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Characterization of a double-sided Si(Li) strip Compton polarimeter

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Abstract. The response of a double-sided segmented Si(Li) detector system has been investigated. The detector has been irradiated with a collimated, highly linearly polarized beam of 53.2 keV photons from the synchrotron radiation source PETRA III at DESY. The detector was mounted on a platform that could be moved with μm precision thus allowing for a defined beam position on the detector surface. In this paper, the effects of the isolation gaps (gap width = 50 μm) between adjacent segments (strips) were studied, in particular with respect to the effect of charge sharing. The fraction of such charge sharing events increases from about 5% (beam hits center of a strip) to over 50% when the beam is focused just on a gap. The fraction of reconstructed Compton scattering events, which is interesting for Compton polarimetry, amounts to about 3% with the beam impinging at a strip center and 2.8% on average. It can therefore be concluded that events related to charge sharing do not critically degrade the performance of the detector as a Compton polarimeter.

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1. Introduction

Heavy few-electron atomic systems provide excellent properties to investigate fundamental light-matter interactions. At the Experimental Storage Ring (ESR) at GSI, Darmstadt highly charged ions (HCI) up to bare uranium are stored and cooled. Photons emitted in collisions with internal targets provide detailed insight into basic photon-matter interaction and are related to e.g. atomic bremsstrahlung, radiative recombination or characteristic transitions. Standard germanium detectors are used to measure the photon energy and angular distribution. Additional information can be extracted from the polarization state of the photons. Since the energy is typically in the hard X-ray regime (few tens of keV to a few 100 keV), the well established methods for polarization measurements for optical and soft X-ray photons fail. For the hard X-ray regime, a technique that has been applied successfully in several experiments [1, 2, 3, 4, 5, 6, 7], is Compton polarimetry [8] with double-sided strip detectors (DSSDs). There,



the 2D-angular distribution of photons Compton-scattered inside the detector is measured to determine the degree and direction of (linear) polarization of the incident photon beam. For this method not only a dedicated detector is required, but also a fast and reliable readout system as well as suitable analysis algorithms. All of these components must be understood in great detail in order to enable precision measurements. In the current report we aim to gain a deeper understanding of the performance of the used 2D Si(Li) polarimeter. In particular, the interaction between the incident photons and matter inside the detector as well as the movement of released charge carriers to the electrodes has to be modeled [9]. By using a well-defined photon beam (energy, position, polarization) available from a synchrotron radiation source, the focus of the current study is to investigate the effect of charge splitting between adjacent detector strips.

2. The 2D Si(Li) polarimeter

The detector has been developed as a dedicated Compton polarimeter within the SPARC collaboration [10, 11]. Its active volume is a lithium-drifted silicon crystal with an area of 80 mm by 80 mm and a thickness of 7 mm. Between the electrodes at the front- and backside a voltage of 800 V is applied. The front and back electrodes are segmented into 32 strips, orthogonal to each other, resulting in a 2D structure of 1024 pseudo-pixels. All 64 strips have a pitch of 2 mm width, resulting in an active area of 64 mm by 64 mm. Adjacent strips are separated by a 50- μ m isolation gap. Each strip is read out via its own charge-sensitive preamplifier and an entire chain of subsequent readout electronics. This configuration enables the detection of independent events in different strips, allowing to record their position (2D), energy and time (with the resolution of ≈ 50 ns) separately. While the detector crystal has to be kept at 77 K, the preamplifiers are operated at room temperature. This leads to a mediocre energy resolution of ≈ 2.1 keV FWHM at 59.54 keV which is mainly determined by the electronic noise of the preamplifiers.

