JLab experience with forward detection
– opportunities for the ePHENIX interaction region?

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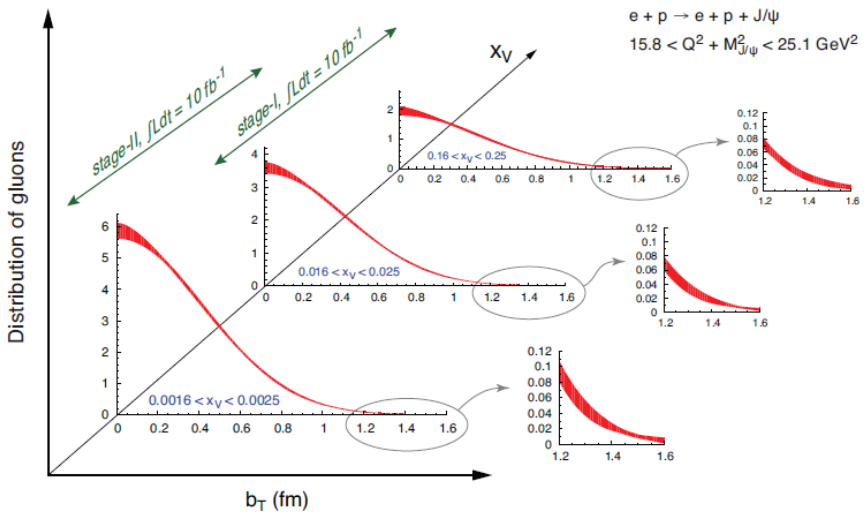
Stony Brook University

Cold QCD meeting, December 13, 2016

Imaging in coordinate space

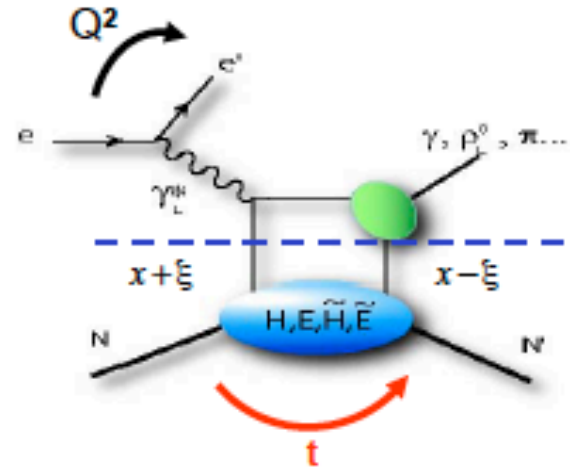
GPDs

2+1 D picture in **impact-parameter space**



Transverse gluon distribution from J/ψ production

Projections from EIC white paper

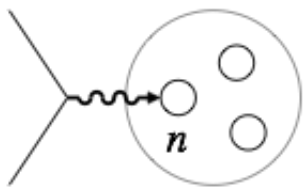


- Capturing the full "image" requires wide coverage in t (large recoil proton acceptance)
  - Small t ⇔ large b
  - Large t ⇔ small b

$$J^q = \frac{1}{2}\int_{-1}^{+1} dx\, x\left[H^q(x,\xi,t) + E^q(x,\xi,t)\right]$$

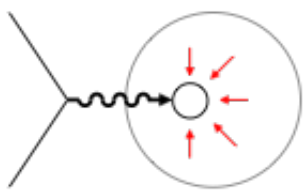
- Also important for (Ji) spin sum rule!

Spectator tagging with (polarized) light ions

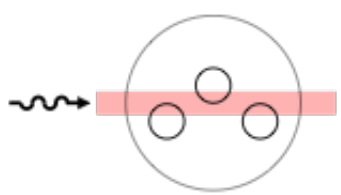


- Neutron structure
  - Flavor decomposition of quark spin, Δg, etc

    Binding, final-state interactions, polarization



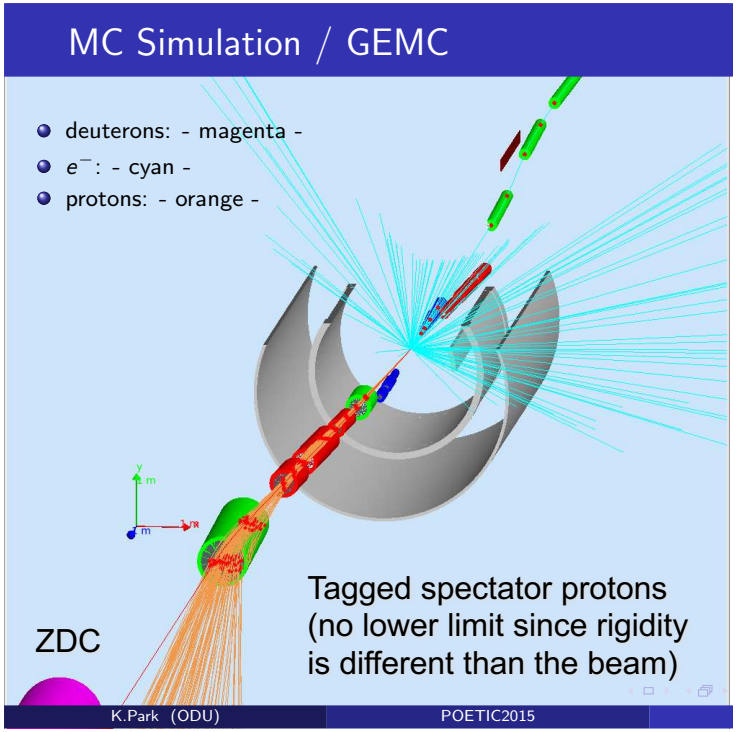
- Bound nucleon in QCD
  - Modification of quark/gluon structure by nuclear medium
  - QCD origin of nuclear forces

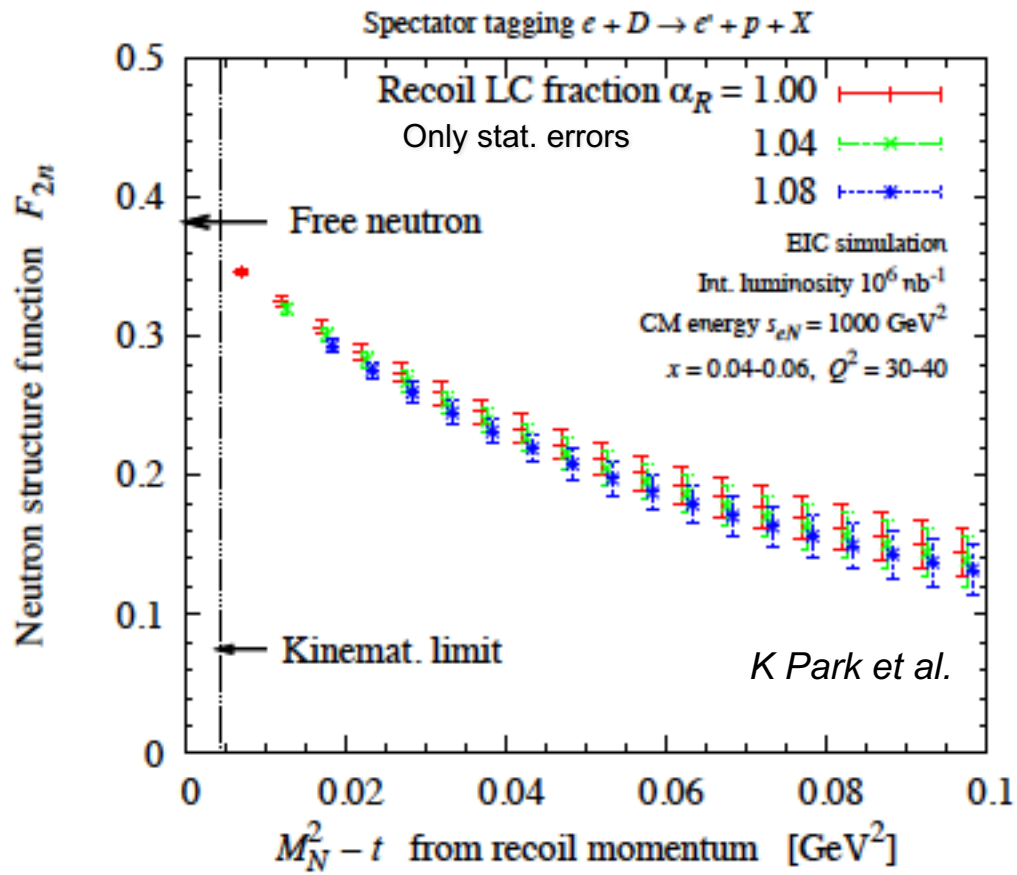


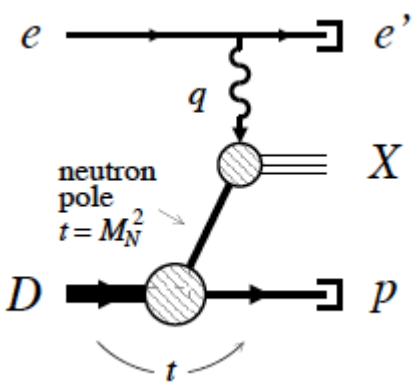
- Coherence and signature of gluon saturation
  - Interaction of high-energy probe with coherent quark-gluon fields

