USING A Timepix3 PIXEL DETECTOR FOR A COMPTON BACKSCATTERING POLARIMETER

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Abstract

The Electron Stretcher Facility (ELSA) in Bonn has the capability to accelerate and extract spin-polarized electrons. A Compton backscattering polarimeter located in the storage ring allows for in situ measurements of the beam polarization degree. Here, a circularly polarized 20 W cw-laser beam is scattering off the stored electron beam. The backscattered photons reach energies of up to some hundred MeV and the photon beam's center of gravity undergoes a polarization dependent vertical shift. Currently an in-house developed silicon strip sensor is used for profile analysis from which the spin-polarization degree is determined. For modernization of the detector assembly, the Timepix3 ASIC pixel detector with 55 µm pitch and a 500 µm thick silicon sensor is a suitable candidate. It allows to obtaining 2D beam information with an excellent time resolution (25 ns), enabling for parallel time resolved horizontal and vertical profile measurements. An in-house developed readout infrastructure allows for high flexibility and adaptability. The detector concept as well as first measurements of the vertical and horizontal profiles from polarized beams under varying conditions are presented.

INTRODUCTION

The electron stretcher facility (ELSA) is a three staged accelerator operated by the University of Bonn. Thermal or spin-polarized electrons are injected into a 26 MeV Linac and accelerated in a fast ramping booster synchrotron to typically 1.2 GeV to fill the ELSA storage ring. Therein, post acceleration occurs up to 3.2 GeV, where several depolarizing resonances have to be crossed. While in the booster synchrotron the crossing of those resonances has negligible impact on the beam polarization, additional precautions have to be taken in the stretcher ring. This is realized by fast ramping tune-jump quadrupole magnets and harmonic orbit correction schemes. For proper setup and fine adjustment of such countermeasures, non-destructive monitoring of the beam polarization is advantageous. To achieve this a laser Compton backscattering polarimeter was set up at the storage ring [1]. The polarimeter uses the spin-dependent angular difference of the backscattered photons to measure the electron beam's polarization degree with a silicon microstrip detector [2]. Since the detector shows signs of aging a new detector system based on a Timepix3 pixel chip detector is in development. First tests with this new detector showed promising results [3].

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COMPTON BACKSCATTERING POLARIMETRY AT ELSA

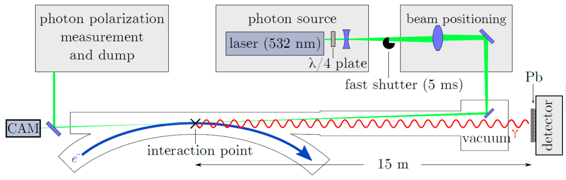

Figure 1: Principle setup of the Compton backscattering polarimeter at ELSA [4].

The Compton backscattering polarimeter [4] uses a 20 W 532 nm continuous-wave laser beam scattering off the stored electron beam (Fig. 1). From the Klein-Nishina scattering cross section [5]

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

a dependency on the polarization of the laser photons and the polarization of the electrons follows. This leads to a vertical shift Δz of the backscattered beam's center-of-gravity if the helicity (S_3) of the laser beam is altered when a vertically orientated electron polarization (P_z) is given:

$$\Delta z = z_R - z_L = \mathscr{D} P_z S_3 \,. \qquad (2)$$

Here $z_{R,L}$ denotes the mean position of the backscattering profile for left or right circular polarized laser light and $\mathscr{D}$ is the analyzing power of the polarimeter, which is approximately 70 µm/100 %.

Since the energy of the backscattered photons is boosted to energies up to some hundred MeV, a conversion target is beneficial to increase the signal yield. For this a 11.2 mm ($2X_0$) lead converter target is used in front of the silicon microstrip detector. The microstrip detector has 768 vertically

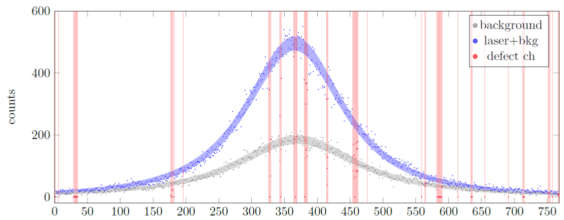

Figure 2: Exemplary vertical backscattering profiles measured with the silicon microstrip detector. Insufficiently operating channels are marked in red [4].

oriented strips of 38.4 mm length at 50 µm pitch. Thus, the active area of the sensor is $38.4 \times 38.4\,\text{mm}^2$.

