“Higher” Precision Møller Polarimetry

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Beam Polarimetry @ JLab

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My Ground Rules

- MOLLER requires 0.4% or better knowledge of the incident electron beam polarization
- Consequently, *my* goal is knowledge and control of all systematic uncertainties at **0.1%** or better. Then we can withstand up to 16 contributions at this level, *if all of the uncertainties can be added in quadrature!*
- Statistical errors are important, too (!), but I won't bother with that here. Just remember that some systematic checks may require thin targets and/or low beam currents, so always check rates.

Reminder

Standard treatment, I will refer to this notation

$$\text{Rate } \mathcal{R}^{\pm} = \left[\int \left(\frac{d\sigma^0}{d\Omega}\right) d\Omega\right] + \left[\int \left(\frac{d\sigma^{\pm}}{d\Omega}\right) d\Omega\right] \; P^{\pm}_{\text{Beam}} \; P_{\text{Target}}$$

$$\text{Assume } P^{\pm}_{\text{Beam}} = \pm P$$

$$\text{Asymmetry } \mathcal{A} = \frac{\mathcal{R}^+ - \mathcal{R}^-}{\mathcal{R}^+ + \mathcal{R}^-} = \frac{\langle\sigma^+\rangle P - \langle\sigma^-\rangle P}{2\langle\sigma^0\rangle} P_{\text{Target}} = \langle A_{zz}\rangle \; P \; P_{\text{Target}}$$

Measure $\mathcal{A}$, Calculate $\langle A_{zz}\rangle$, "Believe" P_{Target}

Lots of corrections pile into $\langle A_{zz}\rangle$

Systematic Uncertainties

1. Magnetization (of pure iron) at “saturation”
2. Spin vs Orbital component of magnetization
3. Target foil angle with respect to holding field
4. Spectrometer tune and magnet currents
5. Analyzing power averaged over acceptance
6. Levchuk effect *(See today’s talk by Dave Gaskell)*
7. Demagnetization from target heating
8. Background contributions to rate
9. Dead time corrections, electronics effects
10. Radiative corrections
11. Deviation from perfect polarization reversal

What did I forget? Transverse polarization?

Magnetization at "Saturation"

C.D. Graham, J. Appl. Phys. 53(1982)2032

Missing Summary Table!

