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IXPE Gas Pixel Detector characterization with the X-ray calibration facility

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ABSTRACT

The X-ray Calibration Facility (XCF) is a table-top, open-design irradiation setup for research, available at the Physics Department of the University of Turin. It offers beams of photons at different energies and with various spatial and polarization configurations. These characteristics allow XCF to be a suitable facility for calibration and test of energy, position and polarization sensitive detectors.

1. Introduction

The Gas Pixel Detector, GPD [1] is the state-of-the-art soft X-rays polarimeter based on photoelectric effect and it is the focal plane detector of the Imaging X-ray Polarimetry Explorer (IXPE), launched on the 9th December 2021. The GPD allows to measure the polarization of the incoming radiation on a statistical basis from the distribution of events $N(\Phi)$ [2,3], where Φ is the angle between the polarization axis and the emission direction of the photoelectron produced in the gas:

$$N(\phi) = A + B\cos^2(\phi - \phi_0), \tag{1}$$

A key parameter of a polarimeter is the modulation factor μ that is the detector response to a 100% polarized radiation. It can be calculated both from the fit of $N(\Phi)$ using Eq. (1) and from the Stokes Parameters[1]

$$\mu = \sqrt{Q^2 + U^2}/I^2 = B/(2A + B) \tag{2}$$

2. The X-ray calibration facility

The XCF is an irradiation setup at the Physics Department of the University of Turin, Italy [4]. It was initially conceived as a calibration source to qualify IXPE Gas Pixel Detectors.

XCF can employ two different radiation sources: a multi-anode X-ray tube (McPhersonMod.642) and a single-anode (Molybdenum) sealed MicroX-raytube. The last one is the source used for the measurements described in this work. The XCF is also equipped with a ^{55}Fe source, used for long term studies of GPD. XCF photon beams can be monitored

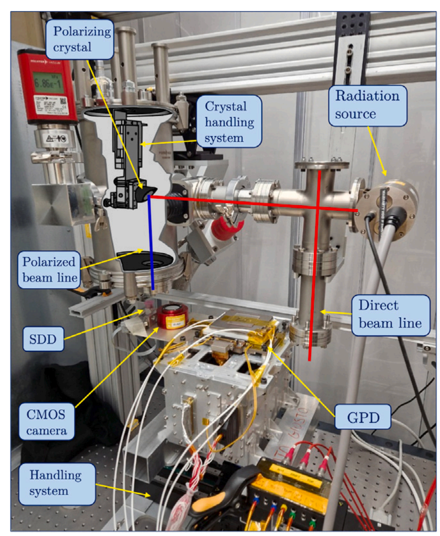

Fig. 1. Scheme of XCF.

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[1] The Stokes parameters allow to describe the polarization: calling ϕ_k the azimuthal angle, $I = N$, $Q = \sum_{k=1}^{N} \cos(2\phi_k)$ and $U = \sum_{k=1}^{N} \sin(2\phi_k)$.

[2] $E = \frac{nhc}{2d\sin\theta}$ with grating constant d, angle of incidence θ, selected energy E and diffraction order n. The polarization is 100% for $\theta = 45°$.

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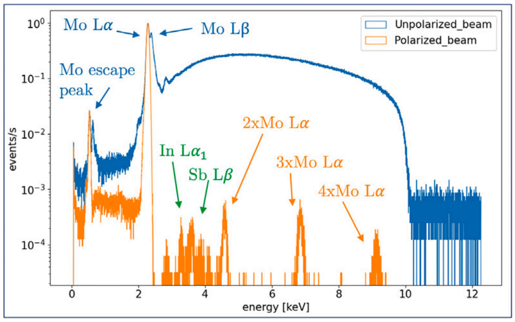

Fig. 2. *SDD* unpolarized (blue) and polarized (orange) spectra for InSb (111).

