Overview of Polarimetry at EIC

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Electroweak and BSM physics at the EIC

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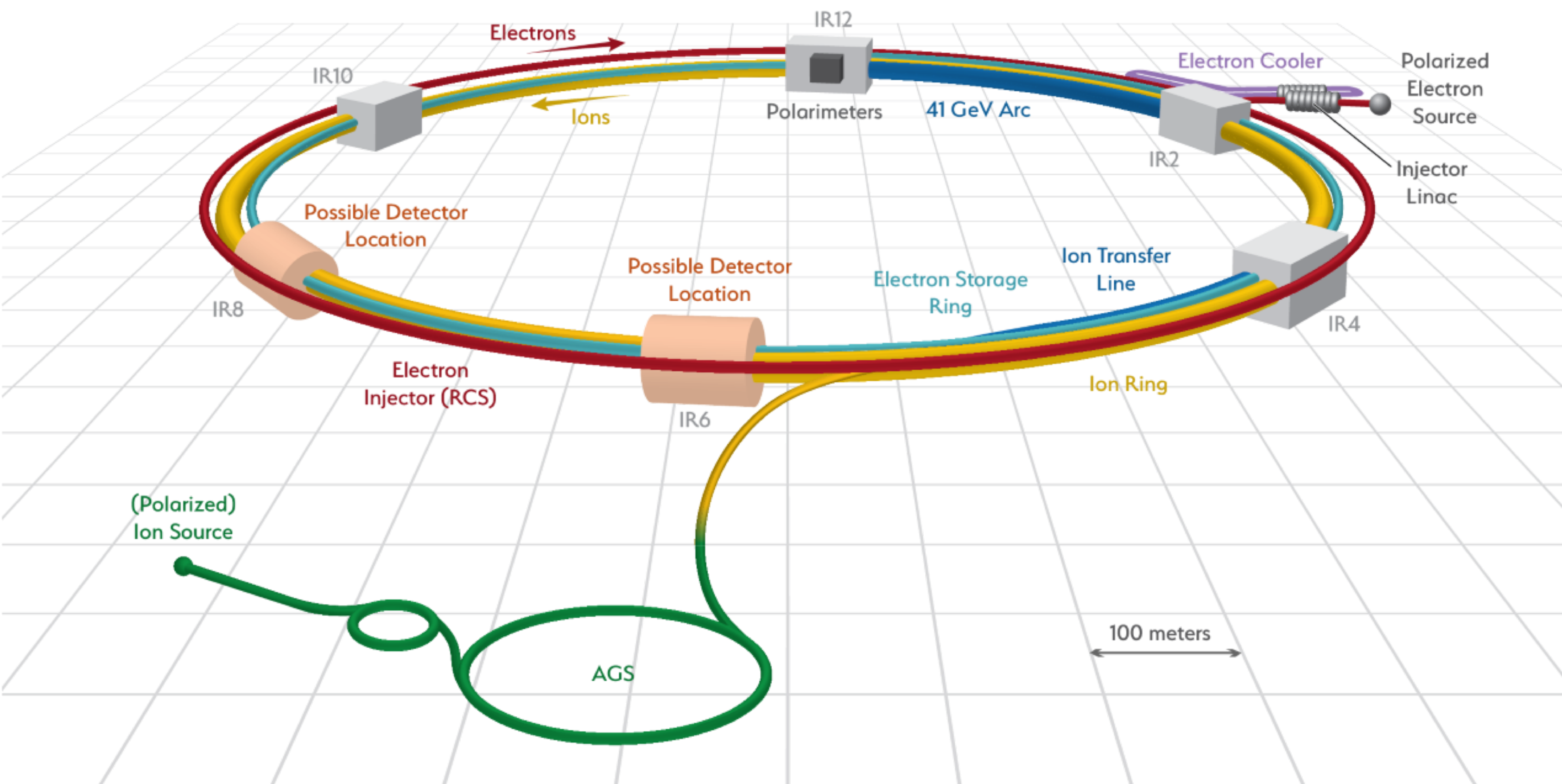
Polarimetry Requirements

- Precise knowledge of hadron and electron beam polarization desired to match excellent statistical precision that will be achieved at EIC
  - $\frac{dP}{P} = 1\%$ for both hadrons and electrons
- Additional requirements
  - Measurement of polarization bunch-by-bunch
  - Ability to measure "polarization profile" – transverse and longitudinal
  - Rapid measurements to track time-evolution of polarization
- Should measure polarization at multiple locations to facilitate machine setup and characterization
  - Source
  - Acceleration
  - Steady-state in ring

Polarimetry Strategy

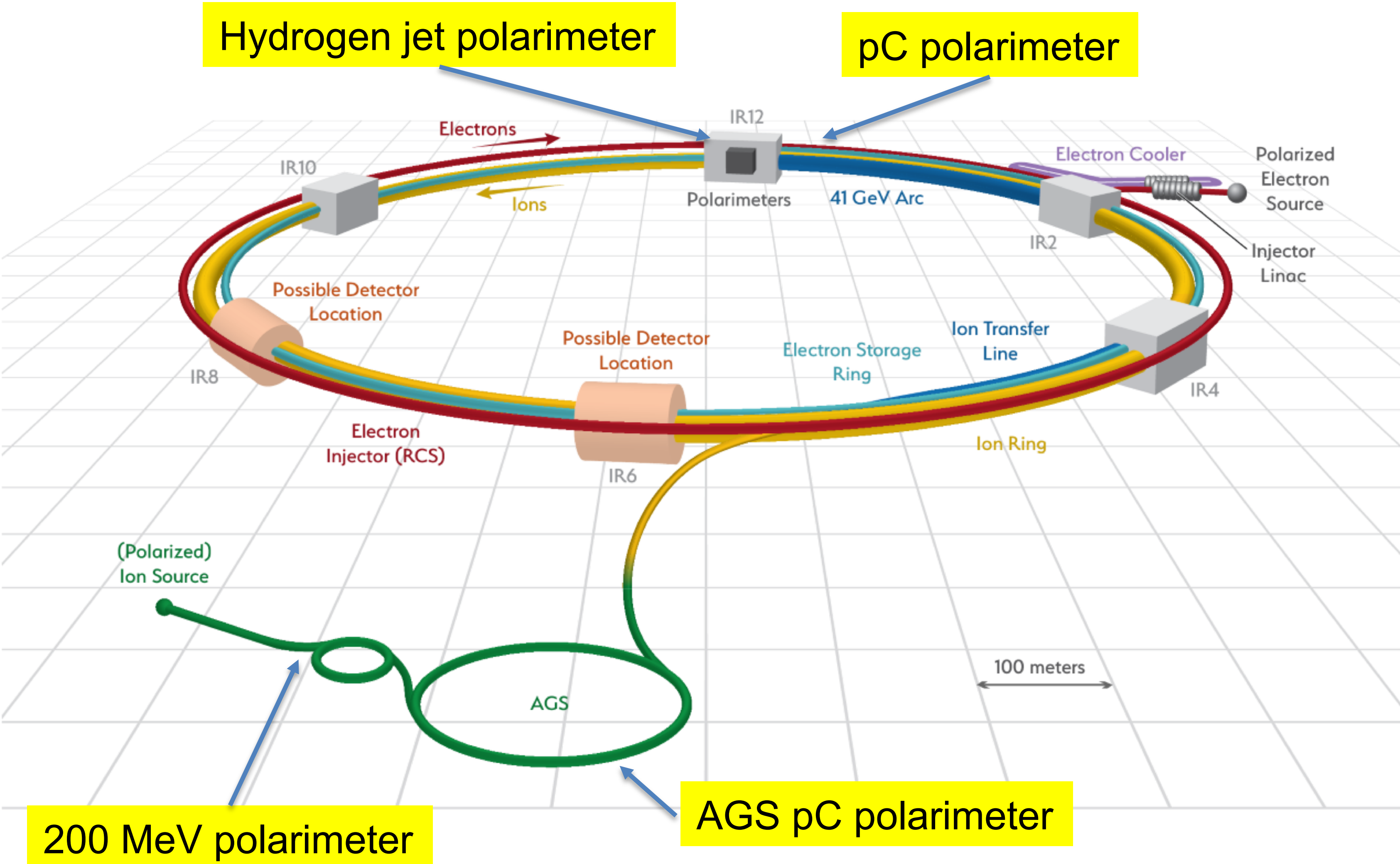
- EIC will make use of existing suite of proton polarimeters
  - 200 MeV polarimeter just after polarized source
  - p-Carbon polarimeter in AGS
  - Hydrogen Jet polarimeter for absolute measurement in ring
  - p-Carbon polarimeter for fast, relative measurements in ring
  - Improvements for polarimeters in ring needed/planned
  - Extend existing polarimeters for use with light ions → ^{3}He (D)
- EIC will require new polarimeters for electron beam
  - Mott polarimeter near source
  - Møller polarimeter for RCS
  - Compton polarimeter(s) in ring

