Electron and Hadron Beam Polarimetry at EIC

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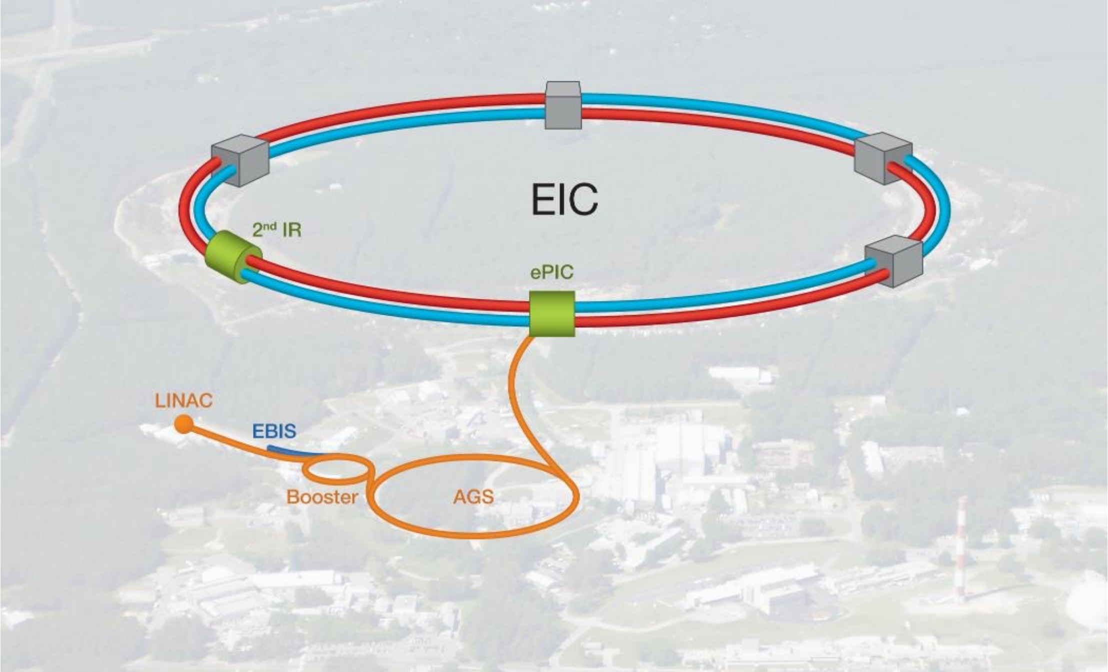
Jefferson Lab

- Polarimetry at EIC
- Electron Polarimetry
  - Mott Polarimeters
  - ESR Compton
  - RCS Compton
- Hadron Polarimetry
  - p-Carbon Polarimeter
  - H-Jet Polarimeter

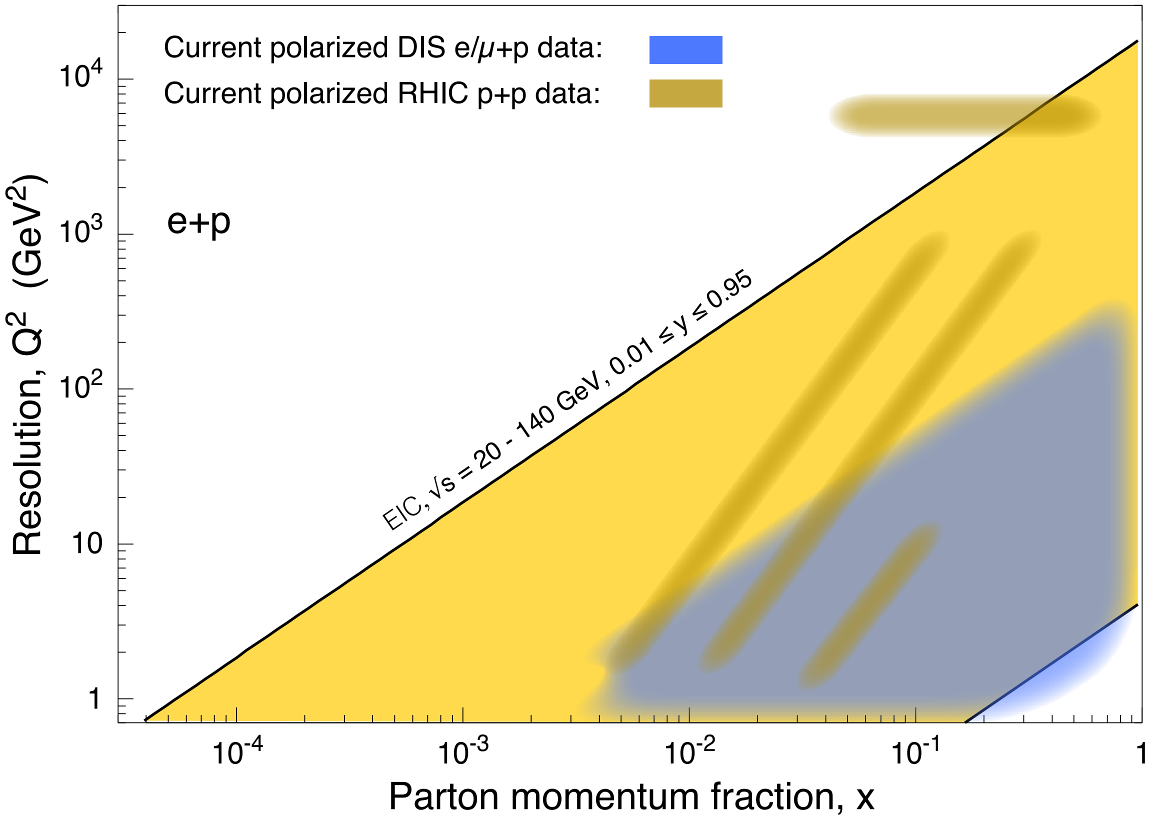


EINN

October 31-November 4, 2023

Physics from Polarized Beams at EIC

- EIC will provide an enormous amount of information in many reaction channels to elucidate the quark/gluon structure of nucleons and nuclei
- ***Polarized beams*** a crucial requirement for achieving physics goals
- 1D polarized quark distributions via inclusive and SIDIS measurements (double-spin asymmetries)
- Access to transverse momentum distributions (TMDs) via SIDIS (single-spin, double-spin asymmetries)
- Total angular momentum in nucleon (GPDs) via exclusive reactions (single-spin, double-spin asymmetries)
- Physics beyond the Standard Model using PV processes



EIC will provide unprecedented statistical precision in many reaction channels due to its high luminosity

→ Require systematic precision to match

EIC Beam Properties and Polarimetry Challenges

EIC will provide unique challenges for both electron and hadron polarimetry

Common to both:

→ Small spacing between electron/hadron bunches (10 ns) at high luminosity configuration (~40 ns at higher CM configuration)

→ Intense beams (0.26 to 2.5 A)

  → Large synchrotron radiation from electron beam results in large effects at detectors

  → Hadron beam intensity results in challenges for polarimeter targets

Polarimetry systematics:
Goal is ***dP/P = 1%*** or better for both electrons and hadrons

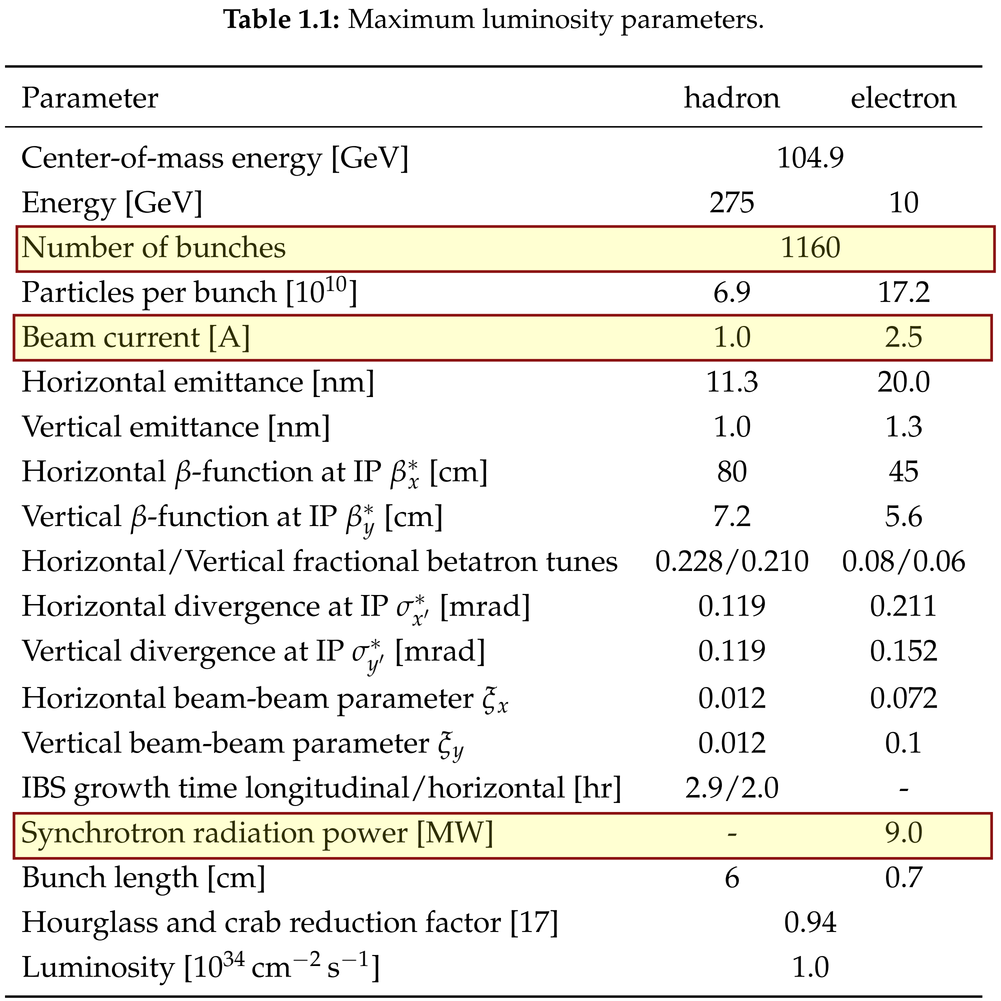


Table 1.1: Maximum luminosity parameters.

Parameter	hadron	electron
Center-of-mass energy [GeV]	104.9	
Energy [GeV]	275	10
Number of bunches	1160	
Particles per bunch [10^{10}]	6.9	17.2
Beam current [A]	1.0	2.5
Horizontal emittance [nm]	11.3	20.0
Vertical emittance [nm]	1.0	1.3
Horizontal β-function at IP β^*_x [cm]	80	45
Vertical β-function at IP β^*_y [cm]	7.2	5.6
Horizontal/Vertical fractional betatron tunes	0.228/0.210	0.08/0.06
Horizontal divergence at IP $\sigma^*_{x'}$ [mrad]	0.119	0.211
Vertical divergence at IP $\sigma^*_{y'}$ [mrad]	0.119	0.152
Horizontal beam-beam parameter ξ_x	0.012	0.072
Vertical beam-beam parameter ξ_y	0.012	0.1
IBS growth time longitudinal/horizontal [hr]	2.9/2.0	-
Synchrotron radiation power [MW]	-	9.0
Bunch length [cm]	6	0.7
Hourglass and crab reduction factor [17]	0.94	
Luminosity [10^{34} cm^{-2} s^{-1}]	1.0	

Beam Polarimetry

Beam polarization determined via measurement of scattering asymmetry with known analyzing power

$$A_{\mathrm{measured}} = P_{\mathrm{beam}} A_{\mathrm{effective}}$$

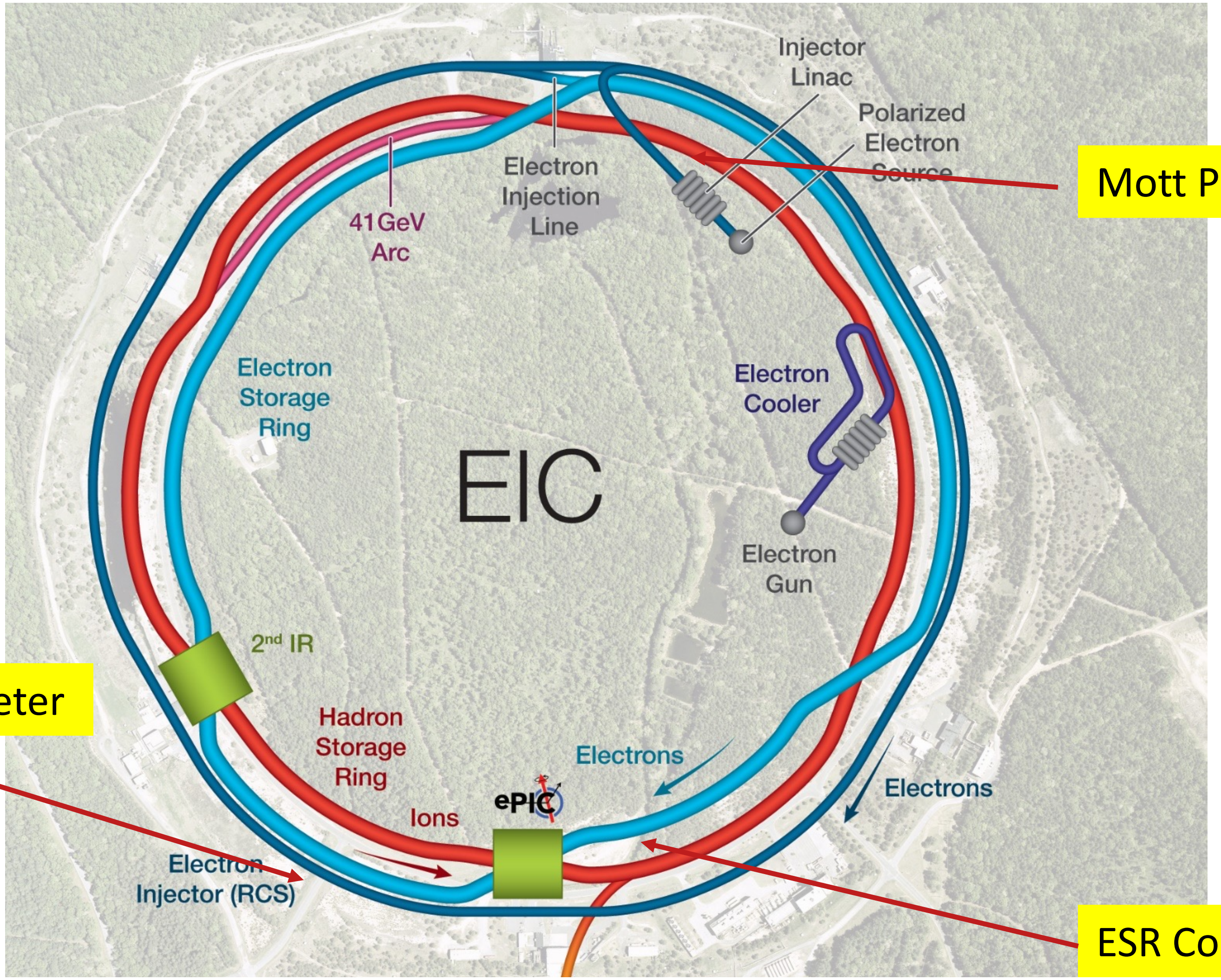
$A_{\mathrm{effective}}$ incorporates theoretical analyzing power, convoluted over polarimeter acceptance
→ May include additional effects (e.g., radiative effects, “Levchuk” effect, etc.)

