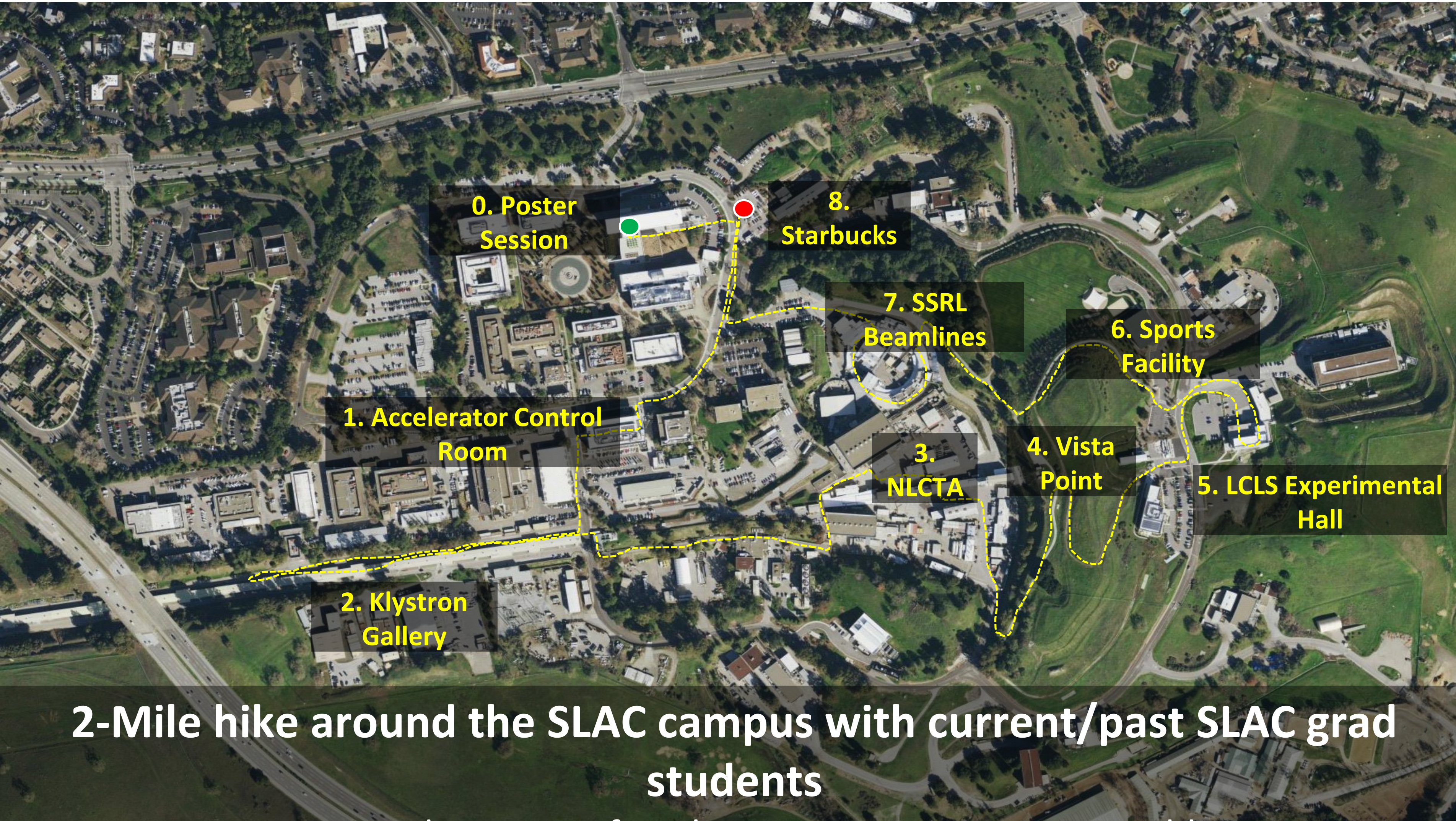
Accelerator Physics at SLAC

Zhirong Huang for SLAC Accelerator Directorate

Stanford Graduate Student Orientation
September 19, 2019

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY



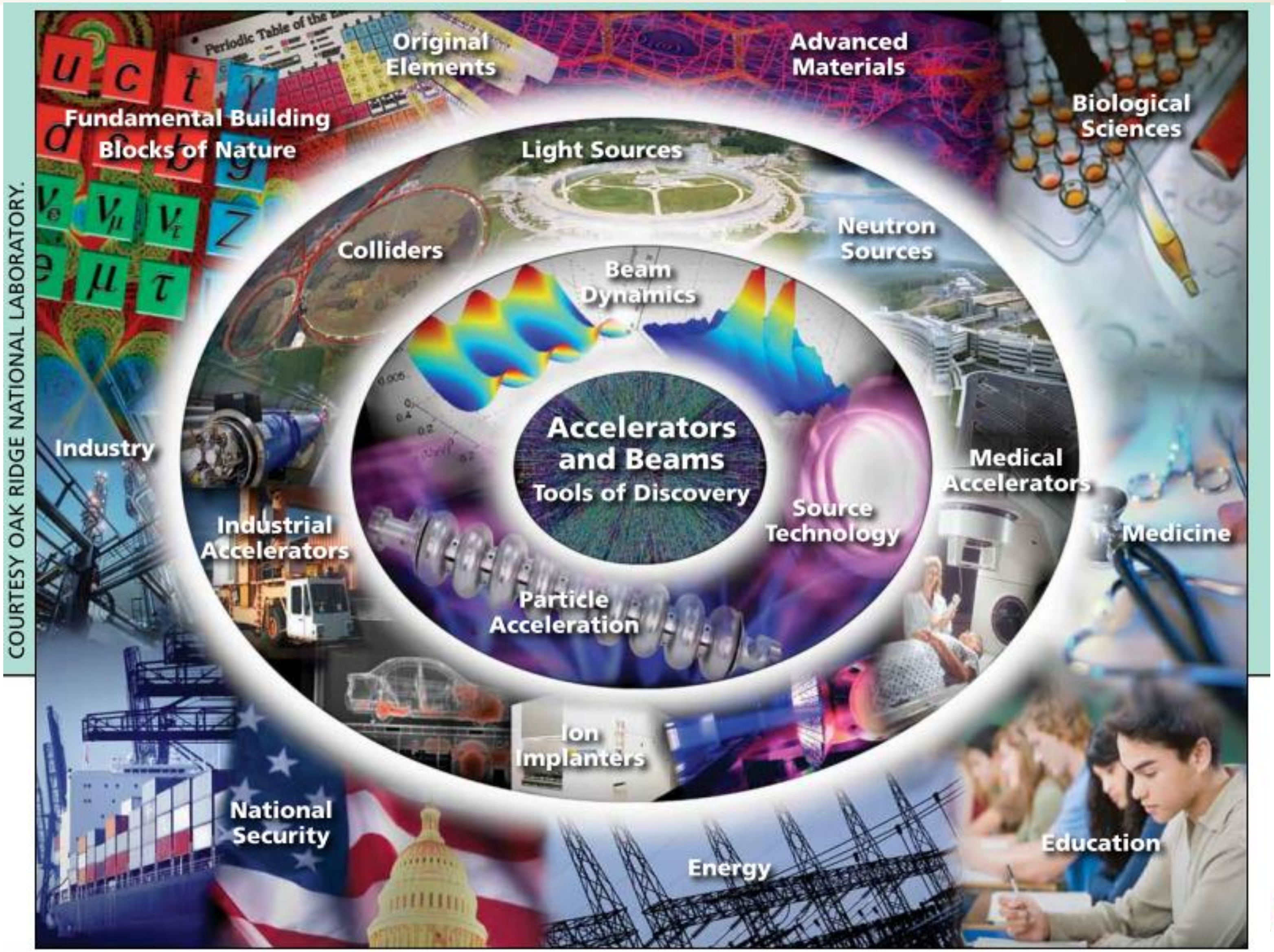
2-Mile hike around the SLAC campus with current/past SLAC grad students

1:00 pm today: meet after the poster session at SUSB Lobby.

Accelerators and Beams: Tools of Discovery

http://www.aps.org/units/dpb/news/edition4th.cfm

SLAC



Why Accelerator Physics?

My experience:

Interplay of wide variety of technologies and scientific fields:
Lasers, cathodes, RF, magnets, superconductivity, large-scale computing, plasma physics…

Relatively small community with large funding.

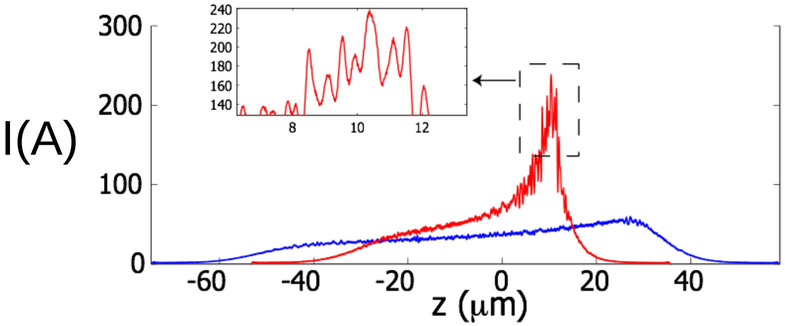
Young scientists given room to grow and advisors interested in their students personal development.

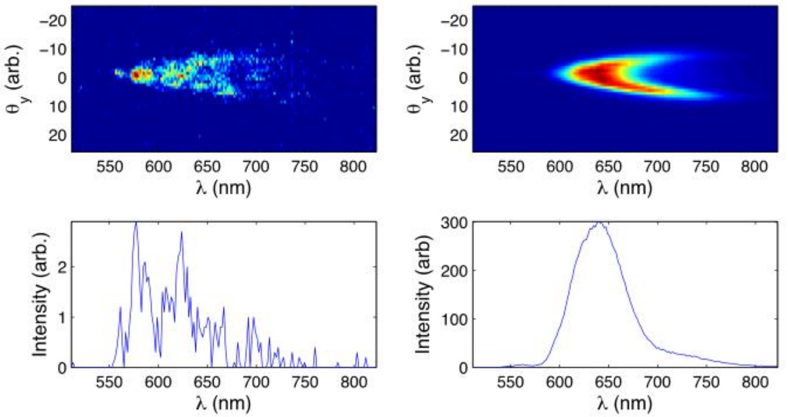
At this specific point in time: opportunity to make a difference in groundbreaking developments.
X-ray FELs, plasma-based accelerators etc. have the potential for shaping science in the coming decades.

