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

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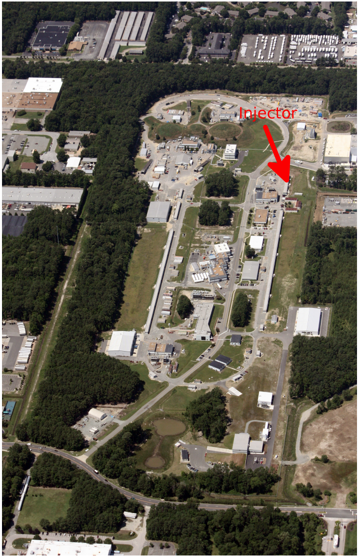
Polarized Sources, Targets, and Polarimetry 2013

Outline

1. Mott Overview & Motivation
   - What is the MeV Mott?
   - Motivation for New Tests
2. Detector Spectra
   - Elastic Spectrum Tails
   - GEANT4 Modeling
3. Beam Dump Upgrade
   - Backscatter
   - Beam Dump Upgrade
4. Future Work

Mott Location



- Located in the injector.
- Measures $\perp$ polarization close to the source.
- Along with spin rotators, sets spin direction for experiments.

Mott Scattering Basics

The eN cross section can be written

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

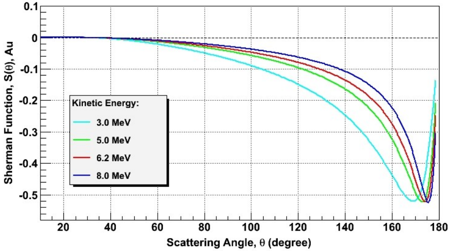
with $\mathbf{n} = \frac{\mathbf{k}\times\mathbf{k}'}{|\mathbf{k}\times\mathbf{k}'|}$. If $\mathbf{n} = \mathbf{x}$ beam comes in, we see an asymmetry in the up and down detectors

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

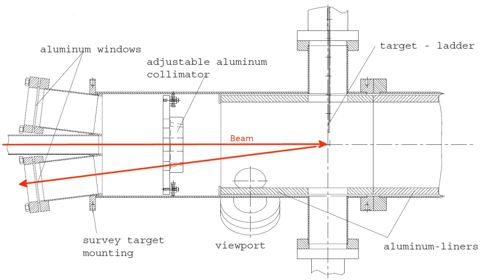
$S(\theta)$ is the analyzing power, known in this case as the Sherman function.

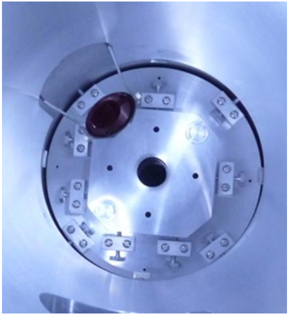
Energy Optimization

- Very large Sherman function in this range
- Operates in the 1 μA current range
- Uses "thick" ($>$ 100 nm) targets for both higher rate and ease of manufacturing.



Mott Layout

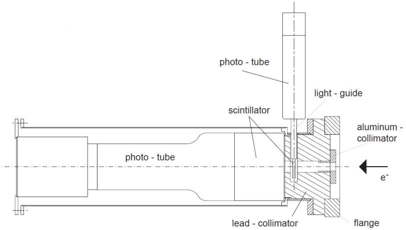


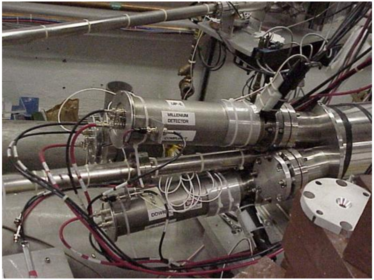


- Targets are 0.01-5 μm of Au, Ag, Cu, C.
- $\theta_{sc} = 172.6^{\circ}$
- Acceptance of 2.1 msr
- $A_{UD} = \frac{1-r}{1+r}$ with

$$r = \sqrt{\frac{N_U^{\uparrow} N_D^{\downarrow}}{N_U^{\downarrow} N_D^{\uparrow}}}$$

Detectors





- $\sim$ 3% Energy resolution
- Coincidence trigger on E+δE detectors (removes neutrals)

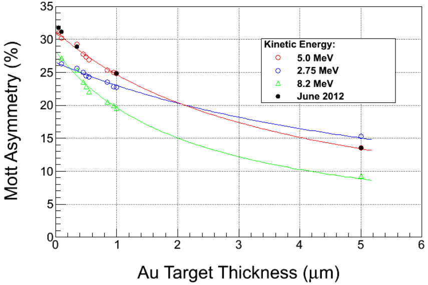
New DAQ

- FADC channels for E and ΔE detectors records event pulse height
- No dead-time issues with < 5 kHz means higher currents possible.
- Handles delayed helicity reporting.
- Collects time-of-flight of detected electrons.

