Update on Moller polarimetry for MOLLER

June 4, 2025

Don Jones

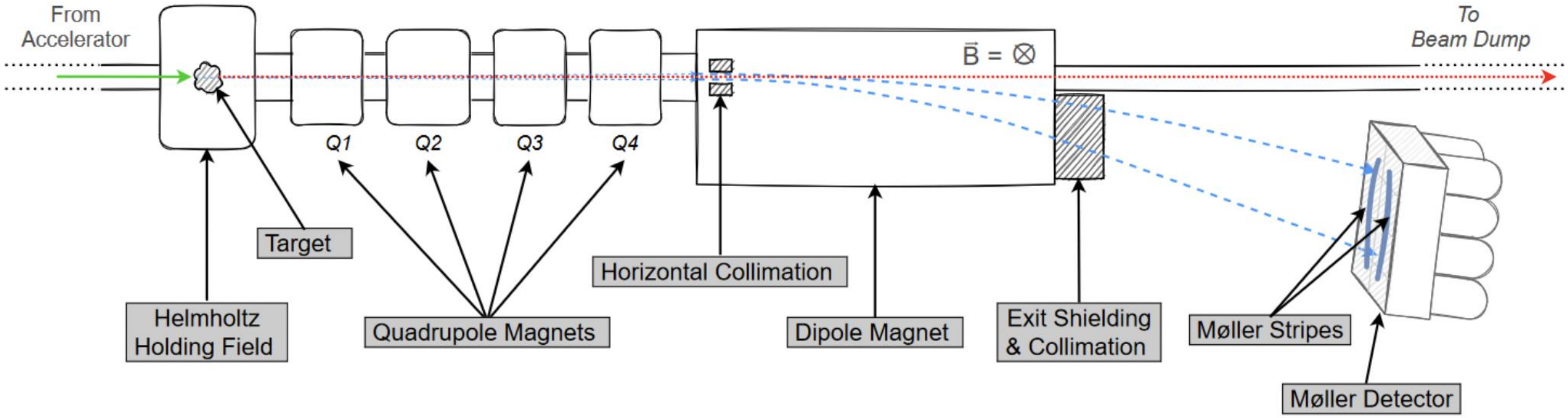
Team: D. Jones, W. Henry (JLab), J. Napolitano, E. King, A. Arcuri (Temple), P. Souder, Faraz Chahili (Syracuse),

with K. Paschke and D. Gaskell consulting

and Hanjie and Zhongling working on a new DAQ

Moller polarimeter in Hall A

- Measure the parity conserving Moller scattering asymmetry from an iron foil target (polarized along beam direction) with a required coincidence between the left and right detectors.
- Four quadrupoles select the events of interest focusing them through left/right slits in the dipole onto a calorimeter.
- Dipole is critical in removing background and helping to reduce the Levchuk effect (correction for electron Fermi motion in target).
- Aiming for 0.40% uncertainty: Note that Compton has already demonstrated this level during CREX but we are at the level where a small oversight or mis-estimation of a systematic error can have a significant effect so it is critical to demonstrate agreement between 2 or more polarimeters with similar magnitude but uncorrelated uncertainties.
- Moller polarimetry is invasive and must be taken at low current during dedicated period of running: added difficulty of trying to assess effects from any changes in beam properties between the measurement and the experiment production data.

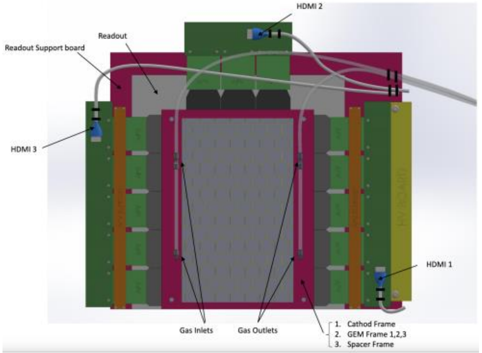


Recent activities

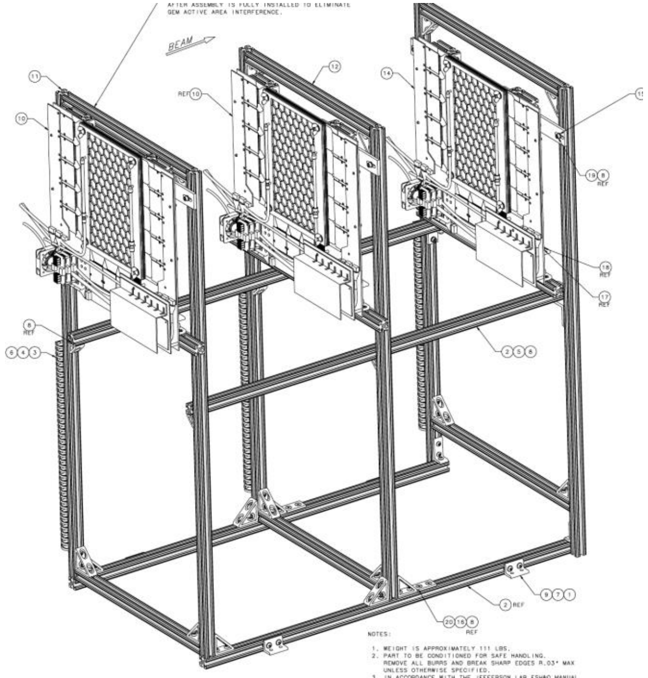
- Took Moller measurement at 5-pass last week. First time since 2016.
  - Old quad power supplies fussed and grumbled but made it through with the exception of one that was swapped out with a spare.
  - Dipole temporarily connected to a power supply that can nearly reach 550A. We are running at 471A.
- New FADC DAQ being developed by Hanjie et al.
- Using detector emulator to study deadtime and accidentals in existing DAQ
- Trying to understand radiative corrections model in G4.

