Moller Polarimetry

NIMA Papers & MOLLER Prep

Eric King – Jan 23, 2023

TEMPLE UNIVERSITY

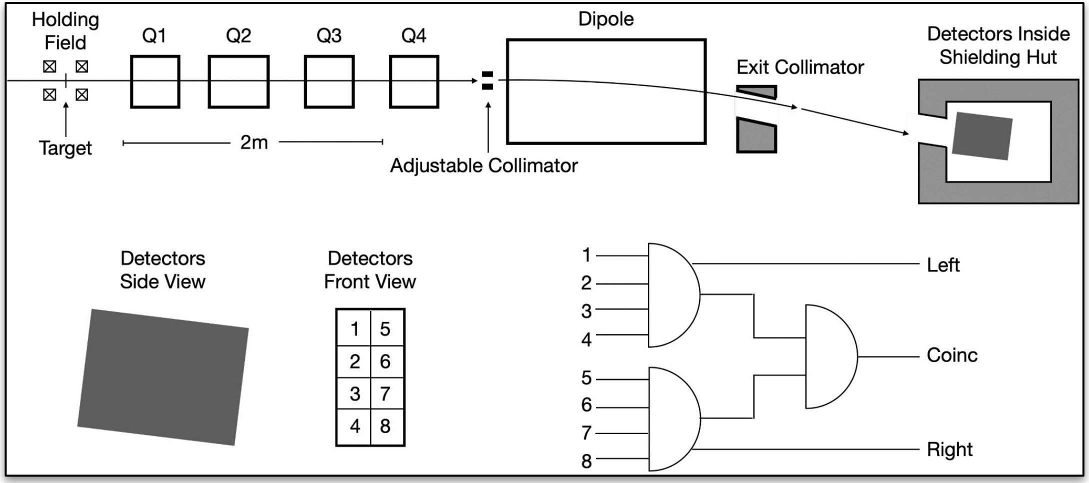
Jefferson Lab
Exploring the Nature of Matter

2023 Winter Hall-A Collaboration Meeting

Outline

- Quick Moller Polarimeter/Polarimetry Overview (for the sake of anyone new)
- NIMA Paper(s)
  - PREX-2/CREX Moller Polarimetry Paper
  - Foil Polarization Paper
- Preparation for MOLLER
  - Ongoing
  - Remaining Concerns

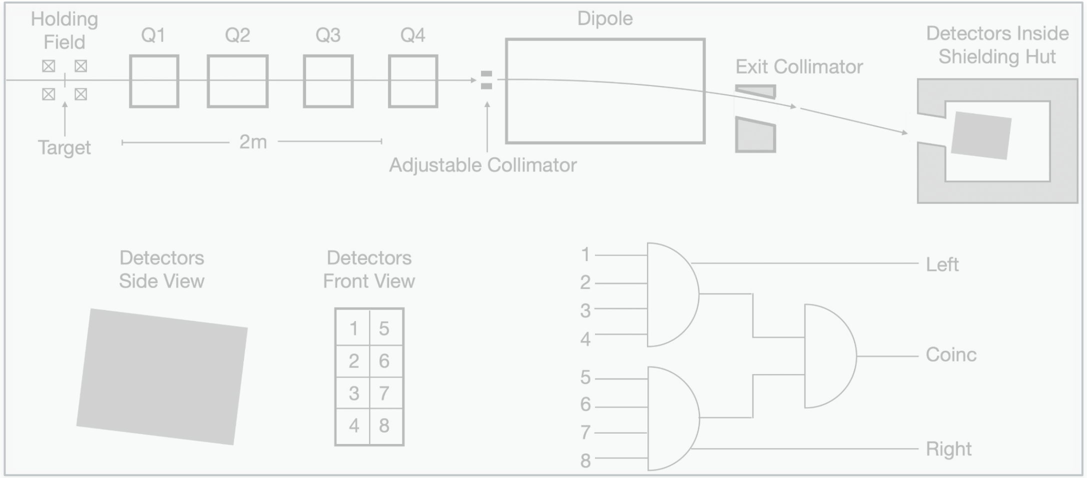
Quick Polarimeter Overview



- Target magnetically saturated – “brute force” – with the target plane perpendicular to beam.
- QQQQD Spectrometer
- Spaghetti lead fiber detector.
- 8PMTs
  - Left / right
  - Analyze Coincidence

Quick Polarimeter Overview

$$A_{zz}(\theta) = \frac{(7+\cos^2\theta)\sin^2\theta}{(3+\cos^2\theta)^2}$$



- Target magnetically saturated – "brute force" – with the target plane perpendicular to beam.
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$$A_{\text{meas}} = \frac{R_{\uparrow\uparrow}-R_{\downarrow\uparrow}}{R_{\uparrow\uparrow}+R_{\downarrow\uparrow}} = -P_{\text{beam}}P_{\text{target}}\boxed{\langle A_{zz}\rangle}$$

We measure this

We want this

We know this

We compute this

- We measure the asymmetry of Moller coincidence hits
- Extract beam polarization given target polarization and computed analyzing power.
  - We verify our computed analyzing power by measuring asymmetry at different magnetic optics settings.

NIMA Papers

*Details for everything skimmed over in these slides **and more** can be found in the papers.*

Two papers published in NIMA:

- Precision Polarimetry for PREX2/CREX – King et al.
  - 10.1016/j.nima.2022.167506
- Determination of Fe/Ni Foil Polariations – Jones et al.
  - 10.1016/j.nima.2022.167444

PREX-2 / CREX Moller Polarimery Paper

Precision Møller polarimetry for PREX-2 and CREX

D.E. King [a,b], D.C. Jones [c,a,*], C. Gal [d,e], D. Gaskell [c], W. Henry [c], A.D. Kaplan [a], J. Napolitano [a], S. Park [d,e], K.D. Paschke [f], R. Pomatsalyuk [g], P.A. Souder [b]

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A R T I C L E I N F O

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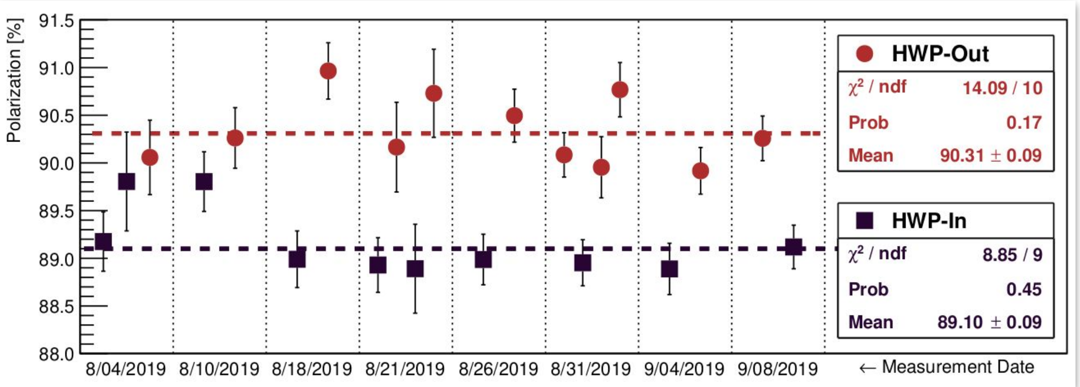
A B S T R A C T

The PREX-2 and CREX experiments in Hall A at Jefferson Lab are precision measurements of parity violating elastic electron scattering from complex nuclei. One requirement was that the incident electron beam polarization, typically $\approx 90\%$, be known with 1% precision. We commissioned and operated a Møller polarimeter on the beam line that exceeds this requirement, achieving a precision of 0.89% for PREX-2, and 0.85% for CREX. The uncertainty is purely systematic, accumulated from several different sources, but dominated by our knowledge of the target polarization. Our analysis also demonstrates the need for accurate atomic wave functions in order to correct for the Levchuk Effect. We describe the details of the polarimeter operation and analysis, as well as (for CREX) a comparison to results from a different polarimeter based on Compton scattering.

