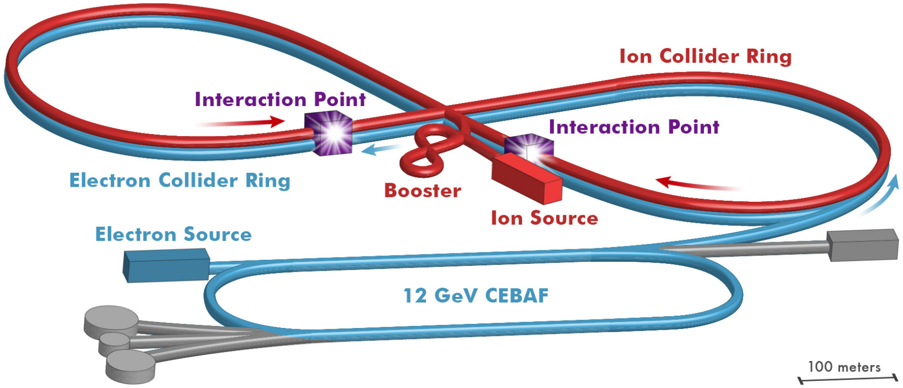
JLEIC IR and Detector Design Considerations

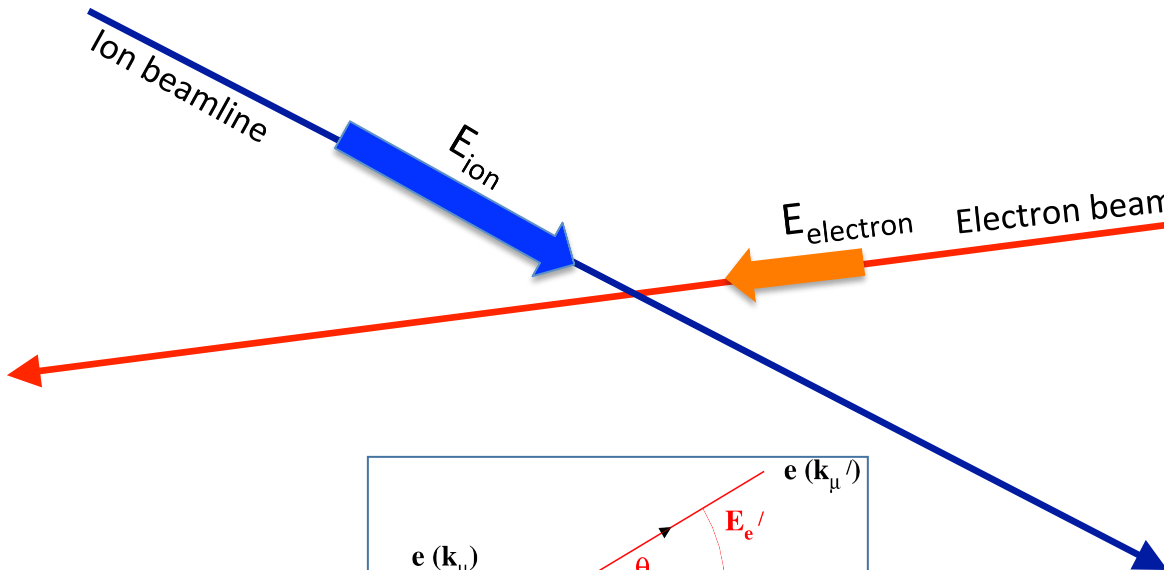
R. Yoshida for the JLEIC Detector & IR Study Group



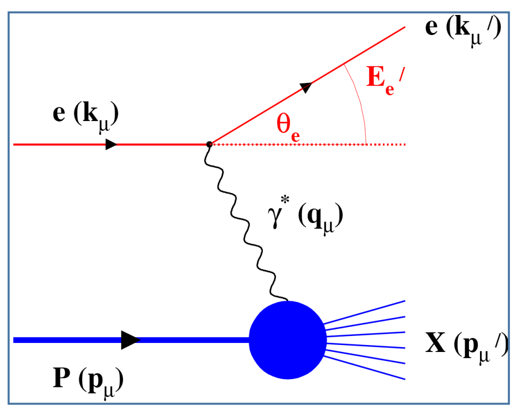
GENERAL DESIGN CONSIDERATIONS

DIS and Final State Particles

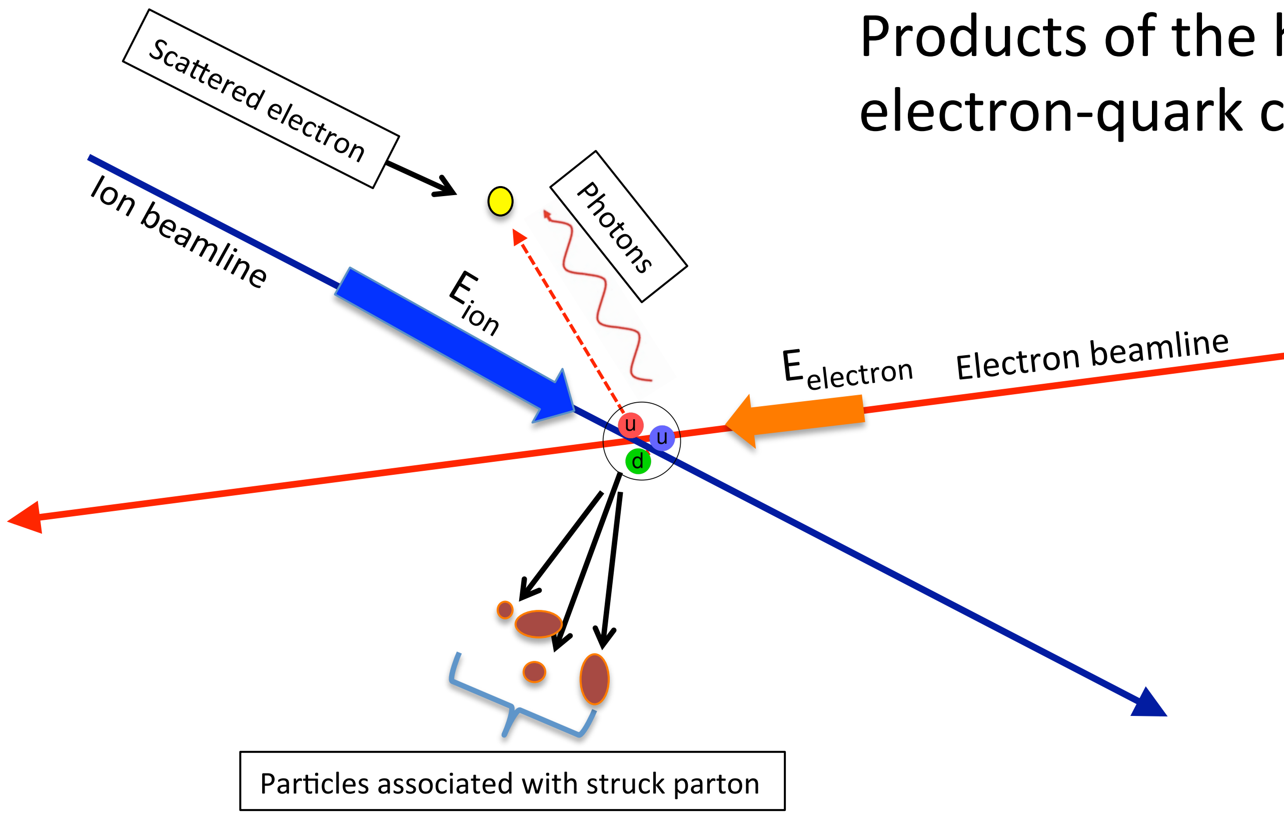
Aim of EIC is nucleon and nuclear structure beyond the longitudinal description. This makes the requirements for the machine and detector different from all previous colliders **including HERA**.



Need more than this



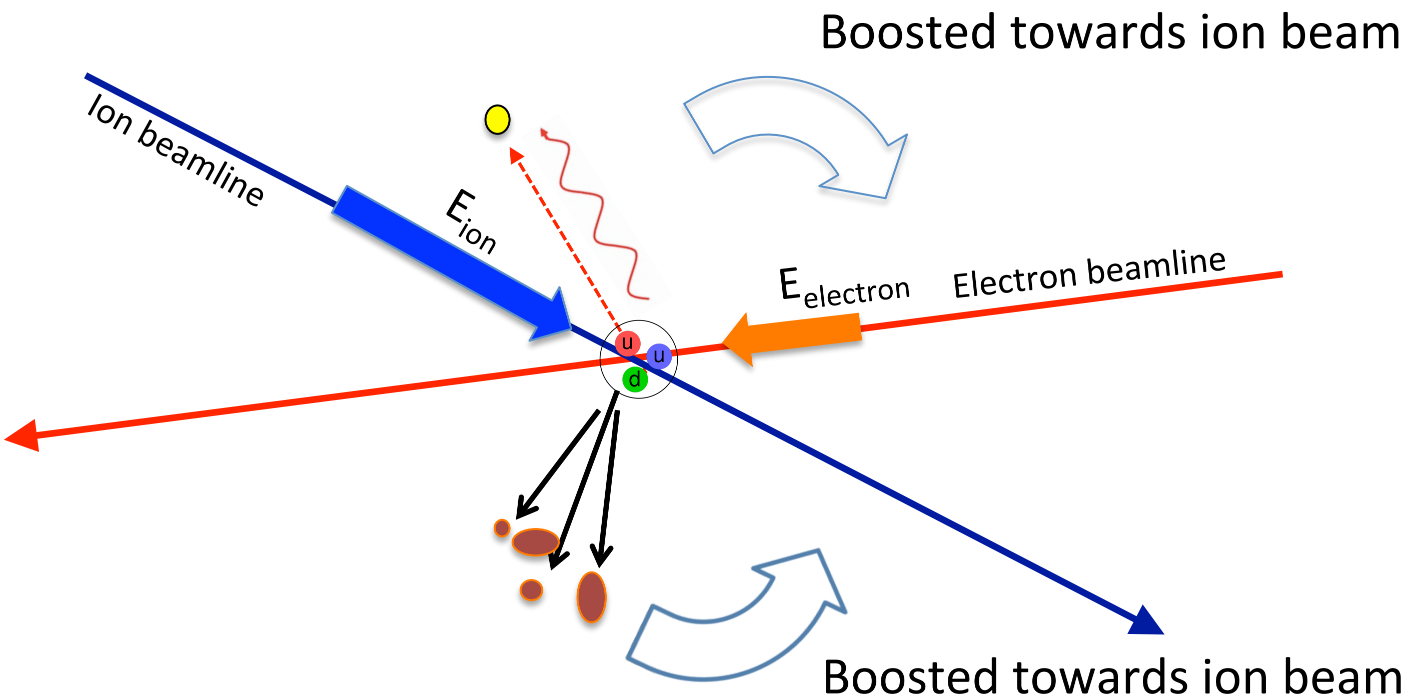
Final State Particles in the Central Rapidity



Products of the hard electron-quark collision

Transverse and flavor structure measurement of the nucleon and nuclei: The particles associated with struck parton must have its species identified and measured. **Particle ID much more important than at HERA**

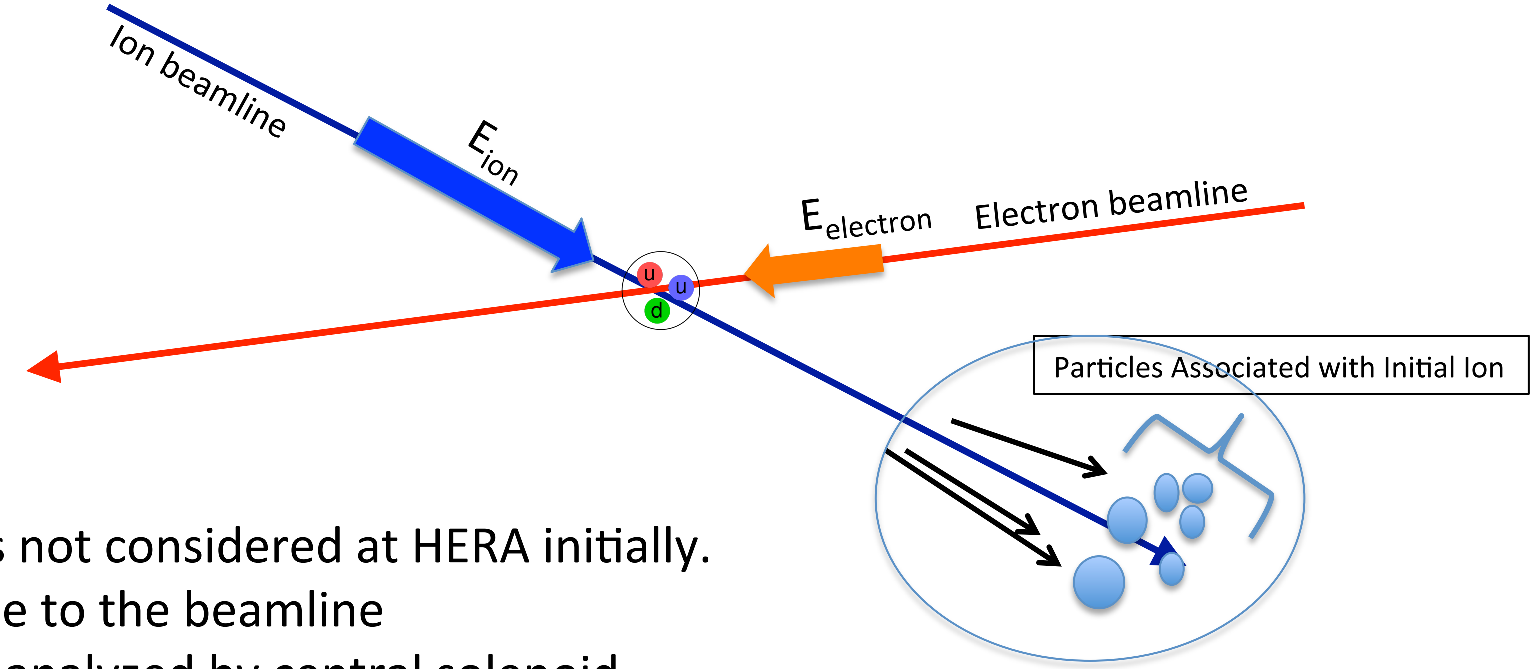
Final State Particles in the Central Rapidity



Asymmetric collision energies will boost the final state particles in the ion beam direction: **Detector requirements change as a function of rapidity**

Particles Associated with the Initial Ion

For EIC, particles of the “target remnant” is as important as the struck parton



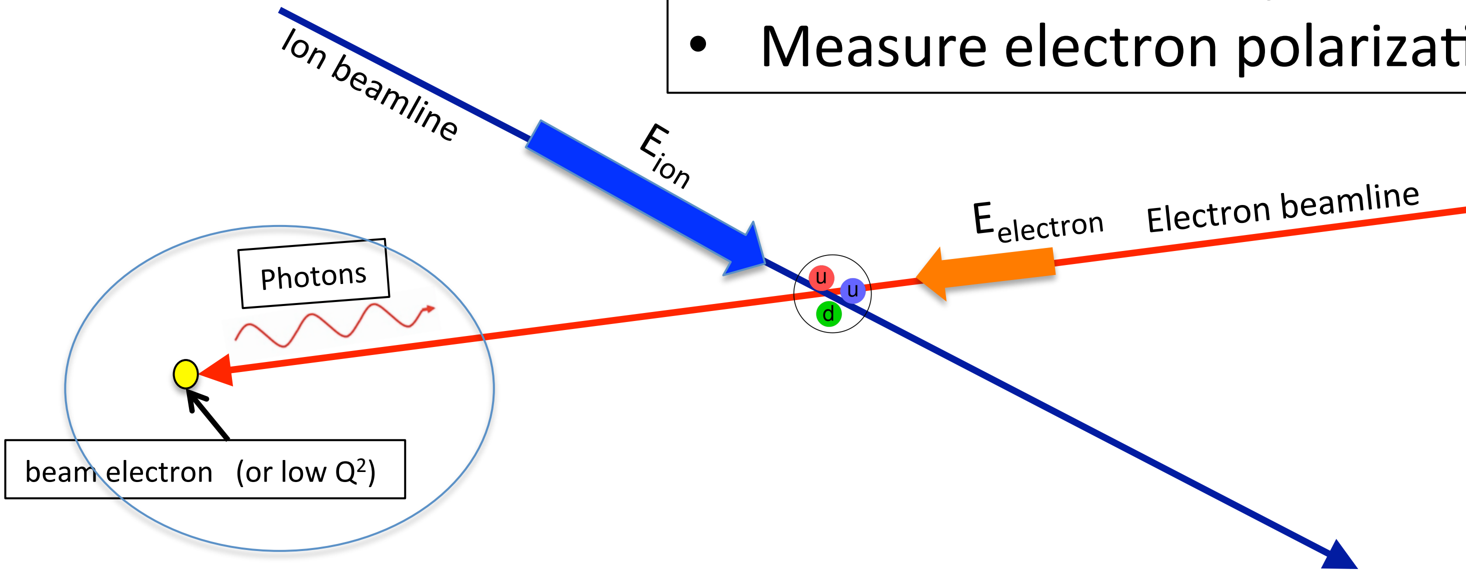
- Was not considered at HERA initially.
- Close to the beamline
- Not analyzed by central solenoid.
- **Aim for ~100% acceptance and good resolution at EIC.**

Remember acceptance is equally important as luminosity!

