Synchrotron Radiation Science at SLAC
Joachim Stohr, SSRL Deputy Director
July 6, 2004
The Big Picture: SSRL Strategic Vision

- 3 GeV synchrotron radiation source, jointly funded by NIH and DOE
- 7-month installation complete (on time and within budget) – first commissioning phase also complete - user program resumed (March, 2004)
- Expansion capacity for new beam lines – 7 ID and 14 bends

- Experiments begun in 2003 using SLAC linac. Added bunch compressor and undulator to produce 80 fsec x-ray pulses
- Stepping stone towards LCLS. High brightness, short pulses. Strong synergy between accelerator and photon science

- World’s first x-ray FEL - in 2nd year of PED funding $54M in FY2005 President’s budget
- Substantial expansion capabilities, both performance and capacity
SPEAR3 – removal of old and installation of new
**SPEAR3 - What are the Science Opportunities and Drivers?**

- Serves an already established, productive and growing user community
  - 2052 users on 400 active proposals at beginning of SPEAR3 operations in March, 2004
  - Operates primarily a support-oriented, general user facility

- Enables world class science in both materials/chemistry and in biology (NIH investment)
  - Structure and properties of materials with **nanoscale** dimensions (brightness)

- Significant expansion capacity

<table>
<thead>
<tr>
<th>Facilities and Capabilities</th>
<th>Chemistry &amp; Environmental Sciences</th>
<th>Materials Science &amp; Condensed Matter Physics</th>
<th>Structural Biology</th>
<th>Accelerator Science and Technology</th>
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</thead>
<tbody>
<tr>
<td>SPEAR3</td>
<td>Average-brightness-driven experiments</td>
<td>Crystal and surface structures, electronic and magnetic properties of nano-scale materials</td>
<td>Very large, complex assemblies — atomic resolution protein structures</td>
<td>Superconducting insertion devices</td>
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<td>Improved time resolution (&gt;100 ps)</td>
<td>Electronic and structural speciation at nm → µm length scale of chemical and environmental systems</td>
<td>Equilibrium dynamics, ms → µs</td>
<td>Microcrystals; intermediates</td>
<td>Enhanced beam stabilization</td>
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<td>Coherence</td>
<td>Structural studies on nano-crystals</td>
<td>Non-equilibrium (pump-probe) dynamics (&gt;150 ps)</td>
<td>Solution structure/changes, sub-ms time scale</td>
<td>High-current accelerator technology</td>
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<td>Coherent imaging</td>
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<td>Spectromicroscopy, nm → µm length scale</td>
<td>Enhanced accelerator performance characterization and control</td>
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**SPEAR3 – Beam Lines and Expansion Capacity**

**Existing Complement of Beam Lines**
- 31 experimental stations on 11 beam lines (4 bend and 7 ID)

**New Beam Lines**
- SPEAR3 – space for up to 14 new bend and 7 new ID lines
- First two new ID beam lines funded
  - BL12: Hard x-ray in-vacuum undulator beam line for macro-molecular crystallography funded by Moore gift to Caltech ($12.4M of which comes to SSRL) – opns. Q1/07
  - BL13: Soft x-ray variable polarization undulator beam line for speckle, microscopy and spectroscopy on nanoscale materials - funded by DOE-BES – opns. Q4/06

**Near Term Opportunities**
- 6 m East Pit straight - double waist chicane for
  - 2 ea ID BL w/ small gap undulators
- 2 ea 3.8 m matching straights
- 2 ea 2.3 m standard straights
- 3 ea bend magnet source points
Numbers of Light Source Users (ALS, APS, NSLS and SSRL) by Discipline

User Profile by Discipline of Experiments

The number of researchers using the light sources is expected to reach \(>>10,000\) annually when beamlines are fully instrumented.

Who funds the light sources?

The Basic Energy Sciences program provides complete support for the operations of the facilities. Furthermore, BES continues as the dominant supporter of research in the physical sciences, providing as much as 85% of all federal funds for beamlines, instruments, and PI support. Many other agencies, industries, and private sponsors provide support for instrumentation and research in specialized areas such as protein crystallography.
Toward X-Ray Lasers:

Time structure
Number of photons/pulse
Coherence
X-Rays have opened the Ultra-Small World

X-FELs open the Ultra-Small and Ultra-Fast Worlds

**Ultra-Small**

- **Nature**
  - Flea
  - Human hair ~30 μm wide
  - Red blood cells & white cell ~5 μm
  - Virus ~200 nm
  - DNA helix ~3 nm width
  - Water molecule
  - Atom

