Electron Polarimetry at the EIC

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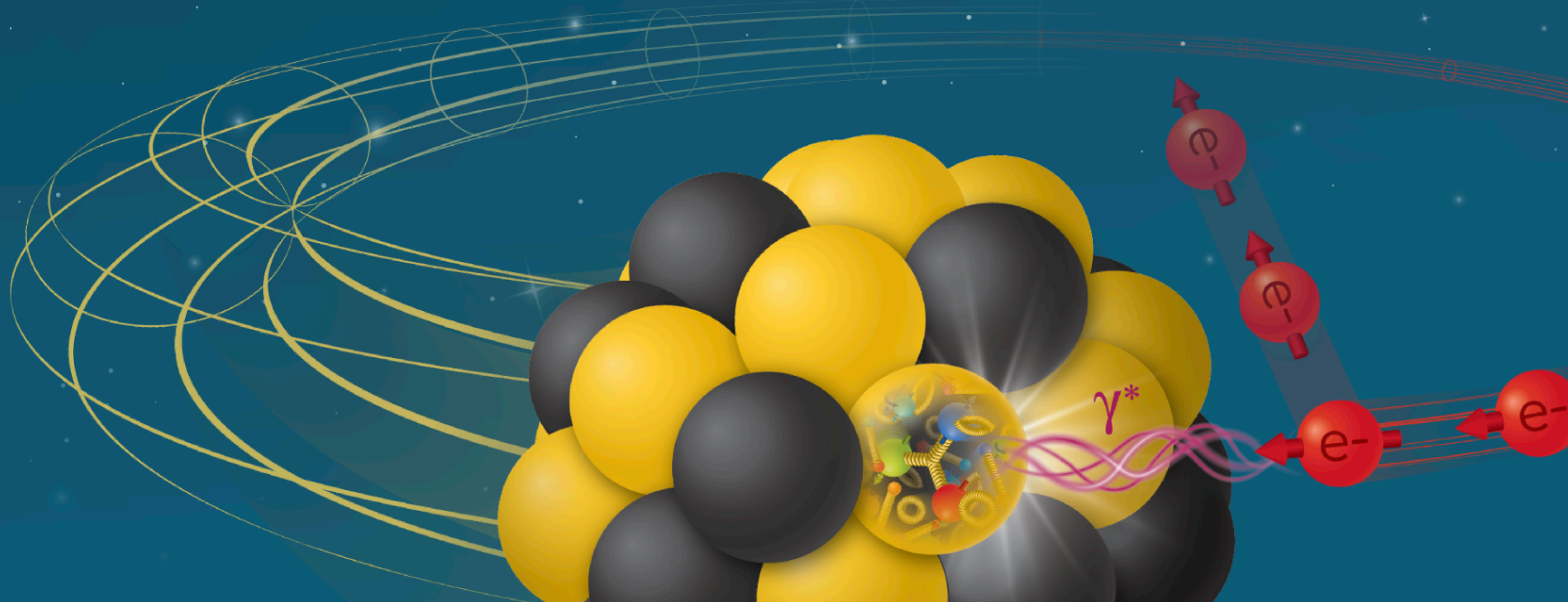
September 1, 2026

The 21st International Workshop on Polarized Sources, Targets, and Polarimetry (PSTP2026)

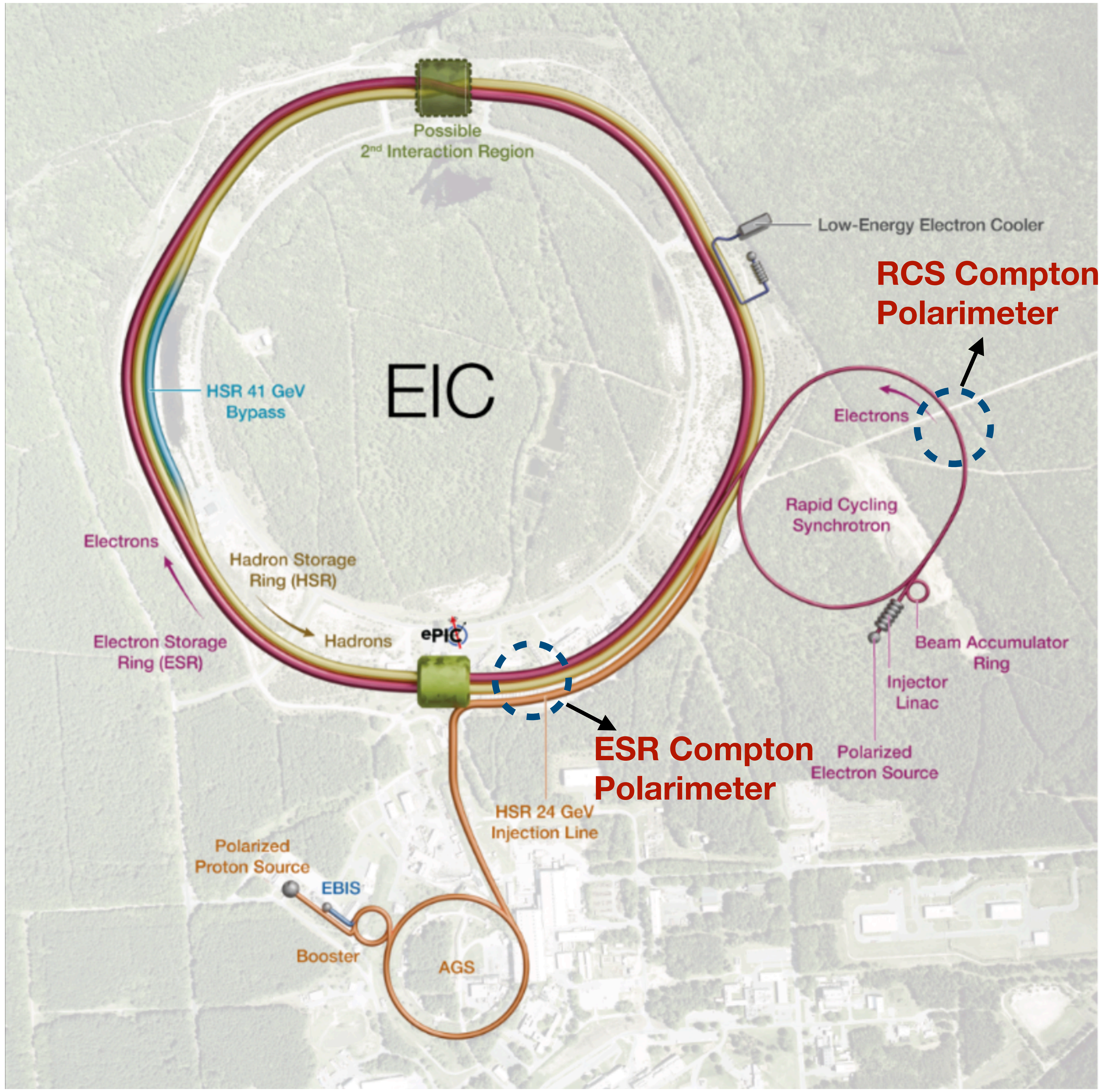
Electron-Ion Collider



Outline

- Beamline Design of the Compton Polarimeter
- Photon and electron detectors
- Exit Window
- Arc Quadrupole Design
- Background - Synchrotron Radiation and Bremsstrahlung
- Summary

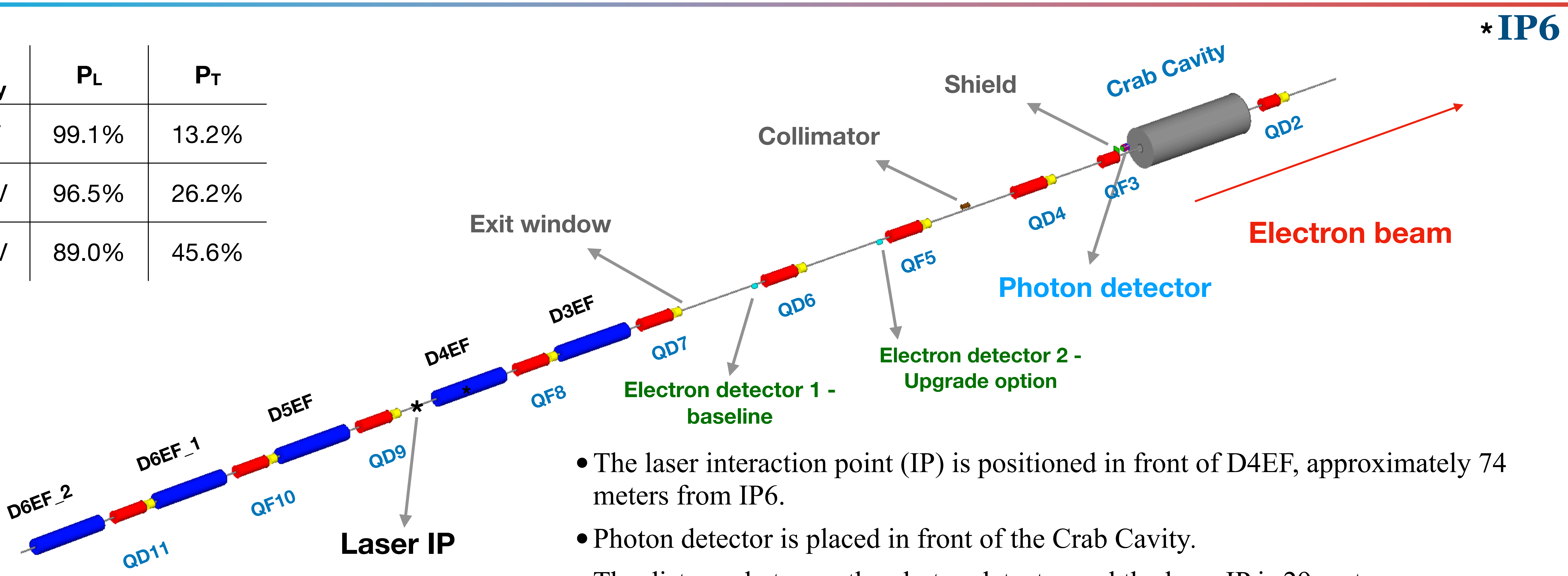
Electron Polarimeters



- **ESR Compton polarimeter on the forward side of IR6**
  - Provides non-destructive, high-precision absolute polarization measurement for experiments
  - Measures both longitudinal and transverse polarization components
  - Enables bunch-by-bunch polarization measurement with target precision **$\Delta P/P < 1\%$**
  - Detects both scattered leptons and backscattered photons
- **RCS Compton polarimeter**
  - Measures electron polarization averaged over several bunches before injection to ESR
  - Challenging due to **100 ms ramp, 400 MeV → 5 GeV or 9 GeV, 1 Hz repetition, 28 nC/bunch**
  - Measures only backscattered Compton photons
- **Main components**
  - Laser system
  - Electromagnetic calorimeter
  - Position-sensitive detectors
  - Readout electronics and DAQ
  - Lepton and laser beam position control systems