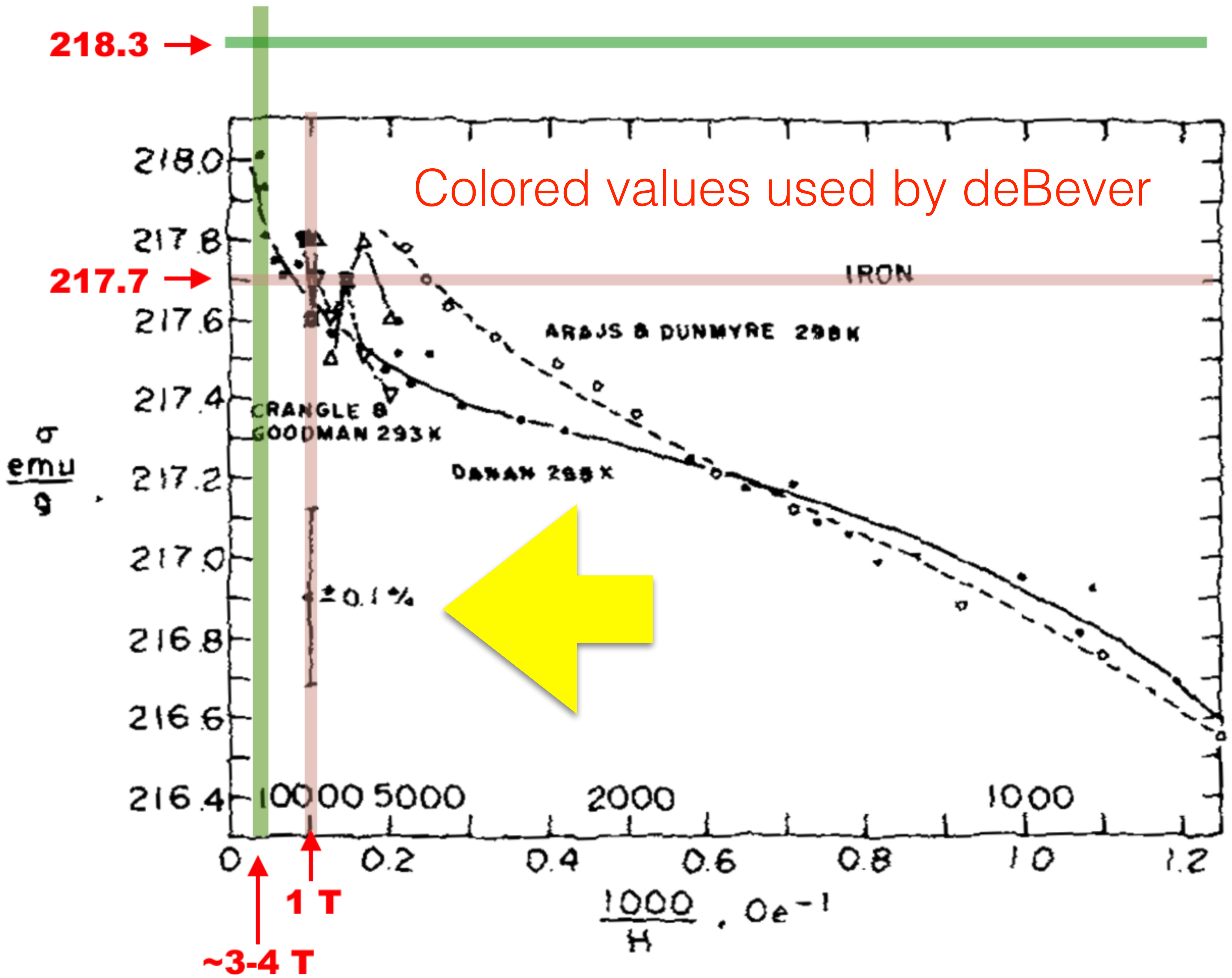


Fig. 5. Magnetization data for iron

<u>Recall</u>: *Magnetization* is *magnetic moment per unit volume*

It seems that iron is indeed understood well enough for 0.1% including corrections for high field and room temperature.

Spin versus Orbital

Not all the magnetization comes from electron spin!

$$\frac{M_{\mathrm{Spin}}}{M_{\mathrm{Total}}} = \frac{2(g'-1)}{g'}$$

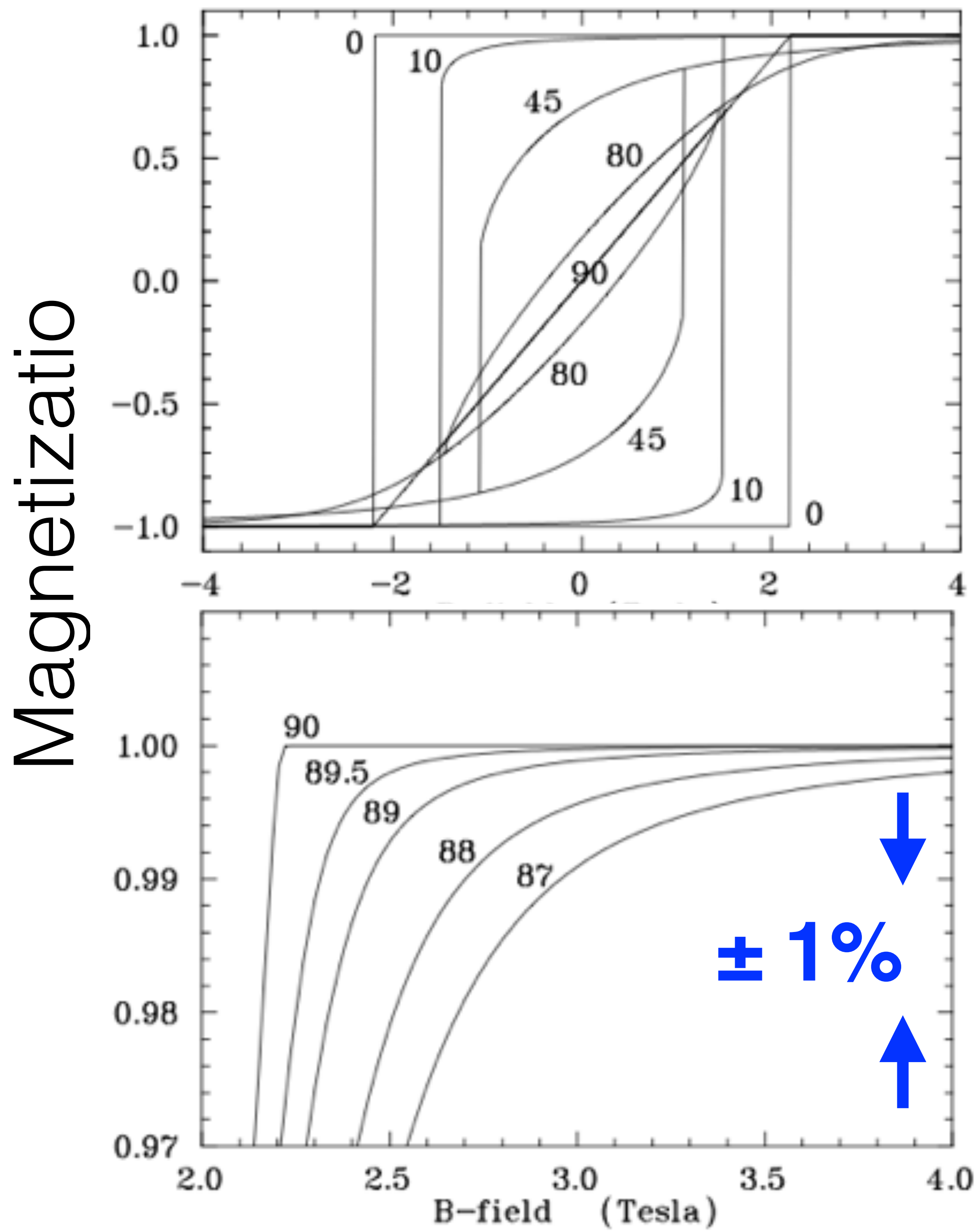
g'=1.919±0.002 (0.1%)
via Einstein-deHaas
G.G. Scott (1962)

This looks like it should be alright, but there has been much research in condensed matter physics to study this effect using other techniques.

