eRD-15: Compton Polarimetry R&D Report

Joshua Hoskins

University of Manitoba

EIC R&D Progress Report

January 28-29 2016

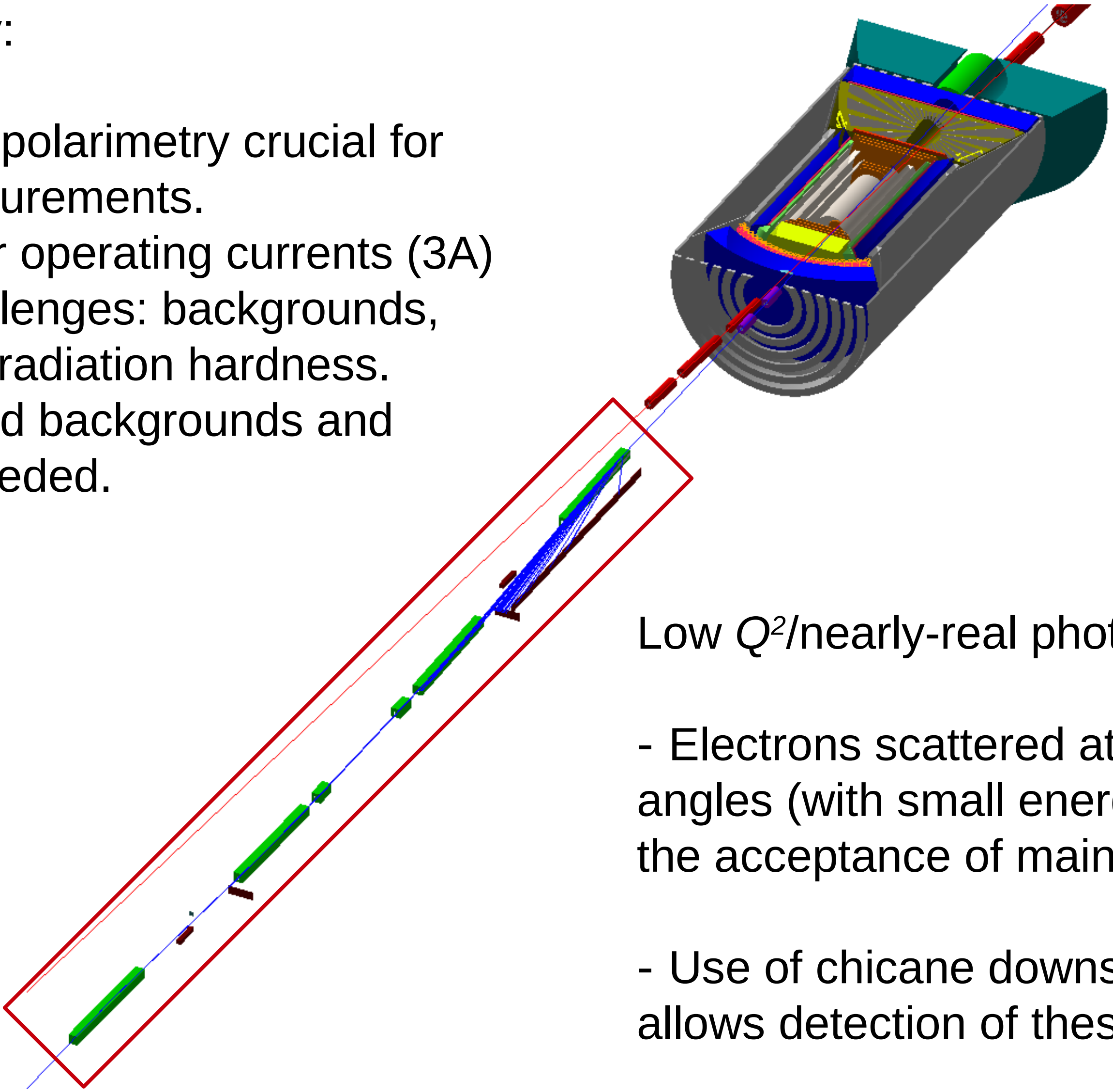
Outline

- Compton polarimetry at Jefferson Lab
- Proposed EIC Compton Chicane
- Electron Detector R&D
- Simulations Efforts in GEANT4
- Future R&D plans

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.

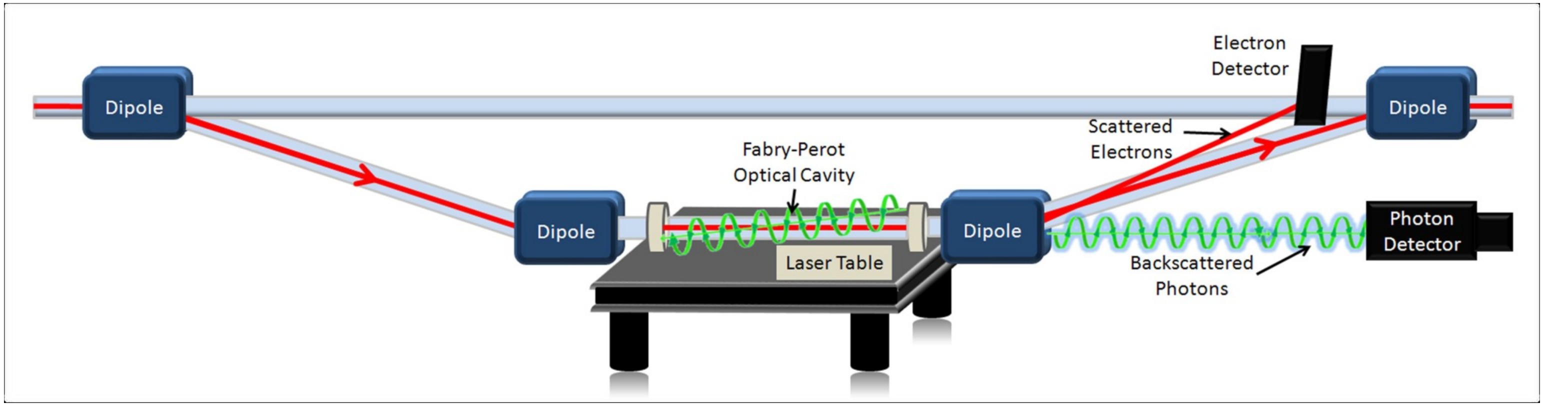


Low Q^2/nearly-real photon tagging:

- 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



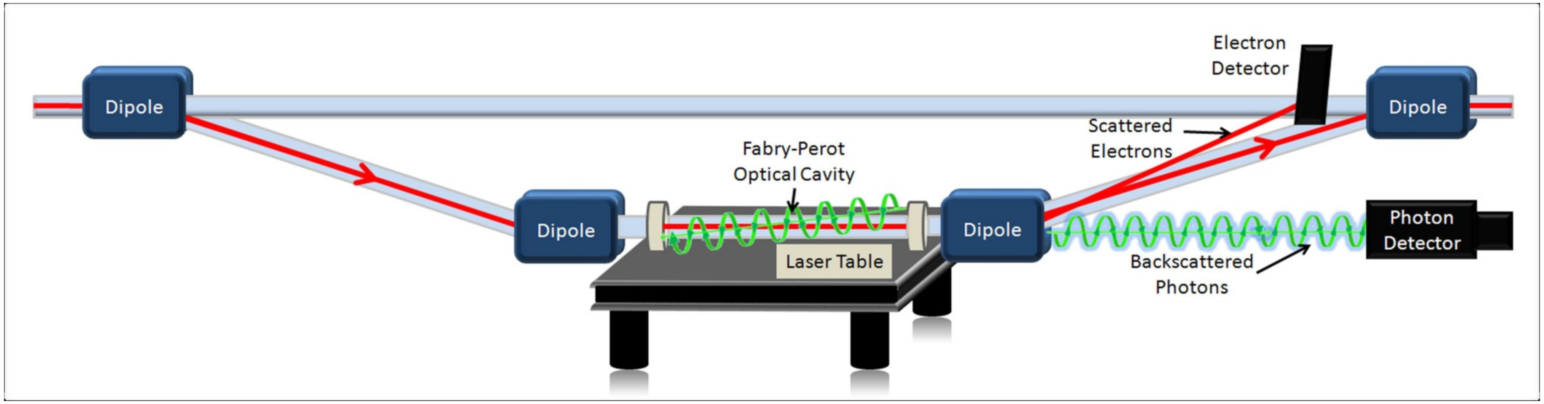
Hall C Compton Layout

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

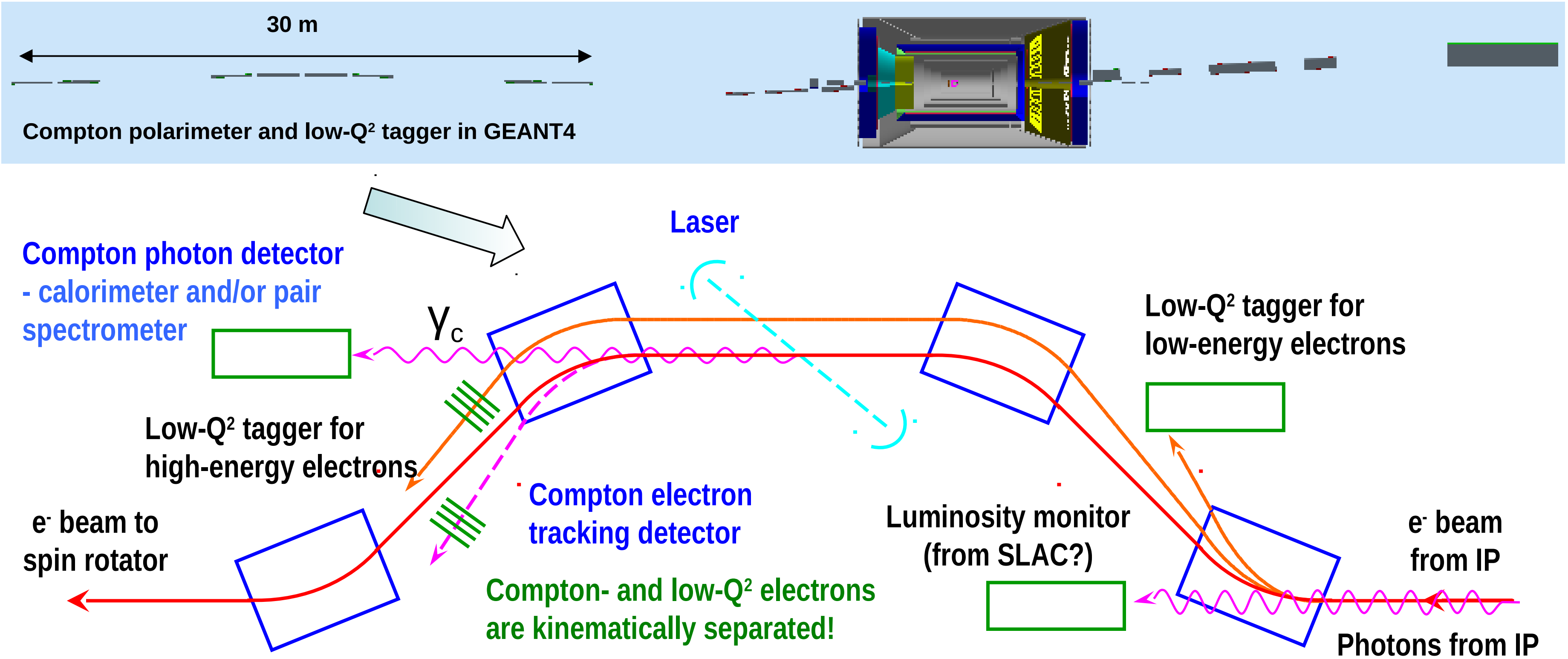
Compton Polarimetry – Experience at JLab



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 (from PEP-II?)

