The JLEIC electron low Q^2 chicane and Compton polarimeter

INPC 2016
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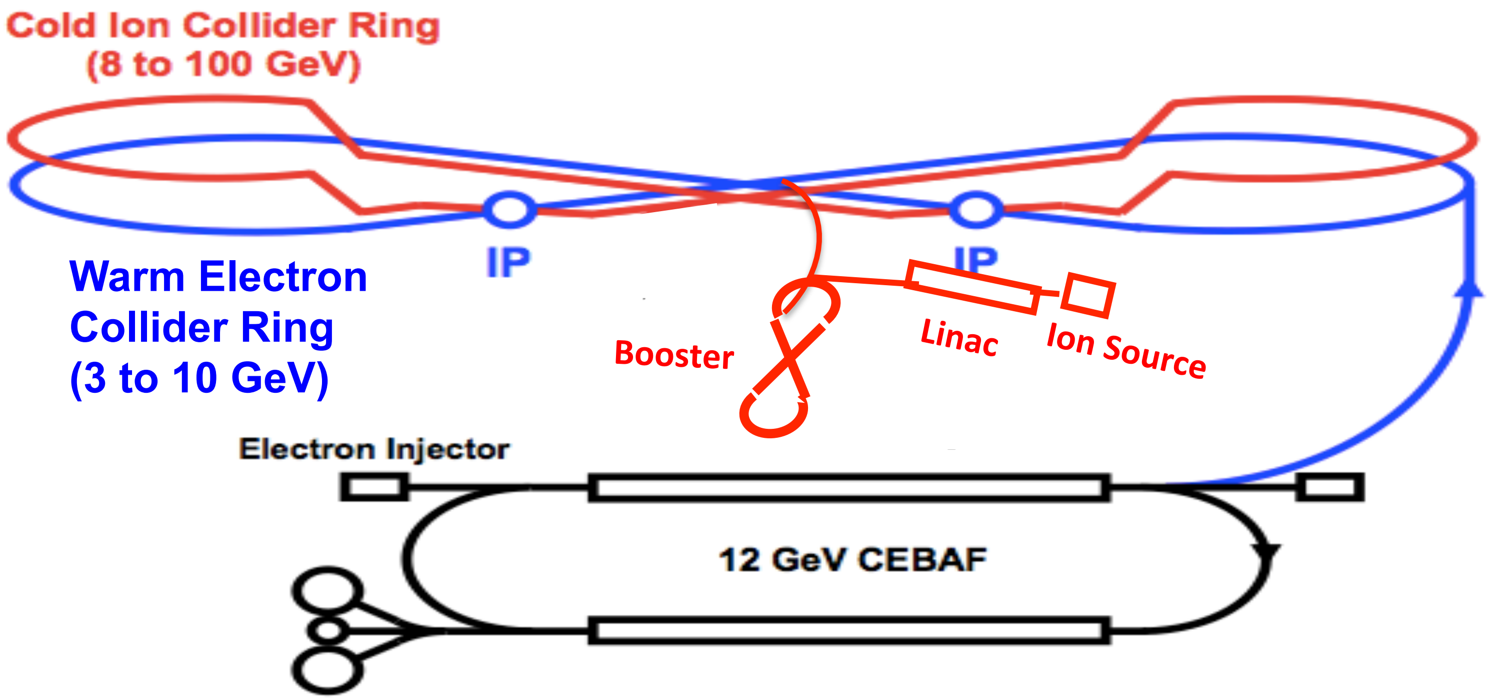
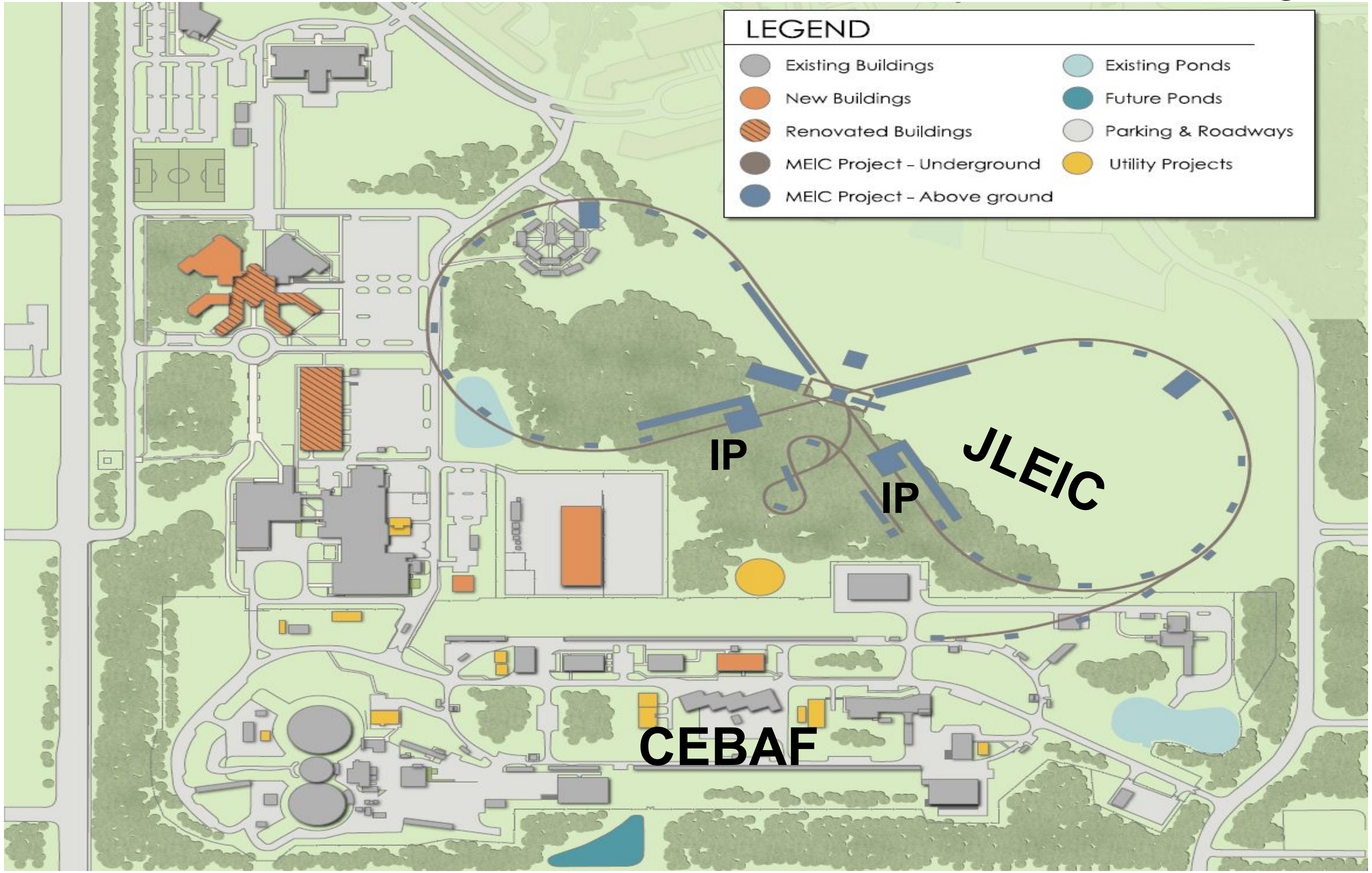
Hall A
Jefferson Laboratory
September 12th 2016

JLEIC Layout



https://arxiv.org/abs/1504.07961

JLAB Campus Layout

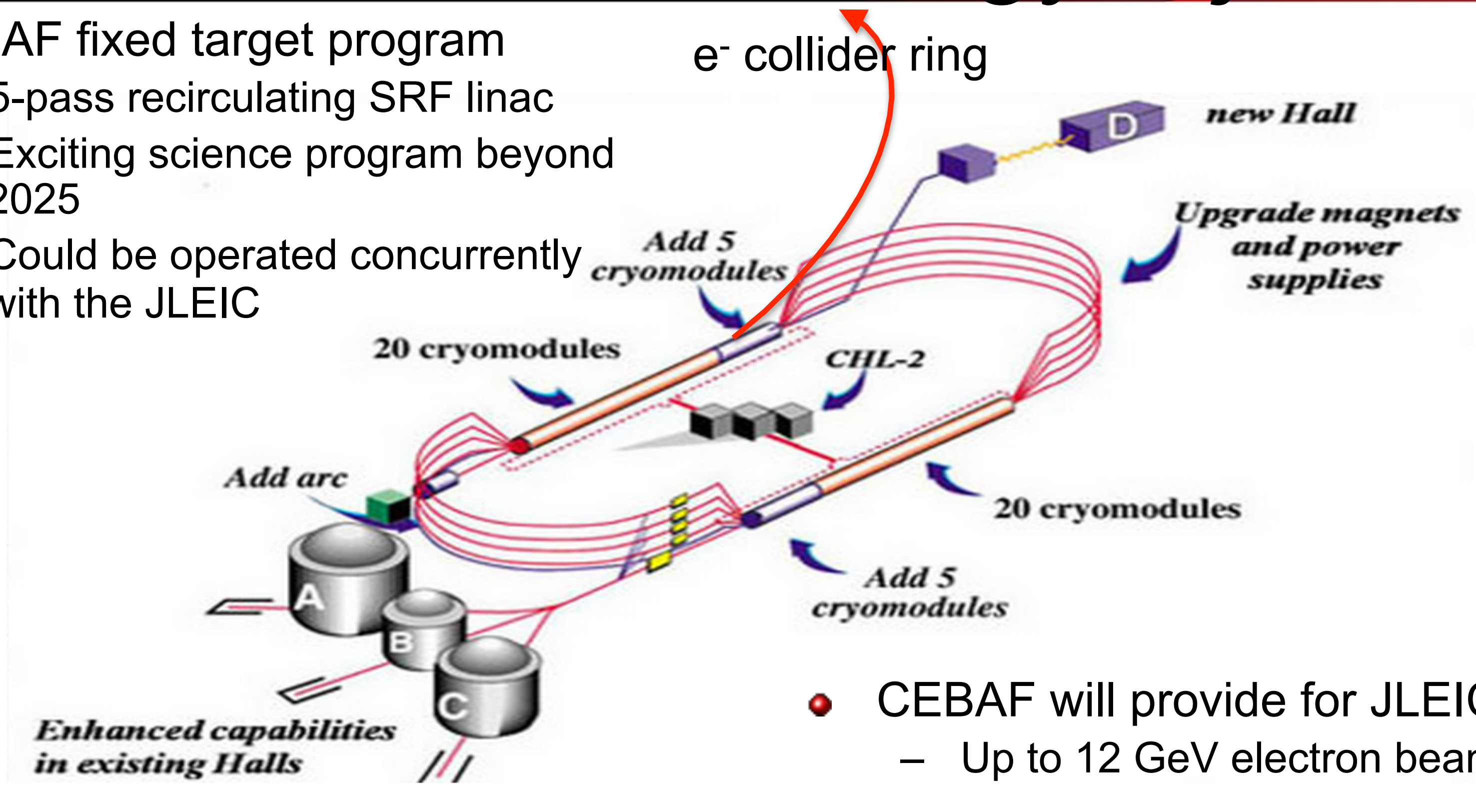


~2.2 km circumference

Tunnel consistent with a 250+ GeV upgrade

CEBAF - Full Energy Injector

- CEBAF fixed target program
  - 5-pass recirculating SRF linac
  - Exciting science program beyond 2025
  - Could be operated concurrently with the JLEIC



