2009 SLUO Annual Meeting

SLAC Science Opportunities and Future Directions

David MacFarlane

Associate Laboratory Director for PPA
SLAC Mission

Explore the ultimate structure and dynamics of matter in the domains of energy, space, and time—at the smallest and largest scales, in the fastest processes, and at the highest energies.
Turn-on in 2009: LCLS will be the World's First X-ray Laser

LCLS: Linac Coherent Light Source

SLAC Science Programs
SLAC Science Programs

Structure of RNA polymerase

Stanford Synchrotron Radiation Laboratory (SSRL)

3rd generation synchrotron light source for investigation of matter at atomic and molecular scales
Linac Coherent Light Source (LCLS)

World's first x-ray FEL: probing the ultra-small, capturing the ultra-fast

LCLS Ultrafast Science Instruments (LUSI)
Turn-on in 2009: LCLS will be the World’s First X-ray Laser

LCLS: Linac Coherent Light Source

SLAC Science Programs

Injector at 2-km point

Existing 1/3 Linac (1 km) (with modifications)

New e− Transfer Line (340 m)

X-ray Transport Line (200 m)

Undulator (130 m)

Near Experiment Hall (underground)

Far Experiment Hall (underground)

X-Ray Transport/Optics/Diagnostics
LCLS: World’s first hard x-ray FEL

• Free electron laser
  – 0.8-8 keV energies
  – $10^{12}$ photons/pulse
  – $\sim 100 \rightarrow \sim 2$ fs
  – Coherent

• Study structure (nm) and dynamics (fs) in materials
  – Collect a scattering pattern in one shot
  – Characteristic time for formation/breaking of molecular bonds
  – Watch chemical processes unfold in real time

April 11: Lasing at 0.15nm after inserting 12/33 undulators
SLAC Science Programs

SLAC-Stanford Institutes for ultrafast structural and electronic dynamics, and key challenges in condensed matter physics and materials science

Photon Science

PULSE Institute for Ultrafast Energy Science

Stanford Institute for Materials & Energy Science (SIMES)
LCLS: The first experiments

Near Experimental Hall

- AMO
- SXR
- XPP

Femtochemistry

- $t_0$
- $t_1$
- $t_2$
- $t_3$
- $t_4$
- $t_5$
- 1 as

Aluminum plasma

Nanoscale Dynamics in Condensed Matter

X-ray Transport Tunnel
200 m

Atomic Physics

Plasma & Warm Dense Matter

Structural Studies on Single Particles and Biomolecules

Start of commissioning, early operations

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Start of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMO</td>
<td>09-09</td>
</tr>
<tr>
<td>SXR</td>
<td>04-10</td>
</tr>
<tr>
<td>XPP</td>
<td>10-10</td>
</tr>
<tr>
<td>CXI</td>
<td>08-11</td>
</tr>
<tr>
<td>XCS</td>
<td>08-11</td>
</tr>
<tr>
<td>MEC</td>
<td>08-13</td>
</tr>
</tbody>
</table>

Tentative instrument operation scheme

Far Experimental Hall

X-ray Laser Physics

CXI
XCS
MEC
Ne^{\text{10+}} from focused LCLS x-ray beam

Time-of-flight mass spectrum of charge states of Ne at ten different LCLS pulse energies, for 2keV x-rays.

Ne^{\text{10+}} requires fluences > \(10^{20}\) photons/cm\(^2\)
Future light sources for the West Coast

- The Challenge: Atomic resolution in energy (meV), space (nm), and time (fs)
  - Need both FELs & CW ring-based machines

- Coordinating strategy with LBNL to address the challenge
  - Goal is to offer full suite of capability to the west coast

- SLAC pieces of the strategy
  - Upgrade the LCLS to extend energy range adding capability and capacity
  - PEP-X: Ultra-bright CW source with nm spatial resolution and meV energy resolution

- Why west coast
  - Unmatched combination of intellectual and technical capability and capacity between LBNL and SLAC in coordinated approach
SLAC Science Missions

Particle Physics & Astrophysics (PPA)

Investigation of the ultimate structure of matter and the forces between these fundamental particles

Kavli Institute for Particle Astrophysics & Cosmology (KIPAC)
Accelerator research:
ILC, high-gradient, plasma-wakefield, laser

Accelerator-based particle physics:
ATLAS & BABAR

Nonaccelerator physics:
EXO-200, CDMS

Astrophysics & Cosmology:
Fermi GST, DES
Current HEP activities & areas of excellence

- Accelerator-based particle physics:
  - Facilitating full exploitation of the unique B Factory dataset
  - Playing a growing role in ATLAS & LHC accelerator
- Leading particle-astrophysics and cosmology:
  - Operating the Fermi Gamma-Ray Space Telescope and continue scientific discoveries with this unique observatory
- World-class accelerator research program:
  - Playing enabling role in technology development for the ILC and leading high-gradient X-band research in the US
- World-leading theoretical programs in particle physics and particle astrophysics and cosmology
- Expertise at the frontiers of detector R&D
  - Device development, end-to-end electronics system architecture and design, & high-performance DAQ system architecture and design
The new gamma-ray sky from Fermi
Fermi-LAT $e^+ + e^-$ spectrum
Searches for New Physics at BABAR

