A new facility for the developement of new X-ray detectors: the X-ray Calibration Facility

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Summary. — The X-ray Calibration Facility (XCF) is an irradiation setup located at the Physics Department of the University of Turin, Italy, and conceived to characterize, test and design X-ray detectors. It can provide beams of photons with different energy and polarization configuration, that make it suitable for calibration and test of energy, position and polarization sensitive detectors.

Keywords: X-ray Astrophysics, Polarimetry, Gas Detectors

1. – Introduction

The X-ray Calibration Facility (XCF) built in the Physics Department of the University of Turin, is a setup able to characterize and calibrate X-ray polarimetry detectors as well as support future detectors designs. One of the primary functions of XCF is the characterization of Gas Pixel Detectors (GPDs), which are currently onboard the Imaging X-ray Polarimetry Explorer (IXPE) space telescope [1]. IXPE is an ongoing NASA mission dedicated to measuring the X-ray polarization from various astrophysical sources. GPDs are the key detectors of the telescope, and XCF ensures their accurate calibration, as well as the monitoring of their performance over time.
XCF can utilize two different radiation sources: a multi-anode X-ray tube (Mc Pherson Mod. 642) and a sealed single-anode (Molybdenum) Micro X-ray tube, covering an energy range from 0.1 to 10 keV. The facility offers two distinct beam lines (Figure 1): the first is the direct unpolarized beam, the second is polarized by a crystal via Bragg diffraction. XCF is equipped with two ancillary detectors: a Silicon Drift Detector (SDD) with an energy resolution of 2% FWHM at 5.9 keV, and a modified CMOS ASI ZWO camera with a resolution of 2822x4144 pixels and 4µm pixel size. Furthermore a mechanical handling system enables different measures.

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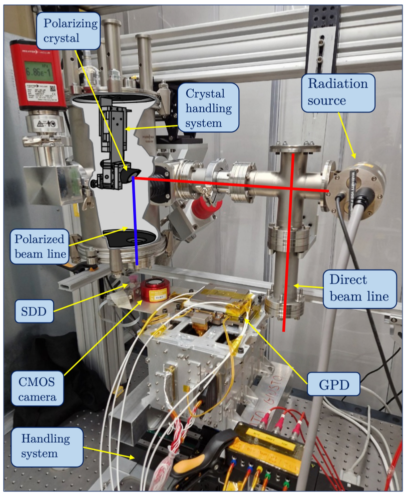

Fig. 1. – Scheme of XCF: the direct beam follows the red vertical line, while the polarized beam exits as the blue line on the left

2. – Polarizing the X-ray beam

The X-ray photons that follow the horizontal beam line (see Figure 1) are polarized via Bragg diffraction [3]. The crystal selects energies according to the Bragg's law:

$$E = \frac{nhc}{2d\sin(\theta)} \tag{1}$$

where d is the crystal lattice spacing, n is the diffraction order and θ is the angle between the incident X-ray direction and the crystal surface. Polarization will be 100% when θ is equal to 45°.

The two X-ray tubes emit different spectra, each composed of Bremsstrahlung X-rays and a characteristic line of the anode. To achieve the highest rate of 100% polarized X-rays, crystals can be selected to match energies as close as possible to the anode's characteristic line (see table I).

Table I. – *List of all crystals available in XCF and selected to match the energy of the corresponding anode*

Anode	**Energy [keV]**	**Crystal**
Mo	2.293 $L\alpha$	InSb 111
Rh	2.697 $L\alpha$	Ge 111
Pd	2.839 $L\alpha$	Si 111
Ti	4.511 $K\alpha$	Si 220
Fe	6.400 $k\alpha$	Si 400
Ti	7.478 $K\alpha$	Ge 422

The obtained spectra using InSb with a Molibdenum anode can be seen in figure 2. In the polarized beam, X-rays with the same energy, or any integer multiple of it, are

