

JLEIC: Compton Polarimetry

Joshua Hoskins
University of Manitoba
JLEIC Collaboration Meeting
March 2016

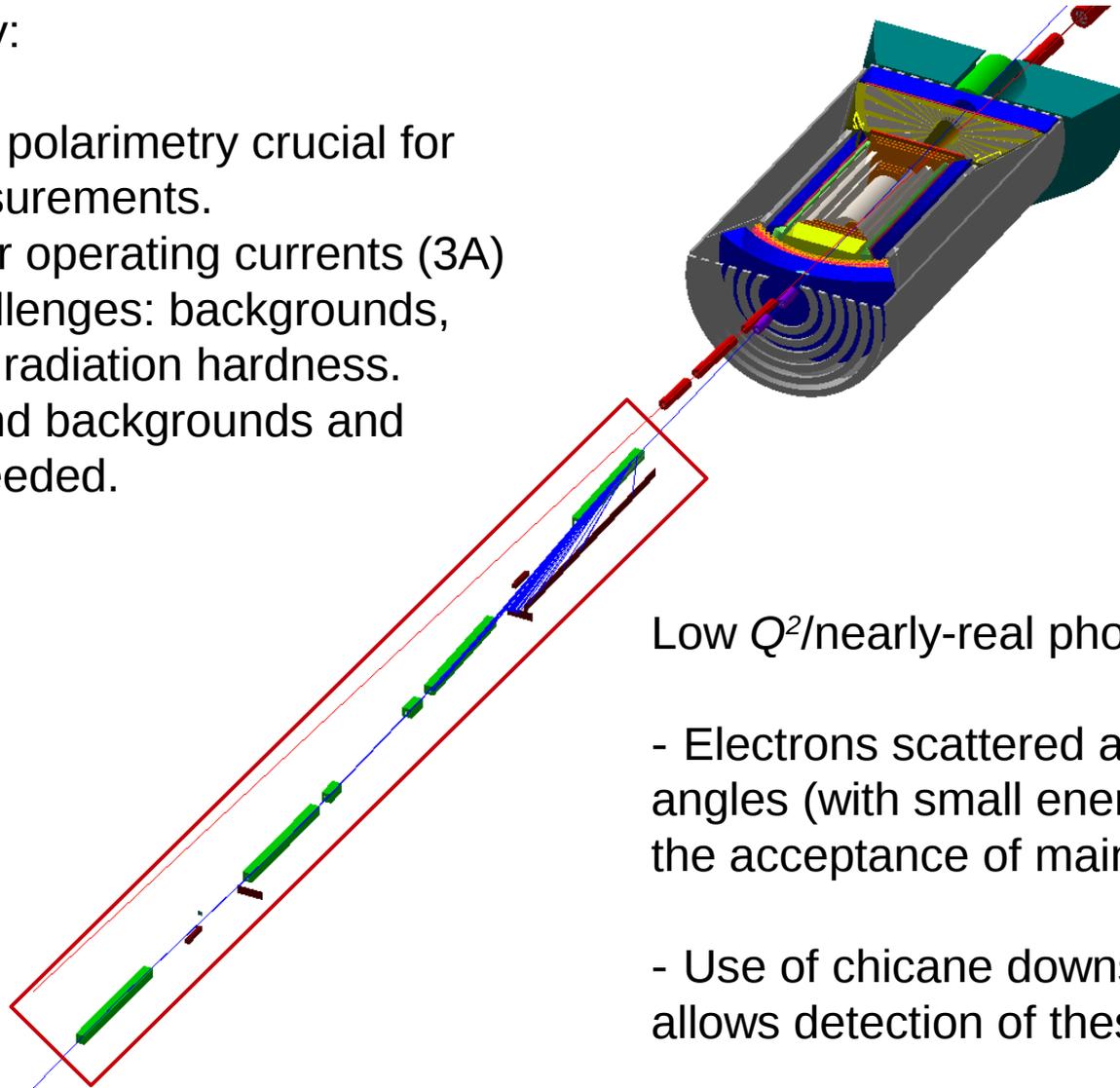
Outline

- Compton polarimetry at Jefferson Lab
- Proposed Compton Chicane
- Electron Detector R&D
- Simulations Efforts

Compton Polarimetry and Low Q^2 Tagger

Electron polarimetry:

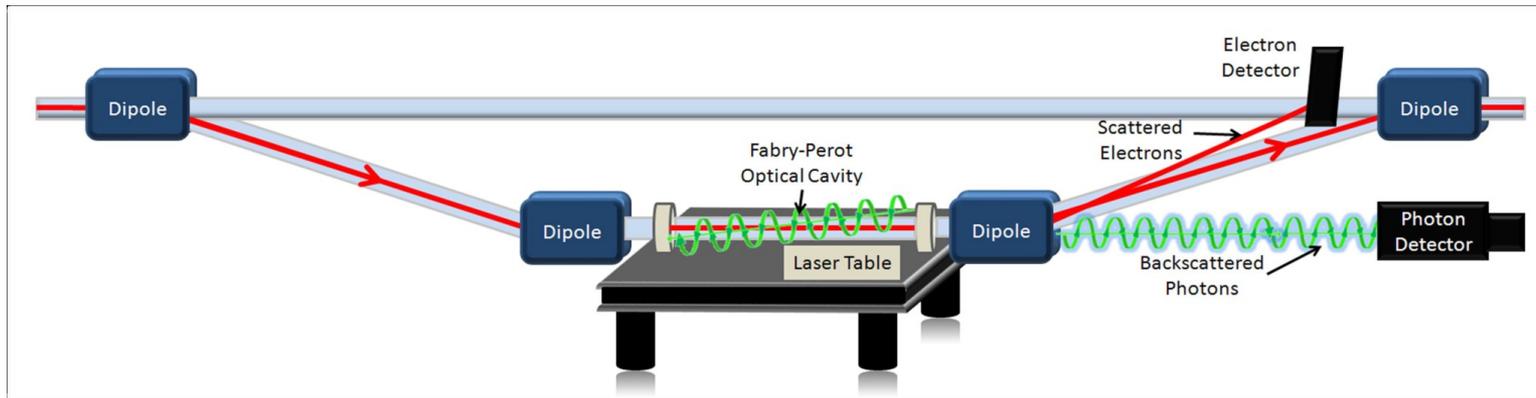
- Precision electron polarimetry crucial for new precision measurements.
- Significantly higher operating currents (3A) introduces new challenges: backgrounds, counting rates, and radiation hardness.
- Need to understand backgrounds and level of shielding needed.



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

Compton Polarimetry – Experience at JLab



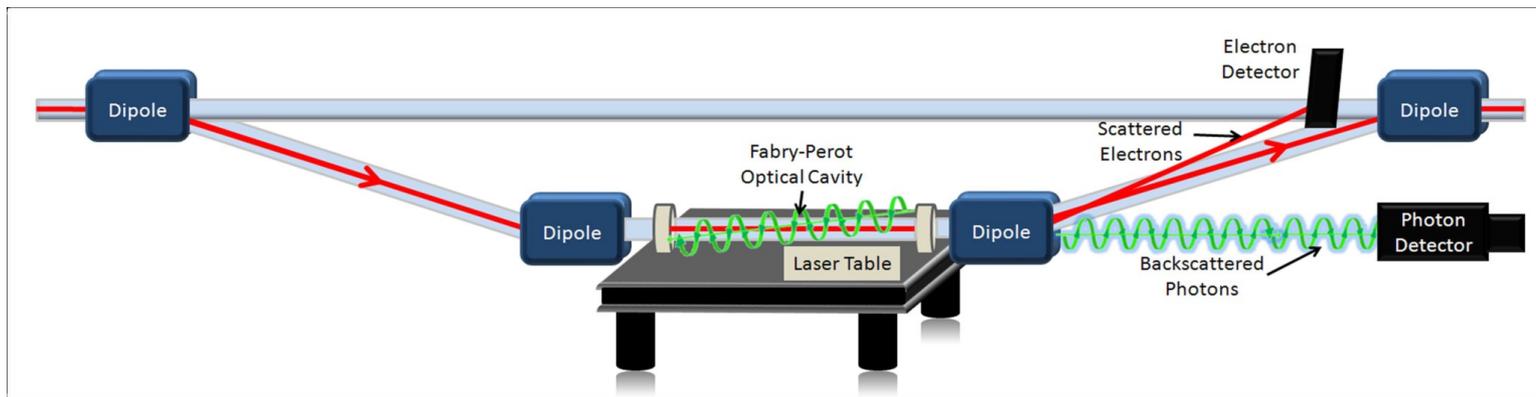
Hall C Compton Layout

Jefferson Lab has built two similar Compton polarimeters in Halls A and C

Important design considerations:

1. Dipole chicane allows simultaneous measurement of scattered electrons and back-scattered photons
2. Electron-laser collision at center of chicane assures no difference in electron spin direction relative to beam before/after chicane