Particles Associated with the Initial Electron

Forward Electron area:

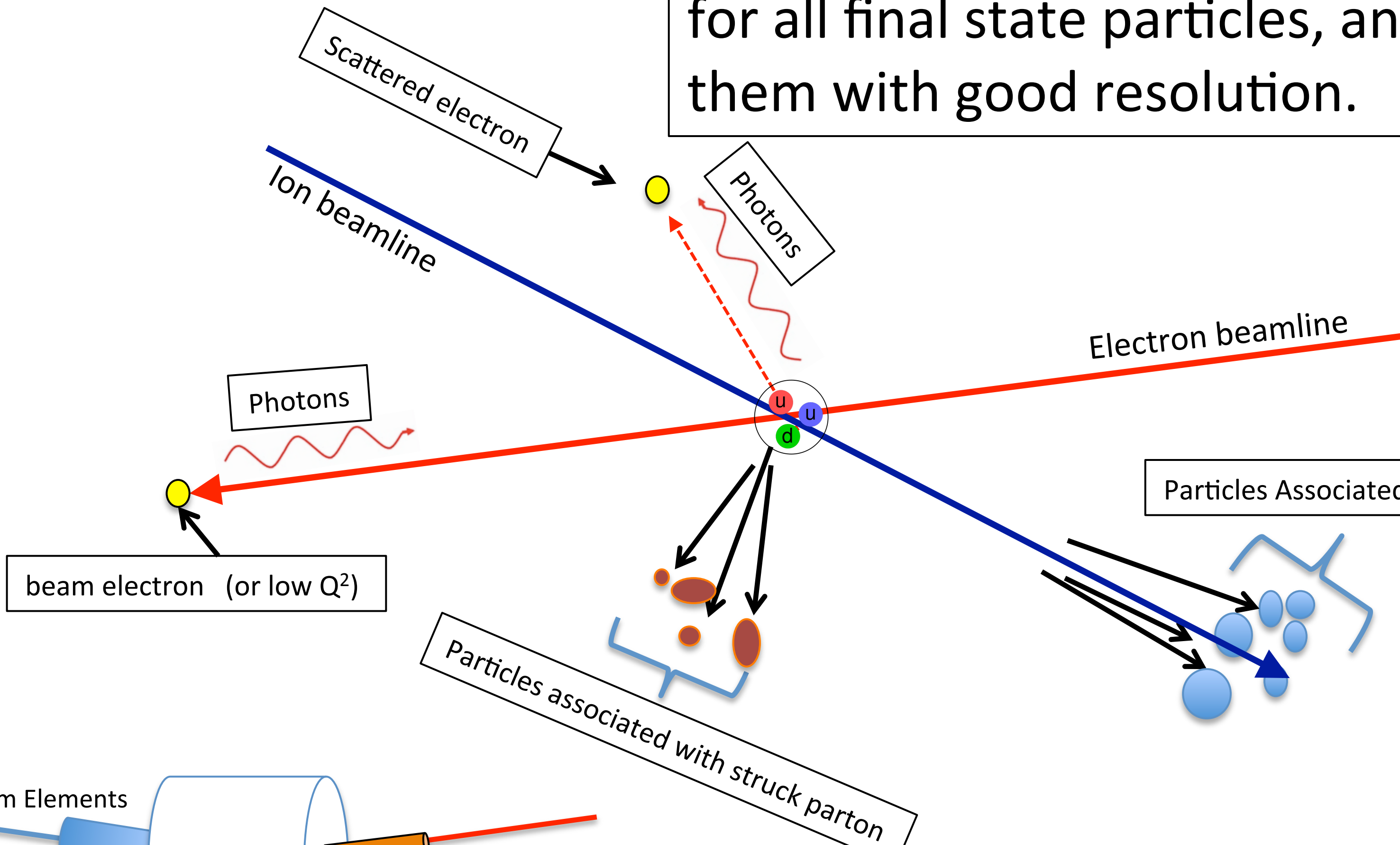
- Tag photoproduction ($Q^2 \approx 0$)
- Measure Luminosity
- Measure electron polarization

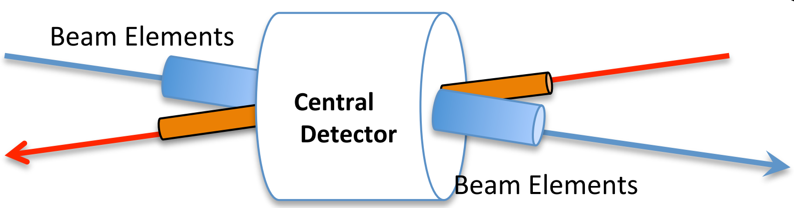


Apply lessons from HERA, JLab and elsewhere

Final State Particles

The aim is to get ~100% acceptance for all final state particles, and measure them with good resolution.



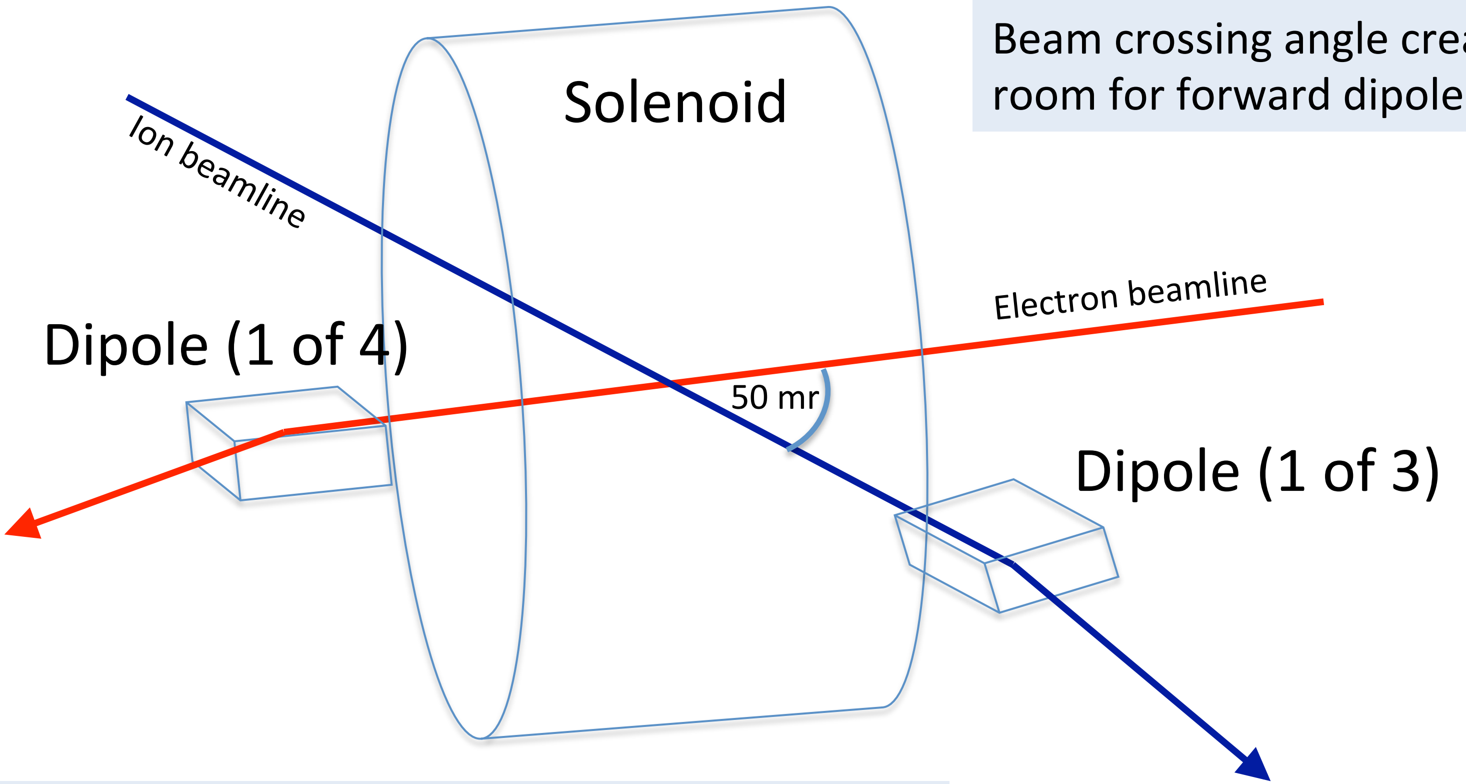


Beam elements limit forward acceptance
Central Solenoid not effective for forward

Interaction Region Concept

NOT TO SCALE!

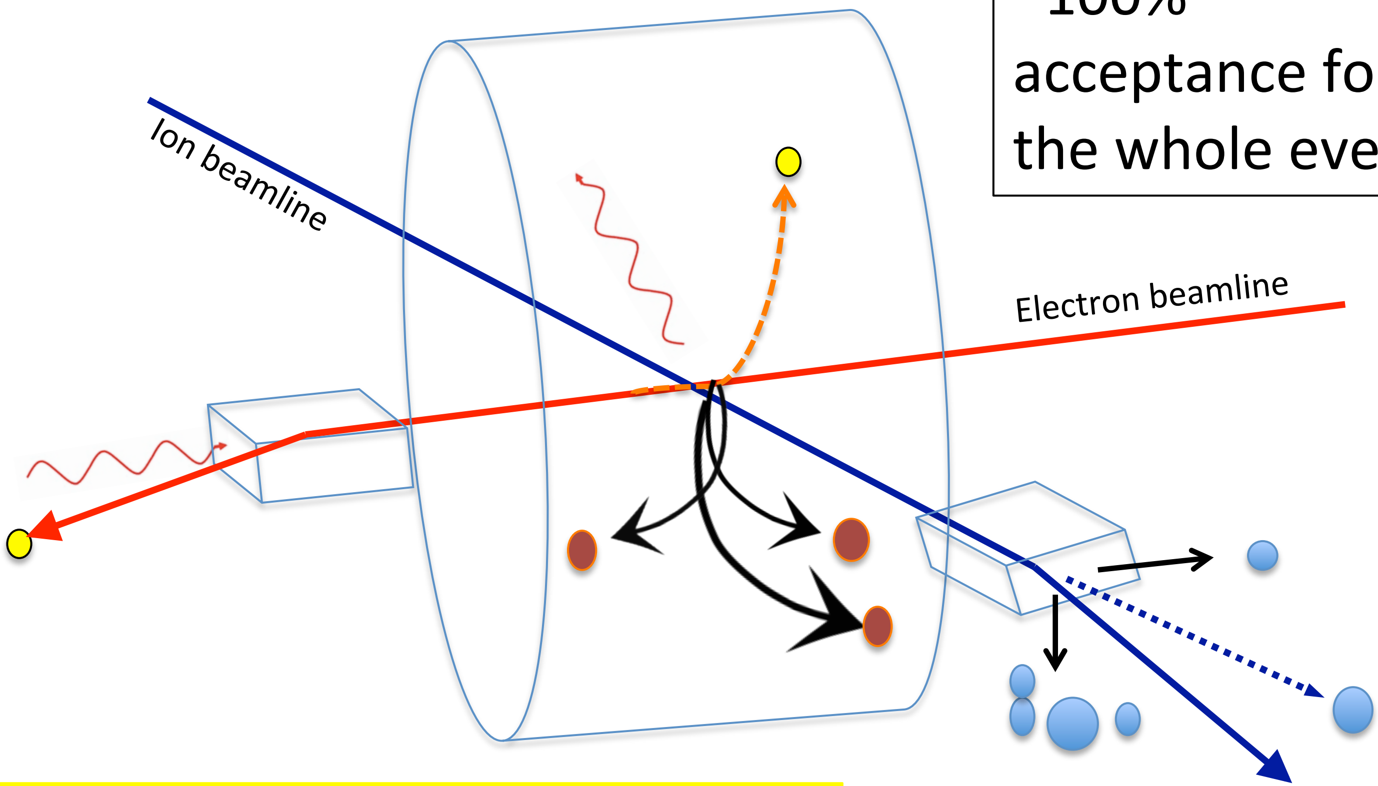
Beam crossing angle creates room for forward dipoles



Dipoles analyze the forward particles
and create space for detectors in the forward direction

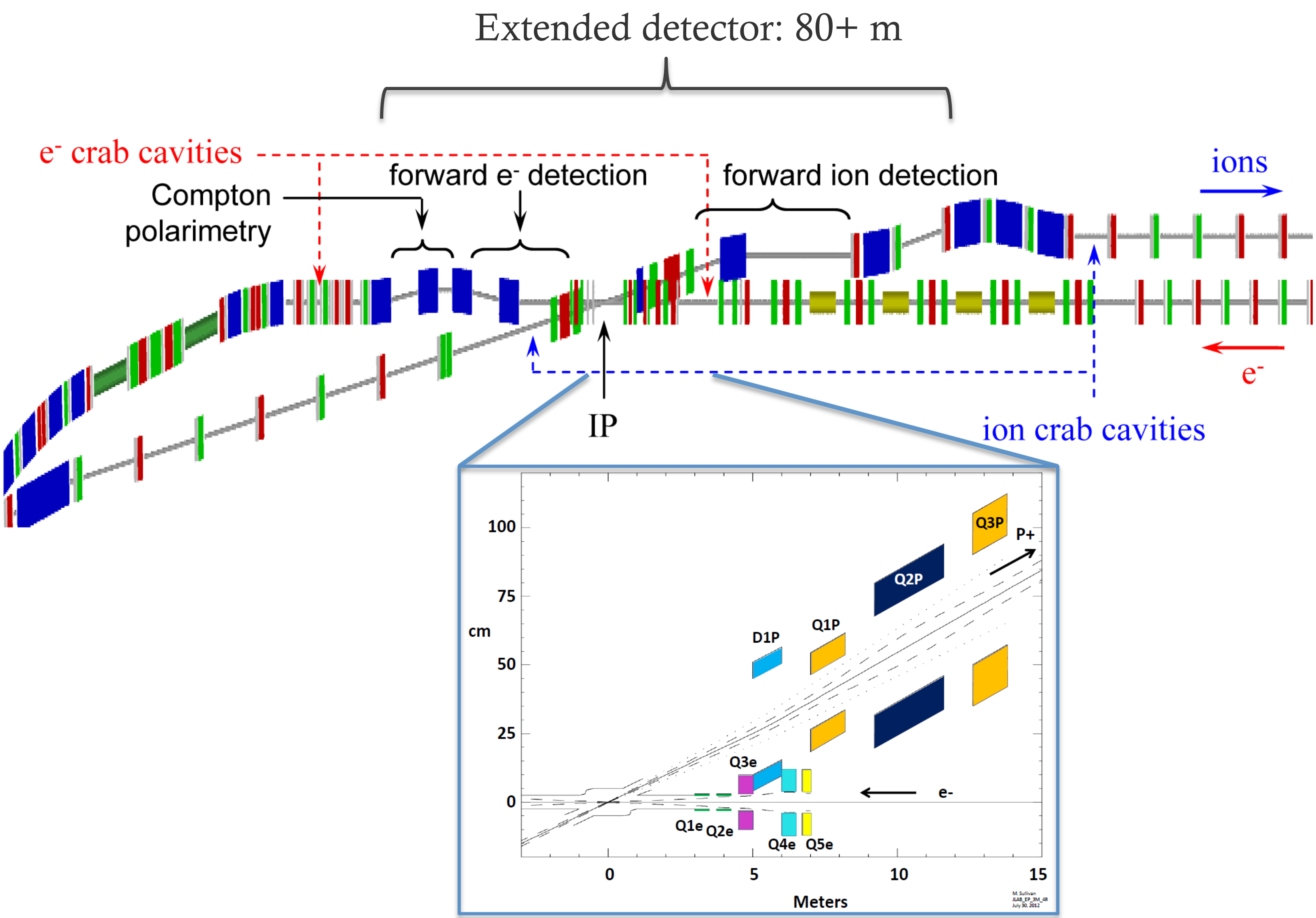
Interaction Region Concept

Possible to get ~100% acceptance for the whole event



Total acceptance detector (and IR)