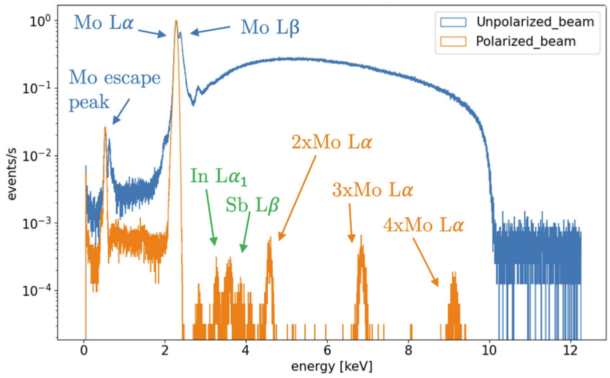

Fig. 2. – Spectra of unpolarized and polarized beams produced by the MXR tube. The polarized spectrum shows different diffraction orders and the crystal fluorescence (In L_α and Sb L_β)

emitted at the same angle as predicted by Bragg's law [1]. Photons are then further selected before the polarized exit using a Hamamatsu capillary plate which serves as a collimator of the beam line letting through only vertical photons (≈ 0.5 degrees spread) which are 100% polarized and corresponds to a range of $\approx 70\,eV$. If the spectrum is not uniform over the selected interval, the spatial image of the polarized beam will show a region with a higher rate of X-rays with the same energy called Bragg's arc (Figure 3).

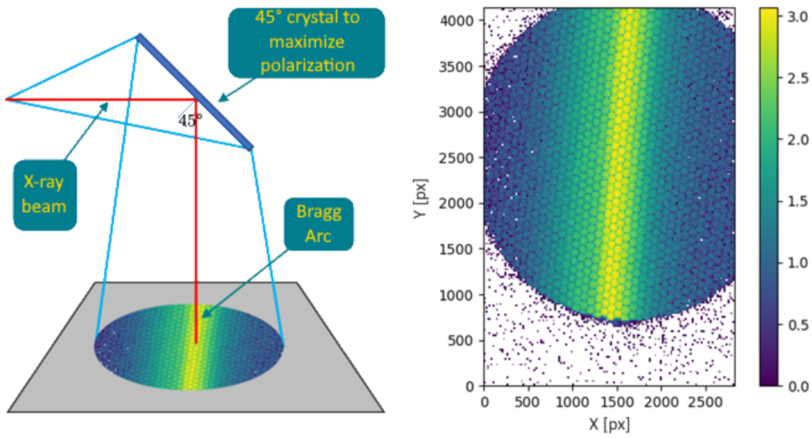

Fig. 3. – Schematic representation of Bragg's arc. The image is acquired using the CMOS camera.

3. – Gas Pixel Detectors

The Gas Pixel Detectors (GPD) [2] represent the state-of-the-art in soft X-ray polarimetry. GPDs are sealed gas detectors equipped with a beryllium window that allows X-rays to enter the gas chamber, which is filled with dimethyl-ether (CH_3OCH_3). Inside the chamber, X-rays interact with the gas via the photoelectric effect [4], emitting a photoelectron. This electron travels inside the gas, generating additional charges through ionization. Ultimately, all charges are collected, and the resulting track is recorded by a readout circuit.

These detectors enable the measurement of the polarization degree and phase of incident photons on a statistical basis, by analyzing the distribution of events $N(\Phi)$, where Φ represents the angle between the photoelectron's emission direction and the polarization axis.

Gas was preferred over solid-state detectors in order to achieve longer tracks, allowing for more precise estimations of the photoelectron emission direction in the 2 to 8 keV energy range.

3˙1. *Berillium windows transparency.* – The beryllium (Be) window placed on top of the GPD allows X-rays to enter the detector while preventing the gas from escaping. The critical aspect for selecting these windows is their transparency, defined as the ratio of transmitted with respect to incident photons.

In XCF, beryllium windows from two different manufacturers were studied and compared. One was the same already mounted on the GPDs (Be_0) manufactured by Materion Corp, and the other one was produced by Shuoyao New Material Technology (Be_1).