3. Experiment

The experiment was conducted at the High Energy Materials Science Beamline P07 at the synchrotron radiation source PETRA III at DESY, Hamburg [12]. The facility provides a photon beam with tunable energy and a degree of linear polarization of almost 100%. The Si(Li) polarimeter was mounted on a movable platform where it was irradiated directly with the incident beam. The beamline is equipped with remote-controlled collimators and attenuators to adjust the beam size and intensity. Both the detector platform and the collimators can be moved with μ m precision. As a first step we determined the calibration that relates the positions of the platform step motors to the beam position on the detector. With this calibration available, any desired beam position on the detector could be set. This was used to perform several scans in the course of the experiment. In this paper, we restrict ourselves to the so-called gap-scan: a horizontal scan over three vertical strips with a stepsize of about 0.05 mm close to the gaps. The scan pattern is depicted in figure 1. For each beam position, events were recorded for about

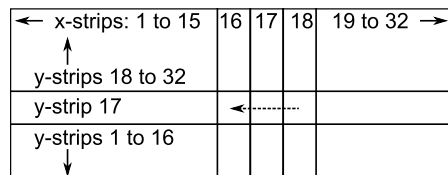


Figure 1. Strip pattern of the detector. The dashed arrow indicates the beam positions for the scan over two vertical gaps.

one minute with an event rate of ~ 1900 Hz. The photon energy was 53.2 keV. A corresponding scan was also performed in the vertical direction. In order to ensure a reliable energy calibration of the detector, several calibration runs were performed during the experiment using standard ^{133}Ba and ^{155}Eu γ -sources.

4. Analysis algorithm

With a DSSD it is possible to reconstruct events of different complexity. The simplest ones are illustrated in figure 2. In figure 2 (a), a single hit is depicted, which corresponds to one energy deposition inside the detector. This event type mainly indicates an absorption of an incident

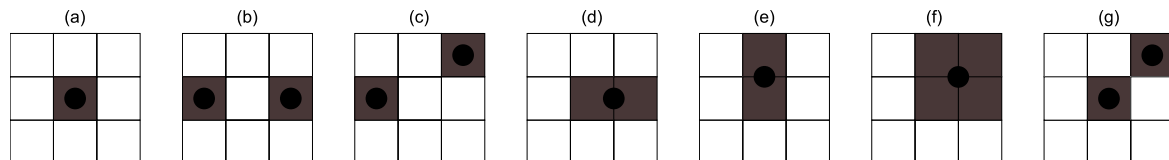


Figure 2. Possible event types in the pseudo-pixel structure of the strip detector: black circles indicate energy depositions, pixels with (without) a signal are grey (white) squares. (a) single hit; (b)+(c) separated double hit; (d)-(f) adjacent double hit due to charge sharing; (g) adjacent double hit from independent energy depositions.

photon. In case of a Compton scattering inside the detector one has two independent energy depositions, one by the recoil electron and one by the scattered photon. These are the events used for polarimetry, but the reconstruction is problematic, if the photon is absorbed very close to the recoil electron, such that signals in neighbouring strips are generated (indicated in figure 2 (g)). First, the direction of the scattered photon has a high uncertainty in this case and second, it cannot be distinguished from the scenario, where a single energy deposition occurred, but charges were collected by more than one strip (figure 2 (d) to (f)). This effect known as charge sharing is the major aspect investigated here. In our analysis, we consider as possible Compton scattering events only separated double hits (figure 2 (b) and (c)), that means on at least one detector side must be at least one strip without signal between the two strips with a signal. The other (adjacent) double hits are attributed to charge sharing events. In order to obtain information about the Compton polarimeter efficiency, for each separated double hit it was checked (by looking at the energy conservation) whether it is related to a Compton scattering event. Therefore the separated double hits shown in the results in section 5 correspond directly to such events that are used for polarization analysis. With this classification into event types, the analysis consists of counting each event type for a given data set which corresponds to one position of the incident beam on the detector. In order to allow a time normalization of the counts, a 10-kHz clock was connected to the data acquisition.

