High-Accuracy 5-MeV Mott Polarimetry at the CEBAF Injector

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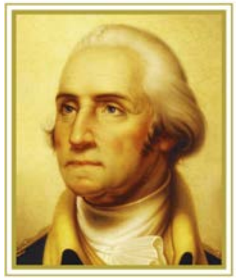
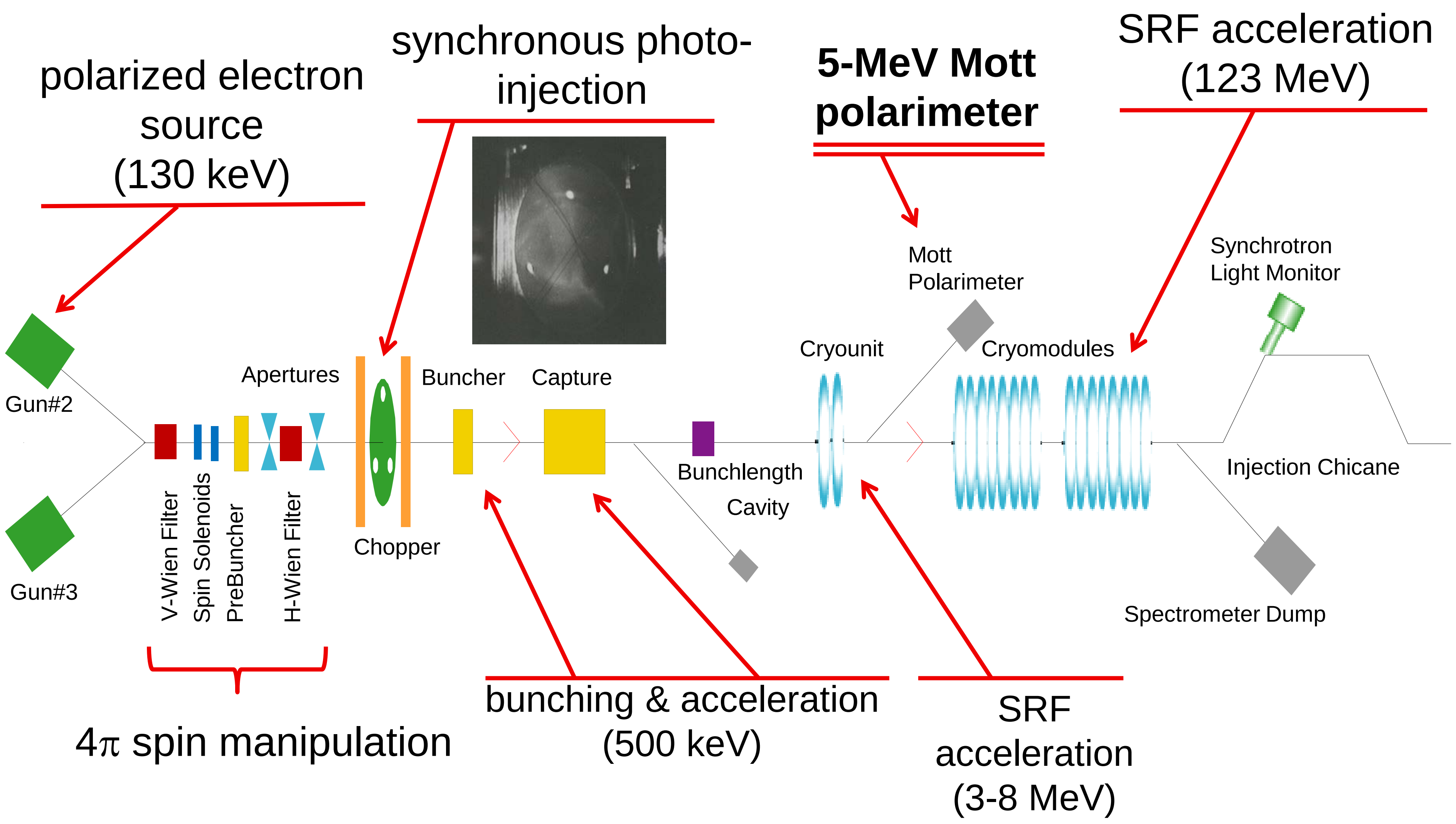
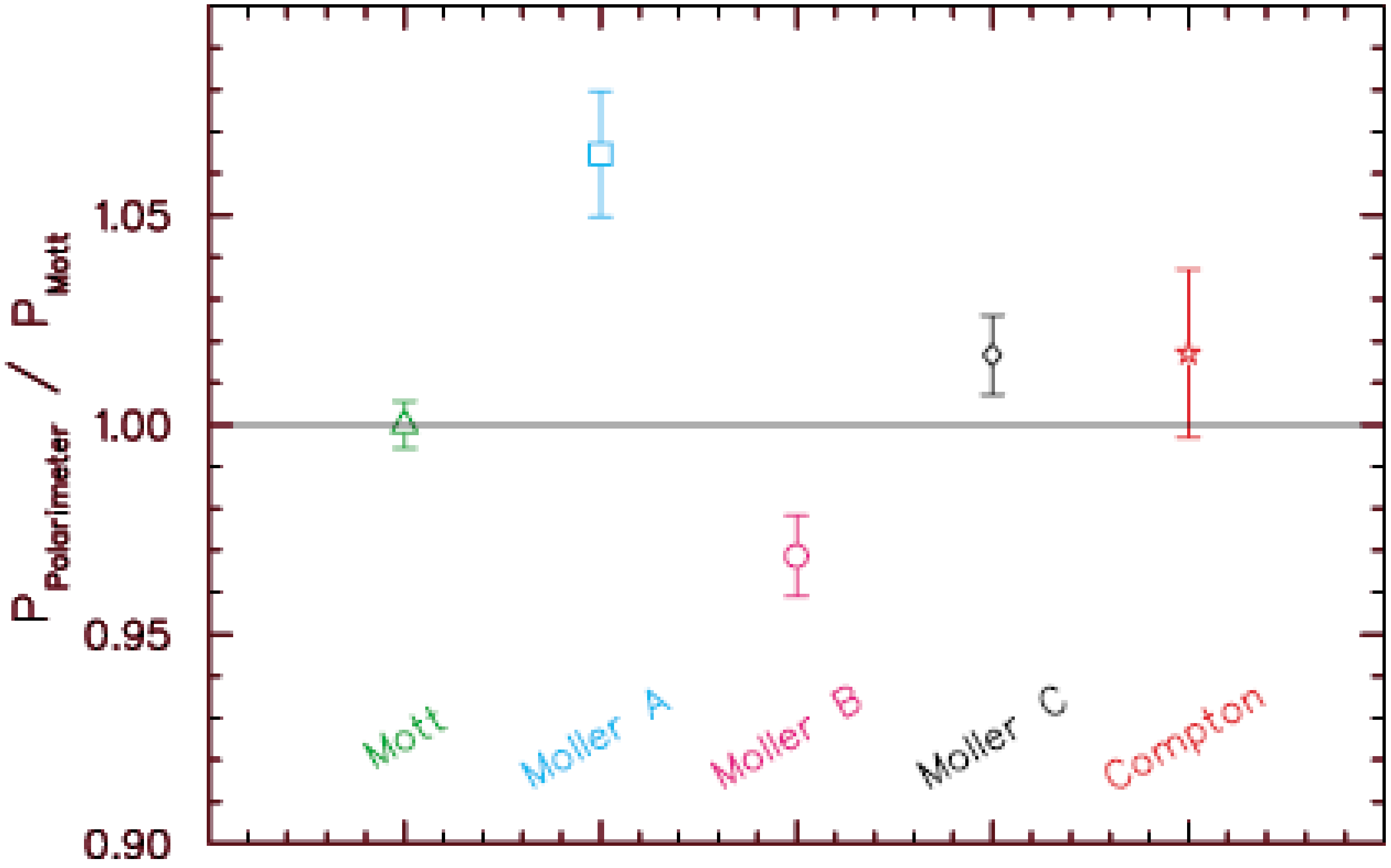
Jefferson Lab



CEBAF Polarized Electron Injector



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: 3%
- Mϕller B: 3%
- Mϕller C: 1%
- Compton: 3%

High-Energy Polarimetry in the Jlab Experimental Halls (2020)

Hall A

Compton: ~ 1%

Mϕller: ~1.8% → 0.4%?

