Electron Polarimetry at JLab

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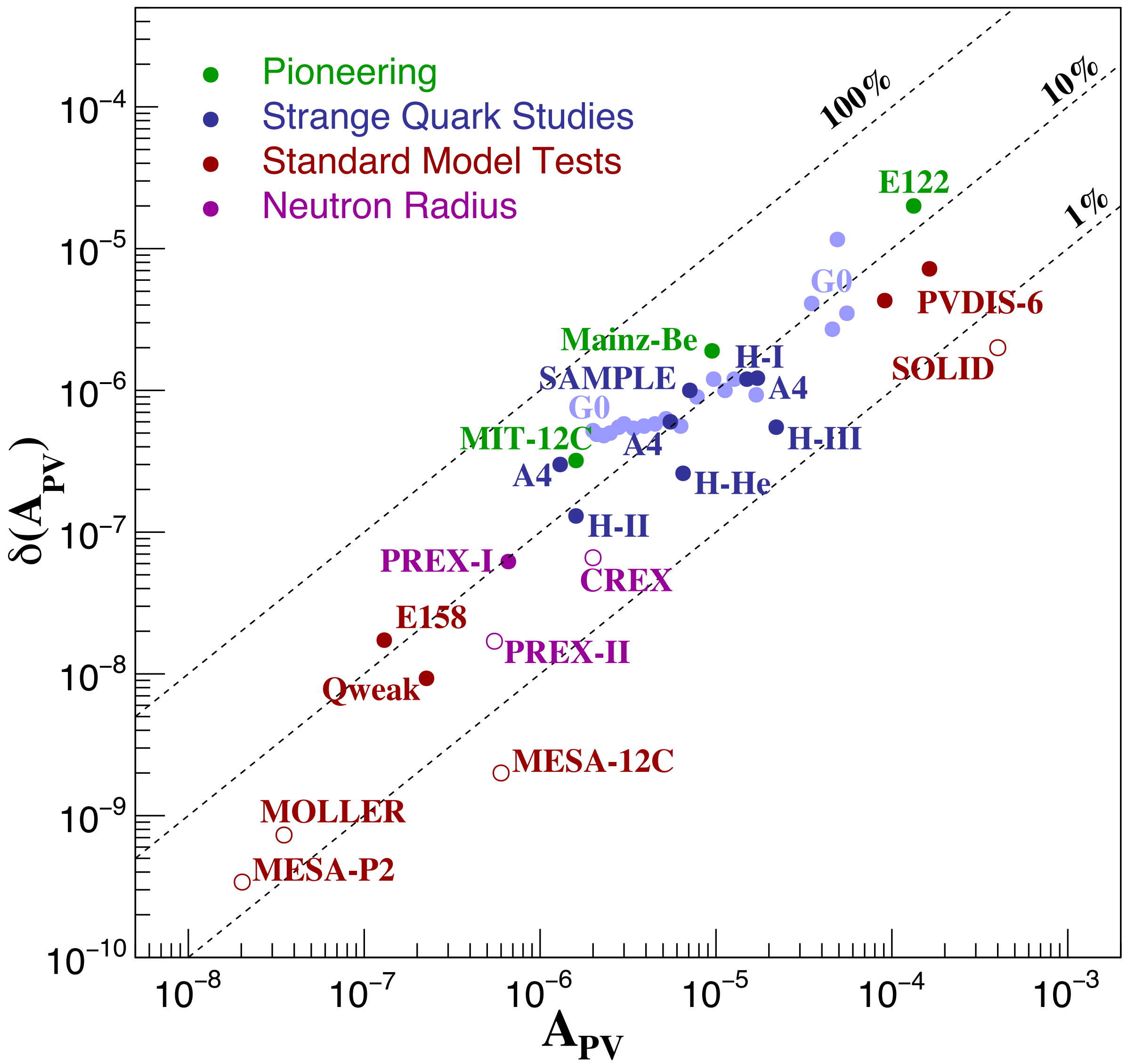
JLab program requires high precision polarimetry



Polarized electron beams used for

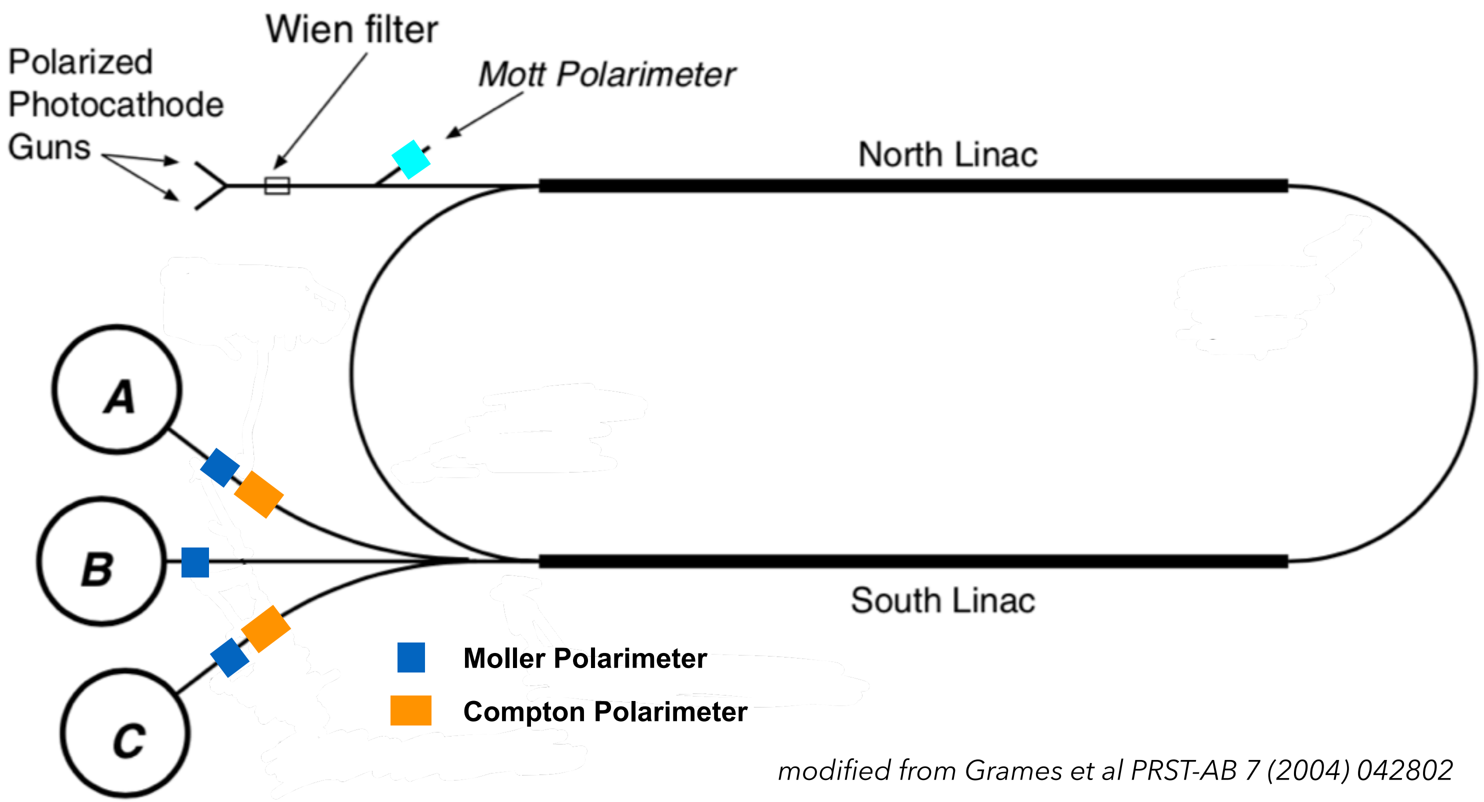
- Spin structure studies with polarized target
- Parity-violation studies

Polarimetry precision requirements driven by parity-violation, with future JLab program needing robust, 0.4% precision at 11 GeV and 6.6 GeV (SoLID-PVDIS)

Beyond Standard Model Searches
Neutron skin of a heavy nucleus
Structure of the nucleon

Recent precision polarimetry experience has been at lower beam energies, 1-2 GeV

Electron Polarimetry at JLab



modified from Grames et al PRST-AB 7 (2004) 042802

HAPPEX-3 (2009)	3 GeV	Integrating Photon	1%
PREX-I (2010)	1 GeV	Integrating Photon / High-Field Moller	1%
Qweak (2010-12)	1 GeV	Compton Electron / High-Field Moller	0.6%/0.85%
PREX-II / CREX (in progress)		High-field Moller to 1%, Compton to 1% at 1-2 GeV	
MOLLER		Aims for 0.4% precision	
SOLID-PVDIS		Must have 0.4% precision	

