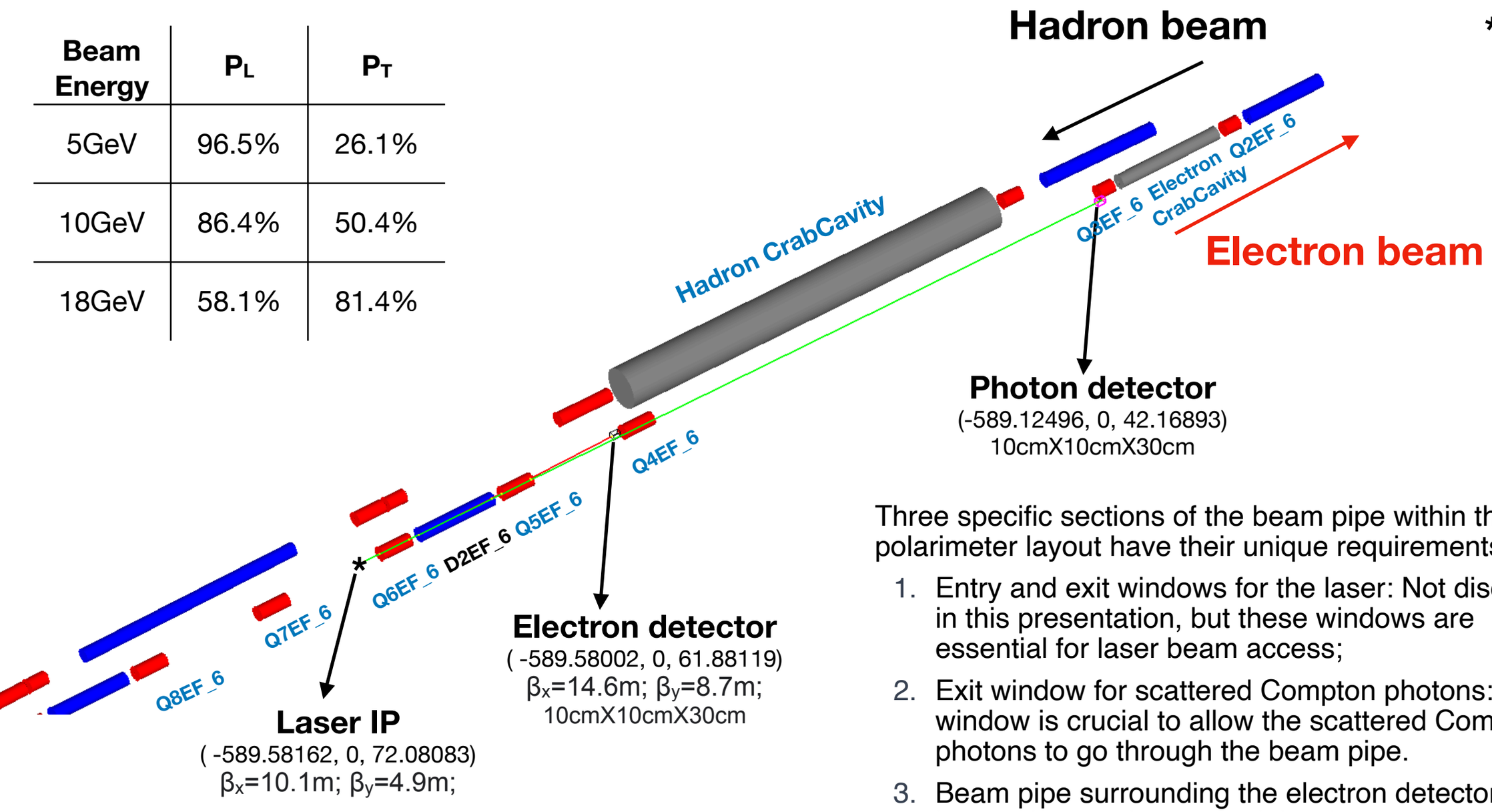
Beam pipe design and synchrotron radiation of electron polarimeter

Zhengqiao Zhang
BNL

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%



Three specific sections of the beam pipe within the polarimeter layout have their unique requirements:

1. Entry and exit windows for the laser: Not discussed in this presentation, but these windows are essential for laser beam access;
2. Exit window for scattered Compton photons: This window is crucial to allow the scattered Compton photons to go through the beam pipe.
3. Beam pipe surrounding the electron detector: The beam pipe section around the detector should be large enough to fit the detector inside the vacuum chamber.

Overview of the beam pipe for polarimeter

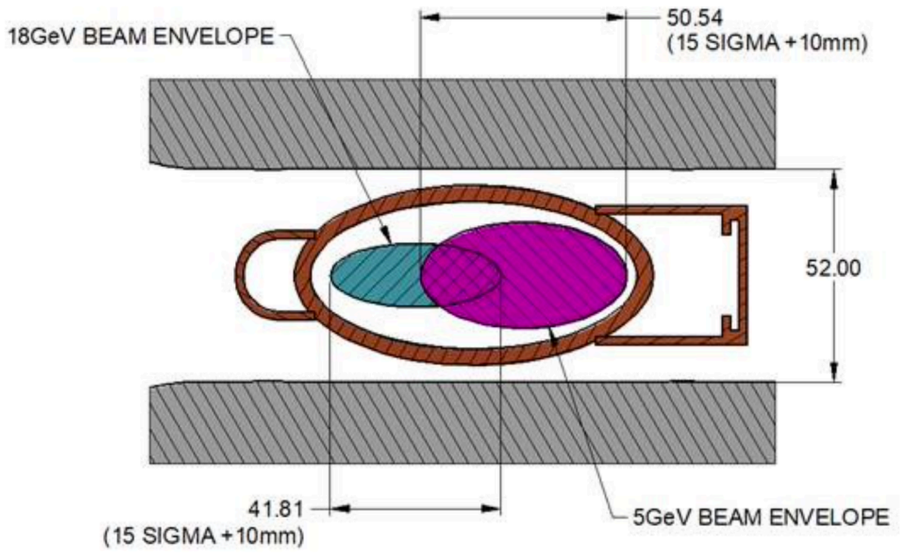


Figure 1.11: Cross section of storage ring vacuum chamber in dipole magnets.

