A Proposal for Compton Electron Detector R&D

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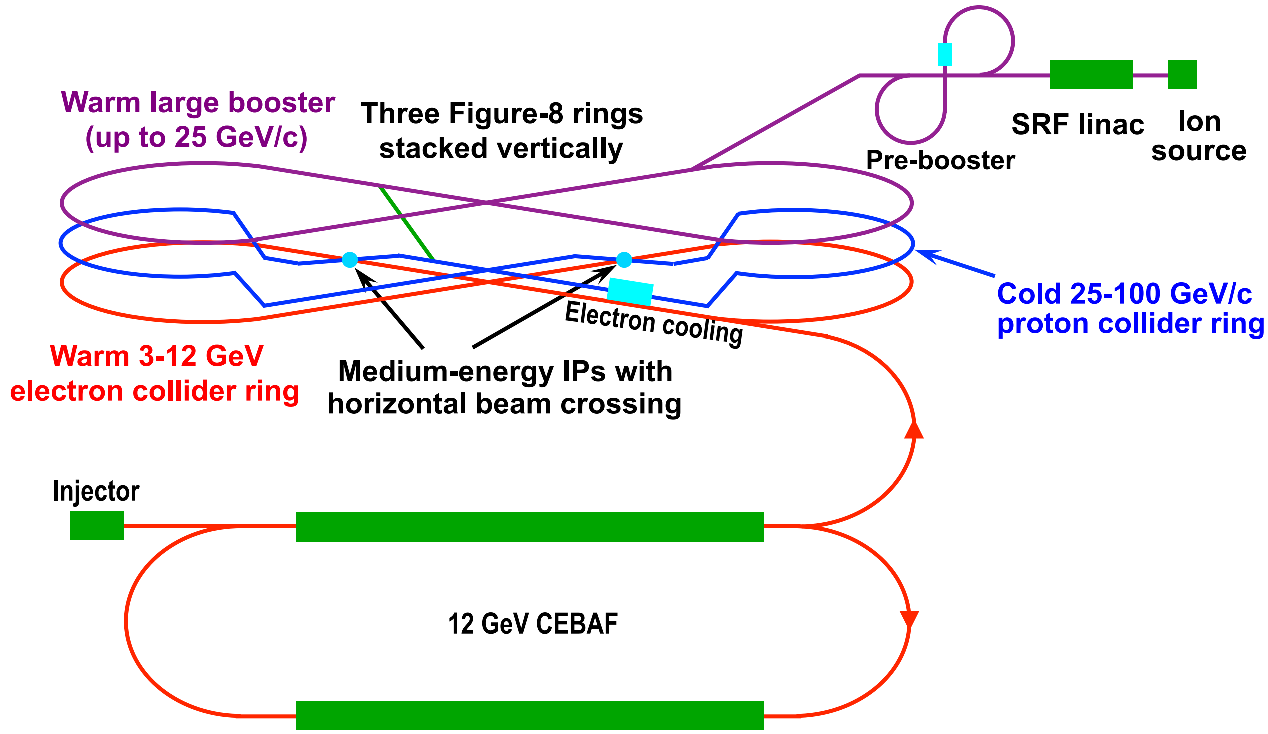
8. College of William and Mary
9. SEDI CEA Saclay

Outline

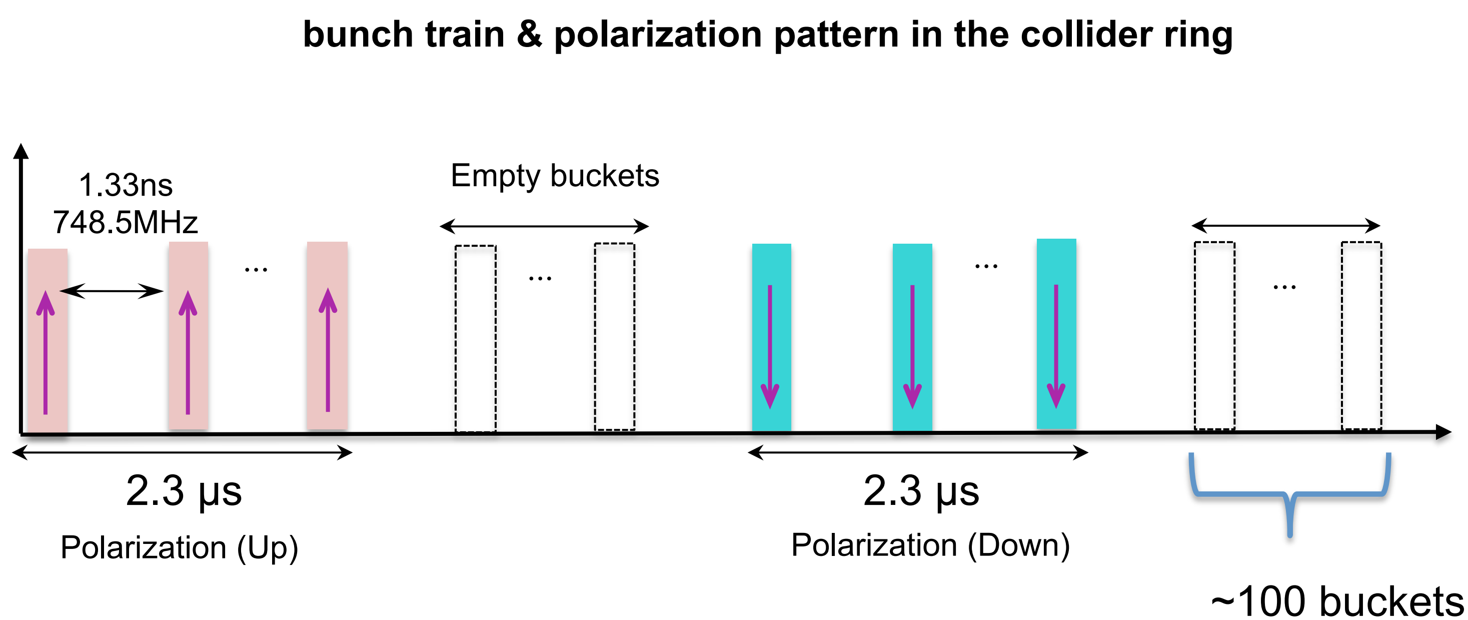
- Electron beam structure and polarization at MEIC
- Compton polarimetry - experience at JLab
- Rates and backgrounds
- Proposed R&D – electron detector development
- Work plan, proposal request

MEIC Beam Structure and Polarization



- Storage ring: 748.5 MHz = 1.33 ns bunch structure
- 3 A at 3 GeV and 130 mA at 12 GeV
- 2 macrobunches with one polarization 2.3 μs
- Every electron bunch crosses every ion bunch

Electron Beam Time structure



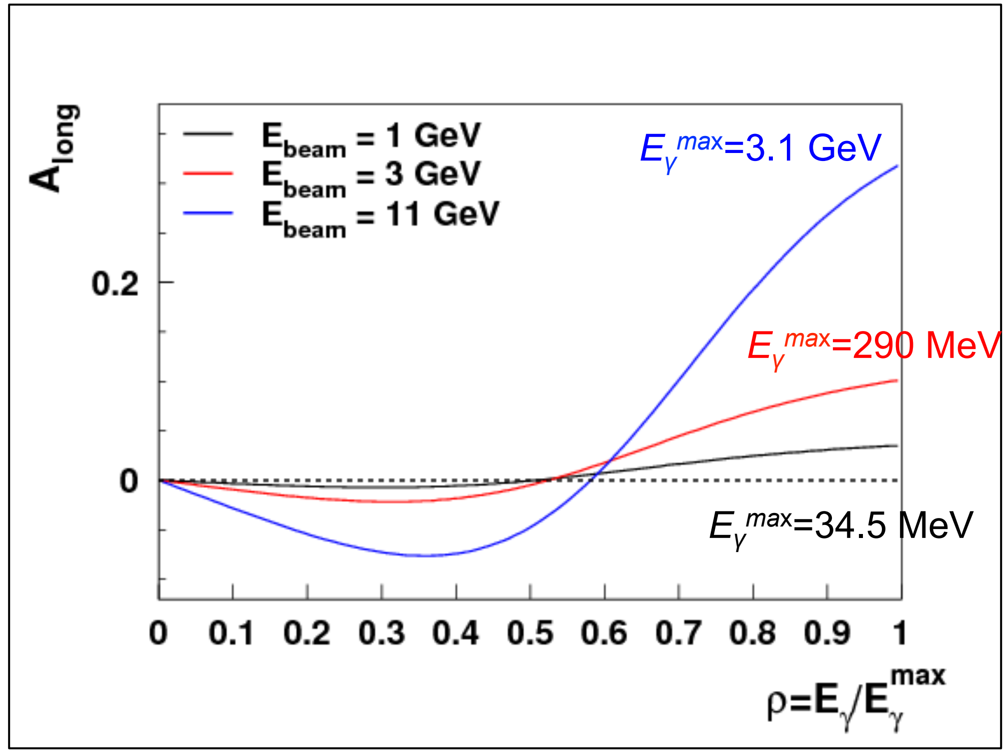
Bunch spacing = 1.33 ns
Macrobunches with opposite polarization = 2.3 μs long

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

Compton Polarimetry

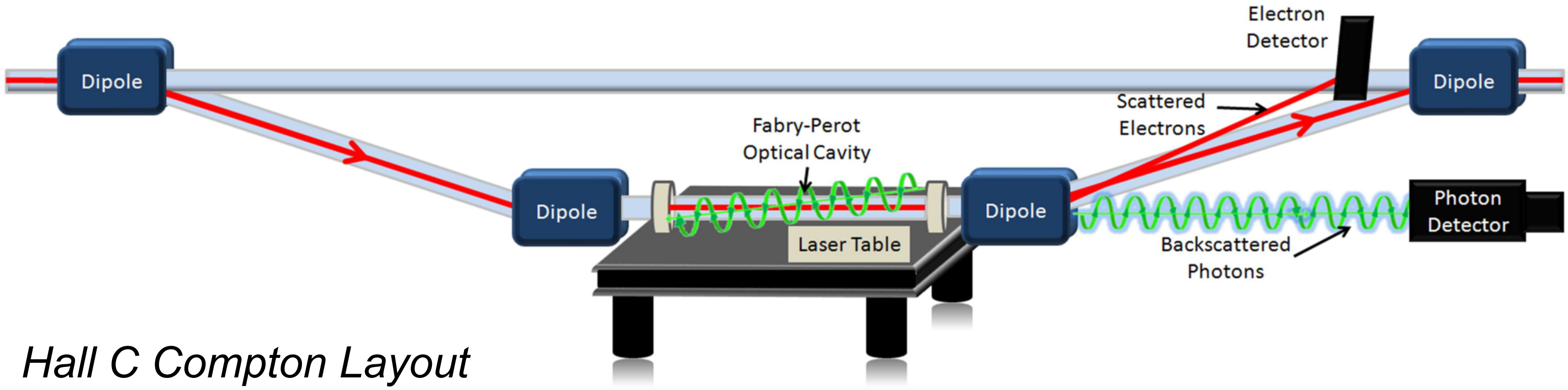
Compton polarimetry ideal method for electron polarimetry at EIC

