Electron Polarimeter

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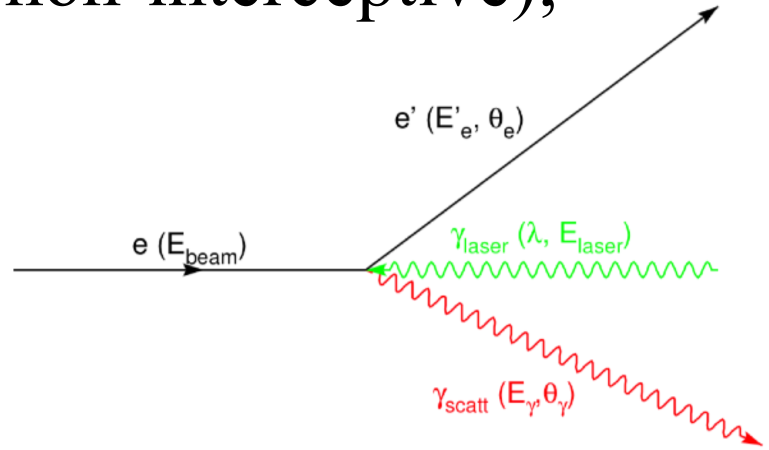
Outline

- Introduction of electron polarimeter;
- Requirements of electron polarimeter for EIC;
- Polarization measurements;
- Discuss the location of polarimeter in IR12;
- Discuss the requirements for the magnets;
- Beam parameters requirement;

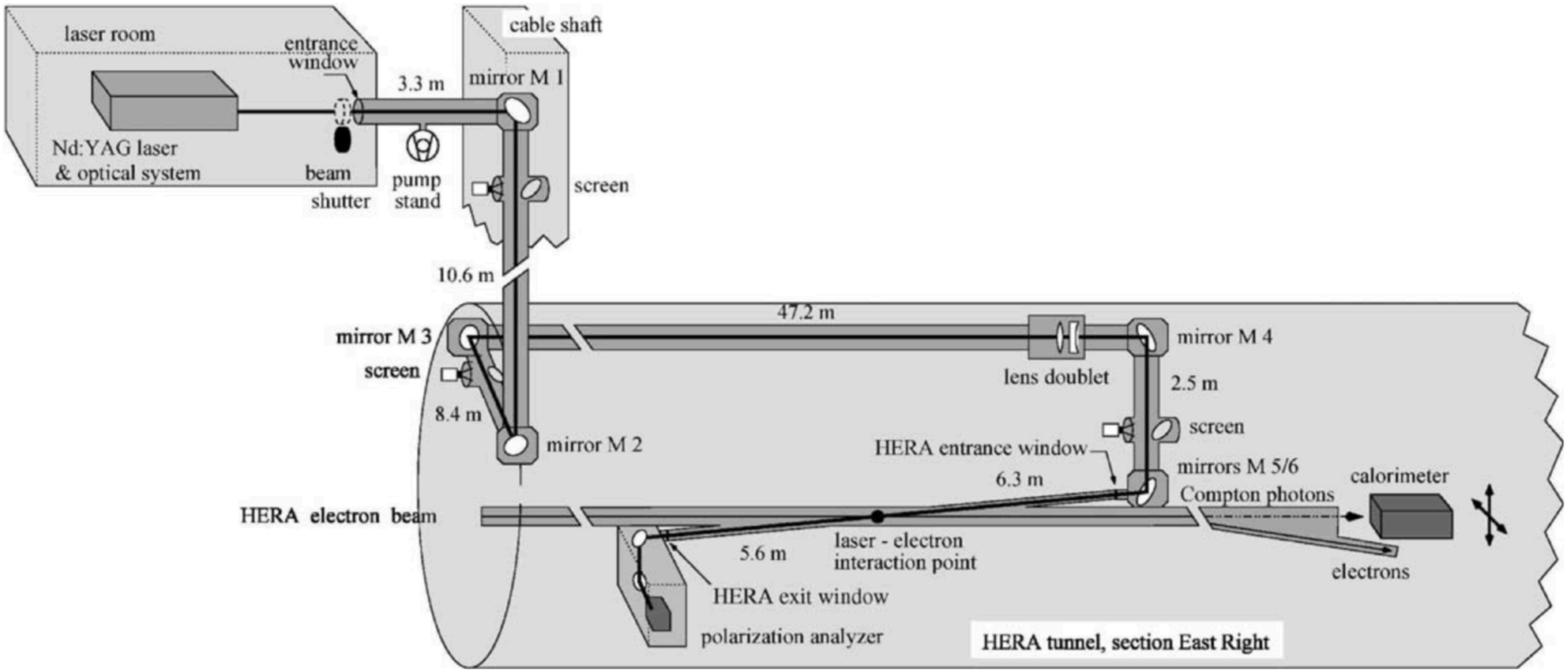
Electron polarimeter

- The electron polarization measurement is critical for EIC physics;
- Common techniques for measuring electron beam polarization:
  - Mott scattering: $\vec{e} + \vec{Z} \rightarrow e$, spin-orbit coupling of electron spin with (large Z) target nucleus (Useful at MeV-scale (injector) energy);
  - Møller scattering: $\vec{e} + \vec{e} \rightarrow e + e$, atomic electron in Fe polarized using external magnetic field (Usually destructive, from MeV to GeV, rapid, precise measurements);
  - Compton scattering: $\vec{e} + \vec{\gamma} \rightarrow e + \gamma$, laser photons scattered from electron beam (Easiest at high energies, non-destructive);
- Møller polarimeter in RCS (interceptive) and Compton scattering polarimeter in storage ring (non-interceptive);



Electron polarimeter in HERA

Layout of the Longitudinal Polarimeter in the HERA East section.



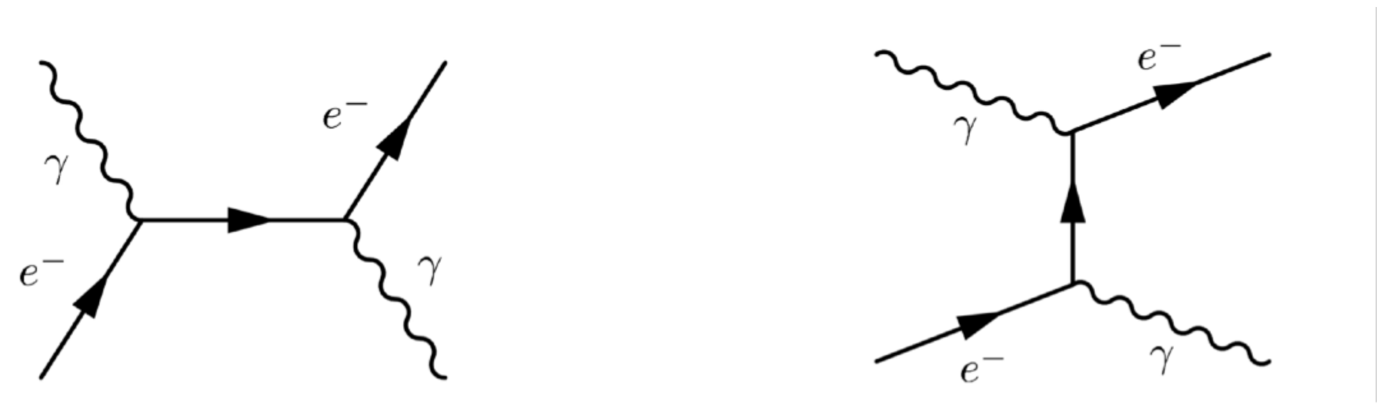
Beckmann M, Borissov A, Brauksiepe S, et al. The longitudinal polarimeter at HERA[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2002, 479(2-3): 334-348.

Requirements of electron polarimeter

- To be placed at IR12;
- Need to measure both longitudinal and transverse components;
  - Highly segmented pre-shower and ECal with good energy resolution for γ
  - Highly segmented ECal with good energy resolution and position resolution for lepton
- Need to measure bunch-by-bunch polarization;
- Need to measure with high precision ~1%;
- Moller polarimeter in RCS (interceptive) and Compton scattering polarimeter in storage ring (non-interceptive);

$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-} = P_e P_\gamma A_l$$

Compton scattering



The two leading-order Feynman diagrams for Compton Scattering

- We can calculate the cross sections for the spin-polarized processes $e^-\gamma \rightarrow e^-\gamma$, $e^-\gamma\gamma$, $e^-e^+e^-$ to order-α^3.
- We can calculate cross sections for circularly-polarized initial-state photons and arbitrarily polarized initial-state electrons.

Swartz M L. Complete order-α 3 calculation of the cross section for polarized Compton scattering[J]. Physical Review D, 1998, 58(1): 014010.

