Luminosity monitor and electron Compton polarimeter

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Luminosity monitor

- Absolute luminosity defined by bunch density, revolution frequency, effective cross section

$$L = \frac{\Sigma_i N_e^i N_p^i f}{2\pi\sqrt{\sigma_{xp}^2 + \sigma_{xe}^2} \cdot \sqrt{\sigma_{yp}^2 + \sigma_{ye}^2}}$$

N_e^i : number of electron in the i^{th} bunch
N_p^i : number of proton in the i^{th} bunch
f : beam revolution frequency
σ_{xp} : spatial spread of proton bunch in x coordinate

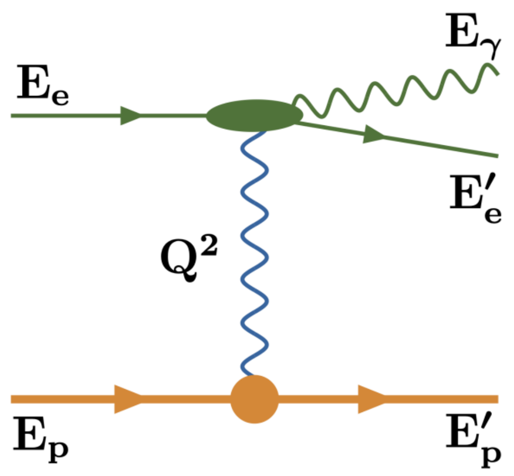
- Luminosity monitoring needs relying on processes with **large and well-known** cross-section

$$L = R/\sigma$$

R: event rate ; σ: cross-section

Bremsstrahlung

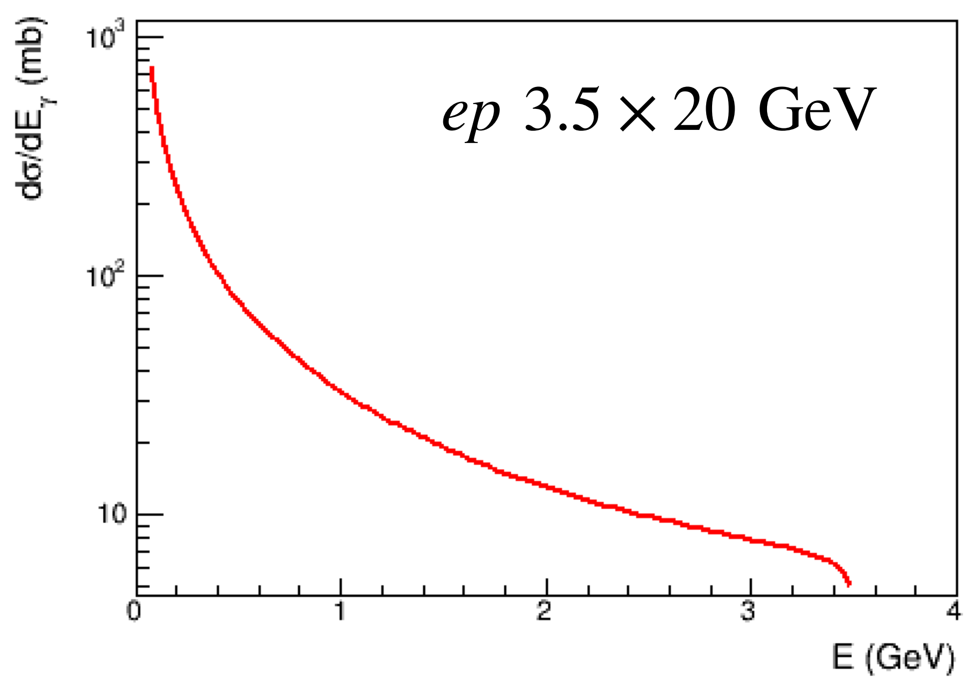
- $e + p \rightarrow e + p + \gamma$

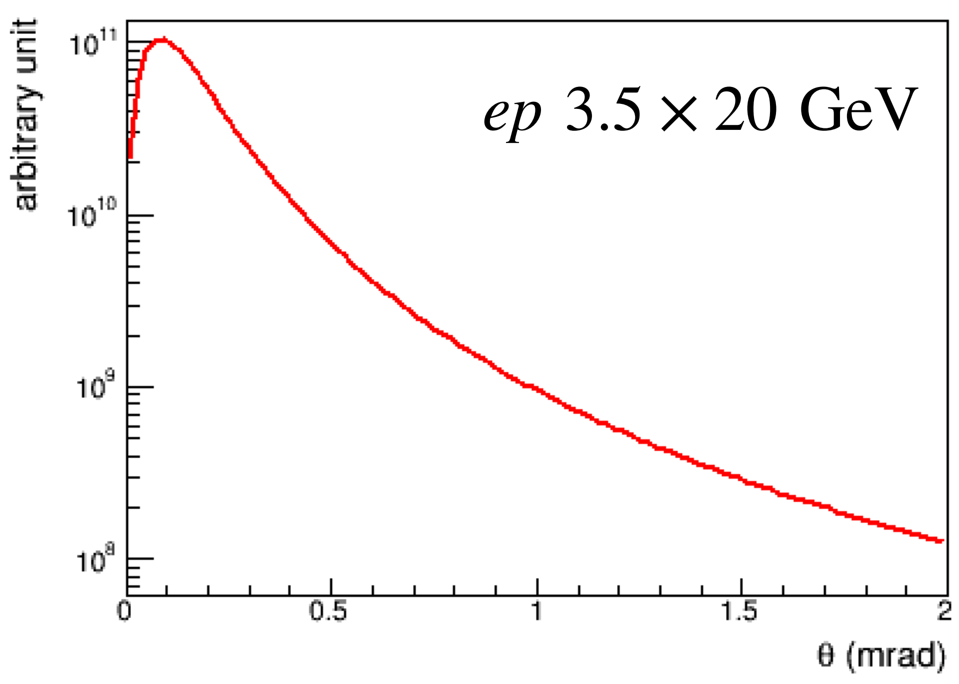


Bethe-Heitler formula

$$\frac{d\sigma}{dE_\gamma} = 4\alpha r_e^2 \frac{E'_e}{E_\gamma E_e}\left(\frac{E_e}{E'_e} + \frac{E'_e}{E_e} - \frac{2}{3}\right)\left(\ln\frac{4\mathrm{E_p E_e E'_e}}{\mathrm{m_p m_e E_\gamma}} - \frac{1}{2}\right)$$

$$\frac{d\sigma}{d\Theta_\gamma} \sim \frac{\Theta_\gamma}{((m_e/E_e)^2 + \Theta_\gamma^2)^2}$$





