The AMO Instrument & Science Drivers
John Bozek, LCLS

- Photon beam parameters
- Sample source
- Spectrometers
- Diagnostics
- Laser
- Layout
LCLS Soft x-rays: 825 – 2000 eV

Low energy limit is determined by the accelerator design

- 6 MeV
  - $\sigma_z \approx 0.83$ mm
  - $\sigma_\delta \approx 0.05$ %

- 135 MeV
  - $\sigma_z \approx 0.83$ mm
  - $\sigma_\delta \approx 0.10$ %

- 250 MeV
  - $\sigma_z \approx 0.19$ mm
  - $\sigma_\delta \approx 1.6$ %

- 4.30 GeV
  - $\sigma_z \approx 0.022$ mm
  - $\sigma_\delta \approx 0.71$ %

- 13.6 GeV
  - $\sigma_z \approx 0.022$ mm
  - $\sigma_\delta \approx 0.01$ %
LCLS Soft x-rays: 825 – 2000 eV

- High energy cut-off by the deflecting optics

15 mrad incidence angle, B₄C coating:

[Graphs showing reflectance vs. photon energy]
## Unique properties of LCLS radiation

<table>
<thead>
<tr>
<th>Property</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon Energy</td>
<td>825 eV</td>
<td>8250 eV</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>120 Hz</td>
<td>120 Hz</td>
</tr>
<tr>
<td>Photons per pulse</td>
<td>$10^{13}$</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Pulse duration (rms)</td>
<td>137 fs</td>
<td>73 fs</td>
</tr>
<tr>
<td>Beam divergence</td>
<td>5.7 $\mu$rad</td>
<td>0.8 $\mu$rad</td>
</tr>
<tr>
<td>1\textsuperscript{st} harmonic bandwidth</td>
<td>0.07%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Peak power in 1\textsuperscript{st} harmonic</td>
<td>5 GW</td>
<td>8 GW</td>
</tr>
</tbody>
</table>
AMO studies fundamental interactions

Through years of investigation, we have a pretty good idea what happens when we hit an atom with an x-ray?

- Consider Ne atoms and ~1keV photons
Ne 1s photoabsorption

Y. Saitoh et al, Spring-8 BL25SU web site
Ne 1s photoelectron spectroscopy

Ne KVV Auger

Ne KVV x-ray emission

What happens when we illuminate atoms with high peak power of LCLS?

- Multiple ionization
- Multiphoton ionization
- Tunneling ionization
- Subsequent de-excitation dynamics
Scientific Goals of the AMO instrumentation

- Investigate multiphoton and high-field x-ray processes in atoms, molecules and clusters
  - Multi-photon ionization/excitation in atoms/molecules/clusters
  - Accessible intensity on verge of high-field regime
- Study time-resolved phenomena in atoms, molecules and clusters using ultrafast x-rays
  - Inner-shell side band experiments
  - Photoionization of aligned molecules
  - Temporal evolution of state-prepared systems
AMO Instrument – Experimental Facilities

- Optics
- High Field Physics Chamber
  - Gas jet
  - Electron TOFs
  - Ion spectrometers
  - X-ray spectrometers
  - Chamber, shielding, pumping, shutter, etc
- Diagnostics Chamber
  - Magnetic bottle electron spectrometer
  - Beam screens
  - Pulse energy monitor
  - Pulse picker
AMO Instrumentation - Schematic

AMO Instrument Schematic (JDB 04/01/08)

Legend:
- Gas valve
- In-line valve for ion/mass and gas lines
- High vacuum gauge (cold cathode)
- Ion vacuum gauge (bonnita)
- X-rayqed camera
- 120 Hz camera
- SNL beam stop
- YAG crystal
- In vacuum laser mirror
- Gas laser analyzer

June 2-3, 2008
AMO Proposal Workshop

John Bozek
JDBozek@SLAC.Stanford.edu
AMO Instrument Design – focusing optics

- Peak intensity depends on size of beam focus – accessible physics depends on intensity

- Interaction region ~140m from source
- Source @ 825 eV - 116μm
- Divergence @ 825eV - 5.7μrad
- Unfocussed beam diameter ~1.1mm
- Focusing optics ~1m from interaction region

<table>
<thead>
<tr>
<th>Focus</th>
<th>W/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1mm</td>
<td>7×10^{12}</td>
</tr>
<tr>
<td>100μm</td>
<td>7×10^{14}</td>
</tr>
<tr>
<td>10 μm</td>
<td>7×10^{16}</td>
</tr>
<tr>
<td>1 μm</td>
<td>7×10^{18}</td>
</tr>
<tr>
<td>100nm</td>
<td>7×10^{20}</td>
</tr>
</tbody>
</table>
Focusing Optics – Elliptical Bender

