European XFEL

Photon beamlines & Experiments Facilities

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- User requirements to the FEL
- Electron and photon beam distribution
  - Photon beamlines
  - Experiments facilities
Scientific experiments

Scientific fields
- Atoms, molecules, cluster phenomena
- High-energy-density states of matter
- Condensed-matter
- Surfaces and interfaces
- Chemistry
- Materials science
- Life-sciences
- Non-linear optics

‘Classes’ of experiments
- Diffraction
- Spectroscopy
- Coherence
- High field

Instrumentation techniques
- Pump-probe experiments
- μ-focusing
- Extreme energy resolution

Requirements to FEL layout and performance follow from the scientific scope

Thomas Tschentscher: European XFEL – Photon beamlines & Experiments facilities
Scientific user community input

Scientific workshops

• XFEL workshops (2000)
  Surface & Interface Science; Nuclear Resonance Scattering; Atomic, Molecular and Cluster Phenomena; Non-linear and Quantum Optics; Hard-Condensed Matter; Chemistry; Life-Sciences
  Methods & Instrumentation
• STI workshop on Accelerator and Science issues (2004)

Reports


Experience with existing facilities

• Synchrotron radiation & high-power laser facilities
• Sub-Picosecond Pulse Source (SPPS)
• VUV-FEL at TTF (Phase 1 and Phase 2)

Other FEL projects

• collaboration and participation in preparation for LCLS
Classification of requirements

**FEL beam parameters**
- Ultrashort pulse duration
- Peak brilliance as simulated: $10^{32} - 10^{34}$ phts/mm$^2$/mrad$^2$/0.1%/s
- Coverage of photon energy range from soft to hard x-ray (few 100 eV to 12.4 keV) **with emphasis on ‘hard’ x-ray range**
- Provision of linear and circular polarized radiation

**Operational conditions**
- multi user facility with many independent instruments
- dedicated instrumentation and experiment support staff
- synchronized optical laser (diagnostics, pump-probe experiments)
- sample preparation laboratories

**Stability of FEL beam**
- SR communities: very high stability with $<< 10\%$ parameter fluctuations
- High-field laser community: fluctuations due to varying laser output
Stability requirements

Experiments will be sensitive to

- location of the beam spot/focus
  - source point (transverse & longitudinal)
  - pointing of FEL beam
- photon energy & energy spread
- pulse arrival time & pulse duration
- coherence

Fluctuations of FEL parameters require single-pulse diagnostics

- in saturation SASE FEL output fluctuates by 5-10%
- pulse-by-pulse diagnostics to measure fluctuations is mandatory

Requirements

- do not increase fluctuations due to SASE significantly
- minimize fluctuations not observable by ‘standard’ diagnostics
- enable future operation with reduced fluctuations (e.g. by seeding)
Requirements for specific experiments

**Diffraction experiments**
- 8-12 keV to enable best resolution and facilitate sample environment
- ‘pure’ beam (size, coherence, monochromaticity)
- ‘shaped’ beam (focii $\geq 10 \mu$m, monochromaticity $\sim 10^{-4}$)
  $\Rightarrow$ Hard-condensed matter, Surfaces, Chemistry, Life-sciences

**Spectroscopy experiments**
- 0.2-9 keV to cover atomic absorption edges
- ‘shaped’ beam (focii $\geq 10 \mu$m, monochromaticity $\ll 10^{-3}$, linear&circular polarisation)
  $\Rightarrow$ Atoms, Molecules, Cluster, Hard-condensed matter, Magnetism

**Coherence experiments**
- 6-12 keV to cover atomic absorption edges
- ‘pure’ beam (size, coherence, monochromaticity)
  $\Rightarrow$ Equilibrium dynamics, nm-Imaging

**Peak brilliance/High field experiments**
- 0.2-12 keV to adjust absorption in matter
- ‘shaped’ beam (focii $< 1 \mu$m, monochromaticity $\sim 10^{-4}$)
  $\Rightarrow$ Plasma physics, Non-linear phenomena
**Electron beam parameters, RF-pulse fill pattern**

**Electron energy changes**
- Variations inter- and intra-RF-pulse of ±1.5% required in spectroscopy exp.s
  - \( \Rightarrow \) **photon energy range**: ±3.0%
- Chirp of the electron energy during a RF-pulse of ±1.5% (peak-to-peak) provides the possibility to collect spectral information within 800 µs
- Likely energy required constant in one beamline while varying in the second

