

# COMPTON POLARIMETRY AT ELSA - BEAMLINE AND DETECTOR OPTIMIZATION\*

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## Abstract

The Electron Stretcher Facility ELSA provides a polarized electron beam with energies of 0.5 - 3.2 GeV for double polarization hadron physics experiments. Monitoring the vertical electron polarization by Compton polarimetry in the stretcher ring has several advantages over the established polarization measurement by Møller polarimetry. The Compton polarimeter setup presented consists of a 40 W cw disk laser featuring two polarized green photon beams colliding head-on with the stored electron beam in ELSA. A silicon strip detector measures the vertical intensity profile of the backscattered photons. The reversal of handedness of the laser beam's circular polarization results in a polarization dependent vertical shift of this profile. From a calibration using the Sokolov-Ternov effect, the polarization degree of the electron beam can be extracted. After recent laser repairs as well as beamline and detector modifications, first measurement attempts of the electron's polarization degree could be conducted. The performance of the beamline and first measurements are presented.

## INTRODUCTION

ELSA is a three-staged accelerator facility consisting of linac, booster synchrotron and storage ring. The electron polarization degree  $P_e$  is measured directly behind the polarized electron source through beam-destructive Mott-polarimetry and amounts  $P_e \approx 80\%$ . Due to depolarizing effects during the acceleration process in booster and stretcher ring, a decreased final polarization degree of only  $P_e \approx 65\%$  is measured at the storage ring's extraction beamlines via Møller scattering. The extraction process and current design of the Møller polarimeter limits the energy range for which polarization measurements are available. In particular, the initial polarization degree of the electron beam right after the injection into the stretcher ring at 1.2 GeV is unknown. However, it is required for the simulation of the spin dynamics. Therefore, a Compton polarimeter is currently being installed in the stretcher ring. Past attempts to measure  $P_e$  via Compton scattering have provided unsatisfactory results due to insufficient statistical laser power and detector noise [1]. Therefore, a revised Compton polarimeter beamline was designed [2], including a more powerful laser and a silicon strip detector for the measurement of the backscattered  $\gamma$ -photons.

## POLARIZATION MEASUREMENT TECHNIQUE

For Compton polarimetry at ELSA, two circularly polarized (polarization degree  $P_\gamma$ ) green (515 nm) light beams provided by a cw laser are brought to head-on collision with the transversely polarized electron beam. If the intensity profile of backscattered photons is detected, calculations show that the position of the vertical center of this profile is a function of  $P_\gamma$  and  $P_e$ . When reversing the handedness of the laser light's circular polarization, this center is displaced by

$$\Delta y = \Delta y_{\max} \cdot P_\gamma P_e. \tag{1}$$

$\Delta y_{\max}$ , the maximum analyzing power, is achieved for polarization degrees of 100% and is obtained by a calibration using the Sokolov-Ternov effect. By measuring  $P_\gamma$  and  $\Delta y$ ,  $P_e$  can be determined. In order to minimize the measurement error for  $P_e$ , maximum laser power for a maximum amount of scattering events is desirable.

The profile of backscattered photons is overlapped by beam gas radiation with similar photon energy. This background has to be evaluated and then subtracted in a separate measurement with blocked laser beams. Signal as well as background are proportional to the electron current.

Figure 1 illustrates a typical ELSA-cycle. After injection of 1.2 GeV electrons, the energy ramping process is started. Here, integer spin tune resonances occur every  $\Delta E \approx 440$  MeV, when the product of the Lorentz factor and the anomalous spin factor of the electron  $\gamma a$  becomes an integer. In addition, depolarizing intrinsic resonances due to  $\beta$ -motion occur. At constant energy, the beam is slowly extracted via excitation of third-integer resonances. Except for a stabilization phase, extraction occurs at an almost constant rate until the internal current falls below a threshold. Then, the beam is dumped and a new cycle initiated.

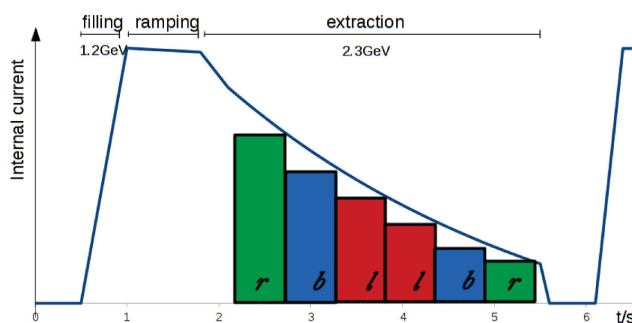


Figure 1: Beam current in the stretcher ring during a typical ELSA-Cycle. The time slots correspond to background measurements (b), backscattered circularly right (r) and left (l) polarized photons.

