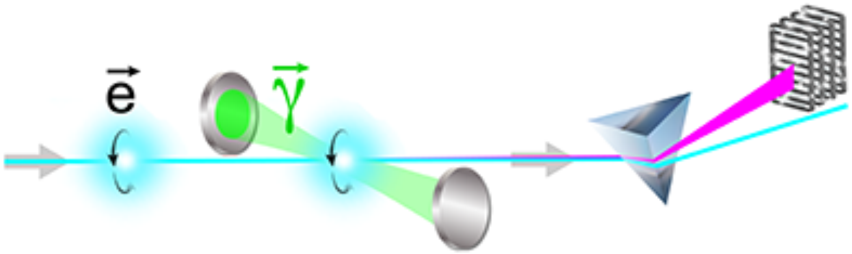
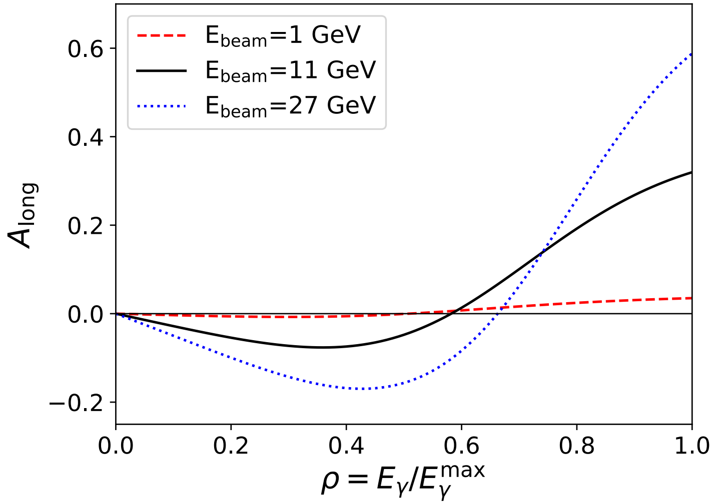
# Electron Polarimetry


Dave Gaskell

Jefferson Lab


EICUG Polarimetry Working Group Meeting

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# Electron Polarimetry Techniques

Common techniques for measuring electron beam polarization

- Mott scattering: $\vec{e} + Z \rightarrow e$, spin-orbit coupling of electron spin with (large Z) target nucleus
  - Useful at MeV-scale (injector) energies
- Møller scattering: $\vec{e} + \vec{e} \rightarrow e + e$, atomic electrons in Fe (or Fe-alloy) polarized using external magnetic field
  - Can be used at MeV to GeV-scale energies – rapid, precise measurements
  - Usually destructive (solid target) – non-destructive measurements possible with polarized gas target, but not commonly done
- Compton scattering: $\vec{e} + \vec{\gamma} \rightarrow e + \gamma$, laser photons scatter from electron beam
  - Easiest at high energies
  - Non-destructive, but systematics are energy dependent

Other polarimetry techniques

- Spin-light polarimetry – use analyzing power from emission of synchrotron radiation
- Compton transmission polarimetry

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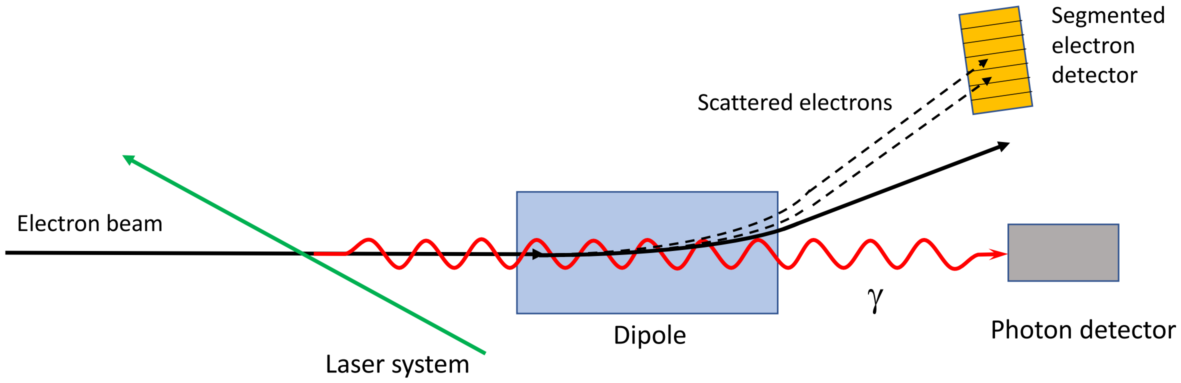
# Compton Polarimetry




| Polarimeter | Energy | Sys. Uncertainty |
|---|---|---|
| CERN LEP* | 46 GeV | 5% |
| HERA LPOL | 27 GeV | 1.6% |
| HERA TPOL* | 27 GeV | 2.9% |
| SLD at SLAC | 45.6 GeV | 0.5% |
| JLAB Hall A | 1-6 GeV | 1-3% |
| JLab Hall C | 1.1 GeV | 0.6% |

Compton polarimetry has been used extensively in both fixed-target and collider environments – standard technique in storage rings since it is non-destructive

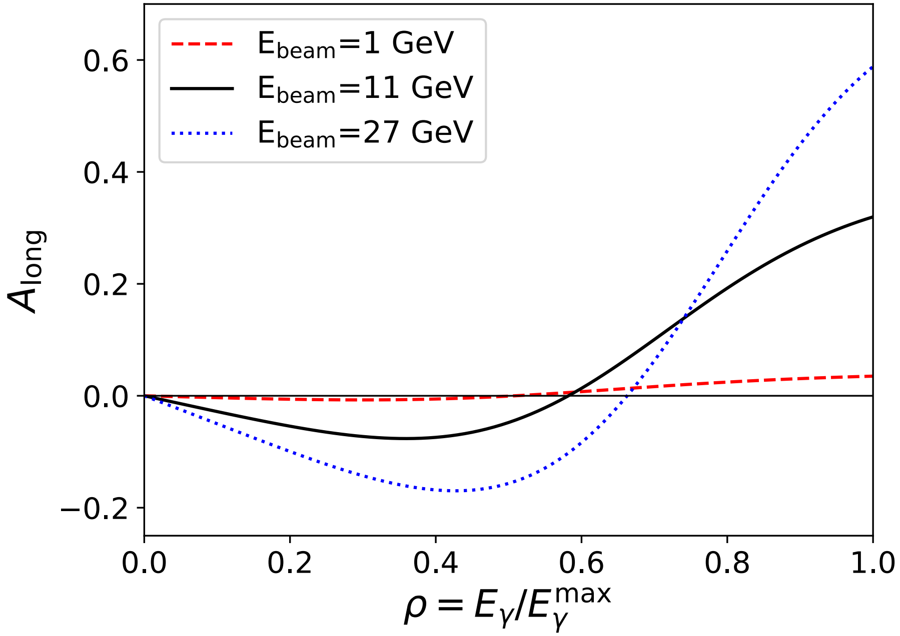
→ Highest precision has been achieved using electron detection, for longitudinally polarized electrons

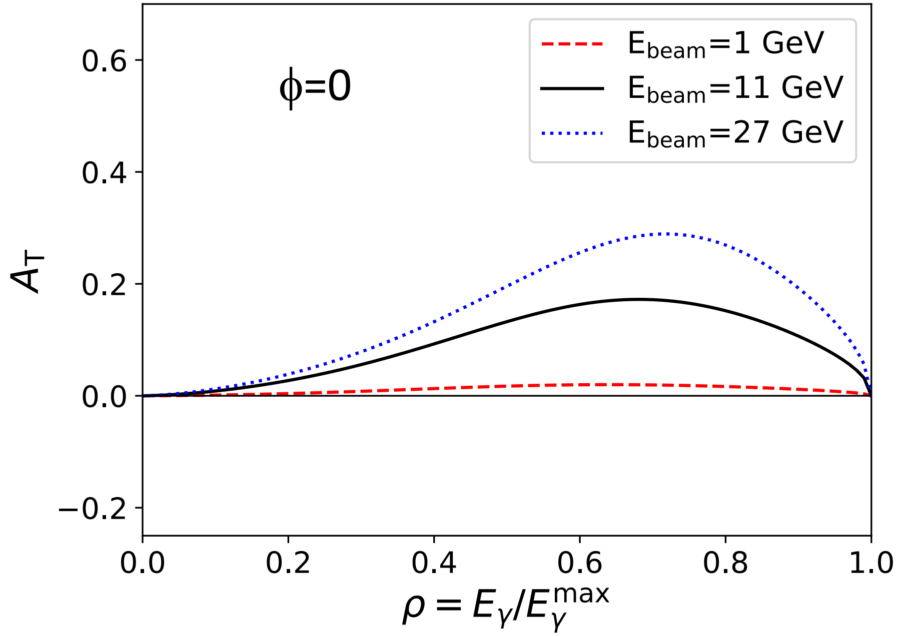
# Polarization Measurement via Compton Polarimetry

Compton polarimetry can be used to measure both longitudinal and transverse electron beam polarization

$$A_{\rm long} = \frac{2\pi r_o^2 a}{(d\sigma/d\rho)}(1-\rho(1+a))\left[1-\frac{1}{(1-\rho(1-a))^2}\right]$$

