Moller Polarimetry

MOLLER Collaboration Meeting – June 2022

Eric King (*on behalf of the Moller Polarimetry Working Group*)

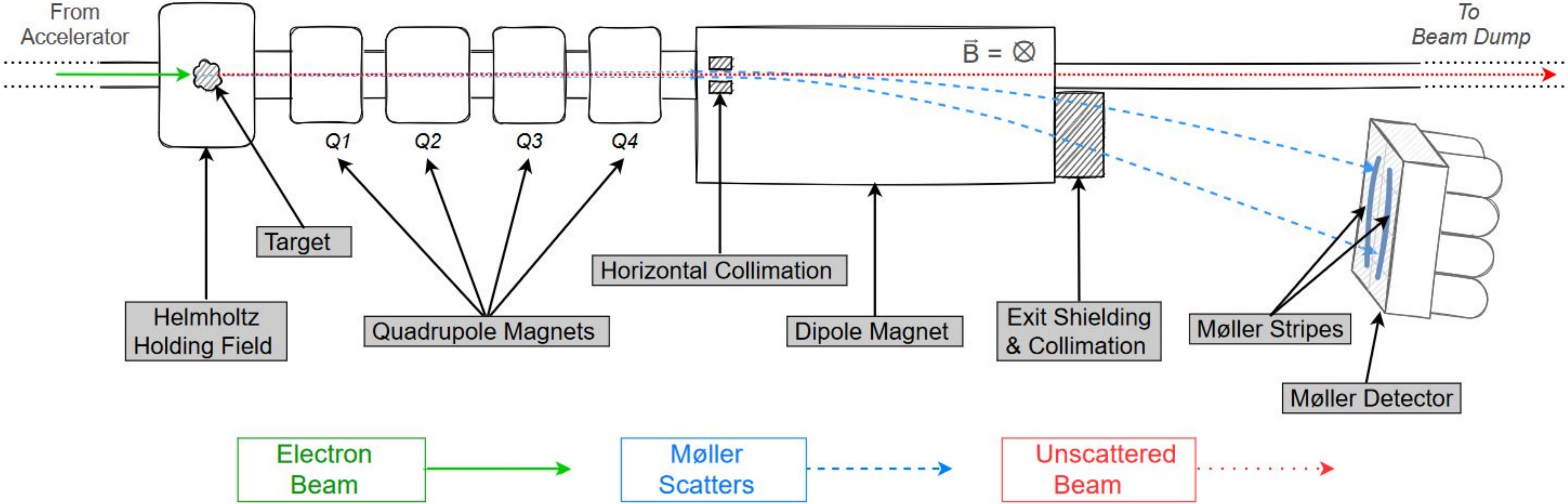
Temple University
U.S. DEPARTMENT OF ENERGY
Jefferson Lab
Exploring the Nature of Matter

The Polarimeter

- Accurate Determination of Fe Foil Polarization

- PREX-2 & CREX Moller Polarimetry

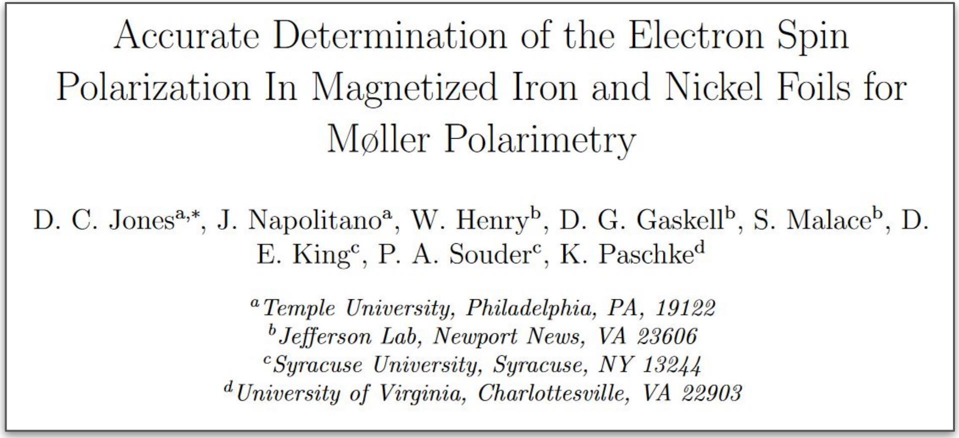
Basic Polarimeter Mock-up



Publications

- Accurate Determination of Fe Foil Polarization
- PREX-2 & CREX Moller Polarimetry

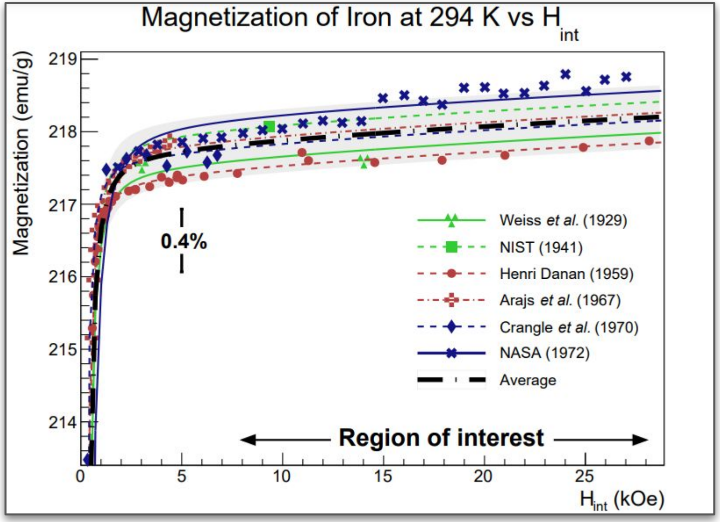
Publications – Fe Foil Magnetization



Accurate Determination of the Electron Spin Polarization In Magnetized Iron and Nickel Foils for Møller Polarimetry

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

[a] Temple University, Philadelphia, PA, 19122
[b] Jefferson Lab, Newport News, VA 23606
[c] Syracuse University, Syracuse, NY 13244
[d] University of Virginia, Charlottesville, VA 22903



Foil polarization known to ~0.24%

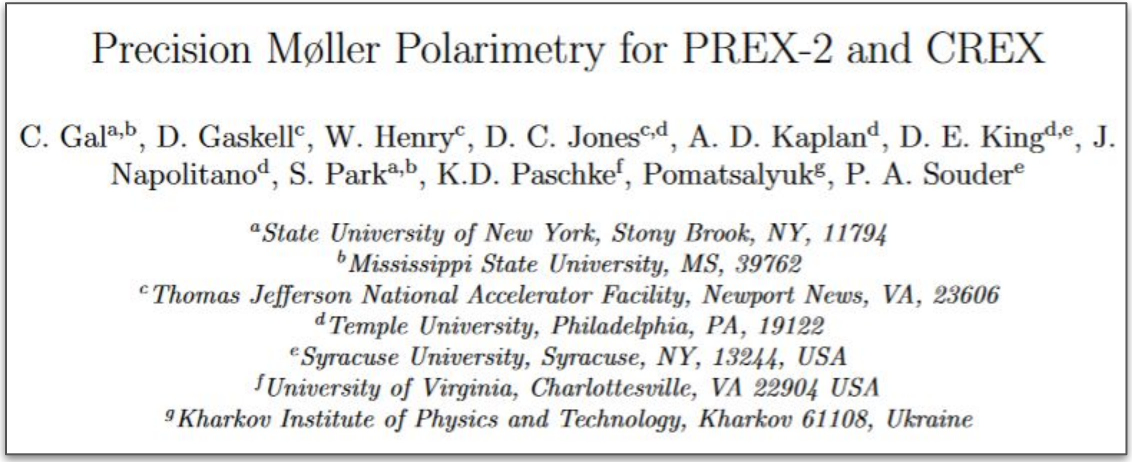
- Extensive literature review of world data on Fe foil spin polarization.
- Mean value for Fe foil electron spin polarization from available world data
- Peer review complete; making final edits.