Hardware overview: changes included in the project

GEMs

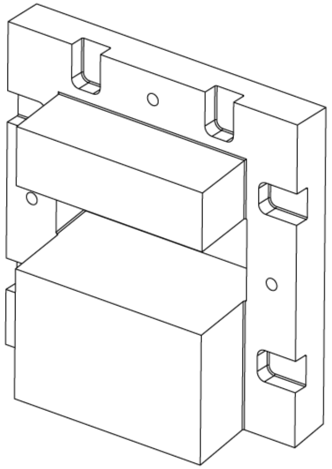


- Design complete including stand
- All four under construction at UVA
- Expected to be done by end of summer
- Working on who is responsible for installation and readout for GEMs



Tungsten Collimator

- Limits vertical acceptance (momentum) on detector to reduce Levchuk uncertainty
- Already manufactured and onsite



Moving Moller target upstream

- Moving SC target magnet upstream 30cm gives more favorable optics and allows near elimination of Levchuk correction

Hardware overview: improvements outside the project

DAQ

- Old NIM/CAMAC-based DAQ working fine, but is now obsolete
  - Swap-in replacements for most parts in hand.
  - Trusted and decently understood
- New FADC-based system under development by Hanjie Liu
  - Early version running capturing raw waveforms last week during Moller measurement.
  - Working to implement this DAQ in parallel during MOLLER
  - Verify its performance and results against old DAQ

Power supplies

- Lots of power supply issues during SBS relating to quads and dipole
  - 4 new quad power supplies on hand and 5th spare ordered. All four will be replaced after this run.
  - Plan is to purchase and replace dipole power supply during FY 2026

Systematic Error Estimates

Uncertainty	CREX	MOLLER
Saturation Polarization	0.28	0.24
Degree of Saturation	0.50	0.15
A_{zz}+Levchuk	0.16	0.15
Dead Time	0.15	0.10
Null Asymmetry	0.22	0.10
Accidentals	0.04	0.10
Electron Source Variation*	0.06	0.10
Current Dependence*	0.50	0.10
Aperture Transmission*	0.10	0.10
Leakage Currents*	0.18	0.00
Total	0.85	0.40

Knowledge of the target polarization

Methodology under investigation

Measured with each Moller measurement

Dedicated studies consisting of several shifts

Progress dealing with systematics

Uncertainty	CREX(%)	MOLLER (%)
Saturation Polarization	0.28	0.24
Null Asymmetry	0.22	0.10
Leakage Current	0.18	0.00
Electron Source Variation	0.06	0.10
Azz + Levchuk	0.16	0.15
Dead Time	0.15	0.10
Accidentals	0.04	0.10
Degree of Saturation	0.50	0.15
Current Dependence	0.50	0.10
Aperture Transmission	0.10	0.10
TOTAL	0.85	0.40

