Electron polarimetry at EIC

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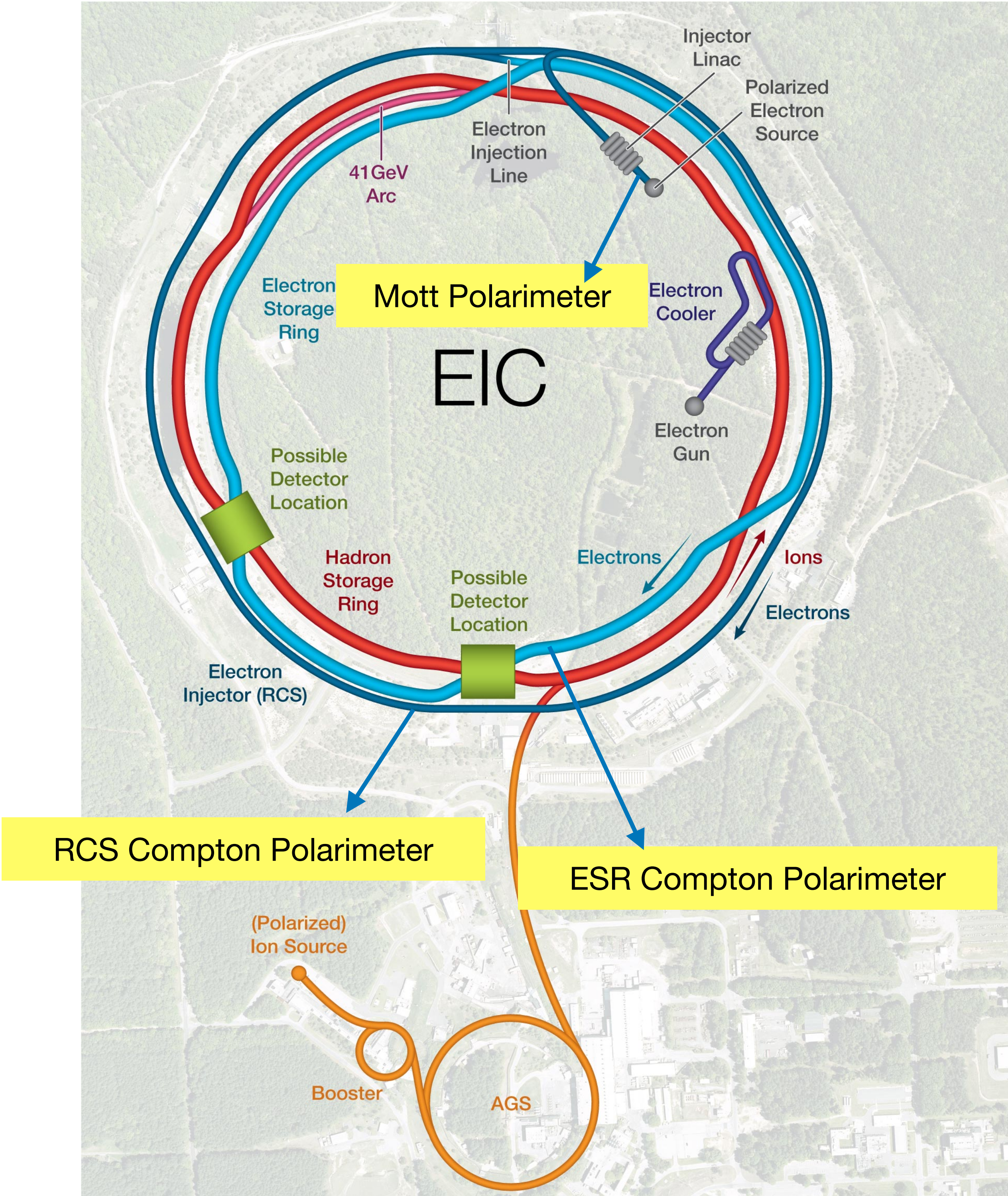
Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY Jefferson Lab U.S. DEPARTMENT OF ENERGY Office of Science

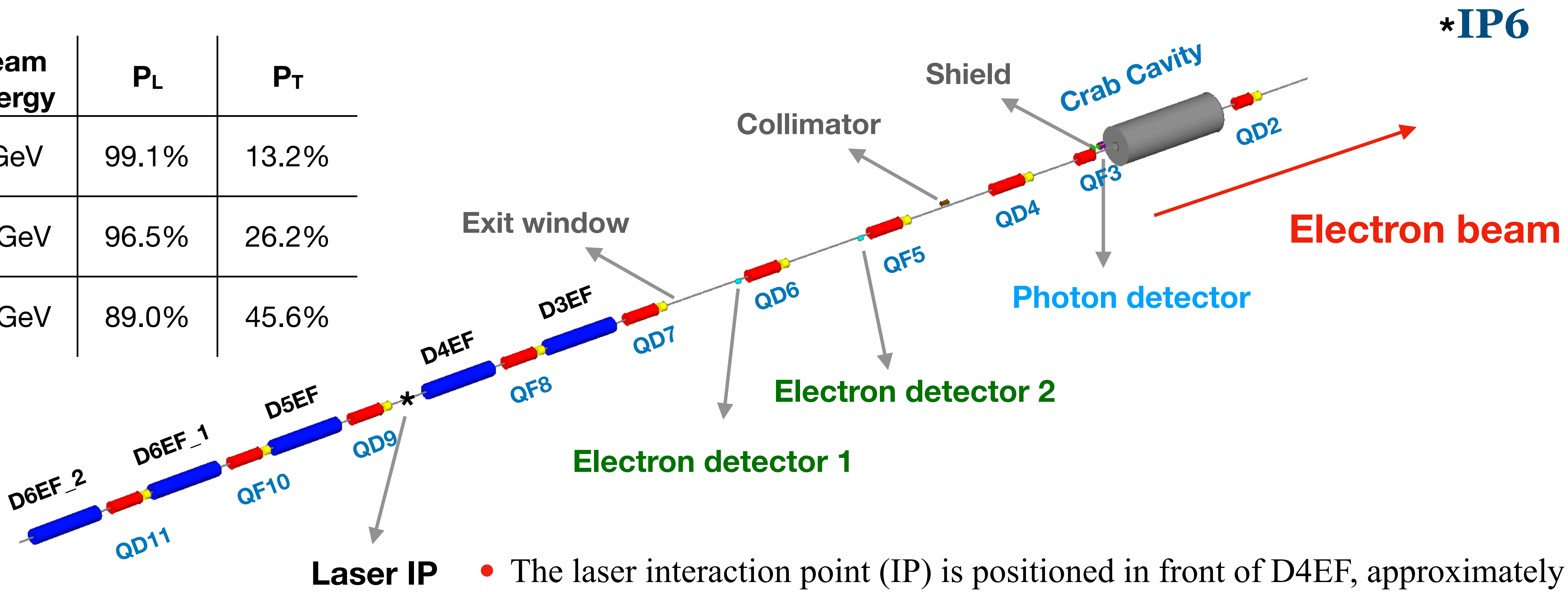
EIC polarimeters



- EIC requires 3 electron polarimeters;
  - Compton Polarimeter in ESR
  - Polarimeter for RCS (A Compton Polarimeter is proposed)
  - Polarimeter at source (Mott Polarimeter)
- Compton polarimeters for RCS and ESR have similarities but will operate in different modes —> ESR single photon/counting mode; RCS multi-photon/integrating mode.

