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

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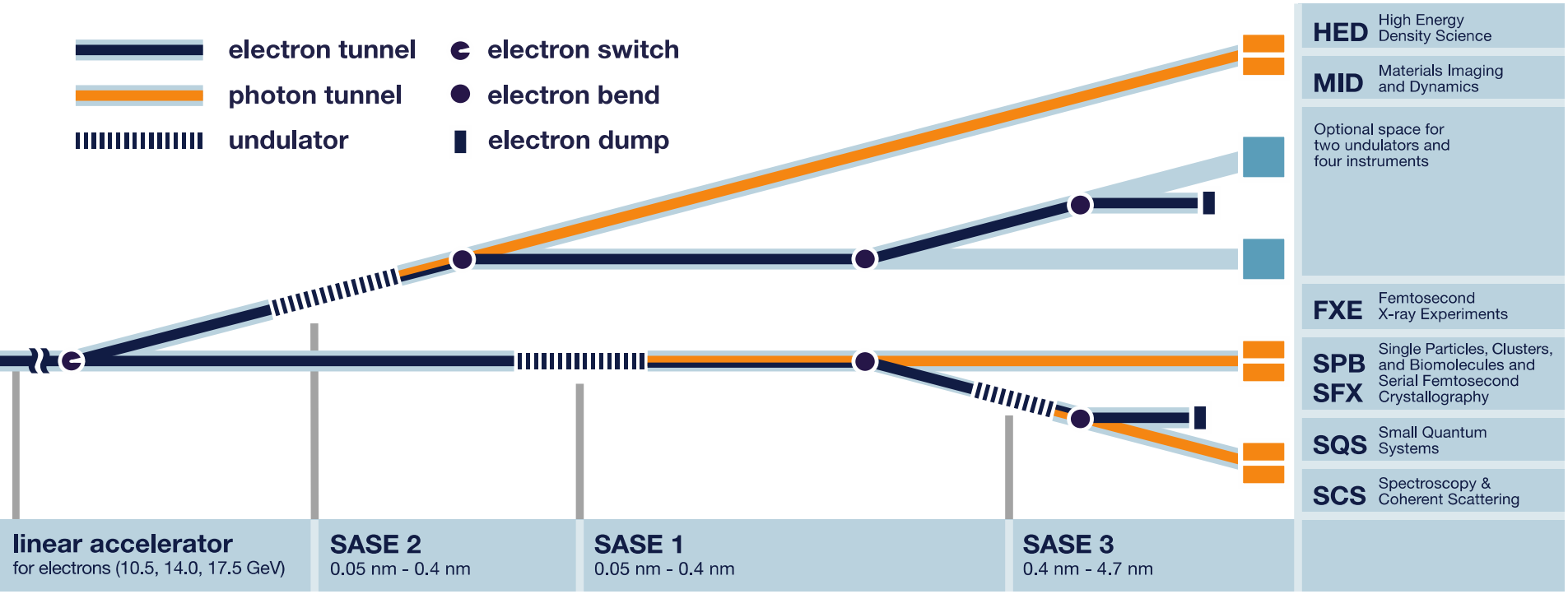
21st International Workshop on Radiation Imaging Detectors – iWoRiD
07. – 12.07.2019, Kolymbari (GR)

Overview

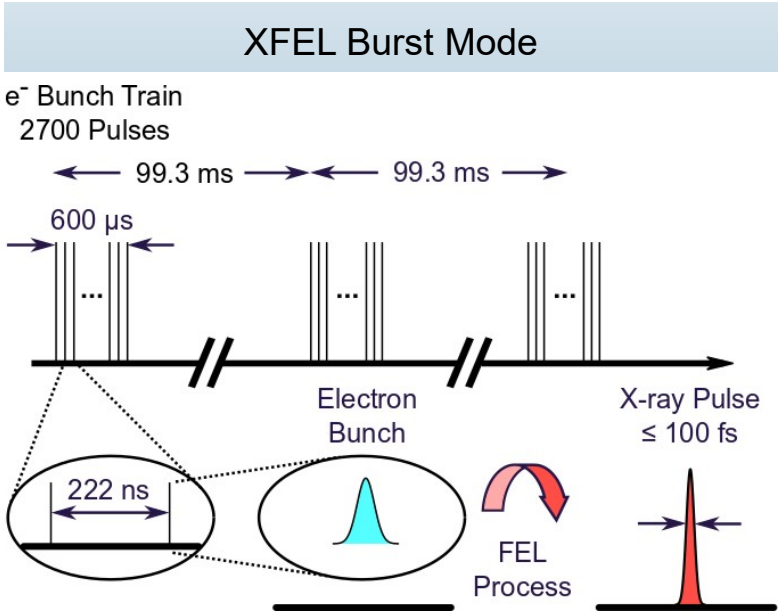
- Introduction
  - Instrument stations at Eu XFEL
  - The JUNGFRAU detector
- Commissioning and operation
  - SPB/SFX
  - FXE
  - HED
  - MID
- Burst mode operation
- Conclusions and outlook

The photon beamlines and instruments



- Hard x-rays (3 – 25 keV)
  - SASE 1 & SASE2
  - (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