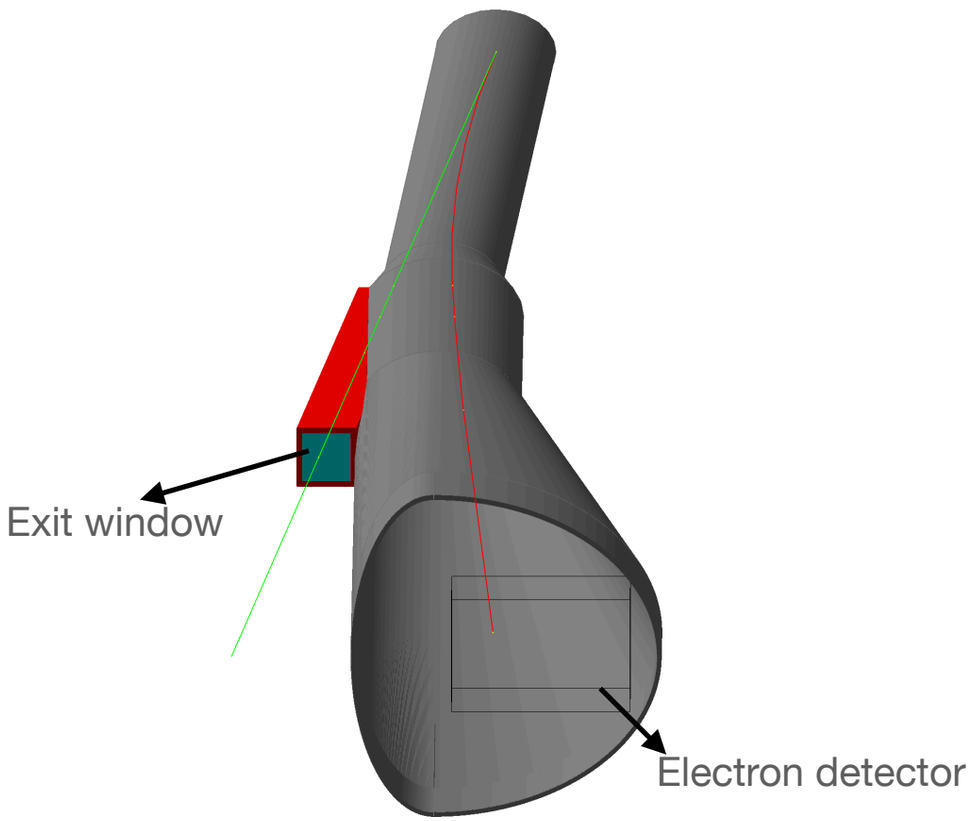
- Here is an illustration of the beam pipe designed for an electron beam in EIC CDR:
- Typically, we employ an elliptical-shaped pipe with a diameter calculated as 30*σX + 20.0mm in the X direction, and 0.7 times the diameter in X for the Y direction. The σ_X is determined by taking the square root of the product of ε_X and β_X ($\sigma_X = \sqrt{\varepsilon_X * \beta_X}$).

Beta function for elements along the layout of the polarimeter:

Name	Type	Length (m)	Beta X (m)	Beta Y (m)
Q7EF_6	Quadrupole	+1.19999999999999996E+000	+1.92214803264335909E+000	+2.40923921167529258E+001
OMIR	Drift	+3.79999999999999982E+000	+5.39423778290748945E+000	+1.00704045882615123E+001
Q6EF_6	Quadrupole	+1.19999999999999996E+000	+1.45879128945105645E+001	+2.51313213440326733E+000
OWW	Drift	+4.00000000000000022E-001	+1.21896712511287646E+001	+2.79112224837674194E+000
D2EF_6	Sbend	+3.00002623326874573E+000	+5.84307048567998688E+000	+5.88950799603383324E+000
OWW	Drift	+4.00000000000000022E-001	+2.49557787342099235E+000	+1.16257063058214491E+001
Q5EF_6	Quadrupole	+1.19999999999999996E+000	+2.10916528333191922E+000	+1.42181569541336010E+001
OMIR	Drift	+3.79999999999999982E+000	+7.35614421746860092E+000	+1.06641736450764597E+001
Q4EF_6	Quadrupole	+1.19999999999999996E+000	+1.95252862917665126E+001	+8.06789697946578421E+000
O3EF_6	Drift	+1.84122615530886478E+001	+6.91898399084460323E+001	+2.66539683370153782E+001
Q3EF_6	Quadrupole	+5.99999999999999978E-001	+1.49274338521067534E+002	+7.04441837680071643E+001
OQC	Drift	+2.99999999999999989E-001	+1.50030816666667135E+002	+7.49775578013695423E+001
O_CRAB_EF_6	Drift	+4.00000000000000000E+000	+1.50000000000000455E+002	+1.00751669137369490E+002
OQC	Drift	+2.99999999999999989E-001	+1.50030816666667050E+002	+1.30432992745663057E+002
Q2EF_6	Quadrupole	+5.99999999999999978E-001	+1.51122294930893901E+002	+1.36170695084401075E+002

