Integration of Polarimetry and Low Q^2 Measurements

Dave Gaskell – JLab

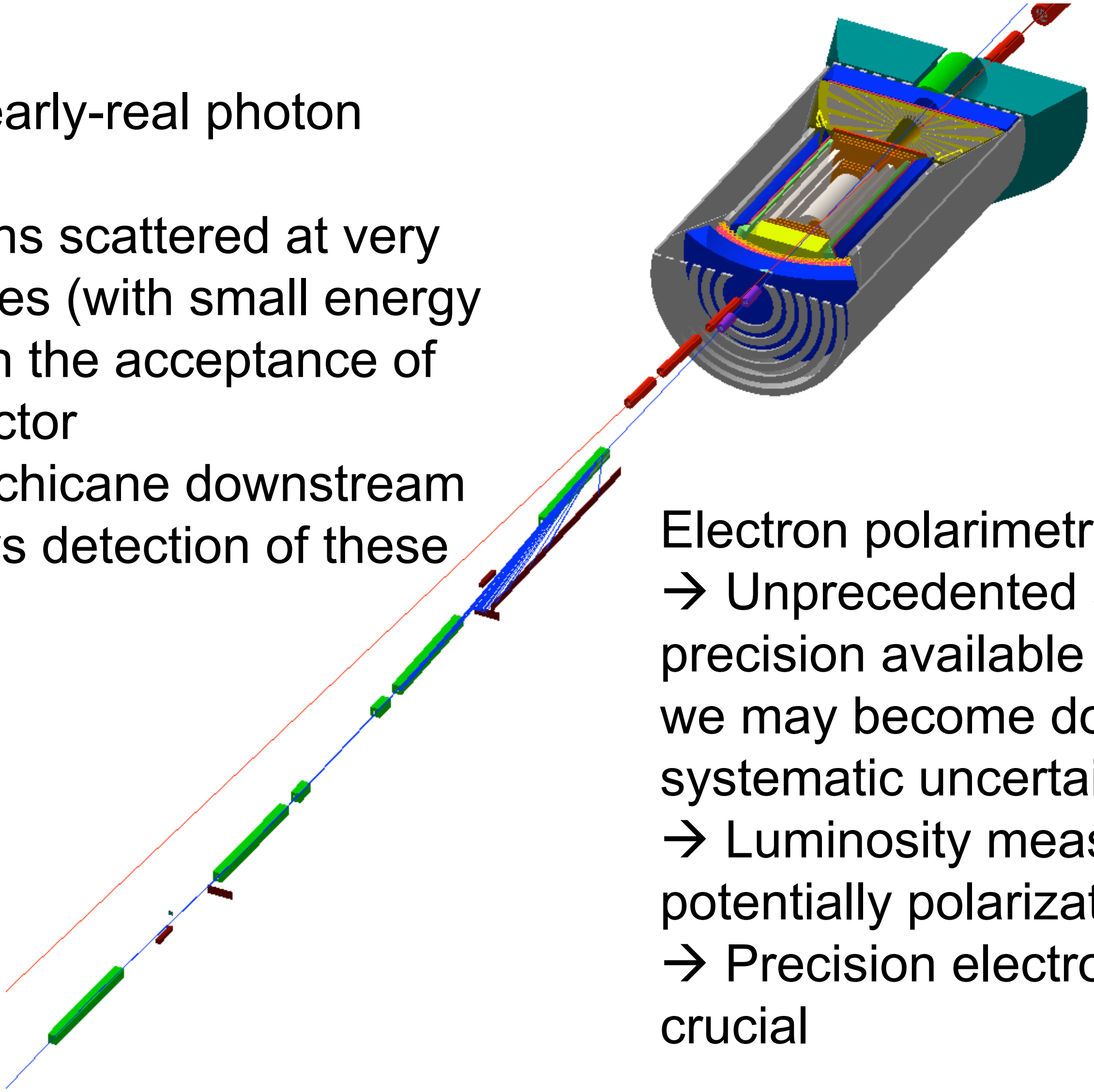
MEIC Collaboration Meeting
October 5-7 2015

Outline

- Chicane for low-Q^2 tagging and Compton polarimetry
- Measuring electron beam polarization at MEIC
- Compton polarimetry - experience at JLab
- Polarimeter "baseline" design
- Future polarimeter R&D

Low Q^2 Tagger and Polarimetry

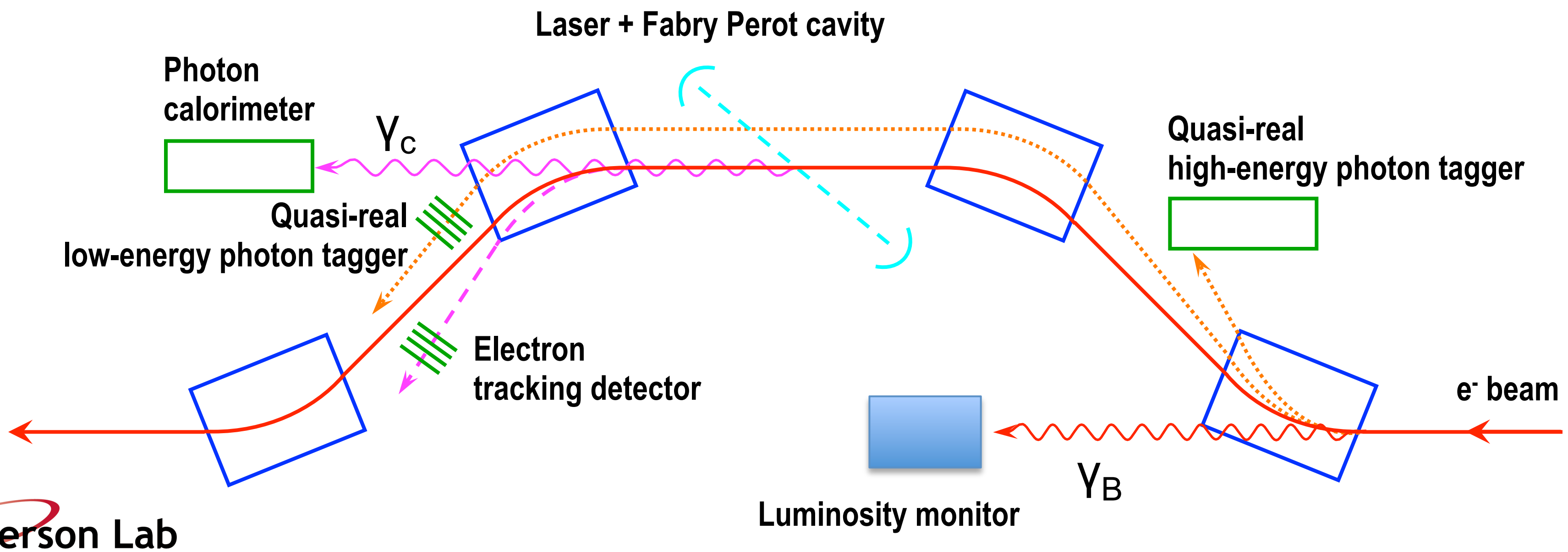
Low Q^2/nearly-real photon tagging:
→ Electrons scattered at very small angles (with small energy loss) not in the acceptance of main detector
→ Use of chicane downstream of IP allows detection of these electrons



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

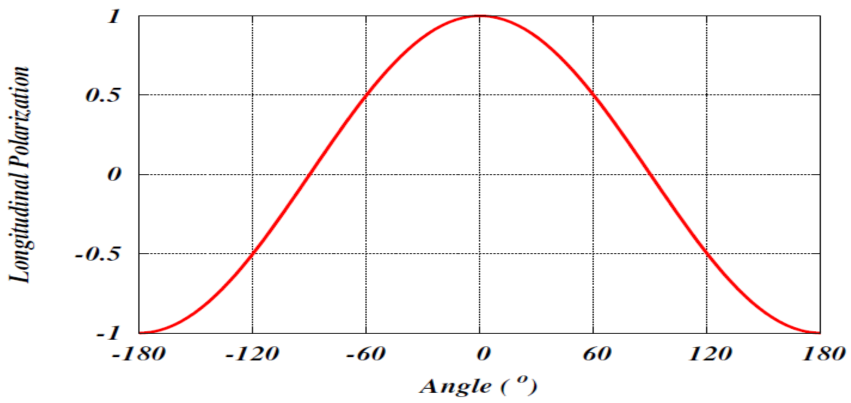
Chicane for Low Q^2 tagger and Compton Polarimeter

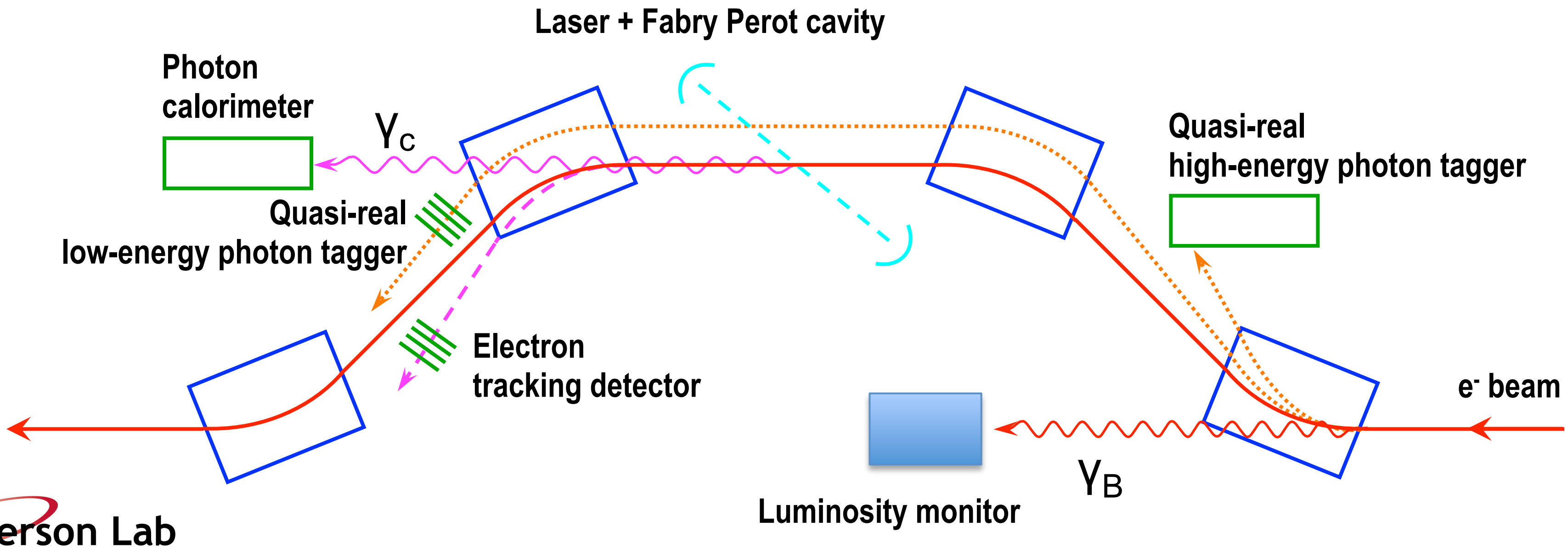
- At MEIC, Compton can share chicane with low Q^2 tagger
- Laser-electron collisions in middle of chicane assures no spin rotation relative to IP
- No interference with electron detectors needed for low Q^2 tagger



