Accelerator Physics Research at SLAC

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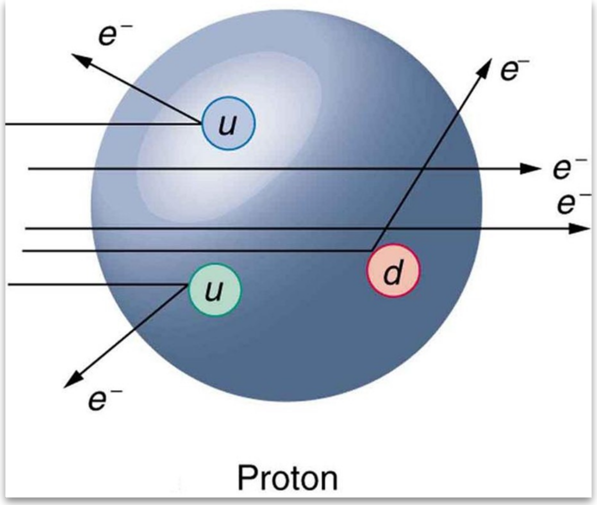
On behalf of SLAC Accelerator and Technology Innovation Directorates

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

Accelerators at SLAC

S-band copper RF structure



Electron-Proton scattering

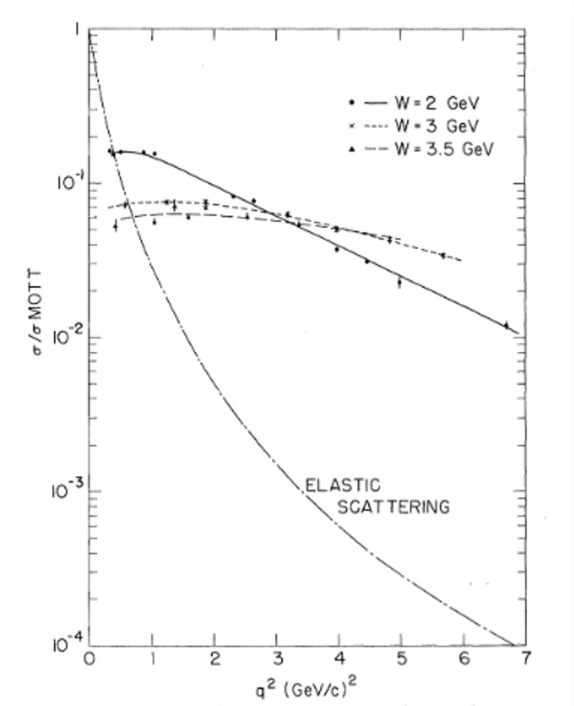


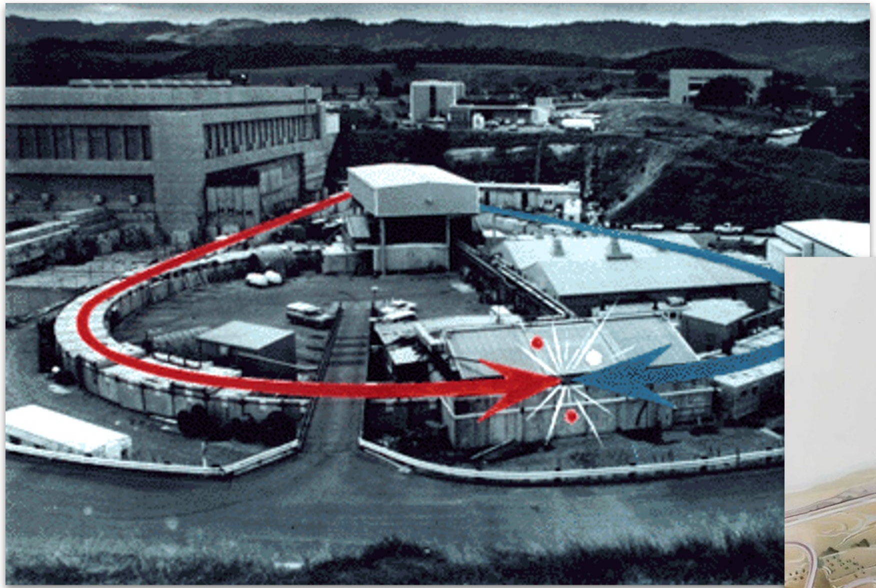
FIG. 1. $(d^2\sigma/d\Omega dE')/\sigma_{\text{Mott}}$, in GeV^{-1}, vs q^2 for W $=2$, 3, and 3.5 GeV. The lines drawn through the data are meant to guide the eye. Also shown is the cross section for elastic e-p scattering divided by σ_{Mott}, $(d\sigma/d\Omega)/\sigma_{\text{Mott}}$, calculated for $\theta = 10°$, using the dipole form factor. The relatively slow variation with q^2 of the inelastic cross section compared with the elastic cross section is clearly shown.

PRL 23, 935, 1969.

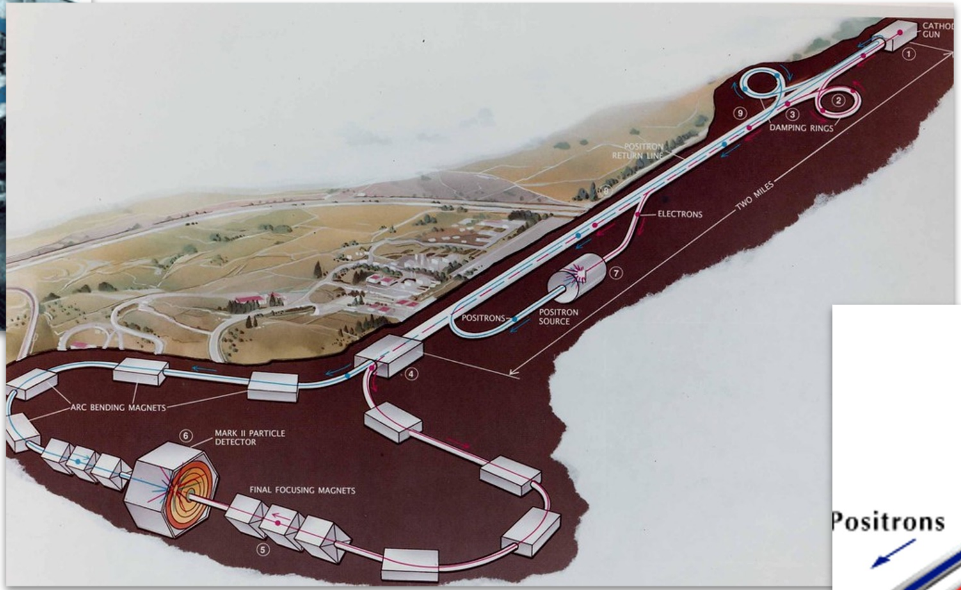
SLAC was approved by the Atomic Energy Commission in 1961.
Quarks were discovered at SLAC just eight years later.

