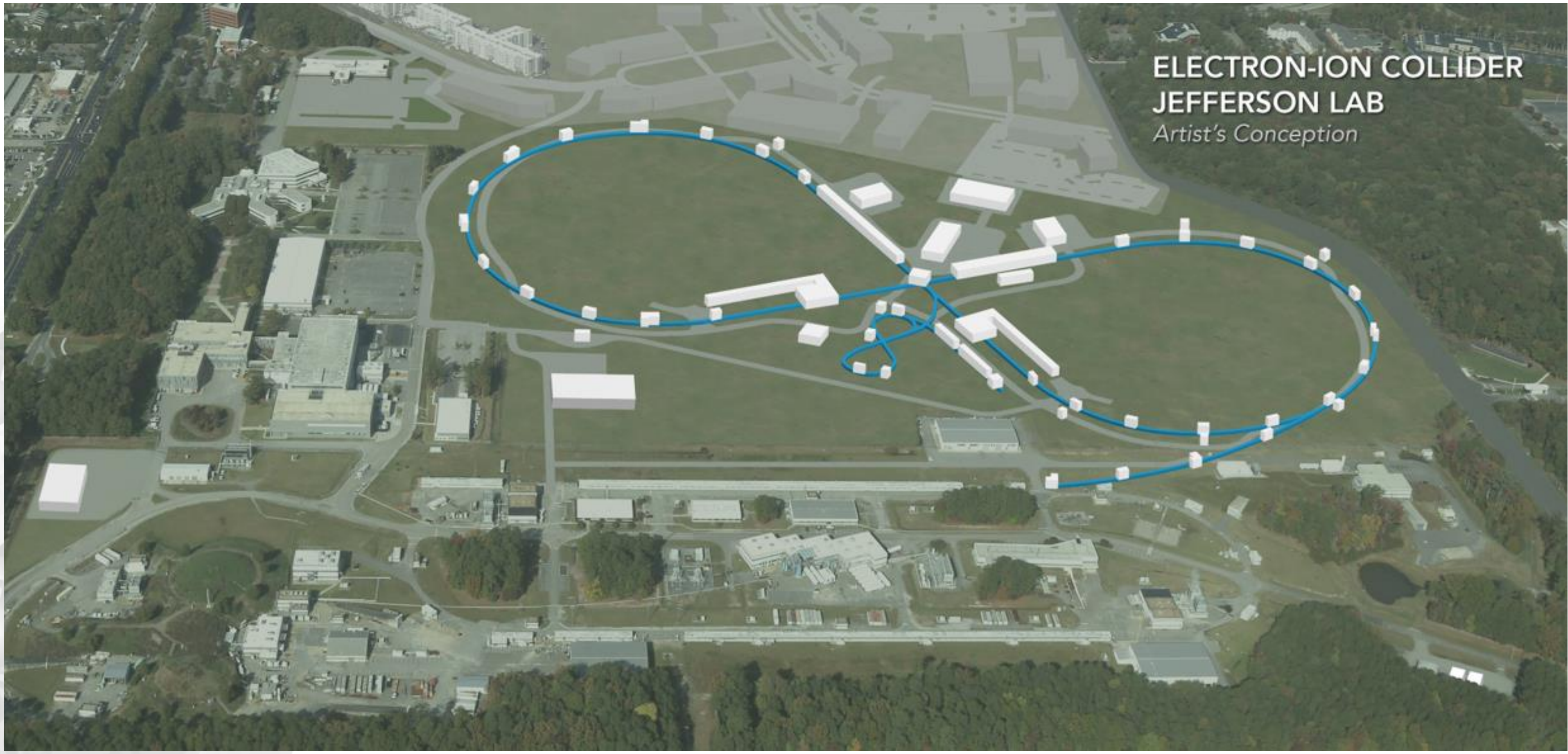
Status of JLEIC and Its Interaction Region Design

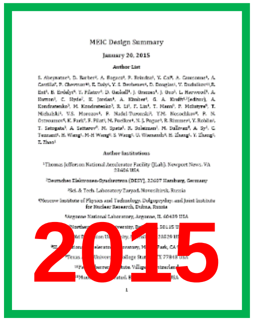
Speaker: V.S. Morozov (JLab)
on behalf of JLEIC Collaboration



Workshop on Deep Inelastic Scattering, Kobe, Japan, April 16-20, 2018

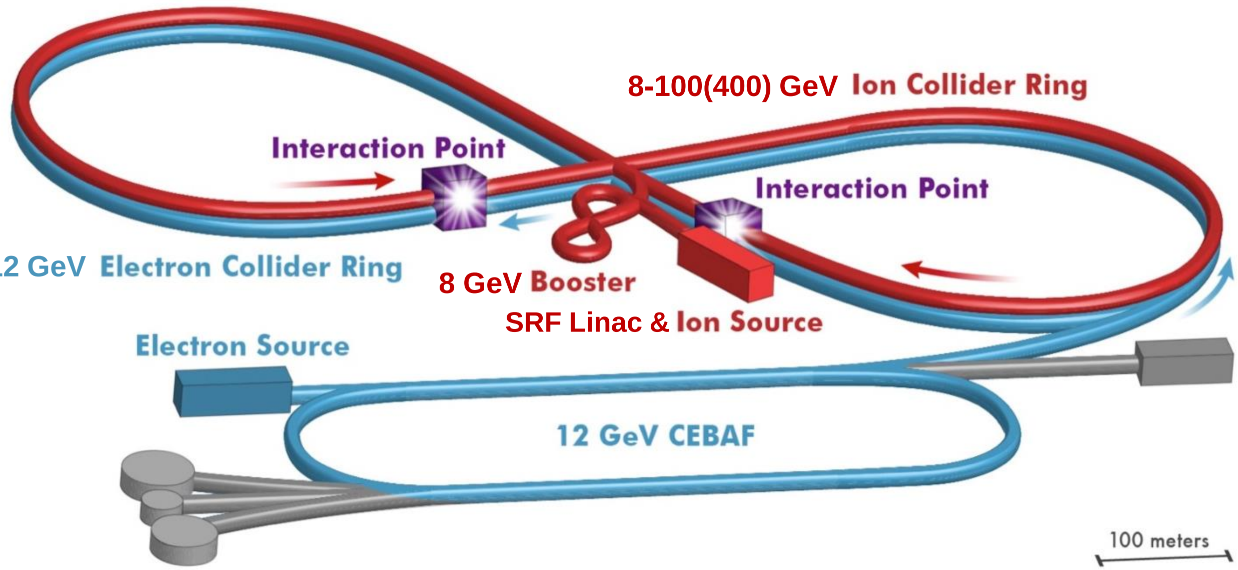
JLEIC Layout

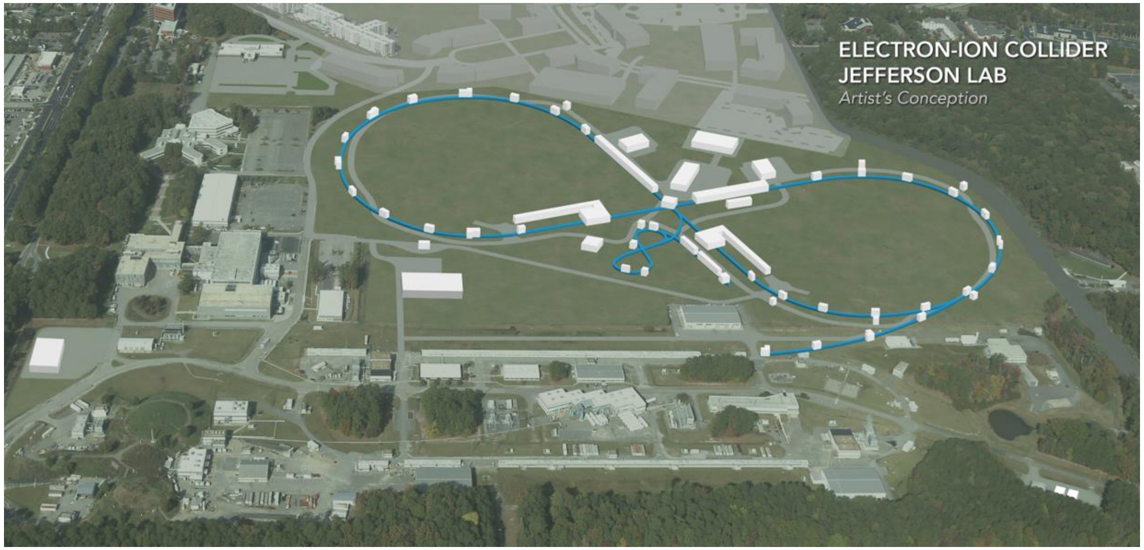
- Electron complex
  - CEBAF
  - Electron collider ring
- Ion complex
  - Ion source
  - SRF linac (285 MeV/u for protons)
  - Booster
  - Ion collider ring
- Up to two detectors at minimum background locations


