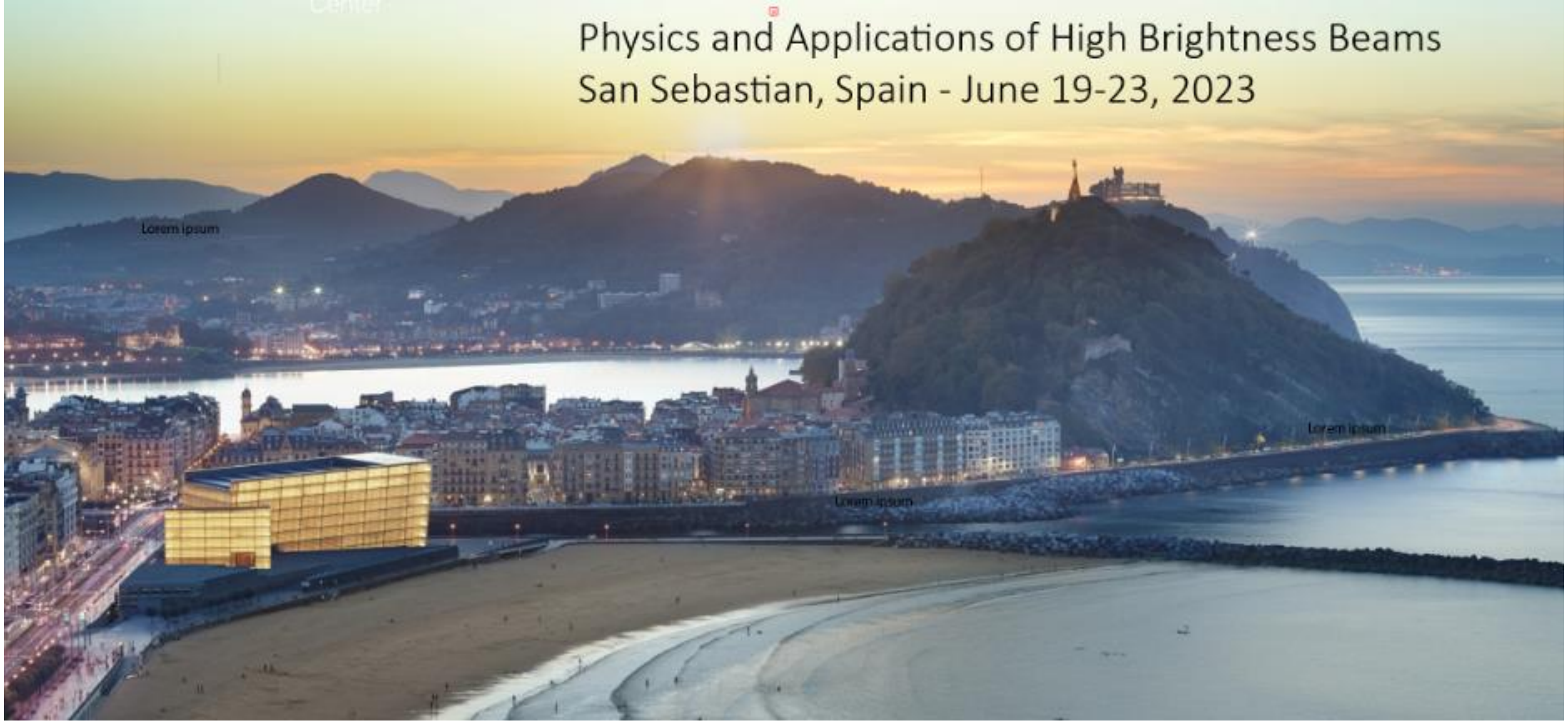
PAHBB 2023 workshop

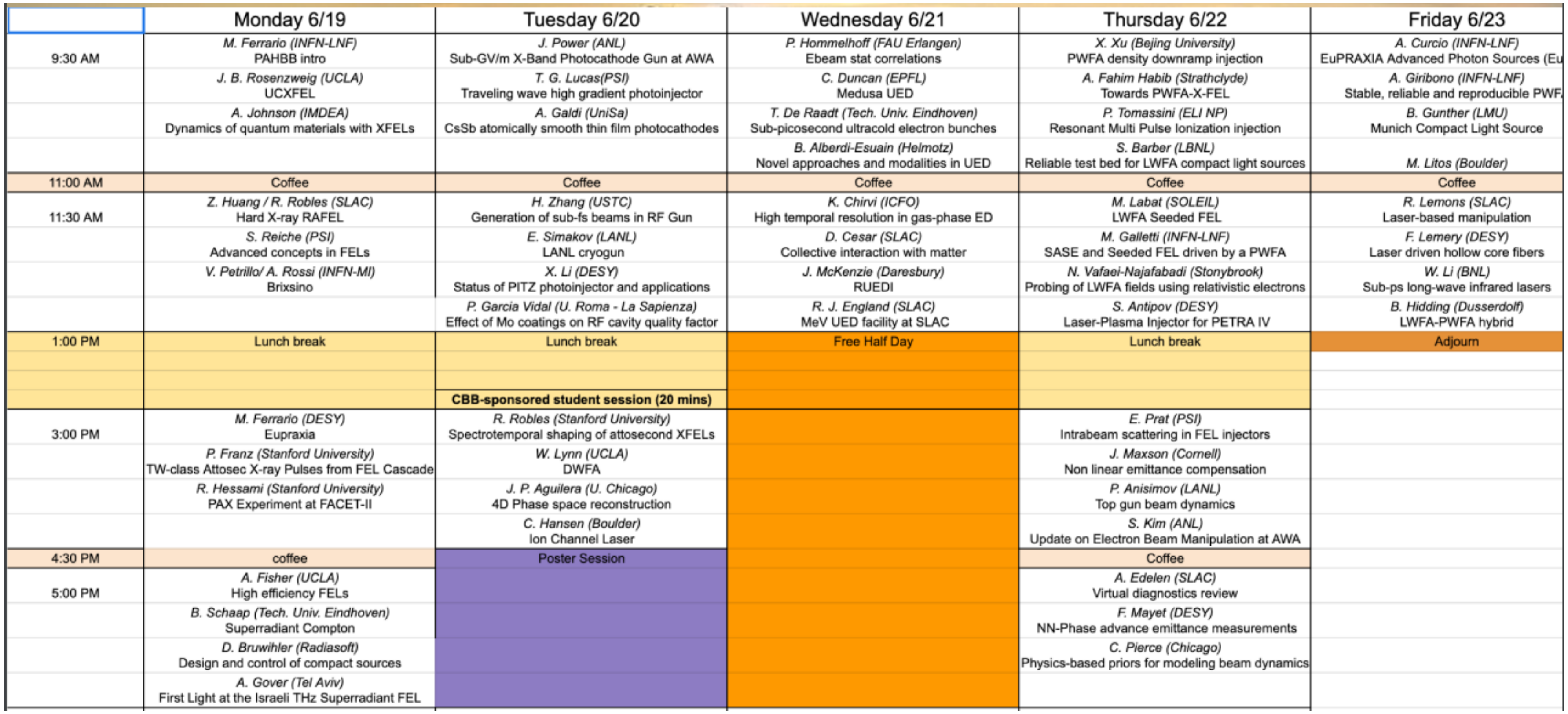


https://indico.classe.cornell.edu/event/2170/overview

X.-K. Li
PPS,12.10.2023

Topics of the workshop

- 5-th generation light source
- FEL and coherent radiation
- High brightness electron source
- Ultra-fast electron probe
- Plasma acceleration
- Beam dynamics and control
- Advanced concepts

