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

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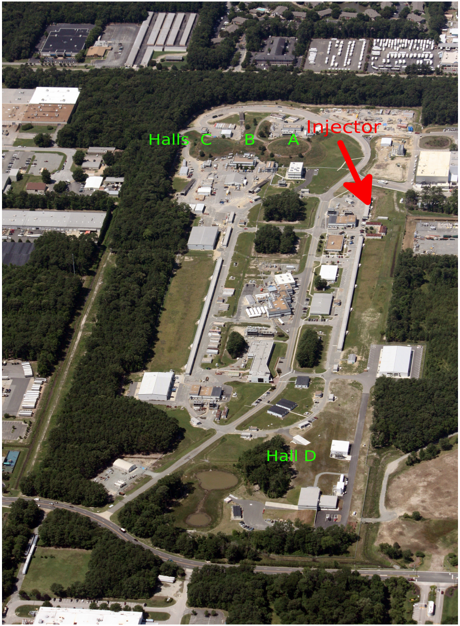
Polarized Sources, Targets, and Polarimetry 2013

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

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

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

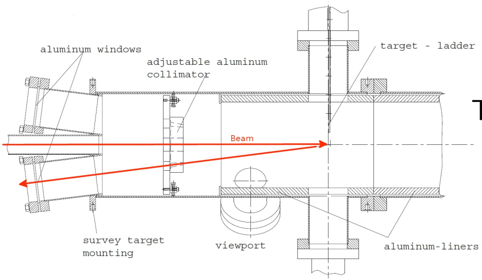
$$A_{UD} = \frac{\sigma_U - \sigma_D}{\sigma_U + \sigma_D} = S(\theta)P.$$

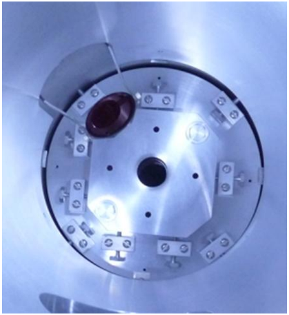
In actuality we use the cross-ratio method:

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

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



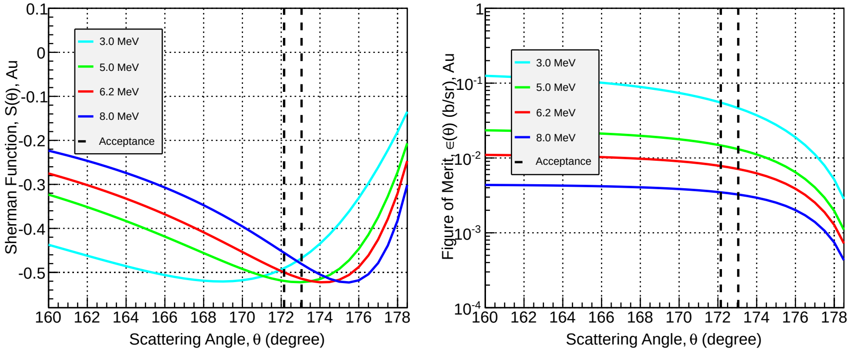


Typical run parameters:

θ_{sc}	$172.6^\circ \pm 0.45^\circ$
$d\Omega$	0.21 msr
I_{beam}	1.0 μA
Beam Energy	5.0 MeV
Event Rate	1 kHz
Spin Flip Rate	30 Hz

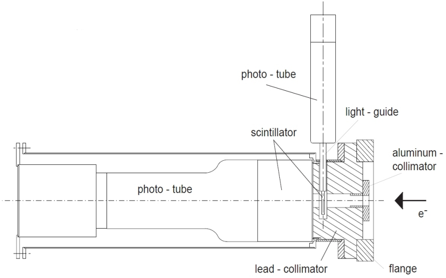
Our target inventory includes Au, Ag, and Cu foils. Mirror collects OTR light for viewer.