Accepted in Aug 2022, Published in Sept 2022

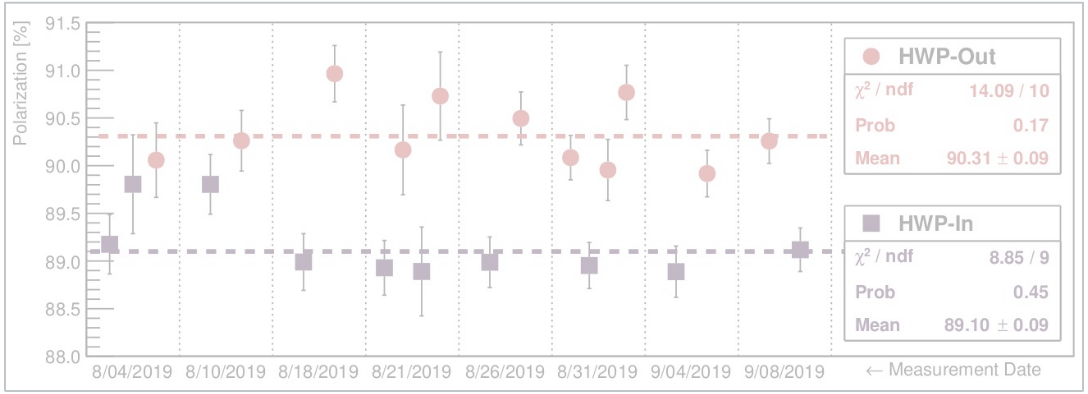
PREX-2 / CREX Moller Polarimetry Paper (cont'd)



- Results of PREX2 polarization measurements reported and detailing
  - Data corrections: **deadtime**; accidentals; charge normalization; null asymmetry; and **foil polarization**.
  - Extrapolation uncertainties: **high-current running**; **leakage current**; and laser polarization/precession/QE

*[Note: **Bold** entries require ongoing work towards MOLLER goals.]*

PREX-2 / CREX Moller Polarimetry Paper (cont'd)



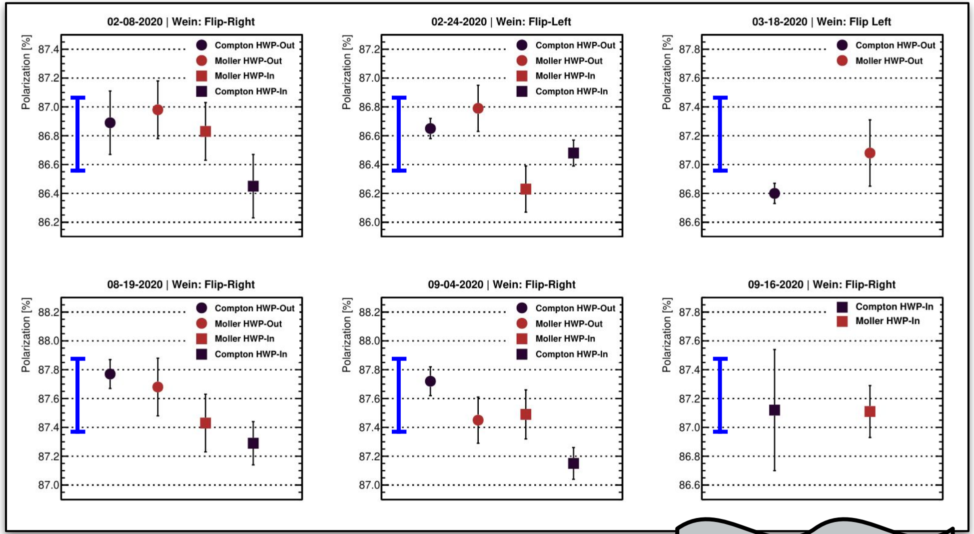
Uncertainty	PREX-2	CREX
$\langle A_{zz} \rangle$	0.20	0.16
Beam Trajectory	0.30	0.00
Foil Polarization	0.63	0.57
Dead Time	0.05	0.15
Charge Normalization	0.00	0.01
Leakage Currents	0.00	0.18
Laser Polarization	0.10	0.06
Accidentals	0.02	0.04
Current Dependence	0.42	0.50
Aperture Transmission	0.10	0.10
Null Asymmetry	0.12	0.22
July Extrapolation	0.23	–
Total	0.89	0.85

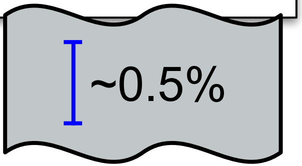
- Results of PREX2 polarization measurements reported and detailing
  - Data corrections: **Deadtime**; accidentals; charge normalization; null asymmetry; and foil polarization
  - Extrapolation uncertainties: **high-current running**; **leakage current**; and laser polarization/precession/QE

Systematics goals of 1.1% exceeded 😀
→ 0.89% PREX2 & 0.85% CREX

*[Note: **Bold** entries require ongoing work towards MOLLER goals.]*

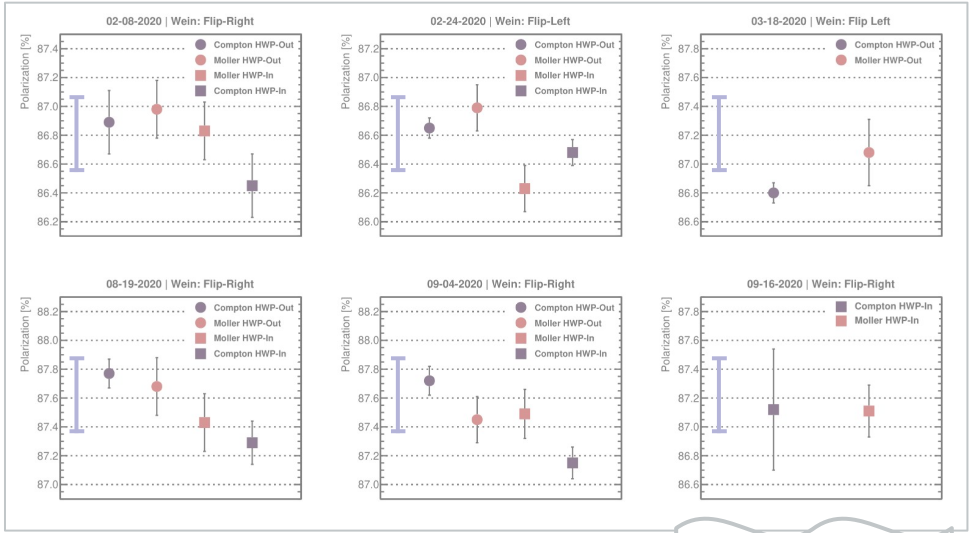
PREX-2 / CREX Moller Polarimetry Paper (cont'd)





- Comparison of Moller measurements to Compton measurements during CREX.
    - Outstanding agreement.

