Operation of FLASH with Short SASE-FEL Radiation Pulses

Juliane Rönsch-Schulenburg
Hamburg University & CFEL

E. Hass, N.M. Lockmann, T. Plath, M. Rehders, J. Roßbach, Hamburg University

The project has been supported by the Federal Ministry of Education and Research of Germany (BMBF) under contract No. 05K10GU2 and FSP301
Operation of FLASH with Short SASE-FEL Radiation Pulses

FEL Radiation Parameters 2014

- Wavelength range (fundamental): 4.2 – 45 nm
- Average single pulse energy: 10 – 500 µJ
- Pulse duration (FWHM): <50 – 200 fs
- Peak power (from av.): 1 – 3 GW
- Spectral width (FWHM): ~ 0.7 – 2%
- Bunch charge: 0.08 – 1 nC

K. Honkavaara - WEB05: “FLASH: ...TWO UNDULATOR BEAMLINES ...”
Operation of FLASH with Short SASE-FEL Radiation Pulses

number of modes in radiation pulse:
\[ M = \frac{\sigma_z}{2\pi L_{coop}} \]

cooperation length: \( L_{coop} = \frac{\lambda_r}{\lambda_u} \times L_G \)

power gain length: \( L_G \)

FEL radiation wavelength: \( \lambda_r \)

undulator periode: \( \lambda_u \)
Operation of FLASH with Short SASE-FEL Radiation Pulses

\[ M = \frac{\sigma_z}{2\pi L_{coop}} \]

\[ M = 1 \Rightarrow \sigma_z = 2\pi L_{coop} \]

coherence time measurements at FLASH:
- \( \tau_c = (2.9 \pm 0.5) \text{fs} \) at 8 nm
  [S. Roling et al., PRSTAB 14, 080701 (2011)]
- \( \tau_c = (1.75 \pm 0.01) \text{fs} \) at 8 nm
  [A. Singer et al., Opt. Express 16, 19909 (2008)]
Operation of FLASH with Short SASE-FEL Radiation Pulses

Longitudinal SASE pulse distribution for an rms bunch duration: 30 fs

SASE spectrum for an rms bunch duration: 30 fs

Longitudinal SASE pulse distribution for an rms bunch duration: 3 fs

SASE spectrum for an rms bunch duration: 3 fs
## Operation of FLASH with Short SASE-FEL Radiation Pulses

<table>
<thead>
<tr>
<th></th>
<th>Typ. FLASH parameters</th>
<th>Single spike operation at FLASH</th>
<th>Single spike operation at FLASH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injector laser pulse duration (rms)</td>
<td>6.5 ps</td>
<td>6.5 ps</td>
<td>1 ps</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>0.08 - 1 nC</td>
<td>20 pC</td>
<td>20 pC</td>
</tr>
<tr>
<td>Bunch duration (rms)</td>
<td>30 - 200 fs</td>
<td>3 fs</td>
<td>3 fs</td>
</tr>
<tr>
<td>compression</td>
<td>220 - 32</td>
<td>2200</td>
<td>330</td>
</tr>
<tr>
<td>FEL pulse duration (FWHM)</td>
<td>30 - 200 fs</td>
<td>3 fs</td>
<td>3 fs</td>
</tr>
</tbody>
</table>

For FLASH:
- rms bunch length: ~ 3 fs
- due space charge forces the bunch charge has to be reduced: ~ 20 pC

- **Shorter photo-injector laser pulse is required**

- a large compression factor (~1000) requires RF tolerances of 0.0014° phase tolerance (3 fs!) and 0.003% amplitude tolerance
Operation of FLASH with Short SASE-FEL Radiation Pulses

standard short pulse operation
simulated measurement

150 pC
$\Delta t_{\text{laser}} = 6.5 \text{ ps (rms)}$

short pulse operation with short pulse laser
simulation

20 pC
$\Delta t_{\text{laser}} = 1.2 \text{ ps (rms)}$

$\sigma_t = 83 \text{ fs}$

$\sigma_t = 12 \text{ fs}$
### Operation of FLASH with Short SASE-FEL Radiation Pulses

**Longitudinal phase space distribution**

<table>
<thead>
<tr>
<th>$\Delta p_z / p_z \cdot 10^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>head</td>
</tr>
<tr>
<td>tail</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$s$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.015</td>
</tr>
<tr>
<td>0.005</td>
</tr>
<tr>
<td>0.015</td>
</tr>
</tbody>
</table>

### Simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1st maximum</th>
<th>2nd maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>peak current (A)</td>
<td>3200</td>
<td>1100</td>
</tr>
<tr>
<td>$x/y$-slice emittance ($\pi$ mm mrad)</td>
<td>0.8 / 1.1</td>
<td>0.2 / 0.5</td>
</tr>
<tr>
<td>slice energy spread (%)</td>
<td>0.16</td>
<td>0.05</td>
</tr>
</tbody>
</table>

### Current profile

- $\sigma_t = 1.7$ fs
- $\sigma_z = 2$ fs

### Longitudinal SASE distribution

### SASE spectrum

*for four different statistical seeds*
Operation of FLASH with Short SASE-FEL Radiation Pulses

Short pulse injector laser

Amplified Laser System:
- Seed laser Origami 10 (OneFive)
  - 1030nm, 260mW, 54MHz, 400fs
- 2 stage amplifier (Amphos)
  - 1030nm, 10W, 1MHz, 800fs (10µJ)

AOM pulse picker
(pulse trains of 10Hz, with 1MHz pulse repetition)

LBO + BBO (forth harmonic)
- 1030nm -> 257.5nm
- (10% efficiency @ 10µJ) -> 1µJ

Stretcher
0.7 – 1.7 ps (rms)
First SASE with short pulse injector laser:

- 9th & 11th of January 2013
- 5 µJ at 13.5 nm, bunch charge 35 pC
- 25 µJ at 13 nm, charge 80 pC

Narrow bandwidth (0.34 % in linear regime, 0.42% at saturation)

Radiation pulse duration at full undulator length is estimated as 50 fs.

Rms bunch duration of lasing fraction of the electron beam: 40 fs.
Operation of FLASH with Short SASE-FEL Radiation Pulses

Measurement: May 2014

Bunch charge: 80 pC

laser pulse duration: 1 ps rms

Optical afterburner measurement of the FEL pulse duration: < 30 fs

Analysis of single FEL pulse spectrum:
• Events: 1768
• $\lambda = 6.97$ nm
• in average: 3.8 spikes
• 2.7 spikes within the FWHM
Operation of FLASH with Short SASE-FEL Radiation Pulses

Measurement: May 2014

Bunch charge: 55 pC

laser pulse duration: 1 ps rms

Analysis of single FEL pulse spectrum:
• $\lambda = 6.98$ nm
• in average: 1.5 spikes within the FWHM

$\Rightarrow$ estimation of the rms FEL pulse duration: $\approx 2.4$ fs
Conclusions

• New photoinjector laser commissioned
• FEL pulses with a few longitudinal modes demonstrated
• Outlook: truely single-spike operation
  – Needs more experience with charges of about 20 pC
Thank you for the attention

And thanks to the whole FLASH team for their support of this project.