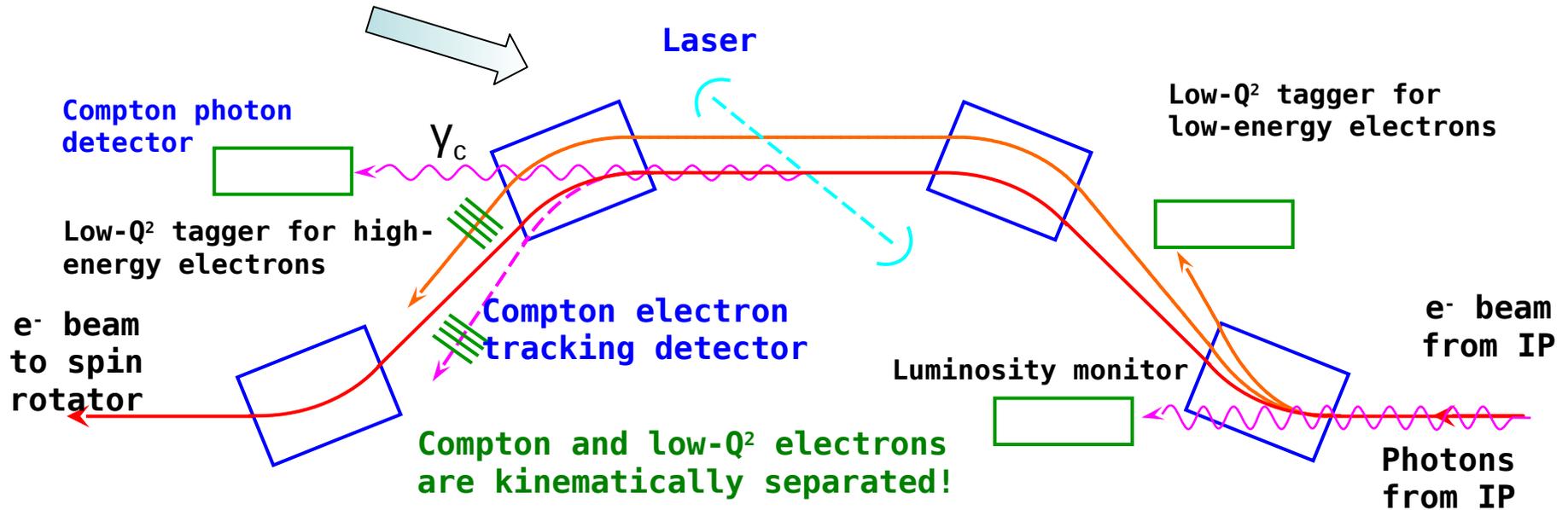
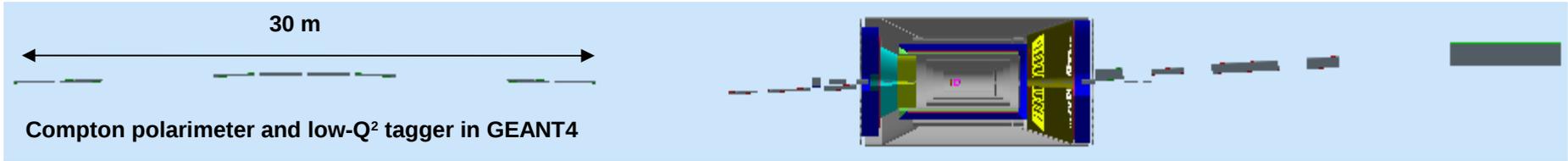
Compton Polarimetry – Experience at JLab



Hall C Compton Layout

- Precision goal for electron beam polarization is $dP/P = 1\%$
- Sub-1% polarimetry has been achieved at:
 - SLC: 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 measurement like SLC done at high energy with asymmetries of order 75% where as Jefferson lab aims to measure asymmetries of a few percent.

Polarimeter at EIC



IP1 will have a large, integrated chicane

- Detection of both Compton electron and photon
- Low synchrotron backgrounds
- Low- Q^2 tagger for photoproduction
- Luminosity monitor

Spin rotators allow for alignment of longitudinal polarization at Compton IP "spin dance".

Transverse measurement not essential.

Electron Detector R&D

Electron Detector Requirements

- Segmented or multi-strip detector → 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.
 - Previous experience with Diamond and radiation hardness make it a leading contender.

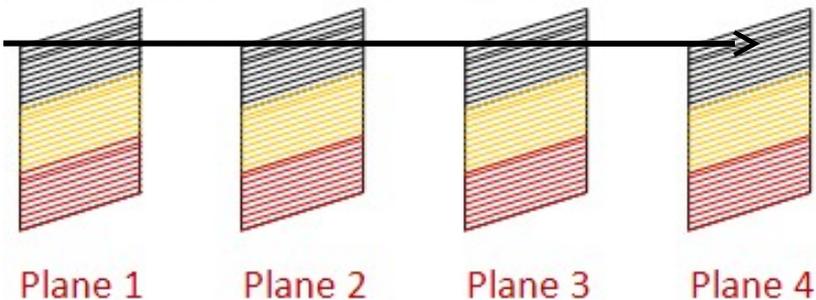
Hall C Compton Electron Detector

Diamond microstrips used to detect scattered electrons.



Radition-hard Diamond Detector

- Radiation hard: exposed to 10 Mrad without significant signal degradation.
- Four 21mm x 21mm planes.
- Each plane: 96 horizontal 200 μ m wide microstrips.
- Rough-tracking based/coincidence trigger suppresses backgrounds



Plane 1

Plane 2

Plane 3

Plane 4

(D. Dutta Mississippi State University)

Baseline MEIC electron detector

Diamond strip detector

- At least 5 cm long
- 200 strips
- 4 planes
- Pros
 - Radiation hard to 10 Mr at JLab
 - Fast detector
 - Experience with Hall C
- Cons
 - Small amplitude

Roman pot

- Need for RF and synchrotron shielding.
- Cooling.
- Detector motion.
- More convenient access to detector.
- Easier placement of electronics close to detector.

Baseline MEIC electron detector

Diamond strip detector

- At least 5 cm long
- 200 strips
- 4 planes
- Pros
 - Radiation hard to 10 Mr at JLab
 - Fast detector
 - Experience with Hall C
- Cons
 - Small amplitude

Roman pot

- More convenient access to detector.
- Easier placement of electronic close to detector.
- Need for RF and synchrotron shielding.
- Cooling.
- Detector motion.

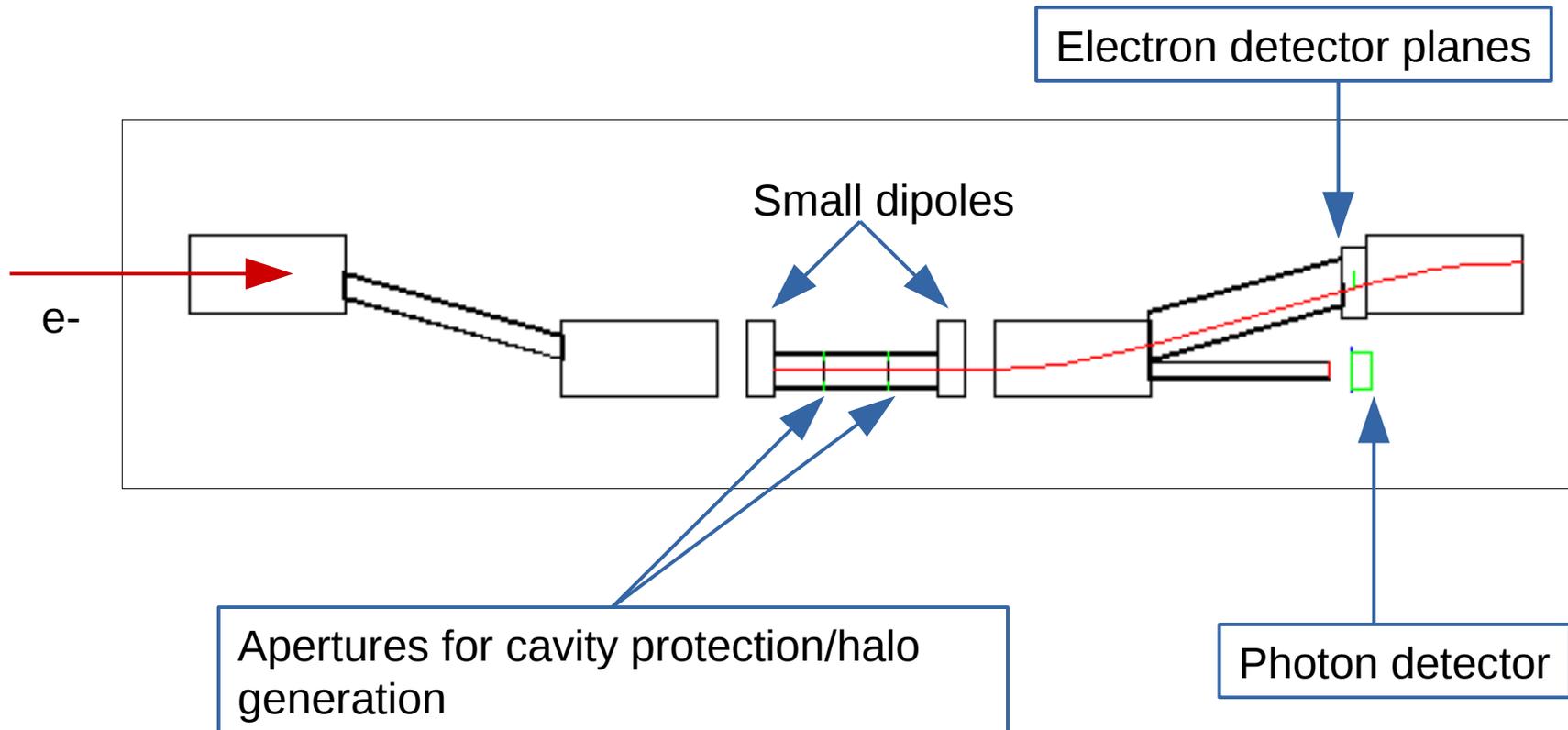
A need for shielding, easy access, and the ability to move the detector in accordance with the Compton edge and zero-crossing make using a Roman pot worth looking into.

