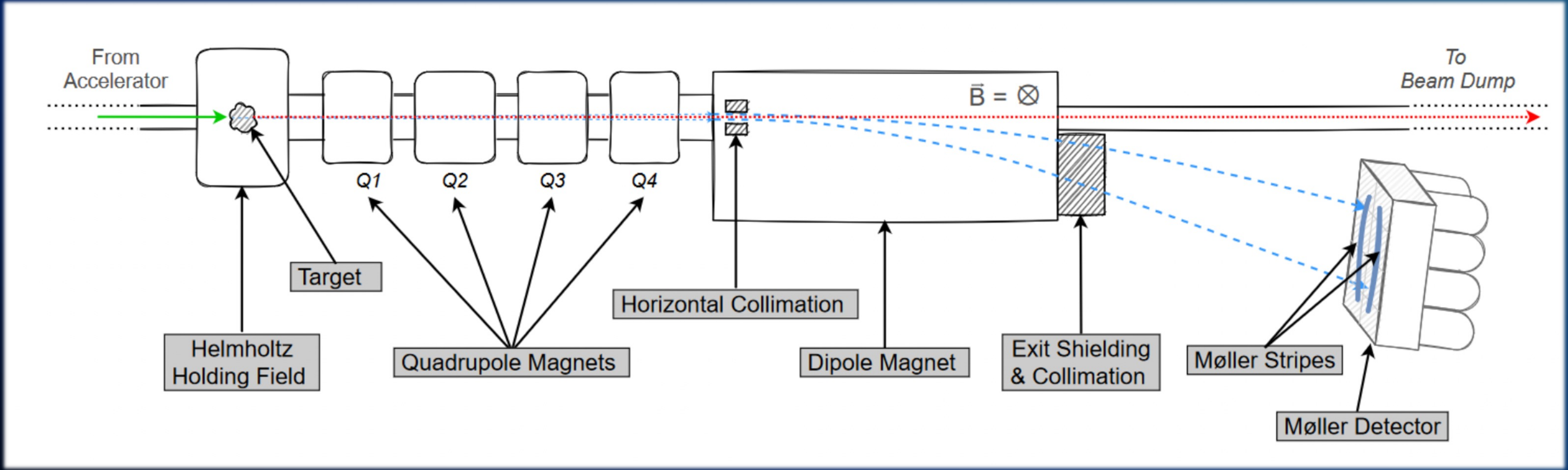
# Hall A Moller Polarimetry

July 2025 ERR for the MOLLER Experiment

Don Jones

# Overview of Moller polarimetry in Hall A

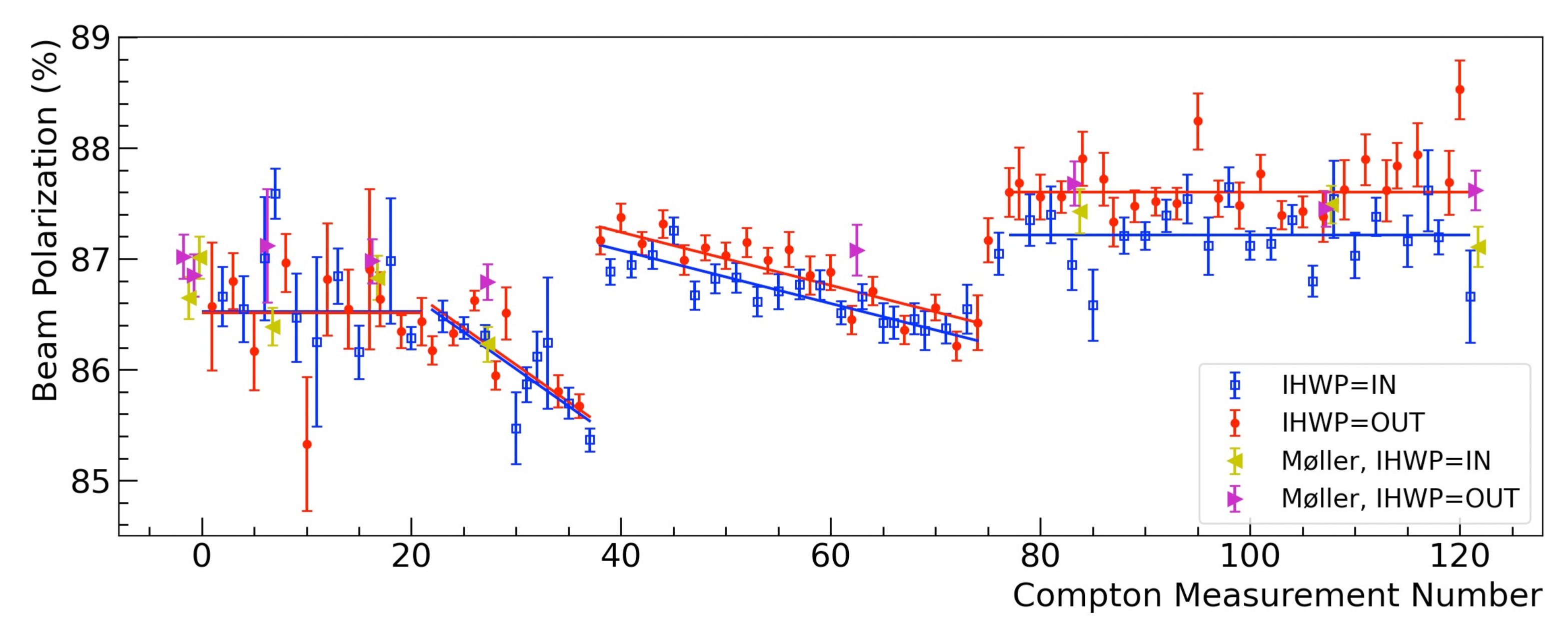
- Superconducting magnet (Helmholtz coils) polarizes 99.99% pure Fe foil at 4T along beam direction
- Four quadrupoles select the events of interest focusing them through left/right slits in the dipole onto a calorimeter.
- Dipole is critical in removing background and helping to reduce the Levchuk effect (correction for electron Fermi motion in target).
- Measure the parity conserving Moller scattering asymmetry (+/-helicity) from an iron foil target (polarized along beam direction) with a required coincidence between the left and right detectors.
- Aiming for 0.40% uncertainty during MOLLER



# Scheduling: weekly measurements during MOLLER

I do not expect Moller polarimetry to be the sole or even primary polarimetry measurement for MOLLER but to work in concert with Compton

- Moller polarimetry is invasive, not taken at production beam conditions, and provides a polarimetry snapshot, whereas Compton provides a continuous monitor of polarization at and during production running.
- However, due to systematic uncertainties and the precision needed it is desirable to have two or more independent measurements at similar levels of uncertainty.
- Moller will likely contribute similarly to what it did during CREX where it was used to normalize the continuous Compton measurement with regularly scheduled measurements.



# Scheduling: installation

All components are expected to be installed during the upcoming SAD and ready for Run 1.

This includes

- Magnet power supplies
- GEMs
- Collimators
- Target magnet relocation 30cm upstream
- New target foils
- FADC-based DAQ with GEMS integrated
- Harp repair

# Personnel

- Don Jones( Hall A/C Scientist) responsible for the Moller polarimeter as a whole
- Hanjie Liu ( Hall A/C Scientist) development of a new DAQ
- Chandan Ghosh(Hall A/C Scientist) can help with integrating GEMs in our DAQ
- Jim Napolitano (Temple U. Prof) leading the Moller polarimetry working group
- Addison Arcuri and Mark Klobukov (Temple grad students) working on MOLLER with focus on Moller polarimetry
- Paul Souder(Syracuse U. Prof) leading understanding of use of GEMs and providing technical oversight for DAQ and analysis.
- Zhongling Xi (post doc at Syracuse U) helping in DAQ development and analysis
- Vidura Vishvanath (graduate student at UVA under Nilanga) focusing on GEM installation and maintenance for the Moller polarimeter.
- Bill Henry(Hall A/C Scientist) expert on Moller polarimetry who can help with measurements as required.
- Ellen Becker(Hall A Engineer) responsible for maintaining target magnet and motion as well as collimator motion.
- DC power responsible for smooth operation of 4 dipole power supplies and dipole power supply.

# Personnel

## Installation:

1. Preparing the target and target magnet: Don, Ellen, Addison
2. Readying/understanding the old CAMAC DAQ: Don, Addison
3. Developing the new DAQ: Hanjie Liu
4. Building a decoder and analyzer: Hanjie, Don, Zhongling, students.
5. GEM installation: Vidura, Don
6. Collimator installation: Don

## Maintenance:

1. DAQ: Hanjie(new FADC/VTP-based) , Don (old CAMAC-based)
2. GEMs: Vidura
3. Power supplies: DC power
4. Analyzer and decoder: Don and students

# Personnel continued

## Running (taking measurements):

- Don, Addison, Vidura, Mark, Bill

## Analysis:

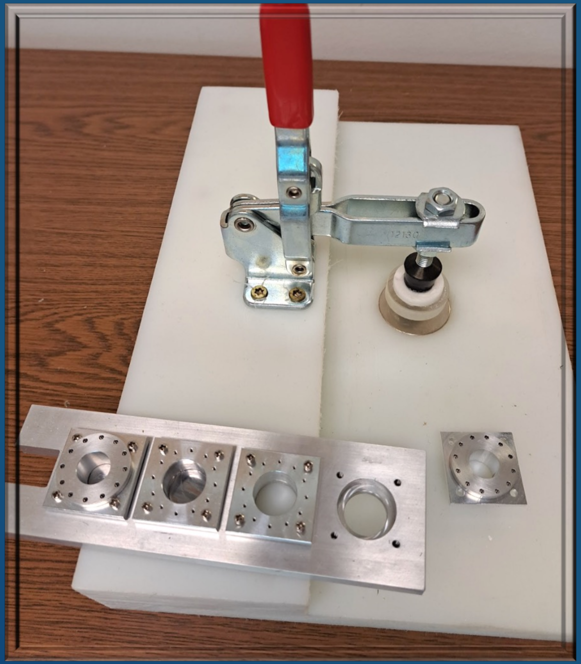
1. Simulation: Mark
2. Systematics: Addison, Vidura, Mark with oversight and help from Jim, Nilanga and Don