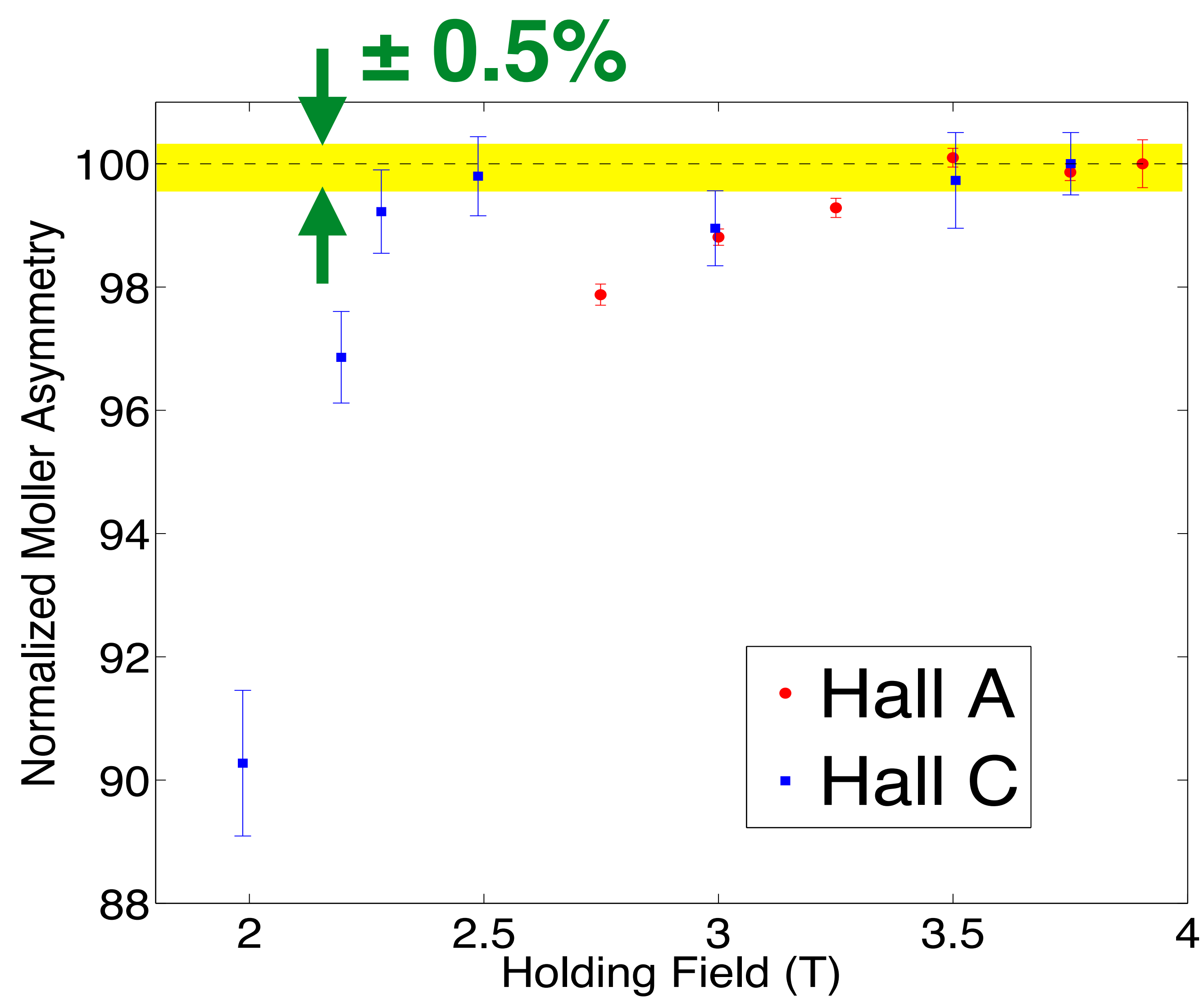
It would be useful to try and verify this value. Bill is looking into the literature, and measurements using X-Ray Magnetic Circular Dichroism (XMCD).

