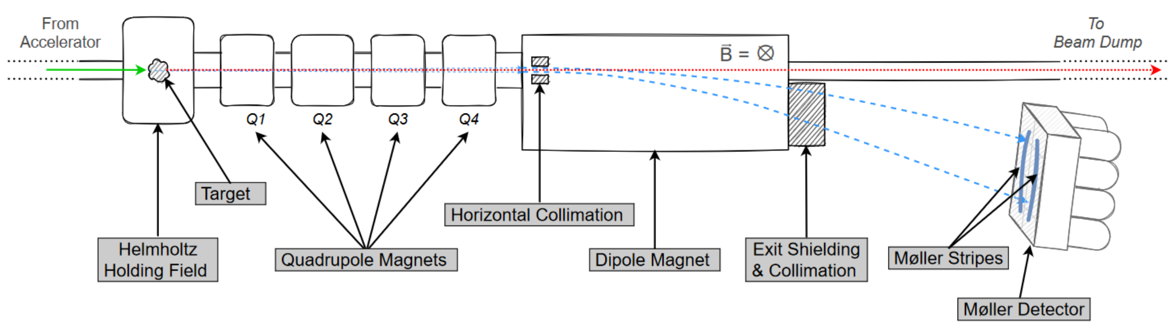
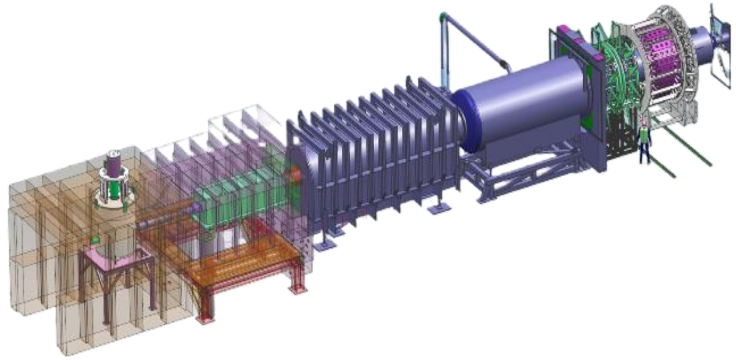




Moller Polarimetry for MOLLER

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

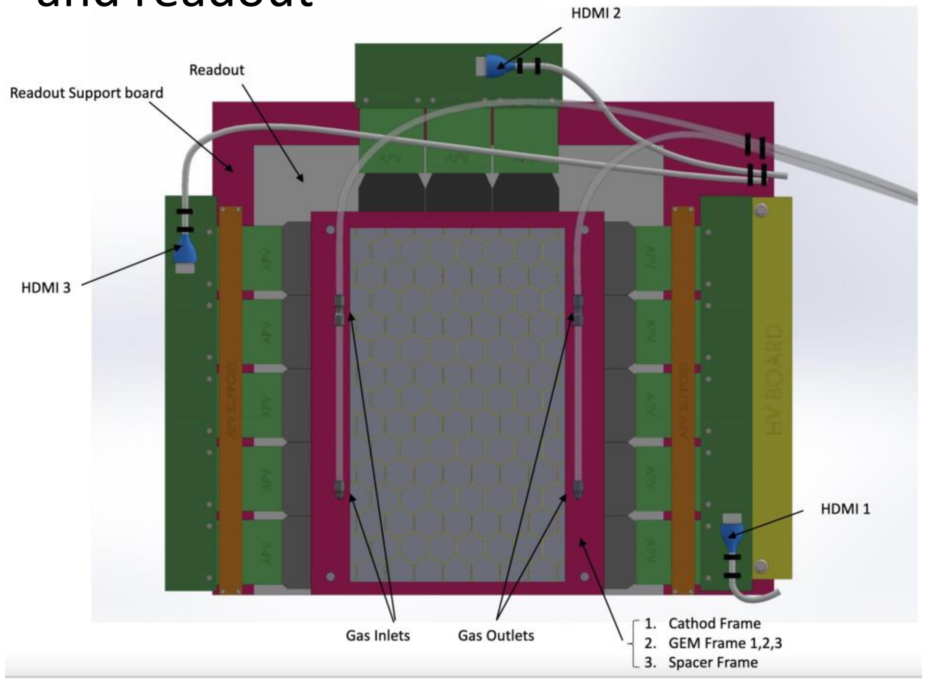
MOLLER Collaboration Meeting – May 2023

TEMPLE UNIVERSITY · U.S. DEPARTMENT OF ENERGY · Jefferson Lab Exploring the Nature of Matter · Open Science Grid

Hardware overview (in project)

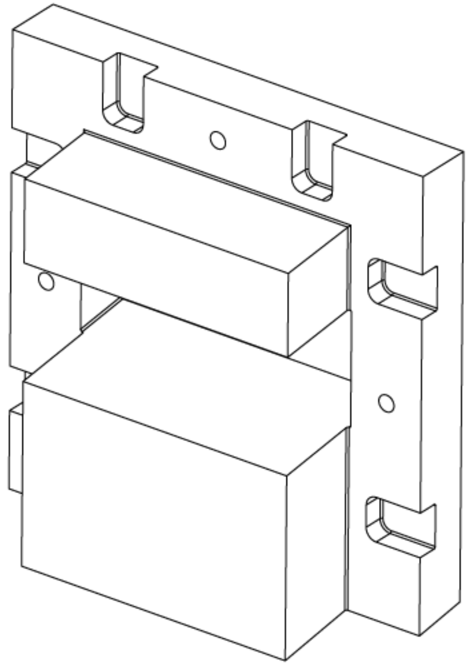
GEMs

- Design complete
- Parts will be ordered soon
- Built at UVA over the next year
- MOLLER collaborators (likely Syracuse and Temple) responsible for installation and readout



Tungsten Collimator

- Limits vertical acceptance (momentum) on detector to reduce Levchuk uncertainty
- Already ordered
- Likely to arrive midsummer
- Discussing whether to delay installation – perhaps perform systematic studies at 6GeV???



Moving Moller target upstream

- Moving SC target magnet upstream 30cm gives more favorable optics and allows near elimination of Levchuk correction
- Part of beamline upgrade planned for MOLLER
- May happen as early as Spring/Summer 2024

Hardware overview (outside project) [cont'd]

DAQ:

- Old NIM/CAMAC-based DAQ working fine, but is now obsolete
  - Swap-in replacements for most parts in hand.
  - Trusted and well understood

- New FADC-based system under development by Bob Michaels
  - Hope to be able to implement this DAQ in parallel during MOLLER
  - Verify its performance and results against old DAQ

Software Notes:

- Will need new decoder and analyzer for new FADC-based DAQ being developed by Bob Michaels.
- Decoder and analyzer for Moller GEMs – Syracuse University is spearheading this.

Hardware overview (outside project) [cont'd]

⚠ Lots of power supply issues during SBS ⚠

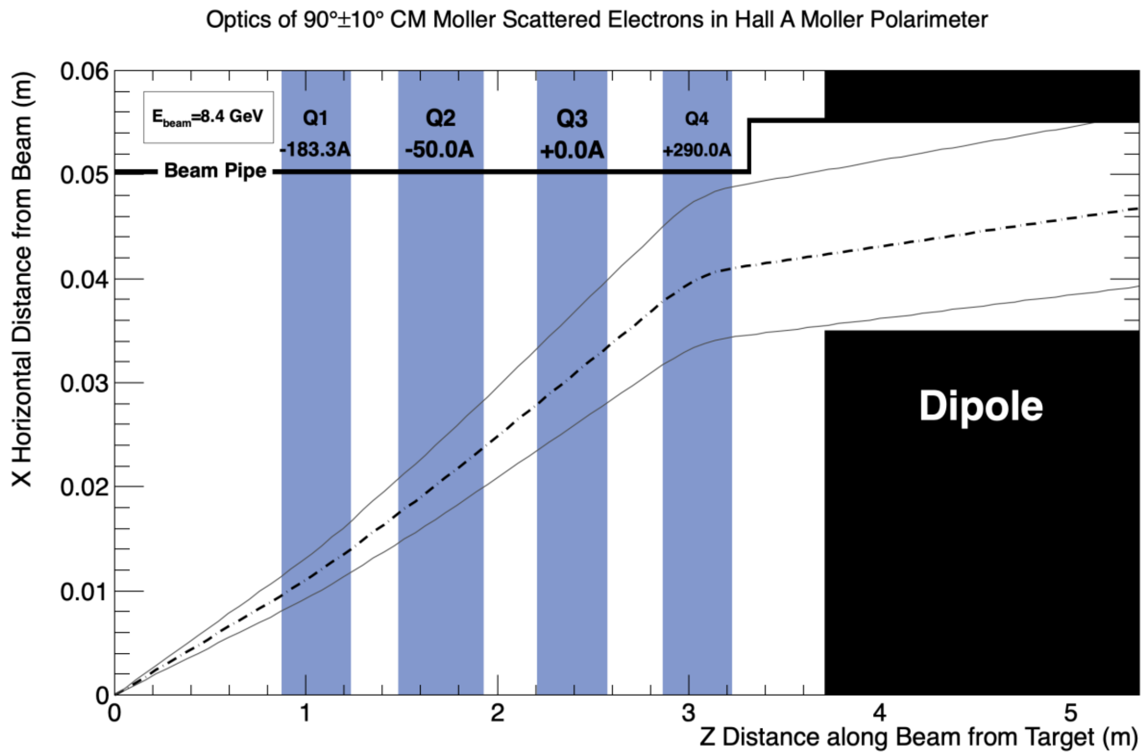
- Quad3 was used for the first time since 2016 and has degraded.
- All four quad power supplies date to the 1990s and DC power highly recommends their replacement.
- The dipole power supply could not maintain ideal current (414 A) for 4-pass running and will not reach required currents for 5-pass (550 A) even for GEp. Will temporarily use BigBite power supply, but DC power recommends replacement.

Plan for MOLLER

- Ideal 'recommended' solution: Replace all power supplies
  - Quads (300A stable to 0.1%) commercially available solution $90k
  - Dipole (600A stable to 0.01%) built in house by DC power $100K.
- More likely: get by with minimum requirement
  - Quad: purchase 2 commercial quad power supplies and replace quad 3 and have single replacement in case another quad power supply fails
  - Replace dipole with new in-house power supply

Maturation in expertise/understanding

- We have two recent publications under our belts detailing our evolution in understanding of systematics.
  - Precision Møller polarimetry for PREX-2 and CREX → https://doi.org/10.1016/j.nima.2022.167506 arXiv:2207.02150
  - Accurate Determination of the Electron Spin Polarization in Magnetized Iron and Nickel Foils for Møller Polarimetry → https://doi.org/10.1016/j.nima.2022.167444 arXiv:2203.11238
- Don recently took stewardship of the polarimeter.
  - Bill and I had experience with the polarimeter.
  - Don had a capable graduate student, Faraz, with him for measurements.
  - A few hiccups in SBS:
    - We managed to work on these in mostly real time redeveloping optics solutions.
    - There was a 1-week issue with the leads of quad 3 being in reverse order and inverting the polarity.
- In March we were given 2 days to study systematics and quad 3 power supply failed on day 1. Determined new optics solution within minutes that allowed Q3 to be off and continued with program.