SLAC: Four Decades of Colliders

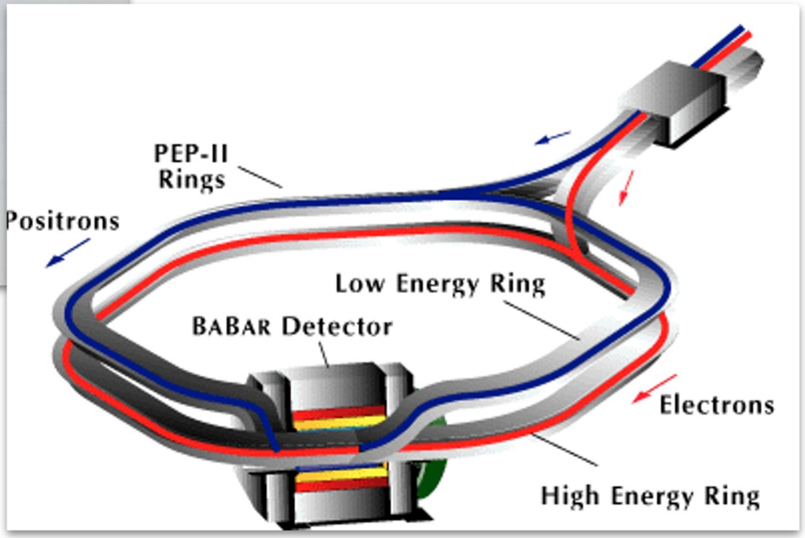
SLAC developed leadership in many areas of collider physics and continues to contribute expertise to the design and operation of colliders around the world.



SPEAR (1972-1990)



SLC (1988-1998)



PEP-II (1998-2008)

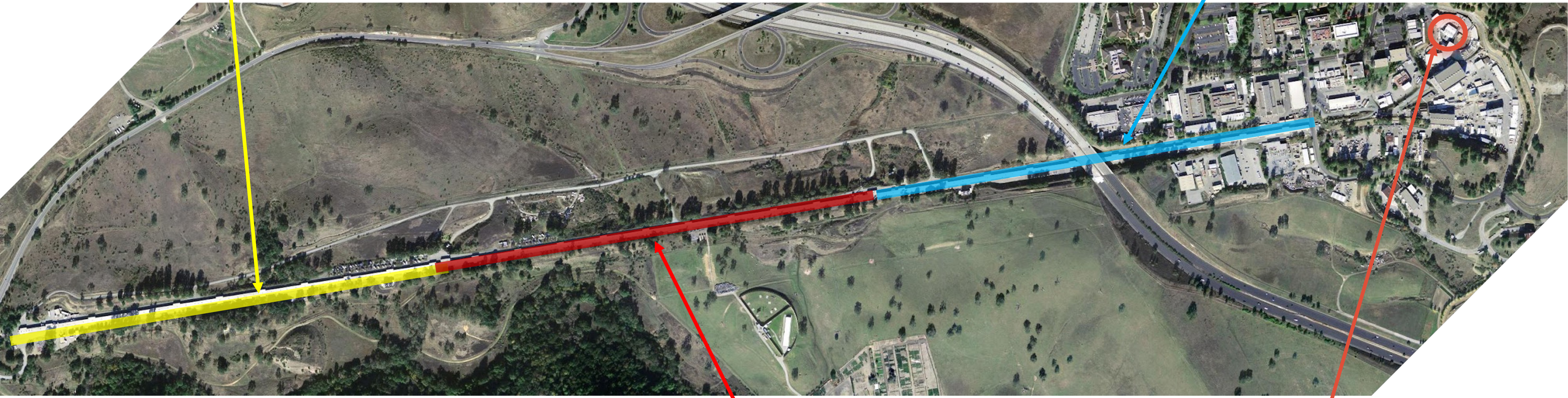
SLAC Evolved: Lightsource Leadership

LCLS-II

World's Highest Rate XFEL

LCLS

World's First X-Ray FEL



FACET-II

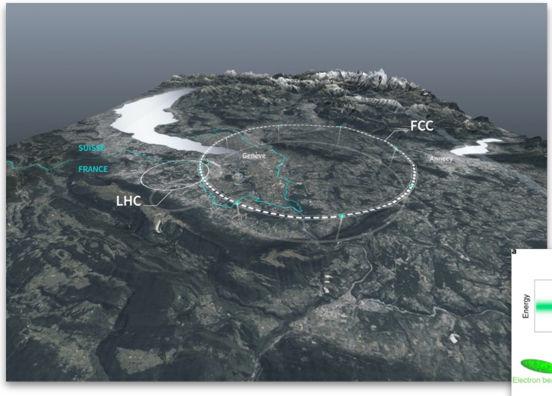
Accelerator R&D Facility

SSRL

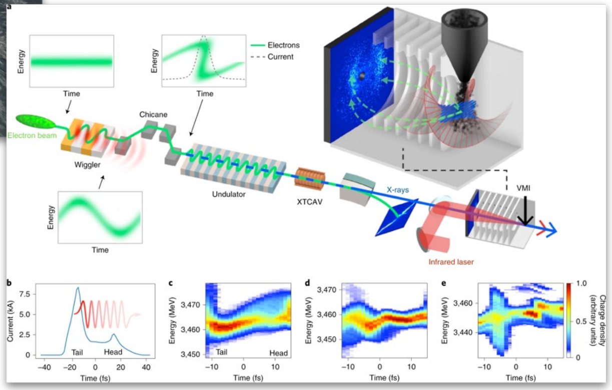
Pioneering synchrotron Light Source

SLAC

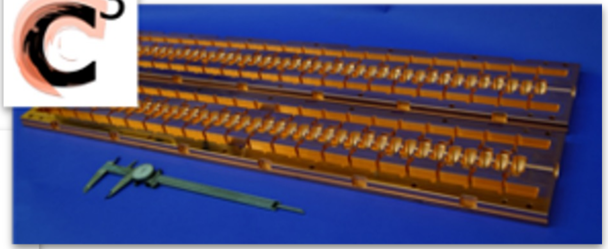
What motivates particle accelerator research?

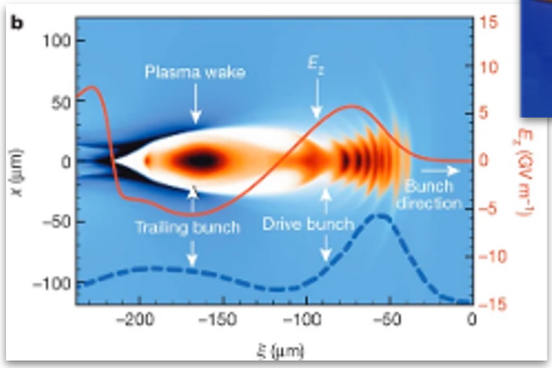


Improve the performance of existing and planned facilities, like the FCC.