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%

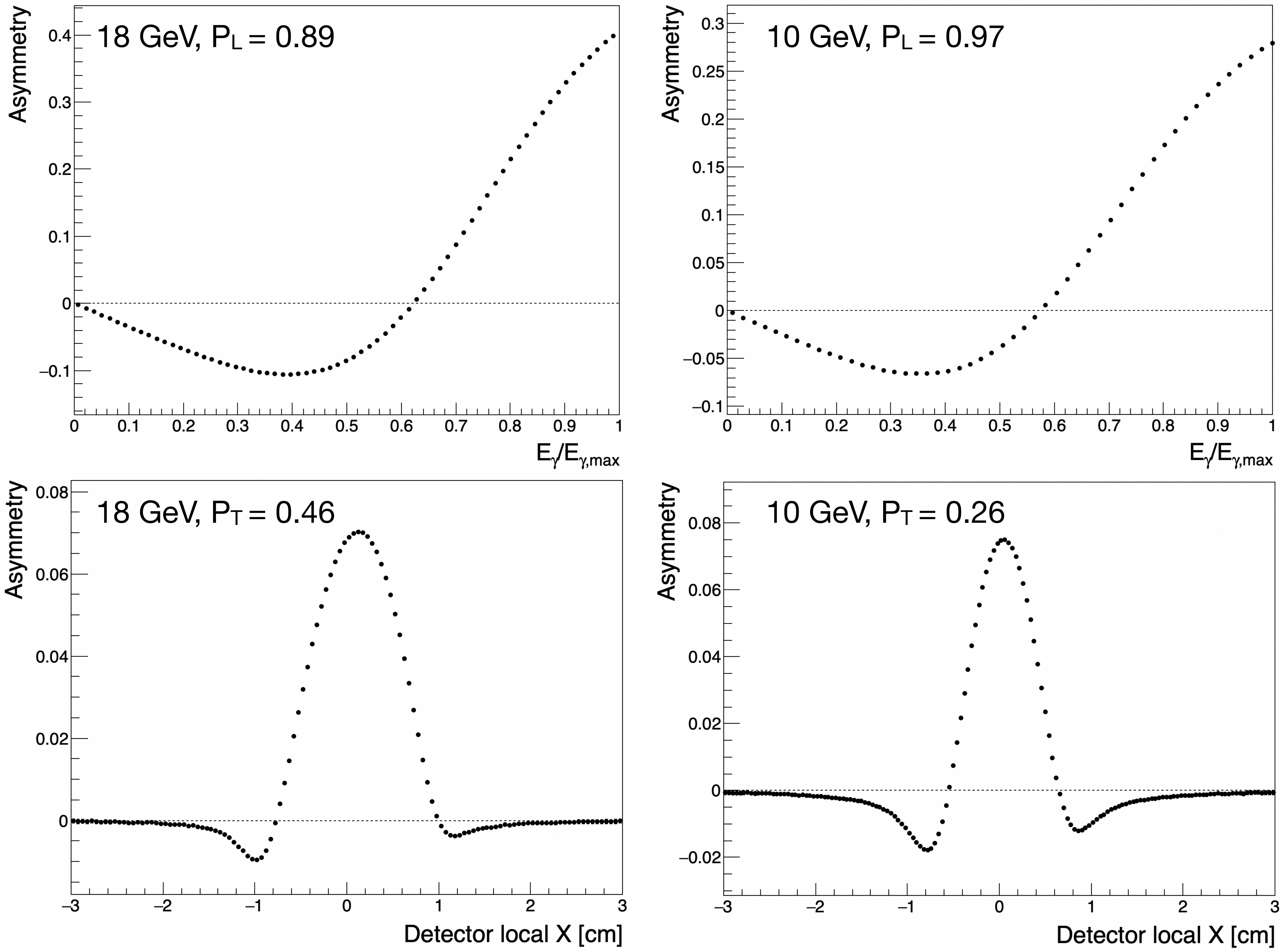


	bending angle	length
D6EF	11.9 mrad	2.73 meters
D5EF, D4EF	1.5 mrad	2.73 meters
D3EF	13.0 mrad	2.73 meters

- The laser interaction point (IP) is positioned in front of D4EF, approximately 74 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.
- The electron detector is located 0.5 m upstream of QD6, with a potential second detector upstream of QF5 in a future upgrade.
- 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.