Process may rely on a double-spin or single-spin asymmetry

→ Double-spin asymmetry → requires (precise) knowledge of the target polarization
→ Single-spin asymmetry → no target polarization, but asymmetry correlated with spatial distribution

→ Electron polarimetry → for all useful processes, analyzing power known with high precision (QED)
→ Hadron polarimetry → No theoretically constrained processes – must rely on previous measurements of analyzing power or clever workarounds

EIC Electron Polarimeter Map



Mott Polarimeters

RCS Compton polarimeter

ESR Compton polarimeter

ESR Compton Polarimeter

Compton polarimetry ideal technique for storage rings
→ Non-destructive
→ Can be used for both longitudinal and transverse polarization

Planned Compton polarimeter location upstream of detector IP

At Compton interaction point, electrons have both longitudinal and transverse (horizontal) components
→ Longitudinal polarization measured via asymmetry as a function of backscattered photon/scattered electron energy
→ Transverse polarization from left-right asymmetry

Beam energy	P_L	P_T
5 GeV	96.5%	26.1%
10 GeV	86.4%	50.4%
18 GeV	58.1%	81.4%

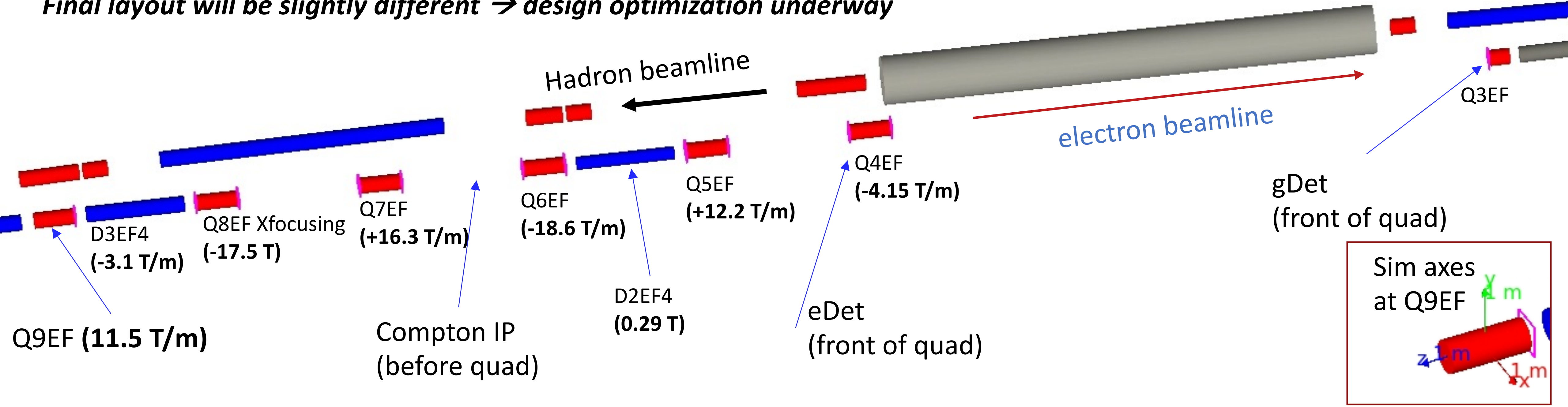
Polarization Components at Compton

Beam polarization will be fully longitudinal at detector IP, but accurate measurement of absolute polarization will require ***simultaneous*** measurement of P_L and P_T at Compton polarimeter

EIC Compton will provide first high precision measurement of P_L and P_T at the same time

Compton Placement

Final layout will be slightly different → design optimization underway



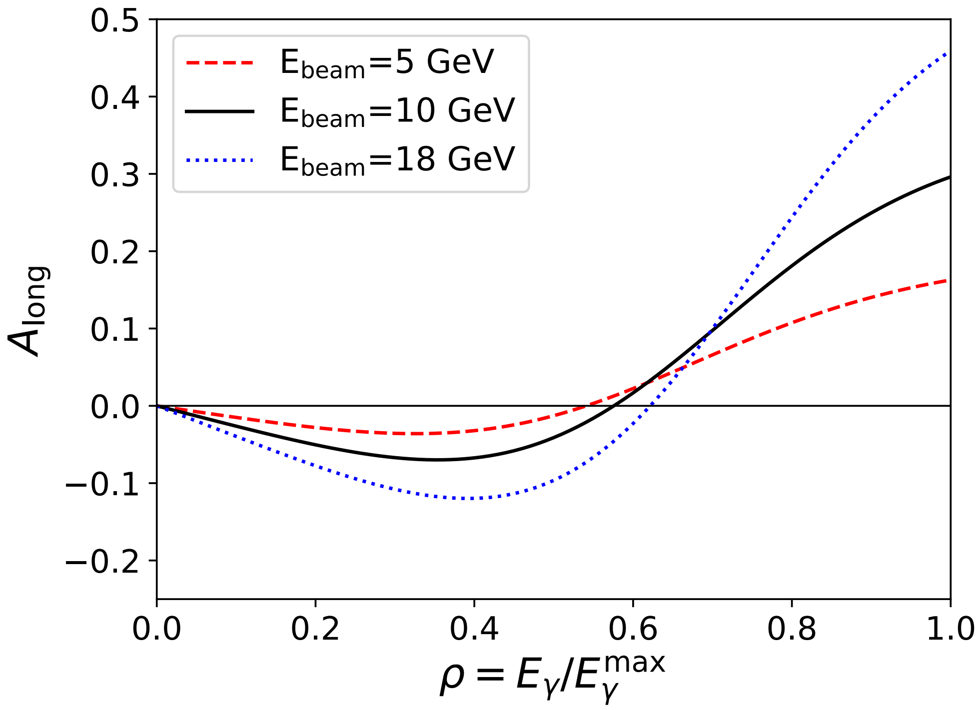
→ Laser IP in field-free area – space to insert laser in beamline
→ Photon detector 29 m from laser/beam IP
→ Quad after dipole (Q5EF) horizontally defocusing – facilitates use of electron detector
→ Synchrotron from D2EF4 impacts electron and photon detectors

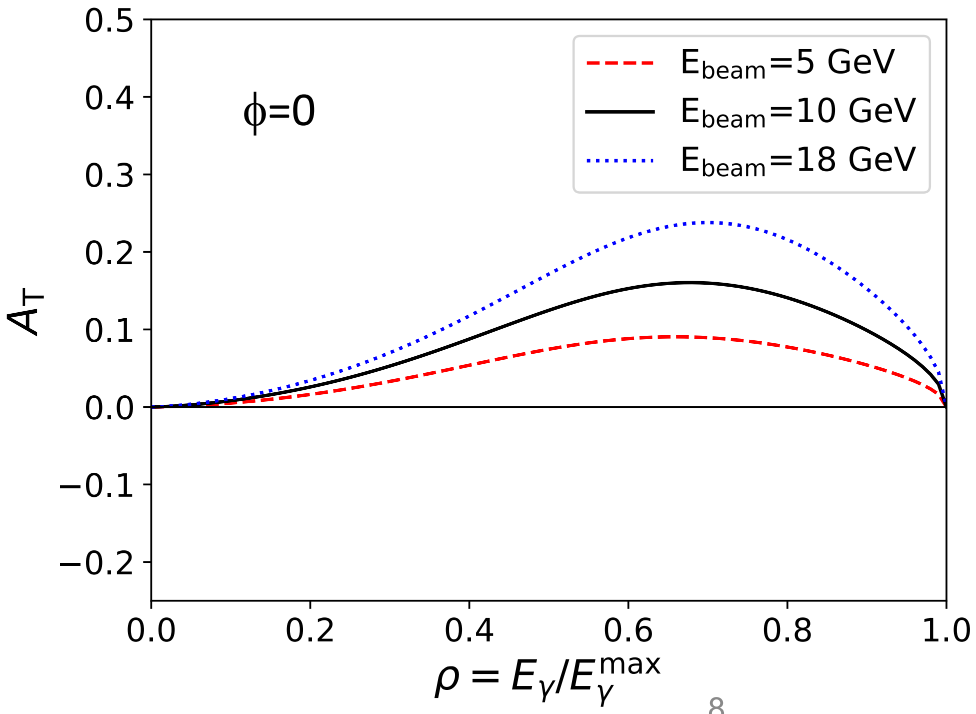
Polarization Measurement via Compton Polarimetry

Compton longitudinal and transverse analyzing powers

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

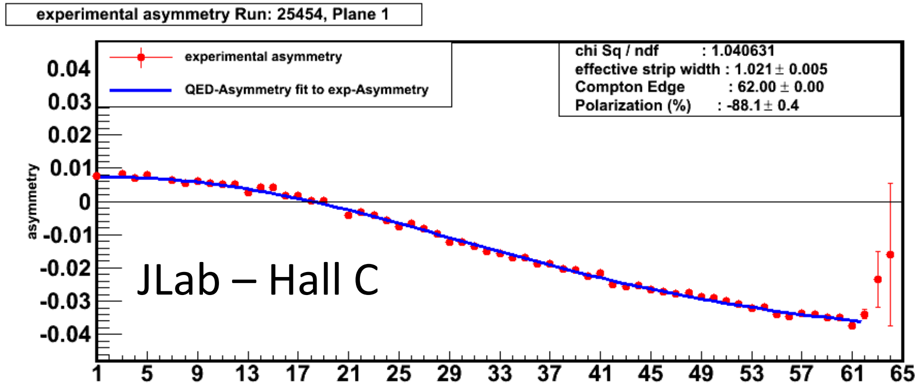
$$A_{\mathrm{T}} = \frac{2\pi r_o^2 a}{(d\sigma/d\rho)}\cos\phi\left[\rho(1-a)\frac{\sqrt{4a\rho(1-\rho)}}{(1-\rho(1-a))}\right]$$



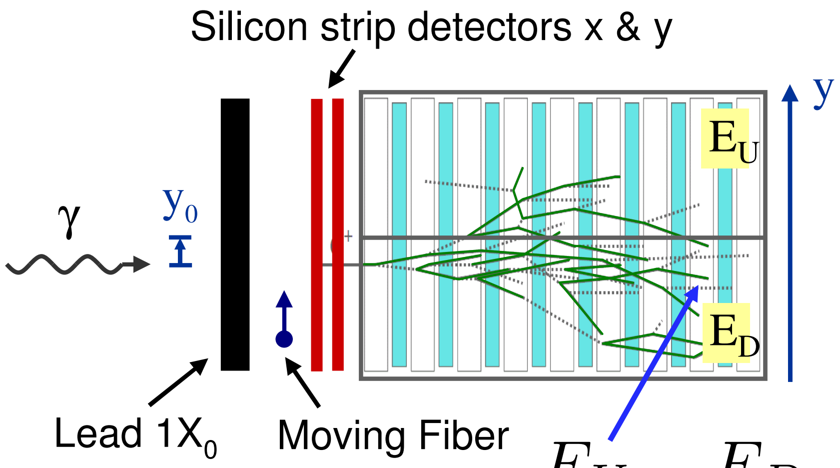


Compton polarimetry – lessons from previous devices

- Longitudinal polarimetry
  - Electron detector – needs sufficient segmentation and coverage to allow self-calibration “on-the-fly”
  - Photon detector – integrating technique provides most robust results – perhaps not practical at EIC? → lower the threshold as much as possible
- Transverse polarimetry
  - Remove η-y calibration issue – use highly segmented detectors at all times
  - Calorimeter resolution → integrate over all energy?
  - Beam size/trajectory important – build in sufficient beam diagnostics
- Common to both
  - Birefringence of vacuum windows can impact laser polarization → use back-reflected light (optical reversibility theorems)



JLab – Hall C

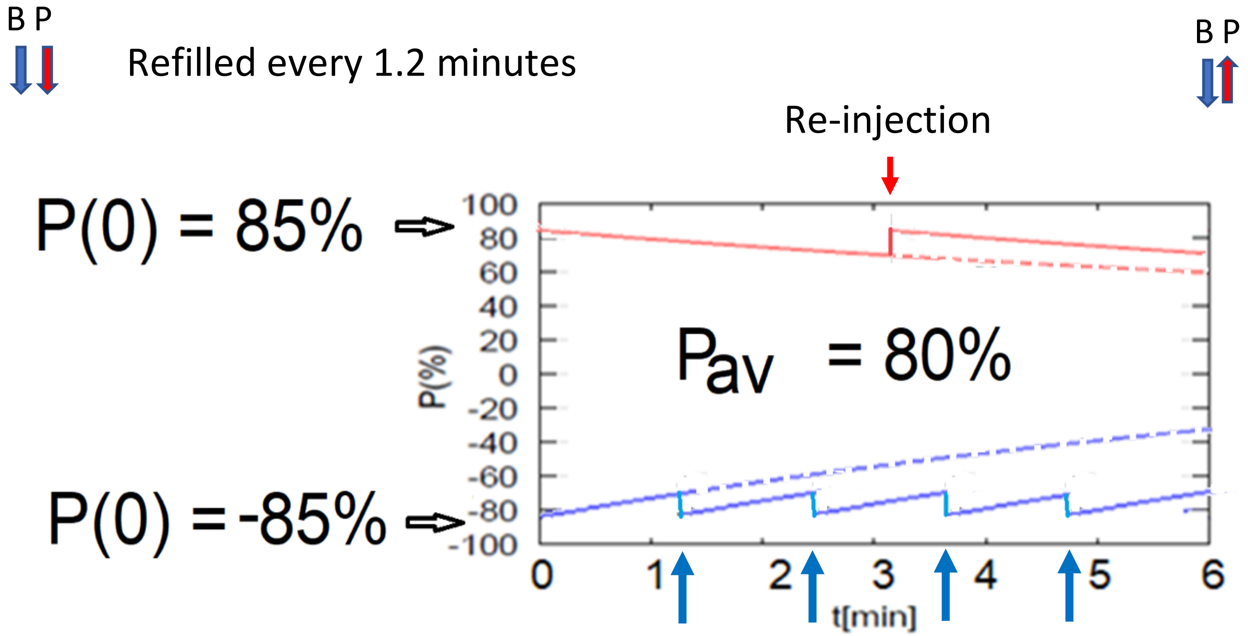


$$\eta = \frac{E_U - E_D}{E_U + E_D}$$

HERA - TPOL

Polarization Time Dependence - electrons

- Electrons injected into the storage ring at full polarization (85%)
- Sokolov-Ternov effect (self-polarization) will re-orient spins to be anti-parallel to main dipole field → electrons will have different lifetime depending on polarization
- Bunches must be replaced relatively often to keep average polarization high
- Bunch-by-bunch polarization measurement required