Working in Accelerator Physics at SLAC

- Working with small groups at large facilities: engage in theory, simulation, and experimental results

$$\left(\frac{1}{D^2}\nabla_\perp^2 - 1\right)E_z = -\int E_z(\vec{X}')\Pi(\vec{X},\vec{X}')d^2\vec{X}'$$

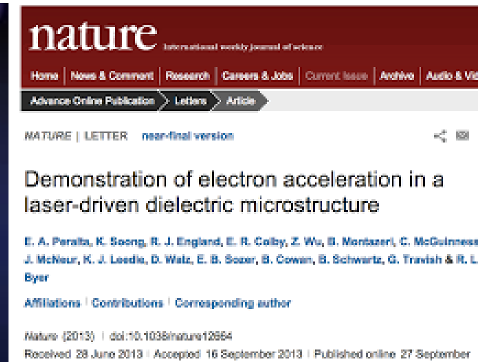




SLAC

Working in Accelerator Physics at SLAC

- Working with small groups at large facilities: engage in theory, simulation, and experimental results
- SLAC actively involved in advanced R&D initiatives leading to publications in high-impact journals



nature international weekly journal of science

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Advance Online Publication > Letters > Article

NATURE | LETTER near-final version

Demonstration of electron acceleration in a laser-driven dielectric microstructure

E. A. Peralta, K. Soong, R. J. England, E. R. Colby, Z. Wu, B. Montazeri, C. McGuinness, J. McNeur, K. J. Leedle, D. Walz, E. B. Sozer, B. Cowan, B. Schwartz, G. Travish & R. L. Byer

Affiliations | Contributions | Corresponding author

Nature (2013) | doi:10.1038/nature12664

Received 28 June 2013 | Accepted 16 September 2013 | Published online 27 September

NATURE PHOTONICS | ARTICLE

日本語要約

Polarization control in an X-ray free-electron laser

Alberto A. Lutman, James P. MacArthur, Markus Ilchen, Anton O. Lindahl, Jens Buck, Ryan N. Coffee, Georgi L. Dakovski, Lars Dammann, Yuantao Ding, Hermann A. Dürr, Leif Glaser, Jan Grünert, Gregor Hartmann, Nick Hartmann, Daniel Higley, Konstantin Hirsch, Yurii I. Levashov, Agostino Marinelli, Tim Maxwell, Ankush Mitra, Stefan Moeller, Timur Osipov, Franz Peters, Marc Planas, Ivan Shevchuk + et al.

Affiliations | Contributions | Corresponding author

Nature Photonics 10, 468–472 (2016) | doi:10.1038/nphoton.2016.79

Working in Accelerator Physics at SLAC

- Working with small groups at large facilities: engage in theory, simulation, and experimental results
- SLAC actively involved in advanced R&D initiatives leading to publications in high-impact journals
- Excellent mentors and room for individual growth: SLAC students, postdocs, staff and faculty consistently receive international awards for achievement in accelerator physics

C. Pellegrini
2015 Fermi Award

Among others:

2009, 2012, 2014 FEL Prize
2011 to 2015 Young FEL Prize
2013 Wilson Prize
2014 Frank Sacherer Prize
2016 M. Oliphant Prize
11 APS thesis prizes!!
(Spencer Gessner most recent winner)

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- SLAC actively involved in advanced R&D initiatives leading to publications in high-impact journals
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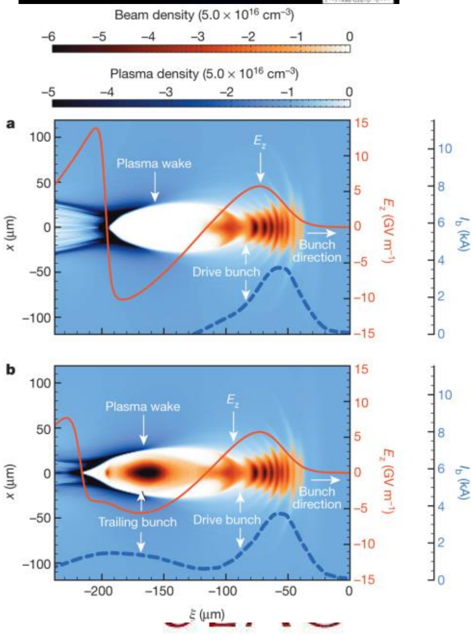
- Large availability of funding in and beyond graduate school! Graduates have opportunities in a variety of academic, laboratory and industrial jobs

FACET-II Plasma Wakefield Accelerator Program

FACET & FACET-II

- Experimental program will begin in 2019 and the experiments are being developed now
  - Opportunity to develop experiments in the early stages
- FACET-II experimental program will continue through 2025+
  - We expect you will graduate sooner ;-)
- FACET-II will be the premiere environment for advanced accelerator research for the next decade

We would be pleased to talk with you in person:



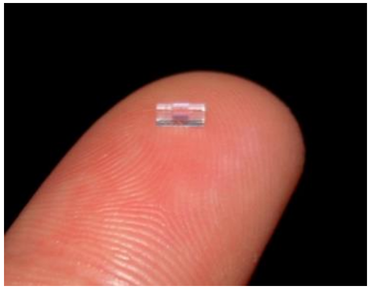
Vitaly Yakimenko
yakimenk@stanford.edu

Mark Hogan
mjhogan@stanford.edu

Dielectric Laser Acceleration Program

www.slac.stanford.edu/dla

The Dielectric Laser Acceleration (DLA) group at SLAC is a joint program with Stanford under the **Accelerator on a Chip International Program** for conducting high-impact student-led experiments using lasers to power dielectric micron-scale particle accelerators.



