Polarimetry at EIC

Zhengqiao Zhang

Brookhaven National Laboratory

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY

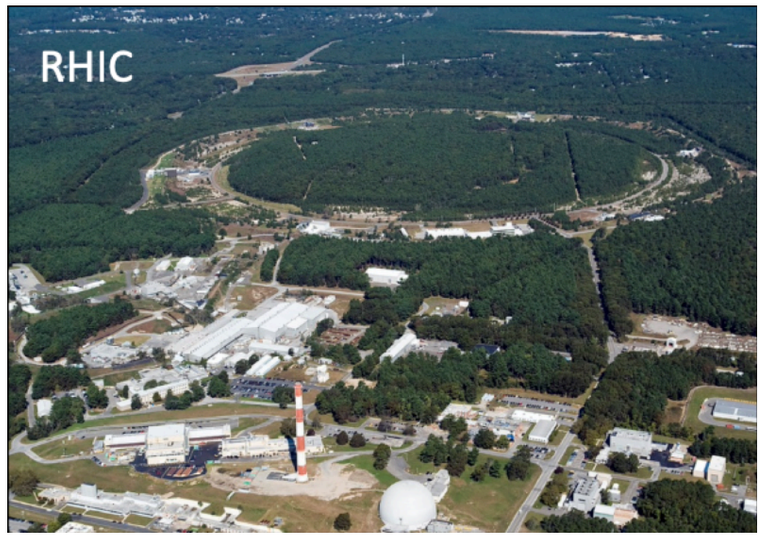
Jefferson Lab

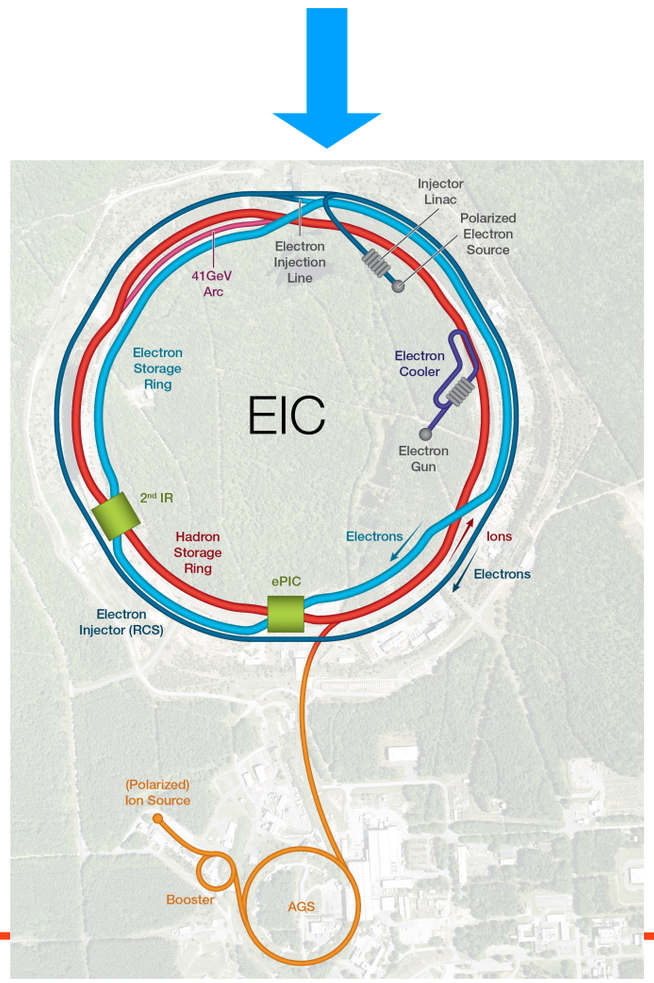
U.S. DEPARTMENT OF ENERGY | Office of Science

Electron-Ion-Collider (EIC)

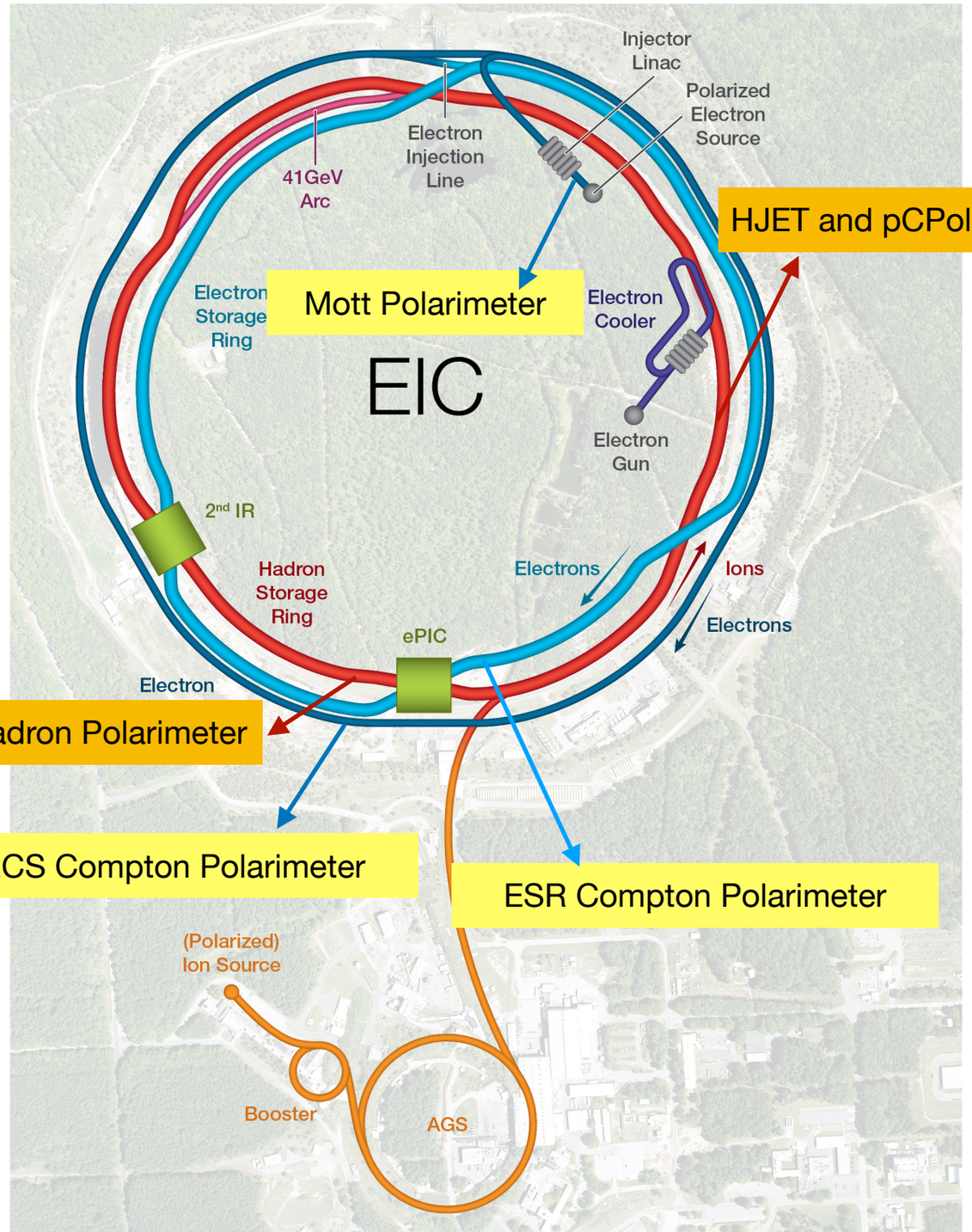
EIC Design Goals:

- Large range of center of mass energies: E_{cm} = 20-140 GeV ;
  - ➡ Access to gluon dominated region and wide kinematic range in x and Q^2
- Large range of ion species: Protons – Uranium;
  - ➡ Access the highest gluon densities ($Q_s^2 \sim A^{1/3}$)
- High Luminosity (100x HERA): L = (0.1-1) · 10^{34} $cm^{-2}s^{-1}$ —>10-100 fb^{-1};
  - ➡ Studying observables as a function of x, Q^2, A, etc.
- Collisions of highly polarized e and p (and light ion) beams with flexible bunch polarization pattern: ≥ 70% ;
  - ➡ Access to spin structure and 3D spatial and momentum structure
- Good background conditions;
- EIC is using part of RHIC facility at BNL;



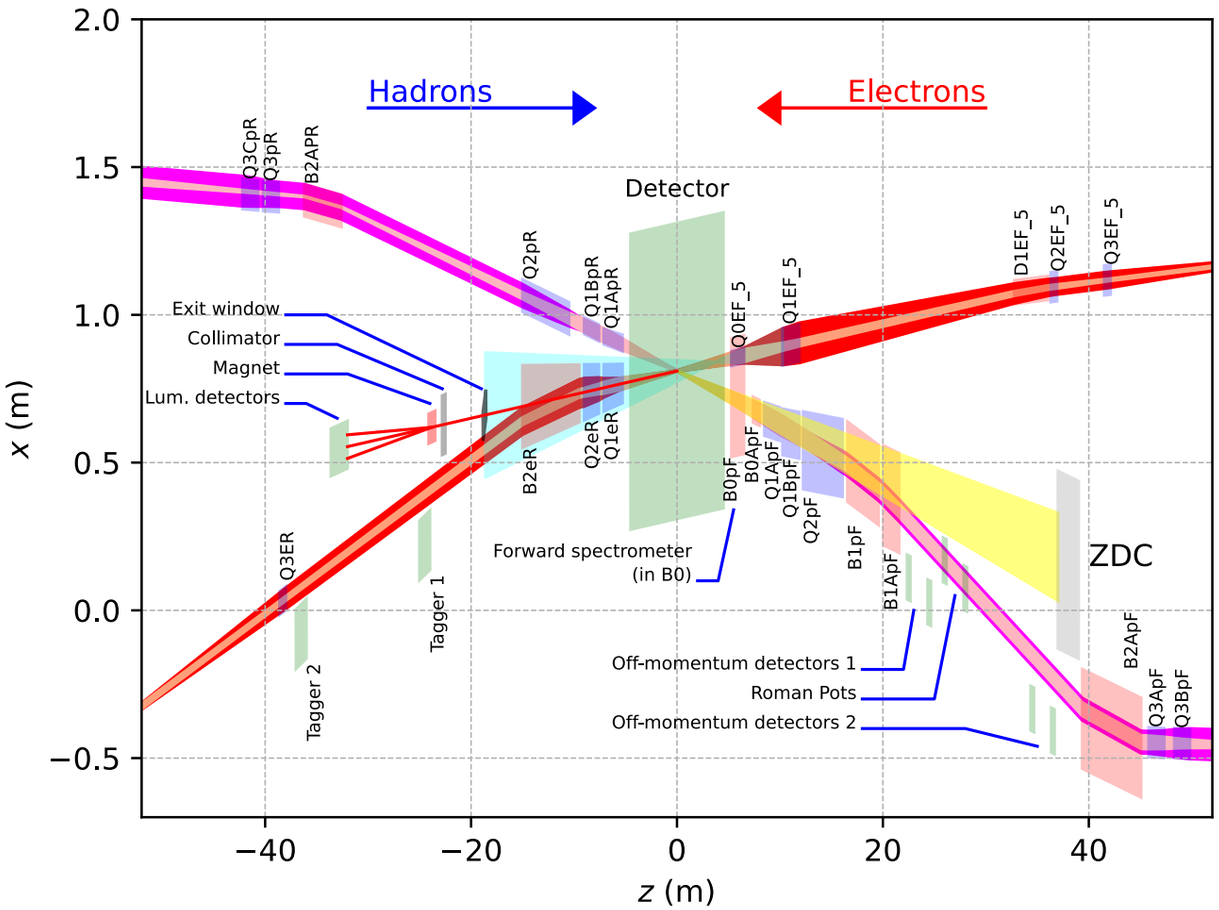


EIC polarimeters



- EIC requires three electron polarimeters;
  - Compton Polarimeter in ESR
  - Polarimeter for RCS (A Compton Polarimeter is proposed)
  - Polarimeter at source (Mott Polarimeter)
- HJET for absolute polarization and pC for time dependence and bunch profile at IR-4;
- pC polarimeter for hadron polarization orientation at IR-6;

