# *Electron Polarimetry at JLEIC (Jefferson Lab Electron-Ion Collider)*

Dave Gaskell
Jefferson lab

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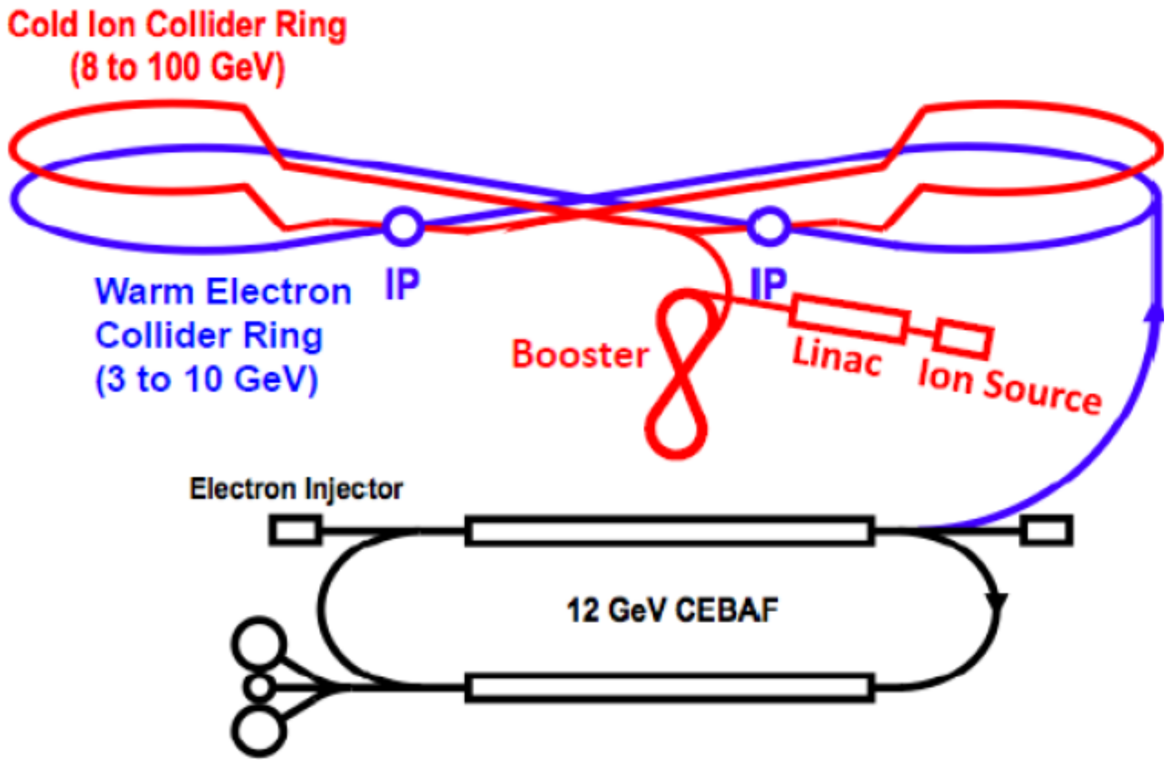
# Outline

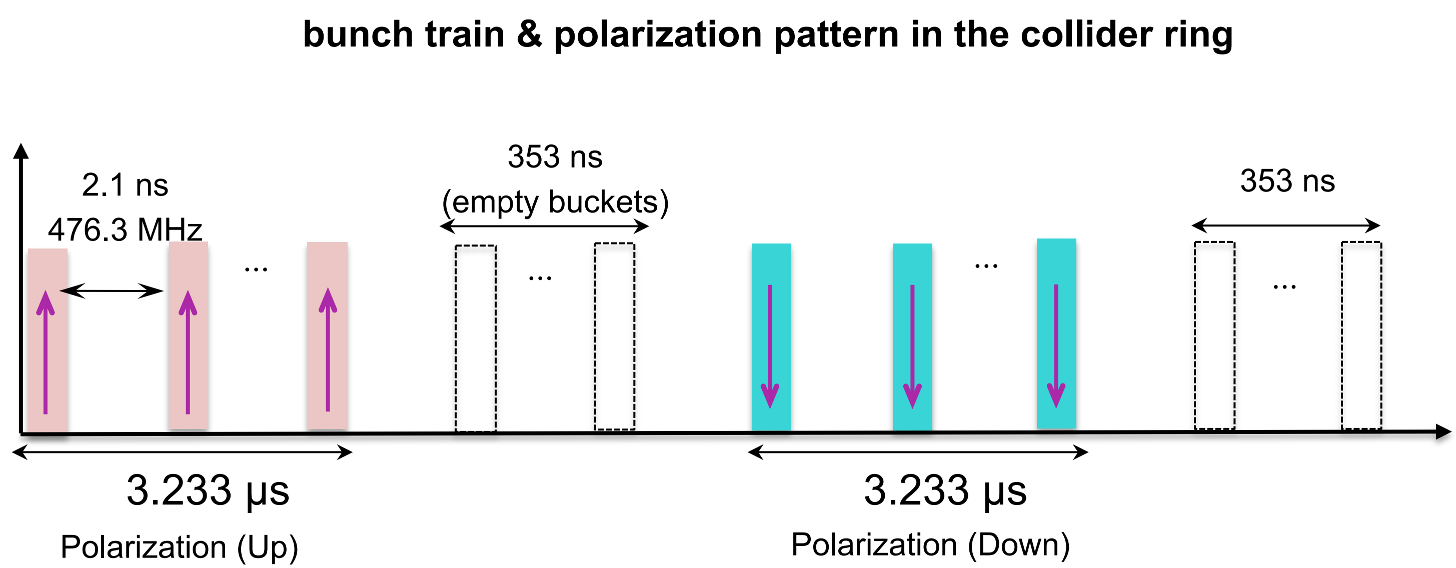
- JLEIC electron beam
- Chicane for low-$Q^2$ tagging and Compton polarimetry
- Compton polarimetry - experience at JLab
- Polarimeter “baseline” design
- Future polarimeter R&D

# JLEIC Electron Beam Structure and Polarization




- Storage ring: 476.3 MHz = 2.1 ns bunch structure
- 3 A at 5 GeV and 720 mA at 10 GeV
- 2 macrobunches with one polarization; each macrobunch = 3.2 μs

# Electron Beam Time structure

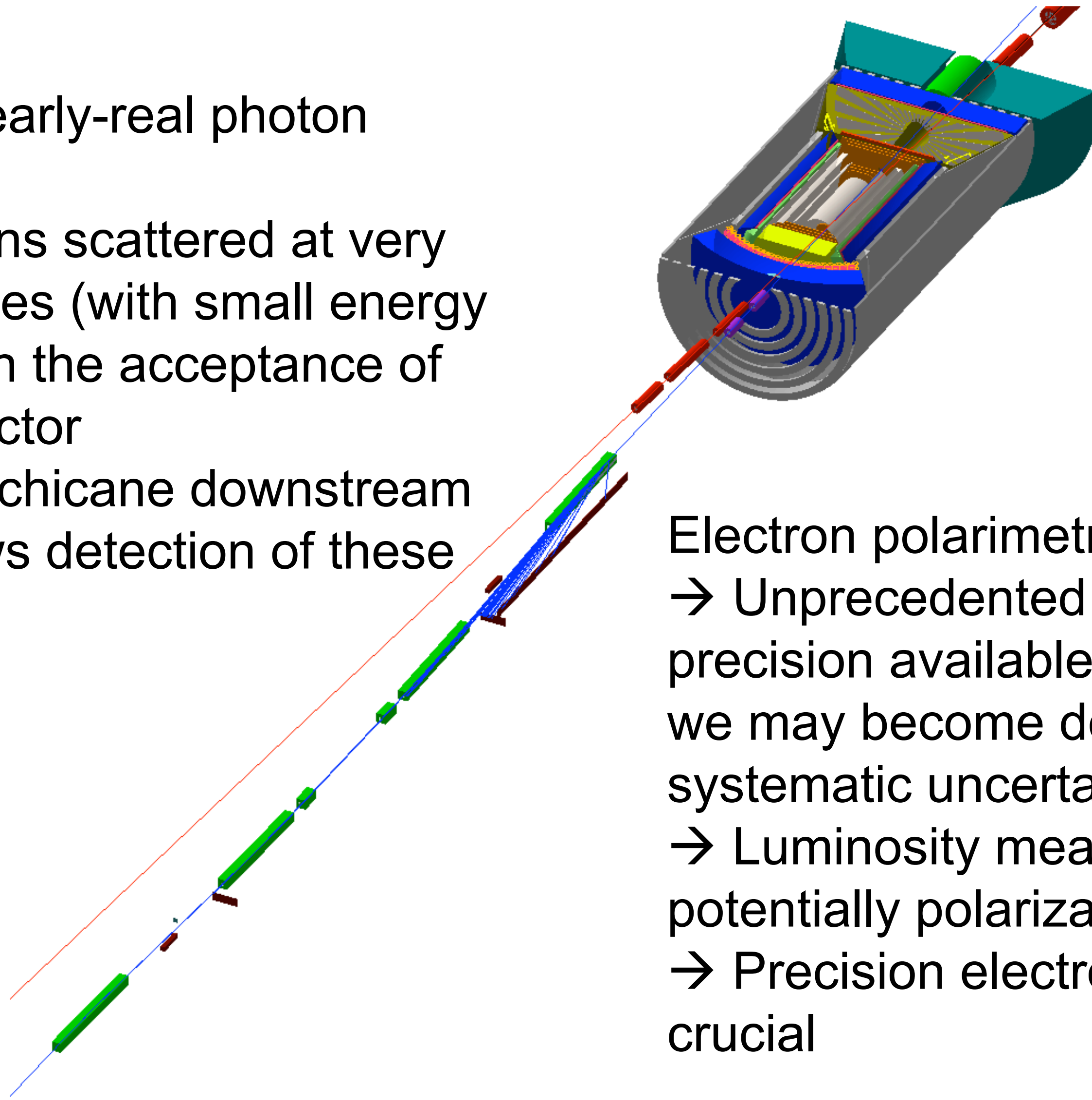



Bunch spacing = 2.1 ns
Macrobunches with opposite polarization = 3.233 μs long

1. Average polarization of beam in ring can be measured with single laser helicity
2. Polarization of each macrobunch can be determined independently by flipping laser helicity