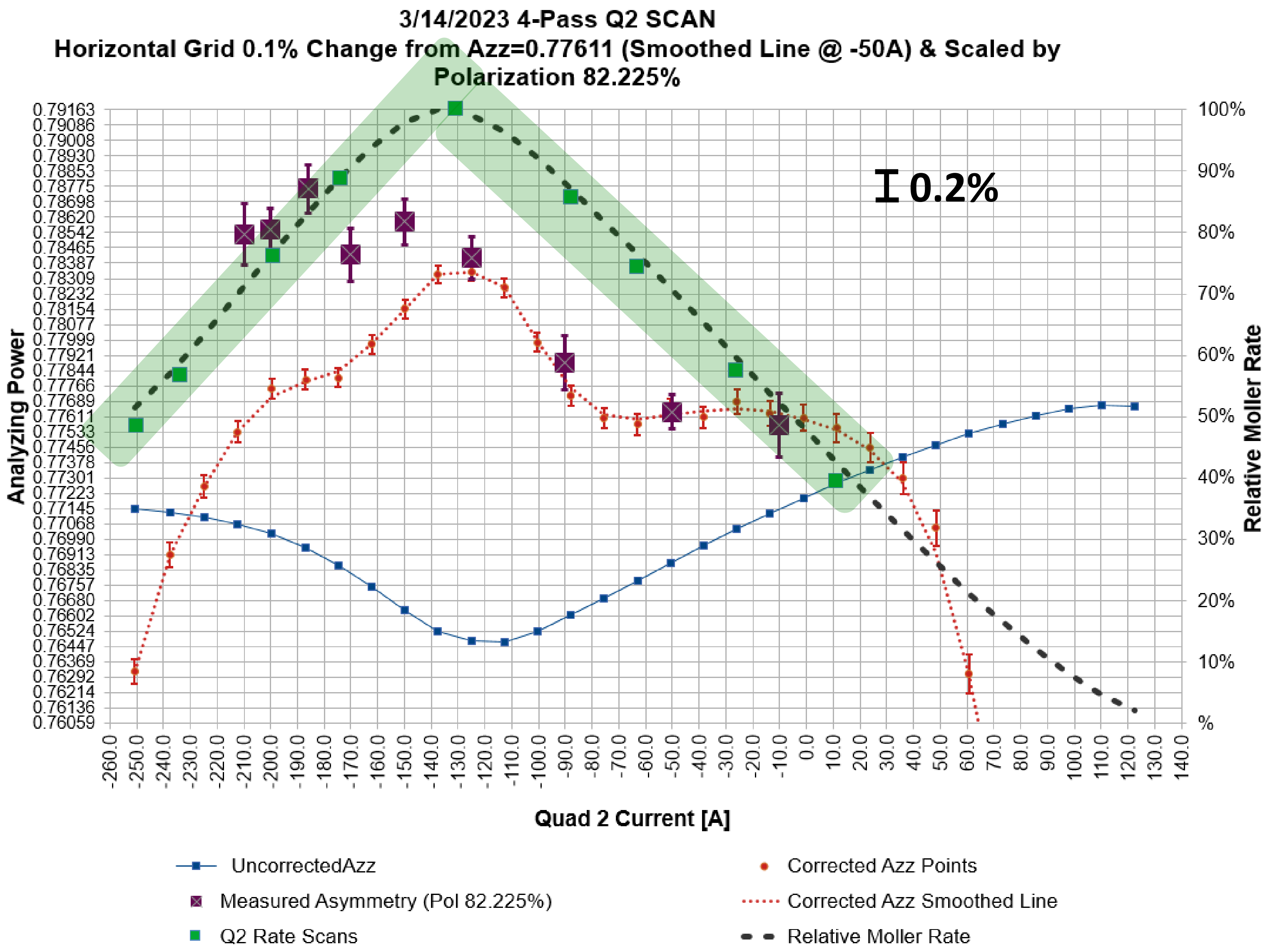
Don wrote code to calculate optics using thick lens approximations for the quads.

Got a lot of good systematics data during SBS!

Results from SBS 4-Pass

4-Pass Data

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



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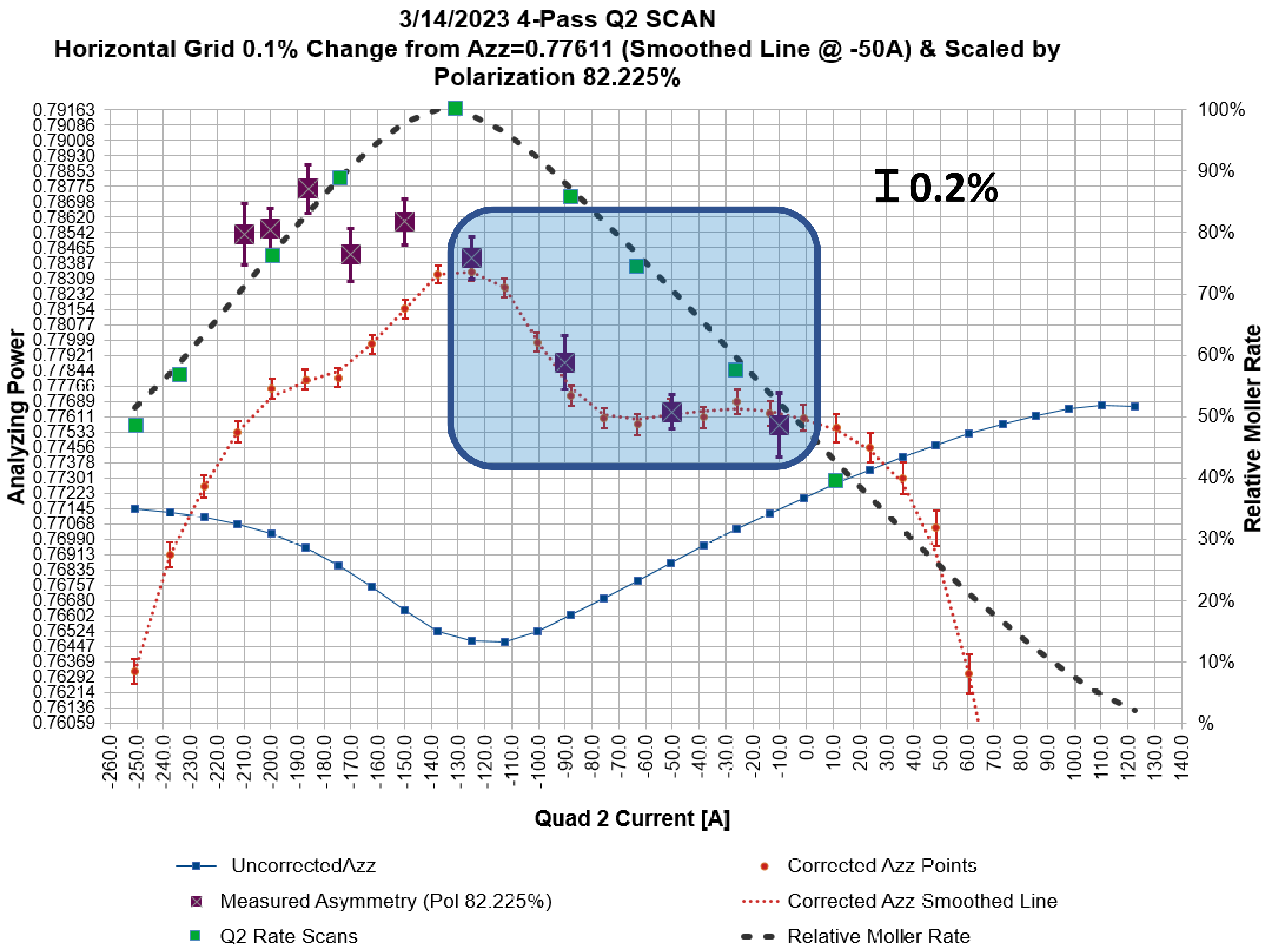
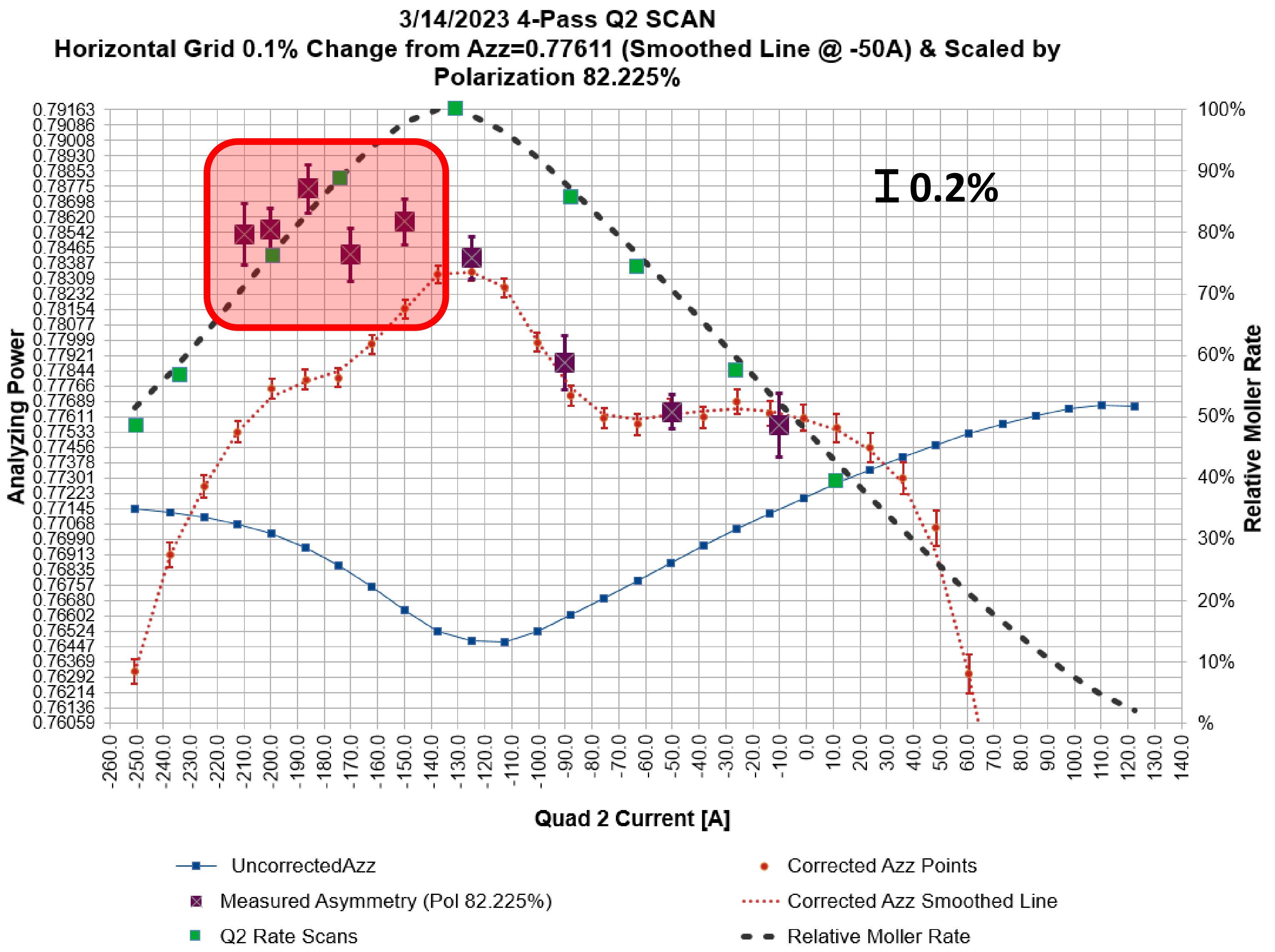


