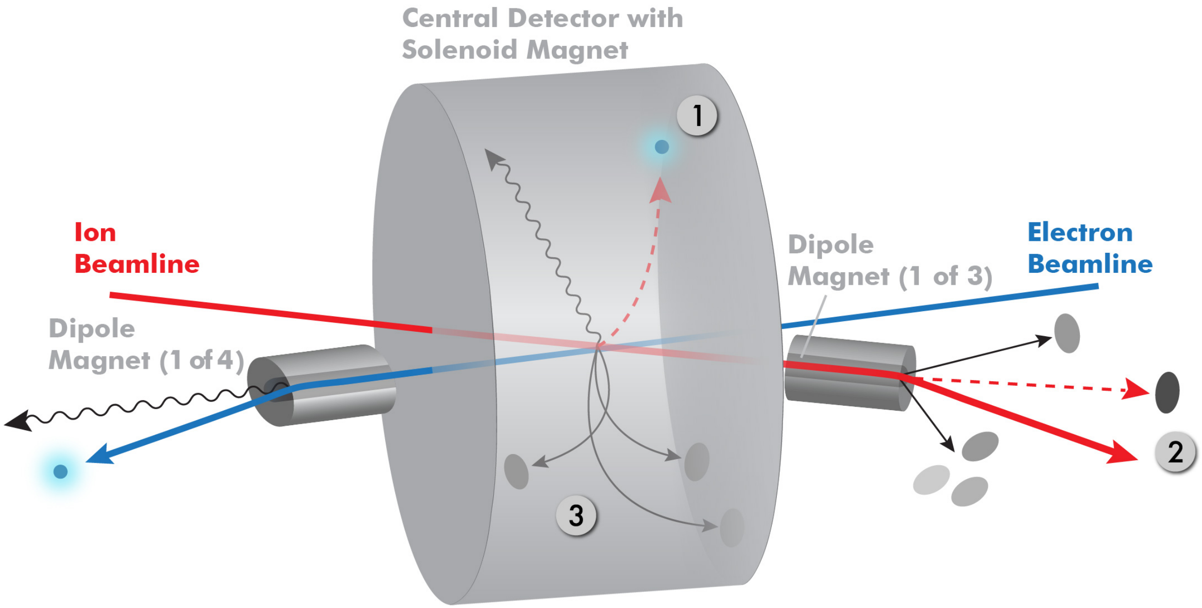
Update on JLEIC Detector Design

Markus Diefenthaler (mdiefent@jlab.org)

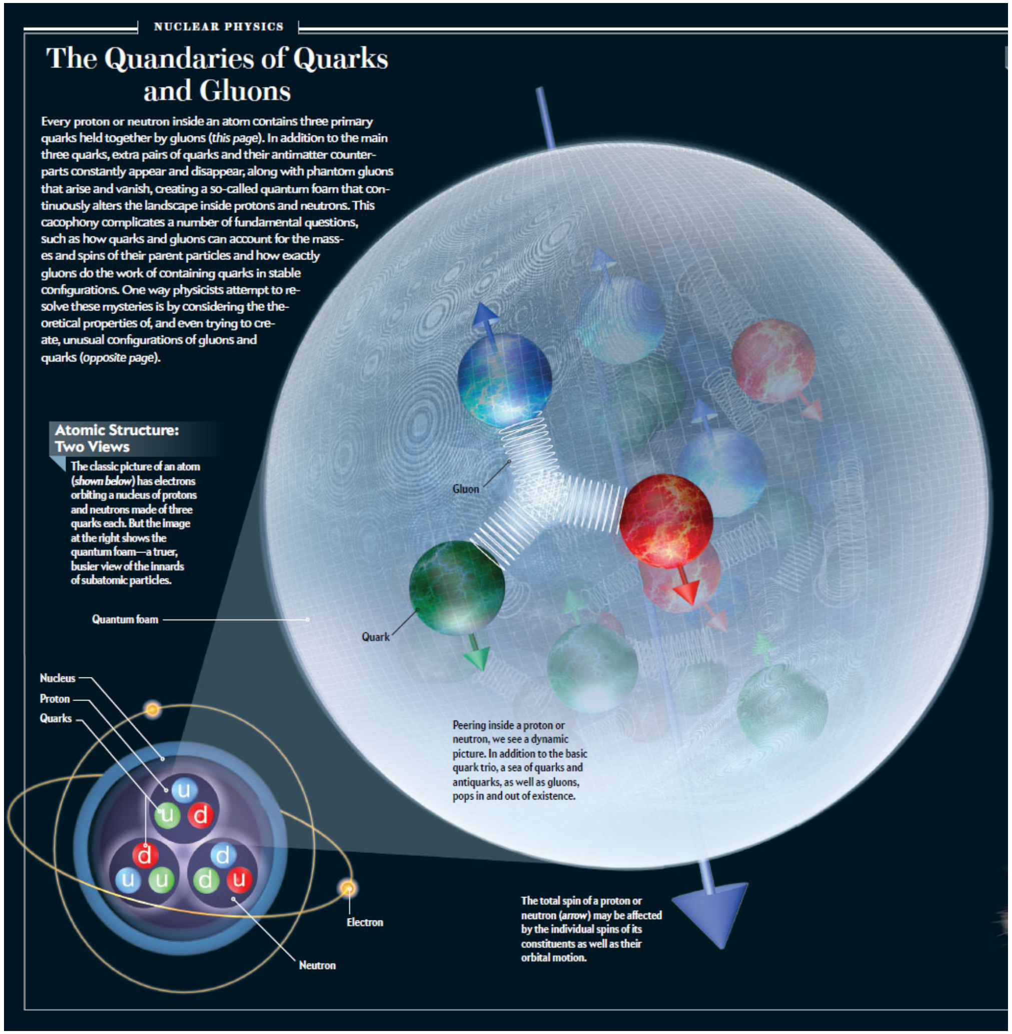


JLEIC Collaboration Meeting Fall 2016,
October 5th- 7th 2016

Prologue

The Electron-Ion Collider Project

The glue that binds us all



NUCLEAR PHYSICS

The Quandaries of Quarks and Gluons

Every proton or neutron inside an atom contains three primary quarks held together by gluons (*this page*). In addition to the main three quarks, extra pairs of quarks and their antimatter counterparts constantly appear and disappear, along with phantom gluons that arise and vanish, creating a so-called quantum foam that continuously alters the landscape inside protons and neutrons. This cacophony complicates a number of fundamental questions, such as how quarks and gluons can account for the masses and spins of their parent particles and how exactly gluons do the work of containing quarks in stable configurations. One way physicists attempt to resolve these mysteries is by considering the theoretical properties of, and even trying to create, unusual configurations of gluons and quarks (*opposite page*).

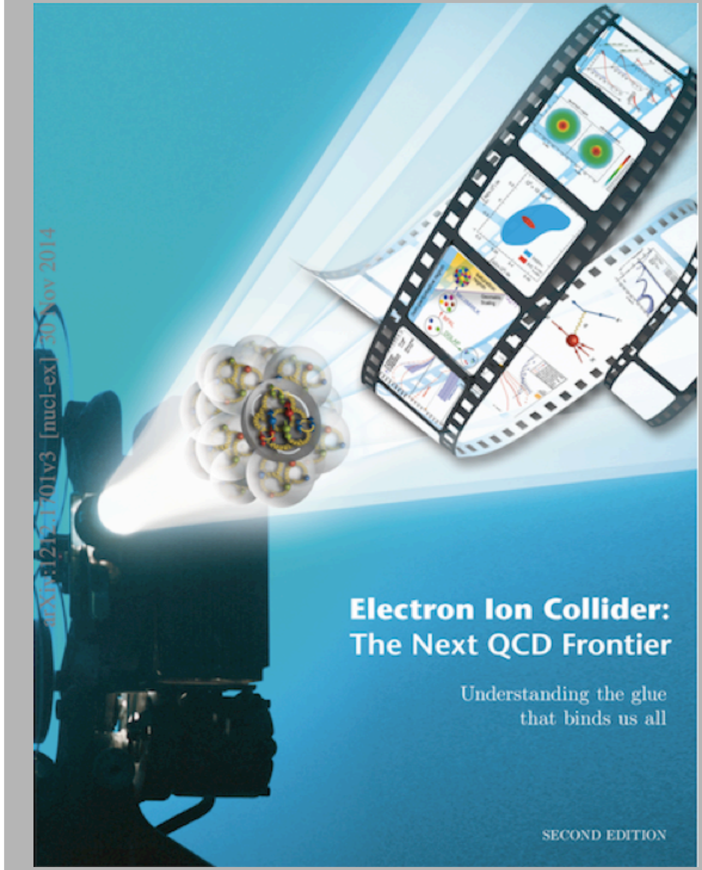
Atomic Structure: Two Views

The classic picture of an atom (*shown below*) has electrons orbiting a nucleus of protons and neutrons made of three quarks each. But the image at the right shows the quantum foam—a truer, busier view of the innards of subatomic particles.

Peering inside a proton or neutron, we see a dynamic picture. In addition to the basic quark trio, a sea of quarks and antiquarks, as well as gluons, pops in and out of existence.

The total spin of a proton or neutron (*arrow*) may be affected by the individual spins of its constituents as well as their orbital motion.

EIC: The Next QCD Frontier



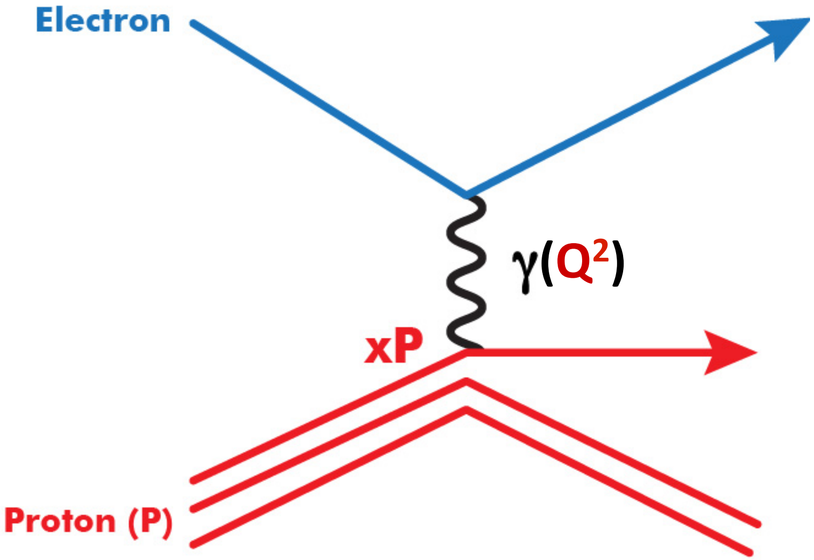
Electron Ion Collider: The Next QCD Frontier

Understanding the glue that binds us all

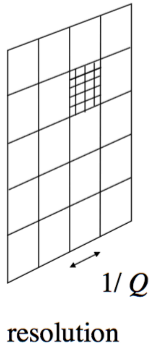
SECOND EDITION

Eur.Phys.J. A52 (2016) no.9, 268

Electron-Proton Scattering

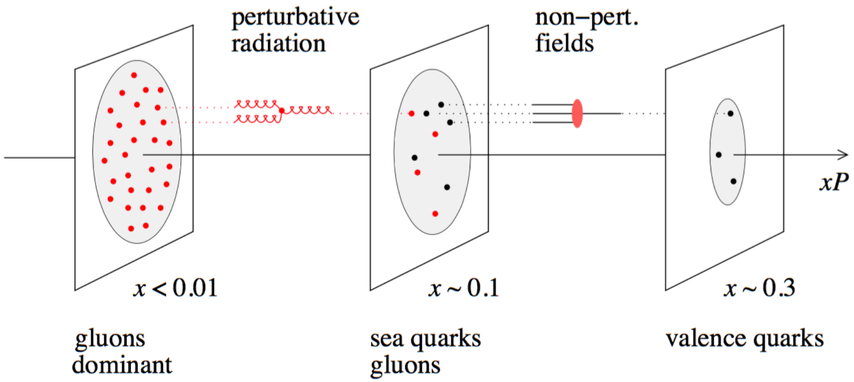


Ability to change Q^2 changes the resolution scale



$Q^2 = 400\ \mathrm{GeV}^2$
$\Rightarrow 1/Q = 0.01$ fm

Ability to change **x** projects out different configurations where different dynamics dominate



