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Commissioning of a Si(Li) Compton polarimeter with improved energy resolution

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ABSTRACT

On the basis of a double-side segmented Si(Li) crystal a new Compton polarimeter was developed within the SPARC collaboration. The new detector is equipped with a cryogenic first stage of the preamplifiers to improve the energy resolution compared to previous detectors with preamplifiers operating at room temperature. We present first results from a commissioning measurement of the new instrument at the ESR storage ring of GSI in Darmstadt, Germany and contrast it with the performance of an precursor polarimeter system.

1. Introduction

In recent years, Compton polarimetry of hard x-rays has proven to be a unique tool to study subtile spin-dependent and relativistic effects in the realm of atomic physics at high field strengths, see [1–7] and references therein. For an overview of various Compton polarimetry measurements performed with double-sided segmented, planar X-ray detectors as they are discussed in the present work, see [8] and references therein. Moreover, it is also expected to allow valuable insights into astrophysical processes [9]. Consequently, the development of hard X-ray polarimeters is an important part of the efforts of the Stored Particle Atomic Research Collaboration (SPARC) [10] to prepare for future experiments at the Facility for Antiproton and Ion Research (FAIR) [11].

Compton polarimetry is based on the anisotropy of the azimuthal Compton scattering cross section with respect to the polarization vector of the incident photon. More specifically, scattering of the photon perpendicular to the incident photon polarization is preferred while scattering in the parallel direction is less likely. Thus, the degree and orientation of the linear polarization of an incident X-ray beam can be determined from the emission pattern of a large number of Compton scattered photons. This can be efficiently performed when using position sensitive X-ray detectors, such as double-side segmented or pixelated semiconductor sensors. In such devices the scattering event is detected due to the energy deposition by the recoil electron in close vicinity to the point where the Compton process happened (the penetration depth for a 50 keV electron in silicon and germanium is about 21 μm and 15 μm, respectively) and the absorption of the scattered photon occurs at a different position within the same detector, see [12] for a detailed discussion of this measurement technique. Thus, each segment of the detector acts as a scatterer and also as an absorber for the scattered photons. During the last decade several position-sensitive Ge(i) and Si(Li) detectors were developed and applied to this purpose within the SPARC collaboration [13–16].

A major drawback of these systems when compared to the standard unsegmented hard X-ray detectors is the limited energy resolution of up to 2.5 keV at 60 keV incident photon energy, resulting from the preamplifiers being operated at room temperature that exhibit a high electronic noise level. These were employed because the large number of small detector segments poses strict requirements on the size and heat load that is allowed for each readout line, rendering the installation of at least a few dozens of preamplifiers in the cryogenic vicinity of the detector crystal challenging. However, as demonstrated recently the use of preamplifier ASICs based on CMOS technology (such as CUBE, XGLab s.r.l.) [17] that are located in the cryogenic environment next to the detector crys-

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tal can lead to a tremendous improvement of the energy resolution of segmented semiconductor detectors [18]. For the new Si(Li) polarimeter presented in this report a two-stage preamplifier design with a cryogenic first stage was employed. In the following we report on the performance of this detector during first test measurements.

2. Performance of the new Si(Li) Compton polarimeter

The detector itself consists of a single 46 mm × 46 mm Li-drifted planar silicon crystal with a thickness of approximately 9 mm. The active area is 32 mm × 32 mm, being surrounded by a guard ring. The front side and back side of the crystal are segmented into 32 strips with a width of 1 mm each – vertically oriented at the front and horizontally at the back. Each segment is connected to its own charge sensitive preamplifier and has its own readout chain, effectively working as an individual detector. Combining signals from both sides results in a pseudo pixel structure providing 2D position information in addition to time and energy resolution. The detector system including the housing of the preamplifiers and the liquid nitrogen reservoir as well as a schematical drawing of the segmented crystal is shown in Fig. 1. By matching the energy and position information on both sides of the detector crystal even multiple coincident hits can be distinguished. Furthermore, the number of strips on each side which show signals above the noise level indicates what kind of interaction process occurred. The events which affect exactly one strip on each side are mostly due to photoionization of an incident photon whereas two signals on both sides are detected most probably as a result of Compton scattering. Higher signal numbers are related to multiple absorption and scattering processes in the detector.