Refilled every 1.2 minutes

B P

Refilled every 3.2 minutes

Re-injection

P_∞= 30%
(conservative)

Re-injections

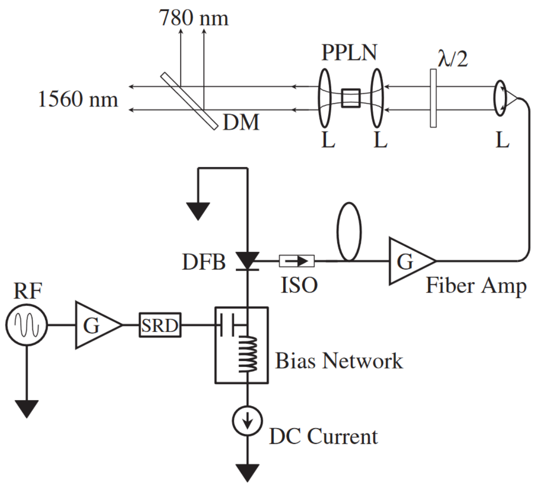
Figure from C. Montag (BNL)

Bunches will be replaced about every 50 minutes at 5 and 10 GeV
→ 1-3 minutes at 18 GeV

Sets requirement for measurement time scale

Compton Laser System

Measurement time requirement met by RF-pulsed laser with average power 5-10 W

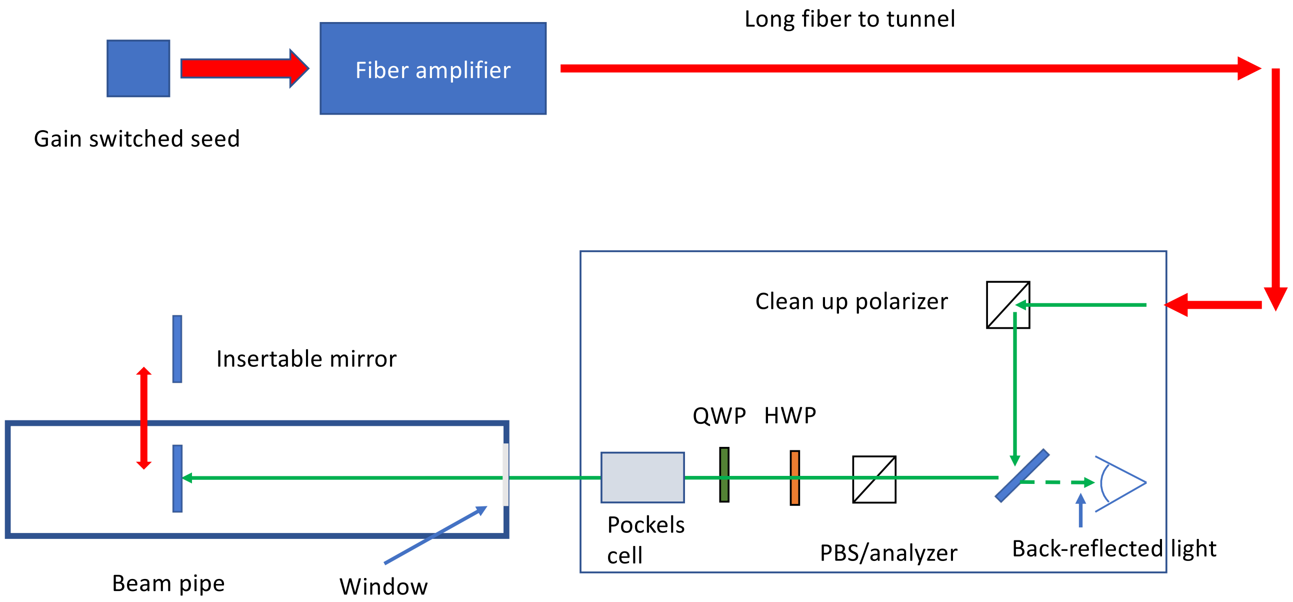


JLab injector laser system

Polarization in vacuum set using “back-reflection” technique
→ Requires remotely insertable mirror (in vacuum)

Proposed laser system based on similar system used in JLab injector and LERF

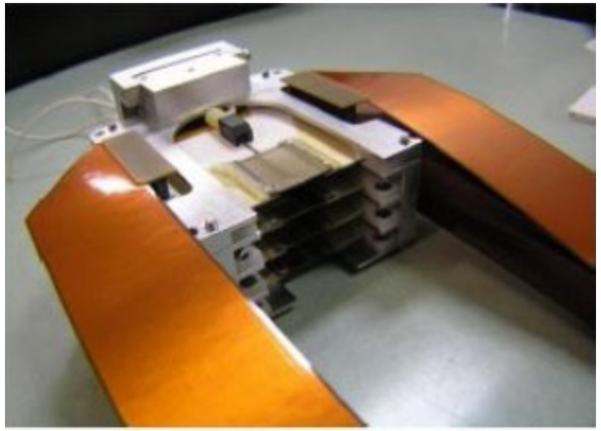
1. Gain-switched diode seed laser – variable frequency, few to 10 ps pulses @ 1064 nm
   - Variable frequency allows optimal use at different bunch frequencies (100 MHz vs 25 MHz)
2. Fiber amplifier → average power 10-20 W
3. Optional: Frequency doubling system (LBO or PPLN)



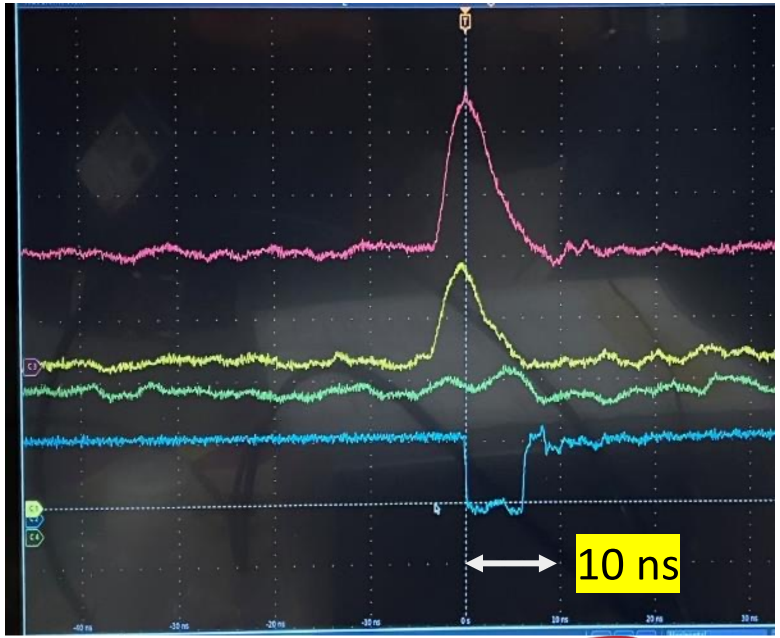
Prototype system under development at JLab

Position Sensitive Detectors

- Position sensitive detectors needed to measure:
    - Scattered electrons → P_L
    - Backscattered photons → P_T
- Technology choice – diamond strips → radiation hard, good time response
- Diamond used during Q-Weak expt at Jlab → no performance degradation after 10 MRad of exposure
- Required detector segmentation = 500 μm (electrons)/100-200 μm (photons)
- Detector size = 6 cm (electrons)/ 5 cm (photons)
- Custom ASIC required → new “FLAT32” chip based on “CALYPSO” (used at LHC) under development for Jlab/MOLLER
    - Already meets timing requirements of EIC (10 ns)



JLab Hall C diamond detector



Transverse Polarization Measurement with EDET

At Compton location – significant transverse beam polarization

- → Unfortunately, this transverse polarization is in the horizontal direction
- → Same coordinate as momentum-analyzing dipole

In the absence of the dipole, the transversely polarized electrons would result in a left-right asymmetry

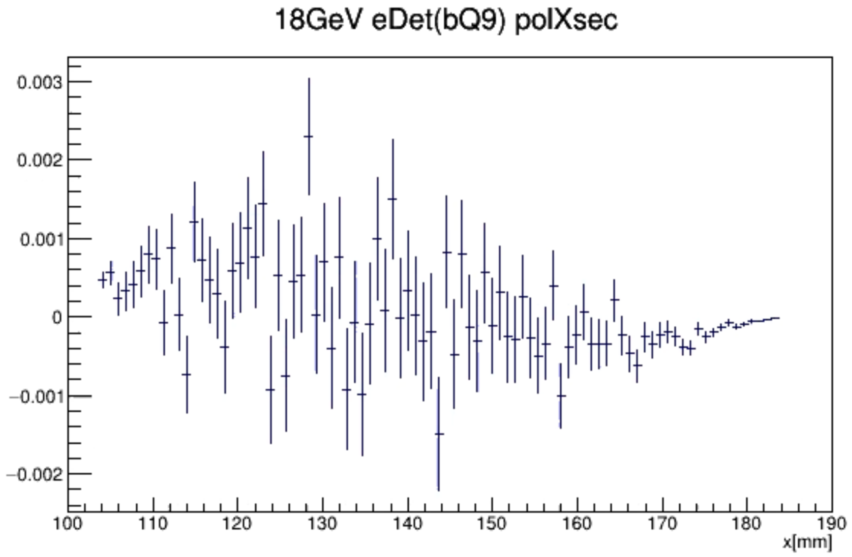
- → The "scattered electron cone" is much smaller than the photons
- → Left-right asymmetry is spread over much smaller distance (μm vs mm)

The large dispersion induced by the dipole makes measurement of the left-right asymmetry impossible

Electron detector can only be used for measurements of ***P_L***

Beam energy	P_L	P_T
5 GeV	96.5%	26.1%
10 GeV	86.4%	50.4%
18 GeV	58.1%	81.4%

100% transversely polarized beam



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Photon Calorimeter

- Good energy resolution required for longitudinal polarization measurements, but fast time response required for bunch-by-bunch measurements
- Tungsten-powder calorimeter (similar to STAR Forward Upgrade) satisfies timing requirements for Compton polarimeters
    - Scintillating fiber embedded in tungsten powder
    - Ample experience with such detectors at BNL
- Detector size 16 x 16 mm^2
- Initially, thought long time component ruled out lead-tungstate
    - Recent publication suggests time response at room temperature may be acceptable

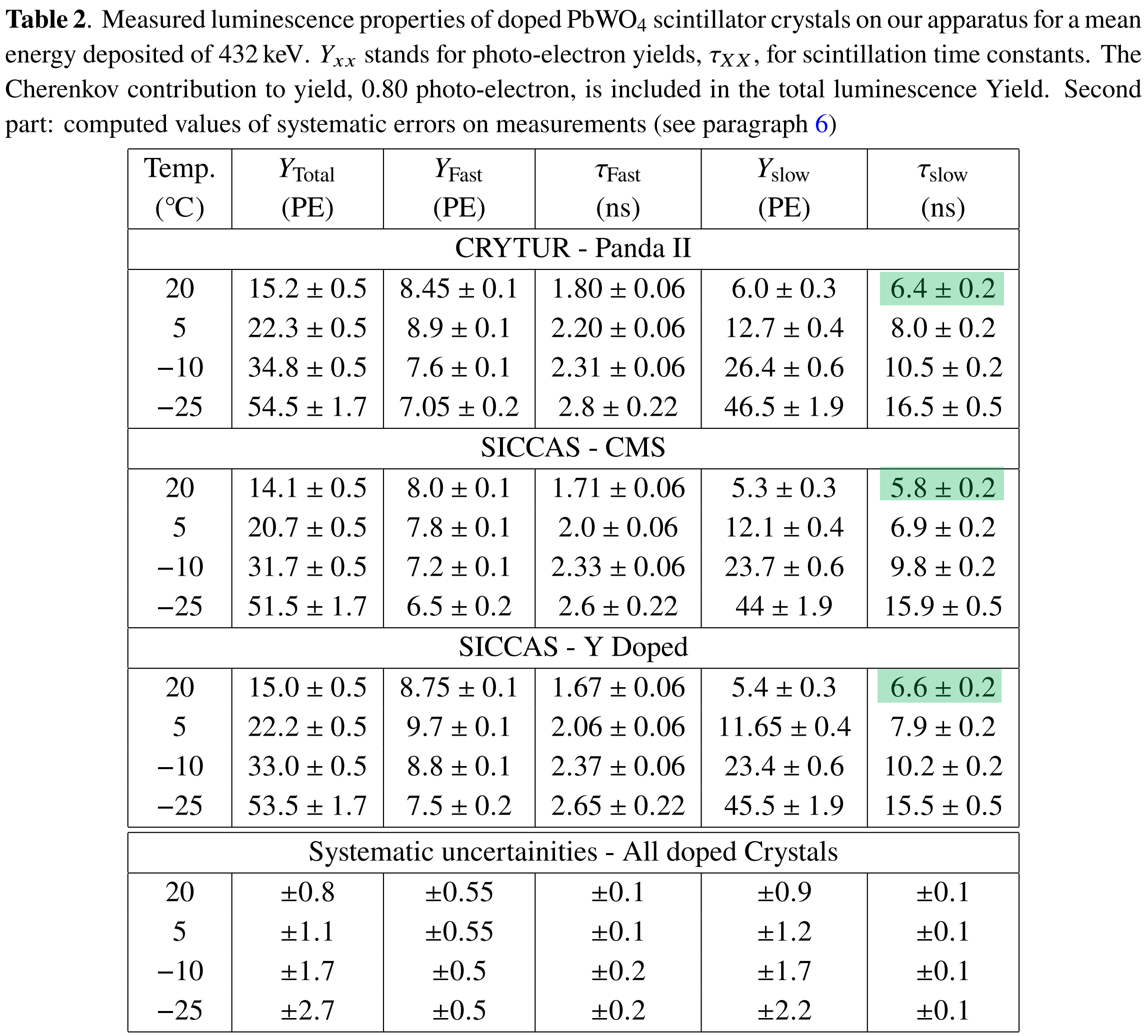


Table 2. Measured luminescence properties of doped $PbWO_4$ scintillator crystals on our apparatus for a mean energy deposited of 432 keV. Y_{xx} stands for photo-electron yields, τ_{XX}, for scintillation time constants. The Cherenkov contribution to yield, 0.80 photo-electron, is included in the total luminescence Yield. Second part: computed values of systematic errors on measurements (see paragraph 6)

