

THE PEPPo CONCEPT FOR A POLARIZED POSITRON SOURCE

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Abstract

Polarized positron beams are identified as an essential ingredient for the experimental program at the next generation of lepton accelerators (JLab12, ILC, CLIC). A proof-of-principle experiment for a new method to produce polarized positrons has been performed at Jefferson Laboratory (JLab). The PEPPo (Polarized Electrons for Polarized Positrons) concept relies on the production of polarized e^+e^- pairs from the bremsstrahlung radiation of a longitudinally polarized electron beam interacting within a high Z conversion target. The experiment was performed at the injector of the Continuous Electron Beam Accelerator Facility at Jefferson Laboratory and investigated the polarization transfer of an 8.25 MeV/c polarized electron beam to positrons produced in varying production target thicknesses. A new dedicated beam-line was designed and constructed to produce, collect and transport positrons in the momentum range of 3.2 MeV/c to 6.2 MeV/c to a polarized iron target for polarization measurements.

THE PEPPo CONCEPT

The interest of the Physics Community in polarized positrons has been expressed in numerous projects involving thermal to very high beam energies (see Ref. [1] for examples). While storage ring facilities can rely on the natural self-polarization build-up from the Sokolov-Ternov effect [2], external beam or continuous wave facilities require new scenarios. These new schemes rely on the polarization transfer from circularly polarized photons interacting in a high Z target to produce longitudinally polarized e^+e^- pairs via the pair creation process [3, 4]. The technique used for the production of polarized photons distinguishes the different schemes.

Within the context of the International Linear Collider (ILC), two techniques were experimentally investigated: Compton backscattering of a polarized laser from a 1.3 GeV electron beam [5], and the synchrotron radiation of a 46.6 GeV electron beam travelling through a helical undulator [6]. Both techniques produced highly polarized positrons, demonstrating the efficiency of the pair production process for a polarized positron beam. However, these require both GeV electron beams and challenging technologies therefore increasing the scale of a potential positron facility.

A novel approach is developed at the Continuous Electron Beam Accelerator Facility (CEBAF) of JLab, that takes advantage of its high performance polarized electron source [7, 8]. Circularly polarized photons originate here from the bremsstrahlung radiation of a few MeV longitu-

dinally polarized electron beam interacting in a tungsten target. Longitudinally polarized e^+e^- pairs are then produced within the same target from the pair creation induced by polarized photons. This technique was initially proposed [9, 10] in the context of the ILC project but was not pursued. The performances of polarized electron sources at that time might have been considered as a strong limitation. Nowadays, the bremsstrahlung of (unpolarized) polarized electrons is commonly used for the generation of (linearly) circularly polarized photon beams. Together with the successful experimental investigations of the photon polarization transfer [5, 6], this novel technique that we identify as the Polarized Electrons for Polarized Positrons (PEPPo) concept should be viable. Additionally, involving a low energy high intensity electron driver [7] the PEPPo concept can potentially open access to low intensity polarized positrons for a wide Community.

THE PEPPo EXPERIMENT

The PEPPo experiment [11] was designed to evaluate and demonstrate the PEPPo concept for a polarized positron source. It involved the construction of a new beam line at the CEBAF injector where up to 8.25 MeV/c polarized electrons were transported towards a tungsten positron production target followed by a positron collection, selection, and characterization system built on parts of the SLAC E-166 experimental setup [12] reconfigured for PEPPo purposes.

General Layout

The CEBAF injector [13] constitutes a full scale continuous low energy polarized electron beam facility with variable energy, providing continuous electron beams up to 200 μ A intensities with 85% polarization, and equipped with the necessary beam characterization apparatus for the completion of an experiment. This comprises the control and monitoring of the beam polarization and intensity, the measurement of the electron beam energy with a dedicated spectrometer line, and the measurement of the beam polarization with a Mott polarimeter. The PEPPo experiment was developed on a new beam line branch section (Fig. 1) composed of four different regions. The first region is dedicated to the electron beam transport to the positron production target (T_1) and is equipped with active elements (quadrupole and corrector magnets to set beam size and position) and beam diagnostics (viewers and beam position monitors). The second region concerns the positron collection and selection made of a strong solenoid lens and a $D\bar{D}$ spectrometer with $\pm 90^\circ$ bend dipoles. Additional beam diagnostic (viewer) and selection device (adjustable collimator) complete instrumentation of this section. The