Parton distribution functions (PDF)

cross-section measurements

decomposed

structure functions

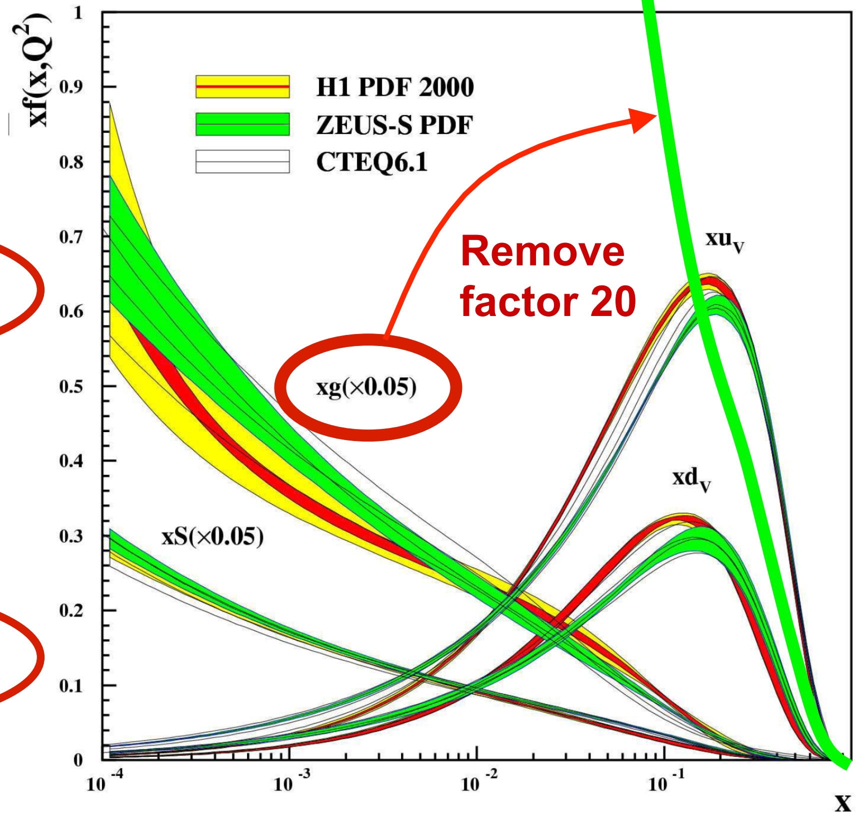
process dependent

QCD analysis using
QCD factorization theorem

PDFs

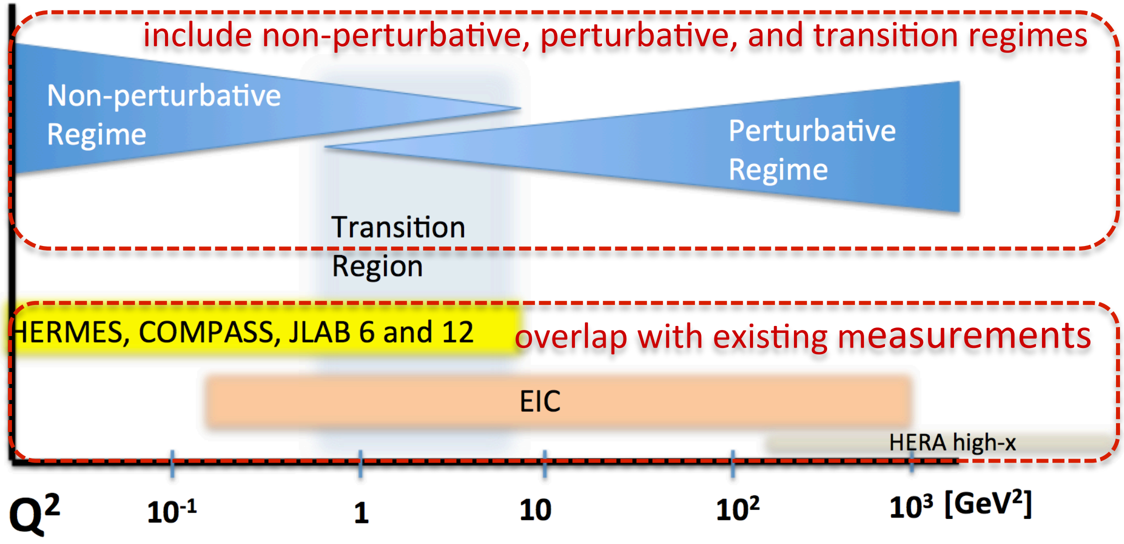
universal

$$F_1(x,Q^2)=\sum_q e_q^2\left(f_1^q(x,Q^2)+f_1^{\bar q}(x,Q^2)\right)$$



Remove factor 20

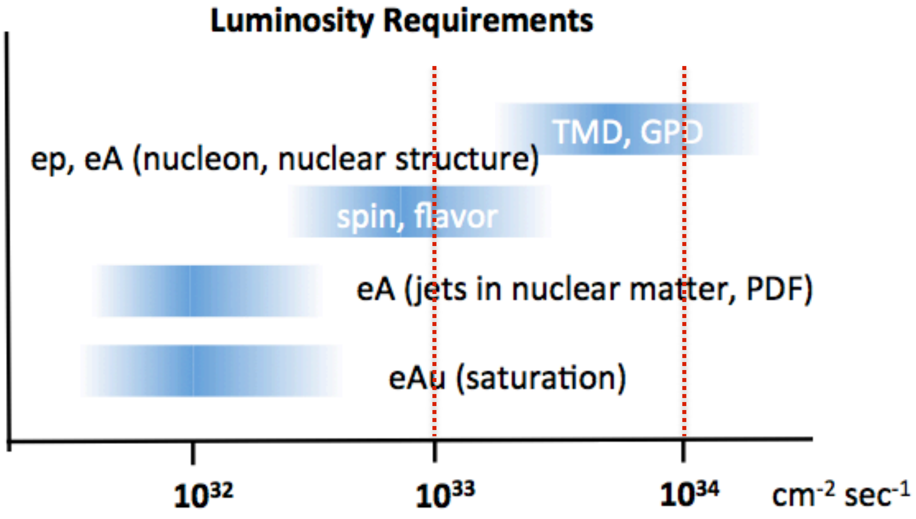
EIC: ideal facility for studying QCD



Various beam energy:

broad Q^2 range for

- studying evolution to Q^2 of ~1000 GeV^2
- disentangling non-perturbative and perturbative regimes
- overlap with existing experiments



High luminosity:

high precision

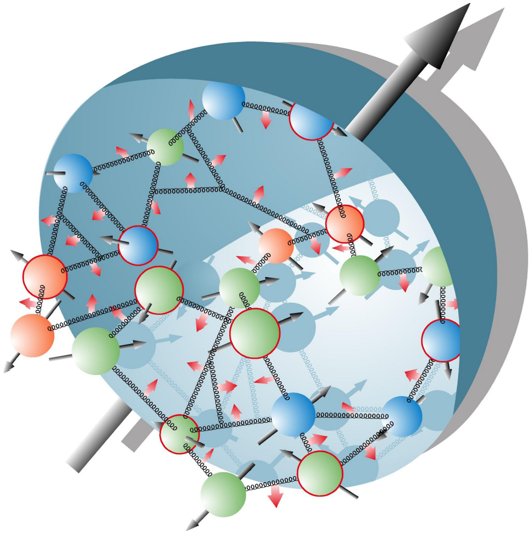
- for various measurements
- in various configurations

EIC: ideal facility for studying QCD

Polarization

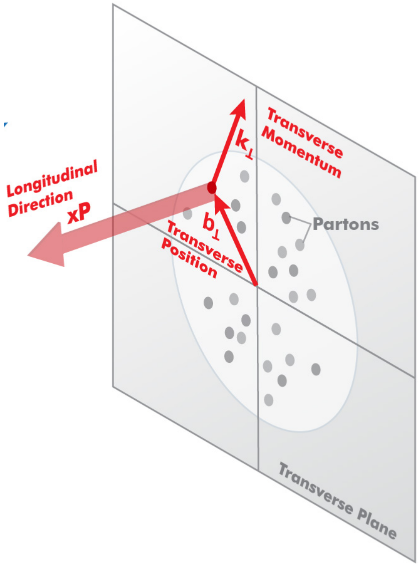
Understanding hadron structure cannot be done without understanding spin:

- polarized **electrons** and
- polarized **protons/light ions**



Transverse and longitudinal polarization of light ions (p, d, ^{3}He):

- 3D imaging in space and momentum
- spin-orbit correlations

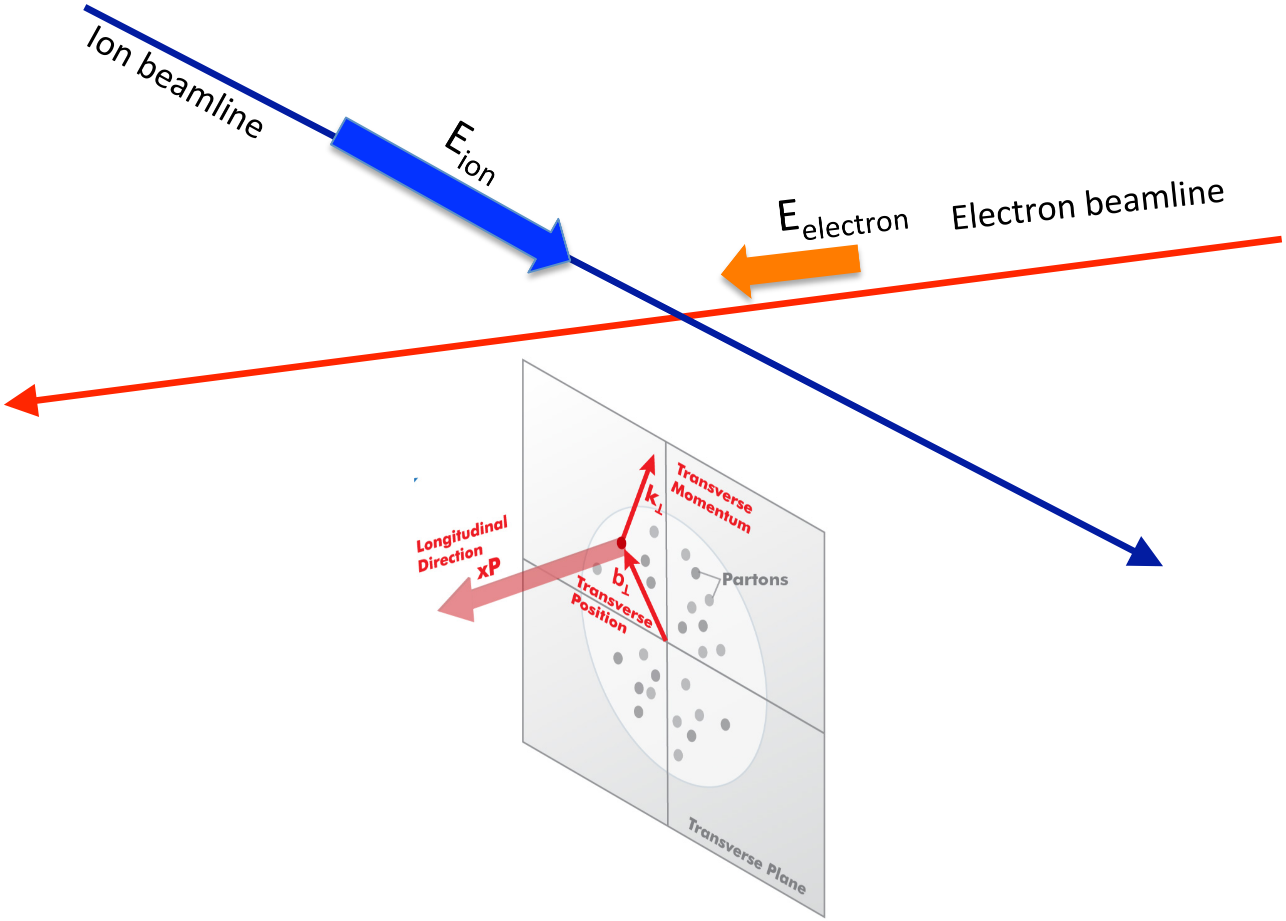


Section

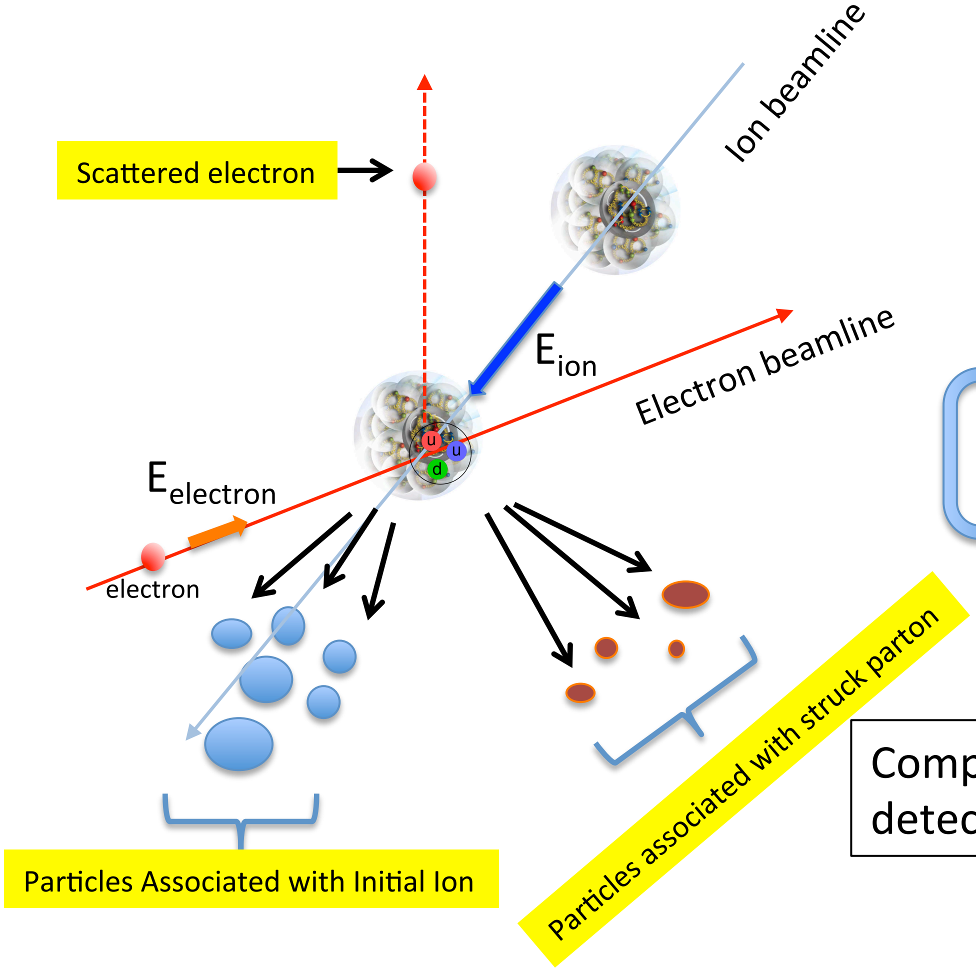
Detector Design – General design considerations

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**.