MEIC Design Summary
January 20, 2015
Author List

arXiv:1504.07961

May 17 update:
https://eic.jlab.org/wiki/index.php/Main_Page

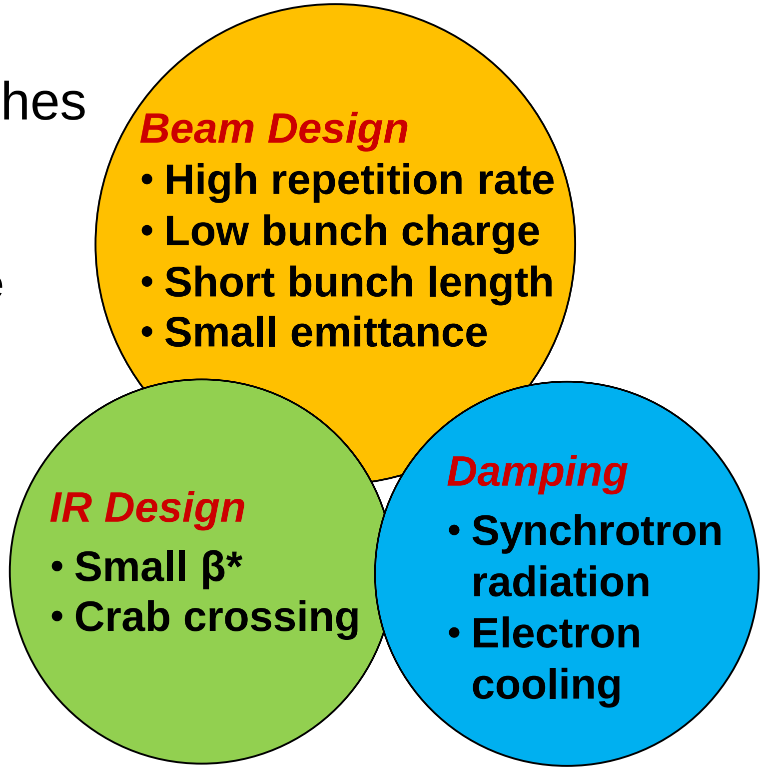




Key Design Concepts

- **High luminosity**: **high collision rate** of short modest-charge low-emittance bunches
  - **Small beam size**
    - Small β* ⇒ Short bunch length ⇒ Low bunch charge ⇒ High repetition rate
    - Small emittance ⇒ **Cooling**
  - Similar to lepton colliders such as KEK-B with L > 2×10^{34} cm^{-2}s^{-1}

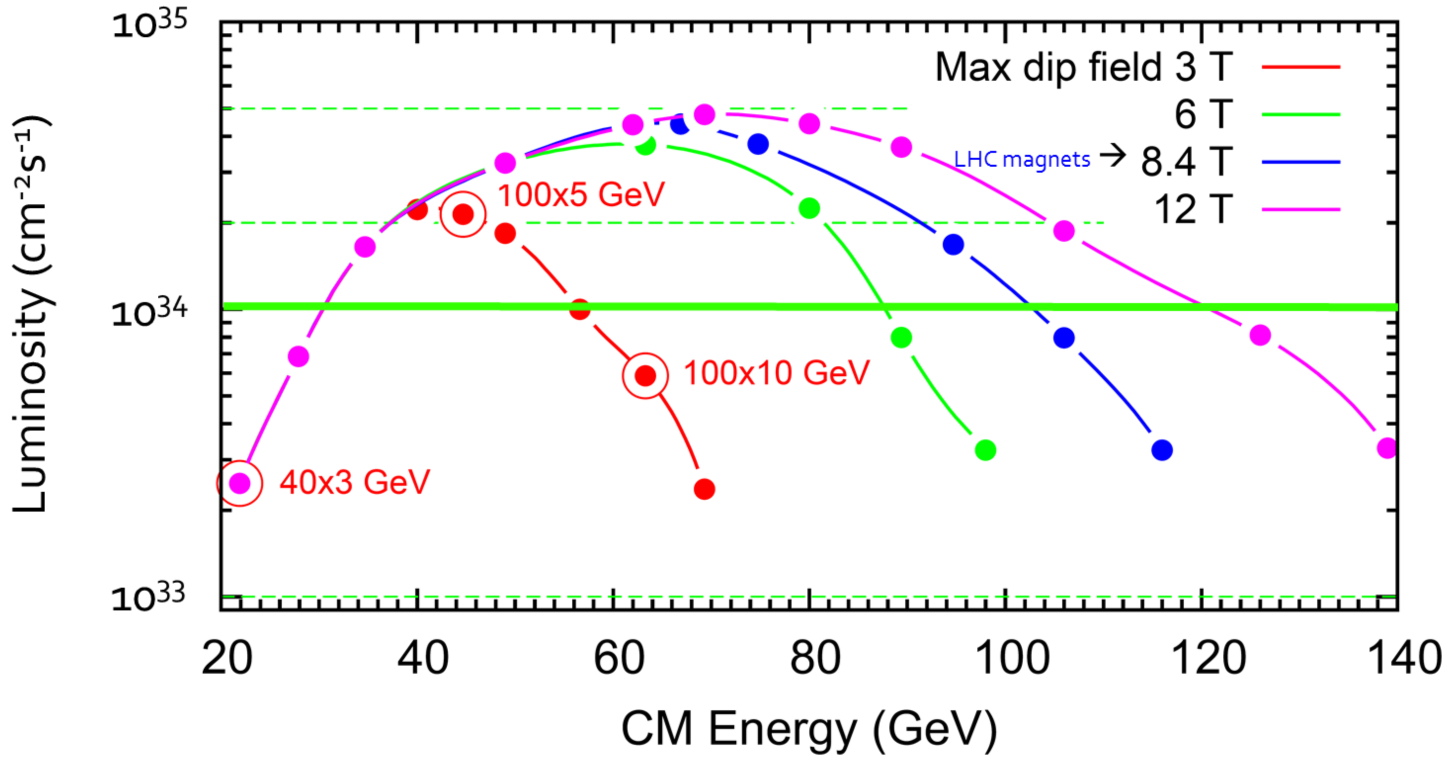
$$L = f \frac{n_1 n_2}{4\pi\sigma_x^* \sigma_y^*} \sim f \frac{n_1 n_2}{\varepsilon \beta_y^*}$$



- **High polarization**: **figure-8** ring design
  - >80% for electrons and protons

- **Full acceptance primary detector** including **far-forward acceptance**

JLEIC Energy Reach and Luminosity



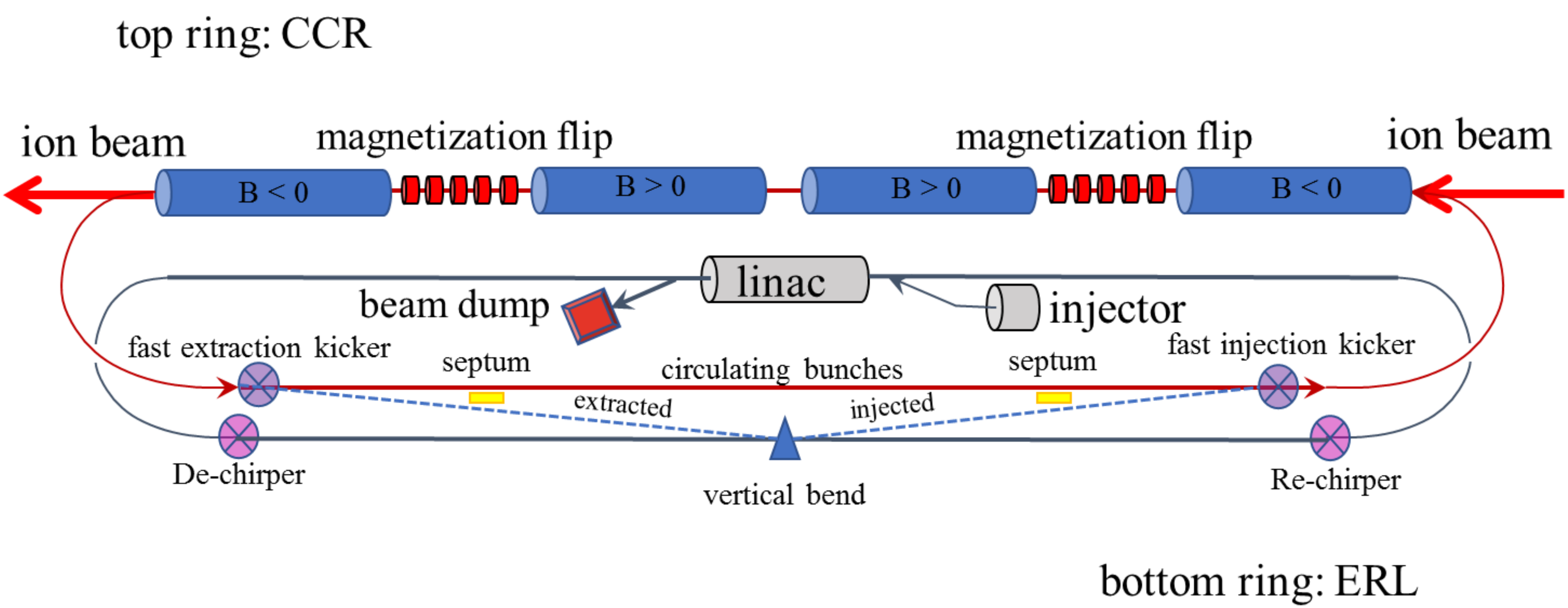
CM Energy (in each scenario)	Main luminosity limitation
low	space charge
medium	beam-beam
high	synchrotron radiation