Constraints on Next-to-Minimal Supersymmetric Models: Light Higgs limits

\( A^0 = \) mixing of a singlet with MSSM-like Higgs
= A-MSSM \( \cos \theta_A \) + A-singlet \( \sin \theta_A \)

\( A^0 \) detectable in \( \Upsilon(2,3S) \rightarrow A^0 \gamma \)

\[ A^0 \rightarrow \mu^+\mu^- \quad A^0 \rightarrow \tau^+\tau^- \quad A^0 \rightarrow \text{invisible} \]

- BR(\( \Upsilon \rightarrow \gamma A^0 \))
  - \( 10^{-3} \)
  - \( 10^{-4} \)
  - \( 10^{-5} \)
  - \( 10^{-6} \)
  - \( 10^{-7} \)
- non-singlet fraction \( \cos \theta_A \)
- \( M(A^0) < 2M(\tau) \)
- \( 2M(\tau) < M(A^0) < 7.5 \text{ GeV} \)
- \( 7.5 \text{ GeV} < M(A^0) < 8.8 \text{ GeV} \)
- \( 8.8 \text{ GeV} < M(A^0) < 9.2 \text{ GeV} \)
Science Directions

- Expanding discovery reach
- Future energy frontier facilities
- Higgs, SUSY, discovery physics
- Properties of new physics
- Accelerator research: ILC, high-gradient, plasma-wakefield, laser
- Accelerator-based particle physics: ATLAS & BABAR
- Non-acCELERator physics: EXO-200, CDMS
- Astrophysics & Cosmology: Fermi GST, DES
- Nature of the neutrino
- Direct dark matter searches
- Dark matter, AGNs
- Dark matter & dark energy
- Inflation, cosmic rays
Future Experimental Tools

- Linear Collider, Project-X
- ATLAS upgrades
- SiD, SuperB
- LHC upgrades

Accelerator-based particle physics:
- ATLAS & BABAR

Non-accelerator physics:
- EXO-200, CDMS
- SuperCDMS, GeODM

Astrophysics & Cosmology:
- Fermi GST, DES

- NeXT, PoGO
- LSST, JDEM
- CMB, AGIS
- EXO

Accelerator research:
- ILC, high-gradient, plasma-wakefield, laser
Investments in future HEP programs

- Expand energy frontier program at LHC and ultimately a future LC
  - Major role in the upgrade of the ATLAS detector and the LHC machine
  - Enhance ATLAS computing for physics exploitation of the LHC data
- Lead US involvement in offshore SuperB Factory at the intensity frontier
- Expand role as a leading center in particle astrophysics and cosmology
  - Construct and operate LSST for cosmology and dark energy studies
  - Develop next generation non-accelerator experiments for neutrinoless double beta decay (EXO) and dark matter searches (SuperCMDS)
- Expand frontiers of long-range accelerator research
  - Enable forefront experiments in beam-driven plasma wakefield acceleration for next generation ultra high-gradients with unique FACET facility
  - Perform state of the art experiments in laser dielectric acceleration and develop high power X-band rf sources
- Expand R&D efforts to enable longer-range future programs such as SiD, SuperB, SuperCDMS/GeoDM, and AGIS
  - Pursue forefront device development, electronics, and DAQ R&D
Major Changes

- Jo Stohr named LCLS ALD as of July 1
- Piero Pianetta named SSRL ALD (Acting) as of July 1
- LCLS, Sector 0-20, & SSRL Accelerator Operations moves into Accelerator Directorate (AD)
- ETS is absorbed into Accelerator Directorate (AD)
- Accelerator Research Division moves from PPA into AD
Why reorganize accelerator activities?

• Our accelerator skills are widely spread across SLAC
  – Need to consolidate, optimize and focus our accelerator core competency for the benefit of the lab as a whole and our shared long term vision
  – Need to appropriately balance near/mid/long term priorities
• Accelerator Research and Operations will be enhanced by being tied more closely together
  – Both performance of current programs will benefit and ties to future science drivers will be improved
• Not all aspects of operations are being managed with the same rigor
  – We can create a more uniform conduct of operations everywhere, with uniform standards and a broader environment for career development
• We take our role as a “National Accelerator Laboratory” seriously
  – Accelerator infrastructure must be managed to optimally support science long-term in a sustainable fashion
AD Organization Chart

Dale Knutson (Acting)
Associate Laboratory Director

Bob Hettel, Deputy
John Seeman, Deputy

SPEAR 3*
Program Division
John Schmerge

LCLS*
Program Division
David Schultz

Sector 0-20
& FACET*
Program Division
Uli Wienands

Accelerator Research
Division
Tor Raubenheimer
Nan Phinney, HEP Deputy
Paul Emma, LCLS Deputy

Strategic
Projects Division
John Galayda

Accelerator
Engineering Division
Karen Fant

Accelerator
Operations & Safety
Division
Roger Erickson

Business
Office
Cindy Lowe (Acting)

*Matrixed to Research Program Leadership as Needed
This is a functional as well as an administrative organization chart. Some names appear in more than one location. Not to be used for headcount purposes.

