High-Precision 5-MeV Mott Polarimetry at the JLab Injector

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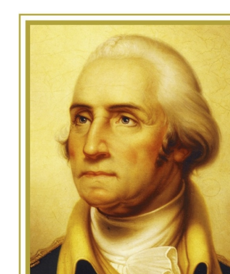
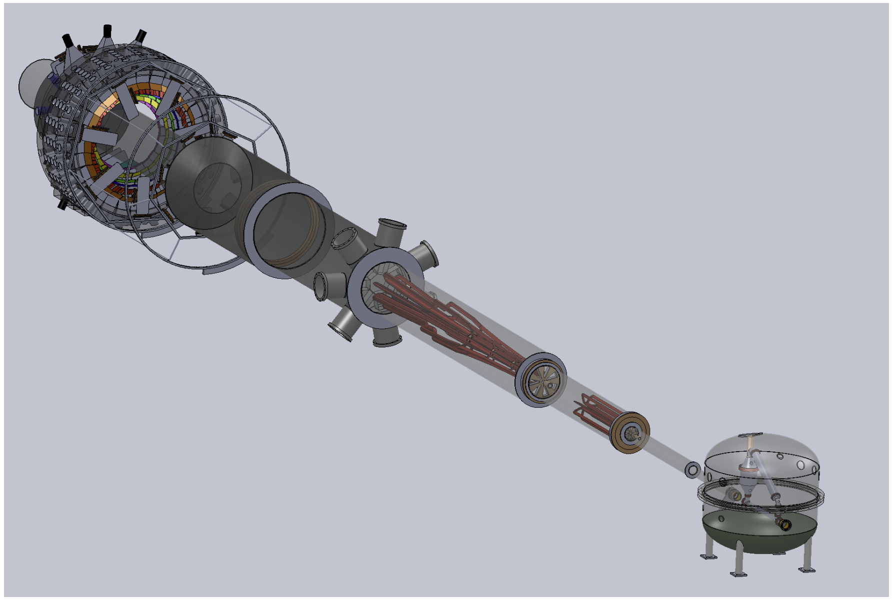
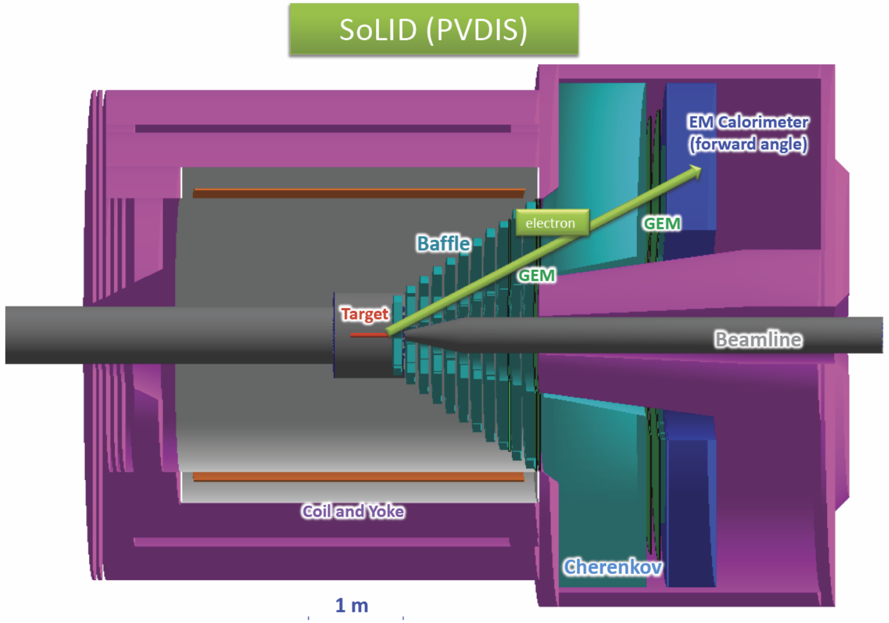
Jefferson Lab



Motivation: the next generation of parity-violation experiments at JLab

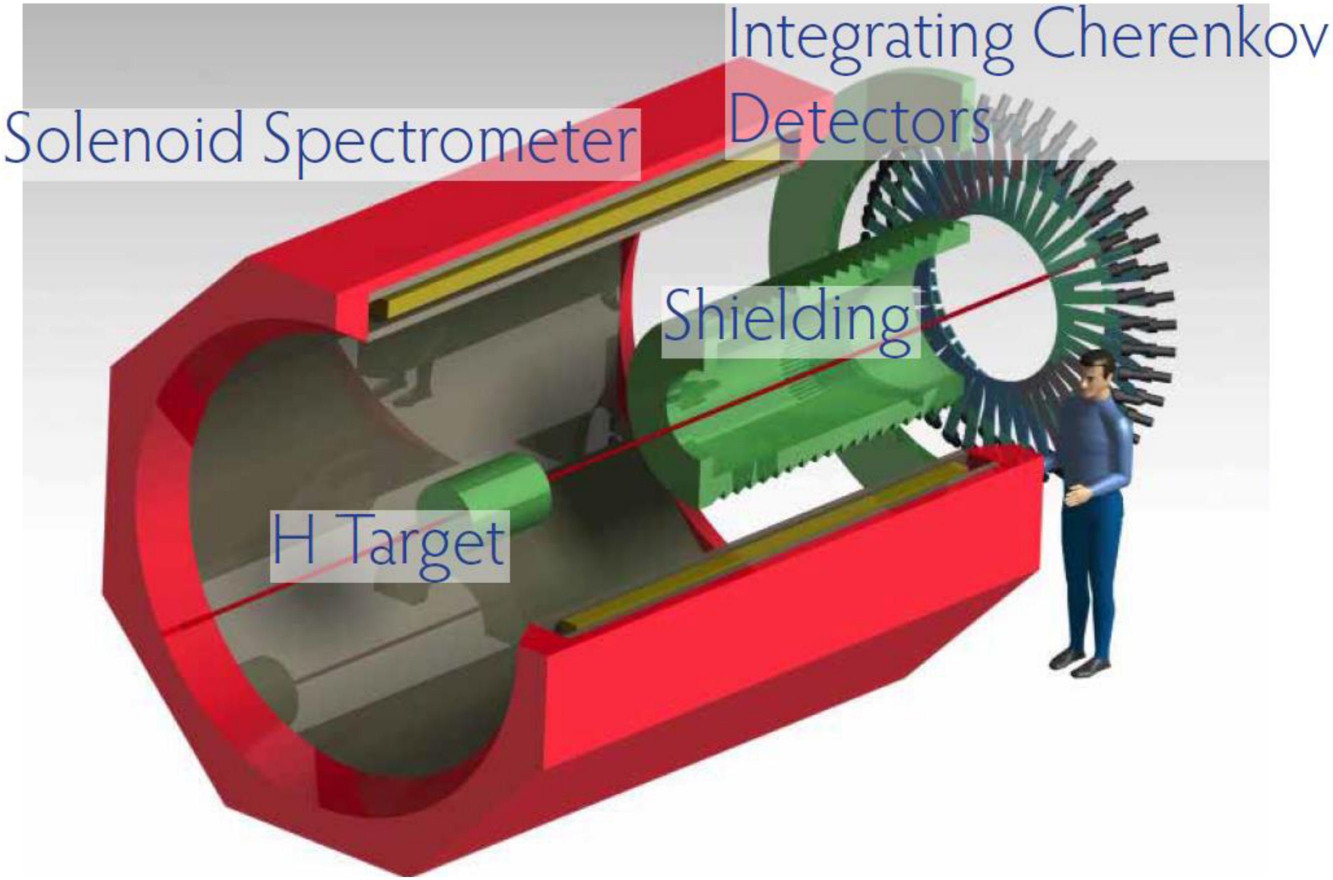
Møller: e^- - H : Statistical polarization accuracy required 1-1.5 %





SOLID/PV-DIS: e^- - ^{2}H: Statistical polarization accuracy required ~0.5%

MESA/P2 will also need high-accuracy electron polarimetry



MESA/P2: e^- - H: Statistical polarization accuracy required ~ 0.5%

High-Energy Polarimetry in the Jlab Experimental Halls

Hall A

Compton: ~ 0.6%

Mϕller: ~1.8% → 0.4%?