Goals of Precision Test

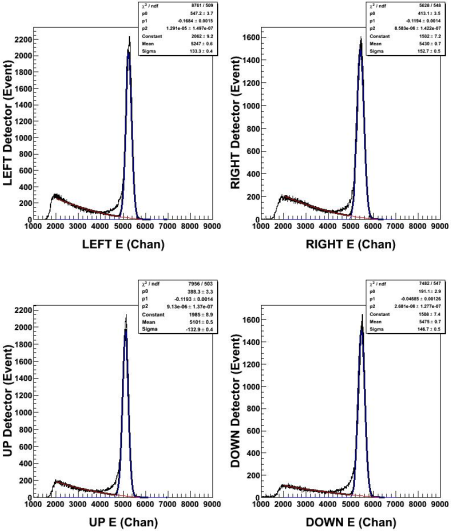
1. Last test results were published in 2000 (Steigerwald SPIN 2000 Proceedings). Need an update and check for agreement.
2. Build GEANT4 model that accurately represents the apparatus.
3. Incorporate Mott Scattering physics into GEANT4 to determine the "Ideal" spectrum for good target events.
4. Update hardware and software to run at higher rates in 12 GeV era.

Effective Sherman Function



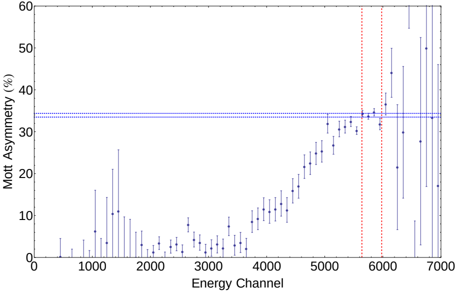
- Empirical fit with $A(d) = \dfrac{PS(\theta)}{1 + \alpha d}$ introduces systematic uncertainties from theoretical Sherman function, target thickness, etc. These uncertainties dominate measurement.
- So far good agreement at a few % from past results. Can we make this better?

Detector Spectra



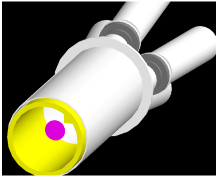
- Clear "tails" in the spectrum.
- Goals of simulation is two fold:
  1. Elastic specrtum shape accurately
  2. Provide insight into $A(d)$

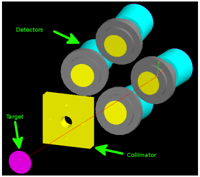
Asymmetry Vs. Energy

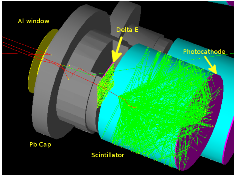


- Measured asymmetry calculated between dotted lines.
- "Tail" carries almost full strength of the physics signal but with lower cross-section.
- Possible that these are good events loosing energy after target and not being counted.

Current Setup

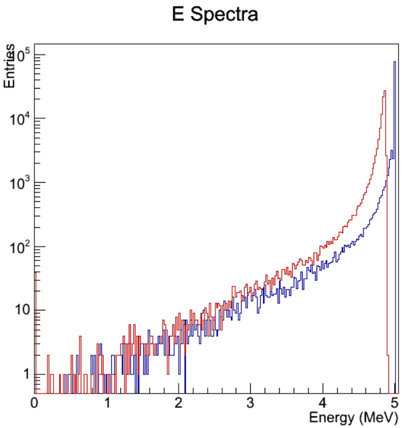






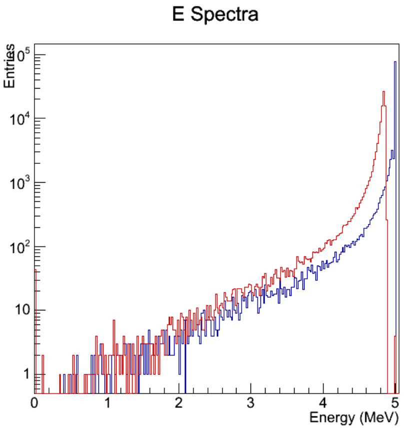
- Currently fires beam from the front or back of the target to the detectors.
- Contains Reaalistic handling of optical photons generated by scintillation and cerenkov processes.

