

Smart*Light for Heritage Science: introduction of 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 varying the energy of the electrons or how laser light is scattered back by the laser. relativistic electrons, gaining energy and being promoted to the X-ray 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 brilliance (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.

Advantages:

- **Narrow Bandwidth:** The bulk of the created radiation is in a narrow bandwidth (approximately 1% ΔE/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

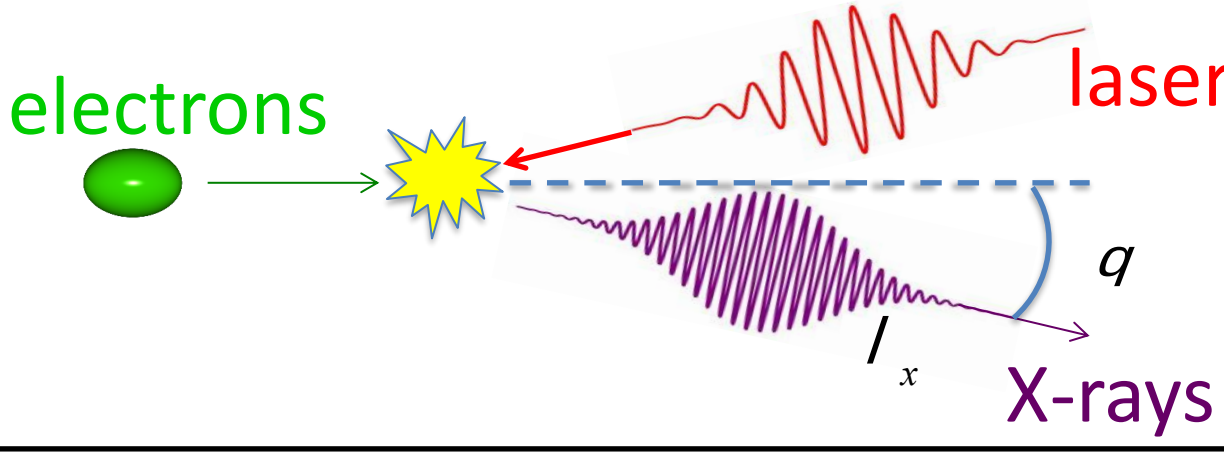


Fig. 1: Principle of Inverse Compton scattering.