→ Photon “target” very thin – no impact on electron beam
→ High precision accessible – sub-1% precision has been achieved (SLD Compton at Stanford Linear Collider and HAPPEX-III at JLab)



Challenges:
→ Maximum analyzing power strongly energy dependent
→ Asymmetry varies significantly as a function of backscattered photon energy

Compton Polarimetry – Experience at JLab



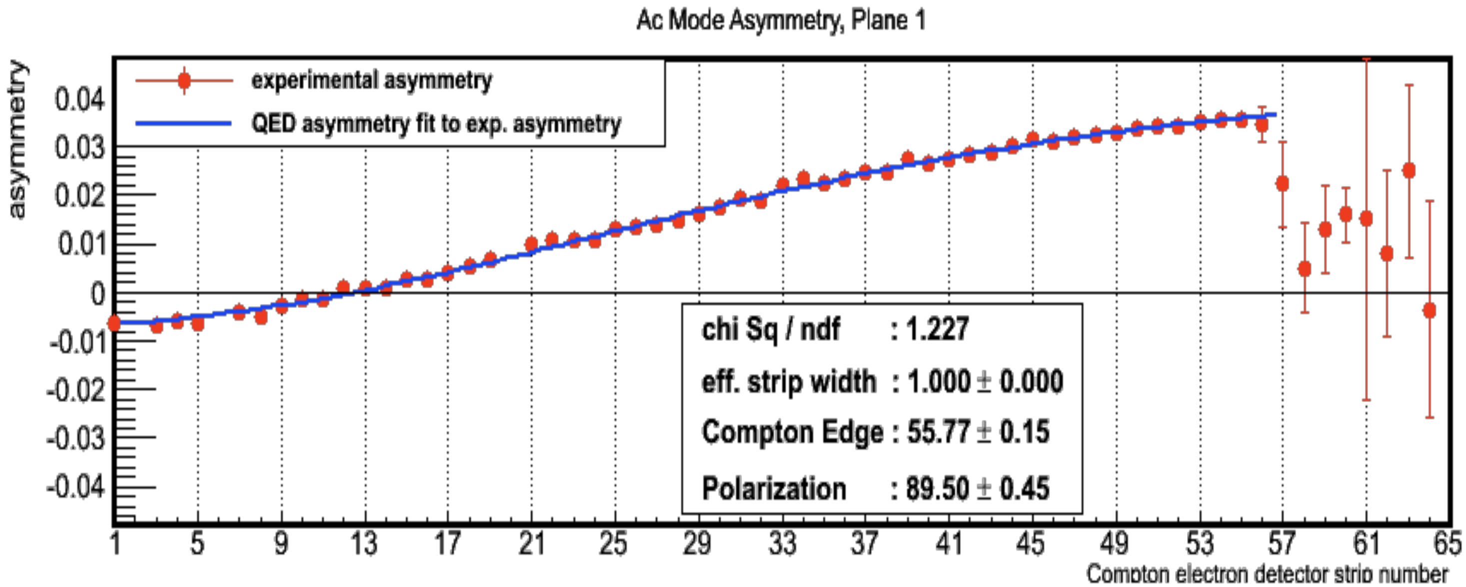
Hall C Compton Layout

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 requires high power CW laser system due to background issues

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

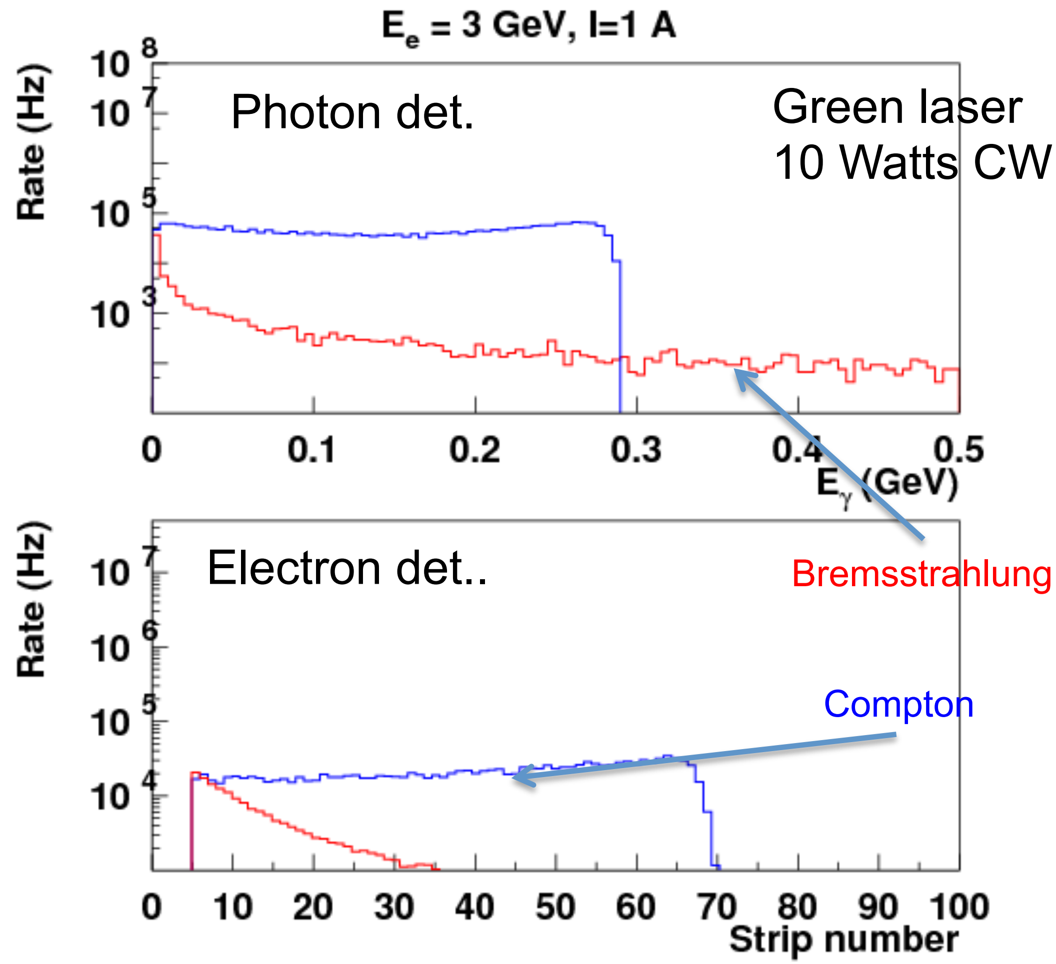
Laser and Backgrounds

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

With CW lasers/beams, backgrounds are too large to use conventional laser

Rates and backgrounds: MEIC



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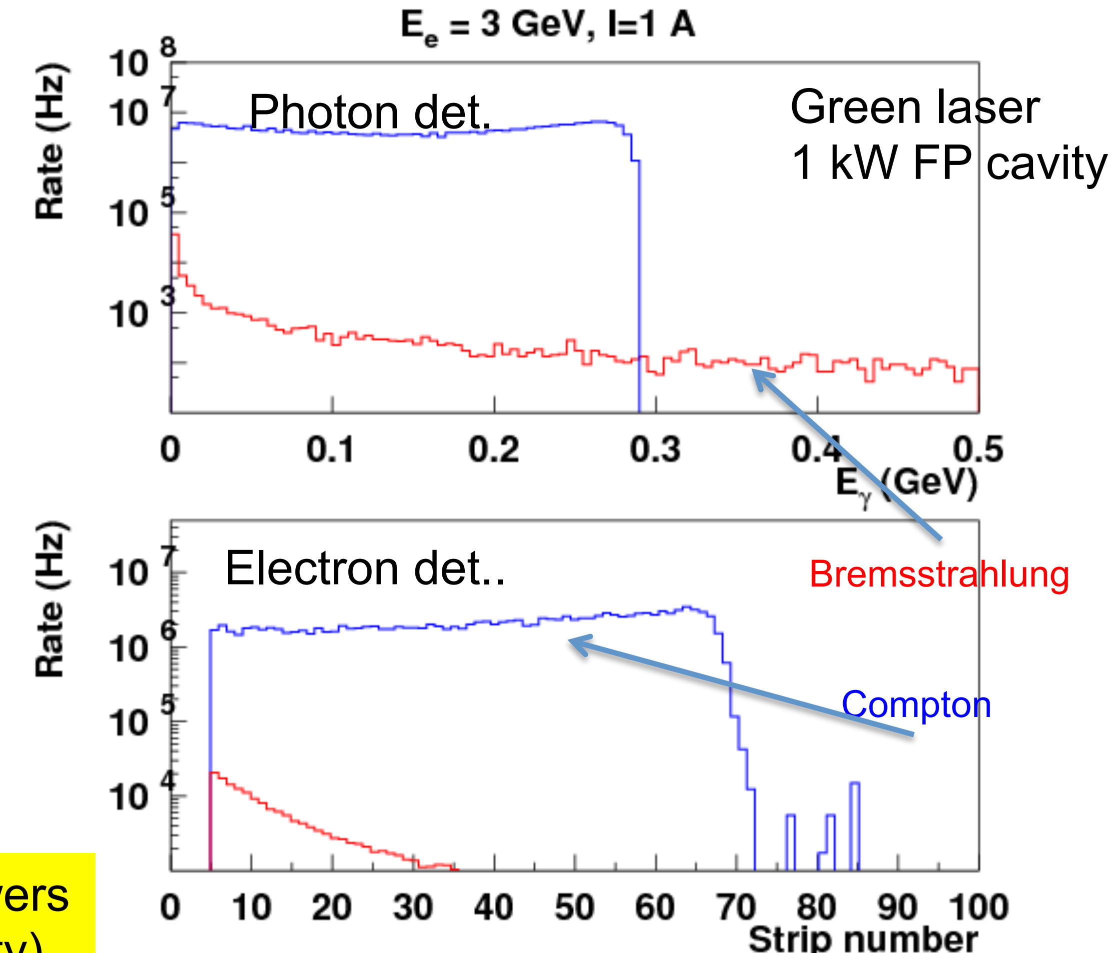
→ High laser powers required (FP cavity)

