires that such data is 'without reference to the scientist'.[80] Although the experimental work, as described above, is of a material nature, often the results are reduced to mathematical equations, numerical data, and graphs:

> By contrast with the expense and bulk of this apparatus, the end product [of an experiment] is no more than a curve, a diagram, or a table of figures written on a frail sheet of paper. It is this document, however, which is scrutinised by participants for its 'significance'.[81]

Hence, the use of the LHC to discover the Higgs boson produced a result that was presented as, and ultimately reduced to, a small bump in a curve on a graphic display.[82]

In summary, scientists involved in high-energy physics experiments are very passionate about their work (which is not surprising, as they are on the edge of both nature and knowledge), but such emotive aspects are not presented in scientific reports in the name of objectivity. Metaphorically speaking, these experiments are alive and have personalities and idiosyncrasies, and, as the detectors aid the scientists' bump-hunting for unique signatures of new particles, each detector is itself a unique signature for the group of scientists working on it.

The kinds of experiments described above are highly complex and multifaceted, involving both human and material aspects, that they raise the question: where does the experiment end? This reveals a new dimension to the measurement problem. Philosopher Karen Barad provides an example of this dimension with respect to the original Stern–Gerlach experiment from 1922, which is a variation on the two-slit experiment described in Section 1.3. This experiment played a vital role in quantum physics, as it demonstrated that properties such as angular momentum, or spin, have quantized values, and also that such measurements are complementary, in

[77] Traweek, Sharon. *Beamtimes and Lifetimes,* p.49
[78] Roy, *Ethnography and the theory of the signature in physics*, p. 485
[79] However, experiments involving the LHC are so complex and expensive, in practical terms they are unique.
[80] Heisenberg, Werner. *Physics and Philosophy: The Revolution in Modern Science.* London: Allen & Unwin, 1958, p.23
[81] Latour, Bruno, and Woolgar, Steve. *Laboratory Life: The Construction of Scientific Facts*. Princeton: Princeton University Press, 1986, p.50
[82] And yet, this bump made people cry, including Peter Higgs (who originally proposed the Higgs boson's existence), when it was publicly revealed at the International Conference on High Energy Physics in 2012 (of which I played an invisibly small role, putting on an official satellite symposium called 'Colliding Ideas: Art, Physics and Society').

that the spin of multiple axes, such as horizontal and vertical, cannot be known at the same time. However, the success of this experiment depended on a chance encounter between the cheap cigar that Stern was smoking and the detector screen – the smoke of the cigar precipitated a reaction upon the detector screen allowing the spin effects to be seen.[83] In this case the experiment literally extended to, and included Stern's cigar. This serendipitous event was the key in completing the apparatus.[84]

Approaching the question 'where dos the experiment end?' from another angle, a pamphlet describing a scanning apparatus at CERN (similar to the MILADY device described in Section 2.3) recommended a specific curtain colour to aid in the viewing of particle events.[85] This suggests that the experiment itself extended to the curtain.[86] In a recent case that illustrates another limit of the LHC experiment, a weasel bit into a power cable and shut down the LHC.[87] Although the animal's terminal interaction with the apparatus didn't contribute to the experiment, it certainly did affect it. This leads to a more open-ended conception of such apparatuses, as is discussed in the next section.

2.5. Epistemic objects

Another uniquely defining factor of the experimental use of massive and complex equipment such as the LHC, which encompasses both technological and human aspects, is that it is 'a mosaic that remains forever incomplete.'[88] A detector such as the CMS can thus be portrayed as an 'object of knowledge' or 'epistemic object' – the latter being a term scientist Hans Rheinberger used to describe:

> any scientific objects of investigation that are at the center of a research process and in the process of being materially defined. Objects of knowledge are characteristically open, question-generating and complex. They are processes and projections rather than definitive things.[89]

To illustrate this point, in describing the detectors at CERN, Knorr Cetina stated:

> Epistemic objects frequently exist simultaneously in a variety of forms. They have multiple instantiations, which range from figurative, mathematical, and other representations to material realizations. Take the case of a detector in a high-energy physics experiment. 'It' continually circulates through a collaborating community of physicists in the form of partial simulations and calculations, technical design drawings, artistic renderings, photographs, test materials, prototypes, transparencies, written and verbal reports, and more. These instantiations are always partial in the sense of not fully comprising 'the detector'.90

Unlike everyday objects, such as a teacup, these objects are not static, conceptually or materially – they are 'continually unfolding', they 'explode' and 'mutate'.[91] Through analysis, a detector unfolds to reveal parameters ranging from the social and cultural, the theoretical, to the genealogical, not to mention its

[83] Barad, Karen Michelle. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press, 2007, pp.163-167

[84] This also supports Feyerabend's stance that scientific development includes chance, complexity, and colourful characters.

[85] Kongsberg Vapenfabrik, *CERN-SHIVA* (Oslo: undated), Accessed February 26, 2016. CERN-ARCH-PIO-01-14-006, CERN Archives,p. 2

[86] I cannot resist including a curtain-raising quote: 'Pay no attention to that man behind the curtain!' Fleming, Victor, dir. *The Wizard of Oz*. Metro-Goldwyn-Mayer, 1939. DVD. Warner Home Video, 2002.

[87] http://www.bbc.com/news/world-europe-36173247

[88] Knorr Cetina, p.130

[89] Knorr Cetina, Karin. "Objectual practice." In *The Practice Turn in Contemporary Theory*, edited by Karin Knorr Cetina, Theodore R. Schatzki, and Eike Von Savigny, 184-197. London: Routledge, 2001, p.191

[90] Ibid., pp.192-193

[91] Ibid., p.191

material form and complexity. Such unfolding could go on indefinitely,[92] thus these objects are not completely definable.

Such epistemic objects are also more than static material embodiments of concepts; they have 'agency', the capacity to interact with and affect other entities. Such agency is not limited to humans - everything from organisations to atoms can be seen to have agency. As Andrew Pickering stated, 'radioactive sources … are instances of material agency – they are objects that do things in the world.'[93] The technological objects used in particle physics are agents in their own right – they are the mediators between the subatomic matter and the scientists who engage with them and respond to the signals they produce.[94] For Pickering 'we should see [apparatuses such as Glaser's] chamber as a locus of nonhuman agency … its material contours and accounts of its character (scientific knowledge) were emergently produced in the real-time.'[95] Invoking the material agency in apparatuses challenges the notion that

> the end of science is to produce representations of how the world really is; in contrast, admitting a role for material agency points to the fact that, in common with technology, science can also be seen as a realm of instruments, devices, machines, and substances that act, perform, and do things in the material world. 96

In agreement with Pickering, physicist John Bell stated that 'the idea that quantum mechanics … is exclusively even about the results of experiments would remain disappointing.'[97] These statements reflect a realisation that there is a deeper and open-ended relationship between the scientist and the apparatus. As Pickering pointed out, such a relationship is 'temporally emergent' as 'the contours of materially agency are never decisively known in advance, scientists continually have to explore [material agency] … problems always arise and have to be solved in the development of, say, new machines.' [98] In Pickering's view, 'both the human and nonhuman …[take] on emergent forms in an intrinsically temporal "dance of agency".'[99]

In describing the relations between devices and the researchers that develop them, Rheinberger revealed an aspect of estrangement implicit in scientific practice:

> Epistemic things are ... things that let something be desired. They stand for a particular relation to the world: a relation of epistemicity. This relation is exploratory, driven by the desire of finding, not of knowing. Experimenters are specialists in arranging situations in which finding becomes possible. Scientific finding neither obeys the logic of chance nor that of necessity. It obeys a logic of its own, composed of elements of both ... It is a game of eventuation, an engagement with the material world that, on the one hand, requires intimacy with the matter at hand, and, on the other, disentanglement, the capacity of rendering strange – of estrangement. I am convinced that the poet's and the artist's activities share the basic feature of this epistemic condition. … I stress the agency of the material one engages with. In this respect, what unites research materials is eventuation: through a material we step away from what is there, sidestep what is actually realized, toward the unrealized by taking advantage of, to go back to the telling phrase Polanyi uses, its "independence and power for manifesting itself in yet unthought of ways in the future." It is the conviction that the sciences and the arts nourish

[92] The fact that there is no apparent limit or cut to such unfolding brings to mind the measurement problem.

[93] Pickering, Andrew. *The Mangle of Practice: Time, Agency, and Science*. Chicago: University of Chicago Press, 1995, p.9

[94] The ethical and moral aspects of technological objects' agency, as developed by Peter Paul Verbeek, is outside the scope of my research.

[95] Pickering, Pickering, Andrew. "The Mangle of Practice: Agency and Emergence in the Sociology of Science." *American Journal of Sociology* 99, no. 3 (1993): 559-589, p. 568

[96] Ibid., p. 563

[97] Bell, John. "Against 'Measurement." *Physics World* 3, no. 8 (1990): 33, p.34

[98] Pickering, *The Mangle of Practice*, p.14

[99] Pickering, Andrew. "New Ontologies." In *The Mangle in Practice: Science, Society, and Becoming,* edited by Andrew Pickering and Keith Guzik, 1-14. Durham: Duke University Press, 2008, p.1 As is described in Chapter 4, I found this insight to be key in informing my practice.

> themselves from the materials they engage with, constantly stepping away from and over what is already there, without ever being able to precisely anticipate the path they are not merely taking, but creating as they tread.[100]

A state of estrangement seems to be the initial condition of an outsider in such a scientific setting. For example, in response to his first day in a research laboratory, ethnographer-cum-philosopher Bruno Latour[101] wrote:

> What are these people doing? What are they talking about? What is the purpose of these partitions or these walls? Why is this room in semidarkness whereas this bench is brightly lit? Why is everybody whispering? … A flood of nonsensical impressions would follow the formulation of these questions.[102]

As is discussed in Chapter 3, estrangement from the object is part of the artists' toolkit; it is also used by the ethnographer. Latour stated 'we shall … attempt to make the activities of the laboratory seem as strange as possible in order not to take too much for granted.'[103] However, as stated by Latour above, and experienced by resident artists in such settings (as is discussed in Chapter 3), a non-specialist outsider within the 'world-in-itself' of the high-energy physics experiment is initially saturated with estrangement. However, ethnographies (or residencies) that 'reflect on the nature of scientific practice as a spectator, not a participant'[104] may miss aspects that reveal themselves through a deeper engagement. In light of this, what is needed is to develop a physical 'intimacy with the matter at hand,'[105] or in other words, as Hacking stated, 'don't just peer, interfere!'[106]

In summary, the apparatuses used in particle physics are epistemic and relational, in terms of the scientists and the knowledge both put into their development of the devices and the data that they produce. They have agency, and are not fixed in terms of form or use, and they change through time. There is a dynamic and open-ended interaction between scientist and apparatus, between human and non-human entities, in a 'dance of agency.'[107] Through intimacy and estrangement, unique insights can be gained into the relationships between the scientist, the apparatus, and the subatomic. As discussed in Chapter 4, this is a methodology I used at such a physics laboratory.

2.6. Models

Another way to comprehend the LHC is as a physical means to model the conditions just after the Big Bang, the hypothesised beginning of the universe. As discussed in Section 2.3, the energies produced in particle

[100] Rheinberger, Hans-Jörg. "On Epistemic Objects, and Around."Accessed January 15, 2016. http://wdwreview.org/think/on-epistemic-objects-and-around/. As mentioned in Section 1.1, Paul Feyerabend declared himself to be a Dadaist, which seems to be an unusual attitude in a scientist, but the above paragraph by Rheinberger lends itself to such a position. Dadaists, as discussed in Chapter 3, developed methods of interrogation which broke down material objects and language, forms and knowledge, turning them inside out to see them anew, in a kind of "total estrangement".

[101] Bruno Latour and Karin Knorr Cetina are key figures in the fields of Science and Technology Studies (STS) and the Social Studies of Science (SSS) (these have informed my research, however a detailed account of STS / SSS is out of the scope of this exegesis). Latour 'revolutionized the field of science studies' by using methods of ethnography and semiotics, yet also saw that semiotic analysis was inadequate as it referred to 'only texts and symbols instead of also dealing with "things in themselves"'. (Waldstein, Maxim. "The Mangle of Practice or the Empire of Signs: Toward a Dialogue Between Science Studies and Soviet Semiotics." In *The Mangle in Practice: Science, Society, and Becoming,* edited by Andrew Pickering, and Keith Guzik, 221-242. Durham: Duke University Press, 2008, p.222).

[102] Latour (1986), p.43

[103] Ibid., p. 50

[104] Barad, *Meeting the Universe Halfway*, p.247

[105] Rheinberger, "On Epistemic Objects, and Around", 2015.

[106] Hacking, *Representing and Intervening,* p.189

[107] Pickering, *The Mangle in Practice*, p.1

collisions are immense, of cosmic magnitudes.[108] However, these energies are localised to basically subatomic regions within the heart of each detector. As the apparatuses push closer to the conditions present in the earliest stages of the universe, scientists build exponentially bigger and bigger devices in order to reach higher and higher energies, in accordance with the 'inverse relationship between length scale and energy in quantum physics, due to the uncertainty principle.'[109] Thus it is impossible to practically probe the ultimate limit of matter, known as the Planck threshold, as it would require a cosmic accelerator the size of our galaxy – the energy of which may actually kickstart another universe. This problem led to scientists (not quite rhetorically!) asking 'could we "create" a universe in the laboratory?',[110] with the observer finally and literally outside the universe they wish to examine, from a Newtonian god-like point of view. From this one could jump to wildly inaccurate interpretations of the meaning of such terms as the 'God particle' (as the Higgs boson is sometimes called).[111]

Models may exist in a state that is both a representation of nature and nature itself, as is in the case of the LHC and its signatures.[112] Many models used in physics are, however, not material, but mathematical. Hacking identified the unique positioning of such models:

> suppose we say there are theories, models and phenomena ... [such] models are doubly models. They are models of the phenomena, and they are models of the theory. Theories are too complex for us to discern their consequences, so we simplify them in mathematically tractable models … At the same time these models are approximate representations of the universe.[113]

Such models are isomorphic, in that the behaviours of the model and phenomena correspond to greater or lesser degrees. Isomorphism plays a key role in the physical sciences, as it explains how models and mathematical theories can predict natural phenomena.[114] Describing a simulation experiment that connects

[108] When the LHC was about to be turned on for the first time, there were concerns that somehow it would destroy the world, or indeed the universe. Some of these concerns were perhaps well-meaning but ill-informed, and some were of the crazy conspiracy theory type. Some people even tried to pre-emptively sue CERN for sucking the world into a black hole! Their claim is as follows: 'CERN itself has admitted that mini black holes could be created when the particles collide, but they don't consider this a risk… my own calculations have shown that it is quite plausible that these little black holes survive and will grow exponentially and eat the planet from the inside… We submitted this application to the European Court of Human Rights as we do not believe the scientists at CERN are taking all the precautions they should be in order to protect human life' (The Telegraph, 30 Aug 2008). However, my ill-informed take on this is that it was in fact a covert publicity stunt initiated by CERN itself – according to CERN gossip, someone there showed someone else the paper on mini black holes. Another example of such doomsday paranoia is the website lhc-concern.info, which has a front page that is 300 pages long! This can be contrasted (in more ways than one) with another site, hasthelhcdestroyedtheworldyet.com – this only has one word on its site: 'Nope'. And yet, a CERN scientist told me despairingly that he believes we *have* built something which may destroy the world – the world wide web itself, which has become used in a way that buries knowledge in the noise of ignorance and idiocy, as shown in the above examples.

[109] Smolin, Lee. *Time Reborn: From the Crisis in Physics to the Future of the Universe*. Boston: Houghton Mifflin Harcourt, 2013, p.111

[110] Barrow, John D. *The Book of Universes*. London: Vintage, 2012, p.232

[111] A CERN physicist told me about the actual conditions that led to this term – apparently Peter Higgs wanted to write a memoir which he wanted to call 'That goddam particle', but his publisher-in-waiting convinced him that would not sell as well as a simplified and more positive version: *The God particle*. This term stuck with the press, but most physicists seem to hate it.

[112] Physical models that represent – yet are – natural phenomena, can also be very simple, by exploiting equivalences between the variables being compared. One basic yet elegant example is that of Eric Holmberg's (1941) use of a moving array of lightbulbs to 'create an analogue model of how two systems of stars would interact with each other by the force of gravity' (Barrow, *The Book of Universes,* p.134). This model of colliding galaxies was a highly accurate simulation of the observed cosmic events, as the effect of gravity over distance and the falloff of light both correspond with the inverse square law. See Holmberg, 'On the clustering tendencies among the nebulae', *The Astrophysical Journal*, 1941 volume 94 number 3

[113] Hacking, *Representing and Intervening,* p.216

[114] As Manuel De Landa stated, 'This isomorphism [between nature and mathematics] has mystified physicists for as long as there has been evidence of its existence, some of them resigning themselves to accept the unreasonable effectiveness of mathematics as miraculous. But … an explanation of this "miracle" can be given using the notion of mechanism-independence… a mathematical model can capture the behaviour of a material process because the space of possible solutions [in the model] overlaps the possibility space associated with the material process' (DeLanda, *Philosophy and Simulation: The Emergence of Synthetic Reason*. London: Continuum, 2011, pp. 16–19). However, there are counter-arguments against 'attempt[s] to reduce scientific representation to similarity or

'the behaviour of equations' with the dynamics of a thunderstorm in a way that is not simply metaphor,[115] philosopher Manuel DeLanda stated:

> the similarity between the two graphic plots [of data from the equation and measuring devices in the storm] suggests that the behaviour of the numerical solutions to the equations is isomorphic to the behaviour of the physical properties inside the apparatus.[116]

There is one iconic mathematical model in particle physics, simply known as the Standard Model.[117] Derived from a combination of the quantum particle equations of Planck, Bohr, Heisenberg and Schrödinger, the Standard Model describes the behaviors of every known particle and force in the known universe, but it has major difficulties incorporating Einstein's Theory of Relativity and gravity.[118] The LHC was arguably built largely to test this model, and verify the existence of the final theorised particle in it, the Higgs boson. Gerard t'Hooft, who helped develop the Standard Model, stated:

> This is a mathematical description of all known particles and all known forces between them, enabling us to explain all of the behaviour of these particles... As far as we know, there is no single physical phenomenon that cannot be regarded as some consequence of the Standard Model, and yet its basic formulae are not terribly complicated. We do admit that the model is not absolutely perfect…119

This model is comprised of 61 particles, including fermions (matter particles) and bosons (force particles),[120] yet there is a catch - it 'requires 20 parameters that cannot be derived from theory but must be obtained by measurement.'[121] The Standard Model is amazingly accurate in its predictions of everything from subatomic interactions to the workings of stars. However, for some physicists, it has fundamental flaws – aside from the gravity elephant,[122] the model cannot explain why the 20 parameters exist, let alone calculate what their values are. Thus, the only way to test such parameters is through physical experiments - hence the LHC.[123]

To summarise, experiments using equipment such as the LHC, and mathematical formulas such as the Standard Model, can both be seen as models, existing between theory and nature. Such models work by analogy, in that compared entities share certain aspects, or isomorphism, in which there is a strong correspondence between the entities in question.

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isomorphism' (Sua´ rez, Mauricio. "Scientific representation: Against similarity and isomorphism." *International studies in the philosophy of science* 17, no. 3 (2003), p.225).

[115] On page 62 of *1000 years of non-linear history*, DeLanda speaks of a 'simplified diagram' that describes how 'sedimentary rocks, species and social classes…[are all] the product of definite structure generating processes … stratified systems, to which not only human bureaucracies and biological species belong, but also sedimentary rocks. (And all of this without metaphor.)' This last bracketed comment I found had both potency and potential – instead of the subjectivity and ultimately arbitrariness that metaphors entail, could I find stronger isomorphic or analogic relations between my practice and that of scientists?

[116] DeLanda, *Philosophy and Simulation,* p.15

[117] This has also led to the notion of a 'Grand Unified Theory' or 'Theory of Everything', a kind of theoreticist realist fantasy, which repulses people like Hacking, who instead wish for 'a plethora of theories'.

[118] When one tries to "collide" the equations of relativity with those of quantum mechanics, they produce impossible infinities, which requires a very ad hoc mathematical process called re-normalisation to get rid of them. Dirac, one of the pioneer quantum physicists (and namesake of the Fermi-Dirac Statistics Law, which makes microprocessors work) 'was very disturbed by these [infinities], and was not impressed by the "renormalisation" procedures by which they are circumvented' (John Bell, *Against Measurement*, p.33).

[119] Baggott, *The Quantum Story,* p.290

[120] Yet even here, there is a rule-breaker, in Helium 4, which can become a Bose Einstein Condensate, a newly created elemental form of matter which exists in a spooky amorphous quantum state.

[121] Baggott, *The Quantum Story*, p.290

[122] The Standard Model, and quantum theory in general, is completely incompatible with Einstein's laws of gravity, and when the two are put together, they produce 'pernicious infinities' (Greene, Brian. *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory*. New York: Norton, 1990, p. 212)

[123] On one level, this seems very theory-centric – billions of dollars spent to test a theory, and yet, the theorists are blind without such things as the LHC, although it may yet deliver unexpected results, as is mentioned in Section 2.7.

2.7. Information

Information in experimental particle physics is built up from data taken from experiments, as described in this chapter. Data can be attributed to changing values of a parameter or variable, often expressed in a signal, and converted to digital/numeric forms. The term 'raw data' is commonly used to mean unprocessed signals, whether of a digital or analogue electrical nature. However, in detectors such as the CMS, where vast amounts of processing and filtering is undertaken at all levels of the experiment (as described in Section 2.3), there is arguably no such thing as raw data, as stated by physicist Wolfgang Adam.[124] He instead speaks of 'pure data', derived when the mechanics of the detector and computer processing has produced the highest possible signal-to-noise ratio. In signal processing, noise is defined as unwanted or unknown parts of a signal or data; in experimental particle physics it is 'all the events that are not understood by any theory.'[125] Thus, information is the knowledge scientists obtain from analysing such data. In other words, information is the human understanding of, or meanings attributed to, data, for example, the unique signatures as discussed in Section 2.3.

A key factor in experimental science is producing the best possible signal-to-noise ratio. In the practice of high-energy physics, this involves adjusting or tuning the apparatus in order to maximise signal whilst minimising noise, filtering out unwanted data whilst retaining data one wishes to examine. However, 'there is no such thing as a perfect tuning of machines,'[126] it is more like an ongoing interplay between the scientists and the forces and energies in the apparatuses. This is pushed to its extreme in the LHC, where data is energy of very specific frequencies and intensities, against a background of intense energy emissions of many frequencies and intensities. As Galison stated, 'a colliding beam experimenter need not only learn about rare decay and Higgs searches but also about computer and electronic problems associated with an environment of intense radiation.'[127] Even such data is filtered and enhanced in a way that is informed or influenced by theoretical factors or biases, as 'theory is everywhere'. Yet, without the context of the operations that have 'purified' such data, it is basically meaningless. To become useful information, the data requires the framework of the experimental setup, and/or the precise explanations presented in scientific reports (as described in Section 2.4).

The data produced in science experiments is seen through specific theoretical frameworks. Hacking dubbed this the 'doctrine that noticing is theory-loaded,'[128] and this can play out in socially dynamic ways. A theory that does not predict certain phenomena can therefore incorrectly interpret or ignore such data. One example of this is (dramatically) called the 'November Revolution' of 1974, when two competing particle collision experiments showed a bump in the data where there was not supposed to be anything. The physicists working on one of the experiments initially 'suspected [it was] a problem with the computer program … then suspected that this was new physics, the resonance indicative of a previously unknown particle.'[129] Each group

[124] Notes from conversation, February 2016.
[125] Hacking, *Representing and Intervening,* p.265
[126] Pickering, *The Mangle of Practice*, p.53
[127] Galison, *Image and Logic,* p.8
[128] Hacking, *Representing and Intervening,* p.179
[129] Baggott, *The Quantum Story,* p.269

was using a different theoretical framework, with one group almost missing the moment, but in a burst of political physics intrigue, they published their results on the same day, which led to a Nobel prize being awarded to both groups. Another experimental discovery of a hitherto unpredicted particle was that of the muon, which led to theoretical physicist Isidor Isaac Rabi famously exclaiming 'who ordered that?'[130] More recently, whilst I was at CERN, rumours were spreading of a new resonance discovered in the CMS and ATLAS detectors.[131] This might have been the signal of a new particle which could change the Standard Model, but the bump in the data of both detectors turned out to be a statistical fluke. CMS spokesperson Tiziano Camporesi later stated (somewhat sadly) 'it would have been a revolution … we would have sent a lot of theorists back to the drawing board,'[132] which also reveals the ongoing dynamics (and tensions) between the theorists and experimentalists.

What are the material aspects of information? IBM scientist Rolf Landauer famously remarked that 'information is physical.'[133] However, as pointed out by quantum physicist David Wallace, this statement 'does not have to mean "the physical is mere information".'[134] Furthermore, data from quantum physics experiments is not always translatable into information that contains meaning; this is a key aspect of entanglement experiments (described in the *Intermezzo*). Contemporary realist theorist Lee Smolin, who disagrees with the notion of the primacy of information, stated that (other) 'contemporary theorists … argue that quantum mechanics is not "about" the physical world, but about the *information* we have about the physical world.'[135] Such a stance, as Smolin pointed out, is derived from Bohr, who held that the data, phenomena and apparatus are fundamentally connected (as discussed in Sections 1.5 and 1.6). Like Bohr, Smolin is an entity realist, yet he also seeks 'theoretical realism'. He stated:

> Something *is* going on in an individual experiment. Something, and only that something, is the reality that we call an electron or a photon. Shouldn't we be able to capture the essence of the individual electron in a conceptual language and mathematical framework?'[136]

As is discussed in Chapter 4, such a notion of conceptually and mathematically capturing the essence of actual events is a key aspect of my practice. (In the *Intermezzo*, an examination of a unique kind of experiment in quantum entanglement sheds a different light on this issue.)

In summary, information from such experiments may exist as data which gains meaning through the context of the experimental setup. However, such contexts are not always easily or directly mapped onto data, and in

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[130] Ibid., p.158

[131] There was a palpable excitement in the air of the Building 40 café, where scientists working on ATLAS (A Toroidal LHC ApparatuS) and the CMS face off in friendly competition. People were huddled in groups gathered around tables strewn with laptops and coffee cups. It was a unique experience to see such a state of energetic uncertainty in the groups, something that Traweek or Latour would have loved.

[132] *Inside CERN* documentary, 51.52.

[133] See Landauer, Rolf. "Information Is Physical." *Physics Today* 44, no. 5 (1991): 23-29. An interesting part of this theory, which ultimately deals with signal-to-noise ratios, is that information in physical computer systems cannot be 100% accurate, or indeed knowable, echoing the uncertainty principle. It is also interesting to note that the base level of this is called the noise floor, analogous to the quantum floor, a poetic term reflecting the lowest possible energy level in a subatomic system (see Section 1.2). This gave rise to Quantum Information Theory, which was established through the work of Bell and Zeh (see Section 1.8) and is championed by people such as Seth Lloyd. Adherents of this theory believe that, in theory, a quantum computer (one that could perform such functions as described in Chapter 1) would be identical to, and indistinguishable from, the universe itself. There is a hypothesis, known as Zero Worlds, a play on Everitt's Manyworlds, that states we are already in such a cosmic quantum computer: we are not made of atoms, but bits of information. See Seth Lloyd, *Programming the universe: A quantum computer scientist takes on the cosmos* (Random House, 2011).

[134] Wallace, David. *The Emergent Multiverse: Quantum Theory According to the Everett Interpretation*. Oxford: Oxford University Press, 2012, p.30, footnote 13

[135] Smolin, *Time reborn*, p.157

[136] Ibid., p. 157

quantum physics, data and experiments coexist in a unique relationship. And yet, although data produces empirical realism, there is still debate regarding the relationship between data and the nature of the reality underlying the phenomena and the theories, between 'entity realism' and 'theoretical realism'.

2.8. Conclusions

To conclude, observation in particle physics more than shapes material reality – the apparatuses create the phenomena they are being used to investigate. As Hacking, the champion of experimentalism, stated, 'to experiment is to create, produce, refine and stabilize phenomena.'[137] Thus, to understand the material aspects of observing subatomic nature, it is important to investigate the devices of observation, the detectors. Building upon Hacking's material insights, Galison observed, 'it is not only experiments but instruments that have a life of their own.'[138] Through the 'point of view'[139] of the apparatuses, insights into the genealogies and cultural conditions of experiments can be gained. Models are intermediaries between theory and material nature. Material and mathematical analogies can produce meaningful experiments and data, but meaning and data can also be counterintuitive, and without context data is arbitrary. Matter and meaning are formed together in physics experiments. Challenging antirealism, entity realism enters the experimental fray. This recasts and intertwines the relations between theory and experiment, macroscopic and subatomic materiality.

In reframing the debate from removed or abstract representations of phenomena to a more dynamic material engagement with nature, Pickering provided an 'ontological vision of the world … in which both the human and non-human are reorganized as open-endedly becoming, taking on emergent forms in an intrinsically temporal "dance of agency".'[140] This notion expresses the essence of this chapter, in terms of the spatio-temporal material–energetic dynamics described above, and the inter-relations between the scientists, the apparatuses and the phenomena.

In this chapter, I have engaged with the experiments and the apparatuses that mediate between the subatomic and human regions of the universe. These 'mediators … texts, instruments, machines … lost their dignity, charm, mystery' due to the representational framework that was imposed upon them by people pushing theory-centrism and scientism. Through the themes I have explored in this chapter, and indeed through my own practice, I have sought to challenge such a framework, and engage with the mediators, the devices, the culture and practice of particle physics. Where does one go from here? Into another mode of practice, experimentation and creation, a different motion in the ongoing dance of matter and meaning, where anything goes: art.

[137] Hacking, *Representing and Intervening,* p.230
[138] Galison, *Image and Logic,* p.424
[139] ibid p. 194
[140] Pickering, *The Mangle in Practice*, p.1

Intermezzo – A Case of Entanglements

This is a case study of the material nature and philosophical interpretations of entanglement experiments, which – as Schrödinger states – are the central and defining traits of quantum mechanics.

Data in quantum physics experiments can be of a most counterintuitive nature, and like Schrödinger's entanglement, reveal the essential difference between the classical and quantum world. Quantum states are simply representations of the knowledge we have of specific experimental setups, according to an interpretation of Bohr by Anton Zeilinger, one of the leading figures in experimental quantum physics, and head of the Austrian Academy of Sciences.[1] Such a statement needs to be unfolded. Up to this point, knowledge has been presented as containing representations of nature that are more or less removed from what they represent. However, quantum states, which are empirically measured data, are different – they are not simply representations of knowledge. As is discussed below, there is a unique interrelation between data and experiments in quantum physics, as is described by Bohr, which seems to be an "entangled" relation between knowledge and nature. But is it an entanglement in the sense as described by Schrödinger (see Section 1.7). In essence, quantum entanglement means that no discrete features of the entangled particles exist before measurement, and upon measurement, the physical elements share the features. It's not just that knowledge of a quantum system doesn't exist before a measurement is made, and the measurement produces knowledge (as Galison remarked, observation is a means of 'producing and recording data'[2]), but there is no material capacity for such knowledge *to* exist. This seems like a radical epistemological stance or material understanding of knowledge, where the extremes of realism and antirealism meet. In fact this may be Bohr's own stance; according to scientific philosopher Henry Folse, it 'makes much sense to characterize Bohr in modern terms as an entity realist who opposes theory realism.'[3]

The unique nature of quantum information can be illustrated by an actual entanglement experiment, known as the "Quantum Eraser" experiment. A specific experiment is set up to measure one of two mutually exclusive or complementary properties of a subatomic entity, for example, particle or wave properties. A measurement is made upon one entity, then, by a subtle trick,[4] the experimental setup is changed, so that the other property of the same entity can be measured. This seems to affect the result of the earlier measurement, or in the case of the wave/particle double slit experiment, "erases" the information about which kind of setup was used in the previous part of the experiment. This has radical implications, including the refutation of '"local realism"' (as discussed in Section 1.7). To

[1] Zeilinger, Anton. *Dance of the Photons: From Einstein to Quantum Teleportation*. 1st ed. New York: Farrar, Straus and Giroux, p.235

[2] Galison, *Image and Logic,* p.185

[3] https://plato.stanford.edu/entries/qm-copenhagen/ Accessed 1.5.17

[4] The details of this "spooky" experiment are however too complex to go into here, for more information, see Barad, *Meeting the Universe Halfway,* 2007, pp. 310–317, and / or Zeilinger, *Dance of the Photons,* pp. 179–188.

paraphrase Bohr, such an outcome is 'shocking'[5] to those who hold a classical viewpoint on physical reality. New materialist philosopher and physicist Karen Barad addresses the philosophical and ontological implications of the experiment, as a key part of her book *Meeting the Universe Halfway: quantum physics and the entanglement of matter and meaning*. According to Barad, 'after it [the particle] has already hit the screen and gone through the apparatus, I am able to determine its ontology, afterwards.'[6] Such an outcome, she says: '[…] is amazing! We can do experimental metaphysics now, which of course is just an indicator of the fact that there has never been a sharp boundary between physics, on the one hand, and metaphysics or philosophy, on the other.'[7] Zeilinger says that 'it is absolutely fantastic that a philosophical position [of local realism] can be ruled out by experimental observation.'[8]

However, like other foundational issues in quantum physics, interpretations of this experiment can differ deeply.[9] Barad and Zeilinger agree that actual future measurements on entangled quantum systems do not influence the physical reality of earlier experimental results. Zeilinger states that they do fundamentally change our interpretations of such data. For Zeilinger, observed events are '*just* events and that's it [italics added].'[10] The data from these events is 'objectively random', existing as a form of 'primary reality'[11] more fundamental than the explanations we may later construct.[12] Although such a definition is not unique to data from quantum experiments, what is unique to entanglement is that such data can be part of completely different future experimental arrangements. It is only 'if we wish to have an explanation, we need to complete the experiment … [which] requires [a] decision that defines the *meaning* of the data already obtained'.[13] For Barad, the 'results simply don't announce themselves; rather, one has to analyze the data in some way.'[14] Barad develops Bohr's concept of phenomena (as discussed in Section 1.4) to interpret the data and the meaning of the experiment. Barad says that there is a 'quantum entanglement between the object and the "agencies of observation",'[15] and from this concludes that 'phenomena are the ontological entanglement of objects and observation.'[16] This is in contrast to Zeilinger, and Schrödinger, whose view of entanglement is 'explicitly epistemic (what is entangled is our knowledge of events).'[17]

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[5] Barad, *Meeting the Universe Halfway,* p.254

[6] Van der Tuin, Iris, and Rick Dolphijn. "Matter Feels, Converses, Suffers, Desires, Yearns and Remembers: Interview with Karen Barad." In *New Materialism: Interviews & Cartographies*, edited by Iris Van der Tuin and Rick Dolphijn, 48-70. Open Humanities Press, 2012, p.65. Accessed March 6, 2013. http://hdl.handle.net/2027/spo.11515701.0001.001

[7] Ibid., p.63

[8] Zeilinger, *Dance of the Photons,* p.137

[9] Discussions with various people about their interpretations of this seem to have the scientists tending towards a position of epistemological precision, and those of a philosophical incline curving towards a wider ontological embrace.

[10] Ibid., p.234

[11] Ibid., p.231

[12] When I discussed the notion of 'objective randomness' with Zeilinger, I raised the point that, although such randomness is completely unpredictable, there is almost an underlying structure that precludes certain types of outcomes in entanglement experiments. After pausing, Zeilinger replied and said, 'yes, it's random, but it's not arbitrary'. This is a subtle distinction which I feel is quite powerful.

[13] Ibid., p.231

[14] Ibid., p.312

[15] Ibid.

[16] Ibid., p.309

[17] Perhaps there is a different way to disentangle the usage of the term, which is to go back to the source. Schrödinger originally uses the German word 'Verschränkung', which is mainly translated as 'entanglement' but can also mean

Barad's interpretation is ontological: 'what is entangled are the "components" of phenomena'[18] – for Barad, phenomena *are* entanglements: 'Instead of there being a separation of subject [the apparatus] and object [of investigation], there is an entanglement of subject and object, which is called the "phenomenon".'[19] Bohr, however, does not appear to state there is an ontological entanglement 'of objects and agencies of observation',[20] outside of such specific experiments as described above – as Barad says, Bohr 'doesn't explicitly articulate the crucial ontological dimensions of his account.'[21] Barad takes her ontological position further, developing what she calls 'agential realism.'[22] Barad posits agential realism as an emergent becoming of relations between previously indeterminate things, their interactions defining them as they are manifested in space, time and matter. Barad uses the term 'intra-active', implying that there is no ultimate outside boundary to the interactions, indeed there is no outside to the universe. Barad says: 'The universe is agential intra-activity in its becoming.'[23] She states (invoking her book title) 'the entanglement of matter and meaning calls into question this set of dualisms that places nature on one side and culture on the other.'[24] On this issue, Barad says:

> matter itself entails entanglements - that this is its very nature. By 'entanglement' I don't mean just any old kind of connection, interweaving, or enmeshment in a complicated situation. Crucially, my use of this term goes to the agential realist ontology that I propose with all its requisite refigurings of causality, materiality, agency, dynamics, and topological reconfigurings.[25]

I find Barad's position insightful and fascinating,[26] and her enframing of a metaphysical argument with actual experiments is a radical philosophical principle that goes to the heart of the matter (in more ways than one). In one sense, she is beating the (more conventional) physicists at their own game, however it is a 'dangerous game.'[27] In 'drawing upon the results of physics not as a metaphorical enterprise,'[28] Barad's "grand unifying induction" is that all matter and meaning is entangled, because phenomena in the experiments described above exhibit entangled behaviours. However, as Barad herself states, 'in the absence of appropriate experimental arrangements, concepts do not have determinate meanings … [and] need to be properly understood as idealizations or abstractions.'[29] But is Barad being abstract, or literal? As stated, entanglement experiments empirically entail that discreet properties of entangled entities do not exist before interaction with the apparatus, and then

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'intertwining' or 'interleaving', and its' linguistic structure can be unfolded to mean 'filing into a cabinet the wrong (or) hidden way' (translations by Jurgen Henschke); or it may even mean 'sharing / restricting' (my translation!) It also has a unique usage in music vocabulary, denoting an end of a phrase in a melody which is also the start of the second phrase. Perhaps this is a more poetically meaningful interpretation - as discussed in Chapters 3 and 4, sound can provide unique insights.

[18] Ibid.

[19] Van der Tuin and Dolphijn, *New Materialism*, p.52

[20] Barad, *Meeting the Universe Halfway*, p.309

[21] Ibid., p.320

[22] I find it curious that although Barad recognises the centrality of 'nonhuman agency' (ibid., p.219) she never mentions Andrew Pickering, who developed 'nonhuman agency' as a central aspect of his view on science.

[23] Ibid., p.141

[24] Van der Tuin and Dolphijn, *New Materialism,* p.50

[25] Barad, *Meeting the Universe Halfway*, p.160

[26] My entry into the philosophical aspects of Bohr's work was through Barad.

[27] I use this quote from Barad critic (and analogue synthesizer expert) Trevor Pinch, but not in the context he has it: 'Using science – and a highly prestigious form of elite science at that – to bolster a view in science studies is a dangerous game' (Pinch, Trevor. "Review Essay: Karen Barad, Quantum Mechanics, and the Paradox of Mutual Exclusivity." *Social Studies of Science* 41, no. 3 (2011): 431-441, p.440) – He seem to think that science and science studies are incommeasurable.

[28] Pinch, "Review Essay", p.440

[29] Barad, *Meeting the Universe Halfway*, p.296

share such properties once measurements are made. As decoherence theorist and entanglement experimentalist Jared Cole states, an 'entangled state [must be] sufficiently isolated from its environment … A cat doesn't appear in [such quantum states] because air molecules, photons, are bouncing off it [… it is interacting with] sound waves, radio waves, cosmic rays, nuclear decay.'[30]

Although Barad stresses the importance of 'unambiguous communication,'[31] her stance seems to me to be very ambiguous: does she mean that culture and nature are entangled when isolated from their environment, and/or are abstract entities, and/or only have discrete properties when observed? This is why I find it to be a dangerous game.[32] As described above, quantum phenomena are abstract concepts unless they are made manifest through apparatuses. Thus, unless Barad is speaking about a specific experiment, her conclusion that matter and meaning are entangled is an abstract proposition … or is it? Can these systems be extrapolated to complex entities such as culture? [33] As Bohr stated, one has to be precise with such language, which is also what Zeilinger said to me when we discussed the use of the term 'entanglement'.[34] Furthermore, Barad extrapolates upon entanglement experimenter Scully, who says that they have experimentally found 'correlations between the measuring apparatus and the systems being observed,'[35] but such correlations, to my understanding, are superpositions, not entanglement phenomena – as Zeilinger said to me, this is a different phenomenon.

Barad's position seems to rest upon an assumption that there is some form of chain of entanglements (not unlike Von Neummann chains) connecting everything in the universe. She states that 'measurements [of such phenomena] create and further extend entanglements.'[36] This does sound like a form of the measurement problem, and in fact Barad says her agential realist account of this 'goes to the core of the measurement problem.' [37] She describes the measurement problem in that 'we don't have an "outside" view of the phenomenon itself, which is what is needed to observe the entanglement … [and in order to do so] such an attempt entails a further entanglement' which means that 'now the phenomenon in question is the new extended' entanglement.[38] She thinks the paradox

[30] Email correspondence between myself and Cole, 05/05/2017

[31] Barad, *Meeting the Universe Halfway*, p.329

[32] If Barad uses the expression "entanglement" metaphorically, she should have made that clearer. Furthermore, whether or not she is using it literally, it should thus be "Sokalproof". This term relates to physicist Alan Sokal, who in the 1990s submitted a physics-jargon filled paper to an arts journal, in order to "scientifically" prove that they didn't understand science and shouldn't use such terms. I find his attitude stinks of scientism and elitism, and is symptomatic of the siloing of the "two cultures" described in Chapter 3. Furthermore, Sokal ended up doing tours talking about how stupid the arts is, instead of practicing physics, which makes me speculate he wasn't a very good scientist, and thus is basically a footnote in the ongoing antagonism between art and science.

[33] This is not just a rhetorical question, there is no explicit empirical upper limit on what could be entangled, and scientists have recently entangled a virus in a double-slit experiment. But, as stated above, the conditions have to be very tightly controlled to make this work, and no outside influences can affect it. Yet once again, the lack of a clear limit brings to mind the measurement problem.

[34] This discussion was at the Wie Alles Begann exhibition, Natural History Museum, Vienna, October 18, 2016. It strengthened my resolve to be as clear as possible in my understanding and written use of such concepts, which although perhaps puts me on the safe side of the epistemic fence, allows for a more critical engagement with science (as is discussed in Chapter 4).

[35] Barad, *Meeting the Universe Halfway*, p.308

[36] Ibid., p.344

[37] Ibid., p.345

[38] Ibid., p.345

is explained by 'entanglements and agential separability [or chains of measurement devices], without the need for any physical collapse mechanism,'[39] but I don't think this explains it, it just reframes it as an infinite recursion of agential cuts instead of an infinite recursion of measurement devices. Her position seems to rest upon the assumption that, quoting entanglement experimenters, 'only if the right [hypothetical] experiment could be performed, one which detects all the multitudinous components of this gigantic entangled state, could quantum behaviour be seen.'[40] Barad then says 'if only we are clever enough, we may be able to detect the extant entanglement.'[41] Again, this rests upon an assumption that may *never* be testable, thus her position may become one of unfalsifiable metaphysics, not experimental metaphysics, countering her claim that her position is scientifically testable.[42] If Barad is speaking literally, it seems to imply what Zeh posits as a central aspect to decoherence theory, in that we are all quantum (see Section 1.8), but Barad only mentions decoherence three times in her book.

To attempt a summary of this seemingly intractably interlaced issue, such experiments either show that quantum information is entangled in the nature of the experiment, or that nature itself is entangled in quantum information, but either way local realism and the classical separation of object and subject are ruled out of court by the experiment itself. Barad uses entanglement as an example of the intertwining of the subatomic and human, the subject and object, but seems to get entangled in empirical ambiguities. However, a key point is that entangled entities aren't pre-defined before their interactions, which shows that matter and meaning (at least in some cases) are co-emergent. What insights can be gleaned from this? In a way, this is a continuation of the realist–antirealist debate, but this time it is an epistemic/ontic debate. However, unfortunately Barad gets her superposition and entanglement phenomena and concepts entangled (puns intended). My perusal of the literature suggests that, aside from Trevor Pinch, nobody in the physics community has scholastically engaged with Barad's argument or clarified the issues I have raised.[43]

[39] Ibid., p.346
[40] Ibid., p.349
[41] Ibid., p.350
[42] Ibid., p.63
[43] On a personal note, it was an unexpected and unforeseen development that led me to this conclusion. I presented a paper at the "Transversal Practices: Matter, Ecology and Relationality" conference, where Barad was a keynote; however, she did not physically attend and gave her presentation via skype, so I was not able to talk to her about her understanding of entanglement. Conversely, when I was at the "Wie Alles Begann" exhibition, by chance I met Zeilinger, and was able to have an informative discussion about entanglement phenomena.

Chapter 3 – The Artist and the Laboratory

In 1916, the Futurist poet and sound artist Ezra Pound expressed a poetic yearning[1] for 'elegies to be written in research laboratories, not country churchyards,'[2] in his desire to tap into the 'exhilaration of twentieth century science.'[3] A century later, artists such as myself are indeed working in such environments. This chapter provides an overview of the developments that have led to interactions and collaborations between artists and scientists, and the paths that artists have taken to scientific research laboratories, with a focus on particle physics.

I examine several art movements and focus upon key artists who have developed works that engage with the physical sciences, and who have personally inspired me. Through such examples, selected for their relevance to my practice, I articulate issues that arise in the practice of art in particle physics research laboratories, and critique projects that do not have a deep or truly cross-disciplinary engagement between the art and science. The chapter is divided into nine sections. In the first section I explore interdisciplinarity and the cultures of art and science. In the second section I investigate experimental practice in art, and its similarities and differences with experimentalism in science (as discussed in Chapter 2). In the sections that follow I explore other aspects of experimental practice: in Section 3.3, I examine the historical origins of experimental practice in Dadaism and Duchamp; Section 3.4 covers the E.A.T. (Experiments in Art and Technology) in the 1960s and 1970s; and Sections 3.5 to 3.6 engage with contemporary artists working with energy and subatomic particles. The question of why artists work with scientists is addressed in Section 3.1. In Sections 3.7 and 3.8 I examine aspects of collaboration between artists and scientists who work in laboratories such as CERN. I present examples from, and critique, the collaboration models such as those offered through Synapse, Artists-in-Labs, and Collide@CERN. My analysis of the types of collaboration between artists and scientists, the ways in which projects have developed, and the artworks that have been produced gives an overall picture of the current state of art and physics practice. Furthermore, it allows comparisons and contrasts to be made with my own practice and experiences, which are discussed in Chapter 4. Section 3.9 concludes the chapter.

3.1. Art and science

In Chapters 1 and 2 I argued that a key aspect of scientific practice is the objective forms of knowledge scientists seek to gain and communicate. How then, does art practice, which 'cannot make objective statements'[4] (and does not need to), engage with a practice that is epistemologically defined as necessarily making objective statements? I shall not explicitly define the relationship between the kinds of knowledge that are gained through artworks and science, as I feel it emerges through the practice of artistic engagement with science, and is manifested in the art itself. In comparison to science, which seeks to

[1] It is out of the scope of this exegesis to engage in an analysis of poetics vs. science, which inexorably leads to Plato vs. Aristotle. Suffice to say I side with Aristotle, in that poetic mimesis distils knowledge and experience; it 'brings knowledge by getting a thing right and simplifying it' (Pappas, Nickolas. "Aristotle." In *The Routledge Companion to Aesthetics*, edited by Dominic Lopes, and Berys Gaut, 15-27. New York: Routledge, 2005, p.20)

[2] Albright, Daniel. *Quantum Poetics: Yeats, Pound, Eliot, and the Science of Modernism*. Cambridge: Cambridge University Press, 1997, p.8

[3] Ibid.

[4] Lamb, Alan. "Metaphysics of Wire Music." *New Music Articles* 9 (1991): 3-6, p. 3.

understand nature objectively, as discussed in Section 1.1, art is arguably 'a distinctive way of understanding human experience,'[5] which can include the experience of nature, and indeed the experience of nature through science. As Susan Sontag stated, through the form and content of artworks, one gains an experiential knowledge, a 'form or style of knowing,'[6] which is not objective and definite, but embraces subjectivity and possibility. Similarly, art theorist Henk Slager wrote: 'the definition – and thus also the method – of the work of art is determined again and again during the artistic process.'[7] Such methods and definitions are illustrated in the examples presented in this chapter.

There are many reasons why artists may wish to work with science, ranging from personal motivations, through wider social interactions, propelled by the current drive for increased cross-cultural engagement, as is seen in contemporary policies in both art and science institutions. Rolf Heuer, the former Director of CERN, sees art as a means to transmit aspects of scientific research which is 'important and it opens horizons.'[8] In such institutional frameworks, art–science residencies are undertaken to broaden communication between scientists, artists and the public. For example, the Laboratorium was an interdisciplinary art–science project in 1999, which was funded by the Wellcome Trust, a British biomedical research charity (which has now become the Wellcome Centre, a major art – science gallery in London).[9] This project had a core goal 'to bridge the gap between the specialised vocabulary of science, art and the general interest of the audience' or public.[10] Whilst I appreciate the underlying sentiment of this premise, I believe that such art is more than a vehicle for scientific communication (see Chapters 4 and 5). A more nuanced reason is that in working together, practitioners in both disciplines can provide a much deeper engagement with the public. This resonates with scientists who have collaborated with artists, such as biologist Lloyd Anderson, who argues that both 'artists and scientists challenge us to re-think and reimagine the scheme of thing around us … they look at the world, record it, and play it back to us in an altered light, at a shifted wavelength.'[11]

This reimagining of the art science collaboration is advanced by the astrophysicist and the executive editor of *Leonardo* Roger Malina. *Leonardo* is an academic journal dedicated to research in art, science, and technology, which is supported by MIT, and began in 1968 by Malina's father, Frank Malina, an artist and aeronautical scientist. Roger Malina describes the promotion of science through art, and the feeding of the 'cultural imagination'[12] as the 'weak case' for undertaking such collaboration. Whilst Malina recognises the benefits of communicating scientific discourse to the public, he advocates that the 'strong case' for such a collaborative encounter is to establish a deeper and richer relationship between the different domains to foster new

[5] Graham, Gordon. "Expressivism: Croce and Collingwood." In *The Routledge Companion to Aesthetics*, edited by Dominic Lopes, and Berys Gaut, 133-145. New York: Routledge, 2005, p.144

[6] Susan Sontag, "On Style." In *Against Interpretation: and Other Essays*, 15-36. London: Penguin, 2009, p.22

[7] Slager, Henk. "Experimental aesthetics." In *Artists with PhDs: On the New Doctoral Degree in Studio Art,* edited by James Elkins, 197-209. Washington: New Academia Publishing, 2014, p.198.

[8] Miller, Arthur I. *Colliding Worlds: How Cutting-edge Science Is Redefining Contemporary Art*. 1st ed. London: W. W. Norton & Company, 2014*,* p.166.

[9] I visited this in June 2016, and met Arthur I Miller, where we discussed a wide range of topics regarding art – science collaboration and projects.

