Accelerator Physics at SLAC

Zhirong Huang for SLAC Accelerator faculty

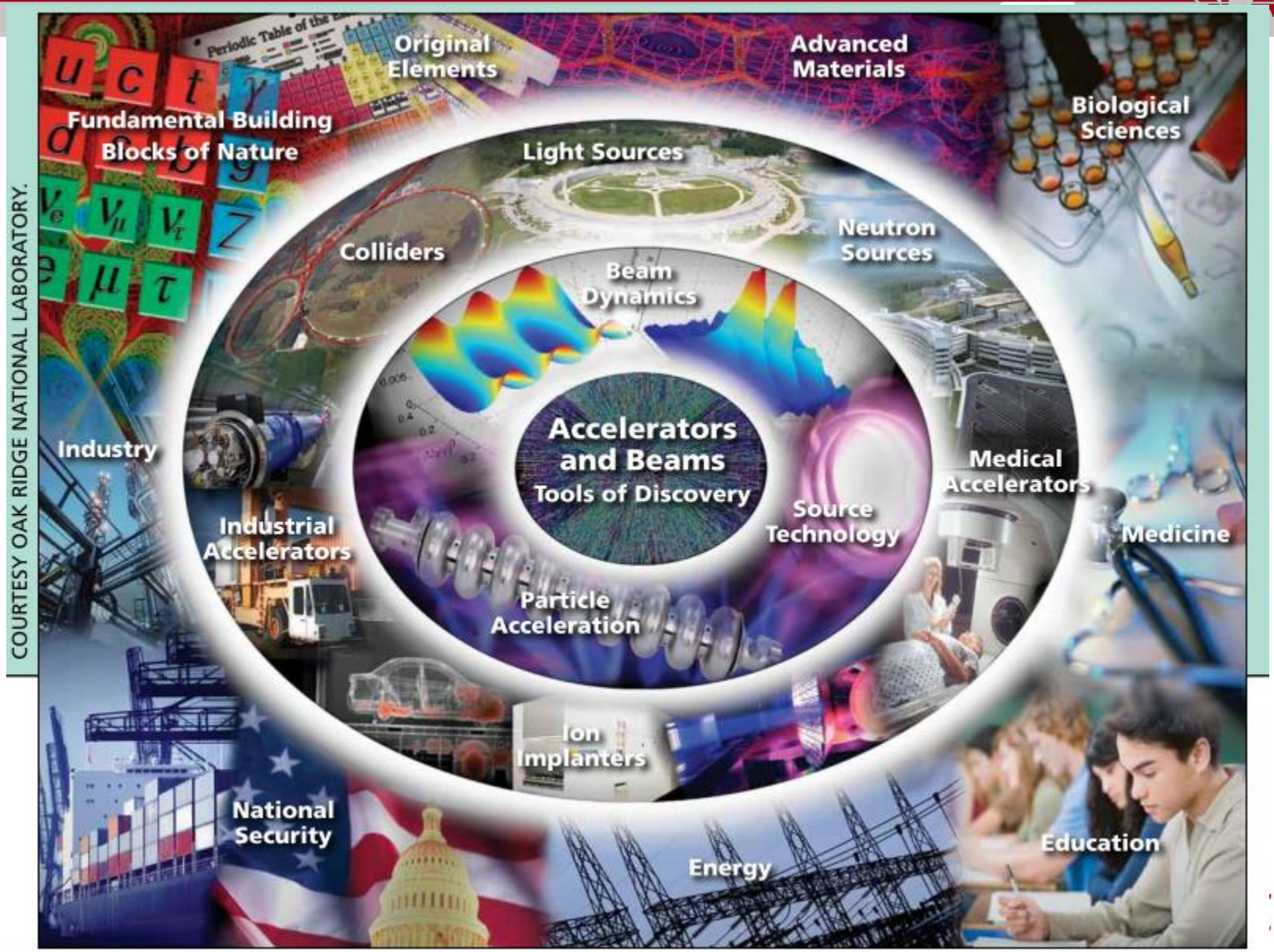
Stanford Graduate Student Orientation
September 17, 2015

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Accelerators and Beams: Tools of Discovery

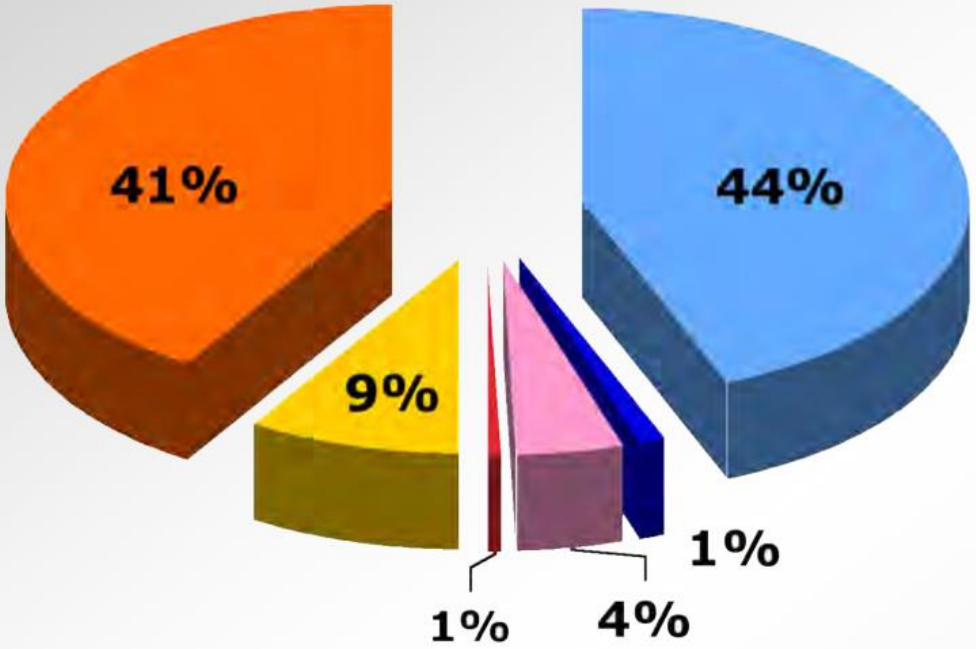
http://www.aps.org/units/dpb/news/edition4th.cfm



Accelerators are Big Business

SLAC

Number of accelerators worldwide
~ 26,000



- Radiotherapy (>100.000 treatments/yr)*
- Medical Radioisotopes
- Research (incl. biomedical)
- >1 GeV for research
- Industrial Processing and Research
- Ion Implanters & Surface Modification