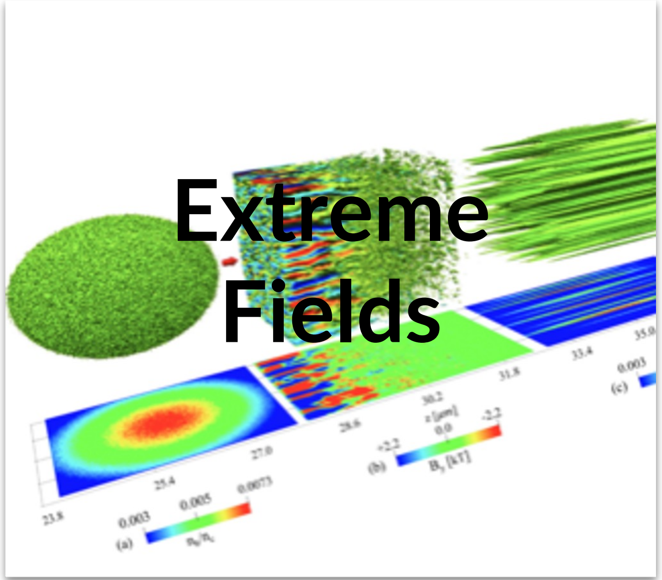
Develop new modes of operation, like the attosecond pulses at LCLS.





Create new accelerator technologies like cryo-cooled copper and plasma wakefields for more compact, less expensive accelerators.

Accelerator Research at SLAC



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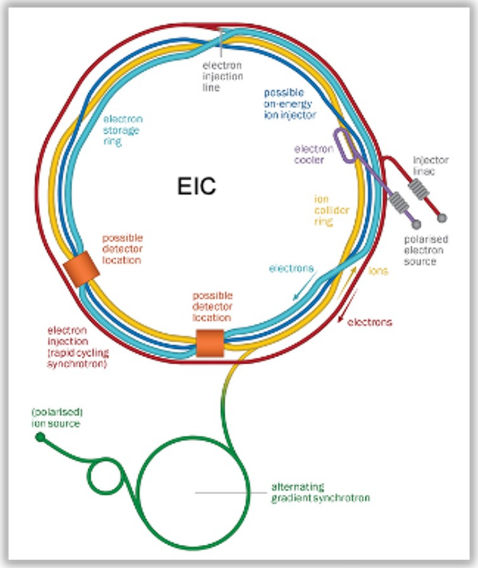
Near-Term Colliders

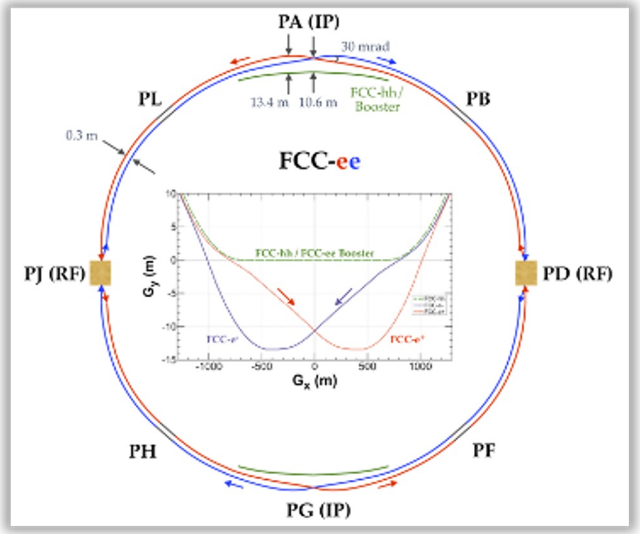
The Electron-Ion Collider at Brookhaven is under way. Student research will address:

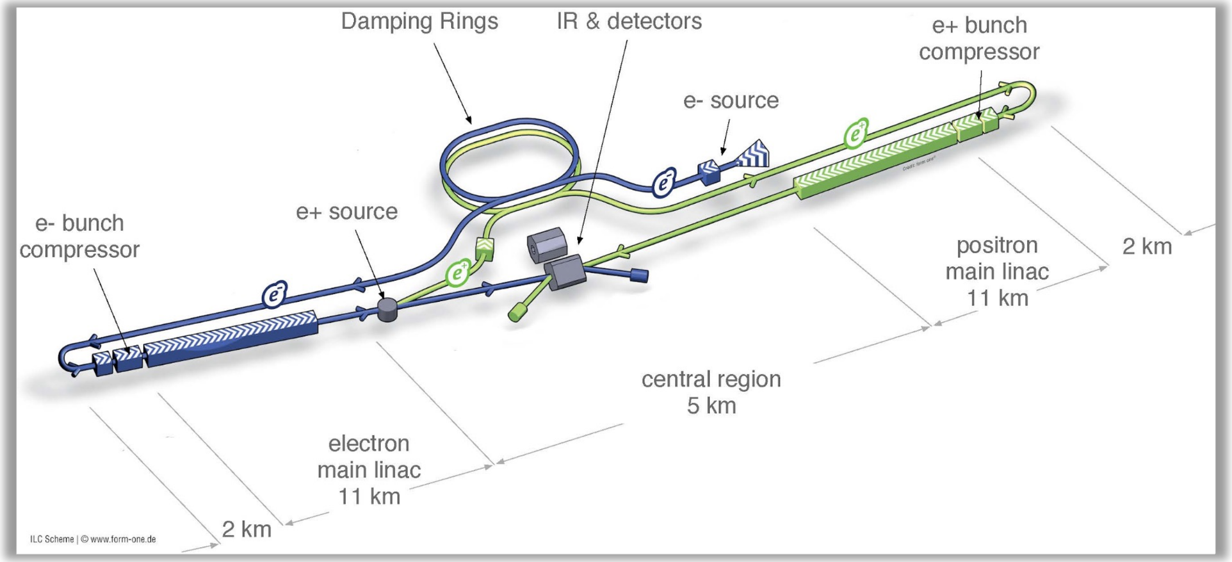
- Beam-Beam effects
- Polarization preservation
- Novel beam cooling techniques

The FCC at CERN and ILC in Japan are candidates for future Higgs Factories. Students will contribute to these facilities with R&D on machine:

- Control of beam instabilities
- Precision energy measurements
- Laser-electron beam interactions







Next-Gen Colliders

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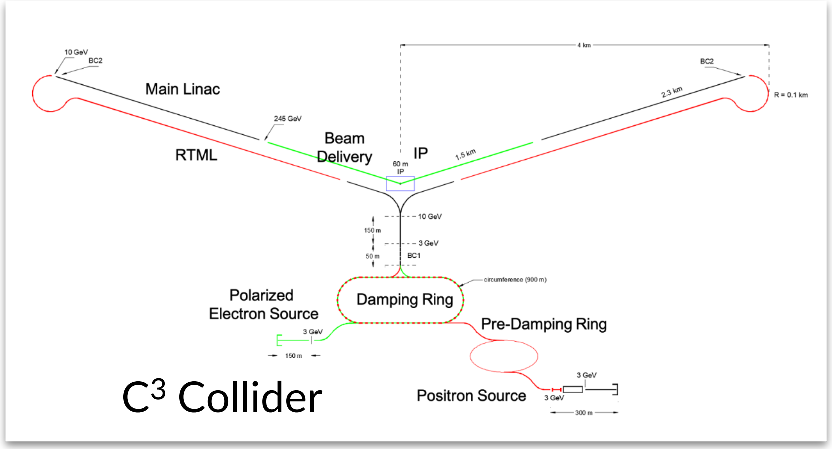

