The Sirepo framework for X-ray optics, linac design, machine learning and controls

Presenter: David Bruhwiler
bruhwiler@radiasoft.net

RadiaSoft LLC
3380 Mitchell Ln
Boulder, CO 80301

Collaborators –
Sirepo team: R. Nagler, P. Moeller, M. Keilman & E. Carlin (RadiaSoft)
X-ray optics: O. Chubar & M. Rakitin (NSLS-II), B. Nash & N. Goldring (RS)
USPAS: K. Ruisard *et al*. (ORNL)
ML: J. Edelen, N. Cook, C. Hall, S. Webb (RadiaSoft)
K. Brown, P. Dyer (BNL), A. Edelen (SLAC)

Seminar – SLAC National Accelerator Laboratory

19 September 2019 – Menlo Park, CA

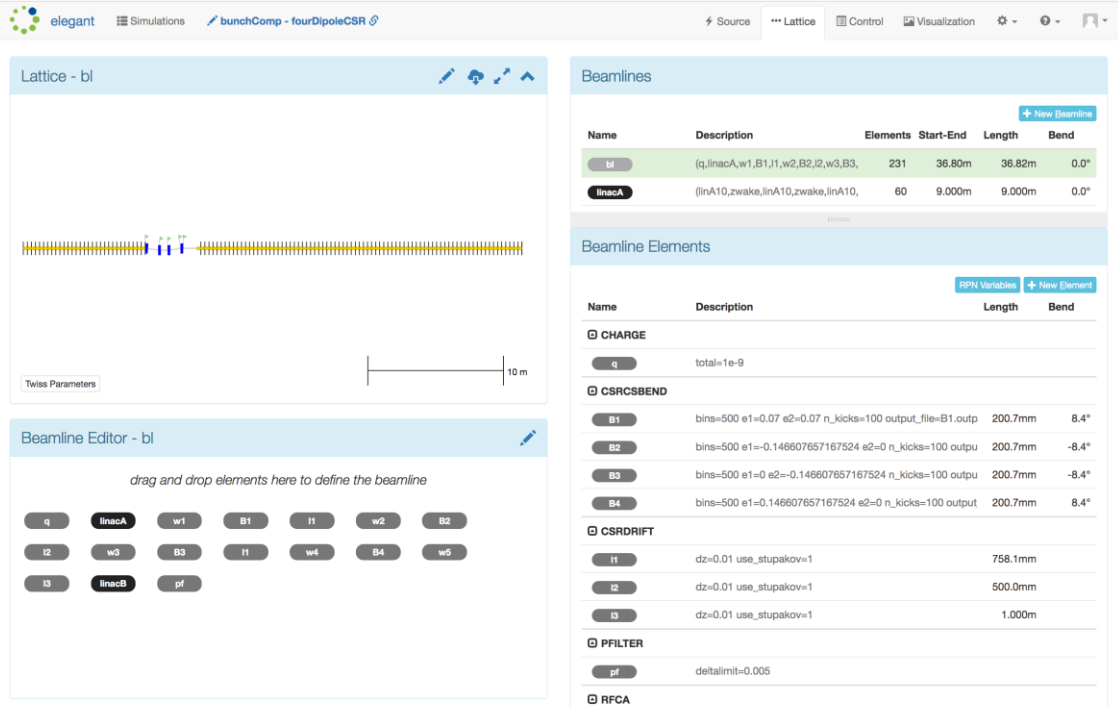
This work is supported by the SBIR program of the US Department of Energy (DOE), Office of Science under Award Nos. DE-SC0011237 and DE-SC0019682 (BES);
DE-SC0011340, DE-SC0013855, DE-SC0015897 and DE-SC0018719 (HEP);
DE-SC0015212 and DE-SC0017181 (NP); DE-SC0017057 and DE-SC0017162 (ASCR).

Outline

- *Brief overview of Sirepo*
- *Sirepo/`SRW` – undulator SR brightness*
- *Sirepo/`elegant` – use for education*
- *Sirepo initiatives for controls & machine learning*
- *Sirepo developments for submitting to NERSC*

https://sirepo.com is a free Scientific Gateway

- Supported Codes
  - *SRW*
  - *elegant*
  - *Warp VND*
  - *Warp PBA*
  - *Synergia*
  - *Zgoubi*
  - *JSPEC (e- cooling, IBS)*



Name	Description	Elements	Start-End	Length	Bend
bl	(q,linacA,w1,B1,l1,w2,B2,l2,w3,B3,	231	36.80m	36.82m	0.0°
linacA	(linA10,zwake,linA10,zwake,linA10,	60	9.000m	9.000m	0.0°

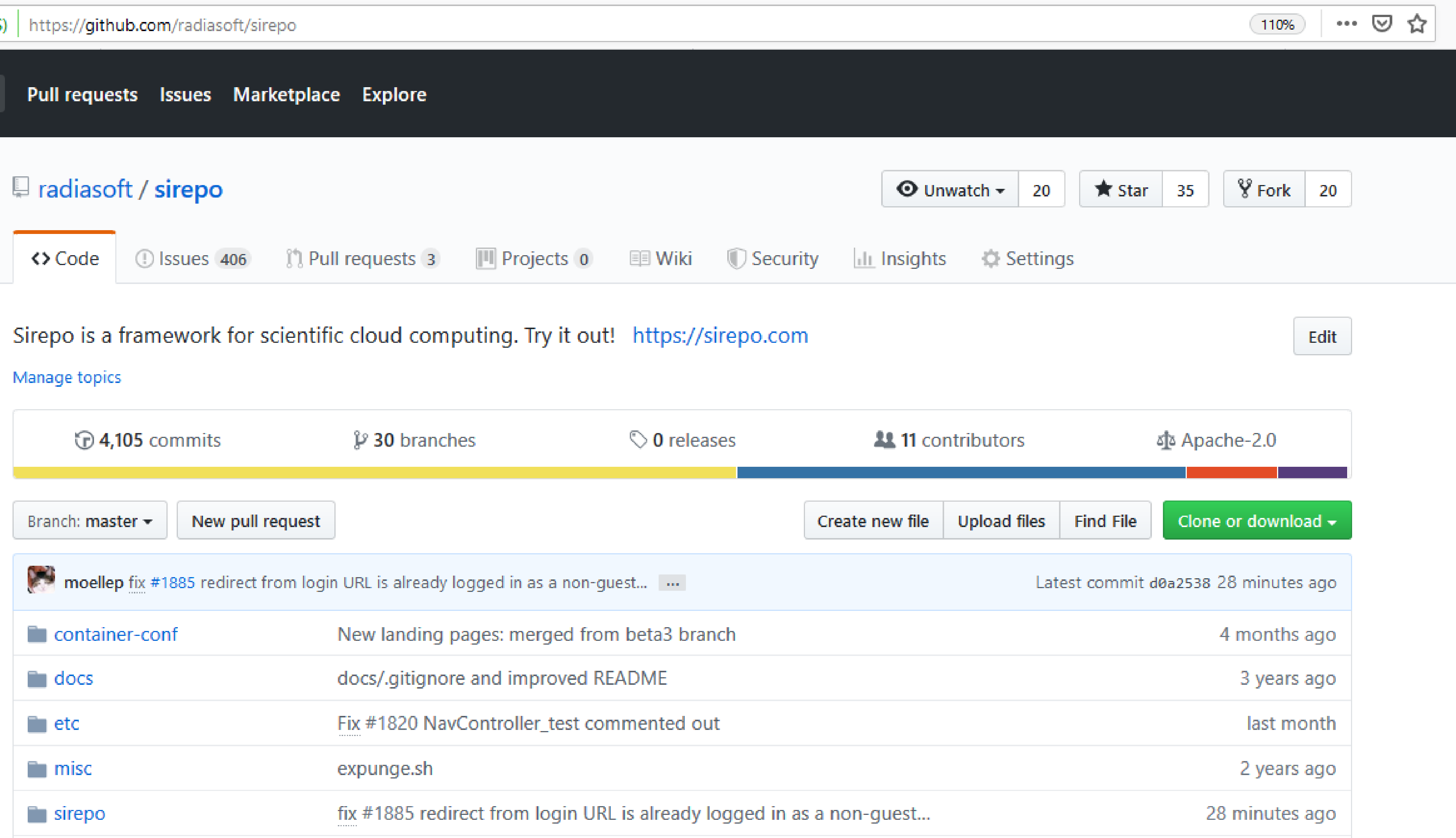
Name	Description	Length	Bend
⊟ CHARGE			
q	total=1e-9		
⊟ CSRCSBEND			
B1	bins=500 e1=0.07 e2=0.07 n_kicks=100 output_file=B1.outp	200.7mm	8.4°
B2	bins=500 e1=-0.146607657167524 e2=0 n_kicks=100 outpu	200.7mm	-8.4°
B3	bins=500 e1=0 e2=-0.146607657167524 n_kicks=100 outpu	200.7mm	-8.4°
B4	bins=500 e1=0.146607657167524 e2=0 n_kicks=100 output	200.7mm	8.4°
⊟ CSRDRIFT			
l1	dz=0.01 use_stupakov=1	758.1mm	
l2	dz=0.01 use_stupakov=1	500.0mm	
l3	dz=0.01 use_stupakov=1	1.000m	
⊟ PFILTER			
pf	deltalimit=0.005		
⊟ RFCA			

D.L. Bruhwiler *et al*., “Knowledge Exchange Within the Particle Accelerator Community via Cloud Computing,” in *IPAC* (2019).

- The power of Sirepo for users
  - *Easy to use: nothing to install, build, or maintain*
  - *Instantaneous collaboration: share your work with a single link*
  - *Archive & save: resume work weeks or months later with zero start-up time*
  - *You're not locked in: export files for command-line execution*

Sirepo is an open framework for cloud computing

https://github.com/radiasoft/sirepo



radiasoft / sirepo

Sirepo is a framework for scientific cloud computing. Try it out! https://sirepo.com

4,105 commits · 30 branches · 0 releases · 11 contributors · Apache-2.0

moellep fix #1885 redirect from login URL is already logged in as a non-guest… … Latest commit d0a2538 28 minutes ago

container-conf	New landing pages: merged from beta3 branch	4 months ago
docs	docs/.gitignore and improved README	3 years ago
etc	Fix #1820 NavController_test commented out	last month
misc	expunge.sh	2 years ago
sirepo	fix #1885 redirect from login URL is already logged in as a non-guest…	28 minutes ago

The Sirepo vision – *computational science in the cloud*

- The browser *is* the Scientific UI
  - *via AngularJS, Bootstrap and D3.js*
    - **3D graphics via VTK.js**
  - *share your full simulation via web link*
    - **…and many other ways**
  - *work from tablet, laptop or desktop*
  - *fast, interactive scientific plotting*
- Server is built on Flask & other technologies

M.S. Rakitin, P. Moeller, R. Nagler, B. Nash, D.L. Bruhwiler, D. Smalyuk, M. Zhernenkov and O. Chubar, “Sirepo: an open-source cloud-based software interface for X-ray source and optics simulations,” *Journal of Synchrotron Radiation* **25**, 1877 (2018).

- Application containers via docker
  - *executable, portable; all codes & dependencies*
  - *a single Linux environment for RadiaSoft to maintain*

Online calculations of X-ray photon brightness

- *Overview of SRW (Synchrotron Radiation Workshop)*
- *Brightness formulas*
- *Calculating brightness with SRW*
- *Example calculation for simulated HBB parameters*
  - *Trojan Horse; Manahan et al., Nature Comm. (2017)*
- *Exercise for the audience*
  - *repeat these simulations yourself –*

https://sirepo.com/srw#/source/kH9BPjRb

Synchrotron Radiation Workshop (SRW) –

a physical optics code for SR emission and propagation

First work on Wavefront Propagation applied to SR beamlines (PHASE code): J. Bahrdt, Appl. Opt. 36 (19) 4367 (1997)

- First official version of SRW was developed at ESRF in 1997-98 (written in C++, interfaced to IGOR Pro); compiled versions are distributed from:
  http://www.esrf.eu/Accelerators/Groups/InsertionDevices/Software/SRW
  Many thanks to Pascal Elleaume.
- SRW was released as Open Source in 2012, thanks to several institutions:

ESRF European XFEL SOLEIL SYNCHROTRON diamond U.S. DEPARTMENT OF ENERGY Office of Science BROOKHAVEN NATIONAL LABORATORY

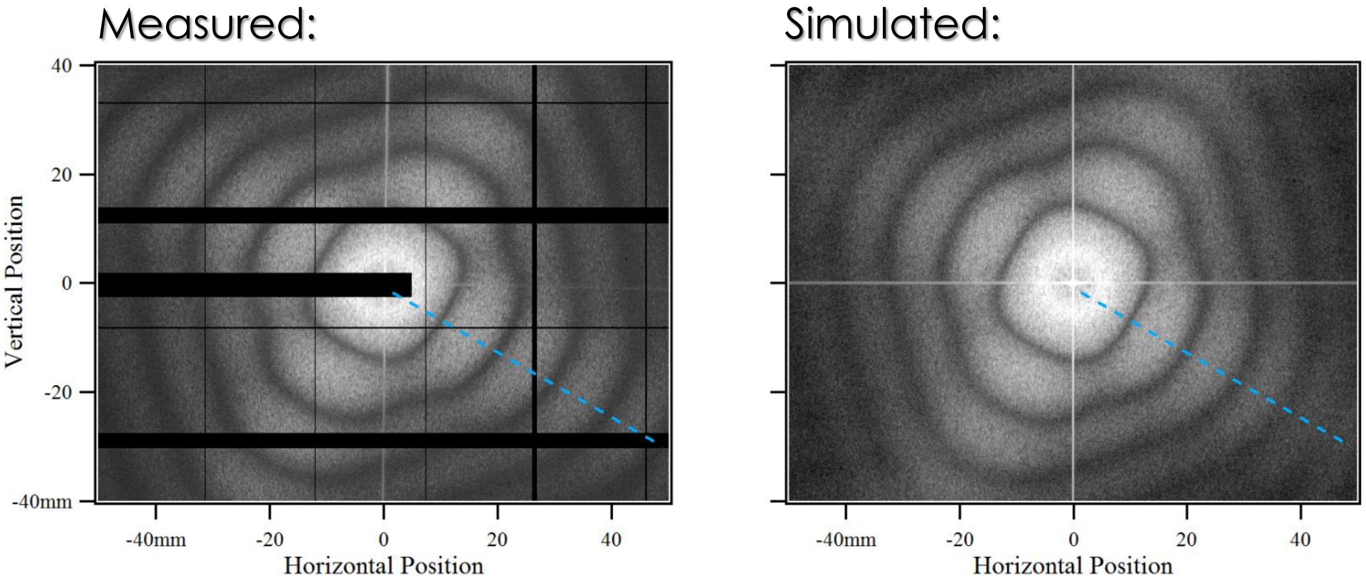
The main Open Source repository, containing all C/C++ sources, C API, all interfaces and project development files, is on GitHub:
https://github.com/ochubar/SRW