Results from SBS 4-Pass

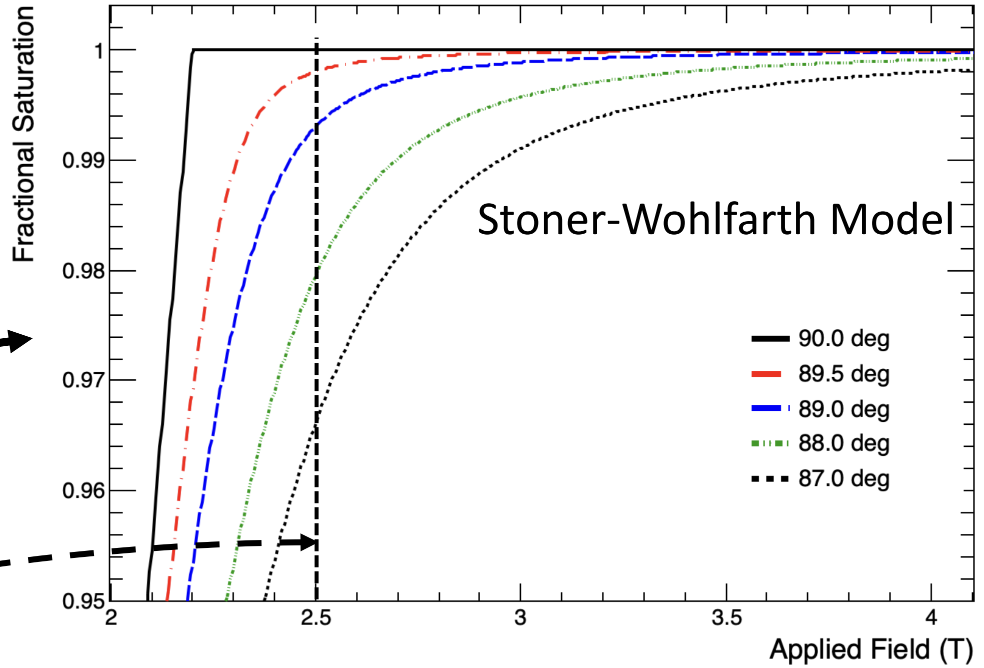
4-Pass Data

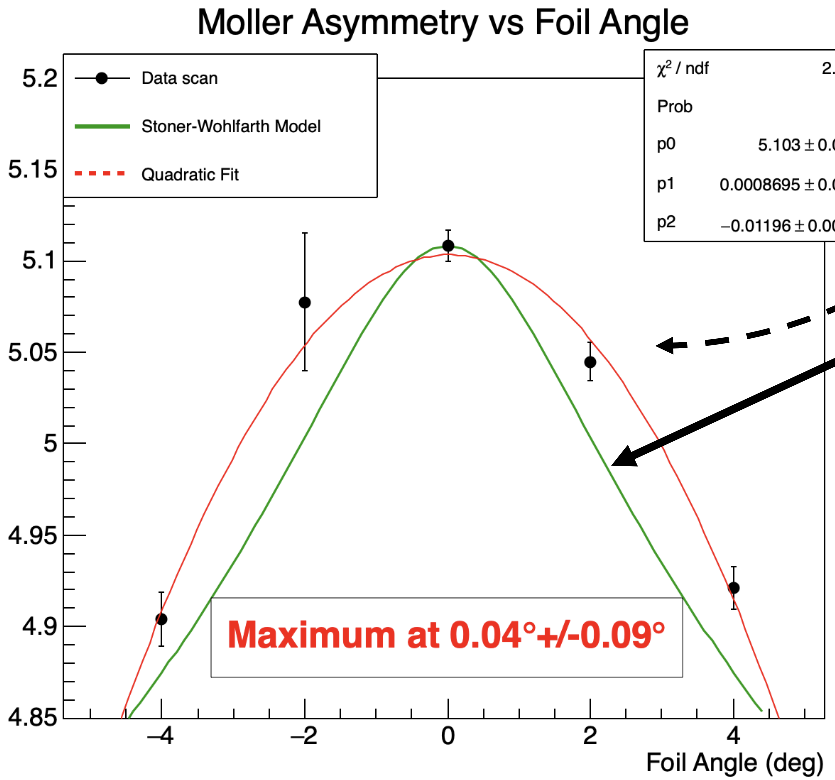
- Rate curves match well
  - Discrepancies within 1% tolerance for magnet characterizations.
- Asymmetry in optimal region matches predicted curve nicely.
- Asymmetry in non-optimal region is off
  - Not critical problem but we want to understand this.
  - Presumably Levchuk-kicked Moller transportation issue.
  - Will be re-running simulations with field maps provided by J. Benesch.



Results from SBS: foil alignment

- Survey showed foil 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 initially appears to overestimate sensitivity to angle (better agreement with quadratic)
- Until correction is made to remove transverse asymmetry component then better agreement with SW model
- Demonstrated we can easily and quickly measure foil angle (short runs sufficient due to large change @2.5T)

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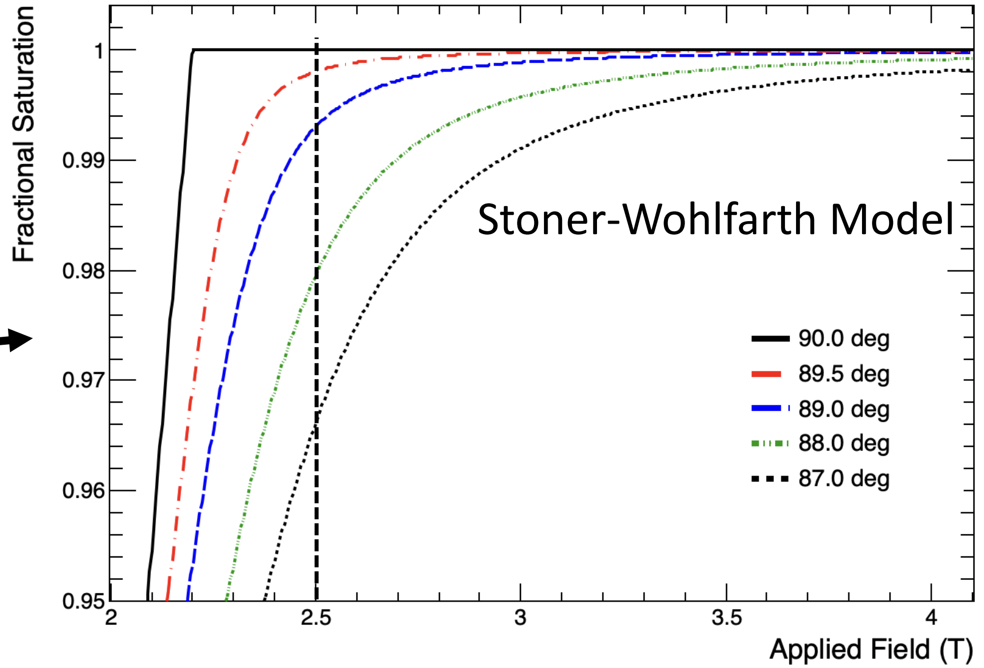

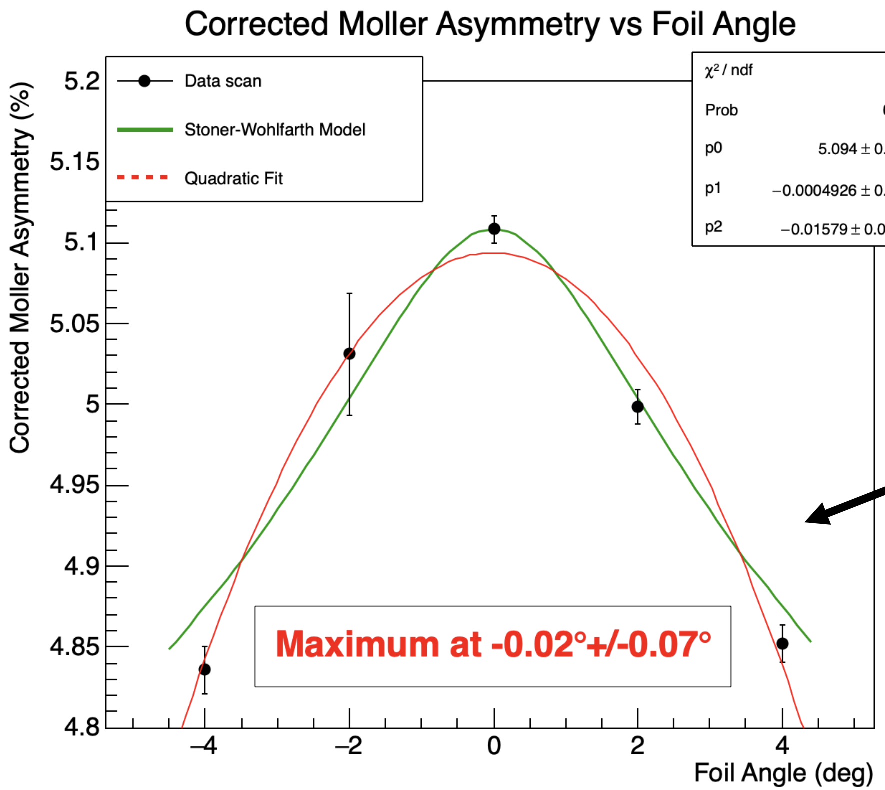

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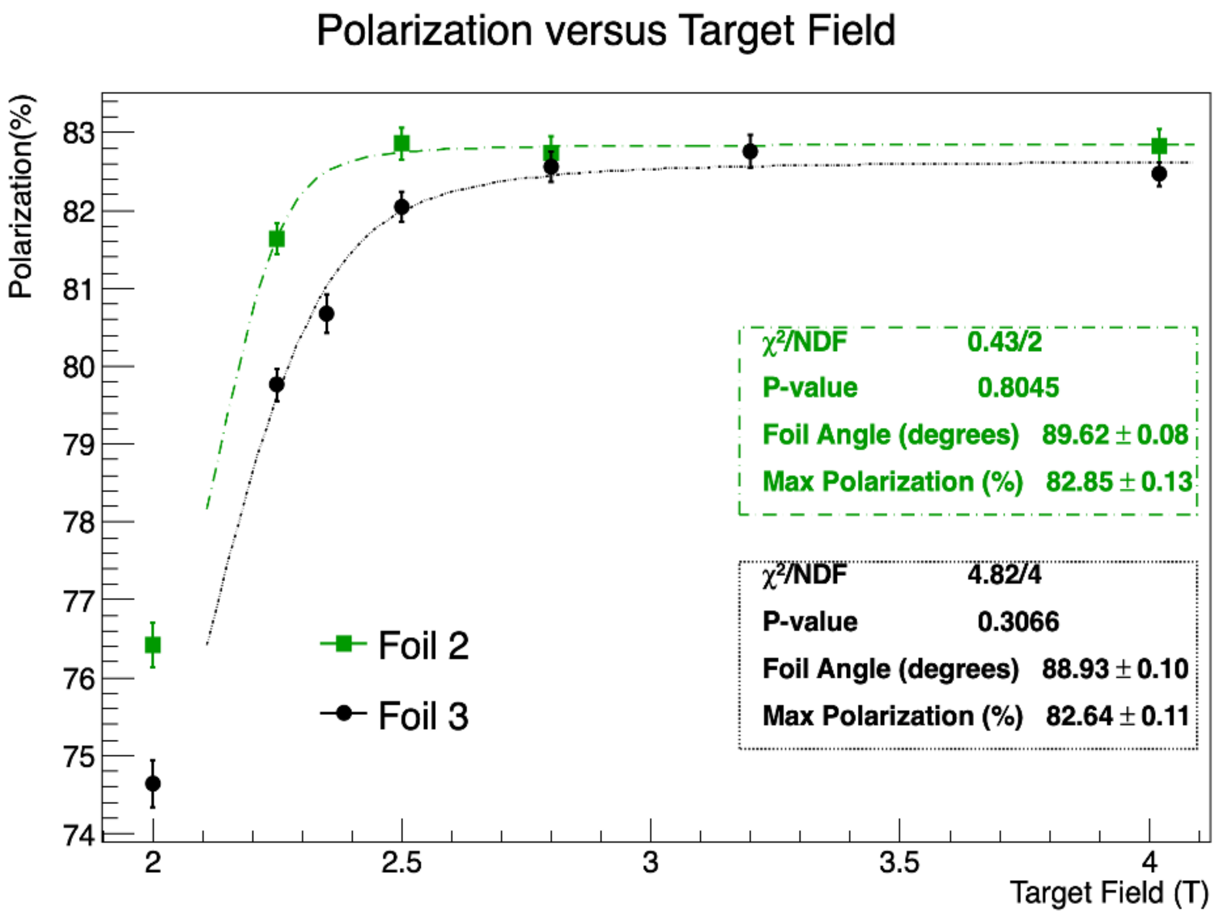
- Demonstrated we can easily and quickly measure foil angle (short runs sufficient due to large change @2.5T)

