

Smart*Light: First Results from the Dutch Inverse Compton Source

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Motivation

X-rays are well suited for the non-destructive investigation of heritage objects. However, the most powerful techniques—such as X-ray Absorption Near Edge Structure (XANES), scanning X-ray diffraction (XRD) imaging, and phase-contrast imaging—are largely restricted to synchrotron (SR) facilities, as they require high-intensity, tunable, coherent, and monochromatic radiation. Access to SR sources is limited, and experiments often necessitate transporting valuable or fragile objects. The Smart*Light (S*L) project addresses this gap by developing a compact Inverse Compton Scattering (ICS) X-ray source. Designed for installation in mid-sized laboratories, such as museum facilities, this technology aims to provide local, accessible synchrotron-like capabilities.

Inverse Compton Scattering

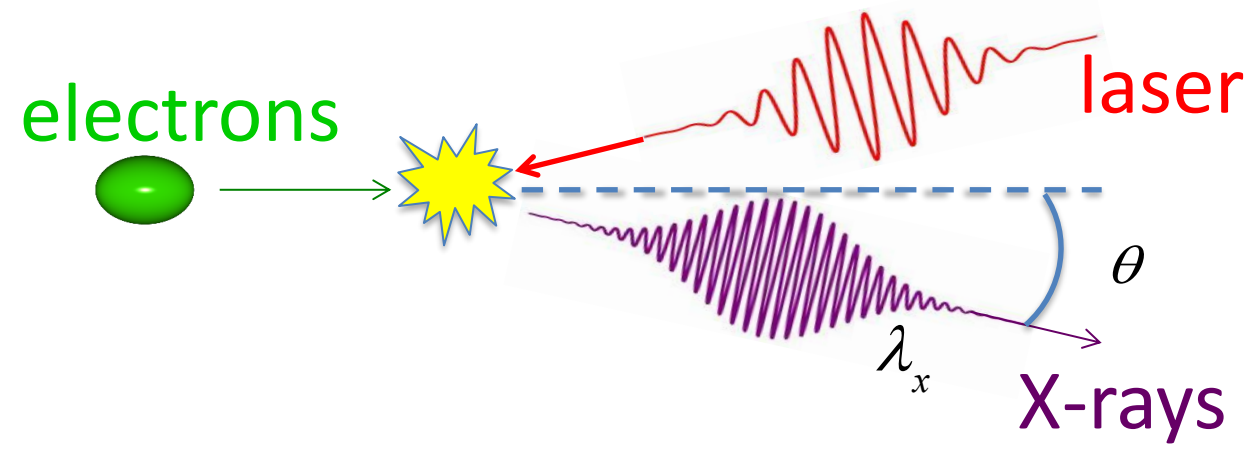
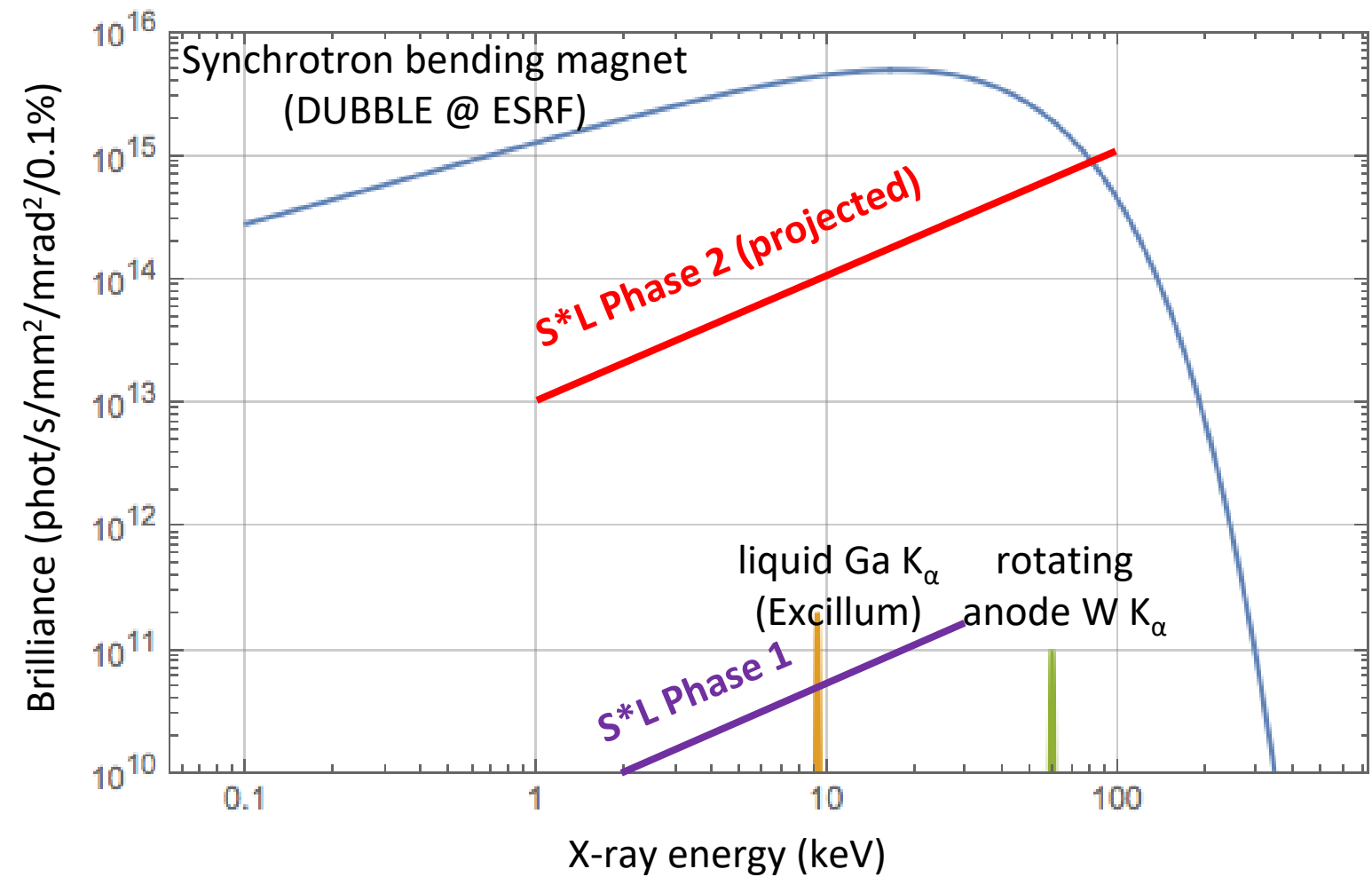