- CEBAF will provide for JLEIC
  - Up to 12 GeV electron beam
  - High repetition rate (up to 1497 MHz)
  - High polarization (>85%)

Performance of JLEIC Baseline Design

- For a full acceptance detector

CM energy	GeV	21.9 **(low)**		44.7 **(medium)**		63.3 **(high)**	
		p	*e*	*p*	*E*	*p*	*e*
Beam energy	GeV	**30**	**4**	**100**	**5**	**100**	**10**
Collision frequency	MHz	476		476		159	
Particles per bunch	10^{10}	0.66	3.9	0.66	3.9	2.0	2.8
Beam current	A	**0.5**	**3**	**0.5**	**3**	**0.5**	**0.72**
Polarization	%	>70%	>70%	>70%	>70%	>70%	>70%
Bunch length, RMS	cm	2.5	1.2	1	1.2	2.5	1.6
Norm. emitt., vert./horz.	μm	0.5/0.5	74/74	1/0.5	144/72	1.2/0.6	1152/576
Horizontal and vertical β^*	cm	3	5	2/4	2.6/1.3	5/2.5	2.4/1.2
Vert. beam-beam param.		0.01	0.02	0.006	0.014	0.002	0.013
Laslett tune-shift		0.054	small	0.01	small	0.01	small
Detector space, up/down	m	3.6/7	3/3.2	3.6/7	3/3.2	3.6/7	3/3.2
Hour-glass (HG) reduction		0.89		0.88		0.73	
Lumi./IP, w/HG, 10^{33}	$cm^{-2}s^{1}$	**1.9**		**4.6**		**1.0**	

- For a high(er) luminosity detector

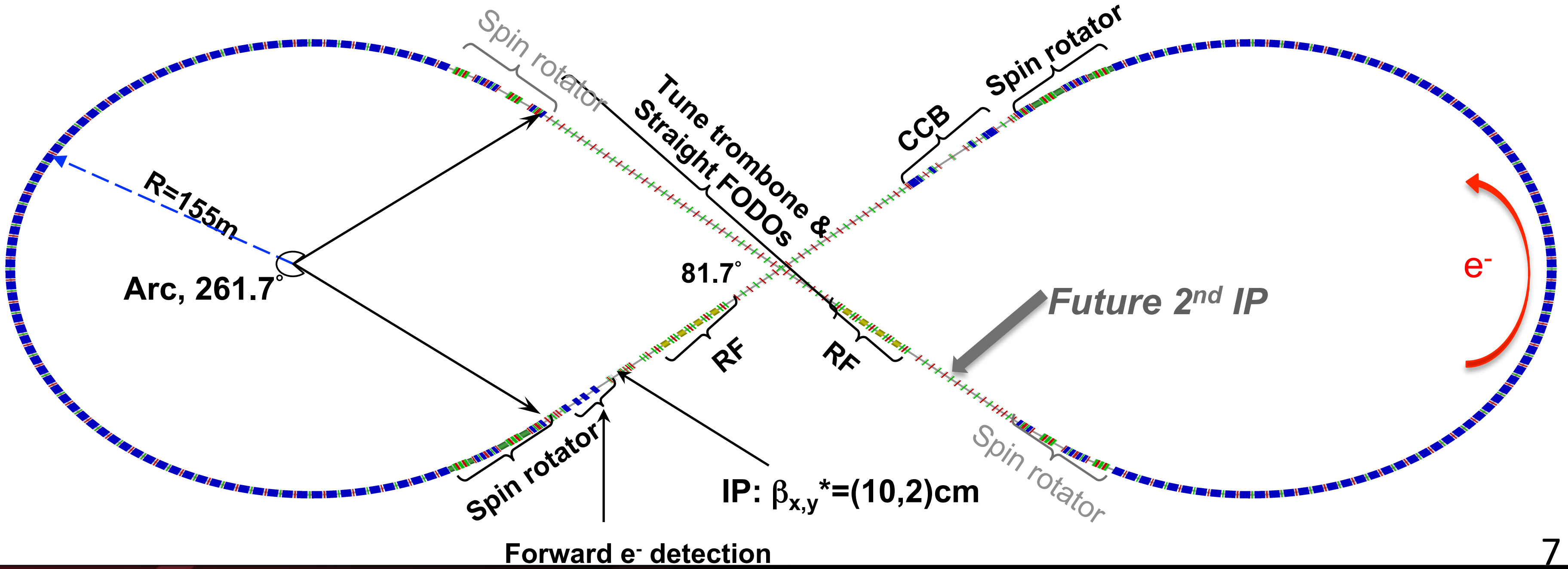
Horizontal and vertical β^*	cm	1.2	2	1.6 / 0.8	1.6 / 0.8	2 /1	1.6 / 0.8
Vert. beam-beam param.		0.01	0.02	0.004	0.021	0.001	0.021
Detector space, up/down	m	±4.5	±3	±4.5	±3	±4.5	±3
Hour-glass (HG) reduction		0.67		0.74		0.58	
Lumi./IP, w/HG, 10^{33}	$cm^{-2}s^{1}$	**3.5**		**7.5**		**1.4**	

Performance of JLEIC Baseline Design

		Electron	Proton	Deuteron	Helium	Carbon	Calcium	Lead
		e	P	d	$^{3}He^{++}$	$^{12}C^{6+}$	$^{40}Ca^{20+}$	$^{208}Pb^{82+}$
Beam energy	GeV	5	100	50	66.7	50	50	39.4
Particles/bunch	10^{10}	3.9	0.66	0.66	0.33	0.11	0.033	0.008
Beam current	A	3	0.5	0.5	0.5	0.5	0.5	0.5
Polarization		> 70%	> 70%	> 70%	> 70%	-	-	-
Bunch length, RMS	cm	1.2	1	1	1	1	1	1
Norm. emit., horz./vert.	µm	144/72	1/0.5	0.5/0.25	0.7/0.35	0.5/0.25	0.5/0.25	0.5/0.25
β^*, hori. & vert.	cm	2. 6/1.3*1 (1.6/0.8)	4/2 (1.6/0.8)	4/2 (1.6/0.8)	4/2 (1.6/0.8)	4/2 (1.6/0.8)	4/2 (1.6/0.8)	5/2.5 (1.6/0.8)
Vert. beam-beam parameter		0.014*2 (0.02)	0.006 (0.004)	0.006 (0.004)	0.006 (0.004)	0.006 (0.004)	0.006 (0.004)	0.005 (0.004)
Laslett tune-shift			0.01	0.041	0.022	0.041	0.041	0.041
Detector space, up & down stream	m	3.2 / 3 (3)	7 / 3.6 (4.5)					
Hour-glass (HG) reduction factor			0.89 (0.74)	0.89 (0.74)	0.89 (0.74)	0.89 (0.74)	0.89 (0.74)	0.89 (0.74)
Lumi./IP/**nuclei**, w/HG correction	10^{33} $cm^{-2}s^{-1}$		4.6 (7.5)	4.6 (9.2)	2.2 (3.7)	0.77 (1.37)	0.23 (0.38)	0.04 (0.08)
Lumi./IP/**nucleon**, w/HG correction,	10^{33} $cm^{-2}s^{-1}$		4.6 (7.5)	9.2 (15.1)	6.6 (11.1)	9.2 (15.1)	9.2 (15.1)	7.8 (17.3)

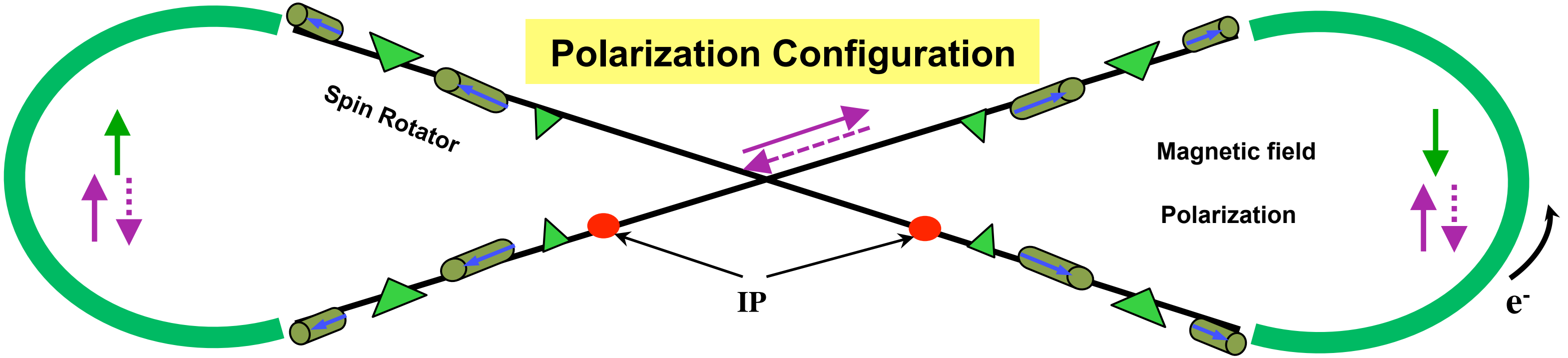
Electron Collider Ring

- Electron collider ring design
  - Circumference of **2154.28** m = 2 x **754.84** m arcs + 2 x **322.3** m straights
  - **Reuses PEP-II** magnets, vacuum chambers and RF
- Beam characteristics
  - **3A** up to 6.95 GeV, **0.72A** at 10 GeV
  - Synchrotron radiation power density **10kW/m**
  - Total power **10 MW**