JLEIC IR Layout

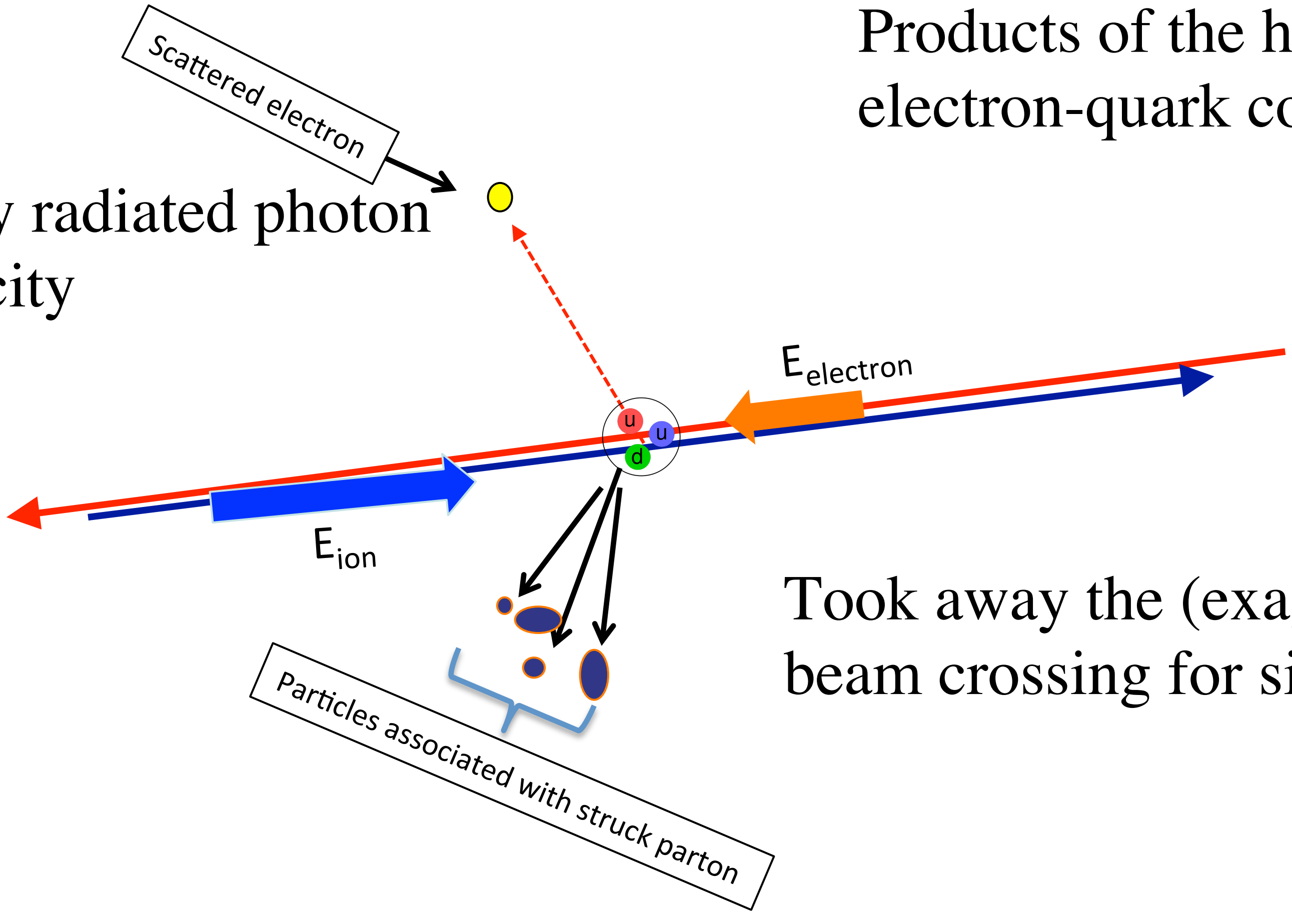


CENTRAL DETECTOR

Final State Particles in the Central Detector

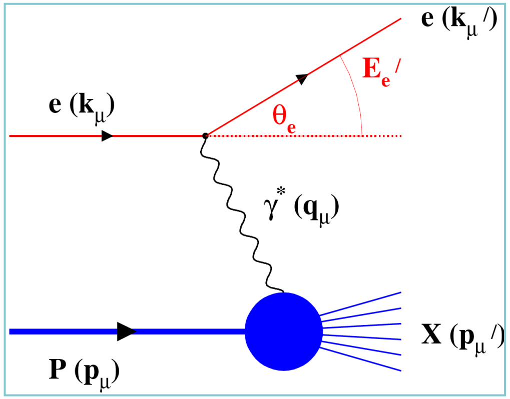
Products of the hard electron-quark collision

Took away radiated photon for simplicity



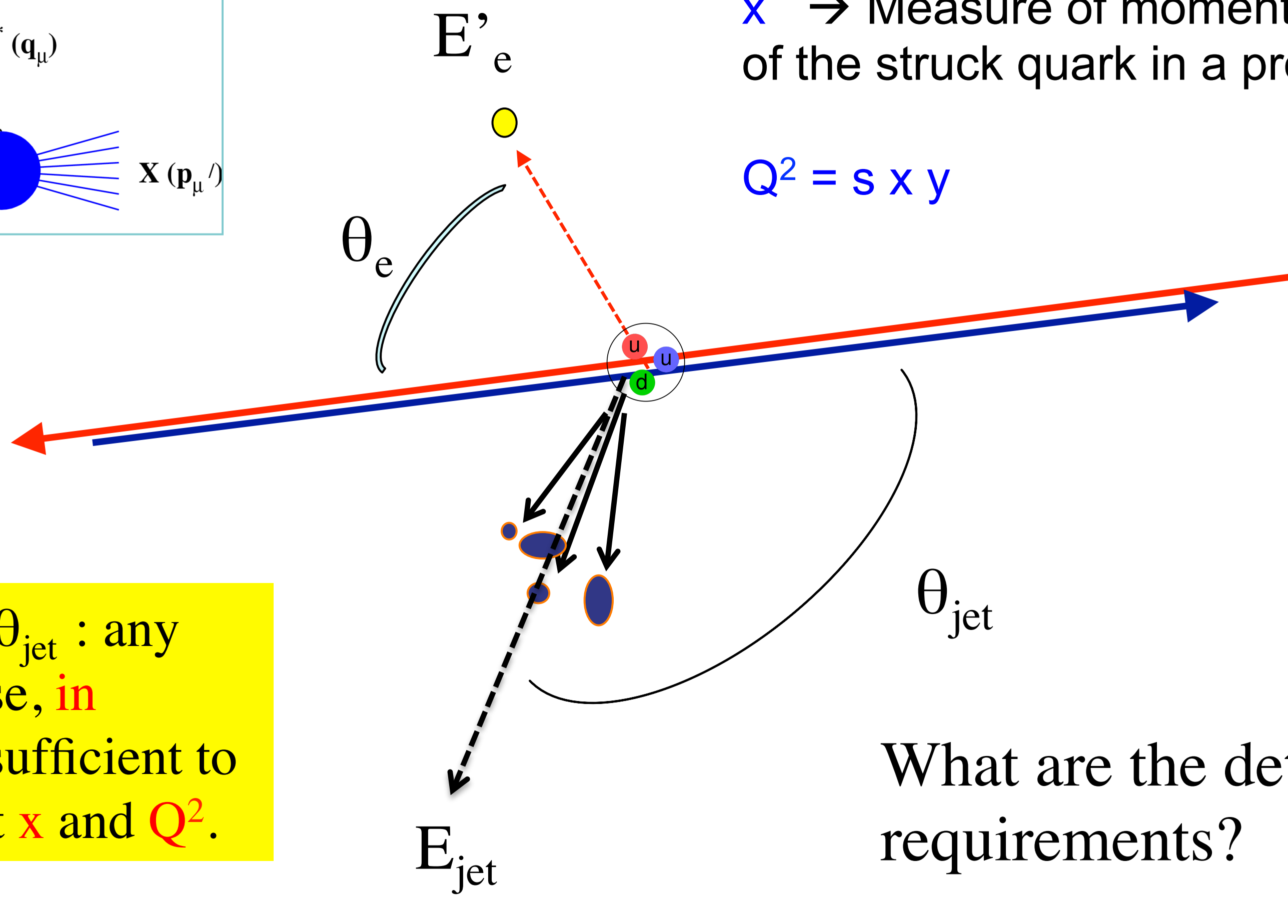
Took away the (exaggerated) beam crossing for simplicity

Basic Kinematic Reconstruction



Q^2 → Measure of resolution
y → Measure of inelasticity
x → Measure of momentum fraction of the struck quark in a proton

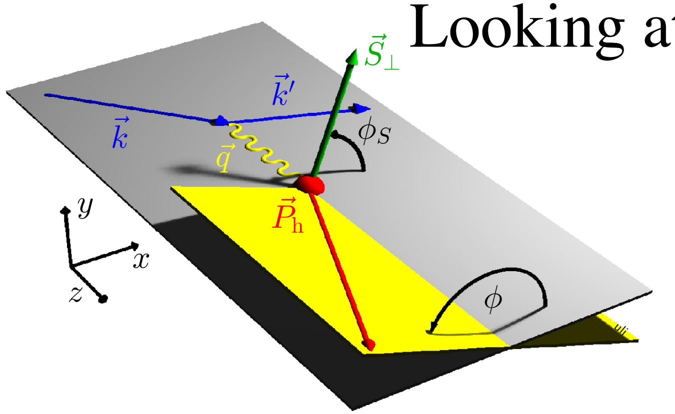
$Q^2 = s\ x\ y$



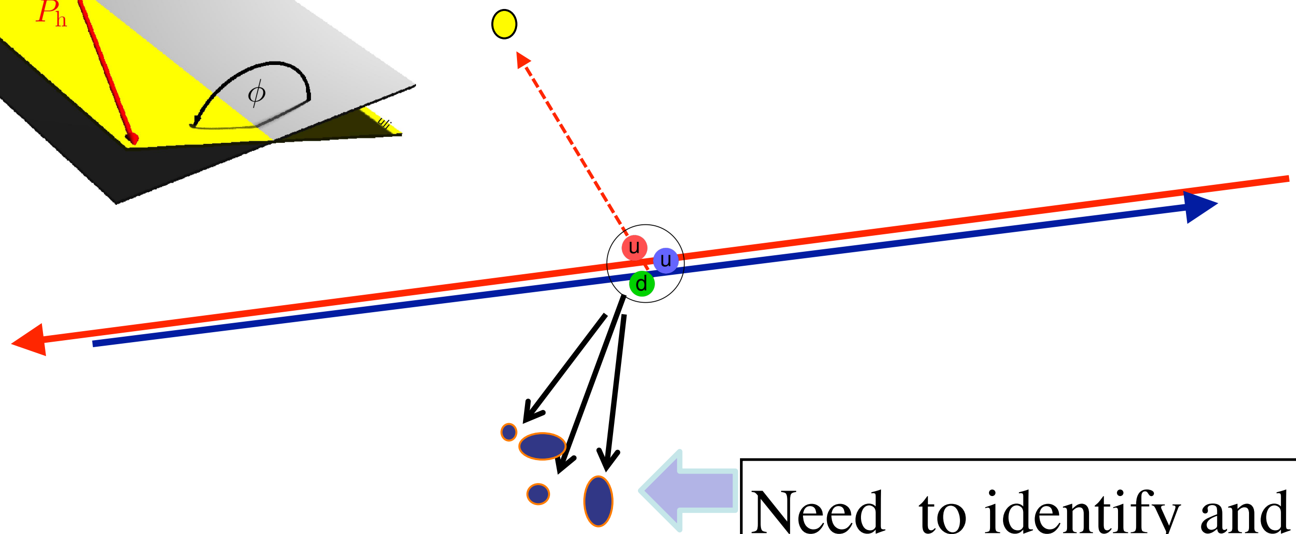
$E'_e, \theta_e, E_{jet}, \theta_{jet}$: any two of these, in principle, sufficient to reconstruct x and Q^2.

What are the detector requirements?

Reconstruction for Transvers Structure



Looking at out-of –plane component in the final state



Need to identify and measure these particles

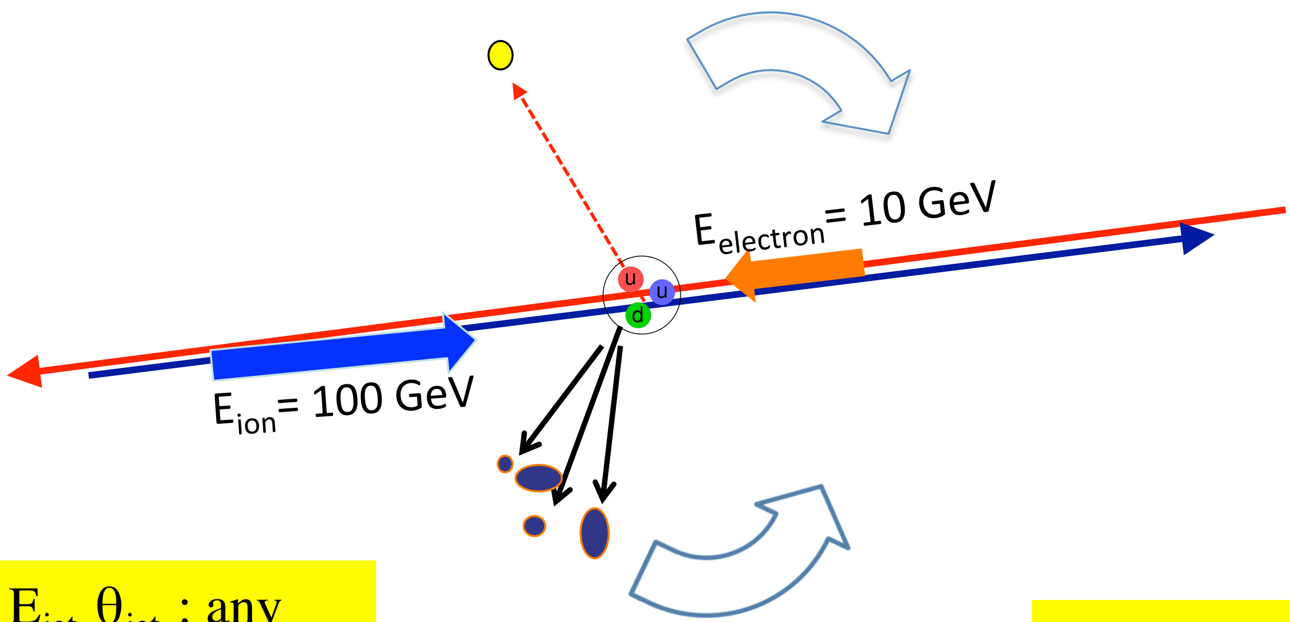
What are the detector requirements?

Note: multiplicities are low (~20 for ep)
Cross-sec x Lumi < 0.01 x HLLHC
< 0.1 interaction/crossing

How Boosted is the Final State?