Target Foil Angle

"Brute Force" polarization needs perpendicular foil

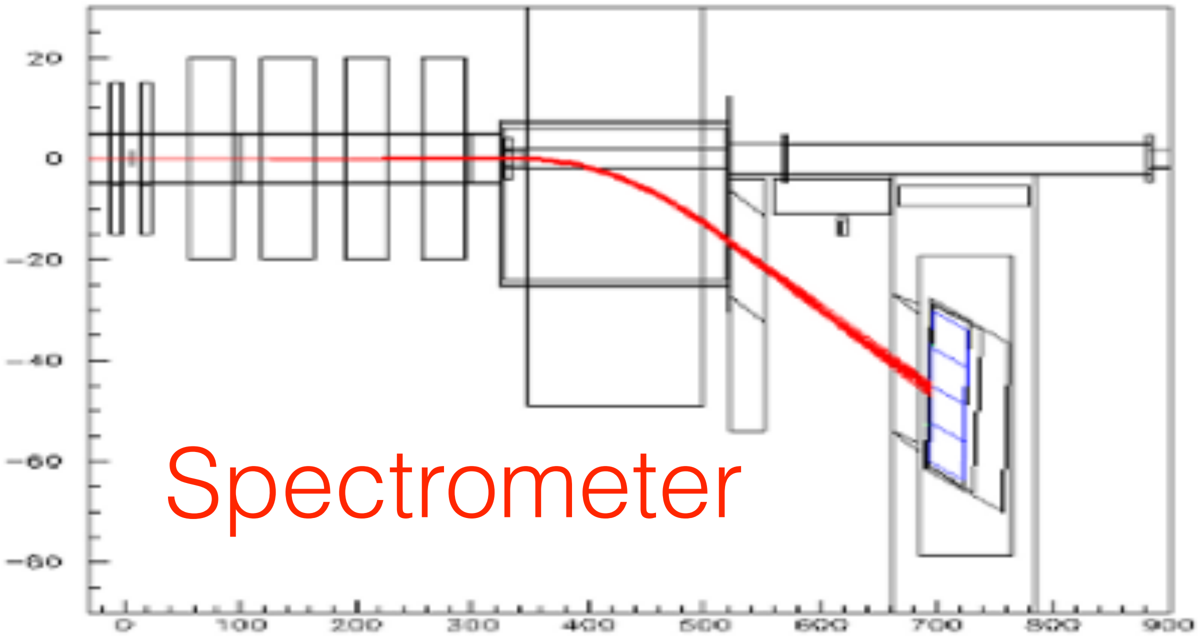


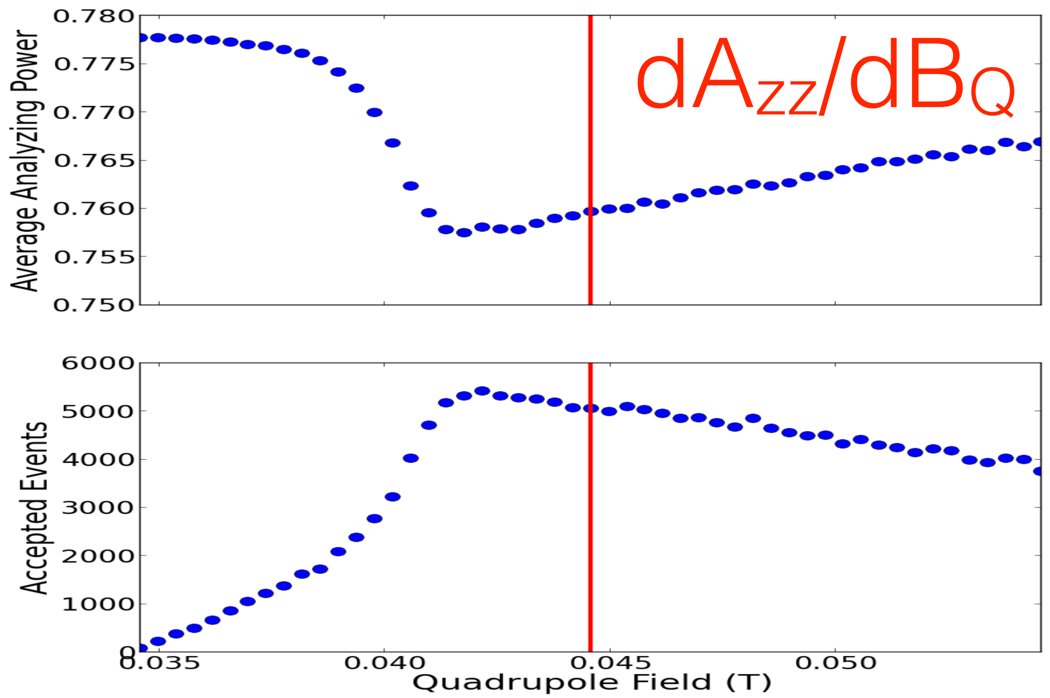
Axial rotation of the target is needed to control this.