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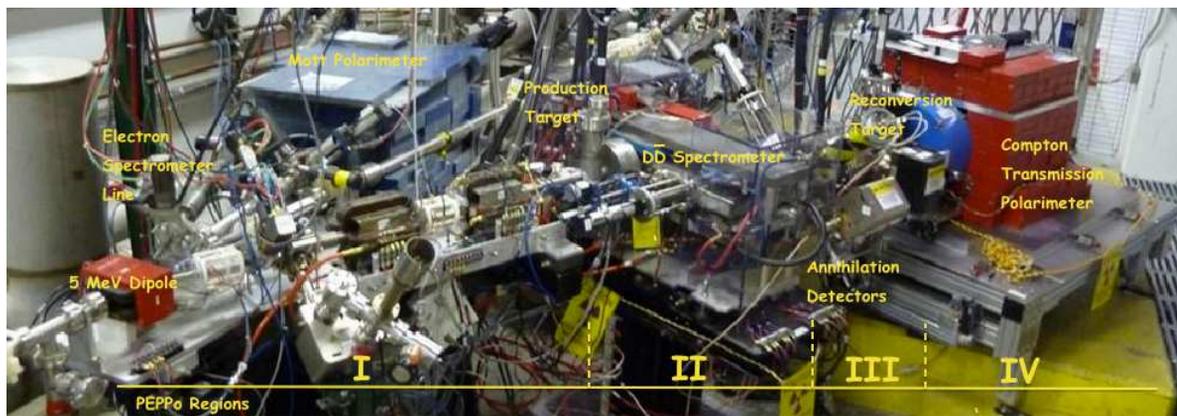


Figure 1: The PEPPo beam line, starting from the so-called 5 MeV dipole branch and extending up to the Compton transmission polarimeter enclosed in a lead shielding housing.

third region is intended to optimize the positron transport to the Compton transmission polarimeter using a short focal length solenoid lens and corrector magnets, and comprises also several beam diagnostic (viewers, Faraday cup) and a specific e^+e^- annihilation detector system designed to detect the presence of positrons at the exit of the spectrometer. The last region of the PEPPo apparatus consists of the electron and positron characterization device where the polarization of incoming particles is measured.

Compton Transmission Polarimetry

PEPPo polarimetry is based on the sensitivity of the Compton scattering process to the polarization of incoming photons. At the exit of the vacuum beam line, incoming polarized electrons or positrons are first converted into polarized photons by bremsstrahlung (and annihilation for positrons) radiation inside a 2 mm W target (T_2). When the interaction takes place with a polarized target, photon absorption inside the target is depending on the relative orientation of the target polarization with respect to the photon. Measuring the number of photons transmitted by the target for opposite target or photon polarization, one obtains a measurement of the initial photon polarization. These photons are subsequently absorbed into a 7.5 cm long polarized iron target, those surviving being measured in a 3×3 CsI crystal array. The experimental asymmetry is measured with respect to the helicity flip of the CEBAF electron beam, and can be written

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

where P_{e^\pm} is the electron/positron polarization, P_T is the target polarization determined from the knowledge of the polarizing magnetic field [14], and A_{e^\pm} is the analyzing power of the detection system [15]. Knowing the initial beam polarization, the experimental asymmetry A_T measures the analyzing power of the detector (electron data) while knowing the analyzing power, A_T measures the polarization of the incoming beam (positron data).

DATA TAKING

Experimental Method

The PEPPo experiment took advantage of the well-known CEBAF electron beam for a full calibration of the apparatus. The gradient of the cryounit cavity was first calibrated with the electron spectrometer providing $\sim 2\%$ measurement of the beam momentum. The lossless transport of this electron beam through the PEPPo line calibrates the DD spectrometer versus electron momentum. Measurement of the Compton asymmetry allows the determination of the electron analyzing power of the Compton transmission polarimeter [15] relying of the Mott measurement of the e^- beam polarization. Inserting a production target at T_1 (0.1 or 1.0 mm W) and optimizing the collection of the degraded electron beam with the Faraday cup at the end of the vacuum section of the PEPPo line calibrates the solenoid collection settings at a given spectrometer momentum. The experimental determination of optical properties of the PEPPo line is in good agreement with beam transport simulations based on the magnetic field mapping of each element prior to installation in the injector tunnel. The experimental electron analyzing power is intended to benchmark the GEANT4 model of the polarimeter from which we obtain the positron analyzing power. Initial electrons and positrons differ from the positron annihilation process. Within the PEPPo calibration procedure, the control of this mechanism is obtained indirectly from interactions of secondary positrons created by multiple interactions of incident electrons and bremsstrahlung photons. Switching for positron measurements is simply achieved by reversing the polarity of the spectrometer.