GEANT Simulations Effort

Simulation of Rates and Backgrounds

Initial background estimates performed using GEANT3.

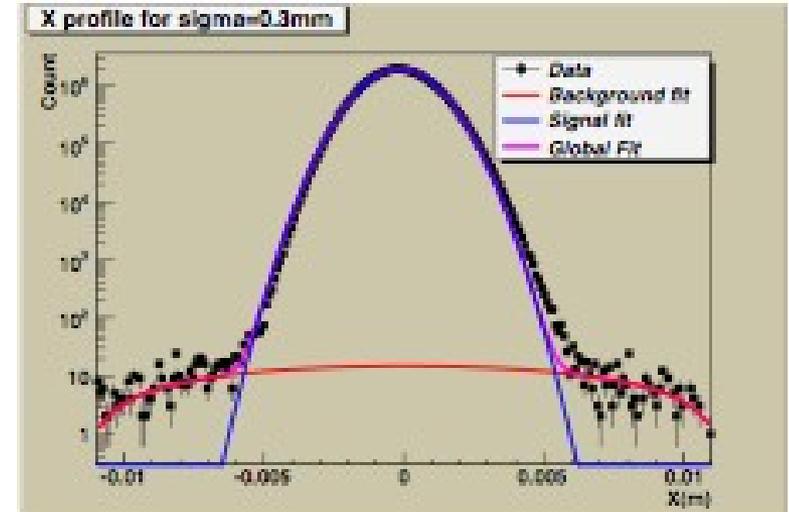
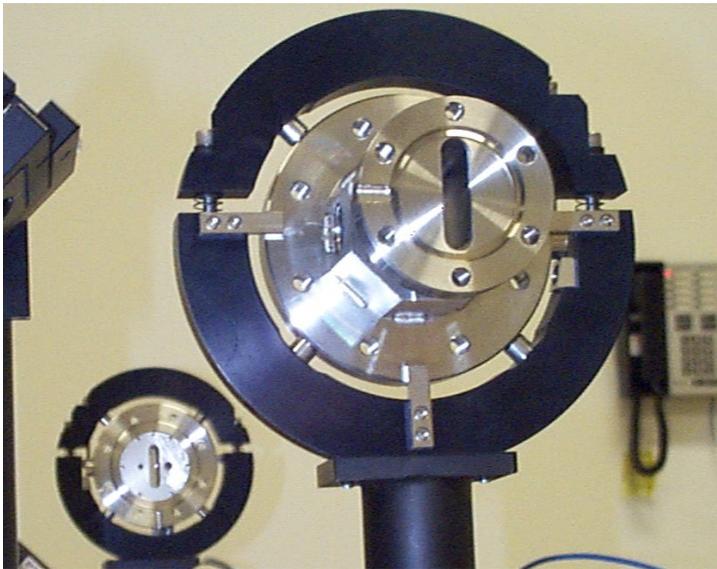
GEANT4/GEMC simulation development in progress.



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 and bad beam properties.



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

The protective apertures can lead to backgrounds due to interactions with beam halo.

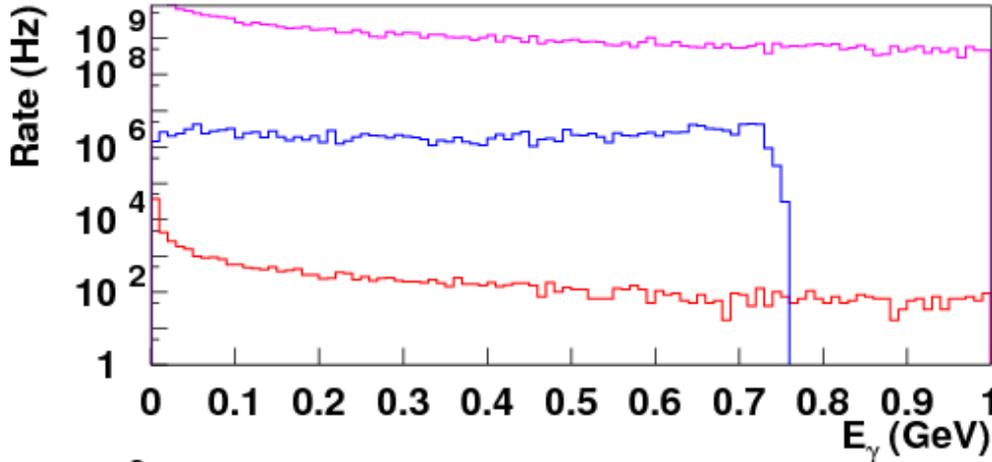
Use of FP cavity at JLEIC depends on understanding halo.

Laser and Backgrounds - Halo

Aperture: 2 cm

$E_e = 5 \text{ GeV}, I = 1 \text{ A}$

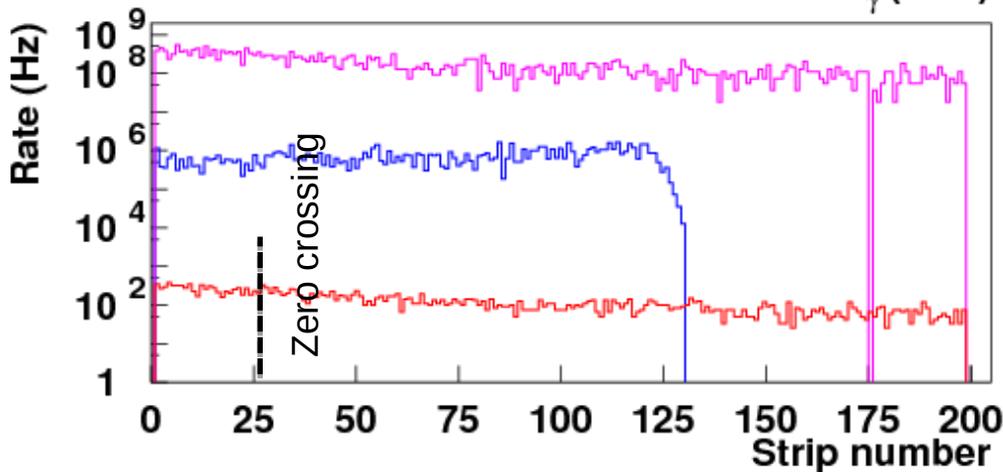
Photon det.



Green laser 1 kW

Varying the cavity aperture size in simulation we can investigate backgrounds.

Electron det..



— Bremsstrahlung
— Compton
— Halo

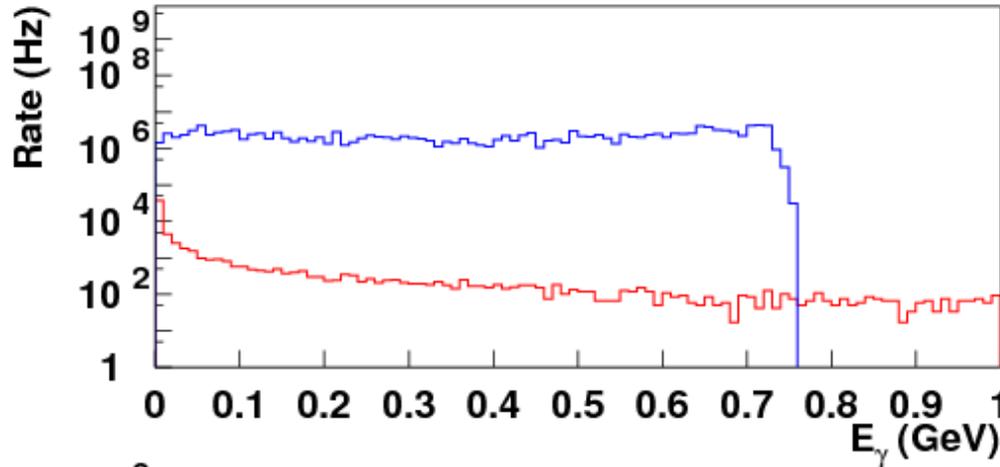
Compton edge 4 cm from beam, zero crossing = 2 cm from beam

Laser and Backgrounds - Halo

Aperture: 4 cm

$E_e = 5 \text{ GeV}, I = 1 \text{ A}$

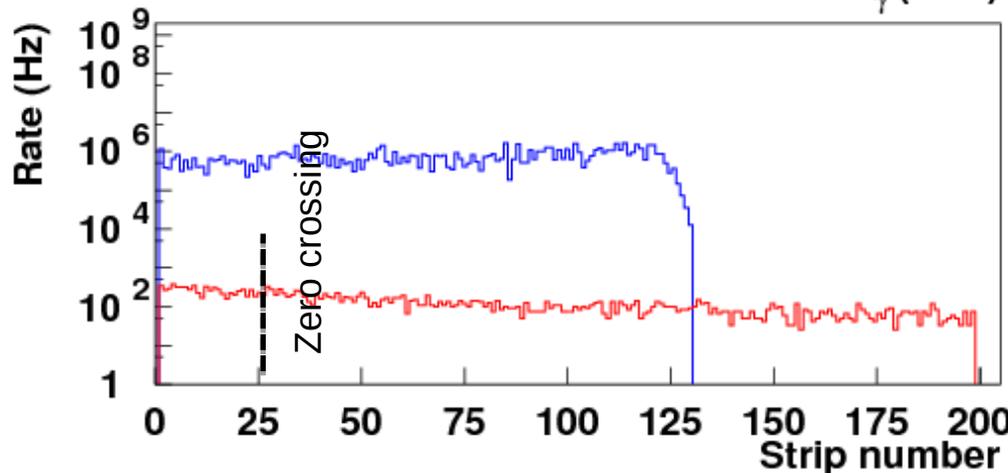
Photon det.