Spectrometer Tune

Work going on to build reliable & understood simulation



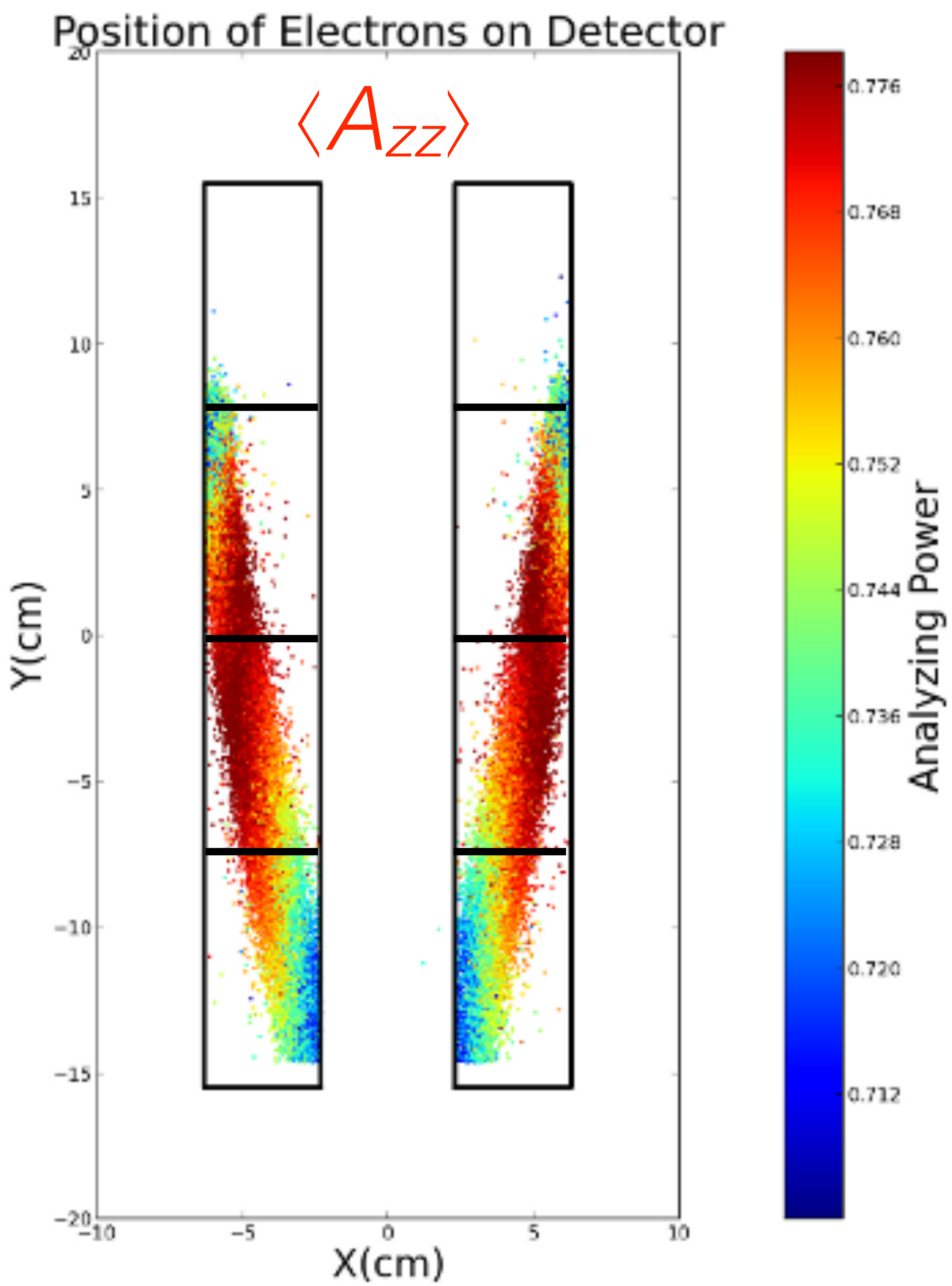


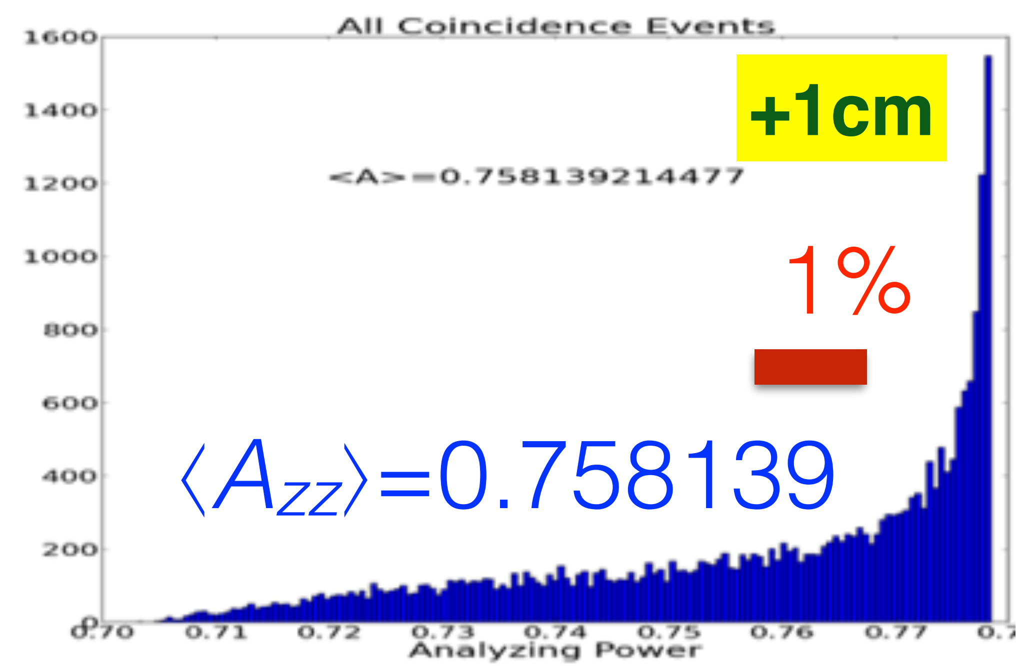
Simulation developed (SNAKE) with realistic magnetic fields, but I guess more expertise in GEANT4 so switching?

