A Summary of the EIC Detector R&D Program

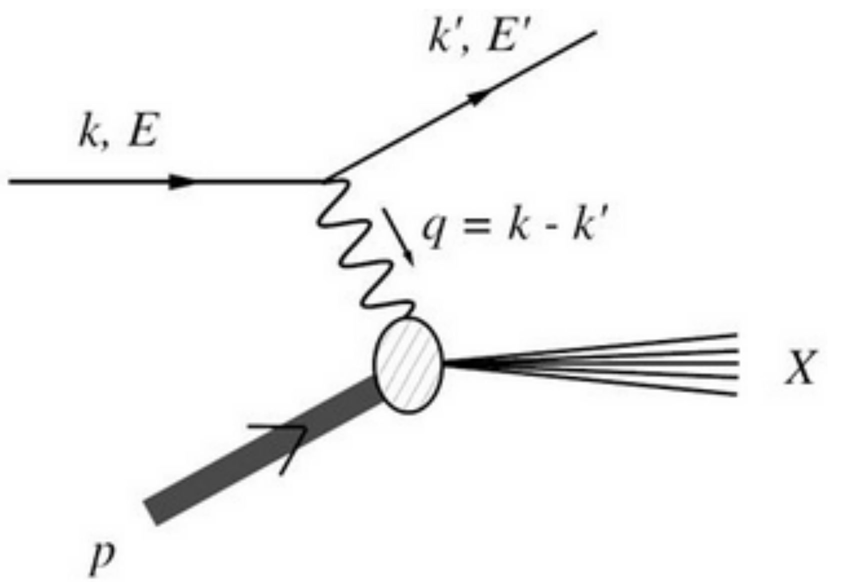
Yordanka Ilieva
University of South Carolina

Based on the work of a large number of physicists carrying out the EIC R&D projects