Mott

- $\vec{e} + Z \rightarrow e$
- spin-orbit coupling
- useful at MeV energy (injector)
- Crucial for beam setup
- Better than 1% systematics

Compton

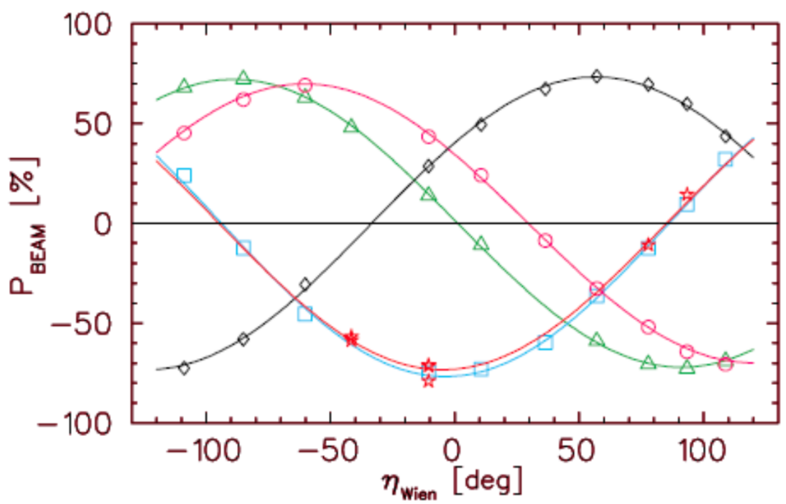
- $\vec{e} + \vec{\gamma} \rightarrow e + \gamma$
- electron-photon scattering
- continuous measurement
- easiest at high energies
- about 0.6% precision at 1 GeV

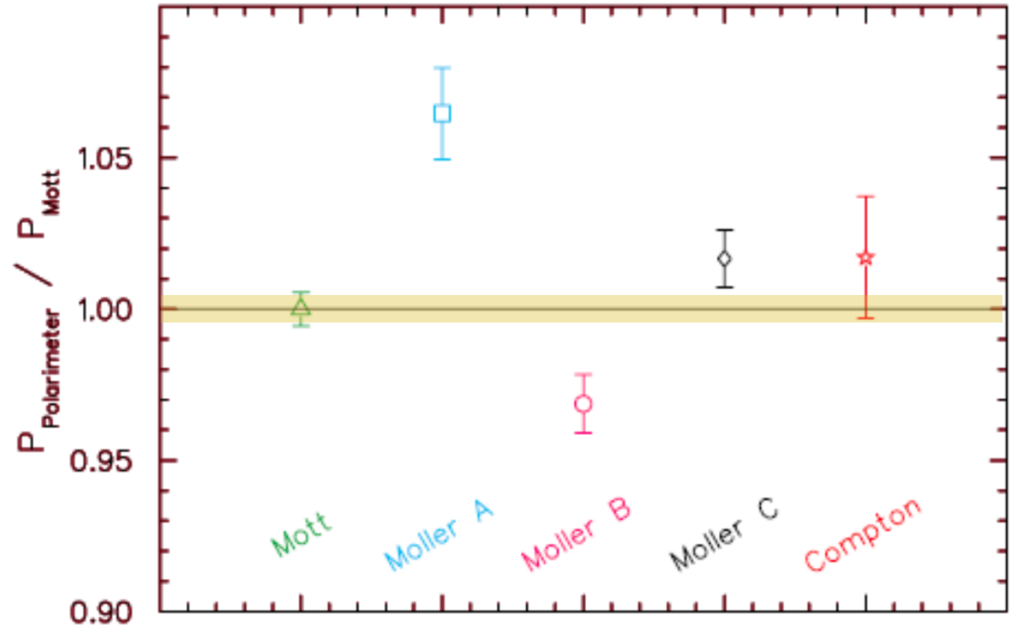
Moller

- $\vec{e} + \vec{e} \rightarrow e + e$
- atomic electron in ferromagnetic foil
- destructive, special configuration
- about 0.5% precision demonstrated

"Spin Dance" comparison of polarimeters

Grames et al, PRST- AB, 7 (2004) 042802





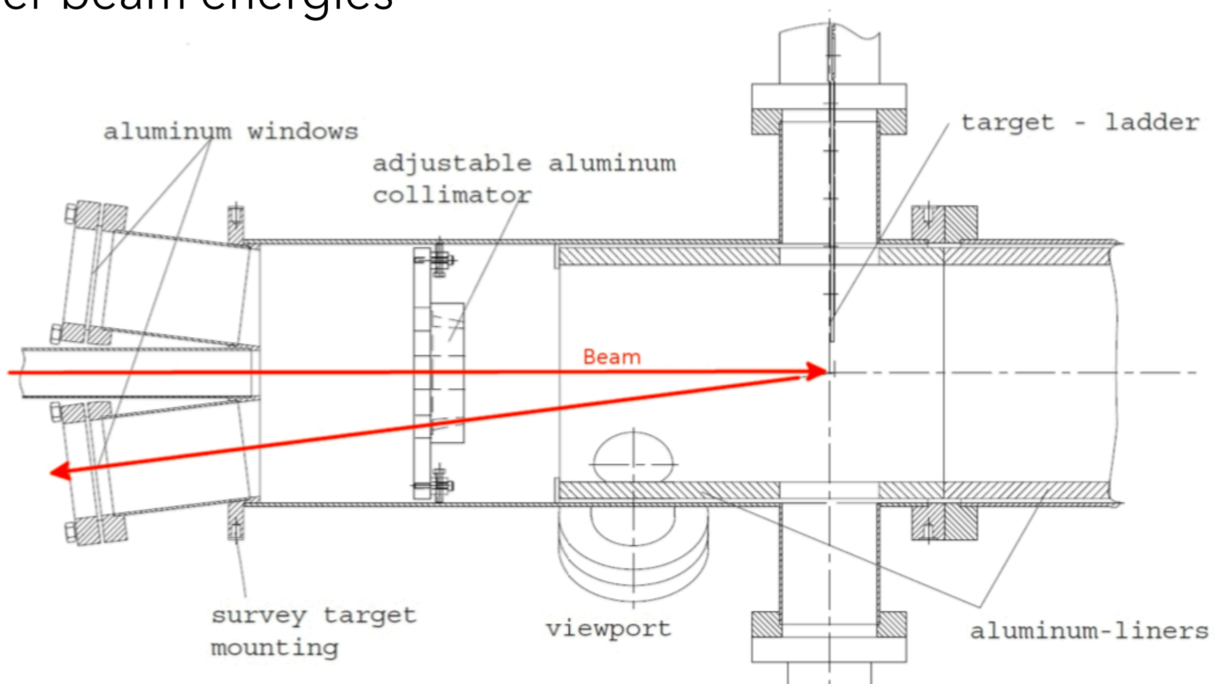
Polarization launch angle changed of broad range, while 5 polarimeters tracked the changes
This is a major experiment!
Much was learned, and similar cross-comparisons will be useful in the future

Mott Polarimeter

spin-orbit coupling of electron spin with high-Z nucleus creates large single spin analyzing power for transverse polarized electrons at back-angle scattering