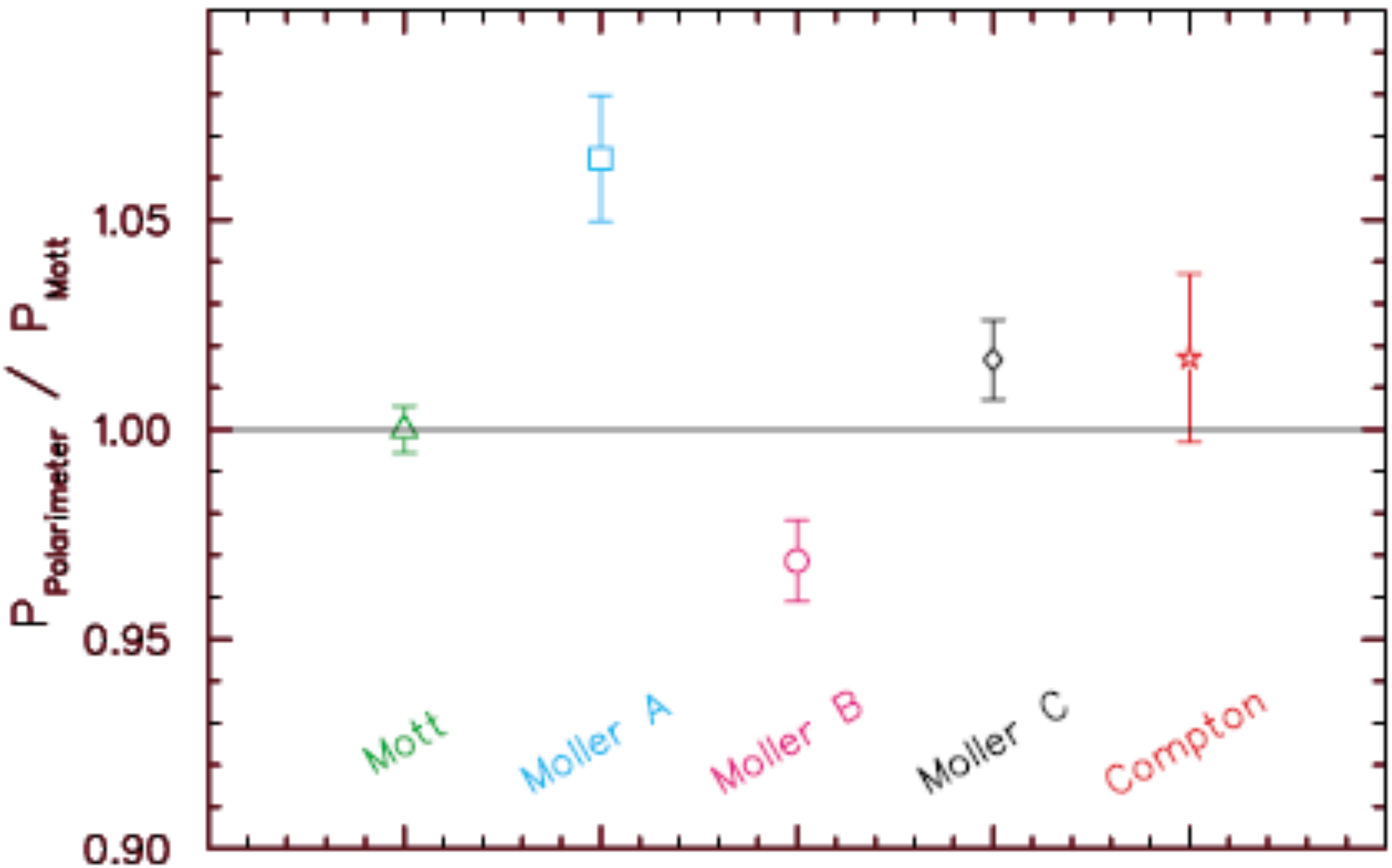
Hall B

Mϕller: ~2.5%

Hall C

Mϕller: ~0.5%

The 2004 CEBAF Spin Dance

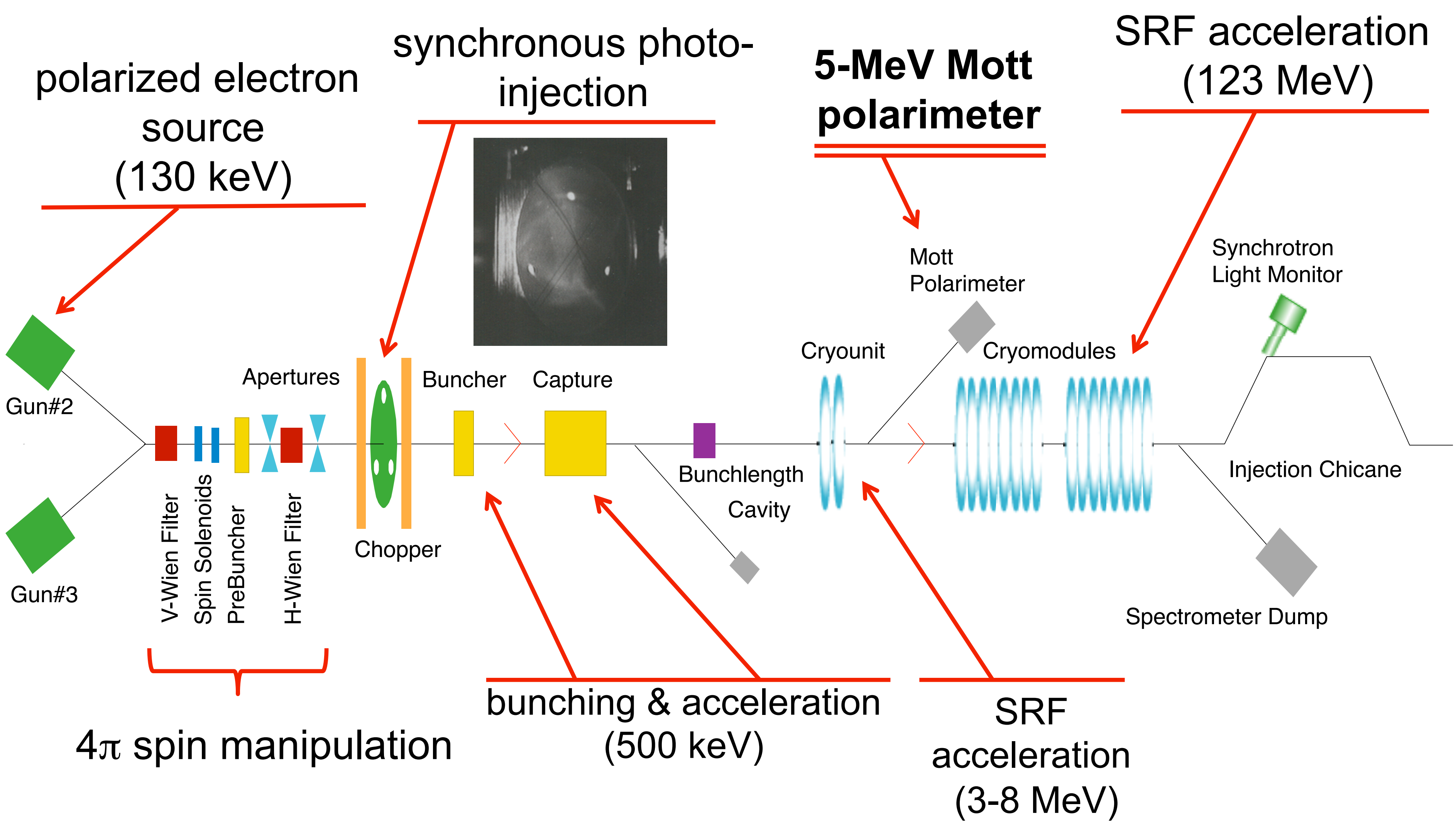


J.M.Grames *et al.*, Phys. Rev. Special Topics Accelerators and Beams (PRST-AB) **7**, 042802 (2004)

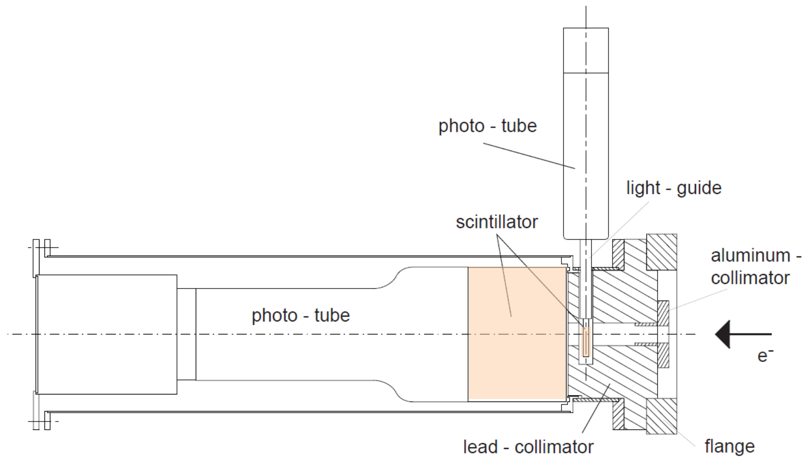
ESTIMATED SYSTEMATICS

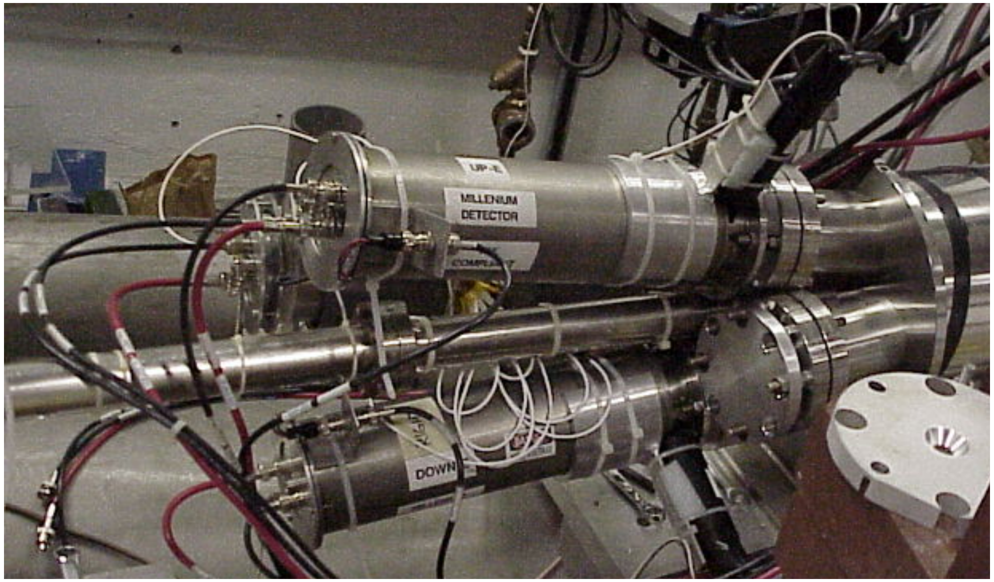
- Mott: 1%
- Mϕller A: 2%
- Mϕller B: 3%
- Mϕller C: 1%
- Compton: 3%

