LCLS-II: An upgrade for the LINAC Coherent Light Source

J. Wu for LCLS team
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1.5-Å FEL Saturation at 65 m (of 112 m)

The success of the LINAC Coherent Light Source (LCLS*) motivates an extension of the capacity, capabilities, and quality of this revolutionary new light source.

LCLS beam should support 25-keV (0.5 Å) FEL at 14 GeV

undulator gap has been increased here

\( \gamma \varepsilon_{x,y} = 0.4 \, \mu m \) (slice)

\( I_{pk} = 3.0 \, kA \)

\( \sigma_E/E = 0.01\% \) (slice)

0.5 Å

K = 1.65

Same beam quality and energy as now

1.5 Å

\( \lambda_r = 1.5 \, \text{Å} \)

\( \gamma \varepsilon_{x,y} = 0.4 \, \mu m \) (slice)

\( I_{pk} = 3.0 \, kA \)

\( \sigma_E/E = 0.01\% \) (slice)
LCLS-II Requirements

- Build new soft x-ray line from 250 to 1800 eV
- Extend hard x-rays out to ~20 keV
- Include seeding options for narrow BW (if $)
- Incorporate 2-pulse, 2-color schemes (if $)
- Provide polarization control
- Use more of 3-km SLAC linac to provide separate sources for independent FELs
- Explore multi-bunch operations (NOW TESTED)
- Find ways to increase capacity (user access)
Possible new undulator tunnel (hall)
- Budget still being developed – within range of 300-400 M$
- LCLS-II incorporates as many of these capabilities as budget allows

P. Emma

All electron beamlines support up to 15 GeV at 120 Hz (or 7 GeV at 360 Hz) and two-bunch operation is available from either gun 3-4 FELs and 2 Electron Sources (& more)
**LCLS-II: New Injector & Accelerator**

- **Use 2nd km of SLAC linac (sector-10 to 20) – greater flexibility**
- **3-15 GeV energy at 120-Hz beam rate; or 3-7 GeV energy (no SLED) allowing 360-Hz beam rate**
- **2nd injector, linac, & bypass line allows 2+ independent FELs serving 2+ experiments simultaneously with flexible parameters**
- **Combining beams allows x-ray pump/probe with decoupled wavelengths, pulse width, energy, and timing; and even THz x-ray pump/probe**
- **Preserves possibility of up to 30 GeV (and still 1 more km left!)**
Phased Enhancement Options for *LCLS-II* FELs

Existing 112-m Undulator (1.2-25 Å)
Phase-1 (2010)

3-15 GeV

Shortened 80-m (1.2-25 Å)

SHAB 30 m

0.62-12 Å

~1 GW

H.-D. Nuhn

[THOCl2]

Phased Enhancement Options for *LCLS-II* FELs
Phased Enhancement Options for LCLS-II FELs

SXR and HXR simultaneous op’s with bypass line

3-15 GeV bypass

240 nm → 6 nm

EEHG*?

6-60 Å adjust. gap

2-pulse 2-color

6-60 Å adjust. gap

full polarization control

self-seeding option

3-15 GeV

Shortened 80-m (1.2-25 Å)

SHAB 30 m

0.62-12 Å ~1 GW

H.-D. Nuhn [THOCI2]

Phase-2

* G. Stupakov, Phys. Rev. Lett. 102, 074801 (2009)
Phased Enhancement Options for LCLS-II FELs

SXR and HXR simultaneous op’s with bypass line

EEHG*? 6-60 Å adjust. gap

2-pulse 2-color

6-60 Å adjust. gap

full polarization control

self-seeding option

SXR1 (36 m)

SXR2 (36 m)

self-seeding HXR option (1 or 2 bunches)

0.62-12 Å (54 m)

0.62-12 Å (54 m)

0.62-12 Å ~1 GW

H.-D. Nuhn [THOC12]

Phase-3

3-15 GeV bypass

240 nm → 6 nm

3-15 GeV bypass

6-60 Å adjust. gap

2-pulse 2-color

6-60 Å adjust. gap

full polarization control

FEE-2

FEE-1

3-15 GeV

5 m

5 m

* G. Stupakov, Phys. Rev. Lett. 102, 074801 (2009)
Two electron bunches observed on OTR screen with TCAV3 separating them

Two FEL beams observed on SXR Antenna

8.4 ns

F.-J. Decker [WEPB33]
“Circular” Polarization Control Options

Soft x-rays

- **Planar + Helical**
  - Stable
  - >90% polarization
  - Slow switching

- **Planar + Crossed Planar**
  - May have fluctuations
  - ~80% polarization
  - Fast switching

- **Planar + Crossed Pair at \( \lambda/2 \)**
  - Stable
  - ~90%
  - Fast switching
  - ~1% of fundamental power

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Z. Huang

Hard x-ray polarization control via crystals
Self-Seeded SXR (6-60 Å) FEL in LCLS-II

FEL spectrum at ~26 m in 2nd undulator for seed of 0.1 MW (black) and 0.01 MW (red).