Note: revolution time = 7.17 μs. Flipping laser helicity may require times of order 40-50 μs, or longer

# Low $Q^2$ Tagger and Polarimetry

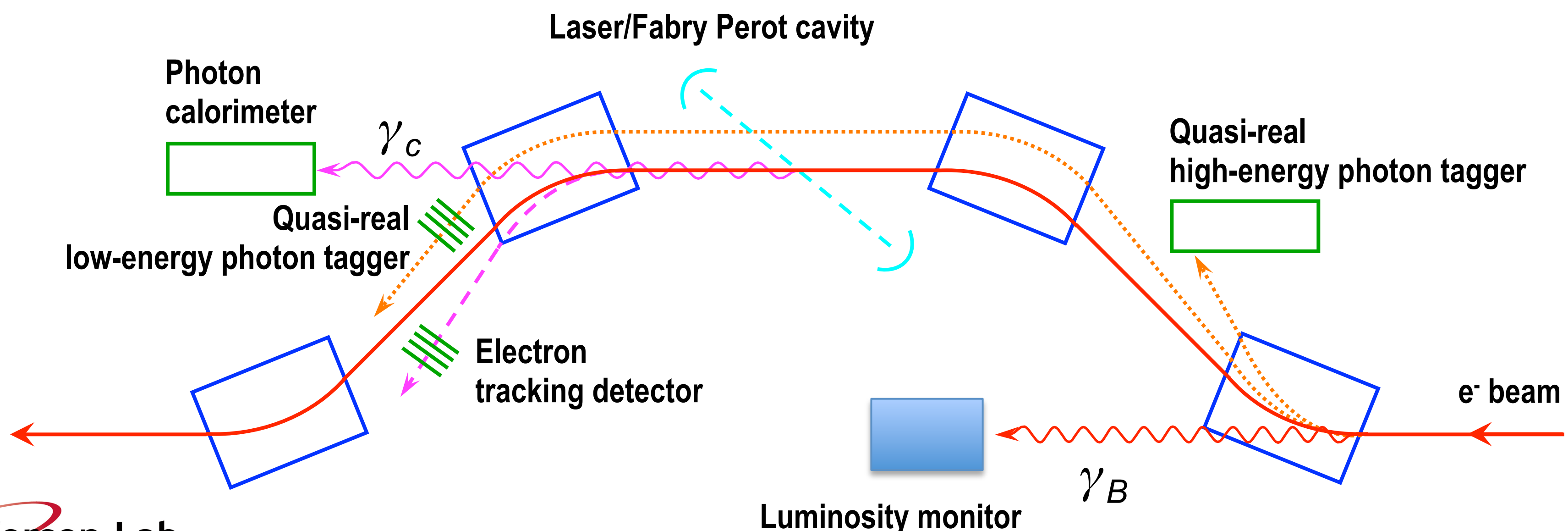


Low $Q^2$/nearly-real photon tagging:
→ Electrons scattered at very small angles (with small energy loss) not in the acceptance of main detector
→ Use of chicane downstream of IP allows detection of these electrons

Electron polarimetry:
→ Unprecedented statistical precision available at JLEIC implies we may become dominated by systematic uncertainties
→ Luminosity measurement also potentially polarization dependent
→ Precision electron polarimetry crucial

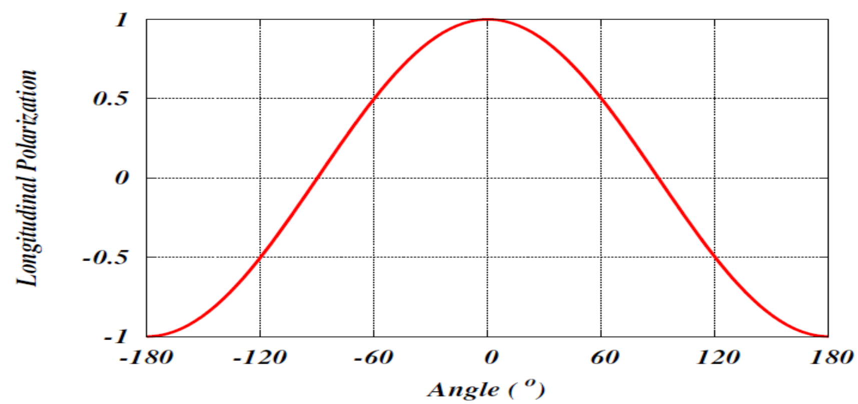
# Chicane for Low $Q^2$ tagger and Compton Polarimeter

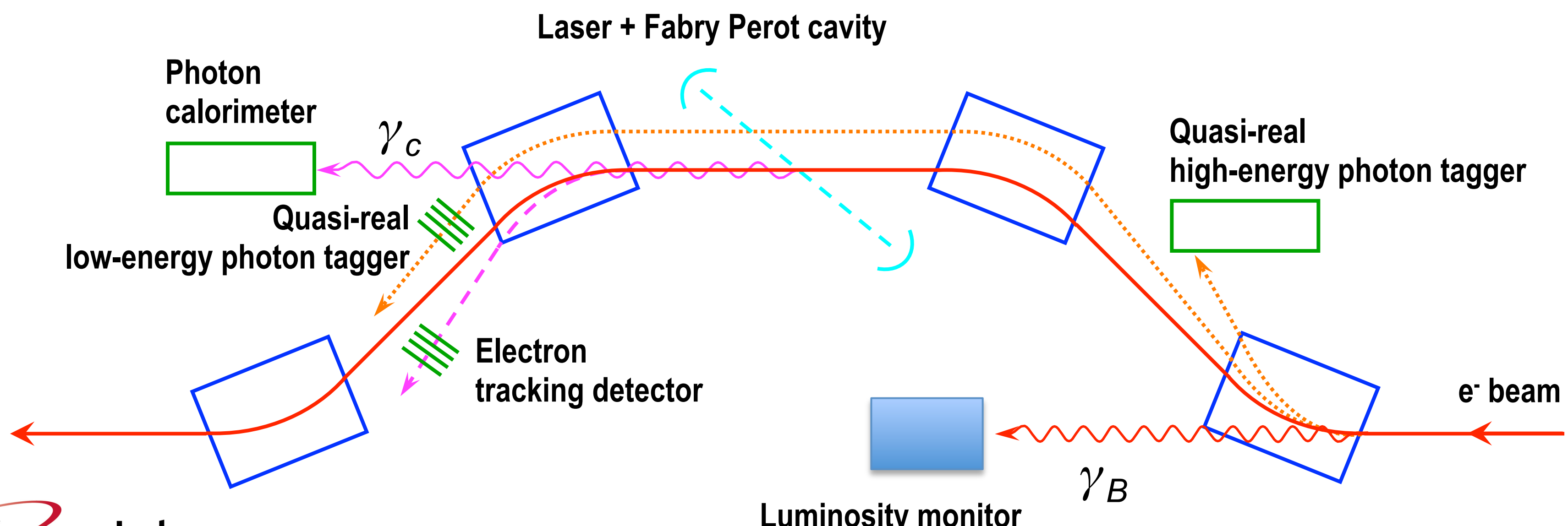
- At JLEIC, Compton can share chicane with low $Q^2$ tagger
- Laser-electron collisions in middle of chicane assures no spin rotation relative to IP
- No interference with electron detectors needed for low $Q^2$ tagger



# Chicane for Low $Q^2$ tagger and Compton Polarimeter

- → At collision with laser, electron beam has same polarization direction as at IP due to net zero bend
- → Use of spin rotators allows us to perform "spin dance" to verify longitudinal polarization at IP