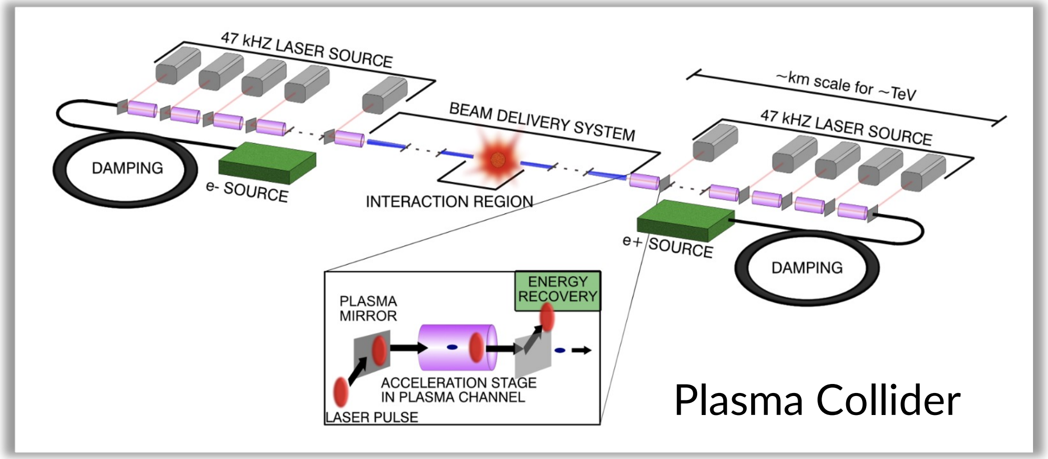

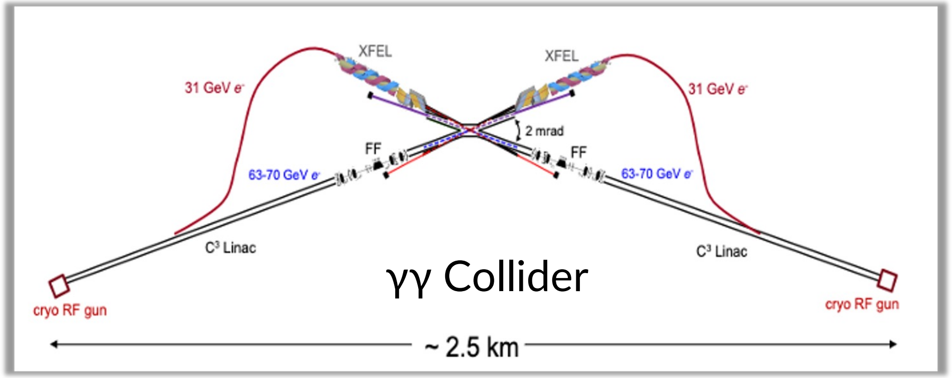

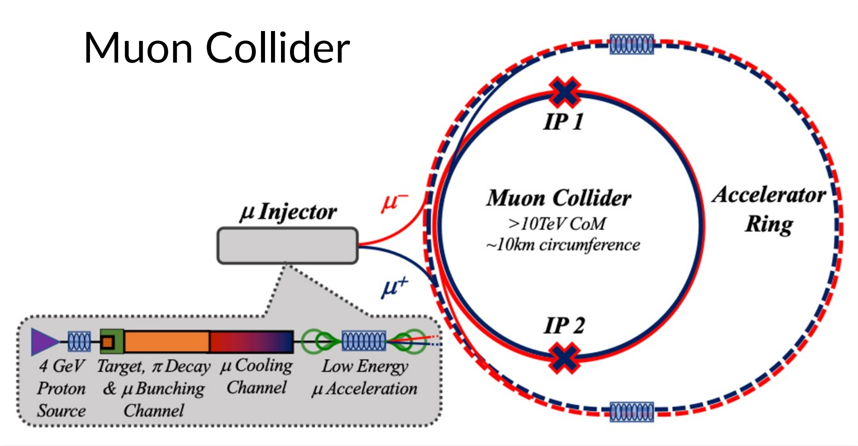

Innovation is required to build new machines that can see beyond the LHC. Graduate students in accelerator physics will strongly influence the path to an HEP collider.

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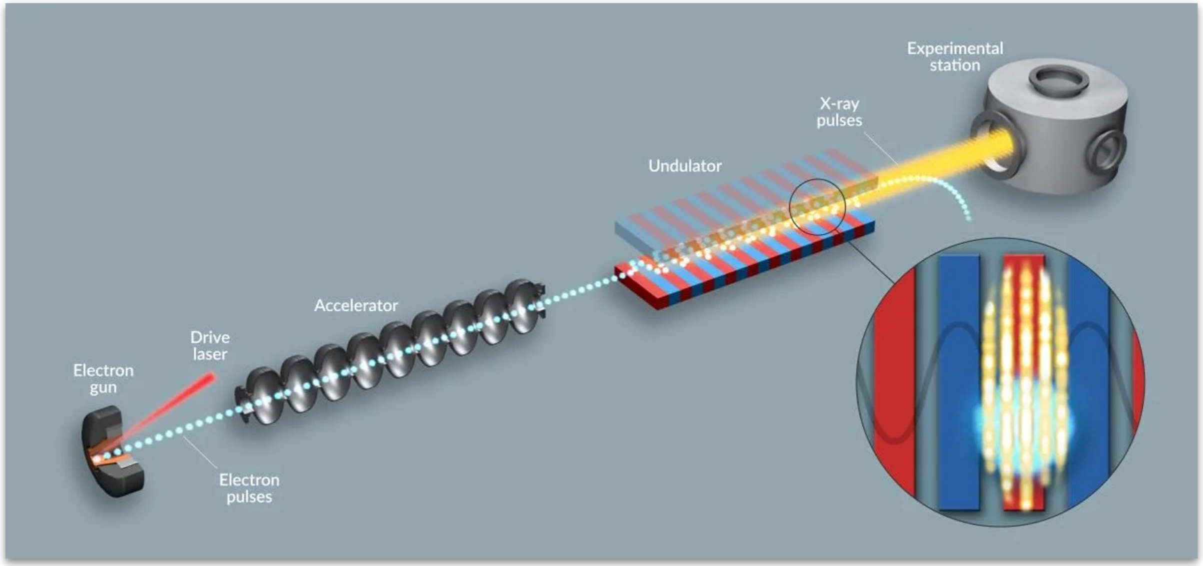
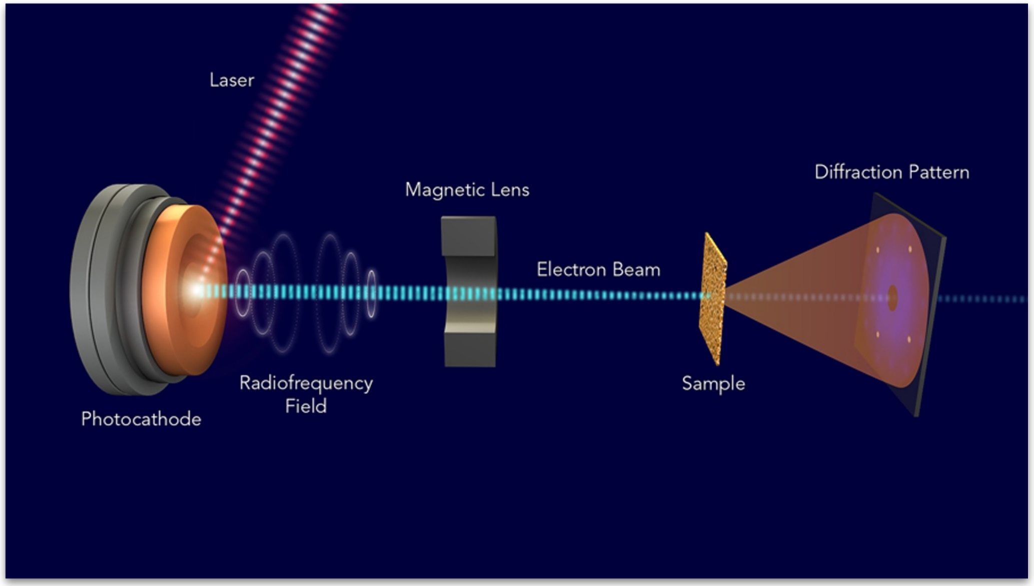
Ultrafast Science