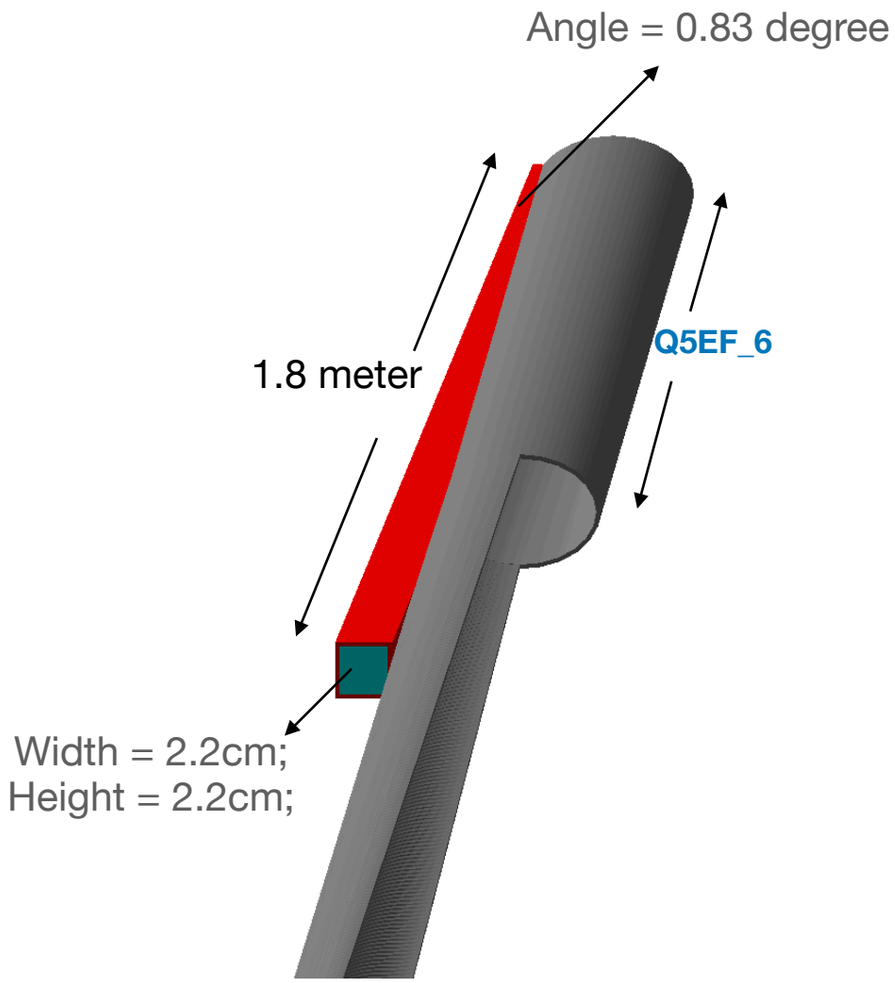
Species	proton	electron
Energy [GeV]	275	18
CM energy [GeV]	140.7	
Bunch intensity [10^{10}]	18.9	6.2
No. of bunches	290	
Beam current [A]	0.69	0.227
RMS norm. emit., h/v [μm]	5.2/0.46	845/70
RMS emittance, h/v [nm]	17.6/1.6	24.0/2.0

Overview of the beam pipe for polarimeter



- We utilized G4EllipticalTube, G4EllipticalCone, G4Torus, and G4ScaledSolid to define standard geometric shapes, while G4TessellatedSolid was employed for specifying the asymmetrical portion near the electron detector.
- All beam pipes have a thickness of 2mm and are made of aluminum, although other materials may also be suitable.
- The beam pipe diameter in the X-axis is 5cm and 3.5cm in the Y-axis, ranging from Q7EF_6 to D2_EF_6. From Q5EF_6 to the electron detector, the X-axis beam pipe diameter gradually expands from 7cm to 20cm, and the Y-axis diameter increases from 4.9cm to 14cm. Between Q4EF_6 and Q3EF_6, the beam pipe diameters are 7cm in the X-axis and 4.9cm in the Y-axis.
- There is an asymmetrical section of the beam pipe extending from the exit window to the electron detector. This is necessary to use a narrower beam pipe on the left side, providing a clear pathway for scattered photons.

Exit window for scattered photons



- Without exit window, the percentage of acceptance is only 60-70%;
- The exit window measures 1.8 meters in length, with a width and height of 2.2 cm; it is situated at an angle of approximately 0.83 degrees relative to the beam pipe;
- The table below displays the percentage of photons that can pass through the window, based on the material and thickness of the front window;
- A well-designed beam pipe should help more photons reach the window, especially for 5GeV. This goal can be explored in future studies;
- HERA's polarimeter has no vacuum chamber before photon detector, but has collimators and sweeping magnets to reduce background;

Vacuum/Air	18GeV	10GeV	5GeV
Arriving the window	99.49%	98.7%	95.9%
2mm Al	97.8%/92.8%	97%/92.2%	94.2%/89.9%
1mm Al	98.6%/93.6%	97.8%/92.9%	94.9%/90.6%
2mm Be	99%/93.9%	98.2%/93.3%	95.2%/90.1%
1mm Be	99.2%/94.13%	98.4%/93.4%	95.4%/91.4%