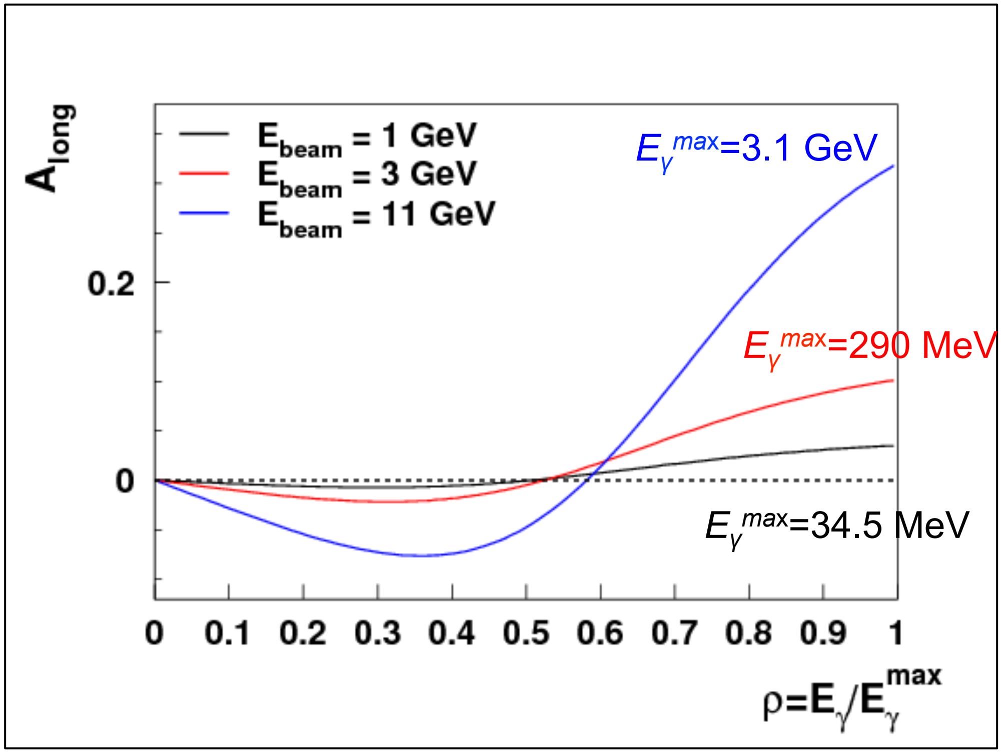



# Compton Polarimetry

Compton polarimetry ideal method for electron polarimetry at JLEIC

→ Photon "target" very thin – no impact on electron beam

→ High precision accessible – sub-1% precision has been achieved



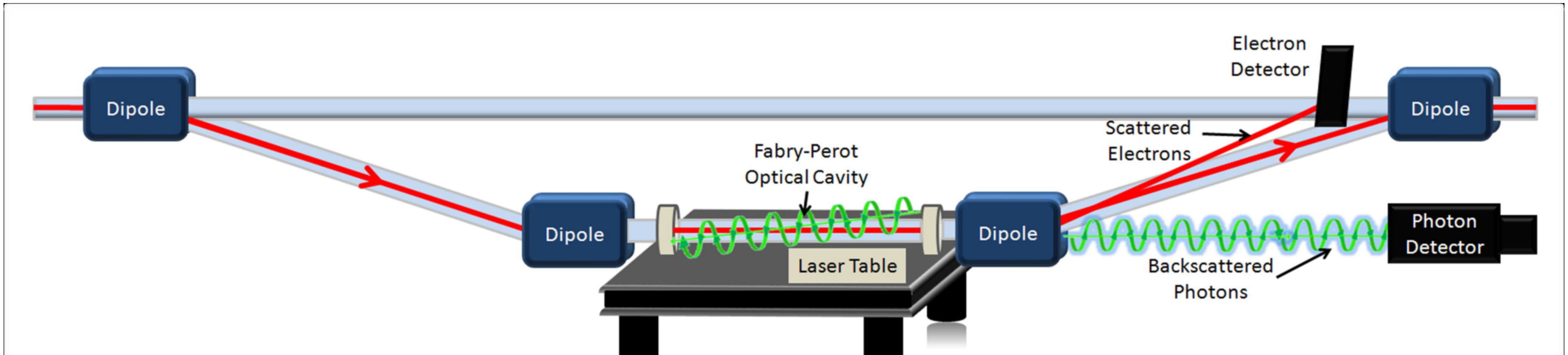

Beam polarization extracted via double-spin asymmetry:

$$A_{meas} = P_{laser} P_{beam} A_{th} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}$$

Laser+electron spins parallel

Laser+electron spins anti- parallel

# Compton Polarimetry – Experience at JLab



*Hall C Compton Layout*

JLab has built two similar Compton polarimeters in Halls A and C
→ Both have achieved ~1% electron beam polarization measurements

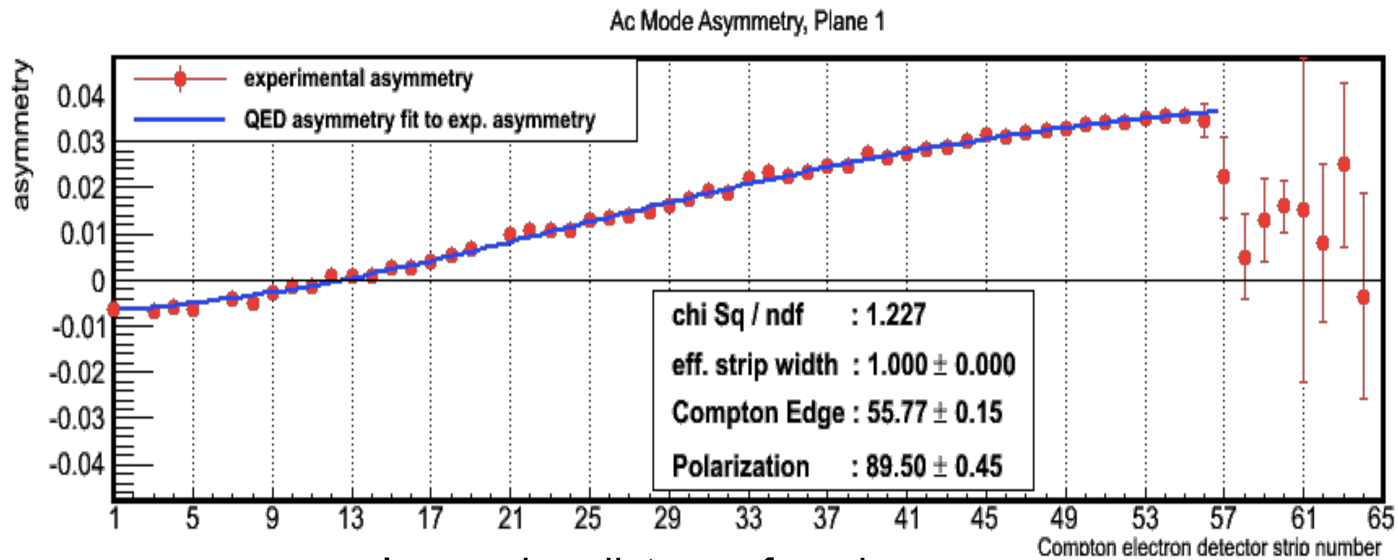
Important design considerations:

1. Dipole chicane allows simultaneous measurement of scattered electrons and backscattered photons
2. Electron-laser collision at center of chicane assures no difference in electron spin direction relative to beam before/after chicane
3. Continuous electron beam might require high power CW laser system due to background issues

# Precision Compton Polarimetry

- Precision goal for electron beam polarization is dP/P= 1%
- Sub-1% polarimetry has been achieved at:
  - SLD → 0.52% at 45.6 GeV (electron detection)
  - JLab Hall A → 1-3 GeV (electron and photon detection)
  - JLab Hall C → 1 GeV (electron detection)
- Sub-1% precision has only been achieved via photon detection using threshold-less, “integrating” technique
  - Large synchrotron backgrounds at JLEIC may make this impossible
- For now, the JLEIC Compton design emphasizes detection of the Compton scattered electron

# Compton Electron Detector




Increasing distance from beam →

Hall C @ JLab: Diamond microstrips used for electron detector

Analysis employs a 2 parameter fit (polarization and Compton edge) to the differential spectrum
→ This has yielded good results → strip width (resolution) is important
→ Zero-crossing must be in acceptance to constrain the fit well

Dominant systematics related to the interplay between trigger and strip efficiency

*More details in* ***Phys.Rev. X6 (2016) no.1, 011013***

# Laser and Backgrounds

- Choice of system depends on backgrounds in Compton polarimeter
- Main sources of background
  - Bremsstrahlung from residual gas in beampipe
  - Synchrotron radiation
  - Beam halo interacting with detector and/or apertures in beamline
- Two potential choices for laser system
  - Single pass, CW or pulsed laser → 10s of Watts easily achievable
  - High gain Fabry-Perot cavity → kW laser powers

# Compton Laser Options

- Single pass laser
  - Advantages: Able to rapidly flip helicity (~ 10 μs), relatively simple alignment
  - Disadvantages: Relatively low power → backgrounds may become problem, requires small crossing angle → interaction point stretched out – more care needed for good beam overlap
- Fabry-Perot cavity
  - Advantages: High power → improved signal:noise
  - Disadvantages: Potential source of background (beam halo), technically complex, beam must be aligned to laser (or movable laser table needed)

# Laser and Backgrounds

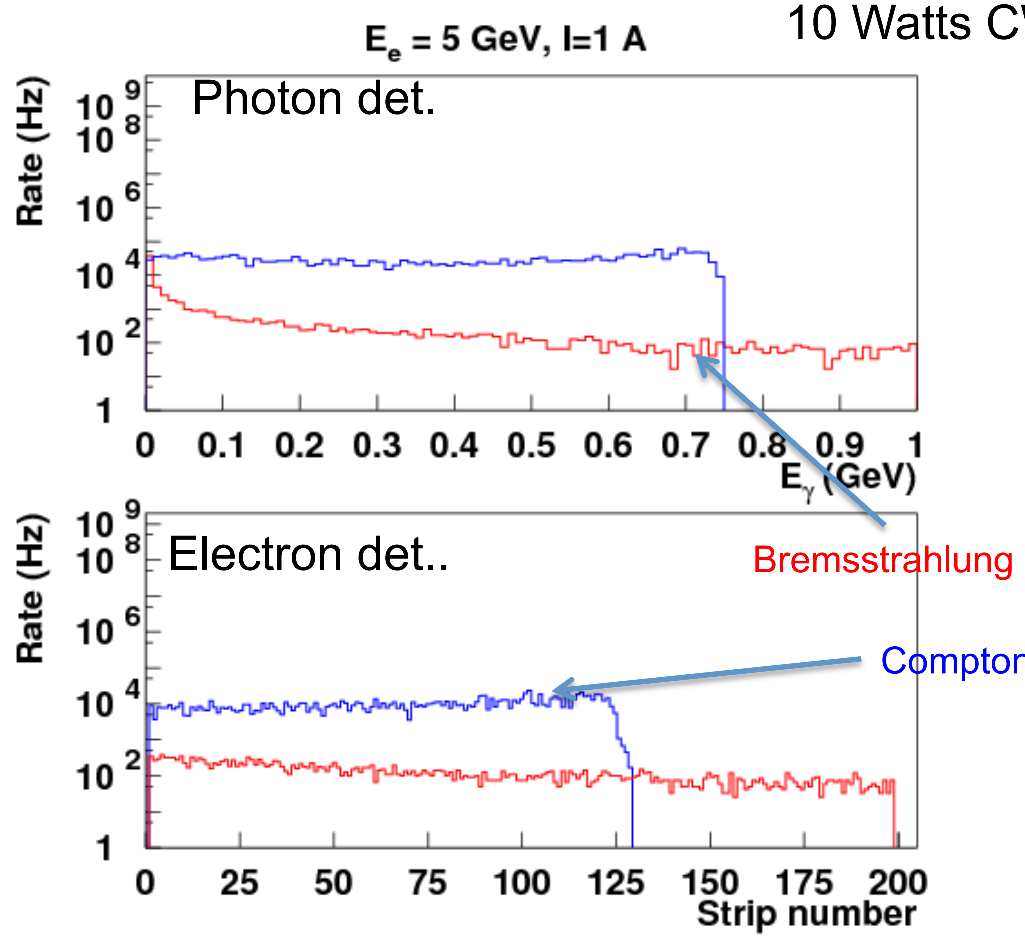
Historically, Compton polarimeters have been able to suppress backgrounds by matching laser pulse structure to beam

→ With modern, CW machines, there is little to be gained in this manner

Conventional CW lasers may be useable if backgrounds can be controlled

Rates and backgrounds: MEIC

Green laser
10 Watts CW




Beamline vac. = $10^{-9}$, laser-beam crossing angle ~ 0.3 deg.