Requirements of electron polarimeter

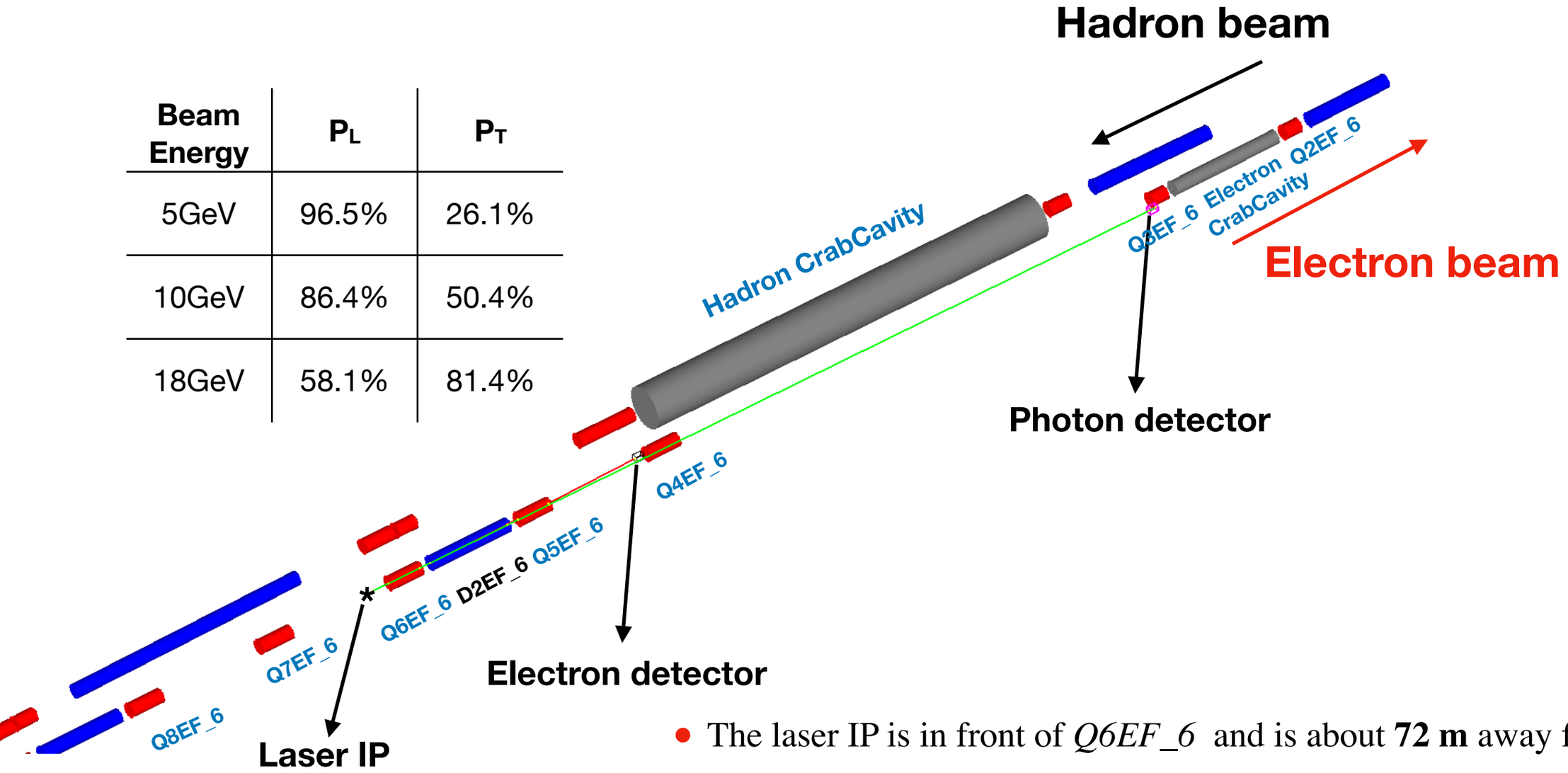


- The polarimeter needs to be placed as close to IP-6 as possible;
- The inner IR-6 region is very crowded, it is not possible to place the whole Compton Polarimeter system;
- Compton Polarimeter in ESR is placed at 72 m away from IP-6;

- Non-destructive
- Need to measure both longitudinal and transverse components;
  - The longitudinal polarization can be measured by an energy asymmetry of the Compton photons & electrons flipping the circular laser polarization direction;
  - The transverse polarization (horizontal) can be measured by a spatial asymmetry of the Compton photons;
- Measure bunch-by-bunch polarization;
- Measure with high precision $\Delta P / P < 1\%$;

Layout of polarimeter in ESR

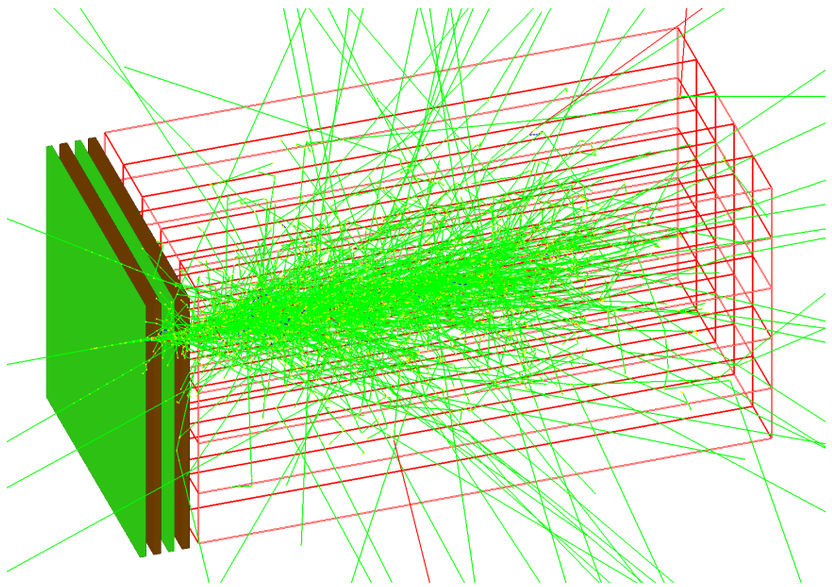
Beam Energy	P_L	P_T
5GeV	96.5%	26.1%
10GeV	86.4%	50.4%
18GeV	58.1%	81.4%

