Electron and Hadron Polarimetry

WBS 6.10.14

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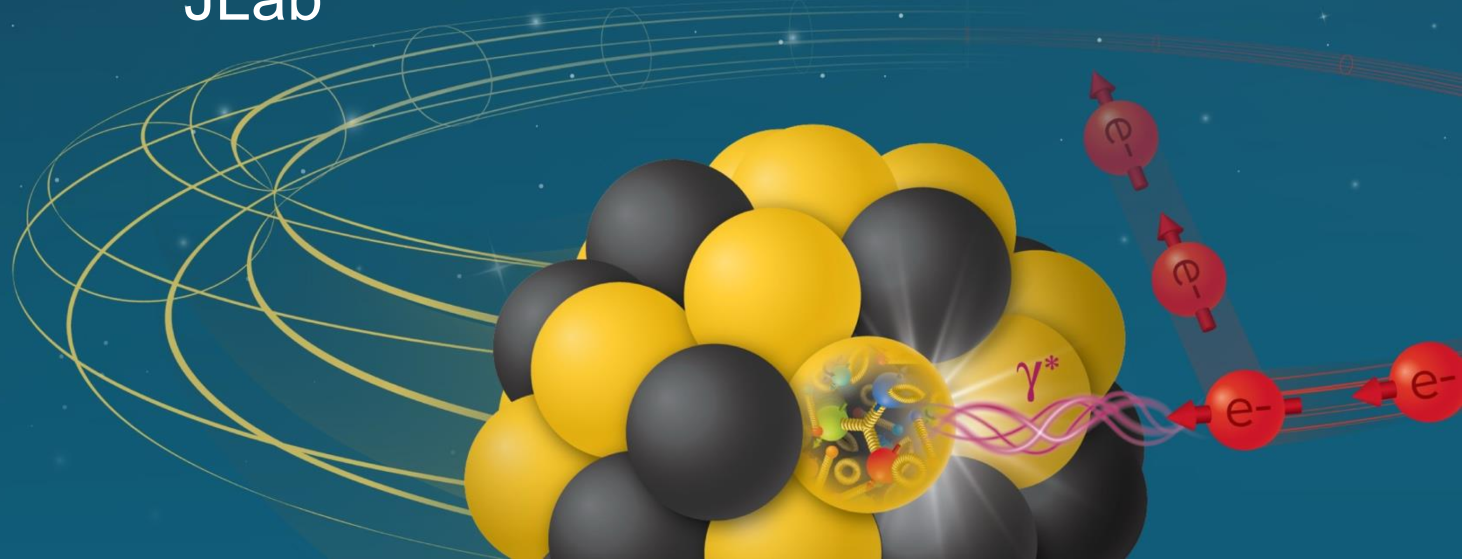
10th EIC DAC Meeting

June 11-13, 2025

Electron-Ion Collider



Charge Questions Addressed

1. Is the design of the ePIC detector and its sub-systems appropriate and progressing well?
2. Are the remaining work and technical, cost and schedule risks adequately understood? Are there opportunities?
3. Will the detector be technically ready for baselining by late 2025?
4. Are the detector integration and planning for installation and maintenance progressing well? Are there areas where further ideas should be pursued?
5. Will the detector be ready for start of construction by late 2026?

Requirements

<table>
<tr><th>Polarized Electron Beams</th><th>Polarized Hadron Beams</th></tr>
<tr><td colspan="2">Highly polarized beams, $P \approx 70\%$</td></tr>
<tr><td colspan="2">Fast feedback for machine setup</td></tr>
<tr><td colspan="2">Excellent measurement of absolute polarization, $\Delta P/P \approx 1\%$</td></tr>
<tr><td colspan="2">Non-destructive polarimetry</td></tr>
<tr><td colspan="2">Bunch-by-bunch polarization measurement
(fill pattern: $P^{\uparrow}$,$P^{\downarrow}$, $\Delta t \approx 10\ \mathrm{ns}$)</td></tr>
<tr><td>Sokolov-Ternov, $\Delta P^{\uparrow} \neq \Delta P^{\downarrow}$</td><td>Polarization decay
($\Delta P \approx 1 - 2\%/\mathrm{h}$)</td></tr>
<tr><td></td><td>Transverse bunch polarization profile</td></tr>
<tr><td colspan="2">Polarization vector at experiment (transverse, longitudinal)</td></tr>
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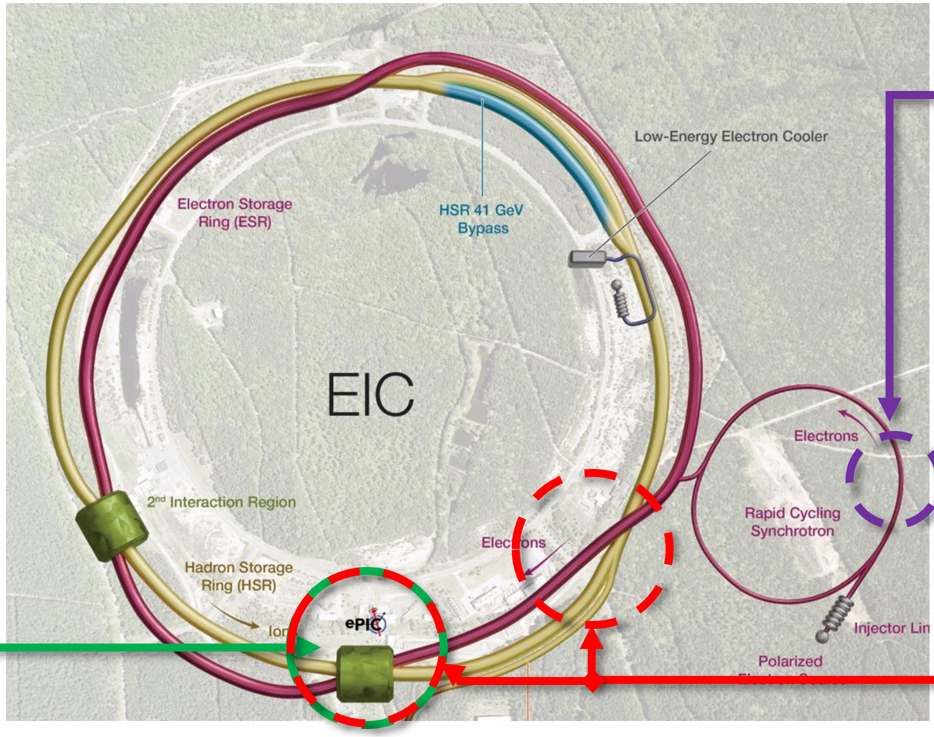
Scope

IR-6

Local polarimetry

- Inside spin rotators
- Fiber target for hadron polarization orientation
- Compton backscattering for electron polarization (ESR)



RCS

- Compton backscattering for electron polarization

IR-4

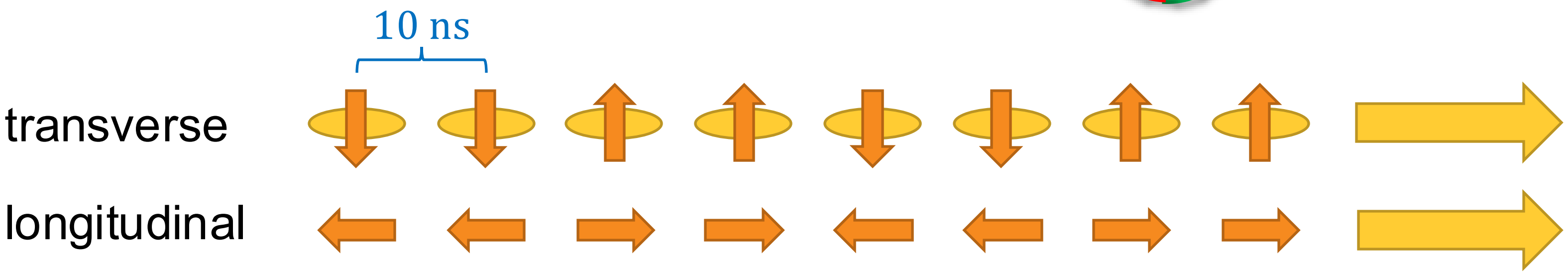
Hadron polarimetry

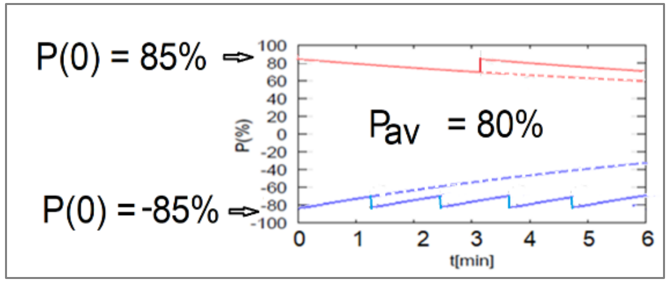
- HJET for absolute polarization

Fiber target for polarization lifetime and bunch profile

IR-6

- C fiber target to ensure $P_{x,y} = 0$





- Electron and hadron bunches stored for several hours.

Electron Polarimeters

Compton Polarimetry

Analyzing powers

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

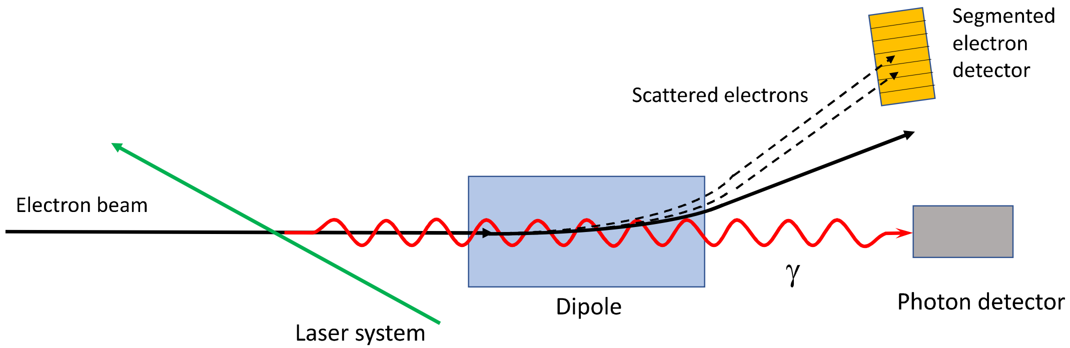
$$\rho = \frac{E_\gamma}{E_\gamma^{max}}$$

Longitudinal analyzing power depends only on backscattered photon energy

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

Transverse analyzing power depends on backscattered photon energy and azimuthal angle relative to polarization direction

Generic Compton Polarimeter



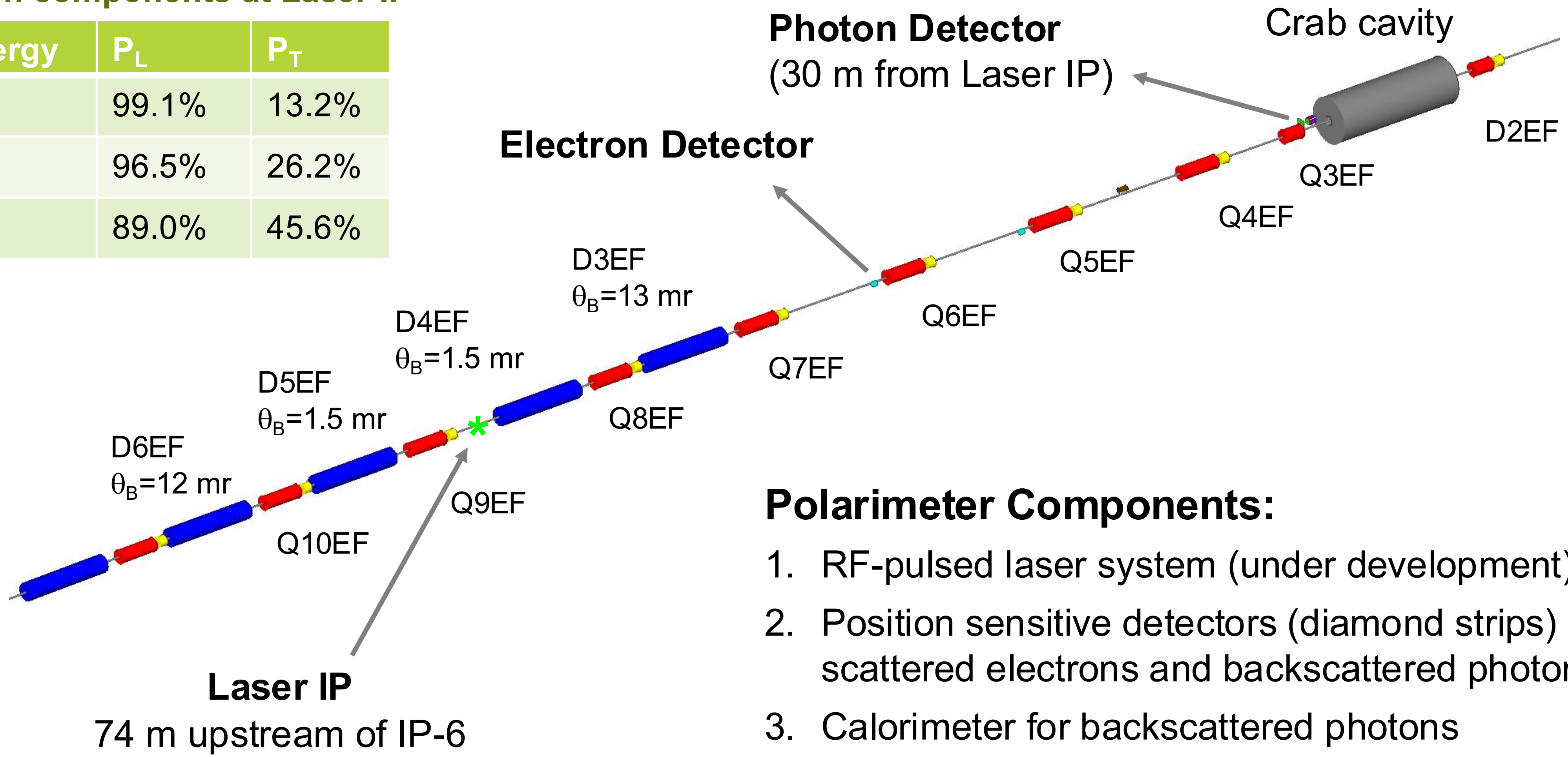
Key systems:
→ Laser
→ Photon and electron detectors
→ Dipole

ESR Compton will measure both P_L and P_T
RCS Compton will measure primarily P_T

Electron Storage Ring Polarimeter

Polarization components at Laser IP

Beam energy	P_L	P_T
5 GeV	99.1%	13.2%
10 GeV	96.5%	26.2%
18 GeV	89.0%	45.6%



Polarimeter Components:

1. RF-pulsed laser system (under development)
2. Position sensitive detectors (diamond strips) for scattered electrons and backscattered photons
3. Calorimeter for backscattered photons

Will operate in single-photon mode

ESR Compton Laser System Requirements

Configuration	Beam energy	Time (minutes)
P_L	18	0.1
P_T		0.8
P_L	10	0.2
P_T		1.4
P_L	5	0.5
P_T		1.8

