Accelerator Performance and Capability Update

• New Undulator & Transport Systems
• SASE Parameters
• Multi-pulse x-ray modes
• Short Pulses
• Seeding Status
• Summary
Upgraded Variable-Gap Undulators (VGU)

Soft X-ray VGU (Horiz. Pol.)

Hard X-ray VGU (Vert. Pol.)
New NC Linac Transport/Undulator Beamlines
(Electron beam sharing)

Kicker/bend allows division of 120 Hz electron bunch train between undulators at program-set max rates

120 Hz Normal Conducting Linac

Fast kicker in each line to allow further independent rate reduction, including on-demand

VGUs allow independent wavelength tunability despite shared linac driver
**FEL Output Parameters - SASE**

Expected undulator output, does not include x-ray transport considerations

<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>$\lambda_f$</td>
<td>0.5 – 12.4</td>
<td>6.2 – 62.0</td>
<td>Å</td>
</tr>
<tr>
<td>Photon Energy Range</td>
<td>$\hbar\omega$ **</td>
<td>25000 – 1000</td>
<td>2000 – 200</td>
<td>eV</td>
</tr>
<tr>
<td>Final linac e- energy</td>
<td>$\gamma mc^2$</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>$L_{ge}$</td>
<td>4.0 – 1.0</td>
<td>2.1 – 1.0</td>
<td>m</td>
</tr>
<tr>
<td>Peak power</td>
<td>$P$</td>
<td>20 – 50</td>
<td>50 – 40</td>
<td>GW</td>
</tr>
<tr>
<td>Pulse duration range (FWHM)</td>
<td>$\Delta\tau_f$</td>
<td>20 – 60</td>
<td>30 – 250</td>
<td>fs</td>
</tr>
<tr>
<td>Nominal pulse duration (FWHM)</td>
<td>$\Delta\tau_n$</td>
<td>30</td>
<td>50</td>
<td>fs</td>
</tr>
<tr>
<td>Pulse Energy*</td>
<td>$U$</td>
<td>0.6 – 1.5</td>
<td>2.5 – 2.0</td>
<td>mJ</td>
</tr>
<tr>
<td>Photons per pulse*</td>
<td>$N_P$</td>
<td>0.15 – 9</td>
<td>7.8 – 62</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Peak brightness*</td>
<td>$B_{PE, SASE}$</td>
<td>7800 – 266</td>
<td>680 – 25</td>
<td>$10^{30}\S$</td>
</tr>
<tr>
<td>Average brightness (120Hz)*</td>
<td>$\langle B \rangle$</td>
<td>280 – 10</td>
<td>40 – 2</td>
<td>$10^{20}\S$</td>
</tr>
<tr>
<td>SASE bandwidth (FWHM)</td>
<td>$\Delta\omega/\omega$</td>
<td>30 – 2</td>
<td>5 – 2</td>
<td>eV</td>
</tr>
<tr>
<td>Photon source size (rms)</td>
<td>$\sigma_s$</td>
<td>8 – 20</td>
<td>22 – 46</td>
<td>$\mu$m</td>
</tr>
<tr>
<td>Photon far field divergence (FWHM)</td>
<td>$\Theta_{FWHM, \infty}$</td>
<td>1 – 12</td>
<td>5 – 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>0.30 – 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>

$\S$ Brightness units are photons/sec/mm²/mrad²/0.1%-BW

*Calculated assuming nominal pulse duration

**Fully extended photon energy range (> 11 keV) by summer 2020**
Dual-Pulse / Dual-Color Modes

Femtosecond spacing
- Double-slotted foil
- “Twin” bunches (Injector laser pulse splitting)
- Split undulator

Nanosecond spacing
- Multi-bunches (Two injector lasers on different RF cycles)

2-4 pulses w/ ns spacing demonstrated

*Modes originate in linac, not compatible with electron beam sharing
Previously demonstrated sub-femtosecond pulses

XLEAP – SXR sub-fs pulses

< 0.5 fs pulses with ~50 uJ per pulse
Space-charge boost = bandwidth-broadening for non-linear science

HXR: Isolated 200 as pulse produced
Nonlinear compression produces High density head with low density tail

Measurements:
179 ± 58 as @ 9 keV (14.4 eV BW)
228 ± 85 as @ 5.6 keV (11.3 eV BW)
10 uJ x-ray pulse from 20 pC bunch

Huang et al, PRL 119, 154801 (2017)

* Siqi Li, Optics Express 26, 4531-4547 (2018)

Also see slotted foil results (400 as pulse): APL 111, 151101 (2017) that also enable 2 pulse delivery
Returning short pulses

Available:

- Slotted Foil (tunable 5-20 fs pulses or less)
- Nonlinear compression mode (< 1 fs hard X-rays)

New commissioning:

- XLEAP-II (< 1 fs soft X-rays) to be commissioned and offered to users *at risk*
Self-seeding for enhanced spectral brightness, narrow linewidth

HXRSS: Mechanical redesign for vert. pol. undulators

SXRSS:

- Heater optimization studies for reduced spectral pedestal
- Improved diagnostics & controls for easier setup
- Improving optics to manage future heat load

Installation and commissioning through run, offered at risk
Summary

• New VGU systems to be driven by NC linac
  - Enable new flexibility in energy tuning and undulator tapering
  - New capability for parallel HXR/SXR programs

• SASE capability to be extended into higher photon energy range

• Several special modes return directly following SASE commissioning
  - Slotted foil
  - “Twin” (fs) pulses
  - Multiple (ns) pulses

• Planned commissioning of new/redesigned systems (at risk)
  - XLEAP-II
  - Hard and Soft X-ray Self-Seeding

More details available at following links:
  - https://lcls.slac.stanford.edu/parameters
  - https://lcls.slac.stanford.edu/machine-faq