Saturation scan

- Two 10 micron foils during Gen
  - Foil 2 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 3 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)



Saturation scan

Conclusions

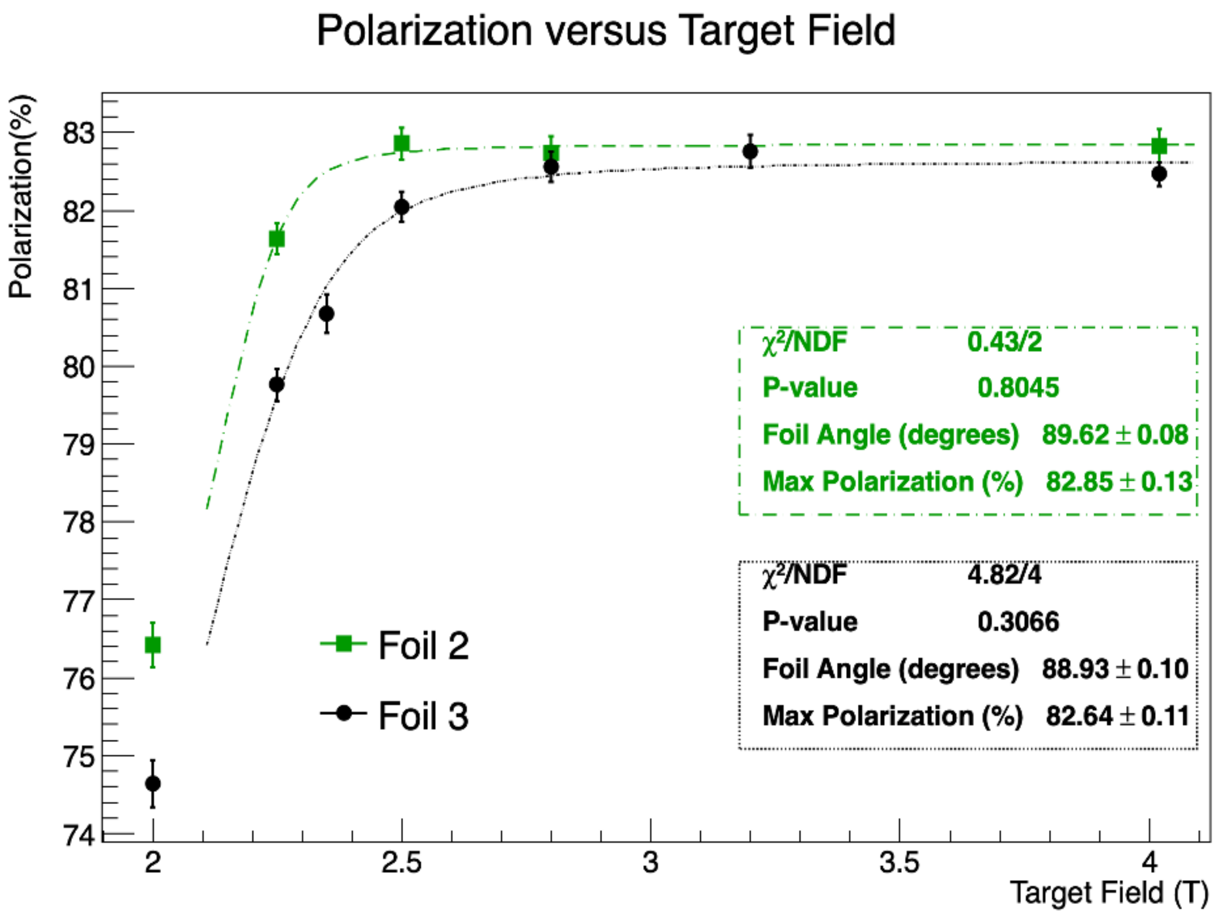
- A well aligned, taut foil is saturated at 3T

  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



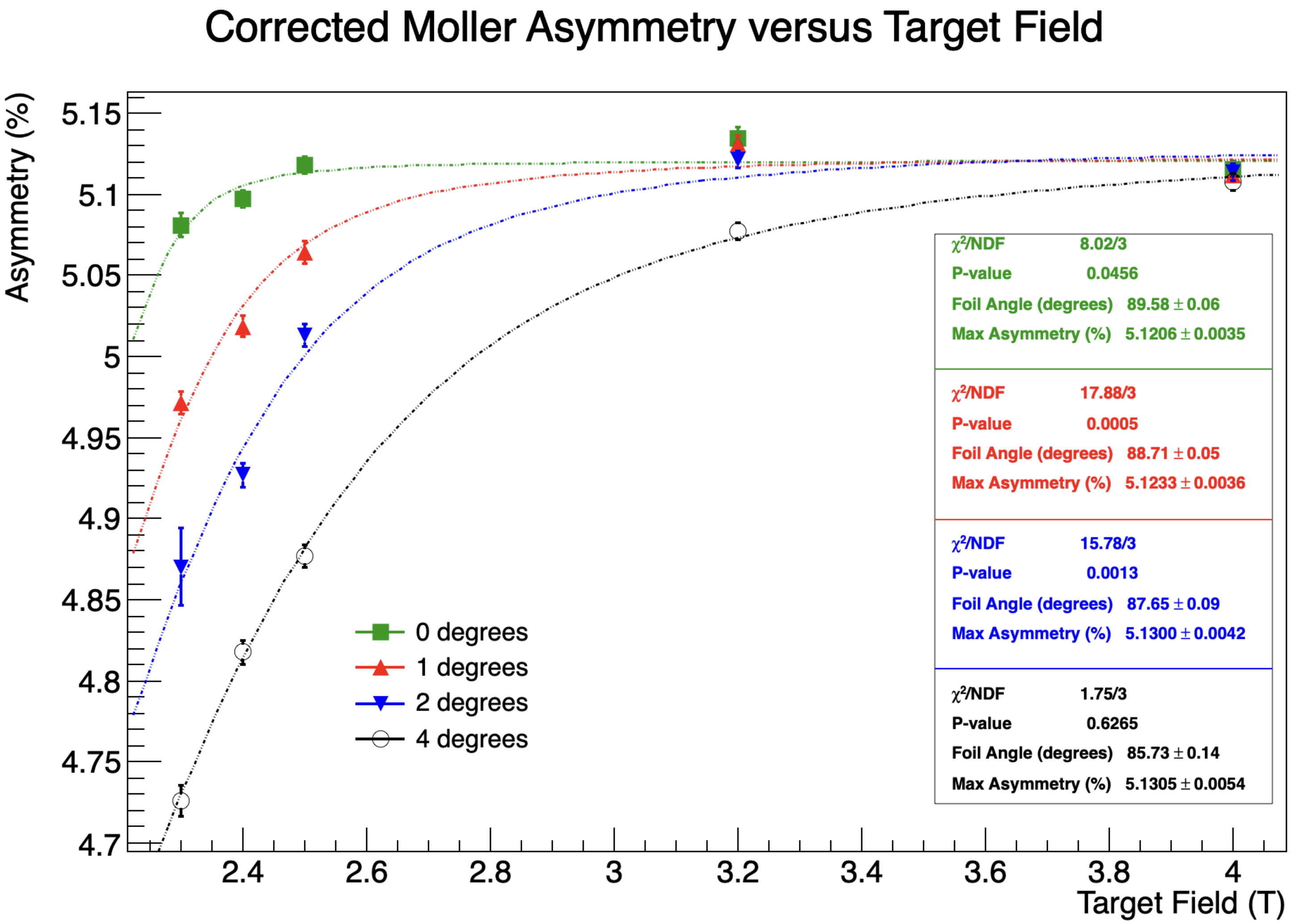
Saturation scan with foil rotation

GEn target exploded so we requested and were given 48 hours of beam time to explore Moller systematics

Took Azz and Saturation scans

Precise (0.1-0.15% per point) but poor setup

- At 4-pass and 17 degrees off longitudinal polarization changes by 0.7% for every 0.01% change in energy
- Large point-to-point changes believed to arise from changing beam conditions rendering precise interpretation difficult



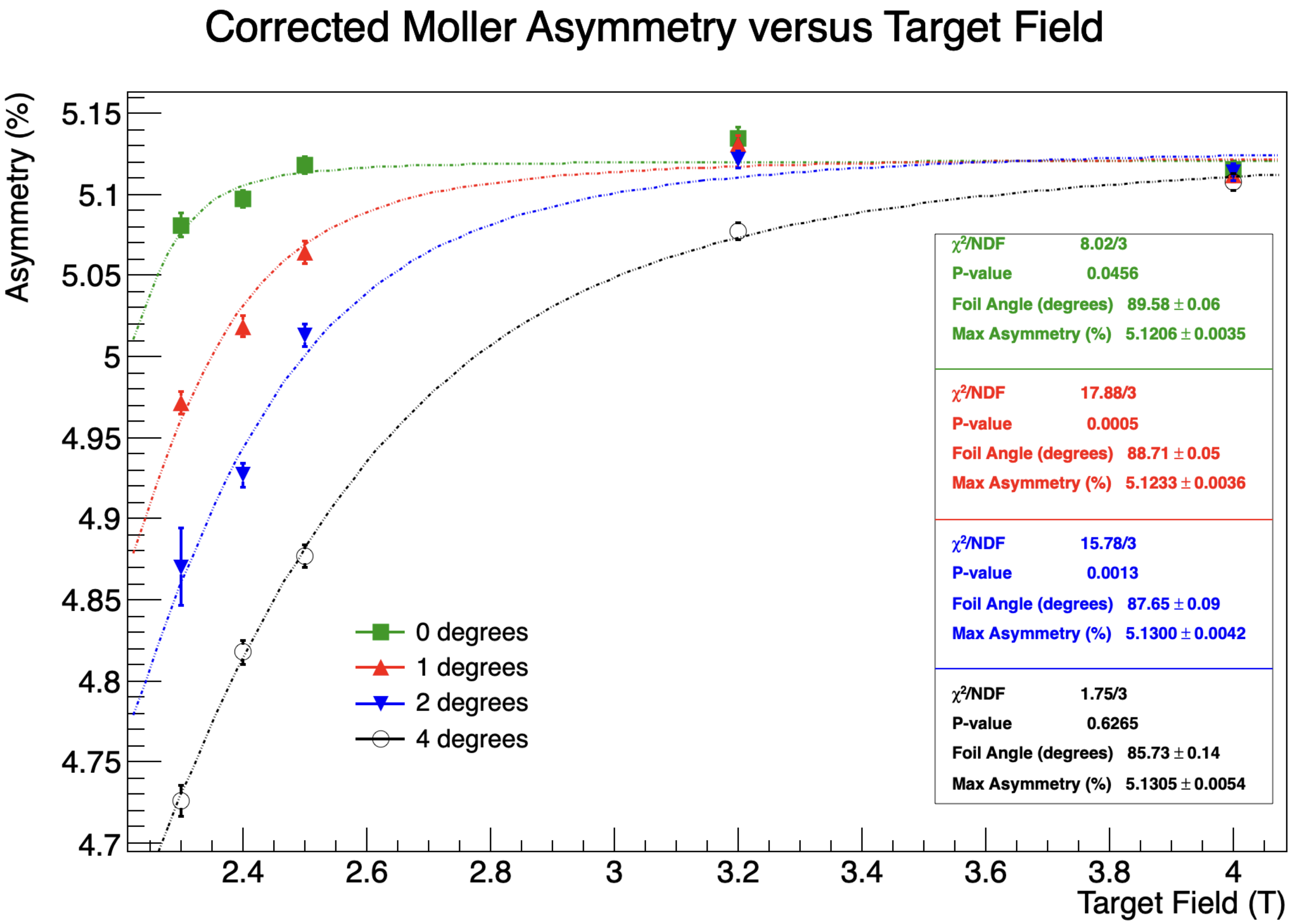
Saturation scan with foil rotation

Overall take-aways valuable

1. Fit to SW model gets foil angle to within a degree

2. Indicates that SW model provides conservative estimate of error

3. Need to be set up in region where insensitive to changes in beam energy/precession if hope to get interpretable curves with indisputable saturation