[10] Slager, "Experimental aesthetics", p.198

[11] Anderson, Lloyd. "On the Nature of Interactions." *Artists-in-Labs Networking in the Margins,* edited by Scott, Jill, and Zürcher Hochschule Der Künste, 23-33. Wien: Springer Verlag, 2006., p.32

[12] Malina, Roger. "Welcoming Uncertainty: The Strong Case for Coupling the Contemporary Arts to Science and Technology." In *Artists-in-Labs Networking in the Margins* edited by Scott, Jill, and Zürcher Hochschule Der Künste, 15-23. Wien: Springer Verlag, 2006, p.17

knowledge. He writes 'that by including art in the scientific environment and creating deep art-science coupling, a "different" kind of science or engineering will emerge.'[13] Thus, such a program is not just to aid scientific discovery, it is an ontological and epistemological challenge to the nature of science as it currently stands. Malina makes key insights into art-science practice, and how it relates to essential aspects of science itself - for Malina, the constraints provided by the human senses require expansion and augmentation by technologies such as the LHC; he also points out issues regarding the constraints provided by such technologies; the epistemologies and ontologies of such apparatuses; and ultimately the limits of the human imagination.[14] He states it is 'perhaps useful to discuss different constraints on what is knowable at a given time, and identify each of these areas as points of artistic intervention'.[15]

What to call this new form of art science collaboration is in flux. Emeritus Professor of History and Philosophy of Science Arthur I. Miller, who has a PhD in physics, raises the question about what to call such a movement.[16] He states that 'terms such as "artsci," "sciart", and "art-sci" seem inadequate,' and concludes, 'I have no doubt that in the future these works will become simply known as "art".'[17] Following Miller, I shall use 'art' to describe works influenced by science or technology; however, for works created through cross-disciplinary practice I will use the term 'art–science collaboration'.

There are differing levels of engagement and interaction between artists and scientists in art-science collaborations, yet there exists a 'competing plethora of terms and initiatives for cross-disciplinary interactions.'[18] I focus upon three terms: *multidisciplinary*, *interdisciplinary*, and *transdisciplinary* practice. Examples of each of these categories are described in this chapter, and e-addressed in Section 3.7 through examples of different collaboration programs – Synapse, artist-in-labs and Collide@CERN. However, I should note that in this context, such categories are not definitive or exclusive, they are ways of examining attributes of artworks that engage with aspects of science. As a way to define the three levels, I begin with generic overviews of academic cross-disciplinary practice, which are then cast in an art–science collaboration framework.

Multidisciplinarity 'draws on knowledge from different disciplines but stays within their boundaries.'[19] In terms of art–science practice, there may be a degree of cross-awareness and interaction, but the science and art are still developed separately.

Interdisciplinarity is defined as a process of 'integrative knowledge practice and exchange.'[20] In the case of art and science, interdisciplinarity implies that practitioners from both domains are actively engaging and exchanging knowledge and methods with each other. In other words, it is

[13] Ibid., p. 18
[14] Ibid., pp. 19–21
[15] Ibid., p. 19
[16] Miller, *Colliding worlds*.
[17] Ibid.
[18] Zilberg, "A SEAD White Papers Working Group Meta-Analysis." SEAD: White Papers, 2013. Accessed April 28, 2015. https://seadnetwork.files.wordpress.com/2013/01/zilberg_meta.pdf, p. 4
[19] Toomey, Anne H., Nils Markusson, Emily Adams, and Beth Brockett. "Inter-and Trans-disciplinary Research: A Critical Perspective." Accessed June 24, 2017.
https://sustainabledevelopment.un.org/content/documents/612558-Inter-%20and%20Trans-disciplinary%20Research%20-%20A%20Critical%20Perspective.pdf, p.1

> not just research in two or more different disciplines … rather, it is an integrated approach … most often connected with applied research that starts with a real-world question and uses different disciplinary ideas and methods not just as guideposts, but rather as tools.[21]

The outcomes of interdisciplinary art practice – the works produced – are still art, but have gone through the processes and apparatuses of science, sometimes literally (as in the case of my final project, discussed in Chapter 4).

Transdisciplinarity transforms the disciplines it encompasses. Art-science researcher Jonathon Zilberg conducted an analysis of 55 research papers on this topic, as part of a major international study on art – science collaboration initiated in 2012. This 'White Paper' study was prepared by Roger Malina, Carol Strohecker, Carol LaFayette, and Amy Ione, and included 200 contributors from a wide range of artists, scientists, and educators.[22] According to Zilberg's 'meta-analysis'[23] of key white papers, transdisciplinary research 'leads to the transformation of the very identity of disciplines by identifying new topics and concerns.'[24] To be truly transdisciplinary, activities have to fundamentally contribute to each discipline 'in a way that does not compromise their disciplinary integrities.'[25] This term is used to promote the notion that 'art can advance basic science and bridge the "two culture" divide,'[26] but as Zilberg warned, to 'overemphasize a transdisciplinary agenda … is problematic … [as] it has not been demonstrated that the arts can contribute to basic science.'[27] Based upon my own experiences and discussions with other artists, I don't think art collaborations should be *required* to advance science; serendipitous discoveries are exciting but should not be a motivating force.[28] To form deep connections between art and science, such collaborative projects would instead ideally question and challenge the nature and boundaries of both disciplines. As Feyerabend noted, testing and challenging boundaries and conceptual systems is 'an essential part'[29] of research, whether it is science or art. Based upon my research of art – science collaborations (in Sections 3.6 – 3.8), and my own experiences (discussed in Chapter 4), I feel that the 'deep art – science connections' Malina advocated cannot be forced or prescribed, they are essentially emergent.

That art and science are different disciplines is not in itself an issue. However, in 1959, the scientist C.P. Snow argued, in his 'Two Cultures' Rede Lecture essay, that there is no communication – or indeed, understanding – between artists' and scientists' cultures.[30] Snow's contention is simplistic and flawed, yet it has cast a shadow upon practitioners working across both disciplines that remains to this day with commentators in both art and science[31] who perpetuate the notion that there is an 'antagonism that exists between science and the

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[20] Blassnigg, Martha, and Michael Punt. "Transdisciplinarity: Challenges, Approaches and Opportunities on the Cusp of History." SEAD: White Papers, 2012, p. 4. Accessed April 28, 2015. https://seadnetwork.files.wordpress.com/2012/11/blassnig_final.pdf

[21] Toomey et al., *Inter- and Trans-Disciplinary Research,* p.4

[22] https://seadnetwork.wordpress.com/.

[23] Zilberg, *A SEAD White Papers Working Group Meta-Analysis,* p.1

[24] Ibid., p.3

[25] Ibid*.,* p.4

[26] Ibid.

[27] Ibid*.,* p.11

[28] When I was young I desired to be the first artist to win the Nobel Prize in Physics, just to show them that it could be done. Now that I have met a few Nobel Laureates (at exhibition openings!) I am glad I am not under such constraints! However, as Zilberg states, an artistic scientist is more likely to be awarded a Nobel Prize (ibid., p. 14).

[29] Feyerabend, *Against Method*, p.174

[30] Snow, Charles Percy. *The Two Cultures and the Scientific Revolution: Rede Lecture 1959*. New York: Cambridge University Press,

[31] One example is the art critic Jonathan Jones, discussed in Section 3.8; others include the physicist Steven Weinberg, whose 'Night thoughts of a quantum physicist' are the kind of one-eyed scientism that gives his colleagues a bad reputation.

humanities'.[32] Refuting this, Lloyd Anderson states that 'an artificial [art–science] dichotomy has been constructed for which we can perhaps lay the blame at the door of C.P. Snow.'[33] Based solely upon his personal experiences of working with scientists and associating with writers, Snow 'believe[s] the intellectual life of the whole of Western society is increasingly being split in two polar groups', with 'literary intellectuals at one pole – at the other[…] the physical scientists.'[34] As has been often quoted since, Snow lamented that writers apparently don't know about thermodynamics, and physicists don't read literature.[35] Whilst arguing that non-scientists are 'ignorant', he stated 'it is bizarre how very little of 20th century science has been assimilated into 20th century art.'[36] This is in itself ill-informed, as is shown throughout this chapter. By example, at the time of Snow's lecture, Gyorgy Kepes, the Hungarian polymath and founder of the MIT Centre for Advanced Visual Studies published 'The New Landscape in Art and Science', which presented scientific images alongside images of artworks. For Zilberg, Snow's assertion is 'unnecessarily divisive,'[37] yet even in contemporary art–science practice, the 'way in which Snow's axiom is taken as an article of faith without returning to the original texts and the criticisms of those texts across the decades is nothing short of remarkable.'[38] I shall not discuss Snow any further, aside to say that the rest of this chapter comprehensively disproves the notion of (the non-communicative) 'Cultures'.

In summary, in this section I provide an overview of Roger Malina's 'weak' and 'strong' cases for art – science interaction, and examine the concepts of multidisciplinarity, interdisciplinarity and transdisciplinarity, and in doing so dismantle Snow's naïve and erroneous conclusions.

3.2. Experimental art

In Chapter 2, I describe the role and nature of the experiment in scientific research In this section I explore how the experiment applies in art. Regarding the development of art practices of the twentieth century, described in this chapter, artist and writer Gary Kibbins states, 'experimental art practice is not exactly science but it's not exactly not science either.'[39] As is discussed in Chapter 2, the idea that an experiment simply validates a hypothesis is simplistic - they develop with each other, indeed they are inextricably intertwined. As described, in experimental particle physics, concepts and materials develop together and inform each other. This also applies to experimental art practices: 'hypothesis–artwork [are] two interdependent, co-present parts of a larger process; the hypothesis emerges from the artwork as much as the artwork emerges from the hypothesis.'[40] In art, as in science, there is a multifaceted interplay between ideas and materials, and the agency of the human and the 'made things' of art, to paraphrase Pickering.[41] In science, experiments are used

[32] Parkinson, Gavin. "Surrealism and Quantum Mechanics: Dispersal and Fragmentation in Art, Life, and Physics." *Science in Context* 17, no. 4 (2004): 557-77, p.558

[33] Anderson, "On the Nature of Interactions", p.23

[34] Snow, *The Two Cultures*, p.4

[35] One of many examples contradicting this assertion is the origin of the name of the quark particle - physicist Murray Gell-Mann called his newly theorised trio of subatomic entities quarks, after the line 'Three quarks for Muster Mark!' from James Joyce's *Finnegan's wake*.

[36] Snow, *The Two Cultures*, p.17

[37] Zilberg, *A SEAD White Papers Working Group Meta-Analysis*, p.13

[38] Ibid., p.4

[39] Kibbins, Gary. "Bear Assumptions: Notes on Experimentalism." *Public* 25, (2002):148-59. Accessed August 13, 2015. http://public.journals.yorku.ca/index.php/public/article/view/30215, p.152

[40] Kibbins, "Bear assumptions", p.154

[41] Pickering, *The Mangle of Practice*, p.3

to test specific variables, in order to see if the theory fits with the experimentally produced data. Art practice also contains material and conceptual variables that are only defined through experiment. As historian Stefanie Kreuzer stated, they may include formal variables (in terms of materials), procedural variables (in terms of processes developed in working with materials), and responsive variables (in terms of audience responses to the things that are produced).[42]

Artists 'render strange' their materials by changing their context and relationships to produce an estrangement with the objects they are working with, in the way Rheinberger described scientific practice (see Section 2.5). As design theorist Tony Dunne advocates, '"poeticizing" the distance between people and objects through "estrangement" and "alienation"'[43] is a way to allow engagements with the objects of investigation that break from the familiarity of everyday experience. Through such practices, Dunne found that experimental practice and theoretical concepts 'evolved simultaneously.'[44]

Based upon the above points by Kibbins, Kreuzer and Dunne, and the insights into scientific experiments in Chapter 2, I define experimentalism as utilising conditions and variables so that the outcomes are not known in advance and thus the experiment has to be undertaken in a physical and material capacity. In other words, experiments are engagements with possibility and uncertainty, through interaction with the agencies of the materials, technologies, or apparatuses. Such a 'dance of agency'[45] equally applies in experimental science and experimental art. In both disciplines the experimenter lacks total control over the situation, but engages with the agency of the other, and together they produce material outcomes. This common mode of experimentalism I found useful when working with scientists, which will be discussed in Chapter 4.

Similarly, Feyerabend's principle of 'anything goes'[46] applies to experimental art practice. As in science, in art I believe there should not be one method but a multitude, 'not unity but absolute plethora.'[47] Inspired by Feyerabend, art theorist Henk Slager advocates 'ironic, experimental strategies, ludic modes, reversible states, contradiction, non-binary, nonlinear associations, paradoxes.'[48] Such irrational and ad-hoc processes are arguably a necessary and vital part of understanding nature itself – as Feyerabend stated, 'without "chaos", no knowledge.'[49] Although the 'anything goes condition'[50] is potentially seen as a derogative term for contemporary art practices, I found such a state the ideal starting point when working in high-energy physics laboratories (as is discussed in Chapter 4). The development of such a condition in art can be traced back to the 'anti-art' of the Dadaists, and the experiments of Marcel Duchamp, as discussed in the next section.

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[42] Kreuzer, Stefanie. Experimente in den Künsten. Transmediale Erkundungen in Literatur, Theater, Film, Musik und Bildender Kunst, 2012, 14, quoted in Dagmar Steffen, "New Experimentalism in Design Research." *Artifact* 3, no. 2 (2014): 1–16, p. 1.4

[43] Dunne, Anthony. *Hertzian Tales: Electronic Products, Aesthetic Experience, and Critical Design*. Cambridge: MIT, 2005, p.22

[44] Steffen, Dagmar. "New experimentalism in design research: Characteristics and Interferences of Experiments in Science, the Arts and in Design Research." *Artifact* 3, no. 2 (2014): p.12.

[45] Pickering, Andrew. "New Ontologies." In *The Mangle in Practice: Science, Society, and Becoming,* edited by Andrew Pickering, and Keith Guzik, 1-14. Durham: Duke University Press, 2008, p.1

[46] Feyerabend, p.7

[47] Hacking, Ian. *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press, 1983, p.218

[48] Sarat Maharaj, quoted in Slager, "Experimental aesthetics", p.199

[49] Feyerabend, *Against Method*, p.160

[50] de Duve, Thierry. "Pardon My French." *Artforum International* 52, no. 2 (2013): 246-253.

In summary, experiments in art have certain crossovers with science experiments, in that certain parameters are unknown until the experiment is undertaken. Through such experiments, in art as in science, hypothetical and material aspects develop together. Estrangement is another process used in both disciplines. Experimentalism is described as a process that contain conditions and variables that are not pre-defined. Experiments have to be materially manifested, in an interplay of human and non-human agency.

3.3. Turbulent worlds

Figure 5. Marcel Duchamp, *3 Standard Stoppages*, 1913-14, and *Network of Stoppages*, 1914.

I commence with an analysis of art and science in the 1910s, an era of radical upheavals. This time is described as:

> the turbulent new world of ideas and means, just prior to the catastrophe of 1914. There was the miracle of electrification of the cities; the futurism screaming from new inventions such as cinema, wireless telegraphy and radio, … the stream of hot news from the laboratories, each more spectacular than the last: x-rays, the electron, radioactivity, relativity, the nucleus, the definitive verification by Jean Perrin of the atomic hypothesis, Niels Bohr's 1913 explanation of the structure of the atom.[51]

During this era, the French artist Marcel Duchamp took an explicit interest in scientific and technological developments. He was the first twentieth-century artist to engage with the concepts and technologies of physics. He incorporated such concepts into various works, several of which I discuss. His painting *Nude Descending a Staircase*, 1912, brings together human and mechanical forms,[52] suggesting 'movements that are too rapid or too subtle for the unaided eye to catch,' such as those found in the chrono-photography of Jules Etienne Marey.[53] Duchamp was directly inspired by physics experiments, as seen in works such as *Three Standard Stoppages*, 1913, where he brought together space, time and chance in the making of unique forms (see fig. 5). Duchamp dropped three metre-long wires onto the ground from a height of one metre, traced the

[51] Holton, Gerald. "Henri Poincaré, Marcel Duchamp and Innovation in Science and Art." *Leonardo* 34, no. 2 (2001): 127-134, p.133

[52] I had an argument with the former director of the Australian Synchrotron about this painting and its spatiotemporal forms. He couldn't make any sense of it, and stormed out shouting, which made me realise that some people who deal with such concepts as space–time on a day-to-day level can still be basically visually illiterate.

[53] Steefel Jr, Lawrence D. "Marcel Duchamp and the Machine." In *Marcel Duchamp,* edited by Anne d'Harnoncourt, and Kynaston McShine, 70-80. New York: Museum of Modern Art, 1973, p.72

curved shapes made by the wires, then cut these forms from three rulers – these became his 'diminished metres'. This playful material experiment was then used in another work, *Network of Stoppages*, 1914. The curves of the 'diminished metres' became forms like the particle tracks produced in the first cloud chambers designed by Wilson a few years earlier (see Section 2.2).

Such works informed Duchamp's masterpiece, *The Bride Stripped Bare by Her Bachelors Even*, 1915–1923, also known as *The Large Glass*, described as 'one of the most hermetic works of the [20th] Century.'[54] This brings to mind the hermetic apparatuses used in particle physics, and also their status as epistemic things (described in Sections 2.4 and 2.5); the paradox of *The Large Glass* is that it is self-referential yet 'so complex and open ended.'[55] This iconic and enigmatic work is 'full of salient entanglements and provocative interactions and elusive relationships,'[56] but when analysed with the science of the time in mind, reveals 'a richer range of interpretations than those detected by art critics with no scientific knowledge.'[57] Distilling Duchamp's interests in 'science and technology – from X-rays and radioactivity to wireless telegraphy,'[58] *The Large Glass* can be seen as a kind of apparatus;– as Duchamp stated (perhaps playfully), 'it was very well connected, … . It could almost work.'[59] Duchamp outlined the forms in the *Glass* with electrical fuse wire, seeking to 'make a painting *of frequency*.'[60] His 'allusions to electromagnetic communication, however, could only be indirect – that is, by means of the apparatus, materials, and functions relating to the emission and detection of Hertzian or wireless telegraphy waves.'[61] This implies that Duchamp sought to imbue the piece with a metaphorical energy, and which suggests 'nonhuman agency' as Pickering described (see Section 2.3).[62]

Duchamp was inspired by the French polymath Poincaré, the 'grandfather of relativity.'[63] Poincaré coined the term 'ready-made' (tout fait) to describe 'the epiphanies resulting from a barrage of pre-established ideas.'[64] According to Poincaré's studies into the nature of human creativity, following an intensive but more or less random input of study, ideas appear to sort themselves out in what he called the unconscious mind. There follows, tout fait, the illuminating flash of insight. Through estrangement, Duchamp created his own readymade: by taking objects out of their usual context, they can be seen in a new light.[65] Duchamp was inspired by scientists but he never worked directly with them, although there have been unsubstantiated reports that he showed his kinetic works at a science fair to see how the scientists would respond. Direct collaborations would have to wait until the post-World War II generation of artists emerged and undertook them on a grand scale.

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[54] Holton, "Poincaré, Duchamp and Innovation in Science and Art", p.132

[55] Steefel, "Marcel Duchamp and the Machine", p.75

[56] Ibid., p.73

[57] Perelló, Josep, and Vicenç Altaió. "Physics of Aesthetics: A Meeting of Science, Art and Thought in Barcelona." *Leonardo* 41, no. 3 (2008): 232-237, p.235.

[58] Henderson, *The Large Glass Seen Anew*, p. 125

[59] Unpublished typescript of interview with Sidney, Harriet, and Carroll Janis (1953) sec. 5, p. 10. Reprinted in Henderson, *The Large Glass Seen Anew*, p.121

[60] Duchamp [1] Box of 1914, in Salt Seller, pp. 23, 25. In Henderson, *The Large Glass Seen Anew,* p. 117

[61] Henderson*,* The *Large Glass Seen Anew,* pp. 117–118

[62] Pickering, Andrew. "The Mangle of Practice: Agency and Emergence in the Sociology of Science." *American Journal of Sociology* 99, no. 3 (1993): 559-589, p. 568

[63] Perelló & Altaió, "Physics of Aesthetics", p. 233

[64] Ibid., p. 235

[65] The influence of Duchamp and his experiments upon art is too great to be addressed adequately in this exegesis. His 'readymades' instigated what has been called the 'anything goes condition', and produced a shift to art being about processes, instead of being a specific outcome such as a painting on a wall of a gallery, as well as the relationship of the viewer to the work of art.

Dada was born into the mechanised violence of World War I. In response, Dadaism sought

> a whole hearted and unremitting attack on all the norms of industrial age bourgeois culture … an absurdist attack on materialism, often employing the means and language of that materialism as weapons of attack. … Dada was in essence 'Anything goes'.[66]

The Dadaists worked with chance and uncertainty in a way that removed determinism and the control of the artist, and thus questioned the role of the artists themselves. Even language was disassembled, reduced to non-semantic material frequencies and amplitudes.[67] As Hugo Ball stated in the Dada Manifesto, 'It will serve to show how articulated language comes into being. I let the vowels quite simply occur, as a cat meows....'[68] Through such processes of extreme estrangement, language is reduced to a kind of raw material. Paul Feyerabend (a self-proclaimed Dadaist, as noted in Section 1.1) described such methods:

> Assume you tear language apart, you live for days and weeks in a world of cacophonic sounds, jumbled words, nonsensical events. Then, after this preparation, you sit down and write: 'the cat is on the mat.' This simple sentence which we usually utter without thought, like talking machines (and much of our talk is indeed routine), now seems like the creation of an entire world … Nobody in modem times has understood the miracle of language and thought as well as the Dadaists for nobody has been able to imagine, let alone create, a world in which they play no role.[69]

This belies both the power of the methods used in Dadaism in revealing the material primacy hidden within language. Through the construction of poems out of 'random variations of words and lines … from an interplay of randomness and control,'[70] poets such as Ezra Pound sought to discover 'poetic atoms'[71] (however, this should be seen as metaphor more than a 'proof of some profound congruence between science and art'[72]). And yet, I find a poetic parallel between the nature of raw data in particle physics and the nature of language when deconstructed by the Dadaists, who in a sense turned words into 'dada data.'[73] The development of combinatory and rule-based processes in Dadaism have informed many contemporary art projects,[74] and aided my initial approach to working with data in particle physics, as is discussed in Chapter 4.

In this section I have examined Duchamp and Dadaism, progressing from the 'anything-goes' attack upon images, sounds, language and meaning to the hybrid human-machine reconstructions. Dada uses randomness and absurdity to decompose everything, including art. As important historical precedents to contemporary art practice, they reflect the scientific and the cultural upheavals of the era. As Dadaism, responding to the destruction of WW1, was a creation of its era, art that engages with current science and technology is of the contemporary era, in which science and technology increasingly impact many facets of society.

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[66] Flam, Jack D. "Foreword." In *The Dada Painters and Poets: An Anthology*, edited by Robert Motherwell, xi-xiv. 2nd ed. Cambridge: Belknap Press of Harvard University Press, 1981, p. xii

[67] Cox, Christoph. "The Alien Voice: Alvin Lucier's North American Time Capsule 1967." In *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts,* edited by Hannah B. Higgins, and Douglas Kahn,171-192. London: University of California Press, 2012, p.176

[68] Hugo Ball, "Dada Manifesto." The Anarchist Library. Accessed March 24, 2017. http://theanarchistlibrary.org/library/hugo-ball-dada-manifesto

[69] Feyerabend, *Against Method*, p.279.

[70] Paul, Christiane. *Digital Art*. 2nd ed. London: Thames & Hudson, 2008, p.11

[71] Albright, *Quantum Poetics*, pp. 1–2

[72] Ibid., p.8.

[73] An online search for this concept proved fruitless, with the exception of the MIT 'dada-data' web exhibition to celebrate Dada's 100th anniversary, see http://docubase.mit.edu/project/dada-data/. It is strange there is not more on the concept of 'dada data', as both dada and data exist in a state of pure reality more fundamental than the meanings we later construct from it, as Zeilinger wrote (see the *Intermezzo*).

[74] Paul, *Digital Art,* p.13

3.4. Art and technology

In this section I discuss the first major development in artists working with engineers and developing complex technologies. During the 1960s, the large-scale interdisciplinary projects of E.A.T. paved the way for contemporary art–science projects. Officially forming in 1966, American artists Robert Rauschenberg and Robert Whitman began working with engineers Billy Klüver and Fred Waldhauer from Bell Telephone Laboratories. Their goal was to 'bring together artists and engineers, creating a network … who sought to collaborate across disciplines.'[75] E.A.T. itself grew 'from small-scale simple requests to technical challenges that took years to bring to fruition,' showing that such processes take time and effort to be productive.[76] Both the artists and engineers involved realised that such collaborations opened new possibilities in art, both formally and critically. As Billy Klüver said, 'I realized I had colors on my palette that nobody else had in NY. I had Bell Laboratories at my disposal.'[77] As Rauschenberg and Klüver stated, 'to accept technology is to embrace the present; to merge art and technology is to confront the public with the present.'[78] Such confrontations began with the chaotic and Dadaistic *Homage to New York* (1960), by Jean Tinguley (with help from Rauschenberg, Klüver and others), a self-destructing kinetic sculpture performance, which sparked the idea for E.A.T. The artists aesthetically engaged with the very technologies they were using. For example, Rauschenberg's *Mud Muse* (1968-1971), is a large sculpture comprised of a bubbling pool of mud controlled by its own sound, in a way that 'performs for the spectator'. The exhibition included the equipment rack which controlled the installation, making the technology part of the art.[79] Amongst many other works, Rauschenberg and Klüver produced *Oracle* (1962–1965), an assemblage of metal objects that emitted sounds via concealed radios and wireless transmitters (which was complex technology at the time). This piece resonated with me when I saw it many years ago; it was like the singing metal objects, which Rauschenberg called 'gifts from the streets,'[80] were expressing themselves joyously.[81] However, as physicist Wolfgang Adam (introduced in Chapter 4) said, the artworks produced by E.A.T. are 'merely optical,'[82] that is, they do not engage deeply with the nature of the technologies they use. Possibly E.A.T.'s greatest collaborative project was *9 Evenings: Theatre & Engineering* (1966), which featured audiovisual and performance works by artists who worked with Bell Labs, including Rauschenberg and John Cage. The events were hugely successful, and drew thousands. This can be contrasted with their ill-fated Pepsi Pavilion at the Osaka Expo in 1970, which was taken over by

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[75] Kuo, Michelle. "Grenzenlos: No Limits." In *E.A.T. Experiments in Art and Technology*, edited by Sabine Breitwieser, 163-181. Köln: Verlag der Buchhandlung Walther König, 2015, p.162

[76] Battista, Kathy. "E.A.T.- The Spirit of Collaboration". In *E.A.T. Experiments in Art and Technology*, edited by Sabine Breitwieser, 28-37. Köln: Verlag der Buchhandlung Walther König, 2015, p.28

[77] Ibid., p.29

[78] Rauschenberg, Robert. "Soundings". In *E.A.T. Experiments in Art and Technology*, edited by Sabine Breitwieser. Köln: Verlag der Buchhandlung Walther König, 2015, p. 68

[79] E.A.T., p.70. This work and its inclusion of the equipment rack reinforced my idea that the wiring is part of the art. During my *Scrape* exhibition at RMIT First Site gallery in 2001, I had an argument with the curator about this very issue – they wanted to hide the cables, I wanted to show them, as I believe they are part of the art.

[80] Ibid., p.58

[81] In fact, whilst writing this chapter I had a dream of Rauschenberg expressing 'joy' in putting together the materials for *Oracle.* Whether Rauschenberg was in fact joyous or not, the quote suggests he liked such found gifts, which can be contrasted with Duchamp's detached stance, stating that he 'did not really love the machine' (Steefel, "Marcel Duchamp and the Machine", p.71)

[82] Personal conversation with the author, July 2015.

commercial interests who basically didn't get what the project was about and instead played Disney music in the space.[83]

Composer John Cage incorporated processes used in particle physics in the production of several projects. Cage used an ILLIAC mainframe computer, developed by John von Neumann and J. Robert Oppenheimer, as a composition tool. These first computers were initially designed for large-scale Monte Carlo simulations (named after von Neumann's uncle's favourite gambling location), using random number generators to simulate neutron scattering in thermonuclear chain reactions.[84] Cage used ILLIAC II, in collaboration with chemist and composer Lejaren Hiller, to develop randomised compositional elements for an audiovisual installation, *HPSCHD,* which ideally was to contain a 'sonic fragmentation' of almost a million pitches.[85] Following on from the Dadaist's use of randomness and chance, Cage developed the concept of indeterminacy as a musical process for 'experimental … compositions that are not objects but processes.'[86] Another of Cage's installation projects, titled *Variations VII* (1966), used cosmic particles as compositional triggers. In the engineering diagrams Cage and his collaborator Herb Schneider drew, it can be seen that the sounds included 'cosmic, gamma' sources, which were detected by Geiger counters.[87] This is the first time such a setup was used in a sound installation, and is a precursor to particle physics sound art (described in Section 3.6) and my own projects (described in Chapter 4). Regarding such technological setups, Cage says that 'in being solved [the technical problems] produce a situation different than anyone could have pre-imagined.'[88] *HPSCHD* took two years to produce, with so many technical problems that Cage later regretted the undertaking. Trying to make such devices do things they don't 'want to' can be a painful process. Such experiences show a shift in the relationship between the artist and their materials; it is no longer a simple process of producing what the artist envisages, it becomes an interplay between the artist and the technology, between the human and the apparatus. As E.A.T. artist Lucinda Childs stated, 'my ideas are generally derived from the laws that govern the materials themselves, and I attempt to allow the qualities and limitations of materials to be exposed in different situations.'[89] Such an interplay of the artist and the material is a dance of agency, literally in the case of Childs' bodily performances.

To summarise, the projects described above illustrate issues that arise when artists collaborate with specialists from other disciplines. One key issue was how the artworks were affected when the artists' 'control of the

[83] This shows the dangers involved when working with organisations who are part of a collaboration but do not understand it, a warning which will be taken up again in Chapter 5.

[84] There were several such computers, with names derived from the original UNIVAC computer, such as JOHNNIAC, named after von Neumann, and the ironically titled MANIAC, used extensively for nuclear weapons development. A similar mainframe device, located in England, was called ERNIE (Electronic Random Number Indicating Equipment). This was used to produce random number sequences from quantum noise for algorithms that simulate nuclear reactions, as well as 'Premium Bond' lotto combinations. Such a dissonant combination of functions led me to produce an artwork and poster called *Monte Carlo Catastrophes*.

[85] Joseph, Branden W. "HPSCHD—Ghost or Monster?" In *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts,* edited by Hannah B. Higgins, and Douglas Kahn,147-169. London: University of California Press, 2012, p.148

[86] Cage, John. "Composition as Process: Indeterminacy." In *Audio culture: Readings in Modern Music*, edited by Christoph Cox, and Daniel Warner, 176-186. New York: Continuum, 2004, p.176

[87] Cage, John. "Variations VII". In *E.A.T. Experiments in Art and Technology*, edited by Sabine Breitwieser, 116-117. Köln: Verlag der Buchhandlung Walther König, 2015. p.117

[88] Ibid., p.116

[89] Childs, Lucinda. "Vehicle". In *E.A.T. Experiments in Art and Technology*, edited by Sabine Breitwieser, 122-125. Köln: Verlag der Buchhandlung Walther König, 2015, p.122.

situation is reduced or when they are submerged in collaboration with engineers.'[90] Another key point is the relationship between the artist and the technological materials they are working with, which is analogous to the relationships between scientists and their apparatuses.

3.5. Energetic art

Figure 6. Robin Fox, *CRT: Homage to Leon Theremin*, 2012.

This section examines the use of energy in art, in method and subject matter. This is different to artworks that play with the concept of energy, such as Duchamp's *The Large Glass*, and works of postwar artists such as of Joseph Beuys' *Capri Battery* (1985).[91] Taking this further are a wide array of artworks that include electromagnetic and acoustic energy as a fundamental part of the art. A selection of these is discussed below; they are important precedents to aspects of my practice, as is discussed in Chapter 4.[92] Sound, as a unique manifestation of energy, is discussed in this section, however, it also reverberates into Sections 3.6 and 3.7. The use of sound as a form of media for communicating scientific data was suggested by the obscure German inventor Maximillian Plessner in 1892, just as cinema was being born. He pondered 'which surprises will await the natural scientist when all visible things in the physical world become audible through illumination?'[93]

[90] Miller, *Colliding Worlds*, p.80

[91] Beuys' *Capri Battery*, or *Lemon Light*, is another personal favorite artwork, as it plays with the fact that lemons can be used as batteries. Although out of the scope of this exegesis, there was an illuminating tension between Beuys and Duchamp, with Beuys believing that the readymade separates art from society, whereas he sought to bring the two together, proclaiming that 'everybody is an artist!' Beuys also stated that art is 'a kind of science of freedom' (Beuys, Joseph. *What is art?: Conversation with Joseph Beuys*. London: Clairview Books, 2004, p. 10), which is associated with Dadaism and indeed Feyerabend: 'For Beuys, the famous Feyerabend slogan "anything goes" represents an artistic project' (Opitz, Alfred. "The Magic Triangle." In *The Cultural Life of Money*, edited by Isabel Capeloa Gil, and Helena Gonçalves da Silva, 107-120. Walter de Gruyter GmbH & Co KG, 2015. Accessed January 20, 2013. https://books.google.com.au/books?id=RJ0FCgAAQBAJ&dq=Alfred+Opitz,+The+Magic+Triangle,&source=gbs_navlinks_s, p. 107)

[92] I could also discuss artists working with light, but space does not permit: such a discussion would range from the experiments of Laszlo Moholy-Nagy through Otto Piene to James Turrell, whose 'first light' works invoke for me (in addition to the dawn) an association with the first energy beam a particle accelerator produces, which is called first light, and is often recorded as blocks of colour on photo-sensitive paper.

[93] Plessner, Maximilian. "The Future of Electric Television, 1892." In *Audiovisuology: See this Sound*, edited by Dieter Daniels, and Sandra Naumann, 627-629. Köln: Verlag der Buchhandlung Walther König, 2015, p.627

Plessner predicted that 'electrical oscillations "are only different manifestations … of one and the same energy filling the cosmos".'[94]

Alan Lamb is a sound artist who has directly inspired me. He began experimenting with acoustic amplification in the 1980s when he attached piezoelectric transducers to abandoned telegraph poles in Western Australia, and recorded the vibrations the wind produced in the wires. Amplification is a key factor in this process, but unlike physics experiments, where the signal-to-noise ratio is vital (as discussed in Section 2.7), Lamb does not filter out anything; it is all part of the signal. Regarding the ultimate source of such imperceptible vibrations, Lamb stated 'Perhaps it is the wind blowing over the star-cooled air… which makes the hum … cosmic winds, of substance like cosmic rays and gravity'.[95] When I first heard the 'infinite song' he found in these wires,[96] it filled me with cosmic awe. In 1997 Lamb built a wind harp for the opening of the SPring8 synchrotron (which itself has unique aesthetic qualities, as it is constructed around, and completely encloses, a grass-covered hill, where his harp was situated) in Harima, Japan. Lamb's work resonates materially with the energy of the wind upon the landscape, and conceptually with the energy of the particles whirling around the accelerator.

As well as amplification, tuning is a key aspect of such works, which also occurs in particle physics experiments (as discussed in Chapter 4). This is exemplified by an artwork exhibited at the Museum of Modern Art (MOMA) in New York, which is completely undetectable without the necessary apparatus. The piece is *88mc Carrier Wave (FM)* (1968), by Robert Barry; its electromagnetic tones can only be detected with an FM radio. Barry built his own radio emitter, which shows his practical knowledge of the medium. I experienced this work (albeit indirectly) at MOMA, as there were no such receivers on site, only a description on the wall. The description allowed me to "tune in" to the invisible frequencies that were permeating the space around me, creating a kind of potential resonance. Although the artwork description stated that it 'expanded traditional notions of sculpture, positing that sound, as well as objects, can define space,'[97] I think it is more than that, it shows that electromagnetic energy defines space through being in it, but also that space itself is much more than we experience with our unaided perceptions. In the same era (1968–1973), artist and member of E.A.T., David Tudor, created a series of sound sculptures, collectively titled *Rainforest*. In these works, Tudor created 'sounds electronically derived from the resonant characteristics of physical materials.'[98] Using frequency generators and oscillators connected to transducer speakers attached to the objects, Tudor would amplify sounds through the objects, tuning into and revealing the objects' natural resonances.[99] Although I did not know about Tudor's work until very recently, I developed a similar process in my *Activated Objects* (2015) installation (discussed in Chapter 4).

Robin Fox is an Australian artist who employs both a conceptual and hands-on understanding of his subject matter. His sound sculpture *CRT: Homage to Leon Theremin* (2012) (see fig. 6) is a monument to the iconic devices that are cathode ray tubes and one of their inventors. Theremin, known mostly for the electric musical

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[94] Ibid., p.620
[95] Lamb, Alan. "Metaphysics of Wire Music." *New Music Articles* 9 (1991): 3-6, p.5
[96] Ibid.
[97] https://www.moma.org/collection/works/137431
[98] https://davidtudor.org/Works/rainforest.html
[99] These methods and indeed their sounds filter through culture: I first heard such sounds during my youth, in the (literal) metal guitar sound experiments of Roland S. Howard of The Birthday Party.

instrument that carries his name, worked on electro-mechanical imaging apparatuses as early as 1925. However, unlike his successful contemporaries in Western countries, such as Cockroft and Walton, Theremin was persecuted by the Soviet state and sent to work on prison farms, and his television-tube technology was seized and repurposed by the KGB as a top-secret military device. The story of Theremin represents the dynamic and irrational side of scientific research, as well as a spectrum of human experience ranging from 'the Bolsheviks to the Beachboys.'[100] In his biography, Theremin recalls being inspired as a teenager by a lecture on electromagnetism, a talk firmly rooted in a directly human and experiential empiricism.

> Unlike [lectures by] others who operated more with mathematical indices, expressions and formulas... it was about objects around us connected to our feelings... and perceived directly by our sensory organs... It was calling me to the real scientific – not the abstract – knowledge of the essence of matter.[101]

This experience led Theremin to discover that the natural electromagnetism of the human body interacted with the electromagnetic field emanating from a device he built. He realised that physical movement could directly alter the energy in the circuit, allowing the 'electricity to sing to him', without any traditional physical interface, 'just the free voice of electrons.'[102] Fox's installation uniquely captures the dynamics of Theremin's inventions, vis-à-vis three transparent towers containing CRT televisions laid bare for all to see their inner workings. In the spirit of Theremin's musical devices, spectator proximity activates both sound and light, whilst movement brings the CRT screens to life, crackling and bursting with energy and colour, accompanied by synesthetic tones and timbres. Audience members become players of this unique sculptural instrument, its audiovisual pulsations an electromagnetic mirror of our movements, the excited electrons bursting forth from the cathodes, their paths dynamically bent by the magnets pulsing in the vacuum tubes. *CRT: Homage to Leon Theremin* is now permanently exhibited at the Australian Synchrotron.[103]

To summarise, the artworks described in this section directly use the energies that are the subject matter of the art. As shown, the artists engage both conceptually and materially with the energies involved, through amplification and tuning. To paraphrase Hacking, these artists are not just peering but interfering with the phenomena, which are more than just part of the art – they are the heart of the art. This discussion of such material engagement with phenomena continues in the next section.

3.6. Art and particles

In this section I discuss the use of subatomic particles in the production of contemporary artworks. To clarify, although related to quantum theory, the subatomic entities are empirically real, manifested through

[100] Glinsky, Albert. *Theremin: Ether Music and Espionage*. Urbana: University of Illinois Press, 2005, p.6
[101] Ibid., p.12
[102] Ibid., p.24
[103] Parts of the above paragraph on Fox's work were taken from an exhibition catalogue article I wrote. I saw this work at the Queensland Gallery of Modern Art National New Media Art Award exhibition in 2012, and prompted the Australian Synchrotron to purchase it for their National Centre for Synchrotron Science exhibition space. This was part of a series of works on display at the Australian Synchrotron National Centre for Synchrotron Science, which I co-curated. A list of about two dozen works was compiled and presented to synchrotron scientists and management, who selected six pieces. This should have been a major and positive event, but it wasn't. Problems included egocentric and belligerent artists and curators – it's not only scientists who can be difficult and painful to work with. When I pointed out a diagram about space–time relativity on a whiteboard to an artist, who had a multiscreen video about space and time, he just sneered and said 'this does nothing for me'.

the apparatuses used in the artworks, so are different to art derived from theoretical physics.[104] In these works, sound plays a key role in communicating abstract quantum properties and manifesting ephemeral and nonvisible subatomic phenomena.[105]

The *Metaphase Typewriter revival project* (2012) is an art project that deals directly with subatomic phenomena, Geiger counters, and quantum concepts. It is based upon a radical experiment undertaken in 1970, when physicist Nick Herbert constructed the 'metaphase typewriter' to see whether the consciousness of the observer could 'collapse' quantum states (see Section 1.3.[106] Herbert was an associate of John Bell, and part of the Fundamental Fysiks Group, one of the 'quantum subcultures' of the 1970s, alongside Fritjof Capra (author of the *Tao of Physics*, 1975).[107] Australian artist Lynden Stone revived the project as an artwork. It is comprised of a radioactive source (from thorium in a gas lantern mantle) and a Geiger counter attached to a computer, which is programmed to turn the particle emissions released from atomic decay into words, spoken out loud via a voice synthesiser. This project, although ultimately manifesting quantum theory, exists somewhere between playfulness and mindfulness. Responses from people at the exhibition were quite extreme – one viewer stated that 'after spending time with the device in the gallery, it had "spooked" her "to the core" and she did not want to go near it again.'[108] Poetically, or spookily, when Stone was uninstalling the work at the end of the exhibition, the 'last output that night was oddly reflective of my own thoughts: it was "i, i the death into".'[109]

A variety of contemporary projects have incorporated cosmic particle detectors. *Cloud Chamber* (2013) is an interactive performance work developed by Alexis Kirke, Antonino Chiaramonte, and Anna Troisi, that uses cosmic particles manifested in a cloud chamber. In dynamic interactions, the particles' motions affect and are affected by a violinist during live performances. The particle forms, via a camera and computer, produce effects upon the audio output of the amplified violin, and the audio produced by the violinist in turn controls magnetic fields in the cloud chamber, affecting the particle paths. Thus, a kind of feedback loop is generated, with person and particles affecting each other, in a sonic dance of human and cosmic agency (to paraphrase Pickering). Yet, the artists stated that 'the use of this approach to generating musical material is not argued as

[104] The intersection of visual art and quantum physics can be traced back to the 1930s, when Einstein argued that cubism and abstract art should be used to engage with the abstract qualities of quantum theory (no, that's not a typo! It was in fact Carl Einstein, the art critic and friend of writer George Battaille). See Parkinson, 'Surrealism and quantum mechanics', pp. 557–577.

[105] Sound may communicate such abstract properties better than images. Jill Scott, of Artists-in-Labs, raised this point during the question-and-answer part of the 'Singularity' panel session in which I was involved during the International Symposium on Electronic Art (ISEA) 2016 conference. I agree, but I think the connection goes deeper. Although I have only anecdotal data to back it up, I believe sound artists are attracted to physics and mathematics, in the same way that mathematicians and physicists are drawn to sound and music. A disproportionate number of physicists I have met are either purveyors of music or are musicians. Moreover, there seems to be a loose correlation between types of physics and music styles: as Barry Barish (the Director of the Laser Interferometer Gravitational-Wave Observatory (LIGO) experiment) said to me, astrophysicists like classical music, whereas an unnerving number of heavy metal bands rehearse at CERN,. In fact, I found a connection during my first visit to CERN in 2010, when an interaction occurred between my iPod, a big detector magnet, and the band The Melvins. Basically the iPod was erased except for their songs – the Melvins are LHC proof! See http://filter.org.au/issue-72/the-sound-of-science-and-the-sound-of-silence-2/

[106] Stone, Lynden. "SPECTRA: Images and Data in Art/Science." Proceedings from the symposium SPECTRA 2012, Adelaide: Australian Network for Art and Technology, 2012: 71–77, p.73

[107] I don't refer further to Capra or *The Tao of Physics*, partially due to its somewhat mystical overtones, although Capra did know what he was talking about when it came to physics. However, I do like the poetic qualities of his image of Shiva as Natraj doing the 'Dance of Destruction', superimposed upon an image of particle tracks in a bubble chamber (Capra, Fritjof. *The Tao of Physics: An Exploration of the Parallels between Modern Physics and Eastern Mysticism*. Boulder: Shambhala, 1975, p.222).

[108] Ibid., p.74

[109] Ibid.

being a meaningful expression of the Standard Model or of quarks. It was mainly used as a framework around which the composer could construct the piece.'[110] The use of random cosmic particle events recalls Cage, yet the artists seem confused, as cloud chambers have little to do with the standard model or quarks, aside from being an historical precursor to the bubble chamber. However, the artists' unique and creative engagement with both phenomena and apparatus, and literally playing with and to the material phenomena, makes this work more than just a cloud chamber display.

French physicist Claude Vallée developed a sound installation triggered by cosmic particles, called *Cosmophone* (2000–2005). Vallée stated: 'the installation magnifies the cosmic radiation of protons that originate within our galaxy and constantly bombard the Earth.' [111] Muons produced by such cosmic radiation are detected in recycled scintillating plastic sensors, which trigger pleasant tones via Musical Instrument Digital Interface (MIDI).[112] However, the project lacks any compelling creative content or expressivity, perhaps because it is developed by people who evidently have little artistic sensibility (although it has been used as accompaniment for some interesting musical performances).[113] Thus, the project is just a kind of auditory illustration of the muon. In a similar manner, artist Tim Otto Roth has produced installations that turn on lights in response to cosmic particles. Roth described *Cosmic Revelation* (2009), a group of lights in a field triggered by a nearby cosmic particle detector array, as 'a minimalist light-based artwork and a scientific experiment as well.'[114] His reasoning for it being art and science, that it is an installation and a 'display solution', seems superficial. Although the work uses (or is attached to) a physics experiment, there is no evident creative or critical engagement with the science involved.

In contrast to the two works described above, Australian artist Joan Brassil used particle detectors in a unique and compelling way. In 1978, at the Sculpture Centre, Sydney, she produced *Austral/Astral Dreaming*, which was part of an installation titled *Can it be that everlasting is everchanging?* (1978). This work was comprised of 'geiger counters set amidst a "forest of aerials",'[115] with cosmic particles triggering the detectors that activated panels of light which in turn illuminated the 'aerial forest'.[116] The transformation of scientific devices into totemic forms gives the installation a unique presence, and poetically brings together cosmic phenomena, scientific and indigenous cultures, in a way that transcends the technology. Regarding her collaborations with scientists in the development of such projects, Brassil stated: 'This art/science split just doesn't exist for me. It's another way of looking. Their way of looking is reverence. I try to appreciate that. It's always inspired by

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[110] Kirke, Alexis, Eduardo Miranda, Antonino Chiaramonte, Anna R. Troisi, John Matthias, Nicholas Fry, Catherine McCabe, Jeff Radtke, and Martyn Bull. "Cloud Chamber: A Performance with Real Time Two-Way Interaction Between Subatomic Particles and Violinist." *Leonardo* 46, no. 1 (2013): 84-85

[111] Ibid.

[112] This can be seen in contrast with my sound work, which does not transpose data into pleasing musical scales. Essentially, anything can sound good when put into a perfect fifth musical form.

[113] See http://cosmophone.in2p3.fr/ One interesting count of coincidence with my projects is that one of the *Cosmophone* installations was also called 'Theatre of the Muons'.

[114] Roth, Tim Otto, and Andreas Haungs. "Cosmic Revelation." *Leonardo* 42, no. 3 (2009): 288-89, p.288.

[115] Sofia, Zoë. "Technoscientific Poeisis: Joan Brassil, Joyce Hinterding, Sarah Waterson." *Continuum: Journal of Media & Cultural Studies* 8, no. 1 (1994): 364-376, p.365

[116] Such a work also brings to mind Joyce Hinterding's amazing electromagnetic installations, such as *Aeriology* (1995), which is basically an apparatus consisting of 20 kilometres of copper wire wound into a large square shape, which turns electromagnetic field energy into sound in the same way that an AM radio antenna works. The installation is also reminiscent of the Charpak-designed wire-filled tracking chambers of the 1960s.

nature. What you feel is what they know.'[117] As well as being a quietly triumphant rebuke to people such as C.P. Snow, this comment encapsulates the attitudes of the physicists I have worked with, as described in Chapter 4.

In summary, the particles used in the artworks described above are components of cosmic radiation (or emissions from thorium). Essentially, the particles trigger responses in detectors that are repurposed by the artists. It is evident that such projects are shaped and limited by the technologies used, like the E.A.T. projects described in Section 3.4. None of the artists mentioned above have worked with high-energy physics due to such limitations.[118] As one artist lamented (discussed below), in order to undertake such projects one essentially needs a particle accelerator, and therefore needs to work in a high-energy physics laboratory.

3.7. Artists and laboratories

This section describes several projects in which artists were placed in scientific research laboratories. They provide insights into art and science processes, and also how collaboration works (or sometimes doesn't), and portray the difficulties of interdisciplinary practice. One of the first contemporary cross-disciplinary institutes (now a leading art - science centre and gallery in London) is the Wellcome trust. In the mid 1990's, they set up conversations between artists and scientists, asking 'what is it about science that attracts artists' and 'what does science gain from these encounters?'[119] Such questions were not meant to be explicitly answered, but instead creatively engaged with through collaborative projects.

In 2003, the Australian Network for Art and Technology (ANAT) initiated the Synapse residency program, in order to support collaborations between artists and scientists. Since its inception, over thirty in-situ art / science collaborations have been undertaken, encompassing areas from biology to cosmology, and which allow artists to practically engage with technologies ranging from nano-engineering to astrophysical supercomputing.[120] As described in an analysis by academic researcher Lorraine White-Hancock,

> ANAT's 'hands off' approach once residencies were granted afforded informants the freedom and discretion to conduct their work as they saw fit. Finally, there was little expectation of product 'outcomes' since the program aimed to support artists in the conduct of their research. These organisational approaches provided space for exploration and experimentation.'[121]

Collectively, the Synapse projects 'involved new ways of thinking about science, working and making connections across disciplinary boundaries.'[122] The Synapse model was seen as an innovative means of cross-disciplinary engagement and communication, an 'opening up [of] the conversation about science-art relatedness and sharing this knowledge'.[123] This seemed apparent to me during a discussion panel at the International Symposium on Electronic Art, in Sydney, Australia, in June 2013.[124] Speakers at the panel

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[117] Sanders, Anne. "Force, Tension, and Working in Threes." *Artlink* 26, no 4 (2006): p.89

[118] One could argue, as does Roth, that some muons produced from cosmic particle interactions with the Earth's atmosphere are high-energy, but they are not a stable and/or deliberate source.

[119] Arnold, Ken, "Preface". In *Experiment: Conversations in Art and Science*, edited by Arends, Bergit, and Davina Thackara. London: Wellcome Trust, 2003, p. 7

[120] http://www.anat.org.au/synapse/

[121] White-Hancock, Lorraine. "Innovation and Arts Practice: Work, Learning and Transgression." PhD thesis, Monash University, 2016, p.152

[122] Ibid., p.152.

