

Smart*light For Heritage Science: A New Inverse Compton X-ray Source From The Netherlands

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Motivation

X-rays allow for a non-destructive investigation of objects. This makes them well suited for the investigation of cultural heritage objects that need to be preserved for coming generations. The most informative X-ray techniques, such as XANES or XRD imaging, are limited to synchrotron (SR) sources as they require tunable, monochromatic primary radiation of high intensity. Experiments at SR sources require the transport of objects, which might be prohibited due to the stress they are exposed to in the process. Further, experimental time at SR sources is limited. The Smart*Light (S*L) project aims to bridge the gap between X-ray tubes and SR sources by developing a compact Inverse Compton Scattering (ICS) source that can be installed in a museum's cellar, minimizing the need for transporting delicate artifacts and maximizing accessibility for cultural heritage research.

Inverse Compton Scattering

The Inverse Compton effect describes how laser light is scattered back by relativistic electrons, gaining energy and being promoted to the X-ray regime (s. Fig 1). Inverse Compton Sources feature several **Advantages**:

- **Narrow Bandwidth**: The bulk of the created radiation is in a narrow bandwidth (approximately 1% $\Delta E/E$).
- **Partial Coherence**: The radiation is partly coherent.
- **Narrow Emission Cone**: The radiation is emitted in a narrow cone.
- **Tunable Energy**: The energy of the emitted radiation can be tuned by varying the energy of the electrons or the laser.

Energy and intensity have a peculiar shape, both declining with scattering angle (s. Fig 2). While not competitive to a full SR source in terms of intensity (s. Fig 3), ICS sources are more compact and require a much smaller investment.

The main reason ICS sources have not been established is the high demands to power and quality of laser and electron beam, but most problems have been overcome for S*L.

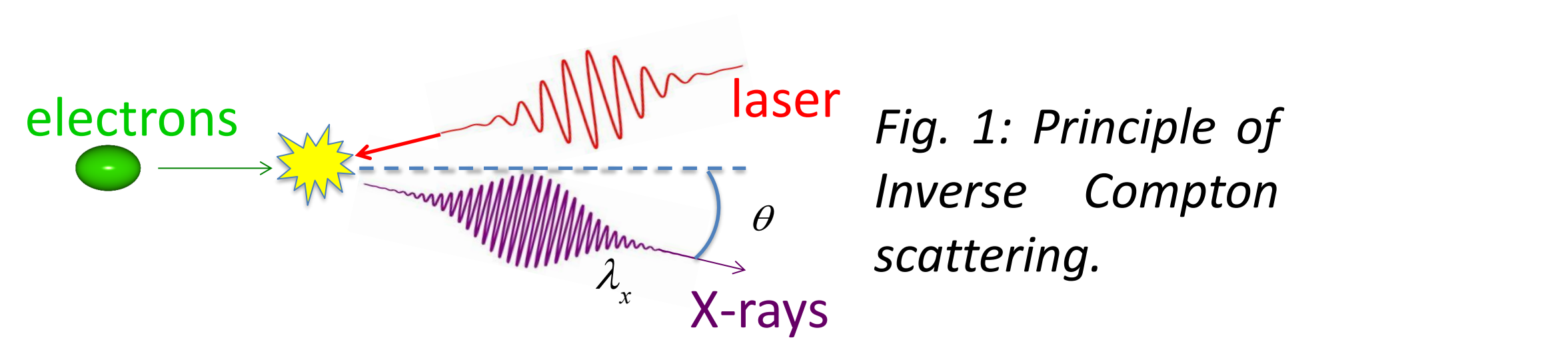


Fig. 1: Principle of Inverse Compton scattering.