Complete

Mature understanding and techniques but still learning

Small improvements from verifying radiative+Levchuk corr

Ongoing efforts on these fronts

Top priority measurements during beam

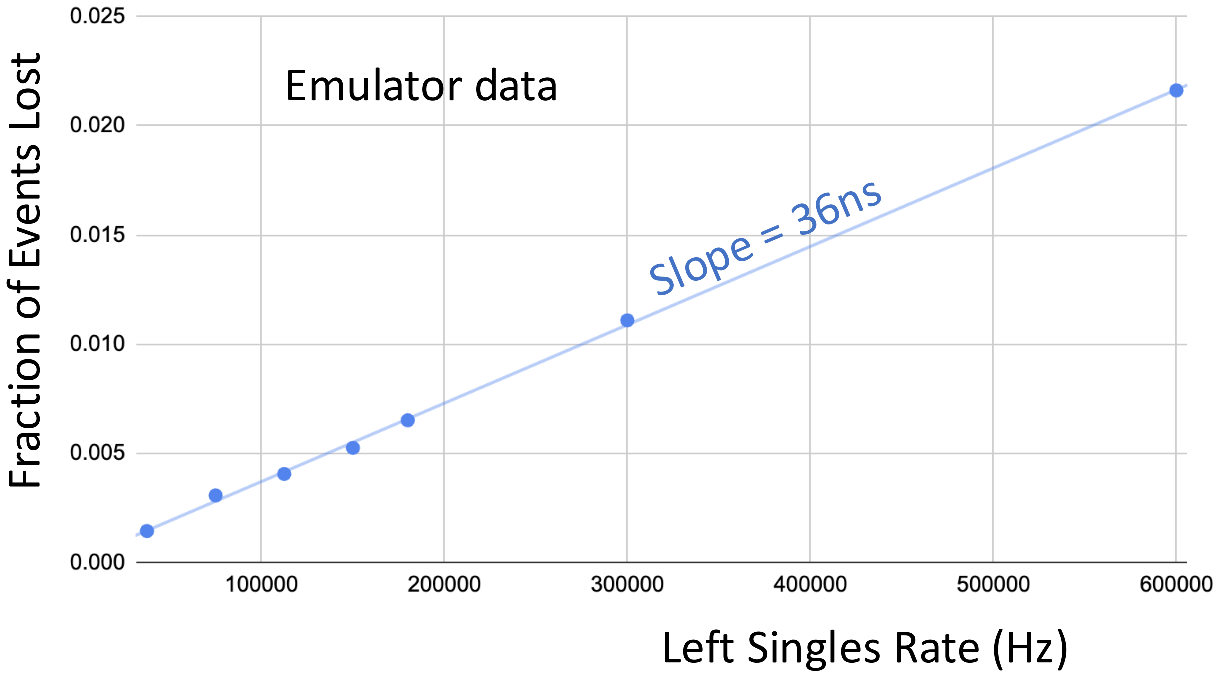
Dead time and accidentals corrections

Our *modus operandi* is to minimize each correction not just the assigned error in case we find out later we are doing the correction wrongly.

Dead time is a good example

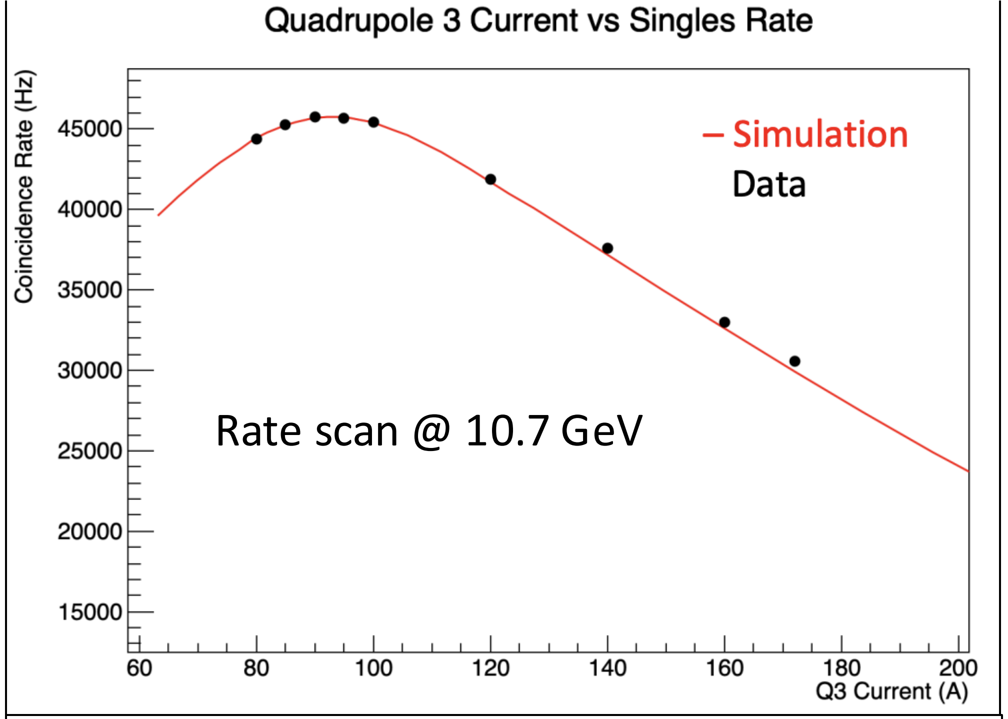
- During PREX/CREX used 4kHz legacy LED flasher to determine dead time.
  - Measured dead time to be 16ns → 0.16% correction at 100kHz
- Measured with new emulator with combination of uncorrelated singles and coincident pairs on parallel left/right channels
  - More than double dead time measured 36ns ->0.36% correction at 100kHz.
- Because we ensure <<1% dead time, even this discovery led to no corrections required in published polarizations.

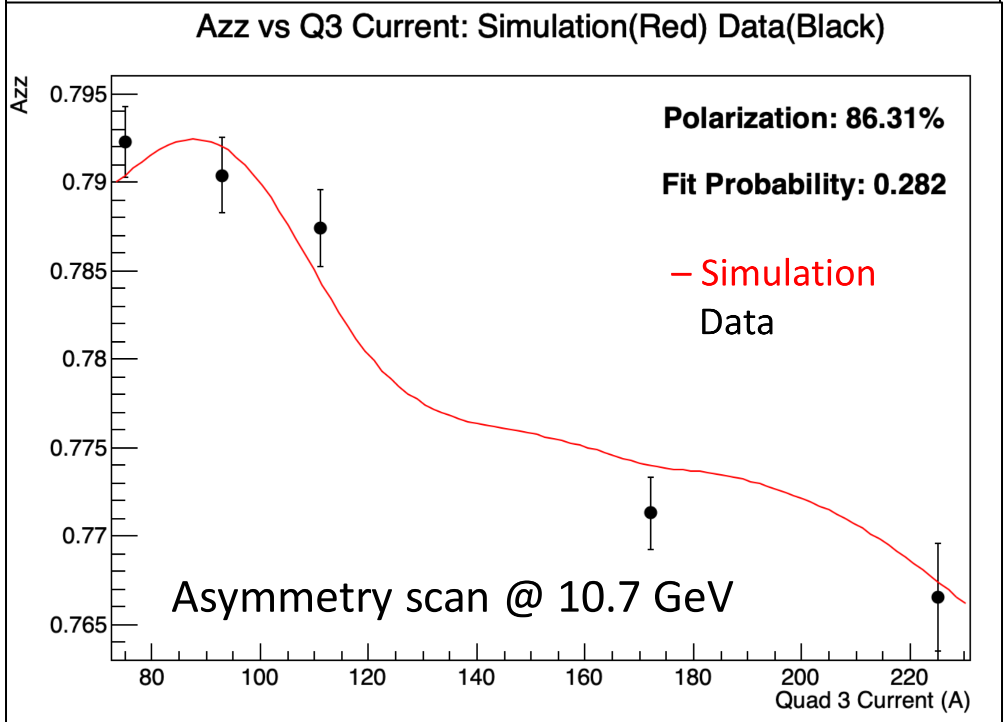
We have also found issues in our accidentals corrections and are likewise investigating with the emulator.