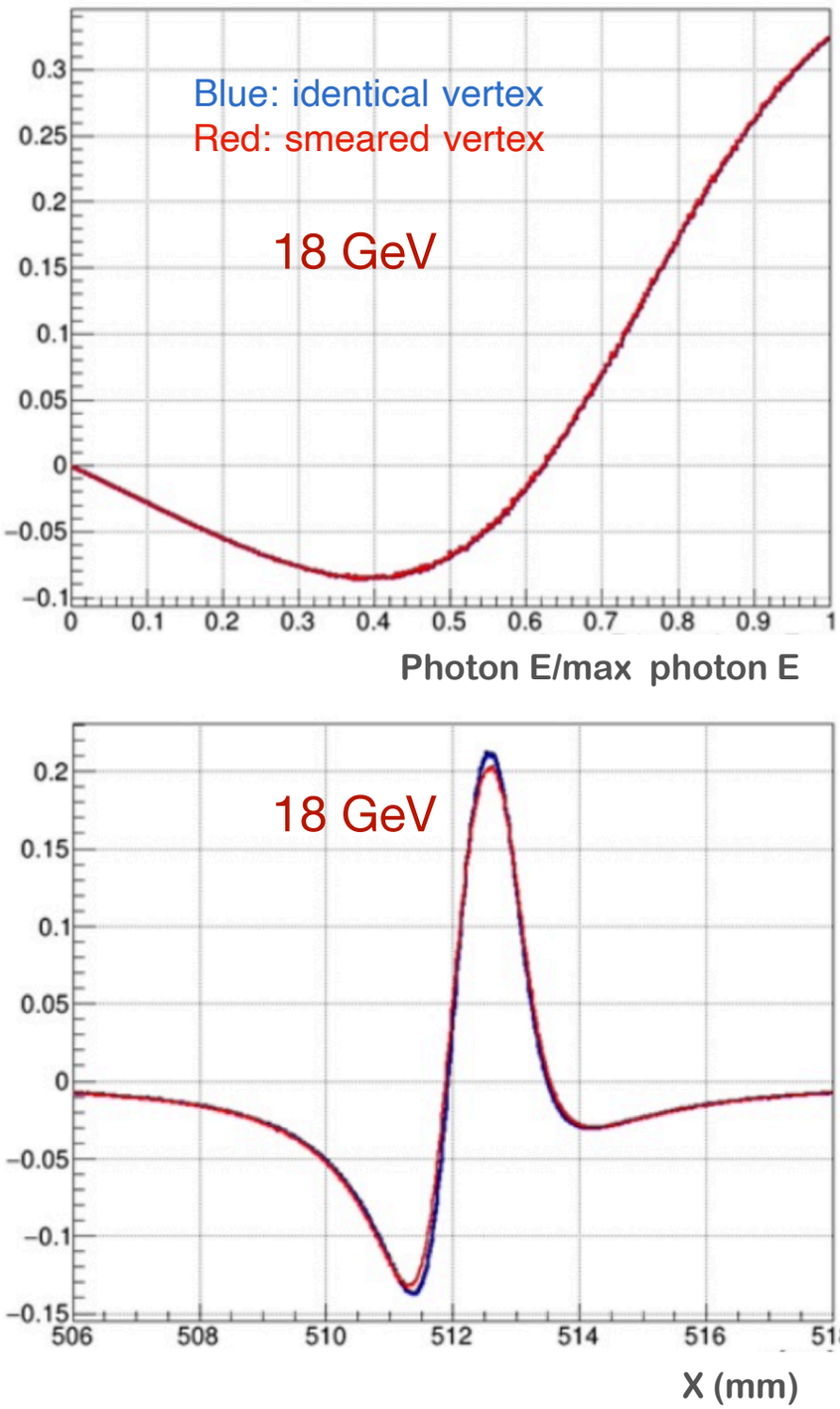


- The laser IP is in front of *Q6EF_6* and is about **72 m** away from IP-6;
- Photon detector is placed in front of the *Q3EF_6*;
- The distance between the photon detector and the laser IP is **29 m**;
- The distance between the electron detector and the laser IP is **9.7 m**;
- Open midplane is required for *Q4EF* to allow the photons to go through and the hole through the yoke is cleared by the magnet expert;

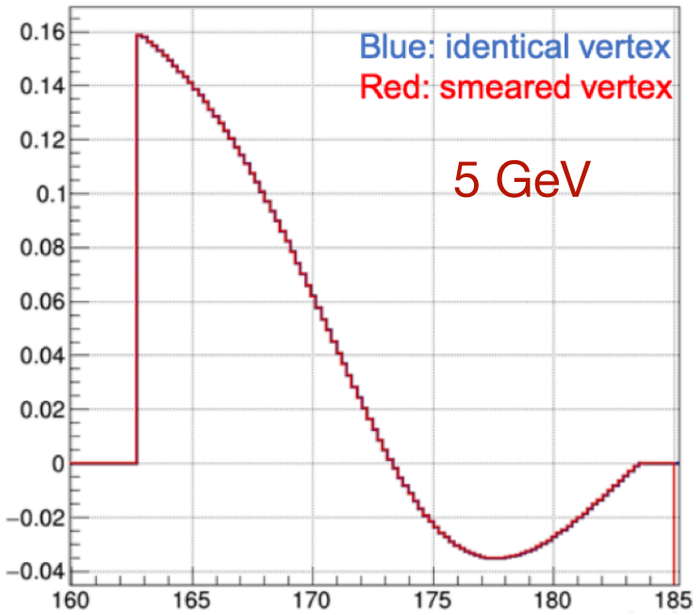
Photon Detector

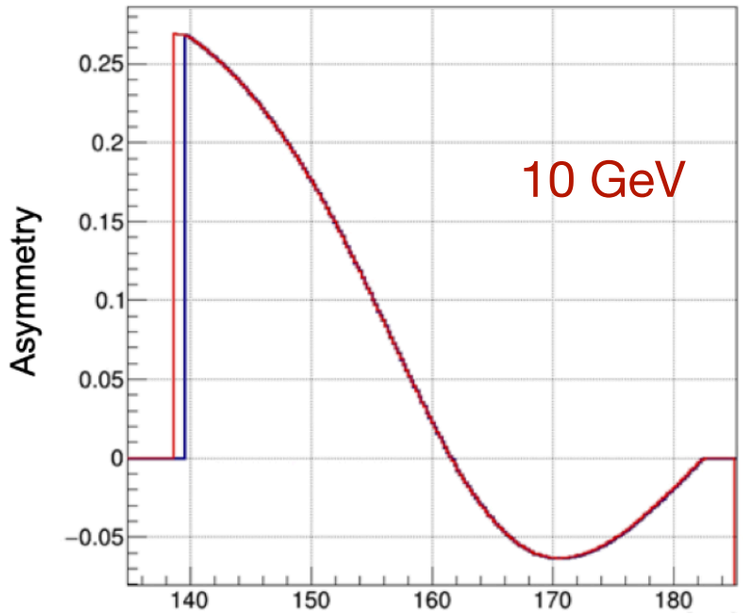
- Photon detector needs 2 components to measure both longitudinal (photon energy asymmetry) and transverse polarization (left-right asymmetry);
- Longitudinal measurement requires good energy resolution from ~0 (as low as possible) to 7 GeV. A homogeneous Calorimeter with Preshower detector is being considered (10cmX10cmX20cm). A fiber-tungsten or lead sampling calorimeter is another (perhaps safer) option, but would likely result in reduced precision for P_L on the photon side;
- Position sensitive detector segmentation determined by highest energy, segmentation on the order of 100-400 μm would work;
- Fast time response is also needed (10 ns bunch spacing);
- Radiation hardness: 80 Gy/h;
- Background studies are being conducted for the photon detector;