EIC Layout



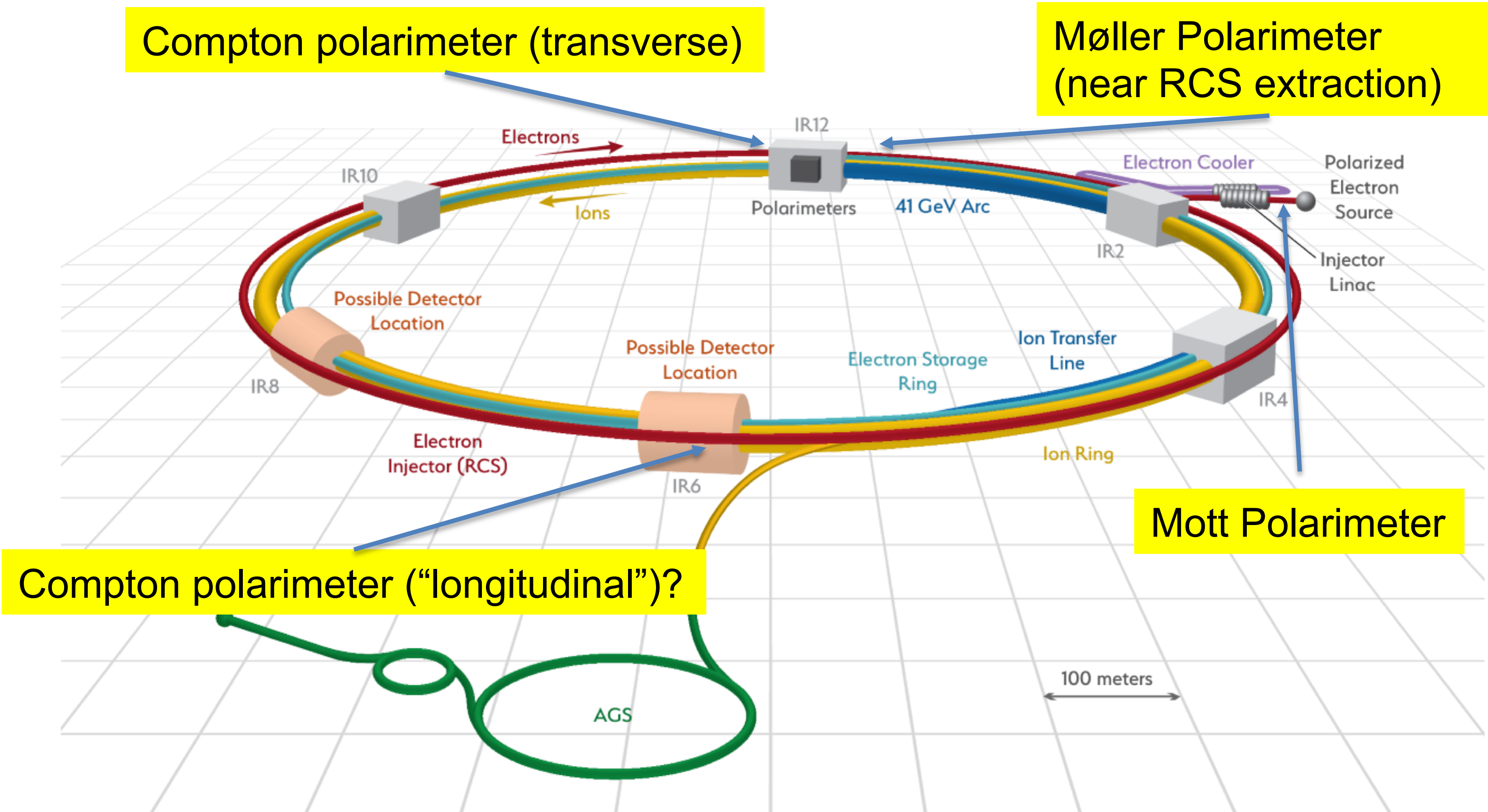
Electrons
IR12
Electron Cooler
Polarized Electron Source
IR10
Ions
Polarimeters
41 GeV Arc
IR2
Injector Linac
Possible Detector Location
Possible Detector Location
Ion Transfer Line
Electron Storage Ring
IR8
IR4
Electron Injector (RCS)
IR6
Ion Ring
(Polarized) Ion Source
AGS
100 meters

EIC Layout



Hadron Polarimeters

EIC Layout


Compton polarimeter (transverse)
Møller Polarimeter
(near RCS extraction)
IR12
Electrons
IR10
Ions
Polarimeters
41 GeV Arc
Electron Cooler
Polarized
Electron
Source
IR2
Injector
Linac
Possible Detector
Location
Possible Detector
Location
Electron Storage
Ring
Ion Transfer
Line
IR8
IR4
Electron
Injector (RCS)
IR6
Ion Ring
Mott Polarimeter
Compton polarimeter ("longitudinal")?
AGS
100 meters

Hydrogen-Jet Polarimeter

Hydrogen-jet polarimeter makes use of elastic p-p scattering in the Coulomb-nuclear interference (CNI) region

→ Beam polarization can, in principle, be extracted via single-spin (left-right) asymmetry

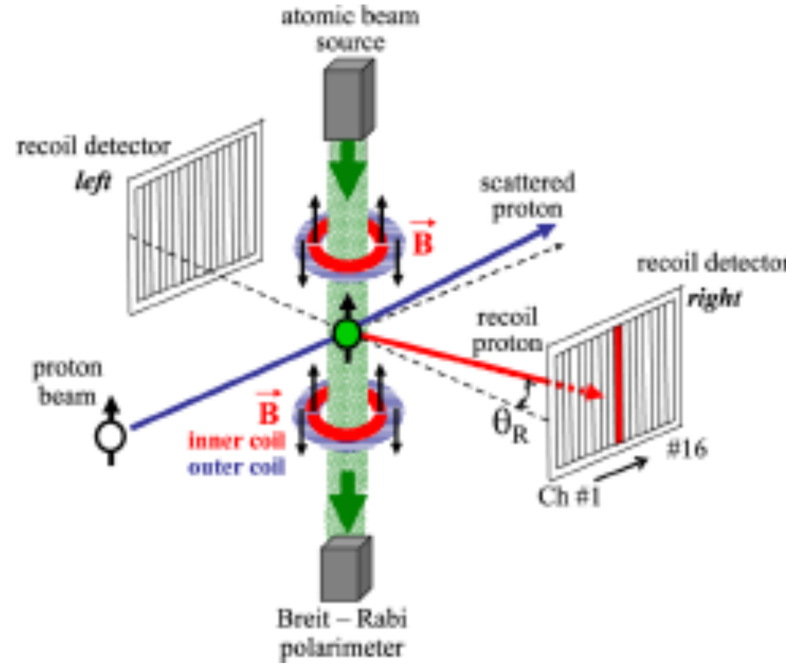
→ Analyzing power not a-priori well known

Use of polarized jet target bypasses sensitivity to analyzing power (A_n):

For asymmetry $\varepsilon = A_N P$:

$$\varepsilon_{beam} = A_N P_{beam}$$
$$\varepsilon_{target} = A_N P_{target}$$

$$P_{beam} = \frac{\varepsilon_{beam}}{\varepsilon_{target}} P_{target}$$



H-Jet polarimeter has achieved high precision at RHIC: $(dP/P)_{syst}$=0.6%

→ Measurements time consuming: $(dP/P)_{stat}$ ~ 2% for 8 hour period

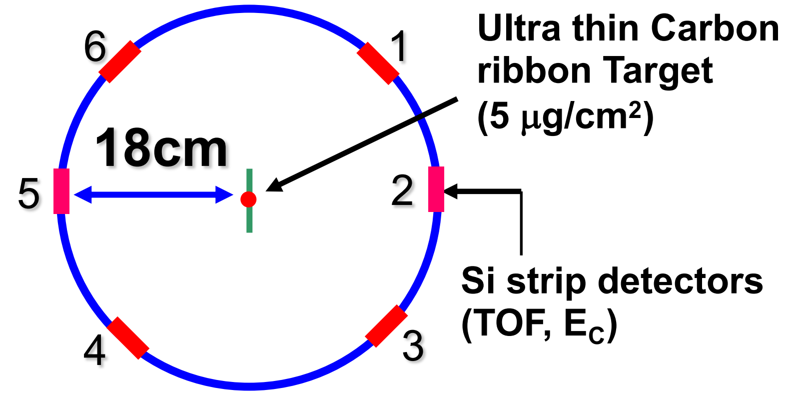
p-Carbon Polarimeter

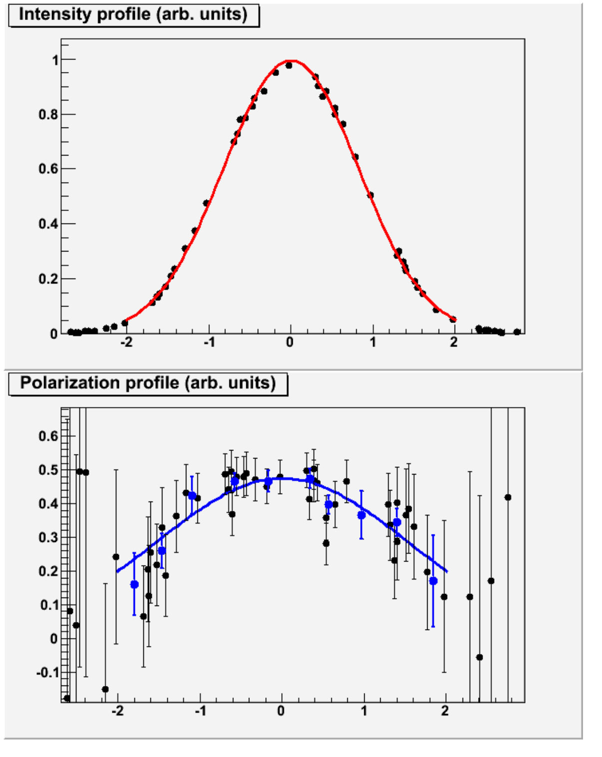
p-Carbon polarimeter also uses elastic scattering in CNI region
→ Uses thin carbon ribbon
→ Very low energy, recoiling carbon detected in silicon strip detectors
→ Polarization extracted via L-R asymmetry

$$P_{Beam} = -\frac{\varepsilon_{Beam}}{A_N} \qquad \varepsilon = \frac{N_L - N_R}{N_L + N_R}$$