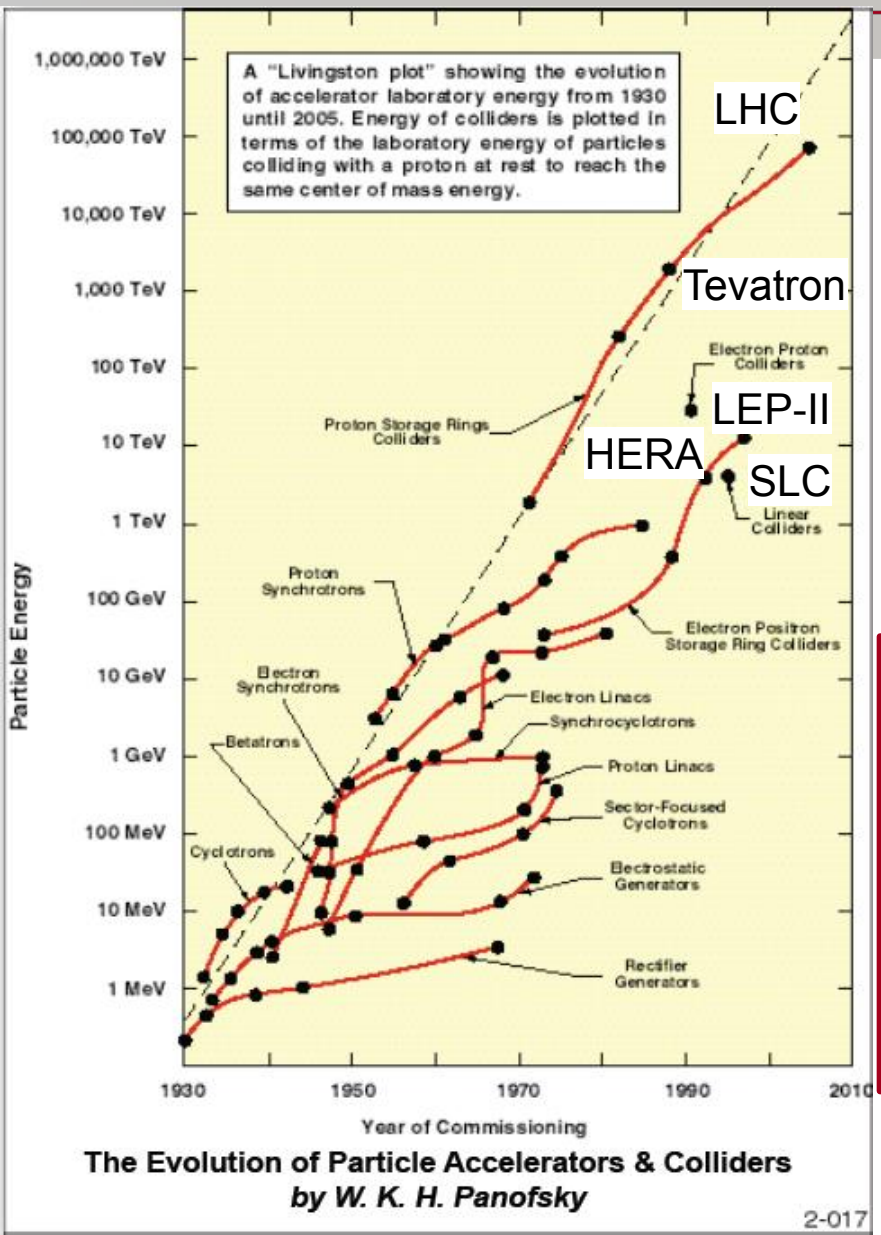
Annual growth is several percent

Sales >3.5 B$/yr

Value of treated good > 50 B$/yr **

Major research machines are a tiny fraction of the total, but…

Field of Accelerator Physics



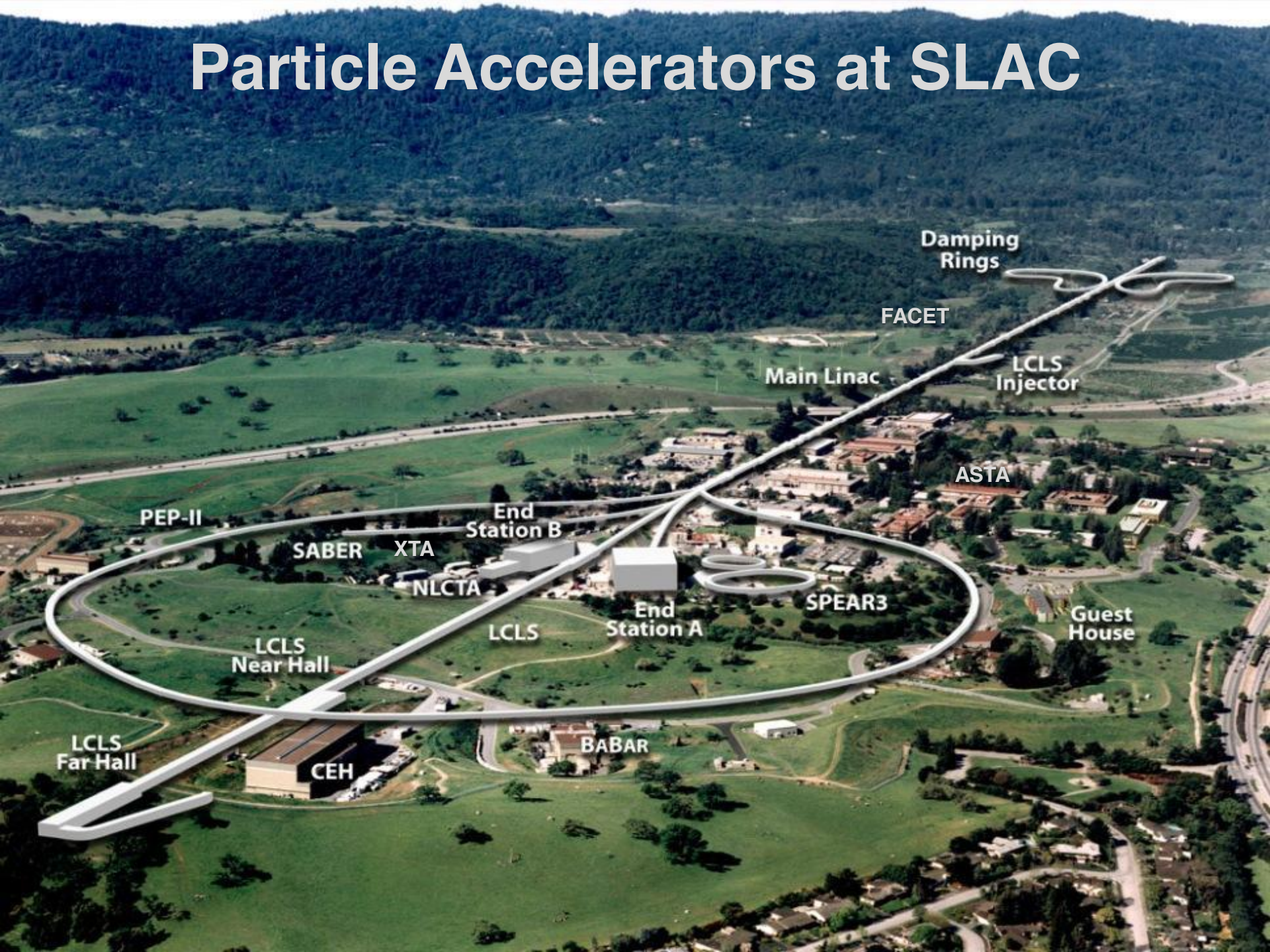
Broad field ranging from engineering some of the largest scientific instruments to plasma physics to materials science to nonlinear dynamics