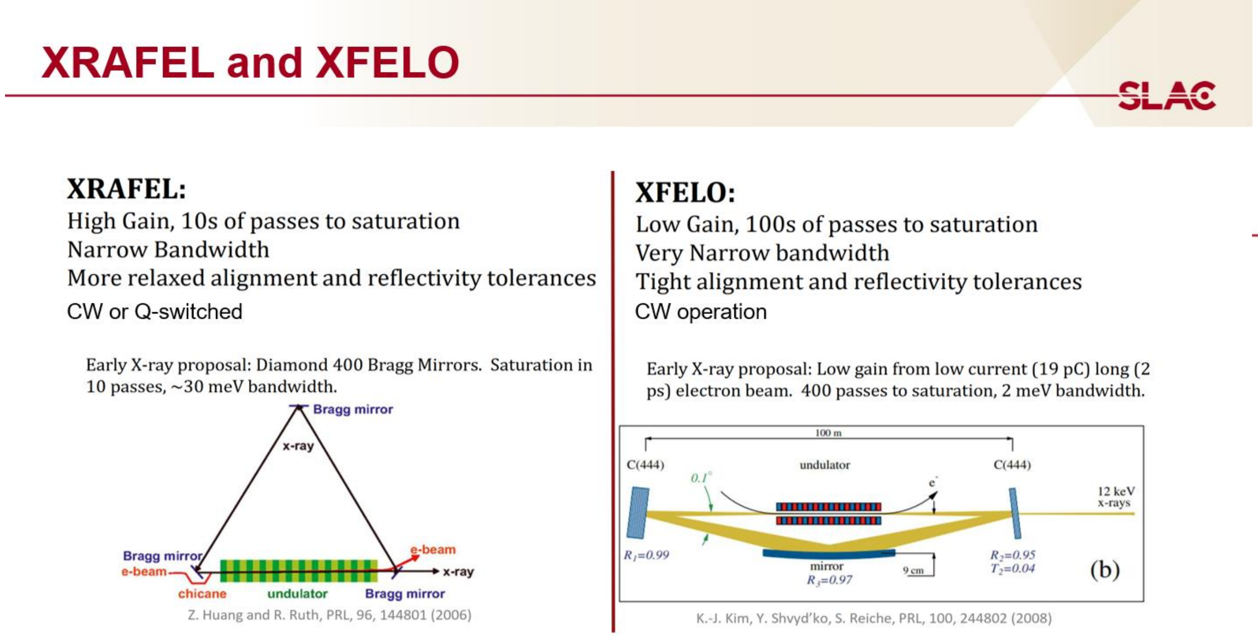


	Monday 6/19	Tuesday 6/20	Wednesday 6/21	Thursday 6/22	Friday 6/23
9:30 AM	*M. Ferrario (INFN-LNF)* PAHBB intro	*J. Power (ANL)* Sub-GV/m X-Band Photocathode Gun at AWA	*P. Hommelhoff (FAU Erlangen)* Ebeam stat correlations	*X. Xu (Bejing University)* PWFA density downramp injection	*A. Curcio (INFN-LNF)* EuPRAXIA Advanced Photon Sources (Eu
	J. B. Rosenzweig (UCLA) UCXFEL	*T. G. Lucas(PSI)* Traveling wave high gradient photoinjector	*C. Duncan (EPFL)* Medusa UED	*A. Fahim Habib (Strathclyde)* Towards PWFA-X-FEL	*A. Giribono (INFN-LNF)* Stable, reliable and reproducible PWF
	A. Johnson (IMDEA) Dynamics of quantum materials with XFELs	*A. Galdi (UniSa)* CsSb atomically smooth thin film photocathodes	*T. De Raadt (Tech. Univ. Eindhoven)* Sub-picosecond ultracold electron bunches	*P. Tomassini (ELI NP)* Resonant Multi Pulse Ionization injection	*B. Gunther (LMU)* Munich Compact Light Source
			B. Alberdi-Esuain (Helmotz) Novel approaches and modalities in UED	*S. Barber (LBNL)* Reliable test bed for LWFA compact light sources	*M. Litos (Boulder)*
11:00 AM	Coffee	Coffee	Coffee	Coffee	Coffee
11:30 AM	*Z. Huang / R. Robles (SLAC)* Hard X-ray RAFEL	*H. Zhang (USTC)* Generation of sub-fs beams in RF Gun	*K. Chirvi (ICFO)* High temporal resolution in gas-phase ED	*M. Labat (SOLEIL)* LWFA Seeded FEL	*R. Lemons (SLAC)* Laser-based manipulation
	S. Reiche (PSI) Advanced concepts in FELs	*E. Simakov (LANL)* LANL cryogun	*D. Cesar (SLAC)* Collective interaction with matter	*M. Galletti (INFN-LNF)* SASE and Seeded FEL driven by a PWFA	*F. Lemery (DESY)* Laser driven hollow core fibers
	V. Petrillo/ A. Rossi (INFN-MI) Brixsino	*X. Li (DESY)* Status of PITZ photoinjector and applications	*J. McKenzie (Daresbury)* RUEDI	*N. Vafaei-Najafabadi (Stonybrook)* Probing of LWFA fields using relativistic electrons	*W. Li (BNL)* Sub-ps long-wave infrared lasers
		P. Garcia Vidal (U. Roma - La Sapienza) Effect of Mo coatings on RF cavity quality factor	*R. J. England (SLAC)* MeV UED facility at SLAC	*S. Antipov (DESY)* Laser-Plasma Injector for PETRA IV	*B. Hidding (Dusserdolf)* LWFA-PWFA hybrid
1:00 PM	Lunch break	Lunch break	Free Half Day	Lunch break	Adjourn
		CBB-sponsored student session (20 mins)			
3:00 PM	*M. Ferrario (DESY)* Eupraxia	*R. Robles (Stanford University)* Spectrotemporal shaping of attosecond XFELs		*E. Prat (PSI)* Intrabeam scattering in FEL injectors	
	P. Franz (Stanford University) TW-class Attosec X-ray Pulses from FEL Cascade	*W. Lynn (UCLA)* DWFA		*J. Maxson (Cornell)* Non linear emittance compensation	
	R. Hessami (Stanford University) PAX Experiment at FACET-II	*J. P. Aguilera (U. Chicago)* 4D Phase space reconstruction		*P. Anisimov (LANL)* Top gun beam dynamics	
		C. Hansen (Boulder) Ion Channel Laser		*S. Kim (ANL)* Update on Electron Beam Manipulation at AWA	
4:30 PM	coffee	Poster Session		Coffee	
5:00 PM	*A. Fisher (UCLA)* High efficiency FELs			*A. Edelen (SLAC)* Virtual diagnostics review	
	B. Schaap (Tech. Univ. Eindhoven) Superradiant Compton			*F. Mayet (DESY)* NN-Phase advance emittance measurements	
	D. Bruwihler (Radiasoft) Design and control of compact sources			*C. Pierce (Chicago)* Physics-based priors for modeling beam dynamics	
	A. Gover (Tel Aviv) First Light at the Israeli THz Superradiant FEL				

X-ray Regenerative Amplifier FEL

River Robles for Zhirong Huang (SLAC)

- Cavity based XFEL (CBXFEL)



XRAFEL and XFELO

XRAFEL:
High Gain, 10s of passes to saturation
Narrow Bandwidth
More relaxed alignment and reflectivity tolerances
CW or Q-switched

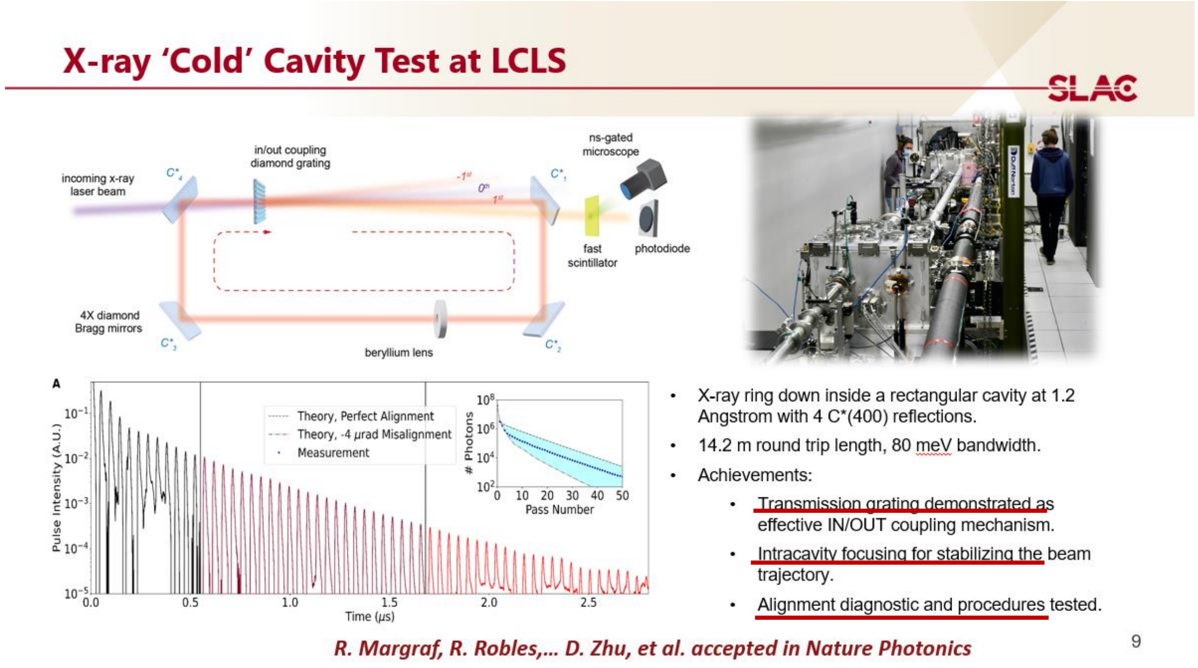
Early X-ray proposal: Diamond 400 Bragg Mirrors. Saturation in 10 passes, ~30 meV bandwidth.

Z. Huang and R. Ruth, PRL, 96, 144801 (2006)

XFELO:
Low Gain, 100s of passes to saturation
Very Narrow bandwidth
Tight alignment and reflectivity tolerances
CW operation

Early X-ray proposal: Low gain from low current (19 pC) long (2 ps) electron beam. 400 passes to saturation, 2 meV bandwidth.

K.-J. Kim, Y. Shvyd'ko, S. Reiche, PRL, 100, 244802 (2008)



X-ray 'Cold' Cavity Test at LCLS

- X-ray ring down inside a rectangular cavity at 1.2 Angstrom with 4 C*(400) reflections.
- 14.2 m round trip length, 80 meV bandwidth.
- Achievements:
  - Transmission grating demonstrated as effective IN/OUT coupling mechanism.
  - Intracavity focusing for stabilizing the beam trajectory.
  - Alignment diagnostic and procedures tested.