→ Analyzing power requires cross-calibration with H-jet polarimeter

High rates, thin target allows extraction of polarization across transverse profile of beam

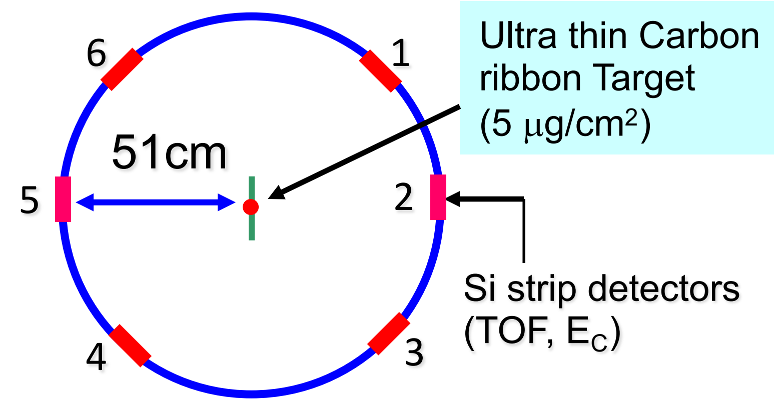


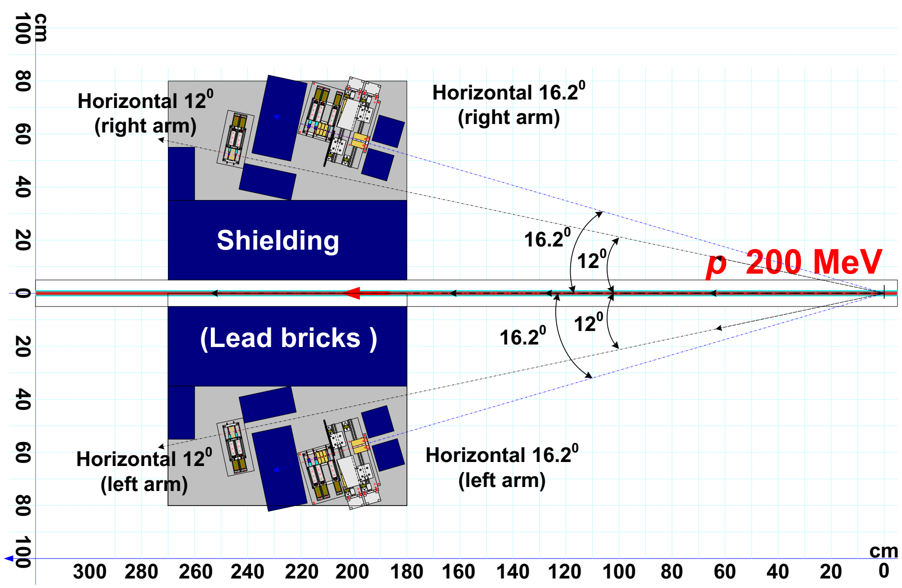


AGS and 200 MeV Polarimeters

AGS p-Carbon polarimeter similar to RHIC p-Carbon polarimeter with slightly different layout

→ Fast, relative measurements
→ Verify beam polarization before injection into EIC ring at ~ 25 GeV

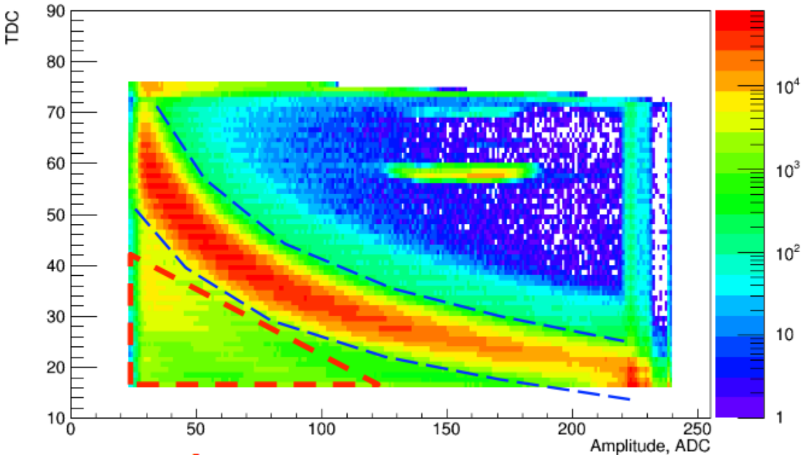


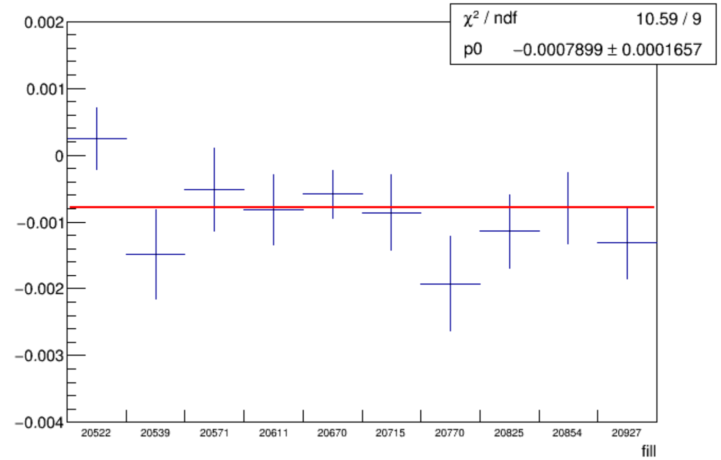


200 MeV Polarimeter located after linac following polarized source
→ Analyzing power well known from measurements at IUCF
A_N= 0.993+/- 0.003
→ Total systematic error dP/P ~ 0.6%

Hadron Polarimetry Challenges at EIC

RHIC – pC data (107 ns bunch spacing)

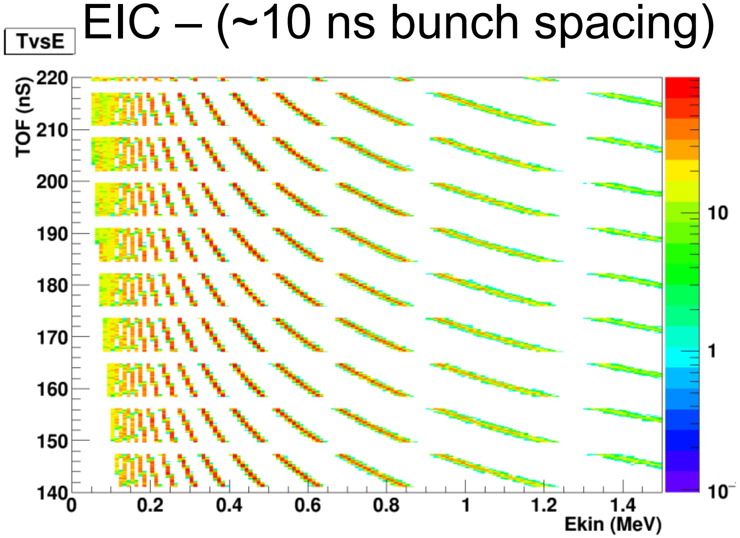




Background asymmetry, 10 measurements of

RHIC pC polarimeters in 2017

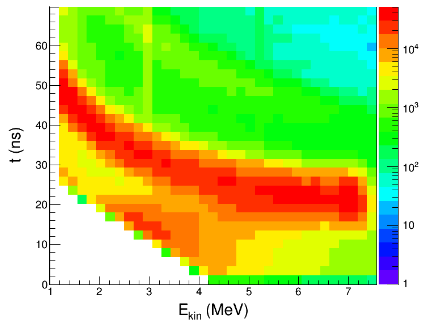
EIC – (~10 ns bunch spacing)



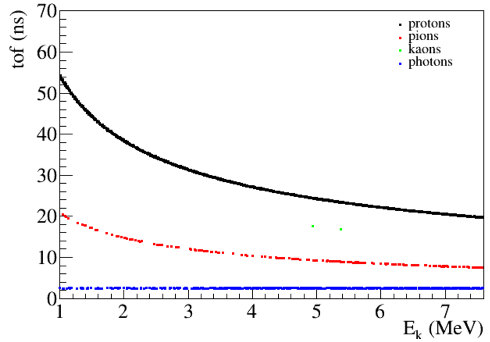
- → Good events selected via Energy-time correlation → "banana plot"
- → Shorter bunch spacing at EIC makes this problematic – more sensitive to backgrounds
- → Prompt background may also carry some asymmetry