Time estimates from Ciprian Gal

Time needed for 1% (statistics) measurement

Estimates assume "differential" measurement, 100% efficiency

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

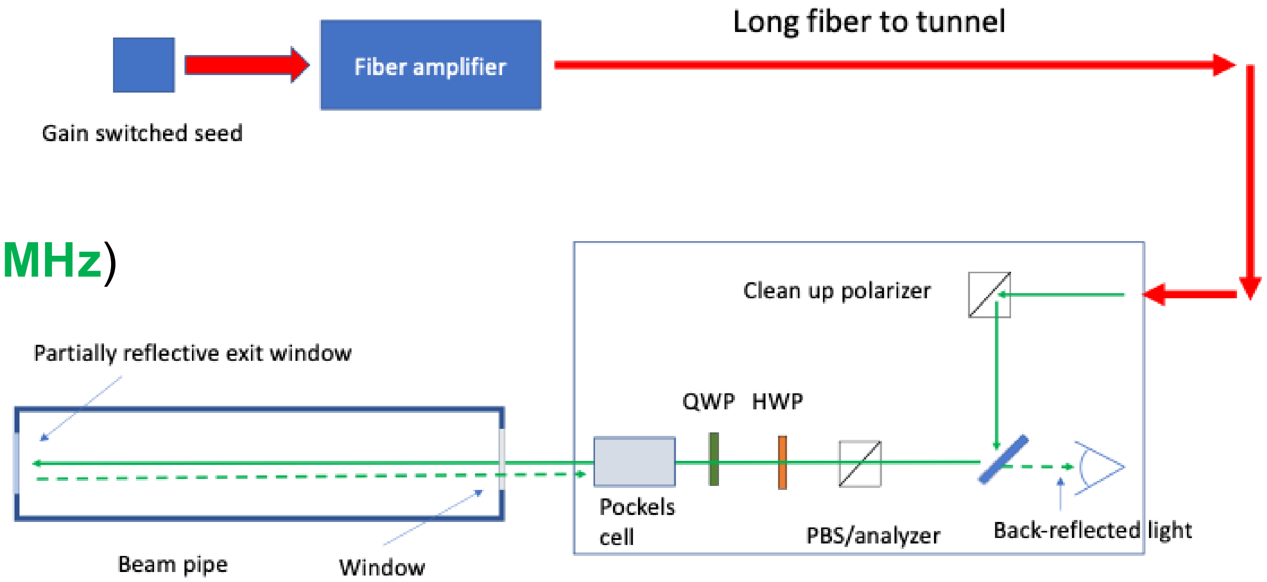
532 nm laser with ~5 W average power at same frequency as EIC electron bunches sufficient

Resulting measurement times as noted above – easily meets beam lifetime constraints → less than 2 minutes

ESR Compton: Laser System

- Laser system based on similar system used in JLab injector and LERF

1. Gain-switched diode seed laser
   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)



4. Partially reflective exit window to monitor reflected laser polarization

- Gain-switched seed laser components procured under earlier generic EIC R&D
- Shukui Zhang (JLab) assisting with seed laser configuration and system testing
- **Fiber amplifier obtained** - work underway in Compton polarimetry laser lab at JLab

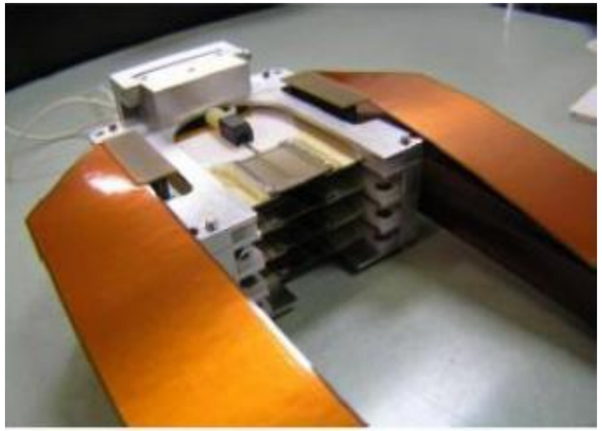
ESR Compton: Position Detectors

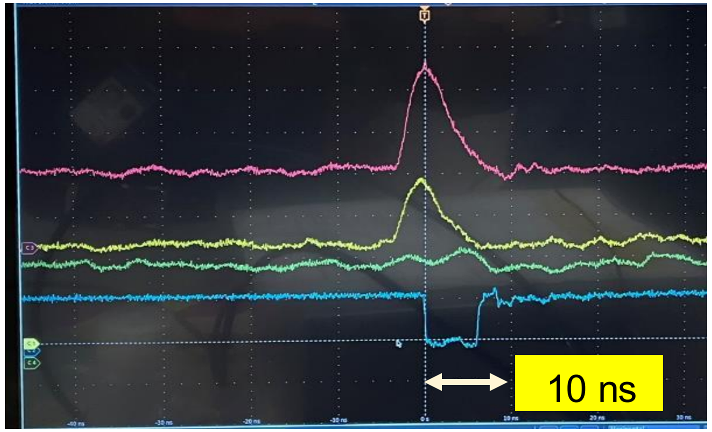
- Position sensitive detectors are needed to measure:
  - Scattered electrons → P_L
  - Backscattered photons → P_T
- Technology choice: diamond strips
  - Radiation hard, good time response
  - No performance degradation after 10 MRad of exposure (Q-weak @ JLAB)

Detector size: 6 cm (electrons) / 5 cm (photons)

- Required segmentation: 250 μm (electrons) / 100-200 μm (photons)
- Custom ASIC readout required
  - **New “FLAT32” chip based on “CALYPSO” (used at LHC) under development for JLab/MOLLER (just completed)**
  - Meets timing requirements of EIC (10 ns)
  - Can also be used for pulse height, pulse integration readout
    - Some minor modifications needed

JLab Hall C diamond detector



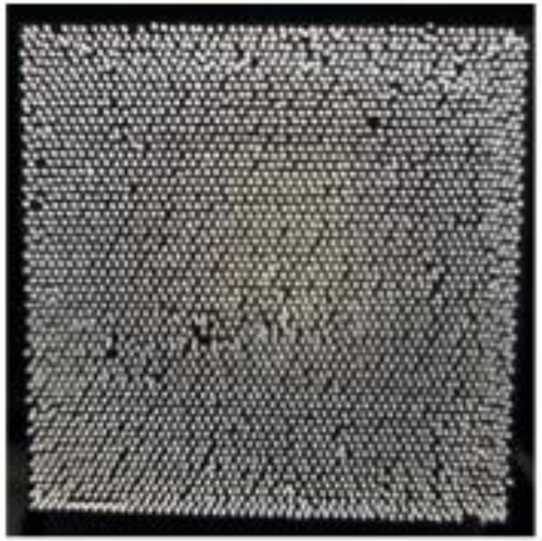


ESR Compton Photon Calorimeter

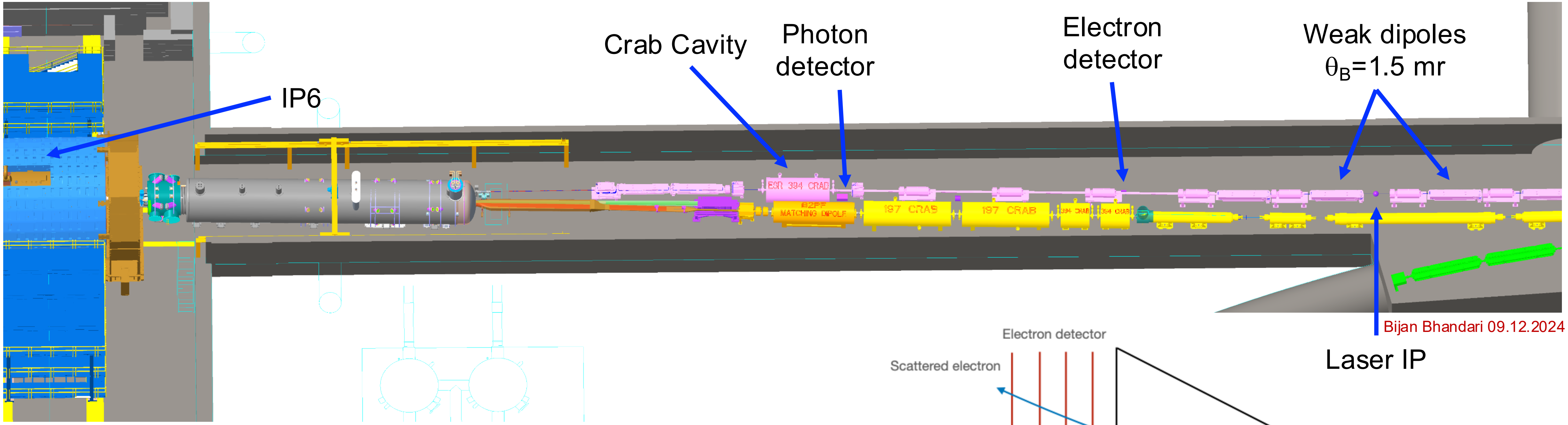
- **Will use a Forward EMCAL module for photon calorimeter**
  - Block of $5\ x\ 5\ x\ 17\ \mathrm{cm}^3$ W/SciFi, subdivided into 4 towers
  - 2 cm light guide from block to PMT
  - Expected resolution:

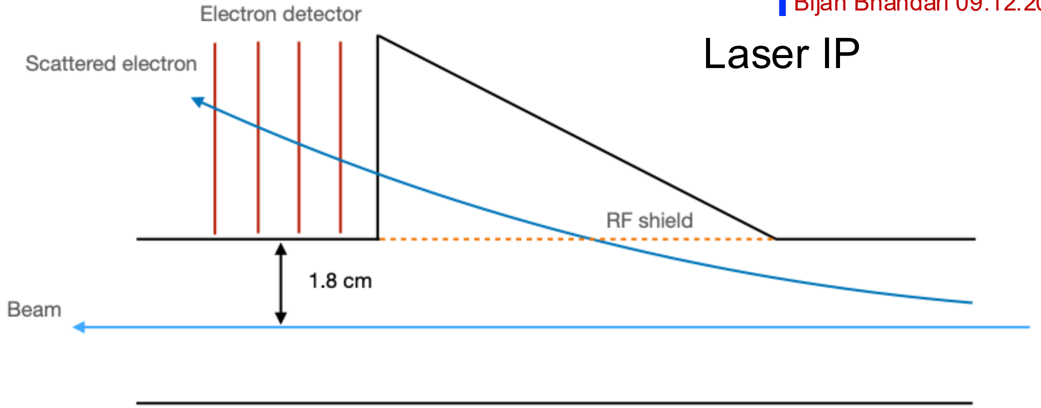
$$\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \bigoplus 1 - 3\%$$

- Only modest resolution required since calorimeter will be used in threshold-less integrating mode for longitudinal polarization measurements



ESR Beamline Design





Current beamline design with RCS removed

→ 2 weak & 2 strong dipoles

→ **mitigates synchrotron radiation (see backup)**

→ only need collimator plus ~ 1 mm W shield

- Electron detector outside vacuum pipe → RF shield used to mitigate beam impedance issues

Rapid Cycling Synchrotron Polarimeter

RCS properties

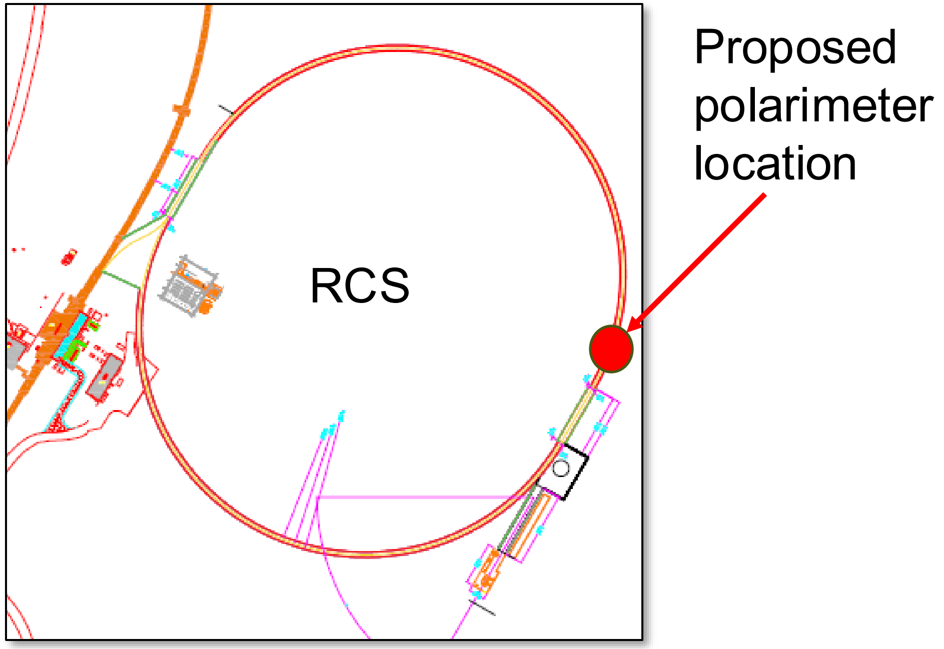
- RCS accelerates electron bunches from 3 GeV to full beam energy (5-18 GeV)
- Bunch repetition rate: 1-2 Hz
- Bunch charge: up to 28 nA
- Ramping time: 100 ms

Polarimetry challenges

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

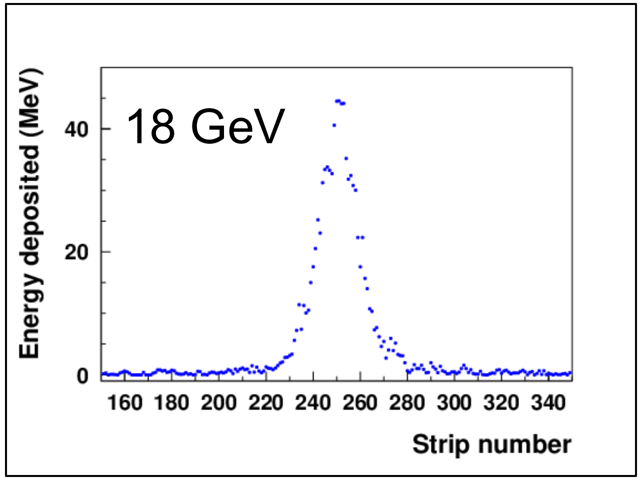
Compton polarimeter will also be used in the RCS

- Average over several bunches – can tag accelerating bunches to get information on bunches at fixed energy
- Requires measurement in multiphoton mode (many backscattered photons/electron bunch)
- **Will use same detector technologies as ESR Compton**

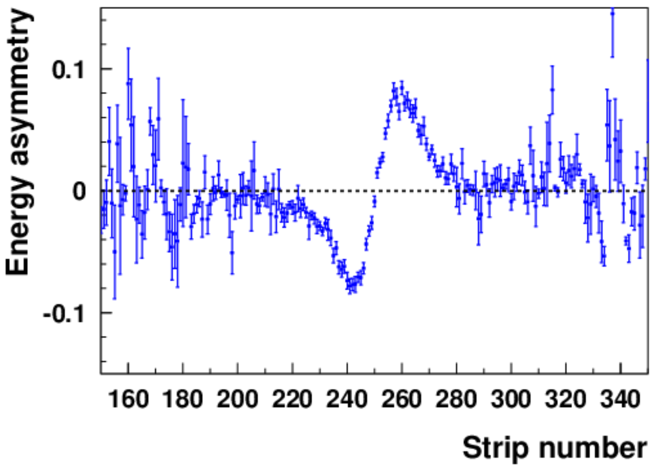


RCS Compton Detector Simulations

RCS Compton polarimeter will operate in multi-photon mode
→ Each laser-electron bunch collision will result in thousands of backscattered photons
→ Polarization will be extracted by measuring the energy-asymmetry
→ total energy deposited in the detector for each laser helicity state