Layout of polarimeter in ESR

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

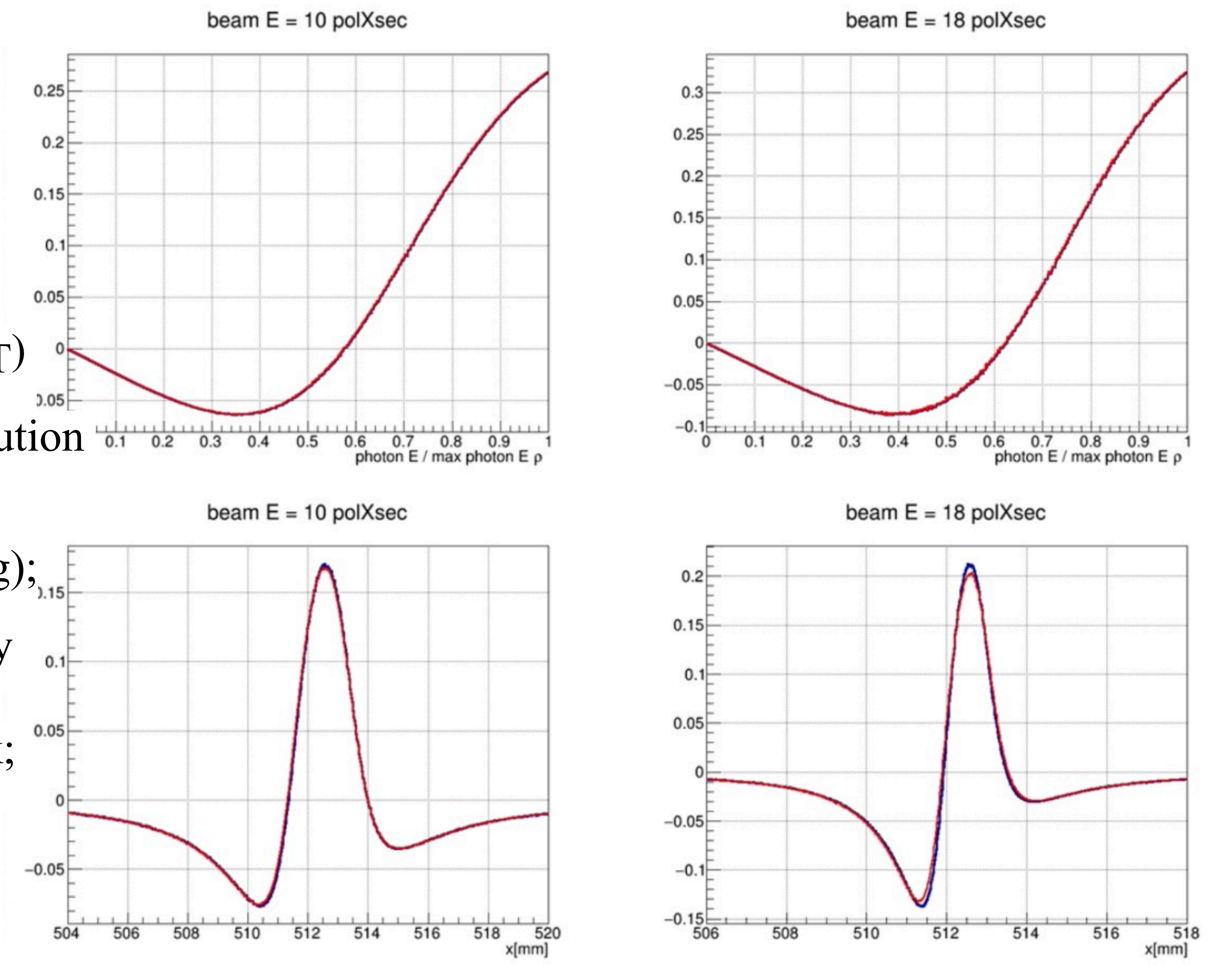


	bending angle	length
D6EF	11.9 mrad	2.73 meters
D5EF, D4EF	1.5 mrad	2.73 meters
D3EF	13.0 mrad	2.73 meters

- The laser interaction point (IP) is positioned in front of D4EF, approximately 72 meters from IP6.
- Photon detector is placed in front of the Crab Cavity.
- The distance between the photon detector and the laser IP is 29 meters.
- To minimize synchrotron radiation background at the photon detector, the beamline design includes two weak dipoles located before and after the laser IP.
- Electron detectors are placed 0.5 meters before QD6 and QF5, respectively.
- QD6, QF5, and QD4 require an open midplane to allow photons to pass through. The clearance for a hole through the yoke has been confirmed by the magnet expert.

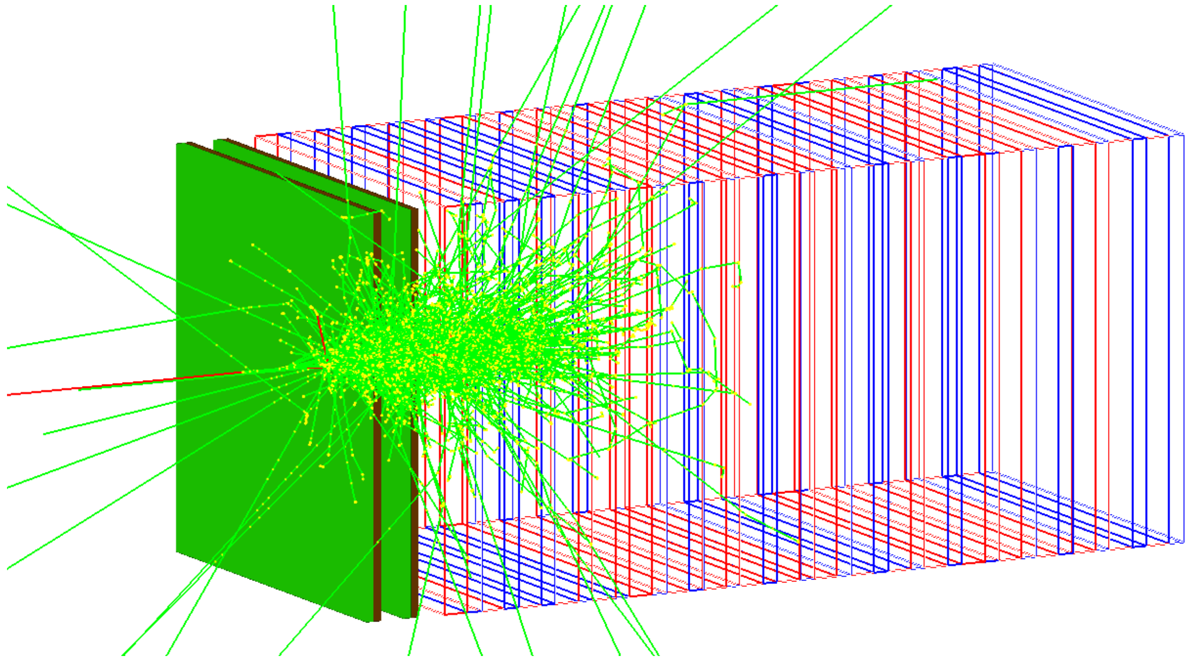
Photon Detector

- Photon detector needs 2 components to measure both longitudinal and transverse polarization;
  - Calorimeter —> photon energy asymmetry (P_L)
  - Position sensitive detector —>left-right asymmetry (P_T)
- Longitudinal measurement requires good energy resolution from ~0 (as low as possible) to 7 GeV;
- Fast time response is also needed (10 ns bunch spacing);
- Position sensitive detector segmentation determined by highest energy, more investigation is needed, but segmentation on the order of 100-400 µm should work;
- Radiation hardness: 80Gy/h;