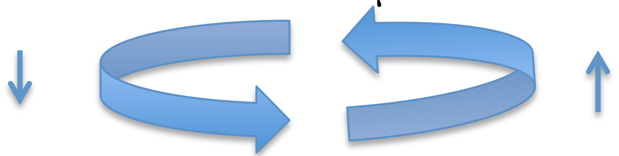


Electron Polarization

- Electron polarization design:
  - Vertically polarized (>85%) electron beam from CEBAF
  - Vertical polarization in the arcs and longitudinal at collision points
  - Spin rotator for the polarization rotation
  - Compton polarimeter provides non-invasive measurements of polarization
  - Average electron polarization reaches above 70%



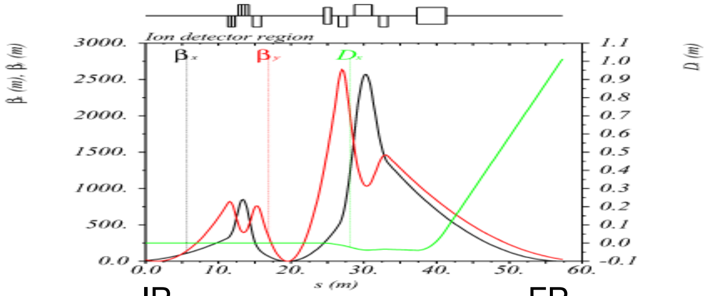
Two macro bunches of 2.3 μs = 1700 x 1.33 ns

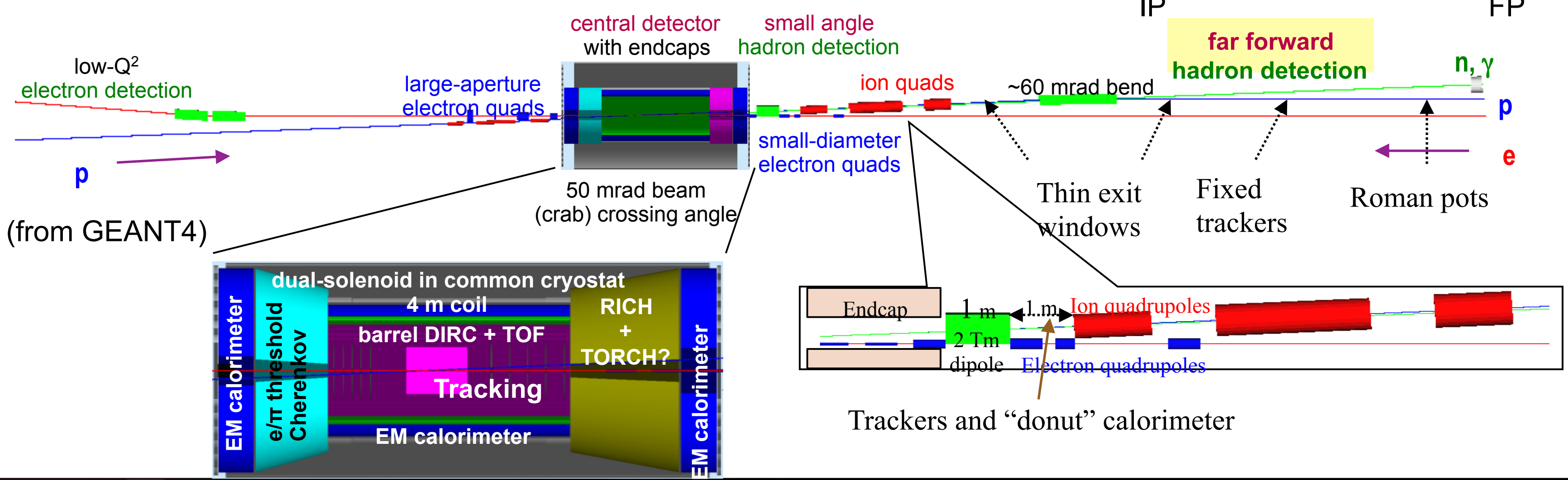


Energy (GeV)	3	5	7	9	10
Estimated Pol. Lifetime (hours)	66	5.2	2.2	1.3	0.8

The low Q^2 chicane

- Dipole to tag electrons associated with quasireal photons

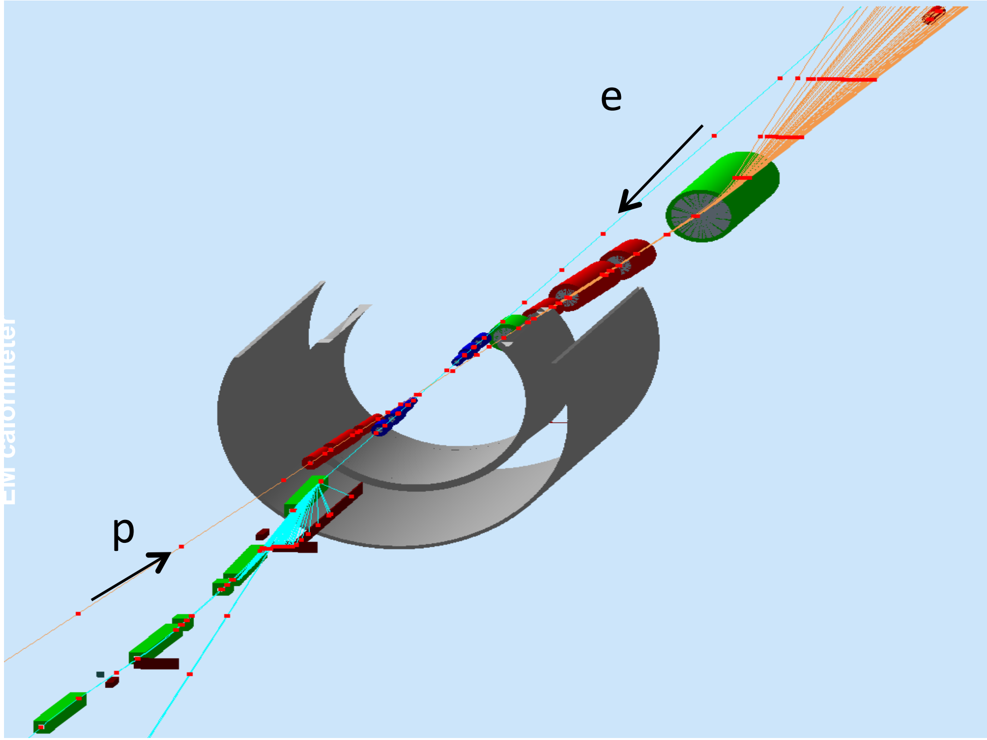




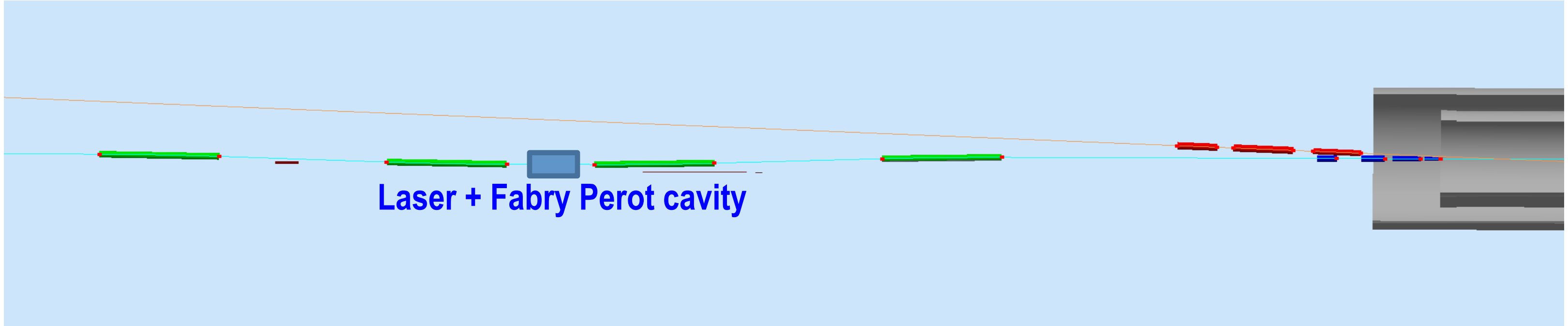
Low Q^2 tagger

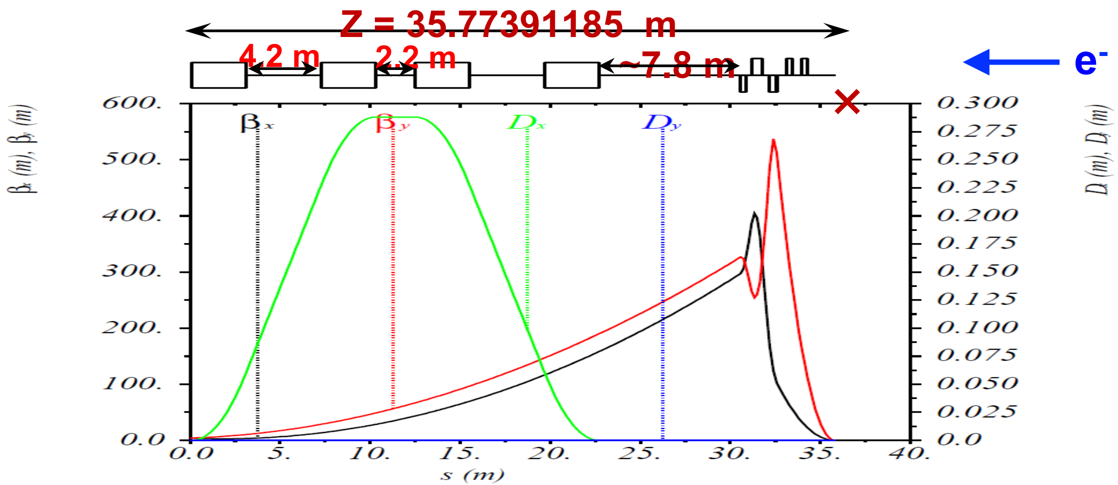
Low-Q^2 electron tagger for quasi-real photoproduction