[123] Ibid., p. 142

[124] http://www.isea2013.org/wp-content/uploads/2013/05/ISEA2013-Conference-Program-PDF.pdf

included Synapse artists Erica Seccombe, Elizabeth Eastland, and myself. We found that we shared traits such as working directly with the scientists, technologies and data, and, through experimentation, developing novel ways to both engage in such research, and communicate our research projects.
As discussed in the Introduction, I undertook residencies at the Australian Synchrotron in 2007 and in 2010 through ANAT. The initial residency was for three months, which involved many trial and error art experiments with the science experiments, which led to the final project which was truly inter-disciplinary and collaborative. Working with several accelerator physicists, I modulated the synchrotron's 'tune', the electromagnetic vibration in the beam, with an audio recording I made of the resident cicada, thereby making the synchrotron essentially sing the cicada's song.[125] In other words, it took me almost three months of daily engagement to get to a point where I could produce a project that engaged deeply and poetically with the science. The second residency picked up where the first left off, playing with data and audio-visually simulating the accelerator, but was not quite as fruitful due to technological problems.[126] To paraphrase Hacking, experiments don't always work. Nevertheless, this did provide the impetus for this current research, and involved a visit to CERN.

Also commencing in 2003, Artists-in-Labs is a contemporary residency program at the Zurich University of the Arts (ZHdK), which has a range of residencies similar to the Synapse program. Christian Gonzenbach is an artist who worked with the Physics Department at the University of Geneva and CERN in 2010. Summarising his experiences, he stated 'I needed my own apparatus, my own synchrotron … [but was not given such access, so] had to accept that I could not make real physics, but I could create images and metaphors about it.'[127] This represents a level of pre-collaboration. In response to the residency, Martin Pohl, head of the Physics Department, stated 'what was beneficial and interesting, was to observe an artist playing with the scientific method.'[128] Pohl also stated 'For us, the outcome … has thus been not to create knowledge, but to comprehend and question the scientific process itself.'[129] Although this is a positive insight into the nature of art practice as a means of generating questions, it also belies an attitude of scientism, in that art is not a valid form of knowledge. Another Artists-in-Labs artist, Australian Nigel Helyer, worked at the Paul Scherrer Institute (PSI) in 2004, where he devised a sound installation that was triggered by cosmic particles. His project and outcome was subtly different from similar works mentioned in this exegesis, in that he developed a self-contained installation, *Theorem*, which emitted light and tones when activated by muons produced from cosmic particle interactions with the earth's atmosphere. He produced a working prototype, intended to be part of a group of such sculptures placed in a field at PSI. *Theorem* differs from Roth's work described in Section 3.6, as Helyer sought to manifest the cosmic particle collisions within his self-contained audio-visual-sculptural forms. However, from Helyer's report, his project was not a collaboration, with the artist feeling a

[125] See http://filter.org.au/issue-68/the-final-experiment/
[126] See http://henschke2010.anat.org.au/page/2/
[127] Gonzenbach, Christian. "I Wish I Was a Physicist." In *Artists-In-Labs: Networking in the Margins*, edited by Jill Scott, 162-166. Vienna: Springer Verlag, 2010, pp.164–165
[128] Pohl, Martin. "The Physics Department at the University of Geneva | CERN." In *Artists-In-Labs: Networking in the Margins*, edited by Jill Scott, 110-112. Vienna: Springer Verlag, 2010, p.111
[129] Ibid.

state of ‘relative isolation,’[130] as the scientists involved seemed to have little spare time or drive for such a ‘coffee-break project.’[131]

As others involved in Artists-in-Labs have stated, such projects need dedicated time and effort from the scientists to make it a collaboration. A ‘main problem was the short duration of the artists-in-labs project. Four months ... is not enough time to seriously examine these complex scientific questions in depth.’[132] Another key aspect is finding a scientist who is keen to develop collaborative projects. The Synapse model is based on prior successful collaborations between the artist and scientist. This is where the Synapse program differs from Artists-in-Labs: it is designed for collaborations in which initial inroads have already been made, through joint submissions by both the artist and scientist.[133]

Finding ways to communicate between specialisations is an issue that any outsiders to specific research areas will have to face, whether they are scientists or artists. As Peter Galison stated, for such trans-specialist communication to work, ‘creoles’ have to develop – hybrid languages which are ‘not a mere application of one language to another, … [but are instead] drawing from both parent languages, and significantly, extending beyond them.’[134] I see the development of creoles as providing a necessary ‘bridge between technical and humanist language.’[135] As I found in my own practice, this is a key part of collaboration (discussed more in Chapter 4).

In summary, art–science collaborations require commitment from both sides. As I have found, an essential ingredient is working with scientists who can understand and communicate with artists. However, projects that may not be so collaborative, such as Helyer’s, can still engage with key concepts in experimental physics such as observation and detectors, as discussed in Chapter 2.

[130] Helyer, Nigel. “Cold Turkey with the Muons.” In *Artists-in-Labs Networking in the Margins,* edited by Jill Scott, 90-93. Wien: Springer Verlag, 2006, p.93

[131] Ibid., p.92

[132] Ibid., p.77

[133] Interestingly, this is acknowledged by Artists-in-Labs: Irene Hediger, co-director of Artists-in-Labs and associate of the current director of ANAT, Vicki Sowry, met me when I undertook my Synapse residency at the Australian Synchrotron in 2010. We discussed collaborations and both agreed that the key ingredient is finding a science collaborator who basically understands art practices.

[134] Galison, Peter. *Image and Logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press, 1997, p.138

[135] Zilberg, “A SEAD White Papers Working Group Meta-Analysis”, p.63

3.8. Artists and high-energy physics

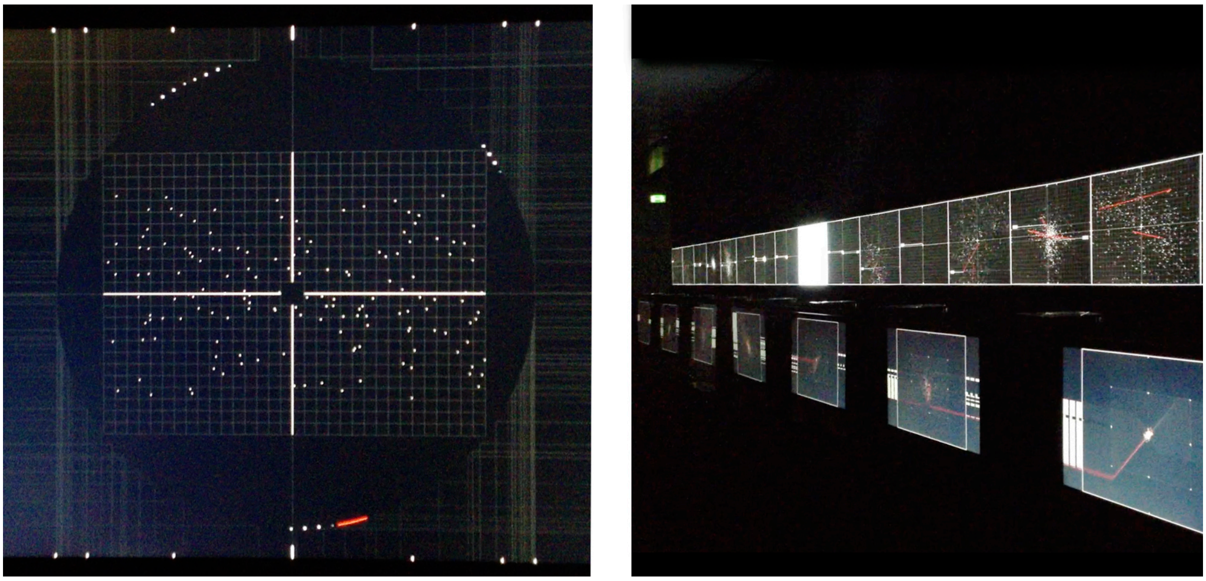

Figure 7. Ryoji Ikeda, *Supersymmetry*, 2015.

As described in Chapter 2, CERN is a research institute which has developed the LHC, the largest and most powerful particle accelerator in the world. Former director Rolf Heuer, who initiated the Collide@CERN program described below, supports artists working at such science institutes, and expresses 'hope that scientists realize the importance of art.'[136] CERN has been officially bringing artists on site since 1999, when a group spent a day visiting the LHC, and developed an exhibition in response, called *Signatures of the Invisible*.[137]

CERN currently supports various current projects involving artists, one of which is art@CMS, which is described in Chapter 4. The first official program, running since 2012, is the Collide@CERN residency. This three-month residency involves several weeks on site at CERN, and the rest of the time producing completed artworks at Ars Electronica in Linz, Austria.[138] Collide@CERN uses a structure more along the lines of Artists-in-Labs than the Synapse model, which is of a longer duration and is not explicitly outcome-based (as described in Section 3.7). The Collide@CERN director, Ariane Koek, thought it was important to commission only short projects, 'so the artist doesn't get too involved in details. Artists shouldn't have to prove themselves to the scientist.'[139] However, this does not guarantee projects and artworks that have deep connections with science, as I argue in more detail below. For example, the first residency, by Julius Von Bismarck, resulted in an

[136] Miller, *Colliding Worlds,* p.166

[137] Although lauded at the time for bringing together art and science, the works were at best visual metaphors of general physics concepts, but they did not actually use any of the physics or data generated at CERN. However, one of the event organisers merely echoed C.P. Snow, and appeared ignorant of the history of art–science interactions when he stated that 'artists today are beginning to realize that science provides fertile territory for the imagination.' http://cerncourier.com/cws/article/cern/28434

[138] I had a tenuous connection with the development of this program - I met Ariane Koek during a visit to CERN in 2010, as part of my Synapse residency; then in 2013, she put on an art–science lunch for me and colleagues (described below) in the CERN "fish-bowl" silver-service restaurant. In 2010, Koek interviewed Mark Boland and myself about our experiences at the Australian Synchrotron and the ANAT Synapse program, as a means of learning how to (or perhaps how not to) set up Collide@CERN.

[139] Miller, *Colliding Worlds*, p. 148

During a trip to CERN in 2013, on my first PhD field trip, I went into the LHC tunnel with a group of people, including CERN physicists, Mark Boland, Ariane Koek and Collide@CERN artist Bill Fontana. Perhaps tellingly, Fontana didn't engage with the other people, and even ignored safety instructions. His final project seemed to be only to record sounds made in the linear accelerator at the start of the LHC, and play some other sounds into the LHC tunnel. As Arthur I Miller later stated to me, this project was not a collaboration.

installation comprised of swinging lights, which was critiqued as only demonstrating 'the paucity of his knowledge of physics.'[140] As Miller stated, 'perhaps a person with a greater involvement with physics might have left a more enduring footprint.'[141] This raises the question as to whether the Collide@CERN method of minimal engagement works on a level of Malina's advocated 'deep art – science coupling',[142] or whether artists should probe deeper, at the risk of becoming 'a handmaiden of science.'[143]

Japanese media artist Ryoji Ikeda put together a much more engaging project for Collide@CERN, but this was not without criticism. I caught up with Ikeda when he had just commenced his on-site residency, and he stated somewhat despairingly that he was 'completely overwhelmed' by it all, echoing Latour's initial experiences of being in a laboratory (see Section 2.5). Perhaps short-duration residencies produce projects that manifest such experiences, and may not be able to probe deeper. I found such an impression in the work Ikeda produced, which was a lot of screens with dynamics of light, movement, and data. Despite being titled *Supersymmetry*, the piece didn't actually delve into the nature of supersymmetry. Screens presented dots moving in circles, followed by explosions of alphanumeric data, manifesting the volume and complexity of data produced at CERN (see fig. 7). The work definitely had Ikeda's unique signature; it was technically precise and impressive, with many synchronised screens and high-resolution projections. It also had cabinets with moving ball bearings and lasers (the first time I have seen him break out of digital media). However, I feel that Ikeda didn't push the connection with experimental physics. The overall feel of the installation could be perhaps seen as unintentionally impressionistic, in that it simply manifested the initial impressions and experiences one would have of such a research laboratory.

Such a limited impression seemed evident in Jonathan Jones' negative review of Ikeda's exhibition, published in *The Guardian*.[144] He described the installation as an 'array of beeps, whooshes, dazzling strobes and light pulses [which] basically seems to be rubbing its head and groaning: "Blow me, this is complicated stuff".'[145] Jones' comments belie his failure to appreciate the nature of 'data art', as championed by Ikeda in many other acclaimed works. Worse however, is his impression that the work 'signifies little more than that physics is weird,' that leads him to conclude 'isn't it time we stopped expecting artists to understand the complexities of science?' [146] This does little more than echo C.P.Snow, and presents an ill-informed belief that artists can't

[140] Ibid.
[141] Ibid.
[142] Malina, Roger. "Welcoming Uncertainty: The Strong Case for Coupling the Contemporary Arts to Science and Technology." In *Artists-in-Labs Networking in the Margins* edited by Scott, Jill, and Zürcher Hochschule Der Künste, 15-23. Wien: Springer Verlag, 2006, p.18
[143] Fenton, Terry, quoted in "Colliding Ideas – Art, Society and Physics Symposium." Jon McCormack's website, published July 3, 2012. Accessed June 1, 2017. http://jonmccormack.info/news/colliding-ideas-art-society-and-physics-symposium
[144] Jones, Jonathan, "Should Art Respond to Science? On this Evidence, the Answer is Simple: No Way." The Guardian, April 24, 2015. Accessed August 10, 2016. https://www.theguardian.com/artanddesign/jonathanjonesblog/2015/apr/23/art-respond-science-cern-ryoji-ikeda-supersymmetry
[145] Ibid.
[146] Ibid.

engage meaningfully with any of the myriad aspects of scientific research.[147] However, had Ikeda's work engaged with the science on a deeper level, it may have challenged such superficial criticism.[148]

I will discuss one final piece that works with quantum phenomena. Called *Quantum Now*, it was exhibited at the Documenta 13 arts festival in Kassel, Germany, in 2013, by physicist Anton Zeilinger. The work is a series of entanglement experiments, complete with blackboard and scientists who discuss the experiments with visitors, and allow limited audience interaction with the apparatuses; thus, this can be seen as a 'scientist-in-gallery' inversion of the Artists-in-Labs concept. The work presents the counterintuitive aspects of quantum physics (as discussed in Chapters 1 and 2), and also seeks to illustrate 'parallels between art and science.'[149] When I initially read about this project I was sceptical about Zeilinger's motives and his claim that (his) science could be art in and of itself, and whether he was informed by contemporary art practice.[150] However, I have partially changed my opinion on his relation to, and understanding of art, after a discussion with Zeilinger.[151] He was approached by Documenta artistic director Carolyn Christov-Bakargiev, who was interested in the realm of physical reality being explored at his laboratory.[152] As Zeilinger and I discussed, the term 'entanglement' is often used in the arts and humanities in a pseudo-scientific manner without clear understanding; to connect with it more deeply, we need to actually engage with the phenomenon, to make the knowledge personal and physical – to paraphrase Hacking, to gain insight not just by looking but by manipulating. Ultimately this doesn't detract from the uniqueness of such phenomena, on the contrary, it allows people to experience it for themselves. However, science is *not* art, and one should challenge projects such as this by developing 'entanglement art' that explores such unique phenomena. I see Zeilinger's 'scientists in gallery' installation as a challenge to the art world - as mentioned in Section 3.1, Feyerabend said that an essential aspect [153] of any research should be to challenge disciplinary boundaries.[154] To date, nobody from the arts has produced such an entanglement artwork. This is discussed further in Chapter 5.

In summary, Artists-in-Labs and Collide@CERN provide limited engagement with scientific research laboratories. In such residencies, a variety of challenges, methods and outputs manifest themselves. Projects engage with concepts, processes and data, albeit sometimes simply. I feel that it takes longer than a few weeks or months to produce art that critically engages with the science. To push deeper, one must develop more nuanced and ongoing interdisciplinary collaborations, which need to be nurtured. And then there is the counterpoint, the 'anti-artists-in-labs' experiments of Zeilinger, which may be a challenge to artists as well as a means of public outreach.

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[147] I can imagine Duchamp's disdain for such a comment – he reacted against an equivalent expression of the early twentieth century, which was 'as stupid as a painter'. http://www.toutfait.com/issues/volume2/issue_5/articles/merritt/merritt1.html

[148] I do however find this a difficult assertion to make, as I don't believe that art should have to work on any prescribed level, whether deep or superficial. Nor should it have to pander to commentators such as Jones and their 'philistinism of interpretation' (Sontag, Susan. "Against Interpretation." In *Against Interpretation: and Other Essays*, 3-14. London: Penguin, p. 8)

[149] https://medienportal.univie.ac.at/uniview/wissenschaft-gesellschaft/detailansicht/artikel/documenta-13-zeilinger-zeigt-quantenphysik-experimente/

[150] I read about his Documenta installations in 2013.

[151] Natural History Museum, Vienna, 18 October 2016. Zeilinger has in fact been at the forefront of bringing the cultures of art and science together, participating in the ground-breaking Bridge the Gap art–science conference in Kitakyushu, Japan, in 2001. He is also friends with Peter Weibel, Director of the Zentrum fur Kunst und Medientechnologie (ZKM) in Karlsruhe, Germany.

[152] See d13.documenta.de

[153] Feyerabend, *Against Method*, p.174

[154] Interestingly, when I mentioned Feyerabend and his 'anything goes' method to Zeilinger, he smiled proudly and said to me 'you know he's Austrian!'

3.9. Conclusions

This chapter commenced with an overview of interdisciplinary and experimentalism in art and its relation to experimental science. I discussed the experiments of chance and randomness of Dada, the scientific plays of Duchamp, and the art–technology collaborations of E.A.T., electromagnetic and electroacoustic energy, and collaborations between artists and scientists in laboratories ranging from the compact to the colossal such as CERN. My exploration shows that the two cultures can and do communicate and work together in art and physics, to varying degrees, as well as in other realms of science.[155]

Key aspects of this chapter include the hands-on nature of experimental art practice and its parallel with experimental science, as shown through the dual application of explanations by Pickering and Hacking. Furthermore, as shown in examples of artists working with physics phenomena and working in physics labs, such relations between practice are more than just metaphor. Developments in art and technology have led to visual, sound and installation projects that practically and conceptually engage with materiality and energy. In particle physics, detector apparatuses and data have been used in various ways and to greater or lesser degrees of creative and critical inquiry. Yet collaboration can be fraught and not always work as hoped. As the examples in this chapter demonstrate, art–science collaborations require time to develop, and a few weeks in a lab produces only superficial outcomes. Negative responses to cross-disciplinary projects such as the Jones review of Ikeda's collide@CERN project illustrates why I believe short-term artist residencies are too limiting. I call for a deeper level of engagement, which can be made possible through interdisciplinary collaboration. As Rolf Heuer said, the 'questions [in science] are so deep they call out for specialization' through collaboration within the scientific discipline, and I see that this also applies across disciplines.[156]

The projects examined were collaborative and interdisciplinary to varying degrees. However, none of the projects that involved work with particle physics identified new topics or concerns – they did not make the leap to being transdisciplinary practices. I feel that this is basically impossible in the area of high-energy physics, due to the highly complex and specialised nature of the field. To paraphrase philosopher Jurgen Habermas,[157] the region is unsurveyable by any individual, whether artist or scientist, or indeed an art–science collaboration. However, this should be not taken as a negative; I believe that the interdisciplinary nature of such collaborations presents plenty of challenges and insights in terms of practice and projects, and in itself leads to unique creative outputs. In my practice, I have sought to engage deeply with the science – the theories, the experiments, the apparatuses – and see what comes out the other side. I discuss the results in the next chapter through a presentation of my own experiences and projects.

[155] I have not mentioned many aspects of art/science practice, such as the expansive area of 'bio-art', ranging from Eduardo Cac's genetically engineered glowing Alba bunny (and the unique custody battle fought between its artists and scientists), through the Symbiotica lab to Stelarc's unique body experiments and manipulations. However, discussion of this fascinating area is out of the scope of this exegesis.

[156] Miller, *Colliding Worlds,* p.166

[157] Habermas, Jürgen. "The New Obscurity: the Crisis of the Welfare State and the Exhaustion of Utopian Energies." *Philosophy Social Criticism* 11, no. 2 (1986): 1-18, 1

Chapter 4 – My Experiments with Particle Physics

In this chapter I discuss my experiences at CERN and the works I produced during my candidacy. In Chapter 3, I critiqued aspects of art–science projects that were not deeply engaging or were not developed through interdisciplinary collaboration. These contrast with my own work, produced at CERN through engagement with the scientists and the experiments both conceptually and materially. This was made possible through the model that used by the art@CMS collaboration at CERN.

In the first section of this chapter I discuss the art@CMS collaboration program, and some of my social interactions with the CERN physicists. In this chapter I describe my studio practice, specifically the development and production of six artworks. These are selected as being representative of the key areas of both my research and practice which engages with particle physics. I also refer to and footnote my other smaller projects and prototypes which have informed these main projects. I begin my discussion with two screen-based media artworks, *Edge of the Observable* and *Nature of the Apparatus*. These respectively explore aspects of the phenomena produced in the LHC and the apparatuses that comprise the experiment. I then discuss my interdisciplinary data sonification installation project, *Song of the Muons*, and the ways in which heuristic methods and creoles developed during my collaboration with CMS physicists. From this I turn to my series of energetic material experiments with objects gleaned from the LHC, *Activated Objects*, via the playful and lo-tech *Potential Objects* exhibition. This leads to my final artwork, *Song of the Phenomena*, essentially a collaboration with an obsolete particle accelerator that I bring back to life. In addition, I make various references (in the footnotes) regarding my personal observations and experiences of working with physicists. These raise insights and issues into the practical aspects of working on such cross-disciplinary projects. A comprehensive list of where the artworks have been exhibited, plus documentation, is in the Appendix.

4.1. art@CMS

art@CMS is an education and outreach program of the CMS experiment at CERN, which fosters collaboration and critical engagement between artists, teachers and researchers at CMS.[1] Each artist is partnered with a CMS scientist, and unlike the programs described in Sections 3.7 and 3.8, the CMS collaborations are not fixed-term residencies. The other art@CMS projects developed differently to mine, and have been shorter in duration.[2] The fact that my art@CMS collaboration has been ongoing for three years has led to a deeper and more enduring relationship, in contrast to the residency models described in Chapter 3. My main collaboration partner was Wolfgang Adam, who has been working with CMS for 15 years and is involved in searches for supersymmetry. He is the senior physicist engaged in analysis of the CMS data at the Institute of High Energy Physics in Vienna, Austria.

[1] This program was initiated by Michael Hoch, a physicist at CMS, who is also an artist working in collage and photomedia. art@CMS ultimately began late one night in 2009, when Michael, using a scissor lift, took hundreds of photos of the face of the CMS detector, which he turned into an ultra-high resolution 1:1 scale image of CMS. This iconic 5 storey high image is now displayed above the detector itself.

[2] Projects range from simple but effective video works, such as Peter Bellamy's *Bike*, via Andy Charalambou's inspiring (yet doubly representational) sculptures of Feynman diagram representations of particle interactions, through the dynamic hip-hop interpretations of high energy physics of *ConSensus*, to an utterly inane Matisse style painting, *Circulez*, of which the only connection with the LHC or CMS was that it was large and circular.

Unlike the limited experiences described by other artists (in Sections 3.6 and 3.7), my ongoing interactions with CERN scientists allowed for more personal relationships to develop via integration in their day-to-day activities.[3] During visits over three years, I gained insights into the way the physicists engaged with each other and their apparatuses, aided by my research into the genealogies of the devices.[4] However, there is a danger involved in such social integration, that of becoming the 'handmaiden of science,'[5] and trying to didactically 'repeat what the scientist has done ... [which] smacks of the dabbler or dilettante.'[6] As artists Gemeinboeck and Dong cautioned, 'artists should be wary of falling into the trap of becoming pseudo-scientists by appropriating theoretical methodologies and paradigms that may not only stifle real debate between the disciplines but, moreover, may actually stymie their own creative potential.'[7] Such environments can be creatively challenging (as shown in Sections 3.7 and 3.8), but what if they push discourse between disciplines and creative potential, and indeed challenge science on its own terms? On this level, my work at CERN tested such notions.

In order to develop meaningful dialogue with the collaborating scientists, and produce works that have a deeper level of engagement than those critiqued in Chapter 3, I had to avoid didacticism. I believe that artists who work in situ at such scientific facilities have to endeavour to understand the science involved if they want to meaningfully interact with the scientists and produce truly interdisciplinary projects. In a sense this is like going native, which Latour warned against, but 'playing native' does have its advantages. Recent studies in ethnography have advocated a more engaged process, in a shift away from the disengaged participant observer, towards deeper engagement with the social subjects, in order to produce a 'richness of the data ... derived from observant participation,' which can help 'cross the great disciplinary divide.'[8] For the outsider who has entered this world of high-energy physics, it can be an overwhelming experience (as shown in Ikeda's response described in Section 3.8), thus one must push past the initial state of shock and awe.

Although I was (and am) unable to fully grasp many of the subtleties of quantum physics embedded in the mathematics, I did not find this to be a major impediment. Instead, I found ways of cross-disciplinary engagement through my insights into the history, philosophy and material cultures of particle physics (as described in Chapter 2). This was aided by the development of creoles and heuristics, discussed in Section 4.4. Through such heuristics I developed processes that connected conceptually and materially with the processes used in high-energy physics at CERN, in a way that manifests the subtleties of human / subatomic interaction.

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[3] Such participation in day-to-day tasks included working on the outreach program, arranging and giving talks to visitor groups and students, and designing and printing booklets and posters for art@CMS. Social integration also led me to meet musically-minded people at CERN, which led to pub visits, parties, playing a gig on a rooftop in Geneva, and a live audiovisual performance, titled *Noise 'n' Science*, at Cinema Spoutnik, a major 'underground' cinema and venue in Geneva, run by a former CERN scientist.

[4] On my first sojourn with art@CMS I found the CERN Library, which instantly became an invaluable resource; a library was something I was familiar with and knew how to use. It led me to Galison and Hacking, and it had a large bust of Niels Bohr by the door. It was also open 24/7, and I spent some great Saturday nights there!

[5] Fenton, Terry, quoted in "Colliding Ideas – Art, Society and Physics Symposium." Jon McCormack's website, published July 3, 2012. Accessed June 1, 2017. http://jonmccormack.info/news/colliding-ideas-art-society-and-physics-symposium/.

[6] Sarat Maharaj, "On Francisco Varela." In *Bridge the Gap?* edited by Akiko Miyake and Hans Ulrich Obrist, 103-117. Köln: Verlag der Buchhandlung Walther König, 2002, p.112

[7] Gemeinboeck, Petra, and Andy Dong, "Discourses of Intervention: A Language for Art & Science Collaboration." In *New Constellations: Art Science and Society*, edited by D. Rye & S. Scheding, 46-51. Sydney: Museum of Contemporary Art, 2006, p.50

[8] Moeran, Brian, "From Participant Observation to Observant Participation: Anthropology, Fieldwork and Organizational Ethnography." Copenhagen: Creative Encounters Working Papers, 2007. Accessed January 30, 2017. http://openarchive.cbs.dk/bitstream/handle/10398/7038/wp%202007-2.pdf?sequence=1.

4.2. *Edge of the Observable*

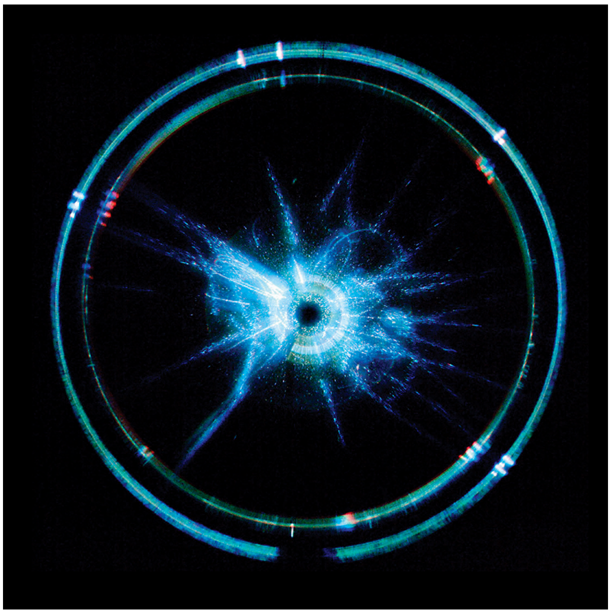

Figure 8. Chris Henschke, *Edge of the Observable*, 2014.

Edge of the Observable is an audio-visual artwork I created in response to my observations of the particle collisions in the CMS detector (see fig. 8). However, instead of visually rendering the three-dimensional digital reconstructions of events, I set up an experiment which optically magnified the formal properties of such collision event reconstructions. I used one specific collision event from the billion occurring each second: event 416497095 of event run 46944.[9] This event in itself has no particularly unique scientific value, but I found it to have compelling expressive qualities. In a sense, it was a unique signature that I felt gave 'expression to the secrets of the physical world, where it shows a universal splendour,' to paraphrase accelerator ethnographer Arpita Roy.[10] In the way that scientists pick specific collision events out of the 'microphysical ocean'[11] according to their unique signatures, so too I fished my event out of the digital ocean of data from CMS. I took this event and re-animated it in a variety of ways, trying to extract something of its essence. I sought to spatio-temporally expand the one event, synchronising it to a compelling sound recording of energy in the apparatus given to me by accelerator physicist Ralph Steinhagen (discussed in Section 4.3). After trying many unsuccessful variations of digital data manipulation, I essentially brought the event out of the data and back into the physical realm.

I wished to manifest a kind of essence of such collision events, on a level that was a kind of primary reality, to use Zeilinger's term. On this level, I sought to provide a raw 'sensory experience [and] reveal the sensuous surface' of the event, to paraphrase Susan Sontag.[12] Also I wished to express the paradox of our relationship to such phenomena, creating a kind of signature. As discussed in Section 2.3, scientists literally create such collision events in apparatuses such as CMS, yet particles such as the Higgs Boson are inferred from secondary

[9] I am not totally sure what this refers to, but it may be the 46,944[th] tick of the LHC time clock.
[10] Roy, Arpita. "Ethnography and Theory of the Signature in Physics." *Cultural Anthropology* 29, no. 3 (2014): 479-502, p.482
[11] Galison, Peter. *Image and Logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press, 1997, p.551
[12] Susan Sontag. "Against Interpretation." In *Against Interpretation: and Other Essays*, 3-14. London: Penguin, 2009, p.13

particle emissions. It is not possible to definitively observe such particles, due to the quantum uncertainty associated with the high energy and short lifetime of the particles, but also due to the technical limits of the apparatuses. I found such a limit actually manifested within the data, a small spherical void-like space right in the middle of the digital reconstructions. This is known as the 'vertex of kinematic indetectability,'[13] and is literally the limit of the detectors' measurement capacity.[14]

I devised an experimental setup, comprised of a beam source, a target and a detector, which reproduced the basic aspects of particle physics experiments (but was by no means scientific). My beam source was a laser (which projects RGB (red green and blue light)), and the detector was a very high-quality video camera. I tried increasingly Dadaistic recombinations and rearrangements of the elements of the setup, putting various objects in the beam path. Eventually I placed a large glass sphere in the middle of the setup.[15] Suddenly, a golden event appeared on the detector screen (the camera viewfinder). Through trial and error, I had found the right combination of objects, and the right distances between them. It was a case of a physical tout-fait flash of insight (to paraphrase Poincaré), with the light of the laser source, magnified and enhanced through the lens, literally flashing upon the detector screen. Although the event's aesthetic and expressive qualities were manifested by chance, I found them ideal. I performed some fine tuning of the physical variables of the experiment, and a touch of post-production colour grading, but essentially the footage I captured at that moment became the final work. The final version of the work is a slow zoom into the spherical void in the middle of the image, in a twelve-minute loop (see plate 1). This void is the essential visual element, as it both physically and conceptually manifests the limit of the detector and the limit of observation. This encapsulates the essence of the LHC, as a device operating literally at the limit of our understanding of the universe at its smallest scale.

Edge of the Observable exists between the mimetic, representing an actual collision event, and the abstract, expressing and enhancing the formal qualities manifested in such events overall. In this way it plays with the tensions between photographic and digital data, as discussed in Section 2.2. In Hacking's style, I gained such insights not just by looking at the digital reconstructions, but by manipulating them. By removing the scientific content of the image, the wireframe manifold of the detector around the events, and other such symbols, tries to present the event as a kind of naked or abject object.[16] This itself plays upon the physicist's ideal of such experiments – as Traweek observed, 'detectors ideally become invisible transparent scientific instruments,'[17] and the collision events, the most ephemeral of phenomena, become the more permanent icons through the

[13] When I was looking for the technical name of the vertex limit effect in detectors at CERN, I found a paper on dark matter titled 'Mono-everything: Combined limits on dark matter production at colliders from multiple final states'. The first Figure shows the 'Pair production of WIMPs ($\chi\chi^-$) in proton-proton collisions at the LHC via an unknown intermediate state' signified by a grey void, which kind of validated *Edge of the Observable*. This also shows that particle physicists are happy working with unknowns and indeed unknowables, as artists do.

[14] The term seemed quite poetic, but when I mentioned this to another physicist (who is more familiar with the apparatus) he stated 'it's just the beam-pipe.'

[15] Not to be confused with Duchamp's *Large Glass*.

[16] I was inspired towards such abjection after a physicist literally hit me across the head (albeit playfully) and told me to 'get over the cathedral of science, and see through its technological complexity to what lies within.

[17] Traweek, Sharon. *Beamtimes and Lifetimes*. Cambridge: Harvard University Press, 1992, p.158

presentation of their signatures upon screens, in scientific reports, and even on t-shirts.[18] However, this was not a collaboration, I was simply given the data and modelling software from CMS physicists and responded to it accordingly. The work is ultimately representational, albeit in a multifaceted way. It represents the digital reconstructions, itself a representation of the actual events in the detector, and the experimental setup of the detector and signatures. Ultimately, it represents a limit of our knowledge of the material universe.

In summary, *Edge of the Observable* manifests expressive qualities inherent in particle collisions, as a kind of formalised signature of such events, and plays with the concept of golden events. Through an optical setup – an experiment in its own right – the work enhances such formal qualities, magnifying the inner limit of the detector, and through this, the limit of observation.

4.2.1. *Edge of the Observable* exhibitions

Edge of the Observable premiered at the art@CMS vernissage, June 25–30, 2014, in the hall literally above the detector itself (see plate 2).[19] The opening of the show was attended by hundreds of CERN scientists, with whom I had lengthy discussions, opening up dialogues that would later prove fruitful,[20] such as with my collaborator-to-be, Wolfgang Adam.[21] The work was then exhibited at the International Conference on High Energy Physics (ICHEP14), in Valencia, Spain, July 2–9, 2014, which I attended with Michael Hoch. The work was initially ignored by the conference attendees. After observing the lack of interaction, I changed the setup into the style of a science information stand, quickly designing and printing scientific-looking posters and brochures, and a four-metre banner emblazoned with the phrase 'Colliding Events – Observable Edge: Turn Every Phenomenon into a Golden Event.'[22] Displaying the work as a mock science installation opened the way to interactions with scientists, who proved much more interested in this form than in its initial presentation as an artwork.[23] A few even thought it was some kind of LHC optical imaging system.[24]

[18] During my first visit to CERN I went to the gift shop, which was selling t-shirts with an equation of the Standard Model on them. This Standard Model t-shirt seemed to me both sublime and ridiculous. How can an equation that supposedly explains all physical phenomena in the universe (except gravity) fit on a t-shirt? But then, after the discovery of the Higgs boson, the gift shop started selling t-shirts with its iconic 4 muon signature upon it. In a sense this itself shows the tension between theory and experiment.

[19] This was my first official exhibition as part of art@CMS. It was also the first time I went down into the CMS cavern (with art@CMS director Michael Hoch) to see the detector itself. This was truly an awe-inspiring experience: it literally gave me goosebumps, partially from the sheer scale and complexity of the detector device, but also from what I both knew and felt occurs in the core of CMS and the unimaginable energies released in its heart. I could almost sense the echo of the collisions and smell the energy! It was a moment of Kant's mathematical sublime.

[20] In fact, even the supposedly simple task of setting up some screens at the site proved to be a complex negotiation with a variety of CMS people, which was ultimately a good way to get to know them and incorporate myself into their social structures. I also had to use various methods of persuasion, which I explained to them later was just part of the artist's toolkit. I was initially meant to present my work on a small computer screen on a table in the corner, so I had to loudly impress upon them the importance of quality of presentation in art and its similarity to quality of scientific apparatuses. I got some trusty people from mechanical engineering to relocate two big screens near the airlock (who luckily didn't bother with all the official paperwork such an activity 'needed'), and set them up in the exhibition hall. I helped with installing these large and very heavy devices, which seemed to impress my future collaborators.

[21] During the vernissage I delivered a small impromptu collaborative sound performance. I got Wolfgang to filter and modulate the sounds I was producing, and meanwhile we discussed basic similarities between electronic music and high-energy physics, in that they both involve filtering and processing. Although very simple, this was the initial inroad which led to a much more complex collaborative project, as is discussed in Section 4.4.

[22] This title, although grammatically erroneous due to my coffee frenzy and lack of time to put it together, also referred to my 'Colliding Ideas' seminar as part of the ICHEP 2013 conference. I had hoped to do a similar side-event in Valencia, but the organisers weren't as flexible. Even getting the space and a screen necessitated another semi-mock outburst of artist's indignation.

[23] One such scientist was CMS data analyst Tom McCauley, who wrote the software I used to model the initial 3D collision event reconstructions. He told me about the genealogy of the block-like forms that appear around the edges of the standard particle tracks in digital reconstructions. These represent the amount of energy produced in the scintillator crystals around the edges of the detector. When collisions were simpler and lower in energy, scientists could intuitively tell what sort of events were taking place just by looking at the sizes of such blocks. This is, however, no longer the case in most CERN experiments.

Edge of the Observable was also exhibited in 'The Small Infinite', at the John Hansard Gallery, the University of Southampton, United Kingdom, between August 5 and September 20, 2014. The show, curated by Lanfranco Aceti and Vince Dziekan, featured works from the series *One Second Drawings* by British artist John Latham. Latham developed a unique oeuvre based on a personal theory of cosmology, derived from a theoretical system which seeks to bring together infinite time and the finite instant of experienced time, through such works as *Time Base Roller* (1972), a kinetic sculpture that manifests representations of different time epochs through abstract and symbolic painted diagrams on a rotating canvas – a kind of cosmological model. My work sat well in such a context, although some people thought it was some type of live video, streamed directly from the LHC.[25] It shared themes of observation and scale, both spatial and temporal, with other works in the exhibition. Please refer to the Appendix for a full list of exhibitions.

4.3. *Nature of the Apparatus*

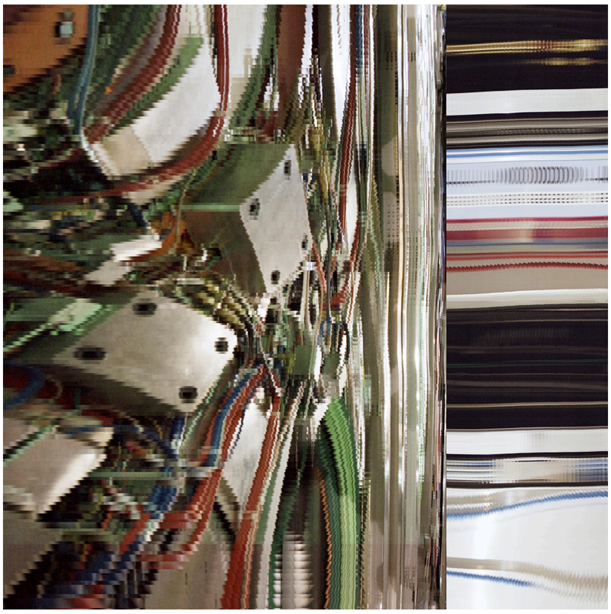

Figure 9. Chris Henschke, *Nature of the Apparatus*, 2014–2016.

Between 2014 and 2016 I developed a screen-based artwork, *Nature of the Apparatus* (see fig. 9). This was derived from ultra-high definition video shot by me and Michael Hoch at various sites across CERN. The locations ranged from the CMS detector, via near-abandoned experimental zones, such as a hundred-metre deep shaft (called UA2), which the CERN scientists refer to as 'The Black Hole,'[26] to the linear accelerator (LINAC 2) where the LHC essentially begins. It is surprising to see the source of the proton beam that is in the LHC: it is a small, humble gas bottle containing hydrogen, which is heated and charged to strip off the electrons. Then the protons are accelerated down the hundred-metre LINAC 2 (which was built in the

[24] By a twist of fate, it was such an actual beam imaging system, known as an "optical telescope", developed by Toshiyuki Mitsuhashi, which first led me down into the LHC tunnel in 2013, with Araine Koek, Bill Fontana, Ralph Steinhagen, Mark Boland, and on the other side (during lunch in the CERN "fishbowl") is where I met Michael Hoch.

[25] I'm not sure what to make of such a confluence of confusion, other than it kind-of showed a shared lack of understanding in the art-world and in the realm of high-energy physics.

[26] Yes, there is a black hole at CERN! I went to UA1 with Mick Storr from CMS and Ralph Steinhagen, who both set up situations where finding a black hole became possible, to paraphrase Rheinberger. Interestingly, Ralph became my camera assistant (even though I was quite humbled when I initially met him), showing the degree of my social integration into the 'CERNiverse' as I dubbed it.

1970s, and looks like an extended V8 car engine), where it is transferred, via a series of smaller synchrotrons, to the LHC itself. In the hangar-sized building that houses the LINAC is a sealed-off section containing discarded and radioactive accelerator components (which informed the works discussed in Section 4.6). Seeing these 'ancestral machines'[27] added an historical dimension to my understanding of the LHC.

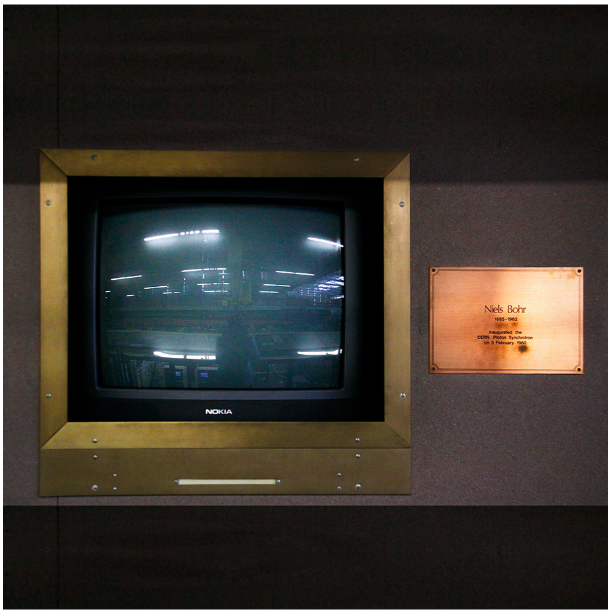

Figure 10. Chris Henschke, "The Bohr Screen", 2014.

Overlooking the LINAC and the radioactive objects was a non-functioning CRT television monitor in a brass frame in the wall, next to a plaque that commemorated Niels Bohr (see fig. 10). I found this material detail quite poetic, and it brought together for me Galison's instrument genealogies (as described in Section 2.1) with Bohr's philosophical–epistemological insights into the relationship between the subatomic entities and apparatuses that produce them (as described in Section 1.5). However, Bohr never defined 'what precisely constitutes the limits of the apparatus.'[28] As I gazed into the 'Bohr screen', reflecting the working, non-working and obsolete devices, I pondered the nature of the apparatus, reflecting upon Barad's question as to where the experiment ends: is it the detector, the computer terminal, the display screen, the scientist viewing it, the organisations responsible for funding the project?[29] This question brought to mind Rheinberger's unfolding, exploding and mutating 'epistemic objects' (as discussed in Section 2.4). Inspired by all this, and Barad's text,[30] I called the work *The Nature of the Apparatus*.

I did not wish to produce a documentary-style video of the inert devices, but instead distilled the above factors into an experimentally energetic intertwining, using the video footage of the apparatuses and energy produced by the accelerator. The footage is manipulated in a way that allows the 'sound' of the beam energy to control the flow of the video. This sound is actually the electromagnetic wave that is vibrating transversely along the energy beam in the Super Proton Synchrotron (SPS), a circular accelerator which feeds particles into

[27] Traweek, *Beamtimes and Lifetimes*, p.51
[28] Barad, Karen Michelle. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press, 2007, p. 142
[29] Ibid., pp. 142–143
[30] Barad used the subheading 'The Nature of an Apparatus', *Meeting the Universe Halfway*, p. 141

the LHC. Such a transverse wave is analogous to the way a vibration passes along a violin string. In a unique experiment, accelerator physicist Ralph Steinhagen 'plucked' the SPS beam and recorded the vibrations, using the system as a diagnostic tool.[31] The peak frequency of this transverse vibration is 2000 Hertz (Hz), within the audible range of human perception, so the sound of the accelerator can be heard, in the same way that an electrical audio signal can be heard when it is plugged into a speaker. Thus, the audio file did not require arbitrary translations, pitch-shifting or transposing, which makes it a more indexical or 'pure' sound. This untreated audio is totally distinctive and compelling; it sounds like a roar of raw energy. It is the aural signature of the SPS.

The sound generated by the SPS is used to modulate the video in a way that algorithmically spatialises the audio dynamics by mapping (video) time across (screen) space. Using the video manipulating software Adobe After Effects, the amplitudes of the sound are analysed and turned into numerical data. I developed an expression script which translates the amplitude data into time-displacement data. This affects the source video footage in a way that maps horizontal or vertical slices of the footage onto the screen, with the resultant effect that the greater the sound intensity is, the larger the temporal splicing.[32] Depending on the movement of the source footage and intensity of the sound, the algorithm spatio-temporally compresses or extends the footage and thus visually compresses or extends the space in the video footage (see plate 3). In a sense, the work itself is an experiment. The manipulation process involved variables which were algorithmically controlled by the data. The output – what would happen to the footage – was unknown before the experiment was undertaken. In this sense the project is experimental (as described in Section 3.2); the video had to be processed and rendered to see what would manifest, what sort of collisions of footage and folding of forms would actually occur.

By embedding the sound of the energy within the footage of the apparatus that produces it, I sought to audiovisually manifest the essence of Bohr's coalescence of phenomena and apparatus (as described in Section 1.6). The material history of the LHC is also present in the video. The first half of the video is a semi-chronological combining of the lineage of apparatuses that precede and feed into the LHC, revealed through a horizontal movement, a kind of time axis. This motion and section concludes at the aforementioned Bohr screen, which then vertically opens to the aspects of the present within the LHC. The second part of the video continues with this verticality, showing components and details of the CMS detector, including scientists who get visually folded into the apparatus,[33] and concluding in a lengthy pan up the face of the detector.[34] At this end segment the video reaches what I called 'the threshold of abstraction': I used sonified data from the

[31] I also heard of a unique experiment performed by a CERN physicist (who must remain anonymous, to avoid losing his job), who 'injected' the first bar of Beethoven's 5th Symphony into the accelerator to make the LHC play Beethoven! This is very similar to my 'cicada experiment' at the Australian Synchrotron, both conceptually and scientifically. I suggested to the scientist involved that he should have perhaps used something heavier and more electrical to keep in the theme of the LHC, such as Black Sabbath.

[32] This method has been used by various artists such as Daniel Crooks, although not in such a manner that links the effect with the data from the devices in the footage.

[33] One version of the project had the footage of the scientists' movements in the detector affected by the sound, which produced a rhythmic dance of agency, to use Pickering's term. Unfortunately, this did not make it to the current cut (there are at least four versions), although it was shown at the art@CMS vernissage, titled *Dynamics of the Apparatus*.

[34] I recorded the source footage for this shot myself, in a scissor lift with Michael Hoch, one evening in CMS. The five-story movement up was literally awesome, only bettered by the slow-motion freefall going back down, made in order to get a motion shot with minimal vibration. A unique experience indeed!

detector itself (see Section 4.4) to process the footage in a way that unfolds it in a spacetime-displacing fluidity, which formally verges on abstract lines of colour, which are the data-carrying cables (see plate 4).

In summary, *Nature of the Apparatus* audiovisually explores various components of the LHC, and visualises the relationship between the matter and energy produced in the experiment, in a way that in itself was developed experimentally. As a screen-based artwork, it raises the question as to whether such physics experiments end at the screen. In dealing with such concepts and processes, it is art about physics. Although I collaborated with physicists in shooting the video footage, and used sonified data given to me by physicists, it is not an interdisciplinary project; however, it paved the way for such a project, as described in Section 4.5.

4.3.1. *Nature of the Apparatus* exhibitions

Nature of the Apparatus has been exhibited at over a dozen locations around the world as part of the art@CMS exhibition tours – see Appendix 1 for a full list. Setting up and exhibiting this work provided insights into some of the challenges of cross-disciplinary practices, which are discussed in this section, illustrated via the diaristic and sometimes dramatic footnotes. The premiere screening of the original version was at the art@CMS vernissage on June 24, 2015, in situ at CMS (see plate 5). This initiated several interesting discussions with scientists, a few of whom thought the video was being manipulated live by the detector (which I thought was a great idea). One scientist, who designed and built most of the part of CMS in the long zoom at the end of the video, was at ease with my treatment and intuitively understood the 'threshold of abstraction' concept. This is in contrast to the response by the head of the physics department at the Karlsruhe Institute of Technology (KIT), where I subsequently showed the work.[35] When I finally got a display working, and played the video, she thought something was wrong with the screen, and I had to say to her 'no, that is the art.'[36]

Another variation of *Nature of the Apparatus* is a five-minute version, rendered at 50 frames per second in HD, made specifically for the group exhibition 'Wie Alles Begann: von galaxien, quarks und kollisionen' (How Everything Began: from galaxies to quarks and collisions), at the Natural History Museum, Vienna, Austria, 19 October 2016 – 20 August 2017.[37] I attended the vernissage, which was opened by Nobel Laureate Peter Higgs,[38] as well as the President of the Austrian Academy of Sciences, Anton Zeilinger (with whom I had a lengthy and insightful discussion, referenced throughout this exegesis). The final version is a synchronised double-screen HD video at 50 frames per second,[39] made for the art@CMS exhibition at the Palais de la

[35] Like the ICHEP conference in Valencia, this was also a difficult setup. What should have been a simple hour-long install took all day, and with the exhibition finally set up and literally minutes from being opened by the Uber-Bürgermeister of Karlsruhe, a physics student decided to poke around the power cablea and shorted everything; then recoiling in horror, he somehow cut the top of his head open on the edge of a Hoch painting, with blood and screams ensuing. Although anecdotal, this shows the social and sometimes chaotic dimensions artists must navigate when working with people who are not used to setting up exhibitions.

[36] After this, she treated me with that special kind of contempt that some scientists still have for artists. This attitude was only reinforced when I gave a talk on art and science at the KIT open day a few days later, and explained to the audience, including her, about the relationship between phenomena and apparatuses according to Bohr, and how the Higgs boson only exists statistically in the device which creates it, with which she uncomfortably had to agree. Although I disagree with Snow's overall edict, there are actually many individual exceptions. As in any social group, there are lots of closed-minded scientists who do not see any value in art.

[37] Even this was not easy to set up. The Natural History Museum (NHM) staff had compressed my version so much it looked horrible, and it took me an entire day to encode a version which was of acceptable quality that would actually work on their media player.

[38] Higgs is the only person I have met who has a subatomic particle named after him, yet he was not at all self-important; instead he was very friendly and almost shy, considering the LHC was built in part to test his theory.

