Overview of Jefferson Lab Electron Polarimeters and Results of an Intercomparison

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Jefferson Lab *Spin Dance 2000* Collaboration

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Overview

Present and proposed experiments at the world's polarized electron accelerators invest considerable resources to design, construct, and operate polarimeters to measure the beam polarization.

While experiments using polarized targets or recoil polarimetry do not generally require high precision electron polarimeters, this is not the case with parity violation experiments.

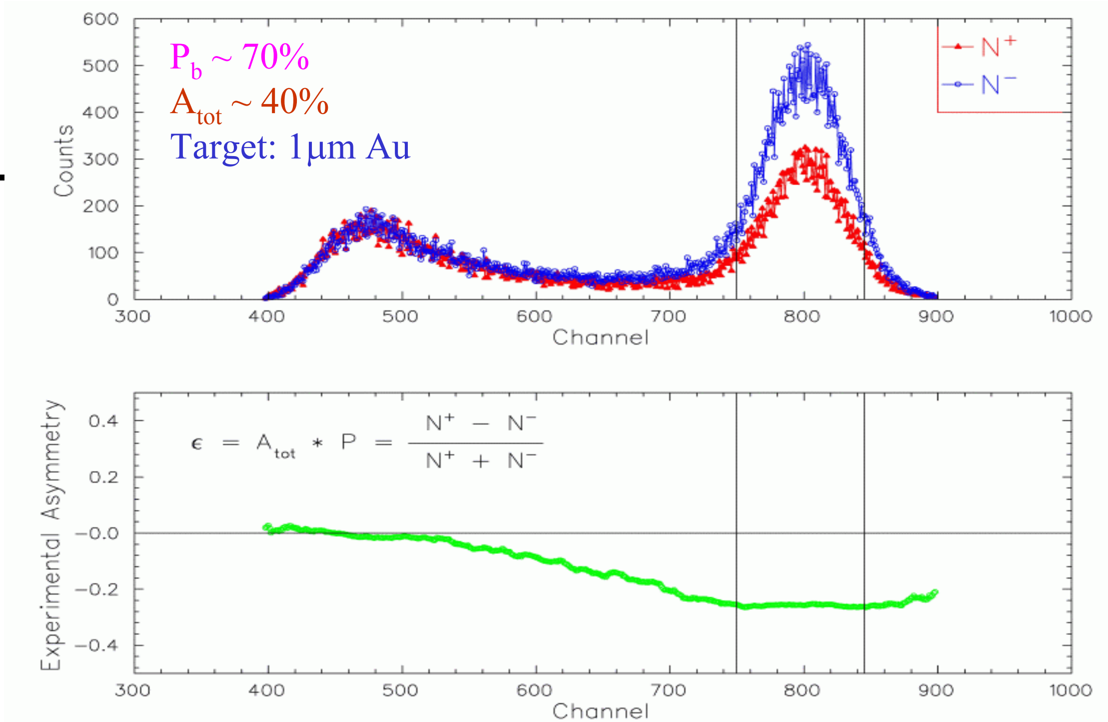
Some of the planned parity experiments desire absolute knowledge of the beam polarization at the 1% level.

- Overview of Jefferson Lab polarimeters
- *Spin Dance 2000* polarimeter comparison

Polarimeter Analyzing Power

$$\varepsilon = A_{tot} \cdot P_b = \frac{N^+ - N^-}{N^+ + N^-}$$

$$N = \left[\left(\frac{\delta P_b}{P_b} \right)^2 \cdot (P_b \cdot P_t \cdot A)^2 \right]^{-1}$$



What are desirable (necessary) features of electron polarimeters?

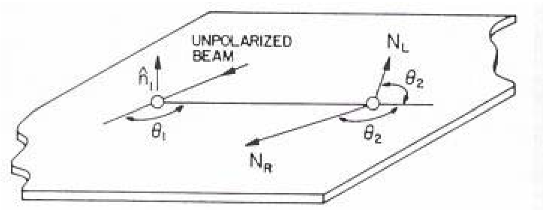
- Large total analyzing power
- Designs with reduced sensitivity to major systematics
- High luminosity to rapidly achieve small statistical uncertainty
- Non-invasive continuous measurement does not disrupt experiment

Why is A_{tot} difficult to know?

Precise knowledge of the analyzing power is limited.

A_{tot} is not a directly measured quantity:

- measurement requires difficult double-scattering experiments



- the analyzing power is often determined by theory and simulation

Factors that affect knowledge of the total analyzing power

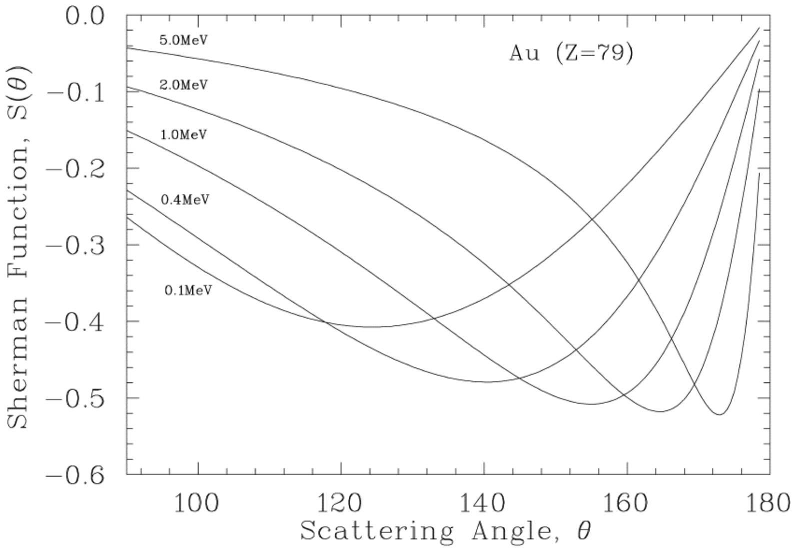
- inferred target polarization
- detector acceptance
- multiple scattering

Mott Scattering

Spin-orbit coupling of the beam electron and the target nucleus.

