Projected Run 19 LCLS FEL Parameters – Update Oct. 1st, 2020

LCLS FEL parameters with hard and soft x-ray undulators (HXU and SXU) driven by the copper linac. Projected values are to be met or exceeded and are based on early Run 18 data along with expected HXU improvement from the completed installation of the full undulator compliment. 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	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 (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)	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	125		125		pC
Total Energy Spread	$\sigma E/E$	10^{-3}		10^{-3}		1
Inject. bunch length (rms)	σ_{z0}	550		550		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
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/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

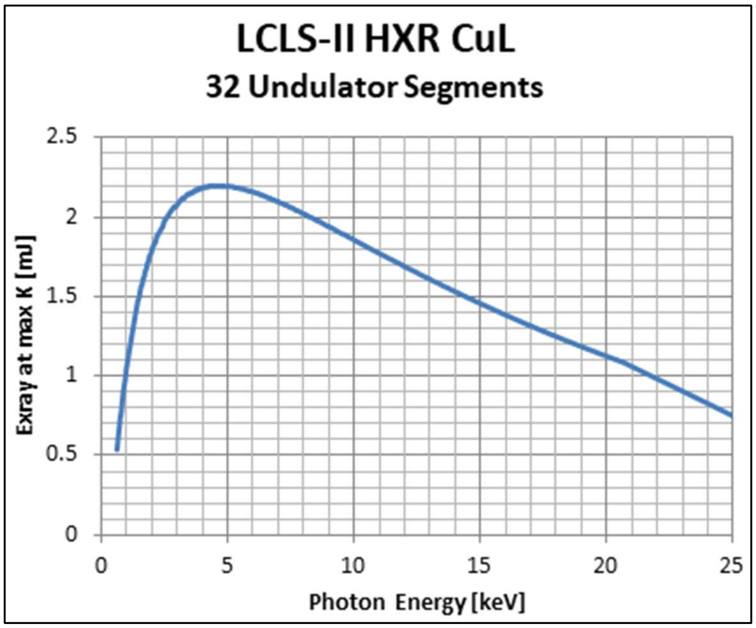
*Calculated assuming nominal pulse duration and maximum undulator strength

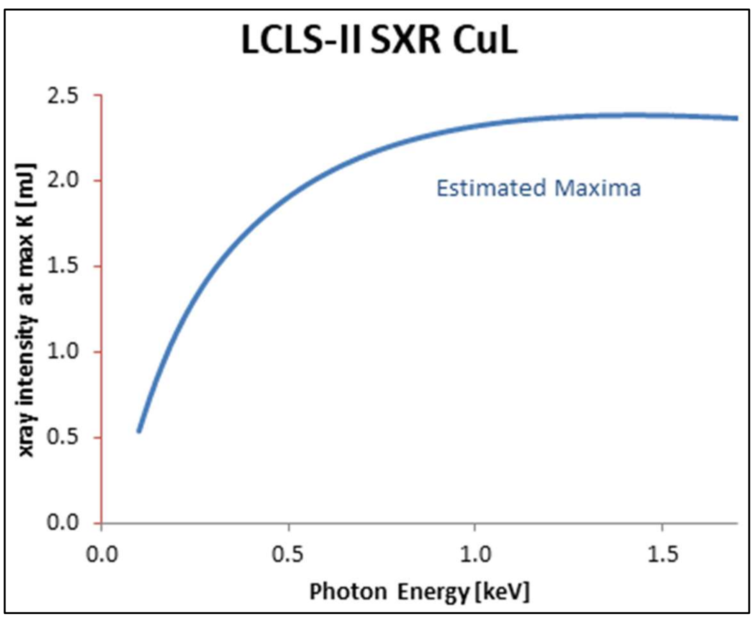
Nominal pulse energy as a function of photon energy

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 the pulse energy at maximum undulator strengths with actual performance expected to meet or exceed this.

Values shown do not reflect effects related to specific 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 ~ 150 meV @ 530 eV ~ 200 meV @ 800 eV	< 25 – 50 μJ @ 20 fs Up to ~ 0.25 mJ with spectral pedestal	20 – 120 fs

Dual Bunch & Dual Energy Parameters

Multi-color Pulse Mode Table - SHORT FORM - Status Nov. 15, 2019

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. **Available after summer 2020.**	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	Requires long setup (laser stacker/injector tune).	Marinelli et al. Nat. Commun. 6, 6369 (2015)
Twin Bunches (fs spacing) w slotted foil	0 - 70 fs	-	+/- 2.5 %	50 uJ		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 - 30 fs	15 fs	Up to factor 2 ratio in photon energies	40 uJ (25 fs pulse duration)	**Available after summer 2020.**	A. Lutman et al. Phys. Rev. Lett. 110, 134801 (2013)
Twin Bunches					Requires long setup (laser stacker/injector tune).	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. Delay/energy separation 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	350 ps increments, up to 120 ns	20 fs	~ 1%	0.5-1 mJ (30 fs duration SASE)		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 compression scheme where the harmonic linearizer is running at a lower voltage level 12-15 MV; 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 is under development for 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 07/12/2019

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	Under development, please contact Point of Contact	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.