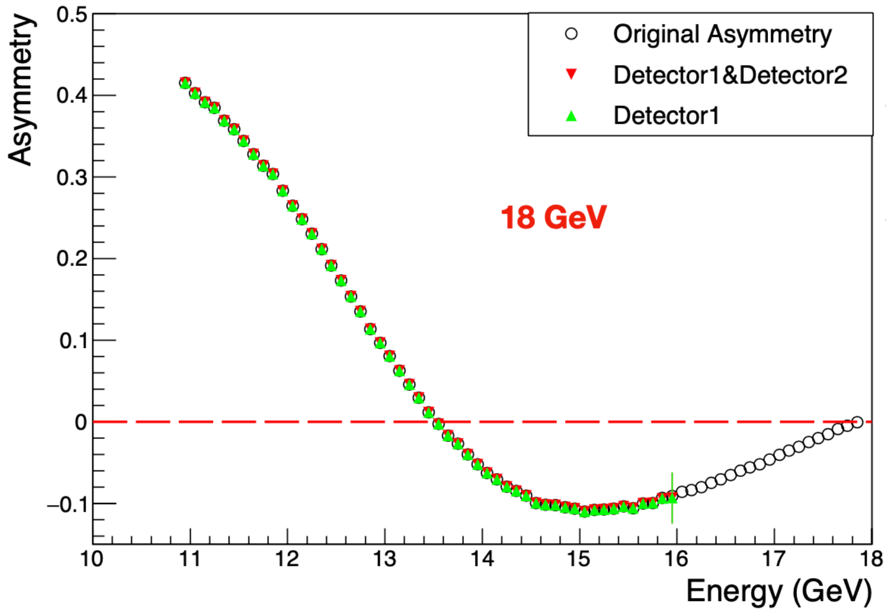
Photon Detector

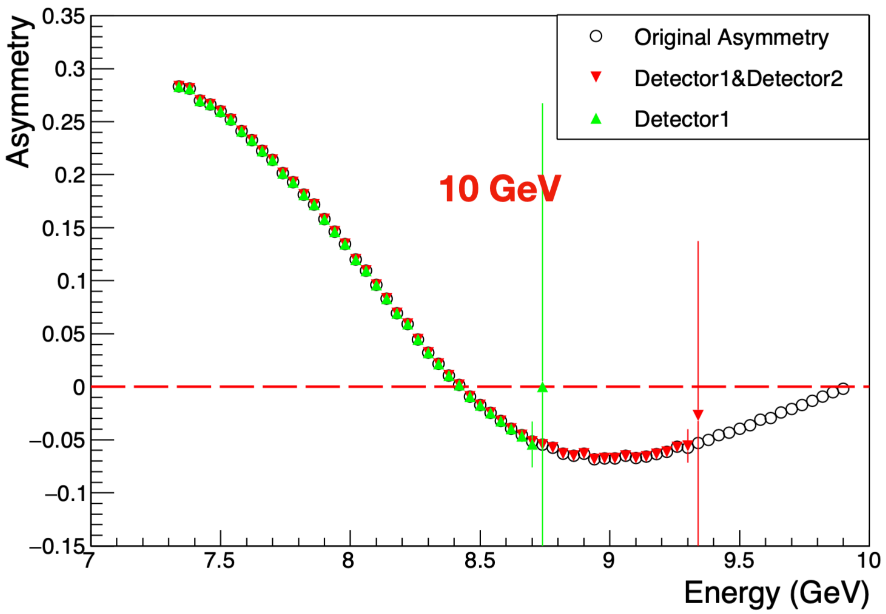
W/SciFi Calorimeter with Preshower detector

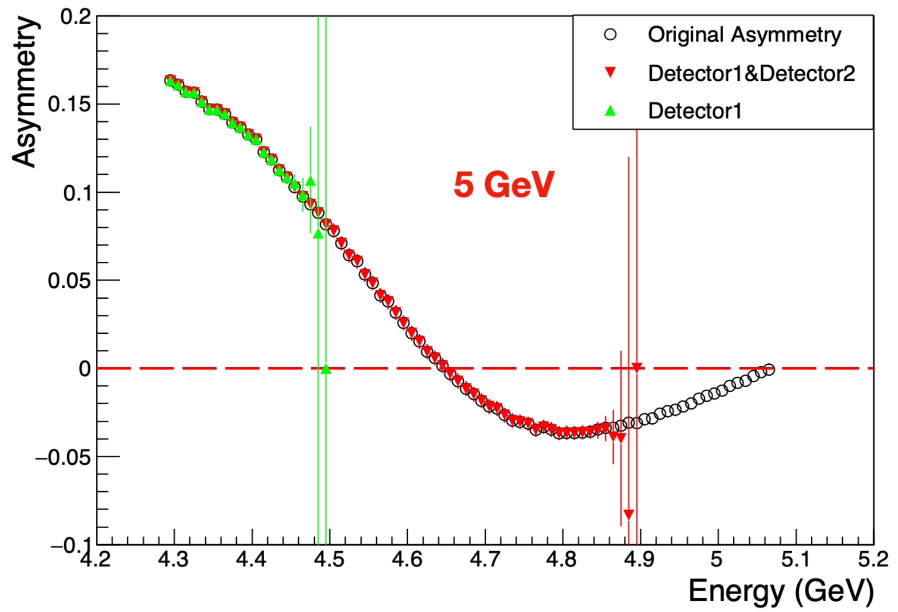


- W/SciFi calorimeter with integrated preshower detector is under consideration to meet the fast time response requirement.
- The preshower is made of two planes of lead followed by silicon sensors.
- The segmentation of the silicon sensor on the order of 100-400 μm is required.
- Operating in threshold-less integrating mode with proper background control would mitigate the issue of W/SciFi's relatively lower energy resolution.
- Comprehensive simulations of detector response and background studies are currently in progress.

