Instruments Operation

Chris Milne on behalf of everyone from MID, HED, SQS, SXP, SCS, FXE, SPB/SFX

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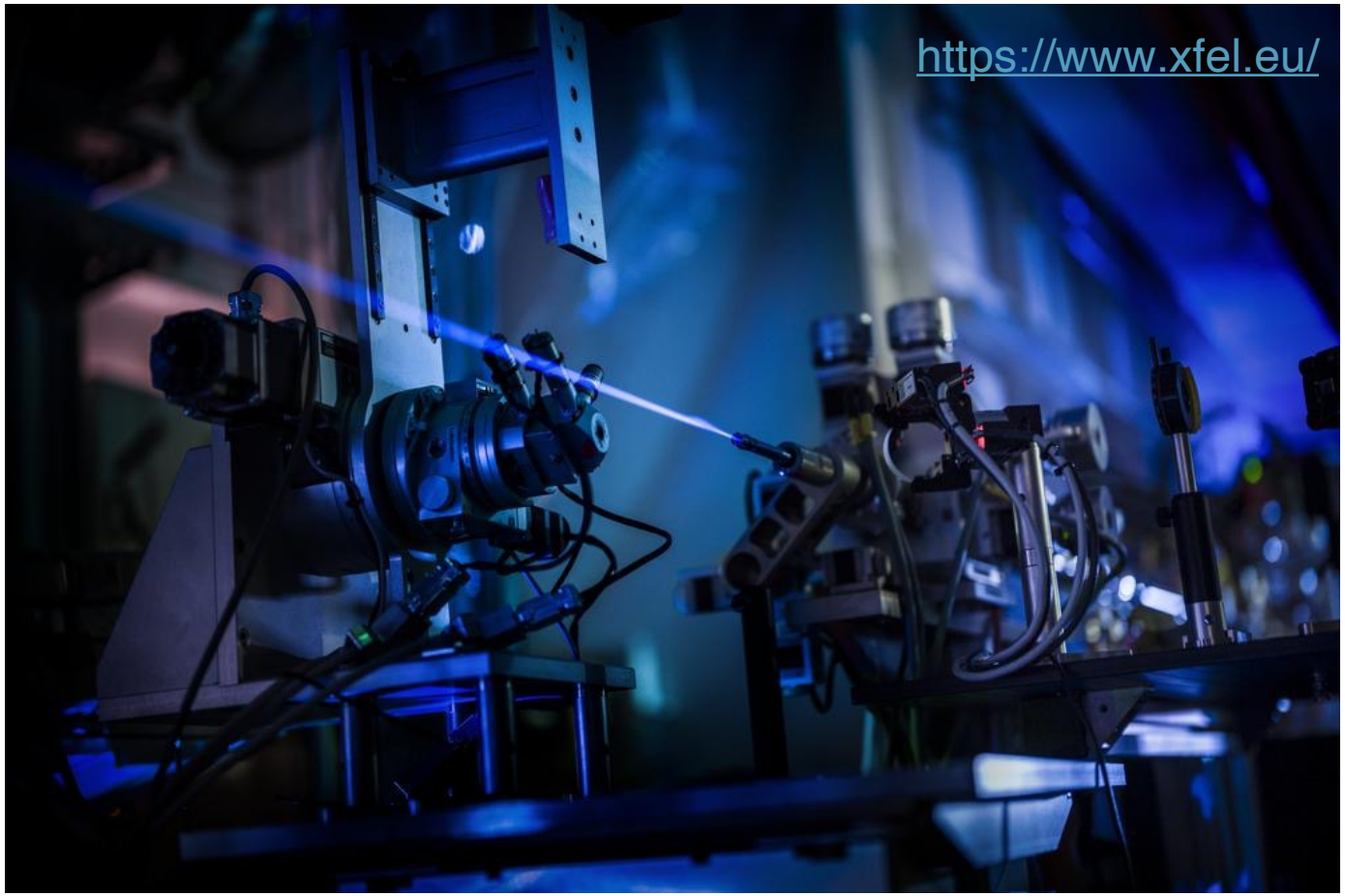


Operations Workshop
Jork, Germany
13-14.11.2025

European XFEL

SASE 1 and 2

- Hard x-rays (3 – 25+ keV)

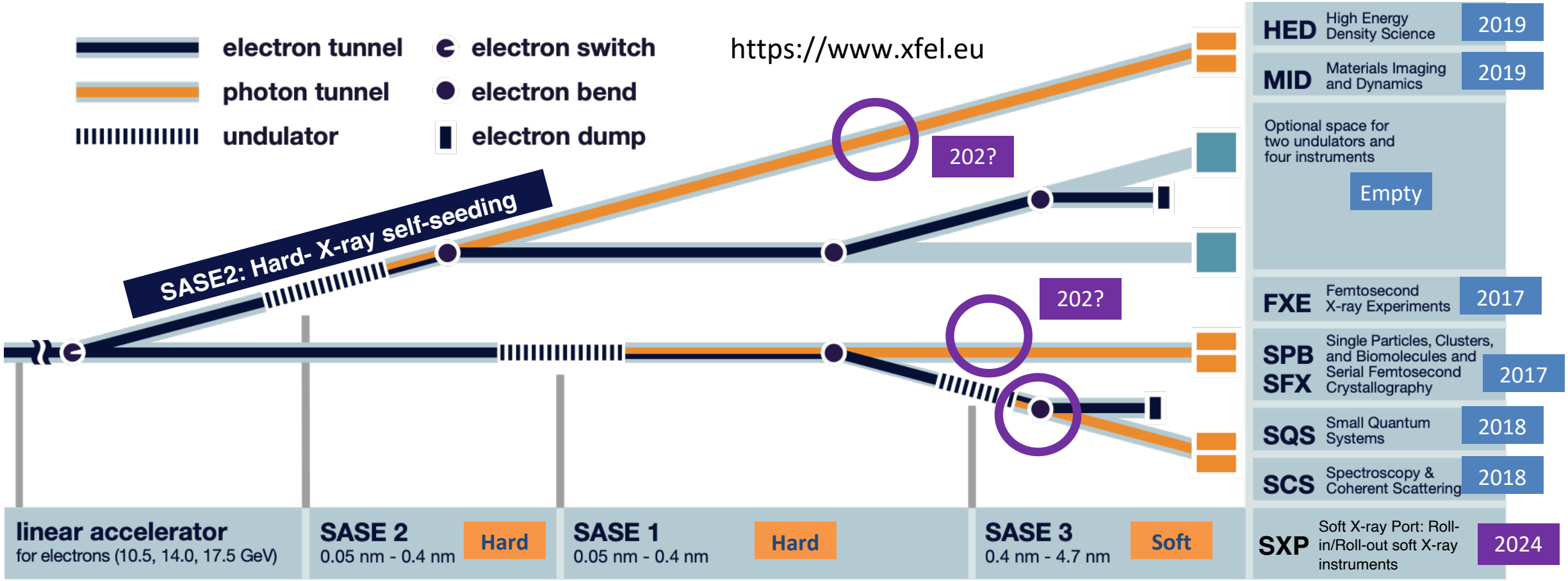
FXE | HED | MID | SPB/SFX

SASE 3

- Soft x-rays (0.26 – 3 keV)