During a measurement, the circular polarization of the laser photons is altered by a rotating $\lambda/4$-plate. During the rotation process the laser beam is blocked by a fast shutter to allow for background measurements of bremsstrahlung radiation from residual gas in the vacuum chamber. Hence, a typical measurement cycle consists of three individual measurements from circular left polarized laser photons, background and circular right polarized photons. This procedure takes typically about three seconds. The result of such a measurement can be seen in Fig. 2. Here it is clearly visible that the detector count rate with laser light (blue) is about three times larger compared to background radiation (gray). The amount of insufficiently operating channels of the microstrip detector is indicated and amounts approximately 10 %. Thus, as successor of the aging microstrip detector a Timepix3 detector is under development.

THE Timepix3 DETECTOR

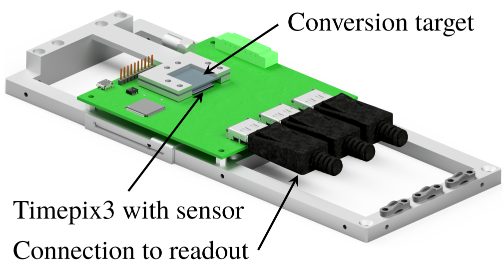

Figure 3: Image of the Timepix3 detector. The Timepix 3 with the 500 µm sensor is hidden under the target.

The Timepix3 detector uses a Timepix3 sensor assembly utilizing a 500 µm pn-silicon-sensor bump-bonded on top of the Timepix3 ASIC. As shown in Fig. 3 the sensor assembly is mounted on a readout board below an exchangeable conversion target. The readout board is further connected to an FPGA (scalable readout system (SRS)) via three DisplayPort cables, which has an ethernet connection to a readout PC.

The Timepix3 ASIC [6] is a pixelized readout ASIC. It has an active area of $14 \times 14\,\mathrm{mm}^2$ containing 256×256 pixels with a pitch of 55 µm. This pitch is similar to that of the microstrip detector, being sufficient for resolving the expected beam profile shift of ~ 70 µm at 100 % electron beam polarization. Each pixel can measure the time of arrival (ToA) and the charge (time over threshold (ToT)) simultaneously offering a time resolution of 1.56 ns. The ASIC can at maximum process 40 $\mathrm{MHits/cm}^2$ read out in a data driven mode such that in principle no dead time occurs. Thus, with the trigger time information from the laser delivery system a reconstruction when post-processing data is easily achievable. As side effect of the 2D-information given by the pixelized read out, not only the beam polarization can be measured, but also the transverse position of the beam.

The firmware and the readout software of the Timepix3 were both developed in-house [7–9], which allows for optimizations towards the use as detector for the Compton polarimeter. Here, especially a feed-in of the laser system's trigger signals into the FPGA needs to be realized to allow more precise mapping of the data to the laser beam polarization states. Also it is possible to combine the readout and analysis chain such that the detector system can process the data in an online mode. First tests of the analysis chain showed that the analysis of a single data chunk takes less than two seconds, such that online analysis of two measurement cycles (~ six seconds duration) seems feasible.

To further improve the performance of the detector, the conversion target is mounted as close as possible (~ 3 mm) to the sensor and built such that an easy exchange of targets is possible. Here different targets are foreseen to be tested: a 1.3 mm tungsten target, a 5.6 mm and a 11.2 mm lead target. According simulations are planned to optimize the results.

FIRST RESULTS

In a few data runs the detector was tested at the Compton polarimeter. Mounted as a temporary device in front of the microstrip detector it utilized a 11.2 mm lead conversion target mounted ~ 2 cm in front of the Timepix3. With this

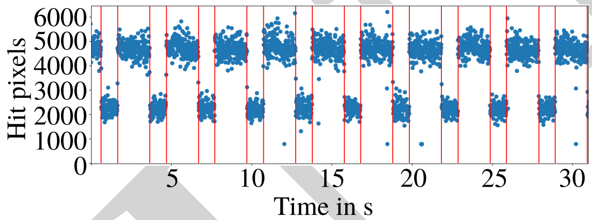

Figure 4: Number of registered pixel hits during a measurement in *storage mode*. The reconstructed time slices for analysis are indicated in red. The change in the hit rate with and without laser radiation is clearly visible.