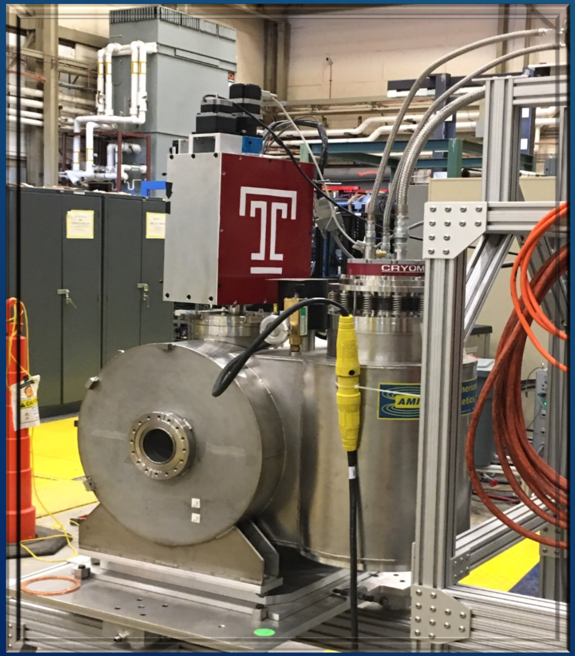
# Equipment readiness: magnets & power supplies

- Superconducting (SC) target magnet ✓
  - Has been in use during SBS: some issues with quenching at high field>3.5T
  - Plan to run at 4T so need to pump on SC vacuum for several weeks and test at high field.
  - Will be moved upstream 30cm during upstream beamline rebuild in 2026
- Quadrupole magnets ✓
  - Magnets old but seem to work fine even at high current
  - Power supplies old and unreliable
  - Hall A purchased 4 new power supplies and 5th spare is on order.
- Dipole magnet ✓
  - Magnet operates well but old power supply cannot reach required currents at 11 GeV.
  - Budgets constraints have delayed the purchase of a new power supply several times and next year uncertain
  - Currently using the old BigBite power supply which reaches the 480A that we need but struggles to reach the 550A specified by the upper end of the hysteresis loop.

# Equipment readiness: target ✓

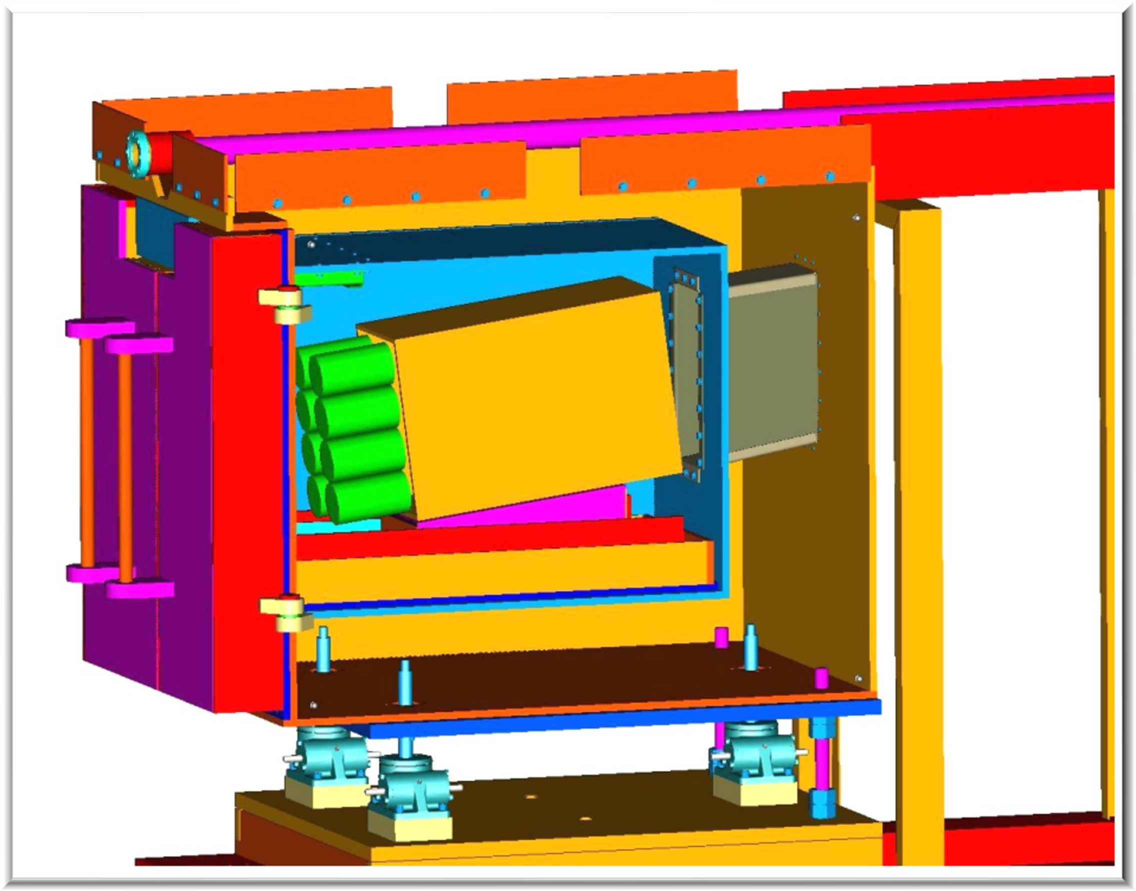
- Need to remove ladder and install new Fe foils (1$\mu$m to 25$\mu$m thickness)
- Previous foils have sometimes had wrinkles or been less than taut
  - Not allowed for MOLLER
  - Working on procedure and equipment to ensure perfect foil installation
- Plan to continue using target motion control (linear and rotational) built by Temple.
  - Worked well over past 5 years.
  - Rotation allows for systematic study of foil angle effects





# Equipment readiness: detector ✓

- 8 PMT "spaghetti lead" calorimeter
  - 30cm tall by 18 cm wide
- Scintillator paddles in front of left and right sides but not used in years.
- LED flasher system for measuring dead time
- New CAEN HV crate + cards
- Everything works as expected.



# Equipment readiness: DAQ ✓

## Existing

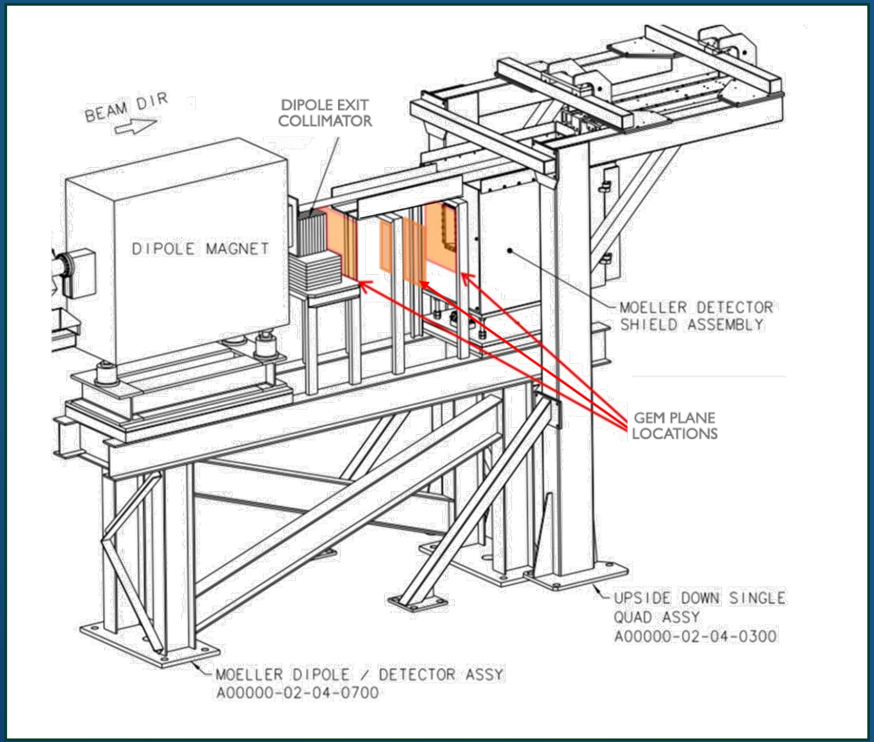
- Old CAMAC+NIM+VME DAQ based on scalers with occasional ADC+TDC readout
- Works well but difficult to maintain and runs on obsolete version of CODA
- Replacement parts on hand for most old CAMAC and NIM modules

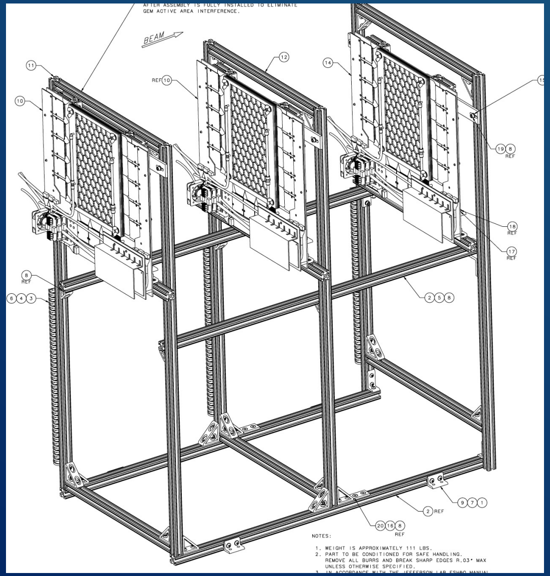
## Under development

- New FADC-based DAQ under development led by Hanjie Liu
- Took some data during recent Moller measurements
- Will save scaler and pre-scaled waveform data
- More complex triggers can be implemented with the flexibility of a VTP-based trigger.
- Still need to build a decoder and an analyzer

# New equipment: GEMS

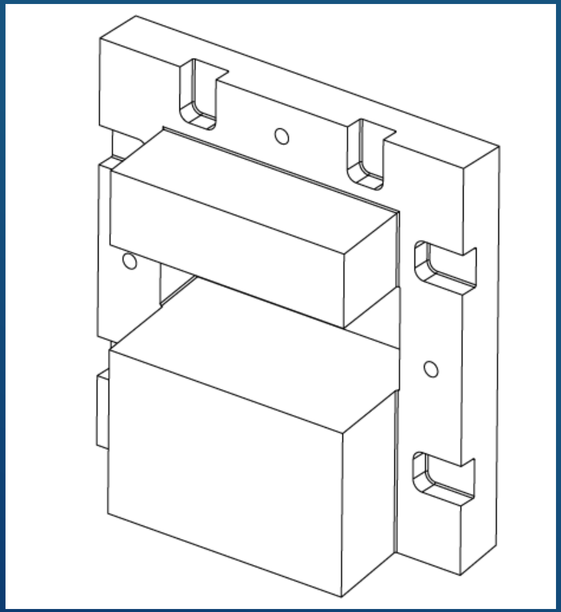
- 4 GEMs currently being built at UVA and expected to be completed by early Fall
- 3 planes will be installed between the dipole and detector for us to verify simulation predictions for things like Levchuk, multiple scattering and radiative corrections.
- These will be installed during the upcoming MOLLER installation and operated by UVA
- We will enlist help from the main MOLLER GEM group to set up the DAQ to read them out