LCLS-II: The most advanced x-ray free-electron laser



UED: Ultrafast electron diffraction



Probing matter with atomic resolution and femtosecond to attosecond timescales.

Research:

- Accelerator development (new injectors, high power linac etc.)
- X-ray and e-beam pulse shaping
- Attosecond pump/probe experiments
- Cavity-based X-ray sources (XLO, XFELO, RAFEL)

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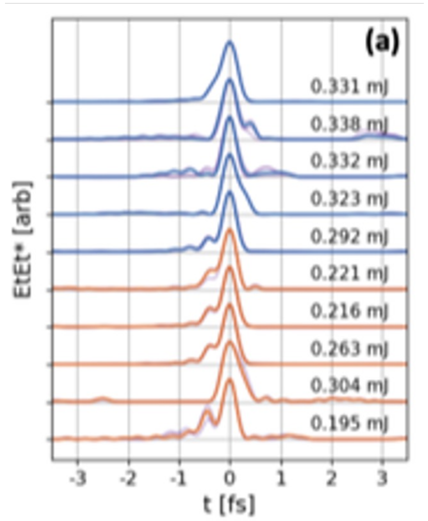
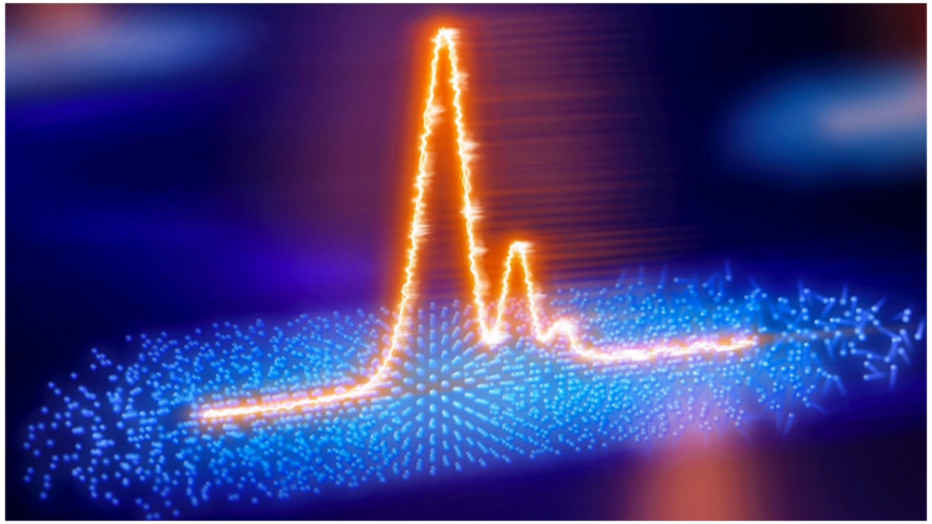
FEL R&D Program





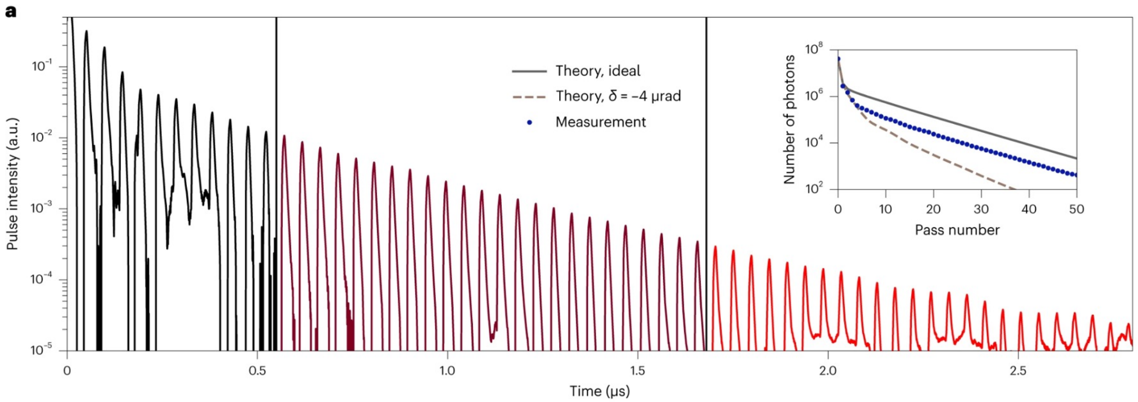
Franz, Paris, et al. *Nature Photonics* (2024): 1-6.

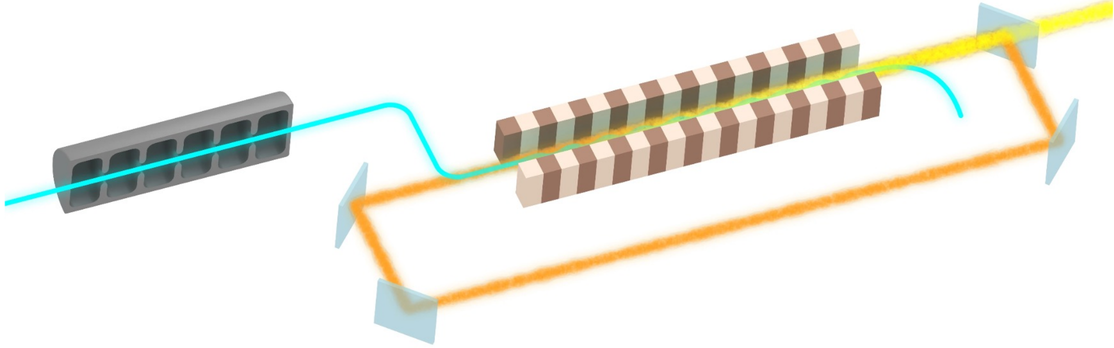
World-leading program in FEL R&D:

Faster, brighter, more coherent pulses.

Enabling and driving new ultrafast science.

Student-led high impact research program





Margraf, Rachel, et al. *Nature Photonics* 17.10 (2023): 878-882.