Systematic Errors

- https://doi.org/10.1016/j.nima.2022.167444 →
- Dedicated measurement during MOLLER
- New device (dual channel detector emulator) purchased by Temple for measuring directly
- Measured along with polarization
- Tracked with EPICS

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

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★ At some point we need to talk about these dedicated measurements.

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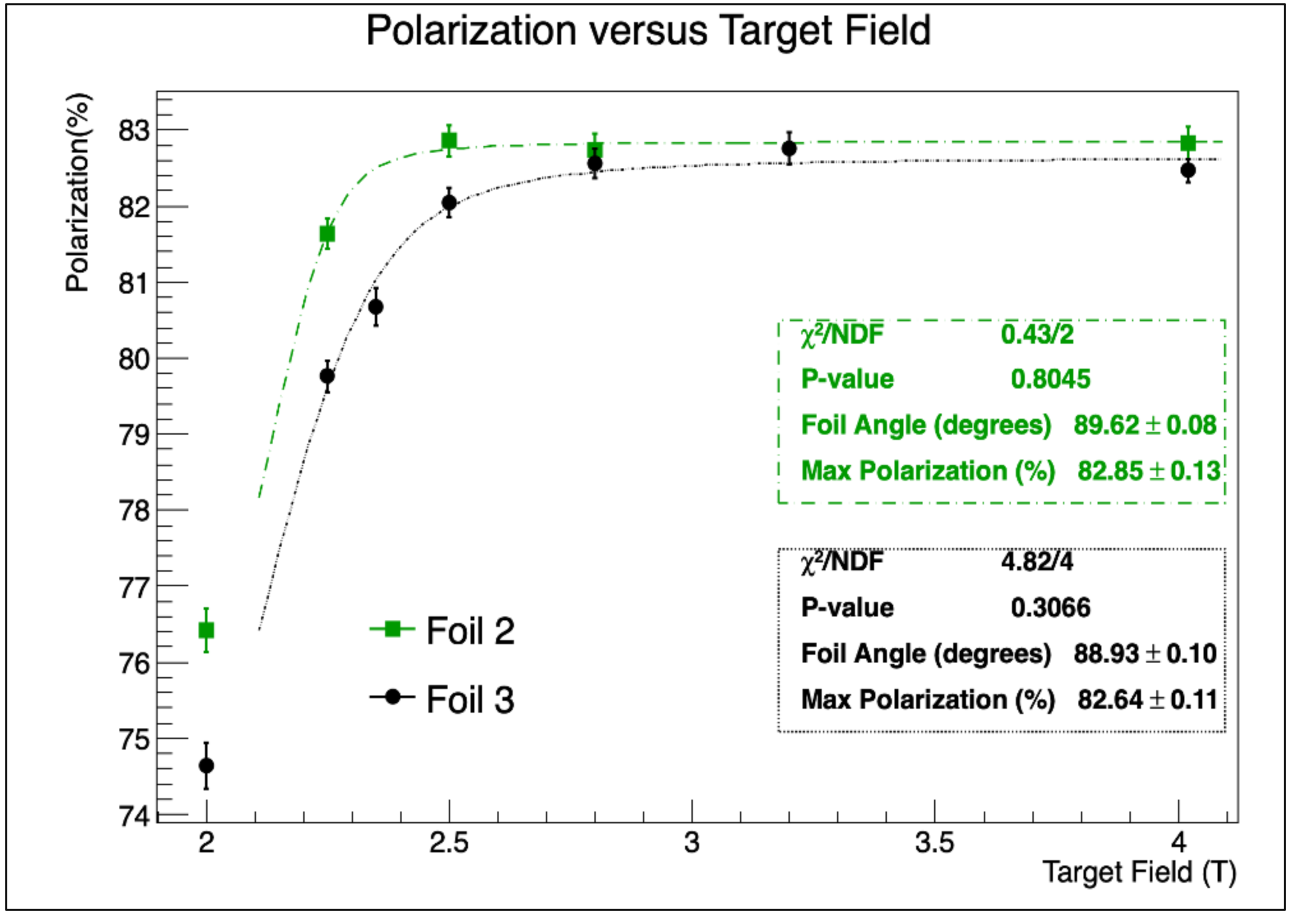
▶ Degree of saturation 0.5%-->~~0.15%~~ 0.2%

We know fairly precisely the polarization of a saturated target, but how close to saturation?

- Data taken during GEn justifies use of Stoner-Wohlfarth model and demonstrates saturation on a taut foil (Foil 2) at ~0.25% per point all the way down to 2.5T

- Estimate of uncertainty from degree of saturation with a similarly mounted foil using SW-model

  - SW-model fit gives $89.6° \pm 0.1°$
  - SW-model gives 99.98% saturation at 3T and $89.5°$ (so negligible error above 3T)



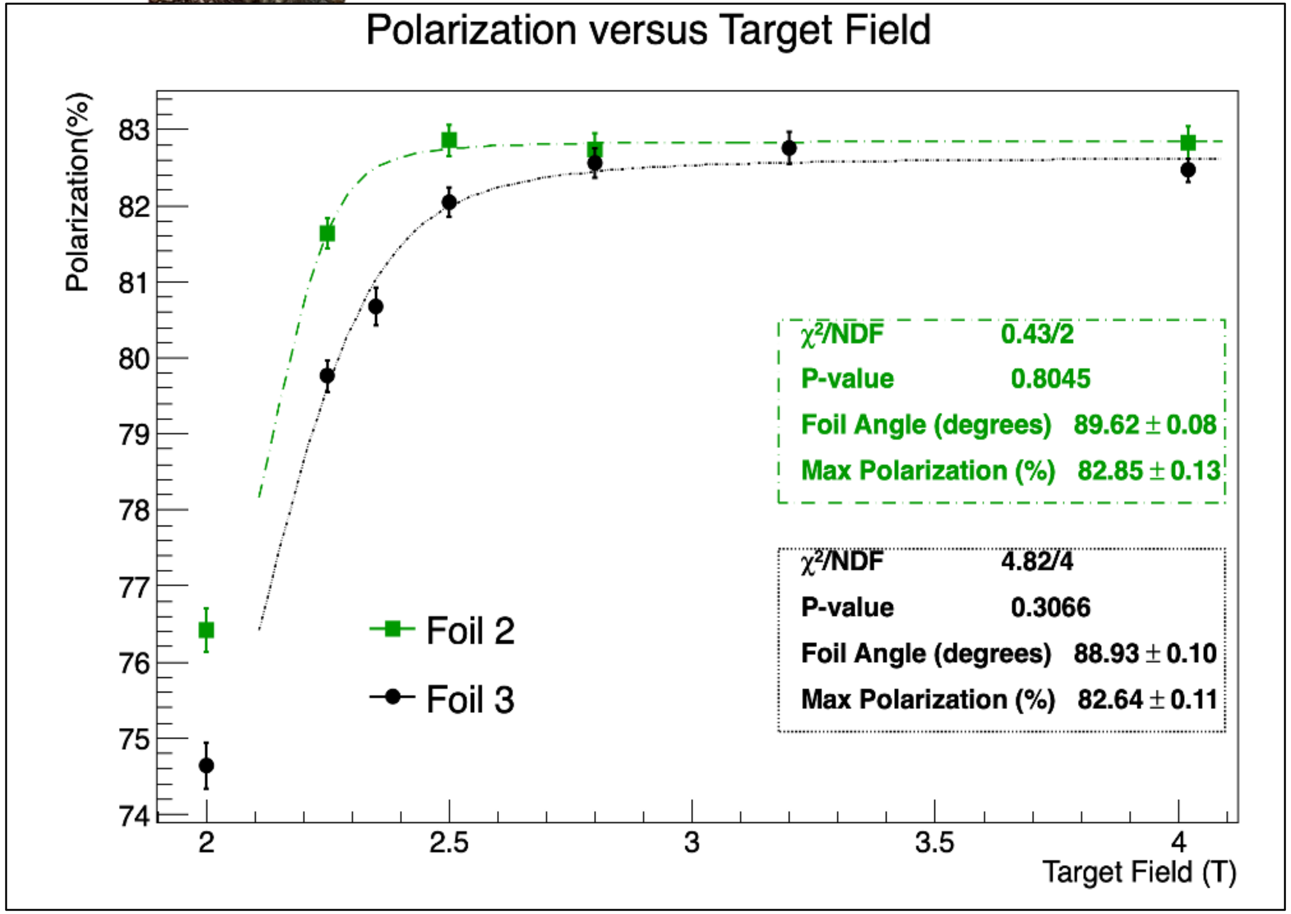
Degree of saturation 0.5%-->~~0.15%~~ 0.2%

- If we didn't have issues replicating these results then we could consider this a closed issue. However, so far, these scans have been difficult to repeat (Gremlins?)

- Estimate where we stand now with GEn data with a well-aligned taut foil $\geq 3\text{T}$:

  ➔ ~0.2%

- Gold standard would be a saturation scan from 2.3T to 4T with 0.1% error bars per point consistent with a constant above 2.8T (1-2 shifts)



Leakage currents and aperture transmission

- Leakage current from Hall C can be 0.1% of the Moller coincidence rate creating an unacceptable 0.2% systematic uncertainty

- Often close aperture 50% or more during Moller measurements to reduce leakage current but this introduces uncertainty due to aperture-dependence

- Solution to both is to ask Hall C to turn off during Moller measurements and then run with aperture open that same as in the experiment

- Otherwise measure aperture dependence?

Current dependence -- Dominant systematic

- Getting this under control is the difference between a 0.40% measurement and a 0.63% measurement
- Panelist from Hall D on GEp ERR last week called out current dependence as an issue with Moller polarimetry→ ***if we don't measure this and rule it out, the community won't accept 0.4% uncertainty***
- Best to measure using beat frequency technique (done previously in 2007) where laser pulses slightly off the 249.5MHz of the machine so that only every Nth pulse goes through the aperture: high current off the photo-cathode but only 1/N gets to the hall
- If every 25^{th} pulse selected then measuring 3 uA in the hall is 75 uA off the photocathode→ take Moller measurement at 3uA in regular configuration (0.05% uncertainty) and then 3uA with beat frequency @ 75 uA (again at 0.05% uncertainty) off the gun and see if there is any difference. **2 shifts**
- Best at low energy and fully longitudinal where precession sensitivity low

Statistical errors

Not used to thinking about statistics for Moller measurements since rate and analyzing power are large. For MOLLER statistics are a concern.