Side shaping required to achieve best shape

Images courtesy of Alexis Smith & YiDe Chuang, LBNL
Focusing Optics – Elliptical Bender

Optics can be reshaped for 2nd focus 1m downstream with slight increase in slope error

Images courtesy of YiDe Chuang, LBNL
Focusing Optics – Surface Coatings

- B4C has good reflectivity up to ~ 2000eV and can withstand intense LCLS beam
- Also good rejection of higher harmonics
  - ~10% reflectivity at 2475eV
  - Five mirrors between source and sample – 66% transmission at 825 eV & $1 \cdot 10^{-5}$ transmission at 2475

![Reflectivity graph](image-url)
Focusing Optics – Surface Coatings

- Regina Soufli @ LLNL has been working on methodology to achieve smooth B4C coatings – slower deposition
- Increased surface stress, however, which may result in delamination
Focusing Optics – Surface Coatings

- Compromise position at 10mTorr sputter pressure
  5-7Å roughness but much lower stress in film

Roughness of ~10Å does not appreciably decrease reflectivity at 2000eV

![Graph showing reflectivity vs. surface roughness](image-url)
Focusing Optics – Mechanical Design
Experimental station - Gas jet

- **Pulsed valve** – type described by Proch & Trickl, Rev. Sci. Instrum. 60, 713 (1989)
Experimental station - Gas jet

Pulsed valve assembly

- Gas supply
- XYZ stages
- Electrical feed through
- Pulsed valve
Experimental station – Pulsed Gas Jet
Experimental station - Gas jet

- Multiple skimmers configuration
- Intermediate chambers
- Gas jet chamber
- Turbo pumps
- Interaction region
- X ray beam
High Field Physics – Ion Spectrometers

- Three different types of Ion Spectrometer
  - Time-of-flight spectrometer – using integrating metallic anode
  - Velocity map imaging spectrometer – using a phosphor screen to image impact location of ions
  - Momentum resolving spectrometer – using a delay line anode to measure position and time of ion impact
High Field Physics – Ion Spectrometers

- Ion spectrometers are interchangeable via common sized flange
- Similar schemes for mounting lenses/meshes & flight tube
- Only integrating ion spectrometer will be used in first year
Experimentation station – Ion TOF

Three different ion detectors/spectrometers:

- m/q spectrometer
- VMI
- Momentum resolving
High Field Physics – Electron Time-of-Flight

Five spectrometers arranged around interaction region at following angles:

<table>
<thead>
<tr>
<th></th>
<th>θ</th>
<th>φ</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0°</td>
<td>90°</td>
<td>Along y-axis</td>
</tr>
<tr>
<td>2</td>
<td>35.3°</td>
<td>90°</td>
<td>Magic angle in xy dipole plane</td>
</tr>
<tr>
<td>3</td>
<td>90°</td>
<td>90°</td>
<td>Along x-axis</td>
</tr>
<tr>
<td>4</td>
<td>54.7°</td>
<td>0°</td>
<td>Non-dipole</td>
</tr>
<tr>
<td>5</td>
<td>90°</td>
<td>35.3°</td>
<td>Non-dipole</td>
</tr>
</tbody>
</table>
High Field Physics – eTOF

- Based on a successful design used by D. Lindle’s group at ALS – designed for up to 5keV electrons
- Relatively flat transmission above 20eV KE

Experimentation station - ETOF

- Aperture 1 - 0V
- Aperture 2 - 2V
- Lens 1 - -4000V
- Lens 2 - -4575V
- Lens 3 - -4850V
- Lens 4 + Flight tube - -5000V
- Ground tube 0V
- Detector
- IR
Experimentation station - ETOF

Detector

Magnetic shielding

Actuators

Electrical lens
Experimentation station - ETOF

- Turbo pump
- Magnetic shielding
- Actuators
- Electrical lens
High Field Physics – eTOF

- Five electron spectrometers arrayed around interaction region
Experimental station - Magnetic shielding

- Mu metal lining
  - Linked to each spectrometer
  - Allow pumping
  - Continuous permeability
Experimental station – Chamber X-Section

- eTOF
- Gas jet port
- Interaction region
- Ion TOF
High Field Physics – X-ray spectrometers

- Two of the electron spectrometers can be removed & replaced with x-ray emission spectrometers
  - Spectrometers require high efficiency for diffuse gaseous targets
  - Single shot capable detectors – either CCD’s/CMOS detectors directly or MCP amplified phosphor screen imaged with camera external to vacuum
  - Two spectrometers – a grating spectrometer for <2 keV and crystal spectrometer for >2 keV
    - Design not yet complete
High Field Physics – X-ray spectrometers