GEANT4 Simulated Spectra



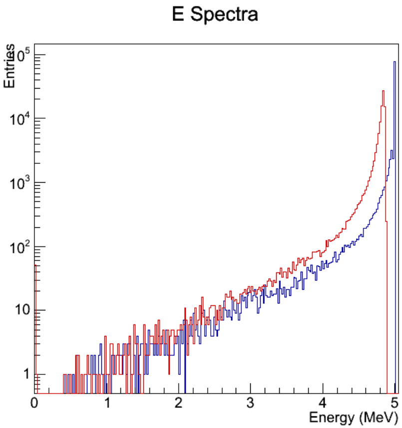
- A mono-energetic 5 MeV beam shot at the detector package.
- Blue: Vacuum, no ΔE
- Red: Including ΔE detector

GEANT4 Simulated Spectra



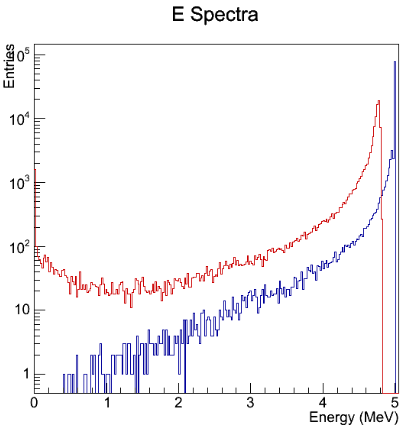
- Blue: Vacuum, no ΔE
- Red: Added Air

GEANT4 Simulated Spectra



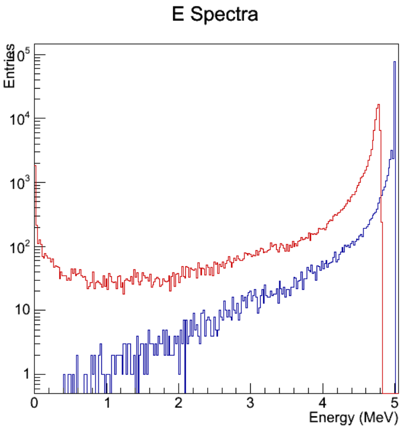
- Blue: Vacuum, no ΔE
- Red: Added external Al collimator and Pb cap.

GEANT4 Simulated Spectra



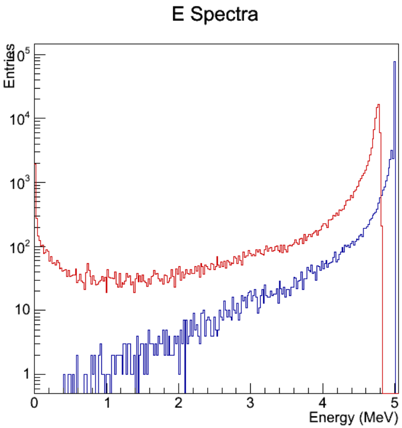
- Blue: Vacuum, no ΔE
- Red: Added external Al window

GEANT4 Simulated Spectra



- Blue: Vacuum, no ΔE
- Red: Raster over acceptance

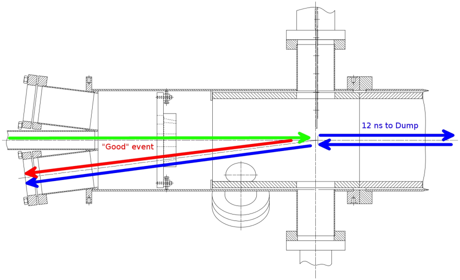
GEANT4 Simulated Spectra



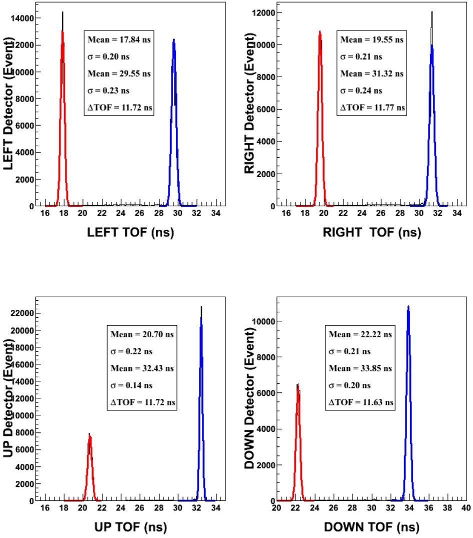
- Blue: Vacuum, no ΔE
- Red: Passes through 5 μm Au foil.