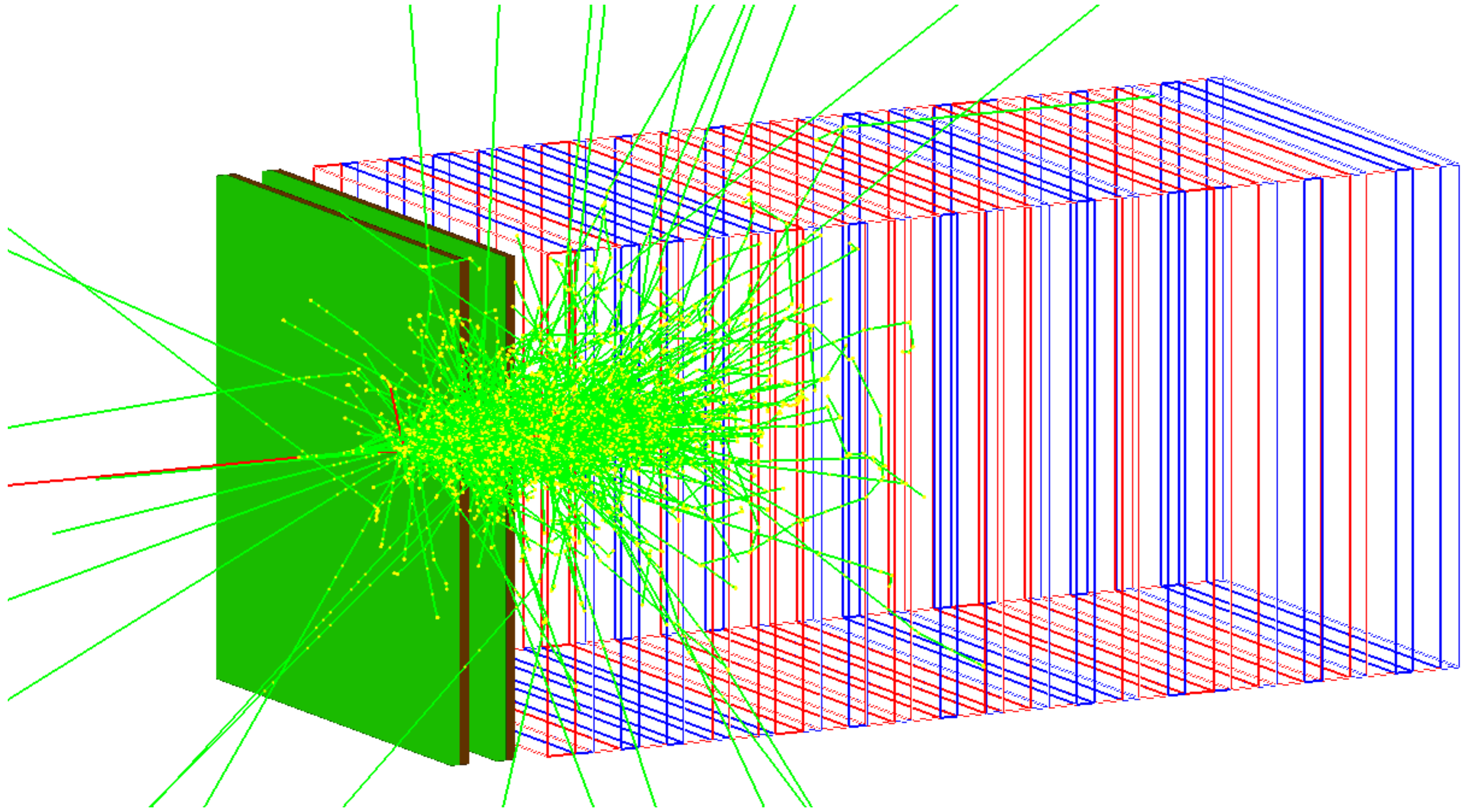
Photon Detector

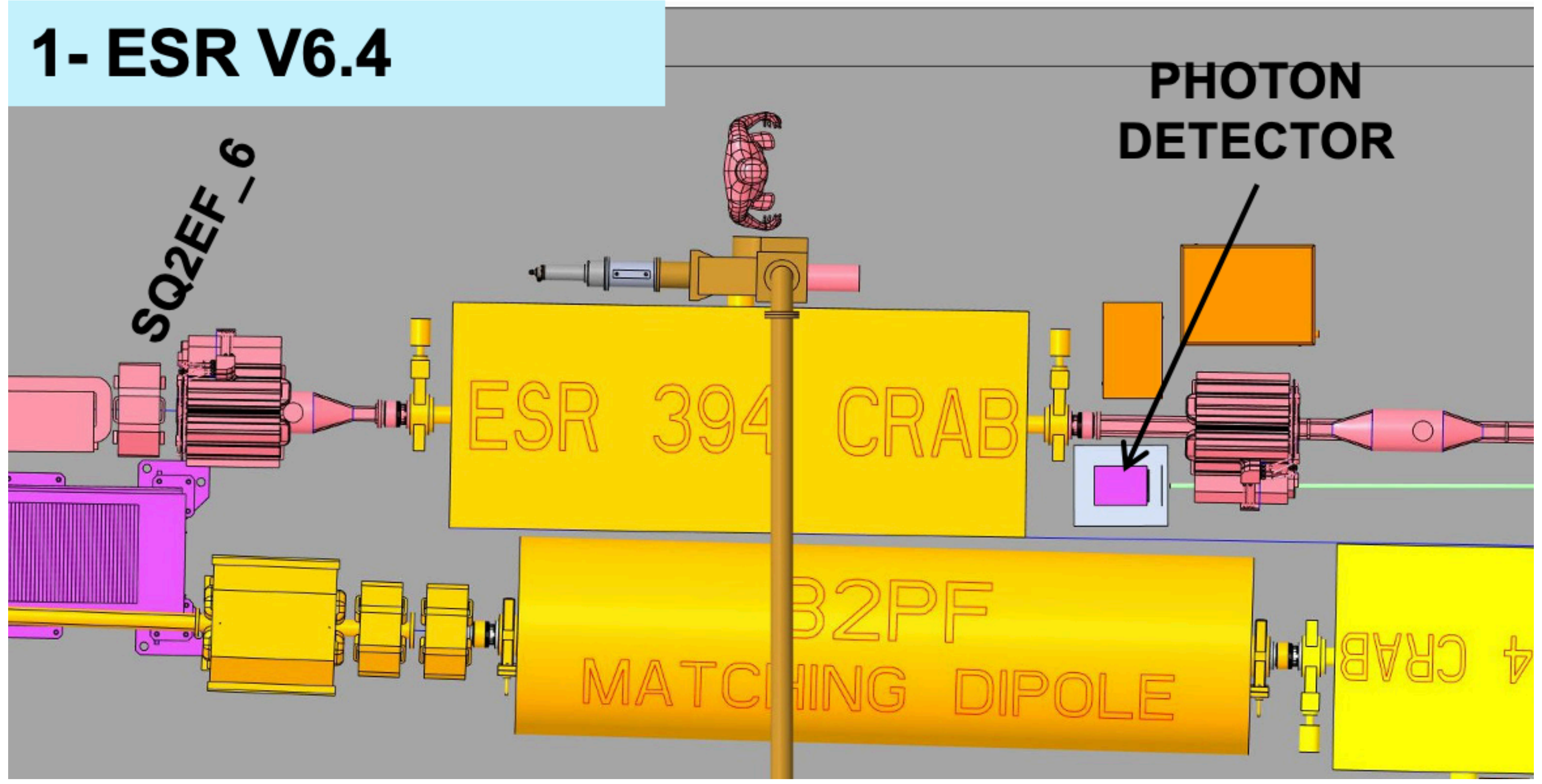
- Photon detector needs 2 components to measure both longitudinal and transverse polarization;
  - Calorimeter —> photon energy asymmetry (P_L)
  - Position sensitive detector —>left-right asymmetry (P_T)
- Longitudinal measurement requires good energy resolution from ~0 (as low as possible) to 7 GeV.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



Photon Detector

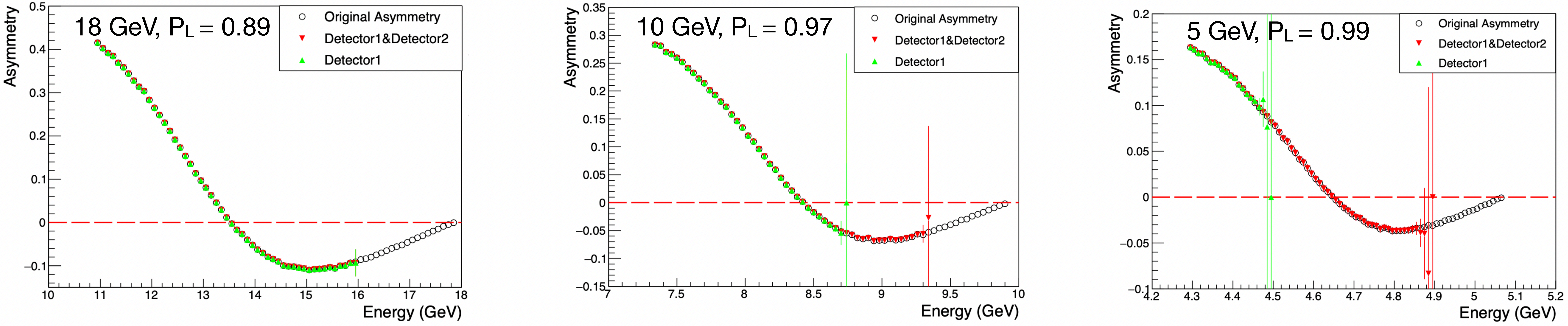
W/SciFi Calorimeter with Preshower detector





- W/SciFi calorimeter with integrated preshower detector is under consideration to meet the fast time response requirement, calorimeter will sit on moveable table to allow alignment relative to backscattered photon cone.
- The preshower is made of two planes of lead followed by diamond sensor.
- 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.