- With guidance from plasma physics and EBIT measurements – concave elliptical crystal spectrometer
- Crystals formed by bending them onto a mandrel
- Energy ranges for crystals that are easily bent:

<table>
<thead>
<tr>
<th>Crystal</th>
<th>d (Å)</th>
<th>Energy range for 45° ≤2θ≤135° (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAP</td>
<td>26.64</td>
<td>1216 504</td>
</tr>
<tr>
<td>PET</td>
<td>8.742</td>
<td>3706 1535</td>
</tr>
<tr>
<td>LiF</td>
<td>4.027</td>
<td>8045 4354</td>
</tr>
</tbody>
</table>
High Field Physics – X-ray spectrometers


With $h = 25\text{mm} & R_0 = 600\text{mm}$

\[
\rho = \frac{h}{1 - \varepsilon \cos \beta}
\]

\[
\varepsilon = \sqrt{1 + \left(\frac{h}{R_0}\right)^2 - \frac{h}{R_0}}
\]
Positioning table

- Load capacity: 1000Kg
- Ranges of motion:
  - All 6 degrees
  - ±50mm in XYZ
  - ±5° in Pitch, Yaw, Roll
  - Repeatability ±1µ
Positioning table

Motorized stages XY
Slave stages XY
Moving frame
Spherical bearing joints
Motorized stages Z
Anchored frame
3 x Spherical head feet
AMO Instrument - Diagnostics

- Diagnostics in a separate chamber with:
  - Magnetic bottle spectrometer
    - Measures photon wavelength and bandwidth
    - Can also be used to measure temporal overlap of FEL & laser beam
  - Total pulse energy monitor
    - Measures pulse energy on each pulse
  - Two beam screens
    - Measures position & size of beam
    - Either geometric or coherent interference based
Diagnostics – Magnetic Bottle

- Magnetic field directs electrons to detector increasing collection efficiency
  - As first described by Kruit & Read, J. Phys. E, 16, 313 (1983)
Diagnostics – Magnetic Bottle

Single shot electron energy spectrum – measure photon energy and bandwidth

Design courtesy of Chris Roedig (Lou DiMauro’s group at OSU).
Diagnostics – Magnetic Bottle
Diagnostics – Beam Viewing Screens

- Two screens separated by ~ 1m to measure beam trajectory & divergence
- 1st screen partially transparent – 500μm of YAG on SiN membrane imaged with CCD (120Hz)
- Second screen can extinguish beam using a thick YAG crystal
Total Energy (Thermal) Sensor provides calibrated measurement of FEL pulse energy

Measures FEL energy deposition through temperature rise

- Cu heat sink
- FEL pulse
- 0.5 mm Si substrate
- Thermistors Nd$_{0.66}$Sr$_{0.33}$MnO$_3$ (On back of substrate)
- Sensor Temperature Rise
- Time [ms] vs. Sensor Temperature [K]
- Thermal diffusion of FEL energy

VG from R. Bionta
Diagnostics chamber – downstream

- Beam profile monitor
- Power monitor
- Beam viewing screen
- Magnetic bottle
- Differential pumping
- Magnetic bottle magnet
- XYZ stage
Beam Shutter

- Upstream of the optics a single pulse beam shutter will be installed in the beamline.
- The shutter is a commercial product that will be modified with coatings to protect the shutter blade.
- <2ms open/close time.
NEH Laser System and Optical Transport
Conceptual Design

- 5 W Nd:YVO₄
- 30 fs Ti:sapphire Oscillator 800 nm
- 20 W Nd:YLF Pump Laser @ 527 nm 1.2 kHz
- 300 mJ Nd:YAG Pump Laser @ 532 nm 10-30 Hz
- 120 mJ Nd:YAG Pump Laser @ 532 nm, 120 Hz
- Pulse Stretcher 30 fs Bandwidth
- Dazzler
- Regenerative Amplifier 1 kHz, <5 mJ
- Optical Transport
- Multi-Pass Preamplifier 10-30 Hz, <30 mJ
- Pulse Cleaner
- 30 fs Ti:sapphire Oscillator 800 nm
- 5 W Nd:YVO₄
- 20 W Nd:YLF Pump Laser @ 527 nm 1.2 kHz
- 300 mJ Nd:YAG Pump Laser @ 532 nm 10-30 Hz
- 120 mJ Nd:YAG Pump Laser @ 532 nm, 120 Hz
- Harmonics
- Topaz OPA