- Advances come from both conceptual research and directed R&D aimed at applications

Field offers opportunity for 'small-scale' experiments at large science facilities

- Small groups:
  - Individuals can engage in theory, simulation, and experimental results

Particle Accelerators at SLAC



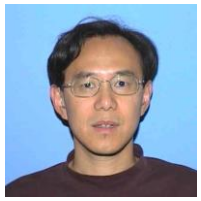
Accelerator R&D and Education

Accelerator R&D is a major effort at SLAC with broad range of research topics:

- Theoretical, simulation, and experimental






8 of the 25 American Physical Society Division of Particle Beam Thesis Award recipients to date completed their graduate research at SLAC:

- Dan Ratner, a student of Alex Chao (2012)
- Ian Blumenfeld, a student of Alex Chao (2011)
- Dmitry Teytelman, a student of John Fox (2004)
- David Pritzkau, a student of Bob Siemann (2003)
- Boris Podobedov, a student of Bob Siemann (2002)
- Shyam Prabhakar, a student of John Fox (2001)
- Zhirong Huang, a student of Ron Ruth (1999)
- Tor Raubenheimer, a student of Ewan Paterson (1994)

SLAC as a national lab has fantastic R&D facilities and a strong faculty and staff and one of the best PhD programs in the nation.

Accelerator Courses offered at Stanford

2014-2015

- **AP207** Laboratory Electronics (John Fox)
- **AP324** Introduction to Accelerator Physics (Zhirong Huang)
- **AP325** X-rays: Past, Present and Future (Tor Raubenheimer)

2015-2016

- **AP201** (Winter) Electrons and Photons (David Reis/Zhirong Huang)
- **AP453** (Spring) Collective Instabilities in Accelerators (Alex Chao)

Summer schools on electron and photon beams was held in 2013 and 2015 at SLAC

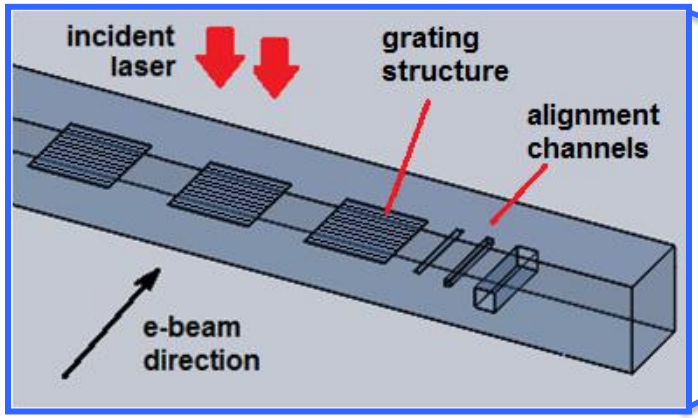
50 senior undergraduates, graduate students and postdoctoral researchers from around the world

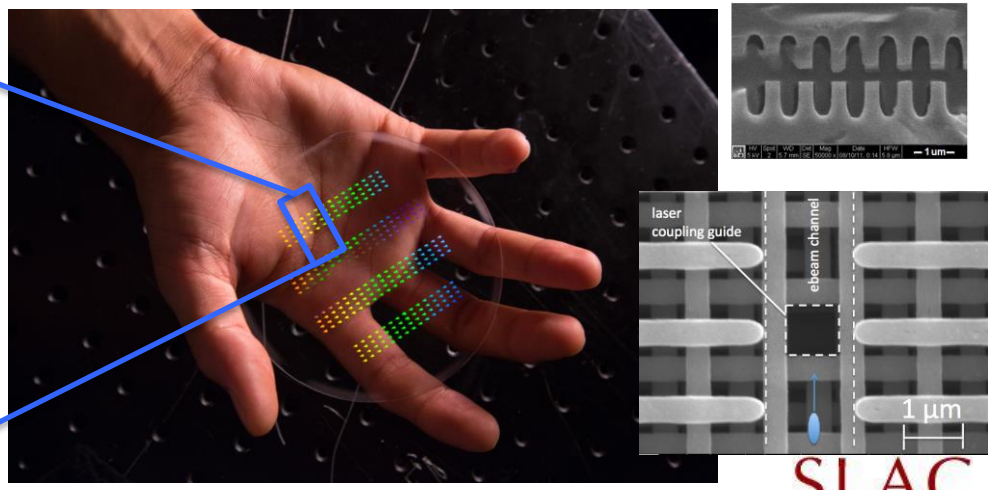
Dielectric Laser Accelerators

Contact:
Dr. Joel England (england@slac.stanford.edu)

A collaborative program with Stanford University for conducting small-scale student-led experiments using lasers to power dielectric micron-scale particle accelerators.

Nature 503, 91-94 (2013)

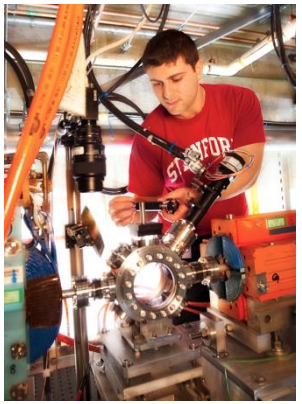


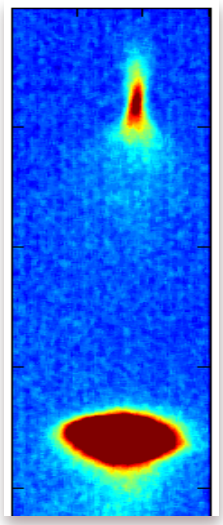


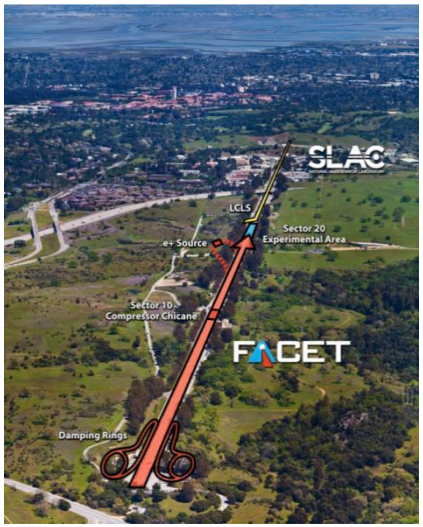
SLAC

Plasma Wakefield Acceleration

- Acceleration gradients of ~50 GV/m (3000 x SLAC!)
  - Doubled energy of 45 GeV beam in 1 meter plasma
- FACET: brand-new 20 GeV test facility for e- & e+
  - Small teams using accelerators, lasers and plasmas to build accelerators of the future
  - High-impact science in a fast paced environment
  - Applications to high-energy colliders, free electron lasers