Temp. (°C)	Y_{Total} (PE)	Y_{Fast} (PE)	τ_{Fast} (ns)	Y_{slow} (PE)	τ_{slow} (ns)
CRYTUR - Panda II					
20	15.2 ± 0.5	8.45 ± 0.1	1.80 ± 0.06	6.0 ± 0.3	6.4 ± 0.2
5	22.3 ± 0.5	8.9 ± 0.1	2.20 ± 0.06	12.7 ± 0.4	8.0 ± 0.2
−10	34.8 ± 0.5	7.6 ± 0.1	2.31 ± 0.06	26.4 ± 0.6	10.5 ± 0.2
−25	54.5 ± 1.7	7.05 ± 0.2	2.8 ± 0.22	46.5 ± 1.9	16.5 ± 0.5
SICCAS - CMS					
20	14.1 ± 0.5	8.0 ± 0.1	1.71 ± 0.06	5.3 ± 0.3	5.8 ± 0.2
5	20.7 ± 0.5	7.8 ± 0.1	2.0 ± 0.06	12.1 ± 0.4	6.9 ± 0.2
−10	31.7 ± 0.5	7.2 ± 0.1	2.33 ± 0.06	23.7 ± 0.6	9.8 ± 0.2
−25	51.5 ± 1.7	6.5 ± 0.2	2.6 ± 0.22	44 ± 1.9	15.9 ± 0.5
SICCAS - Y Doped					
20	15.0 ± 0.5	8.75 ± 0.1	1.67 ± 0.06	5.4 ± 0.3	6.6 ± 0.2
5	22.2 ± 0.5	9.7 ± 0.1	2.06 ± 0.06	11.65 ± 0.4	7.9 ± 0.2
−10	33.0 ± 0.5	8.8 ± 0.1	2.37 ± 0.06	23.4 ± 0.6	10.2 ± 0.2
−25	53.5 ± 1.7	7.5 ± 0.2	2.65 ± 0.22	45.5 ± 1.9	15.5 ± 0.5
Systematic uncertainities - All doped Crystals					
20	±0.8	±0.55	±0.1	±0.9	±0.1
5	±1.1	±0.55	±0.1	±1.2	±0.1
−10	±1.7	±0.5	±0.2	±1.7	±0.1
−25	±2.7	±0.5	±0.2	±2.2	±0.1

M. Follin et al 2021 JINST 16 P08040

Electron Polarimetry Systematics

Beam energy	P_L	P_T
5 GeV	96.5%	26.1%
10 GeV	86.4%	50.4%
18 GeV	58.1%	81.4%

State of the art for Compton polarimetry:

Longitudinal:

SLD @ SLAC: dP/P=0.5% → Electron detector in multi-photon mode

Q-Weak in Hall C @ JLab: dP/P=0.59% → Electron detector, counting mode

CREX in Hall A @ JLab: dP/P=0.44% → Photon detector, integrating mode

Transverse:

TPOL @ HERA: dP/P=1.87% → Photon detector in counting mode

Total polarization extraction will rely on two quasi-independent measurements

While 0.5% for P_L is plausible, P_T is less certain → 1%?

At 18 GeV this results in dP/P=0.86% at 18 GeV

Polarimetry for RCS

RCS properties

- RCS accelerates electron bunches from 0.4 to full beam energy (5-18 GeV)
- Bunch injection frequency → 2 Hz
- Bunch charge → up to 28 nA
- Ramping time = 100 ms

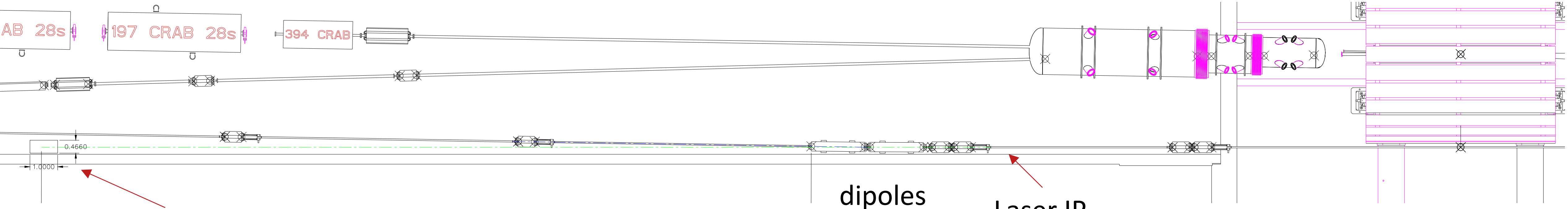
Polarimetry challenges

- Analyzing power often depends on beam energy
- Low average current
- Bunch lifetime is short

Compton polarimeter can also be used for measurement of polarization in RCS

→ Measurements will be averaged over several bunches – can tag accelerating bunches to get information on bunches at fixed energy

→ Requires measurement in ***multiphoton*** mode (~1000 backscattered photons/crossing)



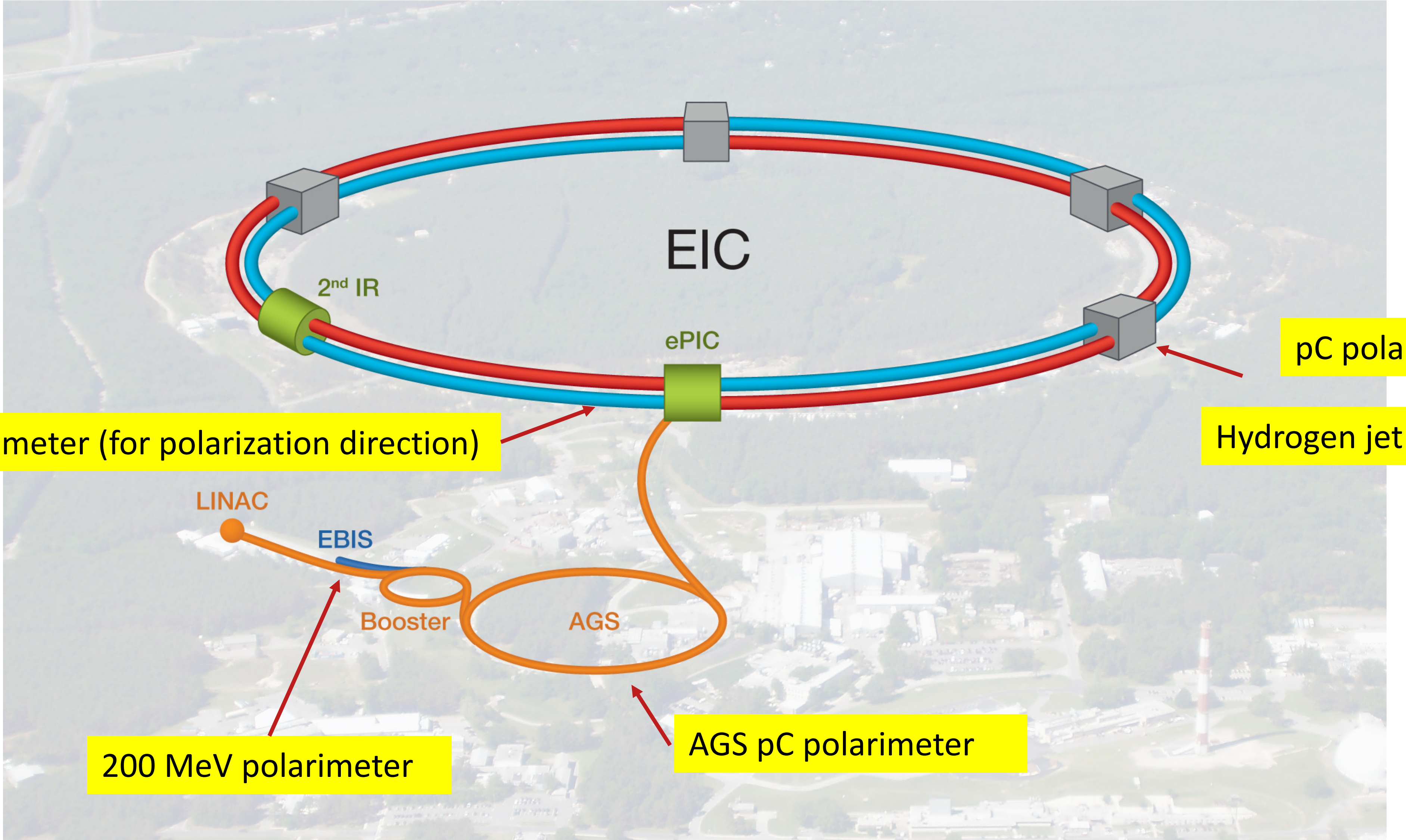
IP6 detector

dipoles

Laser IP

Photon detector

Hadron Polarimeter Map



pC polarimeter

Hydrogen jet polarimeter

pC polarimeter (for polarization direction)

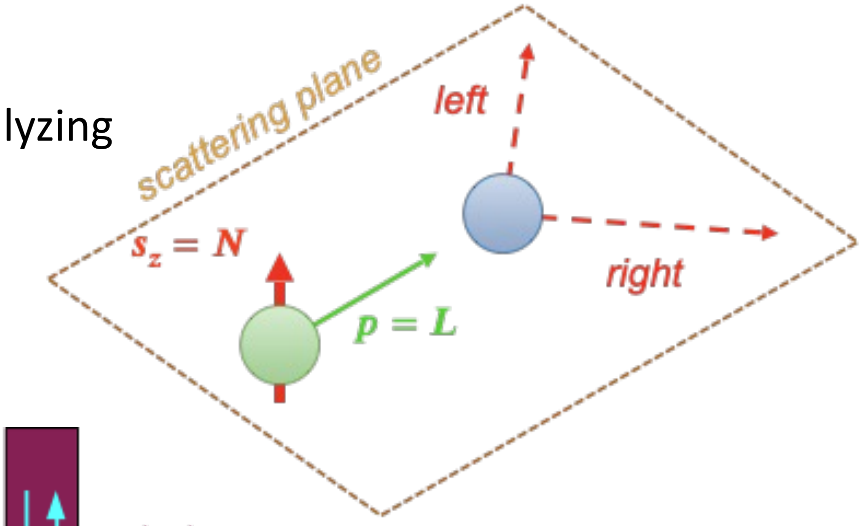
200 MeV polarimeter

AGS pC polarimeter

Measurement of Absolute Polarization

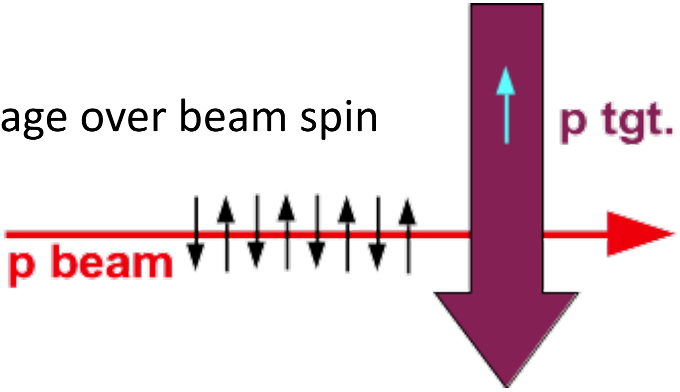
Electron polarimetry benefits from known QED processes (Compton, Møller scattering)
→ No equivalent processes for hadrons to measure absolute polarization → analyzing power a priori unknown

Use of polarized target with polarized beam bypasses need to determine analyzing power from first principles



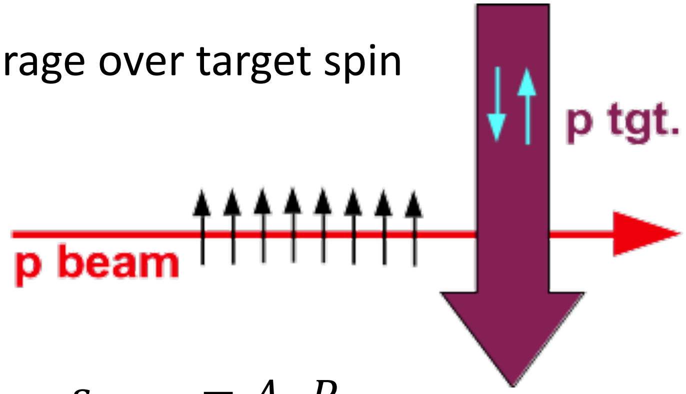
$$\epsilon = \frac{N_R - N_L}{N_R + N_L} = A_N P$$