- SRW for Python (2.7.x and 3.x, 32- and 64-bit) was released in 2012
- Sirepo/SRW brings physical optics to the cloud, via support from the US SBIR program of DOE; available from a free Scientific Gateway, hosted by RadiaSoft
  Sirepo.com

SRW validation: coherent scattering exp'ts at NSLS-II

Speckle patterns:

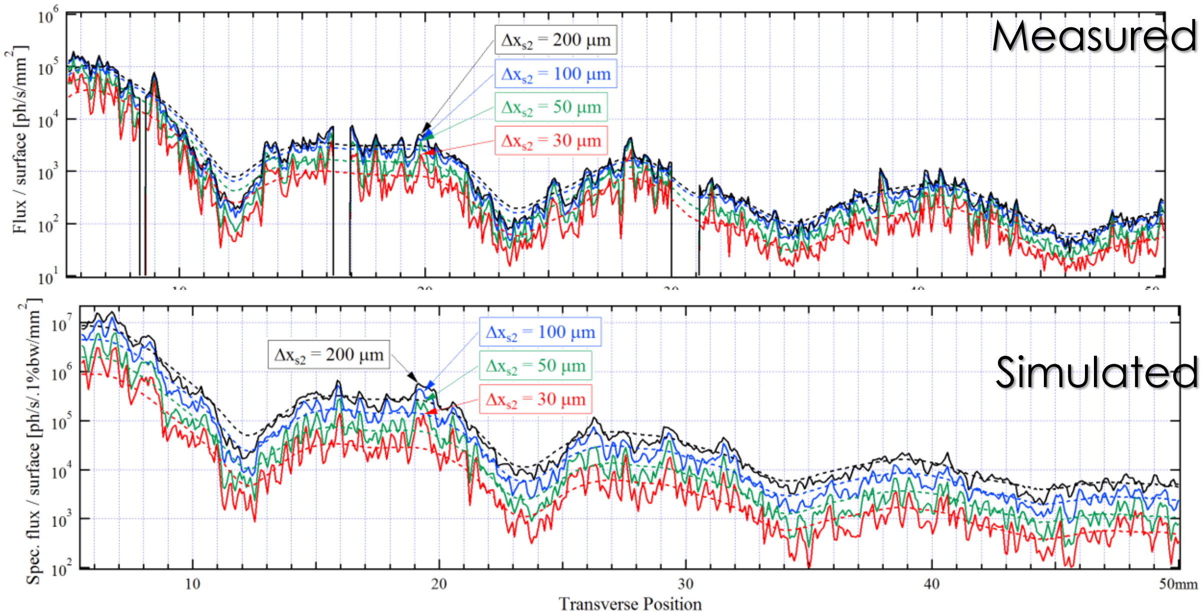
The CHX beamline at NSLS-II



E_{ph} = 9.65 keV

Hor. Slit Sizes:
Δx_{S2}= 50 µm
Δx_{KL}= 60 µm

Intensity along the dashed lines →

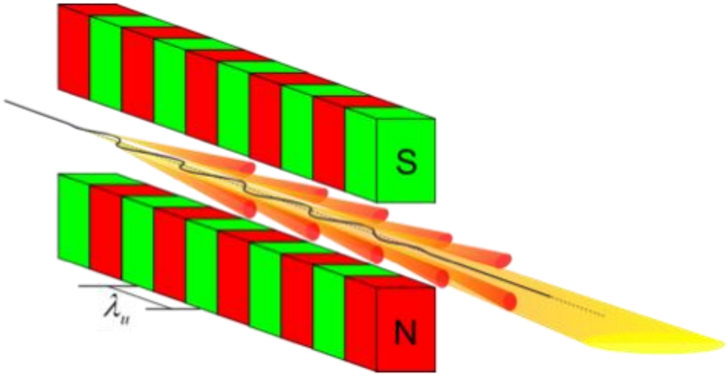


Measurements made using an EIGER X 4M detector (2070x 2167 pixels of 75 µm size) located at ~16 m from sample.

A. Fluerasu
L. Wiegart
M. Rakitin
O. Chubar

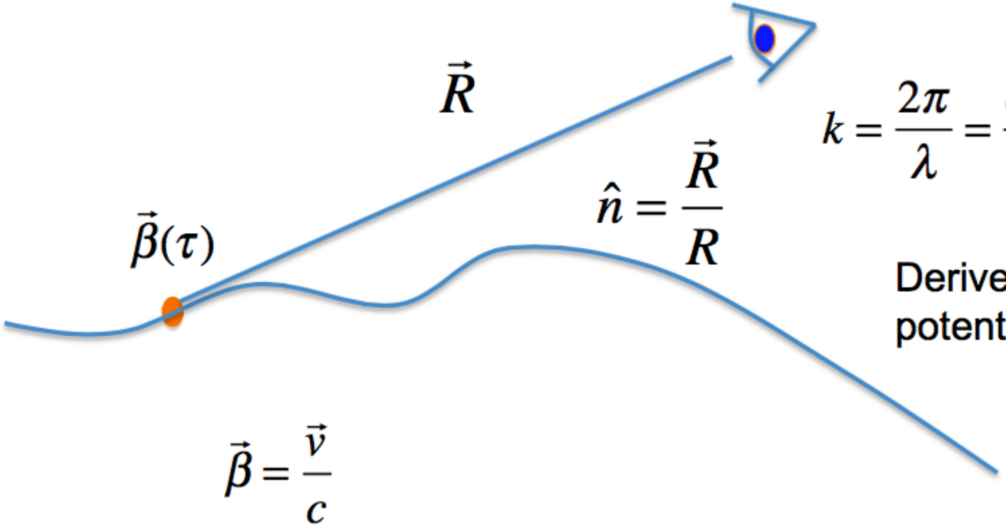
Brightness formulas

Undulator radiation



Radiation from a single electron trajectory:

$$\vec{E}(\vec{R},\omega) = \int_{-\infty}^{\infty} \left[\vec{\beta}(\tau) - \frac{\hat{n}(\tau)}{R} \left(1 + \frac{ic}{\omega R} \right) \right] e^{i\omega\left(\tau + \frac{R}{c}\right)} d\tau$$



$$k = \frac{2\pi}{\lambda} = \frac{\omega}{c}$$

Derived from Liénard-Wiechert potentials

From radiation wavefronts to “brightness”

Brightness is defined as the phase space density of photon flux:

$$\boxed{B = W_{me}(0,0) \approx \frac{\Phi}{4\epsilon_x\epsilon_y}}$$

$$W_{se}(\vec{x},\vec{p}) = \int e^{-i\vec{p}\cdot\vec{y}} E\left(\vec{x}+\frac{\vec{y}}{2}\right) E^*\left(\vec{x}-\frac{\vec{y}}{2}\right) d\vec{y}$$

← Single-electron Wigner func

$$W_{me}(\vec{x},\vec{p}) = \int W_{se}(\vec{x}-\vec{x}_0,\vec{p}-\vec{p}_0) f_e(\vec{x}_0,\vec{p}_0) d\vec{x}_0 d\vec{p}_0$$

← Multi-electron Wigner func

$$\epsilon_x = \Sigma_x\Sigma_{x'}$$

$$\epsilon_y = \Sigma_y\Sigma_{y'}$$

$$\Sigma^2 = \sigma_{eb}^2 + \sigma_\gamma^2$$

← calculated at the “source”

rms e- beam params

rms photon beam params (single e- calc)

Analytic formulae for undulator SR flux

K.-J. Kim, “Brightness, coherence and propagation characteristics of synchrotron radiation”. NIM A **246**, p. 71 (1986).

$\Phi = \pi C_0 N I_b Q_n(K)$ photons / s / 0.1% $\delta E/E_0$

$$C_0 = \frac{\alpha d\omega/\omega}{q_e} = 4.5546497 \times 10^{13}\text{Coulombs}^{-1}$$

$$F_n(K) = \frac{4nq}{1+\frac{K^2}{2}} JJ^2$$

$$Q_n(K) = (1+\frac{K^2}{2})\frac{F_n(K)}{n}$$

$$JJ = \left[J_{\frac{1}{2}(n-1)}\left(\frac{nK^2}{4+2K^2}\right) - J_{\frac{1}{2}(n+1)}\left(\frac{nK^2}{4+2K^2}\right)\right]$$

- *We have generalized Kim’s result in 3 ways:*
  - *allow elliptical undulators*
  - *include effects of e- beam dp/p (also done by Tanaka et al.)*
  - *include off-resonance effects*

Calculating brightness with SRW

Generalization of the total flux calculation (1)

This is previous, unpublished work by O. Chubar (BNL), which has been implemented in the “Igor Pro” interface to SRW, https://github.com/ochubar/SRW

Recently ported to the SRW Python API, and to the Sirepo/SRW web app.

$$\Phi = C_0 N_u I_b \frac{n k_1^2}{1 + \frac{K^2}{2}} \overline{JJ}^2(qq) F_f(\Delta, \epsilon) G(\Delta, k_1, k_2)$$

allows for elliptical undulators →

$$\overline{JJ}^2(n, k_1^2, k_2^2) = \left[J_{\frac{n-1}{2}}(qq) - J_{\frac{n+1}{2}}(qq)\right]^2 + \frac{k_2^2}{k_1^2}\left[J_{\frac{n-1}{2}}(qq) + J_{\frac{n+1}{2}}(qq)\right]^2$$

$$k_1^2 = k_y^2 \cos^2(\phi_x - \phi_0) + k_x^2 \cos^2(\phi_y - \phi_0)$$

$$k_2^2 = k_y^2 \sin^2(\phi_x - \phi_0) + k_x^2 \sin^2(\phi_y - \phi_0)$$

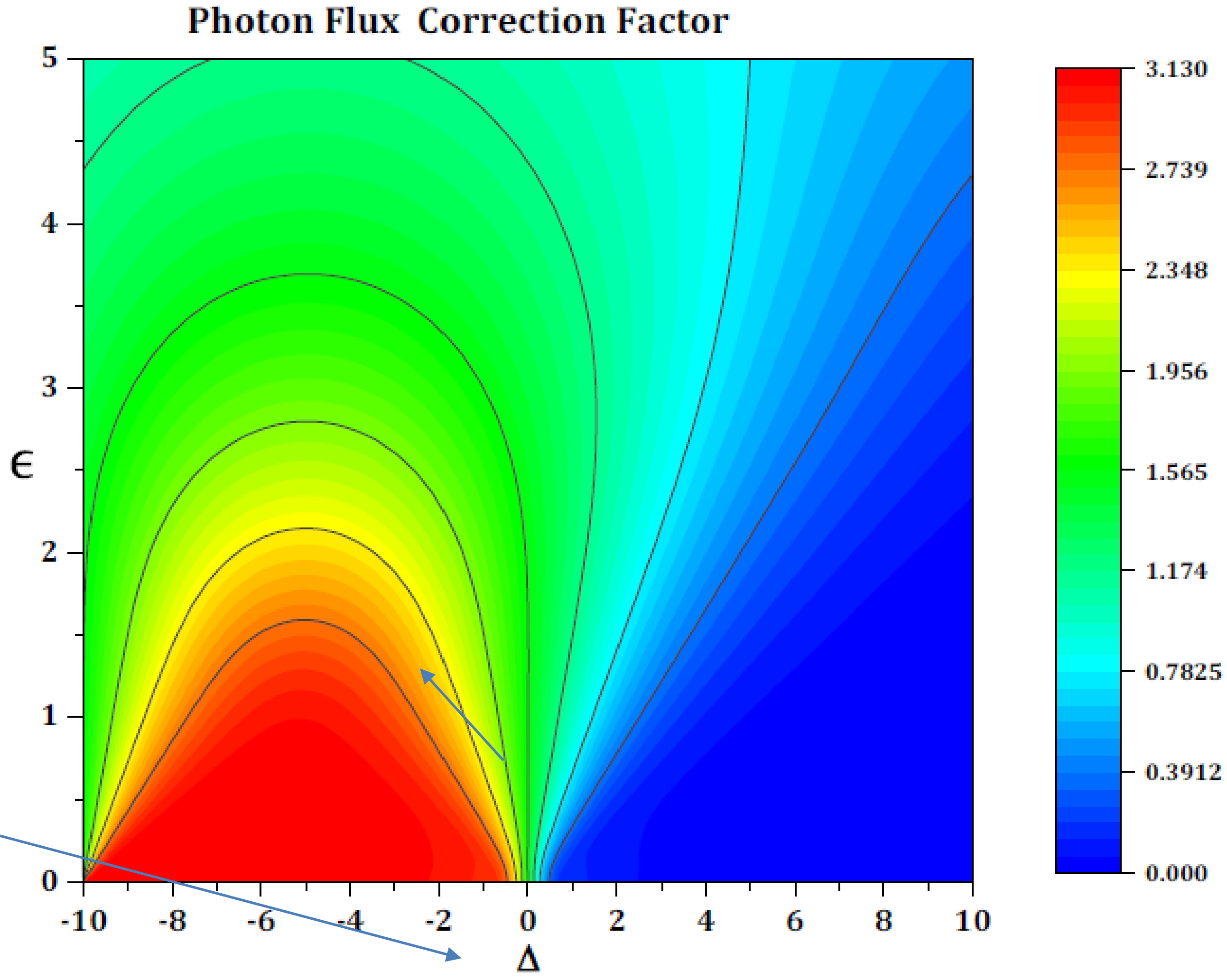
$$qq = \frac{n}{4} \frac{k_1^2 - k_2^2}{1 + \frac{1}{2}(k_1^2 + k_2^2)}$$