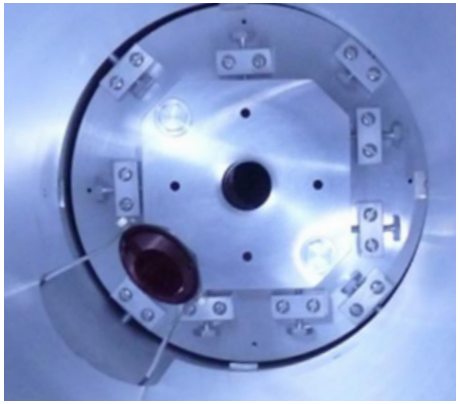
CEBAF Polarized Electron Injector

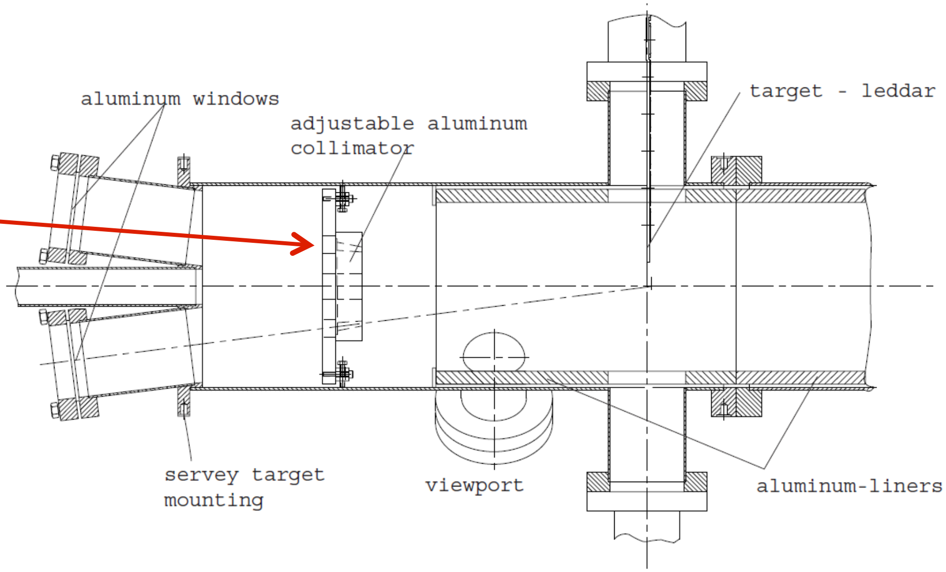


The CEBAF 5-MeV Mott Polarimeter





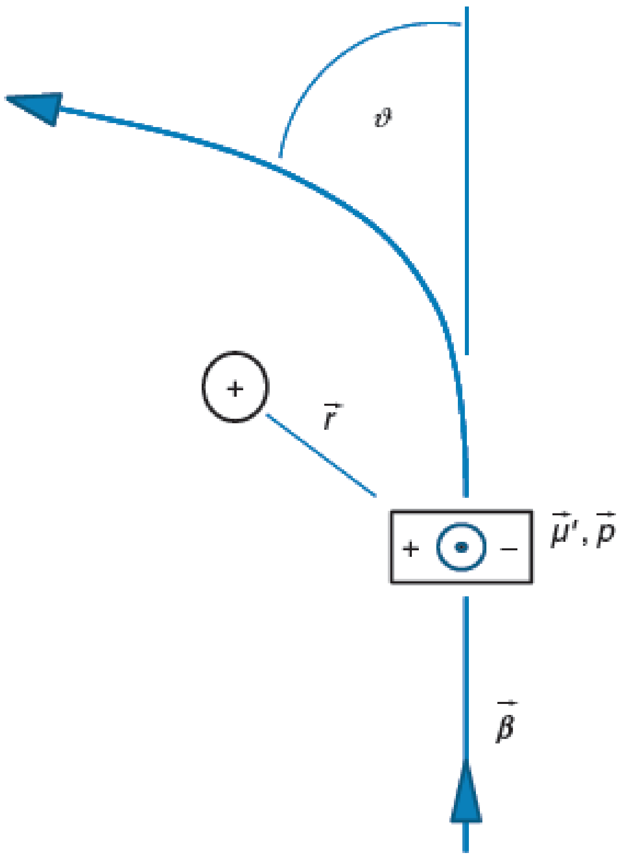




$\theta = 172.6°$

$\Omega = 0.18$ msr

Measuring Mott Asymmetries



$$\vec{p} = \vec{\beta} \times \overrightarrow{\mu'}$$

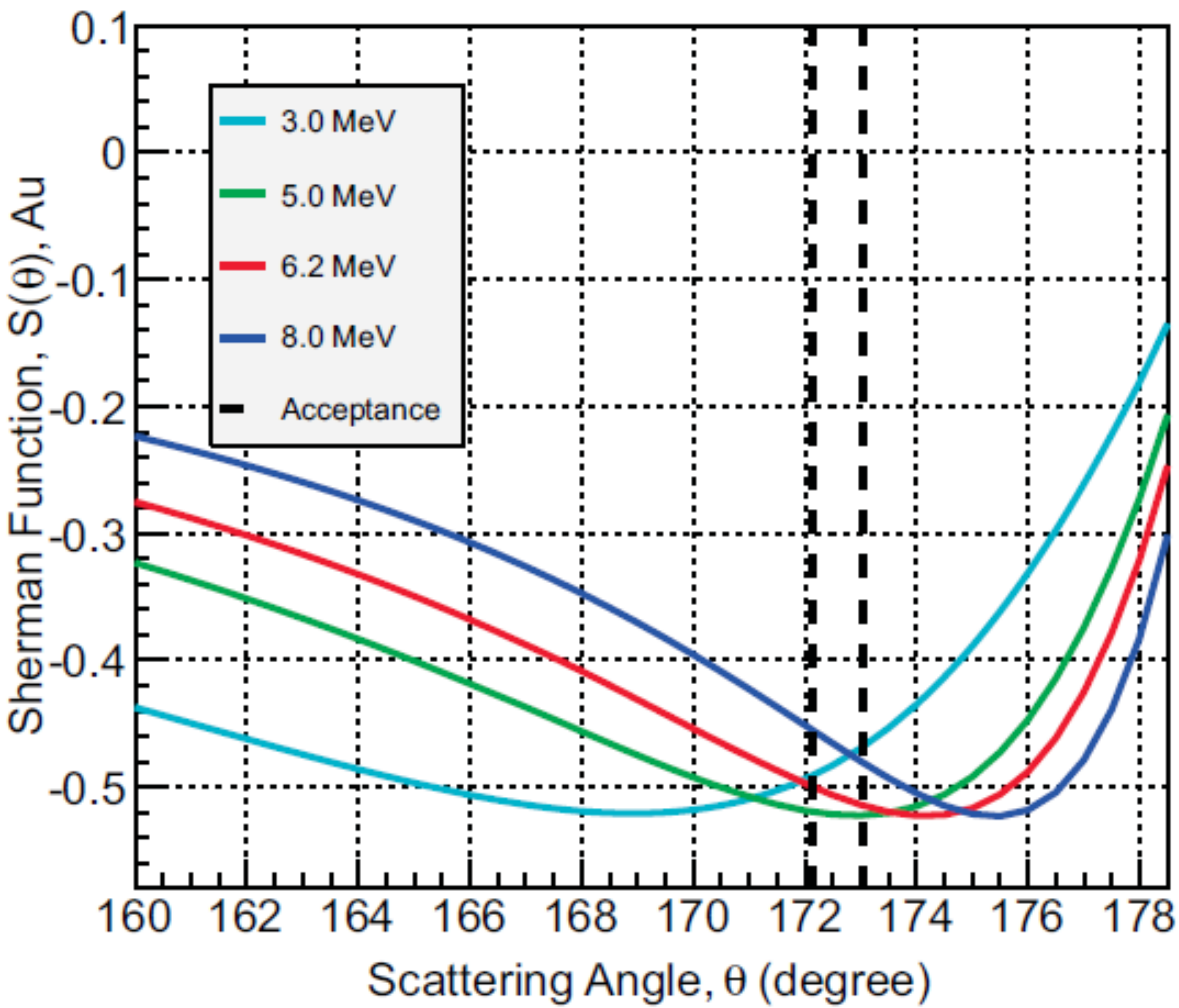
$$A(\vartheta) \equiv \frac{I^R(\vartheta) - I^L(\vartheta)}{I^R(\vartheta) + I^L(\vartheta)} = S(\vartheta) P_e$$

$$A = \frac{1 - r(\vartheta)}{1 + r(\vartheta)}$$

$$r \equiv \sqrt{\frac{I^R(\uparrow) I^L(\downarrow)}{I^R(\downarrow) I^L(\uparrow)}}$$

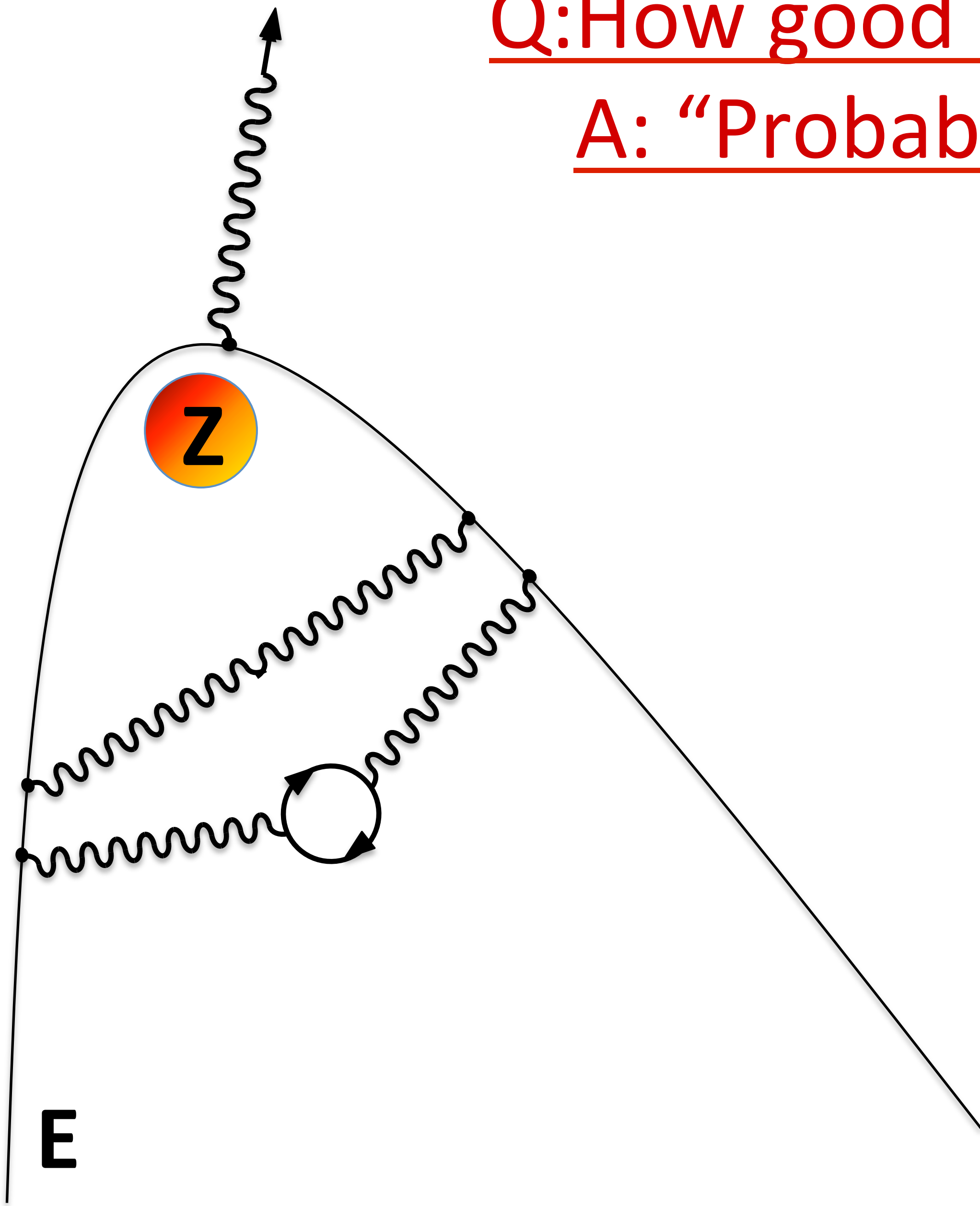
Cross-ratio method cancels false asymmetries from detector efficiency, beam current, target thickness and solid angle.