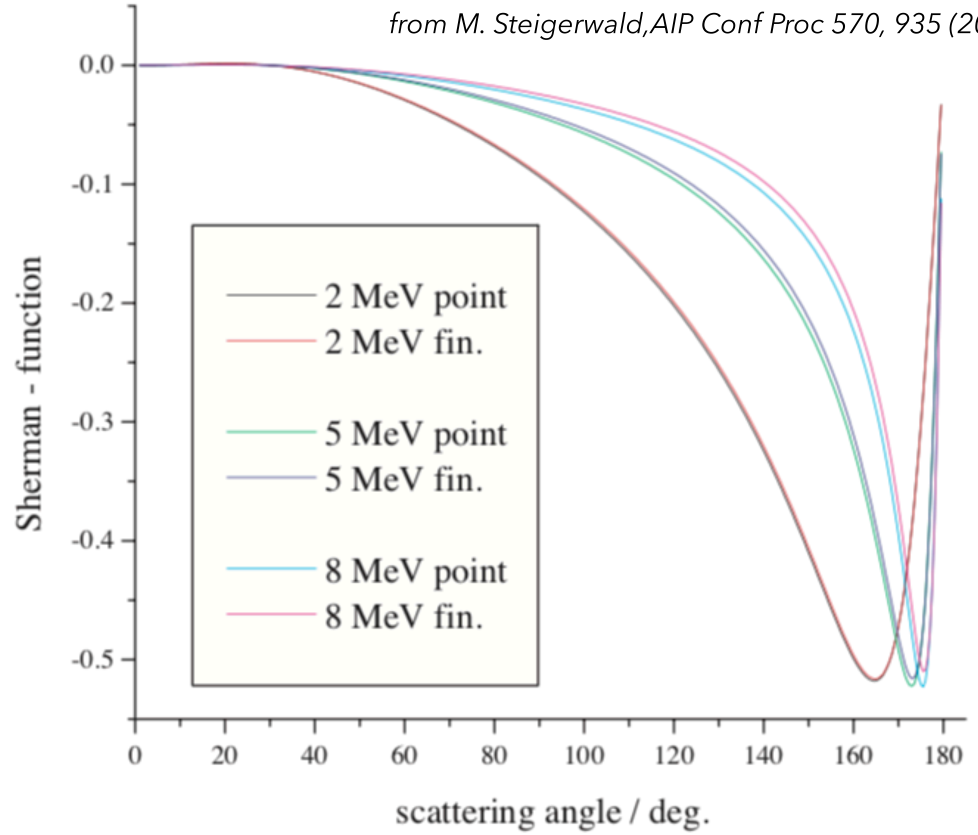
$$\sigma(\theta, \phi) = I(\theta) \left[1 + S(\theta)\, \vec{P} \cdot \hat{n} \right]$$

Ideal at 100 keV - few MeV, but relativistically suppressed at higher beam energies



from Grames, POS(PSTP 2013) 040

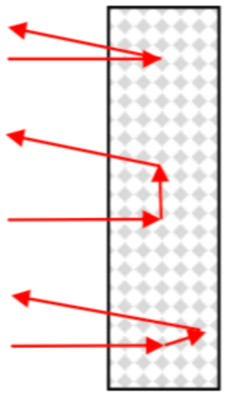
from M. Steigerwald,AIP Conf Proc 570, 935 (2001)

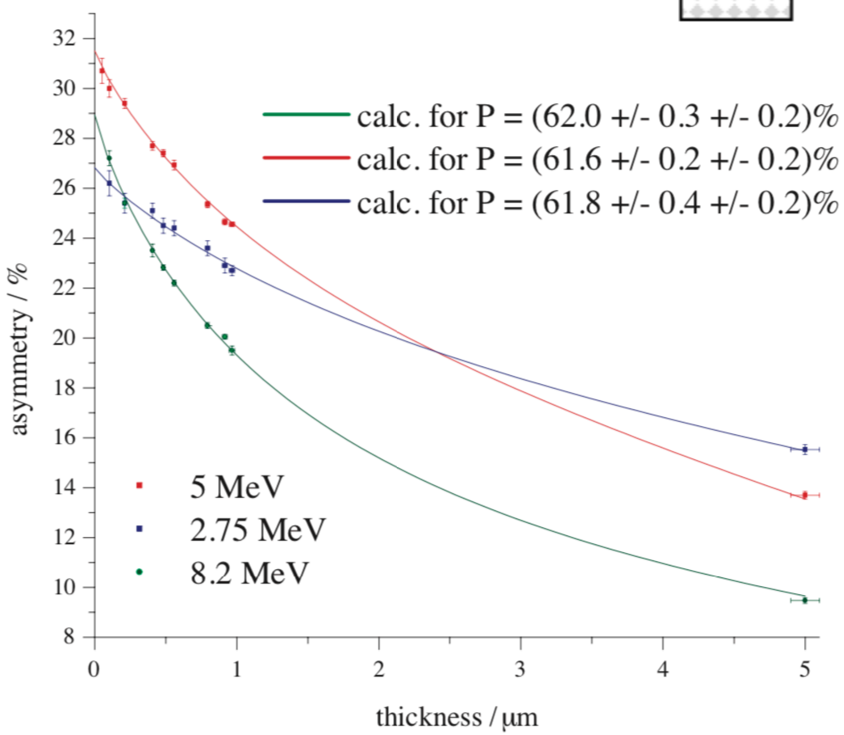


Sherman function calculation requires distorted wave calculation, precise at significantly better than 1%

Mott Polarimetry

Finite target thickness, average analyzing power is averaged over multiple scattering events

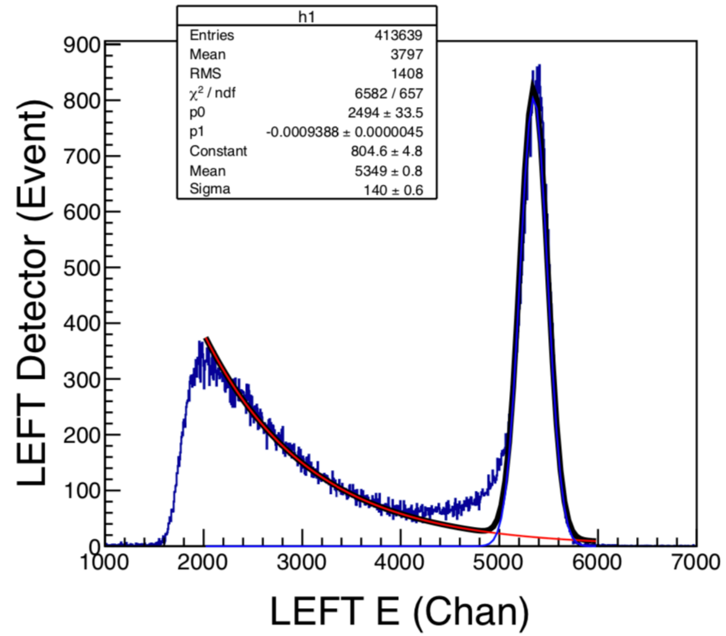


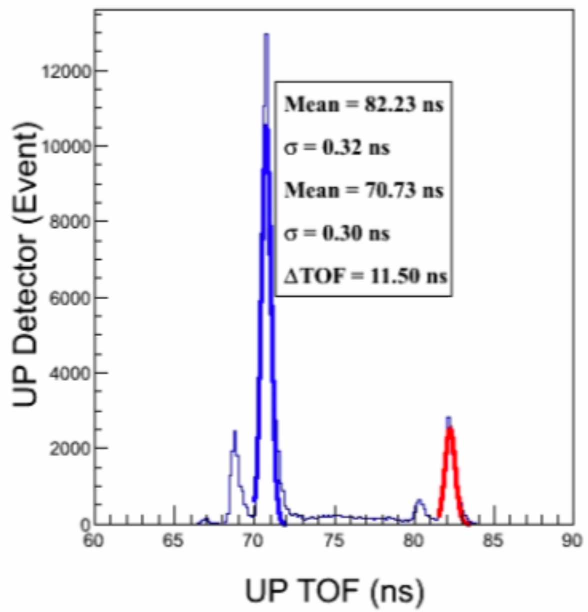


from M. Steigerwald, AIP Conf Proc 570, 935 (2001)

Backgrounds (mostly from vacuum chamber or beam dump) are a challenge

from Grames, POS(PSTP 2013) 040





31 MHz pulsed beam allows separation of target from beam dump scatters to suppress background

- Fast measurements (5 min to 1%)
- Ultimate precision for physics measurements from polarimeters inside the experimental halls

