A NEW COUNTING SILICON STRIP DETECTOR SYSTEM FOR PRECISE COMPTON POLARIMETRY*

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Abstract

A Compton polarimeter is currently being installed at the Electron Stretcher Facility ELSA to monitor the degree of polarization of the stored electron beam. For this purpose, circularly polarized light that is emitted by a laser and backscattered off the beam has to be detected. Above all, as a result of ELSA's beam energies, it is necessary to measure the shift of the center of the photon spatial distribution which is obtained when the polarization of the laser is switched from left-hand to right-hand circular polarization with an accuracy of a few microns. In order to meet the required specifications, a new counting silicon strip detector system has been developed in cooperation with the SiLab/ATLAS group of the Physics Institute of the University of Bonn. In this contribution, the design of the system will be presented and first results will be shown.

MOTIVATION

The fast ramping electron stretcher ring ELSA is able to supply a spin polarized electron beam of up to 3.5 GeV to hadron physics experiments. The degree of polarization is monitored directly after the 50 keV electron source via a Mott polarimeter as well as at the external beamline by a Møller polarimeter. During the acceleration process, depolarizing resonances lead to a polarization loss. In order to minimize this loss, correction measures which require information on the polarization of the stored electron beam have to be undertaken. Since both monitoring methods currently in use require scattering targets, neither of them is appropriate for a parasitic measurement of polarization during operation. Compton polarimetry, by contrast, offers a possibility to determine polarization with negligible electron loss and without other significant negative inpact on the beam. In addition, Compton polarimetry will allow the study of self polarization of the beam. The positions of the existing polarimeters as well as the future position of the proposed Compton polarimeter are shown in Fig. 1.

COMPTON POLARIMETRY AT ELSA

The frontal collision of circularly polarized light of polarization degree P_γ with—as is the case in ELSA—transversely polarized electrons of polarization degree P_e leads to an asymmetric intensity profile of the backscattered photons. When reversing light polarization from left-handed to right-handed, one obtains a vertical displacement of the center of gravity of this profile by a distance D which, in turn, is a measure for electron and photon polarization as given by

$$D = D_{100\%} \cdot P_\mathrm{e} P_\gamma, \tag{1}$$

where $D_{100\%}$ is the displacement for fully polarized photon and electron beams. Since the resolution of detectors is limited, maximizing $D_{100\%}$ is a main concern. The asymmetry in the intensity profile of the backscattered photons increases with distance of the detector from the primary point of interaction. Furthermore, for the detection of Compton backscattering in ELSA, background radiation originating from collisions of electrons on rest gas atoms has to be taken into account. This radiation exhibits energy levels comparable to the energy of the photons to be detected. Therefore, for a high signal to noise ratio, a high laser power is of critical importance. Also, large photon energies lead to larger displacements and a small beam interaction area is favorable. Hence, for Compton polarimetry at ELSA, for low beam divergence and large displacements, the TEM_{00} Mode of a high power 40 W disc laser, emitting light at a wavelength of 515 nm ($E_\gamma = 2.4\,\mathrm{eV}$) is used. Circular polarization is obtained by means of a Pockels cell. The laser beam will collide almost frontally with the electron beam, forming a small angle of $\alpha = 3\,\mathrm{mrad}$ in order to protect the optics from synchrotron radiation. The intensity profile of the backscattered photons is measured at the maximum realizable distance of 15 m from the primary point of interaction, which is set up at a position with a low beam divergence in the vertical plane. Ac-

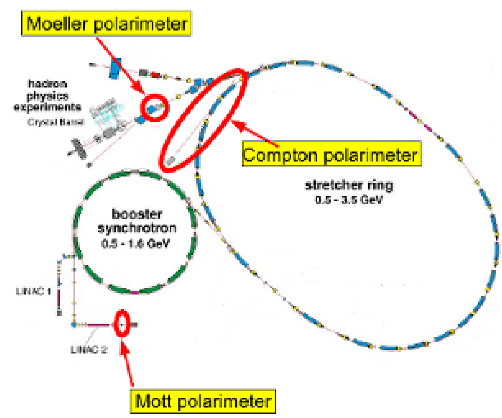

Figure 1: Electron stretcher facility ELSA with the positions of the Mott and Møller polarimeter as well as the proposed Compton polarimeter.