PREX-2 / CREX Moller Polarimetry Paper (cont'd)

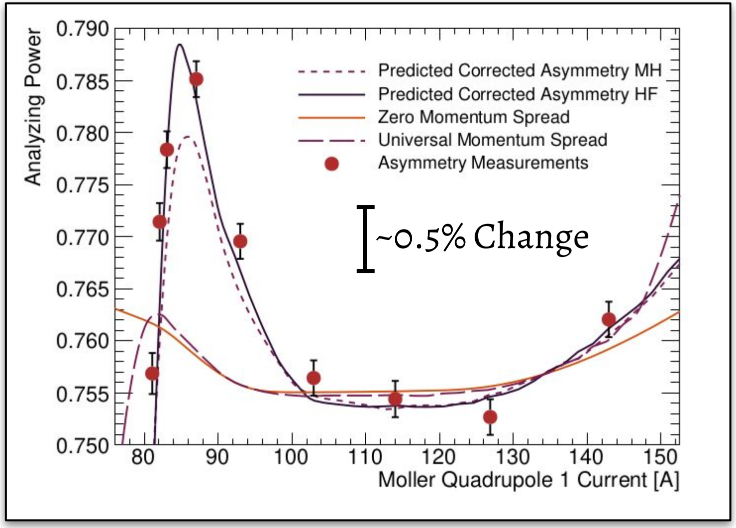


~0.5%

- Comparison of Moller measurements to Compton measurements during CREX.
    - Outstanding agreement.

- Improvements to the polarimeter simulation modeling used to calculate analyzing power – new Hartree-Fock wavefunctions*.

[*Link to Hartree-Fock wavefunctions in backup slide.]*



Foil Polarization Paper

Accurate determination of the electron spin polarization in magnetized iron and nickel foils for Møller polarimetry

D.C. Jones [a,*], J. Napolitano [a], P.A. Souder [b], D.E. King [a,c], W. Henry [c], D. Gaskell [c], K. Paschke [d]

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ARTICLE INFO

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g'

ABSTRACT

The Møller polarimeter in Hall A at Jefferson Lab in Newport News, VA, has provided reliable measurements of electron beam polarization for the past two decades. Past experiments have typically required polarimetry at the 1% level of absolute uncertainty which the Møller polarimeter has delivered. However, the upcoming proposed experimental program including MOLLER and SoLID have stringent requirements on beam polarimetry precision at the level of 0.4% (The MOLLER Collaboration, 2014; The SoLID collaboration, 2019), requiring a systematic re-examination of all the contributing uncertainties.

Møller polarimetry uses the double polarized scattering asymmetry of a polarized electron beam on a target with polarized atomic electrons. The target is a ferromagnetic material magnetized to align the spins in a given direction. In Hall A, the target is a pure iron foil aligned perpendicular to the beam and magnetized out of plane parallel or antiparallel to the beam direction. The acceptance of the detector is engineered to collect scattered electrons close to 90° in the center of mass frame where the analyzing power is a maximum (-7/9).

One of the leading systematic errors comes from determination of the target foil polarization. Polarization of a magnetically saturated target foil requires knowledge of both the saturation magnetization and g', the electron g-factor which includes components from both spin and orbital angular momentum from which the spin fraction of magnetization is determined. Target foil polarization has been previously addressed in a 1997 publication "A precise target for Møller polarimetry" by de Bever et al. (1997) at a level of precision sufficient for experiments up to this point. Several shortcomings with the previous published value require revisiting the result prior to MOLLER. This paper utilizes the existing world data to provide a best estimate for target polarization for both nickel and iron foils including uncertainties in magnetization, high-field and temperature dependence, and fractional contribution to magnetization from orbital effects. We determine the foil electron spin polarization at 294 K to be 0.08020 ± 0.00018 (@4 T applied field) for iron and 0.018845 ± 0.000053 (@2 T applied field) for nickel. We conclude with a brief discussion of additional systematic uncertainties to Møller polarimetry using this technique.

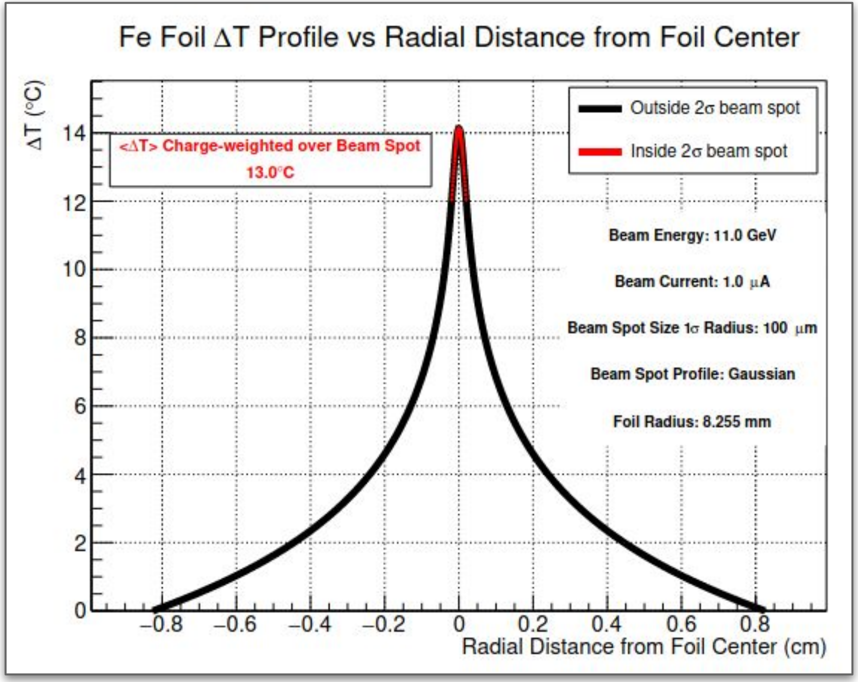
Accepted in Sept 2022

Published in Sept 2022

Foil Polarization Paper (cont'd)

An extensive review of foil polarization issues for Fe foils:

- Covers foil heating issues with beam on target; foil heating affects foil polarization.

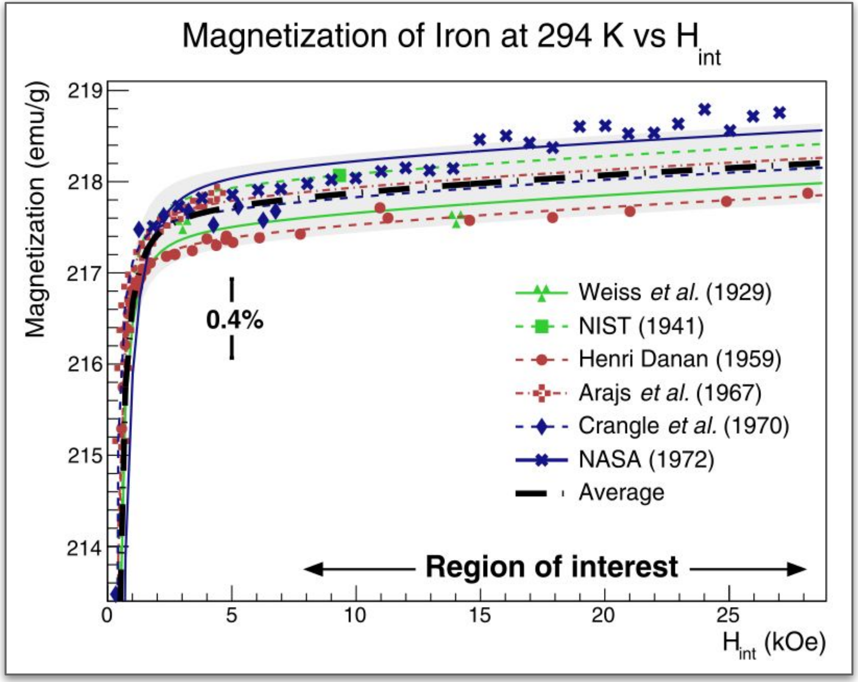


Shown analytical model which agreed with ANSYS @ 11GeV 13.0 v. 13.2K

Foil Polarization Paper (cont'd)

An extensive review of foil polarization issues for Fe foils:

- Covers foil heating issues with beam on target; foil heating affects foil polarization.
- Extensive review of well-documented data on Fe magnetization.



