Commissioning and operation of the JUNGFRAU detector at the European XFEL: status and prospects

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07. – 12.07.2019, Kolymbari (GR)
Overview

- Introduction
  - Instrument stations at Eu XFEL
  - The JUNGFRAU detector

- Commissioning and operation
  - SPB/SFX
  - FXE
  - HED
  - MID

- Burst mode operation

- Conclusions and outlook
The photon beamlines and instruments

Hard x-rays (3 – 25 keV)
- SASE 1 & SASE 2
- (Coherent) diffraction
- (Coherent) imaging
- X-ray spectroscopy

Soft x-rays (0.25 – 3 keV)
- SASE 3
- Coherent imaging
- Particle & X-ray spectroscopy
European XFEL Time Structure

Light at Eu XFEL arrives short pulses
- Short means < 100 fs
- Up to $10^{12}$ ph/pulse

Pulses are grouped in trains

The machine can run at nominal values:
- 10 Hz train rate
- 4.5 MHz pulse rate
- 220 ns spaced
- 2700 pulses per train (divided among instruments)
- 600 μs train duration
The JUNGFRAU detector

- Developed at Paul Scherrer Institut (PSI)
- Dynamic Gain Switching (DGS)
  - Dynamic range ~ 10000 10 keV photons (~ 110 dB)
  - Three gain stages: G0, G1, G2
- 16 storage cells (SCs): 0 – f
  - SCf used in single-cell operation (currently implemented)
  - SC0 to SCf for ‘burst mode’ (still under test)
- Gain stage stored digitally
- Fixed current source for calibration purposes
- Output to pixel buffer

- Array of 4 x 2 ASICs
  - Each ASIC 256 x 256 pixels
  - Total 1024 x 512 ~ 500 kpixel
- Bump-bonded to Si sensor
  - 320 μm thick / 450 μm thick

- Read out by 32 ADC (off chip)
- 40 MHz clock FPGA
JUNGFRAU noise performances

Noise map of a temporary module
- 10 μs exposure time
- RMS of pedestal distribution
- Average ~80 ENC

Noise as function of exposure time
- Average across the module
- Below 200 ENC for 600 μs exposure
- Integrating the whole train
SPB/SFX Instrument Overview

- Large area detectors
- Cover as much reciprocal space as possible
- JUNGFRAU 4M detector (8 modules)
- 4 delivered (3 ‘temporary’)
Serial SFX @ atmospheric pressure

Roadrunner Sample Environment
Meents et al., Nature Comm. 8, 1281 (2017)

JUNGFRAU 4M assembly (currently 1.5 M)

- Allows fixed target (Si Chips) and jet operation
- Triggers the JUNGFRAU acquisition

Commissioning: 30.04. - 05.05.

European XFEL
Results Overview

Resolution

- Resolution of 1.9 Å observed
- Main limitations due to setup geometry

Indexing and hit rate

- Circles are the indexed peaks
- The squares of different colours - (predicted) Bragg peaks for different crystals

- Lysozome hit rate:
  - Chips: up to 60%
  - Jet: up to 30%

- Indexing rate: ~ 50%
FXE: Towards a High-Speed femtosecond Molecular Camera

- A suite of simultaneous X-ray tools:
  - Absorption spectroscopy (XAS)
  - Emission spectroscopy (XES)
  - Wide and small angle scattering
- Probe transient molecular states
  - Time resolved
  - Correlated measurement
- 3 JUNGFRAU modules (of which 2 ‘temporary’)

- 3 JUNGFRAU modules (of which 2 ‘temporary’)

- x-ray
- laser
- $\Delta t$

- XAS
- PIN diode
- sample jet
- LPD
- Scattering pattern
- XES
- Ge(440)
- $K_{\beta}$ XES
- XDS
- Timing tool
- spatial encoding

- Energy diagram:
  - Excited state
  - Short-lived transition states
  - Back to ground state

- Temporal evolution of the reaction:
  - 1. Laser pulse starts the reaction
  - 2. Laser pulse takes snapshots

- European XFEL
Simultaneous XES on Fe Kα and Kβ lines

- Small pixels give better spatial resolution
- Energy resolution
- Wide dynamic range
- Avoid peak intensity saturation
Diffuse scattering and diffraction

*Diffuse Scattering/Diffraction*

1M (450um sensor)

82 mm

77 mm

Occasionally used in place of the LPD

- **Advantages:**
  - Better signal to noise
- **Disadvantages:**
  - Smaller area
  - Less memory cells

*Ag Behenate powder diffraction on JF (by exp. 2118)*

*Bragg peak on JF (by exp. 2112)*
High Energy Density science at European XFEL

Relativistic laser plasmas produced with 200TW laser (>10^{20}W/cm²)

Warm dense matter using laser compression and diamond anvil cells

Detector requirements:
- Compact
- Vacuum compatible
- Small pixels
- High dynamic range
Heated dense plasmas characterization

- Spectrally resolved X-ray scattering
- Highly efficient HAPG spectrometer
- Signal over several orders of magnitude
- Large spectral range w/out losing spectral resolution
  - Large enough FEM area
  - Small enough pixels

Sample: diamond or graphite

[Diagram of JUNGFRAU setup with labels for slider, spacer, crystal, light-tight box, and adapter.]