Average over beam spin



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

Average over target spin



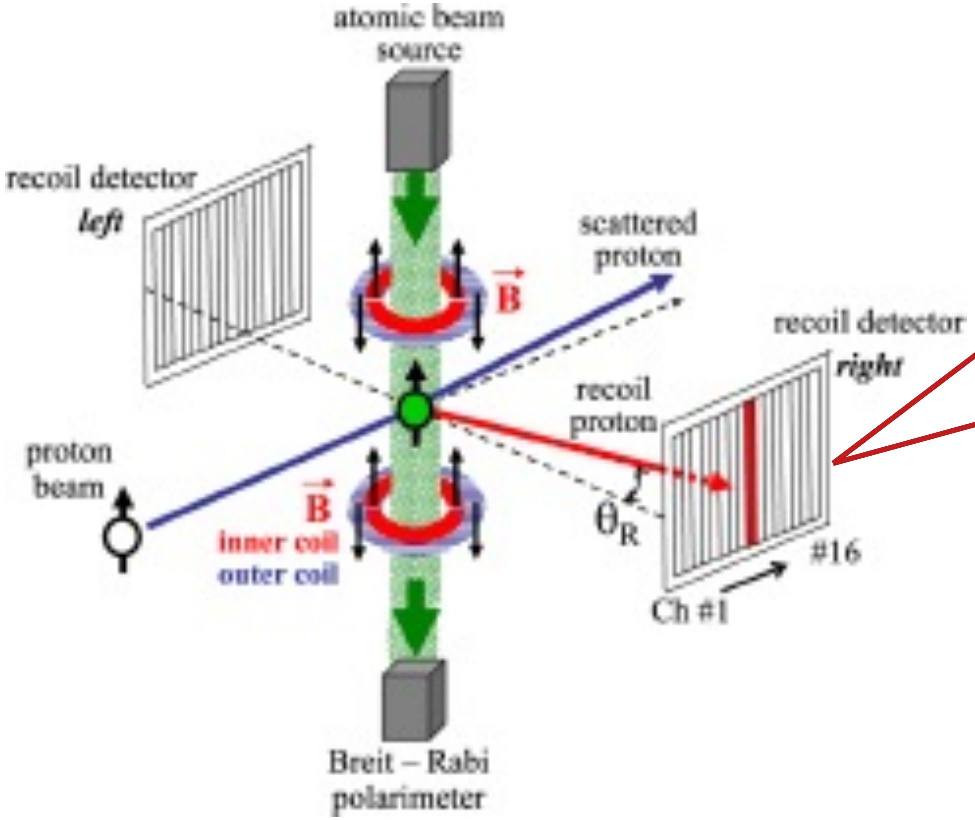
$$\varepsilon_{beam} = A_N P_{beam}$$

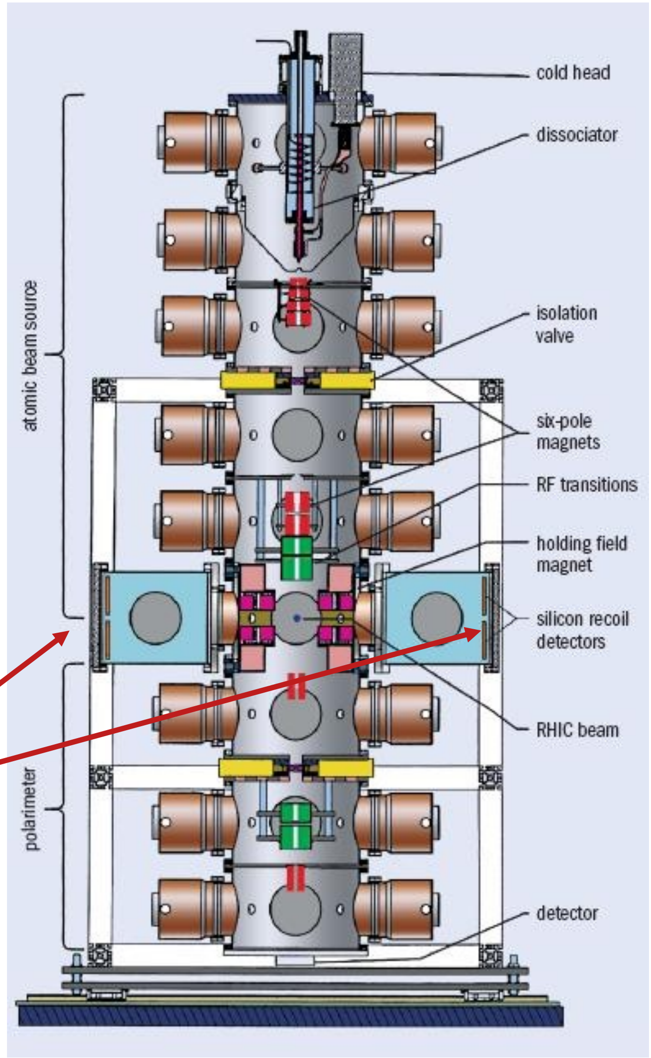
➡ $$P_{beam} = \frac{\varepsilon_{beam}}{\varepsilon_{target}} P_{target}$$

Hydrogen-Jet Polarimeter at RHIC

H-Jet Polarimeter (presently) installed at IP12
→ Uses elastic p-p scattering in the Coulomb-nuclear interference (CNI) region
→ Polarized atomic H source, $1.2\cdot10^{12}$ atoms/cm2
→ Target polarization measured w/ Breit-Rabi polarimeter, $P_{target} \approx 96\%$

→ Silicon strip detectors, 12 strips 3.75 mm pitch
→ H-Jet has achieved high precision at RHIC: $(dP/P)_{syst}=0.6\%$
→ Measurements time consuming:
$(dP/P)_{stat} \sim 2\%$ for 8-hour period

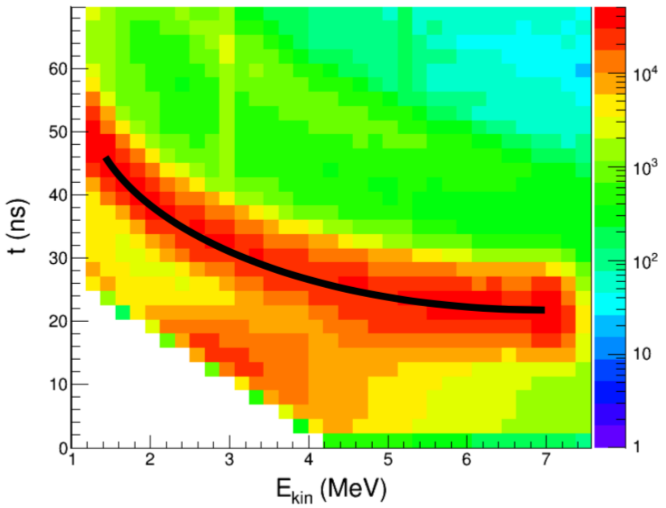




Hydrogen-Jet Polarimeter

Elastic events identified via TOF-Kinetic energy correlation
→ "Banana" plot

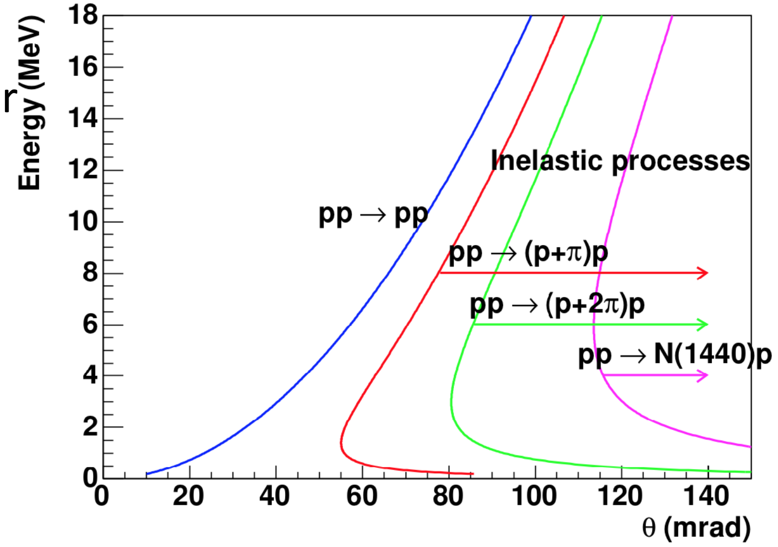
Silicon strip detectors read out with wave-form digitizers that simultaneously provide energy and TOF information

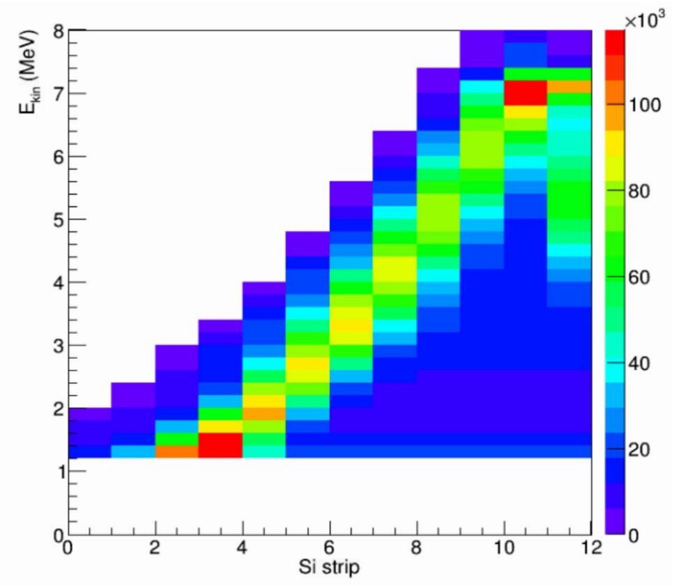


Asymmetry extracted from "cross-ratio" → reduces sensitivity to left-right acceptance differences

$$\epsilon = \frac{\sqrt{N_{R+}N_{L-}} - \sqrt{N_{L+}N_{R-}}}{\sqrt{N_{R+}N_{L-}} + \sqrt{N_{L+}N_{R-}}}$$

E-θ correlation different for elastic and inelastic processes





Strip number → θ

p-Carbon Polarimeter

p-Carbon polarimeter also uses elastic scattering in CNI region

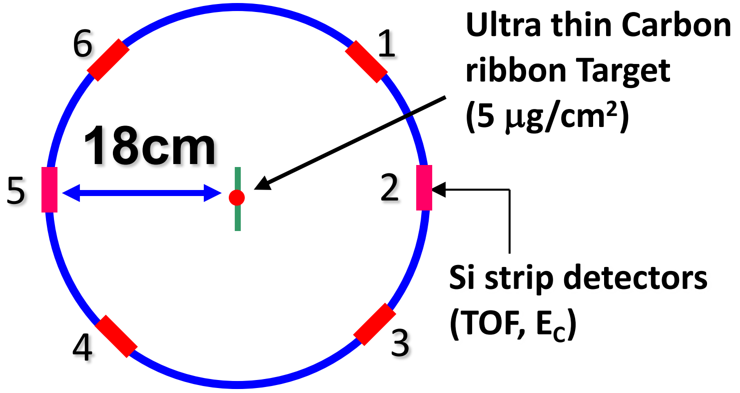
→ Provides rapid, ***relative*** measurement of proton polarization

→ Uses thin carbon ribbon

→ Very low energy, recoiling carbon detected in silicon strip detectors

→ Polarization extracted via L-R asymmetry

2 p-Carbon polarimeters at RHIC → vertical and horizontal target to characterize beam profile



Ultra thin Carbon ribbon Target ($5\ \mu g/cm^2$)

Si strip detectors (TOF, E_C)

Nominal target size:
2.5 cm · 10 μ · 50 nm

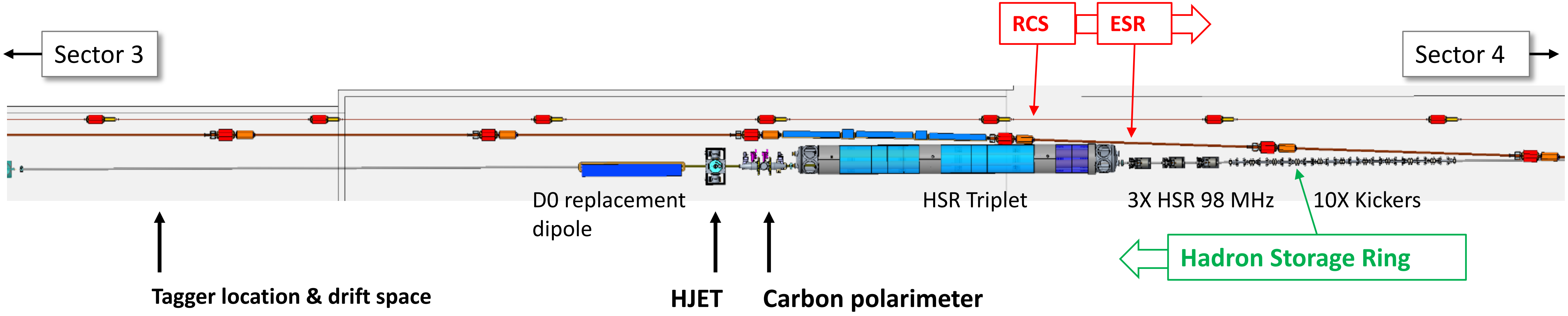
Passed across beam & back
~2-5 sec. in beam each pass
lifetime: few - few hundred passes

Hadron Polarimetry Challenges at EIC

- EIC Hadron Polarimetry will make use of existing H-Jet and p-Carbon systems moved to new location (IP 4)→ not enough room at IP12
- EIC will have shorter bunch spacing than RHIC → challenges for identifying good events
- EIC will have higher beam current → p-Carbon target will likely not survive in beam
- Light-ion polarimetry
  - RHIC polarimeters designed for protons
  - Similar processes can be used for light-ions (^{3}He), but there may be additional backgrounds from breakup
  - Deuteron beams not part of baseline, but are also of interest → analyzing power for deuteron predicted to be much smaller than for p and ^{3}He