Fig. 1 (above): Principle of Inverse Compton scattering.

Fig. 2 (right): Expected performance of Smart*Light



The Inverse Compton effect describes how laser light is scattered by relativistic electrons, being upshifted into the X-ray regime (see Fig 1). Inverse Compton Sources feature several **Advantages**:

- Narrow Bandwidth: approximately 1% $\Delta E/E$
- Partial Coherence
- Narrow Emission Cone
- Tunable Energy: dependent on the energy of the electrons and the laser.

The emitted intensity and photon energy decrease with increasing scattering angle (see Fig. 2). While not competitive to a full SR source in terms of intensity, ICS sources are more compact and require a much smaller investment (see Fig. 3). Widespread adoption of ICS sources has been limited by the demanding requirements on laser power and electron beam quality. These challenges have been largely addressed for S*L.

Smart*Light (S*L)

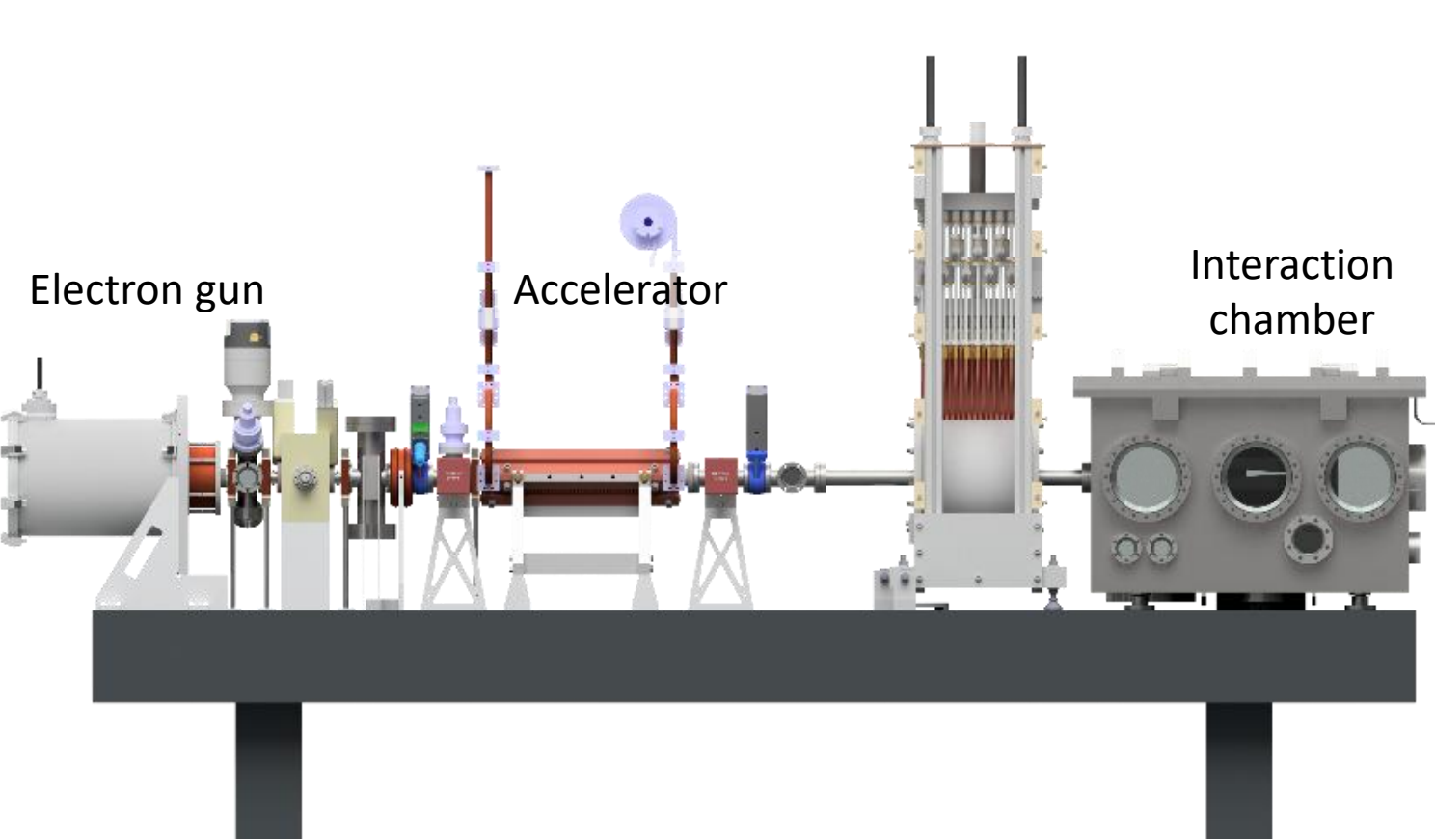


Fig. 3: Design of Smart*Light. Courtesy: D. Nijhof & C. Sweers, TU/e

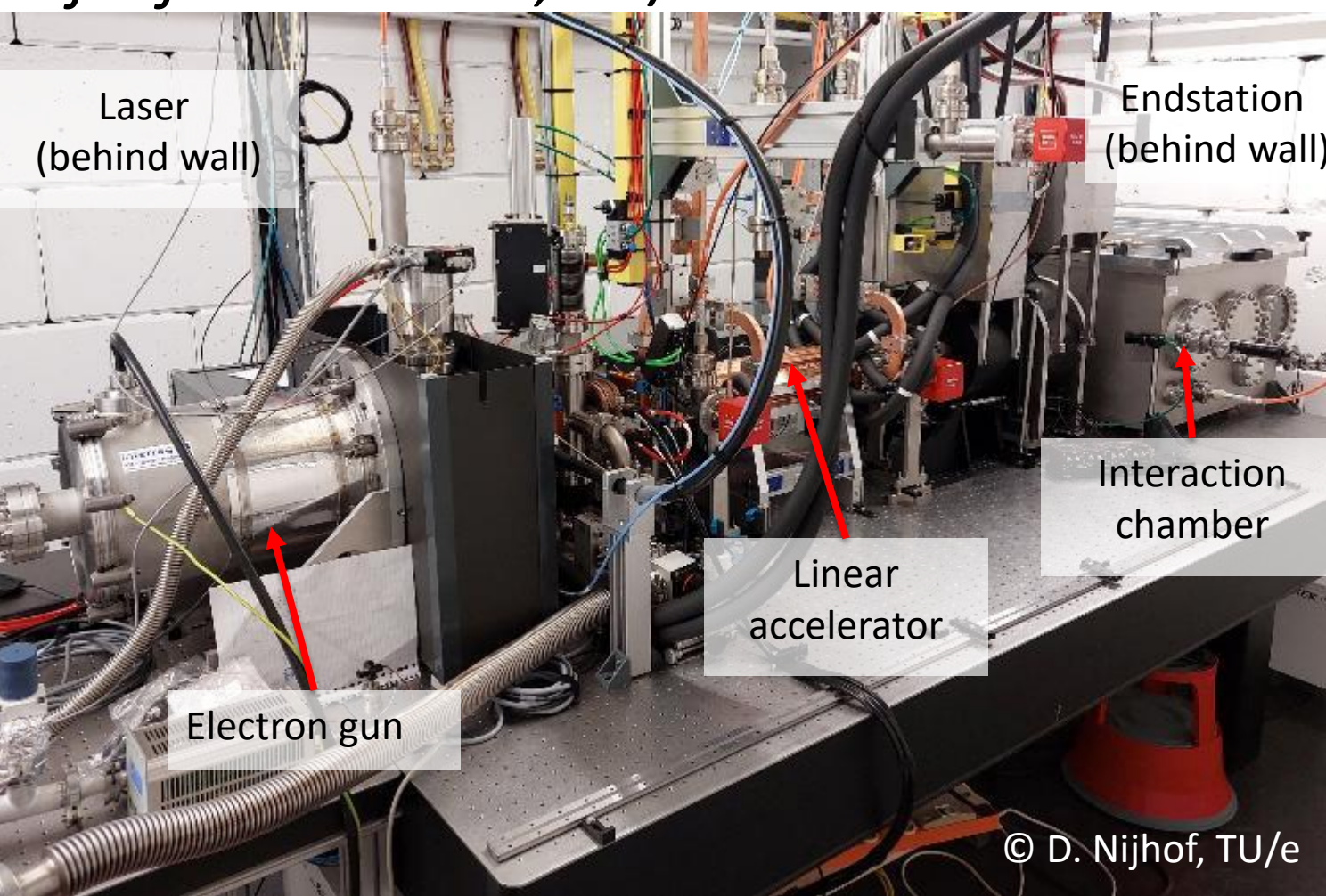


Fig. 4: Photograph of Smart*Light prototype. Laser and endstation are behind the brick walls.

