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

<table>
<thead>
<tr>
<th>Photon Beam Parameters</th>
<th>Symbol</th>
<th>Cu - HXU x-rays</th>
<th>Cu - SXU x-rays</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental wavelength</td>
<td>(\lambda)</td>
<td>1.04 – 12.4</td>
<td>2.5 – 62.0</td>
<td>Å</td>
</tr>
<tr>
<td>Photon Energy Range</td>
<td>(\hbar\omega)</td>
<td>12000 – 1000</td>
<td>5000 – 200</td>
<td>eV</td>
</tr>
<tr>
<td>Final linac e- energy</td>
<td>(\gamma m c^2)</td>
<td>16.5 – 3.3</td>
<td>10.0 – 3.5</td>
<td>GeV</td>
</tr>
<tr>
<td>FEL 3-D gain length</td>
<td>(L_G)</td>
<td>4.0 – 1.0</td>
<td>2.5 – 1.0</td>
<td>m</td>
</tr>
<tr>
<td>Peak power</td>
<td>(P)</td>
<td>20 – 50</td>
<td>40</td>
<td>GW</td>
</tr>
<tr>
<td>Pulse duration range (FWHM)</td>
<td>(\Delta \tau)</td>
<td>10 – 50</td>
<td>10 – 250</td>
<td>fs</td>
</tr>
<tr>
<td>Nominal pulse duration (FWHM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse Energy*</td>
<td>(U)</td>
<td>0.6 – 1.5</td>
<td>2.0</td>
<td>mJ</td>
</tr>
<tr>
<td>Photons per pulse*</td>
<td>(N_e)</td>
<td>0.15 – 9</td>
<td>2.5 – 62</td>
<td>(10^{12})</td>
</tr>
<tr>
<td>Peak brightness*</td>
<td>(B_{\text{SASE}})</td>
<td>7800 – 266</td>
<td>1800 – 25</td>
<td>(10^{30}) §</td>
</tr>
<tr>
<td>Average brightness (120Hz)*</td>
<td>(\langle B\rangle)</td>
<td>280 – 10</td>
<td>110 – 2</td>
<td>(10^{20}) §</td>
</tr>
<tr>
<td>SASE bandwidth (FWHM)</td>
<td>(\Delta \omega/\omega)</td>
<td>30 – 2</td>
<td>10 – 2</td>
<td>eV</td>
</tr>
<tr>
<td>Photon source size (rms)</td>
<td>(\sigma_s)</td>
<td>8 – 20</td>
<td>16 – 46</td>
<td>(\mu m)</td>
</tr>
<tr>
<td>Photon far field divergence (FWHM)</td>
<td>(\theta_{\text{WHMM}})</td>
<td>1 – 12</td>
<td>3 – 25</td>
<td>(\mu rad)</td>
</tr>
<tr>
<td>Max. Beam Rate</td>
<td>(\phi_{\text{FEL}})</td>
<td>120</td>
<td>120</td>
<td>Hz</td>
</tr>
<tr>
<td>Avg. x-ray beam power</td>
<td>(P_x)</td>
<td>0.08 – 0.18</td>
<td>0.24</td>
<td>W</td>
</tr>
<tr>
<td>Linear Polarization (100%)</td>
<td>((\langle P\rangle))</td>
<td>Vertical</td>
<td>Horizontal</td>
<td></td>
</tr>
</tbody>
</table>

### 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) | \(\sigma_\beta\) | 550 | 550 | \(\mu m\) |
| Undul. bunch length (rms) | \(\sigma_z\) | 16 – 3 | 16 – 5 | \(\mu m\) |
| Final peak current | \(I_{pk}\) | 1.0 – 5.0 | 1.0 – 3.0 | kA |
| Proj. Emittance (injector) | \(\gamma s_{\beta s}\) | 0.45 | 0.45 | \(\mu m\) |
| Slice Emittance (injector) | \(\gamma e_{s\beta} \) | 0.37 | 0.37 | \(\mu m\) |
| Proj. Emittance (Undulator) | \(\gamma e_{\Delta\beta}\) | 0.5 – 1.6 | 0.5 – 1.6 | \(\mu m\) |
| Max. Single Bunch Rep. Rate | \(F\) | 120 | 120 | Hz |
| UV laser energy on cath. | \(U\) | 15 | 15 | \(\mu J\) |
| 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) | \(\Delta \xi /\sigma_x\) | 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
### 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.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy Range</th>
<th>Bandwidth</th>
<th>Pulse Energy</th>
<th>Pulse Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>HXRSS</td>
<td>4.5 – 11 keV</td>
<td>0.35-1.5 eV</td>
<td>~ 0.4 mJ</td>
<td>Up to 30 fs</td>
</tr>
<tr>
<td>SXRSS</td>
<td>0.4-1.2 keV</td>
<td></td>
<td>&lt; 25 – 50 µJ @ 20 fs</td>
<td>20 – 120 fs</td>
</tr>
</tbody>
</table>

### Dual Bunch & Dual Energy Parameters

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy Range</th>
<th>Bandwidth</th>
<th>Pulse Energy</th>
<th>Pulse Length</th>
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<tbody>
<tr>
<td>HXRSS</td>
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<td>0.35-1.5 eV</td>
<td>~ 0.4 mJ</td>
<td>Up to 30 fs</td>
</tr>
<tr>
<td>SXRSS</td>
<td>0.4-1.2 keV</td>
<td>~ 100 meV @ 400 eV</td>
<td>Up to ~ 0.25 mJ with spectral pedestal</td>
<td>20 – 120 fs</td>
</tr>
</tbody>
</table>

