The **PEPPo** Concept for a Polarized Positron Source

Polarized Electrons for Polarized Positrons

**Eric Voutier** on behalf of the **PEPPo** Collaboration

*Laboratoire de Physique Subatomique et de Cosmologie*  
*Grenoble, France*

(i) Polarized positron production  
(ii) Experimental setup  
(iii) Commissioning  
(iv) Operation  
(v) Preliminary data
Polarized positron production

**Polarized Bremsstrahlung**

E.G. Bessonov, A.A. Mikhailichenko, EPAC (1996)  
A.P. Potylitsin, NIM A398 (1997) 395

PEPPo has studied the feasibility of using bremsstrahlung from polarized electrons for the production of polarized positrons.

\[ e^- \rightarrow \gamma \rightarrow e^+ \]

Sustainable polarized electron intensities up to 4 mA have been demonstrated from a superlattice photocathode.

R. Suleiman et al., PAC’11, New York (NJ, USA), March 28 - April 1, 2011
Polarization Transfer in Bremsstrahlung and Pair Production

H. Olsen, L. Maximon, PR 114 (1959) 887

**BREMSSTRAHLUNG**

- Kuraev/Bystritskiy/Shatnev/Tomasi
- $Z = 82$
- $\Theta_s = 0.41$ mrd

- $T_e = 3$ MeV
- $T_e = 10$ MeV
- $T_e = 100$ MeV

**PAIR CREATION**

- Kuraev/Bystritskiy/Shatnev/Tomasi
- $Z = 82$
- $\Theta_s = 0.41$ mrd

- $\omega = 3$ MeV
- $\omega = 10$ MeV
- $\omega = 100$ MeV

Shanghai, May 12-17, 2013
**Principle of Operation**

- Longitudinal $e^-$ ($P_{e^-}$) produce elliptical $\gamma$ whose circular ($P_{\gamma}$) component is **proportional** to $P_{e^-}$.
- $P_{\gamma}$ transfers to $e^+$ into longitudinal ($P_{e^+}$) and transverse ($P_{t}$) polarization components. On the average $P_{t}=0$. 

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Eric Voutier
Shanghai, May 12-17, 2013
Experimental setup

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- $P_{\gamma}$ transfers to $e^+$ into longitudinal ($P_{e^+}$) and transverse ($P_t$) polarization components. On the average $P_t=0$.

**PEPPo** measured the polarization transfer from longitudinal electrons to longitudinal positrons in the 3–6 MeV/c momentum range.

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**Simulation**

$I_e = 1 \mu A$

$T_1 = 1 \text{ mm}$

Calorimeter

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Shanghai, May 12-17, 2013
PEPPO ran at the CEBAF injector, taking advantage of the existing beam diagnostics that determine with precision the properties of the polarized electron beam entering the PEPPO apparatus.
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**Experiment Layout**

- **Intensity controls**
  - Laser
  - Gun#2
  - V-Wien Solenoids
  - PCup
  - A1
  - A2
  - H-Wien

- **Polarization controls**
  - Gun#3

- **Energy measurement** (10^{-2})
  - 5MeV Spectrometer
  - Mott
  - FC#2

- **To the rest of the injector**

- **Variable energy** 3-8.5 MeV/c
  - 1/4 Cryo
  - 500 keV Dump
PEPPo ran at the CEBAF injector, taking advantage of the existing beam diagnostics that determine with precision the properties of the polarized electron beam entering the PEPPo apparatus.

- Energy measurement ($10^{-2}$)
- Polarization measurement (1.5%)
- Variable energy 3-8.5 MeV/c

**Experimental setup**

Shanghai, May 12-17, 2013
PEPPo ran at the CEBAF injector, taking advantage of the existing beam diagnostics that determine with precision the properties of the polarized electron beam entering the PEPPo apparatus.

PEPPo Laser

Intensity controls

Gun#2

V-Wien Solenoids

Prebuncher

H-Wien

Chopper

Buncher Capture

Bunchlength Cavity

FC#1

FC#2

1/4 Cryo

10^{-2}

5MeV Spectrometer

Mott

To the rest of the injector

PEPPo

Energy measurement

Variable energy 3-8.5 MeV/c

500 keV Dump

Polarization measurement (1.5%)

Eric Voutier

Shanghai, May 12-17, 2013

E xperimental setup
Experimental setup
Experimental setup

Corrector magnets

Quadrupoles
Experimental setup

- Beam position monitors
- Viewers
- Corrector magnets
- Quadrupoles
Production Target
T₁ (0.1 - 1 mm W)
Experimental setup

Production Target
$T_1$ (0.1-1 mm W)

Positron Selection Device
Experimental setup

Production Target $T_1$ (0.1-1 mm W)

Positron Selection Device
Experimental setup

Production Target $T_1$ (0.1-1 mm W)

Positron Selection Device
Experimental setup

Production Target $T_1 (0.1-1 \text{ mm W})$

Solenoid

Corrector magnets
Production Target $T_1$ (0.1–1 mm W)

Experimental setup

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Experimental setup

Reconversion Target $T_2$ (2 mm W)

Polarized Analyzing Target (7.5 cm Fe)

Compton Transmission Polarimeter
ELEGANT beam optics

RMS Beamsize along PEPPo Beamline

Shanghai, May 12-17, 2013
Experimental setup

**ELEGANT beam optics**

- RMS Beamsize along PEPPo Beamline

- PEPPo branch junction

- Graph showing $\sigma_x$ and $\sigma_y$ vs. $s$ (m)
Experimental setup
The spectrometer current/momentum was calibrated with the electron beam.