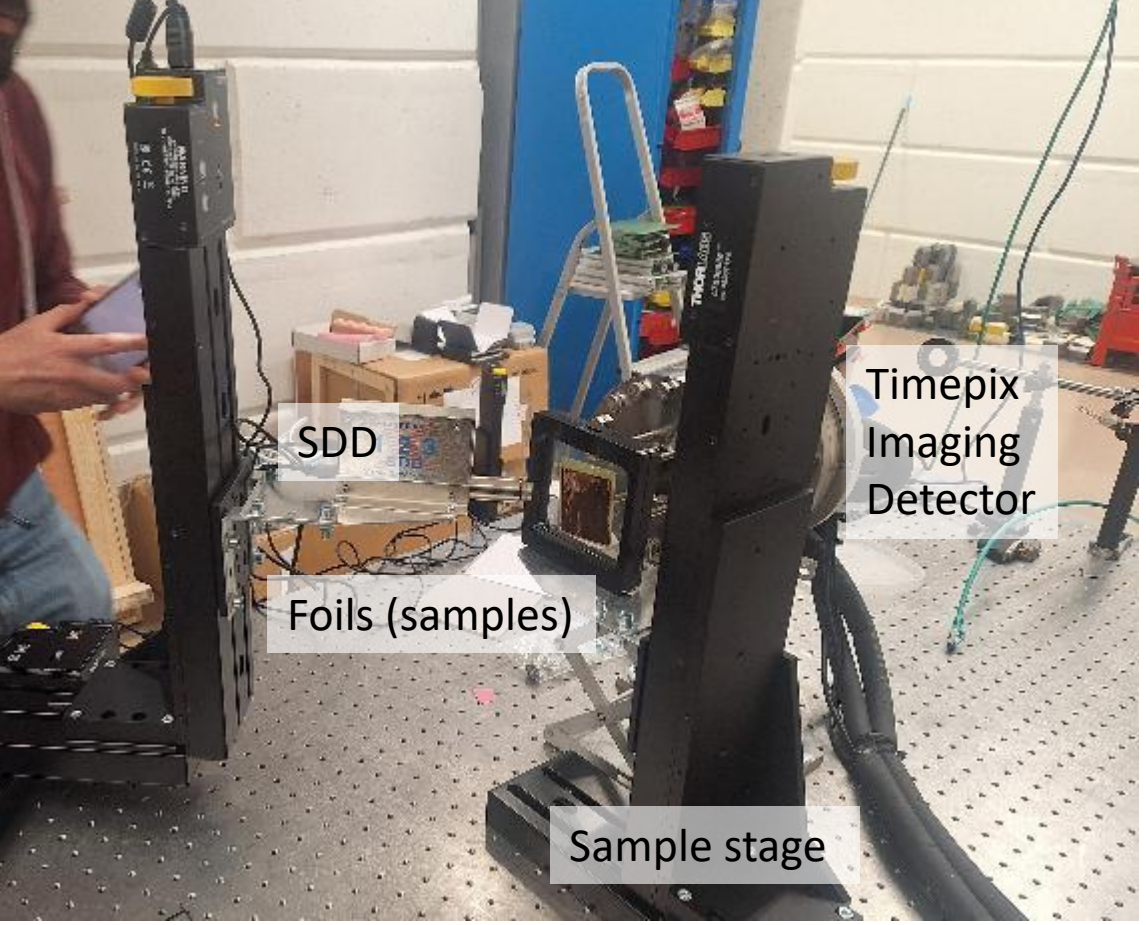


Fig. 5: Preliminary experimental Endstation.

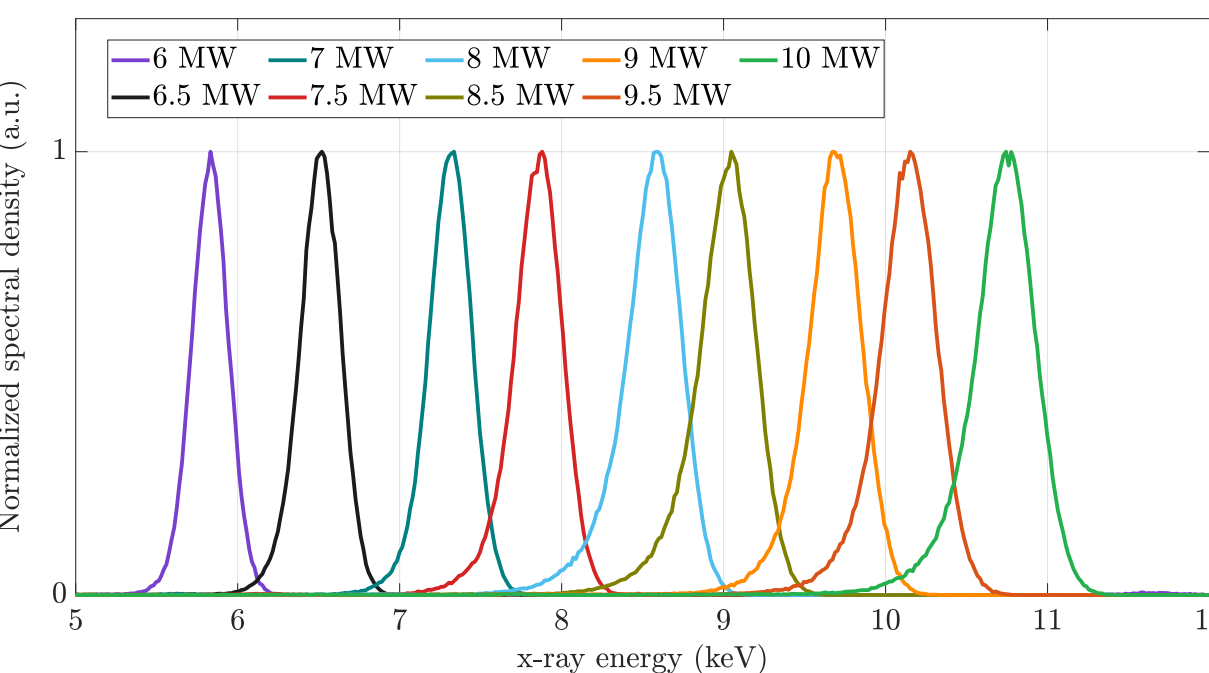


Fig. 6: Primary beam energy tuned by selecting suitable electron beam energies.

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 a beam dump (see Fig. 3&4). The X-rays then pass through a beamline to the preliminary experimental endstation (Fig. 5). 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. Fig. 6).

Electron beam	X-rays	Laser
Beam energy	5-25 MeV	Wavelength
Bunch charge	10 pC	Pulse length
Repetition rate	1 kHz	Pulse energy