Hadron Polarimeter Backgrounds

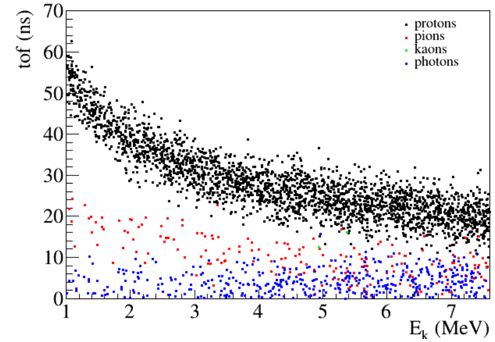
Work ongoing to simulate backgrounds and compare to existing RHIC data
→ Also took data with extra detector layer to see if that helps suppress low energy backgrounds - still under analysis



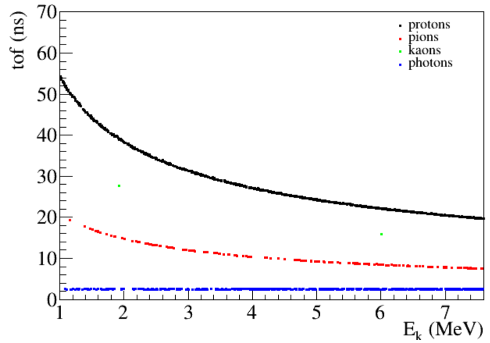
2017 Hjet data



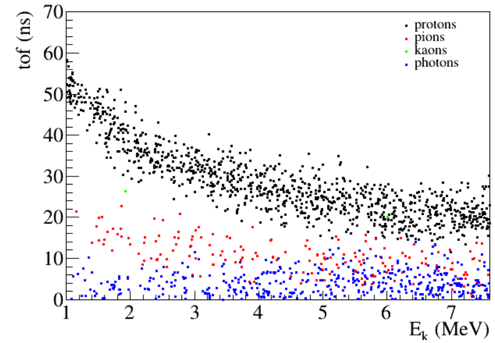
Pythia6 pp simulation
non elastic events, $\sigma_t = 0$



Pythia6 pp simulation
non elastic events, $\sigma_t = 3.7$ ns



Dpmjet3 pp simulation
non elastic events, $\sigma_t = 0$

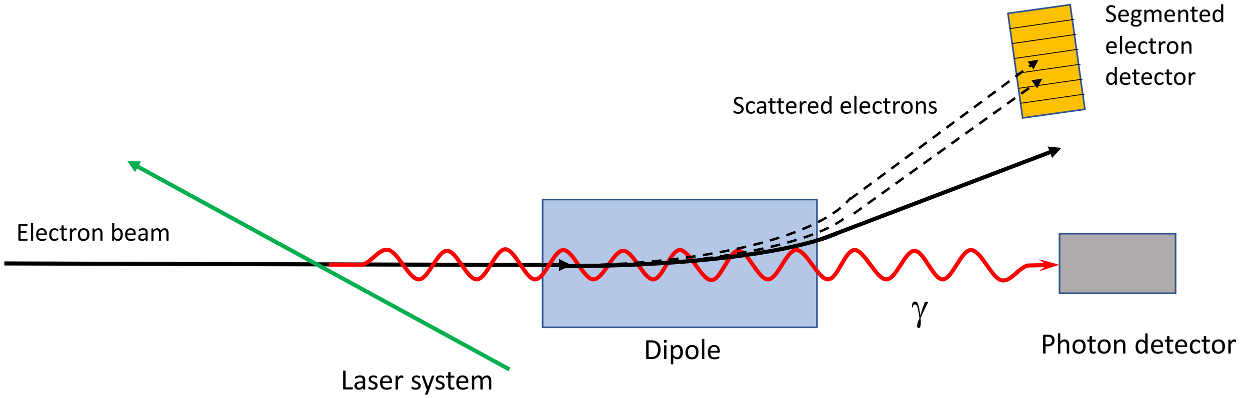


Dpmjet3 pp simulation
non elastic events, $\sigma_t = 3.7$ ns

Other Hadron Polarimetry Issues

- In addition to the backgrounds, there are other issues for the hadron polarimeters
  - Need improved DAQ – probably streaming DAQ, better time resolution for digitization
  - Carbon target lifetime – high currents, heating by wake fields could cause target issues – detailed engineering study required
- Polarimetry for light ions
  - Predictions exist for analyzing powers for polarized D, ^{3}He, but would be useful to get measurements
  - Could possibly be done at RHIC with polarized D/^{3}He jet targets and unpolarized beams
- Possibility to use elastic e-D scattering to measure tensor polarization under investigation

Compton Polarimetry



Polarimeter	Energy	Sys. Uncertainty
CERN LEP*	46 GeV	5%
HERA LPOL	27 GeV	1.6%
HERA TPOL*	27 GeV	1.9-3.5%
SLD at SLAC	45.6 GeV	0.5%
JLAB Hall A	1-6 GeV	1-3%
JLab Hall C	1.1 GeV	0.6%

**Transverse*

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

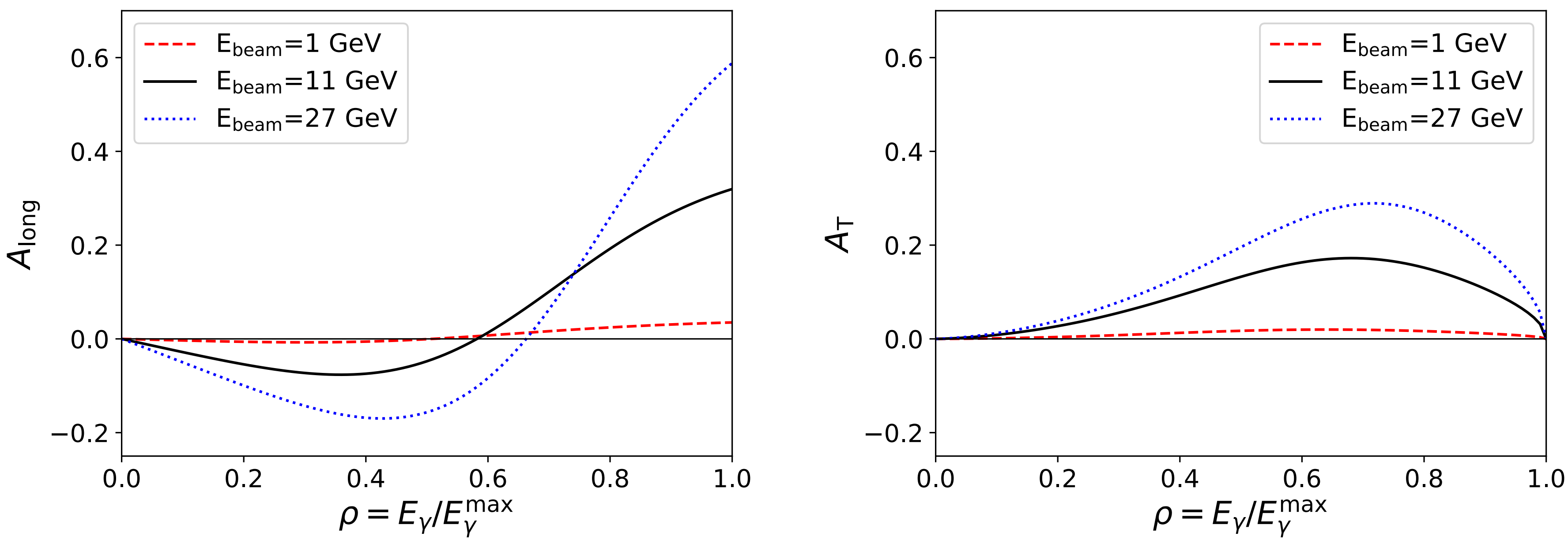
→ Highest precision has been achieved using electron detection, for longitudinally polarized electrons

Polarization Measurement via Compton Polarimetry

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

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

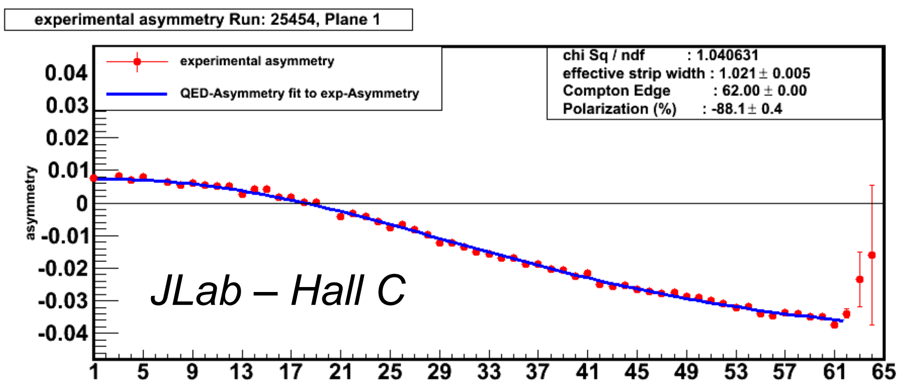
$$A_{\mathrm{T}} = \frac{2\pi r_o^2 a}{(d\sigma/d\rho)}\cos\phi\left[\rho(1-a)\frac{\sqrt{4a\rho(1-\rho)}}{(1-\rho(1-a))}\right]$$