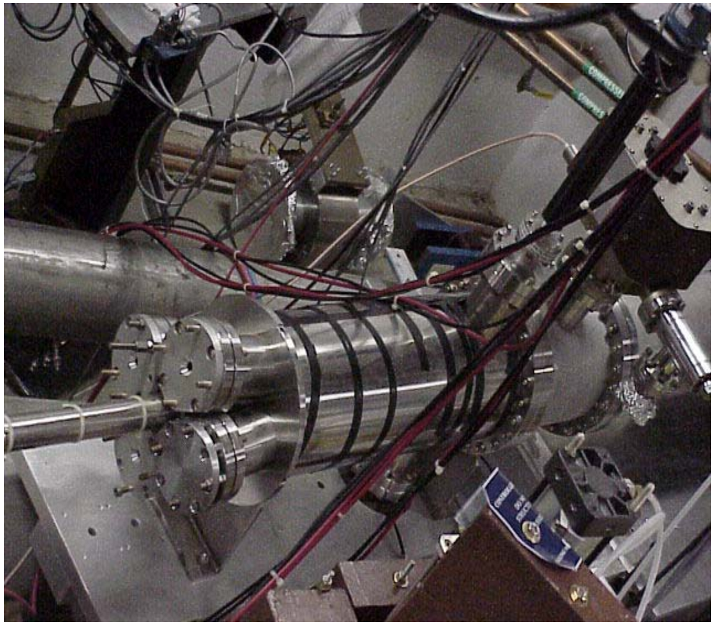
$$\sigma(\theta,\phi) = \sigma_0(\theta)\left[1 + S(\theta)\ \mathbf{P}_b \cdot \frac{\mathbf{k} \times \mathbf{k}'}{|\mathbf{k} \times \mathbf{k}'|}\right]$$

Sherman Phys.Rev. **103(6)** 1956, p1601-7



<u>Operational Points</u>

- Use unpolarized, high-Z solid targets
- Useful at low enregy (keV to MeV)
  - 14 MeV on Pb (MAMI, 1994)
  - 5 MeV on Au (JLAB, 1995)
- Sherman function is large (~ 30-50%)
- Invasive
- Multiple/plural scattering in thick targets