$F_f(\Delta, \epsilon)$ → tabulated “universal function” $G(\Delta, k_1, k_2)$ → analytic function

B. Nash *et al*, “Detailed X-ray Brightness Calculations in the Sirepo GUI for SRW,” AIP Conf. Proc. **2054**, 060080 (2019), https://aip.scitation.org/doi/10.1063/1.5084711

Generalization of the total flux calculation (2)

- *A pre-calculated "universal function" is used to:*
  - *include effects of e- beam dE/E*
  - *include detuning from resonance*



normalized energy spread

$\epsilon = nN\sigma_\delta$

normalized detuning

$\Delta = nN\frac{dE}{E}$

Generalization of the photon beam source size

This is previous, unpublished work by O. Chubar (BNL), which has been implemented in the “Igor Pro” interface to SRW, https://github.com/ochubar/SRW

$$\sigma_{r,\gamma} = \frac{2.740}{4\pi}\sqrt{\lambda_n L}\ F_r(\Delta,\epsilon)$$

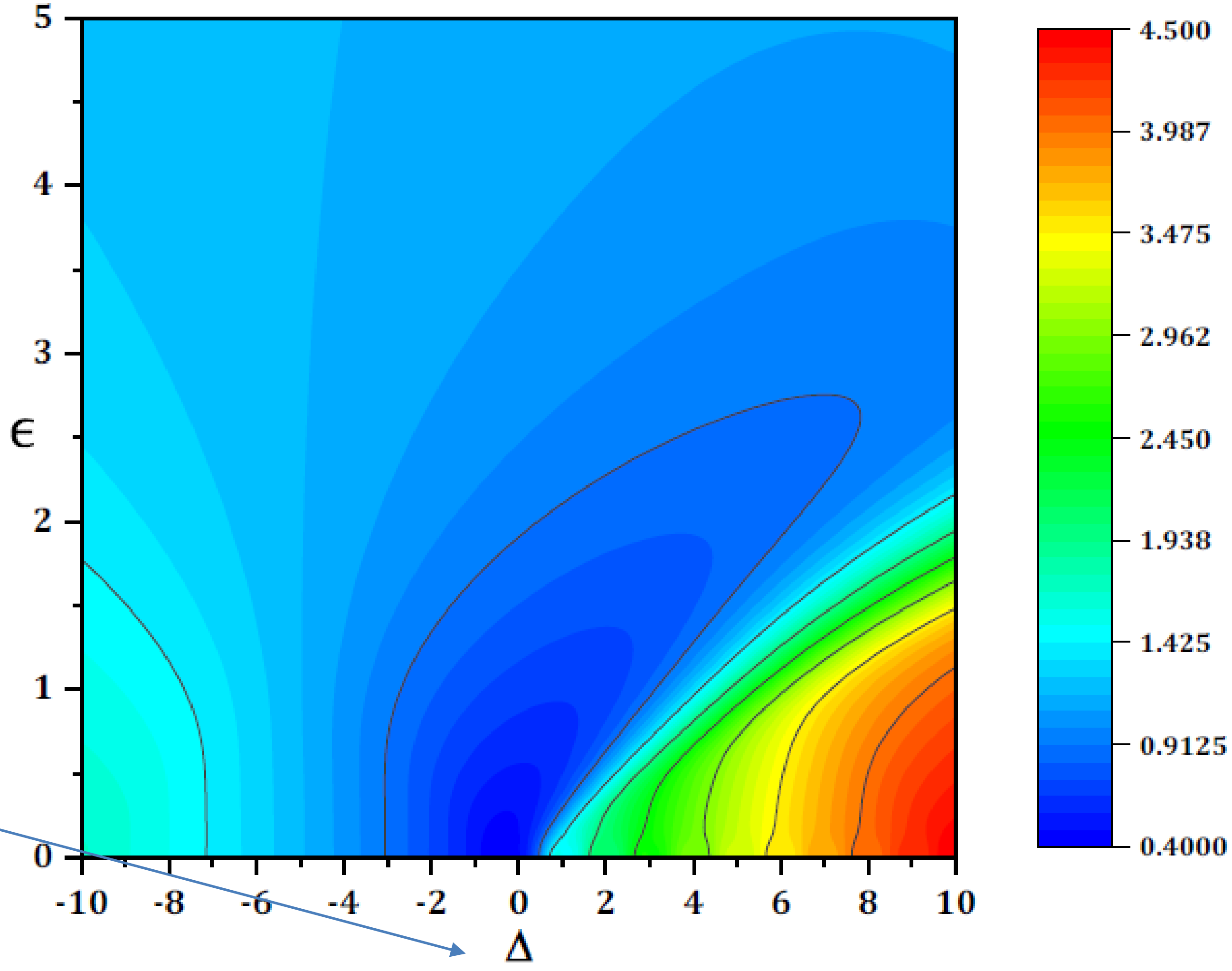
normalized energy spread

$$\epsilon = nN\sigma_\delta$$

normalized detuning

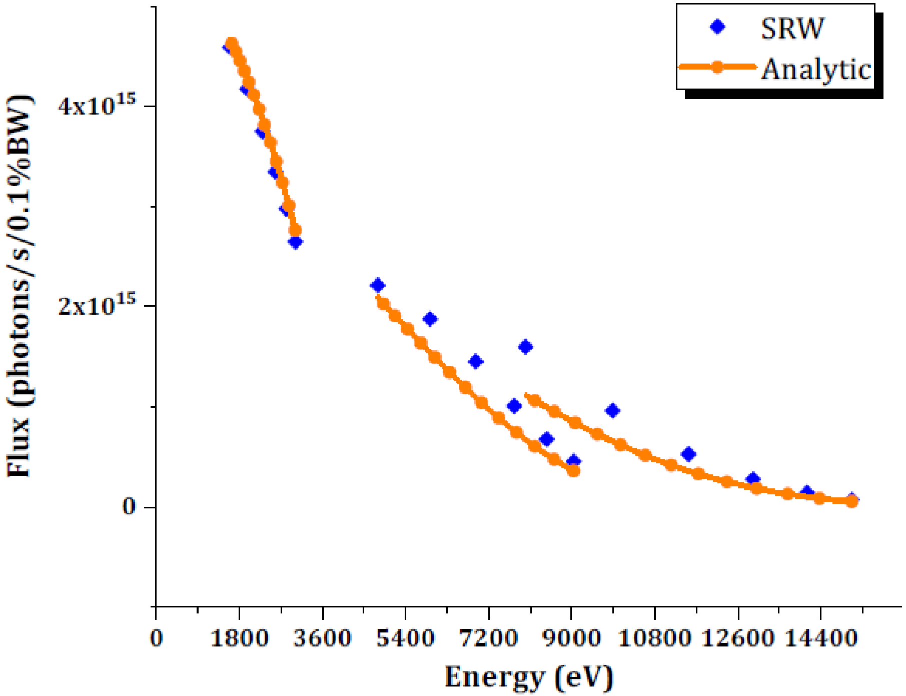
$$\Delta = nN\frac{dE}{E}$$

Photon Beam Size Correction Factor

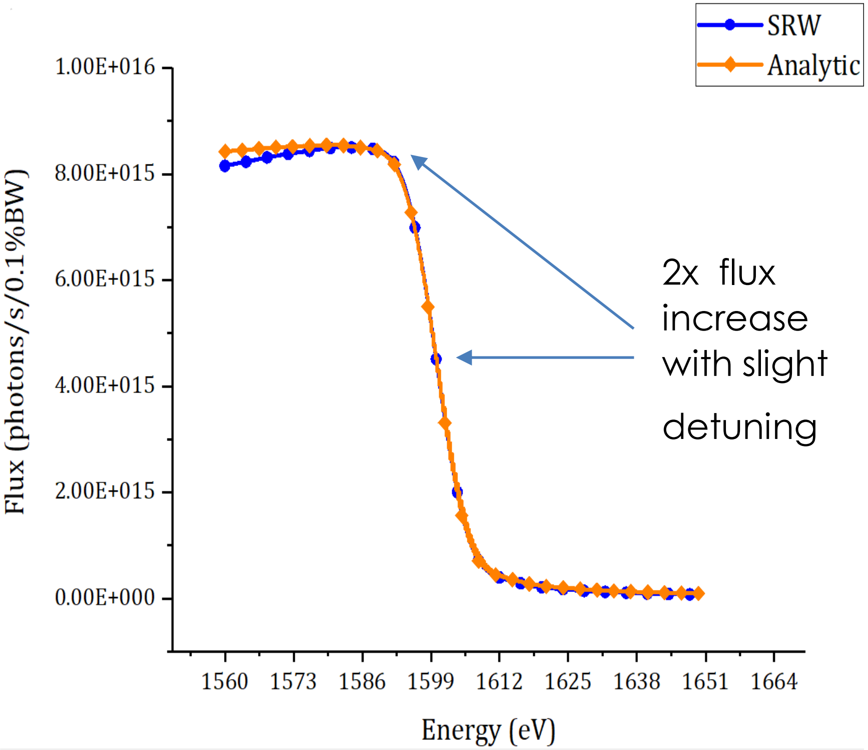


SRW benchmarking results

Flux "K tuning" plot on resonance (SRW calc with SM† method)



Flux "spectral detuning" plot (SRW calc with SM † method)

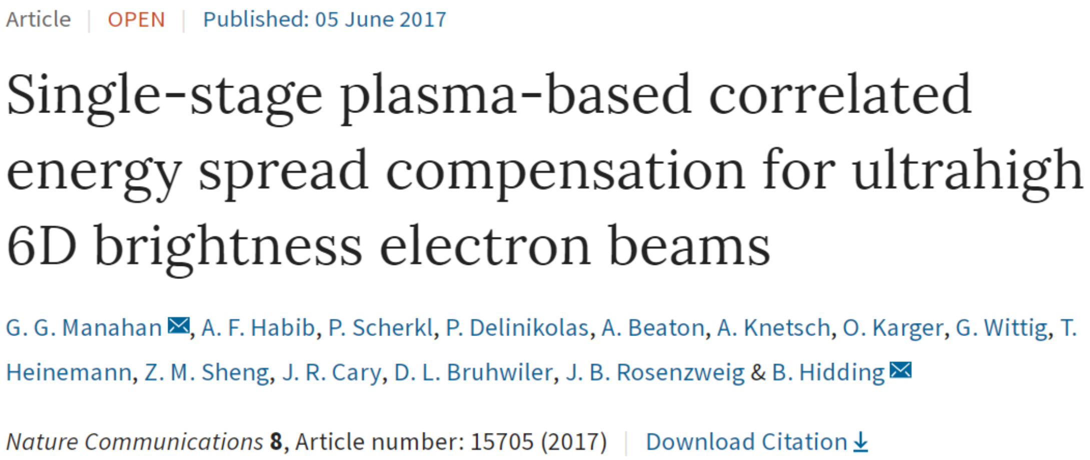


2x flux increase with slight detuning

†SM method includes e- beam emittance and energy spread using a finite collection aperture. These calculations executed with an 8 mm x 8 mm aperture.

Consideration of Trojan Horse e- beam param's

E = 770 MeV
τ = 2.5 fs
Q = 5 pC
x_{rms} ~ 5 μm
dE/E ~ 5% (uncorrected)
dE/E ~ 0.3% (via Manahan *et al.*)



Article | OPEN | Published: 05 June 2017

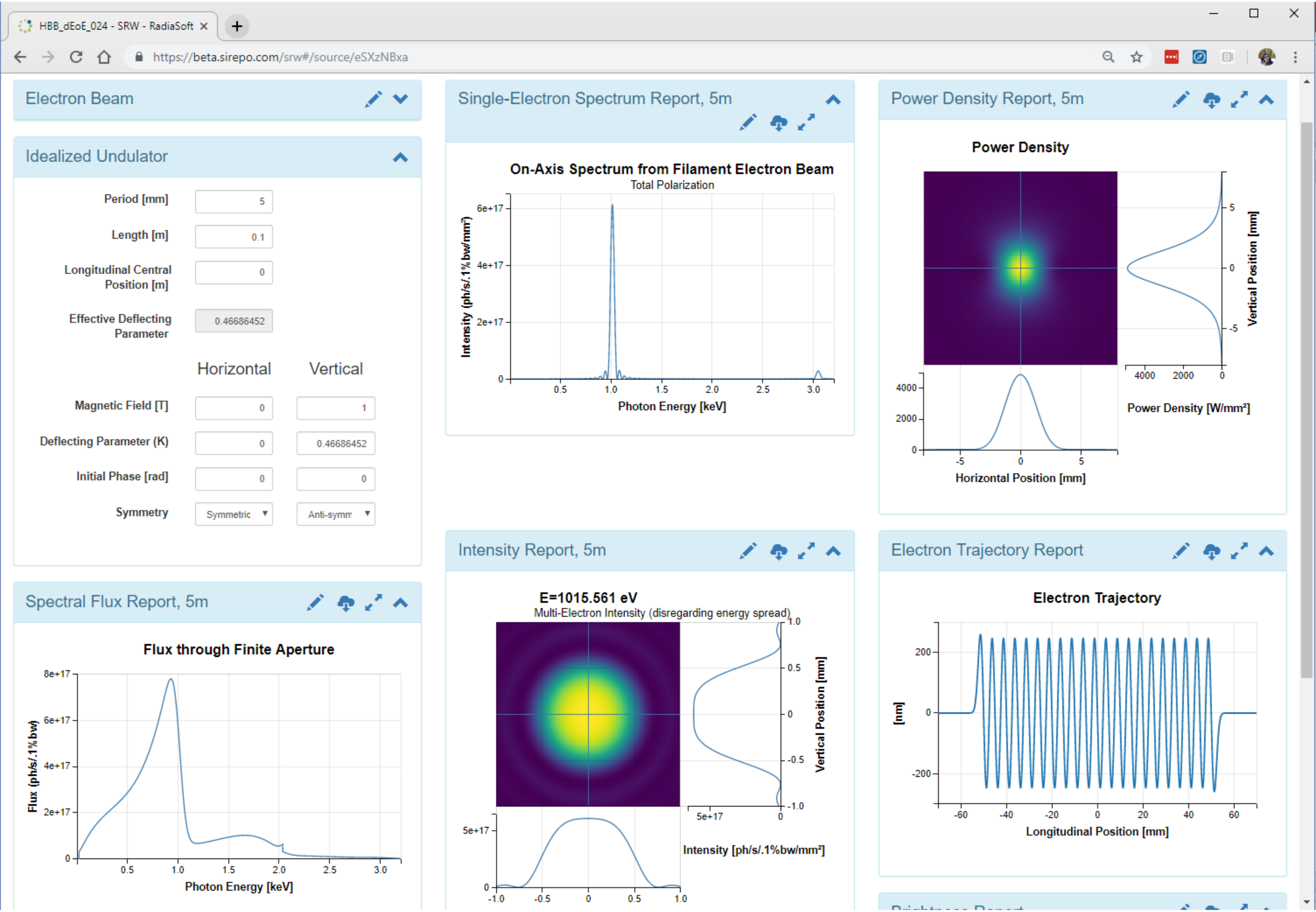
Single-stage plasma-based correlated energy spread compensation for ultrahigh 6D brightness electron beams