# Laser and Backgrounds

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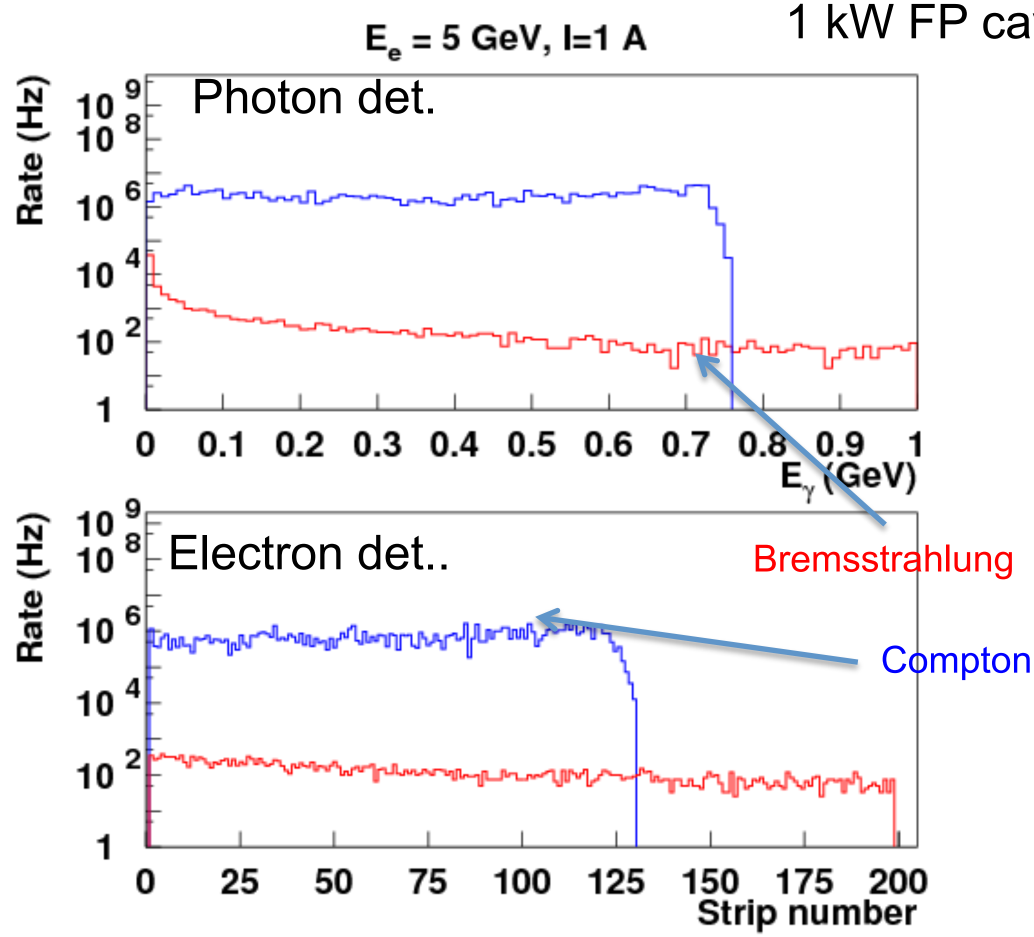
→ Modern CW machines, there is little to be gained in this manner

Conventional CW lasers may be useable if backgrounds can be controlled

→ FP cavity can provide significantly higher rates → improved signal:background

Rates and backgrounds: MEIC

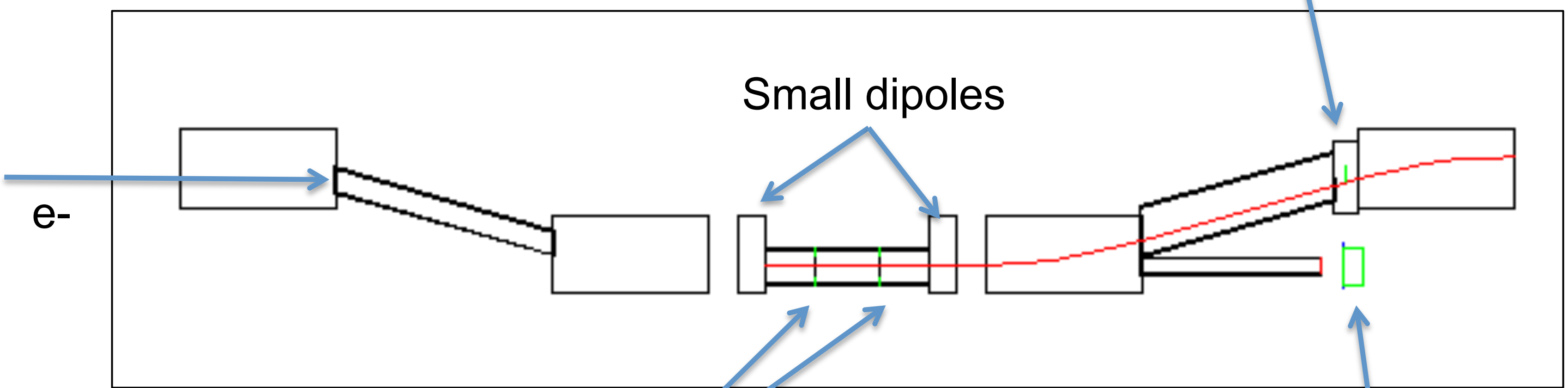
Green laser
1 kW FP cavity




Beamline vac. = $10^{-9}$ Laser-beam crossing angle ~ 2.6 deg.

# Simulation of Rates and Backgrounds

Initial estimates performed using GEANT3
→ *GEANT4/GEMC simulation development in progress*

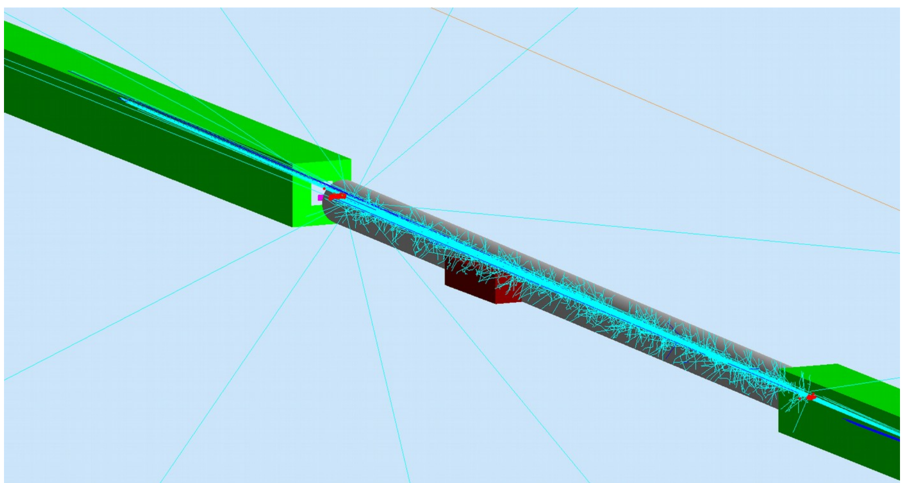


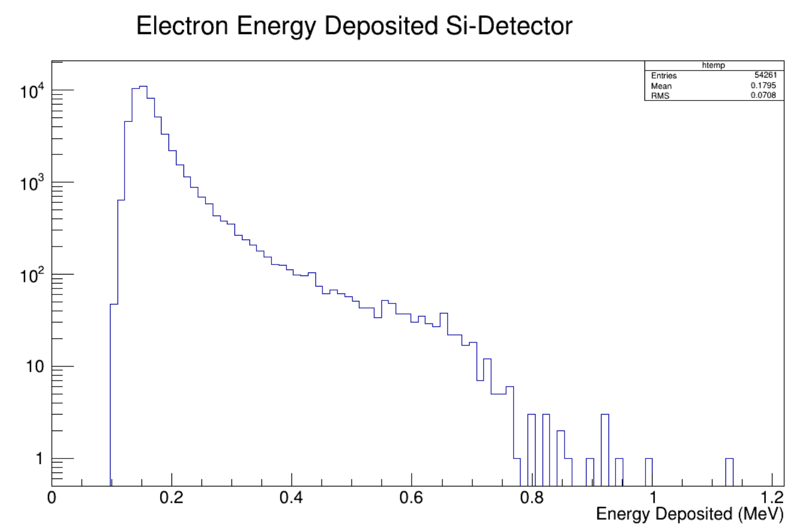

Realistic beam sizes from machine design used

# Simulation of Rates and Backgrounds

Initial estimates performed using GEANT3
→ *GEANT4/GEMC simulation development in progress*

GEANT4 Compton simulation will use same framework (GEMC) as Central Detector simulation → fully integrated into one common simulation