Data from SBS (a few days ago)

- Quadrupole rate scan matches the simulated shape fairly well
- Azz curve from simulation fit to data with single fit parameter of beam polarization.
- Need more accurate data but looks pretty good.
- No “flat region” of Azz like we want during MOLLER. That’s why we are moving the target upstream and installing a collimator.



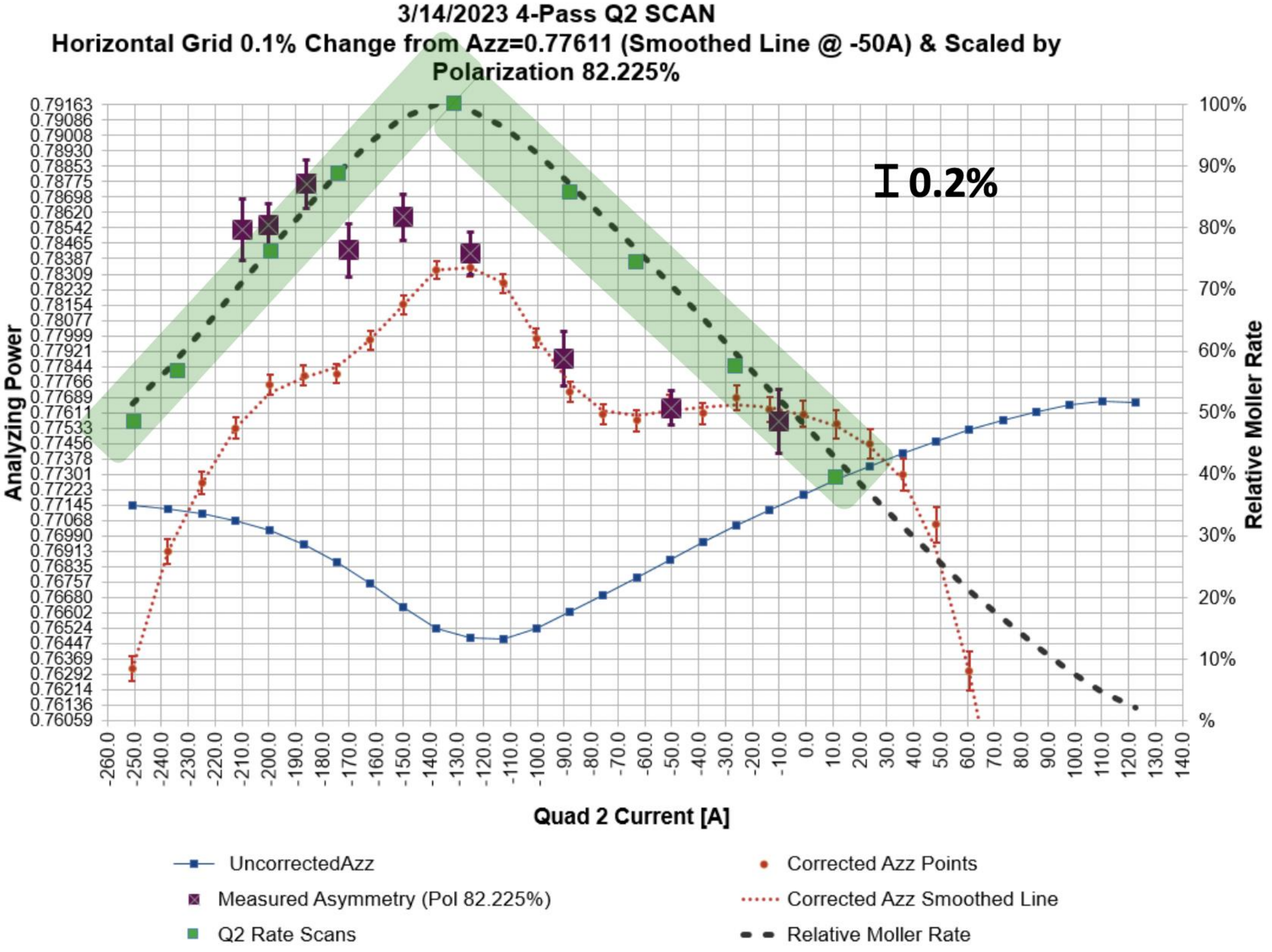


Unresolved discrepancy seen in SBS 4-pass data (2024)