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

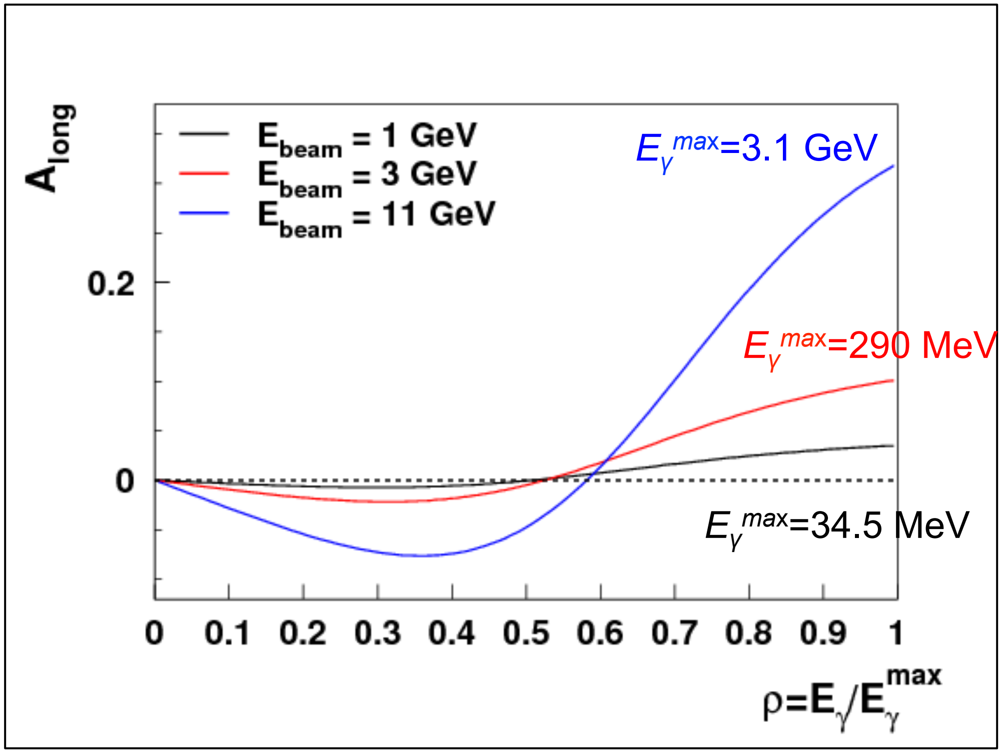




Compton Polarimetry

Compton polarimetry ideal method for electron polarimetry at MEIC

→ Photon "target" very thin – no impact on electron beam
→ High precision accessible – sub-1% precision has been achieved



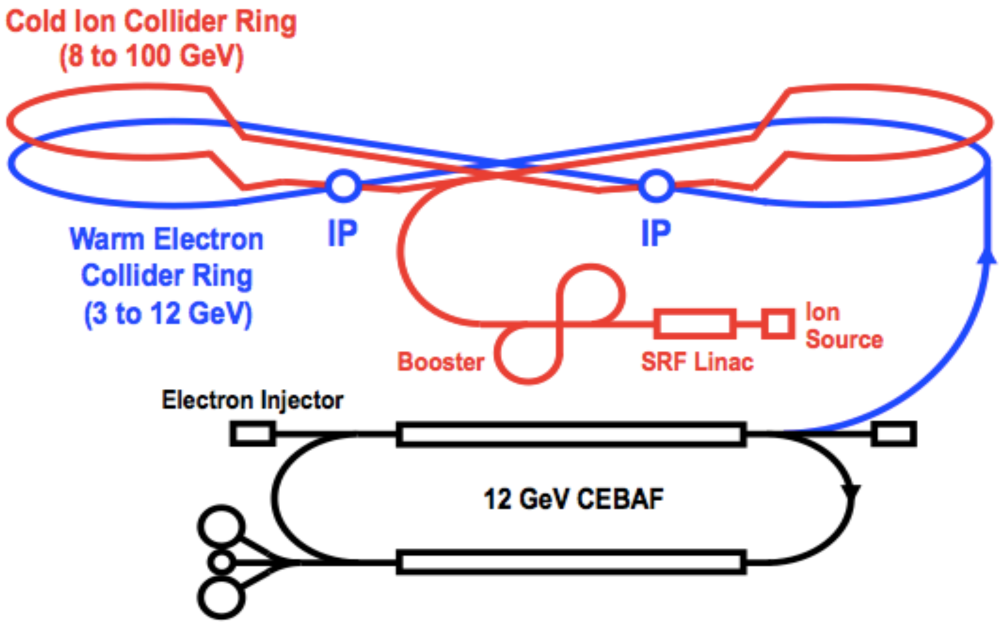
Beam polarization extracted via double-spin asymmetry:

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

Laser+electron spins parallel

Laser+electron spins anti- parallel

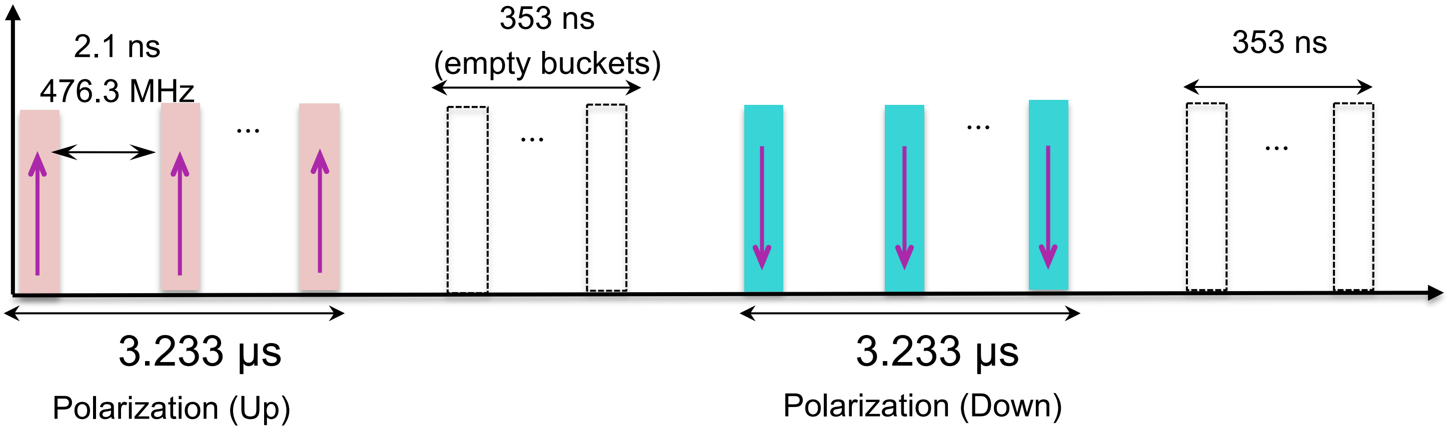
MEIC Beam Structure and Polarization



- 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 train & polarization pattern in the collider ring

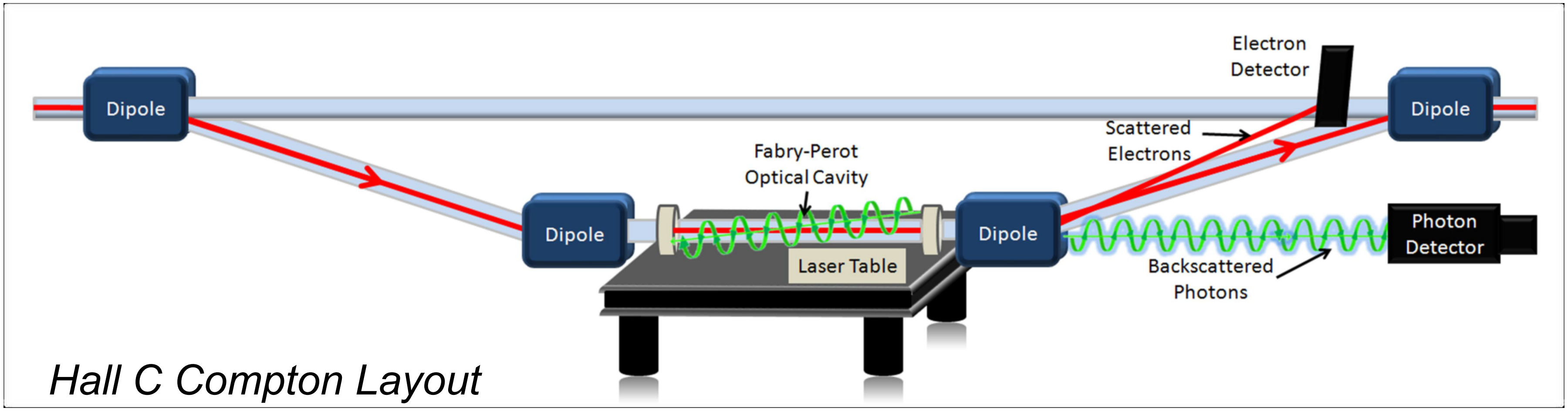


Bunch spacing = 2.1 ns
Macrobunches with opposite polarization = 3.233 μs long

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 – 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