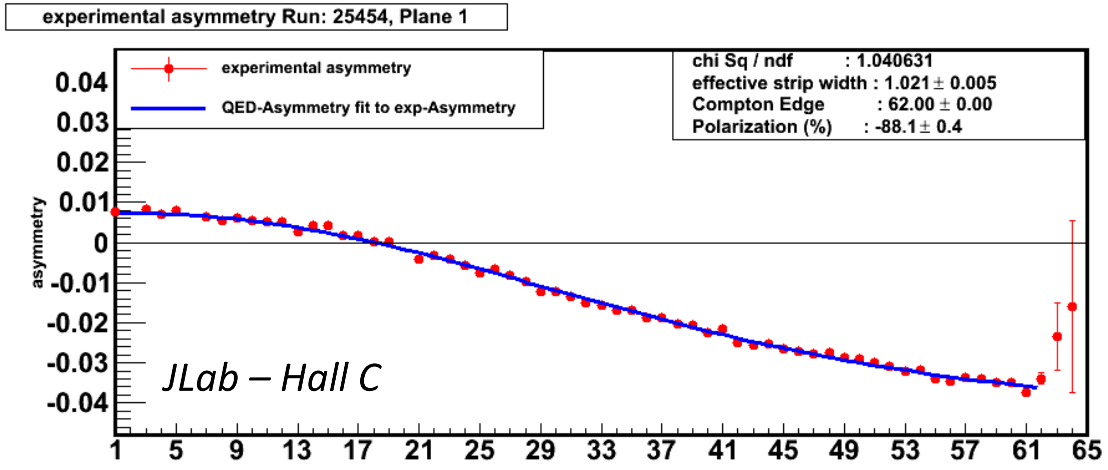
$$A_{\rm T} = \frac{2\pi r_o^2 a}{(d\sigma/d\rho)}\cos\phi\left[\rho(1-a)\frac{\sqrt{4a\rho(1-\rho)}}{(1-\rho(1-a))}\right]$$



# Polarization Measurement via Compton Polarimetry

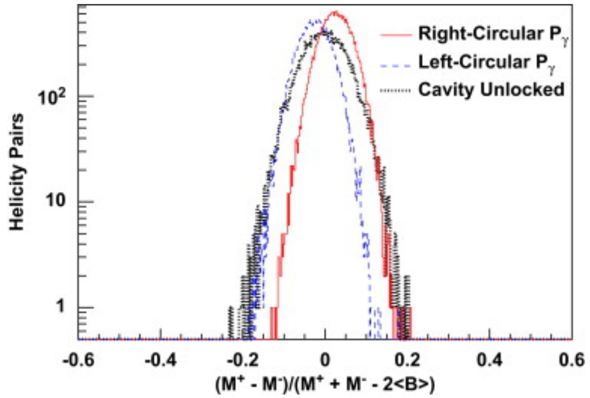
Longitudinal polarization measured via counting asymmetry vs. energy, or energy-integrated asymmetry



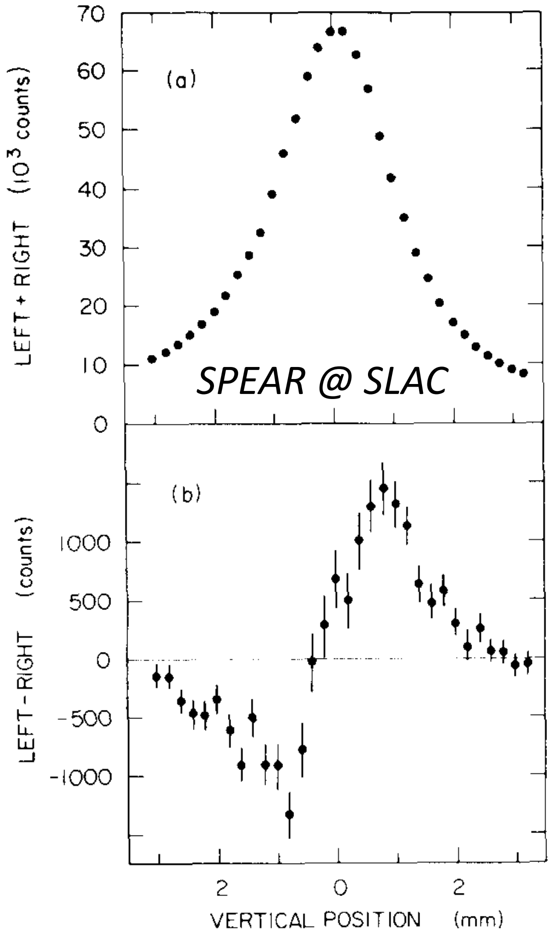

Detector strip # → Scattered electron energy

Photon-energy weighted asymmetry

*JLab – Hall A*




Transverse polarization typically measured via spatial dependence (up-down) of asymmetry



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# Precision Compton Polarimetry – Electron Detection

Highest precision has been achieved using electron detection

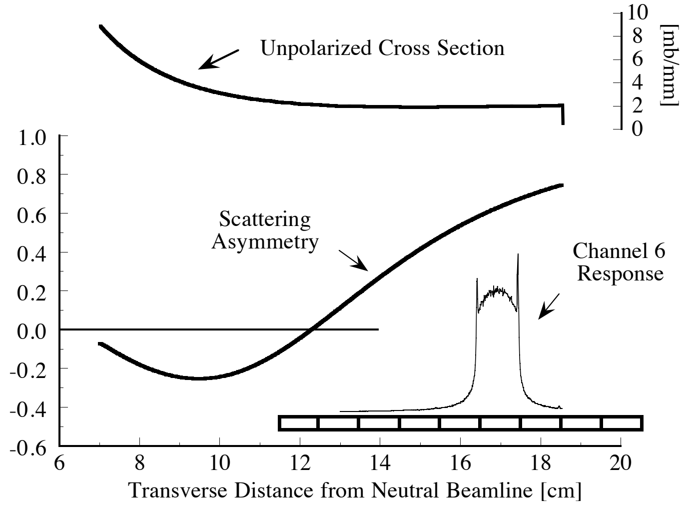
- SLD Compton → dP/P = 0.5%
- JLab Hall C Compton → dP/P = 0.59%

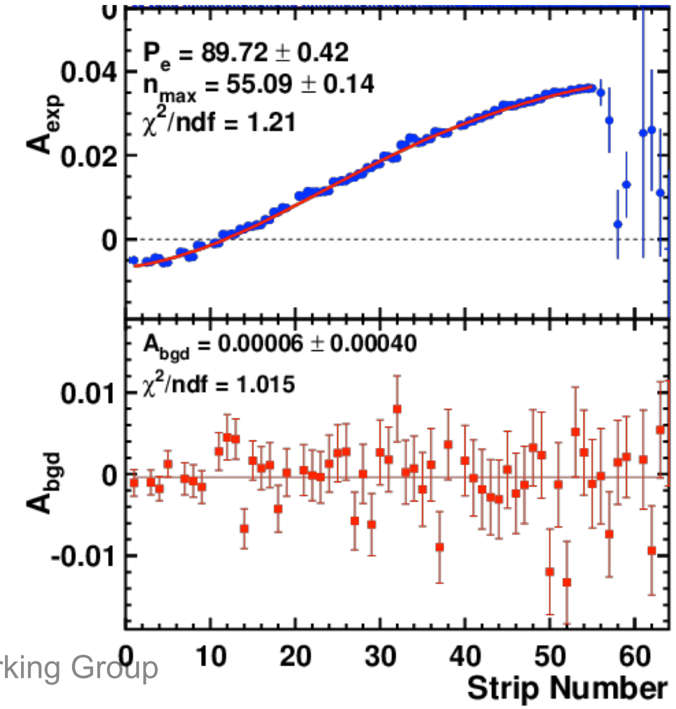
In both cases, Compton spectrum (kinematic endpoint + zero-crossing) used to calibrate detector

SLD Compton operated in low duty-cycle, "multiphoton" mode, Hall C in CW, single photon mode

| | SLD | Hall C (electron) |
|---|---|---|
| Properties | | |
| Beam energy | 45.6 GeV | 1.16 GeV |
| Endpoint $A_{long}$ | 74.7% | 4.06% |
| Laser system | 532 nm, pulsed | 532 nm, FP cavity |
| Detector | Cherenkov | Diamond strip |
| Scheme | Multiphoton | Differential |
| Uncertainties | $dP/P$ (%) | |
| Laser polarization | 0.10 | 0.18 |
| Detector response (linearity, gain) | 0.20 | 0.1 |
| Analyzing power determination | 0.40 | 0.27 |
| DAQ and electronics related | 0.20 | 0.48 |
| Total | 0.50 | 0.59 |

SLAC - SLD



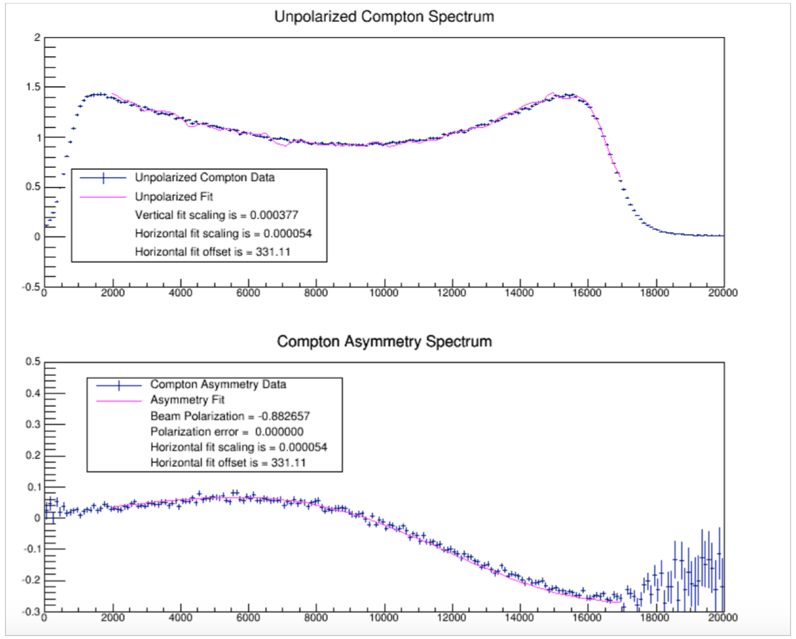




JLab – Hall C

# Precision Compton Polarimetry - Photon Detection

Precision measurements with photon detection challenging due to need to understand detailed detector response
→ Low energy (discriminator or other) threshold can be particularly problematic