JLEIC Parameters (3T option)

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. emittance, hor / ver	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**	5.1/1.0	10.5/2.1	4/0.8
Ver. beam-beam parameter		0.015	0.092	0.015	0.068	0.008	0.034
Laslett tune-shift		0.06	7×10^{-4}	0.055	6×10^{-4}	0.056	7×10^{-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**	

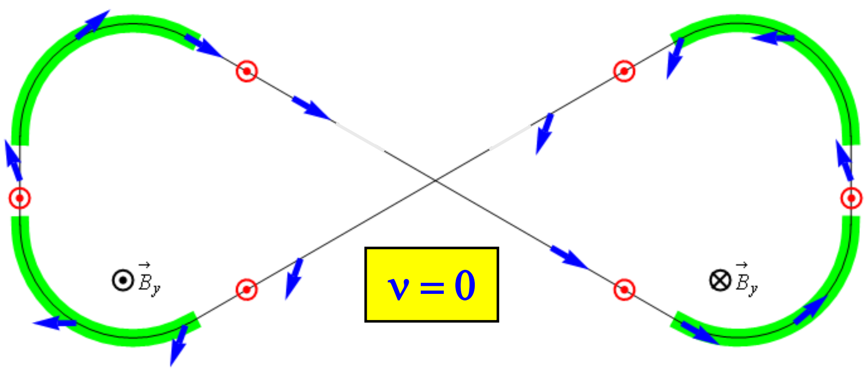
High-Energy Electron Cooling

- Magnetized electron beam for higher cooling efficiency
- Cooling electron beam is energy-recovered to minimize power consumption
- Circulator ring to relax electron source requirements
  - Ultra-fast harmonic kicker to kick electrons in and out of the circulator ring



Ion Polarization

- Figure-8 concept: Spin precession in one arc is exactly cancelled in the other
- Spin stabilization by small fields: ~3 Tm vs. < 400 Tm for deuterons at 100 GeV
    - Criterion: induced spin rotation >> spin rotation due to orbit errors
- No depolarization during acceleration verified by simulations, final P ~80%
- 3D spin rotator: combination of small rotations about different axes provides any polarization orientation at IP or any other point in the collider ring
- No effect on the beam orbit including IP position
- Polarized deuterons
- Frequent adiabatic spin flips with no depolarization