Table 1: Design parameters

First Experiments

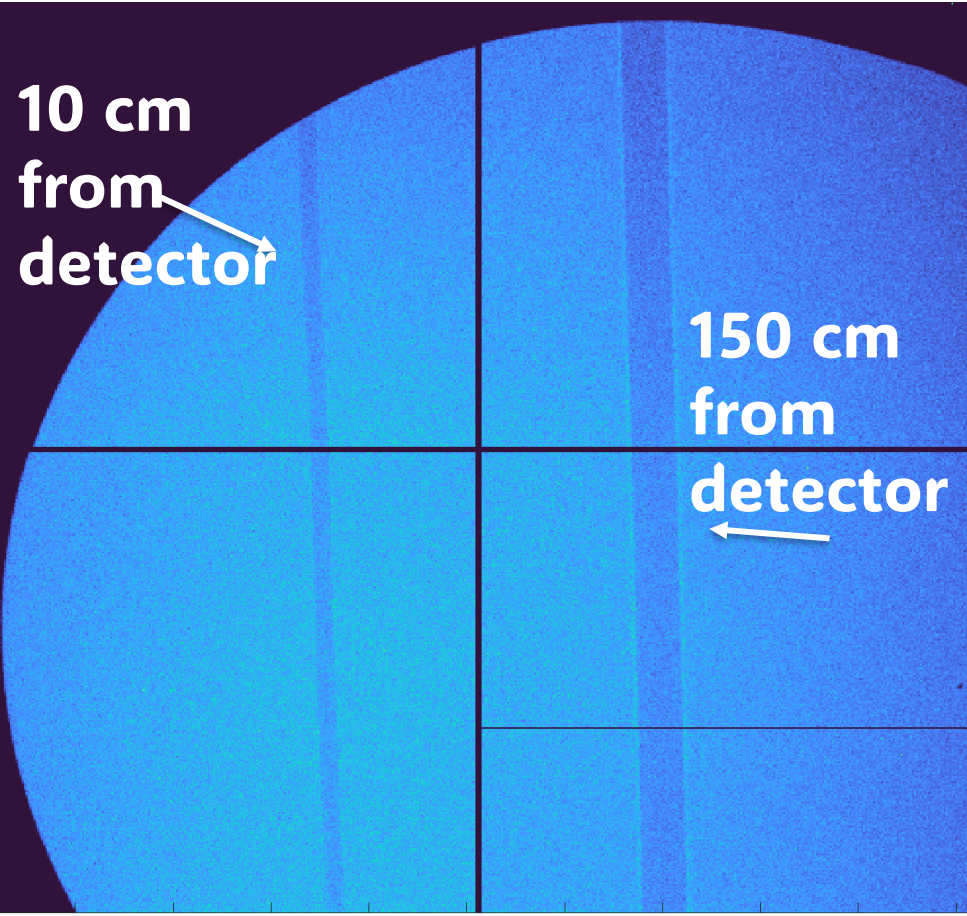


Fig. 7 (above): K-edge imaging: the radiograph above the Cu-K edge is subtracted by the one below to reveal the position of the Cu foil.

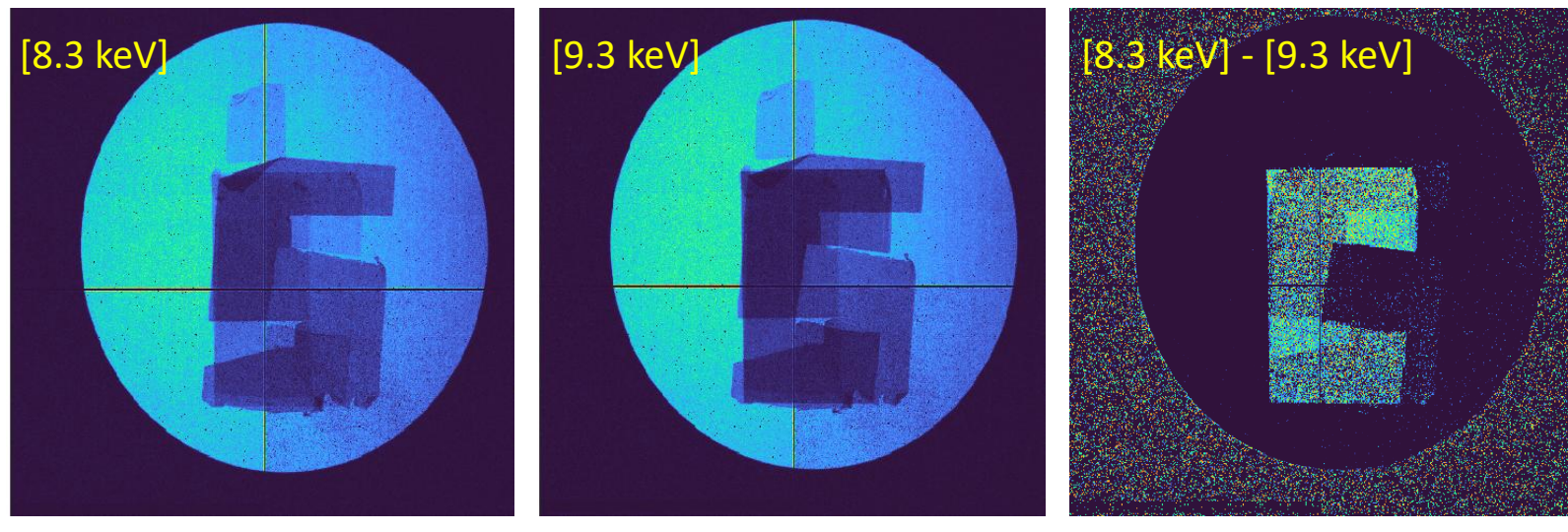


Fig. 8 (left): Phase contrast of 500 μm Nylon wire at 10 keV.