High precision at moderate energies has been achieved using “threshold-less”, energy-integrating techniques (JLab Hall A)
→ Large synchrotron backgrounds at EIC may make this technique not feasible




| Hall A Compton Systematic Errors | |
|---|---|
| Laser Polarization | 0.80% |
| Signal Analyzing Power: | |
| Nonlinearity | 0.30% |
| Energy Uncertainty | 0.10% |
| Collimator Position | 0.05% |
| Analyzing Power Total Uncertainty | 0.33% |
| Gain Shift: | |
| Background Uncertainty | 0.31% |
| Pedestal on Gain Shift | 0.20% |
| Gain Shift Total Uncertainty | 0.37% |
| Total Uncertainty | 0.94% |

At higher energies – spectrum threshold less important

HERA FP cavity-based LPOL achieved 0.9-1.1% precision with differential measurements in single-photon mode @ 27 GeV
→ Unlikely similar precision can be achieved at lowest energies envisioned for EIC



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# Transverse Compton Polarimetry

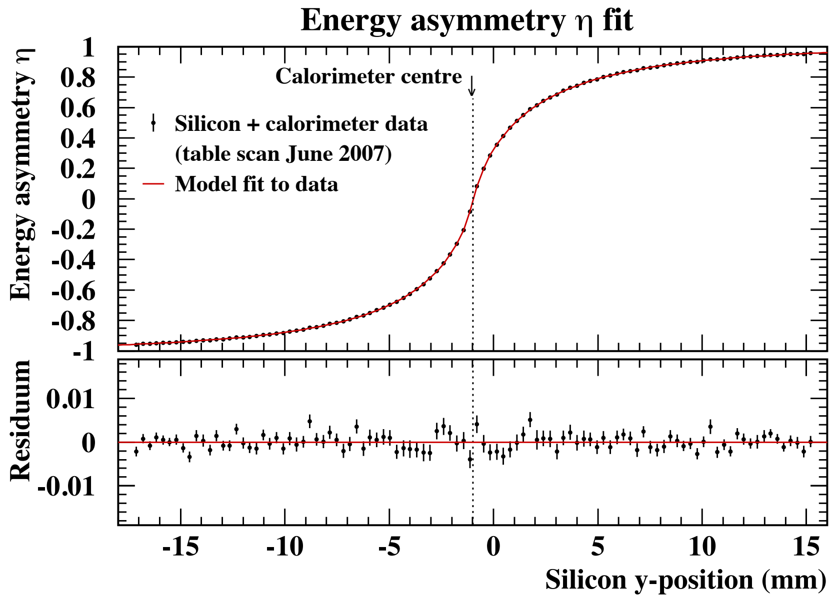
Transverse Compton polarimeters have been relatively common, but not typically used as absolute devices
→ In principle, high precision should be achievable, but fewer examples to learn from
→ Key difference from longitudinal case is need to measure spatial dependence of asymmetry

Most recently, transverse Compton at **HERA** was used to provide absolute polarization measurements with 2-3% precision

Used a sampling calorimeter with top and bottom optically isolated:
→ Polarization measured via up-down energy asymmetry

$$\eta = \frac{E_U - E_D}{E_U + E_D}$$

Key systematic uncertainty is understanding the *η(y)* transformation function
→ Strip detectors provide can be used to help calibrate the detector response
→ With careful polarimeter design, high precision transverse measurements should be achievable




*B. Sobloher et al, DESY-11-259 , arXiv:1201.2894*

# Implementation of Compton Polarimetry at EIC

EIC will provide high intensity beams (>2 A) at high repetition rates – this provides benefits and challenges

→ High intensity yields rapid measurements, but at the same time, large backgrounds – synchrotron radiation

→ Nearly CW beams so polarimeters can be operated in single-photon mode – probably yields better systematic uncertainties

| Energy (GeV) | Current (A) | Polarization (%) | Frequency (MHz) |
|---|---|---|---|
| **JLEIC** | | | |
| 3 | 2.8 | 80 | 476 |
| 5 | 2.8 | 80 | 476 |
| 10 | 0.71 | 75 | 476 |
| **eRHIC** | | | |
| 5 | 2.5 | 70 | 112.6 |
| 10 | 2.5 | 70 | 112.6 |
| 18 | 0.26 | 70 | 28.15 |

→ Measurement of polarization for each bunch will be challenging given small bunch spacing. Fast detectors or other scheme required

→ Variable electron beam energy a challenge – difficult to design for high precision for all energies

Plans for Compton polarimetry at JLEIC and eRHIC → JLEIC: Compton polarimeter after IP, measure longitudinal polarization
eRHIC: Measure transverse polarization at dedicated IP

# JLEIC Compton Polarimeter – Chicane and Low $Q^2$ tagger

JLEIC Compton polarimeter will make use of 4-dipole chicane, downstream of interaction region

→ First dipole will be used for low $Q^2$ tagger and for luminosity monitor

→ Net precession is zero from interaction region → center of chicane and from center of chicane → exit

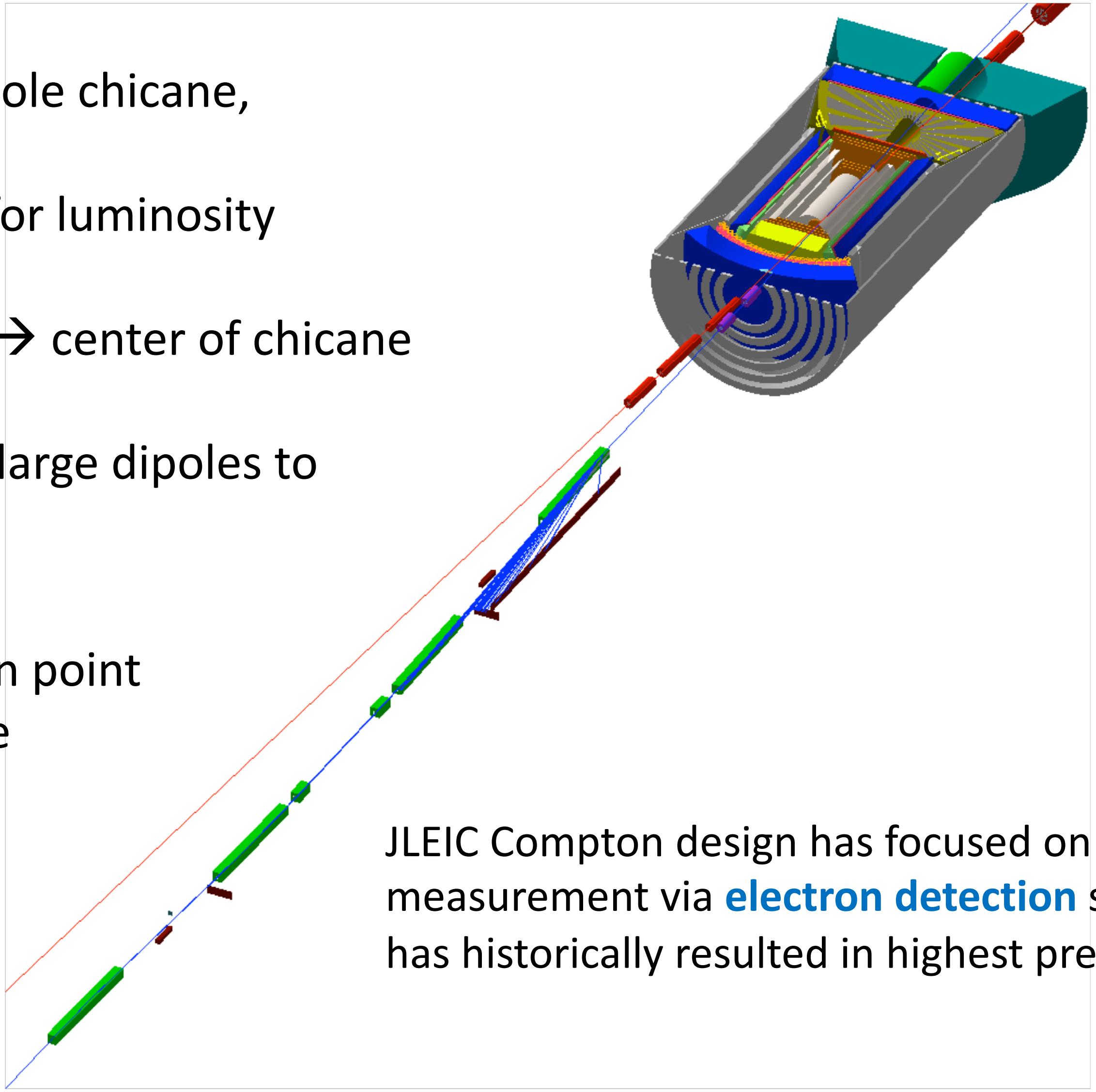
→ Additional small dipoles between 2nd and 3rd large dipoles to moderate synchrotron radiation

Design considerations:

→ Small beam size at detector and laser interaction point

→ Sufficient dispersion/drift to effectively separate Compton scattered electrons from main beam

→ Allow for both electron and photon detection



JLEIC Compton design has focused on measurement via **electron detection** since this has historically resulted in highest precision

