Projected Run 26 LCLS FEL Parameters – Update June 18, 2025

This run will offer capabilities on the soft and hard X-ray instruments using the LCLS copper accelerator at 120 Hz while the superconducting accelerator is undergoing a major upgrade to higher energies under the LCLS-II-HE project.

LCLS FEL parameters are with hard and soft x-ray undulators (HXU and SXU) driven by the normal conducting (NC) linac. Values are based on recent performance. Many parameters vary with energy, pulse duration, and bandwidth. Stability values below are taken over a few minutes.

The following table shows values at fixed photon energies FEL systems can generate. For important details on nominal pulse energy versus photon energy (other parameters fixed), see the figures in the following section.

Values are capability from the FEL source and do not reflect effects specific to beamlines (e.g., transport efficiency/capability/operational beam rate). Please refer to Points of Contact and information for the relevant beamline for further details.

(See table on next page)

Photon Beam Parameters	Symbol	NC linac HXU x-rays		NC linac 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	λ_r	0.5	12.4	2.5	62.0	Å
Final linac e- energy	γmc^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*	$\langle B \rangle$	280 @ 120 Hz	16 @ 120 Hz	138 @ 120 Hz	1.5 @ 120 Hz	10^{20} §
SASE bandwidth (FWHM)	$\Delta\omega/\omega$	30	2	10	2	eV
Photon source size (rms)	σ_s	8	20	16	46	μm
Photon far field divergence (FWHM)	$\Theta_{FWHM,x,\infty}$	1	12	3	25	μrad
Max. Beam Rate	ϕ_{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	$\sigma E/E$	1		1		10^{-3}
Emittance (Undulator)	$\gamma\varepsilon^{u}_{x,y}$	0.5-1.6		0.5-1.6		μm
Undul. bunch length (rms)	σ_{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
Inject. bunch length (rms)	σ_{z0}	550		550		μm
Max. Single Bunch Rep. Rate	F	120		120		Hz
e- energy stability (rms)	$\Delta E/E$	0.02		0.07		%
e- x,y stability (rms)	x/σ_x	15,10		25,20		%
e- timing stability (rms)	Δt	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 undulator strength, and depends on other electron beam parameters

** Highest achievable beam rate will depend on accelerator protection considerations and beamline acceptance

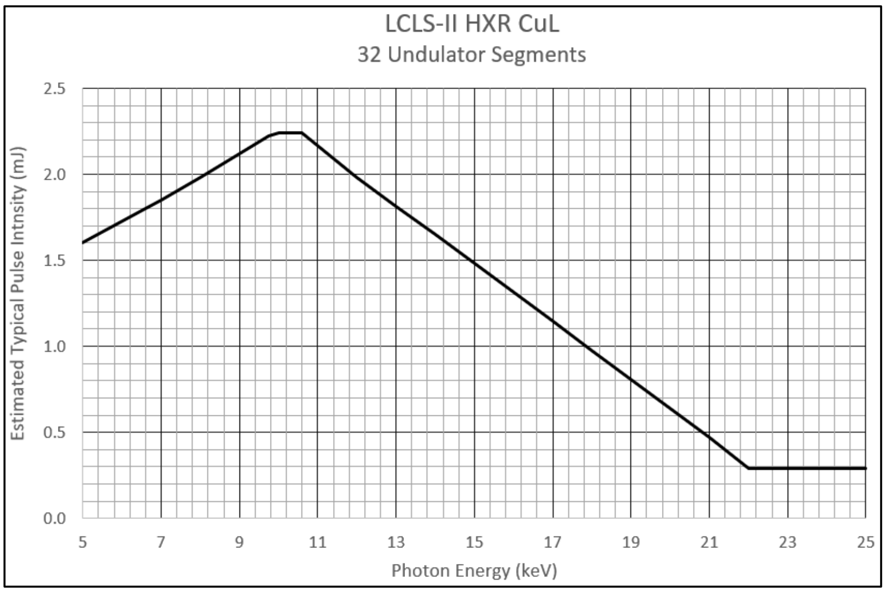
Nominal pulse energy as a function of photon energy

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

For the nominal beam parameters in the previous table, these curves show max pulse energy at the corresponding nominal beam energy.

Values are at the FEL source and do not reflect specific x-ray beamline effects (e.g., transport efficiency/capability/rate), nor any modifications to the above operating parameters (pulse duration, etc). Please refer to LCLS Points of Contact and information on the relevant beamline for further details.

Nominal Hard and Soft X-ray Undulator Performance with NC Linac (~40 fs pulses)



Seeded X-ray Beam Parameters

Hard x-ray self-seeding (HXRSS) is fully available with the NC linac. Soft x-ray self-seeding (SXRSS) is currently unavailable. Please contact your LCLS Point of Contact with any further questions including beamline contributions to this performance.

Mode	Linac	Energy Range	Bandwidth (FWHM)	Max Pulse Energy	Pulse Length
HXRSS*	NC	4.5 – 12.5 keV	0.35-1.5 eV	0.3 – 0.5 mJ	Up to 30 fs
SXRSS**	NC	0.4 – 1.2 keV	~ 100 meV @ 400 eV ~ 150 meV @ 530 eV ~ 200 meV @ 800 eV	< 50 – 200 μJ @ 50 fs	20 – 50 fs
	SC			< 20 – 50 μJ @ 50 fs	20 – 50 fs

* For other HXRSS energies, please inquire with your LCLS POC
** SXRSS is currently unavailable.

Multi-Color, Multi-Pulse Parameters

A variety of methods for generating two or more x-ray pulses are established for the NC linac. Please contact your LCLS Point of Contact for further details.