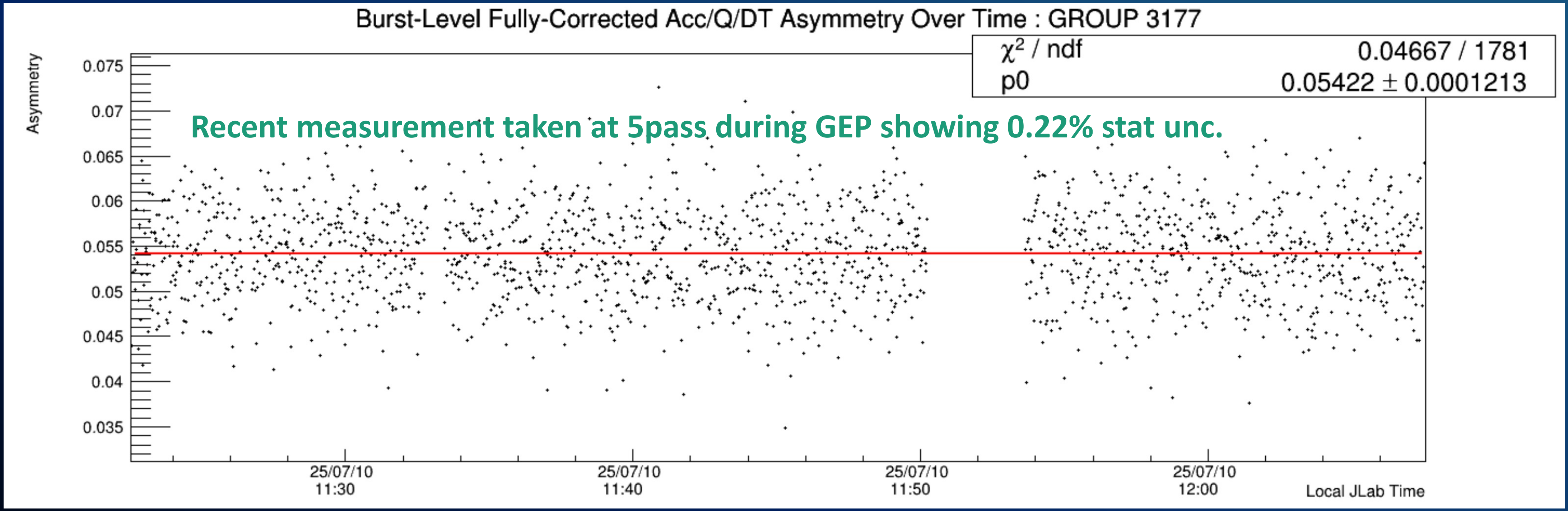
# New equipment: tungsten collimator

- Installs directly upstream of detector inside shielding hut window
- Limits vertical acceptance of detector to reduce uncertainty in Azz and size of Levchuk correction
- Collimator already built and onsite
- Will be installed (three bolts) before GEMS are installed.



# Statistical errors

- 5 pass running during SBS gives 0.2% in 50 minutes
- During MOLLER collimation limits rates so it may take >1hr to reach 0.2%
- 0.2-0.25% statistical error weekly easily sufficient--adds negligible uncertainty
- Including thicker foil 25 micron to help reach statistics faster



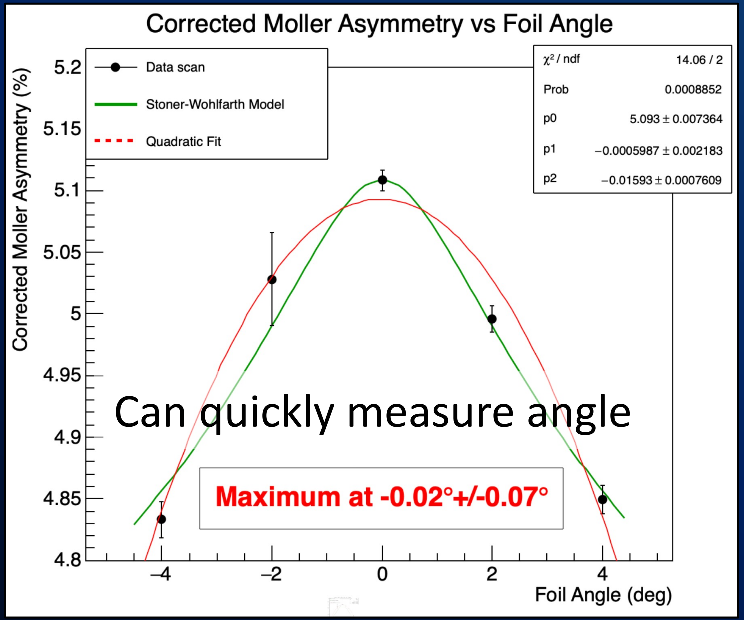
# Systematic errors: goal ~±0.4%

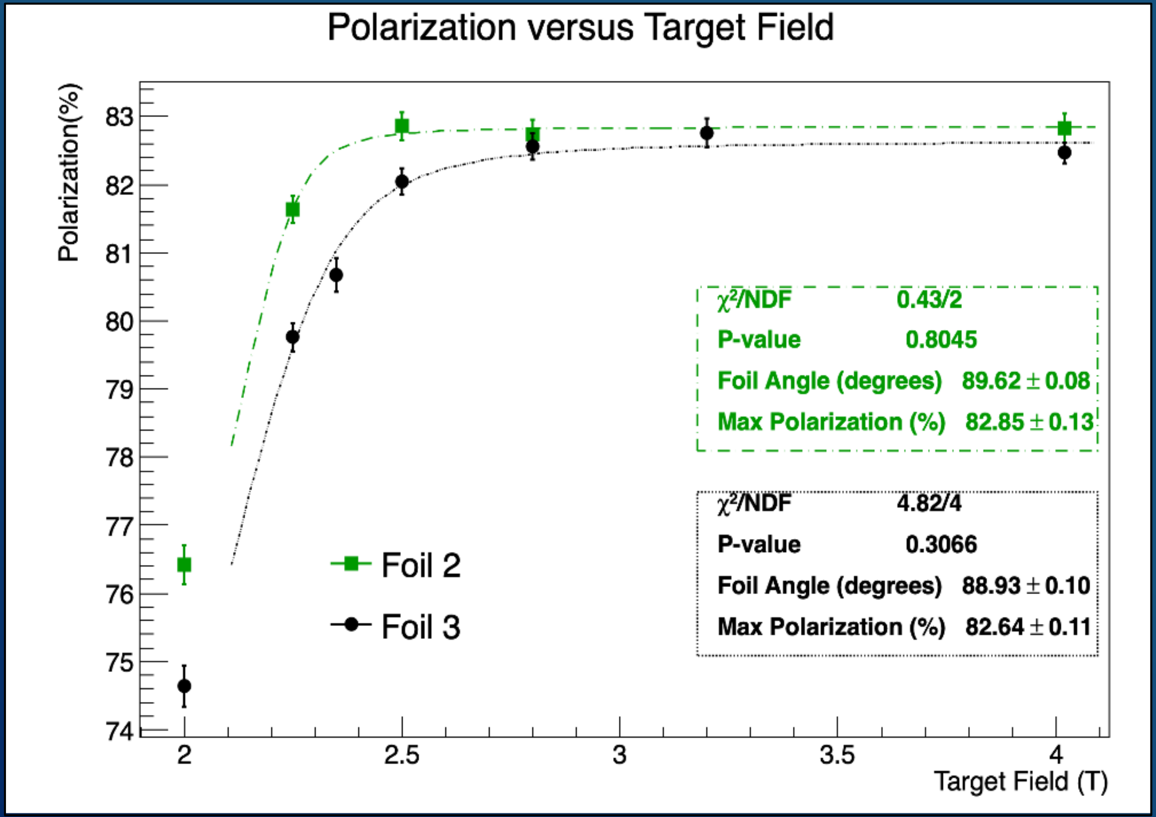
- There is a path to reach our goal comparable to what Compton already reached during CREX—not easy
- Given the large uncertainty related to foil polarization and analyzing power, we can only have a few sources at the 0.1% level
- Examination of each source of systematic uncertainty is either completed, underway or planned.

| Uncertainty Source | CREX(%) | MOLLER(%) |
|---|---|---|
| Foil Saturation Polarization | 0.28 | 0.24 |
| Foil Degree of Saturation | 0.50 | 0.10 |
| $A_{zz}$+Levchuk | 0.16 | 0.15 |
| Dead Time | 0.15 | 0.10 |
| Accidentals | 0.04 | 0.10 |
| Null Asymmetry | 0.22 | 0.10 |
| Electron Source Variation | 0.06 | 0.02 |
| Current Dependence | 0.50 | 0.15 |
| Aperture Transmission | 0.10 | 0.10 |
| Leakage currents | 0.18 | 0.10 |
| Total | 0.85 | 0.40 |

# Systematic errors: foil polarization

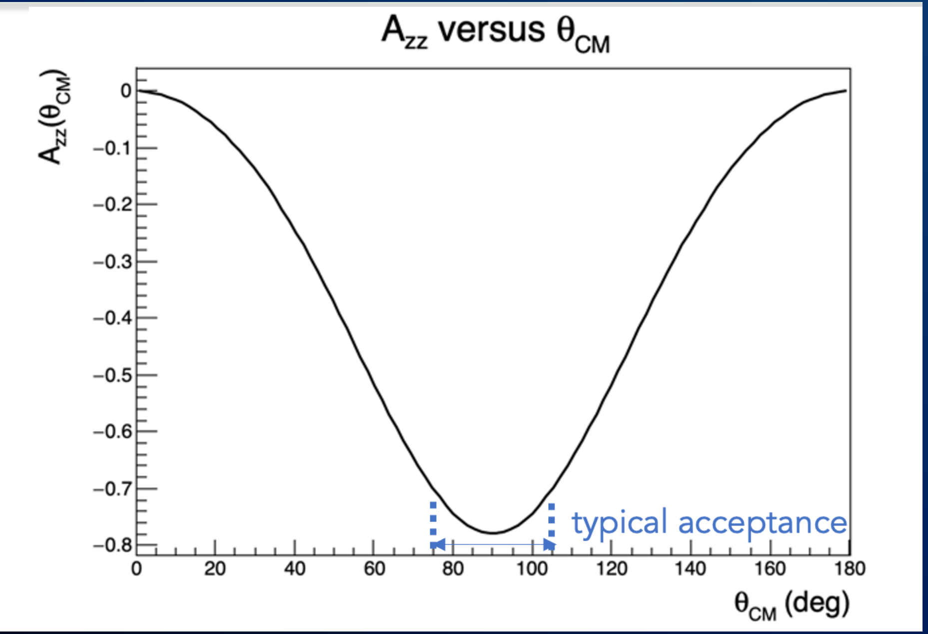
- Saturation polarization taken from literature
- Degree of saturation: how close to saturation?
  - Corrections for temperature and field dependence (due to foil angle and flatness)
  - Need 2-3 shifts to accurately map saturation curves
  - Stoner-Wohlfarth model suggests we need $\pm 0.7°$ alignment to normal to be within 0.1% of saturation at 4T.