Polarization Transfer Data

The measurement of the longitudinal polarization transfer from electrons to positrons has been performed with a 8.25 MeV/c incident electron beam on W targets with different thicknesses (Tab. 1). The momentum scan of the positron polarization spectra has been realized in the range 3.2-6.2 MeV/c for a fixed 1 mm thickness while the thick-

ness dependence was studied at the lowest positron beam energy (Tab. 1). The momentum scan is a core measurement of the PEPPo experiment, intended to demonstrate the reliability of the PEPPo concept. The thickness dependence is also an important measurement expected to show the sensitivity to the details of the physics at work in this concept: particularly, distinguishing between ultra-relativistic [3] and finite lepton mass [4] descriptions of the polarization transfer in bremsstrahlung and pair production processes, and possibly investigating the eventual contribution of virtual pair production.

Table 1: Positron measurements.

p_{e^+} (MeV/c)	I_{e^-} @ T_1 (nA)		Target (mm)
	Set 1	Set 2	
3.2	380	120	1.0
4.2	25	130	1.0
5.5	95	200	1.0
6.3	380	620	1.0
3.2	—	380	0.1

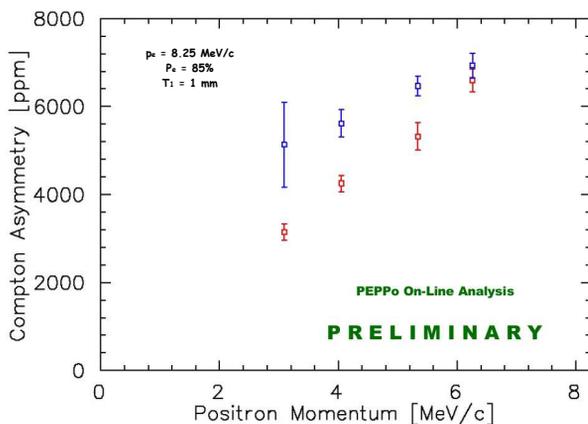


Figure 2: Experimental Compton asymmetries obtained from on-line analysis of positron measurements (Tab. 1).

Experimental data were collected within two separate sets with preliminary (Set 1) and optimized (Set 2) shielding configurations, as well as beam intensities and analysis procedures involving different analyzing power. Each positron momentum point corresponds to a collection of a large number of runs where the experimental asymmetry is measured with respect to the initial electron beam helicity for a given status of the electron source laser polarization (\pm) and of the target polarization orientation (\pm). In order to control and minimize systematic effects, experimental data have been acquired for each configuration following a random sequence. Systematics is further reduced by the helicity structure of the beam which follows a quartet pattern where helicity is flipped at a 30 Hz frequency. The experiment trigger is built from the coincidence between a 1 mm thick scintillator placed prior T_2 at the entrance of the polarimeter, and the central crystal of 3×3 detector array, leading to a drastic reduction of the neutral back-

ground. Each event is tagged by the beam helicity information reported in a delayed mode allowing to electronically decorrelate the helicity and detector signals. The statistically averaged asymmetry over the run sequence is shown on Fig. 2 as function of the positron momentum and separated between the two data sets. Experimental asymmetries in the range 3000-7000 ppm have been measured pointing to high degree of positron polarization.

CONCLUSION

The PEPPo experiment at JLab did measure the longitudinal polarization transfer from 8.25 MeV/c electrons to positrons of different momentum produced via polarized bremsstrahlung and pair production in a tungsten target. The positron polarization was measured with a Compton transmission polarimeter. Significant experimental asymmetries are reported from on-line data analysis indicating high positron polarization. The final data analysis under progress will deliver soon the exact magnitude of the positron polarization.

ACKNOWLEDGMENT

We are deeply grateful to the SLAC E-166 Collaboration, particularly K. Laihem, K. McDonald, S. Riemann, A. Schällicke, P. Schüler, J. Sheppard and A. Stahl for loan of fundamental equipment parts and support in GEANT4 modeling. We also thank N. Smirnov for coordinating delivery of critical hardware. This work was supported in part by the U.S. Department of Energy, the French Centre National de la Recherche Scientifique and the International Linear Collider project. Jefferson Science Associates operates the Thomas Jefferson National Accelerator Facility under DOE contract DE-AC05-06OR23177.

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