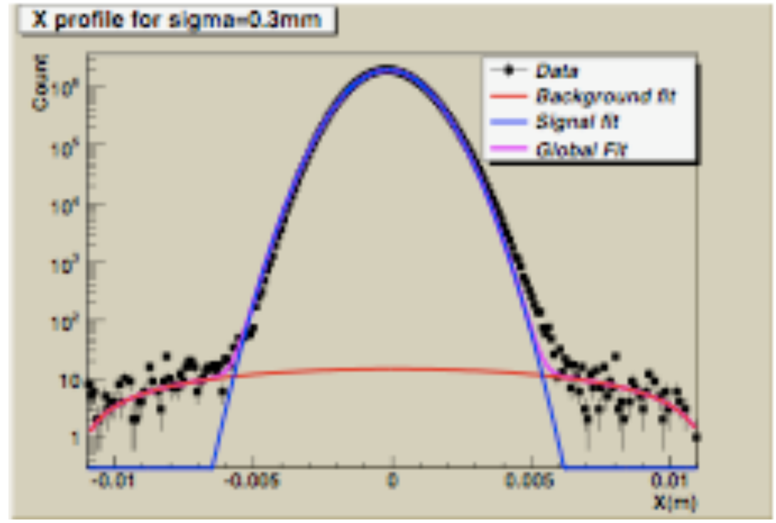




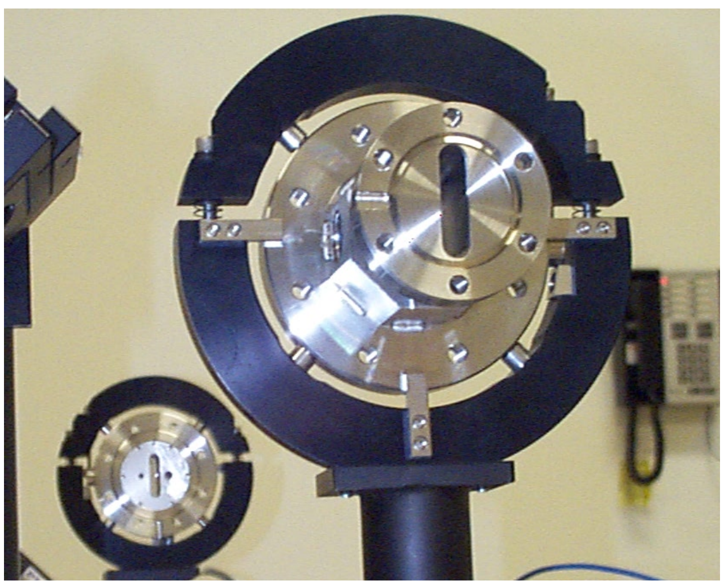

*Josh Hoskins, University of Manitboa*

# Beam Halo and Backgrounds

Halls A and C use CW, Fabry-Perot cavities
→ Both systems have mirrors ~5 mm from the beam
→ Small apertures protect mirrors from beam excursions, really bad beam properties



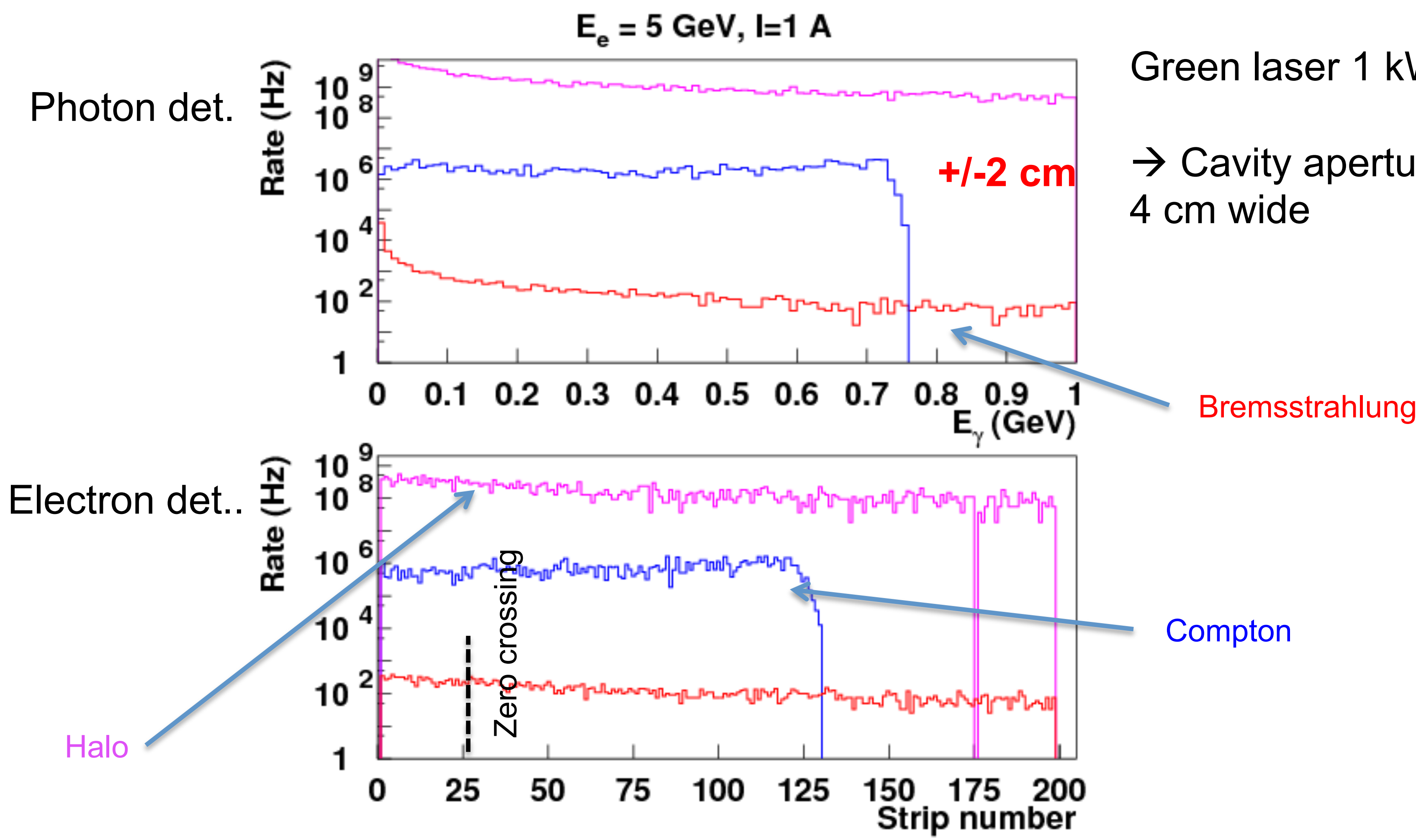

*Yves Roblin and Arne Freyberger*
*JLAB-TN-06-048*



Same protective apertures can lead to backgrounds due to interactions with beam halo

Use of FP cavity at MEIC depends on understanding halo

# Laser and Backgrounds - Halo




Green laser 1 kW

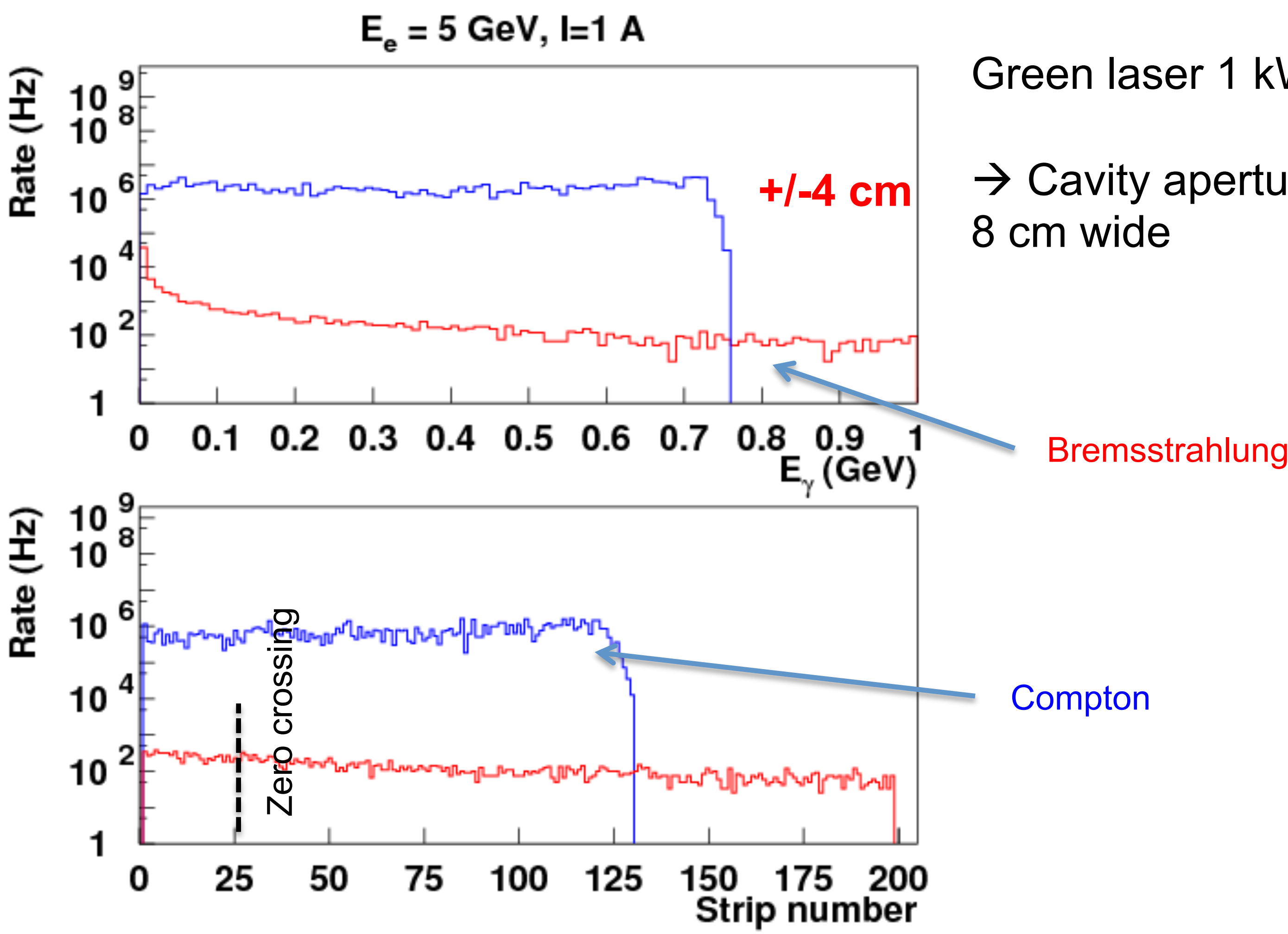
→ Cavity apertures = 4 cm wide

Compton edge 4 cm from beam, zero crossing = 2 cm from beam

# Laser and Backgrounds - Halo

Photon det.

Electron det..