5. Results

Results obtained in this work are event rates and ratios of them as a function of the beam position on the detector. Figures 3 and 4 show plots both for the scan over the vertical strips (detector front side) and the scan over the horizontal strips (detector back side). Position 0 in the plots refers to the center of the central strip. Gaps are located at ± 0.1 cm. Figures 3 (a) and (d) show the total rate of events registered by the detector. For the horizontal strips (d) one can clearly see a decrease in the rate of about 3% at the gap positions. For the vertical strips (a), a decrease of the rate can only be observed at the left gap ($x = -0.1$ cm), and here it amounts to about 1.2%. The missing rate drop at the other gap at $x = 0.1$ cm could not be explained conclusively, one possibility is an instability of the incident beam. In order to cancel this effect, the rate of valid events (valid event: on both detector sides there is at least one strip with a valid signal and total energies on both detector sides do not deviate by more than 6 keV) normalized to the total event rate has been determined (Figures 3 (b) and (e)). For both vertical (b) and horizontal (e) strips the valid events amount to about 97.6% far from the gaps. At the gaps this portion decreases to 96% in case of the vertical strips and 94% for the

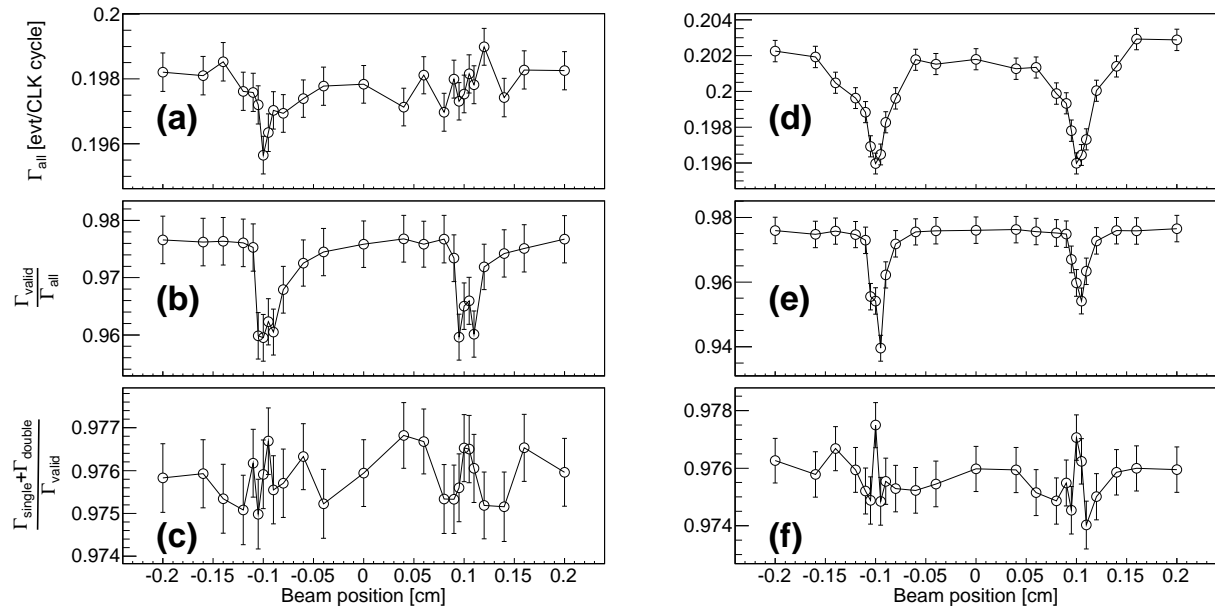


Figure 3. Event rates as a function of the incident beam position on the detector. The scans over the vertical ((a)-(c)) and horizontal ((d)-(f)) strips are shown. Error bars are statistical errors.

horizontal strips. In the next step the composition of the valid events was investigated. Figures 3 (c) and (f) show the sum of single and double (adjacent and separated) hits normalized by the number of valid events. This ratio of about 97.6% varies only by 0.2% with the beam position, which is not statistically significant here. The remaining 2.4% of valid events – which were not analyzed further – correspond to separated double hits that were not classified as Compton events (random coincidences) and events where more than two strips on at least one detector side had a valid signal, which include multiple scatterings. The contributions to the position-independent fraction of valid events, namely the single hits, the separated double hits and the adjacent double hits are shown individually in figure 4. The proportion of valid events that are single hits is shown in figures 4 (a) for the vertical strips and (d) for the horizontal strips. In both cases the ratio decreases from 90% near the strip centers to 40% at the gaps. This decrease is accompanied by a strong increase in the fraction of adjacent double hits (figures 4 (c) and (f)): from 5% near strip centers to 56% at the gaps. On the other hand, the variation in the fraction of separated double hits (figures 4 (b) and (e)) is less pronounced: between 2.4% and 2.9% for the vertical strips (b) and between 1.8% and 3% for the horizontal strips (e). A noticeable feature in the curves for single hits and adjacent double hits is the asymmetry of the peaks around the gaps. The origin of this asymmetry could not be determined from the data, but one possibility is a tilt of the detector. Since usually in experiments the exact position of incident particles is not known, average fractions were calculated for the curves in figure 4. The values are as follows: 84.2% (a), 2.8% (b), 10.5% (c), 86.5% (d), 2.8% (e) and 8.2% (f).