HERA and JLab Hall C polarimeter

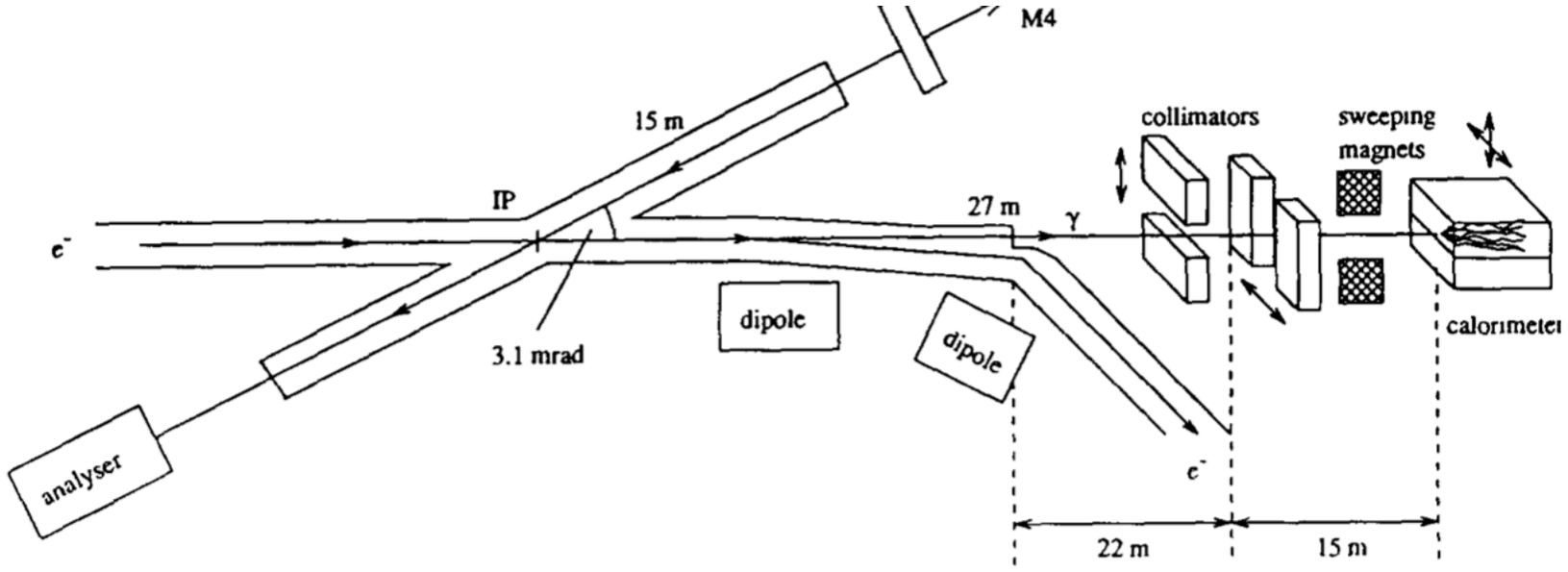
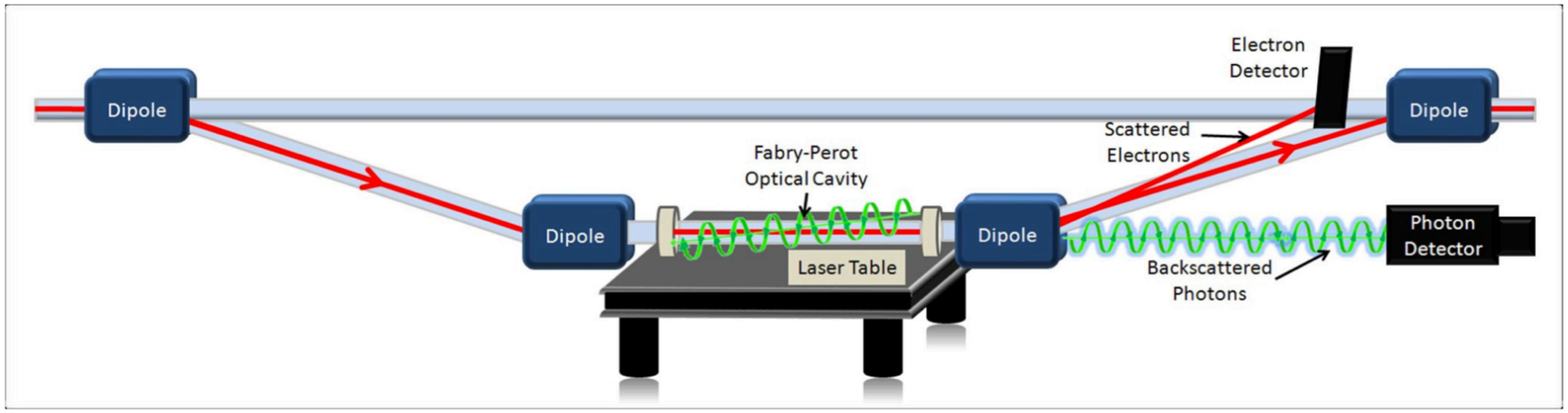
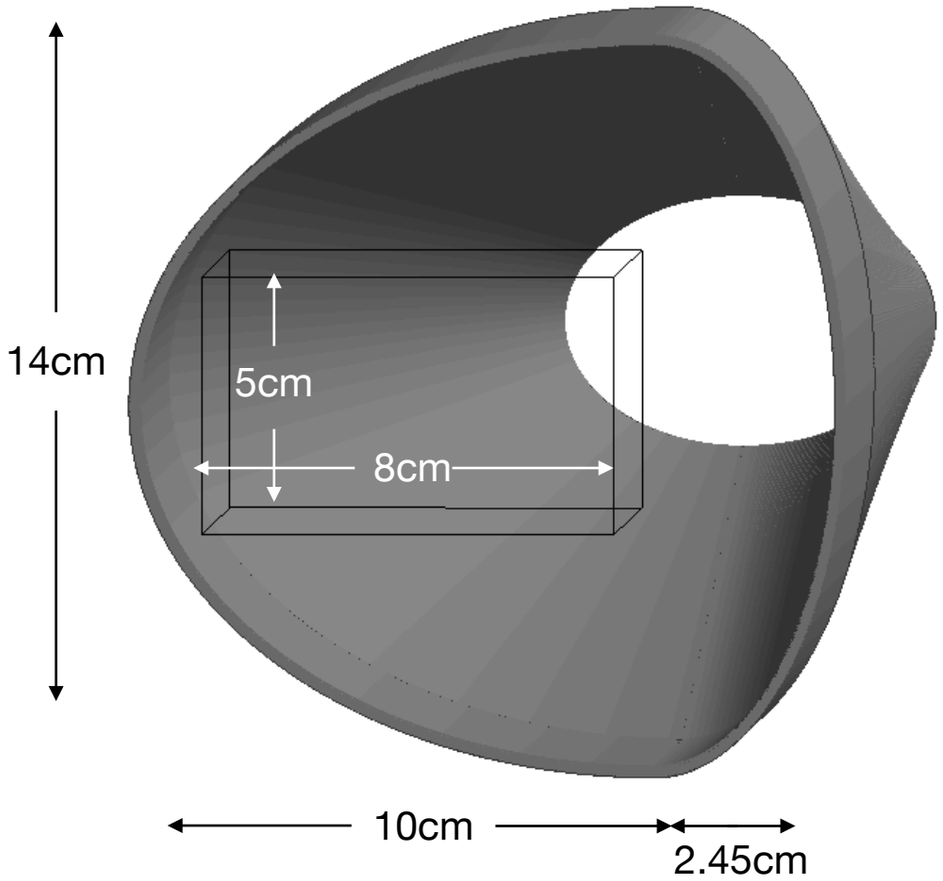