Uncertainties of Mott A_{tot}

Uncertainty of Sherman function

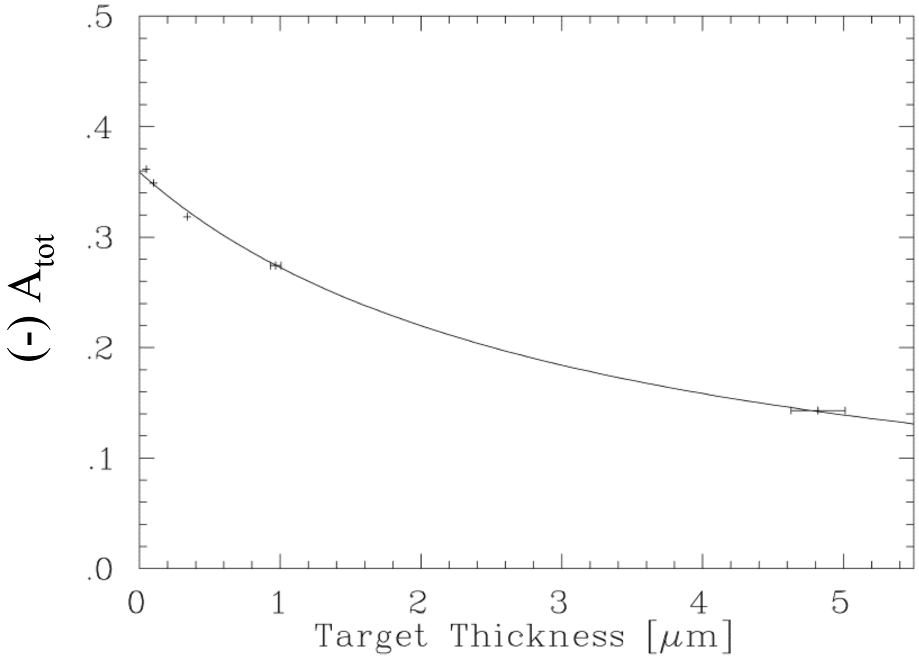
- Coulomb screening at lower energy

  Ross et.al Phys.Rev A **38(12)** 1988, p6055-8

- Finite nuclear size at higher energy

  Ugincius et. al Nucl.Phys. **A158** 1970, p418-32

  1.5% effect at 5 MeV
  20% effect at 14 MeV



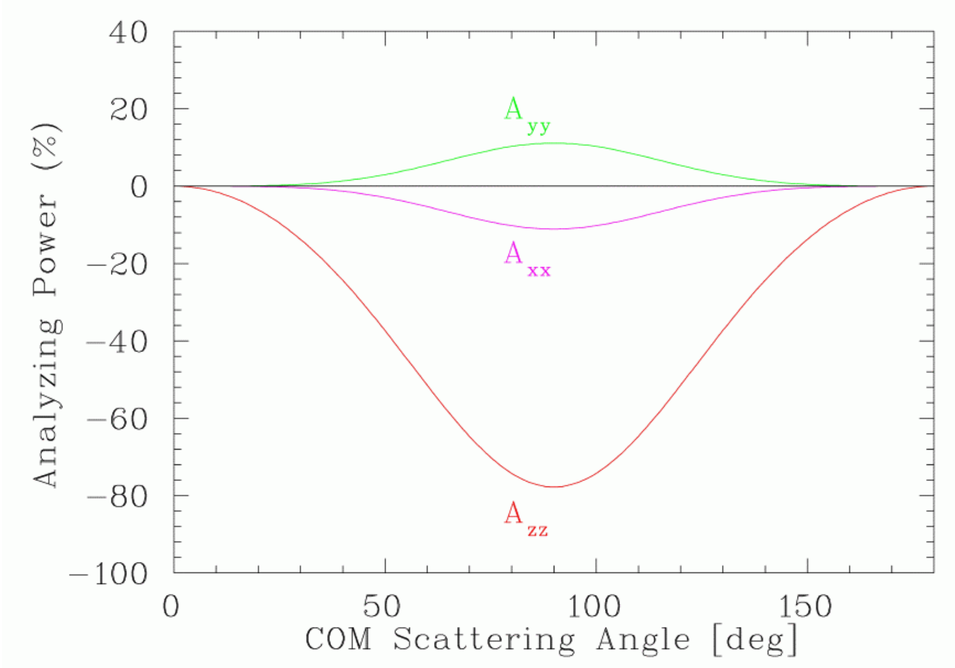
Target thickness effects

- Dilution by multiple/plural scattering
- Sherman function sets scale
- Target thickness extrapolation necessary
- MeV double-scattering is important

Moller Scattering

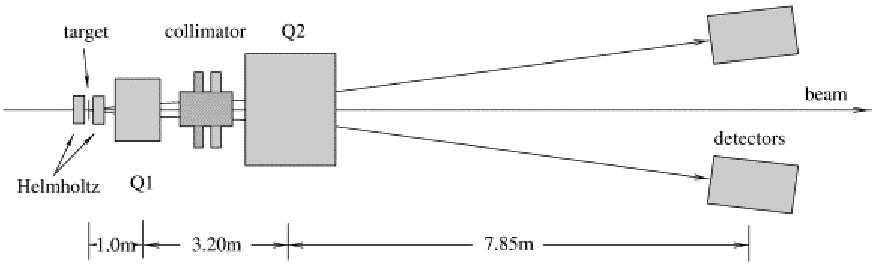
QED spin-spin interaction of a polarized beam electron and a polarized target electron.

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_o}{d\Omega}(1 + \sum_{ij \in x,y,z} A_{ij} P_i^B P_j^T)$$



<u>Operational Points</u>

- Nucleon probe energies (GeV range)
- Large asymmetry A_{zz} = -7/9
- $P_t \sim 8\% \Rightarrow A_{tot} \sim 6\%$
- Good luminosity (~10-100 kHz /µA /µm)
- COM coincidence for >1000:1 S:B
- Invasive
- Limited to <5µA by target heating



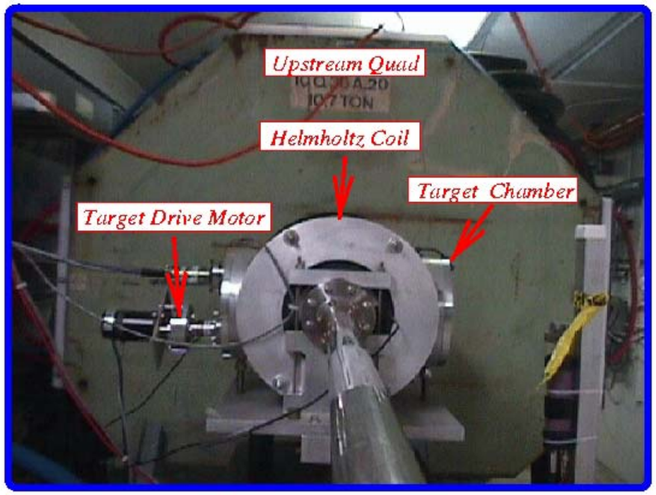
Hall C Moller

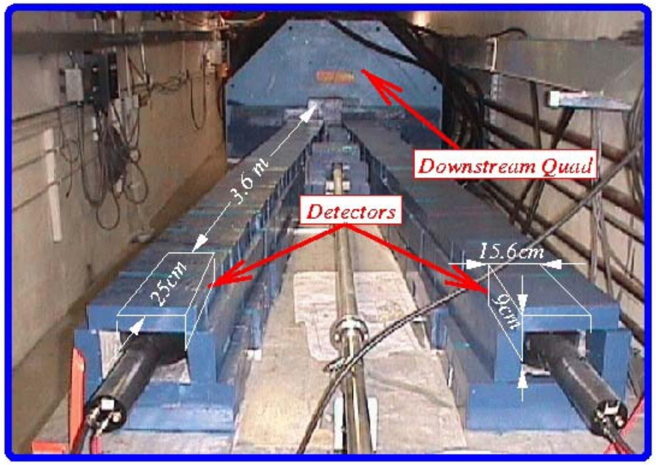
Uncertainties in Moller A_{ij}

Particle identification
- Finite energy acceptance (A_{zz} vs. E)
- Mott background (single vs. double arm)
- Moliere scattering

Levchuk effect (~10%)
- atomic electron motion of core shells
- $p_t \sim 10$ keV

$$\theta^2 = 2m_e \left[\frac{1}{\mathbf{p}'} - \frac{1}{E} \right] \left[1 - \frac{\mathbf{p_t} \cdot \mathbf{n}}{m_e} \right]$$