SCS | SQS | SXP

- All 3 SASEs run in parallel
- Flexible repetition rates
- Flexible number of pulses

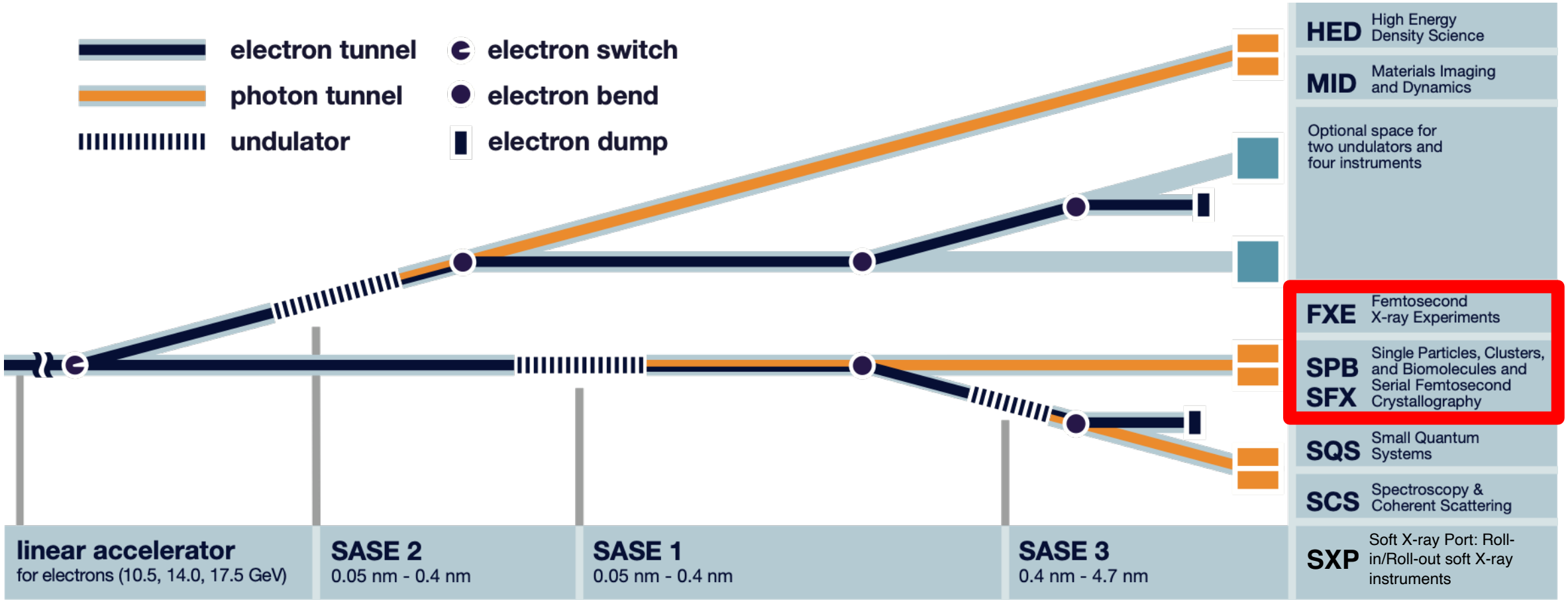


European XFEL: Numbers from the user-side

- First experiments September-December of **2017**
- **7** instruments in-operation – **2** more instrument locations are under construction or in the planning stage
- **1763** total user proposals submitted to date since 2017
- **494** user experiments performed to date
- Total number of different EuXFEL users involved with experiments is **3373**
- Total number of registered users at EuXFEL is **11 028**

Numbers courtesy of Silvia Bertini

SASE1: Hard X-rays



Single Particles, Clusters, and Biomolecules & Serial Femtosecond Crystallography Instrument Overview

SPB/SFX Operations Overview

4 broad experiment classes, approx. equal distribution of beamtime

- **Serial Femtosecond Crystallography (with pump-probe etc.)**
  - Moving toward **12 keV** as standard
  - **564 kHz** (sample delivery limited), **202 pulses** (detector limited), **358 μs RF window**
- **Single particle diffraction imaging**
  - Biological imaging typically **6 keV**, max focusing / **max flux** requirement
  - Quantum dots / aerosol / metallic catalysts etc. at higher energy
  - **1.1 MHz, 352 pulses** (detector limited), **312 μs RF window**
- **Novel microscopies**
  - **18+ keV**
  - Desired beam rate very experiment dependent, max RF window, some **4.5 MHz** use
- **Method development**
  - Variable energy and sample environment
  - Variable: rate, RF window, requirements e.g. short pulse

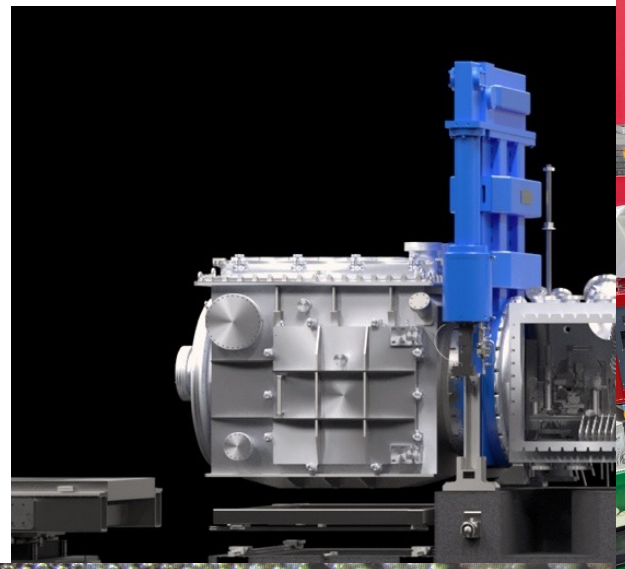
Key topics:

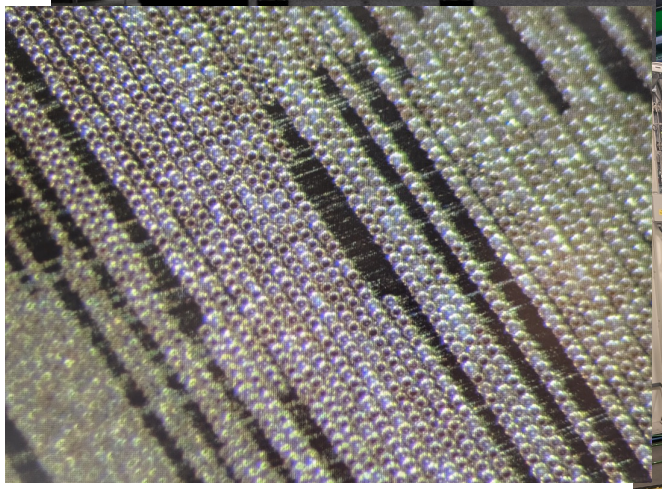
- Available RF window
- Lattice updates (focusing performance)
- Achieved intensities
- Crosstalk with SASE3
- Sample delivery / beam synchronization