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

Transverse measurement not essential.

Electron Detector R&D

Electron Detector Requirements

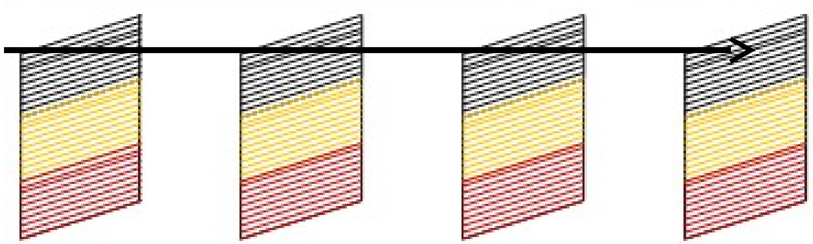
- Segmented or multi-strip detector → allows determination of the beam polarization with high precision by fitting the spectrum.

- 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.



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

(D. Dutta Missipi 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 synchroton shielding.
- Cooling.
- Detector motion.
- More convenient access to detector.
- Easier placement of electronic close to detector.

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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.

Redesigned Detector Chamber

- Proposed redesign of current chamber design. Like Hall C design but with more connectors.

- Flex cable feed through less noisy than current PCB board design.

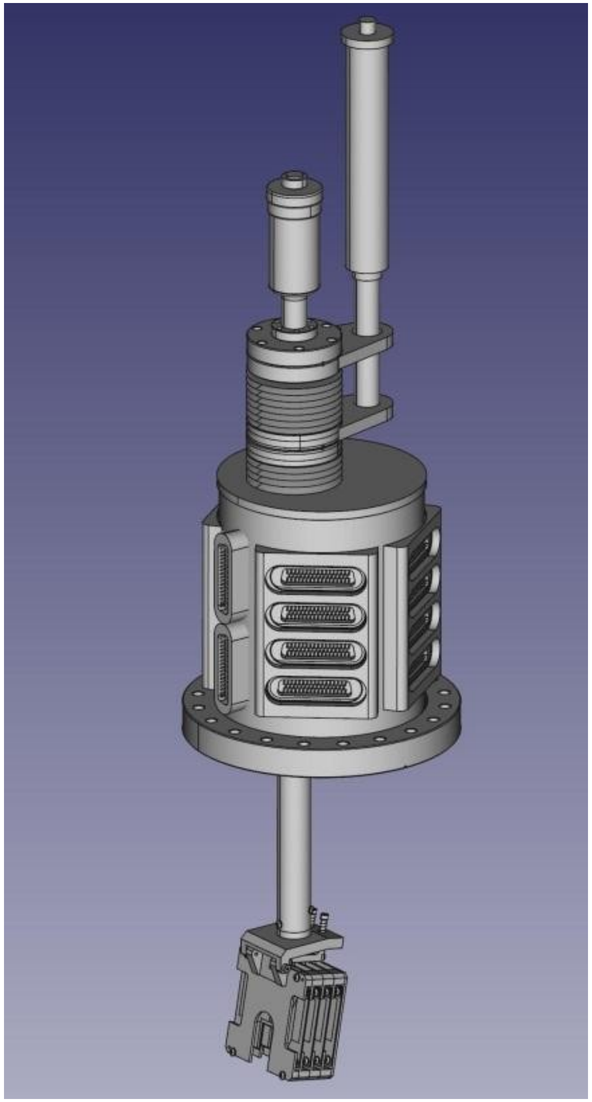
- New top flanges would accommodate 768 channels versus the current 384.

Plans:

- Build lower chamber.

- Test electronics with spare Silicon detectors.

- Build top flange: dependent on funding availability

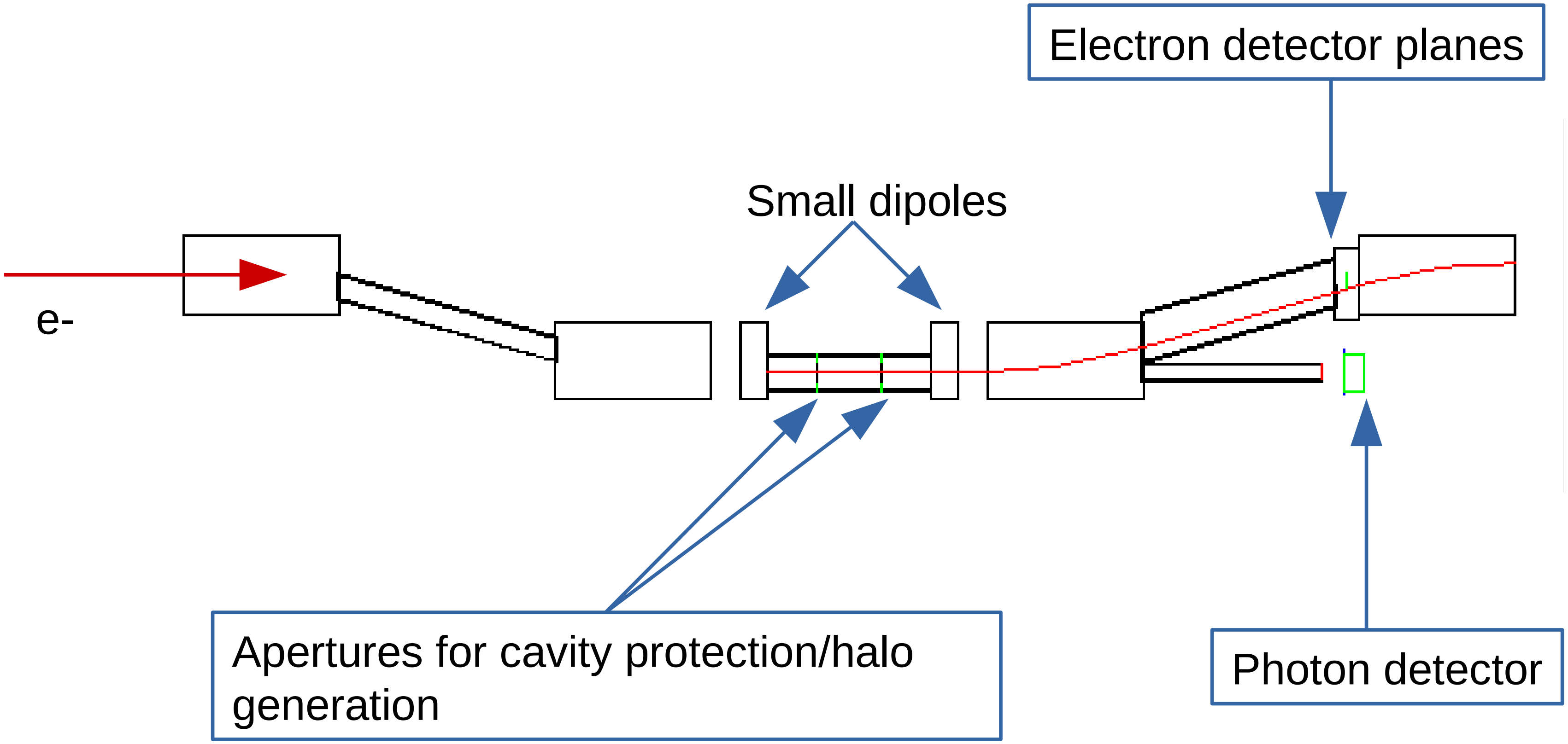


GEANT Simulations Effort

Simulation of Rates and Backgrounds

Initial background estimates performed using GEANT3.

GEANT4/GEMC simulation development in progress.