[Nucleus rest frame view]

“Free” neutron structure at an EIC



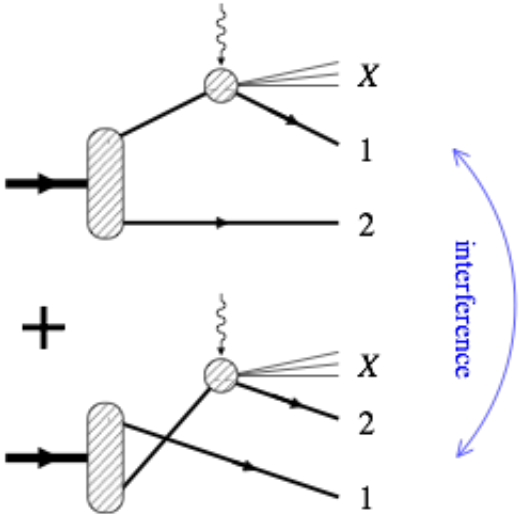


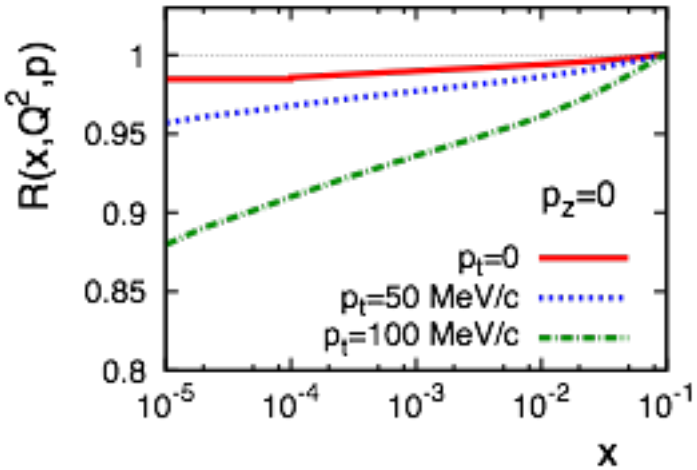


On-shell extrapolation of F_{2n}

- Free neutron at pole - not affected by final-state interactions!
- *Resolution ~ Fermi momentum*
- Resolution scales (deteriorates) with beam energy
- JLab EIC can reach 20 MeV/c with 50 GeV/A deuterium!

Shadowing in light nuclei (deuterium)





- Shadowing at small x
  - Interference between diffractive scattering on nucleons 1 and 2
  - Nuclear effect calculable in terms of nucleon diffractive structure

    Gribov 70's, Frankfurt, Strikman '98, Frankfurt, Guzey, Strikman '02+
  - Determines approach to saturation in heavy nuclei

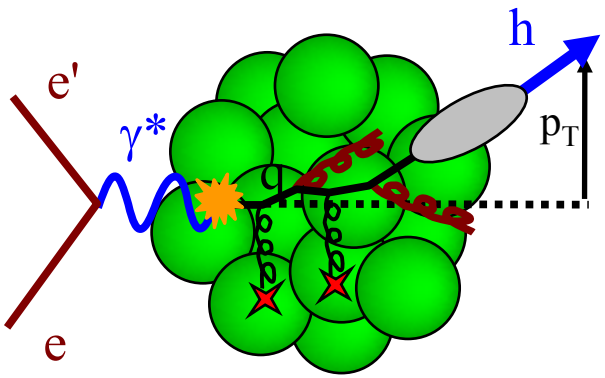
- Shadowing in tagged DIS
  - Strong p_T dependence
  - Clean coherent effect with N=2

    Frankfurt, Guzery, Strikman 2011

Path length from tagging with heavy nuclei

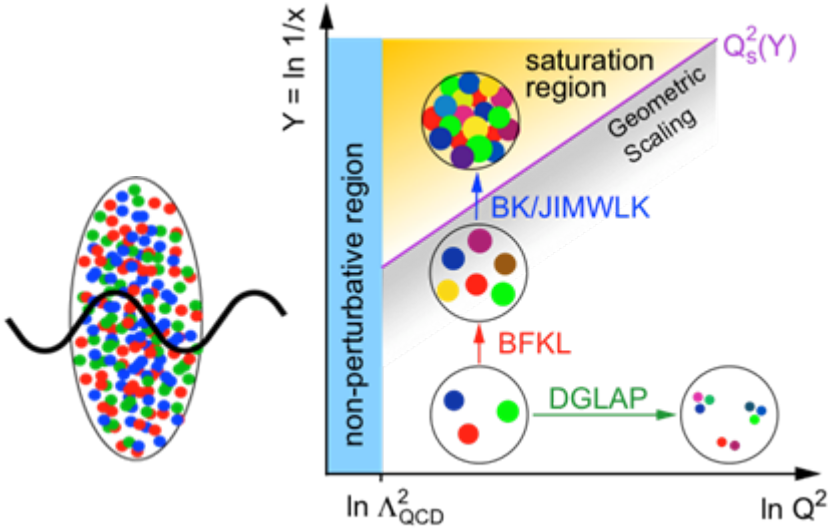
Emergence of hadrons from partons

- The nucleus can be a femtometer laboratory for exploring the interaction of color charge with (nuclear) matter.
  - Energy loss, p_T broadening, etc
- Important to know both the photon energy and path length traversed.
  - In e-A, interaction may not be at surface