SLAC

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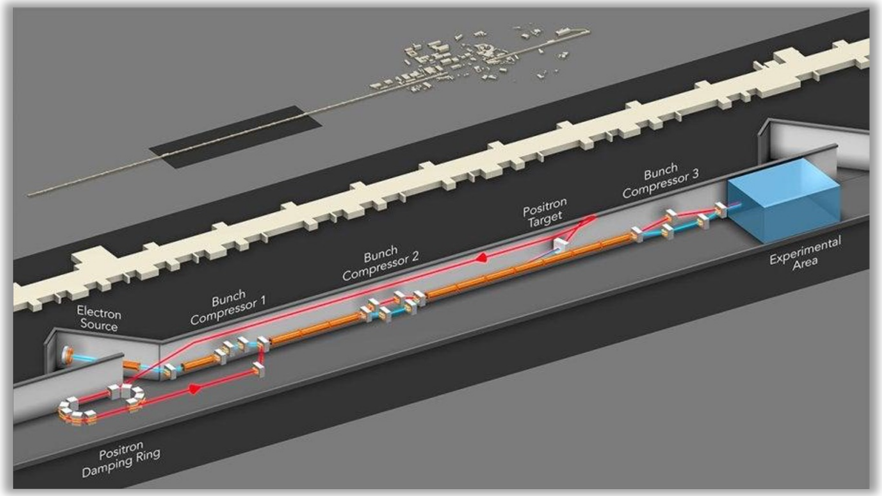
FACET-II provides *unique* beams

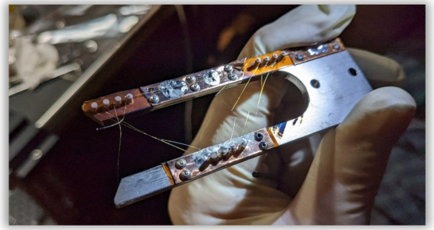
FACET-II delivers electron beams with nanocoulomb charge at 10 GeV energy.

FACET-II has three compressor chicanes to reduce the length of the bunch delivered to experiments.

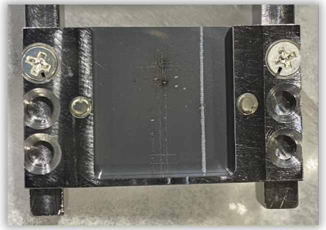
The radial electric field of the electron bunch is about 100 GV/m in the lab frame!



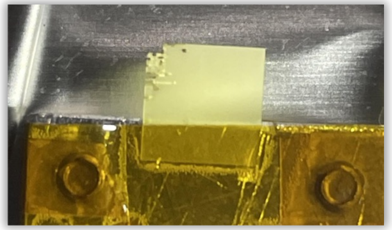
FACET-II facility layout



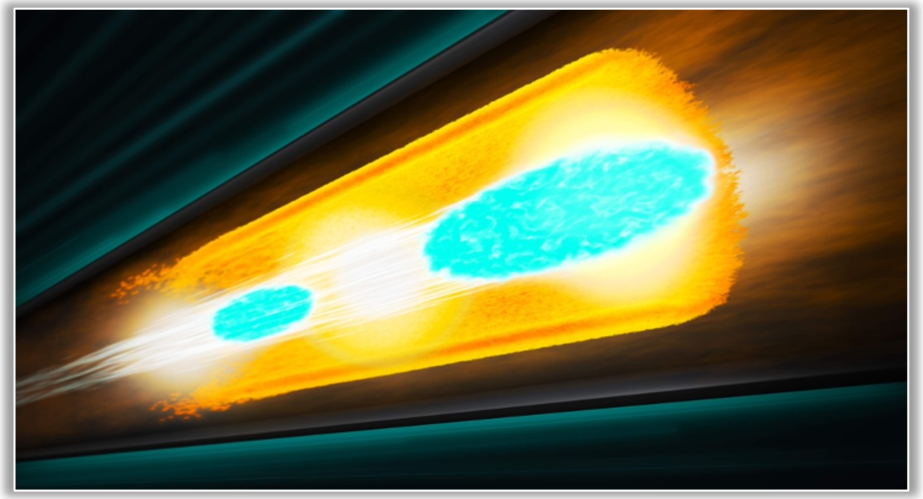
Wire scanner. . . shredded



OTR foil. . . drilled



YAG crystal. . . swiss-cheesed



Beam-Driven Plasma Wakefield

SLAC

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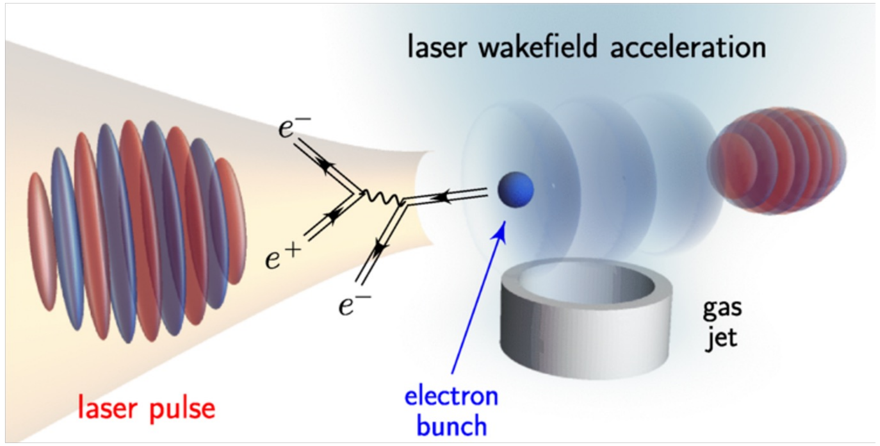
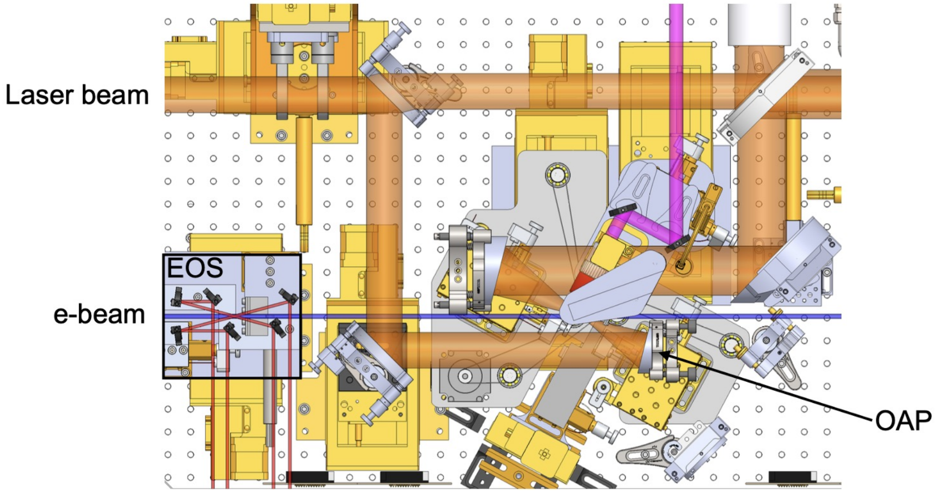
Strong Field QED at FACET-II

FACET-II has a 20 TW laser that can be used to collide with electron beam for inverse Compton scattering experiments.