The 5-MeV Sherman Function



X. Roca-Maza *et al*. – Phys.Rev C **78** (044332) and **87** (014304)

Q:How good is the theory for S?
A: “Probably about 0.5%...”



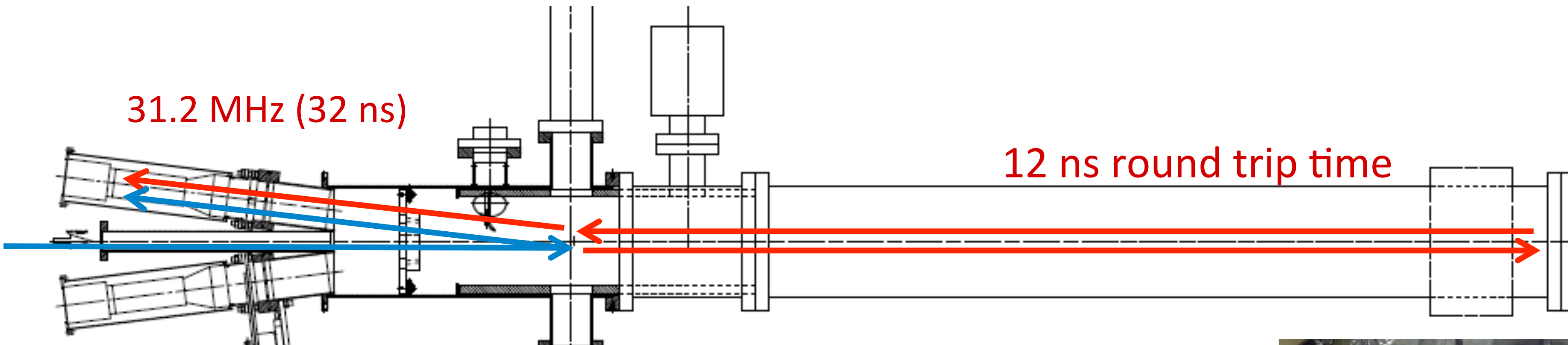
- QED effects (vacuum polarization, self-energy) and bremsstrahlung, which are just starting to become important at 5 MeV, lead to some uncertainty in S, although the *cognoscenti* are “pretty sure” that the effects of vacuum polarization offset those of self energy. (There is some circumstantial experimental evidence to support this.) The effect of bremsstrahlung has not yet been quantified.

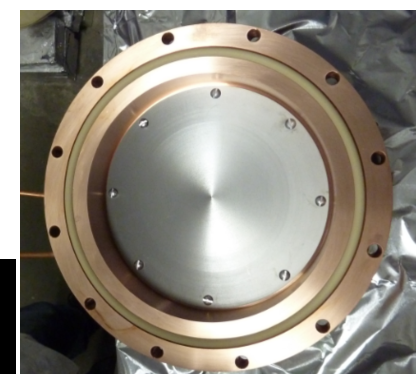
- With Mott precision of < 0.5%, we can test theory indirectly by comparing experimental results with the predictions of theory for the Z- and E-dependence of S.

- New regime for tests of QED

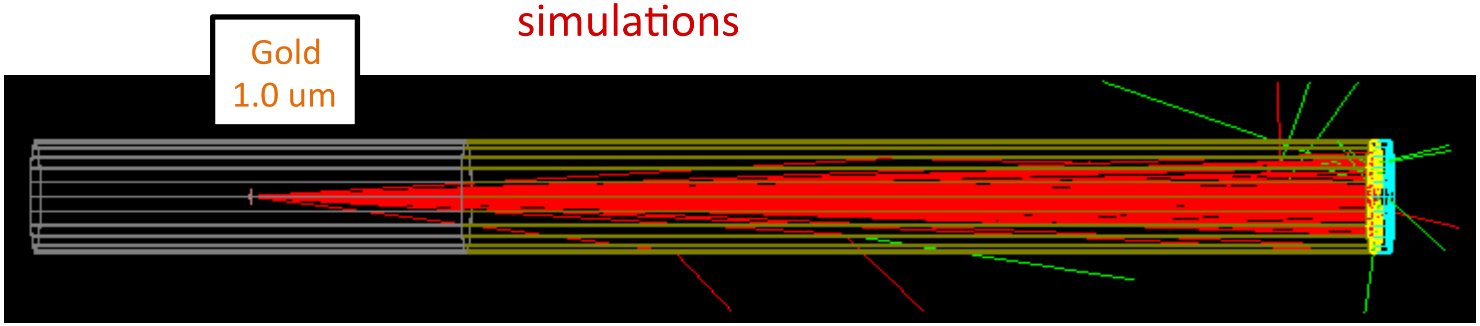
Background & Energy Resolution Issues

Photon vetoing by thin and thick scintillators, TOF discrimination, GEANT simulation, Be backstops….

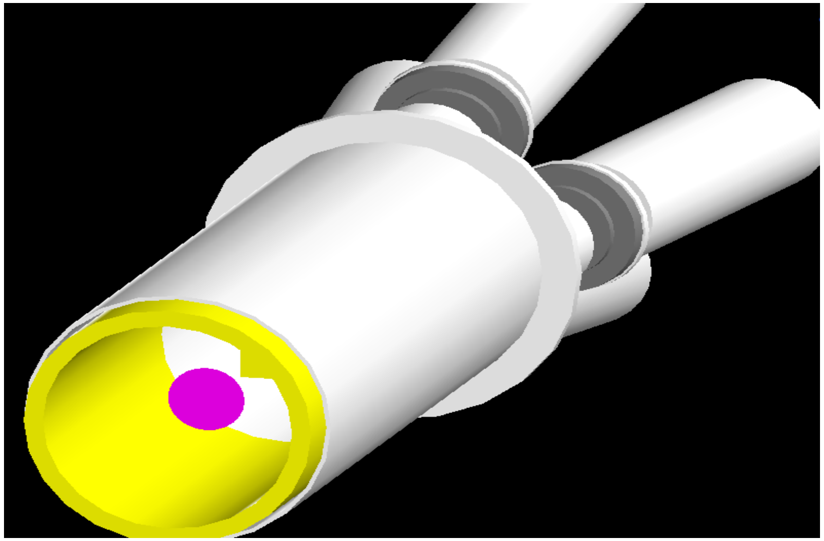




GEANT4 simulations

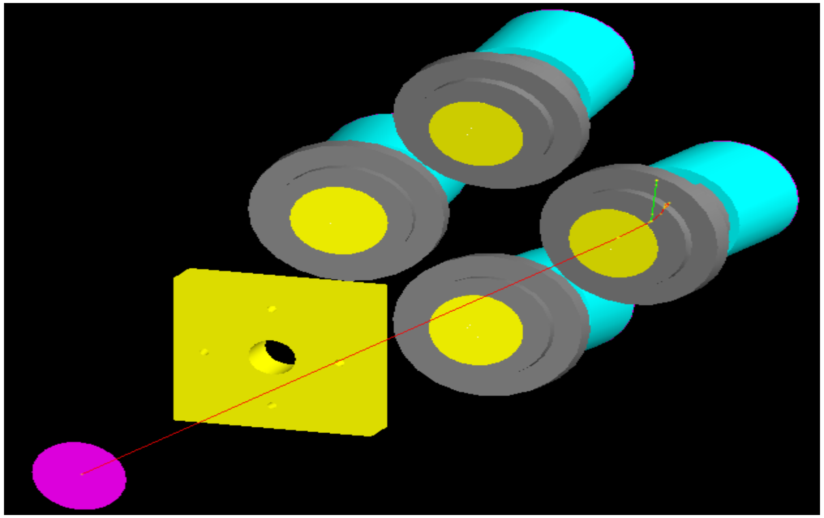


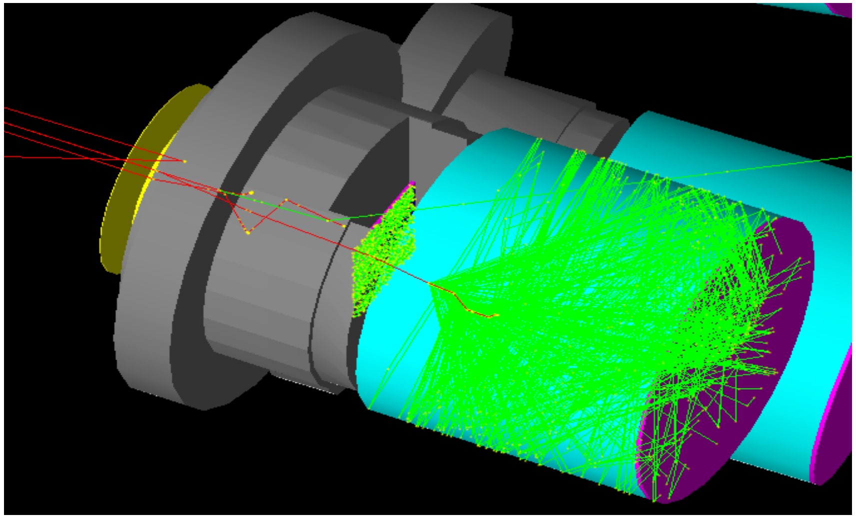
GEANT4 Modeling



Geant4 Mott Model v.2

- Complete modeling of target, collimator
- Detailed model of detector
- Modeling of the entire chamber
- Electron-generator based on theory
- Ongoing benchmarking against commissioning data