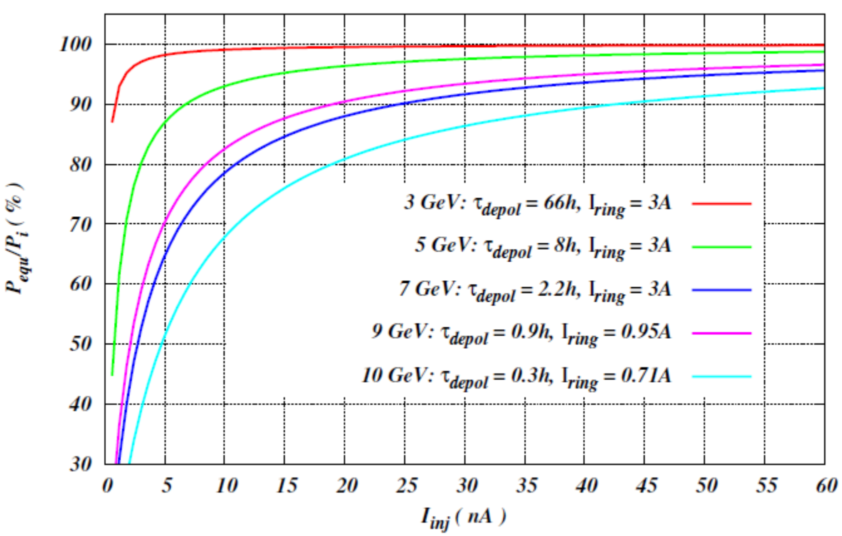


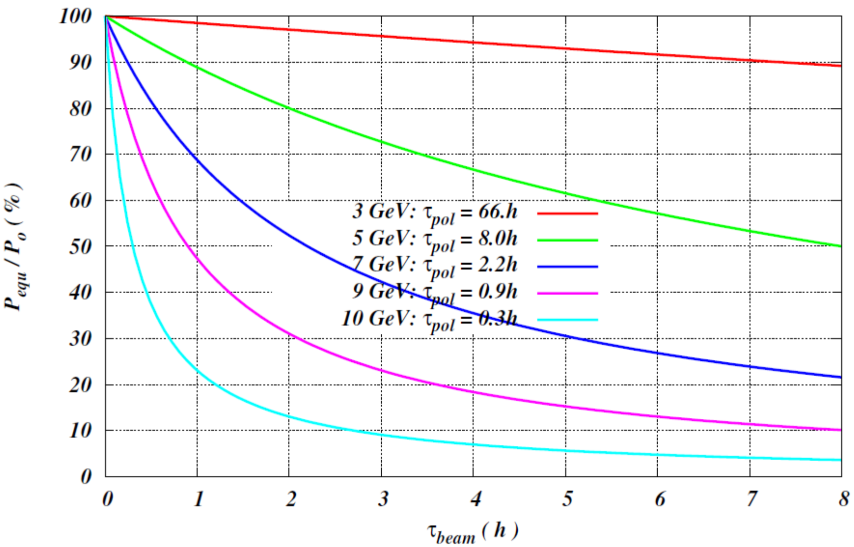
Electron Polarization

- Estimated polarization lifetime

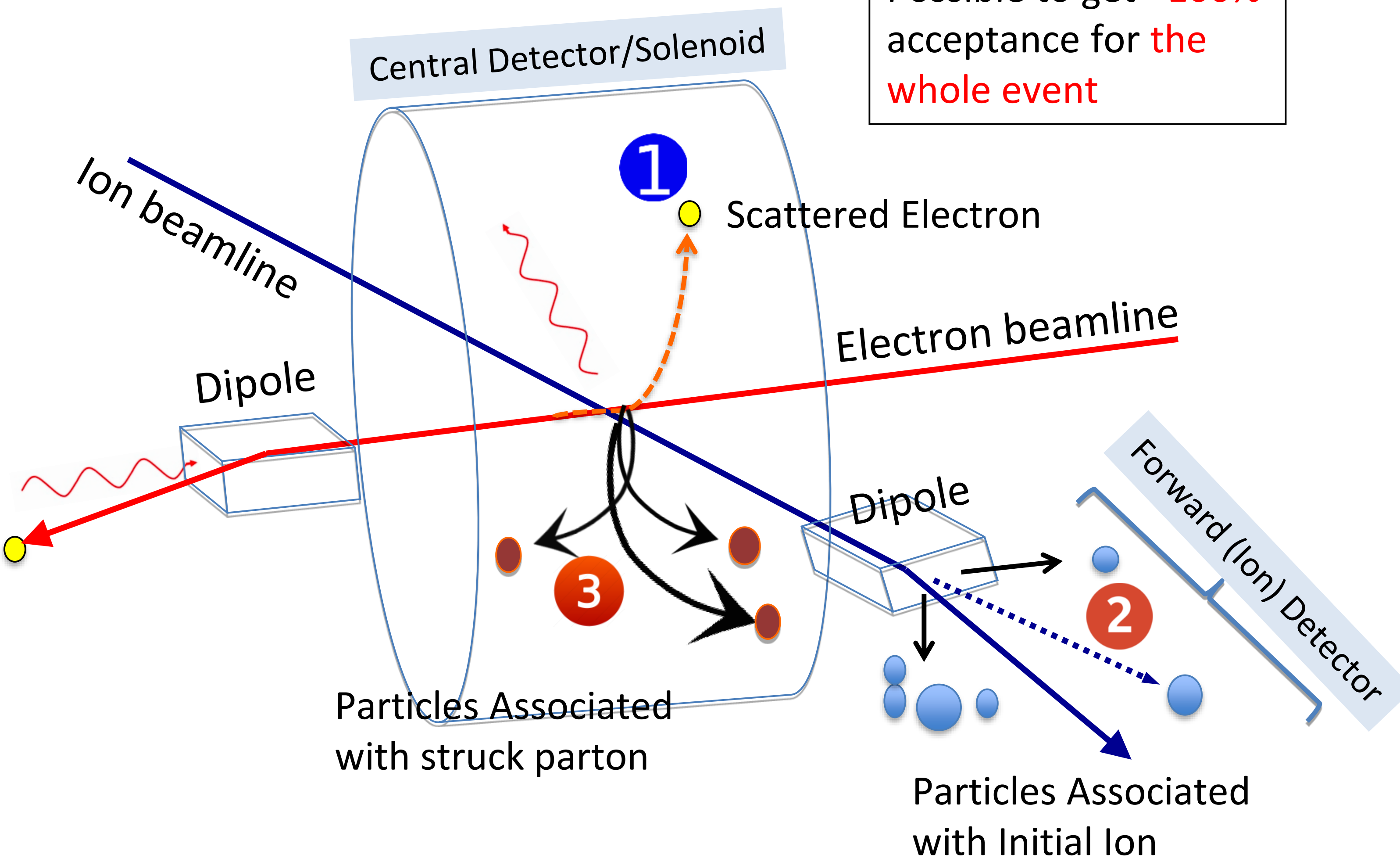
Energy (GeV)	3	5	7	9	10
Lifetime (hours)	66	8	2.2	0.9	0.3

- Constant polarization is maintained by continuous injection of highly polarized (~85%) electron beam from CEBAF
- A relatively low average injected beam current of tens-of-nA level can maintain a high equilibrium polarization in the whole energy range
- Beam lifetime must be balanced with the beam injection rate and $\tau_{beam} \ll \tau_{pol}$





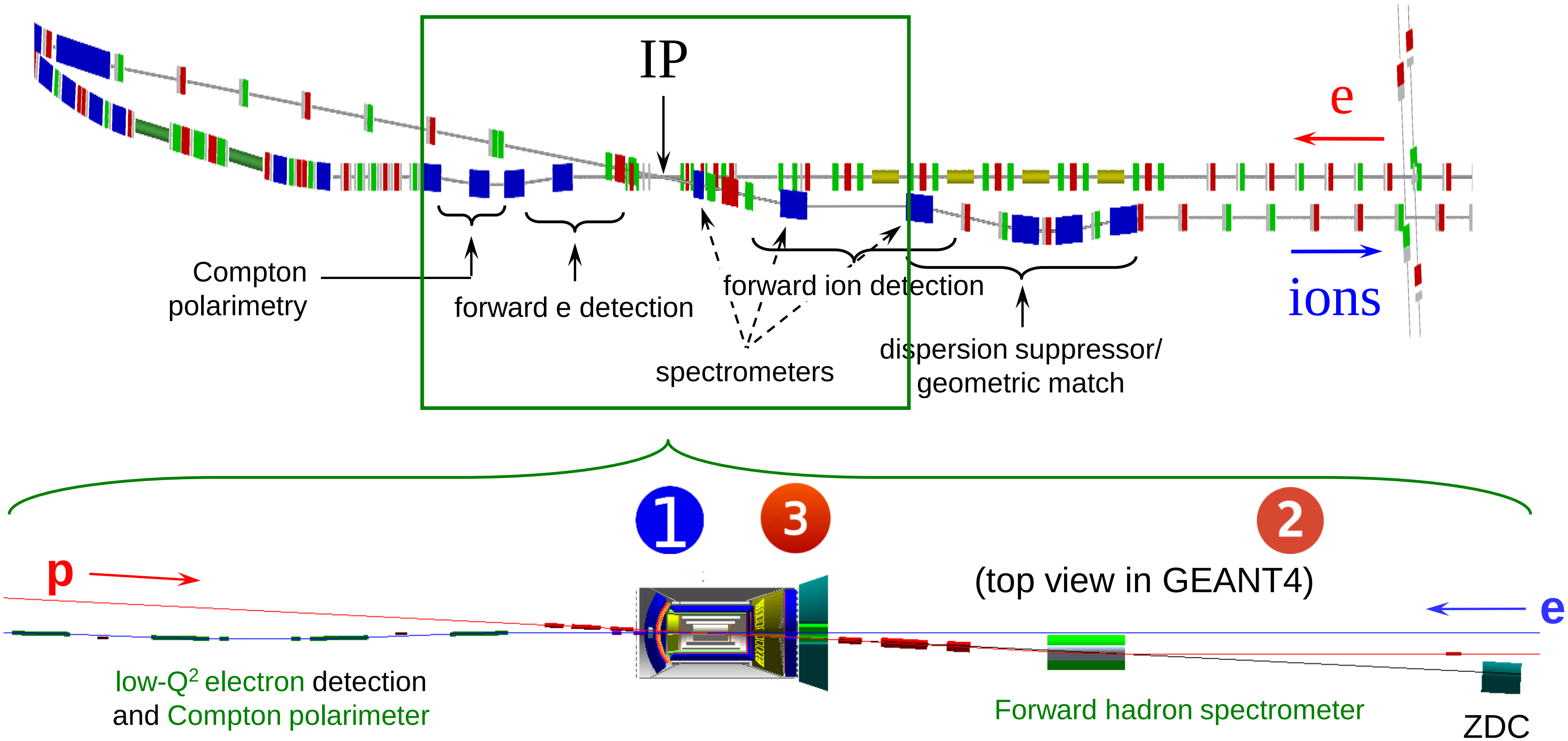
Interaction Region Concept



Possible to get ~100% acceptance for the whole event

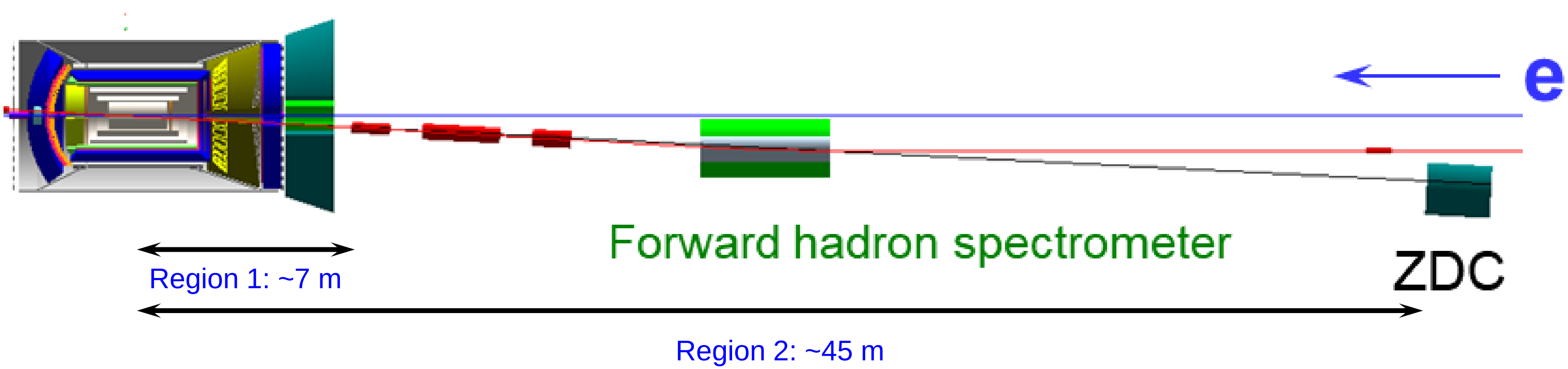
Detector Region

- Integrated detector region design developed satisfying requirements of detection, beam dynamics and geometric match
- GEANT4 detector model developed, simulations in progress



