The 6th International Conference on the Physics Opportunities at an ElecTron-Ion Collider
POETIC VI, 7-11 Sept 2015, École Polytechnique, Palaiseau France

THE EIC@JLAB DETECTOR DESIGN AND INTEGRATION WITH THE ACCELERATOR LATTICE*

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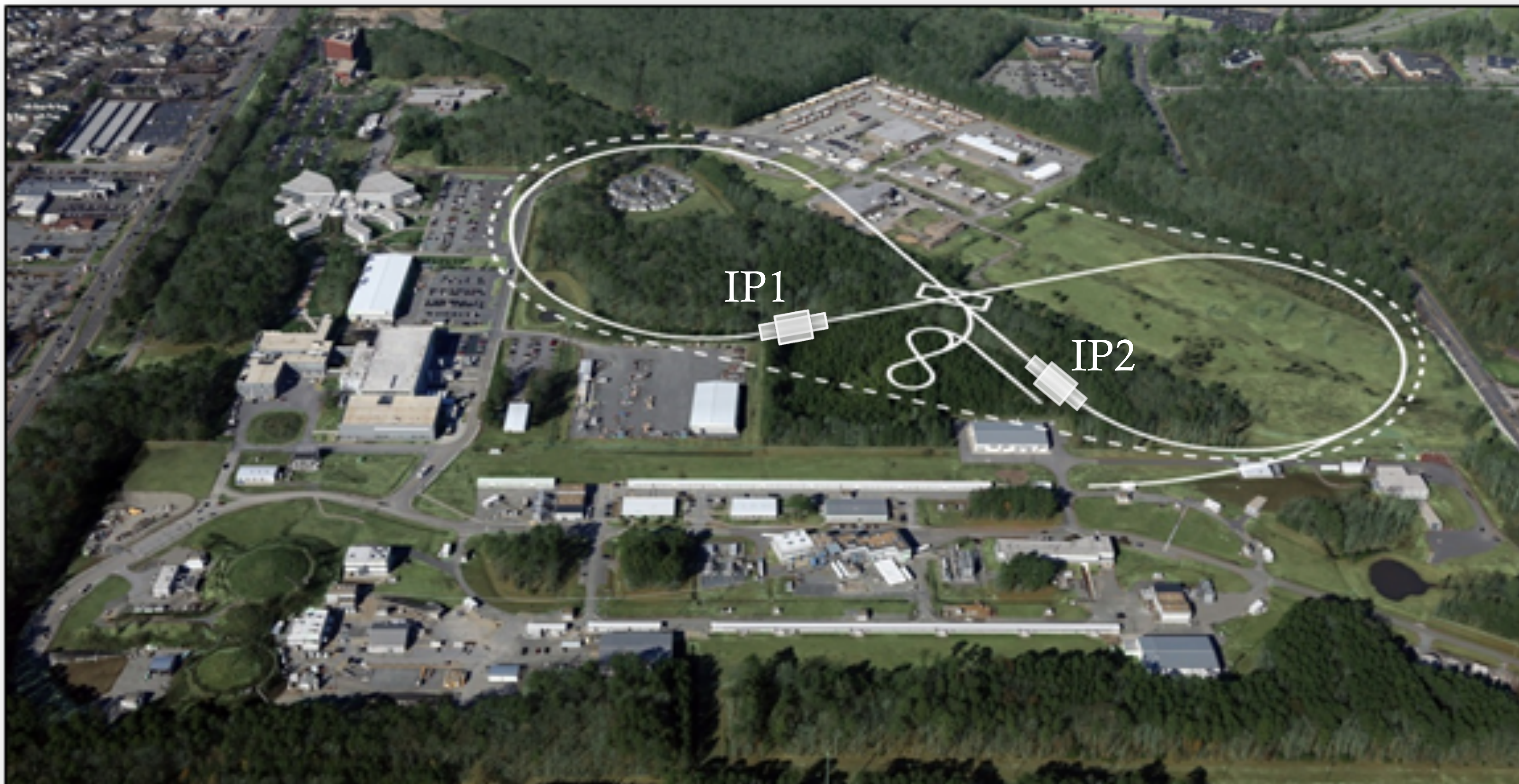
**And the EIC@Jlab Design Team,
with additional input from the
Generic EIC Detector R&D Collaborations**

* The opinions and errors expressed are entirely those of the speaker…

The Electron Ion Collider

- The Glue That Binds Us All: arXiv:1212.1701
- An ideal tool for the study of the QCD structure of matter (quarks too).
  - High Luminosity
  - High CM Energy
    - Broad Q^2 range for studying evolution, higher-twist observables
    - Low-x_{Bj} while still in DIS range Q^2>2 GeV^2 to study transition from DGLAP evolution to Gluon Saturation.
  - Transverse and longitudinal polarization of light ions
    - 3-D imaging in space and momentum: flavor and spin separated
  - Full suite of isotope species across the periodic chart: Hydrogen to Uranium
    - Hadronization in the nuclear medium
    - 3-D imaging
    - The Gluonic EMC effect
    - Gluon Saturation.
  - Hermetic detector, covering full range from exclusive projectile remnants to 0° e^- tagging of quasi-real virtual photons
    - Outside 10σ Beam Stay Clear (longitudinal and transverse)

EIC@JLAB SITE PLAN



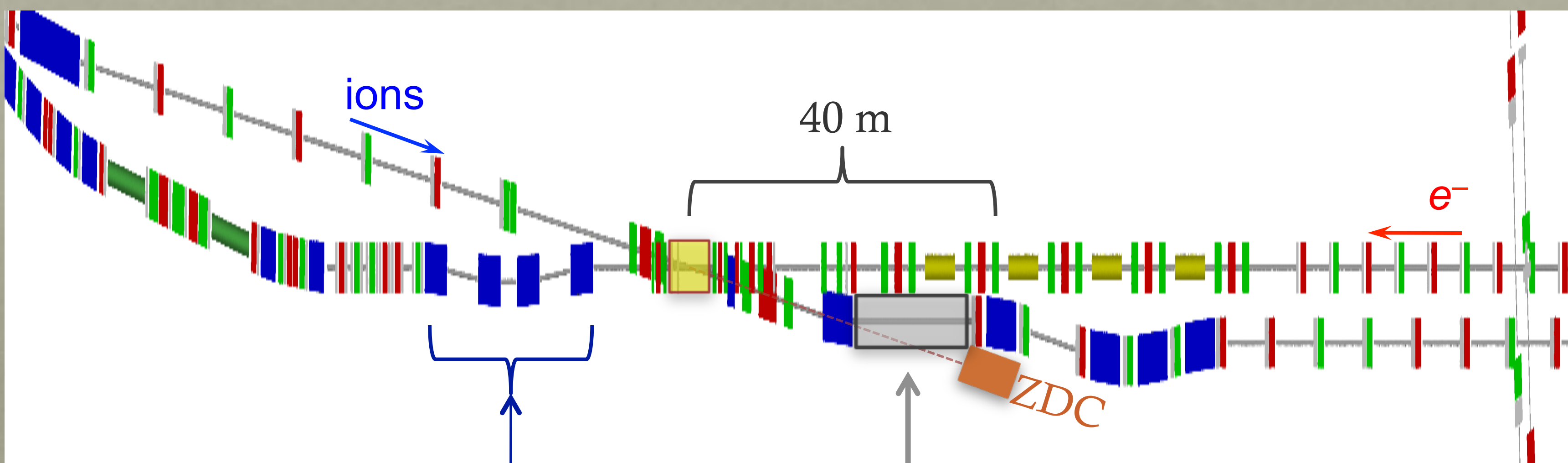
IP1: Full Acceptance Detector

IP2: Jets, ePHENIX Detector

Interaction Point Optics

- Horizontal Focus Quad
- Vertical Focus Quad
- Dipole; IP Solenoid/Central Detector

Figure-8
Crossing



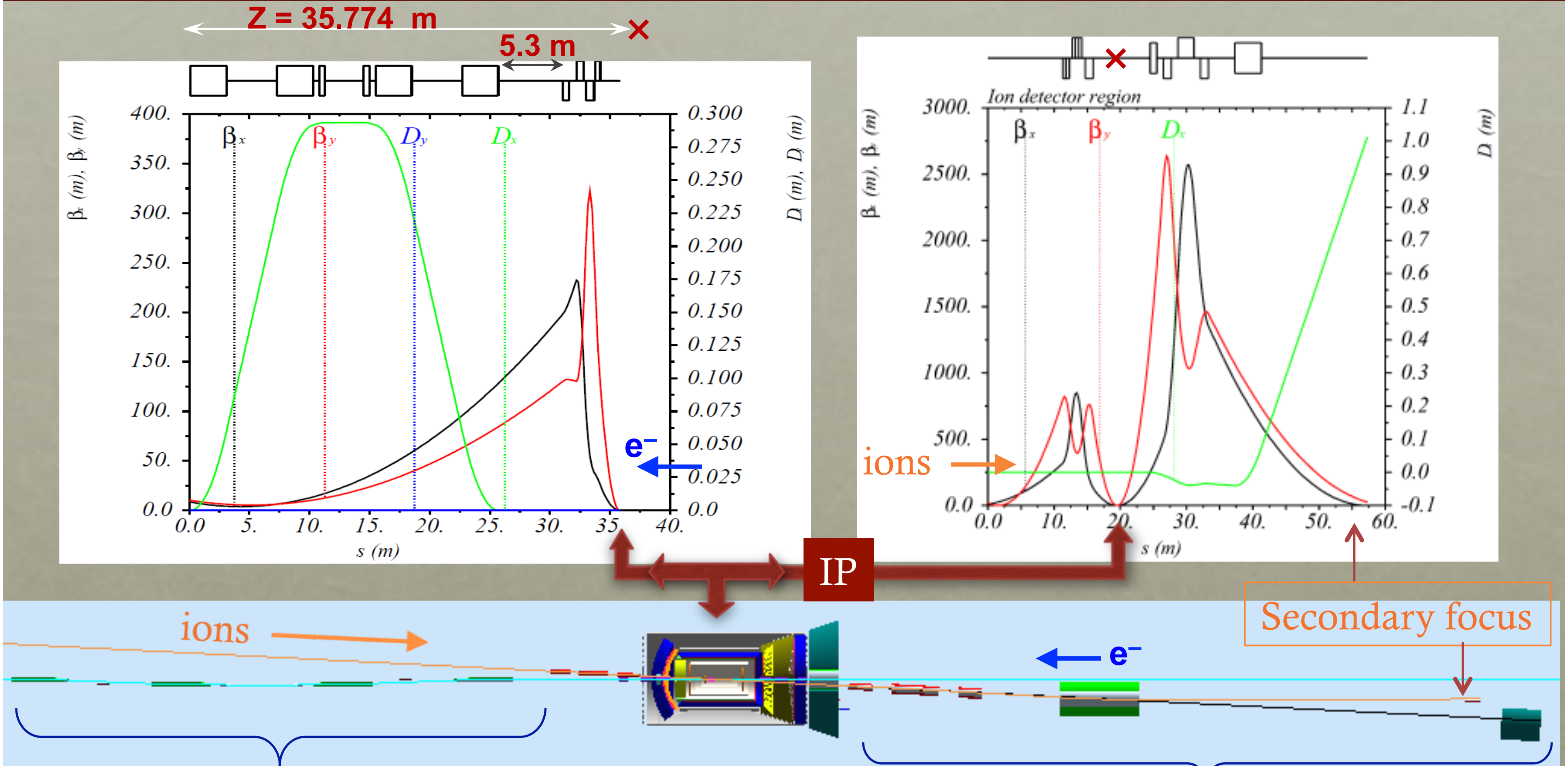
Compton Polarimeter
Chicane & 0° e^- Tagger

Far Forward Tracker:
- Exclusive Reactions,
- Projectile (Baryon) Fragments

FOLLOWING J. BJORKEN'S VISION:

Full Coverage: ion rapidity to e^- rapidity

Uniform detector density per unit rapidity



Compton Polarimeter Chicane, 0° e^- Tagger ($Q^2 \sim m_e^2$)
A.Camsonne, Friday: Future Facilities

Far-Forward Spectrometer
K.Park, Friday: Future Facilities

ep, ed, e^{3}He Physics & Detector

Transverse and Longitudinal Polarized Ion Beams
Longitudinal Polarized Electron Beam

- Polarized Semi-Inclusive DIS:
  Broad Range PID
  - Transverse Momentum Dependent Parton Dist. Functions (TMDs)
  - 3-D momentum imaging.
    High Luminosity
  - Transition to pQCD p_T dependence
  - Projectile Fracture Distributions ($x_F < 0$):
    Forward Dipole & Tracker
    - Flavor-Momentum correlations between target-jet and current-jet hadrons.