Hall B

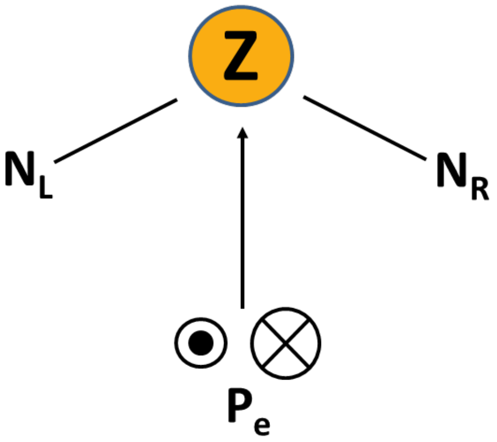
Mϕller: ~2.5%

Hall C

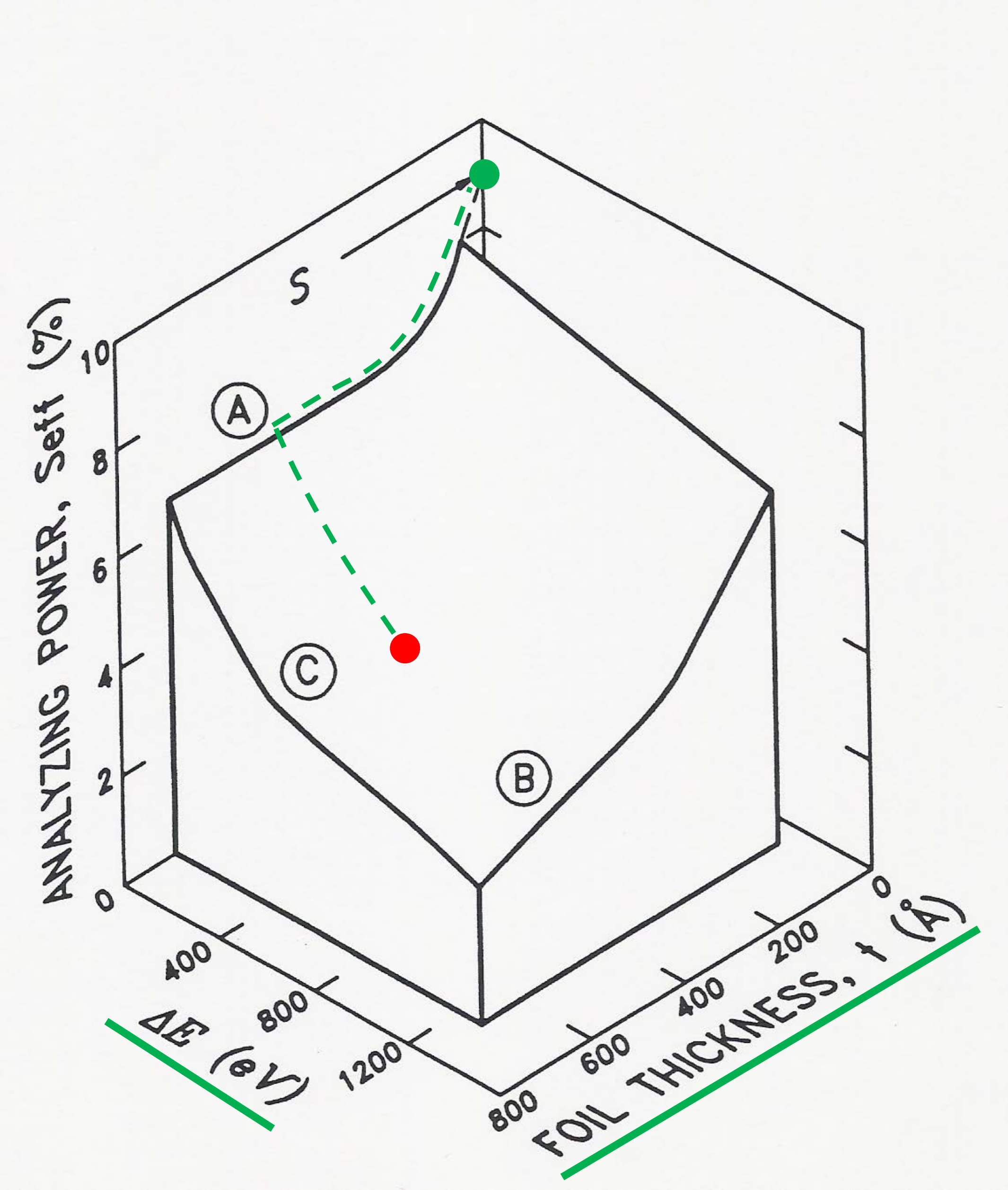
Compton:~0.6

Mϕller: ~0.8%

The Ascent to A $_{TRUE}$

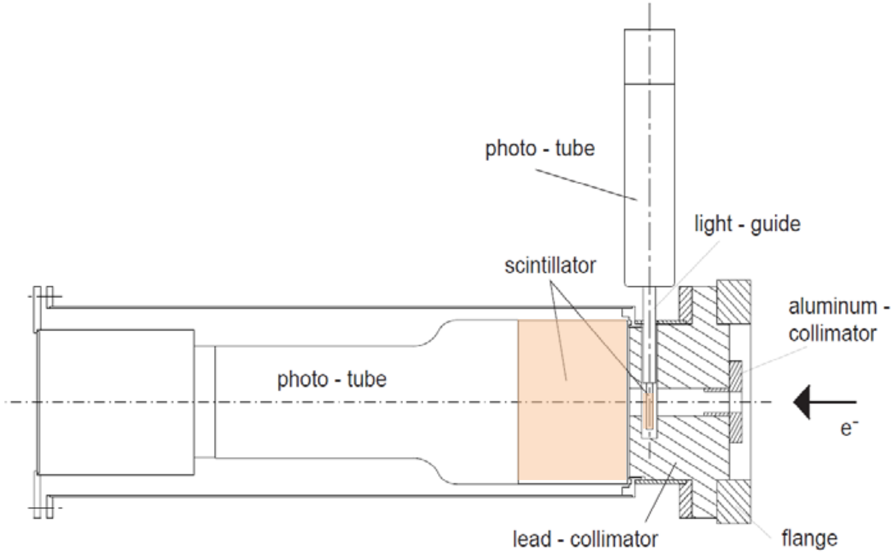


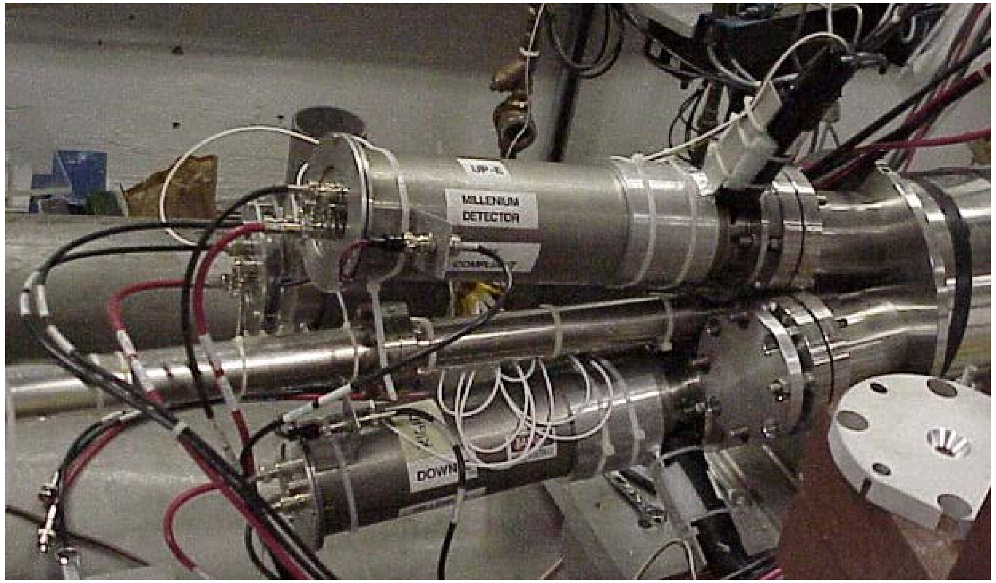
$$A = \frac{N_R - N_L}{N_R + N_L} = S_{eff} P_e$$

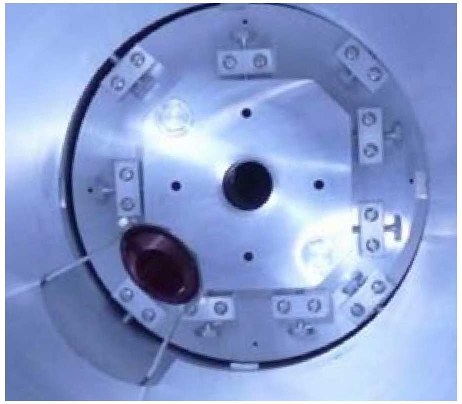


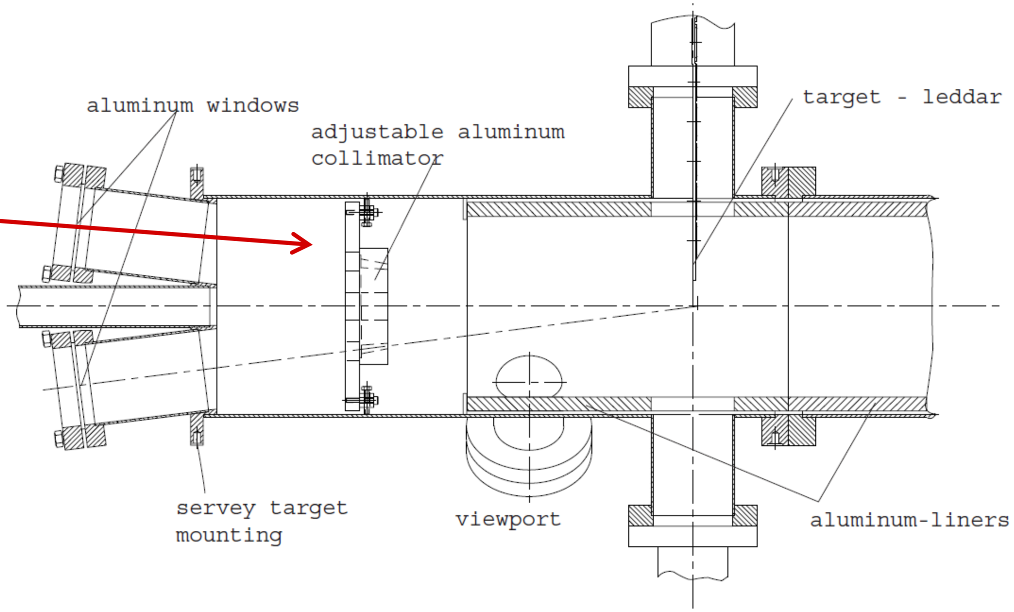
- S = the "Sherman Function"
- Calculate for elastic scattering from single atoms
- The Sherman function is calculated assuming elastic scattering from single atoms.
- As the incident energy increases, the surface of the "effective Sherman function", S_{eff}, flattens out