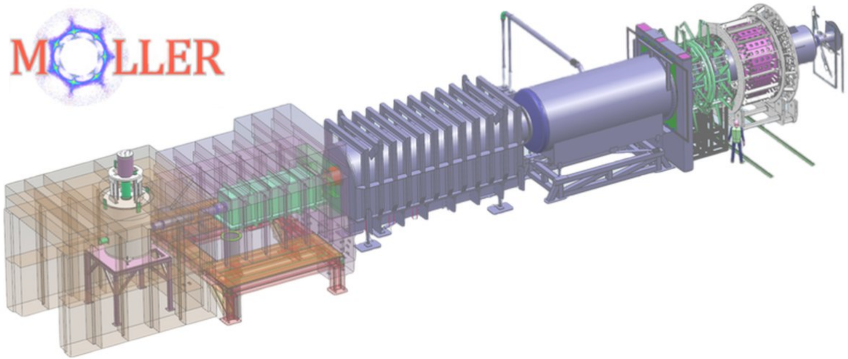
Reliable datasets were temperature-corrected, curve fit to theory and an average along with error taken from the fits.

Foil Polarization Paper (cont'd)

Quantity	T=294 K	T=307 K	Unit
Saturation magnetization M_s	218.04(44)	217.73(45)	emu/g
Saturation magnetization M_s	2.1803(44)	2.1771(45)	μ_B/atom
g'	1.9206(19)	1.9206(19)	–
Orbital fraction: $\frac{M_L}{M_{\text{tot}}} = \frac{g_S - g'}{g'(g_S - 1)}$	0.0425(10)	0.0425(10)	–
Spin component: $M_S\left(1 - \frac{M_L}{M_{\text{tot}}}\right)$	2.0877(47)	2.0847(48)	μ_B/atom
Average electron magnetization	0.08030(18)	0.08018(19)	μ_B
Average electron polarization	0.08020(18)	0.08009(19)	–

- Derived values for Fe foil polarization.
  - ➪ **8.009% +/- 0.019%**
- Reduces our systematic uncertainty on polarization to 0.23%
  - Total allotted uncertainty budget on polarization is 0.25%

MOLLER Preparations



Systematics Goal

0.4%

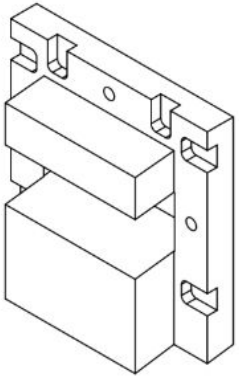
- Detector Collimation
- Target Move Upstream
- Addition of GEM Detectors
- GEM Data Analysis
- Remaining Systematic Concerns

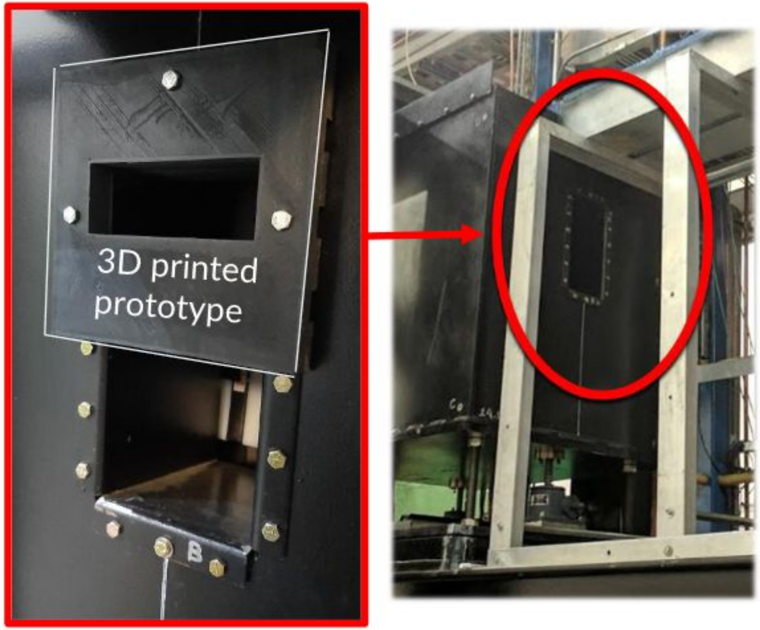
Detector Collimation

- Dipole ‘filters’ acceptance by momentum.

- Tungsten collimating mask designed for the detector box entrance.

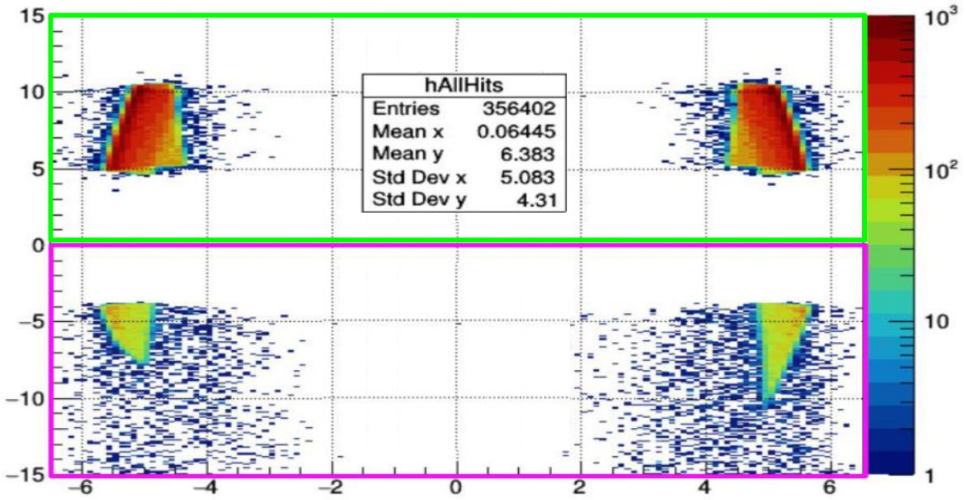
- Limits detector acceptance to $\pm 7^{*}$deg





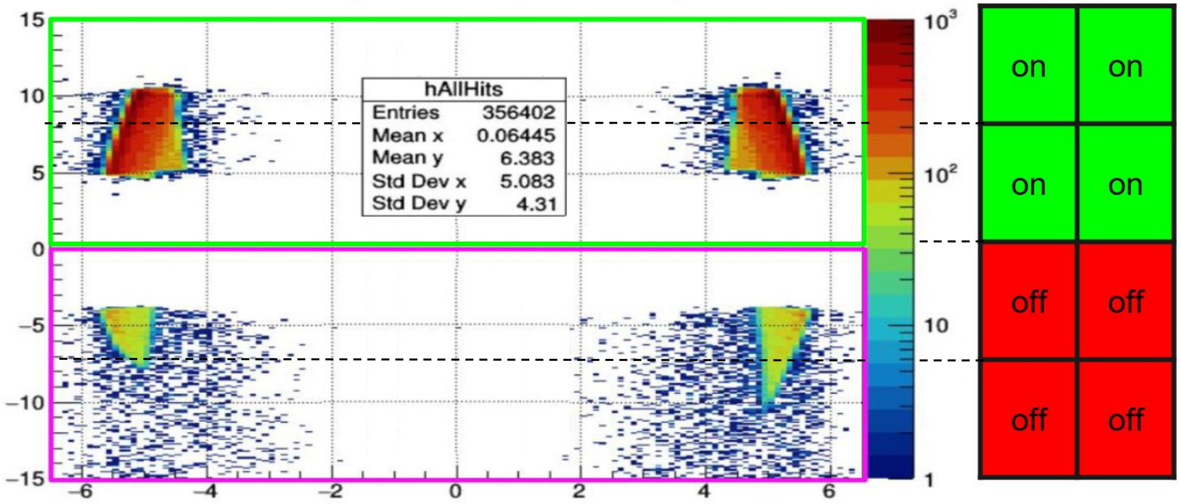
Detector Collimation (cont'd)

- Collimator effectively blocks out unwanted electrons from acceptance.