[39] I had to borrow some HD screens from CERN, via former CERN director Rolf Heuer. Yet even these high-quality screens couldn't sync properly, and I had to resort to pressing the play button on both remotes at once to get them working. Then some self-centred scientist stole the power plug from one screen, which almost resulted in a punch-up, and eventual apologies from another arrogant

Musique et des Congres, Strasbourg, France, which was part of the 2016 IEEE Nuclear Science Symposium and Medical Imaging Conference (an exhibition fraught with complications).[40]

In conclusion, my experiences illustrate the fact that art–science projects can be rewarding; however, they are not easy.[41] These experiences also reveal an oft-overlooked aspect of art practice within the domain of science: educating scientists about contemporary art. Although based upon anecdote and personal experience, I believe I developed some physicists' understanding of contemporary art practice (such as Michael Hoch and Wolfgang Adam), and the subtleties involved in art–science collaboration. An example of such a collaboration is discussed in the next section.

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physicist who had turned my sound down, but later expressed regret. He lamented that even physicists are human (!), telling me that some selfish idiot once stole a power plug from a physics experiment of his, while it was on, which did millions of dollars of damage.

[40] Again, this was a painful setup. In fact, it was quite ridiculous, involving literally 500 emails, bad planning, and a dodgy Russian nuclear physicist, culminating in a 'where's my money?' showdown on the grand staircase of the Congress centre on the last day of the conference. Also, I was not comfortable being funded by nuclear physics, considering I have previously been involved in anti-nuclear weapons activities. During this time, I created an audio-video work, *Cherenkov Blues*, in response to such frustrations. The music I composed had its tempo live-triggered by a radioactive source via a Geiger counter. This mutated the melody so much that it became a kind-of mournful lament, perhaps manifesting my own discomfort. As art – science – ethics researcher Gabrielle Decamous stated, 'for the artist entering the realms of science, and the nuclear one in particular, the challenge goes beyond the still-current debate over the possible merging of the various spheres [of art and science, but instead] constitute a very loaded past that becomes ethically difficult for the artist to avoid' (Decamous, Gabrielle. "Nuclear Activities and Modern Catastrophes: Art Faces the Radioactive Waves". *Leonardo* 44, No. 2, 2011, p.125).

[41] I have mainly discussed those who engaged (positively or otherwise) with my artistic interactions and interventions, but of course there were some at CERN who didn't want to have anything to do with art – in fact one person threatened to call security when I told her I was an artist, and became even more enraged when I showed her my CERN security access card.

4.4. ***Song of the Muons***

Figure 11. Chris Henschke, *Song of the Muons*, 2015.

Song of the Muons is a multichannel sound project I developed in collaboration with Wolfgang Adam. This was my main project for art@CMS. During my time at CERN, I found key processes were shared between experimental art and physics practice, including amplification, filtering and feedback. Practically and conceptually, this was a heuristic link between particle physics and analogue audio synthesis. Through this discovery I realised that particle accelerators are on one level high-energy synthesisers, in a way that is not mere metaphor. As Max Born stated, physicists 'must require that [experiments with subatomic particles] only involve ... quantities such as energies, frequencies, intensities and phases,'[42] and such terms are equally applicable to analogue sound synthesis. This provided me with a point of commonality with Wolfgang Adam's work, and through such shared terms, we were able to develop a working creole, which short-circuited the gap in my (lack of) knowledge of the physicists' formal mathematical 'language'.[43] This greatly assisted in the production of a truly interdisciplinary collaborative project (the development process is discussed in detail in the next section).

Using a custom built eight-channel sound installation (see fig. 11), the project sonically manifests the high-energy collisions between subatomic particles recorded in the CMS detector. In this way, I approached CMS as a kind of microphone that records energies, frequencies, intensities and phases, even though usual descriptions say the detector 'acts as a giant, high-speed camera.'[44] In developing this project, I drew upon the history of the usage of sound in particle detectors. This was first attempted in the early 1960s by Georges

[42] Kragh, Helge. *Niels Bohr and the Quantum Atom: The Bohr Model of Atomic Structure 1913-1925*. Oxford: Oxford University Press, 2012, p. 353

[43] When listening to the physicists speak in mathematical terms, it really is another language, summed up by a line from a song I serendipitously discovered one time whilst flying down to Geneva: 'Hear a man preaching in a language that's completely new.' Nick Cave, "Higgs Boson Blues", *Push the Sky Away*, Bad Seed Ltd. 2013.

[44] https://cms.cern/detector

Charpak,[45] a leading experimentalist at CERN who developed the sonic spark gap chamber (see Section 2.3). In attempting to find more information on this, and possibly the first audio recordings of particle collisions, I explored CERN's archives, including Charpak's personal archives (see plates 14 and 15), which were a fascinating insight and source for other works,[46] but alas contained no sound recordings.[47] I was particularly disappointed by this because, as described in Section 3.6, sound is sometimes a more fitting analogy for subatomic phenomena than images.

In collaboration with Wolfgang Adam, we turned (or tuned) the detector data into a format that is manifested acoustically, developing a system over four visits to CERN. Initially, we had been able to spatialise different particle events as point-like energy tones of different frequencies and magnitudes. We were also able to extract the 'missing energy' between the input from the LHC and the measurements of the CMS detector, in a sense subtracting the output signal from the input signal, and seeing (or hearing) what was left. This is one process used at CMS to search for signs of dark matter.[48] Dark matter is a possible 'exotic matter' particle, part of the spookily titled 'dark sector' of hypothesised particles that have so far been undetectable, inferred from anomalies between theory and observation on a cosmological scale. Although recent experiments at CMS experiments seem to provide 95% certainty that dark matter does not exist within the energy levels Wolfgang and I were exploring,[49] it is possible the data we were playing with contained evidence of this exotic material. In response to this, I developed an artwork called *Dark Sector Echoes* (see Section 4.8).

Following from these sonification developments, I wished to manifest single events, as a kind of aural equivalent of the visual signatures I explored in *Edge of the Observable.* I challenged Wolfgang to explain how to 'slow down' something that happens at almost the speed of light. As Einstein theorised, the speed of light is invariant - light does not slow down (as far as we know);[50] instead, the material universe changes shape around it. Wolfgang used processes known as relativistic Lorentz transforms, or Lorentz boosts, to extend the events in space–time in order to enhance the expressive qualities of the particle collisions. Thus, the process developed were rigorously consistent and mathematically precise, in order to maintain the closest correlation with the data from the CMS experiment. In this way, as Wolfgang said, 'nature itself is ultimately the source of

[45] By a twist of fate Charpak was a kind of mentor of Michael Hoch when he was young, so he was quite surprised when I told him about my explorations Charpak's archives. By another twist of fate, when I mentioned this during a talk at the 2016 ISEA conference in Hong Kong, Colombian artist Andres Eduardo Burbano Valdes stated that he knew Charpak's daughter, and was apparently also working on a 'Charpak archive' project.

[46] One is a prototype animation of an augmented reality project, using the many photos I took of the various items in Charpak's folders, called *A Dive into the Archives*.

[47] I did find lots of other informative and inspiring material, including the original mimetic photo emulsion prints of bubble chamber images that I suspect led to the detection of weak neutral currents, an important discovery made at CERN in the 1970s. These were not in a good state, and when I pointed them out to the archivist, and mentioned that they may have led to a Nobel Prize (which was incorrect) she freaked out. I also found a pamphlet on the CERN SHIVA scanning tables, which provided a poetic clue to Bohr's unspoken question as to where the experiment ends, with an illustration of a curtained space, with the words 'the best colour for the scanning room or curtains is the green one of this picture or similar'. This intersects with Fritjof Capra's image of Shiva superimposed over particle tracks in *The Tao of Physics*. This connection has been taken to an idiotic extreme in crazy fundamentalist videos on Youtube which claim 'in CERN there is a Giant Wheel [CMS]; inside that wheel lives the Hindu God Shiva'! The fact that there is a statue of Shiva as Natraj, which is outside Building 40, where Wolfgang works, is an irony only superseded by a prank human-sacrifice ritual, complete with hooded Satanists, done in front of the Shiva statue, which also went viral on Youtube. I won't delve into a nightmare I had whilst there, in which I was lost in the labyrinthian hallways of CERN, then I opened a door into a dimension full of Hindu demon durgas.

[48] http://cms.web.cern.ch/news/detecting-dark-matter

[49] http://cerncourier.com/cws/article/cern/66165

[50] There is a current theory, known as MOND, or Modified Newtonian Dynamics, which challenges this. Basically, if the speed of light is not constant, this may explain the observed phenomena attributed to dark matter, but it raises a lot of other questions. It is interesting to note the near-sanctity of Einstein's theory of relativity, and that scientists who challenge this are largely regarded as heretical.

the sounds.'[51] More than just an investigation into how to sonically spatialise the data, the work seeks to manifest the actual events in a way that is as pure as possible (as opposed to raw).[52] In this respect my work contrasts with other data sonification projects at CERN, such as the ATLAS-based *Quantizer* project,[53] which transposes collision data into musical sequences. I find such methods too arbitrary, as any data can sound harmonious when put into a major key, or mysterious when it is transposed into a minor key.[54] This did provide a challenge – how to work with data in a way that is not arbitrary. I sought to enhance or amplify aspects that are already there, in a way akin to the unique visual signatures produced in data reconstructions (as described in Section 2.3), which is a point of difference between my use of such data and other artists such as Ikeda.[55]

The final composition is 10 minutes in duration, and follows our process of development of the material in a roughly chronological sequence. It is in three sections: hadronic excitations; muon events; and supersymmetric speculations.[56] The first part, hadronic excitations, is comprised of the initial point-like spatialised sounds; the second part, muon events, is of the Lorentz-extended muon signatures; the third, supersymmetric speculations, is my own speculative take on supersymmetry, in which I have combined and temporally extended several particle events (although not using Wolfgang's algorithms), in a way that suggests such particles are equivalent at high energies, which is the essence of supersymmetry. Overall, the composition moves from short and loud sonic forms to long and smooth spatial tones. Events and transitions are punctuated by noise and distorted tones, where the data translations or imports didn't quite work; other parts are very quiet.[57] When standing in the middle of the installation, one can hear the spatial qualities of the collision events, and the kind of curving forms of the muon tracks and jets. In fact, one of the events is a Higgs boson (although I have forgotten which one it is); it should be possible to discern it through attentive listening, through physically and intuitively grasping the sonified forms.

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[51] Personal discussion, 1 March 2016. By an accidental poetic twist, my notes of this are titled 'W says', which could refer to Wolfgang, or the 'W boson' we were talking about.

[52] As Wolfgang said, when I asked him about the concept of raw data in devices such as the CMS, there is no such thing, there are many processes involved even before such data comes to the human level, but instead it can be said there is "pure data, which has been filtered to maximise signal as much as possible (as described in Section 2.7).

[53] See http://quantizer.media.mit.edu/

[54] Of course, such transposing depends on the desired outcome of the project – as a diagnostic tool it may be better to listen to more harmonious phrasing in order to enhance patterns or differences in such data.

[55] I did get my hands on data, in the form of a CSV (comma separated values) file full of numbers. In itself this data really was arbitrary, and I created some visualisations of it, which manifested as a kind of graph showing some forms, which would need to be combined with countless other datasets to become meaningful. In fact, scrolling through the data file turned it into an Ikeda-esque video, which I did, making it white on black, as a kind of homage. Even though I may be critical of aspects of his work at CERN, I do find his art amazing.

[56] I was not sure how to combine the elements Wolfgang and I had developed until days before the premiere, when I was lying in a Japanese bath and found myself tuning into the stochastic motifs made by the drips of condensation falling from the ceiling. I realised in a flash of inspiration that our original data translation provided the score for the Lorentz-extended parts – all I had to do was sequence the extended sections to the corresponding amplitudes of the stochastic 'click track'. Thus, as Wolfgang had said, nature is the ultimate source of the composition.

[57] This is inspired by a realisation I had at CERN, whilst opening a bottle of carbonated water: in one way the soft fizzing sound was on a par with the energy released in CMS events, which Wolfgang agreed with. It is both extreme, yet delicate on a human scale. 14 trillion electron volts may sound like a lot, but (as noted in an earlier chapter) a mosquito flying across a room has one trillion electron volts of energy overall. To put this in a different perspective, as Wolfgang pointed out, a mosquito has a mass of around 2 milligrams, which would comprise of roughly 4×10^{20} atoms, so even a very small macroscopic object still has a huge number of subatomic particles in it, but if each of these particles had 14 trillion electron volts of energy, such a mosquito would be a cosmological monster – its dance could destroy the universe!

Inspired by Pickering's dance of agency, this work is a 'song of agency'. Ultimately, the project sonically expresses the agency of energetic collision events, in a way that attempts to bridge the gap between the hermetic world of such detectors and the realm of human experience. In this way, audience engagement within the space of the *Song of the Muons* installation allows one to literally feel the energy of such events. In manifesting collision event data in such an expressive form, I seek to engage people with the recorded particle collisions. Perhaps surprisingly, I see a connection between the expressive meanings one can take from this experience and the physicality one experiences at sound performances, whether it be a rock concert or even a disco.[58] In fact, I see parallels between high-energy physics and such music events, in the sense that both work with energetic excitation, amplification and synthesis. Regarding such synthesised physical experiences, Sebastian Klots (who is apparently named after a violin) stated:

> Disco finalises these analytical readings [of the self and the representative universe] by suggesting that meaning and experience can be accessed directly, and made physical on the dance floor, and at the same time, through its openly technological setting, openly admits that it relies on machine driven simulations.[59]

Although *Song of the Muons* does not have the rhythmic and melodic signature of disco, like disco it uses aural technologies as a tool to provide a physical experiential meaning, mediated by machine-driven simulations. And like disco, through amplification of signals it can take people within its energised space to a threshold of energetic ecstasy. One person who experienced *Song of the Muons* said that it filled her with 'cosmic awe.'[60]

4.4.1 Transdisciplinary thresholds

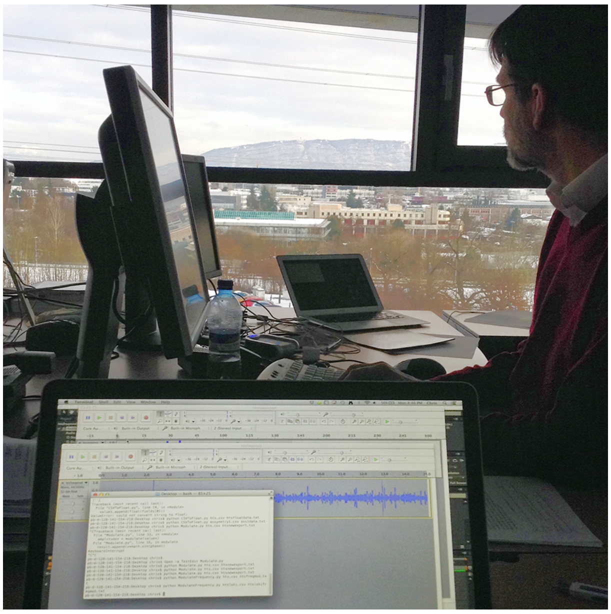

Figure 12. Chris Henschke, "On the threshold of a breakthrough", 2016.

[58] I gave a live performance of an early version, in the basement of a studio in Berlin, August 26, 2014, called *Dark Matter Disco*.

[59] Kloch, Sebastian. "Arcadia, Musicland. Variants of Eloquence in the Renaissance Madrigal in Disco." In *Variantology V, Neapolitan Affairs, On Deep Time Relations of Arts, Sciences and Technologies,* edited by Siegfried Zuelinski, and Eckhard Furlus, 291-309. Köln: Verlag der Buchhandlung Walther König, 2011, p. 306.

[60] People's responses have ranged from awe to open-mouthed horror, as did one less-informed science educator, who thought it was going to be some 'nice, siren-like song' as their colleague humorously described. The Head of the School of Physics at Melbourne University, who graciously supported the development of the installation (even though his School is part of the competing ATLAS collaboration), responded with the exclamation 'wow, what a trip!'

In this section I describe (in a somewhat diaristic manner) key moments in the development of *Song of the Muons*. Descriptions of this process provide insights into interdisciplinary collaboration, and how definitions of interdisciplinarity and transdisciplinarity (as discussed in Section 3.1) are not fixed but dynamic and fluid processes.

During the final phase of development of the process, Wolfgang and I were approaching a technological and conceptual breakthrough. Although Wolfgang stated the process was 'not real physics but more of a "game"', it was constrained by the same rules used in experimental physics, in that 'one can only play with what one measures.'[61] Using the rigorous mathematics of Lorentz boosts was necessary to bring out expressive representational characteristics. Wolfgang developed an algorithm to search the CERN database for 'special events' that would produce unique sonic signatures, which was in a sense his creative input into the project. He specifically searched for Z bosons, tell-tale secondary particles produced in Higgs events (interestingly, through his familiarity with the Z boson, he called it an 'old friend', a sure sign of entity realism!) On a creative level, the collaboration was in setting up the 'rules of the game' and defining the parameters, or the space of possibilities, in which to acoustically express the events with the greatest spatio-temporal dynamics. To paraphrase a discussion I had with Wolfgang, when you can do anything, the way to do something meaningful is to let the data speak as purely as possible. When there are no limits, when anything goes, you have to create the limits – this defines and shapes the art.

Through this process we found shared tools and methods, such as signal processing, modulation and filtering, which apply across both audio engineering and high-energy physics. Also, parallels in digital data processing formed a key practical part of the process. As I know some basic programming, and file type conversions, through trial and error Wolfgang and I were able to develop data formats (32 bit Pulse-Code Modulation (PCM) files) which I could translate into sound.[62] Wolfgang wrote a python-based script which modulated frequencies around a base frequency, arbitrarily set to 1000 Hz. This custom software application is essentially a prototype of an advanced programming interface (API), which I wished to develop further.[63] Such data translation tools are key interdisciplinary heuristic bridges, but they also allow interaction between 'people, machines, artifacts, and non-humans.'[64]

When we were able, finally, to hear the sound of the event data, I believe we comprehended it in a very similar way. For example, I was pointing out certain tones and saying 'that's a high-energy muon!', and Wolfgang replied 'really?… oh yes you're right!'[65] To visually check, we produced graphical frequency plots of our respective files, and although his graphs were of a much higher and different type of energy, the curved forms were equivalent, demonstrating an isomorphism between the two types of energy, and showing that the translation process worked. During such moments there was an excitement in the air; perhaps we realised

[61] Wolfgang Adam, discussion, 1 March 2016

[62] This was done with the Audacity audio editing software, which is simple but robust, and is what Ralph Steinhagen used to turn the SPS beam data into sound.

[63] This proof-of-principle version was meant to be developed into a more functional API, which, alas, didn't happen. I even arranged for a former collaborator to come to CERN with me and help develop this, but after the visit he instead produced his own derivative version of a circular multichannel CERN sound installation. However, I did get his speakers which are now used in *Song of the Muons*.

[64] Harp, Gabriel. "SEAD Themes and Insights Meta-analysis: From Conflict to Coherence." SEAD: White Papers, 2013. Accessed April 28, 2015. https://seadnetwork.files.wordpress.com/2013/01/harp_meta.pdf, p. 26

[65] Wolfgang Adam, discussion, 1 March 2016

that we had found a common ground (see fig. 12, which shows Wolfgang gazing intently into the distance). This was in itself a true transdisciplinary experience, as it was both art and science, yet something more.[66] It had come about from practical experimentation, and in that moment, we were both adding to our respective practices, but blurring the boundaries between them. This was the place we had hoped to get to but initially did not know how to, so we just had to jump in and try various methods until it worked.

Such moments cannot be forced, they have to emerge, and require a variety of subtle interpersonal variables that cannot be pre-defined, with the parties providing the same amount of input. These variables include a familiarity with each other's disciplines, which we had developed, as well as interpersonal connections, which cannot be forced but must grow of their own accord. Also, interpersonal technical/conceptual/social communications must be developed – Galison's 'creoles' (as described in Section 2.2). In fact, through the elaboration of such a creole, I later found I could also meaningfully engage with physicists at other high-energy physics laboratories, not just my immediate collaborators.[67]

4.4.2. *Song of the Muons* exhibitions

Song of the Muons premiered at the 2016 SUSY conference on Supersymmetry in particle physics at the University of Melbourne, July 3–6, 2016.[68] The installation is comprised of eight powered speakers mounted in custom-made tapering columns, in a circle five metres in diameter, inspired by the isosceles trapezoid forms of CMS. The opening event was mainly attended by physicists, some of whom queried me extensively about the precise details regarding the processes developed in the data sonification. When they realised that it was derived from experimental data, and somewhat expressed the signatures of collision events, they were satisfied. In this sense, *Song of the Muons* is a part of the larger CMS experiment, as much as is a data plot presented on the screen at a conference, as Knorr-Cetina argued (see Section 2.4). And, as Barad asked regarding the end of Bohr's apparatus, *Song of the Muons* in a sense questions where the CMS experiment ends. To qualify, *Song of the Muons* has no effect upon the CMS detector itself or collision events, unlike, for example, Stern's cigar. Yet, as I discussed in Sections 2.4 and 2.5, the wider notion of 'experiment' encompasses cultural parameters, including that of human perception and insight through experience. This is very different to the kind of knowledge such as the bump on a graph that statistically proved the existence of

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[66] However, such moments were short-lived. After we had spatialised the collisions into eight audio channels, I said to Wolfgang, 'gosh, that was difficult,' and he said, 'not really,' and I realised that what he does normally is a lot harder than this! I also asked him if we could do the same thing on a different axis – instead of Lorentz transforms along the direction of the beam, doing it front-on. He said 'no, it doesn't exist on that axis', and I said 'it must!' Then we both realised that I didn't understand the subtleties of relativity, and the magic moment was broken. Wolfgang went back to his real work, and I went home to set up the installation.

[67] Evidence for this was produced when I went with Michael Hoch, to the Deutsches Elektron Synchrotron (DESY) in Hamburg, Germany. They are constructing the XFEL, a three-kilometre-long free-electron laser. Even though I was only there for three days, I almost instantly integrated into their culture – I could understand their culture and work practices and discuss more than the basics of their experiment. Whilst at DESY, I did a few quick sketch-like video works, one of which, *Resonance*, I felt perfectly captured the essence of the radio frequency cavity resonator I based the work on.

[68] In addition, I curated and set up an exhibition at the SUSY conference. Titled *Symmetries*, it was the Australian premiere exhibition of works from art@CMS. It included photographs of CMS by Michael Hoch, photomedia by Italian artist Alessandro Catocci in collaboration with physicist Pierluigi Paolucci, a video by British artist Peter Bellamy of Michael Hoch cycling around in a circle above the CMS detector, titled *Bike*, and a video of Swiss artist Yuki Shiraishi discussing a proposed 'sculpture of the universe' with CERN theoretical physicist John Ellis. Although he has spoken with (and at) artists before, I would not say that he was collaborating, in fact he was didactically telling Shiraishi what sort of model she should make, in a scientistic manner. These were alongside my video *Edge of the Observable*, and a three-metre print of a photo-collage I made of the cable-covered manifold of CMS, called Heavy Data. I selected the works for their shared symmetry, in that they all contained circular forms or motions. In addition, in the foyer of the conference area, was a very large, 13-metre wide x three-metre high print of a portion of the CMS detector, part of Hoch's 1:1 scale CMS image.

the Higgs boson,[69] but I see it as a kind of knowledge through experience, 'art as knowledge'. Regarding this form of knowledge, Susan Sontag stated:

> Works of art … present information and evaluations. But their distinctive feature is that they give rise not to conceptual knowledge (which is the distinctive feature of discursive or scientific knowledge …) but to something like an excitation, a phenomenon … the knowledge we gain through art is the experience.[70]

This statement (and indeed my artwork) presents an epistemological challenge to the notion of objective knowledge, as determined by the scientific method (as described in Section 1.1). But, in contrast to the explicit nature of scientific knowledge, I see artworks in general as containing an implicit form of knowledge 'where the thinking is, so to speak, embodied in the artefact.'[71] As Feyerabend asked rhetorically, 'should we transfer to [science] the sole right for dealing in knowledge, so that any result that has been obtained by other methods is at once ruled out of court?'[72]

Song of the Muons was presented at the Palais de la Musique et des Congres, Strasbourg, France, from 25th October – 2nd November 2016, as part of that year's Institute of Electrical and Electronics Engineers (IEEE) nuclear physics conference. The keynote speaker at the conference was Barry Barish, director of the LIGO experiment, which – through data sonification – allowed the sounds of colliding black holes to be heard,[73] described as manifesting 'the soundtrack of the universe.'[74] Whilst in the installation, Barish replied to my comment that only artists like both signal and noise, saying that some scientists (such as him) do as well.[75] Others who positively engaged with the installation included former CERN director, Rolf Heuer (see plate 12).[76] I initially wanted to have *Song of the Muons* installed directly over the CMS detector, and take in live collision event data, so that one could experience it in real time in a way that would manifest the essence of the LHC agency live, but this proved too difficult to accomplish.[77] Had this been possible, the entire CMS experiment would have arguably become a part of the art installation.

In summary, *Song of the Muons* is a data sonification and spatialisation art project. Like *Edge of the Observable*, it seeks to manifest expressive parameters of collision events, however this manifests a correspondence with the experimentally gathered data from CMS in a way that ultimately subatomic nature

[69] Another 'spooky' anecdote: during one of my CERN sojourns, I dreamed about a camel, and told Michael Hoch and Angelos Alexopolis about it the next morning. Not long after, we were driving to CMS (on the other side of the LHC to the main CERN site), speaking about Higgs boson 'bump hunting' and such, then, in a field right across the road from CMS was a camel, complete with bump!

[70] Sontag, *On Style*, pp. 21–22

[71] Frayling, Christopher. "Research in Art and Design." *Royal College of Art Research Papers* 1, no. 1 (1993): 1-5, p.5

[72] Feyerabend, Paul K. *Against Method*. 4th ed. London: Verso, 2010, p.3.

[73] This work may deliver its collaborators the next Nobel prize in physics. The experimental apparatus is essentially a couple of lasers encased in PVC pipes in fields, but with detectors so fine they register vibrations of an attometer (10^{-18} metres), 1000 times smaller than a proton, and thus have to remove the noise produced by such subatomic particles' movements. Although it works with a very different type of fundamental physics, LIGO does make the LHC experiment look a bit heavy-handed.

[74] Rowan, Sheila. "Physics: Soundtrack of the Universe." Nature 532 (2016): 28-29. Accessed July 10, 2017. http://rdcu.be/u8J8

[75] When I met Barish later (by chance on a street corner in Brisbane, at the World Science Festival 2017) he told me he has hooked up the LIGO detector to speakers so that the LIGO scientists can hear live cosmic events. We then got into a discussion about physicists and music, with him stating that cosmologists prefer classical music and I retorting that the scientists at CERN prefer heavy metal. Again, I do not have statistically valid evidence for this, but around the CERN café I saw a lot of posters around advertising gigs by CERN-populated heavy-metal bands, and even saw a few such bands playing at the café.

[76] Heuer rightfully pulled me up on the fact that there was no information panel explaining the project (even though I had made one). This gives the work a more engaging context, or, to paraphrase Zeilinger, completes the experiment (Zeilinger, Anton. *Dance of the Photons: From Einstein to Quantum Teleportation*. 1st ed. New York: Farrar, Straus and Giroux, 2010, p. 231).

[77] In fact, for an ideal version of *Activated Objects*, I did have a 'Teenage-Engineering op-lab' digital/analogue audio translator box, and wanted to get live output, but I was not allowed to plug it into any outputs from CMS. In fact, on the 'op' manual, it says 'do not plug this into nuclear facilities'! Instead I wired it up to some old detector components I gleaned from a bin and was able to extract some odd melodies out of the resistors.

itself is the source of the sounds. Although there were transdisciplinary moments in the making of the piece, the final manifestation as an 8 channel sound installation can be seen as an inter-disciplinary art / science collaboration. In expressively manifesting experimental data, the project questions where the experiment ends and presents an epistemic challenge to the boundaries of scientific knowledge.

4.5. *Potential Objects*

Figure 13. Chris Henschke, *Cosmic Tea Party*, 2015.

Inspired by my experiences at the LHC and Australian Synchrotron, I gave an exhibition at Tinning Street Gallery in Brunswick in April 2015, titled *Potential Objects*. This was a collection of assemblage-based artworks that played with concepts around energy and materiality in physics and everyday life (see plates 6 and 7). Through combinations of everyday objects with new and obsolete scientific and technical devices, the works explored our relationships with technology in a very low-tech and immediate manner, as a kind of counterbalance to my experiences at CERN. However, they are also precursors to my projects, *Activated Objects* and *Song of the Phenomena*, described in Sections 4.6 and 4.7. As the works and concepts in *Potential Objects* are quite simple, they are explained below in a short and simple manner.

The exhibition featured *Cosmic Tea Party*, an installation which utilises cosmic particle detectors attached to household items such as teacups and teapots (see Fig. 13). When a cosmic particle, or muon, passes through a detector, the nearby objects vibrate and emits resonating tones. The overall effect, as well as producing syncopated musical motifs, seeks to make a kind of energetic connection between the viewers, the objects and the cosmos. One aspect of this work, which informed my final project (see Section 4.10), was that it is completely analogue;[78] that is, there are no digital signals or conversions involved. Cosmic particle collisions at the edge of space produce muons, which hit the encased scintillating crystals in the detector, producing

[78] I attempted to produce another compact digital version, using Teviso RD3204 sensors and a Raspberry pi, but there were too many invisible variables, and after a few failed attempts in a basement with some half-hearted scientists and a radioactive hot source, I gave up. Experiments don't always work.

microsecond-long high-voltage jumps (similar to Geiger–Muller tubes), which are turned into one-millisecond pulses from the detector output; they are converted into 10-millisecond control voltage signals; these trigger audio signals in an analogue synthesiser; via a stereo amplifier, these are emitted as sound through the teacups. Thus, the sound output is an analogous representation of the muon interaction, with literally six degrees of separation between the particle and the observer. This brings to mind the Von Neumann chains described in Section 1.8 – there is a countable connection between the everyday world and that of the energetic particles that may have travelled across the universe before becoming part of the tea party.[79]

Another piece, *Monte Carlo Catastrophes*, explores the nature of Monte Carlo simulation computers, developed in the mid-twentieth century to generate random number sequences.[80] One of these, the Electronic Random Number Indicating Equipment (ERNIE), was used to produce random number sequences from quantum noise for algorithms that simulate nuclear reactions, and 'Premium Bond' lotto combinations.[81] Such a bizarre combination of unpredictabilities darkly suggests the disastrous possibilities inherent in such research. The piece also explores the uneasy relationship and tensions that exist between the culture of particle physics and wider society (the Cold War motto of CERN was 'Atoms for Peace', which, although showing utopian ideals, has a dark flipside).[82]

Other works in the exhibition included the following: *Resonance*, a cymatic sound sculpture that uses an analogue synthesiser and a subwoofer speaker to excite distilled water, in a kind of experimental homage to the universe-forming theory of Baryonic acoustic oscillations.[83] Another is *Uncertainty*, comprised of a spinning roulette wheel, which playfully manifests Heisenberg's position/momentum uncertainty principle and the uncertainties of everyday life. However, unlike a normal roulette wheel, this never stops spinning, and thus you'll never know your luck. Additional works include *Dark Sector Echoes*, which uses a black globe, an antique electrostatic speaker, and sonified data of possible dark matter detected at CMS (as described in Section 4.4),

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[79] At the exhibition, some people suddenly became concerned, asking where the cosmic particles came from and if they were dangerous. One normally astute colleague of mine though that CERN was sending a beam of them through the earth to the installation, in the style of the Gran-Sasso Neutrino experiment. This is also superficially reminiscent of the 'Tea Party experiment' devised by the artists Bobby Baker and Richard Hallam for the Wellcome Trust in 2000 (Baker, Bobby and Richard Hallam. "How to Live." In *Experiment: Conversations in Art and Science*, edited by Arends, Bergit, and Davina Thackara, 71-95. London: Wellcome Trust, 2003).

[80] I also produced a physics-poster version of this work, part of a series which I surreptitiously placed around CERN, and at the ICHEP conference in Valencia, as a kind of "poster-bomb", inspired by the sometimes frightening designs of physics conference posters. The poster at CERN, one of three, featured photos of poker chips found on the street in the vicinity of the ICHEP in Valencia. The other two in-situ posters were *We Must, At All Times, Instead of Points, Lines Plains say Tables, Chairs, Beermugs*, derived from a quote by mathematician David Hilbert; and *The Dark Sector and other undetectable delectables*, inspired by a power-point presentation at the ICHEP conference, which featured quotes such as "no bananas in the lab" and "that which does not kill us makes us stronger". The posters had been at CERN for over a year, and blended in almost too well (see fig. 17), until one Sunday, when I was taking some photos and video of *Monte Carlo Catastrophes*, which some scientist seemed to have (finally) noticed. The next morning it had been removed. The other two, to my knowledge, are still there. In a sense, this is an in-situ intervention, an experiment involving the observation skills of the physicists themselves. On my last visit, I also placed several A4 "powerpoint recycling" leaflets around the main building and on recycling bins, offering to rework the physicists' science posters as part of a "data analysis project", half-joking but half serious. I included my email, but did not get any offers. Also, I placed some thought provoking signs around, such as "Dark Matter Hazard" and "Decoherence Hazard".

[81] "Who is ERNIE?" National Savings and Investments. Accessed July 20, 2017. https://www.nsandi.com/ernie

[82] CERN scientists have repeatedly told me that nuclear and particle physics are very different – the nuclear or atomic scale is a level up from the realm of the subatomic. Perhaps this reveals a level of discomfort, for as Oppenheimer said, after the detonation of the Atom Bomb, physicists have known sin. Such a reactionary stance was made clear when I did a live audiovisual performance in Geneva at Cinema Spoutnik, February 26, 2016. Within the 40-minute set, I had about three minutes of manipulated footage of nuclear blasts, and audio samples from the classic Australian film about nuclear testing, *Ground Zero*. After the gig an ATLAS scientist came up to me and instantly hassled me about that segment. He told me that CERN does not engage in nuclear weapons research and asked me why I had included that reference. My reply was 'I know, "Atoms for Peace", but that's the other side of the coin,' to which he begrudgingly agreed.

[83] Wright, Edward. "Listening for the Size of the Universe." UCLA. Accessed July 21, 2017. http://www.astro.ucla.edu/~wright/BAO-cosmology.html

as a homage to both physicists such as Wolfgang Adam and the Dark Sector pioneers such as Fritz Zwicky and Vera Rubin. Another piece, *Entanglement*, comprised of two half-record players and two interlocking records, is spookily pre-emptive of Zeilinger's entangled photon phenomena.[84] Finally, there were a series of *Potential Objects*, which were largely 'accidental assemblages' of objects I had simply found near each other, suggesting possible and impossible hybrid technological objects in a Dadaistic manner. These included a plastic ball attached to a 12V power adaptor, a drill with a record affixed to its end ("Songs of Science" by Crank), a rubber mallet with a pair of headphones plugged into it, a pair of wire cutters plugged into audio cables, and a banana attached to a multimeter.[85] This piece informed my final project (described in Section 4.10).

In summary, *Potential Objects* is a low-tech series of object-based artworks which sits in contrast to the complex and collaborative aspects of CERN. The artworks play upon concepts and objects I have found in my engagement with science and technology. Aspects of the works, such the use of analogue signals and sound, informed my later projects *Activated Objects* and *Song of the Phenomena*, as discussed below.

4.6. *Activated Objects*

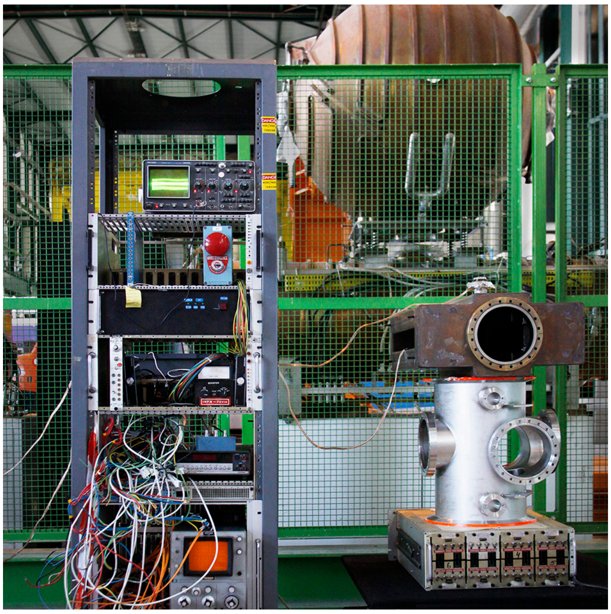

Figure 14. Chris Henschke, *Activated Objects*, 2015.

For the 2015 art@CMS vernissage I produced a site-specific installation titled *Activated Objects* (see fig. 14). The work takes material components of the LHC and reworks formal aspects and processes of the objects' original functions. In a sense, it is a 'machine study', to borrow a term used by accelerator physicists when they are testing the capabilities of the accelerators. Taking a cue from a poster at CERN for the 2015 Higgs Hunting conference, which featured a version of Millet's painting *The Gleaners*, adjusted so that the gleaners were picking up parts of accelerators, I set out to set up a material installation that experimentally

[84] Using a pumped laser firing into 'spontaneous parametric down conversion' crystals, interlocked light forms are produced, an 'entanglement rainbow' which is a physical manifestation of entanglement phenomena. However, it is also symbolic of the concept of entanglement; I find it deeply poetic that the image has such iconic qualities. I also find it a bit spooky that I made my entanglement turntable sculpture before I knew of the existence of the experiment and the entanglement rainbow it produces.

[85] By chance, the cables I used to attach the multimeter to the banana were actually 'banana plugs', which was an unintentional pun.

manifested energetic qualities of the LHC experiment. This led me to glean apparatus parts from the CERN scrapyard (see fig. 15). Engagements with redundant objects have a rich history in twentieth-century art practice, as they can provide unique insights into the social and material realms from which they have been discarded. To paraphrase sociologist Guido Viale: 'trash is indeed an enormous deposit of information of great value and not merely in [or from] the scientific world.'[86]

Figure 15. Chris Henschke, "Higgs Hunting poster", and "CERN gleaning", 2015.

The main object I used was a hollow stainless steel box, originally some kind of cavity resonator. These are designed so that their physical form causes resonance of electromagnetic energy, in a way that is analogous to how pushing a swing at the right moment gives it more and more energy. What I did, in a kind of energy analogy, was take the resonant properties of the object and translate them into a different form of energy. I used an experimental setup to find the acoustic resonant frequency, via a tone generator and resonant plate speakers affixed to the object. This process is similar to David Tudor's (as described in Section 3.6). In a sense, the experiment was a question put to the material: 'what is your resonance?' The 'answer' the object gave me was a physical manifestation of its acoustic resonance, which is analogous to its previous high-energy resonance.[87] Such an experiment is in essence an isomorphism of the behaviour of the object, translating its function from one of particle energising to acoustic emanation. As Manuel DeLanda stated (see Section 2.5), isomorphism plays a key role in experimental science. Through such a transformation of the object's function, from high energy physics to sound sculpture, the work is an experiment to see whether an isomorphism can be found between physics and art.

The title of the work is a play on the term 'activated material', which in high-energy physics denotes materials that are still radioactive after being used in experiments. However, it is highly unlikely this was still 'activated',

[86] Viale, Guido, quoted in Lea Vergine. *When trash becomes art*. Milano: Skira Editore, 2007, p.12

[87] I undertook such experiments in my 'studio' at CERN, a repurposed lab/office in an old building on the main site, which was used by HEPHY, the Austrian High Energy Physics group (see plate 13). By the time I had really tuned into the resonance of the object it was late at night and the sound quietly permeated the whole building. I realised that my interaction with the object had almost hypnotised me, that's when I knew the experiment had worked. The device and I had affected each other.

as radiation safety is paramount at CERN (and I had to undergo comprehensive radiation safety training for site access). The work does, however, exploit the radioactivity paradox, as Traweek pointed out: 'often, actions and things that are forbidden are also sacred: in this case, radiation sources are seen as both necessary for basic knowledge of nature and carcinogenic.'[88]

The installation included functioning and obsolete equipment mounted in a scientific instrumentation rack,[89] such as devices that controlled the acoustic resonation and detected the acoustic emissions, which were displayed on an oscilloscope. There was a big pile of cables (haphazardly stuck into the rack moments before the opening of the exhibition); another connection between high energy physics and analogue audio. This was also a play on the sometimes outwardly chaotic impression one can initially get of such devices; it blurred the boundaries between what worked and what didn't, and whether the work was complete or unfinished, itself a homage to the interplay and tension between current and obsolete scientific devices (see plates 8 and 9). This also developed upon the suggestive assemblages of my *Potential Objects* exhibition.

In addition, the work was a totem to the cathedral of physics that is the CMS detector, which has itself been described as being like the stained-glass window of Notre Dame, although writer Will Self retorted to such notions that 'it's not a stained-glass window, it's a dirty great machine.'[90] I set the installation up in the main hall of CMS, on the edge of the ten-tonne concrete plug which sits over the shaft above the detector cavern. Directly behind the work was a large copper sphere, which is in fact itself an electromagnetic resonating cavity, which was part of the precursor of the LHC, the Large Electron Positron (LEP) collider. I deliberately placed my installation in its proximity, creating a conceptual resonance between the objects, and the installation itself resonated, literally, in the space. Although quiet, the resonating hum emanating from the objects could be heard throughout the machine hall, and had several CMS workers thinking it was some kind of scientific device. And finally, the hum itself was an acoustic analogue of the social activity of the CMS superorganism and the kind of living entity that is the detector itself, as described by Knorr-Cetina (Section 2.3). Furthermore, the 'barely detectable displacement'[91] between the artwork and its environment raised questions regarding what was the science and what was the art, and where the experiment ended.

[88] Traweek, *Beamtimes and Lifetimes*, p.39
One senior figure at CERN confided in me that when the LHC becomes obsolete, it is going to pose some major disposal problems, as it is the world's largest activated object.
[89] This was inspired by Rauschenberg's *Oracle* and *Mud Muse* (described in Section 3.4).
[90] http://www.bbc.co.uk/programmes/b04xxvtb Although Will Self 'Self Orbits CERN' podcast is full of scathing yet warranted attacks upon the superficially grand yet vacuous statements public relations people at CERN make about the LHC unlocking the secrets of the universe, and revealing the meaning of life and such, I do not have the luxury of an analysis of his hour-long counter-diatribes. Suffice to say, he does conclude with the conciliatory realisation that maybe he should learn a bit more about science before attacking it, which in a way plays with, yet seeks to transcend, the C.P. Snow trap.
[91] Smith, Roberta. "Review/Art; Fast Rise, Lasting Role of a Gentle Giant." New York Times, March 12, 1993. Accessed August 8, 2017. http://www.nytimes.com/1993/03/12/arts/review-art-fast-rise-lasting-role-of-a-gentle-giant.html?pagewanted=all&mcubz=0

4.7. *Song of the Phenomena*

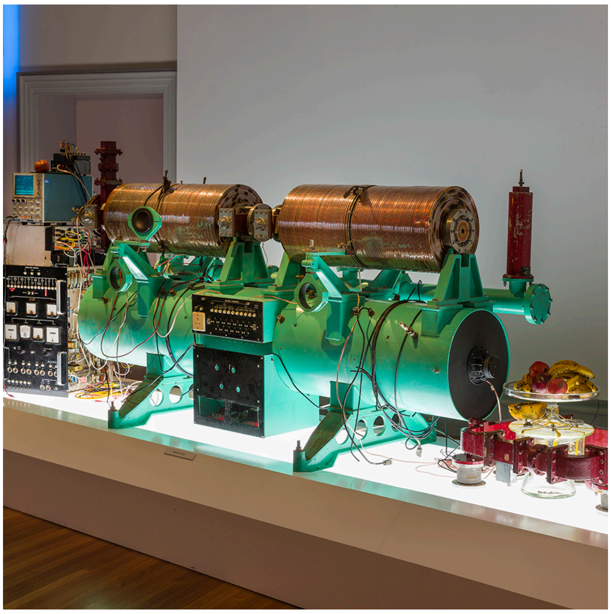

Figure 16. Chris Henschke, *Song of the Phenomena*, 2016.

After my CERN collaborations, I produced a final work, which brings together conceptual and material parameters of my previous projects, literally through a high-energy physics apparatus. Galison stated 'It is not only experiments but instruments that have a life of their own.'[92] Buoyed by this quote, I decided to instil new life into an obsolete apparatus. This artwork is called *Song of the Phenomena* (see fig. 16), and inspired by Galison and Bohr, it manifests the tensions and connections between macroscopic apparatuses and subatomic phenomena. As Bohr stated, the interaction between apparatus and object 'forms an inseparable part of the phenomenon'.[93] Through amplification, resonance and decay, the artwork probes concepts described throughout this exegesis, in an energetically expressive material manner that does not rely on representation or metaphor. Quantifiable phenomena such as 'energies, frequencies, intensities and phases'[94] are the forms manifested by subatomic phenomena when interacting with macroscopic apparatuses. However, I see such manifestations as more than just measurable outputs used to validate scientific hypotheses – they are the expressions of the phenomena in their own right. As Manuel DeLanda stated:

> The characteristics [of wavelength components and vibration frequency] allow both light and sound to produce distinctive effects on animal and human brains, effects that may be used for expressive purposes … by human artists. But possession of a nervous system is not necessary to make expressive use of colour or sound. Even humble atoms can interact … in a way that literally expresses their identity.[95]

For this project, I returned to the Australian Synchrotron, the source of my activities with particle physics. In January 2016, thanks to Mark Boland, I discovered a Met-Vic LINAC in storage at the Synchrotron. Boland, who had worked on this device during his honours studies at the Australian Radiation Laboratory, rescued it from a

[92] Galison, *Image and Logic*, p.424
[93] Barad, *Meeting the Universe Halfway,* p.119
[94] Kragh, *Niels Bohr and the Quantum Atom*, p.353
[95] DeLanda, Manuel. "Matter Matters." *Domus*, 2012, p.7

journey to the scrap-heap.[96] This apparatus was one of three units first operational in Australia in 1956,[97] originally designed for medical radiological treatments, although this one had added solenoid magnet coils designed to produce antimatter in the form of positrons.[98] But what to do with such an apparatus? In a way informed by my *Activated Objects* project, I realised I had to approach the device on its own terms. I had to let the apparatus speak to me (see plate 16).

This section describes the rationale and processes I developed whilst working on *Song of the Phenomena*. Essentially, the process began as a machine study. As described in Section 4.9, accelerator physicists use machine studies to test the capacities of their apparatuses. Although informed by such accelerator physics, and Bohr's apparatus–phenomena relations, my machine study also encompassed the inquisitive intuitive methods of Duchamp (described in Sections 3.3), and the technological–material engagements of E.A.T. artists such as Rauschenberg and Childs (described in Sections 3.4), whose work is 'derived from the laws that govern the materials [and their] qualities and limitations.'[99] Through approaching the LINAC as an epistemic object of open-ended possibility, I explored the conceptual and material parameters of the apparatus in ways that would critically yet playfully engage with the object. Through experimentally engaging with material aspects of the machine, in a way similar to *Activated Objects*, by playing different frequencies through the tube that initially accelerated the particles I found the acoustic resonance of the accelerator to be 220 Hz. This frequency is fed into the accelerator acoustically, via speakers attached to the waveguides which initially convey microwave energy. Although quiet, this frequency resonates through the accelerator's vacuum tube. I realised that, instead of using the LINAC to emit particles as it originally did (which would be difficult and dangerous), I could set it up in a way that would channel subatomic emissions into the apparatus as an inversion of its initial function. As sources of particle emissions I use high-potassium fruit such as bananas and pomegranates, which literally emit electrons and positrons from atomic decay of the radioactive potassium 40 isotopes naturally occurring in them. These are placed in a fruit bowl in front of the accelerator, which would originally have been the biological material target of the accelerator beam. Bananas were a key ingredient, having previously appeared in *Potential Objects* (and my Schrödinger's cat demystification demonstration at ISEA), but this time I included pomegranates, because somehow they intuitively seemed right.[100] The inclusion of fruit turns the work into a kind of Vanitas still life. Vanitas paintings are traditionally associated with the transience of material objects, and are a play upon the obsolescence of technologies, whether a LINAC or the LHC. A Geiger–Muller tube is mounted near the fruit to detects the particle emissions and amplify their signals. This is a play upon the notion of still life – as the Geiger counter demonstrates, things are not still on the atomic scale. In

[96] Interestingly, this was almost destined for a purpose other than the scrap-heap. Ridley Scott's art department was sniffing around it, considering it as a prop for *Alien: Covenant*. The difference between my use and their potential one is fundamental – mine is actual, theirs is fictional.

[97] Thwaites, David and John Tuohy. "Back to the future: the history and development of the clinical linear accelerator."*Physics in Medicine and Biology*, 51 (2006): 343-362, p. 347

[98] However, this solenoid component was never used, until I fed energy through it. This itself raises an interdisciplinary question – if such a component has only has been used for art, does this make it art?

[99] Childs, Lucinda. "Vehicle." In *E.A.T. Experiments in Art and Technology*, edited by Sabine Breitwieser, 122-125. Köln: Verlag der Buchhandlung Walther König, 2015, p. 122

[100] I am generally averse to the arbitrariness of metaphor, but I found plenty of metaphorical juice in the pomegranates. As well as being occasionally a symbol of the forbidden fruit of knowledge in Biblical imagery, in Classical Greek mythology the goddess Persephone took a pomegranate with her into the Underworld. When I mentioned this to a scientist at the opening of the exhibition, he playfully exclaimed 'it makes sense, the underworld is antimatter!'

Song of the Phenomena, the signals from the Geiger Counter activate the electromagnetic coils via analogue sound synthesisers.

The 220 Hz tone played through the accelerator is modulated by the output signal from the Geiger counter, via an analogue computer which uses Boolean functions to affect the frequency, amplitude, and phase of the tone. This analogue computer (part of a "Eurorack" analogue synthesiser), is mounted to an equipment rack from the 1980s used to control particle accelerators, which also has frequency generators and oscillators. This itself is placed upon a part of the original control rack for the LINAC, which also has modulation controls. Thus, three types of signal generator and modulator are brought together (although only the audio one is powered, the others would require up to 10,000 volts). Also, as described in Section 4.5, accelerators are essentially analogue synthesisers, and *Song of the Phenomena* plays with that realisation. The audio output overall also connects high-energy physics ultimately to rock'n'roll, the essence of which, I feel, is amplification.[101] The output from the analogue computer/synthesiser is amplified, using a standard stereo amp, and fed into a section of the coils, which energises them.[102] The electromagnetic field of the energy in the accelerator coil is picked up by a secondary coil, in the same way that an AM antenna works. The audio from this pickup is played through a speaker mounted in the front of the LINAC, so that one can literally hear the sound of the energy field. An analogue CRT oscilloscope allows one to see the output, manifested as nebulous particle forms on the screen.[103] The 220 Hz tone also goes to two speakers mounted in the base of the accelerator, essentially turning it into a subwoofer. This was intended to produce superpositions of waves that change phase when triggered by the particle emissions, as a kind of sonic manifestation of the Schrödinger wave function (as discussed in Section 1.6). Although it didn't quite work as hoped, it produced a deep tone, conveying a sense of energetic potential. To get the coils working required fine tuning,[104] with assistance from accelerator physics PhD candidate Thomas Lucas, who also helped develop the idea of acoustically resonating the waveguides.[105] During the setup, when working with Thomas, an outside observer may have been hard-pressed to detect who was the artist and who was the scientist. Although not a transdisciplinary project in a strict sense, the boundaries between the disciplines were blurred.