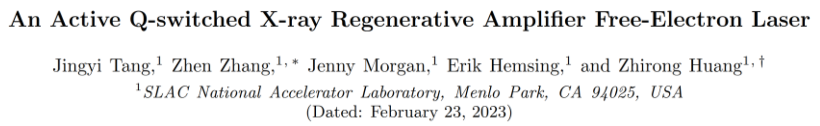
R. Margraf, R. Robles,… D. Zhu, et al. accepted in Nature Photonics

9

- Long term performance is already close to the requirement to initiate amplification towards saturation for XRAFEL

X-ray Regenerative Amplifier FEL

River Robles for Zhirong Huang (SLAC)



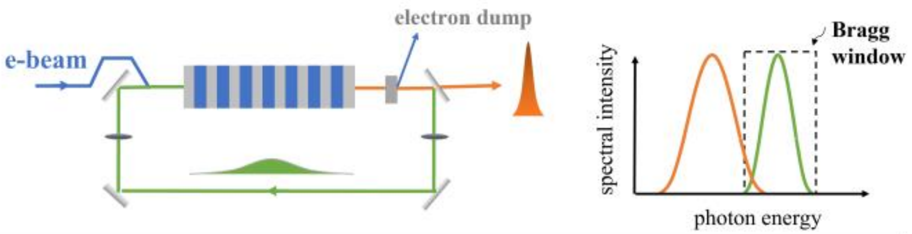
An Active Q-switched X-ray Regenerative Amplifier Free-Electron Laser

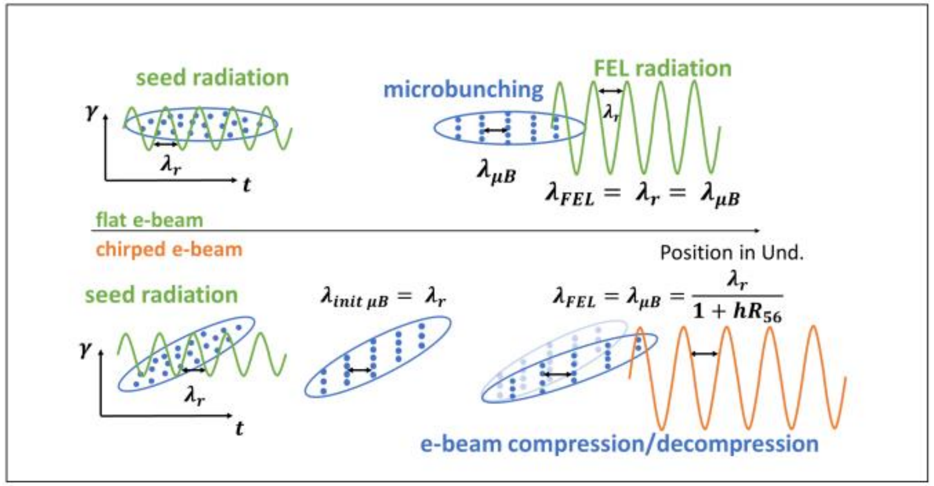
Jingyi Tang,[1] Zhen Zhang,[1,*] Jenny Morgan,[1] Erik Hemsing,[1] and Zhirong Huang[1,†]

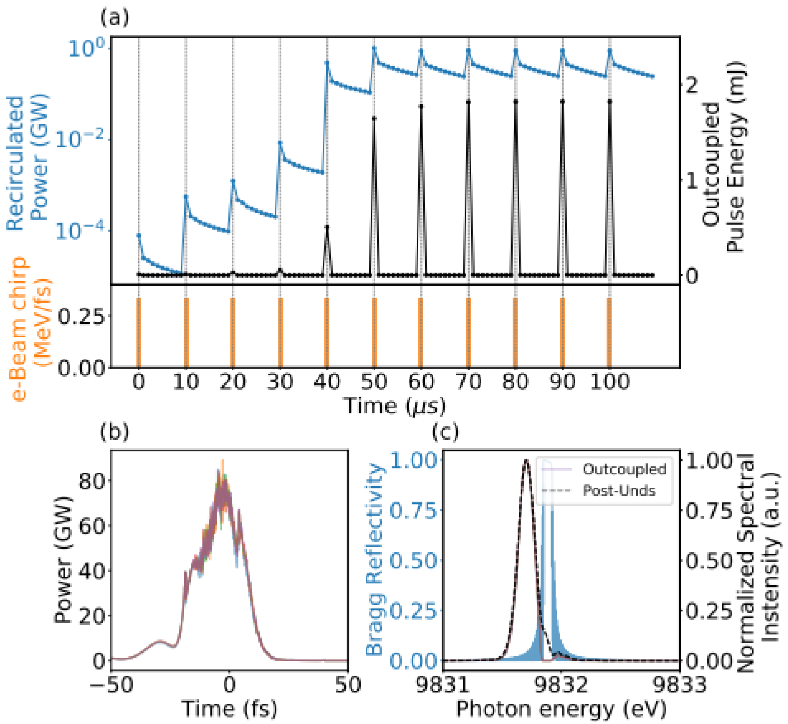
[1]*SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*

(Dated: February 23, 2023)

- Chirp-based Q-switching in regenerative amplifier FELs
  - Use an energy-chirped e-beam to shift X-ray wavelength (slightly) outside the Bragg bandwidth
  - Actively control the cavity Q by manipulating the e-beam energy chirp
  - Keep cavity optics simple and intact







Virtual Diagnostics for High Brightness Beams

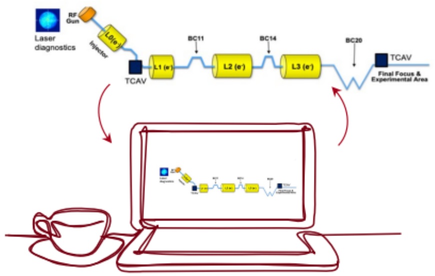
Physics and Applications of High Brightness Beams Workshop
June 22, 2023

Auralee Edelen, Brendan O'Shea, Claudio Emma, Ryan Roussel,
Robbie Watt, Daniel Ratner, Chris Mayes *(SLAC)*

Virtual Diagnostics ←→ Virtual Accelerators

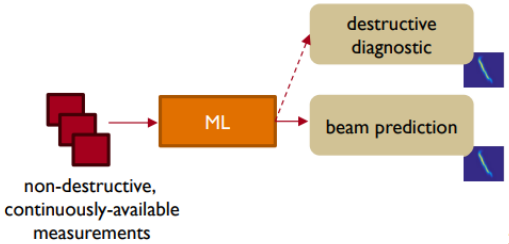
Many long-standing efforts to make **"virtual accelerators"** that closely match machine behavior

- Predict machine behavior that isn't directly accessible
- Related to the idea of "digital twins" when combined with tracking/adapting to changes in the system



A **"virtual diagnostic"** is an extension of this concept

- Predict beam output in cases where a diagnostic does not exist, is destructive, or updates more slowly than desired
- Machine learning enables new capabilities in prediction *→ do not need a physics model, just need sufficiently well-correlated measurements*



destructive diagnostic

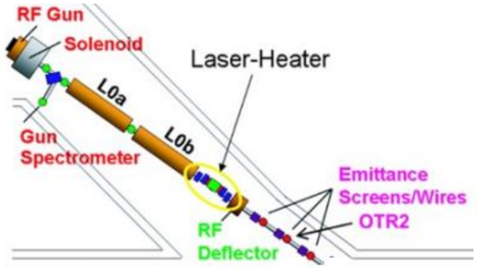
ML

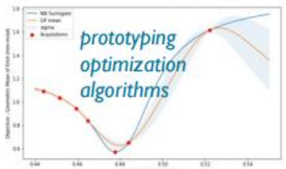
beam prediction

non-destructive, continuously-available measurements

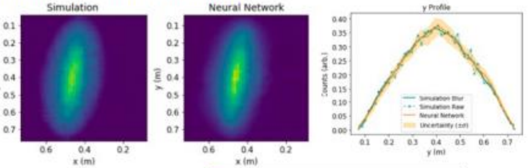
Example of Faster Execution with ML: LCLS Injector

- ML models trained on detailed IMPACT simulations over entire valid range of injector settings and drive laser settings
- Several models with different combinations of output tailored to specific need *(phase space prediction, emittance/match, beam sizes, etc.)*
- Using to develop/prototype new algorithms before testing online (e.g. 20x speedup in emittance tuning: https://arxiv.org/abs/2209.04587)
- Will be deployed online for prediction of beam phase space and Twiss parameters

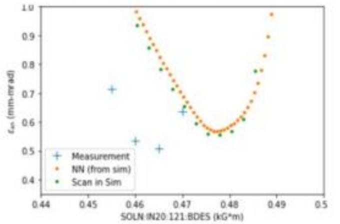




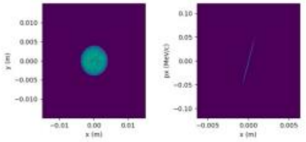
prototyping optimization algorithms



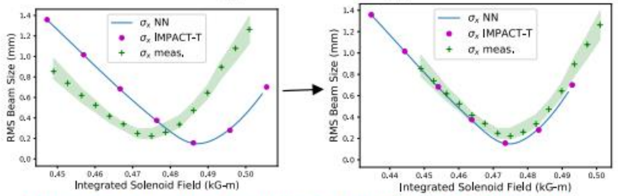
ML model matches simulation under interpolation