- https://arxiv.org/abs/2203.11238

Publications – PREX-2 & CREX Moller Polarimetry

- Reporting of PREX and CREX polarimetry accomplishments.

- Significantly improved Levchuk modeling



Precision Møller Polarimetry for PREX-2 and CREX

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

[a] *State University of New York, Stony Brook, NY, 11794*
[b] *Mississippi State University, MS, 39762*
[c] *Thomas Jefferson National Accelerator Facility, Newport News, VA, 23606*
[d] *Temple University, Philadelphia, PA, 19122*
[e] *Syracuse University, Syracuse, NY, 13244, USA*
[f] *University of Virginia, Charlottesville, VA 22904 USA*
[g] *Kharkov Institute of Physics and Technology, Kharkov 61108, Ukraine*

- Measurement and extrapolation uncertainties for PREX-2 and CREX.

- Effectively ready to submit for review – final version going out to authors next week.

Moller Polarimetry Systematics

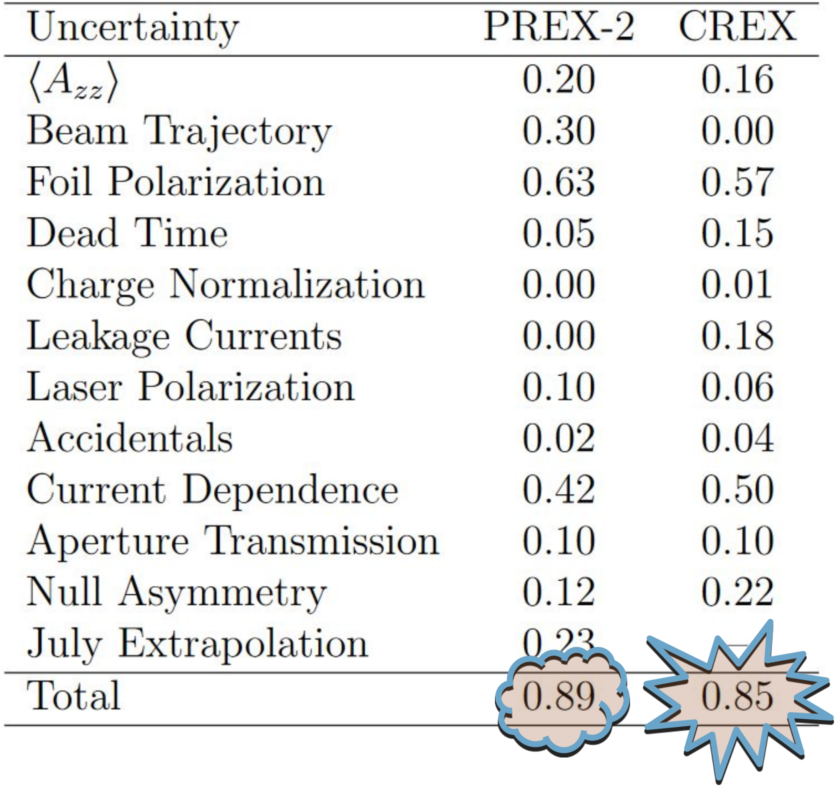
- Key Systematics
- Lessons and Improvements

Moller Polarimetry Systematics

- For PREX-2 & CREX we achieved sub-1% Moller polarimetry measurements.

- The polarimetry systematics goal for MOLLER is 0.45%

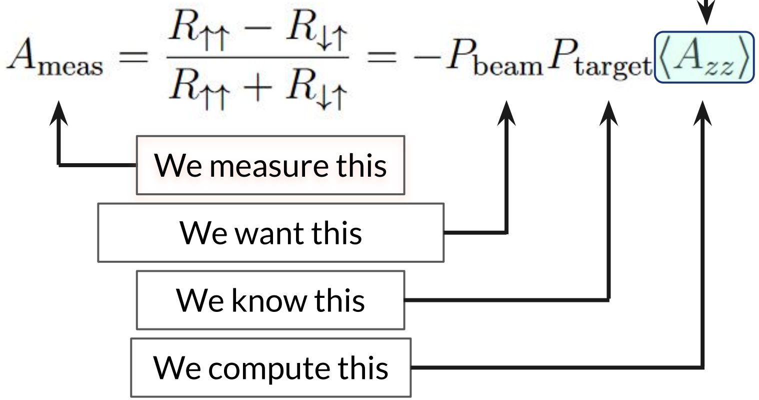
⇒ There’s work to be done.



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

Key Systematic – Analyzing Power

First key systematic is understanding our mean analyzing power $\langle A_{zz} \rangle$.



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

We measure this

We want this

We know this

We compute this

Marked improvement from PREX-2 to CREX.

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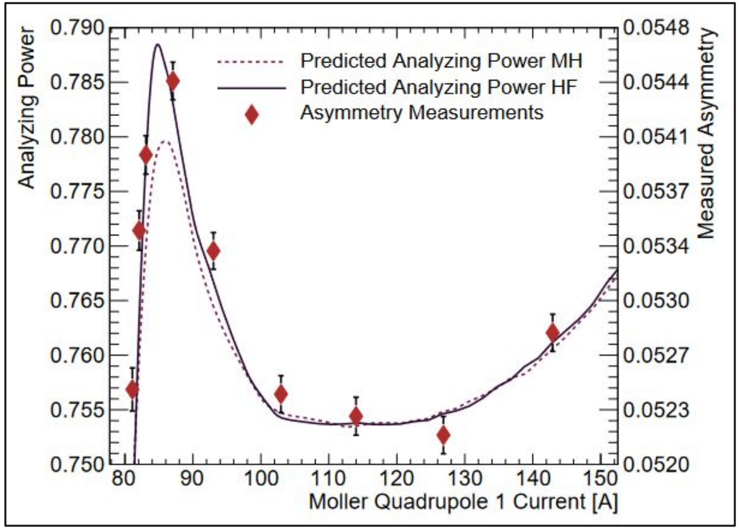
Key Systematic – Analyzing Power