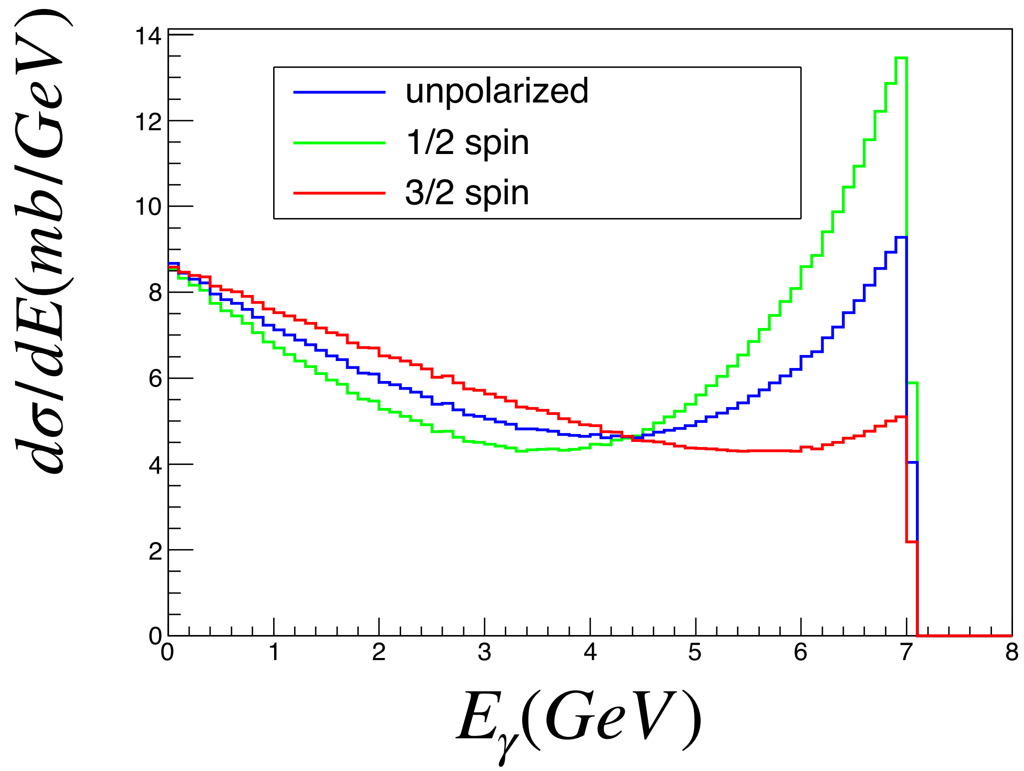
Compton scattering

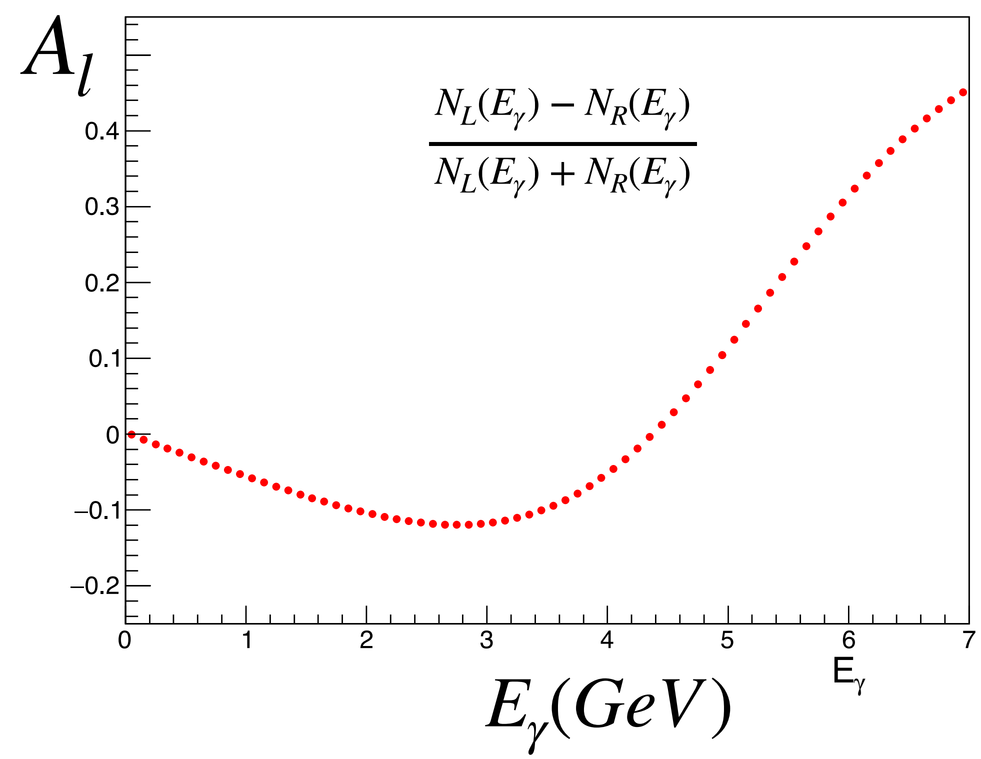
- **The longitudinal polarization can be measured by measuring the asymmetry of the energy spectra measured with left and right helicities laser;**
- **And the transverse polarization can be measured by measuring the spatial asymmetry;**
- **We need to measure both longitudinal and transverse components independent of location;**

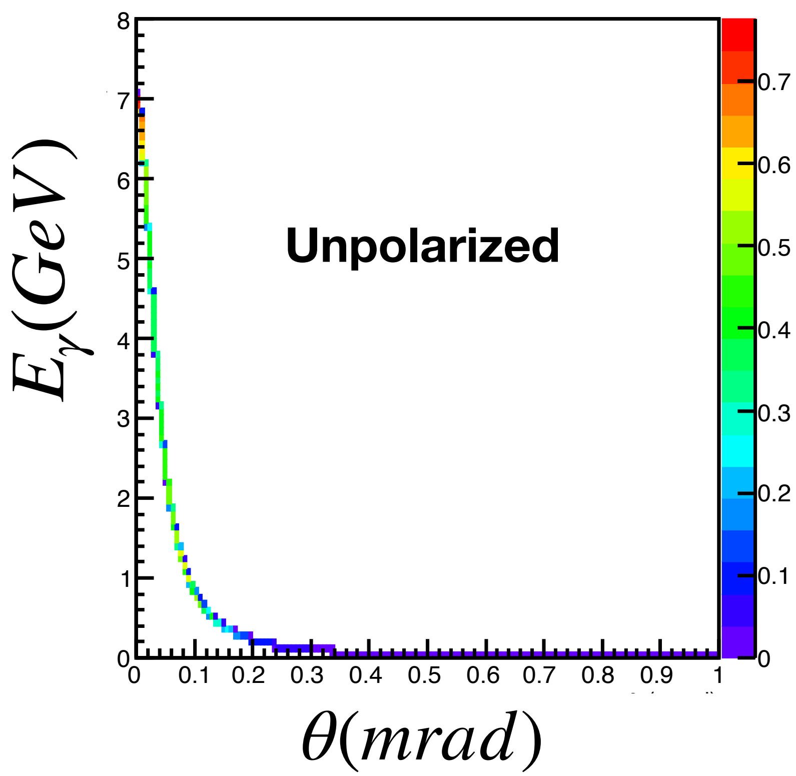
$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-} = P_e P_\gamma A_l$$

