Report Commissioning Group

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(Core) Participants:

- J. Pflüger Undulators (WP 71)
- J. Grünert X-ray Photon Diagnostic (WP-74)
- H. Sinn X-ray Optics & Beam Transport (WP-73)
- R. Treusch FLASH Photon Coordination
- Th. Tschentscher Photon Experiments
- W. Decking, T. Limberg Machine Layout Coordination
- E. Shneydmiller, M. Yurkov FEL Concepts (WP-21), FLASH SASE Tuning
- H. Schlarb LLRF (WP-02)
- S. Schreiber FLASH Coordination

Mandate:
- The European XFEL Project board calls for a working group to plan the commissioning of the facility
- This group will work out the commissioning strategy, the initial operating envelope, the high level goals and their sequence
LCLS Experience and Plans

- **LCLS:** 20,000 hours of pre-beam check-out and commissioning time

- **LCLS-II:** 4,000 hours planned, mainly pre-beam verification, actual beam commissioning time expected to be short
  
  - Beam commissioning of LCLS-II should be faster then LCLS-I
    - Hardware is very similar to that operating in LCLS-I
    - Beamline physics is well understood from LCLS-I
    - Controls and high-level apps are same as LCLS-I
      - Much of LCLS-I effort was writing apps to assist commissioning
    - Experienced team is in place
• First ½ of a 40 page document for the injector

• Every LCLS beamline component was verified in detail before turning on beam

• Will adopt similar procedure for LCLS-II
- Start of injector commissioning mid 2014
- Start of linac commissioning mid 2015
- Observe first SASE by end of 2015

#### Overview XFEL Accelerator Schedule 17.5 GeV

<table>
<thead>
<tr>
<th>Civil Construction</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
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<tbody>
<tr>
<td>XTL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halls XHEE, XHE1</td>
<td></td>
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<table>
<thead>
<tr>
<th>LINAC Fabrication</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tbody>
<tr>
<td>Cavity Production</td>
<td></td>
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<tr>
<td>String Assembly</td>
<td></td>
<td></td>
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<tr>
<td>Module Assembly</td>
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<table>
<thead>
<tr>
<th>XTL Installation &amp; Commissioning</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tbody>
<tr>
<td>Infrastructure</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Machine</td>
<td></td>
<td></td>
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<tr>
<td>final installation &amp; cool down</td>
<td></td>
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</table>

- First beam in Injector
- First beam in LINAC
- Ready for SASE
The accelerator complex and SASE1 start operation when on SASE1 a photon beam is obtained with the intermediate values of Table 4.1, and sufficient equipment is installed and commissioned to perform first scientific experiments.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SASE1 Intermediate Values</th>
<th>SASE1 Final Project Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>&lt; 0.2</td>
<td>0.1</td>
<td>nm</td>
</tr>
<tr>
<td>Peak Brilliance</td>
<td>$10^{30}$</td>
<td>$5 \times 10^{33}$</td>
<td>Photons/s/mm$^2$/mrad$^2$/0.1%BW</td>
</tr>
<tr>
<td>Dimension at sample (no optics)</td>
<td>&lt; 1.0</td>
<td>~ 0.6</td>
<td>mm$^2$, FWHM</td>
</tr>
<tr>
<td>Positional Stability</td>
<td>50</td>
<td>10</td>
<td>% of beam size, rms</td>
</tr>
<tr>
<td>Photon Energy Stability</td>
<td>~ 0.1</td>
<td>~ 0.1</td>
<td>%</td>
</tr>
<tr>
<td>Shot-to-Shot Intensity Fluctuations</td>
<td>Up to a factor 10</td>
<td>0.3 – 0.5</td>
<td>Dimensionless, Peak-to-Peak</td>
</tr>
</tbody>
</table>
A first set of e-beam parameters:

- Beam energy will be 17.5 GeV

- Linac will be operated with several tens of bunches (not single bunch) as fast as possible
  - single bunch operation is useless for LLRF diagnostics and studies

- beam charge around 0.5 to 1 nC
  - General Diagnostics and LLRF
Ready for beam July 2014
Commissioning July 2014 – June 2015 (12 month)
Goal: Stable operation with XFEL parameters
- Full bunch train and repetition rate
- Various bunch charges (1, 0.5, 0.25, 0.1, 0.02 nC)
- Basic commissioning for many sub-systems
Electron bunch trains
(with up to 2700 bunches à 20-1000 pC)

Δt = 220 ns

3-180 fs

FEL process

2-100 fs
Main Linac, Collimation Section & Beam Distribution, Dumps

Ready for beam July 2015
Initial commissioning July 2015 – September 2015
Goal: Stable operation to establish initial lasing
- Single to few (~100) bunches at 17.5 GeV
- One bunch charge (0.5 nC)
- Slow feedbacks for final energy & trajectory

Challenges: Linac: Commissioning of cold linac (cryo, high power RF, LLRF, …)
CS&BD: Transport through collimation section and beam distribution into dump
Dumps: Guarantee beam spot size on dump window
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Bunch Compression System