Rates and backgrounds: MEIC



Projected Rates

Green laser at 1.3 degree crossing angle

Machine	Energy	Rate (kHz/W/A)	Max current (A)	Rate kHz/W
MEIC	3	316	3	948
MEIC	5	298	3	894
MEIC	6	290	2	580
eRHIC	6	290	0.05	14.5
MEIC	7	283	1.1	311.3
eRHIC	7	283	0.05	14.15
MEIC	9	269	0.4	107.6
eRHIC	9	269	0.05	13.45
MEIC	11	258	0.18	46.44
eRHIC	11	258	0.05	12.9

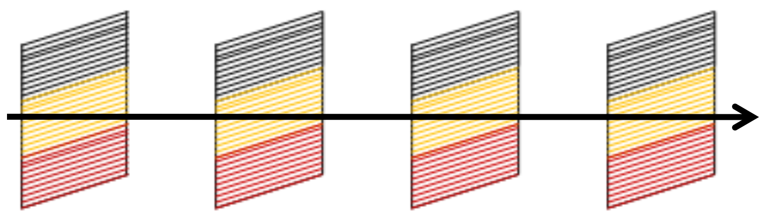
For 1 kW laser system (required for backgrounds) absolute rates = 13 MHz to almost 1 GHz

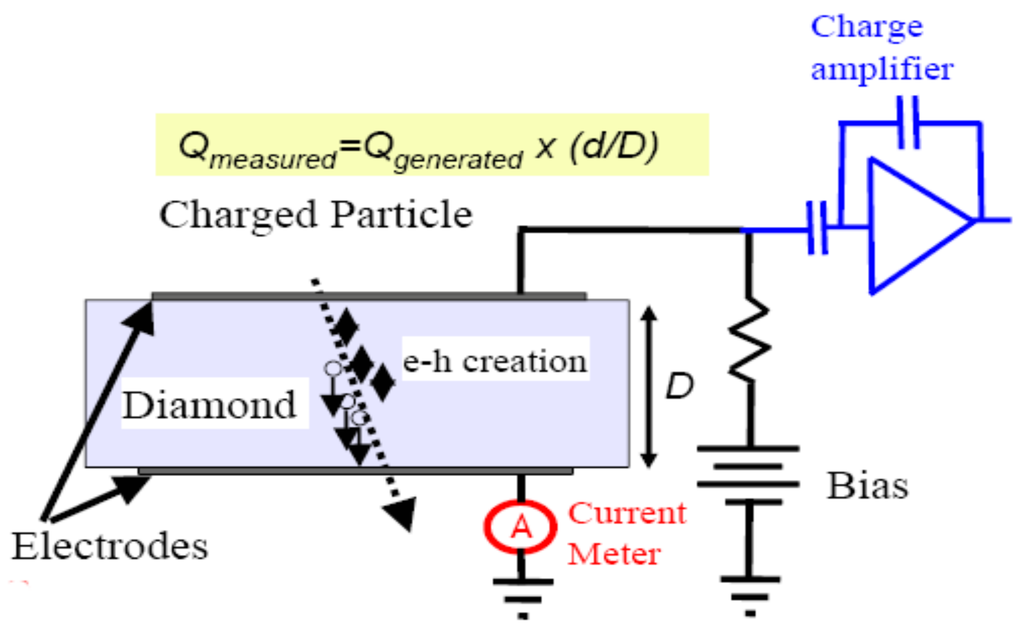
Electron Detector Requirements

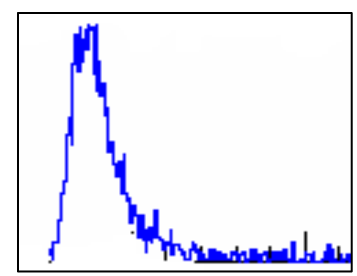
- Segmentation → allows determination of the beam polarization with high precision by fitting the spectrum
- High rate capability
  - Scattered electron rates will be very large
  - Typical “strip” detectors have relatively slow response times → large dead time
  - Integrating mode?
- Radiation hard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







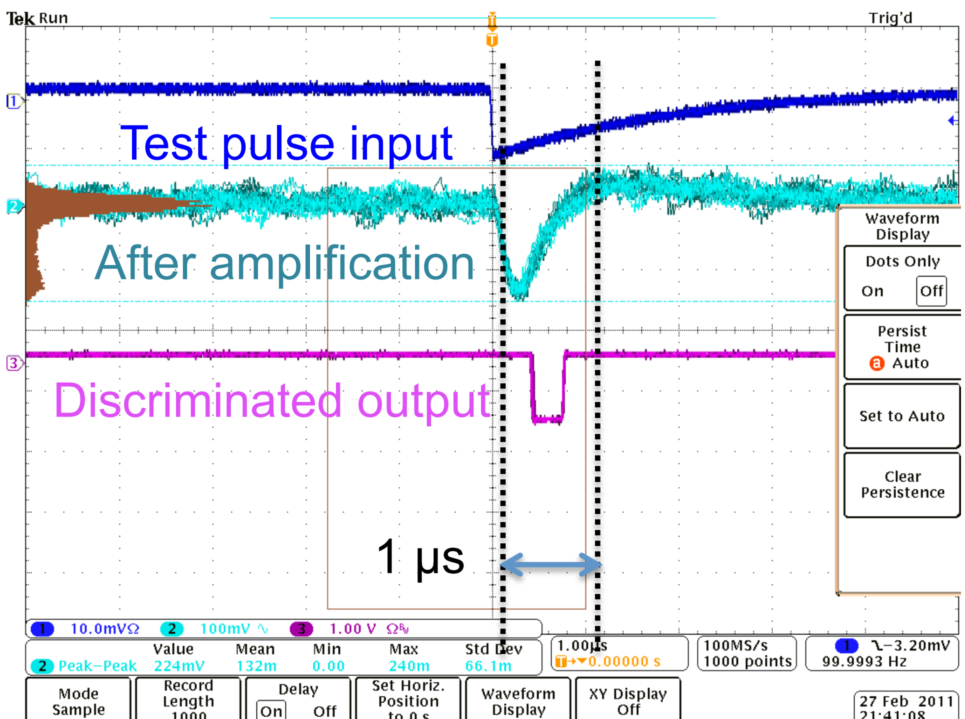
(D. Dutta Missipi State University)

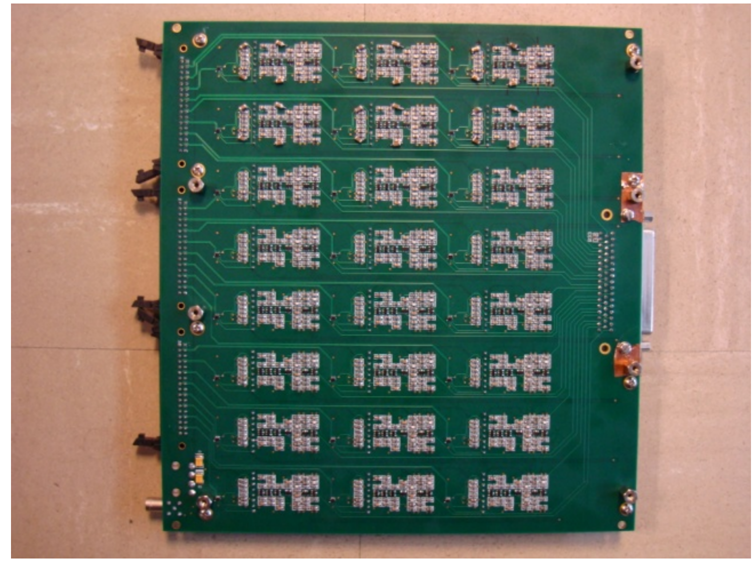
Hall C Compton Electron Detector

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

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

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





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)

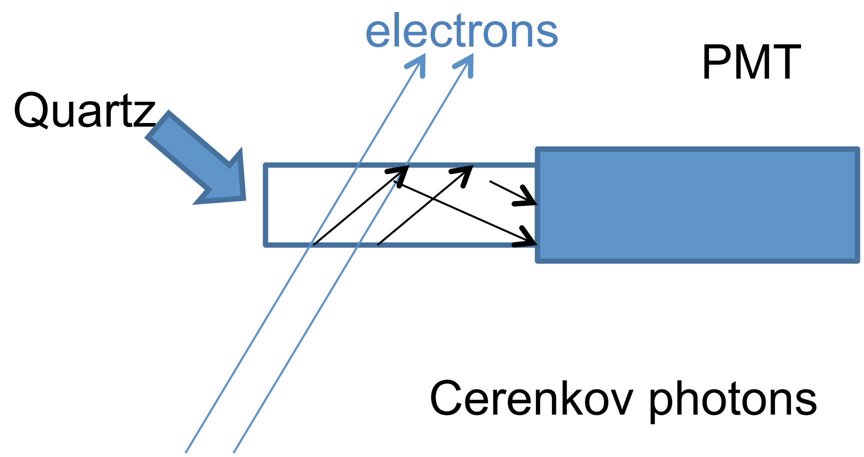
Quartz Detectors

- Quartz successfully used in both Halls A and C for integrating mode detection
- Design for Compton will be based on small quartz detector used for PREX experiment in Hall A
- Pure Cerenkov
- Radiation hard of the order > 1 Grad *[S. Ecklund et. al. NIM A463, 68 (2001)]*