Fig. 9. An overview of the HERA polarimeter.



Hall C Compton Layout

Beam pipe around the electron detector



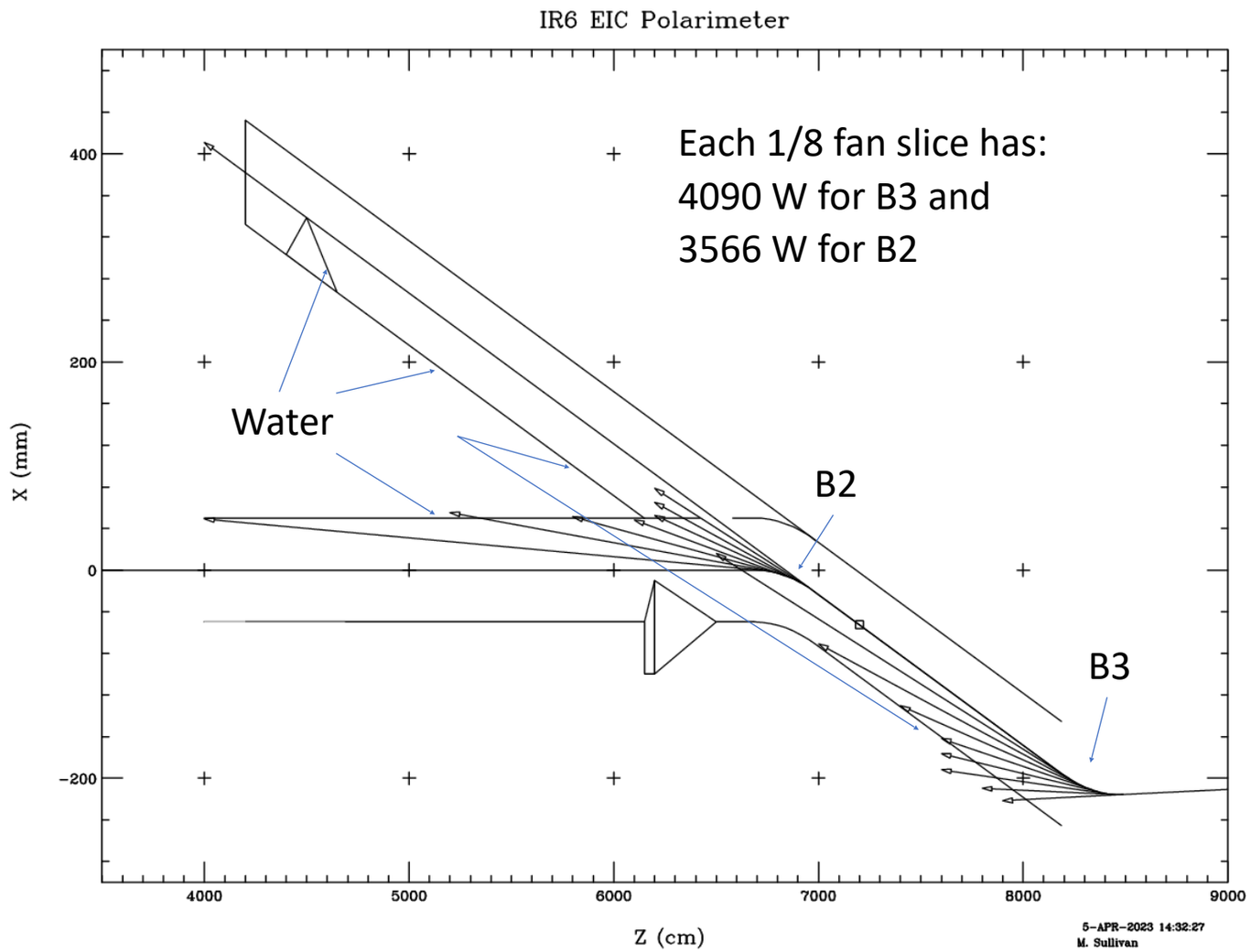
- The electron detector, located within a vacuum chamber, features a Roman pot-style design；
- Currently, the electron detector dimensions are set at 8cm in width, 5cm in height, and 30cm in length. A detailed study of the electron detector is necessary before finalizing its actual geometry and determining the appropriate beam pipe size surrounding it;
- The distance between the detector's edge and the beamline is 0.8cm. It is important to ensure that this distance is safe for a 5GeV electron beam. Additionally, this gap could present a challenge for the asymmetry measurement of 5GeV electrons. Further investigation is needed to address this issue;