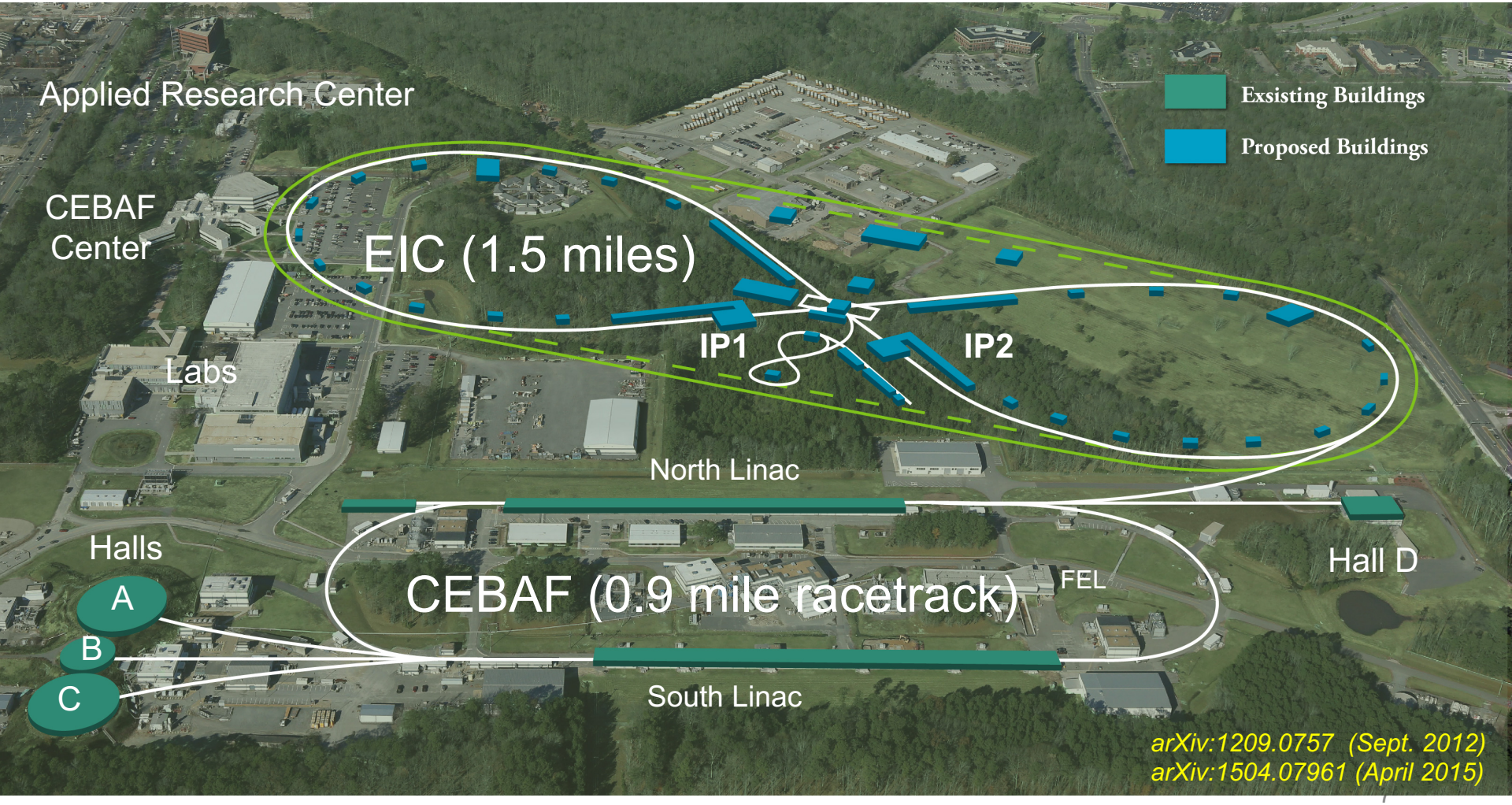


Coherence and gluon saturation

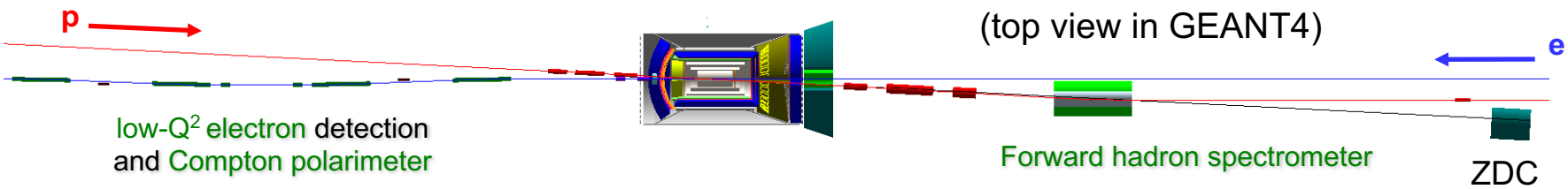
- At low x and Q^2, the probe interacts coherently with all gluons in its path
- The gluon density can be increased by going to lower x (higher cm energy), or increasing the (nuclear) path length
  - Heavy nuclei + selection of large path lengths through tagging
  - Extra boost from non-spherical nuclei?



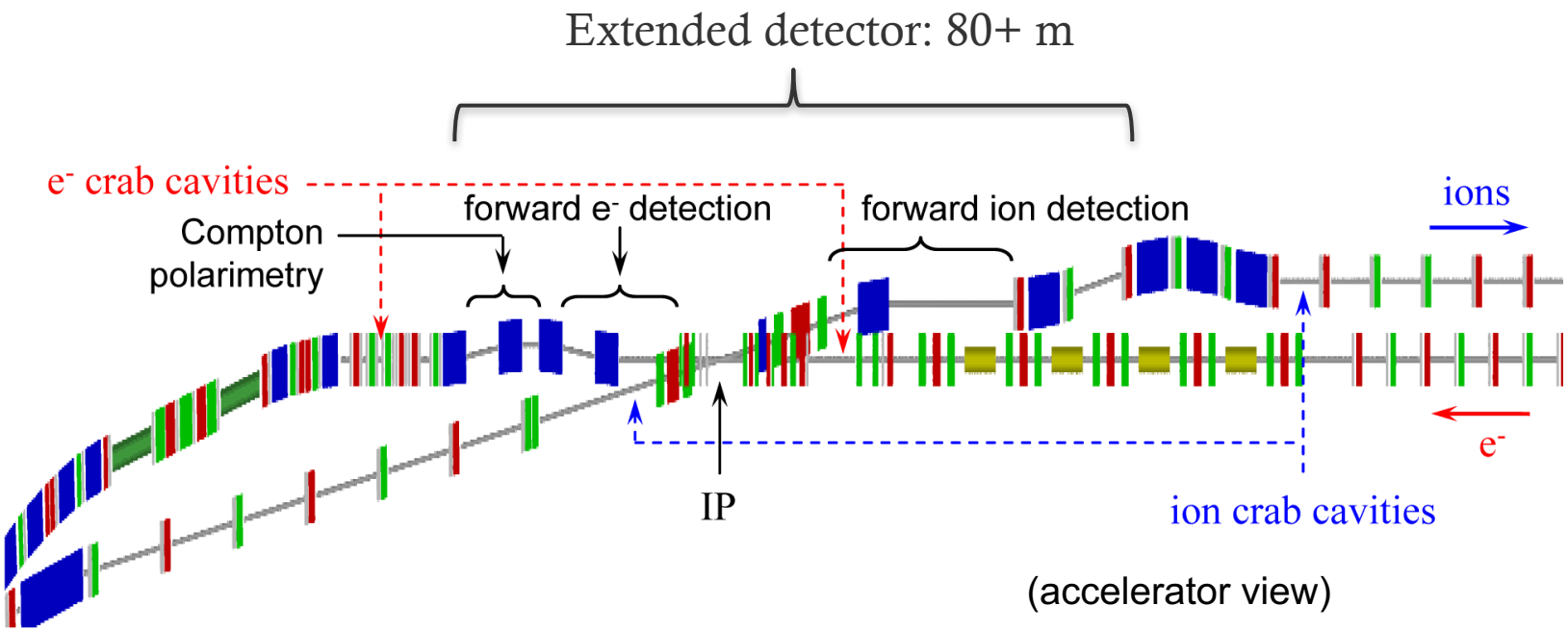
Proposed layout for JLab EIC



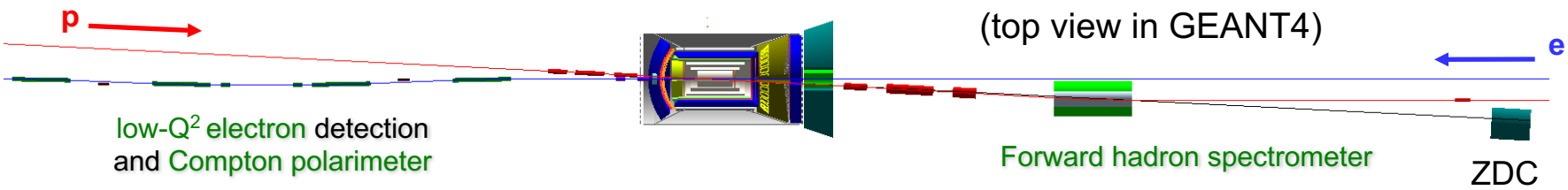
Extended detector and interaction region