FWHM: $3.1 \times 10^{-4}$
Electron bypass chicane and the photon optics can (may have to) be in two orthogonal planes, one in $x$– and the other in $y$–plane.

$R_{56}$ of the chicane is about 3 mm; $h$ (excursion) $\sim$ 10 cm.

(rotational) Planar variable-line-spacing grating $G$;

Constant focal-point mode $\rightarrow$ fixed slit location, but optical delay varies when tuning energy ($\sim$5 ps +/- 10%)

Y. Feng *et al.* [TUPB10]
The next 4 slides will graphically outline 4 future operating modes...

(thanks to H.-D. Nuhn)

1. Hard X-ray SASE
2. Soft X-ray SASE
3. Soft X-ray Self Seeding
4. Two-pulse, two-color soft x-rays (one $e^-$ bunch)
5. Two-pulse, two-color soft x-rays (two $e^-$ bunches)
6. Seeded soft x-ray FEL (‘Echo’)  
7. Self Seeding of hard x-rays (single and two $e^-$ bunches)
One $e^-$ bunch produces 2 SXR pulses (0-10 ps separation) for pump probe

Deliver both pulses to one experiment or split them to two

SX2 pulse color ($\lambda_2$) must be longer wavelength than SX1 ($\lambda_1$)

Angled SX2 suggested by J. Hastings and P. Heimann
Beam Doubler Layout

UNDULATOR HALL
SXRx1 SXR2

~0.1 MRAD

~19 MM

FEL FEL/E-

J. Welch

- INSERTABLE MIRRORS PAIRS FOR 0 OR 60 MRAD DEFLECTION
- FOUR POSSIBLE BEAMLINES, TWO ACTIVE AT ANY TIME

SLAC
NATIONAL ACCELERATOR LABORATORY
5. **LCLS: SX1 & 2 SASE, Two-Bunch, Two-Color**

- **Two** $e^-$ bunches 10-100 ns apart (no pump probe here)
- One fast kicker & one DC – each bunch lases in just one FEL
- Allows 2 SXR experiments simultaneously (*user doubler*)
- Two colors can be any value (6-60 Å)

Suggested by J. Frisch and independently by R. Brinkmann *et al.*
6. **LCLS**: Echo Seeding of SX1 or SX2

- **Sector-10 Gun** 3-7-GeV Beam
- **Sector-20 Gun** 3.4-15-GeV Beam

**External seeding (~30-60 Å) using Echo-Enhanced Harmonic Generation (EEHG*)**

- Allows narrow bandwidth and longitudinal coherence
- Under study now at NLCTA/SLAC ([S. Weathersby [WEOA3]](https://www.sciencedirect.com/science/article/pii/S1359646213004468))

* D. Xiang, G. Stupakov, [TUPB13]
7. **LCLS**: Two-bunch HXR Self-seeding

Before U2

After U2

Spectrum

Y. Ding, Z. Huang, R. Ruth, *PRSTAB* 13, 060703 (2010)

G. Geloni et al. *DESY* 10-033 (2010),

Peak Brightness of LCLS
**LCLS-II Timeline, Compatible with Operations**

300-400 M$

- **R&D**
- **CDR**
- **Installation**
- **ED&I**
- **Fabrication**

**CD 0**
- **FY10**
- **Start Injector Construction**

**CD 1**
- **FY11**
- **Facilities Installation**

**CD 2, 3**
- **FY12**
- **Phase-1 Installation**

**CD 4**
- **FY13**
- **Phase-2 Installation**
- **FY14**
- **FY15**
- **FY16**
- **FY17**

**Annual 3 month summer downtime**

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LCLS-II Summary

**Soft X-Rays:**
- 2-pulse, 2-color, variable delay (6-60 Å) using 1 e⁻ bunch or 2
- Self-seeding for narrow bandwidth (≈10⁻⁴ at 6-60 Å)
- Full polarization control in SASE and self-seeded modes (fast & slow)
- 3-15 GeV bypass line allows simultaneous soft and hard x-ray operations in two separate beamlines with completely independent parameters
- Single femtosecond near-transform limited spike in low-charge mode

**Hard X-Rays:**
- Harder x-rays (0.62 Å) by modifying all undulators
- Few femtosecond pulses possible in low-charge mode
- Full polarization control
- Self-seeding with 2 electron bunches and short chicane (4 m) and 1 e⁻ bunch
- And... 22-30 GeV still possible using both 1-km linacs (+ 1st km still open)
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- Thanks to the committee for invitation

- Thanks to the LCLS team members

- Thanks for your attention