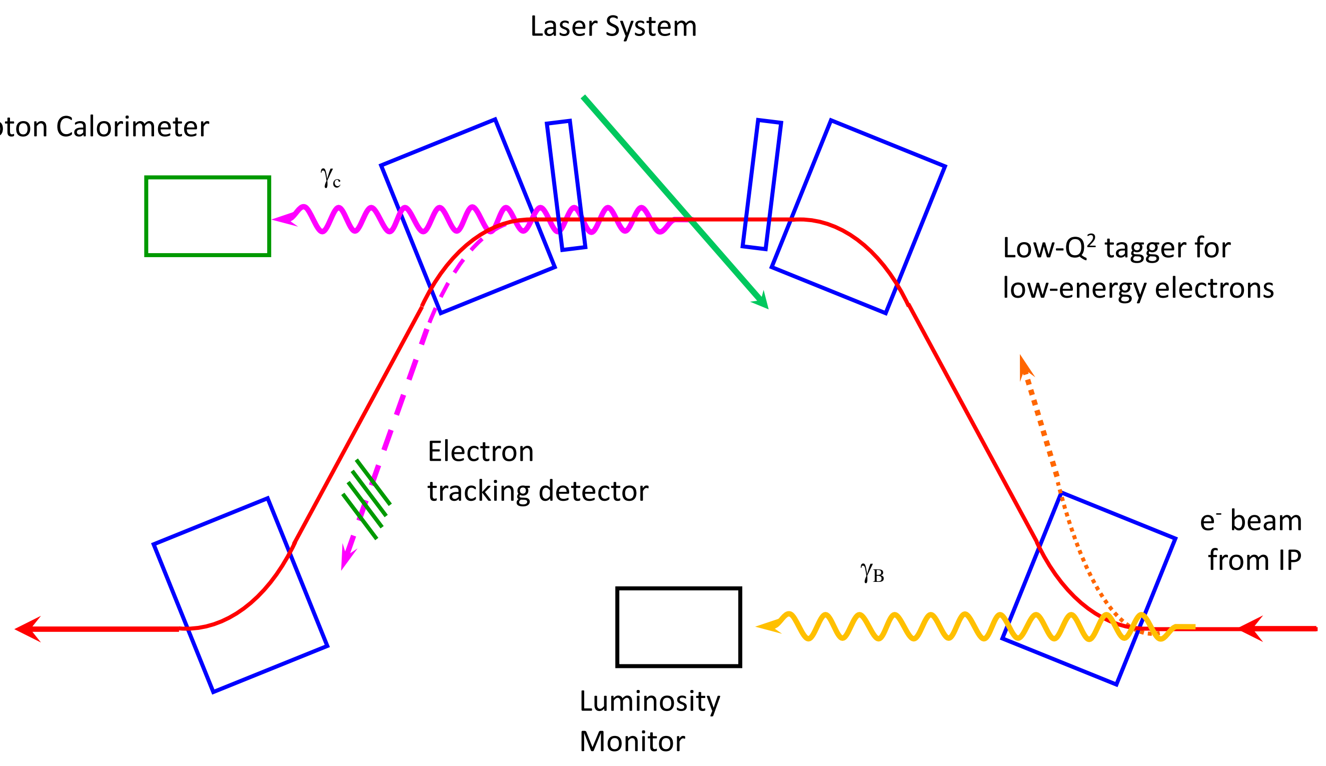
# JLEIC Compton Polarimeter Layout

Overall chicane length ~ 26 meters
→ Large dipole length → 3 m
→ Small dipoles → 0.5 m

Laser-beam interaction region about 3.2 m long
→ Space for either single-pass laser system or Fabry-Pérot cavity

Horizontal beam deflection ~ 30 cm from nominal path

Separation of scattered electron from nominal beam trajectory at kinematic endpoint (asymmetry zero-crossing):
10 GeV → 10.6 cm (5.3 cm)
5 GeV → 5.3 cm (2.6 cm)

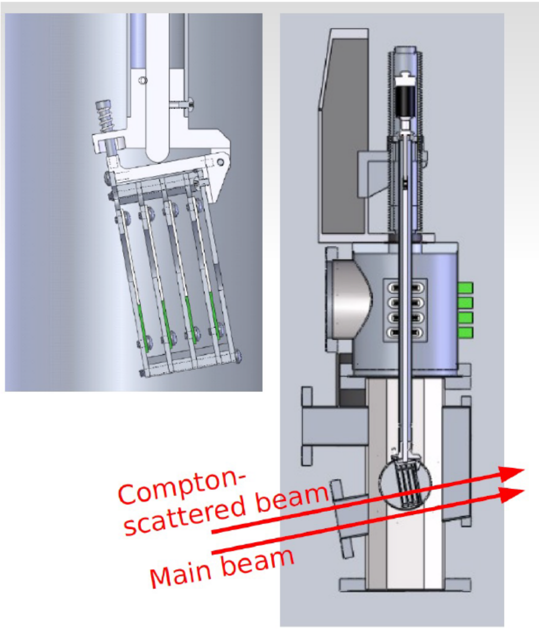


# Compton Electron Detector R&D Project

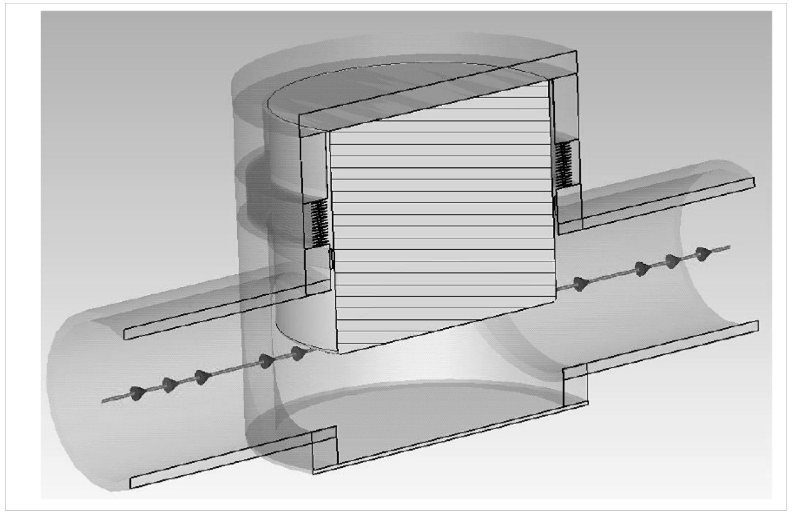
EIC Detector R&D Project for development of electron detection scheme for Compton polarimetry (A. Camsonne, J. Hoskins, et. al.)

→ Default design based on diamond strip detectors similar to those used in Hall C at JLab, but placed in Roman Pot rather than beam vacuum

→ Simulations targeted at understanding backgrounds and studying achievable precision




TOTEM Roman Pot





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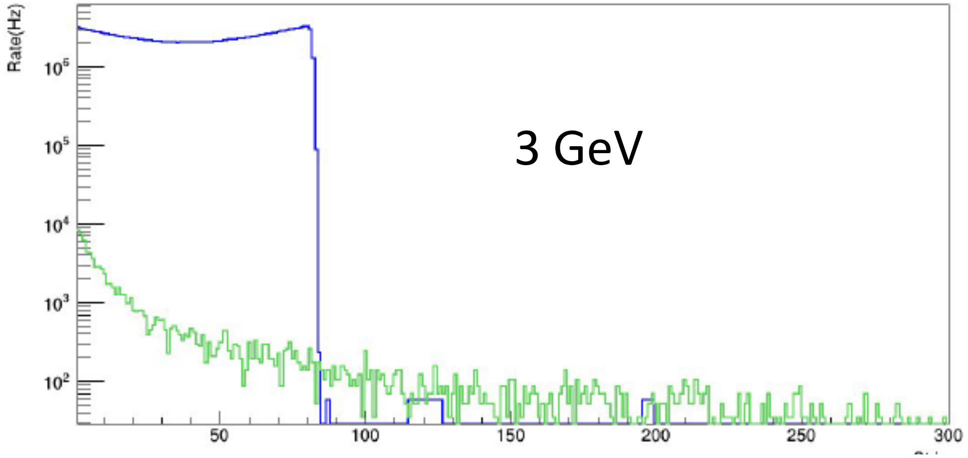
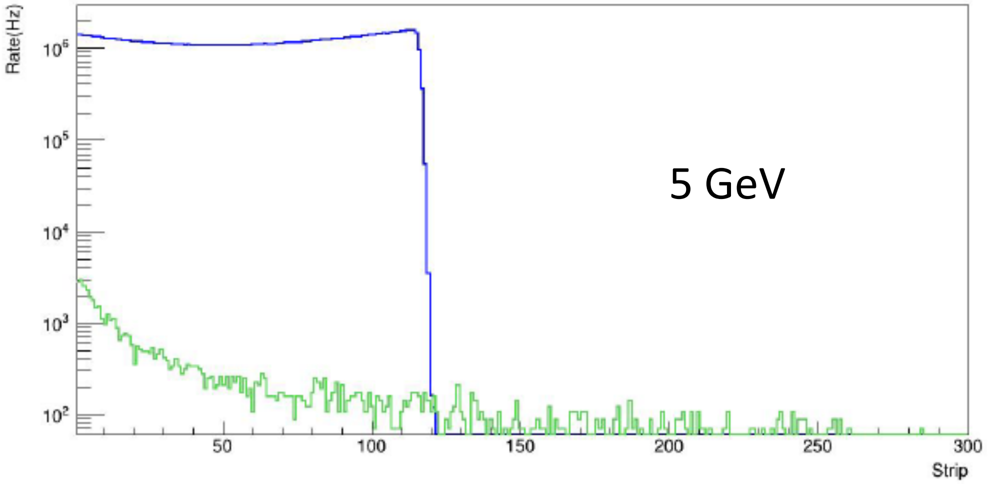
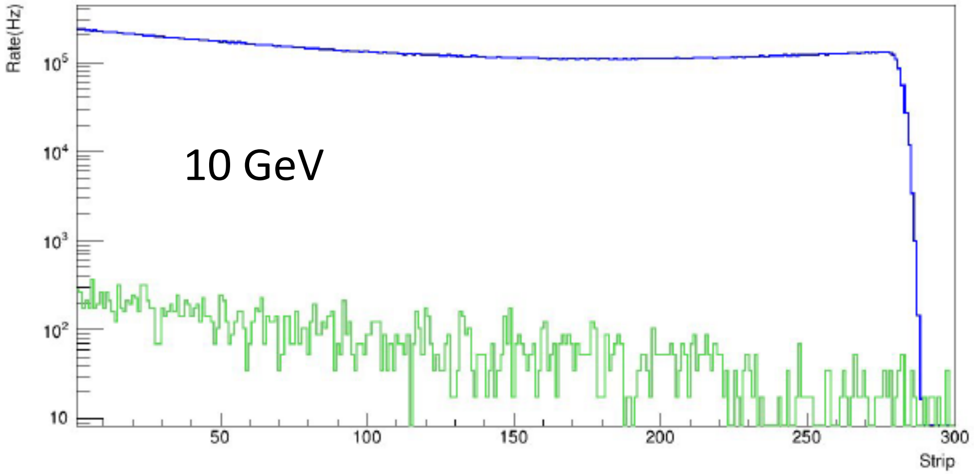
# Compton Signal and Backgrounds at JLEIC

