# Projected Run 20 LCLS FEL Parameters – Update Apr. 27th, 2021

LCLS FEL parameters with hard and soft x-ray undulators (HXU and SXU) driven by the copper linac. Projected values are based on Run 18 & 19 performance. Many parameters vary according to the energy, pulse length and bandwidth. Stability values below are taken over a few minutes.

This table shows nominal values at the minimum and maximum photon energies FEL systems can generate. For more detail on nominal pulse energy versus photon energy, see the next section.

Values do not reflect effects specific to beamlines (e.g., transport efficiency/capability). Please refer to Points of Contact and information pertaining to the relevant beamline for further details.

### General SASE Parameters

| **Photon Beam Parameters** | **Symbol** | **Cu-HXU x-rays** | | **Cu-SXU x-rays** | | **Unit** |
|---|---|---|---|---|---|---|
| | | $\hbar\omega_{max}$ | $\hbar\omega_{min}$ | $\hbar\omega_{max}$ | $\hbar\omega_{min}$ | |
| **Photon Energy** | $\hbar\omega$ | **25000** | **1000** | **5000** | **200** | **eV** |
| Fundamental wavelength | $\lambda_r$ | 0.5 | 12.4 | 2.5 | 62.0 | Å |
| Final linac e- energy | $\gamma mc^2$ | 16.5 | 3.5 | 10.0 | 3.5 | GeV |
| FEL 3-D gain length | $L_G$ | 4.0 | 1.0 | 2.5 | 1.0 | m |
| Peak power | $P$ | 20 | 80 | 50 | 30 | GW |
| Pulse duration range (FWHM) | | 10 – 50 | | 10 – 250 | | fs |
| Nominal pulse duration (FWHM) | $\Delta\tau_f$ | 30 | | 50 | | fs |
| Max Pulse Energy* | $U$ | 0.6 | 2.0 | 2.5 | 1.5 | mJ |
| Photons per pulse* | $N\gamma$ | 0.15 | 14 | 3.1 | 47 | $10^{12}$ |
| Peak brightness* | $B_{pk,\ SASE}$ | 7800 | 425 | 2250 | 19 | $10^{30}$ § |
| Average brightness (120Hz)* | $\langle B \rangle$ | 280 | 16 | 138 | 1.5 | $10^{20}$ § |
| SASE bandwidth (FWHM) | $\Delta\omega/\omega$ | 30 | 2 | 10 | 2 | eV |
| Photon source size (rms) | $\sigma_S$ | 8 | 20 | 16 | 46 | µm |
| Photon far field divergence (FWHM) | $\Theta_{FWHM,x,\infty}$ | 1 | 12 | 3 | 25 | µrad |
| Max. Beam Rate | $\phi_{FEL}$ | 120 | | 120 | | Hz |
| Avg. x-ray beam power | $P_x$ | 0.07 | 0.24 | 0.30 | 0.18 | W |
| Linear Polarization (100%) | $\langle P \rangle$ | Vertical | | Horizontal | | |
| **Electron Beam Parameters** | | | | | | |
| Nominal Bunch Charge | $Q$ | 180 | | 180 | | pC |
| Total Energy Spread | $\sigma E/E$ | $10^{-3}$ | | $10^{-3}$ | | 1 |
| Inject. bunch length (rms) | $\sigma_{z0}$ | 550 | | 550 | | µm |
| Undul. bunch length (rms) | $\sigma_{zf}$ | 16 – 3 | | 16 – 5 | | µm |
| Final peak current | $I_{pk}$ | 1.0 – 5.0 | | 1.0 – 3.0 | | kA |
| Proj. Emittance (injector) | $\gamma\varepsilon_{x,y}$ | 0.45 | | 0.45 | | µm |
| Slice Emittance (injector) | $\gamma\varepsilon^{s}_{x,y}$ | 0.37 | | 0.37 | | µm |
| Proj. Emittance (Undulator) | $\gamma\varepsilon^{u}_{x,y}$ | 0.5-1.6 | | 0.5-1.6 | | µm |
| Max. Single Bunch Rep. Rate | $F$ | 120 | | 120 | | Hz |
| UV laser energy on cath. | $u_l$ | 15 | | 15 | | µJ |
| UV laser beam diam. on cath. | $2R$ | 1.2 | | 1.2 | | mm |
| e- energy stability (rms) | $\Delta E/E$ | 0.02 | | 0.07 | | % |
| e- x,y stability (rms) | $x/\sigma_x$ | 15,10 | | 25,20 | | % |
| e- timing stability (rms) | $\Delta t$ | 50-100 | | 50-100 | | fs |
| Peak current stability (rms) | $\Delta I/I$ | 10 | | 6 | | % |
| Charge Stability (rms) | $\Delta Q/Q$ | 2.5 | | 2.5 | | % |
| FEL pulse energy stability | $\Delta N/N$ | <10 | | <10 | | % |