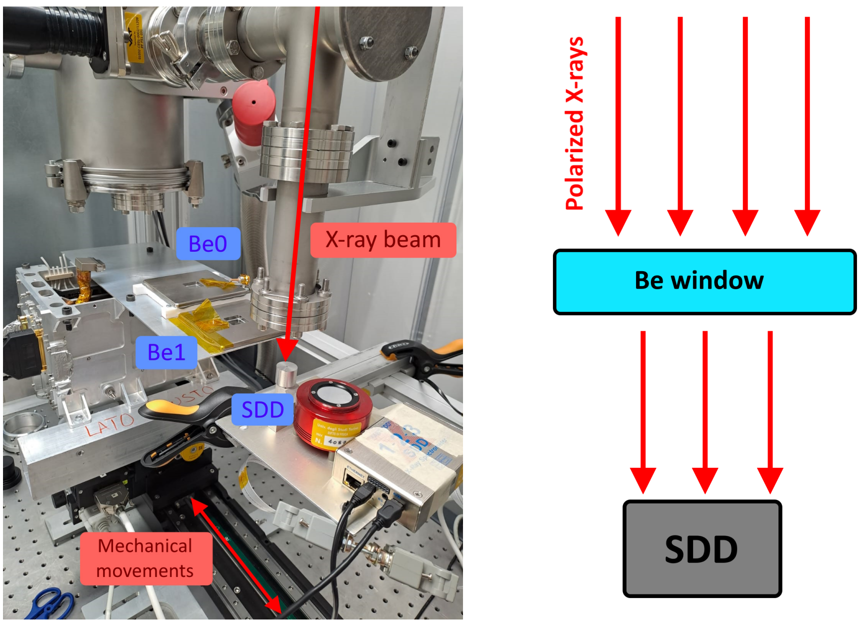

Fig. 4. – Relative transparency measurement setup

This study was conducted by alternating the two windows between the direct X-ray beam and the SDD detector using the mechanical handling system (Figure 4). This process was repeated in a cycle of 10 loops, with each window being measured for 5 minutes, to exclude any long-term variation of the X-ray tube. In total, 10 measurements of the spectrum were taken for each window.

To compare the transparency of the two windows over the IXPE energy range (2 to 8 keV), the spectra obtained from the 10 measurements were summed in order to ensure sufficient statistics in each energy bin. The comparison was made by evaluating the rate of events with Be_0 divided by the rate with Be_1 for each energy bin. The results, as shown in Figure 5, indicate a maximum difference of $(3.4 \pm 0.4)\%$ around 2 keV, while the transparencies are compatible at higher energies.

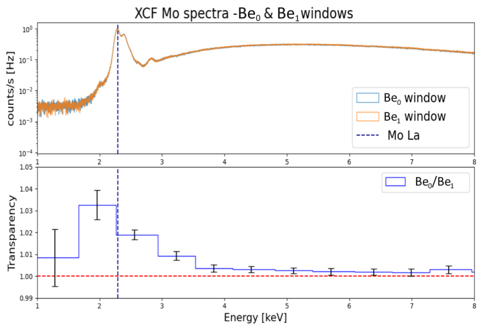

Fig. 5. – Relative transparency of the two windows

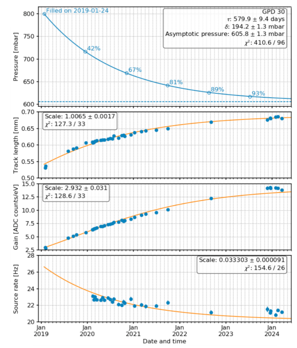

Fig. 6. – GPD n°30 secular variations

3·2. *GPD secular variation.* – GPDs are filled with dimethyl-ether and sealed. When the GPDs were initially assembled, their internal pressure was 800 mbar. However, due to chemical interactions with the glue used during sealing, the pressure is decreasing over time. This variation affects the performance of the GPDs by reducing the interaction probability (which leads to lower detection rates), tracks get longer, and the gain augments in terms of generated charges along the photoelectron track (see also Baldini et al. [2]).

XCF is the only facility which is monitoring the secular variations of 4 GPDs using its ^{55}Fe source which is more stable than the X-ray tube (Figure: 6). Using the source we can measure rate, gain and track length variation over time once every month.

4. – Conclusions

The XCF facility can support the development of X-ray detectors, study long-term variations, and characterize detectors, as demonstrated with the GPDs, by monitoring a set of control detectors identical to those currently operating in space. Additionally, it can meet evolving requirements to support R&D programs for innovative position, energy, and polarization-sensitive X-ray detectors. The facility is also capable of exploring new solutions, such as testing different windows for GPDs.

5. – Acknowledgments

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