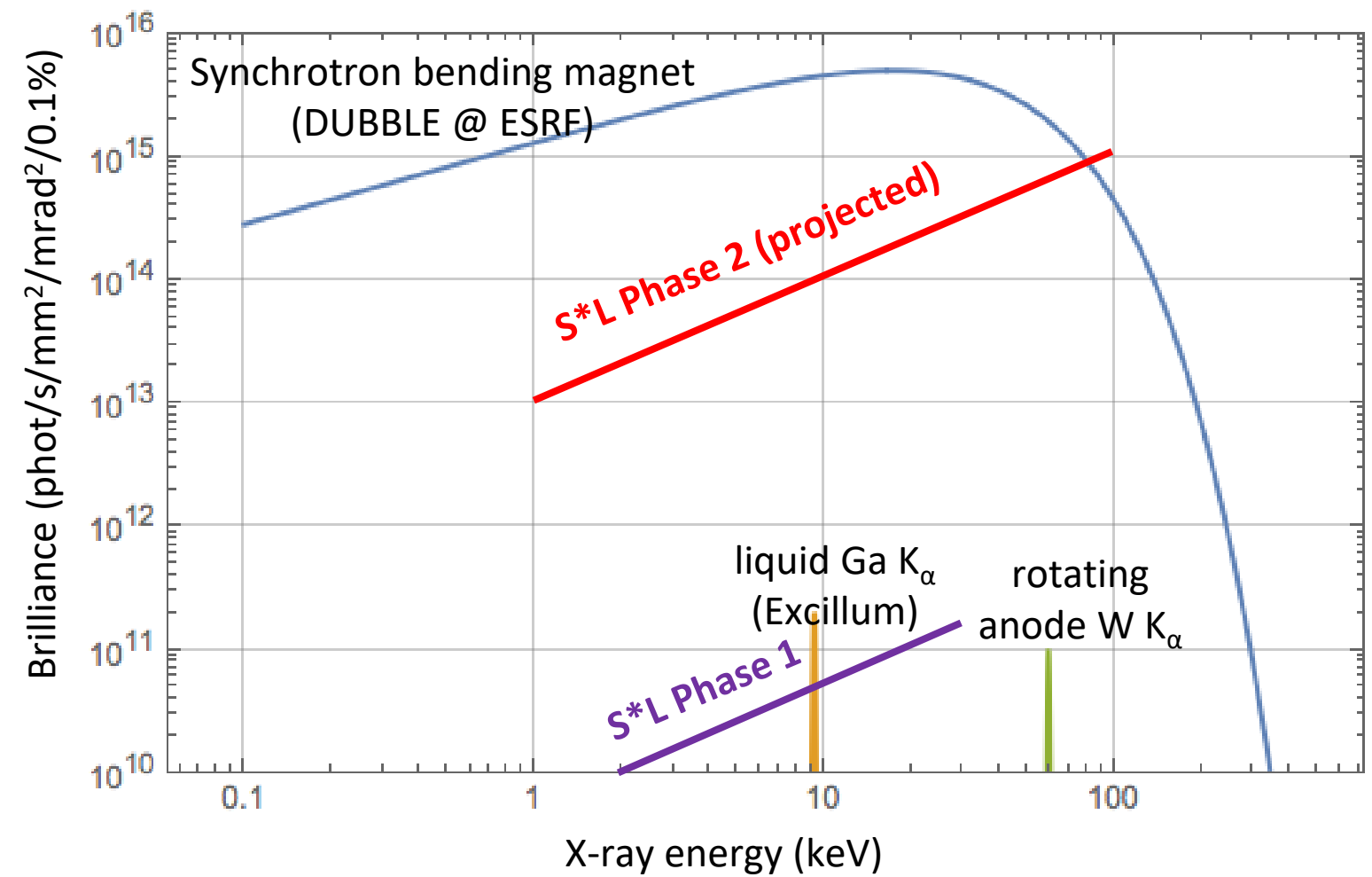


Fig. 3: Expected performance of Smart*Light

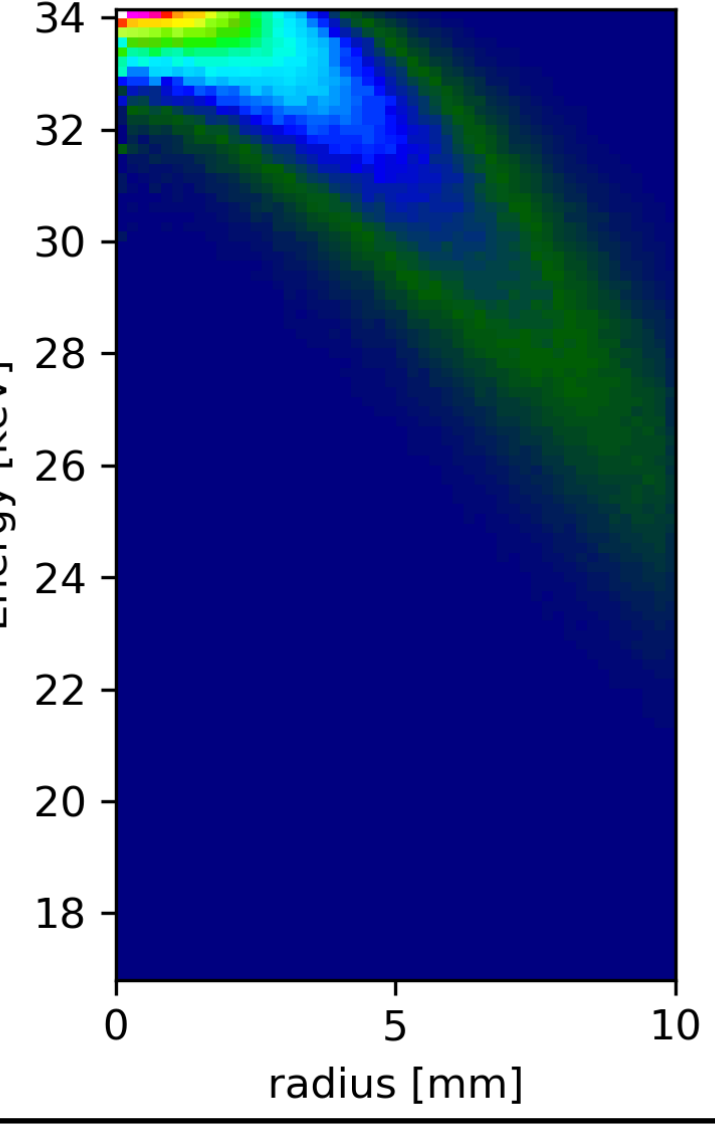


Fig. 2: Example of the expected radial intensity and energy distribution 1 m from the interaction point of electrons and laser.

