JLEIC IR and Forward Detection

Selected Detector Topics

Rik Yoshida

2/7/18 Polarized Light Ions at EIC,
Gent. Belgium

Outline

- JLEIC Accelerator
- What we need to measure
- JLEIC Detector
  - Central Detector
  - Forward Detectors
    - Charged Particle Detection
    - Neutral Particle Detection
    - Some examples
  - Accessing the JLEIC simulation
  - Measuring high-x (low-x) at EIC
- Conclusions

Jefferson Lab Electron-Ion Collider

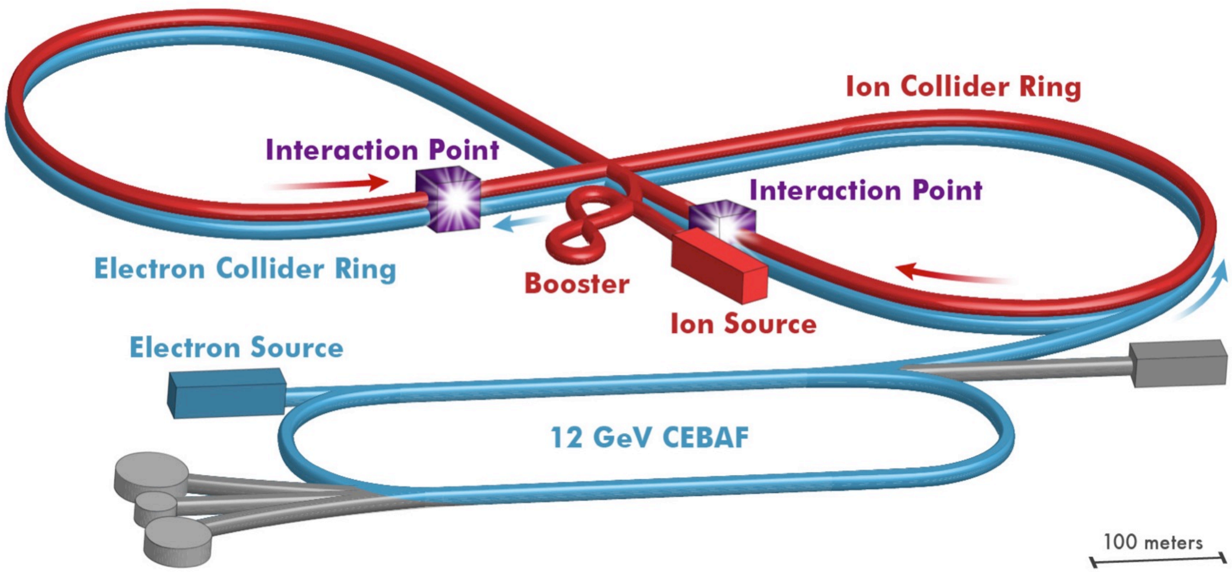
energy range:

E_e: 3 to 12 GeV

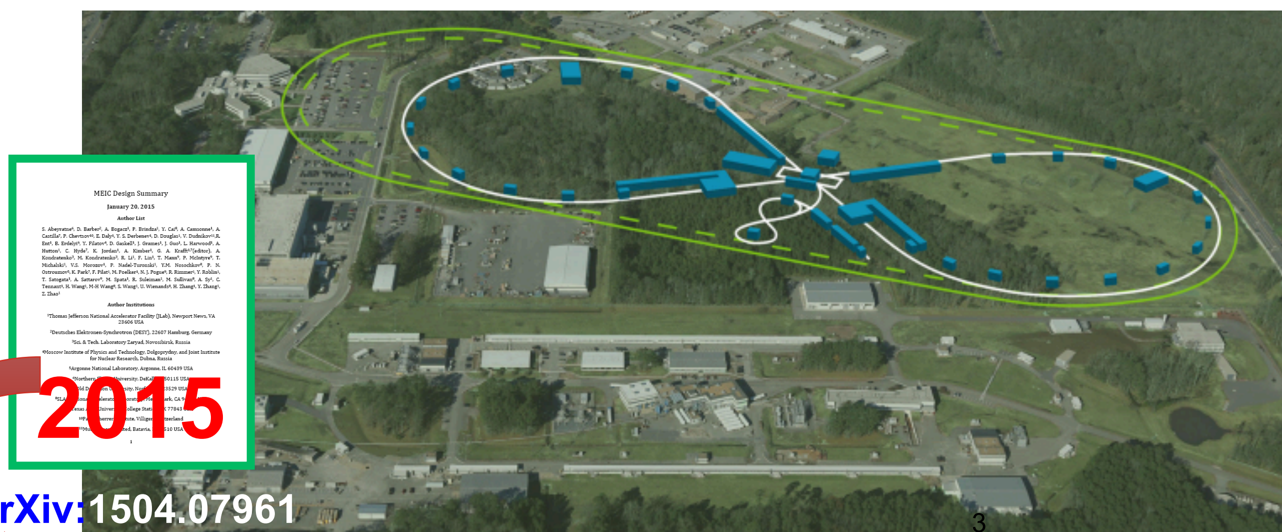
E_p: 40 to 100-400 GeV

$\sqrt{s}$: 20 to 65- 140 GeV

(upper limit depends on magnet tech. choice)



- **Electron complex**
  - CEBAF
  - Electron collider ring
- **Ion complex**
  - Ion source
  - SRF linac
  - Booster
  - Ion collider ring
- Fully integrated IR and **detector**
- DC and bunched beam **coolers**