- C magnet
- Side window with long tracker (scintillator array or scintillating fiber)
- Possible close detector : silicon or diamond strip detector in roman pot for very low energy photon
- Designed momentum resolution of 10^{-3} on electron momentum



Low Q^2 electron chicane





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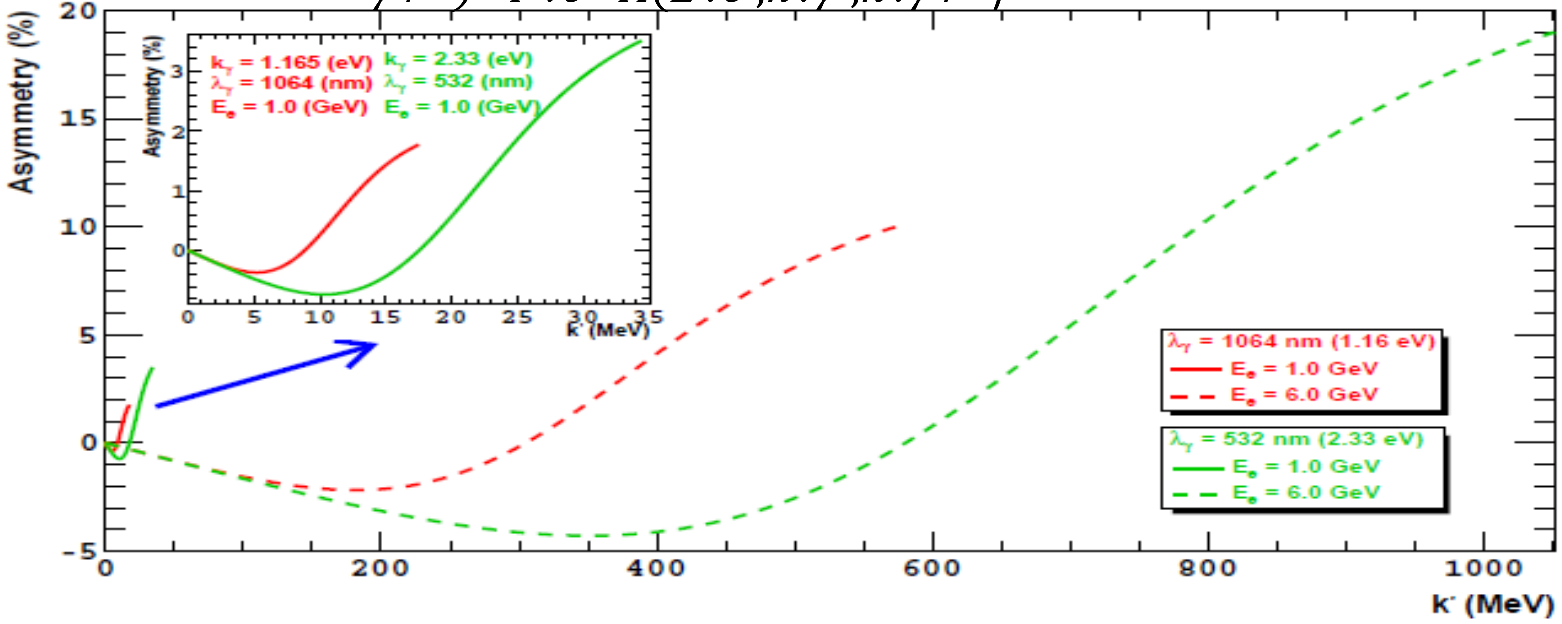
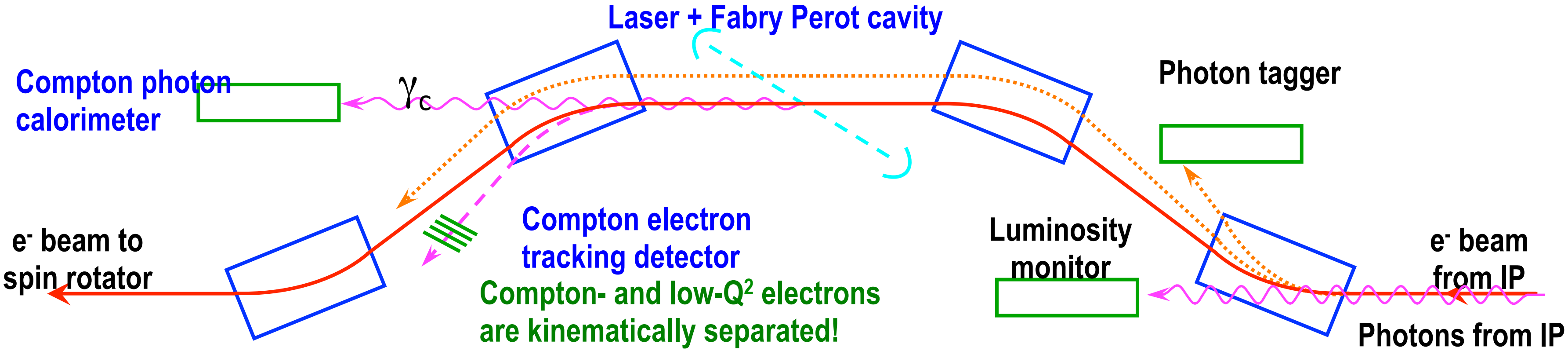
Compton asymmetry

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

$$\frac{N^{+} - N^{-}}{N^{+} + N^{-}}(E_e, k_\gamma, k_\gamma') = P_e * A(E_e, k_\gamma, k_\gamma')$$



Compton polarimeter



Goal is to push the uncertainty of the polarimeter towards 1 % or better

Challenges of EIC Compton polarimetry :

Higher energy = more synchrotron radiation at 11 GeV

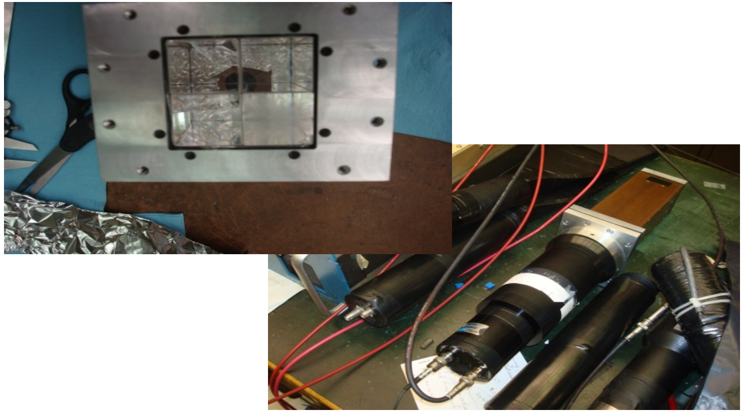
Handle the higher currents ranging from 720 mA up to 3 A

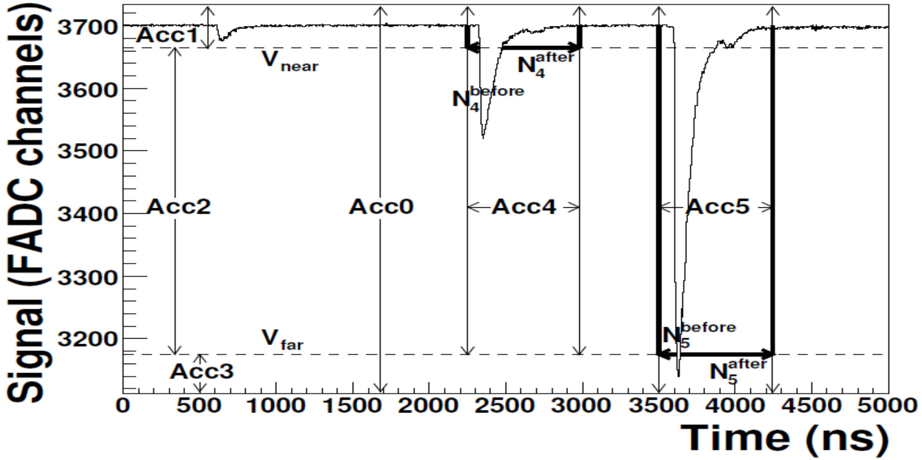
eRD15 : EIC R&D funded to study Compton Electron detector Polarimetry at JLEIC

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

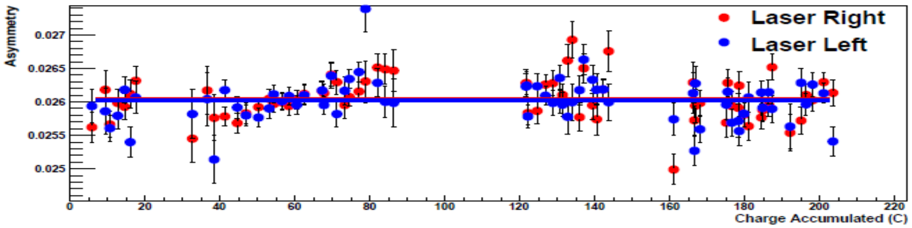
Compton polarimeter photon detector

- Lead tungstate calorimeter instead of GSO for 11 GeV operation
- 2x2 matrix couple to one PMT
- FADC Integrating method to be tested at high energy