The CEBAF 5-MeV Mott Polarimeter







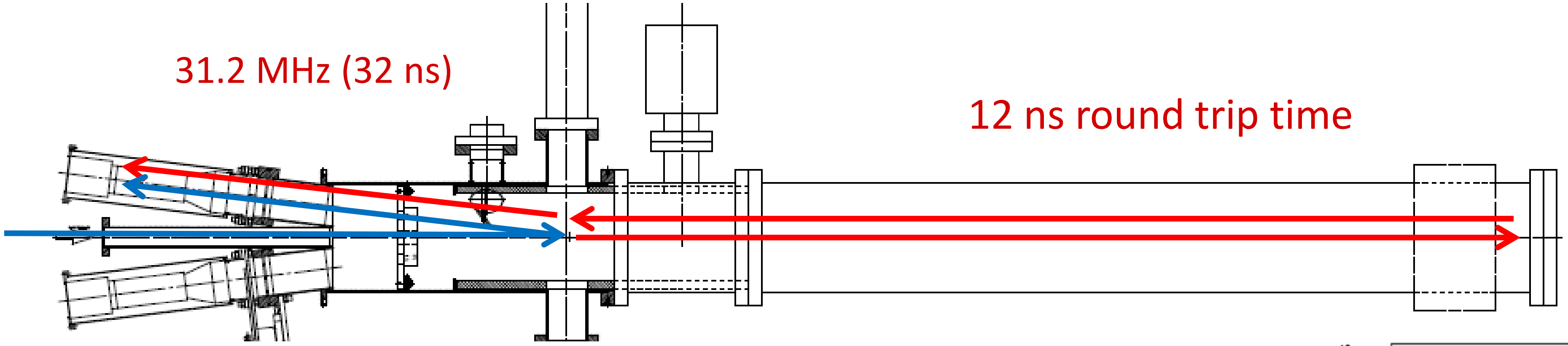


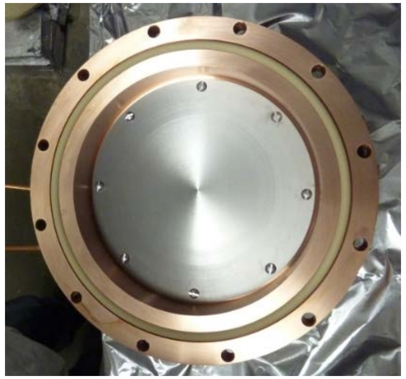
$\theta = 172.6°$

$\Omega = 0.18$ msr

Background & Energy Resolution Issues

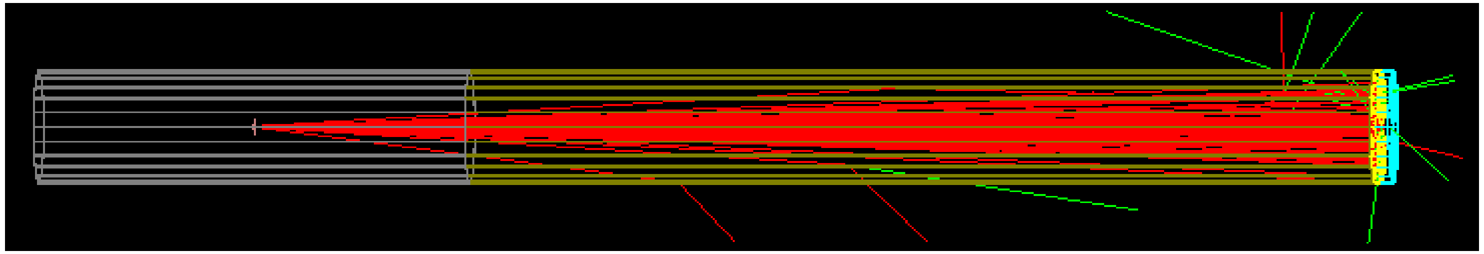
Photon vetoing by thin and thick scintillators, TOF discrimination, GEANT simulation, Be backstops….