Synchrotron Radiation

- The fan height from the far magnet (D3) is 4.5 mm (round up to 5 mm)
- The fan height from the near magnet (D2) is 2.8 mm (round up to 3 mm)
- Suggest we put a horizontal mask into the photon beam pipe down near the window that is high enough to absorb the bend fan radiation about halfway between the laser IP and the photon window
  - Needs to be at least 8mm thick in order to get water cooling into the mask (±4 mm in Y)
  - At the suggested location (44 m – 2 m upstream of the window), the mask would occlude a horizontal slice of the photon window approx. ± 5 mm by 5 cm
  - Can be sloped so that the power density is manageable
  - Cartoon (next slide) has a sloped surface that is 5 cm by 150 cm (could be more)

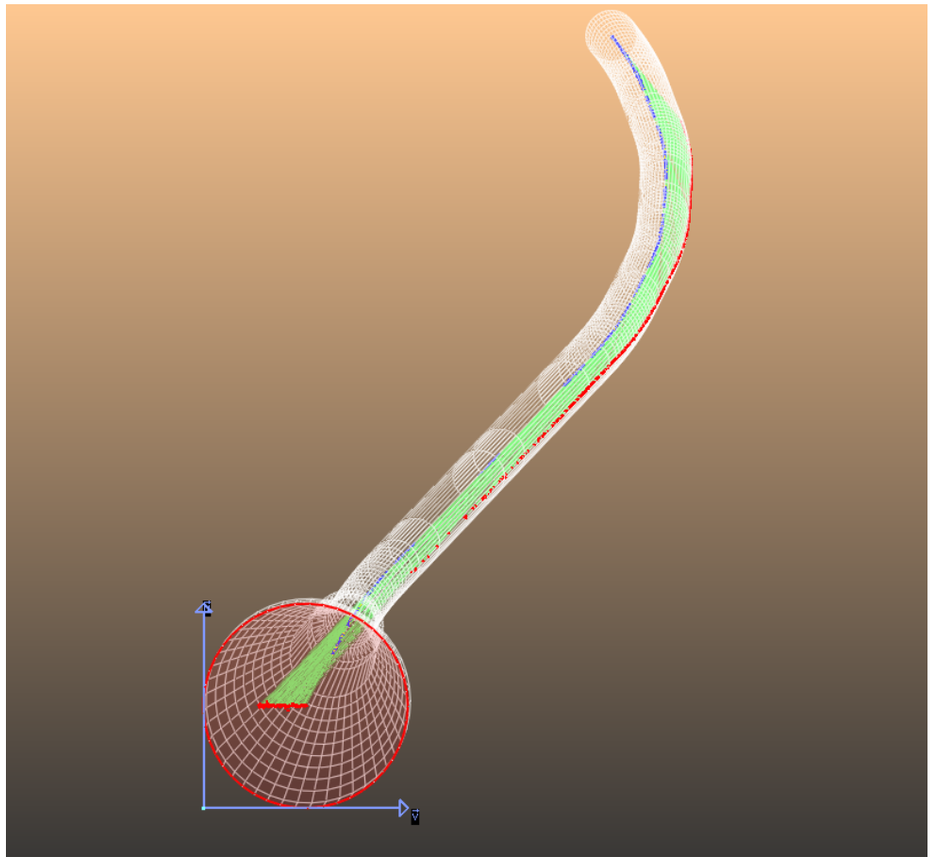
Some details:

1. Hole in beam pipe for the photons is a long oval about 1.6 m in X by 6 cm in Y
2. Propose adding a smaller horizontal slit (3.7 m in X and 1.5 cm in Y) to the above to let the first 3 slices of the B2 fan hit the mask
3. Engineering needed for the crotch area