# Systematic errors: Azz + Levchuk

- Azz taken from simulation
  - 7/9 for 90 degree scattering in COM
  - Acceptance usually around 75-105 deg in COM
  - Simulation provides average over acceptance including Levchuk and radiative effects

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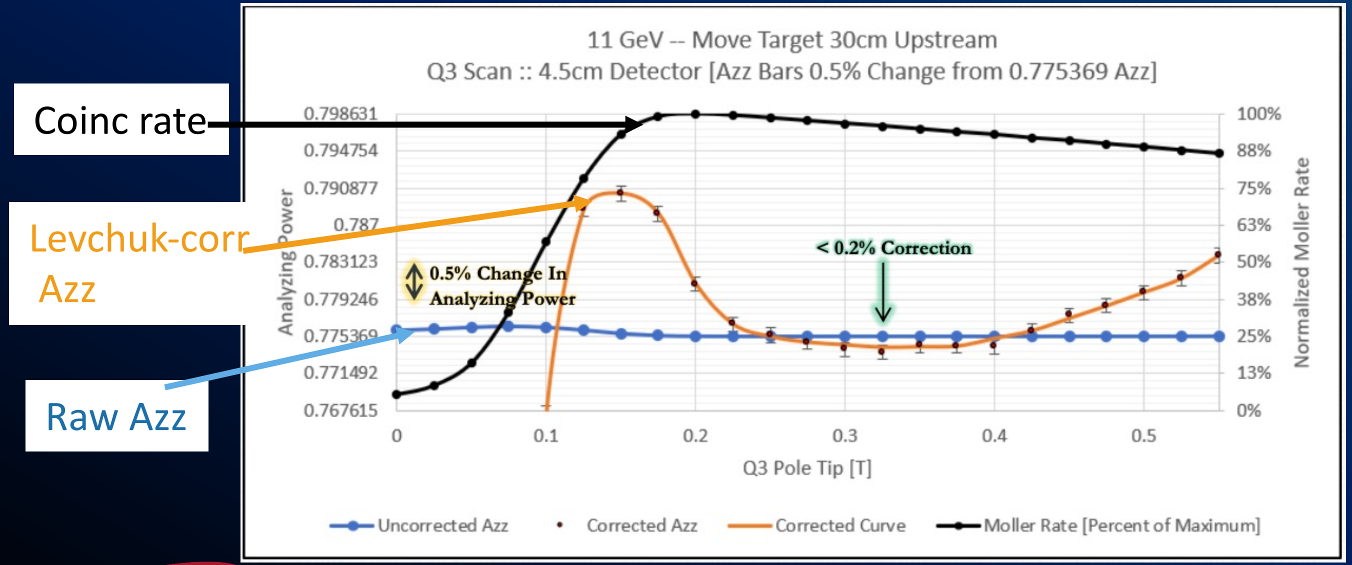
# Systematic errors: Azz + Levchuk

- Levchuk correction
  - Fermi motion of electrons gives transverse kick to electrons changing scattering angle but not momentum
  - Electrons close to dipole aperture edges can either scatter out of or into acceptance
  - Unpolarized inner electrons (highest velocity) most effected
  - Limiting momentum acceptance can sometimes eliminate correction

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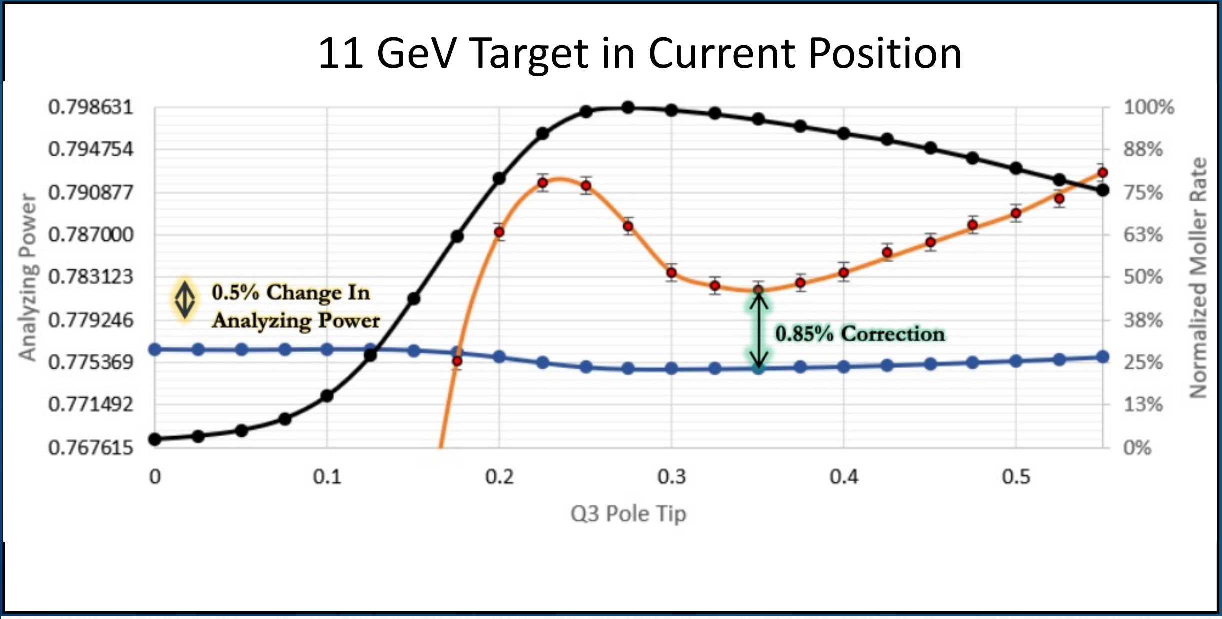
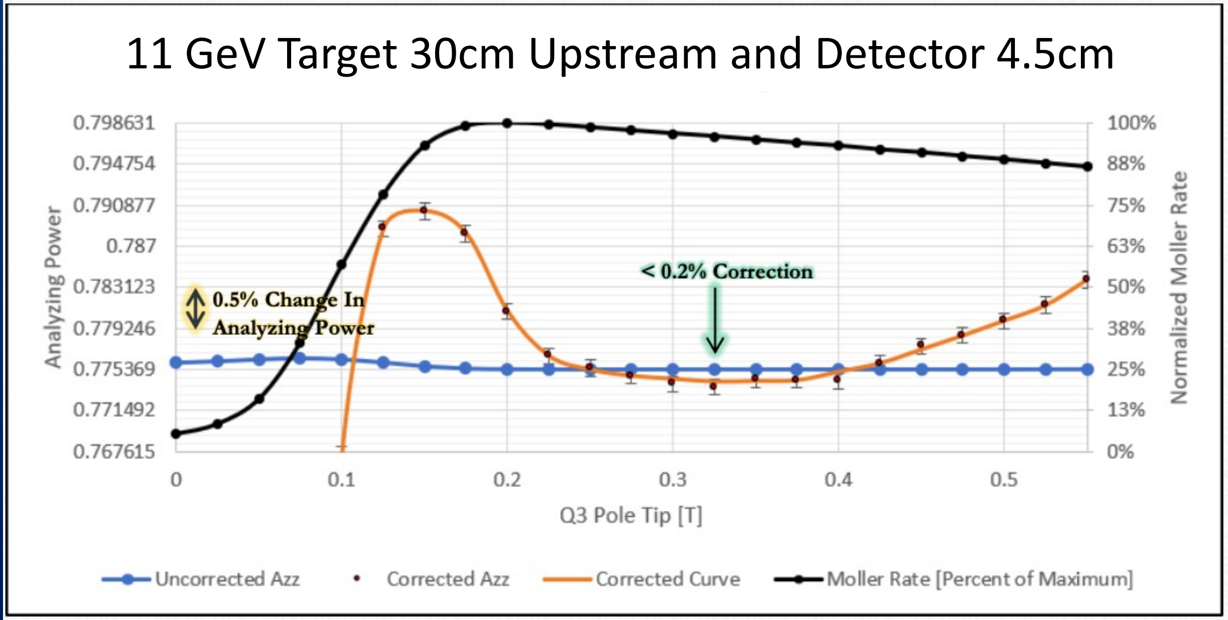
# Minimizing Levchuk correction

- At 11 GeV current spectrometer quads have insufficient strength to focus desired Moller events through dipole (high sensitivity to optical setting and 1% level Levchuk 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




Jefferson Lab

# Systematic errors: beam time measurements

- Null asymmetry (two types)
  1. Measurement with Cu foil
  2. HWP In+Out
- Electron source variation: track degree of linear polarization is introduced into the beam by deliberate changes to zero charge asymmetry
- Current dependence: measure difference in polarization between low and high current
- Aperture transmission + leakage currents: to reduce bleedthrough from other halls, often the main slit (aperture) is partially closed during Moller measurements.
  - Either leave it open and measure the leakage precisely
  - Or close it partially and measure its effect on polarization.
  - Closing it partially cuts the electron pulse and there may be polarization gradients (time structure) across the pulse.

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# Systematic errors: dead time and accidentals

Evidence that neither have been measured and corrected properly to date.