Hadron Polarimeters: IR-4 Layout

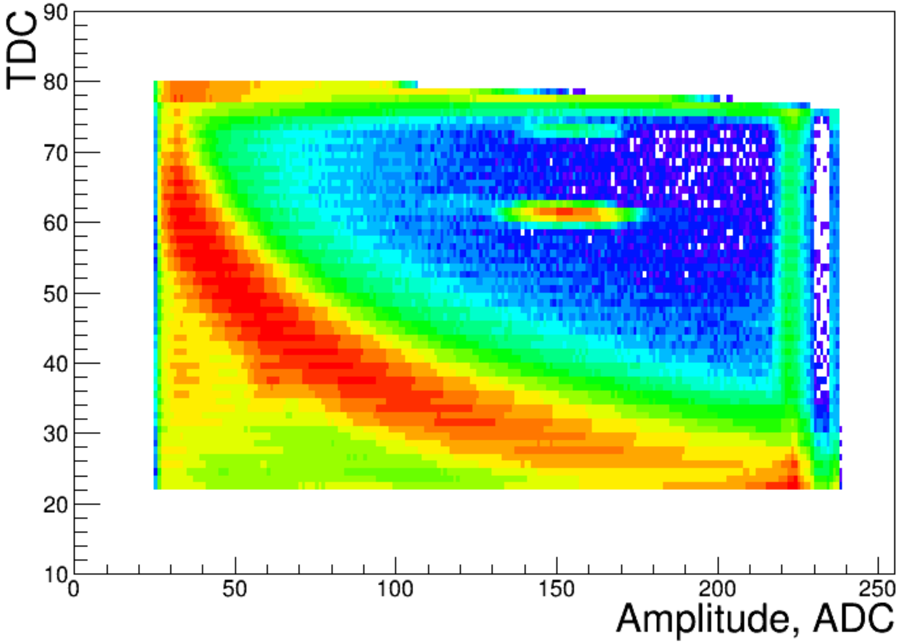
Choice of location driven by size of HJET setup and the following drift space



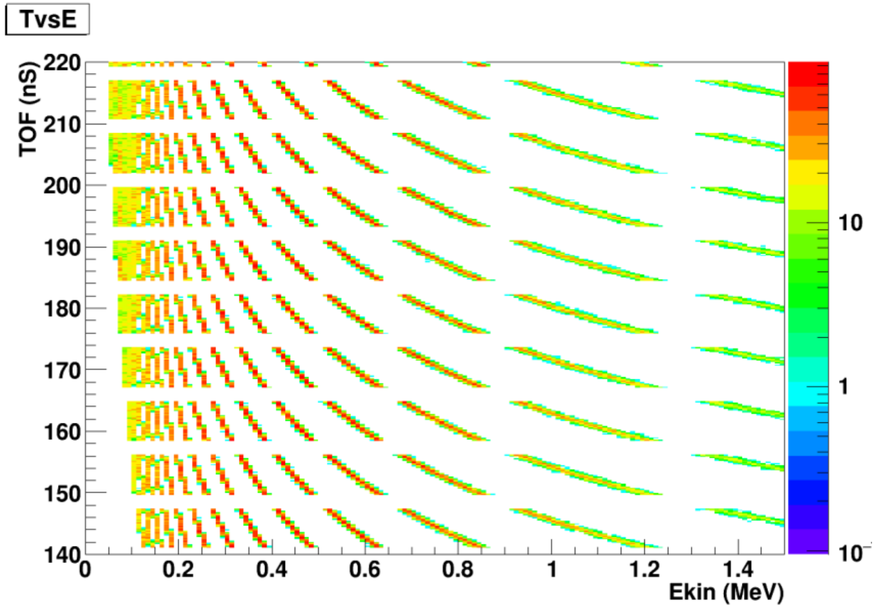
- RHIC polarimeters currently in use at IR-12
- Decommissioning after Run 2025 (07/25)
- Planned HJET setup in BNL Physics (refurbishment / modifications)
  - Double layer silicon detectors
  - Target gas analyzer (H_2 content)
  - Target chamber / magnetic field

Bunch Spacing

RHIC – pC data (107 ns bunch spacing)



EIC – (~10 ns bunch spacing)

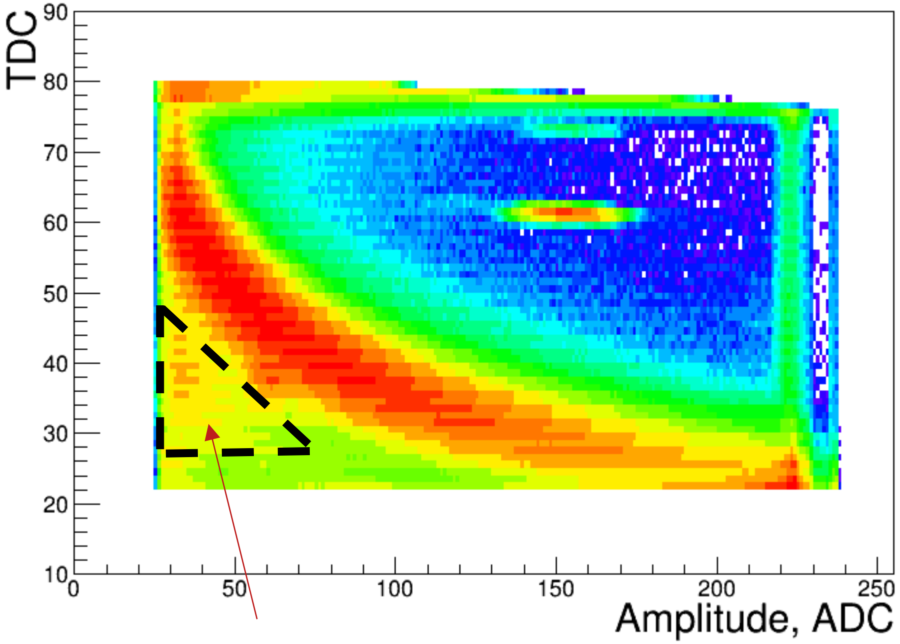


Smaller bunch spacing makes selection of good events via TOF-E correlation impossible

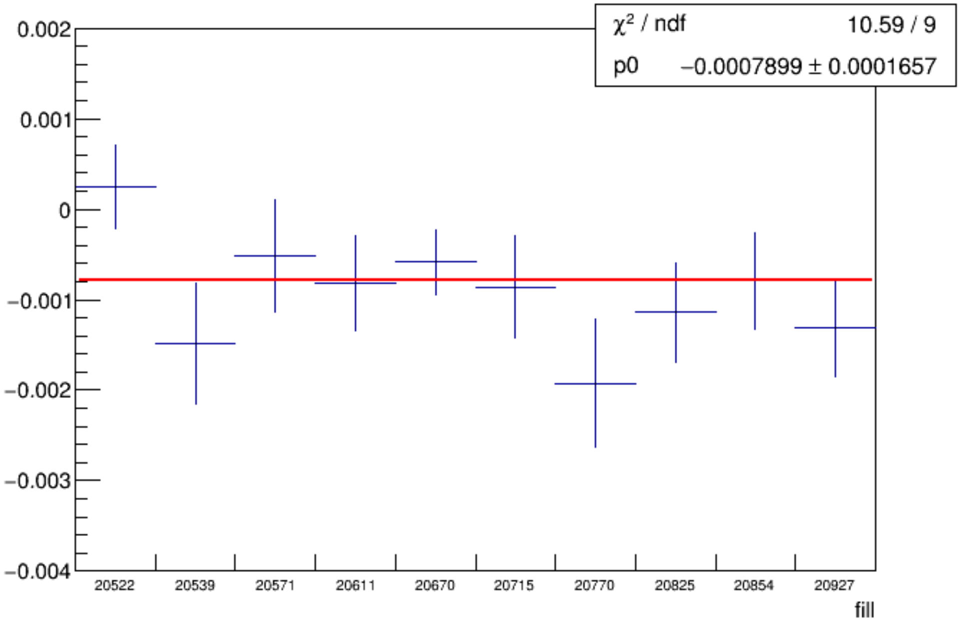
→ Several bunches will overlap

→ Impossible to cleanly identify elastic signal, remove background

Backgrounds



background



Background asymmetry

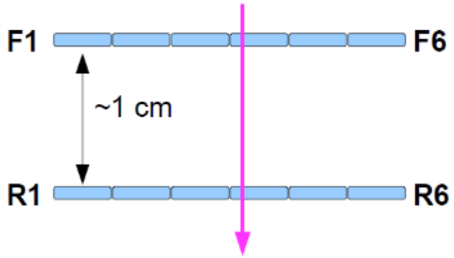
Bunch-spacing issues prevent clean removal of backgrounds
→ Fast particles – pions, photons up to a few GeV
→ Background more than just a dilution – appears to carry non-zero asymmetry

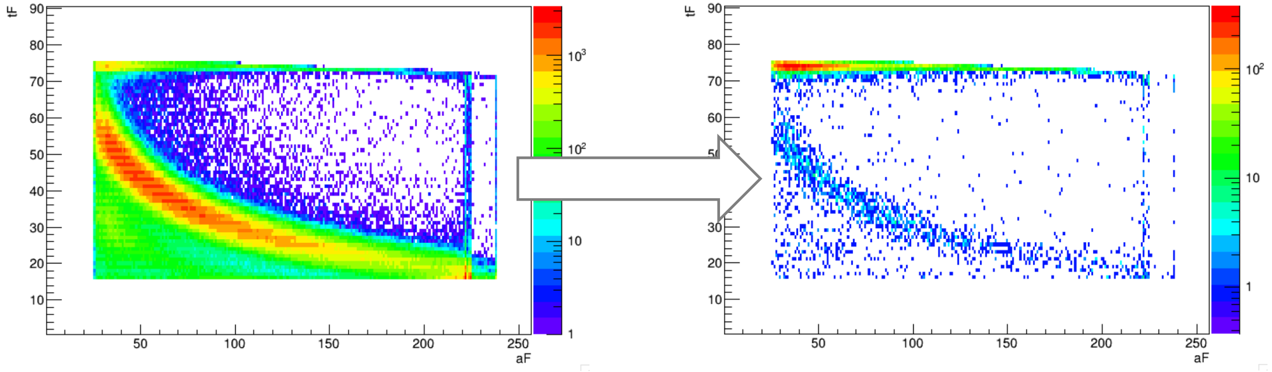
H-Jet will have similar issues

Multi-layer detectors

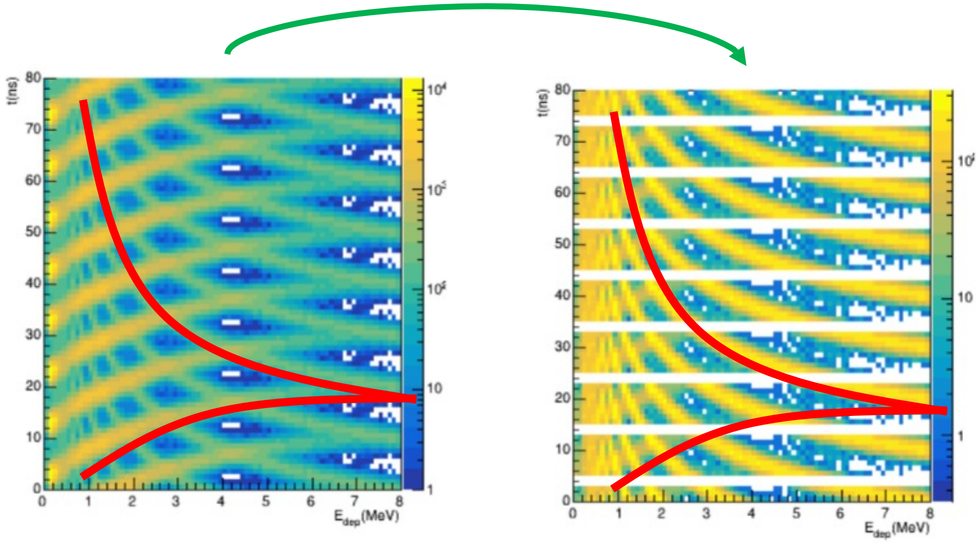
- Use 2nd layer of detectors to reject fast background?
- Second detector layer installed in pC polarimeter
  - Included in DAQ since start of Run22 operations
  - Data from RHIC Run 22

- Hybrid simulation
  - PYTHIA & GEANT
  - Repeated with 10 ns bunch spacing




Tof vs. Ekin in layer 1 (F)

with a match in second layer (R)

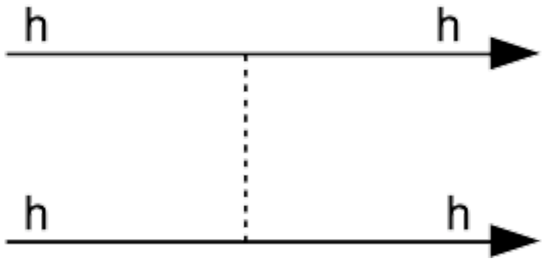

Veto punch through particles

Proton time-of-flight

^{3}He Breakup

Absolute polarimetry with polarized jet target requires elastic scattering

→ Helion can breakup into d+p or n+p+p

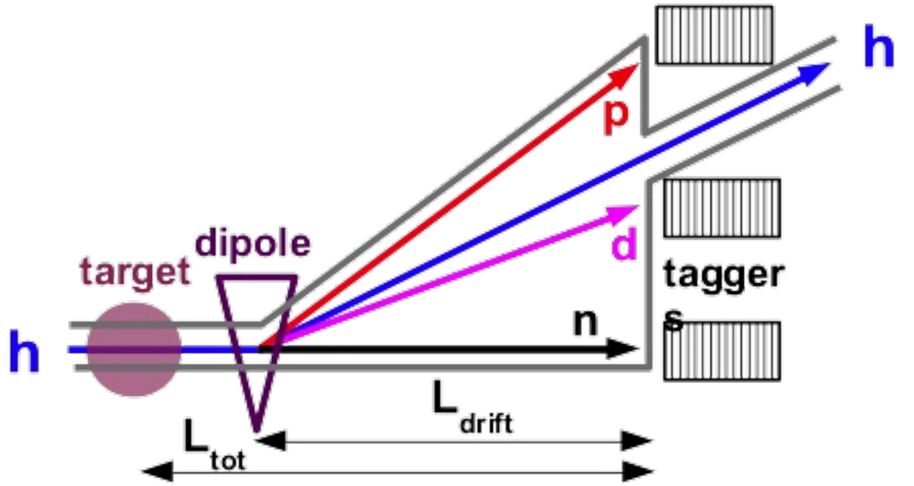


h = helion, ^{3}He
d = deuteron
p = proton
n = neutron

Mass difference between h and (d+p) only 5 MeV → too small to resolve with target recoil detectors
→ For elastic pp, nearest inelastic channel is single pion production, 140 MeV

Need to tag helion breakup fragments and reject from polarimetry analysis

Near threshold, breakup fragments travel colinearly with beam
→ Tagging requires dipole to separate n/p/d
→ Detectors placed at appropriate separation for each