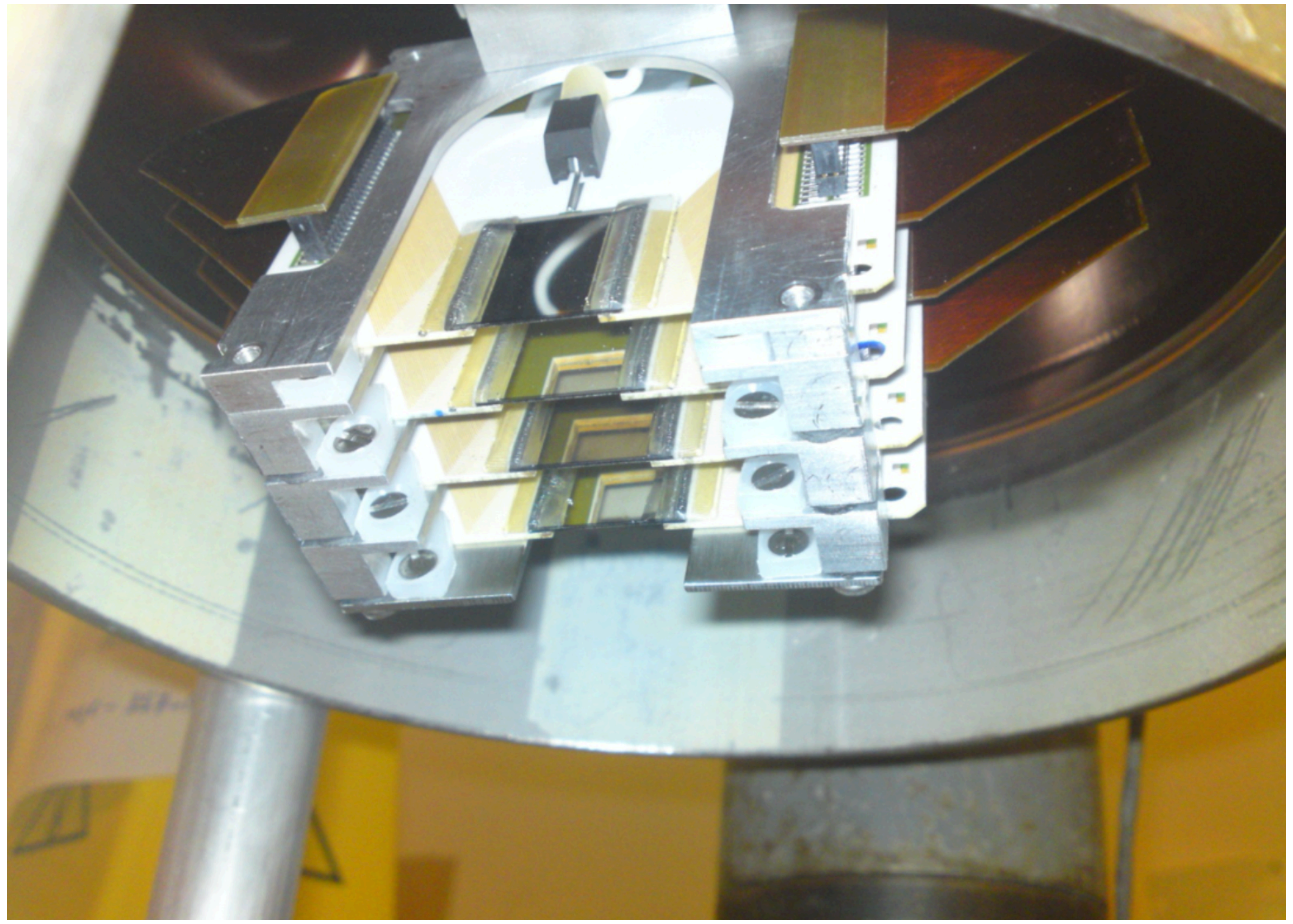
Electron Detector



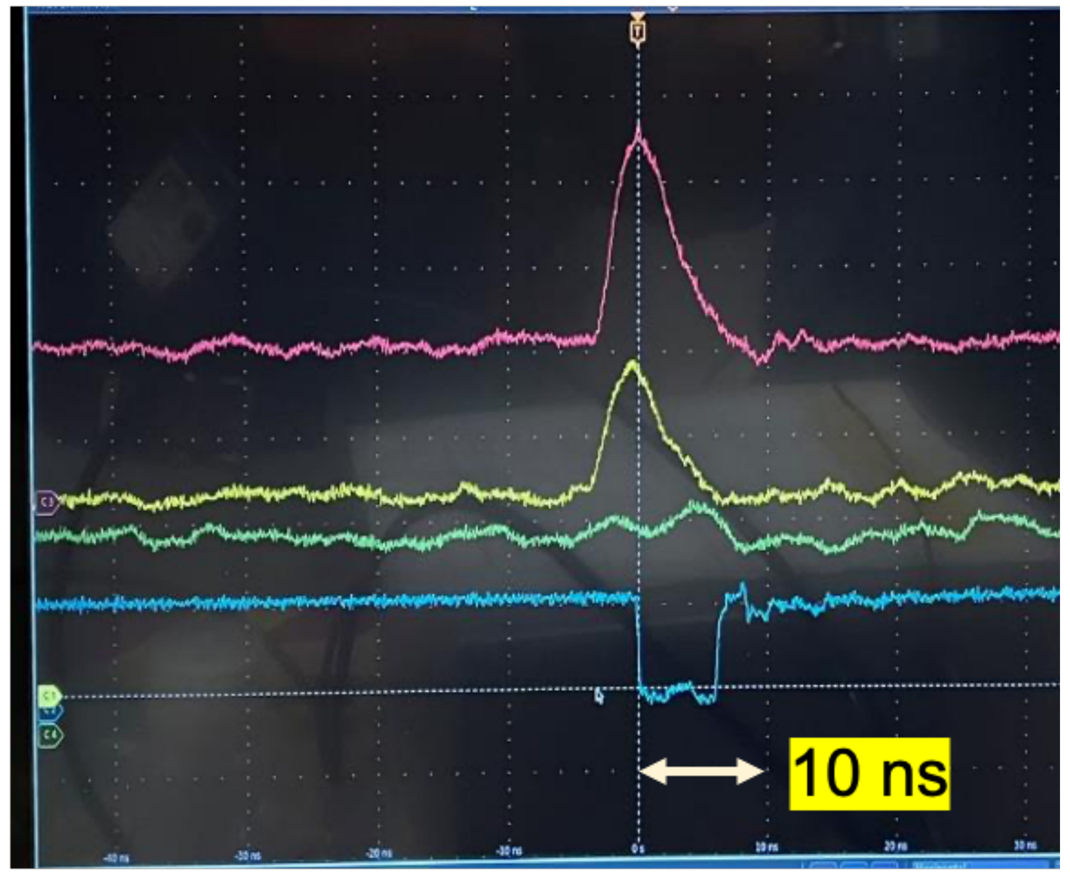
- The minimum width of Detector1 is set at 8.2 cm to account for the spread of recoil electrons from an 18 GeV beam. This width is necessary to capture the full electron spectrum, including the zero-crossing point and the endpoint.
- The segmentation of Detector1 is determined by the spectrum at 5 GeV (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

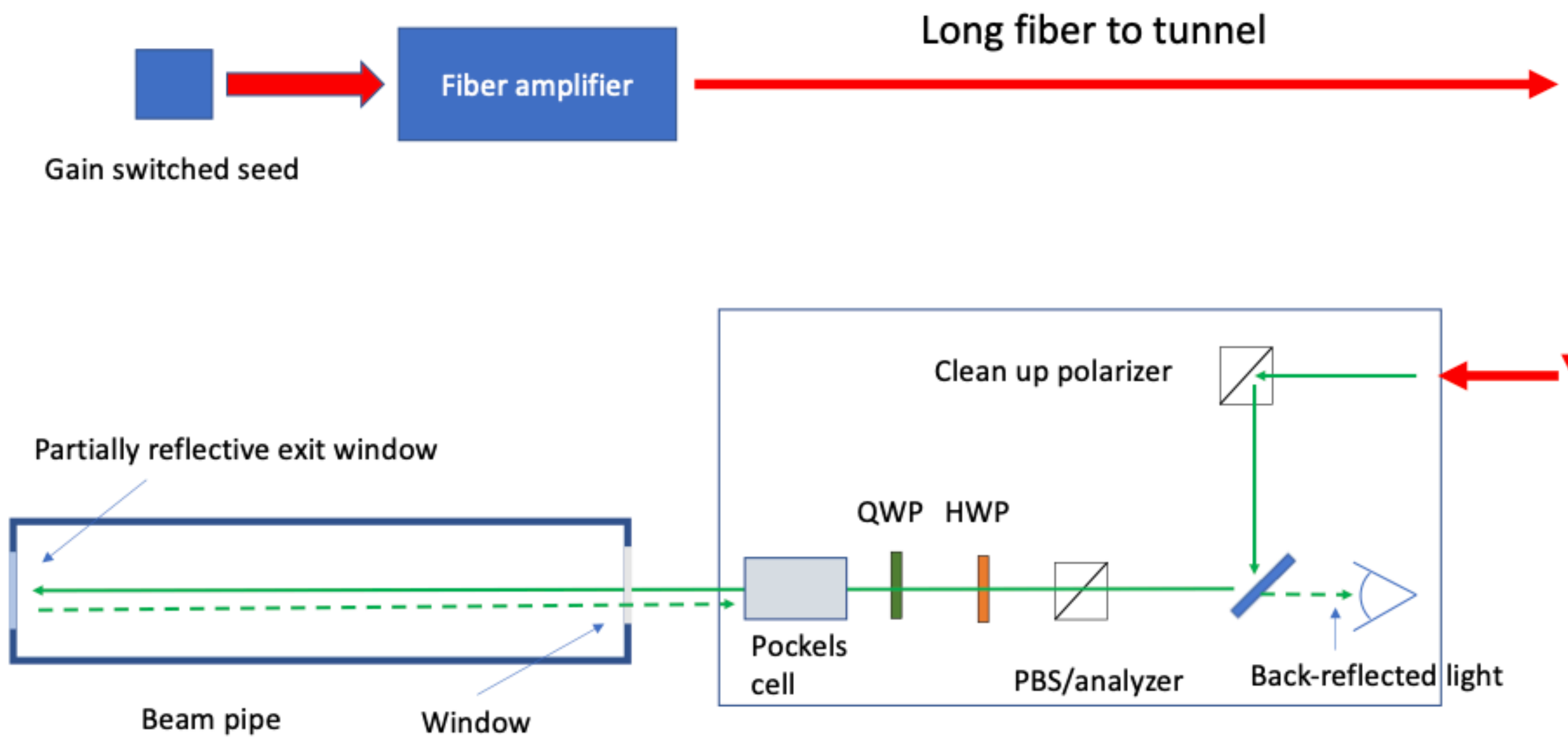


- Technology choice – diamond strips → radiation hard, good time response
- Diamond used during Q-Weak expt at JLab → no performance degradation after 10 MRad of exposure
- Compatible with segmentation requirements.
- Custom ASIC required → new “FLAT32” chip based on “CALYPSO” (used at LHC) developed for JLab/MOLLER. Already meets timing requirements of EIC (10 ns).



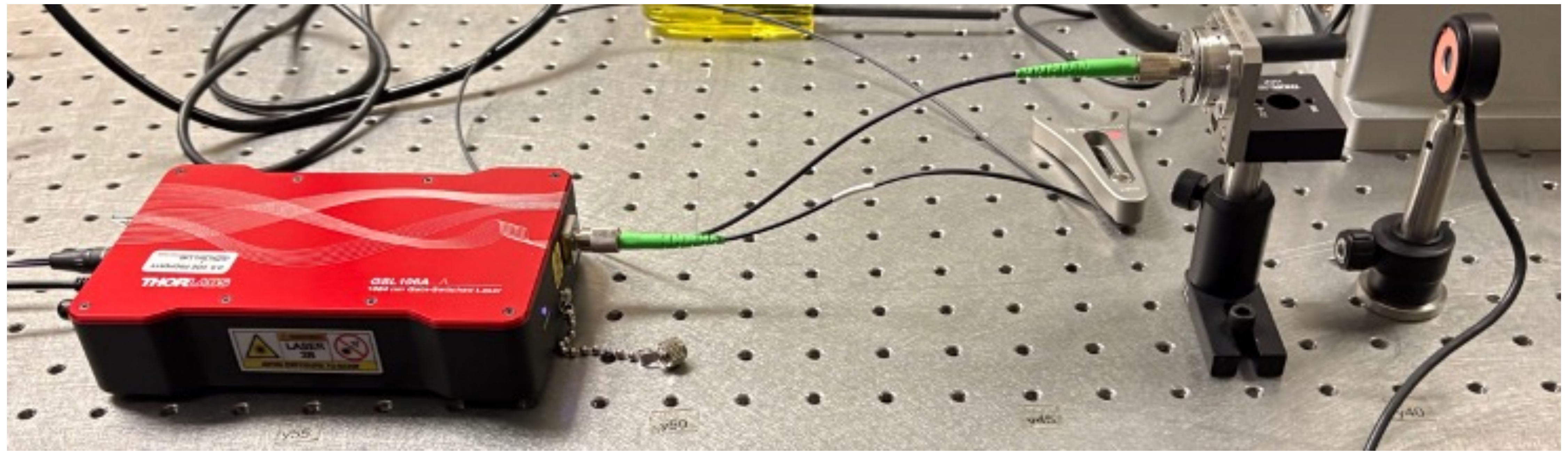
Compton Laser System

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;