6. Conclusion

In this work the effect of the isolation gaps of a double-sided Si(Li) strip detector has been investigated for incident 53.2-keV photons. The average proportion of valid events that are adjacent double hits (charge sharing events) is about 10%. For separated double hits (Compton scattering events) the value is 2.8%, while the corresponding maximum value is about 3%. From that follows that the gaps cause the proportion of valid events that are Compton scattering

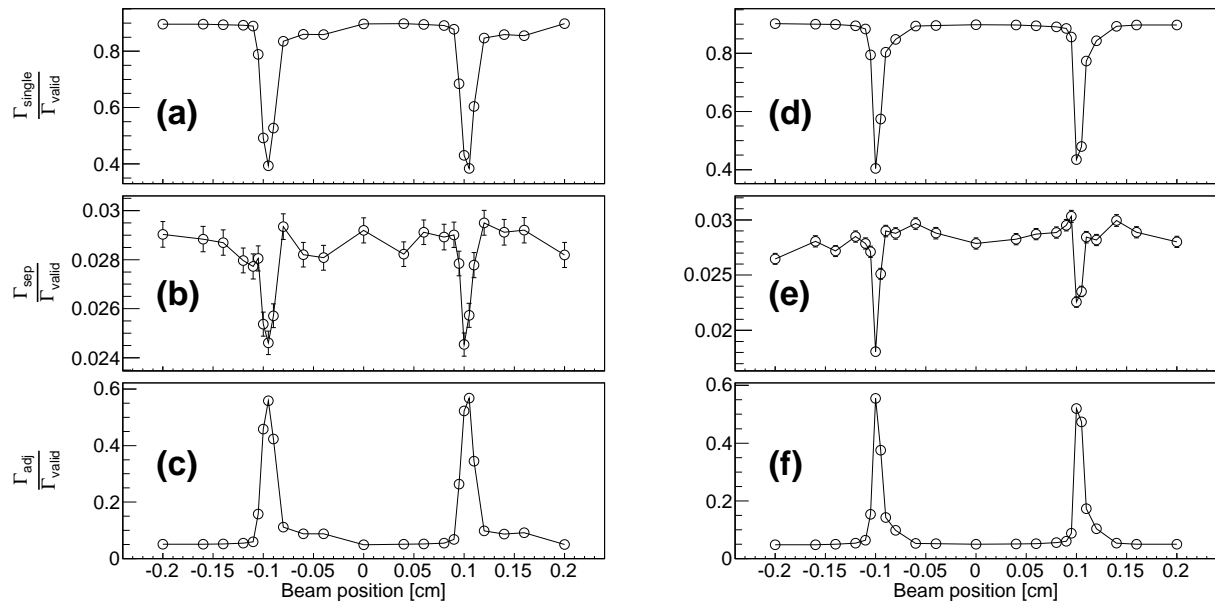


Figure 4. Rates of single and double hits as a function of the incident beam position on the detector. The scans over the vertical ((a)-(c)) and horizontal ((d)-(f)) strips are shown. Error bars are statistical errors.

events to decrease on average by less than 7%. The effect of the gaps is therefore not crucial for Compton polarimetry. We are currently developing a simulation code for the drift of charges inside the detector crystal to model the effects of charge splitting between neighbouring segments for a large range of incident photon energies.

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