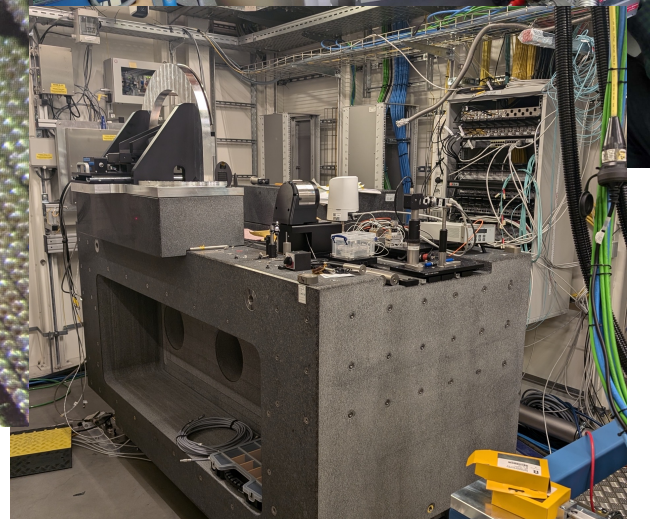
Slide courtesy of Richard Bean

SPB SFX

SPB/SFX Instrument Developments and Considerations





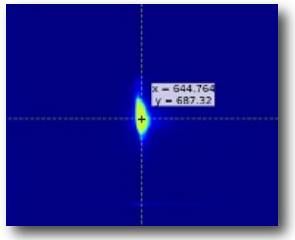


- **AGIPD 4M**
  - Installation planned for spring 2026
  - Commissioning in summer 2026
  - Ambient condition sample environment
  - Spinning disk sample delivery
  - Beam sweeping
- **New capabilities in SASE1**
  - **HXRSS**
  - **XFELO**

Slide courtesy of Richard Bean

Femtosecond X-ray Experiments (FXE) Operations

- Instrument focused on **ultrafast dynamics in the condensed phase**



- In operation since Q4 2017
- 4.6– 22 keV
- X-ray scattering and spectroscopy
- Samples include solutions, powders, thin films, crystal suspensions
- Flexible infrastructure (sample environments, diffractometers, chemistry chamber, user-provided, D3 BTM tests etc.)
- Flexible optical laser setup (UV, visible, infra-red, THz) @ 282 kHz

- We use all electron beam energies (**scanning**)
- Most experiments use ***average*** X-ray flux for the measurement
- Usually have 8 experiments per Run (15-17/year)
- Experiments need 564, 282, 188, 100 kHz, 10 Hz, & Pulse-on-Demand

Typical operation parameters and outlook for FXE

- SASE1 has fewer special modes than SASE2/3 so **often using 'standard' mode**
- User experiments often need **flexible X-ray parameters** (repetition rate, X-ray photon energy etc.) **within one experiment**
- Need efficient instrument operation to handle flexibility of experiments

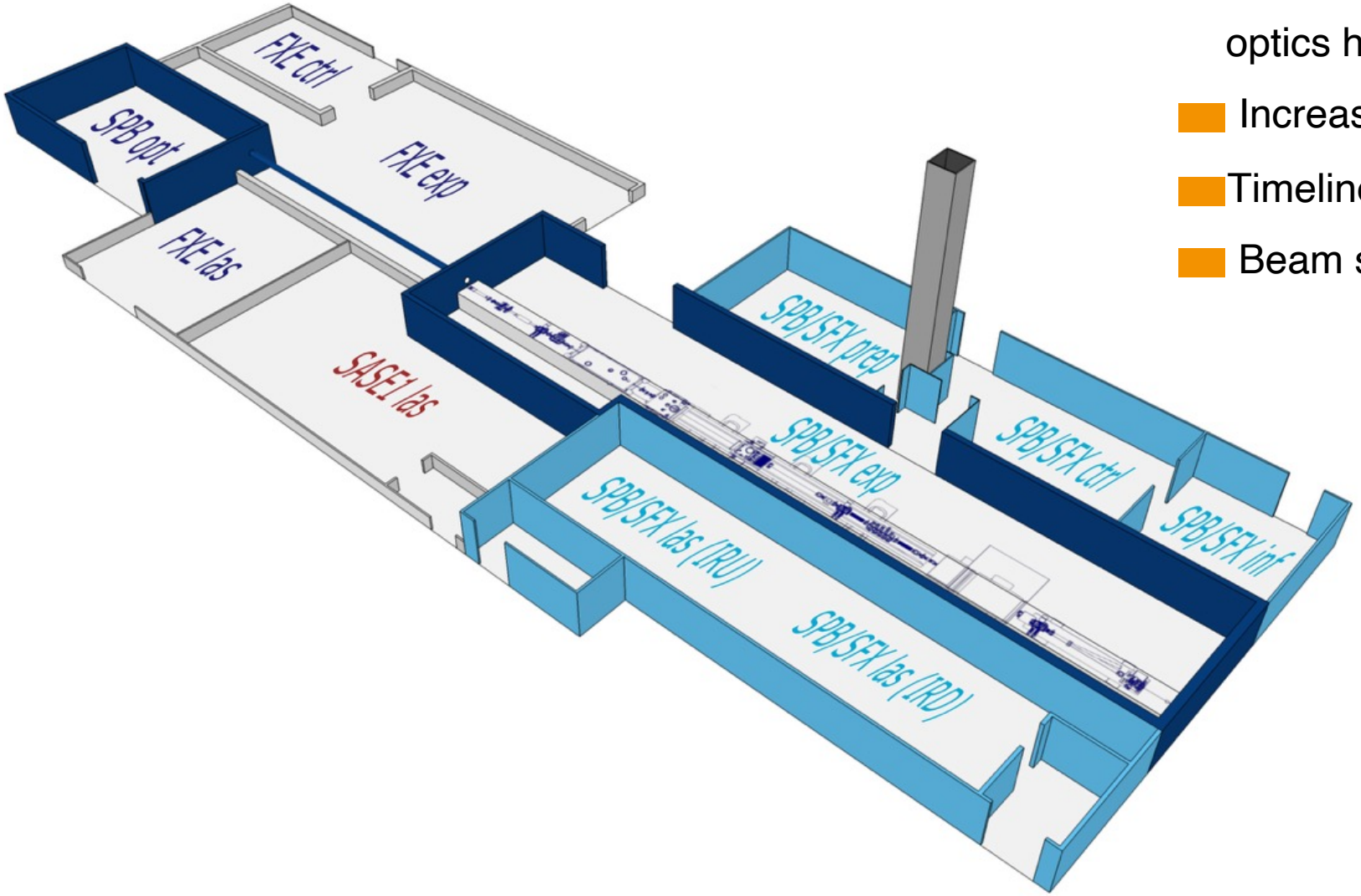
Outlook:

- User Interest in using '**short pulses**' – timing tool and LAM capabilities (LIMP)
- **HXRSS** on SASE1 installation during LIMP
- **XFELO** experiments

Key topics:

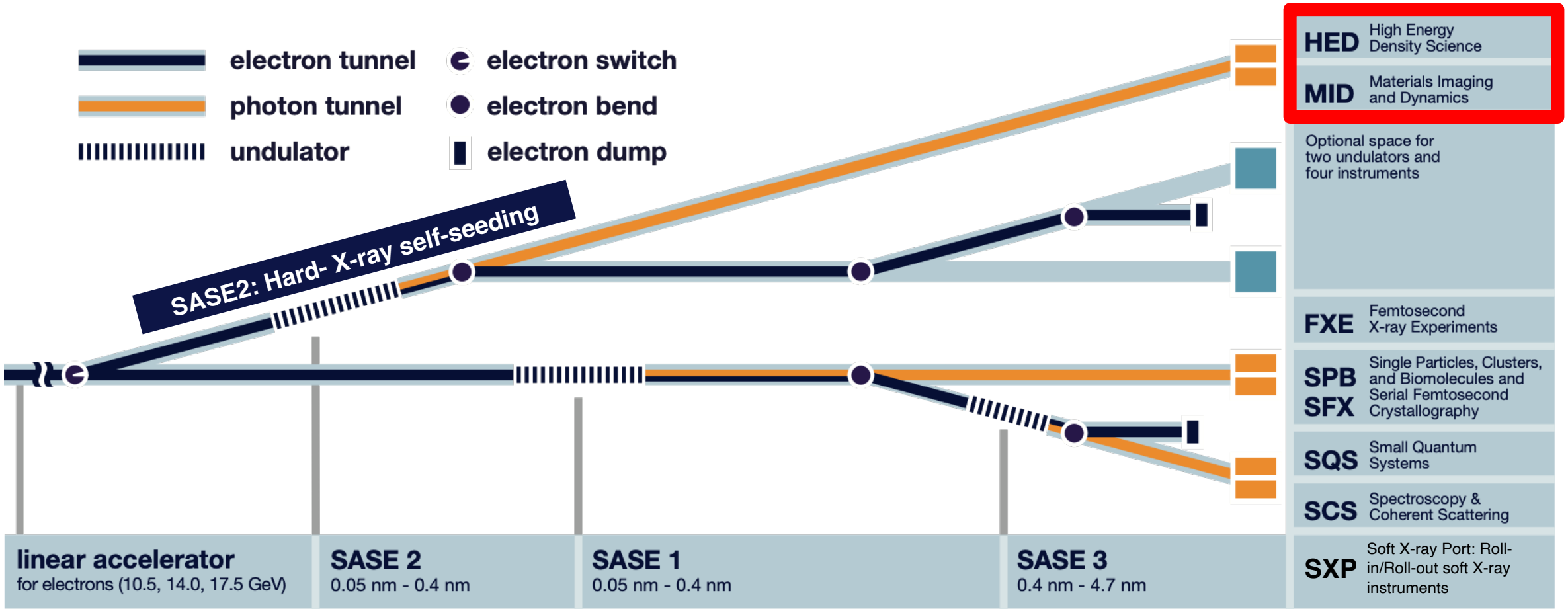
- RF window, number of 'useable' pulses
- Experiment repetition rates
- SASE cross-talk

SASE1 Third Port: *In progress*



- Opportunity to repurpose SPB/SFX optics hutch
- Increase stability for existing platforms
- Timeline for implementation
- Beam sharing options

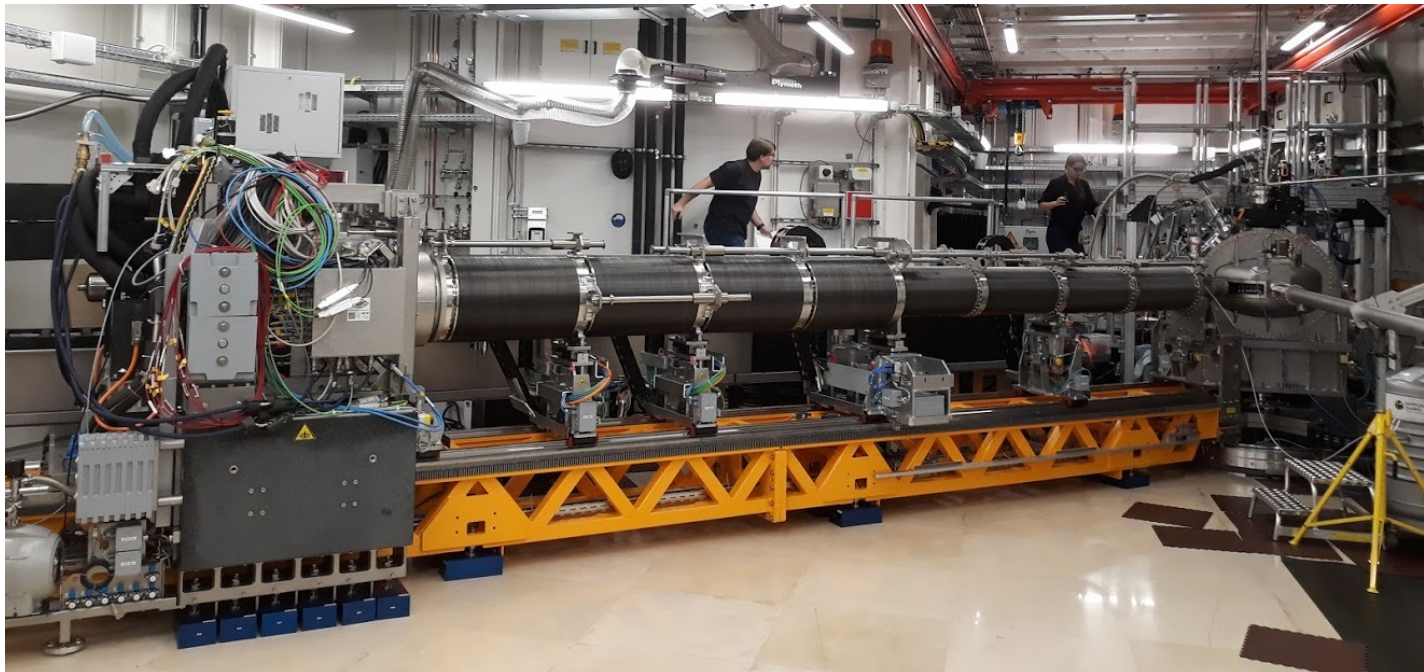
SASE2: Hard X-rays



Materials Imaging and Dynamics instrument (MID)