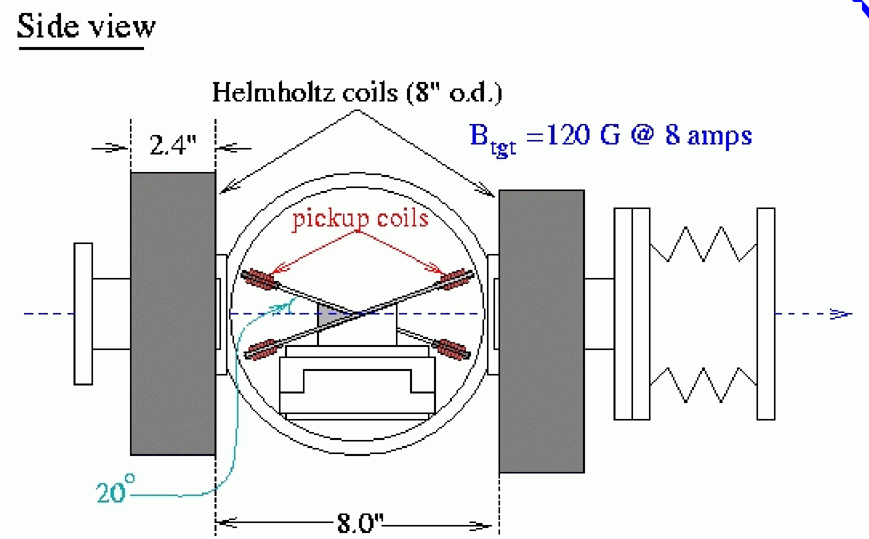




Hall B Moller

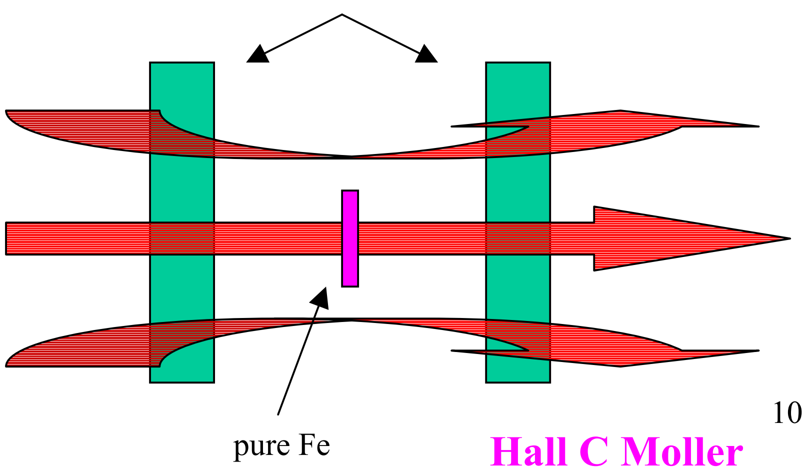
Target Polarization Effects

<u>Conventional Moller</u>
- iron-alloy (Fe, Co, V)
- in-plane magnetization (tilted, B ~ 100 G)
- absolute calibration in beam environment
- thickness inhomogeneity leads to uncertainty between magnetization and flux



Hall B Moller

<u>Novel Moller Design (I. Sick, *et. al*)</u>
- spin-polarization versus magnetization known for pure iron ~ 0.25%
- out-of-plane (normal targets)
- insensitive to target thickness
- high field saturation (3 Tesla)
- field direction and uniformity
- target heating

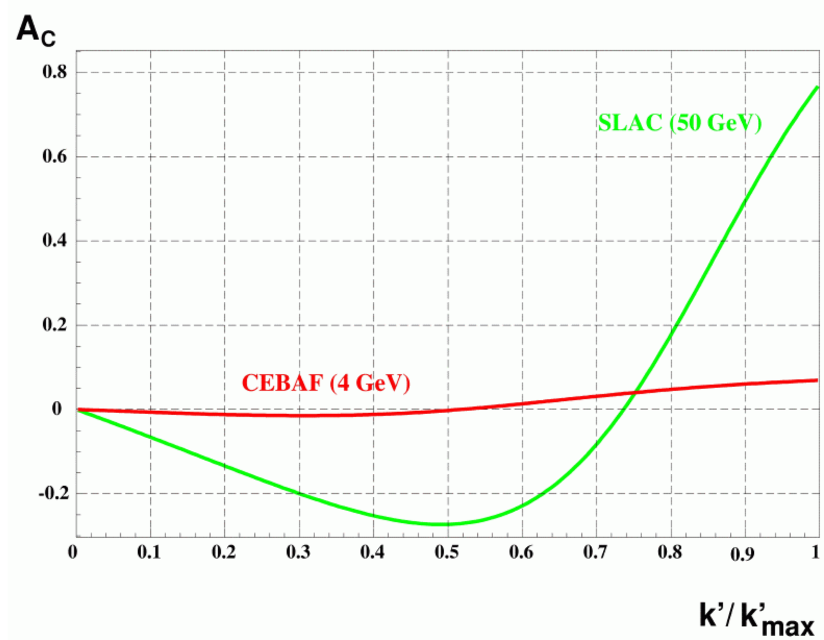


Hall C Moller

Compton Scattering

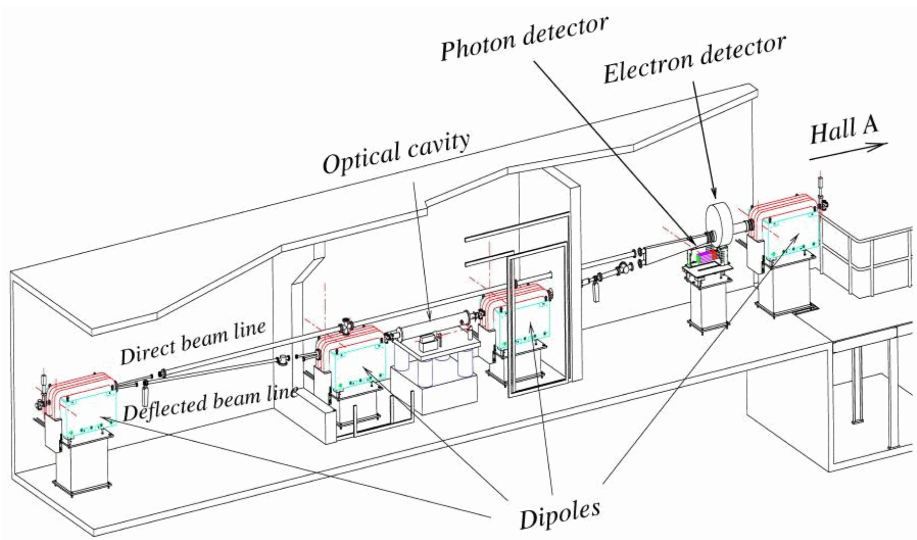
Asymmetric cross-section between longitudinally polarized electron beam and circularly polarized photon beam.