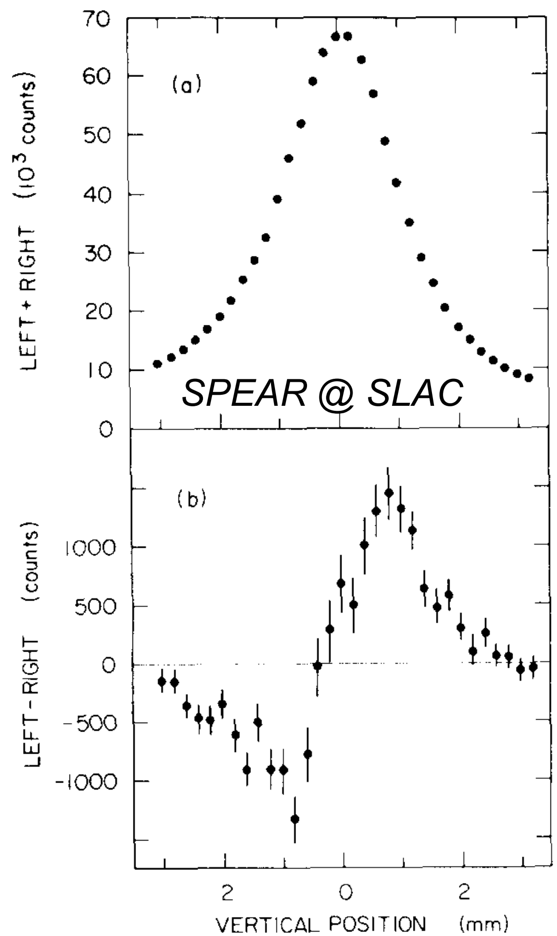
Polarization Measurement via Compton Polarimetry

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

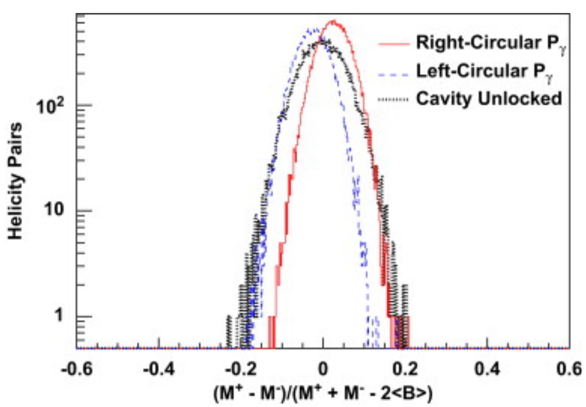
Transverse polarization typically measured via spatial dependence (up-down) of asymmetry



Detector strip # → Scattered electron energy



Photon-energy weighted asymmetry



JLab – Hall A

Compton Polarimetry at EIC

Historically, highest precision Compton polarimeters have measured ***longitudinal*** beam polarization
→ Asymmetry a function of backscattered photon energy

At EIC, the default location of the Compton polarimeter will be at IP12 where beam is ***transverse***
→ Need to measure an up-down asymmetry
→ Backscattered photon cone very small – good position resolution required

Transverse Compton polarimeters used at several facilities, but not typically for *absolute* beam polarization

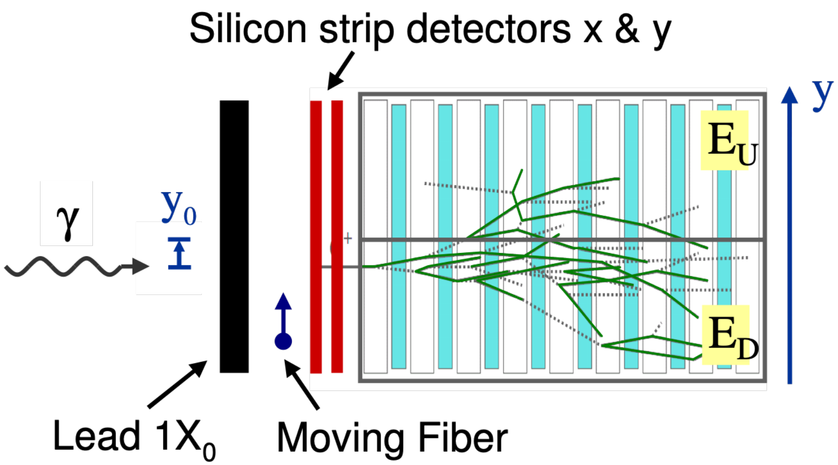
→ Highest precision transverse polarimeter was at HERA

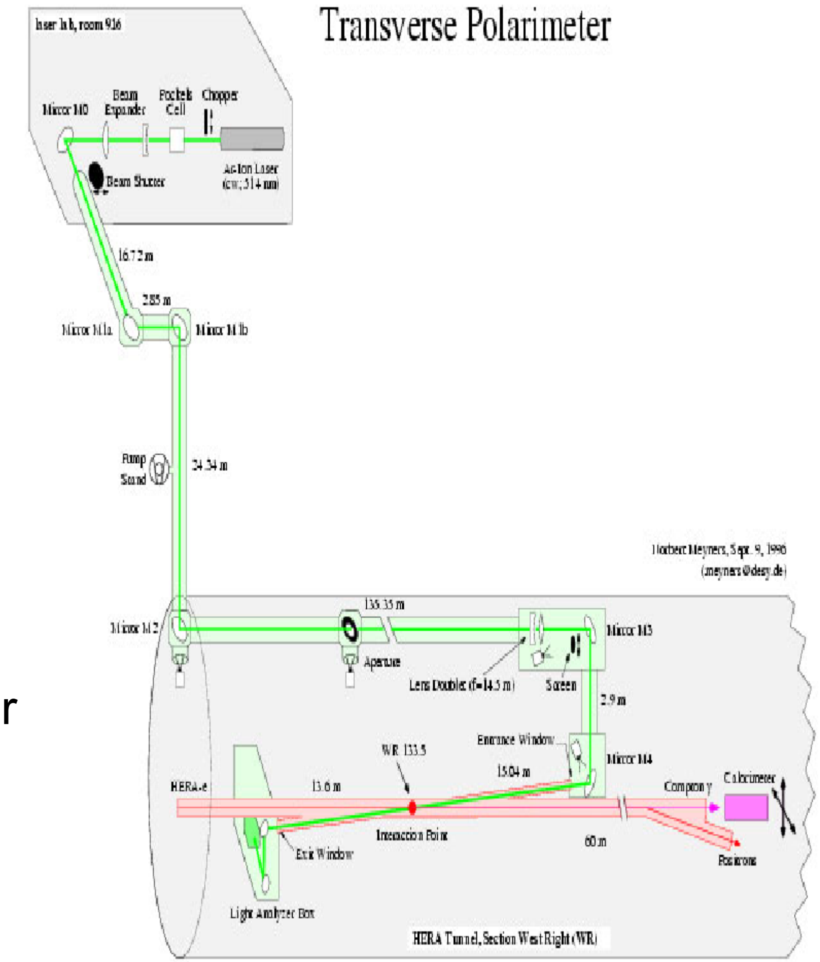
dP/P = 1.9-3.5%

Better precision can be achieved, but careful thought and design required

EIC Compton Polarimeter will incorporate detection of backscattered photon and scattered electron → *first time scattered electrons used for transverse polarization measurement*