4-Pass Data

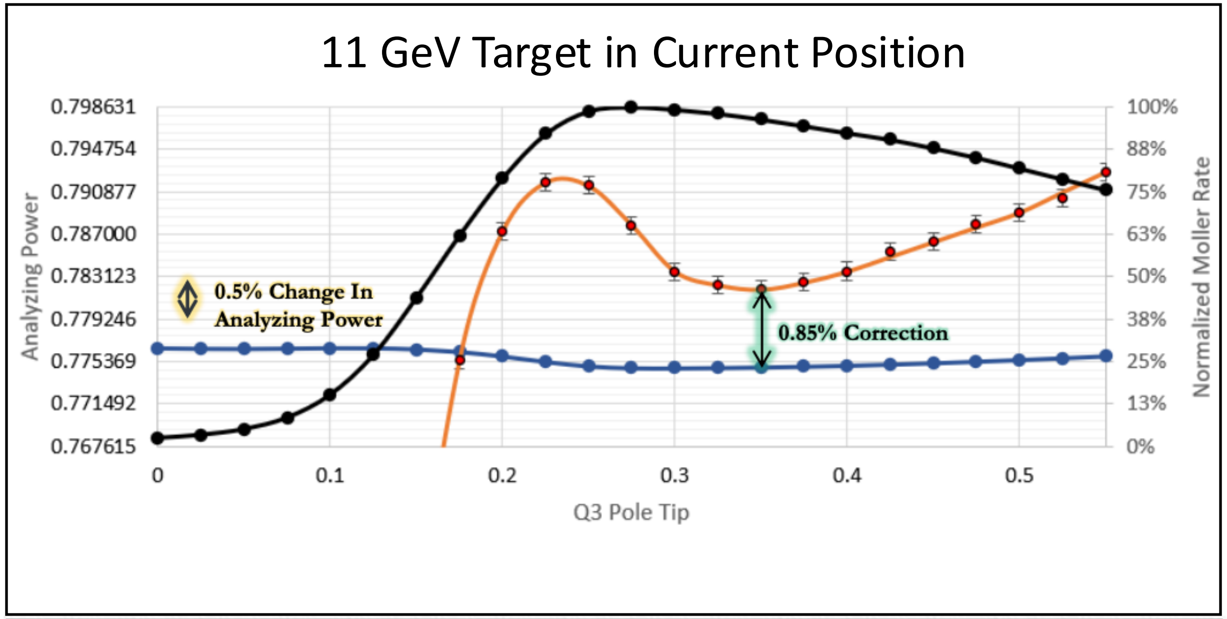
- Rate curves match well
  - Discrepancies within 1% tolerance for magnet characterizations.

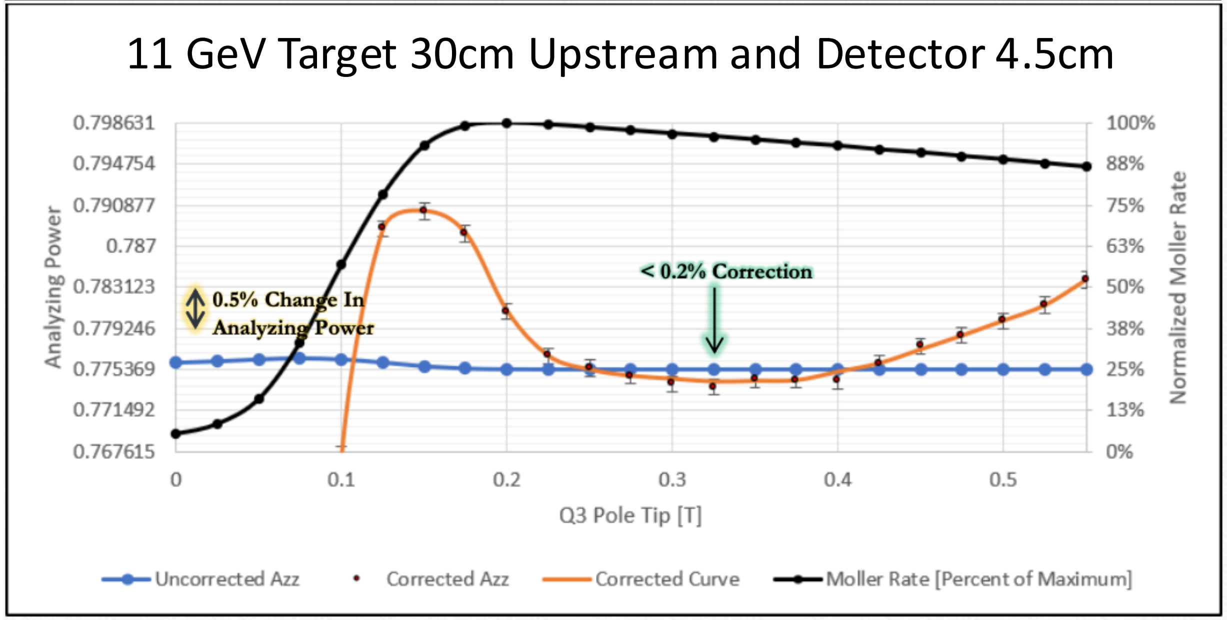
SBS requires 3% precision so we didn't take a long time optimizing the optics.
Possible that we ended up in a particularly sensitive configuration where small uncertainties in beam angle, upstream collimator or positions of dipole apertures had a large effect