E_{ion} and $E_{ion}/E_{electron}$



EIC needs to detect all three types of particles

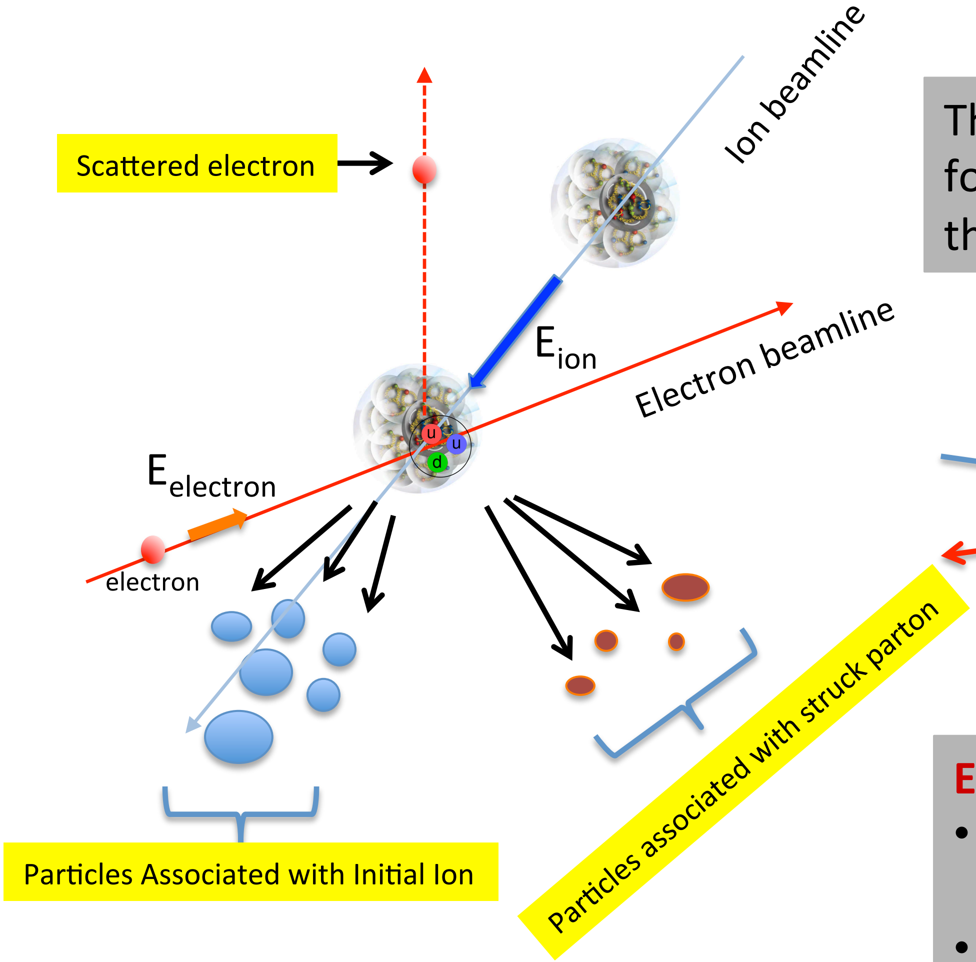
- Scattered electron
- Particles Associated with Initial Ion
- Particles associated with struck parton

These become more forward boosted and harder to measure with increasing E_{ion} and $E_{ion}/E_{electron}$

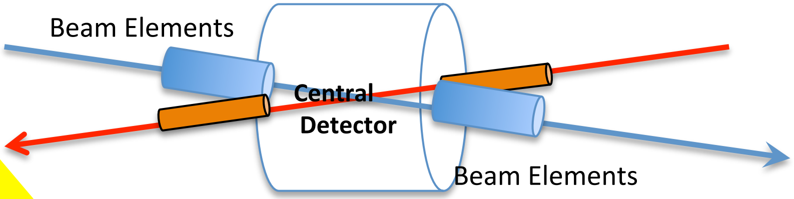
Complicated dependence on beam energies, detector capability and physics goals.

This optimization is on-going: E_{ion} <≈100 GeV and $E_{ion}/E_{electron}$ <≈10, current status → drives JLEIC baseline

Final-state particles



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

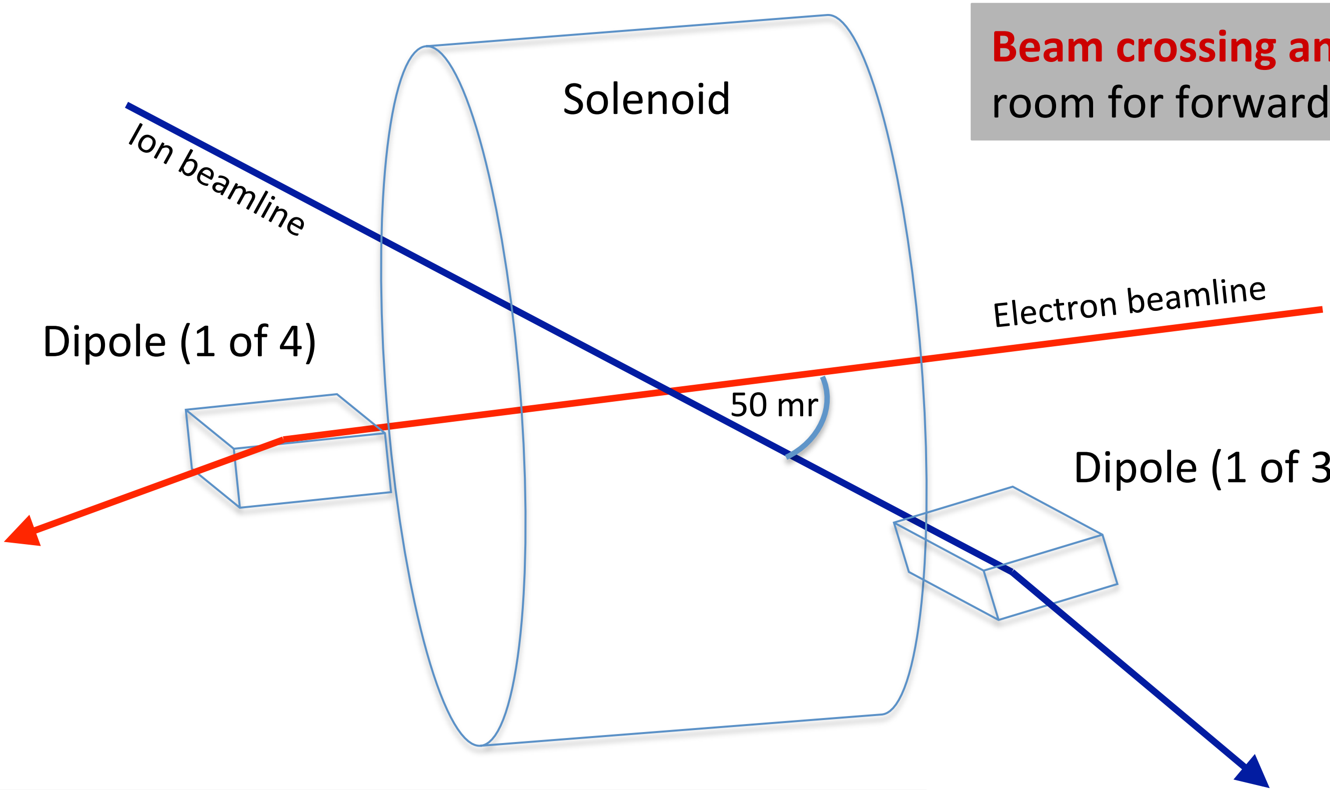


Experimental challenges:

- beam elements limit forward acceptance
- central Solenoid not effective for forward

Interaction region concept

NOT TO SCALE!

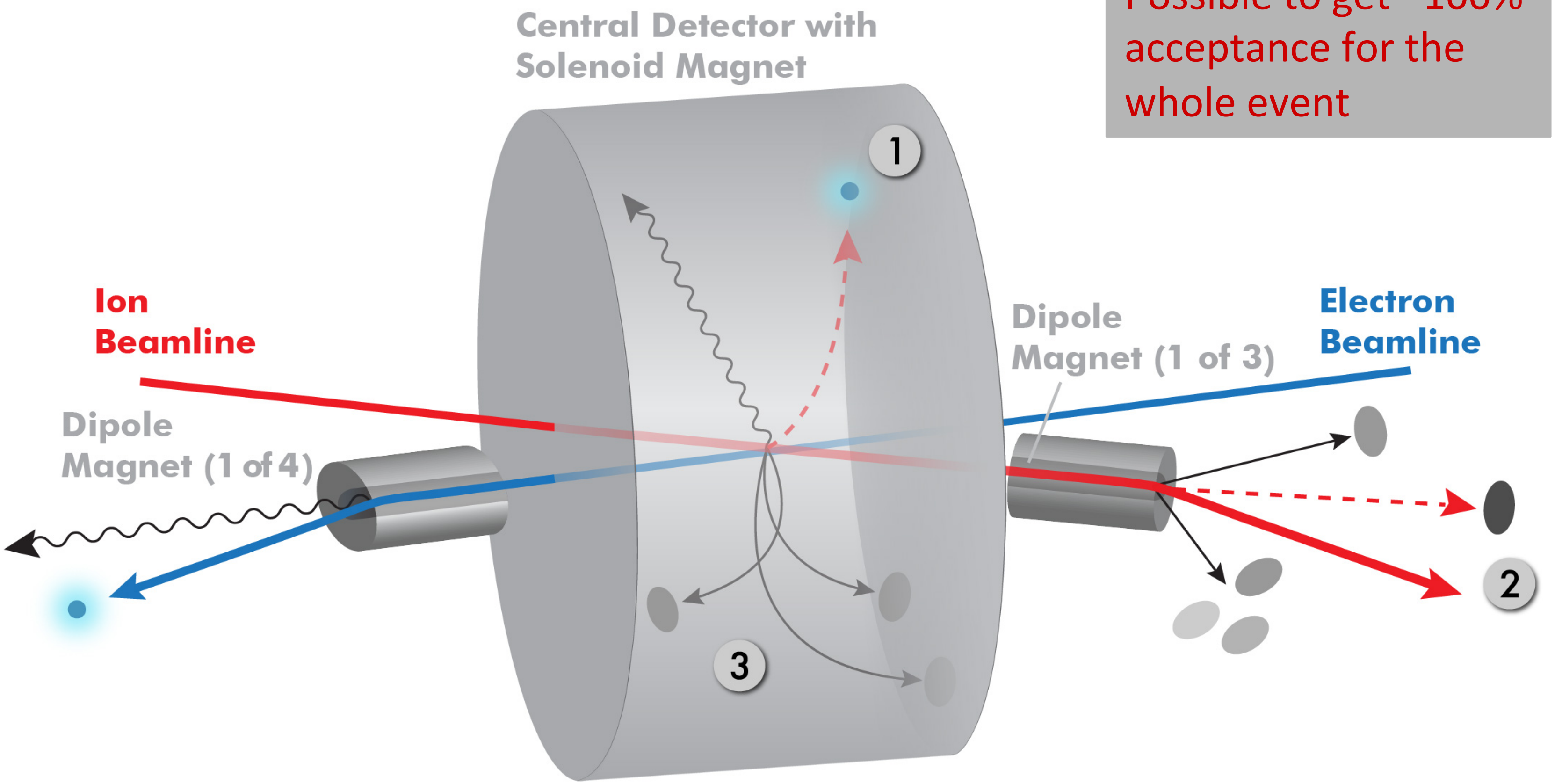


Beam crossing angle creates room for forward dipoles

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

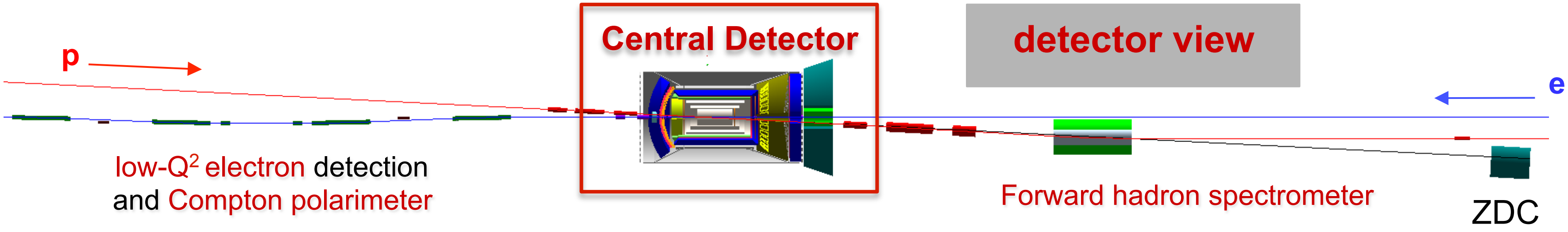
Interaction region concept

Possible to get ~100% acceptance for the whole event



Total acceptance detector (and IR)