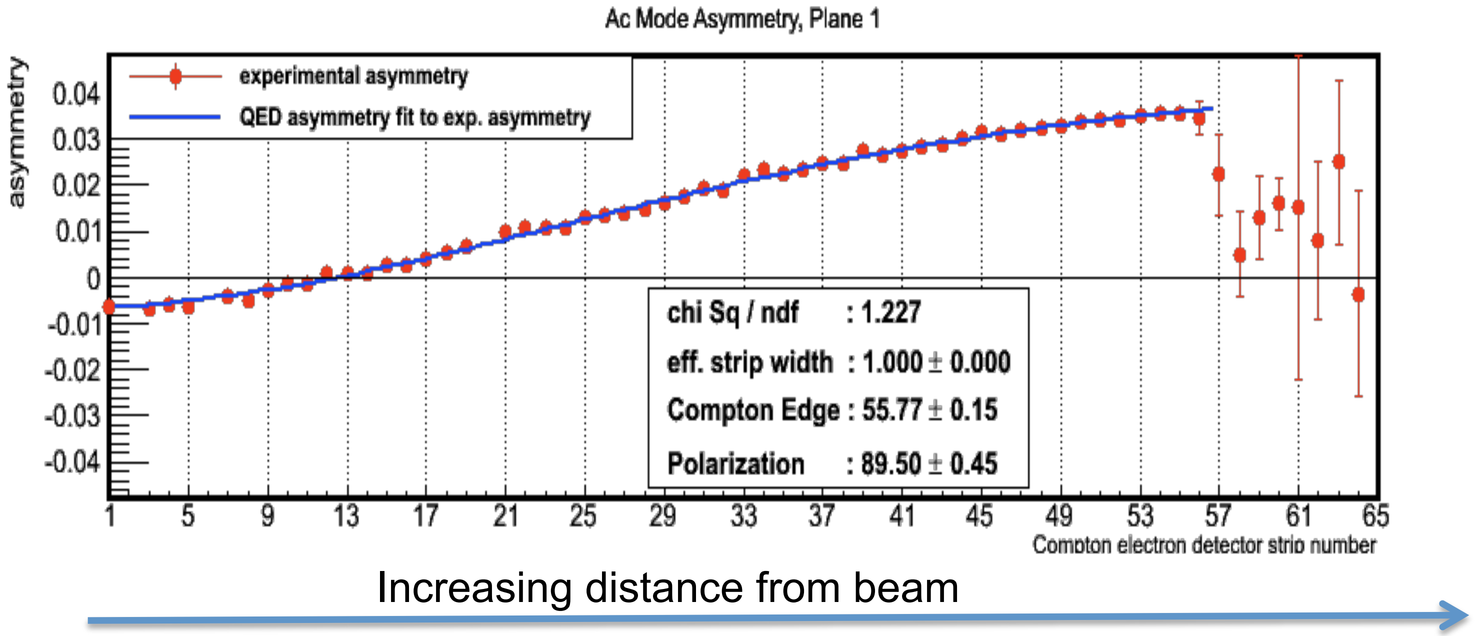
Important design considerations:

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 may make this impossible
- For now, the MEIC Compton design emphasizes detection of the Compton scattered electron

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

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

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

Laser and Backgrounds

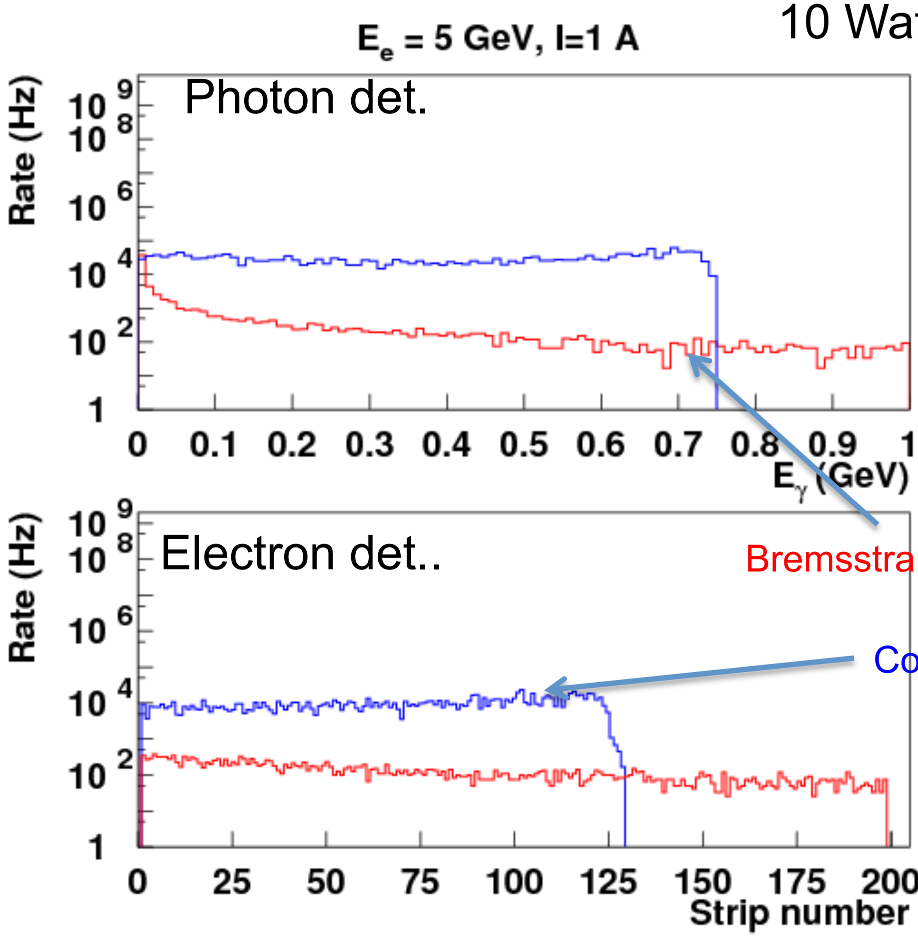
Historically, Compton polarimeters have been able to suppress backgrounds by matching laser pulse structure to beam

→ 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



Bremsstrahlung

Compton

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

Laser and Backgrounds

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

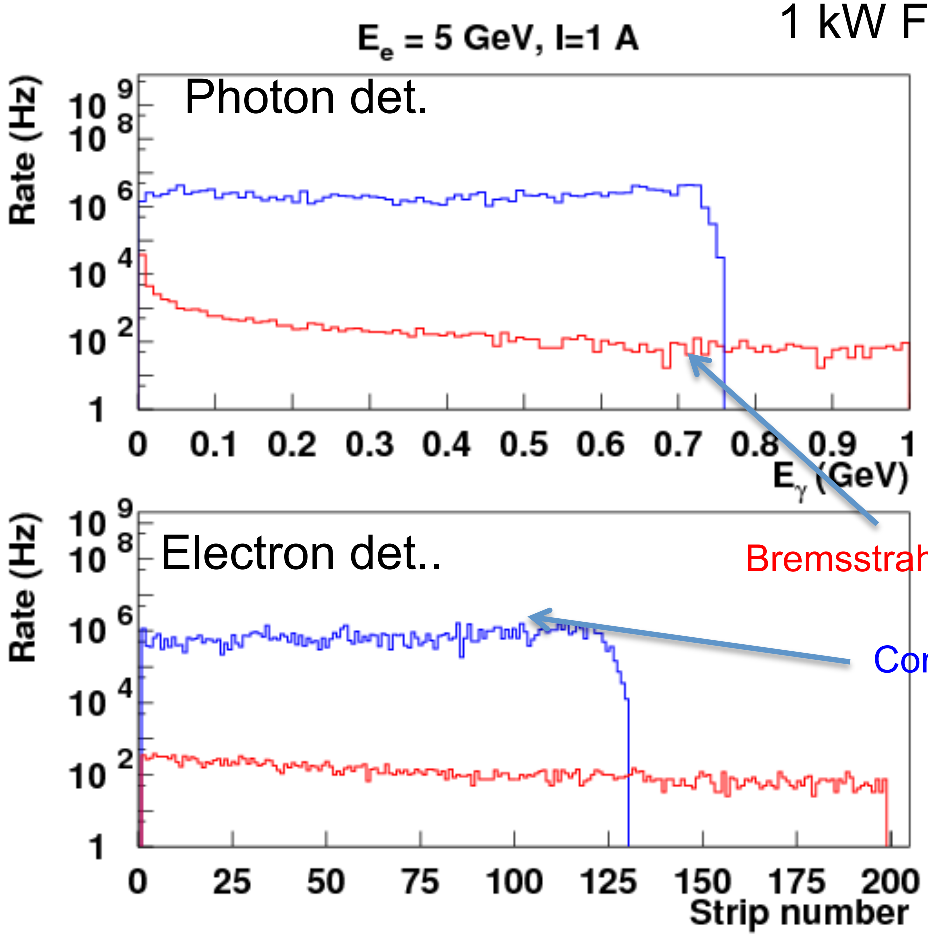
→ Modern CW machines, there is little to be gained in this manner

