Outline of experiment(s) to be performed at IFE instrument and the requirements for such experiments

We are currently defining the IFE instrument. In order instruct this design and the capabilities for research at this instrument, we would appreciate your feedback about the types of experiments you could imagine and the major requirements for such experiments. We appreciate that your description may become more detailed with time, but since we need the design process now your present thoughts do matter. Consider this as well to guide your input to the meeting on Jul 16, 2025, and the subsequent discussion.

Instrument location and layout

The IFE instrument will be located in the photon tunnel XTD 8 and presently free space in the experimental hall

- The tunnel has only a diameter of 4.5 m, transport ways reduce the available space to ~3 m.
- Tunnel length is 360 m. The experimental area is located towards the experiment hall (last 50 to 200 m)
- Tunnel components:
    - Compressor (to be clarified)
    - Harmonic generation and fundamental suppression
    - Target areas
- Experimental hall
    - Cleanroom for laser installation
    - Compressor (to be clarified)
    - Control room

For initial ideas of the IFE instrument and its applications see 2024 workshop (https://xfel.tind.io/record/3916?v=pdf).

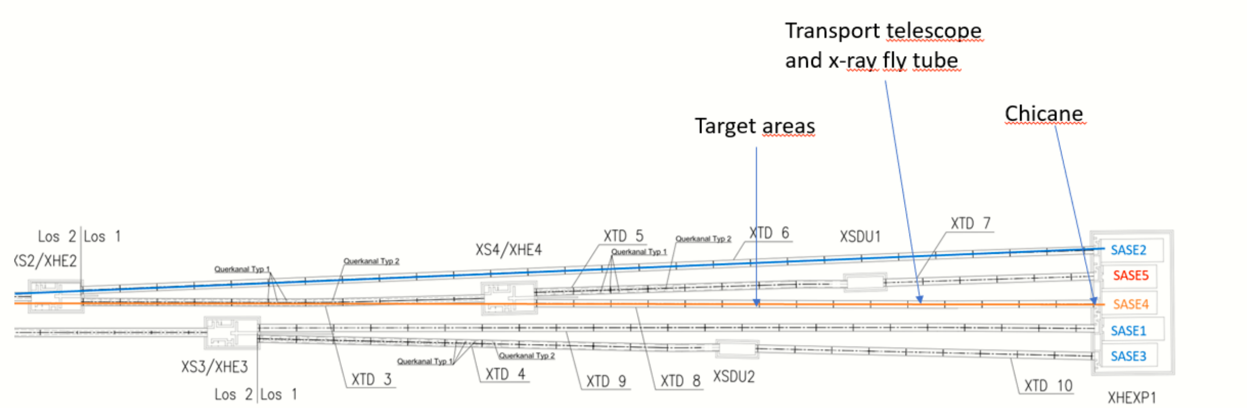

Figure 1: Instrument Location

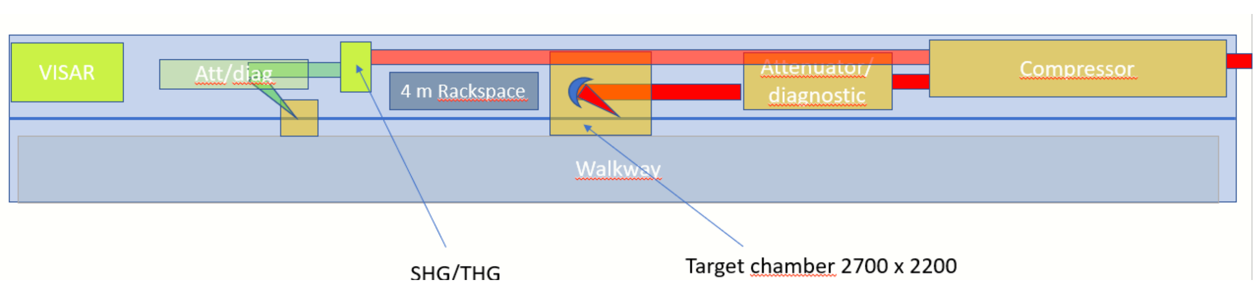

Figure 2: Possible layout of the target area

X-ray parameters

X-ray pulses will be deflected from the SASE2 undulator path towards the IFE tunnel by sets of multilayer mirrors pairs. The photon beam parameters are therefore almost identical to SASE2/HED capabilities (photon energy range, self-seeding, two-color, and attosecond capabilities) including also future upgrades (e.g. SCU afterburner for photon energies > 30 keV). Limitations compared to SASE2/HED capabilities are:

- Reduced pulse energy due to reflectivity of multilayers (about 70% of HED intensities, e.g. 1.4 mJ (6 keV) to 70 uJ (24 keV)
- Only single or few pulses are possible per pulse-train, due to damage sensitivity of multilayers.
- Limited number of fixed energy points, as each multi-layer pair can reflect only one photon energy (bandwidth about 100 eV)
- Wavefront quality/focusing: We expect a degradation of the wavefront due to the multilayer reflections, which is subject of ongoing simulations and future studies. We aim to focus down to about 100 nm before the sample with a sufficiently flat wavefront to allow phase contrast imaging in the expanding beam.
- Beam availability: The IFE instrument is expected to run mostly in beam sharing mode with one of the SASE2 instruments, whenever this is possible. In this mode individual pulses or pulse trains are deflected to the IFE instrument, either in a pre-defined pattern or on demand. The photon parameters (photon energy, pulse length, seeding) have to be the same for both experiments, scanning of the beam energy is in general not possible.

Answers expected from the workshop:

- Which energy setpoints are critically needed?
- With which priority?
- Which beam divergence is required?

Laser parameters

Though the laser parameters are not known in detail yet, we expect the following parameters based on present laser designs and developments to be expected in the near future:

Principal design:

- Laser system with long (ns) and short pulse (sub-ps) capabilities.
- Staged approach, possibility to extend to increase laser energy
- Repetition rate >1 shot/ 10 min (Dipole experiments have shown rates between 1/30s – 1/ 5 min feasible), depending on laser technology, even ~1 Hz shot rates might be possible
- Nd: glass system, wavelength around 1.06 mm

Long (ns) pulse laser:

- Arbitrary temporal pulse shaping 1-30 ns
- Energy starting with 200 J - 400 J, then booster to 2 kJ (fundamental wavelength)
- Further energy increase by adding laser systems
- Beam size squared with ~200x200 mm
- Frequency conversion (2^{nd}/3^{rd} harmonic), fundamental wavelength most likely not available
- Achievable bandwidth with broadband source not defined yet, ~10 nm expected

Short (sub-ps) pulse laser:

- Pulse length ~100 fs
- Energy 200 J
- Bandwidth around 10 nm
- Beam size square ~350x350 mm
- OPCPA front end with Nd: glass booster

Answers expected from the workshop:

- Long pulse laser:
    - Do we need both 2^{nd} and 3^{rd} harmonic? Right from the beginning?
    - Beam smoothing (1D/2D SSD)?
    - Energies/peak power at 2w and/or 3w

    - Peak intensities (focal spot sizes)
- Short pulse laser:
    - Which contrast (-> enhancing 2w or plasma mirror)
    - Pulse lengths?
    - Focusing/intensities
- Interaction chambers:
    - Interest for combined short-pulse/long pulse?
    - Irradiation geometry laser vs. x-ray? Upstream/Downstream?
    - Multi beam options?

Target areas

Currently, we are planning for (at least) two target areas that allow for imaging at the best achievable resolution and to combine this with the capability to perform SAXS measurements. While X-ray optics will be placed close to the sample, detectors for SAXS and imaging will be positioned at a large distance downstream. We expect that the geometry of the chamber will be mainly defined by laser optics.

Answers expected from the workshop:

- Experimental set-ups:
    - Required resolution/FoV for imaging experiments?
    - Imaging concept? (point projection, direct imaging or Talbot imaging)
    - Specifications for SAXS?
    - Additional X-ray diagnostics? (e.g. XRD, X-ray emission)
    - Required photons per shot on sample/SNR

- Interaction chambers:
    - Required X-ray beam sizes
    - Additional X-ray diagnostics? (XRD, X-ray emission)
    - Suitable X-ray optics (on-axis essential?)

- Possible additional experimental setups and/or chambers?
    - Pulsed power
    - X-ray only
    - Fixed laser irradiation setups
    - Future multi-beam irradiation geometries