Luminosity monitoring at other experiments

ZEUS

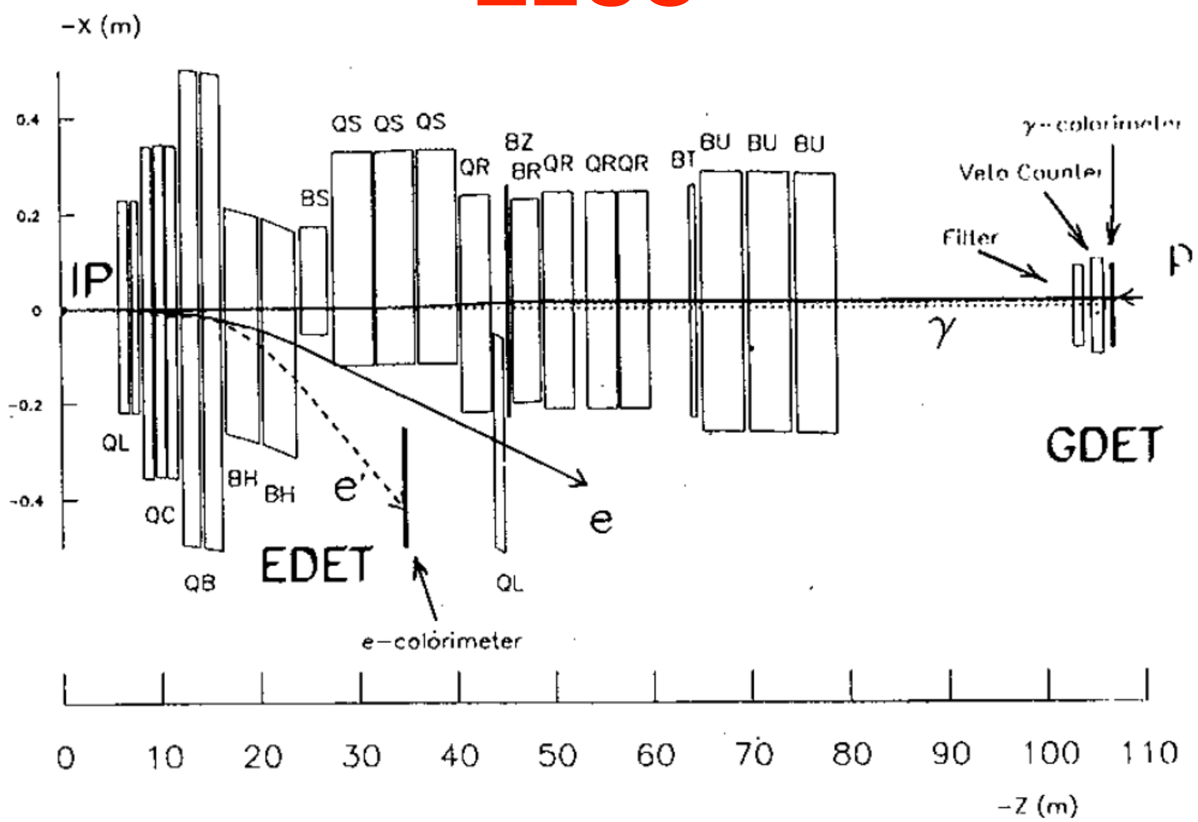


Figure 1: General layout of the luminosity detectors.

US EIC

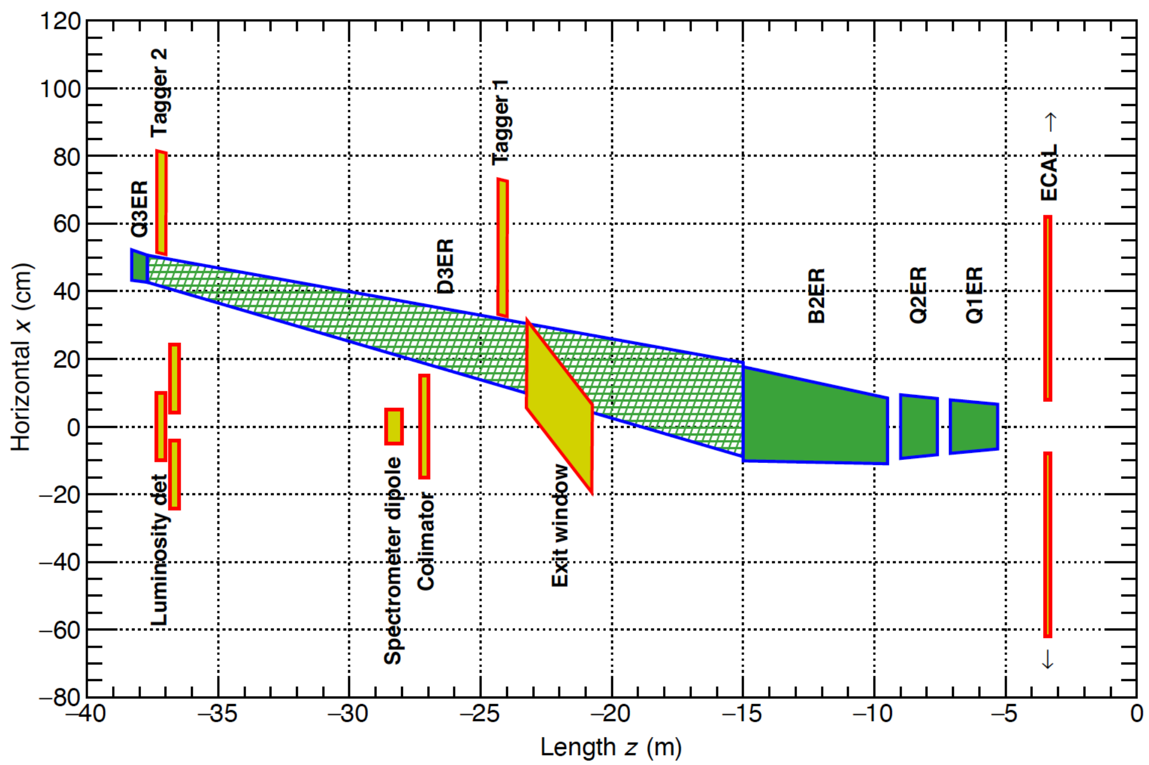


Figure 11.109: The region downstream of the interaction point in the electron direction.

Challenging measurement

Challenging, but successful at HERA (~1.7% uncertainty)

More challenging at high luminosity EIC and EicC

- High event pile-up with increasing luminosity and ion Z
- High synchrotron radiation background
- Beam crossing angle effect
- Both beams are polarized: $\sigma_{\text{brems}} = \sigma_0(1 + a(P_e, P_h))$

Luminosity monitor for EicC

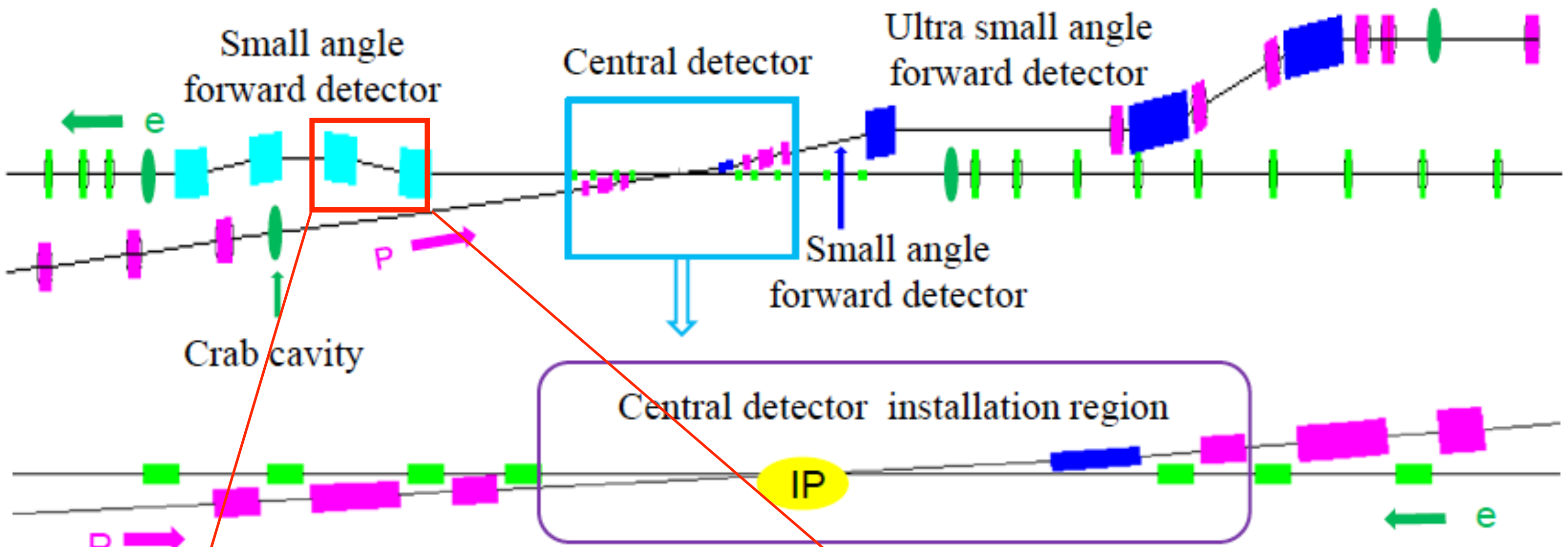
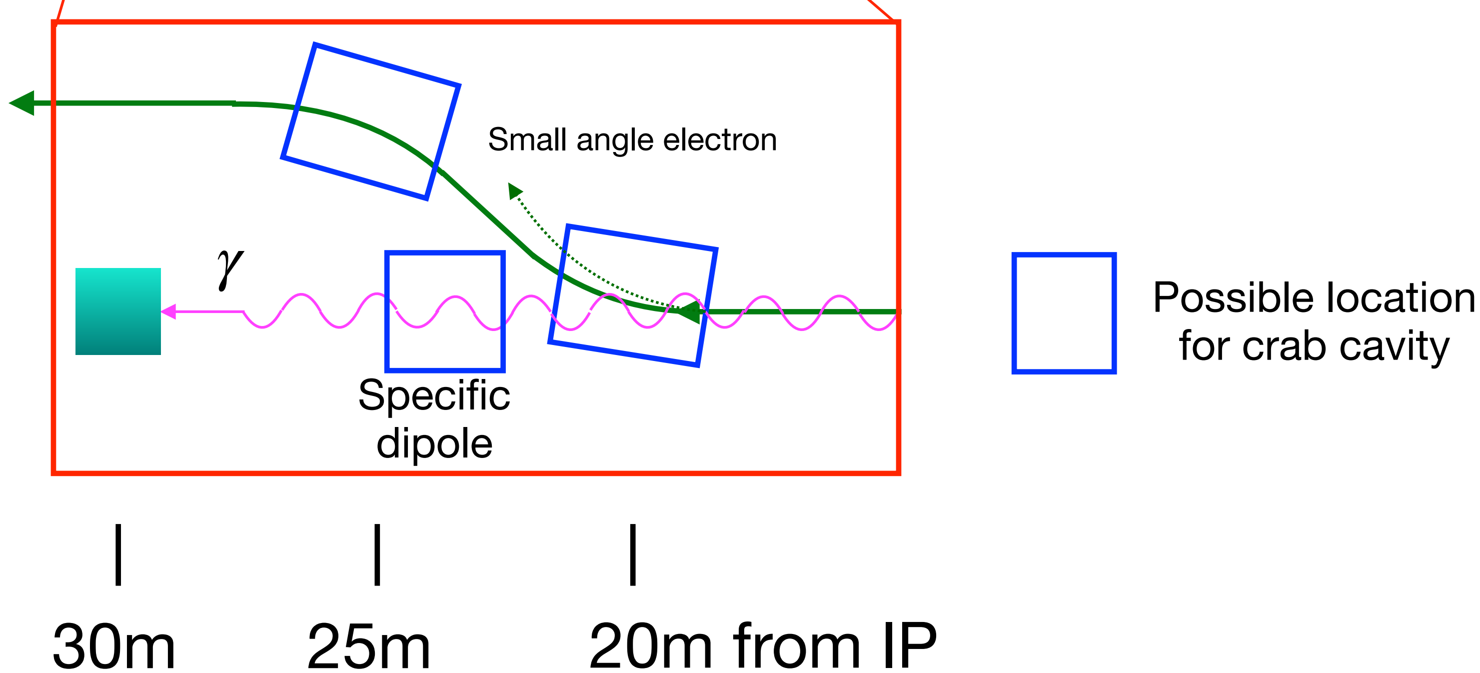


