Accelerator Physics and Facilities
Eric Colby
Advanced Accelerator Research Department
SLAC

Stanford Student Orientation Sept. 16, 2010
SLAC Linac and LCLS

- SLAC 3 km long linac produced 50 GeV e+ and e- and undulator hall for LCLS x-ray laser
SSRL/SPEAR3

SPEAR history: Research at the SPEAR storage ring led to three of the four SLAC Nobel prizes: 1976 physics prize for J/Psi particle, 1995 physics for the tau lepton, and 2006 chemistry prize for RNA using synchrotron radiation.

The SPEAR3 accelerator physicists work to maximize the performance of the Stanford Synchrotron Radiation Lightsource accelerators, develop new operational modes, and probe the limits of accelerator performance to aid in the design of future storage rings.

James Safranek, 926-5438 safranek@slac.stanford.edu
What is accelerator physics?

- It is the science controlling charged particles with static and dynamic electric and magnetic fields.

- Since the goal typically is to accelerate as rapidly as possible, this means understanding:
  - How to produce very large electric fields (100 MV/m-100 GV/m)
  - Exotic pulsed-power systems exceeding 100 MW peak powers
  - Laser systems from gigawatts to petawatts (10^{15} W)
  - Ultrahigh current electron drive beams (e.g. FACET: 20,000 Amps @ 23 billion volts)
  - How to control the fields to provide stable acceleration (10 V/Å = 100 GV/m)
  - Novel metals, dielectrics, and "metamaterials" (e.g. plasmas)

- It also means understanding a range of more subtle effects such as:
  - How to limit the damaging effects of coherent synchrotron radiation
  - How small imperfections, acting repeatedly on the beam, can lead to degradation and loss
  - How to form—and maintain—angstrom-scale structures on the beam
  - How to exploit quantum radiation effects to prepare “quantum degenerate” beams
  - How to manipulate the beam in 6 dimensions to optimize its brightness and current
  - How to apply EM to develop new sources of coherent radiation, especially terahertz
Accelerator research has become strongly interdisciplinary

- Plasma dynamics
- Laser science, high-field science
- Computational complex problems
- New technologies
  - Engineered metamaterials ($\varepsilon<0$, $\mu<0 \Rightarrow n<0$)
  - Photonic crystals
  - Semiconductors and nanofabrication
  - Microwaves and millimeter waves
  - X-ray and Terahertz radiation generation
  - ...
- Ultrafast electronics, DSP, and electro-optics

Students develop a range of practical skills that open up interesting career paths in academia and industry
What careers are available?

Accelerator Physics is one of the few job fields where opportunities significantly outnumber candidates

- **Demand is substantial and growing**
  - ~30,000 operating accelerators worldwide, the majority are electron accelerators used in medicine and industry
  - Many large companies perform active R&D in accelerator science: Varian, Siemens, AS&E, EG&G, IBA, Mitsubishi, Hitachi, ProTom, Still River, GE, others. Typical research group is 20+
  - More than 30 large laboratories and numerous smaller laboratories worldwide have large accelerators and programs in acceleration science
  - 7 Universities in the US have strong accelerator science programs (MIT, Cornell, Indiana, Michigan, UT-Austin, UCLA, and **Stanford**)  

- **Supply is very limited**
  - Of 5915 physics PhDs awarded in US in the last 5 years, just 54 went to accelerator physicists –AIP Statistical Research Center

- Salaries are **competitive**
Accelerator Research groups are small and academically-oriented

- Group size averages 10 or less
- Individual contributions are strongly felt
- Several groups have 3 or more graduate students and postdocs
- Can work on theory, computation, and experiment
- Experience of a working at a large National Laboratory
Accelerator Physics Education

Classroom - Typically 2 courses per year

FALL 2010: R. Ruth, APPPHYS 324 Introduction to Accelerator Physics
Win/Spr: J. Fox, APPPHYS 207/208 Laboratory Electronics

Research

Free Electron Lasers/LCLS – John Galayda (galayda@slac.stanford.edu)

Echo-7, FACET, ILC – Tor Raubenheimer (tor@slac.stanford.edu)
Tom Himel (thimel@slac.stanford.edu)
Ewan Paterson (jmp@slac.stanford.edu)