Simulation and ML model trained on it are qualitatively similar to measurements under interpolation



interactive model widget and visualization tools

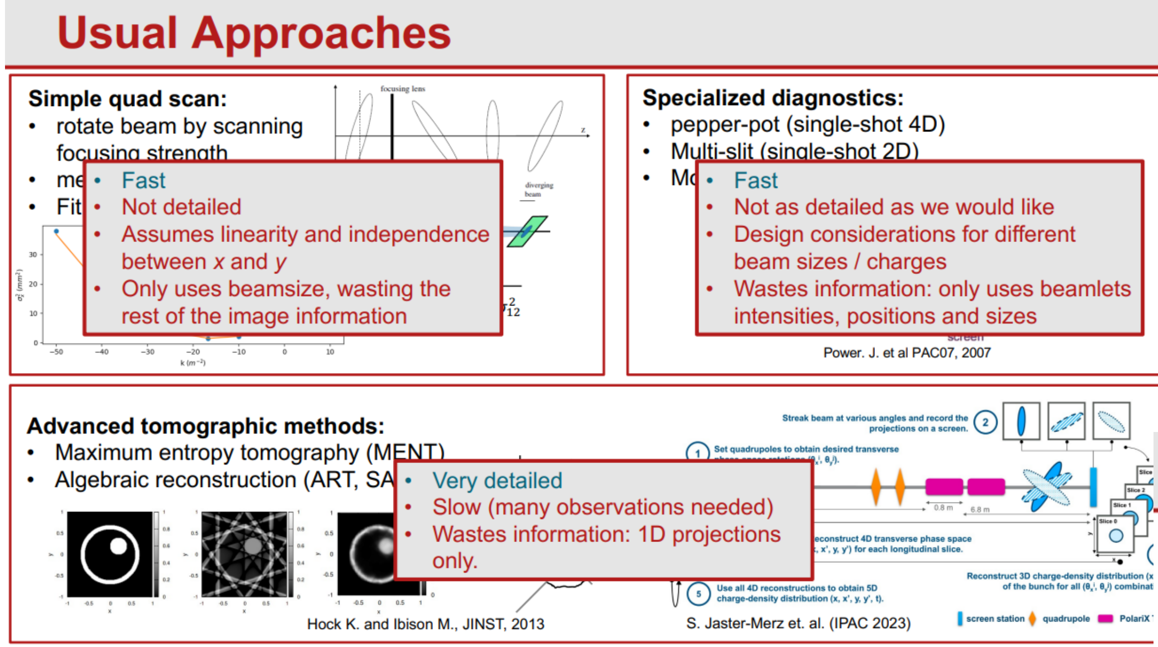


Automatic adaptation of models and identification of sources of deviation between simulations and as-built machine

ML models trained on simulations and measurements have enabled fast prototyping of new optimization algorithms, facilitated rapid model adaptation under new conditions, and can directly aid online tuning and operator decision making

Detailed Phase Space Reconstruction using Neural Networks and Differentiable Simulations

Juan Pablo Gonzalez-Aguilera* (UChicago)



Usual Approaches

Simple quad scan:
- rotate beam by scanning focusing strength
- me
- Fit

- Fast
- Not detailed
- Assumes linearity and independence between *x* and *y*
- Only uses beamsize, wasting the rest of the image information

Specialized diagnostics:
- pepper-pot (single-shot 4D)
- Multi-slit (single-shot 2D)
- Mo

- Fast
- Not as detailed as we would like
- Design considerations for different beam sizes / charges
- Wastes information: only uses beamlets intensities, positions and sizes

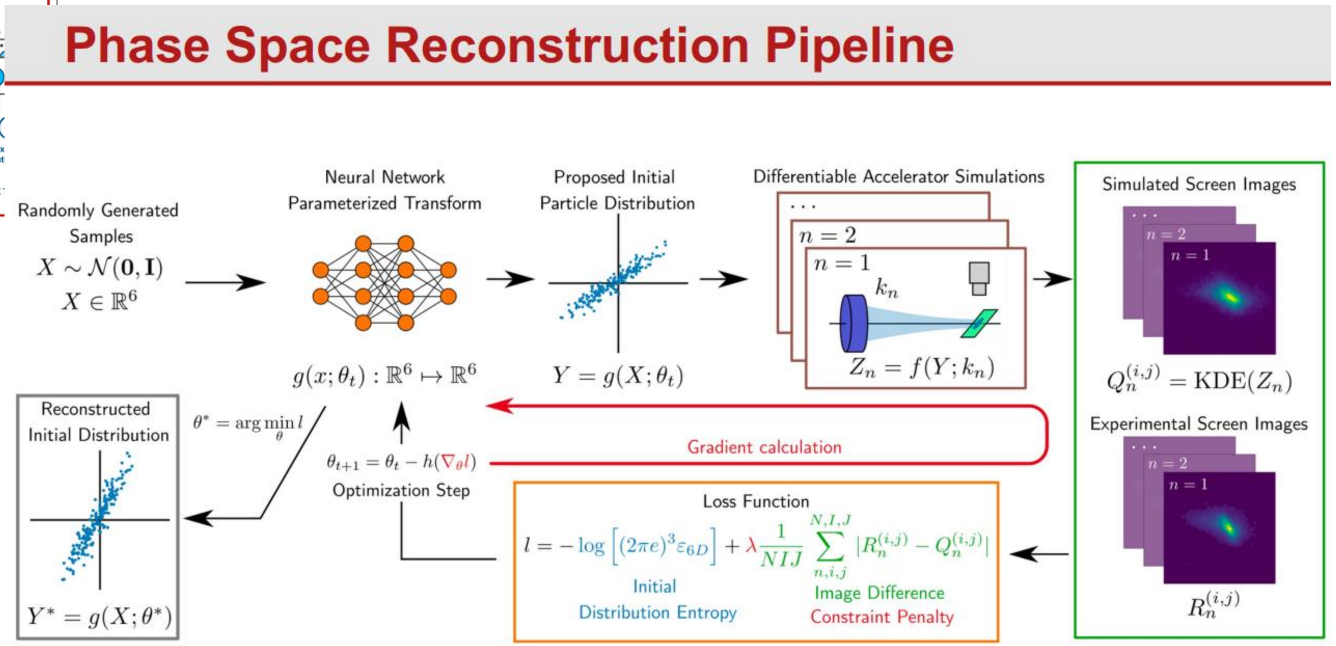
Power. J. et al PAC07, 2007

Advanced tomographic methods:
- Maximum entropy tomography (MENT)
- Algebraic reconstruction (ART, SA

- Very detailed
- Slow (many observations needed)
- Wastes information: 1D projections only.

Hock K. and Ibison M., JINST, 2013

S. Jaster-Merz et. al. (IPAC 2023)



Phase Space Reconstruction Pipeline

$$l = -\log\left[(2\pi e)^3 \varepsilon_{6D}\right] + \lambda \frac{1}{NIJ} \sum_{n,i,j}^{N,I,J} \left|R_n^{(i,j)} - Q_n^{(i,j)}\right|$$

Detailed Phase Space Reconstruction using Neural Networks and Differentiable Simulations