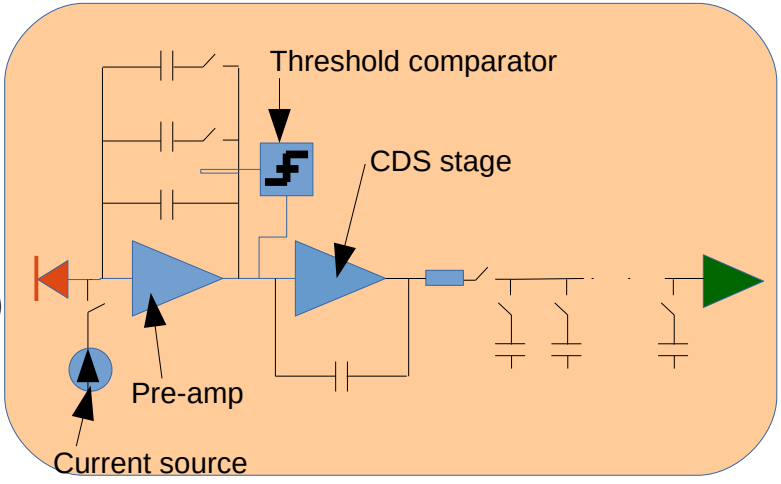
Pulses are grouped in trains

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

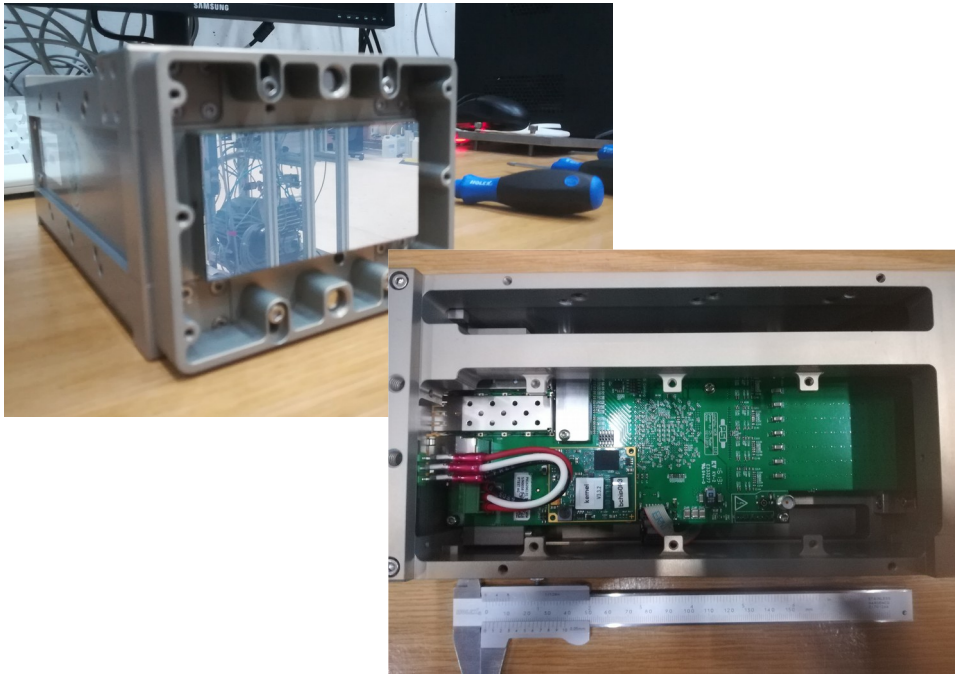
The JUNGFRAU detector

- 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

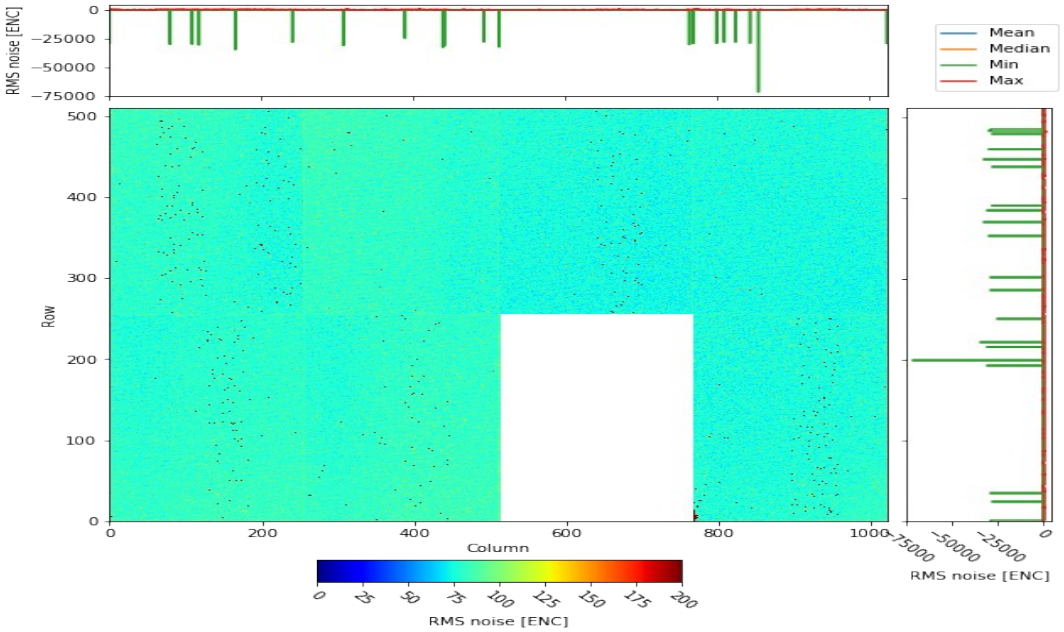


- Array of 4 x 2 ASICs
  - Each ASIC 256 x 256 pixels
  - Total 1024 x 512 ~ 500 kpixel
- Bump-bonded to Si sensor
  - 320 µm thick / 450 µm thick

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

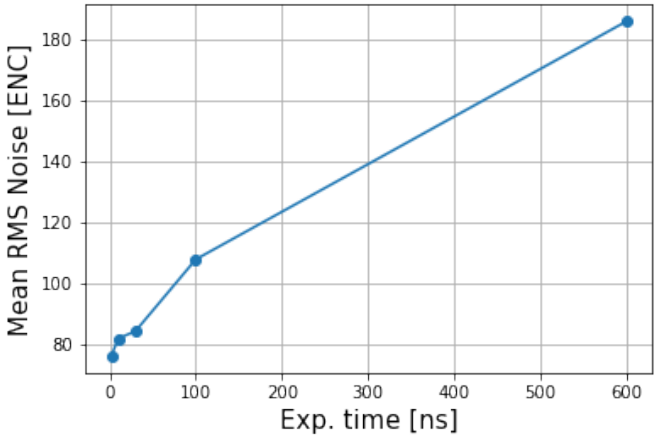


JUNGFRAU noise performances

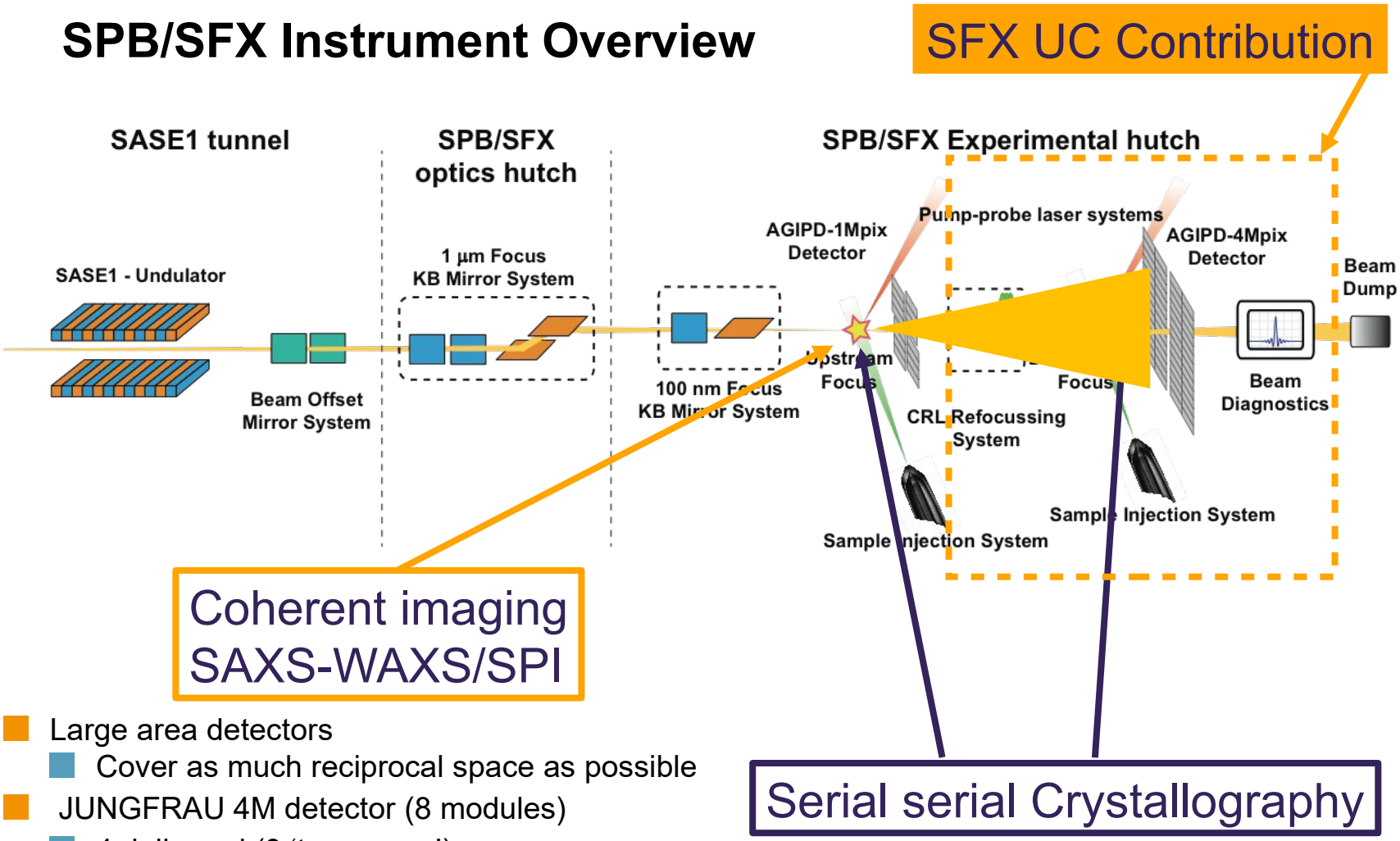


Noise map of a temporary module
- 10 µs exposure time
- RMS of pedestal distribution
- Average ~80 ENC