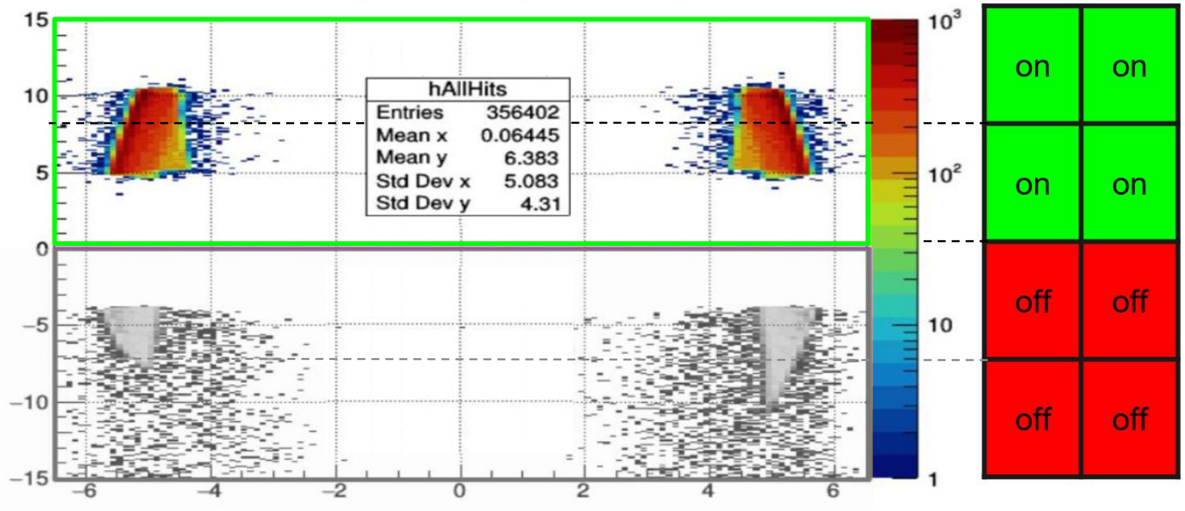
Detector Collimation (cont'd)

- Collimator effectively blocks out unwanted electrons from acceptance.
- We'll be utilizing only the top ½ of the detector.



Detector Collimation (cont'd)

- Collimator effectively blocks out unwanted electrons from acceptance.
- We'll be utilizing only the top ½ of the detector.
- What passes underneath the detector doesn't matter since the PMTs are turned off.
  - Moliere radius of Pb is ~20mm.



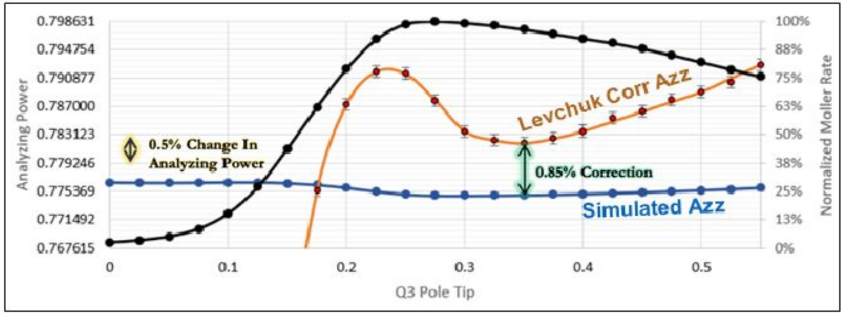
! Dipole Power Supply

- All of these plans were put together on the agreement that we'd receive a new/different power supply.
    - Current dipole power supply has been failing and is capable of only 430A of current (after recent repairs).

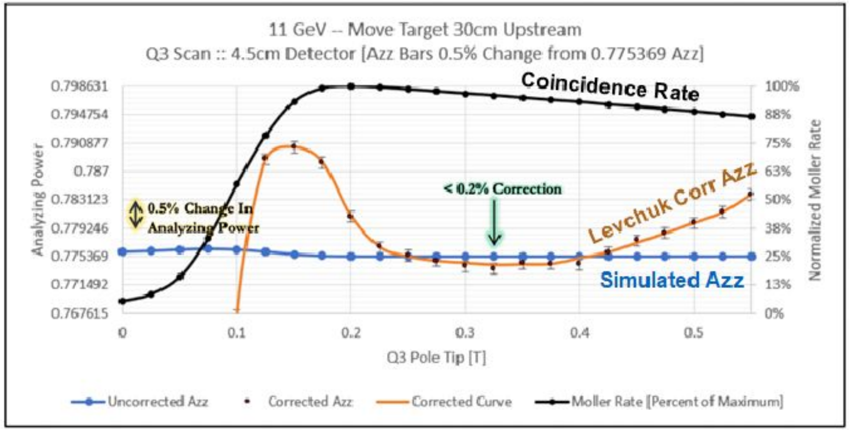
Moller Target Magnet Moved 30cm US (cont'd)

- Move upstream allows for additional natural separation of Moller scatters before quadrupole steering.
- More effective steering allows us to capture desired $\Delta\theta$ range for acceptance.
- Result is a flatter asymmetry curve leaving us less sensitive to quadrupole optics.