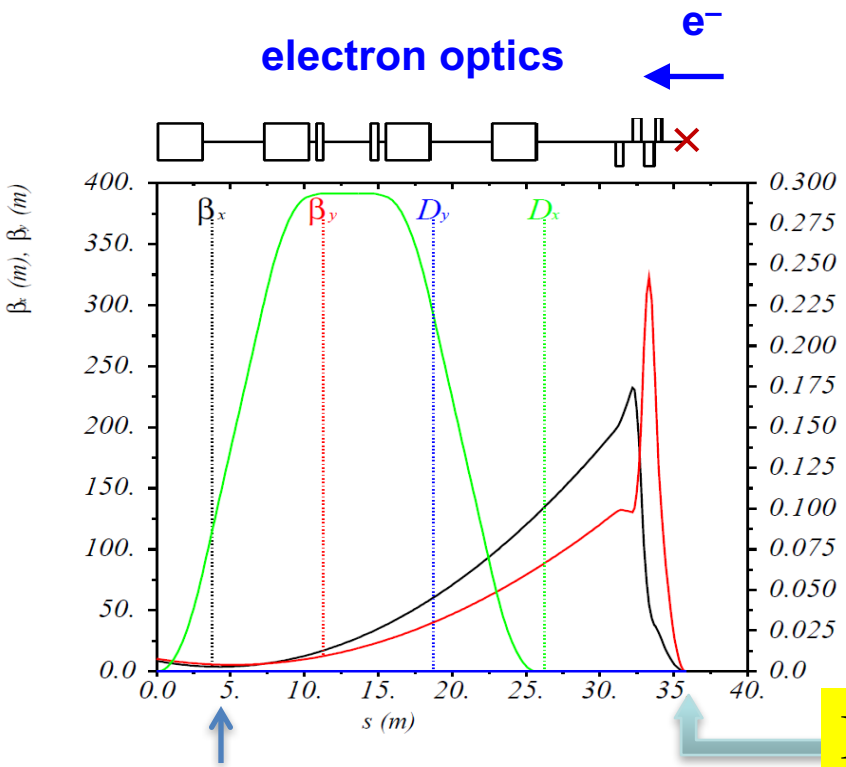


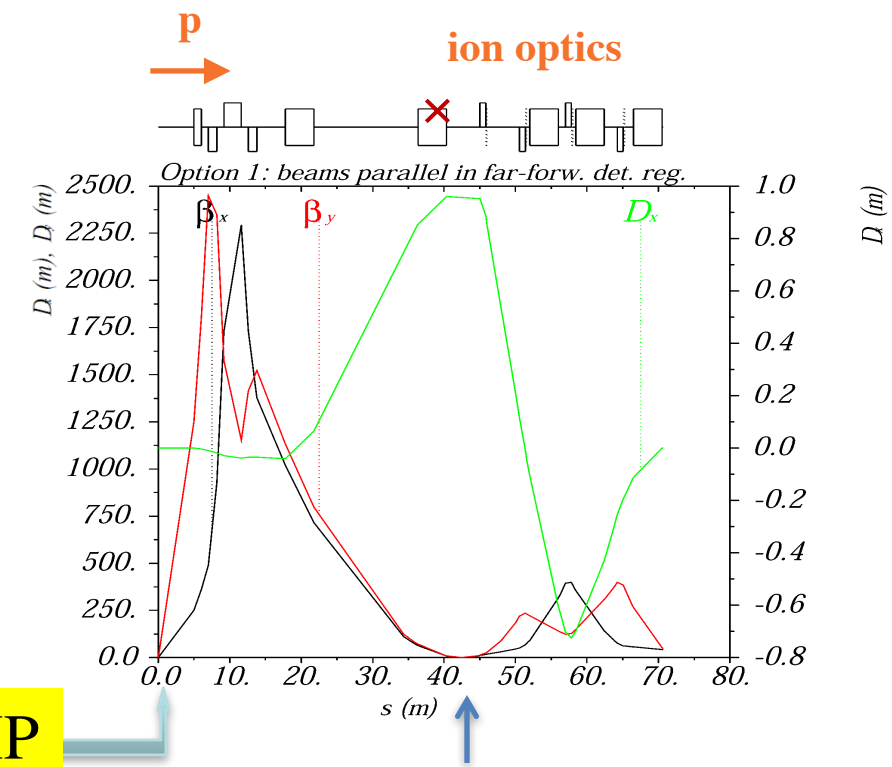
- Integration of extended detector highest priority for JLab EIC design
  - Accelerator layout can be optimized for detector requirements



Interaction region optics







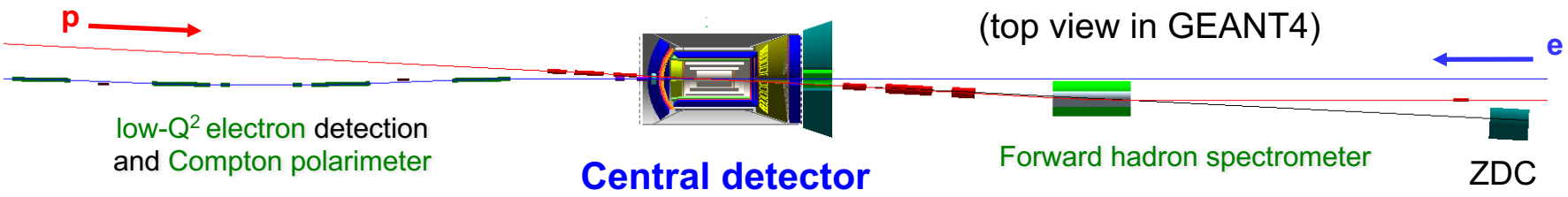
IP

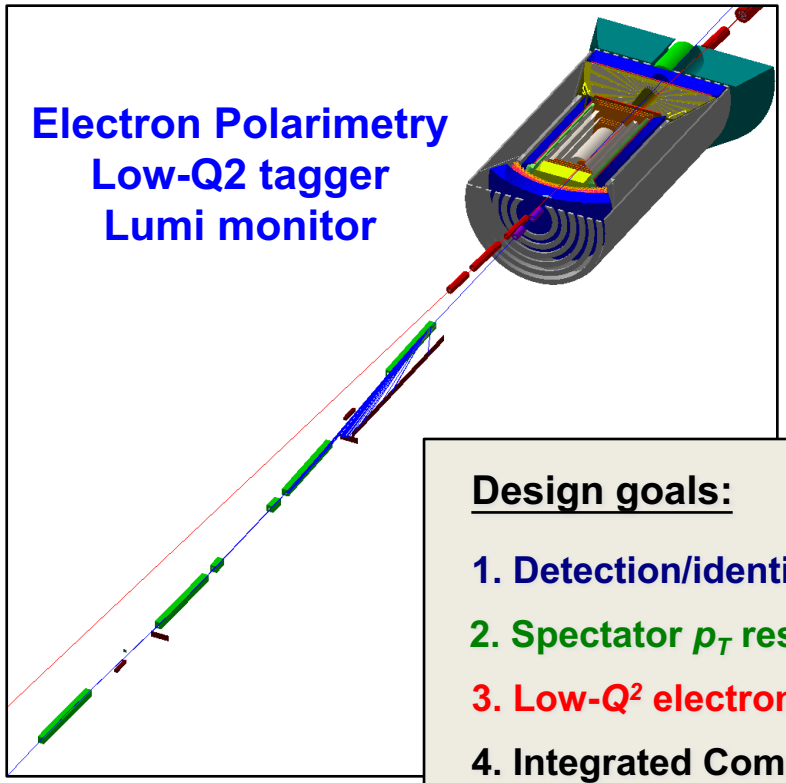
2nd focus on Compton detectors, dispersion for low-Q^2 tagger

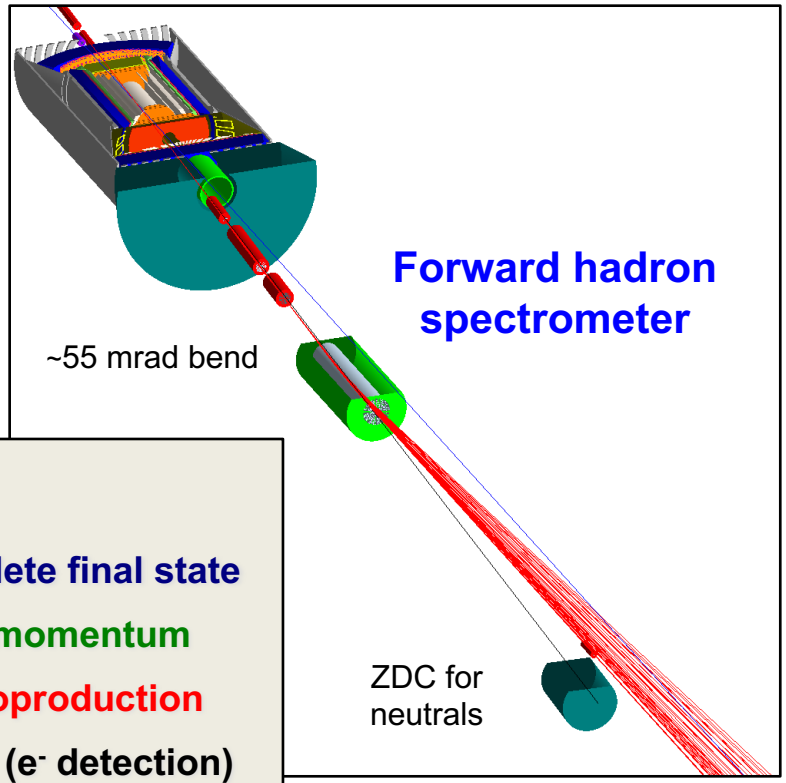
primary focus

2nd focus and large dispersion at Roman pots (for recoil baryon detection)