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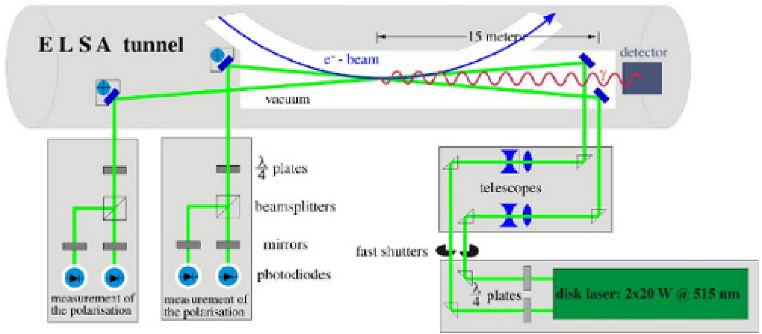

Figure 2: Set-up of the Compton polarimeter.

cording to Eq. 1 it is also necessary to measure P_γ. This is done as illustrated in Fig. 2 where the complete set-up of the Compton polarimeter is outlined. Fig. 3 visualizes the Compton scattering process with the chosen parameters. For detection purposes, the highly energetic photons ($E_{\gamma,\mathrm{f}}$ =5–300 MeV) of the Compton backscattered light are converted into electron-positron pairs by means of a lead block having a width of two decay lengths.

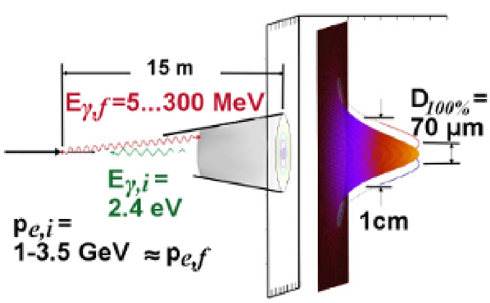

Figure 3: Compton scattering process.

Simulation of the Compton Process

Extensive numerical simulations have been carried out, using the software packet *COMPTONSIM* to study the Compton process in more detail. The software divides the detector area into small area sections and the rate of detected photons is extracted from a fivefold integration of the Compton scattering probability over the whole phase space of the electron beam and the length of the interaction area [2]. These simulations provide quantitative results for the distribution of the backscattered photons in dependence of the parameters selected.

One attains a value of $D_{100\%} \approx 70\ \mu\mathrm{m}$, depending on the beam energy.

For a reasonable accuracy, it will be necessary to record the intensity profile for at least a few minutes. Fig. 4 depicts the dependence of the expected measuring time on beam energy for a measurement error of 2 %.

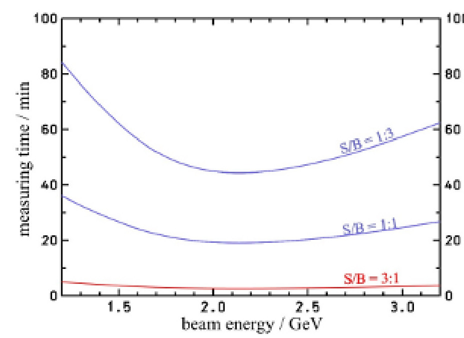

Figure 4: Expected measuring time for an error of 2 %.

DETECTOR SYSTEM

An overview of the whole detector system showing the schematic signal path is given in Fig. 5.

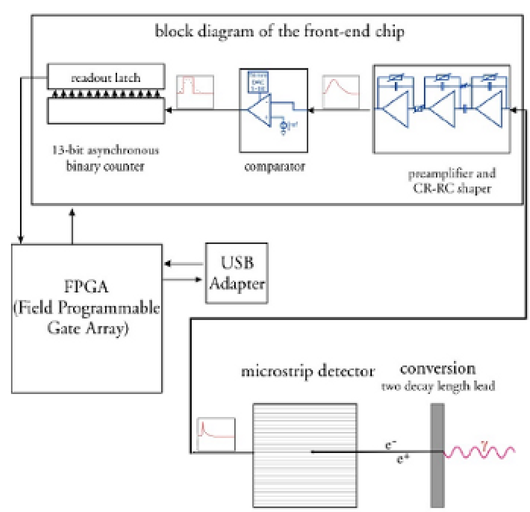

Figure 5: Schematic signal path for the detector system.

A double sided, AC coupled silicon microstrip detector (BABAR 1) with 768 horizontally oriented strips and a 50 μm pitch is used for the experimental setup. It has a total detection area of 41.3 mm × 40 mm. Its coupling capacity amounts to $C_{\text{coupling}} = 200$ pF, its resistance is given by $R_{\text{bias}} = 5$ MΩ. From its thickness of 300 μm one can derive an amount of 24000 electrons that will be generated by a minimum ionizing particle [1]. A voltage of at least 20 V is needed for full depletion.

