Accelerator Research Program

Sami Tantawi

DoE Annual Review

June 12, 2007
Accelerator Science and Technology at SLAC

Accelerators and accelerator science permeate SLAC

- SLAC accelerator science drivers:
  - The Frontier of Particle Physics.
  - The Frontier of Photon Science

- Incorporates:
  - Improvement of existing accelerators
  - Development of new accelerators
  - Development of new accelerator science and technology

- Organization-management: accelerator science is spread out widely:
  - PEP II operations, SPEAR operations
  - LCLS and ILC
  - Accelerator Research Departments
  - Klystron Dept., Surface & Material Science Dept.

- Accelerator physics perspective:
  - Intellectual commonality
  - Technical commonality
  - Among all these activities: short term, long term, specific or generic

Look in more detail at part of this - Accelerator Research, Activities:

- Support the operating accelerators
- Develop accelerator technology and physics for the future
- Explore new ways to accelerate particles
Beam Physics Department
(Yunhai Cai Dept Head)
For 2007-2007 year 67 published papers among them 16 in peer-reviewed journals

Accounts Charged for the Activities

- ~50% accelerator research: beam dynamics and instabilities, FEL physics
- ~50% program support: PEP-II, ILC, LCLS, SEBAR

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Improvement of Machine Optics and Luminosity for PEP-II

Achieved peak luminosity: $1.2 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$, August 15, 2006
 Developed Accurate Online and Offline Models

Comparison of quadrupole strength between LER model and configuration, May 30, 2007

June 12, 2007
A theory of high frequency impedance is developed for various non-axisymmetric geometries such as irises/short collimators in a beam pipe, step-in transitions, step-out transitions, and more complicated transitions of practical importance [PRSTAB 10, 054401 (2007)].

For a flat iris with aperture $2g$ in a flat beam pipe of aperture $2b$, the transverse impedances as functions of $g/b$. 

\begin{align*}
Z_{\perp} &= (\pi^2/2\omega g^2)
\end{align*}

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Impedance & Instabilities in the ILC Damping Rings

- A working group from several departments: PBD, ACD, ASD
- Develop an impedance model and estimate threshold of instabilities, in particular, microwave instability, which may has impact of choice of momentum compaction factor for the damping rings.

![Graph with DR Cavity (scaled Cornell): sigma_z=0.5mm](image)

- Scale = 22.05 V/pC
- Loss Factor = 16.17 V/pC
A new computer code is developed that solves a linearized Vlasov equation in the time domain. The code is implemented in Mathematica; it can be easily modified and augmented.

Growth rate for the CSR induced microwave instability as a function of current.

Phase space of the microwave instability.
• For one overall $P$ and individual $Q$ adjustments, the optimized solution has $q = Q/Q_0$ ($Q_0$ is the matched loaded $Q$) mostly in the range $[1, 2]$

• Optimize gradient of the 26 cavities $\Sigma g_i$ (while keeping boundary conditions) where

$$
g_i = 2\sqrt{Pq_i} \left(1 - e^{-t/q_i}\right) - q_i \left(1 - e^{-(t-t_b \ln 2)/q_i}\right), \quad [t > t_b \ln 2]$$

• 27d optimization $\{q_i, t_b\}$, can be turned into 3d optimization $\{p, t_b, q_{\text{min}}\}$:

For $p = 0.92, t_b = 0.89$, gradient at head and tail of train

- One seed

- Red dots give $(g_{\text{lim}})_i$
Advanced Accelerator Research Department  
At-a-glance (Bob Siemann. Dept Head)

Who We Are

<table>
<thead>
<tr>
<th>Role</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty member</td>
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<tr>
<td>Staff physicists</td>
<td>4</td>
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<tr>
<td>Postdoctoral Associate</td>
<td>1</td>
</tr>
<tr>
<td>Graduate students</td>
<td>4</td>
</tr>
<tr>
<td>Administrative assistant</td>
<td>1</td>
</tr>
</tbody>
</table>

What we do

- Experimental investigation of novel concepts for high-gradient particle acceleration:
  - Beam-driven plasma acceleration
  - Laser-driven dielectric accelerator structures

Publications:

40 since May 2006:
* 34 Conference papers

Graduate Theses since May 2006


Service since May 2006

• Editor of Physical Review Special Topics -- AB
• Technical review committees for Tevatron, SNS
• Reviews of LBNL, BNL, Muon Collider
• SBIR and HEP grant reviews
• Injector Test Facility Task Force Co-chair
• Panofsky Fellowship Committee
• DPB Executive and Education Committees
• Conference session conveners/group leaders for AAC, APS, and DPF
• Conference Committees for AAC, APS, DPF, PAC
• SLAC Liaison to local city government; local science fair judging…

June 12, 2007
Refereed Publications since May 2006

Published


In Preparation


June 12, 2007
Community Service Since May 2006

Eric Colby
- APS-DPB Executive Committee Member-at-large
- 2006 Advanced Accelerator Concepts Workshop Organizing Committee Member and Working Group Leader
- 2007 Particle Accelerator Conference Program Committee Member
- 2007 Director's Review of LBNL Accelerator & Fusion Research Department
- DOE SBIR Proposal Reviewer, 2001 – present
- DOE HENP Grant Renewal Reviewer, 2001 – present
- LCLS Gun Test Facility Task Force Co-leader, 2006 – present
- Panofsky Fellowship Selection Committee Member, 2006
- Member, Accelerator Research Associate Committee, PPA Division
- Member, DOE Office of Independent Oversight Action Item C-2 Response Committee

Mark Hogan
- 2006/2007 Technical Consultant for the DOE Review of the BNL HEP Program
- 2008 Advanced Accelerator Concepts Workshop Organizing Committee Member
- DOE SBIR Proposal Reviewer, 2006/2007
- DOE Grant Proposal Reviewer, 2006/2007
- 2nd SABER Workshop Organizing Committee Member

Rasmus Ischebeck
- 2006 Advanced Accelerator Concepts Workshop Organizing Committee Member and Working Group Leader
- LCLS Design Reviewer, 2006

Robert Noble
- Chair, Accelerator Research Associate Committee, PPA Division
- Referee for Physics of Plasma Journal

Stephanie Santo
- Assistant to the Editor, Physical Review Special Topics - Accelerators and Beams, 2003 – 2007
- AARD Safety Committee Member, 2004 –

Robert Siemann
- Founding Editor, Physical Review Special Topics - Accelerators and Beams, 1998 – 2007
- Chair, Accelerator Systems Advisory Committee of the Spallation Neutron Source, 1998 – 2006
- DOE Tevatron Operations Review, March 2006

James Spencer
- DOE SBIR Proposal Reviewer, 2006
- Physical Review and Physical Review Letters paper referee
- Member, ARD Research Associate Committee
- Judge, Santa Cruz County and Santa Clara Science Fairs
- Member, Accelerator Research Associate Committee, PPA Division
- Member, ETF Committee that assessed SLAC’s commitment to education and outreach with the idea of proposing a broader, more unified program
- Member, SULI selection committee

June 12, 2007
E-163: Laser Acceleration at the NLCTA

E-163 Scientific Goal: Investigate physical and technical issues of laser acceleration using dielectric structures

Build a test facility with high-quality electron and laser beams for advanced accelerator R&D

• Test facility construction completed December 2006
• Accelerator Readiness Review completed December 18th, 2006
• Director’s and DOE Site Office approval to begin operations granted March 1st, 2007
• E163 Beamline commissioning begun March 8th, 2007

First beam to high resolution spectrometer of E163 beamline on March 16th, 2007!

Ce:YAG Crystal Scintillator
Glass graticule (mm)
ICCD 256x1024 camera

Energy

Work supported by Department of Energy contracts DE-AC02-76SF00515 (SLAC) and DE-FG03-97ER41043-II (LEAP).

June 12, 2007
First Laser-Electron Interaction Signature observed on 5/23/07!

- 35 keV modulation from IFEL clearly visible
- Duration (\(\Gamma=1.6\) ps) shows stability of electron & laser beams

Work supported by Department of Energy contracts DE-AC02-76SF00515 (SLAC) and DE-FG03-97ER41043-II (LEAP).
The sub-picosecond timing stability required for laser acceleration experiments has been demonstrated!