## Dead time

- Measured using 4.5kHz LED flasher that illuminates PMTs during beam operation.
- Fraction of lost LED events gives dead time
- This measurement differs by factor of ~2 from new measurements using a detector emulator

## Accidentals

- Measured by delaying left detector signal by 120ns relative to right and forming random coincidences
- Suspect this technique is off by at least 50%

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# Systematics: dead time and accidentals


## Solution: using a CAEN detector emulator

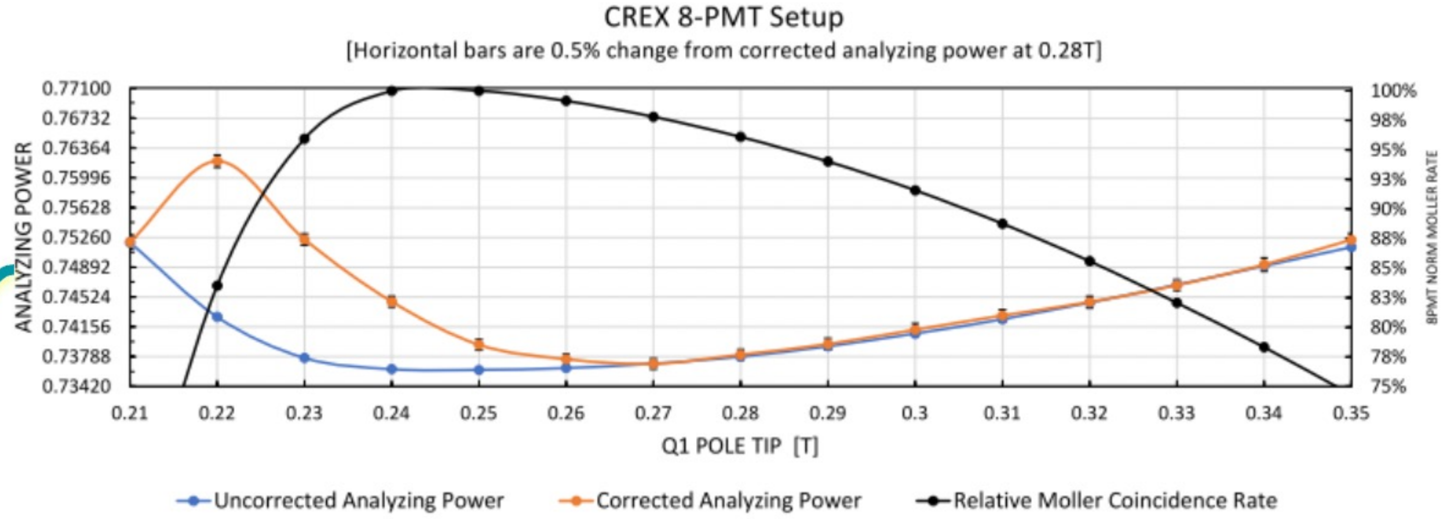
- Emulator outputs two channels of analog pulses
  - Pulses are either fixed regular frequency or random in time at an average user-selected frequency,
  - Pulses are fixed amplitude or following a distribution, and
  - Pulse shape and time duration determined by the user
  - The two channels can have a user-selected mix of independent uncorrelated pulses or coincident pulses with the same pulse sent to both channels. The frequency and time distribution of both coincidence and uncorrelated can be independently set for each channel.
- We are studying ways to use this tool to directly measure the dead time and accidental corrections for the DAQ

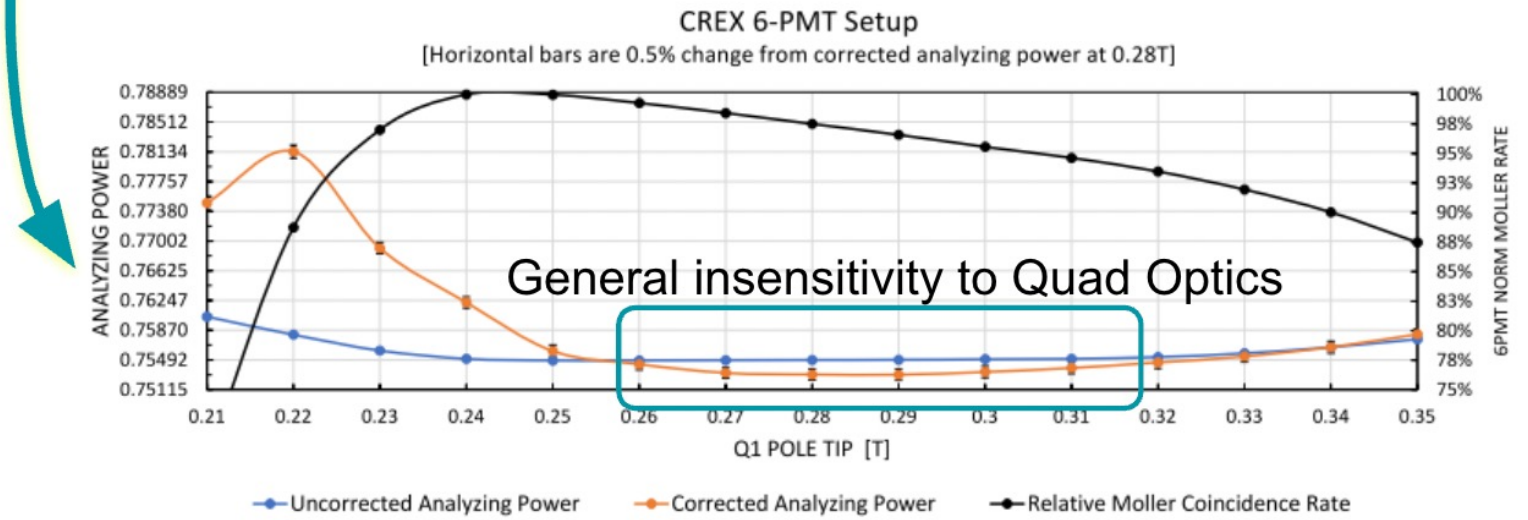
# Conclusions

- Plan to have all hardware installed and operational by the end of the SAM.
- Personnel are in place for installation, maintenance and operation (data taking)
- Systematics studies will continue throughout the SAD and into Run1

# Backups

# [Optics] CREX

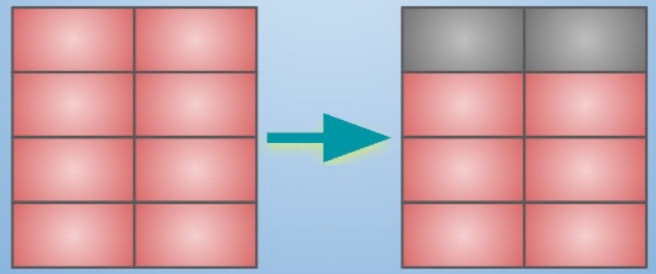


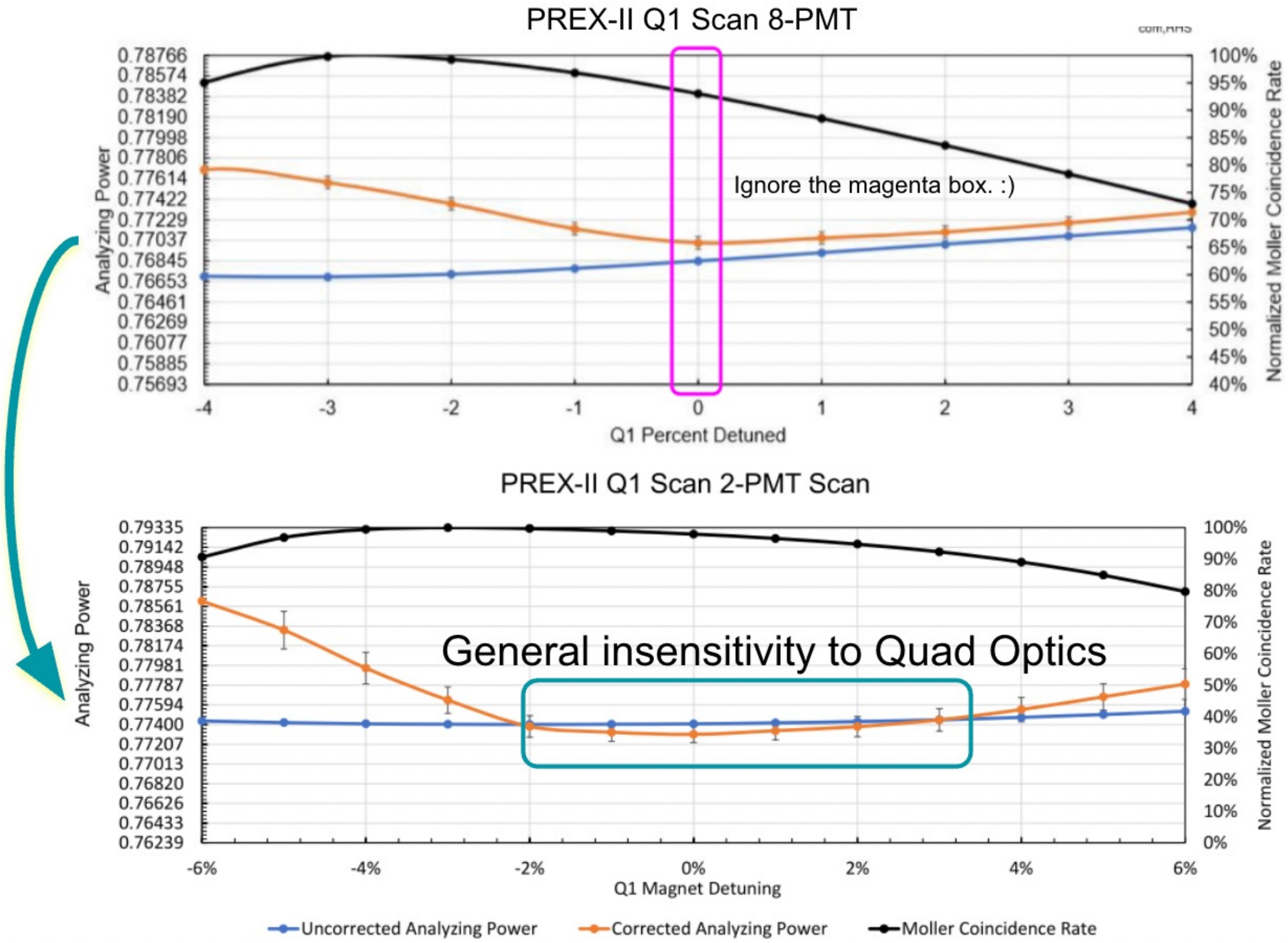

CREX:

Using single pair of PMTs allowed for significant control of analyzing power and eliminated concerns about the optics tuning of the magners.

[Shown] Q1 Scan using all eight (8) PMTs versus just six (6) PMTs.



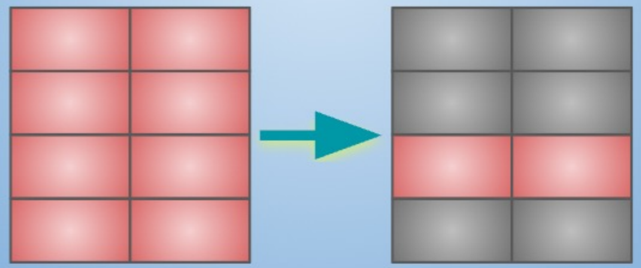
# [Optics] PREX–II




PREX-II:

Using single pair of PMTs allowed for significant control of analyzing power and eliminated concerns about the optics tuning of the magners.