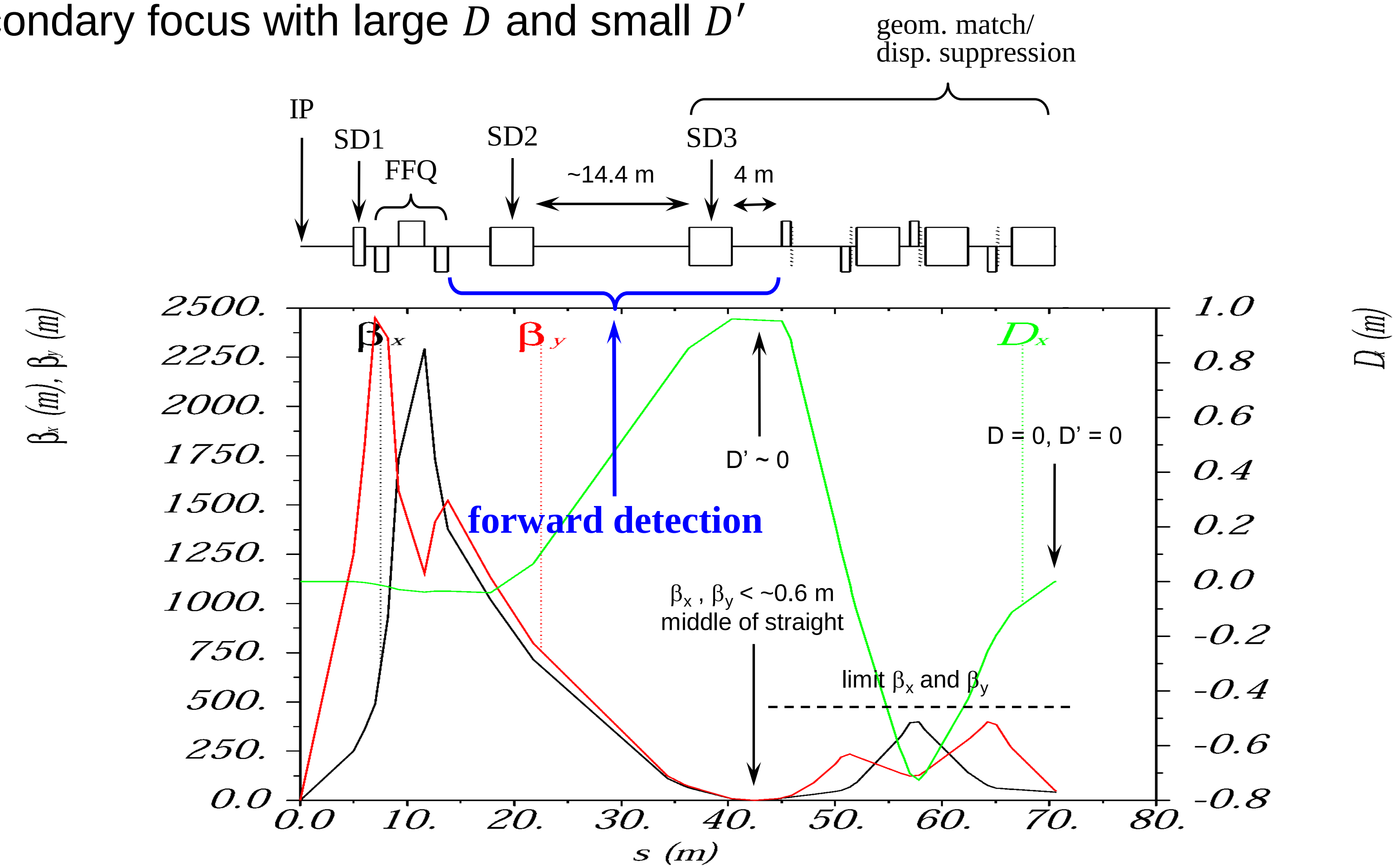
Forward Hadron Detection

- Electron and ion beams have to cross at an angle in an EIC, JLEIC: 50 mrad
  - Create space for independent electron and ion IR magnets
  - Avoid parasitic collisions of shortly-spaces bunches
  - Improves detections
  - Improves detector background
- Two forward charged hadron detector regions:
  - Region 1: Forward, small dipole covering scattering angles from 0.5 up to a few degrees (before quads)
  - Region 2: Far forward, up to 1°, for particles passing through (large aperture) accelerator quads. Subsequent dipoles for precision measurements.
- Neutrals are detected in a zero-degree calorimeter (ZDC)



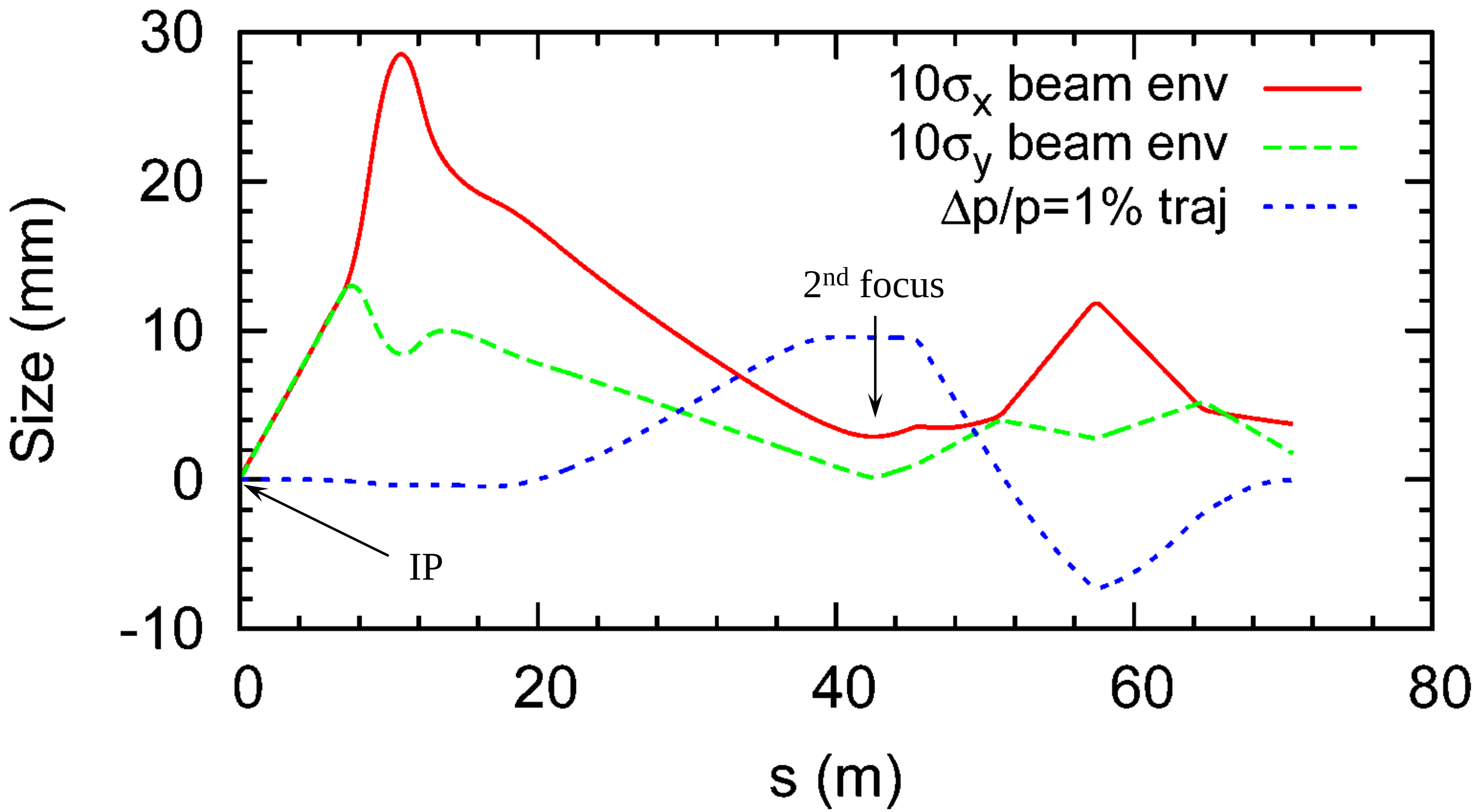
Forward Ion Side of JLEIC IR

- $\beta^*_{x,y}$ = 10 / 2 cm, $D^* = 0$ m, $D'^* = 0$
- Three spectrometer dipoles (SD)
- Large-aperture final focusing quadrupoles (FFQ)
- Secondary focus with large D and small D'



