Polarized Electron Footprint at JLab

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Continuous Electron Beam Accelerator Facility

- Recirculating SRF LINACs
- Three Halls; 3x the physics

Two SRF 600 MeV linacs (1497 MHz)

67 MeV injector (1497 MHz)

RF Lasers (499 MHz)

RF defectors

Double-sided septum

Pockels cell

RF Lasers

A B C

Wien filter

Spin Precession Degrees of Freedom

\[ \psi_{Total} = \frac{eE_{linac}}{m_{e}c^{2}} \left[ 2p^{2} - p(1 - 2\hat{\theta}_{Hall} - 2\alpha) - \alpha(1 - \hat{\theta}_{Hall}) \right] \]
CEBAF’s first polarized e-beam experiment 1995

Now polarized beam experiments comprise ~ 80% of our physics program, in fact, we only deliver polarized electrons

All beam originates via photoemission from a strained superlattice GaAs crystal inside a 100kV DC photogun

Three experimental areas may simultaneously receive:
- high polarization (~85%)
- continuous wave (499 MHz)
- independent intensity (50 pA to 200 µA)
- energy selection (6 GeV now, 12 GeV 2012)

What about positron physics?
- Lepton charge degree of freedom
- But, costly endeavor...
- But, rich e- program keeps us busy...

Everyone Gets Polarized Electrons!
Recent workshop to discuss e+ @ Jlab ... identified “old” & new physics motivations...

- **Generalized Parton Distributions**
- Investigation of **2g exchange** in elastic scattering
- Study of **Coulomb distortion** in the inelastic regime
- Search for a light dark matter gauge **U-boson**
- Measurement of the **$C_{3q}$ neutral weak coupling**
- **Positron Annihilation Spectroscopy**

- $e^+$ beam current > **100 nA** in **CW mode**
- As large as possible $e^+$ beam **polarization**

New interest from the source & accelerator community working at JLab ...
If the shoe fits ...

...then wear it!

10 MeV/10 mA
Power loss/scattering
Compact, low rad

100 MeV/10 mA
Better divergence
Worse energy spread

1000 MeV/1 mA
Easier source
Bigger “driver”

R&D Effort for a **continuous wave [polarized] positron source** at JLab for **fixed target experiments** to take place in the **12 GeV era**.

**J. Dumas, C. Hyde, T. Forest, A. Freyberger, S. Golge, J. Grames, R. Kazimi, E. Voutier**

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S. Golge et al., Proc. of the International Workshop on Positrons at Jefferson Lab, Newport News (VA, USA), March 25-27, 2009

- **A possible concept** involves the construction of a **dedicated e⁺ tunnel** at the end of the injector and parallel to the north linac.
- Positrons would be produced with **120 MeV e⁻ (JLab 12 GeV)** incident on a tungsten target.
- e⁺’s are **selected** with a **quadrupole triplet** and **transported** to the accelerator section.

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**G4beamline simulations indicate a global efficiency of 10⁻⁵ e⁺/e⁻ for 120 MeV e⁻ off a 3 mm W target.**

\[ 10 \text{ mA e}^- \rightarrow 100 \text{ nA e}^+ \]
What about polarized e+?

- **Polarized beta-plus decay:** used in material science

- **Helical undulator:** colliders
  - e\(^-\) beam, Undulator, \(E > 150\, \text{GeV}, \, L > 150\, \text{m}\)
  - G. Alexander et al. PRL 100 (2008) 210801

- **Storage ring:** HERA
  - Storage ring, e\(^-\) beam, bending magnet, e\(^+\)

- **Compton scattering:** colliders
  - \(e^-\) beam, 1 - 6 GeV, \(\gamma\)-ray
  - Laser, e\(^-\), e\(^+\)
Within a high Z target, longitudinally polarized $e^-$'s radiate circularly polarized $\gamma$'s. Within the same/different target, circularly polarized $\gamma$'s create longitudinally polarized $e^+$'s.

So, why not pursued so far ... ?

<table>
<thead>
<tr>
<th>$P_{e^-}$</th>
<th>bulk GaAs</th>
<th>Strained GaAs</th>
<th>Superlattice GaAs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35%</td>
<td>75%</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>35%</td>
<td>75%</td>
<td>85%</td>
</tr>
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<td></td>
<td>35%</td>
<td>75%</td>
<td>85%</td>
</tr>
</tbody>
</table>

Evolution of CEBAF polarized electron source

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

All operating with suitable photocathode lifetime to sustain weeks of operation.
ILC Polarized e+ Schemes/Demos
(synchrotron/Compton polarized photon)

Two ways to get pol. e⁺

1. Helical Undulator
   - e⁻ beam
   - E > 150 GeV
   - L > 150 m
   - E = 50 GeV
   - L = 1 m
   - E-166 Experiment

2. Laser Compton
   - e⁻ beam
   - 1 - 6 GeV
   - γ-ray
   - E_max = 30 MeV

OR

Conventional un-polarized e+ Scheme
(bremsstrahlung photon)

High Polarization, High Current e- Gun
(polarized bremsstrahlung photon)

LIFETIME MEASUREMENTS OF HIGH POLARIZATION STRAINED-SUPERLATTICE Gallium Arsenide AT BEAM CURRENT >1 MILLIAMPERE USING A NEW 100kV LOAD LOCK PHOTOGUN* 