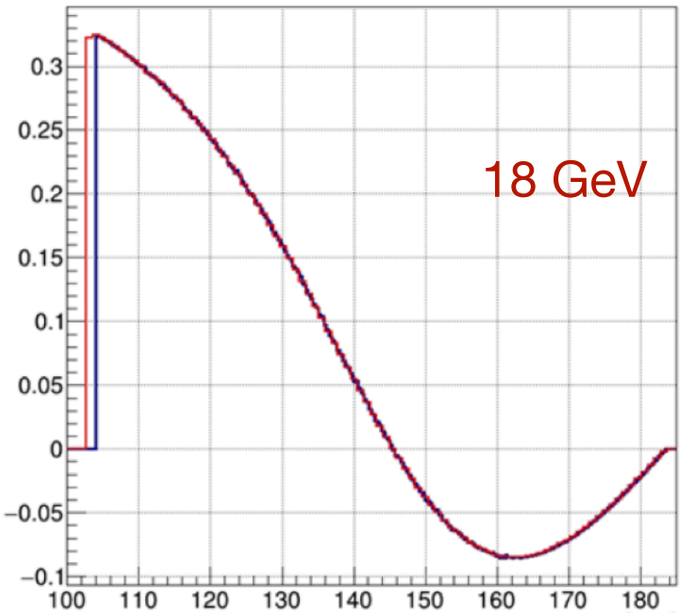


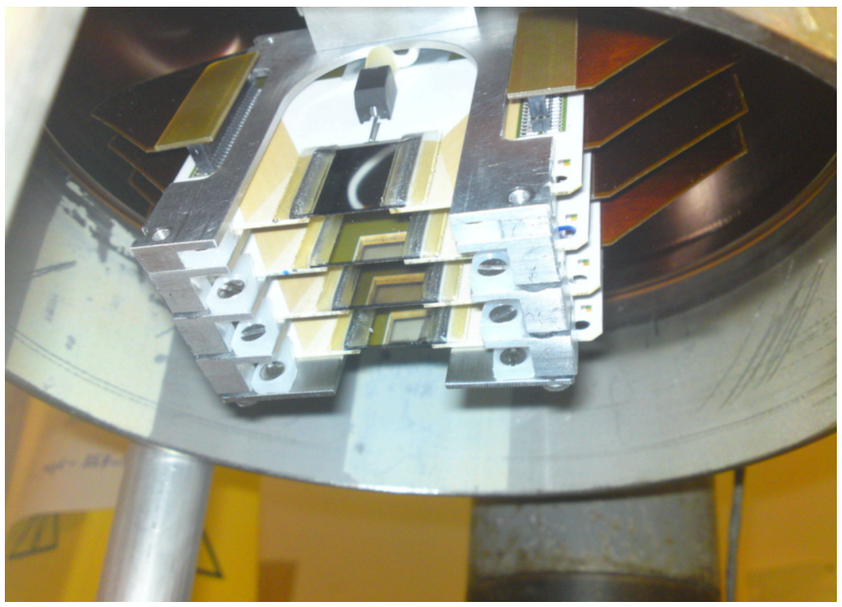


Electron Detector





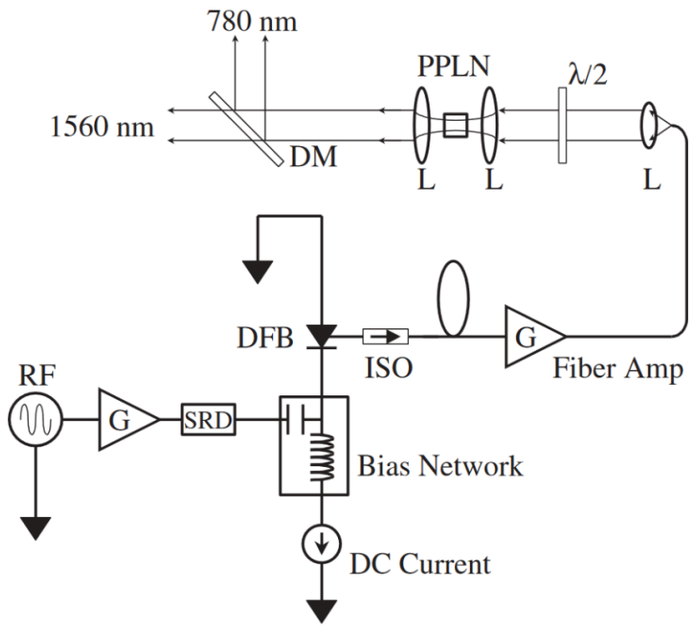




- Electron detector (horizontal) size determined by spectrum at 18 GeV (which has the largest horizontal spread);
  - Need to capture zero-crossing to the endpoint —> detector should cover at least 60 mm;
- Segmentation is dictated by the spectrum at 5 GeV (smallest spread);
  - Need at least 30 bins, so a strip pitch of about 550 μm would be sufficient;
- Electron detector can only be used for the measurements of P_L due to the large dispersion induced by the dipole;
- Diamond strip detector similar with JLab Hall C diamond detector is being considered;
  - Radiation hard, fast time response, compatible with segmentation requirements;

Compton Laser System

Average of 1 backscattered photon/bunch crossing will allow Compton measurements on the ~1 minute time scale —> can be achieved with a pulsed laser system that provides about 5 W average power at 532 nm;