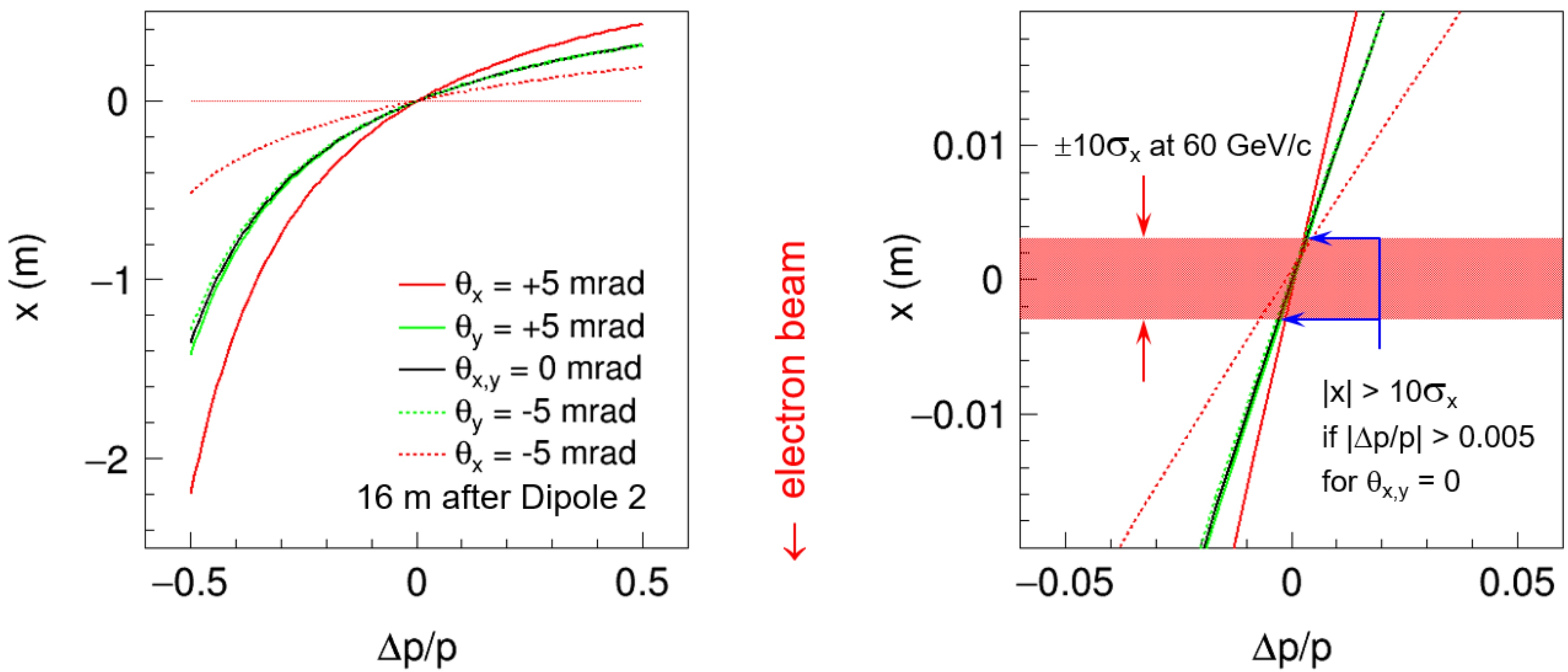
Ion Beam Envelope & 99%p Trajectory

- Assuming beam momentum of 100 GeV/c, ultimate normalized x/y emittances $\varepsilon_{xN}/\varepsilon_{yN}$ of 0.35/0.07 μm, and ultimate momentum spread $\Delta p/p$ of 3×10^{-4}
- The horizontal size includes both betatron and dispersive components



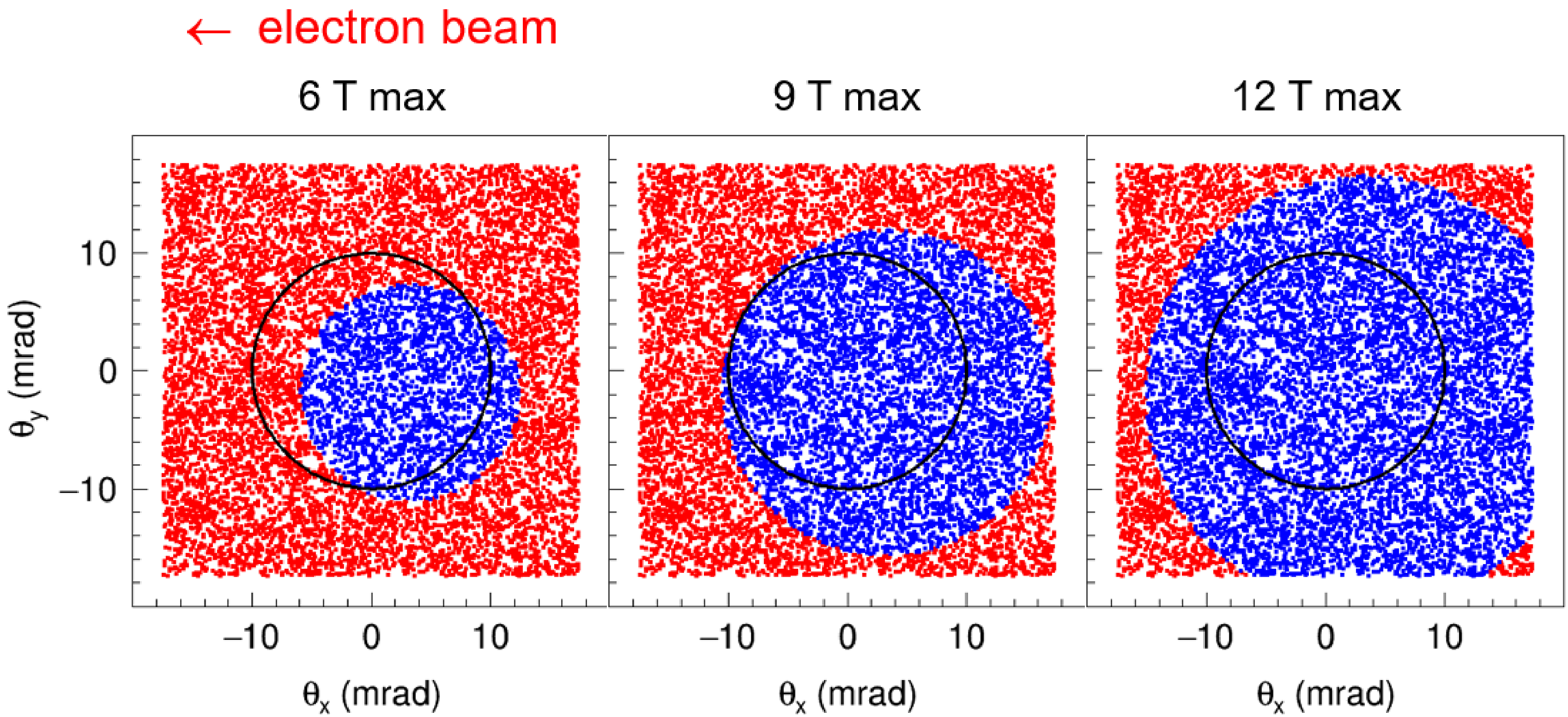
Momentum & Angular Resolution

- Protons with $\Delta p/p$ spread are launched at different angles to nominal trajectory
- Resulting deflection is observed at the second focal point
- Particles with large deflections can be detected closer to the dipole
- Crab tilt at the second focus may reduce momentum acceptance to $\Delta p/p > 1\%$