- **Technology**
  - Head of a pin ~1 mm
  - DVD track
  - 1 μm Electrodes connected with nanotubes
  - Carbon nanotube ~2 nm diameter
  - Atomic coral ~14 nm diameter

**Ultra-Fast**

- **Nature**
  - Hydrogen transfer time in molecules is ~1 ns
  - Spin precesses in 1 Tesla field is 10 ps
  - Shock wave propagates by 1 atom in ~100 fs
  - Water dissociates in ~10 fs
  - Bohr period of valence electron is ~1 fs

- **Technology**
  - Computing time per bit is ~1 ns
  - Optical network switching time per bit is ~100 ps
  - Magnetic recording time per bit is ~2 ns
  - Shortest laser pulse
Science

The length of probe pulses:

- $10^{-9}$ s - 1 ns
- $10^{-12}$ s - 1 ps
- $10^{-15}$ s - 1 fs
- 3rd gen. synchrotron, X-rays, LINAC, X-Ray Lasers
- Shortest laser pulse

Technology

- Computing time per bit
- Magnetic recording time per bit
- Optical network switching time per bit is ~ 100 ps
Growth of X-Ray Brightness and Magnetic Storage Density

Free electron lasers

We are here

each pulse: $10^{12}$ photons < 100 fs coherent
A Perspective on XFEL Development - 2002-2012

2002-2006
Short pulse studies
Beam dynamics
X-ray science (non-FEL)

SPPS
80 fsec FWHM
X-ray Pulses

~8 keV

> 800 eV

~2012
European XFEL

2003-2007
Seeding, harmonic generation,
softer x-ray FEL science

< 200 eV

2008

~2012

80 fsec FWHM
X-ray Pulses

~1 Å

TESLA FEL
SPPS uses ultrashort electron pulses generated in linac by compression with an added chicane.

Added undulator in FFTB produces ultrashort x-ray pulses with high peak brightness.

First opportunity in the world to do science with high brightness, short pulse x-rays – a step toward LCLS.
Electro-Optical Sampling

200 µm ZnTe crystal

Ti:s laser

$e^-$ temporal information is encoded on transverse profile of laser beam

Adrian Cavalieri et al., U. Mich.
LCLS – a New Dimension in X-ray Science

**Schedule**

- **FY2005** Long-lead purchases for injector, undulator
- **FY2006** Construction begins
- **FY2007** FEL Commissioning begins
- September 2008 *Construction complete – operation begins*

**Technical risks well understood – LCLS is ready for construction start**

**Utilizes existing infrastructure (SLAC Linac) and talent/resources at SLAC, ANL, LLNL, and UCLA to build in a cost effective and very timely manner.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>2001</td>
<td>CD-0</td>
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<tr>
<td>2002</td>
<td>CD-1</td>
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<tr>
<td>2003</td>
<td>CD-2a</td>
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<tr>
<td>2004</td>
<td>Title I Design Complete</td>
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<tr>
<td>2005</td>
<td>CD-3b</td>
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<tr>
<td>2006</td>
<td>XFEL Commissioning</td>
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<td>2007</td>
<td>Construction</td>
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<td>2008</td>
<td>Operation</td>
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<td>2009</td>
<td>Critical Decisions Approved</td>
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CD-4
LCLS - a Future with Higher Performance and Capacity

- LCLS conventional facilities and infrastructure being designed with future expansion capabilities in mind – space for 8 or more additional undulator lines, each serving multiple stations fanning out on either side of the first-phase LCLS complex.

- The SLAC linac can already accelerate macropulses containing up to ~60 electron bunches at 120 Hz, if a high repetition rate gun is added. This makes it possible to serve multiple beam lines at high average brightness. In the future, even higher bunch density trains are possible by making use of the full SLAC linac.

- Several technical approaches are being developed to provide for ultrafast x-ray photon pulses (as short as around 1 fsec or even into the attosec regime). Higher energy electron beams can provide higher photon energies. Seeding can be implemented for enhanced temporal coherence and intensity control.
Under ground
The Stanford Ultrafast Science Center at SLAC

- Proposal submitted to DOE in May 04
- Will share LCLS building in 2007
- Ultimately ~ M$ 10 / year
- Based on x-ray and electron beams
- Stanford faculty led
The use of ultrafast electron beams

Need dedicated access to e-beams!
The Ultimate Speed of Magnetic Switching

$t_{\text{pulse}} = 3 \text{ ps}$

Deterministic switching

$t_{\text{pulse}} = 100 \text{ fs}$

Chaotic switching

Under ultrafast excitation the magnetization fractures!
And All This is Only Possible with Strong Support of . . .

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LCLS Collaborating Institutions