Layout of the extended detector



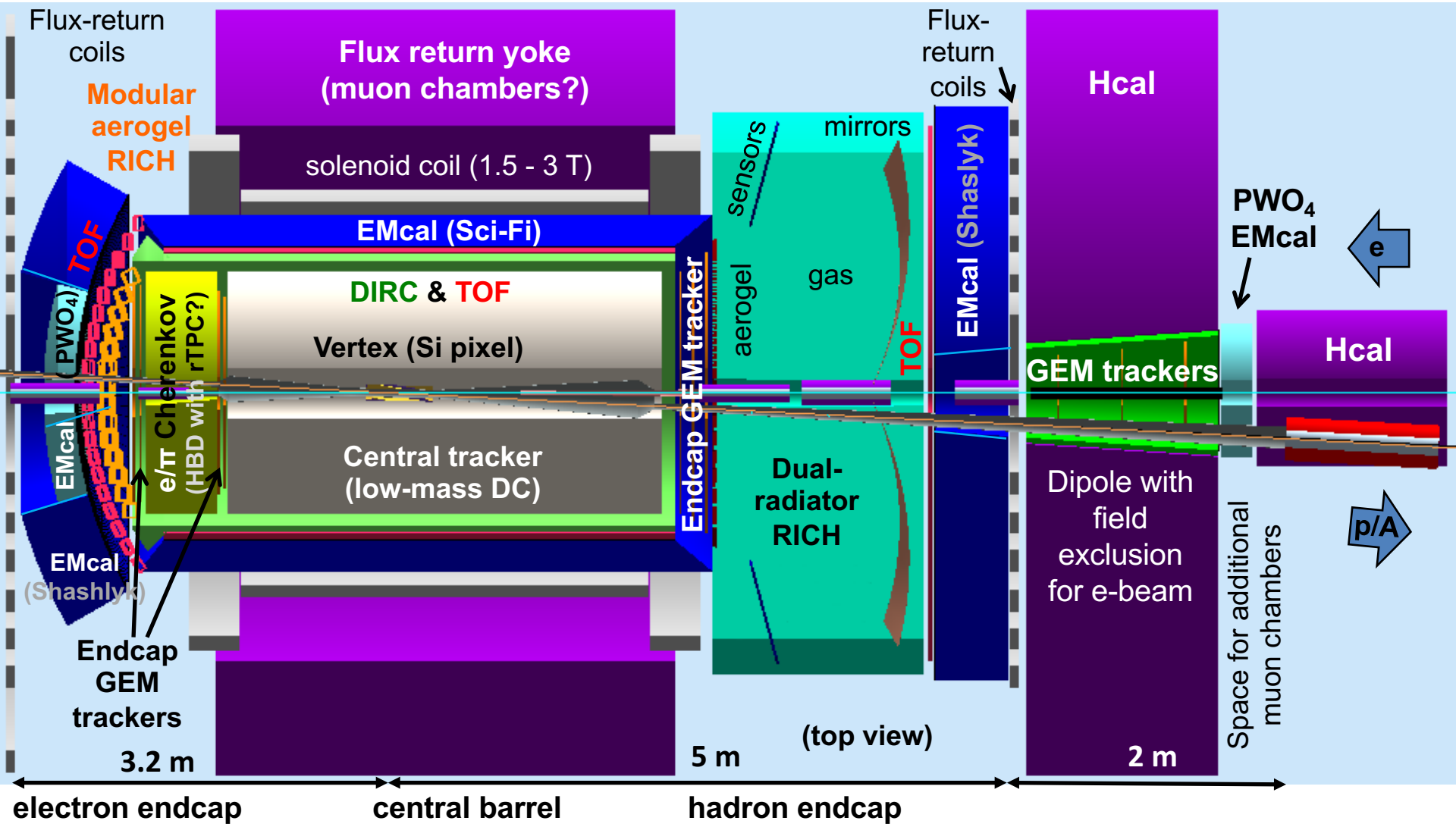




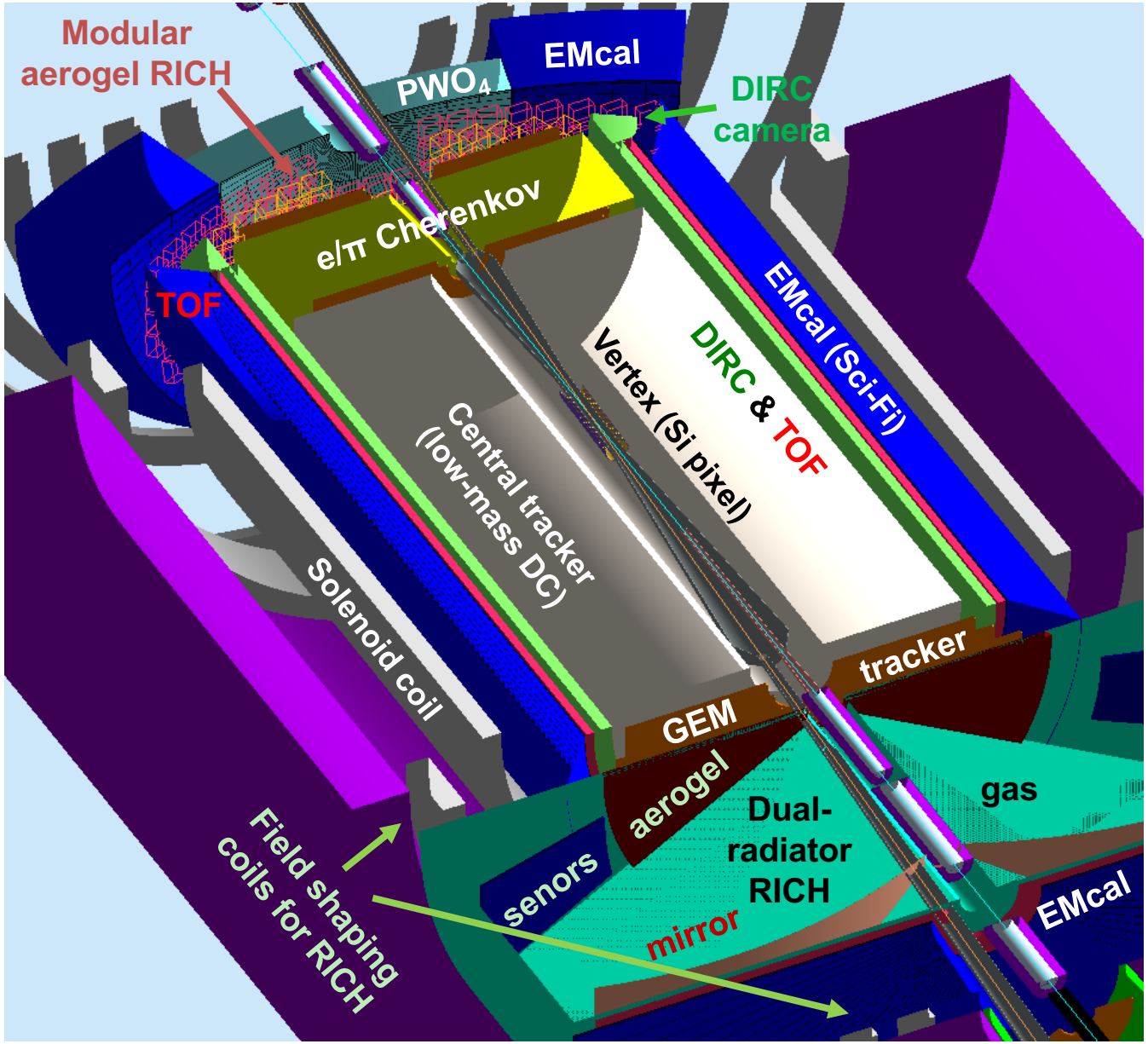
Design goals:

1. **Detection/identification of complete final state**
2. **Spectator p_T resolution < Fermi momentum**
3. **Low-Q^2 electron tagger for photoproduction**
4. **Integrated Compton polarimeter (e^- detection)**

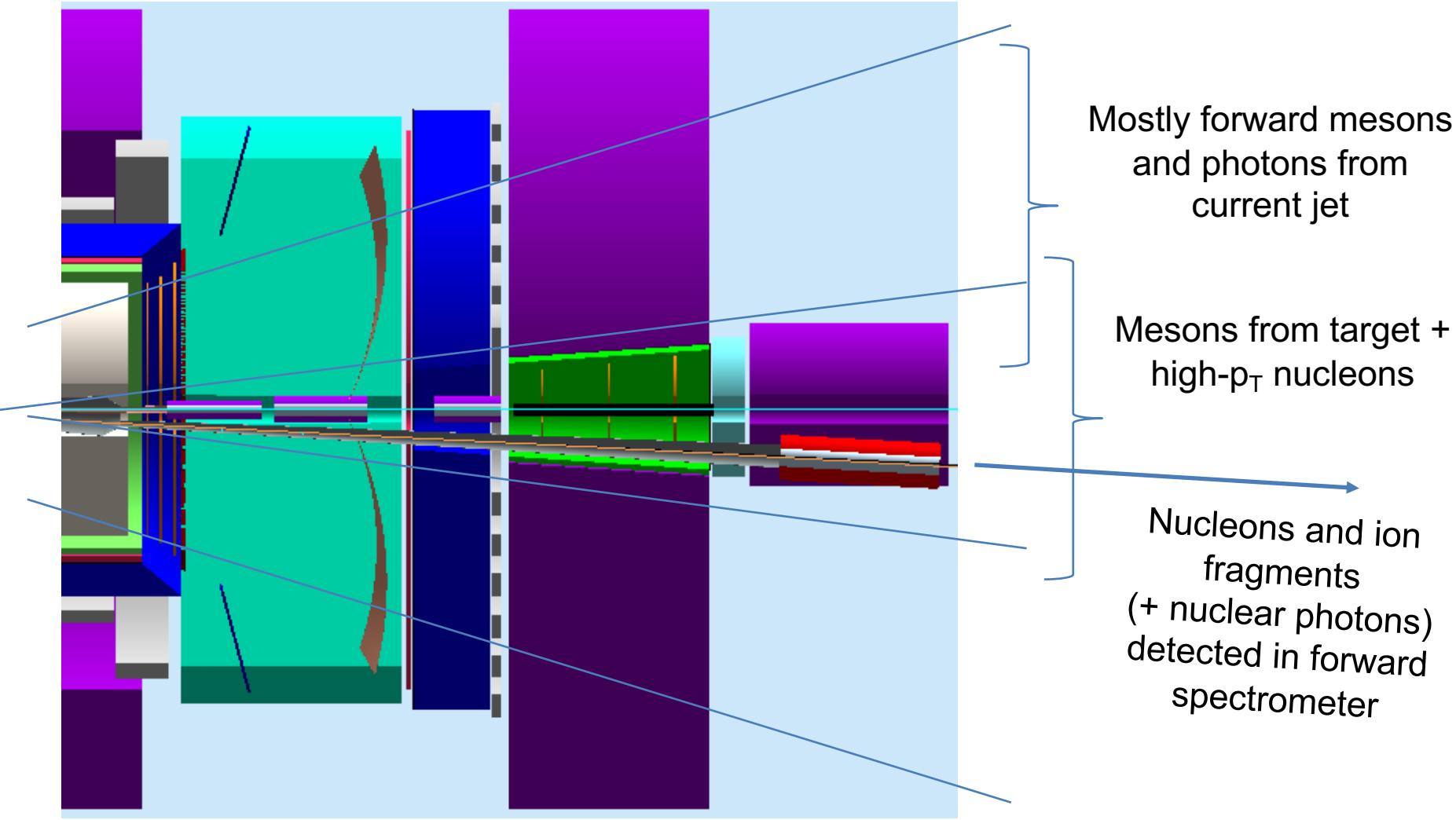
JLab central detector (doubly asymmetric)