G. G. Manahan ✉, A. F. Habib, P. Scherkl, P. Delinikolas, A. Beaton, A. Knetsch, O. Karger, G. Wittig, T. Heinemann, Z. M. Sheng, J. R. Cary, D. L. Bruhwiler, J. B. Rosenzweig & B. Hidding ✉

Nature Communications **8**, Article number: 15705 (2017) | Download Citation ⤓

1 KeV can be achieved:
- requires a micro-undulator, λ_u = 5 mm
- requires strong quadrupole focusing
- L_u is kept short here: 10 cm = 20 periods

Browser-based simulations of X-ray brightness



Period [mm]: 5

Length [m]: 0.1

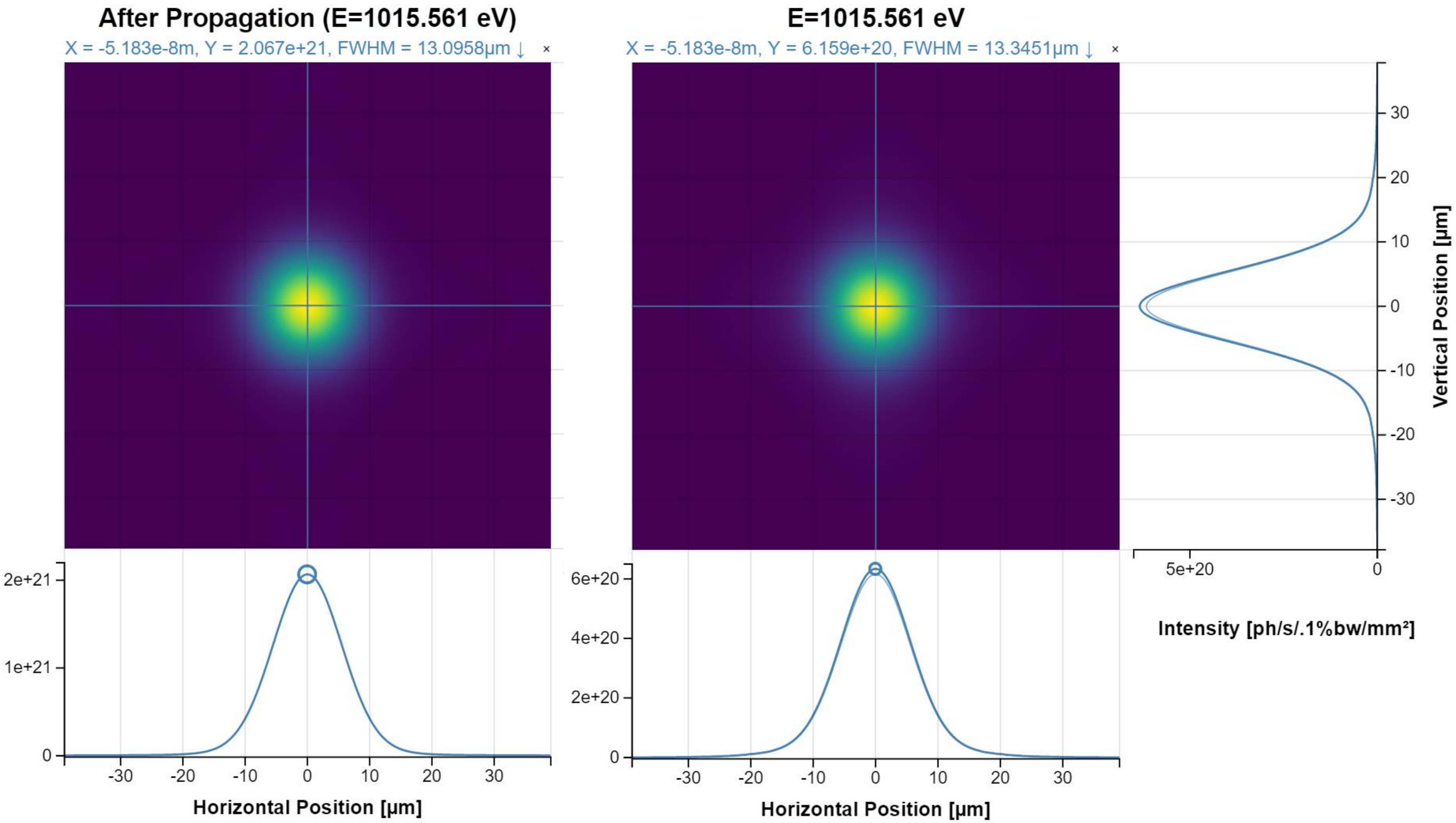
Longitudinal Central Position [m]: 0

Effective Deflecting Parameter: 0.46686452

	Horizontal	Vertical
Magnetic Field [T]	0	1
Deflecting Parameter (K)	0	0.46686452
Initial Phase [rad]	0	0
Symmetry	Symmetric	Anti-symm

Energy spread reduces flux

- *e- beam energy spread of 0.3% to 4.8%*
  - *photon flux decreases by 3x*


After Propagation (E=1015.561 eV)

X = -5.183e-8m, Y = 2.067e+21, FWHM = 13.0958µm ↓

E=1015.561 eV

X = -5.183e-8m, Y = 6.159e+20, FWHM = 13.3451µm ↓

X-ray optics & brightness – conclusions

Classic formula for brightness by K.-J. Kim is a starting point.

This formula needs to be generalized to include energy spread, detuning effects, and to allow for elliptical undulators.

Partially coherent Sirepo/SRW wavefront simulations agree with the generalized brightness formulae

Sirepo provides a convenient GUI for SRW calculations.

Analytic formulae in Sirepo provide rapid feedback for source parameters allowing a starting point for more detailed coherent and partially coherent calculations for realistic x-ray beamlines.

Repeat our calculations yourself:

https://sirepo.com/srw#/source/kH9BPjRb

US Particle Accelerator School – http://uspas.fnal.gov

- intensive 1 & 2 week courses
  - *Sirepo has been used 4 times*
    - used **`elegant`**
- other examples of Sirepo use:
  - *Korea particle accelerator school*
    - used **`Synergia`**
  - *La Trobe University*
    - X-ray optics
    - used **`SRW`**

Current Program

USPAS sponsored by
University of New Mexico
June 17 - 28, 2019
held in Albuquerque, New Mexico

View Details >>

APPLY NOW

Hot Topics

- The APS Division of Physics of Beams has awarded two new scholarships to USPAS students. Read more here....
- The 2019 USPAS Achievement Prize winners have been announced. Read more here....
- The 2019 International Accelerator School on "Ion Colliders" will be held in Dubna, Russia from October 28 to Nov 7. Information is available here.....

Find us on f

Veksler & MacMillan teammates in the January 2018 Accelerator Fundamentals class investigate the inner structure of a 'pillbox cavity' during the RF cavities lab.

Accelerator Tutorials

LHC Superconducting Magnets

Watch this first video, in a sequence of three, explain the role of superconducting magnets in the Large Hadron Collider and also explain how they work and are constructed. Used with permission: CERN

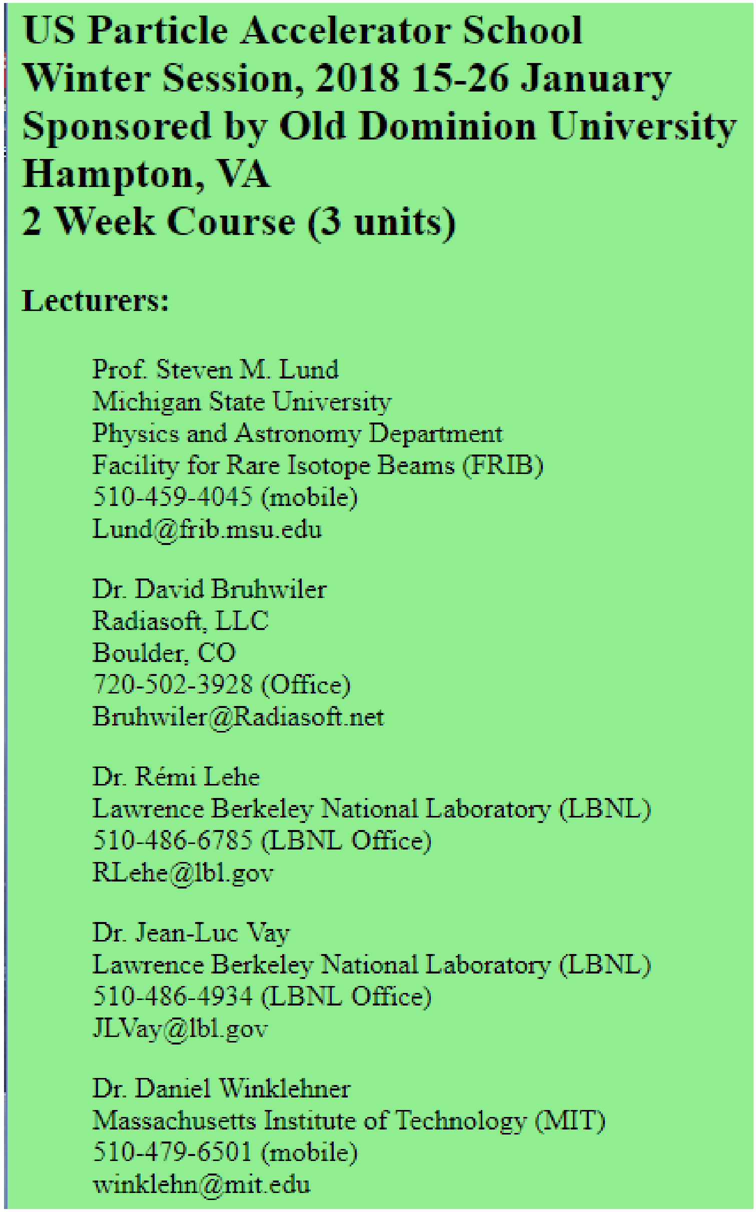
See more Accelerator Tutorials.

© 1981-2019 U.S. Particle Accelerator School, a national training program managed by Fermilab | About | Contact | Site Map | Privacy

Simulation of Beam and Plasma Systems

https://people.nscl.msu.edu/~lund/uspas/sbp_2018

- S. Lund, J.-L. Vay, R. Lehe, D. Winklehner
  - expanded 1 week course to 2 weeks
  - invited me to contribute
- Sirepo/elegant used to discuss CSR
  - principles of bunch compression
  - CSR models and the physical effects
- RadiaSoft now routinely supports schools and workshops with a 400 core cluster
  - JupyterHub and/or Sirepo
  - rapid reconfiguration as needed to support specified number of students
  - other nodes reserved for internal computing
  - nodes are routinely made available to customers or collaborators



US Particle Accelerator School
Winter Session, 2018 15-26 January
Sponsored by Old Dominion University
Hampton, VA
2 Week Course (3 units)

Lecturers:

Prof. Steven M. Lund
Michigan State University
Physics and Astronomy Department
Facility for Rare Isotope Beams (FRIB)
510-459-4045 (mobile)
Lund@frib.msu.edu