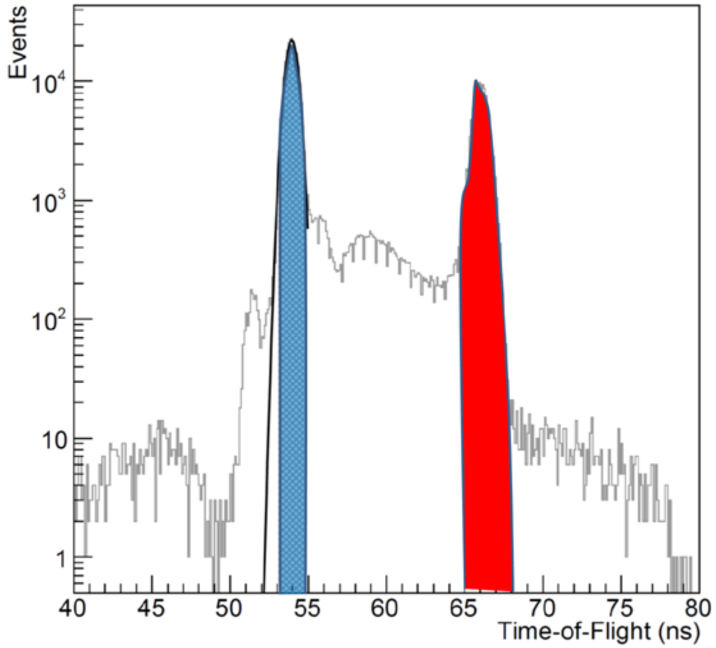




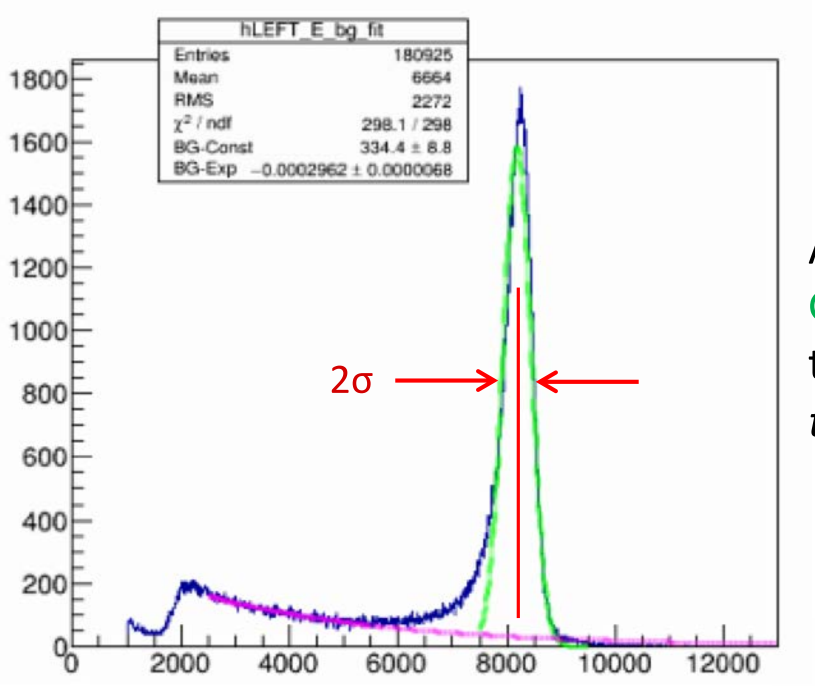
Gold
1.0 um

GEANT4
simulations



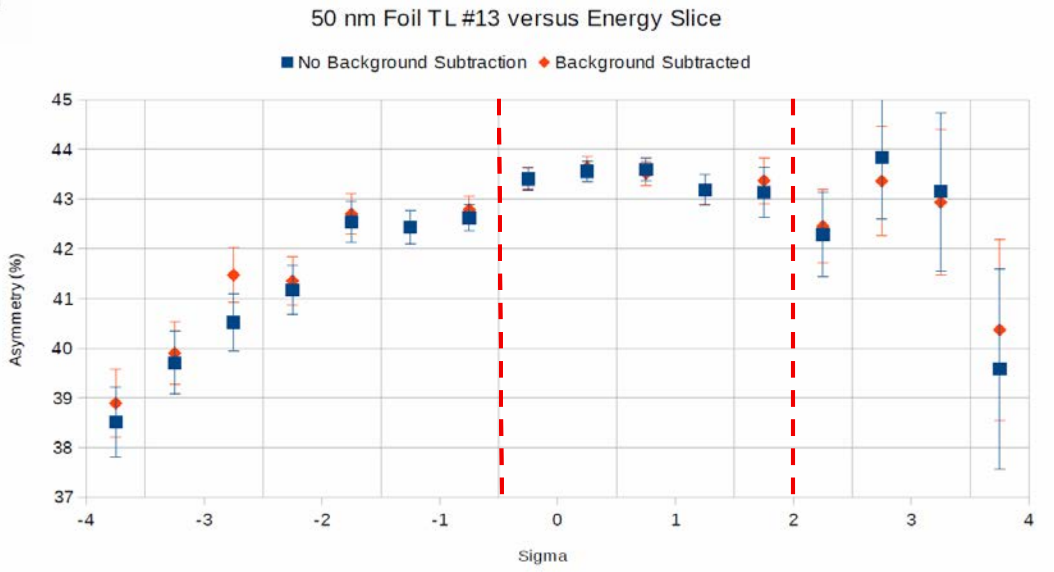


Pulse-Height Analysis & Energy Resolution



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

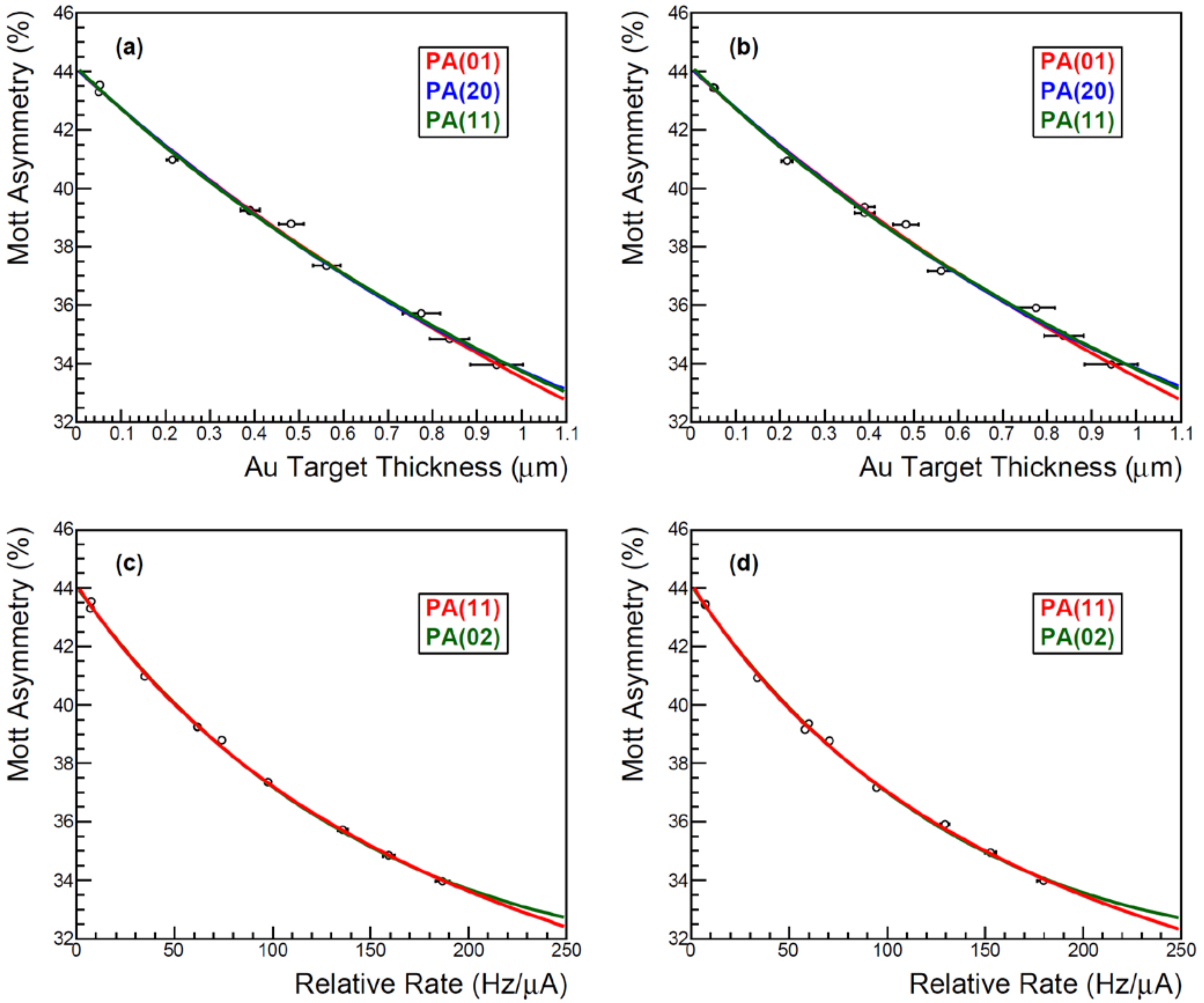


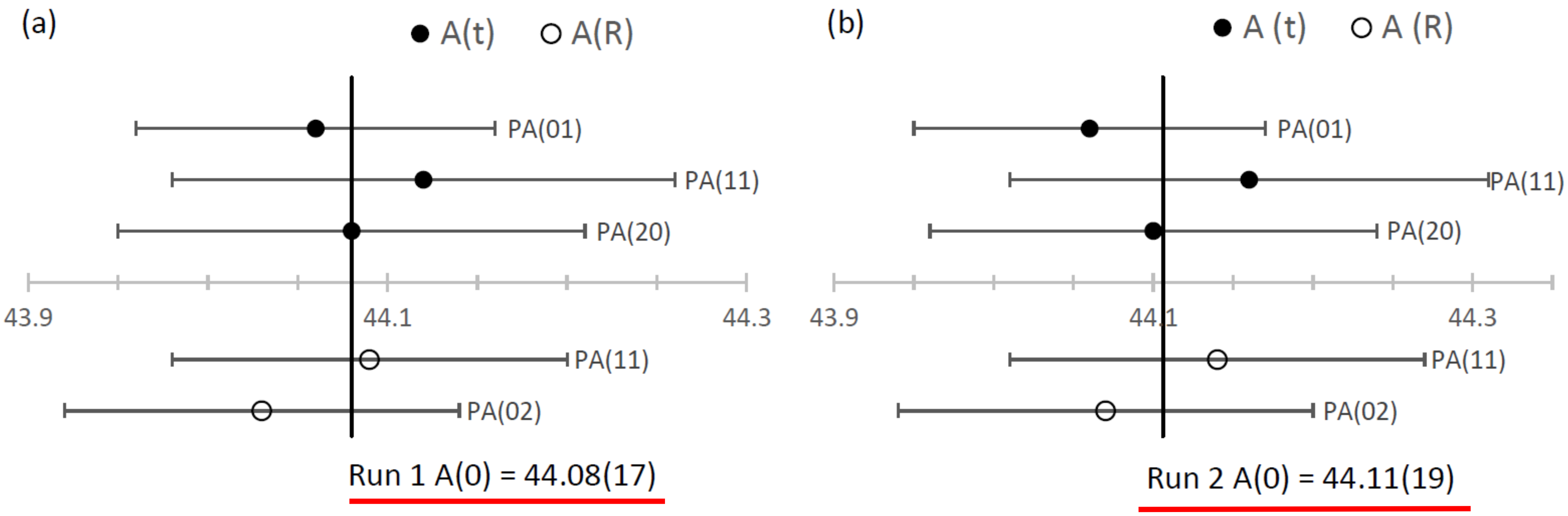
Extrapolation to Single-Atom Scattering

- In parallel with GEANT modeling, we explored multiple fitting functions (see Fletcher et al. PRA **34**, 911 (1986)
- Try both A(t) and A(R)
- Use the method of Pade approximates (suggested by D. Higinbotham):

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





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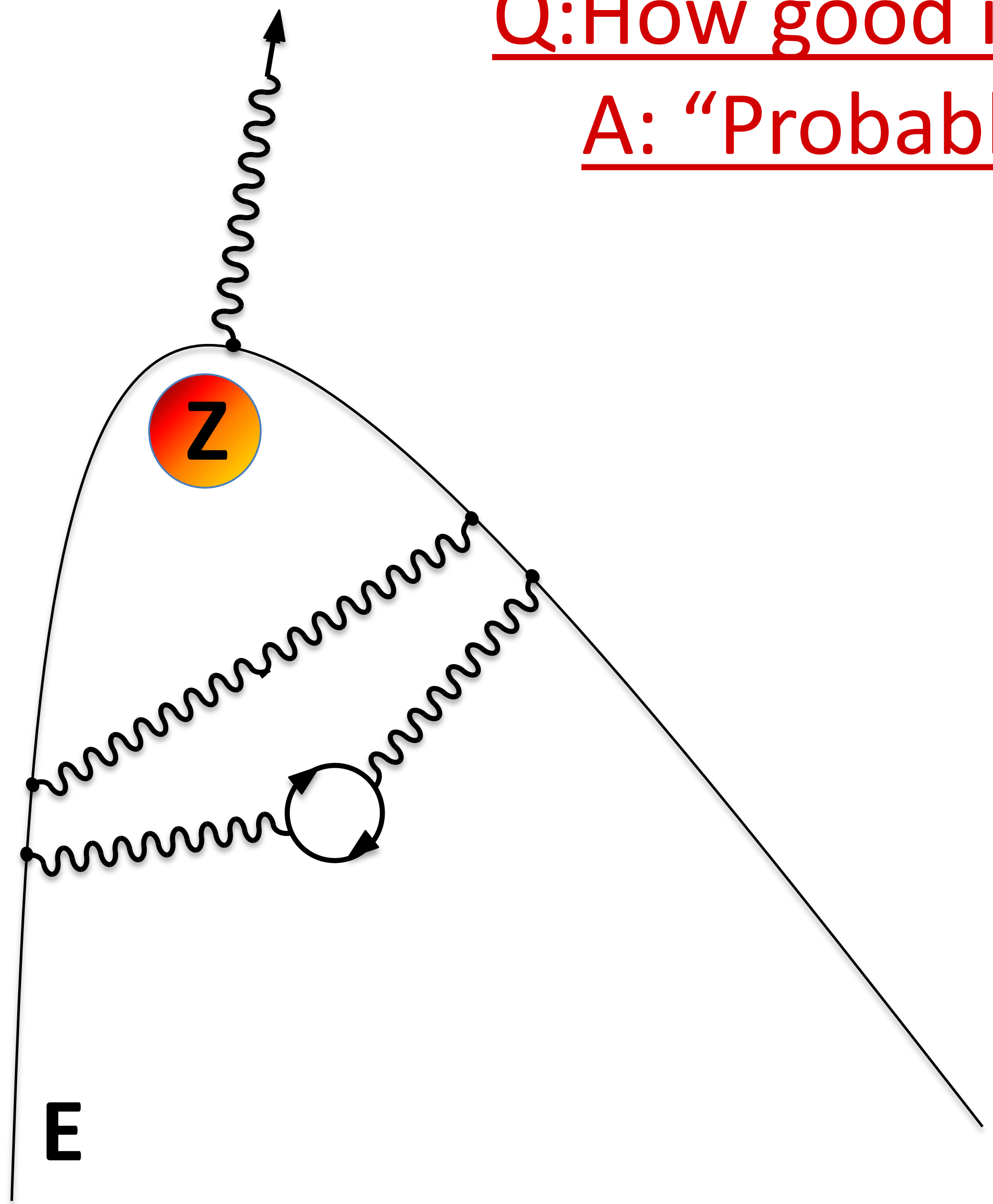
Error Budget and Result

TABLE III. Uncertainty budget for the 5 MeV Mott polarimeter.