$$A_C = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}}$$



<u>Operationally</u>

- Must work for high luminosity
- Non-invasive!
- Excellent target polarization
- A_{tot}(Energy)
- Performance suffers at ~1GeV
- Increased complexity



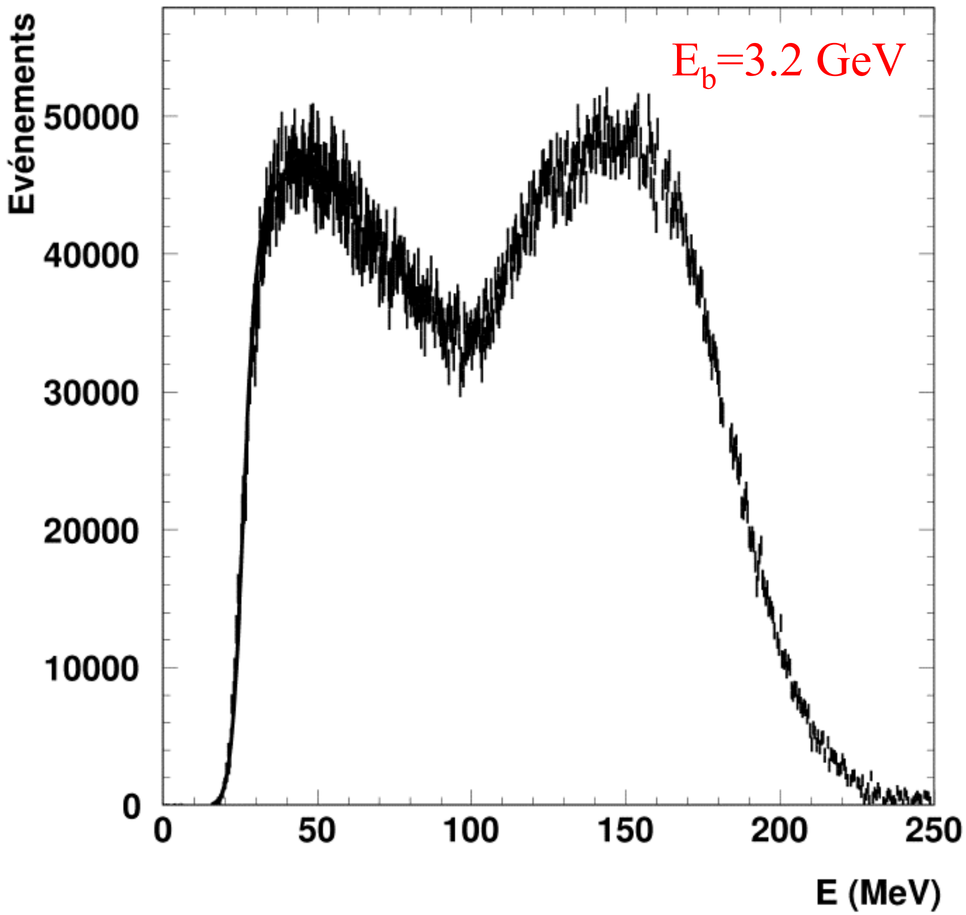
Uncertainties of Compton A_{tot}

Calculation of A_{tot}

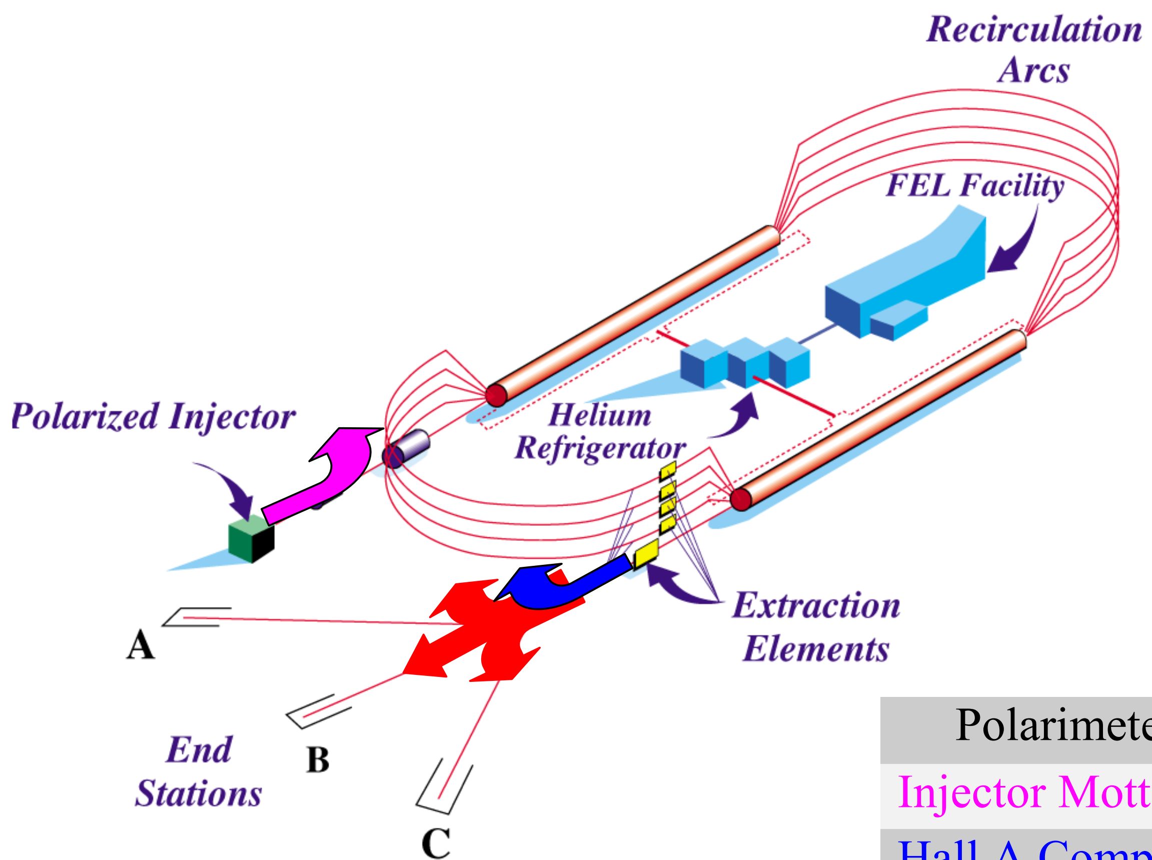
- Compton edge energy calibration
- Low energy threshold resolution
- Model to describe $\sigma^{\uparrow\uparrow}$ and $\sigma^{\uparrow\downarrow}$