Detector and interaction region



p

Central Detector

detector view

e

low-Q^2 electron detection and Compton polarimeter

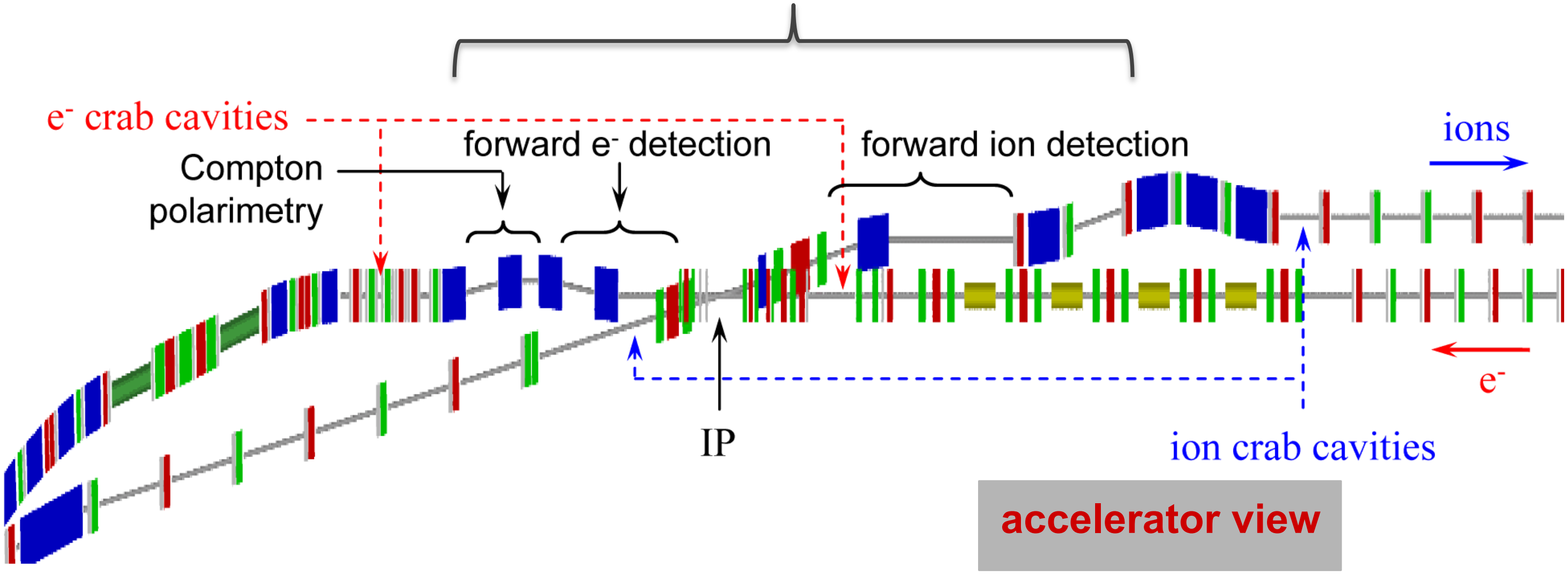
Forward hadron spectrometer

ZDC

Extended detector: 80m

30m for multi-purpose chicane, 10m for central detector, 40m for the forward hadron spectrometer

fully integrated with accelerator lattice



e^- crab cavities

Compton polarimetry

forward e^- detection

forward ion detection

ions

e^-

IP

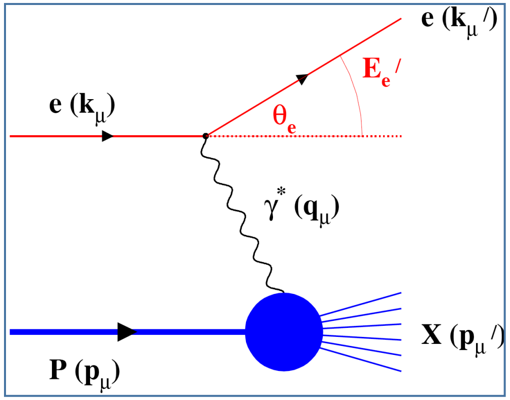
ion crab cavities

accelerator view

Section

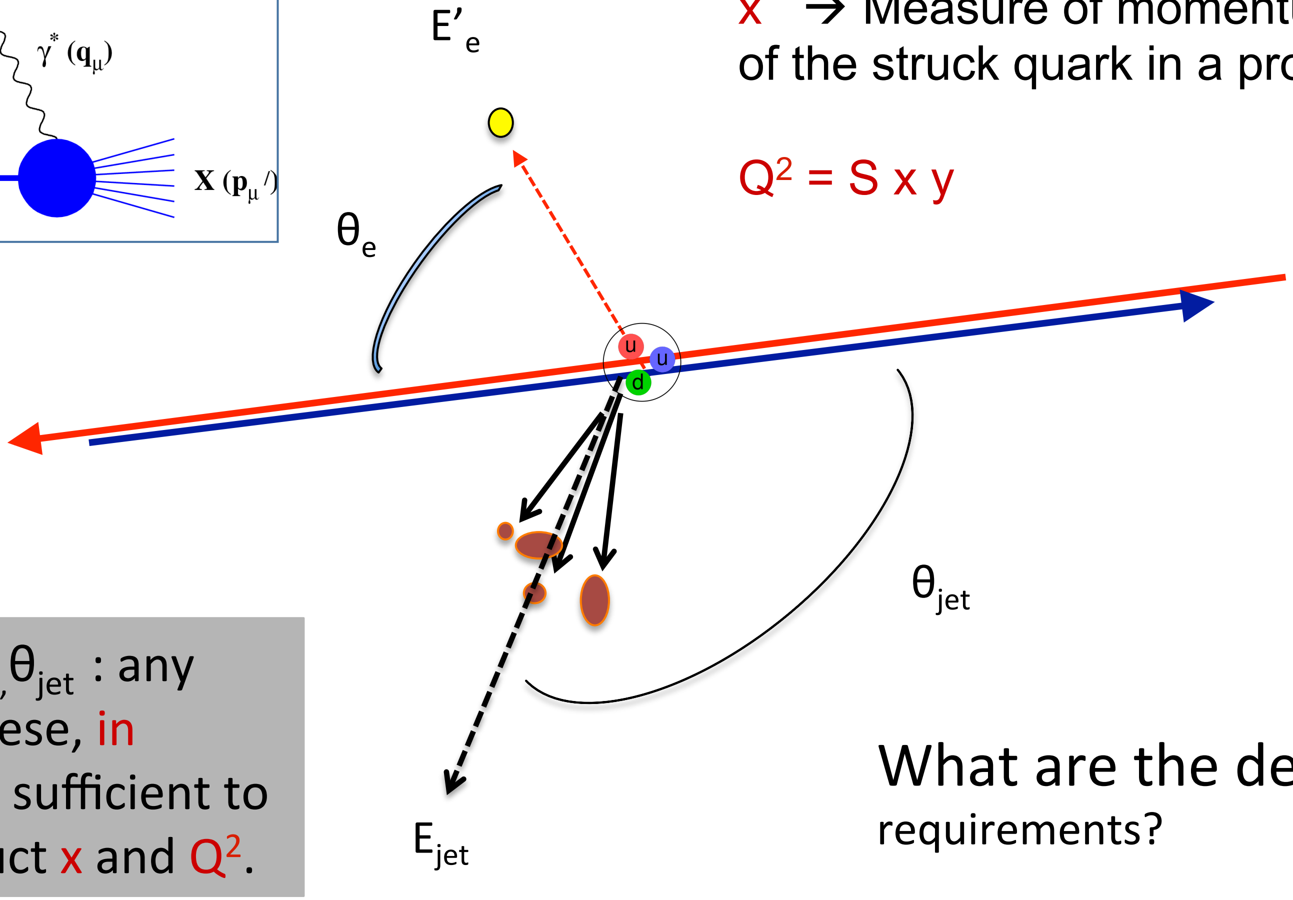
Central Detector

Basic kinematic reconstruction



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

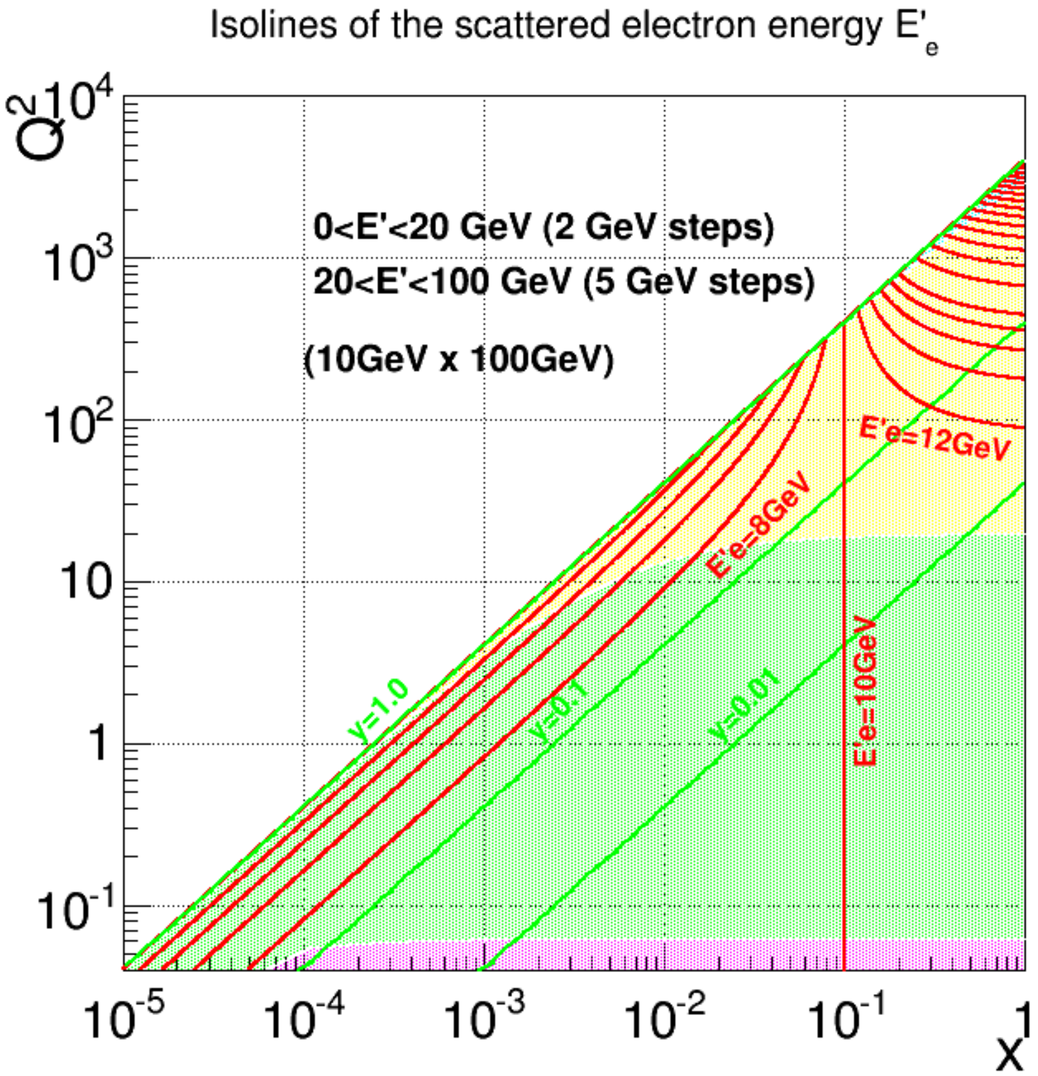
$Q^2 = S\ x\ y$

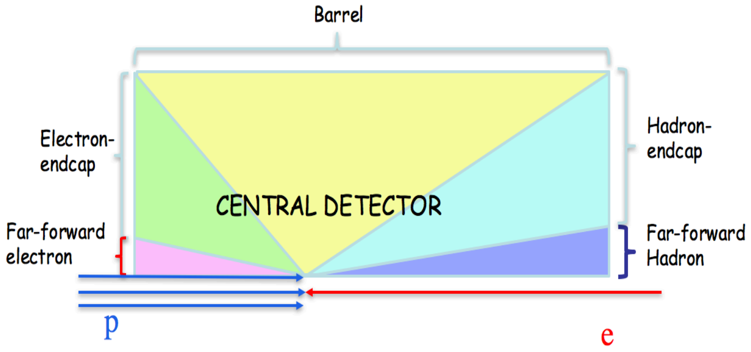


$E'_{e}, \theta_e, E_{jet}, \theta_{jet}$: any two of these, in principle, sufficient to reconstruct x and Q^2.