Not reflected:
1. Department Associates
2. Visiting Physicists
3. Student Research Assistants on a rotating schedule

Personnel matrixed from Accelerator Directorate
Summary

- Photon science
  - World’s first x-ray FEL coming online, with great promise to open up new regimes in the ultra-fast and ultra-small world
  - Developing ambitious plans, together with LBNL, for the next generation of west coast light sources

- Particle physics and astrophysics
  - Fundamental questions confronting us are more compelling than ever with new frontier facilities coming online
  - Toolkit includes satellites, surface observatories, underground experiments, and accelerator-based collider experiments
  - Ambitions to expand energy frontier program, further develop our leading particle astrophysics center, and expand the frontiers of accelerator research
Rich science opportunities and a rich toolkit
Backup
Fundamental Questions

• What are the ultimate Laws of Nature?
  – Are there new forces, beyond what we see today? Do the forces unify? At what scale? Why is gravity so different from the other forces?
  – What lies beyond the quarks and leptons? What completes the Standard Model? How do the neutrinos fit in the picture?

• What is the structure of space and time?
  – Why are there four spacetime dimensions? Are there more? What are their shapes and sizes? What is the quantum theory of gravity?
  – What is the state of the vacuum? What is the origin of mass?

• How did the Universe come to be?
  – What is the dark matter and dark energy? What happened to antimatter? What powered the big bang?
  – What is the fate of the Universe?
X-Rays for the ultra-small -- realm of storage rings

X-Ray lasers for the ultra-small & ultra-fast -- realm of LCLS

The size of things

The Microworld

Flea

blood cells

1 mm

100 μm

10 μm

10 μm

1 μm

The Nanoworld

proteins

water molecule

1 nm

10 nm

100 nm

disk bits

1 μm

10^{-3} m

1 mm

10^{-6} m

1 μm

10^{-9} m

1 nm

The speed of things

macro-molecule motion

molecular group motion

water dissociation

10^{-6} s

1 μs

10^{-9} s

1 ns

10^{-12} s

1 ps

"bit" processing time

camera shutter speed

SSRL

THE ULTRAFAST TECHNOLOGY

VOID

LCLS
“Experiments at the AMO beamline (0.8-2 keV)”

28 proposals were received with 219 scientists from 16 countries involved, many of them in more than one.

<table>
<thead>
<tr>
<th>Scientists</th>
<th>Proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>4</td>
</tr>
<tr>
<td>China</td>
<td>2</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>4</td>
</tr>
<tr>
<td>Denmark</td>
<td>1</td>
</tr>
<tr>
<td>Finland</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>1</td>
</tr>
<tr>
<td>Germany</td>
<td>70</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scientists</th>
<th>Proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ireland</td>
<td>1</td>
</tr>
<tr>
<td>Italy</td>
<td>8</td>
</tr>
<tr>
<td>Japan</td>
<td>6</td>
</tr>
<tr>
<td>Netherlands</td>
<td>4</td>
</tr>
<tr>
<td>Poland</td>
<td>3</td>
</tr>
<tr>
<td>Sweden</td>
<td>26</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1</td>
</tr>
<tr>
<td>United States</td>
<td>83</td>
</tr>
</tbody>
</table>

- Half of the proposals were motivated by single particle imaging.
- 21 proposals want to use the AMO station as built, 5 proposals want to use a special chamber built in Hamburg and moved to LCLS for the experiments, 2 proposals want to use very special chambers which the groups will provide.
“Experiments at the AMO and SXR beamlines (0.8-2 keV)”

62 proposals were received with 469 scientists from 15 countries involved, many of them in more than one.

<table>
<thead>
<tr>
<th>Scientists</th>
<th>Proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>5</td>
</tr>
<tr>
<td>Canada</td>
<td>1</td>
</tr>
<tr>
<td>Denmark</td>
<td>1</td>
</tr>
<tr>
<td>Finland</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>33</td>
</tr>
<tr>
<td>Germany</td>
<td>118</td>
</tr>
<tr>
<td>India</td>
<td>3</td>
</tr>
<tr>
<td>Ireland</td>
<td>4</td>
</tr>
<tr>
<td>Italy</td>
<td>20</td>
</tr>
<tr>
<td>Japan</td>
<td>9</td>
</tr>
<tr>
<td>Netherlands</td>
<td>5</td>
</tr>
<tr>
<td>Sweden</td>
<td>42</td>
</tr>
<tr>
<td>Switzerland</td>
<td>9</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>41</td>
</tr>
<tr>
<td>United States</td>
<td>177</td>
</tr>
</tbody>
</table>

- 24 proposals want to use the AMO, 38 proposals the SXR beamline.
- At the AMO beamline, 15 proposals want to use the AMO instrument as built by LCLS, 9 proposals want to use the CAMP chamber built by CFEL in Hamburg.
- At the SXR beamline, experimental stations will be provided by members of the SXR Consortium and used in collaboration with these groups. More specific, 11 of the proposals want to use the CAMP chamber.