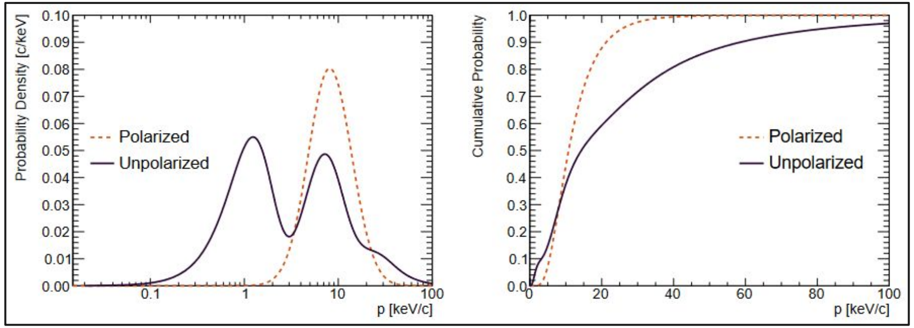
Key lessons learned:

- Developed a method which allowed us to be insensitive to absolute optics.
- Incorporation of improved Hartree-Fock derived electron momentum distributions into our Levchuk model
    - ~40% → ~10% model uncertainty



Plot explanation:

MH: Modified-hydrogen Momentum Distributions
HF: Hartree-Fock Momentum Distributions



Hartree-Fock momentum wavefunction distributions

⭐ *Hartree-Fock wavefunctions computed by Aaron Kaplan of Temple University*

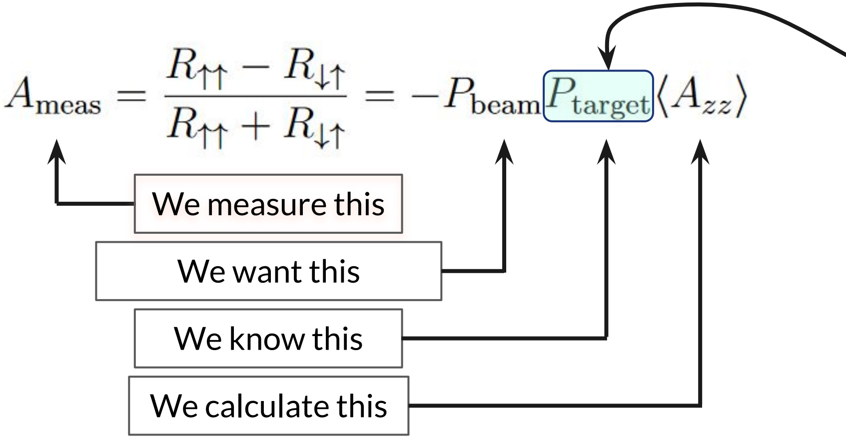
Lessons and Improvements – Measurement Setup

>>> Beam orbit control <<<

- PREX: We identified a setup reproducibility issue.
    - Required extensive measurement setup procedures.
- Post-PREX: Installation of beamline harp.
- CREX Measurement setup: Harp scans
    - Calculate beam orbit angle going into polarimeter.
- CREX: All Moller polarimeter setup calibrations after Jan 2020 harp calibration returned “identical” results.

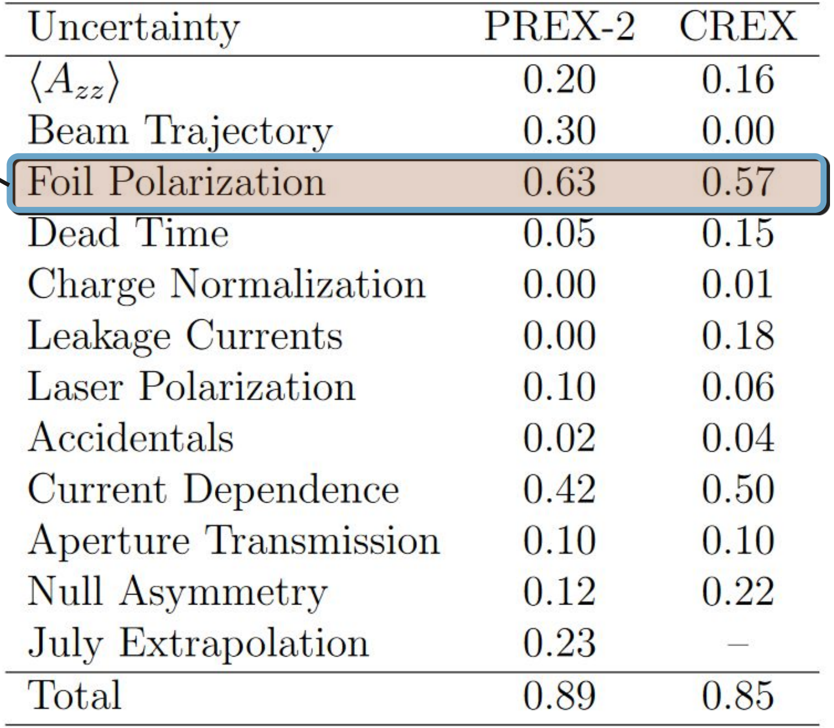
Key Systematic – Target Foil Polarization

Second key systematic is the polarization of our iron target foils



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

This is the topic of the second of the aforementioned publications.



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Key Systematic – Target Foil Polarization

Target foil polarization is largely two components:

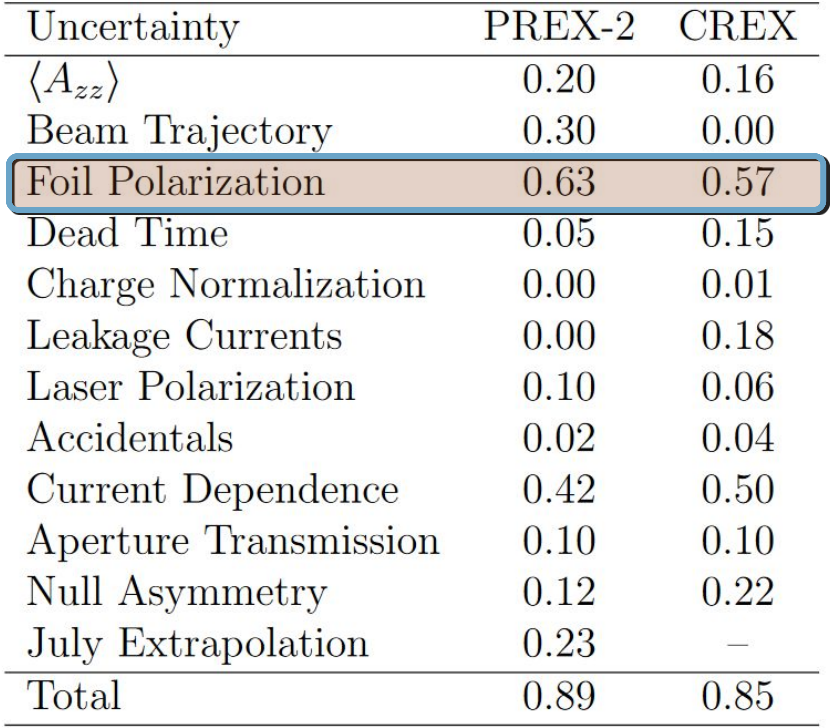
- Magnetization (covered in upcoming publication):

  8.005 ± 0.022% → 8.014 ± 0.018%

- Foil alignment/saturation:

  We've previously assigned a 0.5% uncertainty to this

  ⇒ Alignment study required.
  (I'll return to this)



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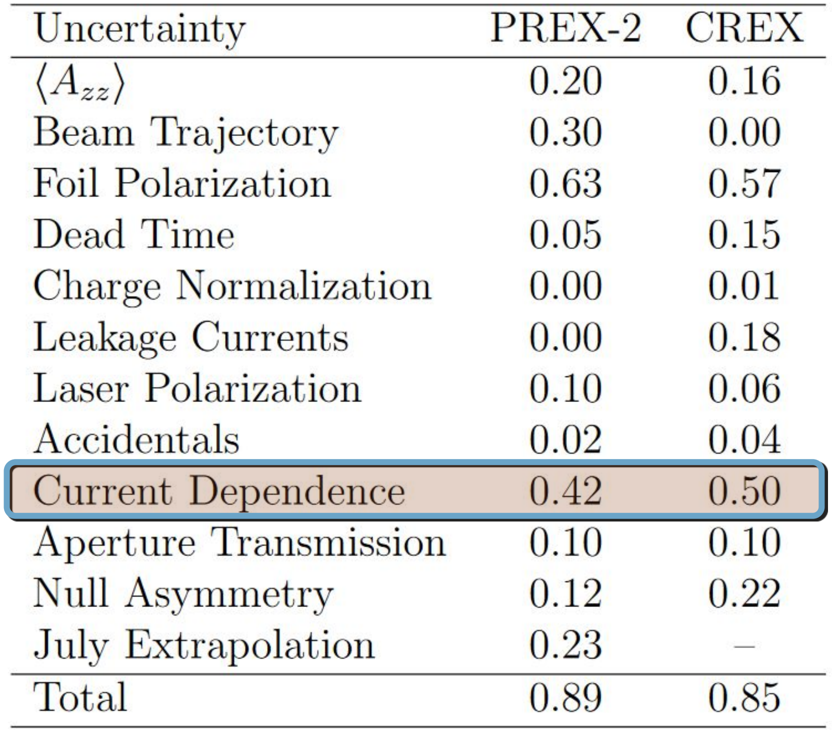
Remaining Systematics

- Matter of minor systematics studies and statistics:
  - Dead Time
  - Leakage/Bleedthrough
  - Aperture/Slit
  - Null Asymmetry
- Planned systematics study:
  - Current Dependence (I’ll return to this)



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Additional Work

GEM Detectors:

- Hardware
- Data / Insights

Equipment:

- Holding Field Move
- Dipole Power Supply Upgrade

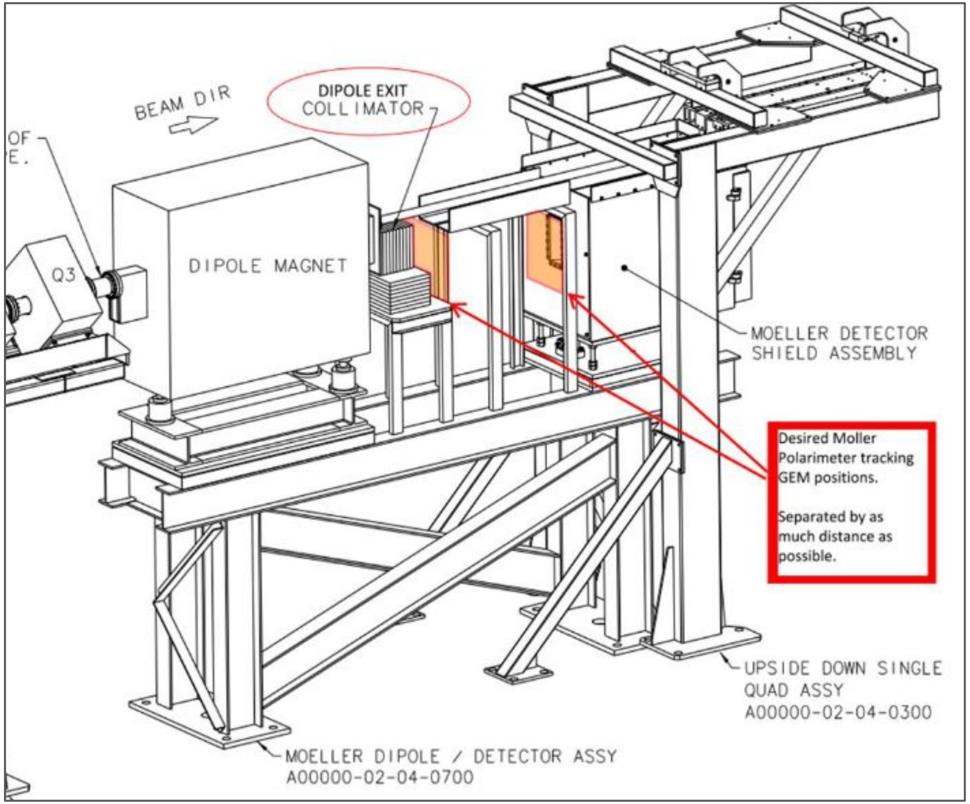
Systematics Study Plans:

- Target Alignment
- High-current Dependence

GEMS – Proposed

Budgeted for the construction of four (4) GEM detectors for the polarimeter.

- Two (2) GEM detectors to be placed at moller dipole exit and prior to entrance of dipole.
- In response to suggestions from last review, added third detector to be placed halfway in-between for track redundancy.
- One (1) spare GEM



Desired Moller Polarimeter tracking GEM positions.

Separated by as much distance as possible.

GEMS – Physical

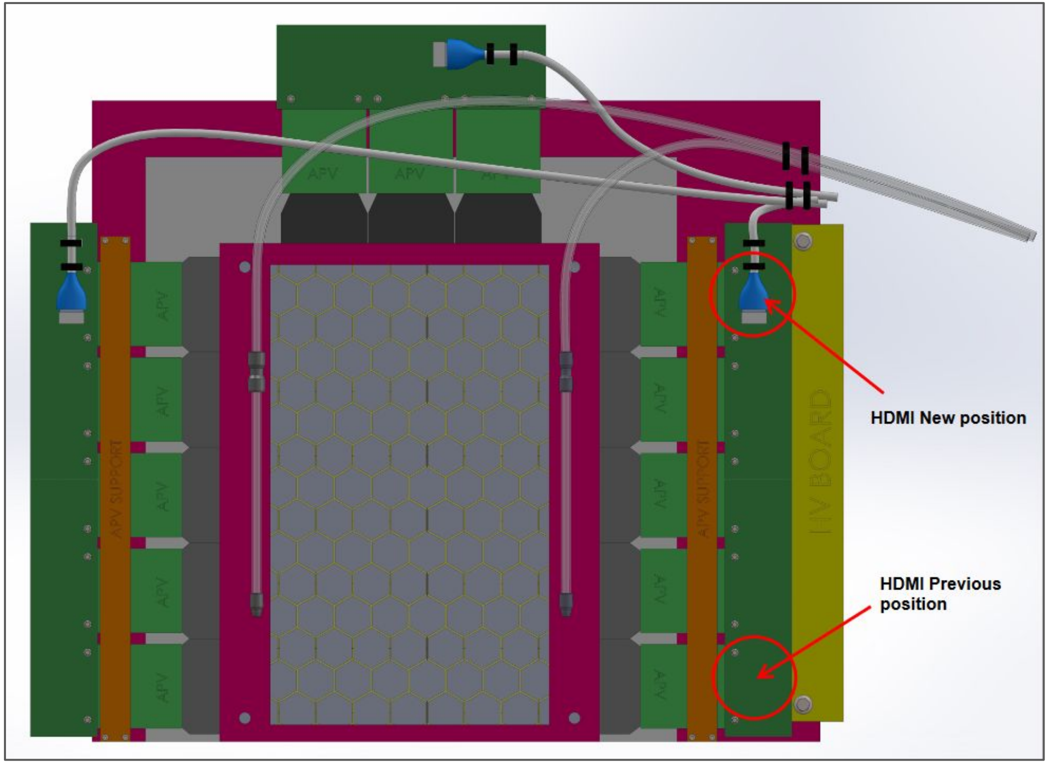
Progress:

- Nilanga's lab has completed the GEM design.
- Expected turnaround time is one year.

Work Remaining:

🔥 Support structure design.

- Paul Souder's post-doc to do the DAQ work.
- Faraz Chahili and Paul Souder working on interpreting the data (ongoing).



Extracting Physics from GEM Chamber Coordinates

Three GEM chamber coordinates are used to reconstruct kinematics:

Chamber Coordinates:

x_1: x-coordinate of GEM hit

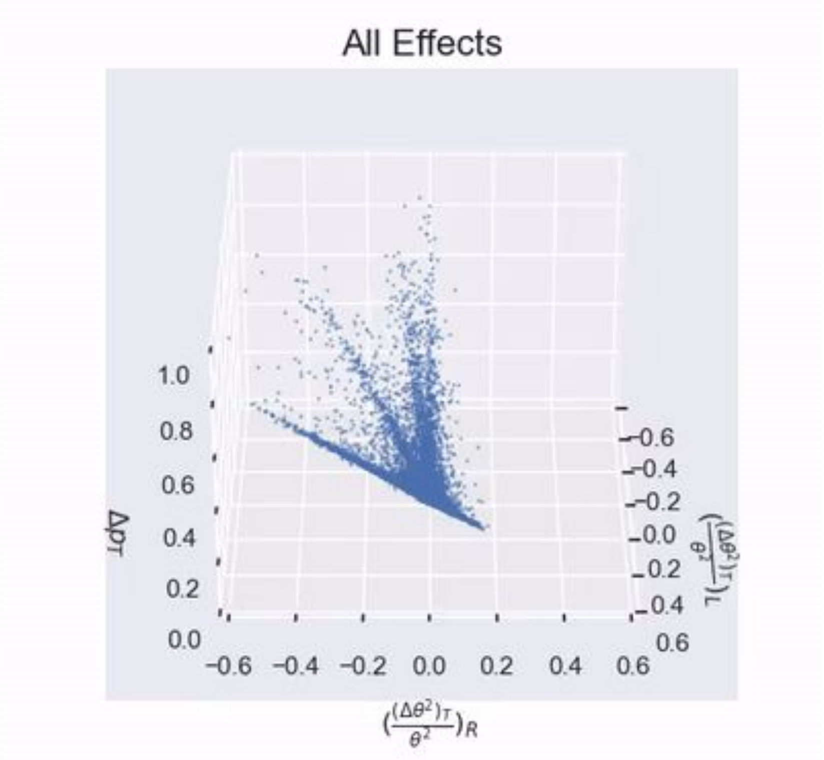
y_1 & **y_2**: y-coordinate from two GEM planes

From these:

Δy: Difference of y-coordinates
∝ bend angle ~ e- momentum

$\bar{y}$: Average of y-coordinates

Values highlighted in orange are the preferred reconstruction variables.



Animated GIF courtesy of Faraz Chahili

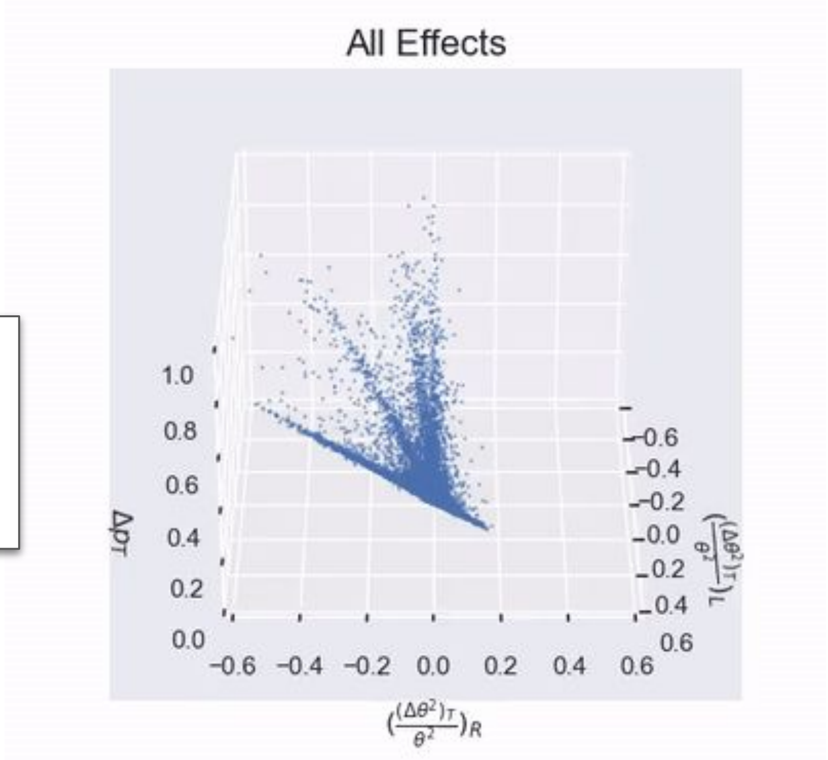
Extracting Physics from GEM Chamber Coordinates

ϱ: 1 / momentum
ϕ: plane of scatter
$\Delta\boldsymbol{\theta}$: angular offset from moller stripe
$\boldsymbol{\theta}$: apparent scattering angle

$$\varrho = f(\Delta\mathbf{y},\vec{\mathbf{y}})$$
$$\phi = f(\Delta\mathbf{y},\vec{\mathbf{y}})$$
$$\Delta\boldsymbol{\theta} = f(\Delta\mathbf{y},\mathbf{y},\mathbf{x}_1)$$
$$\boldsymbol{\theta} = f(\Delta\mathbf{y},\mathbf{y})$$

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

$$\Delta\varrho = \varrho_{\mathrm{beam}} - \varrho_L - \varrho_R$$
$$\boldsymbol{\theta}_T^{\,2} = \Delta\boldsymbol{\theta}^2 + \boldsymbol{\theta}^2$$



Animated GIF courtesy of Faraz Chahili

What was that rotating simulation data???