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



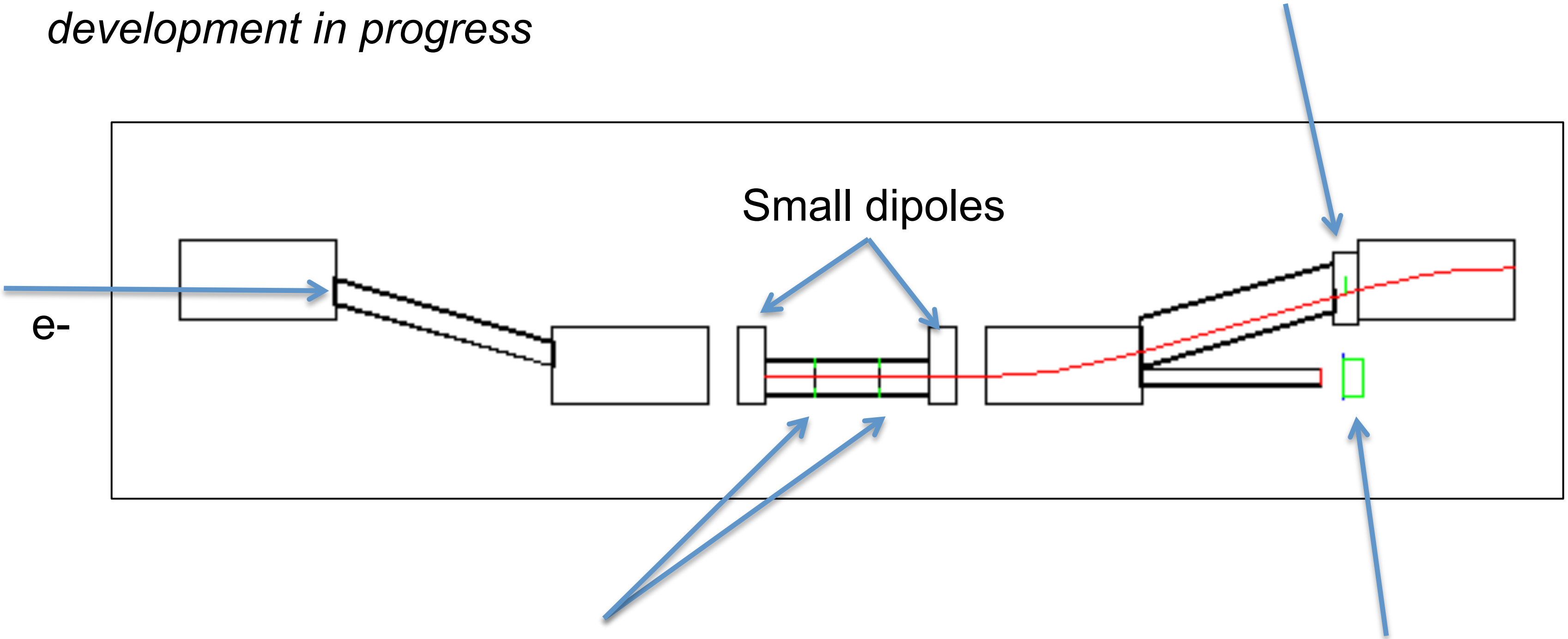
Bremsstrahlung

Compton

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*



Electron detector planes

Small dipoles

e-

Apertures for cavity protection/halo generation

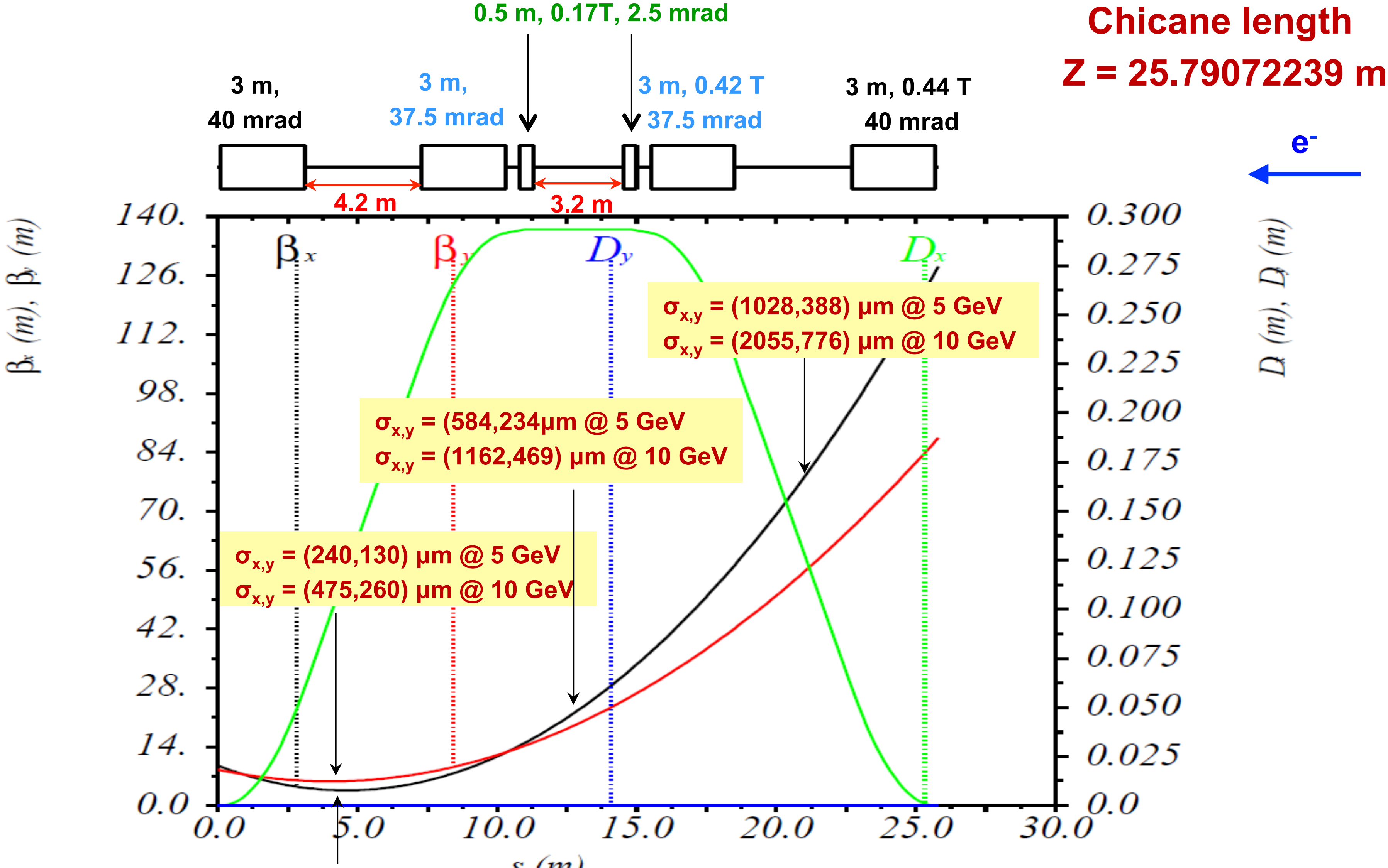
Photon detector

Beam sizes from Fanglei Lin

Chicane Design (baseline)