§Brightness units are photons/sec/mm²/mrad²/0.1%-BW

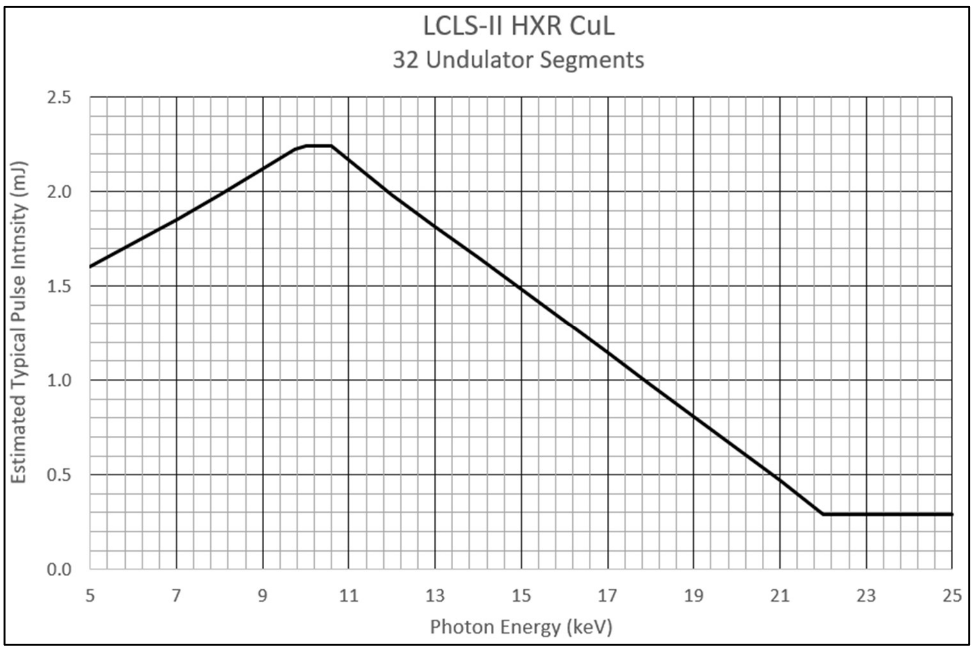
*Calculated assuming nominal pulse duration and maximum undulator strength

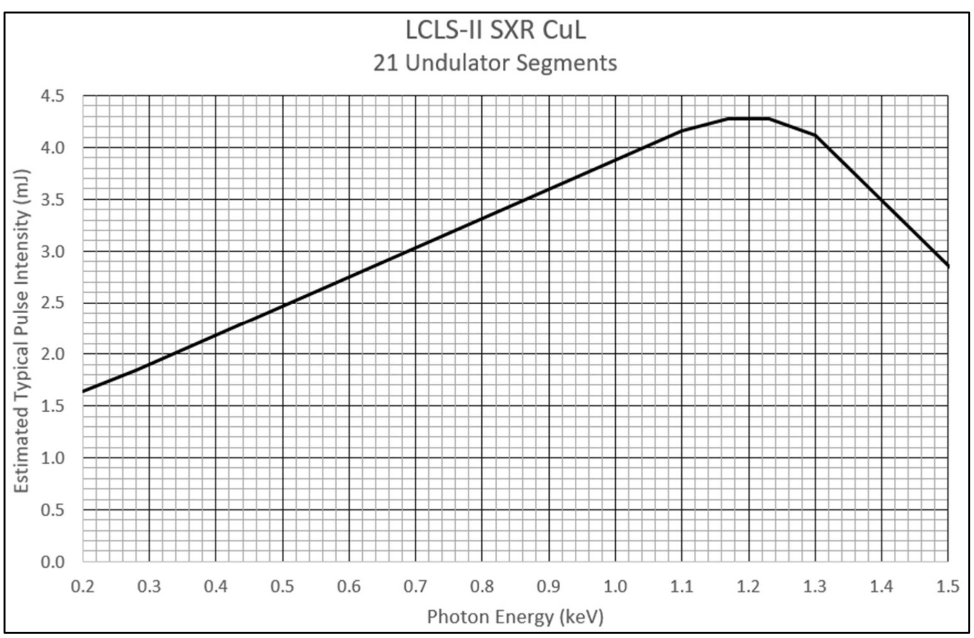
**Nominal pulse energy as a function of photon energy**

