PEPPO: USING A POLARIZED ELECTRON BEAM TO PRODUCE POLARIZED POSITRONS

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on behalf of the PEPPo Collaboration

Abstract

An experiment demonstrating a new method for producing polarized positrons has been performed at the CEBAF accelerator at Jefferson Laboratory (JLAB). The PEPPo (Polarized Electrons for Polarized Positrons) concept relies on the production of polarized e-/e+ pairs originating from the bremsstrahlung radiation of a longitudinally polarized electron beam interacting within a high Z conversion target. This submission describes production of polarized positrons in the range of 3.1 to 6.2 MeV/c using an 8.2 MeV/c polarized electron beam.

INTRODUCTION

Polarized positrons are a powerful probe for the investigation of numerous physics phenomena. At thermal energies polarized positrons may be used to study spintronic properties of materials [1]. Accelerated to GeV energy the comparison between polarized electron and positron scattering cross-sections eliminate model-dependence in the investigation of nuclear structure [2]. At TeV energy polarized positrons are essential for testing the Standard Model in the context of the International Linear Collider (ILC) [3].

Polarized positrons are produced in radioactive beta-decay [4] or by man-made methods such as the Sokolov-Ternov self-polarization of unpolarized positrons in a storage ring [5] or the resulting pair-production by the irradiation of nuclei with circularly polarized gamma rays. For the later method, circularly polarized gamma rays were produced via Compton back-scattering [6] and using a helical undulator [7]. Both techniques produced positrons with a high degree of positron spin-polarization and demonstrating the the potential for high yield. However, both methods require very high electron beam energies 10-100 GeV and elaborate technologies.

In this work we demonstrate a new technique for the production of polarized positrons, and in this case with very low beam energy ~10 MeV. The idea, suggested in the late 1990's in the context of the ILC [8, 9], rely on the electromagnetic shower in a conventional pair-production target to transfer the spin-polarization from the electron beam directly to the outgoing positrons. By demonstrating the technique at low energy, we avoid issues associated with high power targets and activation, illustrating the applicability of this technique to the design of future polarized positron sources, whether at similar or much higher energy where yield may be significantly increased.

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EXPERIMENT

The PEPPo experiment [10] was installed at the Jefferson Lab CEBAF injector where a highly spin-polarized 85% electron beam with energy up to 10 MeV. The electron beam could be delivered to a Mott scattering electron polarimeter, a precision electron spectrometer and the PEPPo apparatus, composed of (see Fig. 1): the production target, a quarter-wave solenoid to collect positions within a large divergence angle, a combined-function spectrometer to select and focus discrete positron momenta slices, a pair of coincidence positron annihilation detectors, and a second solenoid to transport and focus positrons to the PEPPo polarimeter.

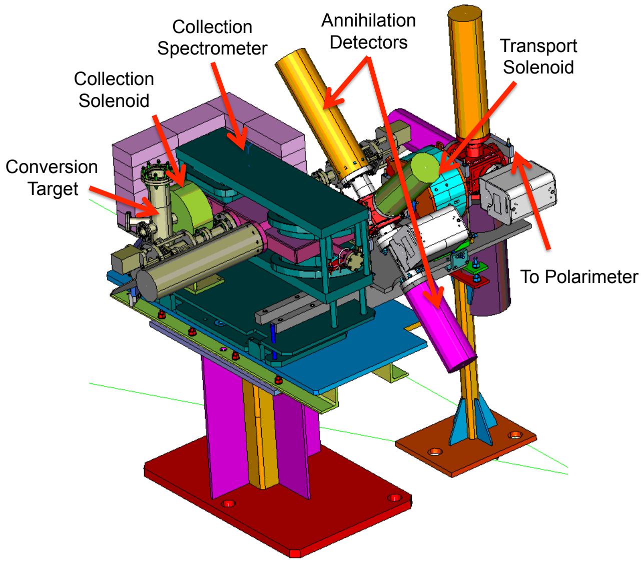

Figure 1: The main components of the PEPPo positron production, collection and detection.