Background

- Bremsstrahlung (residual gas)
- Synchrotron radiation (magnets)



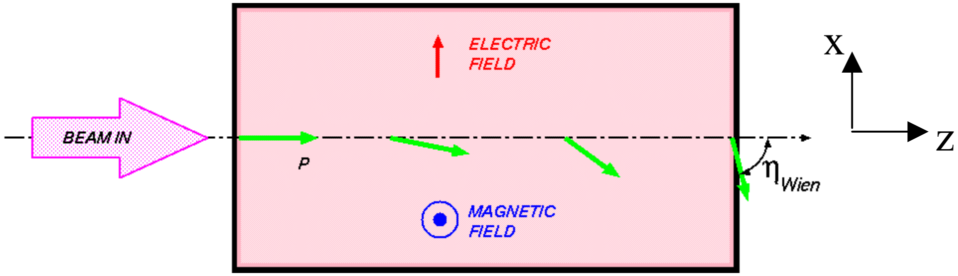
The Experiment at the CEBAF Accelerator

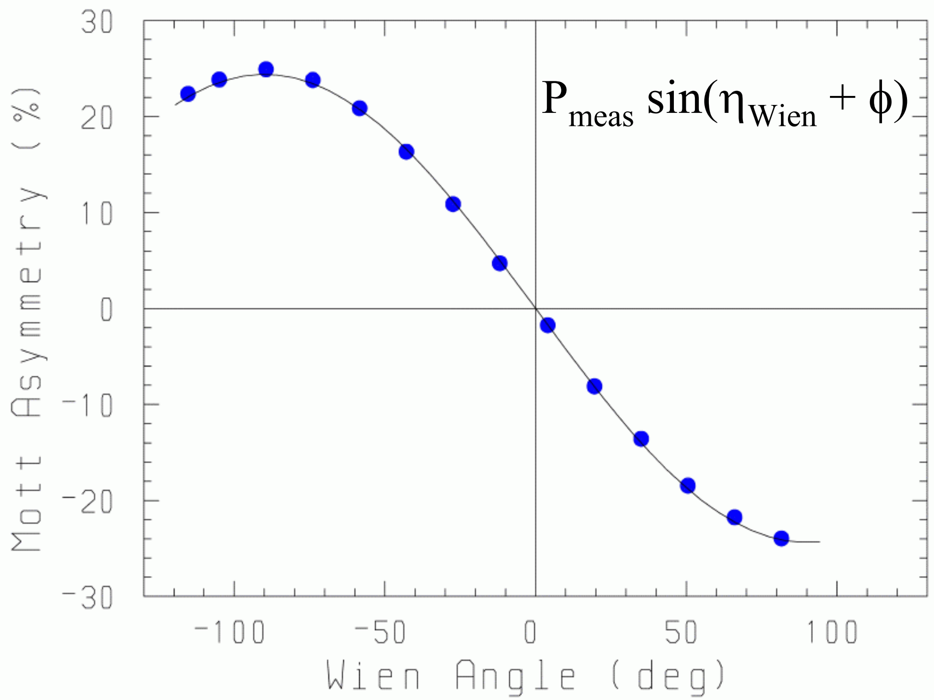


$$\varphi_{spin} = \gamma \cdot \left(\frac{g-2}{2}\right) \cdot \theta_{bend}$$

Polarimeter	I_{ave}	P_x	P_y	P_z
Injector Mott	2 μA	x	x	
Hall A Compton	70 μA			x
Hall A Moller	1 μA	x		x
Hall B Moller	5 nA		x	x
Hall C Moller	1 μA			x