Smart*Light (S*L) and its Cultural Heritage & Characterisation (CH&C) endstation

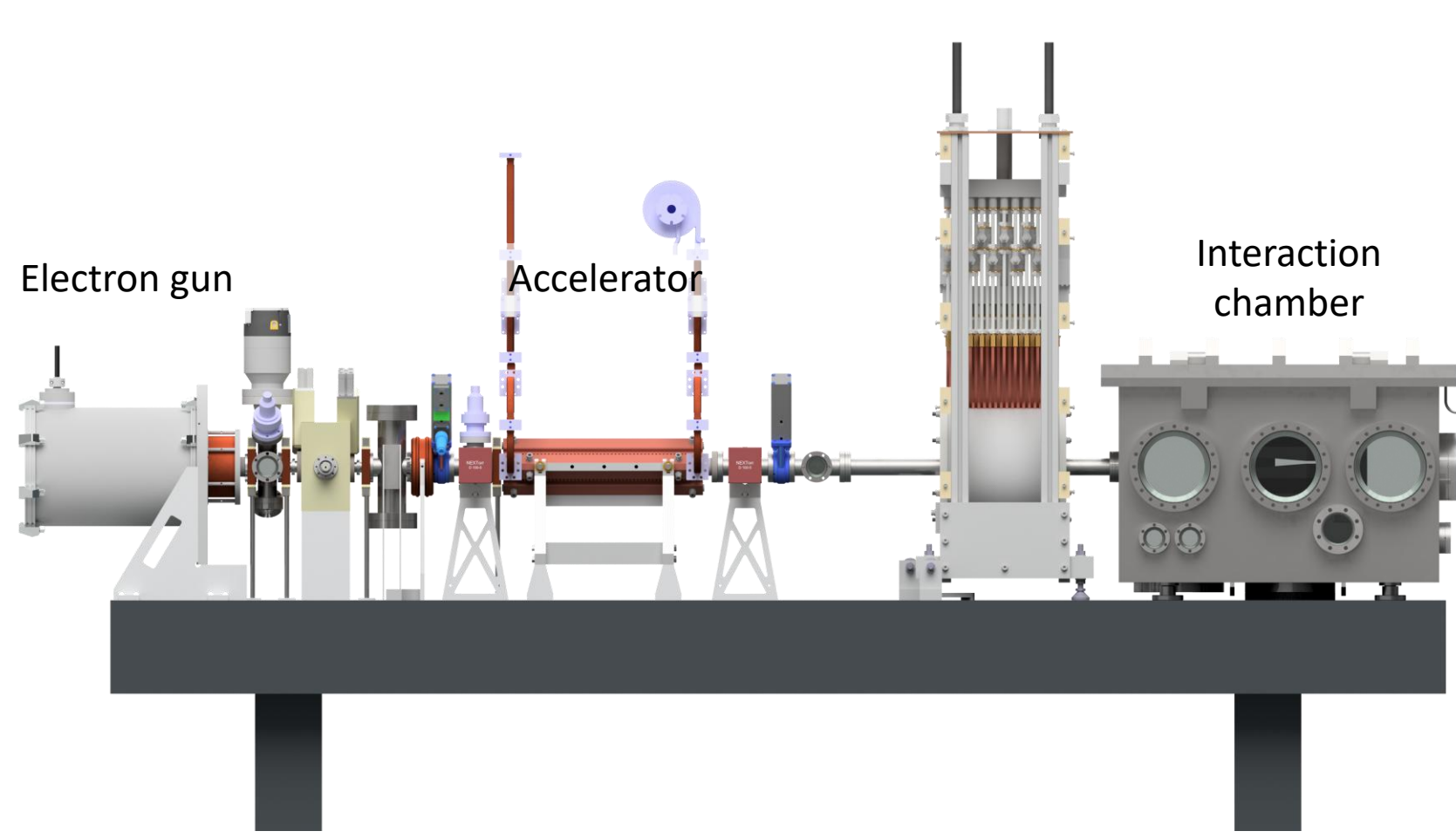


Fig. 4: Design of Smart*Light. Courtesy: D. Nijhof & C. Sweers, TU/e

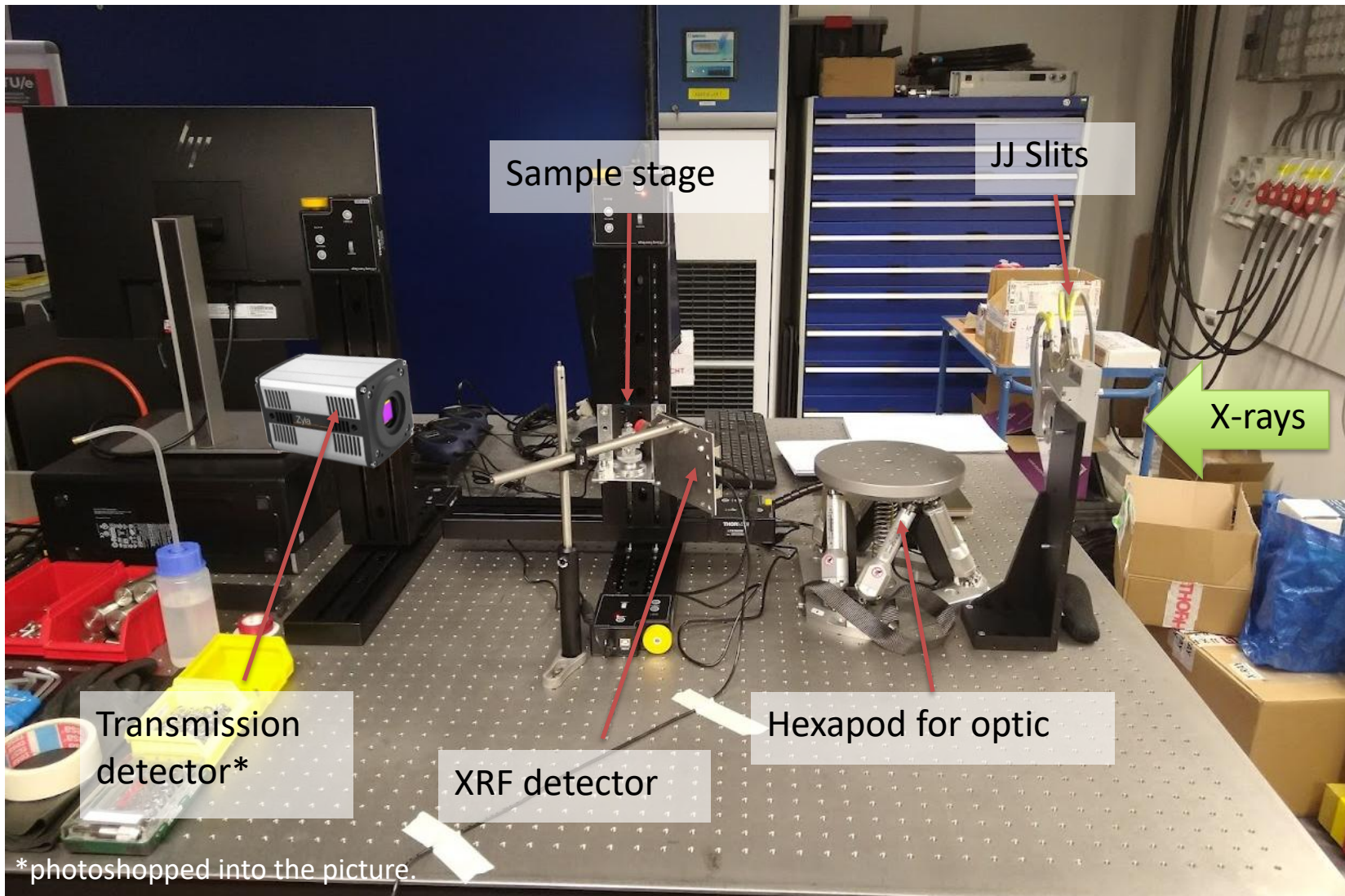


Figure 6: stage test of CH&C endstation of S*L with beam entering from the right,