What are the detector requirements?

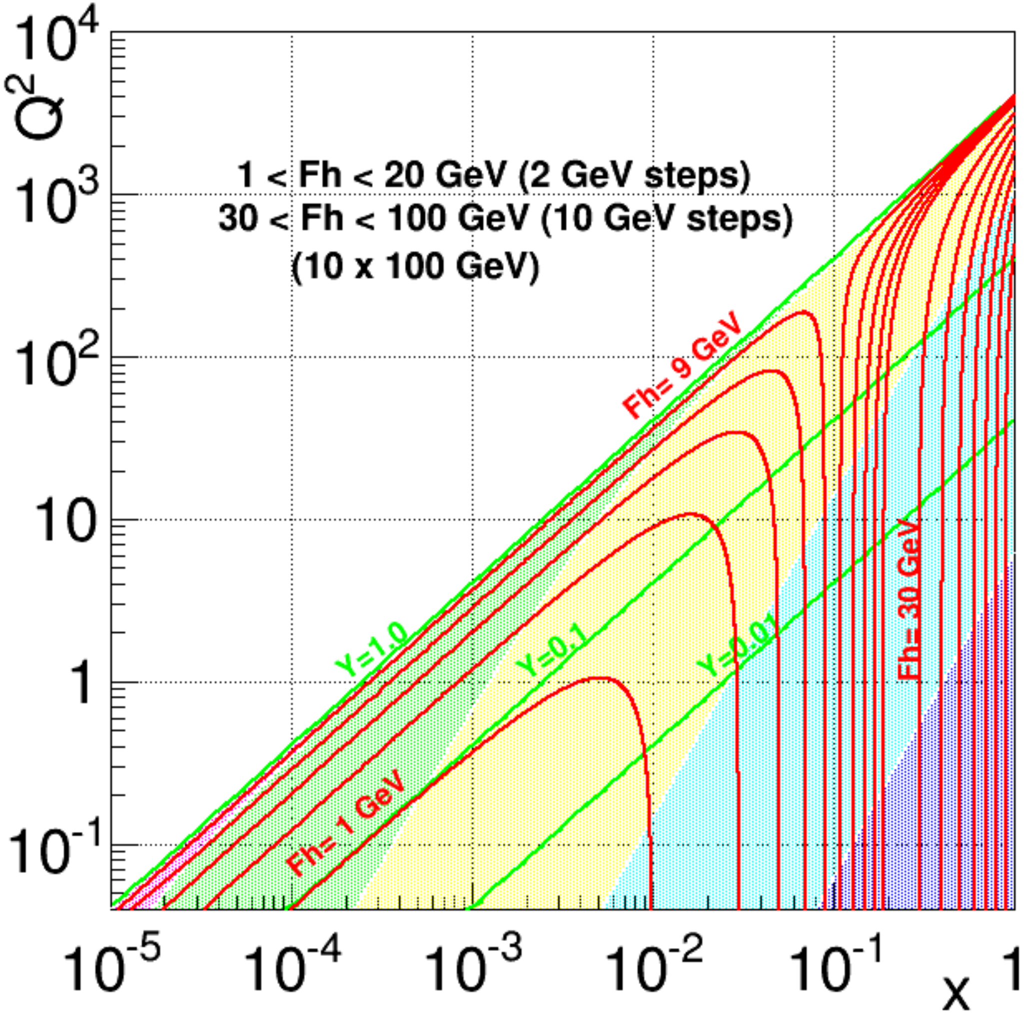
Electron isoline plot

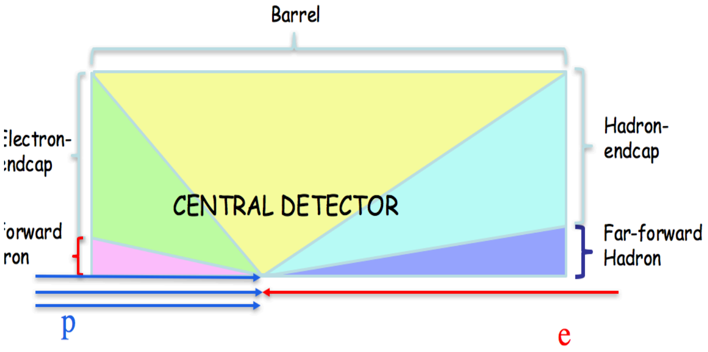




Quark (jet) isoline plot

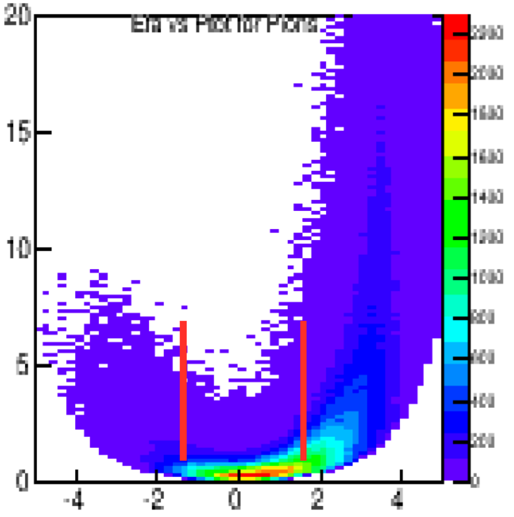
Isolines of the struck quark energy F_h

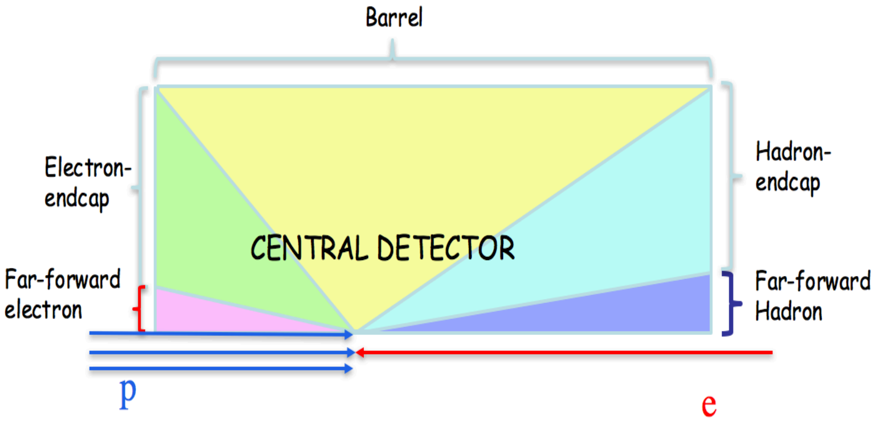




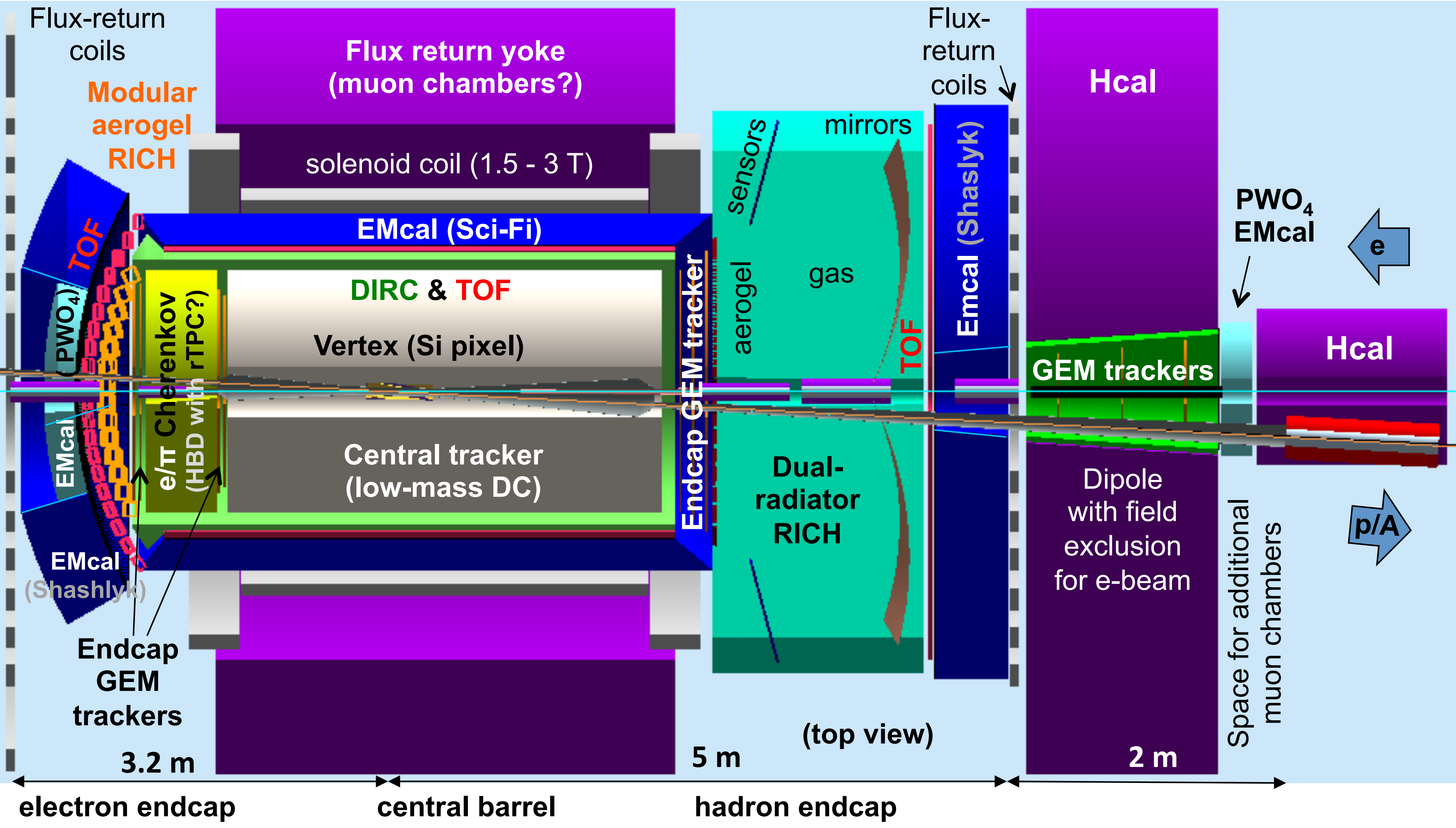
Particle distribution

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

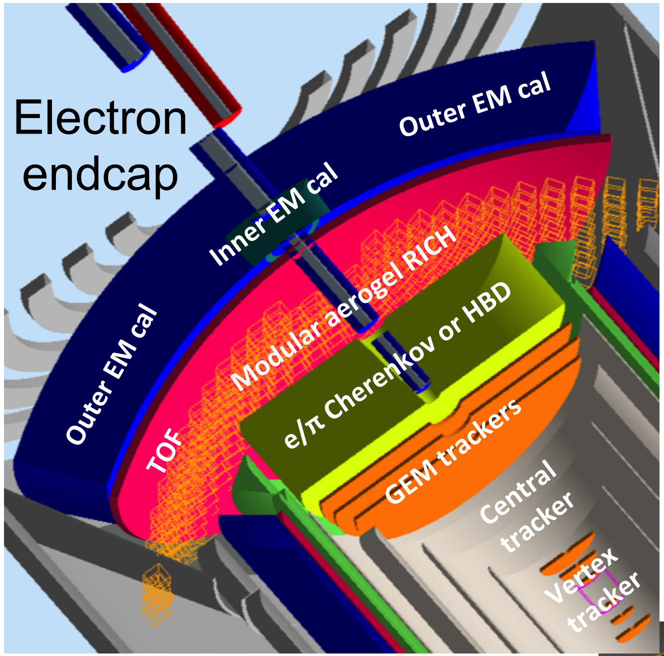


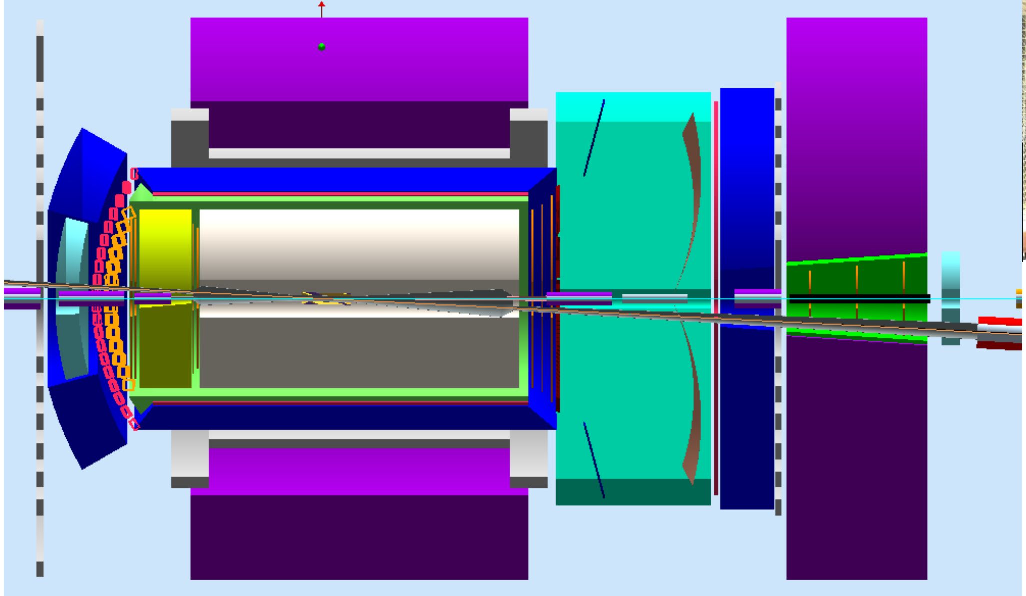


Central detector overview

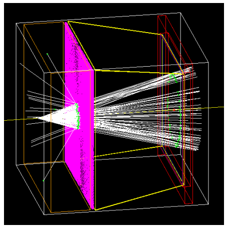


Generic EIC detector R&D program

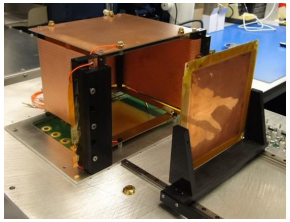




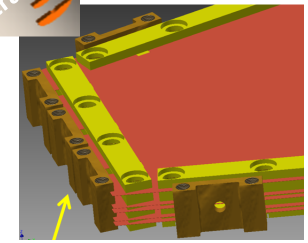
eRD1 – PWO_4 small-angle EMcal