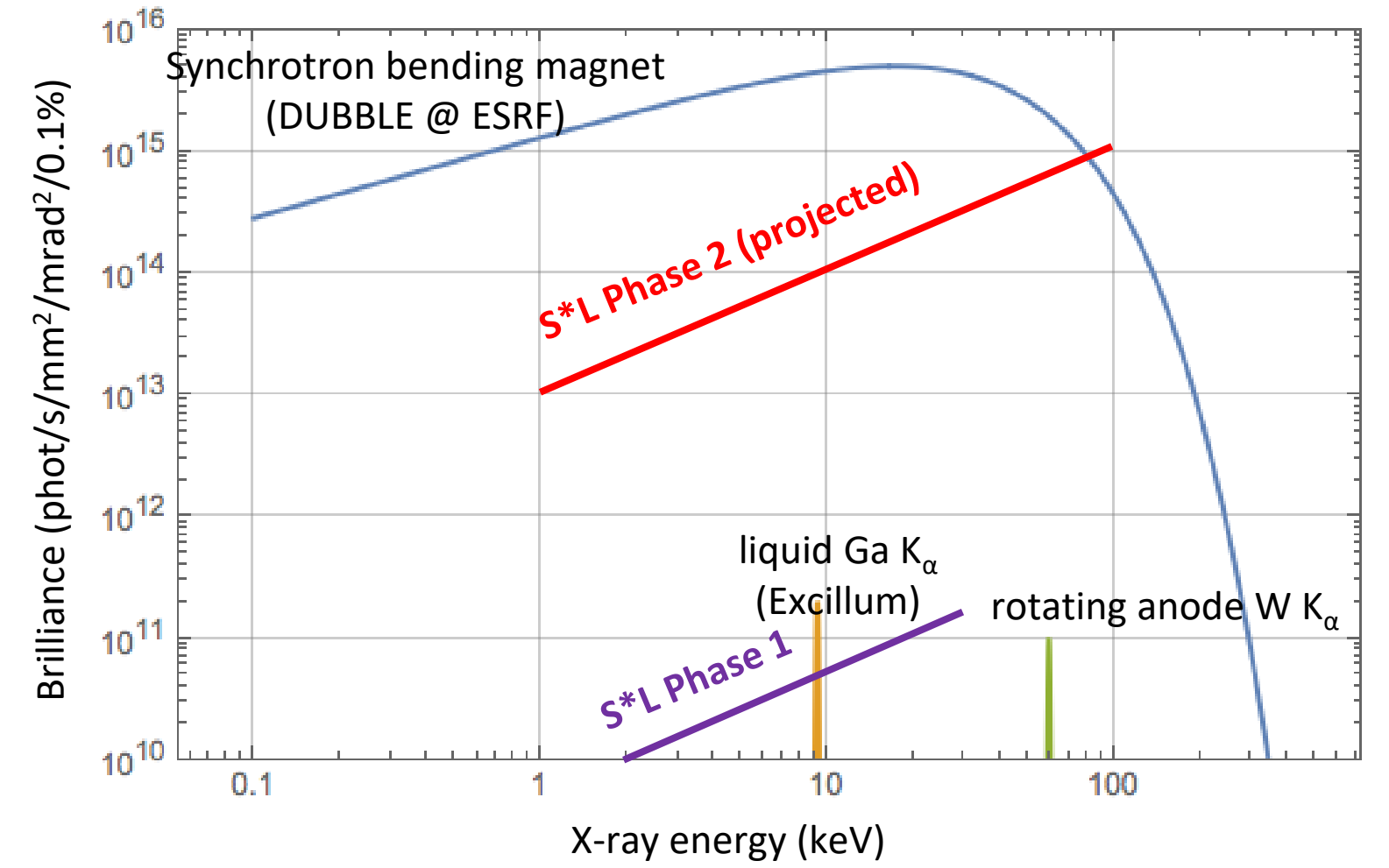


Fig. 3: Expected performance of Smart*Light

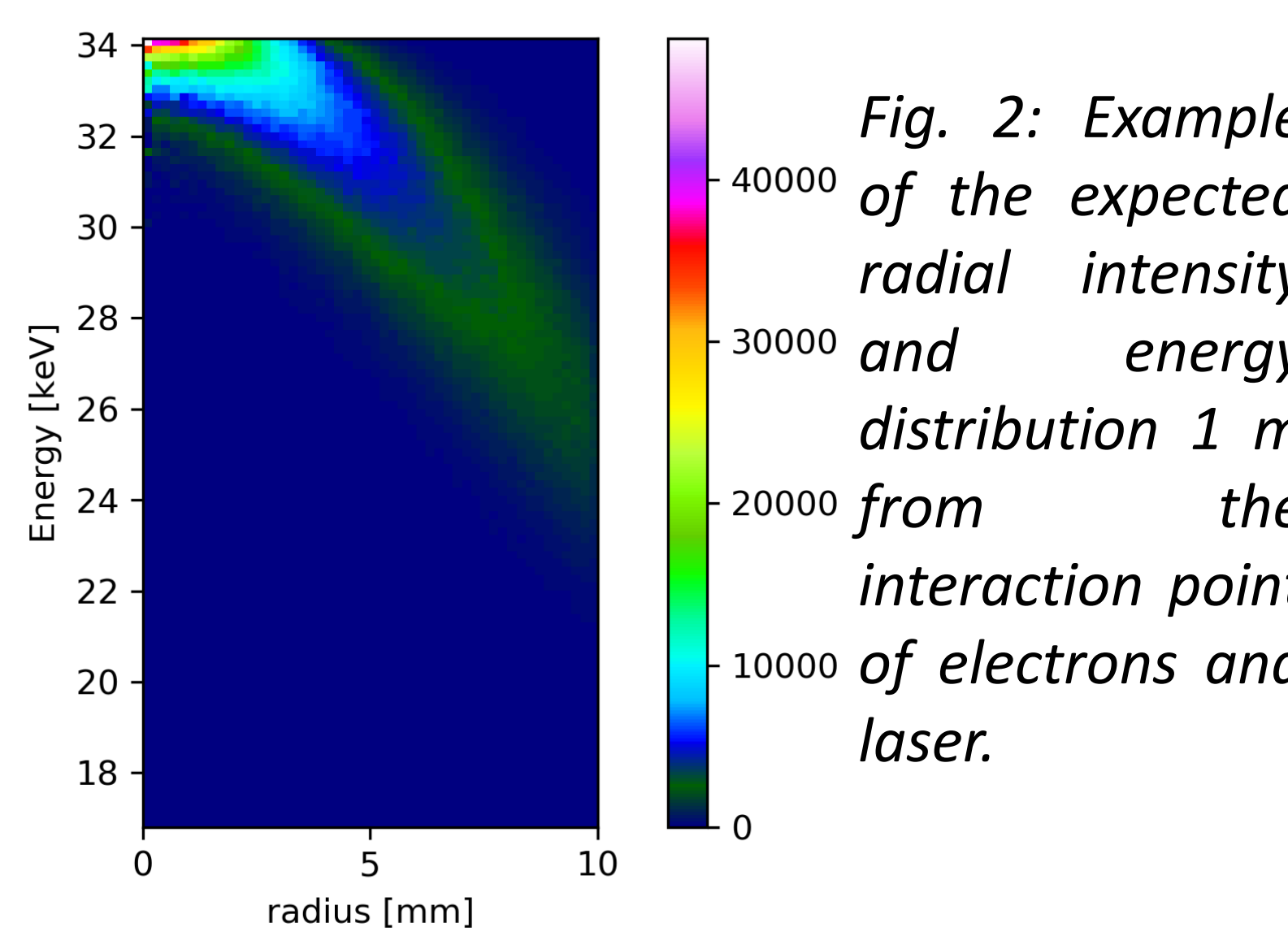


Fig. 2: Example of the expected radial intensity and energy distribution 1 m from the interaction point of electrons and laser.