When driven by the copper linac, photon energy may be varied using either the variable electron beam energy or the variable undulator gap. Optimum performance is achieved using the maximum available undulator strength (minimum gap) and corresponding electron beam energy.

For the nominal electron beam parameters above, these curves show max pulse energy at maximum undulator strength(s). When both undulators operate simultaneously, the secondary program/undulator may not achieve maximum performance.

Values do not reflect effects related to specific x-ray beamlines (e.g., transport efficiency/capability), or any modifications to the above operating parameters (pulse duration, etc). Please refer to Points of Contact and information pertaining to the relevant beamline for further details.



## Seeded x-ray beam parameters

**Important note:** Recommissioning of self-seeding for new undulator systems is expected to continue into 2021. Please contact your LCLS Point of Contact regarding availability.

| Mode | Energy Range | Bandwidth | Pulse Energy | Pulse Length |
|---|---|---|---|---|
| **HXRSS** | 4.5 – 11 keV | 0.35-1.5 eV | ~ 0.2 mJ | Up to 30 fs |
| **SXRSS** | 0.4-1.2 keV | ~ 100 meV @ 400 eV<br>~ 150 meV @ 530 eV<br>~ 200 meV @ 800 eV | < 25 – 50 μJ @ 20 fs<br>Up to ~ 0.25 mJ with spectral pedestal | 20 – 120 fs |

## Dual Bunch & Dual Energy Parameters

**Multi-color Pulse Mode Table - SHORT FORM - Status Apr. 27th, 2021**

**SOFT X-RAYS**

| Technique | Pulse Separation | Min Pulse Duration | Energy Separation | Max Energy/Pulse | Comments | Reference publications |
|---|---|---|---|---|---|---|
| **Split Undulator SASE** | 0 - 800 fs | 15 fs | Up to factor 2 ratio in photon energies | 50 uJ (30 fs duration) | Simple energy/time delay control. Minimally invasive. | A. Lutman et al. Phys. Rev. Lett. 110, 134801 (2013) |
| **Double Slotted Foil** | 15 - 70 fs | ~ 10 fs | +/-1.5% | 20-50 uJ | Minimally invasive, easy to maintain. Delay and energy separation are not independent, minor tuning needed between changes. | Ding et al. Appl. Phys. Lett. 107, 191104 (2015) |
| **Two-(multiple) bucket** | | | | | | Decker et al. under review. |
| **Two bucket (ns spacing)** | 350 ps increments, up to 120 ns | 30-70 fs | +/-2% | 0.5-1.0 mJ | | Decker et al. under review. |
| **Multiple Bucket (up to 8 bunches)** | two trains of 4 pulses. 700 ps between each pulse in the same train. | 30-70 fs | +/-2% | TBD | | Decker et al. under development |
| **Twin Bunches (fs spacing) w/o slotted foil** | 0 - 125 fs | 30 fs | +/- 2.5% | 0.5 mJ | Long setup time. Limits to energy/time separation | Marinelli et al. Nat. Commun. 6, 6369 (2015) |
| **Twin Bunches (fs spacing) w slotted foil** | 0 - 70 fs | - | +/- 2.5 % | 50 uJ | Long setup time. Limits to energy/time separation | Marinelli et al. Proceedings of IPAC 2016, TUZA02 |