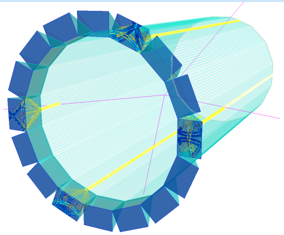
eRD14 – modular aerogel RICH



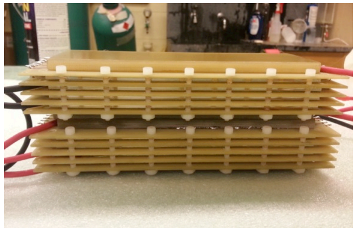
eRD6 – HBD/TPC?



eRD3 & eRD6 – GEM trackers

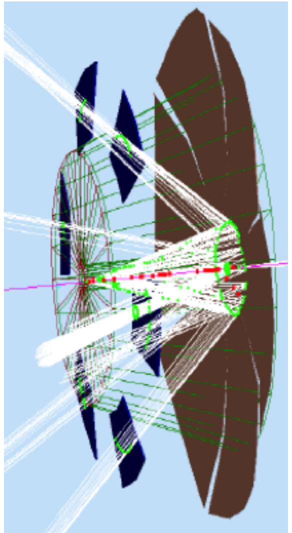


eRD14 – DIRC



eRD14 – MRPC TOF

eRD14 – photosensors



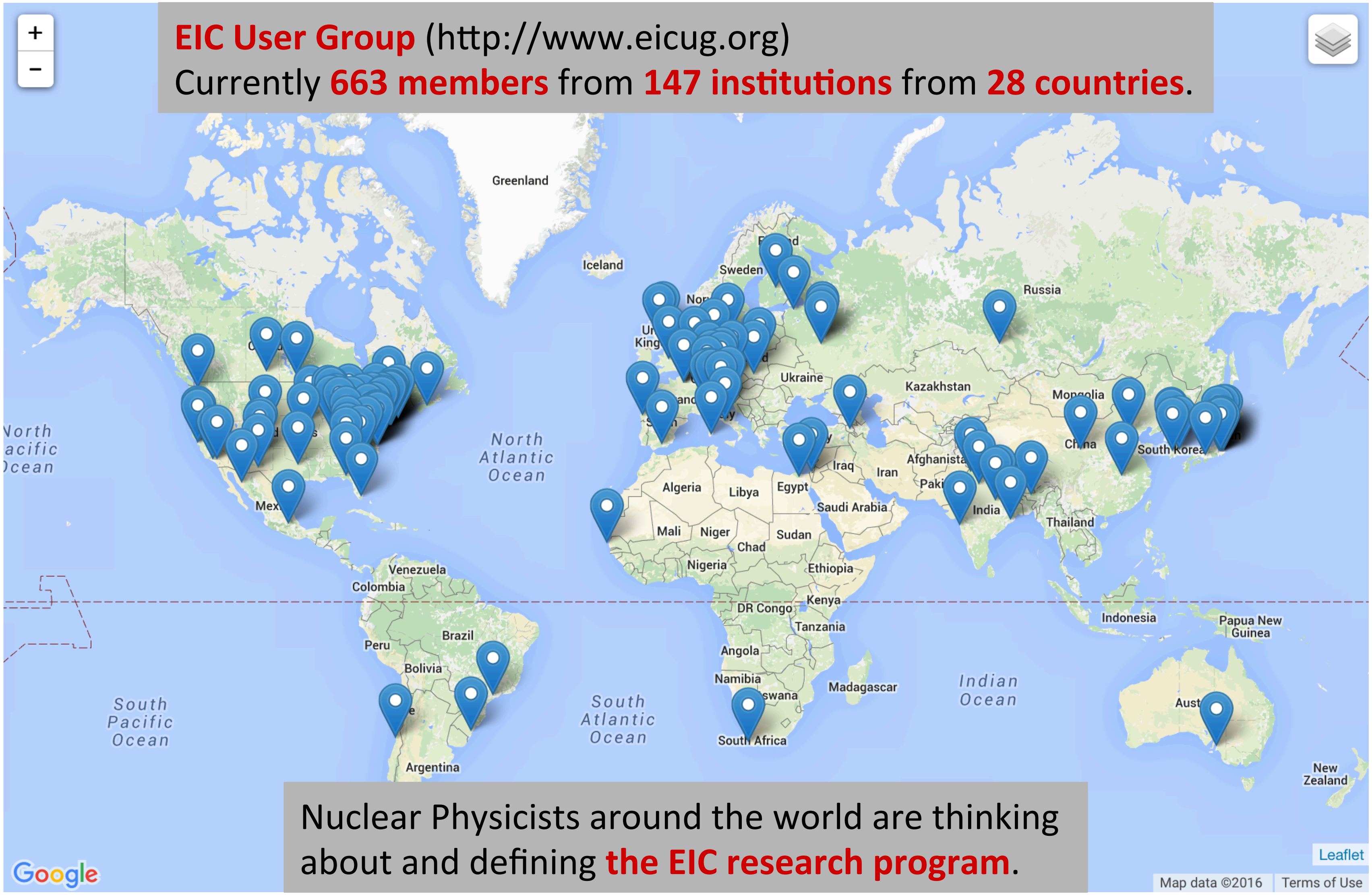
eRD14 – dual-radiator RICH

R&D program managed by Thomas Ulrich
17 proposals, international participation

JLab detector implements many of the projects

EIC User Group

EIC User Group (http://www.eicug.org)
Currently **663 members** from **147 institutions** from **28 countries**.



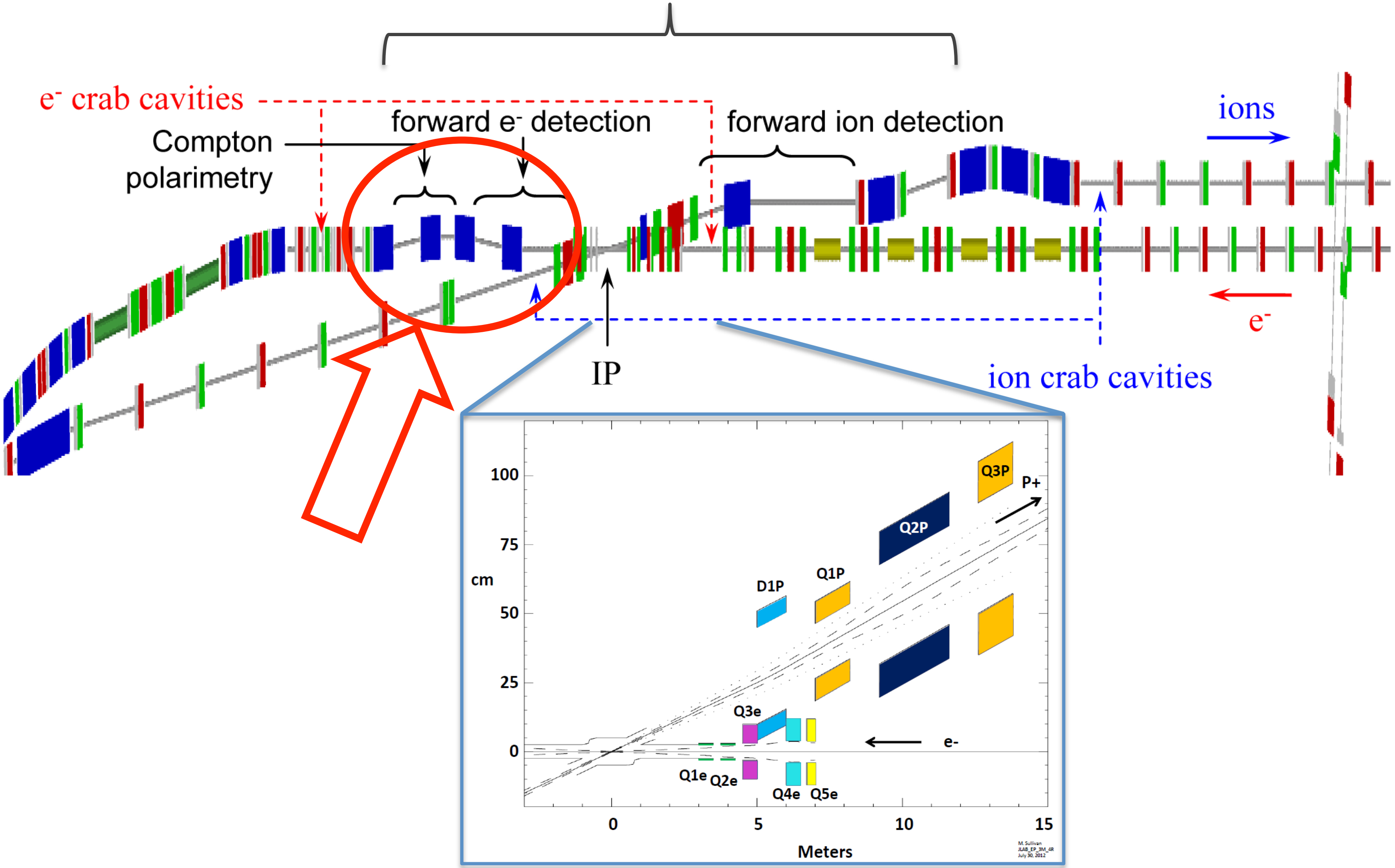
Nuclear Physicists around the world are thinking about and defining **the EIC research program**.