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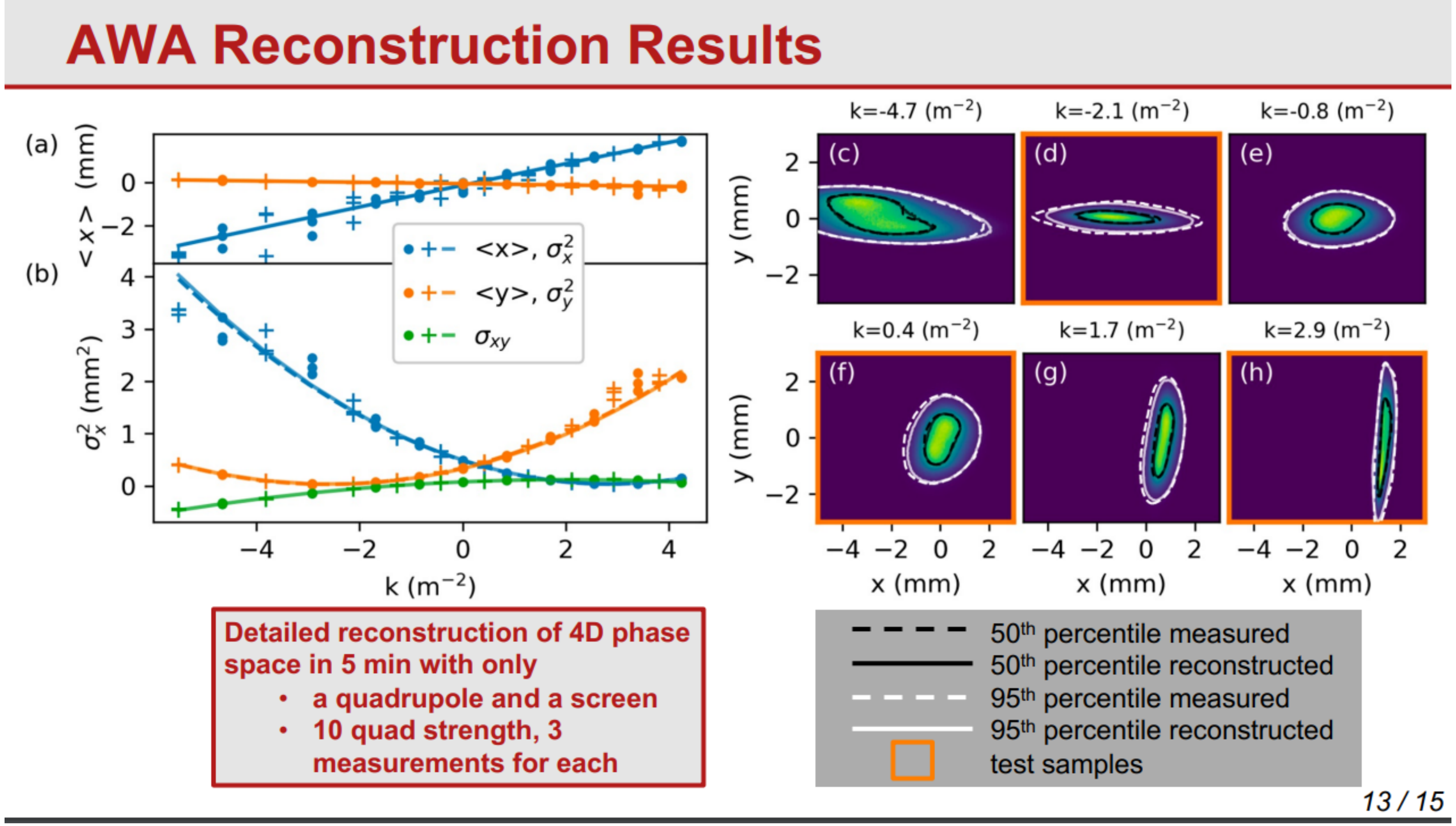


AWA Reconstruction Results

Detailed reconstruction of 4D phase space in 5 min with only

- **a quadrupole and a screen**
- **10 quad strength, 3 measurements for each**

13 / 15

Energy spread increase by IBS and microbunching in FEL injectors

Eduard Prat, FEL Beam Dynamics, Paul Scherrer Institut

$$\sigma_m^2 = \sigma_R^2 + \frac{m_e c^2 \beta \epsilon_n}{E} + \frac{D^2 \sigma_{E,m}^2}{E^2}$$

monitor resolution | natural beam size | dispersive beam size

Many publications on IBS & MBI theory and experiments – e.g. [Di Mitri et al, New J. Phys. 22, 083053 (2020)] and references herein.

IBS, Piwinsky model $\sigma_{E,IBS} \propto \frac{I^{1/2} z^{1/2}}{\beta^{1/4} \varepsilon_n^{3/2}}$

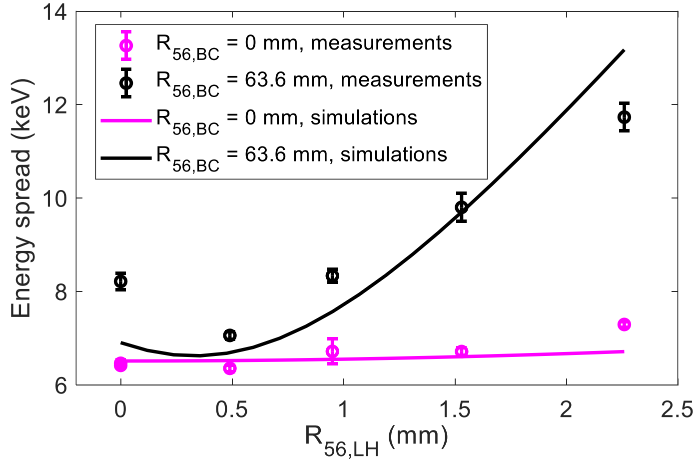
MBI from 1D approximation $\sigma_{E,MBI} = Ibz$

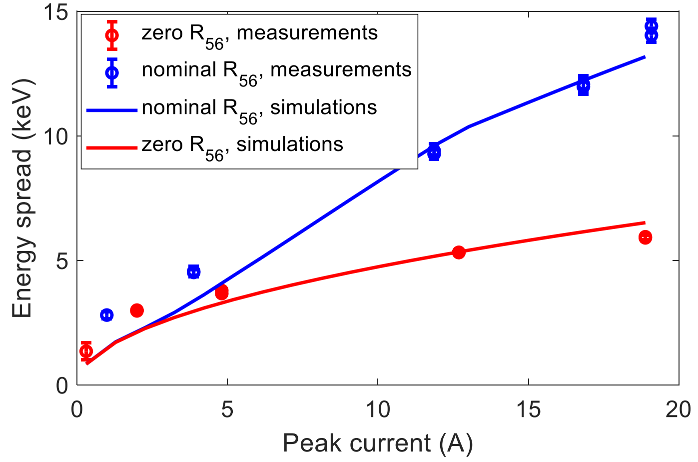
MBI has a strong dependence on longitudinal dispersion or R_{56}

From basic modeling:

- ➢ Different dependence on peak current *I*
- ➢ β-function dependence → IBS
- ➢ R_{56} dependence → MBI

→ **This work: measurements at SwissFEL as a function of peak current, lattice optics (β) and R_{56} → they show that both IBS/MBI effects increase energy spread**



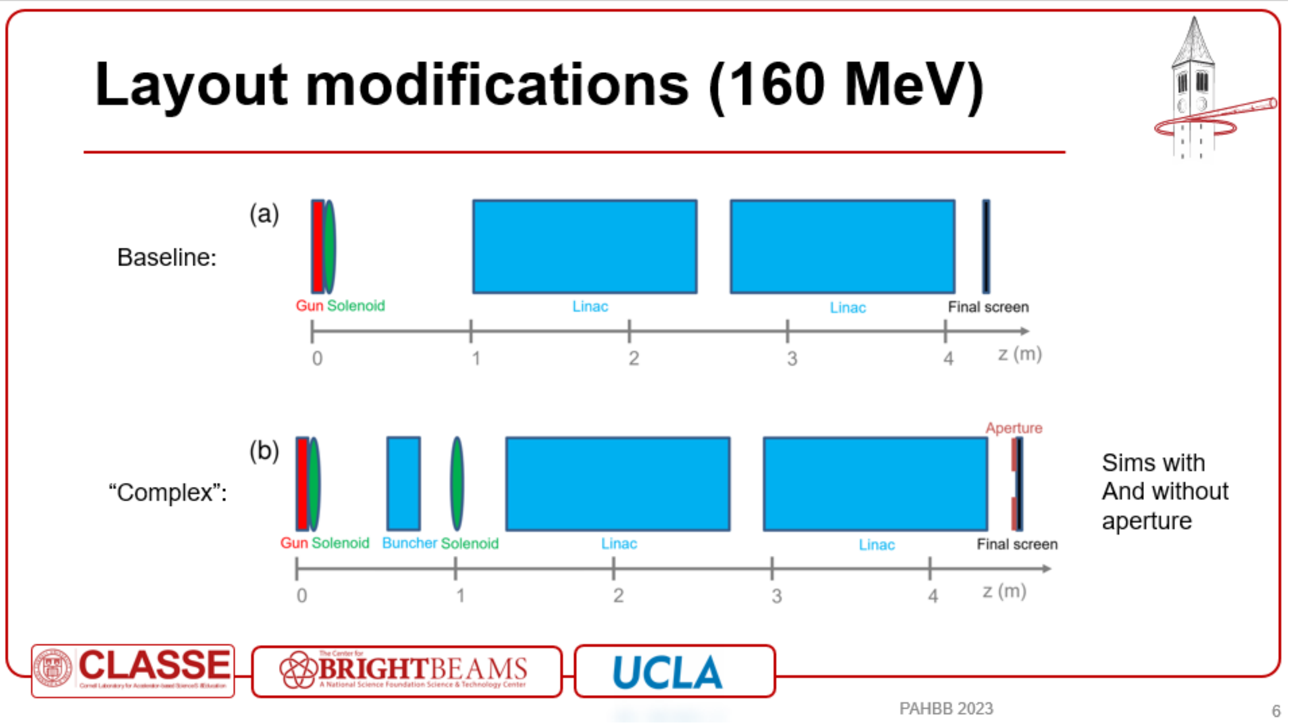


- ➢ Overall a good agreement!
- ➢ … but we require to increase IBS strength by a factor of ~2.4
- ➢ Still, underestimation of energy spread for low peak currents and some R_{56} settings

Photoinjector transverse phase space linearization with sacrificial charge

Jared Maxson (Cornell) and William Li (BNL)

- We looked at two possible improvements in GPT simulations:
  - A more complex injector: add a buncher cavity and an additional solenoid
  - **Emitting more charge (250 pC) than needed (100 pC), and using a collimating aperture to select the beam core.**
- **Upshot: <20 nm emittance growth due to space charge for 100 pC charge after aperture (20-30 A peak current @ 160 MeV)**
- **The *sacrifical charge* is used in a *dynamic way* to linearize slice phase space of the 100 pC core.**



