

# High frame rate RIXS spectroscopy using a JUNGFRAU detector with an iLGAD sensor

N. Duarte<sup>1</sup>, L. Le Guyader<sup>1</sup>, V. Hinger<sup>2</sup>, A. Mozzanica<sup>2</sup>, M. Ramilli<sup>1</sup>, G. Tillmann<sup>1</sup>, C. Broers<sup>1</sup>, J.T. Delitz<sup>1</sup>, N. Gerasimova<sup>1</sup>, D. Lomidze<sup>1</sup>, S. Parchenko<sup>1</sup>, J. Schlappa<sup>1</sup>, M. Teichmann<sup>1</sup>, B. Van Kuiken<sup>1</sup>, A. Scherz<sup>1</sup>, B. Schmitt<sup>2</sup> and M. Turcato<sup>1</sup>

1. European XFEL, Holzkoppel 4, 22869 Schenefeld, Germany

2. Paul Scherrer Institute, Forschungsstrasse 111, 5232 Villigen PSI, Switzerland

Several experimental techniques make use of soft X-rays as a probe, commonly focusing on the energy range between a few hundred eV up to approximately 1 keV. This range is particularly relevant for the study of transition metals and light elements such as C, N and O, which are fundamental components of a large number of materials with intriguing electronic and magnetic properties, from biological matter to superconductors. One such technique is resonant inelastic X-ray scattering (RIXS), a photon-in/photon-out method in which the incident photon energy is tuned to match the absorption edge of the sample. This resonance condition greatly enhances the inelastic scattering cross-section of the system, providing a unique way of accessing information about the intrinsic excitations by measuring the change in energy, momentum, and polarization of the scattered photon [1].

The Spectroscopy and Coherent Scattering (SCS) instrument at the European XFEL is equipped with the Heisenberg-RIXS spectrometer (hRIXS), capable of performing RIXS measurements in the time domain, with time and energy resolution approaching the Heisenberg limit imposed by the uncertainty relations [2]. The unique pulse delivery structure of the European XFEL allows for bursts of pulses within a bunch train to be delivered up to MHz rates, which is beyond the frame rate capability of most detectors. Combining this with the additional requirements of high spatial resolution and large sensitive area, finding a detector capable of fully exploiting the potential of the hRIXS spectrometer becomes a significant challenge. So far, commercial CCD and CMOS cameras with small pixels have been used, providing a satisfactory spatial resolution. However, their limited readout speed allows only for the integration of entire XFEL trains. A faster detector, capable of resolving intra-train pulses, would greatly benefit pump-probe laser experiments, by enabling the use of alternating pumped and unpumped pulses for more reliable data normalization.

In recent years, a collaboration between the Paul Scherrer Institute (PSI) and Fondazione Bruno Kessler (FBK) has materialized into the first prototypes of X-ray-sensitive Inverse Low Gain Avalanche Diodes (iLGADs) sensors compatible with the readout chips of the widely adopted charge-integrating detectors developed by PSI, such as the JUNGFRAU [3, 4]. This detector, already used at several hard X-ray instruments at the European XFEL, is capable of storing up to 16 images in analogue memory cells, offering a maximum acquisition rate of ~200 kHz in bursts. Additionally, its  $75 \times 75 \mu\text{m}^2$  pixels can be easily segmented and reorganized into narrow rectangular pixels of  $25 \times 225 \mu\text{m}^2$  (or narrower), increasing spatial resolution along the energy dispersion axis in spectroscopic experiments. This resolution can be further enhanced by leveraging charge sharing across pixels, through position interpolation methods.

In a recent beamtime, a JUNGFRAU detector equipped with an iLGAD sensor was tested at the hRIXS spectrometer, with positive outcomes. In this work, we present the main findings regarding detector performance, highlighting the spatial resolution achieved using reference solid samples, and comparing it to the previously used commercial cameras. Additionally, we present the first RIXS spectra acquired at multi-kHz rate in combination with pump-probe laser excitation, and analyse how the intense FEL pulses may affect the sample's response to the incoming photons.

[1] Van den Brink, Jeroen. "Resonant inelastic x-ray scattering on elementary excitations." *Rev. Mod. Phys* 83 (2011): 705.

[2] Schlappa, Justine, et al. "The Heisenberg-RIXS instrument at the European XFEL." *Synchrotron Radiation* 32.1 (2025).

[3] Mozzanica, A., et al. "The JUNGFRAU detector for applications at synchrotron light sources and XFELs." *Synchrotron Radiation News* 31.6 (2018): 16-20.

[4] Hinger, Viktoria, et al. "Resolving soft X-ray photons with a high-rate hybrid pixel detector." *Frontiers in Physics* 12 (2024): 1352134.