A chip-sized dielectric accelerator powered by tabletop µJ lasers; fabricated and demonstrated at SLAC and Stanford.

Nature **503**, 91-94 (2013).

Contact Information:
Dr. R. Joel England   england@slac.stanford.edu

Multidisciplinary Research Opportunities

- Photonic structures
- Nanofabrication
- Electron beam optics
- Material science
- Ultrafast lasers
- Accelerator physics

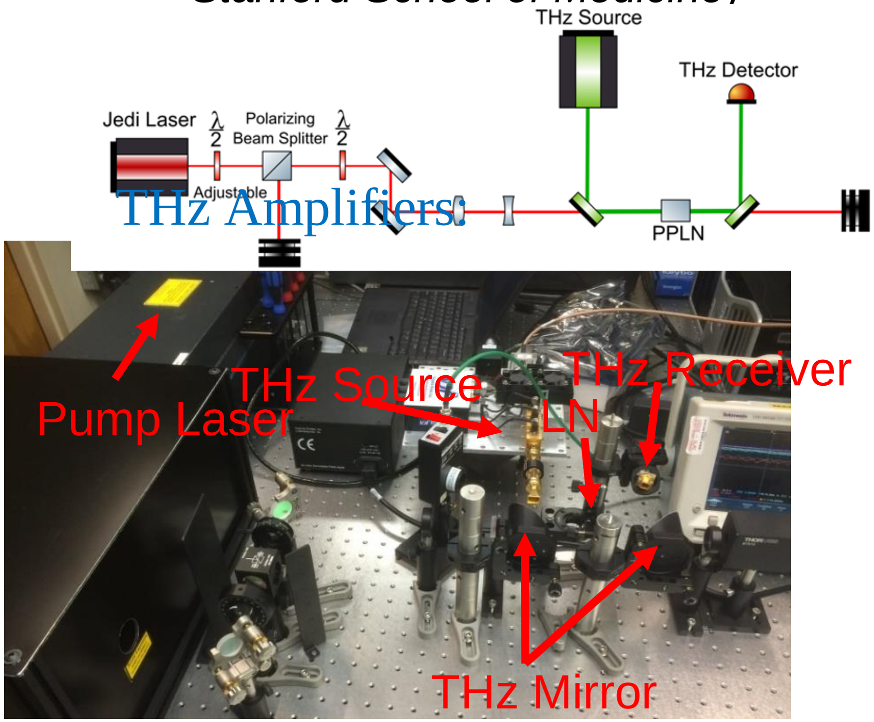
Students & postdocs have opportunity to:

- Design and create new photonic devices.
- Perform cutting-edge research using solid state lasers.
- Conduct electron beam tests of their structure designs.

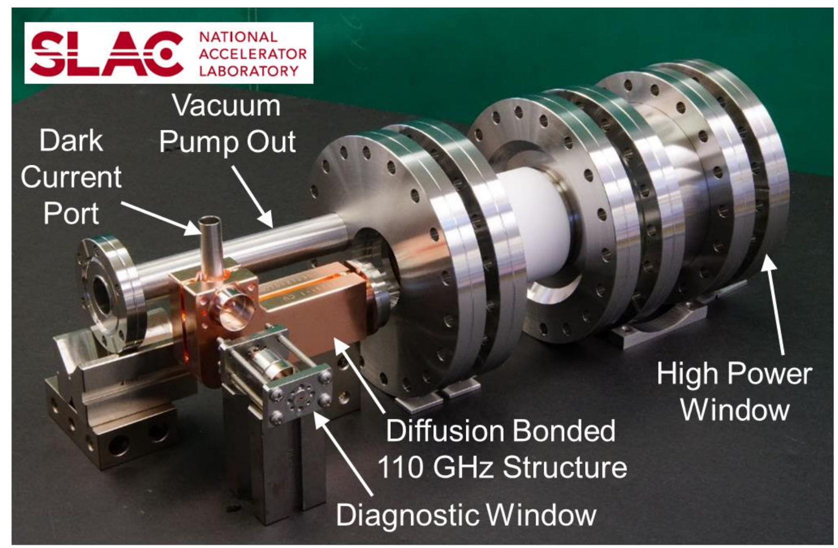
Inventing the next generation of accelerators driving scientific discovery, imaging, radar and medical therapy

- Optically generated THz amplifiers with bandwidth and phase control.
- Compact high-gradient THz accelerators.
- Novel accelerator technology for cancer therapy machines(*in collaboration with the Stanford School of Medicine*)

THz Amplifiers:



Compact High-Gradient mm-Wave/THz Accelerators:

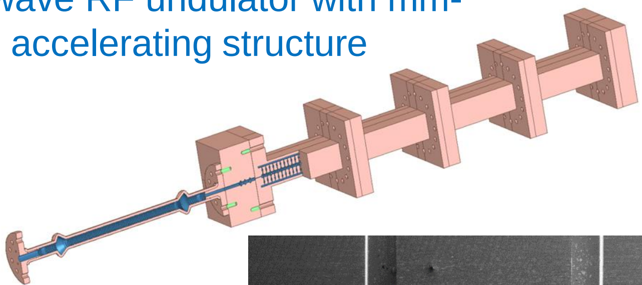


Contact: Dr. Emilio Nanni (nanni@slac.stanford.edu)
Prof. Sami Tantawi (tantawi@slac.stanford.edu)