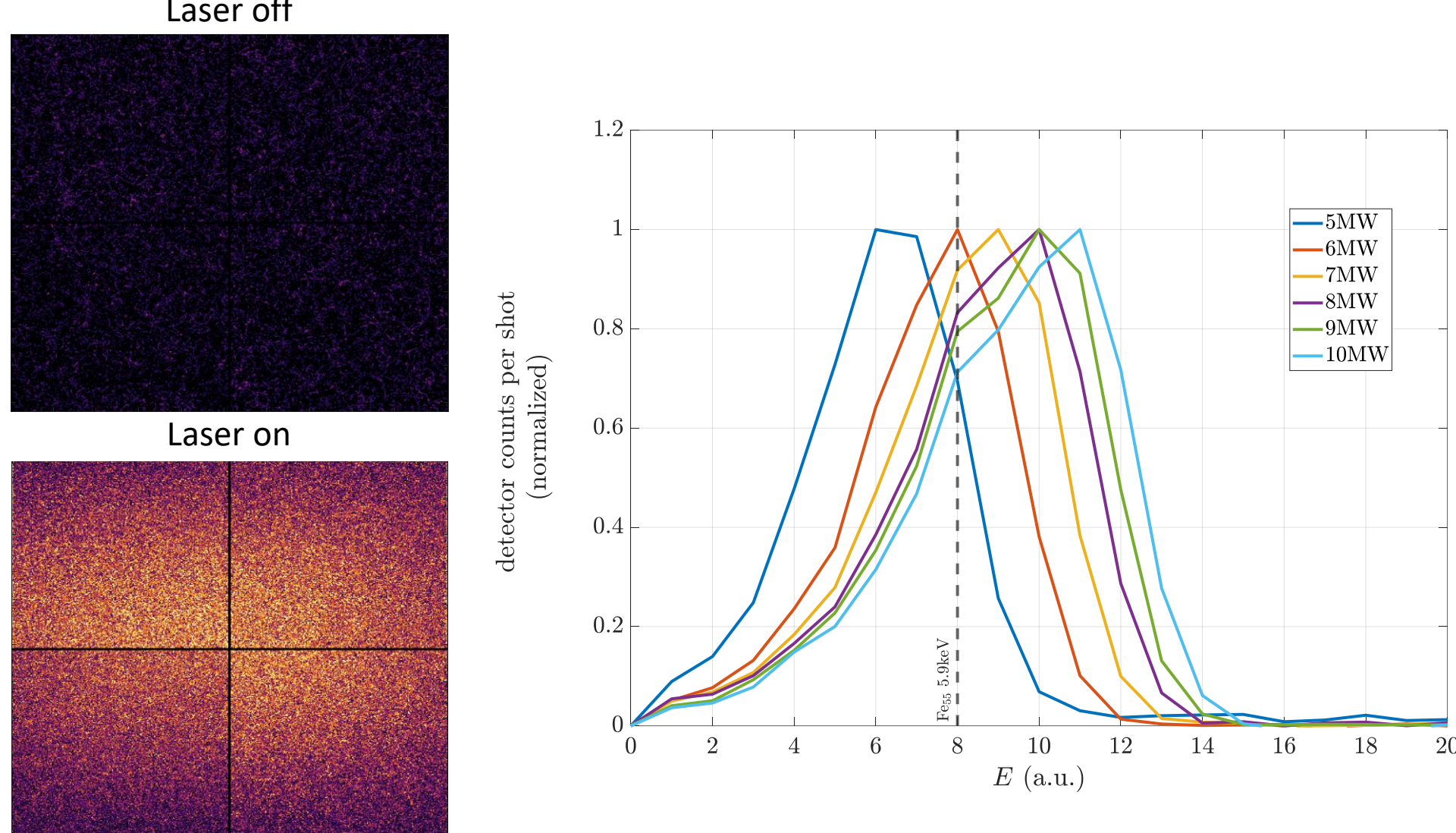


Figure 7: First light, as detected by Medipix pixelated detector in vacuum. Right: Photon counts with different Klystron power.