Contribution to the total uncertainty	Value
Theoretical Sherman function	0.50%
Target thickness extrapolation	0.25%
Systematic uncertainties	0.24%
Energy cut (0.10%)	
Laser polarization (0.10%)	
Scattering angle and beam energy (0.20%)	
Total	0.61%

Q:How good is the theory for S?

A: “Probably about 0.5%...”

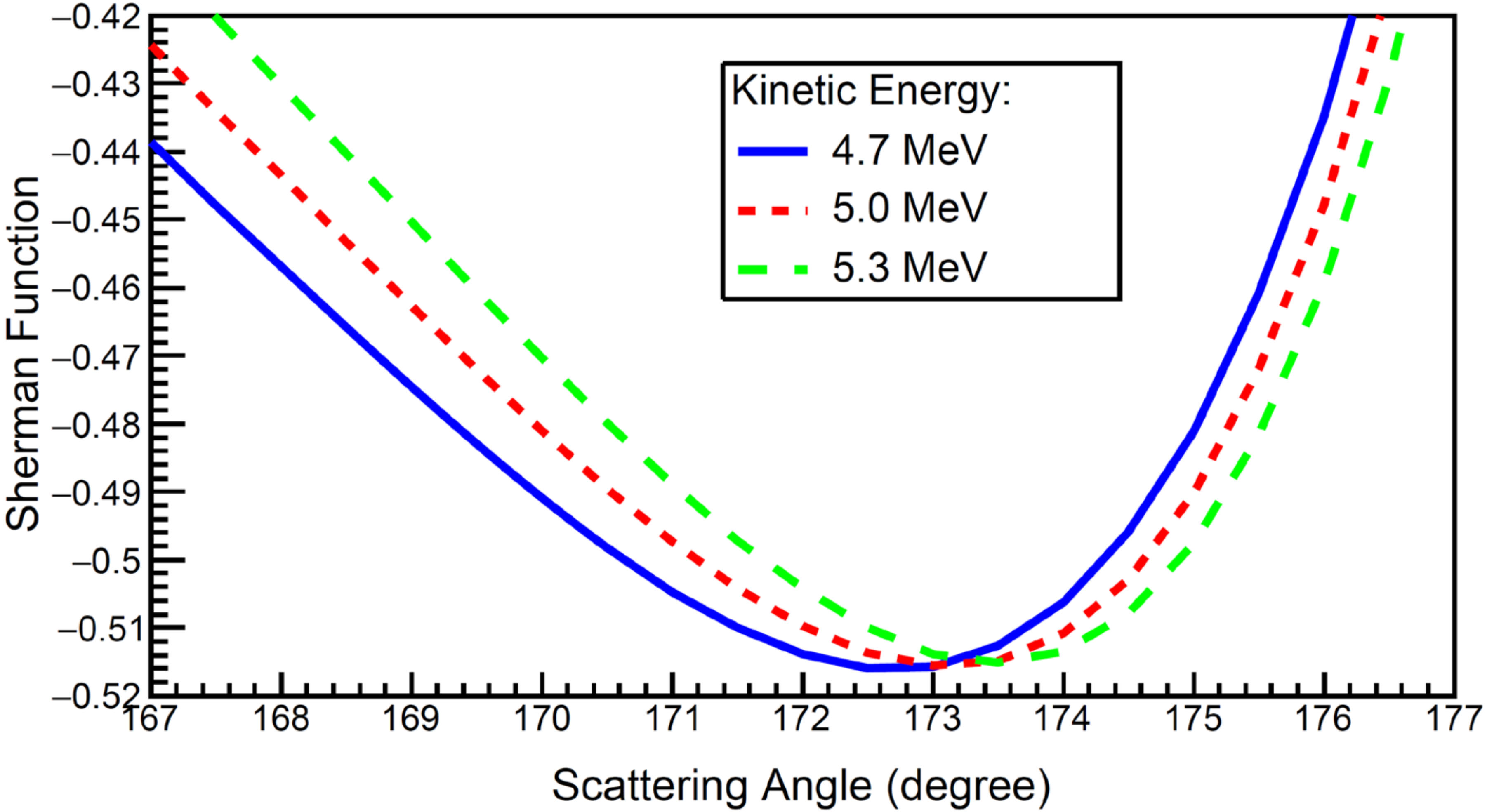


- QED effects (vacuum polarization, self-energy) and bremsstrahlung, which are just starting to become important at 5 MeV, lead to some uncertainty in S, although the *cognoscenti* are “pretty sure” that the effects of vacuum polarization offset those of self energy. (There is some circumstantial experimental 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.

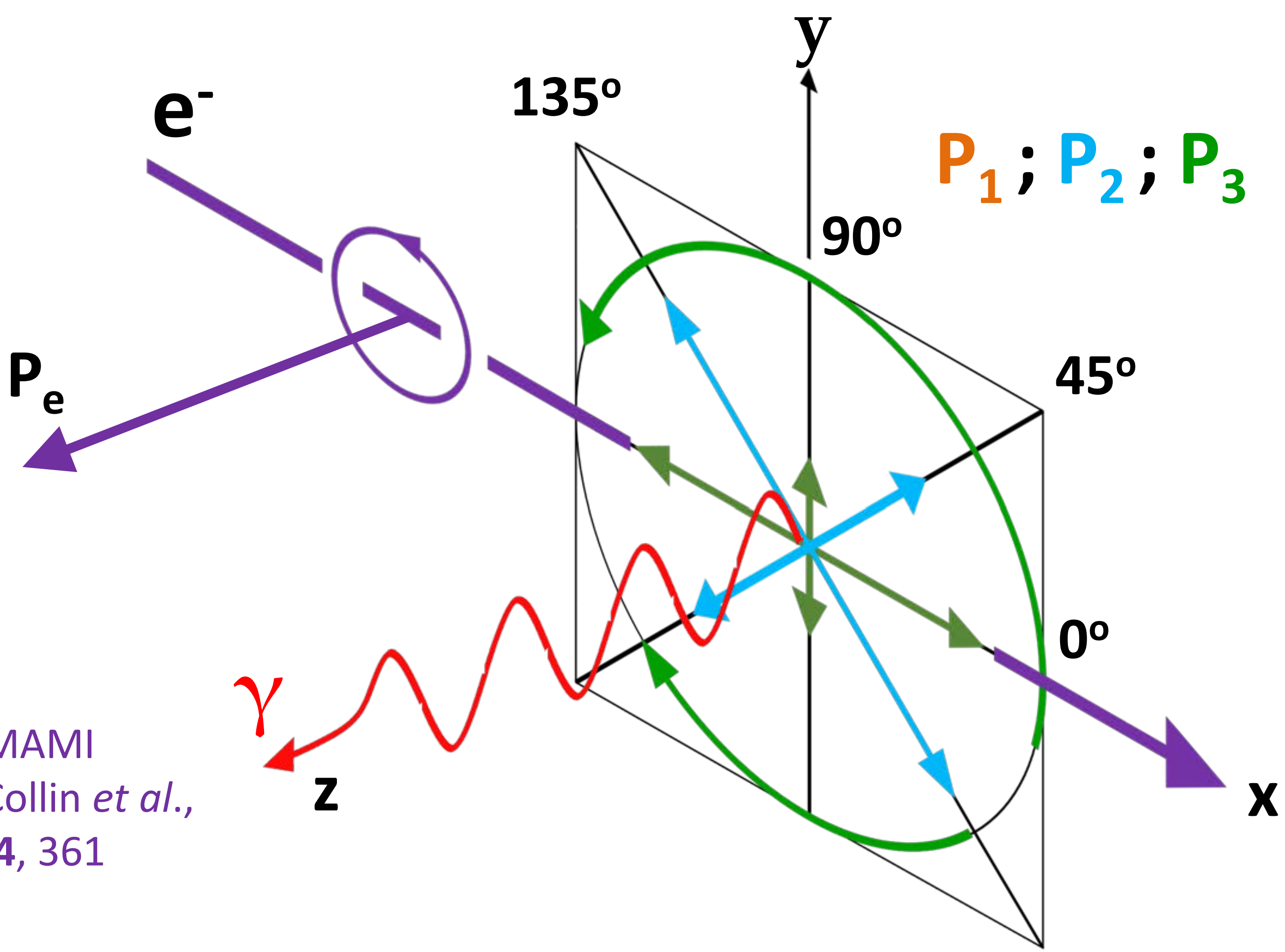
- New regime for tests of QED

Au Sherman Function



- Vary E
- Vary Z
- Monitor A(0)

Acurate Electron Spin Optical Polarimetry (AESOP)



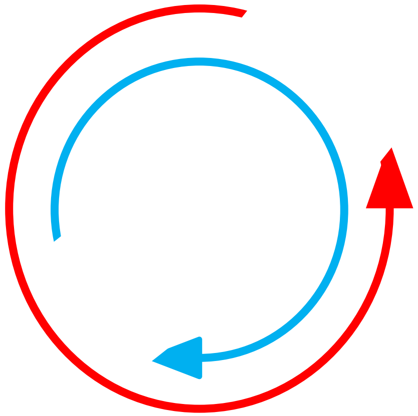
See also MAMI POLO: B.Collin *et al.*, NIM A **534**, 361 (2004)