Layout modifications (160 MeV)

Sims with
And without
aperture

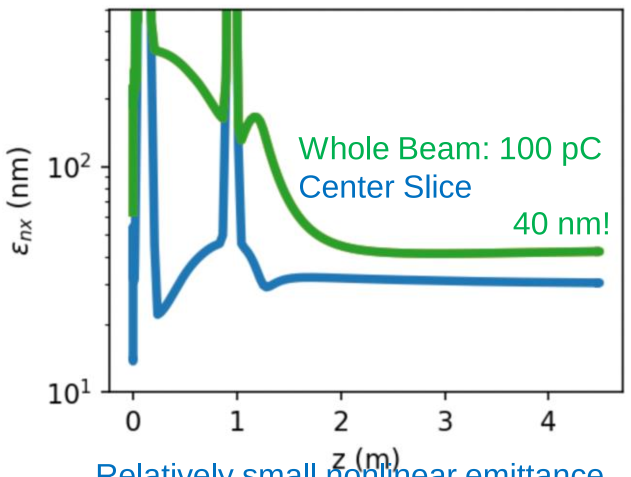
PAHBB 2023

6

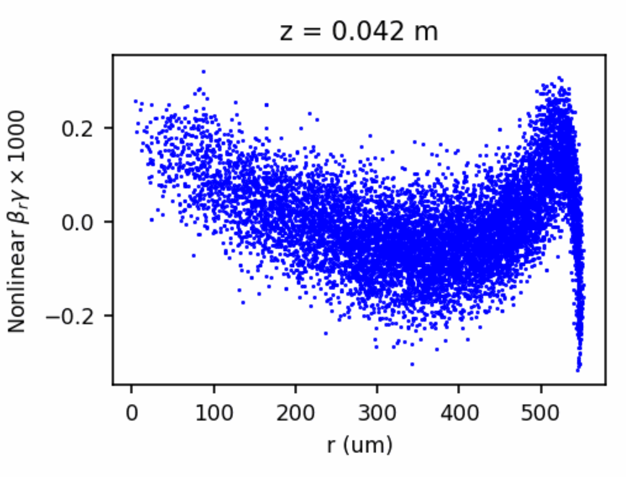
Photoinjector transverse phase space linearization with sacrificial charge

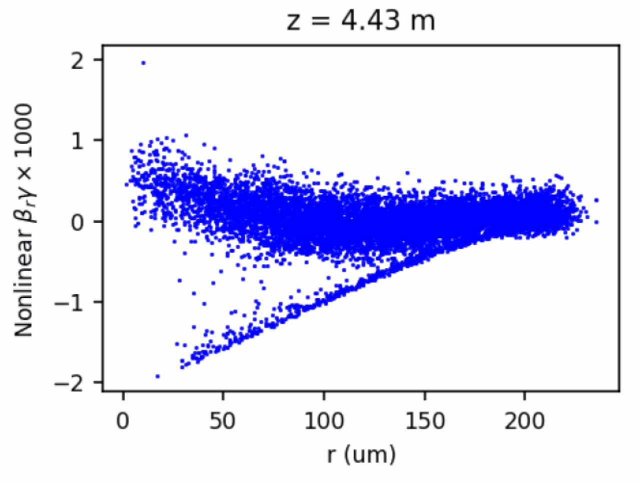
Jared Maxson (Cornell) and William Li (BNL)

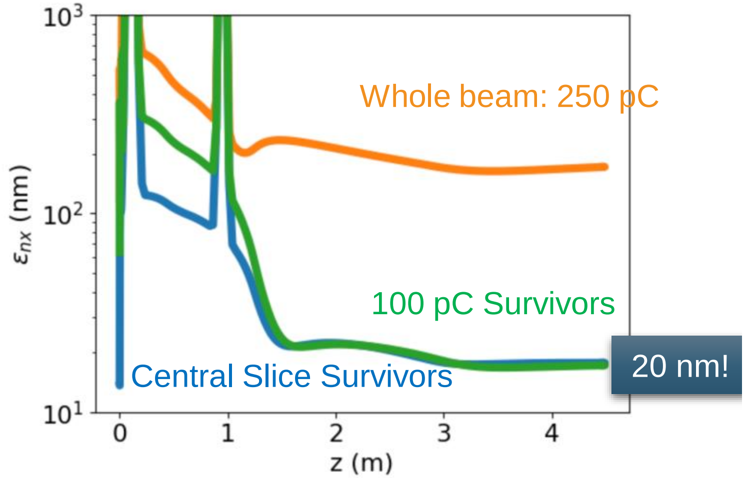
No thermal emittance!

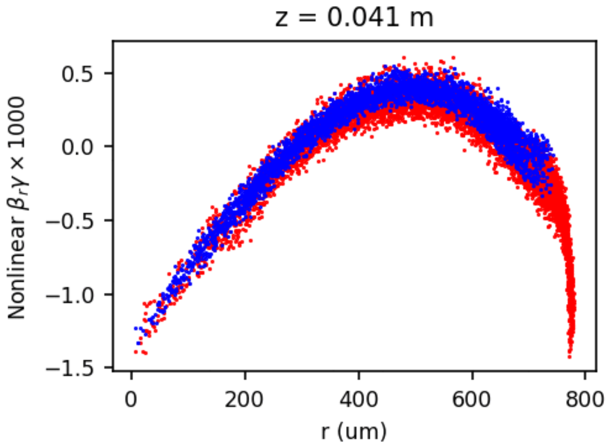


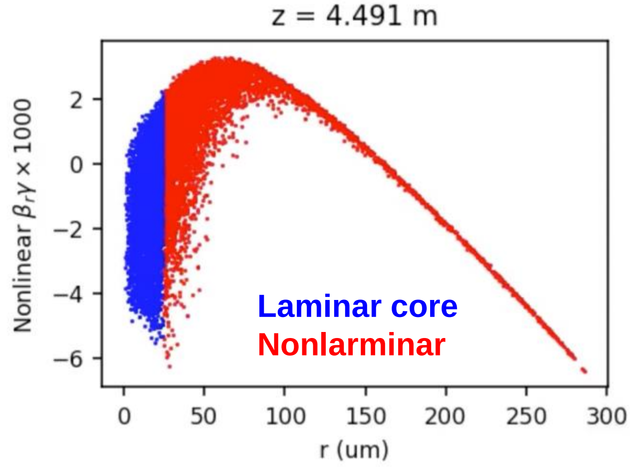
Relatively small nonlinear emittance oscillations







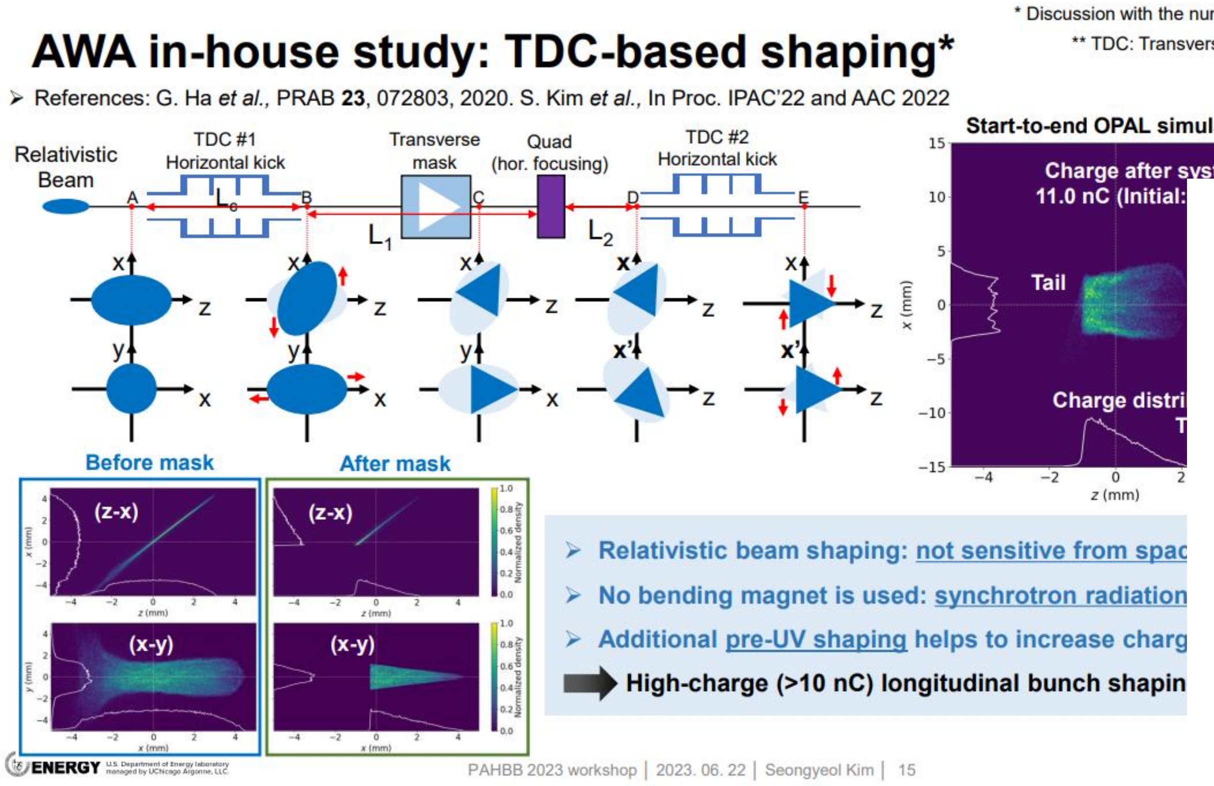




Large slice emittance, then **dramatic drop (!?)**

Update on Electron Beam Manipulation at the Argonne Wakefield Accelerator Facility

