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BEAM POSITION MONITORING AND POLARIMETRY WITH A TIMEPIX3 PIXEL DETECTOR AT A COMPTON BACKSCATTERING POLARIMETER

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Abstract

The ELSA facility at the University of Bonn uses a storage ring to accelerate polarized electrons up to 3.2 GeV. To monitor the polarization degree of the stored beam a Compton polarimeter is used to analyze the profile of the backscattered beam of gamma rays. In addition to a silicon microstrip detector with vertical resolution, a Timepix3 pixel detector is tested as alternative detector for the usage in beam polarimetry and beam position monitoring. The current status of the alternative detector setup is presented.

INTRODUCTION

A Compton backscattering polarimeter is used for measuring the degree of polarisation of the electrons in the storage ring at the ELSA facility [1], as shown in Fig. 1. The storage ring applies a 6 GeV/s energy ramp from 1.2 GeV to 3.2 GeV, making polarimetry essential to fine tune those machine settings which prevent the impact of depolarizing resonances in the highly repetitive synchrotron lattice. The Compton polarimeter has shown advantegous performance [2,3] compared to a Møller polarimeter located at one of the extraction beamlines. We investigate the feasibility of using the Timepix3 pixel detector as alternative device for upcoming user experiments [4], where photoproduction experiments with polarized electrons are favored. The polarisation measurment cycle includes backs-cattered photons from electron and laser light interaction with alternating right- and left-handed circular photon polarization as well as background measurements in-between. While the electron polarisation dependent scattering cross section results in a vertical displacement of the photon profile, the background from Bremsstrahlung radiation from residual gas allows for electron beam position and angle monitoring.

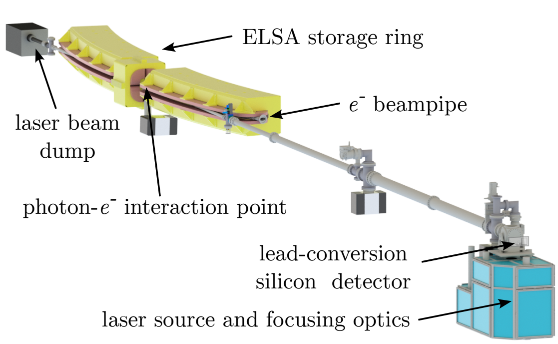

Figure 1: Drawing of the Compton polarimeter at ELSA.

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THE COMPTON POLARIMETER AT ELSA

A 20 W continuous-wave photon beam at 532 nm is circularly polarized and brought to head-on collision with the stored electron beam (see Fig. 2). The Klein-Nishina scattering cross section yields a dependency on photon and electron polarization, $\vec{S}$ and $\vec{P}$ resp., [5]

$$\frac{d\sigma_c}{d\Omega}(\vec{S},\vec{P}) = \Phi_0 + \Phi_1(S_1) + \Phi_2(S_3,\vec{P}), \tag{1}$$

resulting in a vertically shifting scattering profile for alternating photon helicities (Stokes parameter $S_3 = \pm 1$) and vertical electron polarisation P_z:

$$\Delta z = z_R - z_L = \mathcal{D} \cdot P_z \cdot S_3. \tag{2}$$

$z_{R,L}$ are the helicity specific profile means and $\mathcal{D}$ is the device specific analyzing power which amounts approximately 70 µm for the conditions at ELSA [2,3]. To maximize the detector signal, lead converter targets of $2X_0$ width (radiation length $X_{0,\text{Pb}} = 5.6$ mm) are used in front of the silicon-based detectors 15 m downstream from the interaction point.

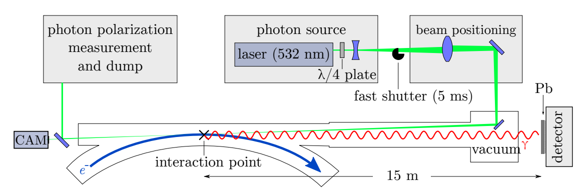

Figure 2: Sketch of the laser, electron and γ photon beamlines.

Measurement Characteristics

Figure 3 shows backscattering profiles measured by the 38.4 mm × 38.4 mm microstrip detector with 768 vertically orientated channels at 50 µm pitch [6]. The relevant contribution of Φ_2 from Eq. (1) is retrieved by subtracting the background from Φ_0, Φ_1 and Bremsstrahlung from electrons and residual gas in the vacuum chamber.

The alternating photon beam helicity $S_{3,\pm} = \pm 1$ is achieved by rotating a $\lambda/4$ wave plate with a pneumatically driven motor. During the switching times of some 100 ms fast shutters block the laser beam, allowing for individual background measurements for each pair of S_3 measurements. Each bin $(S_{3,+}|0|S_{3,-})$ is typically ~1,000 ms long yielding a full measurement cycle of ~3 s length, which is to be multiply repeated to minimize the statistical error of the measurement. Detector hit rates up to some MHz are obtained and statistical measurand accuracies $\delta(\Delta z)$ of 2 % were achieved within 5 minutes and 1.4 % within 15 minutes of measurement time [2, 3].