PEPPO POLARIMETER

The PEPPo polarimeter (see Fig. 2) is a Compton transmission type polarimeter that relies on the bremsstrahlung spectrum produced by longitudinally polarized positrons (or electrons) having small energy and angular distributions interacting with a reconversion target at the entrance of the polarimeter. The polarimeter takes advantage of the differential cross section for the Compton scattering of circularly polarized bremsstrahlung photons with a longitudinally polarized electron target (P_T) writes [11]. The measurement of the circular polarization of the photon beam is essentially obtained from the transmission asymmetry (A_T) of the number of transmitted photons ($N_\gamma^\pm$) for oppositely polarized

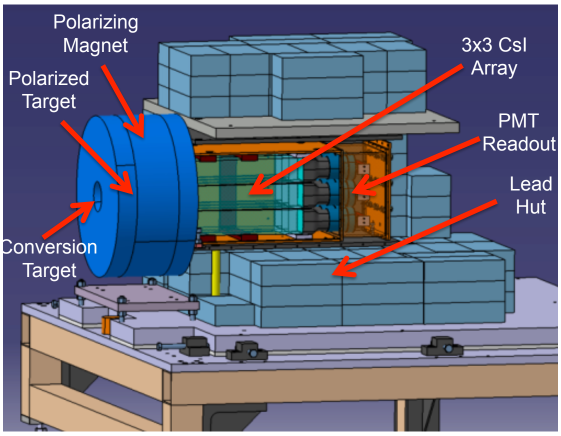

Figure 2: The main components of the PEPPo Compton transmission polarimeter.

target or photon polarization orientations according to

$$A_T = \frac{N_\gamma^+ - N_\gamma^-}{N_\gamma^+ + N_\gamma^-} = P_{e^\pm} P_T A_{e^\pm} \tag{1}$$

where $A_{e^\pm}$ is an effective analyzing power determined either by simulation or experimentally if the beam polarization is already known. In the PEPPo polarimeter bremsstrahlung photons generated in a 2 mm thick tungsten reconversion target interact with a 7.5 cm long and 5 cm diameter iron target longitudinally polarized by a magnetic field close to saturation ($7.06\% \pm 0.05\%_{sys} \pm 0.07\%_{sys}$). Transmitted photons are detected in a segmented 3x3 array CsI calorimeter following the polarized target.

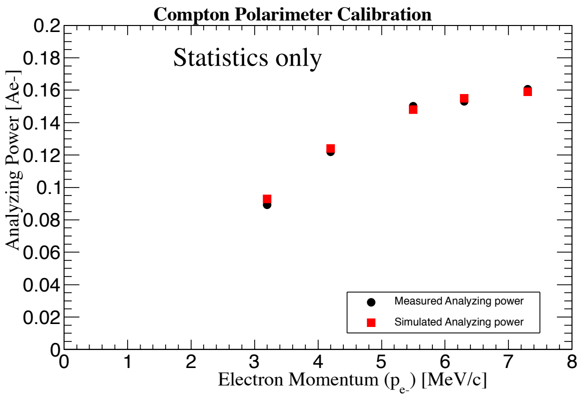

Figure 3: The comparison of the Geant4 simulation and measured analyzing powers for electrons in the PEPPo polarimeter.

A model of the polarimeter was constructed using Geant4 [12] v8.3 with the ultimate purpose of simulating the analyzing power for positrons. However, the *a prior* knowledge of the electron beam polarization via a Mott scattering polarimeter provided a pathway to gain a high level of confidence by first benchmarking the simulation for electrons with a directly measured analyzing power for electrons. To accomplish this an electron beam of measured polarization $83.7\% \pm 0.6\%_{stat} \pm 2.8\%_{syst}$ was accelerated to varying momenta in the range of 3.1 to 7.3 MeV/c and measured using the PEPPo polarimeter. At each momenta the transmission asymmetry was computed in terms of the energy weighted integral of the photon flux, while accounting for the reversal of the beam helicity or target polarization. The Geant4 model and simulation were tested; the major obstacle of which was learning of a bug in the polarized transportation process for releases later than v.8.3. The comparison (statistics only) between the simulated and measured analyzing power for electrons is reported in Fig. 3) for the central crystal of the array. The quality of the simulated analyzing power is presently dominated by the systematic uncertainty of the measured analyzing power, that is, the beam polarization, target polarization and data analysis of the transmission asymmetry (pedestal subtraction, linearity, false asymmetry). Preliminary results suggest the simulation is in agreement with the model at the 4-5% level.

POSITRON MEASUREMENTS

The electron beam was initially used to calibrate the settings of the collection spectrometer (with solenoids off) that efficiently transported discrete settings of beam momenta to the PEPPo polarimeter. After obtaining suitable transport the beam momentum was fixed at 8.2 MeV/c and the 1.0 mm tungsten conversion target was inserted, thus generating pair-produced e+/e- pairs, gamma photons and energy-degraded beam electrons. At a series of four successive momenta in the range 3.1 to 6.2 MeV/c the collection and transport solenoids were optimized for *degraded electrons* by optimizing the yield, respectively, following the collection spectrometer and at the polarimeter reconversion target. Once the solenoids were optimized for the collection of electrons the polarity of the spectrometer was reversed to efficiently transport the desired momentum slice of positrons to the reconversion target of the polarimeter. The transmission asymmetry of positrons (A_T) was measured while accounting for the reversal of either the positron (via the original electron) helicity or the target polarization.