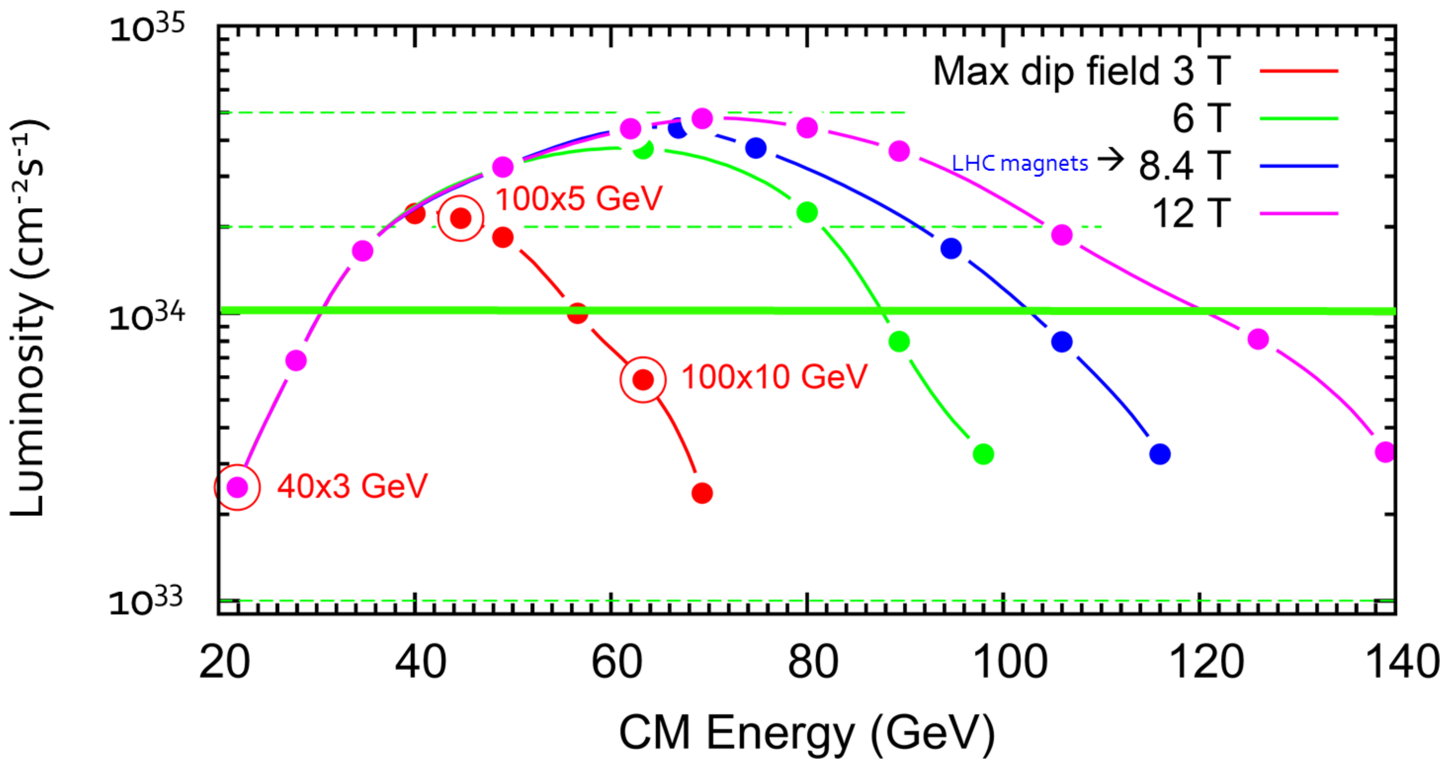
MEIC Design Summary

January 20, 2015

arXiv:1504.07961

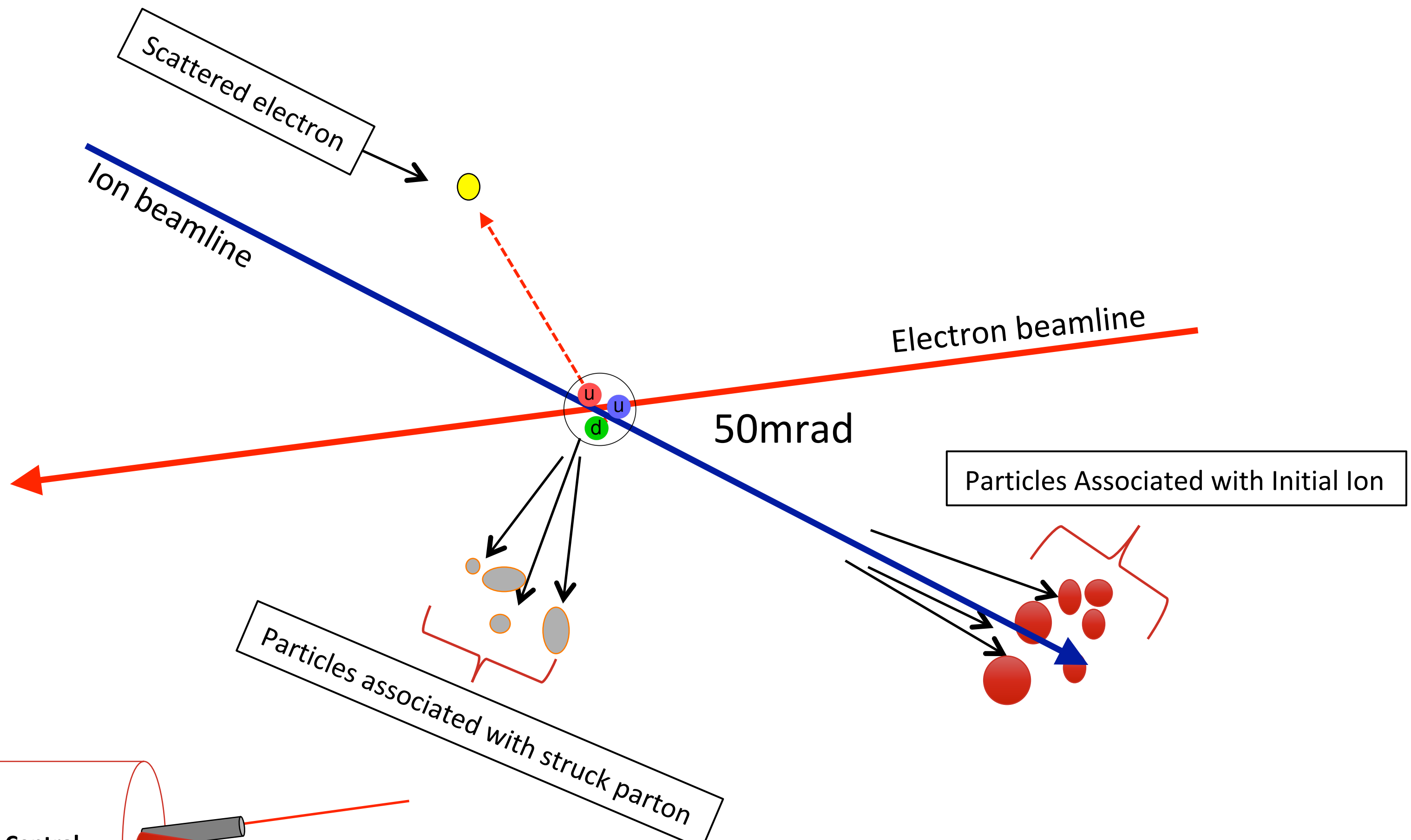
April 2017 Update

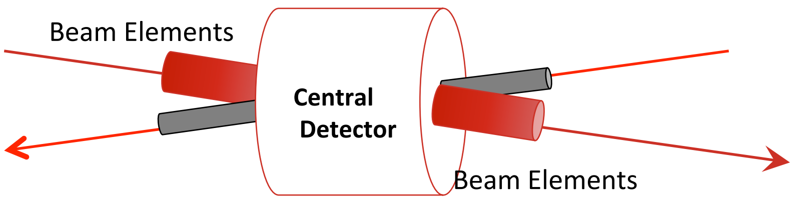
Luminosity and Energy range of JLEIC



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

JLEIC IR Design Considerations



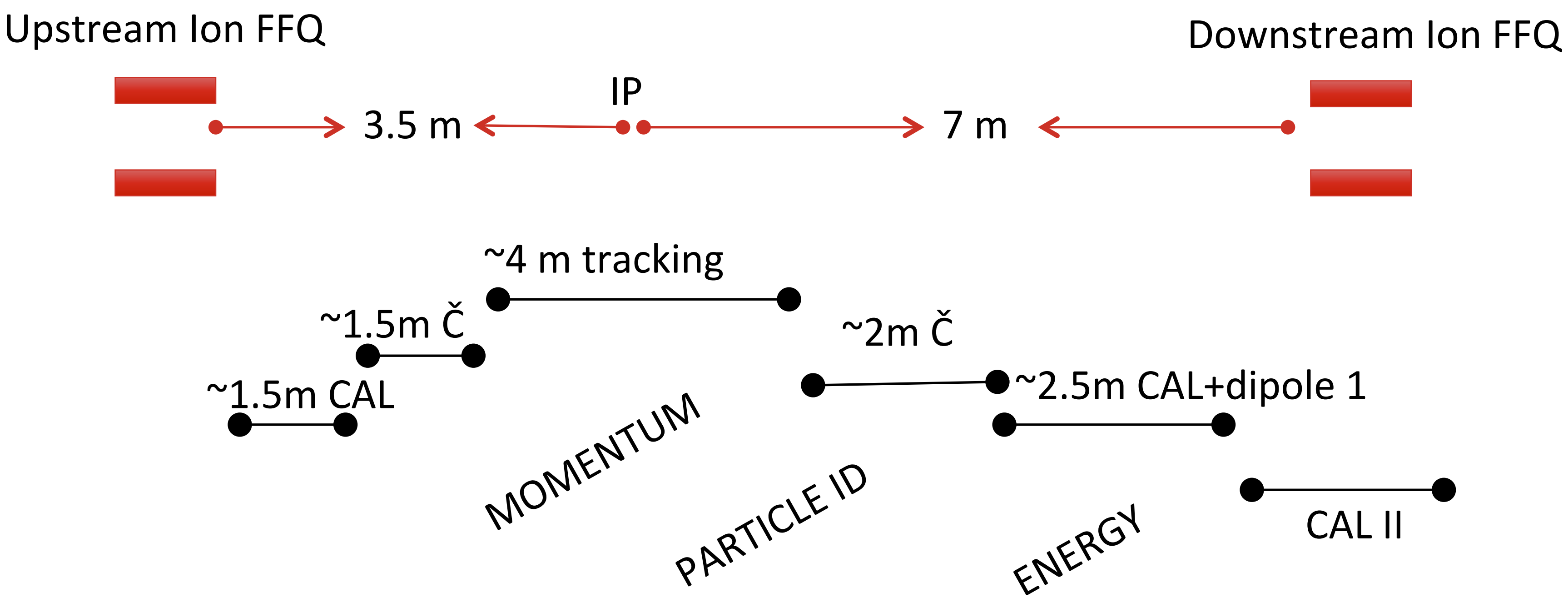


Beam elements limit forward acceptance
Central Solenoid not effective for forward

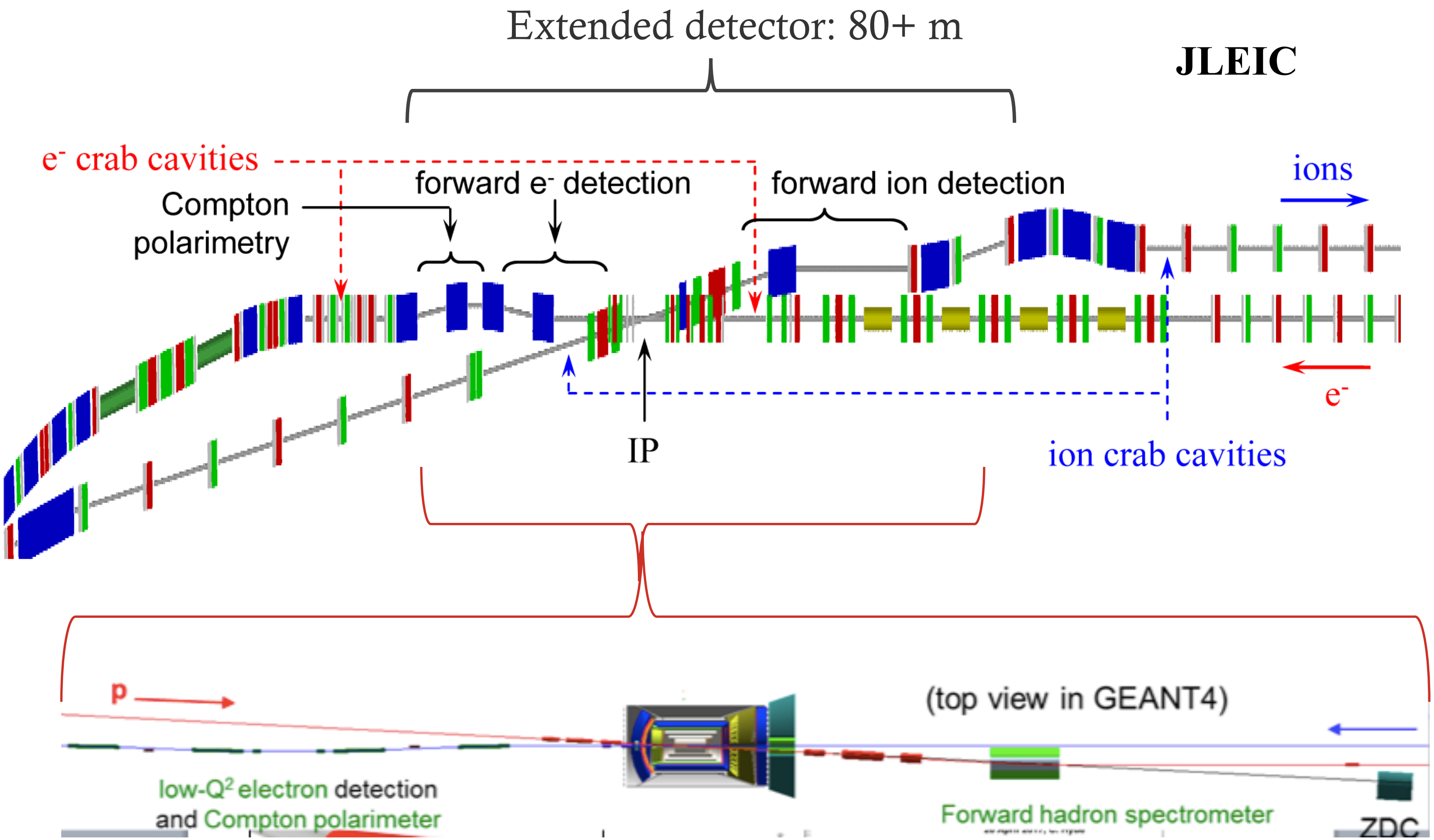
Central Detector General Design

Two opposing needs:

- FFQ's close together for higher luminosity
- Enough space for detector for excellent measurement



Integration of Extended Detector with the Acclerator



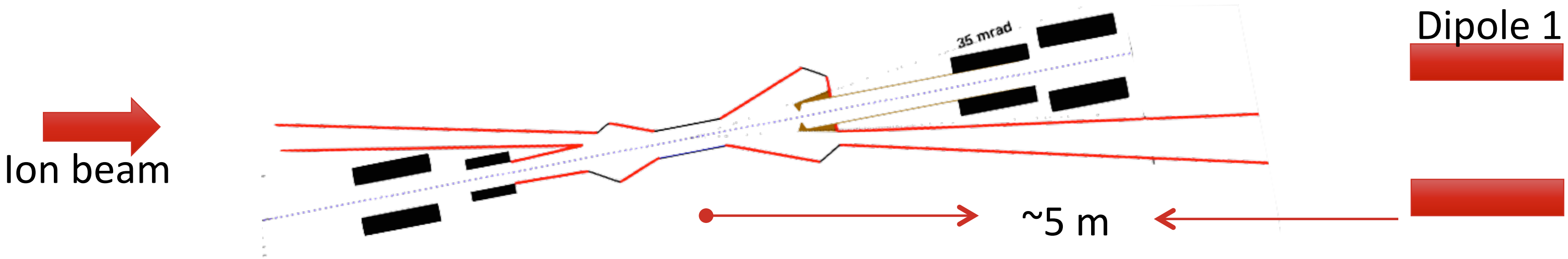
EIC detectors must be extremely well integrated with the accelerator

Crossing Angle and Event Symmetry

Ion-beam Axis: High x jets and proton/ion “remnant”

Goes towards the initial Ion beam direction

Centered about the ion beam axis $(xE_{p\_beam} >> E_{electron\_beam})$

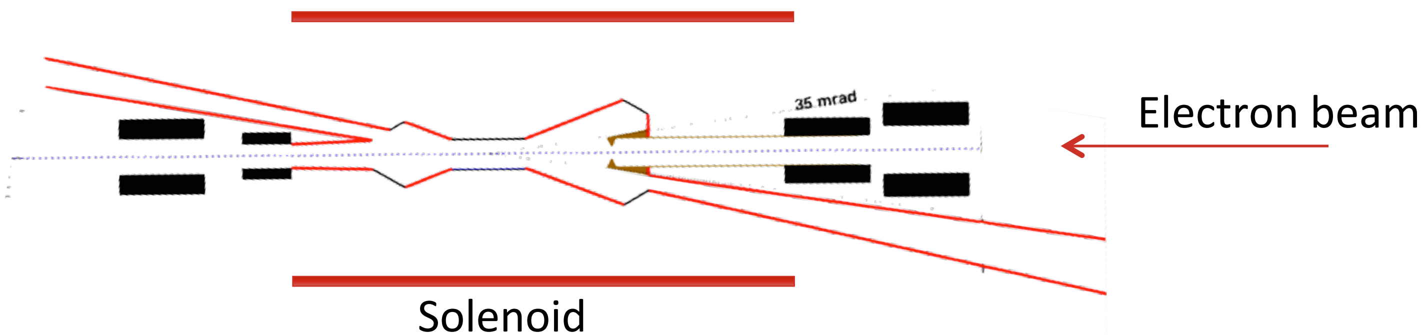


Electron-beam axis: Solenoid axis must align with electron beam

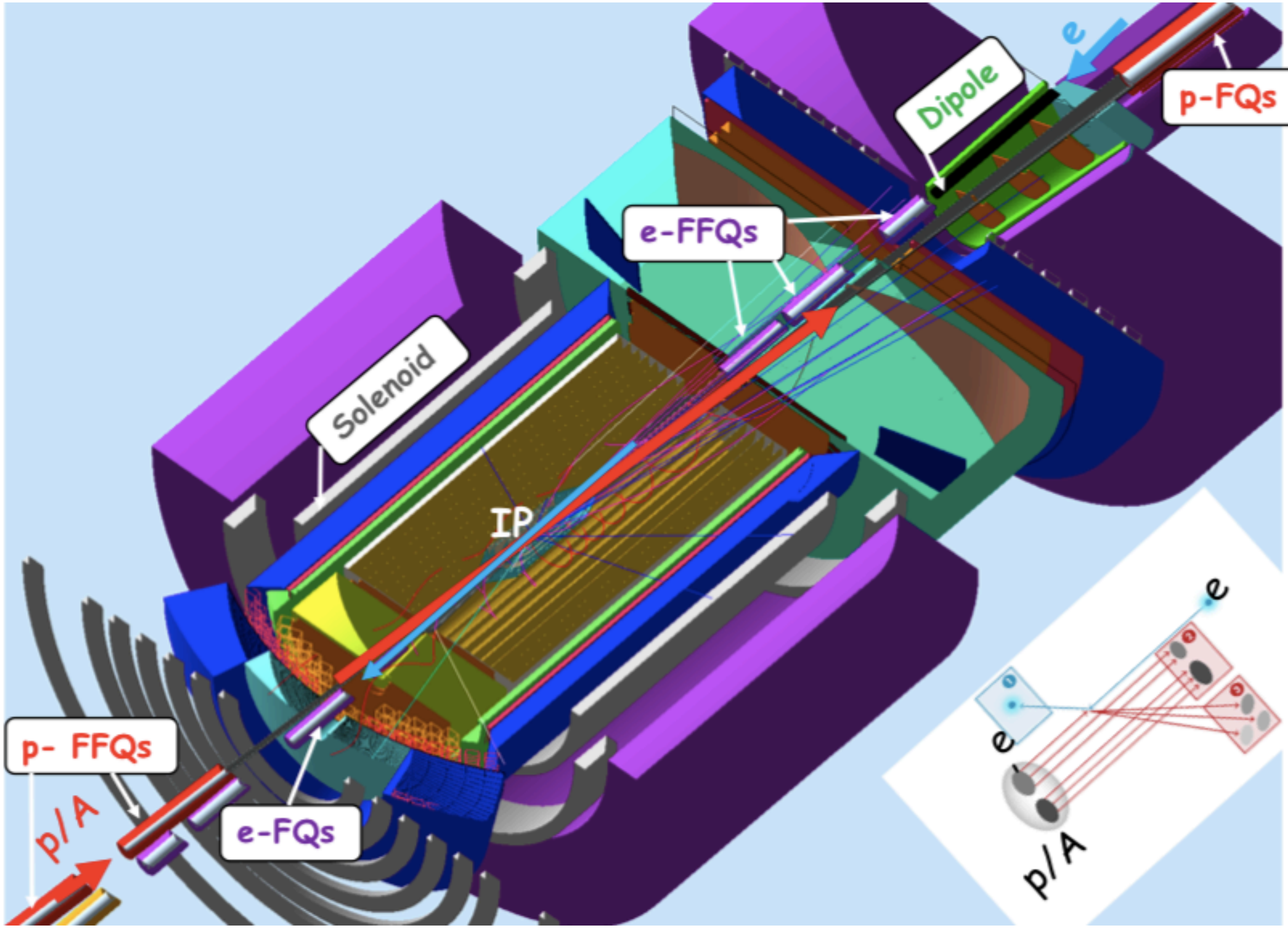
Low-x electrons and “jets”:

Goes toward the initial electron-beam direction

Centered about the electron beam axis $(xE_{p\_beam} << E_{electron\_beam})$

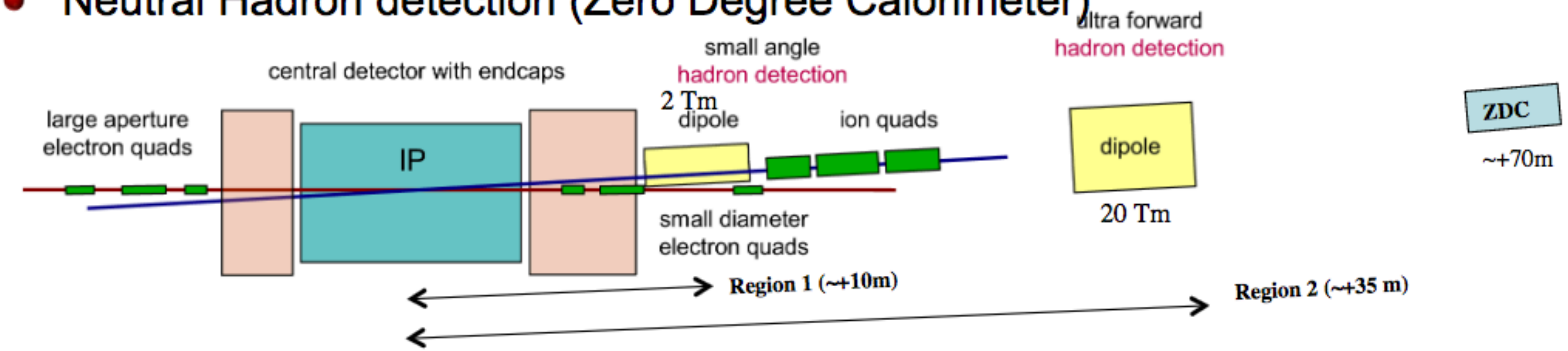


JLEIC Detector (Central Area)



Forward Hadron Detection

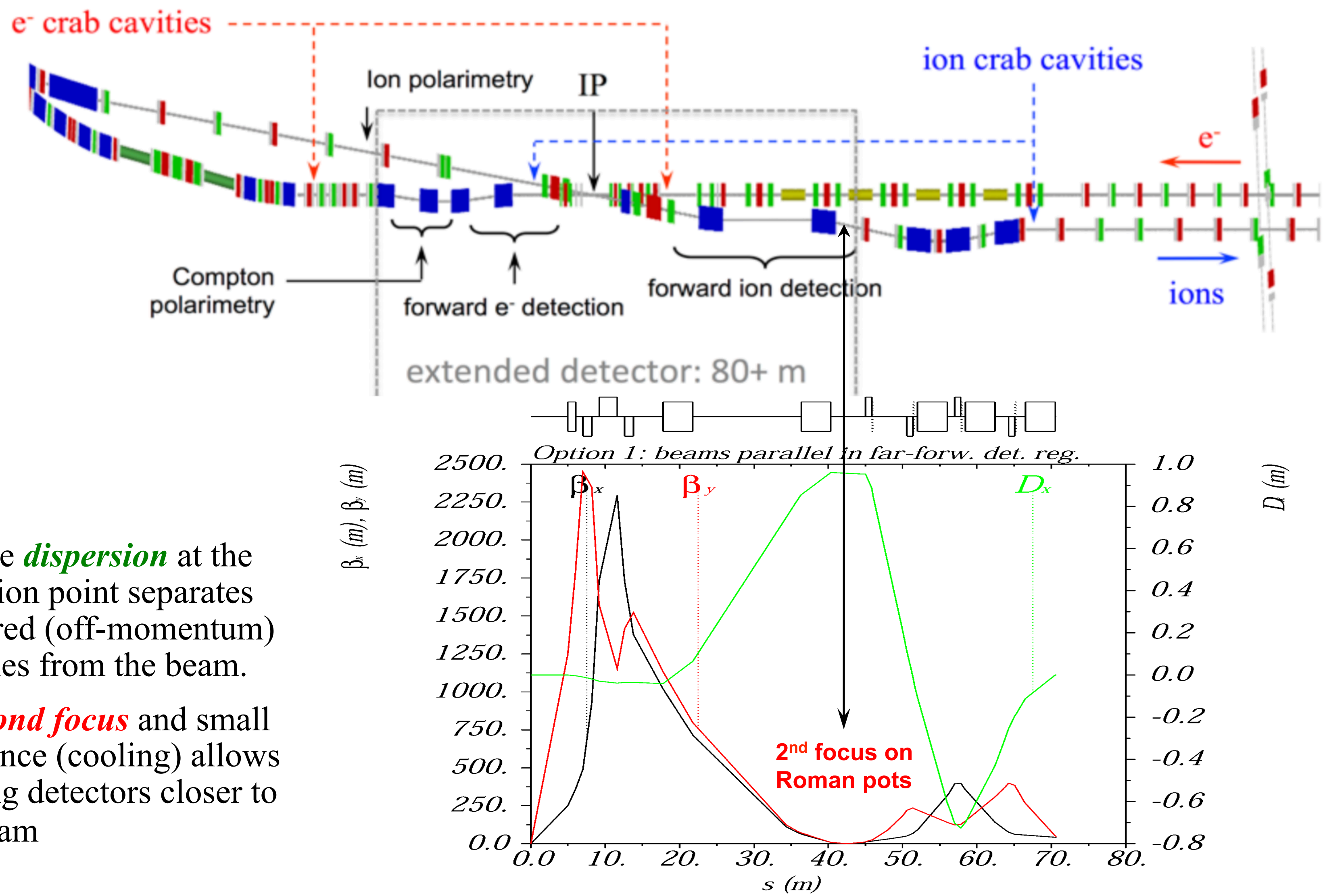
- 50 mrad crossing angle
  - No parasitic collisions, fast beam separation. Room for dipoles and detectors forward. (1m separation of beams at ~+30 m)
- Two forward charged hadron detector regions:
  - Region 1: Small dipole covering scattering angles from 0.5 up to a few degrees (before quads)
  - Region 2: Far forward, up to one degree, for particles passing through (large aperture) accelerator quads. Use second dipole for precision measurement. (Hi Res)
- Neutral Hadron detection (Zero Degree Calorimeter)



~100% acceptance for forward hadrons

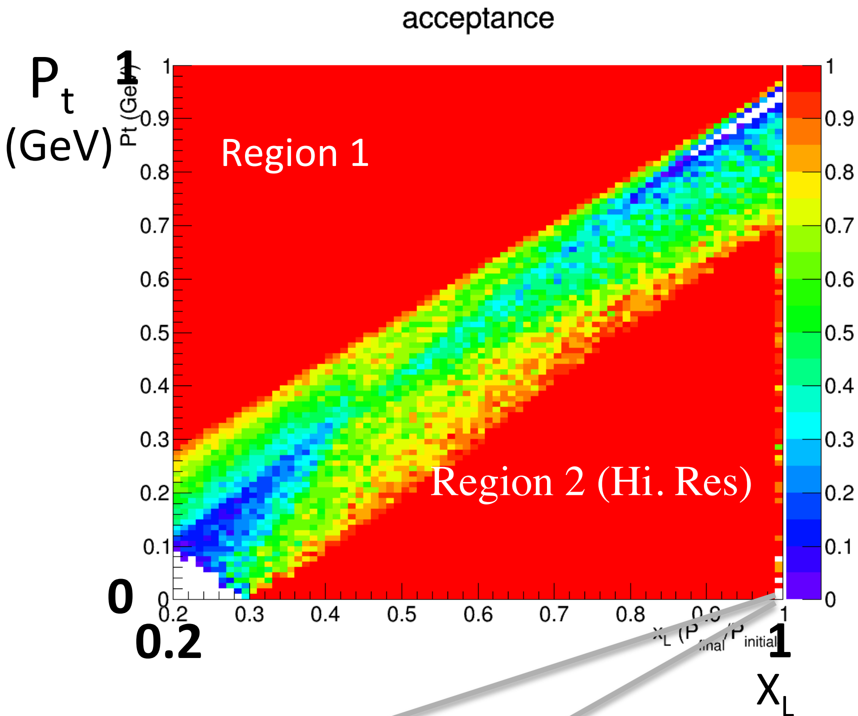
P. Nadel-Turonski, R. Ent, C.E. Hyde

Tracking Charged Particles with Large Momentum

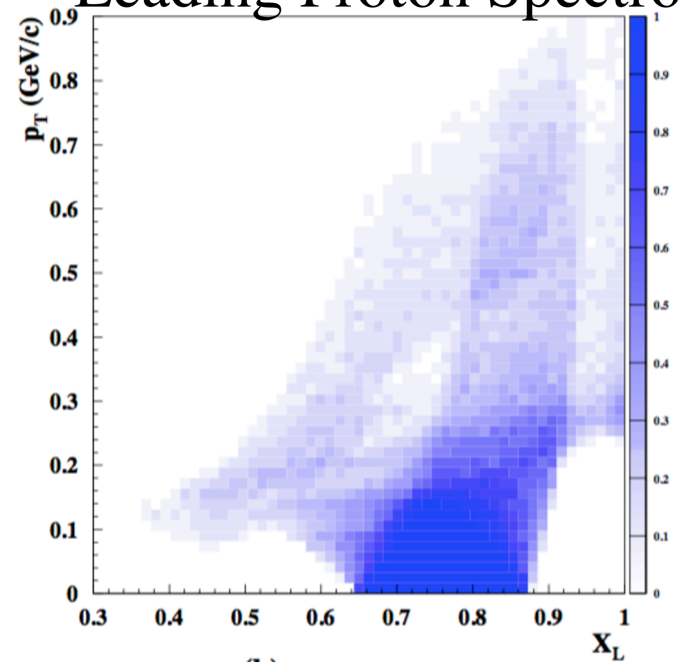


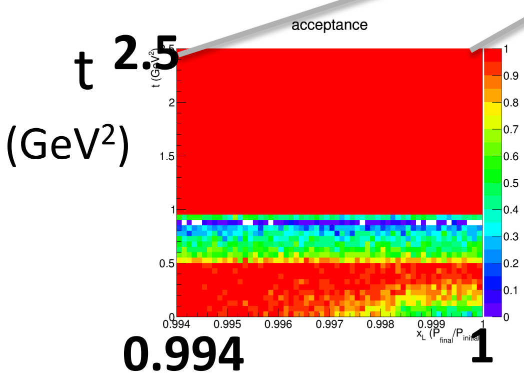
- A large ***dispersion*** at the detection point separates scattered (off-momentum) particles from the beam.
- A ***second focus*** and small emittance (cooling) allows moving detectors closer to the beam

