Lessons Learned From the First Operation of the LCLS for Users

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For the LCLS

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Operating Parameters

- User Beams from 750 eV to 2 KeV
  - Bandwidth 0.2-1% FWHM
- Bunch lengths from 5fs to 300fs FWHM
- ~2mJ high charge, 170uJ low charge (~30GW)
  - $1.5 \times 10^{13}$ photons normal $10^{12}$ low charge
- Intensity stability <10% RMS
What Worked Well

- 11 AMO experiments
- Wavelength, bunch length, and intensity tuning at user request
- Precision timing (~50fs) for pump/probe experiments
- 93% User time (7% includes tuning and parameter changes)
- 1 Km accelerator, 130M undulator, 100M X-ray beam line, AMO chamber, Data acquisition: A remarkable amount of stuff worked!
XFEL is different from a Synchrotron Light Source

Synchrotron:
High Stability, Low Adjustability
Multi-user

XFEL:
Low Stability, High Adjust-ability
Single-user

This led to some issues
XFEL has lots of controls!

Photon Energy
Bunch Length
Wavelength chirp
Pulse energy

The controls are not orthogonal!
Upstream beam changes will propagate down stream. Feedbacks reduce this effect but don't eliminate it.
Energy Change (>1%) takes a few minutes.

Change L3 energy.

Adjust bend strength.

Taper control to maximize intensity.

Focus magnets adjusted after BC2 (Iterative due to errors in magnets and klystron gain).
X-ray Changes from Energy Changes

- Longitudinal changes
  - Bandwidth and chirp change since wakefields will be different
  - Taper changes (from re-optimization) may change spectrum
  - Minimal bunch length change
- Transverse changes
  - Gain changes → different source point
  - Electron matching changes → X-ray optics changes.
  - X-ray beam size and focus changes
Energy Change (<1%)  
~1 second – now under user control

Bend strength unchanged

Beam energy changes orbit in DL2

Change phases
Fast Energy Control

- Change RF phases, magnets unchanged
  - < 1 second response (user control)
  - Pulse to pulse control possible with new software
- Orbit change in DL2 will slightly affect bunch length.
  - Effect is significant for short pulse (5fs) operation.
- Orbit errors and nonlinearities may cause pulse energy changes
- Used for several experiments last run
Fast energy control 8.3 KeV 3% full range photon energy

Pulse energy during wavelength scan no foil

Pulse energy during wavelength scan with Ni Foil

With poor tuning, power changes during scan

Can use this to measure above and below a transition, but need to properly scale data, can't just subtract
Possible future fast energy control

Energy control structure
+/- 10% photon energy

Energy change is after most of the beamline – fewer side effects
Energy Change / Dither Requirements

• How much range and how quickly?
  • Existing system 1% range
  • New RF station ~10% range but $5M
• Side effects – focus, pulse length, etc?
  • No way to get a pure energy change
  • Simple lock-in techniques will not work!

Discuss options during this meeting
Pulse Length Control

Bunch Compressor

L2 Linac phase controls

Pulse length

AMO

For short pulses (5fs) DL2 has some effect

For shortest bunches, undulator length is reduced

Charge control

Undulator
Pulse Length Control

- Only RF is changed – can be pulse to pulse
- What changes for X-rays: **Everything!**
- Changing current changes gain
  - Power, source point, divergence, harmonic content
- Changing current changes wakefield energy loss
  - Photon energy and bandwidth change
- Pulse length not directly related to electron bunch length for short pulses – not all of bunch will lase.
In normal operation, wakefields in the linac cancel the chirp to minimize energy spread.

Can over-compress and let wakefields increase chirp
3.2-15 GeV

135 MeV

Intensity Control

Charge control

Undulator

Taper control to maximize intensity

Intensity control (gas / solid attenuator)
Intensity Control - Taper

- Maximum peak power limited by max peak current
- Above ~3000 Amps beam starts to breakup due to CSR instability
- Short bunch mode has similar peak power ~30 GW
- Taper increases peak power ~X3 but can broaden spectrum

1% wide spectrum with maximum taper (multishot)
Intensity Control: Attenuators

Be Solid Attenuators introduce distortion, but can't use N2 effectively above 2KeV

Attenuation always higher at fundamental than at harmonics.

Attenuating increases harmonic percentage
Harmonics

- Third harmonic usually not transmitted by mirrors. (problem at < 800eV)
- Second harmonic can be a serious problem for multi-photon experiments

Mirror transmission

3rd harmonic image
Typical 0.5-2%

2nd harmonic image
Typical .05%
Beam Diagnostics

- Need to be able to measure all parameters that are important to experiments
- Some can be measured by upstream diagnostics (FEE), others must be measured in the experimental chamber.
- Need good communication between experiment and accelerator!
Pulse Energy Measurement

Energy loss for calibrated measurement

Mirror loss appears to be large (~80%)

Need a calibrated measurement for use after the mirrors: building simple thermal sensor

Gas detectors are non-invasive, non calibrated

Need measurement after KB optics
Photon Spectrum

- Can be measured upstream
  - Harmonic content will change after the mirrors

- Existing system measures multi pulse average spectra

- Various options for single pulse spectral measurement

Non-invasive spectral measurement might be possible using an ETOF or similar
Precision Timing System

- Experiments suggest 50fs noise for full system
Future of Precision Timing

- Conventional RF based technology (including most EO systems) probably limited to 10fs.
- Laser transport from mode-locked laser to experimental chamber probably also limited to a few fs stability.
- LCLS operates with (probably) 5fs FWHM pulses – experiments could benefit from 1fs timing measurement.
- Need in-chamber laser vs X-ray timing measurement (somehow).
Bunch length measurement

Transverse cavity ~20fs RMS resolution

Future X-band cavity could resolve 2fs RMS

Need to develop new techniques for direct X-ray bunch length measurements
Transverse Profile

- Focus spot size and position important to experimental results
- Insufficient distance for natural divergence of the beam from the FEL to allow an accurate full mode measurement.
- Mirrors and attenuators can distort beam.
- **Must study the spot size in experimental chamber as a function of operating conditions, and re-measure as needed.**
Concluding Thoughts

• The increased adjustability and instability of a XFEL relative to a synchrotron light source changes the way experiments need to be done.
• Users have more control over the operating parameters
• Experiments need to pay more attention to measuring beam parameters – some of these can only be measured at the experimental chamber.