THE CALIBRATION OF THE PEPPo POLARIMETER FOR ELECTRONS AND POSITRONS

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on behalf of the PEPPo Collaboration

Abstract

The PEPPo (Polarized Electrons for Polarized Positrons) experiment at Jefferson Laboratory (JLab) investigated the longitudinal polarization transfer from electrons to positrons, with the aim of developing this technology for a low energy (∼MeV) polarized positron source. Polarization of the positrons was measured by means of a Compton transmission polarimeter where incoming positrons transfer their polarization into circularly polarized photons subsequently analyzed by a thick polarized iron target. The measurement of the transmitted photon flux with respect to the orientation of the target polarization (±) or the helicity (±) of the incoming leptons provided the measurement of their polarization. Similar measurements with a known electron beam were also performed for calibration purposes. The calibration of the apparatus was performed at the JLab injector to measure positron polarization in the momentum range 3.2-6.2 MeV/c, specifically to quantify the positron analyzing power from electron experimental data measured over a comparable momentum range.

INTRODUCTION

Polarized and unpolarized positrons are powerful probes for the investigation of numerous physics phenomena. At thermal energies (≤100 keV), positrons are used to measure defects in the electronic density of materials via positron annihilation spectroscopy applied in various domains ranging from condensed matter [1] to life science [2]. In the multi-GeV energy range relevant to the JLab physics program, the comparison between polarized electron and positron scatterings allows to investigate accurately the nuclear matter structure by isolating specific components of the reaction process, otherwise hardly measurable in a model-independent way [3]. At the very high energies involved in the International Linear Collider project, polarized positrons are essential for the completion of the physics program.

In this context covering a wide energy range, the PEPPo experiment [4] was installed at the JLab injector to demonstrate the reliability of a new technique for the production of polarized positrons. It involves a two step process: longitudinally polarized electrons create circularly polarized photons via bremsstrahlung interaction inside a W target (T_1); then, within the same target, polarized photons create polarized e^+e^- pairs via the pair creation process. While each single step of this sequence has already been experimentally demonstrated, the main concern of PEPPo is to evaluate whether the bremsstrahlung generation of circularly polarized photons is efficient enough to produce polarized positron beams at low energies.

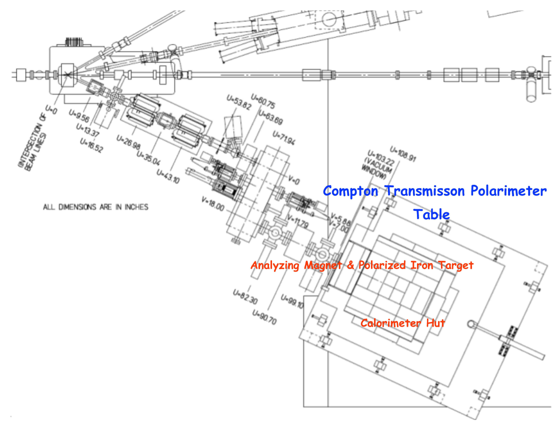

Figure 1: The PEPPo line arrangement terminated by the Compton transmission polarimeter.

The PEPPo experimental setup (Fig. 1) constitutes of a new dedicated beam line where incoming polarized electrons are transported to a target (0.1-1.0 mm W) to produce polarized e^+e^- pairs. The generated positron flux is collected with a short focal length solenoid and selected in momentum with a $D\overline{D}$ spectrometer. At the exit of the spectrometer, a second solenoid focusses positrons onto a Compton transmission polarimeter where positron polarization is measured. Part of this setup was sucessfully used in the SLAC E-166 experiment [5] which demonstrated the production of polarized positrons from a high energy electron beam traveling inside a helical undulator [6]. The operation and calibration of the PEPPo polarimeter is further discussed in this work. A detailed description of the PEPPo experiment can be found in [7].

COMPTON TRANSMISSION POLARIMETRY

The PEPPo polarimeter takes advantage of the sensitivity of the Compton process to the polarization of incoming photons. The differential cross section for the Compton scattering of circularly polarized photons (P_3^γ) off a longitudinally polarized electron target (P_T) writes [8]

$$\frac{d^2\sigma}{d\theta d\phi} = \frac{d^2\sigma^0}{d\theta d\phi} \left[1 + P_3^\gamma P_T A_3(\theta)\right] \quad (1)$$

where σ^0 is the unpolarized Compton cross section

$$\frac{d^2\sigma^0}{d\theta d\phi} = \frac{1}{2}(r_0\,\epsilon)^2 \left[\frac{1}{\epsilon} + \epsilon - \sin^2(\theta)\right] \sin(\theta) \quad (2)$$