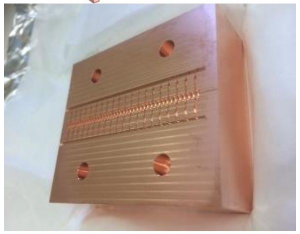
Novel FEL Technologies and Light Sources:

- RF undulators and bunch compression techniques for ultra-short pulses.
- Advanced Accelerator Concepts: Practical design and implementation of Terahertz and far infrared accelerators and components

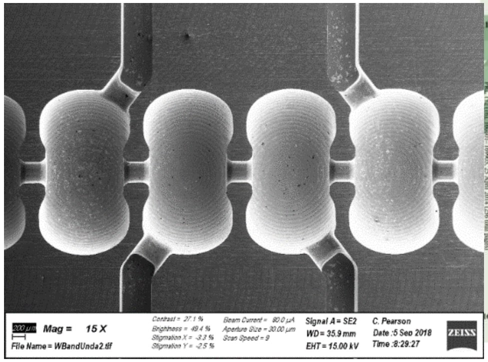
mm-wave RF undulator with mm-wave accelerating structure



The Novel RF undulator



mm-wave accelerating
ture



SEM picture of the mm-wave accelerating structure

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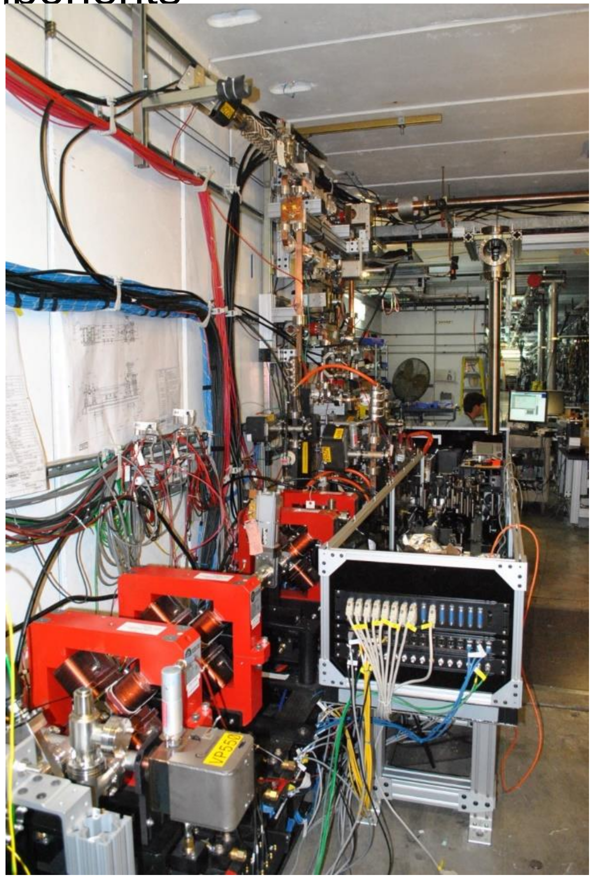
Prof. Sami Tantawi (tantawi@slac.stanford.edu)



Compact High-Gradient accelerator: The XTA Facility

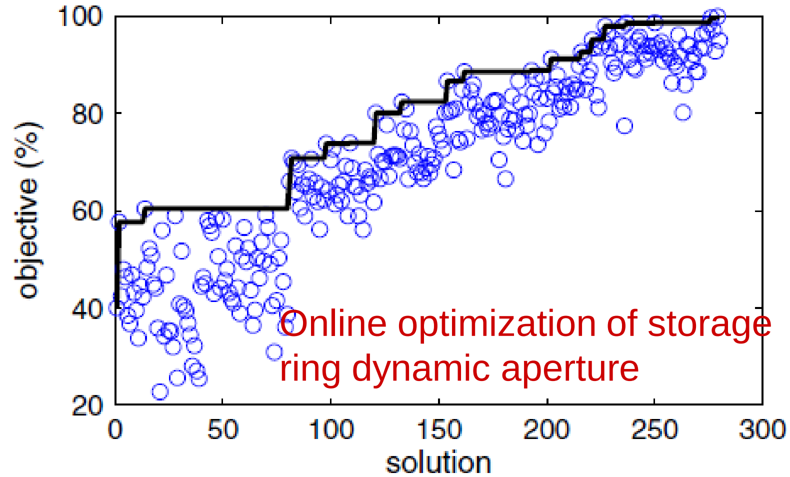
SPEAR3 accelerator research

Beam-based Optimization and Machine Learning for Synchrotrons

Nonlinear beam dynamics

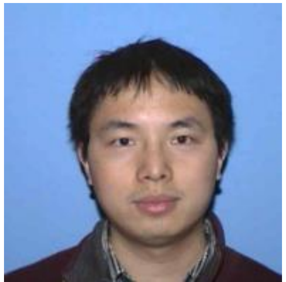
Storage ring short-pulse timing mode w/ Crab cavities

