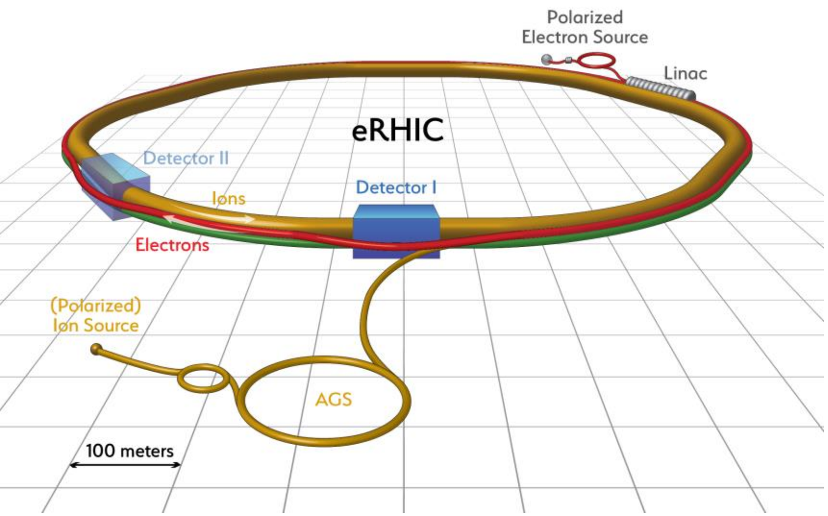
Electron polarimetry for EIC

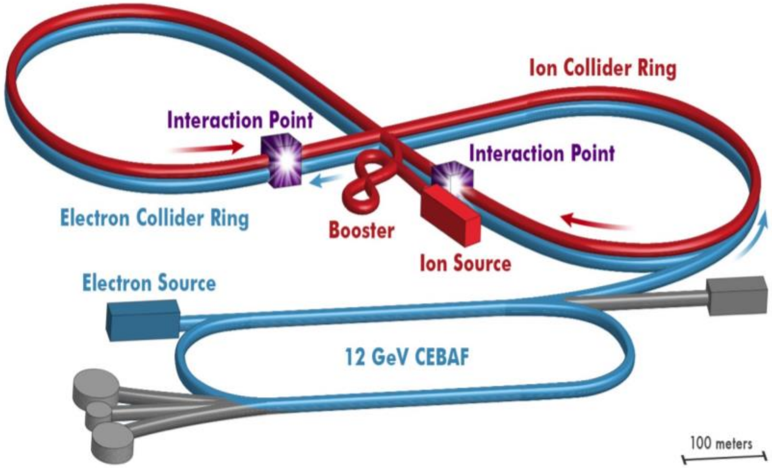
EIC accelerator collaboration meeting
October 10th 2019
Alexandre Camsonne
Hall A Jefferson Laboratory

Outline

- EIC beam parameters
- Polarimetry techniques
- Compton polarimetry
- Compton electron detector JLEIC
- Counting rates / bunch by bunch measurement
- TOTEM Fast amplifier for electron detector
- Photon detection for transverse polarimetry
- Conclusion

Electron Ion Collider designs





Lower luminosity
560 MHz RF
330 bunches
33 ns between bunches
Electron current up to 1.2A
Ion current up to 0.46 A

High luminosity
560 MHz RF
1320 bunches
10 ns between bunches
Electron current up to 2.4 A
Ion current up to 0.92 A

Low and Medium energy
476 MHz RF
1540x2 bunches
2 .1 ns between bunches
Electron current up to 2.8 A
Ion current up to 0.75 A

High energy
476 or 119 MHz RF
385 x 2 bunches
8.4 ns between bunches
Electron current up to 0.75 A
Ion current up to 0.71 A

High luminosity polarized electrons on polarized and unpolarized ions
For electron beam asymmetry measurements polarization can be the dominating error.
Aiming for 1% or better electron polarization accuracy

Main Parameters eRHIC ring-ring for Maximum Luminosity

E_p = 275 GeV, E_e= 10 GeV

		No Hadron Cooling		Strong Hadron Cooling	
Parameter	**Units**	**Protons**	**Electrons**	Protons	Electrons
Center of Mass Energy	GeV	100		100	
Beam Energy	GeV	275	10	275	10
Particles/bunch	10^{10}	11.6	31	5.6	15.1
Beam Current	mA	456	1253	920	2480
Number of Bunches		330		1320	
Hor. Emittance	nm	17.6	24.4	8.3	24.4
Vertical Emittance	nm	6.76	3.5	3.1	1.7
β_{x^*}	cm	94	62	47	16
β_y*	cm	4.2	7.3	2.1	3.7
σ_x'*	mrad	0.137	0.2	0.13	0.39
σ_y'*	mrad	0.401	0.22	0.38	0.21
Beam-Beam ξ_x		0.014	0.084	0.012	0.047
Beam-Beam ξ_y		0.0048	0.075	0.0043	0.084
τ_{IBS} long/hor	hours	10/8	-	4.4/2.0	-
Synchr. Rad Power	MW	-	6.5	-	10
Bunch Length	cm	7	0.3	3.5	0.3
Luminosity	$10^{34} cm^{-2} s^{-1}$	0.29		1.21	

New eRHIC ring ring design : beam interaction frequency going from initial RHIC 10 MHz to 30 MHz with 330 bunches and 100 MHz with 1320 bunches in a 3.8 km ring

JLEIC Baseline New Parameters

CM energy	GeV	21.9 (low)		44.7 (medium)		63.3 (high)	
		p	e	p	e	p	e
Beam energy	GeV	40	3	100	5	100	10
Collision frequency	MHz	476		476		476/4=119	
Particles per bunch	10^{10}	0.98	3.7	0.98	3.7	3.9	3.7
Beam current	A	0.75	2.8	0.75	2.8	0.75	0.71
Polarization	%	80	80	80	80	80	75
Bunch length, RMS	cm	3	1	1	1	2.2	1
Norm. emitt., hor./vert.	μm	0.3/0.3	24/24	0.5/0.1	54/10.8	0.9/0.18	432/86.4
Horizontal & vertical β*	cm	8/8	13.5/13.5	6/1.2	5.1/1	10.5/2.1	4/0.8
Vert. beam-beam param.		0.015	0.092	0.015	0.068	0.008	0.034
Laslett tune-shift		0.06	$7x10^{-4}$	0.055	$6x10^{-4}$	0.056	$7x10^{-5}$
Detector space, up/down	m	3.6/7	3.2/3	3.6/7	3.2/3	3.6/7	3.2/3
Hourglass(HG) reduction		1		0.87		0.75	
Luminosity/IP, w/HG, 10^{33}	$cm^{-2}s^{-1}$	2.5		21.4		5.9	

Ring circumference : 2.4 km

Max number of bunches :3416
Number of bunches : 1540 * 2 two macrobunches
with 2.1 ns spacing between electron bunches

Polarimetry techniques

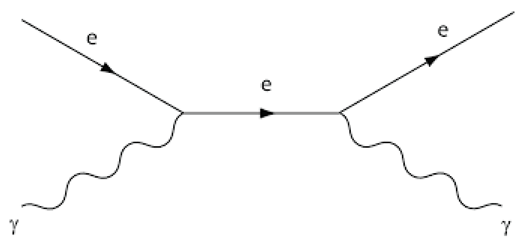
- Mott
  - spin-orbit coupling of electron spin with (large Z) target nucleus
  - Useful at MeV-scale (injector) energies
- Moller

atomic electrons in Fe (or Fe-alloy) polarized using external magnetic field

  - MeV to GeV-scale energies
  - rapid, precise measurements usually destructive (solid target)
  - non-destructive measurements possible with polarized gas target, but has not yet been done
- Compton
  - Compton asymmetry with polarized photon target
  - Works well at energies greater than 1 GeV
  - High current
  - Non destructive
- More exotic
  - RF cavity based https://www.sciencedirect.com/science/article/pii/016890029391076Y
  - Spin light polarimeter based on synchrotron radiation (Dutta) https://arxiv.org/abs/1310.6340

Polarized Compton effect

The polarization of the beam can be measured using the Compton effect.



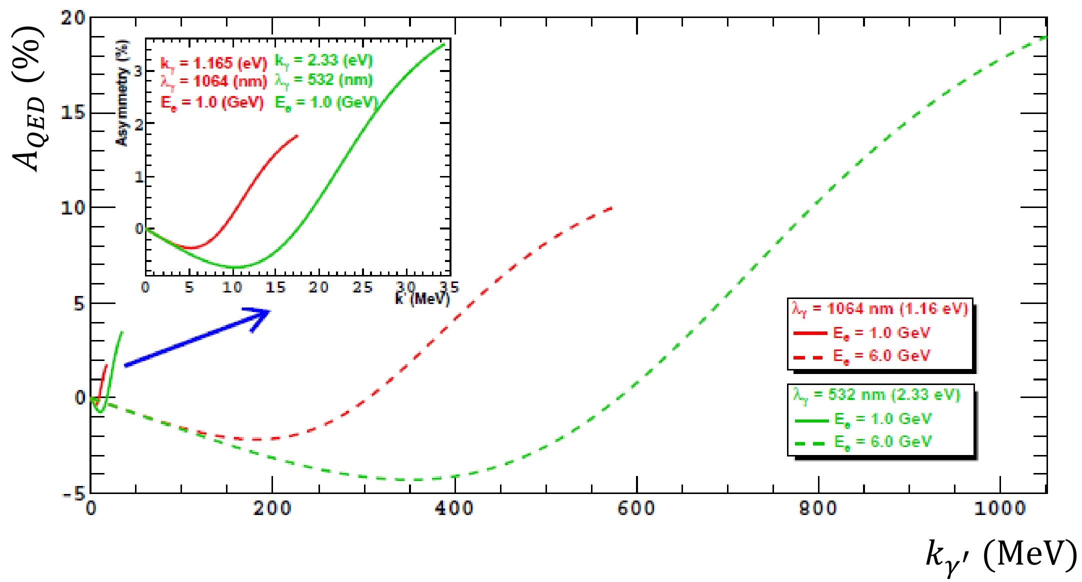
$$\sigma(\ \vec{e} + \gamma \ \rightarrow \ e' + \gamma'\ ) \quad \neq \quad \sigma(\ \overleftarrow{e} + \gamma \ \rightarrow \ e' + \gamma'\ )$$

$$A_{EXP} \equiv \frac{N^+ - N^-}{N^+ + N^-} = \boldsymbol{P_e} * P_\gamma * A_{QED}(E_e, k_\gamma, k_{\gamma'})$$

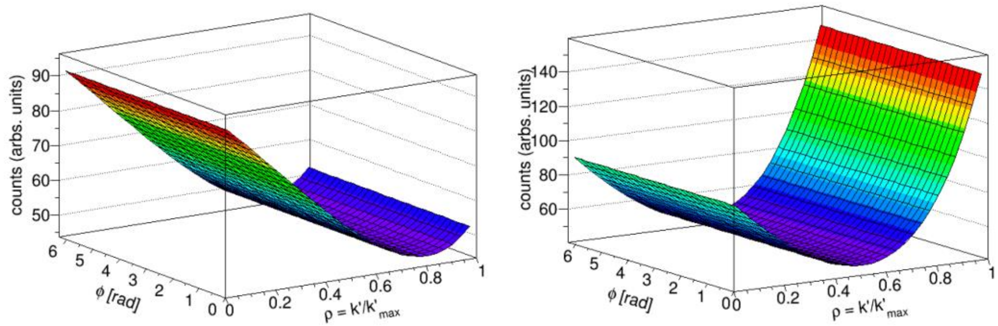
Measured asymmetry

Polarization of the photons (measurable)