Chicane length

Z = 25.79072239 m



0.5 m, 0.17T, 2.5 mrad

3 m,
40 mrad

3 m,
37.5 mrad

3 m, 0.42 T
37.5 mrad

3 m, 0.44 T
40 mrad

4.2 m

3.2 m

e^-

$\sigma_{x,y}$ = (240,130) μm @ 5 GeV
$\sigma_{x,y}$ = (475,260) μm @ 10 GeV

$\sigma_{x,y}$ = (584,234μm @ 5 GeV
$\sigma_{x,y}$ = (1162,469) μm @ 10 GeV

$\sigma_{x,y}$ = (1028,388) μm @ 5 GeV
$\sigma_{x,y}$ = (2055,776) μm @ 10 GeV

Focusing Point β_x~3.7m, β_y~6m

Courtesy Fanglei Lin

Chicane Design: Focus at IP

Chicane length

Z = 25.79072239 m

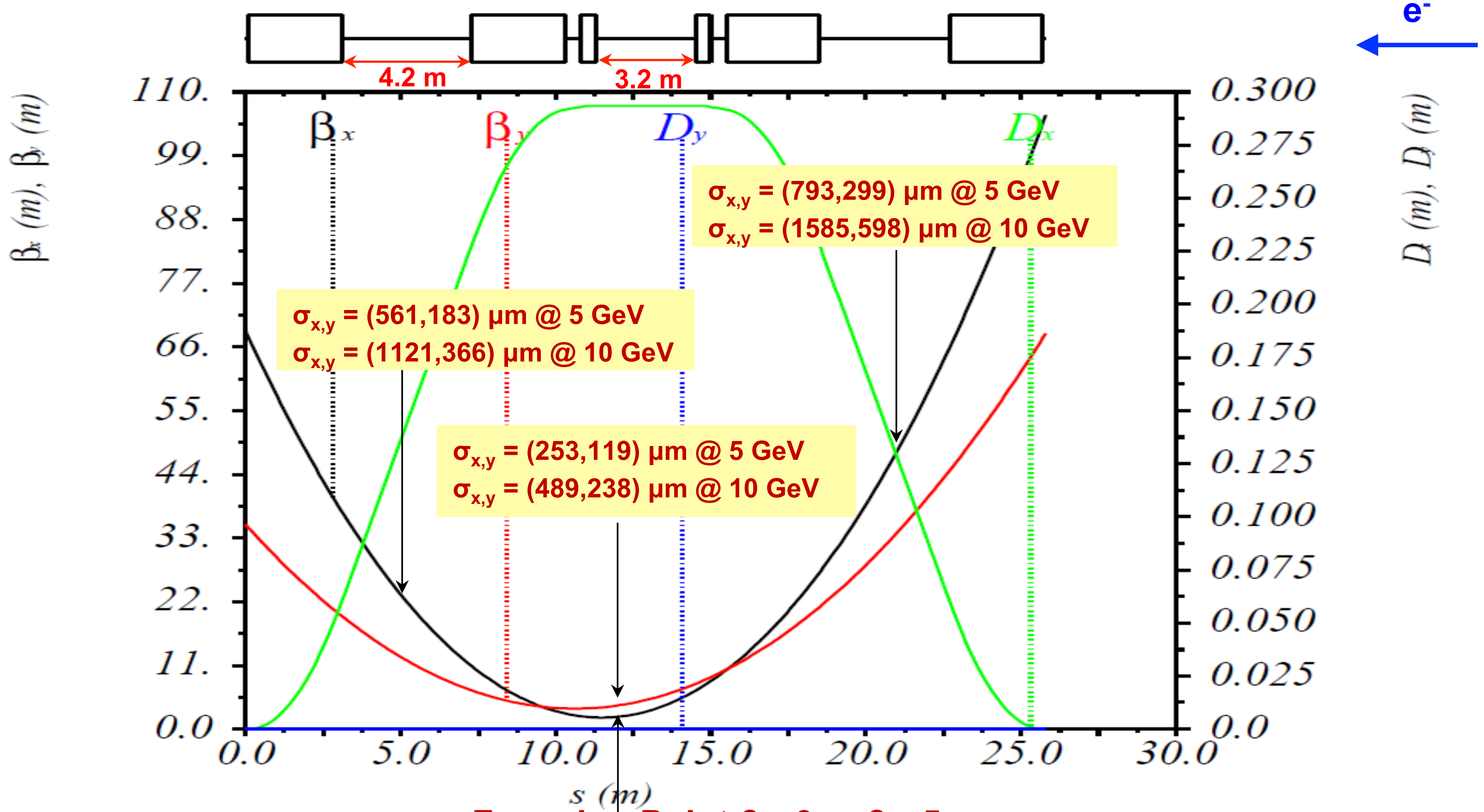
0.5 m, 0.17T, 2.5 mrad

3 m, 40 mrad

3 m, 37.5 mrad

3 m, 0.42 T 37.5 mrad

3 m, 0.44 T 40 mrad



$\sigma_{x,y}$ = (793,299) μm @ 5 GeV
$\sigma_{x,y}$ = (1585,598) μm @ 10 GeV

$\sigma_{x,y}$ = (561,183) μm @ 5 GeV
$\sigma_{x,y}$ = (1121,366) μm @ 10 GeV

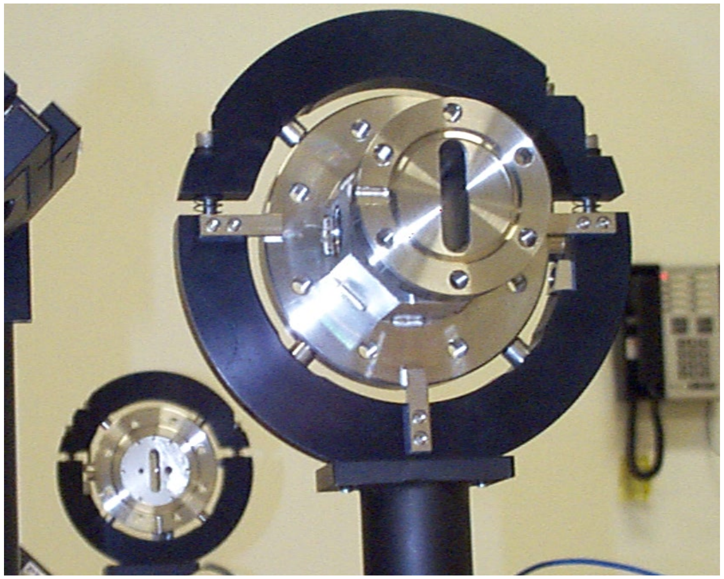
$\sigma_{x,y}$ = (253,119) μm @ 5 GeV
$\sigma_{x,y}$ = (489,238) μm @ 10 GeV

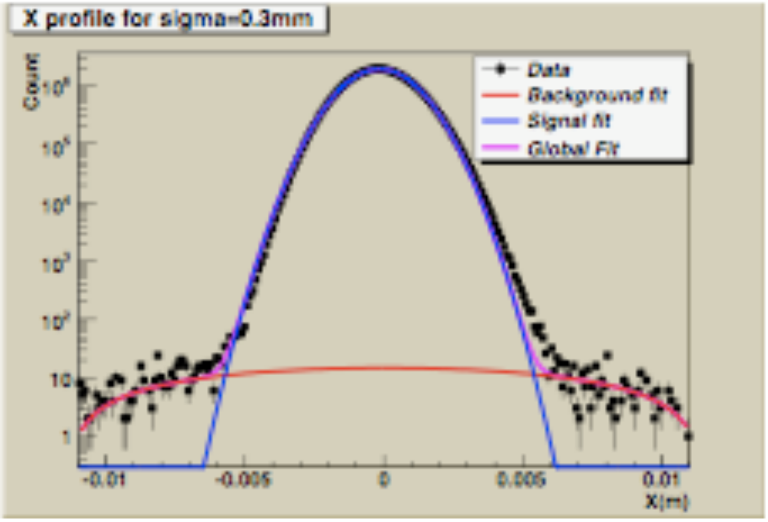
Focusing Point β_x~3m, β_y~5m

Courtesy Fanglei Lin

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

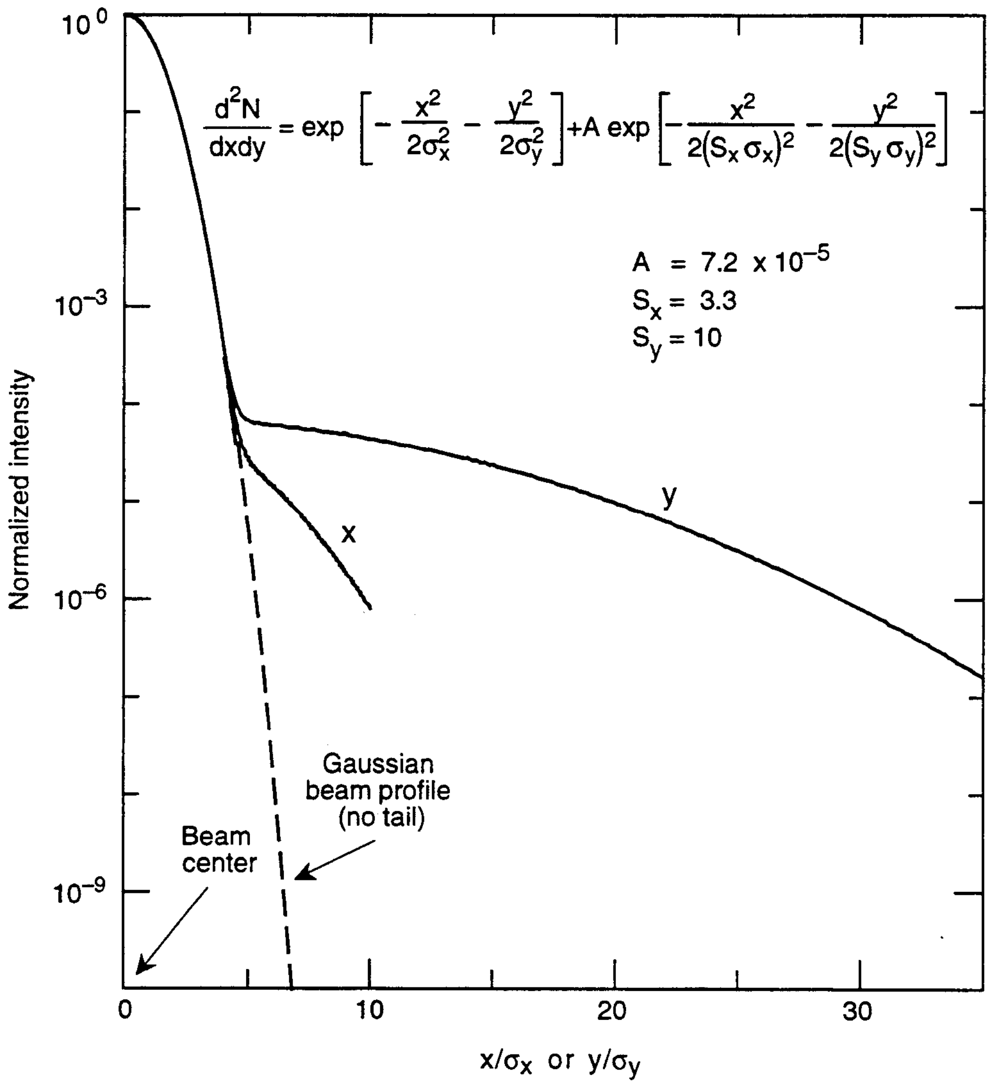
Simulations - Halo

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

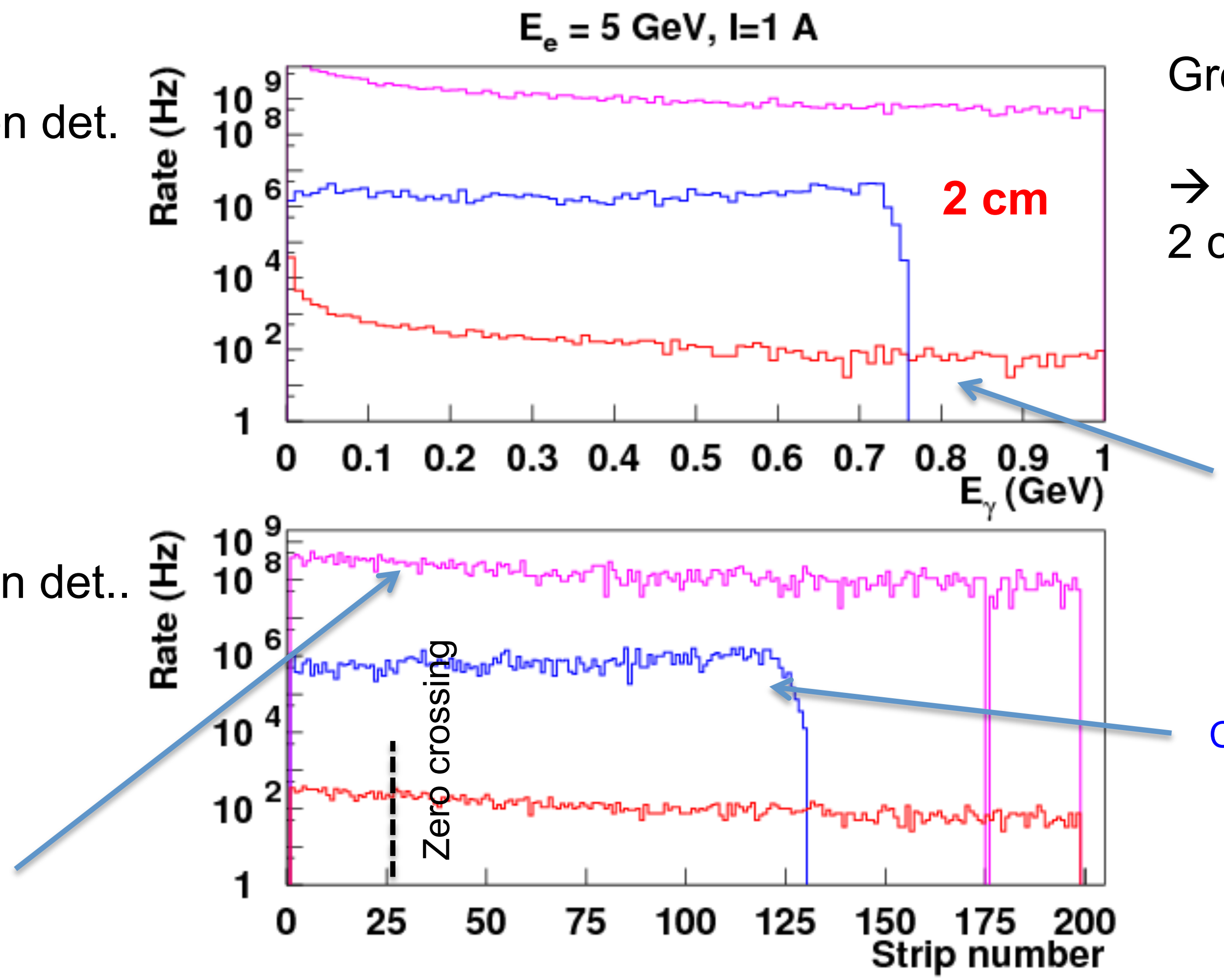
1. Direct strike of electron detector
2. Interactions with FP cavity apertures



Laser and Backgrounds - Halo

Photon det.