Smart*Light (S*L) and its Cultural Heritage & First Experiments

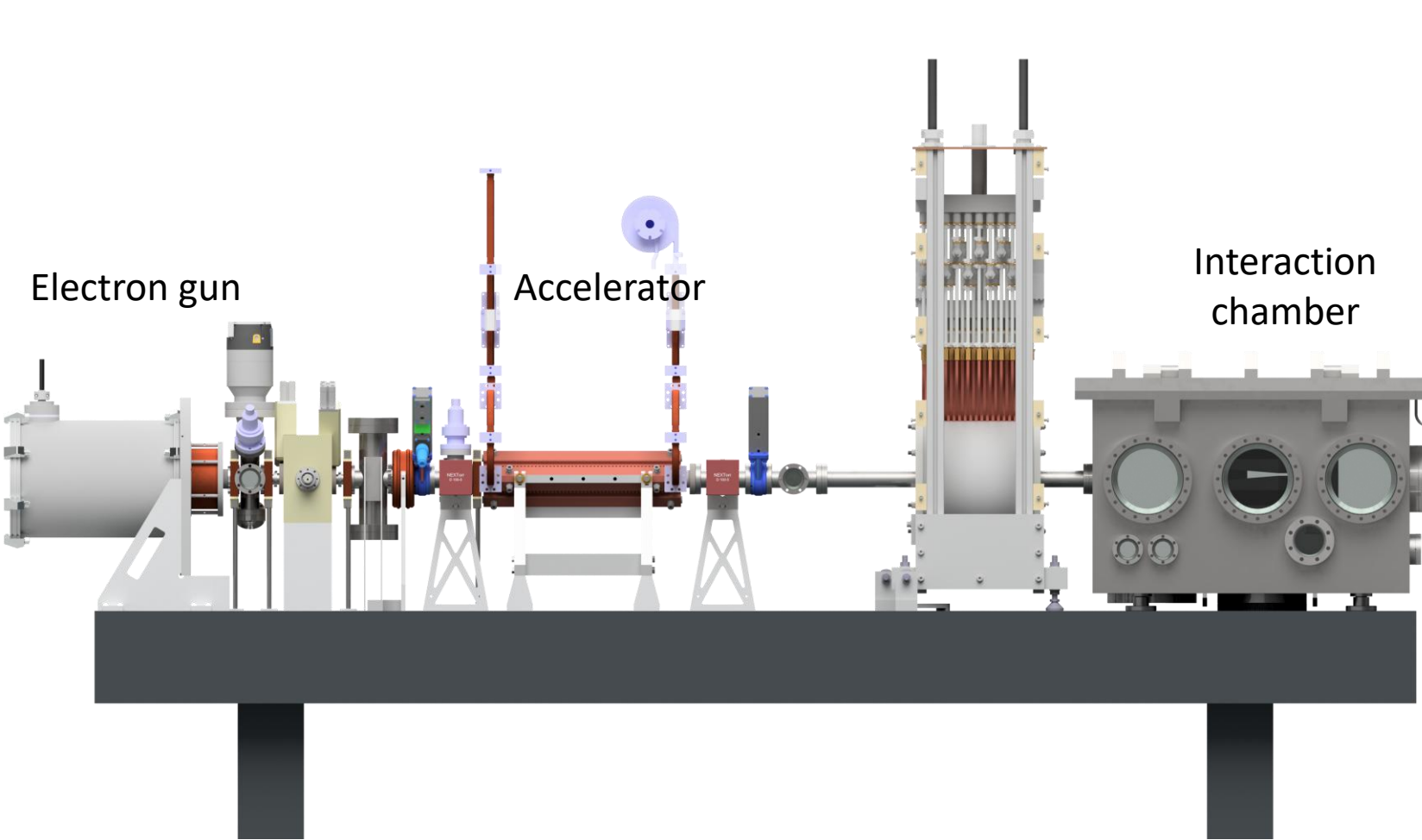


Fig. 4: Design of Smart*Light. Courtesy: D. Nijhof & C. Sweers, TU/e

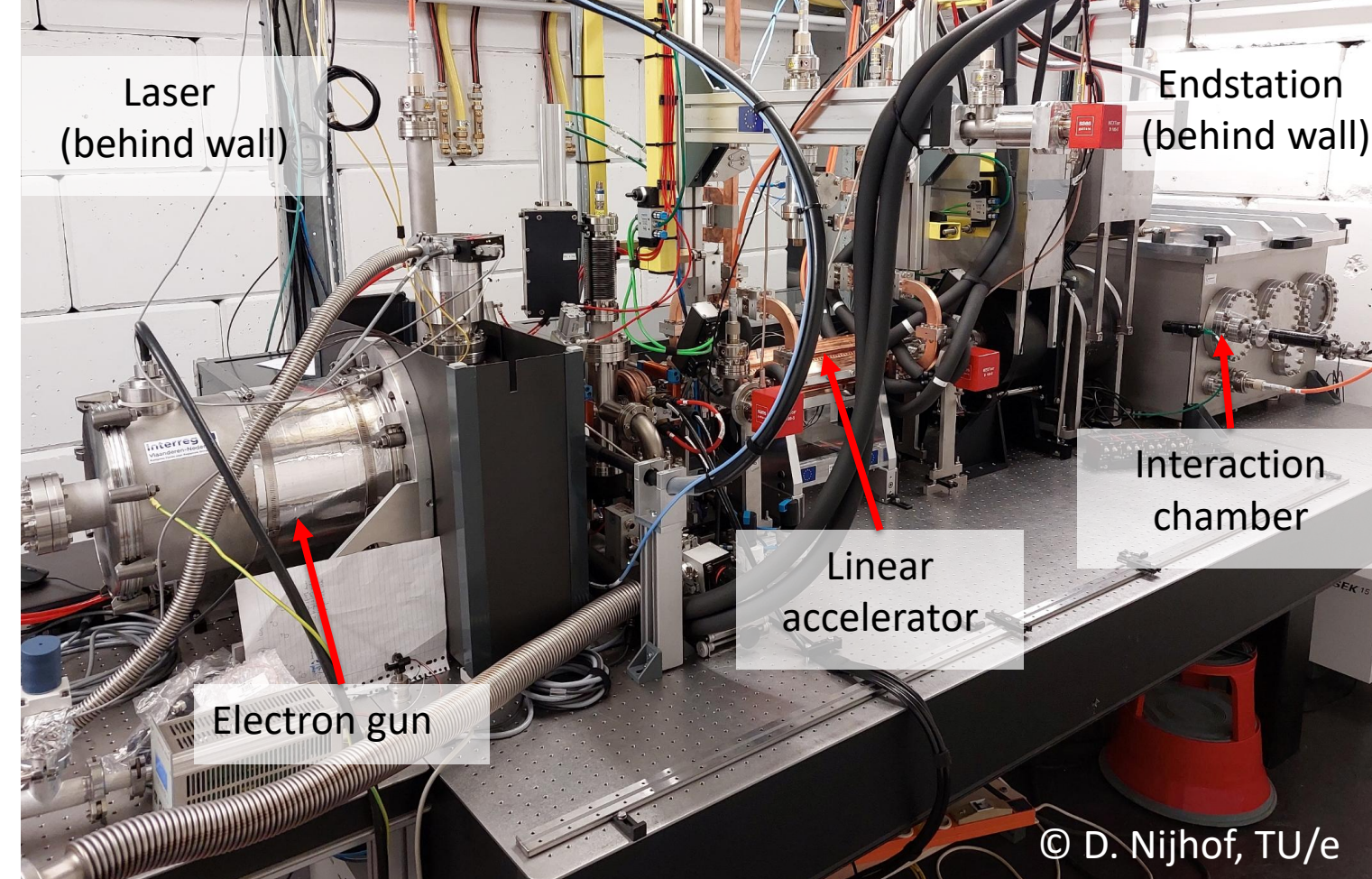


Fig. 5: Photograph of Smart*Light prototype. Laser and endstation are behind the brick walls. Right: Expected performance parameters.

Electron beam	
Beam energy	5-25 MeV
Bunch charge	10 pC
Repetition rate	1 kHz
Laser	
Wavelength	800/400 nm
Pulse length	100 fs
Pulse energy	12 mJ
X-rays	
Energy	0.6 – 30 keV
Brilliance	10 ⁸ – 10 ⁹ (ph/s/mm²/mrad²/0.1%BW)