Green laser 1 kW

Varying the cavity aperture size in simulation we can investigate backgrounds.

Electron det..



— Bremsstrahlung
— Compton
— Halo

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

Projected Rates and Measurements Times

Energy (GeV)	Current (A)	1 pass laser (10 W)		FP cavity (1 kW)	
		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

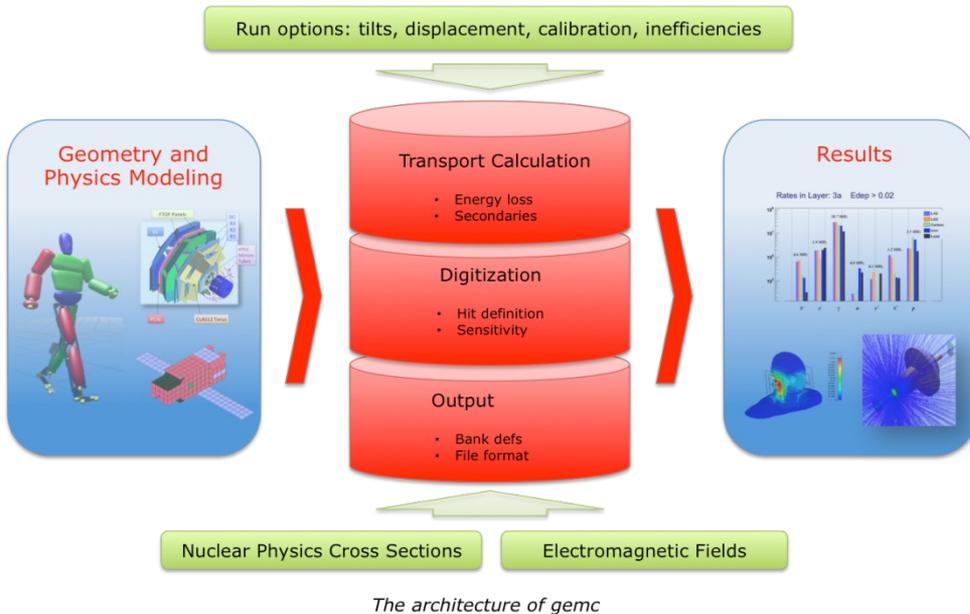
1-Pass laser crossing angle: 0.3 deg.
FP cavity crossing angle: 2.6 deg.

Rates calculated analytically.

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, but both options are viable.

Compton Polarimetry R&D: GEant4 Monte-Carlo (GEMC)



Application built on GEANT4 used to simulate particles through matter.

Intended to make simulations available without the requirement of GEANT4 or C++ knowledge.

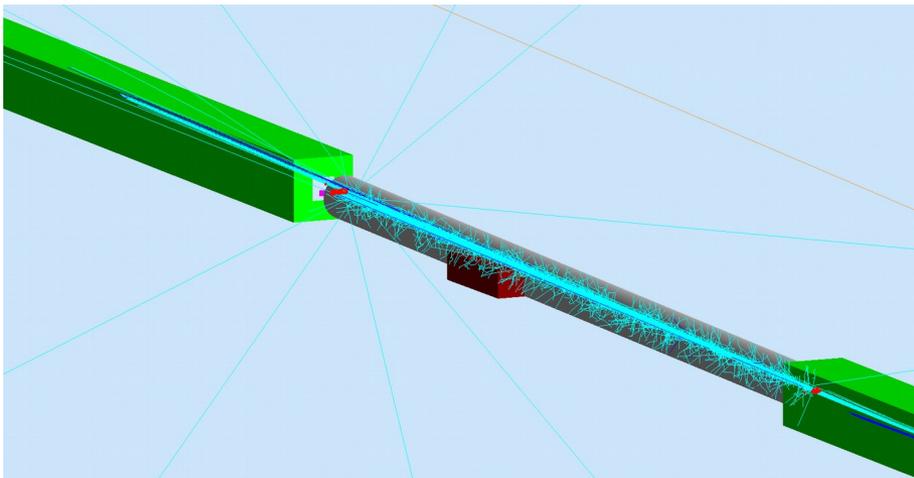
Allows for real-time changes in experimental parameters without the need to recompile

GEMC is the primary simulation framework for the JLab EIC detector design including the Compton polarimetry R&D effort.

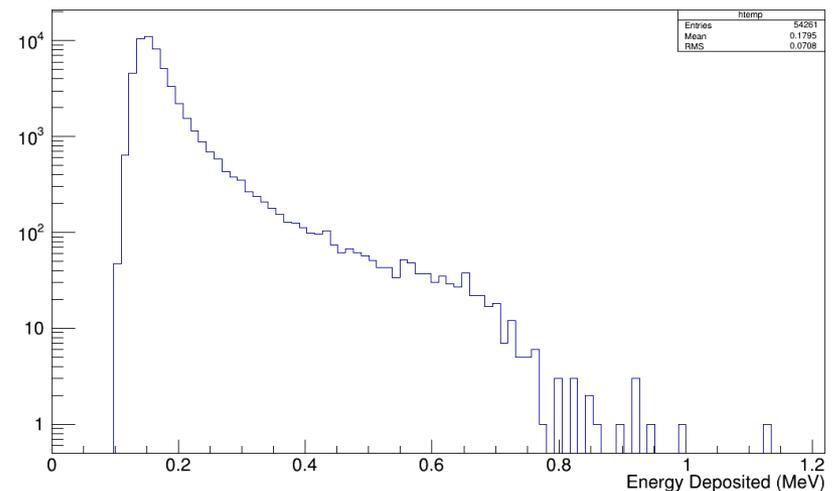
Detector and beamline geometries added via simple perl API

Compton Polarimetry R&D: Background Simulations

- Goal was to provide an integrated model of purposed Compton chicane for the purposed of studying background and shielding.
- Compton chicane implemented into simulation, including simple silicon detector and photon detector.
- Currently working to tune GEANT4 simulation to more closely match result for rates in electron detector from GEANT3.



Electron Energy Deposited Si-Detector



Compton Polarimetry R&D: Background Simulations

- Detailed studies of synchrotron and Bremstrahlung radiation in electron detector.

Studies of the background rates are currently in progress after finishing runtime optimizations. Trying to understand discrepancies between GEANT3 and GEANT4 results before releasing numbers.

- Implementation of Compton generator from Richard Petti (BNL).

Work integrating the provided generator into the local Compton simulation is underway and should be done quickly. No work on the generator is required to first order but the output format is not currently compatible to be fed into GEMC.

- Study backgrounds originating from the IP.

As a longer term goal we plan to add the current Compton geometry into the main simulation to look at potential backgrounds from scattering originating from the upstream IP.

Summary

- Proposed Compton polarimeter builds on the experience and success of the Hall A and Hall C polarimeters at Jefferson Lab.
- 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.
- Investigations of optimum technology for electron detector and performance in Roman Pot is underway.
- Framework needed for GEANT4 simulations in place and studies in progress.

Thank You.