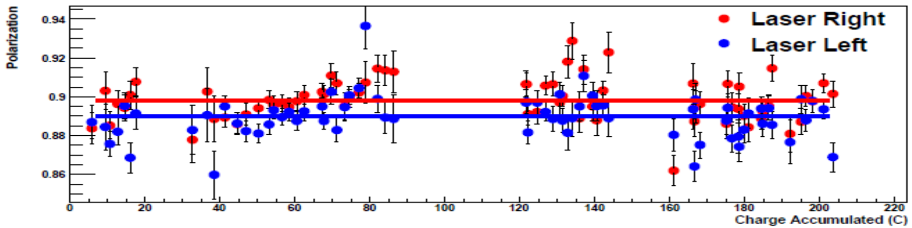




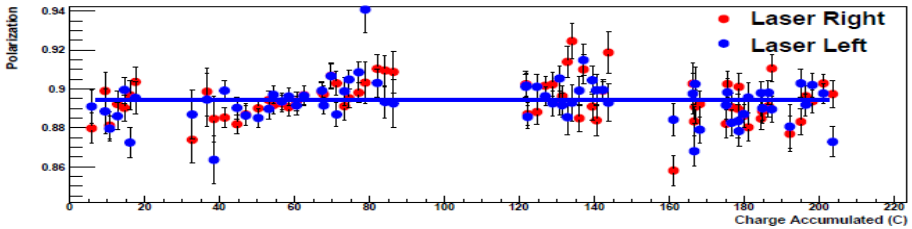
Happex III results (2 GeV)



(a)



(b)



(c)

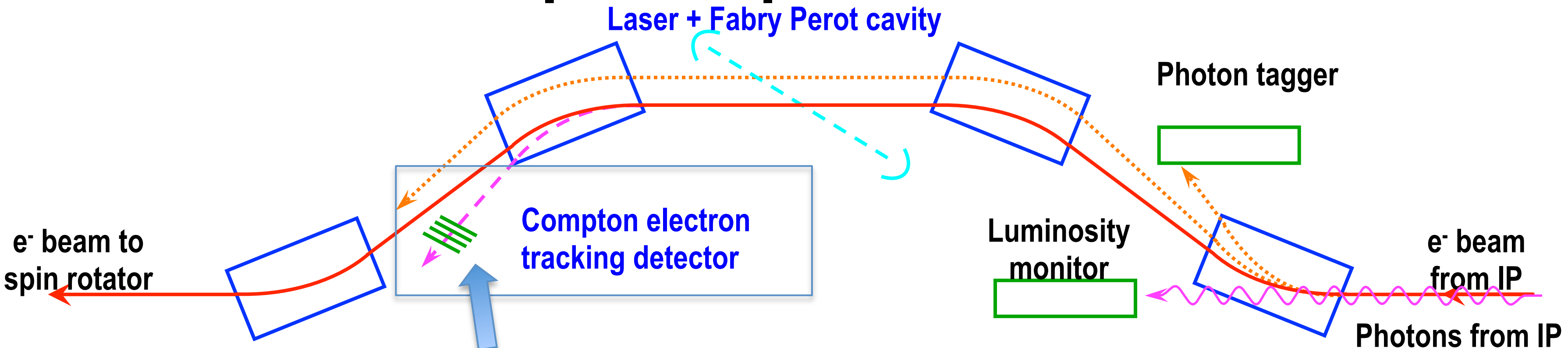
Friend
Nucl.Instrum.Meth. A676 (2012) 96-105

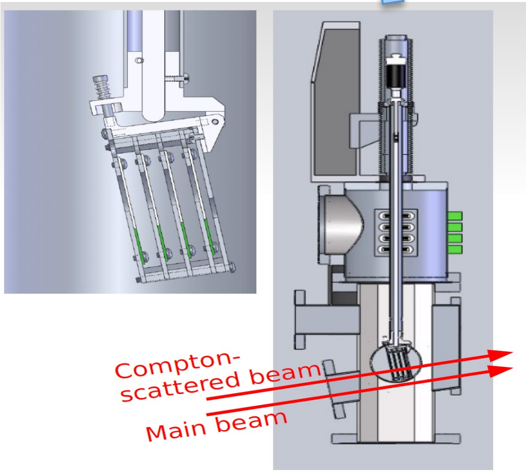
Friend Phd Thesis CMU 2012

Systematic Errors	
Laser Polarization	0.80%
Analyzing Power:	
Non-linearity	0.3%
Electron Energy Uncertainty	0.1%
Collimator Position	0.05%
MC Statistics	0.07%
Total on Analyzing Power	0.33%
Gain Shift:	
Background Uncertainty	0.31%
Pedestal Uncertainty	0.20%
Total on Gain Shift	0.37%
Total	0.94%

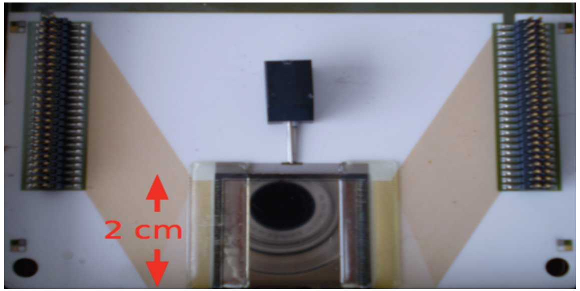
Pe =89.41%

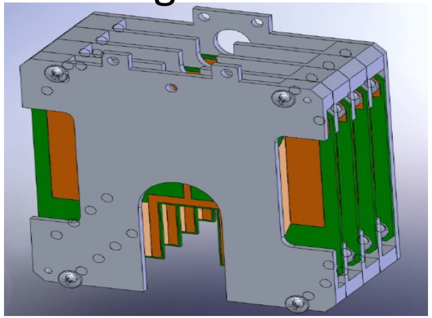
Compton polarimeter



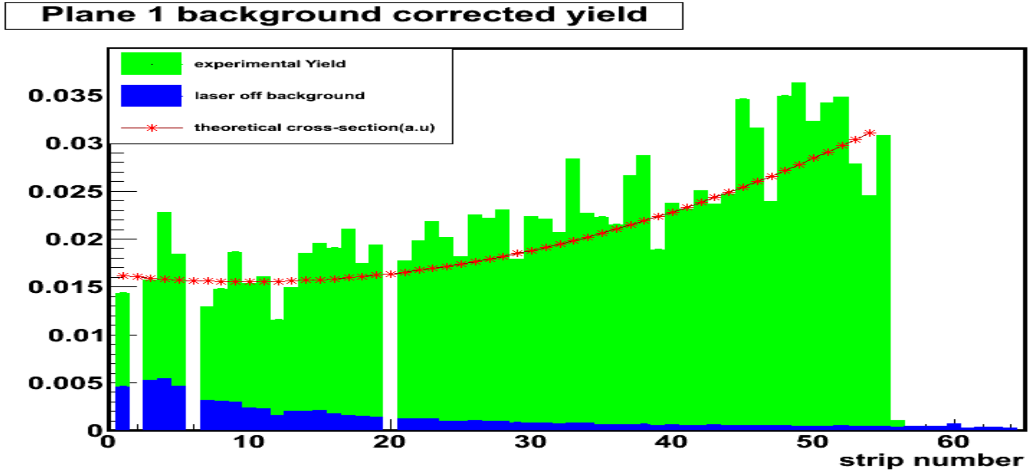


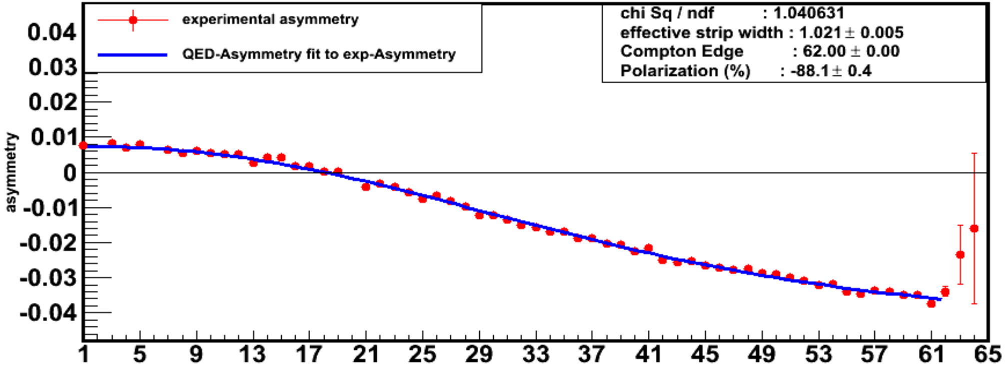
- Silicon or diamond strip option
- About 200 to 250 strips 250 μm width
- 5 cm length to catch zero crossing





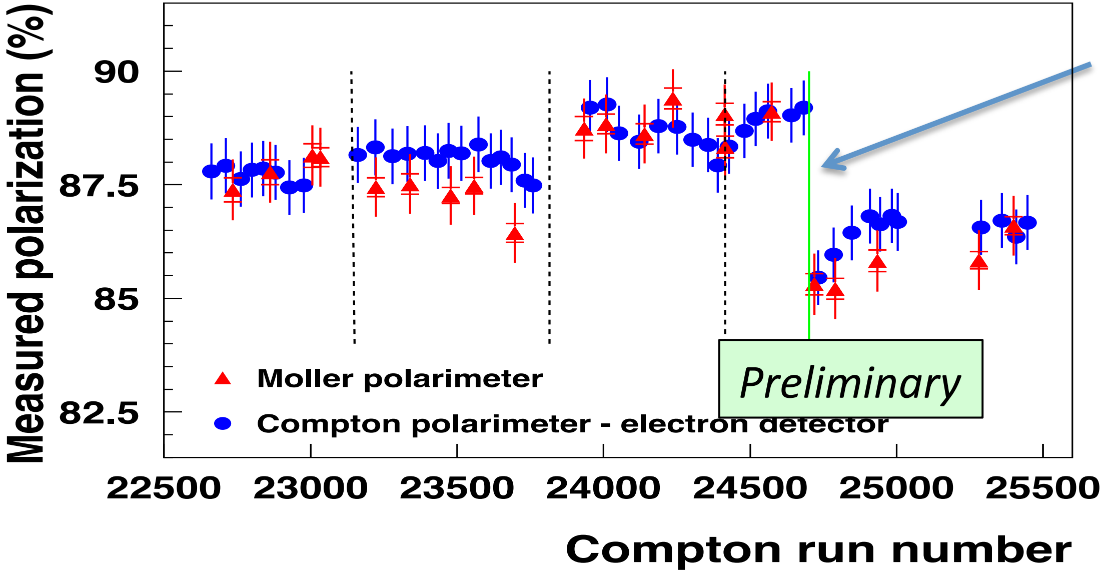
Compton polarimeter electron detector





Qweak measurement (1.1 GeV)