Advanced Accelerators – Sami Tantawi (tantawi@slac.stanford.edu) – High Gradient RF
Bob Byer (byer@stanford.edu) -- LASER
Eric Colby (ecolby@slac.stanford.edu) – LASER-Beam Expt
Mark Hogan (hogan@slac.stanford.edu) - PLASMA

Advanced Electronics/Feedback – John Fox (jdfox@slac.stanford.edu)

Beam Dynamics – Alex Chao (achao@slac.stanford.edu),
Ron Ruth (rruth@slac.stanford.edu)
Yunhai Cai (cai@slac.stanford.edu)
Zhirong Huang (zrh@slac.stanford.edu)

SSRL/SPEAR-3-- James Safranek (safranek@slac.stanford.edu)
Jeff Corbett (corbett@slac.stanford.edu)
Experiment Beam Dynamics

Use of Test Accelerator to study fundamental beam dynamics

Recent experiment: Echo-7 – generating nm-level structure in the beam

Student Opportunities
- Echo-7 experiment at NLC Test Accelerator
  Need help with beam control software, beam operations, diagnostics, beam simulation and experiment modeling
- FACET plasma wakefield acceleration
  Need help with experimental design, beam modeling and simulation

Tor Raubenheimer  926-2474  tor@slac.stanford.edu
Accelerator Technology Research

Research Opportunities:

• **High Gradient Research:**
  – *Host for the US Collaboration on High Gradient Research for Future Colliders*
  – Breakdown in rf structures: theoretical and experimental investigations.
  – High Frequency RF Source Developments.
  – Novel Accelerator structures, designs, manufacturing and characterization techniques.

• **Ultra High Power RF Components and Systems:**
  – Active pulse compression systems and ultra-high-power solid-state devices,
  – Concept of spatially combined devices for ultra-high power semiconductor switches and RF sources

• **Novel FEL Technologies and Light Sources:** RF undulators and bunch compression techniques for ultra-short pulses.

• **Advanced Accelerator Concepts:** Practical design and implementation of Bragg structures.

For more info contact: Prof. Sami Tantawi
tantawi@slac.stanford.edu
650-926-4454
Sample Research Topics—Ron Ruth

• Fully coherent X-ray Beam
  – Idea: Get a fully coherent beam then use FEL as amplifier. Self seeding.
  – Use x-ray beam from beginning to seed end.
  – Not as easy as it sounds. A great topic which is very timely.

• How do nonlinear fields cause instability and can we do something about it?
  – Fundamental question in mathematics
  – Long standing practical question for advanced electron and proton storage rings.
  – History—accelerator questions drove the early theorems (KAM)!
  – Concepts: Dynamic aperture, resonances, coupling, chaotic behavior, renormalization group analysis,…
  – Topic: understanding a specific ‘dynamic aperture’ and how it relates to these more general concepts.
Mission

- Charged particle optics and accelerator design
  - Electron storage rings, high energy colliders, synchrotron light sources
- Analytical impedance calculation and collective effects
  - Coherent synchrotron radiation
- Electromagnetic computation and RF design
  - High-performance scientific computing
- FEL physics and seeding schemes
  - High harmonic generation experiment at NLCTA

Contact: Yunhai Cai (yunhai@slac.stanford.edu)
An accelerator research facility providing:
- 23 Billion Volt electrons + positrons
- 60 femtosecond pulses
- 20,000 Amperes
Unique properties of SLAC e+ and e- beams (ultra-short, high charge) provide worldwide unique opportunities for accelerator research at FACET.

Short bunches and their Tera-Hz radiation open new possibilities to study ultrafast magnetization switching.

Two electron bunches formed by notch collimator will allow study energy doubling, high efficiency acceleration, emittance preservation.

“Sailboat” dual chicane will give unique opportunity to study acceleration of positrons by an electron bunch.