As the entire setup used solely analogue signals, the installation overall remained in the era of the accelerator itself. In other words, the technologies used in the project were all of the LINAC's time, which is a kind of nod to Galison's instrumental history. It is also notable that, in this project, I took a step back from the complexities of contemporary particle accelerators such as those at CERN. Perhaps, to paraphrase Galison, as a way to regain a greater degree of experimental autonomy, I retreated from gigantism back to 'individuals in little

[101] Such an insight can only be gained through engagement. For example, in 2015 I went to an AC/DC concert which was literally a high-energy event, and the experience of a near-rapturous 10-minute guitar solo by Angus Young atop a five-metre-high 20-metre-wide wall of guitar amplifiers took me (and 40,000 others) to the edge of pure sonic abstraction. In this moment, where the very air was resonating, it felt like high-energy physics.

[102] Initially I had used a Kepco power amplifier at the Synchrotron, which, although set to low current, could be changed to a lethal 10 amps at the flick of a switch. We decided against using that for obvious reasons.

[103] In a sense this is a kind of bluff, in that the CRT is literally an electron accelerator (see Section 3.5), so there is a working particle accelerator in the installation.

[104] In trying to tune the machine there were some spectacular failures, such as shorting out amps and oscilloscopes, with sparks literally flying off the coils and amplifier.

[105] In fact, Thomas Lucas' PhD supervisor is also Mark Boland; furthermore, he is also a musician who perhaps not surprisingly plays heavy metal guitar – another piece of anecdotal evidence regarding the connection between particle physics and amplified music.

labs.'[106] The advantage is that the setup was simple enough to allow a keen observer to trace the energetic connections from the source in the fruit, through the Geiger counter, the analogue trigger and tone synthesisers, the amplifier and the accelerator coils, to the audio and visual outputs. As in *Cosmic Tea Party* (Section 4.8), the idea of Von Neumann chains (see Section 1.8) can be used to link the subatomic and perceived phenomena. In this sense the work questioned where the subatomic ends and the macroscopic begins, as a manifestation of the measurement problem, playing with the Schrödinger cat paradox (see Section 1.6), although it was more like Schrödinger's fruit, inspired by Dieter Zeh's fruits of decoherence (see Section 1.8). By the end of the process I realised that this project had become a collaboration with the apparatus itself – it was a dance of agency between myself, the subatomic phenomena, and the accelerator.

The installation expressed an energy analogy of the subatomic phenomena originally produced in the apparatus. However, it inverted the device's original purpose: instead of performing radiological experiments upon biological matter, it was being activated by the amplified subatomic emissions from the biological material. The organic matter in the installation is framed with the technology that feeds upon it.[107] This is formally reinforced through parts of the waveguide I disassembled and reassembled to form a kind of circle around the fruit bowl. The fruit gave the device a new kind of life, by energising it electromagnetically and acoustically.[108]

4.7.1. *Song of the Phenomena* exhibition

Song of the Phenomena was exhibited at RMIT Gallery, as part of the 'Morbis Artis: Diseases of the Arts' exhibition, 16 October 2016 – 18 February 2017 (see plates 10 and 11).[109] Around the accelerator was a five-metre long base with an under-lit translucent white acrylic top, bathing the work in an ethereal glow. As well as the allusion to the end sequence of Kubrik's *2001: A Space Odyssey*, this framing device turned the work into a self-contained hermetic installation. In a sense this was a play upon scientific experiments such as CMS, as well as artworks such as Duchamp's' Large Glass (see Section 3.1). Within the frame were the components of the accelerator and its control systems loosely wired together, with extra cables and bits of the accelerator haphazardly yet precisely placed in relation to each other, manifesting a distilled implicit aesthetic that I found at laboratories such as CERN and the Australian Synchrotron.[110]

[106] Galison, *Image and Logic*, p.315.

[107] This plays upon philosopher Martin Heidegger's concept of 'gestell', the scaffolding that technology provides society, but which inexorably turns the world – from atoms to humans – into mere energy reserves for its own sustenance. In this way, the work critiques the fundamental nature of technology and the relationships between science, technology, humanity and nature itself. See Heidegger, Martin. "The Question Concerning Technology." In *Technology and Values: Essential Readings*, edited by Craig Hanks, (1954): 99–113. Oxford: WIley Blackwell, 2010.

[108] In fact a visiting accelerator physicist from Belgium who helped tune the coils went from originally saying 'I hate art' to exclaiming, without any prompting, 'we have brought the accelerator back to life.' In the end, he didn't want to stop playing with the installation, and created an amazing self-contained electromagnetic feedback loop, which produced uniquely disturbing bassy tones, and which incidentally totally fried an iPad I had attached to the audio input.

[109] Strangely enough, this exhibition was described in the publicity material as a bio-art show, even though I do not consider my work related to this area at all; stranger still, my project was the only one to have any kind of biological material in it.

[110] I also attempted to set up the artwork at the Australian Synchrotron, as a 'rogue installation'. The install itself was unofficial (we had to kind-of sneak the LINAC in through the rear door). Part of this setup involved playing the sound of the cicada through the device, as a homage to my 2007 ANAT project, and indeed to the cicada itself. This only momentarily worked (like my previous cicada experiment!). Unfortunately, after a few months it was still not set up properly, and we had to again disassemble and remove it. Some of the more recalcitrant staff and management didn't like it, or indeed didn't like art – science projects in general. This I discovered on my first day at the Synchrotron bin 2007. See "the hammer threat incident", White-Hancock, "Innovation and Arts Practice", pp. 162–164

Unlike some of my experiences (as described throughout this chapter), the installation of this work was very precisely planned (although it did have its own unique disasters, including breaking a truck trying to get the LINAC to the site).[111] The work was well received, with positive reviews and articles in both science and art publications. Finally, over the course of the exhibition I asked the gallery attendants to log the readings on the Geiger counter at the end of each day. Making such measurements was itself a form of play with the boundary between art and science.[112]

In summary, *Song of the Phenomena* manifests qualities of the subatomic phenomena and the apparatus through energy analogies, inspired by Bohr's epistemology, Galison's genealogies, Pickering's agency, and Hacking's entity realism. It conceptually and materially plays with the form and function of the accelerator. It distils aspects of accelerator physics and its relationship with audio synthesis. It is an experiment, in that it was not known if and how it would work before it was wired up. It is a collaboration with physicists, and with the apparatus itself. It manifests and amplifies the agency of subatomic phenomena, through an accelerator that initially produced similar phenomena. It uses analogue data from particle events, not as a means of analysis but as a means of expression, as a form of 'primary reality'. The science is framed by the art, and has art within it, energising it, giving it a new kind of life. The artwork overall is not a representation of particle physics, it works with and manifests subatomic phenomena, thus it is a kind of entity realism, playing upon both the realism of the subatomic entities and the realism of the artwork. It is a particle accelerator, and yet it is not. It challenges science in its own terms. I see it as an epistemic thing, in that it raises the question of where the science ends and the art begins.

[111] This was another problematic situation! I had been back in Melbourne for a few days after Vienna and Strasbourg, and had literally five days in which to set up *Song of the Phenomena*. I had pre-planned and arranged everything, including transportation, including calling in a favour from a certain international art courier. However, when we put LINAC on the back of the truck, the tray buckled and almost collapsed. The courier blamed me for getting the weight wrong, then drove off, even though I told them the physicists had weighed it and they know what they are doing. I went back inside and there was Donald Trump's face on all the TV screens, having just won the US election. Utter despair. Luckily, another art courier around the corner had a crane truck, and delivered it safely and easily two days later. With help from precision engineering cabinetmakers Troy and Lindon Davey-Milne, with whom I collaborated on the design of the base, the installation was finished with hours to spare before the opening.

[112] If nothing else, this demonstrated that the gallery was open late each Thursday, as seen in the periodic spike in the graphical plot of the data.

4.8. Conclusions

Figure 17. Chris Henschke, “CERN hallways”, 2015.

Overall, during my time at CERN my practice took a ‘turn from representing to intervening.’[113] In my three initial projects, I explored concepts and data in representational ways, and this developed into collaboration with scientists; the final projects were interventions with the materials experimental physics, leading to a collaboration with the apparatus. Wandering the hallways of CERN (see fig. 17), interacting with the people who work there, beholding the LHC experiment and CMS detector - these have been uniquely inspiring experiences (see plate 14). Like any working environment, CERN has influenced me, and as described in this chapter, undertaking art practice in such a rarefied realm is not easy.[114] To invoke Nietzsche, it has not killed me, but has instead made me stronger, or at least has led me to produce a series of focused and unique artworks. However, as I have found, one must not get overwhelmed by such an environment, instead one has to navigate and negotiate a way through the physics. I have encountered fundamental aspects of nature, the incredible complexities of its agency revealed through the technologically-mediated interactions of high-energy physics apparatuses. As Hacking stated, ‘the phenomena of physics … are the keys that unlock the universe. People made the keys – and perhaps the locks in which they turn.’[115] I have been within, and experienced, the intricacies of the lock that is CMS, and I have glimpsed through the keyhole. On the other side is a realm of high-energy agency, abstract and intangible in itself, yet very real in the sense of Hacking’s entity realism, as mediated by the apparatuses that frame and manifest it. In producing the artworks described above, I try to convey these experiences and relationships, in a way that allows others to glimpse or feel such things. As Sontag and Frayling noted (in Section 4.7), there is a type of embedded knowledge in artworks themselves, and through this, experiential knowledge is gained from audience engagement with such objects. Artworks such as *Song of the Muons* and *Song of the Phenomena* present an epistemological challenge to

[113] Hacking, *Representing and Intervening*, p.145.
[114] As in any large social group or institution, there are a wide range of people and personalities, ranging from progressive to reactionary.
[115] Hacking, *Representing and Intervening*, p.228

scientific knowledge, as the materials and data of particle physics experiments are ‘embodied in the artefact[s].’[116] Thus, these projects constitute knowledge, they are interdisciplinary epistemic objects.

[116] Frayling, “Research in art and design”, p.5

Chapter 5 – Conclusion

In this chapter, I synthesise insights gained through my experiences and projects. I argue that my enquiry into, and direct engagement with, particle physics laboratories, has been successful. This is demonstrated in the creoles and processes developed through my collaborative practice, and the artworks produced through this practice. I argue that my collaborations with physicists provide insight into cross-disciplinary practices. I propose future projects involving quantum entanglement experiments, and prospects for art–science research. However, I also caution against prescribed collaborative programs, instead advocating more experimental and open-ended interactions between artists and scientists. I conclude by arguing the artworks I produced reframe and answer my initial research questions.

5.1. Expressive experiments

In my journey through the 'garden of [particle] physics,'[117] I progressed from engagement with scientific concepts, through working with the materials and data of particle physics experiments, to collaborating with the physicists, and ultimately to collaborating with the apparatuses used in particle physics experiments. Through my 'observant participation' [118] in the culture of the CERN particle physics laboratory, I have found shared traits between art practice and high-energy physics, namely that they are both experimental material cultures. I have also encountered, and indeed creatively engaged with the tensions and fundamental differences between these two cultures. I have gained insights into the practices of particle physics, as dynamic and ongoing material-conceptual interactions between the scientists and the apparatuses, through both my in-situ practice and research. Pickering's notion of non-human agency, and his understanding of 'science as a field of emergent human and material agency'[119] provided a framework through which to understand the relationships between the scientists, the apparatuses and the subatomic phenomena. Through the heuristics and creoles developed during my time at CERN, I believe I found a way to meaningfully engage with the scientists and indeed with the experiments, and in a way, make short-circuits between the disciplines, in order to see what occurs. In this way, my entire candidacy itself is an experiment, set up to see what happens when an artist collides with the universe of experimental physics.

Drawing from Dunne (see Section 3.2), I found that my practice and understanding of the concepts of physics informed each other as they 'evolved simultaneously,'[120] through material and conceptual experimentation. From this reflexive practice I have sought to distil and express the 'dance of agency'[121] between scientist, apparatus and phenomena into the works created during the candidacy. For example, the key works I

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[117] Aaserud, Finn, and J.L. Heilbron. *Love, Literature, and the Quantum Atom: Niels Bohr's 1913 Trilogy Revisited*. Oxford: Oxford University Press, 2013, p.105

[118] Moeran, Brian, "From Participant Observation to Observant Participation: Anthropology, Fieldwork and Organizational Ethnography." Copenhagen: Creative Encounters Working Papers, 2007. Accessed January 30, 2017. http://openarchive.cbs.dk/bitstream/handle/10398/7038/wp%202007-2.pdf?sequence=1, pp.20–21.

[119] Pickering, Andrew. "The Mangle of Practice: Agency and Emergence in the Sociology of Science." *American Journal of Sociology* 99, no. 3 (1993): 559-589, p.568

[120] Steffen, Dagmar. "New experimentalism in design research: Characteristics and Interferences of Experiments in Science, the Arts and in Design Research." *Artifact* 3, no. 2 (2014). p.12.

[121] Pickering, *The Mangle of Practice*, p.14

produced, *Song of the Muons* and *Song of the Phenomena*, play "songs of agency", expressed through energetic analogy. Working with the primary reality of signals and data, these works express the interplay of agency of the subatomic phenomena and the apparatuses on a level that is not just metaphor or representation. In order to explore and manifest a more analogous connection between the phenomena and apparatus, I stepped back from the technological complexities of CMS, to engage with a relatively simple apparatus - the LINAC, in *Song of the Phenomena*. I understand *Song of the Muons* and *Song of the Phenomena* as existing alongside the realist forms of art, but which is essentially 'entity realism',[122] to use Hacking's term. These works both informed and manifested my position on the realism–antirealism debate (discussed in Chapters 1 and 2) – I believe the subatomic phenomena I have engaged with *are* real, as they are embodied and embedded respectively in *Song of the Muons* and *Song of the Phenomena*. My entity realist position itself has emerged through my research and practice.

I see my practice as being experimental, as it creatively engages with the material cultures of experimentalism in both science and art. As Hacking stated, 'to experiment is to create.'[123] Also, intuitively following Hacking, in both my research and my practice, I too 'turn[ed] from representing to intervening.'[124] Such a turn is even implicit in the structure of this exegesis, in the shift from descriptive representations of theory and experiment, to personal accounts of my social and material interventions. In terms of my practice, this is seen in the development from my initial work, *Edge of the Observable*, which represented stylised aspects of both experimental setups and data from experiments, in the form of an idealised collision event signature made in an idealised experimental setup; to the other extreme, *Song of the Phenomena*, in which I intervened in the form and function of a particle accelerator, essentially inverting it to manifest its essence. In between, *Nature of the Apparatus* represented aspects of the relationship between the apparatus and the phenomena, the matter and the energy in the LHC experiment, in a way that was a simulated intervention, through the experimental process I used to manipulate the footage of the experiment. *Potential Objects* was a play upon the concepts with which I had been engaging, in a light respite from the heavy-duty and intensive collaborative work undertaken whilst at CERN. *Activated Objects* was a material engagement with parts gleaned from the LHC in a way that expressed an energy analogy. *Song of the Muons* sought to 'capture the essence'[125] of individual muon events in the CMS detector, in a way that was an immersive auditory expression, and allowed people to physically experience this in the same way that one can become deeply immersed in music mediated through the technologies of amplification, whether it be at a rock concert or upon a disco dancefloor.

By bringing together the phenomena of high-energy physics with everyday things, whether they be bananas, teacups, or a disco, these works also sought to bridge the gap between the realm of science and that of wider society. Although there are Dadaistic undertones in playing upon the seeming absurdity of pairing bananas with particle accelerators, for example, I seek also to show the absurdity of people's reactions to such things: bananas *do* emit antimatter, we *all* do from time to time. Although normally invisible to our unaided senses,

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[122] Miller, Boaz. "What Is Hacking's Argument for Entity Realism?" *Synthese* 193, no. 3 (2016): 991-1006, p. 991

[123] Hacking, Ian. *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press, 1983, p. 230

[124] Ibid., p.145.

[125] Smolin, Lee. *Time Reborn: From the Crisis in Physics to the Future of the Universe*. Boston: Houghton Mifflin Harcourt, 2013, p. 157

we are all dancing with the phenomena, we are all part of the ongoing agency of the universe. As scientist and philosopher Michael Polanyi stated, 'the knower does not stand apart from the universe, but participates personally within it.'[126]

5.2. Future entanglements of art and science

As well as my ongoing interactions with CERN,[127] I see future personal art–science projects in other areas of physics. One exciting possibility would be to work with quantum computing, which is currently on the cusp of major breakthroughs.[128] Using entanglement phenomena (as discussed in the Intermezzo), this may herald the biggest change in computer technology since the invention of the computer itself. Art–physics research is, therefore, calling out for ways to creatively engage with entanglement. In this way, I wish to take up Zeilinger's inferred 'entanglement art' challenge (mentioned in Section 3.8). In terms of my practice this would be a shift from high-energy to low-energy particle physics, working with an experiment that could fit into a suitcase (or two) instead of a huge laboratory. Such a project would ideally produce entanglement phenomena, in a precise yet unique manner. For example, this may be in the form of a pair of suitcases, one which contains an interface comprised of two interlocking turntables, which formally and symbolically connect to entangled photon phenomena, the other containing the necessary components required to produce such phenomena. Thus, the term entanglement would be used in a conceptually and experimentally meaningful sense.[129] And, like my other works, it would explore how everyday objects can be used to engage with, and make sense of, how science engages with, and makes sense of, such aspects of nature.

In terms of development in my scholastic research, I am interested in the notion of 'posthumanist decentring',[130] which is found in the philosophies of Barad and Pickering. Barad states:

> Posthumanism refuses the idea of … division between nature and culture ... [it] does not presume man is the measure of all things. It is not held captive to the distance scale of the human but rather is attentive to the practices by which the scale is produced.[131]

Analysing both my practice and the practices of experimental physicists from such a perspective may open up other insights into the interrelations between scientists and their material apparatuses. As Pickering argues: 'one has to see scientific culture as somehow a symmetric joint product of the human and the nonhuman.'[132]

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[126] Polanyi, Michael. *Personal Knowledge: Towards a Post-Critical Philosophy.* Chicago: University of Chicago Press, 1958, p.33.

[127] It seems I may have recently inherited another accelerator part, a five-metre-long cavity resonator from the LEP at CERN, with which I could create a high-energy acoustic apparatus.

[128] see: "Quantum Science." *New Scientist*. Accessed August 1, 2017. https://www.newscientist.com/article-topic/quantum-science/.

[129] This may comprise the following: a High Power 405nm 500mW Blue/Violet OPNEXT Laser Diode; an SPDC crystal, cut for Type II phase matched SPDC pumped by a 405nm laser; an IR Detector Card and video display. Such a setup would produce entangled photons, manifested as interlocking rings of light. Poetically, this is both the signature of the phenomena (like the signature of the Higgs events, as described in section 2.3), and also an iconic symbol of entanglement. Such an installation would physically and analogously entangle art and science on a variety of levels. The two suitcases would be connected through intertwined cables, playing with the analogy of quantum information packages, which are brought together and then separated but are still connected. Furthermore, before audience interaction with the installation experiment, there would be no distinction between the art and the science – only upon physical engagement does it reveal itself. This mirrors the fact that the entangled particles themselves, before they are observed, do not actually have individual properties– this is the essence of entanglement. Then, I would be able to correctly say the project *is* an entanglement of art and science. From this it is evident that I have already begun to take up Zeilinger's challenge!

[130] Pickering, Andrew. "Emergence and Synthesis: Science Studies, Cybernetics and Antidisciplinarity." *Technoetic Arts: A Journal of Speculative Research* 6 no. 2 (2008): 127-133, p.127

[131] Barad, Karen Michelle. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press, 2007, p.136

[132] Ibid.

5.3. The end of the universe?

Whilst there is great potential in expanding the realm of art–science practice and education, there are also great challenges. Such cross-disciplinary practices may be advanced in ways that are creative and critical, inspiring and insightful, in the spirit of Roger Malina's 'collaborative encounters'.[133] However, I can also forecast potential issues, by exploring the past and present.

By example, in the main building of CERN was a metre-wide red LED panel displaying a number. Written in scientific notation, this number, although incomprehensibly large, was decreasing at a steady rate. There was no signage to explain what it was. The display was installed by Ryoji Ikeda, after a discussion he had with a theoretical physicist. The number represented how long the Universe had left before it expired, according to one cosmological theory. On one level this was the ultimate doomsday countdown, but perhaps it was also a play upon context-free data, in typical Ikeda style. Questions regarding its meaning hovered in the air about it, and gave it an uneasy feel, which was perhaps too much for some – the work was soon taken down.[134] The universe is still here, but Ikeda's warning sign isn't.[135] In addition to such evidence of ongoing tension between individuals in both disciplines, for me this illustrates a core issue: how long will the 'universe' of art–science collaboration last?

After tireless advocacy of the pairing of art and design with science and engineering by artists and scientists such as Jill Scott of Artists-in-Labs and Roger Malina of *Leonardo*, this once fringe area of research and practice is now a major global phenomenon. I realised this whilst attending the 'Critical Connections: Art, Design, and STEM' symposium, at the Queensland University of Technology,[136] in March 2017, which featured talks by representatives of Ars Electronica and the Science Gallery. The Science Gallery, which originated in Dublin in 2007,[137] has spread to London, Melbourne, Venice, and Bangalore. The speaker from Ars Electronica was offering courses in how to do art and science according to their method, and presented a map of their global network. art@CMS now also has such a global outreach program and indeed such a map. When I first started with art@CMS, they had put together about a dozen exhibitions, mainly in Switzerland and Austria, and a few in the USA. They have now had over 50 exhibitions in 17 countries across five continents (including my *Symmetries* exhibition – see Section 4.7). These are undoubtedly amazing developments, yet I have concerns about the future of art–science collaborations. Like the failure of E.A.T.'s Osaka pavilion (described in Section 3.4), sometimes bringing art, istiutional and often commercial interests together doesn't work. Companies

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[133] Malina, Roger. "Welcoming Uncertainty: The Strong Case for Coupling the Contemporary Arts to Science and Technology." In *Artists-in-Labs Networking in the Margins* edited by Scott, Jill, and Zürcher Hochschule Der Künste, 15-23. Wien: Springer Verlag, 2006, p.17

[134] In contrast, in the same vicinity is another artwork, a sculpture of curved wire forms, suspended above the staircase, *Feeling Material XXXIV* (2009) by sculptor Anthony Gormley. The still but suggestive spatial forms of Gormley are perhaps more calming and less abrasive than the urgent blinking of the red LEDs.

[135] In a similar vein, there was a humorous website displayed at CERN around the time of the LHC's first activation, with the URL www.hasthelhcdestroyedtheworldyet.com and a single word upon the screen: 'nope'.

[136] "Critical Connections: Art, Design & STEM." QUT. Accessed March 10, 2017. http://www.ciprecinct.qut.edu.au/whatson/2017/critical-connections.jsp.

[137] Miller, Arthur I. *Colliding Worlds: How Cutting-edge Science Is Redefining Contemporary Art*. 1st ed. London: W. W. Norton & Company, 2014, p.320.

such as Pepsi (who took over the E.A.T. pavilion) cannot fit the 'anything goes' methodology of 'ceaseless experimentation'[138] into their organisational hierarchies and corporate outlook.

Herein lies a potential downfall of art–science collaboration - in the laying down of prescribed sets of procedures as opposed to open-ended experimental and emergent forms of collaboration. Presenting one-off experiments as successful models is a potentially flawed logic. Experiments, once established, cease to be experimental, in that the outcomes are already known before the activity is undertaken. For art–science collaboration to work, it needs to probe the unknown, to challenge both disciplines, not be a normalised process, especially before its time. Or is it suddenly time? This may be a normal part of development, and looking at the scientific method itself can provide insightful. Historically, the 'mature' sciences exhibit traits of such stability after a period of upheaval. Kuhn stated, 'the successive transition from one paradigm to another via revolution is the usual developmental pattern of mature science.'[139] But, such mature disciplines are by definition prescriptive: 'No part of the aim of normal [mature] science is to call forth new sorts of phenomena … Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others.'[140]

This provides an insight into what I believe is the essence of art–science collaboration. It is a challenge to both disciplines. But if it becomes normalised, does it retain the capacity to engage and challenge on such a critical level? If processes and methods are prearranged as opposed to exploratory, can it remain as a form of questioning, or is it just an exercise, where the dance steps are precisely pre-planned? If exploration is curtailed and prescribed, it is not genuine experiment, innovation or discovery, it becomes pre-packaged McSciart, the restaurant at the end of the art–science universe.[141]

5.4. Conclusions

To paraphrase Newton, I have been standing on the shoulders of science, and this provides a unique view of the universe and our relations within it. Although undertaking such an interdisciplinary practice has its difficulties, it is also uniquely rewarding. As illustrated through my experiences, the collaborations themselves are unique and experimental processes, and like research at the edge of scientific practice, they are unpredictable and serendipitous. They can only develop through ongoing practical engagement and interaction, which must be nurtured by both parties. It is through such deeply embedded and interpersonal participatory experiences, as I have experienced at CERN, that a form of mutual understanding develops, a creole or lingo is established, and idiosyncratic heuristics evolve, which drive meaningful collaboration.

From 'collaborative encounters'[142] such as mine, what we get is the *scientific* world as reflected in the mirrors of our *artistic* apparatus, to paraphrase Bohr.[143] In support of to Malina's case that 'the challenge is how to do

[138] Tain, John. "E.A.T., Pepsi and Expo 1970 Osaka." In *E.A.T. Experiments in Art and Technology*, edited by Sabine Breitwieser, 156-161. Köln: Verlag der Buchhandlung Walther König, 2015, p.160

[139] Kuhn, Thomas S. *The Structure of Scientific Revolutions*. 3rd ed. Chicago: The University of Chicago Press, 1996, p.12

[140] Ibid., p.24

[141] Apologies to Douglas Adams – this term is taken from his novel *The Restaurant at the End of the Universe*.

[142] Malina, "Welcoming Uncertainty", p.17

[143] Baggott, J.E. *The Quantum Story: a History in 40 Moments.* Oxford: Oxford University Press, 2011, p. 97

[art] with enough rigour and in ways that can feed back into science',[144] collaboratively working with the concepts, processes and materials of science creates feedback with the scientists, and through them it may affect science itself, but in a way that is subtle, implicit, and perhaps barely detectable. Although detectors such as CMS may be hermetically sealed from the wider world, the culture of science isn't, as is argued by Feyerabend (Section 1.1) and Knorr-Cetina (Section 2.4). However, as Zilberg points out, the effect of art upon science is not easy to quantify, and it does not appear to advance basic science, but instead enriches both disciplines 'in different and complex ways'. [145] I don't think such collaborations between artists and particle physicists should explicitly aim to make scientific breakthroughs. Interdisciplinary collaboration itself is both a method and a goal, and the processes developed and artworks produced through interdisciplinary collaboration are in themselves bountiful fruit. I feel a 'stable jump'[146] to transdisciplinary art research in particle physics would be difficult, although not impossible. Based upon my experiences (such as described in Section 4.4.1), I believe that transdisciplinarity itself is an emergent phenomenon. Transdisciplinary practices emerge through open-ended and ongoing experimental processes that welcome chance and uncertainty, in the spirit of 'anything goes'. And through such conditions, Malina's 'deep art – science coupling'[147] may serendipitously emerge.[148]

Collaborative projects such as mine have the potential to set the 'pre-conditions for the creation of new intellectual possibilities,'[149] akin to setting up an experiment in which the inputs are known but not the outcomes. In the words of the biologist and philosopher Francisco Varela, these collaborations are 'interdisciplinary adventure[s]'[150] in which

> the practitioner is taking on a new vocabulary and lingo, other modes of thinking, other sets of procedure...to take bits and pieces from here and there to construct a new assemblage, another kind of aggregation - a collaging from which different, unscripted knowledge effects are squeezed out.[151]

Through my interdisciplinary adventures at CERN, I have collaged together conceptual and material bits and pieces, in an experimental and unscripted manner. Like the experiments undertaken in particle physics, and the region between the subatomic and macroscopic, the borders separating and defining the domains of science and art are not fixed, they change and mutate, they too are in an ongoing dance of agency. Bringing together the concepts that interdisciplinary collaborations are experiments, with that of artworks as being embodied knowledge,[152] the works I produced are interdisciplinary epistemic things, which materially question

[144] Malina, "Welcoming Uncertainty", p. 21
[145] Zilberg, Jonathan. "A SEAD White Papers Working Group Meta-Analysis." SEAD: White Papers, 2013. Accessed April 28, 2015. https://seadnetwork.files.wordpress.com/2013/01/zilberg_meta.pdf, p 19
[146] This is one last quantum physics metaphor, relating to the energetic but unstable short-lived moment where Wolfgang Adam and I shared an equivalent procedural and perceptual state, when I could hear the muons he was looking for whilst developing *Song of the Muons* (described in Section 4.4.1).
[147] Malina, "Welcoming Uncertainty", p.17
[148] Although I did not set out to address the five limits of science Malina identified as potential 'points of artistic intervention' (in fact I was unaware of this), my research and practice serendipitously engages with each of these themes. As referred to in Section 3.1, these five limits are: constraints provided by the human senses; constraints provided by existing technologies; constraints provided by ontology; theoretical limits; and the unimaginable. Malina, "Welcoming Uncertainty", p.19–21.
[149] Gemeinboeck, Petra, and Andy Dong, "Discourses of Intervention: A Language for Art & Science Collaboration." In *New Constellations: Art Science and Society*, edited by D. Rye & S. Scheding, 46-51. Sydney: Museum of Contemporary Art, 2006, p.50.
[150] Varela, Francisco, quoted in Sarat Maharaj, "On Francisco Varela." In *Bridge the Gap?* edited by Akiko Miyake and Hans Ulrich Obrist, 103-117. Köln: Verlag der Buchhandlung Walther König, 2002, p.112
[151] Ibid.
[152] Frayling, Christopher. "Research in Art and Design." *Royal College of Art Research Papers* 1, no. 1 (1993): 1-5, p.5

the limits of – and relationships between – art and science. These works also materially address my initial questions regarding the nature of science, and where the subatomic realm ends and the macroscopic universe begins. As question-generating epistemic things, my experiments and artworks ultimately ask: where does the science end and the art begin?

Plates

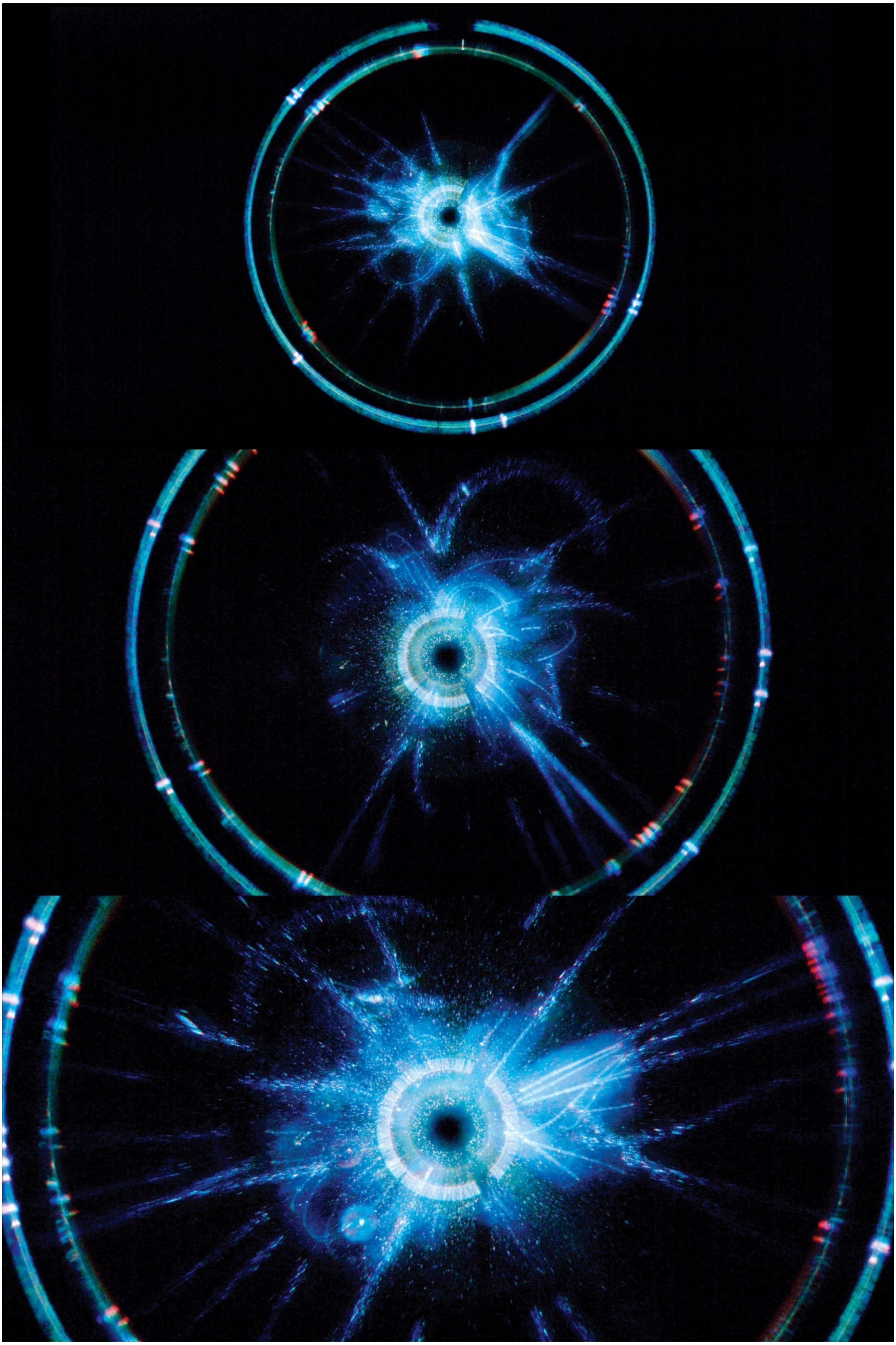

Plate 1. *Edge of the Observable* (2014), stills from video sequence.

Plate 2. *Edge of the Observable* (2014), exhibition images (from top): in-situ at CMS and on screen in CMS control room 2; at John Hansard Gallery, Southampton, UK; presented with "Colliding Events" display at International Conference on High Energy Physics (ICHEP14), Valencia, Spain.

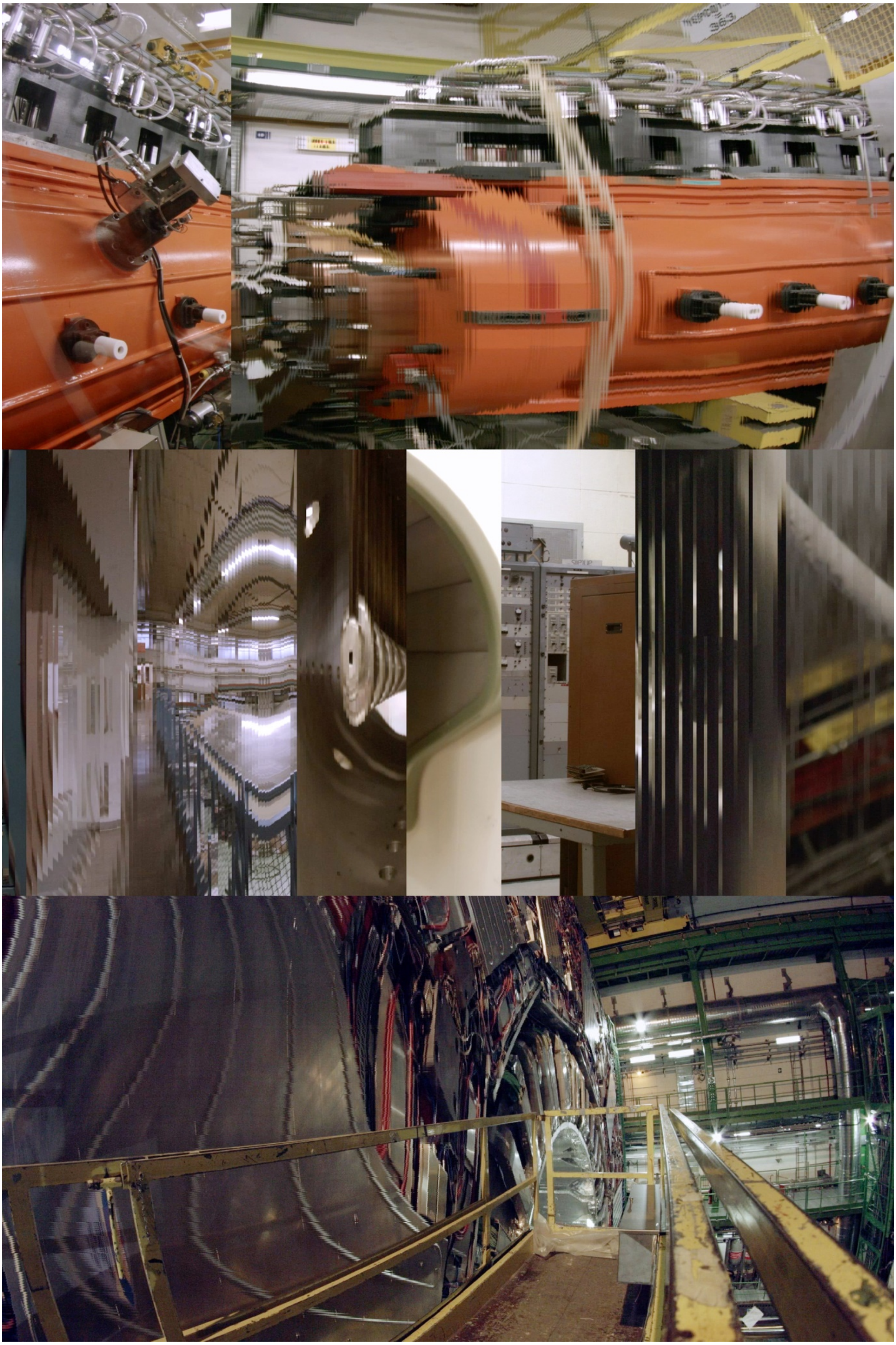

Plate 3. *Nature of the Apparatus* (2015), stills from video sequence.

Plate 4. *Nature of the Apparatus* (2015), stills from video sequence.

Plate 5. *Nature of the Apparatus* (2015), exhibition at CMS.

Plate 6. *Potential Objects* (2015), exhibition images (from top): *Potential Object 5, Potential Object 1, Potential Object 2*; exhibition overview; *Cosmic Tea Party, Monte Carlo Catastrophes.*

Plate 7. *Potential Objects* (2015), exhibition images (clockwise spiral from top left): *Entanglements, Dark Sector Echoes, Music of the Hemispheres, Resonance, Uncertainty.*

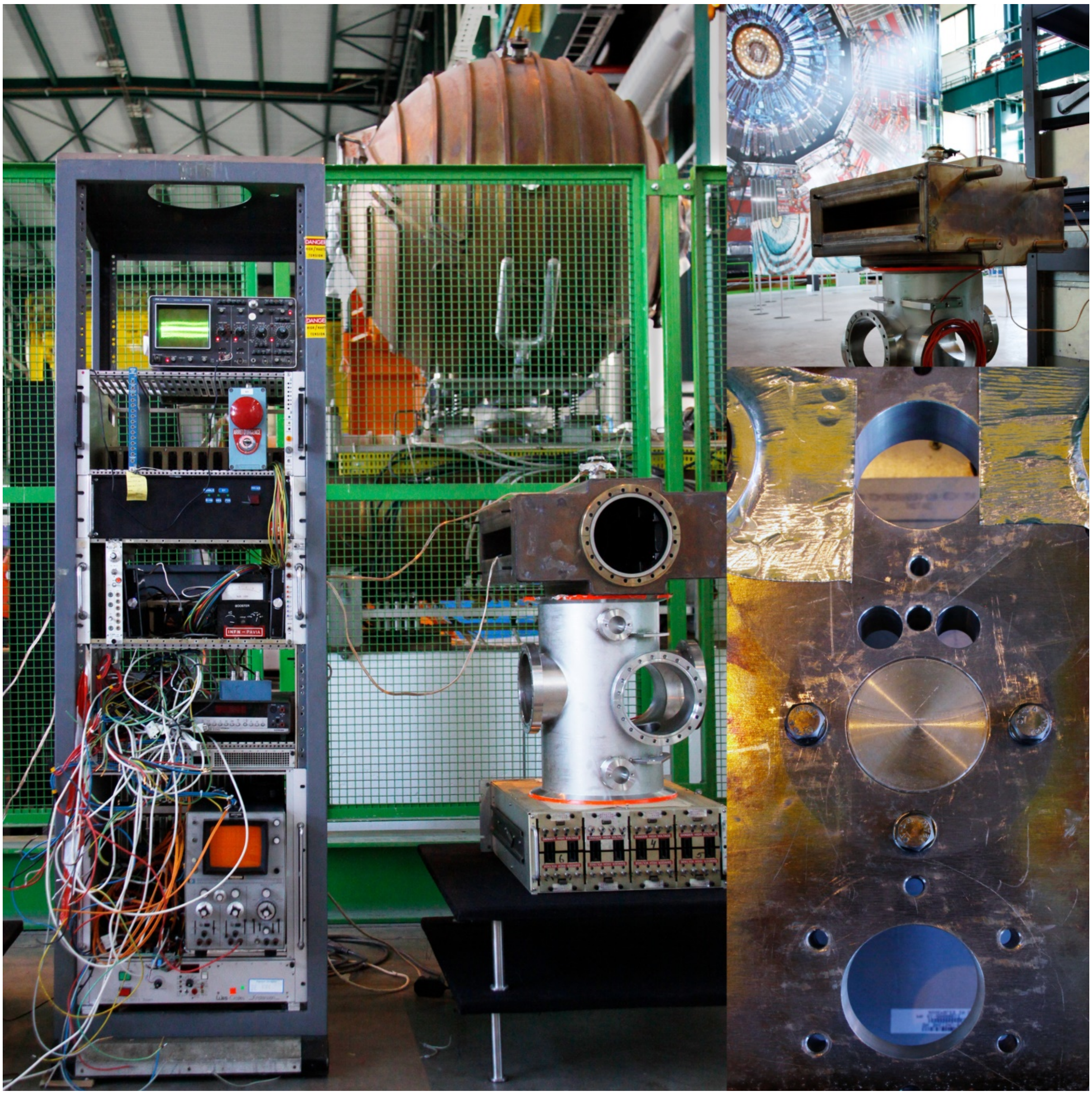

Plate 8. *Activated Objects* (2015), exhibition images at CMS.

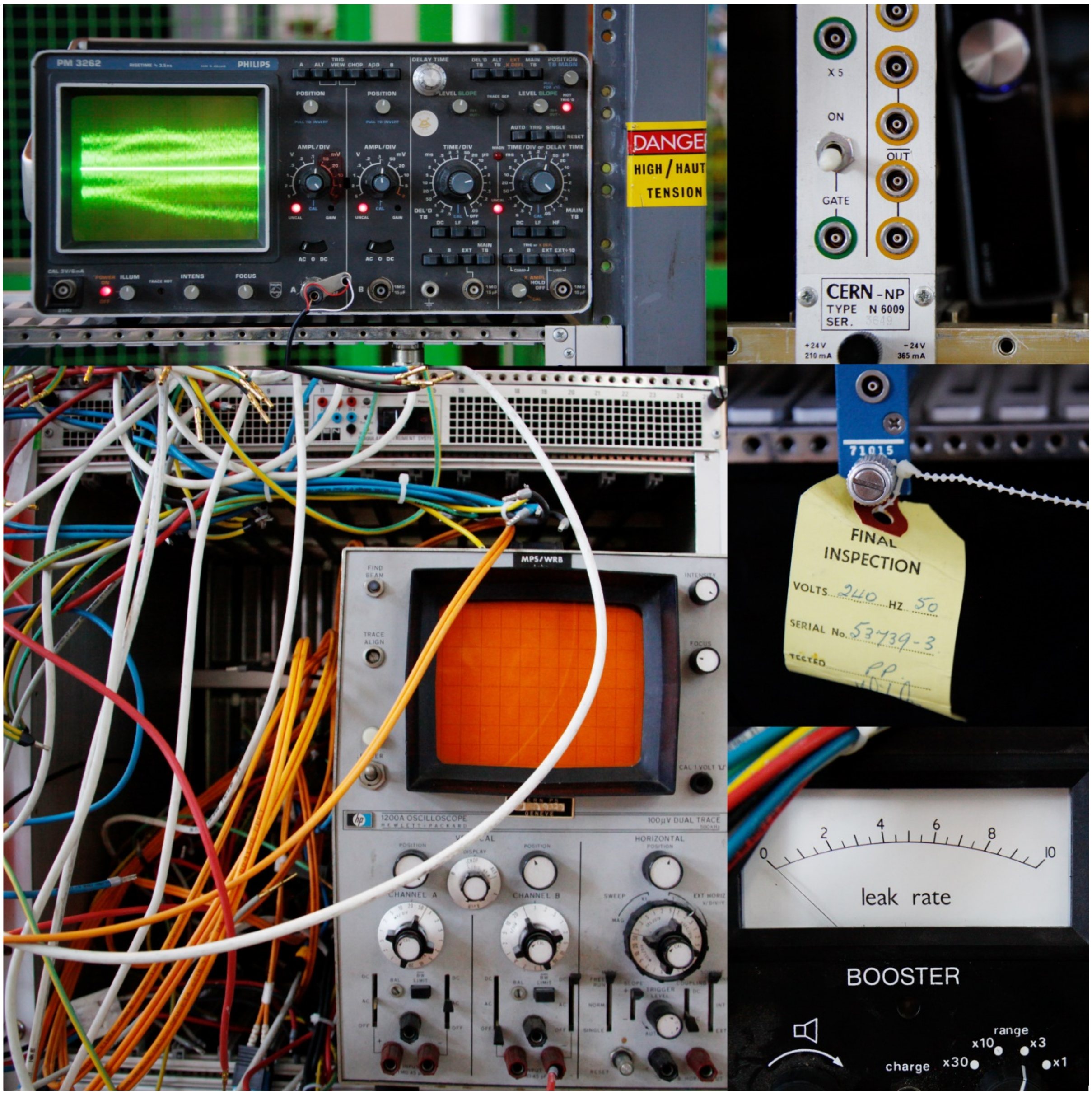

Plate 9. *Activated Objects* (2015) details.

Plate 10. *Song of the Phenomena* (2016). Photographs by Mark Ashkanasy

Plate 11. *Song of the Phenomena* (2016). Photographs by Mark Ashkanasy © RMIT University. Used with permission.

Plate 12. Exhibition images from art@CMS exhibition at the Palais de la Musique et des Congres, Strasbourg, France, (clockwise from top left), *Resonance* (2016), *Song of the Muons* (2016) installation and audience engagement.

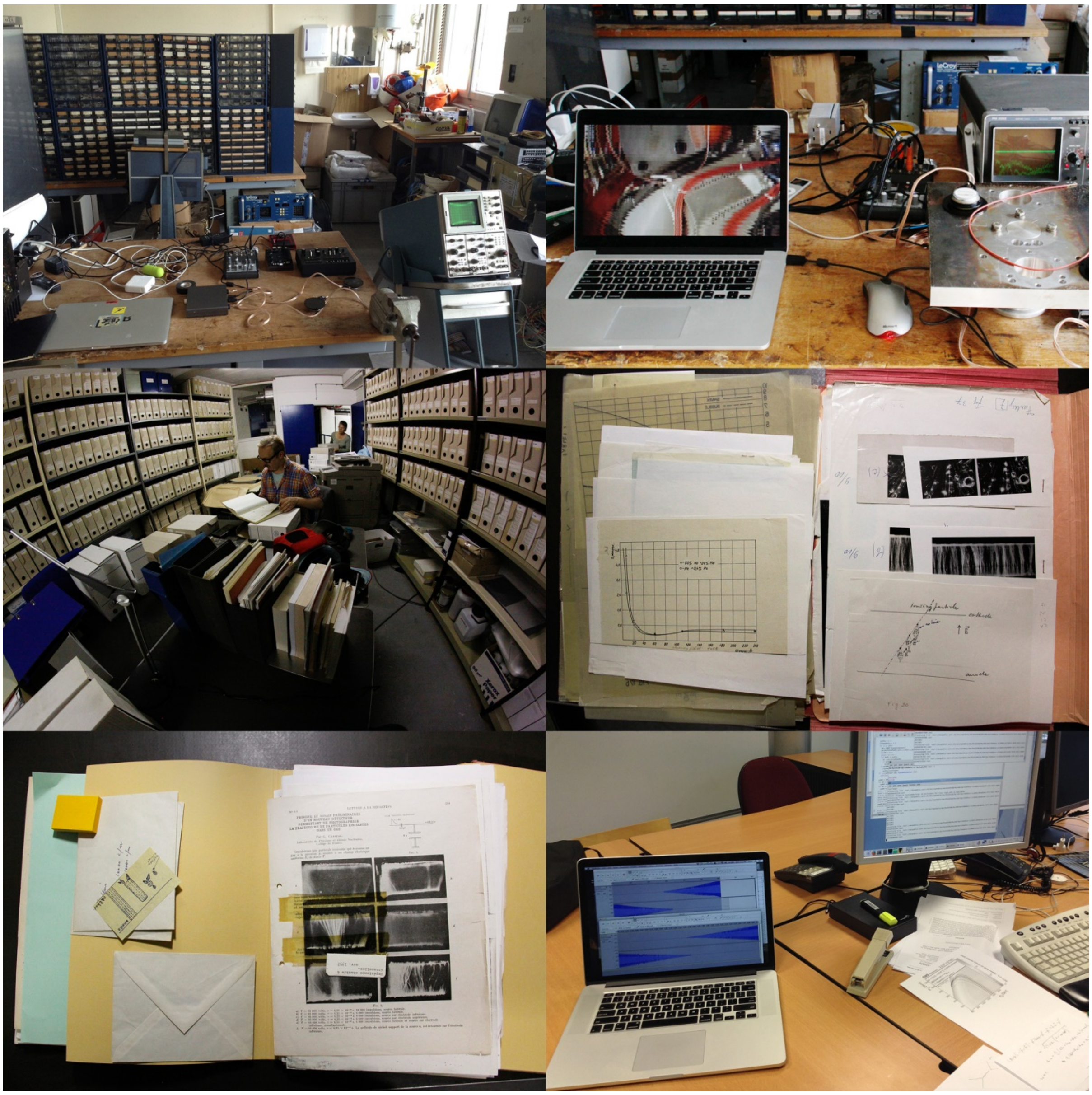

Plate 13. (from top) my studio space at CERN; exploring the CERN Archives; collaborating in the CMS offices.