Green laser 1 kW

→ Cavity apertures = 8 cm wide

Compton edge 4 cm from beam, zero crossing = 2 cm from beam

# Projected Rates and Measurements Times

| Energy | Current | 1 pass laser (10 W) | | FP cavity (1 kW) | |
|---|---|---|---|---|---|
| (GeV) | (A) | Rate (MHz) | Time (1%) | Rate (MHz) | Time (1%) |
| 3 GeV | 3 | 26.8 | 161 ms | 310 | 14 ms |
| 5 GeV | 3 | 16.4 | 106 ms | 188 | 9 ms |
| 10 GeV | 0.72 | 1.8 | 312 ms | 21 | 27 ms |

1 pass laser crossing angle = 0.3 degrees, FP cavity = 2.6 degrees
Time for 1% (statistics) measurement assumes 70% polarization
Rates integrated from asymmetry zero-crossing

Extremely high rates when using FP cavity means that detectors (electron and photon) will have to operate in integrating mode in that case

# Electron Detector Requirements

- Segmentation → allows determination of the beam polarization with high precision by fitting the spectrum
- High rate capability
  - Scattered electron rates will be very large
  - Typical "strip" detectors have relatively slow response times after amplification → large dead time
  - Integrating mode?
- Radiation hard
  - Dose rates will be on the order of 7-25 krad/hour
  - Example: Silicon signal/noise smaller by factor of 2 after 3 Mrad
- Diamond micro-strip detector default choice for JLEIC Compton
  - Excellent performance during Q-Weak experiment in Hall C
  - Exposed to 10 Mrad dose with no degradation in performance

# Baseline JLEIC Compton electron detector

- Diamond strip detector
  - At least 5 cm long
  - 200 strips
  - 4 planes
- Roman pot required
  - Need for RF and detector shielding
  - Cooling required?
  - Detector far enough from beam to use roman pot ( ~1.5 cm = 15 sigma )
  - More convenient access to detector
  - Easier placement of electronic close to detector
  - "Small profile" design needed

# Compton R&D

- Current efforts* focused on detailed simulations related to:
  - Backgrounds, including halo and synchrotron
  - Effect of using electron detector in Roman pot
  - Backgrounds from interactions in upstream IP
- Roman pot design also under investigation – conventional design likely not practical
- In later stages, hope to build "test stand" at JLab to try out Roman pots, and also potentially different detectors
- Operation in integration mode?
- Additional R&D could be performed on the laser system
  - Investigate fast laser polarization flipping – both for single-pass and Fabry-Perot cavity



* *Supported by EIC R&D fund*

# Summary

- Excellent progress in design of chicane for combined Low-$Q^2$ tagger and Compton polarimeter
- Compton polarimeter design in progress, although baseline concept mature
  - Emphasis on electron detection → easiest avenue to achieve high precision
  - One-pass laser and high-gain Fabry-Perot cavity laser solutions both look feasible – choice will be dictated by need for “fast” measurements
- Baseline design will include “simple” photon detection scheme
  - More complex photon schemes (pair spectrometer?) also possible

# Low $Q^2$ tagger/Compton Design team

- JLab:
  - Fanglei Lin, Vasiliy Morozov, Alexandre Camsonne, Pawel Nadel-Turonski, Dave Gaskell, Kijun Park
- SLAC:
  - Mike Sullivan
- Duke:
  - Zhiwen Zhao
- ODU:
  - Charles Hyde
- U. Manitoba
  - Juliette Mammei, Josh Hoskins

# Extra

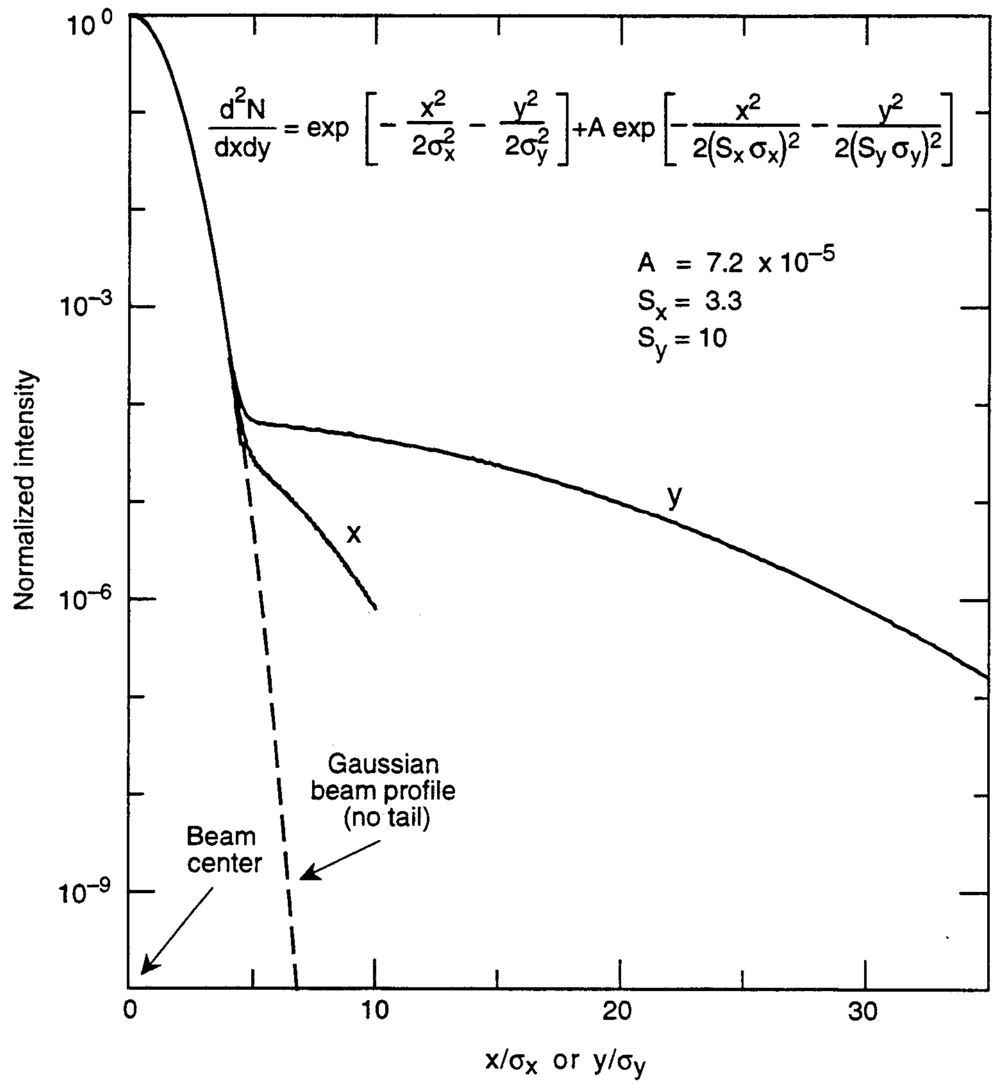
# Simulations - Halo

GEANT3 simulation uses description of beam halo from PEP-II design report (SLAC-R-418 p. 113)

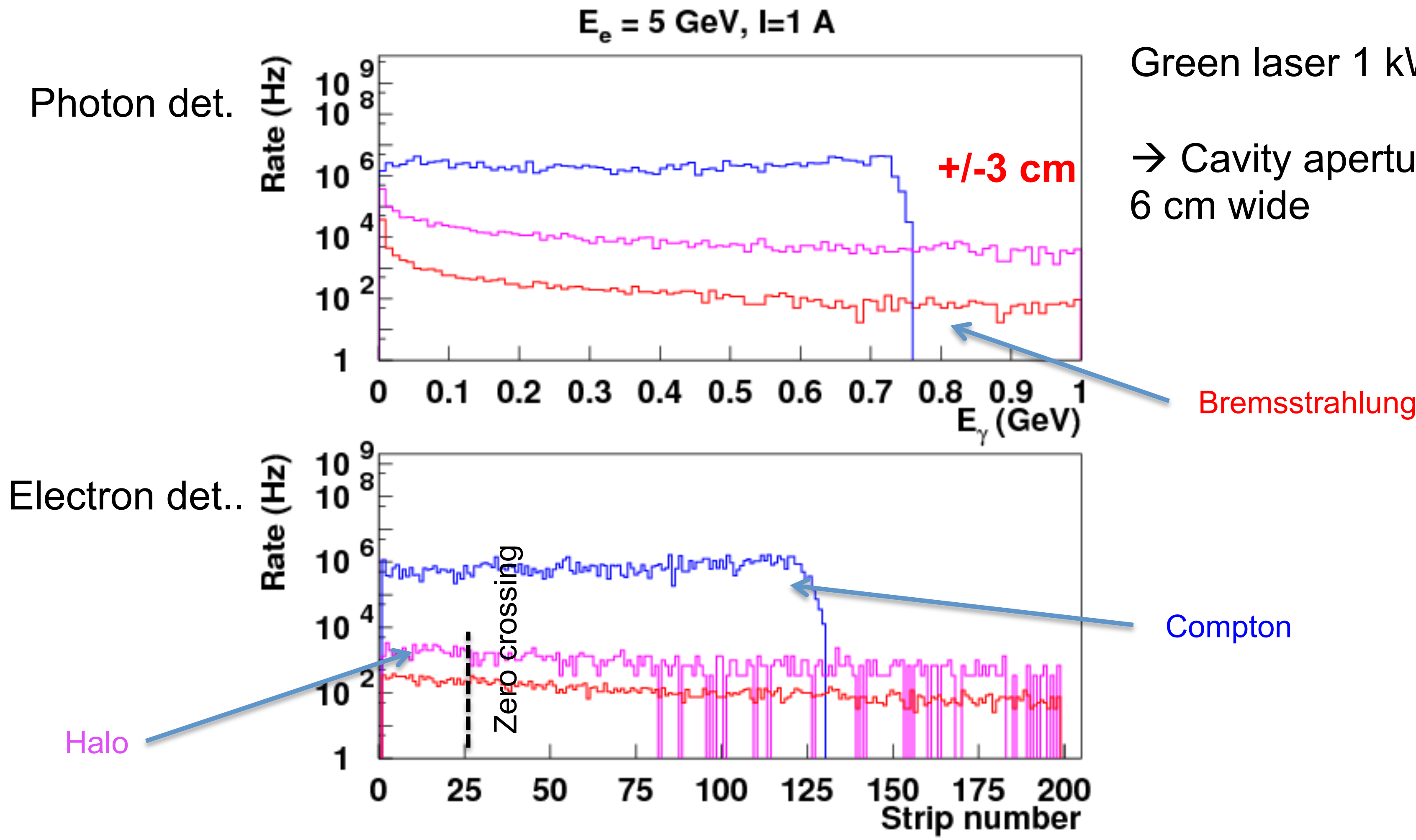
Halo flux is about 0.25% of total beam flux