No Monte Carlo needed to Determine

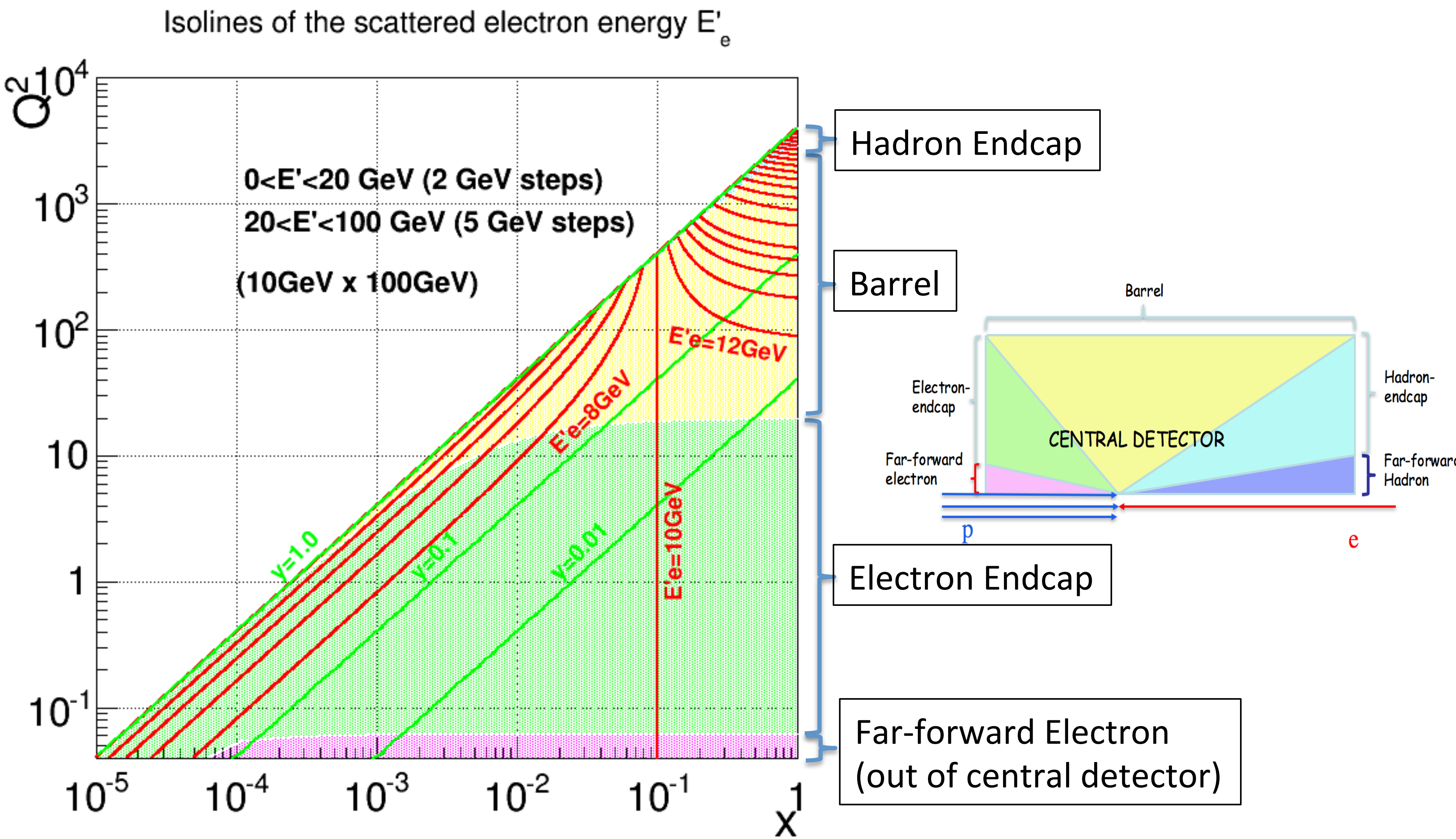
Boosted towards ion beam



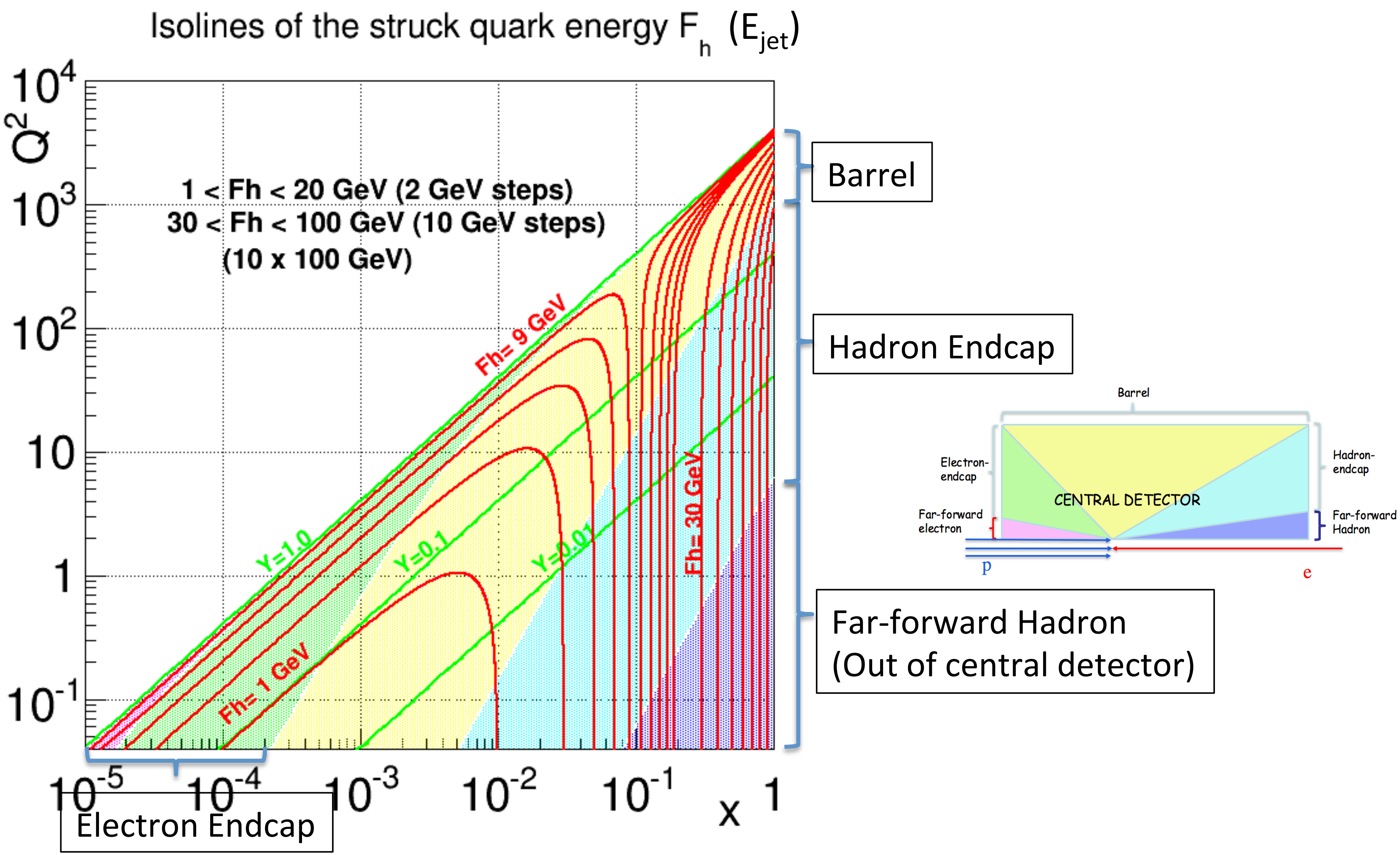
$E'_{e}, \theta_{e}, E_{jet}, \theta_{jet}$: any two of these, in principle, sufficient to reconstruct x and Q^2.

Given x and Q^2, $E'_{e}, \theta_{e}, E_{jet}, \theta_{jet}$ are all fixed

Electron Isoline Plot



Quark(Jet) Isoline Plot

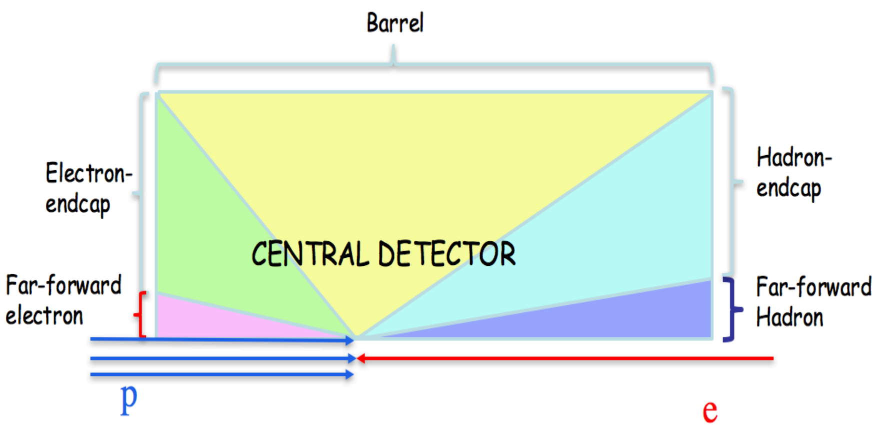


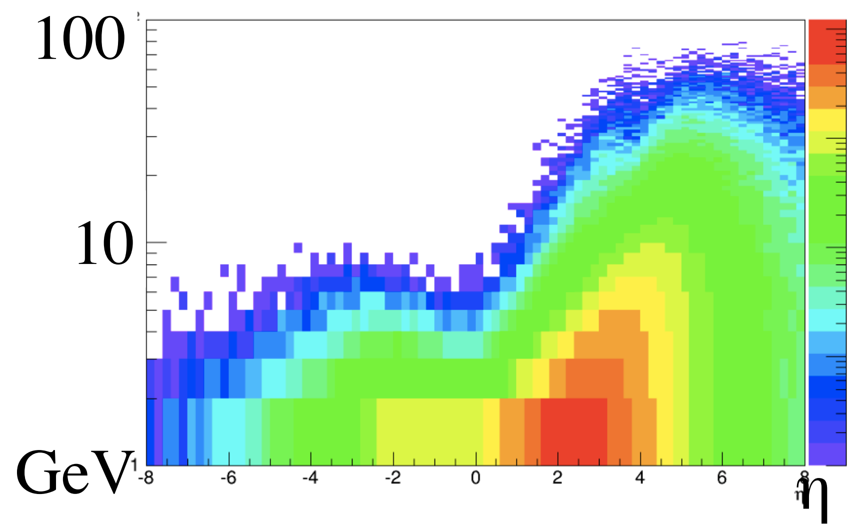
Particle Distribution

	E-endcap	Barrel	H-endcap
E'e	<8 GeV	8-50 GeV	>50 GeV
Ejet	<10 GeV	~10-50 GeV	20-100 GeV
E,hadrons	<10 GeV	<15 GeV	~15-50 GeV
occupancy	low	medium	high