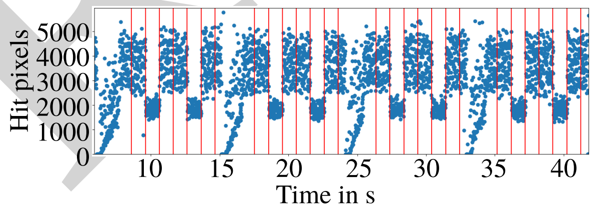

Figure 5: Number of registered pixel hits during a measurement in *booster mode*. The change in the hit rate with and without laser radiation is clearly visible, as well as the injection phase.

setup multiple measurements at different beam energies have been performed. For first measurements the *storage mode* of the accelerator was used. Here the laser constantly repeats the measurement cycle as described before while the stored electron beam is approximately constant. For the analysis a single timestamp was aligned by hand and the further timing is given by the measurement cycle. This is shown in Fig. 4. First results showed that electron beam polarization can be observed with this setup [3]. For another data run the accelerator was operated in *booster mode*, where electrons are injected, accumulated, post-accelerated and slowly extracted into external beamlines for several seconds, before the beam is dumped and a new cycle starts. Thus, typically two measurement cycles (~ 3 s) each can be performed within one cycle of the accelerator. Since the injection timing of the accelerator is varying, timestamps from the laser system had to be used for data timing reconstruction, as shown in Fig. 5. For example, a measurement at 1.6 GeV beam en-

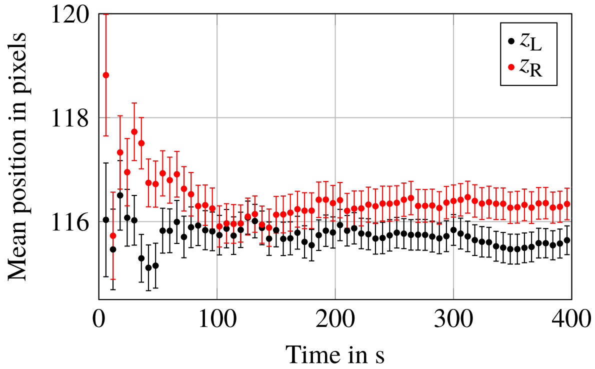

Figure 6: Development of the vertical mean position by accumulating data of multiple measurement cycles for a data set taken with polarized electrons at 1.6 GeV in *booster mode*. A clear shift between left and right circular photon polarization is visible.

ergy with polarized beam was analyzed by fitting a *Pearson VII*-function to the measured profile (compare with [4]. As shown in Fig. 6 a clear separation between z_L and z_R is observed after ~ 200 s of accumulated measurement time. The errors of the measurement are dominated by the fit quality rather than by statistics and thus, after approximately one minute the measurement errors cease to decrease.

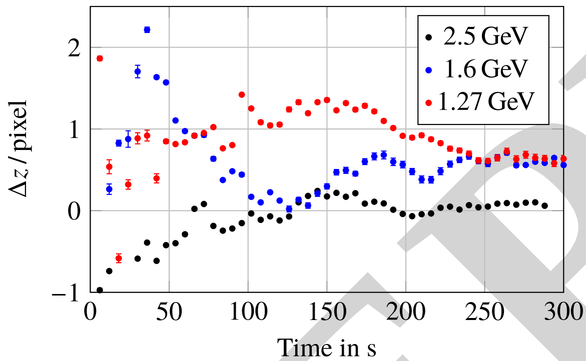

Figure 7: Difference between the means for 1.27 GeV (*storage mode*) and 1.6 GeV (*booster mode*) were taken with a polarized electron beam, while the measurement at 2.5 GeV (*storage mode*) used a non-polarized beam.

A comparison of data taken in *storage* and *booster mode* is shown in Fig. 7. The results of up to 1.6 GeV beam energy are consistent after ~ 3 min measurement time. For these energies no significant polarization loss is expected to occur during the corresponding energy ramp. In contrast, no remaining beam polarization is expected beyond ~ 2.5 GeV, as no polarization preserving countermeasures were applied during the energy ramp in this test. Thus, a null measurement with electrons at 2.5 GeV shows the expected result.

As previous results demonstrate good functionality of the current polarimeter setup, further investigations will include polarimeter calibration trials via self-polarization (Sokolov-Ternov effect) with more optimal placement of the converter target.

CONCLUSION

A new Timepix3 based detector for the Compton backscattering polarimeter was introduced and a feasibility study was performed. We could show that the detector system is capable to determine the stored beam's polarization degree in a reasonable time allowing for quasi-life monitoring. First tests at different beam energies showed the expected behavior. Also, it could be shown that the trigger timing information from the laser system can be used in the analysis chain of the detector, allowing its usage in the *booster mode* in addition to the previously demonstrated usage in *storage mode* of the accelerator. As a next step different conversion target thicknesses and materials will be analyzed to find the optimum working point of the detector.

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