Electron Detector



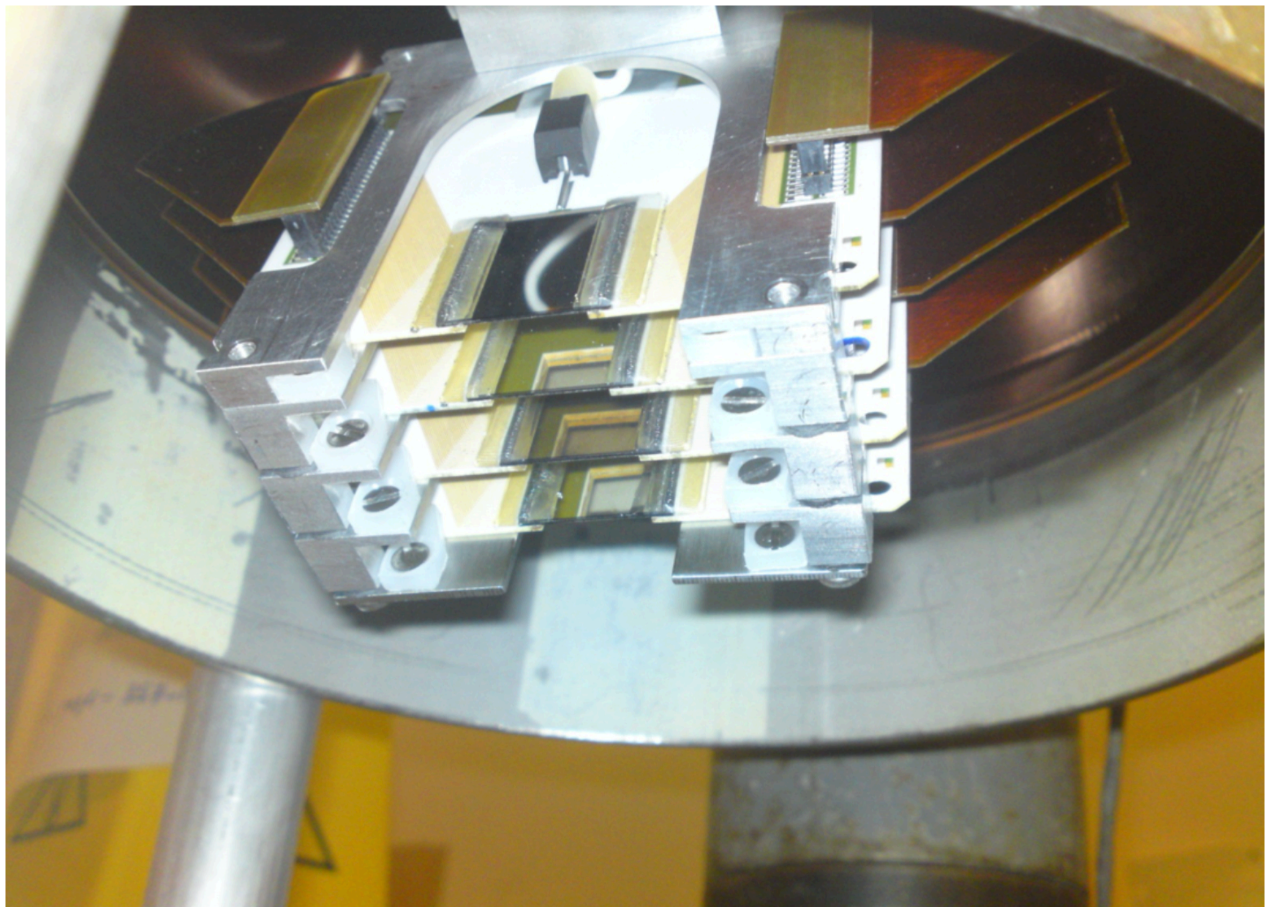




- The minimum width of Detector1 is set at 8.2 cm to account for the spread of recoil electrons from an 18 GeV beam. This width is necessary to capture the full electron spectrum, including the zero-crossing point and the endpoint.
- The segmentation of Detector1 is determined by the spectrum at 5 GeV (which has the smallest spread). To ensure sufficient resolution, we need at least 30 bins, corresponding to a strip pitch of approximately 550 μm.
- At 5 GeV, the coverage of Detector1 is insufficient to capture the zero-crossing. By integrating Detector2, we can extend the range and successfully detect the zero-crossing.
- The electron detector is limited to P_L measurements due to the significant dispersion caused by the dipole magnet.

Electron Detector

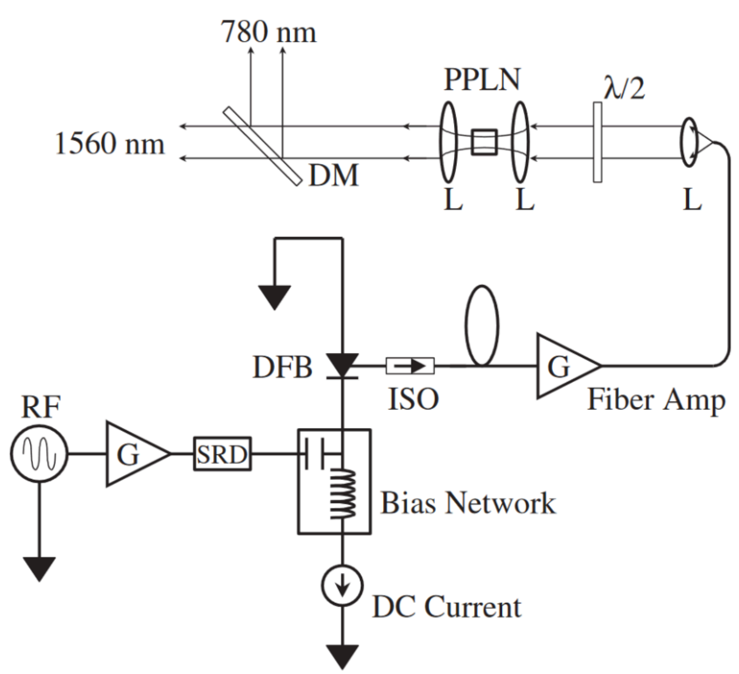
Hall C diamond detector



- Several choices feasible for position sensitive detectors.
- Diamond strip detector similar with JLab Hall C diamond detector is being considered.
  - Radiation hard.
  - Fast time response.
  - Compatible with segmentation requirements.
  - The ASIC under development (FLAT-32) for the MOLLER experiment at JLab compatible with EIC timing 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 5W average power at 532nm;