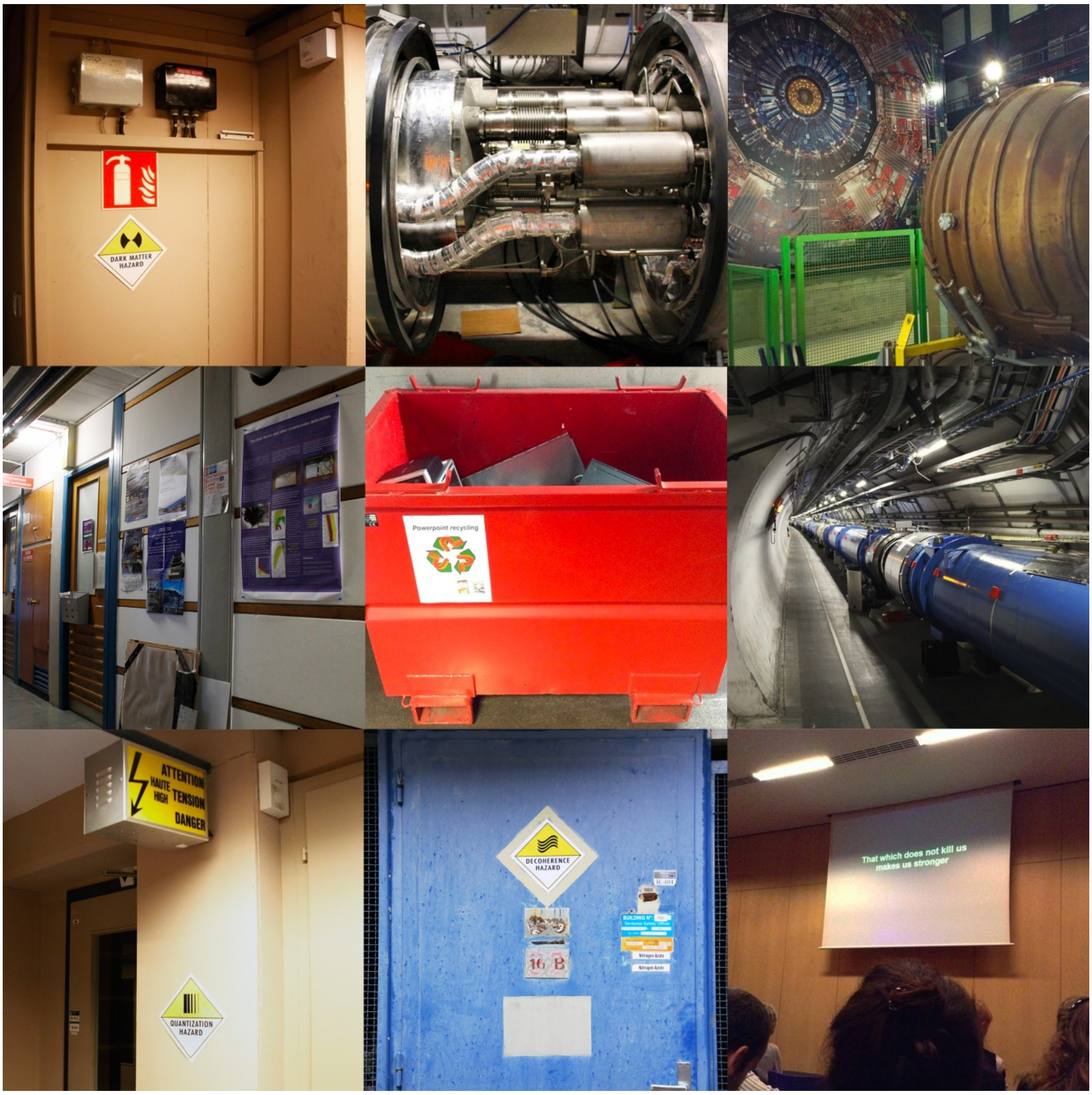

Plate 14. Inspirational CERN images, and poster / signage interventions.

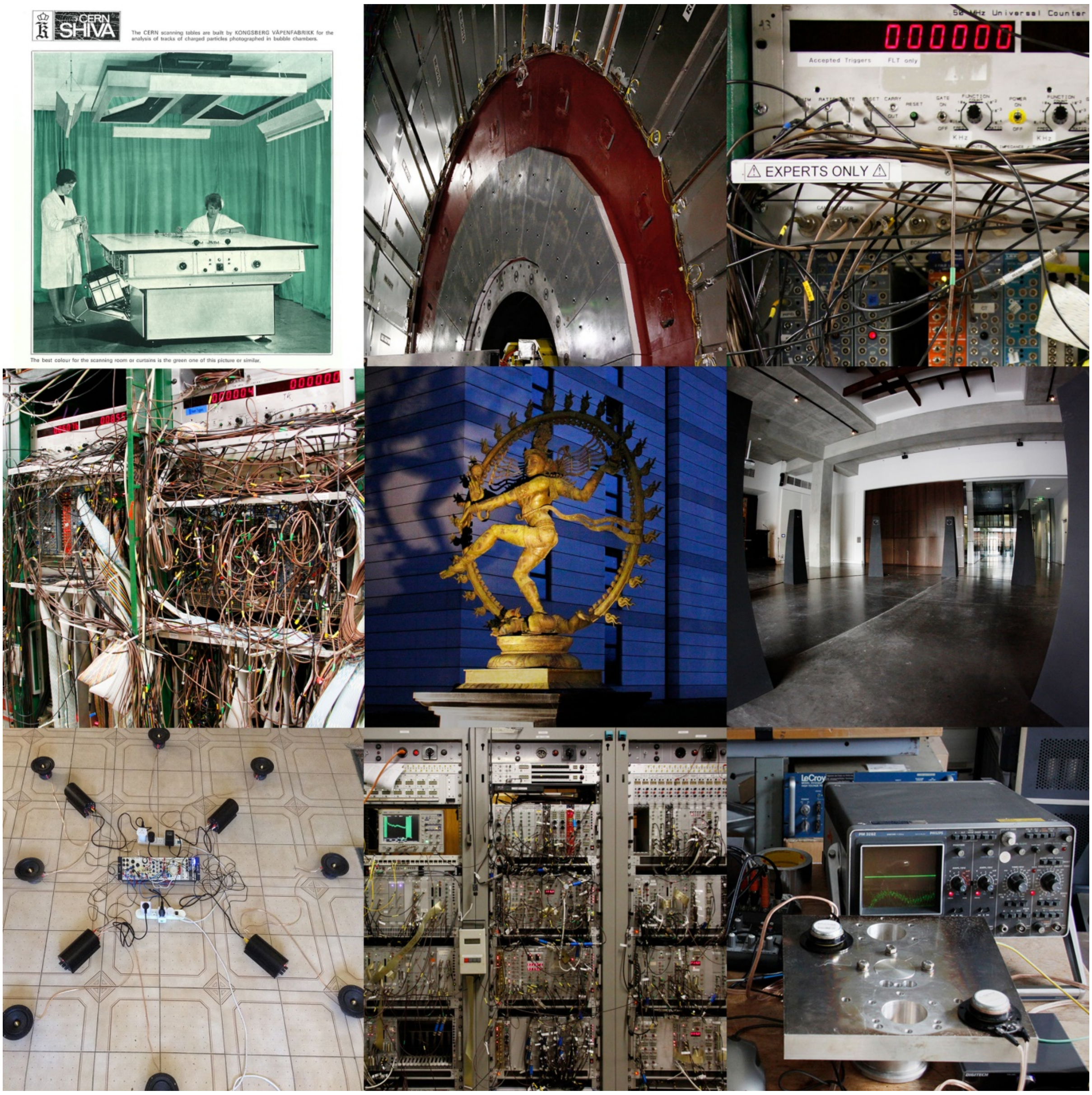

Plate 15. Inspirational CERN images and development of *Song of the Muons*.

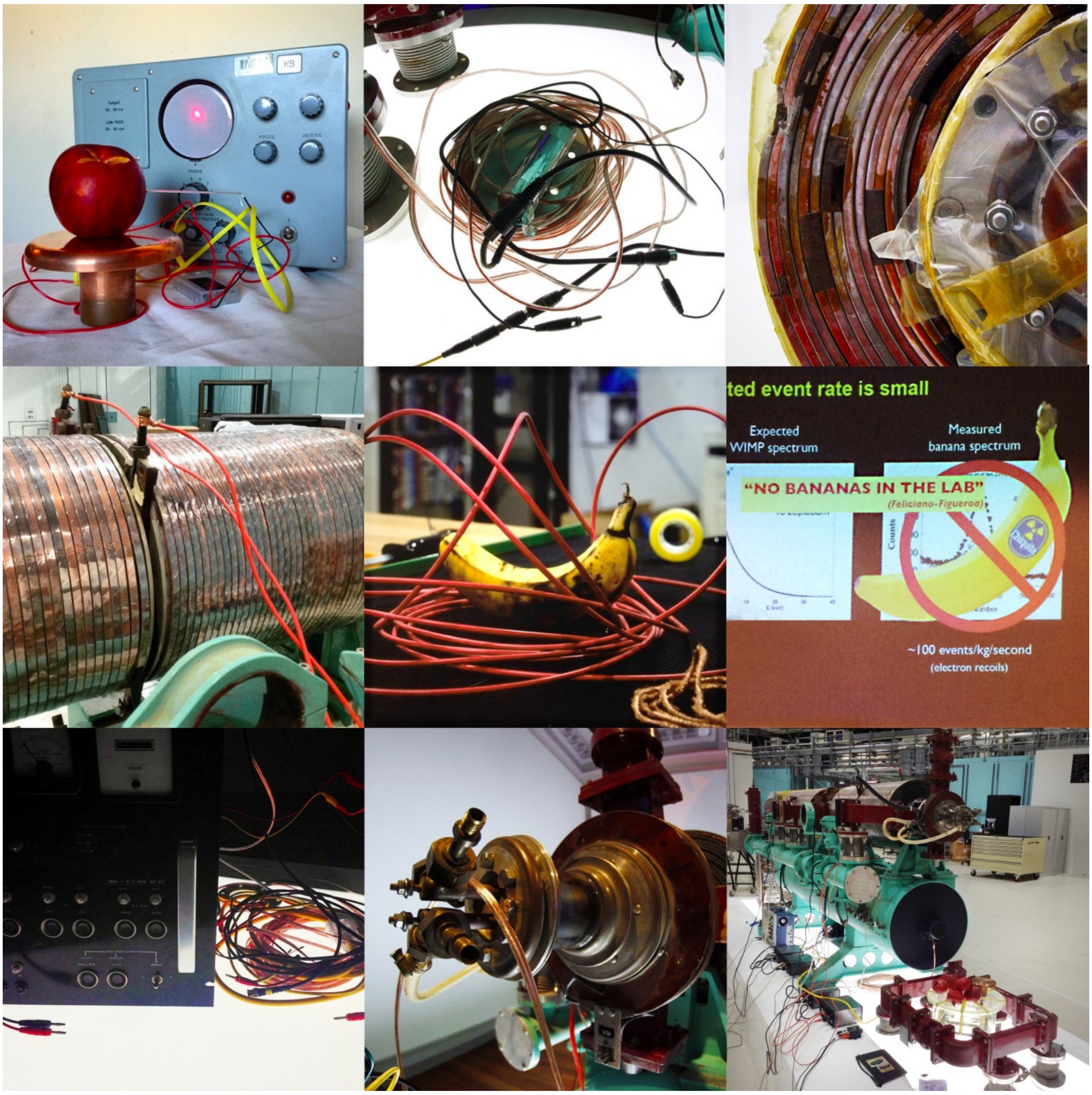

Plate 16. Development and details of *Song of the Phenomena.*

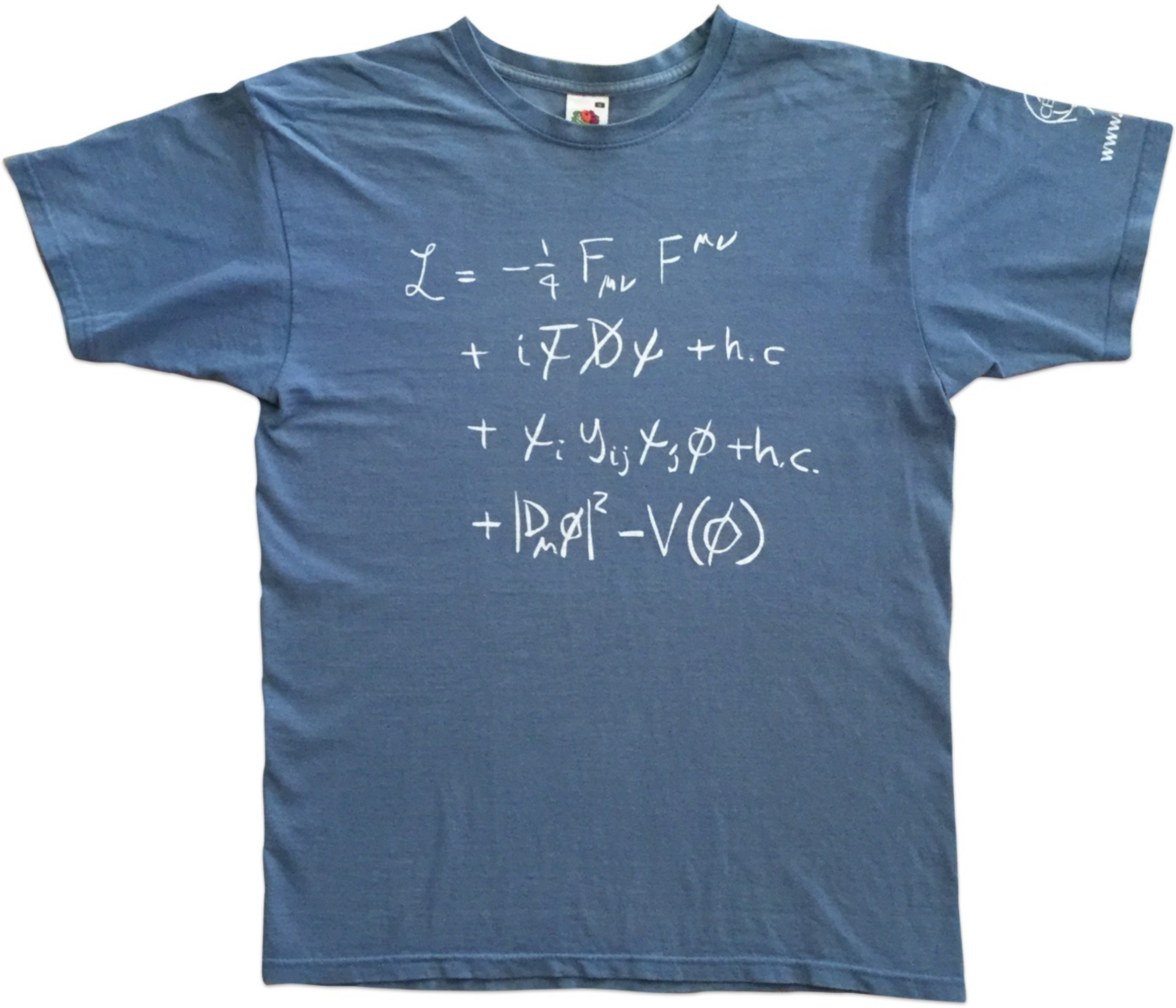

Plate 17. CERN "Standard Model" T-shirt.

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Appendix

Exhibitions

2017

Nature of the Apparatus, 9 – 20 July, Palazzo del Cinema, Lido de Venecia, Venice, Italy.

Song of the Muons, 11 – 14 April, Sofia Science Festival, Sofia, Bulgaria.

Nature of the Apparatus, 15 – 16 April, Sofia VR Summit, Sofia, Bulgaria.

2016

Nature of the Apparatus, 4 – 10 April, Athens Science Festival.

Nature of the Apparatus, 1 – 6 May, Arte & Scienca Scienza-Castello Giusso, VicoEquense, Italy.

Nature of the Apparatus, 22 June – August 5, art@CMS exhibition, CERN, CMS site, Cessy, France.

Song of the Muons, 3 – 6 July, SUSY conference, Melbourne, Australia.

Nature of the Apparatus, 24 – 28 July, "Science of the Unseen", SIGGRAPH 2016 Conference, Anaheim, U.S.A.

Nature of the Apparatus, 22 – 30 August, Global Hands on Universe, HSN, Stord, Norway.

Nature of the Apparatus, 11 September – October 3, IMAGE2016, Ferrari Gallery, Vevey, Switzerland.

Nature of the Apparatus, 18 October 2016 – 20 August 2017 Natural History Museum Vienna, Austria.

Nature of the Apparatus and *Song of the Muons,* 25 October – 2 November, Palais de Congres, Strasbourg, France.

Song of the Phenomena, 16 October – 18 February 2017, 'Morbis Artis: Diseases of the Arts', RMIT Gallery, Melbourne, Australia.

2015

Edge of the Observable, 22 January – 3 March, WELIOS Galerie Wimmer, Wels, Austria.

Edge of the Observable, 2 February – 23 April, Wilson Hall, FERMILAB, USA.

Edge of the Observable, 17 – 22 March, Athens Science Festival, Technopolis Museum, Athens, Greece.

Potential Objects, 9 – 19 April, Tinning Street Gallery, Brunswick, Australia.

Edge of the Observable, 2 – 31 May, Art Center South Florida, Miami Beach, USA.

Edge of the Observable, 14 – 17 May, TIF -Helexpo, Thessaloniki's Science Festival, Thessaloniki, Greece.

Nature of the Apparatus, 24 June – 17 July, art@CMS vernissage, CERN, CMS site, Cessy, France.

Nature of the Apparatus, 26 June – 14 July, KIT-Karlsruhe, Germany.

Nature of the Apparatus, 6 June, "Electronic Visualization & the Arts pre-conference showcase", Victoria & Albert Museum's Digital Futures program, Lime Wharf, London, UK.

Nature of the Apparatus, 19 – 31 July, EPS2015 conference Vienna, Austria.

Nature of the Apparatus, 15 – 20 September, Castel dell Ovo, Naples, Italy.

Nature of the Apparatus, 29 September – 4 October, "Data Body as Artifact", International Symposium on Mixed and Augmented Reality Conference and Exhibition (ISMAR 2015), Fukuoka, Japan.

Nature of the Apparatus, 2 – 5 December, Mediterranean Science Festival, Cyprus.

2014

Edge of the Observable, 25 June, Art@CMS vernissage at CERN, Cessy, France.

Edge of the Observable, 2 – 9 July, ICHEP2014 Conference, Congress Palace, Valencia, Spain.

Edge of the Observable, 10 – 30 July, St. Francis College, New York, USA.

Edge of the Observable, 5 August – 20 September, “The Small Infinite”, John Hansard Gallery, the University of Southampton, UK.

Edge of the Observable, 13 – 30 October, Earth & Man Museum, Sofia, Bulgaria.

Edge of the Observable, 16 December 2014 – 8 January 2015, Academy Palace, Brussels, Belgium.

Conference presentations

2016

"Expressive Experiments: Art and Particle Physics", "Cosmic Tea Party installation", "Nature of the Apparatus" and "Science and Art 1: Quantum Physics" panel, 22nd International Symposium on Electronic Art, Hong Kong, 16 – 21 May.

2015

"Colliding Events: art projects at the Large Hadron Collider", Electronic Visualization and the Arts conference and exhibition, London, UK, 6 – 9 July.

"High Energy Art Experiments", Energies in the Arts, UNSW Art & Design, Sydney Australia, 13 - 15 August.

"Expressive collisions: Art and Particle Physics", Transversal Practices: Matter, Ecology and Relationality, VCA, Melbourne, Australia, 27 – 29 September.

"Bodies, Embodiment and Data Aesthetics" panel, International Symposium on Mixed and Augmented Reality Conference and Exhibition (ISMAR 2015), Fukuoka City Museum and Conference Centre, Japan, 29 September – 4 October.

"Audiovisual experiments @ CERN", Ozviz 2015, University of Technology Sydney, Sydney, Australia, 1 December.

2013

"Sensation, Meaning and Affect in the work of Art / Science / Technology Collaborations" panel, and "Art vs Science", 19th International Symposium on Electronic Art, Sydney, Australia, 7 – 16 June.

Catalogues, programs, brochures, articles

Exhibition catalogue essay for “Australian Synchrotron Art Collection”, Clayton, Australia.

Conference program, 19th International Symposium on Electronic Art, Sydney, Australia.

Exhibition catalogue, “art@CMS”, CERN, Cessy, France.

Exhibition catalogue, “The Small Infinite”, John Hansard Gallery, Southampton, U.K.

Exhibition catalogue, “Circulez”, CERN, Cessy, France.

Conference program, “Energies in the Arts”, UNSW Art & Design, Sydney Australia.

Conference program and abstracts, “Transversal Practices: Matter, Ecology and Relationality”

Exhibition catalogue from “Data Body as Artifact”, International Symposium on Mixed and Augmented Reality Conference and Exhibition (ISMAR 2015), Fukuoka, Japan.

Conference program, 22nd International Symposium on Electronic Art, Hong Kong.

Brochure for “Science of the Unseen”, online exhibition, SIGGRAPH 2016 Conference, Anaheim, U.S.A.

“Science of the Unseen”, online exhibition, SIGGRAPH 2016 Conference, Anaheim, U.S.A.

Exhibition catalogue from “Wie Alles Begann”, Natural History Museum, Vienna, Austria.

Exhibition catalogue, “Morbis Artis – Diseases of the Arts”, RMIT Gallery, Melbourne, Australia.

Brochure for “’Sugar Spin’ Art Meets Science”, Queensland Gallery of Modern Art / World Science Festival, Brisbane.

Review in “The Article” online art magazine, December 2016.

Article in “Lateral” online magazine, Issue 20, March 2017.

Article in “Symmetry: Dimensions of Particle Physics” online magazine, March 2017.

Article in “Synapse: art science collaborations”, June 2017.

Art at the Australian Synchrotron
—
Chris Henschke
2013

Art and physics are often understood to be very different entities. Physics is routinely described as an objective science that explains natural phenomena using logical and testable theories. Art is considered a subjective practice that manifests personal experiences using inspiration-based expressions. At least that's how they may appear. But are these disciplines really so unalike, and what happens when they come into contact in such settings as the Australian Synchrotron's National Centre for Synchrotron Science? What happens when these worlds collide?

The Australian Synchrotron is a device 216 metres in circumference that accelerates electrons to ninety-nine percent of the speed of light. "The Australian Synchrotron" is also the community of scientists, engineers and other personnel who harness the energy emitted from the synchrotron to conduct experiments with. This is done in accordance with the empirical method, a rigorously structured process of developing theories based upon observations of natural phenomena. Scientists undertake experiments to test their theories against the phenomena being examined, and, through adjusting both the theory and the experiment, arrive at a clear and precise fit of theory to observation. This method seems to be at odds with the practice of art, which is generally perceived as subjective, idiosyncratic, and often irrational.

The influential physicist and philosopher Karl Popper states that scientific discoveries are born from processes of stimulation and release of inspiration, which itself is not a scientific or logical process. Popper argues that every discovery contains 'an irrational element or a creative intuition', which the scientist then 'critically judges, alters, or rejects' in accordance with the epistemological framework of falsifiability. [1] Additional non-scientific forces also influence the development of scientific "paradigms", including historical, economic and political factors, as well as the intuitions and passions of the researchers.[2] Such factors are also present in the development of art movements. The art critic Ernest Gombrich pointing out that the 'idea of pure observation has proved a mirage in science no less than in art'.[3]

However, unlike the objective properties the physical sciences deal with, art does not need to precisely define or illustrate specifics. Instead, to use an analogy of philosopher Barbara Maria Stafford, art can be seen as a mirror held up to reflect aspects of the world, which 'collects and brings within its circumference all that lies scattered about us and re-launches it in sharper or cloudier form'.[4] The mirror of art does not perfectly reflect reality, nor does it intend to. It is more like a fun-house mirror, yet it's distortions are sometimes constructed with a precision akin to the exactitude found in science. Such image incongruences employed in the visual arts have led to a mistrust of it amongst the sciences, and even in wider culture. Stafford writes that 'cultural bias, convinced of the superiority of written or propositional language... devalues sensory affective and kinetic forms of communication precisely because they often baffle verbal resolution'.[5] But of course science too can be baffling, as it is often ultra-specialized to a point that it is not possible for non-experts to really understand it – sometimes even the specialists have difficulty in understanding each other's niches of research. Philosopher Jurgen Habermas uses the term "objective obscurity" to describe such a state of unsurveyability or difficulty in contemporary communication.[6] In opposition to this, art tends to exist at the subjective end of the spectrum, but it can use such ambiguity and uncertainty to spark our imaginations and engage us, and this ideally lets anyone to relate to it. The element of subjectivity in art can be seen as a form of energy, encouraging different viewpoints and opinions, creating dialogues between the artist and viewer and between different viewers.

Images play a vital role in the physical sciences. One of the leading pioneers of electricity, Michael Faraday, created diagrams that were fundamental in allowing him to understand electrical and magnetic fields, and his images aided the communication of his revelations. The indirectly observed forces of electromagnetism and Newton's lexical force of gravity became the poles of experimental physics. Between them, the subatomic forces gradually revealed invisible underlying forms that give nature its observed properties. Today these worlds are still being explored, in part by particle accelerators that allow experimenters to plumb the depths of nature and expand our understanding of it with extreme precision. Yet even the most precise measurement does not guarantee an unambiguous picture - there are disagreements in how experiments are interpreted and visualised. Einstein and Heisenberg, two pillars of modern physics, although assenting upon the science involved, fundamentally disagreed on what the same experiments meant, to the point where Heisenberg stated that he found Einstein's visualisations "disgusting".[7] To bridge the differing interpretations of the observed phenomena, their colleague Niels Bohr used art as a visual analogy to explain the apparently contradictory behavior of subatomic particles. He stated that as "in art an object could be several things, could change, could be seen as a face, a limb and a fruit bowl", so too in quantum physics, "depending on how you look at it (what experimental arrangement is used), that is what it is".[8] He coined the term 'complementarity' to describe this state.

It may seem paradoxical in light of such debate around images, but in science the 'witnessing of a phenomenon ... is essential to its acceptance in the body of natural knowledge'.[9] This has been standard since the time of Faraday, who used public demonstrations to increase people's understanding of his electromagnetic theories. In the contemporary public arena, where most people cannot directly observe scientific experiments, video and cinema can be potent 'virtual witnessing technologies'[10] because they can depict natural phenomena in a way that can convince the audience that it accurately reflects the natural world.

Daniel Von Sturmer's *The Cinema Complex* (2010), exhibited as part of the Australian Synchrotron Art Collection, plays with the paradoxes of seeing and believing. In *The Cinema Complex*, everyday objects are brought together in unexpected conjunctions, not just surprising for their combinations, but for how they are assembled. Von Sturmer's work is intriguing in what it does not show, namely that of some seemingly impossible and invisible force that holds the objects together in an evidently unstable manner. Von Sturmer does not use digital effects to create these tableaux - the video documents reality, but something unreal is happening. As the video progresses, it beckons us to try and understand it. The plausibility of Von Sturmer's video work requires the viewer to suspend their disbelief, in a way equivalent to the implicit contract made between science-fiction film-makers and their audience, which demonstrates the paradoxical requirements of visual validation and cinematic mistrust. And as we apprehend this real-yet-impossible demonstration, it connects us to the essence of scientific research – "what is it that makes this possible" we ask ourselves. It tantalizes us with effect, but not the affect that is the result of the action, but not the source; the demonstration of the experiment, but not an explanation of its cause. The innate curiosity within us all is inexorably brought up when viewing the piece - at its deepest level, this is arguably what drives scientific research.

Intuition is the driver of curiosity, creativity, and ultimately science, according to French mathematician and philosopher Henri Bergson. Bergson states that we intuitively perceive nature in "an uninterrupted continuity of unforeseeable novelty".[11] This perception underpins scientific intelligence, which constructs an abstraction of nature through an artificial atemporality, superimposing states of matter into rigorously organised systems, which is expressible in static terms.[12] For Bergson, our experience of time and subsequent reduction of it to a calculable form is innate - we are all by nature mathematicians, and science is just a more precise continuation of this capacity.[13] Bergson states that the physical experience of time transcends science and connects us directly to the universe, poetically describing this through the act of having to wait for a cube of sugar to dissolve in a glass of water. He says that in impatiently waiting for the sugar to slowly dissolve, time "is no longer something thought, it is something lived. It is no longer a relation, it is an absolute".[14] This is a fitting connection with the concept of 'dead time', or 'temps mort', a term used in cinema theory to refer to the lengthy intervals in films where nothing seems to happen.[15] In science, "dead time" refers to the interval between an event being recorded and the next recording, usually due to the technical limitations of the recording device or event trigger.

Dead Time (2012) is the title of another artwork in the Australian Synchrotron Art Collection by Steve Carr. Within the context of the synchrotron's nano-second imaging capabilities, this use of the term has cinematic, scientific and philosophical associations. The ability of technology to expand human perception is a cornerstone of modern science, however this work is not simply a demonstration of this. The choice of subject is symbolic in both science and humanity - the apple on the tree of knowledge is the biblically forbidden fruit that tempted humanity to lust for knowledge. Newton's apple was the mythical stimulus of his revelation that the orbiting moon and the apple falling from a tree were doing exactly the same thing – they were both under the influence of gravity.[16] The multi-screen setup of Carr's work also pays homage to the chronophotography of Eduard Muybridge, one of the pioneers of both scientific photography and cinema. In this respect, the work refers to scientific discovery and also the human drama that accompanies it – Muybridge committed a crime of passion and shot his wife's lover through the heart. However, in contrast to such momentary impulses, this work contains an extended durational element. The video expands the event time one hundredfold, requiring an investment of time and patience from the viewer. Like Bergson impatiently fixated upon the sugar in his glass, the act of waiting brings our perception into connection with the actual time we share with the universe we inhabit. Also, as in scientific research, there is no guarantee of instant results - the moment of impact in the video still takes place quickly, and if we look away, we may miss it.

Within both the disciplines of art and science, the development and transfer of knowledge takes an investment of time and mental energy. In the visual arts, knowledge is embedded and communicated through formal visual elements. Image theorist Mieke Bal champions such a visual epistemology, stating that "the advantage of speaking 'visual texts' is that it reminds the analyst that lines, motifs, colours and surfaces, like words, contribute to the production of meaning; hence that form and meaning cannot be disentangled. Neither texts nor images yield their meanings immediately. They are not transparent, so that images, like texts, require the labor of reading".[17] Combining Bal with Bergson leads to the reasoning that knowledge through art is intuitive and implicit. Susan Jacobs has created a site-specific artwork, *Draw the outside in (fields of force)* (2013), which was implicitly informed by a tour of the Synchrotron facility. The work produced by Jacobs distills the forces and forms found within the synchrotron into a frieze embedded into the walls of the

Exhibition catalogue essay for "Australian Synchrotron Art Collection", Clayton, Australia, 2013.

National Centre for Synchrotron Science's spaces. Cross-sections of circular objects reveal symmetrically uniform structures, like the insides of atoms, but also contain disparate and asymmetrical elements of metallurgical and organic origins. One of the disk-like forms rotates and attracts a metal chain, divulging magnetic properties, and giving the work a kinetic energy. The layout of the objects hints at both celestial and subatomic structures, conveying a feel of the delicate balances within and between the two realms. *Draw the outside in* also contains the frozen dynamism of collision events, akin to how a bowling balls striking its target is a visual analogy of a particle beam hitting a specimen, the effects of the impacts revealing information about the nature of the material being examined. In contrast to the explicit nature of scientific knowledge, this piece demonstrates an artistic epistemology that embeds concepts implicitly in art objects, 'where the thinking is, so to speak, embodied in the artifact'.[18] In such cases, the implicit ideas have to be teased out by the viewer.

Art can distill scientific concepts in a way that transcends illustration. It can also use the science in question as a tool for its creation. *The New Sun* (2008), by Chris Henschke (the author of this essay), is a work that paints a 'synchrotron portrait', using the synchrotron itself as both the subject of the work and the brush used to paint it. Through an ongoing collaboration with scientists and engineers, the work was made by digitally compositing the Synchrotron's engineering diagrams and the light captured from the Optical Diagnostics, Infra-Red, Soft X-ray and Protein Crystallography beamlines, overlaid with the visible spectrum of the sun. This work attempts to convey the overwhelmingly complex and yet finely balanced nature of the synchrotron and its connection with the sun. *The New Sun* visually expresses what scientists describe as the "beauty" within the synchrotron: the beauty of light and energy, of matter and forces. It is the artist's subjective interpretation of the essence of the synchrotron, formally suggesting the device and its operation. But it does not seek to illustrate or define exact properties, it is an expression of the artists' perceived feel of the physics. The mural was initially commissioned to be placed *in situ* at the front of the synchrotron itself. As scientists approach the machine to conduct experiments, they would cross a visual 'sweet spot' where the transparent image would have been superimposed over the concrete-shielded accelerator, creating the illusion of an x-ray-like image of the device and see the unobservable core and the energy emissions emanating from the accelerating particles within.

Since Newton split beams of sunlight with refracting prisms, we know that white light is made from the combinations of different colours or energy frequencies. Ross Manning's *Spectra III* (2012) is in a sense an inverse prism, assembled from consumer goods running on 240 volts. However, *Spectra III* is not just a do-it-yourself Newtonian optics experiment, its combination of delicate balances and unpredictable movement creates a sense of uncertainty, and creates a wavelike kinetic to the sculpture. The ever changing combinations of the light upon the walls around the work are like, indeed are, a visualization of constructive interference occurring when the frequencies of the different lights meet – it is a concrete manifestation of non-linear dynamics. This piece assembles Newtonian optics with wave mechanics, using neon lights and fans instead of complex scientific diffraction technologies.

As Popper stated, the development of science and technology can take an unscientific path, sometimes serendipitous, occasionally perilous. Particle accelerators and televisions have a common ancestry: the cathode ray tube (CRT) was invented in 1897 by German physicist Karl Braun; American inventor Allen B. Du Mont developed one

of the first modern television sets in 1932, harnessing the particles accelerating within the CRT. An early customer was Ernest Lawrence, who invented the cyclotron, the first circular particle accelerator. At the same time, English physicists Cockcroft and Walton were building linear accelerators, shooting particles down an evacuated tube eight feet long. Improving on their accelerator design was Australian physicist Sir Mark Oliphant, who devised the first synchrotron in 1950. CRT televisions soon became household items, and although they are now largely abandoned on the footpaths of suburbia, the elegant physics and engineering within them has not been lost to all. Robin Fox's constructed monument to these iconic devices is suitably titled *CRT: Homage to Leon Theremin* (2012). Theremin, known better for the electric musical instrument that carries his name, worked on experimental electromechanical televisions as early as 1925. However, unlike his contemporaries, Theremin was castigated by the Soviet state and sent to work on prison farms, and his television technology was seized and repurposed by the KGB as a top-secret military device. The story of Theremin is the story of the dynamic and irrational human face of science, encompassing a spectrum of experience ranging from 'the Bolsheviks to the Beachboys'.[19] In his biography, Theremin recalls being inspired as a teenager by a lecture on electromagnetism, a talk firmly rooted in a directly human and experiential empiricism. 'Unlike [lectures by] others who operated more with mathematical indices, expressions and formulas... it was about objects around us connected to our feelings... and perceived directly by our sensory organs... It was calling me to the real scientific - not the abstract - knowledge of the essence of matter'.[20] This experience led Theremin to discover the natural electromagnetism of the human body interacted with the electromagnetic field emanating from a device he built. He realised that physical movement could directly alter the energy in the circuit, allowing the 'electricity sing to him', without any traditional physical interface, 'just the free voice of electrons'.[21] Fox's installation uniquely captures the dynamics of Theremin's inventions, *vis-à-vis* three transparent towers containing CRT televisions laid bare for us to see their inner workings. In the spirit of Theremin's musical devices, spectator proximity activates both sound and light, whilst movement brings the CRT screens to life, crackling and bursting with energy and colour, accompanied by synesthetic tones and timbres. We become players of this unique sculptural instrument, its audiovisual pulsations an electromagnetic mirror of our movements, the excited electrons bursting forth from the cathodes, their paths dynamically bent by the magnets pulsing in the vacuum tubes. In a sense, this work mirrors the workings of the synchrotron itself: the accelerator physicists the conductors of this giant instrument, and its' tune of energized electrons allows us to *see* concealed aspects of our world and ourselves. *CRT: Homage to Leon Theremin* places the Australian Synchrotron into an historical context, as both are descended from the insights and inventions of such bright minds as those of Theremin and Oliphant.

In contrast to the purity of free electrons, Fox's second work in the Australian Synchrotron Art Collection, titled *Magnetic Trap* (2013), investigates the nature of filtered and manipulated signals. In this work, synchrotron 'tune data' has been put through a variety of filtering formulas to produce complex audiovisual forms. The synchrotron 'tune' is the frequency of vertical and horizontal oscillation of the electrons' movement as they spin around the synchrotron's storage ring, or 'magnetic trap', at over a million timer per second, driven by the hundreds of magnets in the ring. Scientists spectrally visualize this tune

via many sensors timed to take snapshots of the movement, in a way analogous to how a strobe light can make a spinning object appear to stand still. In opposition to scientific data analysis, which seeks to filter out noise or unwanted information, this piece has been developed through non-linear and chaotic algorithms written by Fox to amplify other patterns in the signal, using it to generate dynamic compositional structures. Fox states that "any piece of hardware between two signals will have an effect upon the signals".[22] In this respect, *Magnetic Trap* critiques the objectivity of data analysis and visualization, replaying, if you like, Einstein and Heisenberg's arguments over the interpretation of their experiments.

In conclusion, each of the works collected as part of the Australian Synchrotron Art Collection provide insights into, and raise questions about, the workings of science and art. It has been argued in this contextually framed essay that space and time, matter and energy, gravity and electromagnetism, the tools and subjects of particle physics and synchrotron science, are also central to the methods of the artists exhibited here. Having these artworks placed in the context of the Australian Synchrotron shows how both disciplines manifest or make tangible forces and structures that are invisible to our unaided perception, whether it be physical phenomena, or theories and ideas. The works contain the element of curiosity and inquiry common to both disciplines. And they bring to light another force. The physicist David Bohm, a colleague of Einstein and Heisenberg, described the effect of connecting seemingly disparate phenomena or ideas in scientific research as being a "poetic equating of very different things [in which there is] a kind of tension or vibration in the mind, a high state of energy".[23] This is also what occurs when the worlds of art and physics collide – energy is released, the energy of ideas and possibilities. This energy initiates dialogues and reveals differences and commonalities, which in turn can propel us collectively into new areas of research, discovery and creation. These collisions also reveal something fundamental about the nature of being human. To use Bohr's term, art and physics are "complementarities" in how we perceive and understand the universe and our relationship with it.

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1 Karl Popper, "Selections from The Logic of Discovery", in R. Boyd, P. Gasper, & J. Trout (eds.), *The Philosophy of Science*, MIT Press, 1993, p.195

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3 Ernest Gombrich, *Art & Illusion: a Study in the Psychology of Pictorial Representation*, Phaidon, 6th edition, 2002, p.271

4 Barbara Maria Stafford, *Echo Objects, the cognitive work of images*, University of Chicago Press, 2007, p.126

5 Barbara Maria Stafford, *Good Looking: Essays on the Virtue of Images*, MIT Press, 1996, pp. 22-23

6 Jürgen Habermas, *The new obscurity: the crisis of the welfare state and the exhaustion of utopian energies*, translated by Phillip Jacobs, Philosophy & Social Criticism, Sage, 1986, p.2

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8 A. Miller, 'Visualization Lost and Regained', in J. Wechsler (ed.), *On Aesthetics in Science*, Birkhauser, 1988, pp.76 - 77

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10 David Kirby, *Lab Coats in Hollywood*, MIT Press, 2011, p.25

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12 ibid p.37

13 Michael Vaughan, Introduction: Henri Bergson's "Creative Evolution", *SubStance*, Vol. 36, No. 3, Issue 114, 2007, p.13

14 Henri Bergson, in Harold Schweizer, *On Waiting*, Routledge, 2008, p.15

15 Matilda Mroz, *Temporality and film analysis*, 2012, p.40

16 Joel Davis, *Alternate Realities, how science shapes our vision of the world*, Plenum Press, 1997, p.119

17 Mieke Bal, *Travelling Concepts in the humanities: a rough guide*, University of Toronto Press, 2002, p.26

18 Christopher Frayling, *Research in Art and Design*, Royal College of Art Research Papers, Volume 1, No. 1, 1993/4, p.5

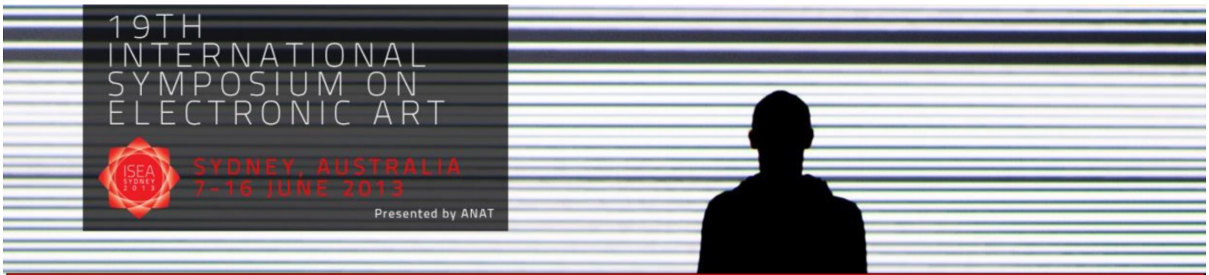
19 Albert Glinsk, *Theremin: ether music and espionage*, University of Illinois Press, 2005, p.6

20 ibid. p.12

21 ibid p.24

22 Telephonic conversation between Chris Henschke and Robin Fox, March 2013

23 Bohm et.al p.33



Thursday, 13th June 2013					
Day 3	**Stream 1**	**Stream 2**	**Stream 3**	**Stream 4**	**Stream 5**
09.30-10.45	**Rogue Troopers: Designing functional and fictional disruptions (panel)** Teresa Dillon David Benque Amanda MacDonald Crowley Peter Hall	**New Media Performance** Sue Hawksley & Garth Paine: *Somatic data as agency in interactive dance* Gorkem Acaroglu: *Mixed Reality Performance Lab* Ian Willcock: *Modelling Performance: Generic formal processes in live digital performance* A. Baki Kocaballi & Liam Loke: *Interplay of scripts and resistance in a participatory workshop* Andrew Sempere: *Experience Catalysts and Invisible Scenography*	**Exquisite, Apart: Remoteness and Resistance (panel)** Charles Walker Maggie Buxton Angela Tiatia Clinton Watkins Laurent Antonczak	**Catching Light (panel)** Megan Monte, Troy Innocent, Ben Kolaitis, Stephen Jones, Pia van Gelder	**Sonics** Arne Eigenfeldt: *Generating Electronic Dance Music without Mirrors: Corpus-based Modelling Without Quotation* Noel Burgess: *The Sound of Memory | An audience derived audio visual experience* Ben Byrne: *Static as a Trope in Electronic Art: David Hall's '1001 TV Sets (End Piece)' and Other Works* Frank Ekeberg: *Manipulating Spaces, Changing Realities –- sound as primary carrier of meaning in art*
10.45-12:00	**Sensation, meaning and affect in the work of art/science/technology collaborations (panel)** Erica Seccombe Barbara Rauch Elizabeth Eastland Chris Henschke	**Visualising Gesture & Effect (panel)** Chris Bowman Roger Mills Sam Spur Michael Day Gavin Perin Daniel Scott	**Mediations of Sensation: Sensory Anthropology and the Futures of New Media Practice (panel)** Chris Salter, Jennifer Biddle & David Howes	**Lovely Veneer: The underbelly of good design (roundtable)** Deborah Maxwell Mel Wood Drew Hemment Ruth Aylett Geraint Wiggins	**NeuroArts-Noise: As glue, as buoyancy (panel)** Jane Grant John Matthias Oron Catts Sue Denham Greg Haing
12.00-13.00	**Lunch**				
13.00-14.30	**Photography and Digital Imaging** Yi-hui Huang: *Realities in Non-real Photographs* Pinar Yalcin: *Digital Art going mobile: the case of the ipad as "digital canvas"* Joonsung Yoon: *The Post-Virtual Calling* Katrina Sluis: *Resistance to digital and digital resistance: curating the networked photograph* Alessandro Ludovico: *Portraits of the XXI century: representations and misrepresentations of face and artistic responses*	**The Sustainability of Future Bodies (roundtable)** Margie Medlin Myriam Gourfink Kasper Toeplitz Paul Gazzola Paul Granjon	**Latin American Forum, title TBC** Juan Jose Diaz Infante: *"Play"* Nahum Mantra: *The Arts Catalys with Mexican artists* Esteban Garcia and TBC (panel): *Imparja TV: Histories of Indigenous remote broadcasting and media production*	**Curating and Collecting the New - Resistance is Futile (panel)** Sarah Cook Vince Dziekan Amanda Slack-Smith Keir Winesmith Angelina Russo	**The Inter-Society for the Electronic Arts Revived? (panel)** Wim van der Plas Vicki Sowry Anne Nigten Ernest Edmonds Peter Beyls Bonnie Mitchell Peter Anders
14.30-15.30	**Keynote - TBC**				
15.30-16.00	**Break**				
16.00-17.00	**Art(ists) in Space (panel)** Sarah Jane Pell Rahni Allan Lowry Burgess Angelo Vermulen Barbara Imfof	**Mixed reality transformations: shifting relationships between movement, embodiment, somatics and image (panel)** Kim Vincs John McCormick Megan Beckwith Stephanie Hutchison	**Memories, Archives and Museums** Andreia Oliveira & Felix Rebolledo: *Narratives of Locative Technologies as Memory Assemblages* Mike Leggett: *'Living with' Alzheimer's through a memory machine.* Alexandra Gillespie: *Humpy - an early Australian architectural projection by artists Ian de Gruchy and Krzysztof Wodiczko* Jihoon Kim: *The Performative Archive: Formations of Social Memory in Interactive and Collaborative Documentary* Peter Ride: *#citizencurators - getting Twitter into museum showcases* Somaya Langley & Trevor Carter: *Managing Multiplatform Materials: Selected Case Studies*	**Spaces and Ecologies** Jan Hendrik Brueggemeier: *From Sound to Waves to Territories* Nancy Diniz & Bennedict Anderson: *Breath - wearing your air* Rewa Wright: *'We see in algorithms': a virtual sculpture project in public space* Vicki Sowry & Jodi Newcombe: *Art and Agency in an Era of Big Data: Ecological and representational challenges for public art - the case of the Echology Making Sense of Data initiative* Nigel Jamieson, Andrea Polli & Robert De Goede: *String, Sounds and Satellites Site-specific Sculpture, Sonics and Mobile Geo-Reality* Elaine Gan: *Mapping Multispecies Temporalities: Diagrammatic Visualizations of Rice Agroecologies*	**Algorithms, Diagrams, Pixels and Scripts** Paul Thomas, Mike Phillips & TBC: *Diagrams, Formulae and Models: Aesthetic and Scientific Strategies of Visualizations* Esteban Garcia: *Stretch: An early software art framework by Aldo Giorgini* Brigitta Zics & William Latham: *The History of the Algorithm in the Digital Arts* Azadeh Emadi: *Pixelated view: investigating the body of the digital image, via historical Persian/Islamic philosophy, as a mean for social change* Benjamin Swift, Alistair Riddell & Andrew Sorensen: *Live Coding the World of Things*
17.00-18.00		**Im-position: a minor politics for interactive art (panel)** Nathaniel Stern Andrew Goodman Andrew Murphie Lone Bertelsen			

Conference program, 19th International Symposium on Electronic Art, Sydney, Australia, 7 – 16 June 2013.

Wednesday, 12th June 2013

Day 2	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5
9.30-10.30	**Large Screens and the Transnational Sphere (panel)** Cecelia Cmielewski Ross Gibson Scott McQuire Matt Jones Audrey Yue	**Assimilate This: Science Fiction and Media Art (panel)** Andrew Frost Lizzie Muller and TBC	**Learning from the CRUMB Method over a cup of tea: reflections on creating and exhibiting digital arts (panel)** Sarah Cook Marialaura Ghidni Dominic Smith Suzy Ohara Victoria Bradbury Graham Harwood Roddy Hunter	**Political Resistance** Glenn D'Cruz & Dirk de Bruyn: *OCCUPY This: an Interpersonal Dialogue* Heba Amin: *Voices from the Revolution* Aralan Londono: *Art, Technology and Dystorpia* Amin Ansari: *Green Art: New Media Aesthetics in Pre- and Post-Election Events in Iran* Zoe Scrogings & Dale Kongmon: *Sex Workers, Info-Activism and Human Rights* Pip Shea: *Resistance is Feral: Digital Culture, Community Arts, and the New Cultural Gatekeepers* Amani Naseem: *Playful Resistance: humor, creativity and courage*	**Interactivity and immersion** Ruth Aylett: *Kinect-Based RGB Detection for 'Smart' Costume Interaction* Alexandra Antonopoulou: *The interactive dream-catcher* Anne Niemetz & Carol Brown: *REVOLVE or the impossible task of performing sleep* Rachael Priddle: *Tangibility* Marie-Claude Poulin: *Intérieur – a multi sensory immersive experience* Thecla Schiphorst: *self-evidence: a fertile resistance : a non-alienated view* Rudi Knoops: *Anamorphosis. A mystery in two acts or a strategy for embodied perception?*
10.30-11.30		**Robots and Robotics** Wade Marynowsky: *The Acconci robot* Paul Granjon: *The Biting Machine project, a performance art experiment in human-robot interaction* Elizabeth Demaray: *The IndaPlant Project: An Act of Trans-Species Giving*			
11.30-13.30	**ISEA AGM & ISEA2014 Presentation**				
13.30-15.00	**Latin American Forum: title TBC** Yto Aranda, Pamela Figueroa: *Origins of Electronic Art in Latin America* Brita MP aka Lila Lars: *Art, Body and Technology Overview* Isabel Cristina Restrepo: *Digital Imaging and Artistic Education* Camilo Martinez, Gabriel Zea & Alejandro Araque or Aisel Wicab: *Mochilabs* Lea Rekow: *Green My Favela*	**Ecology, Cybernetics and Open Systems in Art and Technology (panel)** Andrea Polli Su Ballard Janine Randerson Eu Jin Chua	**SITEWORKS – an annual interdisciplinary research and practice event in the Australian Bush (roundtable)** Deborah Ely Nigel Helyer Josie Starrs Jodi Newcombe Leon Cmielewski Mike Leggett Garth Paine	**Mirroring Sherry Turkle: a discussion on authenticity, humanity and technology (panel)** Janis Jefferies Stacey Pitsillides Anastasios Maragiannis Mari Velonaki	**Mixed and Augmented Realities** Hanna K. Schraffenberger: *From Coexistence to Interaction: Interrelating the Virtual and the Real in Augmented Reality* Ruth Aylett: *Interactive Drama in Virtual and Augmented Reality* Troy Innocent: *Code switching in mixed realities* Wim van Eck: *The Hidden Witnesses (working title)* Greg Garvey: *Sanity and Mental Health in an Age of Augmented and Virtual Realties* Kristin Erickson: *Performatization and the M.T.Brain*
15.00-16.00	**Keynote - Brian Rogers**				
16.00.16.30	**Break**				
16.30-17.30	**Data Visualisation** Tega Brain: *Environmental Data as Sensory Experience: Redesigning the Human-Infrastructure Interface.* Tom Schofield: *Repeating the Past: Lessons for Critical Data Visualisation from the History of Computer Art* Ann Finegan: *The data wars: protest is increasingly an affair of incommensurables.* Drew Hemment: *emoto - Truth and Beauty in the Data Dimension* Brian House: *OpenPaths: empowering personal geographic data*	**Art & Science** Patricia Adams: *Shivering domains: technologically mediated embodiment and ecologies* Andrew Newman & Matthias Tarasiewicz: *Play as Method* Chris Henschke: *Art vs Science* Morten Sondergaard & Jamie Allen: *Design for another future: Reformatting the relation of art and science practices* Elizabeth Eastland: *Quiet terror: studio, lab and experiment at the edge of the known*	**Materialities and Networks** Linda Candy: *The Role of Evaluation in Public Art: The Light Logic Exhibition* Gabriella Arrigoni: *The Pointless Chatroom: Coping with Absence in Web-Based Performances* Frances Joseph: *Collaborative Registers of Interactive Art* Nina Wenhart: *ghosts in daylight on a crowded street. Virality and the arts of social media* Mark Cypher: *The modal weight of an interactive and electronic artwork; relational materiality, distributed cognition and the actor-network* Brian Evans: *A Murmuration of Thought*	**Creator Session** 1. Suzon Fuks, James Cunningham, Ian Winters & Jason Grant: *Waterwheel Patch* 2. Judith Doyle & Fei Jun: *GestureCloud: transposing gesture data between art installations mediated by a virtual world* 3. Wynnie (Wing Yi) Chung, Emily Ip & Thecla Schiphorst: *WO.DEFY - designing wearable technology in the context of historical cultural resistance practices* 4. Megan Hayward & Michael Finucan: *Notes for Walking the space in between time: media art and augmented landscapes.*	**Transdisciplinary Transreal: Mixed and Augmented Reality Arts (MARart) Research Scoping Forum (panel)** Julian Stadon Troy Innocent Andrew Burrell Kuai Shen
17.30-18.30					**Future Nature, Future Culture [s]: Reflections on Balance-Unbalance (panel)** Leah Barclay Ricardo Dal Farra TBC

Introduction:
Claudia-Elisabeth Wulz, CMS Collaboration Board Chair and Tiziano Camporesi, CMS Spokesperson

The notion of Beauty has been a powerful heuristic principle in the scientific quest since the beginning of times. Art@CMS is an attempt to share the beauty that the CMS scientists find in their everyday life with the world.