Acceptance for Forward Protons



ZEUS
Leading Proton Spectrometer



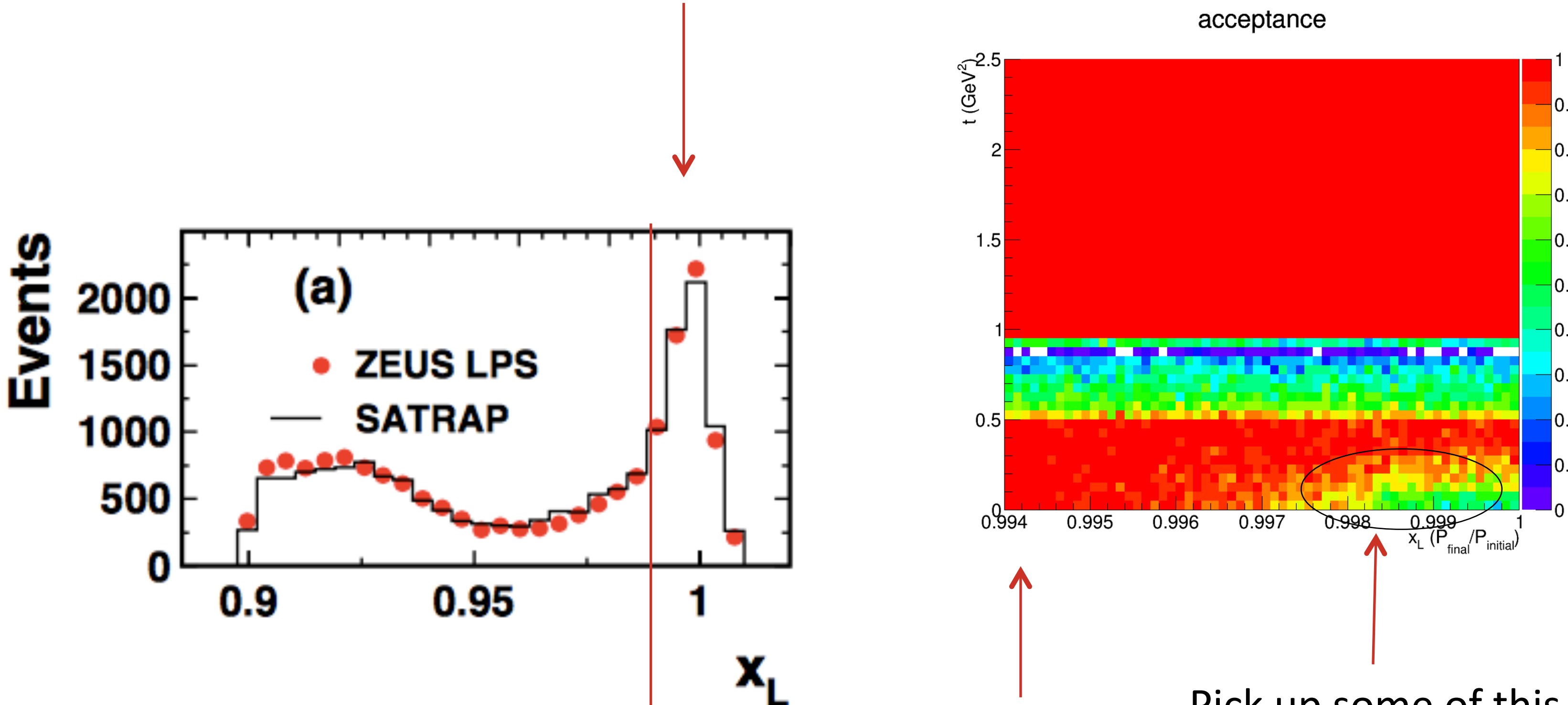


Acceptance in diffractive peak (X_L>~.98)
ZEUS: ~2%
JLEIC: ~100%

Jefferson Lab

Acceptance for $X_L \approx 1$

Diffractive Peak



X_L=0.994

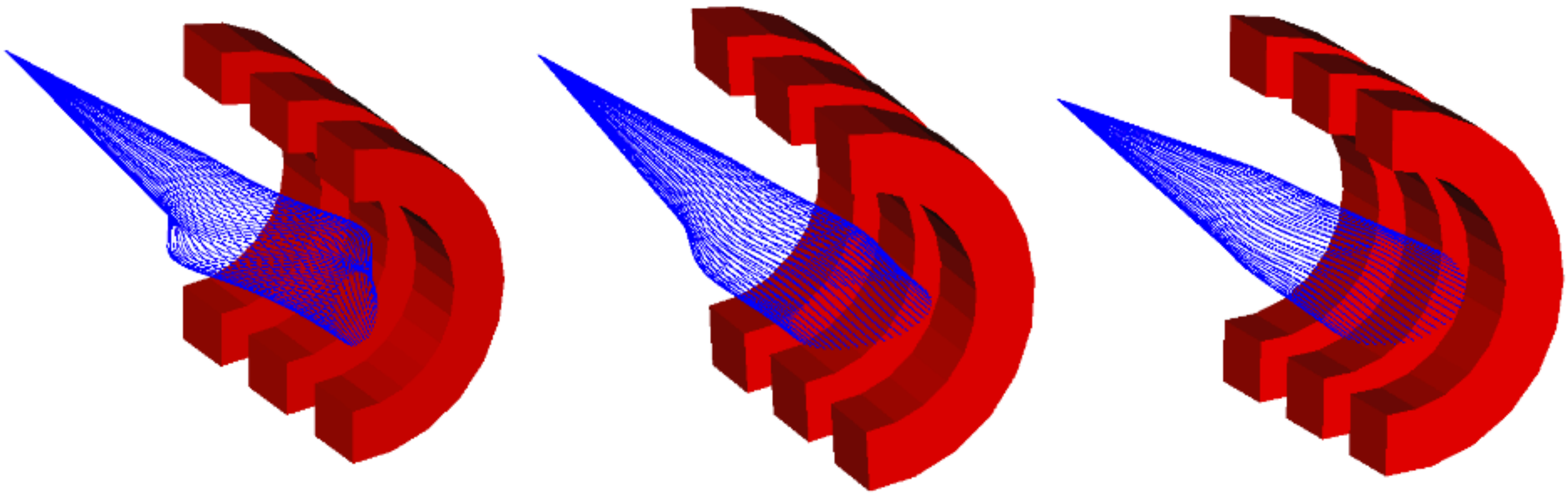
Pick up some of this with detector position optimization.

HERA Diffractive cut X_L>.98

Far-Forward Acceptance for Ion Fragments

(protons rich fragments) ⇐ ⇒ (neutron rich fragments)

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

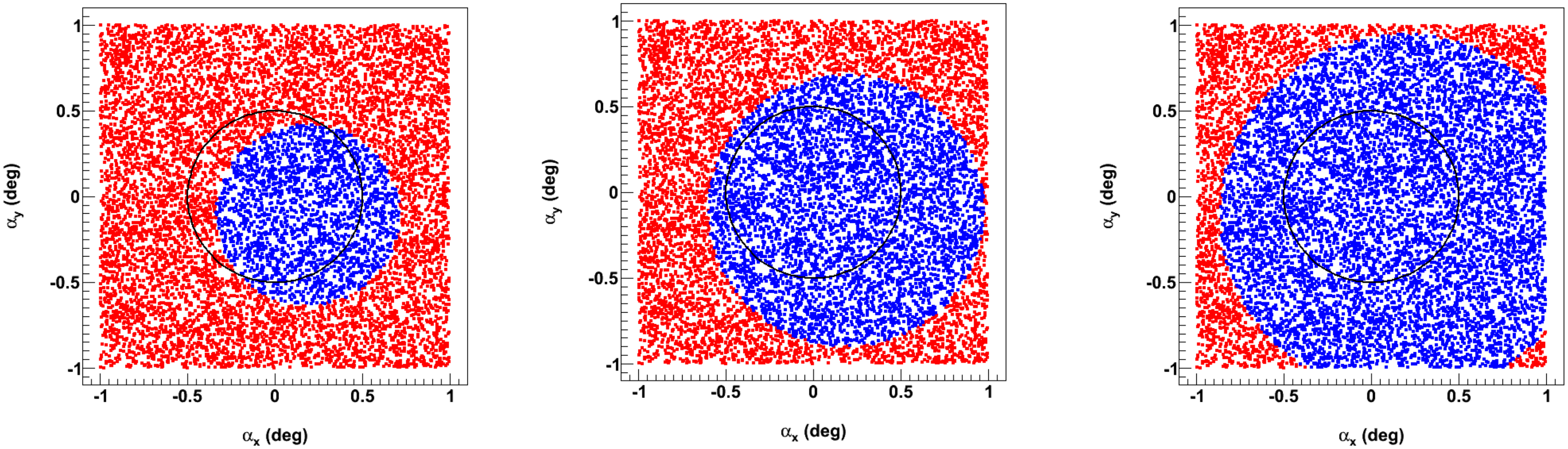


Forward geometry will provide ~100% acceptance for all cases

Very Forward Neutrons

- **Neutrons uniformly distributed within ±1° horizontal & vertical angles around proton beam**
- **Each quad aperture = B max / (field gradient @ 100 GeV/c)**

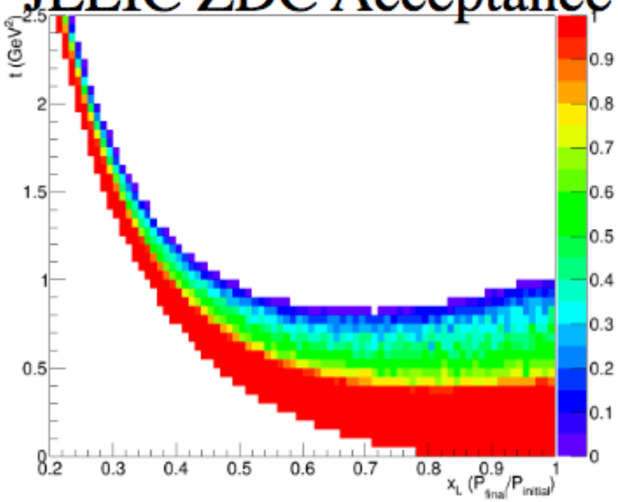
6 T max **9 T max** **12 T max**

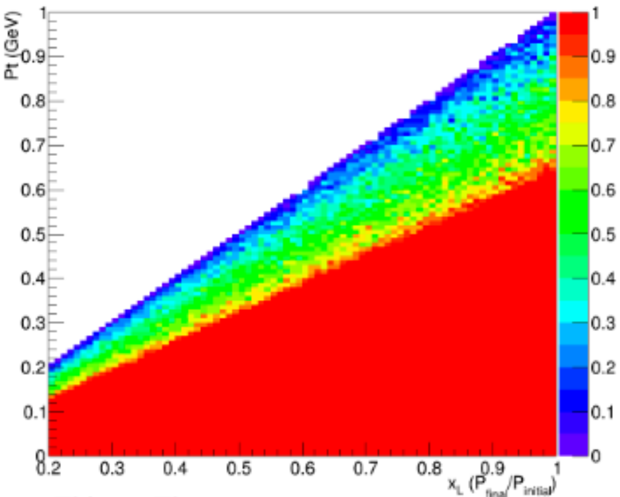


← electron beam

Neutron Acceptance for ep->e'Xn

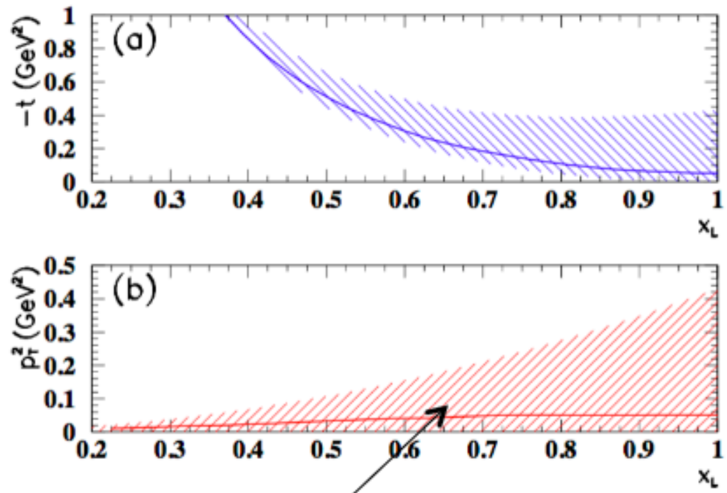
JLEIC ZDC Acceptance





Zhiwen Zhao

ZEUS FNC Acceptance



~20% geometrical accep.