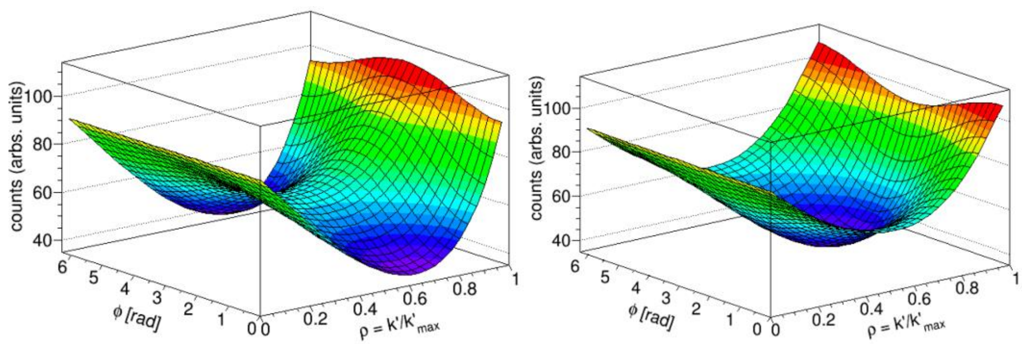
Asymmetry computed using QED



Polarized Compton process



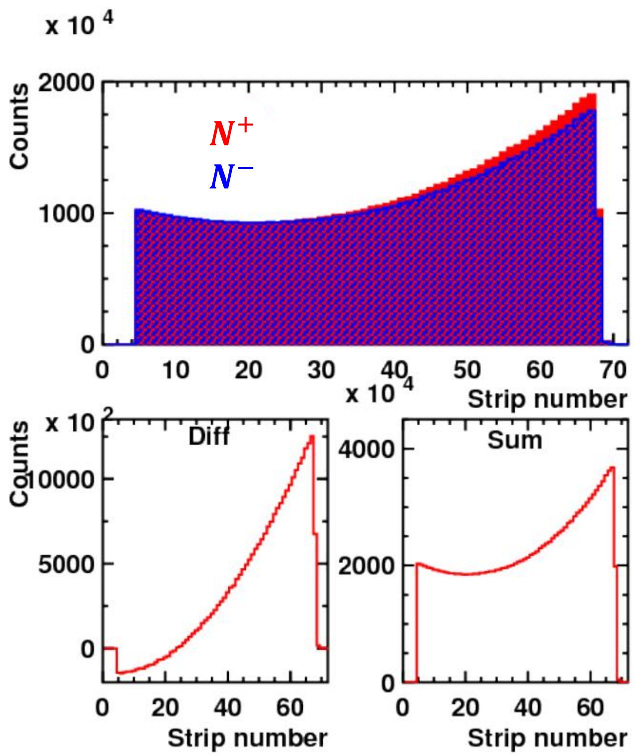
Longitudinal polarization asymmetry

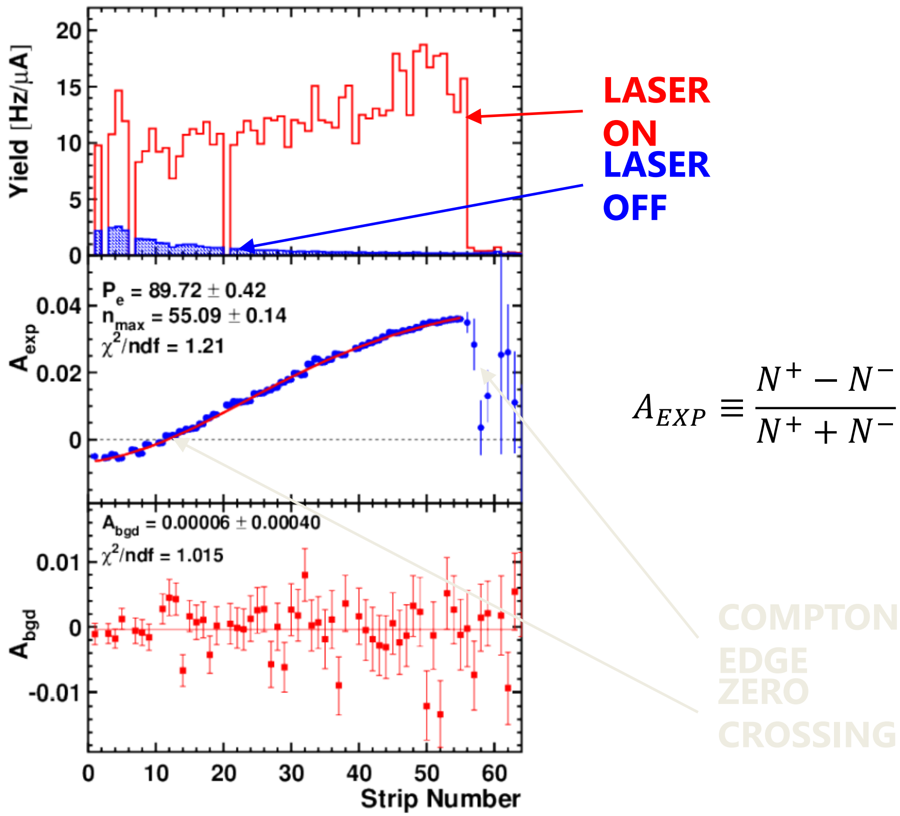


Transverse polarization Compton asymmetry

Polarized Compton process

The hit distributions are used to measure A_{EXP}.



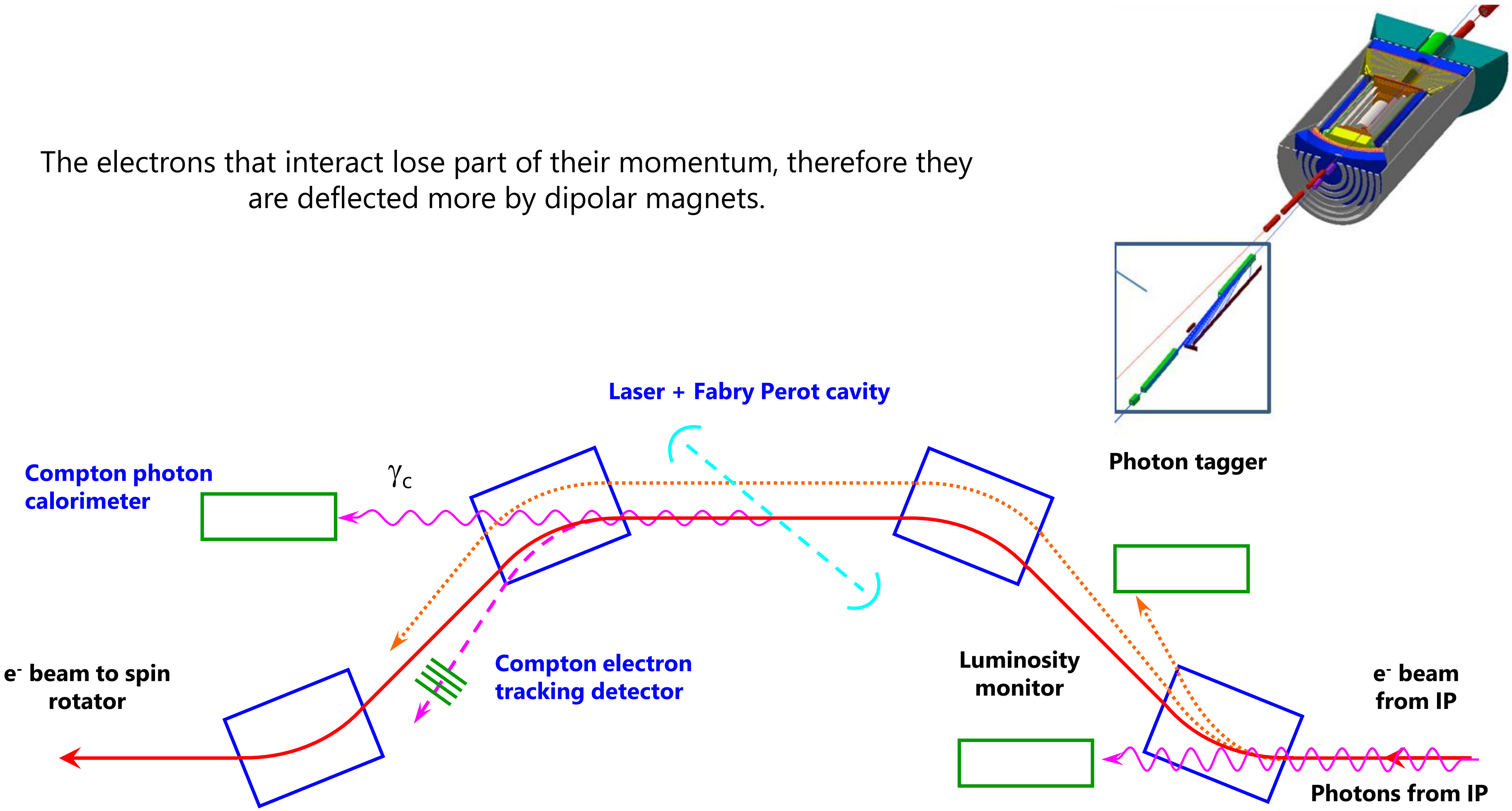


$$A_{EXP} \equiv \frac{N^+ - N^-}{N^+ + N^-}$$

[Precision Electron-Beam Polarimetry using Compton Scattering at 1 GeV](#) (Hall C at Jefferson Lab)

Compton chicane

The electrons that interact lose part of their momentum, therefore they are deflected more by dipolar magnets.

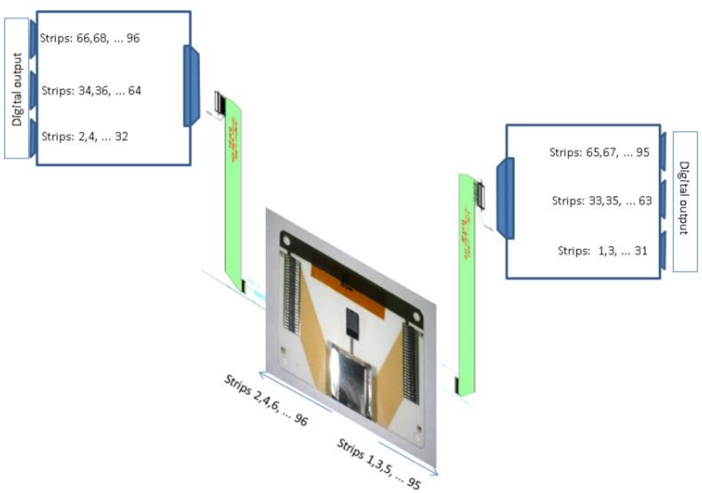


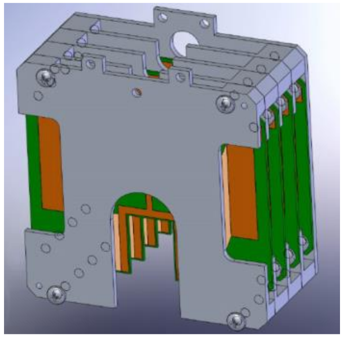
JLab Hall C Compton Electron detector

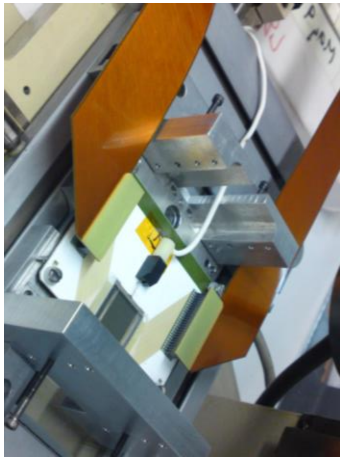
A solid state detector directly in the primary vacuum can approach the beam using a movable support.