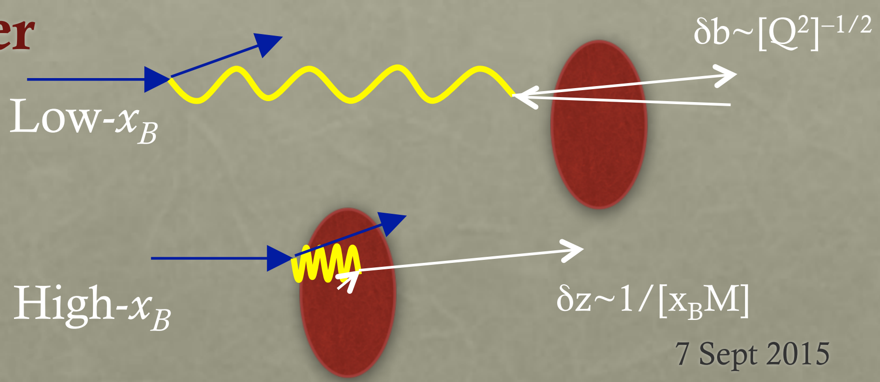
- Deep Virtual Exclusive Scattering
  Far-Forward Spectrometer, Hermeticity, Luminosity
  - Generalized Parton Distributions (Twist-2 and -3)
  - Transverse Spatial Imaging
  - Quark and Gluon Orbital Angular Momentum
- Spectator Tagging: D, ^{3}He Beams
  Far-Forward Spectrometer, High-Resolution ZDC
  - Neutron Structure Functions, Bjorken Sum Rule, $\Delta g(x)$.
  - *u*/*d* flavor separation: *GPDs, TMDs*

eA
Physics & Detector

- Current-jet and Projectile-jet fragmentation
  - Hadronization Mechanism
  - Gluon Saturation signals
- Gluonic EMC effect
  - DIS Evolution: Luminosity, Precision
  - Open Charm: Vertex Detector
- 'Spectator' Multiplicities
  - Proton, Neutron, Light fragments, Evaporation Residue ZDC & Far-Forward Spectrometer
  - Multiplicity tag on current-jet propagation distance:
    - DPMJetHybrid generator:

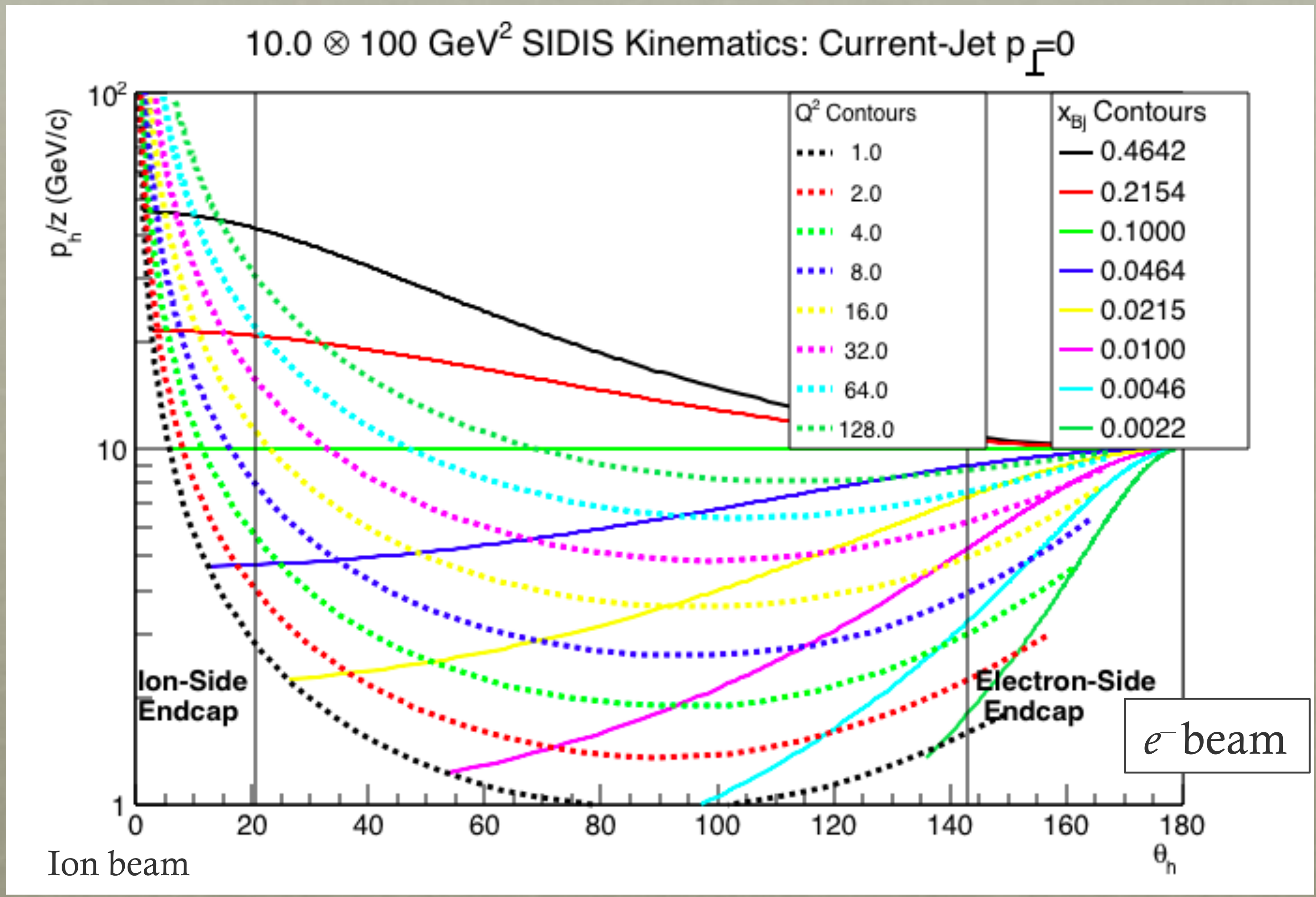
M. Baker EIC R&D, also Z.Citron 1405.4555

- Deep Exclusive Processes
  - 3-D imaging: quark and gluon mass densities *vs* Charge densities
  - Gluon Saturation signals



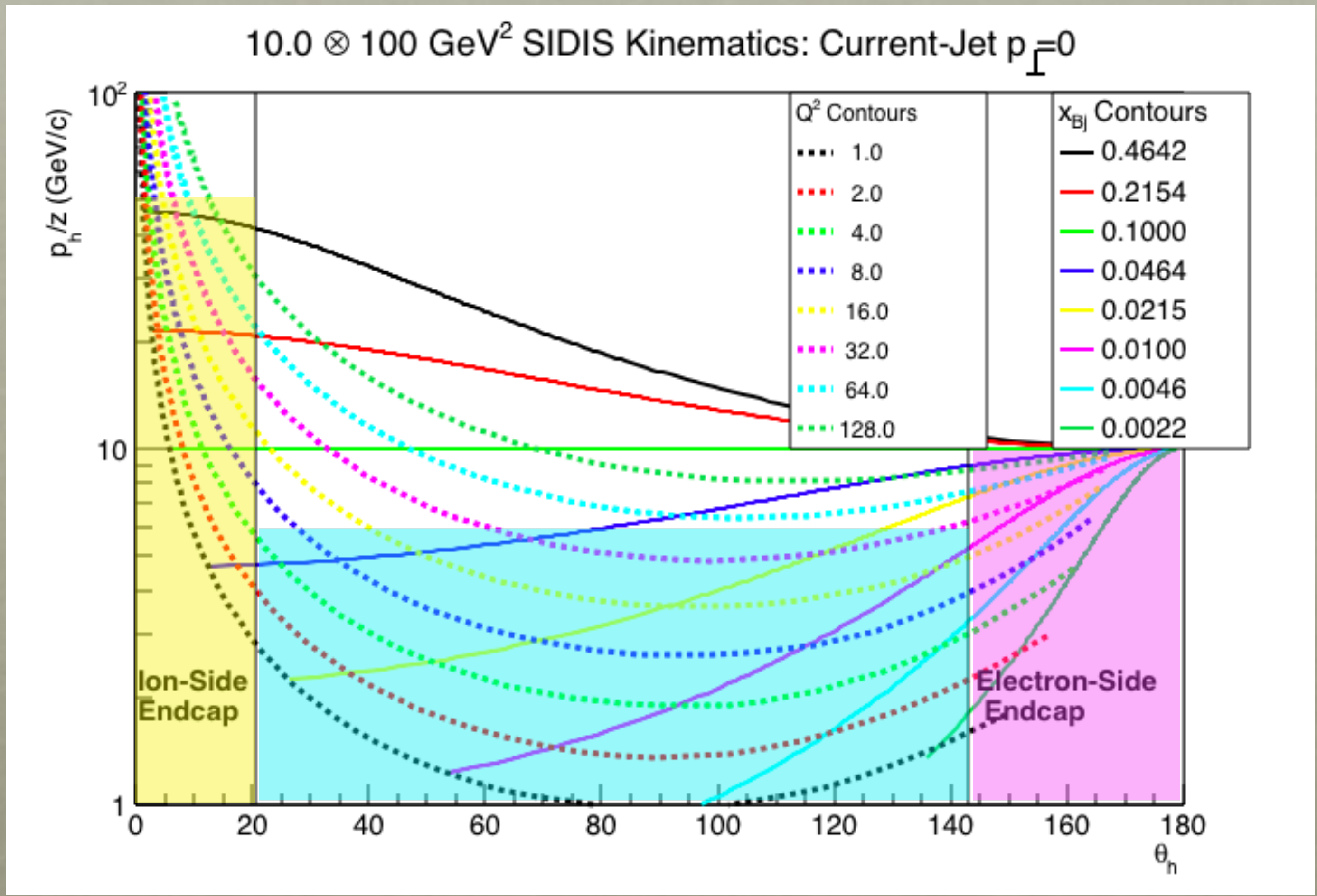
DIS Hadronic Kinematics: *xP+q*

- Maximum hadron momentum *vs* hadron angle in contours of constant Q^2 or x_{Bj}
- Hadron momentum scales with *z*