Polarimeter Optimization

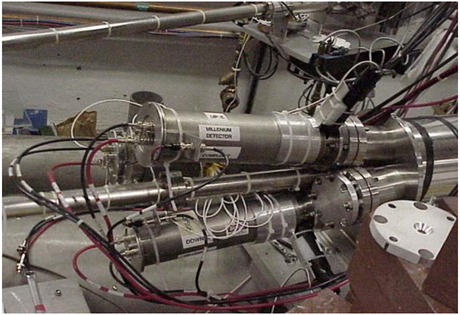


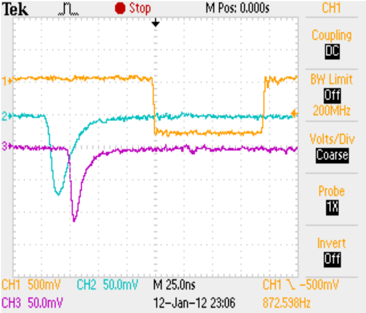
- Figure of Merit, $\epsilon(\theta) = I(\theta)S(\theta)^2$, is inversely related to δP.
- Designed to run on 1μm Au at 5 MeV.
- Can measure polarization to ≈ 1 % statistical uncertainty in 5 minutes.

Detectors

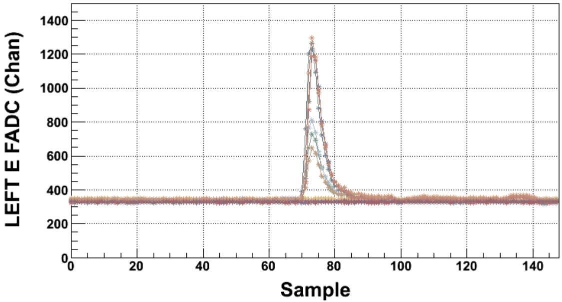


- ≈ 3% Energy resolution.
- Coincidence trigger on E+ΔE detectors (removes γs)



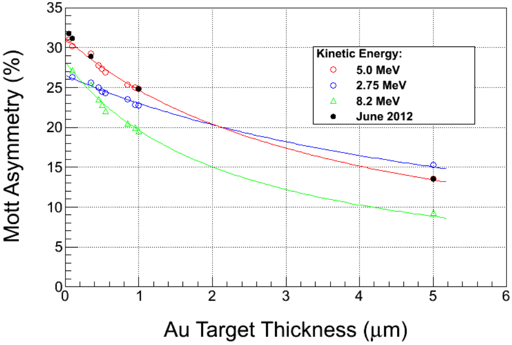


Data Aquisition



- 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.

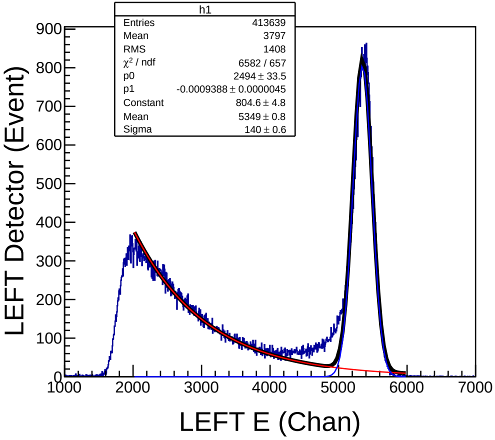
Multiple Scattering and Effective Sherman Function



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

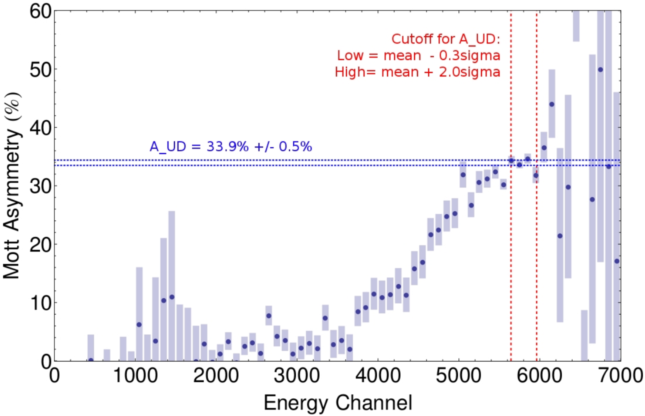
- Tests in 2000 reported a 1.1 % systematic error. Sherman function uncertainties are the largest single issue.
- Since then several changes have been made and the most recent results are slightly inconsistent.
- Two-fold path for improving measurements:
  1. GEANT4 modeling and theoretical inputs for better systematics.
  2. Reducing backgrounds through hardware updates.

