HXRSS Towards User Delivery

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on behalf of the HXRSS commissioning team

Beam dynamics meeting
Hamburg, 08.12.20
Hard X-Ray Self-Seeding

SASE spectrum

HXRSS spectrum

40 eV

40 eV

* First demonstrated at LCLS, now available also at PAL and SACLA

Unique at European XFEL:

- **Superconducting linac**: bunch trains with low bunch-to-bunch energy and trajectory jitter
- **High repetition rate** -> large heat load -> **two chicanes** to increase the SNR and share the heat load on the crystal
- **Large chicane delay**: up to 400 fs (with 11 GeV e⁻ beam) for 2-color applications
- **Long undulator** beam line (35 segments): HXRSS+ post saturation taper
**HXRSS commissioning results**

- Commissioning started in Sept. 2019 (but only 3 tries in 2019)
- Intensive shifts in Sept.-Nov. 2020
- Achieved 1.3 mJ in Oct. 2020

<table>
<thead>
<tr>
<th></th>
<th>9keV</th>
<th>9keV</th>
<th>12.9keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>e- beam energy</td>
<td>14 GeV</td>
<td>14 GeV</td>
<td>16.5 GeV</td>
</tr>
<tr>
<td>e- beam charge</td>
<td>250 pC</td>
<td>100 pC</td>
<td>250 pC</td>
</tr>
<tr>
<td>SASE performance</td>
<td>up to 2 mJ</td>
<td>550 uJ</td>
<td>up to 1.2 mJ</td>
</tr>
<tr>
<td>Best seeding with 1\textsuperscript{st} chicane</td>
<td>900 uJ</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Best seeding with 2\textsuperscript{nd} chicane</td>
<td>1.3 mJ</td>
<td>190 uJ</td>
<td>300 uJ</td>
</tr>
<tr>
<td>Seeding with two chicanes</td>
<td>500-900 uJ</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Seeding bandwidth (FWHM)</td>
<td>~0.7 eV</td>
<td>~0.6 eV</td>
<td>~1 eV</td>
</tr>
</tbody>
</table>
Best performance so far @ 9 keV

- Averaged pulse energy 1.3 mJ (max. 850 uJ @ PAL) -> BG estimated by extracting crystal (<600 uJ)
- Peak intensity jitter ~33% (min. 40% @ PAL)
- Central energy jitter (0.15 eV) and FWHM (0.72 ± 0.15 eV)
- Statistics calculations are limited by the HIREX detector resolution (0.2 eV/ pixel)
High repetition rate runs @ 9 keV

- 400 bunches at 2 MHz repetition rate
- Almost no difference in BW and central energy after adding more input pulse energy on crystal
  -> no visible heat-loading effects at 9 keV

- Spectrum intensity changes along the pulse train
  -> to be further investigated
- Study to be continued at lower photon energies

100 pC run

- Shorter bunch -> shorter lasing window -> narrower BW
- Tried different reflections with different delays
- Double peaks observed when seeding on two bumps

Statistics for C400:

20201023-06_35_21_waterflow.npz,
central energy jitter = 0.11 eV,
peak intensity jitter = 54.55 %,
FWHM rms = 0.58 eV,
FWHM jitter = 0.15 eV
12.9 keV run – SASE vs HXRSS (averaged over 1000 shots)

Signal normalized by the ratio between integrated spectrum (central non-zero region) and XGM readout

<table>
<thead>
<tr>
<th></th>
<th>SASE</th>
<th>HXRSS (19 fs delay)</th>
<th>HXRSS (35 fs delay)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse energy</td>
<td>700 uJ</td>
<td>250 uJ</td>
<td>150 uJ</td>
</tr>
<tr>
<td>Central energy jitter</td>
<td>11.85 eV</td>
<td>0.30 eV</td>
<td>0.25 eV</td>
</tr>
<tr>
<td>Peak intensity jitter</td>
<td>51%</td>
<td>42%</td>
<td>59%</td>
</tr>
<tr>
<td>FWHM rms</td>
<td>-</td>
<td>1.21 eV</td>
<td>1.13 eV</td>
</tr>
<tr>
<td>FWHM jitter</td>
<td>-</td>
<td>0.25 eV</td>
<td>0.20 eV</td>
</tr>
</tbody>
</table>

Preliminary, Unpublished
Data taken by MID spectrometer

Average of 10 pulses
FWHM=0.92 eV
background is negligible

courtesy of Alexey Zozulya (MID)
Summary and future plans

- Commissioned HXRSS at 9 keV and 12.9 keV
- Up to 1.3 mJ achieved at 9 keV with 0.7 eV BW
- 6 user runs planned for HXRSS in 2020
- Seeding with two chicanes demonstrated
  - -> large room for improvements
- Continue to investigate the HXRSS parameter space at different photon energies: 6 keV, 7 keV, 11 keV and >=14.4 keV
- Advanced seeding schemes (multi-color, fresh slice self-seeding etc.) -> will be tested soon!
Thank you!

Special thanks to Gianluca, Svitozar, Marc, Naresh, Sergey, Frank…