### Dual Bunch & Dual Energy Parameters

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pulse Separation</th>
<th>Min Pulse Duration</th>
<th>Energy Separation</th>
<th>Max Energy/Pulse</th>
<th>Comments</th>
<th>Reference publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Slotted Field</td>
<td>15 – 70 fs</td>
<td>~ 10 fs</td>
<td>+/- 1.5 %</td>
<td>30 – 50 fs</td>
<td>Minimal intensity, easy to maintain. Delay and energy separation are not independent, minor tuning needed between changes.</td>
<td>Lu et al., Appl. Phys. Lett. 107, 251104 (2015)</td>
</tr>
<tr>
<td>Two (multipole) buffer</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Becker et al., under review.</td>
<td>Becker et al., under review.</td>
</tr>
<tr>
<td>Two bunches (2-spacing)</td>
<td>300 ps increments, up to 120 ns</td>
<td>30–10 fs</td>
<td>+/- 2%</td>
<td>0.5-1.0 ns</td>
<td>Becker et al., under review.</td>
<td>Becker et al., under review.</td>
</tr>
<tr>
<td>Multiple bunches (up to 8 bunches)</td>
<td>Two trains of 3 pulses, 300 ps between each pulse in the same train.</td>
<td>30–10 fs</td>
<td>+/- 2%</td>
<td>TDE</td>
<td>Becker et al., under development</td>
<td>Becker et al., under development</td>
</tr>
<tr>
<td>Twin Bunches (3-spacing)</td>
<td>40 fs</td>
<td>30 fs</td>
<td>+/- 2.5%</td>
<td>50 ns</td>
<td>Becker et al., Proceedings of PAC 2015, TUEA02</td>
<td>Becker et al., Proceedings of PAC 2015, TUEA02</td>
</tr>
<tr>
<td>Twin Bunches (4-spacing)</td>
<td>0 – 50 fs</td>
<td>-</td>
<td>+/- 2.5%</td>
<td>50 ns</td>
<td>Becker et al., Proceedings of PAC 2015, TUEA02</td>
<td>Becker et al., Proceedings of PAC 2015, TUEA02</td>
</tr>
</tbody>
</table>

### Hard X-rays

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pulse Separation</th>
<th>Min Pulse Duration</th>
<th>Energy Separation</th>
<th>Max Energy/Pulse</th>
<th>Comments</th>
<th>Reference publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin Bunches</td>
<td>0 – 125 fs</td>
<td>~ 20 fs</td>
<td>0.2-2 %</td>
<td>100-200 ns</td>
<td>Twin bunches always higher photon energy</td>
<td>Liu et al., Nat. Commun. 6, 6309 (2015)</td>
</tr>
<tr>
<td>Twin bunches + V slotted foil</td>
<td>+/- 30 fs</td>
<td>+/- 50 fs</td>
<td>+/- 5%</td>
<td>100-200 ns</td>
<td>Twin bunches always higher photon energy</td>
<td>Liu et al., Nat. Commun. 6, 6309 (2015)</td>
</tr>
<tr>
<td>Double Slotted Field</td>
<td>2-20 fs</td>
<td>~ 10 fs</td>
<td>+/- 1.5%</td>
<td>100-200 ns</td>
<td>Minimal intensity, faster setup than twin bunches. Delay/energy separation not independent, minor tuning needed between changes.</td>
<td>Lu et al., Appl. Phys. Lett. 107, 251104 (2015)</td>
</tr>
<tr>
<td>Two (multipole) buffer</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Becker et al., under review.</td>
<td>Becker et al., under review.</td>
</tr>
<tr>
<td>Two bunches</td>
<td>300 ps increments, up to 120 ns</td>
<td>20 fs</td>
<td>+/- 1%</td>
<td>0.5-1 ns (30 fs duration SASE)</td>
<td>Becker et al., under review.</td>
<td>Becker et al., under review.</td>
</tr>
<tr>
<td>Multi bunches (up to 8 bunches)</td>
<td>Two trains of 4 pulses, 700 ps between each pulse in the same train.</td>
<td>20 fs</td>
<td>+/- 1%</td>
<td>-</td>
<td>Becker et al., under development</td>
<td>Becker et al., under development</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>HXR</td>
<td>Pulse Energy</td>
<td>5-10</td>
<td>µJ</td>
</tr>
<tr>
<td></td>
<td>Pulse Duration</td>
<td>200 – 400</td>
<td>as</td>
</tr>
<tr>
<td></td>
<td>Photon Energy</td>
<td>5 – 10</td>
<td>keV</td>
</tr>
<tr>
<td></td>
<td>Bandwidth [FWHM]</td>
<td>4 – 11</td>
<td>eV</td>
</tr>
<tr>
<td>SXR</td>
<td>Pulse Energy</td>
<td>20</td>
<td>µJ</td>
</tr>
<tr>
<td></td>
<td>Pulse Duration</td>
<td>500</td>
<td>as</td>
</tr>
<tr>
<td></td>
<td>Photon Energy</td>
<td>500 - 1000</td>
<td>keV</td>
</tr>
<tr>
<td></td>
<td>Bandwidth [FWHM]</td>
<td>5</td>
<td>eV</td>
</tr>
</tbody>
</table>