Expected Asymmetry Curve Before Move



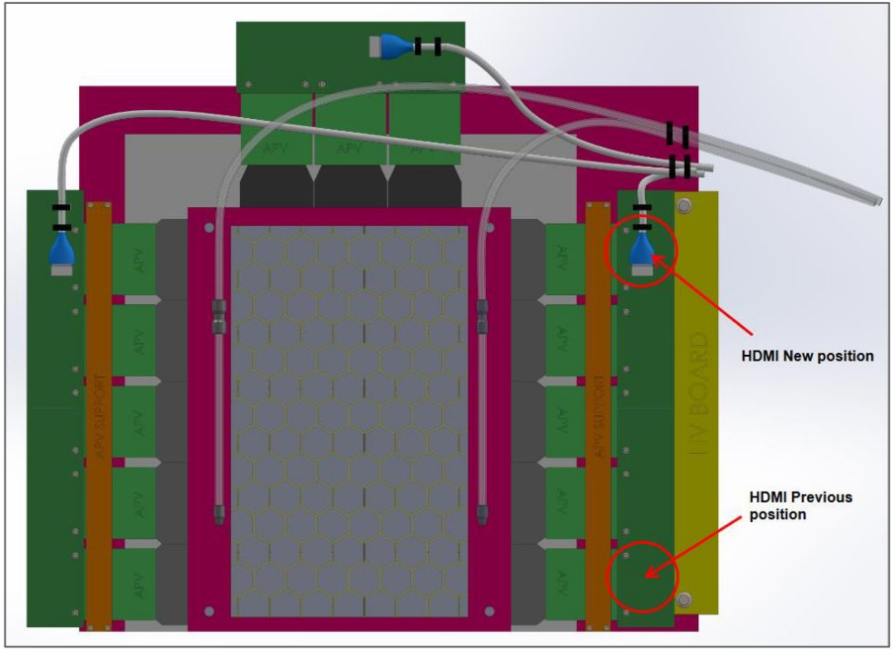
Expected Asymmetry Curve After Move



GEM Detectors

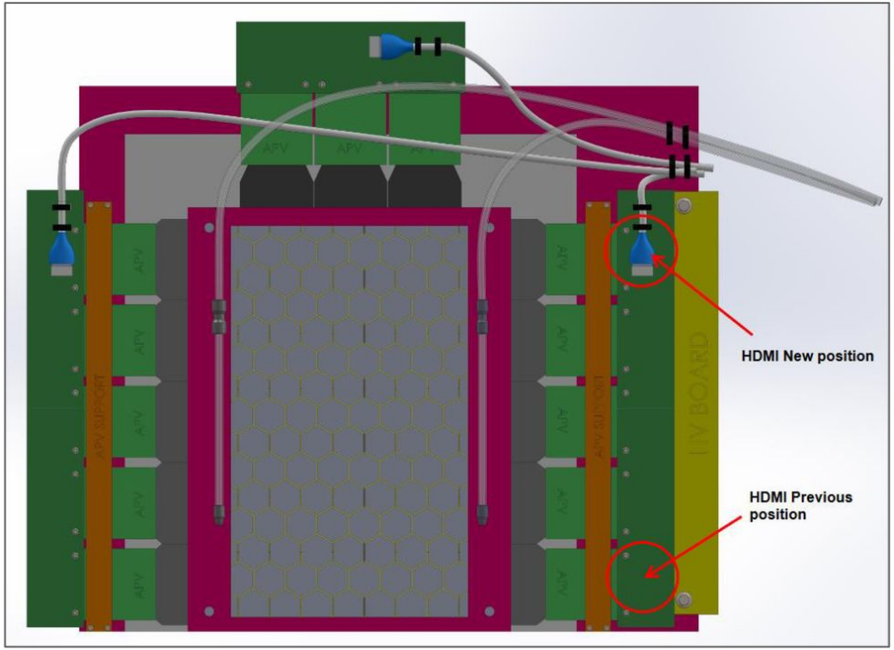
- GEM Detectors are in production and to be install in time for MOLLER commissioning.

- Will be used to provide quantitative insights on poorly benchmarked corrections in simulation:
    - Multiple Scattering;
    - Radiative corrections;
    - Levchuk Effect.



GEM Detectors

- Three GEM planes to be installed
  - Third GEM will aid in increasing tracking efficiency.
- To be placed:
  1. Exit of dipole vacuum box
  2. Entrance to the detector
  3. In-between (1) and (2)
- Each GEM has a left side and right side with independent readouts



GEM Detectors & Analysis

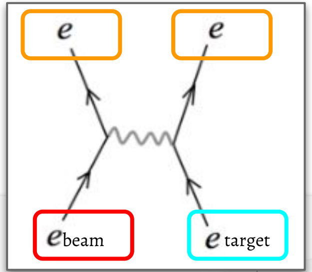
Coordinate data extracted: x_1, x_2, y_1, y_2

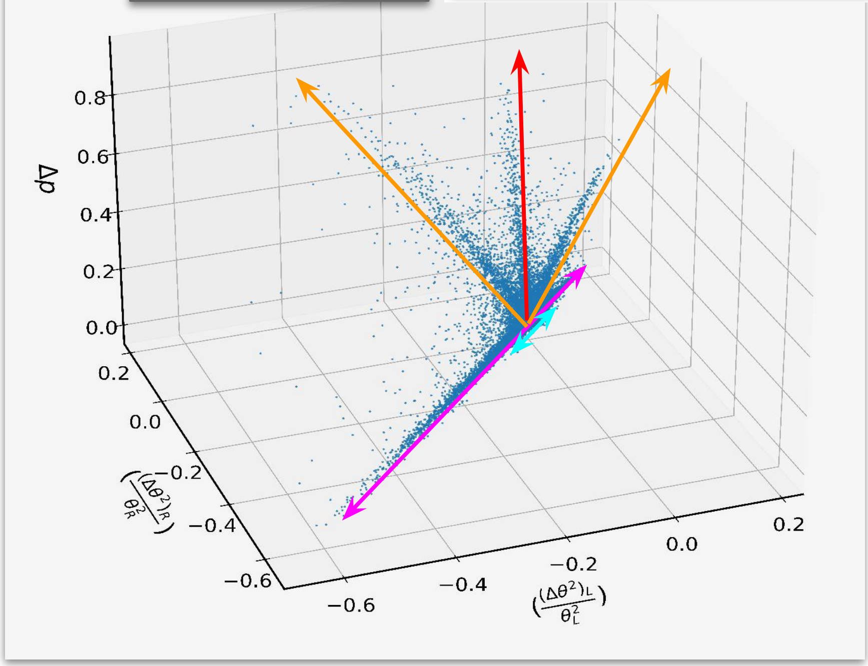
ρ: 1 / momentum
ϕ: Plane of scatter
$\Delta\theta$: Angular offset from Møller stripe
θ: Scattering angle

$$\rho = f(\Delta y, \bar{y})$$
$$\Phi = f(\Delta y, \bar{y})$$
$$\Delta\theta = f(\Delta y, \bar{y}, x_1)$$
$$\theta = f(\Delta y, \bar{y})$$

These are functions of the preferred set of values derived from chamber coordinates and various coefficients $m_1, m_2, b_1, b_2, A, B, C, D$ derived from fitting functions

$$\Delta\rho = \rho_{\text{beam}} - \rho_L - \rho_R$$
$$\theta_T^2 = \Delta\theta^2 + \theta^2$$

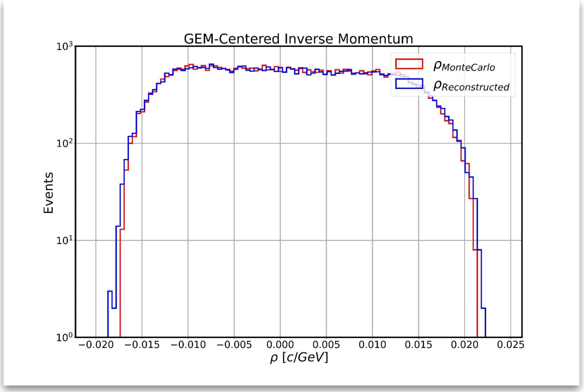


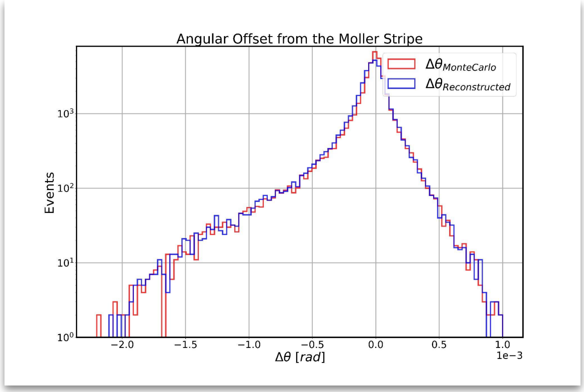


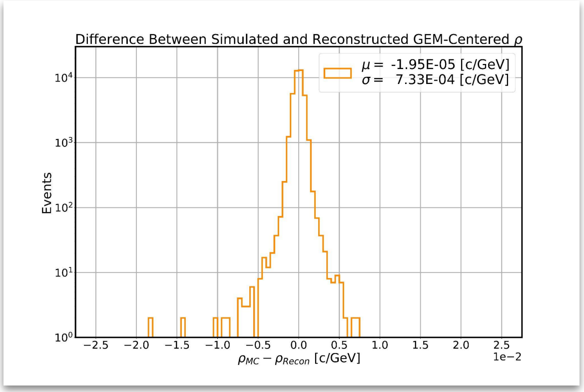
GEM Detector ‘Data’ Analysis

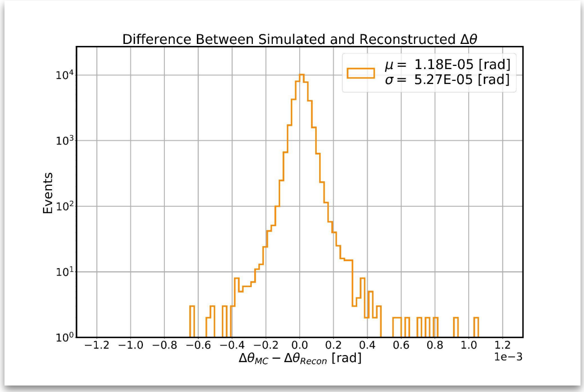
- Reconstruction of Geant4 simulated data works well.
  - (Top images) Reconstruction against simulated.
  - (Bottom images) Differences between reconstruction and simulated.
- Excellent starting point for future data analysis!