The motivation for this research is to probe strong field QED effects:

- Nonlinear Compton scattering
- Coherent pair creation
- Trident cascade
- Violation of local constant field approximation





SLAC E320 Experiment

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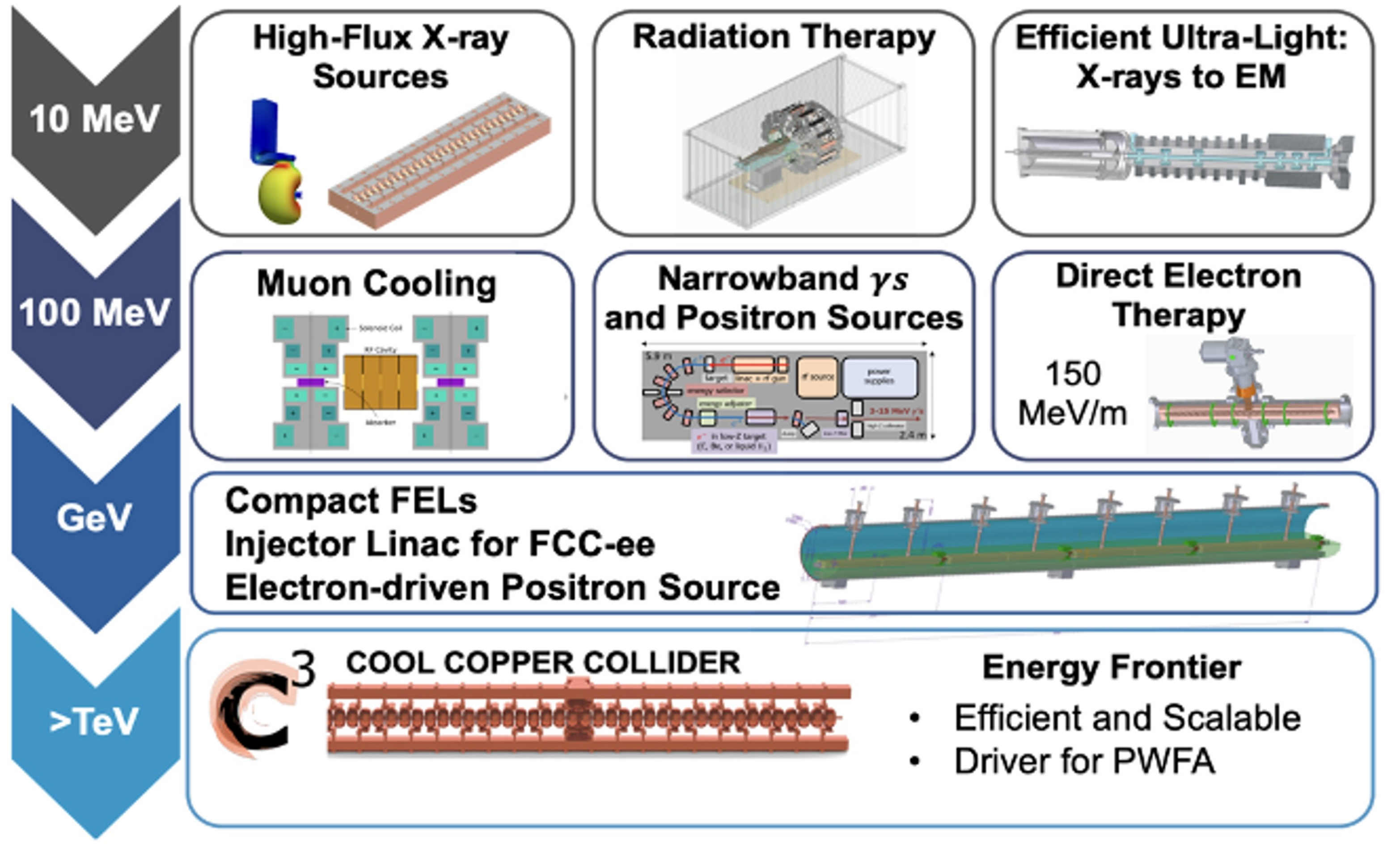
Societal Applications



Near-term applications of particle accelerators for medicine, industry and security provide societal benefits today and pave the way for ambitious science facilities.

Machine Learning

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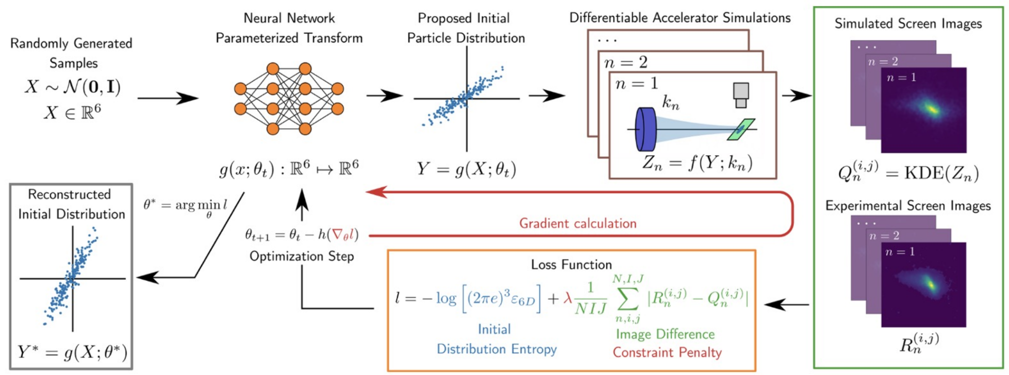
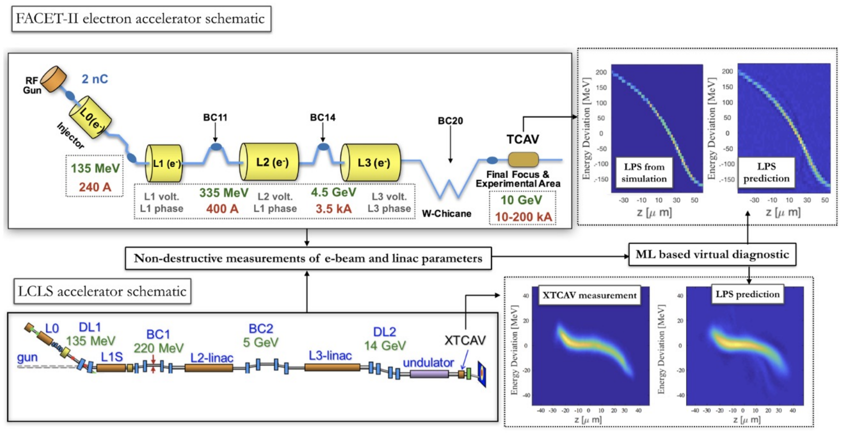
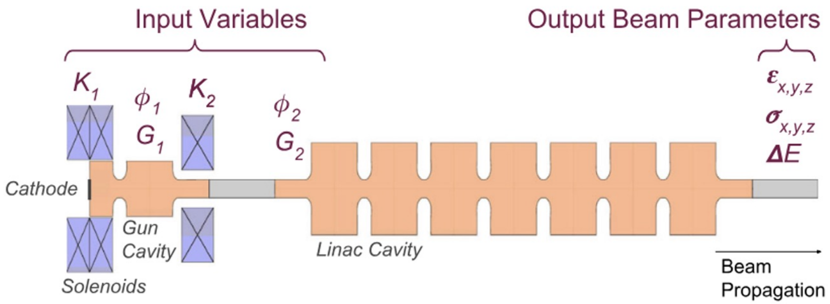
R. ROUSSEL et. al. PHYSICAL REVIEW LETTERS **130,** 145001 (2023)