For detector readout, 6 chips being able to handle 128 channels each are used. For every channel, the incoming signals pass a charge sensitive amplifier, a differential shaper and an integrator. The shaping time of the chips is adjustable, with possible values ranging from 100–800 ns. Tests showed that lowest noise and best linearity are reached with shaping times of 100 ns. The signal is transmitted to a comparator unit where it is compared to an adjustable global reference voltage for all channels. Charge injection for threshold calibration is possible due to circuit design. In further tests, it was shown that setting the threshold at 3000 electrons would be possible. Below this value, undesirable effects would emerge. Threshold dispersion on each chip can be further controlled by a 5-bit TrimmDac for each channel, allowing for optimization. Fig. 6 shows the optimized threshold dispersion of all 768 channels of the detector for an amount of 12000 generated electrons. The different offsets of each chip are a result of process variation.

For every channel, the output signal of the comparator is directed towards the counting unit and saved into a separate 13-bit asynchronous binary counter. The content of these counters is copied into readout latches. All setting changes on the front-end chip are performed by an internal controller on the chip. Further, in addition to allowing a separate readout for each counter, this controller implements some special measurement modes for a fast readout of the system.

A small design flaw in the supply of the counting chips' amplifiers led to an increased noise level. Therefore, also an improved second version of of the chip was designed. Nevertheless, the first version of the chip is working and was extensively tested with results presented in this paper.

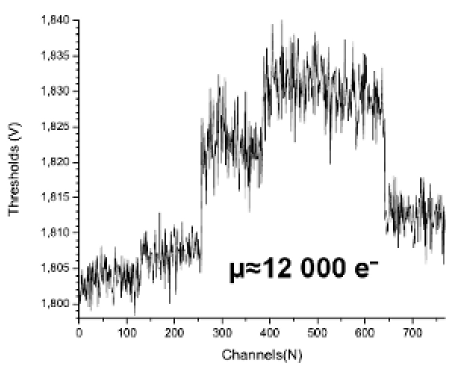

Figure 6: Threshold dispersion of the readout chips.

For the digital parts of the detector system, Low Voltage Differential Signaling Technology (LVDSI) was employed. The data from the readout latches is prepared by FPGA controlled front-end chips enabling USB access.

The detector board consists of three parts: a board hosting a USB-2.0 chip, a hybrid board containing the detector and counting chips and the main board which accommodates among others the FPGA, the voltage supply and the reference voltage controllers.

The detector board prototype used for testing had to be revised due to heat problems during operation (temperatures above 70° C). A new detector board with suitable heat sinks and a better protection against crosstalk was manufactured and tested in combination with the counting chip.

Fig. 7 shows the noise performance of the counting chip in combination with the new detector board in comparison to the chip on the former prototype. Obviously, the matching of channels was improved significantly.

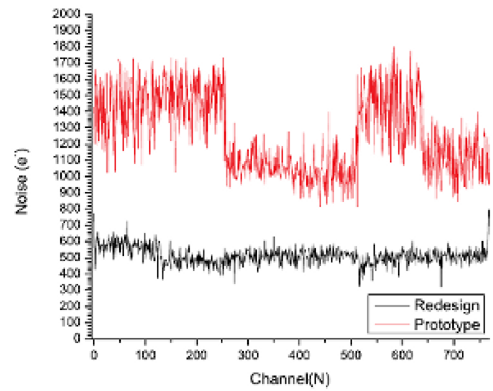

Figure 7: Comparison of noise levels of the counting chip in combination with the new/prototype detector board.

The functioning of the detector design was ensured by carrying out a measurement with an Americium-241 source in a first test. The results were in good agreement with theoretical expectations.

CONCLUSION

By now, the laser with the subsequent optics has been set up at the intended place. The redesign of the Compton detector system has proven to be a success. At least, first results are encouraging. It was shown that rates detected by the system in first tests corresponded well to those theoretically expected. Now, an integration of the new detector in the experimental setup is required. With the hardware installed, we are confident to be able to determine electron polarization with a reasonably high accuracy and short measurement times, as given by simulations. However, we still encounter problems with the used laser and the improved detector chip design in combination with the new board has yet to be tested.

REFERENCES

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[2] W. Hillert et al.: Compton Polarimetry at ELSA, AIP Conf. Proc. 1149, 809 (2009)