Spin Dancing

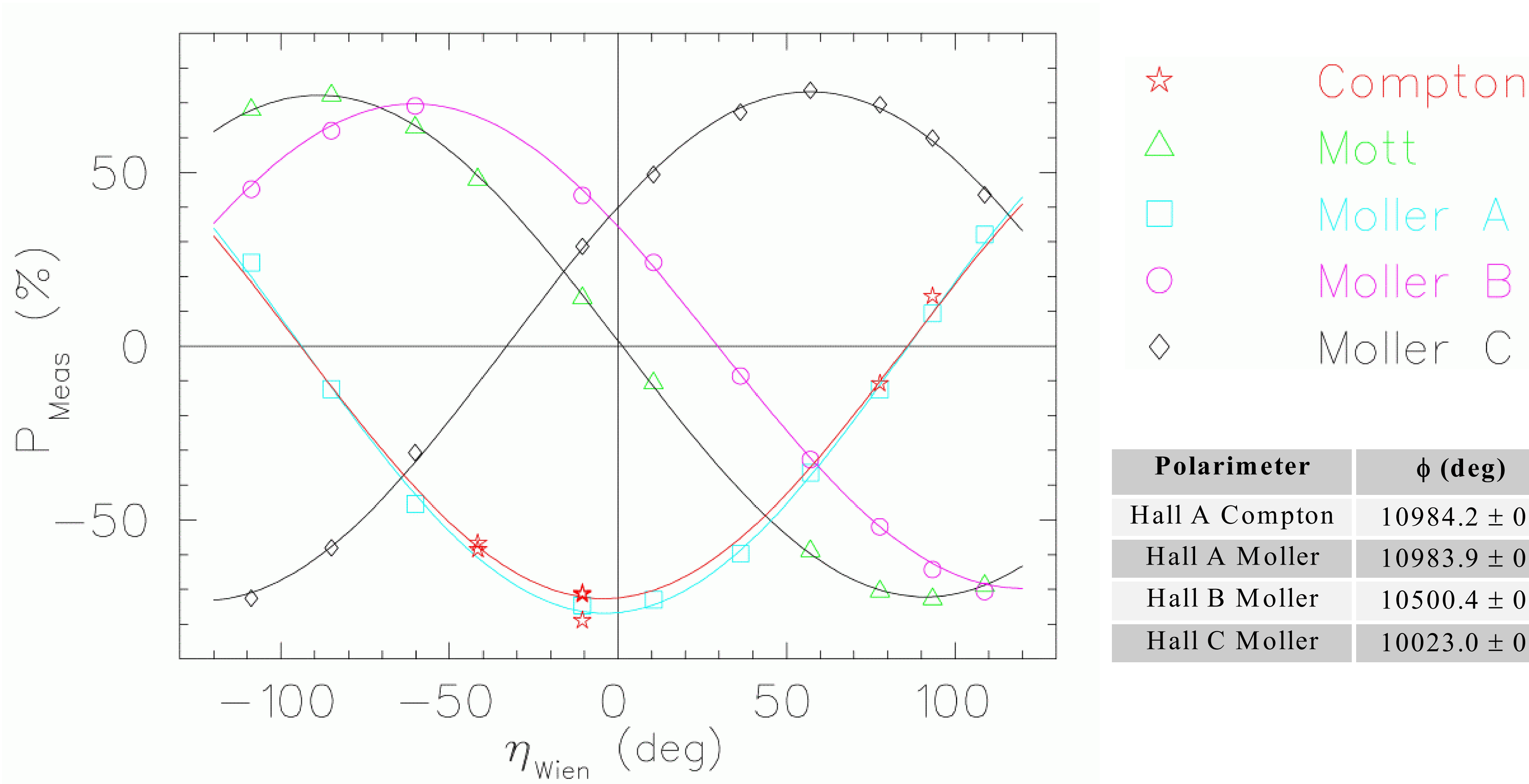




The measured experimental asymmetry is proportional to the fraction of the total beam polarization along some analyzing component of the polarimeter.

Spin Dance 2000 Results

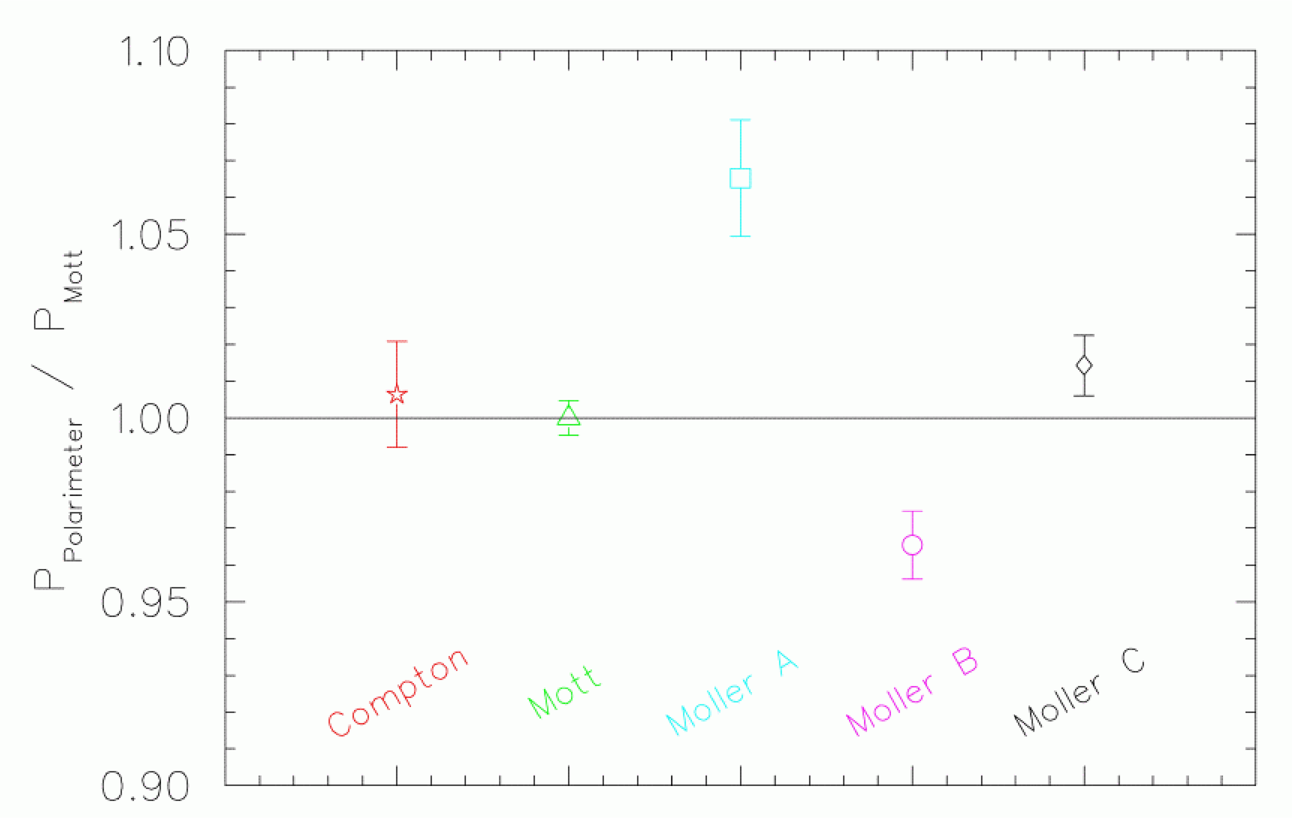
$$P_{meas} \sin(\eta_{Wien} + \phi)$$



Polarimeter	ϕ (deg)
Hall A Compton	10984.2 ± 0.8
Hall A Moller	10983.9 ± 0.7
Hall B Moller	10500.4 ± 0.6
Hall C Moller	10023.0 ± 0.7