*Faraz’s conversion of ρ to p in backup slide.









Reconstructed ρ

Mean Diff: ~2(10^{-5}) c/GeV → 3 MeV/c (*in p)

Width: ~7(10^{-4}) c/GeV → 20 MeV/c (*in p)

Reconstructed Scattering Angles

Mean Diff: ~1(10^{-5}) rad

Width: ~5(10^{-5}) rad

Remaining Systematics Concerns

Moller Polarimetry Systematic Concerns

Current Extrapolation [backup slide of 2007 study]

Polarimeter runs at low current while experiment runs at high current.

1. Need a plan which must be supported by source experts for extended measurements.

Moller Polarimetry Systematic Concerns

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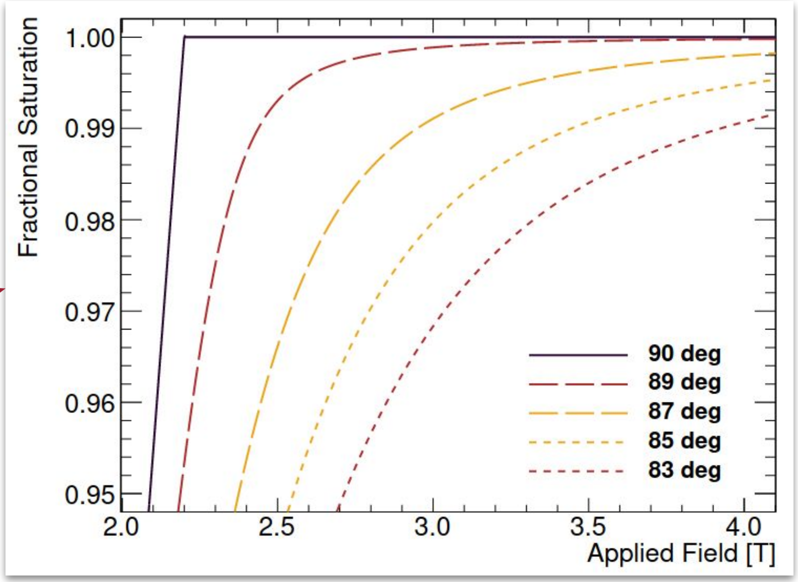
Foil Saturation **[Covered in Fe foil NIMA Paper]**



1. Restore target rotation.
2. Refine a technique for <u>ensuring</u> foils are flat and taut.
3. Need a plan for measurement.

Moller Polarimetry Systematic Concerns

Current Extrapolation [backup slide of 2007 study]

□ Polarimeter runs at low current while experiment runs at high current.

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1. Restore target rotation.
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Bleedthrough/Leakage

We currently don't have a complete plan on how to deal with this.

- Significant bleedthrough recently observed.
- It appears that bleedthrough will continue to be something that needs to be dealt with.

Moller Polarimetry Systematic Concerns

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- Significant bleedthrough recently observed.
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Deadtime

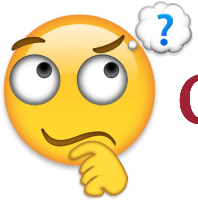
- We need to verify that our current way of dealing with this is accurate.
- *We have the equipment* and just require a pair of hands to take on the project.

Summary of Where We Want to be for MOLLER

- 'Foil Polarization' includes both the foil polarization and foil alignment
- Dead time systematic has previous been very conservative [100% of correction]
- Leakage currents were something that we were hoping to eliminate □.
- Current dependence study is extremely important in meeting

Uncertainty	CREX	MOLLER
$\langle A_{zz} \rangle$	0.16	0.14
Beam Trajectory	0.00	–
Foil Polarization	0.57	0.30
Dead Time	0.15	0.05
Charge Normalization	0.01	0.01
Leakage Currents	0.18	–
Laser Polarization	0.06	0.06
Accidentals	0.04	0.04
Current Dependence	0.50	0.20
Aperture Transmission	0.10	–
Null Asymmetry	0.22	0.05
Total	0.85	0.40

Thank you.



Questions?

Comments.

Moller Polarimetry Working Group

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David Gaskell

Donald Jones

Bill Henry

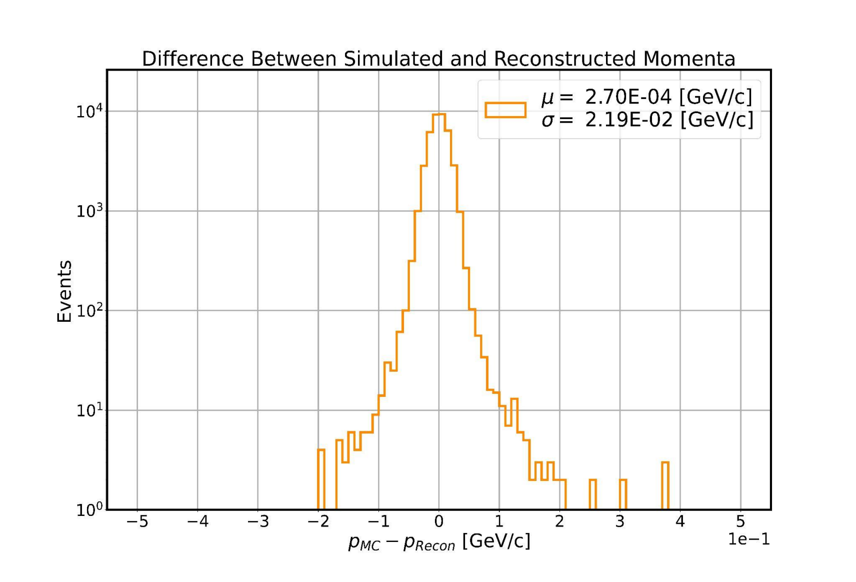
UNIVERSITY of VIRGINIA

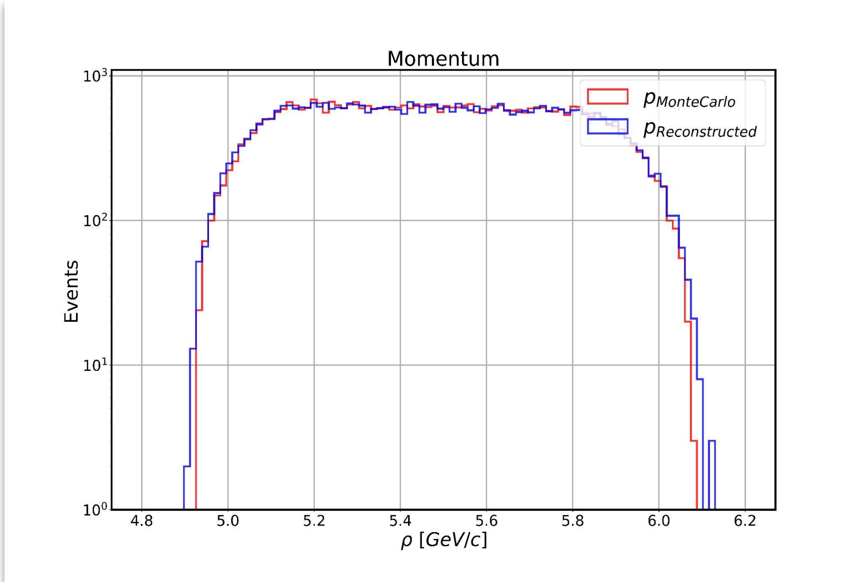
Kent Paschke

Backup Slides

- Faraz's reconstruction converted from rho to p.
- 2007 Hall C study using beat freq, slit changes and attenuator changes for High Current systematic constraint.