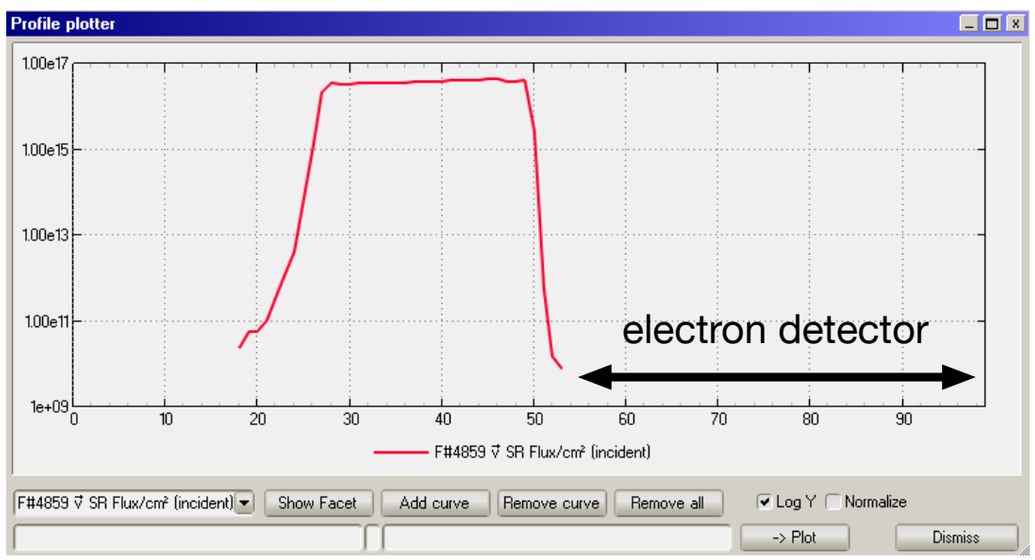


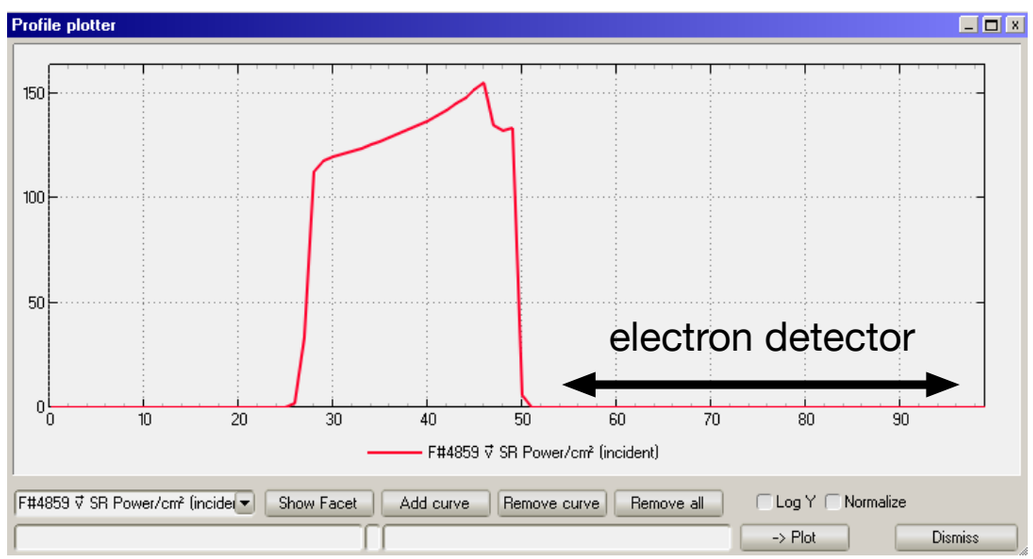
From M. Sullivan

Synchrotron Radiation

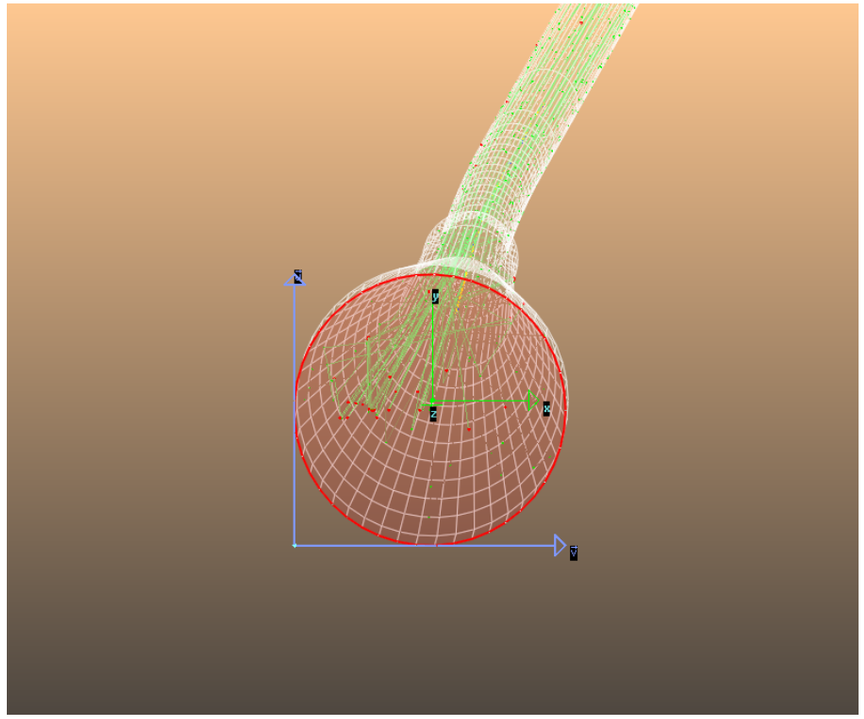


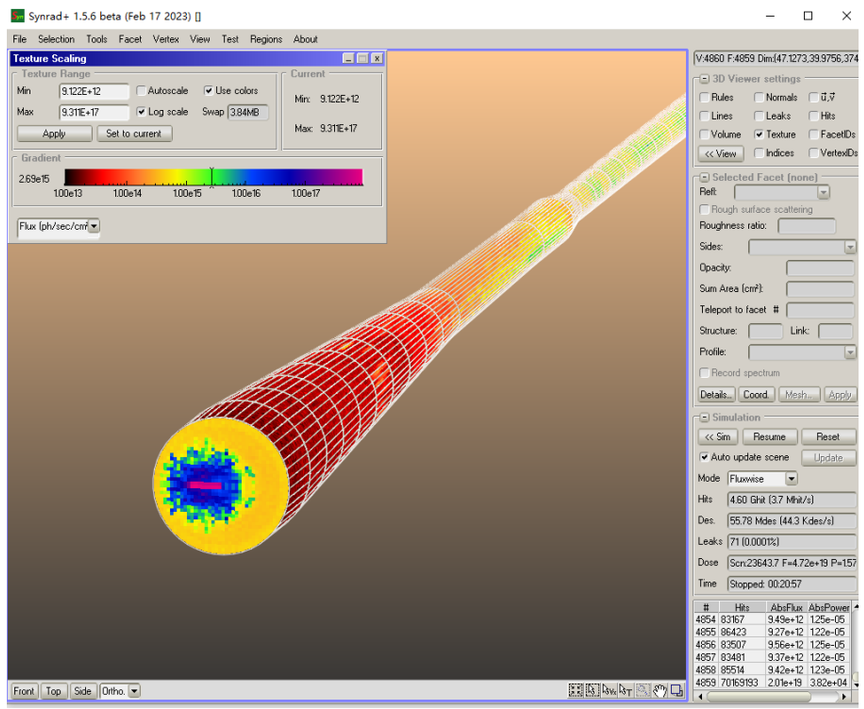
- Four dipoles and seven quadrupoles are added in the Synrad+ simulation;
- Incorporation of beam parameters: emittance, beta function, beam current, and beam spread in the configuration;
- Initial trial with circular beam pipe shapes, with radii set at 5cm, 7cm, and 10cm for different sections;
- Beam pipe material configured as a non-reflective, non-transparent mirror;
- Red facet represents the plane just in front of the electron detector, divided into 100 horizontal sections. Synchrotron radiation negligible for the current setup of the electron detector;