Integration of Particle Identification (PID)



Detection of forward hadrons



Requirements for forward spectrometer

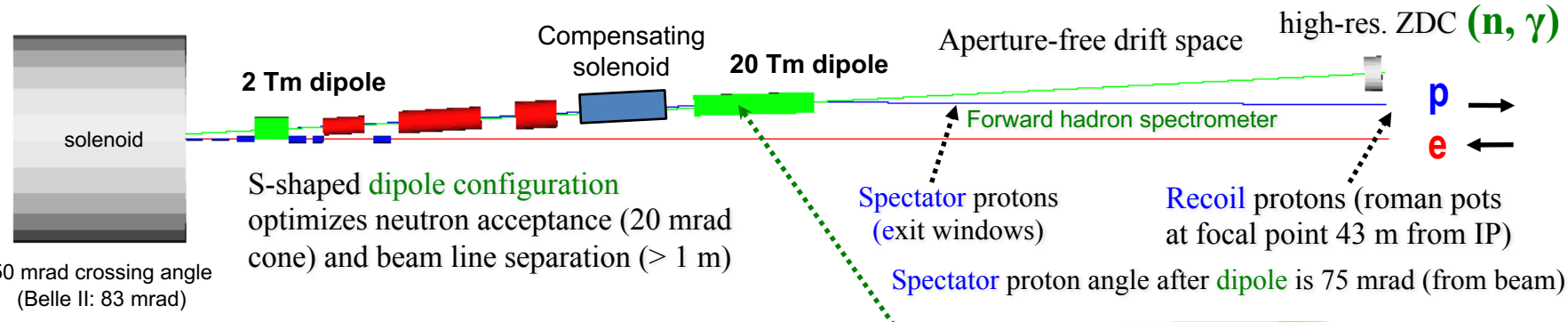
- Good acceptance for recoil nucleons (rigidity close to beam)
  - **Diffractive processes on nucleon; coherent nuclear reactions**
  - Small beam size at detection point (to get close to the beam)

    Secondary focus on roman pots, small beam emittance (cooling)
  - Large dispersion (to separate scattered particles from the beam)

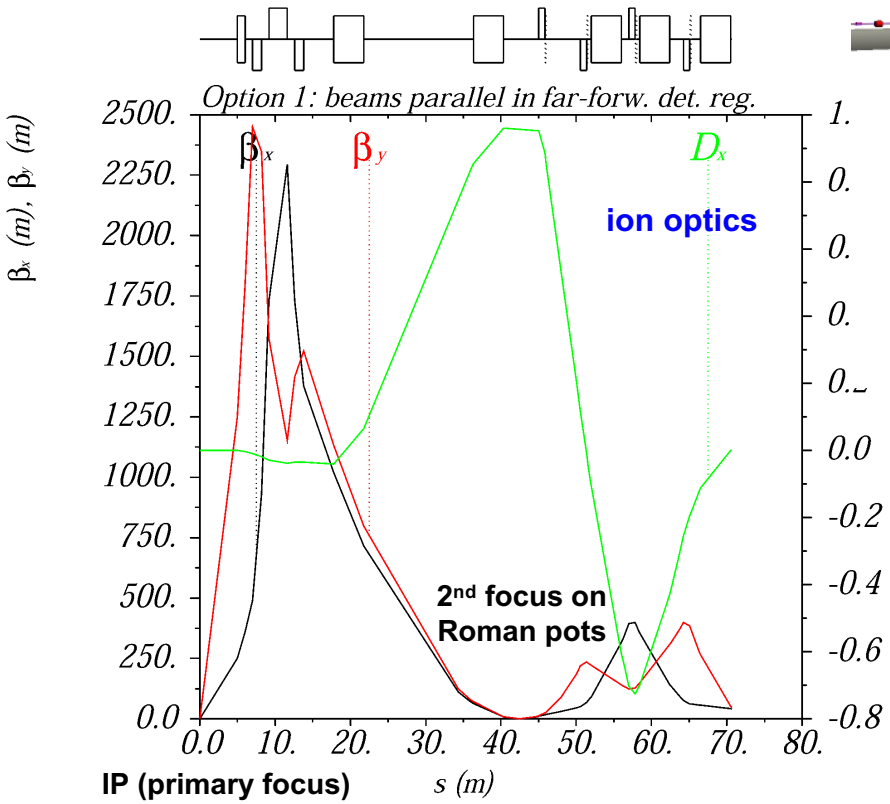
- Good acceptance for fragments (rigidity different than beam)
  - **Tagging in light and heavy nuclei**
  - Large magnet apertures (low gradients)
  - Detection at several points along a long, aperture-free drift region

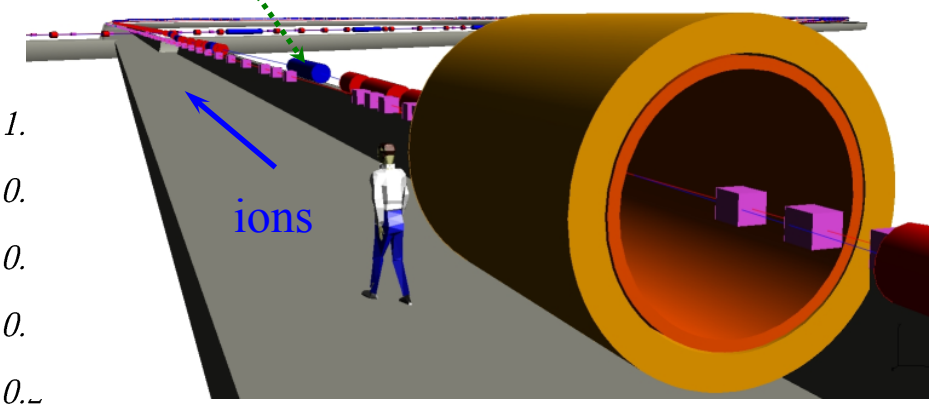
- Good momentum- and angular resolution
  - **Free neutron structure through spectator tagging;**
    3D imaging through recoil baryon detection

Forward hadron detection



S-shaped dipole configuration optimizes neutron acceptance (20 mrad cone) and beam line separation (> 1 m)



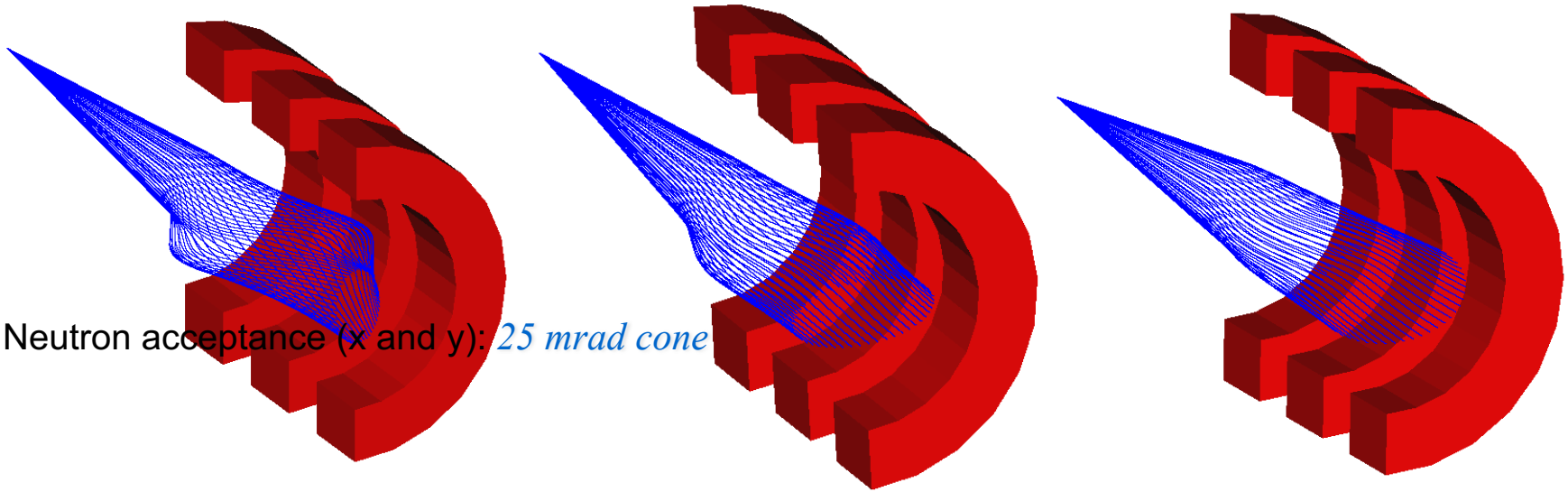


- Large 20 Tm dipole provides excellent resolution
- Large *dispersion* and small *beam size* at secondary focus ensure good acceptance for recoil protons
- Large quadrupole apertures (1 / *max* beam energy) give good acceptance for hadronic and nuclear fragments, charged and neutral (high res. ZDC).