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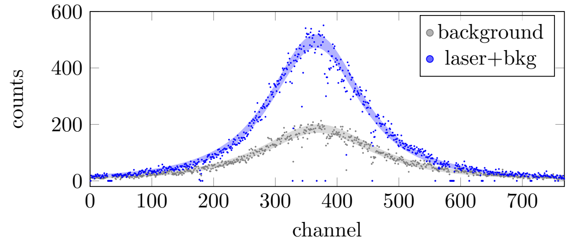

Figure 3: Backscattering photon beam profile obtained from the silicon microstrip detector.

A TIMEPIX3 PIXEL DETECTOR FOR ELECTRON BEAM POLARIZATION MEASUREMENTS

The silicon strip detector currently used for the Compton backscattering polarimeter shows ageing effects and future safe solutions for detector replacements are seeked. For this purpose a pixelized readout ASIC, the Timepix3 [7] combined with a 500 µm P-on-N silicon sensor, was installed and tested. Advantage of this pixelized ASIC is its commercial availability and capability to measure the horizontal beam profile in addition to the polarization relevant vertical profile.

The Timepix3 Sensor Assembly as Photon Detector

The Timepix3 ASIC is a pixelized readout ASIC with 256×256 pixels with a pitch of 55 µm, thus having an active area of $14 \times 14\,\mathrm{mm}^2$. Each pixel is able to measure time over threshold (ToT) and time of arrival (ToA) simultaneously. The maximum time resolution of the ASIC is 1.56 ns and it is capable of a data rate of $40\,\mathrm{MHits\,s^{-1}cm^{-2}}$, making the readout suitable for the polarimeter application. As the energy of the backscattered photons is of $O(100\,\mathrm{MeV})$ the 500 µm thick P-on-N silicon sensor – bump bonded to the readout ASIC – will not be sufficient to convert the photon rate to a sufficient amount of electrons. To circumvent this, a conversion target of 11.2 mm lead ($2X_0$) is placed in front of the detector.

Beam Profiles and Position Measurements

An exemplary profile obtained from the Timepix3 pixel detector is shown in Fig. 4. Figure 5 and Fig. 6 show vertical and horizontal projections, where the pixel values were binned in rows and columns accordingly. Therein, multiple background-subtracted profiles from $S_3 = \pm 1$ signals are summed up and compared to a *Pearson VII* fit function (compare with [2, 3]), from which the profiles' means are obtained. We believe the periodic noise in the signal (see repetitive fluctuating patterns in Fig. 6) is caused by an unstable supply voltage, which is currently under investigation.
The capability for parasitic electron beam position and angle monitoring based on background measurements is shown in Fig. 7. Unfortunately the detector's horizontal dimensions allow only for limited precision in beam position monitoring,

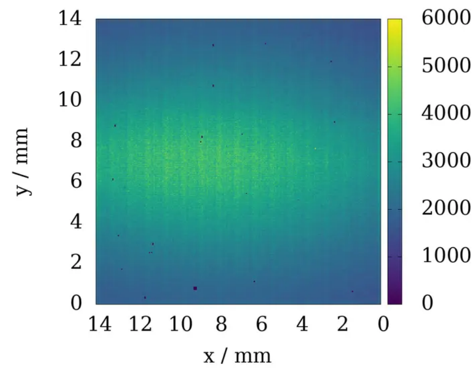

Figure 4: Backscattering photon beam profile obtained from the Timepix3 pixel detector.

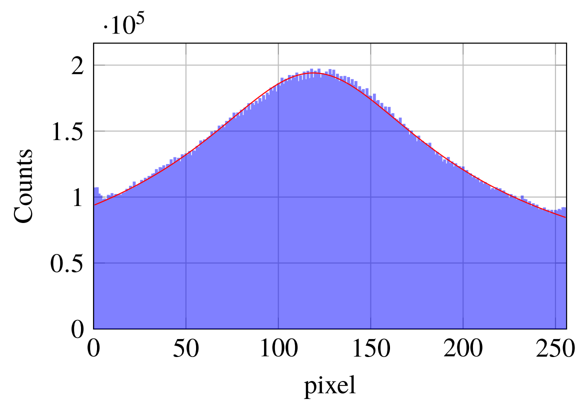

Figure 5: Distribution and fit of the backscattered photons in the vertical plane for a 2.5 GeV unpolarized beam.