Current Beam Dump

- 1.0" thick 8" diameter Al plate in small lead hut
- Heating issues limit beam current
- Large amount of backscatter from dump makes it into the detectors



Backscatter Problem



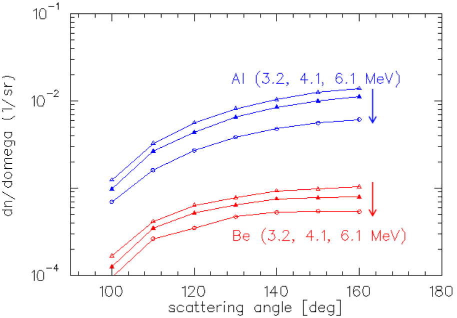
- Total rate from dump comparable to or greater than rate from target in thinner foils.
- Using new DAQ, can select for only in-time events.

Beam Dump Upgrade Goals

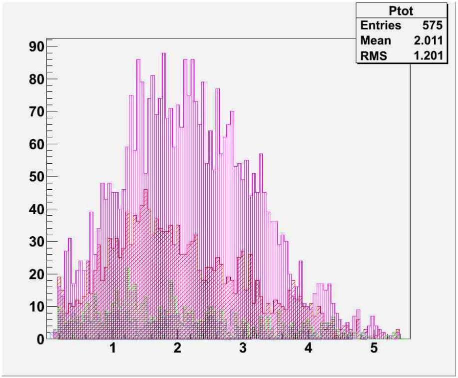
1. Reduce amount of Backscatter
2. Increase amount of current it can handle

Proposed design of 0.25" Be backed with 0.75" Cu should address both of these issues.

Backscatter Solution: Beryllium



Data from Tabata



G4beamline simulation counting backscattered, $p_z < 0$, electrons vs. energy.

GEANT4 Plan

1. Write Single Nucleon Mott Scattering event generator using input from theorists.
2. Test for Asymmetries using this distribution.
3. Include the cross section from (1) into the physics processes and geometrically bias events in order to determine asymmetry as a function of target thickness.
4. Use the error estimates provided from simulation to better constrain the accuracy of our theoretical Sherman function.

Precision Upgrades

1. New targets and target ladders.
2. New beam dump.
3. Ready for beam time by late Fall 2014.

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 $V_{so} = -\boldsymbol{\mu}_s \cdot \mathbf{B}$. 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,

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

Measuring Asymmetries

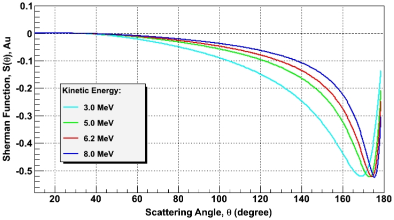
How we actually measure the polarization:

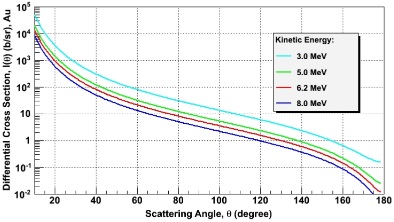
- Measure hits in each detector for one helicity state. Get $N_L^{\uparrow}$ and $N_R^{\uparrow}$.
- Flip helicity, repeat. Get $N_L^{\downarrow}$ and $N_R^{\downarrow}$.
- Calculate the *cross-ratio*, $r = \sqrt{\frac{N_L^{\uparrow} N_R^{\downarrow}}{N_L^{\downarrow} N_R^{\uparrow}}}$.
- Calculate asymmetry $A_{LR} = \frac{1-r}{1+r}$.
- Do the same for the vertical A_{UD}.

The polarization is

$$\mathbf{P} = \frac{1}{S_{eff}(\theta)} \left[A_{LR}\hat{\mathbf{y}} - A_{UD}\hat{\mathbf{x}} \right]$$

Sherman Function Corrections





$S(\theta)$ must account for

- Finite Nucleus. Adjust theoretical prediction.
- Multiple scattering. Shown as dependence on target thickness, d

$$S(\theta) \to S_{eff}(\theta, d) = \frac{S(\theta)}{1 + \alpha(\theta) d}.$$

Run on thinnest possible target.

Mott Layout