Simulation of backgrounds due to Bremsstrahlung

*A. Camsonne and J. Hoskins – eRD15*




- 1 A electron beam
- $10^{-9}$ torr
- 10 W CW laser
- Bremsstrahlung is ok at all energies



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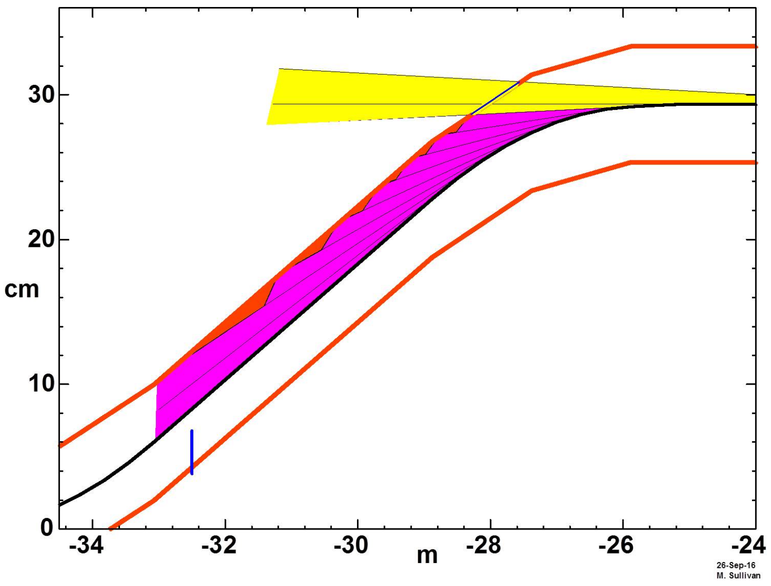
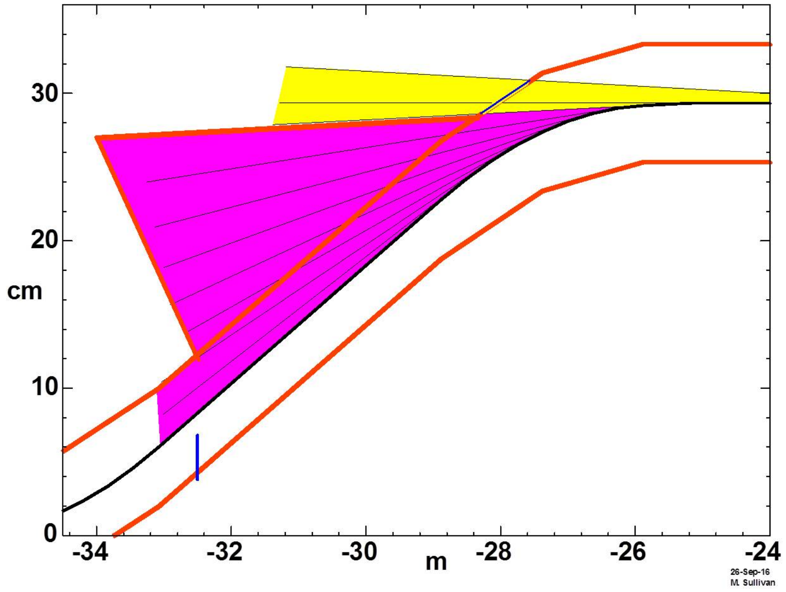
# Synchrotron Radiation

The electron detector is out of the direct fan of synchrotron radiation, but can get backgrounds due to synchrotron bouncing off beam pipe → 10's of kW of power deposited on electron detector




Synchrotron estimates from Mike Sullivan

Synchrotron can be mitigated by possibly using tips in beam pipe or special antechamber

Synchrotron now incorporated in GEMC Monte Carlo – will certify with help of calculations from Mike Sullivan

# Compton Polarimeter Laser

Compton polarimeters at JLab make use of CW lasers coupled to external Fabry-Pérot cavities to provide kW level powers

→ Required at JLab due to relatively low beam currents (10-100 μA) – reduce measurement times to a level practical for testing systematic uncertainties

→ Has benefit of improving signal to noise

JLEIC background studies indicate that Fabry-Pérot cavity not needed to overcome backgrounds, but design incorporates possibility for cavity in case backgrounds larger than expected, or if higher luminosity desired

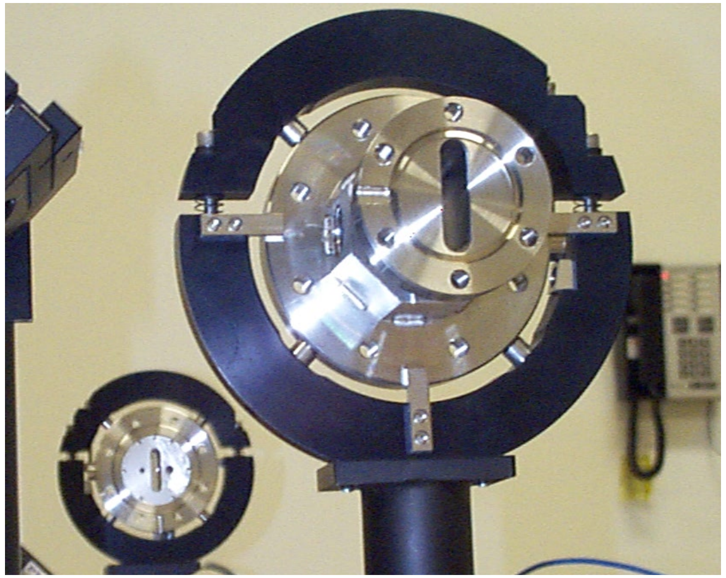
| Energy | Current | 1 pass laser (10 W) | | FP cavity (1 kW) | |
|---|---|---|---|---|---|
| (GeV) | (A) | Rate (MHz) | Time (1%) | Rate (MHz) | Time (1%) |
| 3 GeV | 3 | 26.8 | 161 ms | 310 | 14 ms |
| 5 GeV | 3 | 16.4 | 106 ms | 188 | 9 ms |
| 10 GeV | 0.72 | 1.8 | 312 ms | 21 | 27 ms |

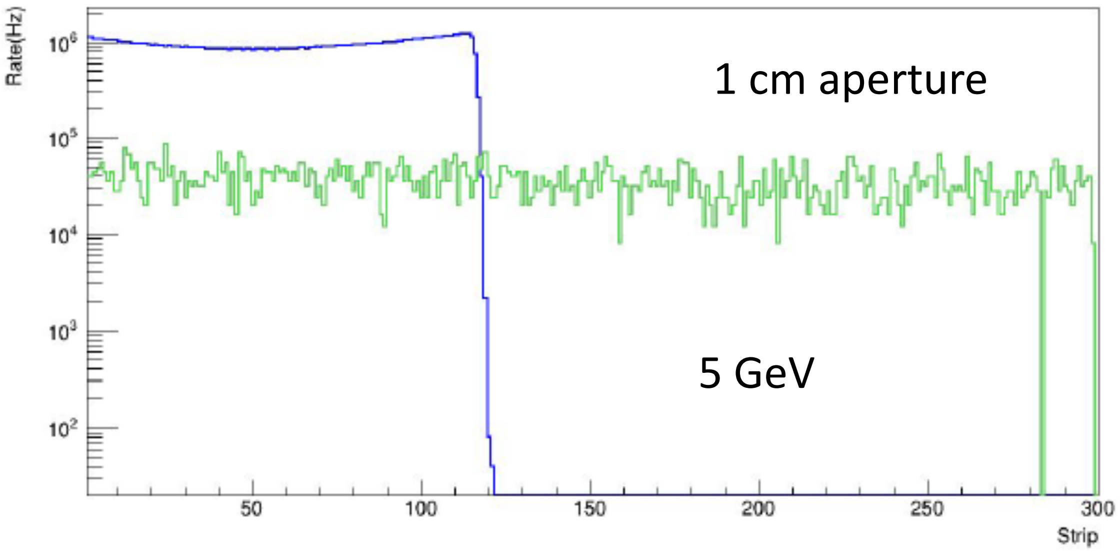
With single-pass, CW laser, measurement times very short. FP cavity measurements might require novel detector technology to handle high rates at 3 and 5 GeV

# Halo contribution for apertures

Fabry-Pérot cavity (if needed) requires narrow apertures to protect low-loss cavity mirrors
→ This can lead to background due to halo interacting with these apertures

Simulations indicate that signal to noise is 10:1 with 1 cm aperture
→ Cavity can easily accommodate larger apertures
→ At 4 cm, no contribution due to beam halo with present model