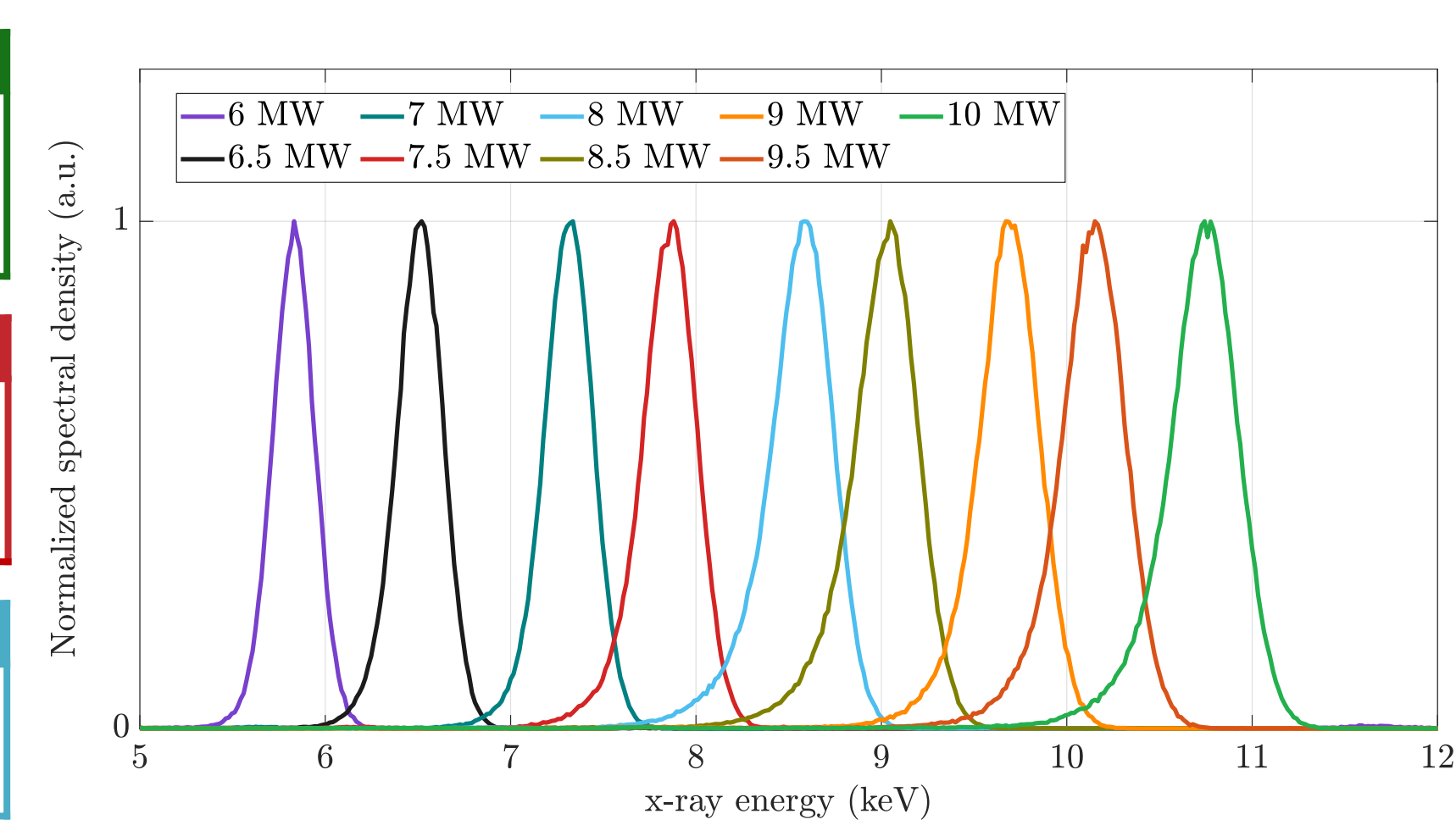


Fig. 6: Primary beam energy tuned by selecting suitable electron beam energies.

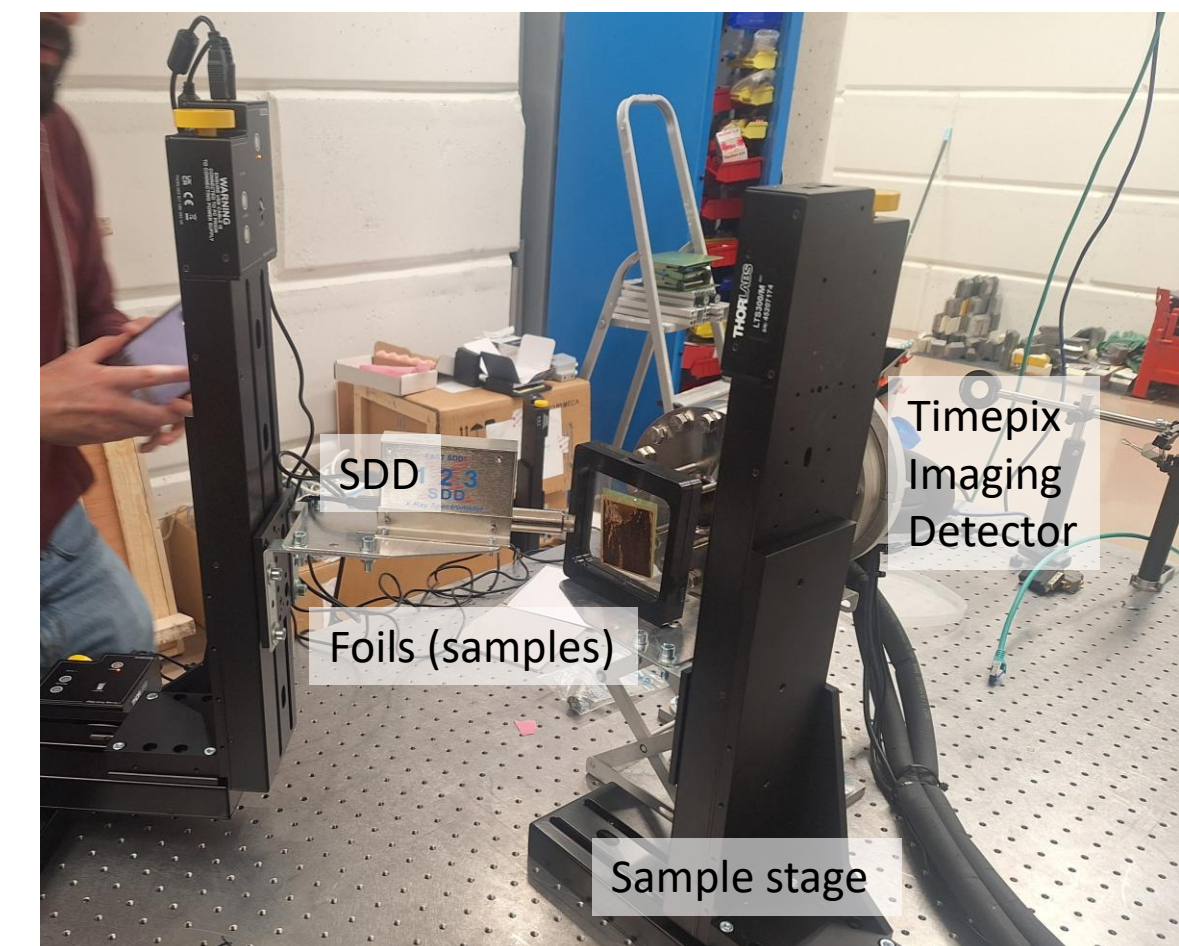


Fig. 7: Preliminary experimental endstation.