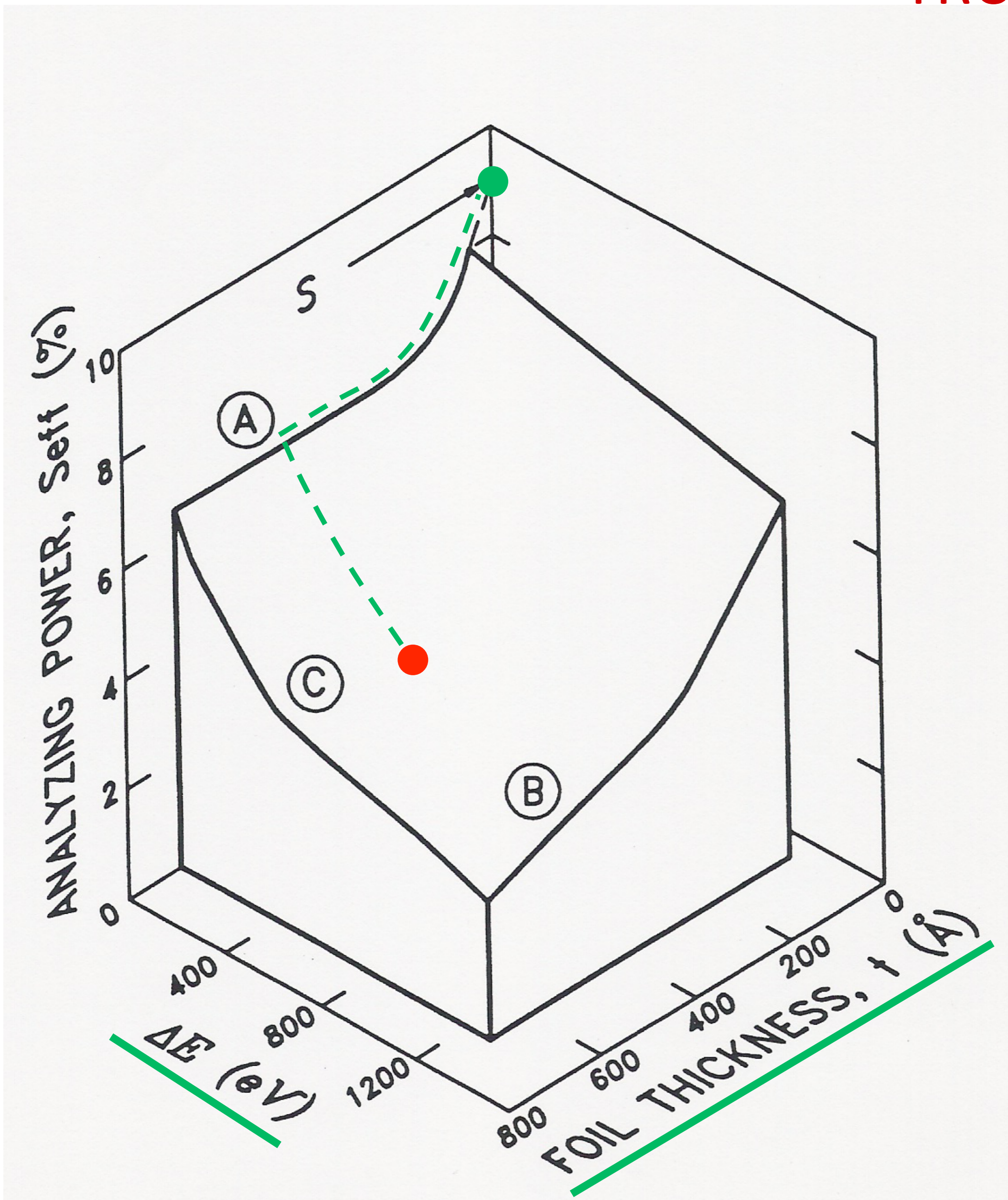




GEANT4 Modeling Summary

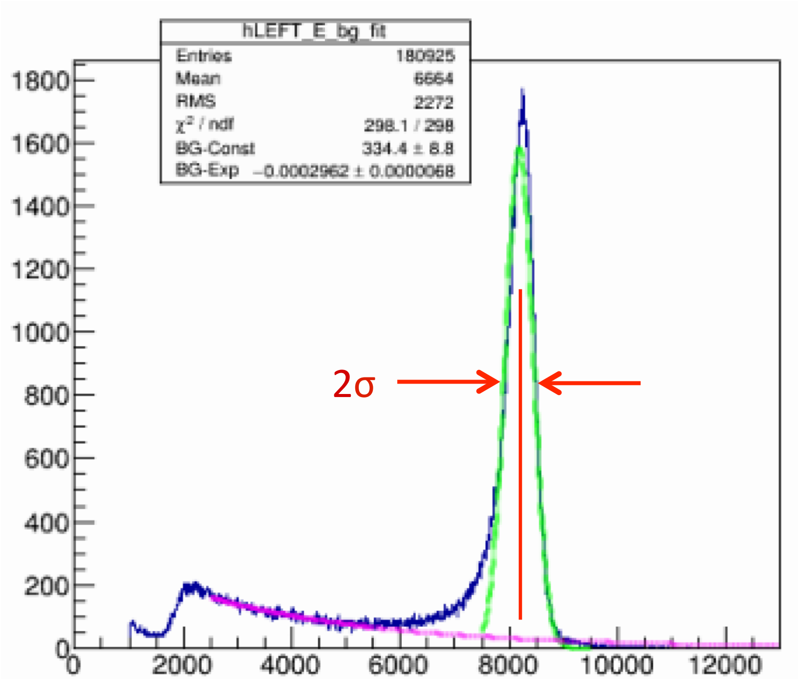
- Single and double scattering considered, with complete polarization information included
- Goal 1: to understand at a detailed level the role of background contributions to the signals in the detectors
- Goal 2: to provide a scattering model-based fitting form for the measured asymmetry as a function of foil thickness

The Ascent to A_{TRUE}



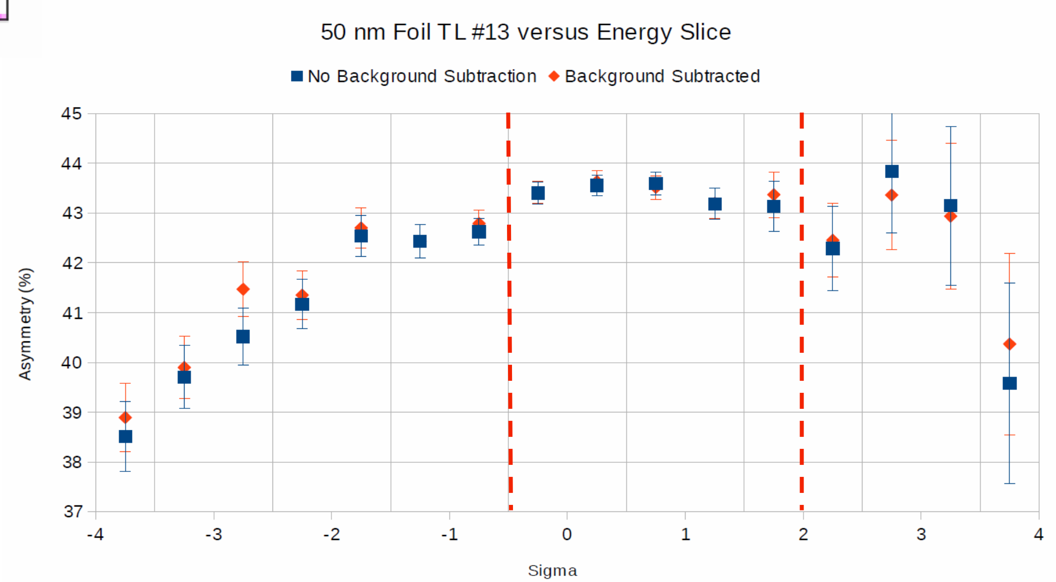
The Sherman function is calculated assuming elastic scattering from single atoms. However, the higher the incident energy, the flatter this landscape becomes. This, and the ease with which TOF corrections can be made, are the major advantages that making measurements at 5 MeV (as opposed to, e.g., 120 keV) give us.

Pulse-Height Analysis & Energy Resolution



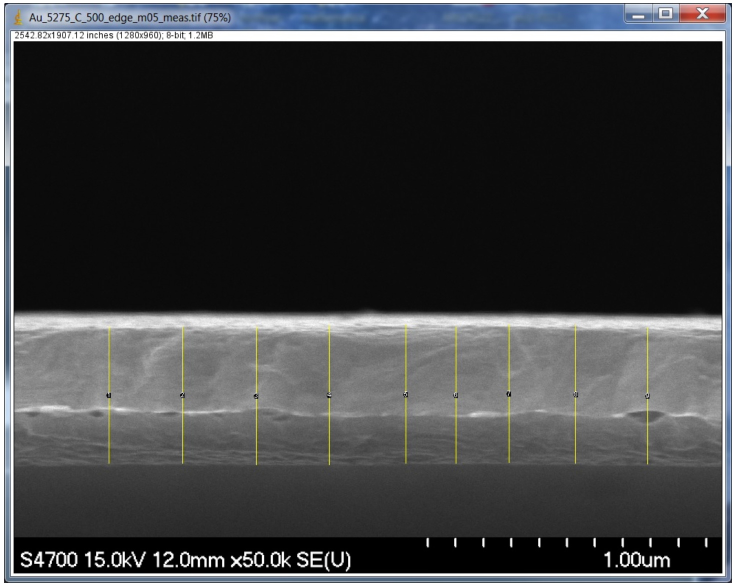
After time-of-flight cuts, the Gaussian fit (green) is made after the exponential quasi-inelastic tail is *temporarily* subtracted.