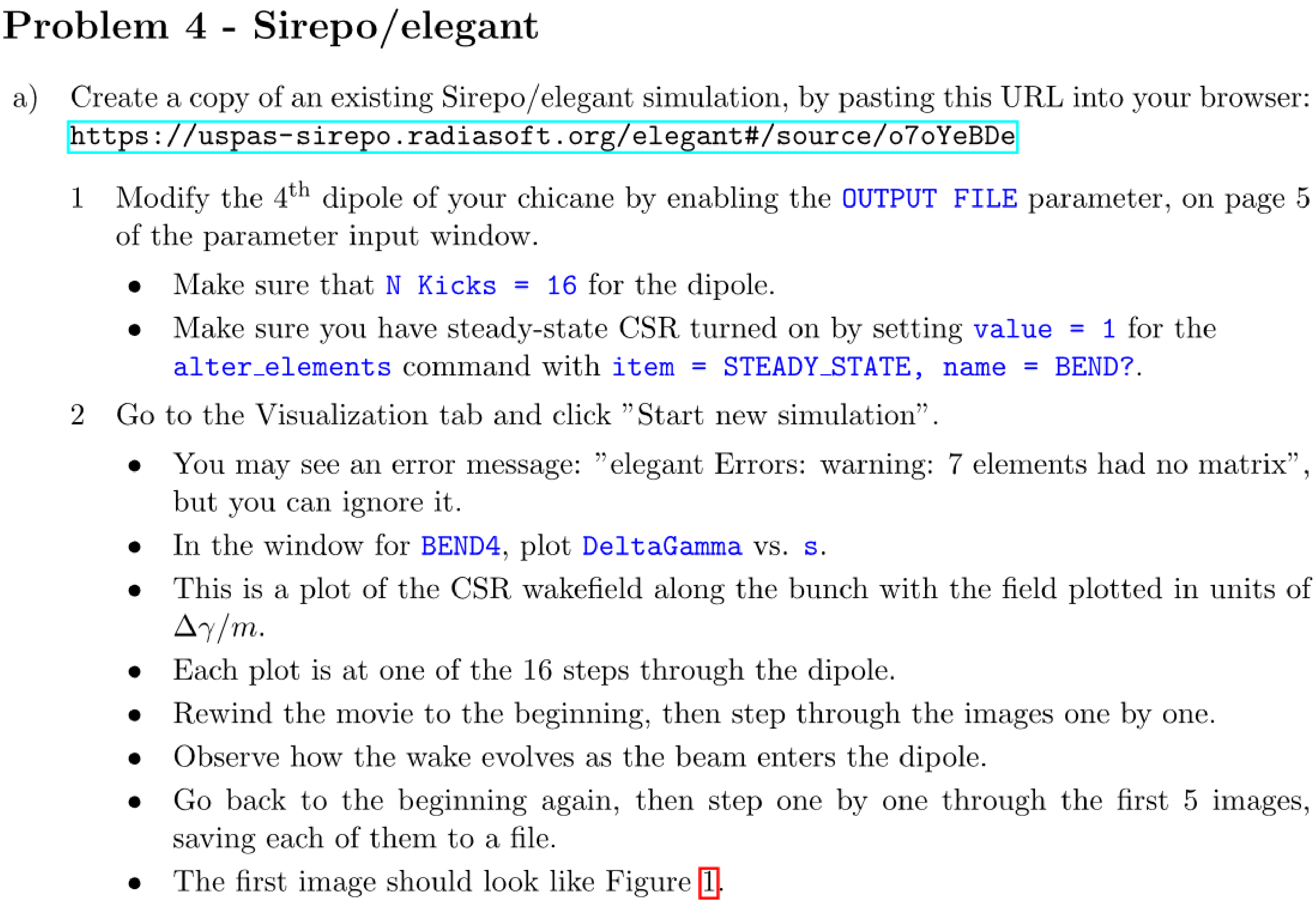
Dr. David Bruhwiler
Radiasoft, LLC
Boulder, CO
720-502-3928 (Office)
Bruhwiler@Radiasoft.net

Dr. Rémi Lehe
Lawrence Berkeley National Laboratory (LBNL)
510-486-6785 (LBNL Office)
RLehe@lbl.gov

Dr. Jean-Luc Vay
Lawrence Berkeley National Laboratory (LBNL)
510-486-4934 (LBNL Office)
JLVay@lbl.gov

Dr. Daniel Winklehner
Massachusetts Institute of Technology (MIT)
510-479-6501 (mobile)
winklehn@mit.edu

Sample from the final exam –



Problem 4 - Sirepo/elegant

a) Create a copy of an existing Sirepo/elegant simulation, by pasting this URL into your browser: `https://uspas-sirepo.radiasoft.org/elegant#/source/o7oYeBDe`

1 Modify the 4th dipole of your chicane by enabling the `OUTPUT FILE` parameter, on page 5 of the parameter input window.

  - Make sure that `N Kicks = 16` for the dipole.
  - Make sure you have steady-state CSR turned on by setting `value = 1` for the `alter_elements` command with `item = STEADY_STATE, name = BEND?`.

2 Go to the Visualization tab and click "Start new simulation".

  - You may see an error message: "elegant Errors: warning: 7 elements had no matrix", but you can ignore it.
  - In the window for `BEND4`, plot `DeltaGamma` vs. `s`.
  - This is a plot of the CSR wakefield along the bunch with the field plotted in units of $\Delta\gamma/m$.
  - Each plot is at one of the 16 steps through the dipole.
  - Rewind the movie to the beginning, then step through the images one by one.
  - Observe how the wake evolves as the beam enters the dipole.
  - Go back to the beginning again, then step one by one through the first 5 images, saving each of them to a file.
  - The first image should look like Figure 1.

Sirepo/Elegant classroom example: USPAS fundamentals of accelerator physics

Kiersten Ruisard

Sirepo User Workshop, Sept. 3, 2019

On behalf of Jan 2019 teaching team: Jeff Holmes, Sarah Cousineau, Nick Evans, Martin Kay

Sirepo/elegant used for a lab in the January & June 2019 "Fundamentals" course

Jan 2019 teaching team:

Jeff Holmes, Sarah Cousineau, Nick Evans,
Kiersten Ruisard & Martin Kay

June 2019 teaching team:

Linda Spentzouris, Pavel Snopok,
Nicole Neveu, Josiah Kunz, Tanaz Mohayai,
Elvin Harms and Bob Zwaska

Jan 2019 Fundamentals Course

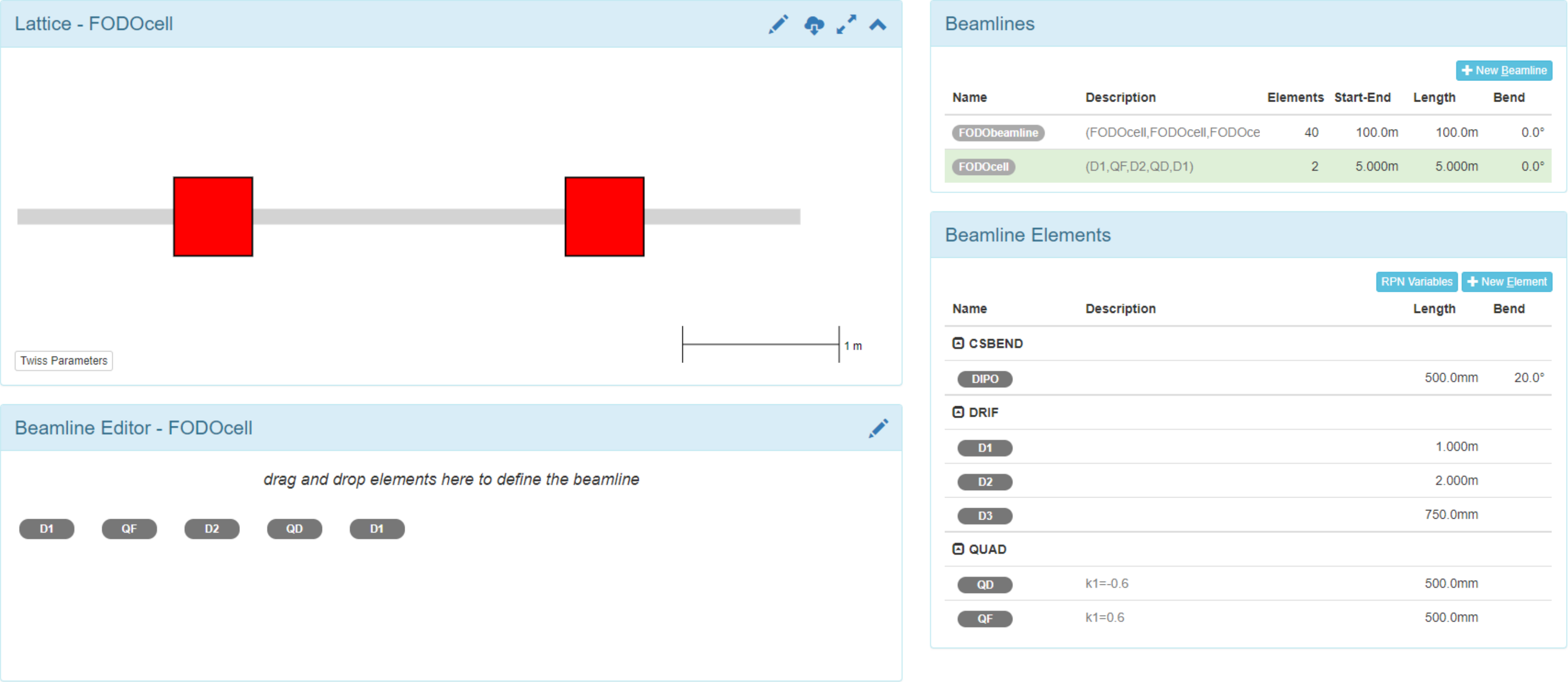
Photo by Irina

The Sirepo lab is comprised of 3 exercises:

1. Matched/mis-matched beam in FODO line
2. Dispersion and chromaticity
3. Build your own beamline (offered as optional/extra credit)

Content on this slide courtesy of Kiersten Ruisard (ORNL)

Exercise 1: Matched/mismatched beam propagation in FODO line



Lattice - FODOcell

Beamline Editor - FODOcell

drag and drop elements here to define the beamline

D1 QF D2 QD D1

Beamlines

Name	Description	Elements	Start-End	Length	Bend
FODObeamline	(FODOcell,FODOcell,FODOce	40	100.0m	100.0m	0.0°
FODOcell	(D1,QF,D2,QD,D1)	2	5.000m	5.000m	0.0°

Beamline Elements

Name	Description	Length	Bend
⊟ CSBEND			
DIPO		500.0mm	20.0°
⊟ DRIF			
D1		1.000m	
D2		2.000m	
D3		750.0mm	
⊟ QUAD			
QD	k1=-0.6	500.0mm	
QF	k1=0.6	500.0mm	

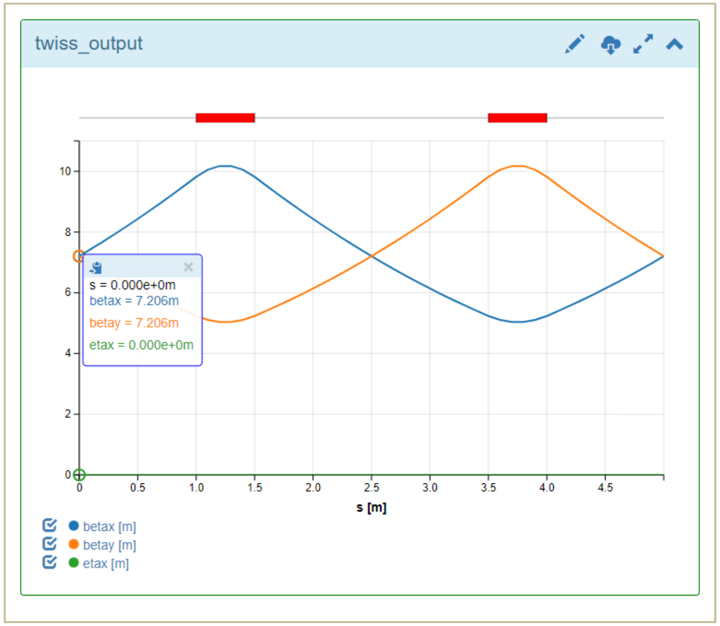
Content on this slide courtesy of Kiersten Ruisard (ORNL)

D. Propagation of mismatched beam

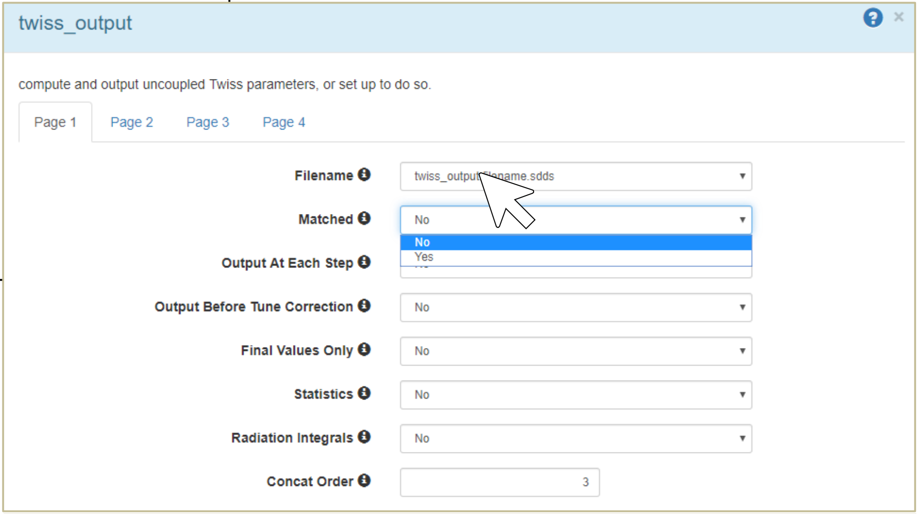
We will initialize our beam with a 10% mismatch and examine the effect this has on transport. In the periodic solution, $\beta_x = \beta_y = 7.206$ meters and $\alpha_x = -\alpha_y = 1.122$. (You can verify this by interacting with the twiss_output plot or downloading the data in CSV format).