The collection and transport solenoid currents were optimized with degraded electrons, and confirmed with produced positrons.
Two NaI detectors were used to measure the back-to-back photons emitted by the annihilation of positrons in an insertable target.

4 MeV/c e\(^+\) collected from 0.5 nA 7 MeV/c e\(^-\) on 1 mm W target
**Operation**

**DAQ Components**

- **CsI crystals** are coupled to PMTs equipped with LPSC custom amplified basis to extend the PMT life-time in the high rate environment of PEPPo.

- The $\sim 2 \mu s$ long and 2 V optimized signal is fed into the JLab custom FADC250 that sampled the signal at 250 MHz.

The flexibility of the FADC250 allows for 3 data taking modes:

- **Sample** (500 samples /detector event);
- **Semi-integrated** (1 integral / detector event);
- **Integrated** (1 integral / helicity gate event).
The integrated mode operates for high rate conditions by integration of the PMT signal over the duration of an helicity gate (PEPPo firmware developed by JLab).

Helicity frequency = 30 Hz  
Helicity delay = 8 windows 
Helicity pattern = quartet (+--- or -++-)

\[ A_T = \frac{E^+ - E^-}{E^+ + E^-} = \frac{E_i^+}{E_i^+ + E_i^-} - \frac{E_i^-}{E_i^+ + E_i^-} = P_e - P_T A_{e-} \]
The PMT signals are registered in the form of one single value corresponding to the time-integrated signal over 2 µs, and is tagged by the helicity status of the electron beam.

Helicity frequency = 30 Hz
Helicity delay = 8 windows and none
Helicity pattern = quartet (+−−+ or −+++)

Experimental asymmetry is determined for each energy bin and a corresponding positron polarization is determined knowing from calibrated simulations the energy dependence of the positron analyzing power.
Data were taken using **two major sequences:**

I. Use the polarized electron beam directly from the CEBAF injector to **calibrate** the **analyzing power** of the Compton transmission polarimeter;

II. Use the Compton transmission polarimeter to **measure** the **polarization transfer** from electrons to positrons.

> The DAQ trigger for positron measurements is a **coincidence** between a thin scintillator placed prior the reconversion target, and the central crystal (PMT5).

**Drastic reduction of the neutral background.**
Preliminary data

Data Taking - I

- Use **Mott polarimeter** to learn about the electron **beam polarization**.
- The **target polarization** is known from in-situ measurement of the **magnetic field** (O. Dadoun et al., MOPWA079).
- Measure **experimental asymmetry** with the **Compton transmission polarimeter**.

<table>
<thead>
<tr>
<th>P_e- (MeV/c)</th>
<th>Mode</th>
<th>I_e- @ T2</th>
<th>Det. Rate (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>Int.</td>
<td>60 pA</td>
<td>112</td>
</tr>
<tr>
<td>4.2</td>
<td>Int.</td>
<td>23 pA</td>
<td>184</td>
</tr>
<tr>
<td>5.5</td>
<td>Int.</td>
<td>25 pA</td>
<td>202</td>
</tr>
<tr>
<td>6.3</td>
<td>Int.</td>
<td>10 pA</td>
<td>471</td>
</tr>
<tr>
<td>7.3</td>
<td>Int.</td>
<td>10 pA</td>
<td>164</td>
</tr>
</tbody>
</table>

Combine results to determine the **analyzing power for electrons** and **benchmark the GEANT4 model** of the polarimeter.
A high quality measurement of the electron analyzing power has been achieved and is currently in the final analysis stage.

Experimental data are as expected selective with respect to simulations, allowing for the calibration of the polarimeter model.
Preliminary Results

- A high quality measurement of the electron analyzing power has been achieved and is currently in the final analysis stage.

- Experimental data are as expected selective with respect to simulations, allowing for the calibration of the polarimeter model.
Data Taking - II

- Use Mott polarimeter to learn about the electron beam polarization.
- The target polarization is known from in-situ measurement of the magnetic field.
- Use electron calibration data to determine the positron analyzing power (A. Adeyemi et al., MOPWA078).
- Measure experimental asymmetry with the Compton transmission polarimeter.