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$$A_3(\theta) \quad = \quad \left[\frac{1}{\epsilon} - \epsilon\right]\cos(\theta) \Big/ \left[\frac{1}{\epsilon} + \epsilon - \sin^2(\theta)\right] \quad (3)$$

and $A_3(\theta)$ is the analyzing power of the Compton scattering representing the sensitivity of the process to the photon circular polarization. $\epsilon = \omega/\omega_0$ is the scattered photon energy in unit of the initial photon energy, θ is the electron scattering angle, and r_0 is the classical electron radius. Considering a monochromatic circular photon beam scattering off a polarized electron target with length L, the transmission efficiency characterizing the probability that a photon exits the target writes

$$\varepsilon_T = \exp\left[-\mu_1 P_3^{\gamma} P_T L\right] \quad (4)$$

assuming the loss of any photon interacting in the target and the dominance of the Compton process; μ_1 is the polarized Compton absorption coefficient defined as

$$\mu_1 = \rho_e \int d\theta d\phi \, \frac{d^2\sigma^0}{d\theta d\phi} A_3(\theta) \quad (5)$$

with ρ_e the electron density of the target. The measurement of the circular polarization of the photon beam is obtained from the number of transmitted photons ($N_{\gamma}^{\pm}$) for opposite polarized target or photon polarization orientations

$$A_T = \frac{N_{\gamma}^{+} - N_{\gamma}^{-}}{N_{\gamma}^{+} + N_{\gamma}^{-}} = \tanh\left(-P_3^{\gamma} P_T \mu_1 L\right) \quad (6)$$

from which the photon circular polarization is obtained.

The photon beam of the PEPPo experiment constitutes of the bremsstrahlung spectrum of longitudinally polarized positrons/electrons having small energy and angular distributions and generated from the interaction ot the polarized beam inside a 2 mm W reconversion target at the entrance of the polarized target. Additionally, the generated photons can also interact via photoelectric and pair creation processes, contributing to the transmission efficiency. The combination ot these effects can be represented by an effective analyzing power $A_{e^{\pm}}$ leading to the expression

$$A_T = P_{e^{\pm}} P_T A_{e^{\pm}} \quad (7)$$

from which the polarization of the incoming beam is extracted. The analyzing target constitutes of a 7.5 cm long and 5 cm diameter iron target polarized by a magnetic field close to saturation. The knowledge of the field magnitude provides the target polarization P_T [9]. The analyzing power of the polarimeter can be experimentally measured with a known polarized beam or simulated with GEANT4 [10] taking advantage of polarized electromagnetic interactions upgrade [11]. PEPPo polarimetry is using these two methods to measure positrons polarization.

DATA TAKING

The PEPPo experiment ran at the JLab injector [12] delivering highly spin polarized electrons (85%) up to 8.25 MeV/c. A dedicated spectrometer line is used to identify the beam momentum ($\sim$2%) and a Mott polarimeter measures the beam polarization ($\sim$2%). This precise knowledge of the electron beam allows to investigate the response of the Compton transmission polarimeter and to calibrate its electron analyzing power. The photons passing through the polarized iron target are detected in a 3$\times$3 CsI crystals array read by photomultipliers (PMT). The energy deposit in each crystal is the PEPPo experimental information registered according to three different methods based on the same FADC250 module: energy integrated, semi-integrated, and sample. The FADC250 module samples the PMT signals at 250 MHz and delivers the time evolution of the signals integrated over 4 ns. The energy integrated method is specific of the high rate conditions of electron calibration measurements: the 4 ns samples are integrated over the time duration corresponding to an established beam helicity status yielding a single energy deposit value per helicity gate. The semi-integrated method for positron measurements relies on the detector trigger which was made from the coincidence between a 1 mm scintillator, upstream of the reconversion target, and the central crystal. For each trigger the FADC250 information is integrated over a 2 μs time window corresponding to the signal duration: the event information corresponds to the energy deposit of a single photon and is tagged by the beam helicity status. The sample method obeys the same trigger and corresponds to the read-out of each 4 ns samples of the 2 μs time window. It was used only for data monitoring. Additionally, the PMT signals are also connected to scalers incremented every time the signal passes a fixed threshold. Two scalers are implemented: one gated by the beam helicity signal, and another gated by the detector trigger.

