Precision test of Jefferson Lab Mott Polarimeter at 3-8 MeV

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Polarized Sources, Targets, and Polarimetry 2013
Outline

1. Mott Overview & Motivation
   - What is the MeV Mott?
   - Motivation for New Tests

2. Understanding Elastic Signal
   - Elastic Spectrum Tails
   - GEANT4 Modeling

3. Minimizing Backgrounds
   - Backscatter
   - Reducing Background events

4. Future Work
Mott Location

- Located in the injector.
- Measures transverse polarization close to the source.
- Along with spin rotators, sets spin direction for experiments.
Mott Scattering Asymmetry

The $eA$ cross section can be written

$$\sigma(\theta) = I(\theta) [1 + S(\theta)\mathbf{P} \cdot \mathbf{n}]$$

with $\mathbf{n} = \frac{\mathbf{k} \times \mathbf{k}'}{|\mathbf{k} \times \mathbf{k}'|}$. If $\mathbf{P}$ is horizontal, we see an up-down asymmetry,

$$A_{UD} = \frac{\sigma_U - \sigma_D}{\sigma_U + \sigma_D} = S(\theta)P.$$

In actuality we use the cross-ratio method:

$$A_{UD} = \frac{1 - r}{1 + r} \quad \text{with} \quad r = \sqrt{\frac{N_U^\uparrow N_D^\uparrow}{N_U^\downarrow N_D^\uparrow}}.$$

This leaves us insensitive to false asymmetries at all orders from detector solid angle and efficiency, beam current, and target thickness and at first order from polarization differences and scattering angle.
Mott Layout

Typical run parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_{sc}$</td>
<td>$172.6^\circ \pm 0.45^\circ$</td>
</tr>
<tr>
<td>$d\Omega$</td>
<td>$0.21 \text{ msr}$</td>
</tr>
<tr>
<td>$I_{beam}$</td>
<td>$1.0 \mu\text{A}$</td>
</tr>
<tr>
<td>Beam Energy</td>
<td>$5.0 \text{ MeV}$</td>
</tr>
<tr>
<td>Event Rate</td>
<td>$1 \text{ kHz}$</td>
</tr>
<tr>
<td>Spin Flip Rate</td>
<td>$30 \text{ Hz}$</td>
</tr>
</tbody>
</table>

Our target inventory includes Au, Ag, and Cu foils. Mirror collects OTR light for viewer.
- Figure of Merit, $\epsilon(\theta) = I(\theta)S(\theta)^2$, is inversely related to $\delta P$.
- Designed to run on 1µm Au at 5 MeV.
- Can measure polarization to $\approx 1\%$ statistical uncertainty in 5 minutes.
Detectors

- ≈ 3% Energy resolution.
- Coincidence trigger on $E + \Delta E$ detectors (removes $\gamma$s)
Data Acquisition

- FADC channels for E and ΔE detectors records event pulse height at sample rate of 250 MHz.
- No dead-time issues with < 5 kHz means higher currents possible.
- Handles delayed helicity reporting.
- TDCs provide time-of-flight with 35 ps resolution.
- BCM cavity measures $I_{beam} > 5$ nA.
Multiple Scattering and Effective Sherman Function

\[ A(\theta, d) = PS_{\text{eff}}(\theta, d) = \frac{PS(\theta)}{1 + \alpha(\theta)d} \]

- Tests in 2000 reported a 1.1 % systematic error. Sherman function uncertainties are the largest single issue.
- Since then several changes have been made and the most recent results are slightly inconsistent.
- Two-fold path for improving measurements:
  1. GEANT4 modeling and theoretical inputs for better systematics.
  2. Reducing backgrounds through hardware updates.
Clear “tails” (low energy shoulders on elastic peak) of unknown cause in the spectrum.

Propose to use GEANT4 simulation for two tasks:

1. Determine the cause of the “tails” by accurately modelling detector geometry and response.
2. Provide insight into $A(d)$ and $S(d)$ by determining effects of target thickness directly.
“Tail” carries almost full strength of the physics signal.

Possible that these are good events loosing energy after target and not being counted.
GEANT4 Modelled Apparatus

- Fires beam from the target to the detectors.
- Contains realistic handling of optical photons generated by scintillation and cerenkov processes.
**GEANT4 Simulated Spectra**

**E Spectra**

- **Blue**: “Vacuum” (i.e. beamline vacuum only between the primary vertex and the E detector). Monoenergetic beam of 5 MeV in all cases.
- **Red**: Added ∆E detector.