Far-Forward Acceptance for Charged Fragments

(protons rich fragments) ⟵ ⟶ (neutron rich fragments)

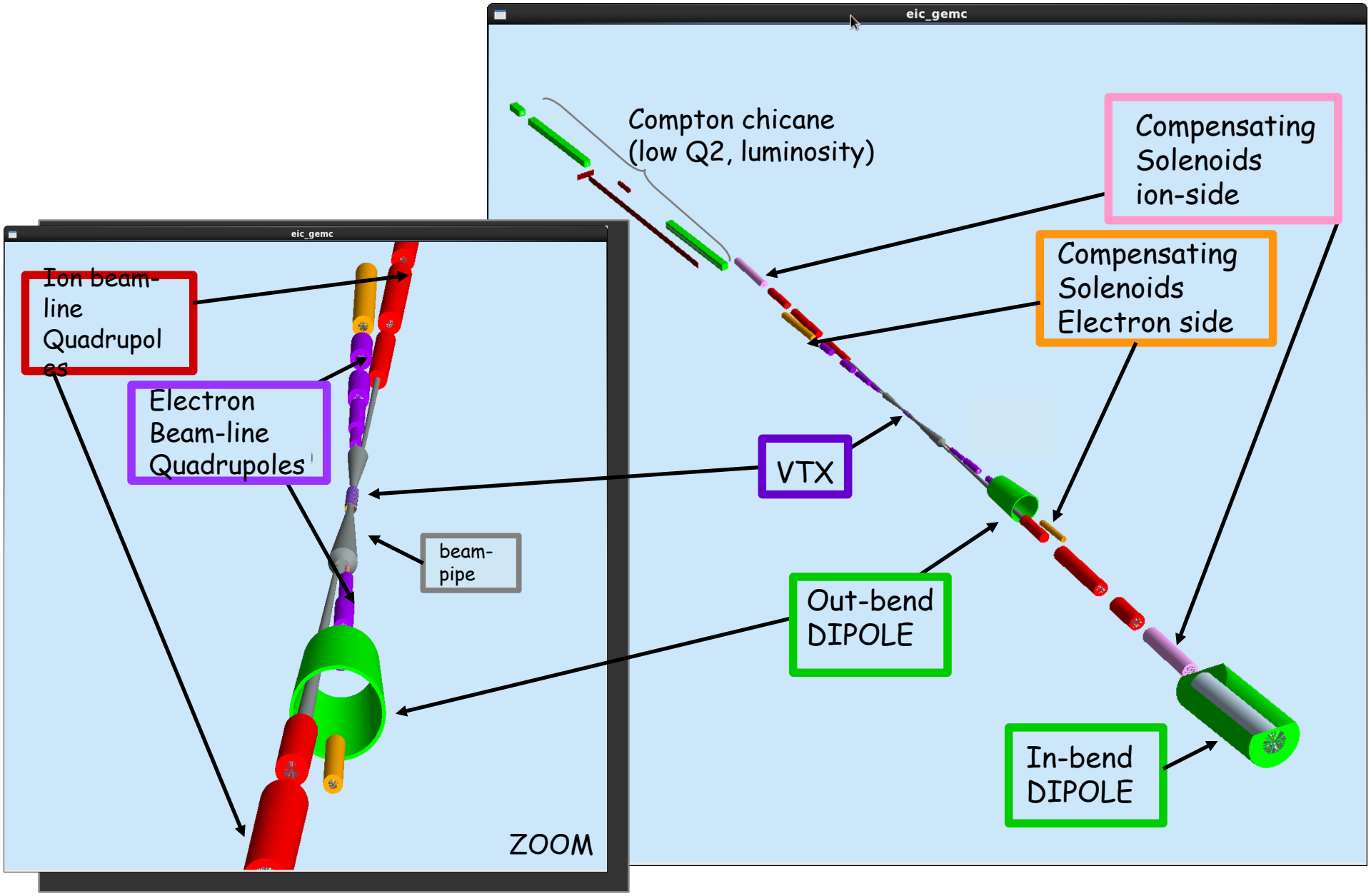
$\Delta p/p = -0.5$	$\Delta p/p = 0.0$	$\Delta p/p = 0.5$
(spectator protons from deuterium)	(exclusive / diffractive recoil protons)	(tritons from N=Z nuclei)



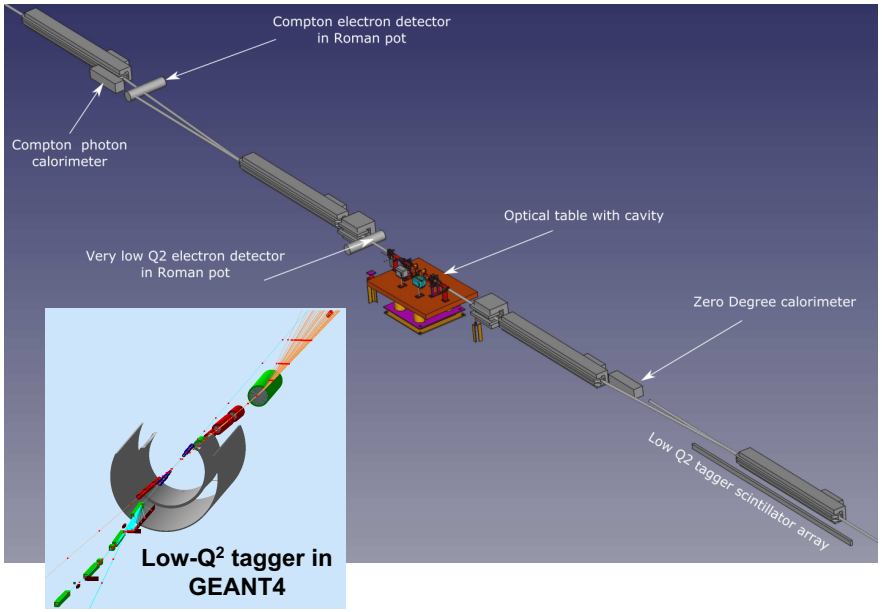
Neutron acceptance (x and y): *25 mrad cone*

- Full acceptance for all partonic and nuclear fragments achieved
- Neutron acceptance (x and y): ~ *20 mrad cone*
- Detector resolution designed to be better than intrinsic momentum and angular spread of the beam
  - Longitudinal (dp/p): *few x10^{-4}*
  - Angular (θ, for all φ): *~ 0.3 mrad*