To initialize a mismatched beam, under the “Control” Tab and “twiss_output” module, set the following fields:

Parameter	**Value**
Matched	No
Beta X (pg 2)	7.206 * 1.1
Alpha X (pg 2)	-1.178
Beta Y (pg 3)	7.206 * 1.1
Alpha Y (pg 3)	1.178

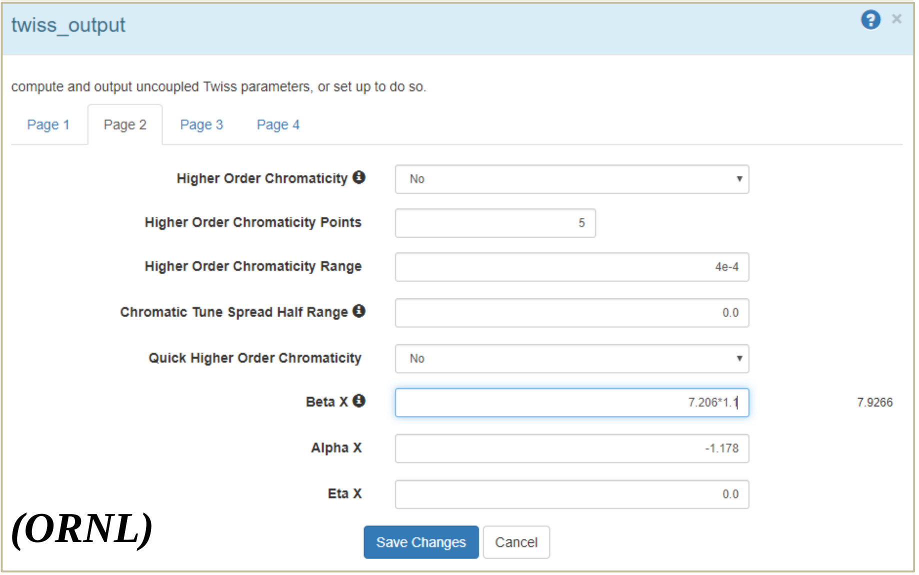


s = 0.000e+0m
betax = 7.206m
betay = 7.206m
etax = 0.000e+0m



compute and output uncoupled Twiss parameters, or set up to do so.

Filename: twiss_output.filename.sdds
Matched: No (options: No, Yes)
Output At Each Step
Output Before Tune Correction: No
Final Values Only: No
Statistics: No
Radiation Integrals: No
Concat Order: 3



compute and output uncoupled Twiss parameters, or set up to do so.

Higher Order Chromaticity: No
Higher Order Chromaticity Points: 5
Higher Order Chromaticity Range: 4e-4
Chromatic Tune Spread Half Range: 0.0
Quick Higher Order Chromaticity: No
Beta X: 7.206*1.1 7.9266
Alpha X: -1.178
Eta X: 0.0

Content on this slide courtesy of Kiersten Ruisard (ORNL)

Simulation Status

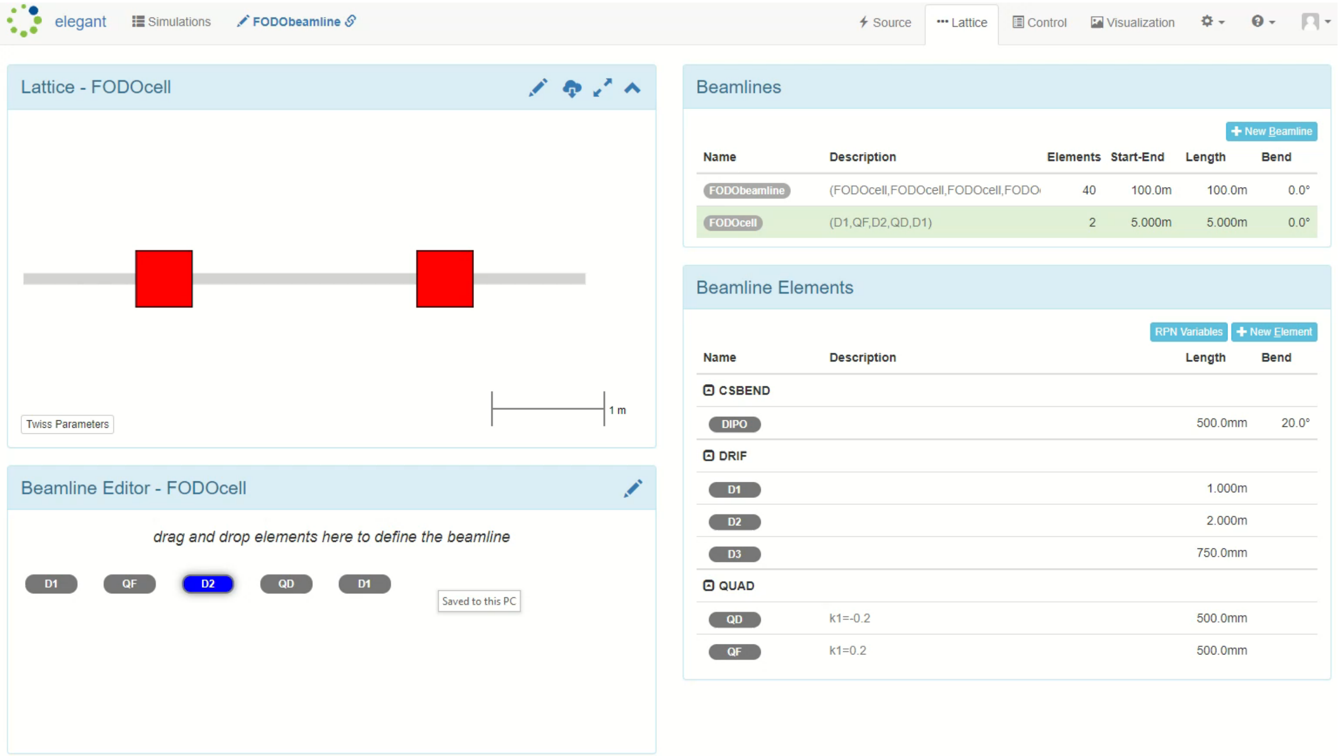
Simulation Completed: Elapsed time: 0 00:00:03

Execution Serial

Beamline FODObeamline

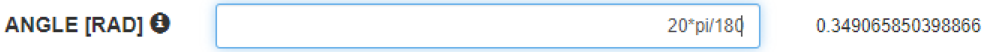
Content on this slide courtesy of Kiersten Ruisard (ORNL)

Exercise 2: Dispersion and Chromaticity



Name	Description	Elements	Start-End	Length	Bend
FODObeamline	(FODOcell,FODOcell,FODOcell,FODO	40	100.0m	100.0m	0.0°
FODOcell	(D1,QF,D2,QD,D1)	2	5.000m	5.000m	0.0°

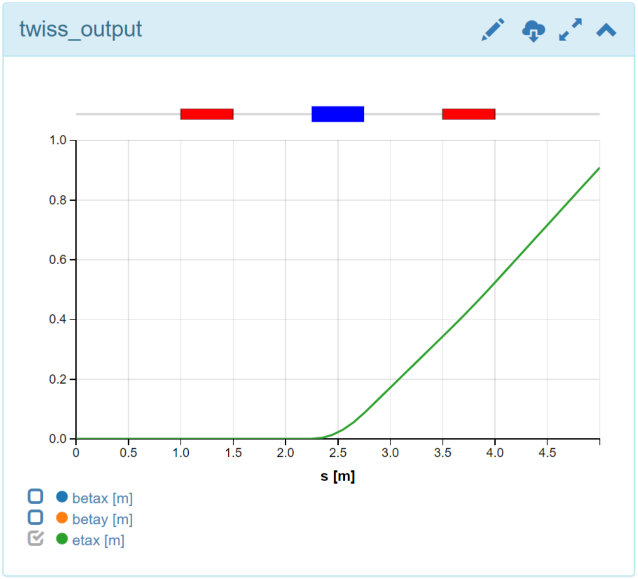
Name	Description	Length	Bend
CSBEND			
DIPO		500.0mm	20.0°
DRIF			
D1		1.000m	
D2		2.000m	
D3		750.0mm	
QUAD			
QD	k1=-0.2	500.0mm	
QF	k1=0.2	500.0mm	

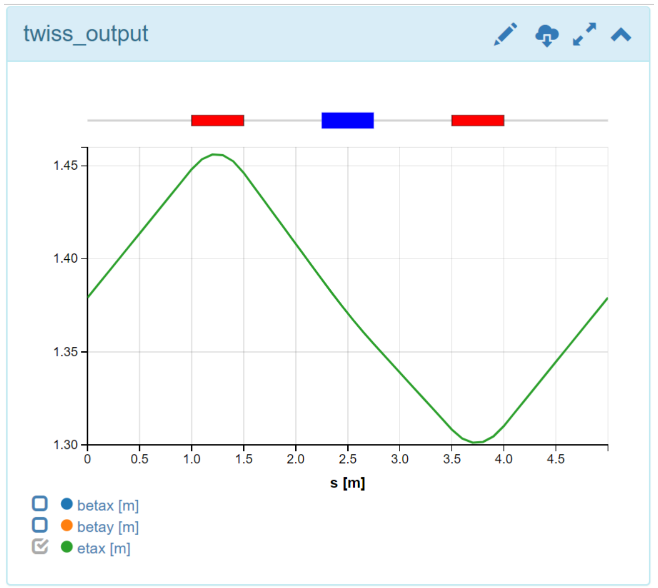


ANGLE [RAD] 20*pi/180 0.349065850398866

https://beta.sirepo.com/elegant#/source/tzedA3Co

Content on this slide courtesy of Kiersten Ruisard (ORNL)





Assuming a 0.1% energy spread in the beam, what is the horizontal beam size we expect in the focusing quadrupole QF? How does this compare to our beam size without energy spread?

$$\sigma_x^2 \ = \ \epsilon_x \beta_x + \eta^2 \frac{\Delta p}{p_0}$$

$\boldsymbol{\sigma_x} =$ ____________________

Content on this slide courtesy of Kiersten Ruisard (ORNL)

B. Zero-dispersion insert

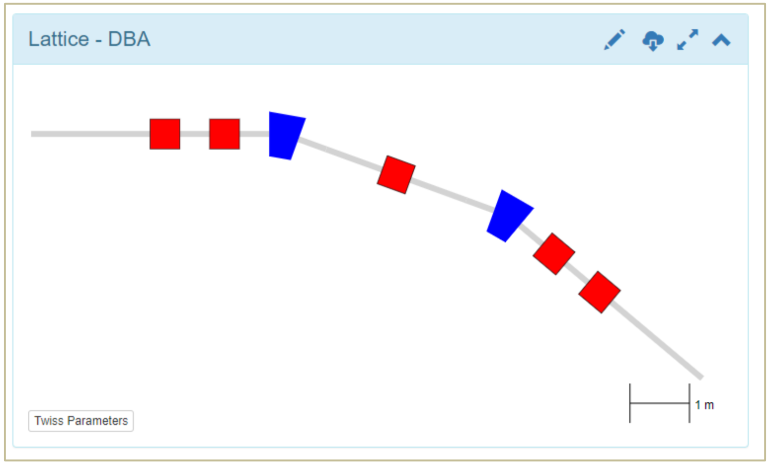
Open simulation DispersionFree (https://beta.sirepo.com/elegant#/source/tzedA3Co)
The lattice cell in this simulation has two 20-degree bends and three quadrupoles. The quadrupoles are initially set to zero-strength and matching is disabled. Run the simulation and observe the evolution of the dispersion η_x through the double bend.

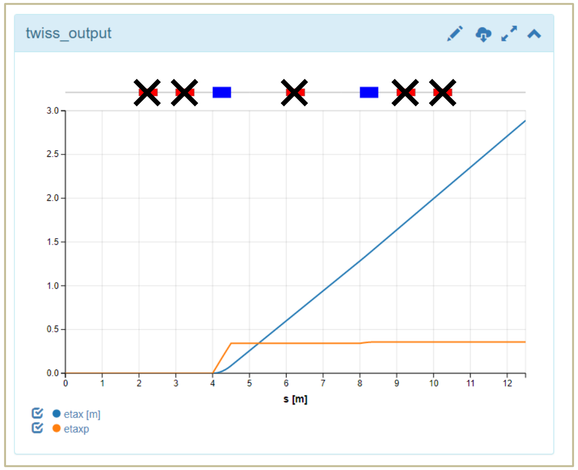
What is η_x and η_x' at the end of the cell? __________________________

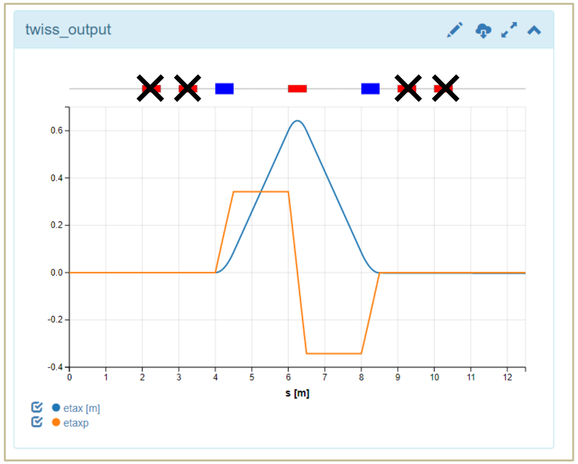
"Turn on" the middle quadrupole (Q1) at $k1 = 1\ m^{-2}$. Note the effect this has on the dispersion function.

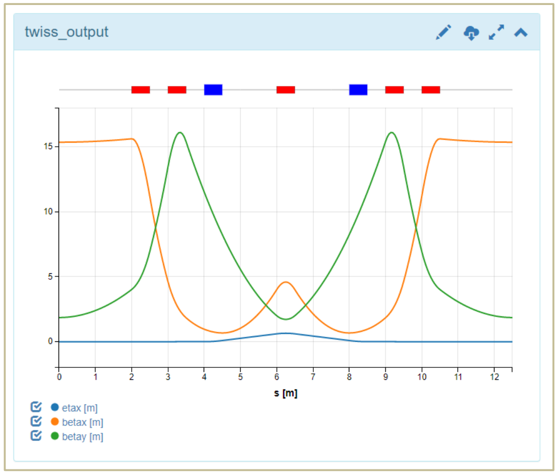
Adjust the strength of Q1 to find the solution for which dispersion is zero after the two bends.