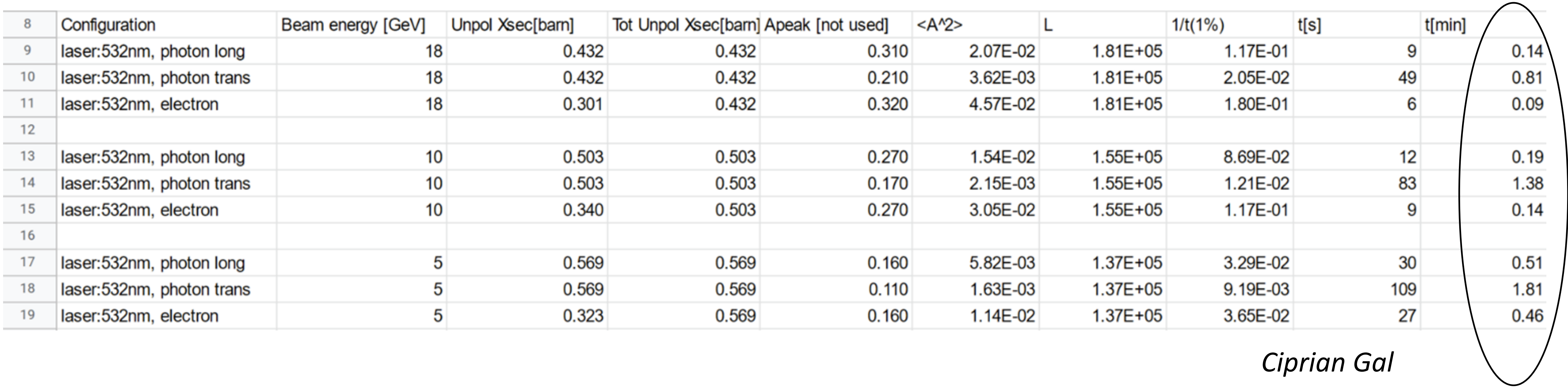
Initial tests performed in 2022 – saw correlated signals in test detectors
Future:
→ Improve tagging
→ Test light ion breakup in future runs

Summary

- EIC goal is to measure both electron and hadron beam polarization to 1%
- Compton polarimeter for electrons
  - ESR Compton must measure both P_L and P_T simultaneously since Compton not at IP
  - High current, short bunch separation pose challenges
  - P_T measurement may be biggest challenge for <1% polarimetry
- Hadron polarimetry will use combination of:
  - H-Jet (absolute)
    - Has achieved dP/P=0.6%
  - p-Carbon (relative)
    - Can measure polarization profile (transverse and longitudinal)
  - Both polarimeters must overcome issues with background rejection
    - Must find new target for p-Carbon polarimeter

EXTRA

Compton Laser System Requirements



8	Configuration	Beam energy [GeV]	Unpol Xsec[barn]	Tot Unpol Xsec[barn]	Apeak [not used]	<A^2>	L	1/t(1%)	t[s]	t[min]
9	laser:532nm, photon long	18	0.432	0.432	0.310	2.07E-02	1.81E+05	1.17E-01	9	0.14
10	laser:532nm, photon trans	18	0.432	0.432	0.210	3.62E-03	1.81E+05	2.05E-02	49	0.81
11	laser:532nm, electron	18	0.301	0.432	0.320	4.57E-02	1.81E+05	1.80E-01	6	0.09
12										
13	laser:532nm, photon long	10	0.503	0.503	0.270	1.54E-02	1.55E+05	8.69E-02	12	0.19
14	laser:532nm, photon trans	10	0.503	0.503	0.170	2.15E-03	1.55E+05	1.21E-02	83	1.38
15	laser:532nm, electron	10	0.340	0.503	0.270	3.05E-02	1.55E+05	1.17E-01	9	0.14
16										
17	laser:532nm, photon long	5	0.569	0.569	0.160	5.82E-03	1.37E+05	3.29E-02	30	0.51
18	laser:532nm, photon trans	5	0.569	0.569	0.110	1.63E-03	1.37E+05	9.19E-03	109	1.81
19	laser:532nm, electron	5	0.323	0.569	0.160	1.14E-02	1.37E+05	3.65E-02	27	0.46

Ciprian Gal

Laser power constraint: sufficient power to result in ~ 1 backscattered photon/bunch-laser crossing
→ Want to make "single photon" measurements – not integrating

532 nm laser with ~5 W average power at same frequency as EIC electron bunches sufficient

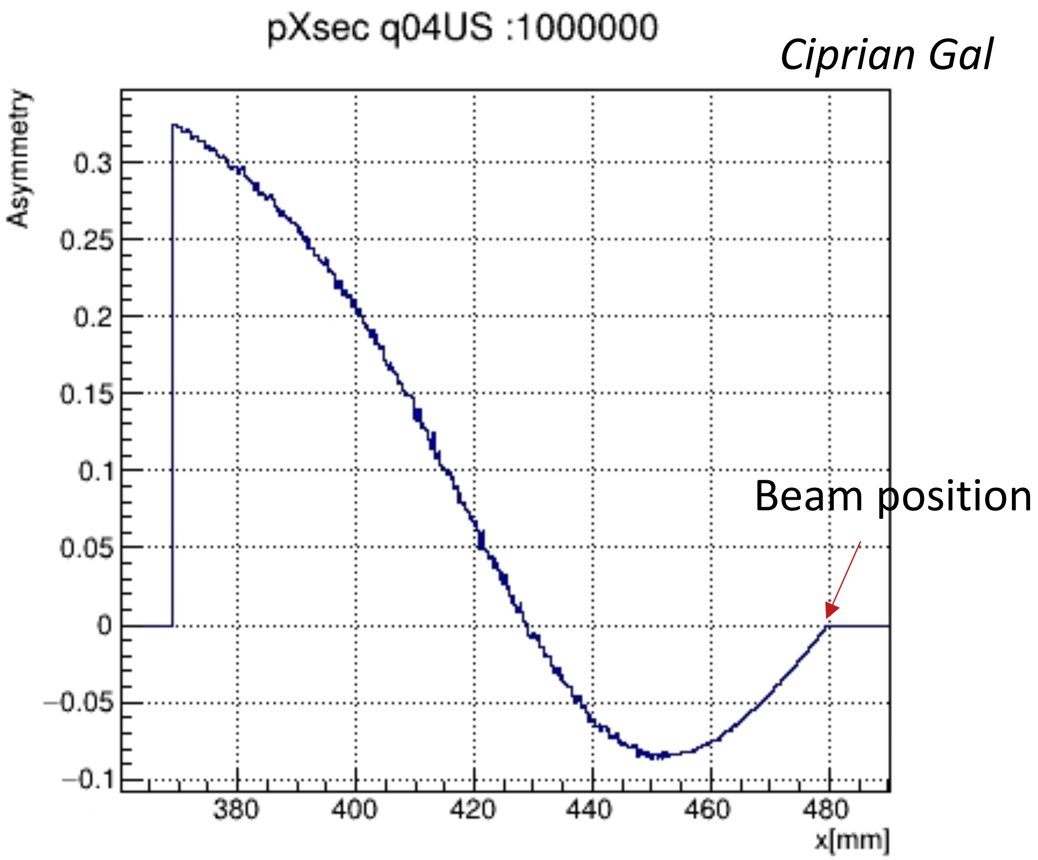
Resulting measurement times (for differential measurement, dP/P=1%) as noted above – easily meets beam lifetime constraints

Electron Detector Size and Segmentation

- Electron detector (horizontal) size determined by spectrum at 18 GeV (spectrum has largest horizontal spread)
  - Need to capture zero-crossing to endpoint → detector should cover at least 60 mm

- Segmentation dictated by spectrum at 5 GeV (smallest spread)
  - Scales ~ energy → 17 mm
  - Need at least 30 bins, so a strip pitch of about 550 μm would be sufficient

- At 18 GeV, zero-crossing about 3 cm from beam
  - 5 GeV → 8-10 mm – this might be challenging

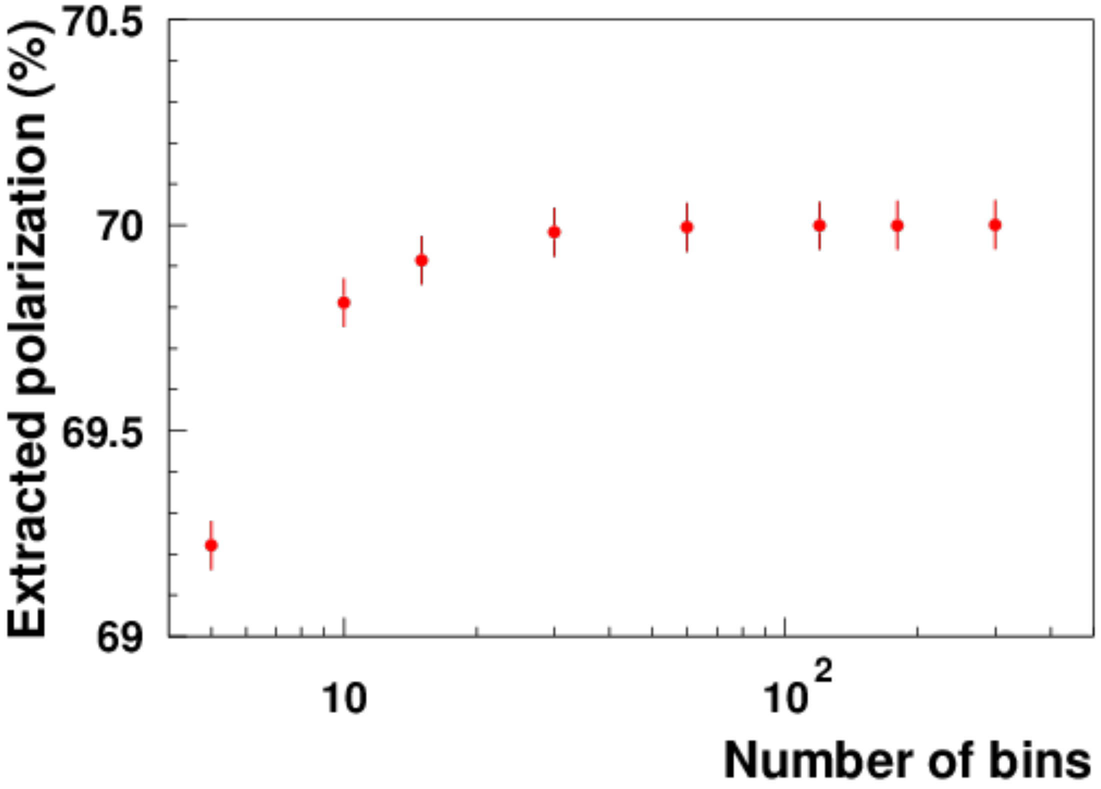


Asymmetry at electron detector @18 GeV

Detector Segmentation – Electron Detector

Detector segmentation driven by requirement to be able to extract polarization (fit asymmetry) without any corrections due to detector resolution (see SLD Compton)

→ Studies with toy Monte Carlo suggest that about 30 bins (strips) between asymmetry zero crossing and endpoint results in corrections <0.1%

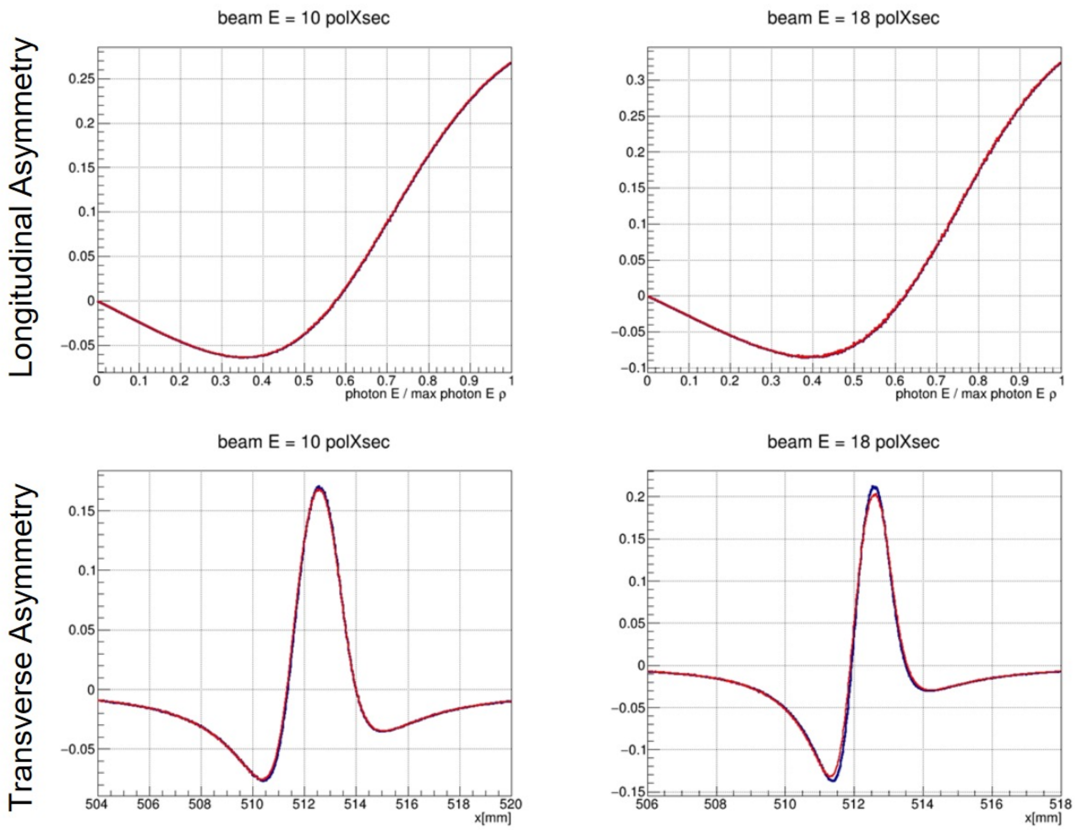


Polarization Measurement with Photon Detector

Photon detector needs 2 components to measure both longitudinal and transverse polarization

- Calorimeter → asymmetry vs. photon energy (P_L)
- Position sensitive detector → left-right asymmetry (P_T)

Beam energy	P_L	P_T
5 GeV	96.5%	26.1%
10 GeV	86.4%	50.4%
18 GeV	58.1%	81.4%



Ciprian Gal

Transverse size of detectors determined by backscattered photon cone at low energy

→ +/- 2 cm adequate at 5 GeV

→ Longitudinal measurement requires good energy resolution from ~0 (as low as possible) to 3 GeV

→ Fast time response also needed (10 ns bunch spacing)

→ PbWO4 a possible candidate (slow component may be an issue)