Multi-color Pulse Mode Table - SHORT FORM - Status June 18th, 2026

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)	Minimally invasive, easy to maintain. Delay and energy separation fully independent.	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 (ns spacing)						
Two bucket	350 ps increments, up to 120 ns	30-70 fs	+/-2%	>1.0 mJ	Requires add'l setup and tuning time	Decker et al. under review.
Multiple Bucket (4 or 8 bunches)	Two trains of 4 pulses. 700 ps between each pulse in the same train.	30-70 fs	+/-2%	To be tested	Requires add'l setup and tuning time	Decker et al. under development
Twin Bunches (fs spacing)						
Two SASE Pulses	25 - 90 fs	20 fs	+/- 2.5%	0.5 mJ	Requires add'l setup and tuning time, 1st/probe pulse always higher photon energy	Marinelli et al. Nat. Commun. 6, 6369 (2015)
With slotted foil (shorter pulses)	0 - 70 fs	< 10 fs	+/- 2.5 %	50 uJ	Requires add'l setup and tuning time, 1st/probe pulse always higher photon energy	Marinelli et al. Proceedings of IPAC 2016, TUZA02

HARD X-RAYS

Technique	Pulse Separation	Min Pulse Duration	Max Photon Energy Separation	Max Energy/Pulse	Comments	Reference publications
Split Undulator SASE	0 - 40 fs	15 fs	+/- 5%	20 uJ (30 fs pulse duration)	Up to 13 keV. Time/energy separation independently controlled. Either color may come first in time.	A. Lutman et al. Phys. Rev. Lett. 110, 134801 (2013)
Twin Bunches						Marinelli et al. Nat. Commun. 6, 6369 (2015)
Two SASE Pulses	25 - 90 fs	20 fs	2%	200 uJ (20 fs duration)	Add'l setup time, 1st/probe pulse always higher photon energy. Delay/energy separation not fully independent. For < 15 keV with lower performance and energy separation at higher energies.	Marinelli et al. Nat. Commun. 6, 6369 (2015)
With slotted foil (shorter pulses)	10 - 50 fs	5-10 fs	2%	50 uJ (10 fs duration)	Add'l setup time, 1st/probe pulse always higher photon energy. Delay/energy separation not fully independent. For < 15 keV with lower performance and energy separation at higher energies.	Marinelli et al. Proceedings of IPAC 2016, TUZA02
Double Slotted Foil	7-20 fs	10 fs	1%	100 uJ	Add'l setup time, 1st/probe pulse always higher photon energy. Delay/energy separation not fully independent. For < 15 keV with lower performance at higher energies.	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)	Requires add'l setup and tuning time	Decker et al. under review.
Multi bucket (4 or 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

Short Pulse Parameters

Hard X-rays

The NC linac now offers a more rapid method for reducing pulse duration to the 10-20 fs range from the nominal 40 fs, at the cost of a corresponding reduction in the number of photons.

For shorter pulses, two methods generate sub-fs pulses in the hard x-ray domain with the NC linac. Both use 20 pC bunch charges, requiring additional preparation time. One is based nonlinear electron bunch compression; the other using a new version of the slotted foil with optimized beam optics. A third option with an XLEAP-like approach (see below) for hard X-rays is now available with advantages in long-term stability and prep time.

Spectral measurements of very short (< 1 fs) pulse modes show about half of shots containing single-spike spectra, while other shots have a few spectral spikes. The estimated duration for the single-spike pulse is about 200 - 400 as with the nonlinear compression scheme giving a bit wider bandwidth. For example, the measured bandwidth was about 11 eV using the nonlinear method at 5.6 keV, while the slotted foil measured bandwidth is about 4.5 eV. These schemes work in the hard x-ray range up to about 12.5 keV with the normal conducting linac.

Soft X-rays

For soft x-rays, the XLEAP method is also available. It uses self-interaction of the electron beam to modulate the beam energy across the beam pulse. Subsequent fine compression generates a beam spike with sub-femtosecond pulses of up to 50 μJ.

For availability and detailed parameters, please inquire with your LCLS Point of Contact.

Energy Range	Parameter	Value	Unit
HXR (NC Linac)	Avg. Pulse Energy	5-10	μJ
	Pulse Duration	200 – 400	as
	Photon Energy	5 – 12.5	keV
	Bandwidth [FWHM]	4 – 11	eV
SXR (NC Linac)	Avg. Pulse Energy	20	μJ
	Pulse Duration	500	as
	Photon Energy	400 – 1000	eV
	Bandwidth [FWHM]	5	eV

(See table on next page for more details on short pulses.)

Ultra short pulse duration - SHORT FORM - Status June 18, 2025

FEW FEMTOSECONDS

Technique	Min Pulse Duration	Energy range	Energy/Pulse	Single Spike rate	Comments	Reference publications
Slotted foil + low charge	< 8 fs	**SXR**	10-20 uJ	Up to 20%	Requires add'l setup and tuning time	Ding et al. Appl. Phys. Lett. 107, 191104 (2015)
"Half Charge"	10 - 20 fs	**Both**	25-50% nominal	~0%	Minimal add'l setup time (+15-30 minutes)	

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%	Requires some add'l tuning	Marinelli et al. Appl. Phys. Lett. 111, 151101 (2017)
Non-linear bunch compression	200 as	**HXR**	10 uJ	45%	Requires some add'l tuning	Ding et al. Phys. Rev. Lett. 119, 154801 (2017)
XLEAP	< 1 fs	**HXR**	15 uJ average, Spikes to 50 uJ	TBD	Requires add'l setup and tuning time	TBD
	300-400 as	**SXR**	Spikes to 100 uJ	--	Requires add'l setup and tuning time	Marinelli et al. under review.

Ultra-short pulse duration can be in general coupled with the split undulator scheme (PRL 110, 134801) to produce pairs of ultra-short pulses at reduced intensity. Please discuss with POC for your application.