It brings to life in vivid colours the images which are at the base of the scientific discoveries which help mankind to understand the most fundamental questions regarding Nature behaviours and the world which surround us.

The images of the giant instrument CMS, the graphic displays of the mysterious conversion of energy into matter and their interpretations by the artists associated with the Art@CMS program help bringing people closer to science in an intuitive way.

The question which the scientists try to answer resonate in the art works that Art@CMS brings to life and provoke similar reaction in the minds of the spectator.

Art@CMS is one of the ways to bring the community closer to Science and one which stimulates the viewer to want to know more.

As physicists we strive to see Nature in a new way. Artists do the same. Both explore uncharted territories, using creativity and imagination. Our language is mathematics, which not everyone is capable to use and understand. And yet, everyone can love science without being a scientist, just as


one can love art without being an artist. Many visitors have told me that our CMS detector is a true work of art. Through its colours and its dimensions people can sense that it has incredible power to uncover the deep secrets of Nature. The event displays not only show great beauty but are also real windows to the Universe. The ancient Greek word τέχνη, from which technology is derived, means craftsmanship and skill as well as art. Science and art are in fact inseparable. The artists and physicists involved in our Art@CMS program mutually inspire each other, and their works of art inspire and fascinate the people that want to learn more about our science and our understanding of the Universe. Discussions about them and the questions that arise from them can also help us physicists gain more insight into our own research.

What is CMS?

The Compact Muon Solenoid (CMS) is one of the four experiments at CERN's Large Hadron Collider (LHC). The LHC smashes groups of protons together at close to the speed of light: 40 million times per second and with seven times the energy of the most powerful accelerators built up to now. Many of these will just be glancing blows but some will be very energetic head on collisions. When this happens some of the collision energy is turned into mass and previously unobserved, short-lived particles which could give clues about how Nature behaves at a fundamental level.

CMS is a particle detector that is designed to see a wide range of particles and phenomena produced in high-energy collisions in the LHC. Like a cylindrical onion, different layers of detectors measure the different particles, and use this key data analysed by scientists around the world to build up a picture of events at the heart of the collision. Scientists then use this data to search for new phenomena that will help to answer questions such as: What is the Universe made of and what forces act within it? And what gives everything substance? CMS also measures the properties of previously discovered particles with unprecedented precision, and is on the lookout for completely new, unpredicted phenomena. In July 2012, two of the LHC experiments (CMS and ATLAS) announced the discovery of a new, Higgs particle. The Higgs boson was postulated to explain why particles have mass and therefore why gravity acts.

Chris Henschke is collaborating with Wolfgang Adam (above).

Paco Falco is collaborating with Pierluigi Paolucci (below).

Wolfgang Adam is senior physicist responsible for CMS data analysis at the institute of High Energy Physics in Vienna, Austria. He has been working for the CMS experiment for 15 years and he is deeply involved in searches for supersymmetry.

Pierluigi Paolucci is senior researcher and professor at the INFN institutes in Naples Italy. He working since 2002 on the CMS experiment and is currently Project Manager of the RPC Muon system.

Exhibition catalogue, “art@CMS”, CERN, Cessy, France, June 22 – 30 2014.

Chris Henschke Biography

Chris Henschke is a Melbourne based artist who has been working with digital media since the late Twentieth Century. His main areas of practice are in the relationships between sound and image, space and time, and art and science. He has undertaken various multi-disciplinary residency projects including residencies at the Australian Synchrotron (2007, 2010); an Asialink Visual Arts residency at Chulalongkorn University, Bangkok, Thailand (2008); and the inaugural online artist in residence at the National Gallery of Australia, Canberra (2004). His artworks have been shown around Australia and internationally, including the Museum of Contemporary Art, Taipei (2012); *Art Now*, Royal Exhibition Building, Melbourne (2010); *Vivid*, Sydney, (2013); *Sonic Residues*, Australian Centre for Contemporary Art, Melbourne (2001).

In 2012 Chris Henschke co-curated of a permanent exhibition of contemporary art at the Australian Synchrotron National Centre for Synchrotron Science, and was the organizer of the *Colliding Ideas - Art, Society and Physics* symposium, a satellite event of the 36th International Conference of High Energy Physics, where the discovery of the Higgs Boson was announced.

Chris Henschke lectures in Media & Communication at RMIT University, and has also taught at the University of Melbourne's Victorian College of the Arts, where he developed a multi-disciplinary 'Art vs Science' seminar series. He is currently undertaking a Doctor of Philosophy candidature at Monash University, conducting practice-led research into methodological and epistemological aspects in the disciplines of media art and particle physics.

Edge of the Observable

Edge of the Observable is an audiovisual artwork which explores the limits of materiality and knowledge, through an experimental manifestation of data taken from experiments at the Large Hadron Collider (LHC). The experiments undertaken at the LHC, the largest particle accelerator in the world, probe the fundamental nature of the universe, through the focusing of trillions of electron volts of energy on unimaginably small subatomic particles that are accelerated to almost the speed of light around the twenty seven kilometre accelerator ring. When the particles collide with each other, immense energies are released for an instant of time, which are captured by gargantuan detectors such as the Compact Muon Solenoid (CMS) detector.

Such spatial, temporal and energetic extremes can be seen as an expression of the sublime. This is a sensation that is described as the apprehension that which is beyond humanity's grasp or limits of understanding. The philosopher Immanuel Kant posits two types of sublime: the "mathematical" which deals with scale, and the "dynamic" which deals with the might and power of nature. According to Kant, we find ourselves at the limits of our ability to intuitively grasp or aesthetically measure such states of the sublime due to the 'limitations of the finite, human faculties of sensibility'. The LHC encapsulates both forms of the sublime, by its unimaginable complexity and the tremendous energy it creates. However, this is a kind of inversion of the Kantian sublime of scale and dynamics - it is the sublime of the near-infinitely small yet near-infinitely energetic.

The LHC manifests another limit, the limit of knowledge itself, as the experiments undertaken are literally at the boundaries of scientific knowledge and our understanding of the universe. In a way the LHC bring together and tests both the theoretical and experimental aspects of knowledge. From a materialist point of view, as described by physicist and philosopher Karen Barad, 'theorizing, like experimenting, is a material practice' (2007).

The LHC can also be described as an 'epistemic object'. Unlike everyday objects that have definite and fixed forms and uses, epistemic objects are, according to scientist Hans Rheinberger, 'objects of knowledge [which] appear to have the capacity to unfold indefinitely. [As they] are always in the process of being materially defined, they continually acquire new properties and change the ones they have [and] can never be fully attained' (1997).

In a sense, the LHC is a manifestation of our dynamic interplay with nature, an ongoing experimental reconfiguration of matter and energy. The universe and us are not classically separate entities, we are intertwined in an ongoing dance of expressive co-definition. To quote 'new materialist' philosopher Manuel DeLanda, 'Even humble atoms can interact with light and energy in a way that literally expresses their identity.'

Edge of the Observable seeks to manifest such sublime and dynamic expressive qualities that are present within the LHC through the extraction of dynamic and expressive qualities from data captured by the CMS experiment. The work specifically manifests one of the billions of particle collisions: event 416497095 of event run 46944. This data is the source material for the artwork, however it is manifested through an experimental physical setup. Taking the basic form of a physics experiment, the data is emitted as light from an energy source; it is then modulated through an optical lens-like device; and is then captured and recorded by a detector. By finely adjusting the physical variables of the experiment, plus some minor digital post-production adjustments, the resultant output contains an essence of both the setup of the artwork as well as that of the LHC experiments. The accompanying sound is data of the LHC beam tune, which is simply pitch-shifted and equalized to enhance its expressive qualities. The final artwork is filmed in 4K ultra-high definition video and presented as a twelve minute looping audiovisual sequence.

References:

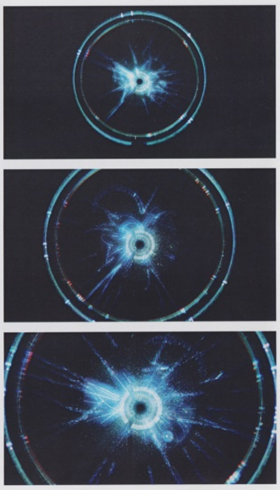
Barad, K., *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, Duke University, Durham, North Carolina, 2007

Burnham, D., *Kant's Aesthetics*, http://www.iep.utm.edu/kantaest/#SH2c

DeLanda, M., *Matter Matters*, Domus, 2012

Rheinberger, H. J., *Towards a History of Epistemic Things: Synthesizing Proteins in the Test Tube*, Stanford: Stanford University Press, 1997

Images (facing page):
Edge of the Observable, 2013, stills from video sequence



Visit

John Hansard Gallery
University of Southampton
Highfield, Southampton, SO17 1BJ
T: +44 (0)23 8059 2158 E: info@hansardgallery.org.uk
W: www.hansardgallery.org.uk

Opening times:
Tuesday to Friday: 11am–5pm | Saturday: 11am–4pm
Free Admission

By Bus: Unilink U1 buses stop at Highfield Interchange, just 2 minutes walk from the Gallery. Services connect with Southampton city centre, Airport Parkway and Central train stations. www.unilink.co.uk
By Train: Southampton Central and Airport Parkway stations
By Car: Pay and display parking on University Road. Limited parking on campus – permits available. Parking free after 5pm / weekends.
Access: Designated accessible parking at rear of building. Gallery is single storey with ramped access. Fully accessible toilet for wheelchair users. Guide Dogs admitted.

John Hansard Gallery is part of the University of Southampton and supported using public funding by Arts Council England

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John Hansard Gallery

What's On
August – September 2014

World-class contemporary art in Southampton, open to all
www.hansardgallery.org.uk

Current Exhibition

The Small Infinite
5 August – 20 September 2014

Featured Artists:
Mark Amerika | Elif Ayiter | Bill Balaskas | Bronwen Buckeridge | Sophie Clements | Susan Collins | Max Eastley | Tim Head | Henriette Heise | Chris Henschke | John Latham | Mark Lewis | Karl Lemieux | Patrick Pound | Charlie Sofo | Paul Thomas and Kevin Raxworthy

The world of today functions at the most extreme of scales, from big data and the endless expanse of the digital realm to global capital and consumption. In stark contrast, **The Small Infinite** celebrates the strength and endurance of the minuscule. Rejecting the current trend for grandiose gestures, this exhibition reflects upon a world where worth and value are often represented through the most disproportionate of terms.

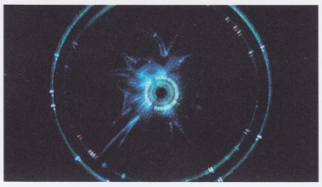
The Small Infinite unites a diverse collection of international artists whose work focuses on more intimate perceptions of reality, ranging from photography and works on paper to sculpture, video installation and digital interventions.

The exhibition explores the theme of the infinitesimally small through a range of fine art practices as diverse as particle physics, the economic crisis, utopianism, hacking, virtual worlds and the materiality of film. Central to the exhibition is the inclusion of works from the series *One Second Drawings* by British artist John Latham (1921–2006).

The Small Infinite returns us to a sense of humanity through discrete perceptual experiences that reject the spectacular, revealing profundity within the unseen, the intimate and the fragile. The exhibition serves to remind us that, under the hammer-blows of life and time, what endures is the small.

The Small Infinite is a John Hansard Gallery exhibition curated by Lanfranco Aceti with Vince Dziekan, in partnership with Winchester School of Art.

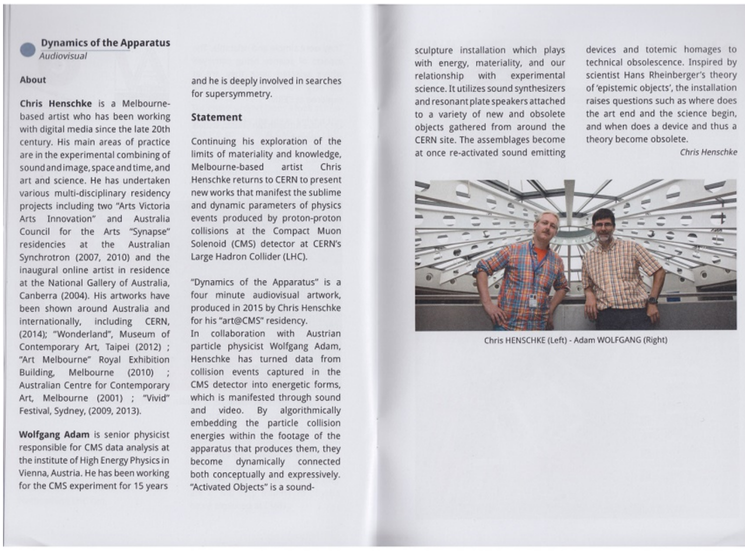
Operational & Curatorial Research | UNIVERSITY OF Southampton



Top to bottom:
Chris Henschke, *Edge of the Observable*, 2014. Courtesy the artist.
Mark Amerika, *Lake Como Remix*, MOGA, 2012. Courtesy the artist.
Charlie Sofo, *Cracks, faults & fractures*, 2012 (video still). Courtesy the artist and Darren Knight Gallery, Sydney.

Cover: Patrick Pound, *Small Worlds*, 2013–14. © the artist. Courtesy Stills Gallery, Sydney.

Exhibition catalogue, "The Small Infinite", John Hansard Gallery, Southampton, U.K., 5 August – 20 September 2014



Dynamics of the Apparatus
Audiovisual

About

Chris Henschke is a Melbourne-based artist who has been working with digital media since the late 20th century. His main areas of practice are in the experimental combining of sound and image, space and time, and art and science. He has undertaken various multi-disciplinary residency projects including two "Arts Victoria Arts Innovation" and Australia Council for the Arts "Synapse" residencies at the Australian Synchrotron (2007, 2010) and the inaugural online artist in residence at the National Gallery of Australia, Canberra (2004). His artworks have been shown around Australia and internationally, including CERN, (2014); "Wonderland", Museum of Contemporary Art, Taipei (2012) ; "Art Melbourne" Royal Exhibition Building, Melbourne (2010) ; Australian Centre for Contemporary Art, Melbourne (2001) ; "Vivid" Festival, Sydney, (2009, 2013).

Wolfgang Adam is senior physicist responsible for CMS data analysis at the institute of High Energy Physics in Vienna, Austria. He has been working for the CMS experiment for 15 years and he is deeply involved in searches for supersymmetry.

Statement

Continuing his exploration of the limits of materiality and knowledge, Melbourne-based artist Chris Henschke returns to CERN to present new works that manifest the sublime and dynamic parameters of physics events produced by proton-proton collisions at the Compact Muon Solenoid (CMS) detector at CERN's Large Hadron Collider (LHC).

"Dynamics of the Apparatus" is a four minute audiovisual artwork, produced in 2015 by Chris Henschke for his "art@CMS" residency.
In collaboration with Austrian particle physicist Wolfgang Adam, Henschke has turned data from collision events captured in the CMS detector into energetic forms, which is manifested through sound and video. By algorithmically embedding the particle collision energies within the footage of the apparatus that produces them, they become dynamically connected both conceptually and expressively.
"Activated Objects" is a sound-sculpture installation which plays with energy, materiality, and our relationship with experimental science. It utilizes sound synthesizers and resonant plate speakers attached to a variety of new and obsolete objects gathered from around the CERN site. The assemblages become at once re-activated sound emitting devices and totemic homages to technical obsolescence. Inspired by scientist Hans Rheinberger's theory of 'epistemic objects', the installation raises questions such as where does the art end and the science begin, and when does a device and thus a theory become obsolete.

Chris Henschke

Chris HENSCHKE (Left) - Adam WOLFGANG (Right)

Con Sensus
Science Rap

Anti-Matters
This track explores the life of an anti-proton, positron and other subatomic particles making an interesting link to the confrontation present in gang culture. The analogy song describes he opposing sides coming together to complete annihilation !

Verse one (part)
I see some of them moving 'anti', Opposite sides they're taking.
I'm a pro but they're trying to face me like mirror, opposite side...adjacent.
Still stable inside but strange because somehow the masses describe us the same.
Just opposite sides of the positive vibes, you just lost your life to a signed arrangement.
Watch for the signs in life's equation,
unless you go for the violation,
It's best you don't if you get too close, it will end in total annihilation...

Verse Two (part)
I see some of them moving 'anti', like they're against what we're trying to be.
They claim they have positive reach, but from origin probably not as it seems
Though the masses say they're like me, I'm charge of a larger opposing team like..
If you're in our sights and not on our side, that's loss of your life to a signed arrangement,
Watch when you try those violations, we've got it like light in hibernation.
Get too close ? I expect you won't, it will end in total annihilation...

Dark Matters
A conceptual track that explores the nature of the universe (more specifically dark matter) and compares the search to the exploration of self. ('I am the universe', 'I am a cluster of galaxies') What is dark matter, why is it important ?

Chorus
I am the matters of the universe the entire whole. The mind and the body that evolved.
What is seen in effect of what seen and what's not yet known. The weight of the situation now told.
I am the light and the darkness combined and so much more that you don't see cos you're blind.
I'm what's embodied that caught natural light. My thoughts are the dark matter behind.

Chris Henschke
Dynamics of the Apparatus (2015)
Audiovisual

Exhibition catalogue, "Circulez", CERN, Cessy, France, 22 – 27 June 2015.

Energies in the Arts Conference
13–15 August 2015 | Sydney Australia

Museum of Contemporary Art Australia
UNSW Art & Design

EN– ER– GIES

The *Energies in the Arts* conference examines the dynamic relationship between art and energy. Bringing together scholars and artists, it aims to uncover the seemingly elusive properties and potentials of *all kinds of energy* - both real and imagined - to investigate how they have been understood and used in the arts and related areas of music, literature and philosophy; how various energies configure and influence one another; and how artworks and theories might be better understood through them.

At the outset of the 21st century any discussion of energy is inextricably linked to the politics of power and environmental catastrophe. The conference extends this understanding of energy to encompass a more heterogeneous field in the arts. Art's relationship with energy extends well beyond light and colour to the kinetic, sonic, electronic, metabolic, physical, physiological, neurological, solar and sensory. Scratch below the surface of modernist shock or global communications and you will find flashes and systems of energy. Ask musicians what they work with and they may say 'the energy in the room'. Ask activists what fills candidates' coffers and foreshadows the fate of the world and they may point to the politics of old and new sunlight. For theorists, energy courses through networks and assemblages, animates bodies, fuels affect, and moves through the shimmering turbulence of existence. Despite all these vibrations, radiations, fluxes and flows, the prevailing comprehension of energies in the arts is still relatively static. The *Energies in the Arts* conference is an opportunity to broaden our historical knowledge, deepen our analytical rigour and generate new artistic provocations and possibilities.

Co-presented by the Museum of Contemporary Art Australia (MCA) and the National Institute for Experimental Arts (NIEA), at UNSW Art & Design to coincide with the exhibition *Energies: Haines & Hinterding*, 25 June —6 September, 2015 at the MCA.

Conveners: Anna Davis (MCA), Douglas Kahn (NIEA, UNSW Art & Design) and Josh Wodak (NIEA, UNSW Art & Design)

mca.com.au/events/energies-arts-conference

Museum of Contemporary Art Australia

UNSW Art & Design

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Image right: David Haines and Joyce Hinterding, Pulse no.4, 2011, pure carbon digital print from scanned etching plate

Conference program, "Energies in the Arts", UNSW Art & Design, Sydney Australia, 13–15 August 2015.

Saturday 15 August

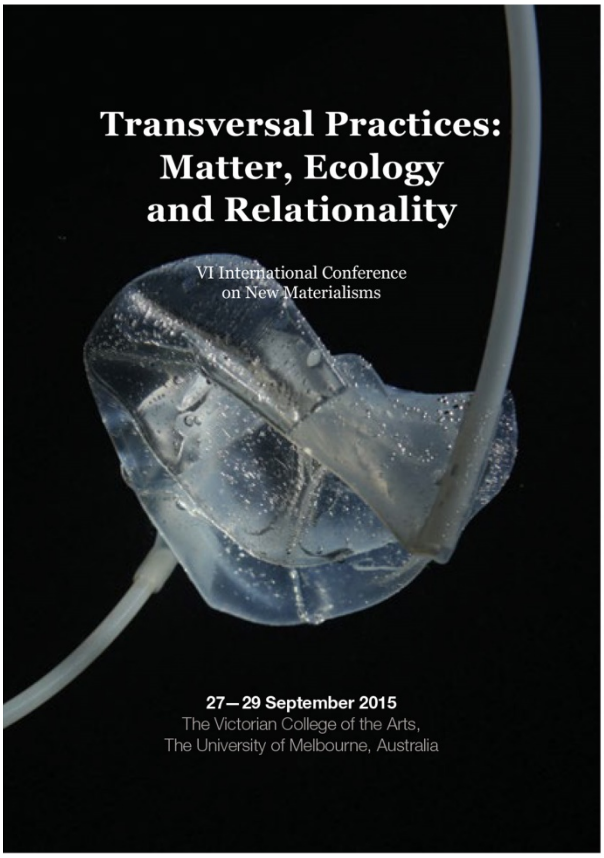
UNSW Art & Design, Greens Rd, Paddington, NSW 2021

	EG02 Lecture Theatre	F205 Seminar Room
9.30	Registration	
9.45	Welcome Josh Wodak (Associate Lecturer, UNSW Art & Design)	
10:00	A Constellation of Energies in German Radio, April 1930 Heather Contant (PhD Candidate, UNSW Art & Design)	Visual Moonbounce and the Cosmic Flaneur Daniela de Paulis (Artist & PhD Candidate, University of Amsterdam)
10:30	The Aesthetics of Transmission in Contemporary Art Nancy Muro-Flaude (Artist & Research Fellow, Creative Exchange Institute (CxI), University of Tasmania)	High Energy Art Experiments Chris Henschke (Artist & Lecturer, RMIT)
11:00	The Weight of Information Julian Priest (Artist & Senior Lecturer, Massey University, Wellington)	Winds Section instrumental Cameron Robbins (Artist, Melbourne)
11.30	Morning Tea	
12.00	On Tremulation Jonathan Kemp (Artist, London)*	
12.30	Occulted Energies: Earth, Alchemy, Electronics and Technology Martin Howse (Artist, Berlin/London)*	
1.30	Lunch (BYO, own arrangements)	
2.30	Media Ecologies of the Anthropocene Erin Obodiac (Mellon Postdoctoral Fellow, Cornell University)	Alexander Hector's Colour Music Instruments and his Correlation of the Sciences Pia van Gelder (Artist & PhD candidate, UNSW Art & Design)
3.00	Energy In Equals Inergy Out Josh Wodak (Associate Lecturer, UNSW Art & Design)	Electrobotany: Tree Microphones and Plant Audio Interfaces Vincent Wozniak-O'Connor (Artist & PhD Candidate, UNSW Art & Design)
3.30	The Derwent Project: Visualising Energy Flows and Environmental Change Across a Watershed David Stephenson (Artist & Associate Professor, University of Tasmania) & Martin Walch (Artist & Lecturer, University of Tasmania)	Living Systems: the Work of Emily Morandini and Alan Lamb Nathan Thompson (Artist & PhD Candidate, UNSW Art & Design)
4.00	Wrap Up Roundtable	
4.30	Close of talks, day 3	

	Red Rattler, Marrickville
8.00 — — late	Special Event: Transductions Performances by: Martin Howse*, Pia van Gelder & Peter Blamey 6 Faversham Street, Marrickville Tickets $20 available at the door

* Acknowledgement of support
Linda Henderson's and Martin Howse's visit to Australia is supported by UNSW Art & Design.Jonathan Kemp's visit to Australia is supported by Arts Tasmania, Creative Exchange Institute and Miss Despoinas Critical Engineering Salon.

Marcus Boon is a Macquarie University, Faculty of Arts, Visiting Research Fellow.



HUB SEMINAR ROOM ③	FOUNDERS GALLERY ④	ART AUDITORIUM ⑤
The Sidestep: Transversality in Neighbourhood Art Projects Chair: Janine Randerson **The Chasing Fog Club (Est. 2014): Free Participation, Free T-Shirt** Layne Waerea Art and Design, AUT University **Making as Currency, Connecting the Everyday Social** Monique Redmond AUT University **Ecologies of Practice: Seawater and Dust** Janine Randerson Art and Design, AUT University	**Experimental Practices** Chair: Laura Woodward **Carceri: Prisons of Invention** Tero Nauha and Karolina Kucia COST Action IS1307 Theatre Academy, University of the Arts, Helsinki **Elastic Perspective: The Diagonal Line and the Production of Deep Space** Rochelle Haley University of New South Wales **Imag(in)ing the Impossible —A Case Study in Drawing and the Process of Designing States of Experience** Luke Tipene Whitehouse Institute of Design, Australia **The Performance Lecture** Mark Shorter Victorian College of the Arts, The University of Melbourne	
Sonic Spaces, Vocal Relations Chair: Erin Stapleton **SPEAK!** Julieanna Preston College of Creative Arts, Massey University **Bodily Collisions: Towards a New Materialist Understanding of Art as Energy** Dorota Golanska University of Lodz **Practices, Trajectories and the Travels of Musical Instruments** Alejandro Miranda University of Western Sydney **Ears to the Ground: New Materialist Practices of Voice in Contemporary Art** Norie Neumark Victorian College of the Arts, The University of Melbourne	**Digital Ecologies, Digital Materialities** Chair: Ilona Hongisto **The Shifting Context of Clouds, Matter and Aesthetics** Paul Thomas University of New South Wales Art and Design **Expressive Collisions: Art and Particle Physics** Chris Henschke Monash University and Australian Synchrotron	

subjected to the undoubted material pressures of ecological crises, don't we now, more than ever, need the novel to do some 'work'? Then again, surely we cannot look to fiction to change the real world? Can we expect it to bear such a burden?

This paper considers whether the 'work' of literature could be to engender our resistance to ecological crises. It focuses upon the intensive qualities of the novel and the idea, inspired by New Materialist thought, that literature can nurture ecological 'sense': by breaking open the cracks in how we represent the world; by conveying the material agency of the non-and-more-than-human; by expressing the traumatic effects of crises; by prompting non-and-more-than human becomings; and through the expressions of damaged Minorities (Deleuze and Guattari).

I will respond to some questions that put these ideas under critical pressure. Is a literature that deconstructs Humanisms becoming passé? Is the written page really an adequate substitute for getting 'out there' in 'Nature' amidst all that 'vibrant matter' (Bennett)? Aren't we always, already, unavoidably 'out there'? If we cannot already sense the effects that flow from ecological crises then surely the work of art cannot reach us? If we are looking for an Australian Minor Literature for ecological crises, then won't it be indigenous and, if so, where does this leave non-indigenous fiction? I will conclude by considering what we should (not) expect of the writer and the reader entering into these literary assemblages.

David Harris is a writer of fiction and an academic based in South West Victoria. He is completing a PhD at Deakin University. His research focuses upon New Materialist and Deleuzian approaches to the 'work' literature might do to nurture ecological 'sense' and to engender our resistance to and renewal amidst ecological crises (climate change, planetary degradation, mass extinction, Capitalism and crises of agency). The current focus of this research is upon contemporary Australian novels.

Rachael Haynes
Boxcopy Contemporary Art Space

Object Relations, Transformational Encounters in the Studio Archive

'Object relations' is a lecture performance which takes as its provocation Lygia Clark's 'relational objects' and Eva Hesse's material encounters in the studio, drawing together an archive of images that document material engagements in the studio by women artists. At play in these images is the relational nature between the feminine subject and the materiality of the object, gendered implications of the body, and interventions within these codes through self-representation in the context of the historically male dominated domain of the studio.

Taking on the challenge set by Griselda Pollock in her conception of the Virtual Feminist Museum (VFM), this archive is arranged by a 'feminist rather than phallocentric logic' and emphasizes a subjective and affective engagement with these images. This paper offers a feminist perspective on the archival impulse and utilizes the strategy of 'Re-vision' to open up new critical directions for feminisms own histories and archives. The lecture performance as a format draws together research, pedagogical modes, embodied language and performativity and as a strategy responds to feminist archives while at the same time, performs a subjective feminist archive through practice. As Griselda Pollock aptly asserts in relation to the VFM: 'The purpose is … a rereading which is also a remembering – a word that in English involves not only recalling from oblivion, but also reassembling as an act – for a feminist future' (Pollock 2007, 14).

Rachael Haynes is a Lecturer in Creative Practice (Visual Arts) at Deakin University. Previously, she was a tutor and lecturer at Queensland University of Technology in Art History/Theory and Studio Art Practice for ten years. Haynes completed her PhD, an exploration of the ethics of exhibition practice, examining encounters between artworks and audiences in terms of difference, with the support of an Australian Postgraduate Award in 2009. Her current research investigates feminism and relational practices, through solo creative works and as part of the collective, Level. Rachael is the Gallery Director of Boxcopy Contemporary Art Space.

Chris Henschke
Monash University / Australian Synchrotron

Expressive Collisions: Art and Particle Physics

Through my residencies at the Australian Synchrotron (2007, 2010) and my current 'art@CMS' residency at CERN, I have been increasingly interested in the nature of matter and energy when it is pushed to its experimental extremes. In collaboration with particle physicists, and using the tools of experimental physics, I seek to manifest the expressive qualities of both macroscopic and subatomic matter at high energies, in order to creatively explore the limits of, and connections between, the material and energetic, the corporeal and the evanescent.

I have developed a heuristic-based trans-disciplinary art / physics practice, which allows for a relational understanding between the two cultures. However such practice also challenges the scientists' ownership of the phenomena manifested through high energy physics research, as well as their reductionist outcomes and dogma of equivalence - for example in opposition to such scientific concepts that all electrons are indistinguishable, I am developing experiments that increase particles' degrees of freedom which, in the words of Manuel DeLanda, allows 'even humble atoms [to] interact with light in a way that literally expresses their identity' and makes each particle expression a unique and dynamic becoming.

I have also developed a practical interest in Karen Barad's "agential realist" stance on Niels Bohr's theory of "complementarity" in quantum mechanics, and its application in both the subatomic and human domains. Inspired by Barad, I have conducted quantum-optical "metaphysical experiments", in collaboration with physicists, the outcomes of which have poignant material and philosophical implications.

In conclusion, I argue that the apparatuses and the phenomena produced in experimental physics, whether for art or science, can be understood as "epistemic things", a term coined by scientist Hans Rheinberger to denote knowledge-embedded objects which have an unfolding ontology and are being continually materially defined, such as the devices used in particle accelerators.

Chris Henschke is an artist whose areas of practice and research are in sound and visual relationships, and collaborative art / science experiments. He has exhibited around Australia and internationally, including the Australian Centre for Contemporary Art (2001), and the National Gallery of Australia (2004), and has undertaken residencies at the Australian Synchrotron (2007, 2010), and the 'Art@CMS' residency at CERN, the European Organisation for Nuclear Research (2014-15), Switzerland. He developed and lectured courses in time-based and interactive media at RMIT University, and the *Art vs Science* seminar series at the Victorian College of the Arts Centre For Ideas, and is currently undertaking a Doctorate of Philosophy at Monash University.

Jan Hogan
Tasmanian College of the Arts,
University of Tasmania

Transversing Truganini Track: Materiality and Sensation in Drawing the Land.

The Australian landscape tradition privileges a viewer separated from the land. This perspectival view of representation describes but also conditions perception encouraging a hegemonic gaze to enjoy the spoils of Empire. The art traditions of Aboriginal Australians have demonstrated other ways of depicting the Land that emphasise the need for negotiations between differences.

As a settler Australian I explore visual art processes to develop a new language to depict the land we share, that responds to the propositions seen in Aboriginal art but also acknowledges the colonial impact on the land. Through process-led research I examine the site of Truganini Track, named in memory of a Nuenonne woman, contentiously called the last Aboriginal Tasmanian. I place paper in the land to act as a membrane between nature and culture, acquiring knowledge through the materiality of the site.

In working with art as a membrane of memory my aim is to allow a continual performativity where memory brings forward the past to imagine a better future. My processes of art making encourage knowledge to be acquired through sensation, where concept and materiality are intertwined. I argue that through working directly on site, art processes reveal traces in the land of past events. The geological history and the social histories interweave in a dialogue between artist and place. My research explores the importance of touch in the gaining and depiction of knowledge about the land. I propose that depictions of the land developed from 'the haptic' in contrast to 'the gaze' communicate knowledge of the environment in terms of sensation.

Jan Hogan is a practicing artist and academic currently living and working in Tasmania. Her art practice is interwoven with daily life exploring concepts of belonging and dispossession. She works in situ in the environment, on sites allocated as a commons. Her work is a dialogue with the land and its people, searching for a way that difference can occupy the

Conference program and abstracts, "Transversal Practices: Matter, Ecology and Relationality", VCA, Melbourne, Australia, 27 – 29 September 2015.

ISMAR 2015 Exhibition

DATA BODY AS ARTIFACT

Curated by Julian Stadon

Exhibition Catalog

ISMAR 2015

CHRIS HENSCHKE

Dynamics of the Apparatus

"Dynamics of the Apparatus" is an audiovisual project developed as part of the 'art@CMS' residency at the European Organization for Nuclear Research (CERN). During the residency, Chris Henschke filmed various experimental areas of the Large Hadron Collider (LHC). The experiments undertaken at the LHC, the most complex scientific experiment in the world, probe the fundamental nature of the universe, through the focusing of trillions of electron volts of energy on unimaginably small subatomic particles that are accelerated to almost the speed of light around the twenty seven kilometre accelerator ring. When the particles collide with each other, immense energies are released for an instant of time, which are captured by gargantuan detectors such as the Compact Muon Solenoid (CMS) detector.

Although the raw footage is compelling in itself, Henschke sought to convey a sense of the spacetime bending energies present in the LHC, by embedding particle beam and collision event data into the video. The video is algorithmically manipulated in a way that uses the electromagnetic 'sound' of the particle beam vibration to control the flow of the video, plus sonified particle collision events produced in the CMS detector. These sounds were used to affect the video footage of the detector through a computer algorithm that uses the intensity of the sound to map time onto space, and in essence folds the energy and events back into the device that produces it. This manifests the dynamic nature of experimental physics in the way that Niels Bohr describes as a state of ‚complementarity'. For Bohr, the interaction between the object of investigation and apparatus producing and measuring it 'forms an inseparable part of the phenomenon'. The final audiovisual output, itself a kind of experimental outcome, seeks to capture and distil both the overwhelming energies and technologies manifest in the LHC, plus the sensations one feels within such a particle accelerator.

Bio

Chris Henschke is a self-taught artist whose areas of practice and research are in sound and visual relationships, and collaborative art / science experiments. He has exhibited art works around Australia and internationally, including the Australian Centre for Contemporary Art (2001), the National Gallery of Australia (2004) and the University of Southampton John Hansard Gallery (2014). He has undertaken various art residencies, including two at the Australian Synchrotron, supported by an Arts Victoria Arts Innovation grant (2008), and the Australia Council for the Arts Synapse program (2010). He has developed and lectured courses in timebased and interactive media at Monash University, RMIT University, and the 'Art vs Science' seminar series at the Victorian College of the Arts Centre For Ideas. Currently, he is underaking a Doctorate of Philosophy at Monash University, which includes on-site research at the European Organisation for Nuclear Research (CERN), Switzerland / France, as part of the 'art@CMS' collaborative artist residency program.

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Exhibition catalogue from "Data Body as Artifact", International Symposium on Mixed and Augmented Reality Conference and Exhibition (ISMAR 2015), Fukuoka City Museum and Conference Centre, Japan, September 29 – October 4 2015.

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THURSDAY'S 2ND PARALLEL SESSIONS

CMC Room 1	CMC Room 2	CMC Room 3	CMC Room 4	CMC Room 5	CMC Room 6	CMC Room 7
T2.1 - Panel - Education *Session Chair: Daniel Howe* *Computer Programming Education and Creative Arts* Waiching, Bryan Chung, HKBU; Pong Lam, Kun Shan University; Winnie Soon, Aarhus University, Denmark	**T2.2 - Panel - Games 2: China** *Session Chair: Lindsay Grace* *Games and Gaming in China* Peichi Chung, The Chinese University of Hong Kong; Ling-Yi Huang, Nanfang College of Sun Yet-sen University; Bjarke Liboriussen, University of Nottingham Ningbo China	**T2.3 - Panel - Science and Art 1: Quantum Physics** *Session Chair: Peter Anders* *The Affect of Quantum Phenomena on Media Art* Paul Thomas, University of New South Wales; Mike Phillips, Plymouth Univesrity; Frederik de Wilde; Chris Henschke, Royal Melbourne Institute of Technology	**T2.4 - Papers - Ghosts & Supernatural 1** *Session Chair: Bogna M Konior* *"This is a techno-necklace from my great grandmother": Animism-Inspired Design Guidelines for Digitally Ensouled Jewellery* Doros Polydorou, University of Hertfordshire; Kening Zhu, City University of Hong Kong; Alexis Karkotis, Unaffiliated scholar; Antje Illner, University of Hertfordshire; Nicola De Main, University of Hertfordshire *'The Familiar': technology-being-with-us*	**T2.5 - Artist / Work-in-Progress Talks - Dance** *Session Chair: Koala Yip* *Dance of infinity :installation exapmle.* Flower Red pig, Red pig flower *MAVi: Movement Aesthetic Visualization Tool and its use for dance video making and prototyping* Ewelina Bakala, Facultad de Ingenieria; Philippe Pasquier, Simon Fraiser University *Locus* Jung In Jung, University of Huddersfield *Impossible Choreographies: the database as creative tool*	**T2.6 - Artist / Work-in-Progress Talks - Cultural Heritage and Preservation 2** *Session Chair: Tamas Waliczky* *Ephemeral Art and Interactive Art: the quest for preservation and dissemination* SUZETE VENTURELLI, University of Brasília; ANTENOR FERREIRA CORREA, university of brasília *Footnoting as art: thinking about a poetics of historical examination* Seth Ellis, Griffith University *Reconfiguring the negotiation*	**T2.7- This session intentionally left blank (for now)**

Contact and Spectatorship in Interactive Installations Ka Wa Cheung, City University of Hong Kong *AURALROOTS: Cross-modal Interaction and learning* JILLIAN SCOTT, ZHDK - ZÜRICH UNIVERSITY OF THE ARTS	*Session Chair: Olli Tapio Leino* *Livestreaming in theory and practice: Four provocations on labour, liveness and participatory culture in games livestreaming* Emma Witkowski, RMIT University; Ge Zhang, RMIT University; James Manning, RMIT University; Daniel Recktenwald, Hong Kong Polytechnic University	*Hector Rodriguez* *Expressive Experiments : Art and Particle Physics* Chris Henschke, RMIT University *Symmetry: Breaking Through the Looking Glass* Douglas Easterly, Victoria University of Wellington	**psychology** *Session Chair: Kening Zhu* *inTouch: Ambient Remote Communication in Parent-Child Relationships* Jinsil Hwaryoung Seo, Texas A&M University *Ear Ball for Empathy: To realize the sensory experience of people with Autism spectrum disorders.* Taisuke Murakami, Aichi Shukutoku University	*Session Chair: Bogna M Konior* *The Anomaly: Noise, Ghosts and the Multiverse* Jane Grant, Plymouth University *Occult computing for artists* Nancy Mauro-Flude, Norwegian University of Science and Technology	**as Archive** *Session Chair: Minka Stoyanova* *CCAA WOW* Cedar Zhou, individual; Iris Long, individual *Accumulated Memory Landscapes: Real-time On-line 3D Landscapes Based on Prosthetic Memory Data* Rodolfo Segrera, Chronus Art Center *The USB Finger Project: Storing a digital work of art within the body* Tara Cook, University of Melbourne *Hacking the Body 2.0 Performance* Camille Baker, University for the Creative Arts, Epsom; Kate Sicchio, New York University	**Memories** *Session Chair: Leung Chi Wo* *Je me souviens* Andres Salas *Memories and Rememories* Kyoungah Kwon; Joonsung Yoon *Souvenirs (Corcovado series)* Gabriel Menotti Gonring, UFES *How Far is Up? The Remediation Loop From Picture Book to App to Animated Film to Picture Book* Betty Sargeant, RMIT University

FRIDAY'S 1ST PARALLEL SESSIONS

CMC Room 1	CMC Room 2	CMC Room 3	CMC Room 4	CMC Room 5	CMC Room 6	CMC Room 7
☐ **F1.1 - Artist / Work-in-Progress Talks - Politics, Democracy, and the Posthuman** *Session Chair: Roberto Simanowski* *Acceleration Toward Post-Human, Post-Anthropocene* Milena Popov, John Jay College of Criminal Justice, The City University of New York *Global Change App* Zane Cerpina *ABSTRACTION OF THE GAZE AND POV AS POLITICAL BATTLEFIELD* Mitra Azar, indipendent *China Made in Germany* Dorothea Etzler, l"angelo d"oro *SOCIAL GLITCH. Radical Aesthetics and the Consequences of Extreme Events* Gerald Nestler, TIM. theories in mind; Sylvia Eckermann, TIM. theories in mind; Maximilian Thoman, TIM. theories in mind	☐ **F1.2 - Artist / Work-in-Progress Talks - Cultural Heritage & Politics** *Session Chair: Peter Anders* *Internet of Props, new media ontology for cultural artifact.* Gianni Corino, Plymouth University *Grottspace* Peter Nelson, City University Hong Kong *AIDS Quilt Touch Project* Anne Balsamo, The New School; Dale MacDonald, The New School; Leticia Ferreira de Souza, The New School; David Wilson, The New School; Sean Landers, The New School *Resurrect From Digital, Interactive Site-Specific Projection Mapped Sculpture (2)* Benjamin Poynter, New York Institute of Technology *Heritage: ComposingYou - Chinatown* Judy Jheung	☐ **F1.3 - Artist / Work-in-Progress Talks - Robots 1** *Session Chair: Lau Ho Chi* *Processing/Lampreys, Photo-Fiction as Digital Parasite Aesthetics* Yvette Granata, SUNY Buffalo *The Exhaustive, Inexhaustible Philosopher* Colin Johnson, University of Kent *a robot that sleepwalks* Dean Terry, University of Texas at Dallas *Abstract History Machine* Daniel Franke, Chronus Art Center *Towards Play Design for Machines* Michael Straeubig, Plymouth University *DISsCERN* Daniel Franke, Cronus Art Center	☐ **F1.4 - Artist / Work-in-Progress Talks - Makers** *Session Chair: Marco de Mutiis* *Performativity and computer art. Towards a DIY society* Paz Sastre, Universidad Autónoma Metropolitana - Unidad Lerma; Francisco García García, Universidad Complutense *Heartwood* Tiffany Sanchez, Texas A&M University; Jinsil Hwaryoung Seo, Texas A&M University *Embrace in Progress* Rosalie Yu *Future Heritage تراث المستقبل* Jasmin Theresa Grimm, Public Art Lab; Sally Abu Bakr, Ramallah Municipality *Utopia, Experiment, Hack, Prototype. Transformative Rhetoric and Action in Net Art and Contemporary Maker Culture* Tapio Makela *23' Download* Jerry Galle	☐ **F1.5 - Artist / Work-in-Progress Talks - Interactivity, minds and bodies** *Session Chair: Minka Stoyanova* *Virtual 3D Sound Sculptures for Realtime Performance: Reapropration of game engines for visual music performance.* Andrew Blanton, San José State University *S T R A T I C* Vygandas "Vegas" Šimbelis, KTH; Anders Lundström, KTH *Interactive Mirroring - Being and Thing Become Space* June Kim, Queensland University of Technology	☐ **F1.6 - Artist / Work-in-Progress Talks - Science and Art 3** *Session Chair: Jane Prophet* *Watermarks* Anastasia Tyurina, Griffith University *Turbidity Paintings* Thomas Asmuth, University of West Florida; Sara Gevurtz, Virginia Commonwealth University *Vessels* Sofian Audry; Stephen Kelly; Samuel St-Aubin *Cosmic Tea Party installation* Chris Henschke, RMIT University *The Cat's Eyes Nebula* Clarissa Ribeiro, University of Fortaleza; Mick Lorusso, Art|Sci Center and Lab *Nature of the Apparatus* Chris Henschke	☐ **F1.7 - Artist / Work-in-Progress Talks - Disc*very Channel: Philonature** *Universal Objects: Garden* Tatjana Tanja Vujinović Kušej *Rock Hospital* Lora Nouk *Forty-Nine Views of Denali (Mt. McKinley)* Miho Aoki, University of Alaska Fairbanks *Conversation Pieces: Art Objects from Rare Earth Elements* Tiare Ribeaux

Brochure for "Science of the Unseen", online exhibition, SIGGRAPH 2016 Conference, Anaheim, U.S.A., 24 – 28 July 2016.

"Science of the Unseen", online exhibition, SIGGRAPH 2016 Conference, Anaheim, U.S.A., 24 – 28 July 2016.
http://science-unseen.siggraph.org/

EINE REISE ZUM URSPRUNG DES UNIVERSUMS

Die Ausstellung „Wie alles begann. Von Galaxien, Quarks und Kollisionen" lädt ein zu einer Spurensuche, die über 13 Milliarden Jahre zurück in die Vergangenheit, zum Ursprung des Universums, führt. Entstanden als Zusammenarbeit zwischen dem Naturhistorischen Museum Wien und dem Institut für Hochenergiephysik (HEPHY) der Österreichischen Akademie der Wissenschaften (ÖAW), thematisiert die Ausstellung Fragen, die die Menschen seit Jahrhunderten beschäftigen und uns an die Grenzen nicht nur unseres Wissens, sondern auch unseres Vorstellungsvermögens führen: *Woraus besteht unser Universum? Was ist dunkle Materie? Hat das Universum einen Anfang und ein Ende? Was war vor dem Urknall?* Antworten darauf bieten die neuesten wissenschaftlichen Erkenntnisse aus der Teilchenphysik und der Kosmologie. Zeitgenössische Werke von Kunstschaffenden machen die Unendlichkeit des Weltalls, die gigantischen Zeithorizonte und die Erforschung des Urknalls auf völlig konträre, sinnliche Weise erfahrbar.

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Herausgeber: Naturhistorisches Museum Wien
und Institut für Hochenergiephysik der ÖAW
ISBN 978-3-903096-12-7

WIE ALLES BEGANN
VON GALAXIEN, QUARKS
UND KOLLISIONEN

VORWORT

Univ.-Prof. Dr. Christian Köberl
Generaldirektor Naturhistorisches Museum Wien

Univ.-Prof. Dr. Jochen Schieck
Direktor Institut für Hochenergiephysik der ÖAW

Wir leben in einer faszinierenden Zeit! Neue Entdeckungen und Erkenntnisse haben unser Verständnis vom Ursprung und der Beschaffenheit des Universums grundlegend verändert und erweitert. Beispielsweise haben der experimentelle Nachweis des Higgs-Teilchens am CERN (2012) oder die Entdeckung der Gravitationswellen (2015) – die Bestätigung Einsteins großer Theorie – eine neue Ära sowohl in der Teilchenphysik als auch in der Astrophysik eingeleitet. Die Suche nach weiteren entscheidenden Bausteinen, die erklären, woraus unser Universum besteht und wohin es sich entwickeln wird, geht weiter.

Für das Naturhistorische Museum Wien (NHM Wien) sind die wissenschaftlichen Durchbrüche der letzten Jahre ein erfreulicher Anlass, gemeinsam mit dem Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften, das heuer sein 50-jähriges Bestehen feiert, eine Ausstellung zur Entstehung und Entwicklung des Universums zu gestalten. Damit setzt das NHM Wien seinen erfolgreichen Weg fort, das klassische Ausstellungsspektrum durch aktuelle naturwissenschaftliche Themen zu ergänzen.

Mit faszinierenden Bildern, spannenden Wissenschaftsexponaten, interaktiven Stationen und begehbaren Kunstinstallationen unternimmt die Ausstellung „Wie alles begann. Von Galaxien, Quarks und Kollisionen" eine einzigartige Reise vom Anfang bis zum vermeintlichen Ende unseres Universums.

Dabei werden jene Fragen thematisiert und teilweise beantwortet, die die Menschheit seit Jahrhunderten beschäftigen und die uns oft an die Grenzen unseres Wissens und unseres Vorstellungsvermögens führen. Neueste wissenschaftliche Erkenntnisse der Teilchenphysik, der Astronomie und der Kosmologie werden in der Ausstellung anhand von faszinierenden Aufnahmen, beeindruckenden Grafiken und spannenden Exponaten veranschaulicht.

Unterstützt wurden wir dabei von renommierten Kollegen aus der Astrophysik und der Teilchenphysik, die als wissenschaftliche Kuratoren den aktuellen Forschungsstand in die Ausstellung eingebracht haben.

Es freut uns auch sehr, dass wir für die Mitwirkung herausragende österreichische Künstlerinnen und Künstlern gewinnen konnten, die ihre Sichtweisen und Positionen zu diesem Thema eingebracht haben. Gezeigt werden die Installationen „Galaxies" von Manfred Wakolbinger und „Nebel im Kosmos" von Eva Schlegel, Barbara Imhof & Damian Minovski, eine Lichtinstallation zum „Urknall" von Brigitte Kowanz sowie eine Interpretation der Supersymmetrie von Kurt Hofstetter. Daneben werden auch künstlerische Arbeiten von Michael Hoch und Chris Hentschke präsentiert, die inspiriert vom CMS-Experiment am CERN entstanden sind.

Unser Dank gilt natürlich auch allen Kooperationspartnern und Partnerinnen, die wesentlich zur Realisierung dieser Ausstellung beigetragen haben.

Wir wünschen Ihnen einen spannenden und informativen Ausstellungsbesuch. In der Zwischenzeit geht die Suche nach neuen Erkenntnissen weiter!