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

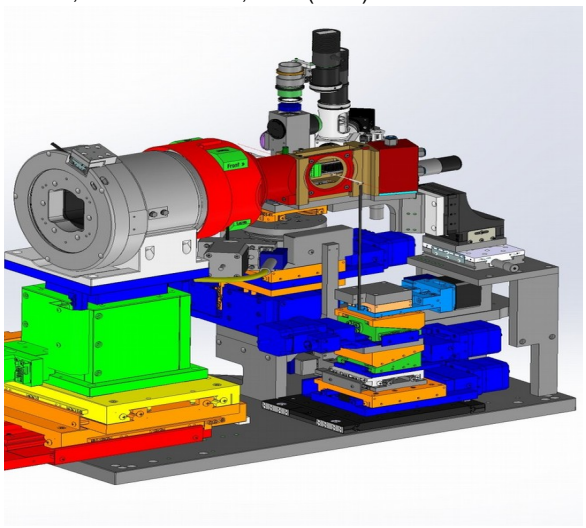


- Large area detectors
  - Cover as much reciprocal space as possible
- JUNGFRAU 4M detector (8 modules)
  - 4 delivered (3 ‘temporary’)

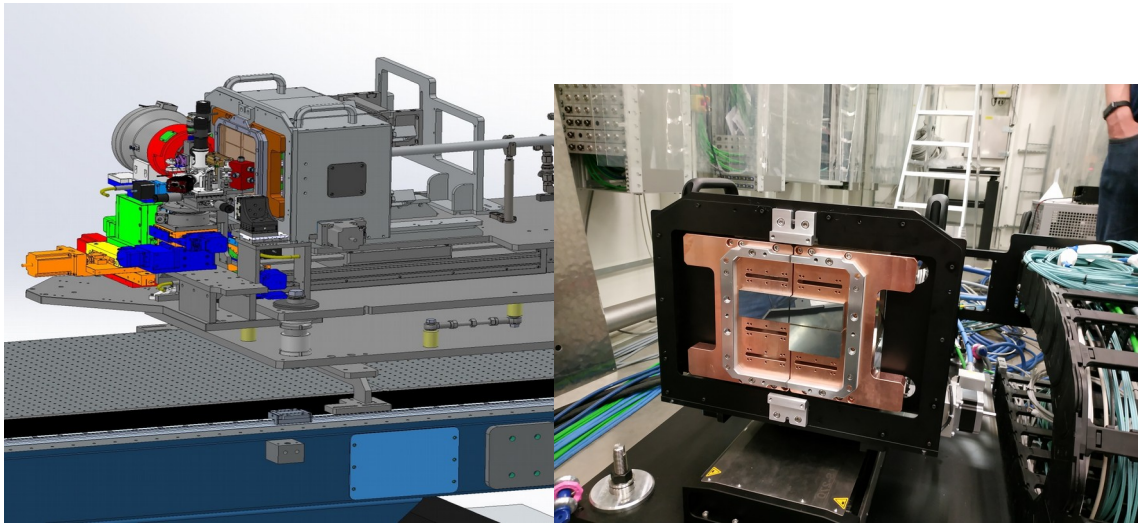
Serial SFX @ atmospheric pressure

Roadrunner Sample Environment

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



JUNGFRAU 4M assembly (currently 1.5 M)

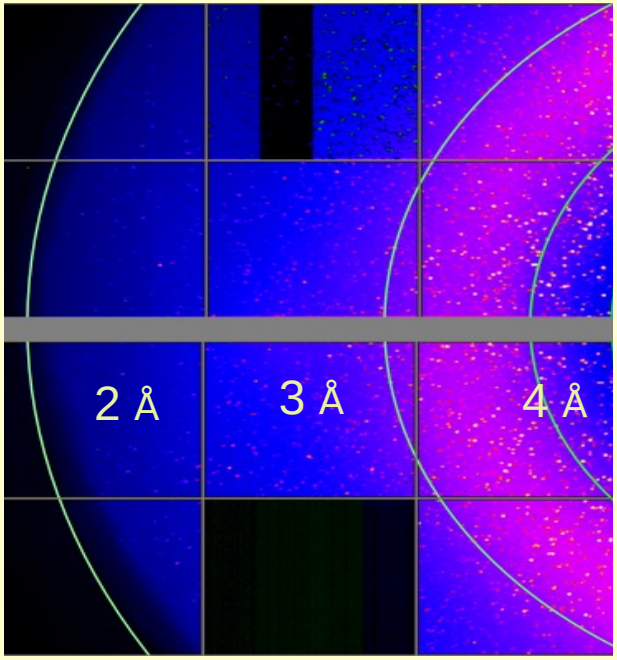


- Allows fixed target (Si Chips) and jet operation
- Triggers the JUNGFRAU acquisition

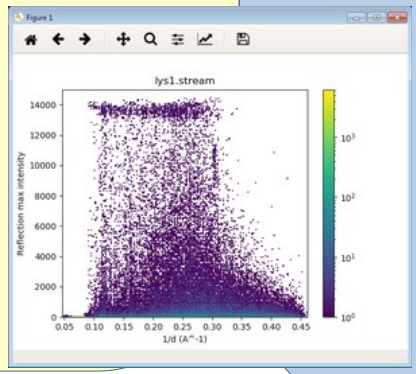
Commissioning: 30.04. - 05.05.