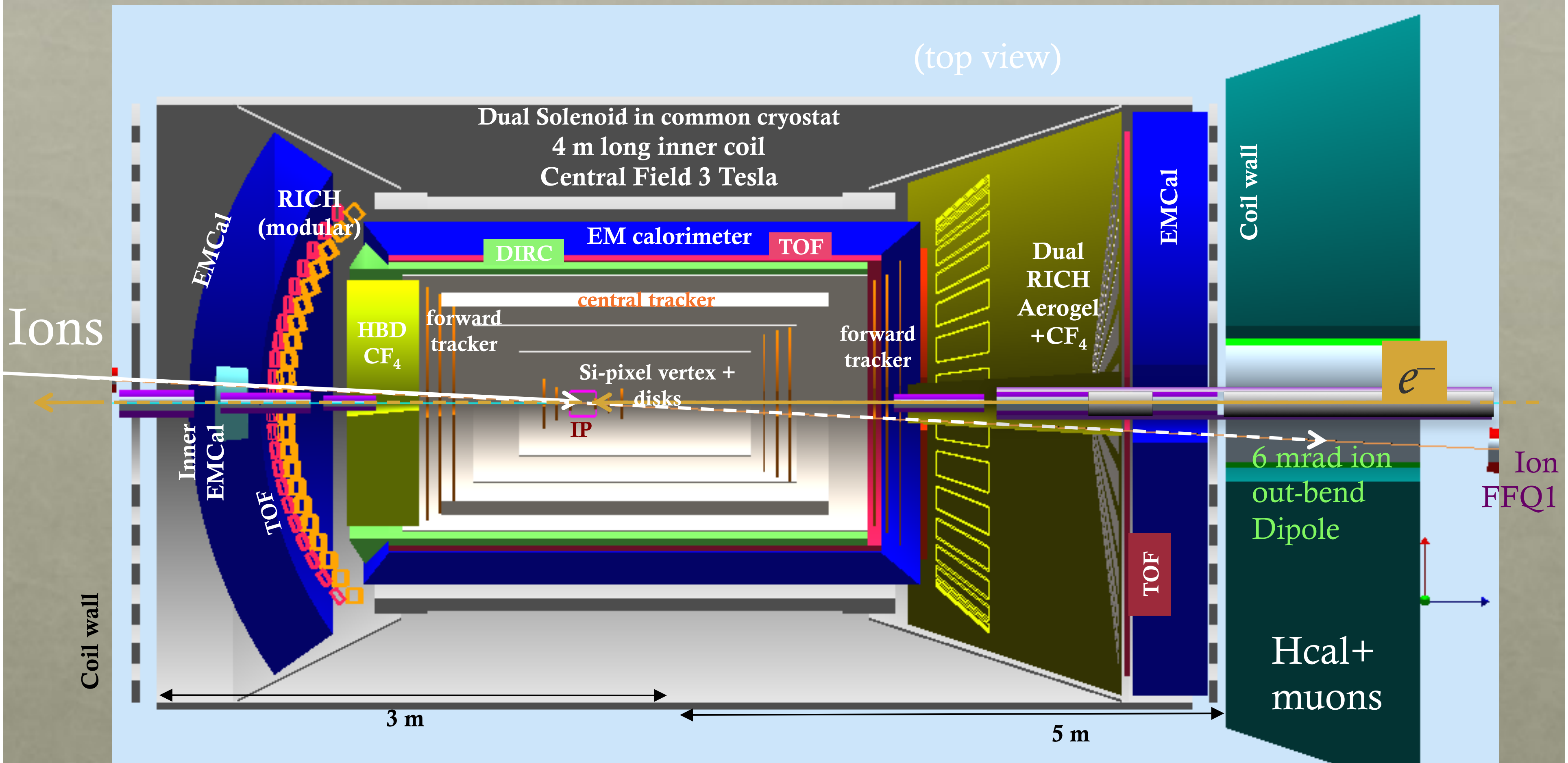
DIS Hadronic Kinematics: $xP+q$

- Projected π/K PID.
- 2 decades in x_B, Q^2.
- Kinematic points outside PID region are accessible for $z < 1$.



MEIC CENTRAL DETECTOR
WITH DUAL SOLENOID MAGNET
(Geometrically compatible with 1.5 T CLEO Solenoid)

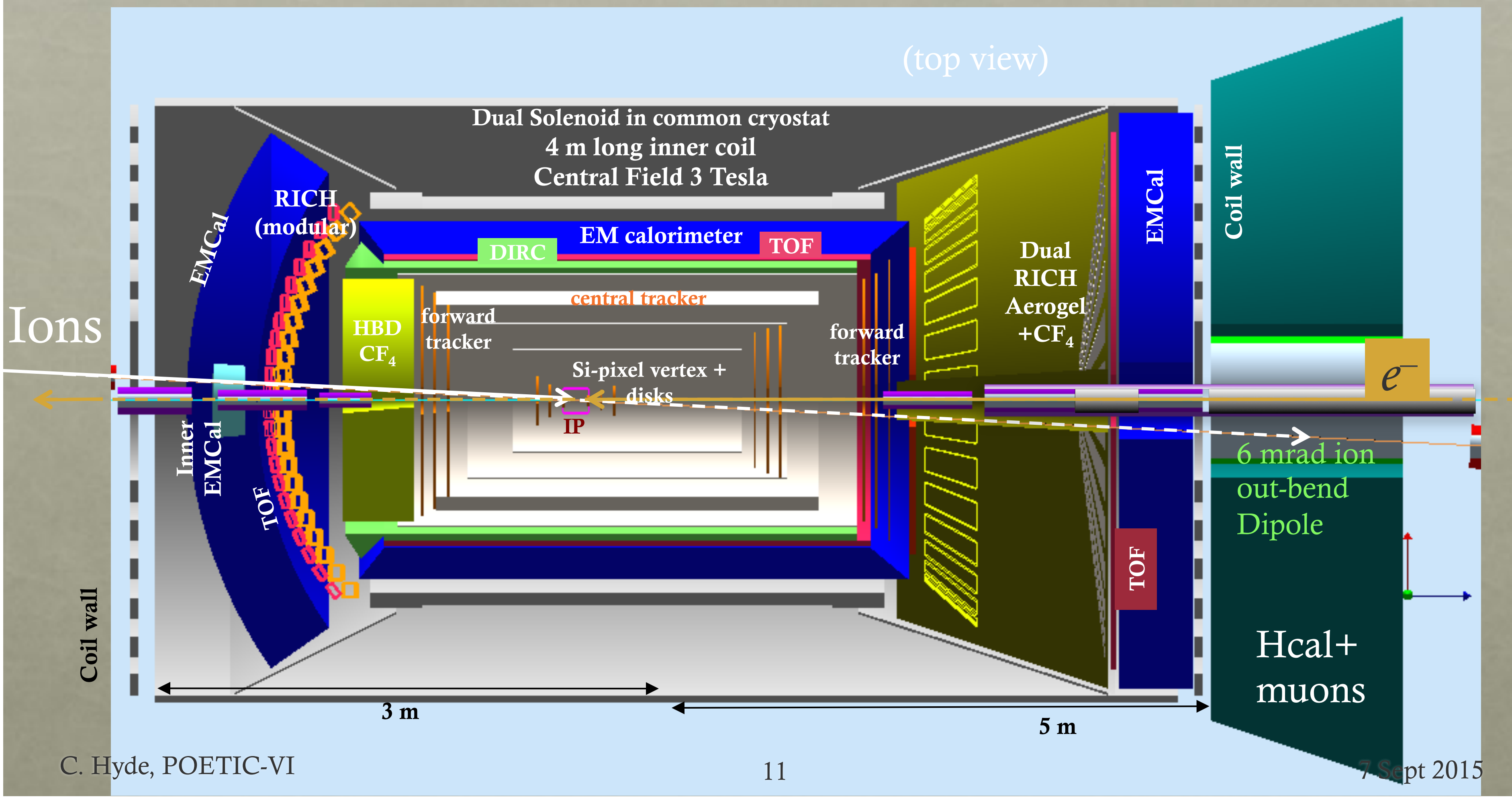
Electron End-Cap: •HBD (CF_4+UV-GEM) or TRD, •Aerogel RICH (Modular), •TOF(MRPC), •EMCal (Shashlyk+ inner $PbWO_4$)



MEIC CENTRAL DETECTOR
WITH DUAL SOLENOID MAGNET
(Geometrically compatible with 1.5 T CLEO Solenoid)

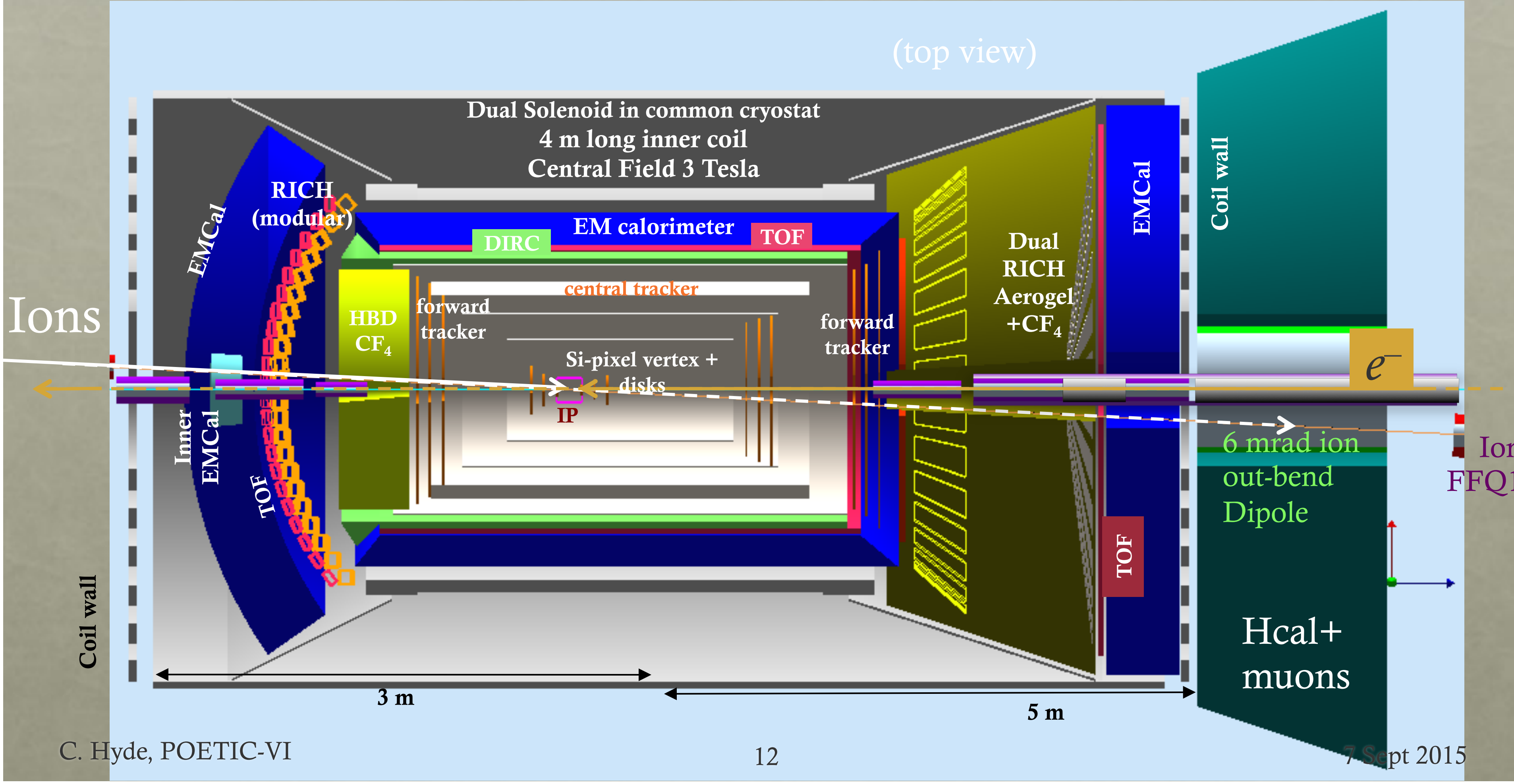
Barrel Region:

•DIRC (π,K,p to ≤6 GeV/c), •TOF(MRPC), •EMCal (W or Pb sampling)



MEIC CENTRAL DETECTOR
WITH DUAL SOLENOID MAGNET
(Ion End-Cap Detectors)

- Dual RICH: Aerogel + CF_4 (Out-focussing 1- or 2-bounce mirror)
- TOF(MRPC), • sampling EMCal, Hcal/Muon Tracker (CLEO)

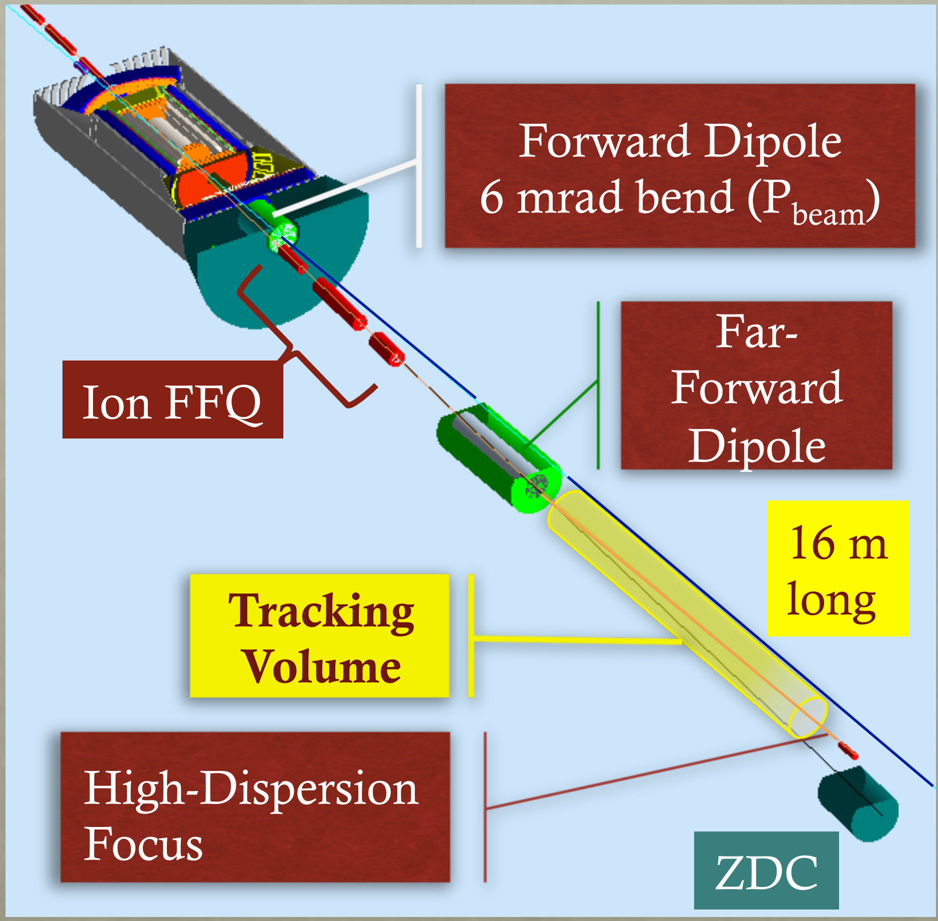


Ion Forward and Far-Forward Regions

- Forward Dipole (z=5.5m)
  - 2 T-m (scaled to 100GeV/c proton)
    - Flux exclusion for *e*-Beam
  - Acceptance 25 < θ ≤ 80 mr (relative to electron axis)
  - > 50cm Tracking space after magnet
- FFQ triplet acceptance:
  - ± 10 mr horiz, ±14 mr vert, for |Δp/p|≤ 0.5
  - 25 mrad cone (full opening) line-of sight to ZDC
- High Dispersion Focus @36m
  - Full Acceptance:

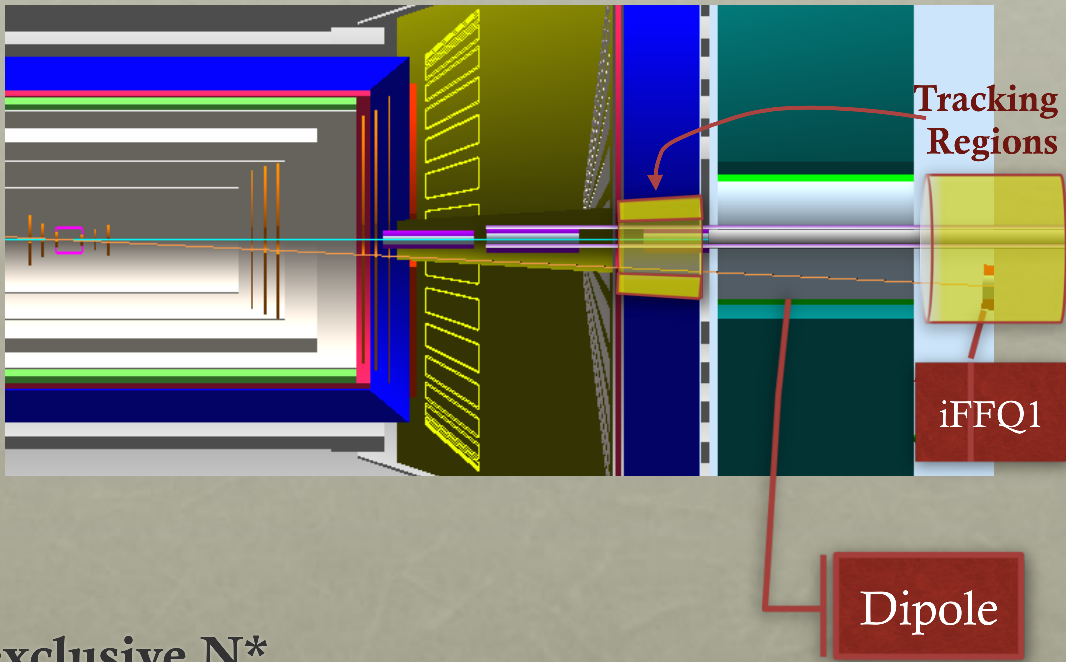
    0.5 > | $\Delta P/P$| > 0.005

    or θ_{IP} > 4 mrad



FORWARD REGION
(scales to 100 GeV/c incident)

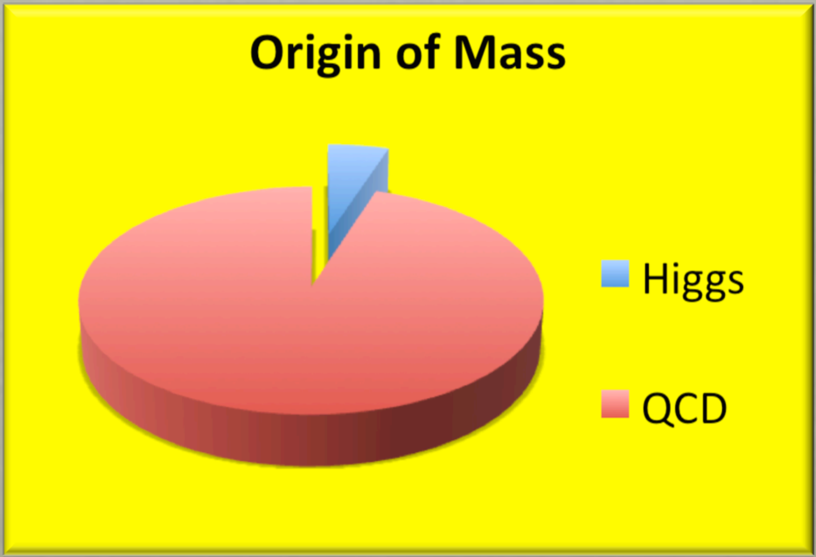
- **2 Tesla-m Dipole (z=5.5m)**
  - (*cf.* For θ < 80 mrad, Solenoid Bdl < 0.6 T-m)
- **Full Reconstruction of Projectile Fragmentation**
  - High-P_T, or
  - Small $-x_F$ (low rigidity)
  - Mesons from decay of near exclusive N*
- **NN correlations in heavy nuclei**
  - $P_T/P_{||}$ < (1 GeV/c)/(40 GeV/c) = 25 mrad relative to ion-beam < 75 mrad relative to electron axis