Figure 3.8: The interaction region of the EicC accelerator facility.



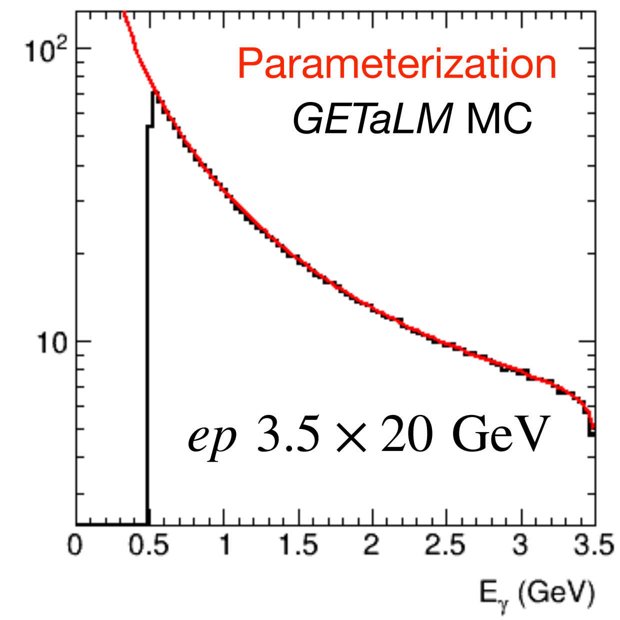
Thanks to *Xiao Ding (IMP)*

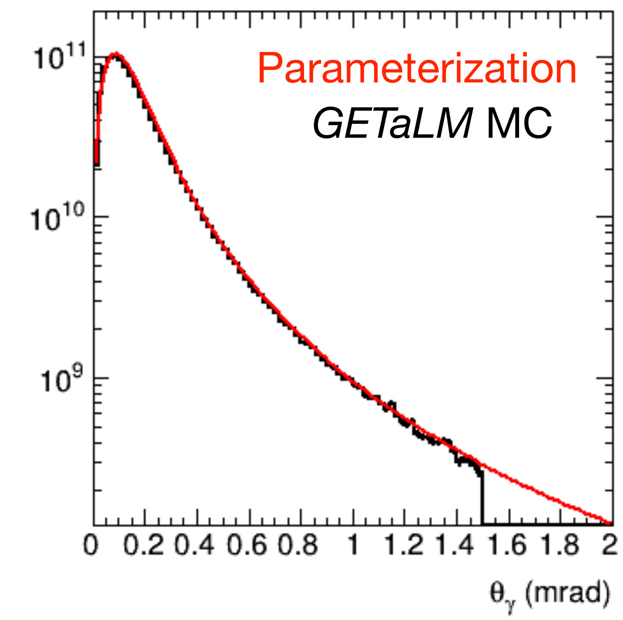
Bremsstrahlung fast simulation

GETaLM **-** Generator for Electron Tagger and Luminosity Monitor

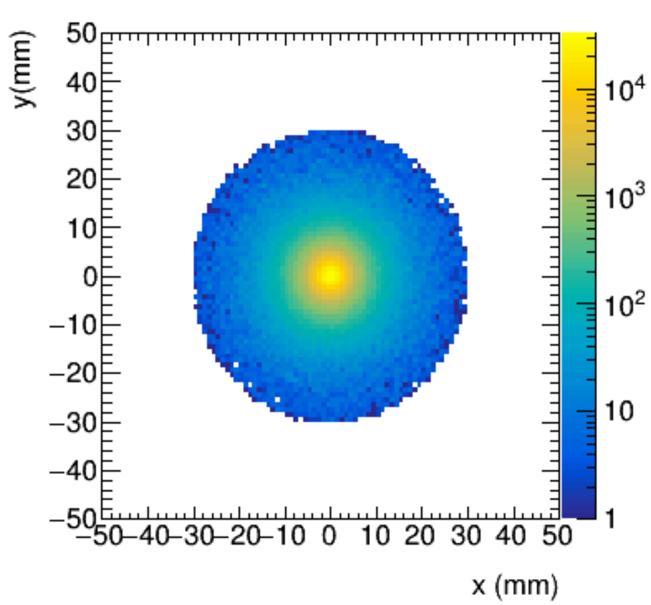
J. Adam, Com. Phys. Com. 272, 108251 (2022)