HERA Transverse Polarimeter





HERA TPOL operated in single-photon mode w/CW laser

→ Used calorimeter segmented into upper and lower halves

→ Up-down energy asymmetry serves as proxy for up-down position asymmetry

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

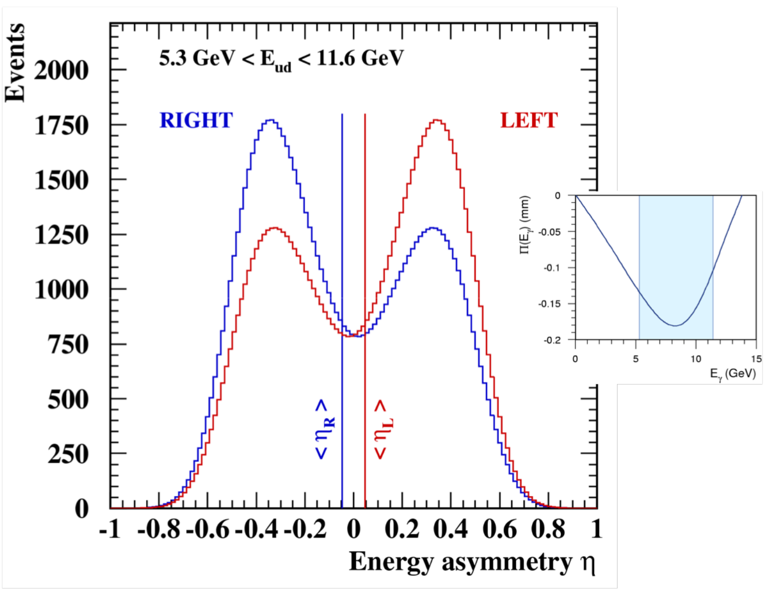
Blanka Sobloher, PSTP 2009

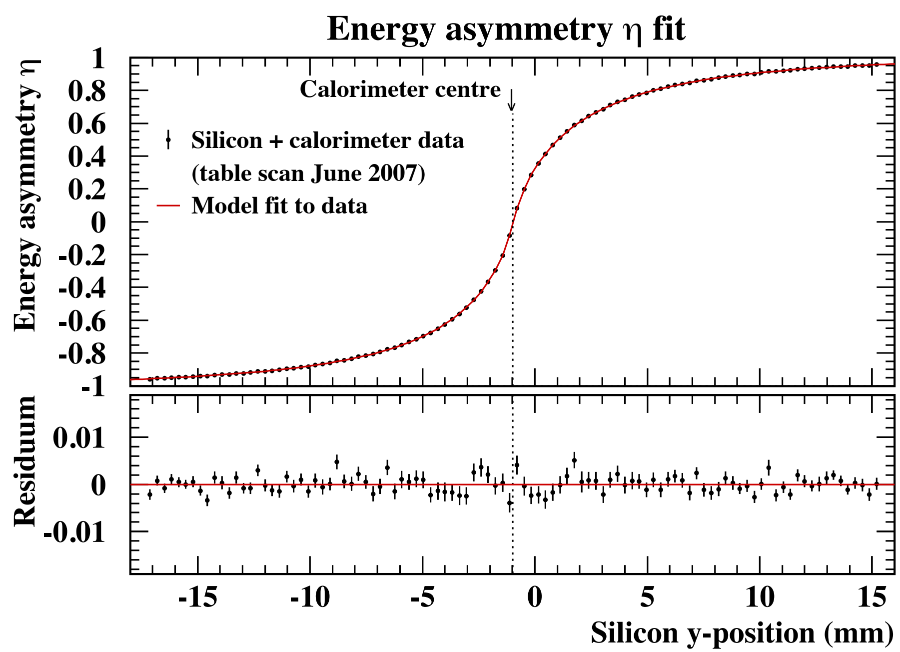
HERA Transverse Polarimeter

Key systematic uncertainty related to mapping energy asymmetry to position
→ Measured in-situ with position sensitive strip detector
→ Systematic uncertainty in η-y calibration dominated by strip pitch → 0.5%

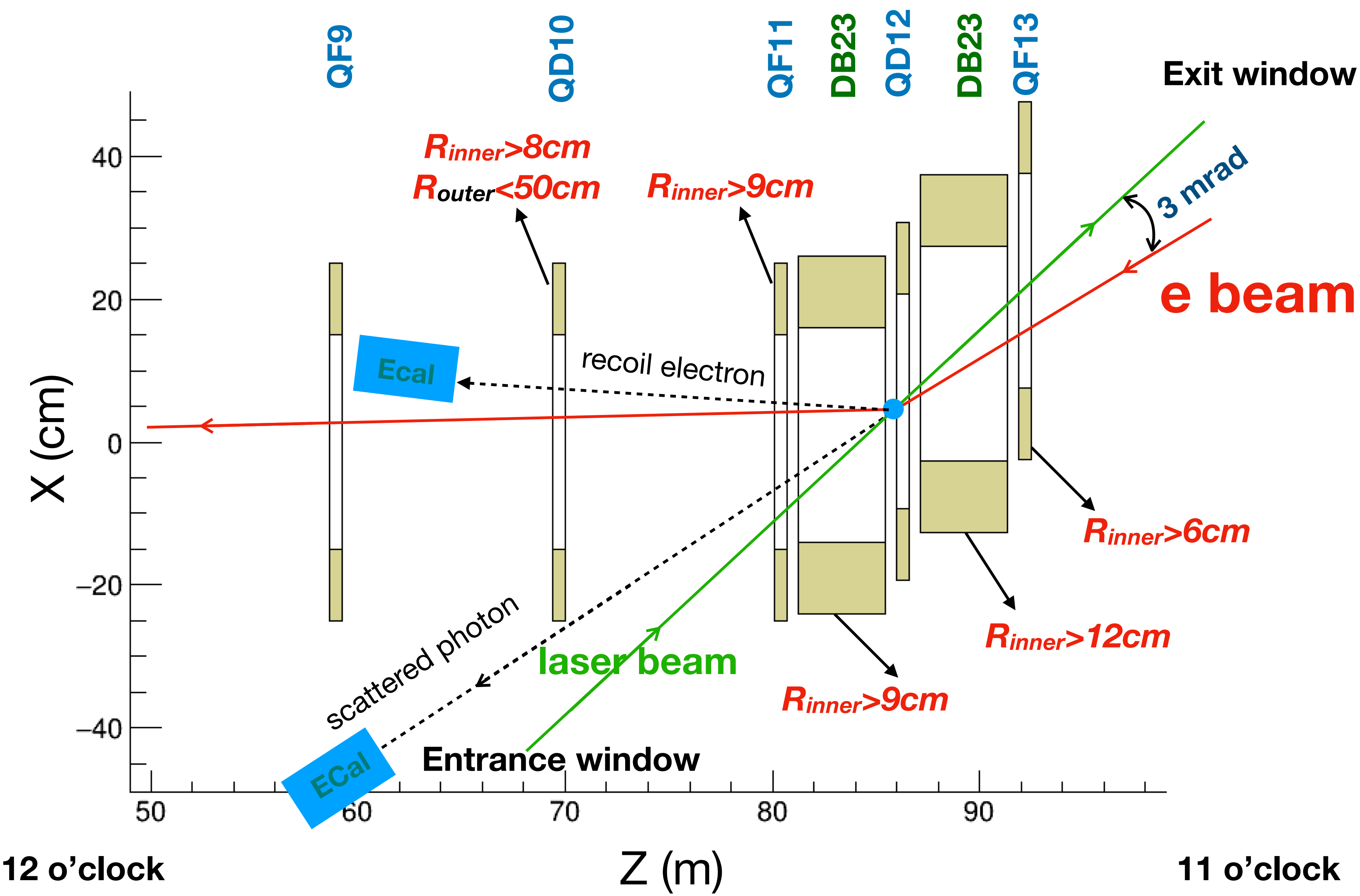
Other significant contributions to systematic uncertainty include:
→ Beam optics and position
→ Detector energy resolution

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





EIC Compton Polarimeter at IR12



Zhengqiao Zheng (BNL)

Recoil Electron Detection

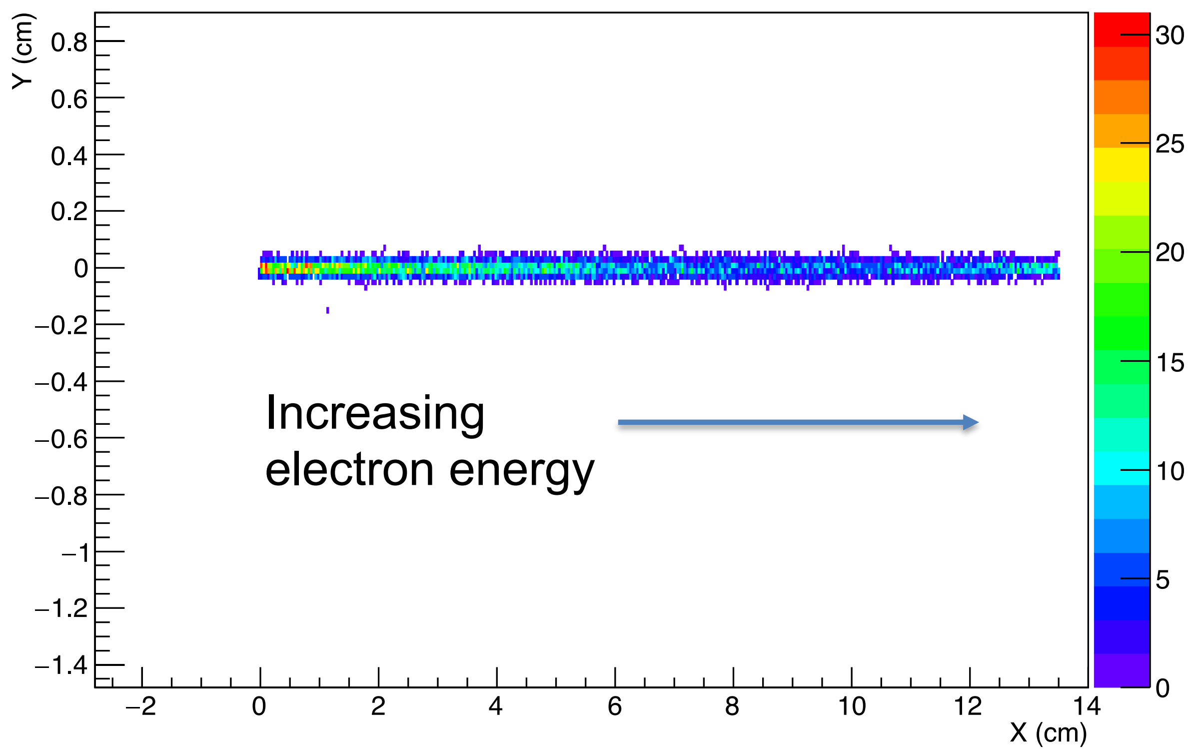
Transverse Compton polarimeters typically detect backscattered photon
→ Would like to detect scattered electron as well