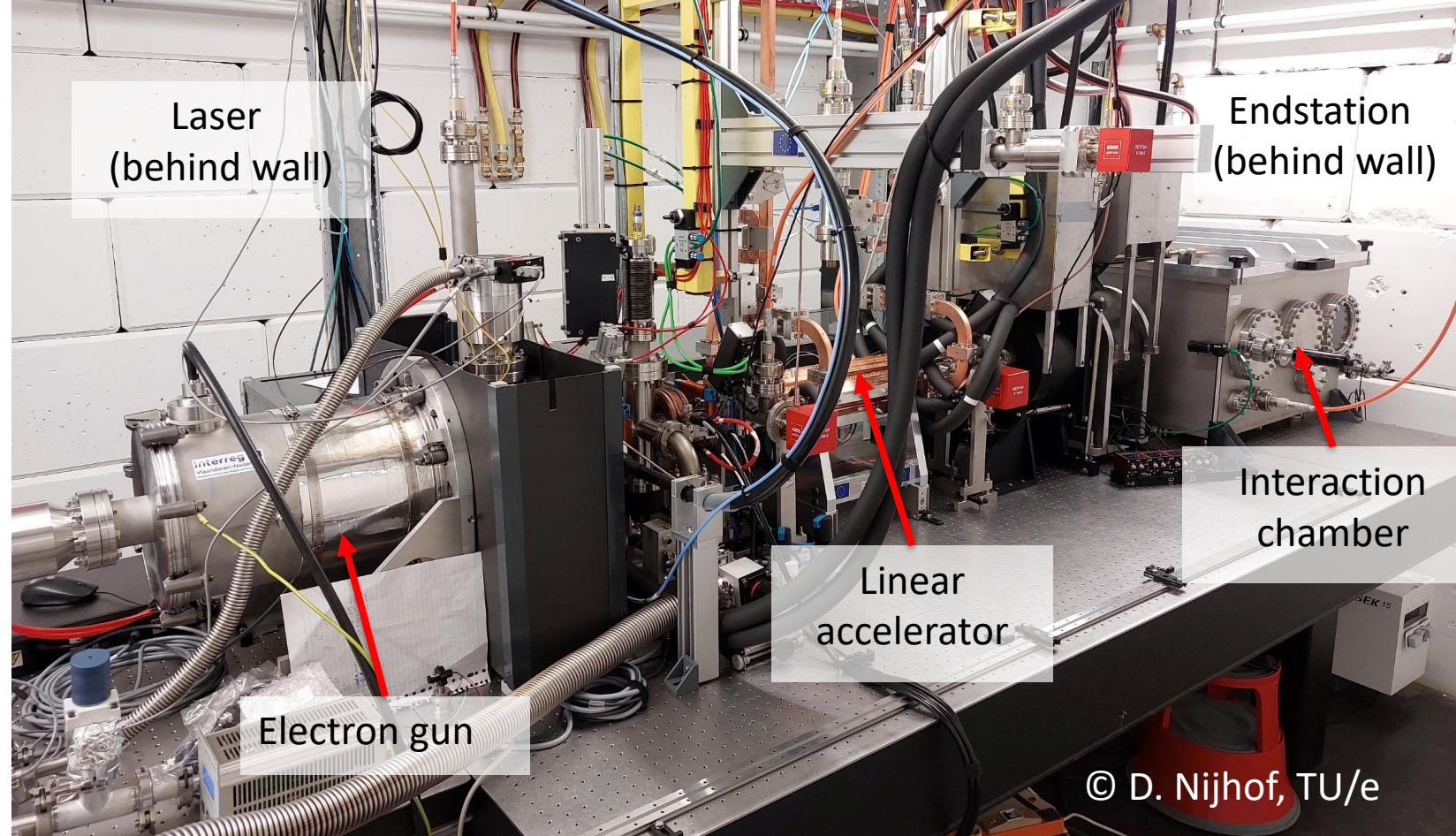


Fig. 5: Photograph of Smart*Light prototype. Laser and endstation are behind the brick walls. Right: Performance parameters. Courtesy: D. Nijhof & C. Sweers, TU/e.

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/mm ² /mrad ² /0.1%BW)

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 experiment.

Cultural Heritage & (Beam) Characterisation endstation (CH&C, Figure 6):

The beam enters from the right, is collimated by flexible (JJ) slits, optionally focused by an optic on the hexapod, before interacting with the object on the sample stage. Behind the object is a transmission detector.

First Light (Figure 7):

A Medipix detector was used to acquire the first light with an energy resolution of a few keV, featuring ~1200 photons per pulse. The difference in obtainable energy was demonstrated by varying the Klystron power.

Perspective

Acknowledgements

The first experiments scheduled later this year will focus on the characterisation of the X-ray beam, its size, intensity, energy distribution and stability. These initial findings will serve as the basis for selecting appropriate monochromator and optics for the subsequent project phase. The aim is to enhance Smart*Light's capabilities for high-resolution X-ray Fluorescence (XRF) and XRD mapping with high-resolution K-edge imaging. These combined techniques will facilitate the examination of historical documents with unprecedented clarity and detail. 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.

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