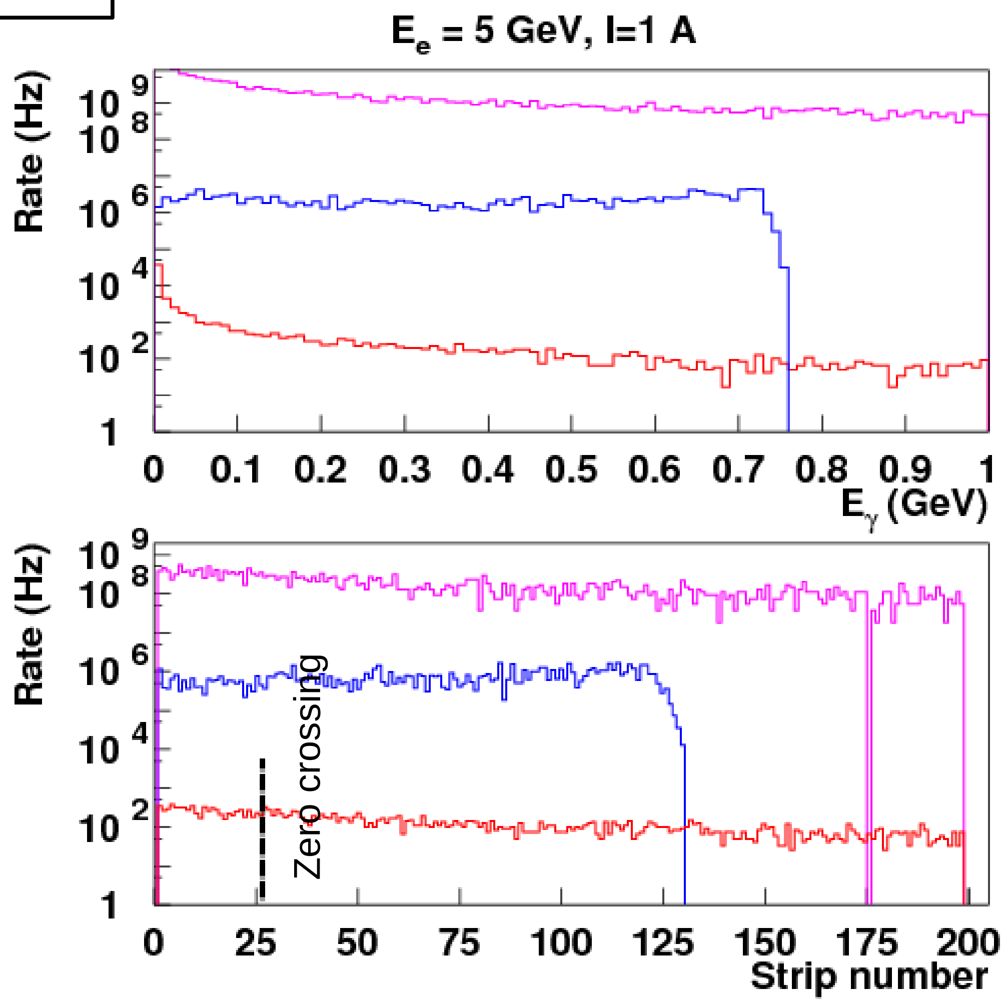
 * Beam sizes from Fanglei Lin

Laser and Backgrounds - Halo

Aperture: 2 cm

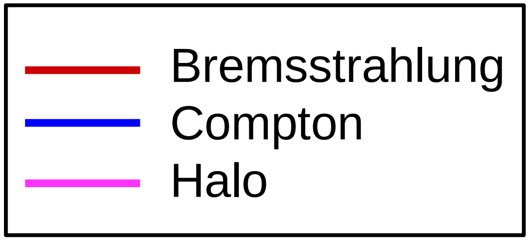
Photon det.

Electron det..



Green laser 1 kW

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



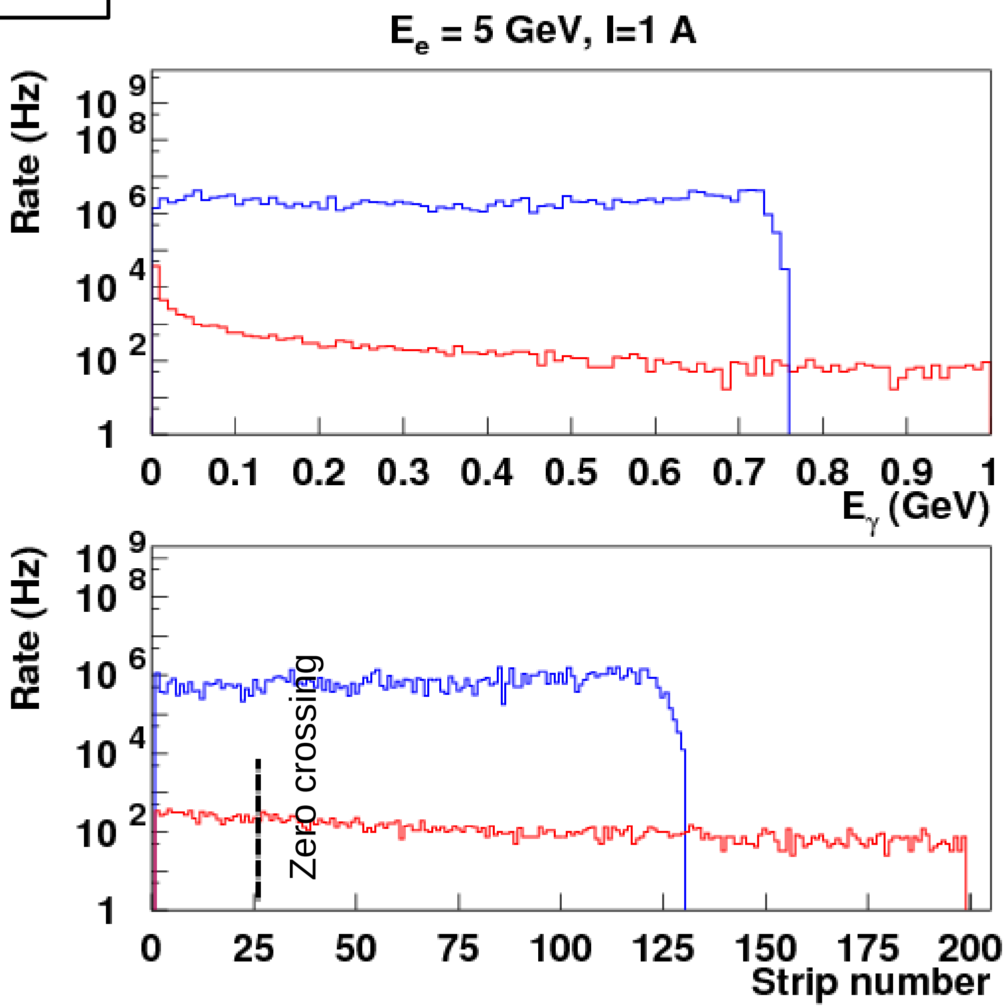
Compton edge 4 cm from beam, zero crossing = 2 cm from beam

Laser and Backgrounds - Halo

Aperture: 4 cm

Photon det.

Electron det..



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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

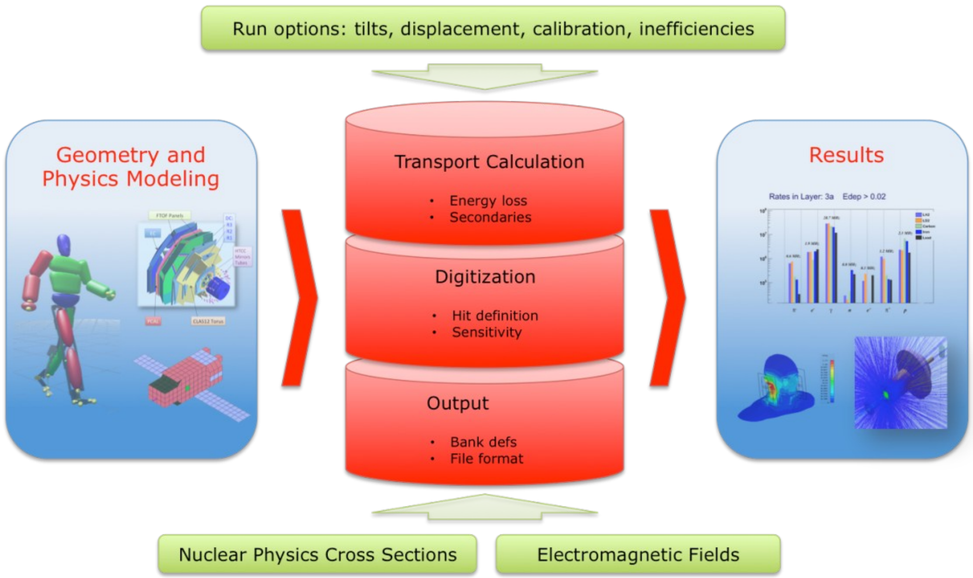
1-Pass laser crossing angle: 0.3 deg.
FP cavity crossing angle: 2.6 deg.

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)



The architecture of 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.

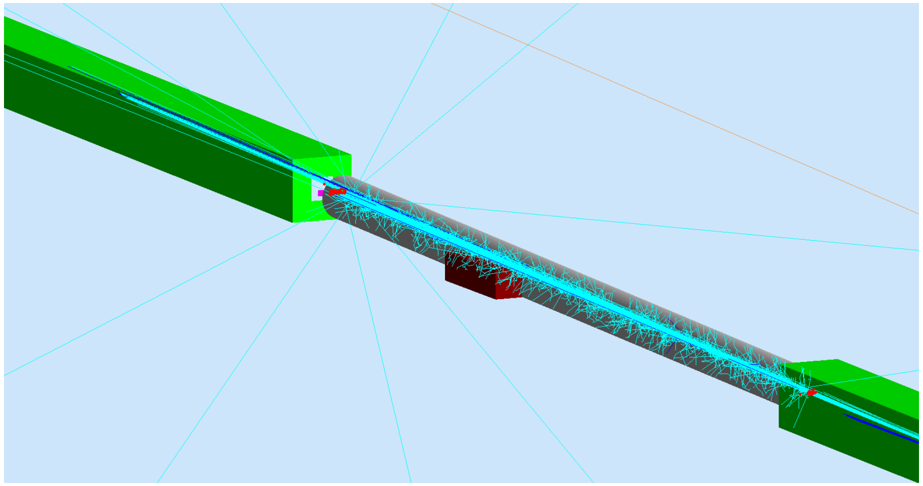
Detector and beamline geometries added via simple perl API

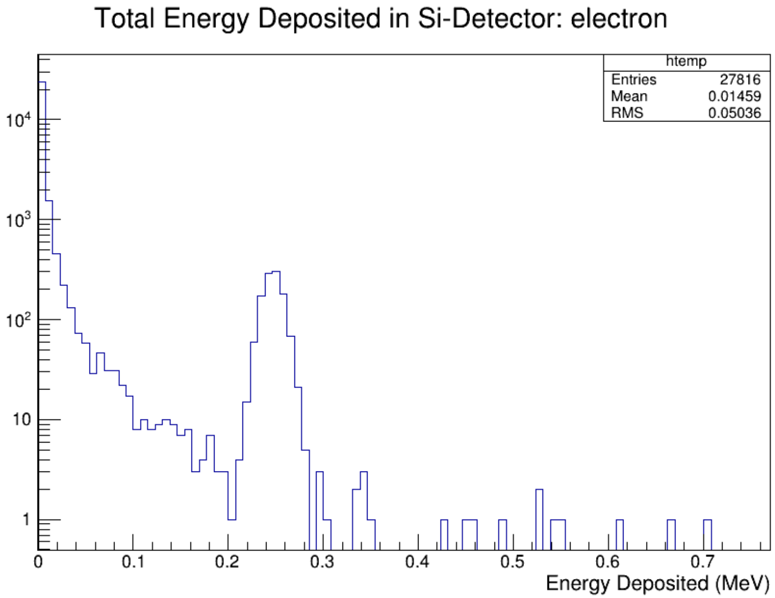
Compton Polarimetry R&D: Background Simulations

- Additional geometries added to GEMC framework.