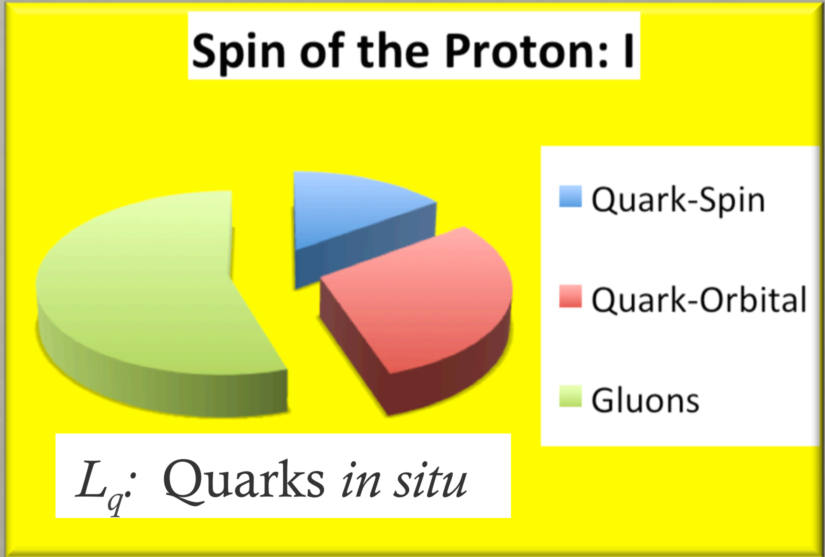


FAR-FORWARD SPECTROMETER

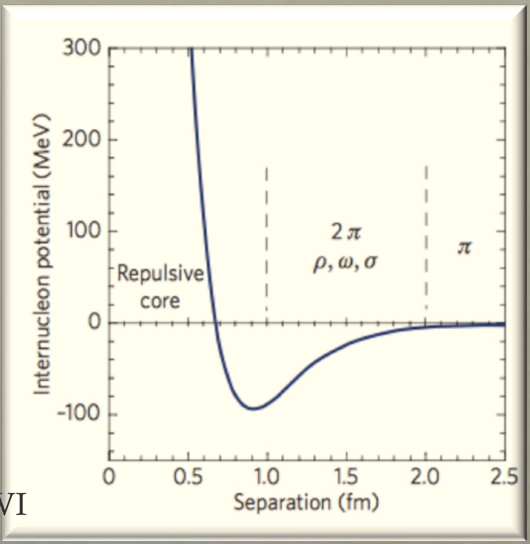
- **Deep Virtual Exclusive Processes. Acceptance:**
  - x_{Bj}>0.005, or $-t \sim (P_T)^2 > (400\ MeV/c)^2$ @ *100 GeV/c*
- **Spectator Tagging**
  - P_p ~0.5 P(deuteron), 0.33 P(^{3}He),
    tracking resolution ≈ beam emittance
  - ZDC can achieve $30\%/\sqrt{E_n} \approx 4\%$ for spectator neutrons
    ~ 20 MeV/c longitudinal resolution
    ~ 10 mm/40 m = 0.25 mrad transverse ➔ $\sigma(p_T)$=12.5 MeV/c
    P_T acceptance for neutrons and protons up to 700 MeV/c
- **Nuclear Fragmentation**
  - Neutron evaporation, $p_T \approx 100$ MeV/c ➔ $\theta_n \leq 2.5$ mrad
  - Evaporation Residues: Z/A ≠ rigidity of incident nucleus
  - Nuclear disassembly, $p_T \approx 200$ MeV/c ➔ $\theta_n \leq 5$ mrad
    - ^{3}He fragments from N=Z nuclei have rigidity 4/3 × incident ion
    - Fragment ID from dE/dX

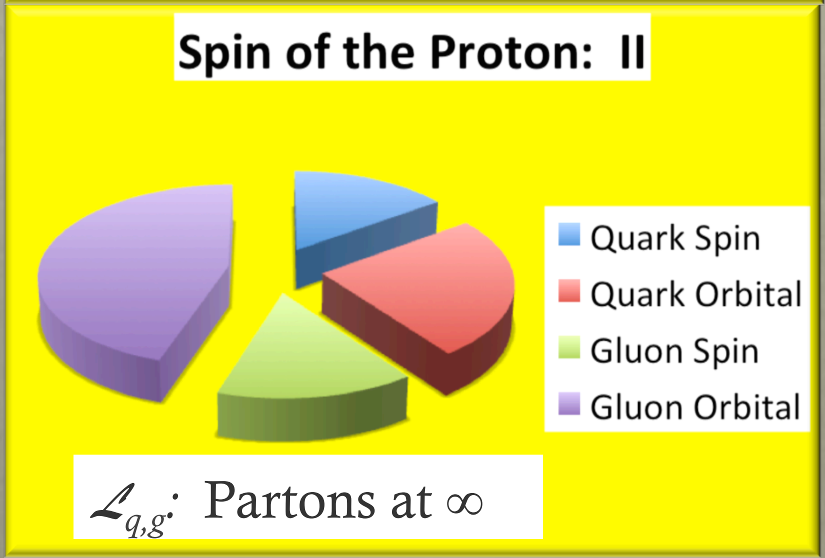
The Big Questions





NN Force & Nuclear Binding

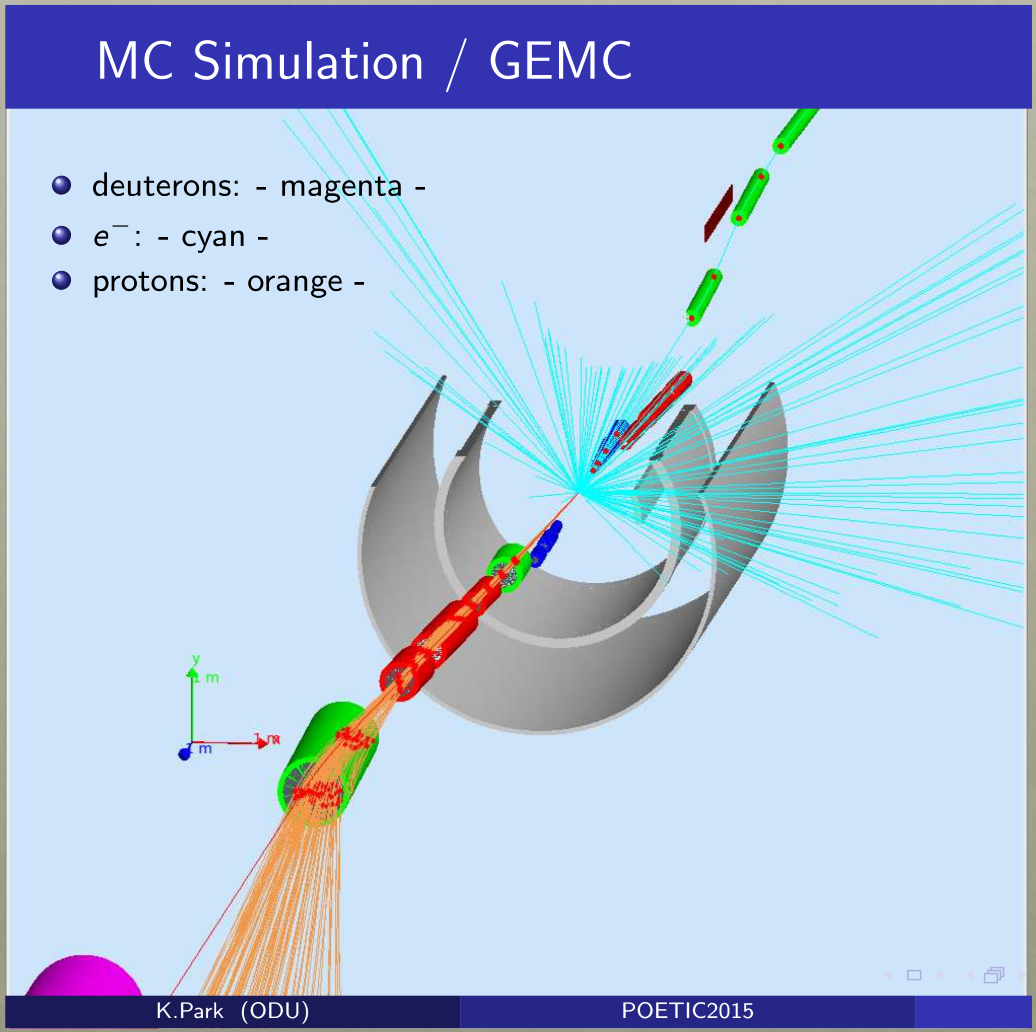




CONCLUSIONS

- **Our goal:**
  Design an Accelerator, Interaction point optics, and Detector to optimally provide experimental insight into these challenging questions.

- **Thanks to Zhiwen Zhao and KiJun Park for GEMC detector images and simulations, and P. Nadel-Turonski who could not attend.**