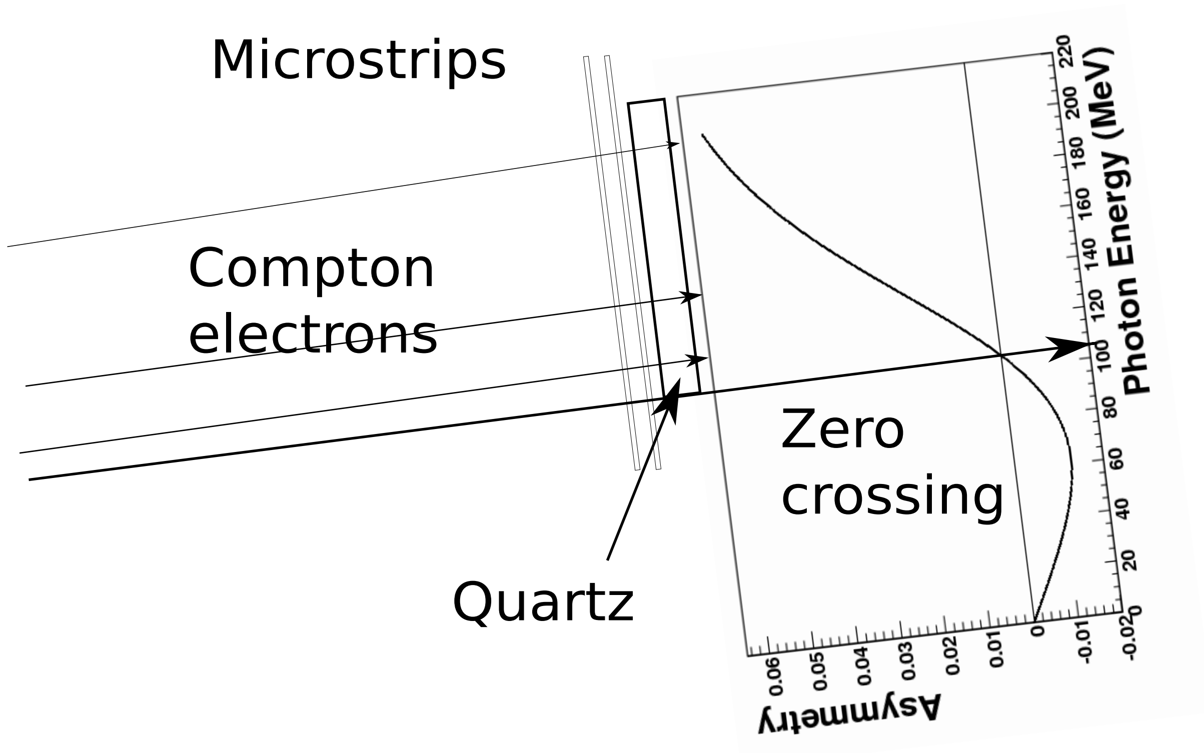
- Integration method
  - No deadtime correction
  - Can handle very high rates

PREX detector principle

- Thin quartz to reduce shower
- Light collection through internal reflection
- PMT readout in integrated mode



Tracking-Integrating Hybrid System



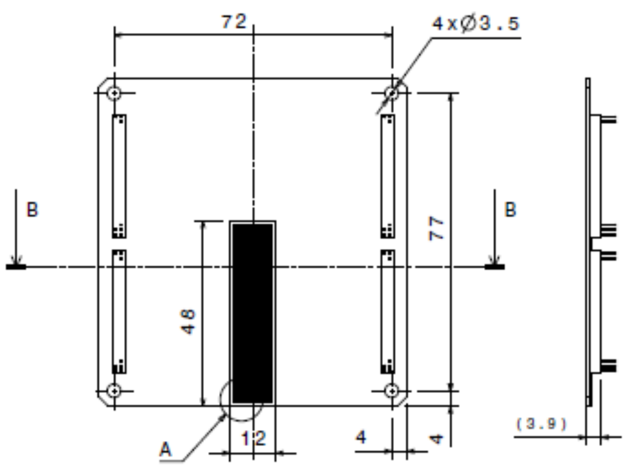
Quartz detector lacks segmentation, so no "built-in" knowledge of the analyzing power from fitting spectrum

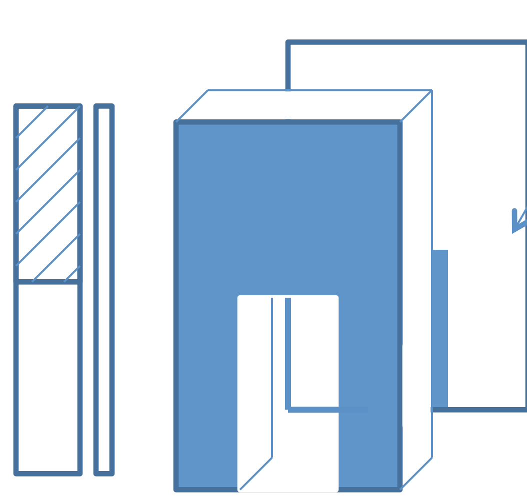
→ Will investigate using microstrip detector in tandem with chunk of quartz

→ Periodic measurements at lower luminosity will allow use of strip detector to constrain analyzing power

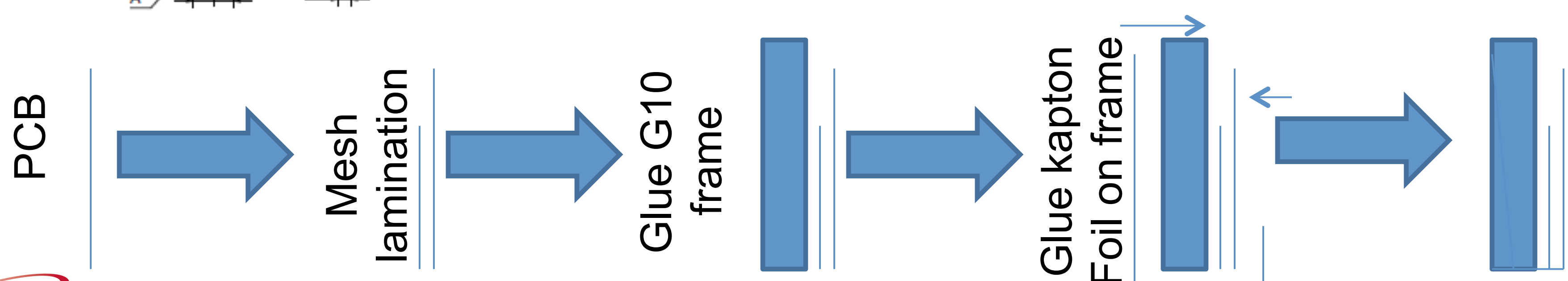
Micromegas

- R&D for small edge MM detector as alternative to diamond or silicon strip detector

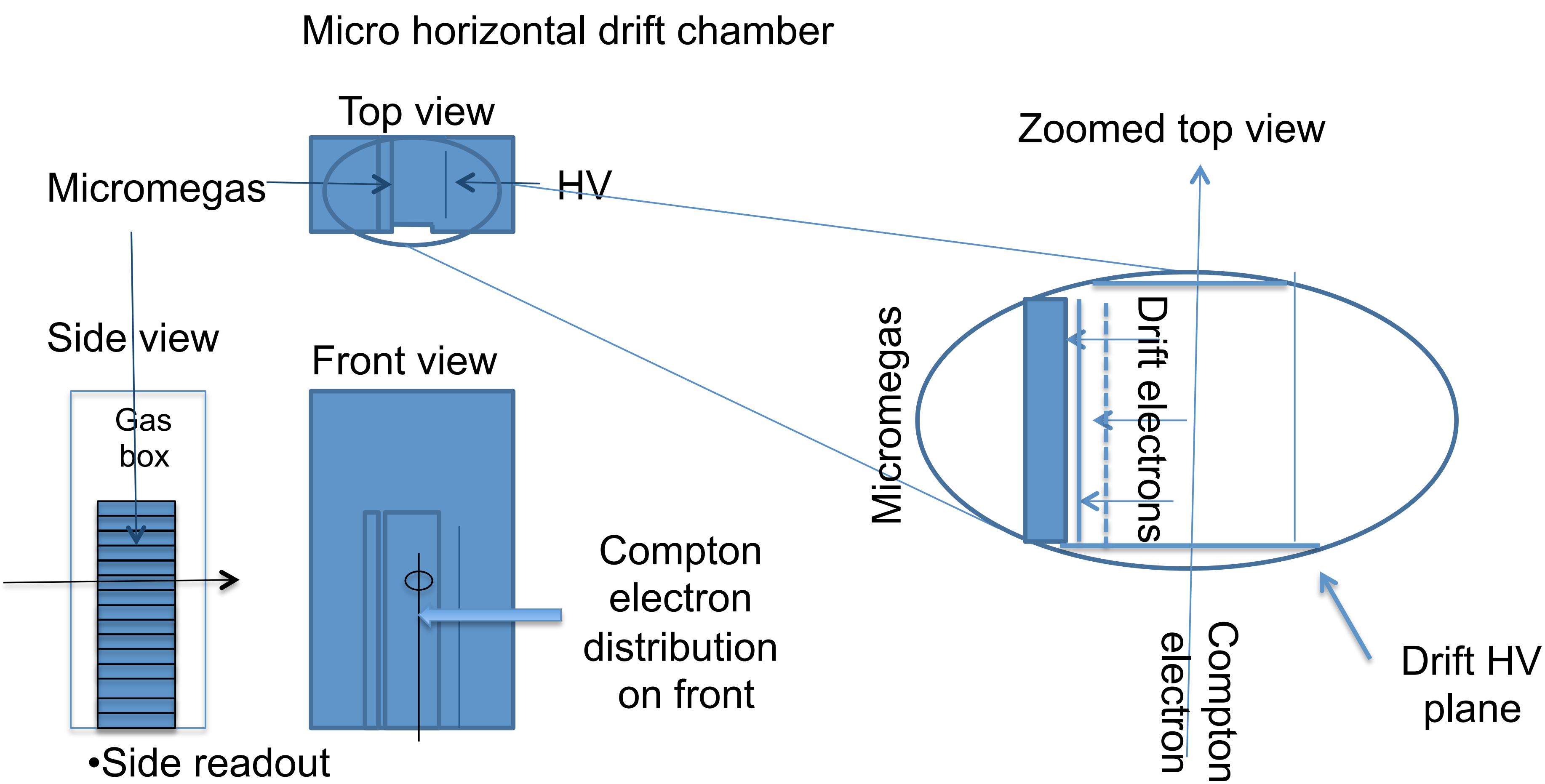




- Readout similar to silicon detector
- Bulk process to laminate
- G10 Frame in front of readout
- Gas tightness using mylar or kapton