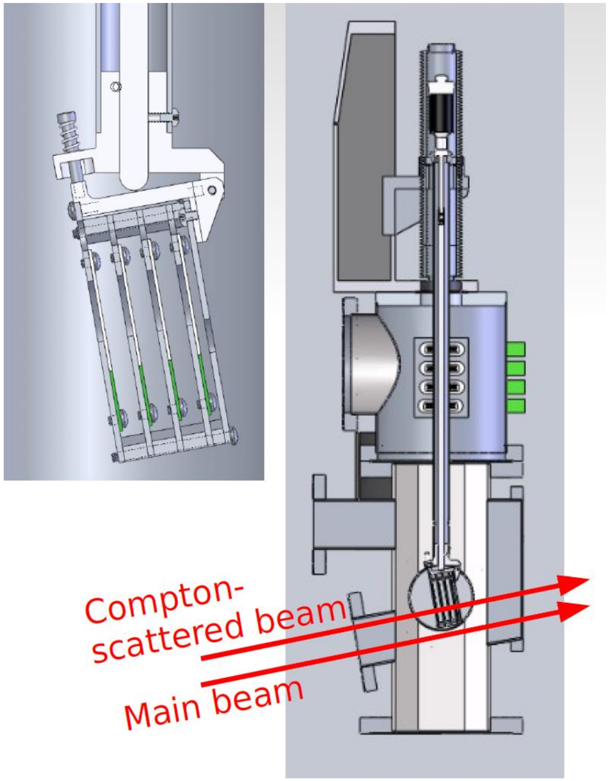
Silicon or diamond strip detectors
About 200 to 250 strips 250 mm width
5 cm length to catch zero crossing and Compton edge
Present system used at JLAB Hall C : electronics connected with flat cables

Bad for SNR and speed!







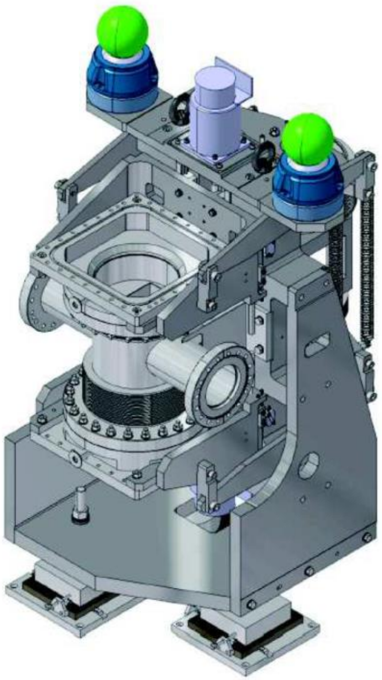


Challenges at EIC

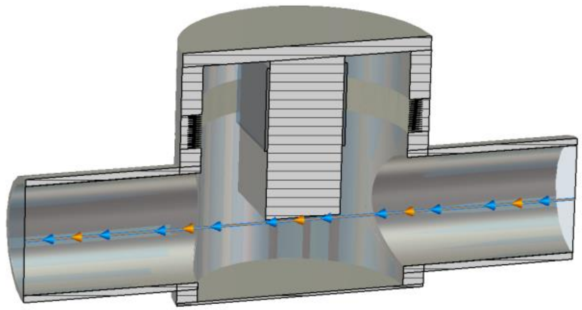
- Large beam current (3 A vs 200 uA at JLab)
  - Wakefield power deposit by beam can be significant
  - Synchrotron radiation (more severe than JLab)
  - Background
    - Bremsstrahlung
    - Halo
  - Detector radiation hardness

Proposed EIC Compton electron detector

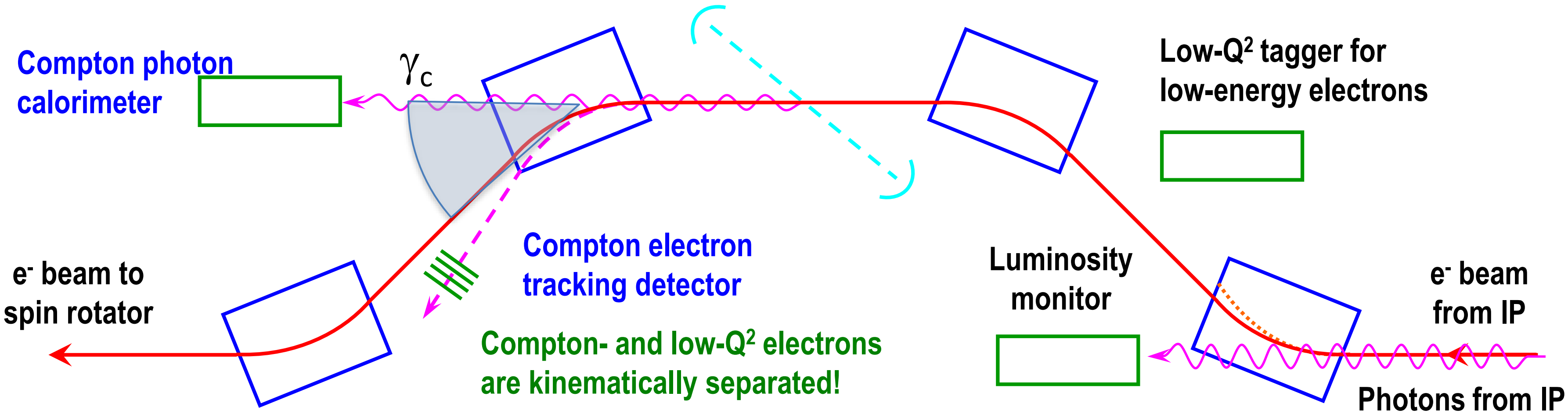
- Use Roman Pot for electron side too
- Pros :
  - Access to detector without breaking main vacuum
  - Electronics can be closer to electronics (no flex cables)
  - Cooling of detector easier
- Con :
  - Additional material in front of detector