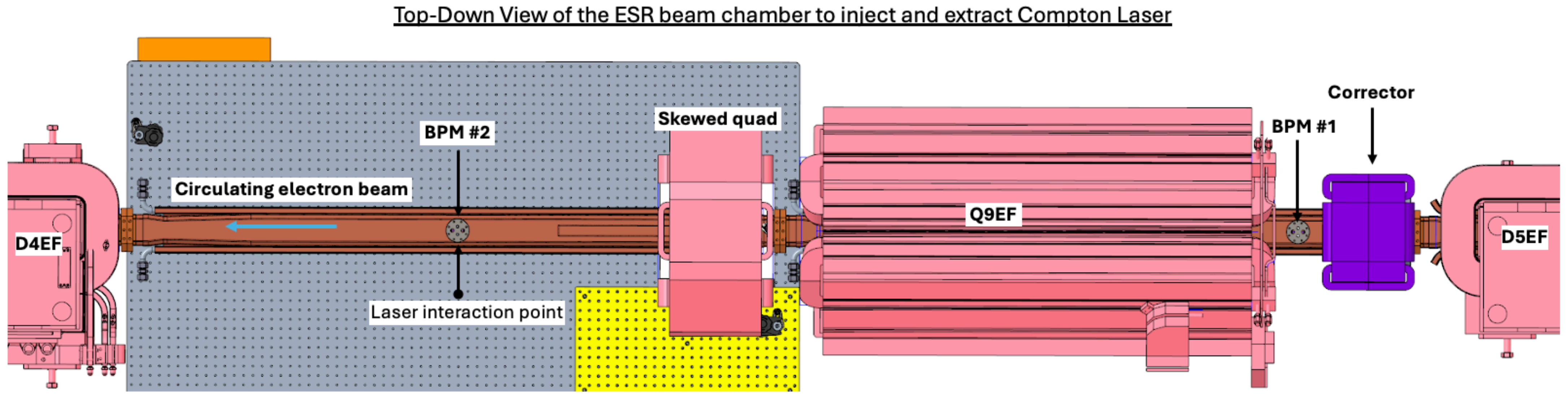
Laser system

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

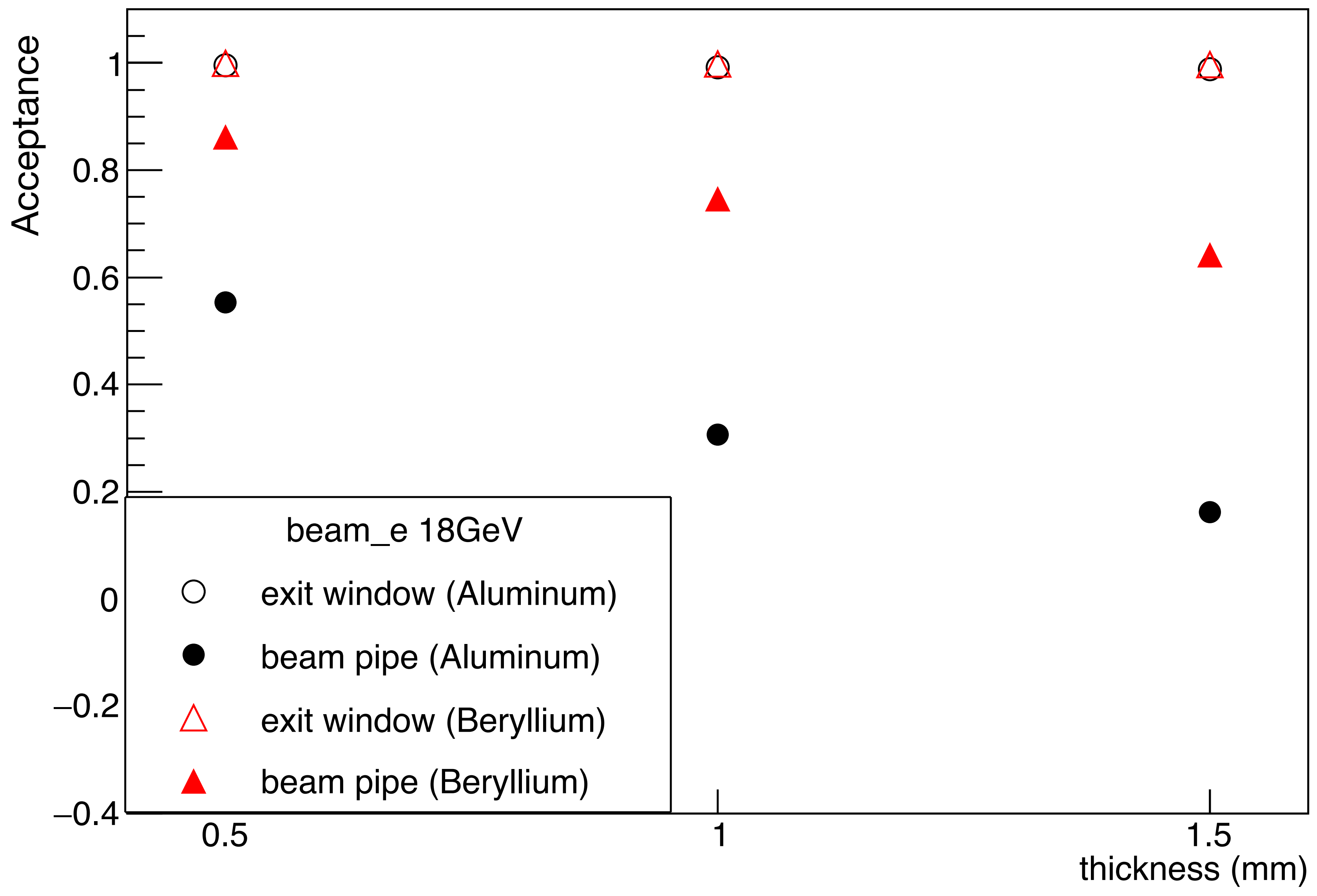


The laser system is currently under development at JLab, based on similar systems used in the JLab injector and LERF

- Gain-switched diode seed laser -variable frequency, few to 30 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