Results Overview

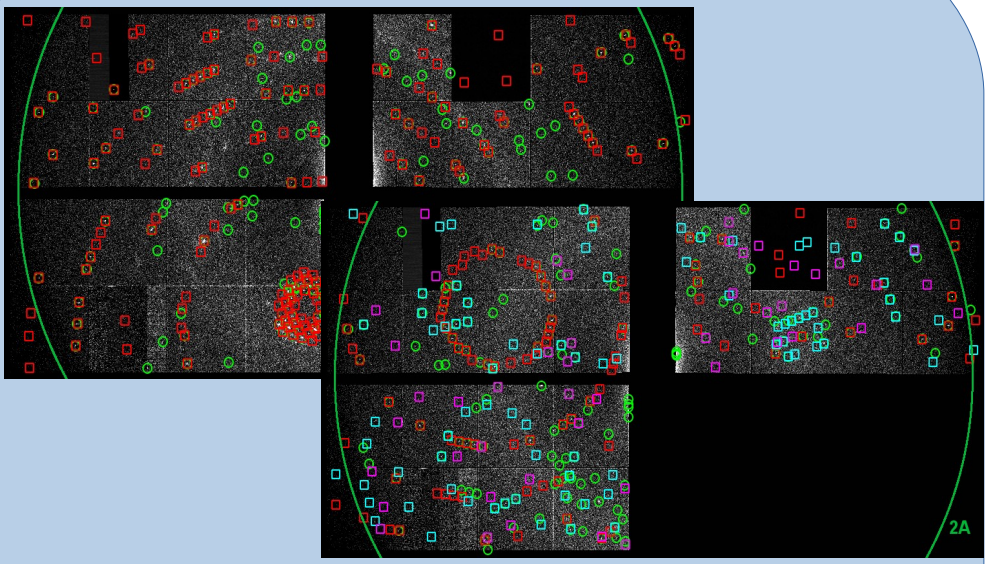
Resolution



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



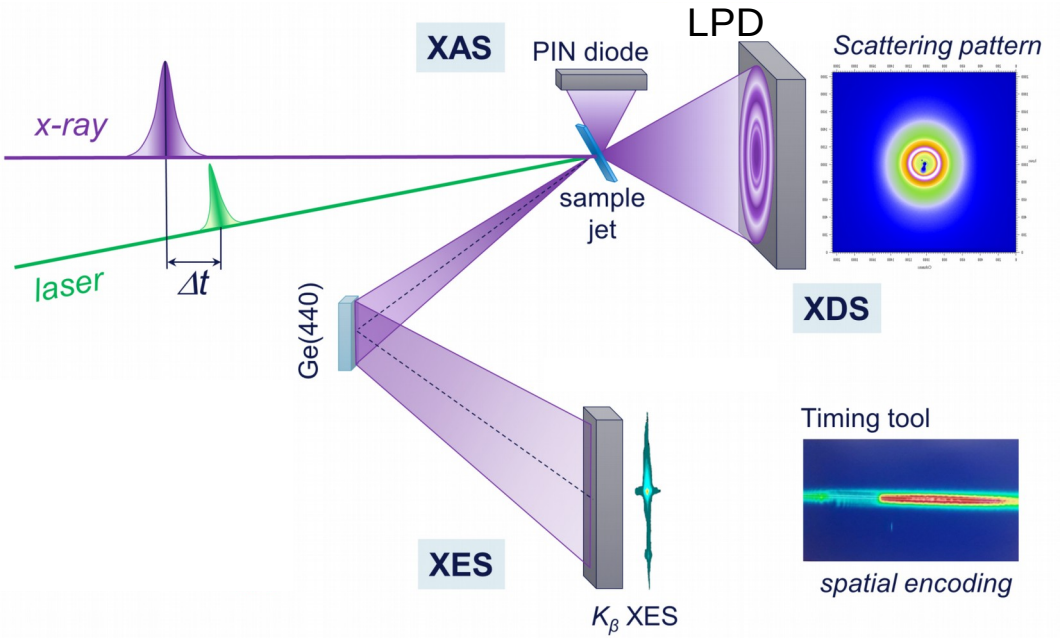
Indexing and hit rate

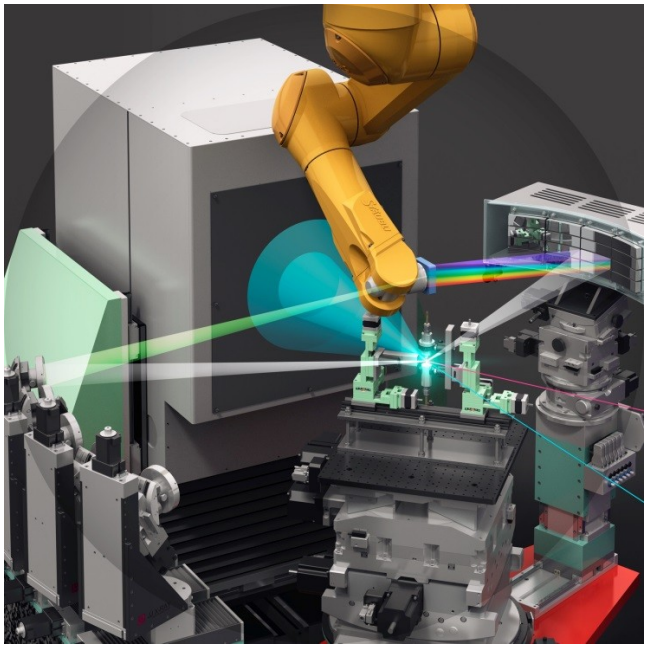


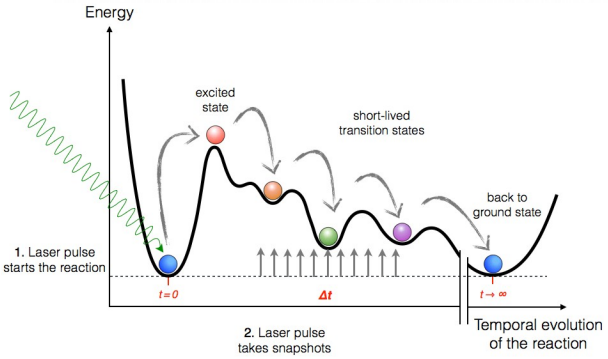
- circles are the indexed peaks
- the squares of different colours - (predicted) Bragg peaks for different crystals

- Lysozome hit rate:
  - Chips: up to 60%
  - Jet: up to 30%
- Indexing rate: ~ 50%

FXE: Towards a High-Speed femtosecond Molecular Camera

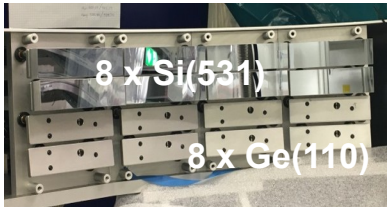


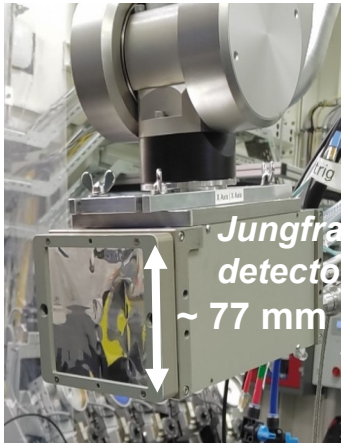


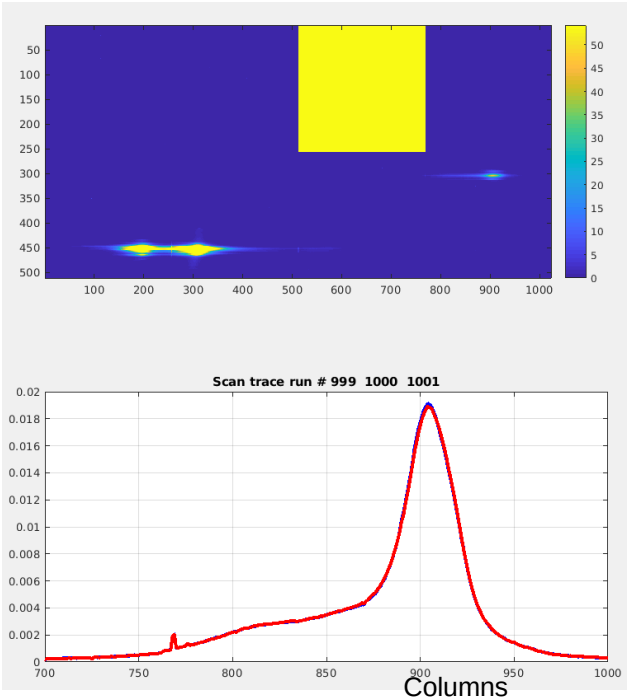


- A suite of simultaneous X-ray tools:
  - Absorption spectroscopy (XAS)
  - Emission spectroscopy (XES)
  - Wide and small angle scattering
- Probe transient molecular states
  - Time resolved
  - Correlated measurement
- 3 JUNGFRAU modules (of which 2 ‘temporary’)