Pulse-height cuts made between - 0.5σ and +2.0 σ



Foil Thickness Extrapolations

- 10 foils used with nominal thicknesses ranging from 50 nm to 1000 nm, with duplicates at 50 and 350 nm
- Stability checks made with the 1000 nm foil
- FESEM measurements of thickness used in extrapolations; consistent with Lebow specifications
- Uncertainties due to FESEM measurement reproducibility, thickness variability across a sample, FESEM resolution and imaging systematics, and manufacturer-specified sample-to-sample variation for a given, specified thickness



Extrapolation to Single-Atom Scattering

- In parallel with GEANT modeling, we explored multiple fitting functions (see Fletcher et al. PRA **34**, 911 (1986)

- Also try A(R)

- Use the method of Pade approximates (suggested by D. Higinbotham):

$$y = \frac{a_n x^n + a_{n-1}x^{n-1} + \ldots + a_2 x^2 + a_1 x + a_0}{b_m x^m + b_{m-1}x^{m-1} + \ldots + b_2 x^2 + b_1 x + b_0},$$

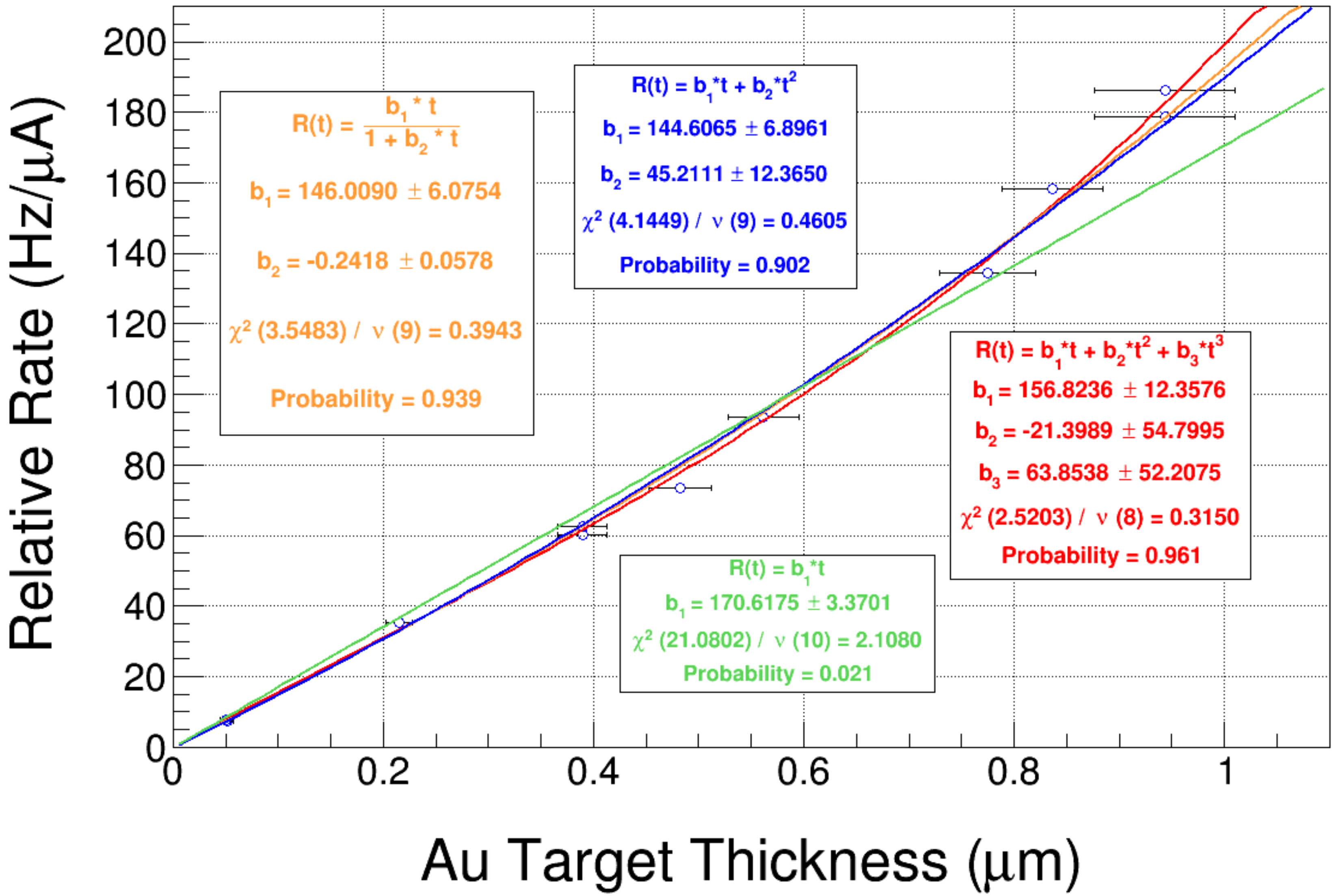
or (n,m),

- Previous Mott scattering zero-thickness extrapolations have considered forms (1,0), (0,1), (1,1), (0,2), (2,0), and (∞,0)

- Reject fits based on poor reduced chi-squared values and the outcomes of F-tests

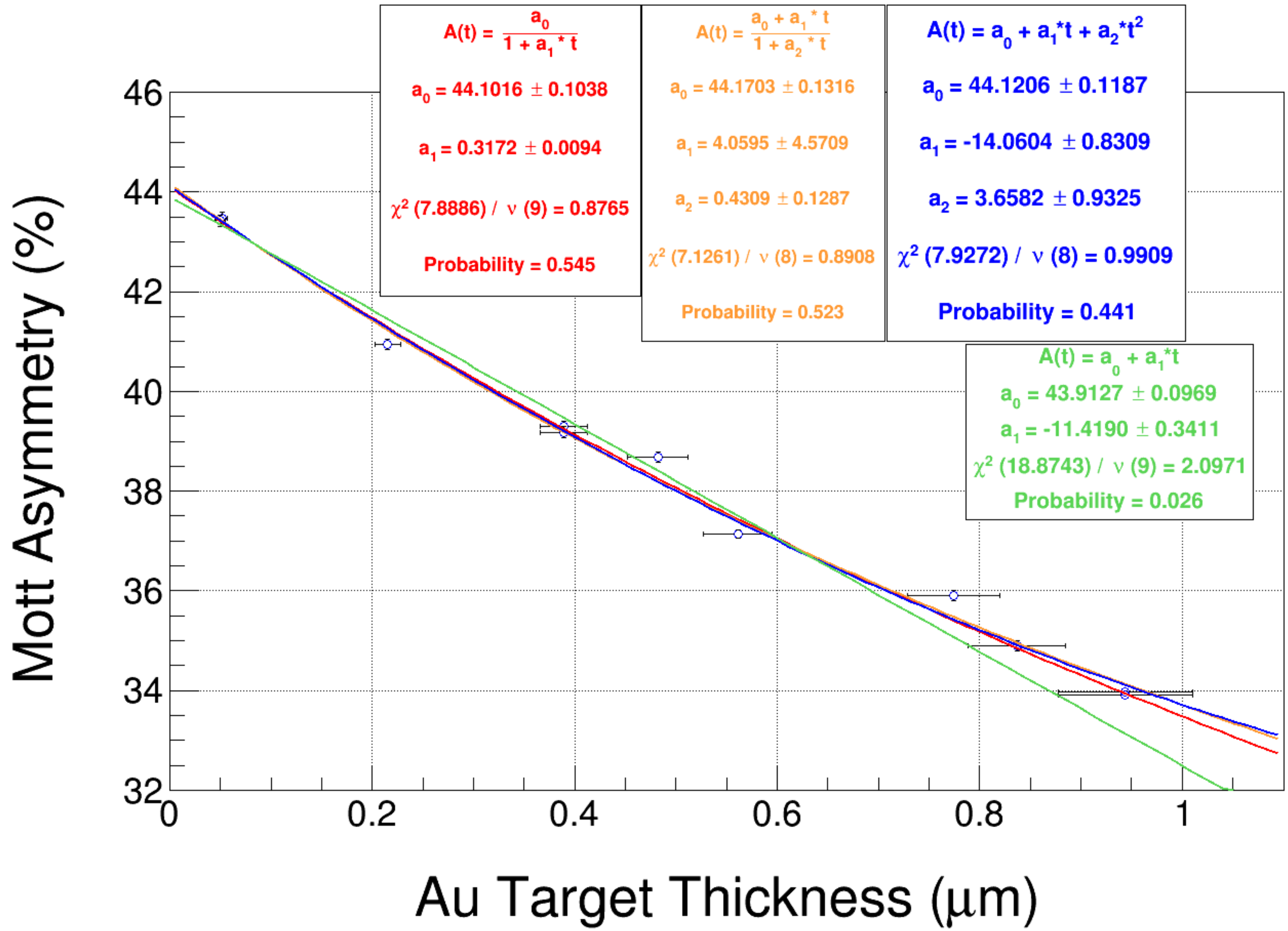
- Expand statistical uncertainty to include all reasonable fits

Run 2 R(t)



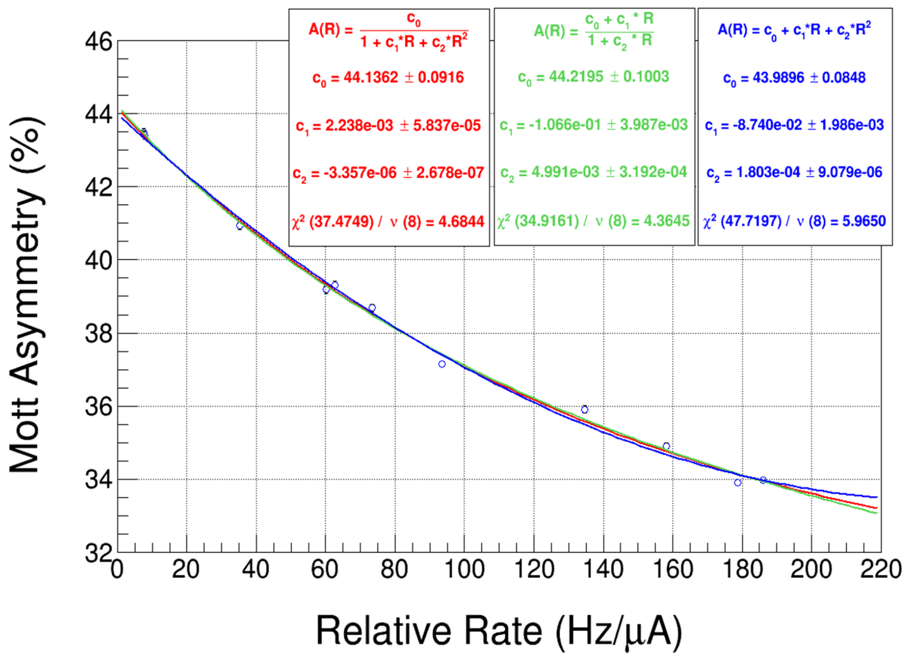
R(t) = b1 * t / (1 + b2 * t)
b1 = 146.0090 ± 6.0754
b2 = -0.2418 ± 0.0578
χ2 (3.5483) / ν (9) = 0.3943
Probability = 0.939
R(t) = b1*t + b2*t2
b1 = 144.6065 ± 6.8961
b2 = 45.2111 ± 12.3650
χ2 (4.1449) / ν (9) = 0.4605
Probability = 0.902
R(t) = b1*t + b2*t2 + b3*t3
b1 = 156.8236 ± 12.3576
b2 = -21.3989 ± 54.7995
b3 = 63.8538 ± 52.2075
χ2 (2.5203) / ν (8) = 0.3150
Probability = 0.961
R(t) = b1*t
b1 = 170.6175 ± 3.3701
χ2 (21.0802) / ν (10) = 2.1080
Probability = 0.021
Relative Rate (Hz/μA)
Au Target Thickness (μm)
0
20
40
60
80
100
120
140
160
180
200
0
0.2
0.4
0.6
0.8
1