User experiment 2180

[Graph showing intensity vs. photon energy with labels for elastic and inelastic scattering, K-edge.]
JUNGFRAU at MID

- Hard X-rays (5-20 keV)
- High spatial resolution of speckle patterns due to small 75x75 µm² pixel size.
- Low noise (high gain) and thus single photon sensitivity, required for XPCS.
- High dynamic range (10⁴ ph/px/pulse@12 keV) required for CDI.
- 16 memory cells for burst mode with >200kHz.
- In vacuum installation allows windowless operation between sample and detector
- 2 modules required
- 1 ‘temporary’ just delivered
**Burst mode: status**

- **Reset**
  - Pixel electronic components are reset
- **Exposure time**
  - Storage capacitance switches in
  - 2 μs
- **Signal voltage**
  - Storage capacitance switches out
  - Voltage level at this point is stored
  - 500 ns

**Maximum frame rate**

- 2 μs dead time
- 1 μs min exposure
- Tested at SPB/SFX:
  - 1.13 MHz bunch rate
  - 1.43 μs exposure
  - 280 kHz reached
  - 1 bunch every 4

**Gain calibration**

- Difference in gain single SC/burst mode:
  - Different capacitance of the SCs
  - Difference from SC15 and the others
- Gain calibration procedure:
  - Dependence from SCs
  - Re-calibrate G0 with single photon spectra
  - Rescale accordingly other gain stages
- Test at HED end of July
Conclusions and Outlook

- JUNGFRAU detector developed at PSI
  - Dynamic Gain Switching
  - 75 um pixel pitch
  - Single photon sensitivity in the ‘hard X-rays’ instruments energy range (3 – 25 keV)

- Commissioned at all the ‘hard X-rays’ scientific instruments at Eu XFEL
  - SPB/SFX first commissioning (4 out of 8 modules)
  - FXE: user experiments since October 2018 (2 out of 3 modules)
  - HED: first user experiment in May 2019 (1 out of 4 modules)
  - MID: starting the commissioning now (1 out of 2 modules)

- Burst mode operation:
  - First tests performed at SPB/SFX
  - Successfully achieved 280 kHz frame rate (1 pulse every 4 at 1.1 MHz)
  - Test gain calibration procedure for all the 16 storage cells (commissioning beamtime at HED)
  - Goal: fully implemented for first SFX user experiment (November 2019)
Backup slides
Data Flow Concept (as implemented 2019)
Calibration Web Service – Workflow

Established tools

Development

Expert Usage

Production

Monitoring

Continuous feedback, rapid feature implementation
The European XFEL Facility

**Schenefeld**
- Experiment hall
- Laboratories
- Offices

**Osdorfer Born**
- Electron beam to photon beamlines
- Undulator systems begin

**DESY-Bahrenfeld**
- Electron source
- Linear accelerator begins

**FEL Parameters**
- Baseline photon energy: 0.25–25 keV
- Pulse duration: < 100 fs
- Pulse energy: a few mJ
- Superconducting linac: 14 – 17 GeV

**DESY Campus**
- 3400 m
# XFEL Scientific Instruments

<table>
<thead>
<tr>
<th>Hard X-Rays</th>
<th>Soft X-Rays</th>
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<tbody>
<tr>
<td><strong>SPB</strong> Single Particles, Clusters and Biomolecules and Serial Femtosecond Crystallography**</td>
<td><strong>SCS Soft X-Ray Coherent Scattering/Spectroscopy</strong></td>
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<tr>
<td>Will determine the structure of single particles, such as atomic clusters, viruses and biomolecules</td>
<td>Will determine the structure and properties of large, complex molecules and nano-sized structures.</td>
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<tr>
<td><strong>MID</strong> Materials Imaging &amp; Dynamics</td>
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<tr>
<td>Will be able to image and analyse nano-sized devices and materials used in engineering</td>
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<tr>
<td><strong>FXE</strong> Femtosecond X-Ray Experiments</td>
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<td>Will investigate chemical reactions at the atomic scale in short time scales molecular movies</td>
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<td><strong>HED</strong> High Energy Density Matter</td>
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<td>Will look into some of the most extreme states of matter in the universe, such as the conditions at the center of planets</td>
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<td><strong>SQS</strong> Small Quantum Systems</td>
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<td>Will examine the quantum mechanical properties of atoms and molecules.</td>
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