Ready for beam July 2015
Initial commissioning September – October 2015
Goal: Establish first lasing working point
  • Single to few (~100) bunches at 17.5 GeV
  • One bunch charge (0.5 nC)
Challenge: Commissioning of longitudinal diagnostics
Ready for beam September 2015
Initial commissioning SASE1/SASE3  September – November 2015

Goal: Beam transport and alignment
  • Single to few (~100) bunches at 17.5 GeV
  • One bunch charge (0.5 nC)

Challenge: Trajectory alignment in undulator
Electron Bunch Distribution

- **SASE 1**
  - tunable, planar
  - 3 – 24 keV

- **SASE 2**
  - tunable, planar
  - 3 – 24 keV

- **SASE 3**
  - tunable, planar
  - 0.26 – 3 keV

27,000 bunches/sec to (up to) 5 beamlines
Commissioning should start with SASE1 and continue with SASE3:

• eases initial e-beam operation
• allows parallel commissioning of SA1 and SA3 photon beam lines
• if no SASE is reached in SASE1, SASE3 could be put into operation with much looser tolerances to diagnose e-beam parameters
• if availability of components prevents installation of SASE3 and SASE1 the decision to install SASE2 first should be made as early as possible
• it is recommended from FLASH experience to focus activities on one beam line and commission this fully to benefit from the lessons learned and not double errors

SASE search should be performed with fully closed gaps

(i.e., 0.19 nm wavelength at SASE1)
1. First Beam through Linac
   
   • A 17.5 GeV beam is transported through the linac to the TLD dump.
   
   • Pattern: 10-100 Hz, single bunch, 0.5nC, C=100 (total longitudinal bunch compression factor)
   
   • Control: Charge, peak current, energy and trajectory are controlled by slow feedbacks.

2. First Beam to TD4 (SASE1 and SASE3)
   
   • A 17.5 GeV beam is transported through the linac to the T4D dump.
   
   • Pattern: 10-100 Hz, single bunch, 0.5nC, C=100
   
   • Control: Charge, peak current, energy and trajectory are controlled by slow feedbacks.
   
   • Electron beam based trajectory alignment in undulator
3. **First Lasing in SASE1**
   - First lasing is observed at 0.19 nm
   - Commissioning of photon diagnostics & beam line with spontaneous radiation
     - Photon based alignment of undulator gap and phase shifter setting (if nec.)
   - SASE search

4. **Lasing in SASE 3**
From here on parallel operation photon/electron development appears possible.

5. Multi-bunch operation
   • Pattern: 10 Hz, 600 bunches, 0.5nC, C=100
   • Control: Charge, peak current, energy, trajectory and arrival time are controlled by slow and fast feedbacks.

6. Quasi-simultaneous operation of SASE1 and SASE2 beam line
   • Pattern: 10 Hz, 600 bunches, 0.5nC, C=100
   • Control: Charge, peak current, energy, trajectory and arrival time are controlled by slow and fast feedbacks.
   • Tasks:
     • Bunch pattern control by fast switching elements

7. First lasing in SASE 2

8. Flexibility in wavelength and bunch length
   • Pattern: 10 Hz, 2700 bunches, 0.02-1nC, C=2000-50
   • Control: Charge, peak current, energy, trajectory and arrival time are controlled by slow and fast feedbacks.
   • Tasks:
     • establish procedures to change bunch length/bunch charges
     • establish procedures to change photon wavelength by changing energy/undulator gap
## High Level Milestones: an Attempt to Sort