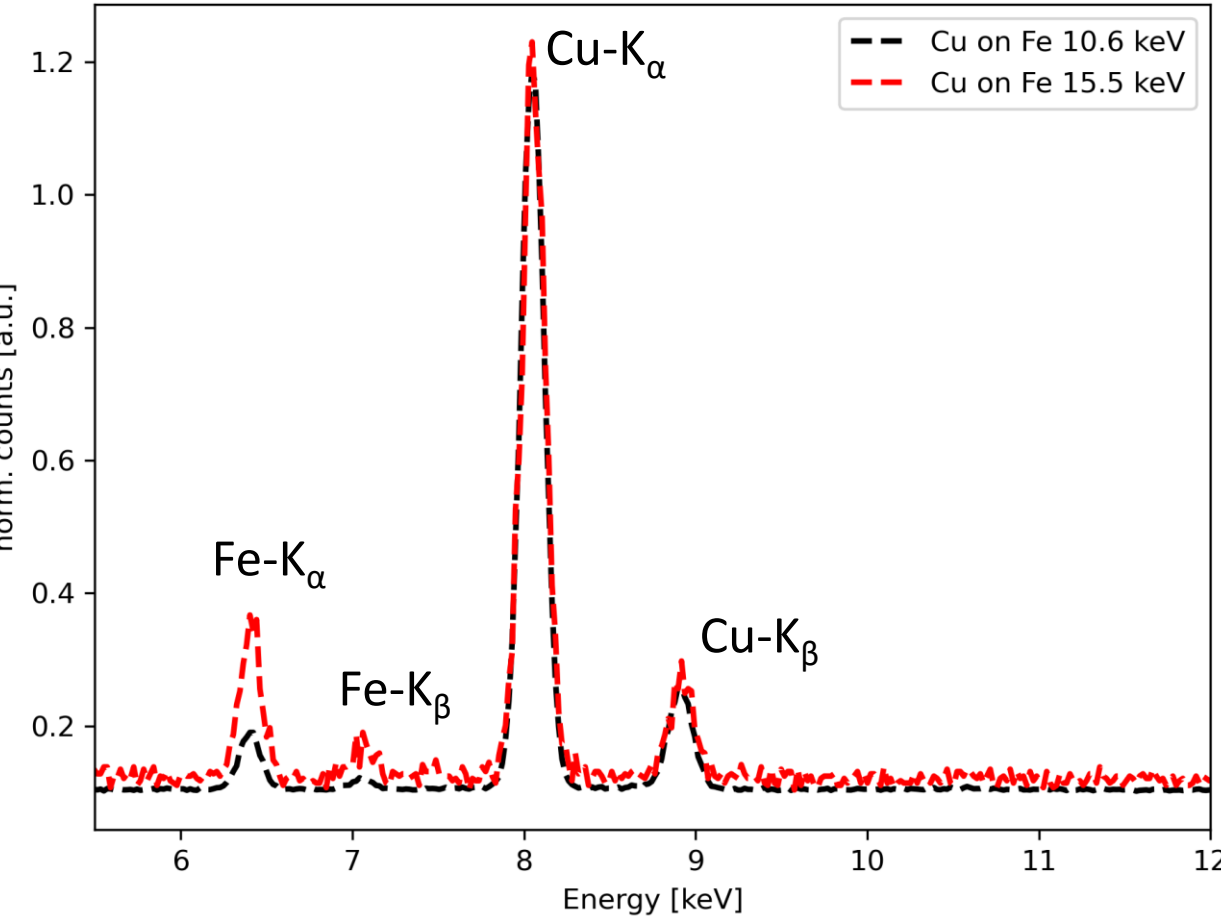


Fig. 9: XRF spectra of superimposed Fe and Cu foils at different primary energies.