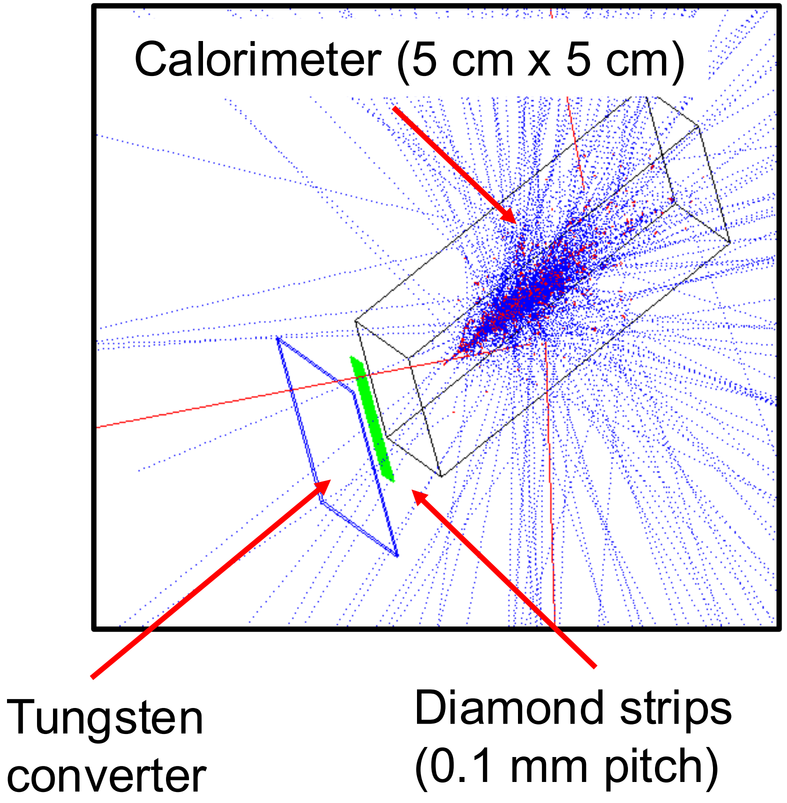


Energy deposited in each strip of diamond detector



Energy asymmetry

$$A_{strip} = \frac{E^{+}_{strip} - E^{-}_{strip}}{E^{+}_{strip} + E^{-}_{strip}}$$



Simulated 10 laser pulses → 10,000 backscattered photons per pules

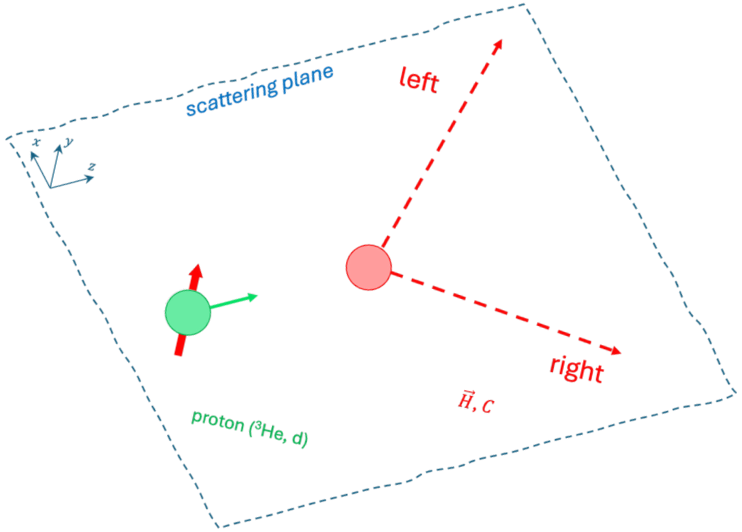
Tasks for CD-2 readiness: Electron polarimeters

- Details for polarimeter and beamline integration
  - Both laser system and photon/electron detector exit ports need careful integration
  - Impedance issues must be included in design
  - Integrate polarimeter layout details in machine model
- Complete DAQ design
  - Specify modules
  - Determine readout mode (streaming vs. triggered)

Will have 2nd Preliminary Design Review at the end of 2025

Hadron Polarimeters

Hadron Polarimetry: CNI region



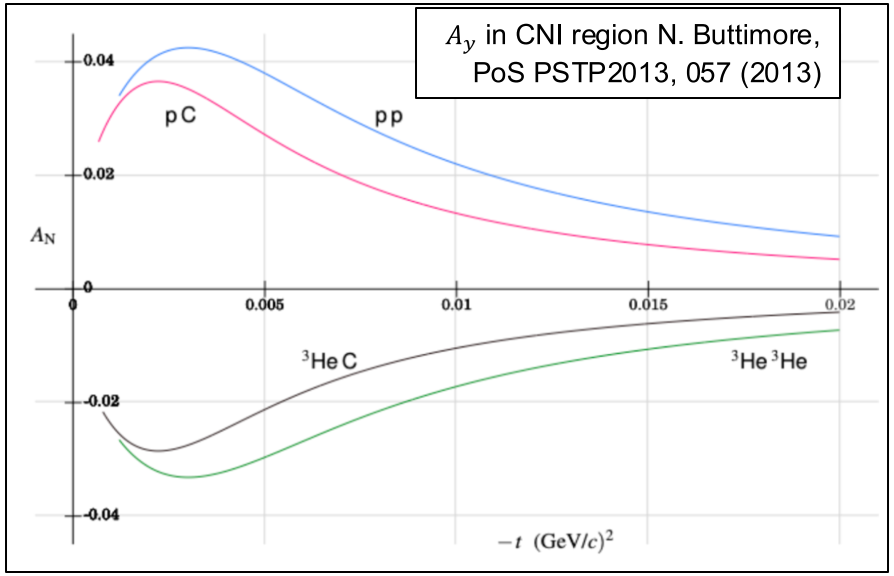
Spin-dependent cross section

$$\sigma(\theta,\varphi) = \sigma_0(\theta)\left[1 + P_y\, A_y(\theta)\cdot\cos\varphi\right]$$

- σ_0 unpolarized cross section
- P_y vertical component of beam polarization $\vec{P} = (P_x, P_y, P_z)$
- A_y Analyzing power, polarization sensitivity ot scattering process

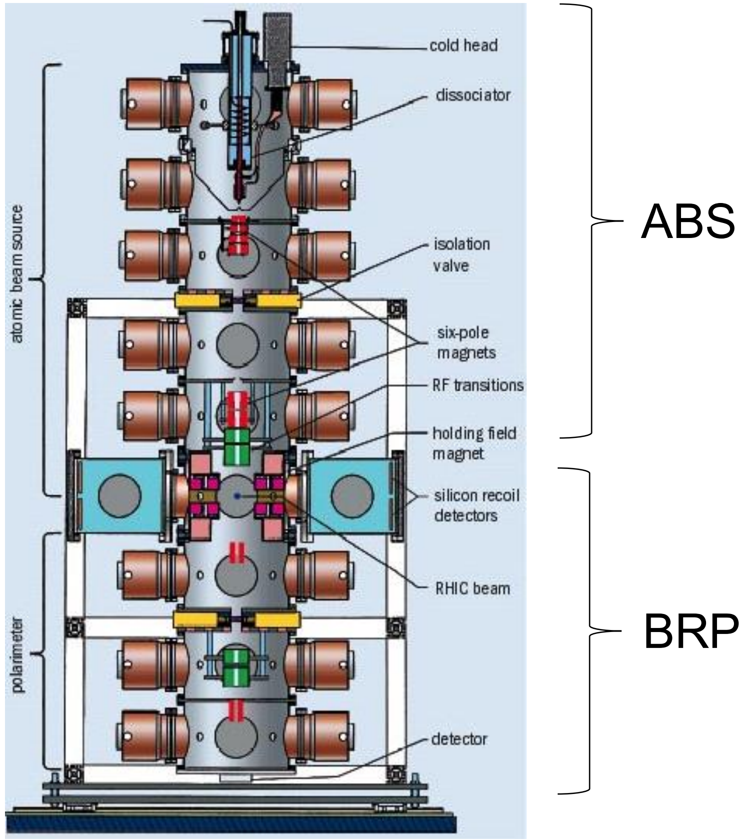
$$A_y = \frac{L-R}{L+R}, \text{ where e.g., } L = \int_\Omega \frac{dN_L}{d\Omega}(\theta,\varphi)d\Omega$$

- At AGS, RHIC, EIC energies, no processes available with A_y known to sufficient accuracy for $^{\Delta P}/_{P} \leq 1\%$
- Interference of EM & strong interaction (CNI) at small angles → sizeable A_y for pp and pN scattering



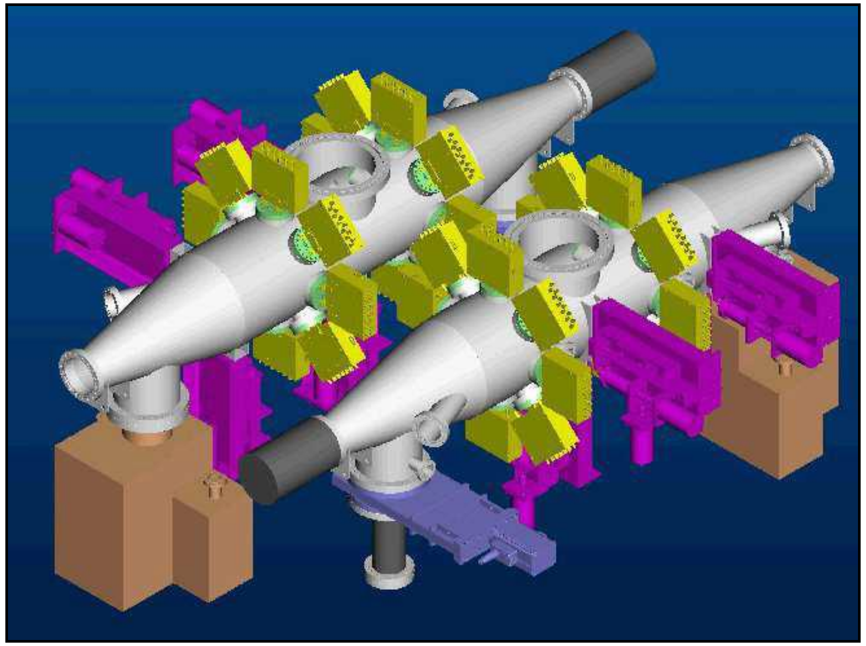
Hadron Polarimetry at EIC

HJET polarimeter (absolute, slow)



- $\frac{\sigma_P}{P} \approx 3\%$ per 4 hours

pC polarimeters (fast, relative)



- $\frac{\sigma_P}{P} < 1\%$ per scan
- + polarization profile

Polarimetry at EIC: Timing

		EIC		
ring	RHIC	HSR	HSR	ESR
species	proton	proton	proton	electron
mode	flattop	injection	flattop	flattop
Energy [GeV)]	250	23.5	275	10
Number of bunches	120	290	1160	1160
Bunch length [cm]	55	24	6	0.7
Bunch frequency [MHz]	9.38	22.65	90.68	90.68
Bunch spacing [ns]	106.6	44.14	11.02	11.02

Hadron polarization measurements foreseen at:

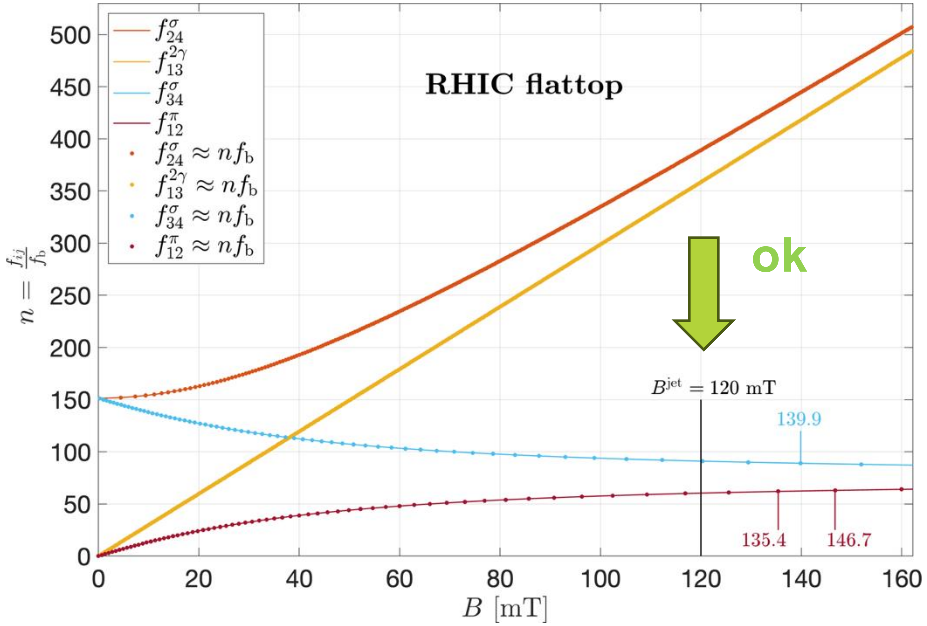
1. **Injector chain** Beam polarizations measured at 200 MeV linac and AGS
2. **HSR** absolute polarization measurements at:
   - injection (½ h electron cooling period)
   - Flattop through store

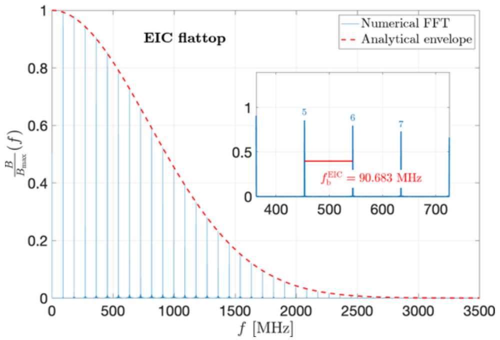
→ Routine operation of pC and HJET

HJET at EIC: bunch field depolarization

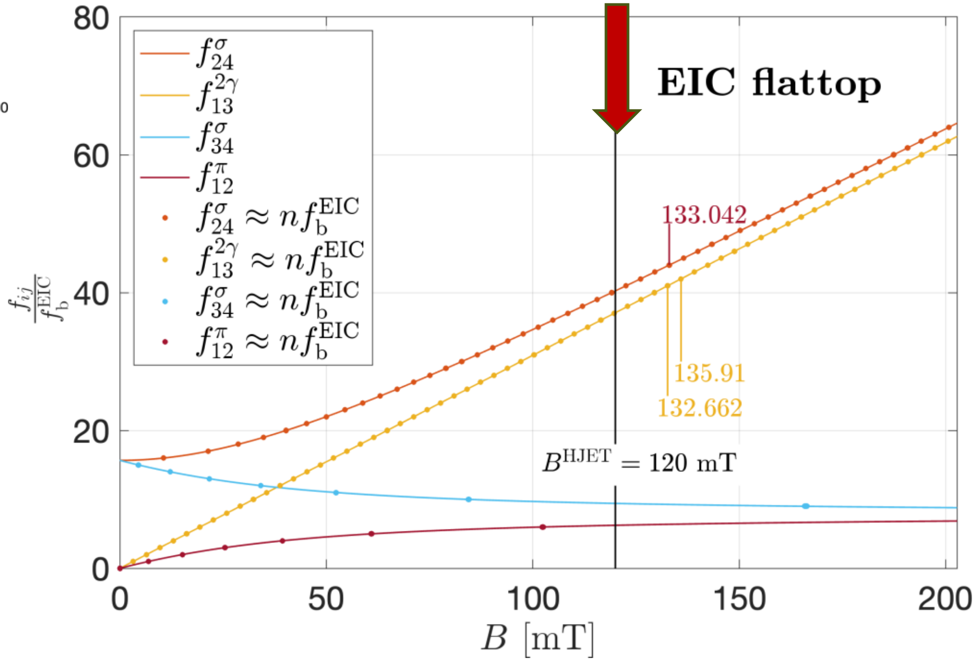
1. Bunch repetition frequency increased by factor of 10
   → enhanced **bunch-induced depolarization** at EIC