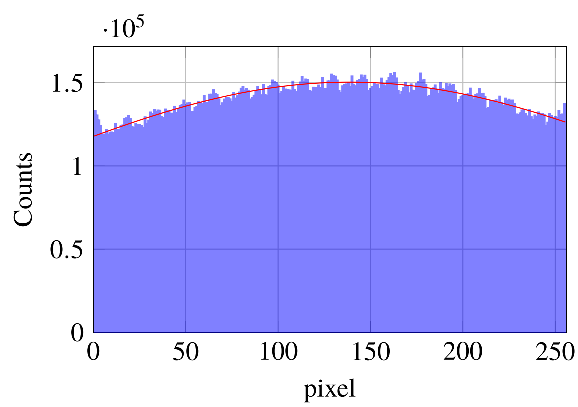

Figure 6: Distribution and fit of the backscattered photons in the horizontal plane for a 2.5 GeV unpolarized beam.

while the vertical detector size is sufficient for good profile resolution.

Polarization Measurements

Measurements with polarized electrons at 1.27 GeV beam energy were performed in order to test the performance of the detector and its capability to resolve Δz (see Eq. (2)). The data taking took about five minutes accumulating a total of 100 measurement cycles. These measurements were

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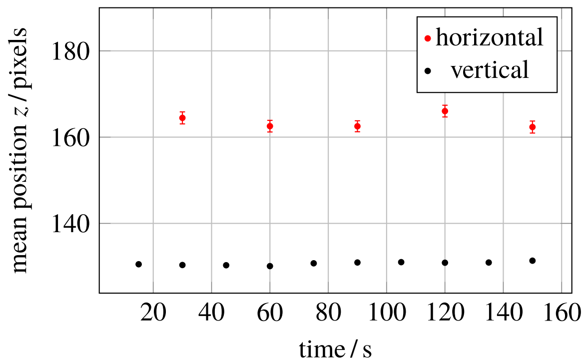

Figure 7: Electron beam position monitoring from Bremsstrahlung background signals.

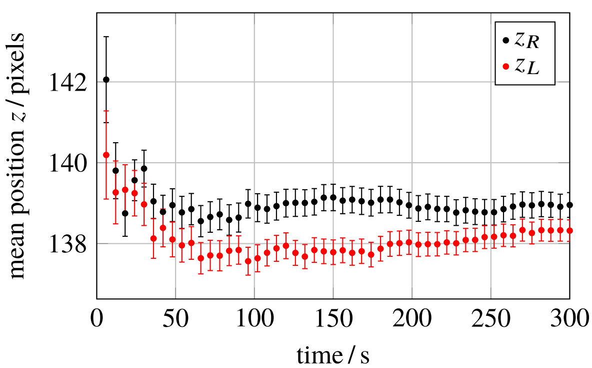

Figure 8: Development of the vertical mean position and error by accumulating data of multiple cycles for a data set taken with polarized electrons at 1.27 GeV. A split-up between the two laser beam helicities is observable.

added one by one after the background was subtracted and a *Pearson VII* fit was applied from which the mean positions z_R and z_L were determined. The results are shown in Fig. 8. Therein it is clearly visible that after approximately one minute the position of the mean and its statistical error in the vertical plane is converging. The data shows a clear difference of up to $\Delta z \leq 1.35$ px ($\sim$74.5 µm).

For comparison a data set from an unpolarized electron beam at 2.5 GeV is shown in Fig. 9. Therein, a similar converging response is observed: After approximately one minute the means coincide within the error margins, indicating no observable beam polarization.

CONCLUSION

We are currently testing a Timepix3 pixel detector as successor for an ageing microstrip detector for beam polarization measurements at the ELSA Compton polarimeter. First results show that the vertical size and resolution is satisfactory in terms of beam tracking and polarization measurements. The rather narrow horizontal size of the 14 mm wide chip is disadvantageous in respect to horizontal beam capture and monitoring, potentially demanding two neighbouring chips to cover the required range. Continued tests will show if enhanced polarization measurements are feasible with this setup and if a similar precision compared to the microstrip detector can be reached.

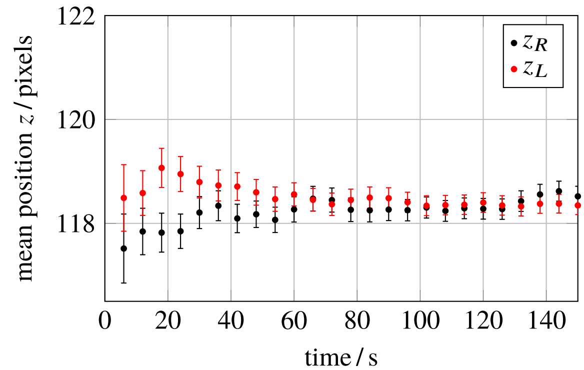

Figure 9: Development of the vertical mean position and error by accumulating data of multiple cycles for a data set taken with unpolarized electrons at 2.5 GeV.

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