SEONGYEOL KIM On behalf of Argonne Wakefield Accelerator Group



* Discussion with the numerical simulations

** TDC: Transverse deflecting cavity

AWA in-house study: TDC-based shaping*

➢ References: G. Ha *et al.*, PRAB **23**, 072803, 2020. S. Kim *et al.*, In Proc. IPAC'22 and AAC 2022

➢ Relativistic beam shaping: not sensitive from spac

➢ No bending magnet is used: synchrotron radiation

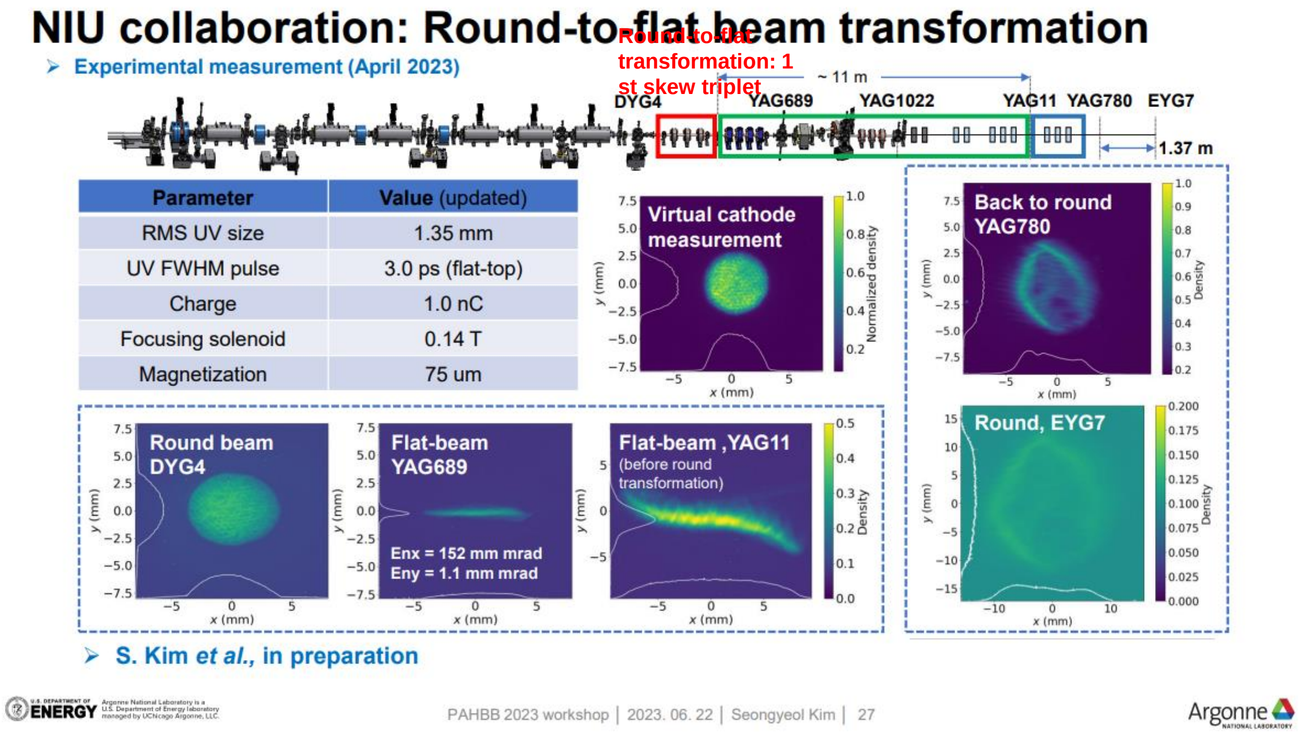
➢ Additional pre-UV shaping helps to increase charg

➡ **High-charge (>10 nC) longitudinal bunch shapin**

ENERGY U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

PAHBB 2023 workshop | 2023. 06. 22 | Seongyeol Kim | 15

High-gradient, high-transformer ratio wakefield generation:
High-charge bunch shaping (e.g., triangular longitudinal distribution)



NIU collaboration: Round-to-flat beam transformation

➢ Experimental measurement (April 2023)

Parameter	Value (updated)
RMS UV size	1.35 mm
UV FWHM pulse	3.0 ps (flat-top)
Charge	1.0 nC
Focusing solenoid	0.14 T
Magnetization	75 um

➢ S. Kim *et al.*, in preparation

ENERGY Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

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Argonne NATIONAL LABORATORY

Flat-to-round and back-to-round **provides the flexibility of emittance partitioning** for various applications such as hadron cooling, damping-ring-free injector, and asymmetric PWFA

Thank you

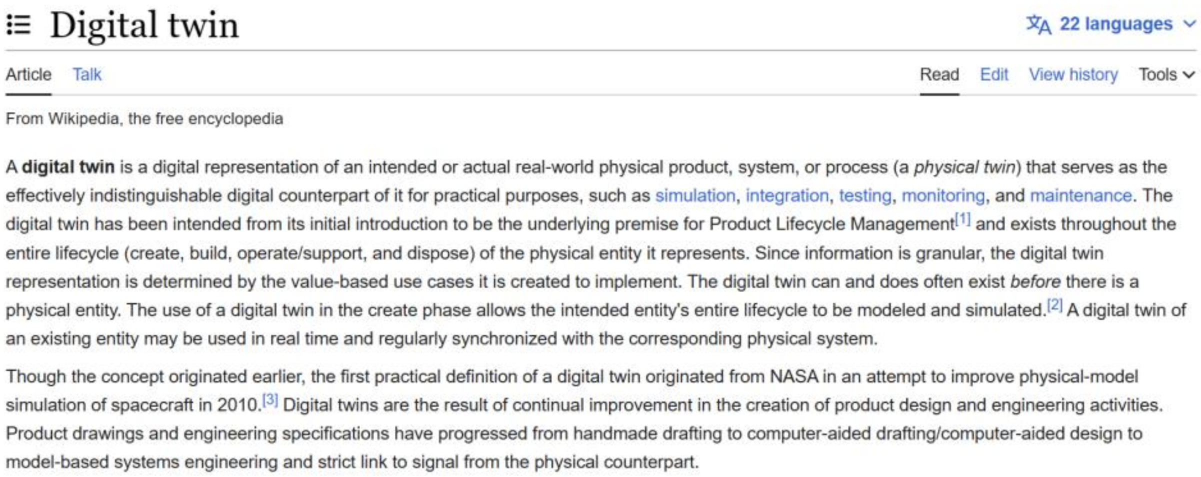
An open source platform for integrated design and contribution

D.L. Bruhwiler, RadioSoft

Digital twins for particle accelerators & key subsystems

The words ‘digital twin’ are becoming more common.
Is this practical for particle accelerator technology?
Papers have recently started appearing; proposals are being written.

It means a lot more than ‘an accurate computational model’.
Need high-fidelity modeling at ~kHz rep rates for control systems.