Backgrounds due to halo can contribute in 2 locations

1. Direct strike of electron detector
2. Interactions with FP cavity apertures



# Laser and Backgrounds - Halo




Green laser 1 kW

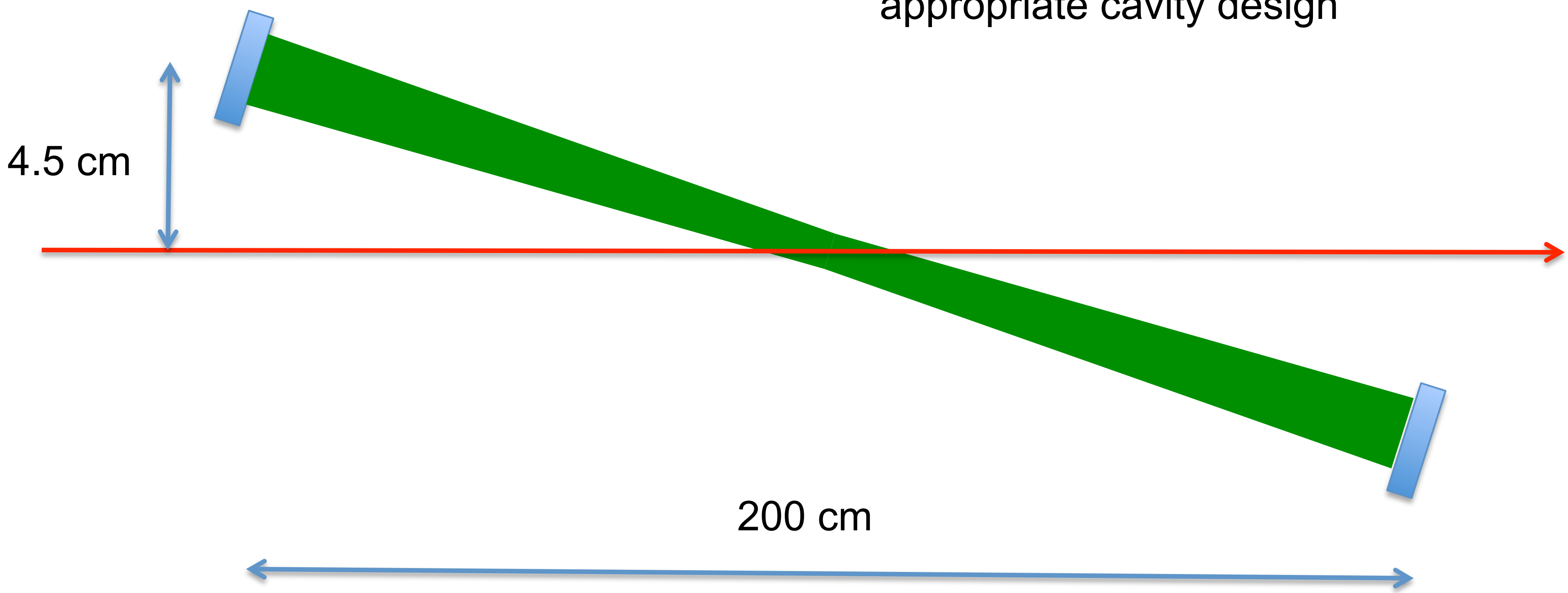
→ Cavity apertures = 6 cm wide

Compton edge 4 cm from beam, zero crossing = 2 cm from beam

# Fabry-Perot Cavity Design

Mirror size ~ 1 cm diameter

Halo contributions no problem with appropriate cavity design

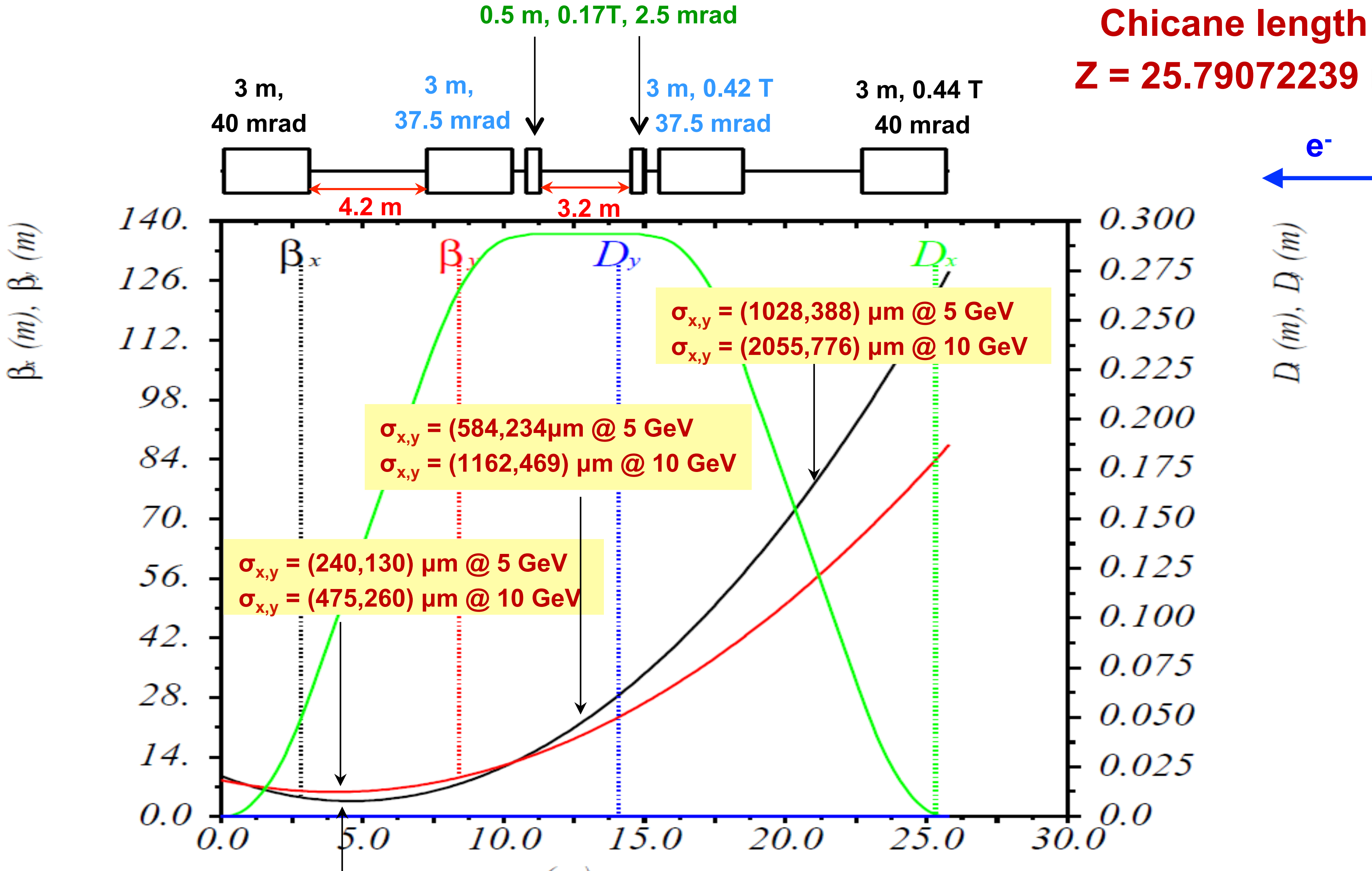



Electron-laser crossing angle = 2.58 degrees
Mirror radius of curvature = 120 cm
Laser size at cavity center $(\sigma_x,\sigma_y)$ = 151.4 um

Cavity gains of 1000-5000 easily achievable

# Chicane Design (baseline)

**Chicane length**
**Z = 25.79072239 m**



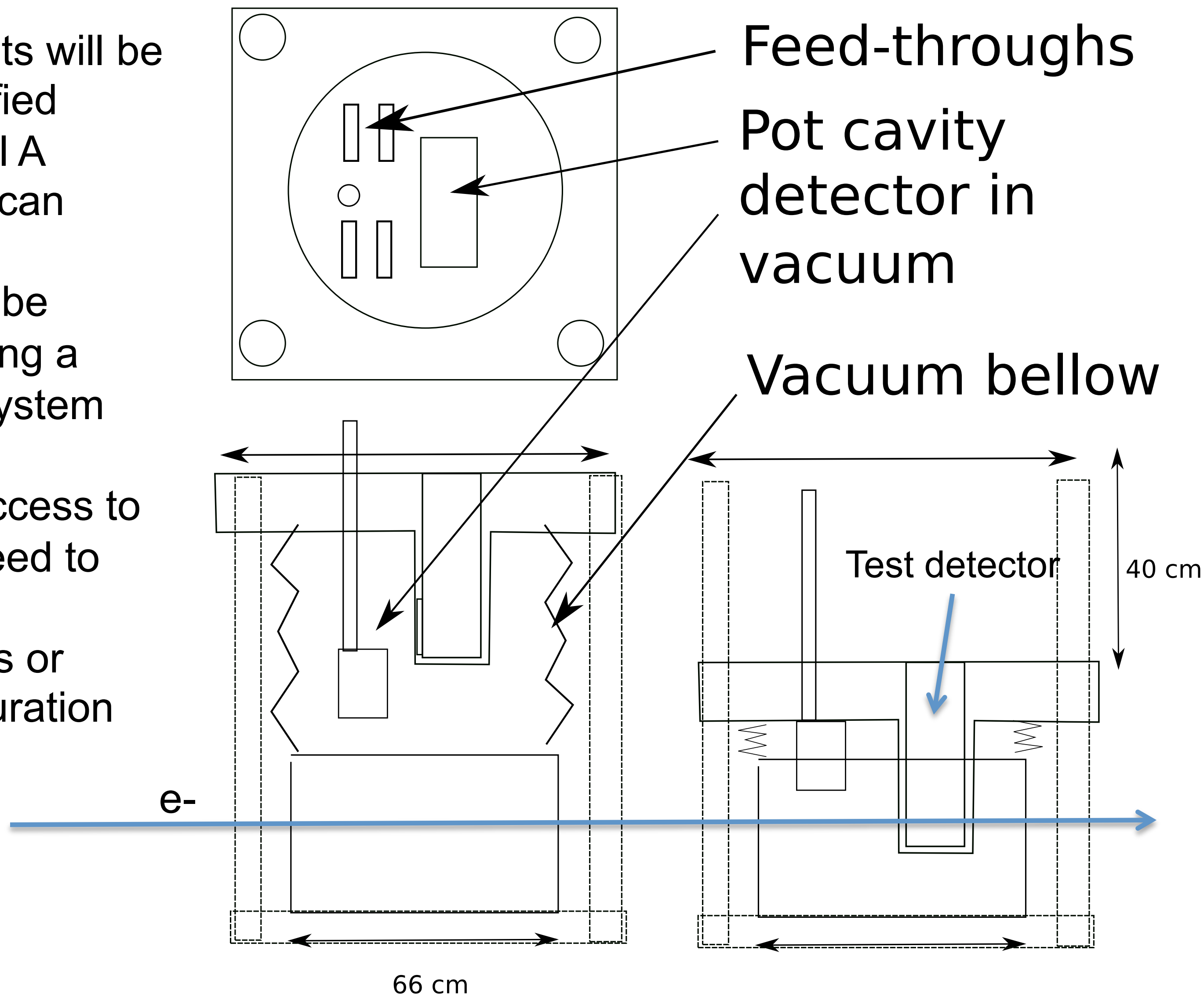

**Focusing Point $\beta_x$~3.7m, $\beta_y$~6m**

# Roman Pot

Initial detector tests will be done with a modified version of the Hall A electron detector can