June 12, 2007
Linac running all out to deliver compressed 42GeV Electron Bunches to the plasma
Record Energy Gain
Highest Energy Electrons Ever Produced @ SLAC
Significant Advance in Demonstrating Potential of Plasma Accelerators

Some electrons double their energy in 84cm!

Advanced Accelerator Research Department

We are focused on challenging technologies that offer unique capabilities as accelerators

Beam Driven-Plasma Wakes
- Extraordinary gradient
- New Regimes of Beam/Matter Interaction
- THz Generation

Dielectric Laser-Driven Accelerators
- High Gradient
- Photonic Crystals
- Attosecond pulses
- Unparalleled compactness

We combine analytical, computational, and experimental skills to perform interdisciplinary, collaborative research in accelerator physics, plasma physics, and laser science. These diverse aspects make Advanced Accelerator R&D very attractive to students.

Some of the AARD Alumni since 2003

June 12, 2007
ACD will continue to play a major role in DOE computing initiative Scientific Discovery through Advanced Computing (SciDAC) new Community Petascale Project for Accelerator Science and Simulation (COMPASS) project.

Focuses on:

- **Parallel code development** in electromagnetics and beam dynamics for accelerator design, optimization and analysis
- **Application to HEP accelerator projects** such as the International Linear Collider (ILC), LHC, PEP-II, etc…
- **Large-scale parallel simulations** on DOE’s supercomputers at NERSC (Seaborg, Bassi) and NCCS (Phoenix) with 3 allocation awards and petascale simulations in SciDAC2
- **Computational science research** through collaborations with SciDAC CET’s computer scientists and applied mathematicians
- **Multi-disciplinary education and training** of next generation computational scientists (PhD and summer students, USPAS,…)

June 12, 2007
SciDAC Tools for Accelerator Applications

ILC - The suite of codes (Omega3P, S3P, T3P, Track3P, GUN3P) is being applied to the ILC R&D using flagship computers at NERSC and NCCS:

- **Accelerating Cavity (DESY, KEK, JLab)** – TDR, Low-loss, ICHIRO & Superstructure designs
- **Input Coupler (SLAC, LLNL)** – TTFIII multipacting studies
- **Crab Crossing (FNAL/UK)** - Deflecting cavity design
- **Damping RIng (LBNL)** – Impedance calculations
- **L-band Sheet Beam Klystron** – Gun and window modeling

LHC – Beam-beam effects

LCLS RF Gun – Simulation using 2D FEM PIC code

**Support for other SLAC projects** – High gradient structure, photonic crystal accelerator, etc

June 12, 2007
Imperfection Studies for TDR Cavity

- Frequency shift caused by fabrication errors and subsequent application of stiffening rings during the tuning process

TTF module 5: 1st/2nd dipole band meas. data

Hollow: meas.; Solid: omega3p; Ideal cavity; Surface deformed cavity

Fit well!

Wakefields from distorted cavities will be used for Lucretia beam dynamics studies.
MP simulations are carried out in support of ILC test stand at SLAC (LLNL) to study the cause of the TTFIII coupler’s long processing time.
Multipacting in coax of TTFIII Coupler

Cold coax

Track3P Simulation

(F. Wang, C. Adolphsen, et. al)

After high power processing

<table>
<thead>
<tr>
<th>Simulation power (kW)</th>
<th>170~190</th>
<th>230~270</th>
<th>350~390</th>
<th>510~590</th>
<th>830~1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power in Coupler (kW)</td>
<td>43~170</td>
<td>280~340</td>
<td>340~490</td>
<td>530~660</td>
<td>850~1020</td>
</tr>
<tr>
<td>klystron power (kW)</td>
<td>50~200</td>
<td>330~400</td>
<td>400~580</td>
<td>620~780</td>
<td>1000~120</td>
</tr>
</tbody>
</table>

June 12, 2007
Crab Cavity Design for BDS

Improve FNAL design for:

- Better HOM, LOM and SOM damping
- Reduction of HOM notch gap sensitivity (to 0.1 MHz/μm from original 1.6 MHz/μm)
- Elimination of LOM notch filter
- Elimination of SOM twist to avoid x-y coupling

Omega3P damping calculation

Notch gap sensitivity

A copper model is being built in UK lab based on SLAC design.
Trapped modes in ILC cryomodule

ILC cryomodule consisting of 8 TDR cavities

A dipole mode from Omega3P

SciDAC2 petascale computing required to model an entire rf unit consisting of 3 connected cryomodules
• 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.
  – New test setup for inexpensive, accurate characterization of High Power RF properties of materials.