→ Beam halo near electron detector also relevant

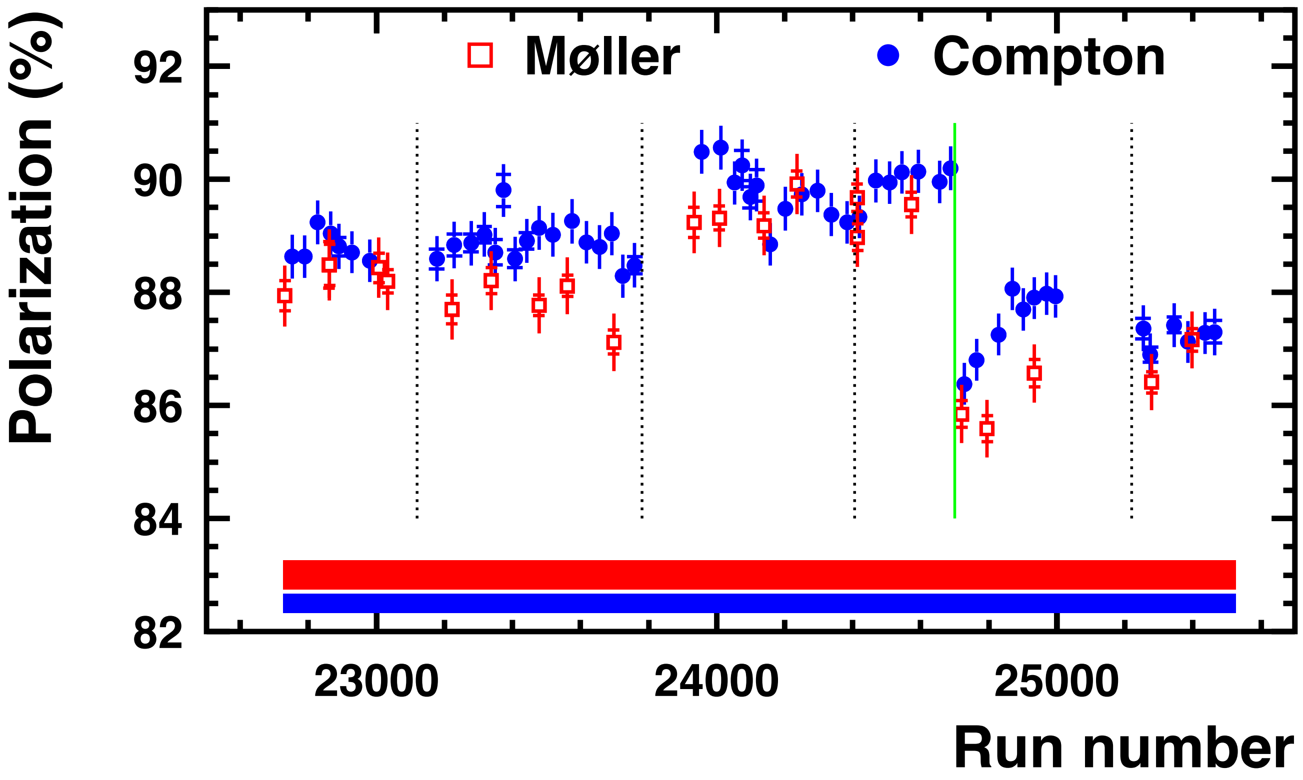
# Beyond Compton Polarimetry at EIC

Precision polarimetry benefits greatly from multiple techniques

→ Robust check of systematic uncertainties
→ Helps diagnose potential issues with polarimeters more quickly

JLab – Mott, Møller, and Compton polarimetry play important role in accelerator setup and experiments

EIC would also benefit from multiple techniques/devices




JLab – Hall C: Polarization measurements during Q-Weak

# Mott Polarimetry

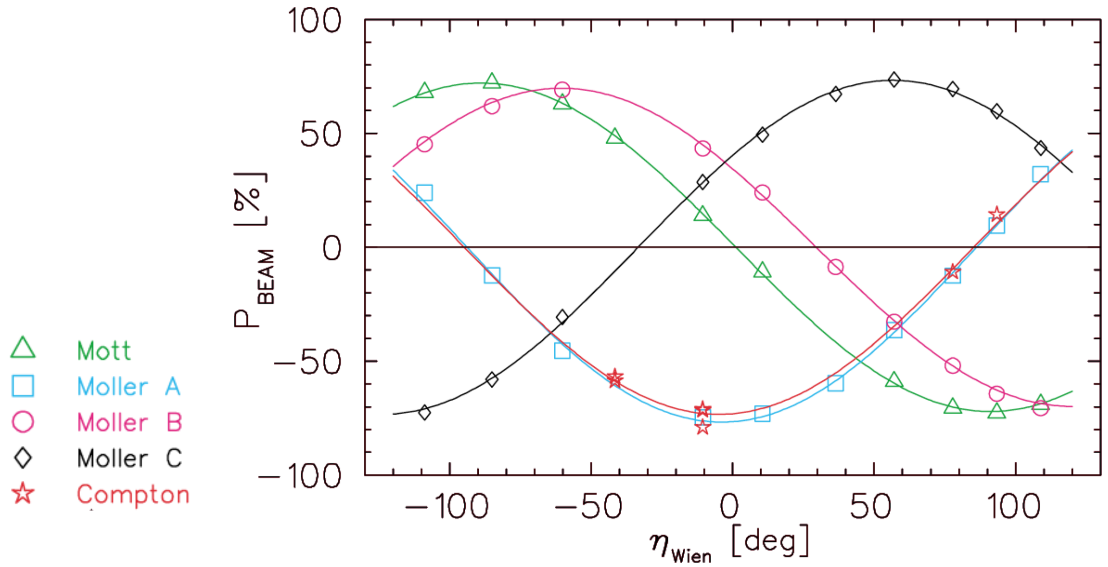
Mott polarimetry a crucial tool at accelerators with polarized electron sources

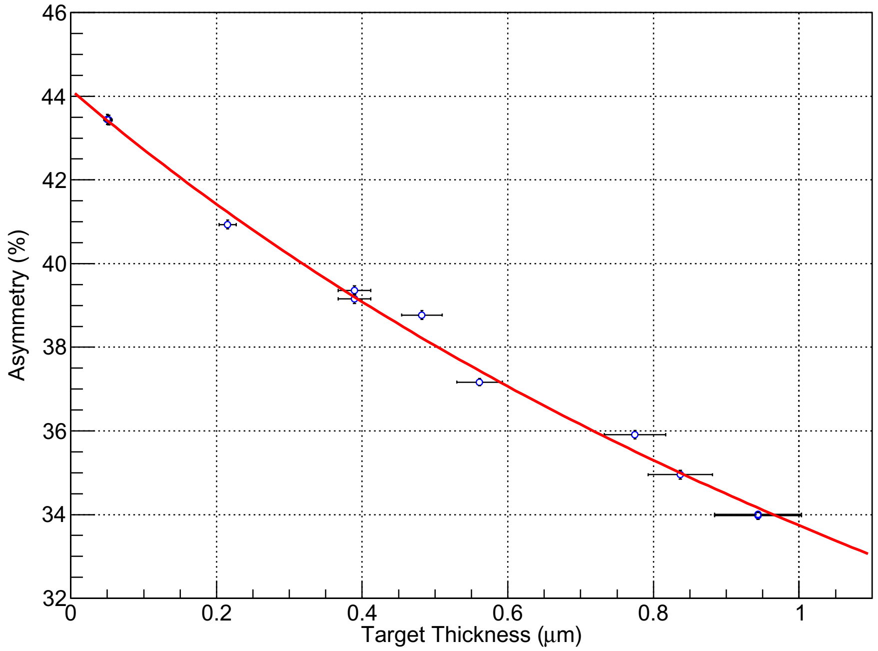
→ Relatively easy to implement – uses single-spin asymmetry so no polarized targets

→ Can be implemented near the electron source – direct measurement of source performance

→ In the MeV-regime, Mott polarimeters can achieve high precision (1%) → dominant systematic comes from knowledge of Sherman function. Improved extrapolation techniques are reducing this uncertainty

→ Provides useful cross-check of measurements at experiment




→ In context of EIC, Mott will play the same important role



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# Møller Polarimetry

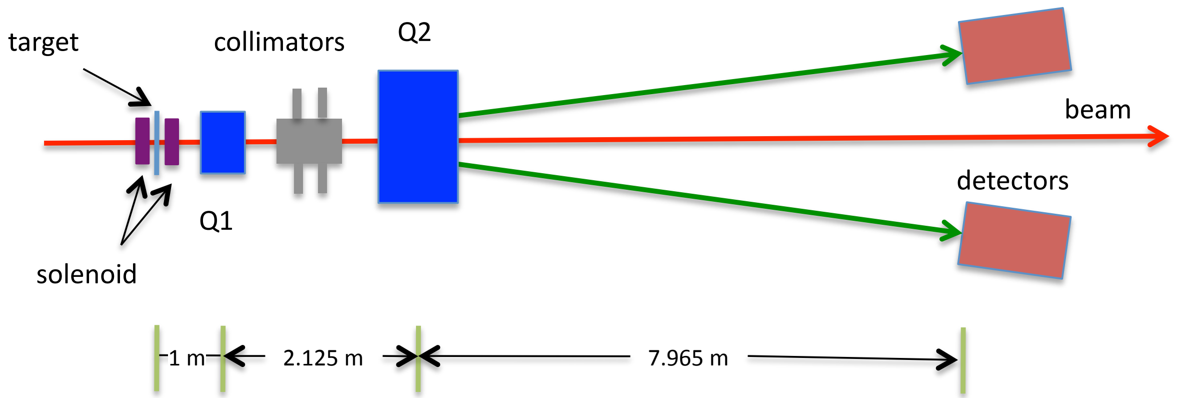
Møller Polarimetry common at fixed target facilities

→ Large analyzing power

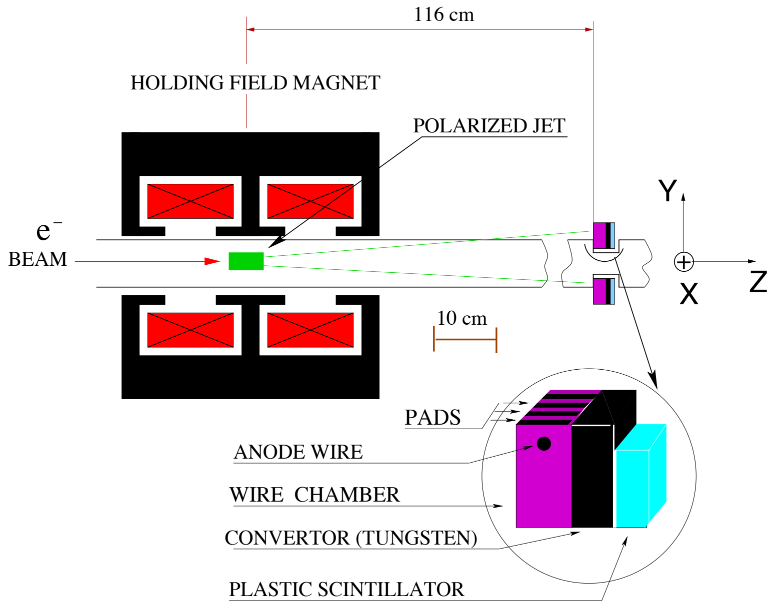
→ Analyzing power essentially independent of beam energy