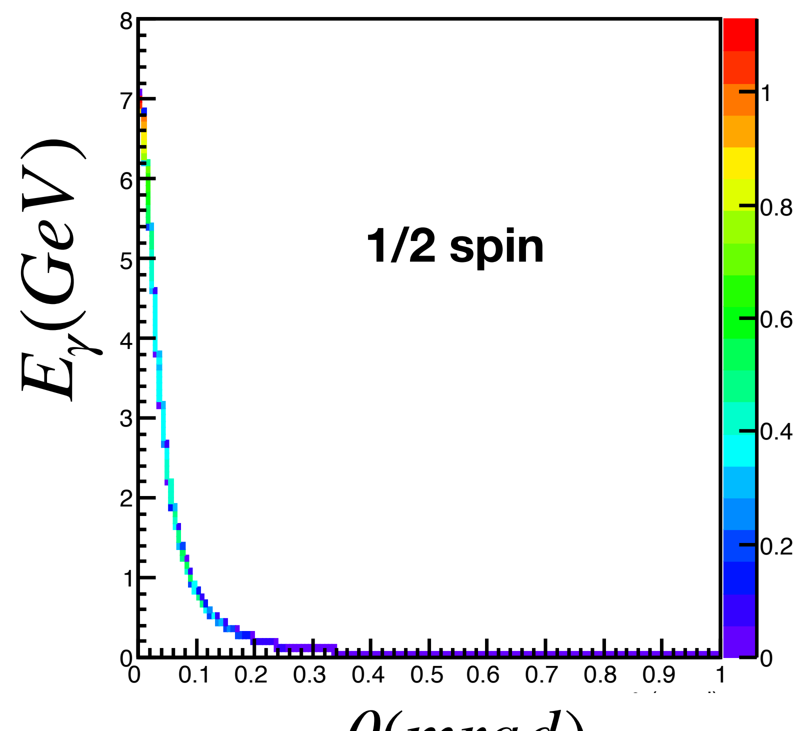
$$P_e = \frac{A_{exp}}{P_\gamma A_l}$$

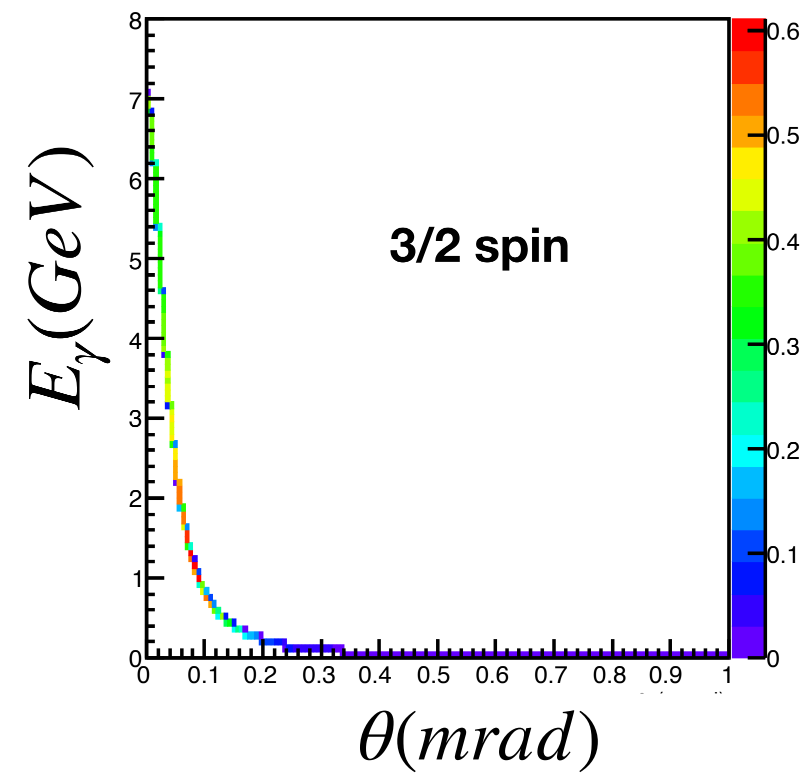
Longitudinal polarization



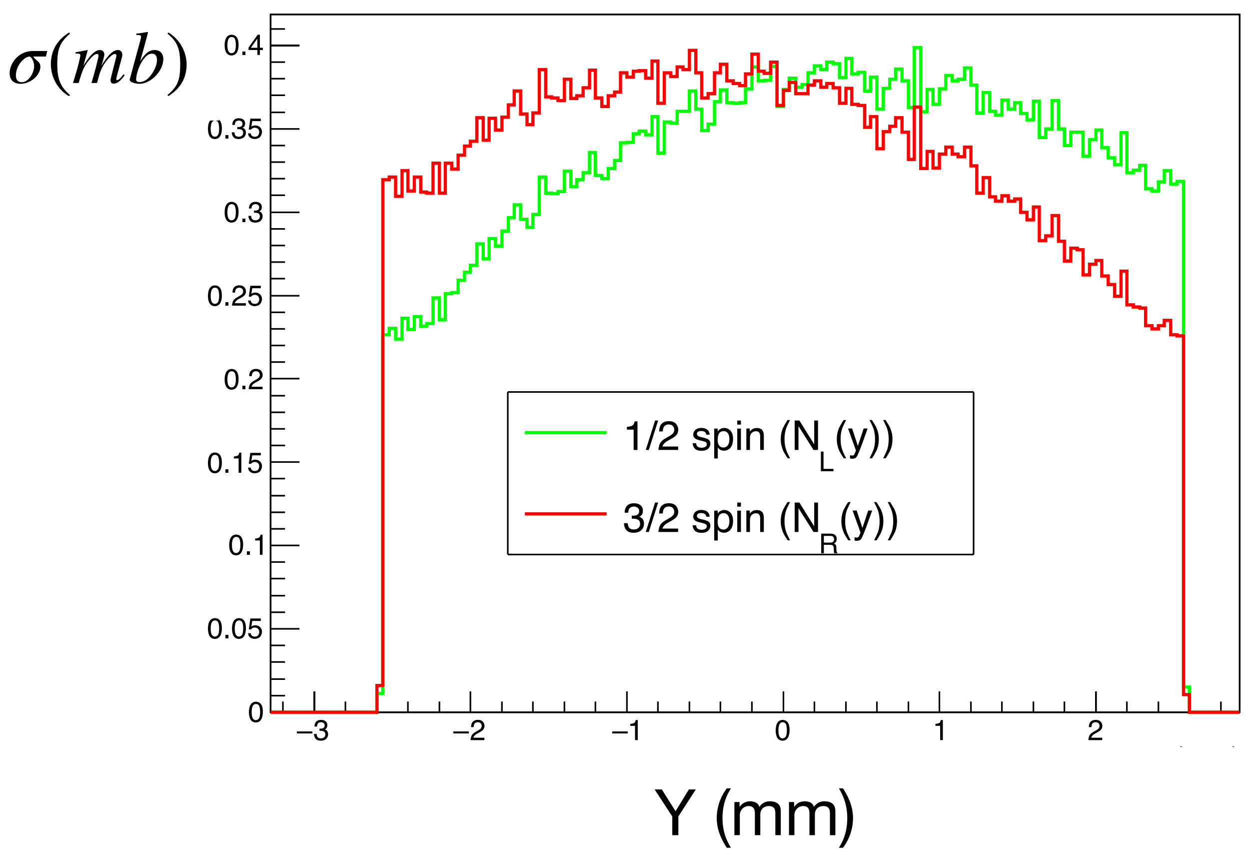


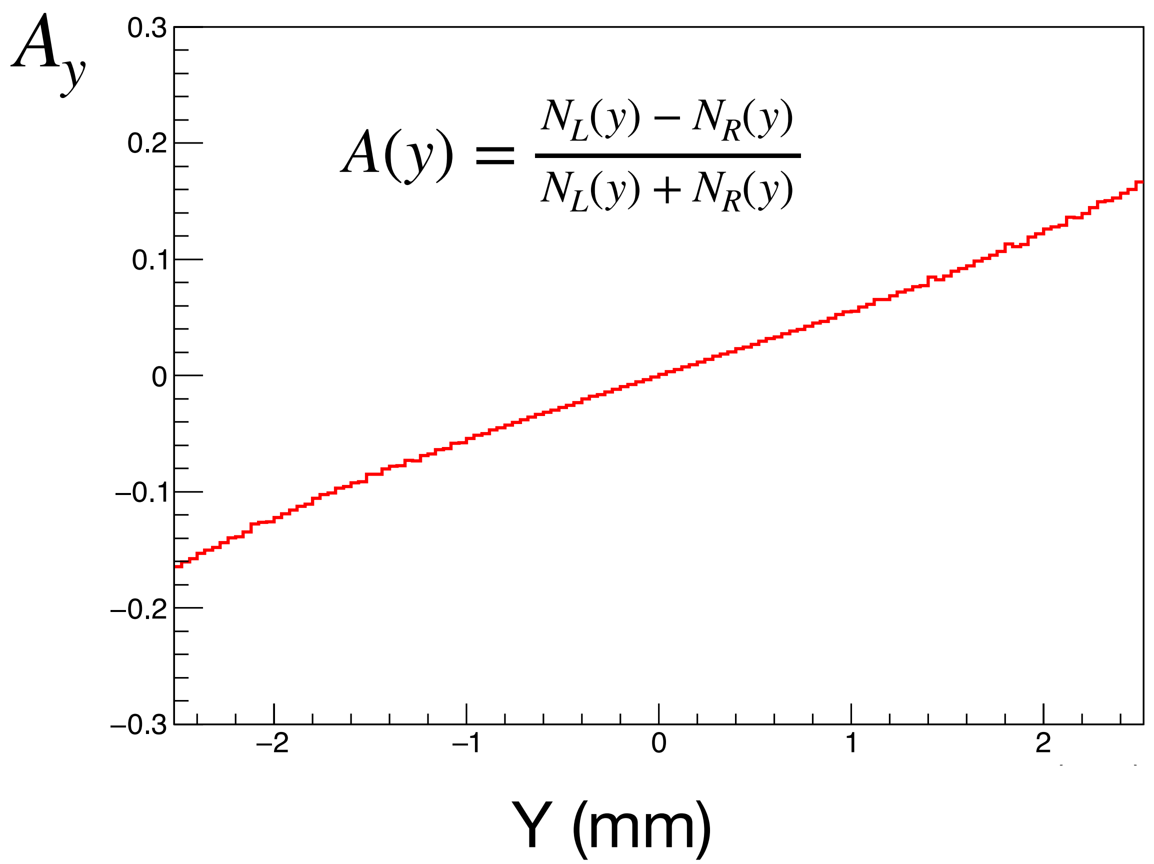






Transverse polarization

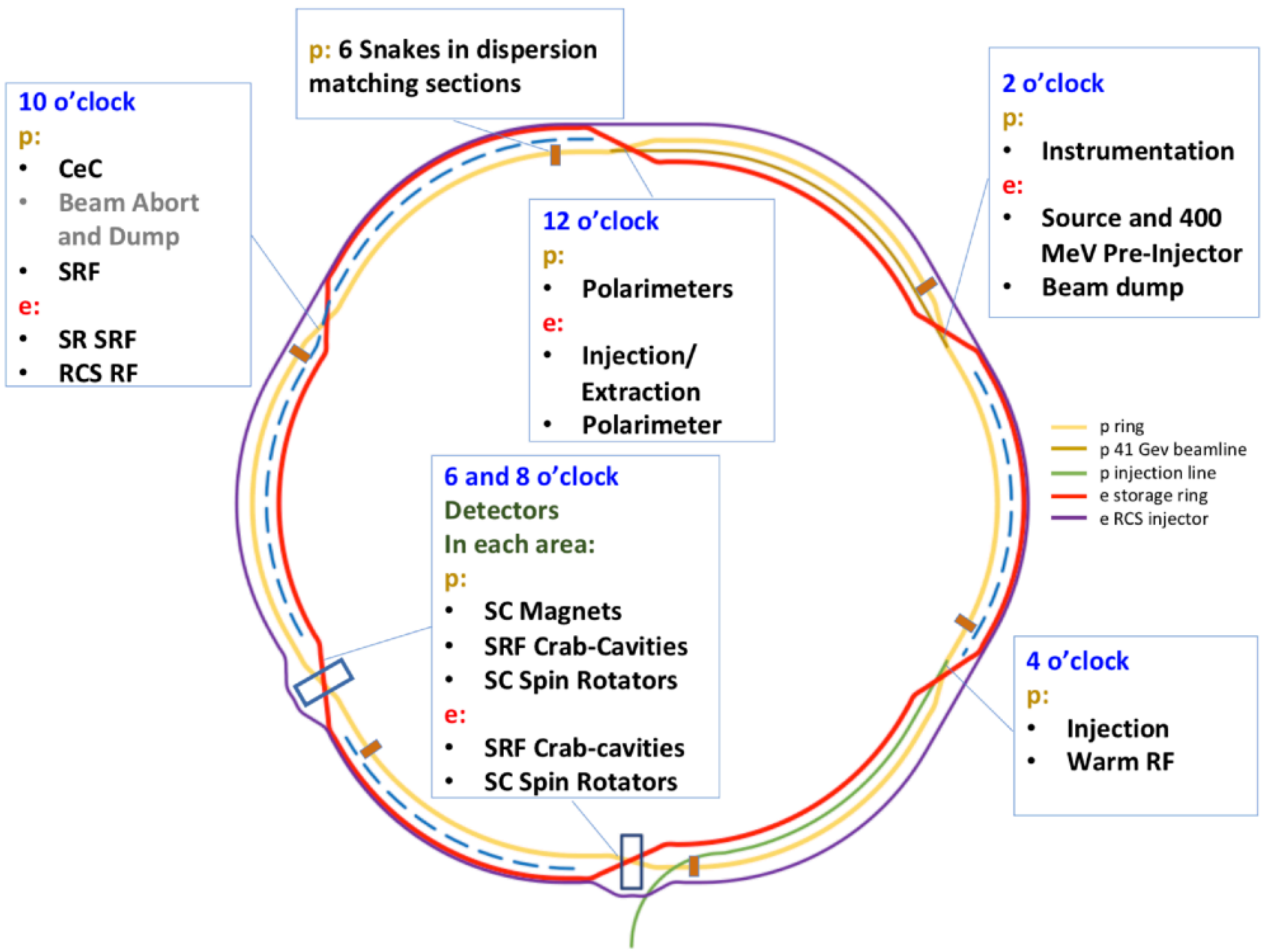




$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-} = P_e P_\gamma A_y$$