Q-Weak Run 2 – November 2011 to May 2012



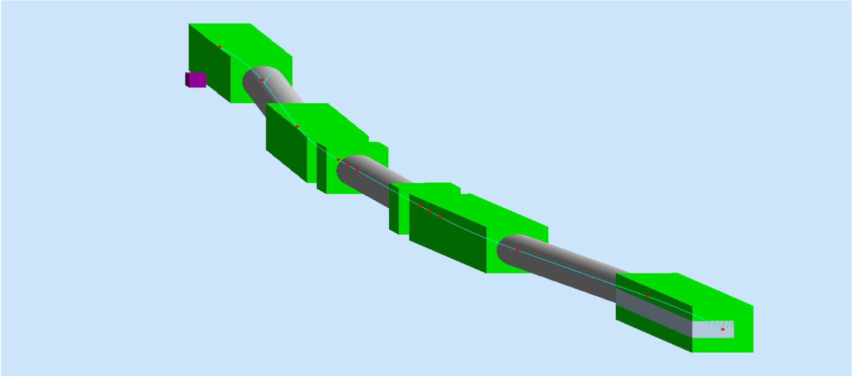
Photocathode re-activation

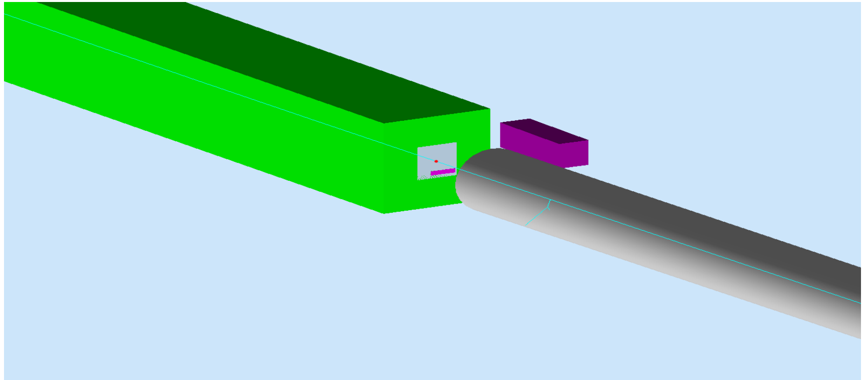
P_{Moller} +/- stat (inner) +/- point-to-point systematic (0.54%)

$P_{Compton}$ +/- stat +/- preliminary systematic (0.6%)

0.64% normalization unc. not shown

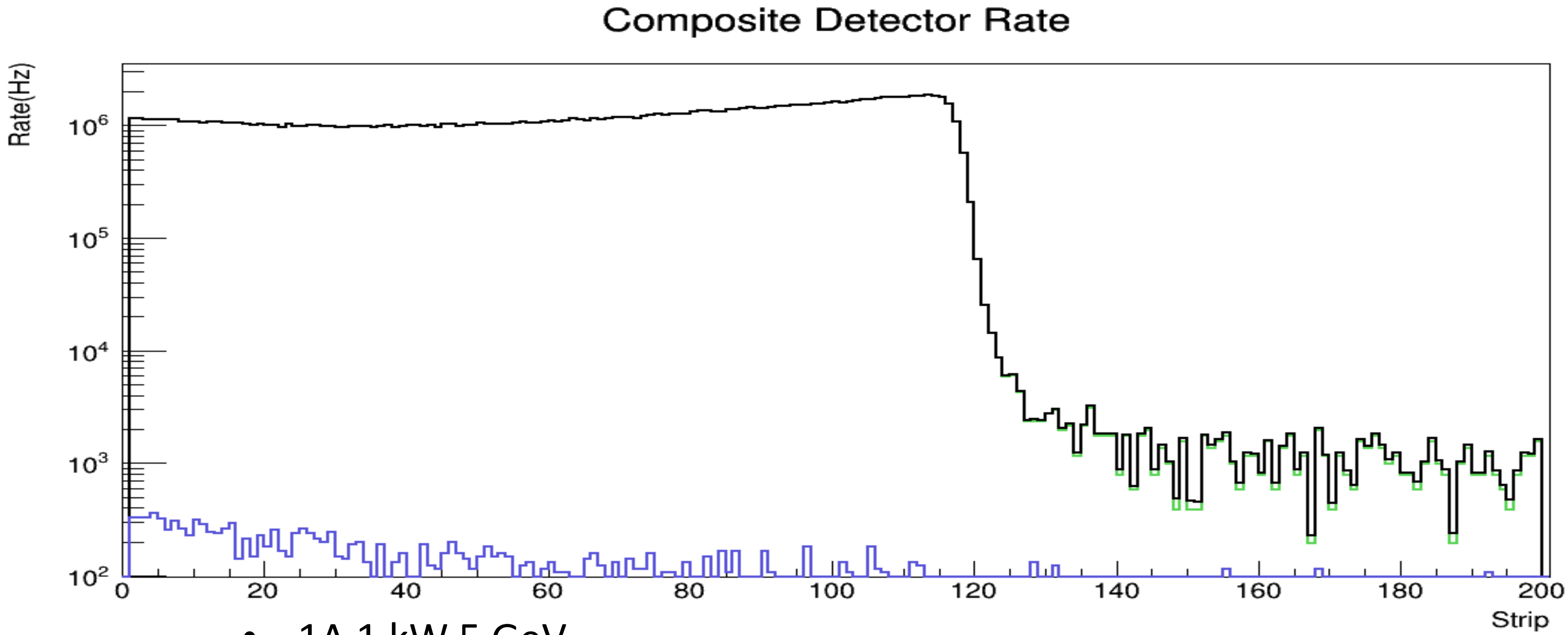
Beamline Geometry in GEMC





- GEMC : Geant4 Monte Carlo is a front end to Geant4
- Beam pipe implemented
- All presentation simulation results only done with the chicane to speed up the studies
- Installed on batch computer farm to run high statistics and full setup

Signal to background with GEMC



- 1A 1 kW 5 GeV
- All Geant4 processes, chicane only
- Signal is consistent with Geant3 simulation
- Can simulate with full detector and IR
- Need to implement beam

Measurement 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

Typical measurement takes less than 1 second even at 10 Watts of laser power
Baseline is no cavity unless additional background dominates

Conclusion

- The low Q^2 chicane location was integrated in the initial JLEIC design for photoproduction studies
- A Compton polarimeter naturally find its place in the Low Q^2 chicane with detection of photon and electron
- Electron beam polarization measurement at 1% level achieved for JLab 6 GeV
- Studies of detector at 11 GeV and development to handle the EIC higher current
  - Simulation work on going to optimize the design and background aiming at 1% accuracy
  - R&D on electron detector and electronics for fast radiation hard Compton electron detector in Roman Pot

Electron-Ion Collider User Group Satellite Meeting
Adelaide Convention Centre, L2 Meeting Room (Plaza Level)
Monday, September 12 from 5:45 to 7:00 pm
Science And Status Of The Electron Ion Collider In The US
Prof Abhay DESHPANDE (Stony Brook University)
Hall L 13:35 Friday September 16th 2016

Backup

TOTEM detectors

- Diamond detector

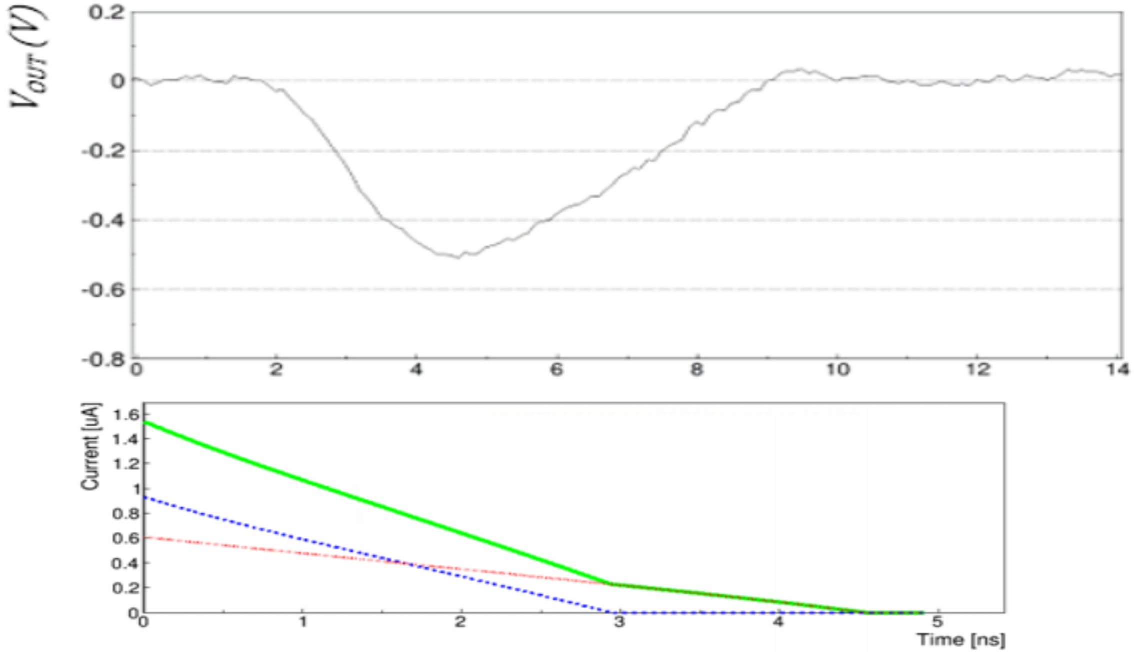
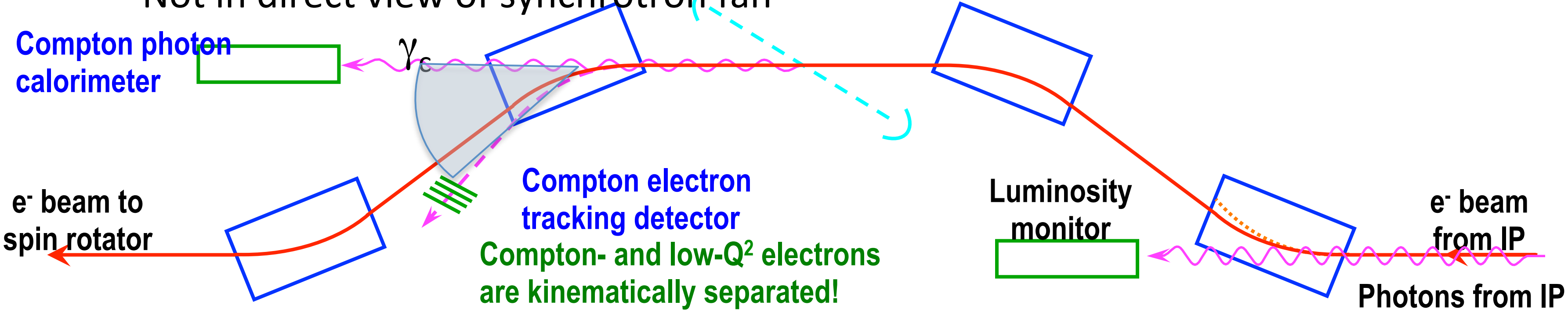