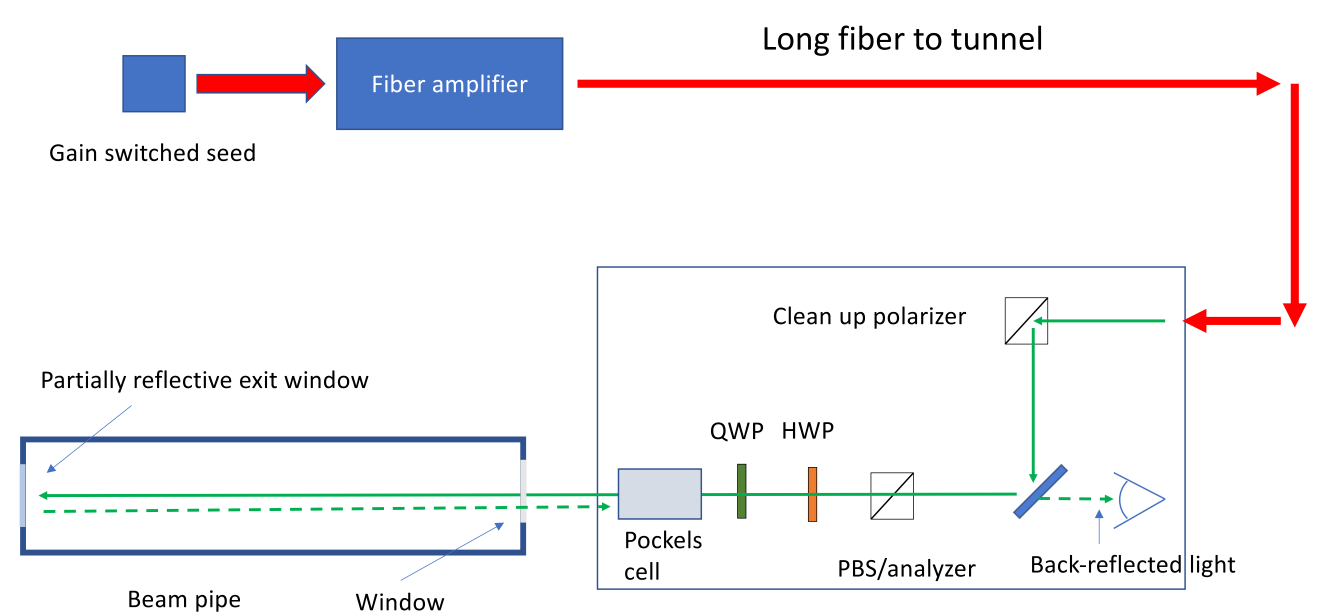


JLAB injector laser system

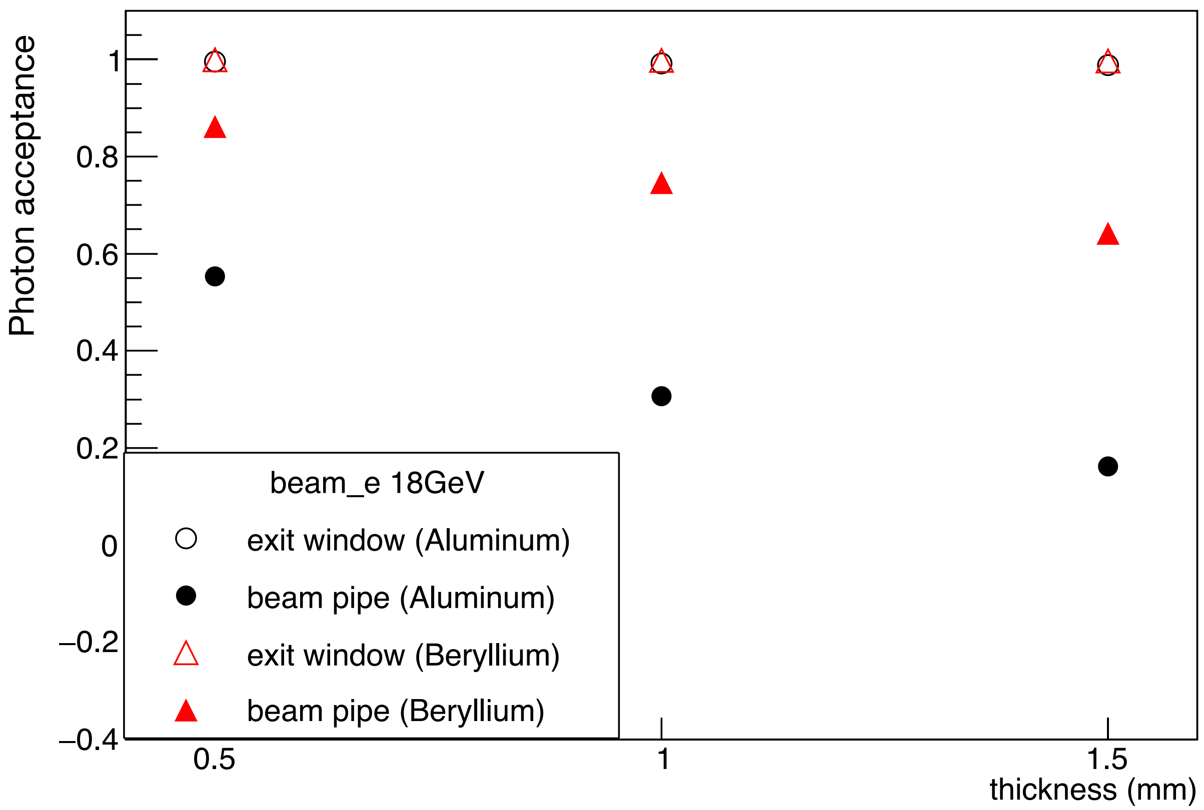
Polarization in vacuum set using "back-reflection" technique —> Required remotely insertable mirror (in vacuum)

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

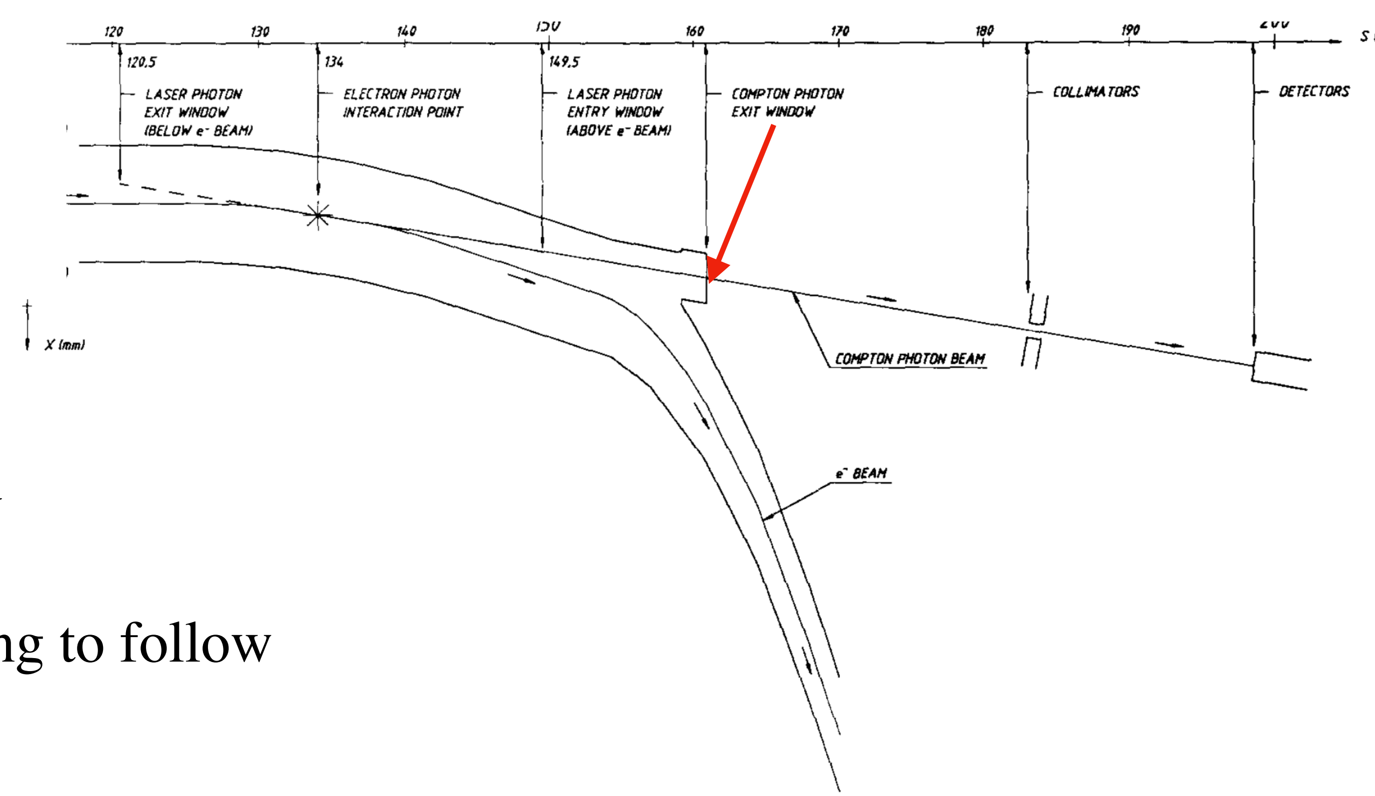
- Gain-switched diode seed laser -variable frequency, few to 10 ps pulses @ 1064 nm —> Variable frequency allows optimal use at different bunch frequencies (100 MHz vs 25 MHz)
- Fiber amplifier —> average power 10-20 W
- Optional: Frequency doubling system (LBO or PPLN)
- Insertable in-vacuum mirror for laser polarization setup