The positron polarization is computed as $P_{e^+} = \frac{A_T}{P_T \cdot A_{e^+}}$ where A_{e^+} is the simulated analyzing power of the polarimeter for positrons. A comparison of the benchmarked analyzing power for positrons and electrons for the PEPPo polarimeter is shown in Fig. 4. The enhanced analyzing power of the positrons is expected, primarily a consequence of in-flight annihilation of positrons in the reconversion target.

Finally, the preliminary result of the positron polarization (statistics only) is shown in Fig. 5. Contributions of systematic uncertainty being presently addressed are the target polarization (<2%), data analysis of the transmission asymmetry (5-7%), and accuracy of the Geant4 model of the polarimeter (4-5%). Dependence of the simulated analyzing power on the positron distribution have begun.

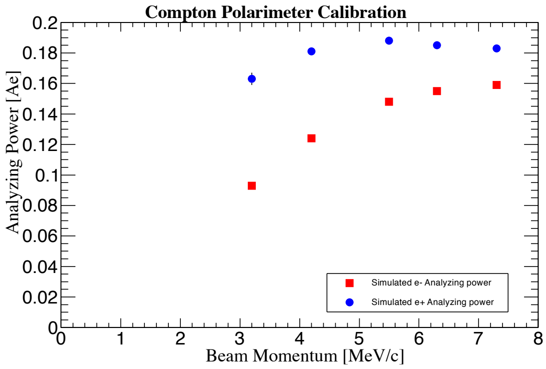

Figure 4: Comparison of the Geant4 simulation of the PEPPo polarimeter analyzing power for electrons and positrons.

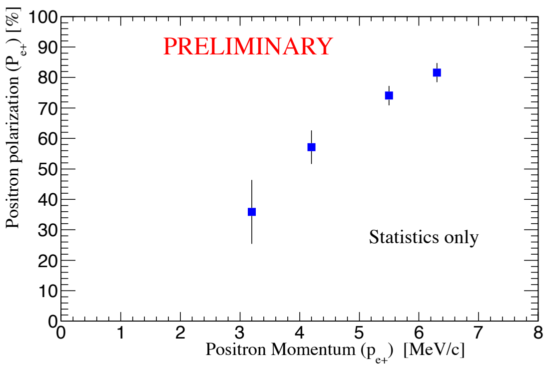

Figure 5: Preliminary results of the the polarization of positrons produced in the PEPPo apparatus.

In addition to positron polarimetry, a pair of NaI detectors (energy calibrated with a Na^{22} source) were located following the collection spectrometer to detect and measure the yield of positrons annihilated in a 11 mil target ($99.5\% Al_2O_3, 0.5\% Al_2O_3Cr_2O_3$) oriented at 45° to the beam. The coincidence and deposited energy of two 511 keV annihilation x-rays indicated the presence of positrons. The raw (upper) and background subtracted (lower) energy spectra are demonstrated in Fig. 6. Although shielded, the accidental rate of both detectors suffered from proximity to the positron production target. When corrected for solid angle (0.1 sr), annihilation probability (0.25%) and detector efficiency (49% at 511 keV) the detected coincidence rate indicates a yield of 1 positron per 10^6 electrons, consistent with the proposed efficiency of the experiment.

CONCLUSION

We have demonstrated a new means to produce polarized positrons. Using a spin-polarized (84%) electron beam of momentum 8.2 MeV/c and a 1 mm thick tungsten pair-production foil, positrons in the range of 3.1 to 6.2 MeV/c were magnetically collected and their polarization analyzed by a Compton transmission polarimeter. Preliminary analysis indicates the positrons attained polarization with polarization increasing with momentum transfer and of very high degree near the end-point.

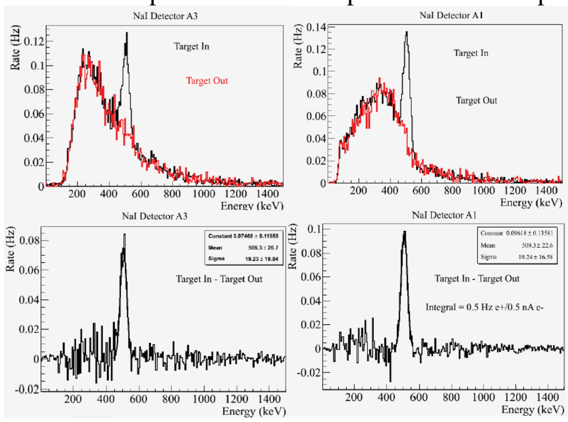

Figure 6: The coincidence detection of positrons with (upper) and without (lower) background subtraction.

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