RHIC	EIC
9.381 MHz	90.683 MHz





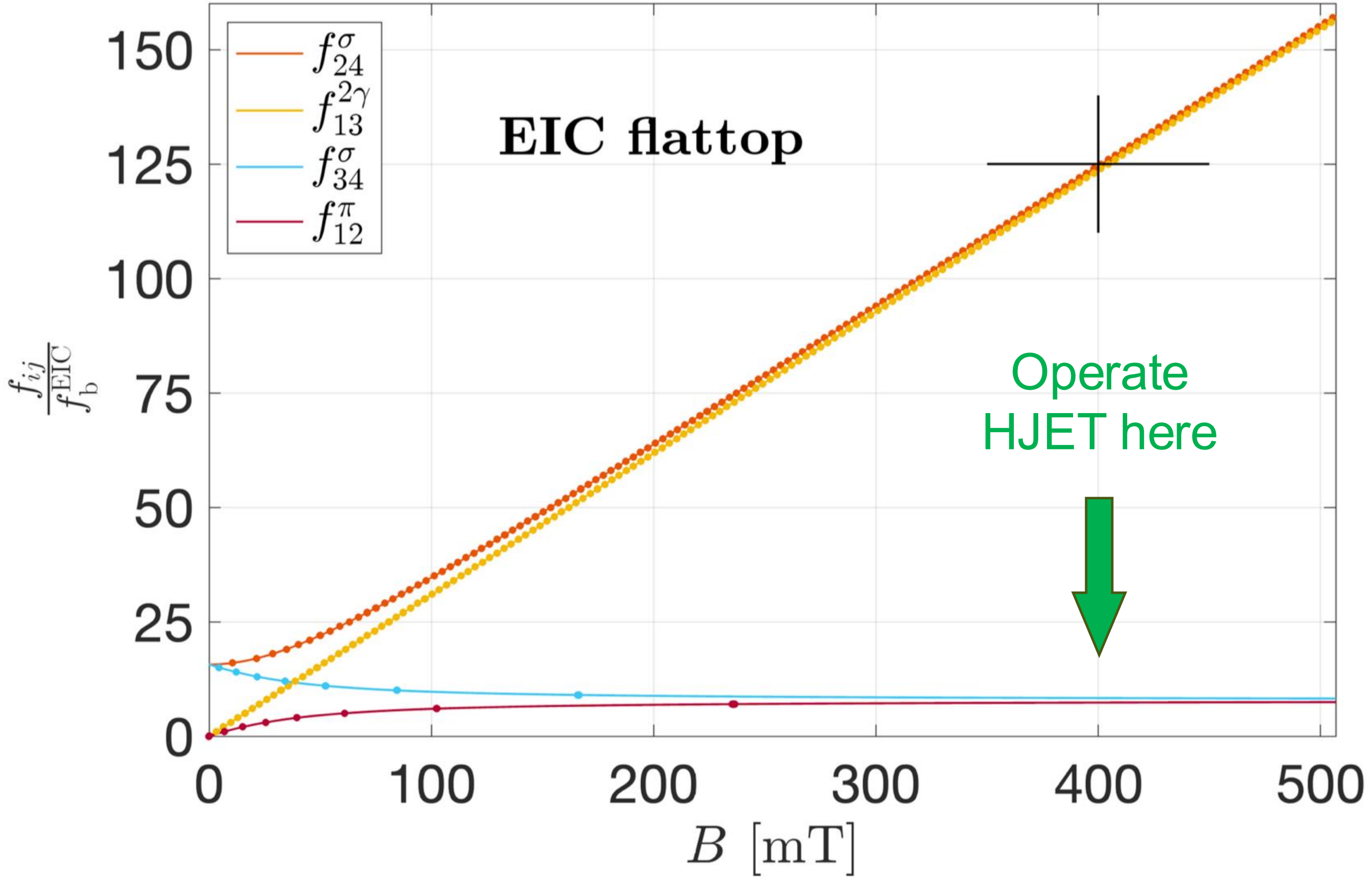
No operation like that at EIC



Depolarization analysis for HJET show that we need to to avoid low harmonic numbers

HJET at EIC: mitigation

Avoid bunch-induced depolarization by HJET operation at $\mathbf{B \approx 400\ mT}$



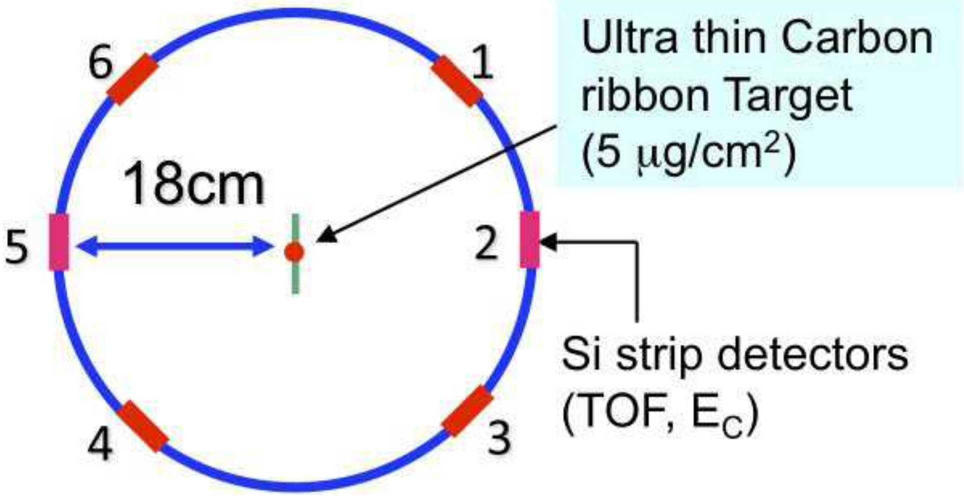
HJET at EIC: planned modifications

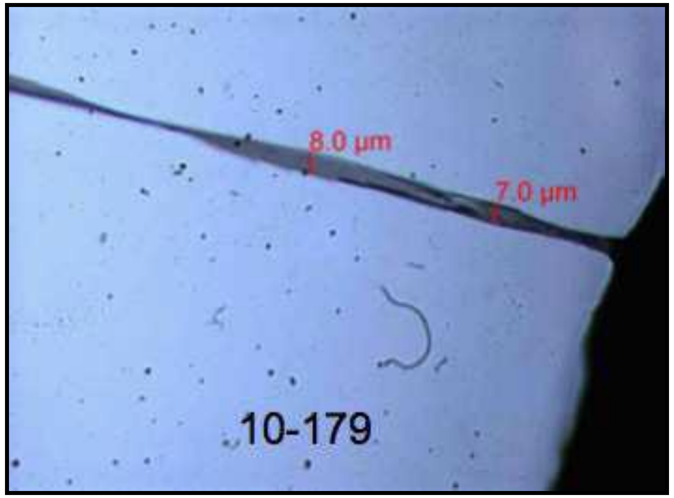
2. Design holding field system (in progress)
3. Design new target chamber to accommodate holding field (in progress)
4. Upgrade BRP with mass analyzer (in progress)
    - improve e.g., H_2 background determination
5. Upgrade detector system (in progress)
    - obtain $\vec{P}$
    - cope with EIC bunch frequency
6. Upgrade HJET slow control system, ensure compatibility with EPICS database
7. Impedance calculation for HJET addressed when concepts for 2. and 3. available

Aim of proposed changes: improve systematics to get to $\frac{\Delta P}{P} \leq 1\%$

- **Next:** In early 2026: HJET move to 510 for refurbishment/upgrade work: items 2. to 5.

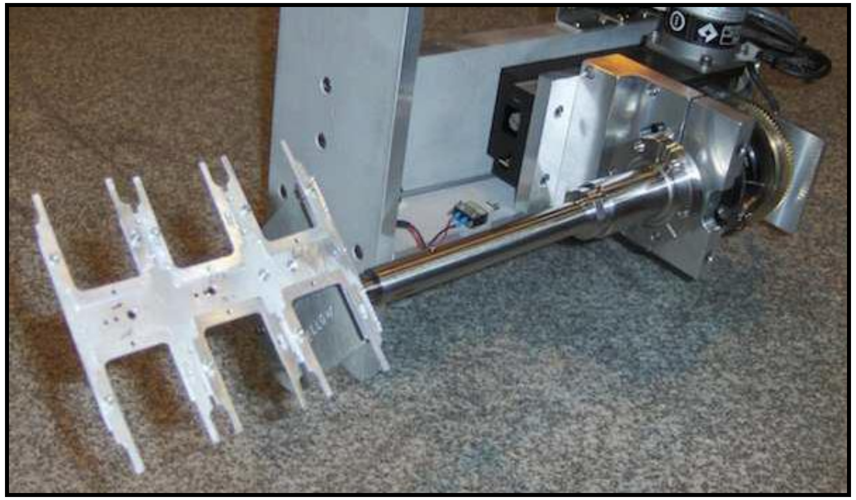
C fiber target polarimeter: present system





Ultra-thin ribbon targets:

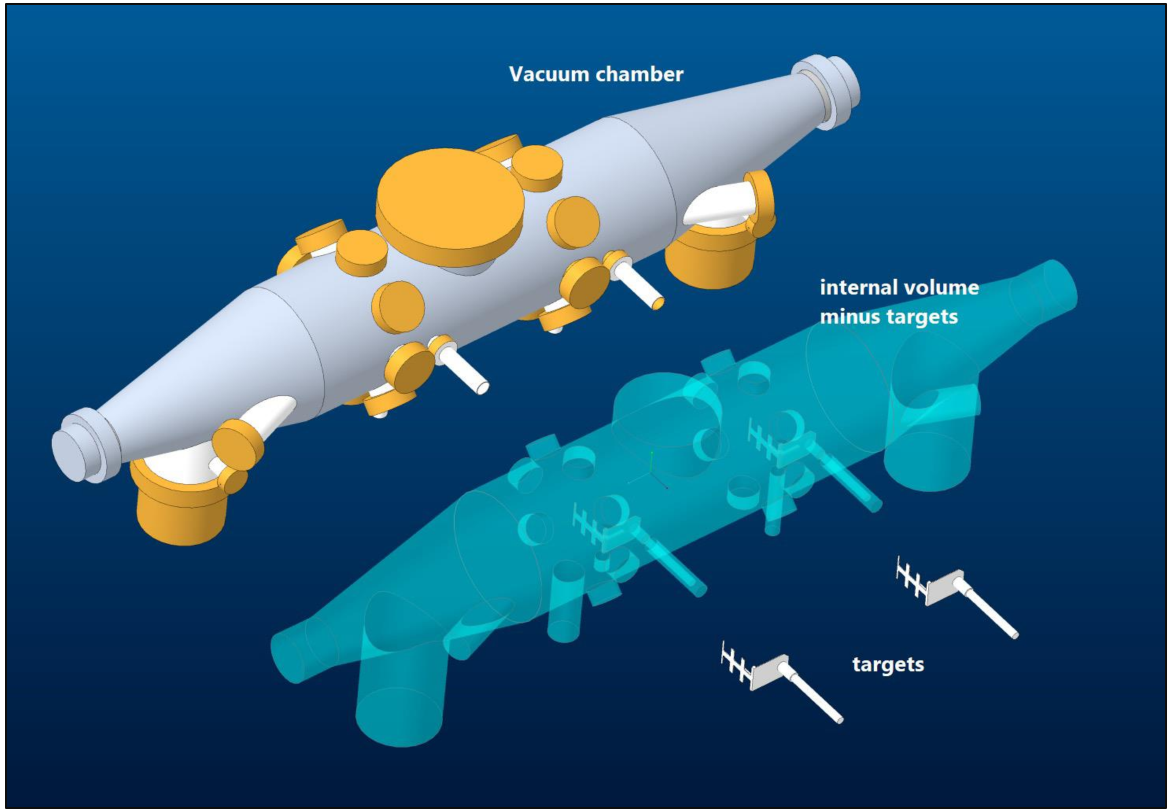
- $\approx 10\ \mu\mathrm{m}\ \times\ 50\ \mathrm{nm}$
- target holder inside beam pipe
- For RHIC: target length $25\ \mathrm{mm}$



C fiber target polarimeter: upgrades for EIC

EIC conditions with 10 ns bunch repetition and $\approx 3 \times$ higher current require:

1. Estimate C target temperatures
2. Effects of increased wake field power in target chamber and target holders
3. Develop vacuum transfer chamber
    1. One target at a time in chamber
    2. improve target conditioning & installation
    3.
4. Upgrade detectors and readout systems
    1. cope with timing requirements
5. For EIC, due to larger beam size in IP4, targets need to be 2×25 mm long



pC target chambers will be moved to 510 for refurbishment and upgrades in early 2026

C fiber target polarimeter: target heating

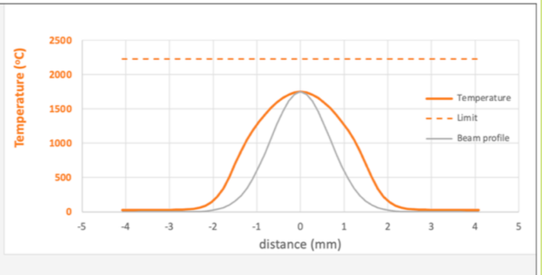
Target heating (code by Peter Thieberger)

- **With realistic beam sizes, target heating about same at RHIC and EIC**

RHIC typical conditions

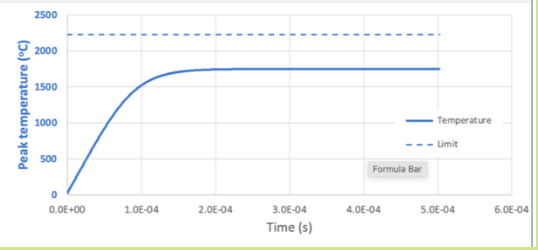
- 250 GeV
- 111 bunches
- 16×10^{10} protons per bunch
- $\sigma_r^{95} = 0.68\,\mathrm{mm}$

TARGET	GRAPHITE	TUNGSTEN	CARBON
Density (g/cc)	2.26	19.3	2.26
LET (MeV cm^2/g)	1.76E-03	1.12E-03	6.33E-04
Thermal conductivity [W/(K * m)]	390	173	390
Emissivity	0.8	0.35	0.8
Specific heat (J/ (gm K)	0.72	0.134	0.72
Thickness (nm)	50	100	50
Sublimation or melting limit (°C)	2227	3422	2227