Source Property

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Electron beam energy</td>
<td>50 GeV - Undulator</td>
<td>10 MeV - Conversion</td>
</tr>
<tr>
<td>Electron beam polarization</td>
<td>Unpolarized</td>
<td>85%</td>
</tr>
<tr>
<td>Photo Production</td>
<td>Synchrotron</td>
<td>Bremsstrahlung</td>
</tr>
<tr>
<td>Converter Target</td>
<td>Tungsten Foil</td>
<td>Tungsten Foil</td>
</tr>
<tr>
<td>Positron Polarization</td>
<td>80% (measured)</td>
<td>40% (Simulation)</td>
</tr>
</tbody>
</table>

Positron Yield scales with Beam Power
- Replace GeV-pulsed with MeV-CW
- Reduce radiation budget
  - Remain below photo-neutron threshold
- Bunch/Capture to SRF linac
  - Compact source vs. Damping Ring

Unique capabilities
- First CW source with helicity reversal
Simulation are performed within the GEANT4 framework, taking advantage of the polarization capabilities developed by the E166 Collaboration.

R. Dollan, K. Laihem. A. Schälicke, NIM A559 (2006) 185

The source files are modified to select complete screening (where T~0 or T~60 MeV)


\[ P_{e^-} = 85\% \quad T_w = 100 \mu m \]
The Figure of Merit is the quantity of interest for the accuracy of a measurement which combines the incident flux of particles and its polarization.

$$\Delta \theta_{e^+} = \pm 10^\circ \quad \Delta E_{e^+} = \pm 0.25 \text{ MeV}$$

$$\text{FoM} = I_{e^+} \times P_{e^+}^2$$

$I_{e^-} = 1 \text{ mA}$
Simplistic cuts are applied to mimic a capture system and the accelerator acceptance.

Thickness sensitivity is under study...
An experiment to test the production of polarized positrons is currently designed. The goals are to measure the yield and polarization distributions as a function of the beam energy.

- The ATF/KEK & E166 successful set-up serves as a conceptual guidance towards the final design.
- Polarimetry would consist of a Compton transmission polarimeter.
- Calibration and check of the analyzing power can be performed with the polarized electron beam.
- The Compton asymmetry would be measured by reversing the beam (up to 1 kHz frequency of random change) and/or the target polarization.

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G. Alexander et al, PRL 100 (2008) 210801
G. Alexander et al, physics.ins-det:0905.3066

Compton Transmission Polarimeter

Detector solid angle = +/- 8°

Average asymmetry for $P_{\gamma,\text{circ}} = 10\%$
What about CEBAF 10 MeV injector at milliamps?

100kV Gun

$\varepsilon_{x,y}$ filter $\varepsilon_z$ filter SRF

<table>
<thead>
<tr>
<th>Condition</th>
<th>Repetition Rate</th>
<th>Bunch Charge</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical</td>
<td>499 MHz</td>
<td>0.2 pC</td>
<td>100 uA</td>
</tr>
<tr>
<td>G0 (2003)</td>
<td>31 MHz</td>
<td>1.25 pC</td>
<td>40 uA</td>
</tr>
<tr>
<td>G0-like</td>
<td>1497 MHz</td>
<td>1.25 pC</td>
<td>1900 uA</td>
</tr>
</tbody>
</table>

Operating at higher gun voltage...

- Improves transmission (stiffer beam)
- May improve photocathode lifetime

For high bunch charge guns (like ILC/CLIC)
Essential to overcome photoemission limit
Field Emission - Critical Issue for Higher Voltage

"Conventional" cathode electrode mounted on metal support structure

"Inverted" no SF6 and no HV breakdown outside chamber

Stainless Steel (vs. gap)

Niobium (50 mm gap)

5 MV/m

Work of Ken Surles-Law, Jefferson Lab

Thanks to P. Kneisel, L. Turlington, G. Myneni
Conventional Ceramic
• Exposed to field emission
• Large area
• Expensive (~$50k)

Medical x-ray technology

New Ceramic
• Compact
• ~$5k

Want to move away from “conventional” insulator used on all GaAs photoguns today - expensive, months to build, prone to damage from field emission.
July 2009 - Assembling the inverted gun chamber
New CEBAF “Inverted” Polarized e-Gun

Installed July-August:
✓ Vacuum => extractor ~3E-12 Torr, IP ~20pA
✓ HV Process to 110kV => no FE or VAC activity
✓ New HVPS => Increased to 150kV supply
✓ New Photocathode => QE>1% and P~85%

Just began running about a week ago.
We’ll begin characterizing lifetime & photocathode...

to 90.24, very easy keeping Wien quads OFF.
Polarization: (85.54 +/- 1.09stat +/- 1.03sys) %
, Polarization: (84.98 +/- 1.07stat +/- 1.02sys) %
ott. Turned off prebuncher. Helped. Adjusted Hall after the measurement. In brief, Hall E needs some

, Polarization: (85.77 +/- 1.23stat +/- 1.03sys) %
Polarization: (84.38 +/- 1.28stat +/- 1.01sys) %
off, very nice spectra, no changes required.
Polarization: (85.32 +/- 1.11stat +/- 1.02sys) %
, Polarization: (85.07 +/- 1.05stat +/- 1.02sys) %