- In operation since **2019**
- 5-25 (and beyond) keV
- AGIPD for **MHz rep rate**
- sample to detector distance **0.15-8m**, 2θ: 0-50 deg
- Additional smaller detectors
- SAXS, WAXS, LFOV configuration
- in-air or in-vacuum setup (very flexible)
- Various sample environments: liquid jet, PUlsedMAgnet, goniometer…
- Split and Delay line
- Very versatile

- Dynamics in soft and condensed matter using **MHz XPCS**
- **Pump-probe** scattering and diffraction
- **Imaging** (Pump-probe, holography/CDI, Dark Field Microscopy)
- Nuclear resonant scattering techniques
- Pair Distribution Function measurements
- Ultrashort pulses (**<fs**)



Slide courtesy of Anders Madsen

Typical parameters and key topics for MID

- Photon energy typically **above 8keV**
- **HXRSS** is beneficial for most experiments
- Regular request and **use of 4.5MHz**
- Attosecond experiments
- Twin-bunches
- Higher photon energies (up to **30keV** and above)

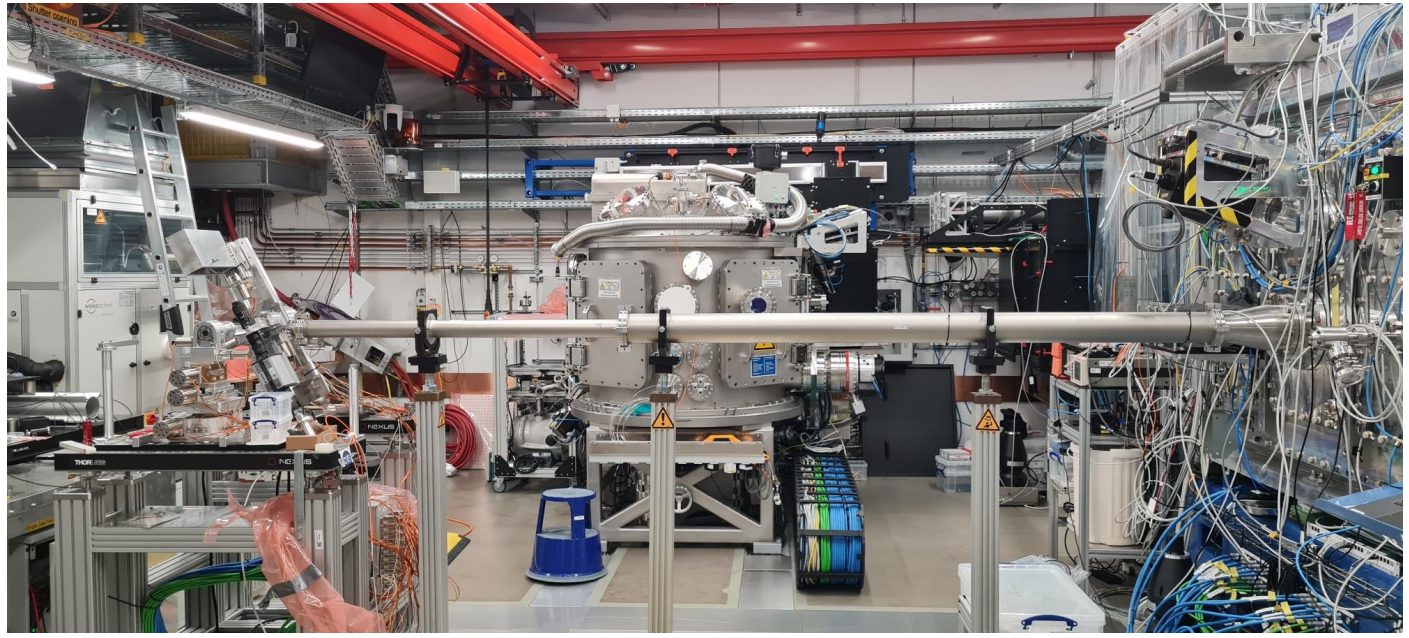
Key topics:

- Planning and delivery of special modes
- **Seeding** performance (stability, setup, operation)
- **Attoseconds**
- Scheduling in blue weeks

High Energy-Density instrument and Helmholtz International Beamline for Extreme Fields user consortium (HED-HiBEF)

- In operation since **5/2019**
- 5-25 (and beyond) keV
- AGIPD 500K for MHz rep rate
- Additional smaller detectors: JF
- sample to detector distance 0.15-4m, 2θ: 10-170 deg
- IC1, IC2, **6 standard configurations**
- Usually **in-vacuum** setup (IC1, flexible)
- Various sample delivery: solids, tape targets, cryo jet, DAC, cryogenic (PMF)
- 30 fs ultrarelativistic laser ReLaX
- Shock-compression laser DiPOLE 100X

- Dynamics of matter in extreme conditions
- X-ray imaging of shocks in opaque matter and foams
- Precision XRD for structure of matter at high pressure
- Scattering and Emission spectroscopy to study atomic physics
- **HXRSS** (for scattering), **4.5 MHz** (for DAC), **long-trains**
- Single bright **“on-demand” x-ray pulses** (brighter than plasma)



Slide courtesy of Ulf Zastrau

Typical parameters and key topics for HED

- Photon energy typically 7.5, 7.7, 8.2 keV single bright pulses with **HXRSS**, or **18-20 keV** for XRD (**single pulse or MHz**)
- Regular request and use of 4.5MHz for fast processes in DAC, and “long-train” for slower DAC and pulsed magnet

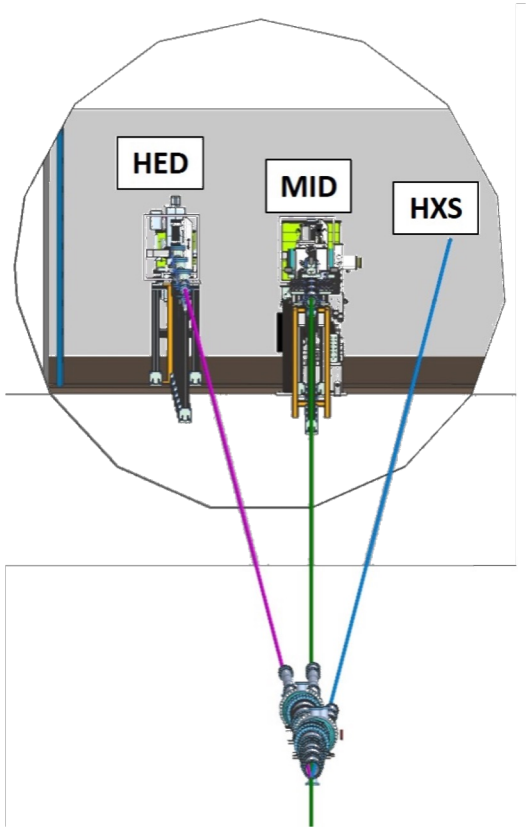
- Interest in “**Twin-bunch** mode”
- Higher photon energies (up to **30keV** and above)