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

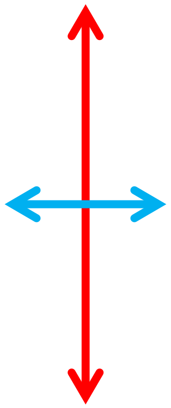
The General Electron Optical Polarimeter Equation

$$P_e = \frac{P_3}{[a + bP_1]}$$

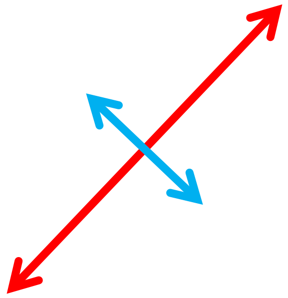
NB – a,b, exactly computable



P_3 → Electron polarization in the direction of the emission direction



P_1 → Analyzing Power



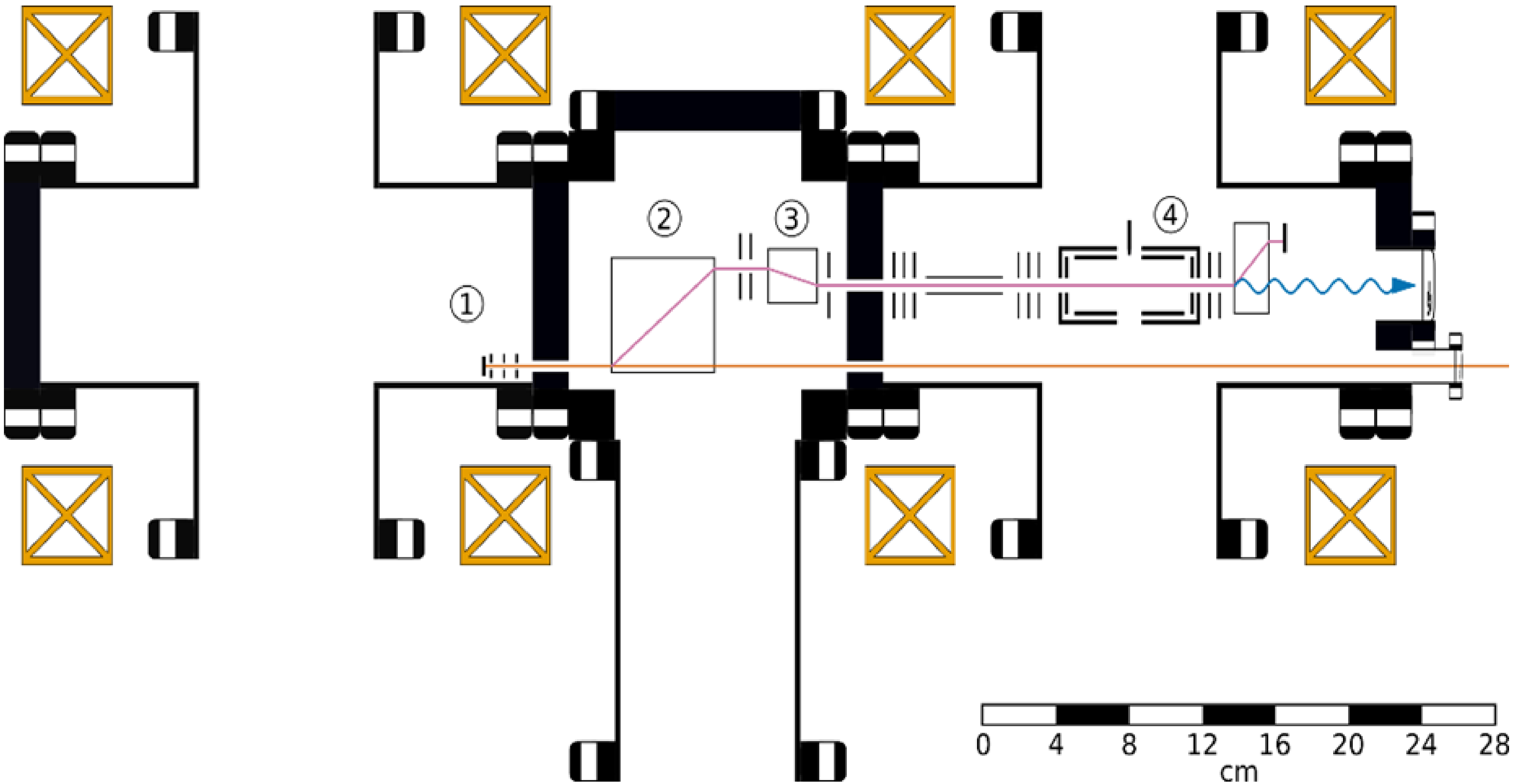
P_2 → Validity of the kinematic assumptions

Skeletons

- Low (< 20 eV) beams required
- Low efficiency compared with Mott scattering
- Rogue gas loads
- Cascades
- Energy dependence of efficiency $\oplus$ energy dependence of polarization within the beam width (use strained lattices)
- Hanle depolarization
- Pressure dependence of the Stokes parameters

Mott Calibration

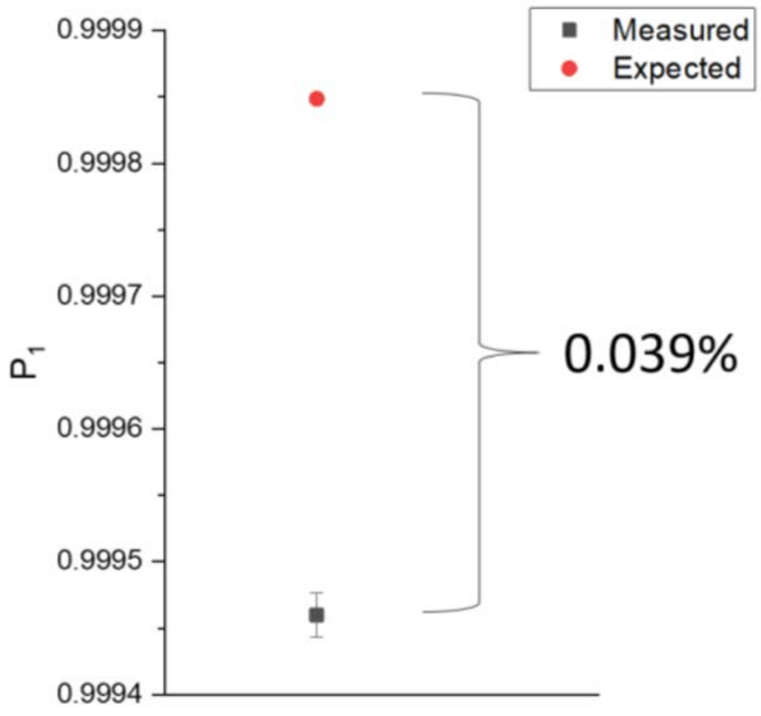
- Goal: A 0.4% calibration with the 0.3% precision - now demonstrated - would give give an *accuracy* of 0.5%
- This would allow direct checks of the theoretical Sherman function calculations

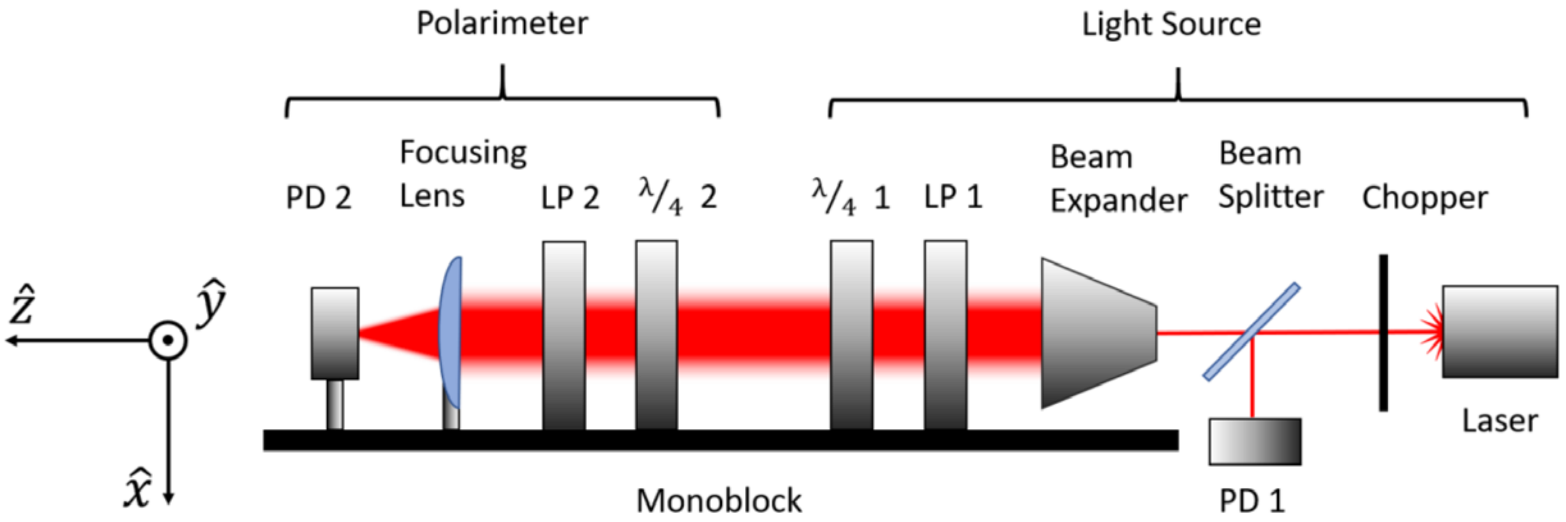


Scale drawing of the combined GaAs/trochoidal monochromator AESOP prototype showing: (1) GaAs photocathode (source of polarized electrons); (2) trochoidal deflector and (3) trochoidal monochromator; (4) target cell with optical 2-axis access.