Electron det..



Green laser 1 kW

→ Cavity apertures = 2 cm wide

Bremsstrahlung

Compton

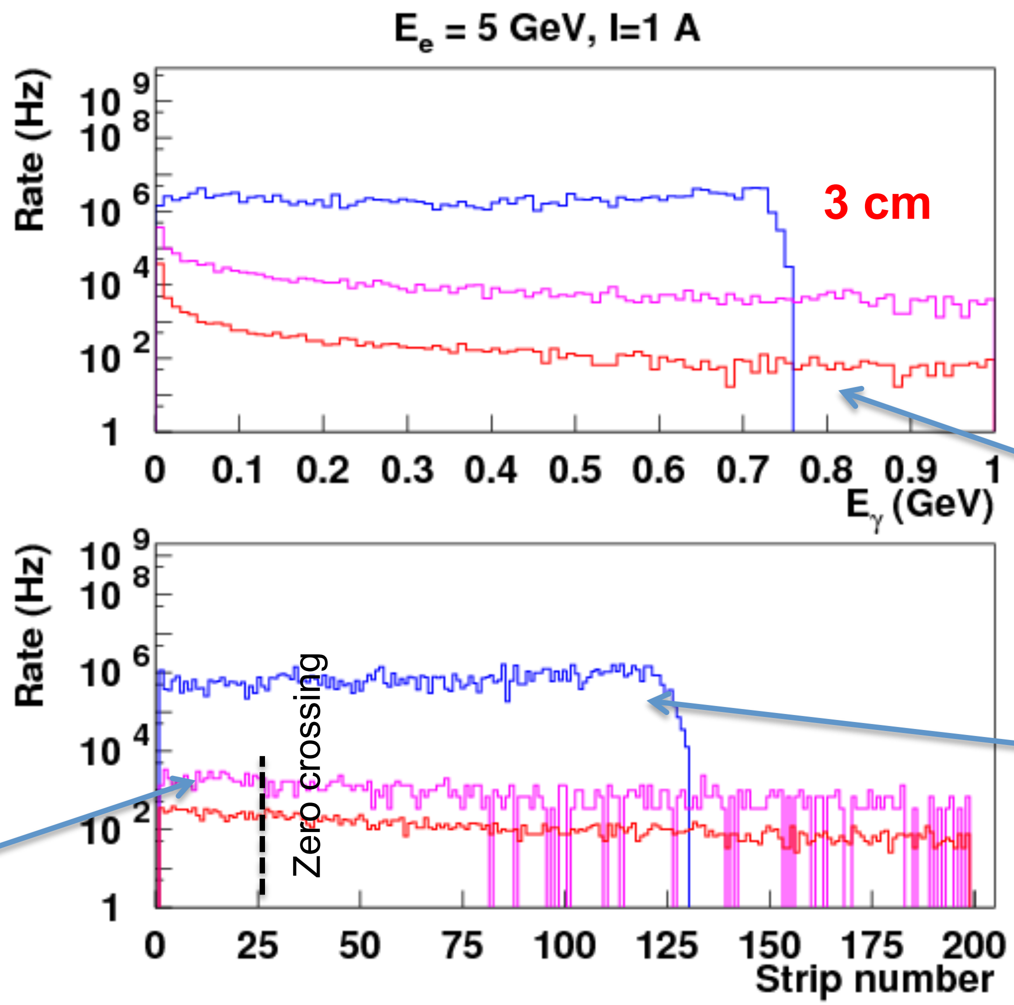
Halo

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

Laser and Backgrounds - Halo

Photon det.

Electron det..



Bremsstrahlung

Compton

Halo

Green laser 1 kW

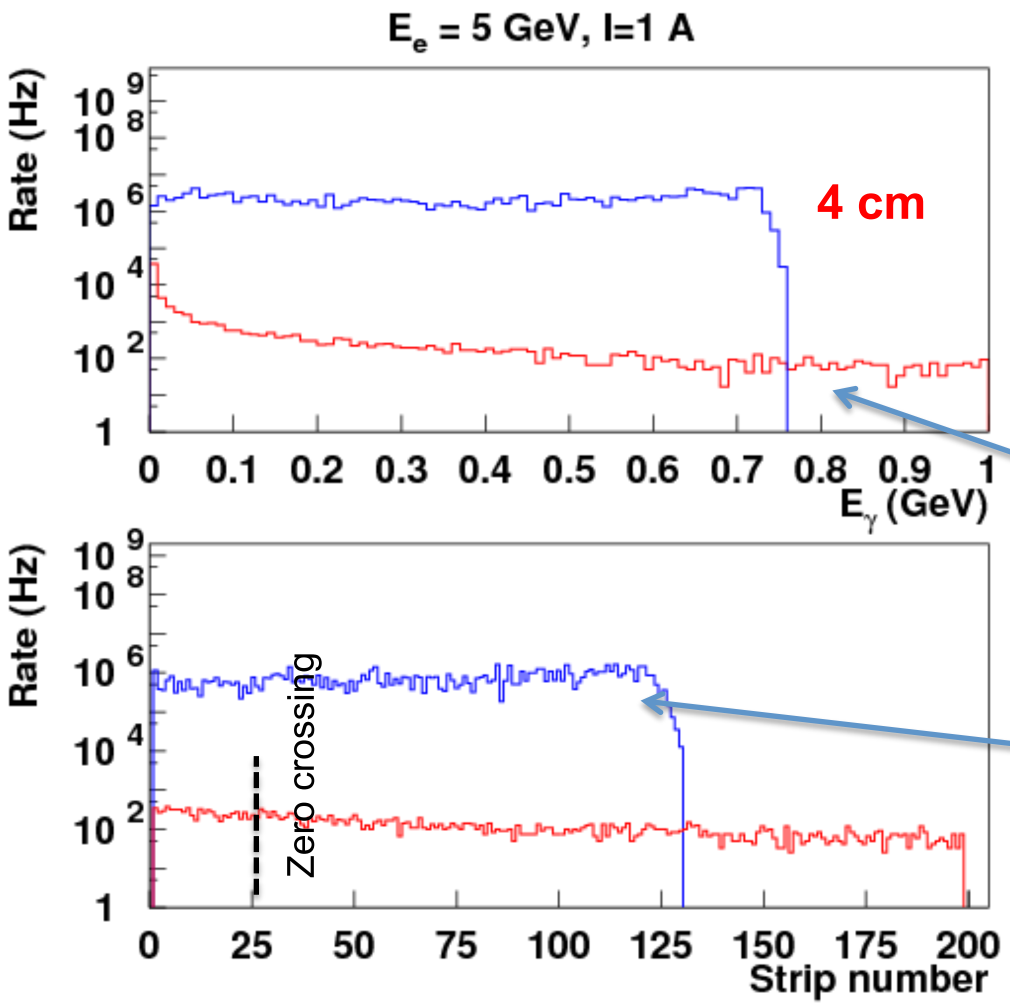
→ Cavity apertures = 3 cm wide

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

Laser and Backgrounds - Halo

Photon det.

Electron det..