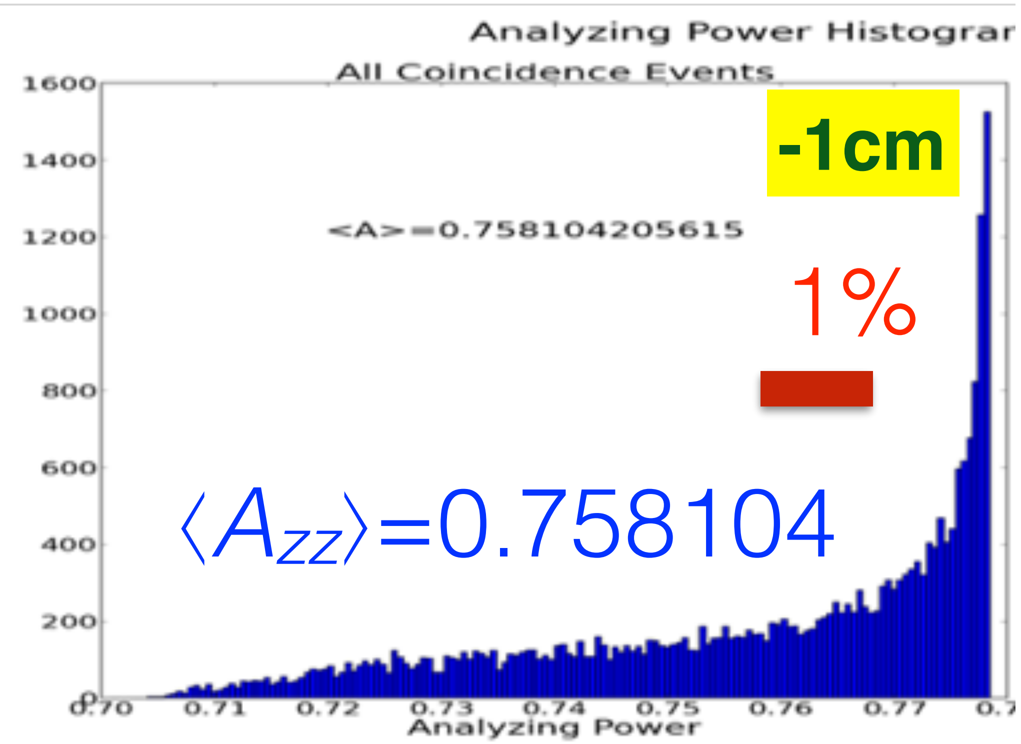
One result: A_{zz} depends on quadrupole fields. (Sasha has data that optimizes asymmetry, should be equivalent.)

Analyzing Power ≠ 7/9

Need good simulation to know $\langle A_{zz} \rangle$ to 0.1%







Levchuk Effect

Gaskell !

Different kinematics for deeply bound electrons in iron

L.G. Levchuk, NIM A345(1994)496

Table 2
The influence of the motion of electrons bound in target atoms on the analyzing power for the MIT-Bates polarimeters [4,5]

E_0 [MeV]	Target thickness [μm]	Target inclination to the beam, α [deg]	θ_0 [deg]	$\Delta\theta/\theta$ [%]	P_t [%]	Effective target polarization [a] [%]
250	13	45	3.66	5.2	7 5	8.0
574	13	30	2.42	10.7	8.0	8.55
868	13	30	1.96	8.7	8.0	8.8

[a] When intra-atomic motion of bound electrons is taken into account.

10% Effect!