$k1 =$ ___________









Content on this slide courtesy of Kiersten Ruisard (ORNL)

C. Tune in a ring

Repeat your cell 9 times to create a ring; propagate particles;
Record x and y tunes (to 3 significant figures):

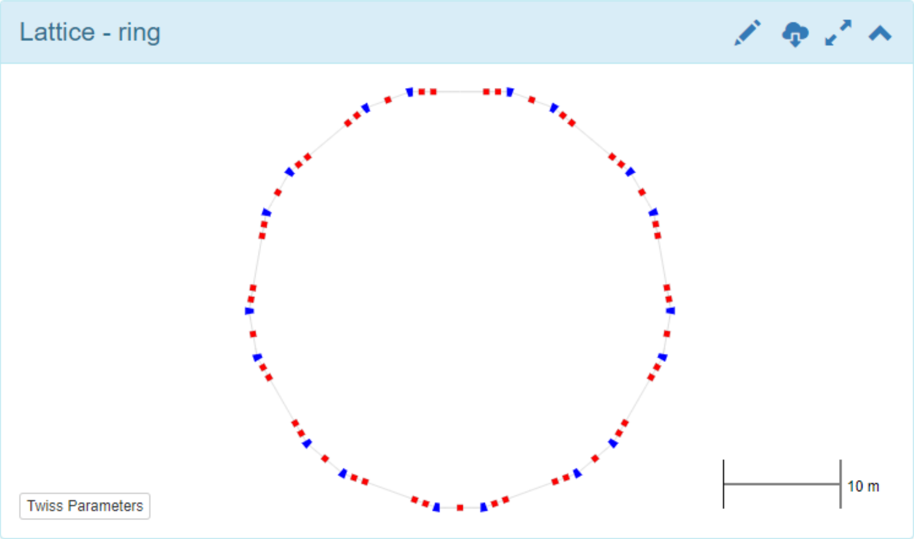
$\nu_x =$ ______________ $\nu_y =$ ____________

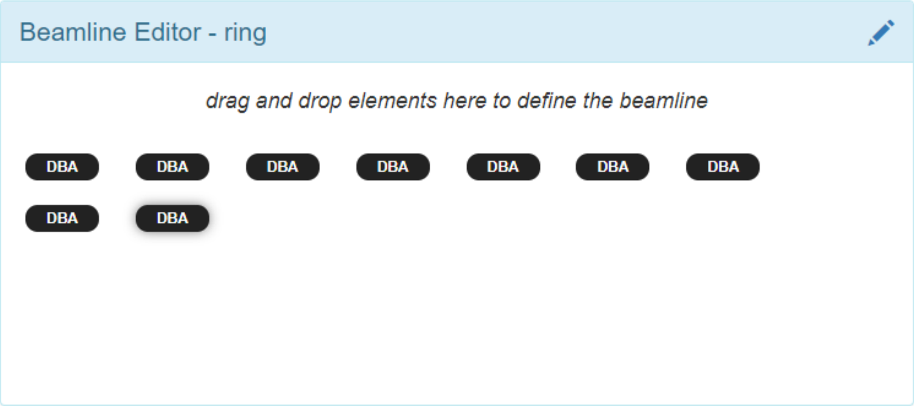
Note that this lattice still has chromaticity; that is, although off-momentum particles will not increase the beam size in the dispersion-free drifts, they will still feel different focusing strength and have a tune different from the on-momentum particles. **For a 0.1% energy spread in the beam, what is the spread of tunes due to chromaticity?**

$\Delta\nu_x = C_x \frac{\Delta p}{p_0}$

hint: in Elegant Twiss output, look for dnux/dp and dnuy/dp for chromaticity values

$\Delta\nu_x =$ ______________ $\Delta\nu_y =$ ______________





Content on this slide courtesy of Kiersten Ruisard (ORNL)

Summary of USPAS experience

- *One of the established "Fundamentals" labs has recently been replaced with a Sirepo/`elegant` lab*
- *Sirepo/`elegant` lab focuses on beamline design, lattice functions*
- *Generally positive student feedback*
- *Portability and GUI are great for instructional use*
- *Recent interest at USPAS in "modernizing" computer labs → continued use of Sirepo*

Machine Learning @ RadiaSoft:

An overview of recent developments and projects

Jonathan Edelen, Nathan Cook, Christopher Hall and S. Webb

with the Sirepo team

Kevin Brown, Philip Dyer

Auralee Edelen

Adapted from a recent presentation for:

Advanced Control Methods for Particle Accelerators

Santa Fe, New Mexico – 21 Aug 2019

RadiaSoft projects involving ML/Controls/Optimization

- 🟥 Machine Learning
- 🟦 Machine Learning + Controls
- 🟧 Optimization
- 🟪 Optimization + Machine Learning

🟪 Optimization of PMQ Lenses for Electron Microscopes

🟦 High Efficiency X-ray FEL Development

🟥 X-ray Treatment Plans for Prostate Cancer

🟥 Emittance Measurement at FAST

🟦 Machine Learning for Accelerator Controls

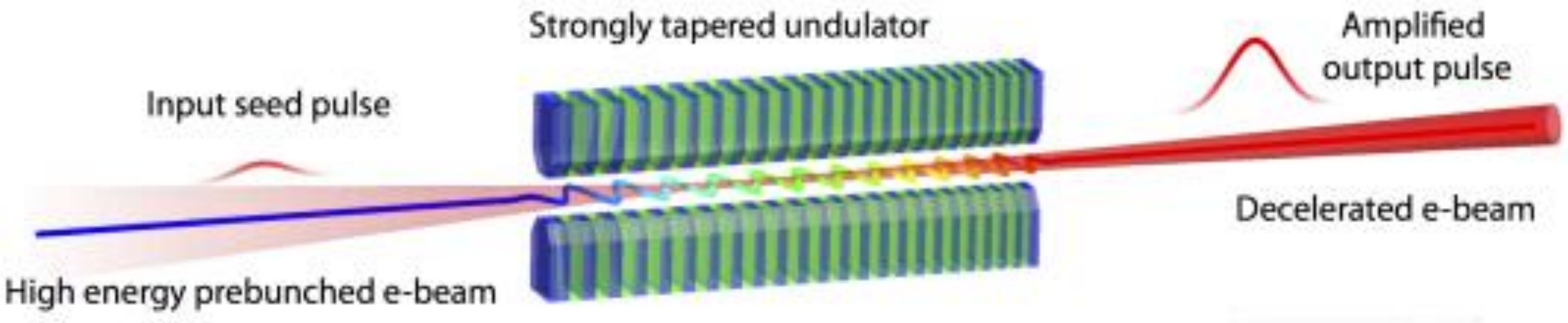
🟪 Optimization of Thermionic Energy Converters

🟦 Web-based Toolkit for Accelerator Controls

🟧 Massively Parallel Magnet Design with Radia

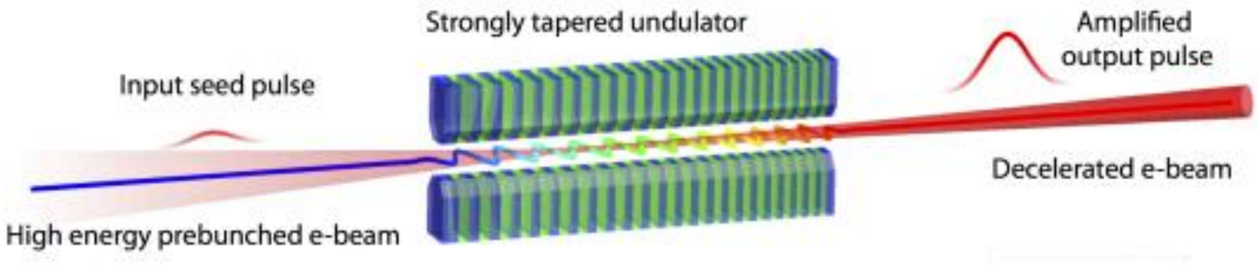
The TESSA-266 proof-of-principle experiment
a high-efficiency FEL

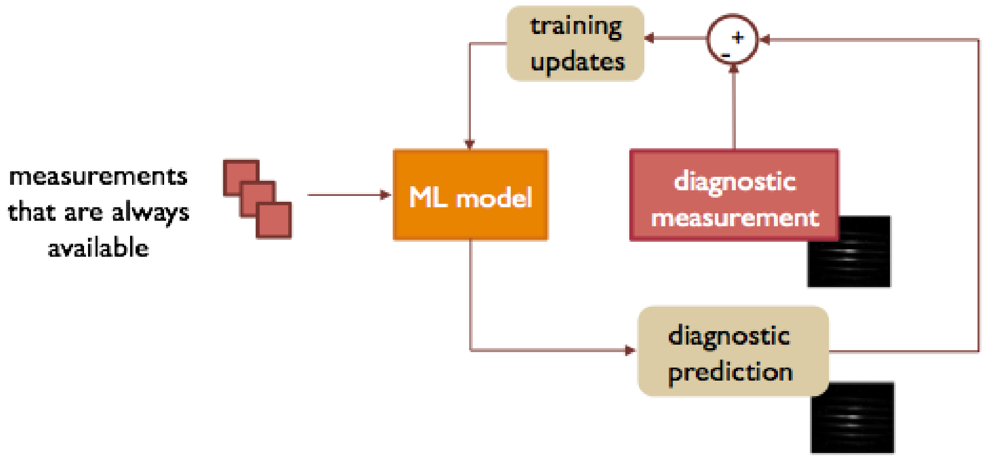
A collaboration between ANL, UCLA, RadiaBeam and RadiaSoft

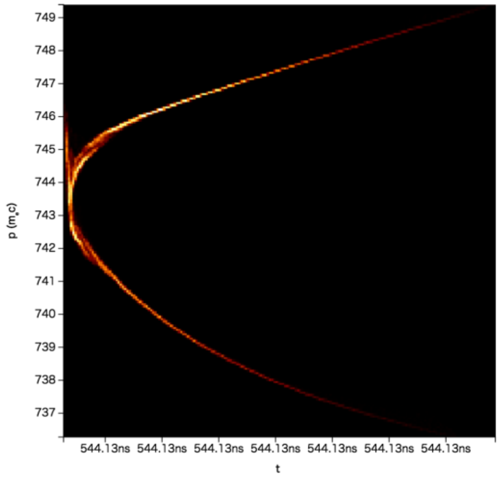


J. Duris *et al*. “Tapering enhanced stimulated superradiant amplification”, *New J. Phys*. (2015).

TESSA-266: plans for virtual (non-intercepting) phase space diagnostics



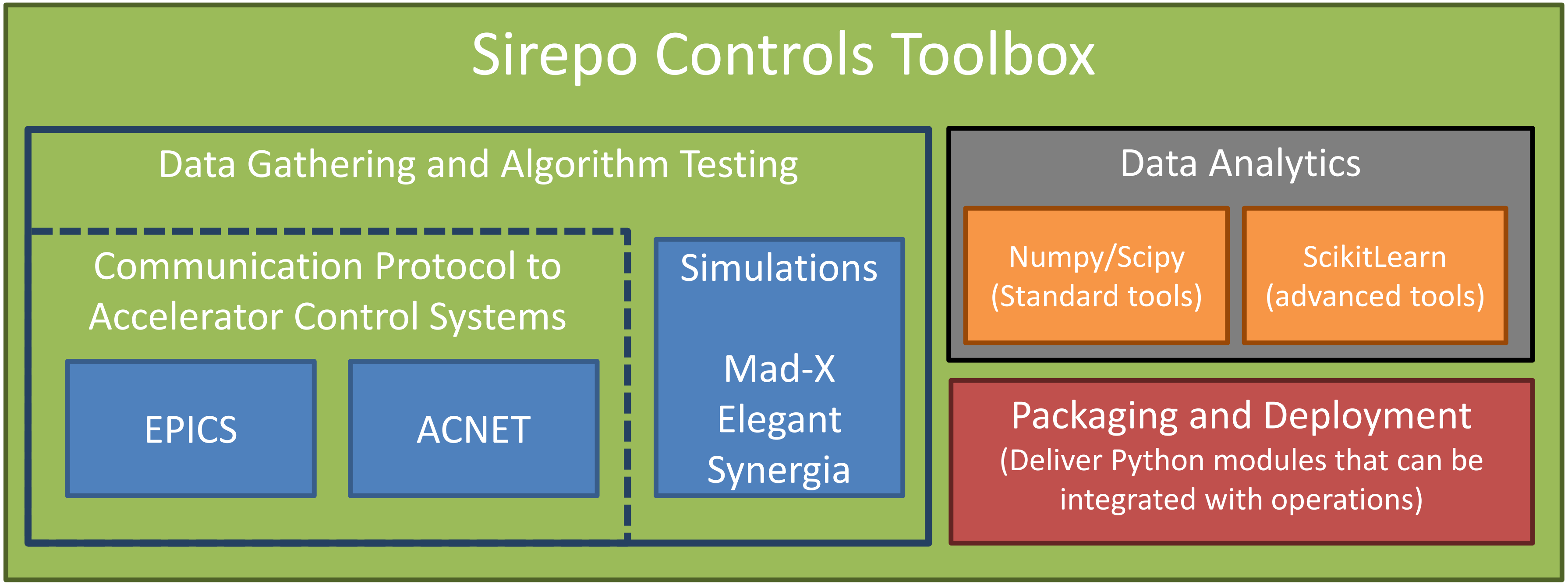




- We want to know the shot-to-shot longitudinal phase space going into the tapered TESSA undulator, which is an intercepting diagnostic
- LEA beamline has CSR, wake fields, and longitudinal space charge, which can cause shot to shot variation in the LPS that we need to understand to analyze TESSA performance

A web-based toolkit for accelerator controls

- Develop an easy to use framework using Sirepo for developing and testing control algorithms and improving operations