PROTON BEAM	RHIC 2017	EIC	XX bunch
Beam rms width (mm)	0.68	1.2	
# of protons per bunch	1.60E+11	6.90E+10	
# of bunches	111	1160	

Thermal conductivity multiplier	1
Simulation time step (ns)	500



→ changed ID #128 in Risk Registry to low

EIC for highest luminosity

- 275 GeV
- 1160 bunches
- 6.9×10^{10} protons per bunch
- $\sigma_r^{95} = 1.2\,\mathrm{mm}$

TARGET	GRAPHITE	TUNGSTEN	CARBON
Density (g/cc)	2.26	19.3	2.26
LET (MeV cm^2/g)	1.76E-03	1.12E-03	6.33E-04
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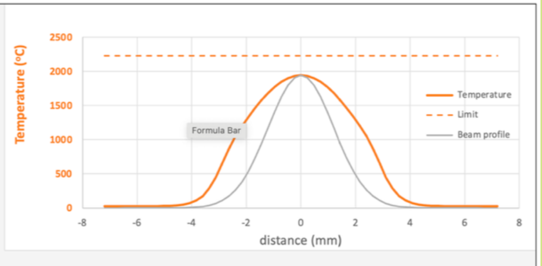

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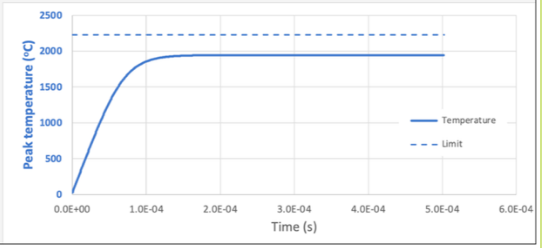
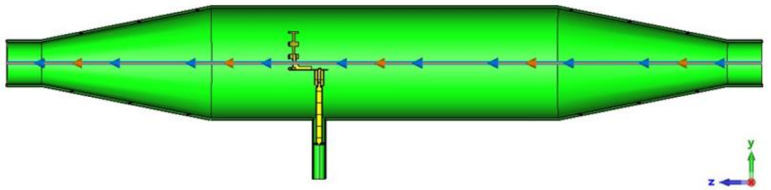


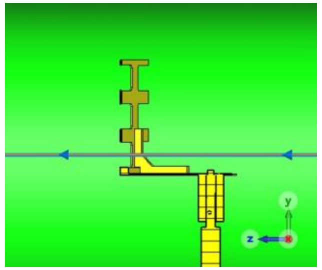
Independent modeling approach of C target heating by proton beams (in progress)

C fiber target polarimeter: impedance calculations I

Shorter $10\ \mathrm{ns}$ bunch spacing at EIC

- Fiber target chambers ok for single-bunches
- Higher order modes → pumping ports → RF shielding

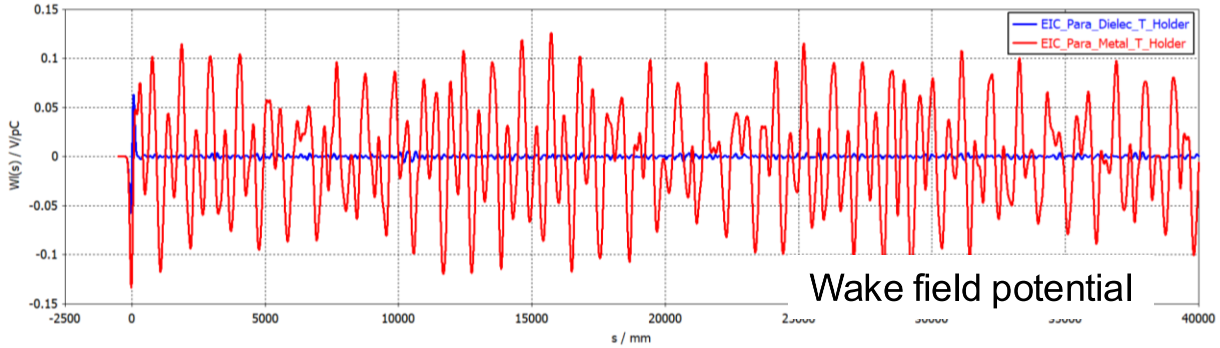


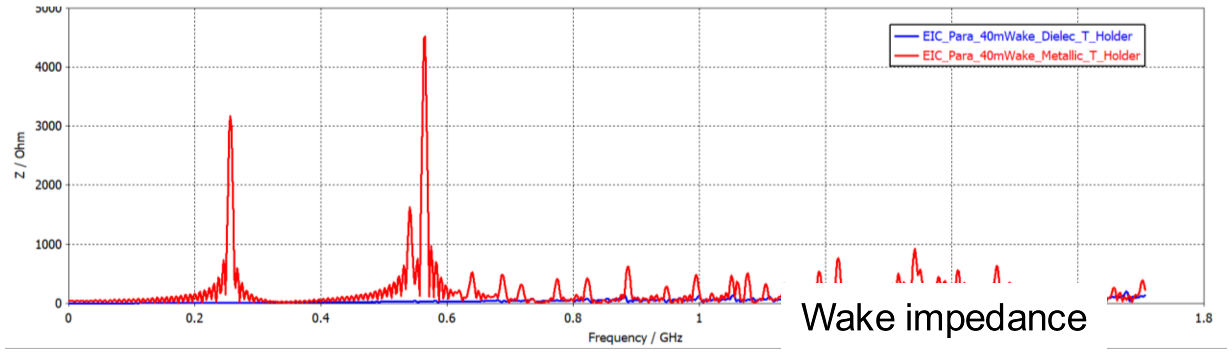


- C target chambers (steel 316L) will work for EIC
- **Simulations of C target holders**

  Studies involved target holders made from Al, SS and dielectric (e.g., Al_2O_3)
  - Preliminary results favor dielectric target holder over metallic ones
  - $10\ \mathrm{nm}$ gold layer to avoid charging up of target
  - Operation: one target in chamber at a time
    - → design vacuum transfer chamber
  - No adverse effect from shifted targets positions

Fresh results from Medani Sangroula (CAD)



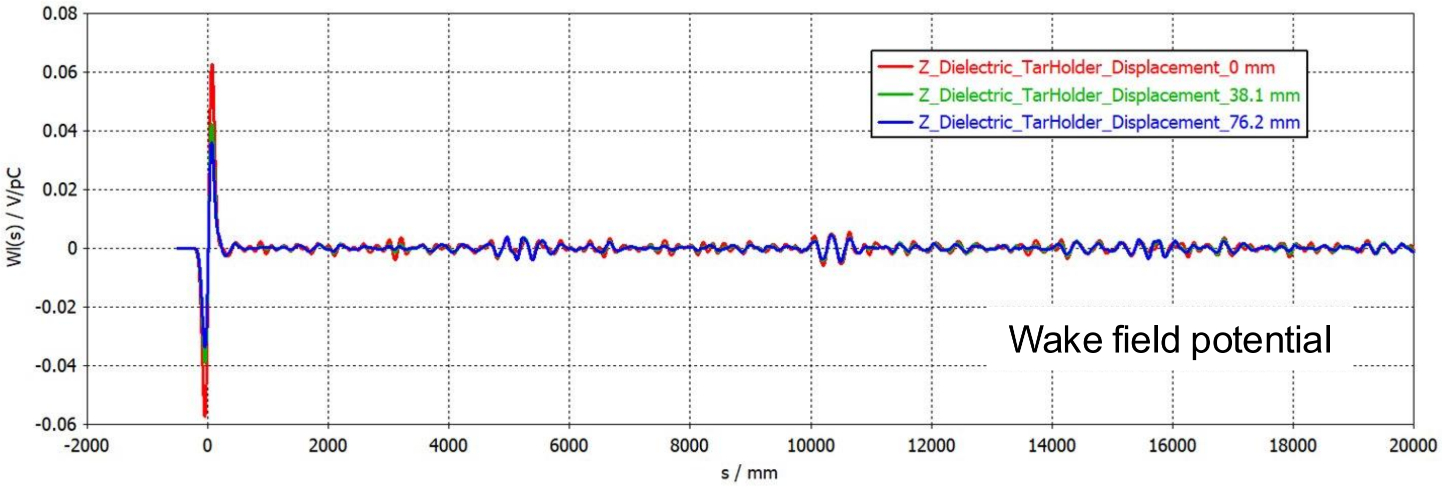


Improved performance of machine when dielectric target holder will be used

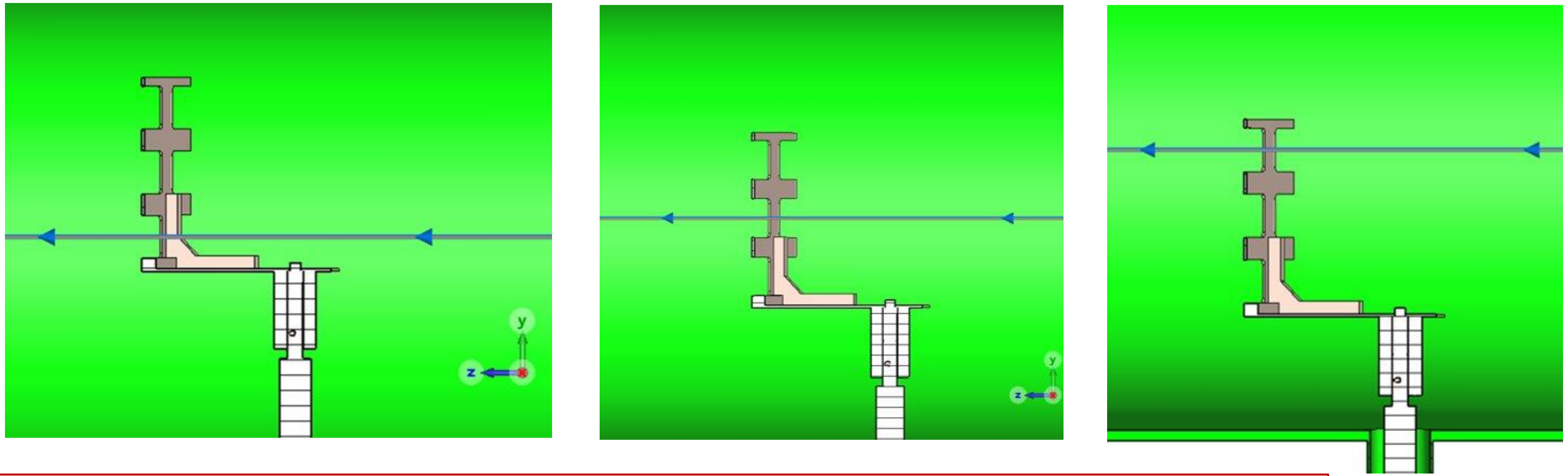
C fiber target polarimeter: impedance calculations II

Shifted dielectric target positions:

- Like RHIC, EIC will use multiple targets on same target holders



Wakefield amplitude decrease with target holder shifted down

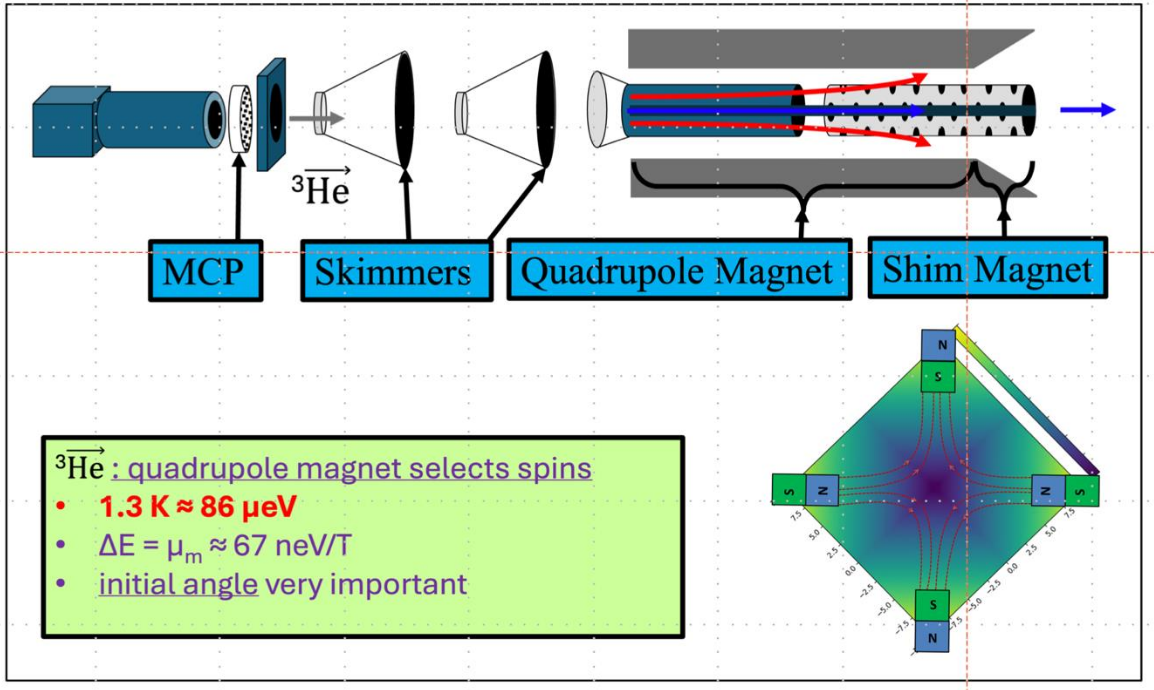


Similar behavior when different C targets are inserted into beam from same target holder

New development: ³He atomic beam

Provide absolute polarization measurement for $^3\overrightarrow{\mathrm{He}}^{++}$ beams

- MIT development for nEDM exp't at Oakridge (discontinued)
  (P. T MohanMurthy, J. Kelsey, J. Dodge, R. Redwine, R. Milner, P. Binns, B. O'Rourke)