Detector Spectrum



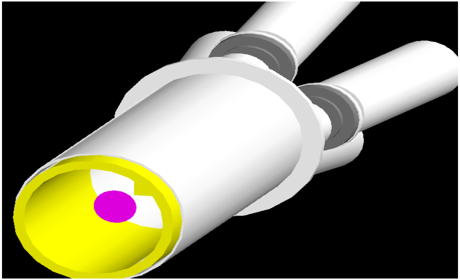
- Clear "tails" (low energy shoulders on elastic peak) of unknown cause in the spectrum.
- Propose to use GEANT4 simulation for two tasks:
  1. Determine the cause of the "tails" by accurately modelling detector geometry and response.
  2. Provide insight into $A(d)$ and $S(d)$ by determining effects of target thickness directly.

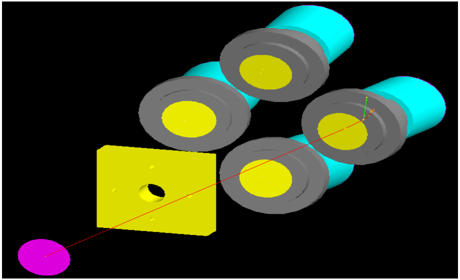
Asymmetry Vs. Energy

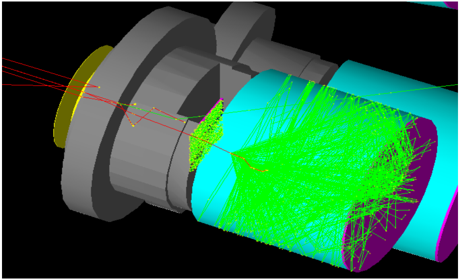


- "Tail" carries almost full strength of the physics signal.
- Possible that these are good events loosing energy after target and not being counted.

GEANT4 Modelled Apparatus

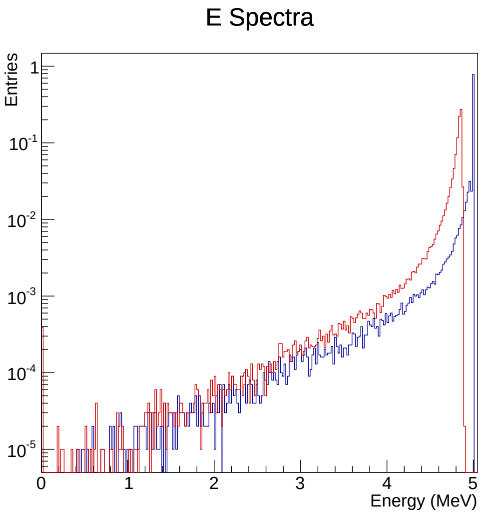






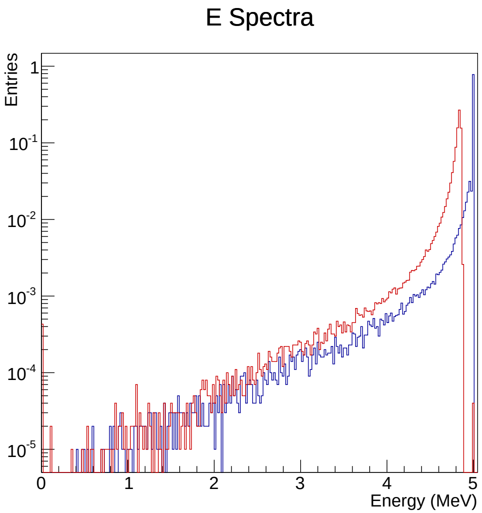
- Fires beam from the target to the detectors.
- Contains realistic handling of optical photons generated by scintillation and cerenkov processes.

GEANT4 Simulated Spectra



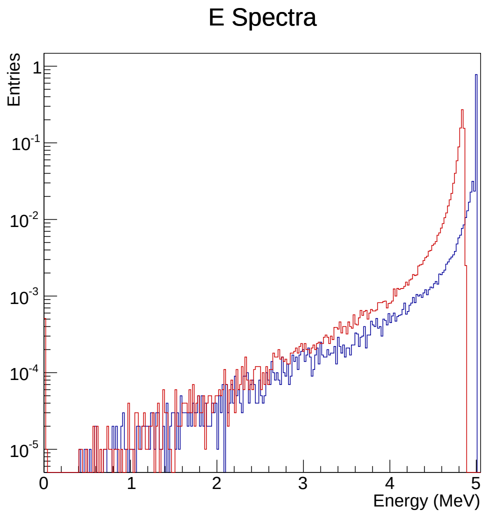
- Blue: “Vacuum” (i.e. beamline vacuum only between the primary vertex and the E detector). Monoenergetic beam of 5 MeV in all cases.
- Red: Added ΔE detector.

