Operation and Upgrades of the LCLS

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LCLS Accelerator

0.45 x 0.37um
135 MeV

S-Band
25MV/M
250pC

X-band -160°

BC1
250A

L2 Linac
5 GeV, -36°

L3 Linac
0-10 GeV

Undulator

S-band -22°

Linear chirp

250A

Laser
Heater

1-3 KA

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Injector Emittances

Emittance < 0.4 um both planes at 250pc.

Emittance <0.2um both planes at 20pc (low charge mode)

Note: Emittance 95% cut
Emittance at end of LINAC

0.7 X 0.7 um Emittance at 14 GeV compressed beam (3KA)

Result of extensive experience tuning the SLAC LINAC: LCLS had > 1 year to tune the injector and LINAC!

Orbit bumps used to cancel wakefield tails
Emittance History

Emittance typically 0.5um at 135 MeV
Emittance X BMAG at undulator entrance 0.7-3um depending on energy and peak current.
User Operation

• Adjust to match user requirements
  – FEL wavelength
  – Pulse length
  – Trade-off between power and spectral bandwidth (adjust undulator taper)

• Schedule
  – 12 hour experiment shifts
  – 1 day / week for maintenance / upgrades
  – 1 day/week for machine development
LCLS User Run 2

- 4 month user run
- Bunch Length: 500fs
- Bunch Charge: 250pC
- Photon Energy: 9 KeV
- Operation at user requested wavelength and pulse length
FEL Power

2% RMS stability under best conditions

Highest operating power is at 2KeV, 150fs pulse
Generally > 1mJ from 500eV to 9 KeV
Shorter bunches (down to 50fs) result in lower output pulse energy.

Best stability 2% RMS, more typically 5-10% RMS
Several users requested low charge (20pC) operating mode for very short pulses.

No direct pulse length measurement available, but believed to be < 5fs FWHM.

\[ \Delta T = 5.0\text{fs} \quad \text{we typically operate here} \]

\[ \Delta T = 2.3\text{fs} \]

\[ \Delta T = 1.9\text{fs} \]

\[ \Delta T = 1.1\text{fs} \]

\[ \Delta T = 0.5\text{fs} \]

\[ \Delta T = 0\text{fs} \]

\[ \Delta T = -0.5\text{fs} \]

\[ \Delta T = -1\text{fs} \]

Genesis Simulation for over compression 5fs FWHM.
“Slotted Foil” short bunches

6 \mu m emittance

1 \mu m emittance

No direct pulse length measurement

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Short Pulse User Operation

• Low Charge Mode (20-40pC)
  – Low emittance → high peak power
  – Couple hours to switch from normal to low charge
  – Recently developed 100pC mode to fill the gap between 40 and 250pC

• Slotted foil mode (at 250pC)
  – Fast pulse length tuning (just move foil)
  – Rapid switching from normal operation

• Both modes used for experiments
Low Charge AND Slotted Foil

X-ray spectrum with 20pc operation – few spikes suggest ~5 fs pulses

With 20pc and slotted foil see single spike spectrum suggests very short pulses

No direct measurement but may be producing ~1fs X-ray pulses
Short Pulse Timing

• FEL can probably produce sub femtosecond pulses
• Most useful for pump / probe experiments to study ultra-fast phenomena
• Existing optical lasers can produce few-femtosecond pulses (100as in the UV)
• Need precision timing control / measurement: State of the art is still~50fs.
Near Term Upgrades

Harmonic Afterburner:

Existing undulator - enough sections to saturate

Undulator with reduced K to tune for $\frac{1}{2}$ wavelength. Bunched beam radiates at 2\textsuperscript{nd} harmonic wavelength

18 KeV ~100uJ

Self Seeding

Seeding undulator

Diamond crystal band-stop filter

Gain Undulator

Energy extraction taper

Gianluca Geloni Vitali Kocharyan Evgeni. Saldin

Produce high power narrow band hard X-rays
LCLS_II will modify 1km of the existing SLAC linac as a second 14 GeV accelerator.

Can drive a new set of undulators in a new tunnel and experimental hall.

Can be used in conjunction with existing LCLS linac for up to 28 GeV for ultra-hard X-rays or a high peak power FEL.
3-D Genesis Simulation by
Zhirong Huang

- 27 GeV with 0.6um emittance
- 5KA peak current
- 1.4MeV energy spread
- 4.5cm undulator K=4.95
- 3% taper amplitude
- 30M beta function
LCLS Future Possibilities

• Existing beam brightness sufficient for 30-50 KeV FEL
• Use of 28 GeV LINAC (2 km) with self-seeding could produce > 1TW at 1Å
• 2 bunch (8.4 ns separation) lasing demonstrated. RF pulse can support 10 bunch operation
• Operation at 360 Hz at reduced energy being studied