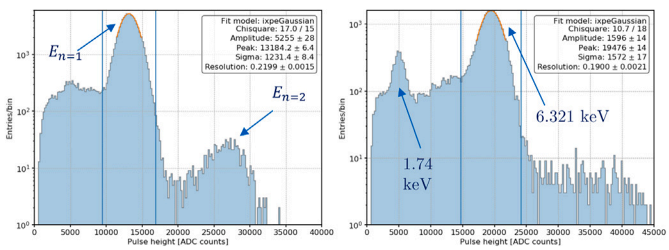

Fig. 3. GPD spectra for Si (220) (*left*) and Si (400) (*right*) crystals.

using a Silicon Drift Detector (*SDD*) (energy resolution of 2% FWHM at 5.9 KeV), and a CMOS ASI ZWO camera (2822×4144 4 μm pixel array).

The X-ray tube can be mounted in a vertical or in an horizontal position (Fig. 1): in the first configuration, X-rays photons follow the direct beam line, while in the second one they are polarized via Bragg diffraction on a polarizing crystal, thus obtaining a polarized beam line. According to the Bragg law [5] it is possible to select and polarize photons at a particular energy.[2] Fig. 2 shows how the polarized spectrum differs from the unpolarized one: only the energies that satisfy the Bragg law together with the crystal fluorescence lines are visible.

3. Preliminary results with XCF

The XCF was equipped with a set of different crystals positioned at the Bragg angle to obtain $\sim 100\%$ polarized beams at different energies in the range 2–8 keV [6], working as monochromators. InSb (111) crystal selects the X-ray tube characteristic Mo fluorescence line at 2.293 KeV, while using other crystals higher energies can be achieved, but with lower rates by diffracting photons from the Bremsstrahlung tail. Fig. 3 shows the GPD energy spectra for Si (220) (*left* panel) and Si (400) (*right* panel) crystals. In the first spectrum, the second diffraction order peak is visible while in the second spectrum the Silicon fluorescence peak at 1.74 KeV can be seen (these photons do not show any polarization).

Fig. 4 shows the modulation factor measured at different energies with the XCF: μ has been calculated both from the fit of the modulation curve (Eq. (1)) and from the Stokes parameters (Eq. (2)) and in both cases the results are in line with the expectation from simulations made for IXPE's GPDs. As the energy of the incoming X-ray increases, the track into the GPD is longer and the photoelectron emission direction is better reconstructed, so μ increases with energy.

4. Conclusions

XCF can have different applications as GPD long term studies, by monitoring a set of control detector identical to those currently

[2] $E = \frac{nhc}{2d\sin\theta}$ with grating constant d, angle of incidence θ, selected energy E and diffraction order n. The polarization is 100% for $\theta = 45°$.

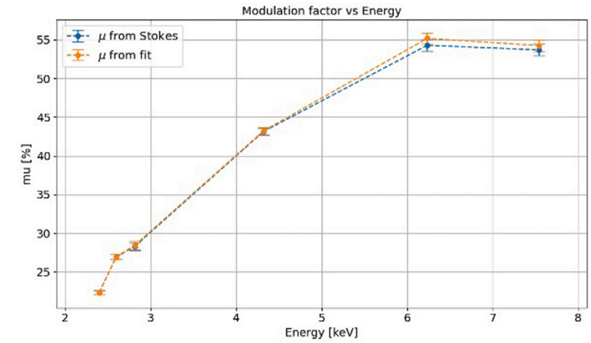

Fig. 4. GPD $\mu(E)$ from the fit and from the Stokes parameters.

operating in space or studies of the transparency of different windows for future X-ray detectors. It can also satisfy evolving requirements to support *R&D* programs of innovative position, energy and polarization sensitive X-ray detectors.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: All the authors reports equipment, drugs, or supplies and travel were provided by Italian Space Agency. Frassa' Andrea reports financial support and equipment, drugs, or supplies were provided by Government of Italy Ministry of University and Research. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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