Sirepo Controls Toolbox

Data Gathering and Algorithm Testing

Communication Protocol to Accelerator Control Systems

EPICS

ACNET

Simulations

Mad-X
Elegant
Synergia

Data Analytics

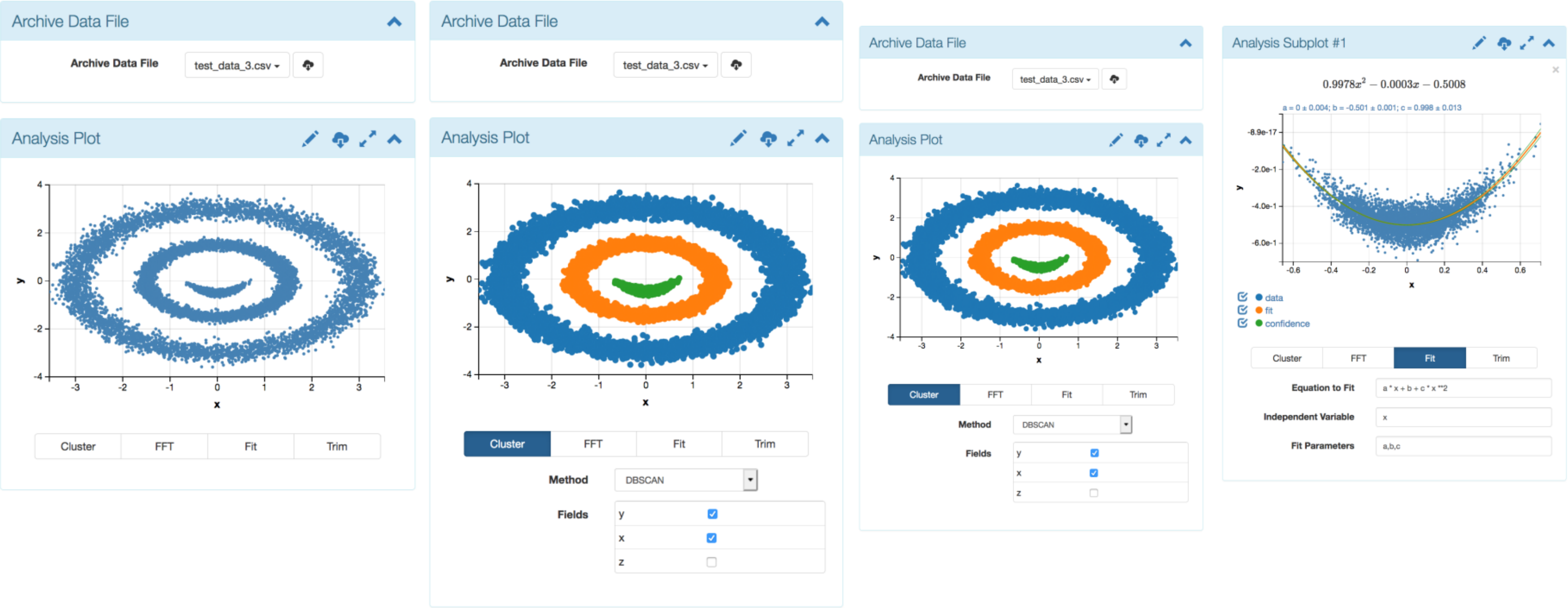
Numpy/Scipy (Standard tools)

ScikitLearn (advanced tools)

Packaging and Deployment (Deliver Python modules that can be integrated with operations)

Prototype web interface for data analysis

- Develop interface and connect with analytics toolboxes
- Currently implemented features:
  - *Curve fitting, clustering, frequency analysis , plotting and data-splitting*
- Features to be implemented in Ph-1
  - *2-D histograms , 2-D frequency analysis*



Archive Data File: test_data_3.csv

Method: DBSCAN

Fields: y ☑ x ☑ z ☐

$0.9978x^2 - 0.0003x - 0.5008$

a = 0 ± 0.004; b = -0.501 ± 0.001; c = 0.998 ± 0.013

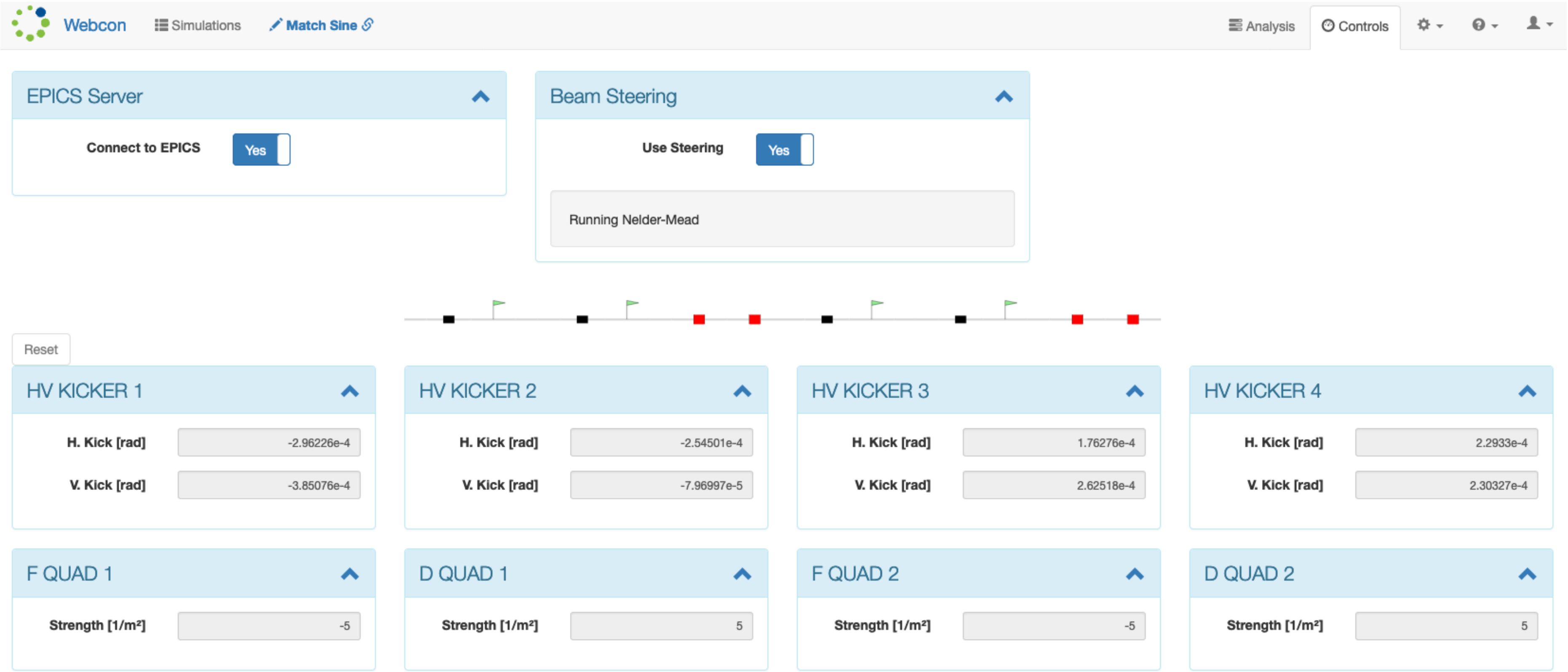
Equation to Fit: a * x + b + c * x **2

Independent Variable: x

Fit Parameters: a,b,c

radiasoft

Prototype web interface for control development



EPICS Server

Connect to EPICS: Yes

Beam Steering

Use Steering: Yes

Running Nelder-Mead

HV KICKER 1

H. Kick [rad]: -2.96226e-4

V. Kick [rad]: -3.85076e-4

HV KICKER 2

H. Kick [rad]: -2.54501e-4

V. Kick [rad]: -7.96997e-5

HV KICKER 3

H. Kick [rad]: 1.76276e-4

V. Kick [rad]: 2.62518e-4

HV KICKER 4

H. Kick [rad]: 2.2933e-4

V. Kick [rad]: 2.30327e-4

F QUAD 1

Strength [1/m²]: -5

D QUAD 1

Strength [1/m²]: 5

F QUAD 2

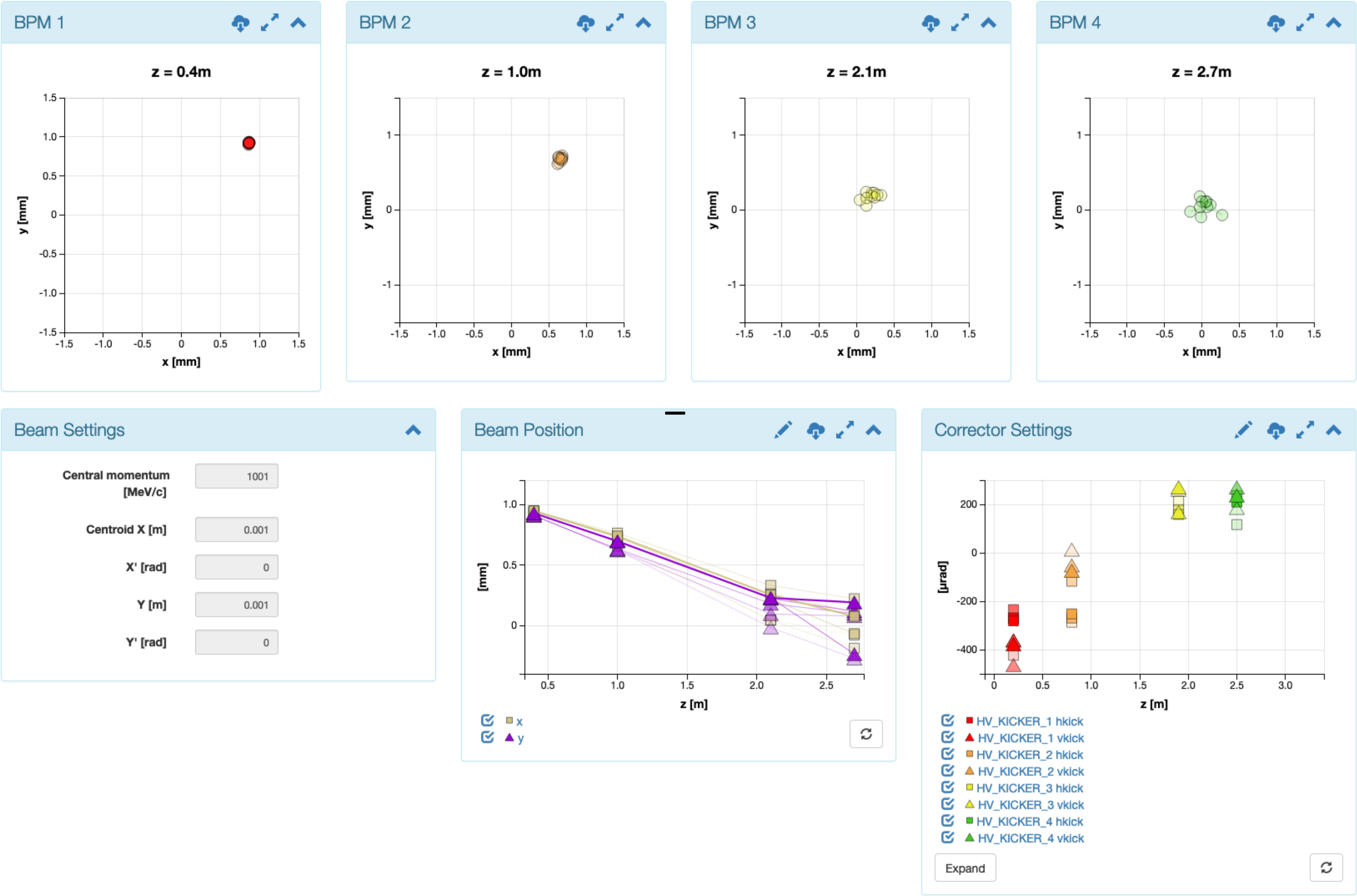
Strength [1/m²]: -5

D QUAD 2

Strength [1/m²]: 5

- Interface connects to EPICS database currently running an elegant simulation of a simple beam-line

Prototype web interface for control development



Central momentum [MeV/c] 1001

Centroid X [m] 0.001

X' [rad] 0

Y [m] 0.001

Y' [rad] 0

Present initiative: single-click supercomputing

- *Sirepo web server does not require HPC resources*
  - *simulation requests are submitted to other nodes*
  - *available servers are configured when Sirepo server is started*
  - *typically a moderately sized cluster*
  - *MPI-based codes are typically executed on a single node*

- *How do you increase the resolution or particle number?*
  - *it would be convenient and powerful to submit jobs at NERSC*

- *Present server-side technology is being refactored*
  - *Celery provides an asynchronous job queue for executing long-running simulations and provides cluster management*
  - *It uses RabbitMQ as a message broker for communication between the web server and the execution nodes.*

Present initiative: single-click supercomputing

- *We need to support Torque, SLURM, PBS, etc.*
  - *Sirepo's job management system is being redesigned*
  - *implementing a Docker-based job execution environment*
    - ***more efficient, robust and secure than Celery/RabbitMQ***
- *The new implementation will rely on Tornado*
  - *highly concurrent web server/framework*
  - *provides a microservice called the "Job Supervisor"*
    - *manages the Sirepo job queue*
    - *can start "Job Agents" on remote clusters and supercomputers*
    - *also for local use – development & single-node deployments*
  - *Agents create a WebSocket to communicate with Supervisor*
    - *enables fast, asynchronous inter-process communication*
    - *will go through common firewalls*
  - *Agents will start jobs, cancel jobs, extract in situ visualizations, report job progress, etc.*

Present initiative: single-click supercomputing

- *Sirepo will be enhanced to support single-click execution on supercomputers and remote clusters*
  - *Users will be asked for a token or other credentials*
  - *The Sirepo NERSC interface will use multifactor authentication,*
    - ***create a token that Supervisor uses to login via NERSC Web Toolkit (NEWT) interface***
    - ***will invoke an Agent running inside NERSC's SHIFTER environment***
    - ***departmental clusters may require users supply SSH keys***

- *implementation should be completed in 2019*

Thanks!

This work is supported by the SBIR program of the US Department of Energy (DOE), Office of Science under Award Nos. DE-SC0011237 and DE-SC0019682 (BES);
DE-SC0011340, DE-SC0013855, DE-SC0015897 and DE-SC0018719 (HEP);
DE-SC0015212 and DE-SC0017181 (NP); DE-SC0017057 and DE-SC0017162 (ASCR).