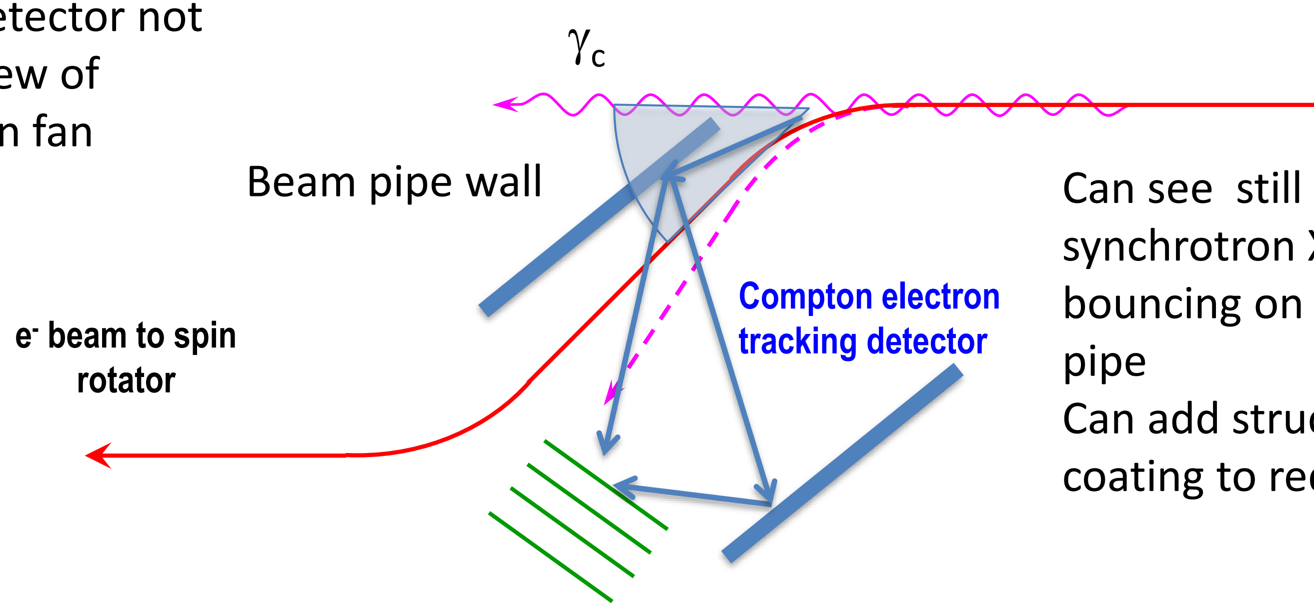
TOTEM Roman Pot



Synchrotron radiation



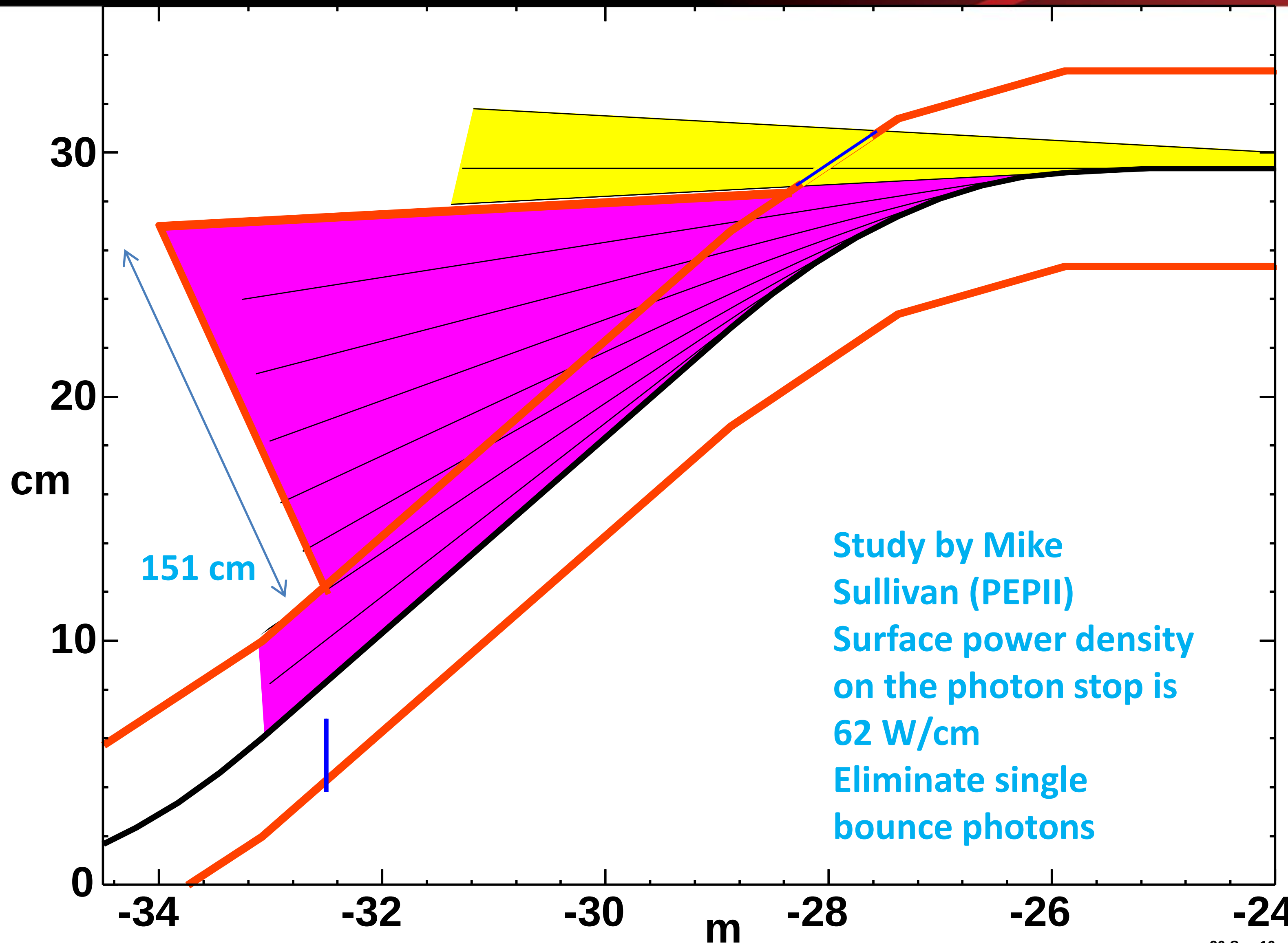
Electron detector not in direct view of synchrotron fan



Can see still see synchrotron X-rays bouncing on the beam pipe

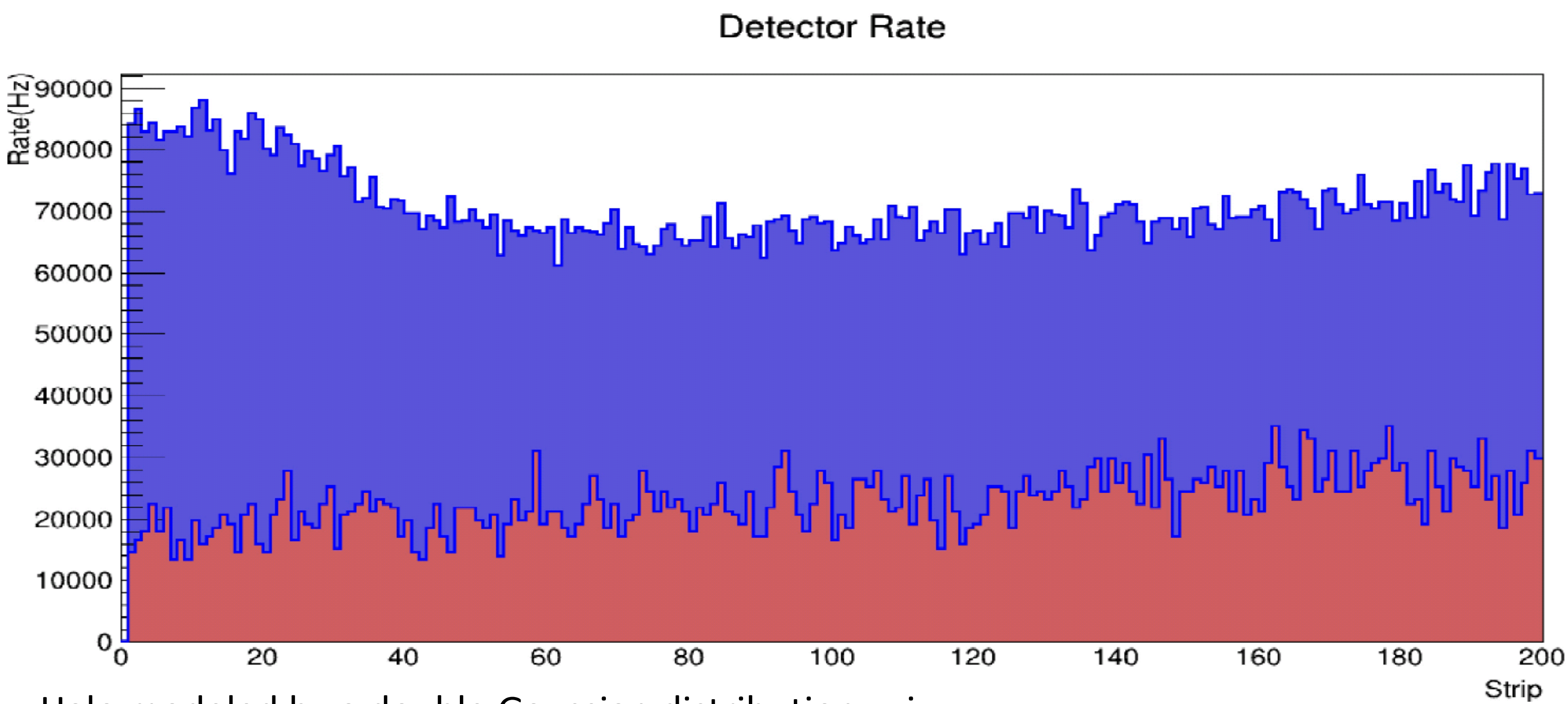
Can add structure and coating to reduce rate

Ante-chamber method



Study by Mike Sullivan (PEPII)
Surface power density on the photon stop is 62 W/cm
Eliminate single bounce photons

Halo background

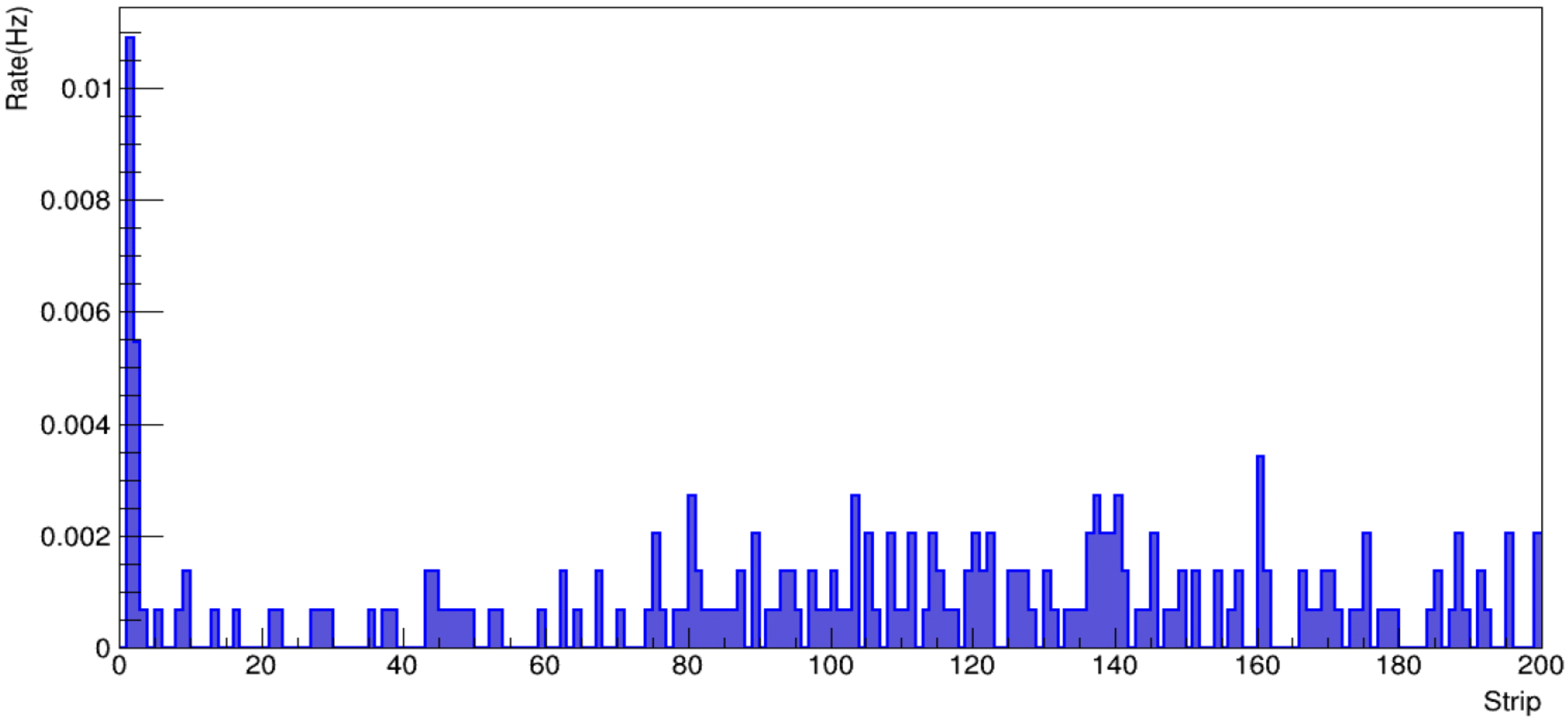


- Halo modeled by a double Gaussian distribution u: beam size from PEPII
- Halo rates for 1 cm (blue) and 2 cm aperture (salmon)
- Can be used to reevaluate when more realistic halo available