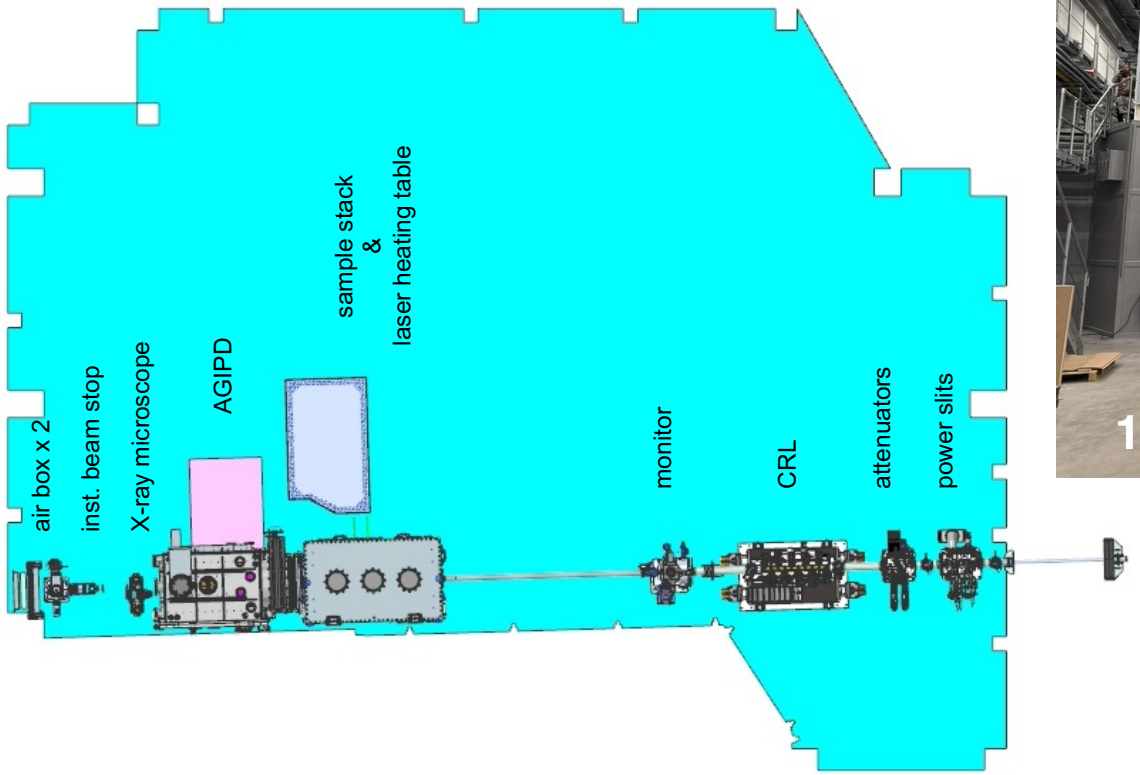
Key topics:

- Planning and delivery of special modes
- **Seeding** performance (stability, setup, operation)
- Future of single (10 Hz) bright pulses
- Future of **20 keV 4.5 MHz pulse trains**

Slide courtesy of Ulf Zastrau

SASE2 Third Port: Hard X-ray Science (HXS)





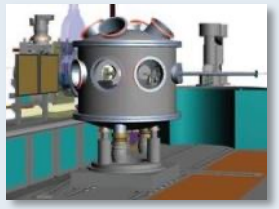
- Same source as MID and HED
- Common optics and diagnostics in XTD1
- Same horizontal offset mirrors M1 and M2 in XTD6
- Beam deflection to HXS by M4