Moller Polarimetry

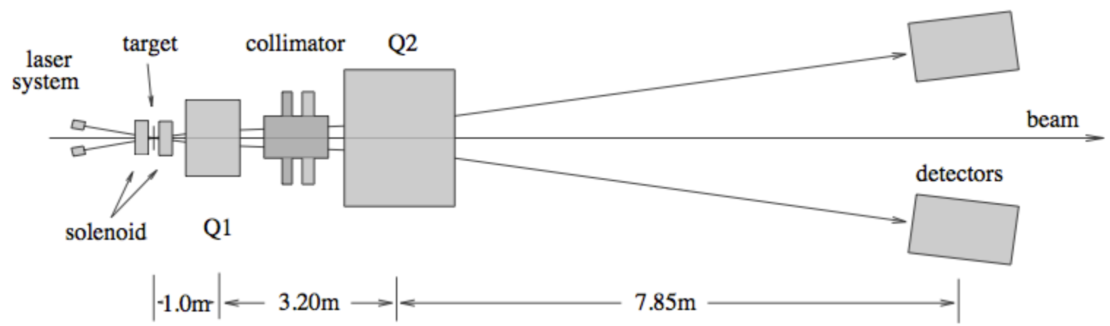
- Elastic *ee* scattering from iron foil
- Detect *ee* pair in coincidence
- Critical sources of uncertainty:
  - Target polarization
  - Levchuk effect on analyzing power

$$\vec{e} + \vec{e} \rightarrow e + e$$

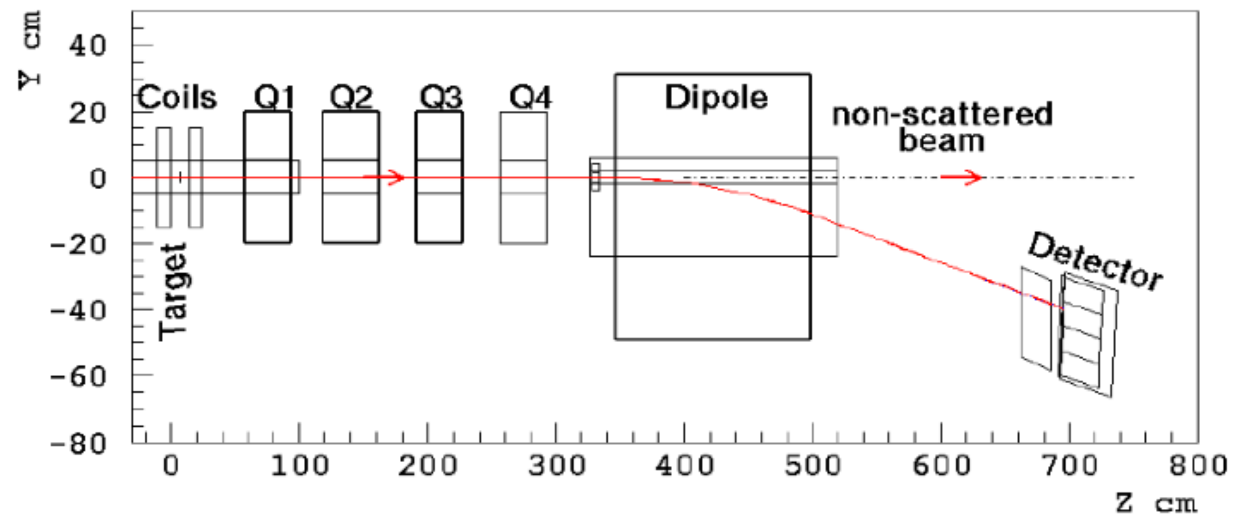
$$A_{zz} = -\frac{\sin^2\theta_{CM} \cdot (7 + \cos^2\theta_{CM})}{(3 + \cos^2\theta_{CM})^2}$$

Peak analyzing power at 90° CM

Hall C Moller polarimeter



Hall A Moller polarimeter

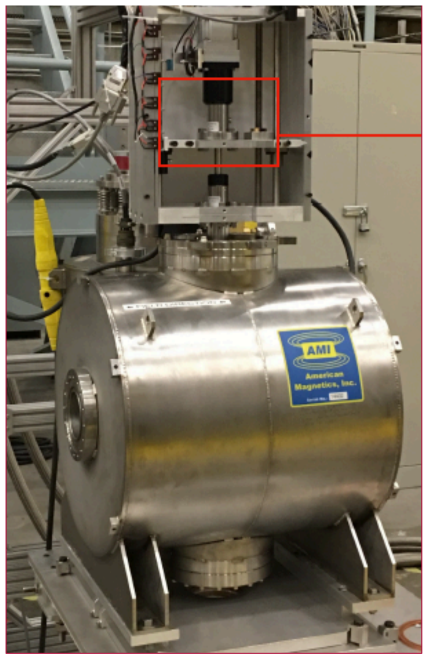


Controlling Moller polarimetry systematic uncertainties

Pure Iron at High Field

- Pure iron foil at 3-4 T applied field
- Magnetization saturated
- Spin polarization known to ~0.3% from previous studies of iron magnetization
- Can be studied using Kerr effect for alignment, thermal, foil annealing to test saturation

Target solenoid, cryostat, refrigerator



Studies of Levchuk effect

- Tests of Hall A spectrometer acceptance demonstrated insensitivity to Levchuk effects
- Excellent agreement with simulation gives confidence in model

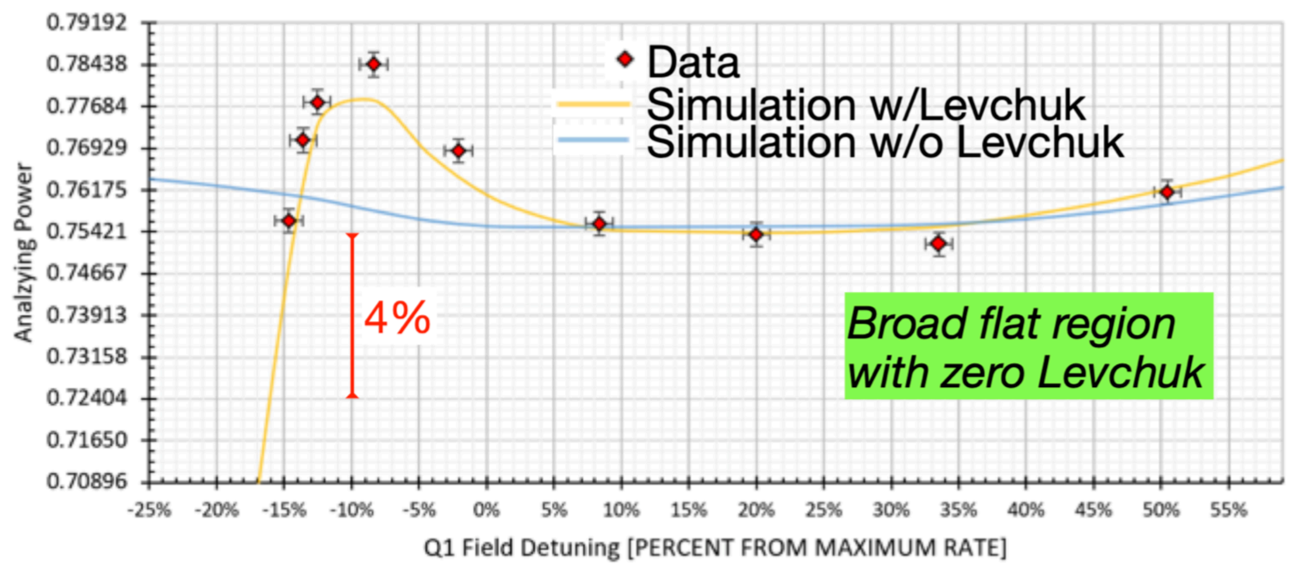
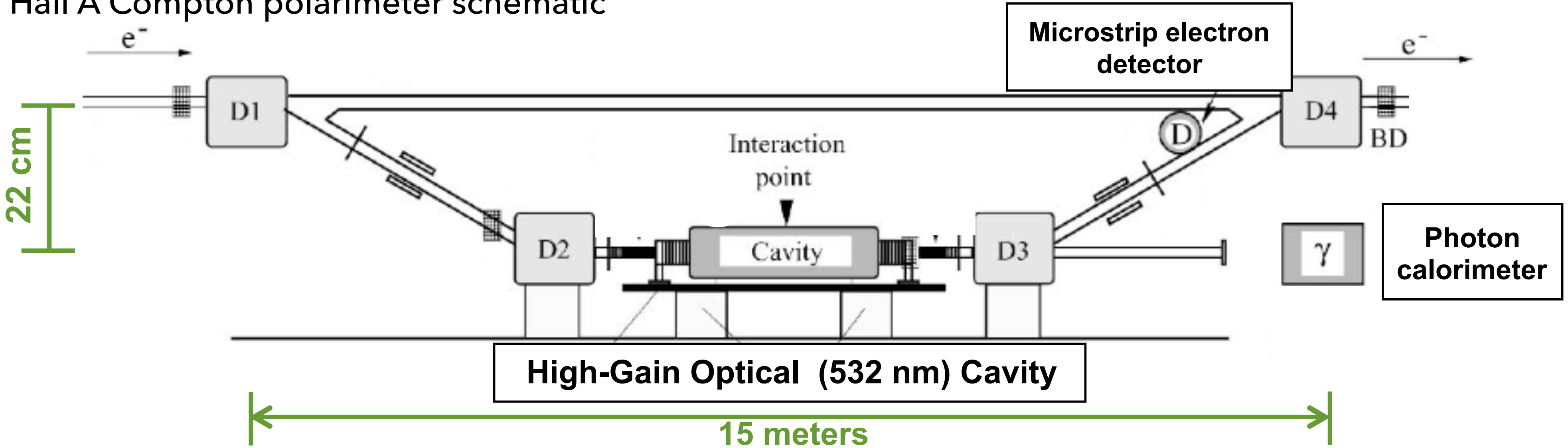