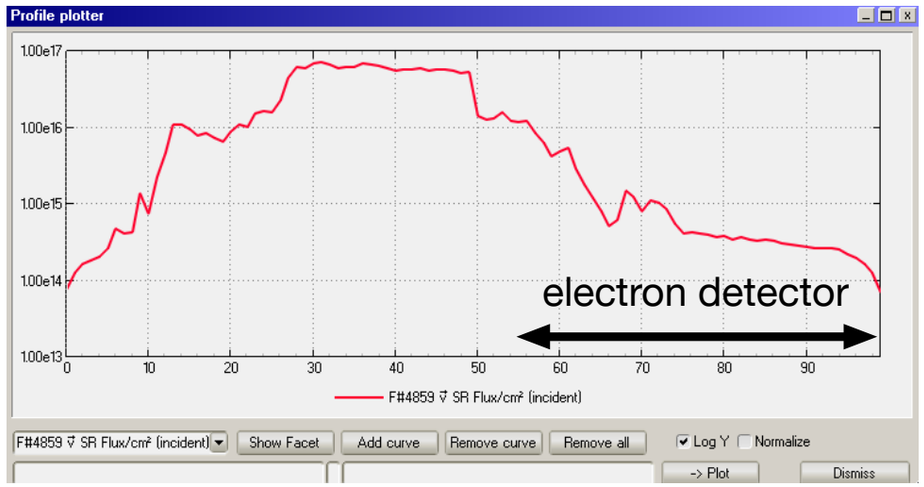


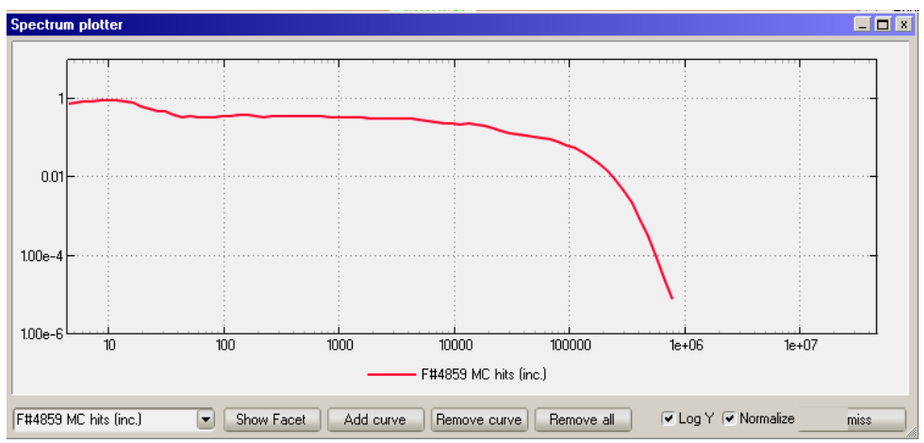
Synchrotron Radiation





- Beam pipe material now set to Aluminum, then the synchrotron photons would bounce within the pipe;
- Synchrotron radiation greatly influenced by beam pipe geometry and material;
- With the current configuration, synchrotron radiation flux significantly increases in the electron detector range; shielding and coating may help reduce SR background;

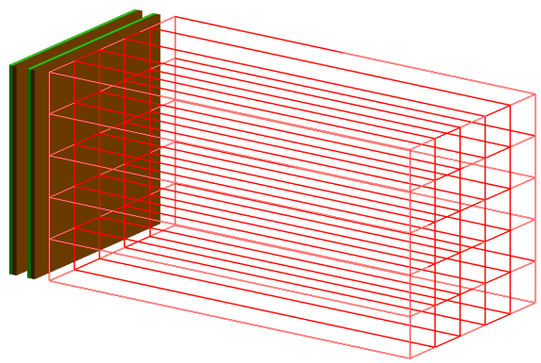




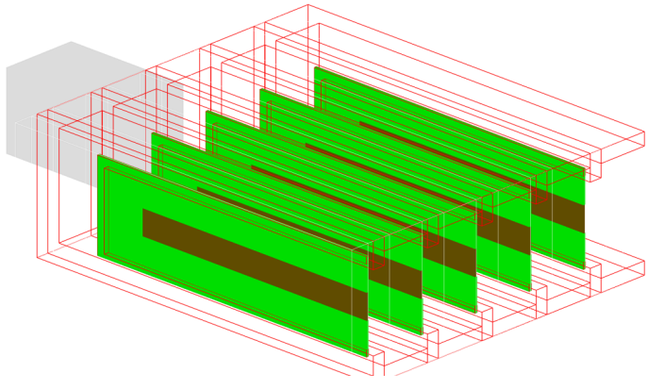
Next step

- Optimize the beam pipe design and integrate precise geometry into Synrad+ simulation;
- Obtain the information of synchrotron radiation (SR) photon for both photon and electron detectors in the Compton polarimeter;
- Implement detailed detector into Geant4 simulation and study the tracking and reconstruction;
- Merge SR photons with the Compton events in the simulation to assess the impact of the background;
- A lot of work to do…any suggestions?

Homogeneous Calorimeter with Preshower detector for Compton photon detection



Electron detector



Summary

- A preliminary design for the beam pipe along the layout of the electron polarimeter is introduced. The majority of the pipe features an elliptical shape；
- We have developed a specialized design for the exit window, examining various materials and thicknesses;
- The electron detector is accommodated by a large, asymmetric beam pipe configuration;
- Further optimization and in-depth investigation are required to refine the overall design of the beam pipe system；
- Full simulation including background is the next step;

https://github.com/ZhengqiaoZhang/ComptonPolarimeter.git