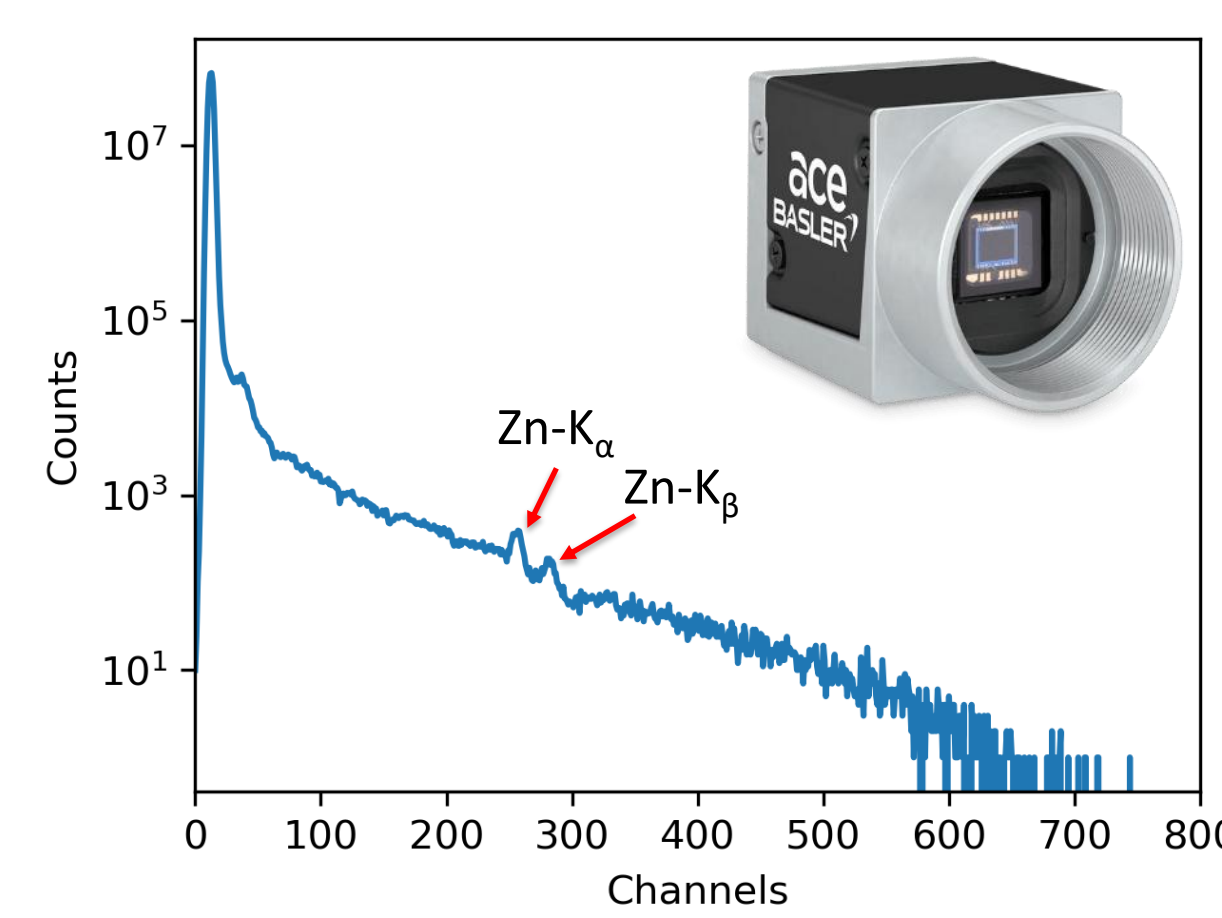


Fig. 10: XRF spectrum acquired with a Si CMOS camera and an X-ray tube on a Zn L-bracket.

K-edge imaging was demonstrated, revealing the distribution of metals in a Ni, Cu, Zn sandwich structure (Cu distribution shown in Fig. 7). The feasibility of phase contrast imaging was demonstrated using two 0.5 mm thick Nylon wires (s. Fig. 8). To develop depth sensitive XRF, measurements on superimposed Fe and Cu foils were conducted. It could be shown that the signal of the Fe foil located behind the Cu foil is enhanced when the primary beam energy is raised from 10 keV to 15 keV (s. Fig. 9). XRF measurements were limited by the short X-ray pulses to a count rate equivalent to the laser frequency. To allow parallel detection of photons from the same pulse, pixelated CMOS detectors are being tested as energy dispersive X-ray detectors (s. Fig. 10).

Perspective

The current work focuses on enhancing the brilliance of Smart*Light for faster measurements and selecting appropriate monochromators 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 XRD and XANES experiments. Advanced sources like Smart*Light hold significant promise for revolutionizing the investigation of cultural heritage artifacts using X-rays, by installing within museum facilities.

Acknowledgements

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