$$P_e = \frac{A_{exp}}{P_\gamma A_y}$$

IR12 layout



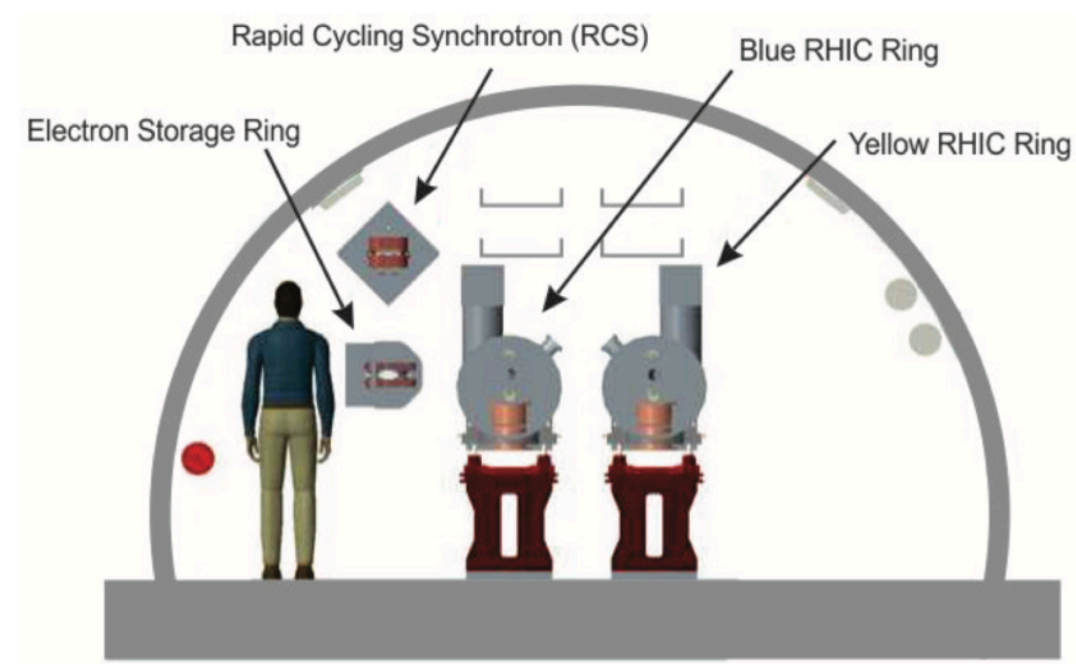
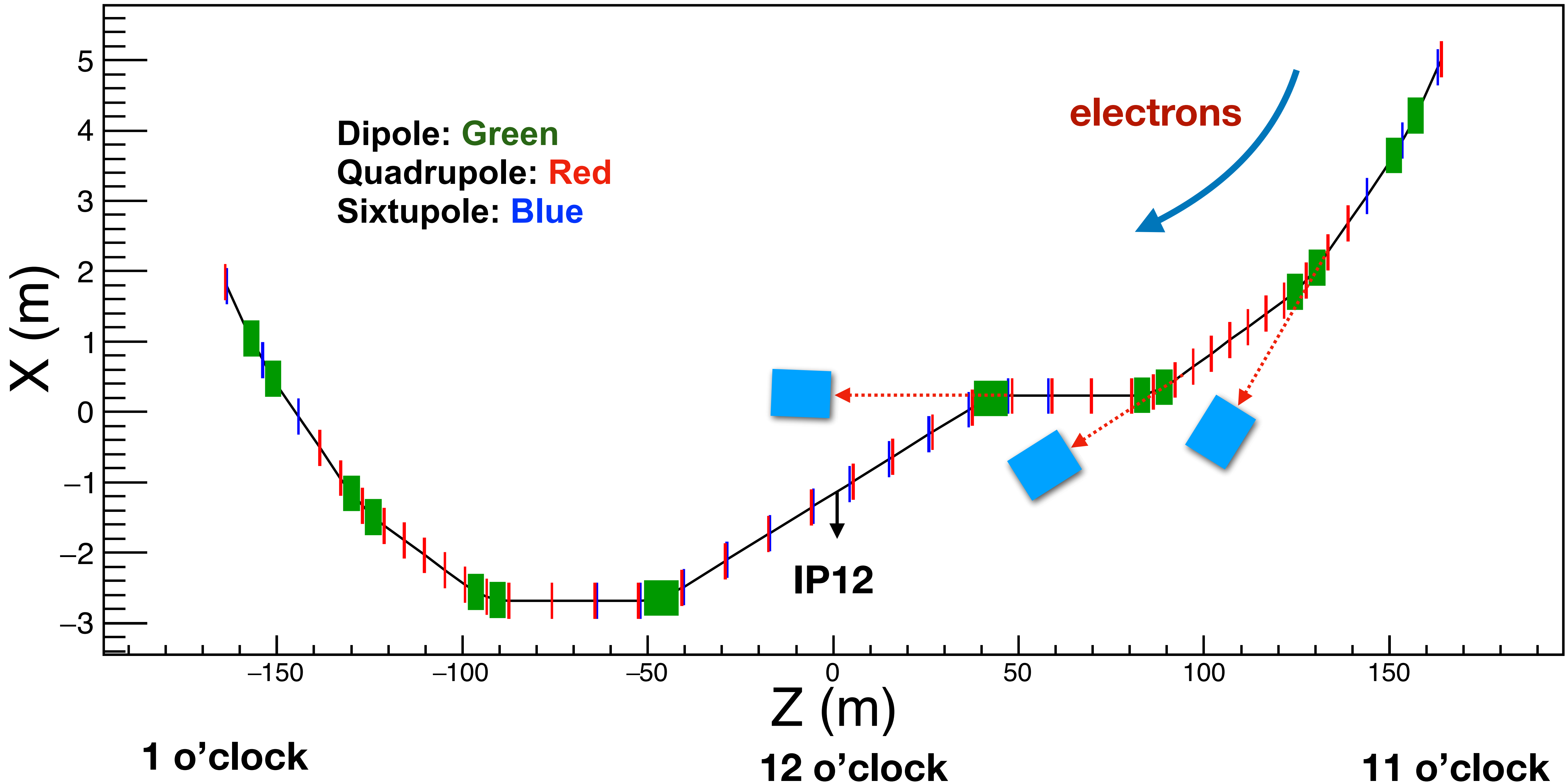


Figure 1.7: Schematic view of the location of the electron storage ring in the tunnel arcs. The Rapid Cycling Synchrotron injector is mounted above the collider ring plane.