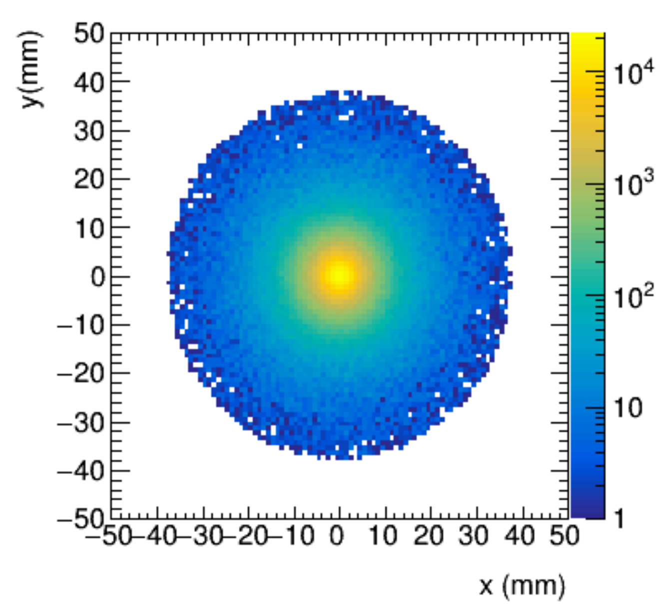
https://github.com/adamjaro/GETaLM

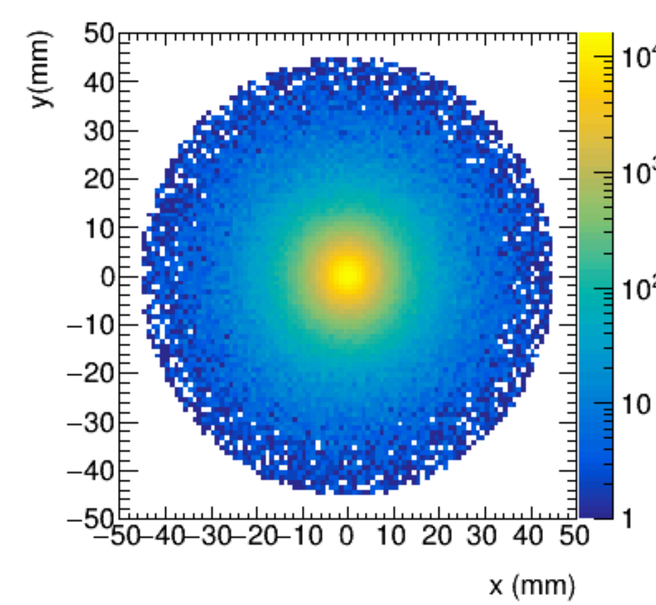




- Photon spot at z = 20m z = 25m z = 30m







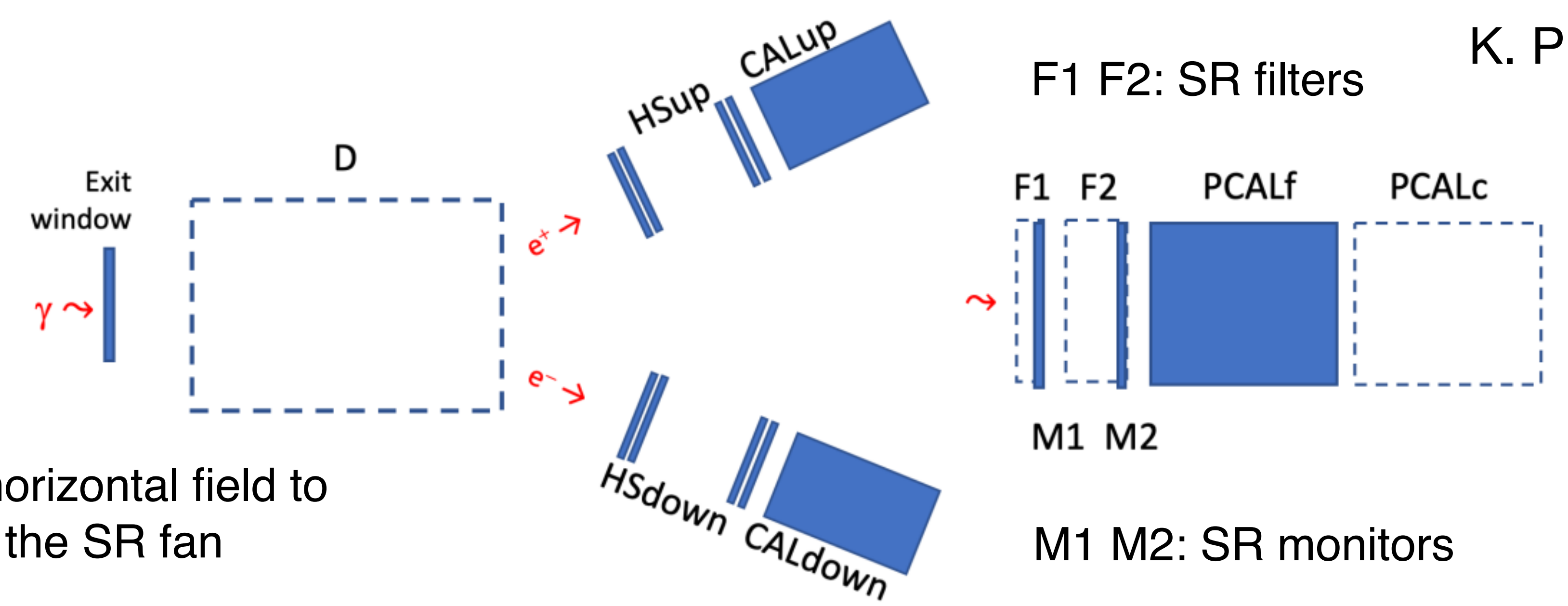
Detector concept

- Following example of ZEUS and EIC
- Two separate methods to detect the bremsstrahlung photons
  - Photon conversion to e+e- for precise luminosity calibration
  - Direct photon detection for instantaneous luminosity monitoring

K. Piotrzkowski 2021

Exit window: as thin as possible to reduce spectrometer event multiplicity

F1 F2: SR filters



Spectrometer dipole: horizontal field to bend e^+e^- away from the SR fan

M1 M2: SR monitors

Figure 3. Conceptual layout of the bremsstrahlung photon detection setup (side view), composed of two parts. The spectrometer part will measure the e^+e^- pairs from the photon conversion in the exit window, and consists of a small dipole magnet D with adjustable horizontal field, two calorimeters, CALup and CALdown, and two hodoscopes, HSup and HSdown. The direct part will measure the unconverted photons and includes two movable calorimeters, PCALf and PCALc, for use at high and low luminosity, respectively, and two different SR filters, F1 and F2, which can be remotely inserted, and are instrumented with the SR monitors, M1 and M2.

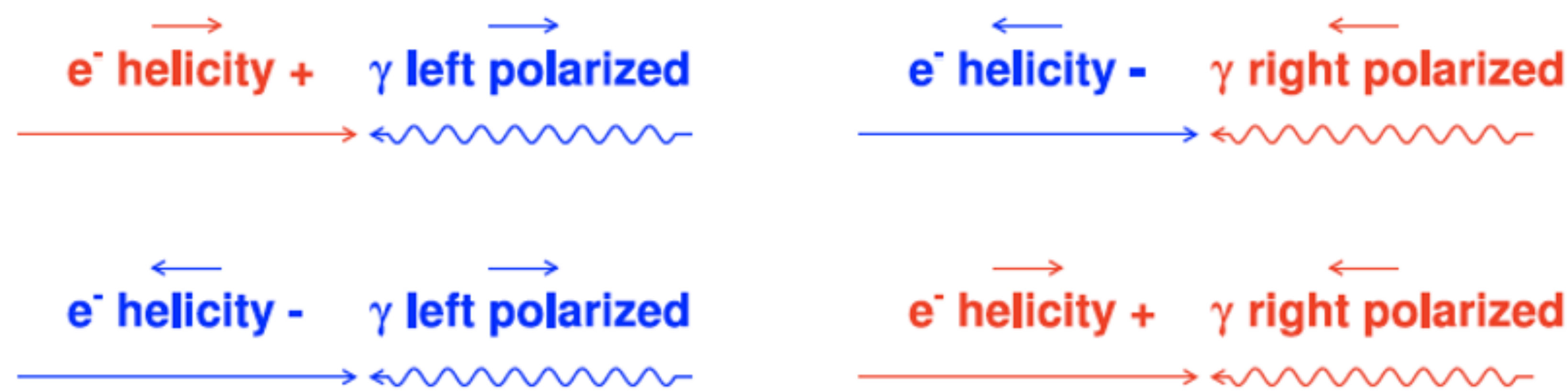
Luminosity monitor in CDR

1. Motivation and principals
2. History review
3. Conceptual design
4. Fast simulation of Bremsstrahlung process
5. Detector concept
6. Discussion