figure from Eric King, Syracuse

Compton Polarimetry

Hall A Compton polarimeter schematic

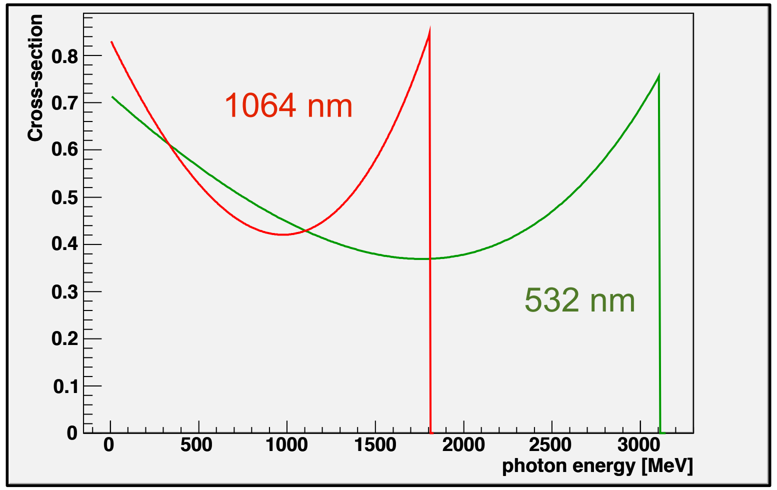


- e-photon scattering from high-power laser cavity
- Independent detection of backscattered photons and recoil electrons
- continuous, non-invasive measurement

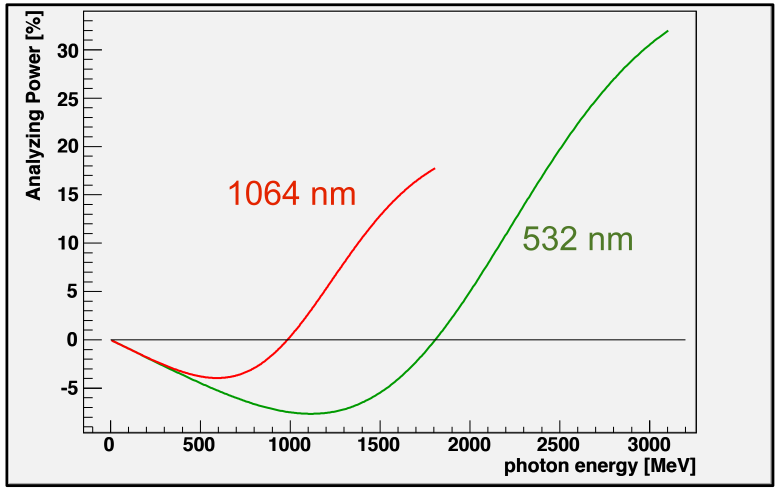
$$A = \frac{2\pi r_0^2 a}{(d\sigma/d\rho)} \left(1 - \rho(1+a)\right) \left[1 - \frac{1}{(1-\rho(1-a))^2}\right]$$

where $\rho = E_\gamma / E_{max}$

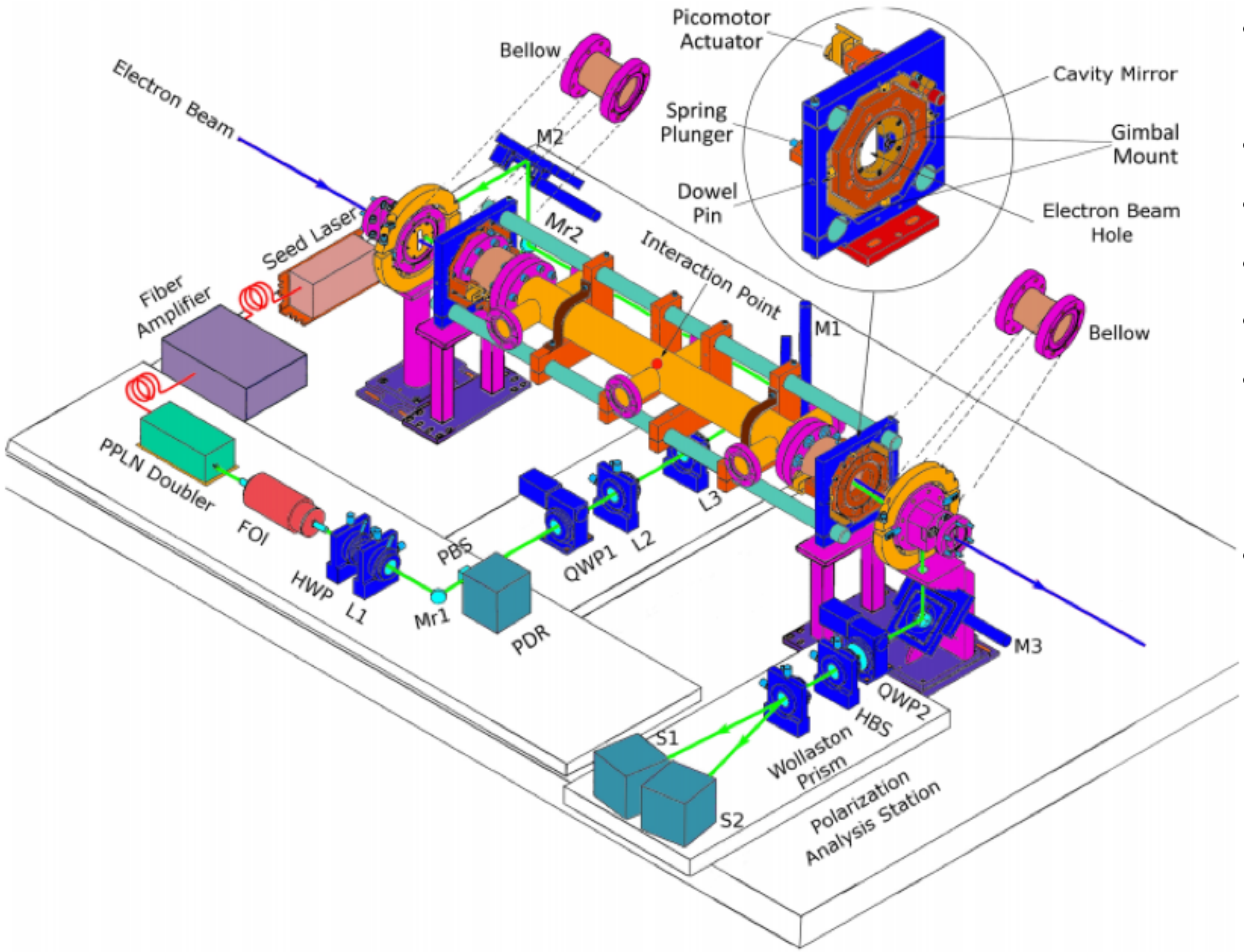
Cross-section (11 GeV)



Analyzing Power (11 GeV)