C. EMMA *et al.* PHYS. REV. ACCEL. BEAMS **21,** 112802 (2018)



AURALEE EDELEN *et al.* PHYS. REV. ACCEL. BEAMS **23,** 044601 (2020)



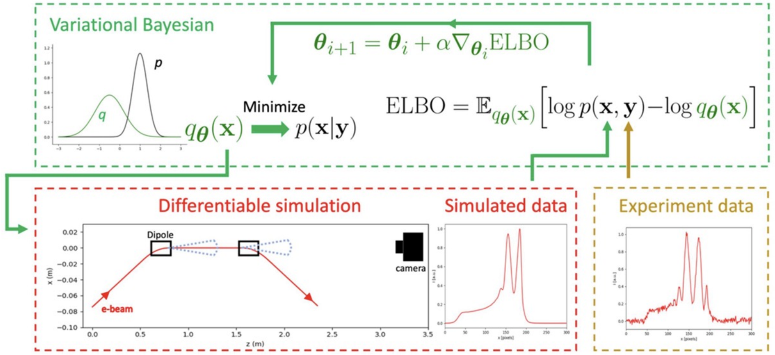


Figure 7
Flow diagram showing a variational Bayesian inference scheme using a differentiable simulation. The posterior distribution is approximated by a multivariate Gaussian $q_\theta(\mathbf{x})$ with parameters θ. Samples are taken from this distribution and used as the inputs for a simulation. The simulation output and measured intensity profiles are used to calculate the ELBO where $p(\mathbf{x}, \mathbf{y}) = p(\mathbf{y}|\mathbf{x})\, p(\mathbf{x})$. Using automatic differentiation, the gradient of the ELBO with respect to θ is calculated. By minimizing the ELBO, the difference between q_θ and $p(\mathbf{x}|\mathbf{y})$ is also minimized.

J. Synchrotron Rad. (2024). **31**, 409–419 Watt and O'Shea • Differentiable simulation package **417**

SLAC hosts a world-leading team of researchers that apply AIML techniques to challenges in accelerator physics.

The Accelerator Physics PhD Experience

1. Theory/simulation of a concept under development.

1. Hardware development for testing with beam.

1. Experimental beamtime at one of SLAC's facilities.

1. Data acquisition and analysis.

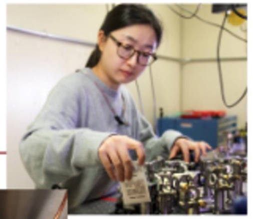
1. Write-up results for publication.

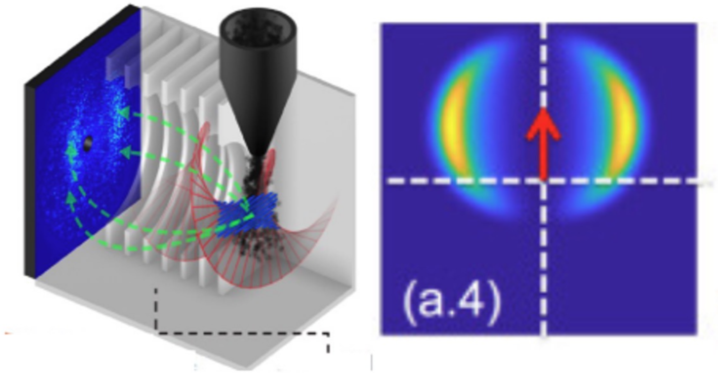
Graduate students in accelerator physics can expect to contribute to the theory, execution, and analysis of experiments.

SLAC

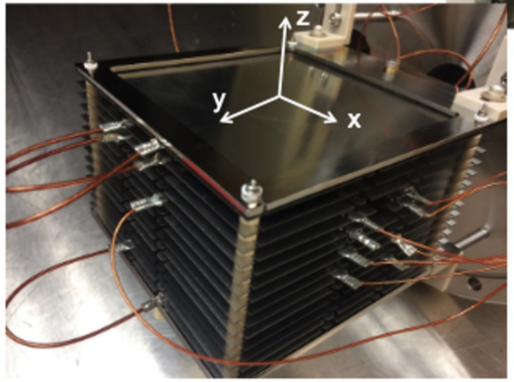
The Accelerator Physics PhD Experience

Examples of Recent PhDs

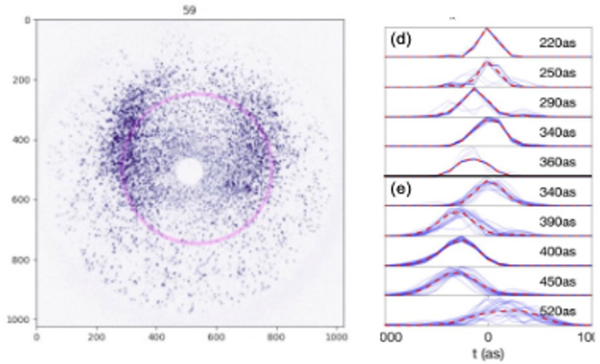




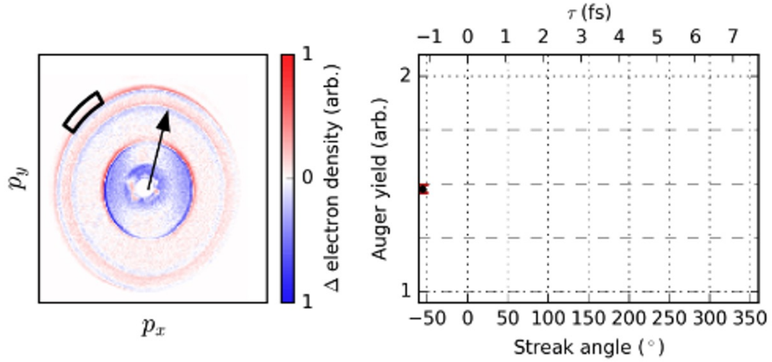
Optics express 26.4 (2018): 4531-4547



AIP Advances 8.11 (2018)



Nature Photonics 14.1 (2020): 30-36.



Science 375.6578 (2022): 285-290.

Siqi Li

- Stanford Ph.D. 2020
- APS DPB Thesis Prize 2020
- SLAC Staff Scientist 2020-2024
- University of Hawaii Faculty 2024 –

SLAC

Opportunities

Accelerator physics is a deep and diverse field of research with excellent career prospects at national laboratories and universities.

Graduate students can have an enormous impact in accelerator physics and influence the future of High Energy Physics and Next-Gen Light Sources.

If you are interested in pursuing a Ph.D. in Photon Science, consider rotating with an FEL group for a quarter to learn about FELs and how they might be improved in the future.

If you are interested in pursuing a Ph.D. High Energy Physics, especially Collider Physics, consider rotating with an accelerator physics group. Students are critical to the success of the field!