- Full Compton chicane implemented into EIC simulation. Including simple detectors, initial beam pipe simple geometry

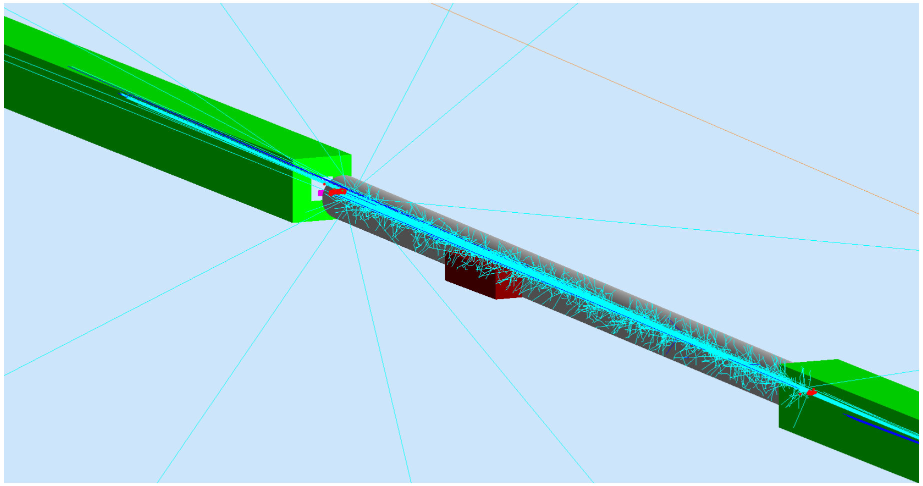
- Initial simulations seem to show everything is working properly.

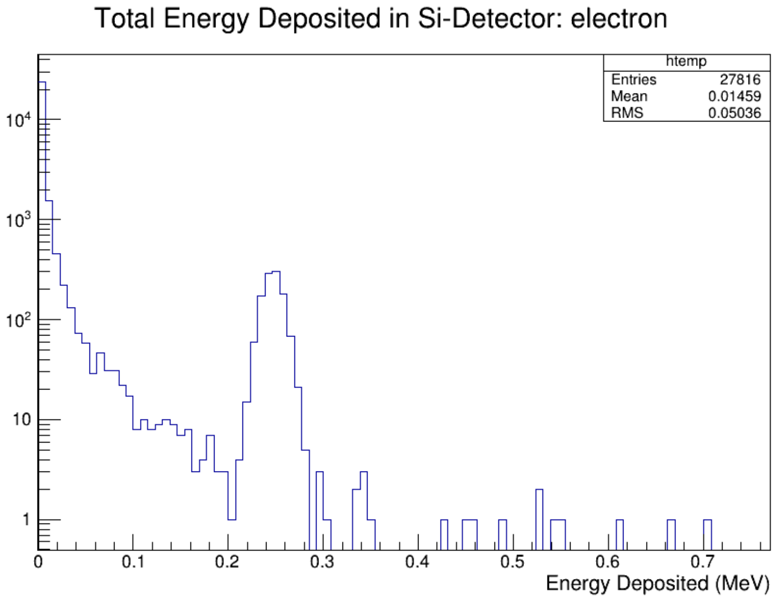




Compton Polarimetry R&D: Background Simulations

- Detailed studies of synchroton and Bremstrahlung radiation in electron detector.
- Add custom physics list functionality to GEMC. Currently only available for hadronic processes.
- Implementation of Compton generator from Richard Petti : signal to noise ratio systematic on polarization extraction
- Study backgrounds originating from the 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 set to begin soon.

Thank You.

Extra

Report summary

- The Committee recognizes that the MEIC crossing rate likely precludes resolving individual crossings, but repeats the comment that the interaction with the machine structure and dependencies of emittance growth and instabilities on bunch charge need to be studied by the accelerator experts.

Separate effort lead by Balsa Terzic : code exists, optimization in progress, a presentation could be given at the next meeting or next January meeting if deemed interesting

- Unlike the CEBAF single-pass fixed target operation, bunches in a collider will evolve with time. Since all electron bunches in the MEIC collide with all ion bunches, absent the ability to time-resolve crossings, only the time-average can be measured, making it compelling to develop the initial simulations noted by the authors to the point that external reviewers can be convinced.

First simple model implemented by David Gaskell, plan to complete the study for July meeting

- The authors note that further studies of the background are needed and mention that more studies of the synchrotron background is needed for an MEIC, due to the location of the chicane after the IP. A location for the polarimeter has not yet been determined for the eRHIC lattice and choices upstream of the IP are under consideration, in part to reduce background rates. The authors also mention methods to improve laser power, including pulsed laser options, and the Committee takes note of the multi-kW lasers developed and in operation for the JLab Hall A and C Compton polarimeters.

Joshua Hoskins from University of Manitoba will spend 50 % of his time on the eRD15 simulation. Learning the simulation software GEMC, expect to have preliminary results for July meeting. First beam pipe geometry implemted

Report summary

-
- The Committee recommends further contact with various groups that have built silicon strip and pixel devices, in particular concerning timing performance and integration of electronics with sensors to minimize noise and footprint, as well as concerning radiation-resistant electronics.

Followed Glen Young advice and contacted CLAS12 vertex tracker group. Expertise and wirebonding hardware available at Jefferson Laboratory, perfect for ASIC testing

- Contact with the TOTEM experiment and the CMS-TOTEM Precision Proton Spectrometer is recommended to learn about their approach to the experimental issues.

Contact with Kansas Group Michael Murray and Christophe Royon, they are interested in the improved timing resolution. Might have a separate or joint proposal for July meeting

- The committee encourages the simulation studies leading to a full design of the polarimeter and the pursuit of an initial test chamber that would allow studies with the Hall C diamond detector. Bench studies of cooled and local (ASIC) electronics coupled to diamond detectors are encouraged as well to understand noise and timing performance.

Contracts are in place. JLab designers will give accurate cost of test stand for summer meeting

Report summary

- It is suggested to engage the JLab ion-source group to determine if a test using a 10 MHz rep-rate laser at the existing polarized ion source could be done to study polarimeter operation at 10 MHz bunch rate. The group should evaluate the direction of future development at the next meeting of the Committee
- This was suggested when the digital lasers were being implemented at JLab. Digital lasers could give any repetion rate. Digital lasers proved to be unstable at the beginning of the 12 GeV commissionning and were given up. Only 31 MHz CW is available.

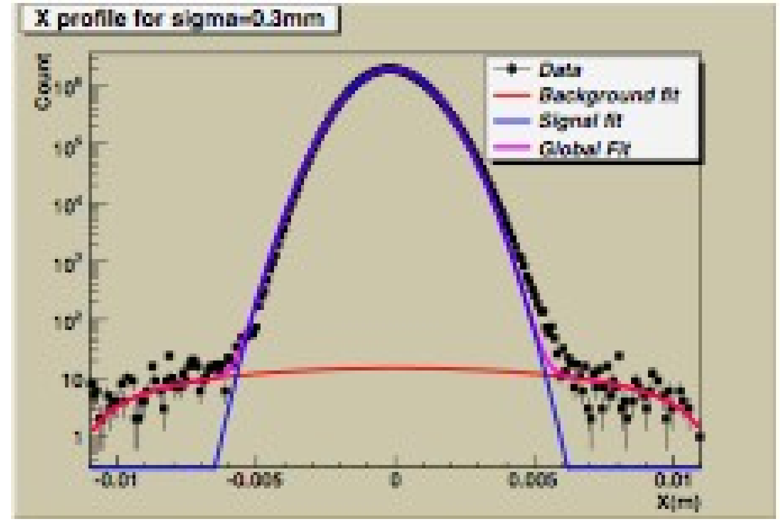
Also would require significant effort and dedicated beam so this would need to be figured out (PAC proposal ?)

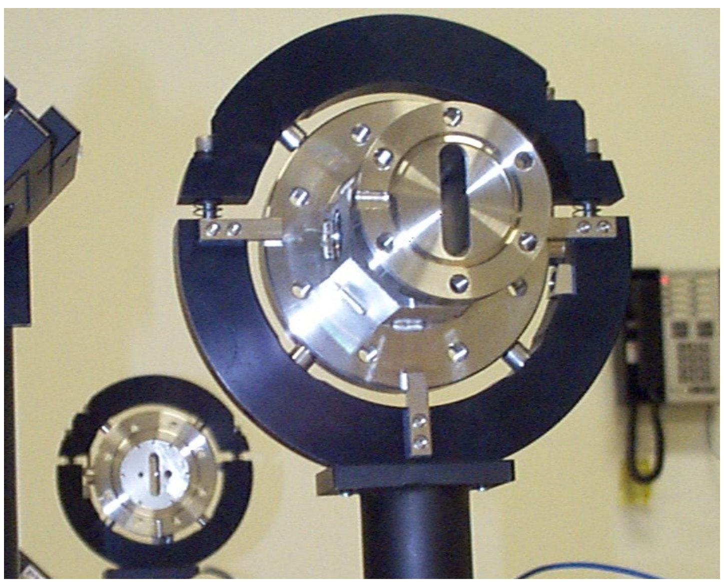
Can look at tune beam option

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 EIC depends on understanding halo.