Digital twin

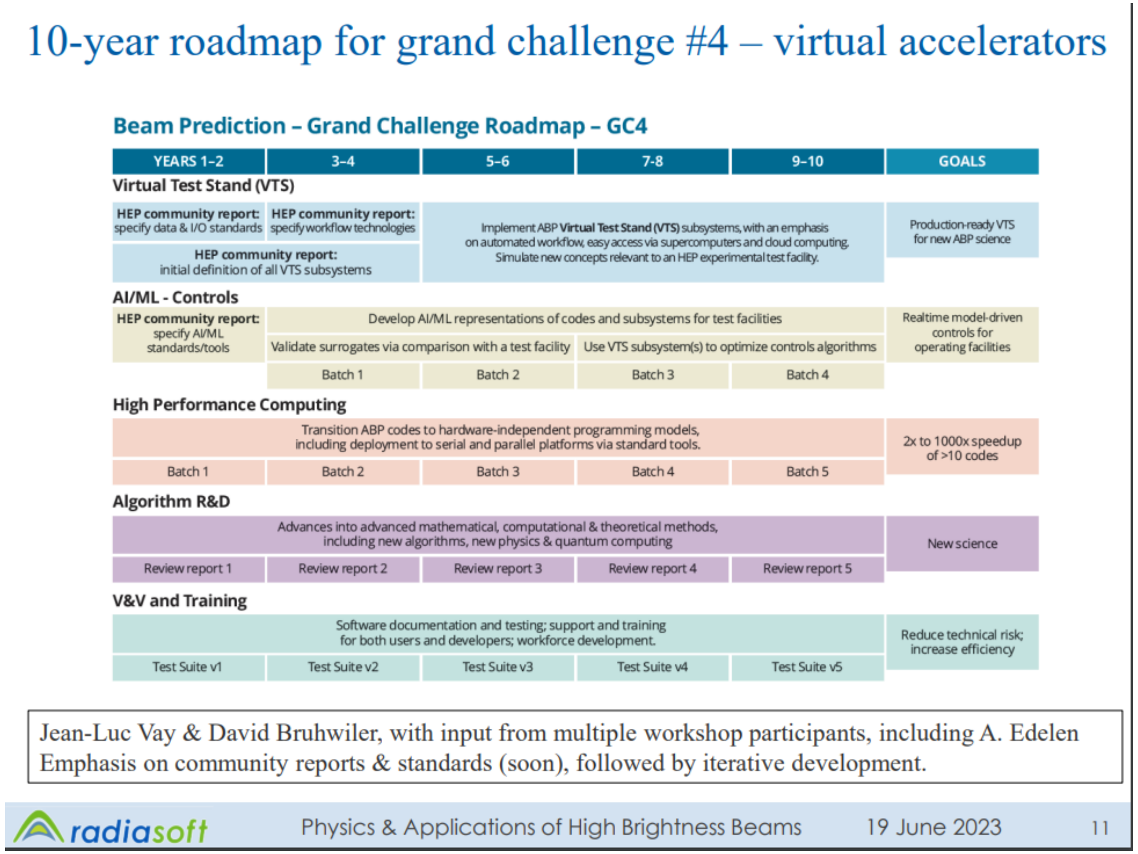
22 languages

Article Talk

From Wikipedia, the free encyclopedia

A **digital twin** is a digital representation of an intended or actual real-world physical product, system, or process (a *physical twin*) that serves as the effectively indistinguishable digital counterpart of it for practical purposes, such as simulation, integration, testing, monitoring, and maintenance. The digital twin has been intended from its initial introduction to be the underlying premise for Product Lifecycle Management[1] and exists throughout the entire lifecycle (create, build, operate/support, and dispose) of the physical entity it represents. Since information is granular, the digital twin representation is determined by the value-based use cases it is created to implement. The digital twin can and does often exist *before* there is a physical entity. The use of a digital twin in the create phase allows the intended entity's entire lifecycle to be modeled and simulated.[2] A digital twin of an existing entity may be used in real time and regularly synchronized with the corresponding physical system.

Though the concept originated earlier, the first practical definition of a digital twin originated from NASA in an attempt to improve physical-model simulation of spacecraft in 2010.[3] Digital twins are the result of continual improvement in the creation of product design and engineering activities. Product drawings and engineering specifications have progressed from handmade drafting to computer-aided drafting/computer-aided design to model-based systems engineering and strict link to signal from the physical counterpart.



10-year roadmap for grand challenge #4 – virtual accelerators

Beam Prediction – Grand Challenge Roadmap – GC4

YEARS 1–2	3–4	5–6	7-8	9–10	GOALS
Virtual Test Stand (VTS)					
HEP community report: specify data & I/O standards	**HEP community report:** specify workflow technologies	Implement ABP **Virtual Test Stand (VTS)** subsystems, with an emphasis on automated workflow, easy access via supercomputers and cloud computing. Simulate new concepts relevant to an HEP experimental test facility.			Production-ready VTS for new ABP science
HEP community report: initial definition of all VTS subsystems					
AI/ML - Controls					
HEP community report: specify AI/ML standards/tools	Develop AI/ML representations of codes and subsystems for test facilities				Realtime model-driven controls for operating facilities
	Validate surrogates via comparison with a test facility		Use VTS subsystem(s) to optimize controls algorithms		
	Batch 1	Batch 2	Batch 3	Batch 4	
High Performance Computing					
Transition ABP codes to hardware-independent programming models, including deployment to serial and parallel platforms via standard tools.					2x to 1000x speedup of >10 codes
Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	
Algorithm R&D					
Advances into advanced mathematical, computational & theoretical methods, including new algorithms, new physics & quantum computing					New science
Review report 1	Review report 2	Review report 3	Review report 4	Review report 5	
V&V and Training					
Software documentation and testing; support and training for both users and developers; workforce development.					Reduce technical risk; increase efficiency
Test Suite v1	Test Suite v2	Test Suite v3	Test Suite v4	Test Suite v5	

Jean-Luc Vay & David Bruhwiler, with input from multiple workshop participants, including A. Edelen
Emphasis on community reports & standards (soon), followed by iterative development.

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An open source platform for integrated design and contribution

D.L. Bruhwiler, RadioSoft

Sirepo – Open Scientific Gateway

Sirepo by RadiaSoft

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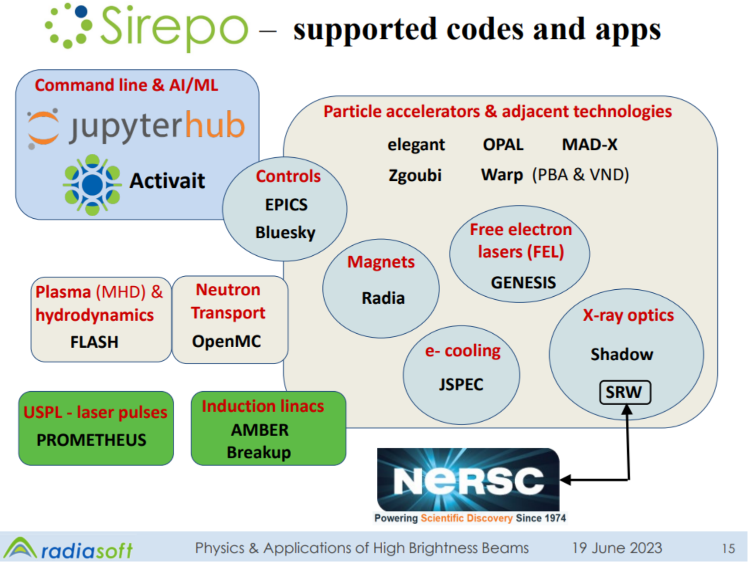

Sirepo – supported codes and apps

Command line & AI/ML
jupyterhub
Activait

Particle accelerators & adjacent technologies
elegant OPAL MAD-X
Zgoubi Warp (PBA & VND)

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EPICS
Bluesky

Magnets
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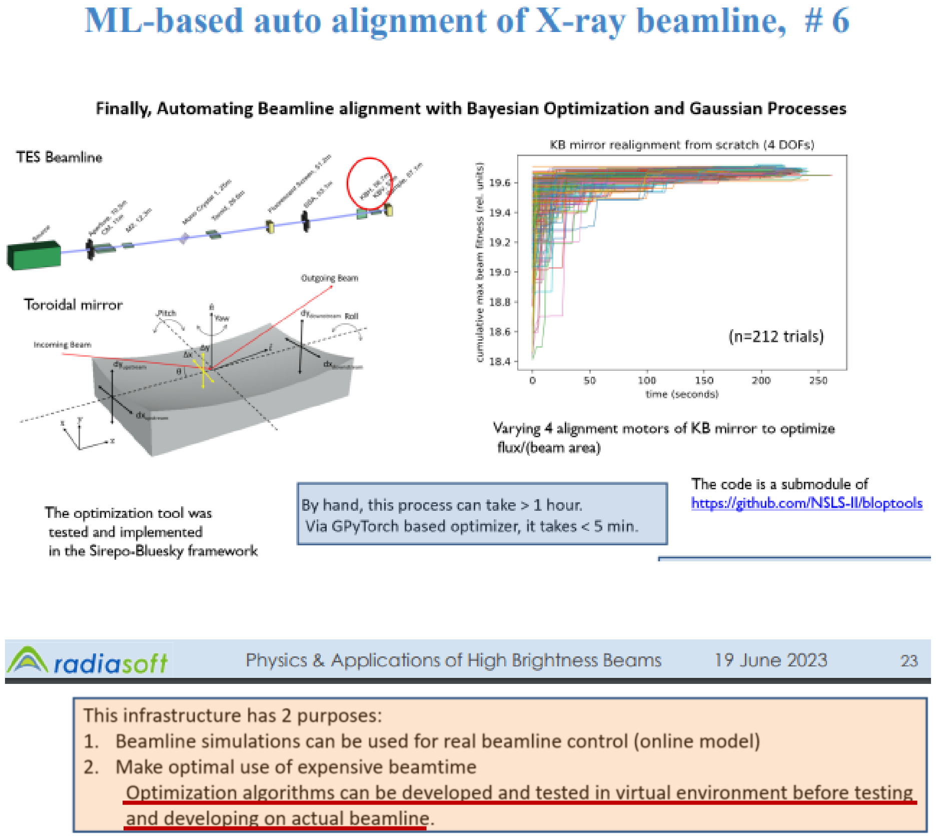

ML-based auto alignment of X-ray beamline, # 6

Finally, Automating Beamline alignment with Bayesian Optimization and Gaussian Processes

Varying 4 alignment motors of KB mirror to optimize flux/(beam area)

The optimization tool was tested and implemented in the Sirepo-Bluesky framework

By hand, this process can take > 1 hour.
Via GPyTorch based optimizer, it takes < 5 min.

The code is a submodule of https://github.com/NSLS-II/bloptools

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This infrastructure has 2 purposes:

1. Beamline simulations can be used for real beamline control (online model)
2. Make optimal use of expensive beamtime
   Optimization algorithms can be developed and tested in virtual environment before testing and developing on actual beamline.