Backscattered photon cone small – on the scale of few mm at 25 m

→ Scattered electron cone much smaller

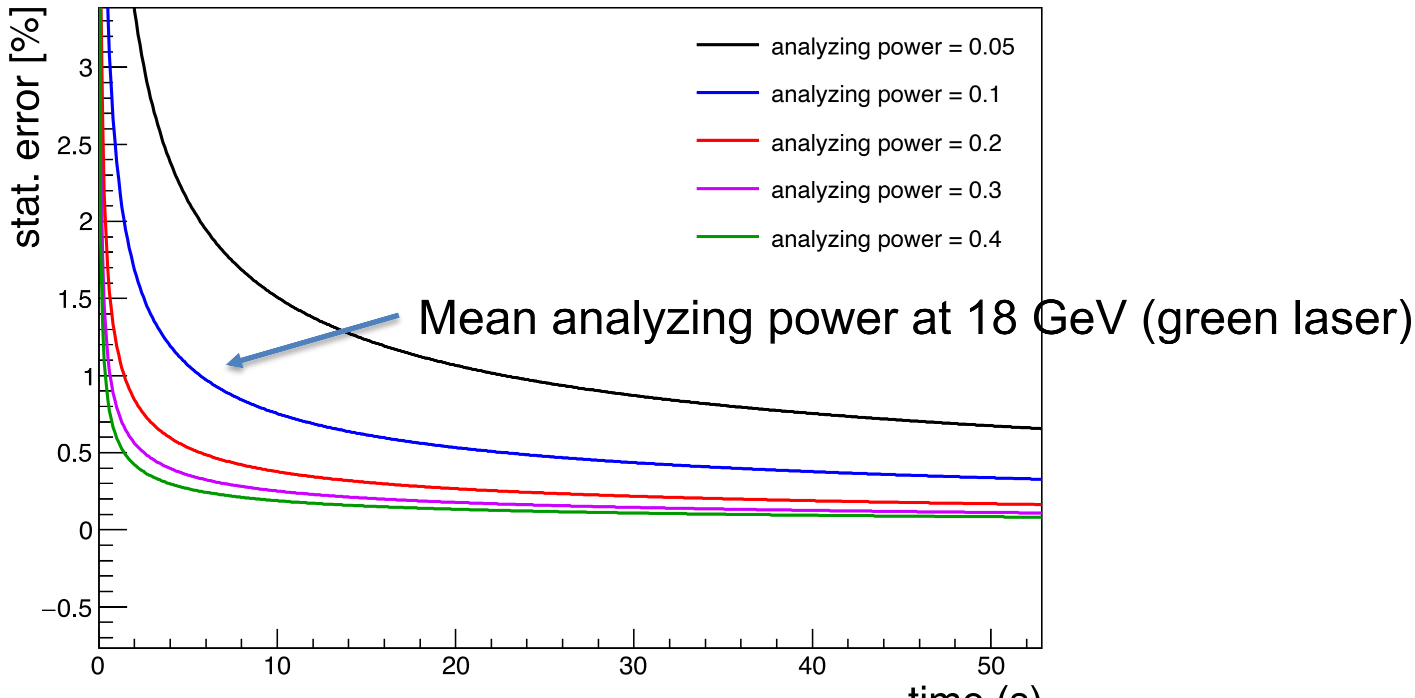
→ Dipole will spread out electrons horizontally, but some vertical defocusing may be required to measure up-down asymmetry

→ Quads likely complicate analysis



Zhengqiao Zheng (BNL)

Rate Estimates (time requirements)



Zhengqiao Zheng (BNL)

$\beta_x = 10m; \beta_y = 50m;$

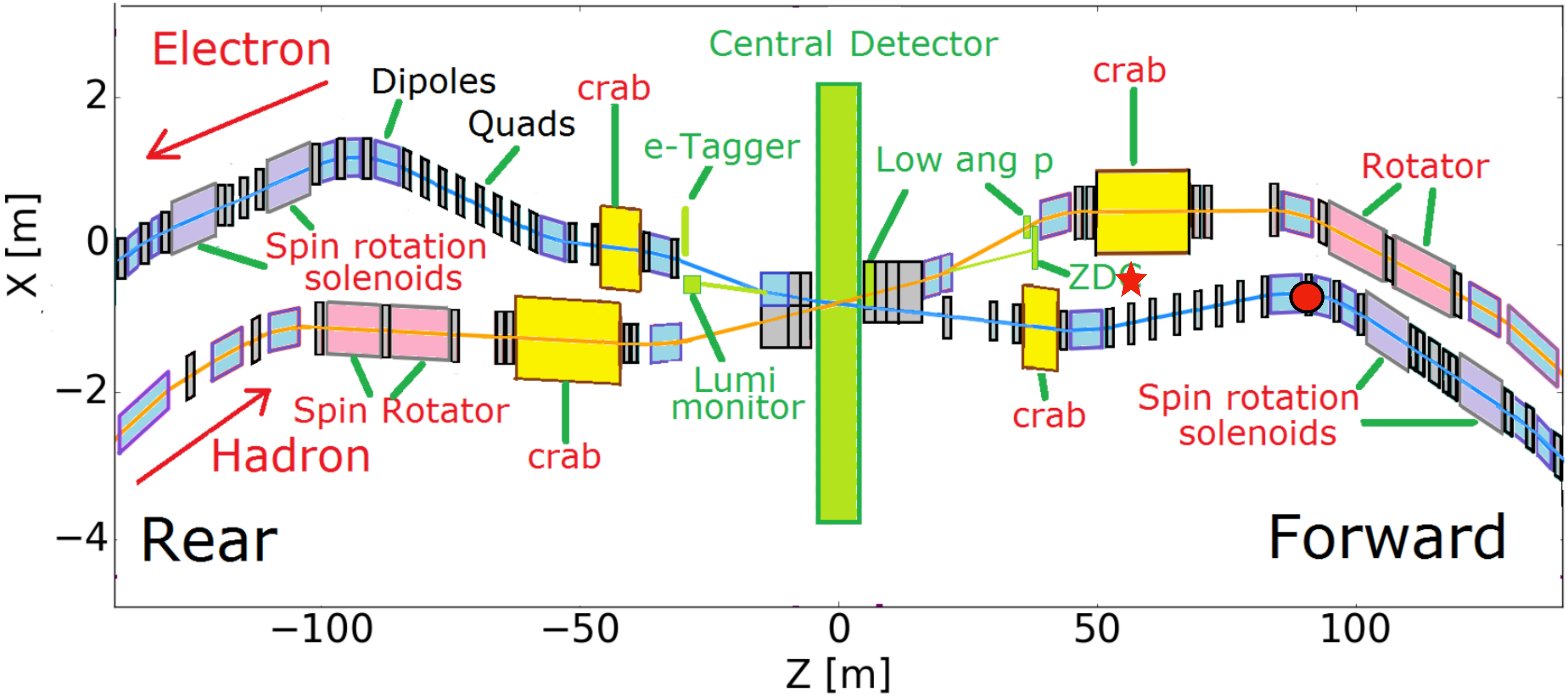
Rate estimates assuming 1-shot, 10 W laser pulsed at beam frequency at 18 GeV

→ Need to carefully consider number of backscattered photons per crossing – if multiplicity >1, may complicate measurement

→ Short bunch spacing (10 ns below 18 GeV) may prove challenging – fast detectors required

→ Can “sample” beam bunches if detector response an issue, but would increase measurement time

Compton Polarimeter at IR 6



Investigating option of having additional polarimeter closer to IR

→ Electron beam would be significantly longitudinal – less spin transport to extract polarization at IP