Micromegas detector



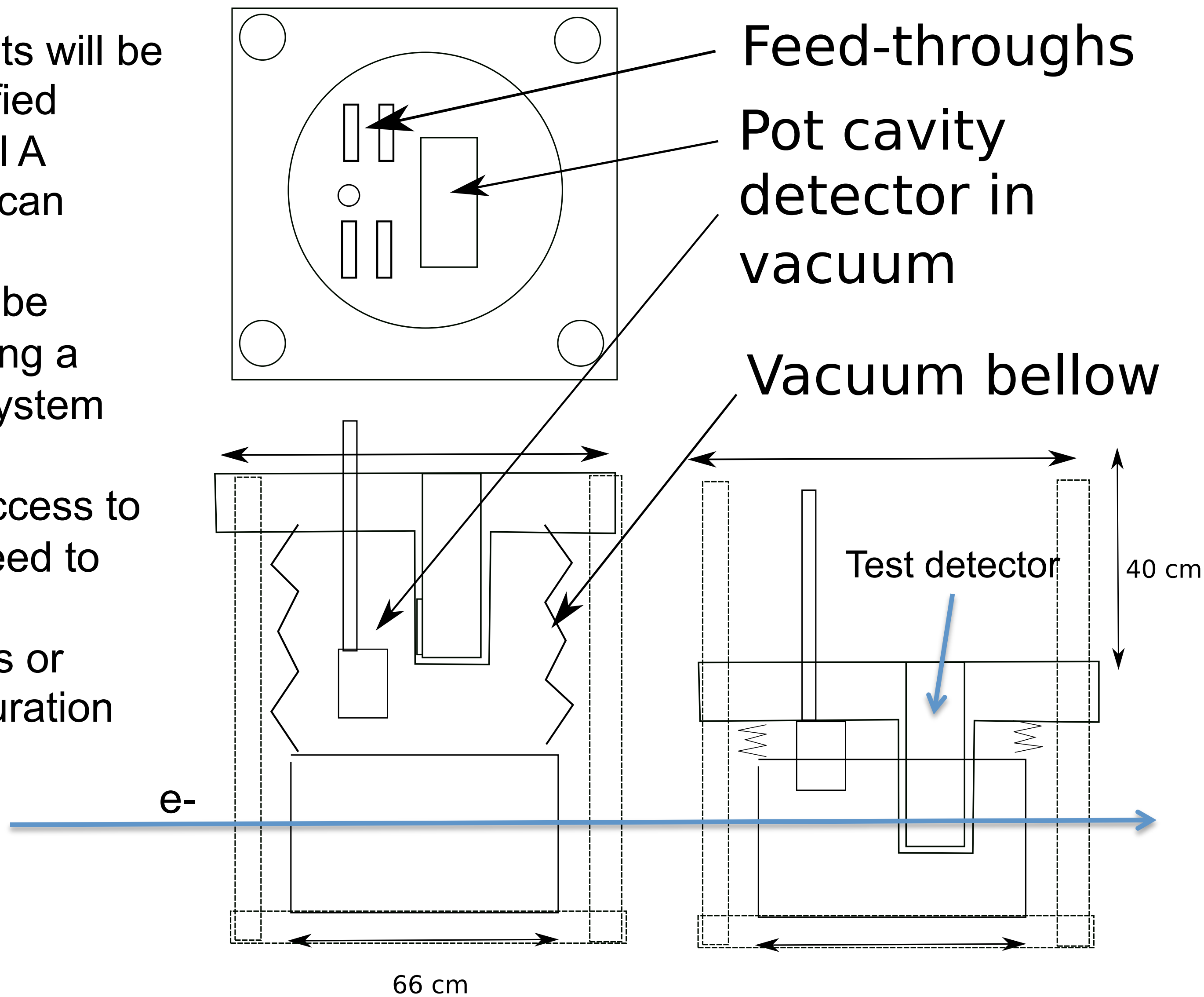
- Side readout
- Drift electrons are detected on the side by a Micromegas
- Use fast drift gas and optimize mesh distance to minimize pulse width
- Detector designed to be easily replaceable

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



Work Plan

- 2015
  - Diamond strip detector: acquire 2 new planes, investigate operation in integrating mode (Miss. State, Manitoba)
  - Quartz detector test (Idaho State, Stony Brook)
  - Manufacture Micromegas prototype (CEA-Saclay)
- 2016
  - Modify electron detector chamber in Hall A (JLab)
  - Fabricate optimized quartz detector (Idaho State, Stony Brook)
- 2017
  - Manufacture Roman Pot to facilitate testing multiple detectors (rapidly) and test atmospheric gaseous detectors (Jefferson Lab)

Work break-down

- Study optimal detector placement
  - V. Morozov, F. Lin (JLab)
- Detector simulation and testing
  - A. Camsonne and D. Gaskell (JLab) + graduate student
- Diamond detector procurement and fabrication
  - J. Mammei (Manitoba) with D. Dutta (Mississippi State)
- Micromegas protoype
  - Stephan Aune (CEA Saclay)
- Quartz detector
  - D. McNulty (Idaho State), K. Kumar and S. Riordan (Stony Brook)
- FADC readout for quartz detector
  - G. Franklin and B. Quinn (CMU), W. Deconinck
- Electron detector vacuum chamber modifications
  - (JLab)
- Roman pot design
  - Alexandre Camsonne + designer (JLab)

Funding Request

Year	Detector	Amount
2015	Diamond strip	45 K$
2015	Micromegas prototype	20 K$
2015	Quartz readout	15 K$
2015	Graduate student	30 K$
2015	Travel fund	15 K$
2015	Total	125 K$
2016	Vacuum Chamber	45 K$
2016	Quartz dedicated integrating detector	20 K$
2015	Graduate student	30 K$
2016	Travel fund	15 K$
2016	Total	110 K$
2017	Roman pot	185 K$
2015	Graduate student	30 K$
2017	Travel fund	15 K$
2017	Total	230 K$
Total		465 K$

Extra

Diamond detector budget

Item	price
2 Diamond strip planes	25K$
Feedthrough	9 K$
Vacuum chamber	10 K$
Detector holder	2 K$
Motion system	8 K$
Total	58 K$
Overhead	32 K$
Total over 2 years	90 K$

Quartz Detector Budget

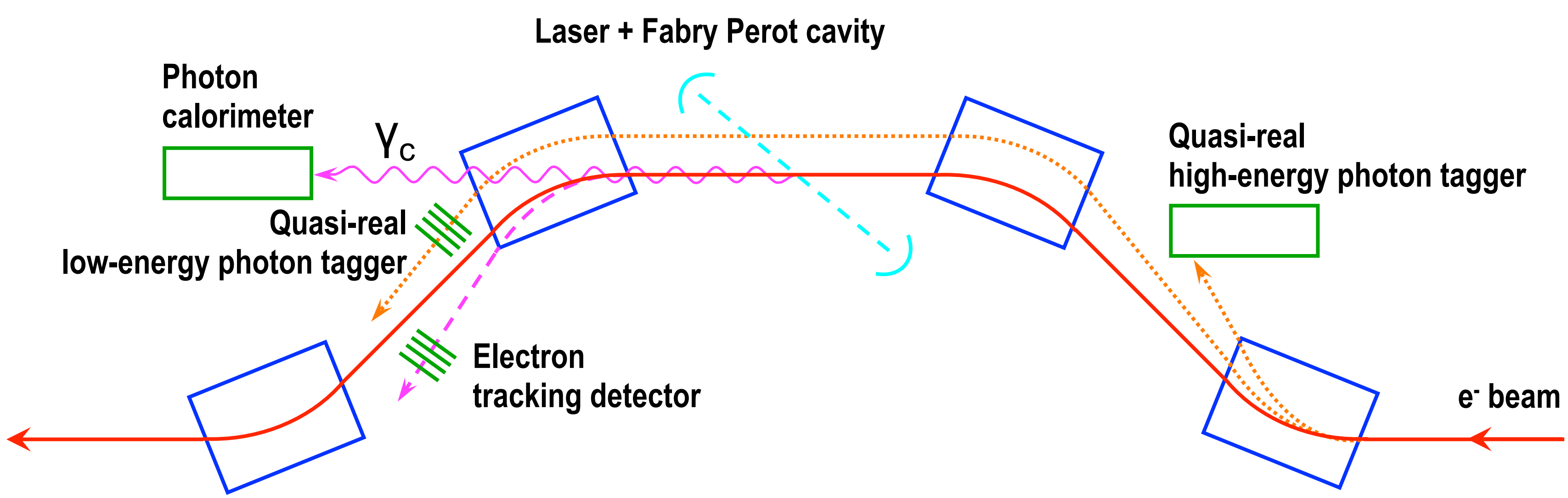
Item	price
Semiconductor photosensor for vacuum	10K$
Dedicated quartz pieces	10 K$
Detector holder	2 K$
Total	22 K$
Overhead	13 K$
Total over 2 years	35 K$

Micromegas Budget

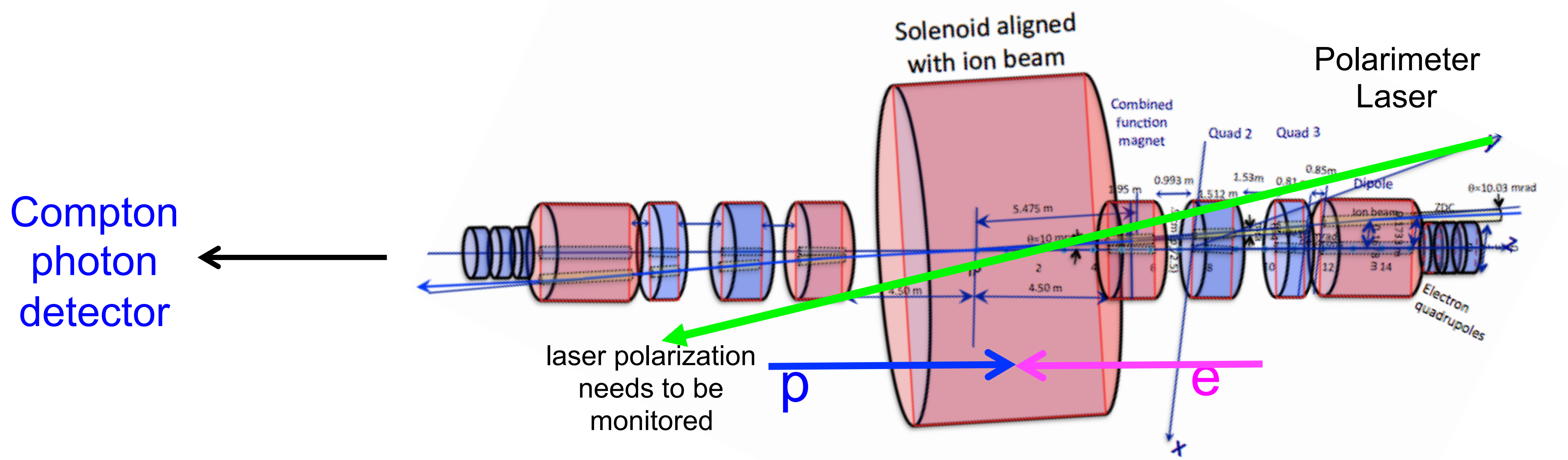
Item	price
PCB gerber design	7 K$
PCB board	3 K$
Mesh	1 K$
Supplies	2 K$
Connectors	0.5 K$
Gas box	0.5 K$
Total	13 K$
Overhead	7 K$
Total over 2 years	20 K$

Possible implementation in low Q^2 Tagger for MEIC

- At MEIC, Compton could 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



eRHIC lepton polarimeter: Location?