Compton Design team

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

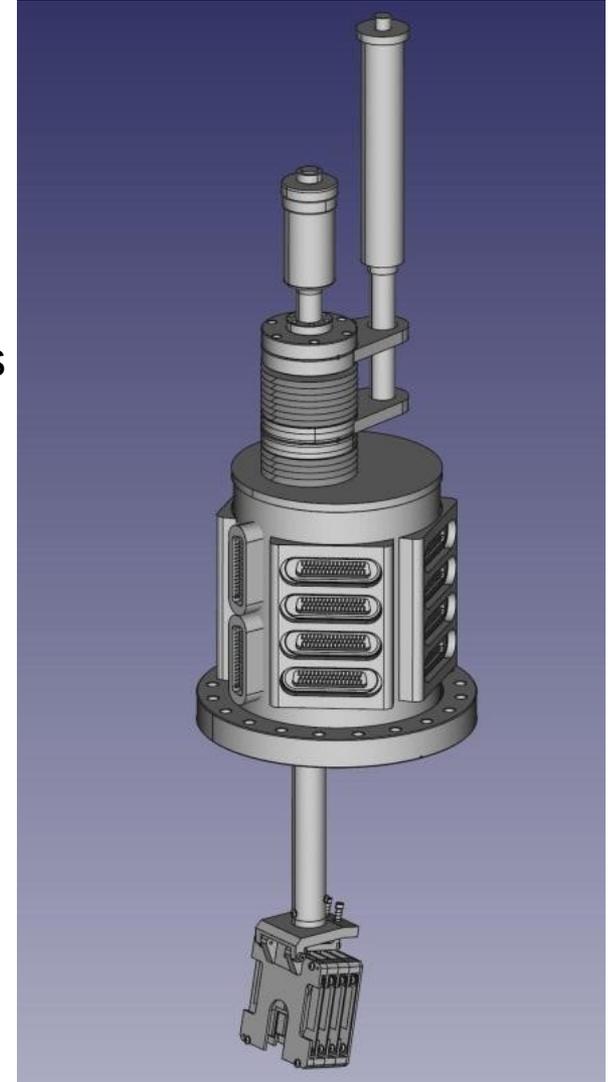
Extra

Redesigned Detector Chamber

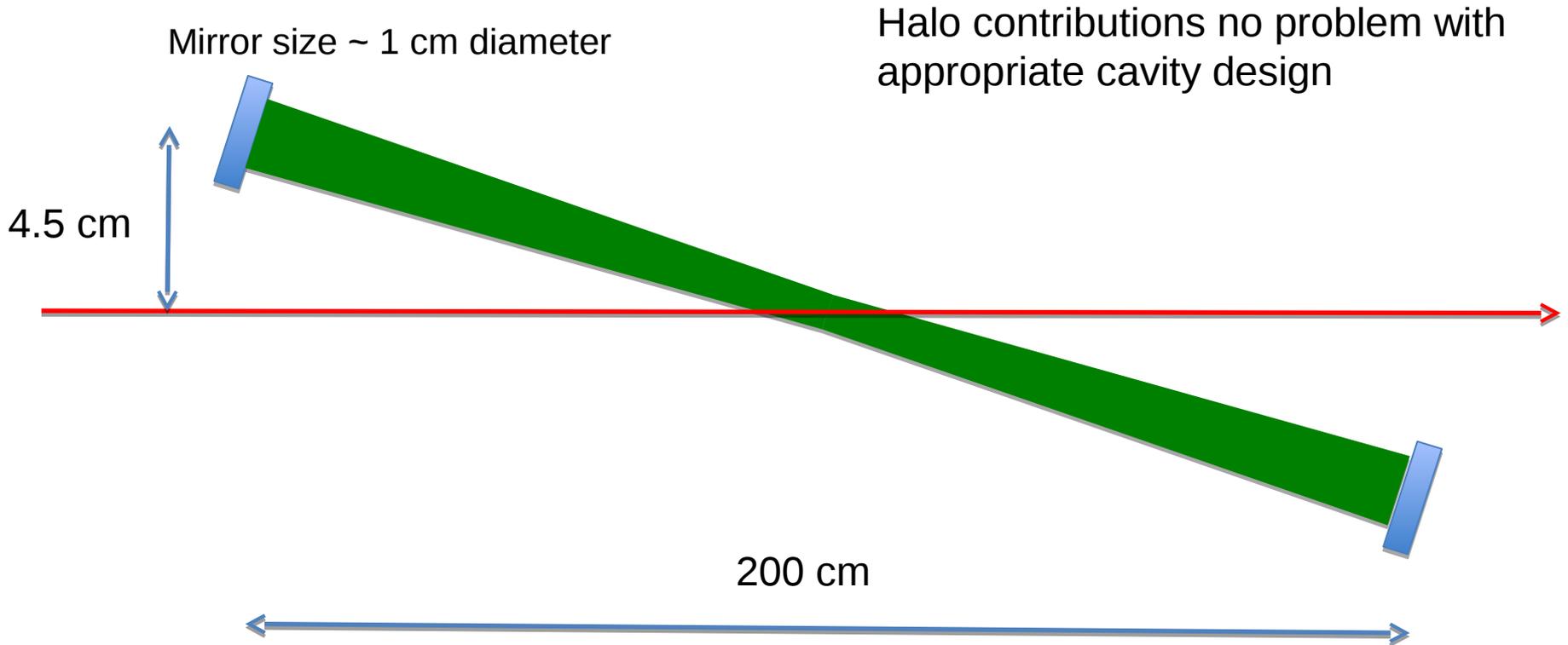
- Proposed redesign of current chamber design.
- Flex cable feed through less noisy than current PCB board design.
- New top flanges would accommodate 768 channels versus the current 348.

Plans:

- Build lower chamber.
- Test electronics with spare Silicon detectors.
- Build top flange: dependent on funding availability