DIS2018 Workshop, 16 - 20 April 2018

Detector Requirements

Inclusive Measurements

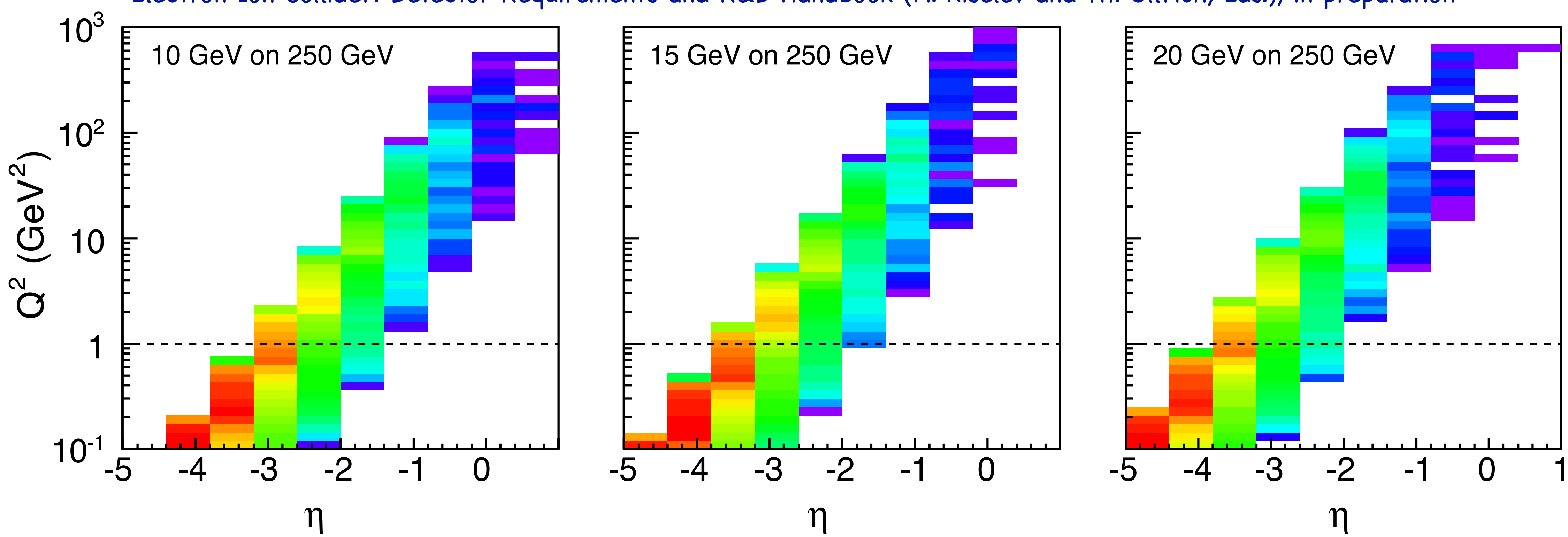


- Detection of scattered electron

  OR
- Detection of all scattered hadrons

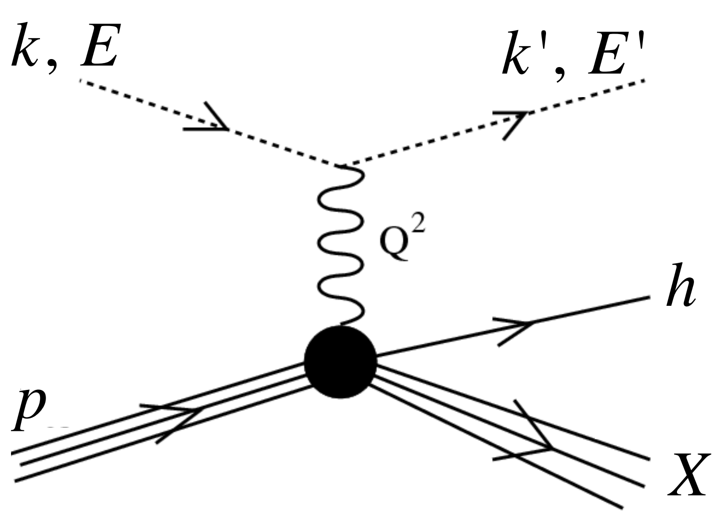
- The larger the electron-beam energy, the more forward electron-scattering angles (strong Q^2 and E_e dependence): needed suppression of photons and hadrons by 10^2 - 10^4, depending on kinematics
- Electron ID needed in 4π: p (tracking) and E (calorimetry)
- Excellent energy/momentum and angular resolution for scattered electron.

Electron Ion Collider: Detector Requirements and R&D Handbook (A. Kiselev and Th. Ullrich, Eds.), in preparation