Exit Window



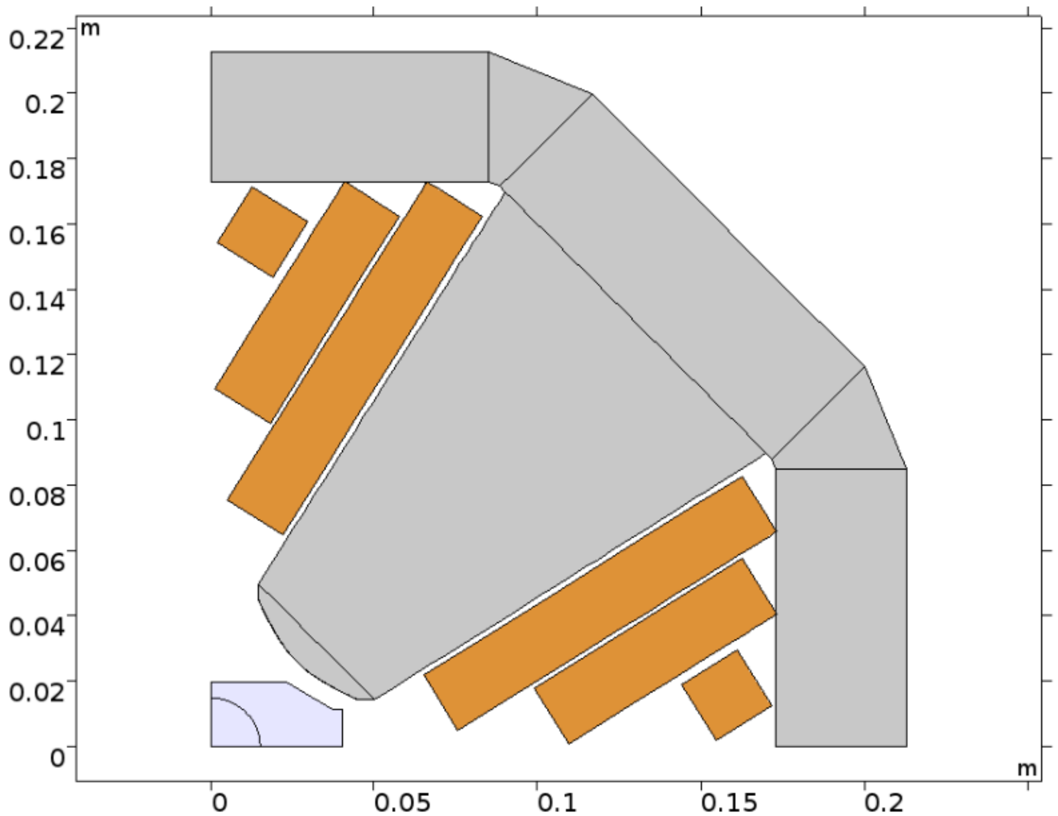
- Geant4 simulations show the acceptance for scattered photons at 18 GeV beam energy, with and without the exit window.
- The presence of the exit window significantly improves photon acceptance.
- Similar improvements are observed for electron beam energies at 10 GeV and 5 GeV.



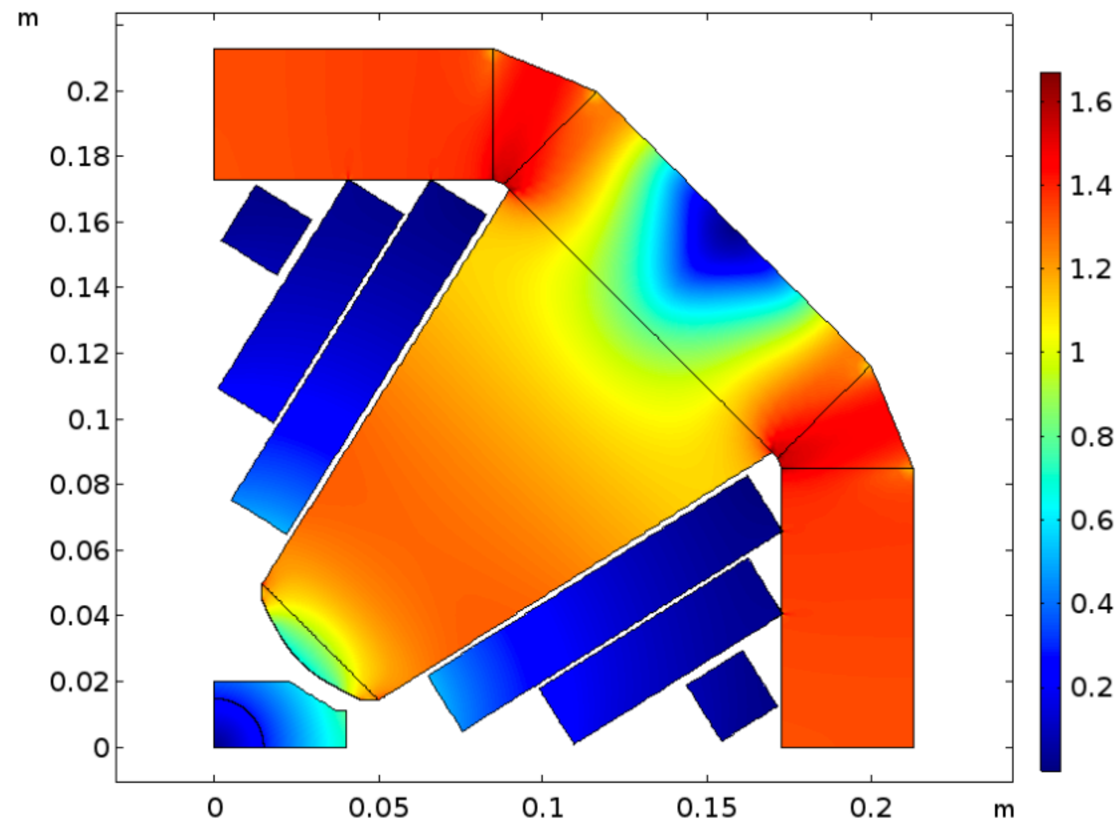
Barber, D. P., et al. "The HERA polarimeter and the first observation of electron spin polarization at HERA." *NIMA*, 329.1-2 (1993): 79-111.

- The exit window is located near QD7 and positioned perpendicular to the scattered photon trajectory.
- The exact geometry is still under development, aiming to follow the design principles used in the HERA setup.