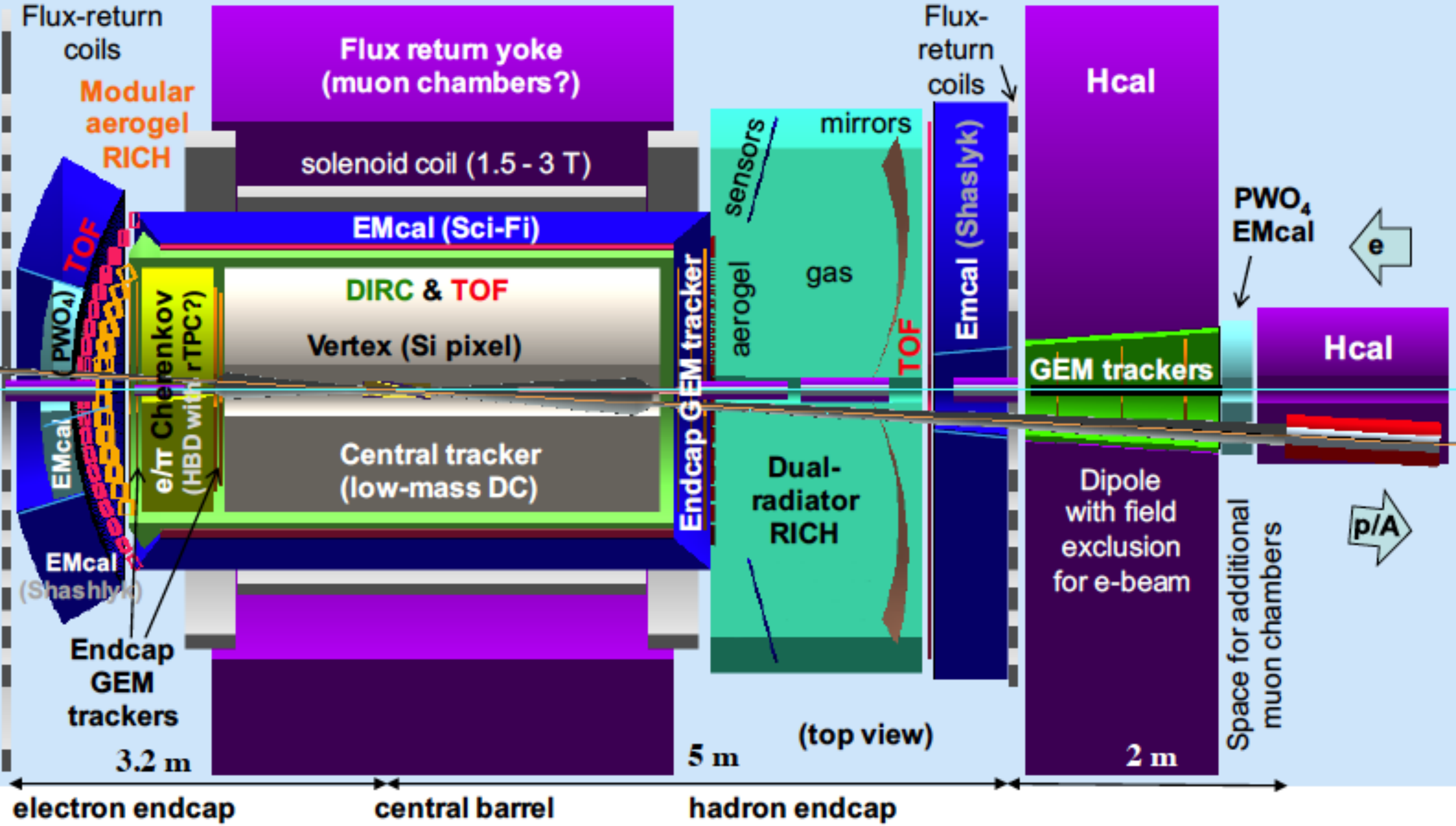
Pythia MC

$\pi^{\pm}$ Energy



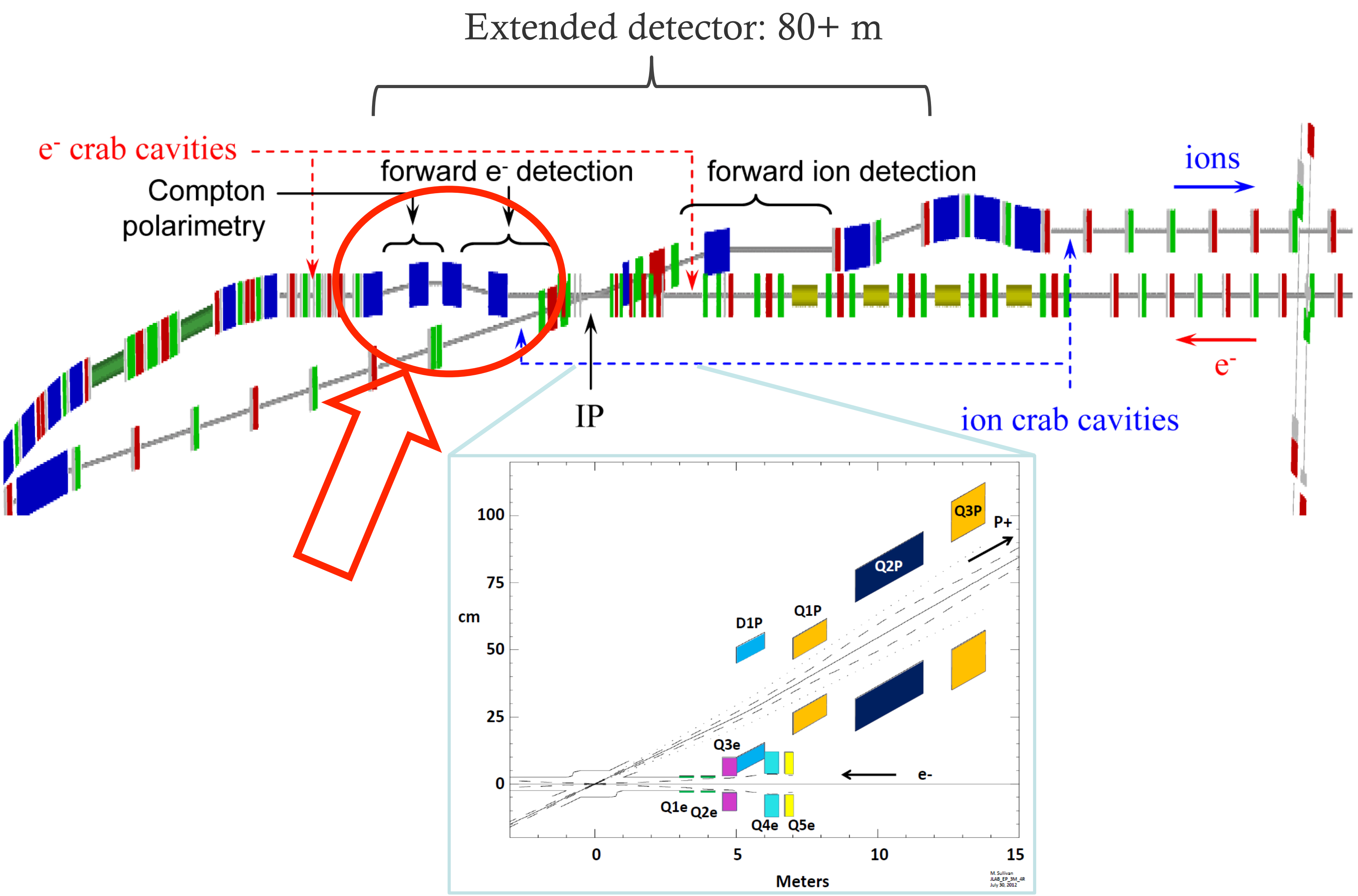


Current JLEIC Concept



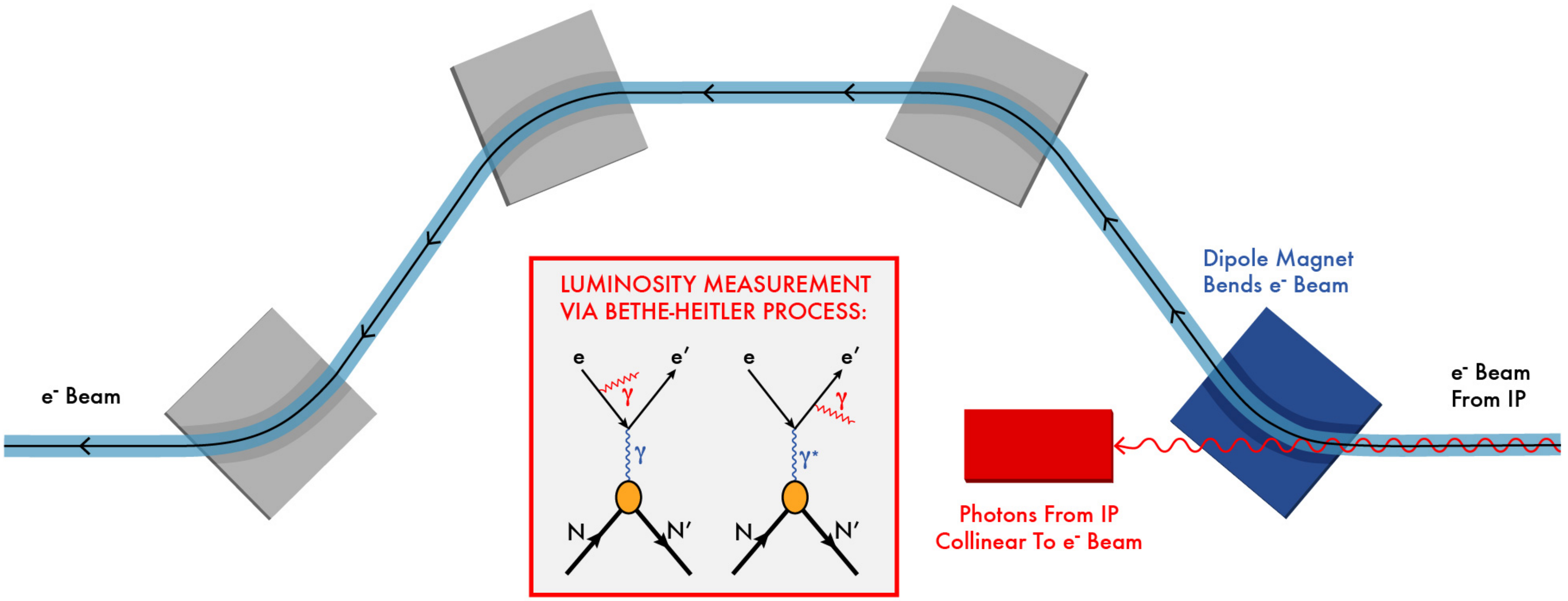
ELECTRON-BEAM DIRECTION

Chicane for Electron Forward Area

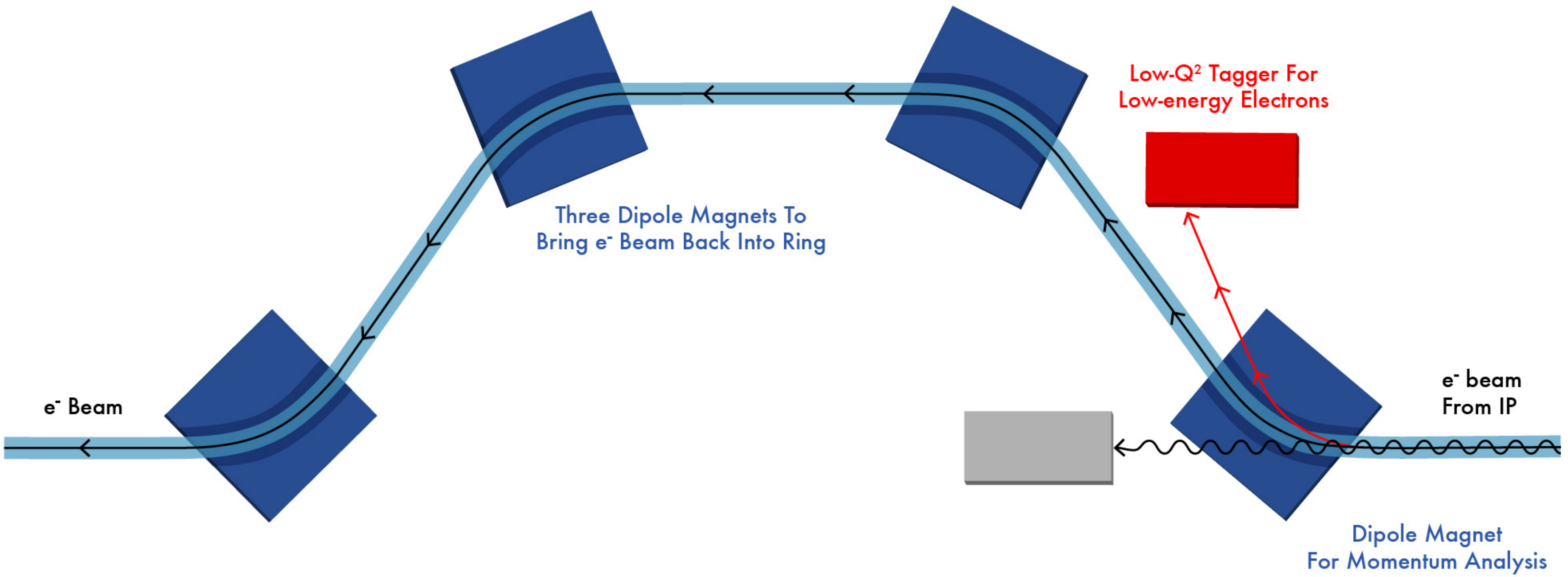


Luminosity Measurement

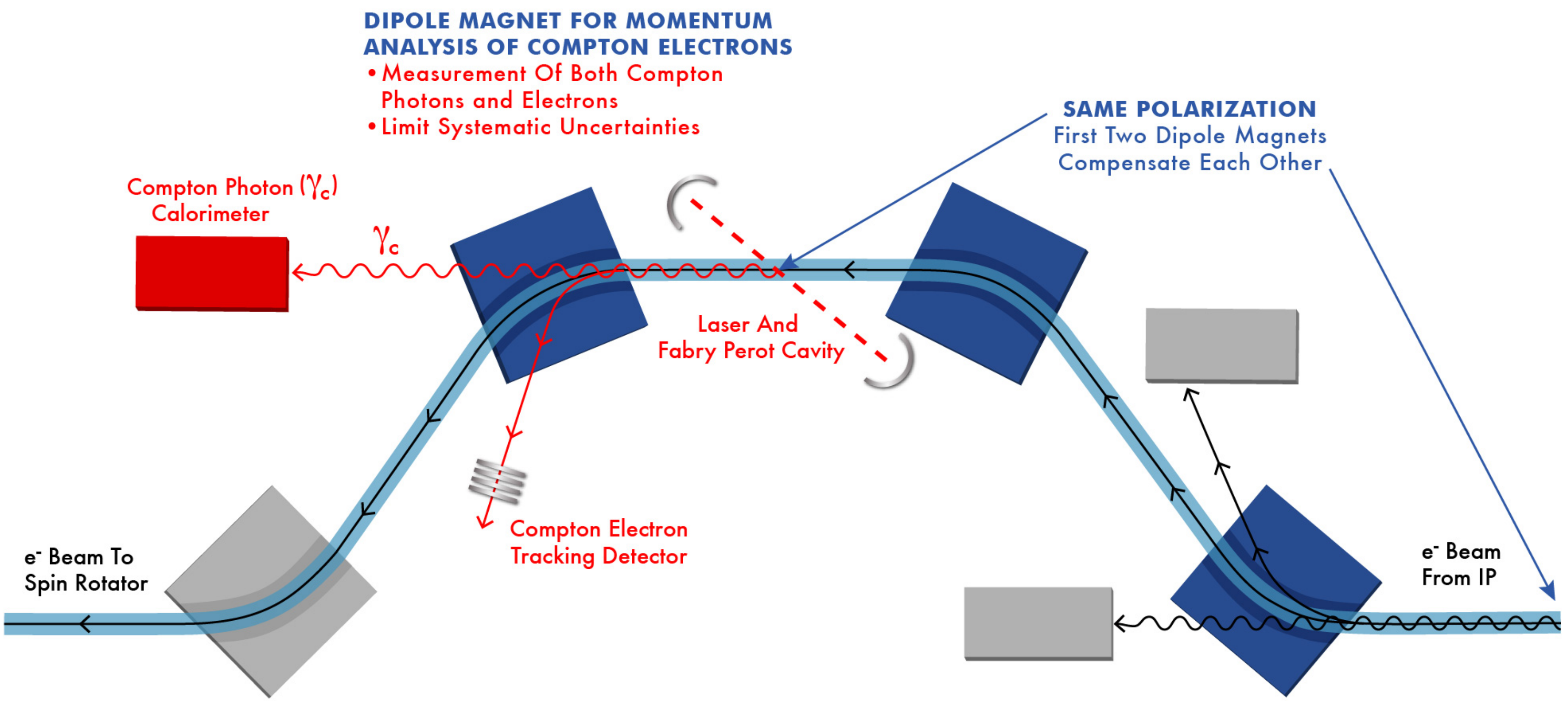
Use Bethe-Heitler process to monitor luminosity: same as HERA



Low Q^2 Tagger

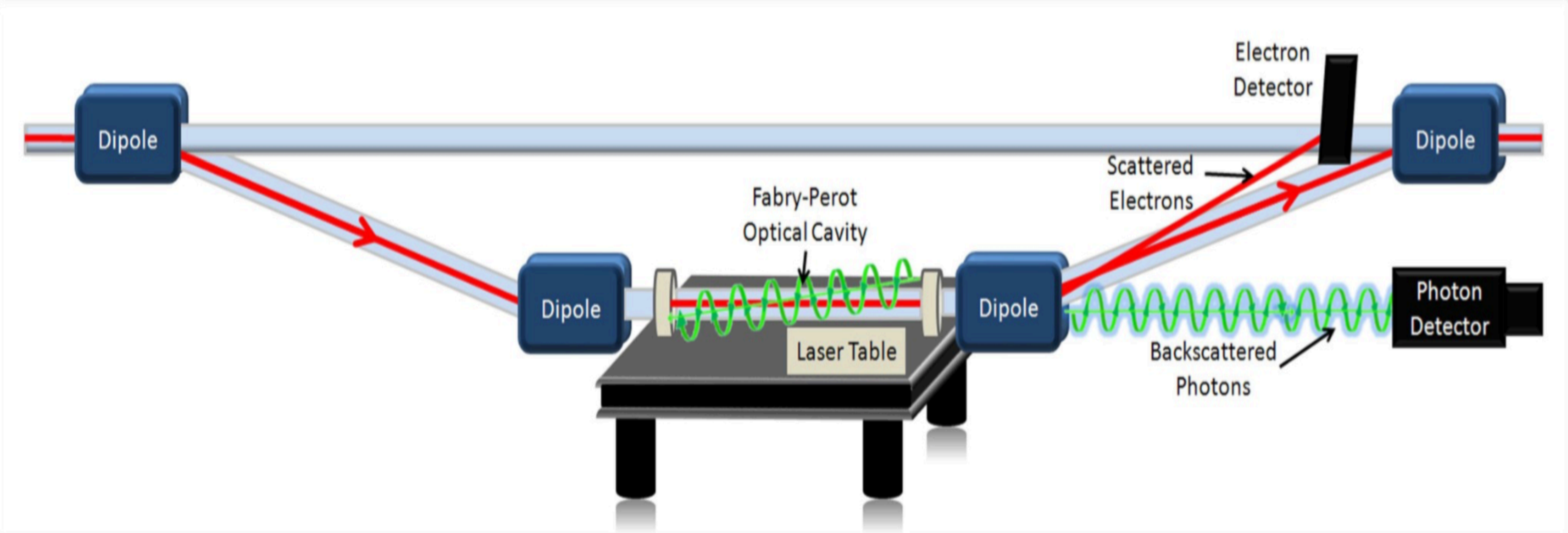


Polarization Measurement



Note the off-momentum electrons from IP does not enter the Compton tracker for polarimetry.

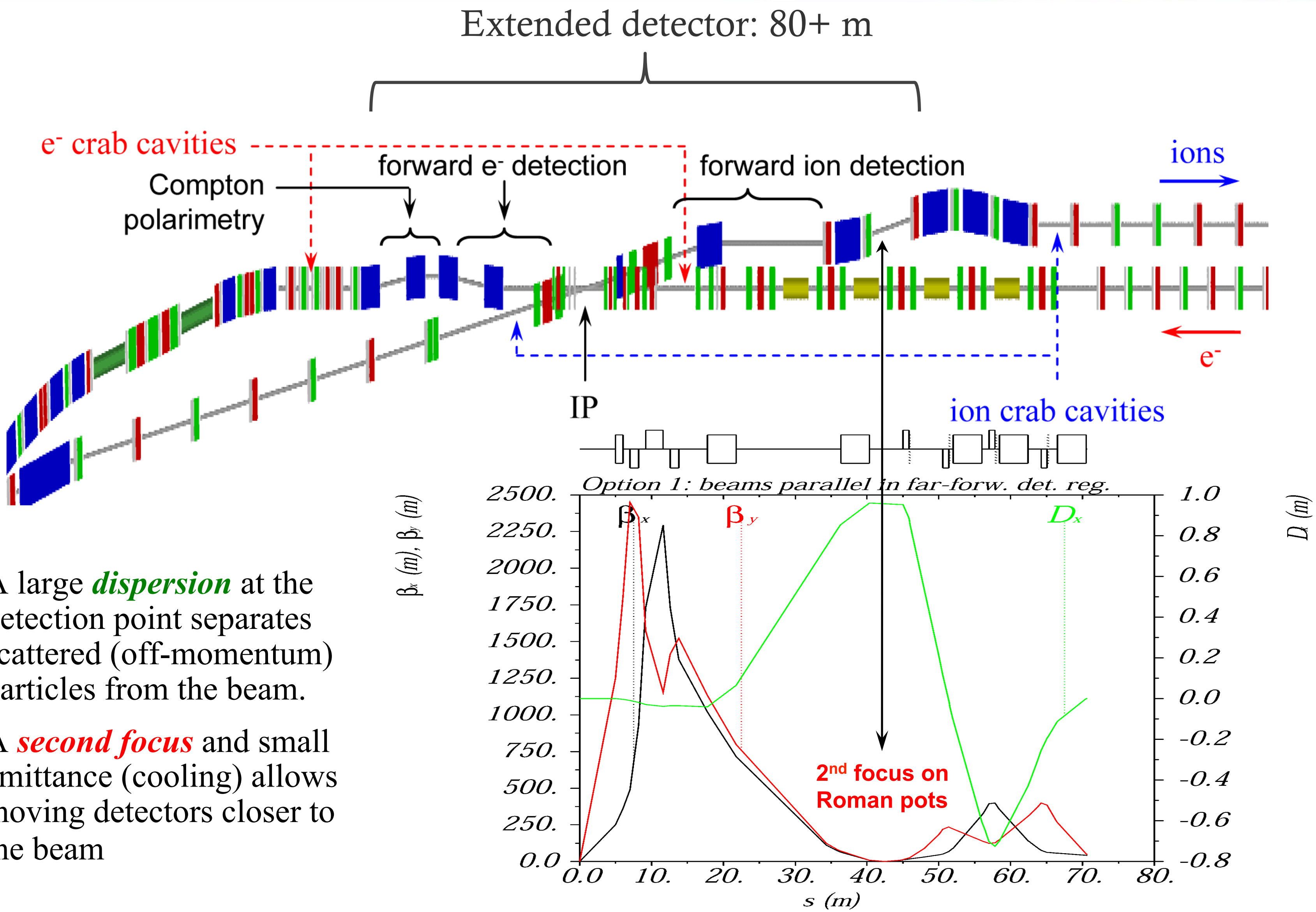
Compton Polarimetry



Existing Polarimeter in Hall C at JLab: Achieved 1% Precision

ION-BEAM DIRECTION

Ion optics for near-beam detection



- A large ***dispersion*** at the detection point separates scattered (off-momentum) particles from the beam.
- A ***second focus*** and small emittance (cooling) allows moving detectors closer to the beam

EIC forward detection requirements

- 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)

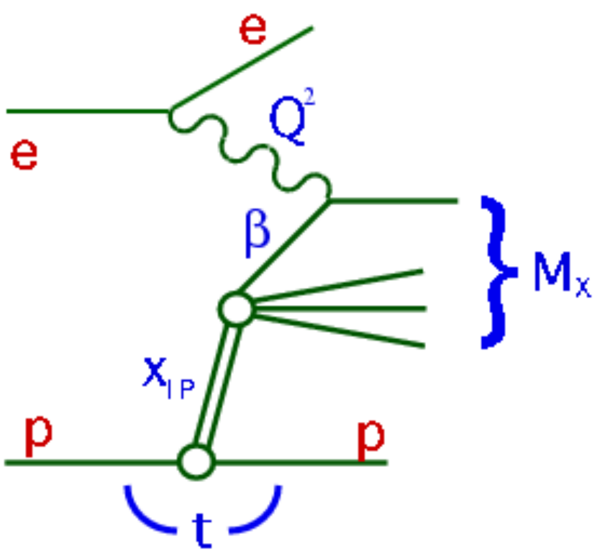
    Secondary focus on roman pots, small beam emmittance (cooling)
  - Large dispersion (to separate scattered particles from the beam)

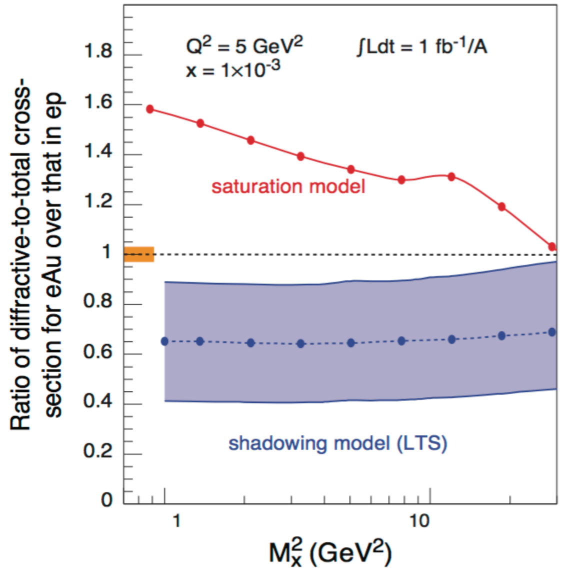
- Good acceptance for fragments (rigidity different than beam)
  - **Tagging in light and heavy nuclei, nuclear diffraction**
  - Large magnet apertures (low gradients)
  - Detection at several points along a long, aperture-free drift region

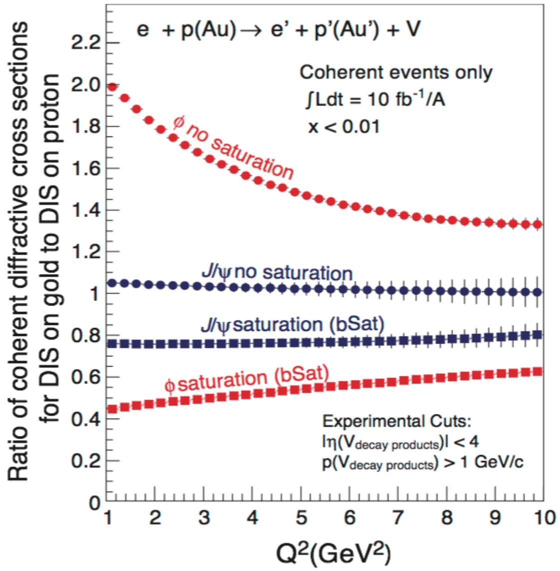
- Good momentum- and angular resolution
  - **Free neutron structure through spectator tagging, imaging**
  - Both in roman pots and fixed detectors

An Example: Diffractive DIS

Signature for Saturation (among other things)