Fabry-Perot Cavity Design



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

Cavity gains of 1000-5000 easily achievable

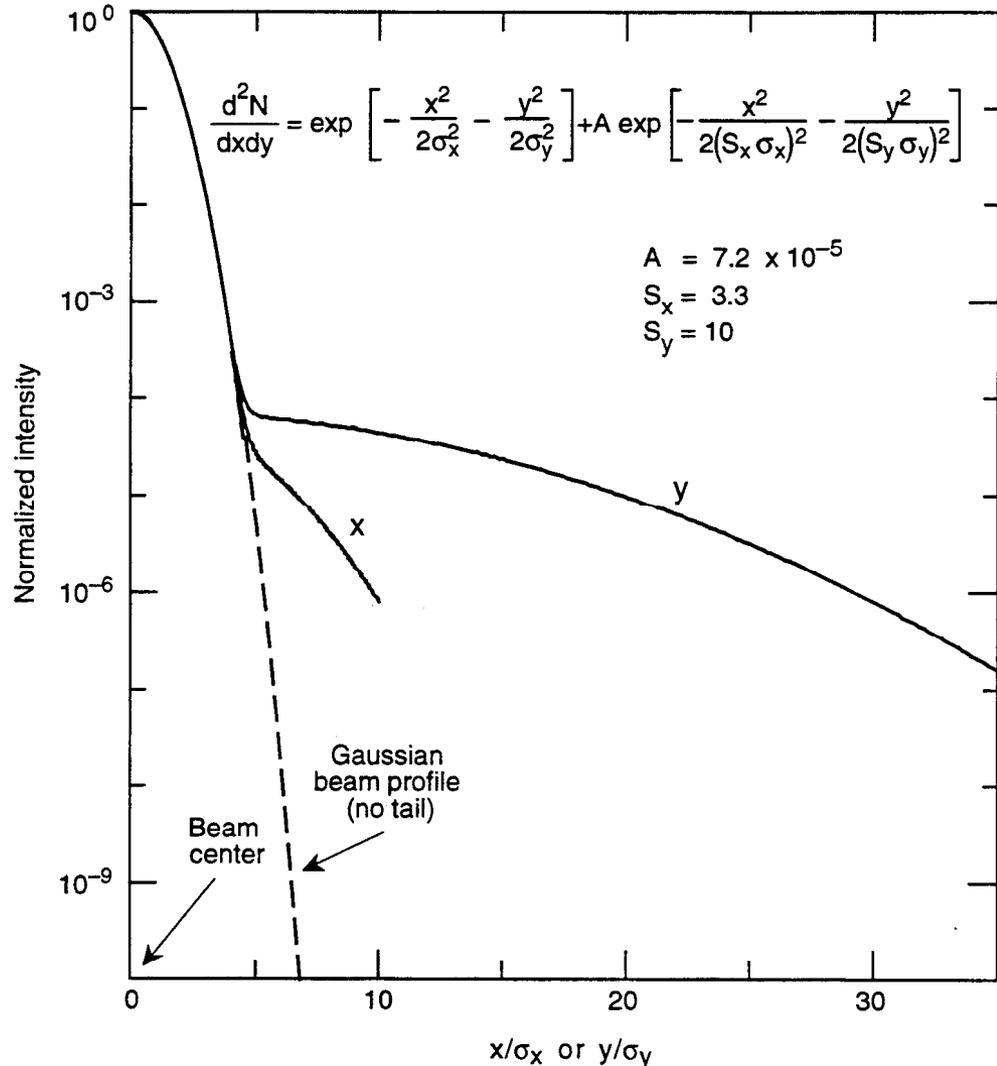
Simulations - Halo

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

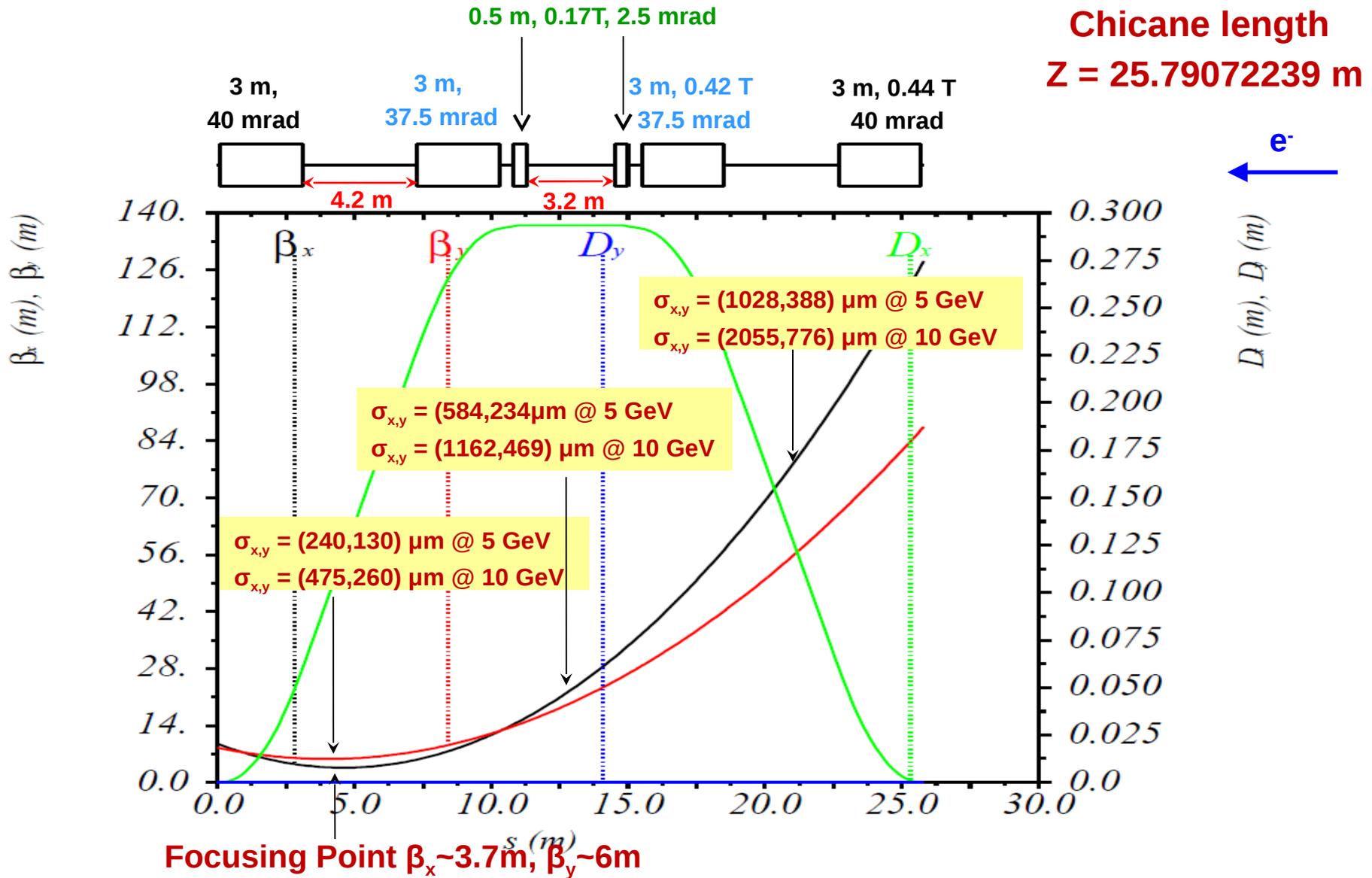
1. Direct strike of electron detector
2. Interactions with FP cavity apertures



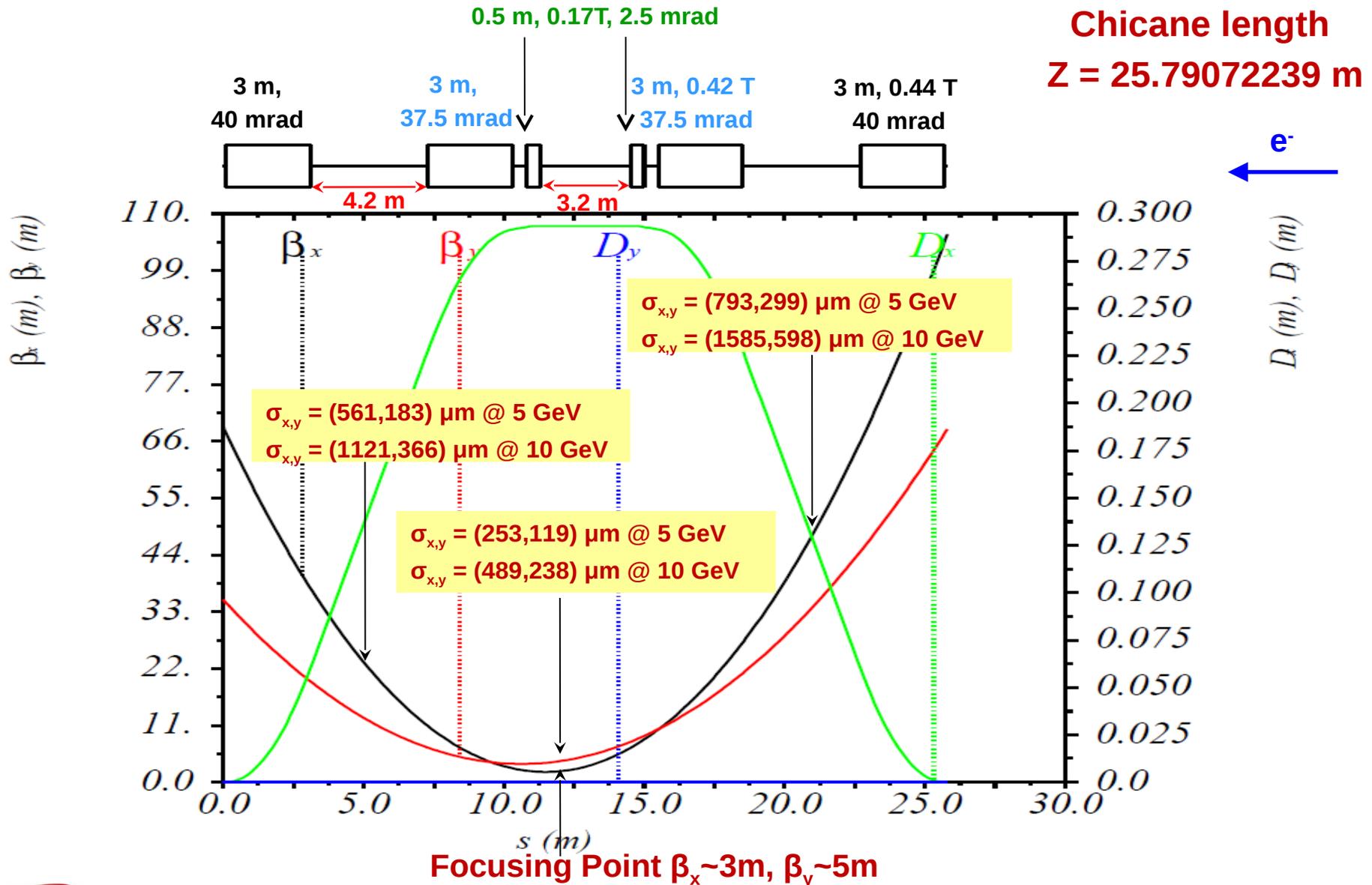
Laser and Backgrounds

- 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

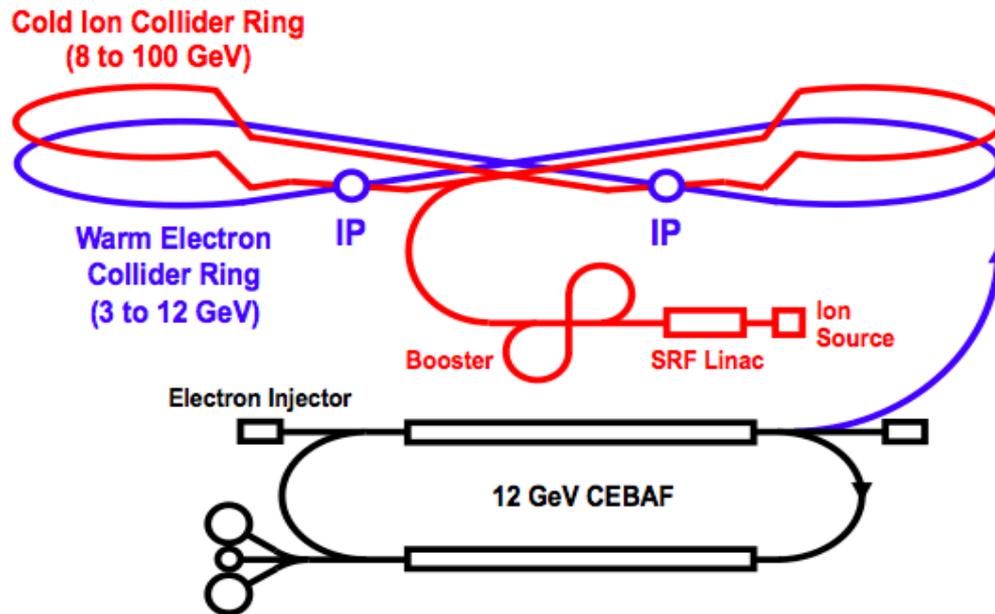
Chicane Design (baseline)