Normal practice for each measurement during parity experiment

- 5 distinct measurements:
  - Bleedthrough (beam off in A on in BCD)
  - Polarization on Fe foil for IHWP In and Out
  - Null asymmetry on Cu for IHWP In and Out
- Usually, we aim for 0.25% statistics on each point (25 minutes), BUT we usually have ~100kHz coincidence rate on 10um foil
- For MOLLER we expect ~20kHz coincidence rate (on 10um foil) due to high energy cross section drop off and reduced acceptance + collimator

Statistical errors (cont'd)

- Plan to increase statistics by some combination of the following: opening adjustable collimator and increasing foil thickness to 25 microns and increasing current.
  - There is a limit to how high we can adjust the current before diminishing returns arise from increased dead time and accidentals
- For relative systematic studies (Azz scan, saturation curves, current dependence) may need to further increase rates by increasing current and even removing the collimator. (For relative measurements things like dead time, accidentals, foil heating, Levchuk etc are not important to know absolutely provided they remain constant)

Questions?

Comments?

Moller Polarimetry Working Group

TEMPLE UNIVERSITY

Jim Napolitano **Eric King**

- Systematics reduction.
- Reviewing design issues.

Syracuse University

Paul Souder **Faraz Chahili**

- Working on GEM insights.
- GEM event reconstruction of simulated events.

Jefferson Lab

David Gaskell **Donald Jones** **Bill Henry**

- Maintain hardware.
- Coordinate project deadlines.
- Technical operators.

UNIVERSITY of VIRGINIA

Kent Paschke

- Insight
- Advice

BACKUP SLIDES

TRANSVERSE SUBTRACTION

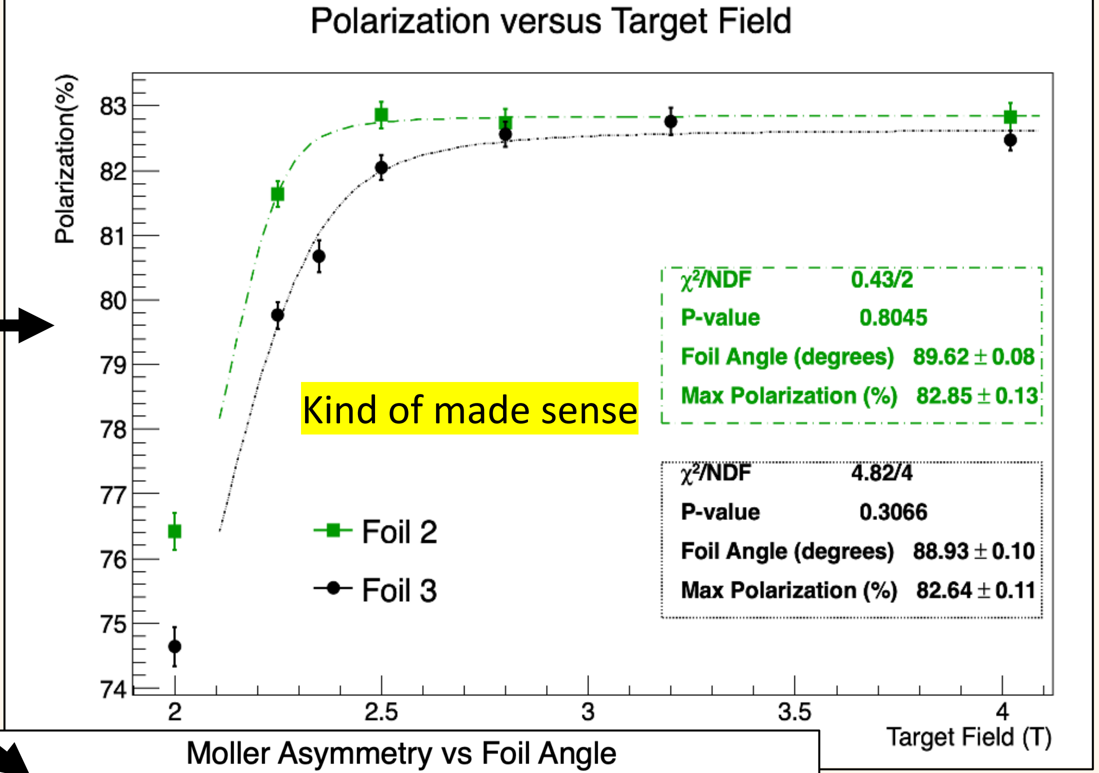
Moller polarimetry results with transverse asymmetry correction

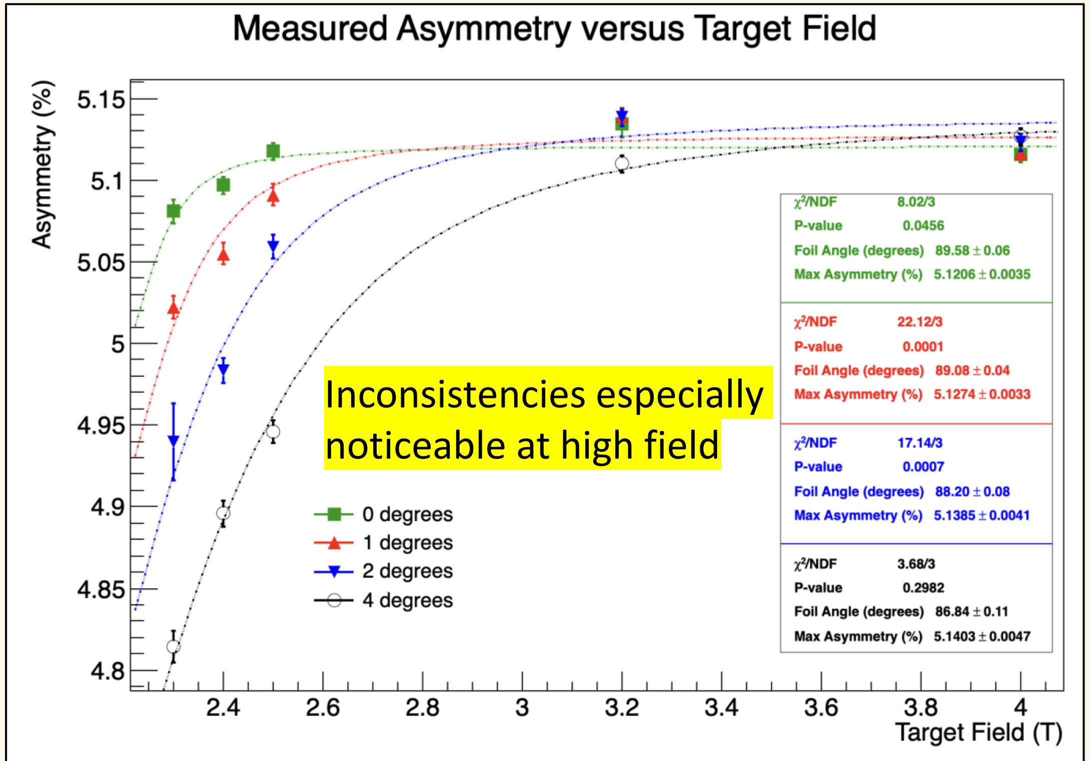
Don Jones

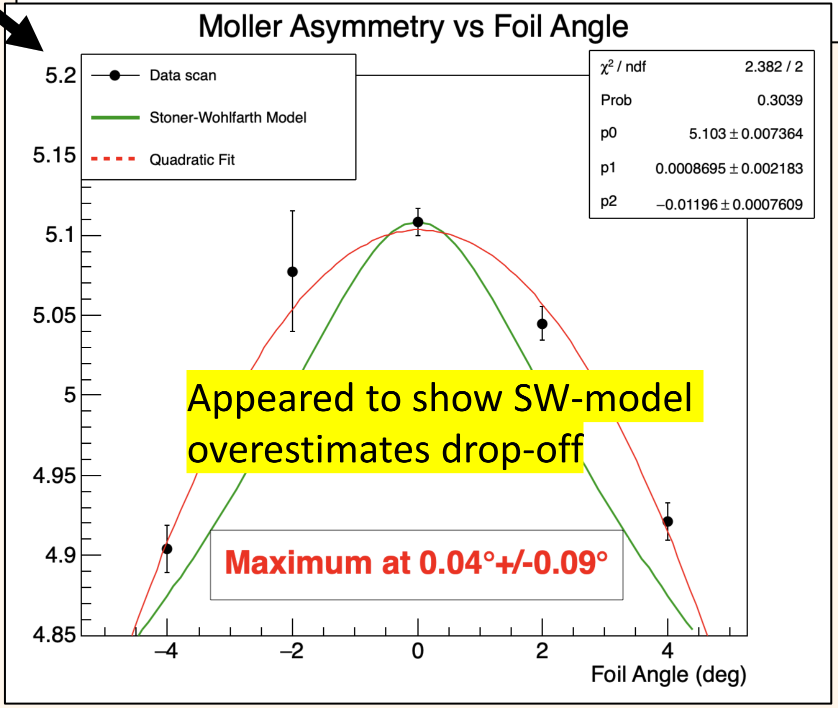
May 1, 2023

Systematics studies during GEn

- Took saturation scans on two foils with ladder locked normal
- Took angle scans to determine alignment
- Took saturation scans at various angles