Electron beam polarimetry

- Requirements:
  - Non-destructive to beam
  - 1% or better precision
  - Bunch by bunch
  - Rapid and provide timely feedback to injector
- Basic principle： $A_{measured} = P_{beam} P_{target} A_{physics}$
- Options:
  - MOLLER: $\vec{e}\vec{e} \rightarrow ee$, JLab Hall A/C
  - COMPTON: $\vec{e}\vec{\gamma} \rightarrow e\gamma$, **HERA**, SLAC, JLab Hall A/C

Compton polarimetry

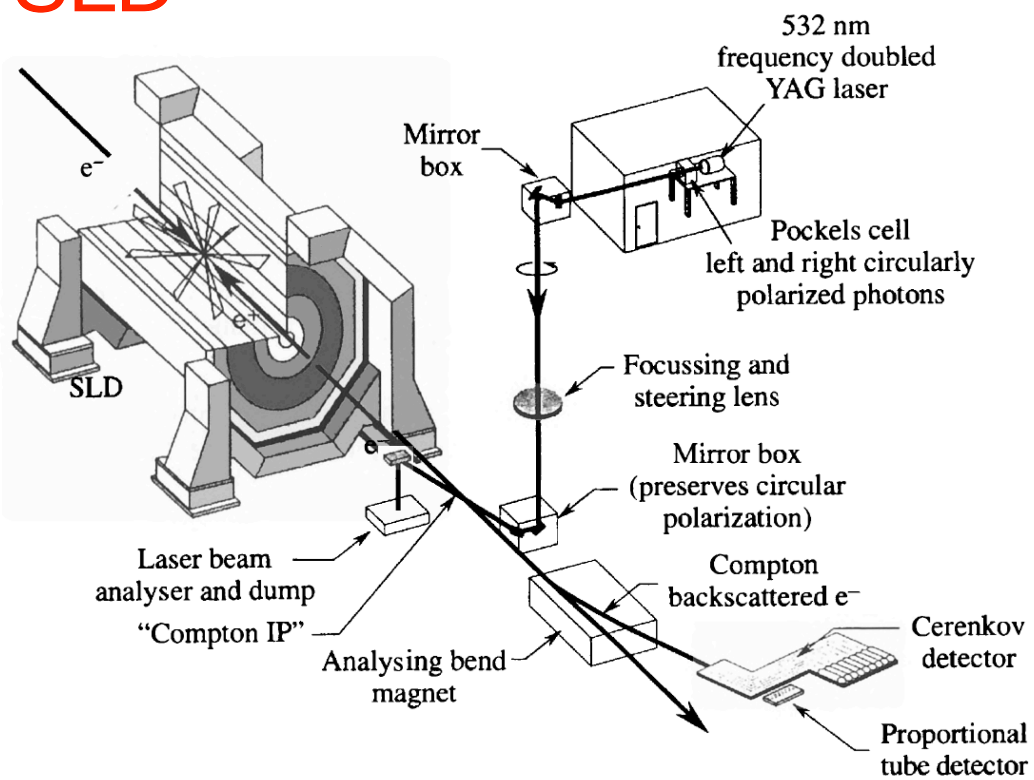


$$\left(\frac{d\sigma}{d\rho}\right)_{Compton} = \left(\frac{d\sigma}{d\rho}\right)_{Unpolarized}[1 + P_\gamma P_e A_l(\rho)] \qquad P_e = \frac{A_{measured}}{P_\gamma A_l}$$

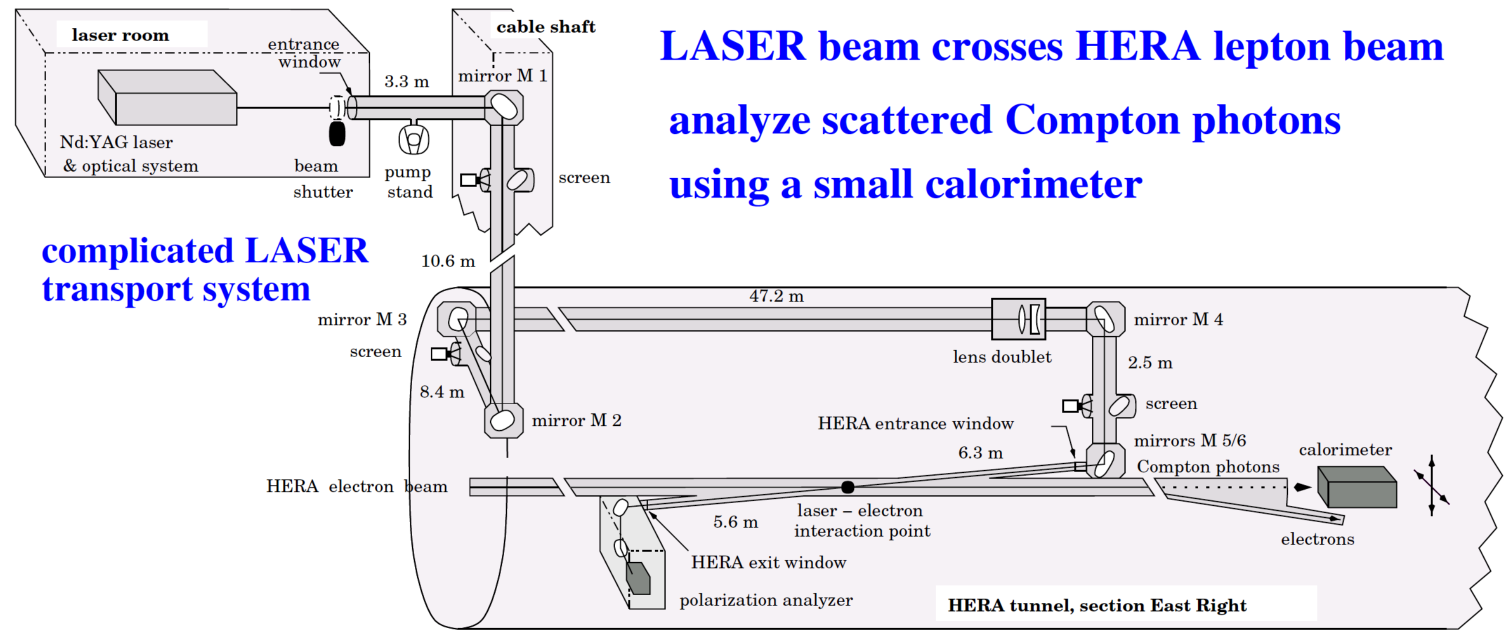
- Quasi-head-on collision with high-power 100% circularly polarized laser
- Independent detectors for electron and photon of $\vec{e}\vec{\gamma} \to e\gamma$
- Noninvasive and continuous measurement of asymmetries between left and right handed laser polarization states