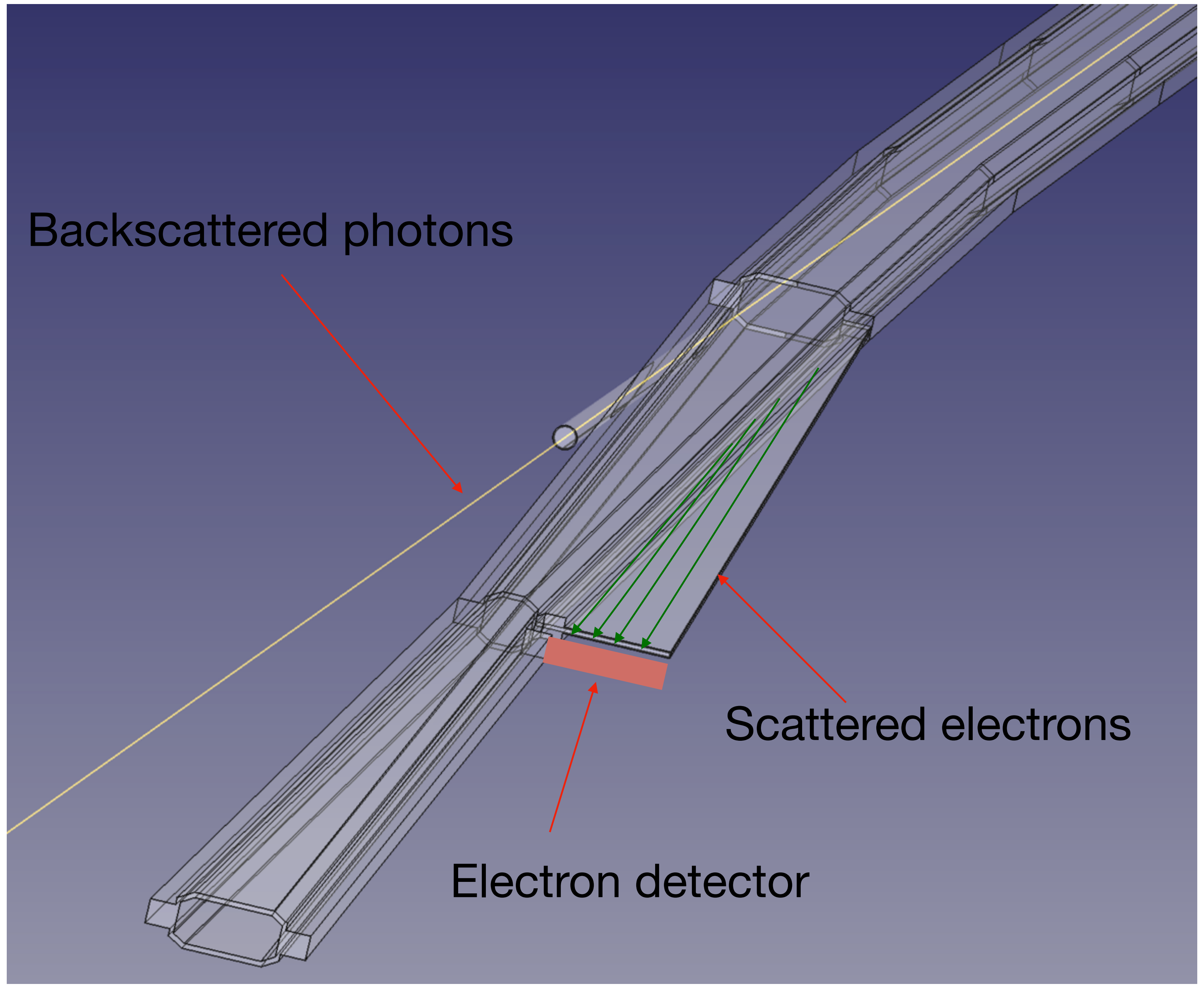


Exit Window

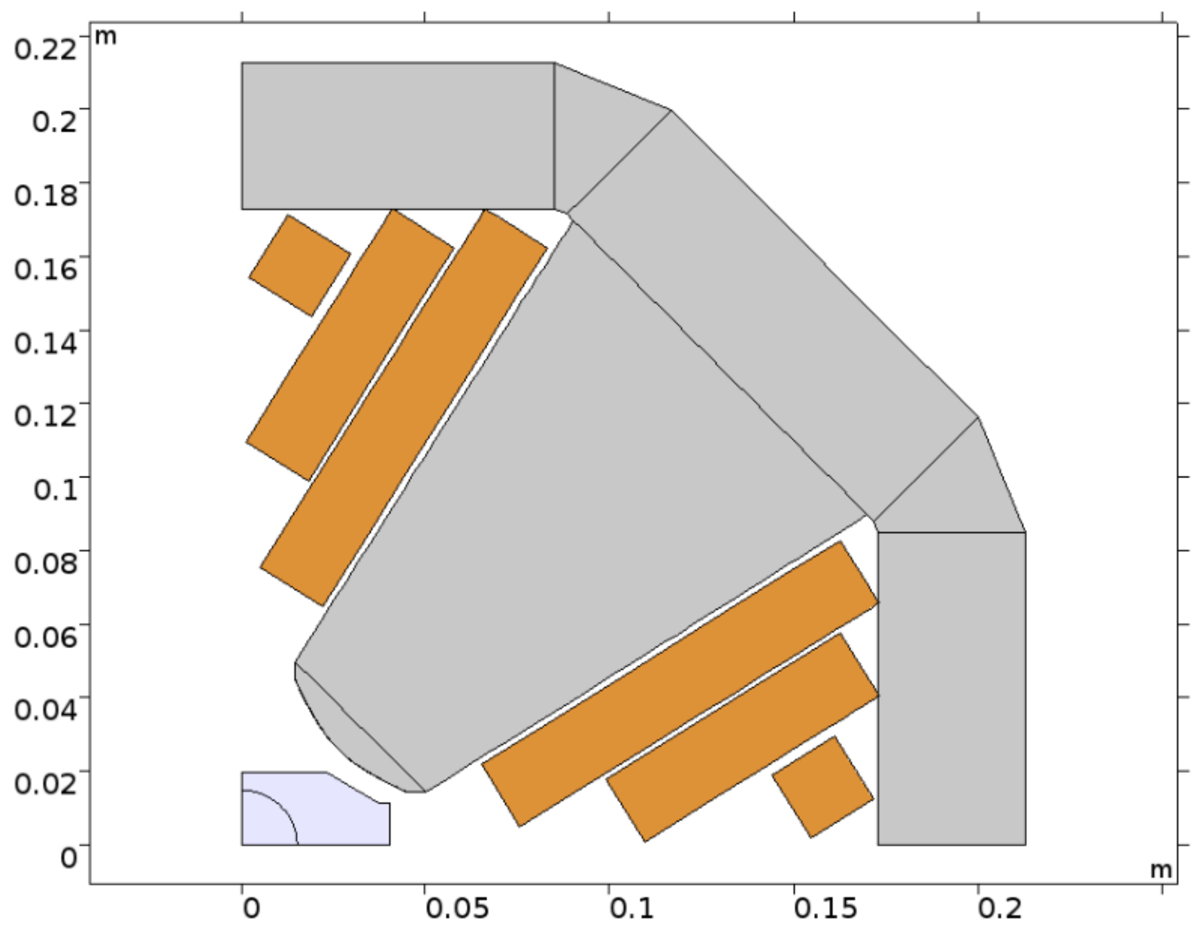


- The exit window is located near QD7 and positioned perpendicular to the scattered photon trajectory.
- The exact geometry is still under development, aiming to follow the design principles used in the HERA setup.

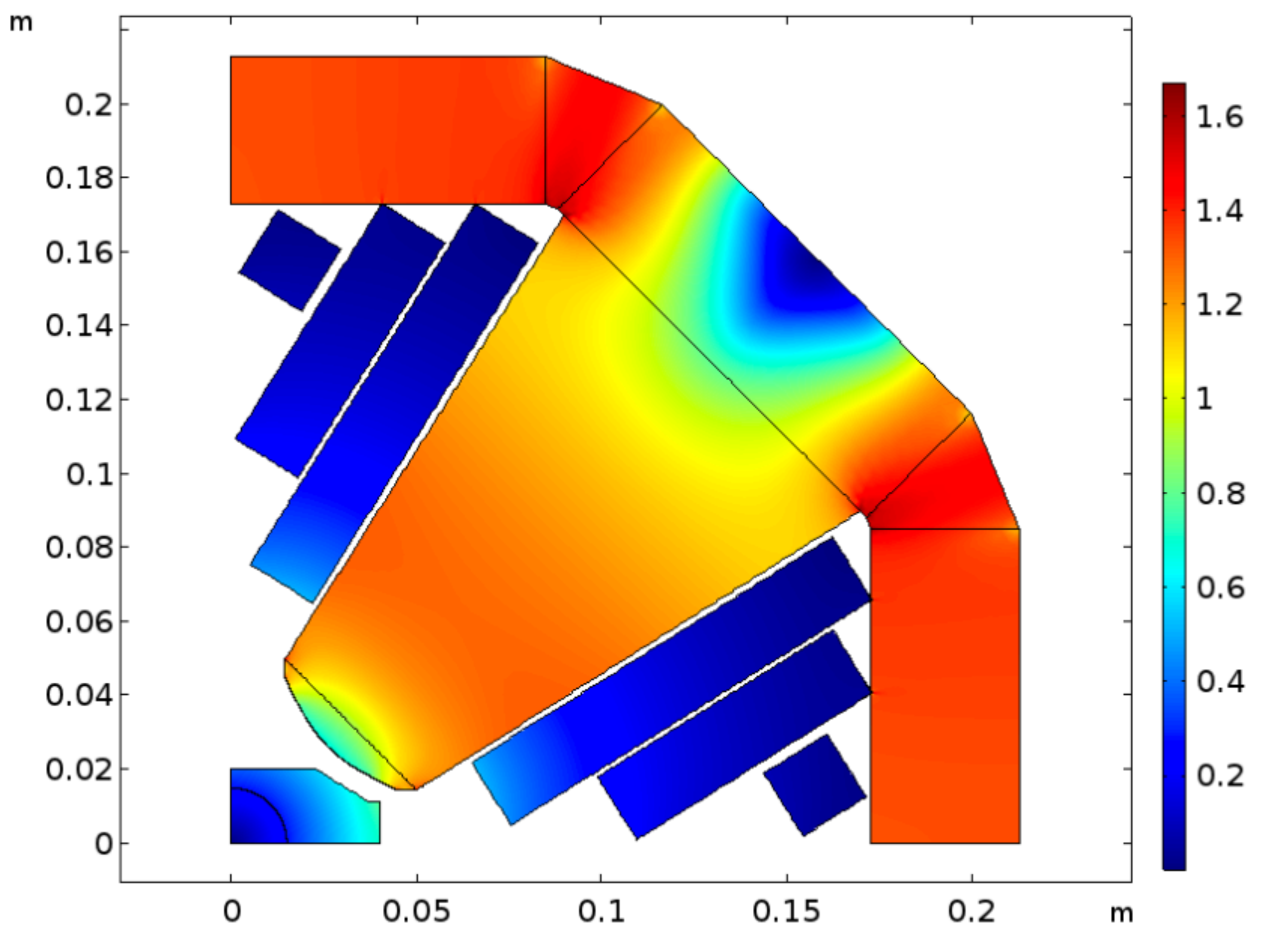
- Geant4 simulations show the acceptance for scattered photons at 18 GeV beam energy, with and without the exit window.
- The presence of the exit window significantly improves photon acceptance.
- Similar improvements are observed for electron beam energies at 10 GeV and 5 GeV.