Minimizing Levchuk correction

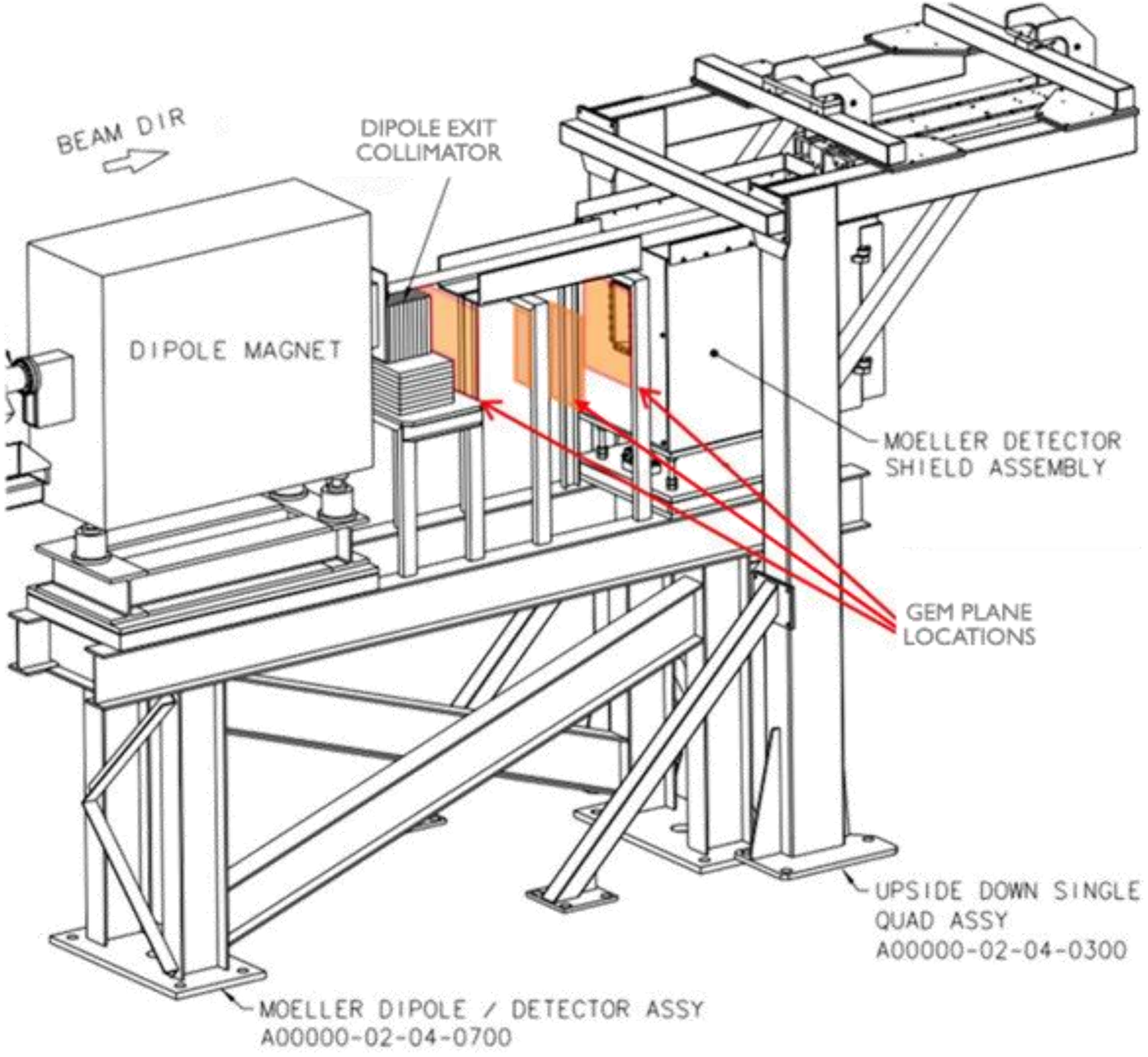
- At 11 GeV current spectrometer had insufficient strength to focus desired Moller events through dipole (high sensitivity to optical setting and 1% level correction)
- Moving target upstream 30cm and limiting vertical acceptance on detector nearly eliminates Levchuk and reduces sensitivity.
- We will map this out like we did in CREX to prove the model gets Levchuk right