→ Region very crowded – needs very careful consideration of detailed geometry

Mott Polarimetry

Mott scattering: $\vec{e} + Z \rightarrow e$

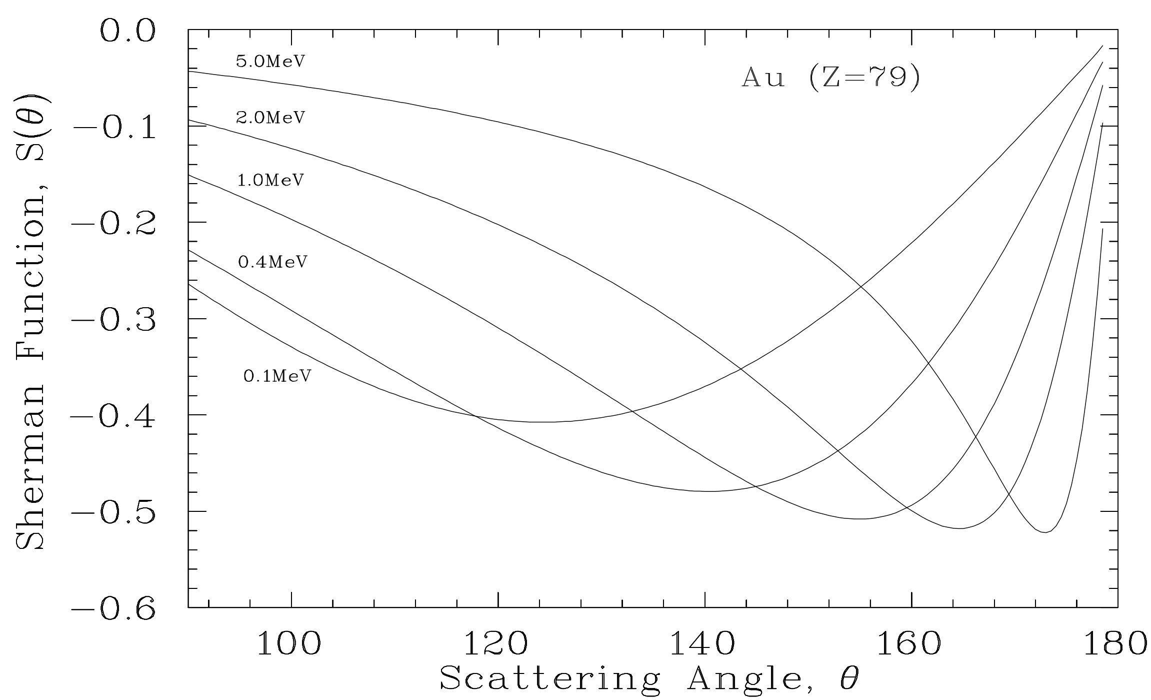
→ Spin-orbit coupling of electron spin with (large Z) target nucleus gives single-spin asymmetry for transversely polarized electrons

Mott polarimetry useful at low energies

→ ~ 100 keV to 5 MeV

→ Standard technique for use in polarized electron injectors

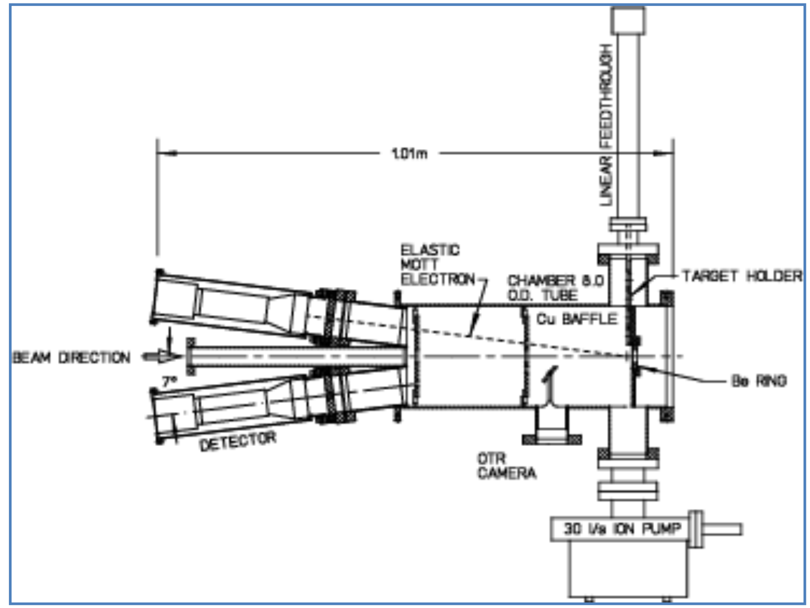
Mott polarimeter highly desirable for use in EIC injector



JLab 5 MeV Mott

Routinely used in CEBAF injector

- Optimized for operation at 5 MeV
  - Studied between 3-8 MeV
- Detectors at 172.7 degrees
  - Thin and thick scintillators
- Typically uses thin gold target (1 μm or less)
- Some backgrounds possible due to nearby beam dump
  - Has been studied using lower duty cycle beam + time of flight
- Recent extensive systematic studies suggest overall systematic uncertainty < 1%



Jefferson Lab 5 MeV Mott Polarimeter

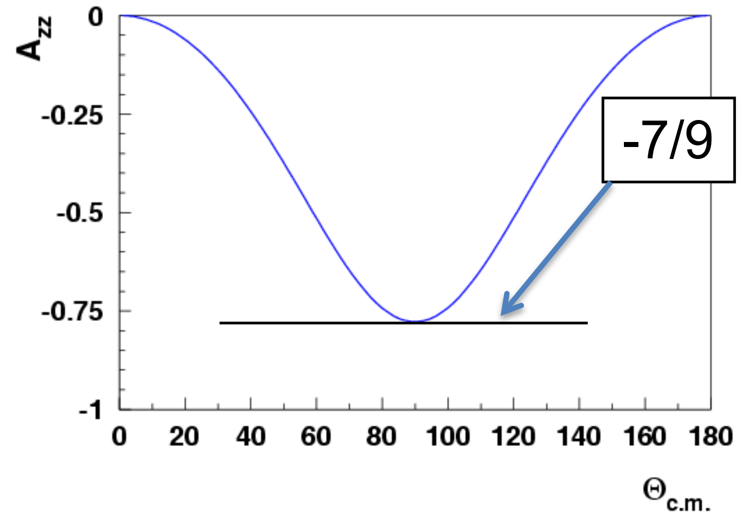
Polarimetry for RCS

- Rapid Cycling Synchrotron (RCS) will accelerate an electron bunch up to 18 GeV once per second
- Polarimeter needed for RCS to help diagnose possible polarization issues
- Challenge: Beam is continuously accelerated – will not be able to measure each bunch multiple times at same beam energy
- This can be mitigated by operating the RCS in multi-ramp or flat-top mode
- Compton polarimetry difficult to implement over a wide range of beam energies → analyzing power, backscattered photon energy change rapidly
- Møller polarimetry might be better option

Møller Polarimetry

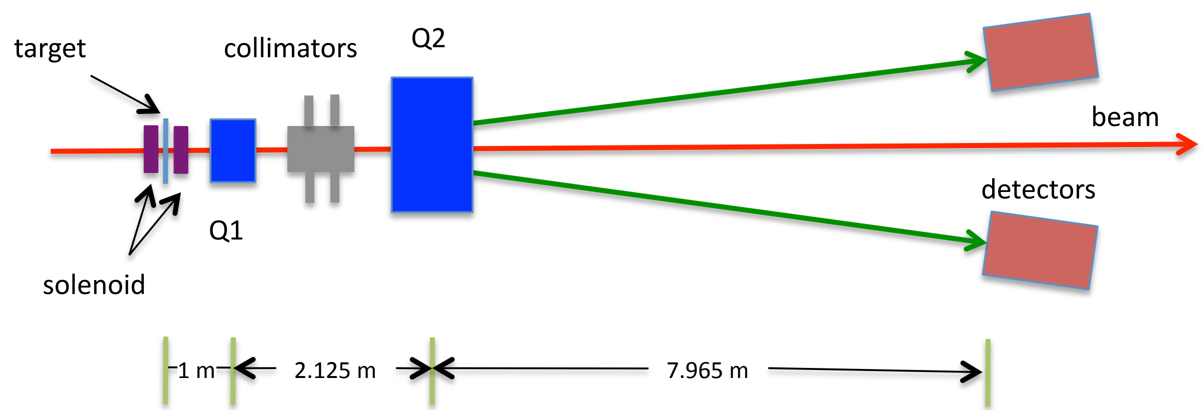
- Møller polarimetry benefits from large longitudinal asymmetry → -7/9
  → Asymmetry independent of energy
- Rates are large, so rapid measurements are easy
- The need to use Fe or Fe-alloy foils means measurement must be destructive

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



2-quad spectrometer provides (nearly) energy-independent analyzing power

Hall C Møller polarimeter



Summary

- EIC will use existing H-Jet and pC polarimeters from RHIC with some improvements
  - Local hadron polarimetry also desirable to track polarization with time, verify direction optimization
  - 200 MeV and AGS polarimeters will provide additional information on evolution of polarization through the machine
- EIC will require new polarimeters for electrons
  - Transverse Compton polarimeter will be located at IR12
    - Plan to incorporate photon and electron detection
    - Rates and detector requirements under study
  - Mott polarimeter desired to provide polarization information at electron source
  - Møller polarimeter likely solution for RCS polarimetry

CFNS Workshop – Polarization and Polarimetry

https://indico.bnl.gov/event/7583/ **June 26, 29, July 1, 2020**

….The aim of this workshop is to bring together experts in electron and hadron beam polarimetry as well as experts in polarized beams in accelerators. The program will include several invited talks, but contributed submissions are also welcome. Abstracts may be submitted through the conference web site (https://indico.bnl.gov/event/7583/abstracts/) and will be accepted until May 31.

Due to the ongoing COVID-19 pandemic, we will hold the workshop online (through Zoom). To facilitate a wider collaboration we have decided to split the workshop over 3 separate days with a reduce schedule (June 26th, June 29th and July 1st). Please register in order to get connection information.

Organizing Committee:

Elke Aschenauer (BNL), Ciprian Gal (Stony Brook), Dave Gaskell (JLab), Haixin Huang (BNL), Vasiliy Morozov (JLab) Vadim Ptitsyn (BNL) and Ferdinand Willeke (BNL)

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EICUG Polarimetry Working Group *and*

EICUG Yellow Report Polarimetry/Ancillary Detector Working Group

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- Alexandre Camsonne (JLab)
- Joe Grames (JLab)
- Ciprian Gal (Stony Brook)