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

Using Far Forward Detectors

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

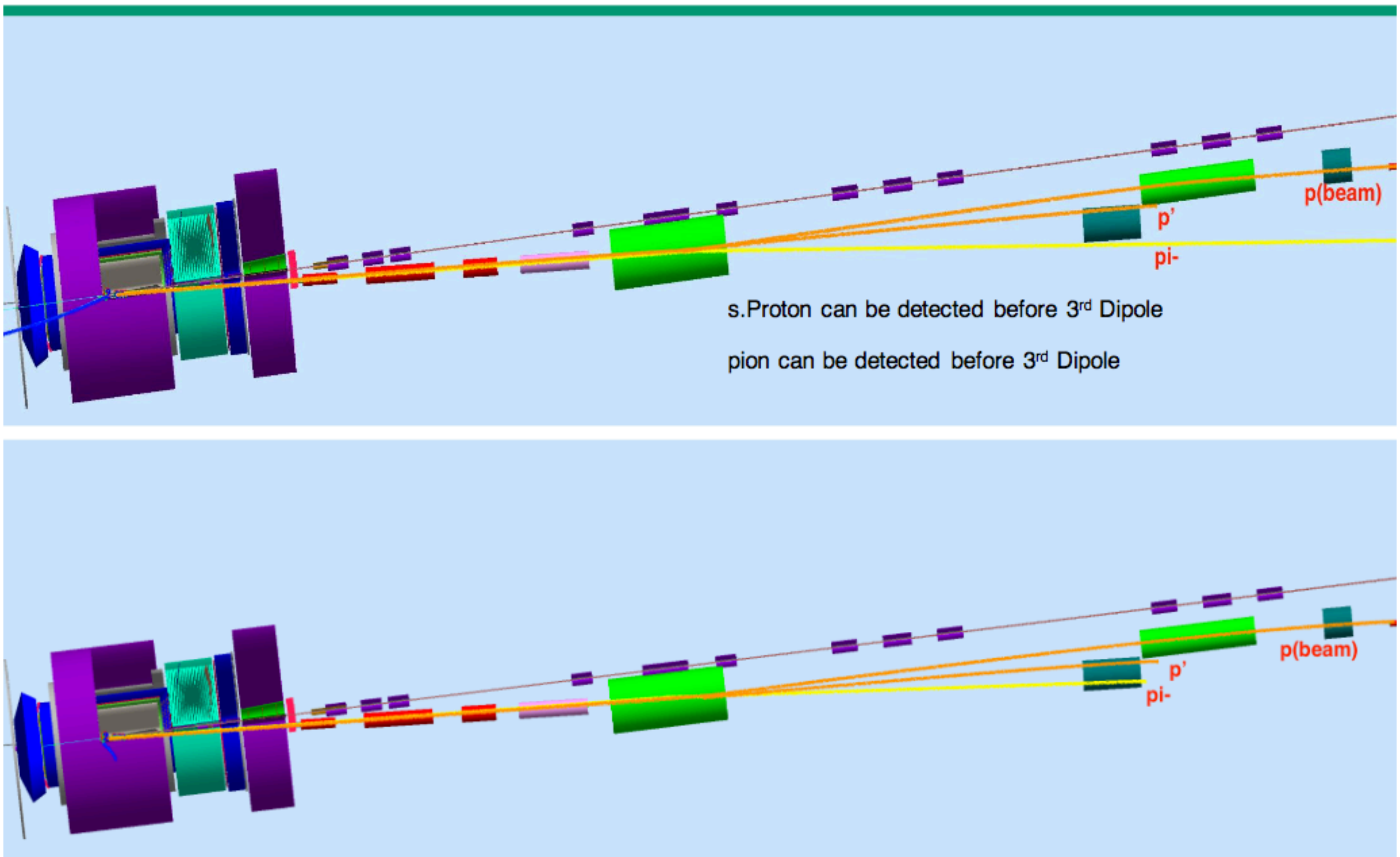


Figure from K.Park

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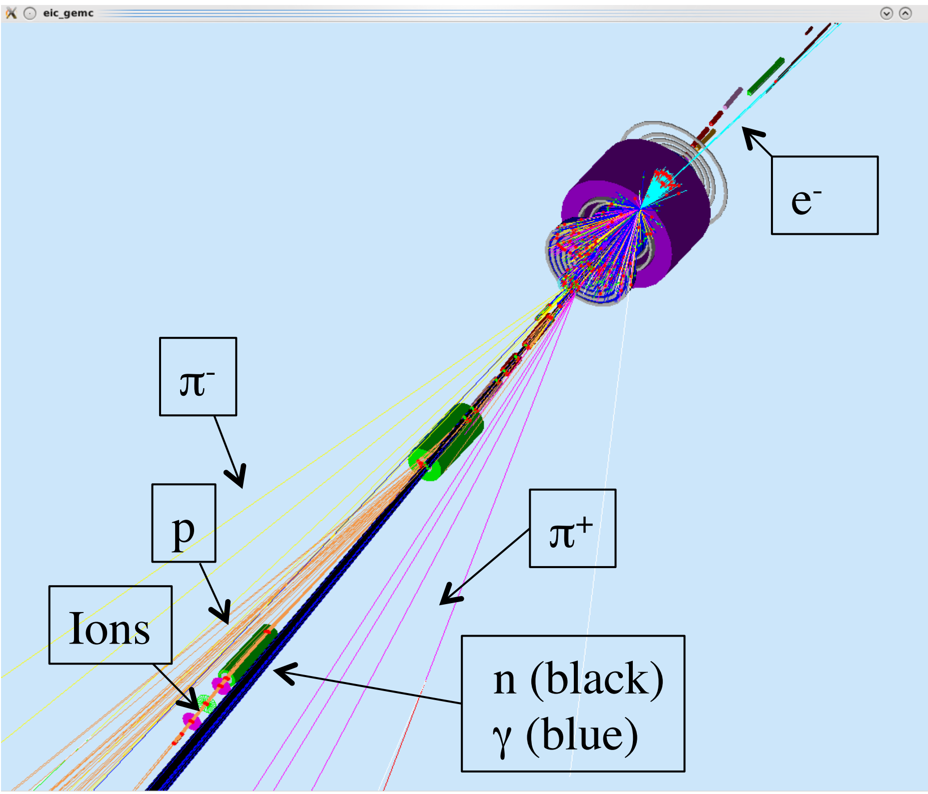
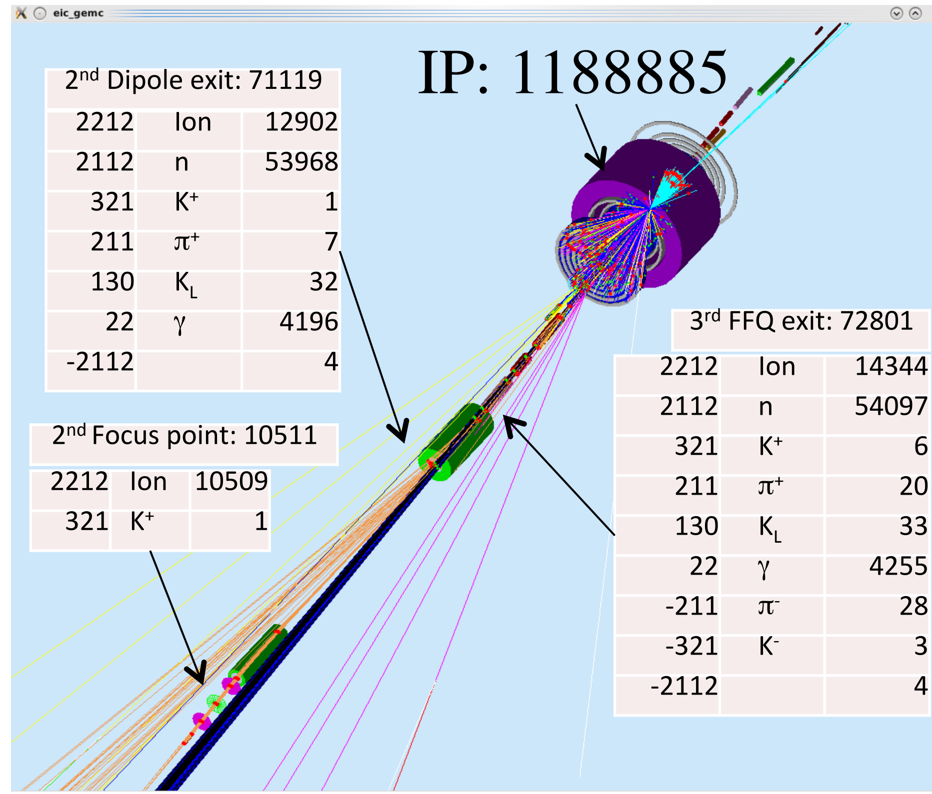
Using Far Forward Detectors

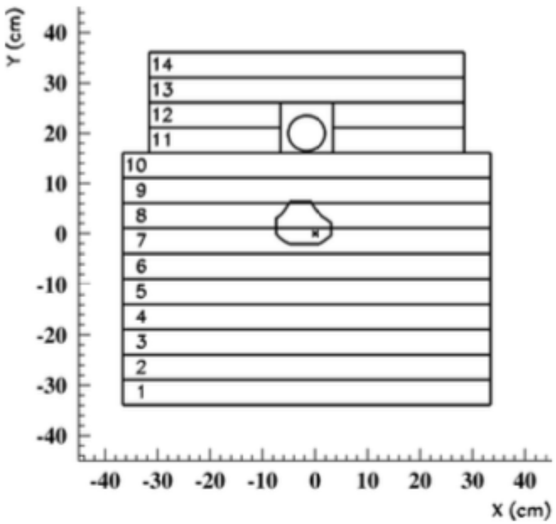
- e+Pb208 collisions at 10 x 40 GeV/u

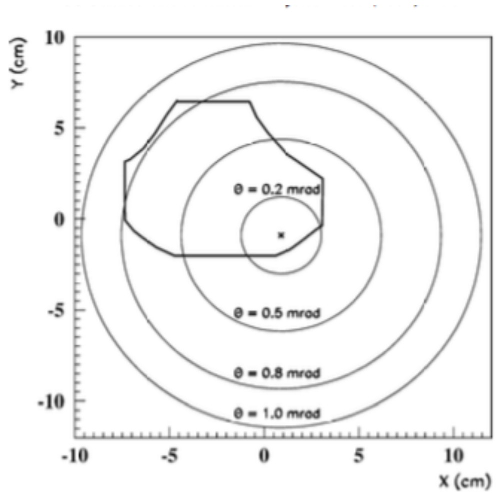




Vasiliy Morozov   Geometric Tagging R&D at JLEIC

Neutron Calorimeter Example (ZEUS)

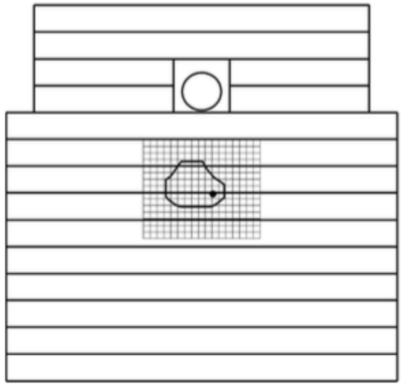




- Lead-Scintillator (compensating) calorimeter
- 7 interaction-length
- Had resolution of 65%/√E
- "Forward Neutron Tracker" was installed later

(Width ~1.5 cm)

500 GeV Neutron → 3% Energy Resolution



Neutron Calorimeter at EIC

$E_{EIC} = E_{HERA}/10$, so now neutrons are ~50 GeV

65%/√E →9% resolution

ZEUS Uranium-Scintillator Calorimeter was 35%/√E so 5% resolution.

Is this good enough? Do we need something better? What is the position resolution we need?

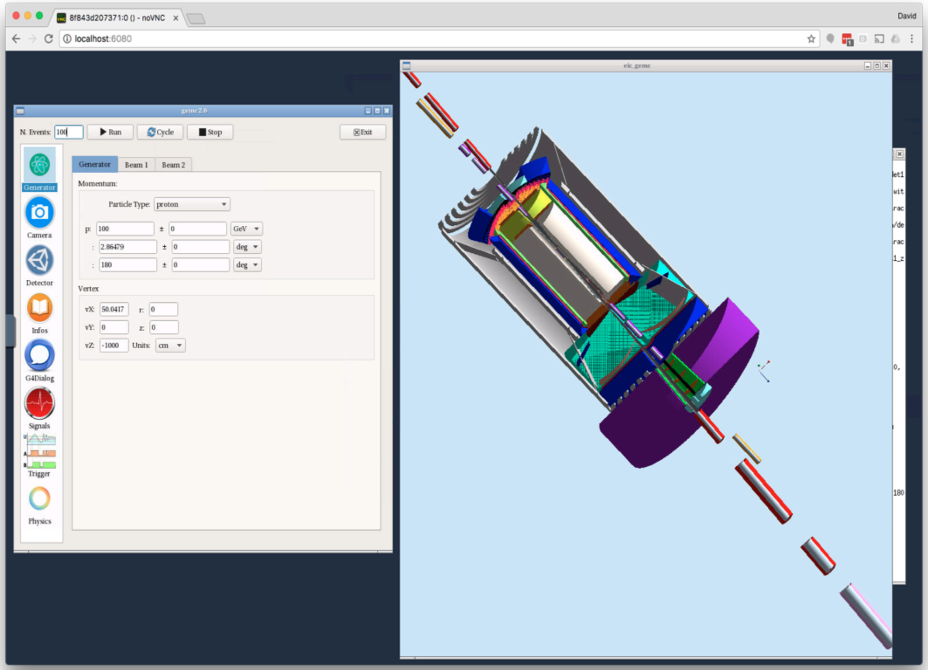
What about Λ -> n pi ? 36% br. Is it possible? Better acceptance than p pi? Can we reconstruct this?

JLEIC Simulation in Container

GEMC environment is relatively complex to set up. Running JLEIC simulation in GEMC on a new platform (e.g. your laptop) used to take a considerable effort.