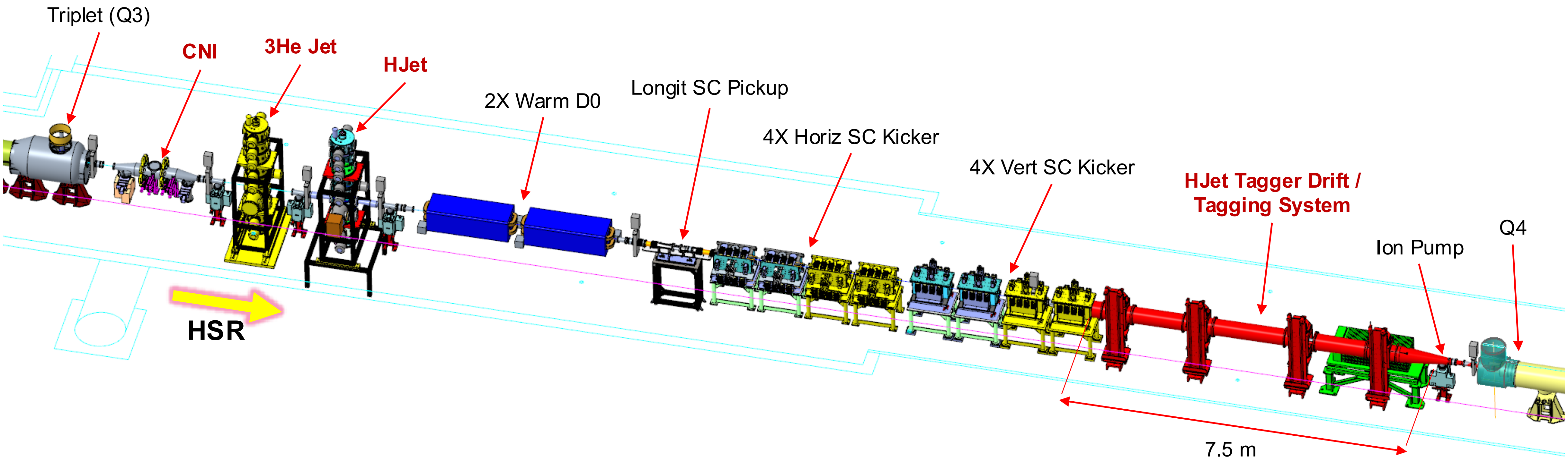
High flux device with beam at 1 K

- $\geq 10^{14}\,\frac{\mathrm{atoms}}{\mathrm{s}} \rightarrow d_t \geq 10^{13}\,\frac{\mathrm{atoms}}{\mathrm{cm}^2}$
- ideal for absolute $^3He^{++}$ polarimetry at EIC

³He beam polarimetry will be needed a few years after initial EIC commissioning

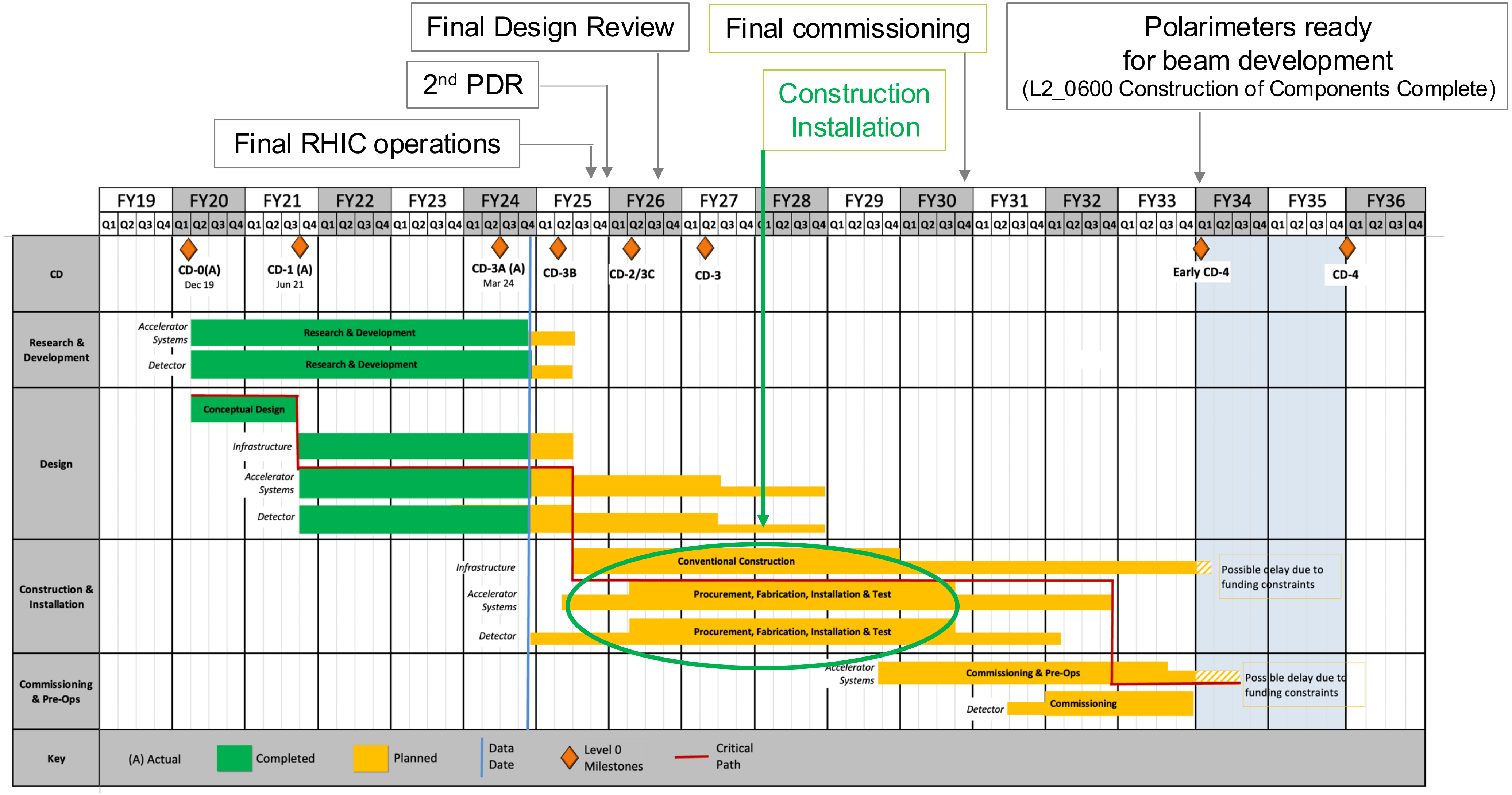
Hadron polarimetry overview: Layout at IP4

- Choice of location driven by required drift space
- **Carbon and polarized H and ^{3}He targets all located in one place**
  - minimize spin rotations between polarimeters
  - Enables efficient use of common infrastructure



E. Link
5/16/2025

Polarimeter Schedule



Polarimeter systematics: previous experiments

Electron polarimetry: systematic uncertainties from previous Compton polarimeters

Longitudinal:

- LPOL @ HERA (collider): $(\sigma_P/P) < 1.2\ \%$ → Photon detector in multi-photon mode
- Q-Weak in Hall C @ JLab (fixed target): $(\sigma_P/P) < 0.59\ \%$ → Electron detector, counting mode
- CREX in Hall A @ JLab (fixed target): $(\sigma_P/P) < 0.36\ \%$ → Photon detector, integrating mode

Transverse:

- TPOL @ HERA (collider): $(\sigma_P/P) < 1.87\ \%$ → Photon detector in counting mode

EIC Compton polarimeter designs make use of lessons learned from these devices

Hadron polarimeters

Transverse:

- Systematic error for RHIC proton beam polarization (P_y) in run 17
  - **SSA:**$(\sigma_P/P) \cong 1.3\ \%$, **DSA:**$(\sigma_P/P) \cong 2.4\ \%$

Longitudinal

- P_z is at present not directly accessible at RHIC

- **Goal of $(\boldsymbol{\sigma_P/P}) \approx 1\%$ not needed on day 1**
- Systematics of absolute polarimetry during first years of operation will benefit from upgrades (slides 22 & 24)

Tasks for CD-2 readiness: hadron polarimeters

- **Hadron polarimeters**
  - Accelerator integration of hadron polarimetry available
  - HJET modifications
    - to be integrated: target chamber with holding field, QMA for BRP, detector system
  - Present RHIC pC polarimeter system applicable at EIC
    - Temperature estimates of C ribbon targets with updated EIC beam sizes → at IP4, targets will hold
      - corresponding estimates for targets at IP6 to be done
    - Wakefield calculations indicate use of dielectric target holders
    - Redesign of existing chamber to accommodate vacuum loading system for targets
  - New ^{3}He atomic beam target development is in progress and aligned with EIC ramp up & commissioning
  - Readout/detector choice for C, HJET, and 3He polarimeter required

Will have 2nd Preliminary Design Review at the end of 2025

Summary

- Basic polarimetry methods and detector technologies established
- Design progressing towards CD-2 in FY26 and CD-3 in FY27
- Demands at EIC significantly higher than at previous facilities
  - designs in place to meet demands
- Future modifications beyond EIC baseline not precluded with current designs
- All polarimeters shall be ready for operation at start of polarized beam commissioning
  - Primary purpose of RCS polarimeter is beam development
  - All other polarimeters will be used for beam development in addition to later monitoring

Backup

Scope Definition

WBS	WBS Name	WBS Description
6.10.14.01	e-Polarimetry	**Scope Definition:** Activities to design and construct the electron polarimeters for the EIC RCS and the ESR. **Deliverables:** Design and installation of components required for the electron polarimeters for EIC ESR and RCS
6.10.14.01.01	Lepton Polarimetry in the Storage Ring	**Scope Definition:** Activities to construct a compton polarimeter with a systematic uncertainty of order 1% and high statistical precision to measure polarization bunch-by-bunch. One wants to measure both the compton scattered lepton and the backscattered compton photon. A compton polarimeter consists of a laser system, 1 electro magnetic calorimeter, 2 position sensitive detectors, their readout electronics and DAQ system and lepton and laser beam position control systems. **Deliverables:** Design and installation of all compnents required for ESR Compton polarimeter, including laser system and diagnostics, related detectors
6.10.14.01.02	Lepton Polarimetry in the RCS	**Scope Definition:** Activities to construct a compton polarimeter for the RCS. The development is critical as the RCS parameters of 100 ms ramp from 400 MeV to 18 GeV with 1Hz ramp repetition rate and 10 nC in bunch are demanding to measure polarization. One wants to measure only the backscattered compton photon. A compton polarimeter consists of a laser system, 1 electro magnetic calorimeter, 1 position sensitive detector, their readout electronics and DAQ system and lepton and laser beam position control systems. **Deliverables:** Design and installation of all components required for the RCS Copton polarimeter, including laser system and diagnostics, related detectors
6.10.14.02	h-Polarimetry	**Scope Definition:** Activities to upgrade the hadron polarimeters to the needs for the EIC physics and machine requirements. For an EIC one needs like for RHIC an absolute polarization measurement and measurements, which provide the polarization lifetime and the polarization over the transverse size of the hadron bunch. In addition design and constructing of a hadron polarimeter in the IR to measure the degree of spin orientation, this is particularly critical if the direction of the hadron beam polarization is longitudinal. **Deliverables:** Installation of hadron polarimeter system consisting of HJET setup and vacuum chambers with silicon detectors in IR-4, installation of vacuum
6.10.14.02.01	Hadron Polarimetry at IR-4	**Scope Definition:** Activities to update the current RHIC polarimeters to reach the required systematic uncertainties ~ 1% and to work under the more demanding EIC machine parameters, high beam intensity and high bunch frequency. The updates include a new DAQ-systems, new silicon detectors for both the H-Jet and the pC polarimeters and a new target station for the pC polarimeters. **Deliverables:** Installation of HJET setup at IR-4, installation of vaccum chamber with double-target setup at IR-4, installation of silicon detectors in HJET and pC polarimeters, integration of readout and data acquisition system
6.10.14.02.02	Hadron Polarimetry at IR-6	**Scope Definition:** Activities to construct a pC polarimeter located as close as possible to the IP. It needs to be situated between the spin rotators. The plan is to copy the pC polarimeter setup from IP-12. This means a scattering chamber, a C-target station, silicon detectors and a data acquisition system are needed to be built.

ESH and QA

Electron polarimeters:

- **ESH:** Compton polarimeter laser safety systems will use common approach with other EIC laser systems (i.e., detector gain monitoring , etc.)

  Requirements:
  - Interlocked laser room outside accelerator tunnel
  - Interlocked laser enclosures where laser interacts with electron beam

  Needs have been identified in dependency review

  QA: Compton laser and detector components will be tested at JLab before installation at EIC
  - Laser → seed laser, amplifiers, fiber, reflective window
  - Diamond detectors → tests of detectors and FLAT32 with cosmics and radioactive sources
  - Photon calorimeters → tests with cosmics and sources. Tests in JLab polarimeters possible depending on beam schedule

Hadron polarimeters:

- After 20 years of operating experience with pC and HJET polarimeters at RHIC, ESH and QA related issues have been ironed out.

Polarimetry design: status review

Committee:
Dipangkar Dutta (Mississippi State University)
Jenny List (DESY)
Paolo Lenisa (Ferrara University)
Frank Rathmann (FZ Jülich)

Review: January 17-18, 2023

Summary of Recommendations

Electron Polarimetry

1. Develop alternative detector concept based on silicon
2. Detailed simulations including all backgrounds and shielding
3. Explore transverse polarization measurements using synchrotron radiation
4. More detailed detector requirements for RCS polarimeter

Closed
On-going/scheduled

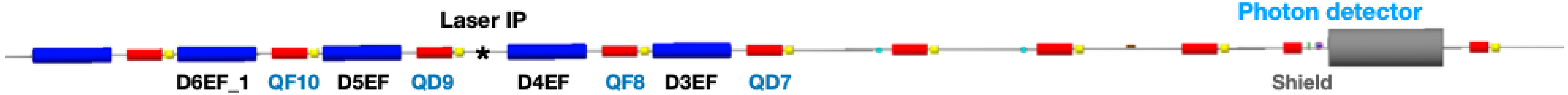
Hadron Polarimetry

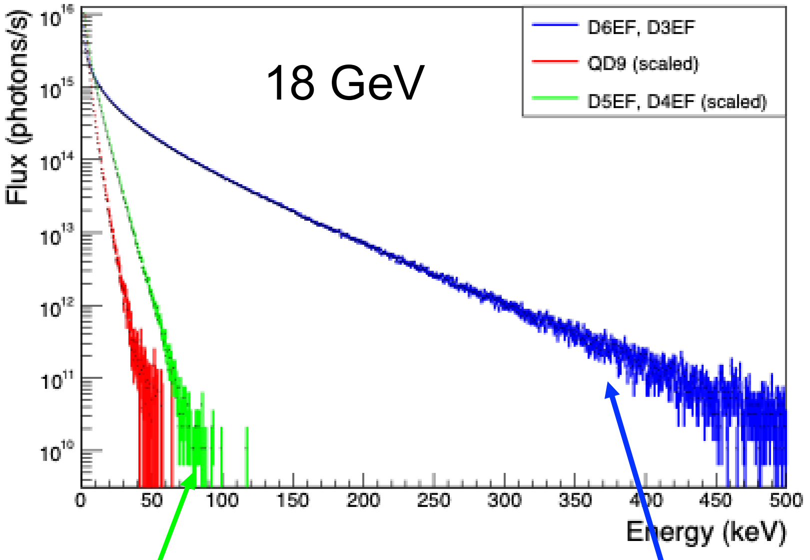
1. Target gas analyzer should be used to determine molecular fraction in the HJet
2. Explore using thinner Si detectors in both HJet and pC polarimeters to veto punch through events
3. In addition to exploring new target materials for pC polarimeter, explore larger beam size
4. Obtain beam time with AGS pC polarimeter to test detectors
5. Theoretical assessment of A_y in ^{3}He-^{3}He elastic
6. Further ^{3}He studies during remaining RHIC runs