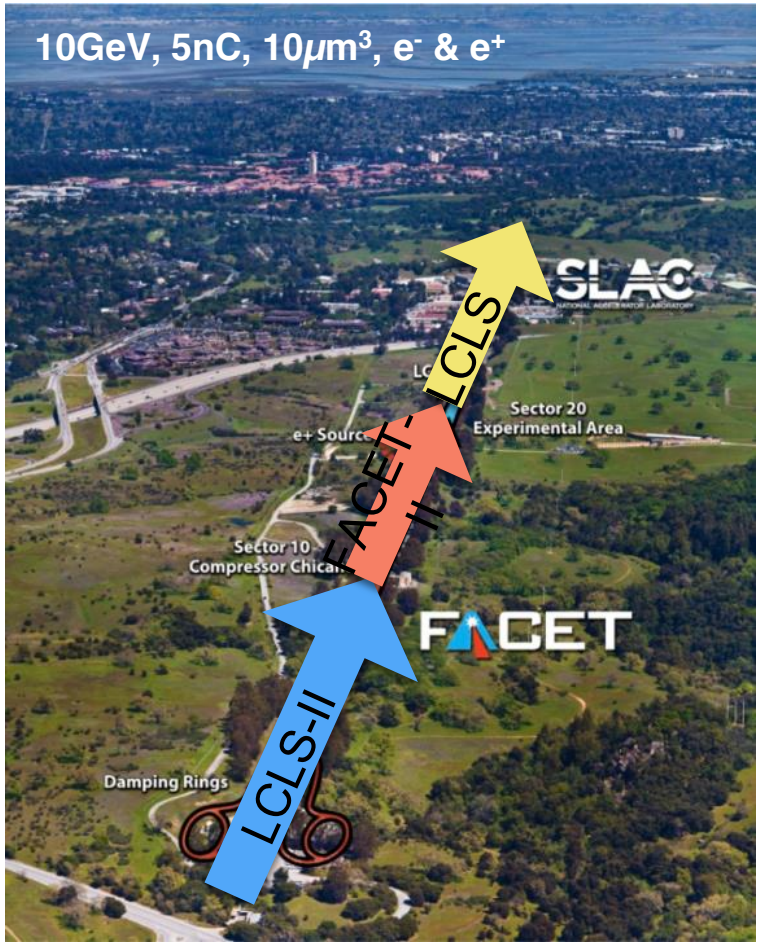






Contacts:
Dr. Mark Hogan 926-2951
Dr. Vitaly Yakimenko 926-3053

FACET-II: next-generation plasma wakefield acceleration



Key R&D Milestones:

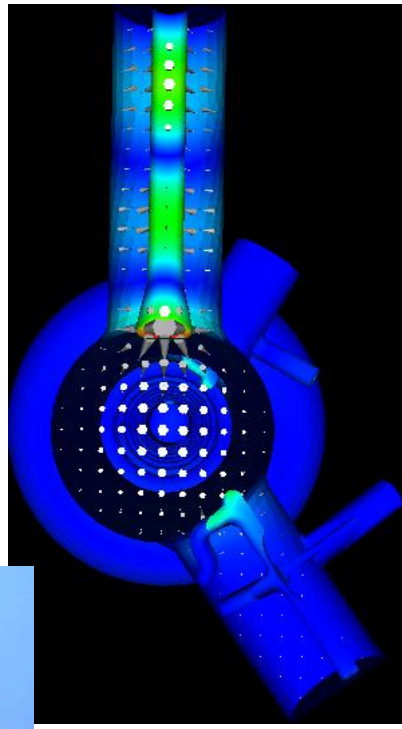
- Staging with witness injector
- High brightness beam generation, preservation, characterization and applications
- e+ acceleration in e- driven wakes
- Generation of high flux THz and gamma radiation

FACET-II will enable research for a broad user community.
You are welcomed to join FACET-II Workshops: Oct.12-16 2015, SLAC

Accelerator Beam Physics and Computing

Broad set of topics ranging from concepts for future high-energy physics and photon science facilities, to massively parallel simulations, to beam theory

- Developed many of the innovative concepts of the field including:
  - Linear collider designs
  - Linac Coherent Light Source (X-ray FEL)
  - PEP-X and other future light sources
  - Massively parallel electromagnetic calculations



Faculty: Alex Chao (926-2985), Ron Ruth (926-3390)

Department heads: Yunhai Cai
and Cho Ng

Accelerator Technology Research

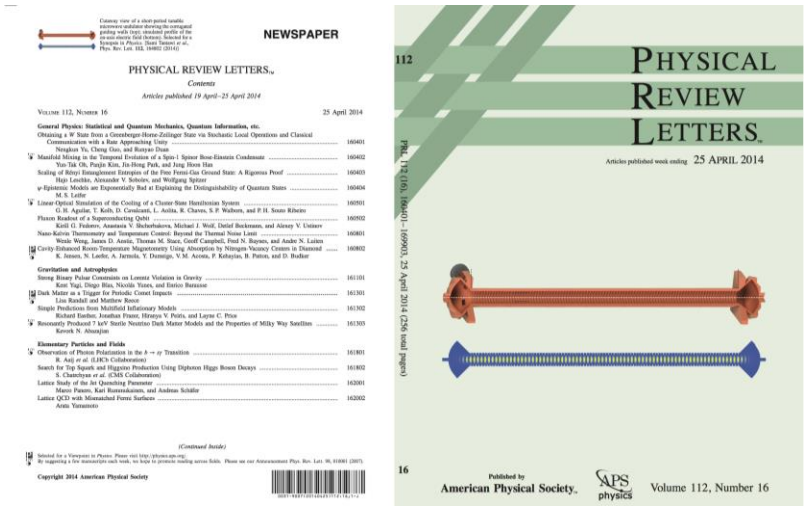
SLAC

High Gradient Research:

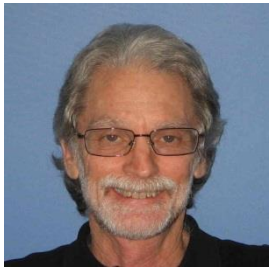
- RF Superconducting Material Characterization, Geometrical Effects, Frequency scaling,.
- High Frequency RF Source Developments.
- Novel Accelerator structures
- Novel accelerator technology for cancer therapy machines(***in collaboration with the Stanford School of Medicine***)

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



The Novel RF undulator



Dr. Michael Fazio
650-926-5765

Dr. Jeff Neilson
650-926-4403

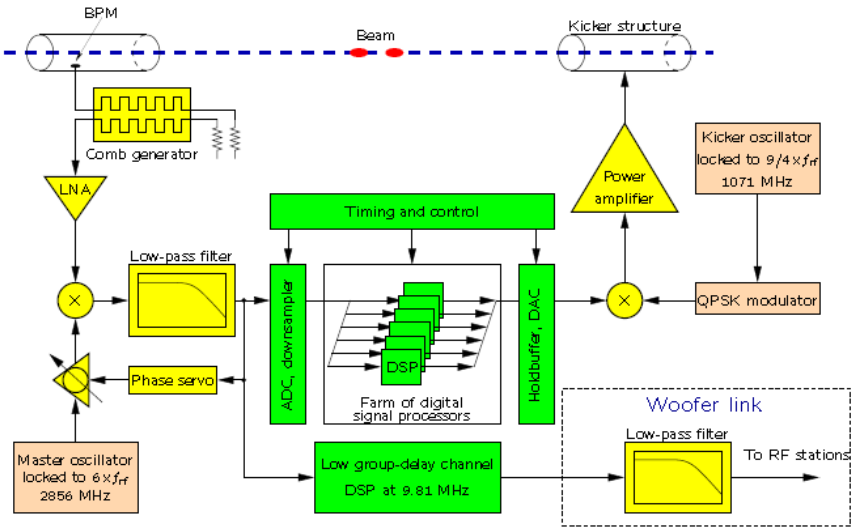
For more info contact:
Prof. Sami Tantawi
650-926-4454

SLAC

Advanced Instrumentation and Feedback

SLAC

- Signal processing systems for beam instrumentation and feedback control systems. Develop DSP with 4-8 GHz processing bandwidth for SPS and LHC, participate in machine measurements.
- System modeling and simulation of unstable systems under feedback control → stabilize jitter in LCLS
- Machine physics studies and system dynamics characterization of the LHC RF↔beam interaction



The group comprises SLAC staff, Toohig Fellow and Stanford Ph.D. students.

Two APS Dissertation Prizes in Beam Physics have been awarded to past students.

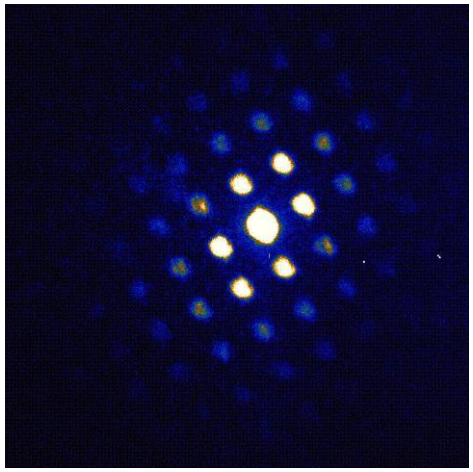
Contact: John Fox, 926-2789

STANFORD UNIVERSITY

Ultrafast Electron Diffraction & Microscope

SLAC

Develop the world leading electron scattering instrumentation facility, complementary to the LCLS X-ray FEL. The UED/UEM facility will possess unique capabilities that enable Grand Challenge science in chemistry, material science, physics and biology.



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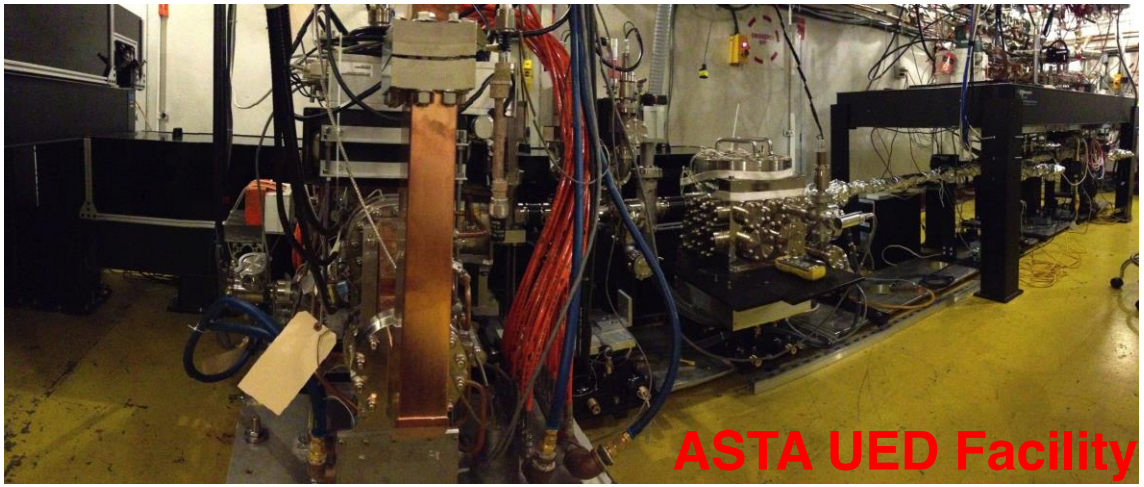