4 cm

Bremsstrahlung

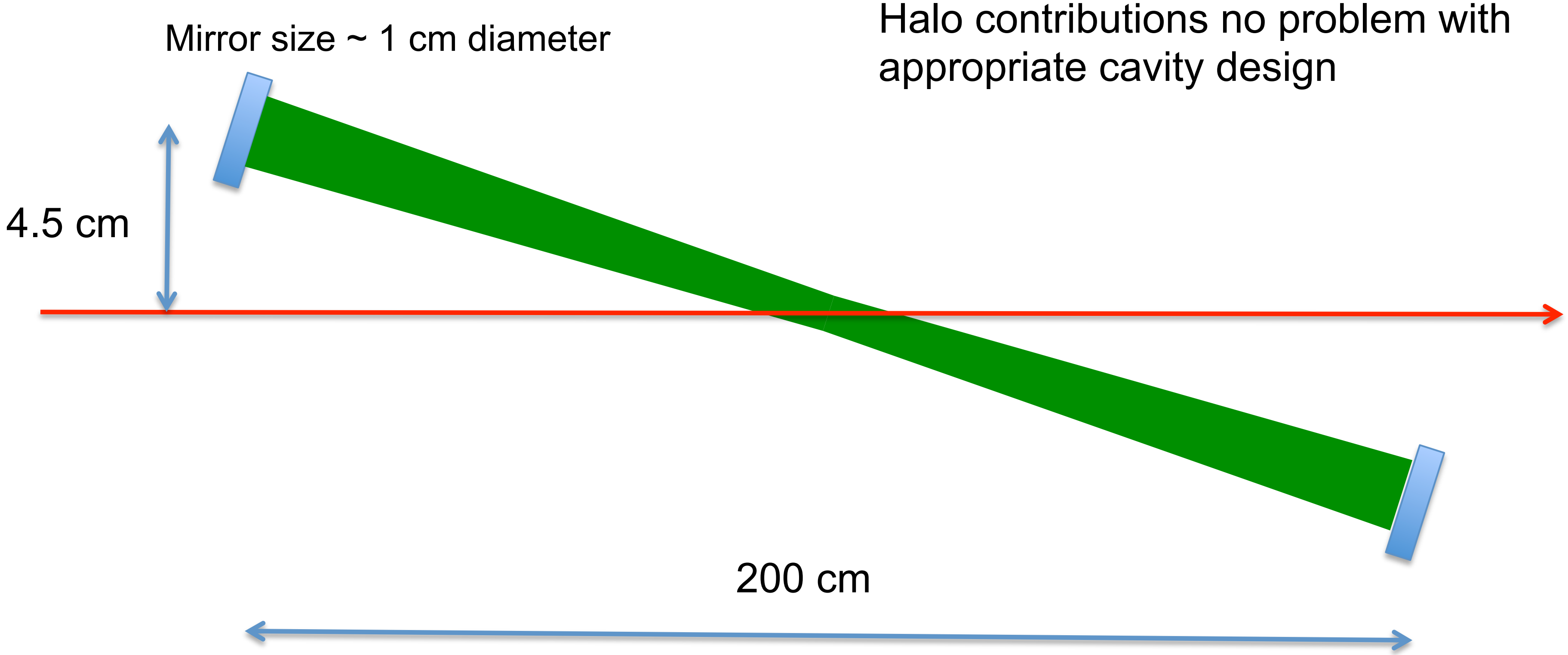
Compton

Green laser 1 kW

→ Cavity apertures = 4 cm wide

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

Fabry-Perot Cavity Design



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

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

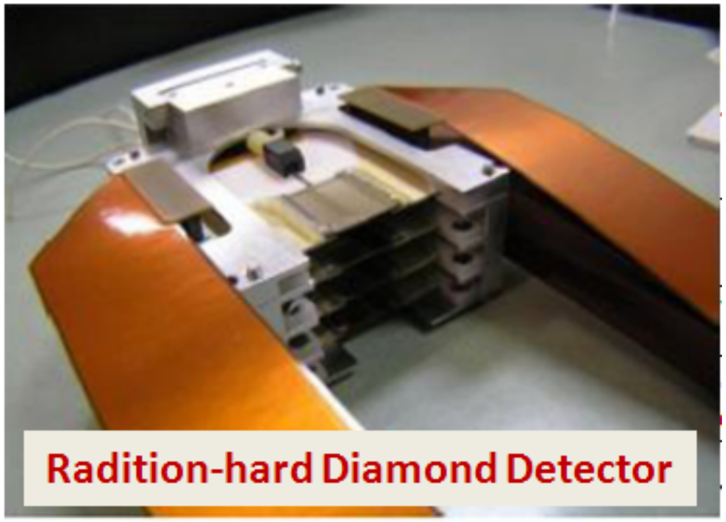
Extremely high rates when using FP cavity means that detectors (electron and photon) will have to operate in integrating mode in that case

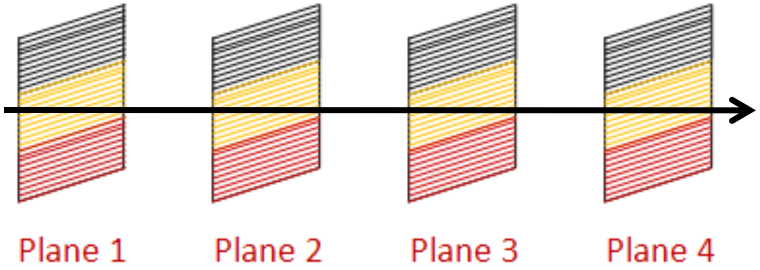
Electron Detector Requirements

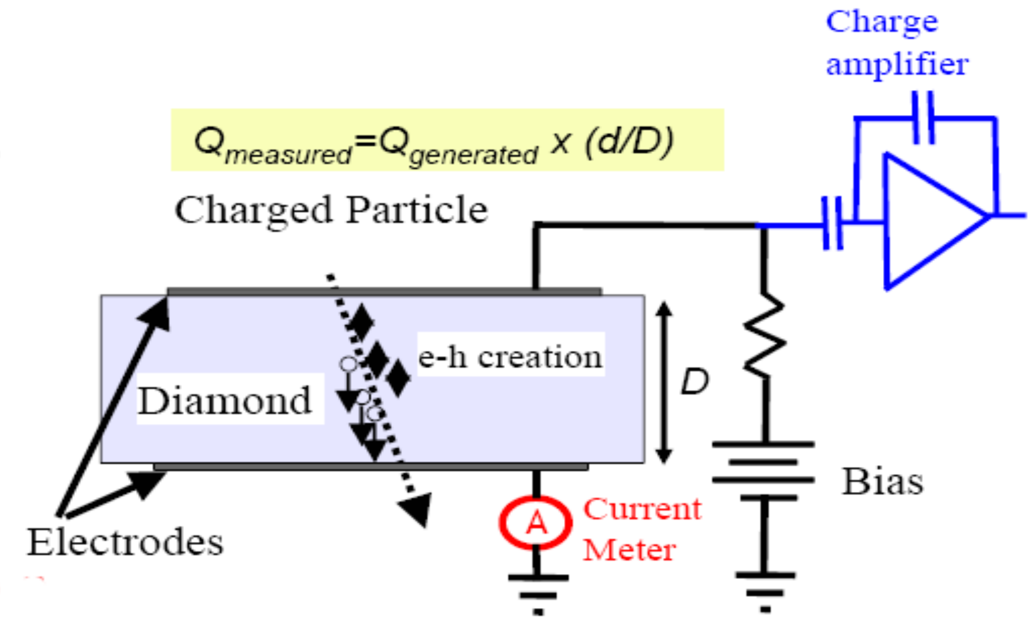
- Segmentation → allows determination of the beam polarization with high precision by fitting the spectrum
- High rate capability
  - Scattered electron rates will be very large
  - Typical "strip" detectors have relatively slow response times after amplification → large dead time
  - Integrating mode?
- 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

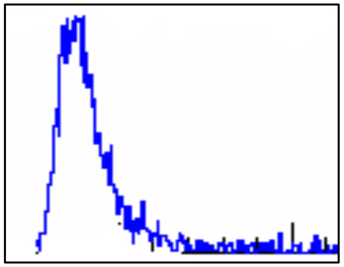
Hall C Compton Electron Detector

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)

Baseline MEIC electron detector

- Diamond strip detector
  - At least 5 cm long
  - 200 strips
  - 4 planes
  - Pros
    - No damage so far up to 10 Mrad at JLab
    - Fast detector
    - Experience with Hall C
  - Cons
    - Small amplitude
- Roman pot
  - Need for RF shielding
  - Need detector shielding
  - Cooling
  - Detector motion
  - 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

Compton R&D

- EIC R&D proposal recently awarded for work related to Compton electron detector (A. Camsonne et. al.)
- Initial award for detailed simulations related to:
  - Backgrounds, including halo and synchrotron
  - Effect of using electron detector in Roman pot
- 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

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
- EIC R&D award for investigations of optimum technology for electron detector and performance in Roman Pot → initial award for detailed simulation work in FY2016