Unique science opportunities for variety of fields:
- e- and e+ plasma acceleration as primary goal
- Plasma lens for compact focusing
- Bent crystal for beam collimation or photon source
- Dielectric wakefield acceleration
- Generation of THz radiation for materials studies

Mark Hogan  926-2951
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Laser-driven “Accelerators on a Chip”

Photonic Band Gap Fibers
- Confines light by selective interference in dielectric lattice
- Made by conventional fiber drawing techniques in industry

Planar Grating Structure
- High gradient, wide aperture accelerator
- Producing structures at the Stanford Nanofabrication Facility

Silicon “Woodpile” Structure
- Producing structures at the Stanford Nanofabrication Facility

Bragg Planar Dielectric Structure
- Accelerating mode guided by two-sided Bragg multi-layer waveguide
- Grating couples laser from side and converts it to accel mode
- Producing structures at the Stanford Nanofabrication Facility

HC-1550-02 fiber:
- Producing structures at the Stanford Nanofabrication Facility

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SPEAR3 accelerator research

- Short pulses/THz beamline
  - LDRD funding to design THz beamline
  - Primary rotation research focus
  - Beamline purpose:
    - Characterize bunch shape
    - Measure shielded CSR impedance
    - THz for photon experiments
- Accelerator optics/Nonlinear dynamics
- PEP-X (future light source)
- Gun development
- Diagnostics development
- Hands-on work opportunities

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Short Pulse Production and Measurement

pump/probe physics

photocathode research

Jeff Corbett /SSRL 926-3645
corbett@slac.stanford.edu
Advanced Electronics - New Projects and Opportunities

Signal processing systems for beam instrumentation and feedback control systems. LHC Ecloud feedback requires 4-8 GHz processing bandwidth with digital processing filters. Develop E-cloud control systems for SPS and LHC, participate in machine measurements. (J. Fox, Alex Bullitt)

System modeling and simulation of unstable systems under feedback control. Possible applications include state-estimator techniques to stabilize energy jitter in x-ray sources. (C. Rivetta, O. Turgut)

Machine physics studies and system dynamics characterization of the LHC RF systems interacting with the beam. Understand limits via commissioning measurements. (C. Rivetta, T. Mastorides)

Contact John Fox (jdfox@slac.stanford.edu) Check out http://www.slac.stanford.edu/grp/ara/
Some Alumni of Stanford Accelerator Physics

- Tomas Plettner—Researcher at KLA-Tencor
- Caolionn O’Connell—Dept. of Defense
- Themis Mastoridis—Toohig Fellow SLAC, CERN, FNAL?
- Devon MacDonald—Strategic Planning, KLA-Tencor
- Bruce Rohrbough—Instructor at West Point
- Neil Kirby—Postdoc, UCSF
- Jiaxing Xu—Postdoc, SLAC
- Chris Barnes—Researcher at Solyndra
- Zhirong Huang—APS Thesis Award, Scientist, SLAC
- Ian Blumenfeld—Scientist, Archimedes Group
- Boaz Nash—Scientist, Brookhaven Nat’l Lab
- Dmitry Teytelman—APS Thesis Award, Founder of Dimtel, Inc.
- Ben Cowan—Scientific code developer at Tech-X
- David Pritzkau—APS Thesis Award, Big Bear Networks
- Ben Cowan—Scientific code developer at Tech-X
- Chris Sears—Researcher at KLA-Tencor
- Boris Podobedov—Scientist, Brookhaven
- Jiquan Guo—Scientist, SLAC
- Chris Sears—Researcher at KLA-Tencor
- Rod Loewen—Scientist at Lyncan Technologies
- Greg Schussman—Scientist, SLAC

Current Careers:
Blue=Industry 40%
Red=Academia 20%
Gold=Nat’l Labs 40%
Current Stanford Accelerator Students

Chris McGuinness
Laser Driven Accelerators

Ozhan Turgut
Instabilities & Feedback

Muhammad Shumail
Advanced Microwave Technology

Edgar Peralta
Laser Driven Accelerators

Themis Mastoridis
Instabilities & Feedback

Joel Frederico
Plasma Wakefield Accelerators

Ken Soong
Laser Driven Accelerators

Alex Bullitt
Instabilities & Feedback

Panagiotis Baxevanis
FEL Physics

Daniel Ratner
FEL Physics
NLCTA Tour:
120 MeV Electron Accelerator
Seeding, IFELs, THz Generation
Laser-Driven Acceleration
High Power RF
Posters on FACET & Plasma Acceleration

Accelerator Tour 4:30-5:30  Leaves from Lot A

Reception:
Accelerator staff, postdocs, and graduate students will be available to discuss research opportunities!