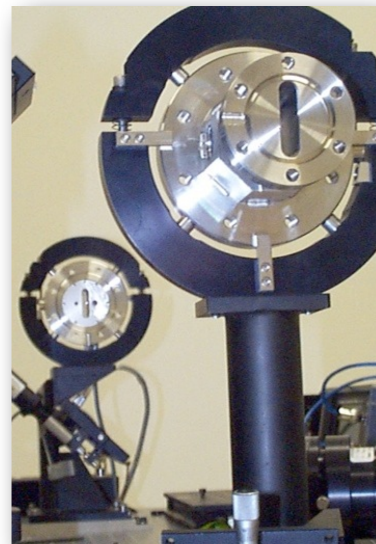


Hall A Laser Cavity

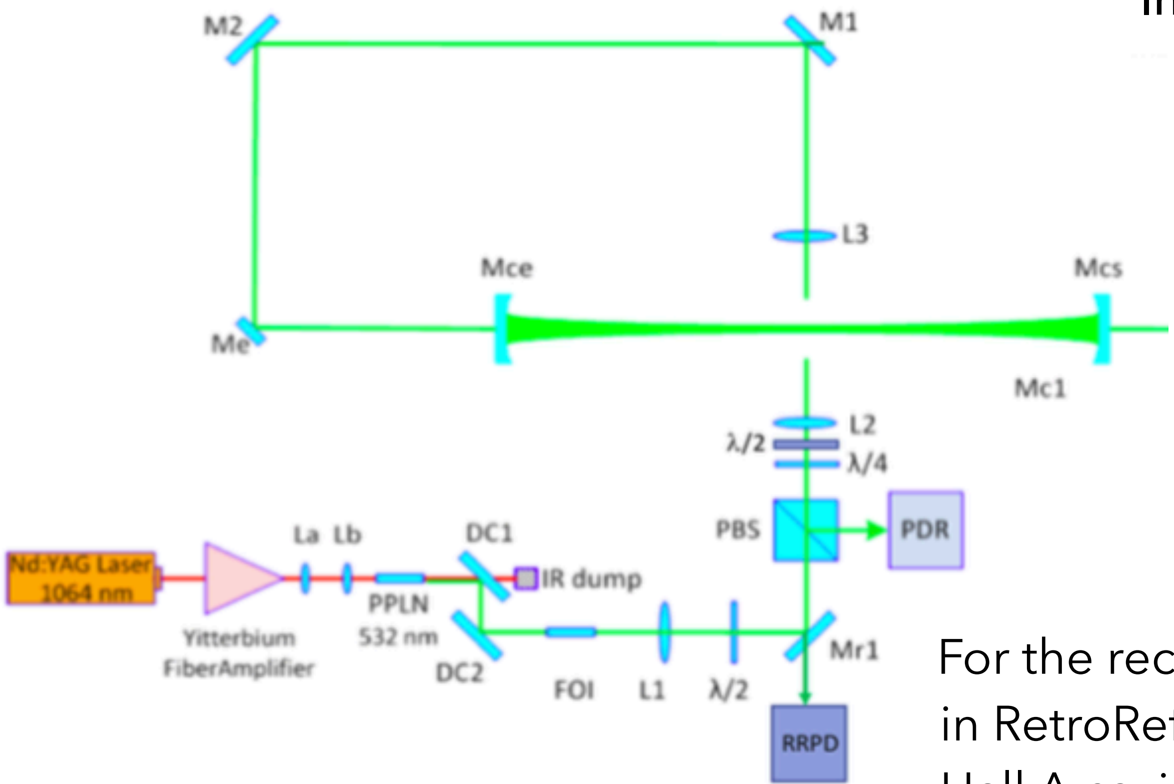


Fabry Perot cavity at 532 nm

- Narrow line width 1064 nm seed laser, fiber laser amplifier, PPLN frequency doubling, ~ 1W 532 nm light
- Robust PDH laser lock, ~2 kW stored
- provides ~1 kHz/μA, S/N>20
- 0.5% measurements in ~5 minutes at 11 GeV
- Laser On/Off easily to measure backgrounds
- Polarization inside cavity
  - technique to optimize injection polarization
  - birefringence in cavity mirrors
- Small crossing angle and limited length requires narrow beam apertures



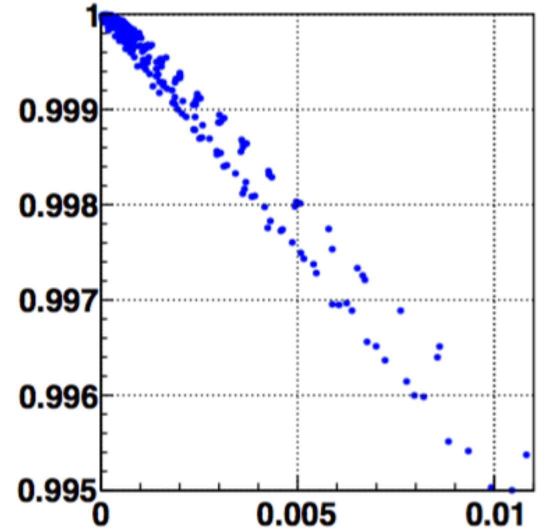
Laser Polarization in Cavity



Input polarization to cavity ~100% by Optical Reversibility Thm

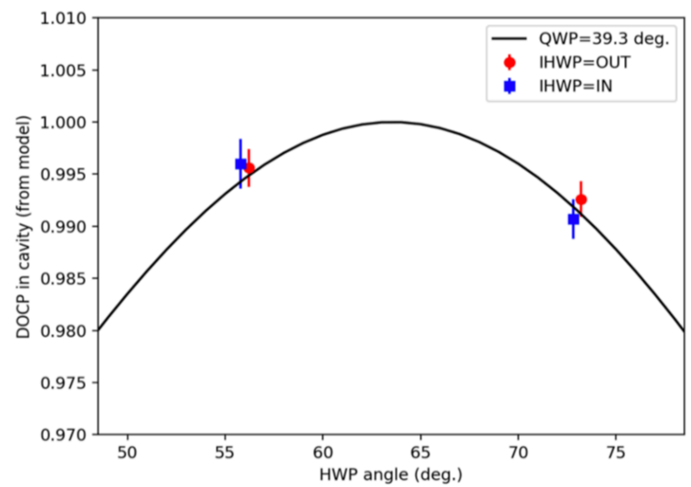
"If input polarization is linear, polarization at cavity is circular only if polarization of the reflected light is linear and orthogonal to input"

Used during Qweak (lower power cavity) to achieve 0.2% uncertainty in laser polariization



RetroReflected Light RRPD

For the recent PREX run, we observed increase in RetroReflected power with laser locking: the Hall A cavity polarization state does not match input polarization

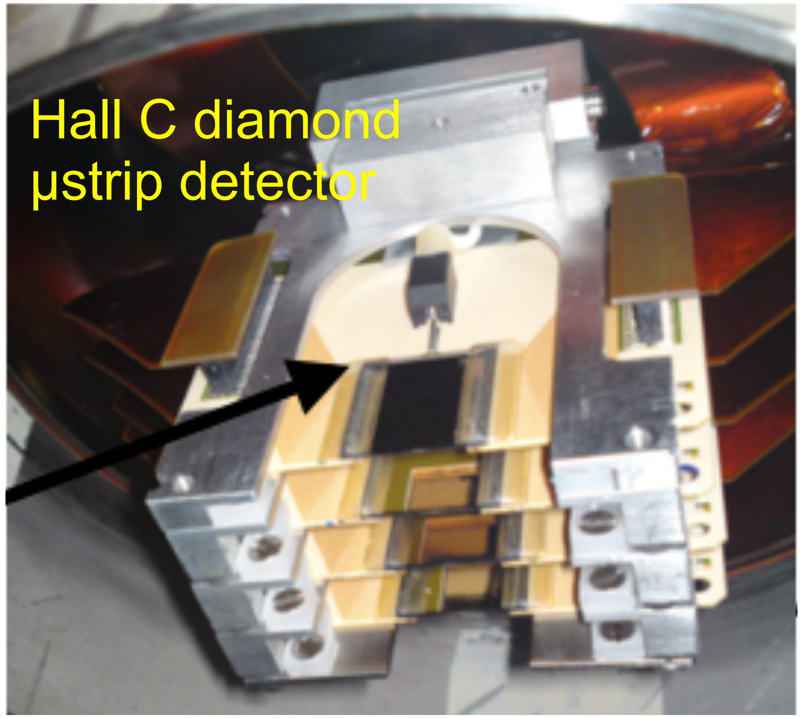


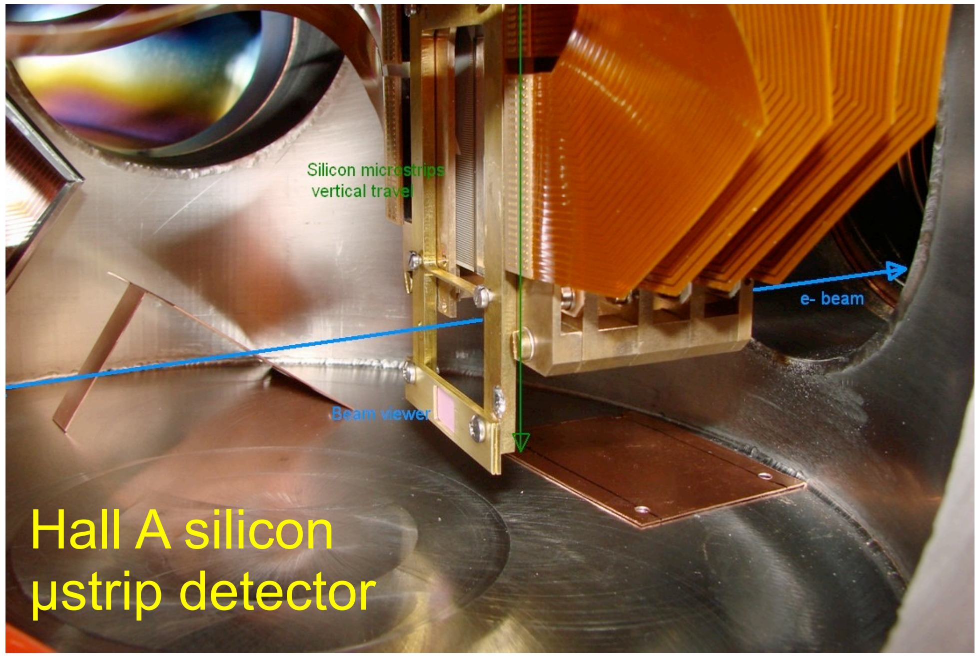
Careful characterization of locked cavity birefringence using transmitted vs input light