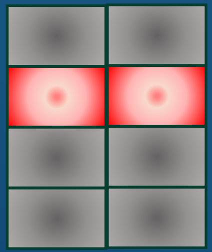
[Shown] Q1 Scan using all eight (8) PMTs versus just two (2) PMTs.

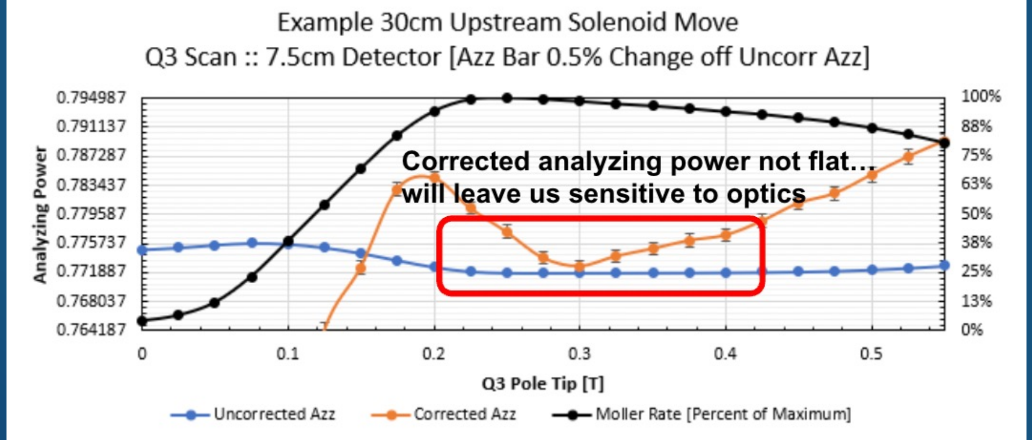


# Azz+Levchuk

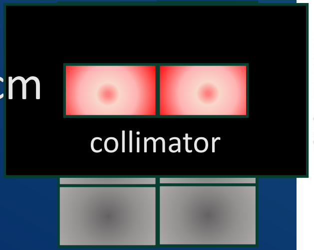
- Limiting detector vertical acceptance (cut in momentum space) can decrease Levchuk and flatten sensitivity of Azz to optics

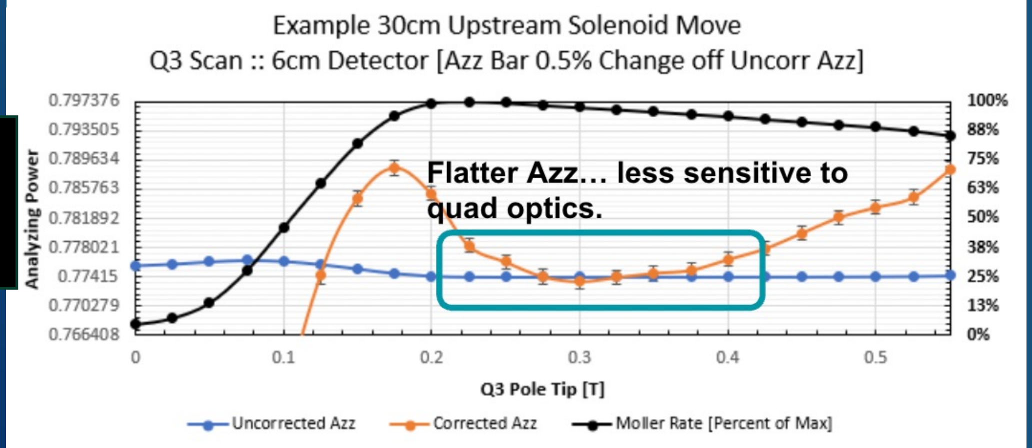
7.5cm



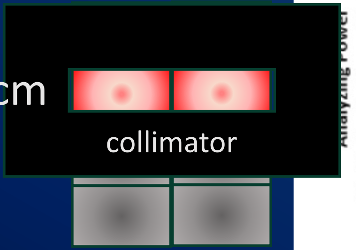


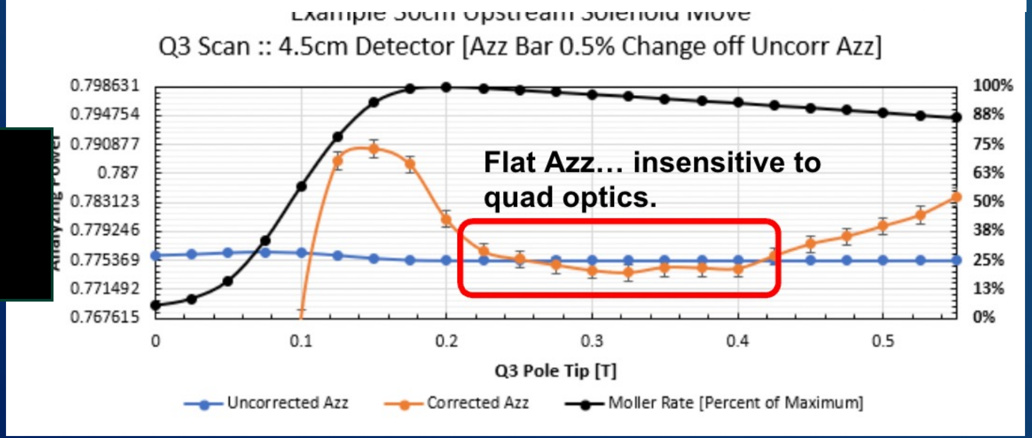

6.0cm



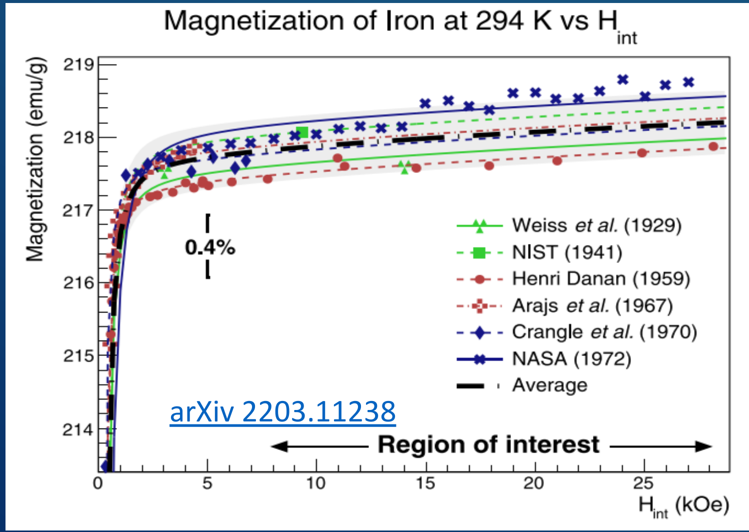

4.5cm

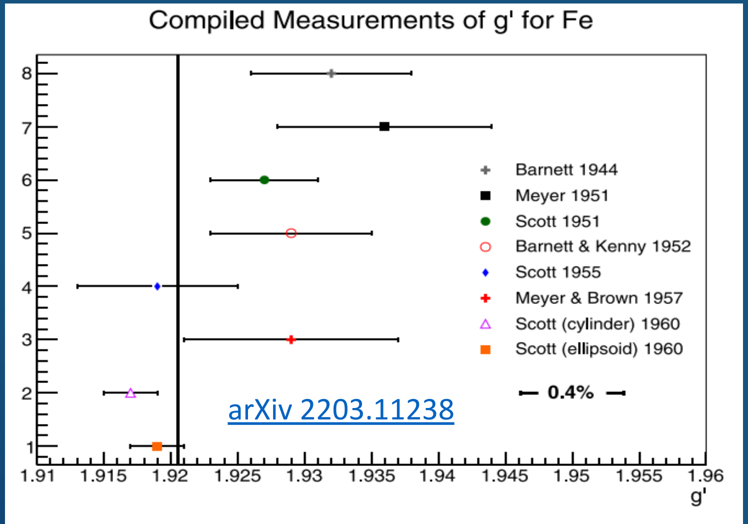


# Fe foil target polarization

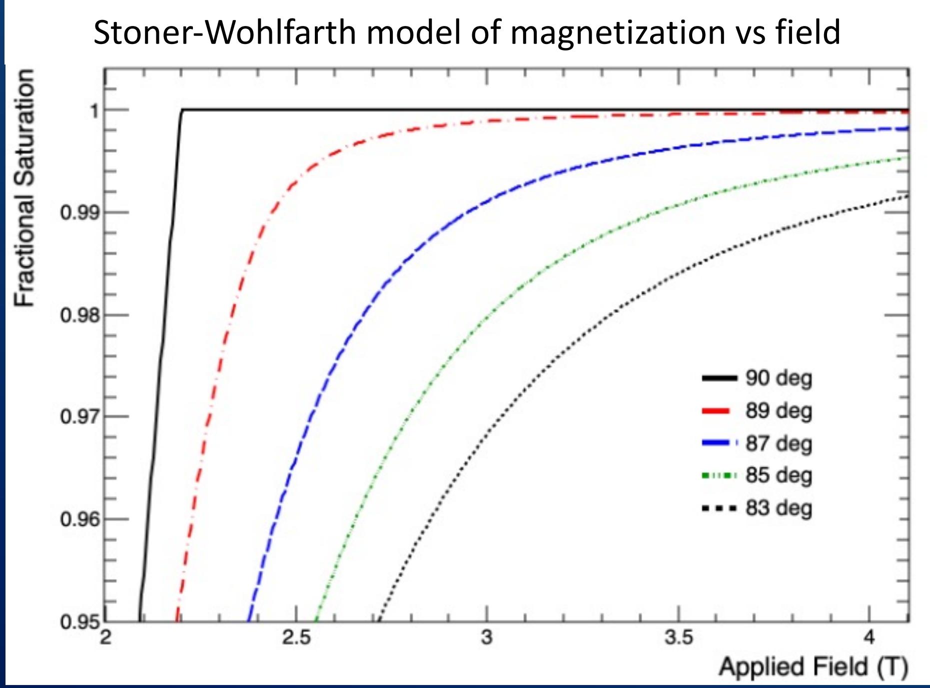
In a recent publication we demonstrate using world data on saturation magnetization and on the fraction of magnetization from spin that electron polarization in Fe foils is known to ±0.24%.
Difficult to improve.