Run 2 A(t)



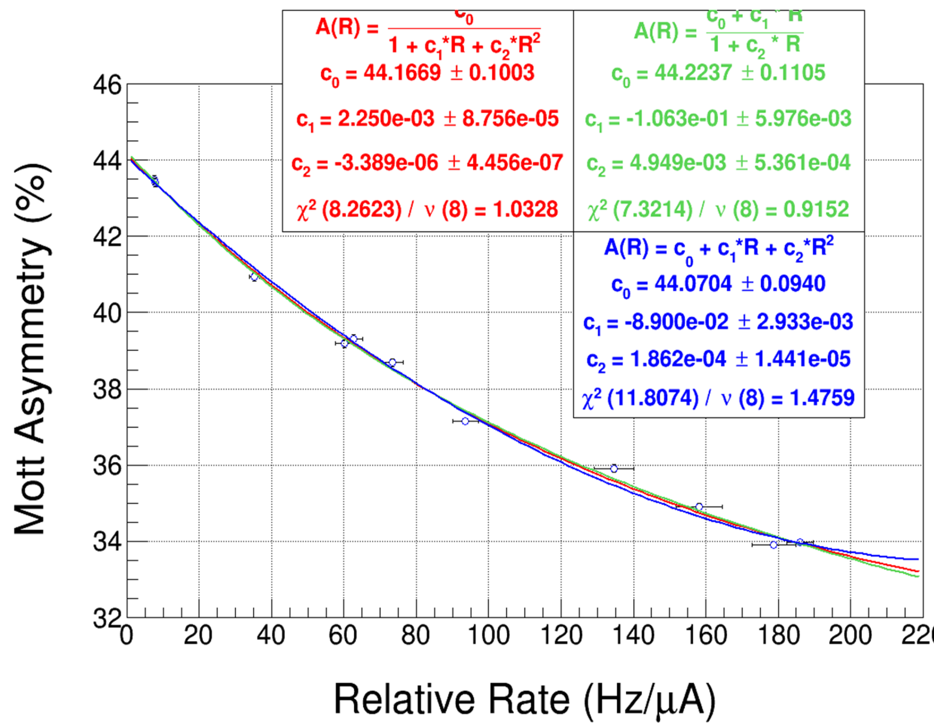
A(t) = a0 / (1 + a1 * t)
a0 = 44.1016 ± 0.1038
a1 = 0.3172 ± 0.0094
χ2 (7.8886) / ν (9) = 0.8765
Probability = 0.545
A(t) = (a0 + a1 * t) / (1 + a2 * t)
a0 = 44.1703 ± 0.1316
a1 = 4.0595 ± 4.5709
a2 = 0.4309 ± 0.1287
χ2 (7.1261) / ν (8) = 0.8908
Probability = 0.523
A(t) = a0 + a1*t + a2*t2
a0 = 44.1206 ± 0.1187
a1 = -14.0604 ± 0.8309
a2 = 3.6582 ± 0.9325
χ2 (7.9272) / ν (8) = 0.9909
Probability = 0.441
A(t) = a0 + a1*t
a0 = 43.9127 ± 0.0969
a1 = -11.4190 ± 0.3411
χ2 (18.8743) / ν (9) = 2.0971
Probability = 0.026
Mott Asymmetry (%)
Au Target Thickness (μm)
46
44
42
40
38
36
34
32
0
0.2
0.4
0.6
0.8
1

Run 2 A(R)



With best estimates of uncertainties in relative R values

With heuristically-increased uncertainties



Single- and Double-Scattering in GEANT4

Including the effects of double scattering, our GEANT4 simulations predict

$$R(t) = at + bt^2,$$

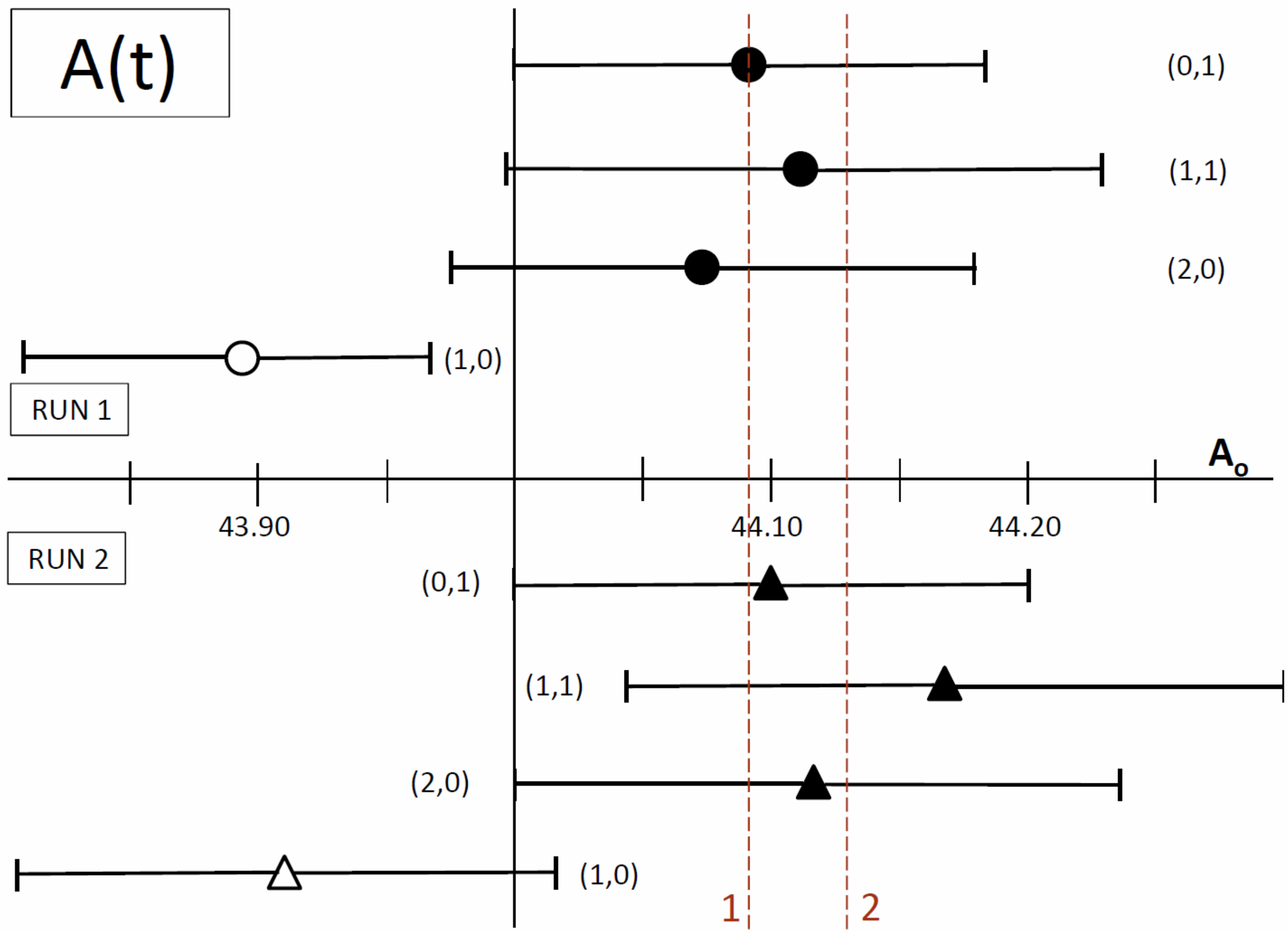
and

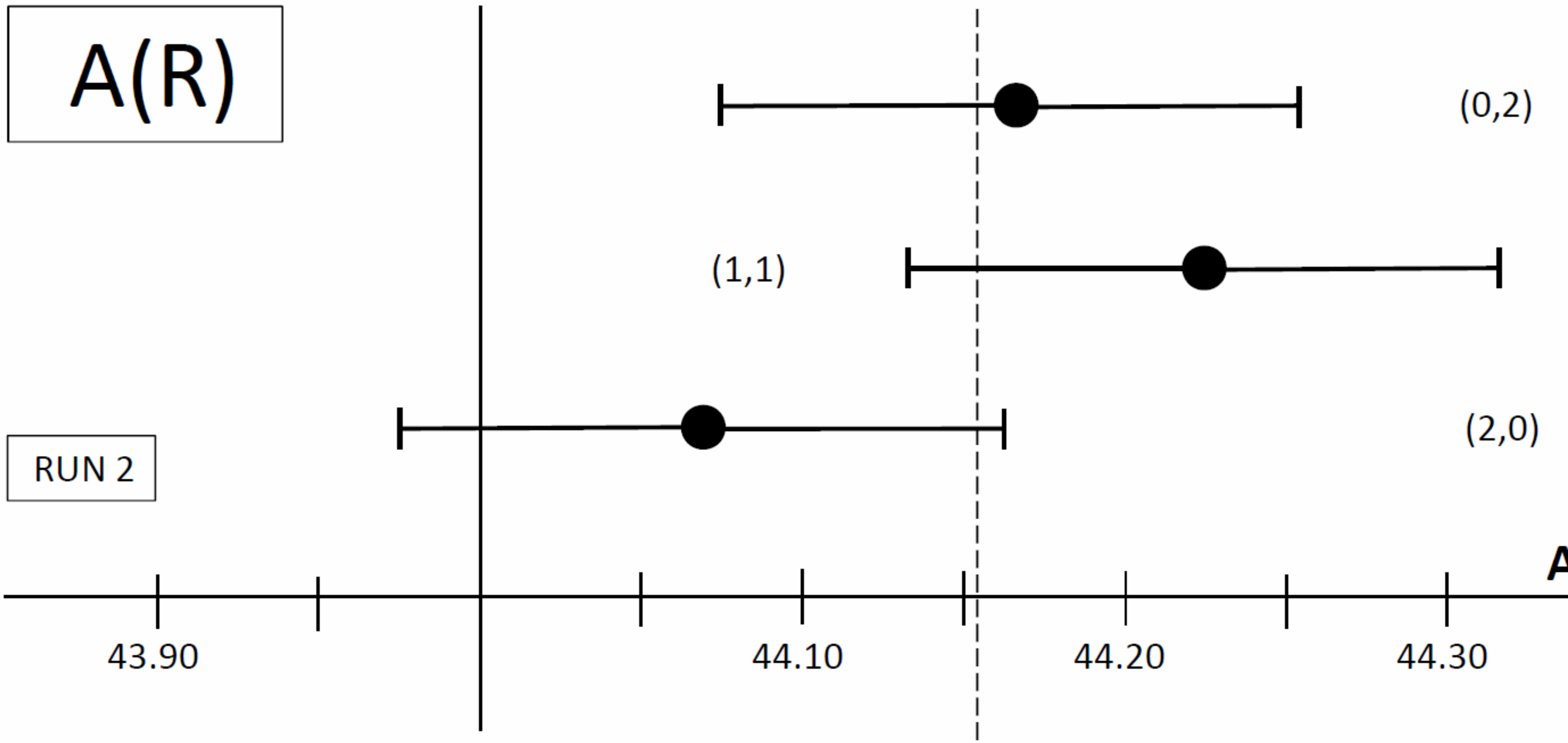
$$A(t) = \frac{A_0 + \alpha t}{1 + \beta t}.$$