GEANT4 Simulated Spectra



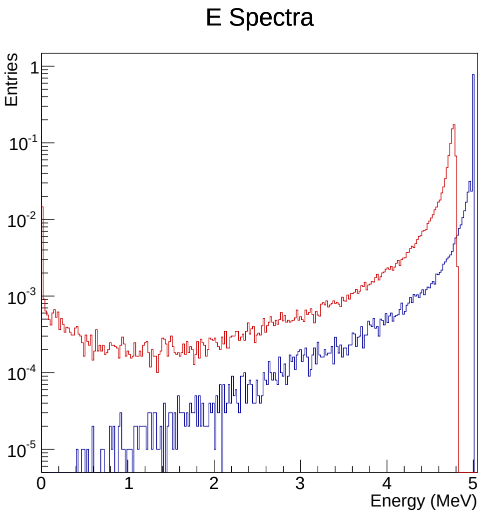
- Blue: Vacuum
- Red: ΔE detector + Air.

GEANT4 Simulated Spectra



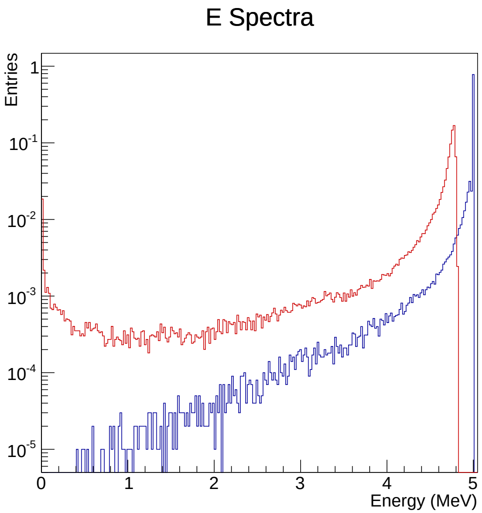
- Blue: Vacuum
- Red: ΔE detector, Air + Al nose and Pb cap.

GEANT4 Simulated Spectra



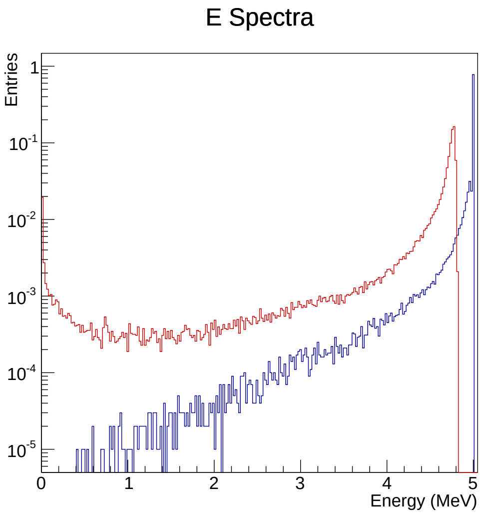
- Blue: Vacuum
- Red: ΔE detector, Air, Al nose and Pb cap + 8 mil Al window

GEANT4 Simulated Spectra



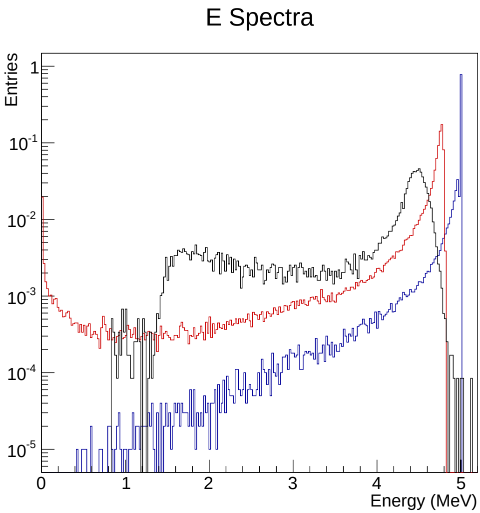
- Blue: Vacuum
- Red: All components in place. Illuminating entire acceptance.