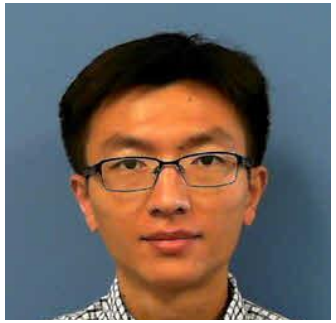
Xijie Wang

UED&UEM R&D

Hermann Durr

Ultrafast Science

Renkai Li



UED&UEM R&D

SLAC

SPEAR3 accelerator research

Accelerator optics/Nonlinear dynamics

Online optimization algorithm development

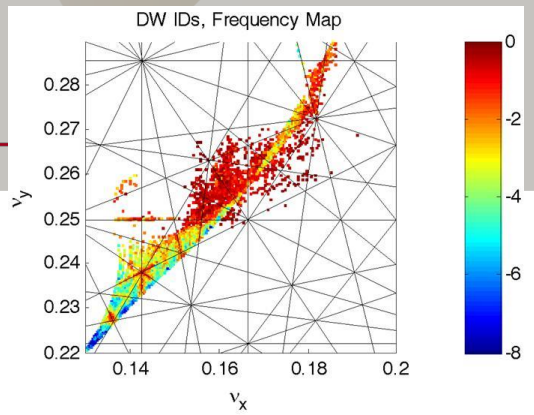
- Genetic algorithms
- Particle swarm

Storage ring short-pulse timing modes

Gun development

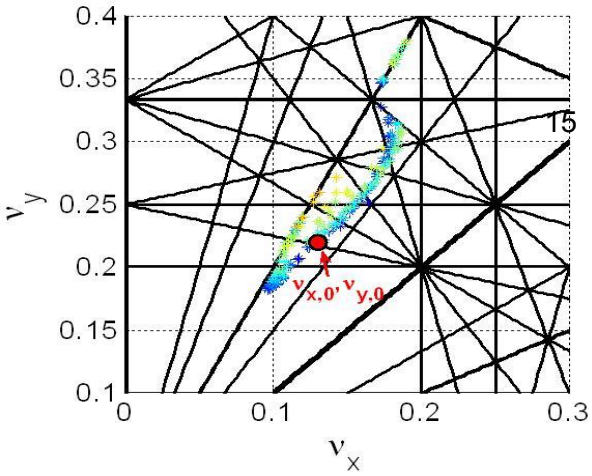
Diagnostics development

Simulated:

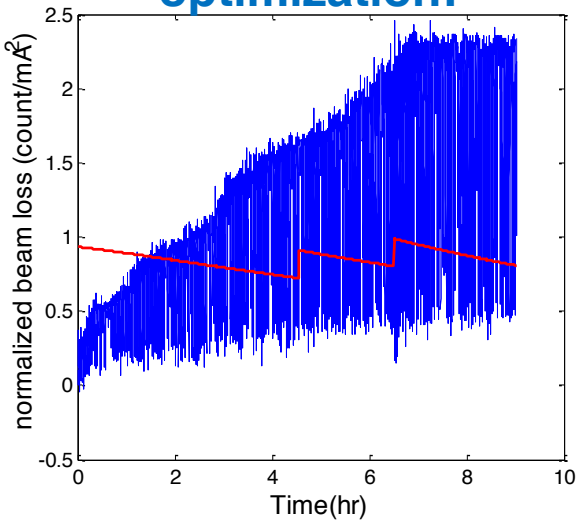


Nonlinear dynamics:

Measured:

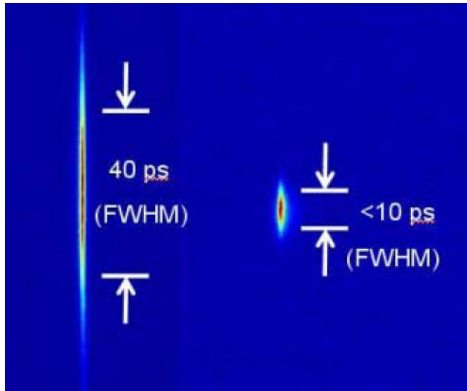


Beam-based genetic optimization:



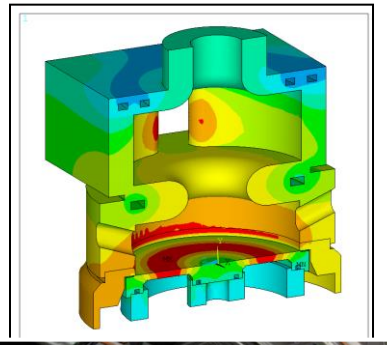
James Safranek,
926-5438

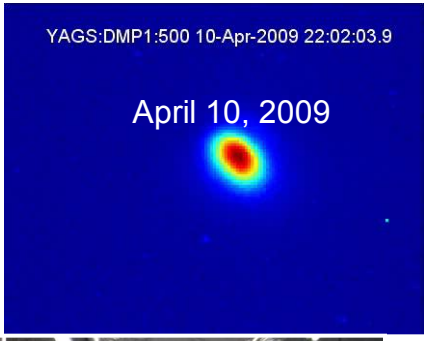
Measured SPEAR bunch:

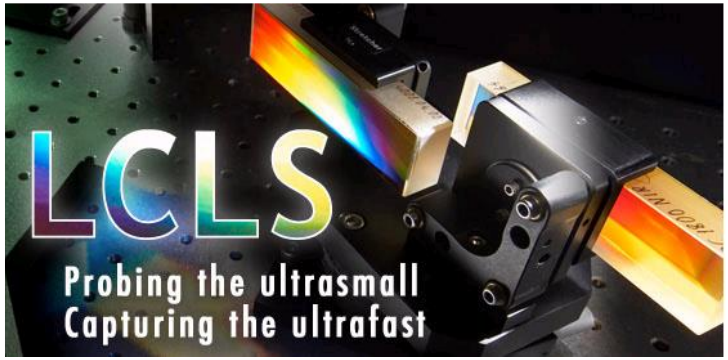


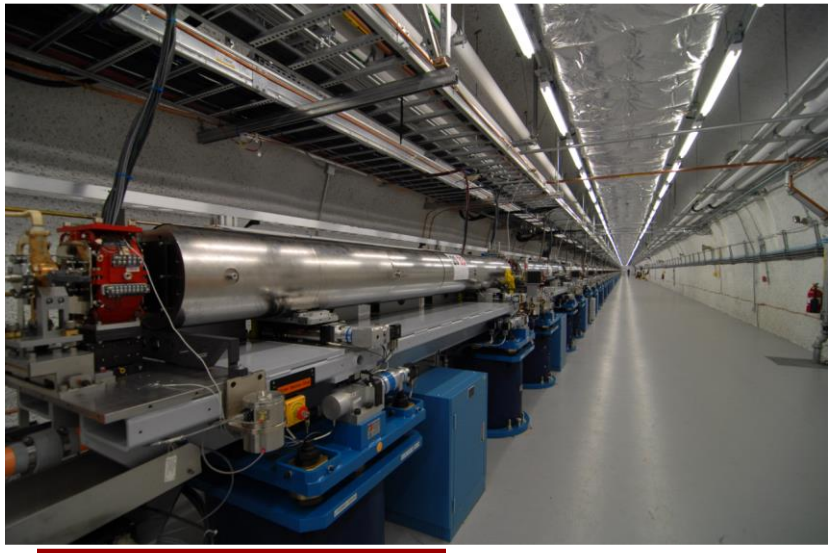
Linac Coherent Light Source (LCLS)