Simultaneous XES on Fe Kα and Kβ lines

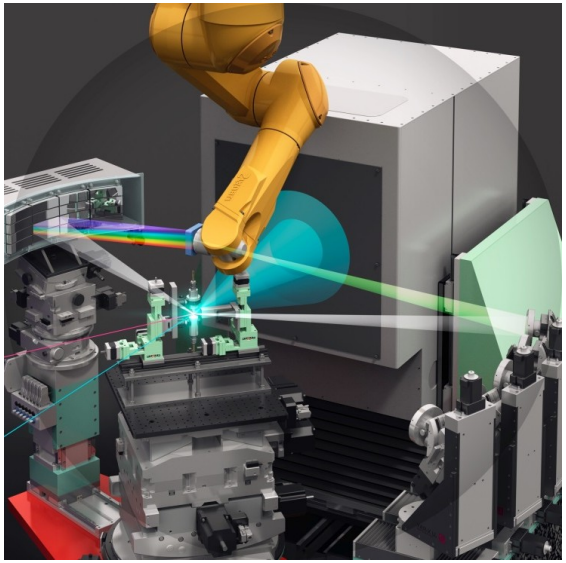




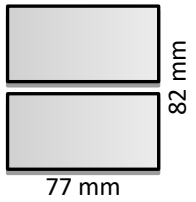


- Small pixels give better spatial resolution
  - Energy resolution
- Wide dynamic range
  - Avoid peak intensity saturation

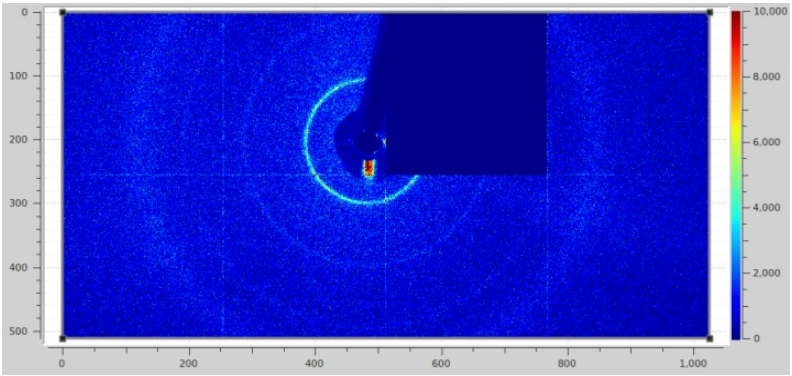
Diffuse scattering and diffraction



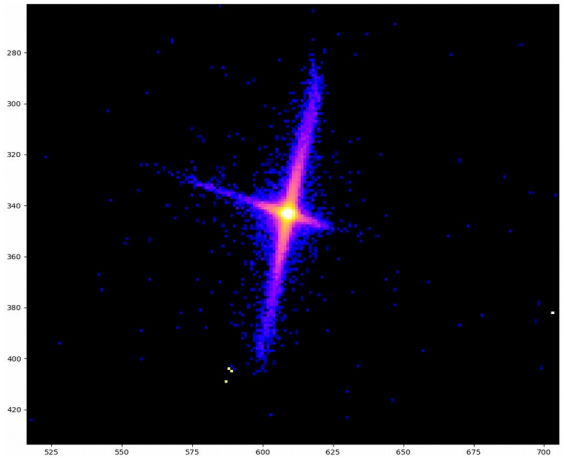
Diffuse Scattering/Diffraction



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



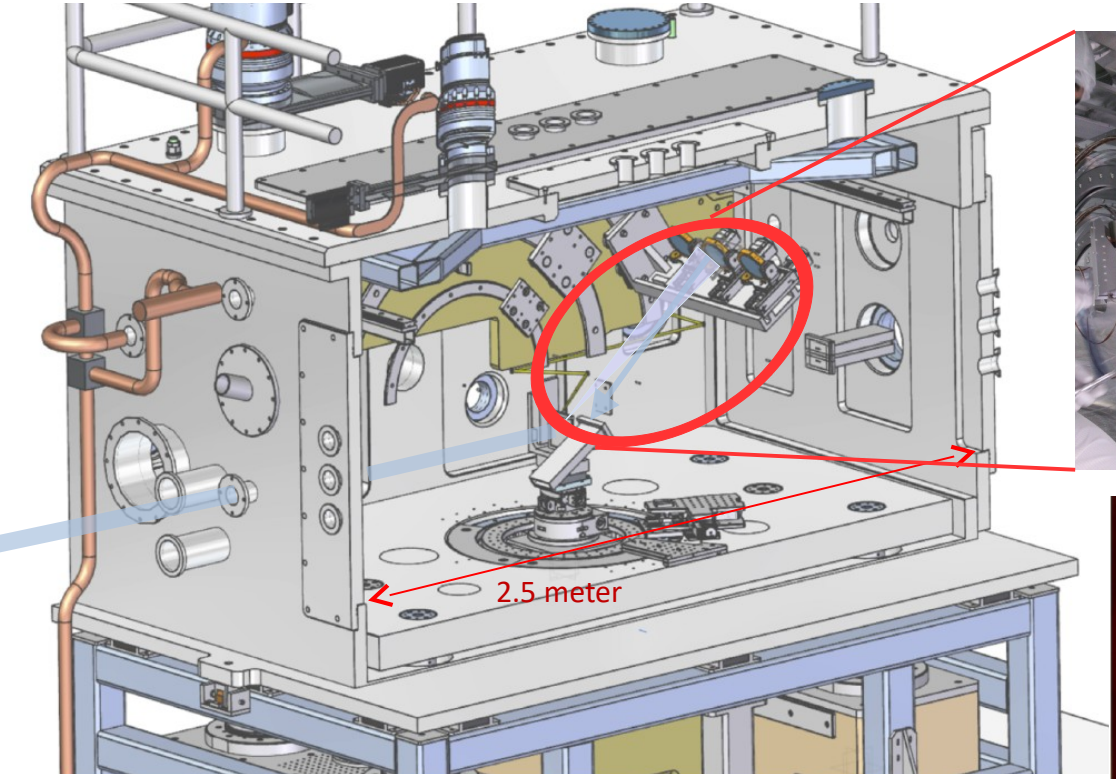
Bragg peak on JF (by exp. 2112)

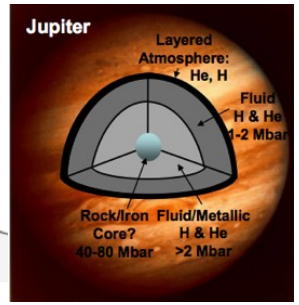


Occasionally used in place of the LPD

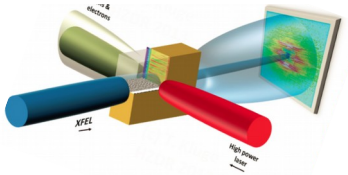
- Advantages:
  - Better signal to noise
- Disadvantages:
  - Smaller area
  - Less memory cells

High Energy Density science at European XFEL

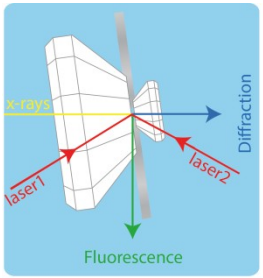




Relativistic laser plasmas
produced with 200TW laser
(>10^{20}W/cm²)