Compton at other experiments

SLD



HERA



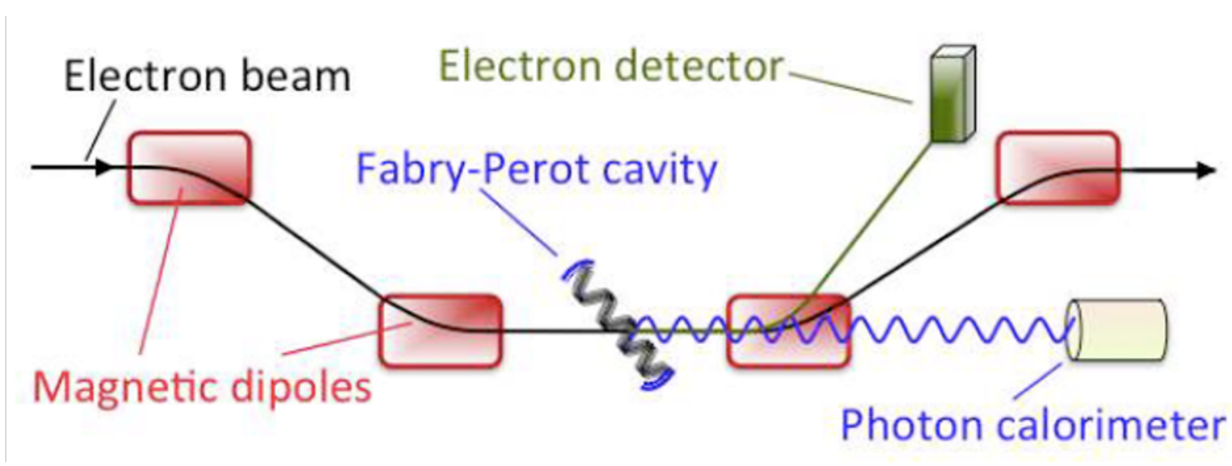
LASER beam crosses HERA lepton beam

analyze scattered Compton photons

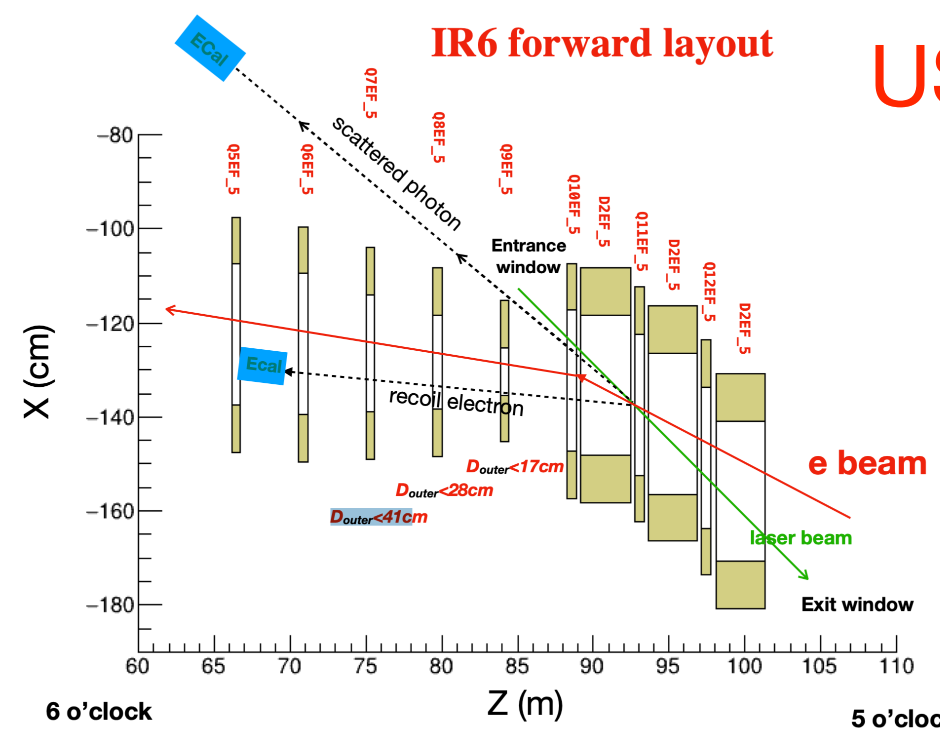
using a small calorimeter

complicated LASER transport system

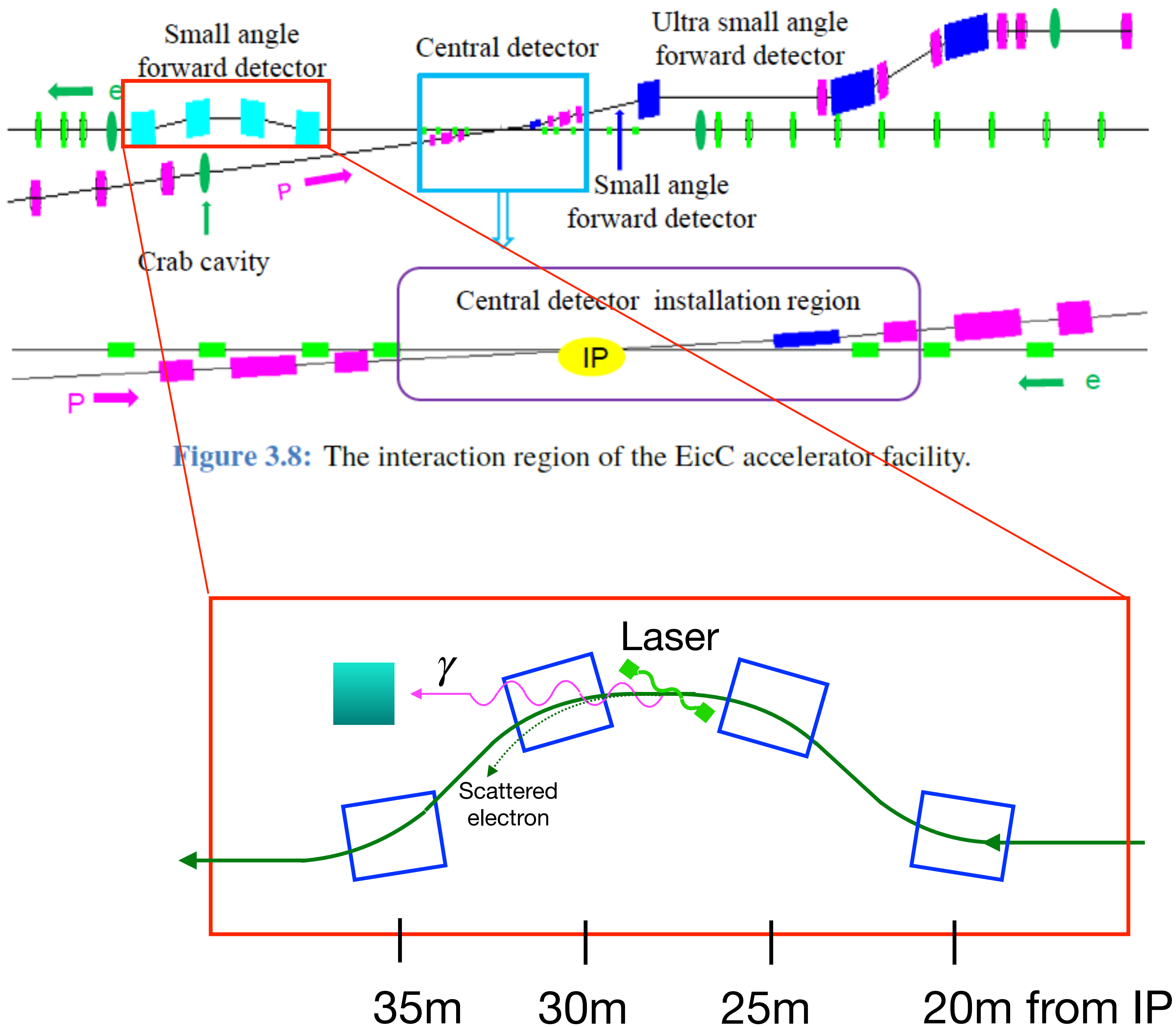