Energy (MeV) vs. Entries.
GEANT4 Simulated Spectra

E Spectra

Blue: Vacuum
Red: ΔE detector + Air.
GEANT4 Simulated Spectra

E Spectra

- Blue: Vacuum
- Red: $\Delta E$ detector, Air + Al nose and Pb cap.
GEANT4 Simulated Spectra

E Spectra

- Blue: Vacuum
- Red: ΔE detector, Air, Al nose and Pb cap + 8 mil Al window
GEANT4 Simulated Spectra

E Spectra

- **Blue**: Vacuum
- **Red**: All components in place. Illuminating entire acceptance.
GEANT4 Simulated Spectra

E Spectra

- **Blue**: Vacuum
- **Red**: All components in place. Illuminating entire acceptance. Passes through 5 $\mu$m Au foil.
GEANT4 Comparison

E Spectra

- Blue: Vacuum
- Red: Passes through 5 µm Au foil.
- Black: Actual 1 µm Au data.

Conclusions about “tails”:
1. γ’s in the detector are a part.
2. Radiative losses in window and scraping on collimator contribute.
3. More work is needed.
Background Source Beam Dump

- 1.0” thick 8” diameter Al plate in small lead hut.
- Large amount (% varies with $d$ and $E$) of backscatter from dump makes it into the detectors.
- Can’t separate out using TDC cuts in typical running conditions.
ToF Selection

- Total rate from dump comparable to or greater than rate from target in thinner foils.
- Effects “tails” and lower elastic peak.
- Using new DAQ, can select for only in-time events with low rep rate.
Normal Operation Issues

- Dump contributes as much as 8% of signal under elastic peak ($2\sigma$) on 1 $\mu$m Au.
- When we run at high rep rate, can no longer remove background.
- **Proposed Solution**: switch to a low Z material in the beam dump.
Tabata predicts a factor of $\approx 10$ reduction.

Using 0.25” Be backed by 0.75” Cu (red) we see a reduction by a factor of 4 over Al.
Future Plans

1. Use input from theorists to implement Mott physics with smallest uncertainties possible.
2. Transition from modelling detector response to modelling whole polarimeter → numerically predict $A(d)$.
3. Put new hardware (beam dump, target ladder ...) in place.
4. Ready to take beam whenever it comes back.
The End
Thermal model of Mott Dump

• No contact of Be disk back to Cu disk front
• Contact on Be disk side only

\( \frac{dE}{dx} = 1.6 \text{ MeV cm}^2 \text{ g}^{-1} \)

• \( I_{\text{beam}} = 10 \mu\text{A} \)
• No contact of Be disk back to Cu disk front
• Contact on Be disk side only
Electron-Nucleus Scattering

Electron moves in the nuclear Coulomb field, \( \mathbf{E} = \frac{Ze}{r^3} \mathbf{r} \). Magnetic field induced in electron’s frame, \( \mathbf{B} = -\frac{1}{c} \mathbf{v} \times \mathbf{E} \). Therefore

\[
\mathbf{B} = \frac{Ze}{cr^3} \mathbf{r} \times \mathbf{v} = \frac{Ze}{mcr^3} \mathbf{L}
\]

Magnetic field couples to the electron’s spin \( V_{so} = -\mu_s \cdot \mathbf{B} \). Scattering potential:

\[
V(r, \mathbf{L}, \mathbf{S}) = V_C(r) + V_{so}(r, \mathbf{L}, \mathbf{S}) = \frac{Ze}{r} + \frac{Ze^2}{2m^2c^2r^3} \mathbf{L} \cdot \mathbf{S}.
\]
Detailed Sherman Function

The single scattering cross-section for a point like nucleus is

$$\sigma(\theta) = I(\theta) \left[ 1 + S(\theta) \mathbf{P} \cdot \mathbf{n} \right]$$

with $$\mathbf{n} = \frac{\mathbf{k} \times \mathbf{k}'}{|\mathbf{k} \times \mathbf{k}'|}$$. The spin-averaged cross section is

$$I(\theta) = \left( \frac{mc}{p} \right)^2 \left[ \left( \frac{Ze^2}{mc\beta} \right)^2 (1 - \beta^2) \frac{|f(\theta)|^2}{\sin^2(\theta/2)} + \frac{|g(\theta)|^2}{\cos^2(\theta/2)} \right]$$

and $$S(\theta)$$ is the Sherman Function,

$$S(\theta) = \frac{2}{I(\theta)} \left( \frac{mc}{p} \right)^2 \left( \frac{Ze^2}{mc\beta} \right) \frac{\sqrt{1 - \beta^2}}{\sin(\theta/2)} \left[ f(\theta)g^*(\theta) + f^*(\theta)g(\theta) \right]$$