additional material

Electron polarimeter

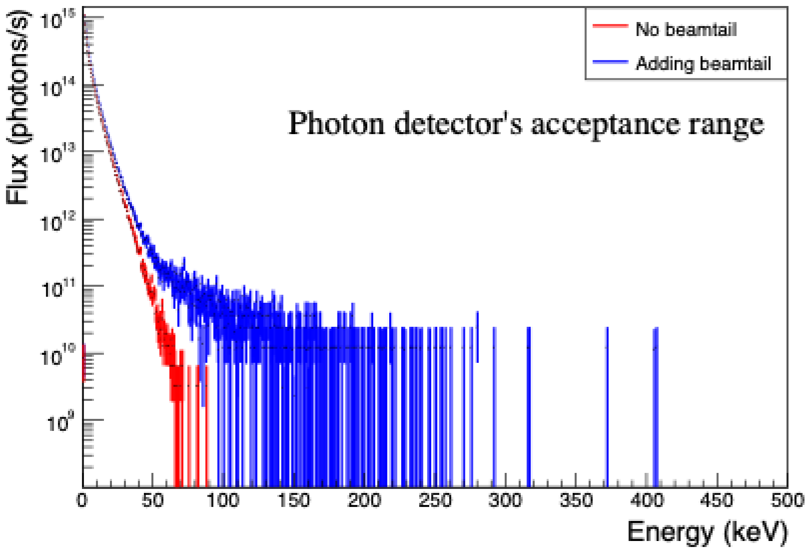
Synchrotron Backgrounds in ESR Compton





Weak dipoles

Strong dipoles

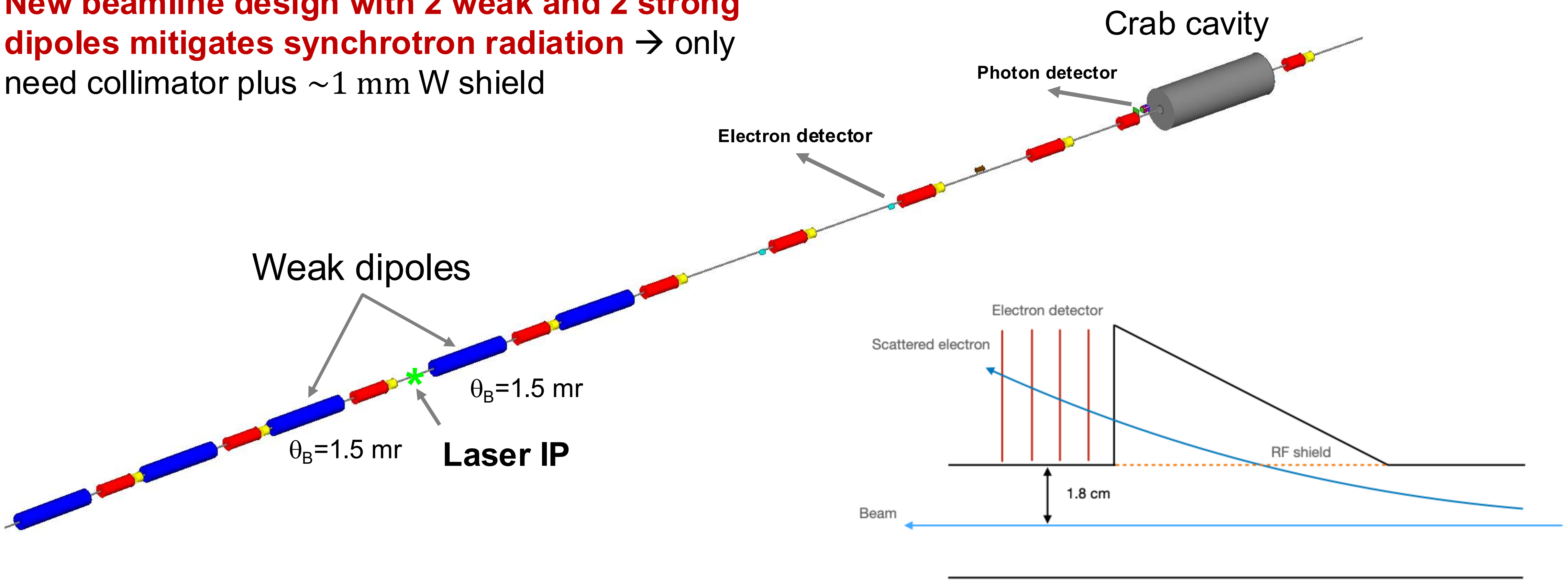


Simulations by Zhengqiao Zhang (Synrad+ and Geant4)

Synchrotron radiation from strong dipoles (D6EF, D3EF) too large – thick shield needed for photon detector
→ Weak dipoles with small bend will re-direct synchrotron flux from strong dipoles to be outside photon detector acceptance

ESR Beamline Design

- **New beamline design with 2 weak and 2 strong dipoles mitigates synchrotron radiation** → only need collimator plus $\sim 1\ \mathrm{mm}$ W shield

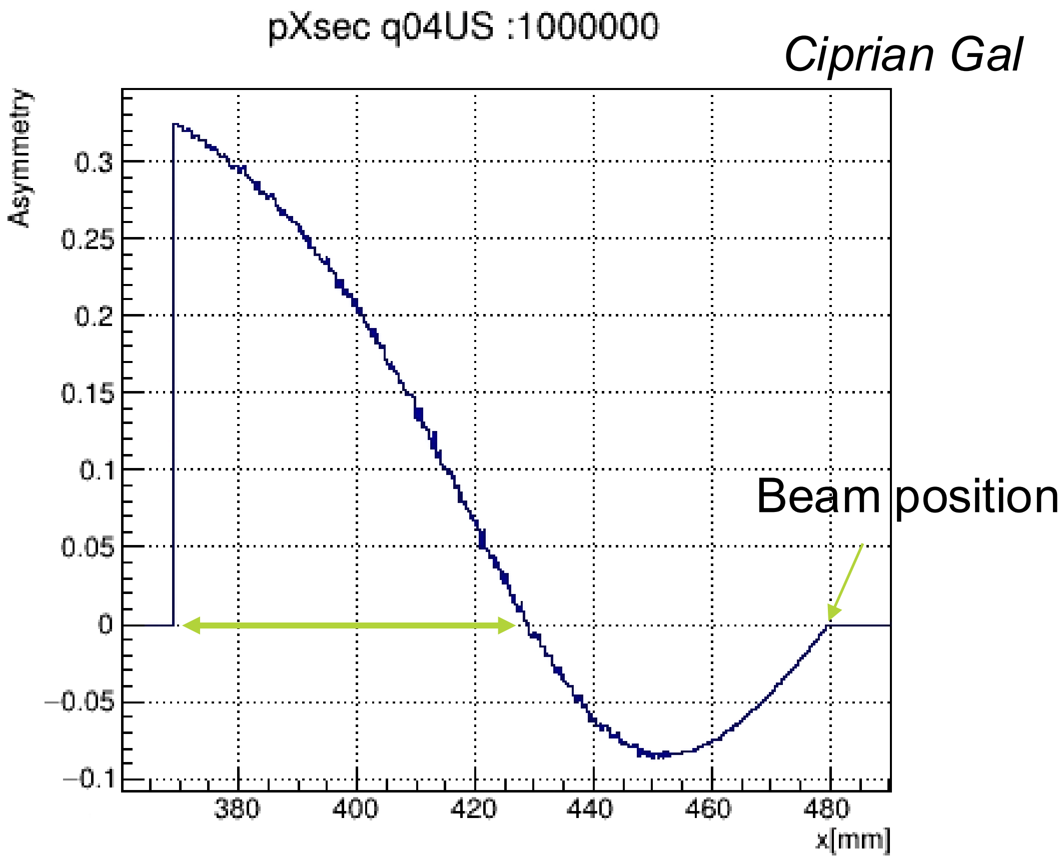


- Electron detector outside vacuum pipe → RF shield used to mitigate beam impedance issues

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

Ciprian Gal



Asymmetry at electron detector @18 GeV

RCS Compton Rates Rate and measurement time estimates

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

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.

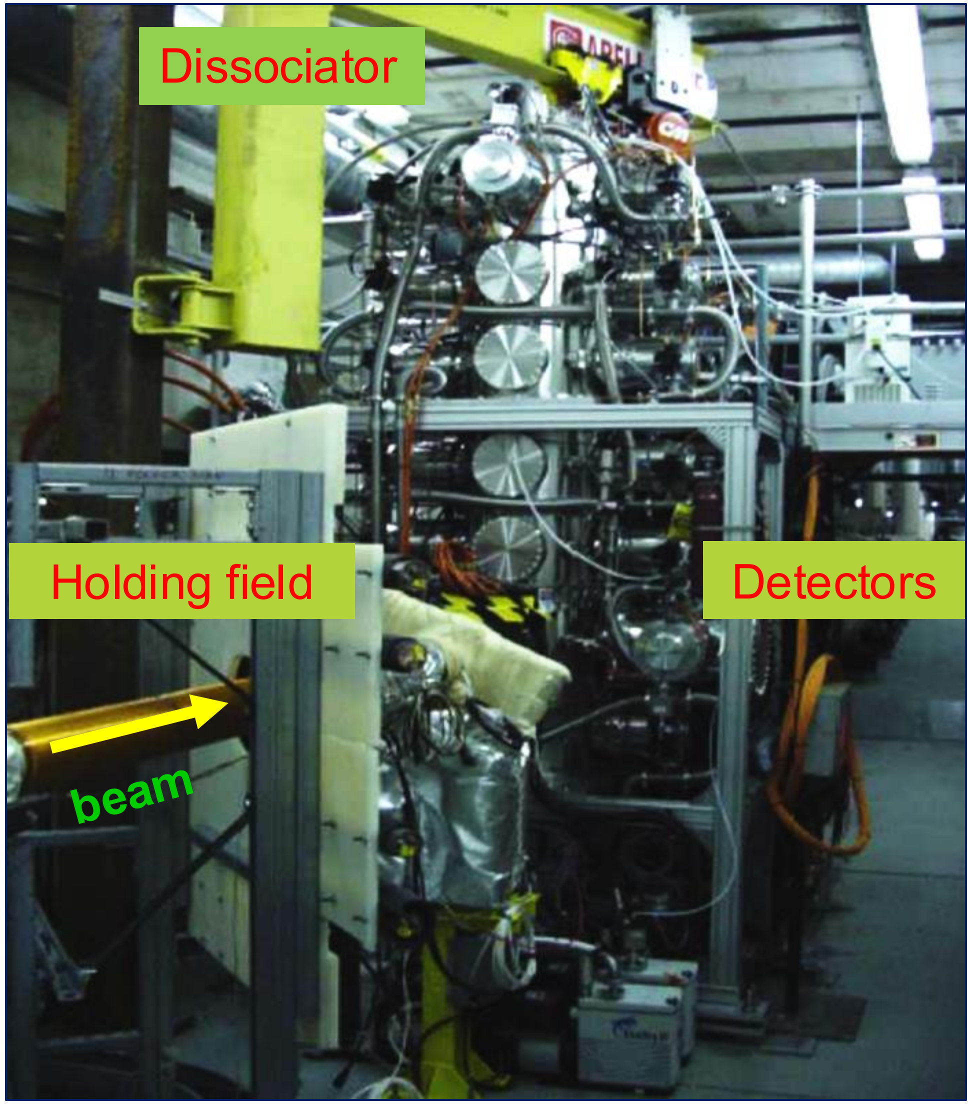
Assuming 80% polarization, $\langle P_{laser} \rangle$= 6mW, 300 μm beam spot size…, → time for 1% measurement

E_{beam}	A_{avg}	T_{avg}	A_{energy}	T_{energy}	A_{diff}	T_{diff}
5	4.51%	243 s	5.78%	148 s	5.48%	164 s
10	7.79%	92 s	10.15%	54 s	9.56%	61 s
18	11.29%	51 s	14.91%	29 s	13.96%	33 s

additional material

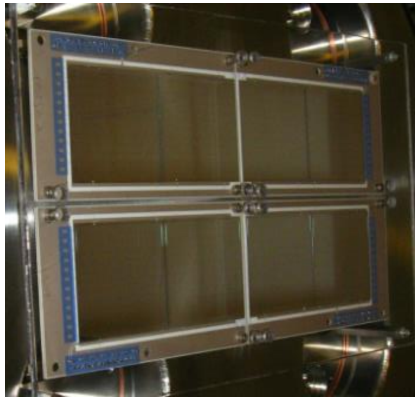
Hadron polarimeters

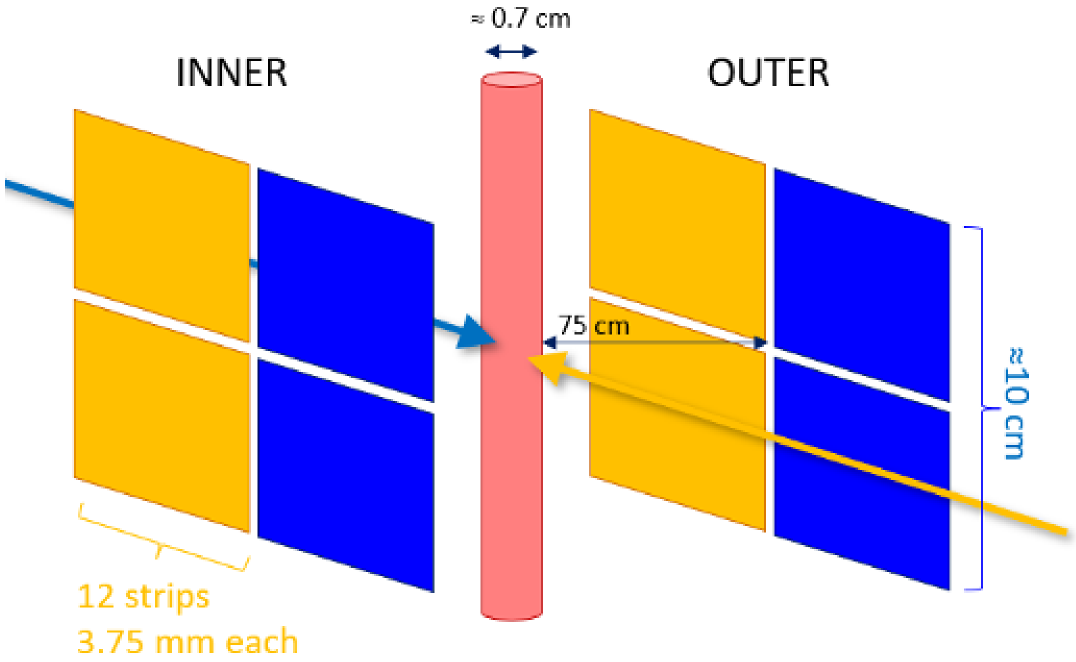
Polarized Atomic Hydrogen Jet Target



Set of eight Si strip detectors

- 12 vertical strips
  - 3.75 mm pitch
  - 500 µm thick





Coulomb-Nuclear interference I

Coulomb-Nuclear interference I

Need for calibration

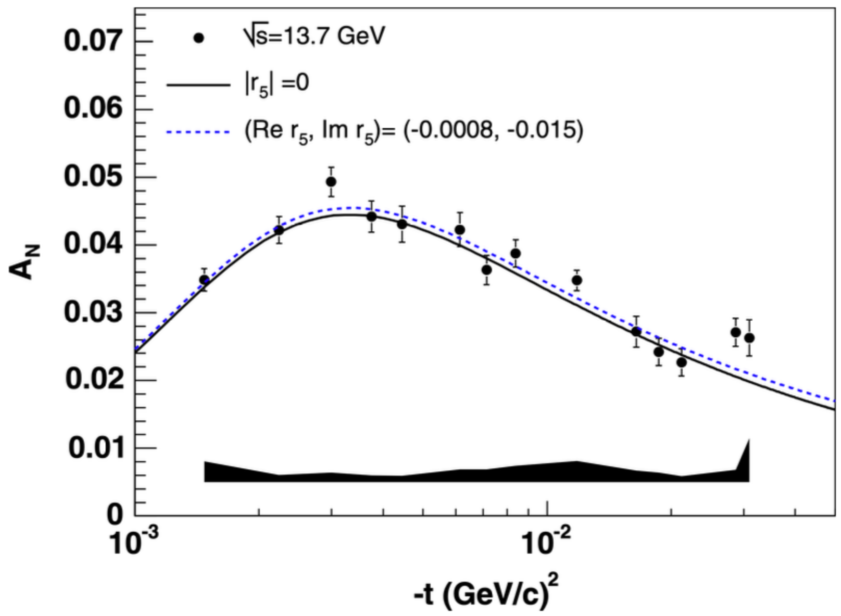
- Asymmetry from CNI region constitutes basis of RHIC high-energy (absolute) polarimeters
  - derived from same EM amplitude that generates anomalous magnetic moment

$$\mu_p = g_p \frac{e\hbar}{2m_p} = g_p \mu_N, \quad g_p \approx 5.585$$
$$g_p - 2 \approx 3.585 \Rightarrow \mu_p^{\text{anomalous}} \approx 1.792\, \mu_N \tag{26}$$