Chicane Design: Focus at IP



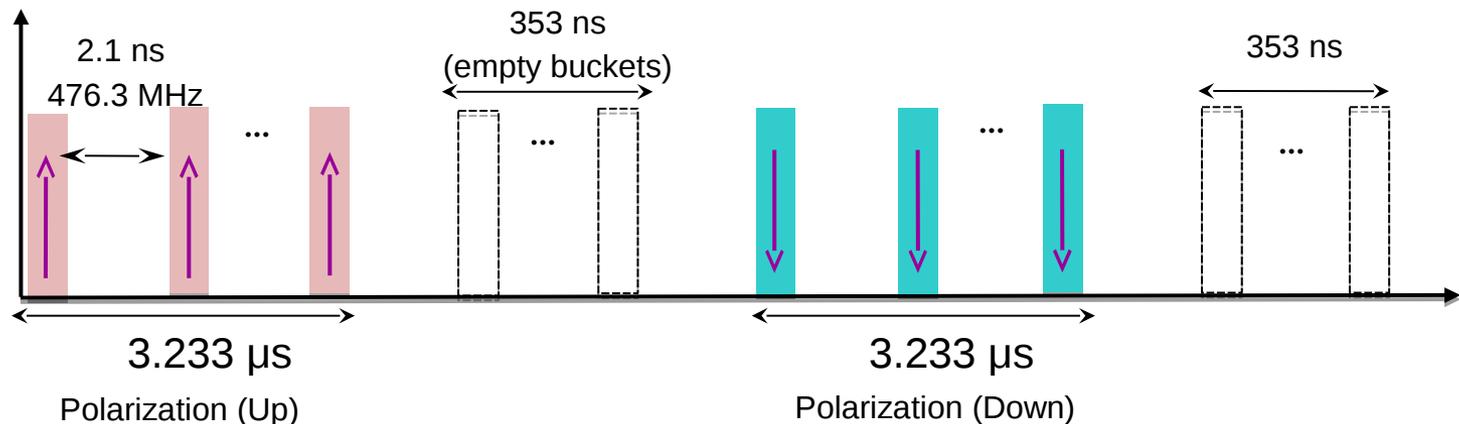
MEIC Beam Structure and Polarization



- 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 μ s

Electron Beam Time structure

bunch train & polarization pattern in the collider ring



Bunch spacing = 2.1 ns

Macrobunches with opposite polarization = 3.233 μs long

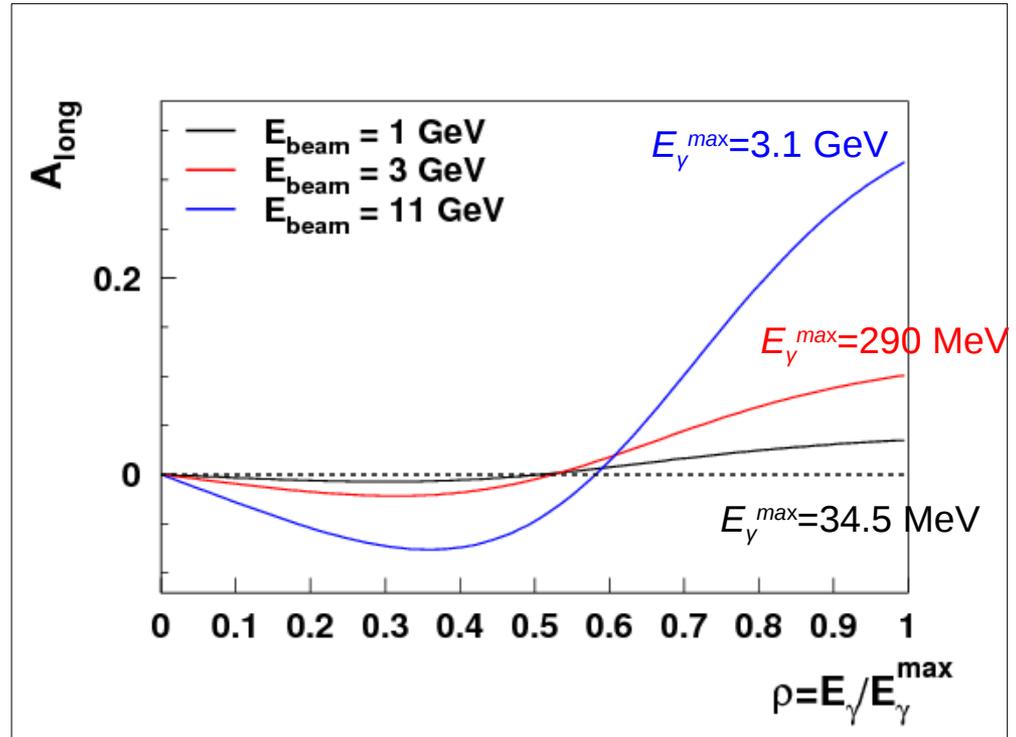
1. Average polarization of beam in ring can be measured with single laser helicity
2. Polarization of each macrobunch can be determined independently by flipping laser helicity

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

Compton Polarimetry

Compton polarimetry ideal method for electron polarimetry at MEIC

- 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:

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

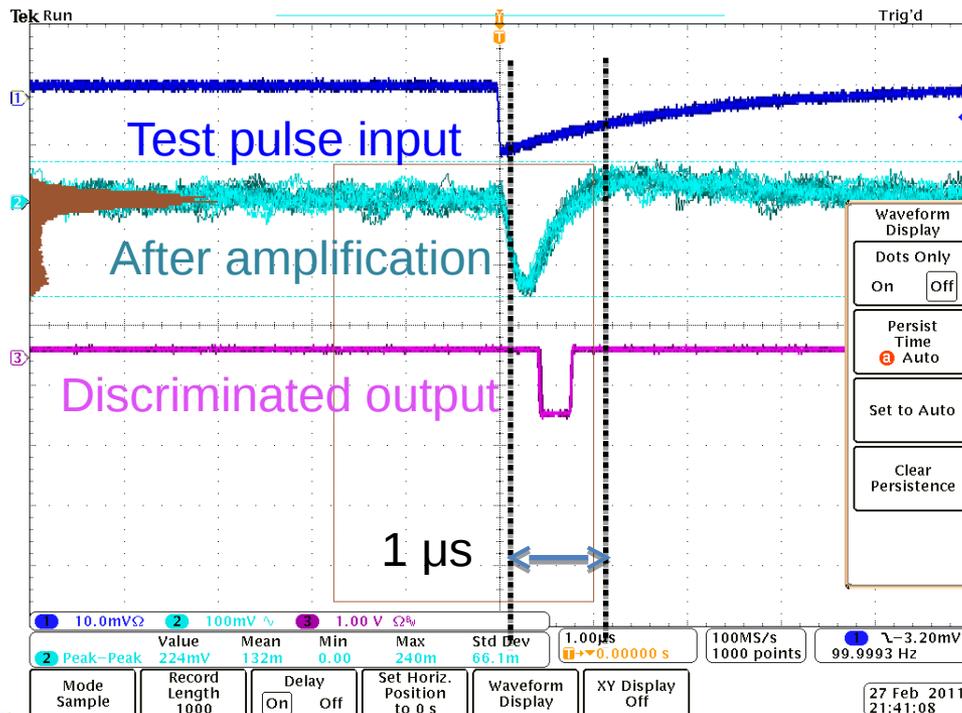
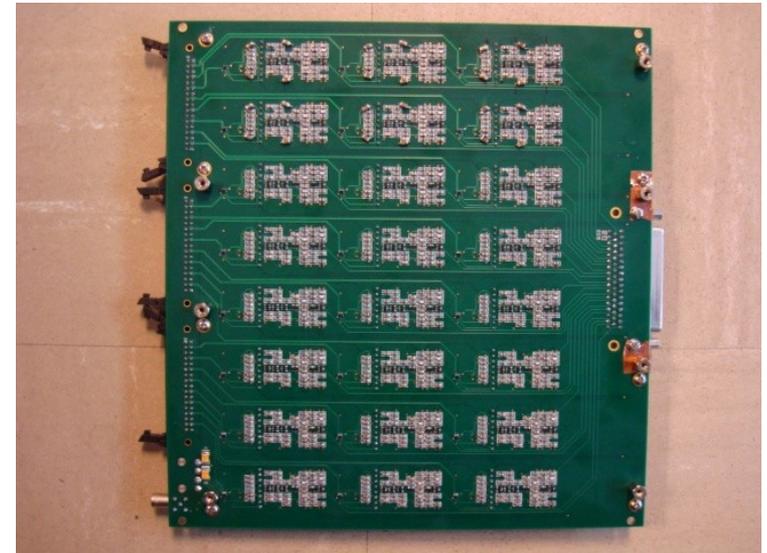
Laser+electron spins parallel

Laser+electron spins anti-parallel

Hall C Compton Electron Detector

Diamond detector read out using
Custom amplifier-discriminator
(QWAD)

$$\text{Gain : } \frac{200 \text{ mV}}{(10 \times 10^3) \times (1.6 \times 10^{-19})}$$
$$= 120 \text{ mV / fC}$$