**Degree of saturation**: two key things prevent reaching full saturation magnetization

1. Magnetic field not strong enough
   - Difficult to magnetize out of plane
   - Crystal imperfections and stresses/strains create stubborn domain walls (ideal crystal fully saturated at 2.2T)
2. Imperfect alignment of foil (not taut, wrinkles, not precisely normal to magnetic field)

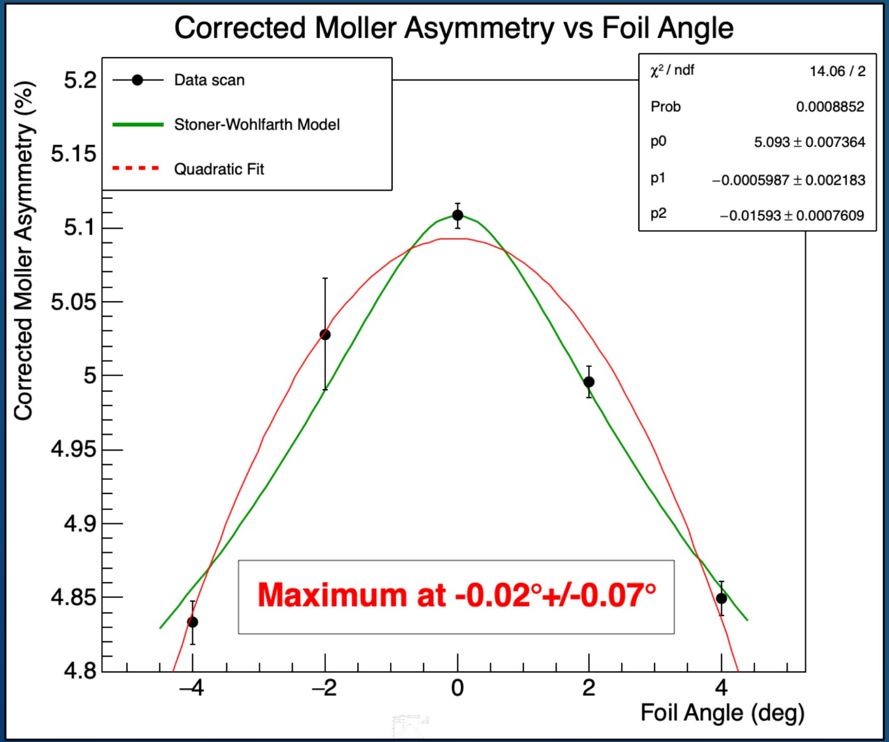


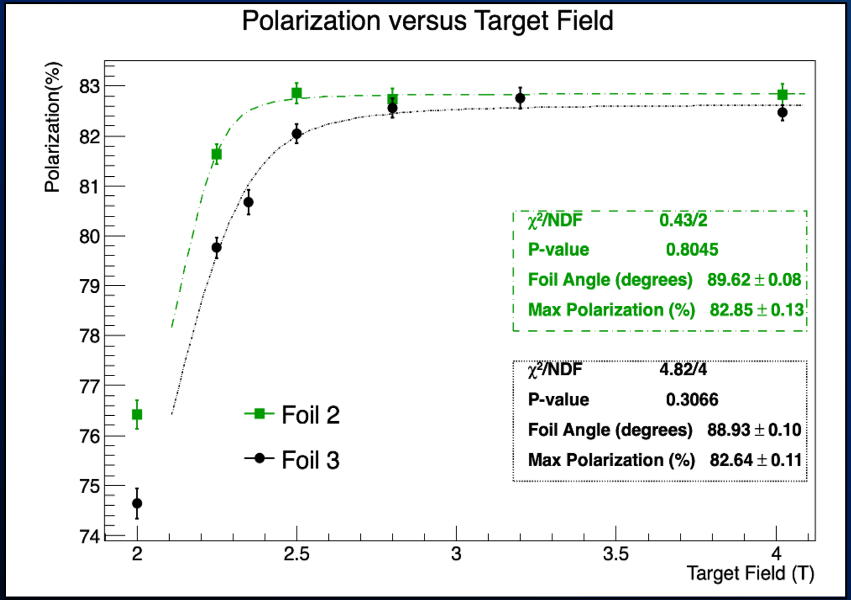
# Fe foil target polarization

Ideal: demonstrate saturation precisely using an asymmetry vs. field scan

Previous scans/data have demonstrated

- Apparent agreement with Stoner-Wohlfarth model and ability to align foils to within a fraction of a degree of normal using asymmetry vs foil angle scans
- Results with two foils apparently aligned to within $\pm 1°$ agree at 1.24**σ on** saturation polarization.



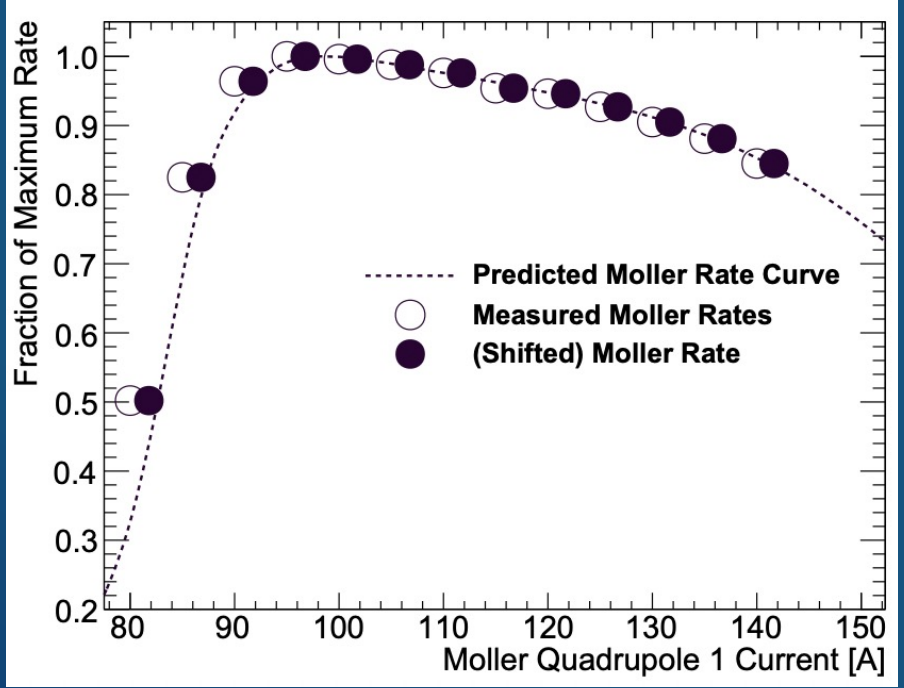

Wrinkle in foil during PREX2 showed 1% lower polarization

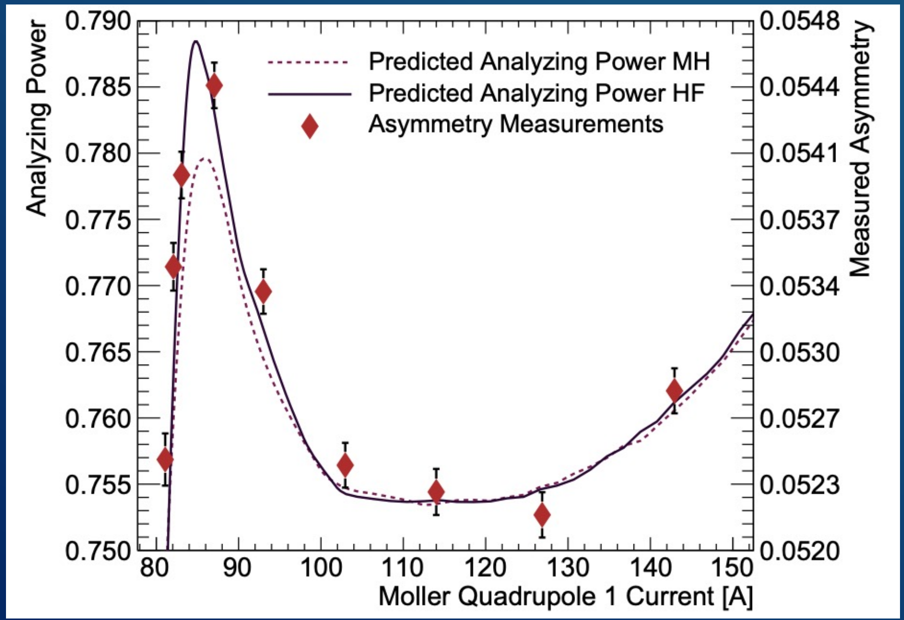
Also, loosely mounted foils may contribute to interpretation difficulties as the foil angle is not completely correlated with the ladder angle

Working on techniques to ensure foils mounted taut and flat and perpendicular to field

# Azz+Levchuk uncertainty

- Only know quad and dipole optics to few percent
- Rather than rely on absolute settings we
  1. Set 3 of the 4 quads to nominal current
  2. Scan the remaining quad (usually Q2 or Q3) and calibrate its setpoint as a fraction of the rate maximum to the point of least sensitivity on the Azz curve
  3. Use similar method for dipole
  4. Simulation shows negligible sensitivity to precise absolute optics settings using this method
- Rate maximum usually is usually close to Levchuk "peak" of maximum correction size due to Moller pair envelope being close to aperture wall(s)
- New momentum Hartree-Fock model-based momentum distributions for Fe provide good agreement with size of "peak"
  - Use this agreement to determine Levchuk uncertainty