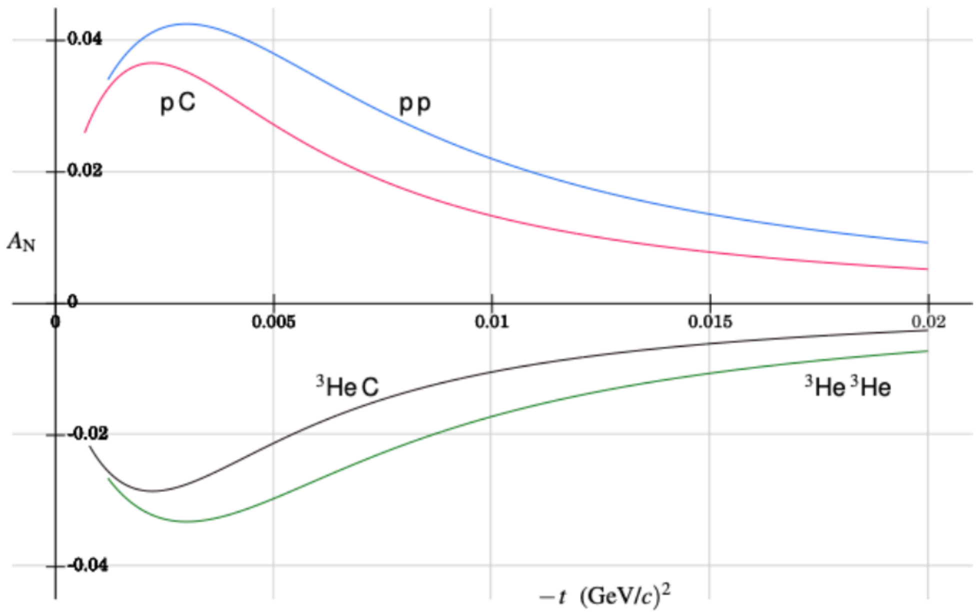
  - E704 at Fermilab used 200 GeV/c $\vec{p}$ from hyperon decay to detect asymmetry in scattering from H target [16]. Largest $A_y \approx 0.04$ with large statistical errors.
  - Meanwhile, accurate measurements of A_y are available from RHIC [17]
- Asymmetry measurements involve normalization uncertainties and calculations of A_y are subject to uncertainties in amplitudes of strong interaction. **Therefore, accurate calibration of reaction required.**

Coulomb-Nuclear interference II

Coulomb-Nuclear interference II



Measured A_N from RHIC in the CNI region at $\sqrt{s} = 6.8\,\text{GeV}$ ($E_{\text{lab}} = 23.7\,\text{GeV}$) [17].



Calculation of A_y in the CNI region by Nigel Buttimore [18].

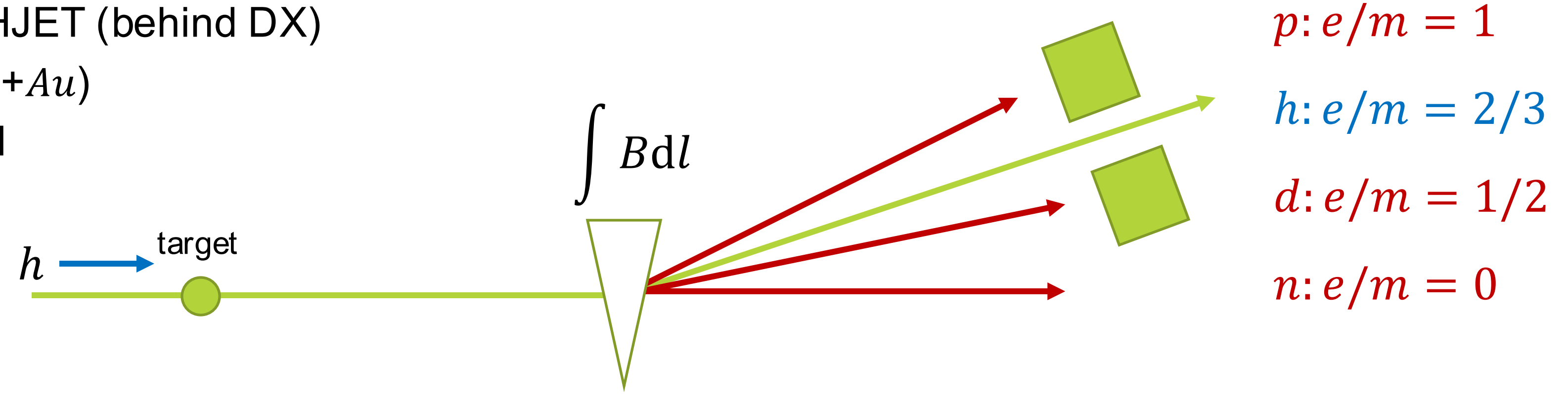
Hadron Polarimetry R&D

(Part of WBS 6.02.03 Accelerator R&D)

$^3\mathrm{He} \rightarrow pd$ break-up

- Tagging with hadron calorimeters
- ZDC's installed downstream of HJET (behind DX)
- Operational in RHIC Run 23 (Au+Au)
- Neutron peak calibration needed

Deflection angle $^Z/_A$

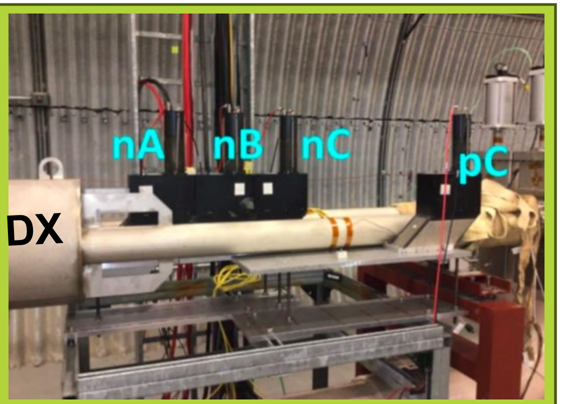


During RHIC Run 24

- $^3\mathrm{He}^{++}$ beam from EBIS source ready
- Successful APEX 100 GeV in July/August 2024

Installation at IP12

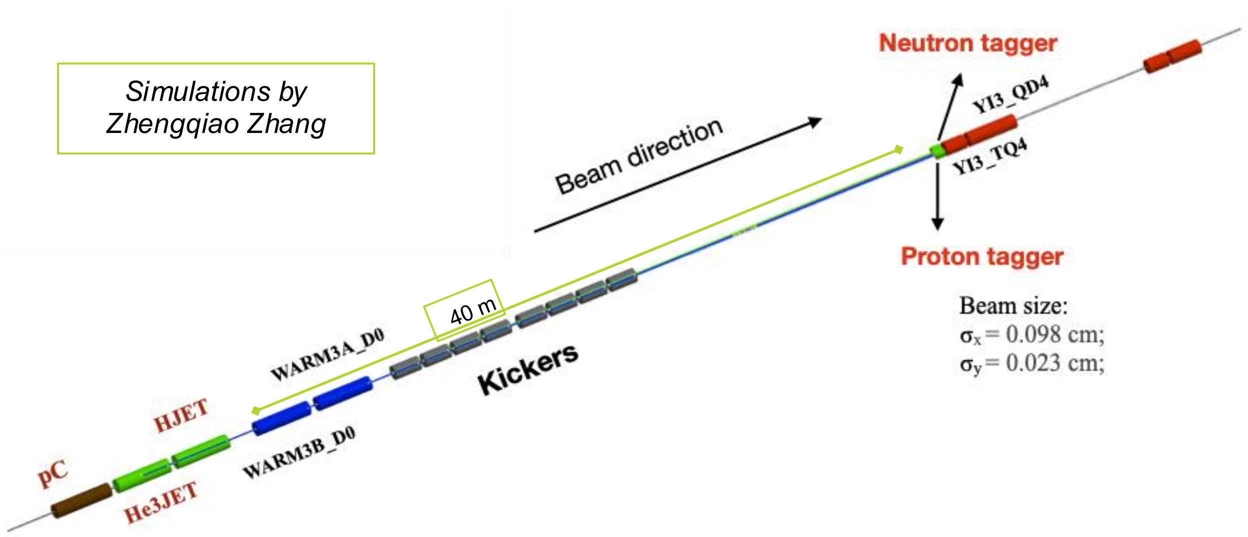
- 3 modules between beam pipes
  - nA, nB, nC
- 1 module outside beam pipes
  - pC
- All modules operational



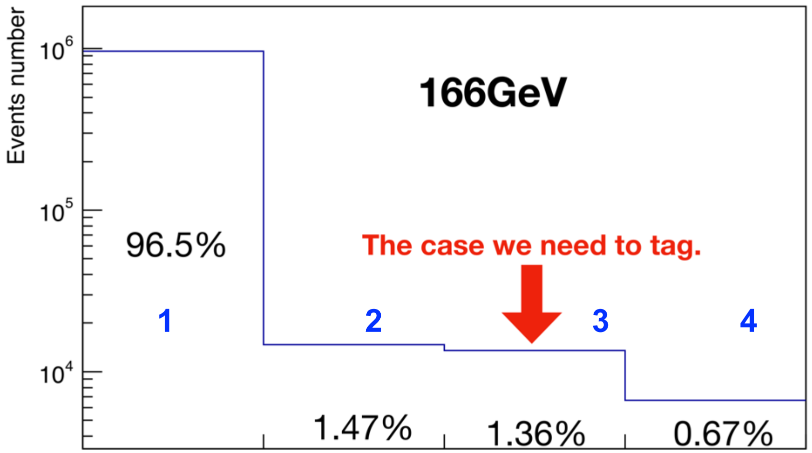
Simulation of ^{3}He-^{3}He tagger in IP4

- Two warm dipoles behind polarimeter targets
- Drift region includes stochastic kicker tanks

Simulations by Zhengqiao Zhang



- DMP jet model to simulate hh fixed target collisions
- Four types of events:
  1. All ^{3}He break up
  2. Breakup of ^{3}He target
  3. Breakup of ^{3}He beam
  4. All ^{3}He stay intact
- Tag events where ^{3}He beam breaks up, as detectors identify 3He recoil

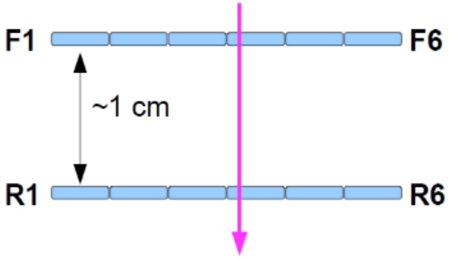


Hadron Polarimeter R&D

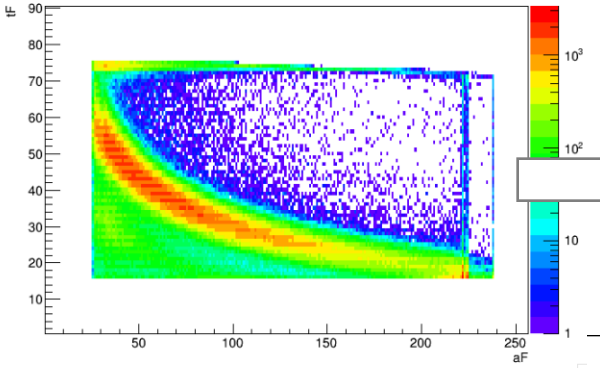
(Part of WBS 6.02.03 Accelerator R&D)

Second detector layer installed in pC polarimeter

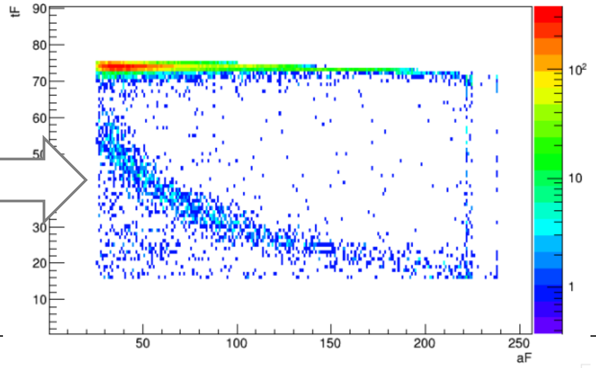
- Included in DAQ since start of Run22 operations
- Data from RHIC Run 22



TOF vs. E_{kin} in layer 1 (F)

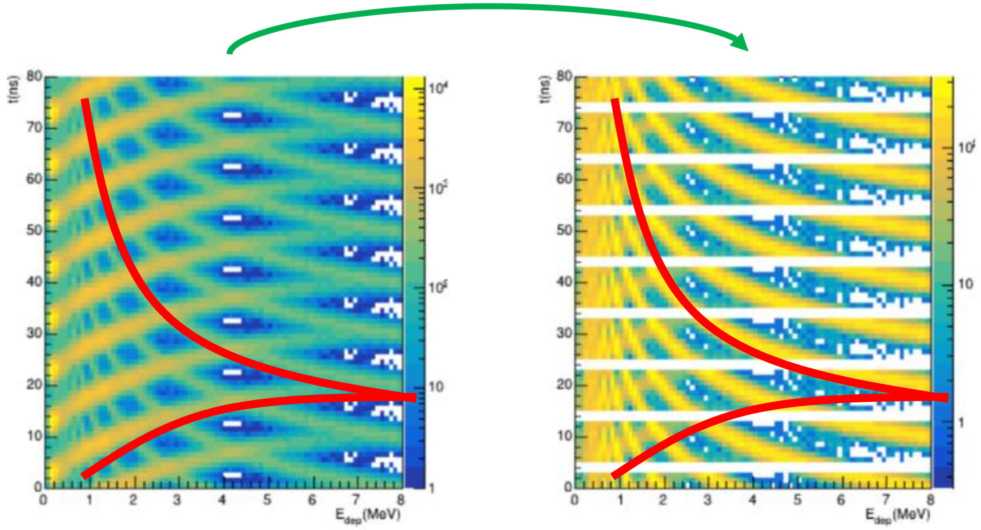


with a match in second layer (R)



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

Veto punch through particles



Proton time-of-flight