

PEPPo: USING A POLARIZED ELECTRON BEAM TO PRODUCE POLARIZED POSITRONS

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Abstract

An experiment demonstrating a new method for producing polarized positrons has been performed at the CEBAF accelerator at Jefferson Laboratory. 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 1.0 mm tungsten pair-production target. This paper describes preliminary results of measurements using an 8.2 MeV/c electron beam with polarization 84% to generate positrons in the range of 3.1 to 6.2 MeV/c with polarization as high as $\sim 80\%$.

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 energies, the comparison between polarized electron and positron scattering cross-sections tests the precision of the electromagnetic interaction for the investigation of nucleon and nuclear structure [2]. At TeV energies, 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 resulting from pair-production following the irradiation of nuclei with circularly polarized gamma rays. For the latter method, circularly polarized gamma rays can be produced via Compton back-scattering [6] or using a helical undulator [7]. Both techniques produced positrons with a high degree of positron spin-polarization and demonstrated 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 with very low beam energy ~ 10 MeV. The idea, suggested in the late 1990's in the context of the ILC [8, 9], relies on the production of circularly-polarized gamma rays by the bremsstrahlung produced using polarized electrons; these photons then create polarized positrons via pair-production on nuclei. 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 84% electron beam with energies up to 10 MeV could be provided. The electron beam could be delivered for characterization to either a Mott scattering electron polarimeter or a precision electron spectrometer; alternatively it could be sent to the PEPPo apparatus (see Fig. 1) which included: the e^+/e^- 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 through an 8 mil Al window to the PEPPo polarimeter.

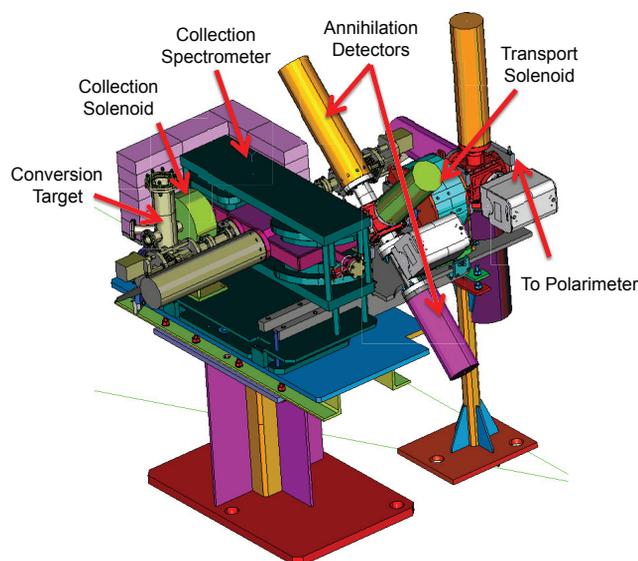


Figure 1: Vacuum beam line includes the insertable production target, a solenoid to collect e^+ , a double-bend spectrometer to define the momentum acceptance, a positron annihilation detector, and a second solenoid to transport e^+ to an exit vacuum window in front of the polarimeter.

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) [11]. The measurement of the

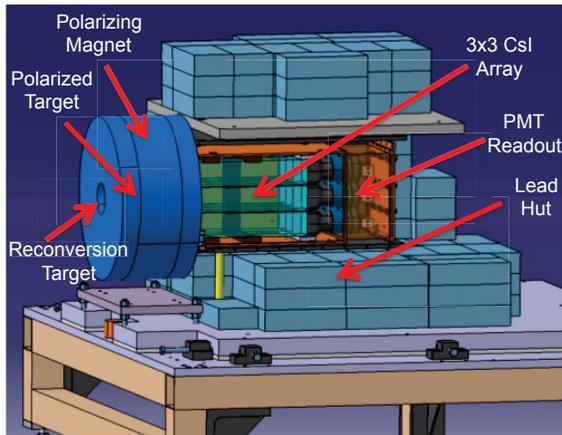


Figure 2: PEPPo Compton transmission polarimeter includes a positron (or electron) to gamma conversion target, an iron core target polarized by a magnet, and a CsI calorimeter to measure the flux and energy of transmitted photons.

beam (positron or electron) polarization is essentially obtained from the transmission asymmetry (A_T) of the number of transmitted bremsstrahlung photons (N_γ^\pm) for oppositely polarized target or beam polarization orientations according to

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

where A_{e^\pm} is an effective analyzing power determined either by simulation or experimentally (e.g. by using the polarized electron beam with a measured polarization directly). 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.