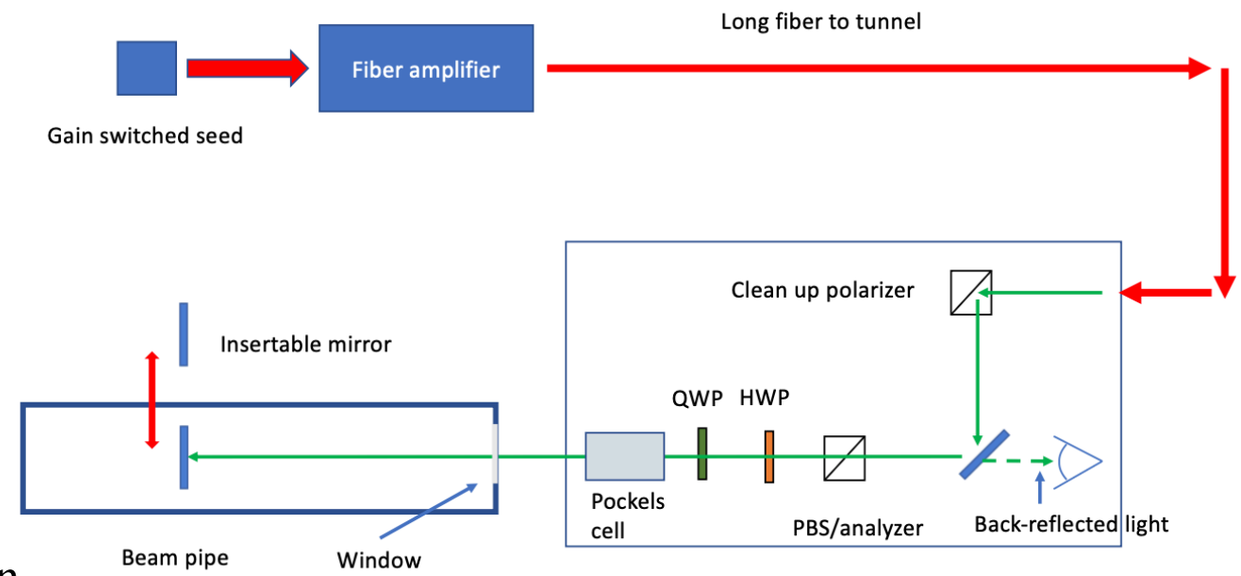


JLAB injector laser system

Polarization in vacuum set using "back-reflection" technique —> Requires remotely insertable mirror (in vacuum)

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

- 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)
- Fiber amplifier —> average power 10-20 W
- Optional: Frequency doubling system (LBO or PPLN)
- Insertable in-vacuum mirror for laser polarization setup



RCS Compton Polarimeter

RCS properties

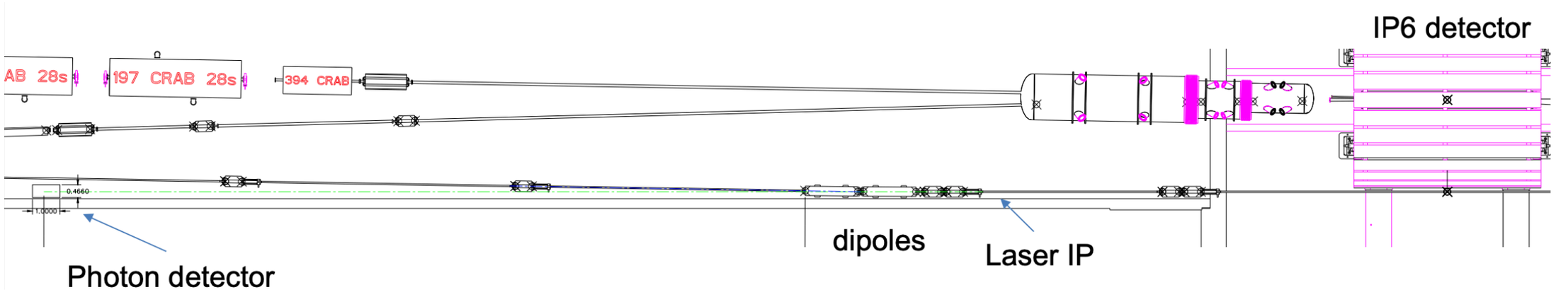
- RCS accelerates electron bunches from 0.4 GeV to full beam energy (5-18 GeV)
- Bunch frequency —> 2 Hz
- Bunch charge —> up to 28 nA
- Ramping time = 100 ms

Polarimetry challenges

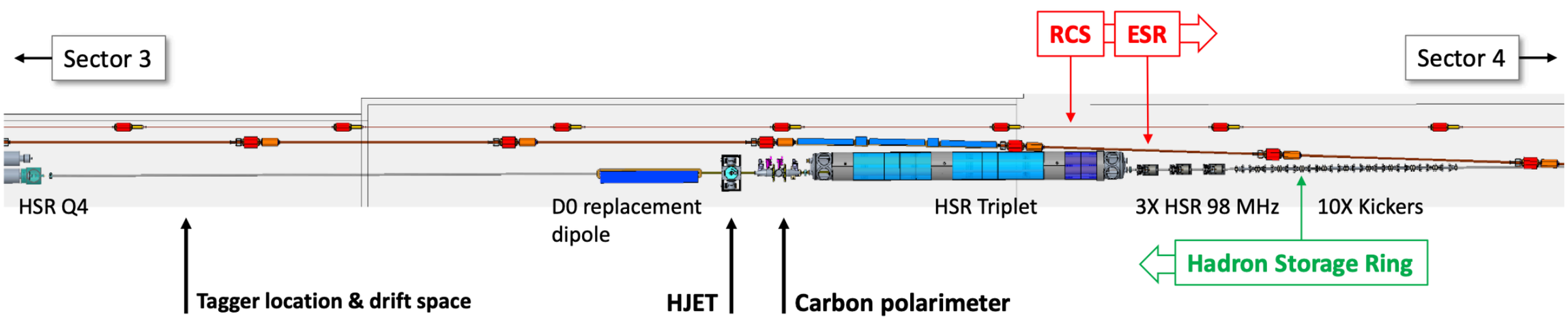
- Analyzing power depends on beam energy
- Low average current
- Bunch dwell time is short

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)