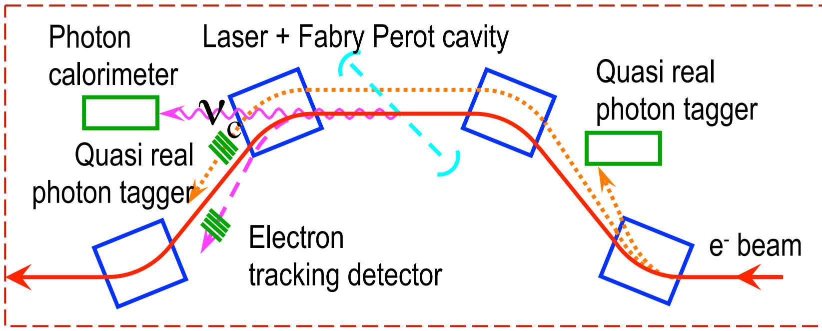
Later tests would be facilitated by adding a Roman Pot-like system

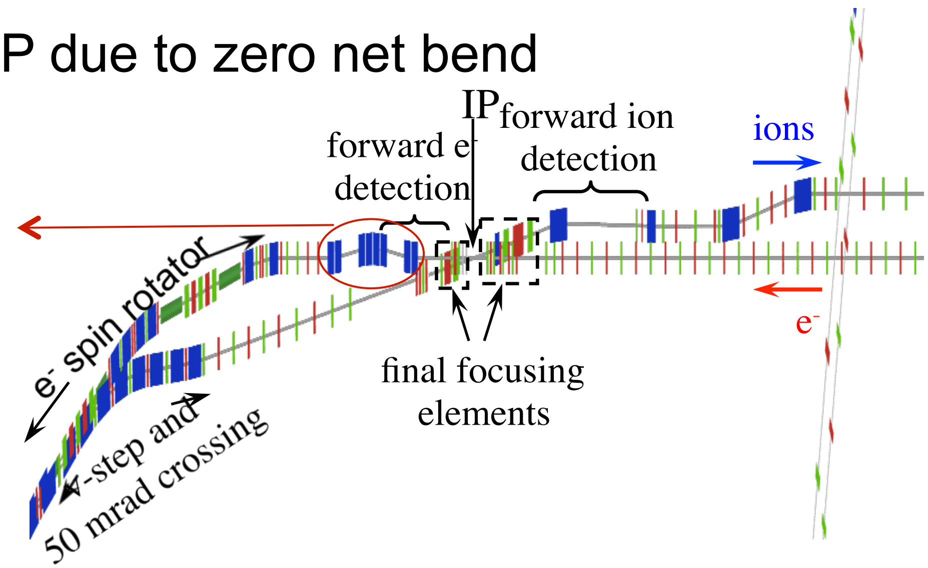
→ Allow easier access to detector (no need to break vacuum)
→ Swap detectors or change configuration rapidly



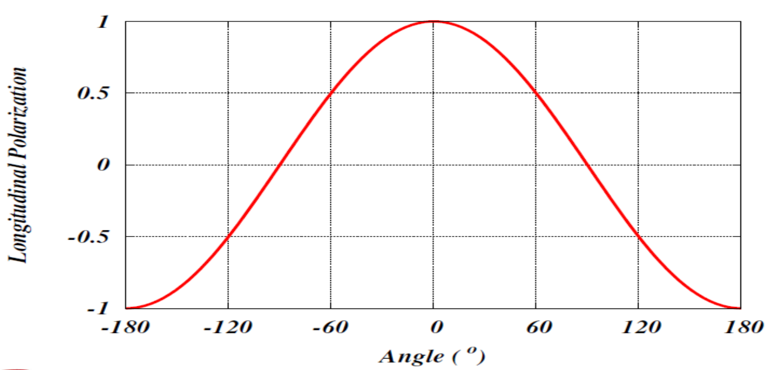
# Polarization Measurement

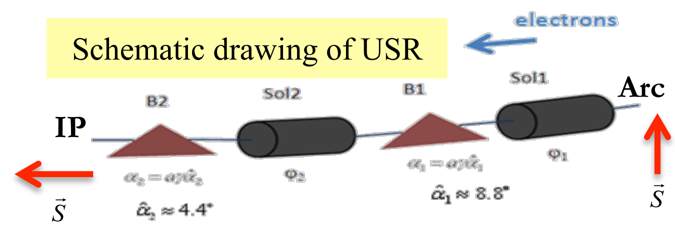
- Compton polarimetry:
  - same polarization at laser as at IP due to zero net bend

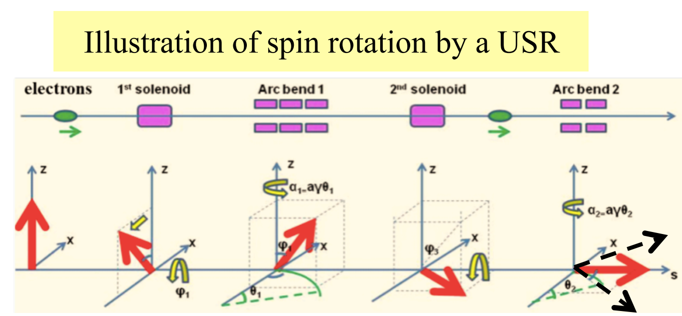



- Spin dancing (using spin rotators):
  - Experimentally optimize (calibrate) longitudinal polarization at IP



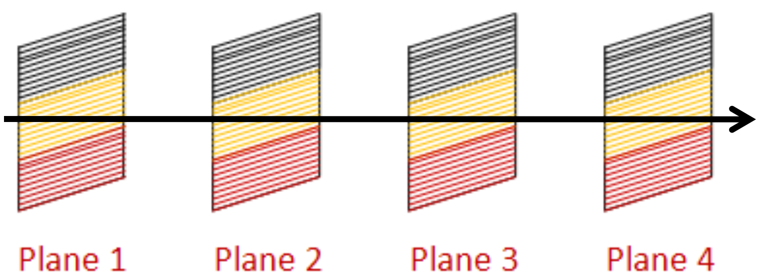
# Hall C Compton Electron Detector

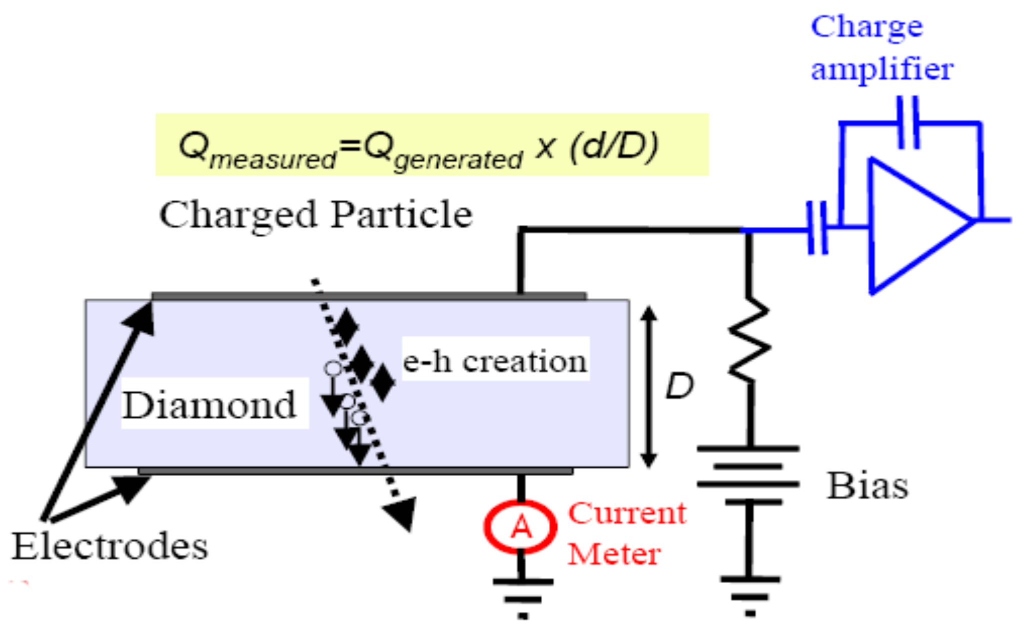
Diamond microstrips used to detect scattered electrons

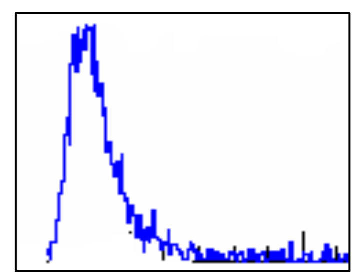
→ Radiation hard: exposed to 10 MRad without significant signal degradation

→ Four 21mm x 21mm planes each with 96 horizontal 200 μm wide microstrips.

→ Rough-tracking based/coincidence trigger suppresses backgrounds

(D. Dutta Missipi State University)