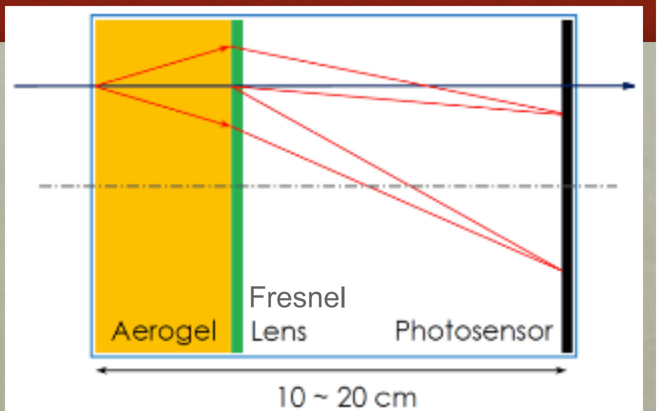


Detector Subsystems

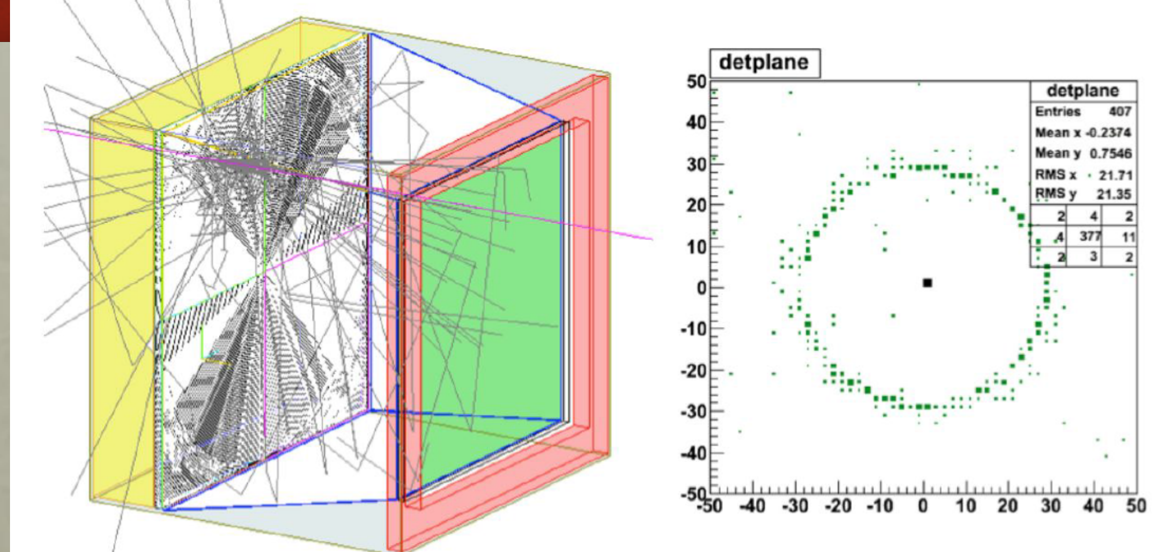
and R&D Efforts

MODULAR RICH

Conceptual Design

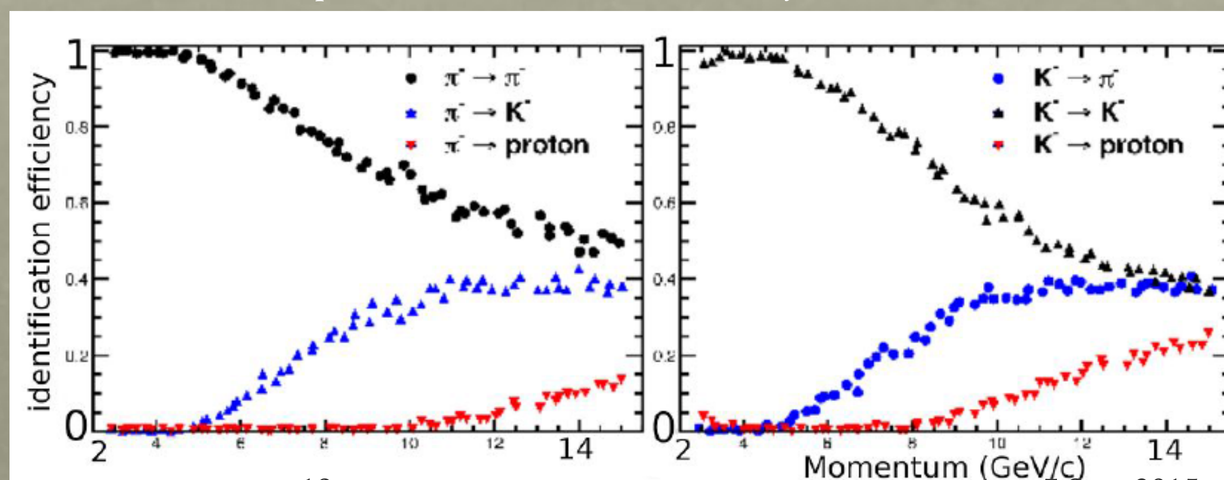


Simulation in **GEMC**



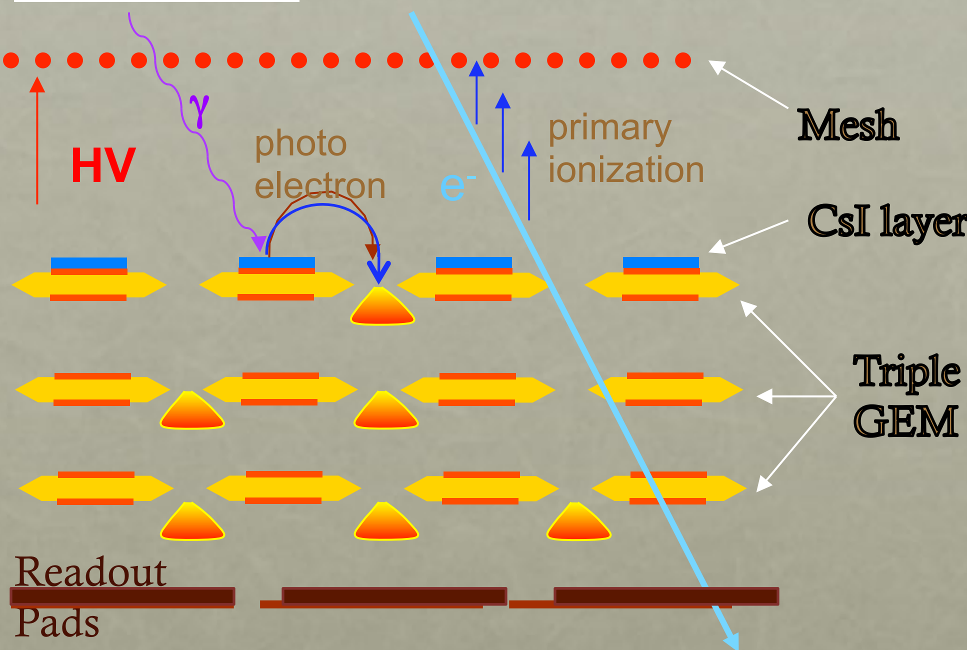
- Compact π/k PID $p \leq 10$ GeV/c
- Flexible arrangement, can be projective to IP

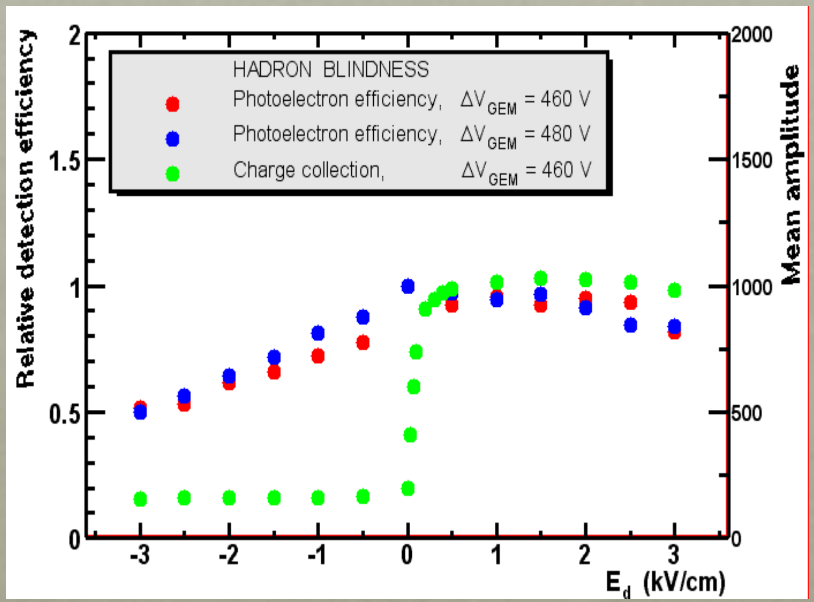
Final performance simulation : Efficiency and mis-ID VS momentum



EIC R&D eRD11

HADRON BLIND DETECTOR(HBD)



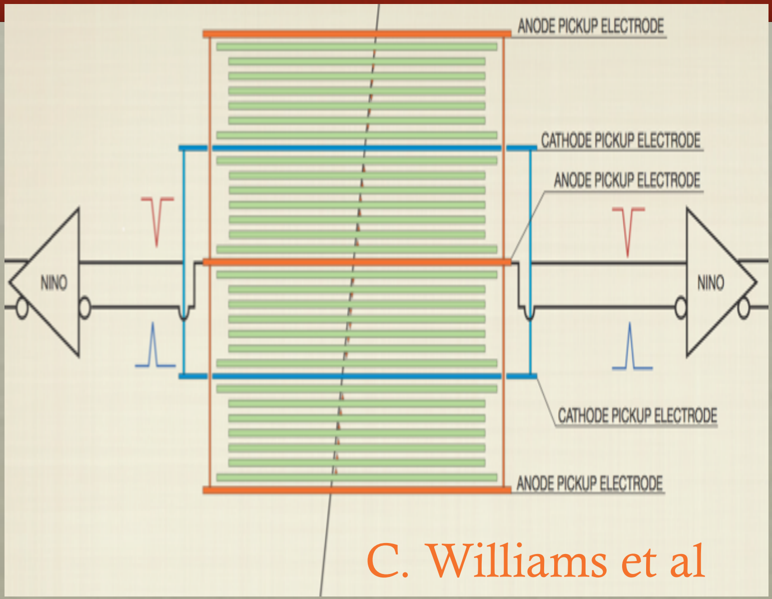


- compact e/π PID detector
- Blind to hadron <4GeV with CF_4 gas at PHENIX

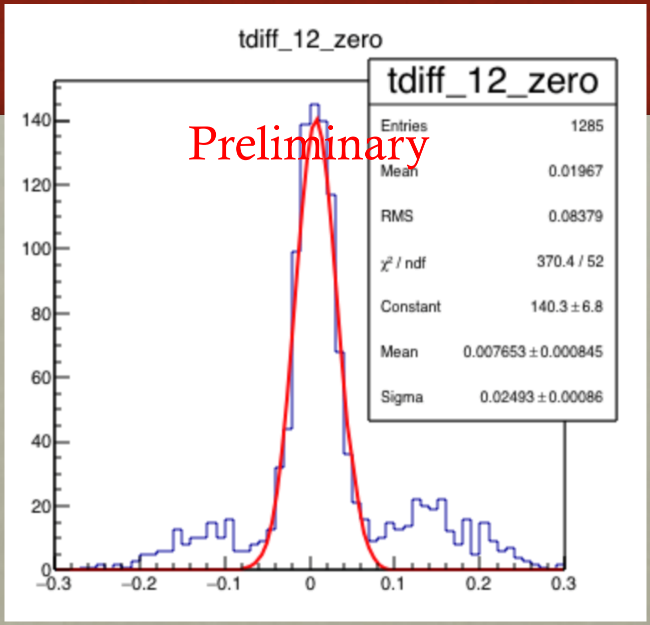
Tom Hemmick

TOF (MRPC)