Arc Quadrupole Design

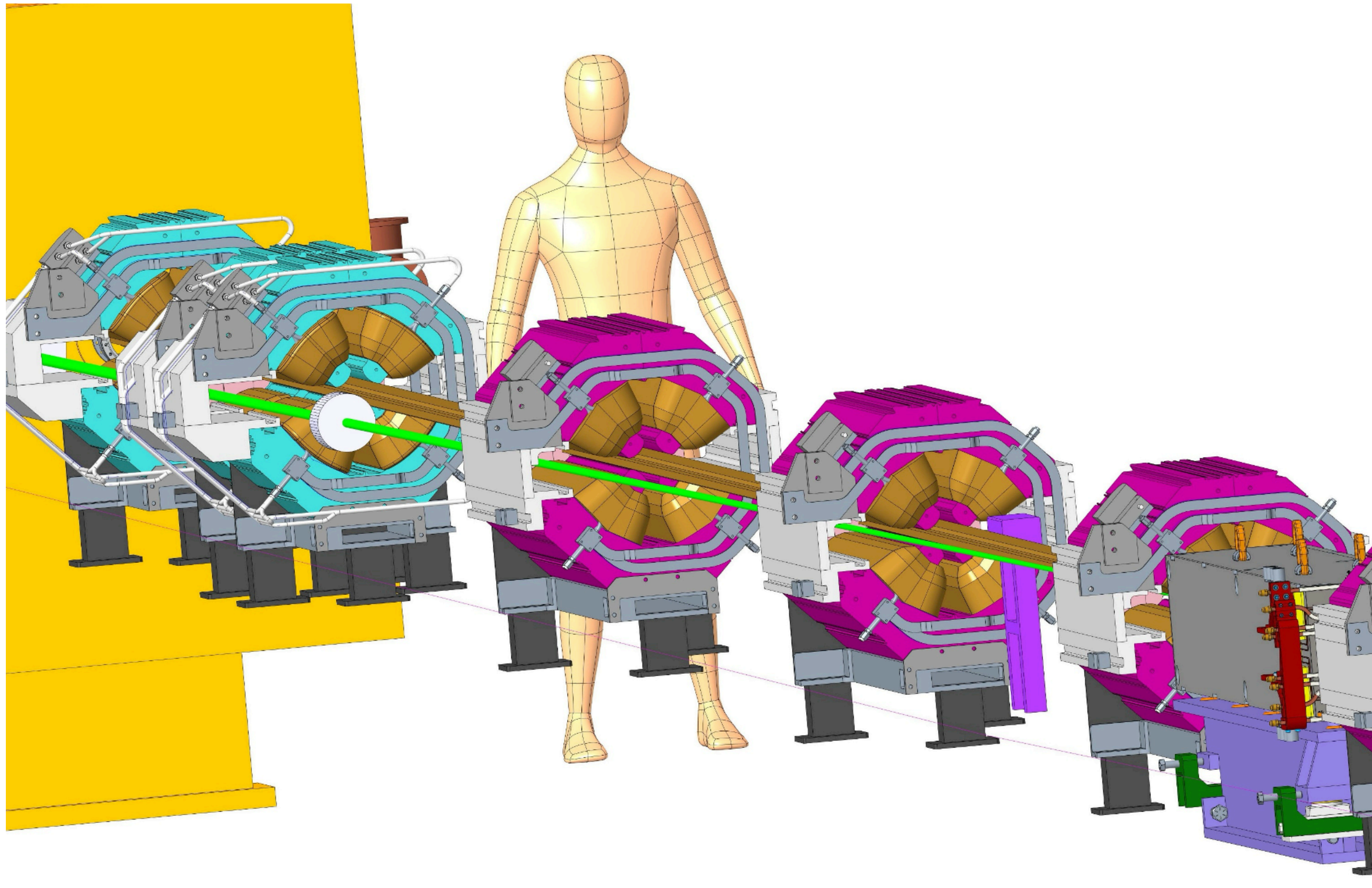


(a) Geometry of the arc quadrupole magnet



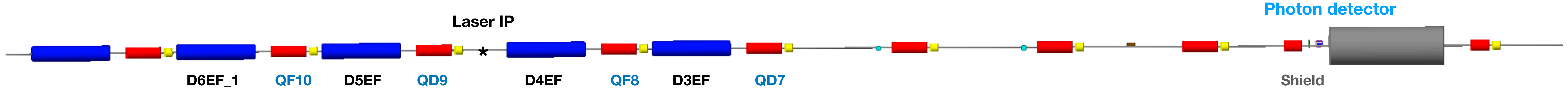
(b) Magnetization

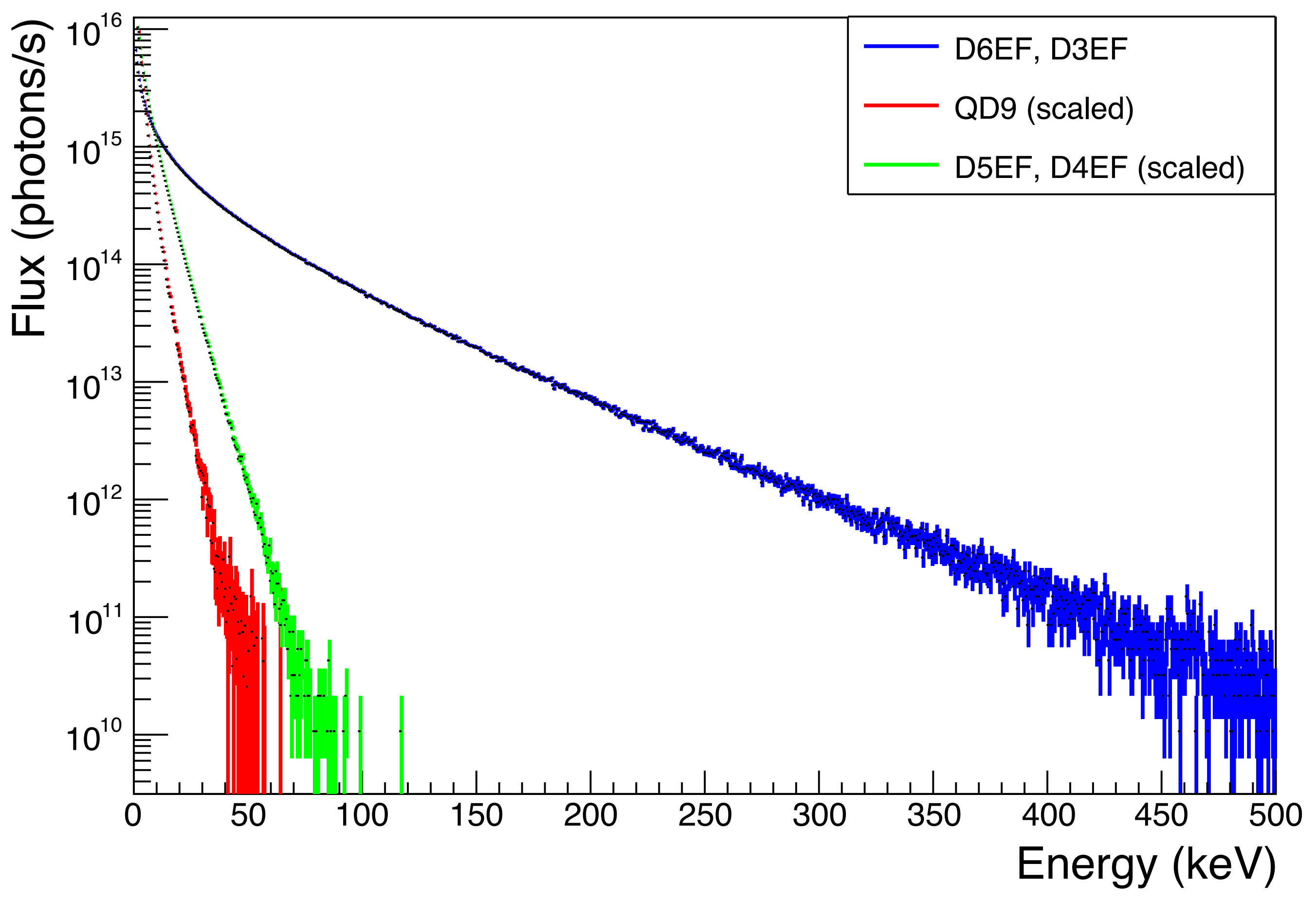
“EIC Conceptual Design Report”, BNL, Up- ton, NY, USA, Rep. **EIC CDR, 2021**

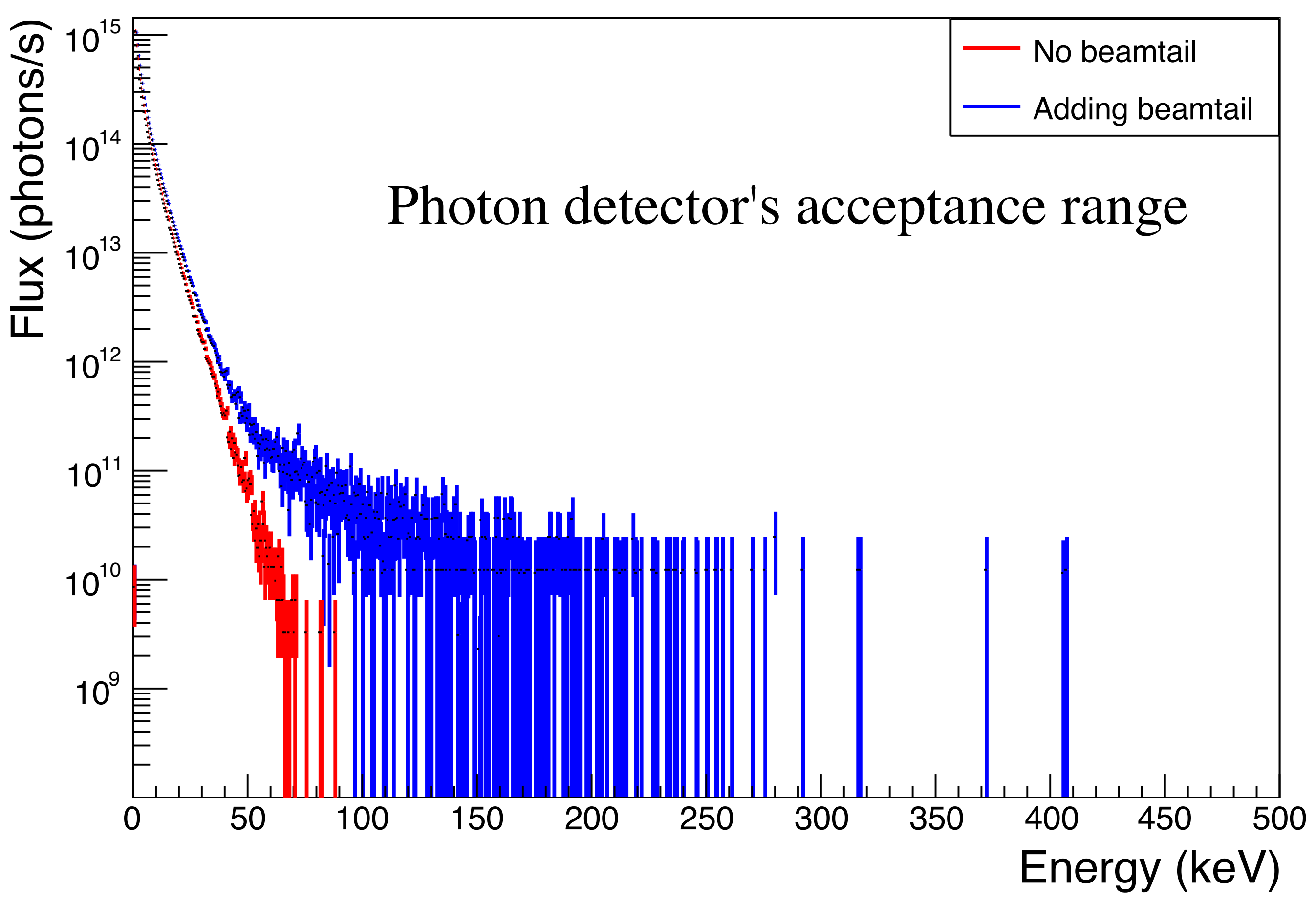


- A quadrupole design is required which delivers about 18.4 T/m over a length of 0.6 m. A relatively large inscribed radius of 37 mm is necessary to clear the beam pipe.
- Open midplane or a hole in the return yoke (hole radius ~ 2cm) is required for QD6, QF5, and QD4 to allow the clearance for “photon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