Hadron Polarimeters at IR-4

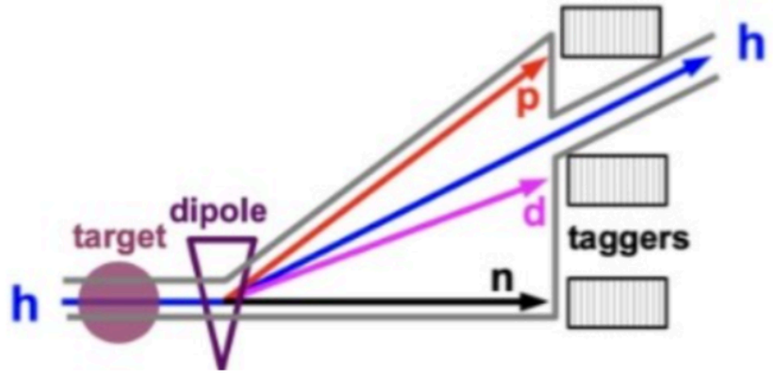


Recoil particles from elastic scattering

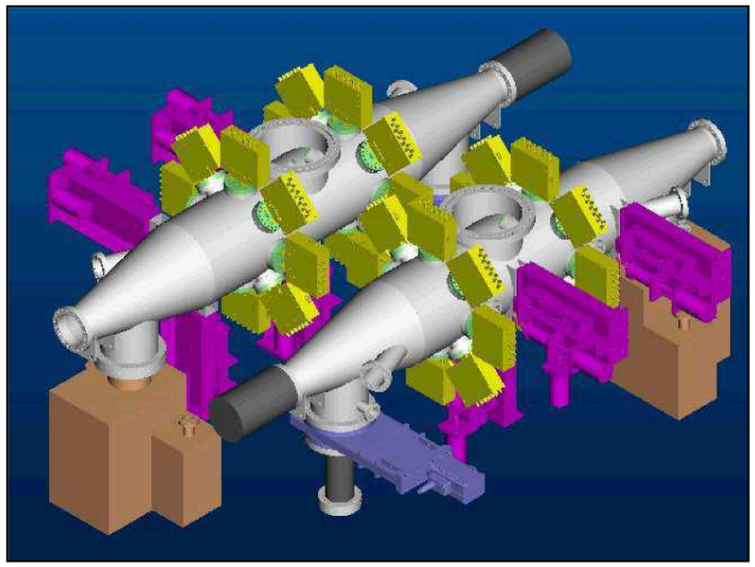
- Strong dipole magnet, vacuum chamber with exit windows and drift space and space for taggers
- HJET polarimeter move from IR-12 to IR-4 after RHIC shutdown (06/2025)
- Update/refurbish some components
- Upgrade silicon detectors and readout
- Add target gas analyzer

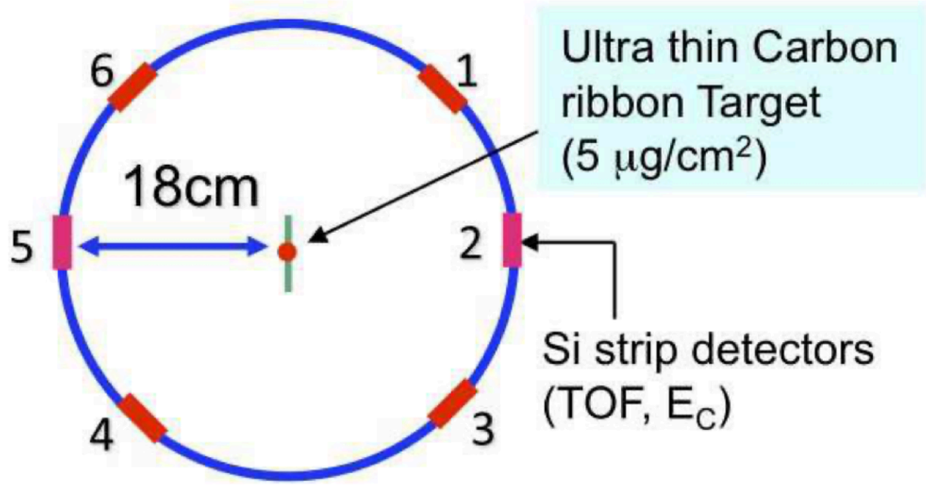
$$A_N = \frac{d\sigma_{left} - d\sigma_{right}}{d\sigma_{left} + d\sigma_{right}}$$

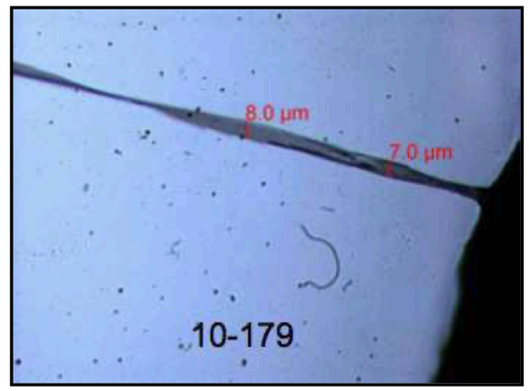
$$P_{Beam} = \frac{\varepsilon_{Beam}}{\varepsilon_{Target}} P_{Target}$$