mRPC TOF

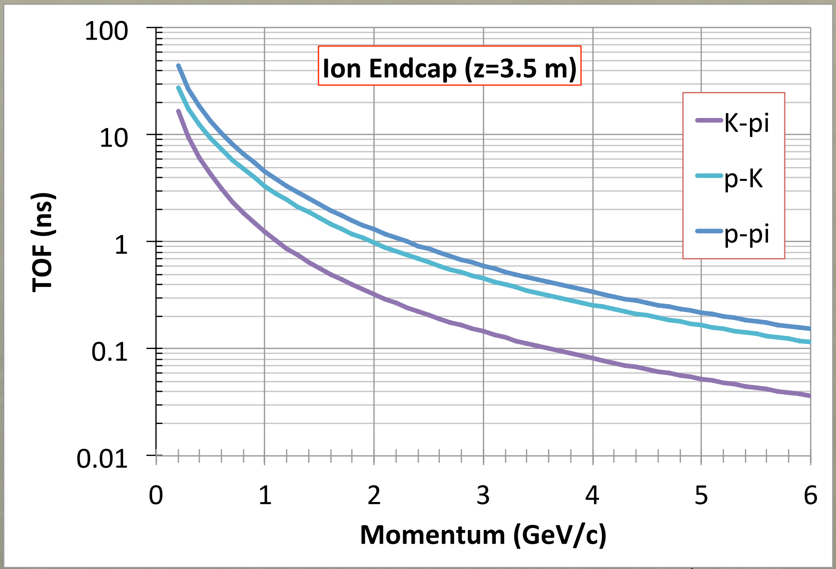


C. Williams et al



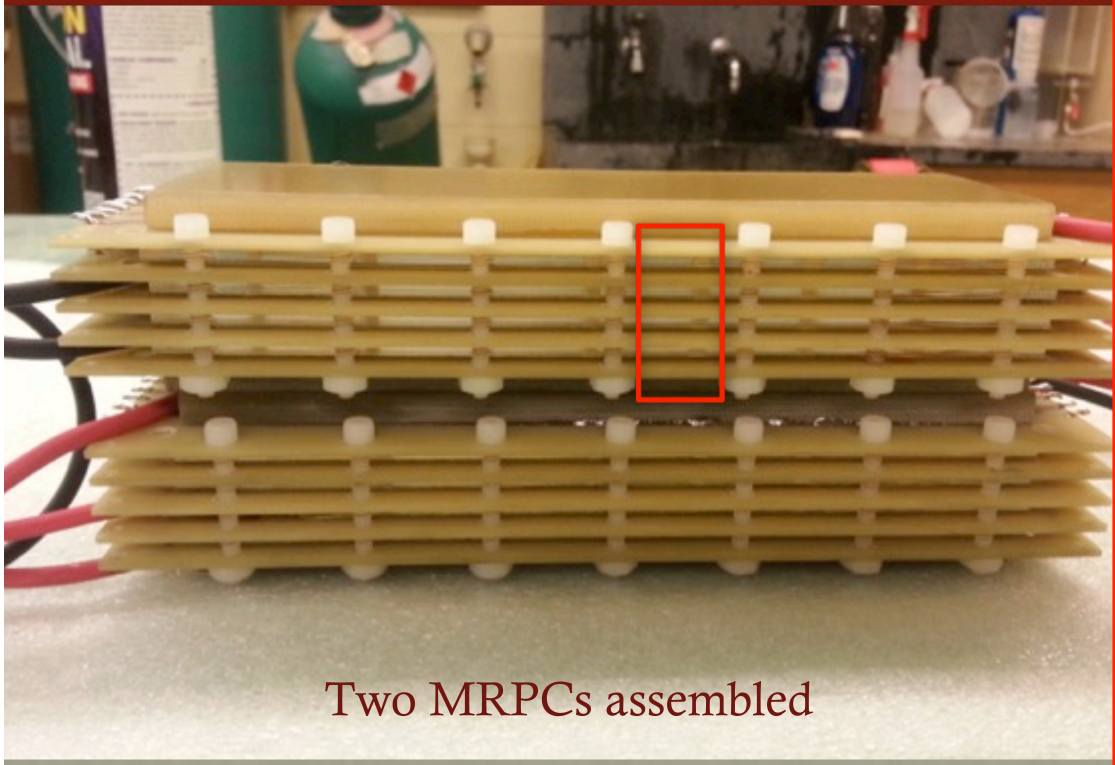
$\Delta t = t_2 - t_1$
$= 25$ ps
$\sigma_t = \Delta t/\sqrt{2}$
$= 18$ ps

EIC R&D
UIUC
eRD14

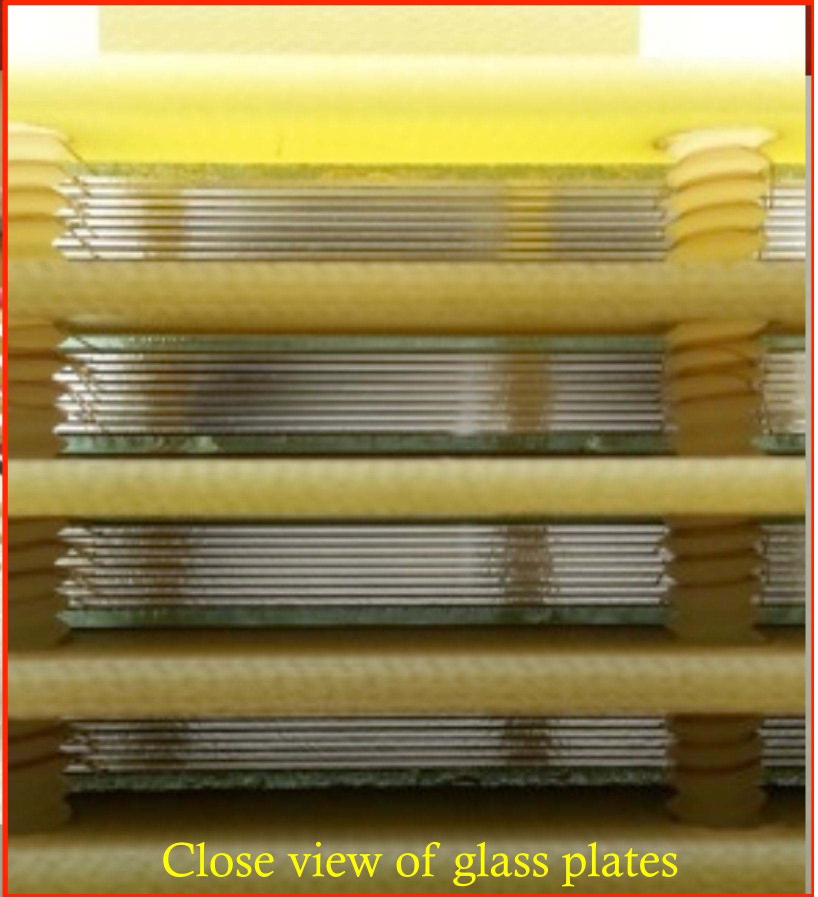


- compact PID detector
- Flexible arrangement, can be projective to IP and at barrel

MRPC Prototypes Assembled

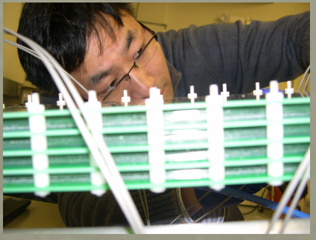


Two MRPCs assembled

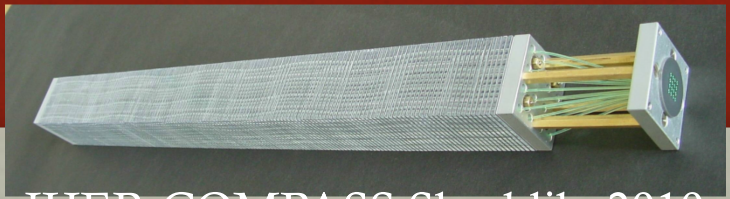


Close view of glass plates

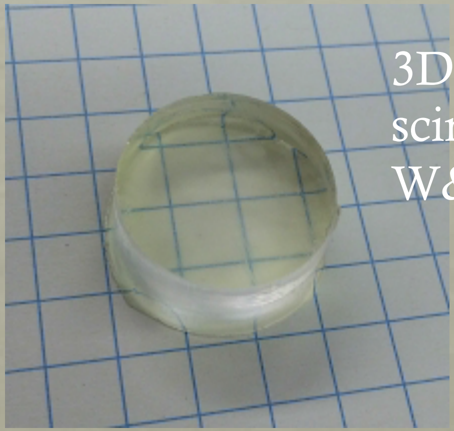
All done at UIUC by eRD10 post-doc Ihnjea Choi



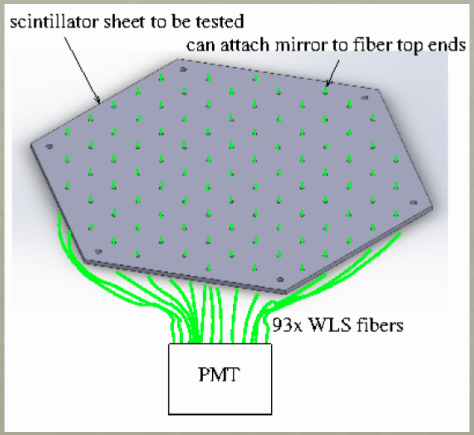
EMCAL (Shashlik+Crystal)



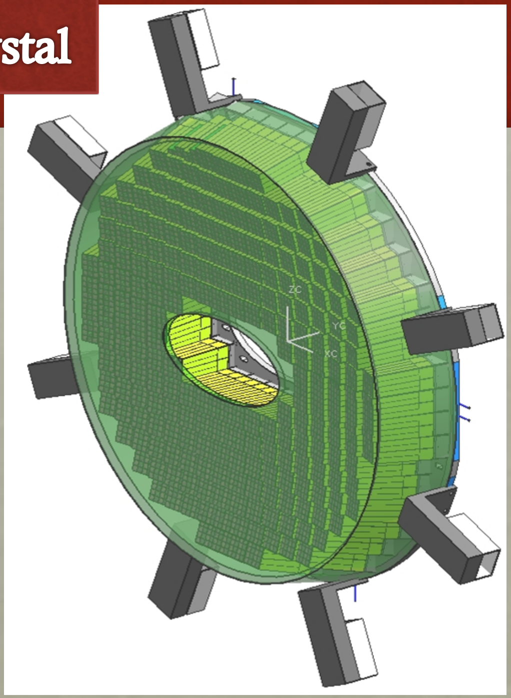
IHEP, COMPASS Shashlik, 2010



3D-printed scintillator at W&M



Panda Crystal endcap



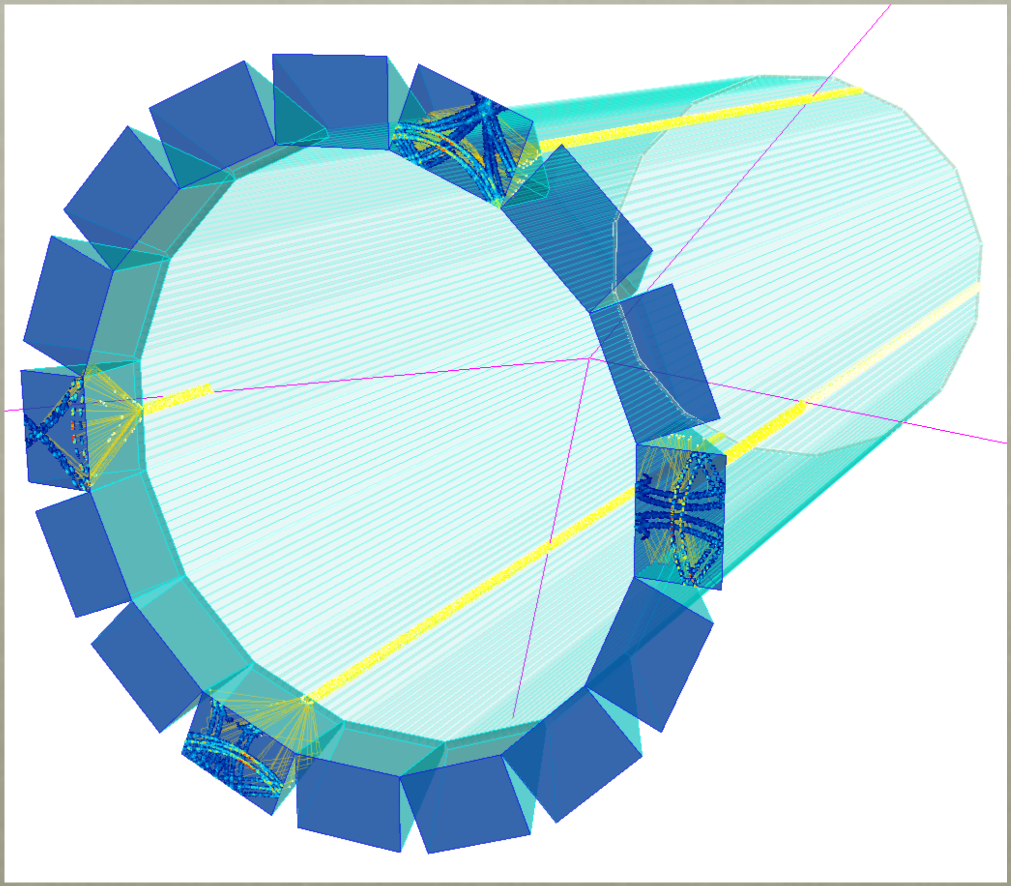
$PbWO_4$

- **Projective can help PID performance**

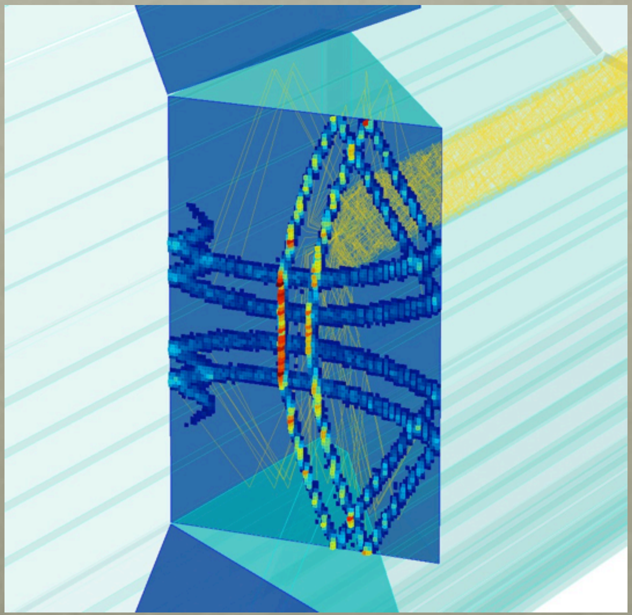
- **Crystal calo near 180° (electron endcap) compensates lower tracking resolution**
- **Working with Crytur and SICCAS to qualify $PbWO_4$ production**