Background - Synchrotron Radiation



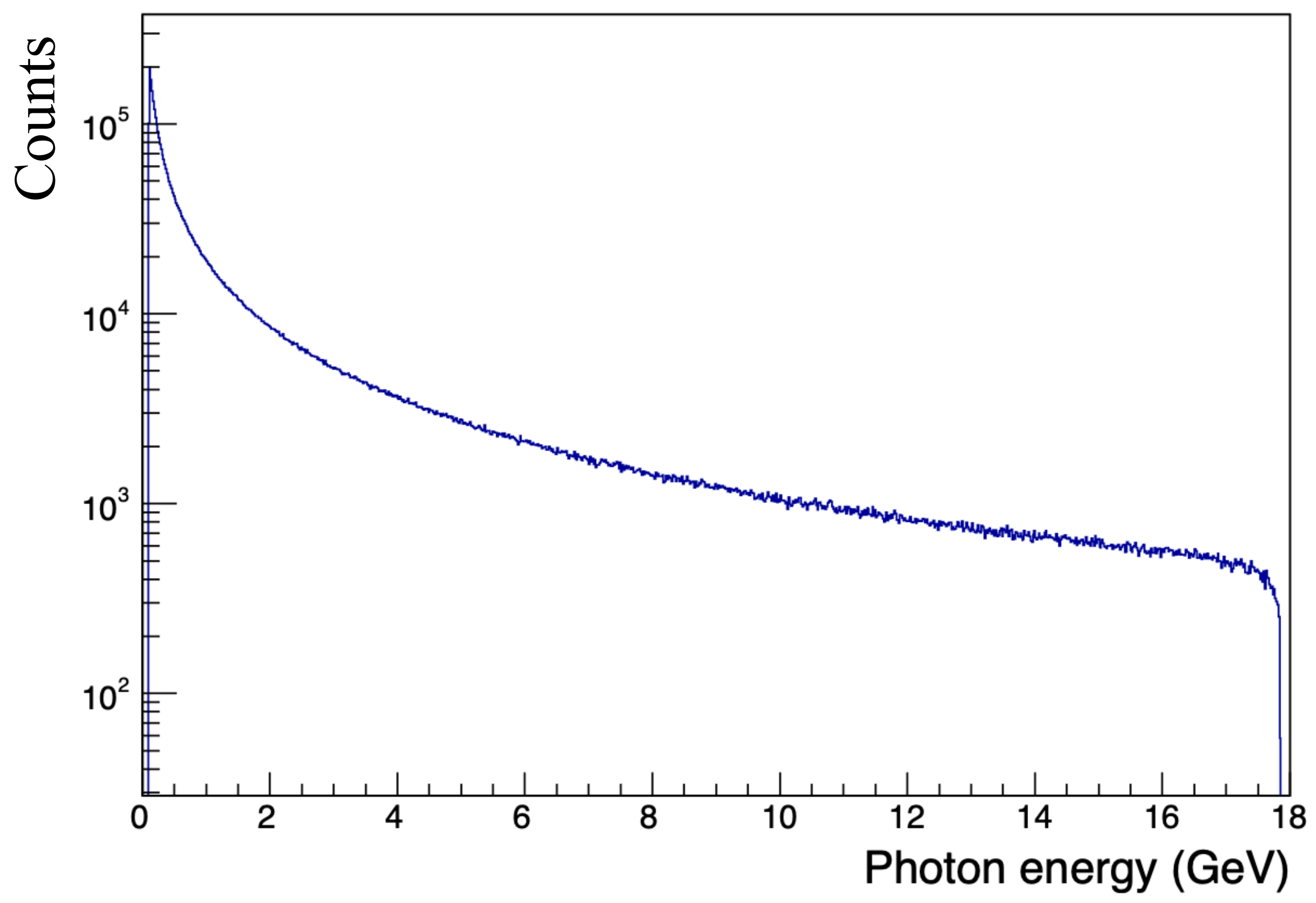


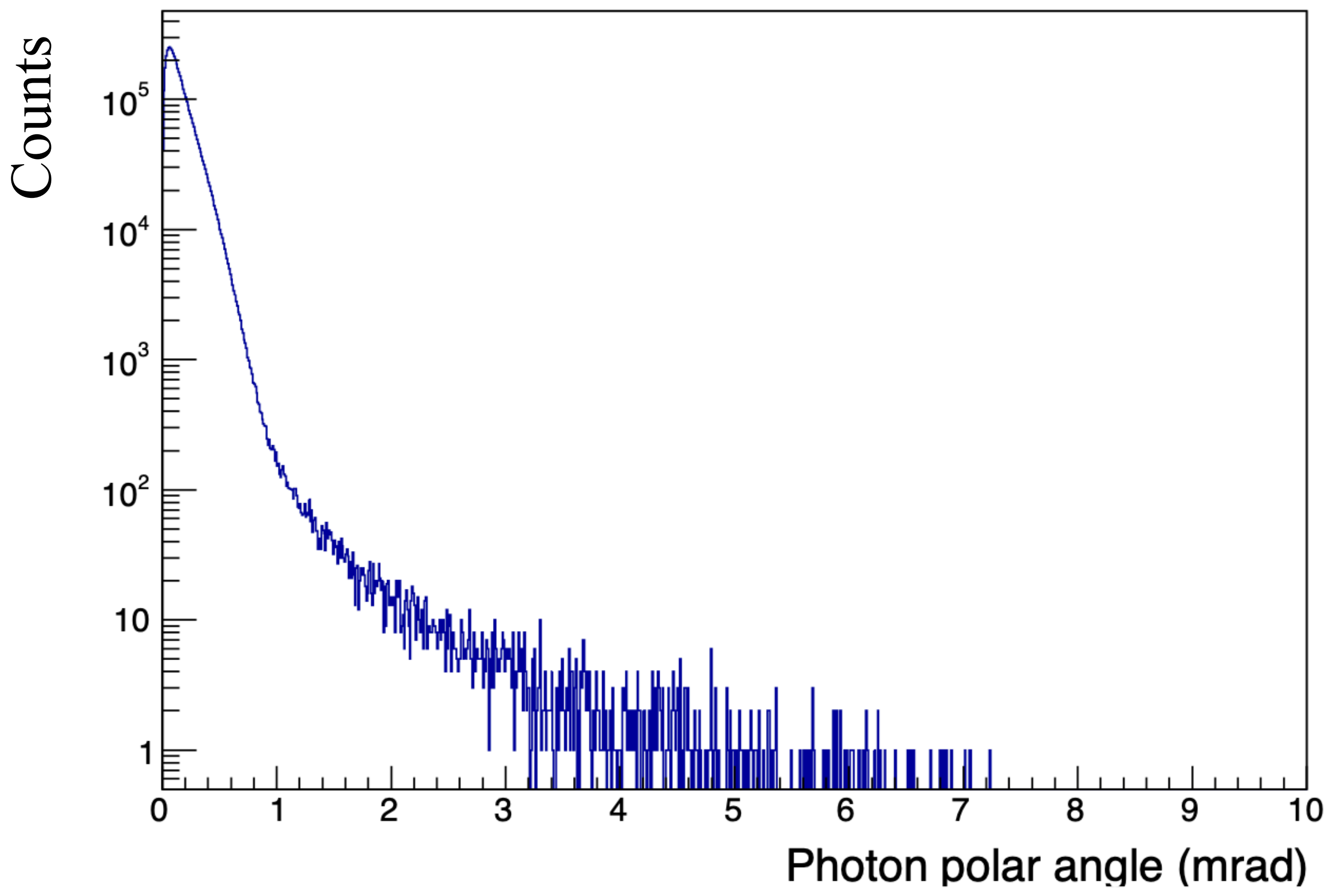


- Use Synrad+ for synchrotron radiation simulation, record photon data, and integrate it into the Geant4 electron polarimeter setup.
- A 2 cm tungsten shield is needed to block SR from strong dipoles (D6EF, D3EF), but it degrades energy resolution and makes position measurements nearly impossible.
- 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.





Summary

- Compton polarimeters are located in both the Electron Storage Ring (ESR), near IR6, and the Rapid Cycling Synchrotron (RCS) to measure 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.
- Further detector, beamline, and engineering optimization is underway toward achieving high-precision electron polarimetry at the Electron-Ion Collider (EIC).