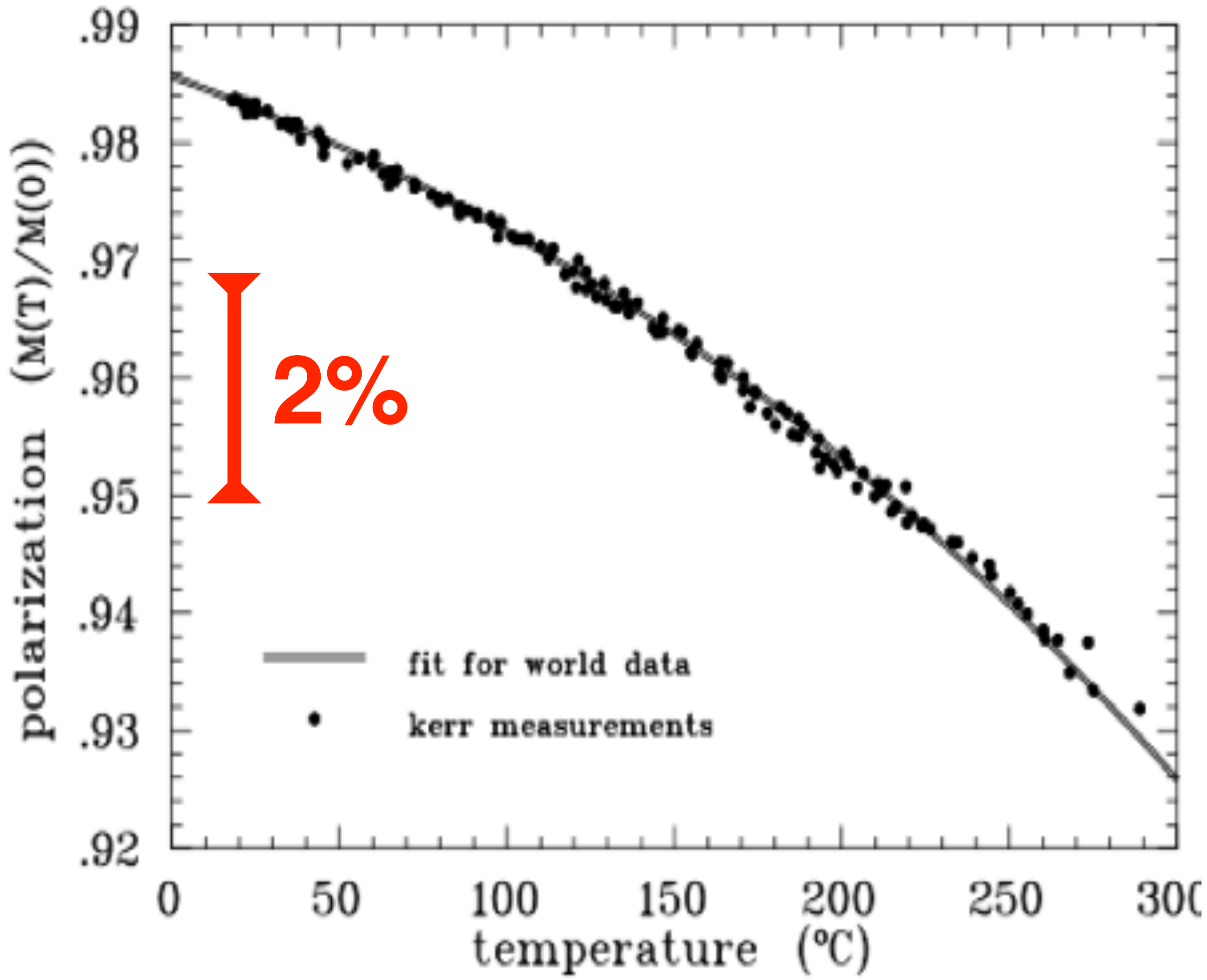
See confirmation by M. Swartz, et al, NIM A363(1995)526

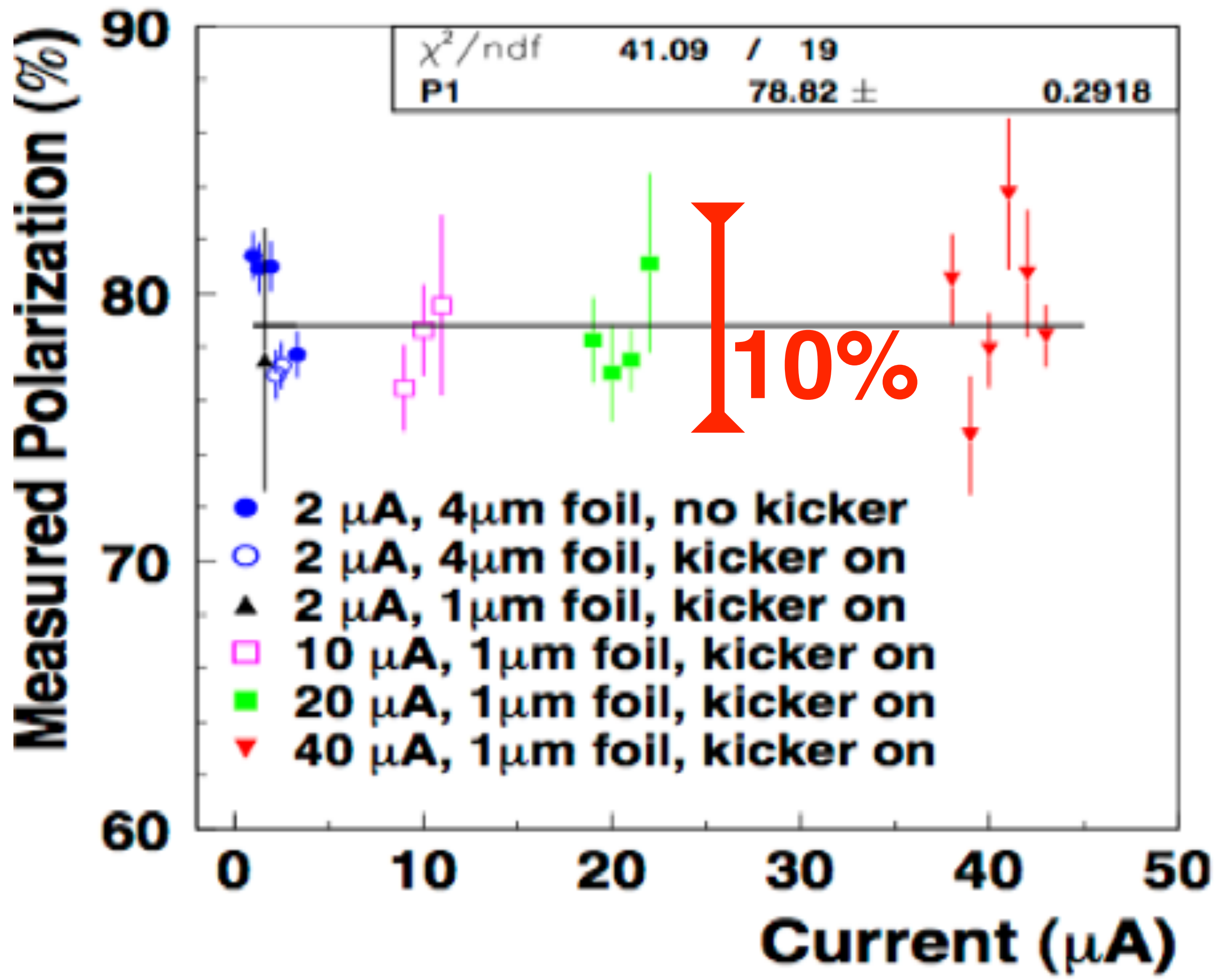
We could have a good opportunity to study this with the Hall A and Hall C polarimeters (very different optics).