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The phase of constant extraction rate is adjustable between  $T=1-60$  s (typically  $\approx 6$  s) and defines the timeslot during which Compton polarimetry at ELSA is possible. A measurement scheme is shown in Fig. 1. The scheme starts i.e. with the detection of circularly right polarized backscattered photons (**r**, shown in green) for a time of  $T_{\text{slot}}$ . Then the laser beams are blocked by fast optical shutters. During the shutting time of 15 ms, the intensity recording is suspended. It follows a background measurement (**b**, blue) of length  $T_{\text{slot}}$  which occurs during the rotation of quarter-wave plates in the laser beamline. This takes about 800 ms and thereby limits the shortest possible length of  $T_{\text{slot}}$  (and therefore  $T$ ). After reopening the shutters, a measurement with circularly left polarized photons (**l**, red) in the successive timeslot  $T_{\text{slot}}$  is pursued.

With these three measurements only, the background measurement **b** underestimates the true **r**-background, while the **l**-background is overestimated. Therefore, three additional measurements are performed in reverse order, resulting in the shown sequence “**r**, **b**, **l**, **l**, **b**, **r**”. The sequence starting with reversed polarization: “**l**, **b**, **r**, **r**, **b**, **l**” would fulfill the same purpose. Since determining  $P_e$  with useful accuracy requires data sets from many ELSA-cycles, for each one the measurement sequence can be randomly altered between these two options. The sufficiently long time between two ELSA-cycles allows for the potentially needed rotation of the quarter-wave plates. This minimizes measurement errors caused by deviations from constant extraction rates.

For the calibration measurement, where the self polarization of a stored, initially unpolarized electron beam is observed over long timescales ( $\approx 1$  h for ELSA’s energy region),  $T_{\text{slot}}$  is set to 1 s. There is no need for a randomly alternating measurement scheme that would require additional time for rotating of the quarter-wave plates between each “**r**, **b**, **l**, **l**, **b**, **r**”-sequence.

## LASER BEAMLINE

A Yb:YAG disk laser<sup>1</sup> with folded resonator provides two linearly polarized cw photon beams at 515 nm. In-house developed pneumatically driven quarter-wave plates provide left- or right-handed circular polarization. A concave and convex lens pair ( $f_1 = -400$ ,  $f_2 = 1300$ ) refocuses the photon beam into the electron-photon interaction region within a horizontally defocusing quadrupole. Mounted on a motorized stage, the focal plane can be adjusted during beam operation in order to maximize the scattering rate. The measured beam width at the waist is  $\omega_r = (0.57 \pm 0.02)$  mm, being in the order of the electron beam size. A pair of motorized mirrors is installed in each photon beamline which allows to adjust the photon beam angles and displacements. Due to geometric limitations, the photon beamline includes more mirrors than shown in Fig. 2. As  $p$  and  $s$ -planes have different mirror reflection coefficients, mirrors are installed always in pairs to preserve the initial circular polarization.

<sup>1</sup> ELS MonoDisk Gemini 20

To measure the degree of photon polarization that is needed according to Eq. 1, the laser beam is coupled out of the vacuum and deflected into an analyzer box: A quarter-wave plate relinearizes the polarisation and a polarizing beam splitter (PBS) reflects or transmits the beam, depending on its transverse polarization. Position sensitive quadrant diodes (PSD) measure beam position and intensity behind the deflecting mirrors in each branch. In addition, CCD cameras capture both transverse laser beam images and provide additional position and beam size information.

## Initial Tests

Initial test runs have shown that laser, beamline optics and diagnostics were performing below specifications. Some issues, however, could be eliminated:

- Previous laser beam deflection was performed using polarization preserving deflection prisms based on total internal reflection. Thermal lensing effects of the prisms, with time constants in the order of  $T_{\text{slot}}$ , altered beam shape and the focal plane’s position. This effect was visible when the fast shutters were opening and the beam penetrated the optics. Replacement of the prisms in favor of mirrors enabled stable conditions. So far beamline 1 has been upgraded.
- The PSD signals were originally digitized outside the shielding tunnel, requiring long cable connections that resulted in noise gain. A new PSD design with AD conversion directly installed on the circuit board increased the SNR by a factor of 20.
- The laser’s beam quality and power indicates a slightly detuned resonator and outlet optics. Typical measured beam power is 12 W for each beam. In beamline 2, an additional set of optics was used to correct for a large beam divergence.

## THE DETECTOR SYSTEM

An appropriate detector system for Compton polarimetry at ELSA needs to be sensitive to photon energies in the range of 5-300 MeV, corresponding to the expected energy range of the Compton-backscattered photons. Therefore, a silicon microstrip detector in combination with a lead conversion target of two radiation lengths was chosen.

Numerical simulations of the Compton-Process with the particle tracking toolkit Geant4 were carried out, taking into account the Gaussian nature of the laser beam, ELSA’s beam parameters as well as the dimensions, important electrical characteristics and materials involved in the buildup of the detector system. The Si-sensor is AC-coupled and has a thickness of 300  $\mu\text{m}$ . It covers a surface of approx. 4 cm x 4 cm with 768 horizontally orientated strips of 50  $\mu\text{m}$  pitch. With an expected width of the intensity profile of backscattered photons of about 1 cm and  $\Delta y_{\text{max}} \approx 70$   $\mu\text{m}$ , this should allow for a polarization measurement with an error of less than 1%.