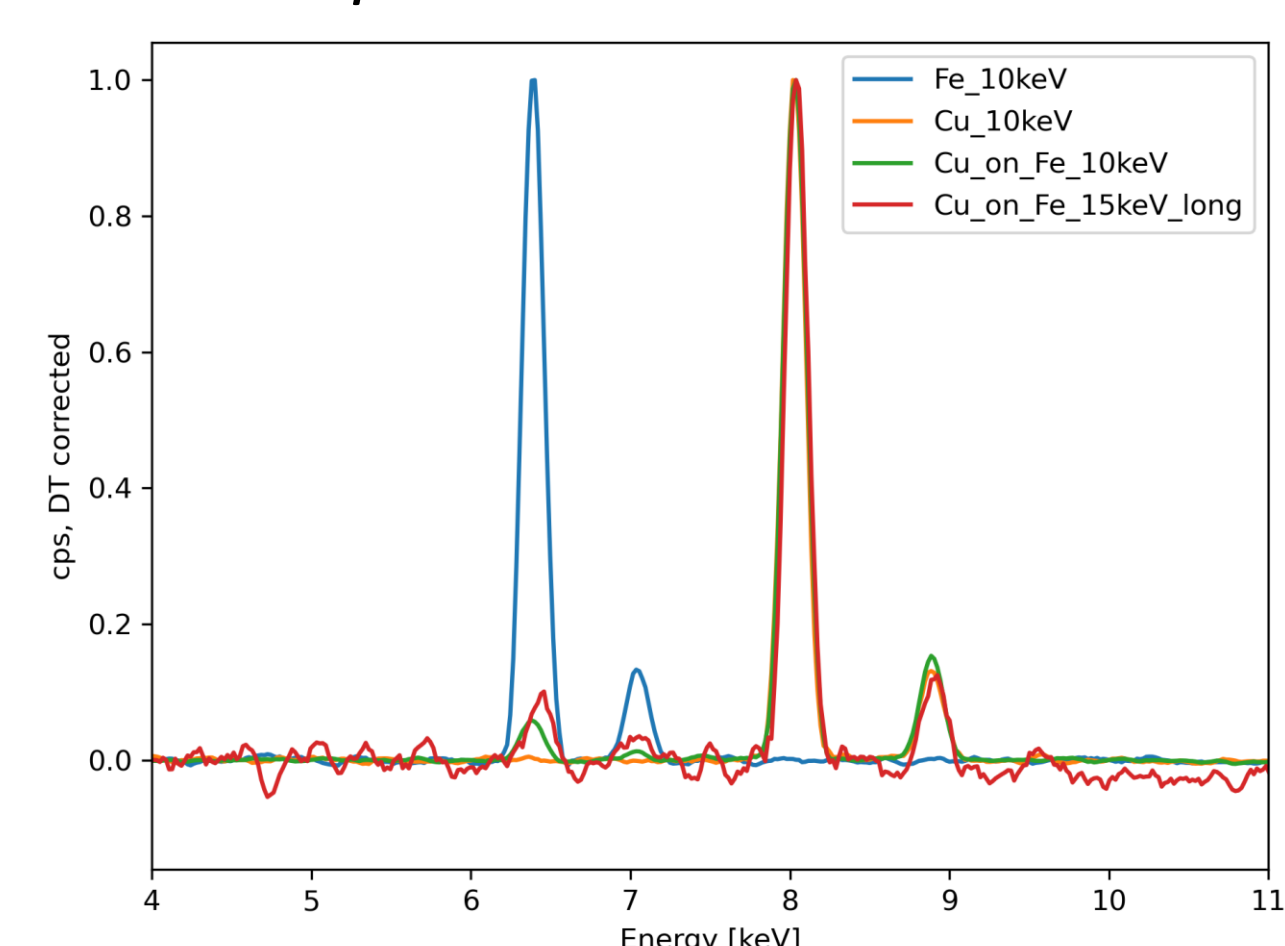


Fig. 8: XRF spectra of superimposed Fe and Cu foils at different primary energies.