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

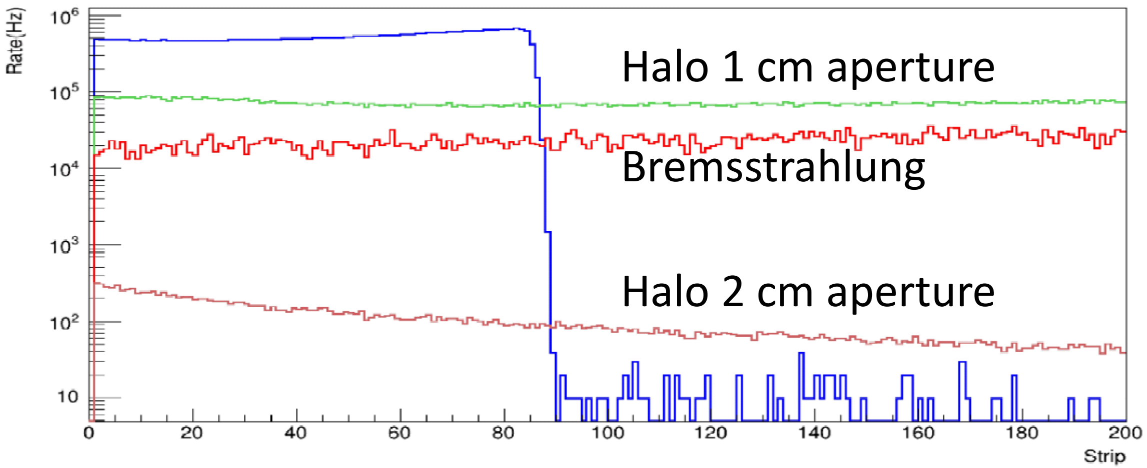
$$A = 7.2 \times 10^{-5}$$

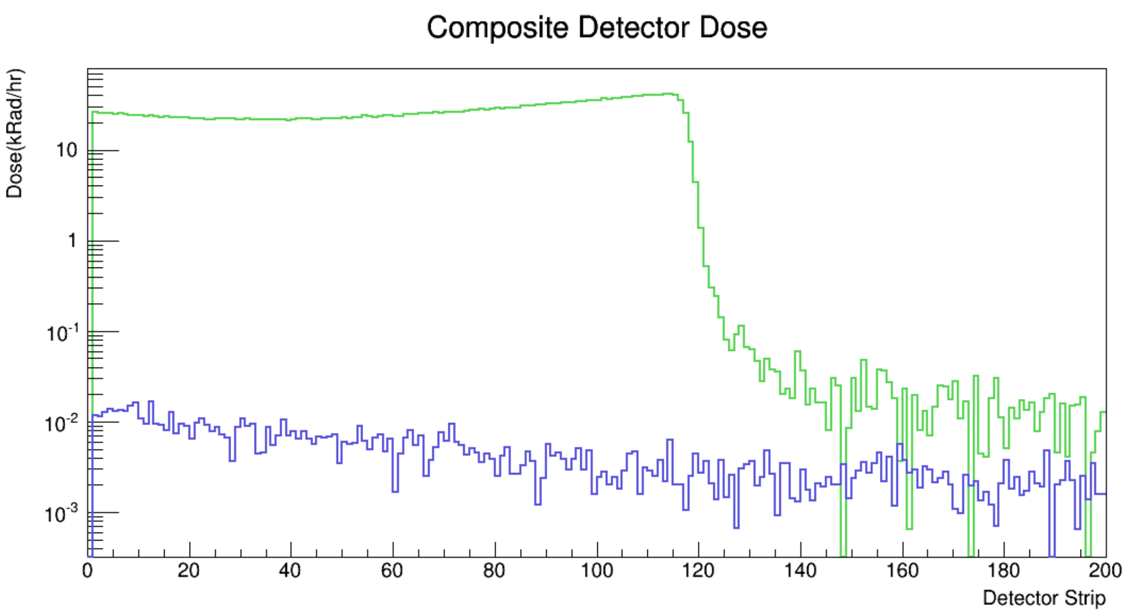
Compton Electron Rates from IP



- Use Pythia event generator
- Transport to Compton Detector
- Preliminary rate is negligible compared to other backgrounds

Compton Electron Det. Rates





Joshua Hoskins

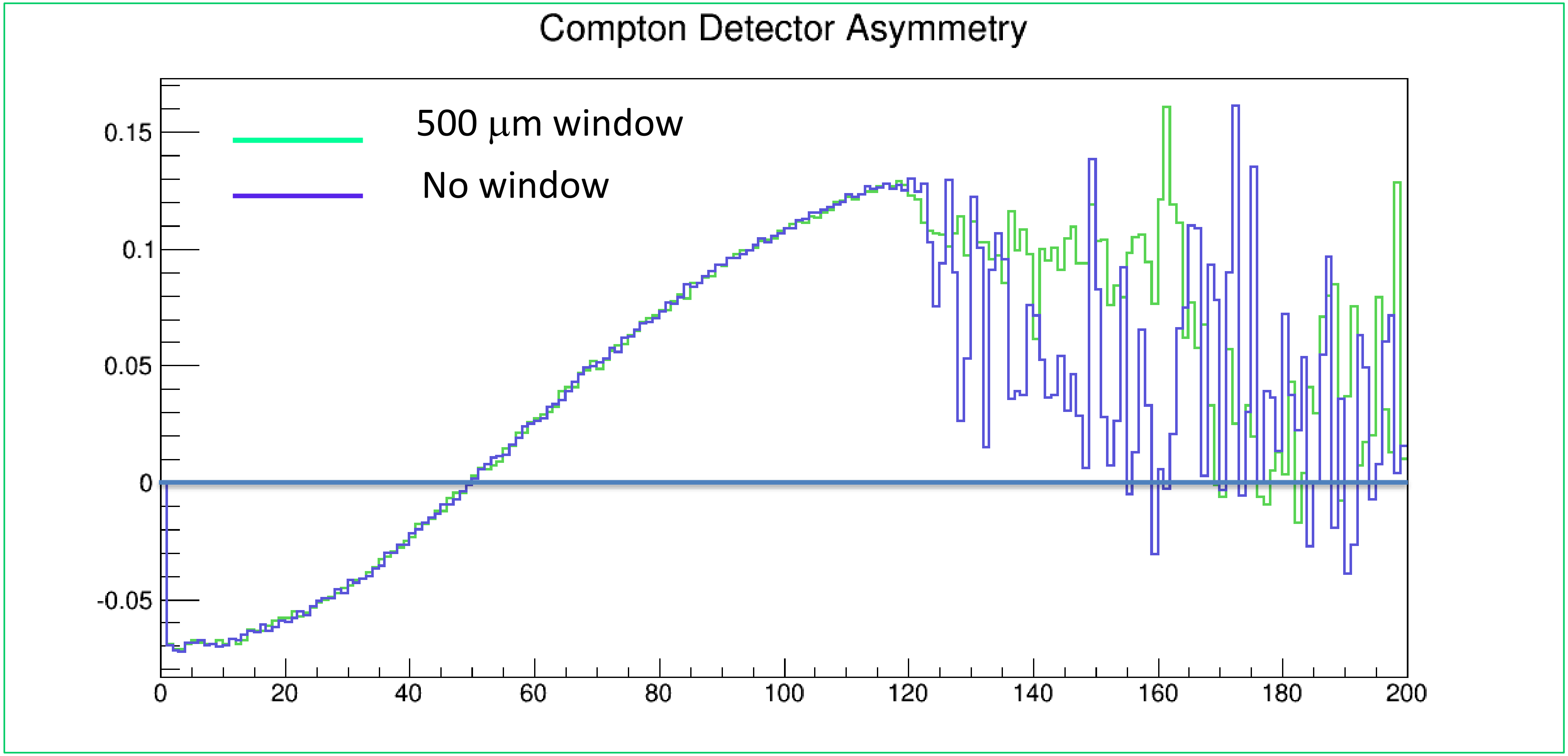
- 10 W
- 1 A of beam
- Green laser

- Compton and Bremsstrahlung assuming 10^{-9} Torr

- Corresponding radiation dose for signal and background about 20 kRad per hour

(typical silicon SNR divided by 2 after 1 Mrad
No change for diamond after 2 Mrad from Qweak , MAPS possible option)

Compton asymmetry with window



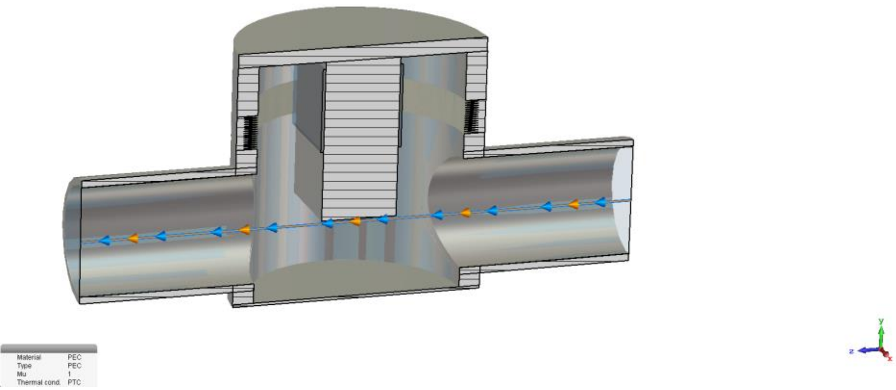
- Higher statistics MC comparison

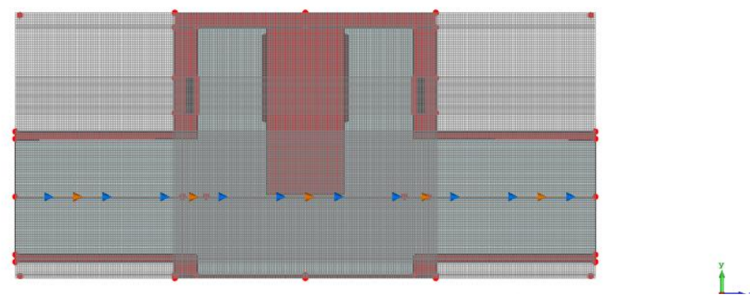
Compton asymmetry with window

	Polarization	Compton Edge	χ^2/NDF
No Window	84.90 ± 0.39	118.24 ± 0.18	1.74
Window	84.40 ± 0.40	118.36 ± 0.28	2.48

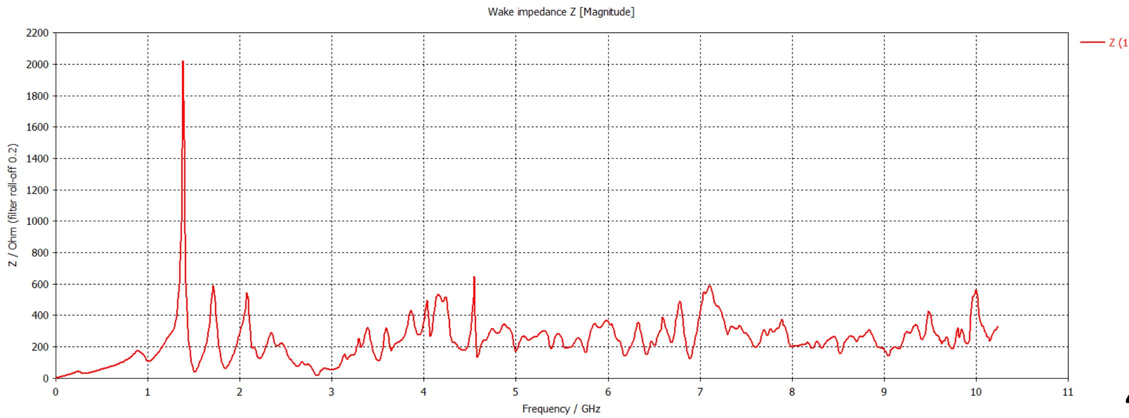
- Extracted polarization with and without window
- Number consistent at 1% level
- Need to study systematics with high statistics to evaluate best accuracy possible