EIC R&D eRD14

GEANT4 DIRC Simulation: Narrow radiator bars grouped to common prism/photosensor array

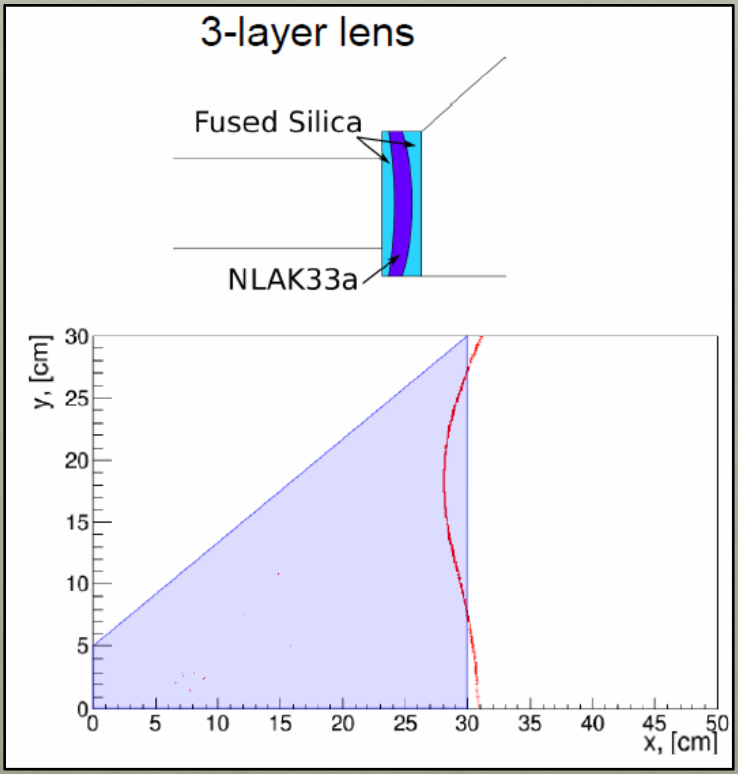


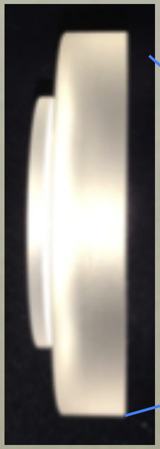
- Standalone Geant4 simulation
  - Developed at GSI
  - Installed at JLab
  - Can be integrated with various frameworks (GEMC, eicROOT)

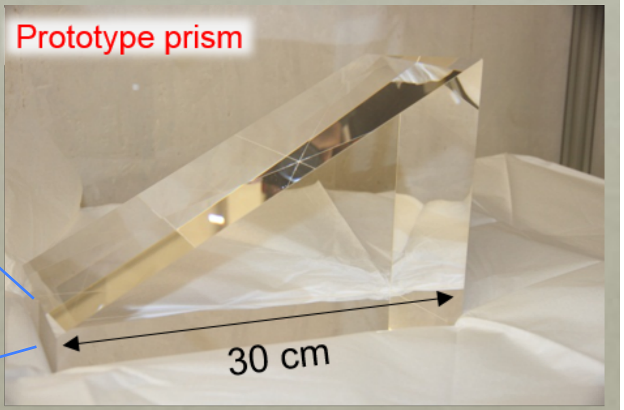


- Close-up view of focal image with spherical 3-layer lens (no air gap)

DIRC imaging: 3-Layer spherical Lens with Flat Focal Plane

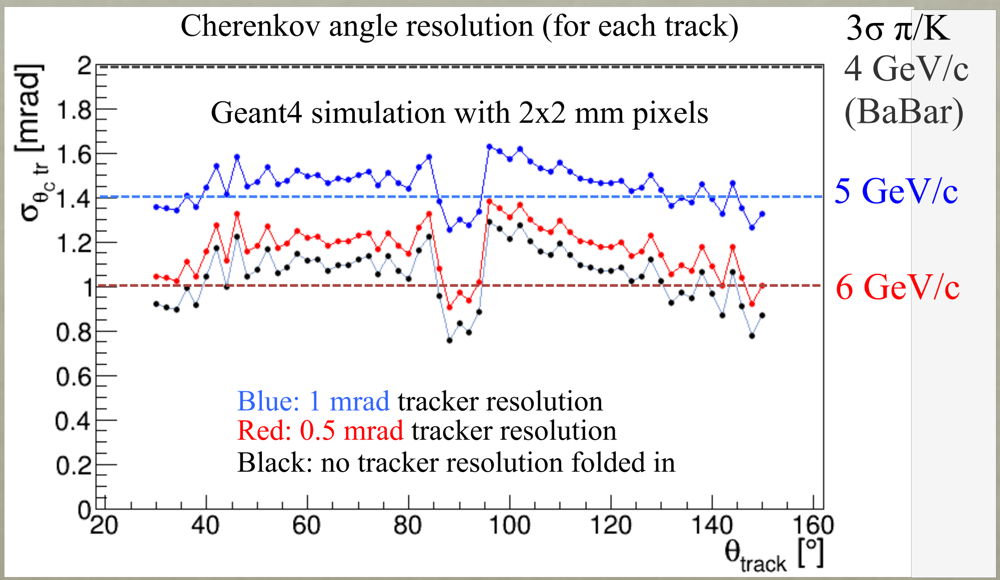






- The prototype lens was matched to the existing GSI prototype prism
  - The focal plane can canted to align the sensors with perpendicular to the B-field.
- In the simulation, a wider prism is used, covering an entire bar box

Full System DIRC Cherenkov Angle Reconstruction

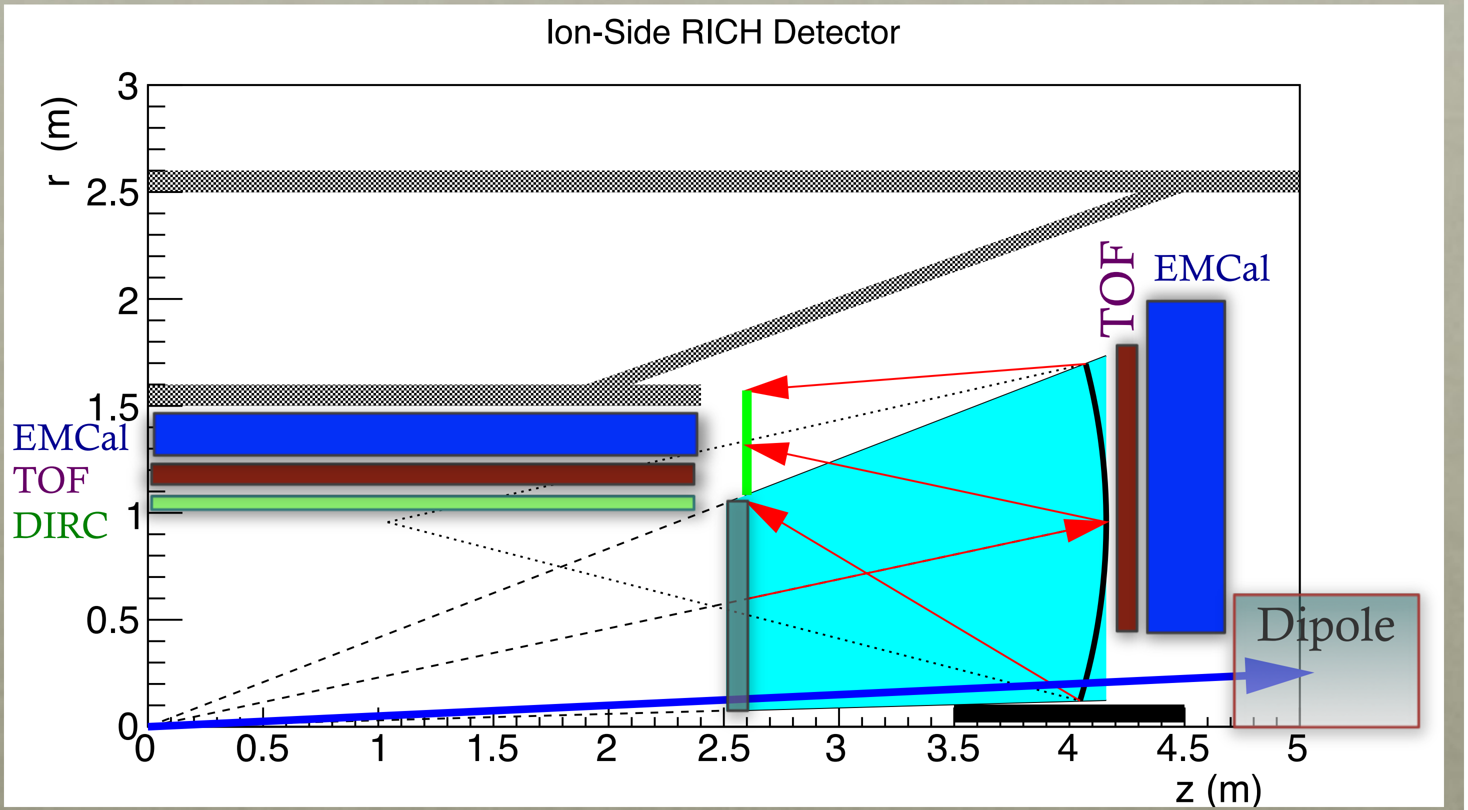


- The per-track resolution *vs* track polar angle, for three assumptions of track incidence angular resolution.
- With a tracker angular resolution of 0.5-1.0 mrad and a sensor pixel size of 2-3 mm, the lens-based EIC DIRC will reach Cherenkov angle resolution close to 1 mrad corresponding to a 3σ π/K separation up to 6 GeV/c.

EIC R&D Milestone reached: The feasibility of a high-performance EIC DIRC has been demonstrated and using a compact readout "camera."

Single Bounce Dual RICH:

- Aerogel with Fresnel lens ~75 cm focal length: image at focal point of mirror (also filter UV)
- CF_4 gas (visible + UV)
- 2nd mirror to place photo sensors in weaker field?



In contrast, ePHENIX and BEAST concept have in-focussing mirrors