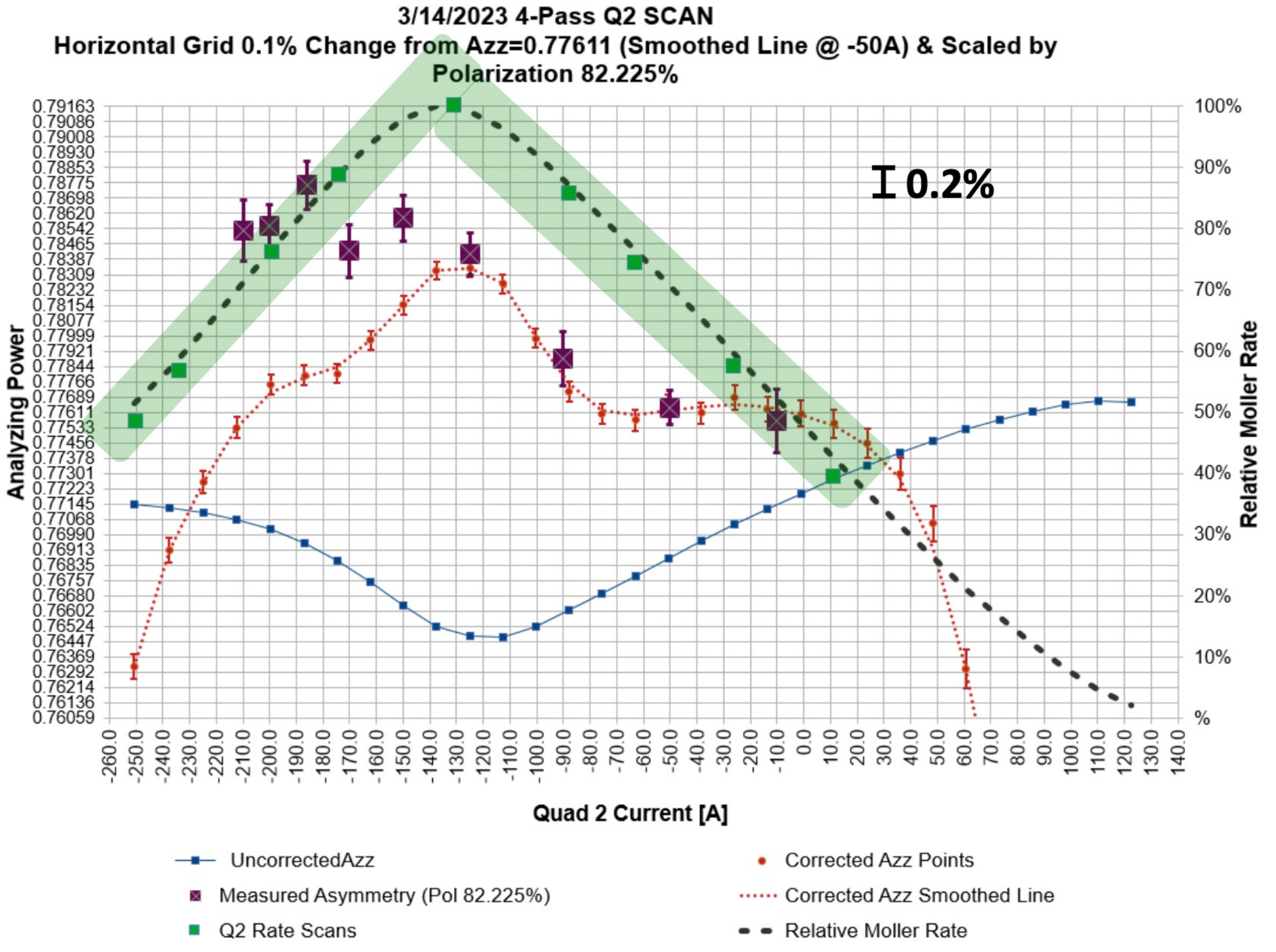


# Unresolved discrepancy seen in SBS 4-pass data

## 4-Pass Data

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



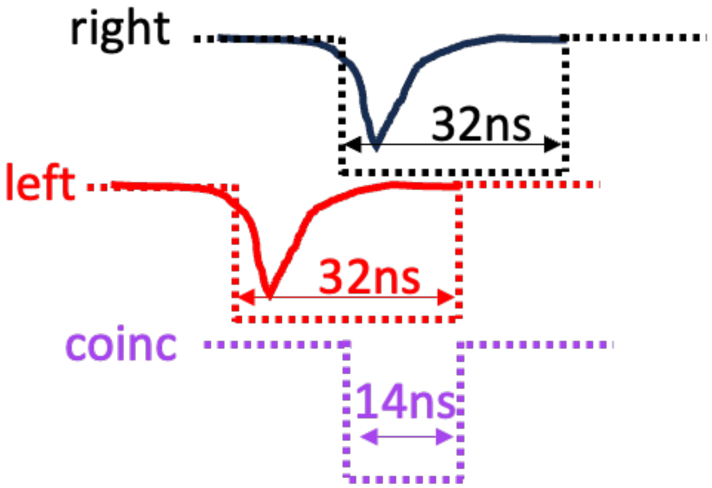

SBS requires 3% precision so we didn't take a long time optimizing the optics.
Possible that we ended up in a particularly sensitive configuration where small uncertainties in beam angle, upstream collimator or positions of dipole apertures had a large effect

# Accidentals

- We measure them by delaying the left detector signal 117ns relative to the right and forming coincidences
- This measures three classes of accidentals (latter two may not even happen given timing and dead time but are still measured and included in correction by this technique)

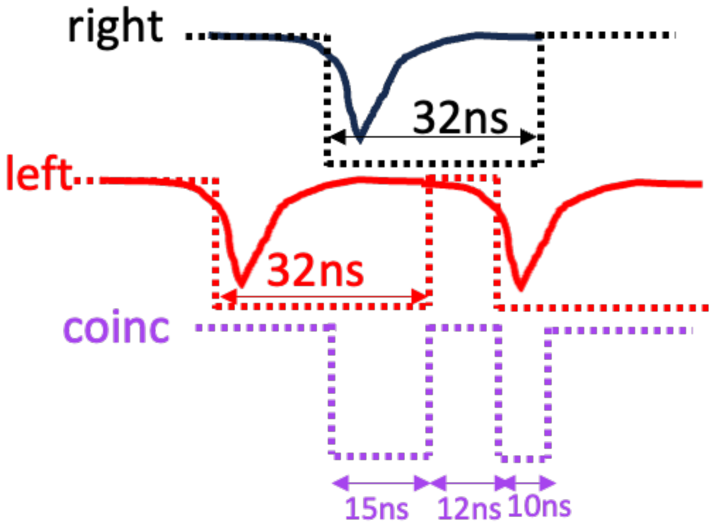
**Single + Single**

Two uncorrelated single arm events that happen within coinc time window



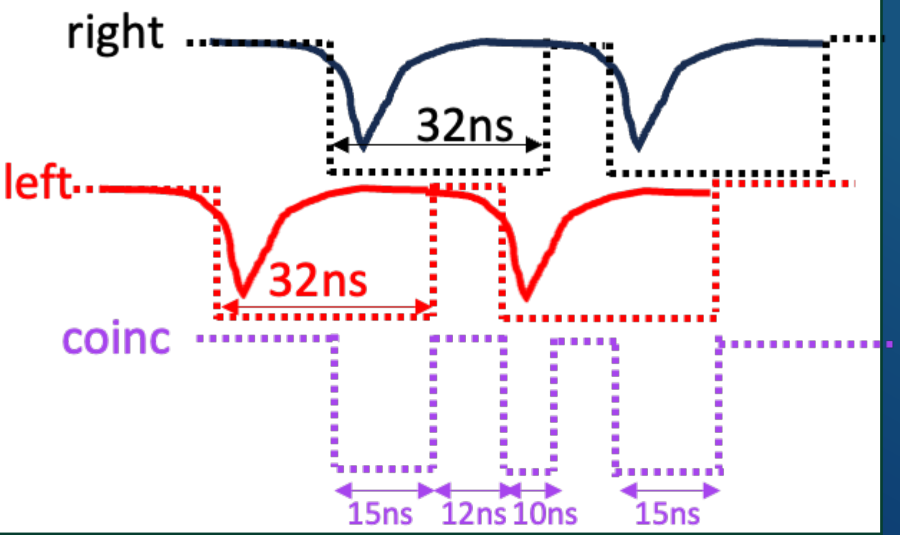

**Single + Coinc**

A single arm event close to a coincidence with time offset such that the coinc logic triggers twice




**Coinc + Coinc**

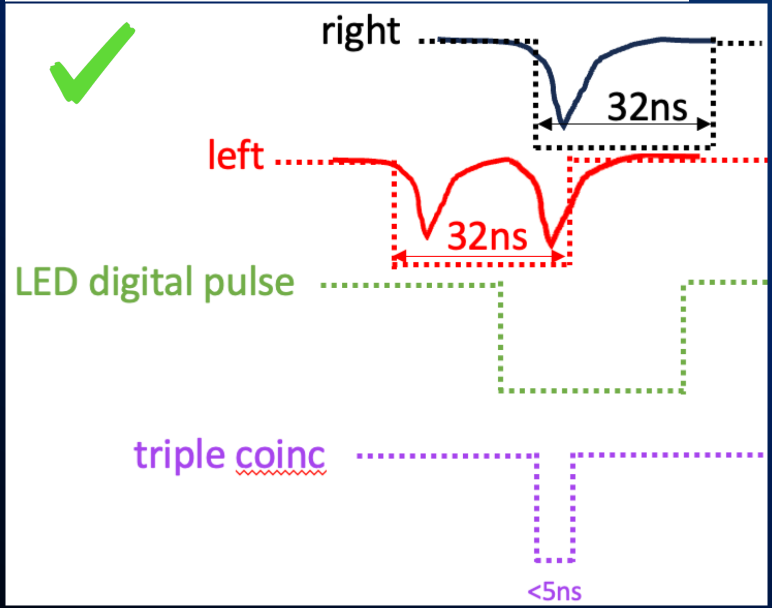
Two coincidence events so timed that the trigger logic fires 3 times for 2 coincidences



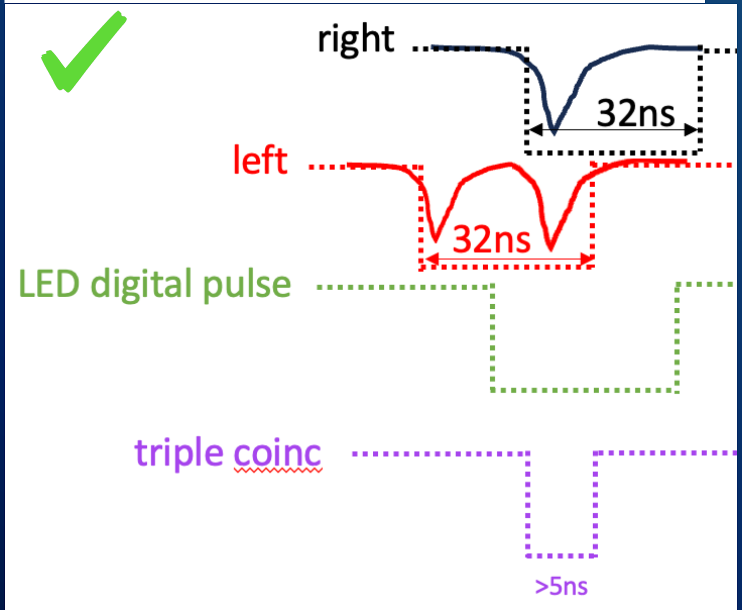
# Dead time

- Currently measured using 4.5 kHz LED flasher during beam operations.
- Triple coincidence (Left+Right+LED timer) at different beam currents allows measurement of fraction of LED events lost as a function of detector rate
- Preliminary data with emulator indicates this method underestimates by 2x

Sensitive to this dead event class




Does not measure this event class




Insensitive to this dead event class