Section

Detectors in electron-beam direction

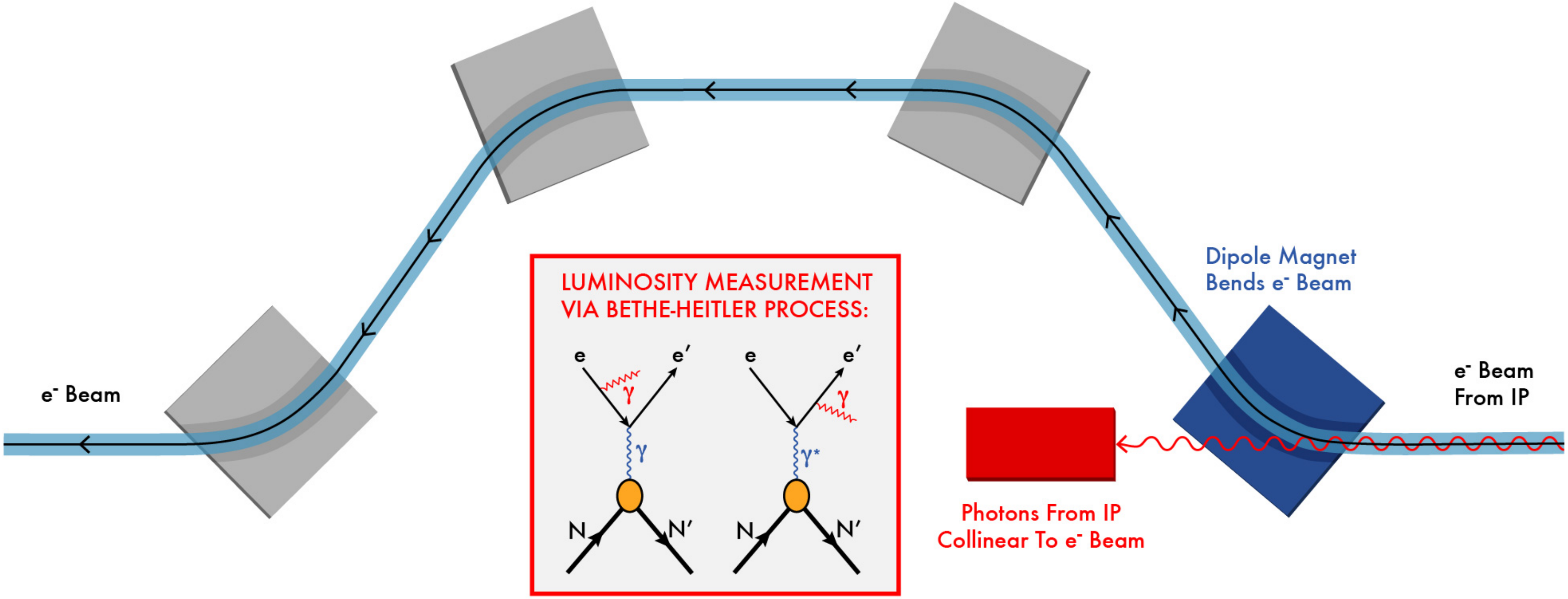
Chicane for electron-forward detection

Extended detector: 80+ m

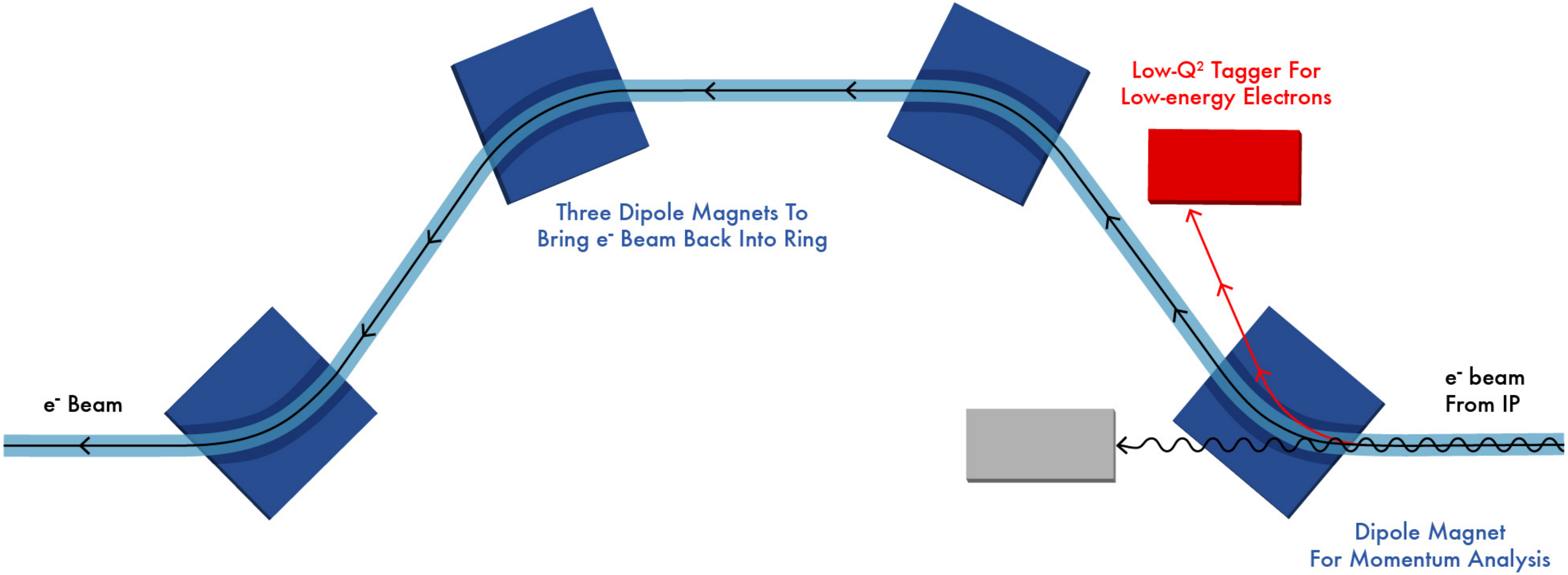


Luminosity measurement

Use Bethe-Heitler process to monitor luminosity (same as HERA)