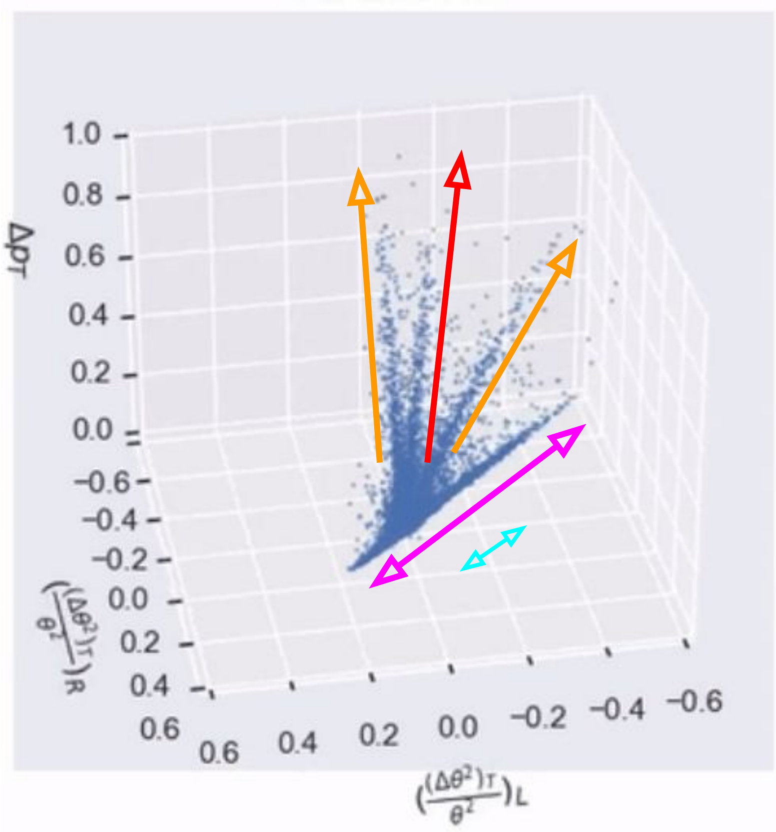
Radiative Corrections:

— Initial state beam

— Initial state target

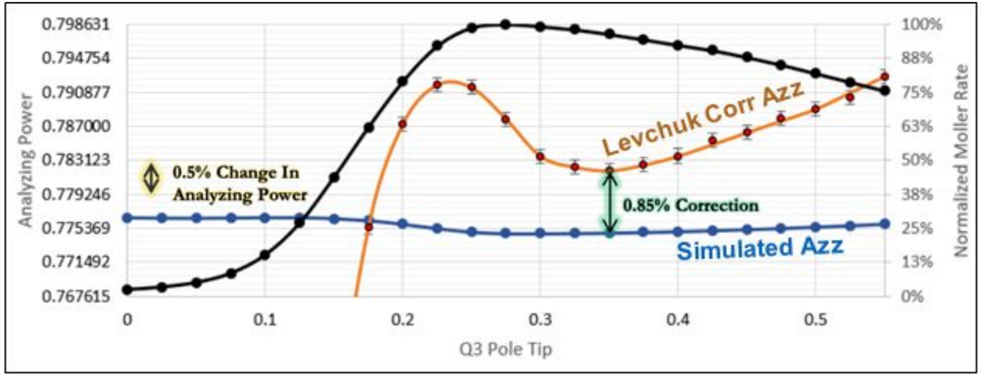
— Final state radiation
(1 per moller e-)

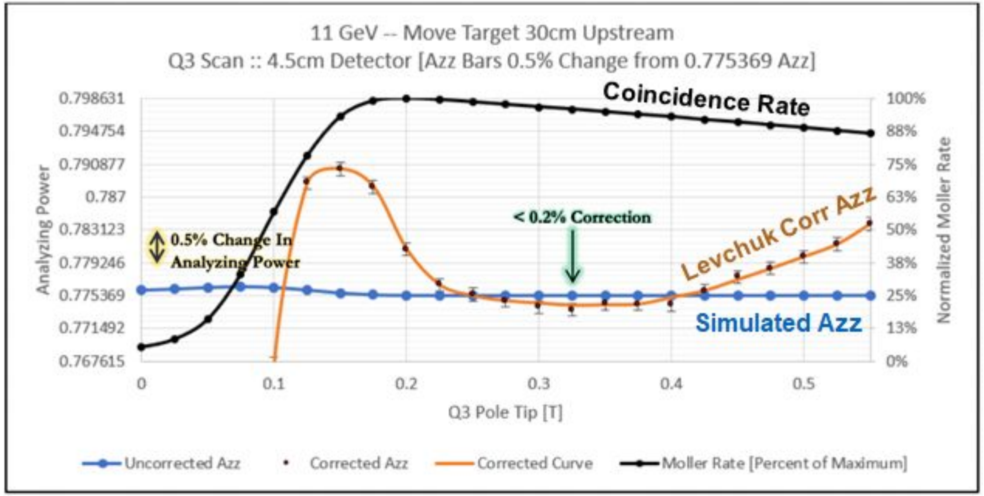
— Levchuk Effect



Target Move 30cm Upstream

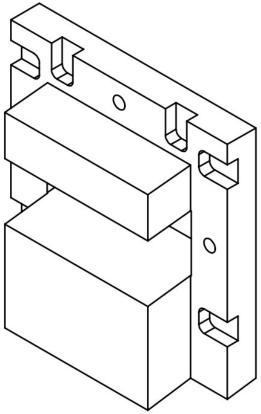
- (Top Image) Design as is. Minimally achievable Levchuk Correction is ~0.85%
- (Bottom Image) Moving the target 30cm upstream.
  - Allows for additional unaided separation of mollers from beamline center for better quad steering.
  - Avoids running quadrupoles at maximum power rating.

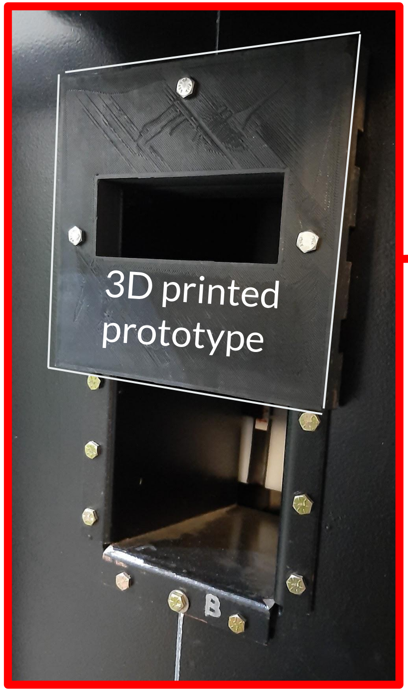


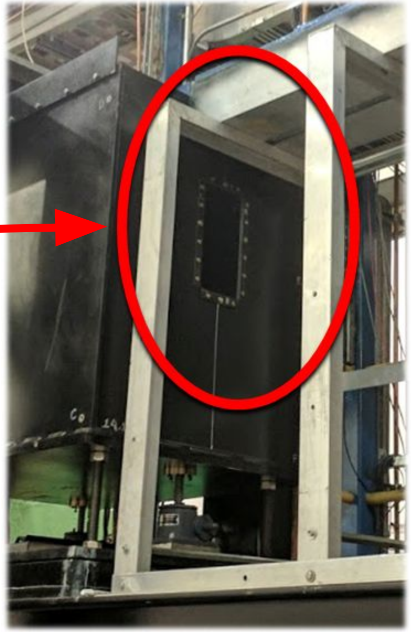


Detector Collimator – General

- Will be milled from Tungsten (hevimet).
- Is 2.5” Thick°
- Resigned to be inserted into detector window and attached using existing bolt locations.
- Leaves 2” ~ 5cm vertical acceptance, which is ~±7°