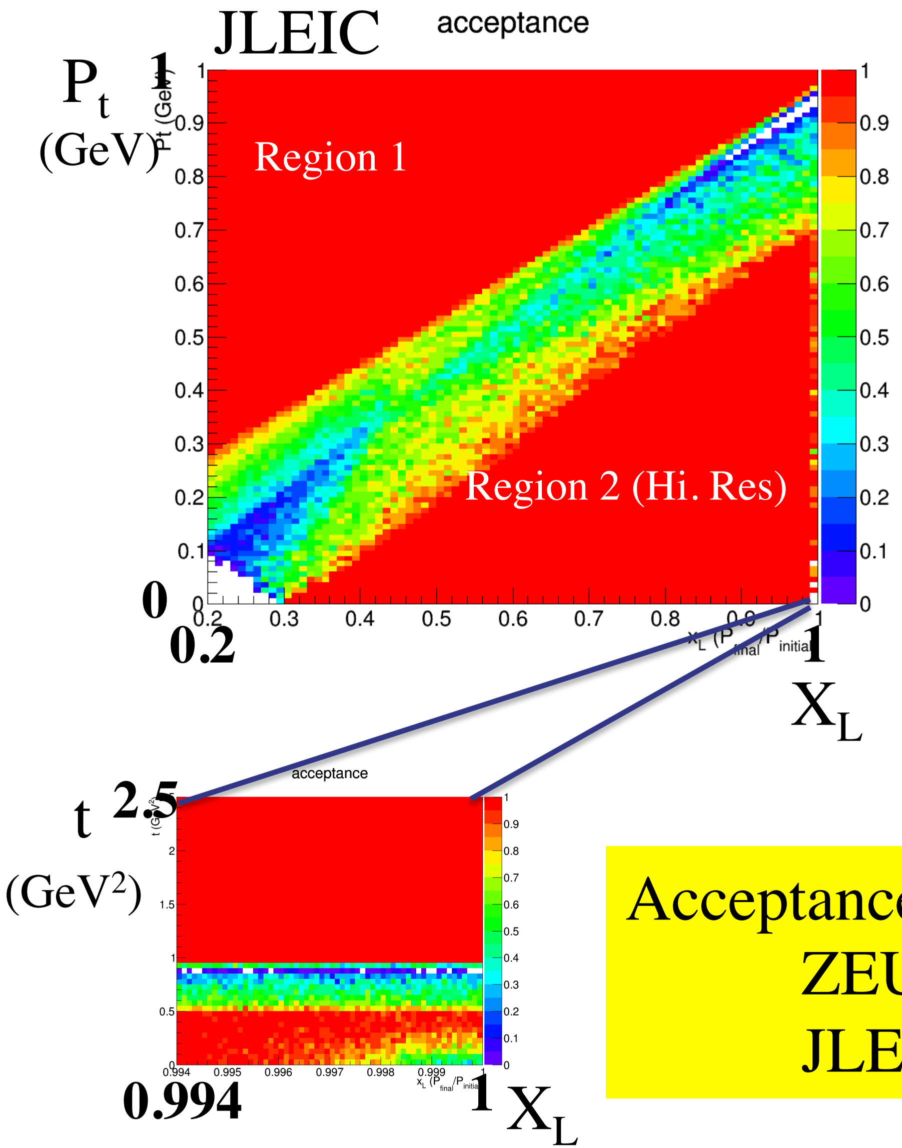


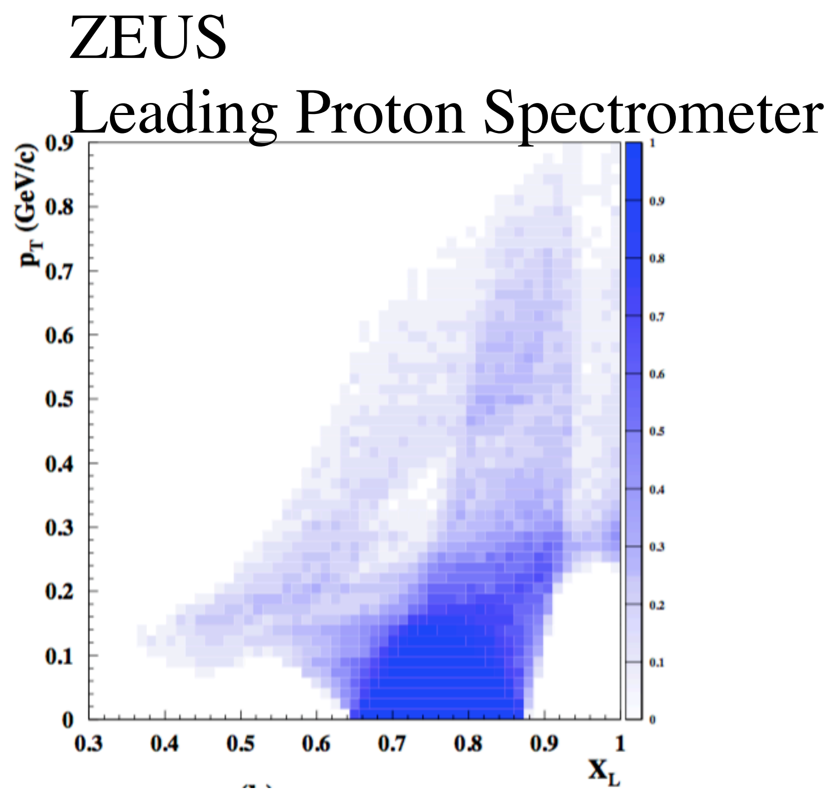




Identify the scattered proton: distinguish from proton dissociation
Measure $\mathbf{X_L = E_p'/E_p}$, and $\mathbf{P_t}$ (or **t**) (equiv. to measuring M_x)

Acceptance for p' in DDIS





Acceptance in diffractive peak (X_L>~.98)

ZEUS: ~2%

JLEIC: ~100%

Summary

- EIC project will revolutionize our understanding of nucleons and nuclei
- The physics program of EIC demands a *total acceptance detector*. (This means excellent forward coverage in addition to the central coverage.)
- Determining machine parameters, IR and detector design must go hand in hand, paying close attention to the emerging physics program of the EIC.
- JLEIC is an integrated (accelerator, IR and detector) effort focused on the EIC physics goals.
- Detector R&D proposals must make sense with respect to the physics program. Physics of nucleon and nuclear structure must drive the design.

BACKUP

Bunch spacing and identification

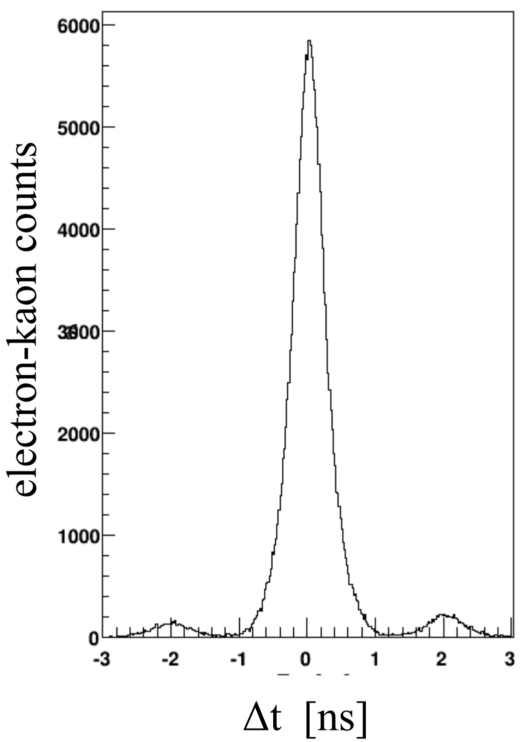
- Existing detectors (CLAS, BaBar, etc) at machines with high bunch crossing rates have not had problems in associating tracks with a specific bunch.

- Example: CLAS detector at JLab 6 GeV
  - 2 ns bunch spacing (500 MHz rep. rate)
  - 0.2 ns TOF resolution (0.5 ns FWHM)
  - The figure shows time matching of kaons in CLAS with electrons in the (low-Q^2) tagger, in turn matched to the accelerator RF signal

The 2 ns bunch structure is clearly resolved

  - CLAS12 aims at a TOF resolution of 80 ps

K-e coincidence time in CLAS 6 GeV data



- The bunch spacing in the MEIC is similar to CLAS and most e^+e^- colliders
  - PEP-II/BaBar, KEKB/Belle: **8 ns**
  - Super KEKB/Belle II: **4 ns** *(2 ns with all RF buckets full)*
  - MEIC: **1.3 ns** [750 MHz]
  - CERN Linear Collider (CLIC): **0.5 ns** [2 GHz]

Instantaneous rates

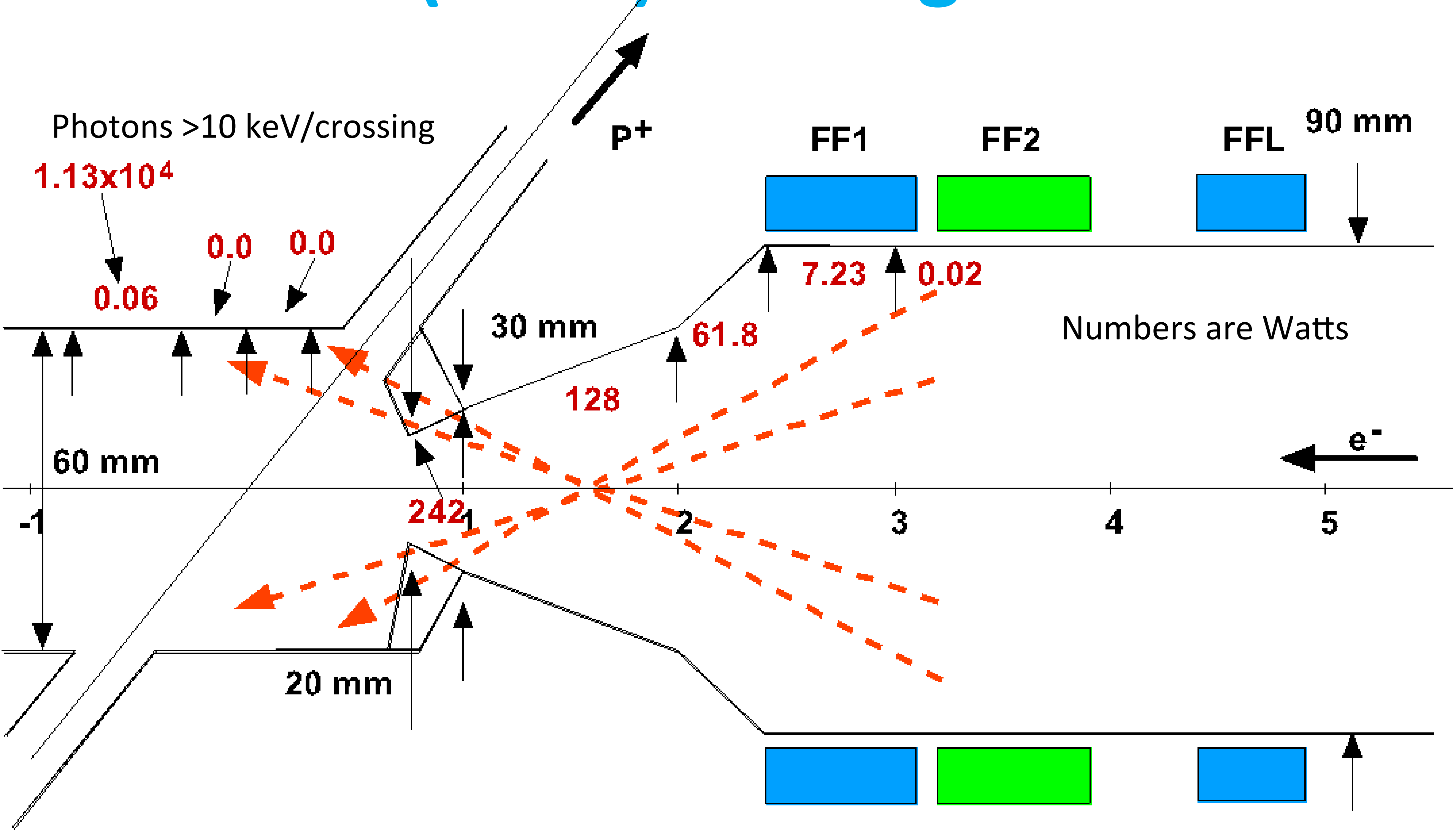
- For a given luminosity, increasing the crossing rate reduces the number of collisions per crossing, making it easier to resolve individual events.
  - Note that the *average collision rate* does not depend on the bunch structure
- The number of collisions per crossing in the MEIC is comparable to HERA.

Events (e-p collisions) per bunch crossing	1.33 ns spacing (MEIC)	133 ns spacing (~HERA)
DIS @ L=10^{34}	10^{-3}	10^{-1}
photo @ L=10^{34}	10^{-1}	10
DIS @ L=10^{32}	10^{-5}	10^{-3}
photo @ L=10^{32}	10^{-3}	10^{-1}

Order-of-magnitude estimates of the instantaneous DIS and photoproduction rates based on a 7.5 mb total e-p cross section.

- Event spacing is particularly important for time matching of tracks in the central and far-forward detectors.
  - Only the former pass the vertex tracker
  - Photoproduction events also give rise to hadrons at small angles.
- Matching is further improved by good resolution in the far-forward detectors.
  - Angular for path-length corrections
  - Momentum for β corrections
  - Timing < 1 ns

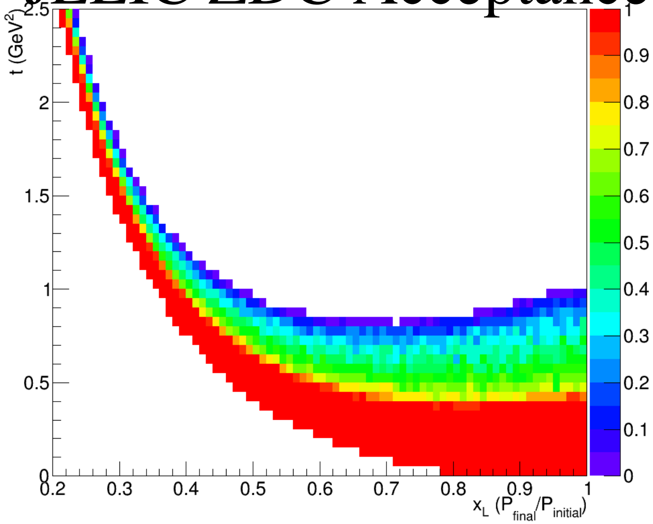
10 GeV (0.7 A) with tighter mask



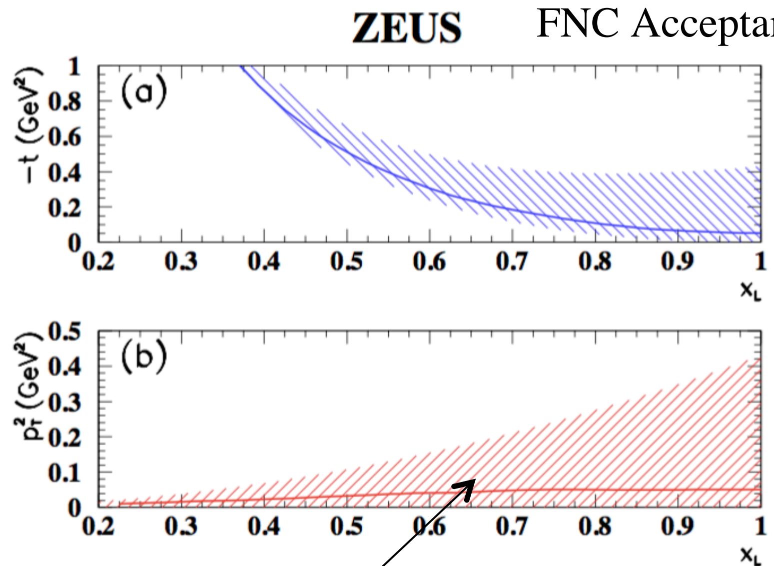
Mike Sullivan, SLAC

Neutron Acceptance for ep->e'Xn

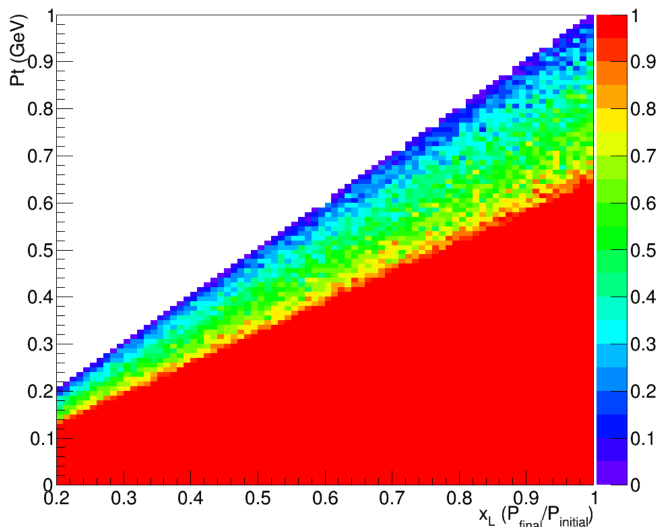
JLEIC ZDC Acceptance



FNC Acceptance



~20% geometrical accep.