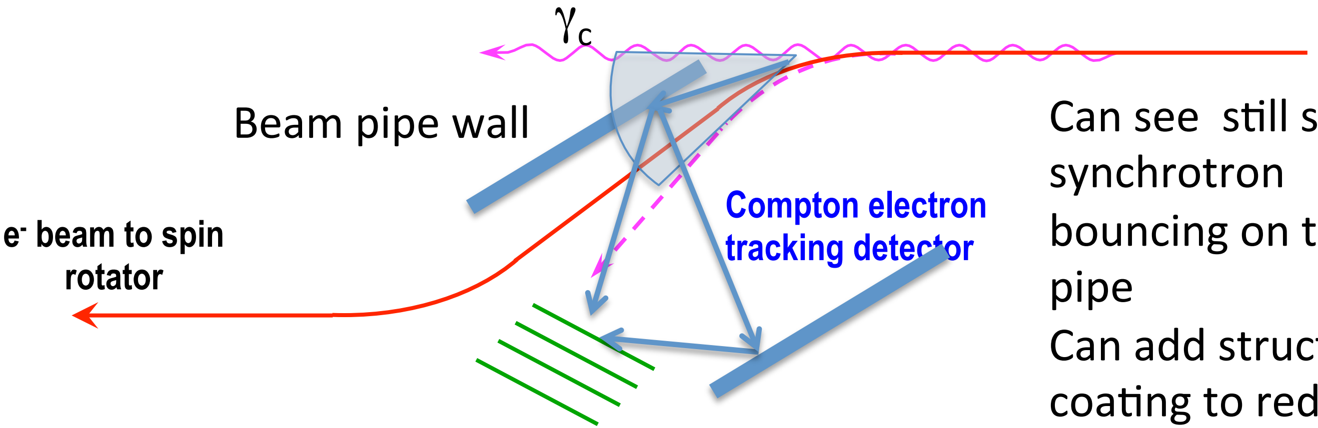
Figure 4.4: *Signal produced by a MIP passing through a 500 μm diamond simulated using Weightfield2 [67]. The red dotted line represents electrons, the blue dashed line is for holes and the green solid line is the sum of the two contributions.*

- Current TOTEM detector and electronics should accommodate eRHIC need to separate the different source
- Polarimetry only needs moderate timing resolution : will test with amplifier

Synchrotron radiation

Not in direct view of synchrotron fan



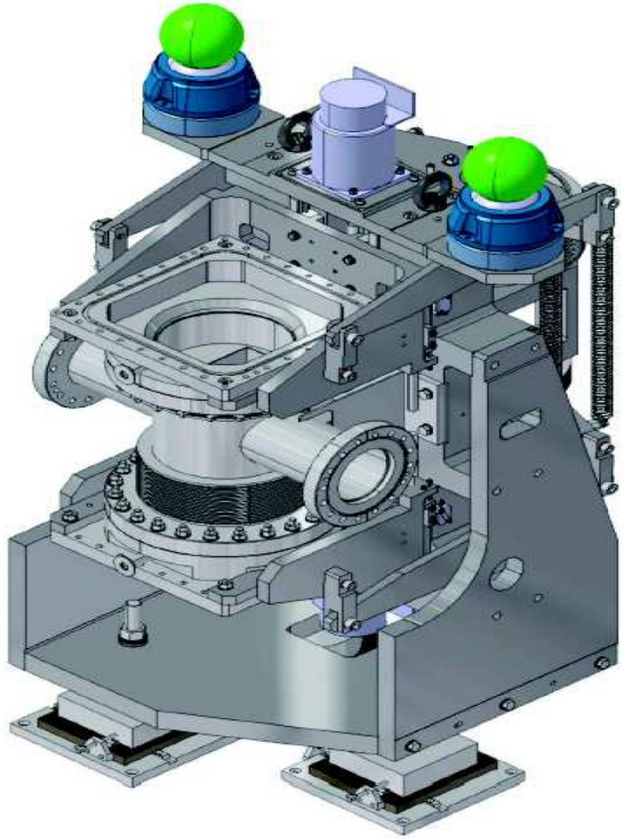


Can see still see synchrotron bouncing on the beam pipe

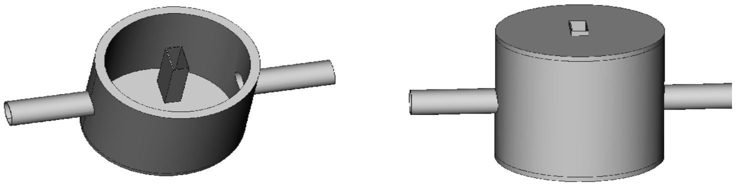
Can add structure and coating to reduce it

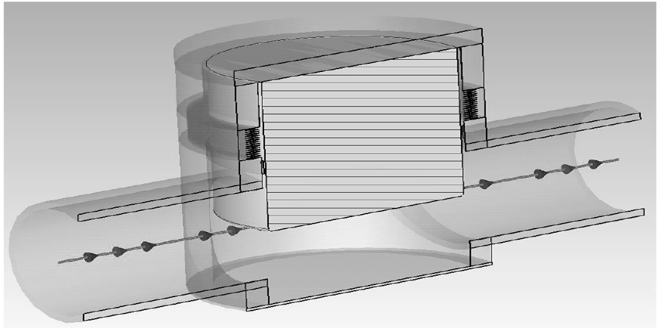
Roman pots from TOTEM

- For small angle detection
- Two chambers
- Thin window
- Can be moved in and out from beam
- Typical 10 to 15 sigma
- Up to 4-5 sigma in optimal places
- Might work for electron side at both JLEIC and eRHIC to be studied



Wakefield progress





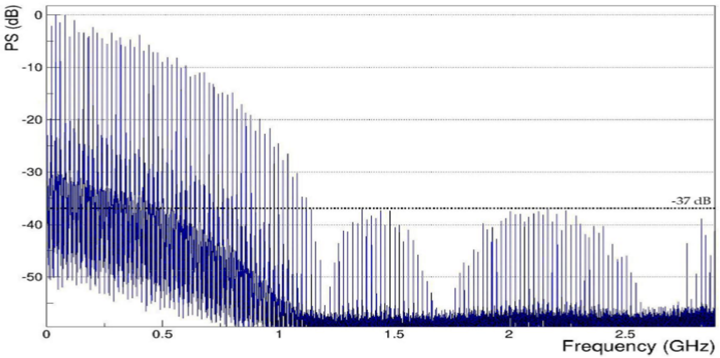


Figure 2.1: *LHC Power spectrum, measured before LS1 [33]. The power spectrum is more than* 37 dB *attenuated above* ∼ 1.2 GHz.

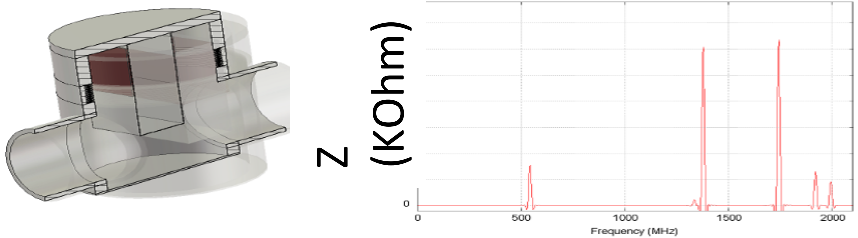


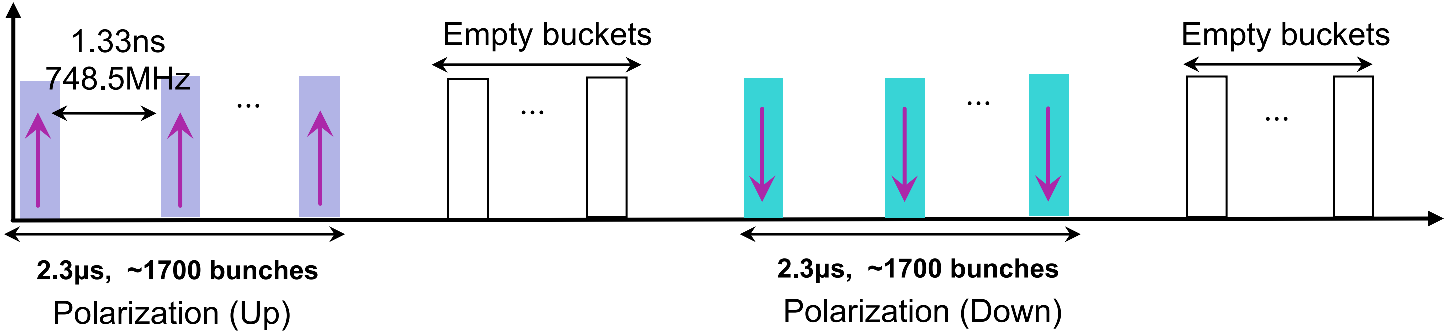
Figure 2.2: *Before LS1 all Totem Roman Pots were box shaped (left). The empty space between the RP and the flange resonate at low frequency (*∼ 500 MHz*) as visible in the simulated longitudinal impedance without ferrites (right).*