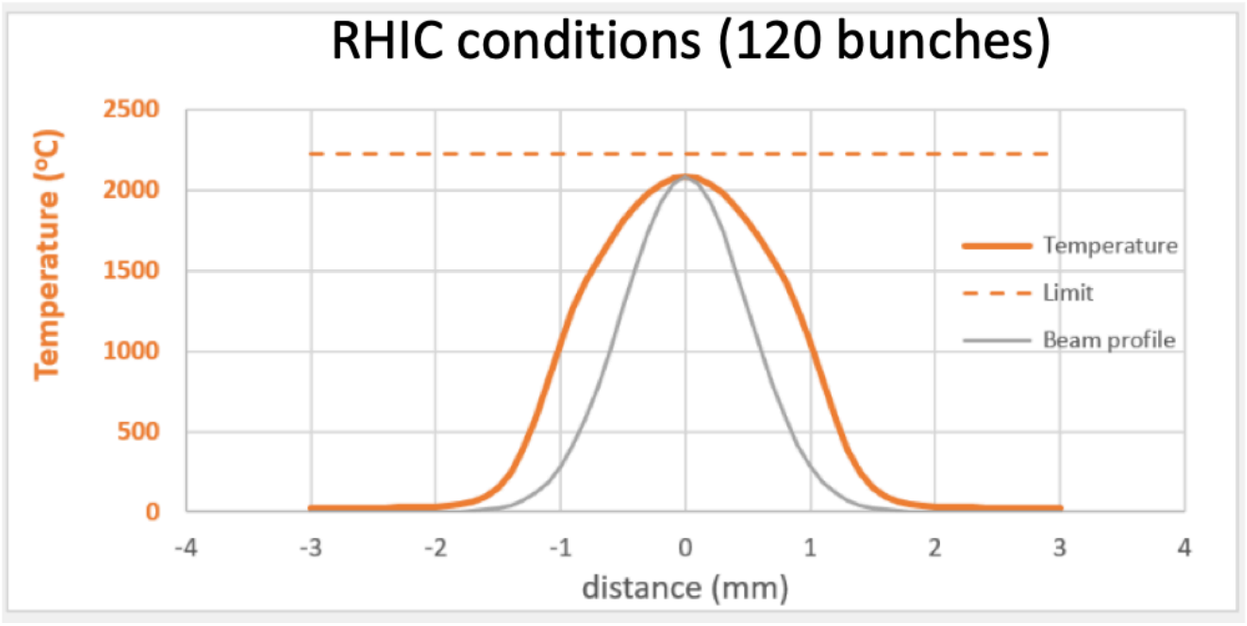
Fiber Target Polarimeters





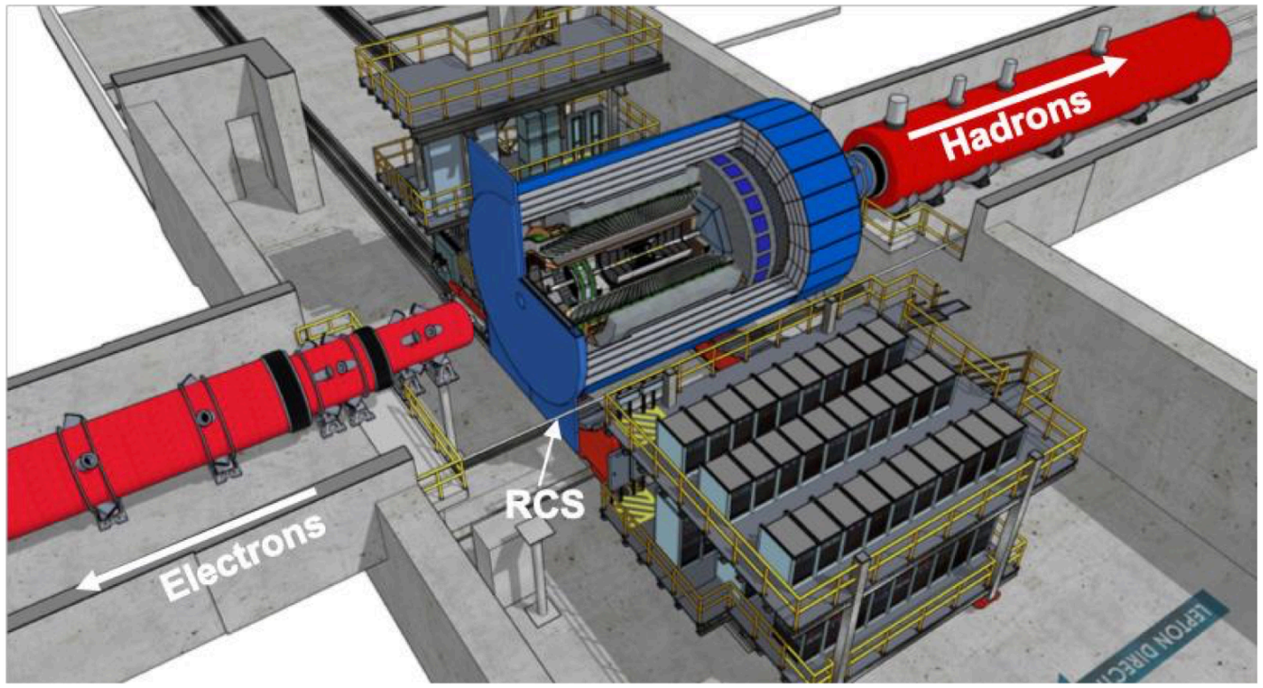


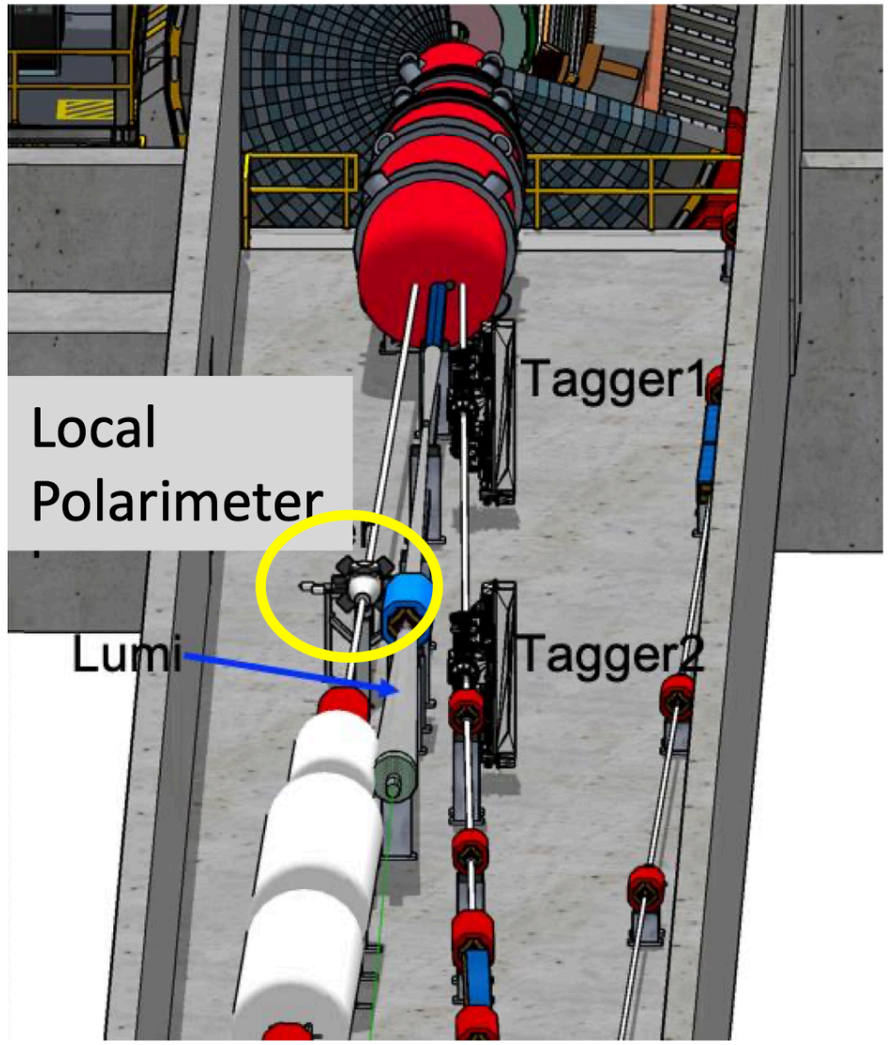
- Ultra-thin ribbon targets: ≈ 10 μm x 100 nm
- Target holder inside the beam pipe
- Targets heat up due to energy loss of proton beam
- Two p-C polarimeters exist, move double target chamber to IR-4, move single target chamber to IR-6



Hadron Local Polarimeter at IR-6

- Spin rotators for longitudinal polarization→monitor degree of polarization
- Crab cavities for increased luminosity in collision → monitor possible impact
- Limited space in hall / straight section
- Polarimeter in incoming hadron beam





Summary

- Polarimeters are necessary for polarized beam commissioning (04/2031)
- ESR Compton polarimeter design is based on experience from previous transverse and longitudinal polarimeters
  - Investigating suitable photon detectors to meet all requirements
  - Diamond strip are default position sensitive detectors
  - Laser system is higher power version of JLab polarized source laser
- Hadron polarimeters are based on existing devices at RHIC
  - $\sigma_P/P \approx 1.4\%$ has been achieved
  - HJET provides absolute beam polarization measurement and limited information about polarization lifetime.
  - Transverse polarization profile may require changes to the target and/or other mitigation of rapid heating

Thanks.