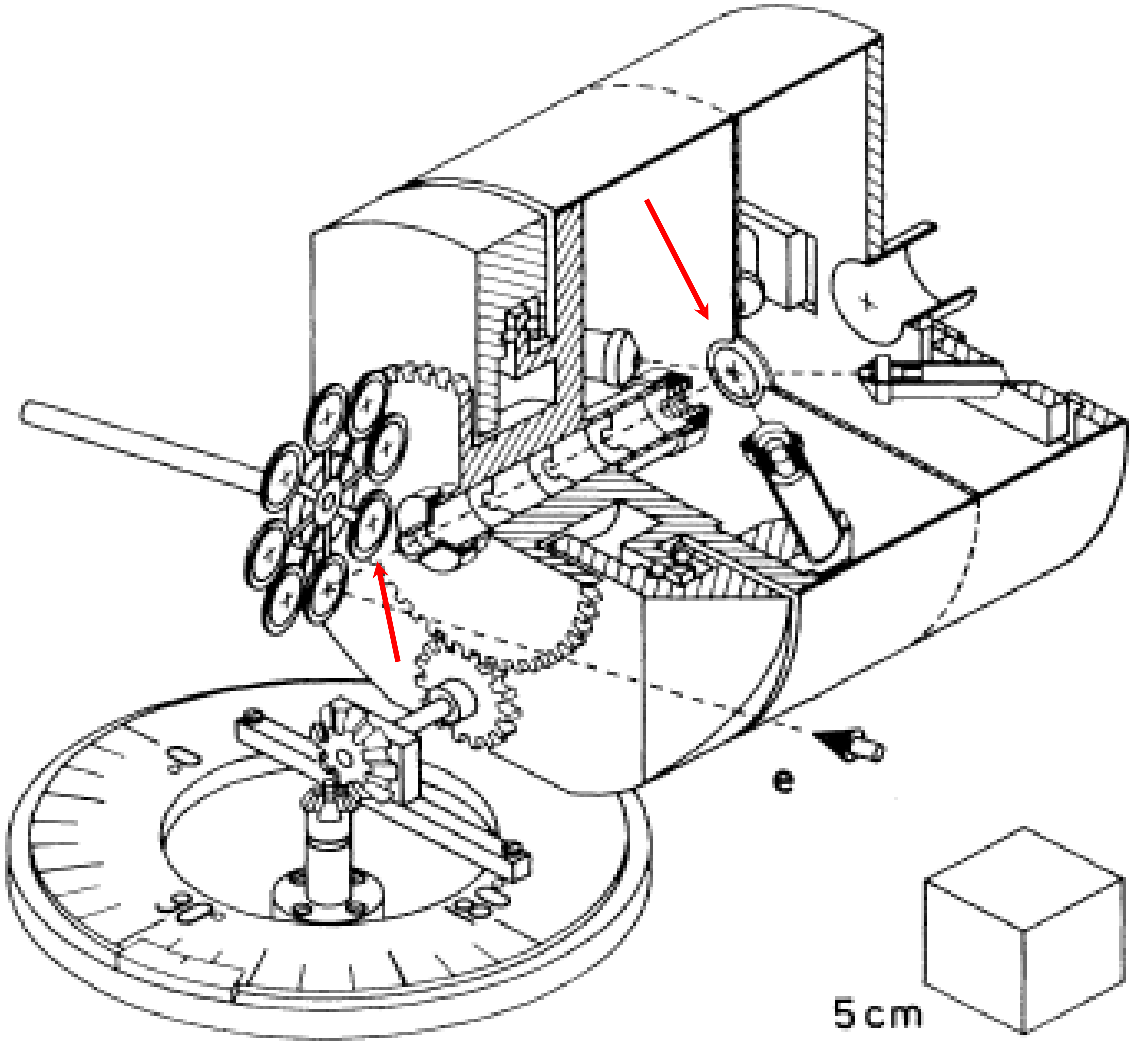
AESOP Optical Polarimeter Tests

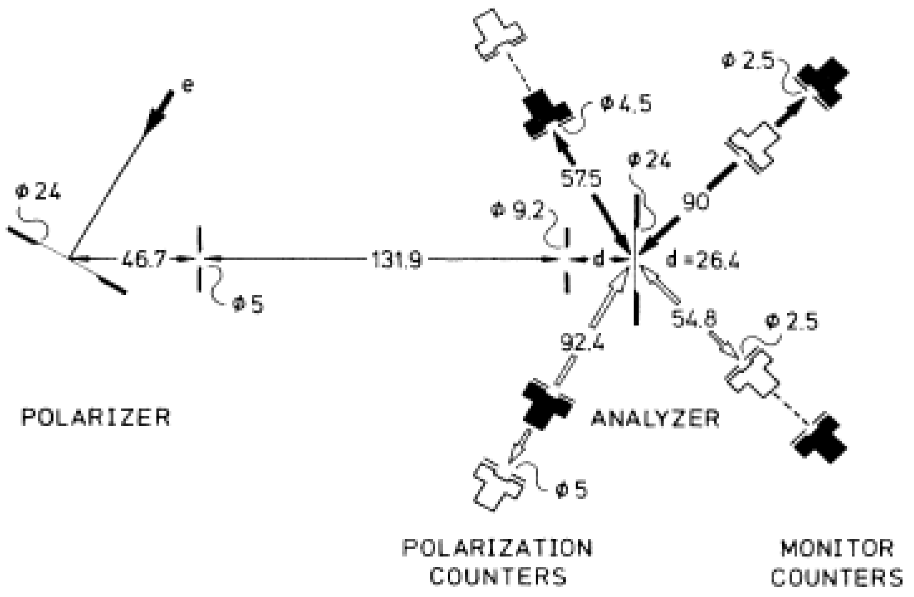
K.W. Trantham, K.D. Foreman, and T.J. Gay, "Demonstration of vacuum strain effects on a light collection lens used in optical polarimetry" Appl. Opt. **59**, 2715 (2020).





Double Scattering Calibrations – see the next talk!