June 2-3, 2008
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NEH Laser

Laser Hall

Hutch 2

30 fs Mode Locked Ti:sapp @ 800 nm

30 W Nd:YVO₄

5 W Nd:YVO₄

30 W Nd:YLF Pump Laser @ 527nm 1.2 kHz

Regenerative Amplifier 1kHz, <5 mJ

Pulse Compressor (Single Grating)

Pulse Cleaner

Optical Transport

Optical Transport

DIAGNOSTIC SUITE

-Spectrometer
-Autocorrelator
-Frog
-Beam Analyzer
-Power Meters
-Oscilloscopes

Experiment Chambers
Laser Hall Laser Tables

- Laser Hall Entry
- Master Oscillator
- Regen Amplifier
- Equipment Racks
- 3X, Optical Transport Tubes
- 15'
- 12'
- 26'
- 5'
NEH (AMO) Laser Configuration

- 120 Hz, 2-3mJ
- Ti:Sapphire
- Oscillator & regen upstairs in laser lab
- Vacuum beam transport to hutch
- Compressor, color conversion in hutch
- Two arms – one to experiment, other to diagnostics

by Greg Hays
Introducing Laser into AMO Chamber

- Laser introduced on-axis using mirror with hole
- All focusing/steering outside vacuum
Introducing Laser into AMO Chamber

Laser beam diam. ~20-60 um at interaction region
## AMO Focused Beam Parameters and Peak Intensities

<table>
<thead>
<tr>
<th>Focal Length</th>
<th>Focal Spot Size</th>
<th>Peak Intensity</th>
<th>1.0 cm Diameter</th>
<th>2.0 cm Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 cm</td>
<td>43 μm</td>
<td>4x10^{15} W/cm²</td>
<td>21.4 μm</td>
<td>2x10^{16} W/cm²</td>
</tr>
<tr>
<td>50 cm</td>
<td>61.1 μm</td>
<td>2x10^{15} W/cm²</td>
<td>30.6 μm</td>
<td>8x10^{15} W/cm²</td>
</tr>
</tbody>
</table>

- **Calculations Assume:**
  - TEM₀₀ M²: 1.2
  - Pulse width: 35 fs
  - Pulse Energy: 2.0 mJ
Photoelectron sidebands – an example

- Above threshold Ionization processes giving rise to sidebands
  - Requires spatial and temporal overlap of two beams

![Diagram showing photoionization of Ar and photoelectron spectrum with sidebands](Image from FLASH web site)
Sidebands – measurements at FLASH

- First experiments at FLASH used a psec laser
  - Modeling with time-dependent Schroedinger eqn required to extract temporal overlap from SB intensity

Diagnostic - Temporal Resolution

- Using fsec optical laser able to reduce temporal uncertainty to 50 fs
  - Measured relative jitter between two beams of 250 fs rms using Xe 5p photoionization

Controls & Data Acquisition

- EPICS will be used to control instrumentation
- All motions, voltages, etc. under remote control
  - Test-stands already being built
Controls & Data Acquisition

- Acqiris DC282 high-speed 10-bit cPCI Digitizer
  - 4 channels
  - 2-8 GS/s sampling rate
  - Acquisition memory from 1024 kpoints to 1024 Mpoints (optional)
  - Low dead time (350 ns) sequential recording with time stamps
  - 6U PXI/CompactPCI standard, 64 bit, 66 MHz PCI bus
    - Sustained transfer rate up to 400MB/s to host SBC
Layout of AMO experiment

Design currently being finalized...completion in June
Location of AMO experiment

Front End Enclosure

Near Experimental Hall

to the Far Experimental Hall

Near Experimental Hall

1 2 3

FEE NEH AMO

FEH
What’s there July 2009?

- Focusing Optics
- High Field Physics Chamber
  - Pulsed gas jet
  - Ion TOF (Wiley McLaren type)
  - Electron TOFs
- Diagnostics
  - Effusive gas jet
  - Magnetic bottle TOF
  - Beam screens
- Synchronized Laser
And what’s commissioned later?

- Pulse picker (12/09)
- High Field Physics Chamber
  - Velocity map imaging ion spectrometer (10/09)
  - Momentum resolving ion spectrometer (reaction microscope/CoITRIMS) (2/10)
  - X-ray spectrometers (1/10)
- Diagnostics
  - Pulse energy monitor (11/09)
The Path Forward

- **Preliminary Design Review Completed**
  - Finish detailing high field physics chamber, diagnostics
- **Finalize Design & Review** – June 08
- **Procurement phase** – Jul-Dec 08
- **Assembly & Testing** – Jan-Jun 09
- **Ready for first light** – July 09

- Lots of help from engineering, controls, etc.