Arc Quadrupole Design



(a) Geometry of the arc quadrupole magnet

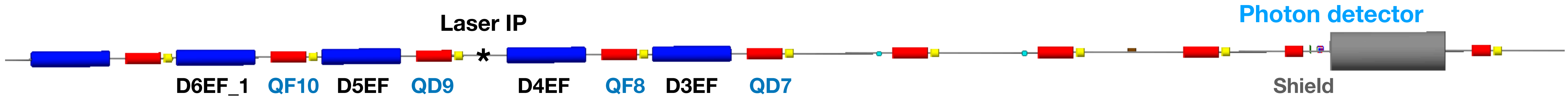


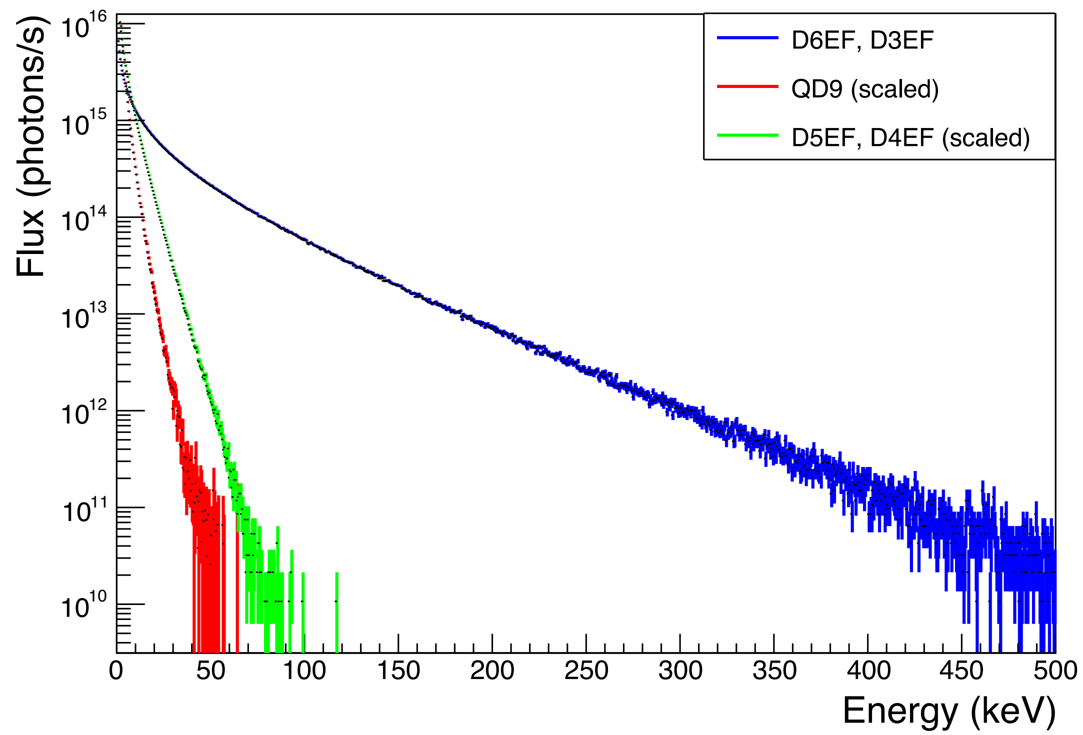
(b) Magnetization

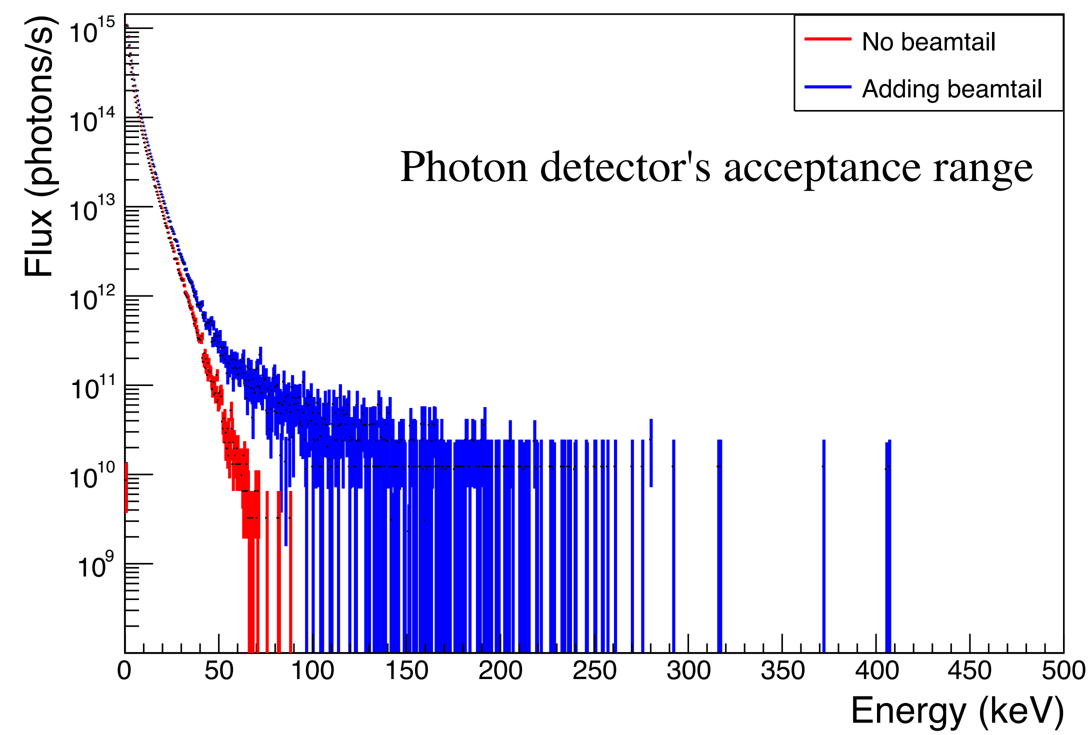
"EIC Conceptual Design Report", BNL, Up- ton, NY, USA, Rep. **EIC CDR, 2021**

- A quadrupole design is required which delivers about 18.4 T/m over a length of 0.6 m. A relatively large inscribed radius of 37 mm is necessary to clear the beam pipe.
- Open midplane or a hole in the return yoke (hole radius ~ 2cm) is required for QD6, QF5, and QD4 to allow the clearance for "photon cone".
- By carefully designing the coils, we can make the space for this requirement.