Diagnostics development



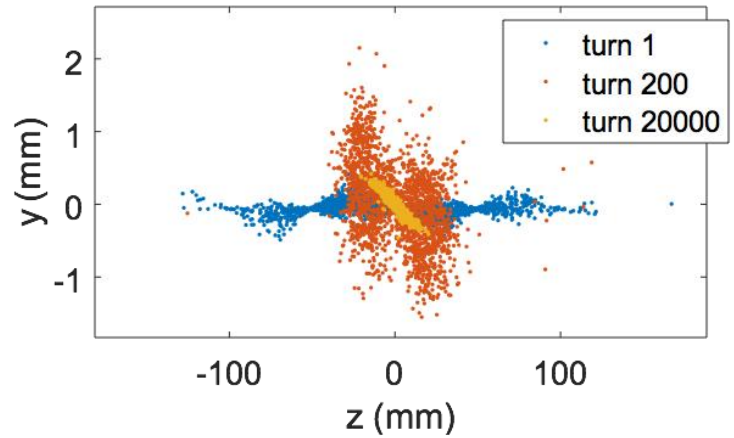
Online optimization of storage ring dynamic aperture

James Safranek, 926-5438



Xiaobiao Huang 926-5056

The SPEAR3 storage ring

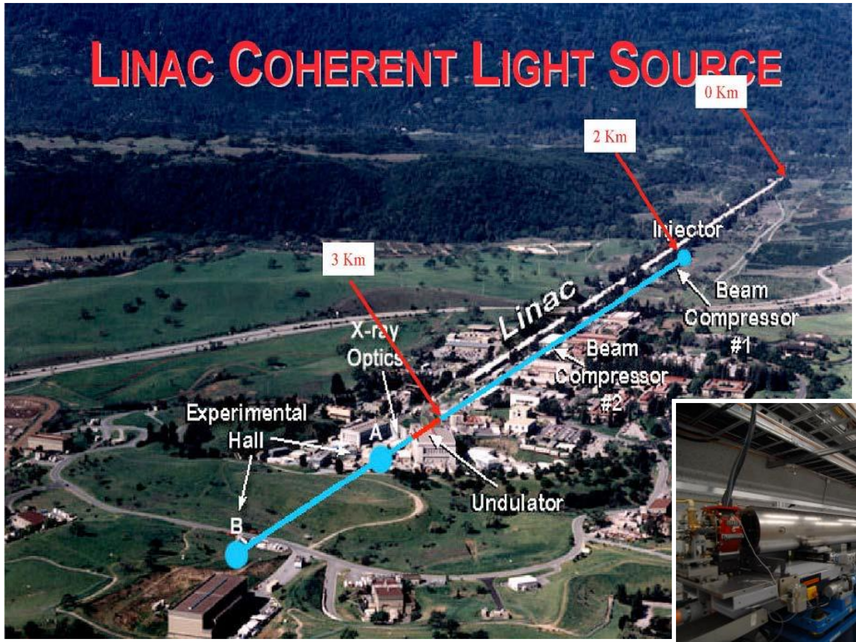


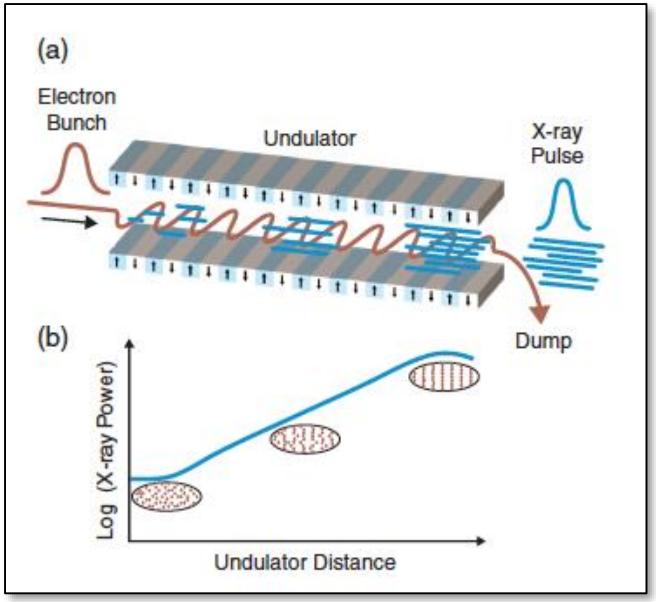
Chirp the electron beam with crab cavity to obtain short pulses

SLAC

Linac Coherent Light Source (LCLS)

- World's first x-ray laser – a Free Electron Laser
  - Commissioned in 2009 and constantly advancing new concepts
  - 10 Orders of magnitude improvement of brightness over previous technology!
  - Enables for the first time science at the femtosecond AND Angstrom scales.





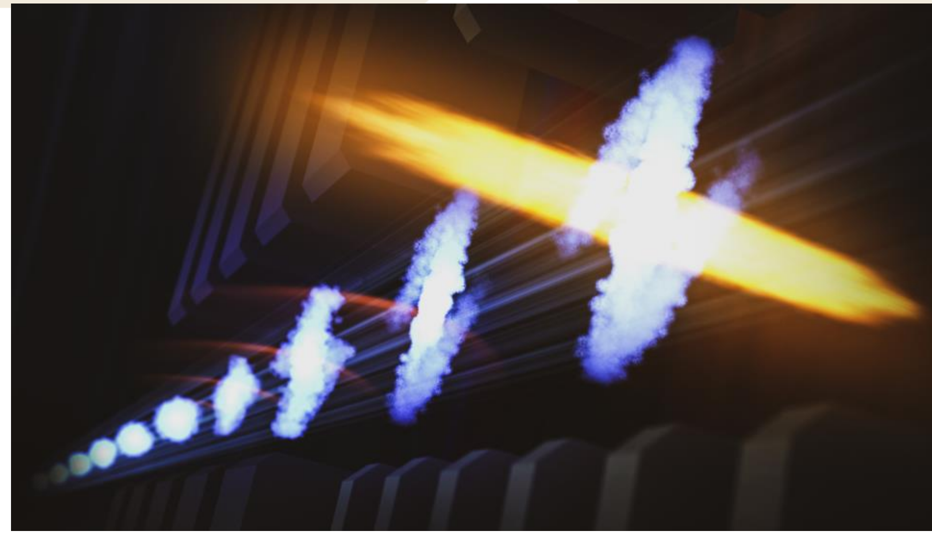
XFEL R&D

1) Shaping X-ray lasers:

- X-ray pump/probe capabilities
- Seeding
- Polarization control

2) Attosecond X-ray science:

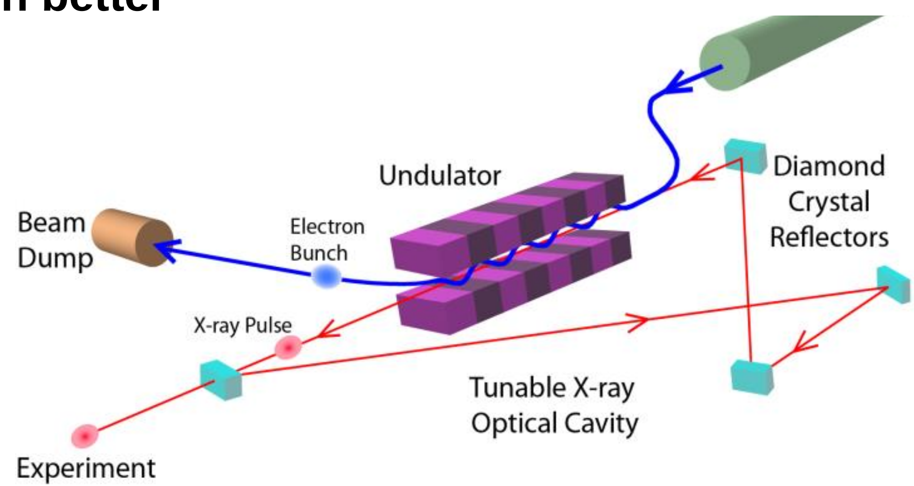
- developing attosecond X-ray source
- attosecond pulse diagnostics
- attosecond molecular movies



Attosecond FEL pulses 10^6 x HHG power

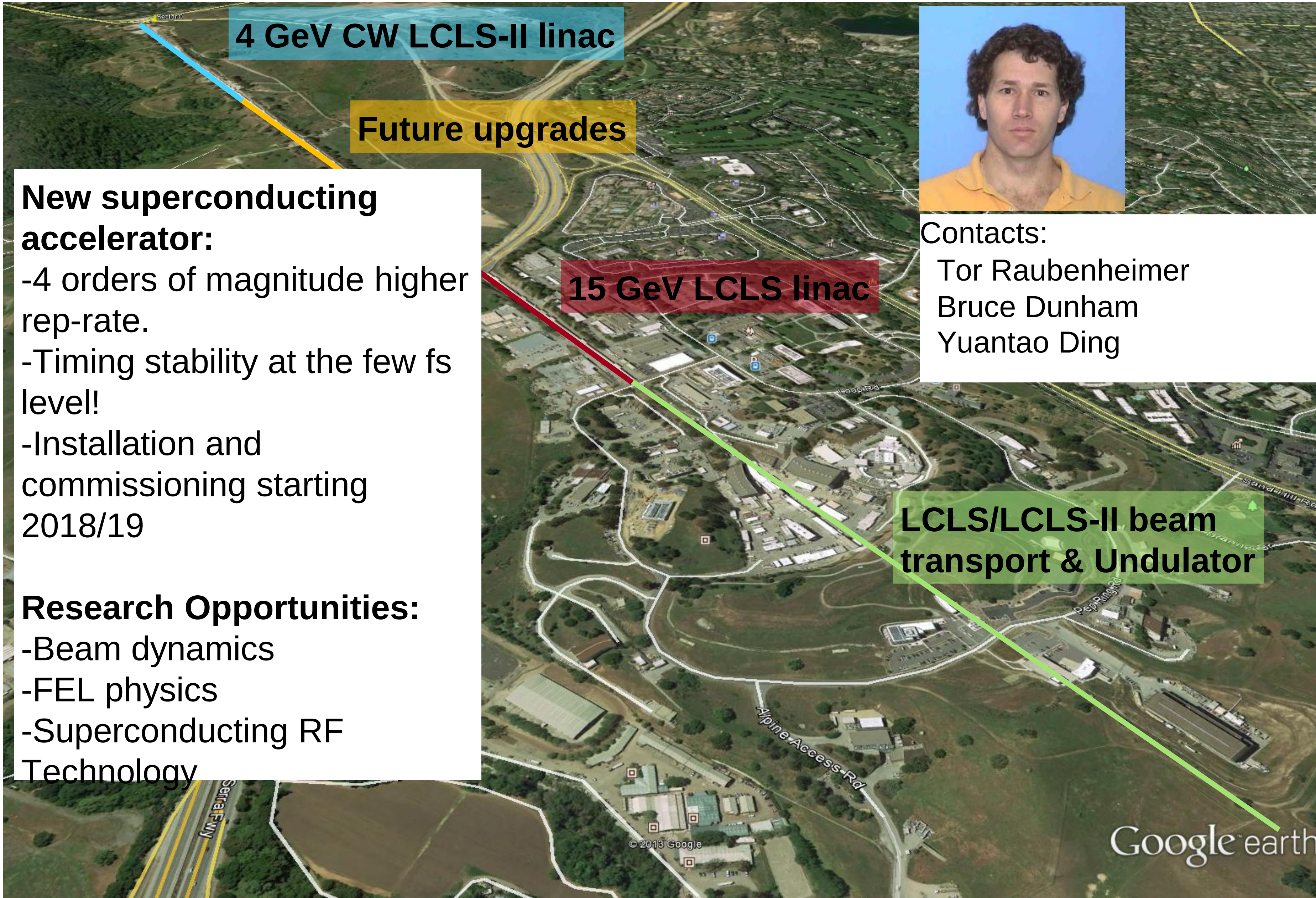
3) X-ray Regenerative Amplifier and oscillators