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VIDEO- UND SOUNDINSTALLATION (2015)

NATURE OF THE APPARATUS

Chris Henschke

Der in Melbourne lebende Künstler Chris Henschke beschäftigt sich seit mehr als 20 Jahren mit digitalen Medien. Chris Henschke bewegt sich an den Schnittstellen von wissenschaftlicher Interdisziplinarität und Kunst. Schwerpunkte seines Schaffens bilden die experimentelle Verbindung von Ton und Bild sowie von Raum und Zeit. Seine Arbeiten werden seit Anfang 2000 in zahlreichen Ausstellungen und Installationen sowohl in Australien als auch international präsentiert.

Das LHC-Video wurde algorithmisch manipuliert, sodass die Klänge des Beschleunigerstrahls und des Detektors den Ablauf des Films steuern. Das Projekt zeigt nicht nur die ungeheuren Größenskalen und Energien im LHC auf, sondern bemüht sich auch, den Zusammenhang zwischen Apparat und physikalischen Erscheinungen zum Ausdruck zu bringen. Inspiriert von Niels Bohrs Einsichten in die Teilchenphysik faltet das Kunstwerk im Wesentlichen die Energie in das Gerät zurück, von dem sie produziert wird.

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Exhibition catalogue from "Wie Alles Begann", Natural History Museum, Vienna, Austria, 18 October 2016 – 20 August 2017.

Song of the Phenomena (2016)
10 KV linear particle accelerator and components, Geiger-Muller tube, scintillator detectors, induction coils, analogue synthesizers, electronics, amplifiers, audio speakers, lights, cathode ray accelerator, high-potassium fruits.
Light based engineering and construction by Davey-Milne Design.
Courtesy the artist. LINAC courtesy of Mark Boland, the Australian Synchrotron.

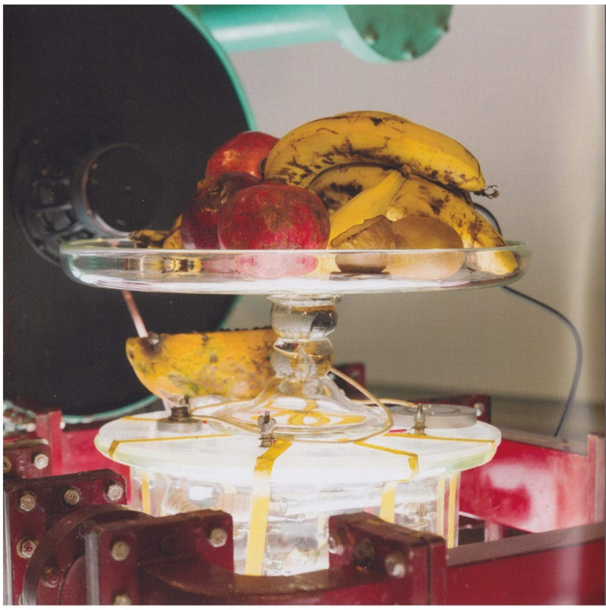
CHRIS HENSCHKE

Born Melbourne, Australia, 1972, lives Coburg, Australia.

The concept of "phenomena", developed by pioneering physicist Niels Bohr, explains the relationship between subatomic particles and the apparatuses used to produce and detect them. This installation engages with such phenomena, using particle emissions from organic matter attached to a linear particle accelerator (LINAC). Originally designed for radiological biological experiments, the LINAC is activated by natural radiation from the atomic decay of potassium in the organic material. The accelerator electromagnetically resonates in response to the subatomic emissions, via amplified signals from particle detectors, which is manifested as sound and light. Through amplification, resonance, and decay, the artwork experimentally and conceptually probes the relationships between living and non-living matter, technology and biology, the macroscopic and subatomic. The installation provides an energetic analogue of the phenomena originally produced in the apparatus, but also inverts its purpose, giving the device a new kind of life, by enframing the organic matter with the technology that feeds upon it.

Chris Henschke is an artist who works with analogue and digital media. He exhibits internationally, and is currently undertaking a PhD candidature at Monash University, which includes on-site work at the European Organisation for Nuclear Research (CERN) Large Hadron Collider, as part of the 'art@CMS' collaboration.

Exhibition catalogue, "Morbis Artis – Diseases of the Arts", RMIT Gallery, Melbourne, Australia, 17 November 2016 – 18 February 2017.



INTRODUCTION

The artworks in this exhibition together with the curators' essay and wall texts aim to address a range of current social relationships: between art and science, between art and contemporary economic values, and between the human and non-human world using metaphors of diseases as a means of evoking the destructive relations.

The curators, Darrin Verhagen and Sean Redmond, propose that in an era of pervasive 'economic rationalism', of neoliberal policies, the arts may be perceived as a form of disease: a potentially invasive social agent that they conceive, metaphorically, as biological pathology. It is left to the viewer to consider the artworks of (((20hz))), Alison Bennett, Drew Berry, Cameron Bishop, Chris Henschke, Harry Nankin, Andrea Rassell, Sean Redmond, Joshua Redmond, Simon Reis, Jodi Sita, Lienors Torre and Anne Scott Wilson as a form of poetic contagion in the body politic, and to speculate on the artists' reflections on the status of contemporary art in relation to the sciences, civil society and ecology.

This trans-disciplinary engagement with transformative research outcomes, in the context of a professional museum of art, is a longstanding approach to exhibition making at RMIT Gallery. So too is the manifestly transformative approach to installation design and relationships between materiality and technology. This continuing focus on the creative achievements of RMIT, particularly alumni, demonstrates such a capacity not just within the university but importantly sharing these developments with the broader community of the city, nationally and reaching out to an international audience. This is a cornerstone of RMIT Gallery's curatorial program development.

The commitment to international impact is realised electronically through our extensive social media communication channels including on-line virtual tours, substantial YouTube content, Periscope live video streaming, podcasts, Instagram and gallery blog as well as this catalogue and related hard and soft collateral. A further component for engagement with the city is our contribution to the activities of *White Night*, when the gallery will remain open through the night of 18 February 2017 with the façade of Storey Hall, the building in which the gallery is located, stunningly illuminated by works of Jazmina Cininas, Josh Batty and Andy Thomas in an empathetic external dialogue with the exhibited works in *Morbis Artis*.

The curatorial process and decisions around installation design have been much more the concern of both Darrin Verhagen and Sean Redmond than is normally the case and we thank them for their intense engagement. But as is familiar, it has been the RMIT Gallery team, Peter Wilson, Helen Rayment, Megha Nikhil, with Robert Bridgewater, Nick Devlin and Fergus Binns who have controlled the logistics, installation, problem solving in support of artist involvement, and delivered a professional museum standard exhibition.

Beyond the exhibition is the Public Program running through 18 November to 13 December 2016 and including, importantly, the Annual Ursula Hoff Contemporary Lecture, this year titled *Hybrid Worlds: When Art and Science Collide*. We thank Evelyn Tsitas for her contribution organising this and the social media coverage. And we thank Professor Calum Drummond, DVC Research and Innovation, whose support has enabled the remarkable 2016 Program of RMIT Gallery's 20th Year.

Suzanne Davies, Director and Chief Curator, RMIT Gallery
November 2016

The exhibition is composed of 11 artistic works, with each piece using a different media or art form to explore the catastrophic chaos of the world it draws upon. Each artist imagines disease differently, and yet within the terror of their imaginings there is simultaneously great beauty, and much hope. Disease, then is rendered sublime in this exhibition: both awfully malign and deliciously exquisite.

In **Andrea Rassell's** intimate work the membranes of the microscope are turned on the pathogen but here the relations between seeing and knowing, clean and unclean is reversed, so that the human becomes the seen and not the investigative seer. In this post-human frame, life and bacteria, technology and cell cross–connect like the dawning of a new species. In **Drew Berry's** video projection work, infectious cells are set free onto walls so that the very connective tissue of the exhibition room teems with the droplets of life and death. Herpes, influenza, HIV, polio and smallpox bacteria take flight, are magnified, so that those entering the space are hit by scale and size, and take part in this chorea of the senses.

In **Alison Bennett's** touch-based screen work, the viewer is presented with a high-resolution scan of bruised skin. Invited to touch the soft and damaged tissue before them, their eyes become organs of touch, and their fingers work as sensory digits that feel as they move over what becomes a damaged but delicate bio-art surface. What does it feel like to touch a bruise and be bruised? In **Ann Scott Wilson's** balloon installation and symphonic video projection, we explore the poetics of gravity and the chrononormativity of time to account and prepare us for the not-living that eventually befalls us all. The stillness of the balloon, tied to its egg-like placenta, and the movement of the ballet dancer, together speak to the material divide between the body that lives, that dies, and that then, perhaps, floats away. All matter is diseased by the power of life and death.

In **Chris Henschke's** work we explore anti-matter as we bare witness to how radiation is released by organic matter. Using an actual particle accelerator, the work shows how the humble banana or kiwi-fruit emits antimatter on a regular basis. In an age where we fear the way antimatter impacts upon the nature of everyday life and the workings of the cosmos, we see how the organic itself brings potential dissolution to the human world. This is bio-art praxis on a grand scale: machine, human, and organic placed in the same reverberating cylinder of decaying positron particles. In **(((20hz)))** sound-image installation we explore the way audio-visual fields can wildly affect the well-being of the hearing-viewer. With two catastrophic audio-vision soundtracks that register as sickly encounters, one can choose to hear without commentary, or to hear about how and why the soundscape induces nausea. Pulsating light beams and reflections accompany these sound pieces like a cosmos is dying and exploding before us. The piece is both one that draws hearing and seeing into the way sound is a conduit for understanding how we are inadvertently and intermittently penetrated by disease, and a statement about how we are instructed to hear and see ourselves as well or ill.

In **Jodi Sita's** photographic series it is the disease of vision that their work is concerned with. Images of the eye, the retina, and the fovea are transformed into intergalactic landscapes so that 'looking in' is transformed into an open geography of affective and expansive valleys and seas – like new vistas of possibility and potentiality open out before us. These lunar and oceanic eyes are composited from both healthy and diseased eyes, however, so that the strangeness of vision is mapped onto or into macular degeneration. These are eyes already failing, or dying, like the dark stars we are also apart of. **Lienor Torre's** multi-media and glass work on degenerative vision explores how our view of the world is metered and tainted by digital technologies. Consisting of two large glass eyeballs, a liquid animation set behind them, and a glass cabinet full of glass jars filled with water in varying degrees of opacity and with engraved eye images on them, eyes quickly become raindrops, as the liquidity of vision is brought to watery life. There are tears and scars that reflect across the eyes of this exquisite art-piece.

In **Harry Nankin's** nine, multi-panel palimpsests displayed on light boxes, lake becomes semi-arid land as the impact of the contemporary ecological crisis finds its root and branch in starlight and shadowgram as live invertebrates mourn the age of the anthropocene. The work 'photo-poetically' memorializes this erasure, resurrecting the dry lakebed into a focal plane upon which primal starlight is used to imprint photographic films on moonless nights. The environmental disease at the heart of this work is human-made: as we lay waste to our planet, the stars are slowly going out. In **Joshua and Sean Redmond's** three-screen video installation, ants become a different type of political disease. Combining found and actuality footage, the work uses the metaphors of ant invasion to re-envision the current refugee crisis and the way stateless people are made to be matter-out-of place. The central image of the piece, a flimsy toy dinghy floating on the salty water, recalls Australia's turn back the boat policy, and the haunting truth that it is children who are made to suffer most. This is a disease of political undertaking. **Cameron Bishop and Simon Reis's** mechanical installation seeks to rid the art world of all diseased art. This playful machine aesthetic flattens and standardise art, as they are pressed and turned through the machine, coming out cleaned of line and shape, and a sickly green colour. The blank green surface we are left with is the ultimate neo-liberal art piece – instantly copyable and immediately forgettable. This is a final mediation on where we started this essay with – the commodification of art and art as a form of capitalist disease. It as if we never were and never will be again.

Sean Redmond and Darrin Verhagen, Curators

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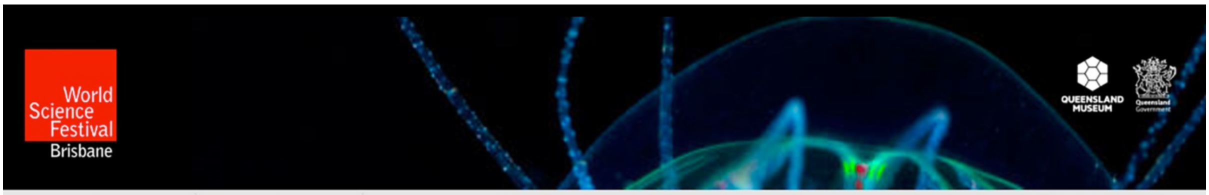

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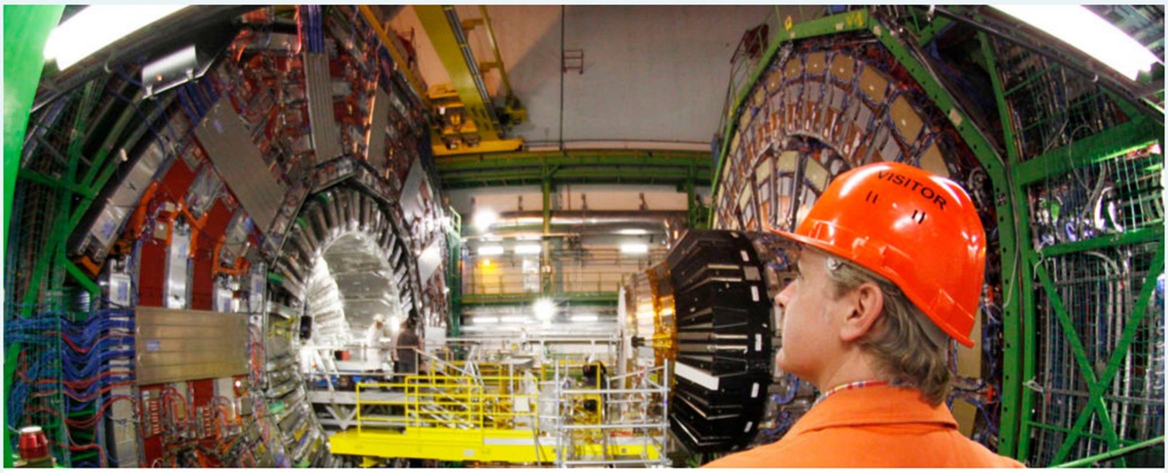
LOOK OUT TEACHER PROGRAM: 'SUGAR SPIN' ART MEETS SCIENCE

23 MARCH 2017 QAGOMA



VENUE	LOCATION	DATE	TIME	COST
QAGOMA	GOMA, Stanley Place, South Brisbane, Queensland, Australia	23 March 2017	4:15pm - 5:30pm	Free

SUMMARY

Investigate the interplay between art and science within 'Sugar Spin: you, me, art and everything', through the lenses of:

* Geraldine Barlow, Exhibition Curator, (Curatorial Manager, International Art QAGOMA)
* Chris Henschke, Melbourne-based Artist, (Lecturer, RMIT)
* Nurin Veis, Human Biology and Medicine Senior Curator, (Manager Science Works, Museum Victoria); and
* Dr Guy Barry, Neuroscientist, (Team Head, Neurogenomics, QIMR Berghofer).

Each speaker will relate their practice to an aspect of 'Sugar Spin', highlighting synergies between art and science. The exhibition brings together over 250 artworks from the Gallery's collection, creating a collision of ideas from across times and cultures.

This is an event for teachers of STEM and Art who seek to provide students with project-based learning opportunities that inspire transdisciplinary lines of inquiry and unlock new ways of thinking about how we come to know the world and our place within it.

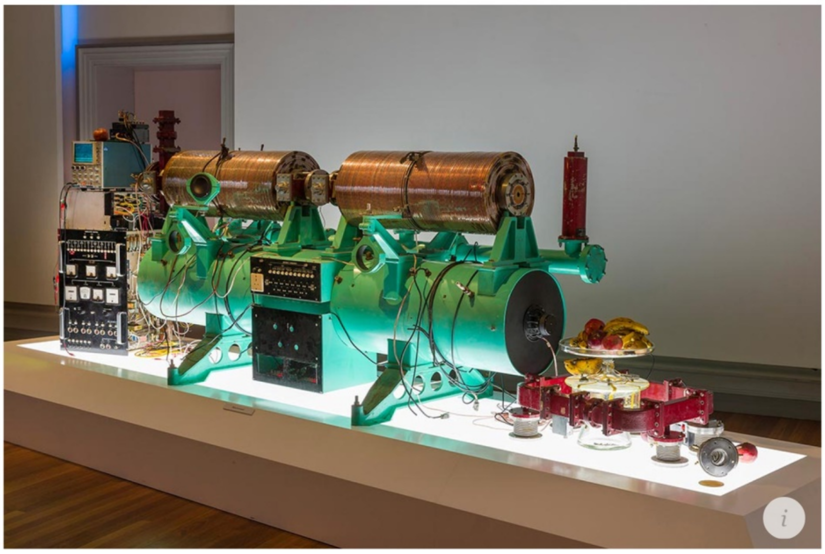
Brochure for "'Sugar Spin' Art Meets Science", Queensland Gallery of Modern Art / World Science Festival, Brisbane, Australia, 23 March 2017.

the Article
(http://thearticle.com.au)

December 5, 2016

The Ghosts In The Machines: Morbis Artis

by Sam Leach(http://thearticle.com.au/author/samleach/)

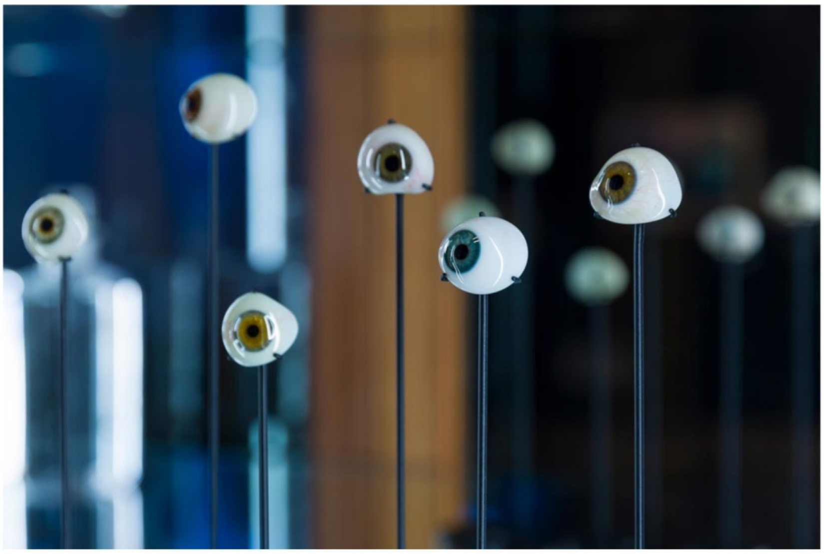


(http://thearticle.com.au/go/cinema-nova/)

In Chris Henschke's *Song of the Phenomena*, a bowl of decaying fruit is the focus of a retired linear particle accelerator. As the viewers look at the fruit, so does this massive machine. A bowl of decaying fruit is the emblem of still-life painting, *Natur Morte* or *Vanitas*. In still-life painting, the subject is arrested in the moment of death – a reminder of mortality and the transient nature of the physical world. Where the painted still-life is essentially static, the decay forever caught in the image, in this work the decay is an ongoing, noisy chaotic process. As Henschke explains, "the LINAC [linear accelerator] is

Review in "The Article" online art magazine, December 2016.
http://thearticle.com.au/2016/12/the-ghosts-in-the-machines-morbis-artis/

activated by natural radiation from the atomic decay of potassium in the organic material." This activation takes the form of uneasy sound and noise. The accelerator is huge. A hulking beast of a machine with oversized copper coils exuding like metallised entrails. The sense of mass is palpable, as though we can feel its gravitational pull. And yet this machine is seemingly floating on a streamlined, glowing plinth, as though defying the physics of its scientific heritage. Henschke has made this machine into a massive analogue synthesiser – playing the subatomic orchestrations of rotting and putrefying vegetation.



This spectacular work is the first piece encountered on entering the exhibition 'Morbis Artis,' brilliantly curated by Sean Redmond and Darrin Verhagen. The title translates to "diseases of the art" and the premise is described as an exploration of "the radical conjunction between the biomolecular and the artistic, and the thin doorway between life and death housed within discourses of disease." The themes of disease and the biomolecular are sometimes more and sometimes less literally interpreted across the various installations in this show.

At the more literal end, Drew Berry presents an animated rendering of biomolecular processes within the body of an organism. This video is compelling and fascinating. But it would also be at home as a sequence in a high-budget science documentary. Berry's skill in producing this kind of work is without question. But one of the challenges in the sub-genre of art/science is the tendency to present artwork as illustrative of science. As James Elkins (and others) have pointed out, this makes of an awkward pairing of art and science. Fortunately, the other works in this show are less overtly illustrative, and Berry's piece has enough visual appeal to justify its inclusion.

The human body remains central to most of the works in 'Morbis Artis.' 20Hz provide an interactive installation using lights, sounds and sensors to perhaps induce nausea or something like motion sickness – directly impacting the physical body of the viewer. The damaged human body is aestheticised in Alison Bennett's *Bruise*, an interactive video work in which bruised human flesh can be manipulated and moved on a screen. The viewer seemingly touching and manipulating the damaged organ, just to see how it looks, reminiscent of the Iain M Banks' bruise artist in his SF novel *Use of Weapons*.

A more allegorical or metaphorical thread is followed in Harry Nankin's work *Szygy*. Astronomical images from glass plate negatives taken from observatories are exposed onto photographic paper along with the silhouettes of insects formed, according to the wall-text, with "camera-less photography." Insects seem to be suggested as emblematic of disease, pestilence, or infection of an image, but the works are poetic and quite beautiful. Nankin's photographic works combine elements of scale, time, the human and the non-human in a highly effective way. The result is an emphasis on connection rather than threat or disruption.

Joshua Redmond and Sean Redmond's video work *Invasion of the Ants* also draws analogies between the human and non-human world by juxtaposing images of refugees and ants. This, rather unfortunately, brings to mind the British columnist Katie Hopkins comparison of refugees to cockroaches in the UK newspaper *The Sun* in 2015. The premise of the show leads us to think that the insects are a symbol of pestilence, so I take this work in part as a critique of the mindset of commentators like Hopkins. Are refugees then a symptom of a societal disease symbolised by ants? Ants are amazing creatures capable of extraordinary feats so perhaps this is intended more as a consideration of humans as a super-organism.

In Andrea Rassell's *We Are Silently Surveilling one Another* the viewer looks into the eyepieces of a microscope to see a video of humans milling on a street. The allusion here to humans as a pathogen is clear. Though there is a secondary reference, as most people are familiar with the image of milling bacteria though popular science programs, rather than directly viewing through a microscope. So the work deals equally with the idea of the human view of the microscopic world as it does with the *Matrix*-like "humans are like a virus" allegory.

Finally, the disease of the human is eradicated in *The Zero Monument (or the Human Stain Remover)* by Simon Reis and Cameron Bishop. This work is a large machine into which replica Malevich paintings are fed and which produces smooth green monochrome canvases. Although I did not have a chance to see this machine in operation, if indeed it does operate, it certainly looked like it would function. As the artists observe, Malevich's experiments with the end of painting still bore the problematic traces of human production. The work eliminates these traces and proposes "green as the colour of the future." Like the green-screen of video production, anything could be projected onto this surface. The monstrous machine occupies a corner of the gallery and, as the title suggests, is a modernist monument in itself. The clean lines of the constructed object hint at a world in which the unclean smudge of human contact has finally been eradicated.

'Morbis Artis' has some stunning high points and includes some spectacular work. The curatorial texts refer frequently to bio-art, which is usually understood to mean work made using organisms. This was not foregrounded in the work included, so perhaps the curators are suggesting a new interpretation. The works provide scope for a poetic and elliptical understanding of the interactions between humans and non-humans and the ideas of connection and contamination. But the most compelling works, such as Henschke's *Song of the Phenomena*, operate on their own terms.

Morbis Artis
Nov. 17, 2016-Feb 18, 2017
RMIT Gallery, City campus

Photo Credits:
Header Image: Chris Henshke, Song of the Phenomena. Photo: Mark Ashkenazy Mark Ashkanasy © RMIT Gallery.

By Jo Khan (/articles/?author=589b944e3a0411d26d78d136)

UNEXPECTED HARMONIES (/ARTICLES/ISSUE-20/UNEXPECTED-HARMONIES)

March 13, 2017 (/articles/issue-20/unexpected-harmonies) · Issue 20 (/articles/?category=Issue+20), Physical Science (/articles/?category=Physical+Science)

EMOTIONLESS PHYSICS DATA CAN BE TRANSFORMED THROUGH A PROCESS CALLED SONIFICATION. CHRIS HENSCHKE USES THIS TO TEASE THE MUSIC OUT OF LIGHT.

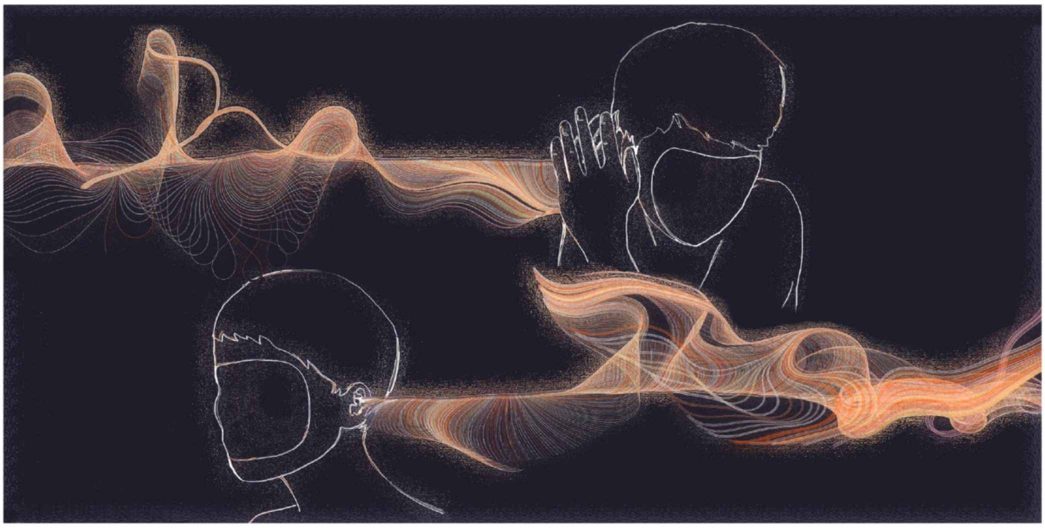


Illustration by Olivia Baenziger

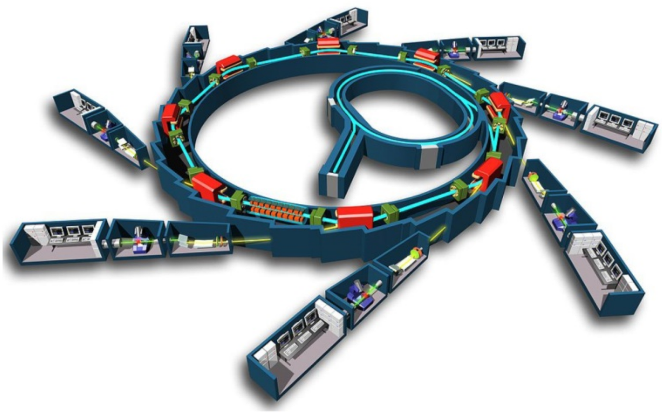
Article in "Lateral" online magazine, Issue 20, March 2017.
http://www.lateralmag.com/articles/issue-20/unexpected-harmonies/

It may have crashed the Synchrotron, but the experiment was still a success. The scientists cheered; “It’s your first beam dump! Woohoo!”

On the final day of his residency at the Australian Synchrotron (http://www.synchrotron.org.au/), multimedia artist Chris Henschke joined the ranks of a special group of physicists — those who have meddled with the high energy electron beam of the particle accelerator, and caused it to crash into the walls of the vacuum chamber in which it exists. Ultimately, a harmless error that can occur during experiments, but a headache nonetheless.

It was summer, and it had been one of those oppressively hot Melbourne days. Earlier, Henschke had been out in the car park listening to cicadas humming in the sun and wondered if a synchrotron's tune might sound like that, if it was audible. Synchrotrons (http://www.synchrotron.org.au/synchrotron-science/what-is-a-synchrotron) are large circular machines that accelerate electrons to almost the speed of light — they aren’t exactly known for their musical abilities. But if they could create a tune, it would come from the complex combination of variables that keep the electron beam stable as it whizzes around and around the 200m-circumference ring.

With the Australian summer reflecting off the bitumen of the car park, Henschke recorded the cicada’s song, translated the audio into amplitude data, and then changed the synchrotron “tune” by feeding the recording into the accelerator. The result surprised everyone in the room. “The cicada song resonated with the synchrotron tune, gave it too much energy, and made the beam dump,” said Henschke. In a brief moment of poetic connection, Henschke had managed to bribe the synchrotron into singing the same song as the cicada.



A synchrotron is a large, circular particle accelerator. An electron beam flies around the inner ring at 99.98% the speed of light. If the beam is kept in "tune", the beam then moves to the outer storage ring where it passes through magnetic fields to create a very bright light. This light is split off into different wavelengths (i.e infrared, x-rays) and directed down straight beamlines to be used in precise experiments. Copyright © EPSIM 3D/JF Santarelli, Synchrotron Soleil/Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Sch%C3%A9ma_de_principe_du_synchrotron.jpg)

It's been 10 years since Henschke wandered through the halls of the Australian Synchrotron for the first time, his mind boggling at the immensity of the establishment and its operations. The first artist to reside at the Synchrotron, even those in charge couldn't quite fathom Henschke's presence. The common query was: "Where's your paintbrush, your easel?" But at no stage was paint involved. Instead, Henschke chose particle physics as his medium — manipulating data into sound.

When it comes to the seemingly unusual compatibility of music and physics, Henschke, paraphrasing the Nobel Prize-winning physicist Richard Feynman, said: "Physics is creativity in the tightest of straight jackets." Henschke argues that music and physics are not so dissimilar. "Music is something that we use as a tool to understand the universe, as is high energy particle physics." While physicists study particles to help comprehend our world, music has the potential to increase people's understanding of physics itself.

In fact, the link between music and physics, or art and science more broadly, is completely natural. For synchrotron physicist Dr Mark Boland, the increasingly appreciated science-art interface can be seen as "closing a loop that was opened probably a few centuries ago, when there was a separation of art and science and religion." While Dr Boland believes that art and science "seem to be coming together again quite naturally," he realises that the intersection may be surprising "for people who are used to the segregated paradigm" that society has embraced for so long. Dr Boland has worked with Henschke on several of his projects at the Synchrotron and, like Henschke, he believes that art and science are just "different aspects of human endeavours that are trying to understand the meaning of it all".

> “
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> Music is something that we use as a tool to understand the universe, as is high energy particle physics
>
> — Chris Henschke

According to Henschke, there are three loose categories of science art: art inspired by science, art that in some way engages with scientific concepts or findings, and art that uses science in its creation.

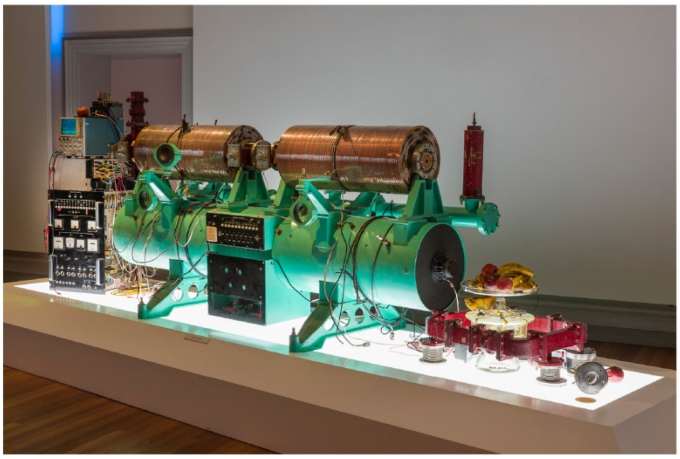
Henschke’s work with particle physics ensures that he is firmly rooted in the third category. He uses both the data and the equipment from particle accelerators to create art and music. Emotionless physics data can be transformed, literally and figuratively, through a process called sonification (https://www.google.co.nz/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=sonification&*). Sonification is the auditory equivalent of data visualisation and it allows scientists to hear anomalies or irregularities in their data that they are unable to see (http://www.economist.com/news/science-and-technology/21694992-scientific-data-might-be-filled-important-things-waiting-be-discovered). However, sonification is more than a data exploration tool. Henschke believes that there’s huge potential for sonification to aid in the understanding of complex physics concepts.

One of his first attempts to combine the two led him to Switzerland, where, for the last few years, he has collaborated with scientists at the European Council for Nuclear Research (CERN (https://home.cern/about)) in the Art@CMS (http://artcms.web.cern.ch/artcms/) project. In collaboration with experimental physicist Wolfgang Adam, Henschke crafted a sound installation based on the high-energy particle collisions occurring within the Large Hadron Collider (LHC (https://home.cern/topics/large-hadron-collider)) — the world's largest and most powerful particle accelerator (its 27km rings make the Australian Synchrotron's paltry 200m circumference seem tiny). Once Adam had mathematically transformed the particle collision data, Henschke was able to compose the various collision events into a 10-minute sound piece called Song of the Muons (https://www.youtube.com/watch?v=y73CsBtzUQE).

The fruit of their labour was exhibited during the IEEE Nuclear Science Symposium (http://www.ieee.org/conferences_events/conferences/conferencedetails/index.html?Conf_ID=36109) in October 2016, much to the delight of Professor Barry Barish, a long-time member of the sonification cheer squad who led the LIGO project (https://www.ligo.caltech.edu/)which first detected gravitational waves. But, it wasn't just physicists who appreciated the project. The Song of the Muons installation consisted of eight tall oblong speakers positioned in a circle, where each speaker is an individual sound channel. When combined, it allowed people to experience the sound of particle physics.

It starts off as indistinguishable noise — like torrential rain on a tin roof — which is the detection of hadrons (https://en.wikipedia.org/wiki/Hadron) and muons as recorded from the LHC. The sound transitions to the second section of the piece, narrowing in on specific events, like listening to individual rain drops. The final section of the sound installation emphasises and extends some particle events even further, drawing them out to the point where time itself is almost stopped. The piece is a genealogy of particle collision events, travelling through different time-scales, from particle to human, of which Henschke said: "nature itself is the source of the composition."

Closer to home, Henschke recently finished exhibiting a project at the RMIT Gallery in Melbourne inspired by reversing the Synchrotron cicada experiment. Using an old linear particle accelerator from the Australian Synchrotron and a bowl of fruit, the Song of the Phenomena (https://rmitgallery.com/2016/12/09/photography-particle-accelerators-harry-nankin-chris-henschke-at-rmit-gallery/) explores the connection between the quantum and macroscopic worlds. Instead of using the accelerator to produce particles (as it once did for medical radiological experiments) the atomic emissions from the fruit are recorded by a Geiger counter, which then modulates the 220Hz sound waves that pass through the accelerator tube. This elaborate method produces a gentle hum, interspersed with clicks and beeps when the accelerator senses electrons and positrons emitted from the high potassium fruit. Nature is again the composer, decaying fruit providing the background music to unsuspecting gallery-goers.



Witnessing the decay of fresh fruit, the Song of the Phenomena converts positrons and electrons emitted from the potassium-filled fruit to clicks and beeps. © Mark Ashkenazy (used with permission)

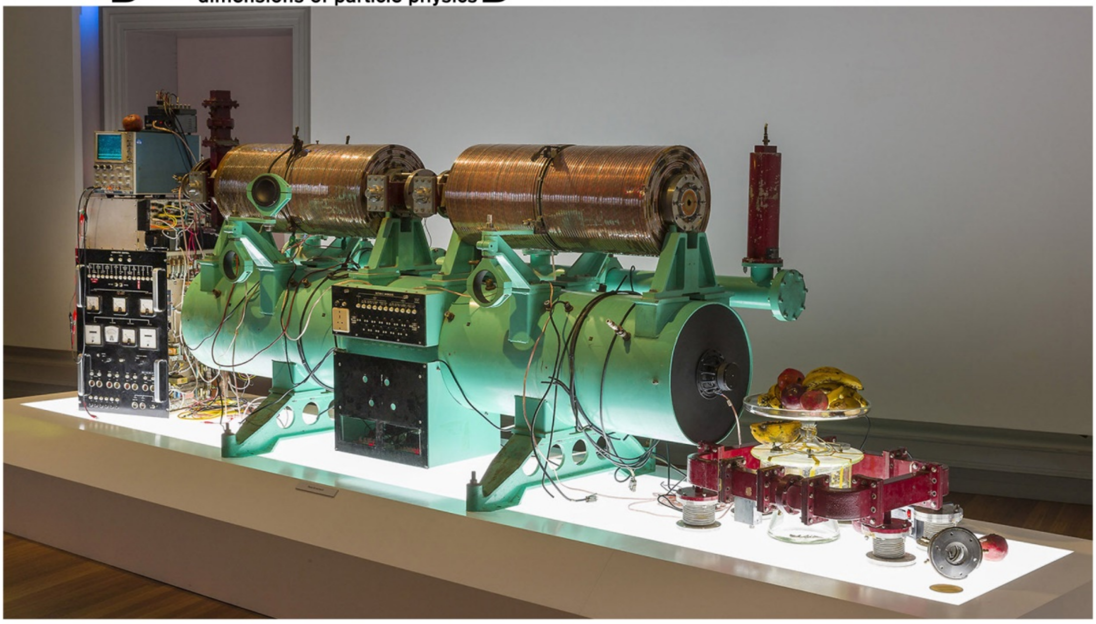
Henschke has long been fascinated by the relationship humans have with machines and devices. The tiniest discoveries in particle physics often rely on gargantuan machinery, with particles such as the Higgs boson only really existing within the machine that created them. A larger ambition of the Song of the Phenomena is to convey this concept that the phenomenon and the apparatus are fundamentally intertwined, that one cannot exist without the other. Without the machinery, you'd just have a bowl of fruit. But without the fruit, you're simply displaying a feat of engineering, and you don't get a sense of how it works. Through his sonification projects, Henschke hopes to explain confusing physics concepts like these using art.

High energy particle physics is a complicated field. “It's important [for scientists] to have an artist's mindset, in order to interpret what's going on in a different way. Because often the paradigm in which they are working is quite far removed from basic concepts that the public deal with,” said Dr Boland. When humans interact with technology it is usually with images and sound, so if the visual communication of particle physics isn't working, then perhaps sonification and music are the future. As Henschke says, “digital media is so malleable, communication has been re-established between art and science practice." It may not even be that far off, as sonified data from CERN has already made its way onto the stage at a music festival (https://home.cern/about/updates/2016/05/make-music-atlas-data).

Throughout his career working on science art, Henschke has found that sound waves are the common language connecting him with particle physicists. The scientists work with frequencies and amplitudes and so do musicians and composers — just at a much lower energy. Henschke might be one of the first to use the power of music and sound to explore the world of particle physics, but he certainly won't be the last to strive for this unexpectedly harmonious connection between science and art.

Edited by Tessa Evans and Bryonie Scott

symmetry
dimensions of particle physics



Mark Ashkenazy

Art intimates physics

04/03/17 | By Liz Kruesi

Artist Chris Henschke's latest piece inspired by particle physics mixes constancy with unpredictability, the natural with the synthetic.

Artist Chris Henschke has spent more than a decade exploring the intersection of art and physics. His pieces bring invisible properties and theoretical concepts to light through still images, sound and video.

Article in "Symmetry: Dimensions of Particle Physics" online magazine, March 2017.
http://www.symmetrymagazine.org/article/art-intimates-physics/

His latest piece, called "Song of the Phenomena," gives new life to a retired piece of equipment once used by a long-time collaborator of Henschke, University of Melbourne and Australian Synchrotron physicist Mark Boland.

Crossing paths

The story of "Song of the Phenomena" begins in the 1990s. In 1991, Henschke enrolled in the University of Melbourne to study science, but he turned to sound design instead. Boland entered the same university to study physics.

Personal computers were just entering the market. Sound designers and animators began coding basic programs, and Henschke joined in. "I was always interested in making sounds and music, interested in light and art and physics and nature and how it all combines—either in our heads or the devices that mediate between us and nature," he says.

Boland completed his thesis in physics at the Australian Radiation Laboratory (now called the Australian Radiation Protection and Nuclear Safety Agency). He was testing a new type of electron detector in a linear accelerator, or linac. The linac used radio waves to guide electrons through a series of accelerator cavities, which imparted more and more energy to the particles as they moved through.

That particular linac spent more than 20 years with the Australian Radiation Protection and Nuclear Safety Agency, where medical physics professionals used it to accelerate electrons to different energies to create calibration standards for radiation oncology treatments. Once they no longer needed it, Boland's former advisor contacted him to ask if he'd like the accelerator or any of its still-working parts. He said yes, though he was unsure what he would do with it.

An artist’s view

In 2007 Henschke came to the Australian Synchrotron as part of an artist-in-residence program. Boland was familiar with his artwork; he had seen Henschke’s first piece exploring particle physics in the pages of *Symmetry* (http://www.symmetrymagazine.org/article/may-2005/gallery-chris-henschke). Boland grew up with an appreciation for art; he says his parents made sure of that by “dragging” him through many galleries in his youth.

When Henschke and Boland met, they got into an hours-long conversation about physics. “We hit it off, we resonated,” Boland says, “and we’ve been working together ever since.”

Since that first residency program, Henschke has spent significant time at the Australian Synchrotron facility and at CERN European research center and has taken shorter trips to the DESY German national research center.

His process of creating artwork echoes the scientific process and the setup of an experiment, Boland says. Henschke thinks through the role that each piece of the artwork plays. Everything is where it is for a reason.

“He’s a perfectionist, he doesn't settle for second best,” Boland says. “He has the same level of professionalism and tenacity as an artist as a physicist does. It’s as if there’s a five-sigma quality test on his work as well.”

Once accelerator, now art

Boland mentioned the linac he had to Henschke during a conversation in early 2016. “Chris ran with it,” Boland says. “He took it and made it into his installation.”

Henschke discovered the machine hums at 220 hertz—the musical note of A—as it produces its resonant waves. “In a sense, particle accelerators are gigantic, high-energy synthesizers because they are creating high-energy waves at very specific frequencies and amplitudes,” Henschke says.

Henschke explored different aspects of the machine, still unsure how each part would come together as a final piece of art. “I have to let it speak to me, I have to let it speak for itself,” he says.

Finally it dawned on him; the art could be an echo of the accelerator’s past.

The accelerator no longer accelerates electrons. Instead Henschke feeds it a steady supply of electrons and their antimatter partners, positrons. He does this by placing it beside a pile of bananas, which release the particles as their potassium decays. (Using decaying fruit was a nod to Dutch still-life vanitas paintings, Henschke says.)

Observers cannot see the electrons and positrons in the piece, but they can hear them. Henschke ensured this by adding a Geiger counter, which emits a chirp each time it detects a particle.

Visitors can also hear the accelerator itself. Henschke attached speakers and pumped up the sound of the machine’s natural hum with a stereo amp (a bit too much at first; they blew up an oscilloscope they were using to measure the frequency). He used an AM radio coil to amplify the sound of the accelerator's electromagnetic field.

"Song of the Phenomena" plays upon resonance, amplification and decay, Henschke says. "It creates this tension between the constant hum of the device versus the unpredictability of the subatomic emission."

The idea of playing with the analogy between the linac's resonance and sound resonance is one that Australian Synchrotron Director Andrew Peele appreciates. "A lot of science communication is about how you find analogies that people can engage with, and this is a great example," Peele says.

Henschke displayed "Song of the Phenomena" at the Royal Melbourne Institute of Technology Gallery from November 17, 2016, to February 18, 2017. Since then, the apparatus has returned to the Australian Synchrotron, where it sits in a vast, open room where some of the facility's synchrotron beamline stations used to stand. Scientists meet nearby for a weekly social coffee break.

Henschke is currently writing his thesis for his PhD in experimental art (with Boland as his advisor). In his next project, he hopes to tackle the subject of quantum entanglement.

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Welcome to ANAT's Synapse Alumni Network

art science collaborations
synapse
ALUMNI NETWORK

FEATURE :: SYNAPSE ALUMNI

In the lead up to our inaugural event in October, the Australian Network for Art & Technology (ANAT) is eager to showcase some of the former, fabulous, art+science residencies that have taken place over the past 18 years. First to feature is:

Chris Henschke + Associate Professor Mark Boland at the Australian Synchrotron

Article in "Synapse: art science collaborations", June 2017.
http://www.anat.org.au/synapse/

Image: L-R, Chris Henschke and Mark Boland, Delphi experiment, CERN. Photo by Donna Kendrigan.

Getting in Sync

In July 2007, the Australian Synchrotron opened its doors to the national and international scientific community and, in October of the same year, Chris Henschke became its first Artist in Residence.

This initial residency, supported by ANAT and Arts Victoria's Innovation Residency Program, gave Chris an opportunity to work with Associate Professor Mark Boland. Together, they created an audio-visual interface to explore the nature of the synchrotron's 'tune' – what scientists call the complex frequency harmonics generated from the synchrotron's beam status and position data – and to make this real-time data available to other artists and researchers.

Mark says Chris fitted into the Synchrotron's working culture, and noticed parallels in their working practice. "Artists are similar to scientists in many ways – late starts to the day, bursts of enthusiasm followed by long periods of head-scratching and self-questioning and doubts, followed by breakthroughs and euphoria."

During this first residency, Chris developed image-manipulation processes to visualise the synchrotron's frequencies, producing some spectacular images in the process. He also created a mesmerising sound recording of the synchrotron's tune, making it audible to the human ear using the 'vocalisation' of a cicada recorded at the building's entrance.

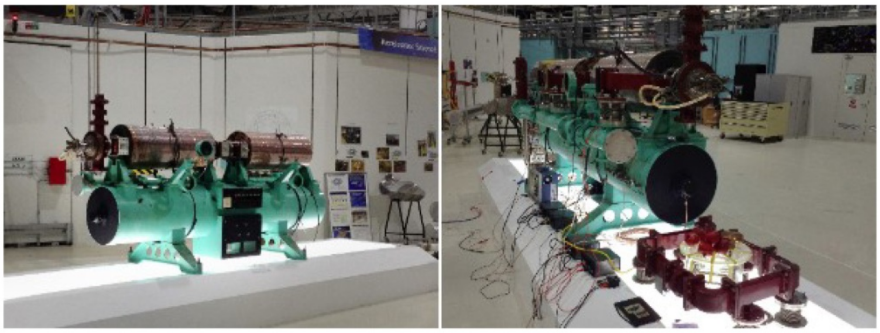

Image: *Song of the Phenomena, in-situ installation, day one and two*. Photos courtesy the artist.

Synapse Residency

In 2010, Chris returned to the Synchrotron as a Synapse resident, to again work with Mark, this time on the *Lightbridge Project*.

The *Lightbridge Project* is an animated visualisation of light captured at the heart of the synchrotron, using processes similar to those employed by the resident scientists. Chris describes it as an expression of his perception of the physics, and Mark agrees, describing the work as “a visual journey into the physics and technology of particle accelerators. It felt in many ways like I was looking at my physics through fresh eyes with a different understanding and different imperatives.”

One resulting work, *Lightcurve*, was exhibited at Sydney’s Powerhouse Museum as part of the *Synapse: A Selection* show at ISEA2013.

From Australia to CERN

At Mark’s invitation, Chris joined him on the first of many visits to the European Organisation for Nuclear Research (CERN) in Switzerland and France, where they spent most of the time with the CMS experiment at the Large Hadron Collider.

Chris continues to be involved in the art@CMS program, which is comprised of multiple projects, all underpinned by the goal of speaking to new audiences by fostering creative synergies between scientists, students, educators and artists from around the world.

Chris and Mark’s Synapse residency was also used as a case study in the establishment of Collide@CERN’, the prestigious artist’s residency program delivered in partnership with Ars Electronica.

Following from his work at the CMS experiment, Chris produced the *Symmetries* exhibition, held during the 24th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2016), organised by the ARC Centre for Excellence for Particle Physics at the Terascale in Melbourne. The exhibition was the Australian premiere of works from art@CMS and featured artwork by Michael Hoch, Alessandro Catocci with Pierluigi Paolucci, and Yuki Shiraishi with John Ellis.

Most recently, Chris's work *Song of the Phenomena* (pictured) - a $3 million particle accelerator powered by a banana - was included in the exhibition Morbis Artis at RMIT Gallery, curated by Sean Redmond and Darrin Verhagen. As Chris explains it, *Song of the Phenomena* "has manifested as, perhaps, my final synchrotron project. Instead of using digital data and synchrotron simulation software, I'm feeding analogue data into and out of a real particle accelerator Mark and I have wired up, and it works!"

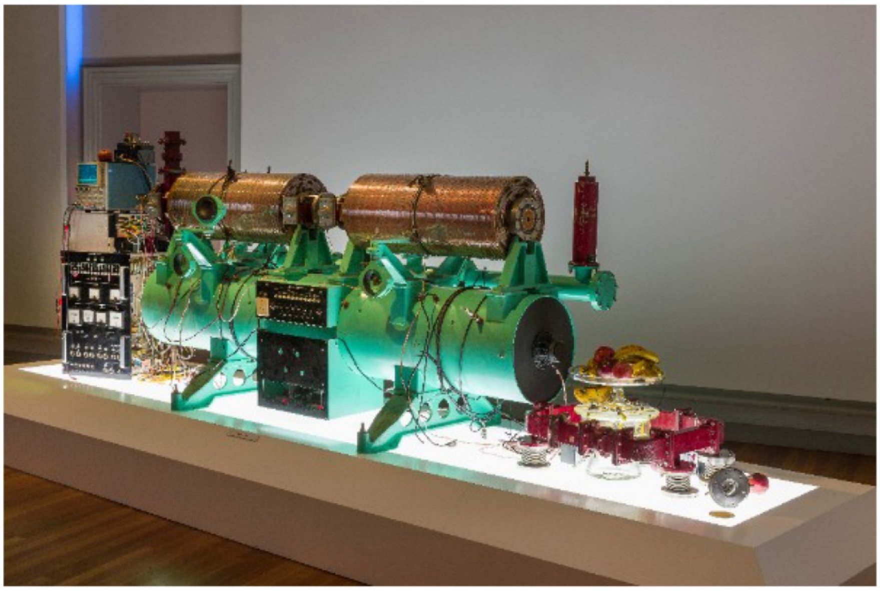

Image: '*Song of the Phenomena', at the 'Morbis Artis' exhibition, RMIT Gallery, 17.11.16 - 18.02.17.*

Photo: Mark Ashkanasy © RMIT Gallery.

Chris and Mark's long-term collaboration underlines the value of the Synapse model for art/science research residencies, with their focus on speculative research and the establishment of partnerships that optimise the potential to engage deeply.

It is no surprise that such partnerships continue well past the residency conclusion, speaking to the long time-frames necessary for this type of research. Patrick Woods, Deputy Vice-Chancellor and Vice President, Resources at the University of Technology Sydney noted recently that "the average pay back time for 'deep research' is 17 years."

For his part, Chris says he knew that the day he walked into the synchrotron and began working with Mark, he was at the very beginning of a long-term project. "At the time I realised to make any discoveries would take a very long time. Seven years later I'm almost there!"

Read more:
http://henschke2010.anat.org.au/
http://henschke.anat.org.au/
http://filter.org.au/issue-72/the-sound-of-science-and-the-sound-of-silence