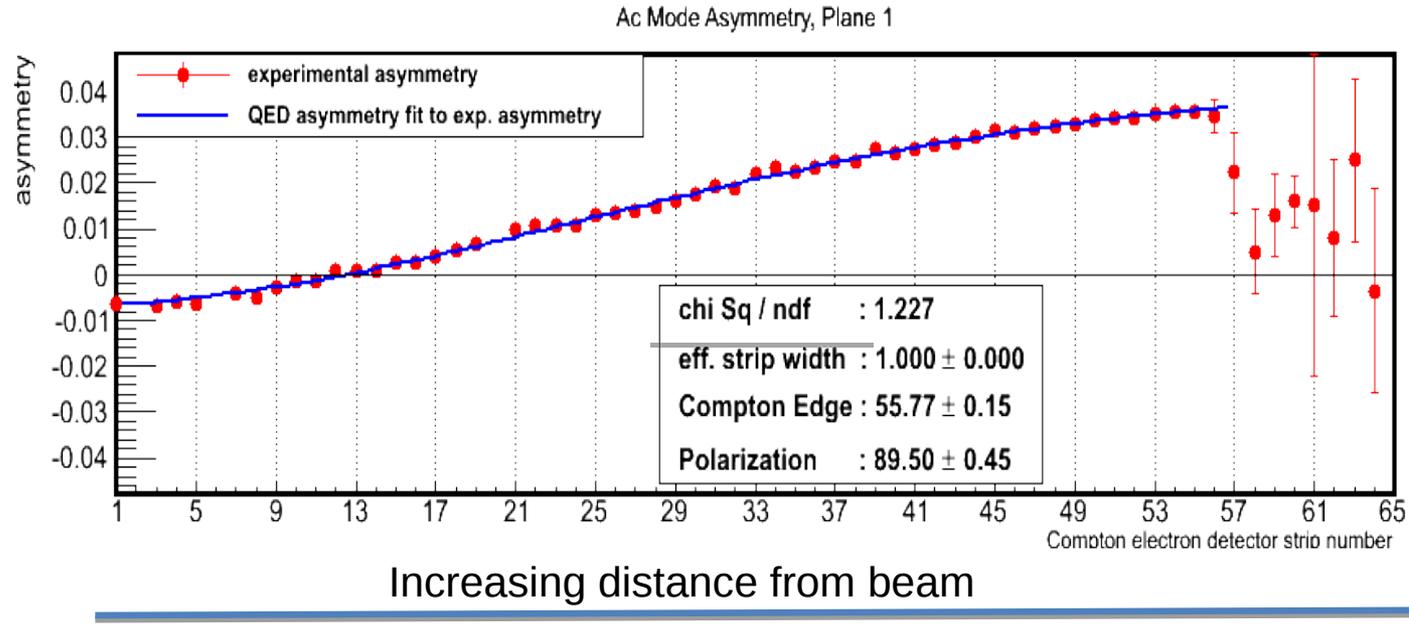


Output pulse relatively long after amplification – time scales of order 1 μ s

□ Diamond intrinsic pulse is faster – shaping electronics produces long pulse

□ Counting at high rates challenging – operate in integration mode? (new or modified electronics)

Compton Electron Detector



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

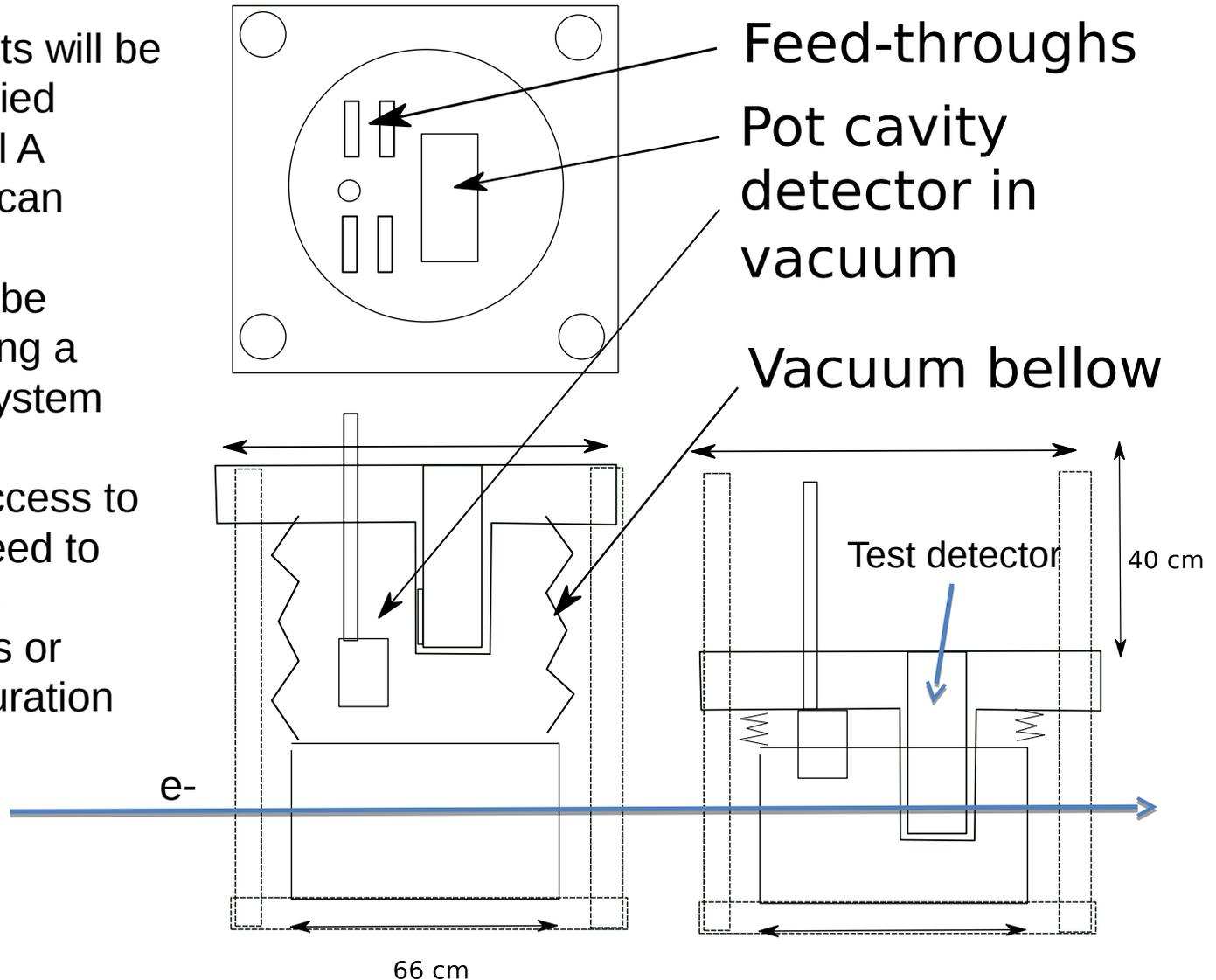
Dominant systematics related to the interplay between trigger and strip efficiency

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

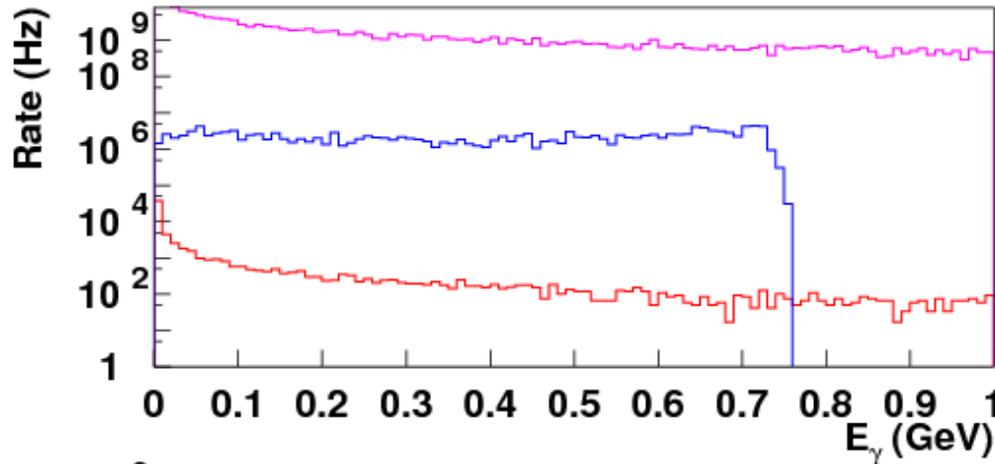


Laser and Backgrounds - Halo

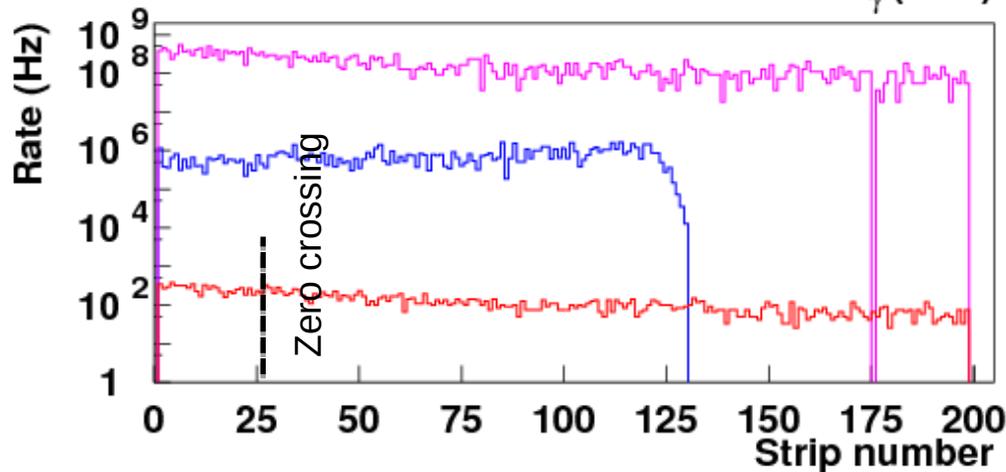
Aperture: 2 cm

$E_e = 5 \text{ GeV}, I = 1 \text{ A}$

Photon det.



Electron det..



Green laser 1 kW

Varying the cavity aperture size in simulation we can investigate backgrounds.



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