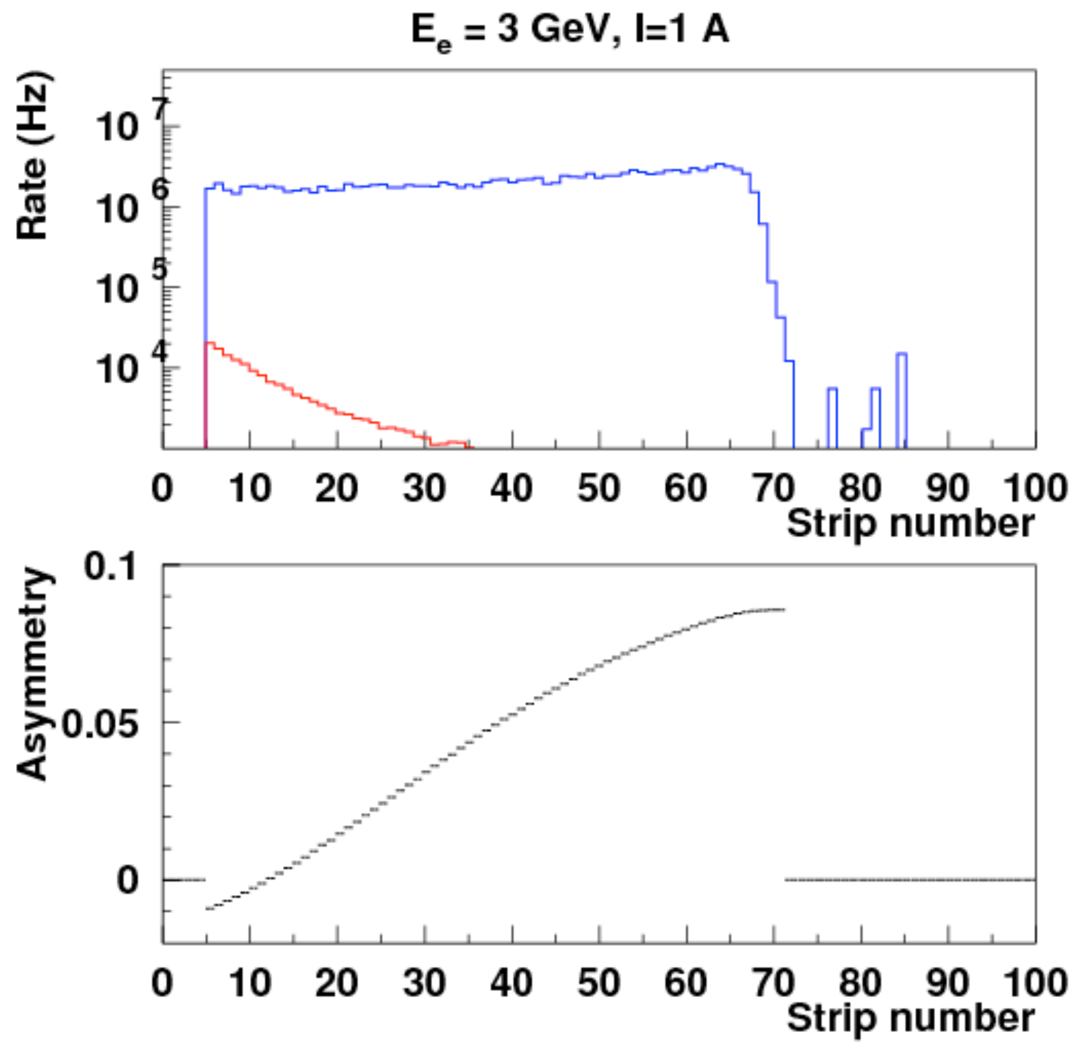


• Option to measure at IP with empty hadron bunch
•Measure after dipole in machine ?
•Dedicated chicane ?

•Constraint on detector technology for the Gatling gun design : detectors signal shorter than 100 ns

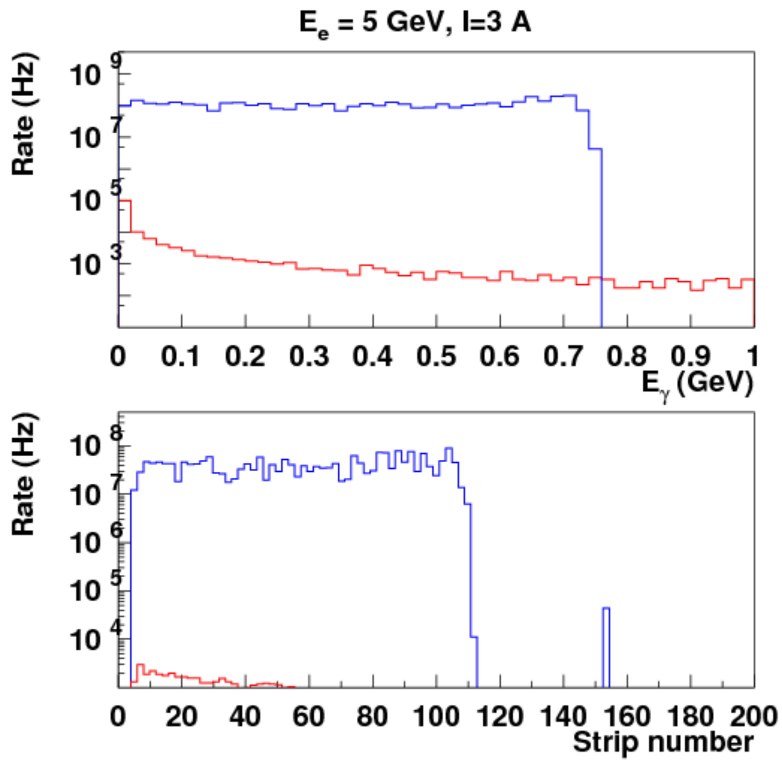
(E. Aschenauer)

E_{beam}=3 GeV
I = 1 A
Laser=532 nm, 1 kW
Vacuum = 1E-9
Detector = 9 mm from beam



Cavity Design Considerations

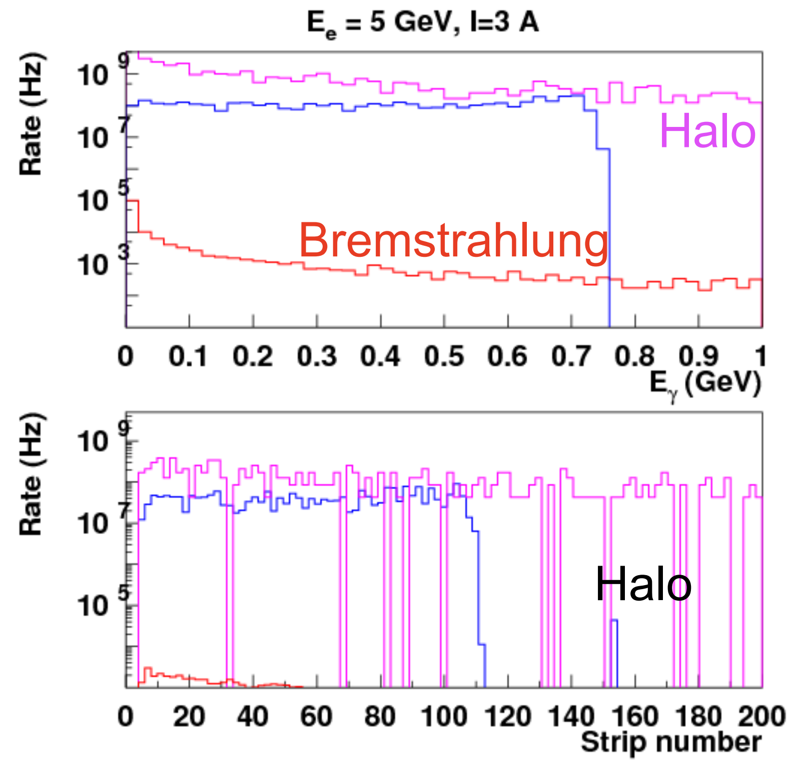
2 cm cavity aperture



Photon detector signal

Electron detector signal

1 cm cavity aperture



- Electron detector further from beam at higher energy → smaller backgrounds
- Background is worse for photon detector than elecron detector
- Need to pay attention to apertures which can generate background from halo
- Understanding halo important → work with CASA to develop reliable model