Complicated by significant depolarization for locked cavity in air (required low power)

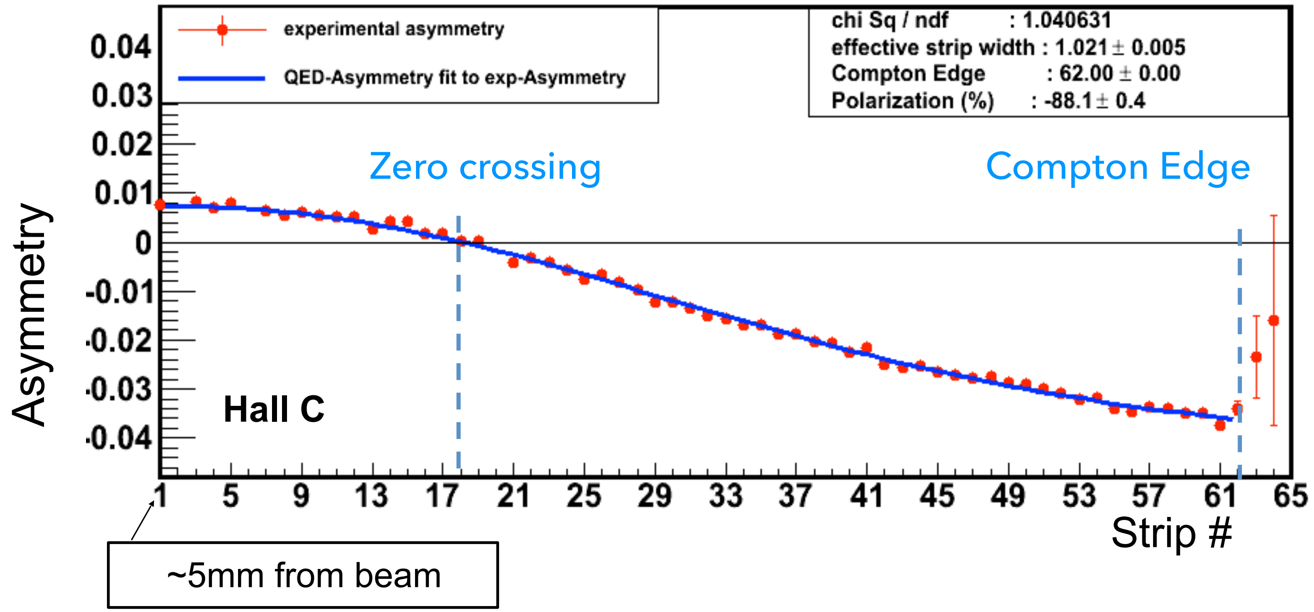
Finally verified optical model with locked/unlocked cavity in situ, and measuring Compton asymmetry with varying polarization in cavity

Electron detection

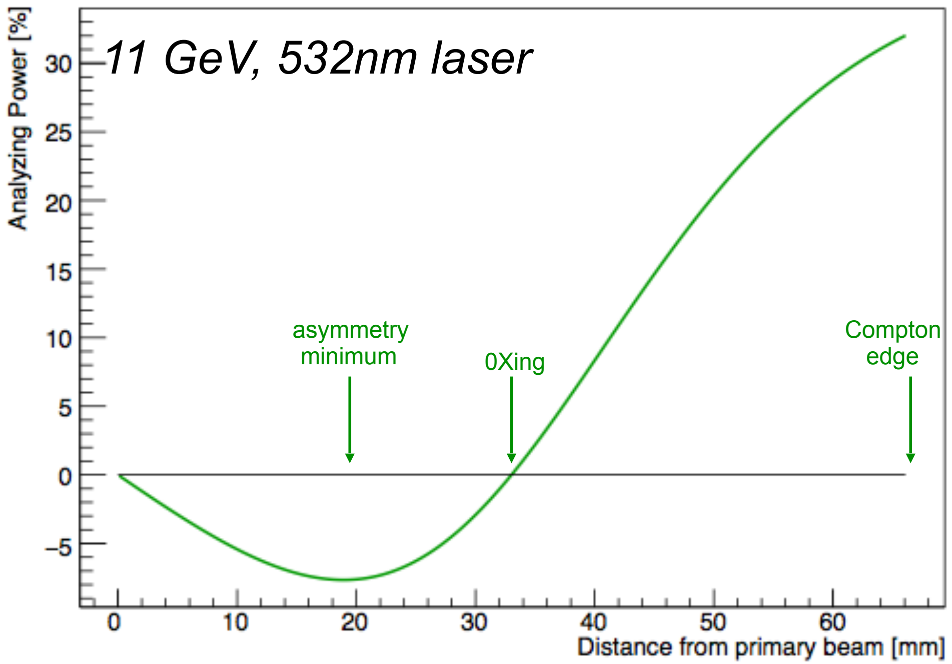




Qweak successfully used diamond microstrips and asymmetry fit at low beam energy



Electron Detector for 11 GeV



Multiple analysis techniques to calibrate analyzing power

- **Asymmetry Fit:** using Compton edge, 0xing, asymmetry shape
- **Edge "single strip":** single microstrip at the Compton edge
- **Minimum single strip:** use the asymmetry minimum

Will be upgrading electron detector system

- more robust electronics, improved radiation hardness
- new diamond microstrips (Applied Diamond)
- HVMAPS development underway in Manitoba

Photon detection

Lead-tungstate calorimeter for high energy photon detection

Counting technique requires calorimeter response function to fit the photon asymmetry spectrum

Low energy (1-2 GeV) analysis uses a smaller, GSO calorimeter with the asymmetry averaged over an energy-weighted integration of the photon signal

$$E^{\pm} = LT\int_0^{E_{\max}} \varepsilon(E)E\frac{d\sigma}{dE}(E)\left(1 \pm P_e P_\gamma A_l(E)\right)dE$$