Relative Analyzing Powers Compared

- Only statistical uncertainties used to reveal systematic uncertainty.
- Polarimeters of 3 types (Mott, Moller, Compton) agree.
- Uncertainty in Wien angle induces < 0.2% relative effect.

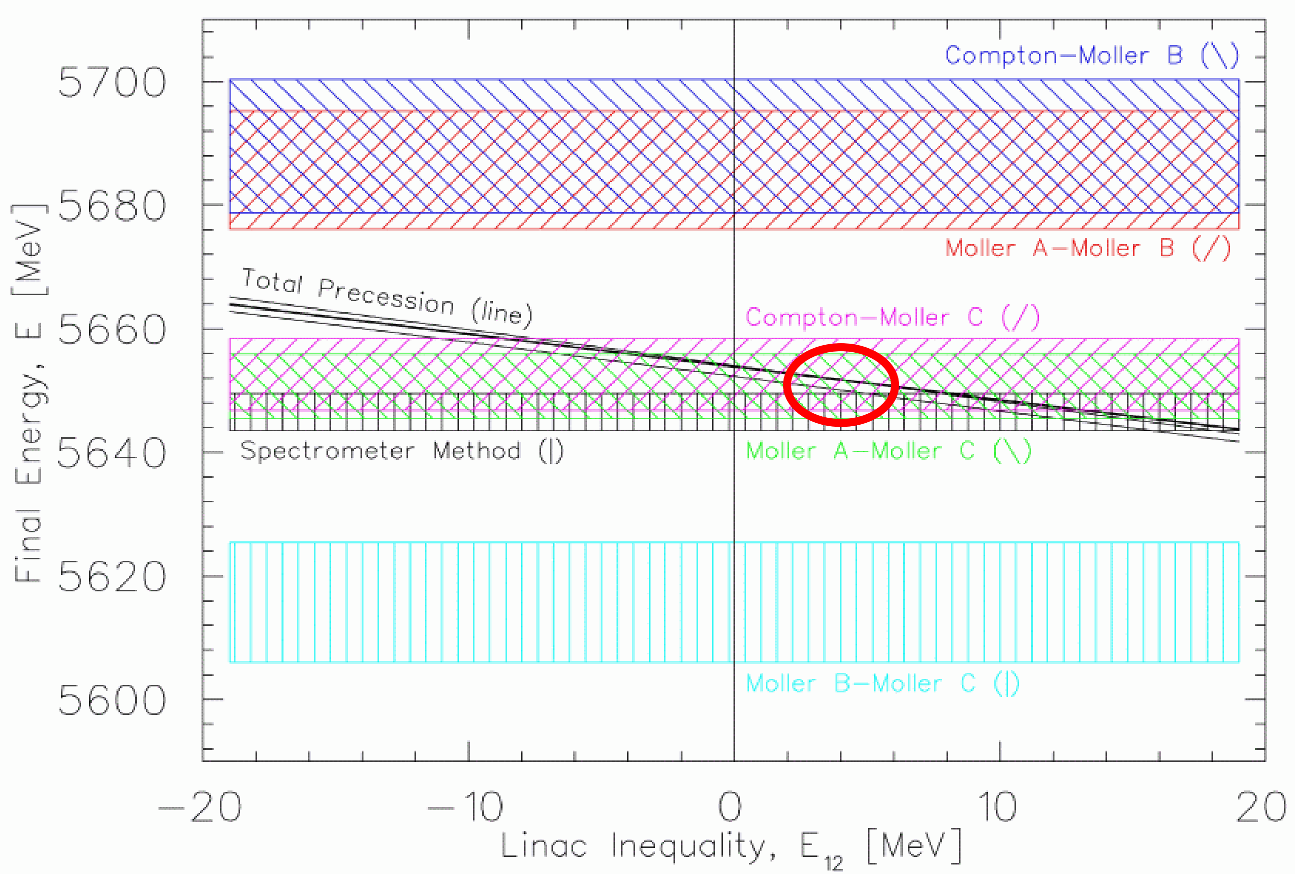


P_{meas} normalized to Mott for reference

Spin Based Energy Measurements

$$E = \frac{\frac{4m_e\Psi}{g-2} - E_0(\theta_t - \theta_h) - \frac{nE_{12}[\theta_t - \theta_h + (n-1)\theta_{12}]}{(2n-1)}}{\theta_t + \theta_h}$$

$$E = \left[\frac{2m_e c^2}{g_e - 2}\right] \cdot \frac{\Delta\Psi}{\Delta\Theta}$$



Conclusions

Jefferson Lab has started down the path of developing high precision polarimetry, which presently can be inferred only by intercomparison of different polarimeters with different systematics using a beam known to have the same polarization for all the polarimeters.

The *Spin Dance 2000* experiment:

- First high precision comparison between Mott, Moller, and Compton
- All five polarimeters do not agree within quoted systematic uncertainty
- Three different polarimetry techniques (Mott, Moller, Compton) agree
- Revealing systematic differences is a first step toward understanding them

Often, the polarimeter is viewed only as the tool, but to reach the 1% mark it must continue to be the experiment.