Warm dense matter
using laser compression and diamond anvil cells

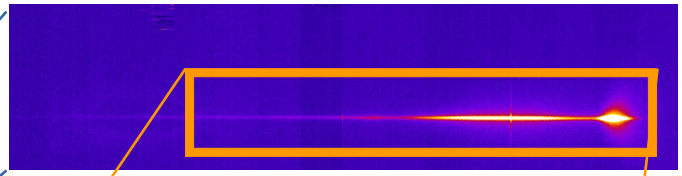


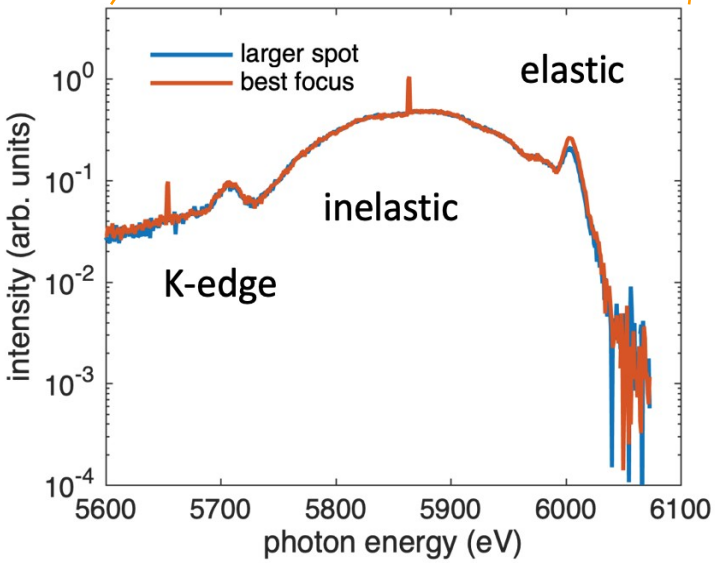
Detector requirements:
- Compact
- Vacuum compatible
- Small pixels
- High dynamic range

Heated dense plasmas characterization

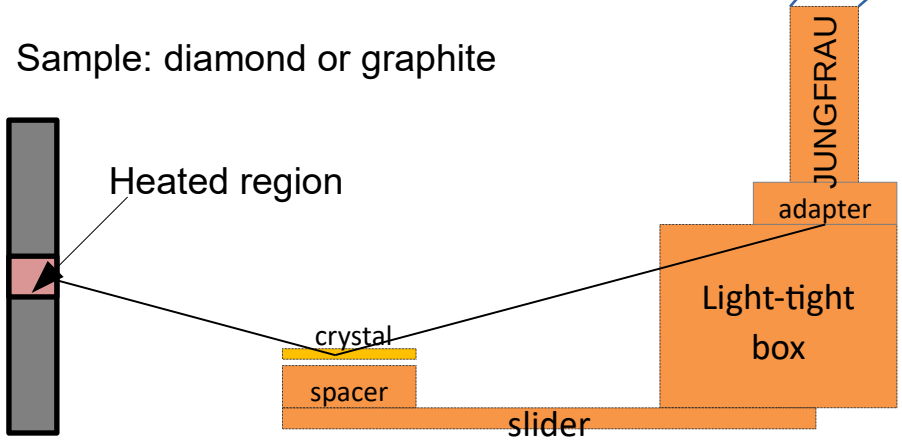
- Spectrally resolved X-ray scattering
- Highly efficient HAPG spectrometer
- Signal over several orders of magnitude
- Large spectral range w/out loosing spectral resolution
  - Large enough FEM area
  - Small enough pixels

User experiment 2180

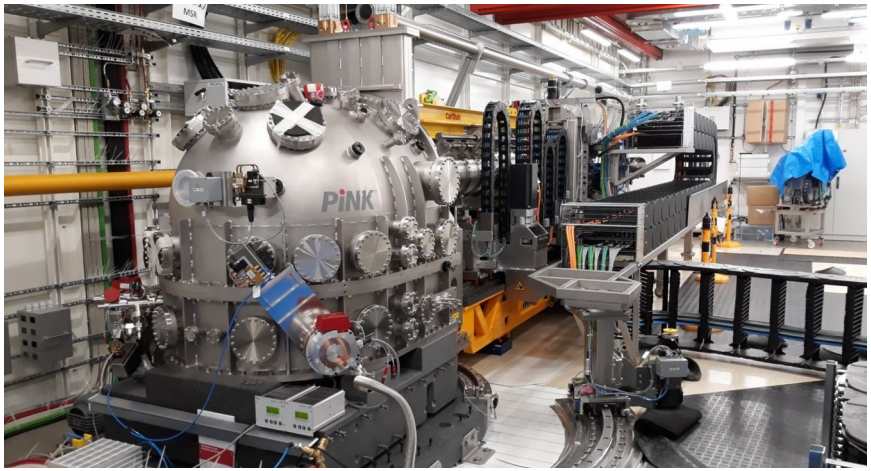




Sample: diamond or graphite



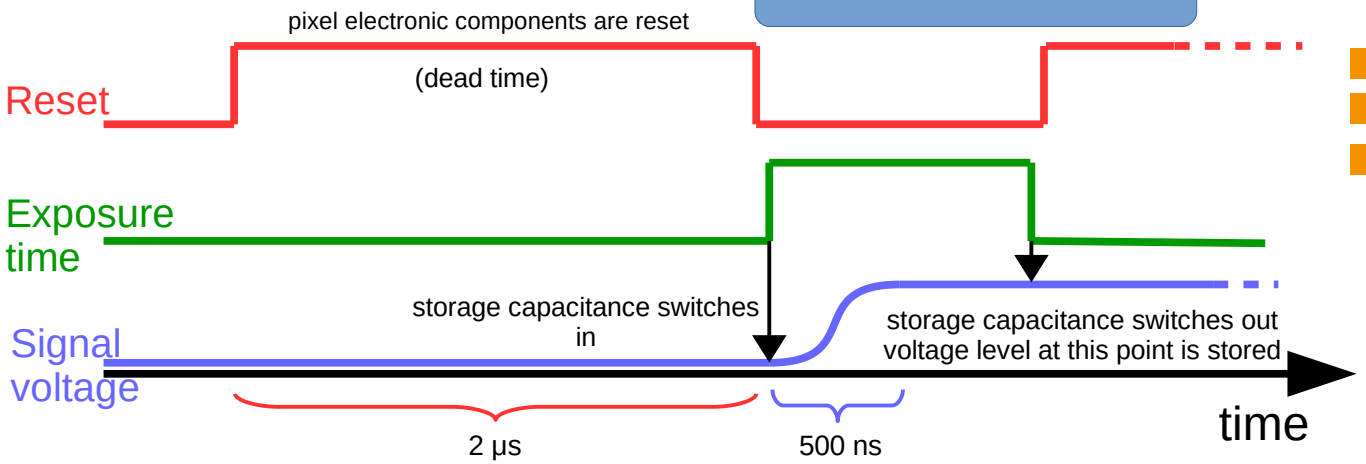
JUNGFRAU at MID



- 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 (10^4 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