Wakefield study

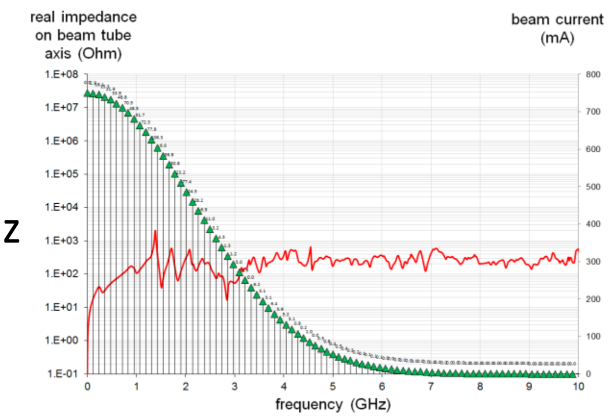




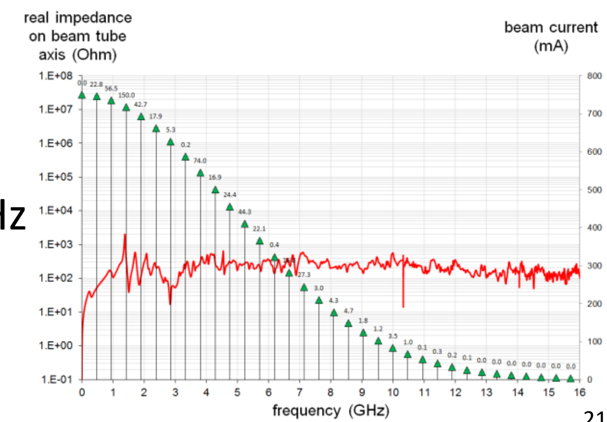
Impedance after 10 days of computation



119 MHz



476 MHz



Around 2160 W at 3A at low and medium energy
And 540 W at 0.75 A for high energy
Doable and will be reduced after optimization

Compton counting rates

JLEIC

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

Only considering Compton cross-section: no background
Total average polarization in 27 ms

Bunch polarization for 5 GeV for 3400 bunch = 30.6 seconds at 1 kW

High energy 850 bunches = 22 seconds at 1 kW

1 kW or 10 kW cavity desired for bunch
to bunch measurement

Note : 1 GHz electrons = 0.16 nA

Charge still negligible compared to store charged

Example polarization lifetime JLEIC

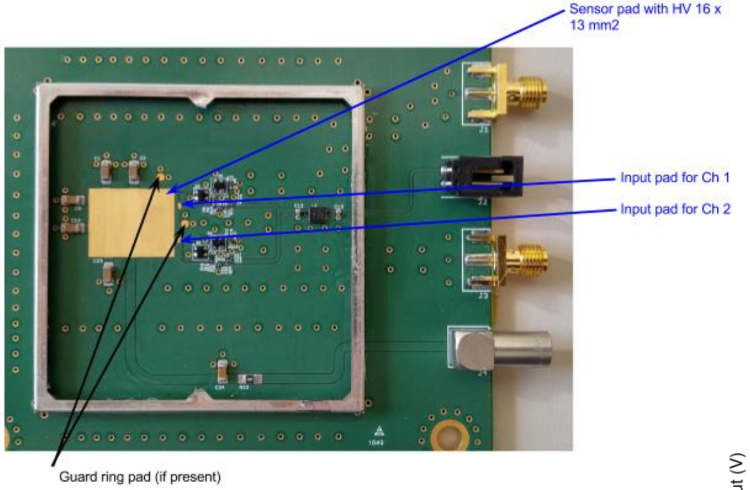
Energy (GeV)	3	5	7	9	12
Lifetime (hours)	116	9	1.7	0.5	0.1

- Low and medium energy
  - 1 kW OK at low energy
  - Can use subfrequency of beam by factor 10 : 5 mins measurements 20 ns spacing
  - Or use fast detector and same frequency as beam for faster measurement
- 10 kW power required to sample the shorter lifetime at high energy
  - Beam spacing 10 ns
  - 2 second measurement per bunch allow sampling over 6 minutes lifetime

Electronics for very fast detectors

TOTEM electronics designed by Kansas University

A two channels board was designed and manufactured for the characterization of different solid state detectors.



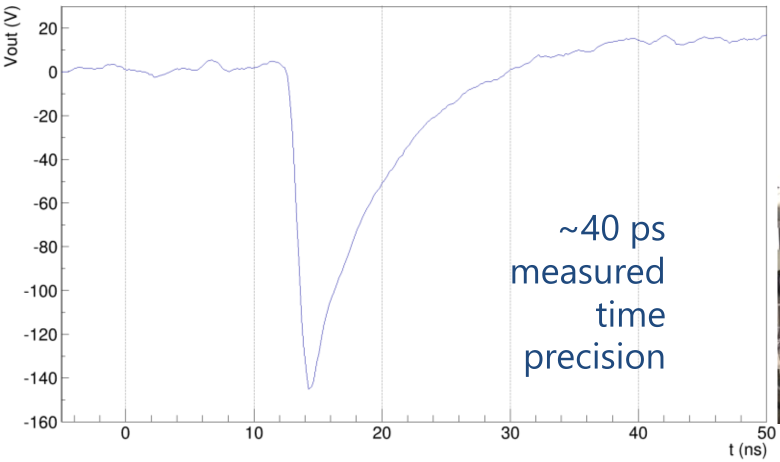
Sensors up to 16x13 mm^2 can be glued and bonded.

The components can be easily adapted to accommodate:

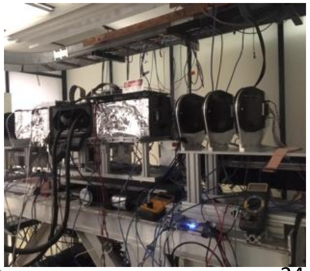
- Diamond sensors: ~1 nA bias current, both polarities, small signal
- Silicon sensors: ~100 nA bias current, small signal
- UFSD ~100 nA bias current, ~ larger signal
- SiPM: ~ 5 uA bias current, large signal

The board was optimized to achieve a good time precision with different sensors, however it can be modified to have an output signal shorter (but less precise)

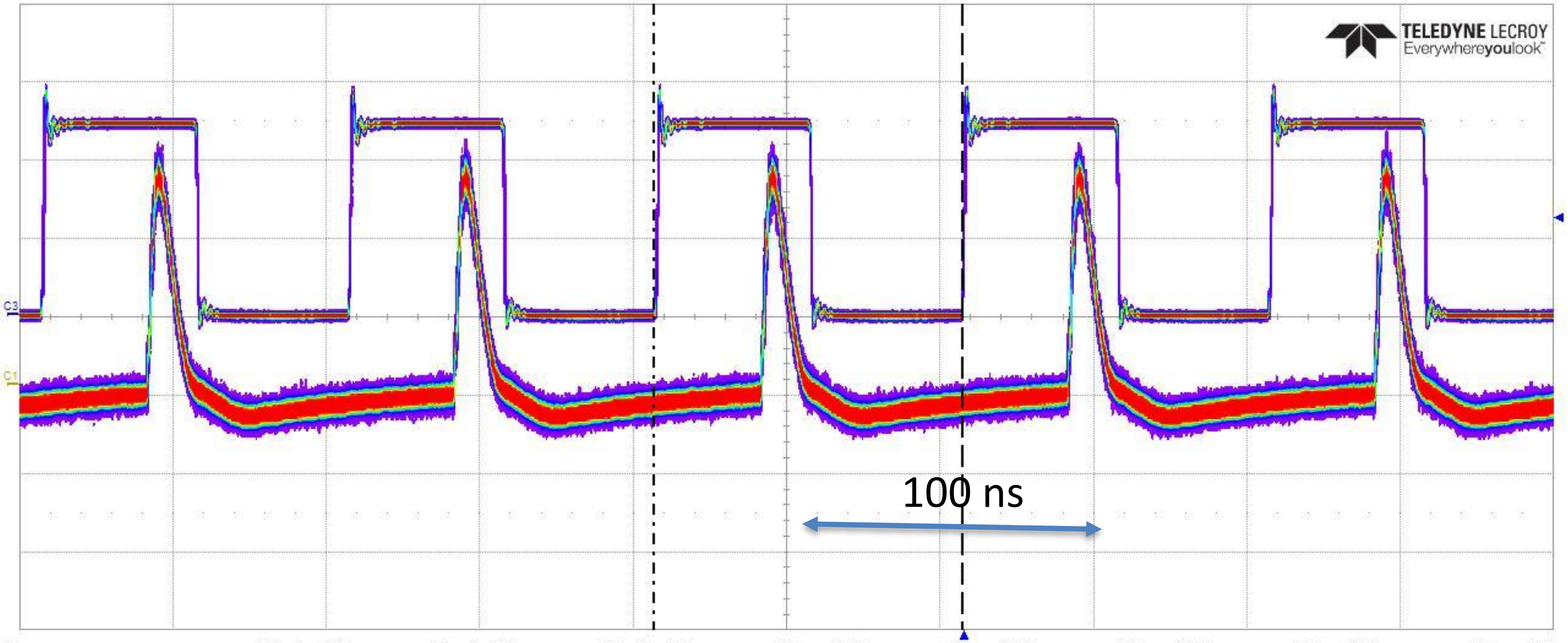
[Test of Ultra Fast Silicon Detectors for Picosecond Time Measurements with a New Multipurpose Read-Out Board]

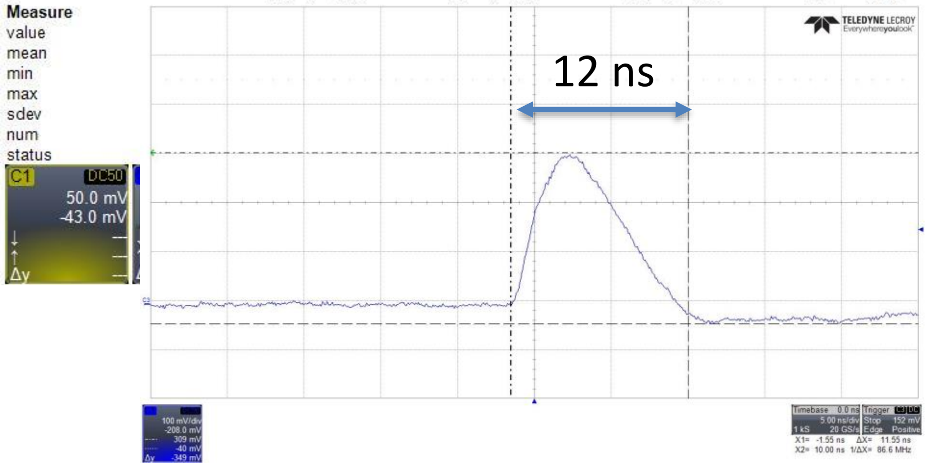


3x3 mm^2 UFSD MIP beam test @ Fermilab



Silicon pulsed with laser at 10 MHz



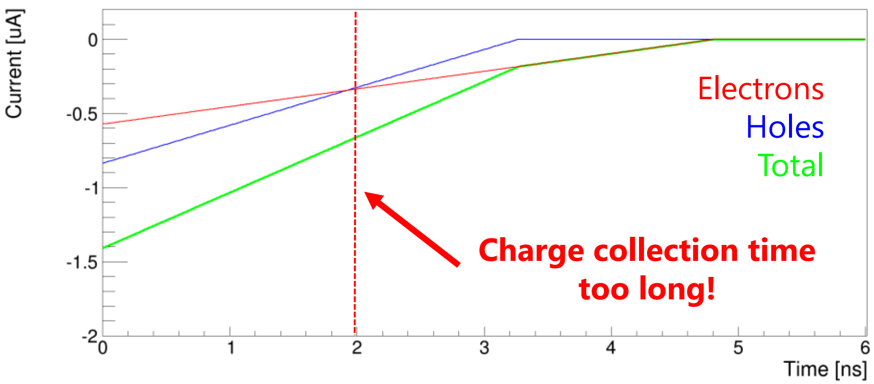


Amplifier with silicon detector fast enough to separate successive sources for eRHIC Linac Ring at 10 MHz