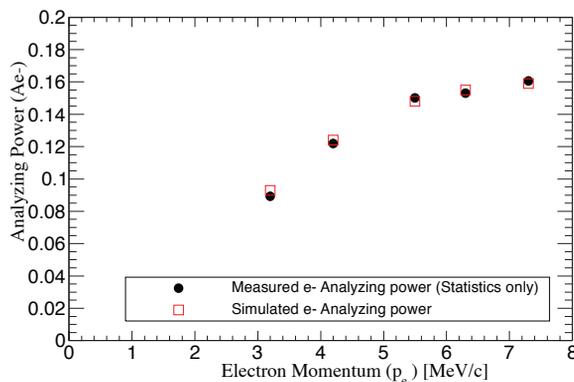


Figure 3: The comparison of the Geant4 simulation and measured analyzing powers for electrons in the PEPPo polarimeter.

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 priori* 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 $83.7\% \pm 0.6\%_{stat} \pm 2.8\%_{sys}$ was accelerated to varying momenta in the range of 3.1 to 7.3 MeV/c and measured using the PEPPo polarimeter. At each momentum 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 shown in Fig. 3 for the central crystal of the array. Initial assessment of the simulated analyzing power appears dominated by the systematic uncertainty of the measured analyzing power, i.e., the beam polarization, target polarization and data analysis of the transmission asymmetry (pedestal subtraction, linearity, false asymmetry), and then to a lesser extent on the simulated dependencies of the electron beam distribution. Preliminary results suggest the simulation is in agreement with the measurement at the $\sim 5\%$ level.

POSITRON MEASUREMENTS

The electron beam was initially used to calibrate the settings of the collection spectrometer (with solenoids off) that efficiently transported discrete slices 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 of 3.1 to 6.2 MeV/c the collection and transport solenoids were optimized for *degraded electrons* by optimizing the yield after 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 as a consequence of in-flight annihilation of positrons in the reconversion target.

Finally, our preliminary result for the positron polarization (statistics only) is shown in Fig. 5. We are evaluating

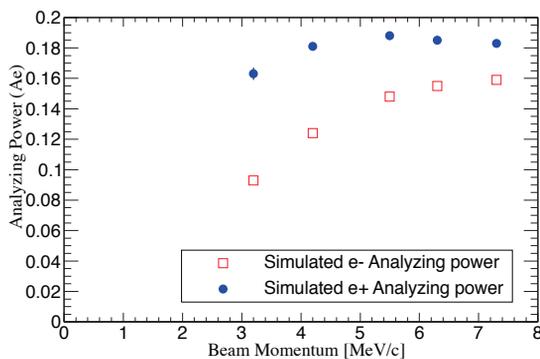


Figure 4: Comparison of the Geant4 simulation of the PEPPo polarimeter analyzing power for electrons and positrons.

the contributions of systematic uncertainties, in the target polarization ($<2\%$), the data analysis of the transmission asymmetry ($<7\%$), and the accuracy of the Geant4 model of the polarimeter ($<5\%$). Dependence of the simulated analyzing power on the positron distribution have begun.

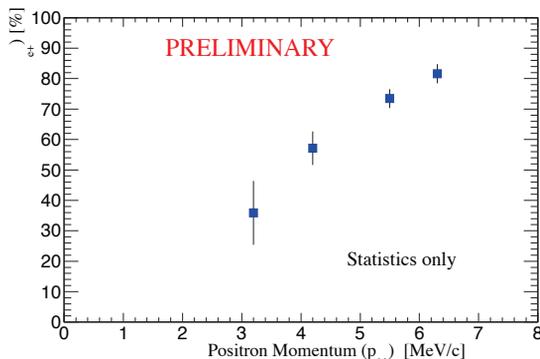


Figure 5: Preliminary results of the polarization of positrons produced in the PEPPo apparatus.

In addition to positron polarimetry, a pair of NaI detectors (energy calibrated with a ^{22}Na 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% $\text{Al}_2\text{O}_3\text{Cr}_2\text{O}_3$) 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 measured coincidence rate indicates a yield of 1 positron per 10^6 electrons, consistent with the expected efficiency of the experiment.

CONCLUSION

We have demonstrated a new means to produce polarized positrons. This paper described preliminary results of

measurements using an 8.2 MeV/c electron beam with polarization 84% to generate positrons in the range of 3.1 to 6.2 MeV/c with polarization as high as $\sim 80\%$.

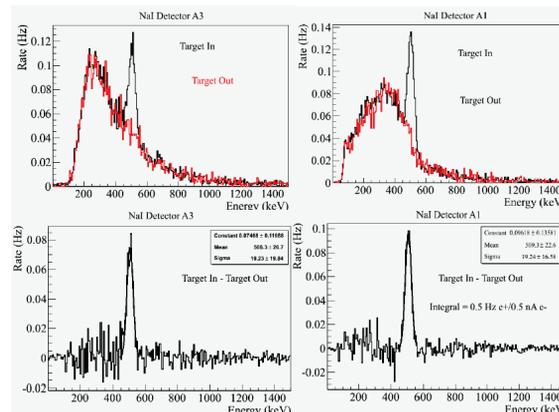


Figure 6: The coincidence detection of positrons with (upper) and without (lower) background subtraction.

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