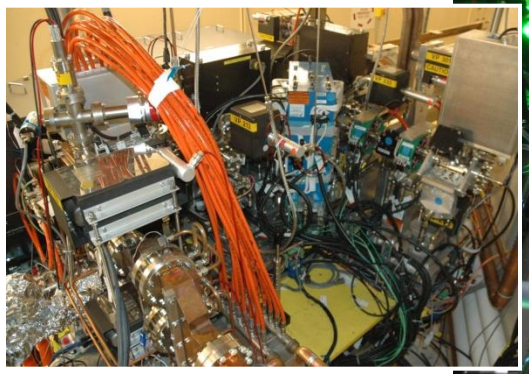
- World's first x-ray laser – a Free Electron Laser
  - Commissioned in 2009 and constantly advancing new concepts

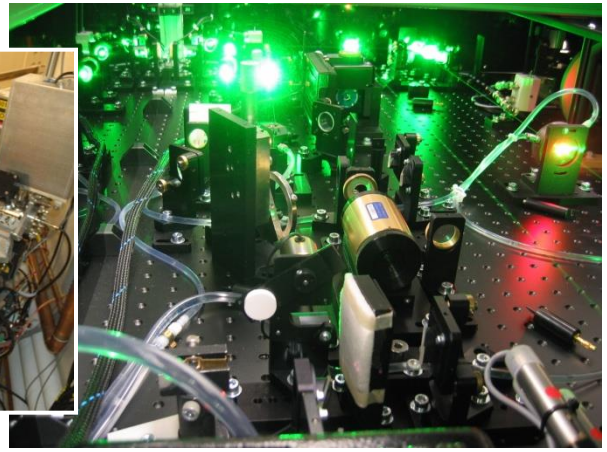






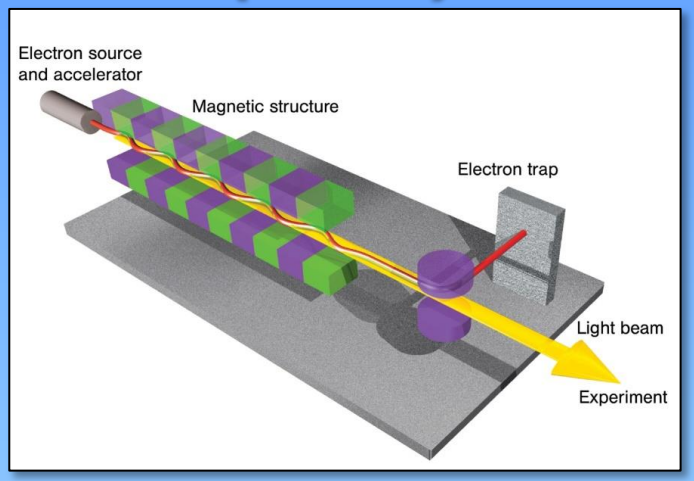




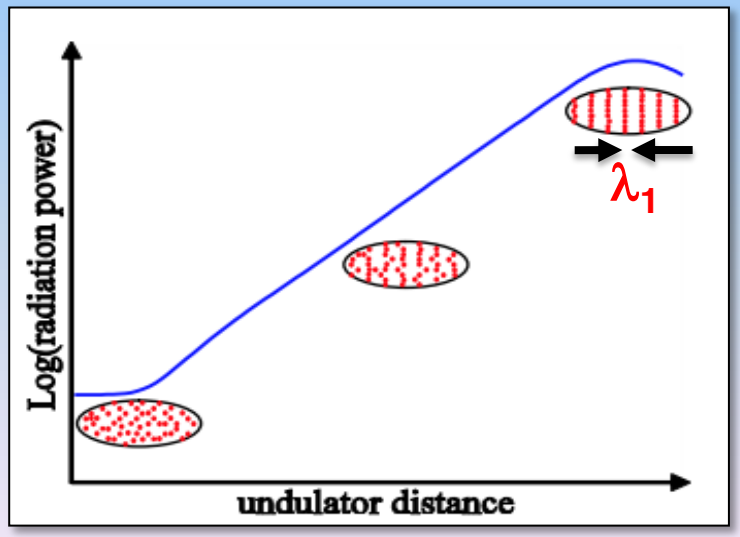


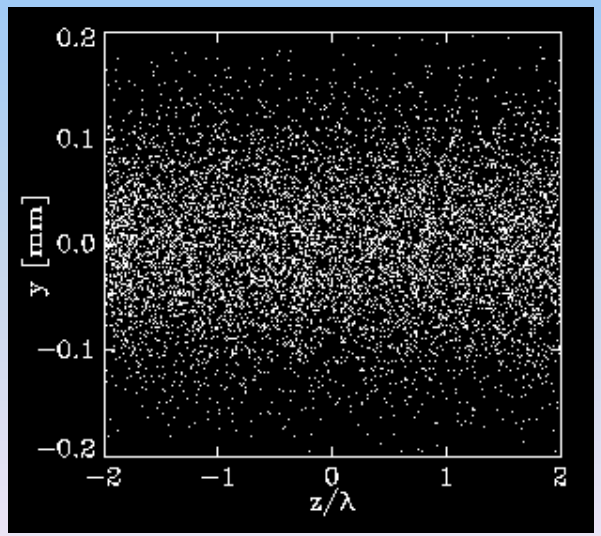
Free Electron Laser (FEL)

- **Resonant interaction** of electrons with EM radiation in an undulator^
- **Coherent radiation intensity ∝ N^2 due to beam microbunching**
  (N: # of e^- involved ~10^6 to 10^9)



- At x-ray wavelengths, use **Self-Amplified Spontaneous Emission*** **(a wonderful instability!)** to reach high peak power