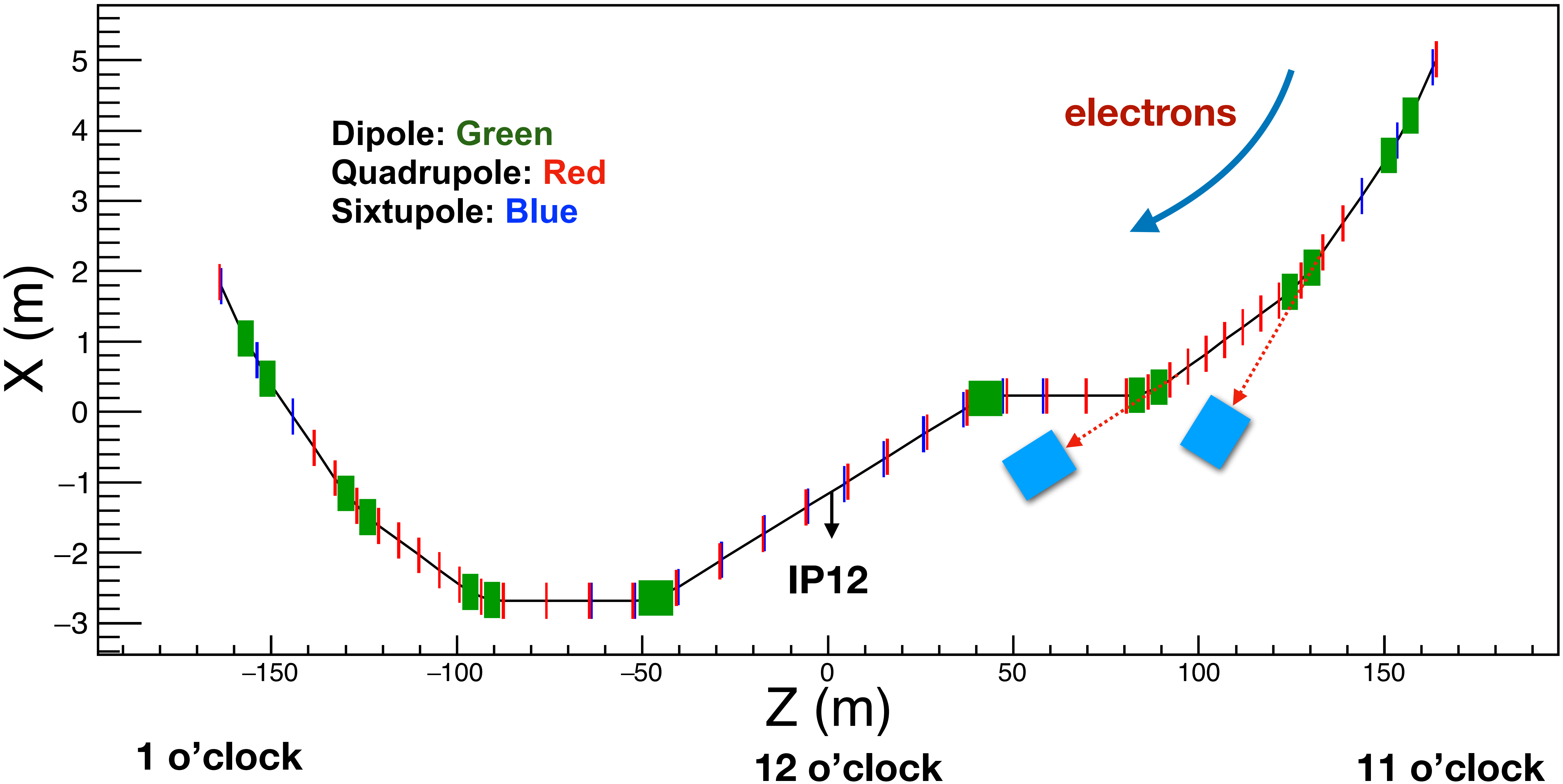
- **We want the position of the polarimeter as close as the IP, unfortunately the IR is crowded. Only IR12 has enough space for the polarimeter;**
- **The polarimeter has to be installed on the 11 o'clock side of IR12 (or in-between the triplets), because on the 1 o'clock side the beamlines between Q3 and Q4 will be different, depending on energy; ——————Christoph Montag**

IR12 layout

- We need dipole to bend the electron beam so we can separate the scattered photon;
- In the region near 11 o'clock side, the outer side of the Electron Storage Ring has more space than the inner side;