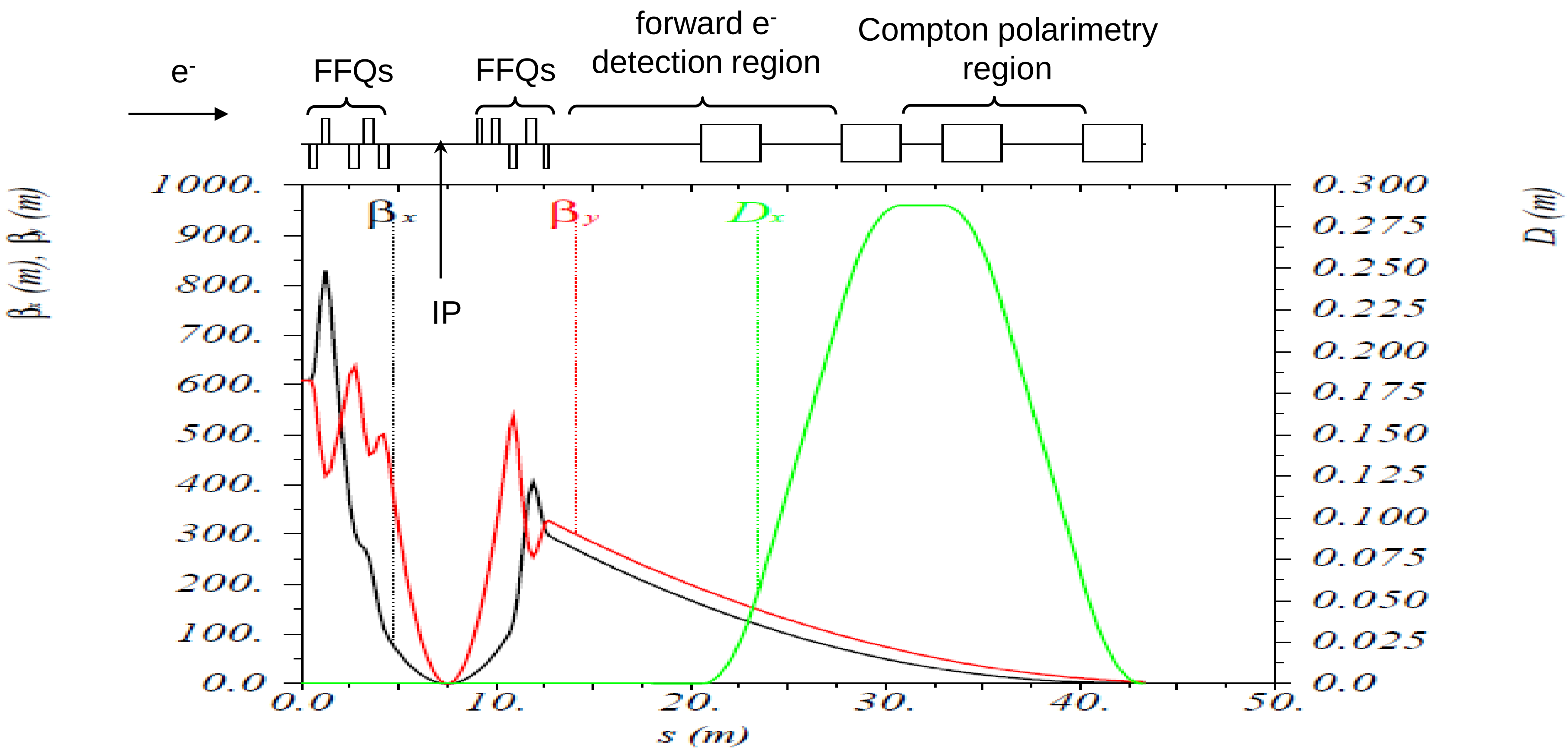
Acceptance to Neutrals

- Transmission of neutrals with initial x and y angular spread
  - Quad apertures = B max / (field gradient @ 100 GeV/c)
  - Uniform neutral particle distribution of $\pm 1^\circ$ in x and y angles around proton beam at IP
  - Transmitted particles are indicated in blue (the circle outlines $\pm 0.5^\circ$ cone)



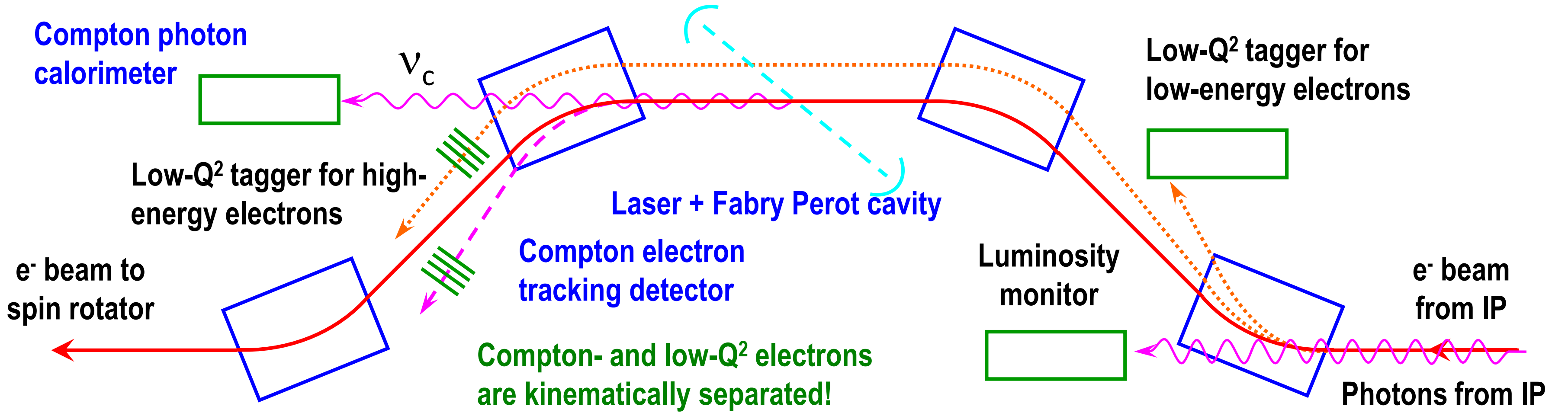
Electron IR optics

- IR region
  - Final focusing quads with maximum field gradient ~63 T/m
  - Four 3m-long dipoles (chicane) with 0.44 T @ 10 GeV for low-Q^2 tagging with small momentum resolution, suppression of dispersion and Compton polarimeter



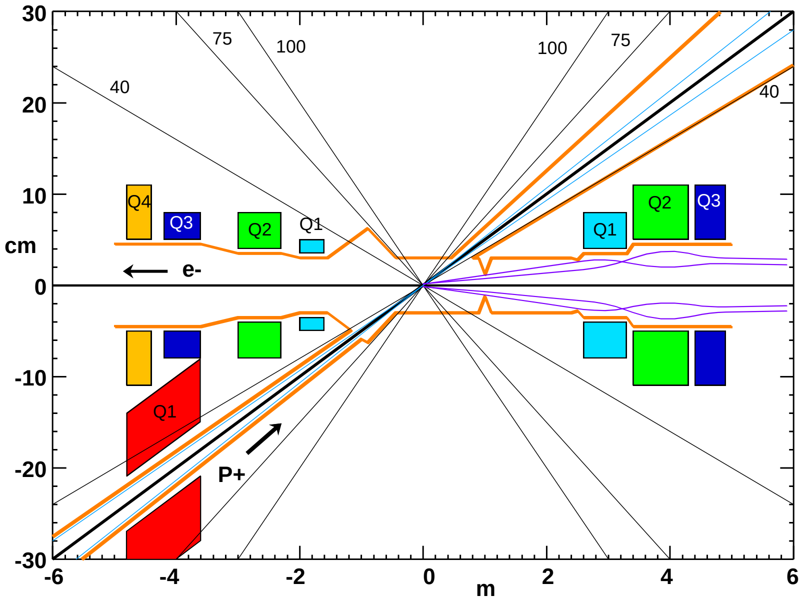
Forward e$^-$ Detection & Polarization Measurement

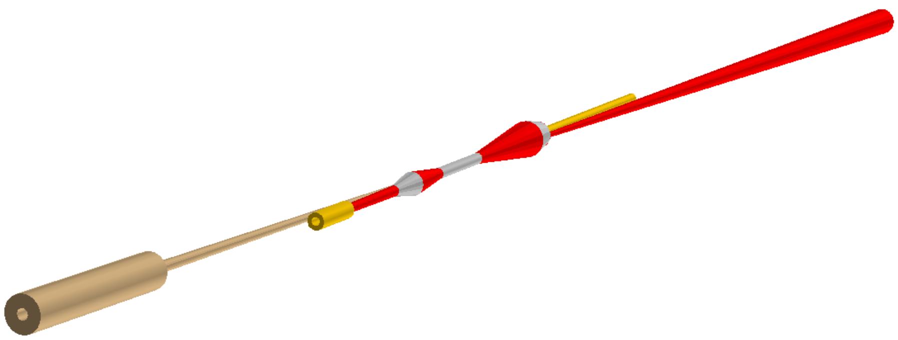
- Dipole chicane for high-resolution detection of low-Q^2 electrons
- Compton polarimetry has been integrated to the interaction region design
  - same polarization at laser as at IP due to zero net bend
  - non-invasive monitoring of electron polarization