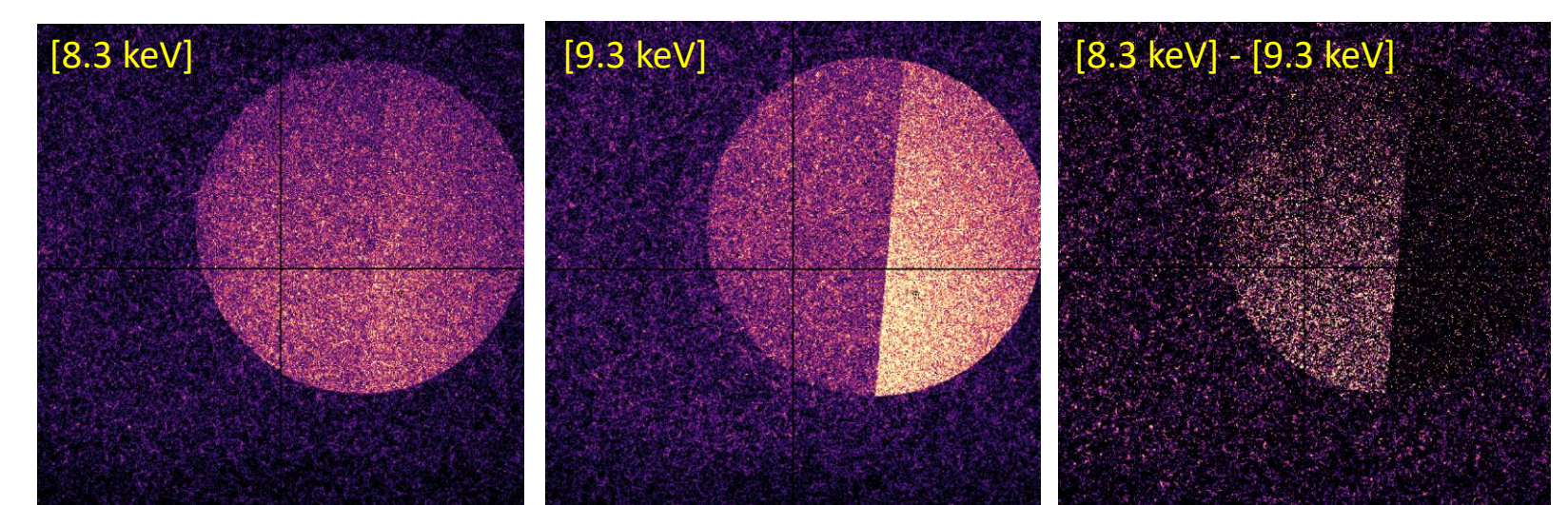


Fig. 9: K-edge imaging: the radiograph above the Cu-K edge (8.98 keV) is subtracted by the one below to reveal the position of the Cu foil.

Smart*Light (S*L, Figure 4&5):

Electrons are emitted from the electron gun and accelerated towards the interaction chamber, where they scatter the laser light under inverse Compton conditions, before being diverted into the beam dump. The X-rays pass then through a beamline in the wall to the preliminary experimental endstation (Figure 7).

First Experiments:

After first light was achieved in September 2024 it was demonstrated that the beam energy could be tuned by varying the electron beam energy, making use of a Timepix detector (s. Figure 6).

The feasibility of K-edge imaging was demonstrated on a Cu foil (see Figure 9). To develop depth sensitive XRF, measurements on superimposed Fe and Cu foils were done. It could be shown that the signal of the Fe foil covered by the Cu foil is enhanced when the primary beam energy is raised from 10 keV to 15 keV (Figure 8).

Perspective

The current work focuses on enhancing the brilliance of Smart*Light for faster measurements. Once stable parameters are found, the X-ray beam will be characterized in terms of its size, intensity, energy distribution and stability. These findings will serve as the basis for selecting appropriate monochromator and optics for the subsequent project phase. This configuration will be used for basic XRF, XRD, K-edge imaging and radiography/tomography experiments. In follow up projects Smart*Light's

capabilities will be enhanced for high-resolution X-ray Diffraction (XRD) and X-ray Absorption Near Edge Structure (XANES) measurements. Advanced sources like Smart*Light hold significant promise for revolutionizing the investigation of cultural heritage artifacts using X-rays. The prospect of installing such sources in or near museums presents an opportunity to apply advanced X-ray methodologies across a broader spectrum of objects, thereby alleviating the demand on Synchrotron Radiation (SR) facilities.

Acknowledgements

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