JLab



US EIC



Compton for EicC

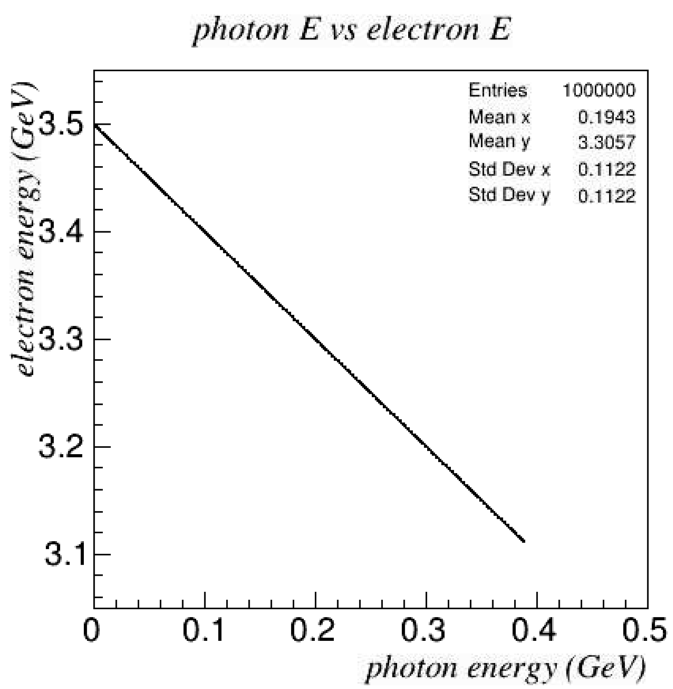


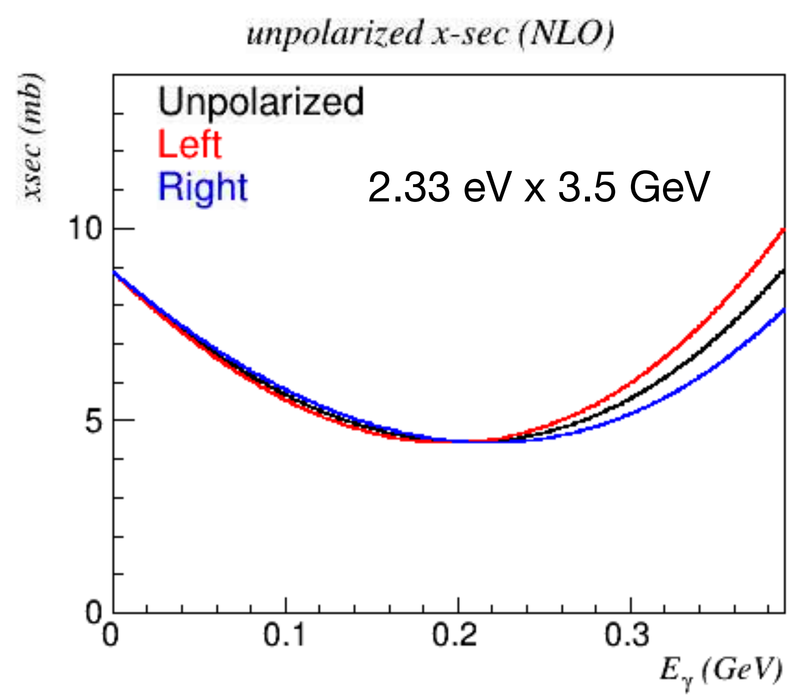
Compton fast simulation

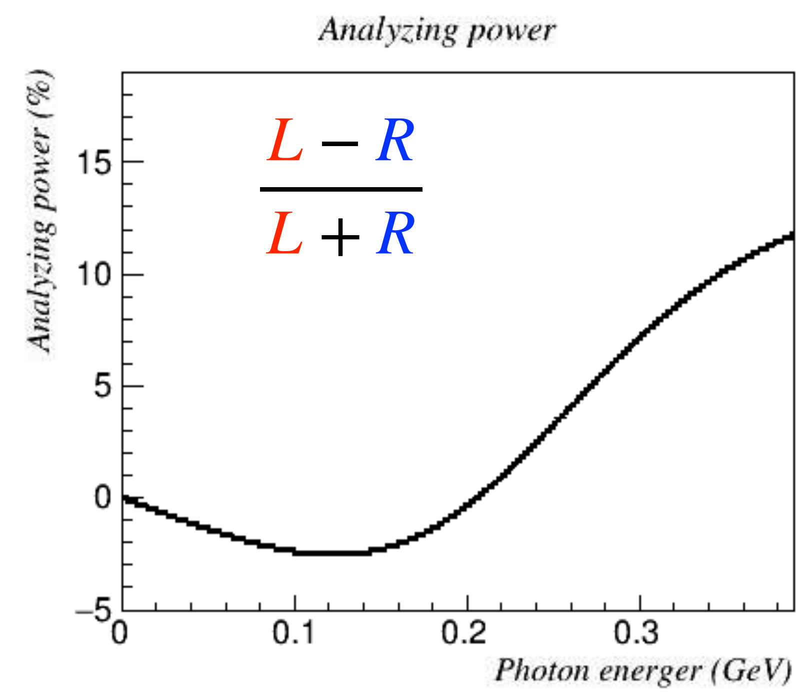
COMRAD generator

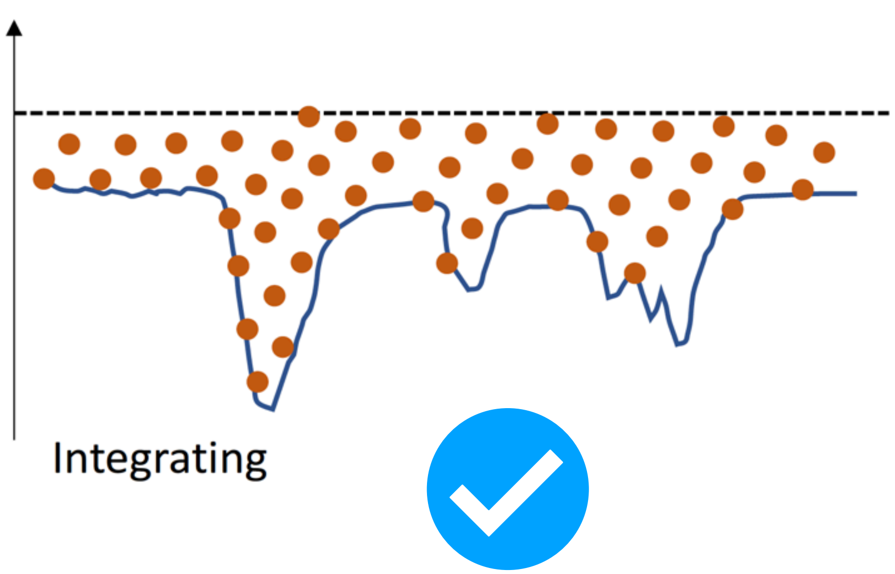
Electron beam energy: 3.5 GeV; Photon energy: 2.33 eV (532nm)