GEANT4 Simulated Spectra



- Blue: Vacuum
- Red: All components in place. Illuminating entire acceptance. Passes through 5 μm Au foil.

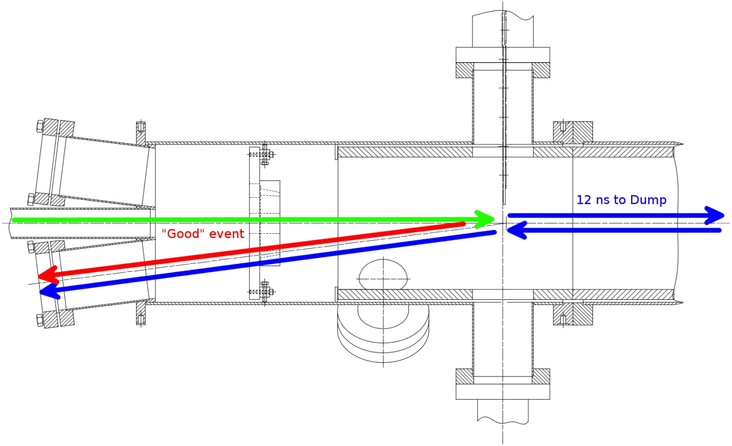
GEANT4 Comparison



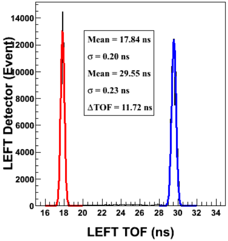
- Blue: Vacuum
- Red: Passes through 5 μm Au foil.
- Black: Actual 1 μm Au data.
- Conclusions about "tails":
  1. γ's in the detector are a part.
  2. Radiative losses in window and scraping on collimator contribute.
  3. More work is needed.

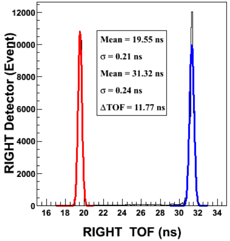
Background Source Beam Dump

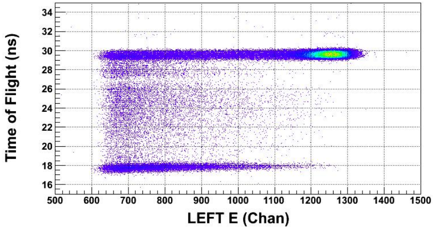
- 1.0" thick 8" diameter Al plate in small lead hut.
- Large amount (% varies with d and E) of backscatter from dump makes it into the detectors.
- Can't separate out using TDC cuts in typical running conditions.

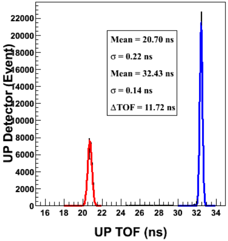


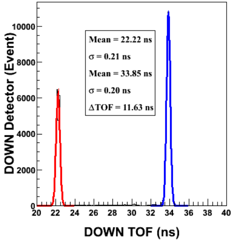
ToF Selection





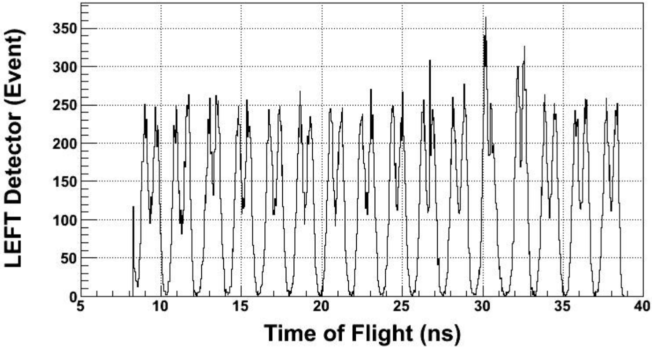






- Total rate from dump comparable to or greater than rate from target in thinner foils.
- Effects “tails” and lower elastic peak.
- Using new DAQ, can select for only in-time events with low rep rate.

Normal Operation Issues



- Dump contributes as much as 8% of signal under elastic peak (2 σ) on 1 μm 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.