• Ultra High Power RF Components and Systems:
  – Active pulse compression systems and ultra-high-power solid-state devices,
  – Novel low-field fundamental mode RF couplers
  – 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.

• Advanced Concepts for the ILC : fundamental mode couplers, RF distribution, fast kickers.

• Advanced Electronics:
  – Instability control formalism and machine diagnostics for accelerators and light sources.
  – Next-generation reconfigurable signal processing (demonstrated at KEK, PEP-II, and Dafne)

June 12, 2007
Proposed an Improved Alternative Structure Design for Positron Source with Mechanical Simplicity, Effective Cooling and Lower Pulsed Heating:

- Capture sections: Simple $\pi$ mode short SW sections.
- Pre-Acceleration: High phase advance TW structures.

- **125 MeV**
  - **0.5T Solenoids**
  - **3 x 4.3m TW Sections**

- **400 MeV**
  - **8 x 4.3m TW Sections**
  - **0.5T Solenoids**

**Welding Cooling System**

**LCLS Injector Gun**

**RF Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_\pi$ (MHz)</td>
<td>2856 MHz at 35°C</td>
<td>2856 MHz at 36.2°C</td>
</tr>
<tr>
<td>Q0</td>
<td>13960</td>
<td>14062</td>
</tr>
<tr>
<td>$\beta$</td>
<td>2.1</td>
<td>2.03</td>
</tr>
<tr>
<td>Mode Sep. $\Delta f$ (MHz)</td>
<td>15</td>
<td>15.17</td>
</tr>
<tr>
<td>Field Balance</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Design of S-band Standing Wave Deflector for Production of ps X-ray Pulses at Argonne APS

- Four structures will produce 4 MeV initial kick and 4 MeV recovery kick if powered by one 20 MW klystron. Set of two structures will occupy less than 50 cm of beam space.
- Low-order- and high-order- modes are loaded by 6 ridged and 4 rectangular waveguides with internal broadband loads.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.815 GHz</td>
</tr>
<tr>
<td>Deflecting voltage</td>
<td>2 MV per structure</td>
</tr>
<tr>
<td>Available power</td>
<td>4 MW per structure</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>(~1000) Hz</td>
</tr>
</tbody>
</table>

Surface electric field for 2 MeV kick, maximum surface electric fields 60 MV/m
Accelerator Dynamics and Control, High Speed Instrumentation and Technology Development.

- Major Activities in 2006/2007
  - **PEP-II High Current Instability Studies**
    - Coupled-bunch studies (HOM driven instabilities), tuning/configurations of LFB and LLRF systems.
    - Instability Studies at LNF-INFN, KEKB, ATF.
  - **RF-Beam Dynamics, RF system stability modeling.**
    - Development of nonlinear LLRF model –
      Quantification of PEP-II Limits.
    - Development of new control techniques, intermodulation distortion control.
Accelerator Dynamics and Control, High Speed Instrumentation and Technology Development.

- **Technology Development**
  - iGp (500MS/sec instability control) – in use at PEP-II, KEKB, LNF-INFN.
  - Gboard Technology development – Next generation 1.5 GS/sec reconfigurable processor.
  - LCLS X-Band Instrumentation
  - LCLS RF Gun temperature control dynamics modeling.

- **Publications**
  - Conference papers (EPAC, DIPAC and PAC), Journal papers, Internal MAC reviews.

- **Teaching**
  - Applied Physics, US Particle Accelerator School.