Solved by using "Containers" (Docker)

- Container = very lightweight Virtual Machine
  - Not running full OS with all its daemons and services
  - Does not reserve large amounts of system resources (RAM, CPU)
- Primary use: Provides complete software stack with all dependencies
  - Running on laptop/desktop
  - Running on batch farm



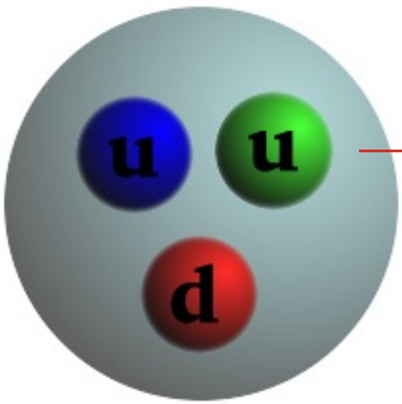
Reduces installing and running JLIEC simulation to 4 steps.
Takes ~10 min. depending on your download speed. Runs on Mac/PC/linux.

D. Lawrence, M. Diefenthaler, M. Ungaro, Z. Zhao

Full Instructions Coming Soon!

High-x at EIC

Highly asymmetric collision at the parton level



Parton carrying xE_{proton_beam}

$E_{electron\_beam}$

Since x ->1, this is like the beam energy

Parton energy ~100 GeV

Electron Beam ~10 GeV

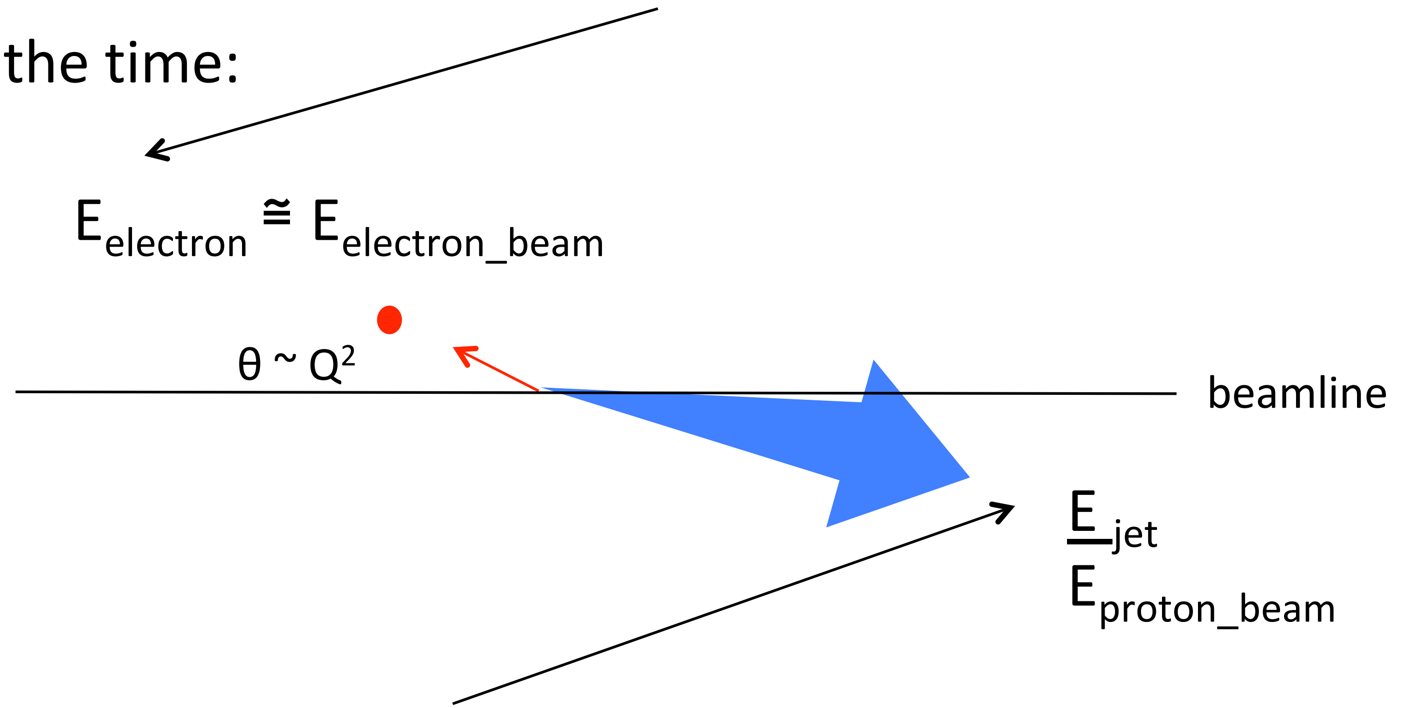
Where does the final state go?

High-x configuration at EIC

Need a very precise measurement to get x

Most of the time:

$E_{electron} \cong E_{electron\_beam}$

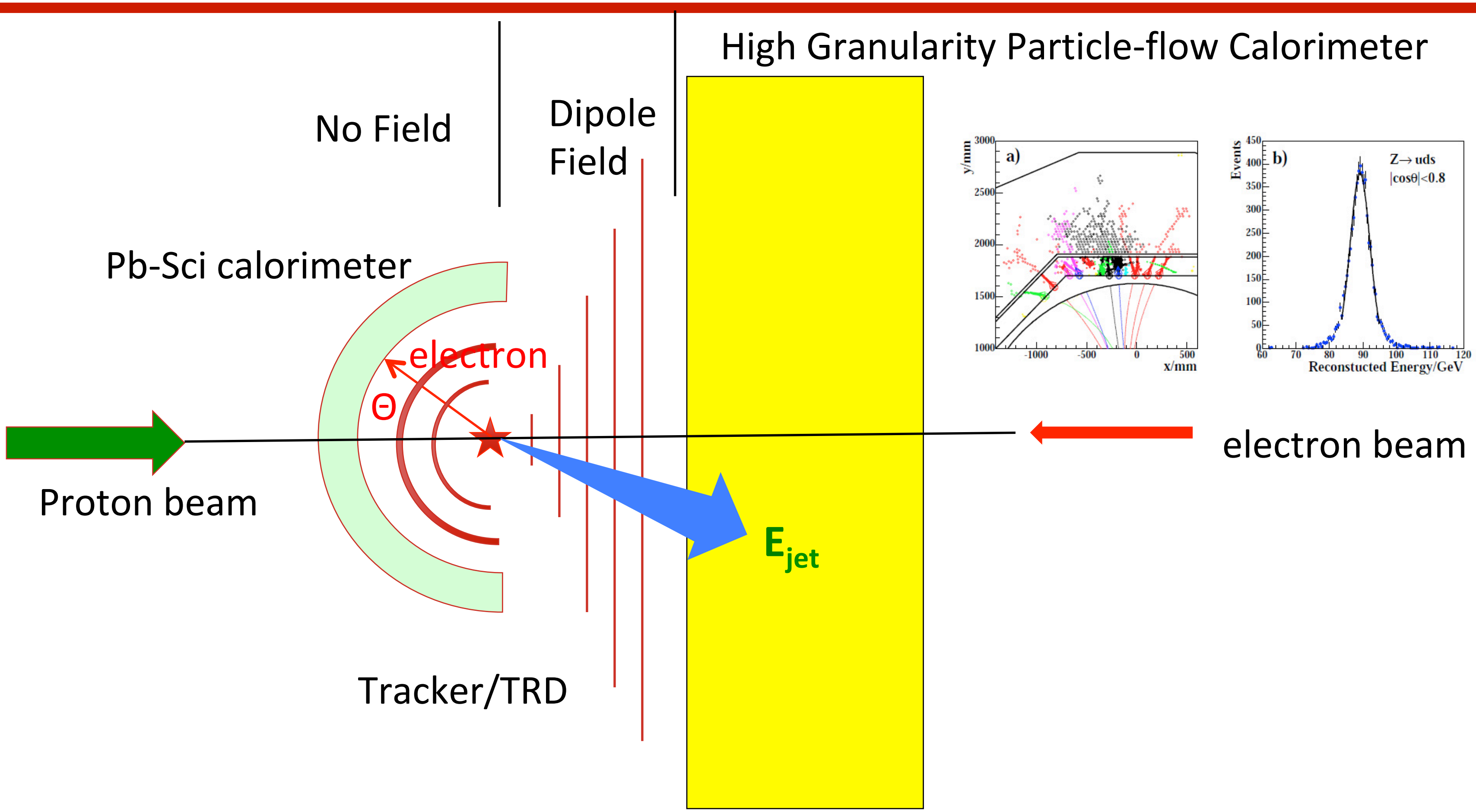


$$\frac{E_{jet}}{E_{proton\_beam}} = X$$

This is hard to measure: a jet close to beam pipe

This is why HERA measurement have big bins for high-x
Can we do better at LHeC and EIC? Yes.. in principle..

Detector Concept for High-x I



Electron is “always” 10 GeV: use TRD to ID, use conventional calorimeter. Measure angle to get Q^2.

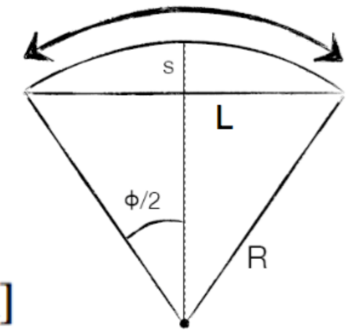
Jet energy needs to be measured as well as possible for x: use particle flow. 30%/root(E)? If so 3-5% resolution on x (0.5 to 1)

Detector Concept for High-x II

How well does the
electron need to be measured?

"Dipole"

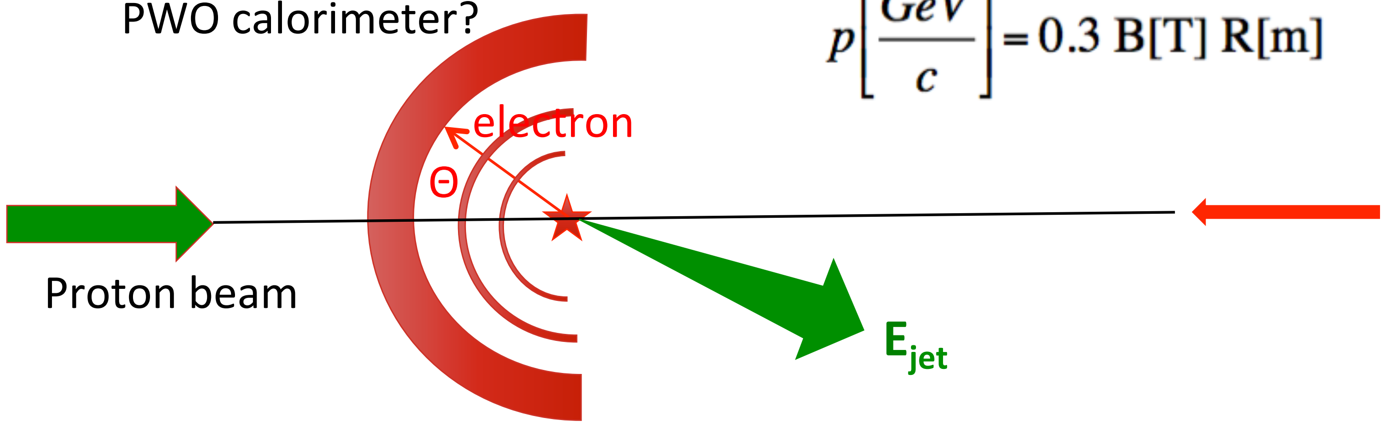
Tracking? →



$$p\left[\frac{GeV}{c}\right] = 0.3\ B[T]\ R[m]$$

$$s = \frac{L^2}{8R}$$

PWO calorimeter?



Proton beam

electron beam

Tracker/TRD

Tracking solutions?
For L = 1.5m, B = 1T and p= 10 GeV
s ≈ 10mm
so 100um measurement of s gives
a ~1% measurement of p at 10 GeV.
(Needs checking!)

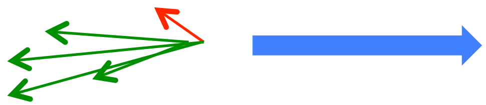
Calorimeter solution?
PbW ~ 3%/√E and 1-2% constant term?
Absolute calibration? Difficult but not impossible?