**Repetition rate & electron beam pattern**
- Experiments ask for wide range of different pulse patterns
  - \( \Rightarrow \) **single-pulses at <1 – few Hz repetition** .... up to ....
  - \( \Rightarrow \) **complete pulse train filling at 10 Hz**
  - \( \Rightarrow \) ideally higher repetition rate of pulse trains
- ‘Simultaneous’ experiments can have different requirements

**Repetition rate vs. orbit stability**
- electron feedback methods require preceding electron bunches
- employ ‘un-used’ part of RF pulse and kick-out ‘un-wanted’ pulses
  - \( \Rightarrow \) **fast electron kicker**
  - \( \Rightarrow \) **fast photon shutter**
Requirements to the beam distribution

Choice of undulator distribution and parameters

- Small number of undulators & photon beamlines
- Main area of applications in the 10-12 keV range
- Only one such FEL per electron beamline
  ⇒ but 2nd FEL can operate at ~4 times smaller photon energy
  ⇒ undulators for spontaneously emitted synchrotron radiation
- New schemes to be applied to run user experiments ‘simultaneously’
  ⇒ Parallel operation of as many experiments as possible
  ⇒ Minimize down-time of beamlines/experiments: ideally use every pulse
- Fast switching of e-beam to make best use of all beamlines

Requirements for optics and geometry

- photon beams require drift to reduce power density
- separation of electron and photon beams requires drift sections
- keep free drift sections for future options for undulators
Baseline design

- 2 SASE FELs for hard x-ray FEL radiation
- 1 SASE FEL for soft/medium x-ray FEL radiation
- 2 undulators for spontaneously emitted synchrotron radiation (optionally replace U 1 by additional SASE FEL for soft X-ray range)
- Use spent beam for soft x-ray FEL and spontaneous radiation undulators
**SASE 1:** Diffraction experiments; extension to 15 keV; seeding
- operation standard at $\geq$12 keV
- electron energy tunability (12.4 keV @ 17.5 GeV; d=10 mm)

**SASE 2:** Spectroscopy and coherence experiments at varying photon energy
- varying x-ray energy according to experiments needs (3-12 keV)
- gap & electron energy tunability (12.4 keV @ 17.5 GeV; d=19 mm)

**SASE 3:** Spec. & coh. experiments using soft x-rays – AMC, plasmas, etc.
- varying soft x-ray energy according to experiments needs (0.8-3 keV)
- gap & electron energy tunability (3 keV @ 17.5 GeV; d=23 mm)
- variable polarization
Civil engineering of FEL beam distribution area

Layout of the XFEL switchyard
(Oct 2004)
Generic photon beamline

0.1 nm beamline

- Absorbers for FEL intensity control
- Beam stop for bremsstrahlung

Photon diagnostics
- FEL commissioning & diagnostics
- Monitoring FEL beam parameters

Standard x-ray optics
- $10^{-4}$-bw monochromators
- double-bounce mirrors

Power consideration
(0.1 nm, 1 µrad, 100 µm, 10 Hz à 1700, 17.5 GeV)
- Total power 40 W
- Power density $|_{\text{source}} \sim 3.5$ KW/mm²
- Power density $|_{\text{optics}} \sim 100$ W/mm²
- Total peak power 24 GW
- Peak power density $|_{\text{source}} \sim 2 \times 10^{14}$ W/cm²
- Peak power density $|_{\text{optics}} \sim 6 \times 10^{12}$ W/cm²
Photon diagnostics for FEL commissioning

Gap /K-parameter tuning

Phasing of undulator segments

Select energy and analyse spatial profiles for single / adjacent undulator segments
⇒ Sensitivity to μm gap changes
⇒ Phasing after K-variation

Requirement:
Energy stability < 10^{-3}
Pointing stability < 10^{-2}


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Beamline end-stations include

- Special X-ray optics
- Diagnostics
- Vacuum systems
- Diffractometers and spectrometers
- Detectors

Optical femtosecond laser

- Laser beam distribution

Preparation laboratories

- Sample preparation and testing
- Off-line tests using optical laser
- Optics and detector labs
5 beamline end-stations

- Optics hutch for special optics
  ⇒ High-resolution monochromators
  ⇒ Beam-splitter/delay units
- Extreme focusing integrated in experimental setup

- Up to 3 experimental stations
- Control area
- 17 m spacing between BL
- 42x15x4 m³ for experiments

Example of beamline end-station layout
R&D topics

Photon beamlines
  • verification of diagnostics
  • spike resolving measurements of spectral distribution of FEL radiation
  • time properties diagnostics
  • peak power and full pulse train power load on optics
  • coherence effects / wavefront propagation

Experiments
  • special optics & instrumentation
  • detailed layout of experimental stations

General
  • stability issues with respect to pointing stability of 0.1 µrad
The end