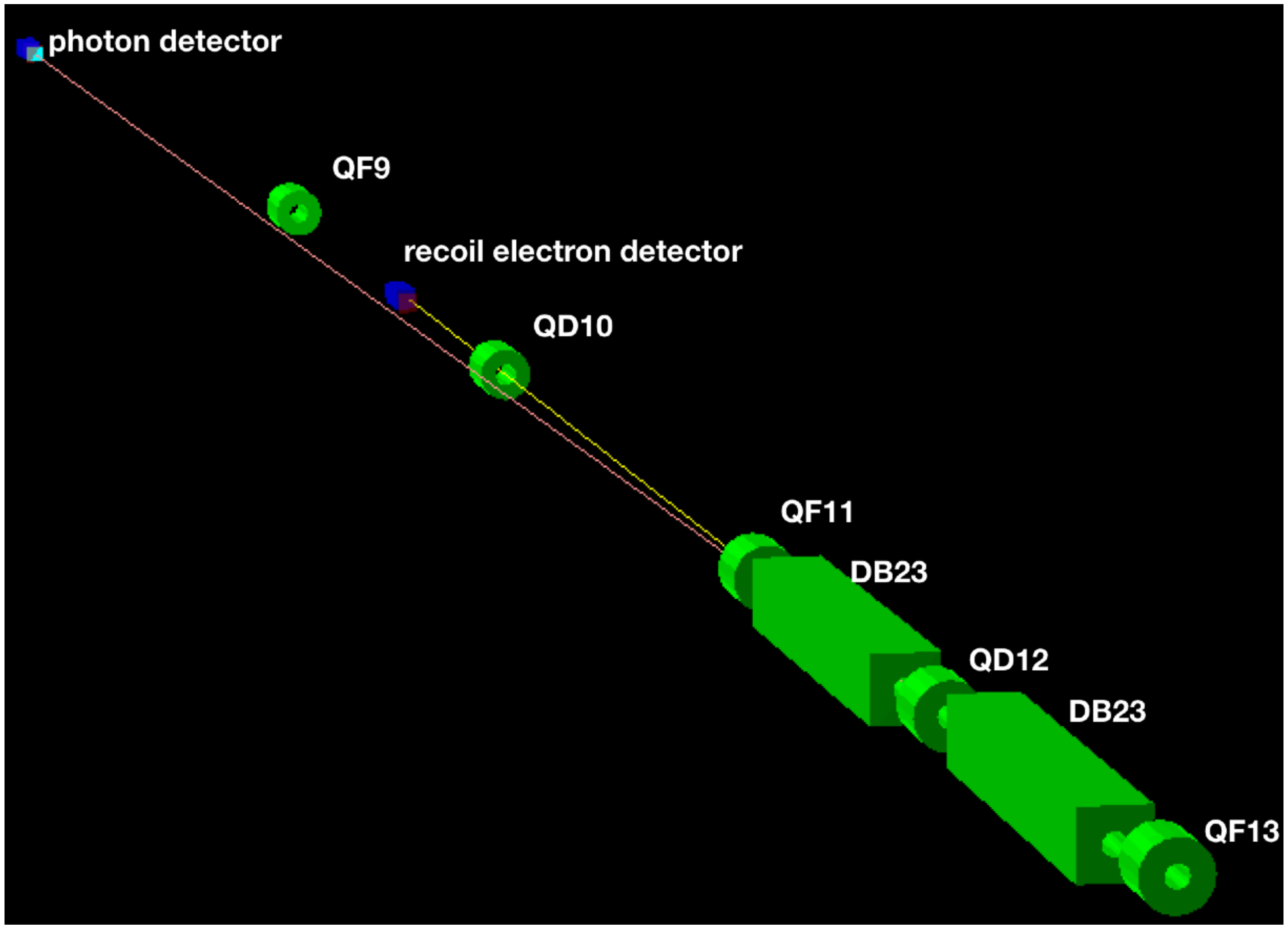


IR12 layout

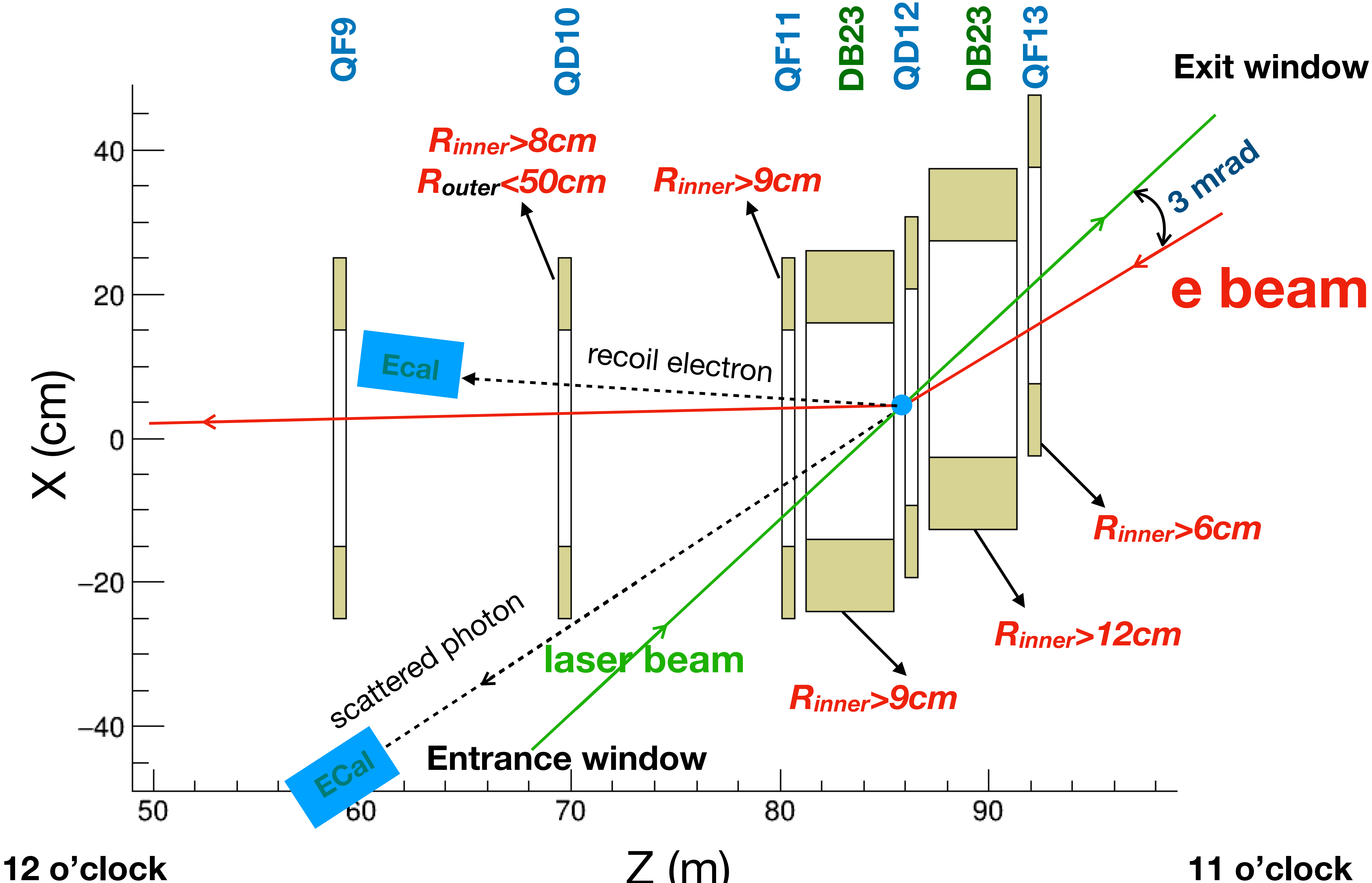


electrons
Dipole: Green
Quadrupole: Red
Sixtupole: Blue
IP12
X (m)
Z (m)
5
4
3
2
1
0
−1
−2
−3
−150
−100
−50
0
50
100
150
1 o’clock
12 o’clock
11 o’clock

IR12 layout



- The interaction potion of Compton scattering is at (0.274464m, 85.73037m) in IR12, just between DB23 and QD12;
- The entrance window of laser is near QF11 and the exit window is near QF13;
- The laser would go through five magnets from QF13 to QF11;
- The scattered photons can't pass through the magnets if the inner radius is too small;



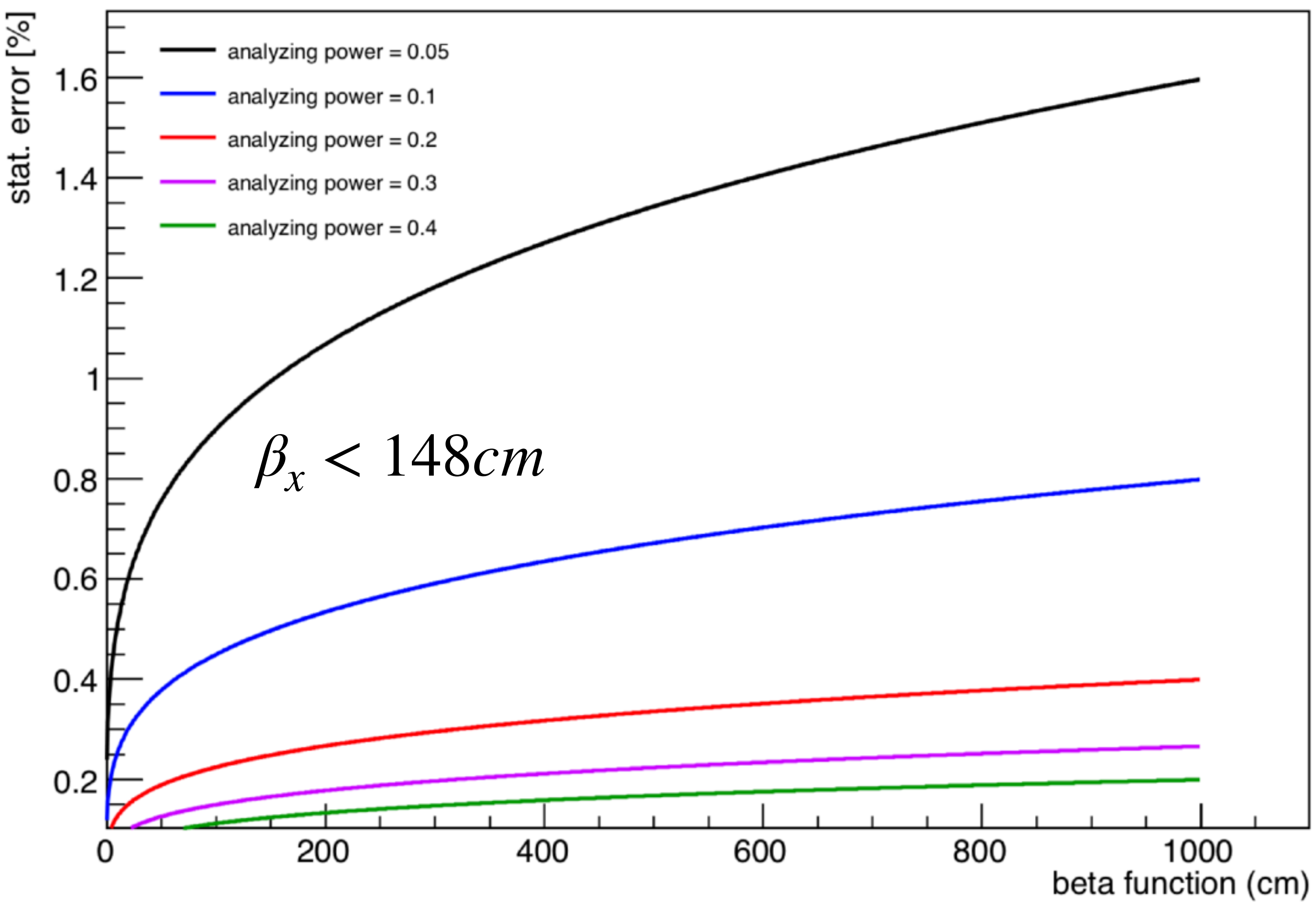
QF9
QD10
QF11
DB23
QD12
DB23
QF13
Exit window
R_inner>8cm
R_outer<50cm
R_inner>9cm
3 mrad
e beam
Ecal
recoil electron
R_inner>6cm
R_inner>12cm
scattered photon
laser beam
R_inner>9cm
ECal
Entrance window
X (cm)
40
20
0
−20
−40
50
60
70
80
90
Z (m)
12 o'clock
11 o'clock

Beam Parameters

$L = f_b N_e \lambda_\gamma G$

Geometric factor

$$G = \sqrt{\frac{2}{\pi}} \frac{1}{\theta\sqrt{\sigma_{e,x}^2 + \sigma_{\gamma x}^2}}$$



$f_b = 9.4MHz; Ne = 1.7 \times 10^{11}; \lambda_\gamma = 8.6 \times 10^8 (10W); \theta = 3mrad;$

$\sigma_{\gamma x} = 0.1mm; \sigma_{\gamma y} = 0.1mm; \sigma_{\gamma z} = 1.3mm; \sigma_z = 10mm; \sigma_{x,y} = \sqrt{\epsilon_{x,y}\beta_{x,y}}, \epsilon_x = 20n$

$\delta P_e \approx \frac{1}{A\sqrt{N}}; N = 2minute * L * CrossSection * 0.8 * f_b/20$

Beam Parameters

- The detector is positioned at the maximum distance from the IP within the constrains of the tunnel geometry;
- The Twiss parameters of the electron beam at the Compton scattering IP has to been chosen to minimize the vertical spot size of the projected electron beam;
- The distribution of the initial electrons would also produce a smearing of the Y distribution of the scattered photon; let's assume the distance between the Compton scattering IP and the photon detector is 40m;

$$\sigma_{e,y}(D) = \sqrt{\epsilon_y \beta_y(D)} = \sqrt{\epsilon}\sqrt{\beta_y(0) - 2\alpha_y(0)D + \gamma_y(0)D^2}$$

$$\sigma_{e,y'}(0) = \sqrt{\epsilon \gamma_y(0)} = \sqrt{\epsilon_y \frac{1+\alpha_y^2(0)}{\beta_y(0)}}$$

$$\alpha_y(0) = \sqrt{\frac{\sigma^2_{e,y'}(0) * \beta_y(0)}{\epsilon_y} - 1} \qquad \gamma_y(0) = \frac{\sigma^2_{e,y'}(0)}{\epsilon_y}$$

$$\sigma_{e,y}(D) = \sqrt{\epsilon_y \beta_y(D)} = \sqrt{\epsilon}\sqrt{\beta_y(0) - 2 * \sqrt{\frac{\sigma^2_{e,y'}(0)\beta_y(0)}{\epsilon_y} - 1}D + \frac{\sigma^2_{e,y'}(0)}{\epsilon_y} * D^2}$$