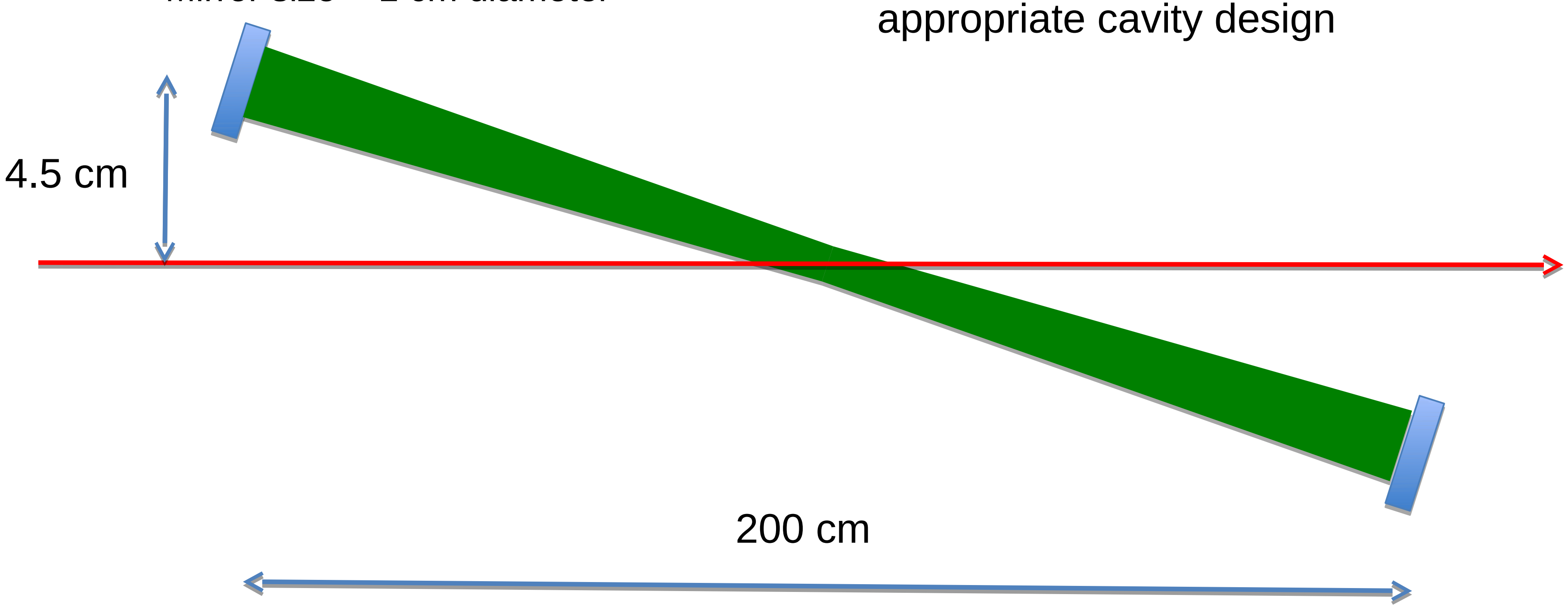
Compton Design team

- 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

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 (σ_x,σ_y) = 151.4 um

Cavity gains of 1000-5000 easily achievable

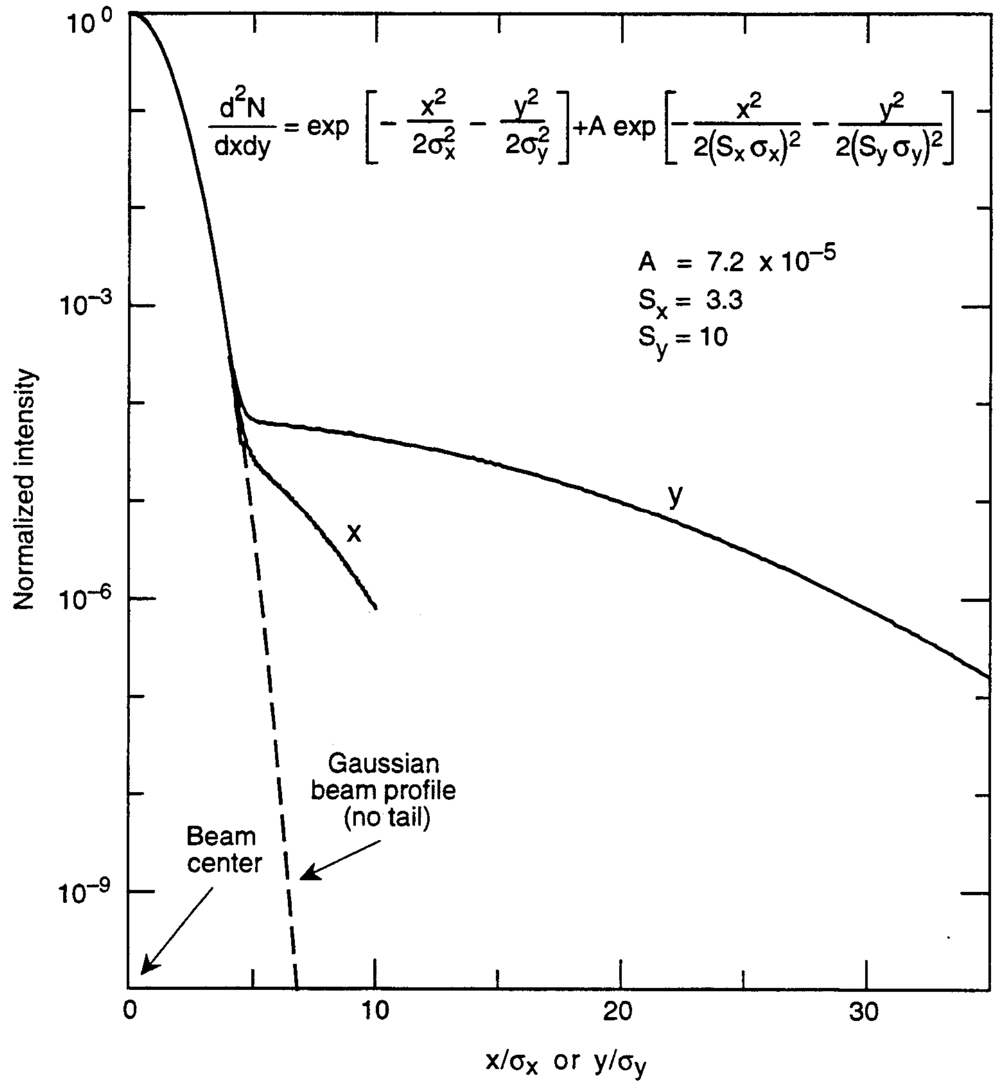
Simulations - Halo

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

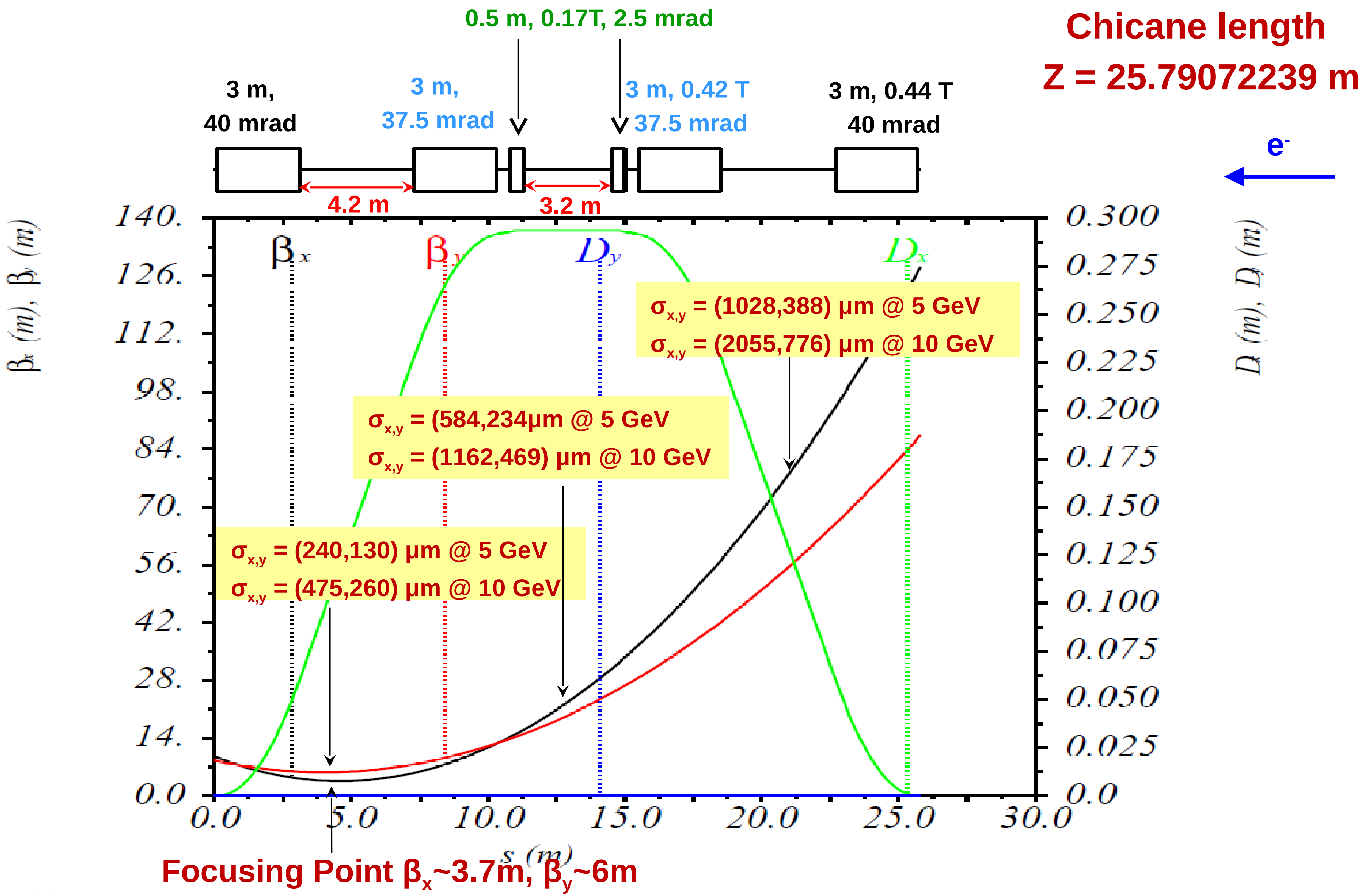
1. Direct strike of electron detector
2. Interactions with FP cavity apertures



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

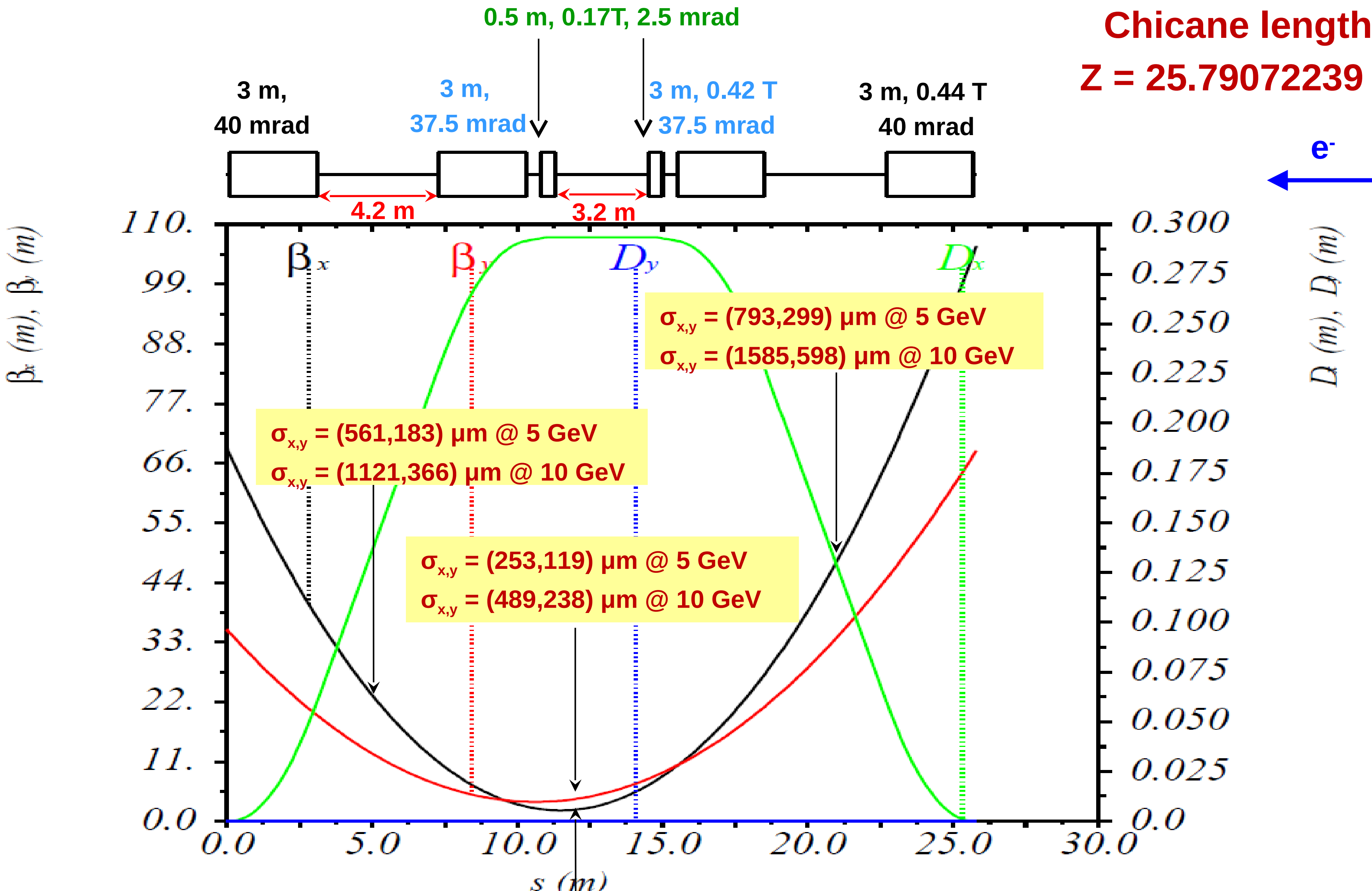
Chicane Design (baseline)