- **new paradigm of XFELs with much better coherence and brightness**



marinelli@slac.stanford.edu
zrh@slac.stanford.edu

Linac Coherent Light Source II and HE



New superconducting accelerator:

-4 orders of magnitude higher rep-rate.

-Timing stability at the few fs level!

-Installation and commissioning starting 2018/19

Research Opportunities:

-Beam dynamics

-FEL physics

-Superconducting RF Technology

Contacts:

Tor Raubenheimer

Bruce Dunham

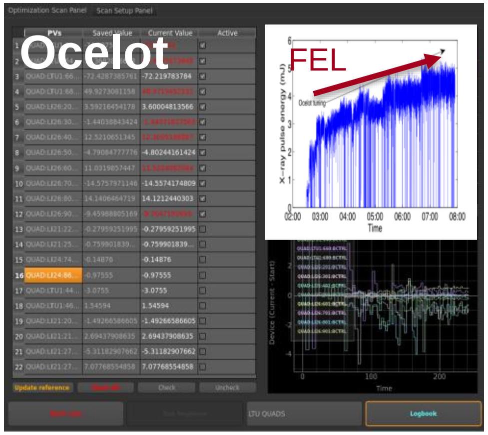
Yuantao Ding

Machine Learning/Big Data for an X-ray Laser

SLAC

Machine learning and data science opportunities at LCLS and AD:

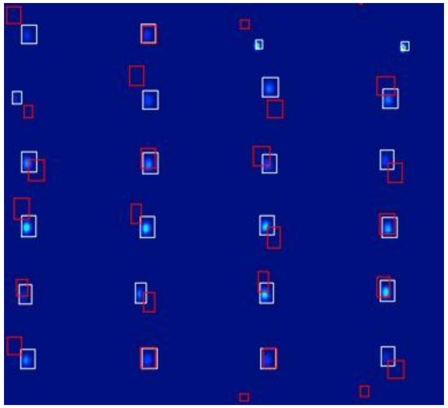
ML tuning



Automated tuning platform for LCLS

1. **Big data:** Archive has a trillion data points to mine for new physics!
2. **How to tune 50 knobs simultaneously:** find 50 people… or use Bayesian optimization.
3. **Predict the future:** prevent failures, identify poor machine configs, create smart alarms
4. **Apply the latest CS to physics:** computer vision, data programming, ADMM, POMDPs.
5. **Develop new science!** Ghost imaging, compressive sensing with x-rays and e⁻

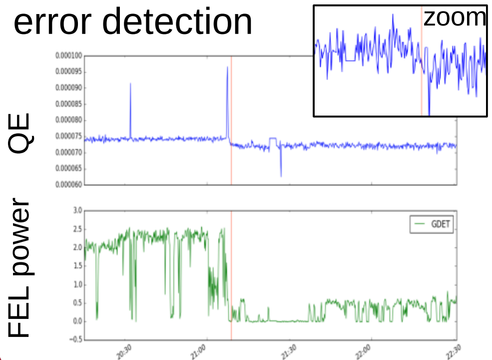
Computer vision



Process screens w/ neural network

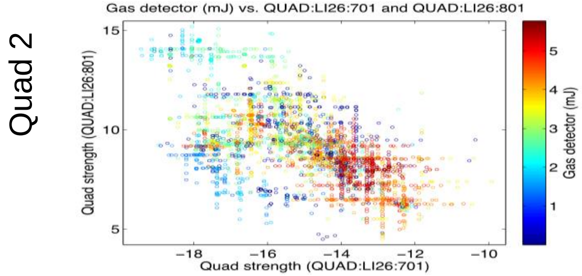
Predicting errors

Prognostics, alarm handling, error detection



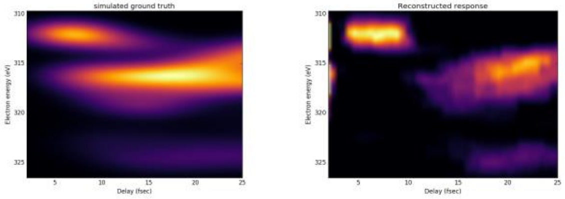
Check out SLAC's AI seminar series:
https://confluence.slac.stanford.edu/display/AI/AI+Seminar

Learning from the past



New Science: e.g. ghost imaging

Intersection of accelerator physics, user science and machine learning



Take Home Messages

- **Accelerator physics: small science projects at big science facilities**
- **Wide range of research topics from lasers to plasma physics!**
- **SLAC: phenomenal accelerator R&D facilities, faculties and staff**
- **Excellent availability of funding during and after graduate school!**