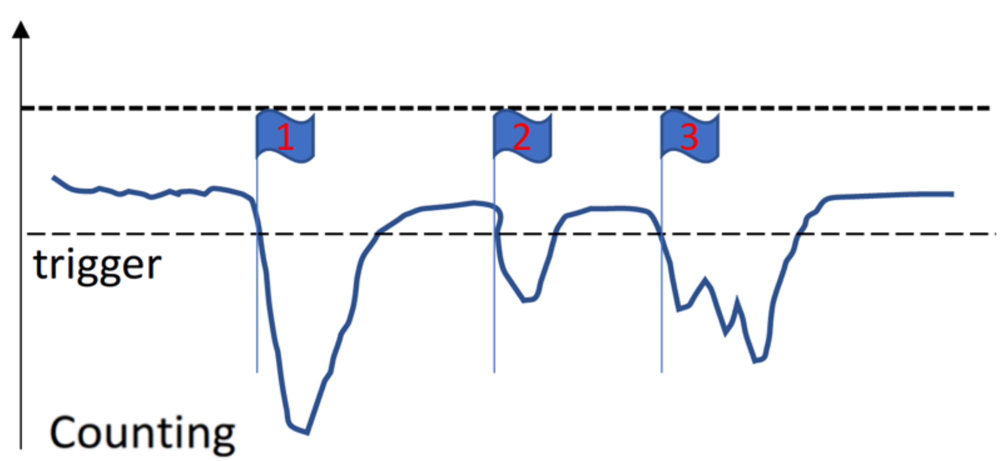
100% polarized



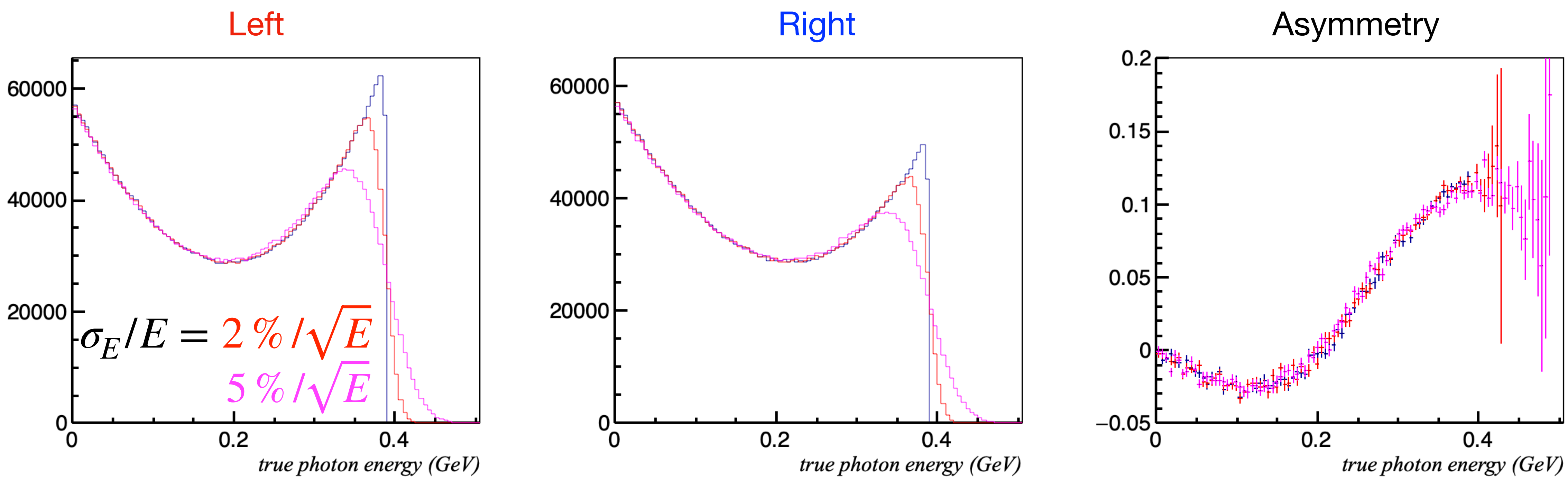








Requirement of energy resolution



asymmetry (true): 0.0260 +/- 0.0004
asymmetry (2%/√E): 0.0260 +/- 0.0004
asymmetry (5%/√E): 0.0261 +/- 0.0004

- Smear energy with 2%/√E and 5%/√E
- Negligible impact comparing to statistical uncertainty

Challenge: bunch by bunch

Problem:

eRing: 500 MHz RF; 270 Bunches; Circumferences 809.44 m (EicC white paper)

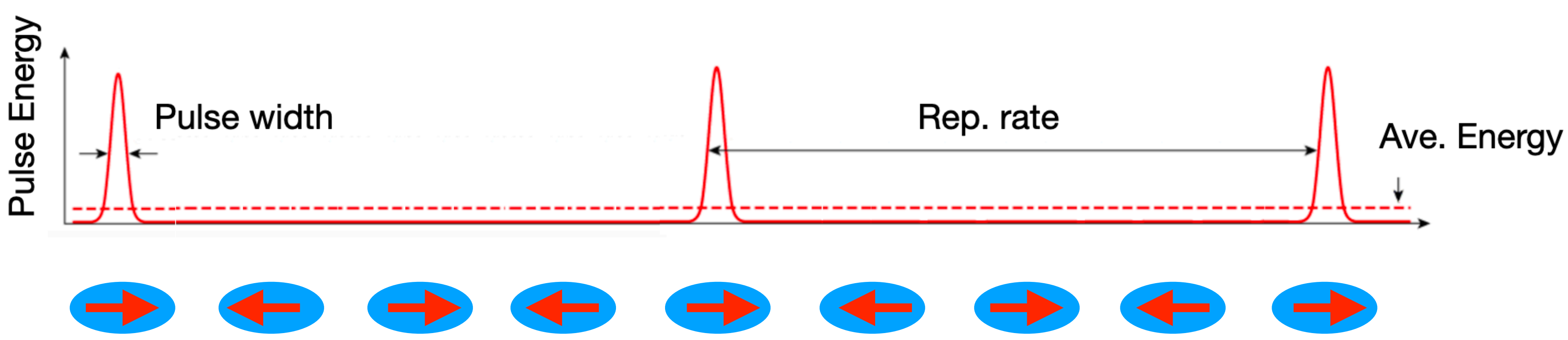
Time gap between neighboring bunches are very short, ~nanosecond

Calorimeter + electronics can not distinguish signals from neighboring bunches

Solution (US EIC):

Enlarge time gap between neighboring scattered bunches by using **pulsed** laser

Short (~30ps) and dense laser pulse with fine controller and precise timing, can pick up any bunches.



Electron polarimetry in CDR

1. Motivation and principals
2. History review
3. Conceptual design of Compton
4. Fast simulation of Compton process
5. Discussion of laser target
6. Discussion of other options beside Compton

Summary

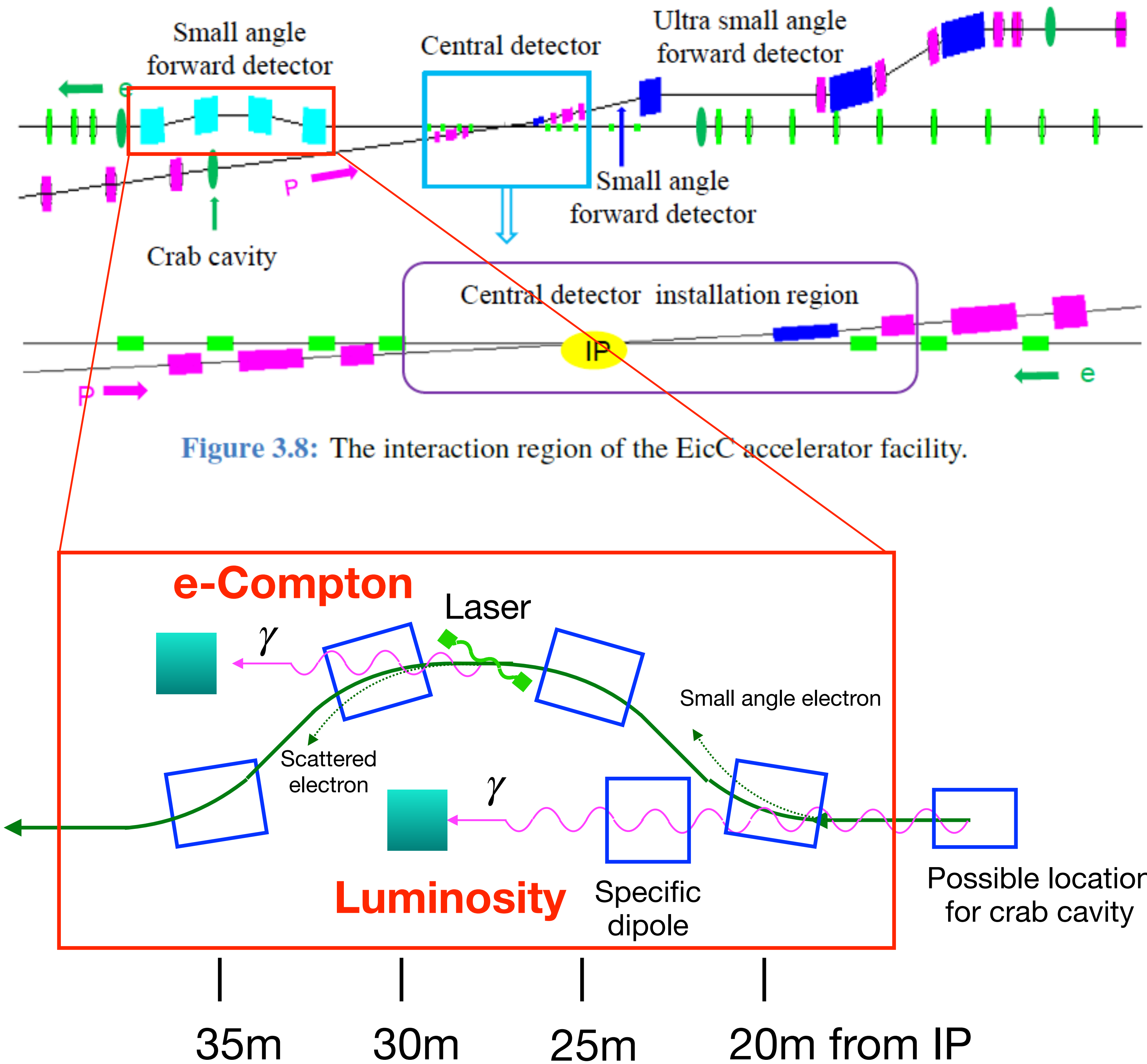


Figure 3.8: The interaction region of the EicC accelerator facility.

- Luminosity monitor and polarimetry are largely independent and essentially supportive "experiments"
- Relatively simpler subsystems but complex requirement overall e.g. coordination with accelerator, specific calorimeter and DAQ systems, etc.
- CDR draft is being updated.

Thank you !