Faraz’s Reconstruction $\rho \to p$

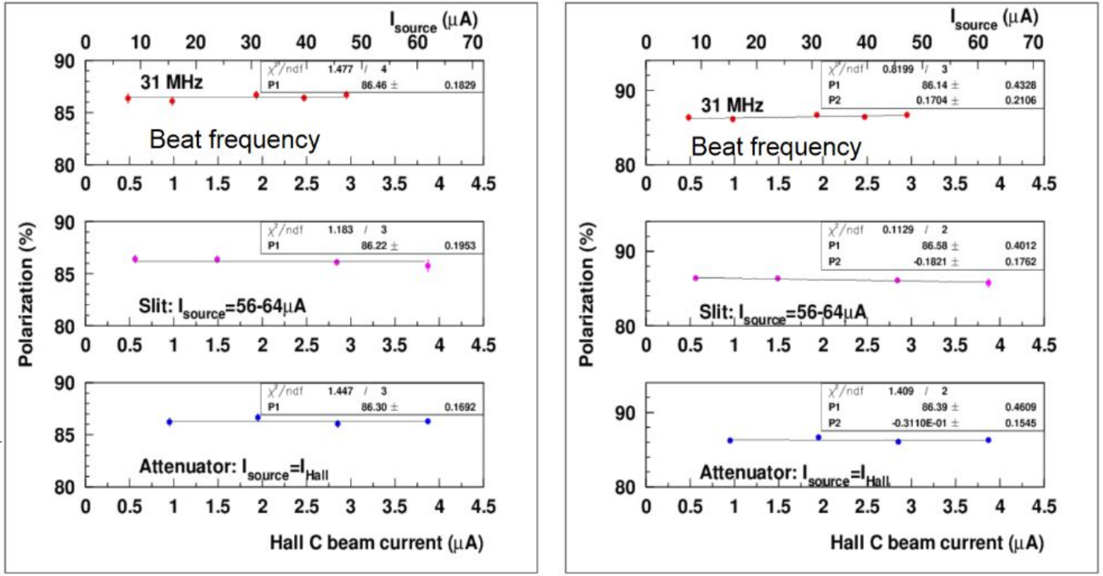




Faraz’s reconstruction converted to momentum rather than rho.

High-current Systematics Test

- This is our main to-do item
- Will require a detailed plan of action in order to complete.
- Several methods available.
- We need to decrease this further.



- Previous systematic studies performed in Hall-C in 2007 limit this systematic to 0.5%.

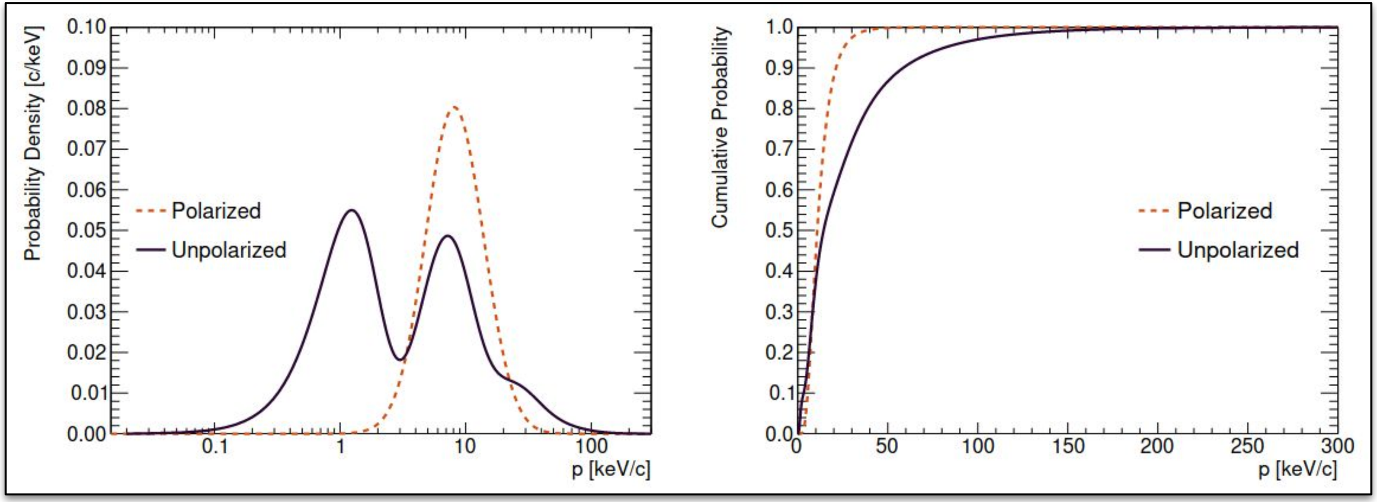
Hartree-Fock Wavefunctions

Data:

Hartree-Fock Calculated Momentum distributions [here]

Repository: gitlab.com/dhamil/levchuk-dft-corrections/-/tree/master/

File: data files/Fe BBB93 shell decomposition.csv

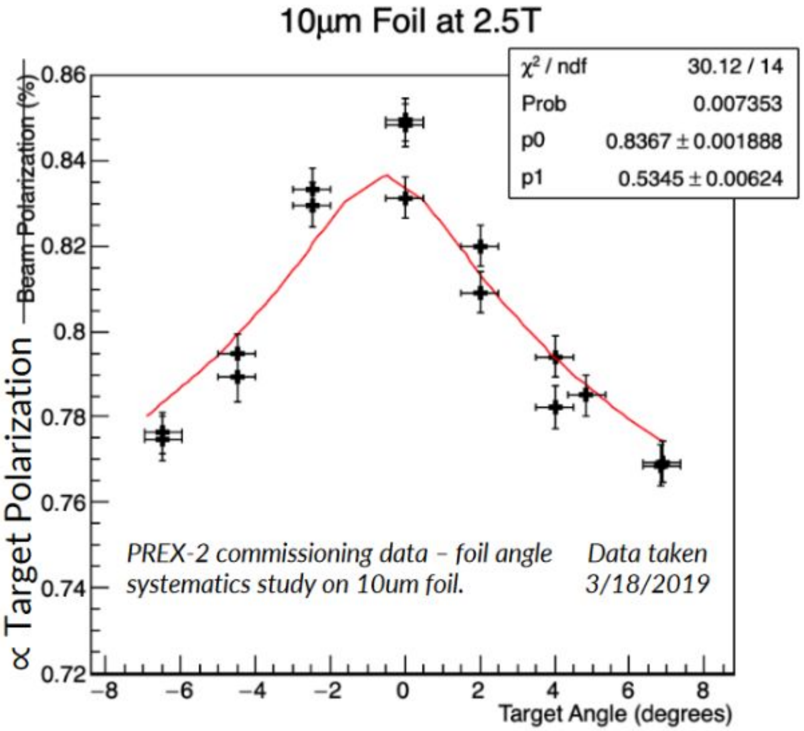


Target Alignment

- Moller polarimeter target ladder has the ability to rotate.
- Foil magnetization is maximized when the foil plane plane is perpendicular to B-field.

☆ Covered in Fe foil polarization publication.

- Systematic studies will be need to be run in order to determine foil alignment.
- Compare data to Stoner-Wolfarth model predictions.



Note: The y-axis label is "improperly" labeled; however, since Pbeam is constant this axis is still proportional

$$A_{\text{meas}} = \frac{R_{\uparrow\uparrow} - R_{\downarrow\uparrow}}{R_{\uparrow\uparrow} + R_{\downarrow\uparrow}} = -P_{\text{beam}} P_{\text{target}} \langle A_{zz} \rangle$$