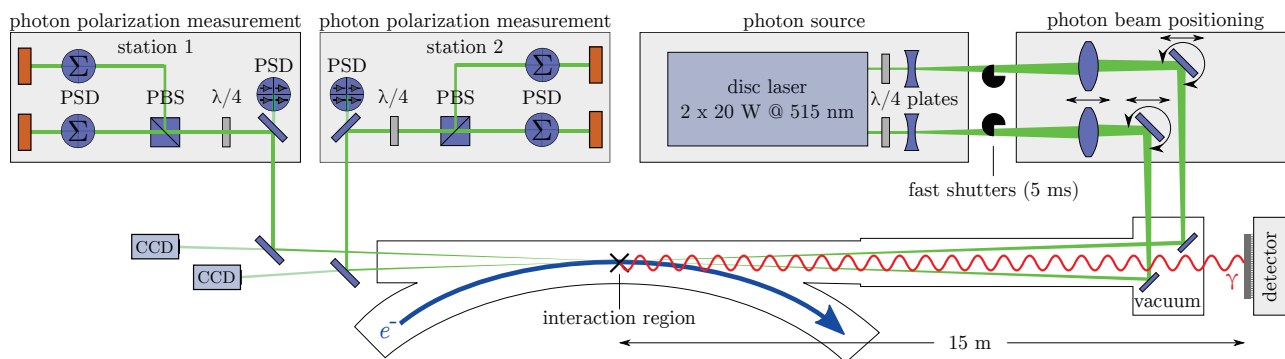


Figure 2: Layout of the laser beamline. In order to maximize the photon density in the interaction region, the beam is broadened and refocused. A laser beam polarization measurement station includes CCD and PSD diagnostics.

The detector readout electronics is FPGA based and allows the processing of the expected photon rate which approximately amounts 1 MHz. For this purpose, dedicated ASIC chips were developed in close cooperation with the SiLab/ATLAS group of the university of Bonn. One ASIC controls 128 of the 768 Si strips. The response of the channels was first tested by the injection of defined test charges through the discharging of capacitors integrated in the ASICs and connected to one Si-strip each. The charge threshold for which a hit is counted was set to 3500 electrons (with a minimum ionizing particle producing about 23000 electrons in 300 μm Si). This results in a noise rate of less than 1 count/min.

Since a calibration through the built-in ASIC capacitors didn't result in satisfying intensity profile measurements of the backscattered photons, an additional channel-to-channel calibration was performed. For this purpose, the Si-sensor was irradiated by a broad electron source with an energy of about 300 MeV and almost constant intensity over all 768 channels. At ELSA, such an electron beam is available near the bremsstrahlung target at the experimental stations.

Different measurement programs were implemented in the FPGA's firmware to allow self polarization measurements and polarization measurements on a beam originating from the polarized electron source. The cycle time  $T$  is sent to the detector by ELSA's control system through an ethernet/USB connection. The "extraction start" and "electron helicity" information is provided by ELSA's timing system through TTL signals. A manual and a user-adjustable continuous readout program for general purpose measurements is also implemented in the FPGA.

The detector system provides two TTL outputs. One initiates the rotation of the quarter-wave plates at a manually set or measurement scheme given point in time. The other one likewise drives the opening/closing of the fast shutters.

### First Measurement of Backscattered Photons

Figure 3 shows the integral intensity profile of the background radiation taken during 160 measurement sequences (yellow) and the intensity profile of Compton-backscattered photons superimposed by background radiation (green). The

signal to background ratio is yet to be maximized by variation of laser beam angle and position. As gaps within the profile indicate, about 3% of all channels are dysfunctional. Care must be taken to center the profile in a way that allows an interpolation over broken channels with marginal distortion of the profile.

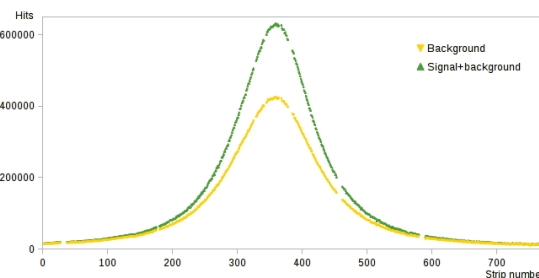


Figure 3: Detector intensity profile showing background only (yellow) and superposition with backscattered photons (green).

## CONCLUSION

The ELSA Compton polarimeter, consisting of laser beamline and  $\gamma$ -detector, are installed and operational. Profiles of Compton-backscattered photons were successfully measured. As thermal lensing effects have yet prevented the precise polarization measurement, the disruptive optical elements were identified and exchanged. The laser beam positioning equipment has been improved and will help to obtain a better signal-to-background ratio. Sufficiently accurate polarization measurements are expected to be conducted within the upcoming accelerator run.

## REFERENCES

- [1] D. Doll *et al.*, "A counting silicon microstrip detector for precision compton polarimetry", *Nucl. Instr. Meth.*, vol. 492, pp. 356–364, 2002.
- [2] W. Hillert *et al.*, "Compton Polarimetry at ELSA", *AIP Conf. Proc.*, Charlottesville, Virginia, Oct. 2008, vol. 1149, pp. 1160–1164, 2009.