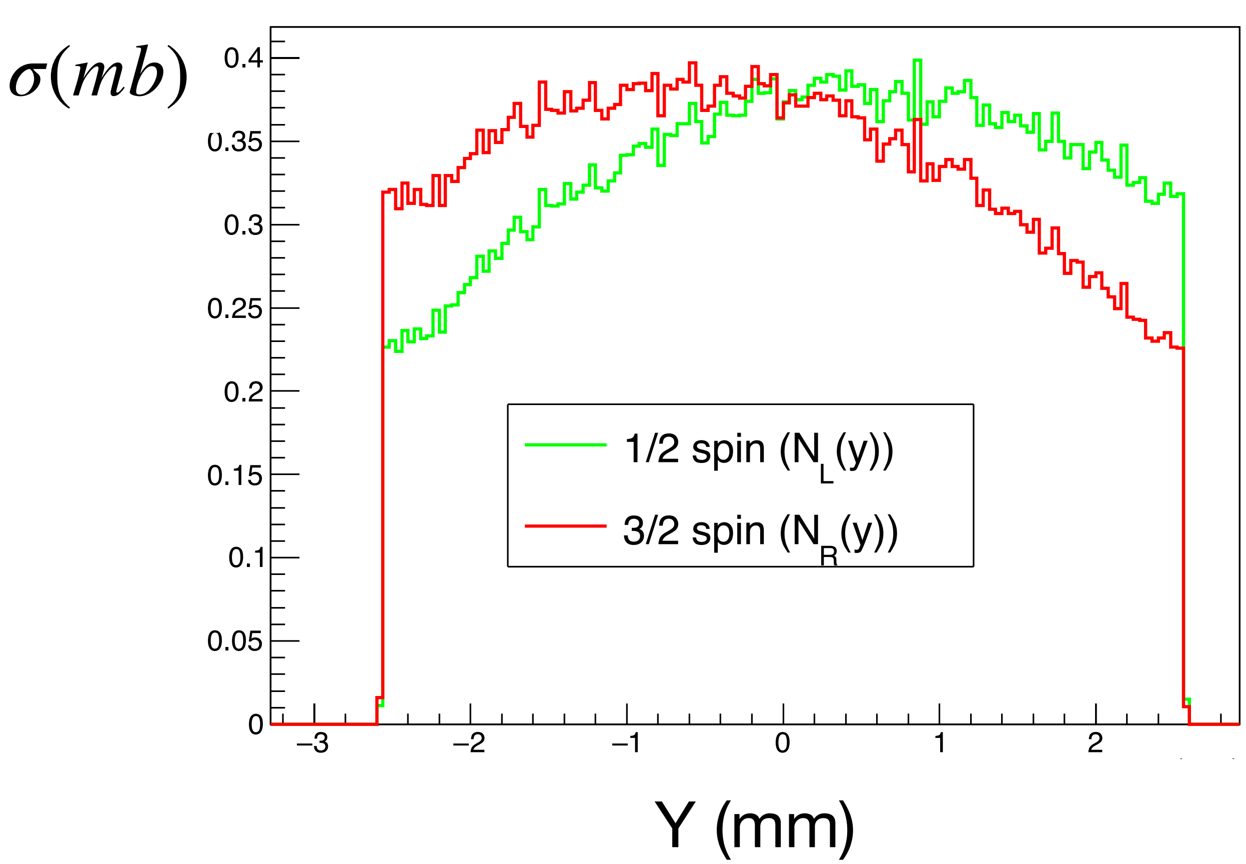
$$\beta_y < 3000cm; \sigma_{y'} < 8\mu rad \rightarrow \ \sigma(4000) < 250\mu m$$

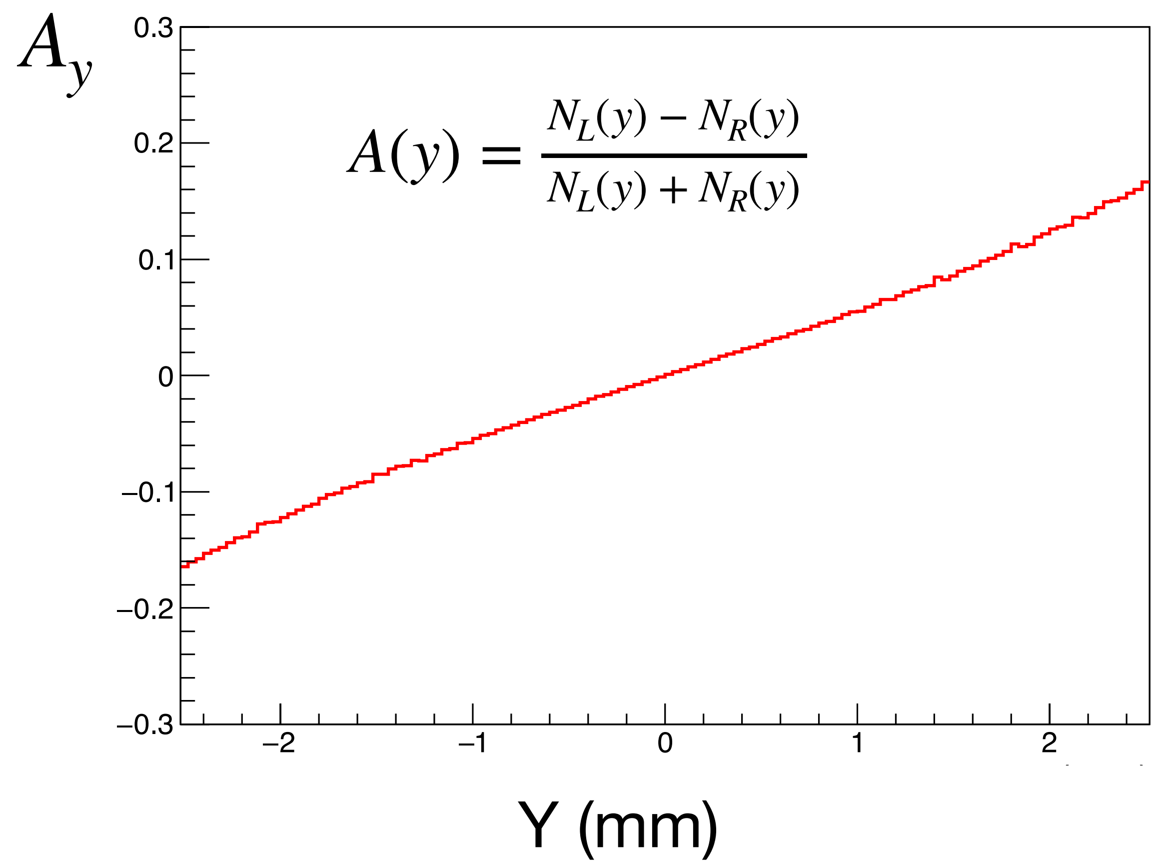
Summary

- For now, the polarimeter is in IR12;
- Can we meet the requirements for the magnets?
- We may need to optimize the beam condition in the interaction point of the Compton scattering polarimeter;
- We may discuss the Møller polarimeter in RCS in the near future;