→ Background-free (coincidence detection of scattered and recoiling electron)

→ Drawback for EIC: measurement is "destructive" – foil target typically used. At first glance, not compatible with storage ring




Møller Polarimetry at EIC could be pursued with a jet target




VEPP-3

Issues to consider:

→ Systematic uncertainty on target polarization

→ Backgrounds

→ Ultimate precision

*A. Grigoriev et al, Proceedings of EPAC 2004*

# Summary

- Compton Polarimetry is the clear technique of choice for electron polarimetry at EIC
  - Mott polarimetry required for characterization of the source – can also be used to provide cross-check with Compton
  - Additional techniques at full beam energy would be desirable to check systematics – Møller polarimetry with jet targets?
  - In absence of alternate technique, multiple devices would be helpful
- High precision (1%) Compton polarimetry has been achieved – but EIC presents novel and challenging operating conditions
- Areas of future study
  - Further characterization of backgrounds – especially synchrotron radiation
  - Realistic model of beam halo
  - Fast detectors or other options for possible bunch-by-bunch measurements
  - Precision transverse Compton polarimetry
  - Simultaneous measurement of longitudinal and transverse polarization components

# Extra

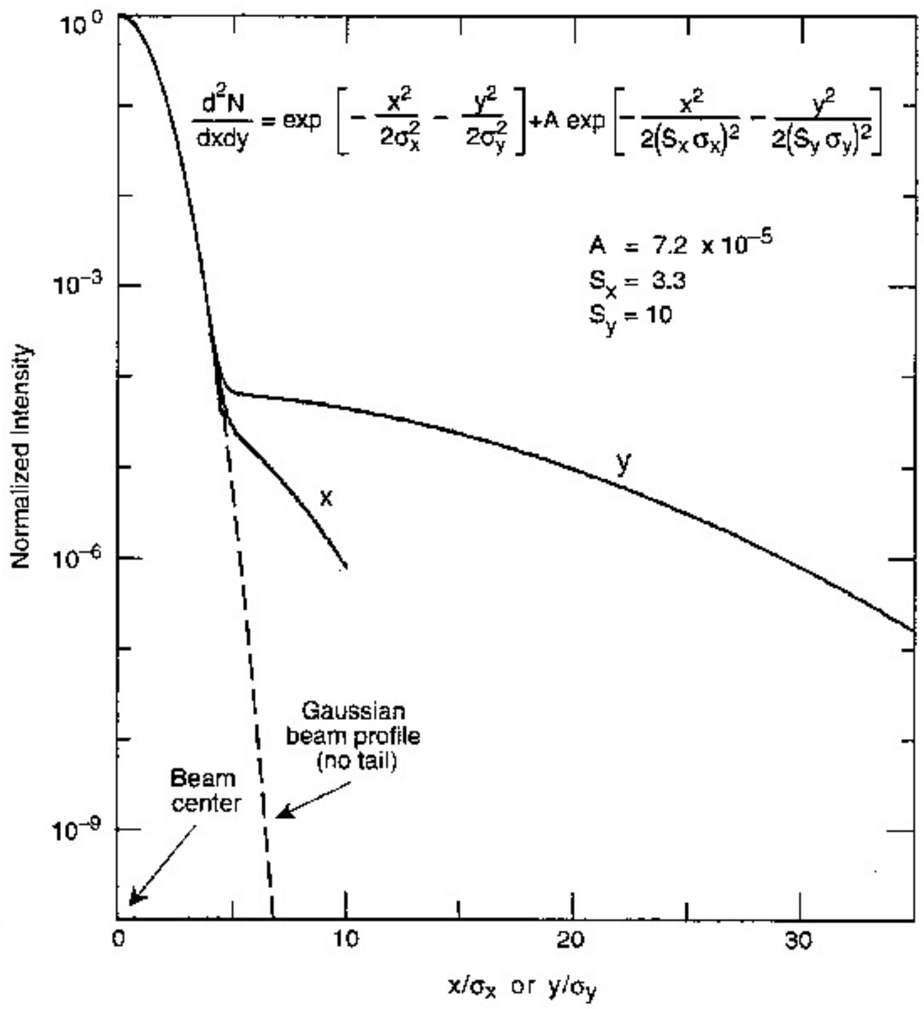
# Halo

JLEIC Compton simulations use description of beam halo from PEP-II design report

Halo flux is about 0.25% of total beam flux

Backgrounds due to halo can contribute in two locations

1. Interactions with cavity apertures
2. Direct strike of electron detector



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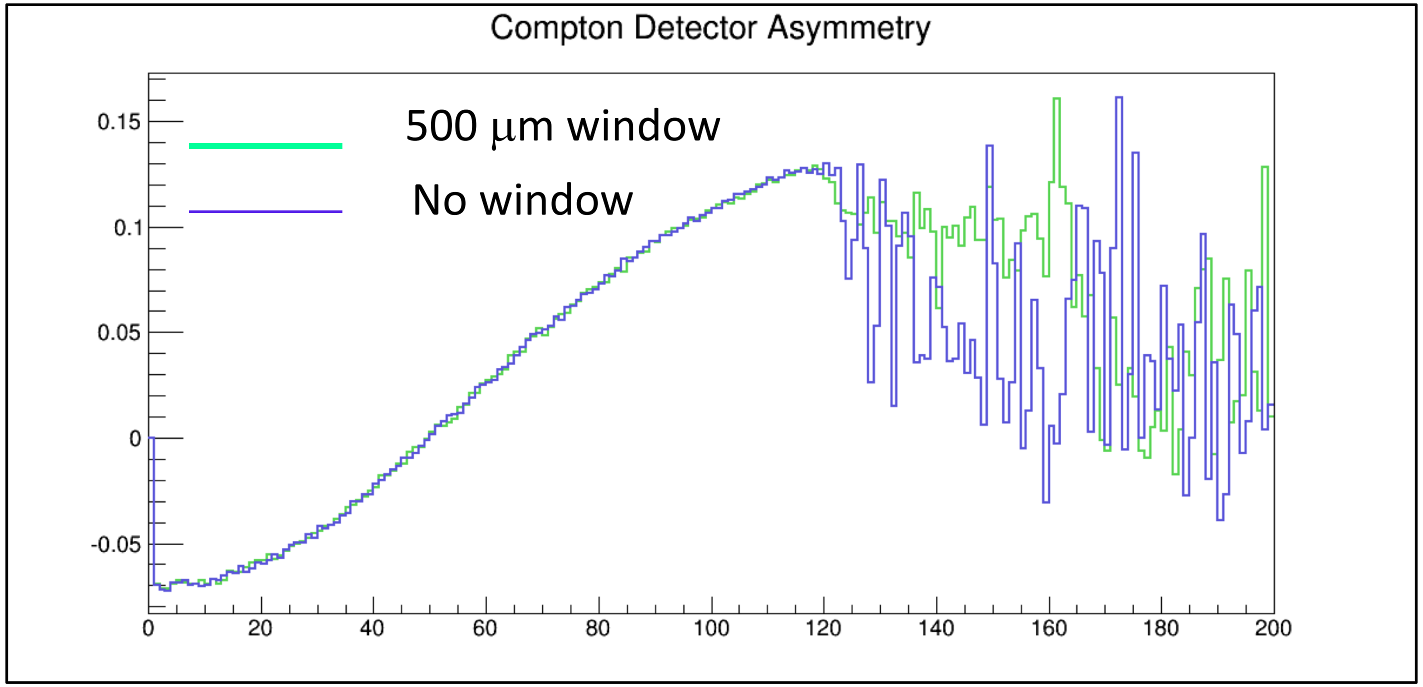
# Effect of Roman Pot Window

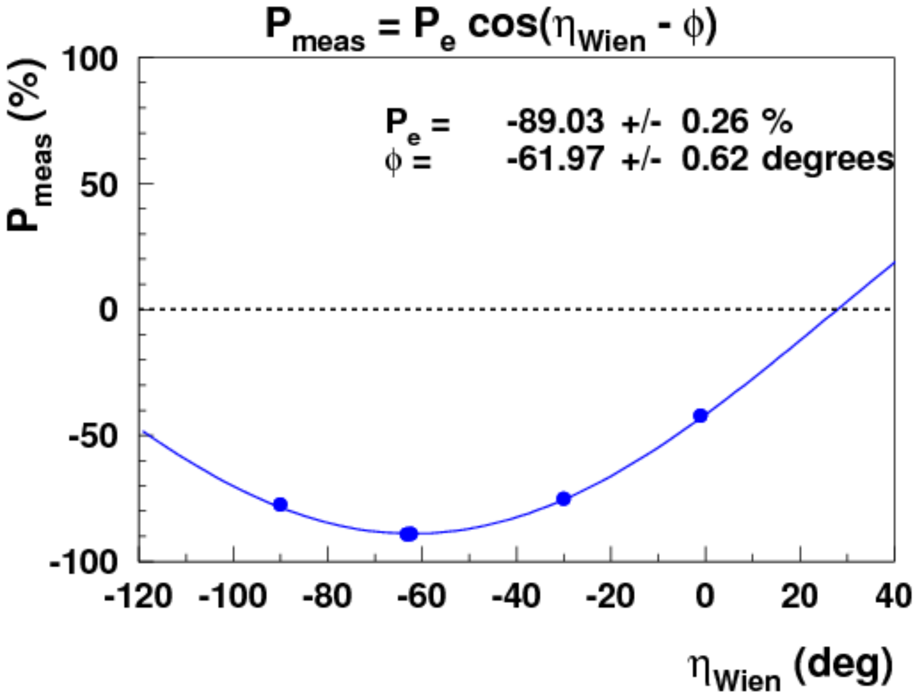
- Hall C/Hall A electron detectors share same vacuum space as electrons
- At EIC, high currents require that detector lives in separate (shielded) space
- Extra material potentially has impact on extracted polarization due to multiple scattering
  - Effect observed in Hall C when using multiple detector planes
- Effect of window not large - some polarization correction at 3 and 5 GeV will be required at larger thickness
- Consistent with input polarization of 97% within 1% uncertainty