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

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NSF

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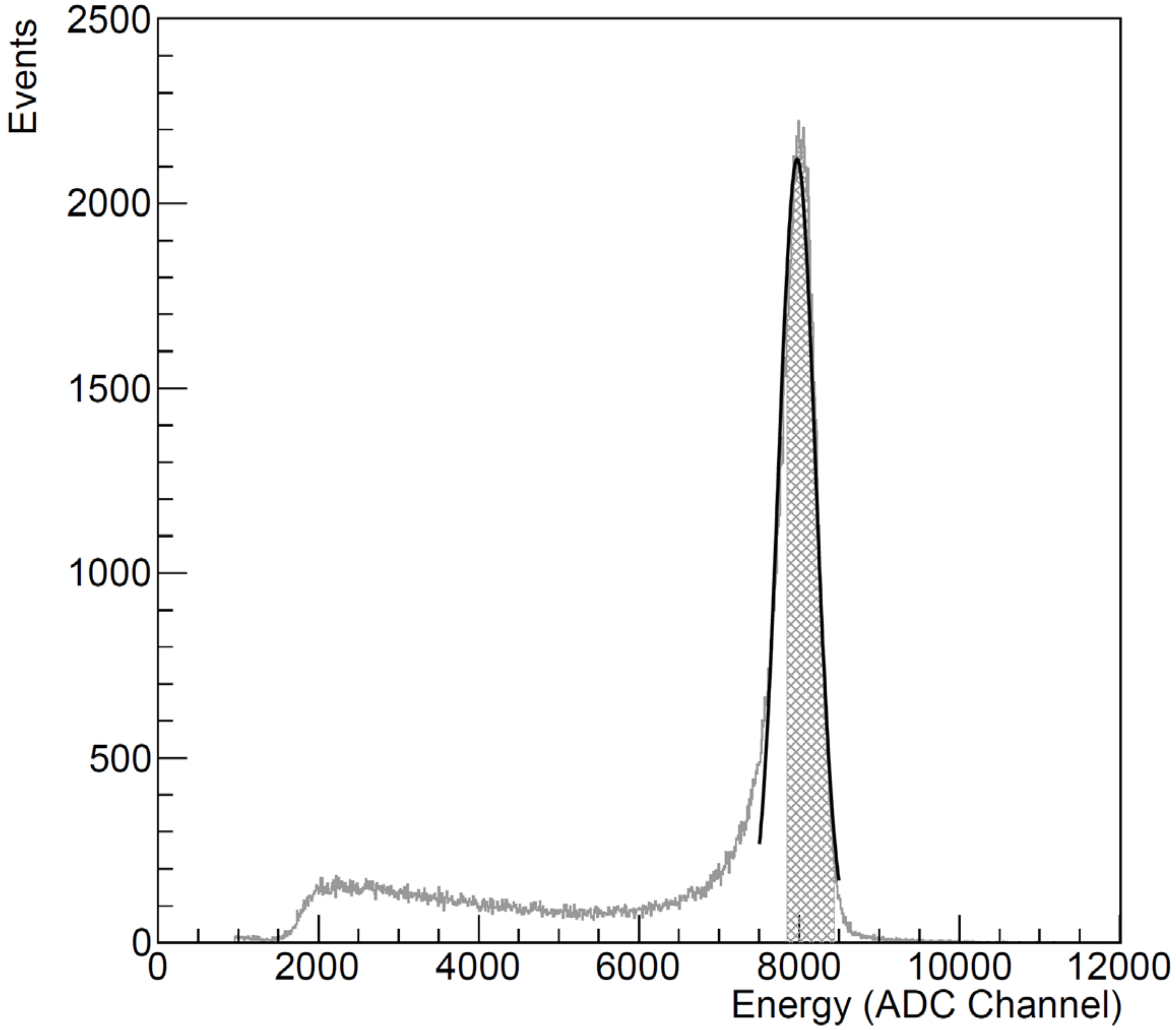
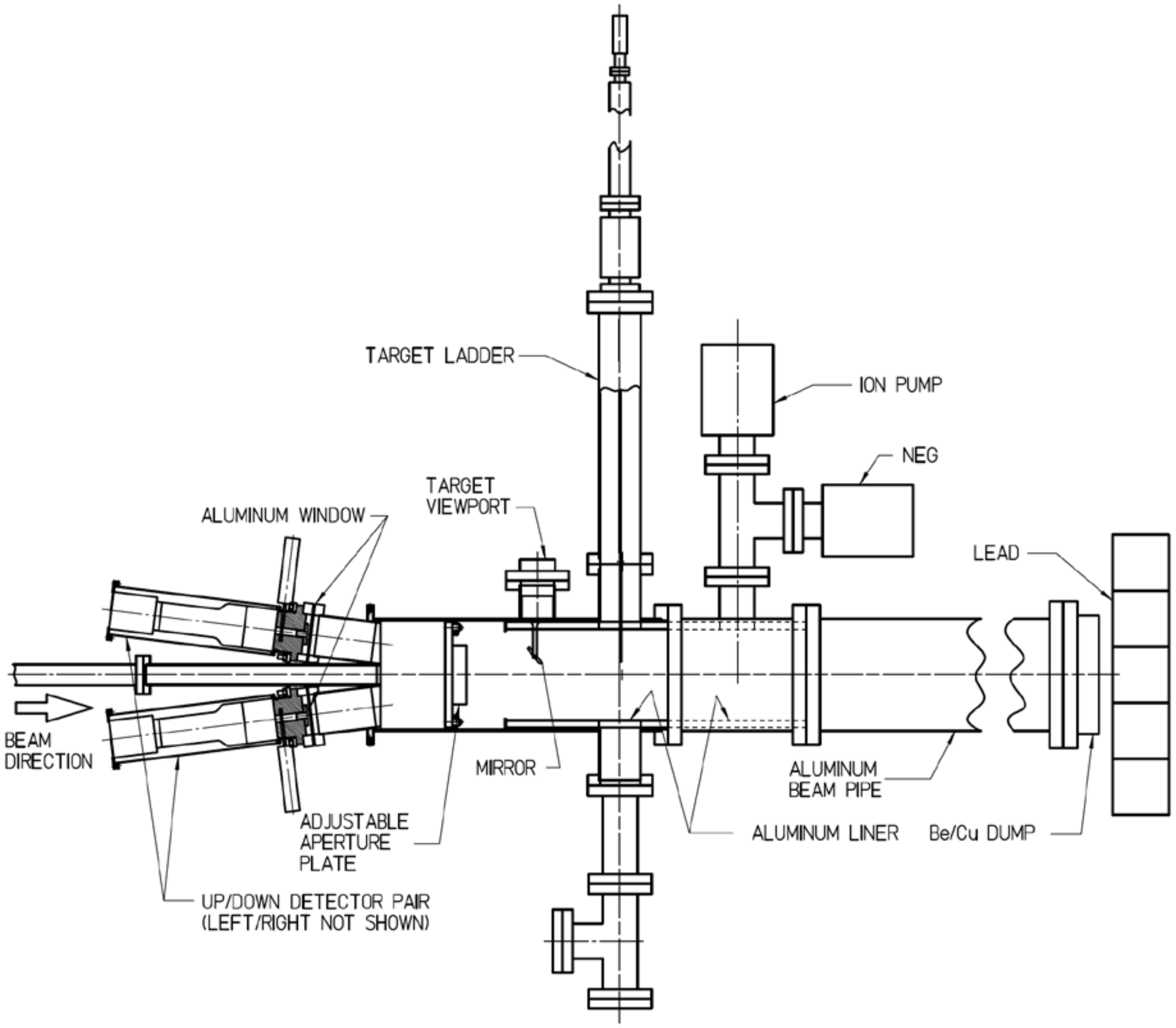
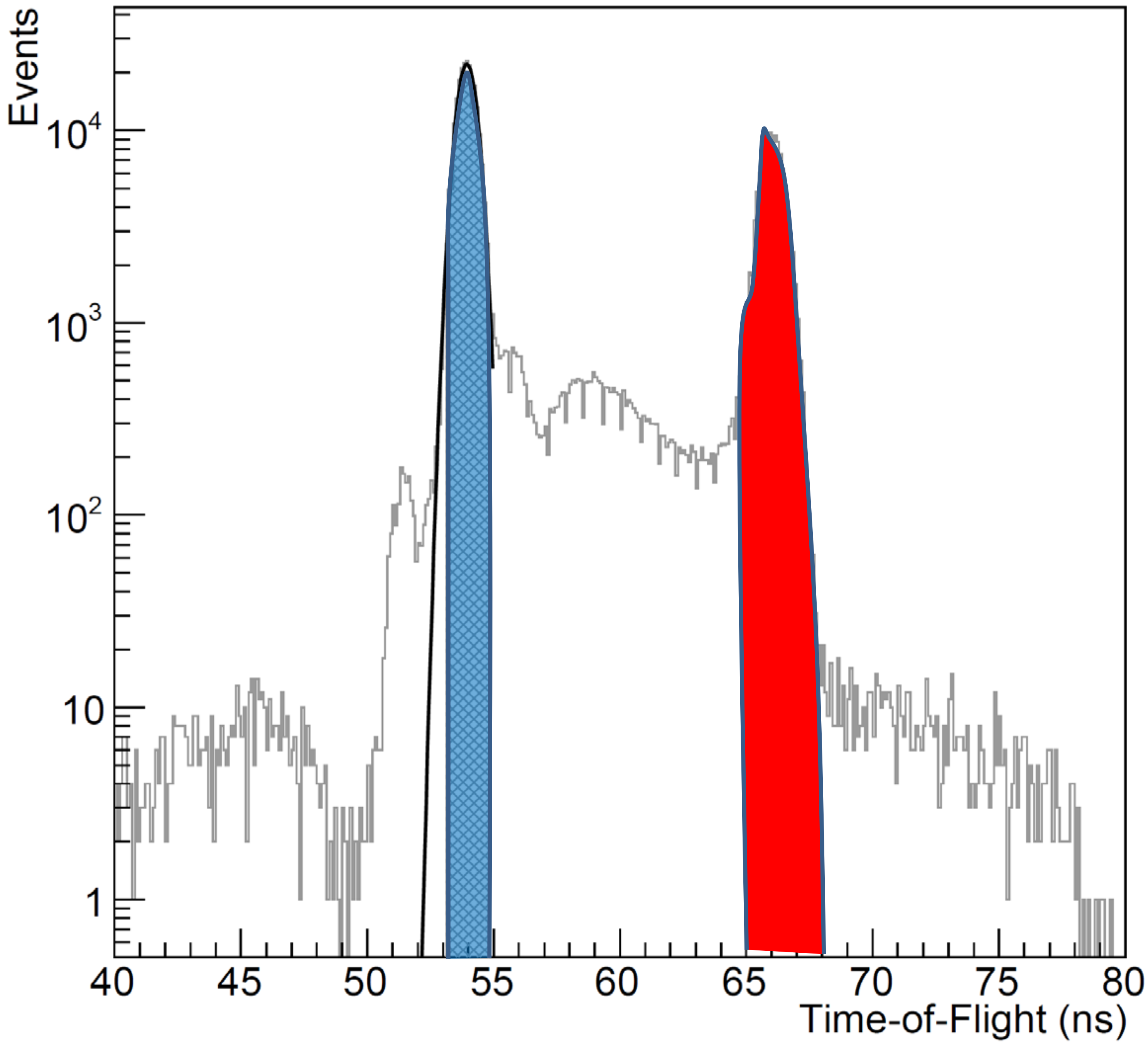
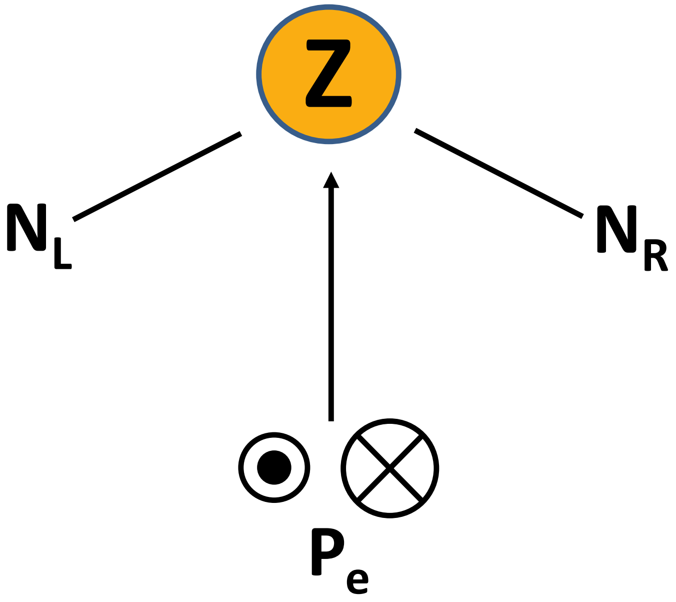


Events
2500
2000
1500
1000
500
0
0
2000
4000
6000
8000
10000
12000
Energy (ADC Channel)


TARGET LADDER
ION PUMP
NEG
TARGET VIEWPORT
ALUMINUM WINDOW
LEAD
BEAM DIRECTION
MIRROR
ALUMINUM BEAM PIPE
ADJUSTABLE APERTURE PLATE
ALUMINUM LINER
Be/Cu DUMP
UP/DOWN DETECTOR PAIR
(LEFT/RIGHT NOT SHOWN)



Events
10^4
10^3
10^2
10
1
40
45
50
55
60
65
70
75
80
Time-of-Flight (ns)


Z
N_L
N_R
P_e