Diamond Anvil Cells

Fast dynamic piezo DAC

Pulsed laser heated DAC

X-ray heated DAC

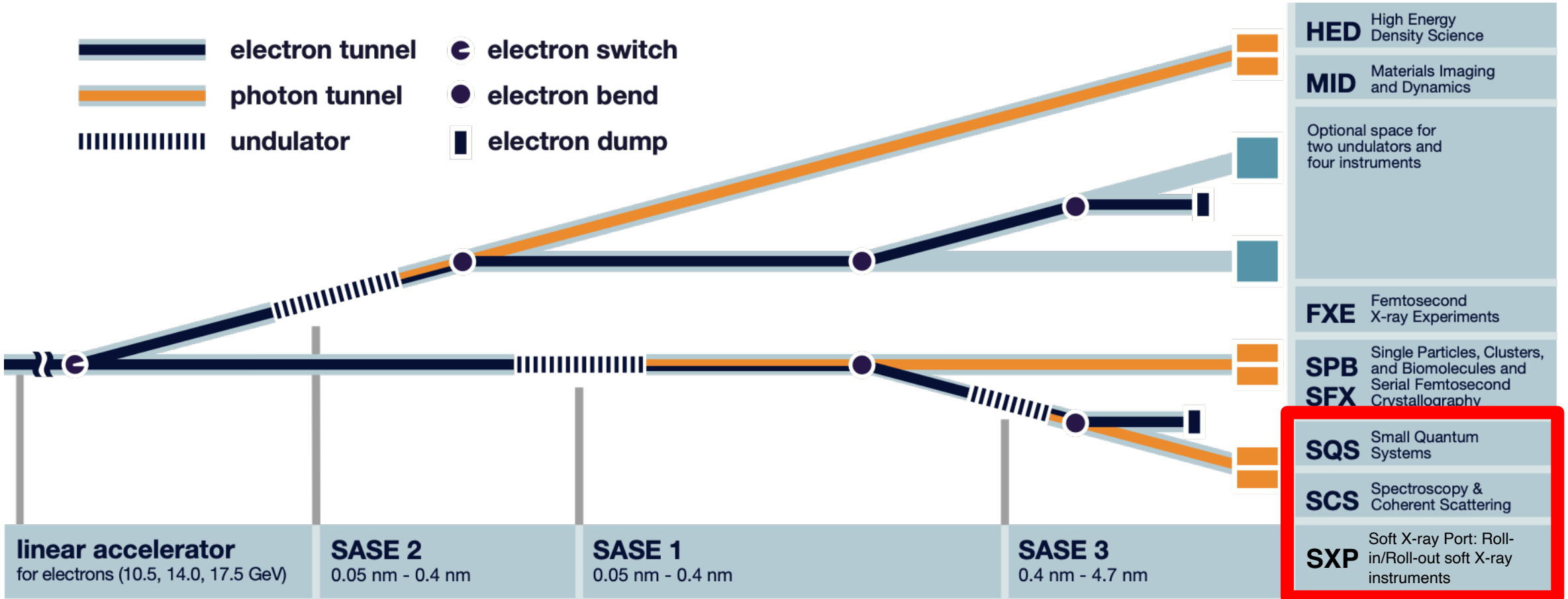


18 to 25 keV

European XFEL

Slide courtesy of Ulf Zastrau and Cornelius Strohm

SASE3: Soft X-rays

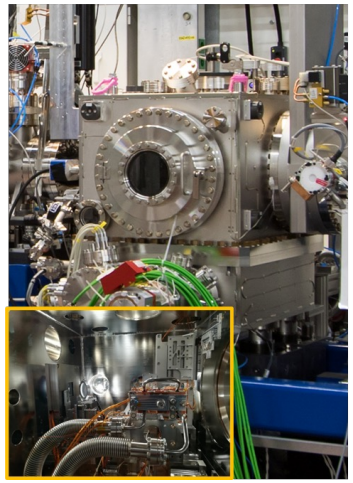


Spectroscopy and Coherent Scattering (SCS)

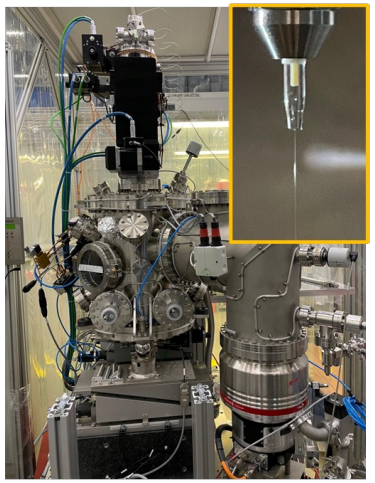
- In operation since **Nov 2018**
  - 6 – 8 proposals per run (semester)
  - 26 user publications
- 400 - 3000 eV
- 3 end stations: FFT, CHEM, XRD
- DSSC for **MHz rep rate** (Imaging, XAS)
- hRIXS spectrometer for XRD and CHEM
- XAS with beam-splitting Off-axis Zone plate (BOZ)
- Various sample environments: pulsed magnet, cryostat, liquid jet, goniometer...
- Very versatile

- **Dynamics in condensed matter**
- Quantum materials
- Ultrafast chemical science
- Ultrafast magnetism
- Coherent scattering (Pump-probe SAXS, holography, imaging)
- **Nonlinear X-ray** matter interaction
- Ultrashort pulses (**< fs**) and **2 colors** mode

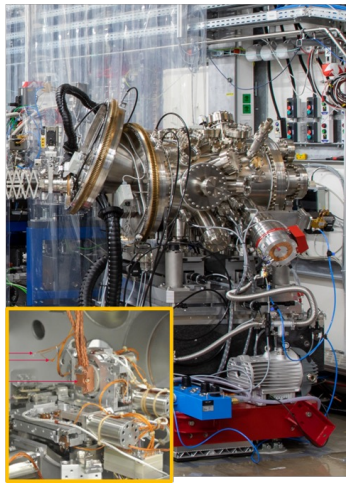
FFT experiment station
Since Oct 2018



CHEM experiment station
Feb 2022



XRD experiment station
Sep 2022



Slide courtesy of Laurent Mercadier

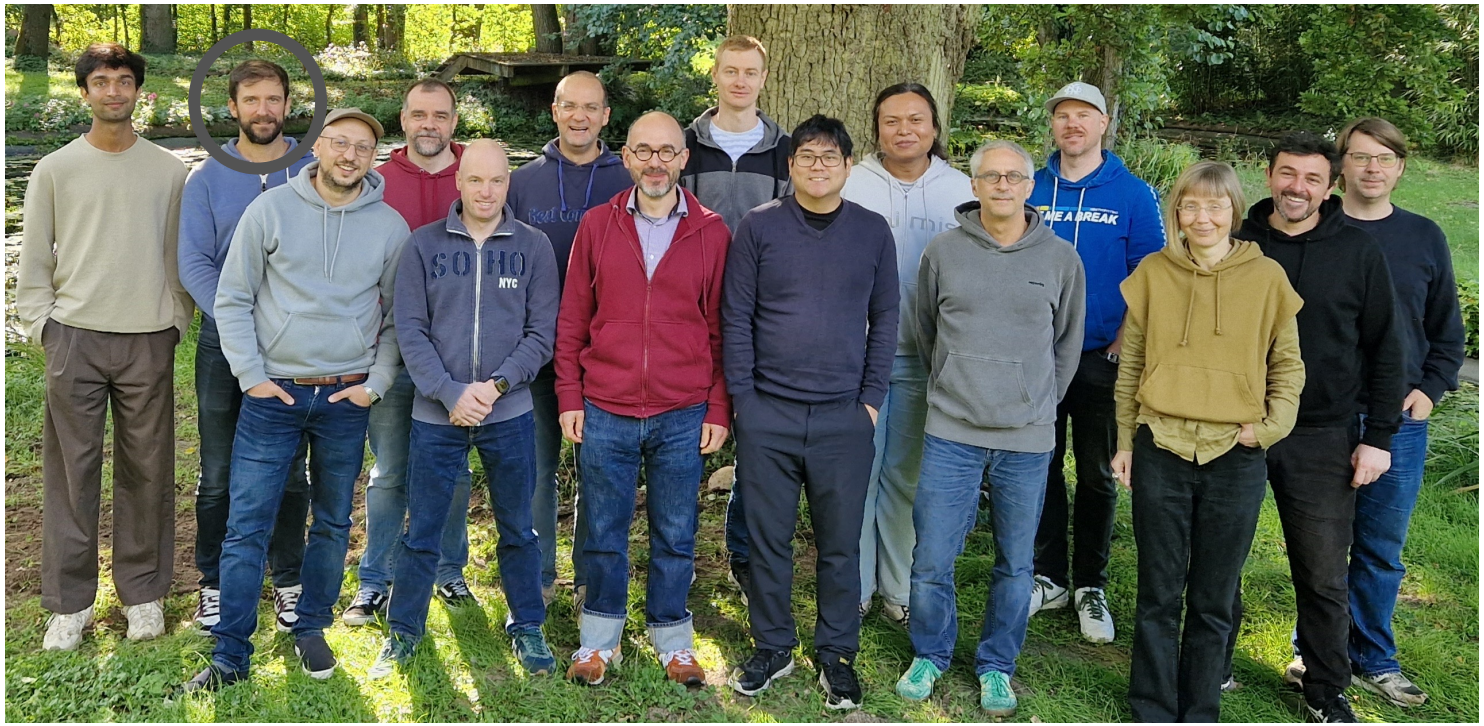
Typical parameters and key topics for SCS