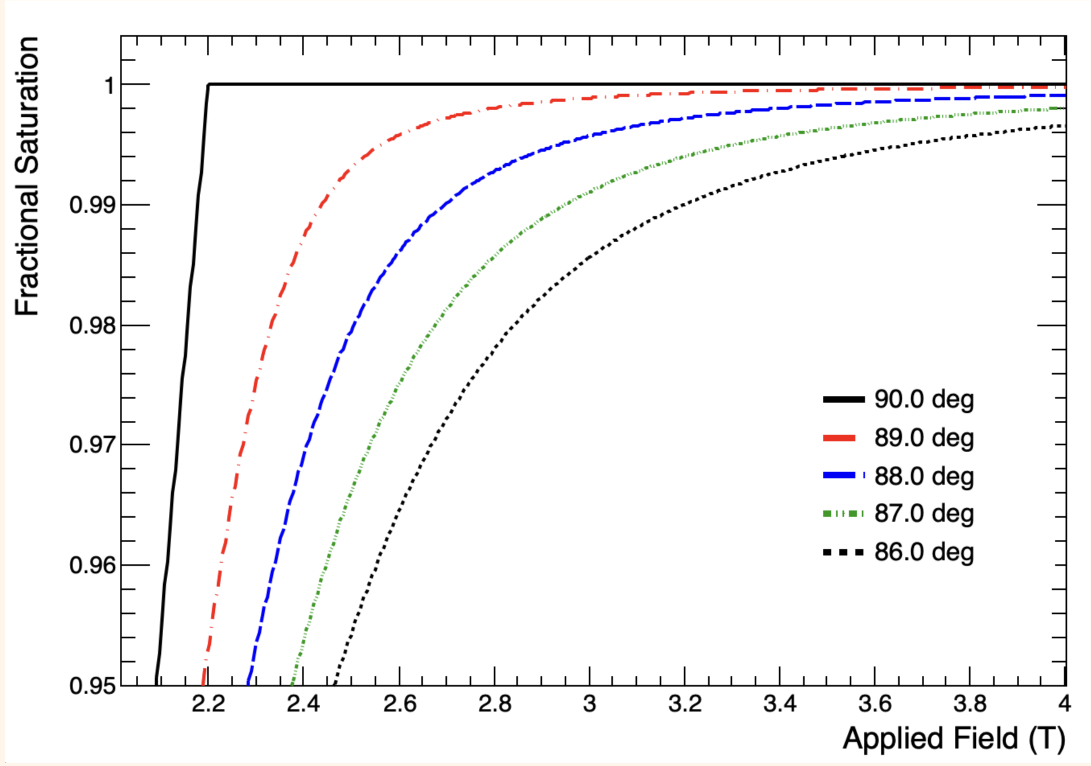


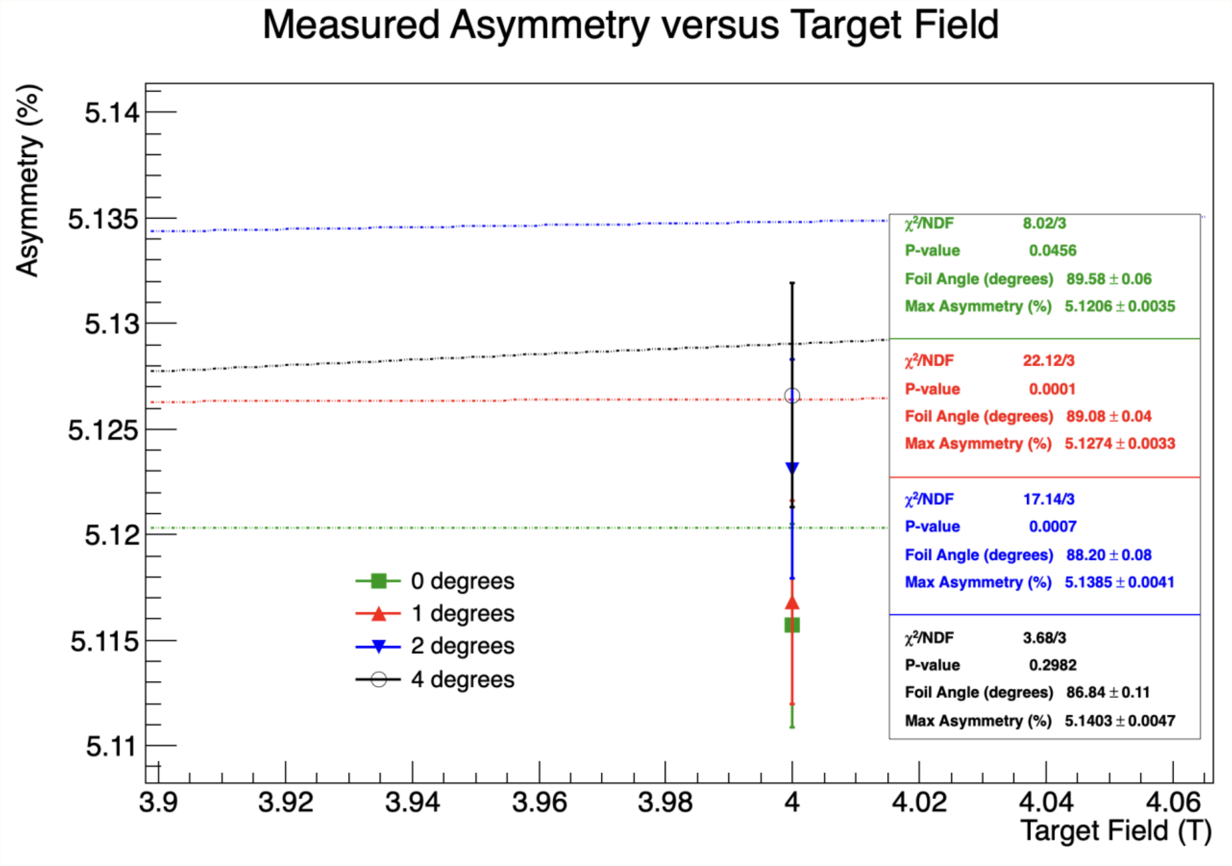




Expectation from Stoner-Wohlfarth

- Expect at 4T that 86° degree foil will have 0.35% drop in polarization relative to 90°
- Instead we saw reverse order with 86° having largest asymmetry and 90° having smallest
- Changes in beam energy insufficient to explain
- Realized recently we haven't corrected for transverse asymmetry





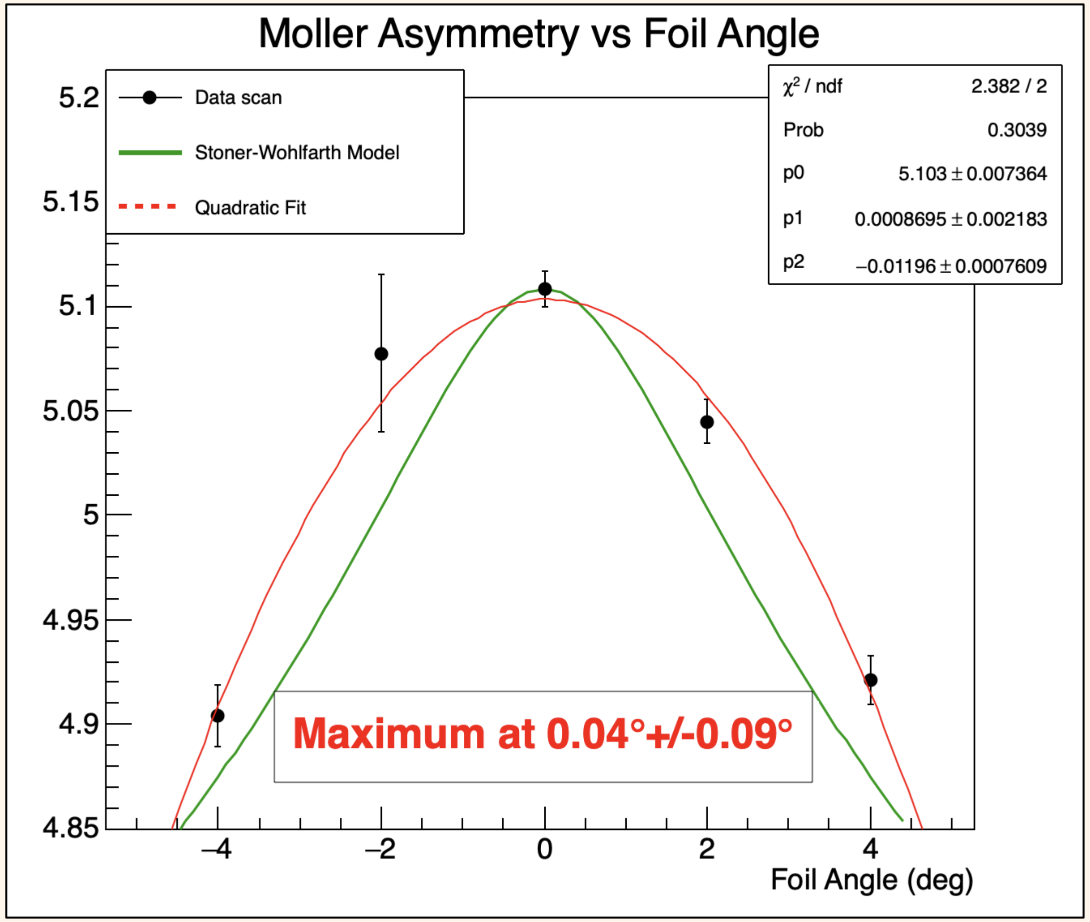
Transverse asymmetry correction

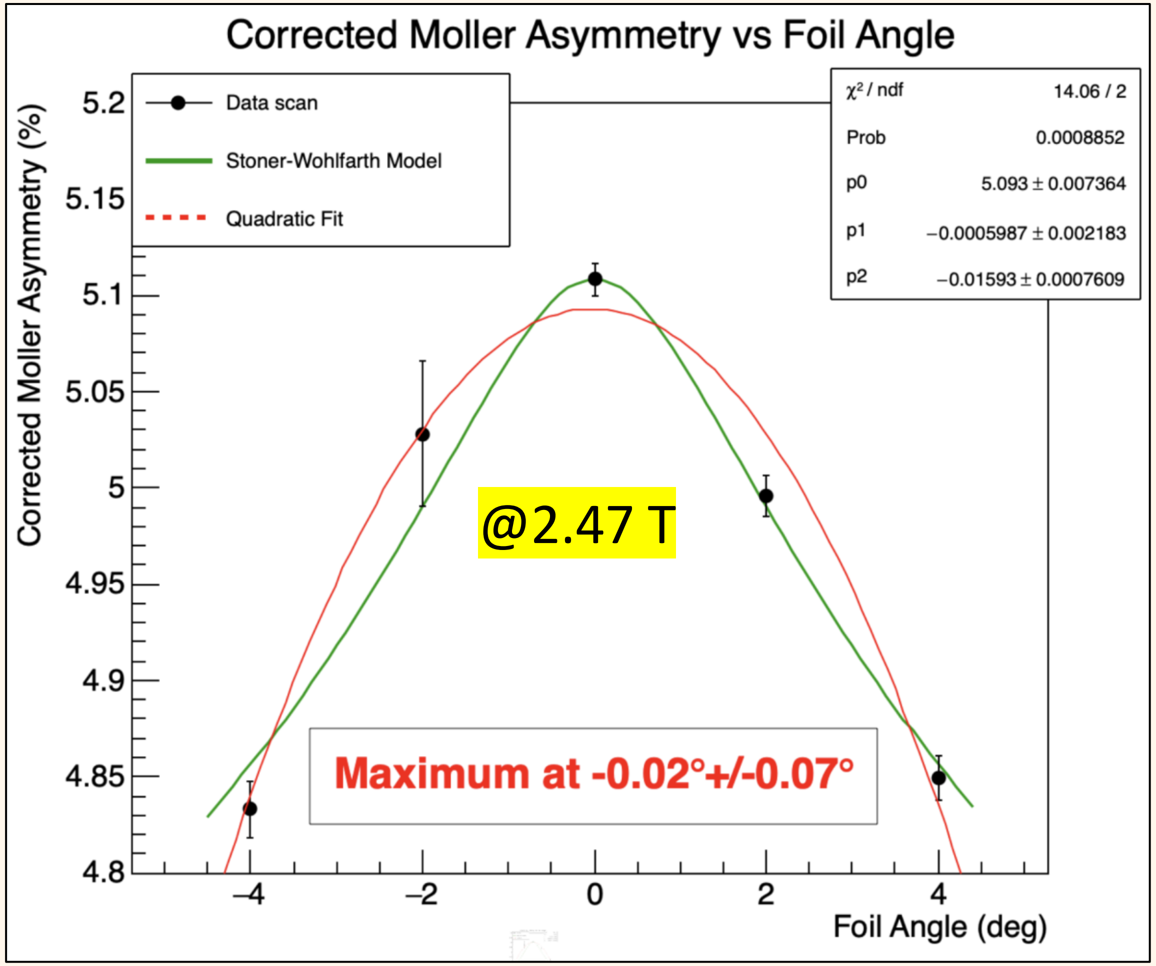
- Specifically talking about Axx which couples horizontal transverse asymmetry with horizontal transverse target polarization
- Axx/Azz = 1/7
- We were running nominally $17.3°$ off longitudinal so the ratio of beam transverse asymmetry to longitudinal is $\tan(17.3°)$ =31%
- We also had the target rotated by a few degrees so picked up polarization in-plane as well. Estimated this using polarization along magnetic field Pz from SW-model: $P_x^2 = 1 - P_z^2$
- Removed the transverse component from asymmetry using the following correction

$$A_{corr} = A_{meas} / \left(1 + \frac{Axx}{Azz} \tan(17.3°) \frac{P_x}{P_z}\right)$$