Low-Q^2 tagger

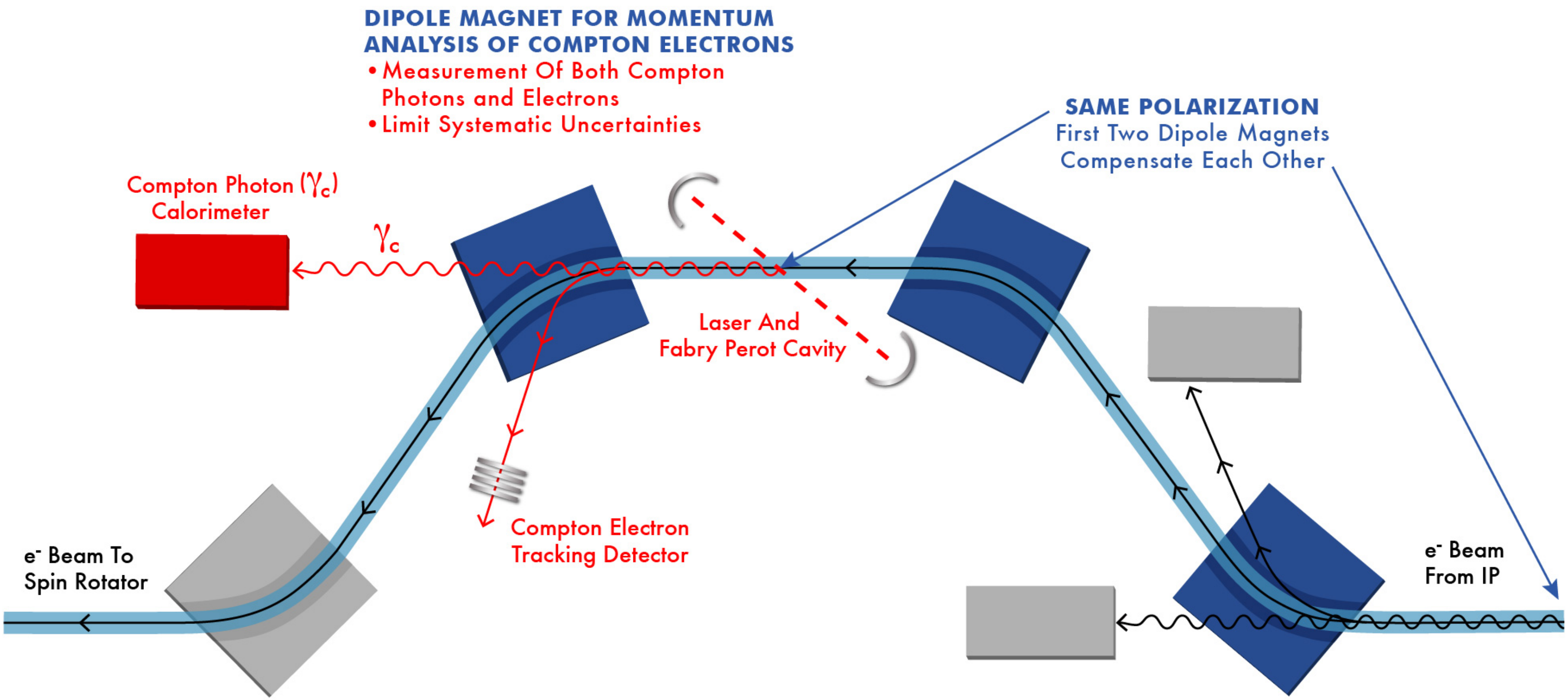


Low-Q^2 Tagger For Low-energy Electrons

Three Dipole Magnets To Bring e⁻ Beam Back Into Ring

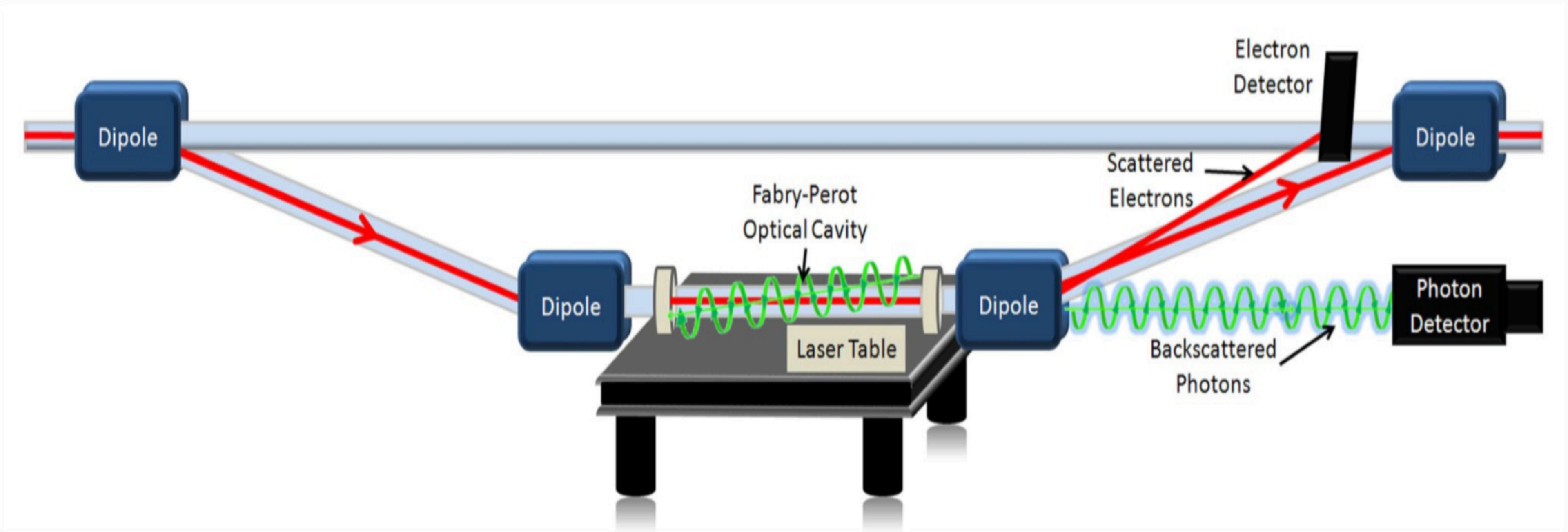
Dipole Magnet For Momentum Analysis

Polarization measurement



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

Compton polarimetry

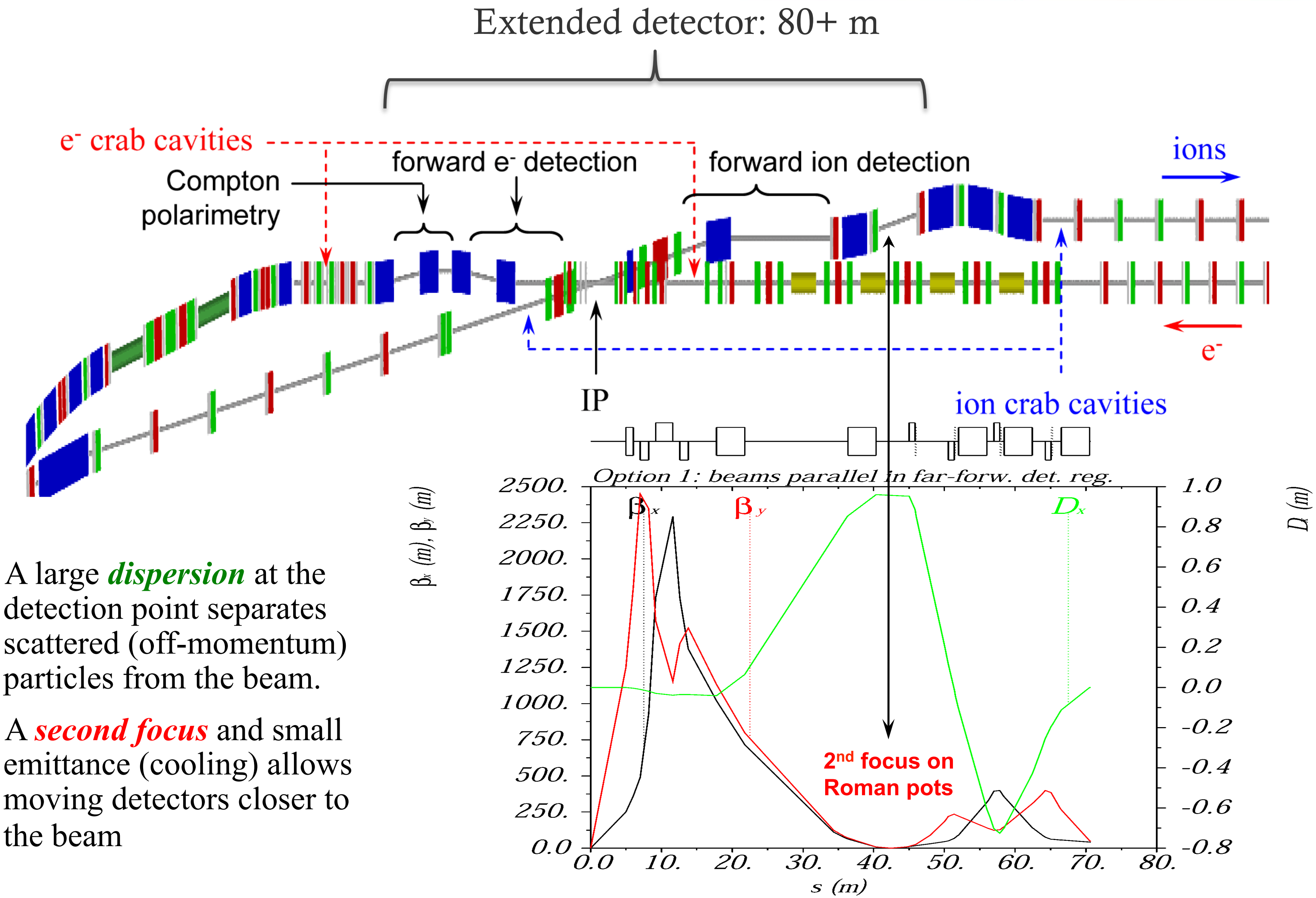


Existing Polarimeter in Hall C at JLab: Achieved 0.6% Precision

Section

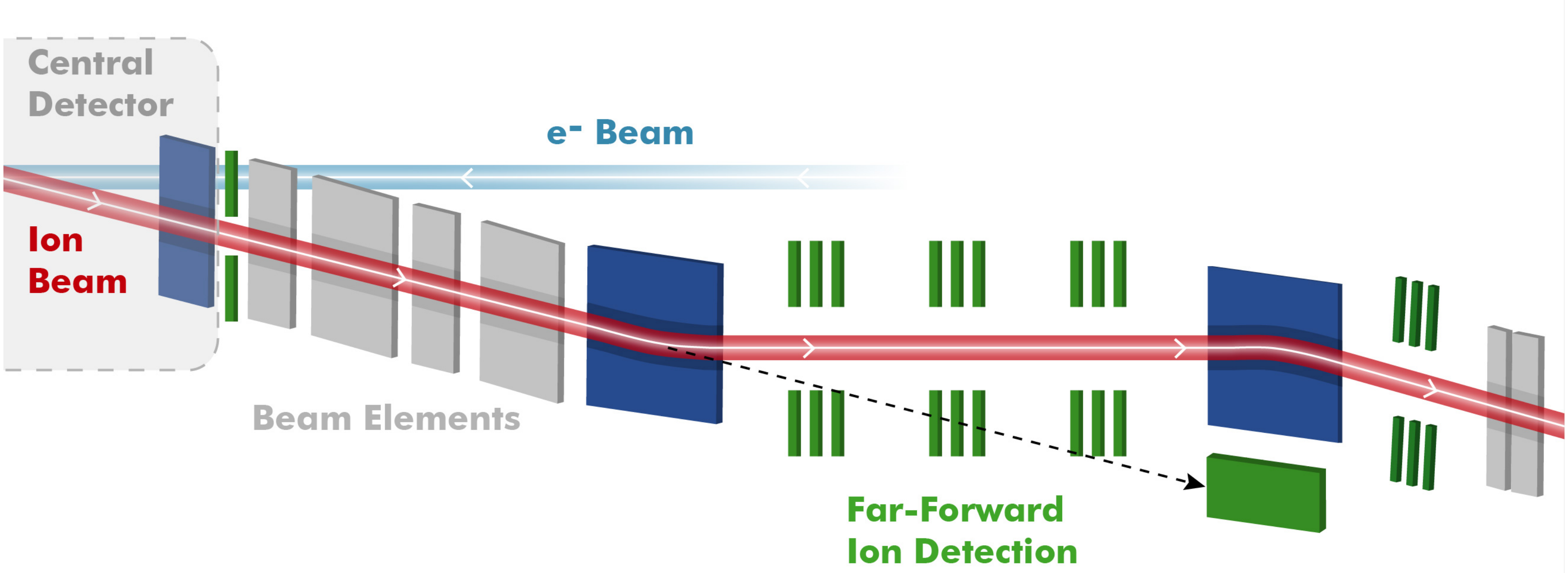
Detectors in ion-beam direction

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

Far-forward ion detection

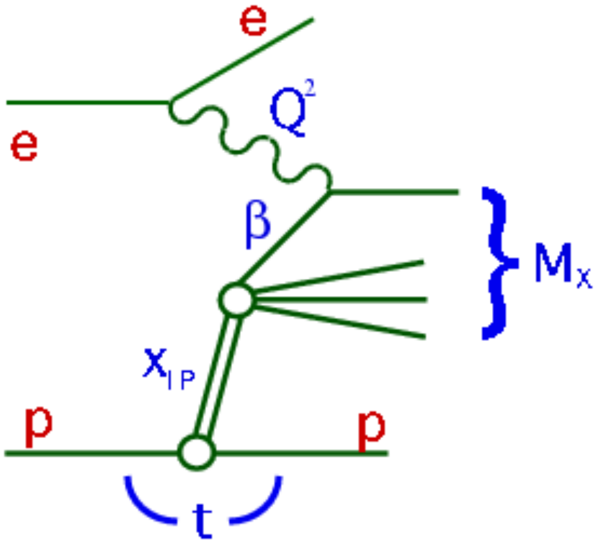


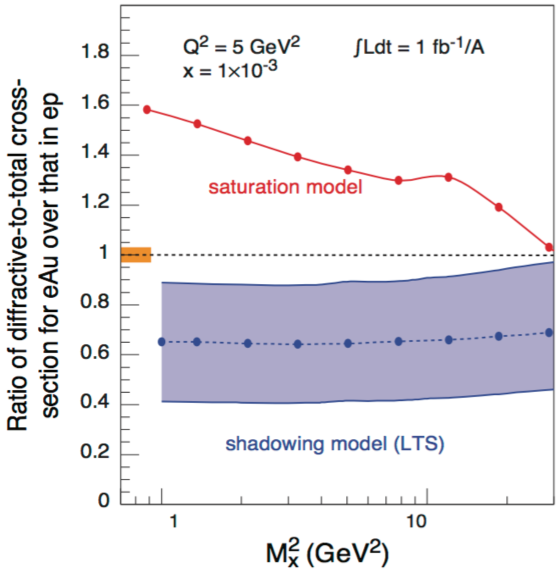
Forward detection requirements:

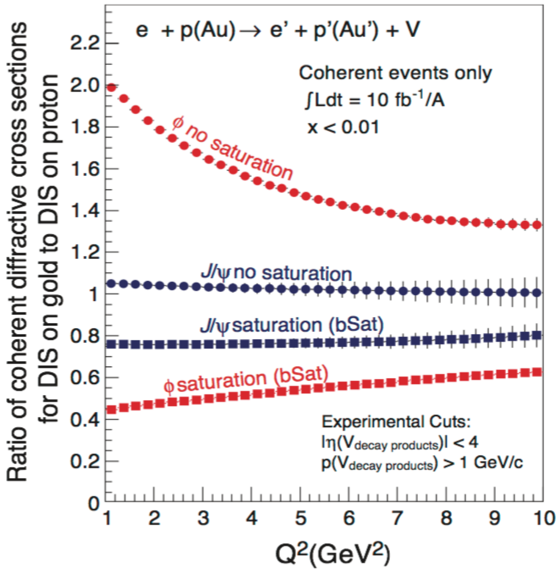
- good acceptance for recoils nucleons (rigidity close to beam)
- good acceptance for fragments (rigidity different than beam)

An example: Diffractive DIS (DDIS)

Signature for Saturation (among other things)



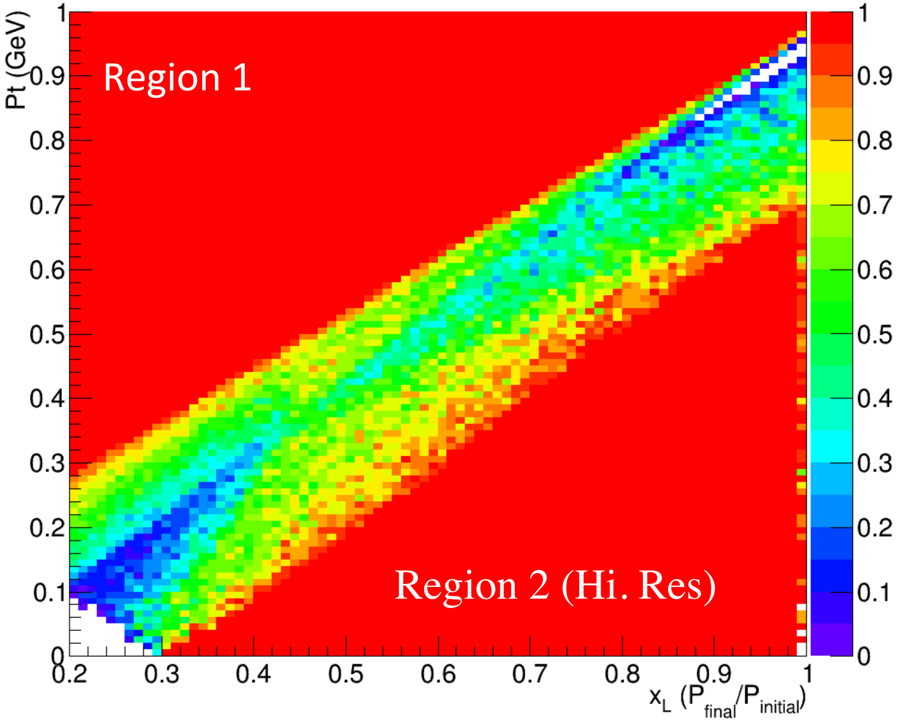




Identify the scattered proton: distinguish from proton dissociation
Measure $X_L = E_p'/E_p$, and P_t (or t) (equiv. to measuring M_x)

Acceptance for p’ in DDIS

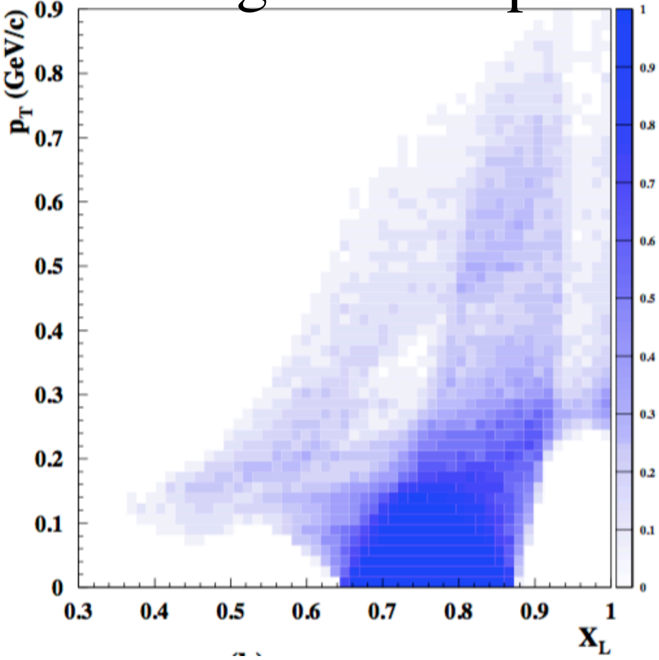
JLEIC acceptance



Zhiwen Zhao

ZEUS

Leading Proton Spectrometer



Acceptance in diffractive peak (X_L>~.98)

ZEUS: ~2%

JLEIC: ~100%

Epilogue

Concluding remarks

Complementary detector scenarios

- two detectors optimized for different capabilities and using complementary technologies allow better performance and improved cost-effectiveness
- complementary sensitivity to physics, backgrounds and fake effects
- cross-checks on discoveries and important physics results
- combine results for precision measurements:
  - a combined reduction of systematics
  - in a ring-ring collider: detector luminosities can be added
- higher efficiency of operation
- increase scientific productivity

IP1: multi-purpose, full acceptance detector (this presentation)

- focus on single track reconstruction and PID
- optimized to support the broad physics program in the white paper

IP2: complementary, smaller detector

- focus on jet reconstruction and calorimetry

Towards the realization of the EIC

JLEIC Documentation Series – 001

Jefferson Lab
Electron-Ion Collider (JLEIC):

An Introduction to the Interaction Region and Detector Design

Authored by the JLEIC Detector and Interaction Region Group

Jefferson Lab Electron-Ion Collider is a proposed realization of the Electron-Ion Collider (EIC) [1]. The EIC has been chosen as the highest priority new construction for Nuclear Physics in the US [2]. We discuss the main drivers for design of the JLEIC interaction region and the detectors, and the layout that was developed in response to these drivers.

[1] A. Accardi et al., Electron Ion Collider: The Next QCD Frontier - Understanding the glue that binds us all, JLAB-PHY-12-1652, 2012.
[2] A. Aprahamian et al., Reaching for the horizon: The 2015 long range plan for nuclear science, 2015.

Jefferson Lab JLEIC

- Accelerator Physicists, Experimentalists, and Theoreticians are thinking about and defining the EIC research program. It's important that many labs and universities - not only from within the NP community - get involved.
- **Close collaboration** among Accelerator Physicists, Experimentalists, and Theoreticians at Jefferson Lab.

- Concept finalized for the **JLEIC Interaction and Detector Region**.
- Documentation in preparation.
- Detailed detector simulations are required to verify the design and optimize the physics reach.