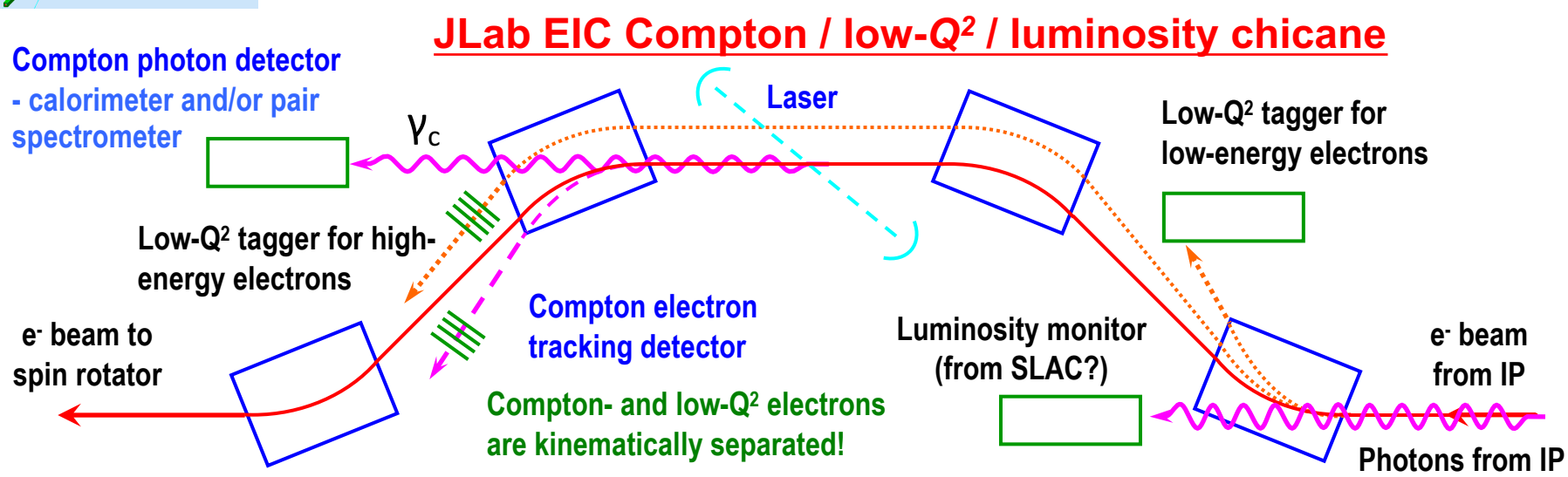
Interaction region magnets in GEANT4



Electron polarimetry and photoproduction

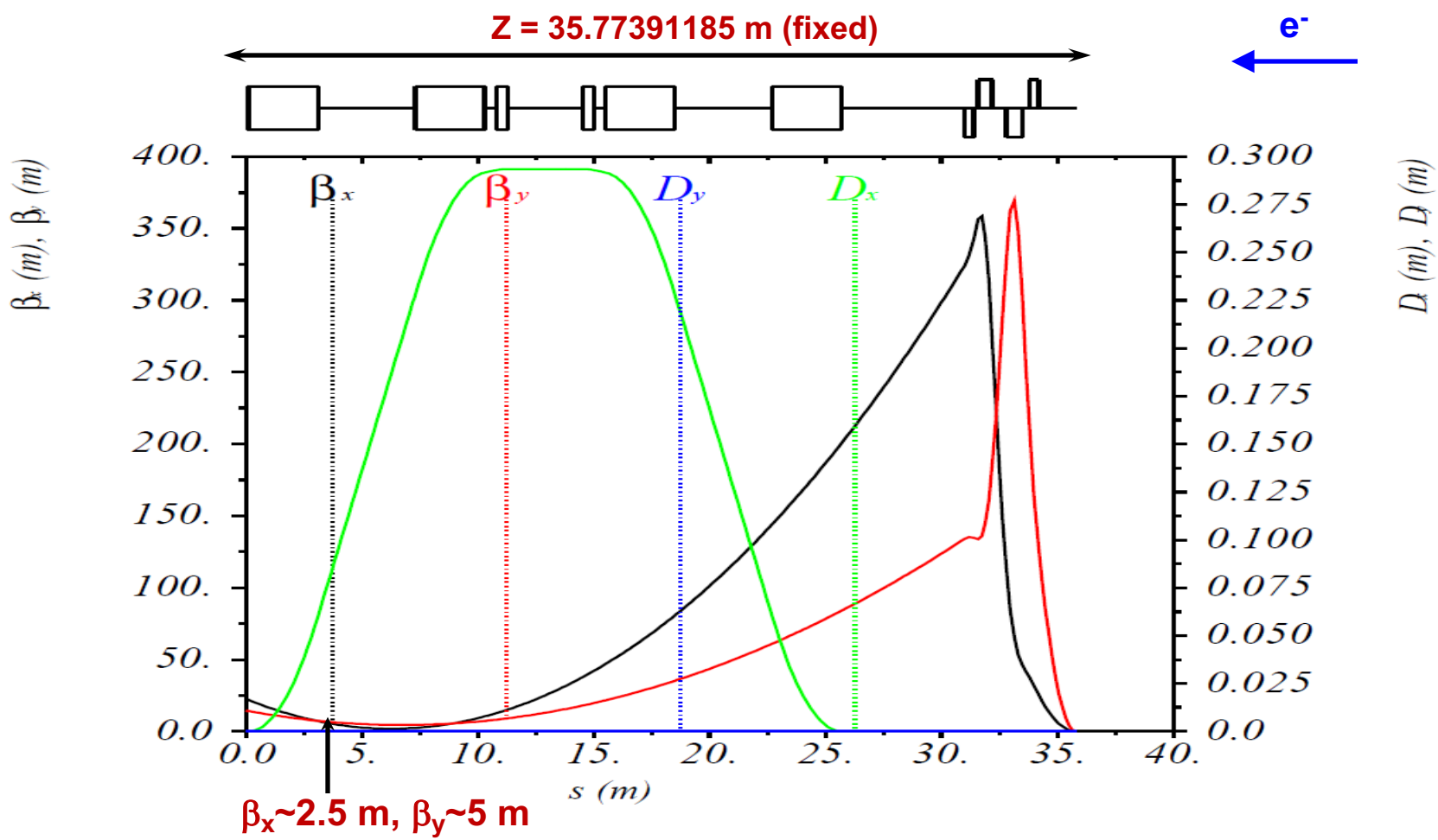


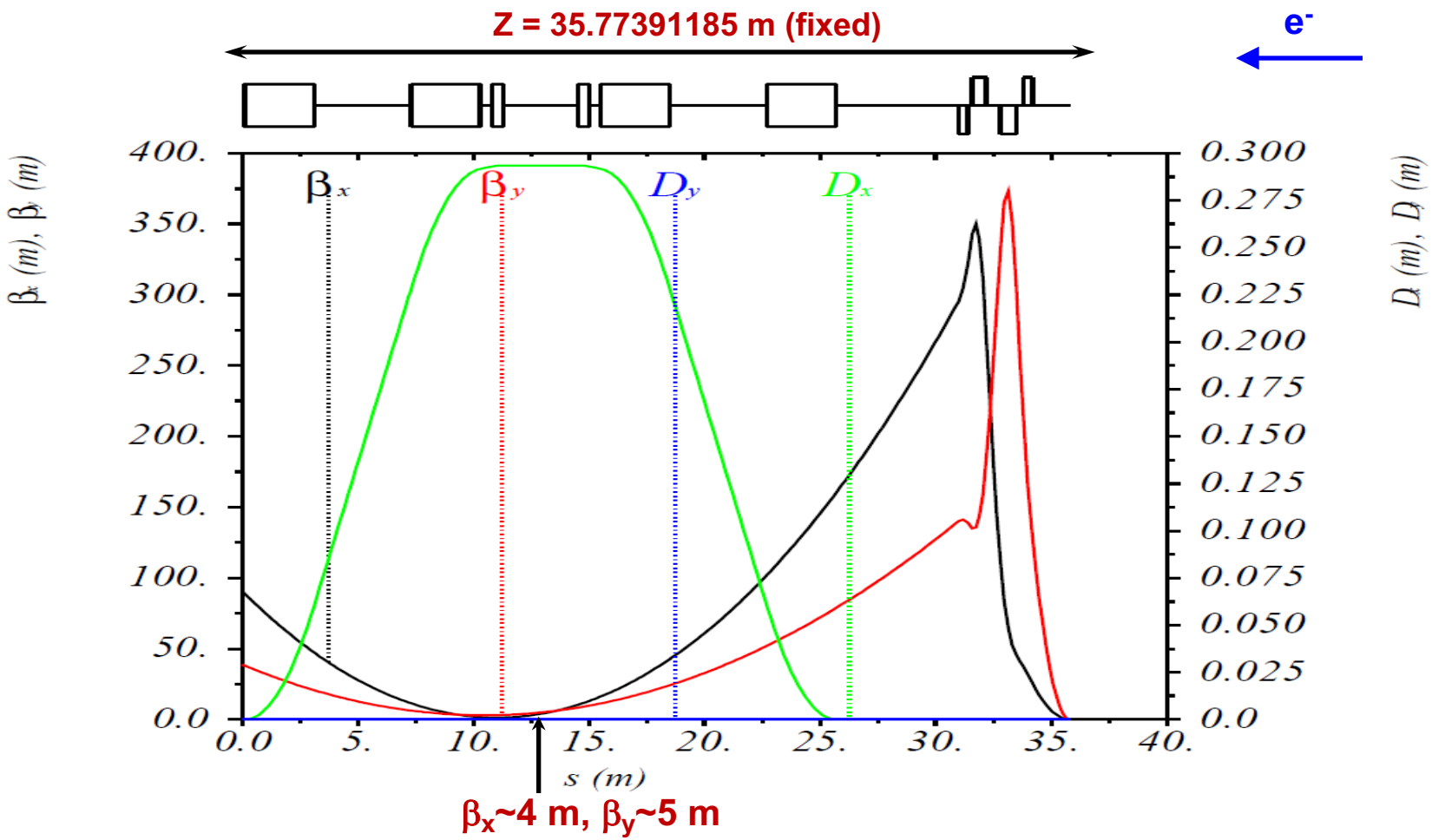
- Compton polarimetry experience from JLab and SLAC important for the EIC
  - SLAC reached 0.5% detecting (high-energy) Compton electrons
  - JLab Halls A/C reach < 1% detecting both γ *and* e at low energy (small asymmetry)
- (Tagged) photoproduction of heavy quarkonia (*e.g. J/ψ*) is important for imaging the gluon distribution



Electron optics: focus on detector (laser w/o FP cavity)

- FFQs @ 10 GeV: **14.7**T/m 0.4m; 42.6T/m 0.7m; 34.9T/m 0.6m; 5.2T/m 0.4m.



Electron optics: focus on FP cavity

- FFQs @ 10 GeV: **15.7**T/m 0.4m; 43.3T/m 0.7m; 38.5T/m 0.6m; 9.7T/m 0.4m.