Run 18 LCLS FEL Parameters – Update Nov. 15, 2019

LCLS FEL parameters with hard and soft x-ray undulators (HXU and SXU). The values are general guidelines describing those expected achievable by the FEL. Many parameters vary according to the exact energy, pulse length and band-with. Stability values (at bottom) are taken over a few minutes.

Values shown do not reflect effects related to specific beamlines (e.g., transport efficiency/capability). Please refer to contacts 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**
Fundamental wavelength	λ_r	1.04 – 12.4	2.5 – 62.0	Å
Photon Energy Range	$\hbar\omega$	12000 – 1000	5000 – 200	eV
Final linac e- energy	γmc^2	16.5 – 3.3	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 – 50	40	GW
Pulse duration range (FWHM)		10 – 50	10 – 250	fs
Nominal pulse duration (FWHM)	$\Delta\tau_f$	30	50	fs
Pulse Energy*	U	0.6 – 1.5	2.0	mJ
Photons per pulse*	$N\gamma$	0.15 – 9	2.5 – 62	10^{12}
Peak brightness*	$B_{pk,\,SASE}$	7800 – 266	1800 – 25	10^{30} §
Average brightness (120Hz)*	$\langle B \rangle$	280 – 10	110 – 2	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	0.08 – 0.18	0.24	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

Seeded x-ray beam parameters

Important note: Seeding recommissioning for new undulator systems are expected to commence after the summer of 2020. 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	~ 0.4 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. It uses the interaction of a laser beam with the electrons 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.

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.