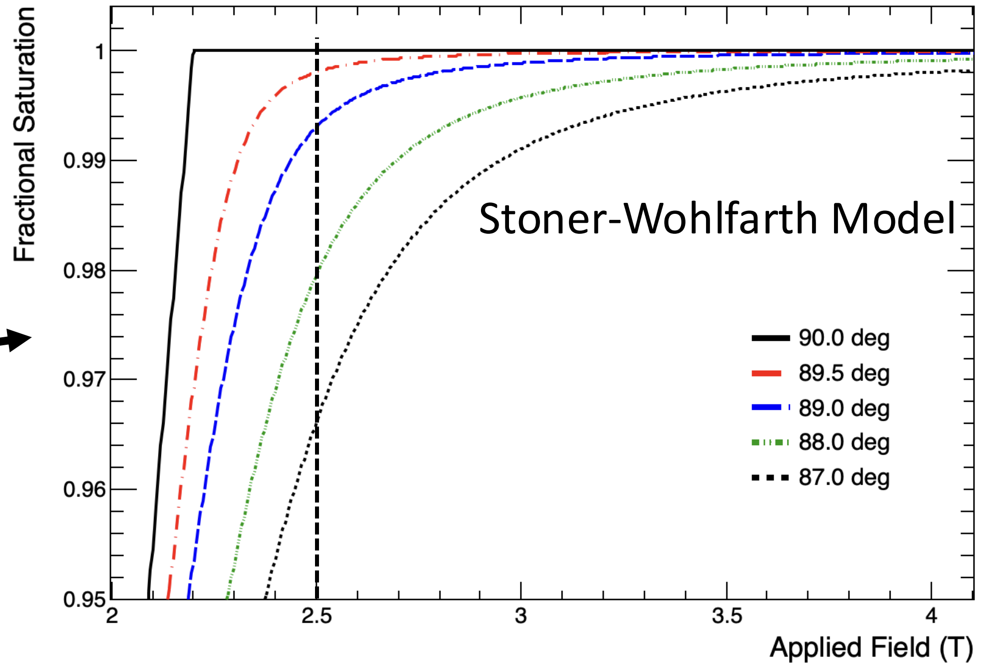
Addition of GEMs

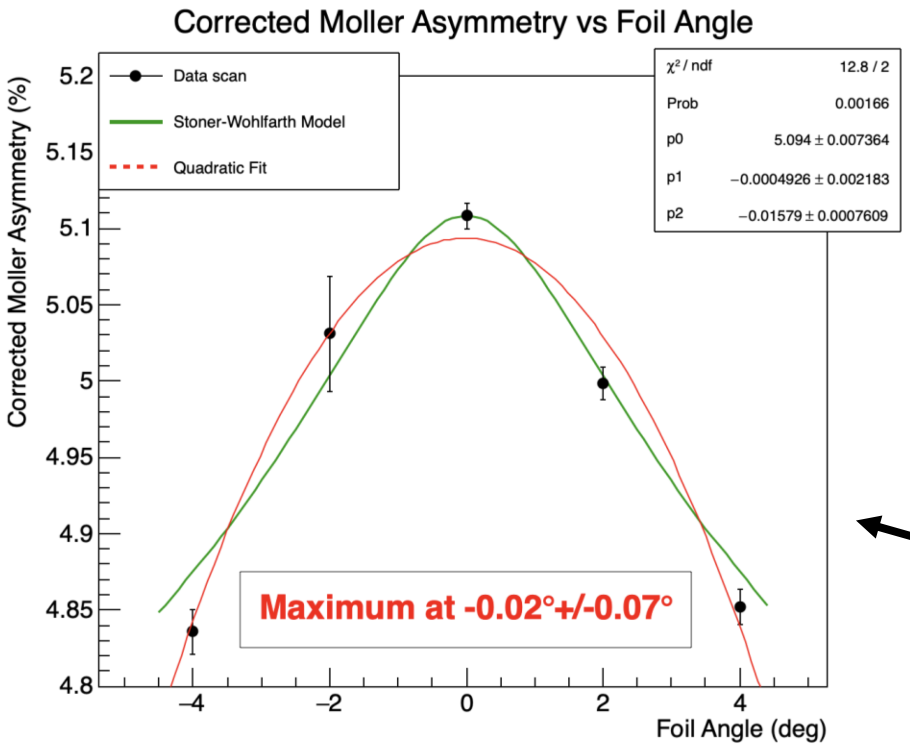
- We expect the new GEMs will help us discover some of the subtle differences between our G4 model and reality
- Hope to further validate Levchuk and benchmark radiative corrections (small but currently unverified)



Results from SBS: foil alignment

- Survey showed ladder aligned very close to normal: $< 0.04°$ in yaw and $< 0.11°$ in pitch
- Stoner-Wohlfarth shows negligible difference between perfectly normal and $0.5°$ off normal down to 3T





- Asymmetry vs foil angle data taken during Gen at 2.5 T also showed good alignment in yaw
- Stoner-Wohlfarth model (after correction to remove transverse asymmetry component) gives decent agreement with SW model
- Demonstrated we can easily and quickly measure foil angle (short runs sufficient due to large change @2.5T)

Saturation scan

- Two 10 micron foils during GEn
  - Foil 3 gives slightly lower polarization (0.21+/-0.17%) and roll-off is consistent with slightly worse alignment (likely not mounted perfectly tight and flat)
  - Foil 2 appears to be almost perfectly aligned and saturated all the way down to 2.5T (2.2T is theoretical saturation point for perfectly aligned flawless monocrystalline foil)