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**Klystron driver amplifier characteristics**

**ATF longitudinal studies**
Test Facilities for the High Gradient Collaboration

From The two Klystrons (2 x 50 MW)

• Unique ultra-high power X-band testing facilities
• Over-moded test cavities for material characterizations: pulsed heating at room temperature and quenching fields at cryogenic temperatures

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High power tests at X-band which was performed during the last few month

- Molybdenum CERN structure
- Copper CERN Structure
- Old NLC structures
- Single Cell traveling wave structures
- ANL dielectric structure
- Semiconductor (si) breakdown test
- Superconducting Material Test
- Single Cell Standing wave accelerator structure
- CERN’s Pulsed heating
Standing-Wave Structure Result Summary at Repetition Rate of 60 Hz (a/l~0.21)

- Breakdown rate [#/hour] vs. Gradient [MV/m]
- Data points for 50 ns, 70 ns, and 90 ns

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Summary of Structure Testing Results

• Standing wave structure > 100 MV/m for very low breakdown rate at 90 flat pulse width after the filling time (equivalent 180 ns for TW structures) \( a/\lambda \sim 0.21 \)

• H75vg4S18, it is < unity at 94 MV/m with 150 ns pulses. \( a/\lambda \sim 0.17 \)

• T53VG3MC, it is < unity at 100 MV/m with 150 ns pulses. \( a/\lambda \sim 0.13 \)

June 12, 2007
Klystron Department (Chris Pearson Dept Head)
RF and Electrical Design

ILC SBK Development

HV Seal

Focus Electrode

Cavity Coupling Antenna

Focusing PPM Structure

June 12, 2007
Objectives

- Develop high average power 95 GHz RF source
- Validate sheet beam klystron concepts (beam formation, beam transport and RF stability) in an inexpensive vehicle
- Validate 3-D simulation codes for sheet beam klystrons
- Prototype tube built and tested – validated beam formation, beam transport, zero-drive stability and small signal gain predictions
- Full power tube nearly complete – testing to begin in July 2007
- Specifications - 50 kW peak power, 2.5 kW average power, 74 kV, 3.6 A
- Beam size 6 mm x 0.5 mm

Fabrication and Test

- Prototype tube built and tested – validated beam formation, beam transport, zero-drive stability and small signal gain predictions
- Full power tube nearly complete – testing to begin in July 2007
- Specifications - 50 kW peak power, 2.5 kW average power, 74 kV, 3.6 A
- Beam size 6 mm x 0.5 mm

One half of the eight cavity RF circuit for WSBK. Circuit halves are diffusion bonded. Multi-gap cavities increase impedance and lower electric fields in output cavity.
Surface and Materials Science Department R&D
(Bob Kirby Dept. Head)

RF Gun Photocathodes:
- Development of in-gun cleaning of rf copper photocathodes, using hydrogen-ion bombardment and thermal gas desorption techniques.
- Qualification for photo-quantum efficiency (QE) of copper photocathodes for LCLS injector guns.
- Deposition of oxidation-resistant higher QE, low-emittance cathode materials (e.g., CsBr) onto existing copper gun cathode surfaces.

Electron Cloud Instability:
- Secondary electron yield and surface chemistry measurements on beam chamber materials, leading to coatings (TiN and NEG) that suppress the electron cloud effect.
- Suppression of secondary electron emission in LER Al beam chambers by using electron-trapping grooved surfaces. Installed extruded-grooved chambers into LER.
Copper Photo-Cathodes

- Lab system for testing LCLS cathodes
  - cathode cleaning (H$^+$ ion bombardment)
  - measure QE, chemistry (XPS)
  - deposit higher QE overlayer (e.g., CsBr)

Copper cathode QE and work function change with H$^+$ ion-cleaning dose

June 12, 2007
Accelerator Research at SLAC

- Push the envelope of operating accelerators
  - PEP-II + flavor factories world wide—all operating facilities
- Research in Beam Physics and Development of Accelerator Technology and for next generation facilities.
  - ILC
  - Future Multi-TeV Linear Colliders—High Gradient Research
- Push the state of the art in computational tools
  - To bridge the gap between theory and technology
- Explore Advanced Accelerator Research
  - Laser Acceleration
  - Plasma Acceleration
- Exploit unique facilities for Accelerator Research
  - Final Focus Test Beam (SABER)
  - NLC Test Accelerator (NLCTA)
- SLAC provides
  - Accelerator Science leadership though its outstanding faculty and staff.
  - A unique facility infrastructure
  - A unique technical development environment.
  - Integrates of all aspects of accelerator physics and technology
  - Develops the accelerator-based foundation for particle physics and photon science

June 12, 2007