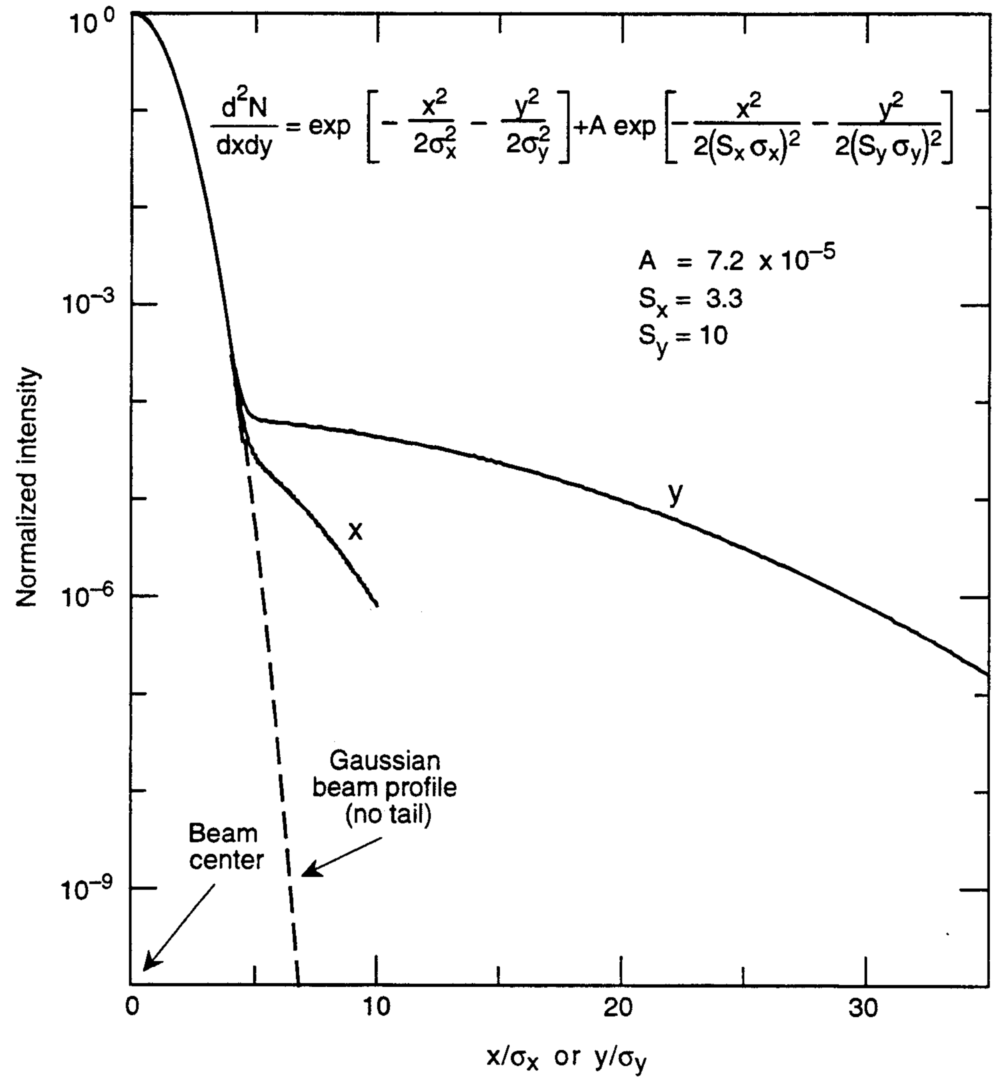
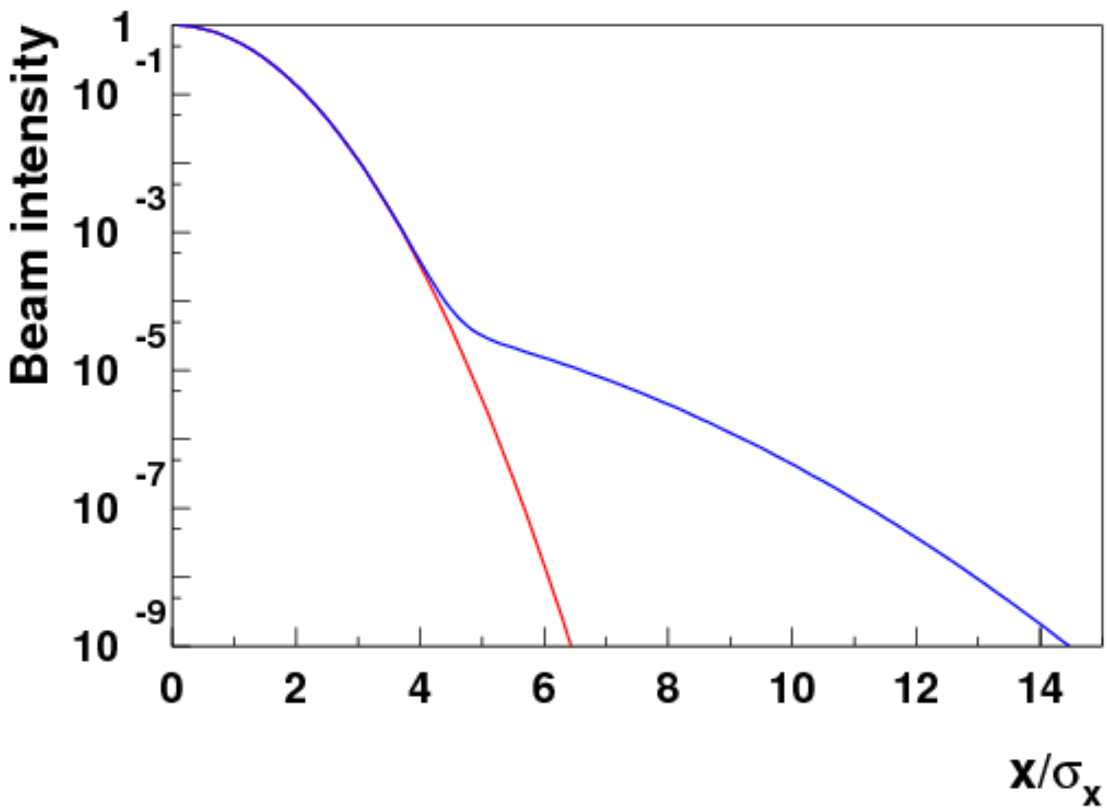


Fig. 4-51. Plot of the beam profiles assumed for the calculation of detector backgrounds due to synchrotron radiation. The integral of the background Gaussian is about 0.25% of the main beam Gaussian.

Jefferson Lab

Halo Model

$$\frac{dN}{dxdy} = e^{-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}} + Ae^{-\frac{x^2}{2(S_x\sigma_x)^2} - \frac{y^2}{2(S_y\sigma_y)^2}}$$



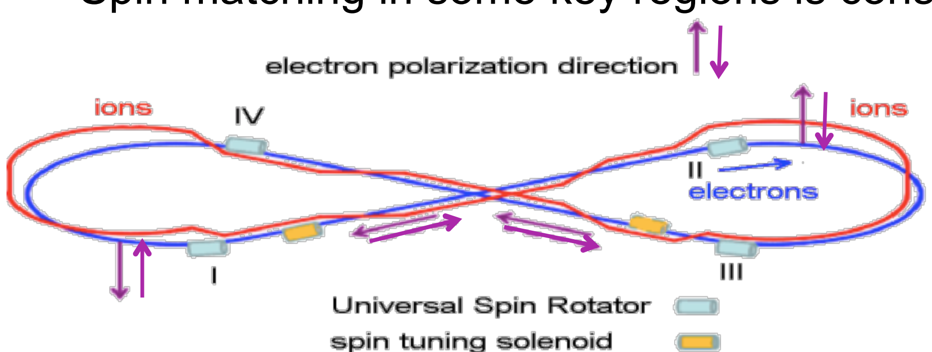
S_x=S_y=3.0

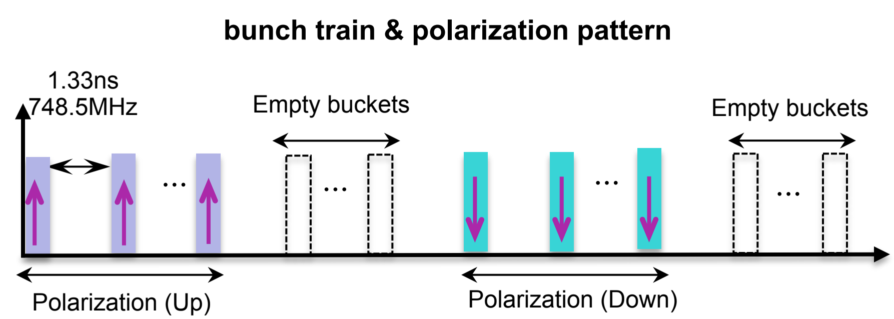
A=1.1E-4

Integrated strength=0.1%

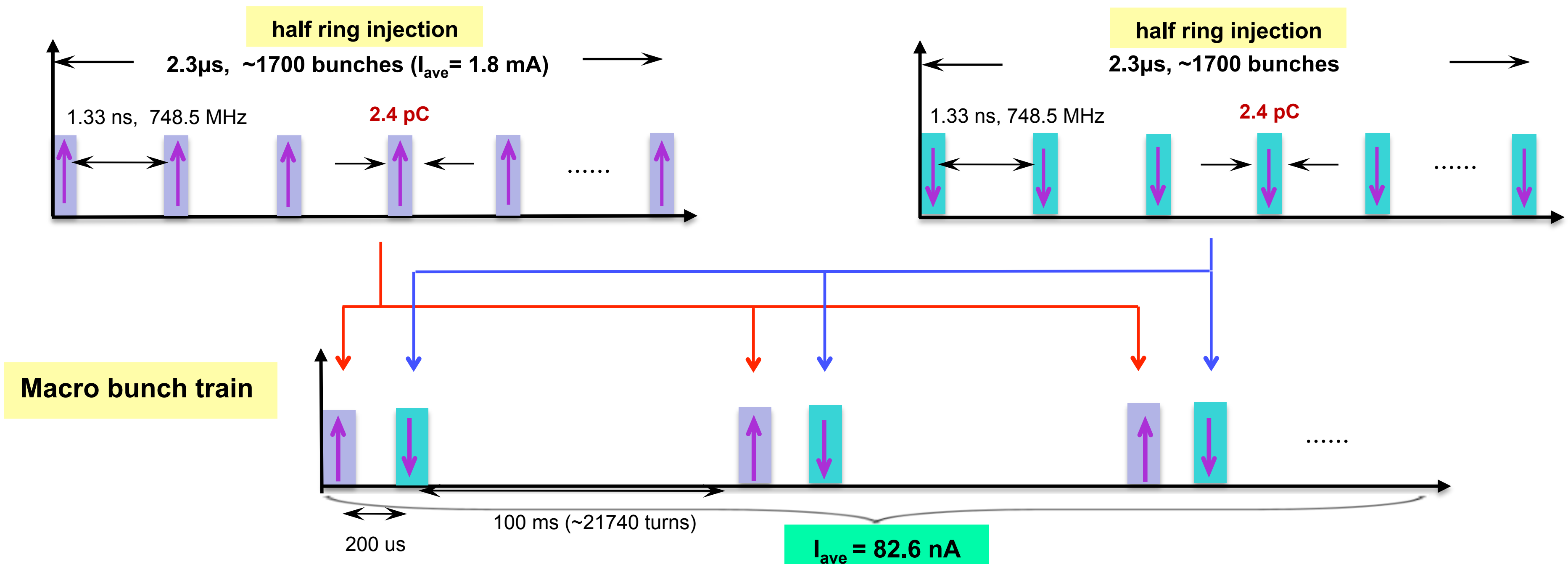
Overview of e⁻ Polarization Strategies

- Highly vertically polarized electron beams are injected from CEBAF
  - avoid spin decoherence, simplify spin transport from CEBAF to MEIC, alleviate the detector background
- Polarization is designed to be vertical in the arc to avoid spin diffusion and longitudinal at collision points using spin rotators
- Universal spin rotator rotates the electron polarization from 3 to 12GeV
- Desired spin flipping is implemented by changing the source polarization
- Compton polarimeter is considered to measure the electron polarization
  - Two long opposite polarized bunch trains (instead of alternate polarization between bunches) simplify the Compton polarimetry
- Polarization configuration with figure-8 geometry removes electron spin tune energy dependence
- Continuous injection of electron bunch trains from the CEBAF is considered to
  - preserve and/or replenish the electron polarization, especially at higher energies, and
  - maintain a constant beam current in the collider ring
- Spin matching in some key regions is considered if it is necessary