Low Q^2 tagger/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

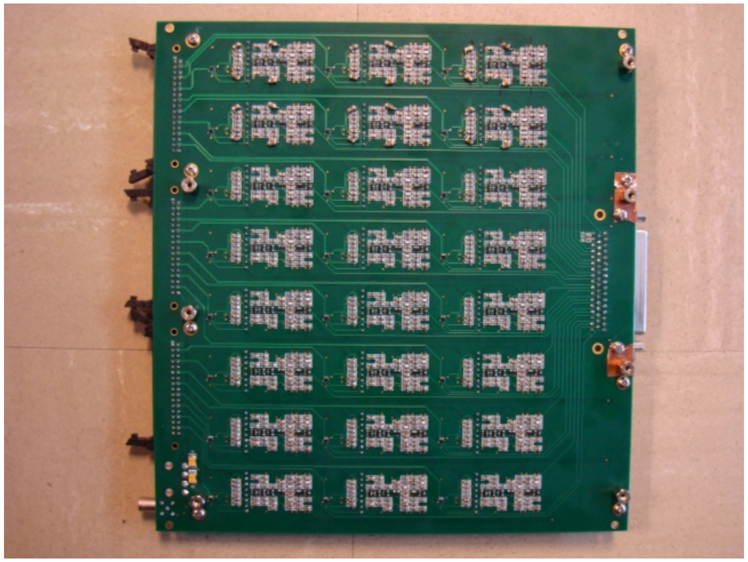
Extra

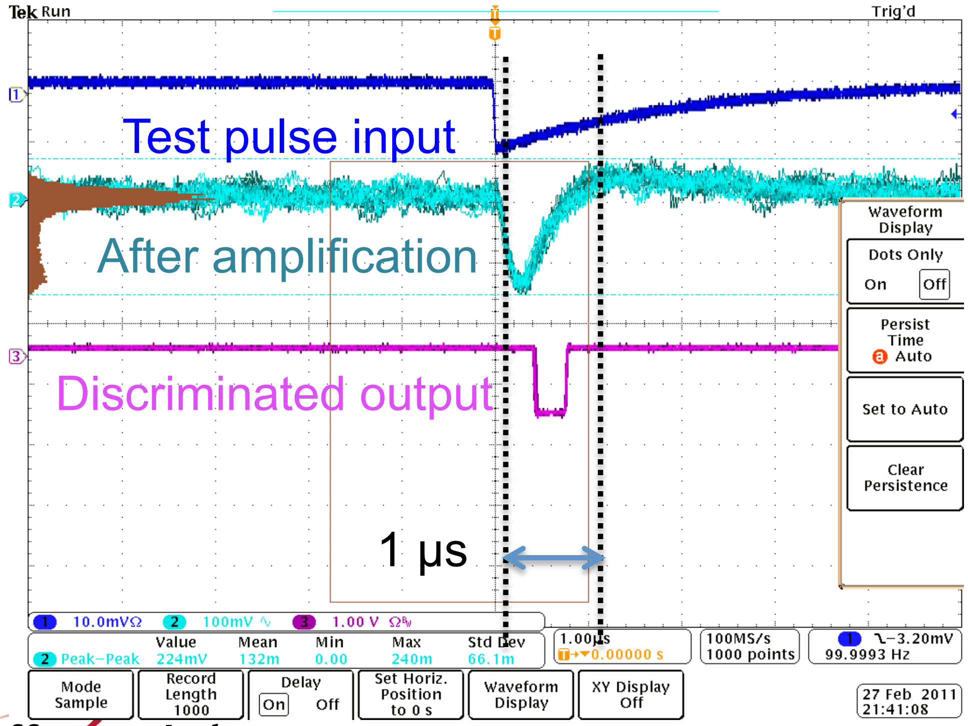
Hall C Compton Electron Detector

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

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

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





1 10.0mVΩ 2 100mV 3 1.00 V ΩBW

2	Value	Mean	Min	Max	Std Dev
Peak−Peak	224mV	132m	0.00	240m	66.1m

1.00µs T→▼0.00000 s

100MS/s 1000 points

1 −3.20mV 99.9993 Hz

27 Feb 2011 21:41:08

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

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

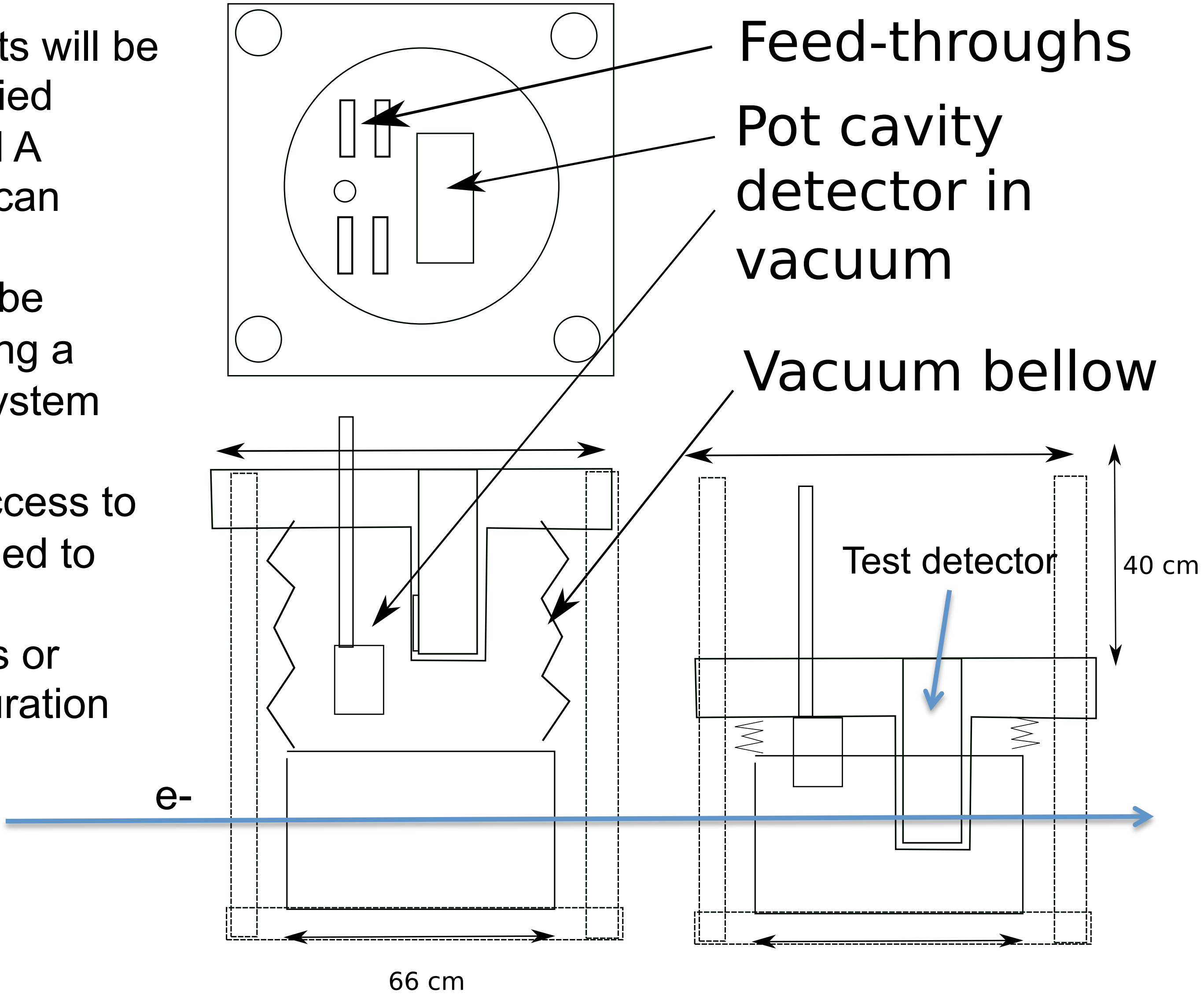
→ Counting at high rates challenging – operate in integration mode? (new or modified electronics)

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



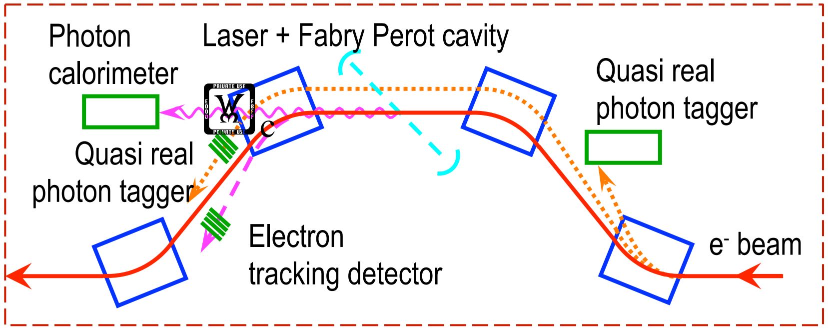
Feed-throughs

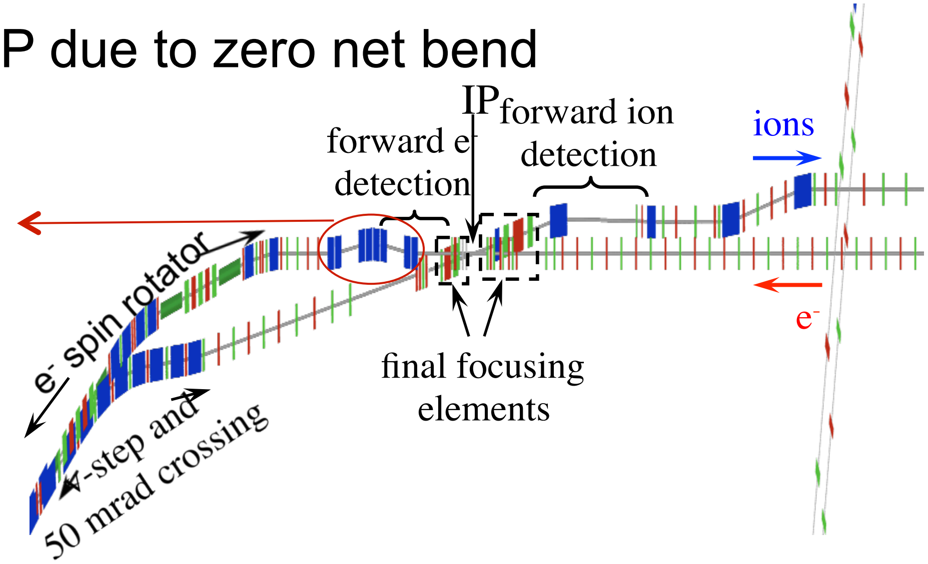
Pot cavity detector in vacuum

Vacuum bellow

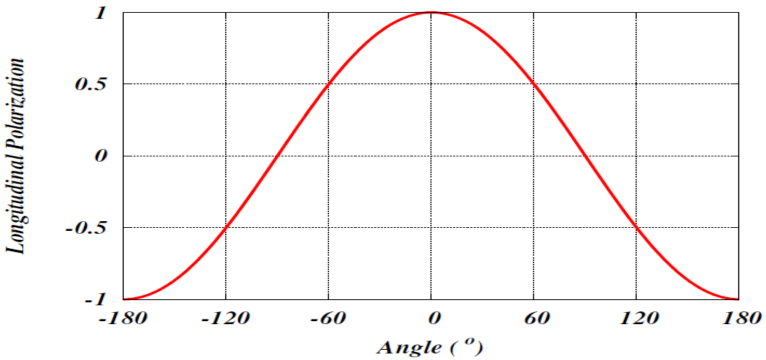
Polarization Measurement

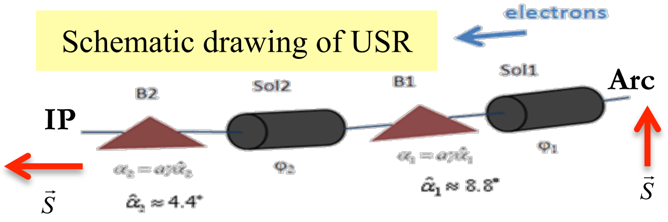
- Compton polarimetry:
  - same polarization at laser as at IP due to zero net bend





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




Schematic drawing of USR

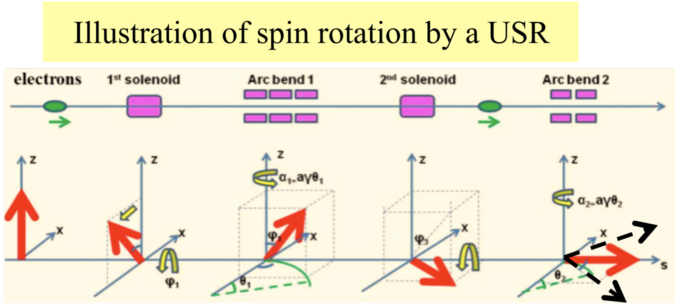


Illustration of spin rotation by a USR