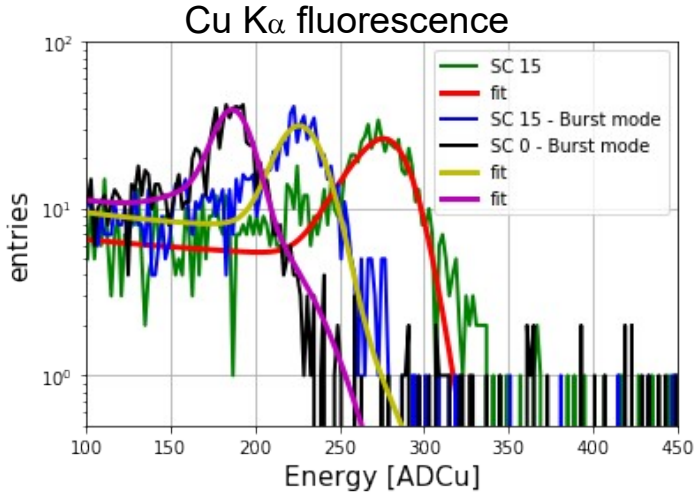
Burst mode: status

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



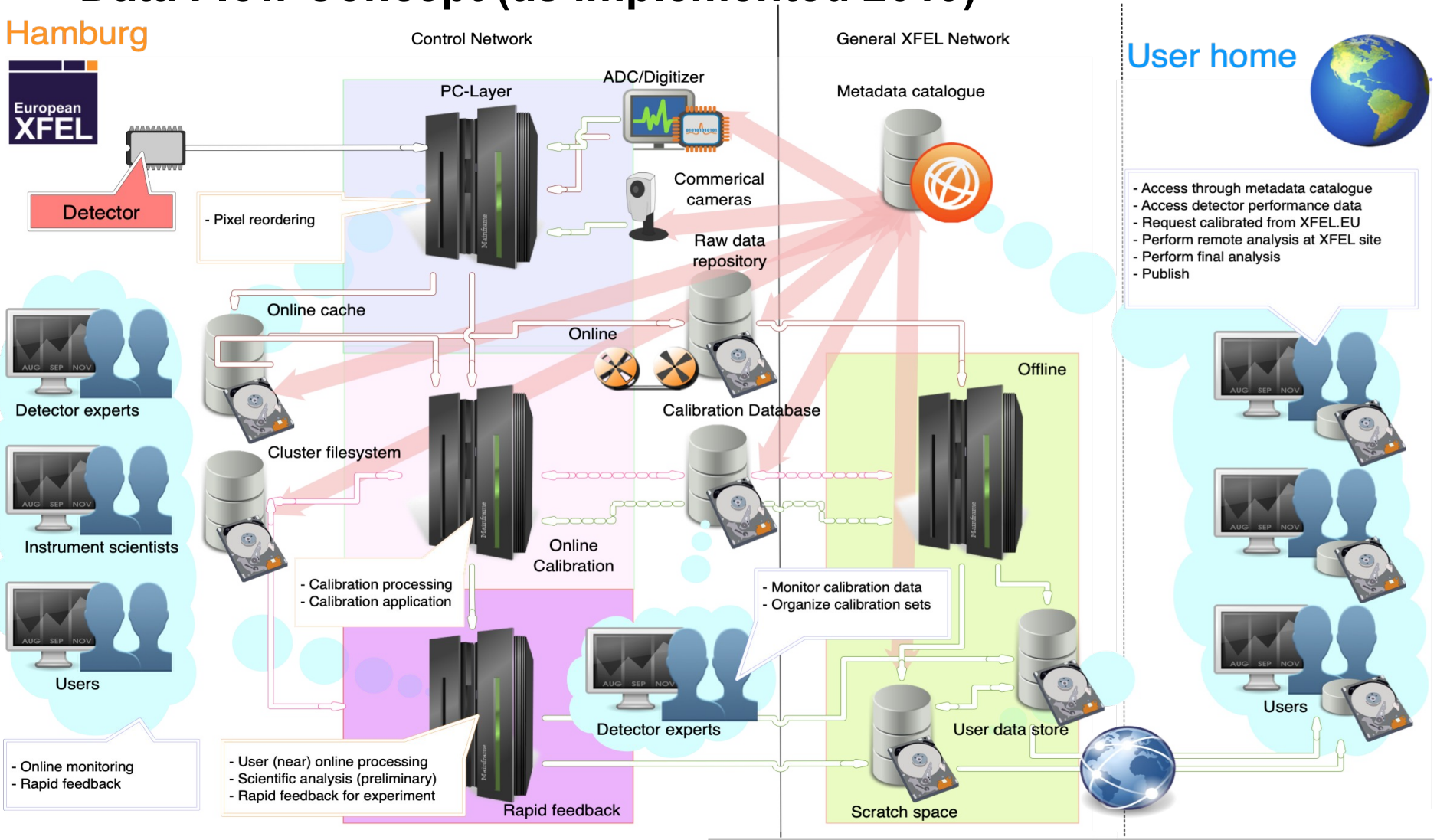
- Difference in gain single SC/burst mode:
  - Different capacitance of the SCs
  - Difference from SC15 and the others
- Gain calibration procedure
  - Dependence from SCs
  - Re-calibrate G0 with single photon spectra
  - Rescale accordingly other gain stages
- Test at HED end of July

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:
  - Firs 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)