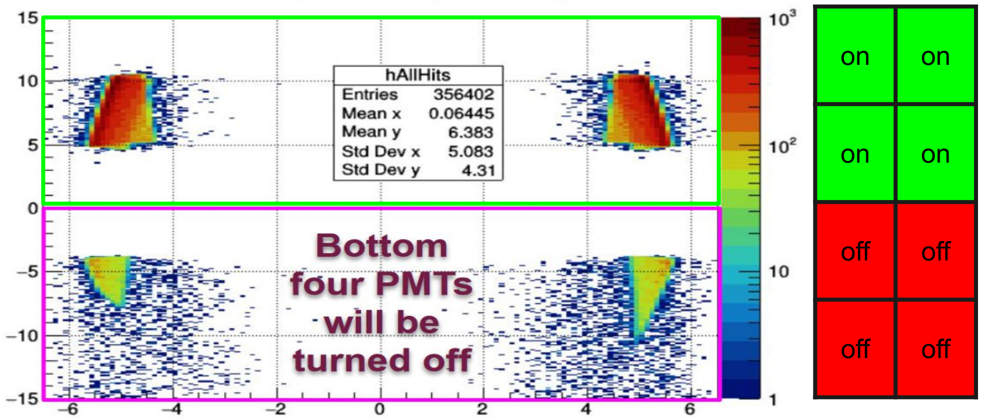


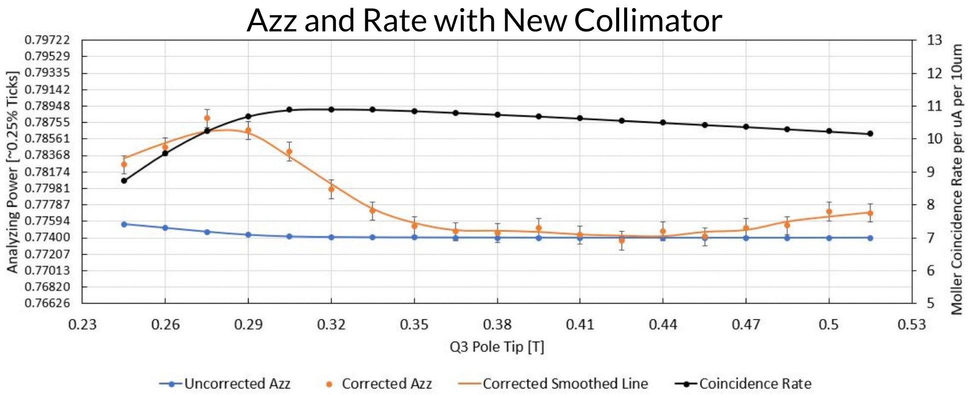
Moller Polarimetry – Eric King – MOLLER Collaboration Meeting, June 2022

Detector Collimator – Simulation Results

Broad stokes review:

- Image to the right shows all above-threshold detector hits for 11 GeV.
- Top two PMT's will be active and bottom four PMTs will be turned off
- Collimator does an exceptional job at limiting acceptance.





Dipole Power Supply Upgrade

- Current dipole power supply capable of <= 1.3T field

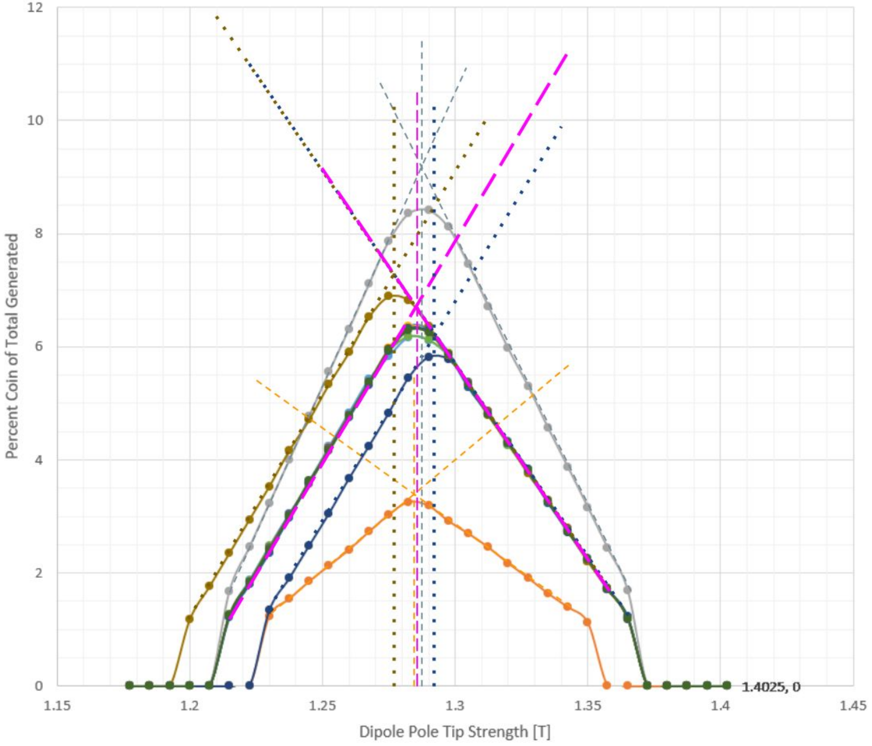
- In order to center our acceptance into collimator window we need a field of 1.285T @ 10.6 GeV

- This is above 1.3T for 11 GeV

- We also need to be able to achieve higher fields for dipole tuning.

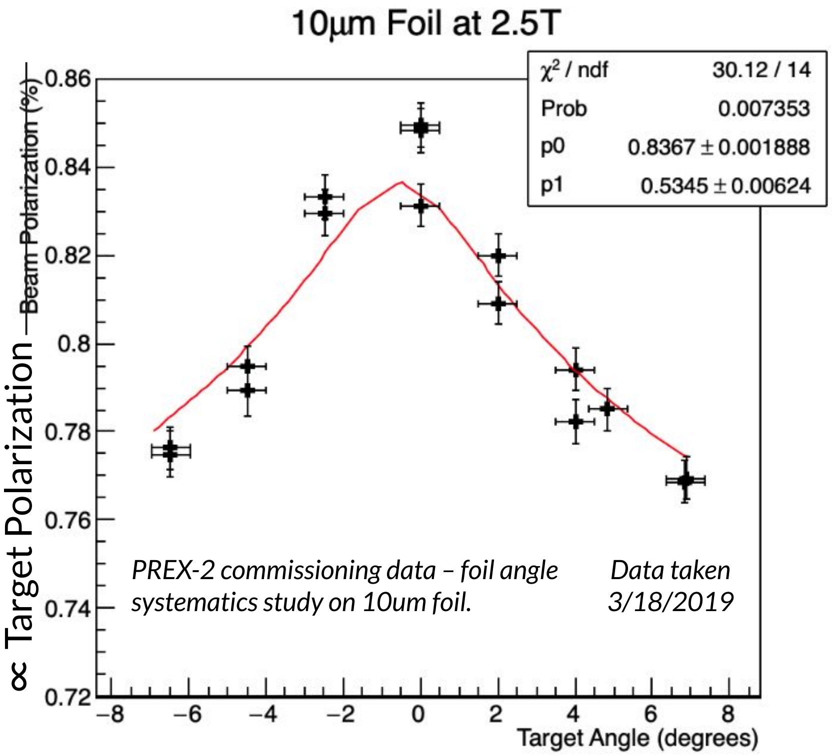
➢ We need to upgrade the dipole supply to meet our needs.