Low-x configuration at EIC

y ~ 1 (lowest x)

electron energy < E_{beam} Relatively high angle

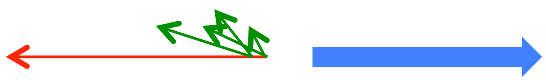
10 GeV total



"remnant", p for diff.

y ~ 0.1 (same Q^2, somewhat larger x)

10 GeV total

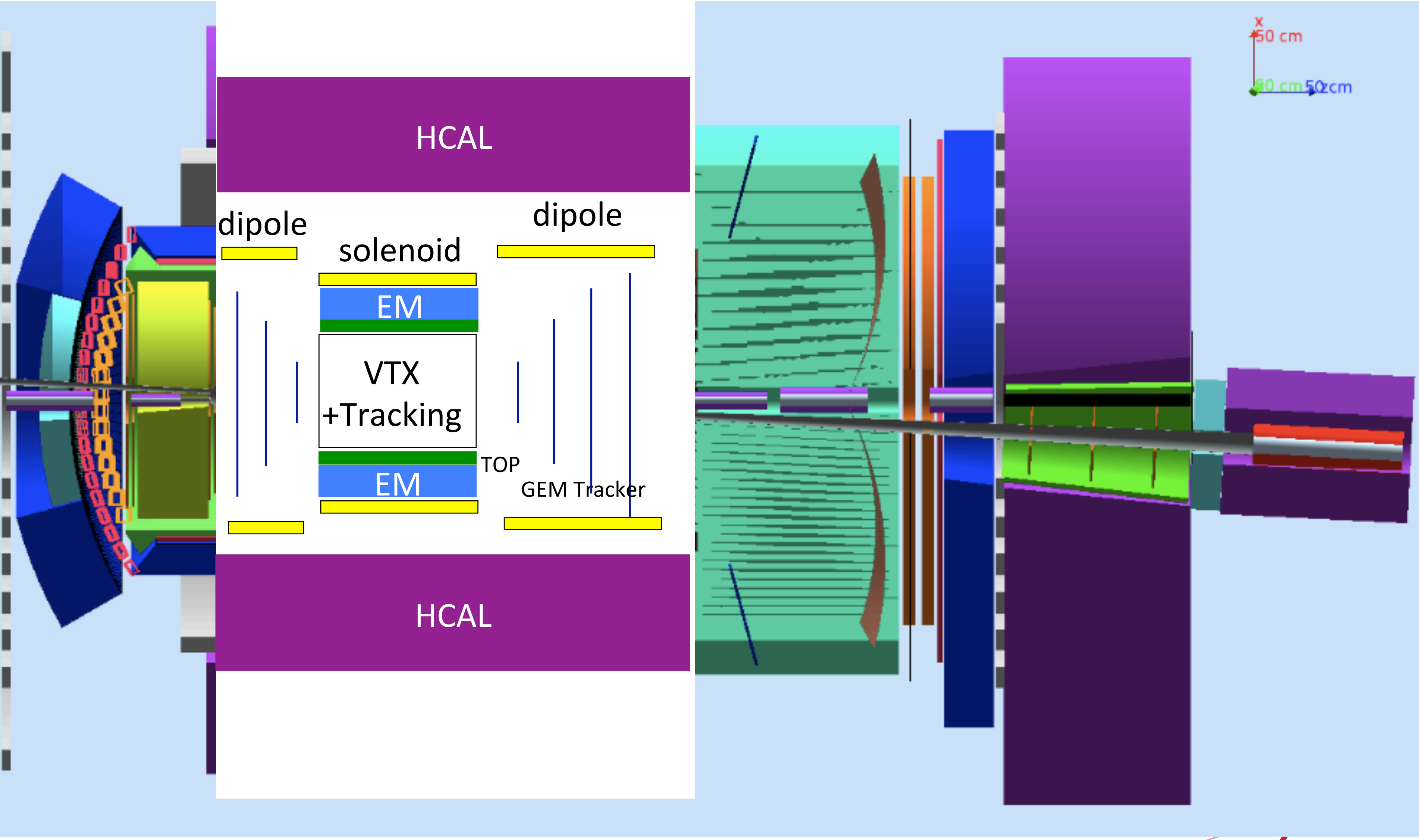


"remnant", p for diff.

electron energy ≈ E_{beam} Low angle

Left side is essentially fixed target kinematics

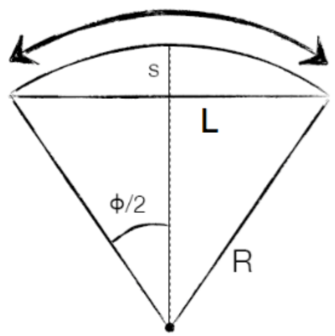
Large Dipole Concept



Tracking Resolution for Small tracker

Can we live with the smaller central tracking volume?

$$p\left[\frac{GeV}{c}\right] = 0.3\ B[T]\ R[m]$$

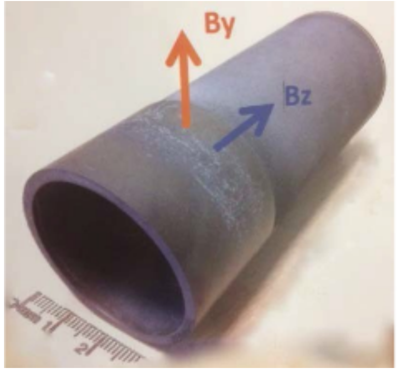


For L = 0.5 m, B = 1.5 T and p= 10 GeV
s ≈ 5mm
so 50 um measurement of s gives
a ~1% measurement of p at 10 GeV.

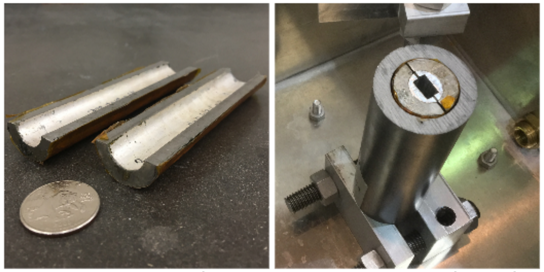
Doesn't sound impossible.

Electron Beam Shield

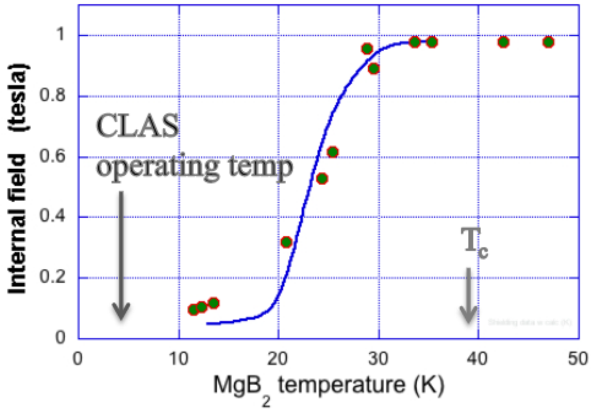
Can we get the electron beam though the dipoles?

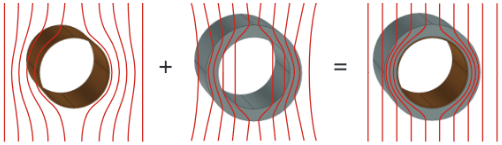


MgB_2 Shield Prototype
Statera et al.



Stony Brook Magnetic Cloak
N. Feege et al.





Conclusion

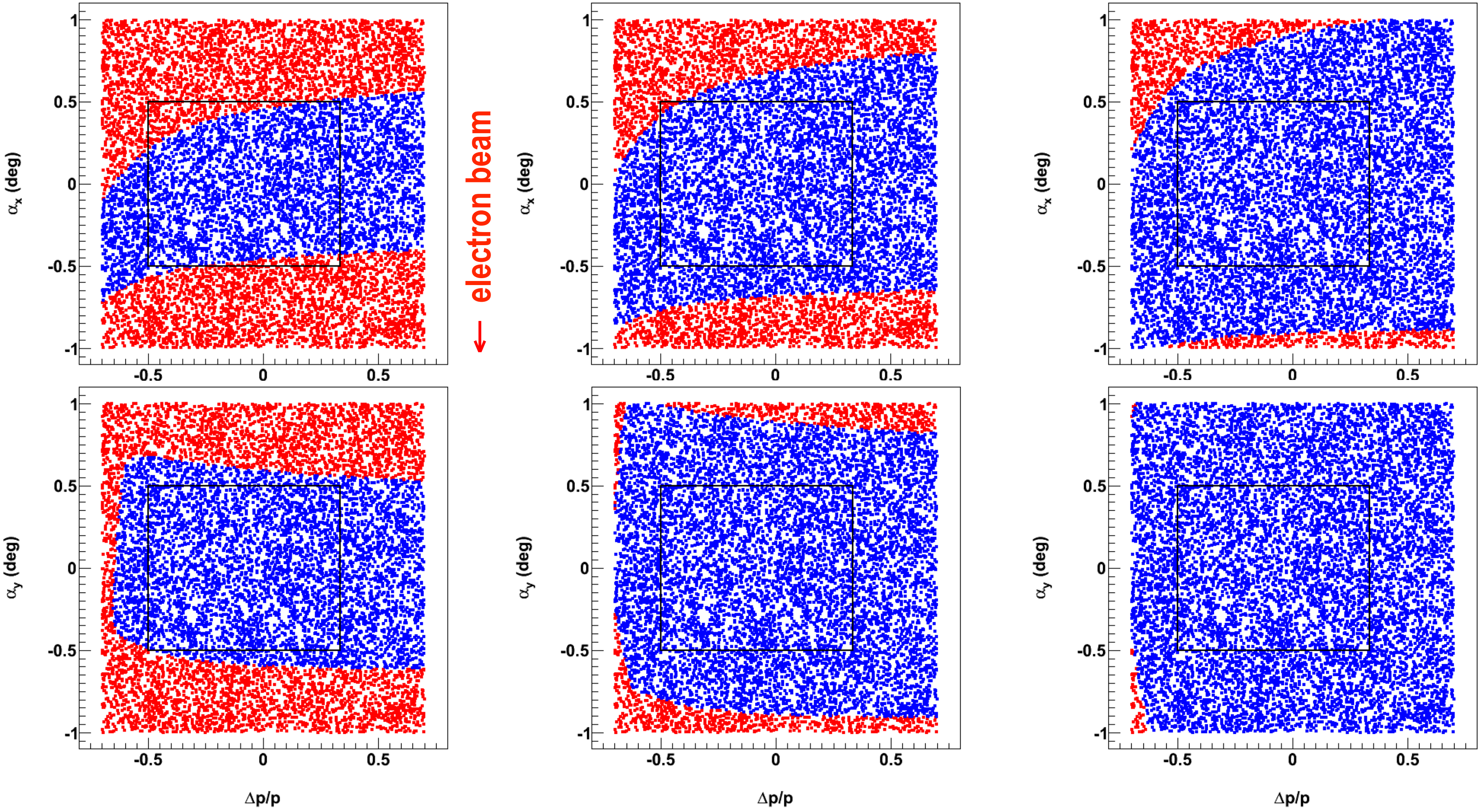
- Reviewed some aspects of the current JLEIC detector design.
- Designed to have nearly 100% acceptance for all parts of the event including the far forward part.
- Fully integrated with the accelerator design.
- Simulations Container to test performance for your favorite physics coming soon!
- High-x was not a high priority consideration in this phase of the design.
- Some thoughts on high-x (and low-x) performance enhancements were presented.