- Standard machine configuration (using monochromator): most experiments
  - High demand for **10.5 and 11.5 GeV** (N and O K-edges)
  - **Long RF window** (RIXS is photon-hungry)
  - Circular and vertical **polarization**
  - 1 MHz
- **Attosecond two-colors**: one or two experiments per year
  - FFT and/or CHEM chambers available in one run per year only

Key topics:

- Planning and delivery of **special modes**
- Two color mode and ultrashort pulses
- Scheduling in blue weeks

Laurent

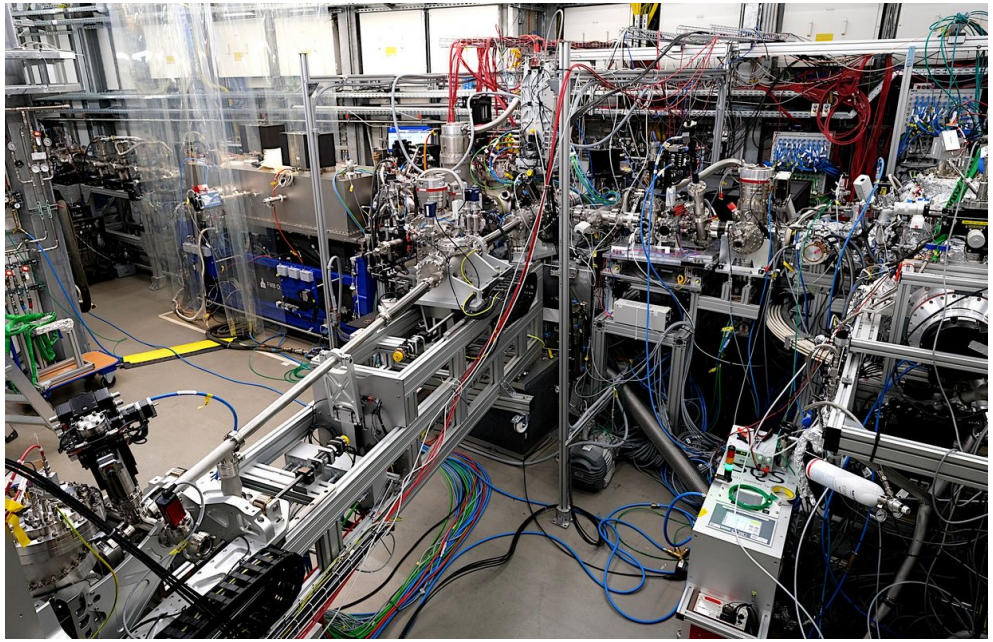


Slide courtesy of Laurent Mercadier

Small Quantum Systems (SQS)

- In operation since Nov. **2018**
- 300 – 3000 eV
- Gasphase: atoms, molecules, clusters
- Ultra-high vacuum (10^{-8} - < 10^{-11} mbar)
- Electron, ion and fluorescence
- Coincidence spectroscopy
- Coherent Diffraction imaging
- Different experimental chambers (AQS, NQS, REMI, EBIT)
- Various sample delivery: effusive jet, molecular beam, cluster source, aerosol source, He-droplet

- Multi-photon processes
- **Two-Color** Pump-Probe experiments
- Electronic relaxation of highly excited states
- **Attosecond** spectroscopy
- Molecular structure & dynamics (Coulomb Explosion Imaging)
- Dynamics of nanoparticles and biomolecules (CDI)



Slide courtesy of Michael Meyer

Typical parameters and key topics for SQS

- Photon energy: Strong focus on **300 – 600 eV** (C, O, N K-edges), but also 1 – 3 keV
- **Two-bunch** mode with magnetic chicane
- High intensities (several mJ)
- Short pulses (**attosecond mode**)
- Variable polarization (**APPLE-X**)

- Non-linear studies
- Pump-probe experiments (more than 50% of proposals)
- Sub-femtosecond dynamics
- Dichroic studies of chiral systems

Key topics:

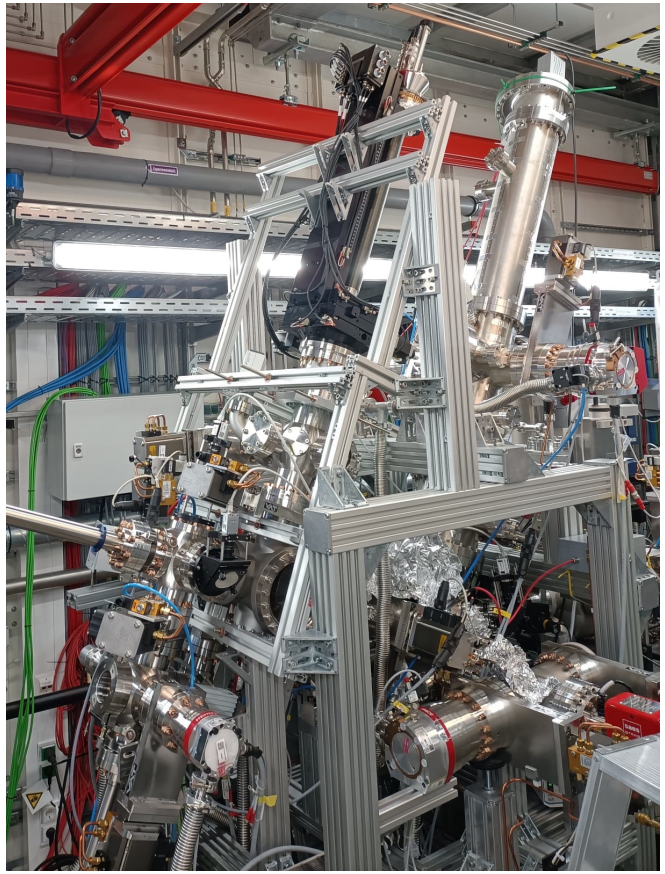
- Planning and delivery of **special modes**
- **Attosecond** pulse generation
- Organization of (Availability in) blue weeks
- Low photon (low electron) energy modes

Tommaso

Slide courtesy of Michael Meyer

SXP Soft X-ray Port

- In operation since **2024**
- Mostly **1 – 3 keV**
- MCP-DLD detectors (commercial)
- **Solid samples** on omicron plates
- UHV conditions ($5 \cdot 10^{-10}$ mbar)



- Time-resolved photoelectron spectroscopy on solids
- **Pump-probe experiments** with OL (with FEL possible)
- **Attosecond** pulses (not yet implemented)

Slide courtesy of Manuel Izquierdo

SXP Typical parameters and operation interests

- Mostly 1 – 3 keV, lower desired
- Very low pulse energy, many pulses
  - 4.5 MHz & large RF window ➔ ideal
- Variable polarization ➔ LV standard configuration

Key Topics:

- Low pulse energy at high photon energy
- Increasing the number of pulses (RF, Rep. Rate)
- Frequency missing with the undulators to access lower pulse energies at high acceleration energies
- Attosecond pulses

Slide courtesy of Manuel Izquierdo

Looking forward to more successful operation !