Chicane Design: Focus at IP

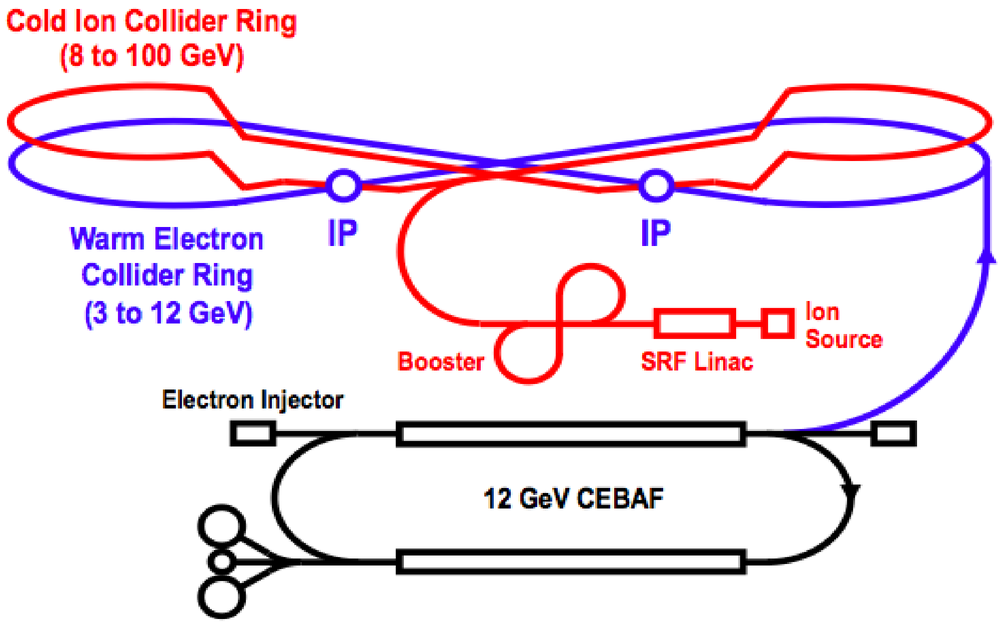
Chicane length

Z = 25.79072239 m



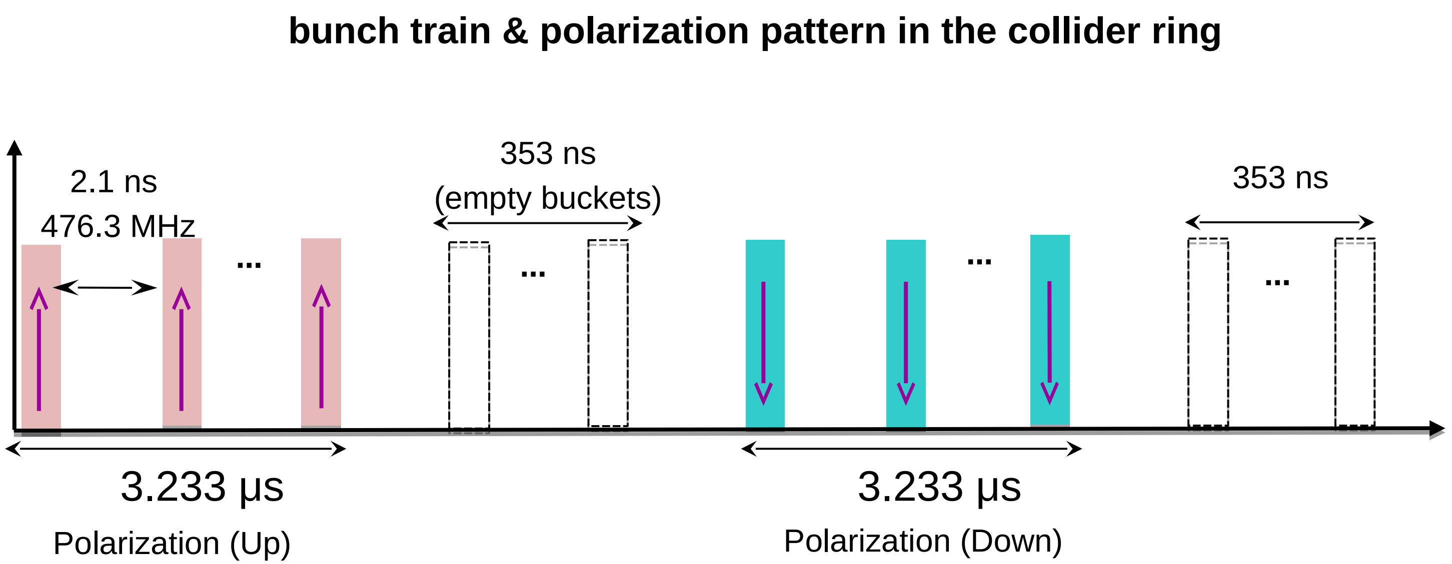
Focusing Point β_x~3m, β_y~5m

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 μs

Electron Beam Time structure



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

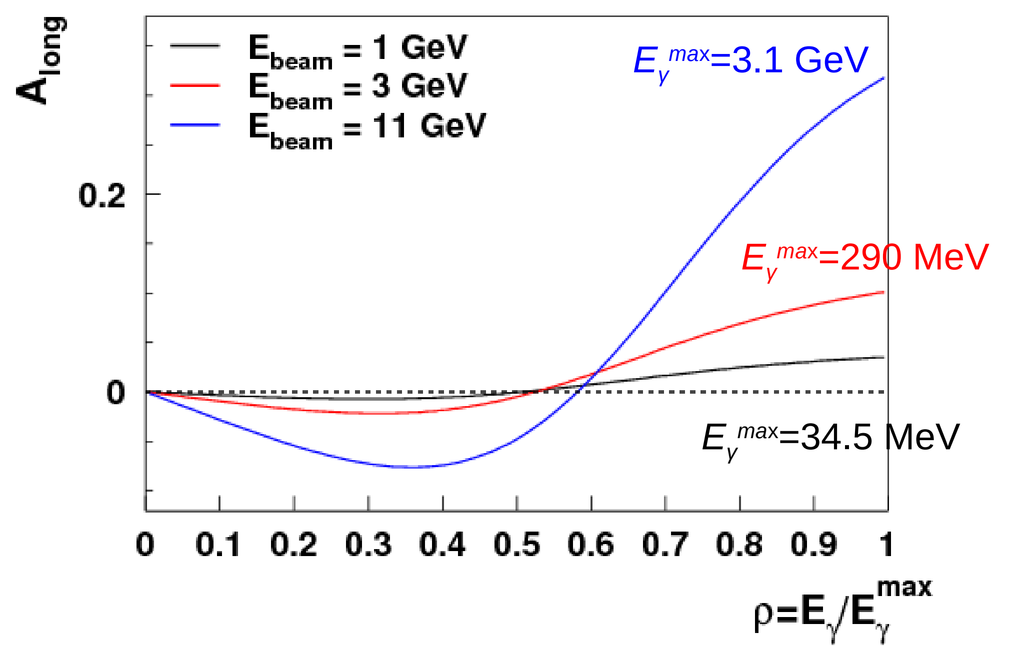
1. Average polarization of beam in ring can be measured with single laser helicity
2. Polarization of each macrobunch can be determined independently by flipping laser helicity

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

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:

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

Laser+electron spins parallel

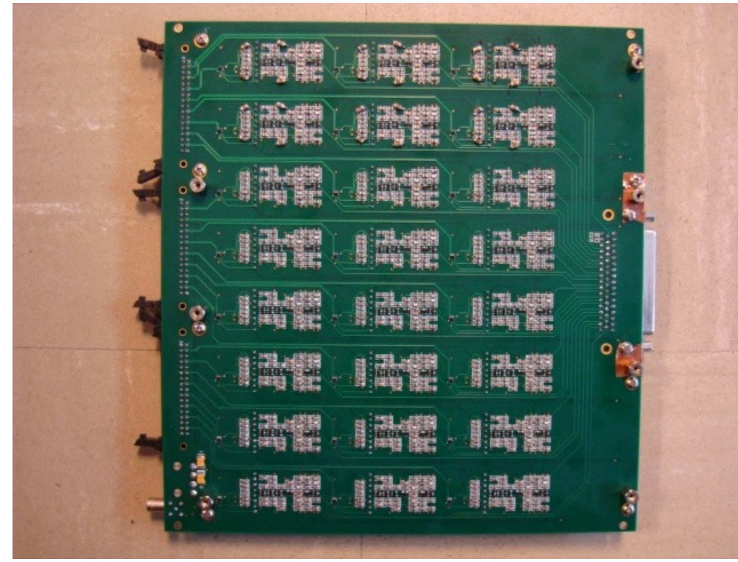
Laser+electron spins anti- parallel

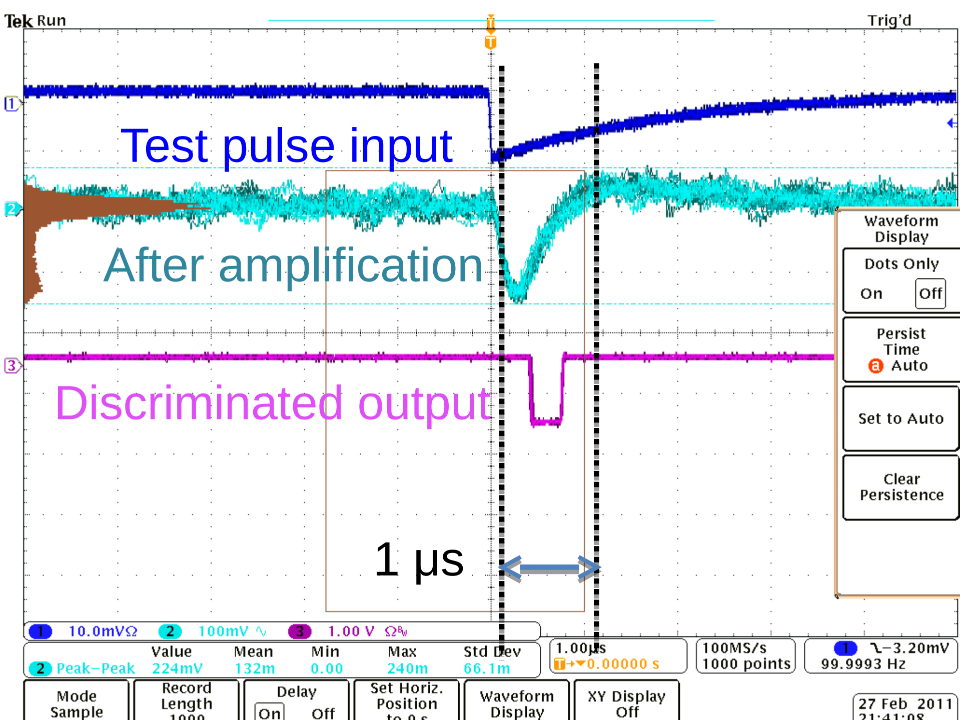
Hall C Compton Electron Detector

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

$$\text{Gain : } \frac{200 \text{ mV}}{(10\times10^{3}) \times (1.6\times10^{-19})}$$

$$= 120 \text{ mV / fC}$$



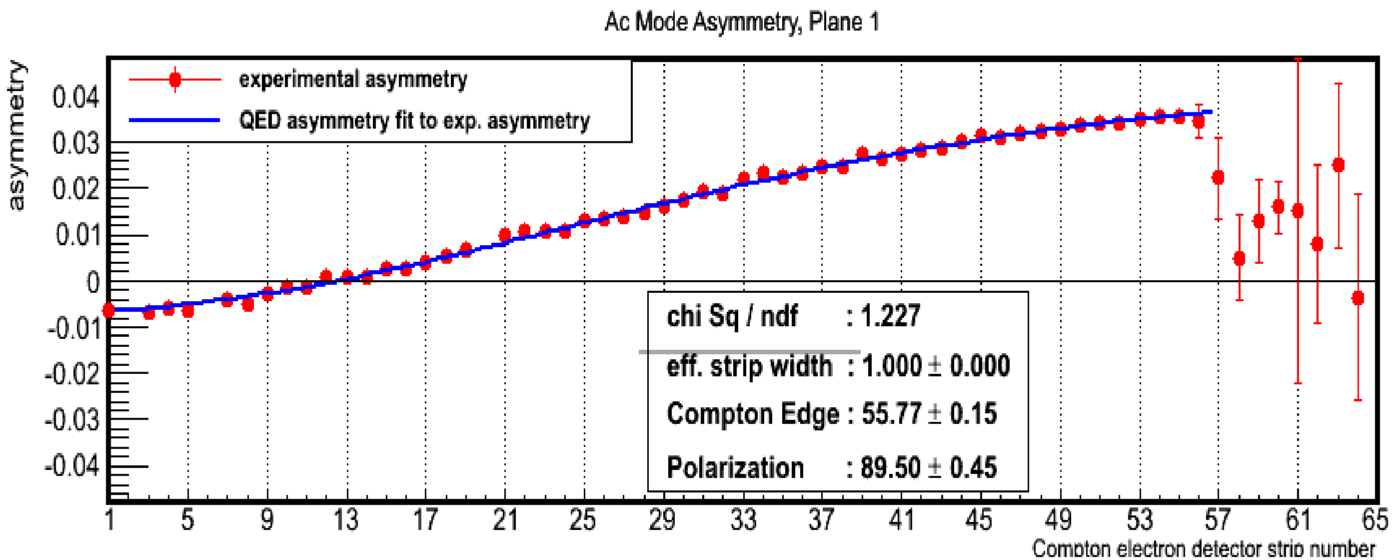


Output pulse relatively long after amplification – time scales of order 1 µs

 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



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

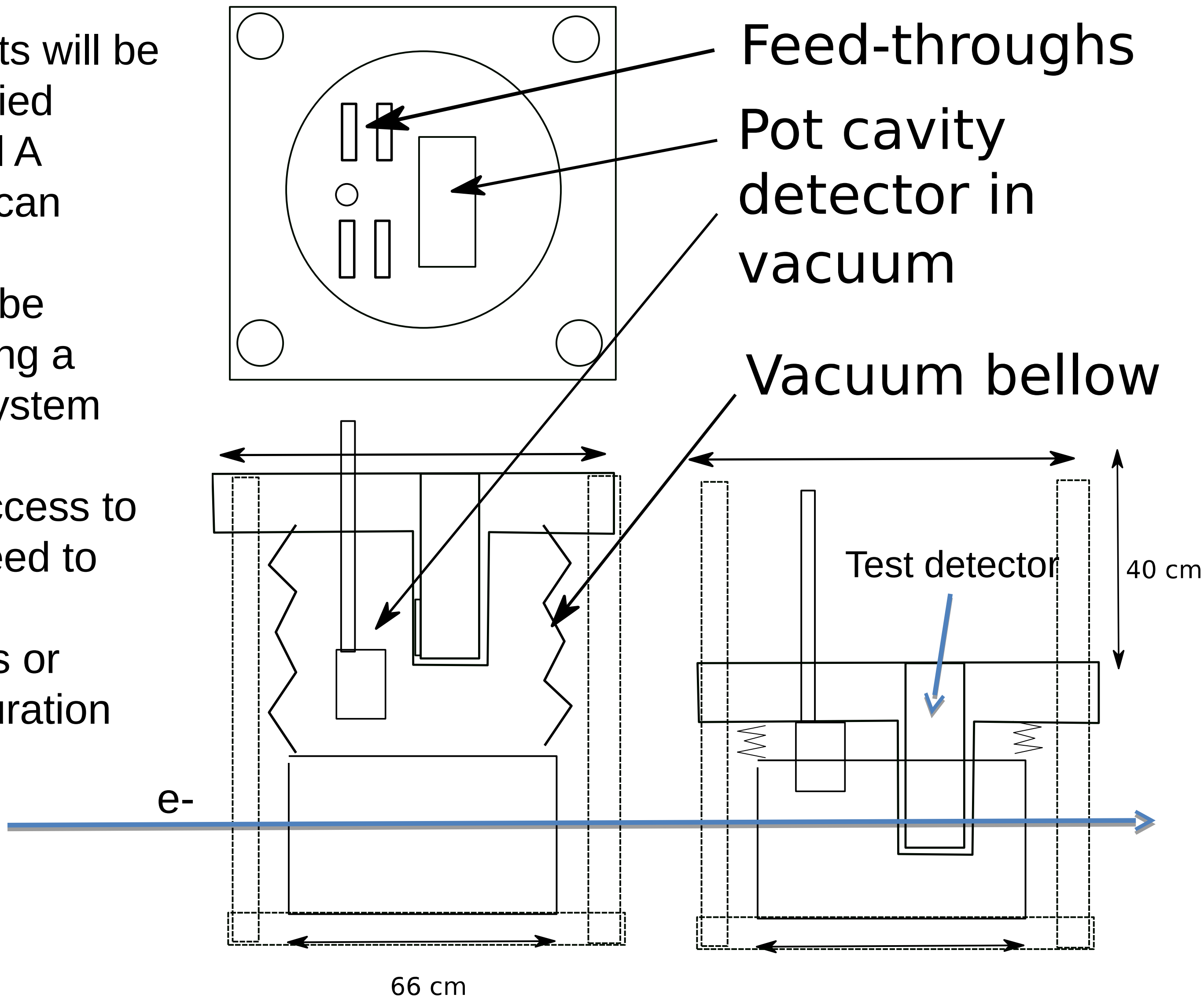
Dominant systematics related to the interplay between trigger and strip efficiency

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



Minimal budget request (K$)

Item	Unit price	Quantity	Total	Overhead	Request
Postdoc	25	1	25	13.625	38.625
Travel	5	1	5	2.725	7.725
Design	5	1	5	2.725	7.725
				Total	54.075

Hardware budget request (K$)

Item	Unit price	Quantity	Total	Overhead	Request
Electronics	5	4	20	10.9	30.9
Front end	10	1	10	5.45	15.45
Lower chamber	10	1	10	5.45	15.45
Detector holder	2.5	1	2.5	1.3625	3.8625
Test flange	10	1	10	5.45	15.45
				Total	81.113

Total : 135.2 K$

Ideal budget request (K$)

Item	Unit price	Quantity	Total	Overhead	Request
Electronics	5	4	20	10.9	30.9
Front end	10	1	10	5.45	15.45
Lower chamber	10	1	10	5.45	15.45
Detector holder	2.5	1	2.5	1.3625	3.8625
Test flange	10	1	10	5.45	15.45
Feedthrough	2.25	18	40.5	22.0725	62.573
Motion system	8	1	8	4.36	12.36
					156.05