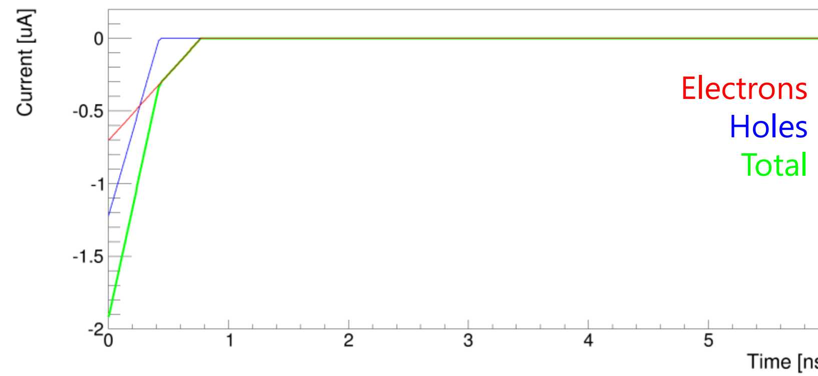
(New proposal for up to 476 MHz)

Fast detector R&D

Diamond sensors are among the fastest available



500 µm scCVD diamond @ 800V



80 µm scCVD diamond @ 500V

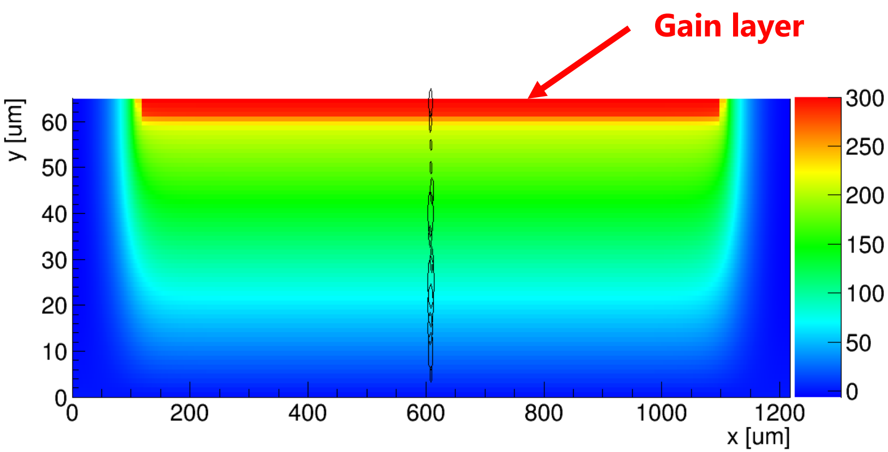
The collection time t_c depends on the thickness *d* $t_c \sim {}^{d}/_{v_s}$

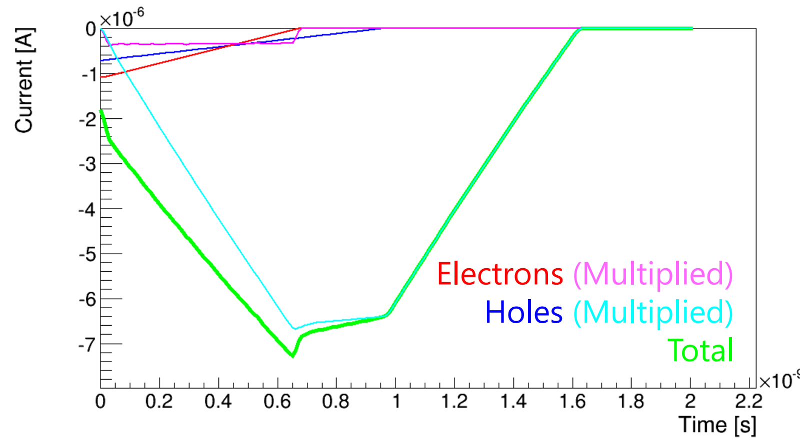
NOTE: the collected charge $Q_c = \int i\,(t)\,dt$ also depends on the thickness *d* $Q_c \sim d$

However, the deep current mainly depends on the carriers' velocities, i.e. electric field $|i_{MAX}| \sim {}^{Q_c}/_{t_c}$

Fast detector R&D

Ultra Fast Silicon Detectors: as fast as diamond, but with a gain layer!



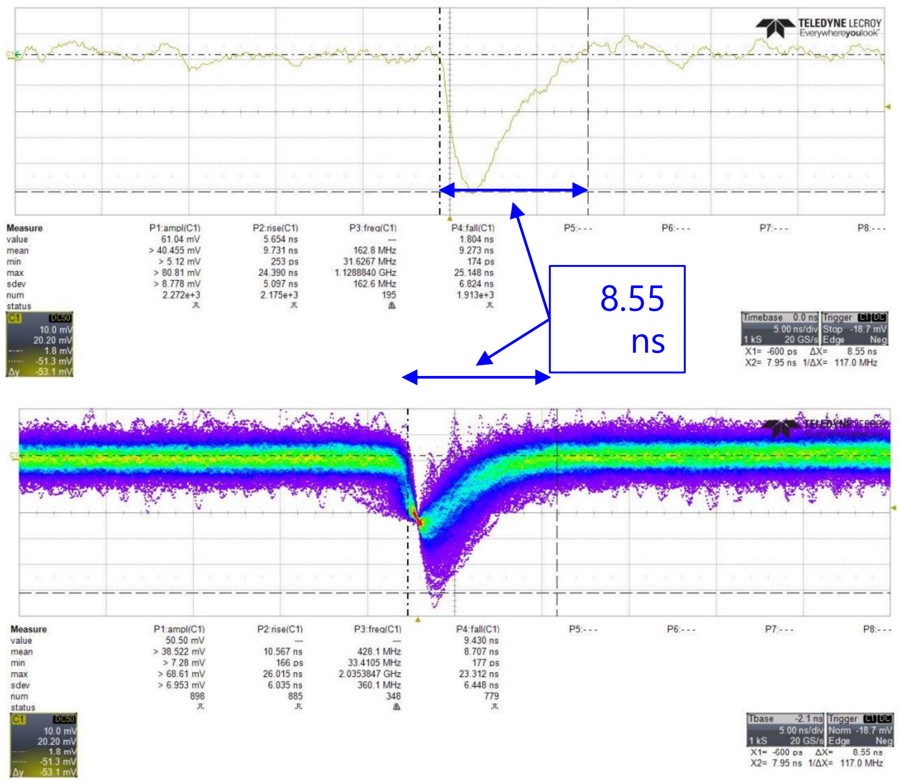


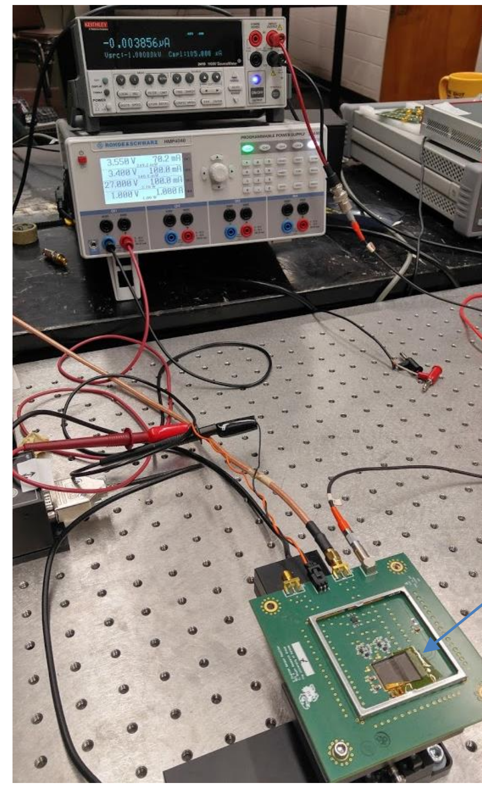
UFSD: 50 µm LGAD

Fast collection time (50 µm thick) and larger signals, thanks to the gain layer

Electronics for very fast detectors

This board was also used to test the performance of a diamond sensor using a Sr^{90} β^- source.



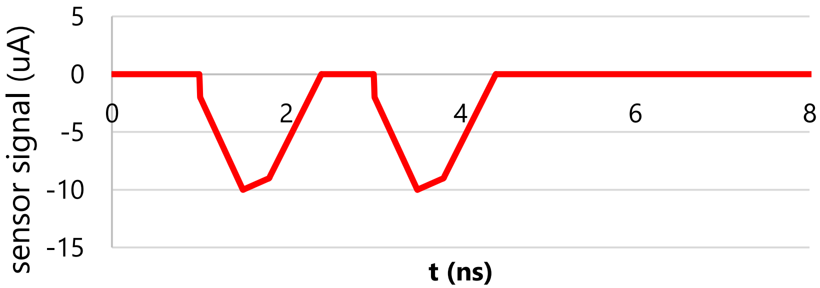


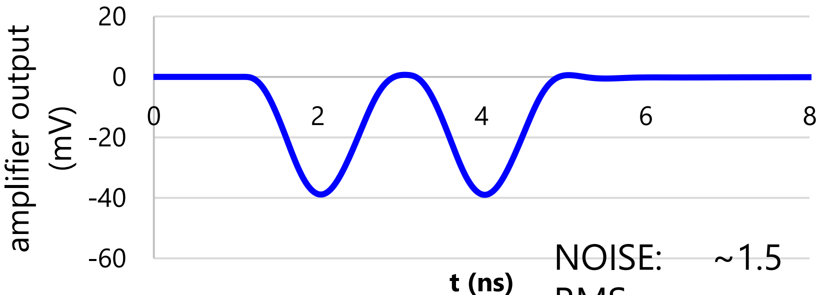
500 µm pcCVD diamond

Fast detector R&D

Simulated results:

UFSD

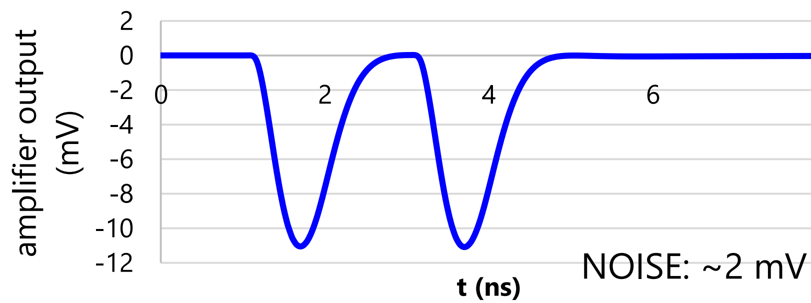




NOISE: ~1.5 mV RMS

SNR ~ 25

80 μm scCVD diamond sensor



NOISE: ~2 mV RMS

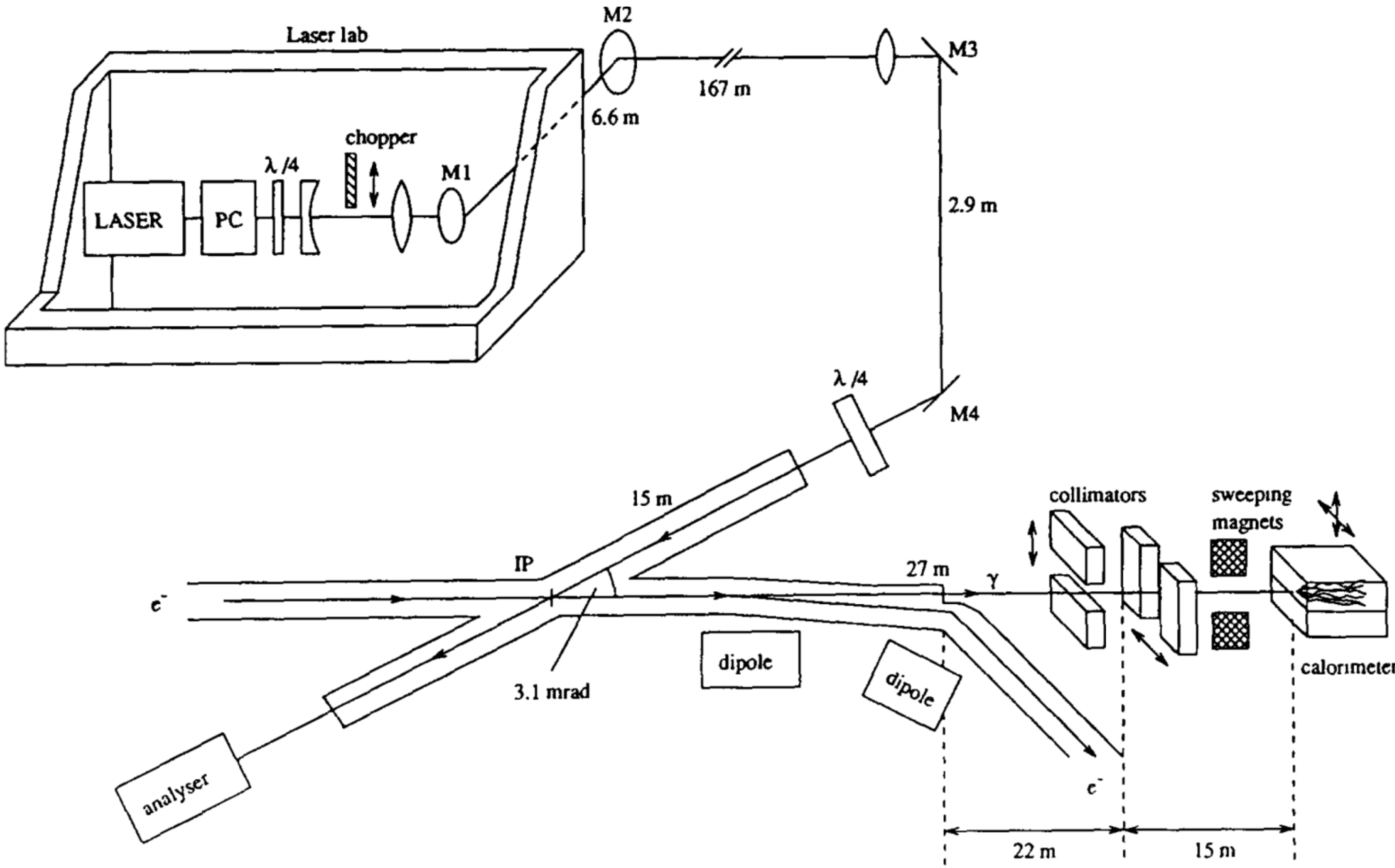
SNR ~ 5

Study by Nicola Minafra

Photon detector

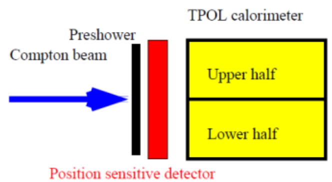
- Same can be done with photon detector
- Pro:
  - Redundant measurement with electron detector
  - Can measure transverse polarization
- Con:
  - More sensitive to synchrotron background

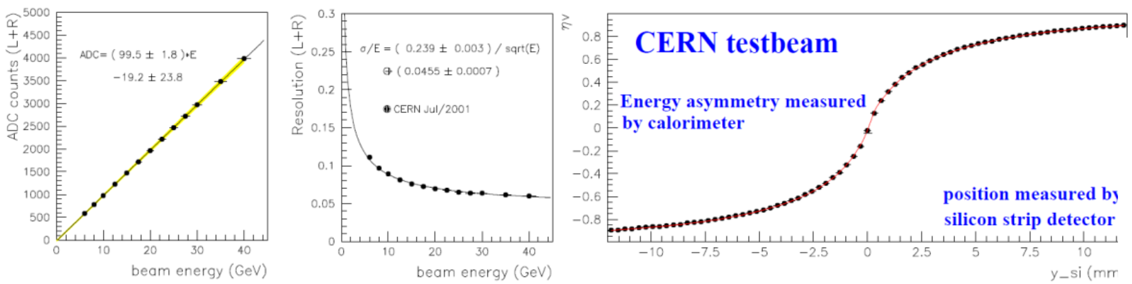
HERA TPOL

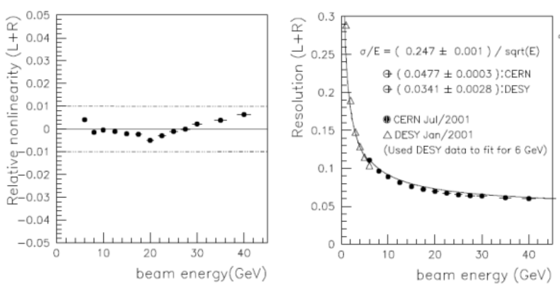

Laser lab
M2
M3
167 m
6.6 m
chopper
λ /4
M1
LASER
PC
2.9 m
λ /4
M4
15 m
collimators
sweeping
magnets
IP
27 m
γ
e-
dipole
3.1 mrad
dipole
calorimeter
analyser
e-
22 m
15 m

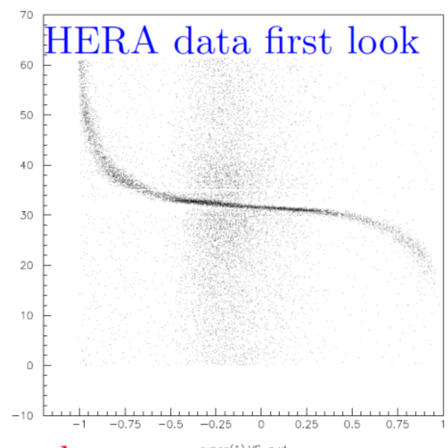
HERA transverse polarimeter

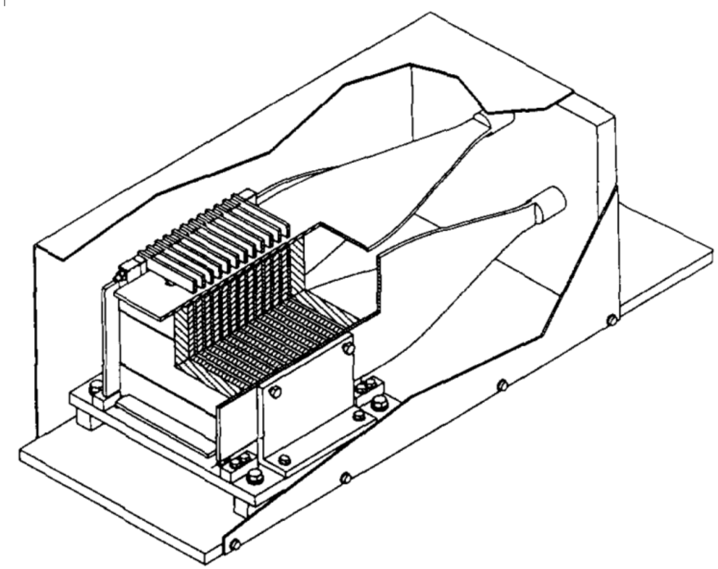
TPOL silicon detector











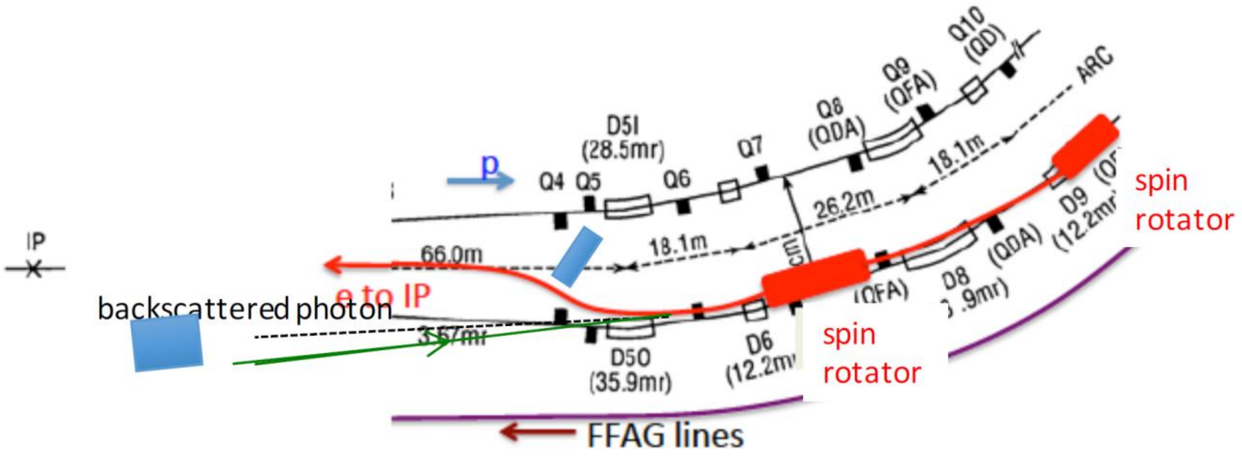
CERN and DESY testbeam results:

Calorimeter response confirmed

$\eta - y$ transformation determined

First results from HERA beam look good

EIC R&D eRD12



- Study for eRHIC Linac Ring
- Found adequate location
- 2 minutes measurement
- Need more refined study

To do list

- First approximation as expected Compton Polarimeter best candidate for polarimetry at high energy polarimetry
- To do :
  - Optimize geometry for HOM
  - Include more realistic geometry of detector, include all apertures
  - Realistic model of halo would be useful for both eRHIC/JLEIC
  - Beam induced background and vacuum design need to be studied
- Possible challenge
  - JLAB top off and eRHIC bunch replacement scheme (maybe consider beam test at photon source like APS or NSLS)

Conclusion

- Compton polarimetry good candidate for precision polarimetry measurements especially at high energy
- Main challenge of EIC is handling the high beam current and repetition rate
- Compton electron diamond detector in Roman Pot seems a workable solution for JLEIC
- Bunch by bunch measurement can be done in a few seconds
- Some detector R&D for the 476 MHz beam structure, current technologies should be ok for 119 MHz JLEIC and 100 MHz eRHIC
- Radiation hard or cheap detector desired : diamond, MAPS
- Photon source : RF pulsed cavity and fast flip R&D needed
- Transverse polarimeter location and feasibility study done. Need to look into full simulation for photon detector for both JLEIC and eRHIC to study backgrounds