Manpower

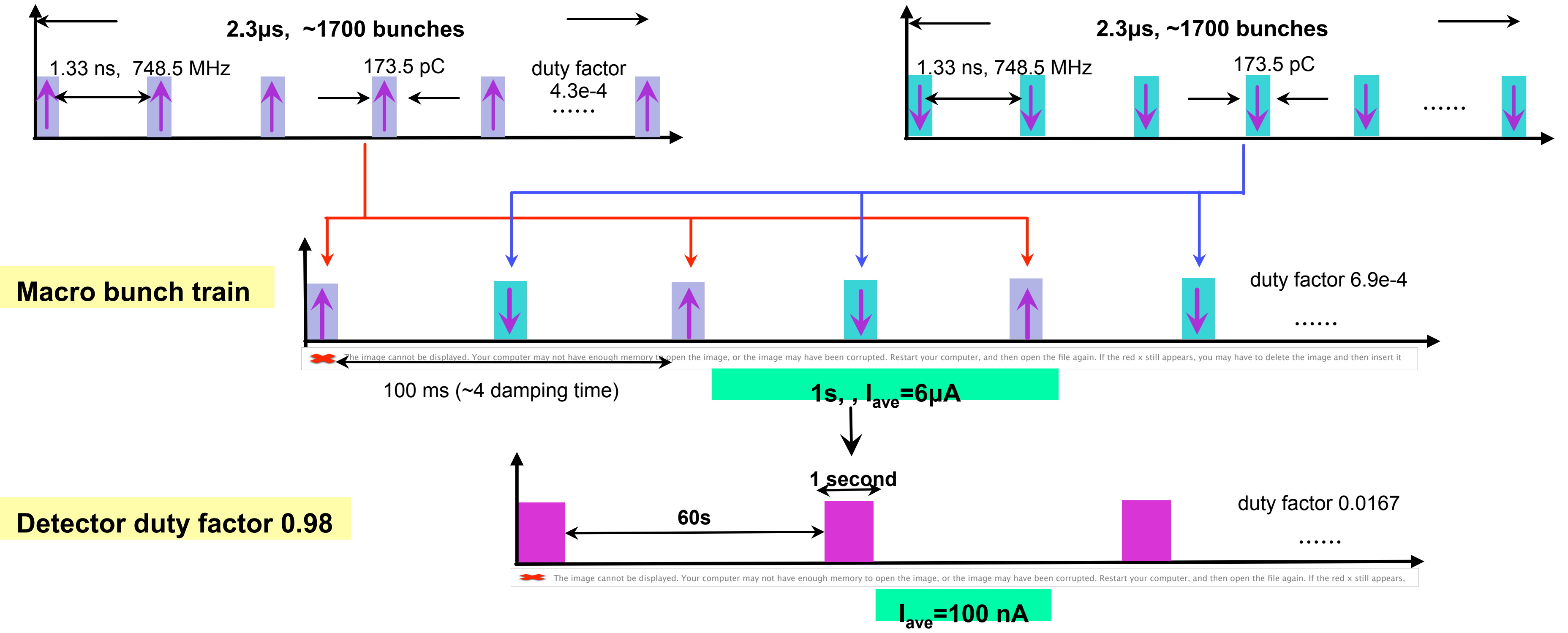
Individual	Institution	Task
Alexandre Camsonne	Jefferson Lab	Wakefield, general, postdoc supervision
David Gaskell	Jefferson Lab	Geant3, laser system, postdoc supervision
Joshua Hoskins	U. Manitoba	GEMC full simulation
Michael Sullivan	SLAC	Synchrotron
Haipeng Wang	Jlab SRF	Wakefield
Robert Rimmer	JLAB SRF	Wakefield
Christophe Royon	Kansas U.	Detector, electronics, Wakefield
Nicola Minafra	Kansas U.	Detector, electronics, Wakefield
Michael Murray	Kansas U.	Detector, electronics, Wakefield

Bunch Structure In Collider Ring

bunch train & polarization pattern in the collider ring

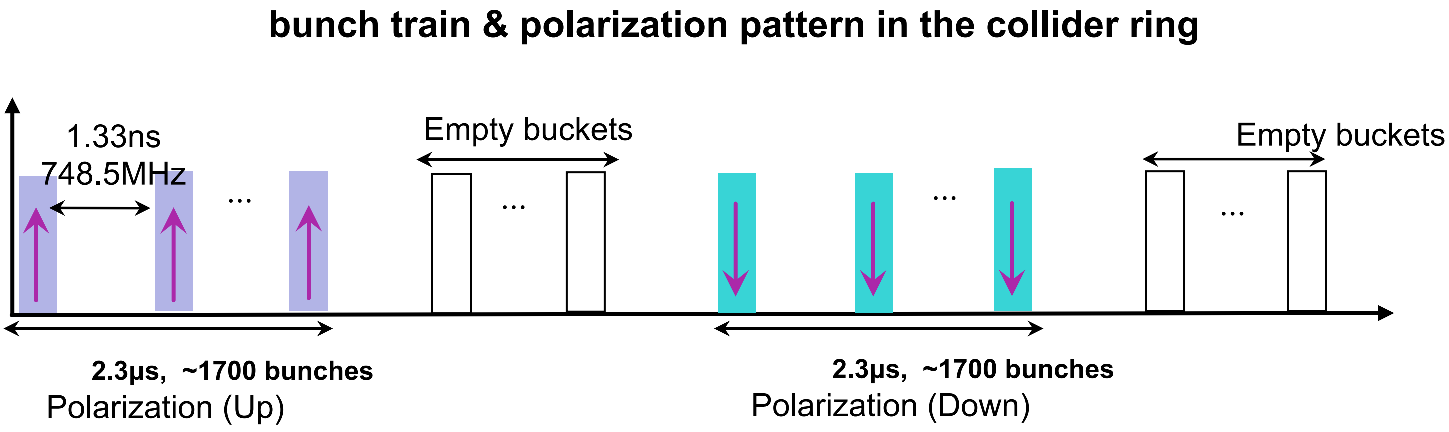


Bunch Pattern for Continuous Injection



- At 100nA average injected current, $\mathbf{P_{equ}/P_0 > 96\%}$ for the whole energy range

Bunch Structure In Collider Ring



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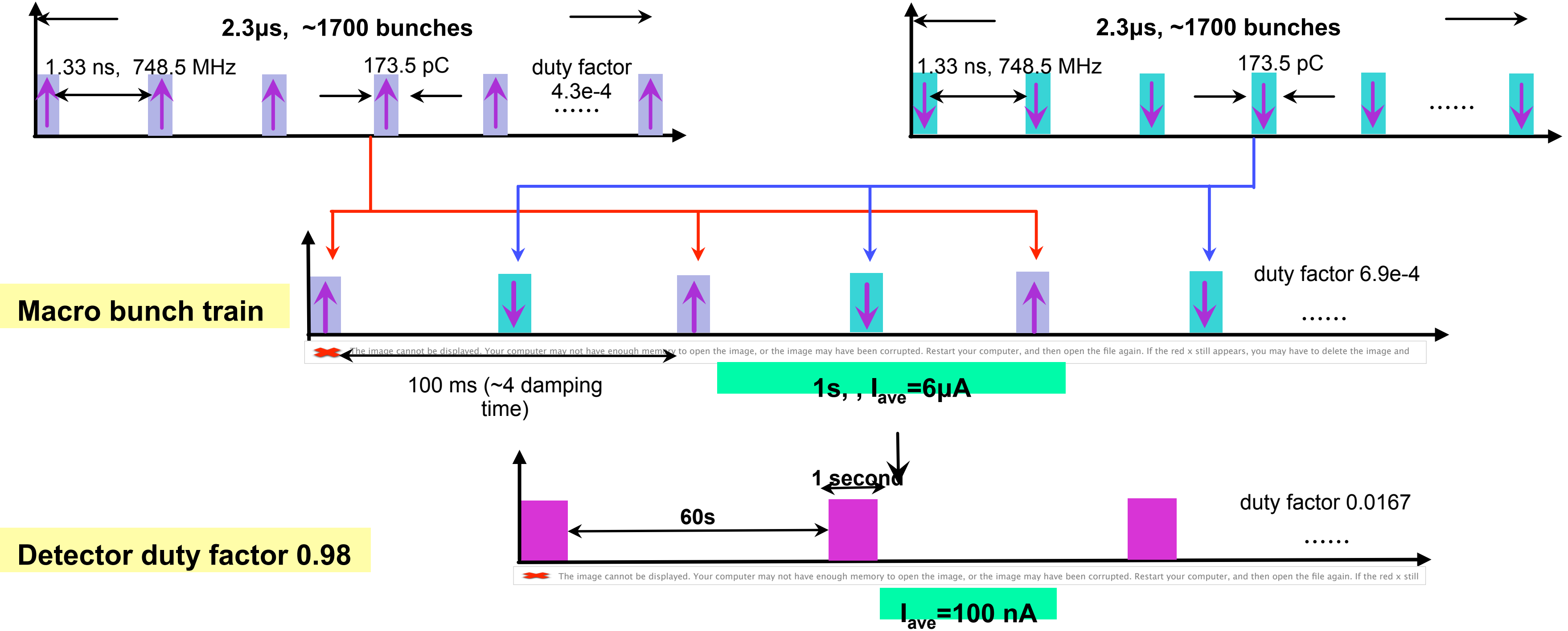

- At 100nA average injected current, $\mathbf{P_{equ}/P_0}$ **> 96%** for the whole energy range