S. Reiche

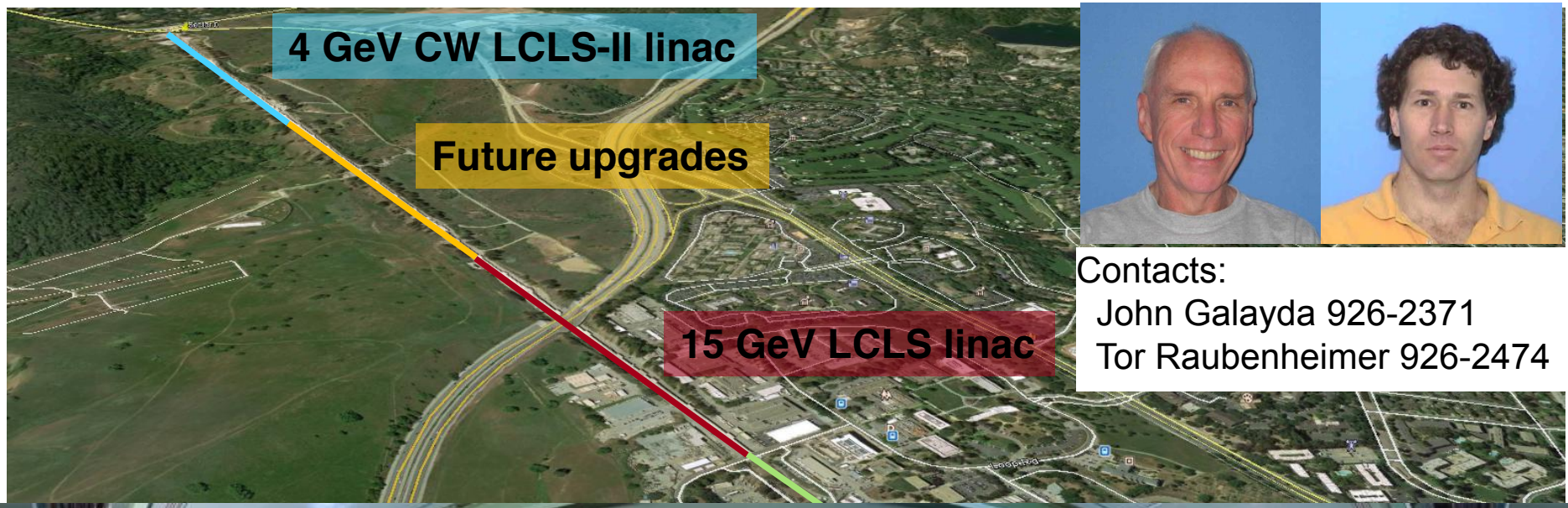
^ *J. Madey, J. Appl. Phys., 1971*

* *Kondradenko, Saldin, Part. Accel., 1980*
* *Bonifacio, Pellegrini, Narducci, Opt. Com., 1984*

A world-wide growth spurt in XFELs

- EUV/soft X-rays: FLASH (2005), FERMI (2012), SXFEL (2017)
- LCLS-II (2020): a new SC CW FEL at 1 MHz rep. rate

Linac Coherent Light Source II

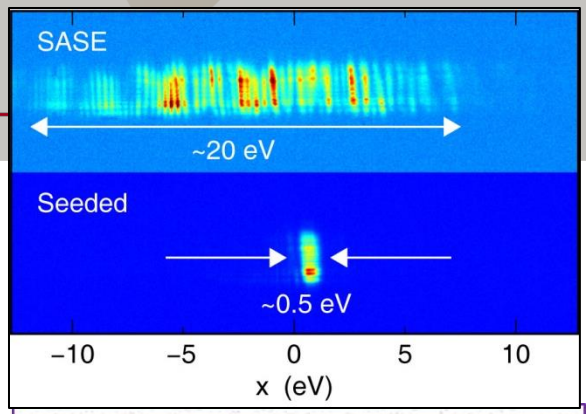


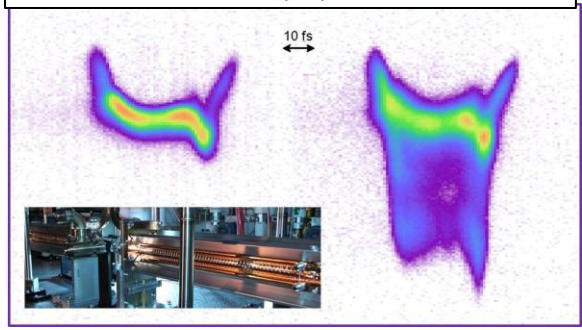
Contacts:
John Galayda 926-2371
Tor Raubenheimer 926-2474

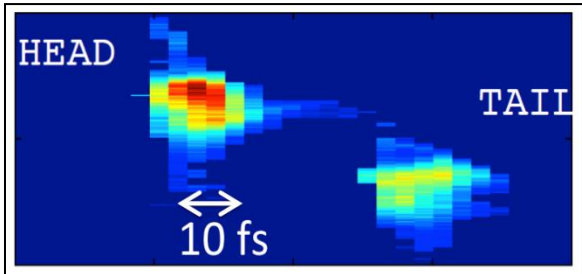
FEL R&D

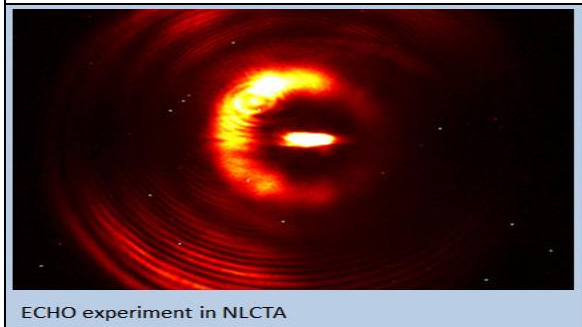
- Development of self-seeding that improve SASE temporal coherence in both hard and soft x-ray regimes
- Generation and characterization of X-ray pulse length down to a few fs or sub-fs
- Two-color FEL for x-ray pump and x-ray probe at high intensities
- Using beam echo effect for generation of short-wavelength coherent radiation

Contacts:
Zhirong Huang 926-3947
Tor Raubenheimer 926-2474









Take Home Messages

- **Accelerator physics: small science projects at big science facilities**

- **SLAC: phenomenal accelerator R&D facilities, faculties and staff**

Examples of Recent PhD Theses

SLAC

- Panos Baxevanis: “Theoretical study of novel concepts for compact, high-gain free electron lasers”
  - Advisor: Ron Ruth, 2015, Present position, SLAC research associate
- Ken Soong: “Demonstration of Electron Acceleration and Diagnostics with Microstructures”
  - Advisor: Bob Byer, 2014, Present position, Intech, scientific consulting co.
- E. Peralta: “Grating-based Dielectric Microstructures for Laser-Driven Acceleration of Electrons”
  - Advisor: Bob Byer, 2014
- Dan Ratner, “Much Ado about Microbunching: Coherent Bunching in High Brightness Electron Beams,”
  - Advisor: Axel Chao, 2011, Present position: Staff Scientist, SLAC
- Themis Mastorides "Radio Frequency Station - Beam Dynamics Interaction in Circular Accelerators"
  - Advisor - John Fox, 2010, Present Position: Assistant Professor (Physics) California Polytechnic University
- Ian Blumenfeld, "Scaling of the Longitudial Electric Fields and Transformer Ratio in a Non-Linear Plasma Wakefield Accelerator,“
  - Advisor: Alex Chao, 2009, Present position: Scientist, Modeling Group, Archimedes Inc.
- Neil Kirby, "Properties of Trapped Electron Bunches in a Plasma Wakefield Accelerator,"
  - Advisor: Alex Chao, 2009, Present position: Postdoc, Radiation Oncology Department, UC San Francisco.
- Chris Sears, "Production, Characterization, and Acceleration of Optical Microbunches,"
  - Advisor: Robert Siemann, 2008, Present position: MPI Munich.