<table>
<thead>
<tr>
<th>Mom (MeV/c)</th>
<th>Mode</th>
<th>Set</th>
<th>(I_e) @ T1 (nA)</th>
<th>Det. Rate (kHz)</th>
<th>Target (mm)</th>
</tr>
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<tbody>
<tr>
<td>3.2</td>
<td>Sem.</td>
<td>1</td>
<td>380</td>
<td>9</td>
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<tr>
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<tr>
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<td>Sem.</td>
<td>2</td>
<td>120</td>
<td>2</td>
<td>1</td>
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<tr>
<td>3.2</td>
<td>Sem.</td>
<td>2</td>
<td>380</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>4.2</td>
<td>Sem.</td>
<td>2</td>
<td>130</td>
<td>2</td>
<td>1</td>
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<tr>
<td>5.5</td>
<td>Sem.</td>
<td>2</td>
<td>200</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>6.3</td>
<td>Sem.</td>
<td>2</td>
<td>620</td>
<td>6</td>
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Measure polarization transfer from electrons to positrons.

- Use Mott polarimeter to learn about the electron beam polarization.
- The target polarization is known from in-situ measurement of the magnetic field.
- Use electron calibration data to determine the positron analyzing power (A. Adeyemi et al., MOPWA078).
- Measure experimental asymmetry with the Compton transmission polarimeter.

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The location of the 511 keV peak is used for in-situ monitoring of the effective gain of the read-out chain to detect and correct for eventual radiation damage of the crystals or PMT aging.

The bremsstrahlung end-point is used for additional in-situ monitoring of the effective positron beam energy.
Experimental asymmetries in the range 2000-10000 ppm are measured, pointing to an efficient polarization transfer from Polarized Electrons to Polarized Positrons.
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PEPPO operated at higher beam energy as initially planned, improving yields and beam-time efficiency.

The measured energy dependence of the experimental asymmetry is consistent with expectations.
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PEPPPo Collaboration

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Many thanks for advice, equipment loan, GEANT4 modeling support, and funding to

SLAC E-166 Collaboration
International Linear Collider Project
Jefferson Science Association Initiatives Award

Shanghai, May 12-17, 2013
Polarized positrons have been obtained in high energy storage ring taking advantage of the Sokolov-Ternov effect which leads to positrons polarized parallel to the magnetic field.

Polarization builds up exponentially with a time constant characteristic of the energy and the curvature of the positrons

\[ \tau = \frac{8}{5\sqrt{3}} \frac{m_e^2 c^2}{\hbar e^2} \frac{p^3}{\gamma^5} \]

\[ \tau \sim 20 \text{ mn} @ \text{HERA} \]
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Not compatible with CW beam delivery at JLab.
Fixed Target Schemes

- The principle of polarization transfer from circular photons to longitudinal positrons has been demonstrated in the context of the ILC project.

**Compton Backscattering**

T. Omori et al, PRL 96 (2006) 114801

**Undulator**

G. Alexander et al, PRL 100 (2008) 210801

\[ P(e^+) = 73 \pm 15 \pm 19 \% \]
**Fixed Target Schemes**

- The principle of polarization transfer from circular photons to longitudinal positrons has been demonstrated in the context of the ILC project.

- Polarized positrons production

- Eric Voutier, Shanghai, May 12-17, 2013

\[
P(e^+) = 73 \pm 15 \pm 19 \%
\]
The PEPPo target ladder constitutes of 3 tungsten production targets with different thicknesses and a viewer. It is water cooled to allow for maximum beam currents.

<table>
<thead>
<tr>
<th>Incoming electron kinetic energy [MeV]</th>
<th>2</th>
<th>5</th>
<th>8</th>
<th>Necessary for Experiment [uA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Material</td>
<td>Max Current [uA] for 5W deposited</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Target = 0.1mm</td>
<td>Tungsten</td>
<td>15.9</td>
<td>27.6</td>
<td>30.1</td>
</tr>
<tr>
<td>Production Target = 0.5mm</td>
<td>Tungsten</td>
<td>5.0</td>
<td>3.0</td>
<td>3.7</td>
</tr>
<tr>
<td>Production Target = 1mm</td>
<td>Tungsten</td>
<td>4.9</td>
<td>2.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**Target Ladder**

Shanghai, May 12-17, 2013
PEPPo polarimetry relies on the sensitivity of the Compton process to the polarization of the photons generated in the $T_2$ target from interactions of incoming electrons/positrons.

$$A_T = P_e \pm P_T A_{e \pm}$$

Expected experimental asymmetries are small ($1 - 8 \times 10^{-3}$).
4π spin rotator determines e⁻ polarization orientation

- Fast reversal of electron beam polarization at 30 Hz through experiment.

- Slow systematic reversal of electron polarization with optical wave-plate (source) and target polarization (Compton).

- Orient polarization in x,y,z direction using 4π spin rotator.
The model of the analyzing magnet developed within OPERA-2D is controlled by the measured magnetic map of the fringe field of the solenoid at ±60 A operational current.
Magnetic Flux Measurement

- The iron core target is equipped with 3 pick-up coils measuring the magnetic flux generated by the magnet current variation (ramping-up, polarity reversal).
- Specific cycling procedures are used during the experiment to monitor the target polarization.

From E-166@SLAC
\[ \langle p_T \rangle = 0.069 \pm 0.002 \]

G. Alexander et al., NIM A610 (2009) 451
Energy Dependent Asymmetry

$e^+ \text{ Data} @ 6.3 \text{ MeV/c}$

- Statistics corresponds to $1/72$ of data at this energy.