What we find for these parameters are:

	GEANT4 Simulation	Run 2 Fit
a (Hz/(μA·μm)	198(1)	145(7)
b (Hz/(μA·μm^2)	62(15)	45(12)
α (μm^{-1})	-0.003(1)	-0.041(46)
β (μm^{-1})	0.31(8)	0.43(13)

Extrapolation Summary



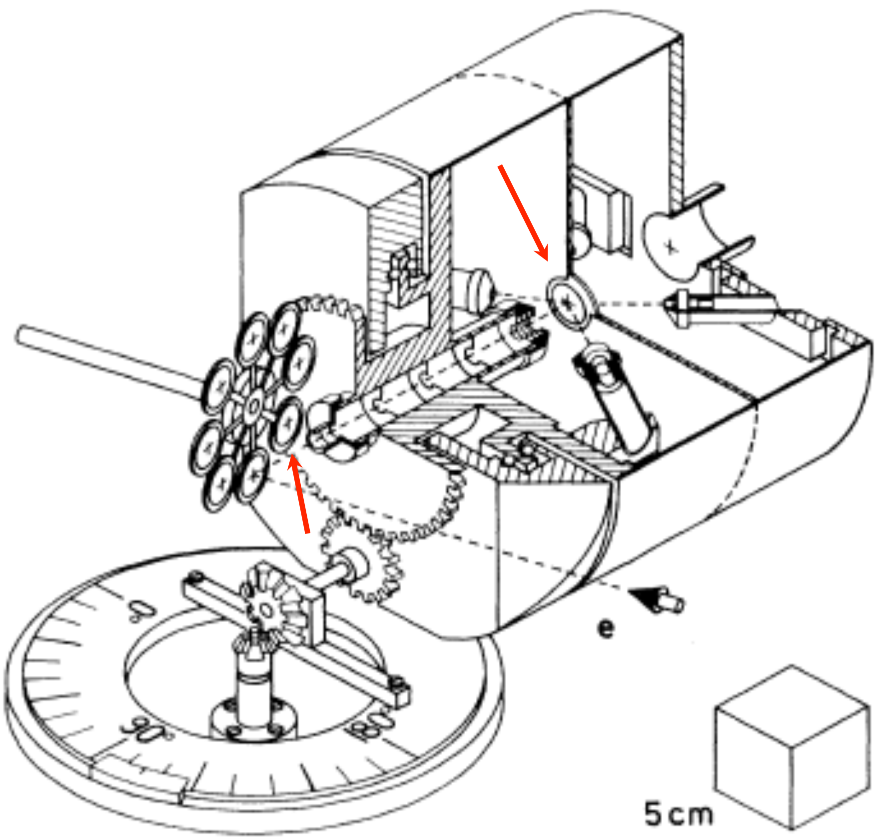


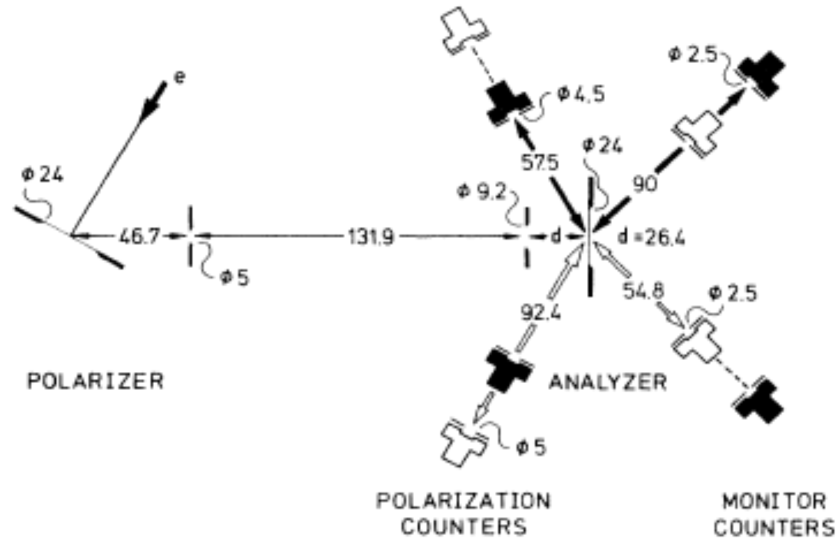
Run 1: A(t=0) = 44.089(121)% [0.27% relative]

Run 2: A(t=0) = 44.131(172)% ; A(R = 0) = 44.154(181)%

Final Run 2: A(t,R = 0) = 44.142(125)% [0.28% relative]

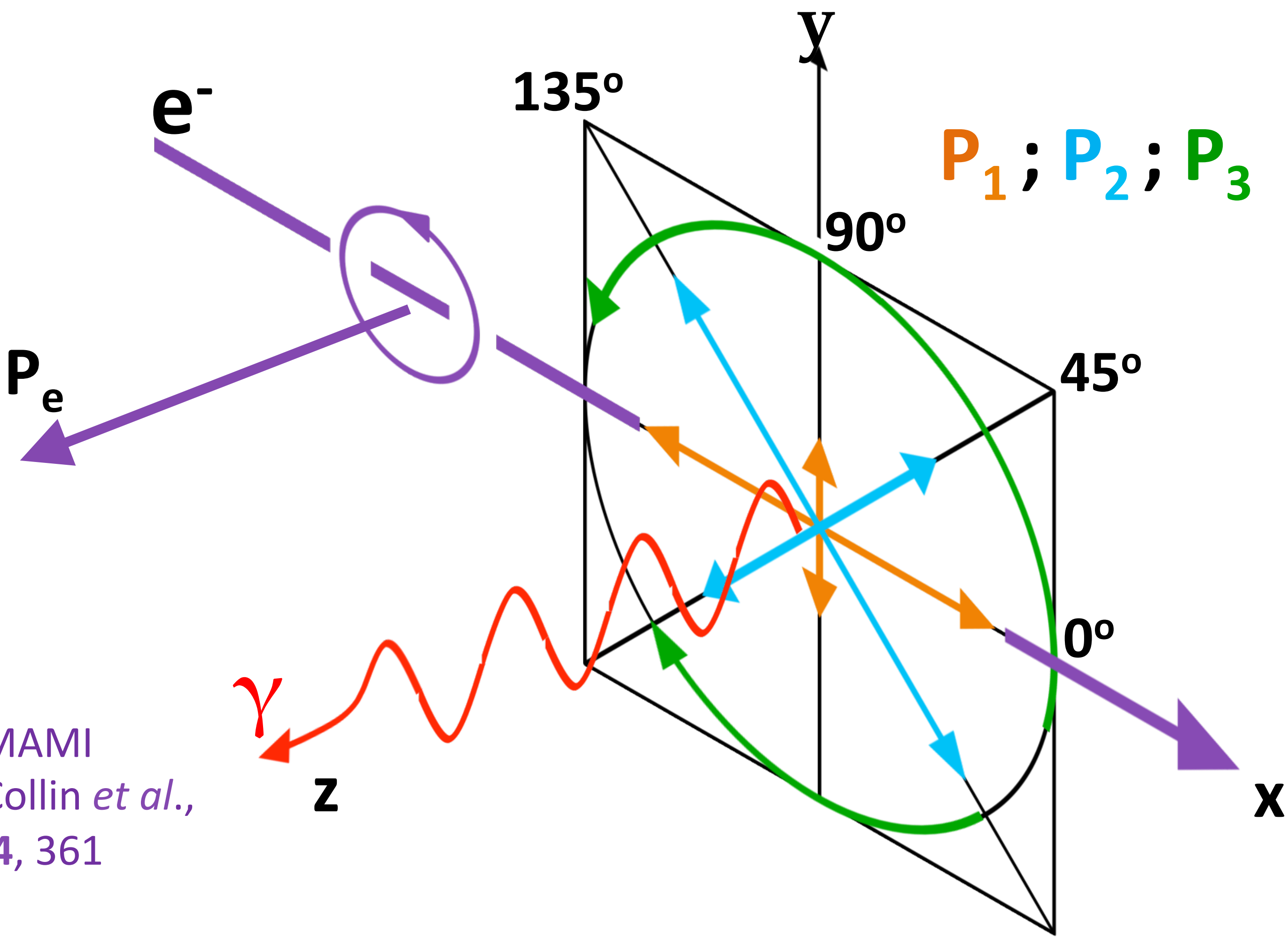
Double Scattering Calibrations





A. Gellrich u J.Keβler, Phys. Rev. A **43**, 204 (1991)

Acurate Electron Spin Optical Polarimetry (AESOP)



See also MAMI POLO: B.Collin *et al.*, NIM A **534**, 361 (2004)

$$e^-(20eV) + Ar\left(3p^6\left(^1S_0\right)\right) \rightarrow Ar\left(3p^5 4p\left(^3D_3\right)\right) \rightarrow Ar\left(3p^5 4s\left(^3P_2\right)\right) + \gamma(811nm)$$

Calibration

- Ongoing efforts at MAMI with double scattering; earlier optical efforts (NIM A **534**, 361 (2004)) discontinued
- Development of AESOP funded at UNL
- Goal: A 0.4% calibration with the 0.3% precision - now demonstrated - would give give an *accuracy* of 0.5%
- This would allow direct checks of the theoretical Sherman function calculations

¿e?

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