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1 First Beam in Injector</td>
<td>I1D</td>
<td>0.13</td>
<td>10</td>
<td>1-2700</td>
<td>0.5</td>
<td>0.05</td>
<td>-</td>
<td>12</td>
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<tr>
<td>2 First Beam in BC2</td>
<td>B2D</td>
<td>2</td>
<td>10</td>
<td>1-100</td>
<td>0.5</td>
<td>5</td>
<td>-</td>
<td>0.5</td>
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<tr>
<td>3 First Beam in TLD</td>
<td>TLD</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>1.5</td>
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<tr>
<td>4 Bunch compression</td>
<td>TLD</td>
<td>17.5</td>
<td>11</td>
<td>1-100</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>1</td>
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<tr>
<td>5 First Beam in T4D</td>
<td>T4D</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
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<tr>
<td>6 Lasing in SASE 1</td>
<td>T4D</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.5</td>
<td>5</td>
<td>0.19</td>
<td>0.5</td>
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<tr>
<td>7 First Beam in T5D</td>
<td>T5D</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>0.5</td>
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<tr>
<td>8 Lasing in SASE 3</td>
<td>T4D</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.5</td>
<td>5</td>
<td>4</td>
<td>0.5</td>
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<tr>
<td>9 Lasing in SASE 2</td>
<td>T5D</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.5</td>
<td>5</td>
<td>0.19</td>
<td>0.5</td>
</tr>
<tr>
<td>10 1 MHz Operation</td>
<td>TLD</td>
<td>17.6</td>
<td>11</td>
<td>600</td>
<td>0.5</td>
<td>5</td>
<td>0.19</td>
<td>1.5</td>
</tr>
<tr>
<td>11 Lasing with 1 MHz bunch trains</td>
<td>T4D</td>
<td>17.5</td>
<td>10</td>
<td>600</td>
<td>0.5</td>
<td>5</td>
<td>0.19</td>
<td>1</td>
</tr>
<tr>
<td>12 Parasitic lasing SASE1 and SASE 3</td>
<td>T4D</td>
<td>17.5</td>
<td>10</td>
<td>600</td>
<td>0.5</td>
<td>5</td>
<td>0.19/4</td>
<td>0.25</td>
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<tr>
<td>13 Slow 10 Hz switch between 1 &amp; 2</td>
<td>T4D/T5D</td>
<td>17.5</td>
<td>10</td>
<td>600</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>0.25</td>
</tr>
<tr>
<td>14 Fast switching and arbitrary bunch patterns</td>
<td>T4D/T5D</td>
<td>17.5</td>
<td>10</td>
<td>600</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>0.25</td>
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<tr>
<td>15 Compression at various bunch charges</td>
<td>TLD</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.05-0.5</td>
<td>5</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>16 Lasing with short pulses</td>
<td>T4D</td>
<td>17.5</td>
<td>10</td>
<td>1-100</td>
<td>0.05-0.5</td>
<td>5</td>
<td>0.19</td>
<td>1</td>
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<tr>
<td>17 Wavelength variation</td>
<td>T4D/T5D</td>
<td>10.5-17.5</td>
<td>5</td>
<td>10</td>
<td>600</td>
<td>0.5</td>
<td>5</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>18 Multi Bunch operation</td>
<td>TLD</td>
<td>17.5</td>
<td>10</td>
<td>2700</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>
Prerequisites, Steps and time needed to reach:

- **Milestone #2** (beam through SASE1 and SASE3 beam lines)
- and **Milestone #3** (first SASE)

**Prerequisites:**

- Photon beam line closed and evacuated
- Technical commissioning finished
- Beam Protection System tested (without beam, possible for limited bunch numbers)
- Personal Interlock finished
- Radiation Safety approval
Steps with (dedicated) beam:

- each commissioning steps takes roughly 1-2 shifts
- (not so sure about times needed for radiation tests)

1. Radiation safety measurements with spontaneous radiation (shutter tight?), Personal interlock (?)
2. Beam on FS before mirrors
3. Test of absorber system
4. Test of gas monitor system
5. Test of slit system
6. Beam through double mirror system (beam on FS after mirrors)
7. If beam needs to go to experimental hall:
   - Further radiation tests (interlock?) of shutters towards experimental hall
   - Beam in XTD9
8. Beam through 600 m of pipe (min. 2 intermediate FS)
9. Adjustment of focus of mirrors
10. Test of beam protection system / test of beam absorbers (mass spectrometer)
11. Test of BPM at beam line end
12. Beam in experimental hall

total 12-18 dedicated shifts for X-ray beam commissioning
Photon Diagnostic Items to Characterize SASE

- Transmission & 2D Imagers (Screens)
- K-Mono Instrument
- Diode
- MCP
- XGMD
- (XBPM)

Total instrument commissioning time: 5-10 shifts
Commissioning Sequence

- 2015 30 Jun - XTL tunnel closing
- 2015 30 Sep - beam through XTL
- 2015 30 Sep - XTD2, XTD4, XTD9, XTD10 tunnel closing
- 2015 15 Dec - First lasing SASE1 (FXE or SPB)
- 2016 15 Jan - Beam through 2nd electron branch
- 2016 30 Jan - First lasing SASE3 (SQS or SCS)
- 2016 31 Mar - 'First' user experiment at SASE 1 (SPB & FXE)
- 2016 30 Apr - 'First' user experiment at SASE 3 (SQS & SCS)
- 2016 31 May - First lasing SASE2 (MID or HED)
  - Hereafter commissioning of fast switching starts
- 2016 31 Jun - 'First' user experiment at SASE 2 (MID & HED)
  - From this moment onwards baseline (TDR) beam delivery specifications are considered to be reached
- 2017 31 Dec - Extended beam delivery specifications reached
  - End of extended accelerator and x-ray system commissioning
  - Start delivery of full number of hrs for user operation
'First Lasing' and 'First User Experiments'

- Conditions for 'First Lasing'
  - x-ray beam according to initials beam conditions as described in convention
  - up to 30 electron bunches per train
  - transport of x-ray beam to XHEXP
  - performance of 1st 'simple' experiment at one of the instruments at this BL

- Conditions for 'First User Experiments'
  - experiments can use x-ray beam at TDR performance, but with limited flexibility in terms of pulse pattern, pulse length and photon wavelength