backup

Transverse polarization

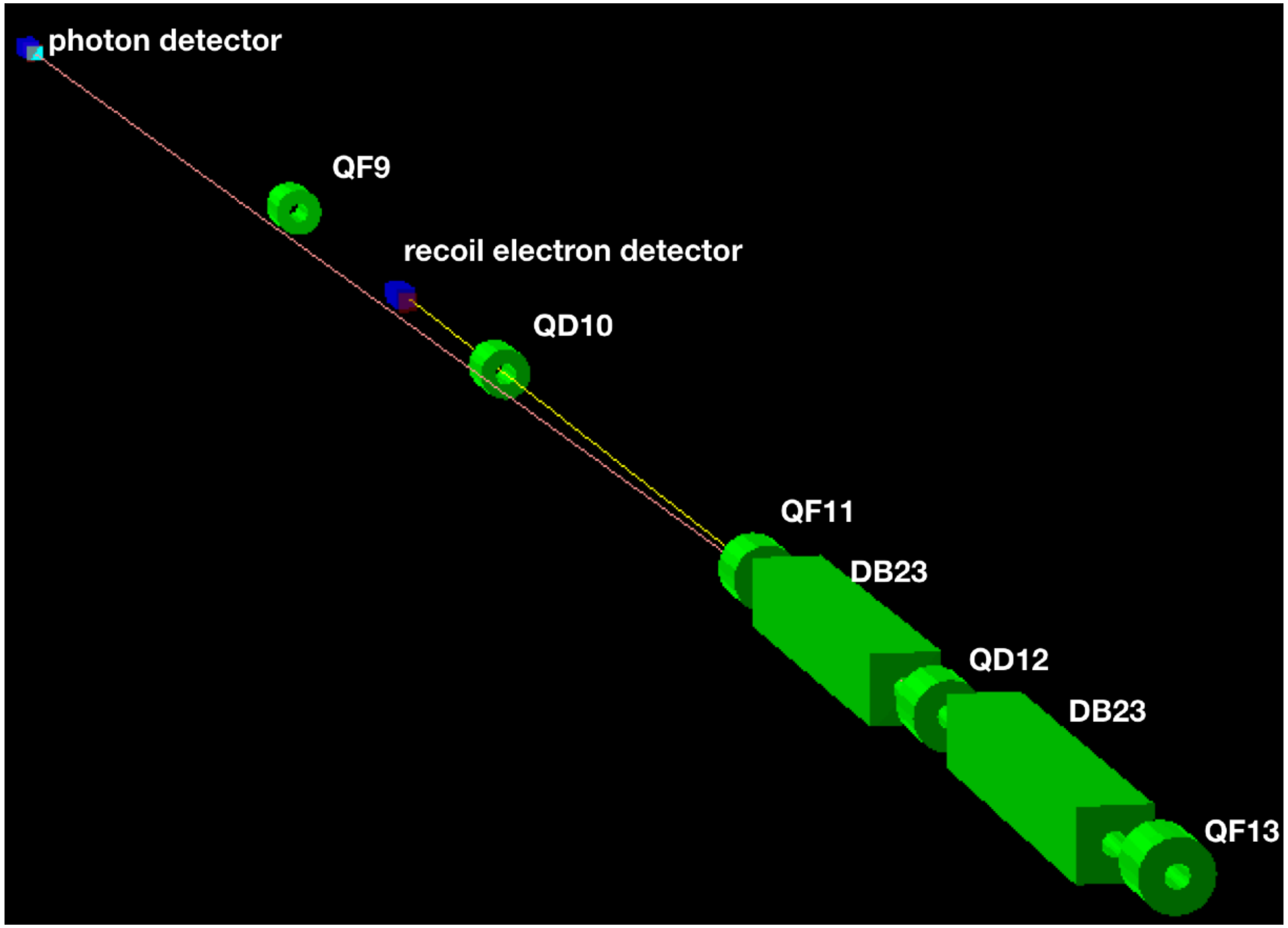




$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-} = P_e P_\gamma A_y$$

$$P_e = \frac{A_{exp}}{P_\gamma A_y}$$

IR12 layout



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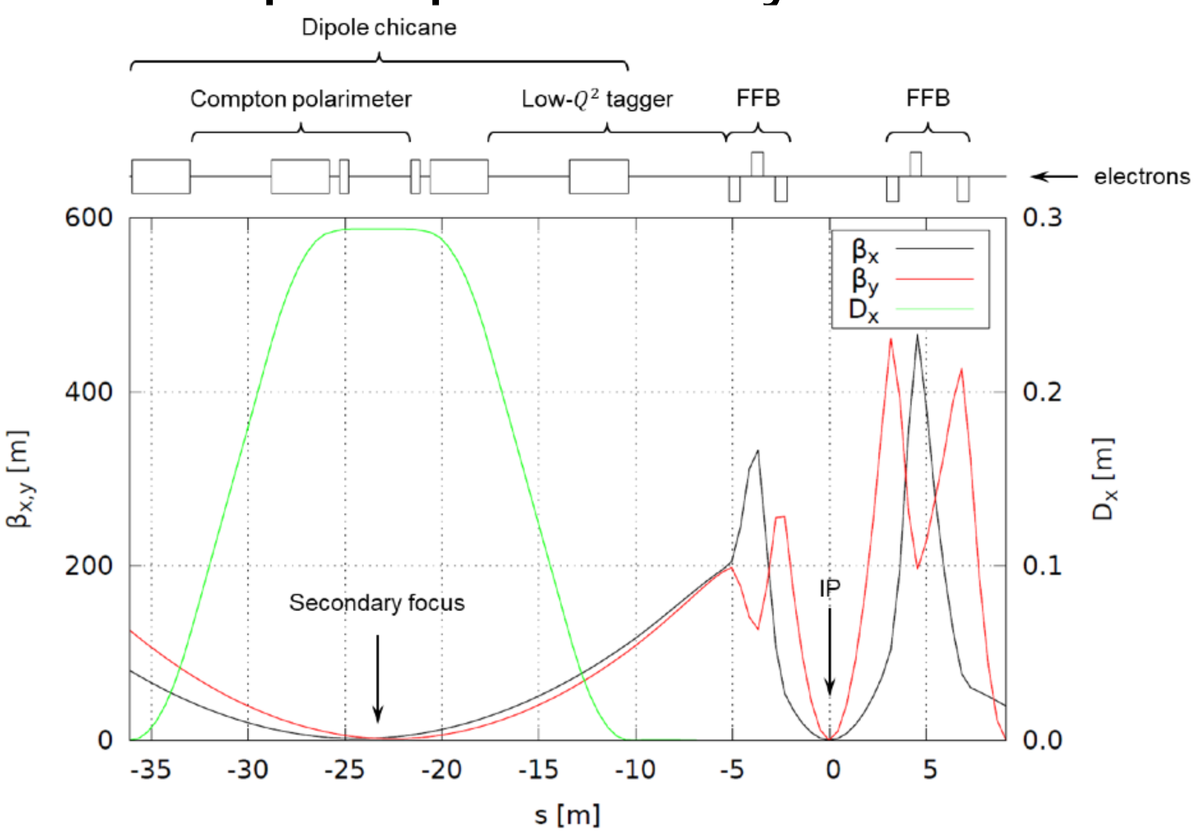
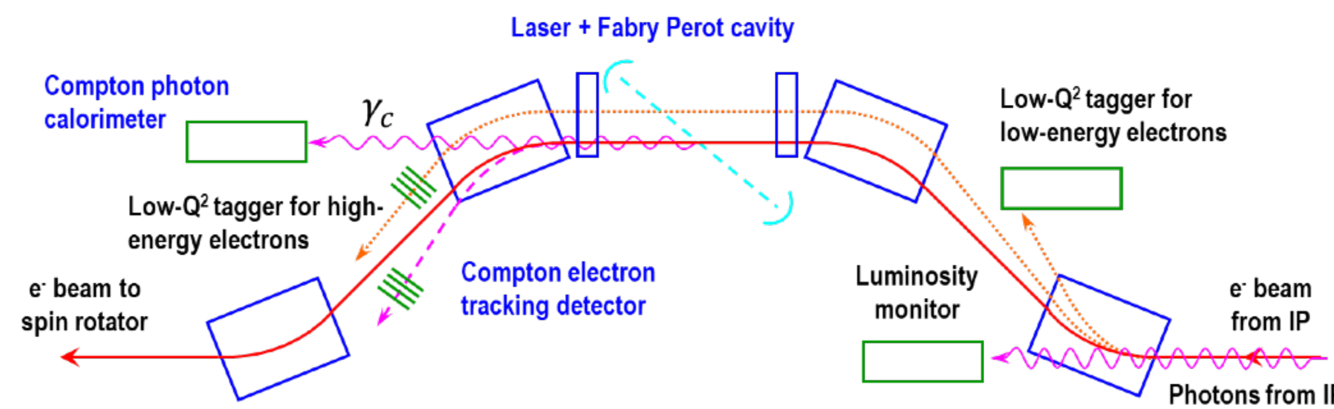
Polarization Measurement

- Dipole chicane downstream of IP: same polarization at laser as at IP due to zero net bend
- Compton polarimetry: non-invasive monitoring of electron polarization



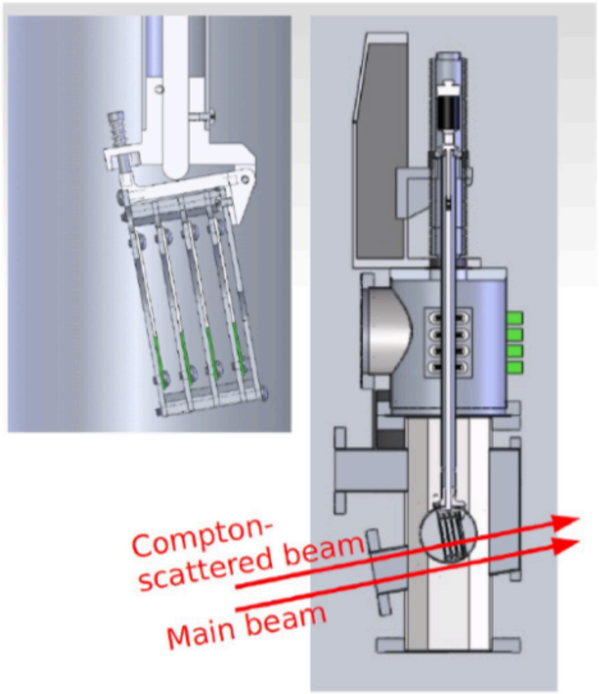


Compton Electron Detector R&D Project

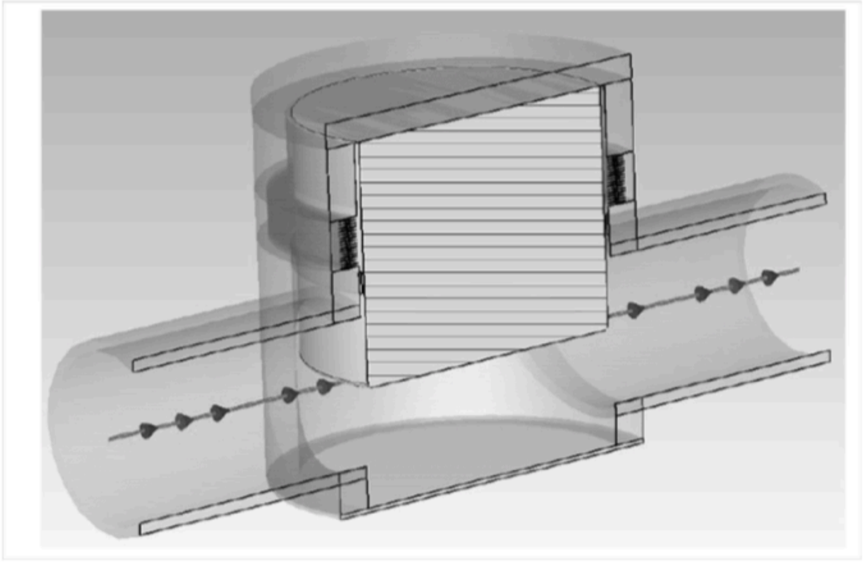
EIC Detector R&D Project for development of electron detection scheme for Compton polarimetry (A. Camsonne, J. Hoskins, et. al.)

→ Default design based on diamond strip detectors similar to those used in Hall C at JLab, but placed in Roman Pot rather than beam vacuum

→ Simulations targeted at understanding backgrounds and studying achievable precision



TOTEM Roman Pot



Recoil electron positon