Position sensitive detector segmentation determined by highest energy → 18 GeV

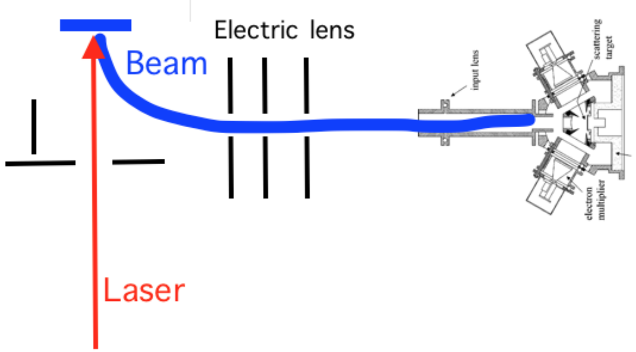
→ More investigation needed, but segmentation on the order of 100-400 μm should work

Mott Polarimetry at EIC

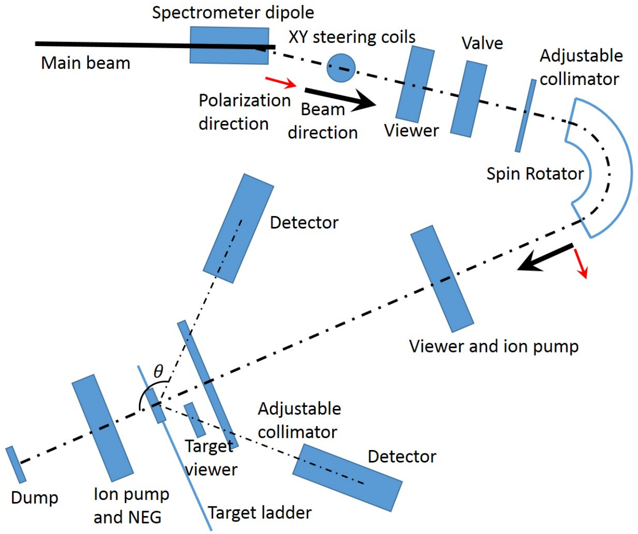
EIC will make use of two Mott polarimeters to measure the electron polarization from the source

1. Low voltage Mott polarimeter
→ Measure polarization at 20 keV immediately after photocathode

2. High voltage Mott polarimeter
→ Measure at 300 keV, in the beamline, before electron bunching
→ Requires spin rotator to change electron from longitudinal to transverse spin



Low voltage Mott polarimeter



High voltage Mott polarimeter

Luminosity

Luminosity for CW laser colliding with electron beam at non-zero crossing angle:

$$\mathcal{L} = \frac{(1+\cos\alpha_c)}{\sqrt{2\pi}} \frac{I_e}{e} \frac{P_L \lambda}{hc^2} \frac{1}{\sqrt{\sigma_e^2 + \sigma_\gamma^2}} \frac{1}{\sin\alpha_c}$$

Pulsed laser:

$$\mathcal{L} = f_{coll} N_\gamma N_e \frac{\cos(\alpha_c/2)}{2\pi} \frac{1}{\sqrt{\sigma_{x,\gamma}^2 + \sigma_{x,e}^2}} \frac{1}{\sqrt{(\sigma_{y,\gamma}^2 + \sigma_{y,e}^2)\cos^2(\alpha_c/2) + (\sigma_{z,\gamma}^2 + \sigma_{z,e}^2)\sin^2(\alpha_c/2)}}$$

$N_{\gamma(e)}$ = number of photons (electrons) per bunch

Assumes beam sizes constant over region of overlap (ignores “hourglass effect”)

Beam size at interaction point with laser dictates luminosity (for given beam current and laser/electron beam crossing angle)

Analyzing Power and Measurement Times

Measurement time depends on luminosity, analyzing power, and measurement technique

$$t^{-1} = \mathcal{L}\sigma \left(\frac{\Delta P}{P}\right)^2 A^2_{method}$$

Average analyzing power: $A^2_{method} = \langle A \rangle^2$ → Average value of asymmetry over acceptance

Energy-weighted: $A^2_{method} = \left(\frac{\langle EA \rangle}{\langle E \rangle}\right)^2$ → Energy deposited in detector for each helicity state

Differential: $A^2_{method} = \langle A^2 \rangle$ → Measurement of asymmetry bin-by-bin vs. energy, etc.

$$\langle A \rangle^2 < \left(\frac{\langle EA \rangle}{\langle E \rangle}\right)^2 < \langle A^2 \rangle$$

Transverse Polarimetry in Multi-Photon mode

Highest precision transverse Compton polarimeter operated in **single photon** mode (HERA)

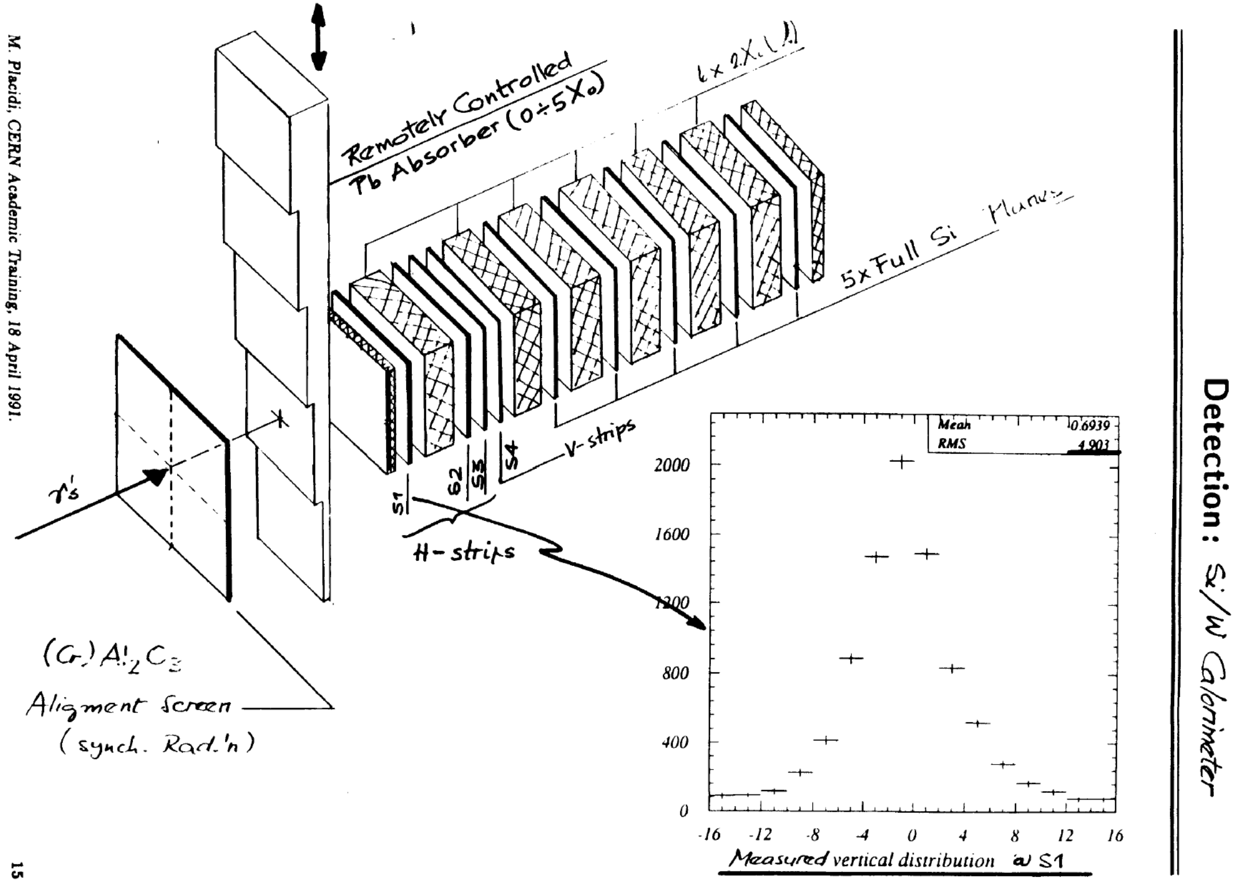
→ RCS requires position sensitive measurement in **multi-photon** mode

Need highly segmented detector sensitive to signal size (not just counts above threshold)

→ LEP polarimeter operated in this fashion, although with relatively low precision

Simulations will guide the detector technology choice based on requirements for radiation hardness and position resolution

Note: RCS Compton only needed for machine setup



Systematics and Luminosity Measurement

Collision luminosity measured via the Bremsstrahlung process: *ep* → *ep*γ
→ Successfully used at HERA – precisely known cross section, high rates

Unlike HERA, both beams polarized → results in a polarization dependent term:

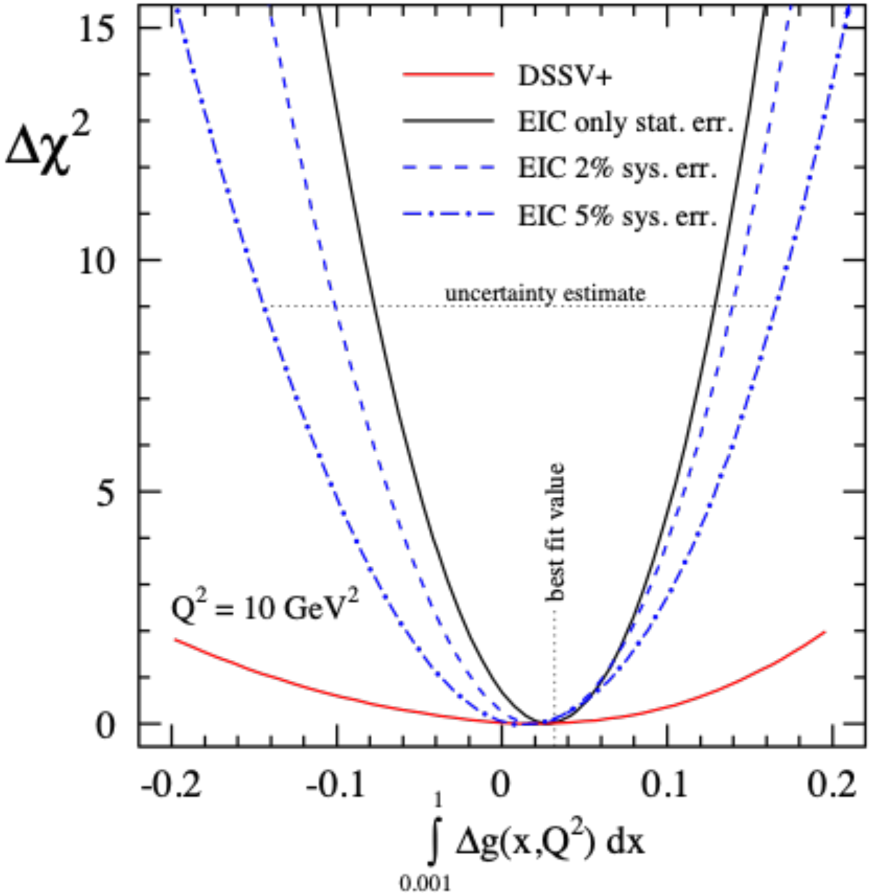
$$\sigma_{Brems} = \sigma_0(1 + aP_eP_h)$$

Precision in luminosity measurement for double-spin asymmetries coupled to polarimetry

$$A_{\|} = \frac{1}{P_eP_h}\left[\frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}\right]$$

$$R = L^{++}/L^{+-}$$

Polarimetry systematics:
Goal is ***dP/P = 1%*** or better for both electrons and hadrons



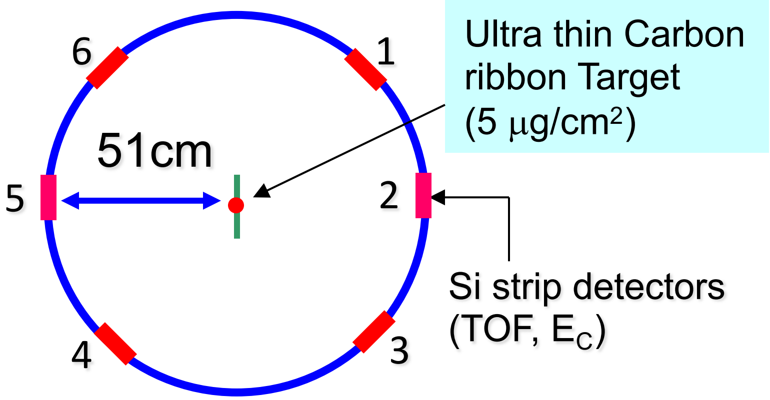
Impact of systematic uncertainties on Δg

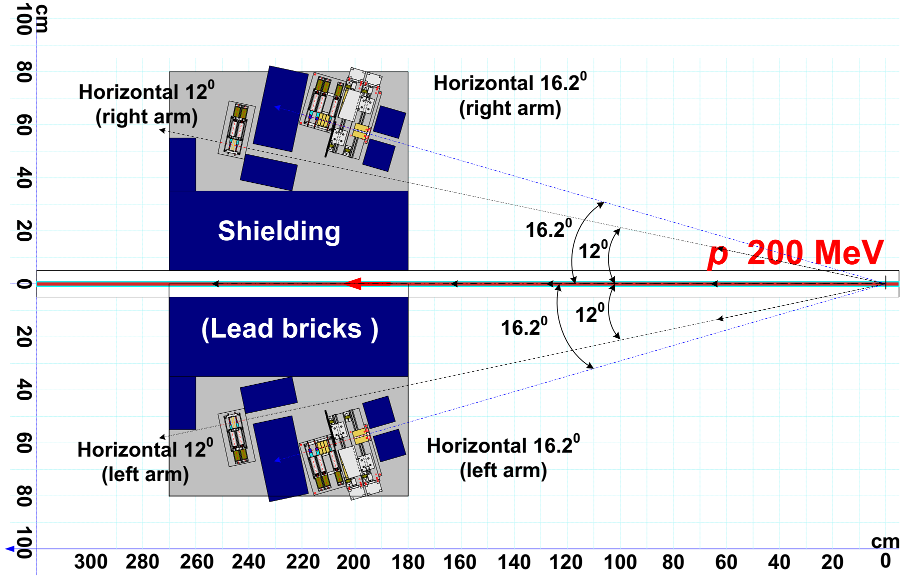
AGS and 200 MeV Polarimeters

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%