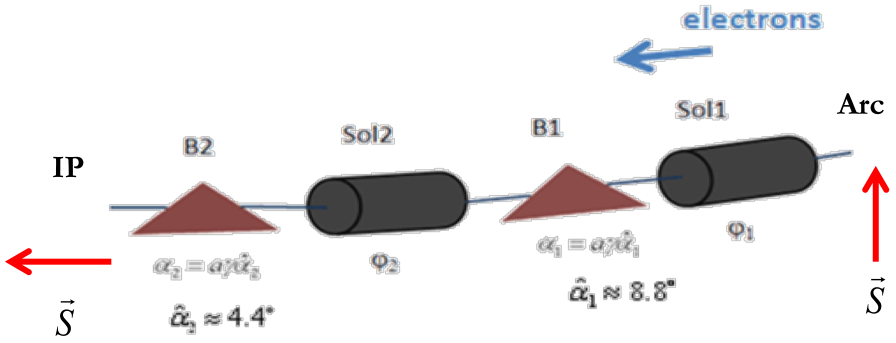



*A. Camsonne and J. Hoskins –eRD15*

# Polarization Direction Optimization

Electron polarization direction set using Universal Spin Rotator (USR)
→ Nominal: Vertical in arcs, longitudinal at IP/Compton

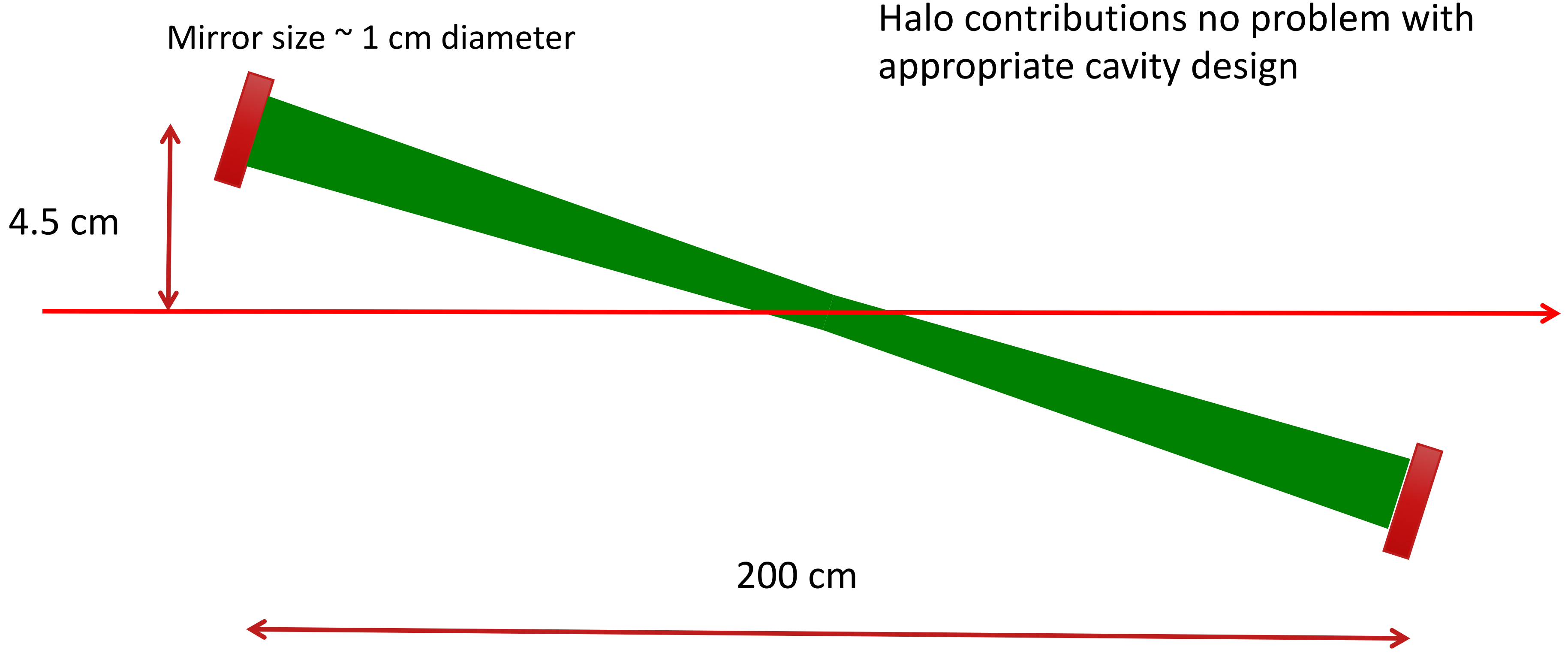



USR can be used to manipulate spin arbitrarily
→ Using Compton polarimeter we can measure longitudinal polarization as a function of in-plane and out-of-of-plane spin angles
→ Maximize measured asymmetry to verify settings for longitudinal polarization
→ "Spin-dance" - routinely done at JLab (using Wien filter at injector) to verify spin setup

# Fabry-Perot Cavity Design

Halo contributions no problem with appropriate cavity design

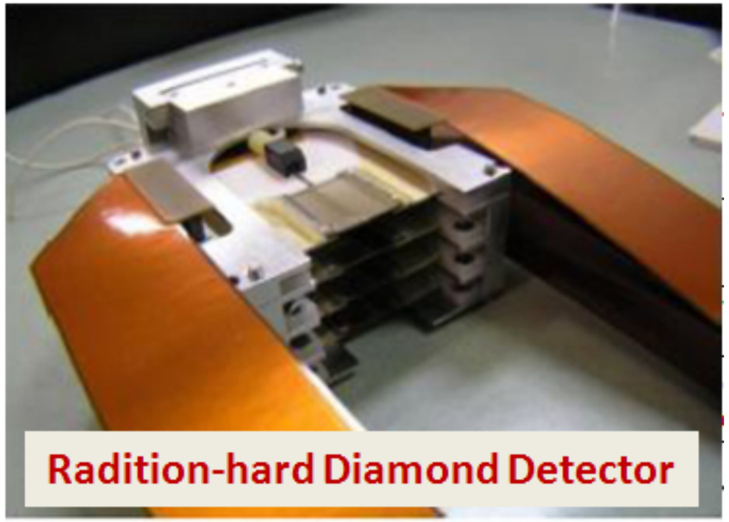


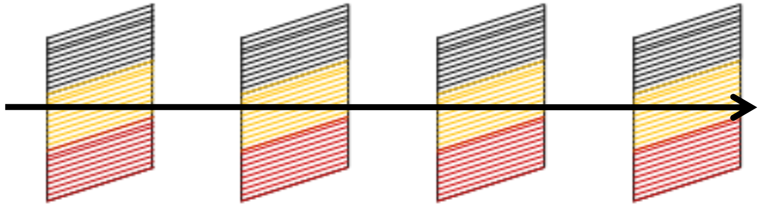

Electron-laser crossing angle = 2.58 degrees
Mirror radius of curvature = 120 cm
Laser size at cavity center $(\sigma_x,\sigma_y)$ = 151.4 um

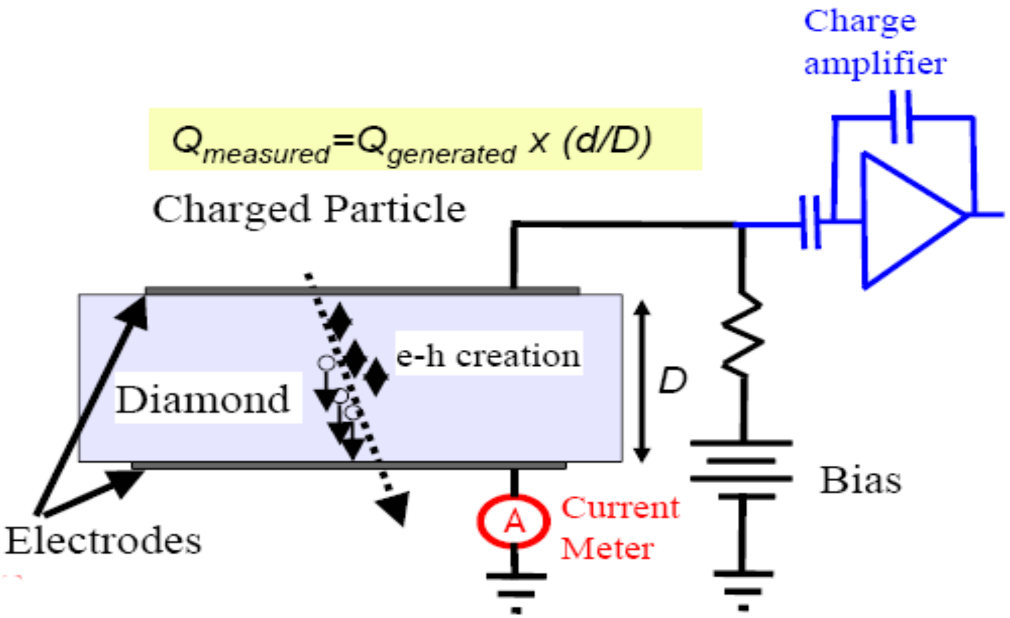
Cavity gains of 1000-5000 easily achievable

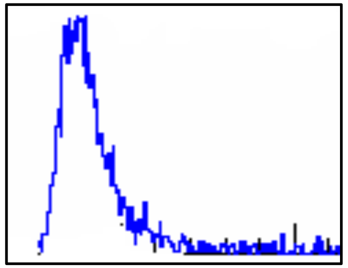
# Hall C Compton Electron Detector

Diamond microstrips used to detect scattered electrons
→ Radiation hard: exposed to 10 MRad without significant signal degradation
→ Four 21mm x 21mm planes each with 96 horizontal 200 µm wide microstrips.
→ Rough-tracking based/coincidence trigger suppresses backgrounds



(D. Dutta Missipi State University)