Beam Pipe Design

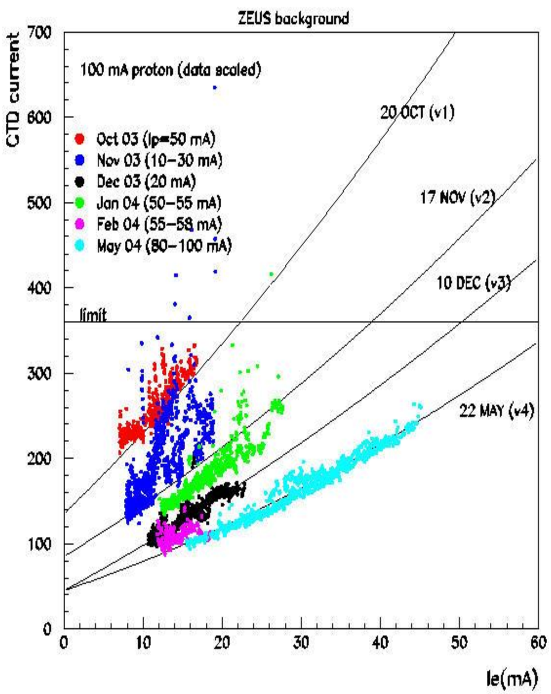
- Minimum multiple scattering in the beam pipe material
- Synchrotron radiation collimation
- Impedance
- Vacuum
- L. Elouadrhiri et al. (JLab), C. Hyde (ODU), M. Sullivan (SLAC)

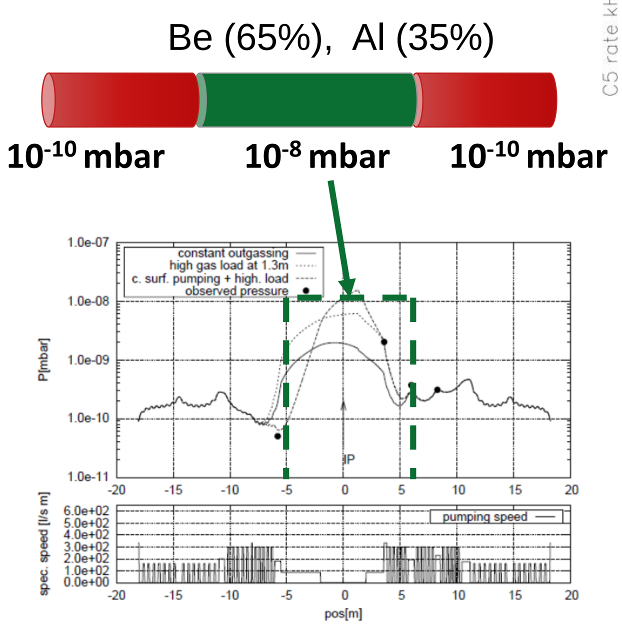


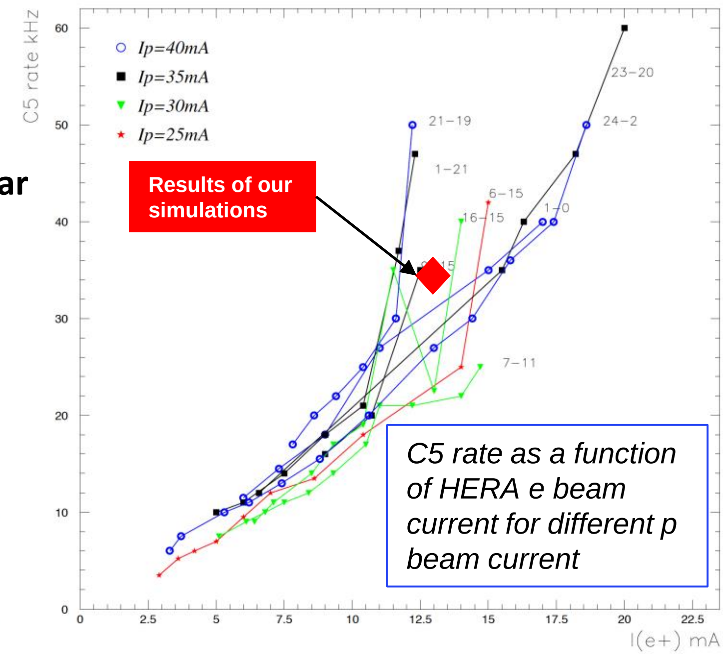


Detector Background

- Performance of ZEUS at HERA was limited by background in the Central Tracking Detector (CTD)
- Background was generated by ion beam scattering on residual gas generated by electron beam's synchrotron radiation
- Background was monitored using a small scintillator counter C5
- Simulation tools and procedures validated using HERA data (L. Elouadrhiri et al.)







Detector Simulations

Detection of $^1H(e,e'K^+)\Lambda$

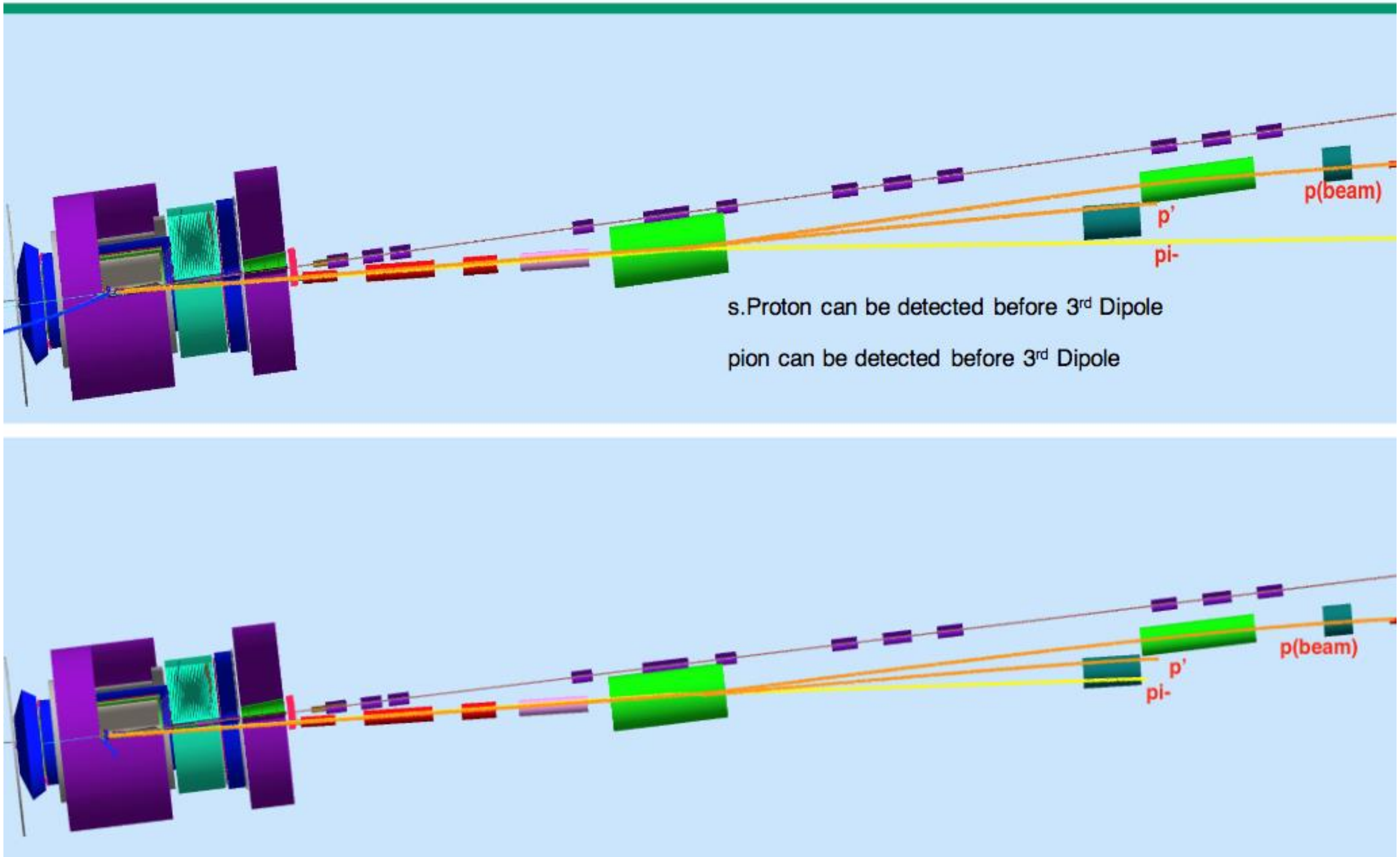


Figure from K.Park

12

Conclusion

- JLEIC conceptual design is nearly complete
- Key features:
  - High luminosity
  - High polarization
  - Full-acceptance detection
- The detector region has been closely integrated with accelerator design and optimized for forward detection
- Work in progress
  - Verification of consistency of the JLEIC design
  - Completion of a pre-CDR
  - Detector region design
    - Engineering design: magnets, cryogenics, vacuum
    - Beam pipe design
    - Detector background studies
    - Physics simulations
    - Polarimetry