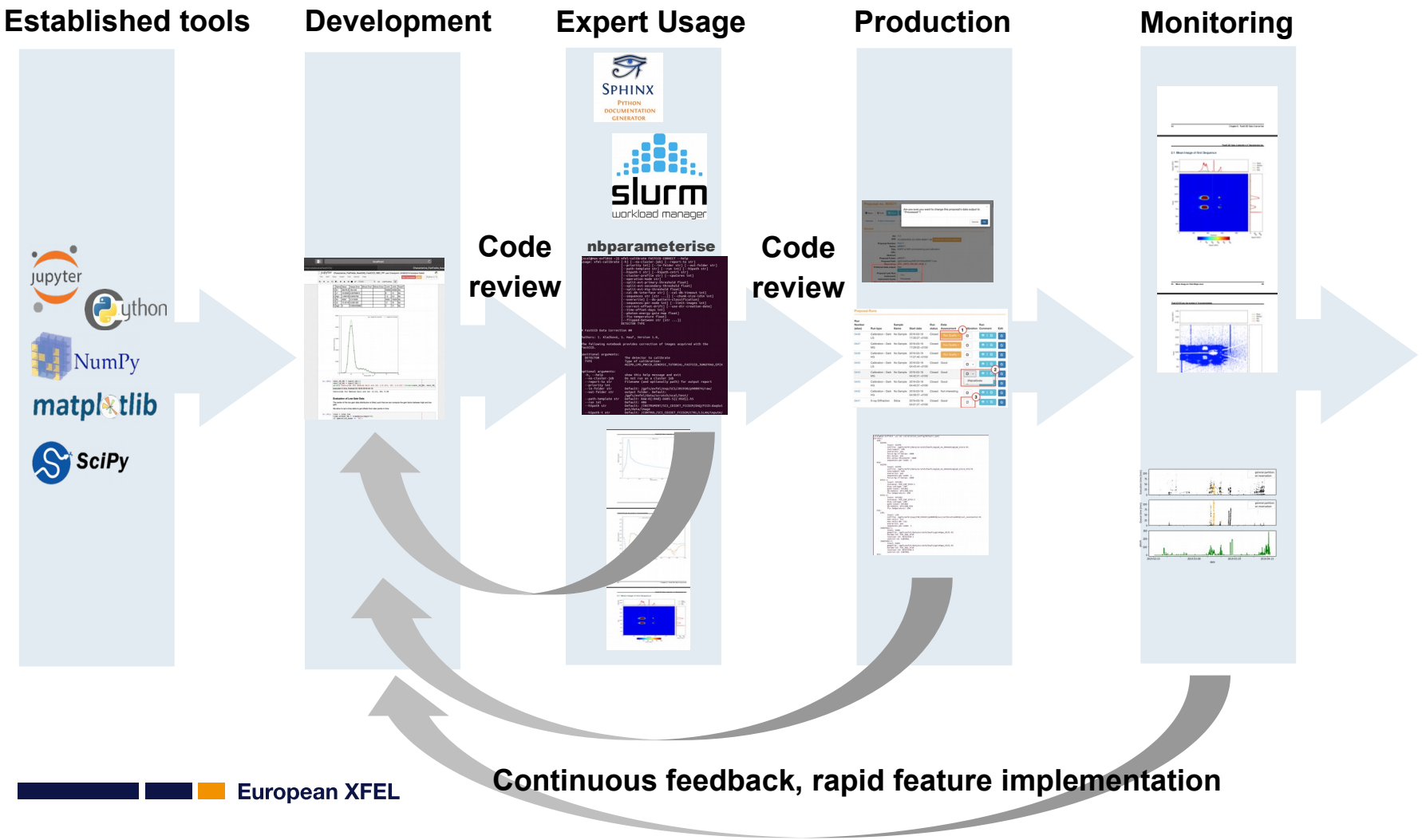
Backup slides

Data Flow Concept (as implemented 2019)



Not shown is technical infrastructure such as switches.
Alignment datasets are shipped with the data products and tools for coordinate system conversion are provided by the facility.

Calibration Web Service – Workflow



The European XFEL Facility

Schenefeld

Experiment hall

Laboratories

Offices

Osdorfer Born

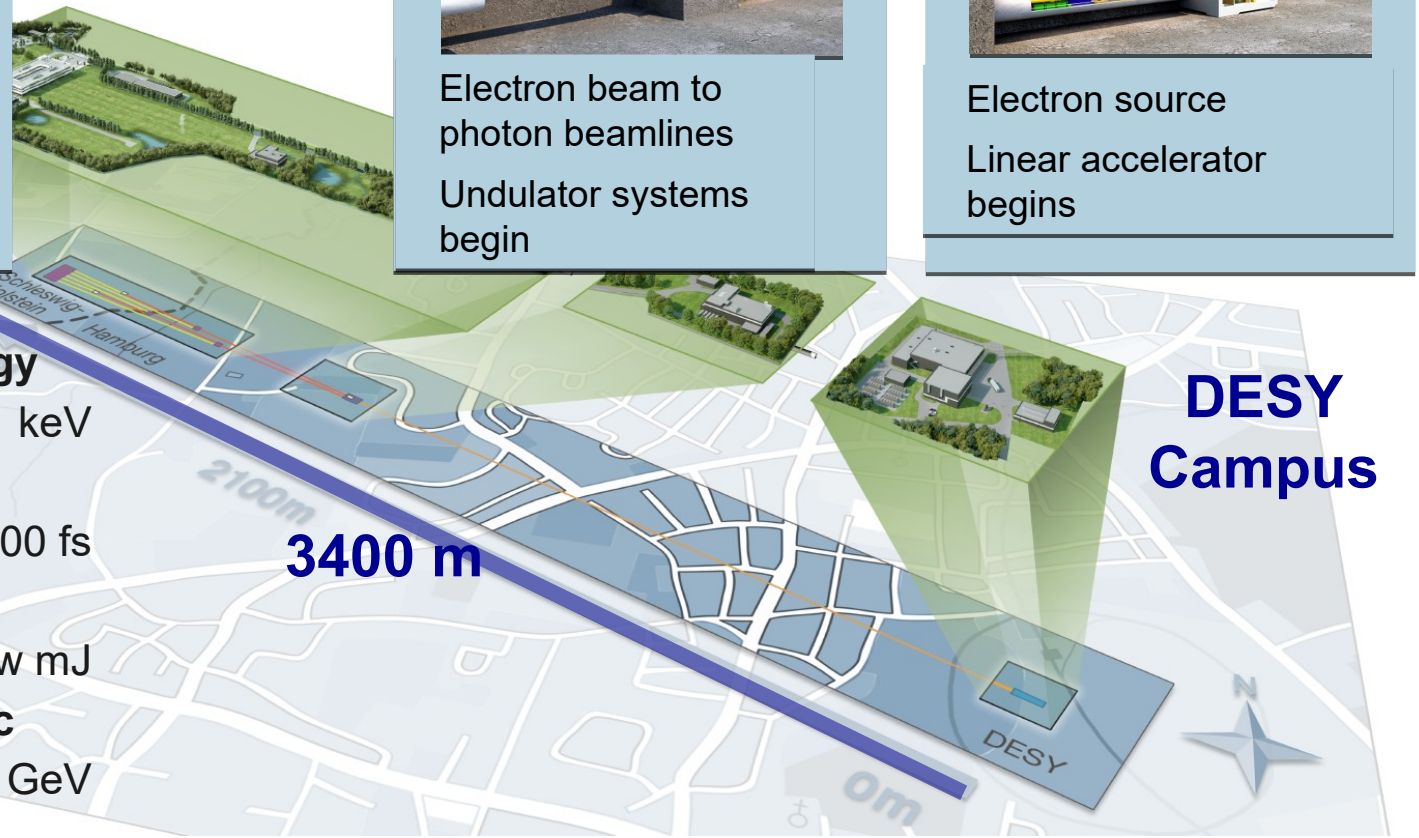
Electron beam to photon beamlines

Undulator systems begin

DESY-Bahrenfeld

Electron source

Linear accelerator begins



DESY Campus

FEL Parameters

Baseline photon energy

0.25–25 keV

Pulse duration

< 100 fs

Pulse energy

a few mJ

Superconducting linac

14 – 17 GeV

XFEL Scientific Instruments

Hard X-Rays

SPB Single Particles, Clusters and Biomolecules and Serial Femtosecond Crystallography

Will determine the structure of single particles, such as atomic clusters, viruses and biomolecules

MID Materials Imaging & Dynamics

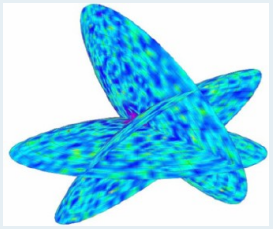
Will be able to image and analyse nano-sized devices and materials used in engineering

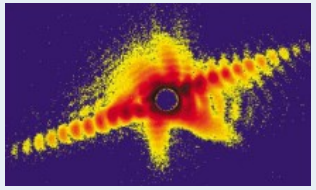
FXE Femtosecond X-Ray Experiments

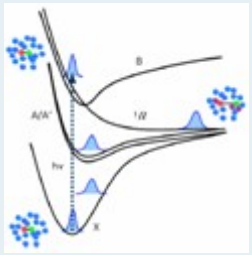
Will investigate chemical reactions at the atomic scale in short time scales molecular movies

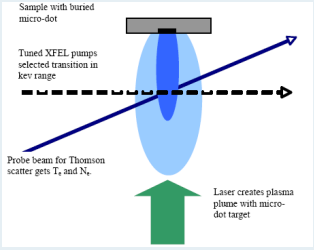
HED High Energy Density Matter

Will look into some of the most extreme states of matter in the universe, such as the conditions at the center of planets









Soft X-Rays

SQS Small Quantum Systems

Will examine the quantum mechanical properties of atoms and molecules.

SCS Soft X-Ray Coherent Scattering/Spectroscopy

Will determine the structure and properties of large, complex molecules and nano-sized structures.