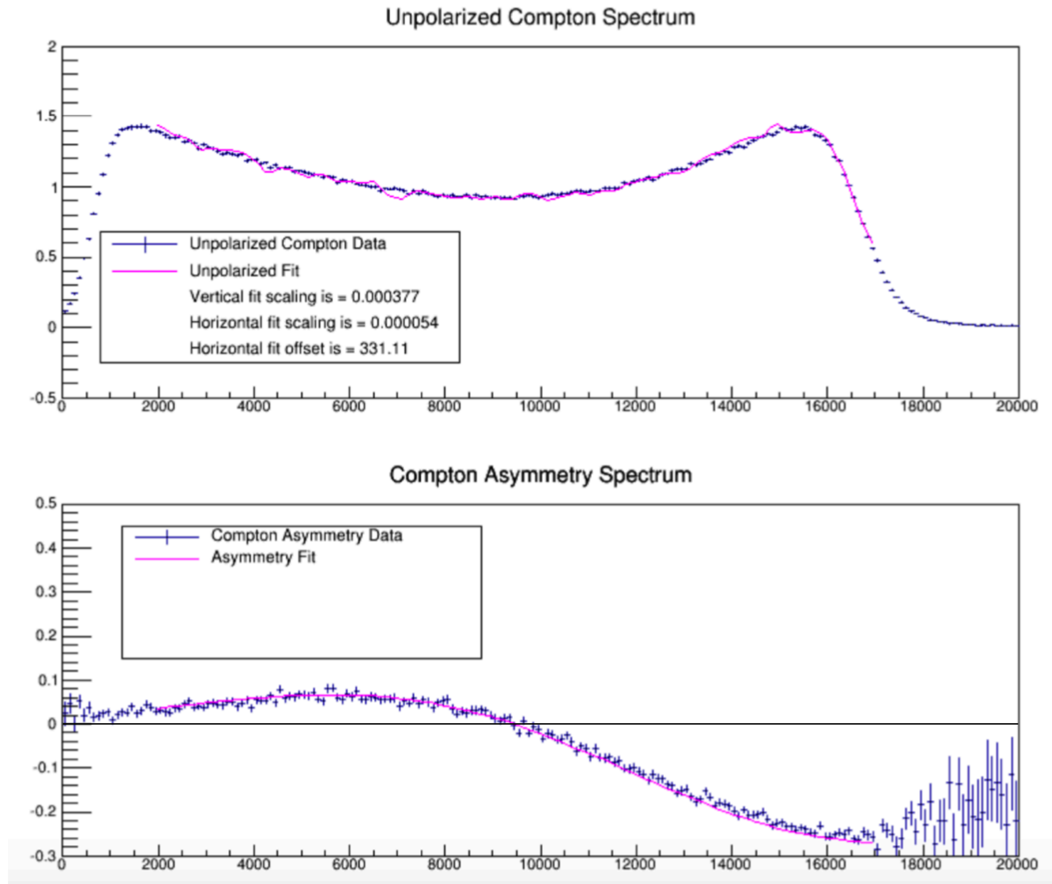
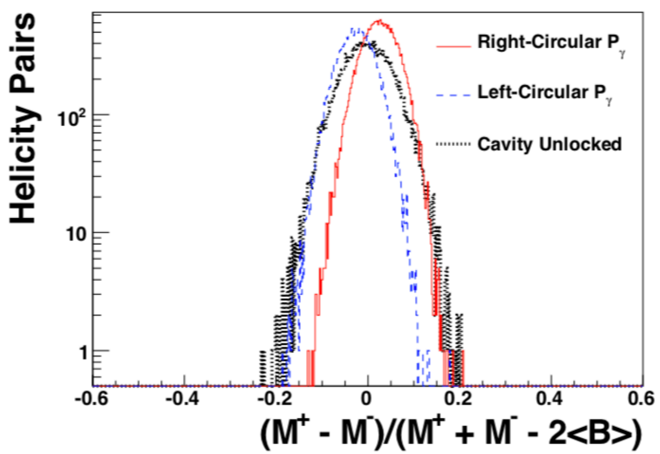


Figure courtesy Alexa Johnson



Energy calibration of the photon spectrum is not required.
The technique is still sensitive to linearity of the detector response.

Published results vs future goals

Qweak

TABLE I. Systematic uncertainties.

Source	Uncertainty	ΔP/P%
Laser polarization	0.18%	0.18
Helicity correl. beam	5 nm, 3 nrad	<0.07
Plane to plane	Secondaries	0.00
Magnetic field	0.0011 T	0.13
Beam energy	1 MeV	0.08
Detector z position	1 mm	0.03
Trigger multiplicity	1–3 planes	0.19
Trigger clustering	1–8 strips	0.01
Detector tilt (x, y and z)	1 degree	0.06
Detector efficiency	0.0–1.0	0.1
Detector noise	up to 20% of rate	0.1
Fringe field	100%	0.05
Radiative corrections	20%	0.05
DAQ efficiency correction	40%	0.3
DAQ efficiency pt.-to-pt.		0.3
Beam vert. pos. variation	0.5 mrad	0.2
Spin precession in chicane	20 mrad	<0.03
Electron detector total		0.56
Grand Total		0.59

A. Narayan, PRX 6, 011013 (2016)

HAPPEX-3

Systematic Errors	
Laser Polarization	0.80%
Analyzing Power:	
Non-linearity	0.3%
Electron Energy Uncertainty	0.1%
Collimator Position	0.05%
MC Statistics	0.07%
Total on Analyzing Power	0.33%
Gain Shift:	
Background Uncertainty	0.31%
Pedestal Uncertainty	0.20%
Total on Gain Shift	0.37%
Total	**0.94%**

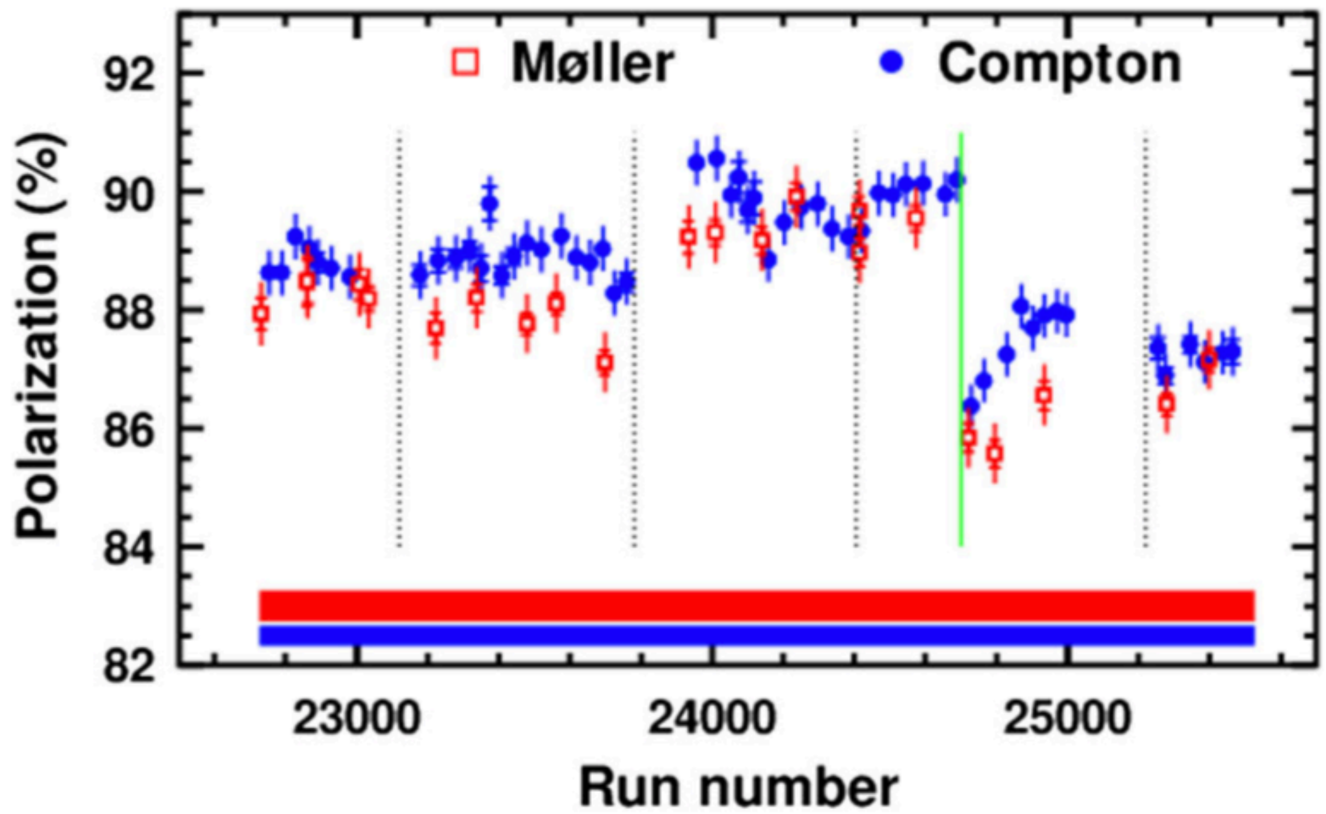
M. Friend, NIM A 676 (2012) 96-105

Goal for MOLLER (2025)

Relative Error (%)	**electron**	**photon**	
Position Asymmetries	-		correlated
E_{beam} and λ_{laser}	0.03		correlated
Radiative Corrections	0.05		correlated
Laser Polarization	0.2		correlated
Background/Deadtime/Pileup	0.2	0.2	uncorrelated
Analyzing Power Calibration / Detector Linearity	0.25	0.35	uncorrelated
Total	0.38	0.45	

Both results have largest contributions from known and solved problems

Hall C Compton and Moller comparison



Over the course of the Qweak run

Agreement within systematic uncertainties

- The experimental program at JLab requires ever higher precision polarimetry
- Recent experience suggests that the polarimeters in the injector and Halls A & C, based on Mott, Compton, and Moller techniques, are on a path to meet this challenge
- One caveat is that our experience at 11 GeV is still limited.
- Cross-comparisons between polarimeters are crucial for robust uncertainty estimates, so redundancy in polarimeters is required. Such tests have led to surprises in the past!