EXTRAS

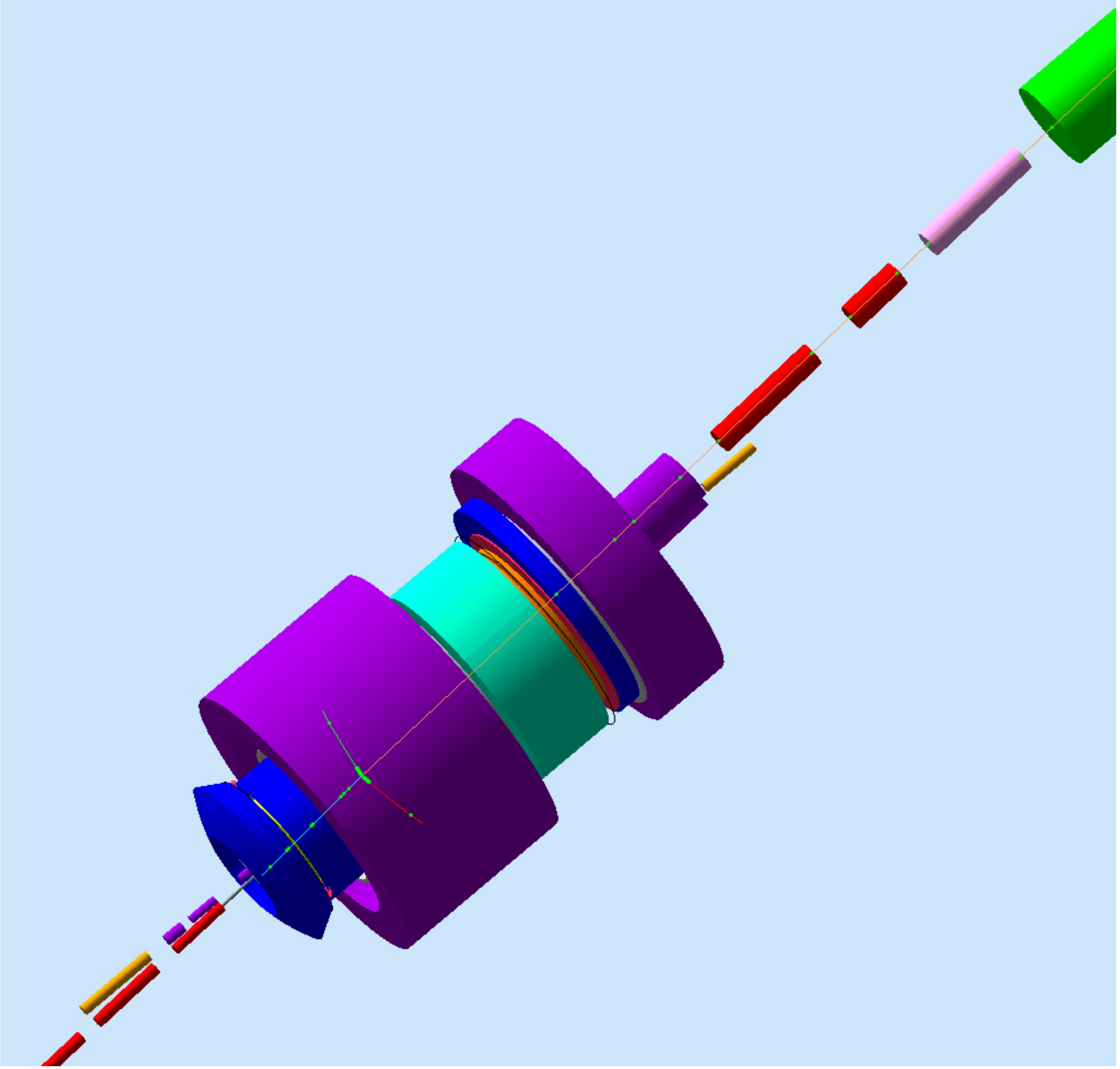
Angular Acceptance of

- **Quad apertures = B max / (field gradient @ 100 GeV/c)**

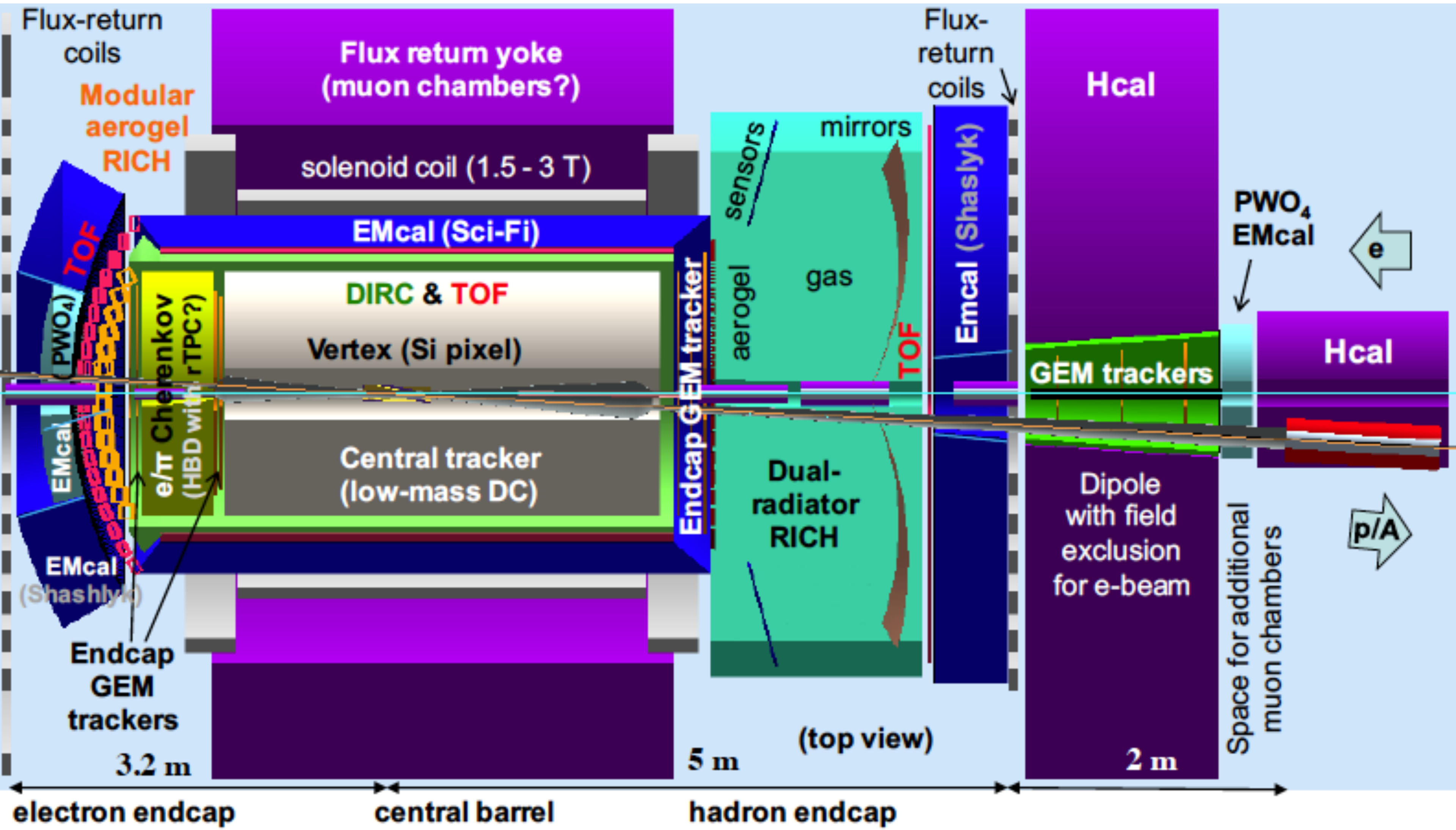
6 T max **9 T max** **12 T max**



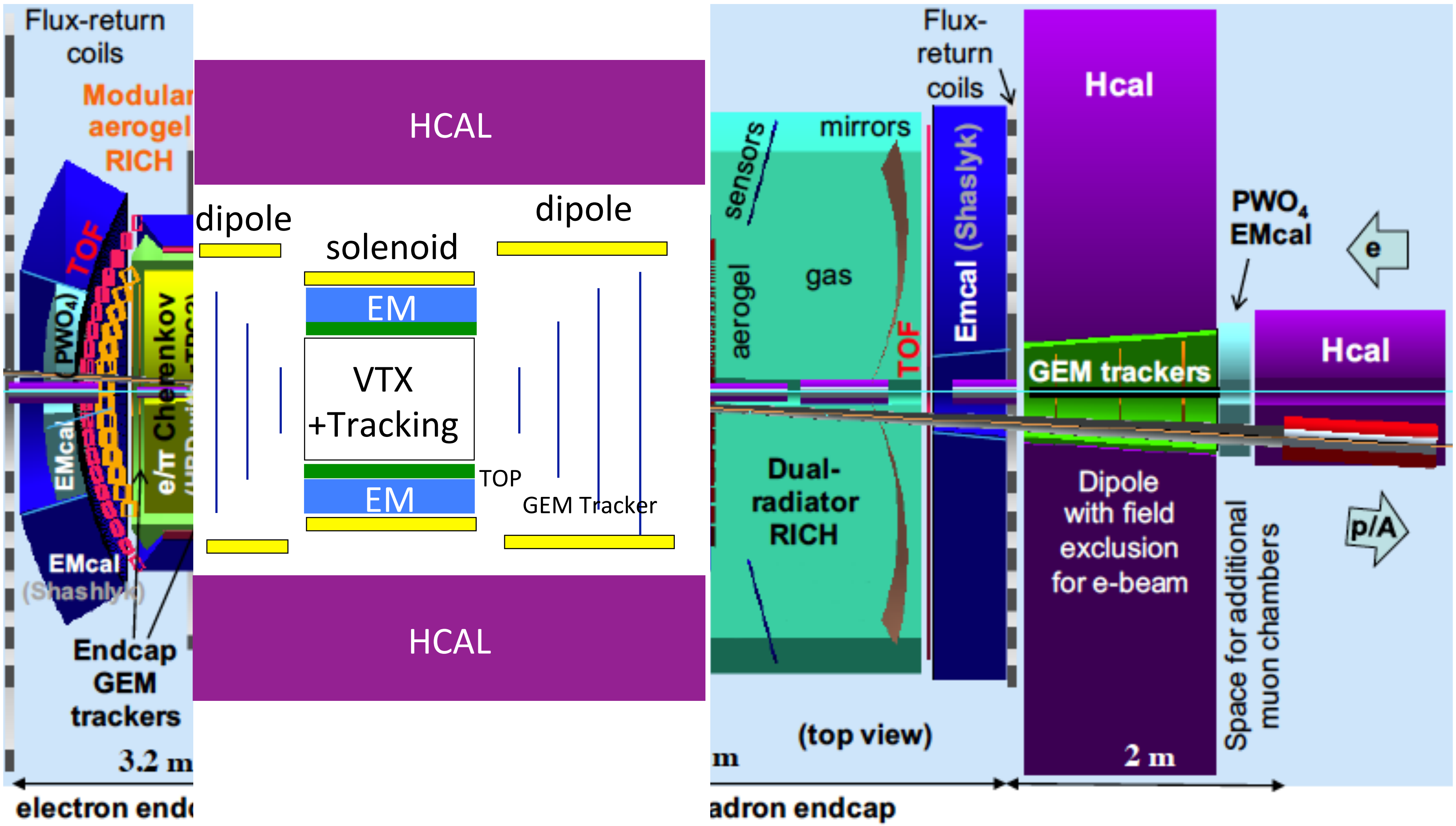
Elastic J/Psi Production in the EIC Detector



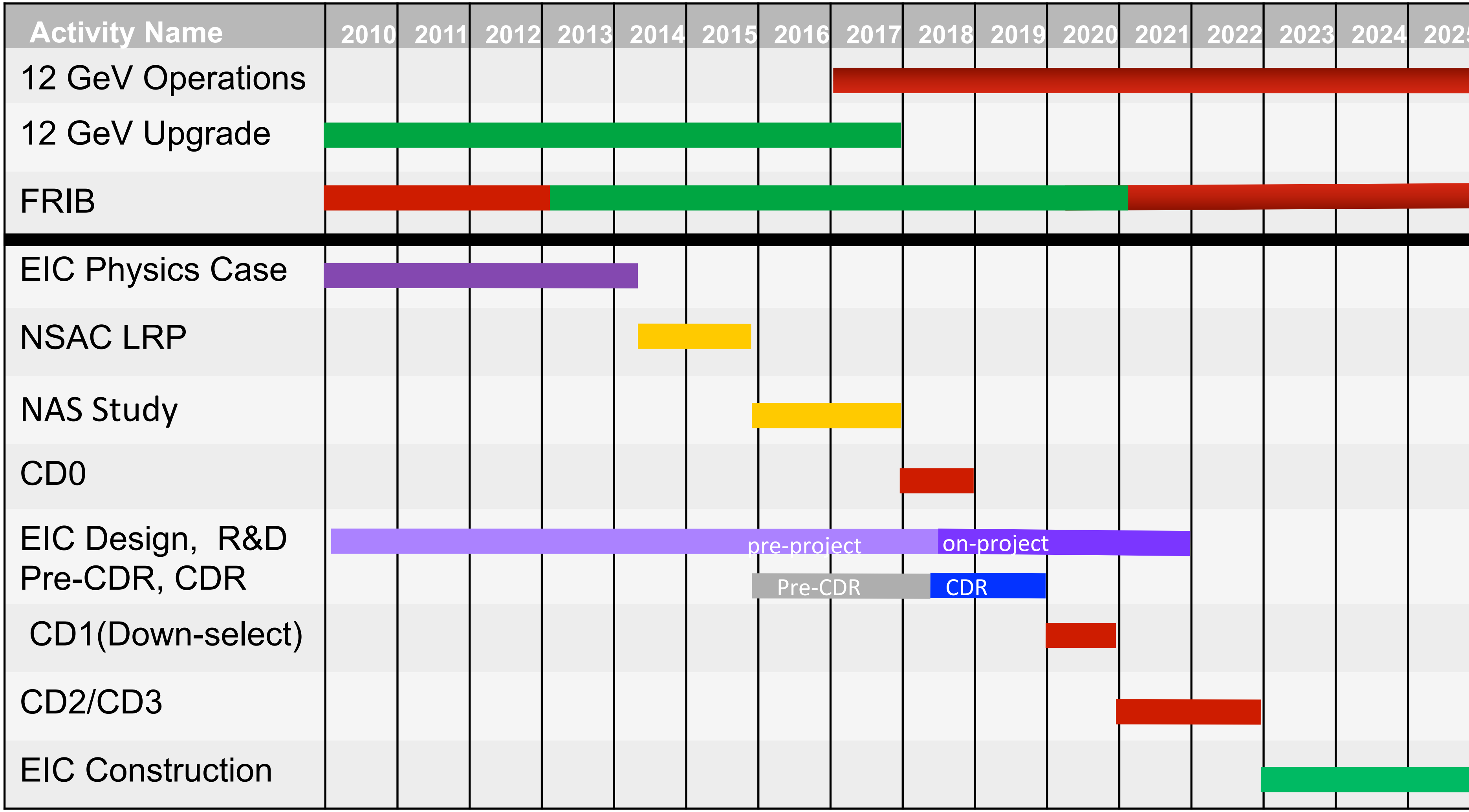
JLEIC Detector (Central Area)



Large Dipole Concept



Jefferson Lab



CD0 = DOE "Mission Need" statement; **CD1** = design choice and site selection
CD2/CD3 = establish project baseline cost and schedule