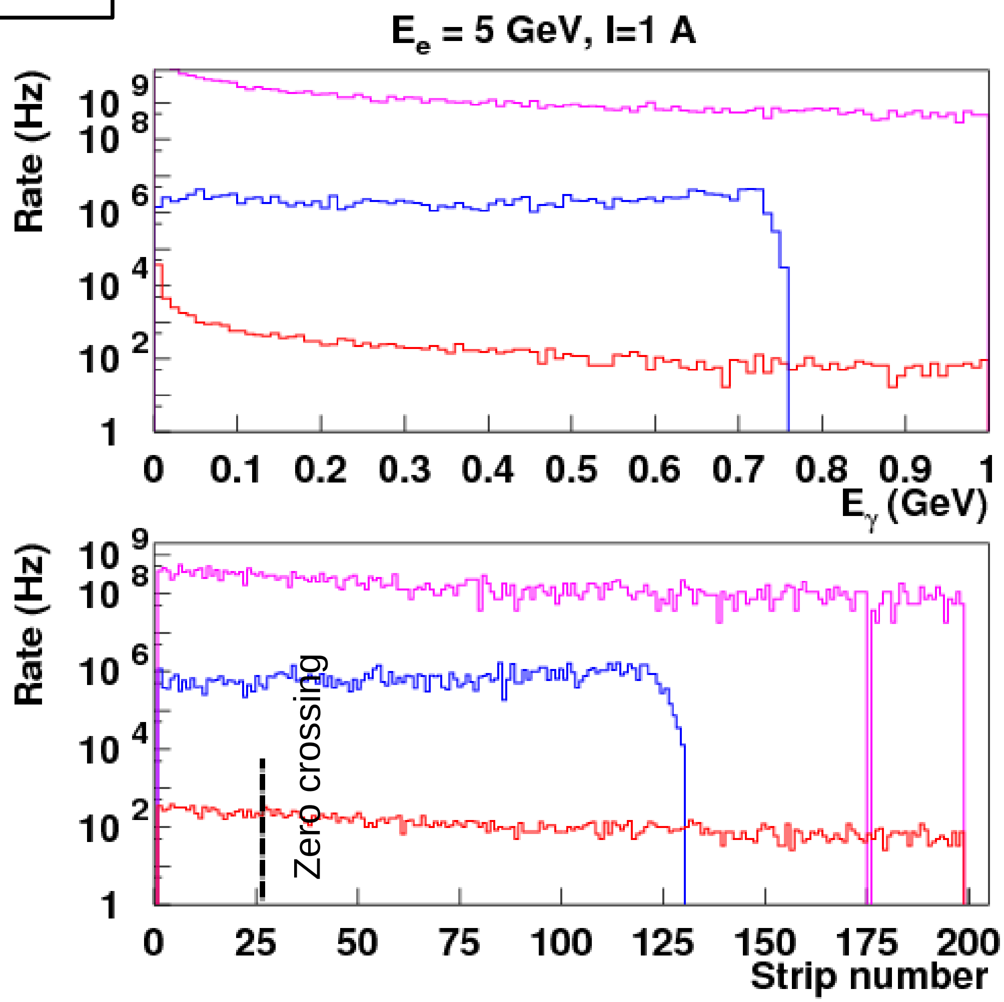
Total : 210.2 K$

Laser and Backgrounds - Halo

Aperture: 2 cm

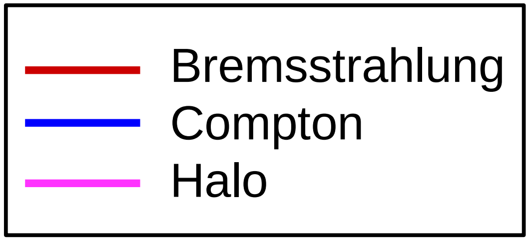
Photon det.

Electron det..



Green laser 1 kW

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

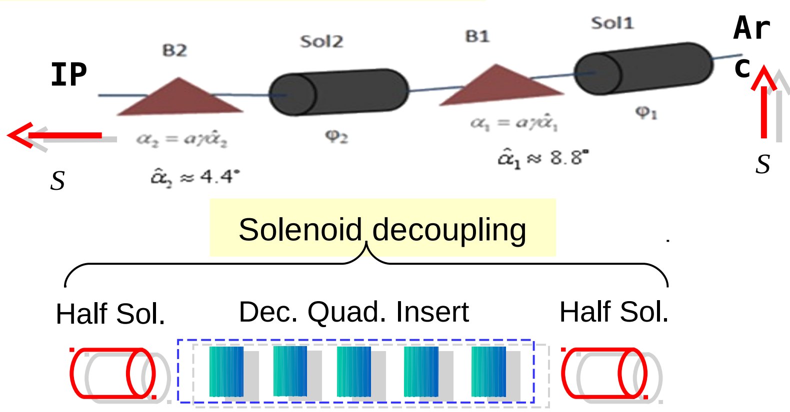


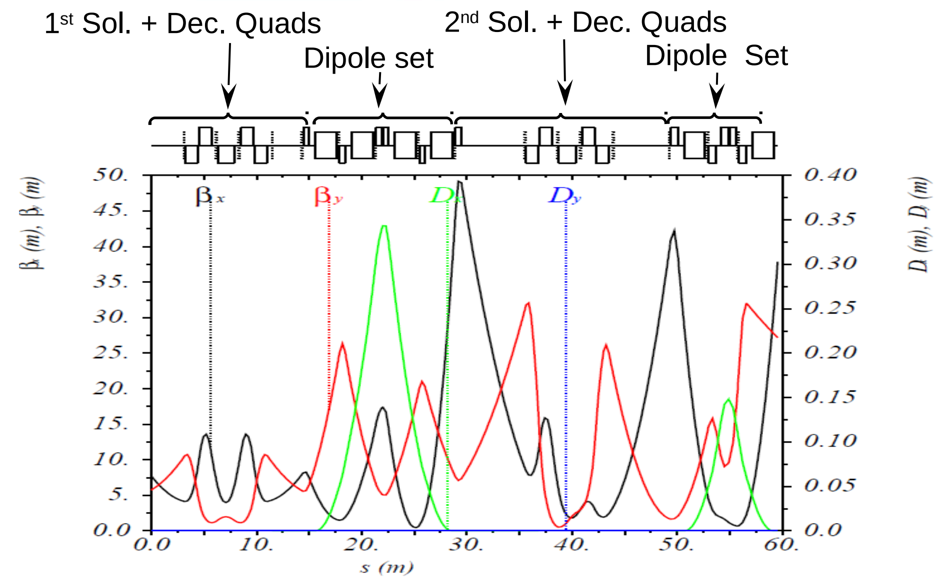
Compton edge 4 cm from beam, zero crossing = 2 cm from beam

Electron Polarization Design

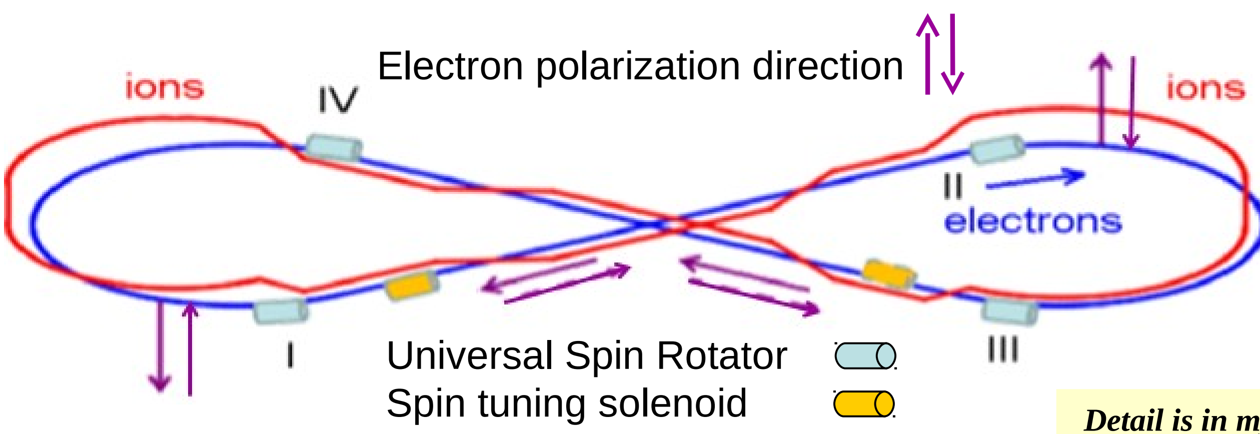
- Schematic drawing and lattice of USR

P. Chevtsov et al., Jlab-TN-10-026





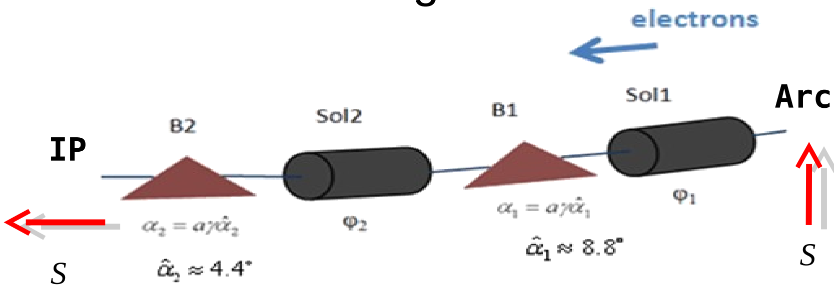
- Electron polarization configuration to achieve: two polarization states simultaneously in the ring with 70% (or above) longitudinal polarizations at IPs



Detail is in my talk on electron polarization

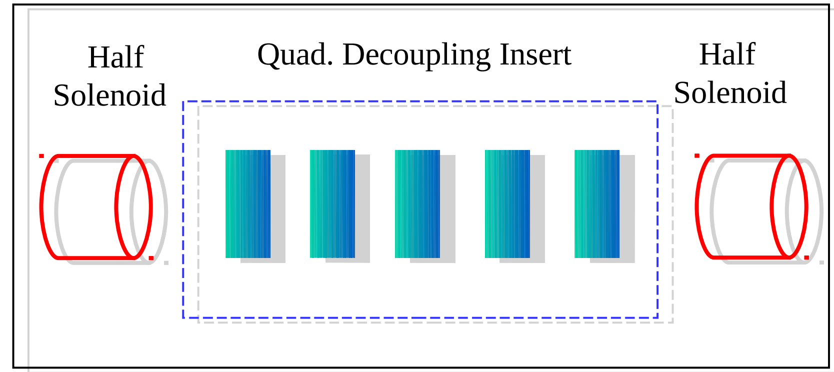
Universal Spin Rotator (USR)

- Schematic drawing of USR



P. Chevtsov et al., Jlab-TN-10-026

- Solenoid decoupling & Lattice function



- Parameters of USR for MEIC

E	Solenoid 1		Arc Dipole 1	Solenoid 2		Arc Dipole 2
	Spin Rotation	BDL	Spin Rotation	Spin Rotation	BDL	Spin Rotation
GeV	rad	T·m	rad	rad	T·m	rad
3	π/2	15.7	π/3	0	0	π/6
4.5	π/4	11.8	π/2	π/2	23.6	π/4
6	0.62	12.3	2π/3	1.91	38.2	π/3
9	π/6	15.7	π	2π/3	62.8	π/2
12	0.62	24.6	4π/3	1.91	76.4	2π/3