Initial Injection Bunch Pattern

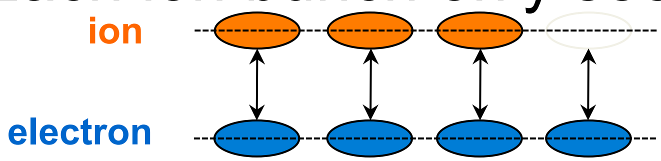


Beam energy	Gev	3	5	6	7	9	12
Beam current	A	3	3	2.0	1.1	0.4	0.13
Injection time	min	2.8	2.8	1.9	1.0	0.4	0.12

- Such injection bunch pattern needs no upgrade of CEBAF beyond 12 GeV upgrade

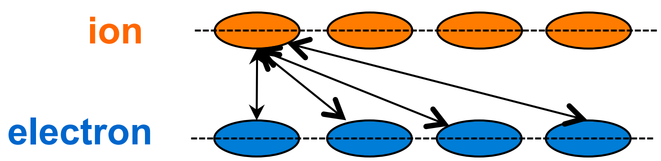
Polarization Collision Pattern

- HERA:
  - Each ion bunch only sees the same electron bunch



$$FOM \propto \left\langle \sum_j q_{ion,j} q_{ele,j} P^2_{ion,j} P^2_{ele,j} \right\rangle$$

- MEIC:
  - Each ion bunch sees all electron bunches



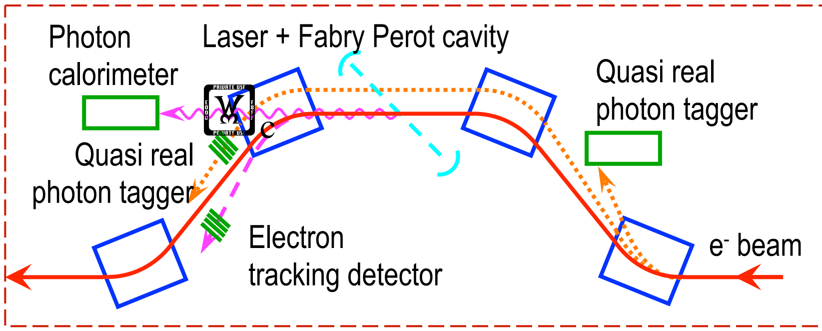
$$FOM \propto \left\langle \sum_m q_{ion,m} P^2_{ion,m} \right\rangle \left\langle \sum_n q_{ele,n} P^2_{ele,n} \right\rangle$$

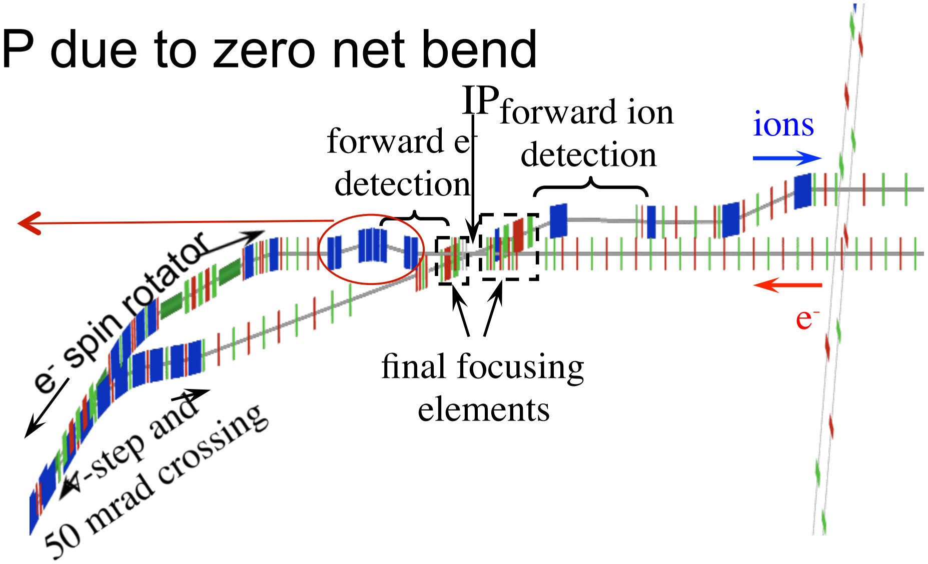
  - No non-colliding bunches

➡ Therefore, in the MEIC
  - Bunch-to-bunch variation does not contribute to the uncertainty
  - One can measure average polarization of each macro bunch train

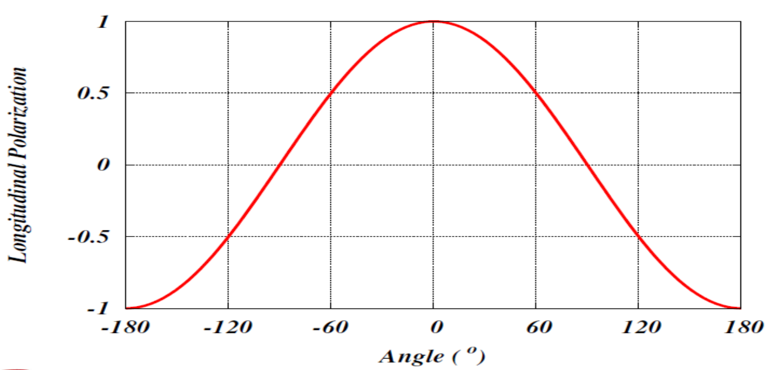
Polarization Measurement

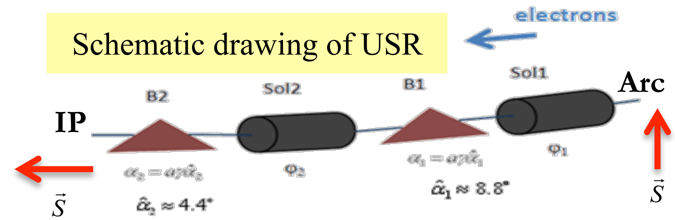
- Compton polarimetry:
  - same polarization at laser as at IP due to zero net bend

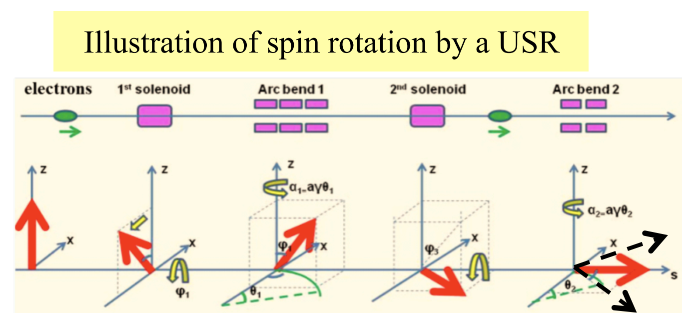




- Spin dancing (using spin rotators):
  - Experimentally optimize (calibrate) longitudinal polarization at IP

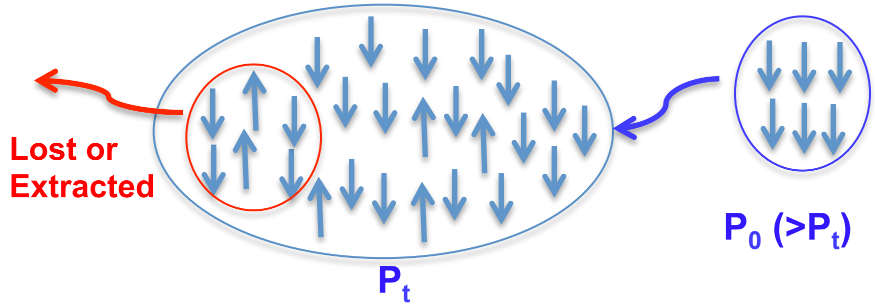


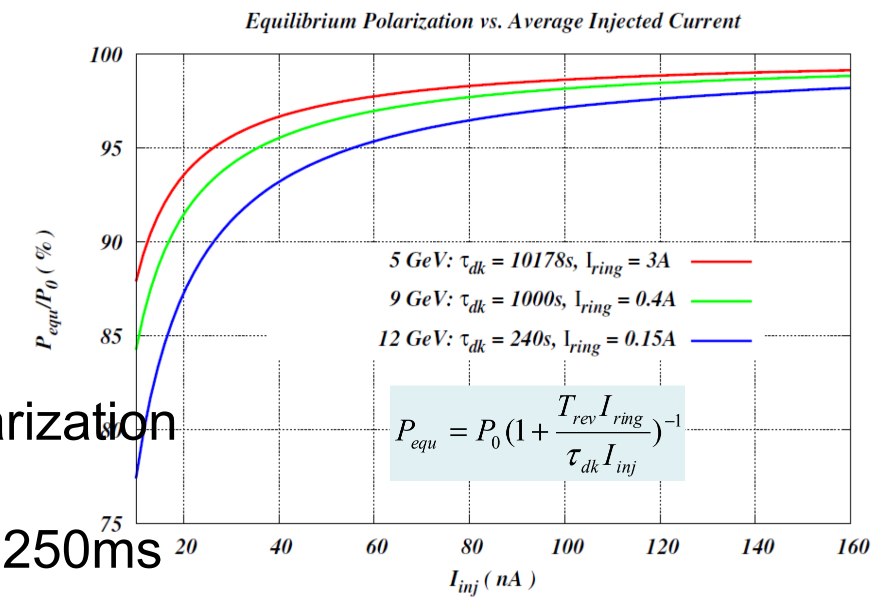




Continuous Injection Option

- Continuous injection principle





- Low injected current preserves high polarization
- One possible injection bunch pattern
  - Damping time at energy > 5 GeV << 250ms
  - No beam dump needed