Obviously important that we understand this very well!

Target Heating

Some results from Hall C; Possible goal for Kerr apparatus





Probably good idea to address this with calculations.
The program COMSOL has been recommended.

Background Contributions

- I don't know of any studies. Please tell me if you do.
- It's probably easy enough to calculate *quasi-elastic* scattering and tabulate expected accidental rates. Perhaps someone has done this already?
- If contribution to the Møller scattering coincident rate is on the order of 0.1% or more, then we need to understand the uncertainties in the calculation.

Dead Time Corrections

$$\text{Dead time } \tau \qquad \text{Rate } \mathcal{R} \qquad \tau \ll 1/\mathcal{R} \quad \Longrightarrow \quad \mathcal{R}_m = \mathcal{R}\,(1 - \mathcal{R}\tau)$$

$$\mathcal{R}^{\pm} = \mathcal{R}^0 \pm \Delta \qquad \Delta \ll \mathcal{R}^0$$

$$\mathcal{A}_m = \frac{\mathcal{R}_m^+ - \mathcal{R}_m^-}{\mathcal{R}_m^+ + \mathcal{R}_m^-} \approx \frac{\Delta}{\mathcal{R}^0}(1 - 2\mathcal{R}^0\tau) = \mathcal{A}(1 - 2\mathcal{R}^0\tau)$$

$$\mathcal{R}^0 = 10^5/\text{sec (?)} \qquad \tau = 10^{-7} \text{ sec (?)} \qquad \text{means } 2\% \text{ effect!}$$

This might be important, deserves some more study.

Radiative Corrections

Need to know corrections to the Møller asymmetry, and also how they affect cross section and $\langle A_{zz} \rangle$

Two references:

- Jadach & Ward, PRD 54(1996)743 *(for SLD)*
- Shumeiko & Suarez, J.Phys.G 26(2000)113

Jadach & Ward: "*The size of the radiative effects, ≈10%, necessitates that they be computed with good precision in any discussion of Møller polarimetry with a precision tag better than 10%.*"

Lessons to be learned from PRAD collaboration?

Polarization Reversal

$$\mathcal{R}^{\pm} = \mathcal{R}^0 + P^{\pm}_{\text{beam}}\Delta \qquad P_{\text{Beam}}\Delta \ll \mathcal{R}^0$$

$$\text{Assume } P^{\pm}_{\text{Beam}} = \pm P + \epsilon \qquad \text{i.e. } P^{+}_{\text{Beam}} + P^{-}_{\text{Beam}} = 2\epsilon$$

$$\mathcal{A} = \frac{\mathcal{R}^+ - \mathcal{R}^-}{\mathcal{R}^+ + \mathcal{R}^-} = \frac{P\Delta}{\mathcal{R}^0 + \Delta\epsilon} \approx \mathcal{A}_{\text{True}}\left(1 - \epsilon\frac{\Delta}{\mathcal{R}^0}\right)$$

$$\Delta/\mathcal{R}^0 = 0.05 \qquad \epsilon = 0.01\ (?) \qquad \text{means} < 0.1\% \text{ effect}$$

We can check this by reversing the target hold field, *which is probably a good idea anyway!*

Conclusions

- It is challenging to demonstrate 0.4% uncertainty in beam polarization, but we see no show stoppers.

- A team effort is needed to knock off each source of systematic uncertainty, including documentation of all calculations and measurements.

- Cross check with Compton polarimetry will be the ultimate test. These will have to agree to 0.4% or better to convince everyone that either is correct.