G4PEPPO

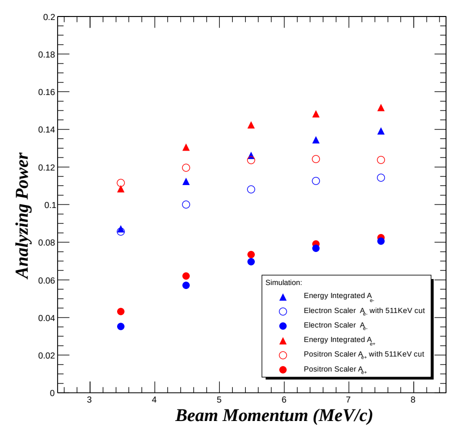

Figure 2: Simulated analyzing power of the central crystal for different read-out electronics methods assuming an incoming pencil beam.

A precise modeling of the PEPPo experiment has been developed within the GEANT4 framework, starting from E-166 Collaboration earlier work [5]. It involves in an independent way the different sections of the PEPPo line: electron beam transport and positron production; positron collection, selection, and transport to the end of the vacuum line; positron propagation to the reconversion target, interactions within the analyzing magnet, and CsI detector response. The simulated energy deposit into each crystal is processed according to the data read-out electronics method. Simulations allow to link the different methods characterized by different analyzing powers (Fig. 2) and to calibrate any read-out method against experimental data.

ANALYZING POWER CALIBRATION

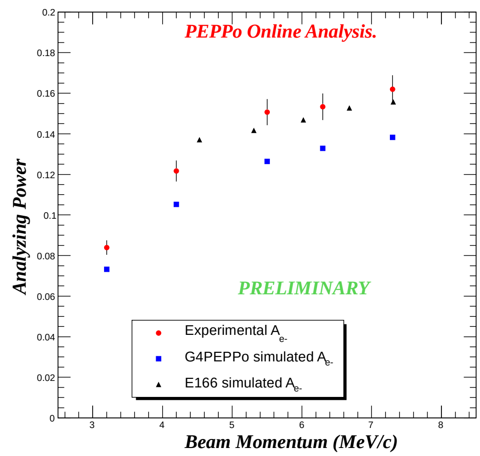

Figure 3: Experimental electron analyzing power of the central crystal obtained from on-line PEPPo data analysis and compared to E-166 and G4PEPPo simulated analyzing power.

The methodology of the analyzing power calibration of the PEPPo polarimeter relies on electron experimental data. The comparison between experimental and simulated Compton asymmetries allows to benchmark the GEANT4 physics packages describing polarized electromagnetic processes and resolves related systematic uncertainties. This procedure requires a precise knowledge of the beam optics which is achieved through separate G4BEAMLINE simulations constrained by the measured field maps of each magnetic elements of the PEPPo line. This sensivity expresses in the difference between E166 and G4PEPPo simulations performed here for a pencil beam (Fig. 3). The agreement between preliminary PEPPo data and E166 simulations is indicative of the final potential quality of G4PEPPo simulations.

The positron analyzing power is obtained directly from calibrated simulations. The main difference between electrons and positrons is the annihilation reaction which is a driving process for positrons while appears at second order in the electron case, from the positrons produced within the electromagnetic cascade. In this way, electron calibration data also calibrate the positron analyzing power of the polarimeter. Positron data are acquired following the semi-integrated method (Fig. 4), allowing to deconvolute the energy dependence of the analyzing power from the data, leading to a higher figure-of-merit.

CONCLUSION

The PEPPo experiment at JLab did measure the longitudinal polarization transfer from electrons to positrons using a Compton transmission polarimeter in the range 3.2-6.2 MeV/c. The accurate knowledge of the electron beam allowed to calibrate the electron analyzing power of the polarimeter against experimental data. This calibration is

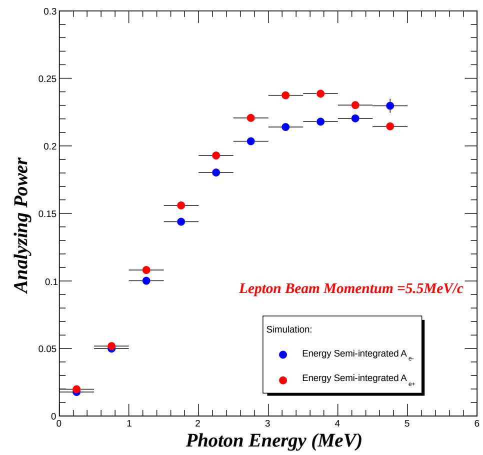

Figure 4: Simulated semi-integrated analyzing power for 5.5 MeV/c incident leptons.

transported to positrons via GEANT4 simulation of the apparatus and of the optics of the PEPPo line. This procedure is expected to resolve systematic uncertainties about physics processes within the GEANT4 framework

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