Conclusions

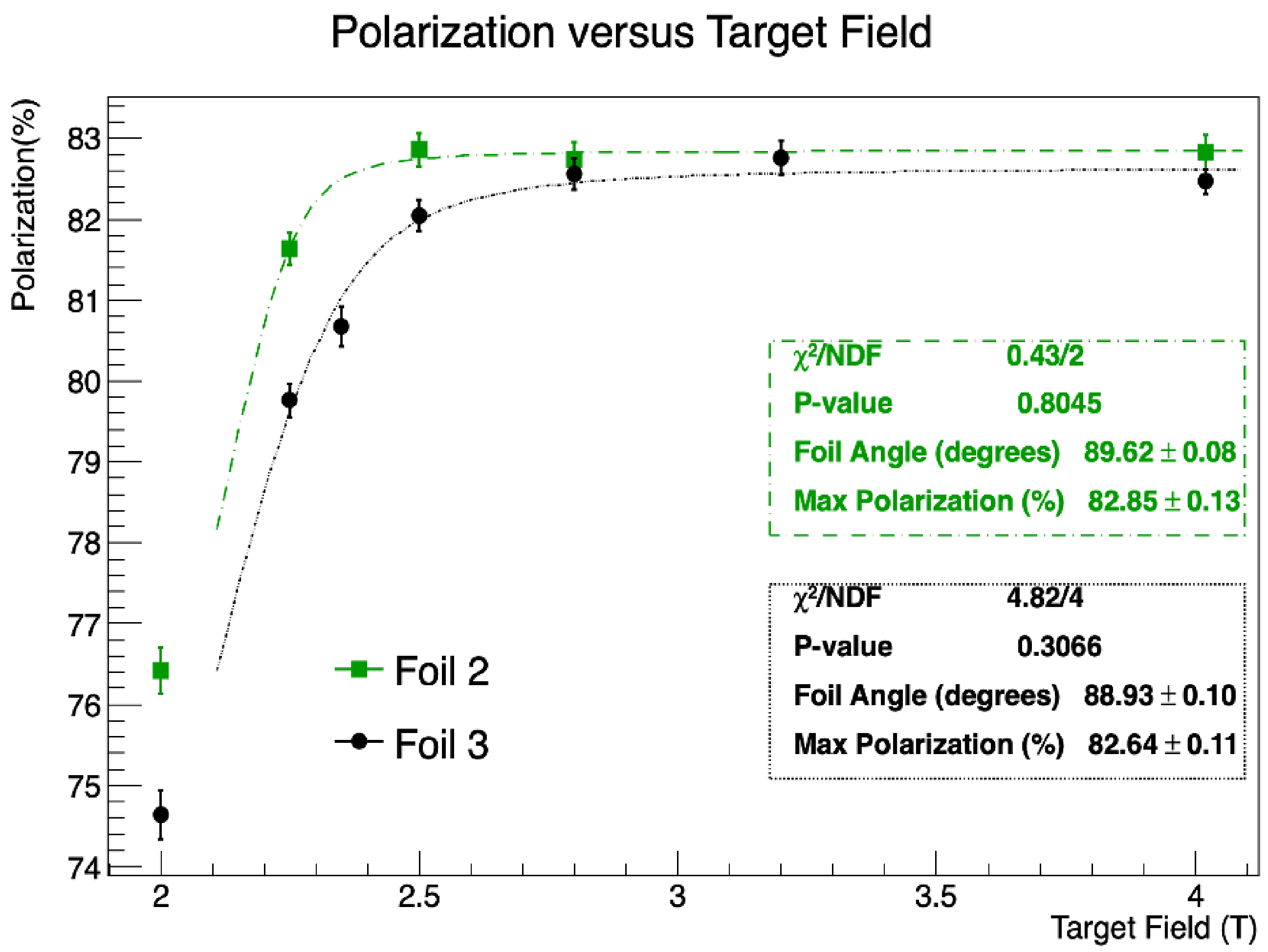
- A well aligned, taut foil is saturated at 3T

  Takes 15.5 minutes to ramp from 3T to 4T, so save ~0.5hr per measurement.

- A poorly aligned or loose foil can easily lead to a 0.3% level systematic error

Comments

- Suspicion is an imperfectly taut foil leads to inconclusive results like we have seen eg. lower polarization at higher field
- Need agreement from >1 foil to convince ourselves we have reliable results.
- Need at least 1 saturation curve with 0.1% per point errors



High current extrapolation

- Large uncertainty due to the fact that production data is taken at 70uA where the Moller measurements are taken at 1uA. Is there any evolution of polarization with current?
- We can in principle repeat a “beat frequency” study from 2006 where the laser frequency is tweaked off the 499 MHz frequency of the chopper such that only every Nth pulse goes through the main aperture and the remaining pulses drop on the aperture face. Keeps current off photocathode high while current in the hall remains low.
  $N = \frac{F_{laser}}{|F_{laser} - F_{chopper}|}$
- Example: Take a Moller measurement at 4uA under usual injector setup. Set up the laser frequency such that every 16^{th} pulse goes through the A-aperture in the master slit (469.6471 MHz). Take another measurement at 4uA in the Hall corresponding to 64uA off the photocathode. Revert to usual 499 MHz laser and take final measurement at 4uA. Compare.
- Collaboration will have to decide on the relative value of such systematic studies but they are the only way we can reach our goals.

Summary

- Steady improvements on understanding the systematic errors and the apparatus and we are going through the process of reducing each one
- New hardware improvements will increase accuracy and reliability
- Optimistic that we can reach the vicinity of 0.40% but it will depend somewhat on what the collaboration deems appropriate to give in terms of systematic studies with beam time.