Backscatter Solution: BeCu Dump-Plate

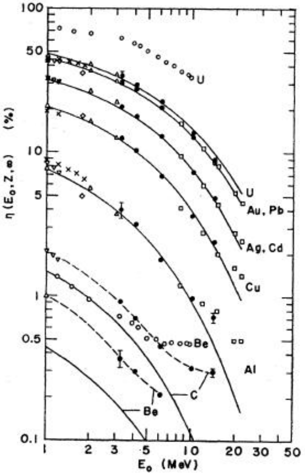
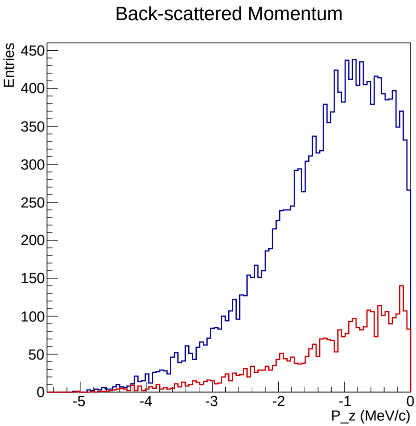


FIG. 8. Dependence of total backscattering coefficient $\eta(E_0, Z, \infty)$ for semi-infinite targets upon incident energy E_0.

Tabata predicts a factor of ≈ 10 reduction.

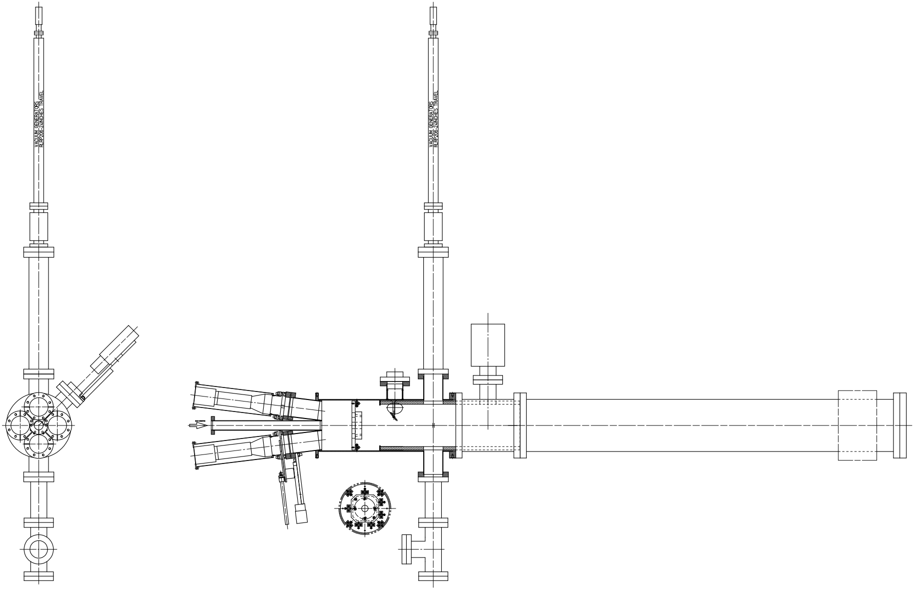


Using 0.25" Be backed by 0.75" Cu (red) we see a reduction by a factor of 4 over Al.

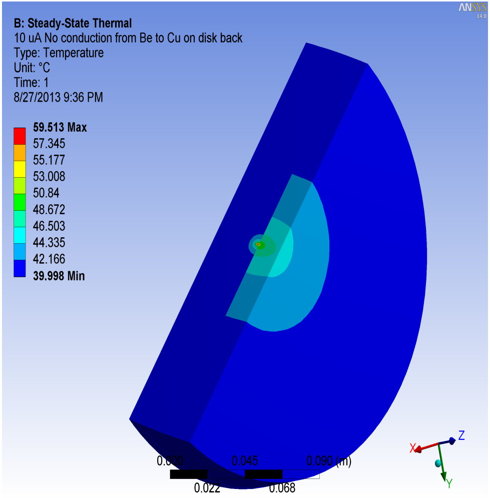
Future Plans

1. Use input from theorists to implement Mott physics with smallest uncertainties possible.
2. Transition from modelling detector response to modelling whole polarimeter $\rightarrow$ 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



- $\frac{dE}{dx} = 1.6\, MeV \frac{cm^2}{g}$
- $I_{beam} = 10\mu A$
- 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 $V_{so} = -\boldsymbol{\mu}_s \cdot \mathbf{B}$. 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,

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