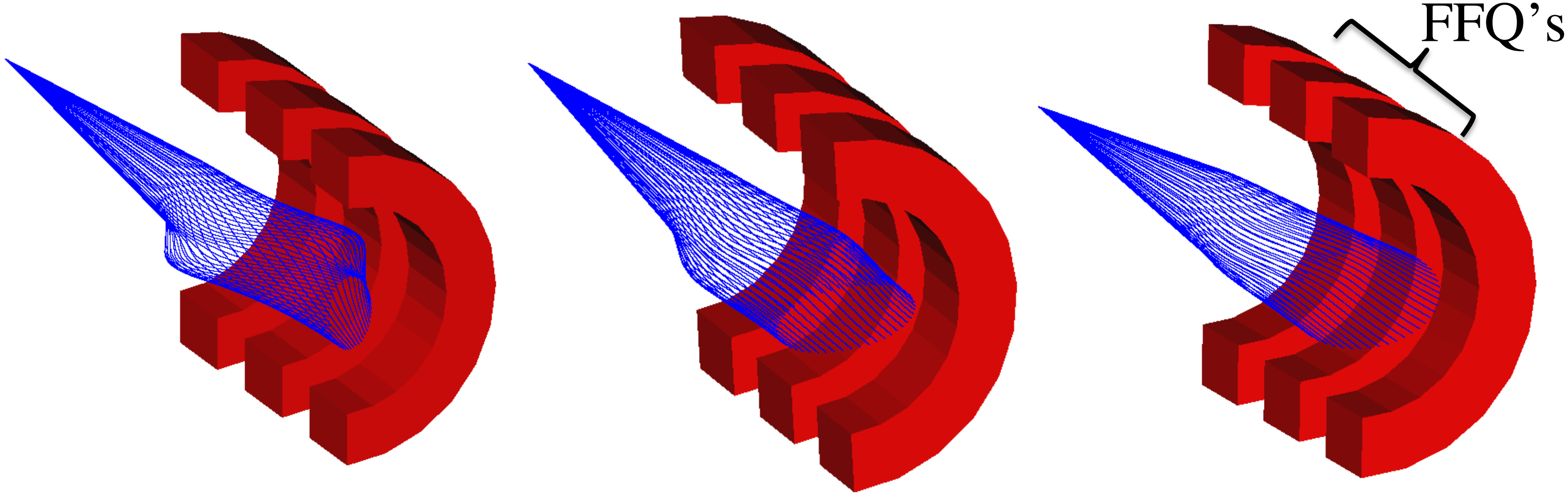
Zhiwen Zhao

Doubles kinematic coverage
~5-10 times acceptance
compared to HERA

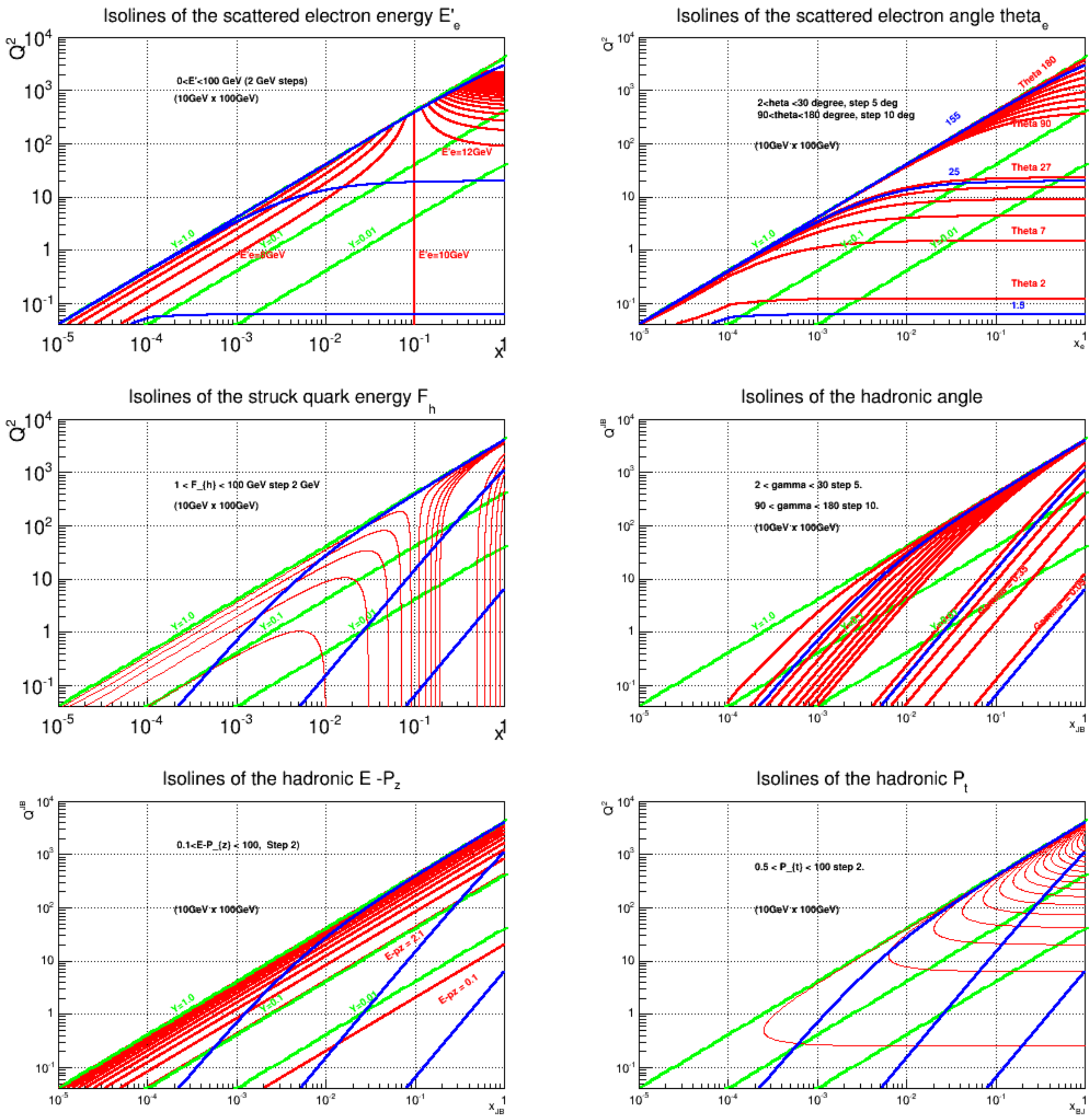
Far-Forward Acceptance for Ion Fragments

(protons rich fragments) ← → (neutron rich fragments)

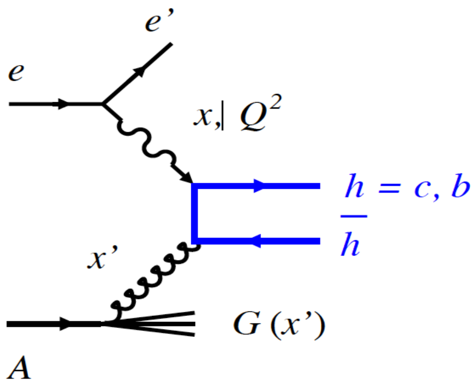
Δp/p = -0.5 (spectator protons from deuterium)	Δp/p = 0.0 (exclusive / diffractive recoil protons)	Δp/p = 0.5 (tritons from N=Z nuclei)



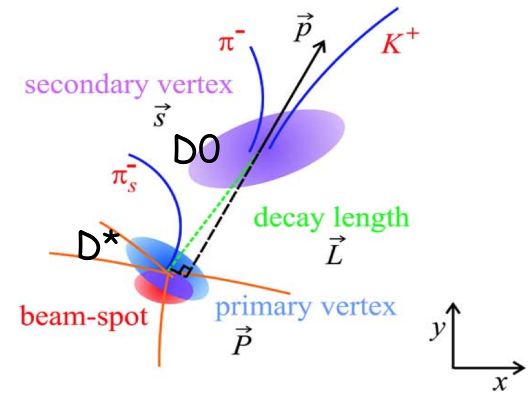
Forward geometry will provide ~100% acceptance for all cases


Isolines of the scattered electron energy E'e
0<E'<100 GeV (2 GeV steps)
(10GeV x 100GeV)
E'e=12GeV
E'e=8GeV
E'e=10GeV
Y=1.0
Y=0.1
Y=0.01
Isolines of the scattered electron angle theta_e
2<theta <30 degree, step 5 deg
90<theta<180 degree, step 10 deg
(10GeV x 100GeV)
Theta 180
155
Theta 90
25
Theta 27
Theta 7
Theta 2
1.5
Isolines of the struck quark energy F_h
1 < F_{h} < 100 GeV step 2 GeV
(10GeV x 100GeV)
Isolines of the hadronic angle
2 < gamma < 30 step 5.
90 < gamma < 180 step 10.
(10GeV x 100GeV)
Isolines of the hadronic E -P_z
0.1<E-P_{z} < 100, Step 2)
(10GeV x 100GeV)
E-pz = 2.1
E-pz = 0.1
Isolines of the hadronic P_t
0.5 < P_{t} < 100 step 2.
(10GeV x 100GeV)

Vertex. Heavy quarks



Heavy quarks
(Boson Gluon Fusion)

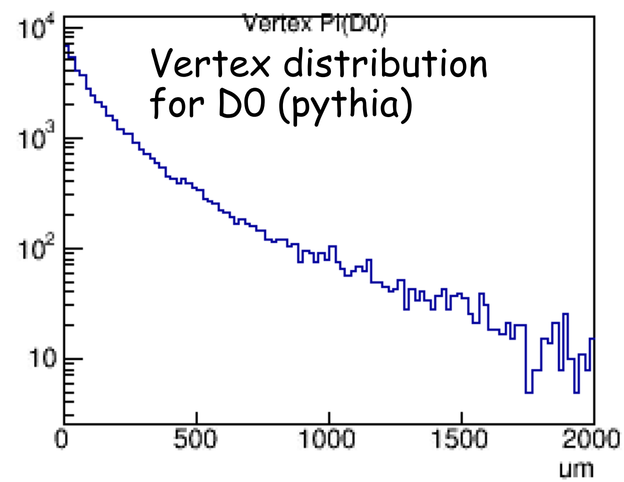


-cτ (D (B) mesons) ~ 100 (400) µm
=> displaced vertex =>

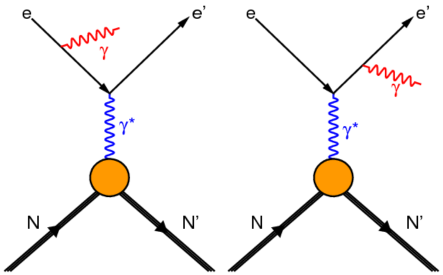
Need Vertex detector with good resolution

- c (b) quark -> D,B mesons -> π,K

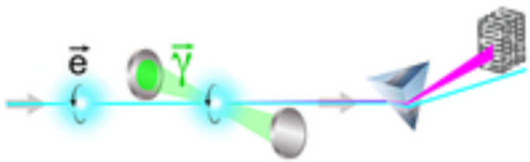
=> Particle identification (prev. slides)



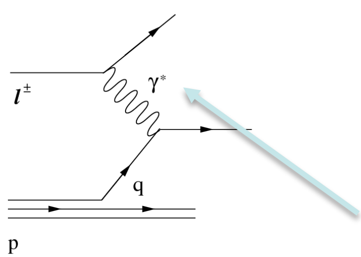
Particle associated with the e-beam



Bethe-Heitler process to monitor luminosity (photons collinear to electron beam)



Electron-beam polarization measurement

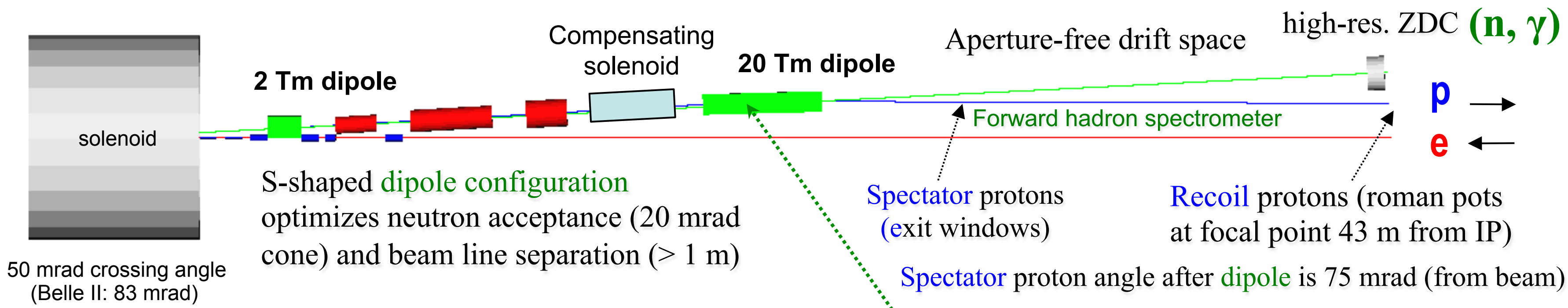


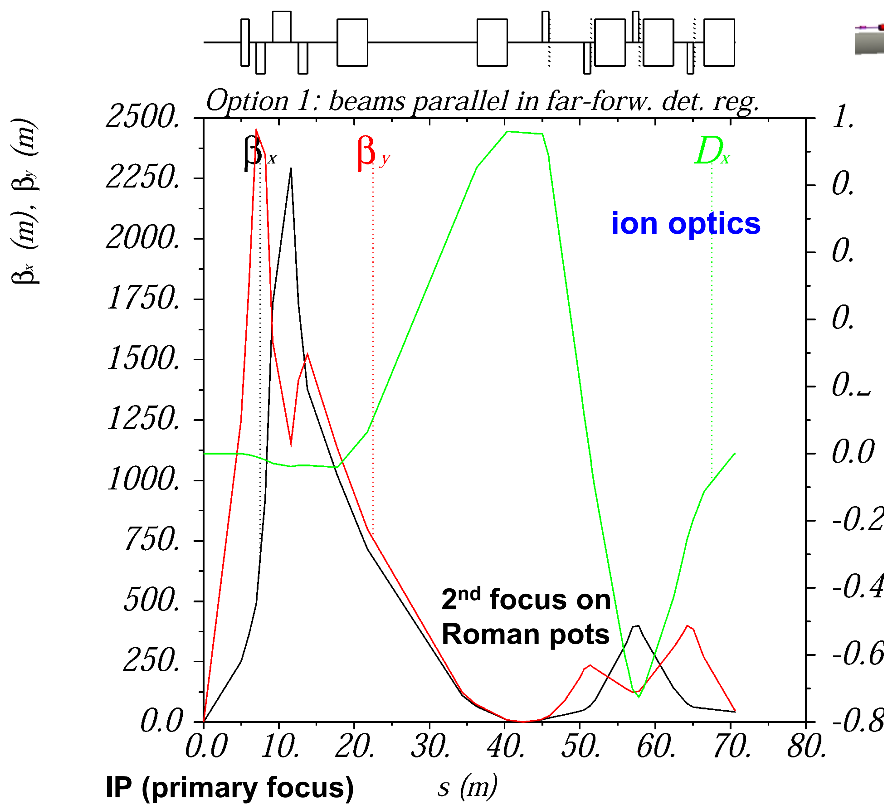
Tagging electrons for photo-production (scattered electron moving in the beam direction)

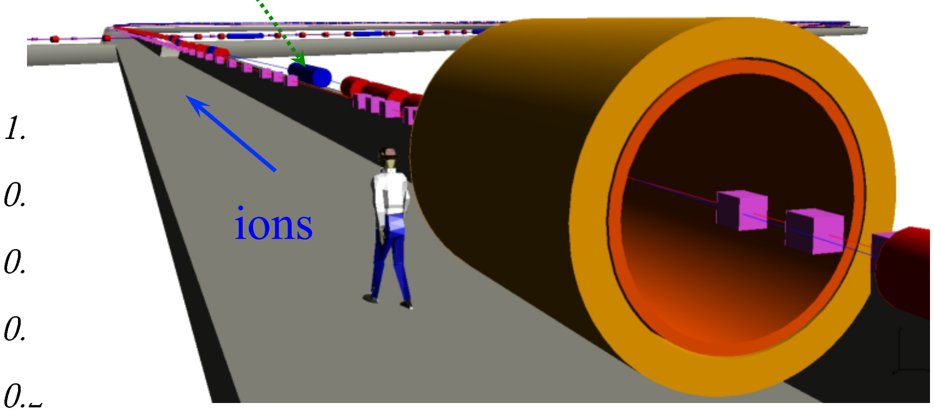
Almost real

All of these particles are moving in the e-beam direction

Forward hadron spectrometer







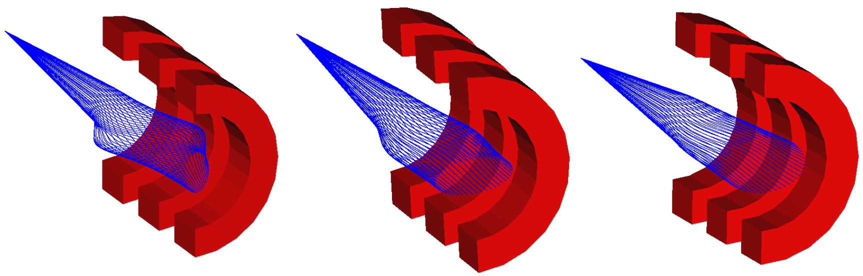
- Large 20 Tm dipole provides excellent resolution
- Large *dispersion* and small *beam size* at secondary focus ensure good acceptance for recoil protons
- Large quadrupole apertures (1 / *max* beam energy) give good acceptance for hadronic and nuclear fragments, charged and neutral (high res. ZDC).