- Biggest corrections for largest angles and lower fields
  - No correction for normal foil
  - For $86°$ foil at 2.5T field $\frac{P_x}{P_z}$=31.4% so largest corrections 1.4%

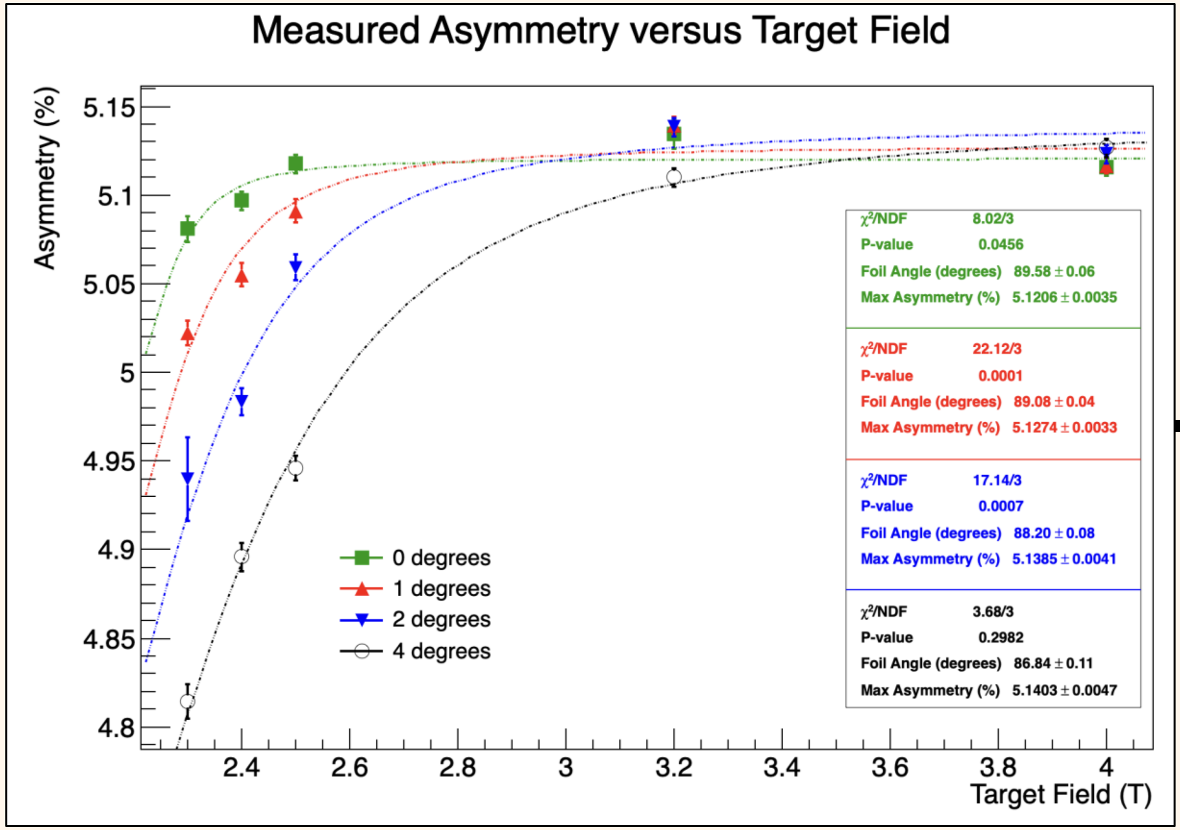
After correction angle scan at 2.5T

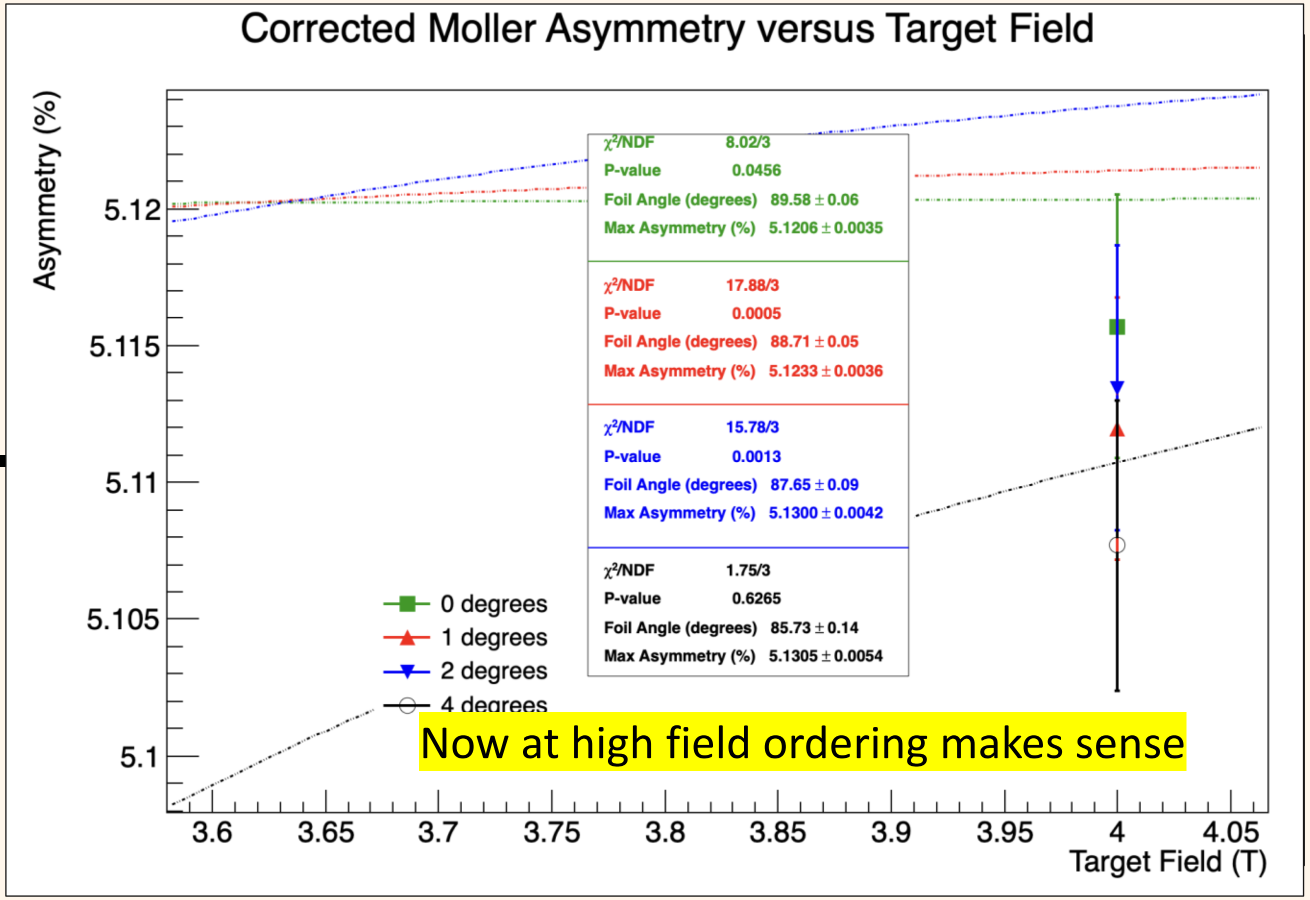




At 2.47T the data fit well. Don't know the accuracy of the field map provided by the manufacturer.

After correction





Now at high field ordering makes sense

Bottom line

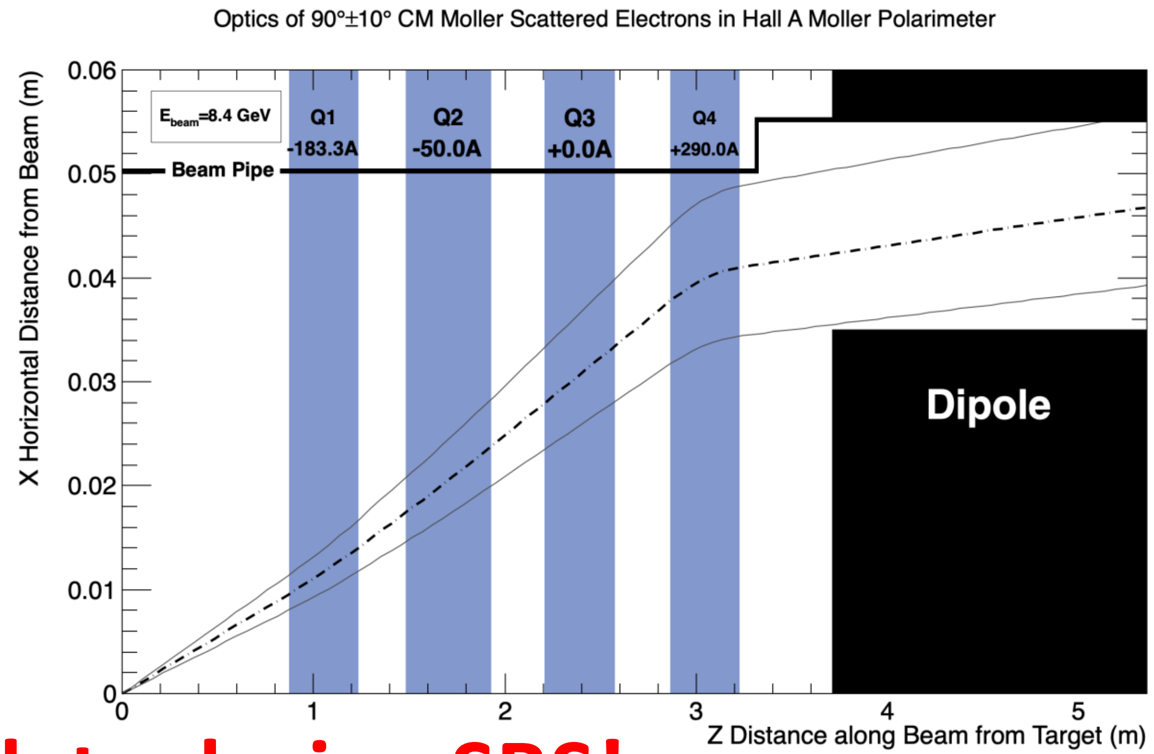
- We have transverse asymmetries mixed in with our longitudinal due to the non-optimal off-longitudinal beam polarization setup during GEn
- The data starts making more sense once an estimated correction is applied
- If you want to take precision saturation or target angle scans you need fully longitudinally polarized beam

Maturation in expertise/understanding

- We have two recent publications under our belts detailing our evolution in understanding of systematics. We are confident that we understand target saturation polarization, Levchuk, target heating corrections…
- Had to learn on our feet

Shortened slide for time…

  - Don took stewardship of the Hall A Moller polarimeter but had never operated it before. He was working with awesome student Faraz who also had no experience and they
  - Fortunately, Bill and Eric had previous experience.
  - First measurement got almost no coincidences and in real time scanned to find a new optics solution that we later realized was required because quad 3 was wired in reverse polarity
  - Within a few days we confirmed the reverse polarity and Eric almost immediately provided a new analyzing power based on these optics
  - In March we were given 2 days to study systematics and quad 3 power supply failed on day 1. Determined new optics solution within minutes that allowed Q3 to be off and continued with program.



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