**HARD X-RAYS**

| Technique | Pulse Separation | Min Pulse Duration | Energy Separation | Max Energy/Pulse | Comments | Reference publications |
|---|---|---|---|---|---|---|
| **Split Undulator SASE** | 0 - 40 fs | 15 fs | Up to 10% difference in photon energies | 30 uJ (25 fs pulse duration) | Simple energy/time delay control. Minimally invasive. Greater photon energy separation possible at cost to performance. | A. Lutman et al. Phys. Rev. Lett. 110, 134801 (2013) |
| **Twin Bunches** | | | | | Long setup time. Limits to energy/time separation | Marinelli et al. Nat. Commun. 6, 6369 (2015) |
| Two SASE Pulses | 0 - 125 fs | ~ 10 fs | 0.2-2% | 0.3 mJ (20 fs duration) | 1st/probe pulse always higher photon energy | Marinelli et al. Nat. Commun. 6, 6369 (2015) |
| Twin bunches + V slotted foil | +/- 50 fs | ~5-10 fs | ~2% | 40 uJ | | Marinelli et al. Proceedings of IPAC 2016, TUZA02 |
| **Double Slotted Foil** | 7-20 fs | ~ 10 fs | +/-1.5% | 100-200 uJ | Minimally invasive, faster setup than twin bunches. Limits to energy/time separation, tuning needed between changes. | Ding et al. Appl. Phys. Lett. 107, 191104 (2015) |
| **Two-(multiple) bucket** | | | | | | Decker et al. under review. |
| **Two bucket** | 350 ps increments, up to 120 ns | 20 fs | ~ 1% | 0.5-1 mJ (30 fs duration SASE) | Longer setup time. Some tuning between changes. | Decker et al. under review. |
| **Multi bucket (up to 8 bunches)** | two trains of 4 pulses. 700 ps between each pulse in the same train. | 20 fs | ~ 1% | to be tested | Under development | Decker et al. under development |

**For detailed information and trade-off decisions, contact the LCLS Point Of Contact**

## Attosecond Pulses

### Hard X-rays

Two methods have been demonstrated at the LCLS for generating sub-fs pulses in the hard x-ray domain. Both methods used 20 pC bunch charges. One is based on a nonlinear electron bunch compression scheme; the other method used a new version of the slotted foil with optimized beam optics.

Measurements based on spectrometer show about half of the shots containing single-spike spectra, while other shots have a few spectral spikes. The estimated pulse duration for the single-spike pulse is about 200 - 400 as. Spectra data show that the nonlinear compression scheme gives a bit wider bandwidth. For example, at the 5.6 keV, nonlinear method measured bandwidth about 11 eV, while the slotted foil measured bandwidth about 4.5 eV. These two schemes should work in all the hard x-ray range about 5 - 10 keV.

### Soft X-rays

For soft x-rays, the XLEAP system has been commissioned in Run 19. It uses the interaction of a beam-generated burst of light with the electron beam itself to modulate the beam energy across the beam pulse. Subsequent compression using an undulator and chicane generates sub-femtosecond pulses of up to 50 μJ. For availability and other information, please inquire with your LCLS Point of Contact.

| **Energy Range** | **Parameter** | **Value** | **Unit** |
|---|---|---|---|
| **HXR** | Pulse Energy | 5-10 | μJ |
| | Pulse Duration | 200 – 400 | as |
| | Photon Energy | 5 – 10 | keV |
| | Bandwidth [FWHM] | 4 – 11 | eV |
| **SXR** | Pulse Energy | 20 | μJ |
| | Pulse Duration | 500 | as |
| | Photon Energy | 500 - 1000 | keV |
| | Bandwidth [FWHM] | 5 | eV |

**Ultra short pulse duration - SHORT FORM - Status Apr. 27th, 2021**

**FEW FEMTOSECONDS AT SXR**

| Technique | Min Pulse Duration | Energy range | Energy/Pulse | Single Spike rate | Comments | Reference publications |
|---|---|---|---|---|---|---|
| Single slotted foil and low charge | single spikes | SXR | 10-20 uJ | 20% | | Ding et al. Appl. Phys. Lett. 107, 191104 (2015) |

**ATTOSECONDS**

| Technique | Min Pulse Duration | Energy Range | Energy/Pulse | single-spike rate | Comments | Reference publications |
|---|---|---|---|---|---|---|
| Slotted foil / optics / taper | 400 as | HXR | 5 uJ (76% fluct.) | 65% | | Marinelli et al. Appl. Phys. Lett. 111, 151101 (2017) |
| Non-linear bunch compression | 200 as | HXR | 10 uJ | 45% | | Ding et al. Phys. Rev. Lett. 119, 154801 (2017) |
| XLEAP | TBD | SXR | TBD | TBD | | Marinelli et al. under development. |

**Ultra-short pulse duration can be in general coupled with the split undulator scheme (PRL 110, 134801) to produce pairs of ultra-short pulses. Performance still to be assessed.**