Forward acceptance and resolution

dp/p

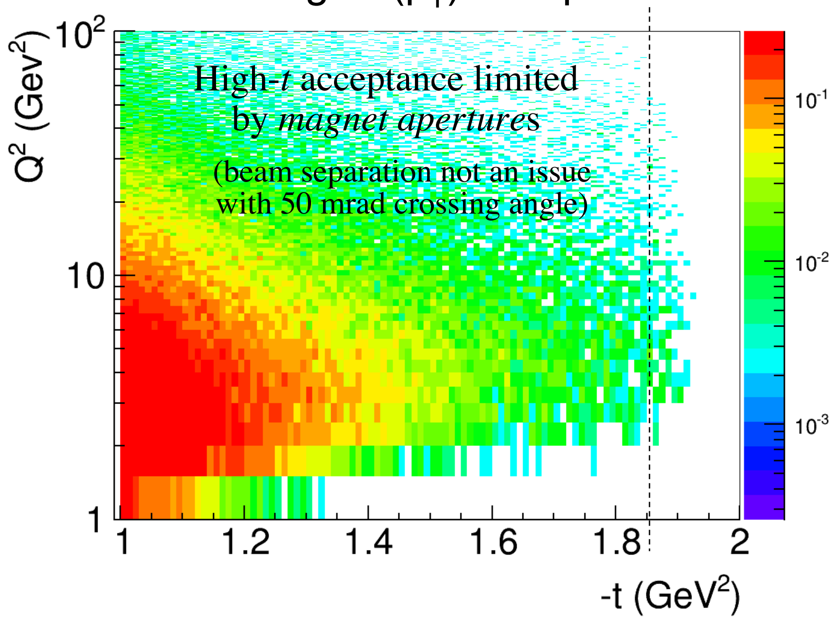
proton-rich fragments
"spectator protons from ^2H"

neutron-rich fragments
"tritons from N=Z nuclei"

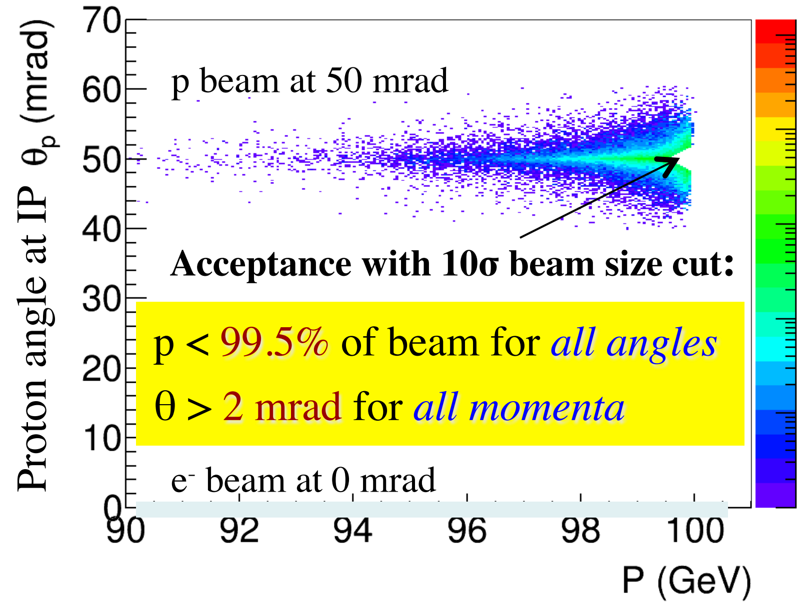


- Full acceptance for all partonic and nuclear fragments (different rigidities)
  - Large coverage in p_T for recoils
- Detector resolution designed to be limited by intrinsic spread of the beam ($dp/p \sim$ few x 10^{-4}, $d\theta < 0.3$ mrad)

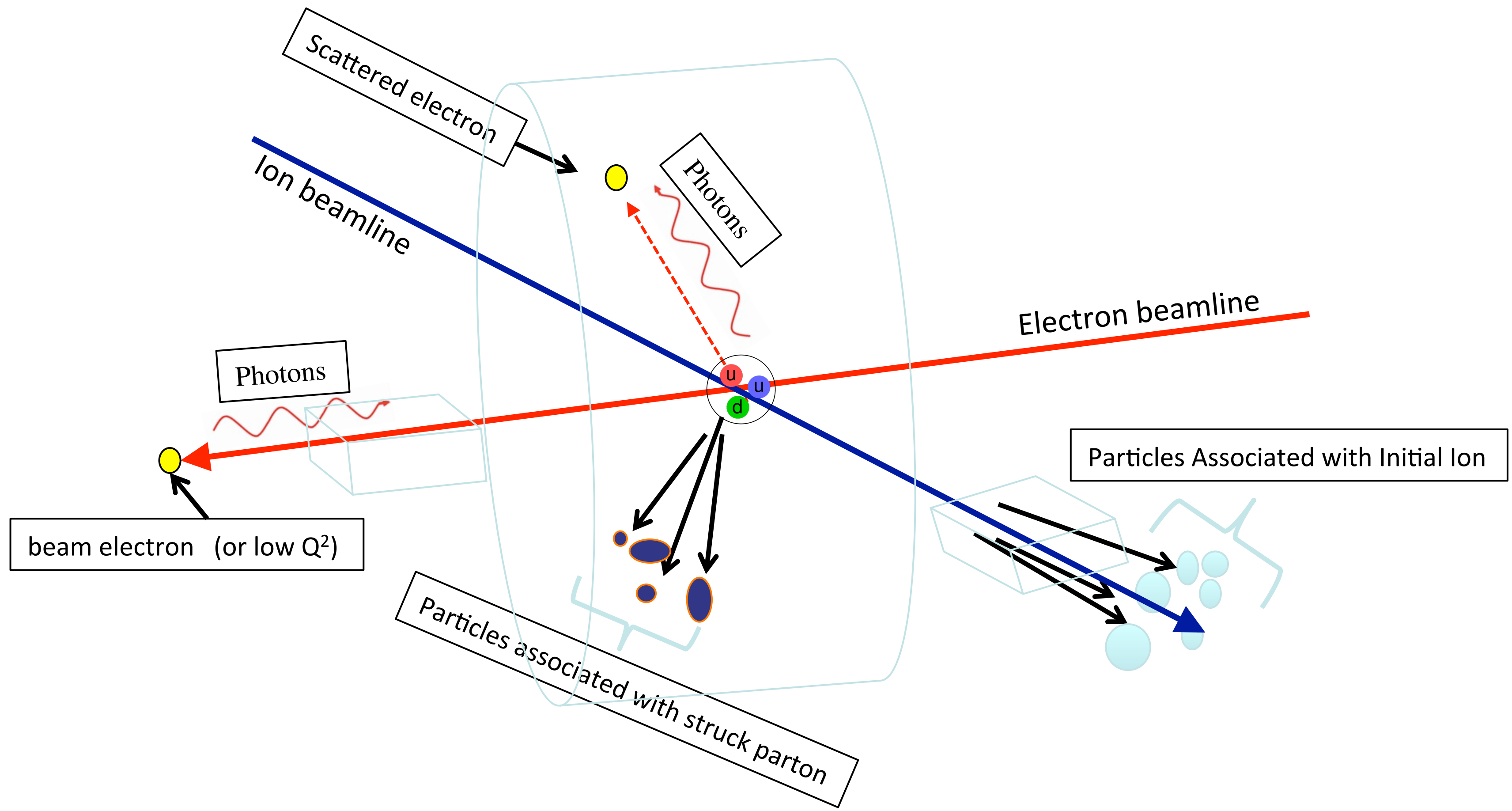
DVCS high-*t* (p_T) acceptance



DVCS low-*t* (p_T) acceptance



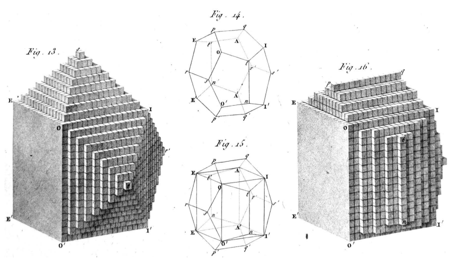
DIS and Final State Particles



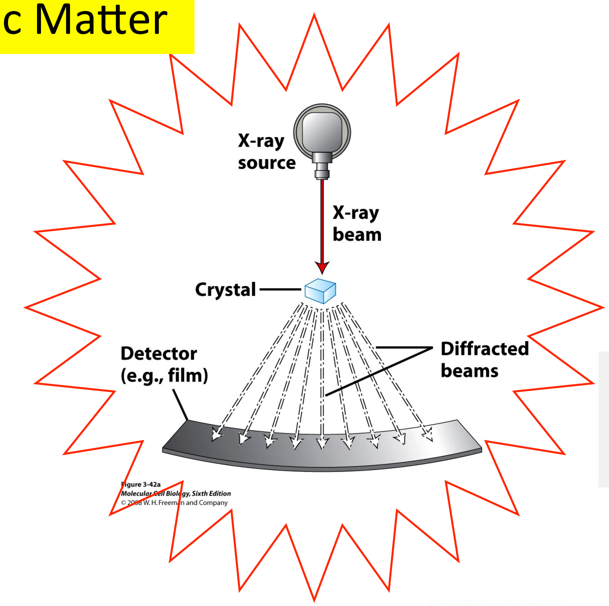
PHYSICS OF EIC

New Probes and New Science

Example: Structure of Atomic Matter

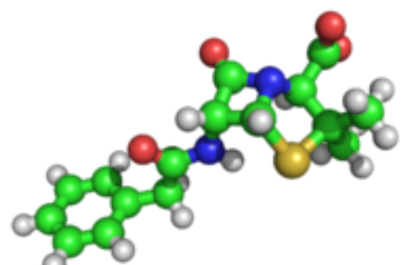


Crystal Structure: 1801

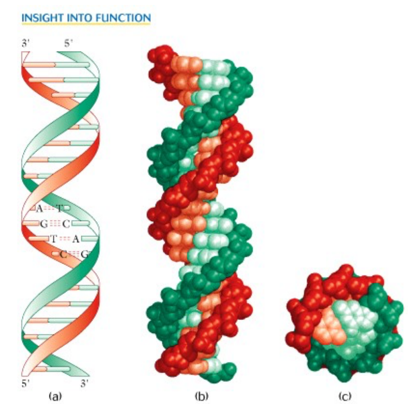


Advent of
X-ray Diff.
1912

Probe with the right scale!



3D structure of penicillin: 1945

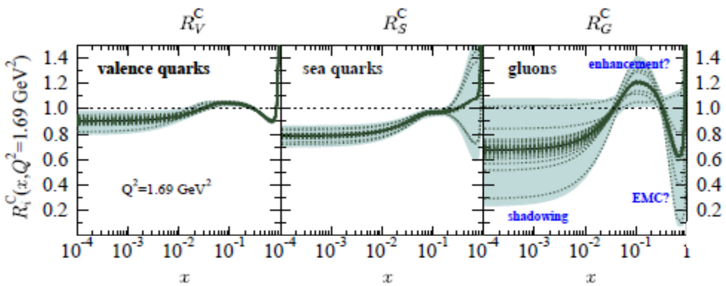


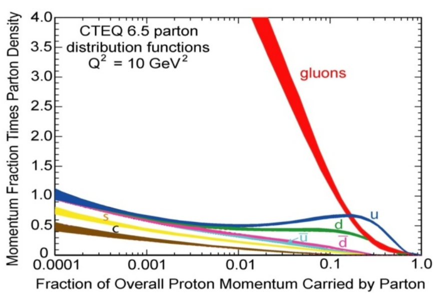
Double Helix: 1953

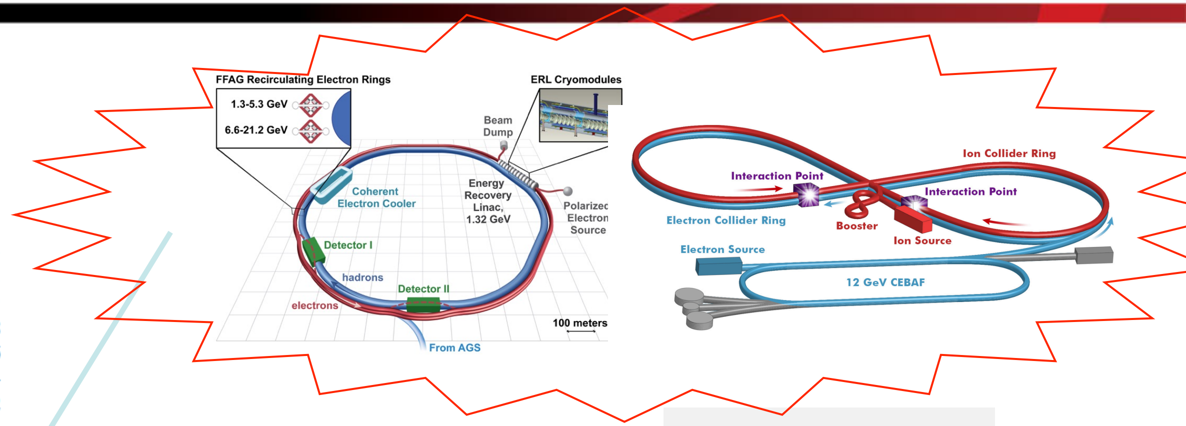
Precise understanding of structure leads to rich new sciences

New Probe for Nuclear Science

2016

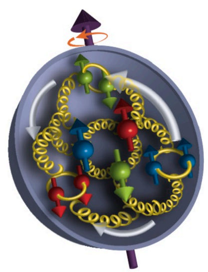


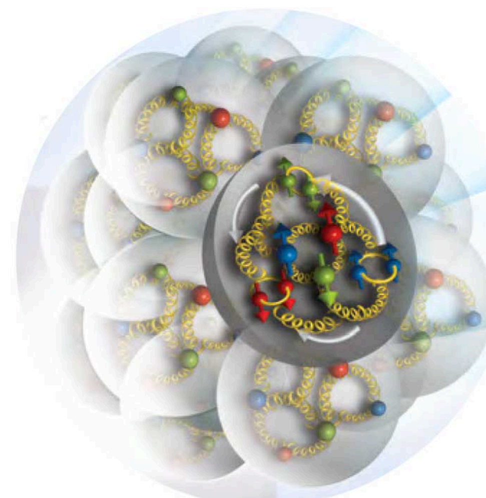




Advent of EIC: ~2027

Probe with the right scale!

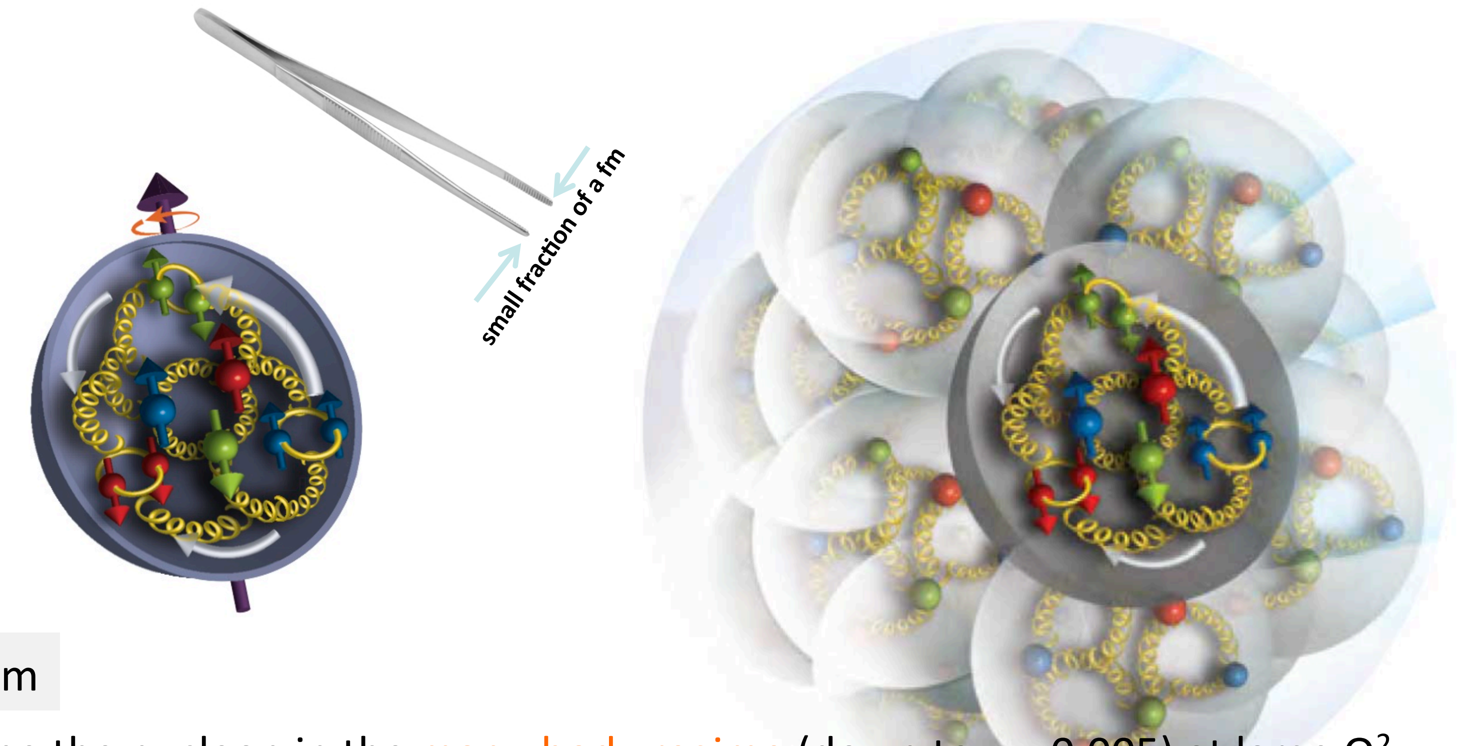




Precise understanding of structure and dynamics: dawn of new science

EIC Physics Program

Program aim: Revolutionize the understanding of nucleon and nuclear structure and associated dynamics. Explore new states of QCD.

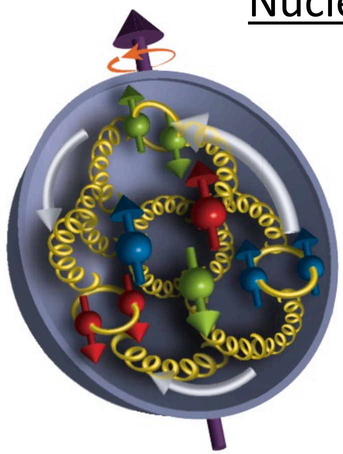


Program

- Probe the nucleon in the many-body regime (down to x ≈ 0.005) at large Q^2
- Probe the nuclei in the N-N and multi-N interaction regime at large Q^2
- Extend our understanding of QCD (saturation, jets in cold nuclear matter)

Boring? Sounds like you've heard this for 30 years? No! Not Really!

Understanding the Nucleon at the Next Level



<u>Nucleon: A many-body system with challenging characteristics</u>

Relativistic ($M_{proton} >> M_{quark}$)

Strongly Coupled (QCD)

Quantum Mechanical (Superposition of configurations)

Measure in the Multi-Body regime:
- Region of quantum fluctuation + non-perturbative effects → dynamical origin of mass, spin.

For the first time, get (almost?) all relevant information about quark-gluon structure of the nucleon and nuclei will be accessible.

Designing EIC, IR and Detector → Designing the right probe

- Resolution appropriate for quarks and gluons
- Ability to project out relevant Q.M. configurations of the nucleon and the nuclei