Background - Synchrotron Radiation



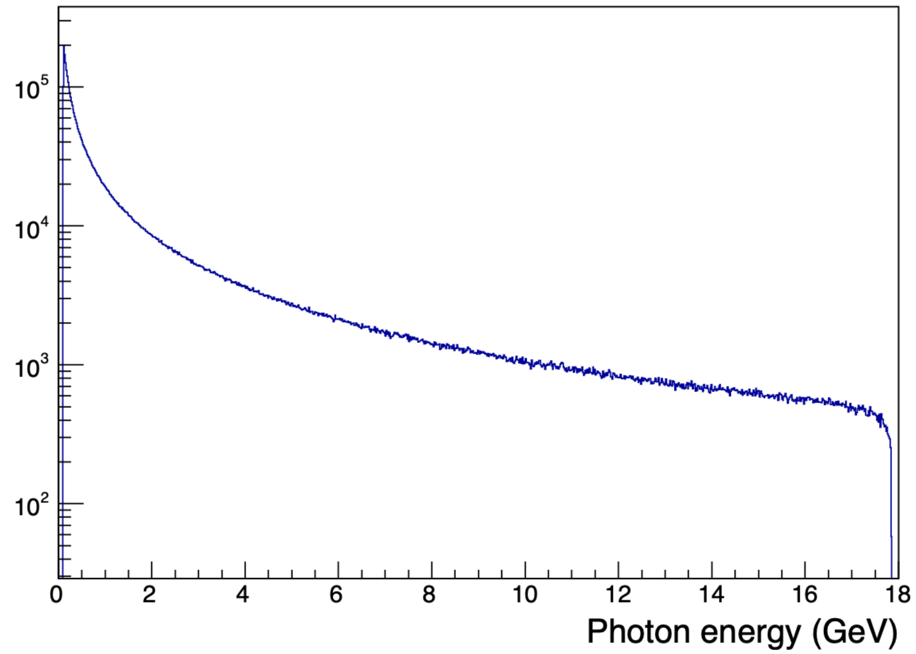


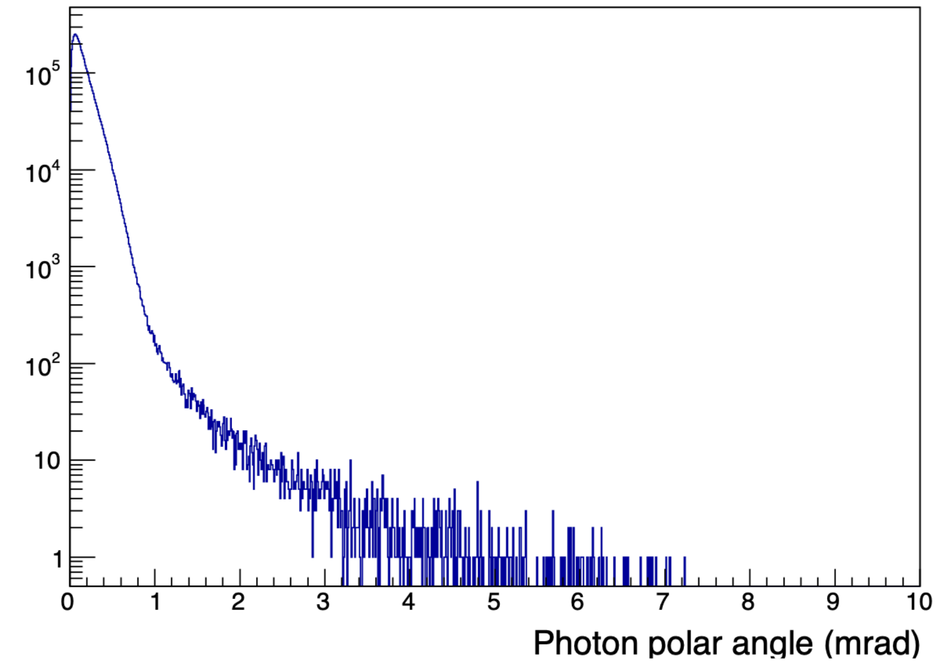


- Use Synrad+ for synchrotron radiation simulation, record photon data, and integrate it into the Geant4 electron polarimeter setup.
- A 2 cm tungsten shield is needed to block SR from strong dipoles (D6EF, D3EF), but it degrades energy resolution and makes position measurements nearly impossible.
- Adding two weak dipoles before and after the laser IP can prevent SR from strong dipoles reaching the photon detector. SR from quadrupole QD9 reliably enters the photon detector's acceptance range.
- In current beamline, a **2 mm** Be exit window and **0.5 mm** W shield can effectively block SR.
- For beam tail considerations, a **1.2 mm** W shield is needed (assuming the beam tail is 5% of the core's integral, with X sigma 4x and Y sigma 10x larger than the core).

Background - Bremsstrahlung

- We consider electron collisions with residual H_2 gas inside the beam pipe, assuming uniform gas pressure of 1.0e-08 mbar, typical around IP6. This will be updated if more specific data from the electron polarimeter region becomes available.
- By integrating the double differential cross section for Bremsstrahlung, including beam effects, Bremsstrahlung events were generated along the 40-meter beamline, focusing around the laser IP. The total cross section for photons with $E_\gamma > 0.1$ GeV is 185.723 mb.
- Photon energies range from 0.1 GeV up to the beam energy, with Bremsstrahlung photons primarily in the forward direction.
- Scattered electrons are deflected by the magnet, allowing only Bremsstrahlung photons to reach the photon detector.
- The main photon source is concentrated around the laser IP, between 3752 and 3764 meters along the beamline.
- The photon detector registers about 1.76e5 GeV of energy per second from Bremsstrahlung. With 2.29e7 bunches per second, the energy deposited from Bremsstrahlung per bunch is approximately **0.0077 GeV**. Given that Compton events deposit around **3.4 GeV** per bunch, the Bremsstrahlung contribution is negligible by comparison.





RCS Compton Polarimeter

RCS properties

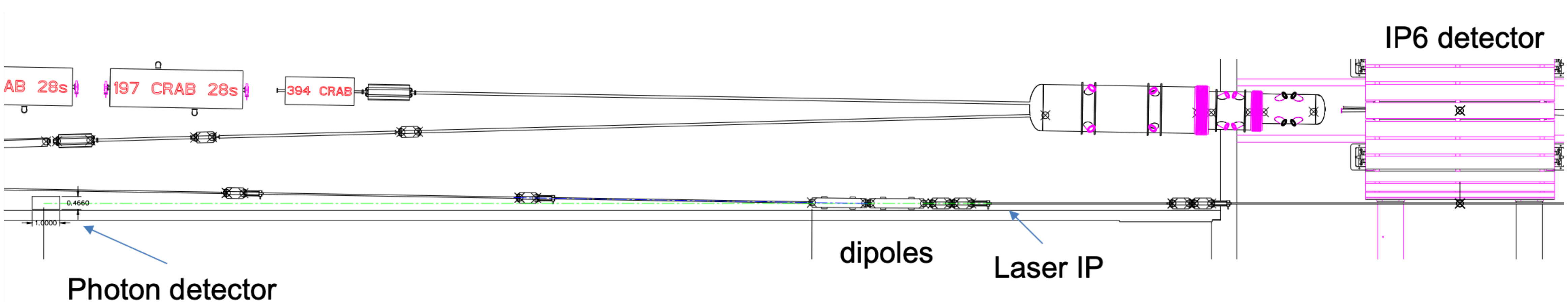
- RCS accelerates electron bunches from 0.4 GeV to full beam energy (5-18 GeV)
- Bunch frequency —> 2 Hz
- Bunch charge —> up to 28 nA
- Ramping time = 100 ms

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)



Summary

- A Compton Polarimeter is placed at IR6 in in the Electron Storage Ring (ESR) to measure both longitudinal and transverse electron polarization.
- The Compton laser system is currently under development.
- Ongoing studies focus on the detailed design of the beam pipe for exit window and electron detectors.
- Comprehensive simulations of detector response and background studies are crucial for accurate measurements.
- Development of a Compton Polarimeter for the Rapid Cycling Synchrotron (RCS) is in progress.
- Further work is needed to ensure the success of electron polarimetry at the Electron-Ion Collider (EIC).

Thanks.