Image of systematic studies of dipole tuning at *10.6 GeV*



Target Alignment – Plan

- 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.



PREX-2 commissioning data – foil angle systematics study on 10um foil.

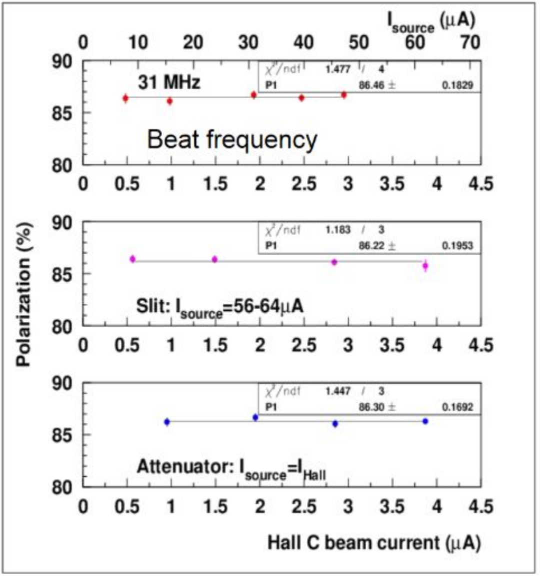
Data taken 3/18/2019

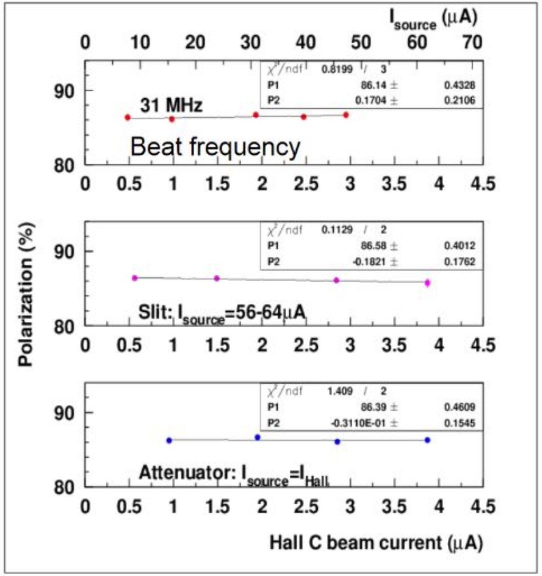
Note: The y-axis label is "improperly" labeled; however, since Pbeam is constant this axis is still proportional

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

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.





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

Miscellaneous Mentions

Bob Michaels is working on a new FADC DAQ which could be utilized to upgrade the existing decades old electronics

- This was already covered in a talk by Paul King.

We [Temple] are looking at acquiring a detector emulator to test the DAQ

- This was largely to convince ourselves that the deadtime measurement method utilized is correct

- With a pending new DAQ this would be a vital piece of equipment.

Summary

- Moller Polarimetry Working Group
- Systematics for MOLLER
-

Moller Polarimetry Active Personnel

TEMPLE UNIVERSITY


Jim Napolitano


Eric King

- ⇒ Systematics Reduction
- ⇒ Continued review of design issues.

Syracuse University


Paul Souder


Faraz Chahili

- ⇒ GEM data insights
- ⇒ Paul’s post-doc will work on DAQ.

Jefferson Lab


David Gaskell


Donald Jones

Bill Henry

- ⇒ Don Jones is now the heir to the polarimeter
- ⇒ Coordinate project deadlines
- ⇒ Technical operators.

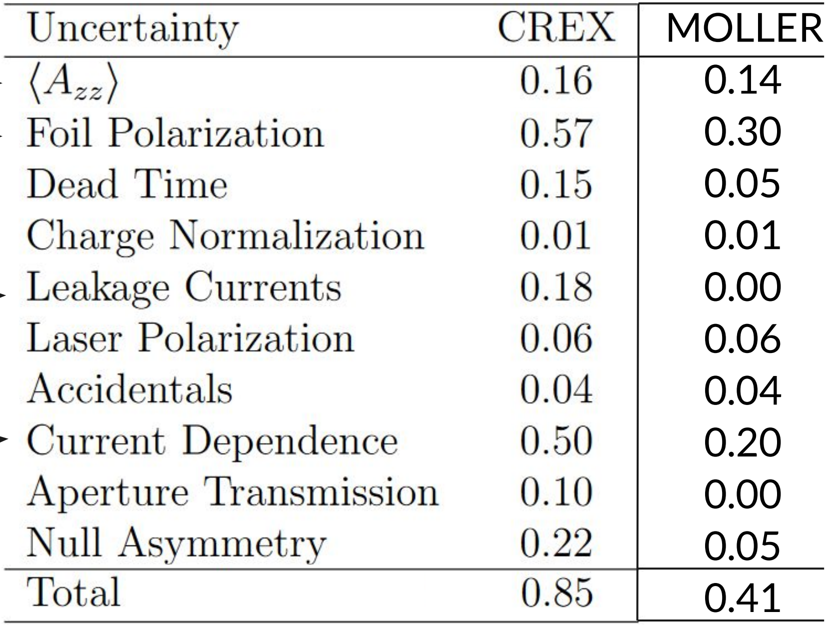
UNIVERSITY of VIRGINIA


Kent Paschke

- ⇒ Insight
- ⇒ Advice

Systematics for MOLLER → How we get there...

- Analyzing power systematic reduces with new Levchuk correction model.
- Foil polarization systematic will require foil angle studies.
- Dead time systematic was conservatively overestimated for PREX & CREX
- Leakage / Bleedthrough
- Current Dependence will require a systematic study to limit this to the 0.2% uncertainty level



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Laser Polarization	0.06	0.06
Accidentals	0.04	0.04
Current Dependence	0.50	0.20
Aperture Transmission	0.10	0.00
Null Asymmetry	0.22	0.05
Total	0.85	0.41

Questions / Comments

Hopefully, I have convinced everyone present that the polarimetry systematic uncertainty goal for MOLLER is achievable for the Moller Polarimeter.

Our goal hinges on:

⇒ High-current extrapolation (a.k.a. current dependence).

Questions?

Comments?