In contrast to the previously developed double-side segmented Si(Li) and Ge(i) detectors [13,14] the first stage of the preamplifiers - this means the field-effect transistor (FET) and the feedback resistor and capacitor - is placed on printed circuit boards (PCB), which are mounted next to the detector crystal. These PCBs and the input stage of the preamplifiers are cooled together with the Si(Li)-detector down to ≈ 120 K. The lower operating temperature of the FETs on the one hand and the (much) smaller capacitance (reduced wire length) between the detector strips and the FET-input on the other hand reduce the electronic noise drastically. Fig. 2 shows a spectrum summed over all strips of the new detector stemming from an ^{241}Am gamma source in comparison with the same measurement conducted with an older detector system developed as a dedicated Compton polarimeter by the SPARC collaboration [13]. Aside the mounting of the first stage of the preamplifiers this already well established detector system features similar characteristics, such as strip width and the size of the detector crystal and is therefore well suited for the comparison. As can be seen clearly, the cryogenic preamplifiers result in a much better energy resolution. For the 59.54 keV ^{241}Am peak the FWHM was reduced from about 2 keV to less than 1 keV. Likewise, the threshold level, below which most signals are due to random fluctuations of the baseline and not due to energy deposition inside the detector, i.e. the noise level, was reduced from roughly 6 keV to values below 3 keV. This enables the trigger threshold for the readout of the detector to also be reduced from roughly 15 keV to about 7.5 keV under experimental conditions. The strongly reduced noise level does not only improve the energy resolution but does also significantly decrease the low energy threshold for the reconstruction of Compton scattering events inside the detector. This detection limit is reached when the typical energy of an recoil electron drops below this threshold, see [19] for a detailed discussion. Fig. 3 shows again spectra of the ^{241}Am source in comparison for the detector system with room temperature preamplifiers (a) and the new system with cryogenic preamplifiers (b), with addition of the reconstructed Compton events (red). The lower electronic noise level due to the cooling of the first stage of the preamplifiers subsequently results in the extension of the accessible range for Compton reconstruction down to values of roughly 50 keV photon energy. Compared to that, reconstruction with the previously used system was only possible down to about 60 keV.

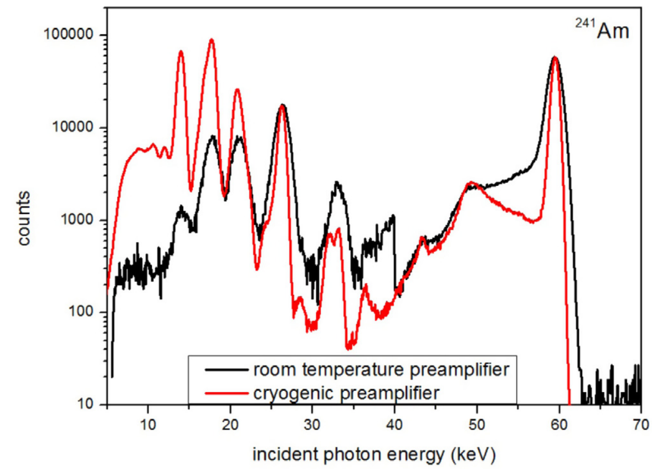

Fig. 2. Spectra recorded for an ^{241}Am gamma source. The performance of the new detector system with LN_2-cooled preamplifiers (red) is contrasted to a detector system with preamplifiers operating at room temperature (black). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

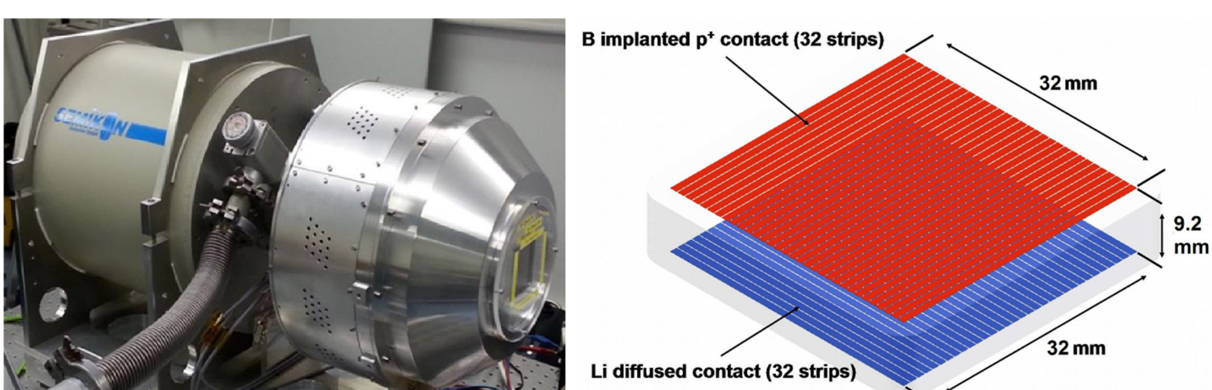

Fig. 1. Left: New Si(Li) polarimeter system including LN_2 Dewar. Right: schematical drawing of the segmented detector crystal (right).

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