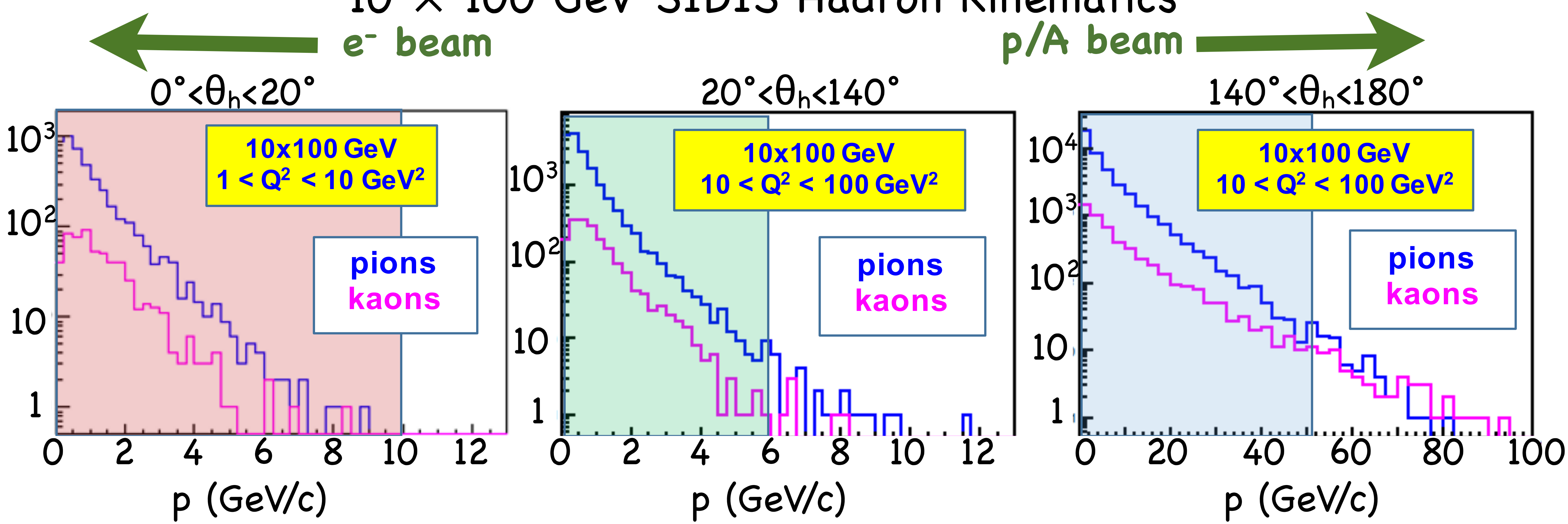
Detector Requirements

Semi-Inclusive Measurements



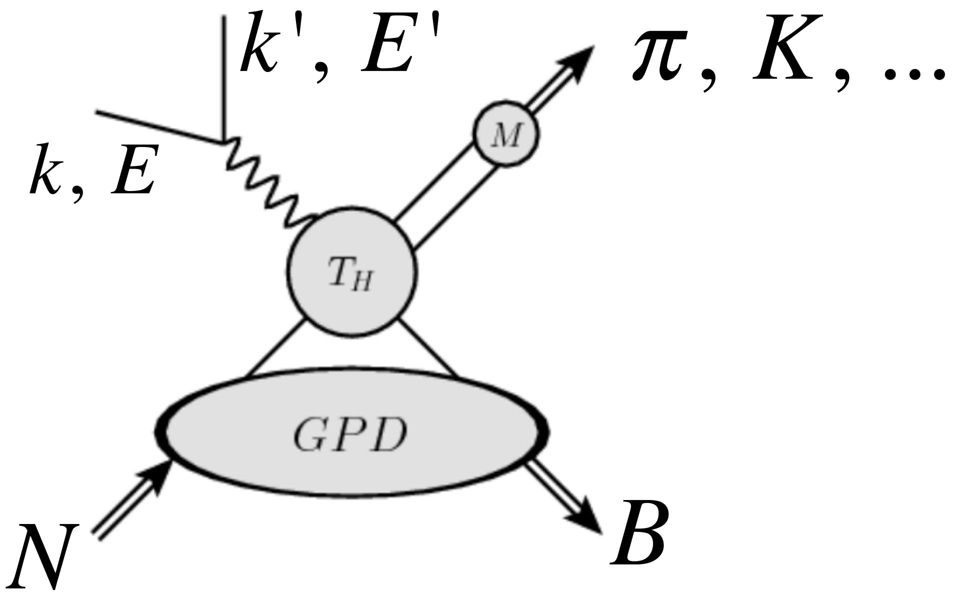
- Detection of scattered electron and at least one scattered hadron
  - excellent π/K/p separation in a wide momentum range
  - excellent vertex resolution (charm, bottom)

10 × 100 GeV SIDIS Hadron Kinematics



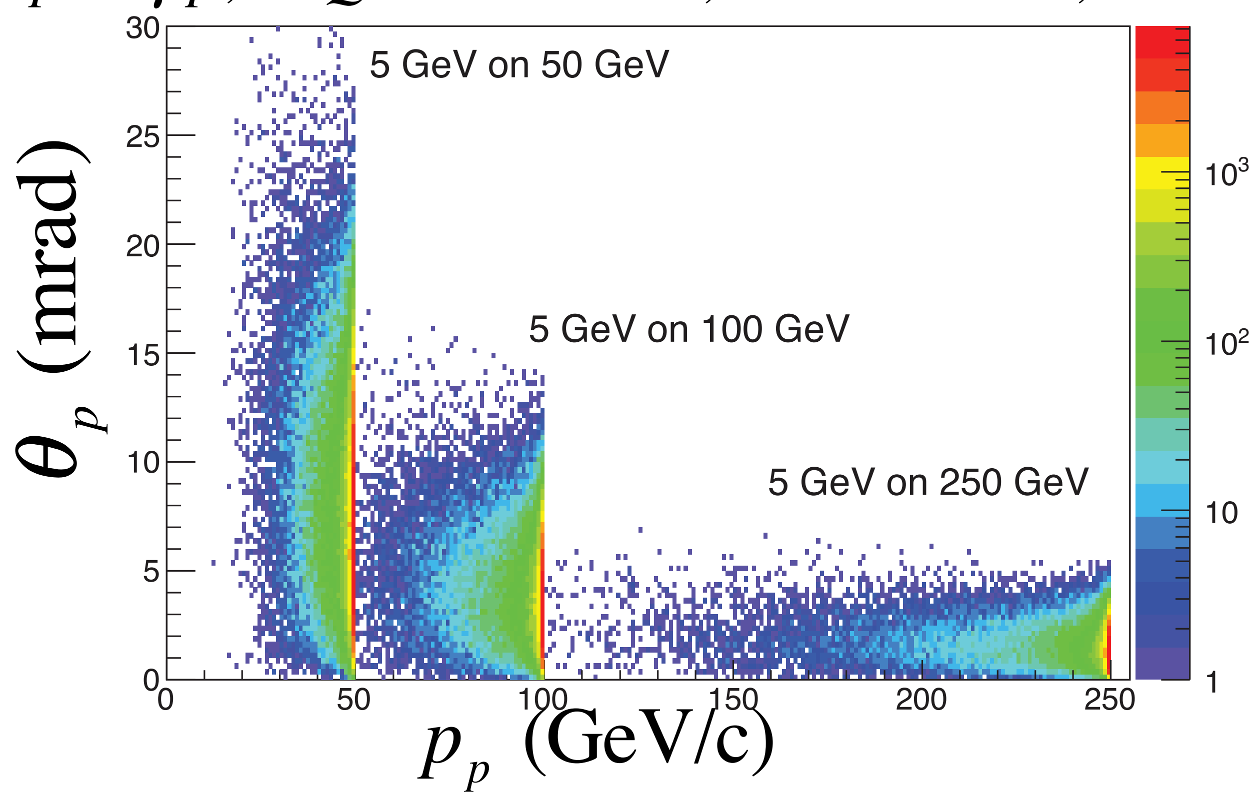
Detector Requirements

Exclusive Measurements

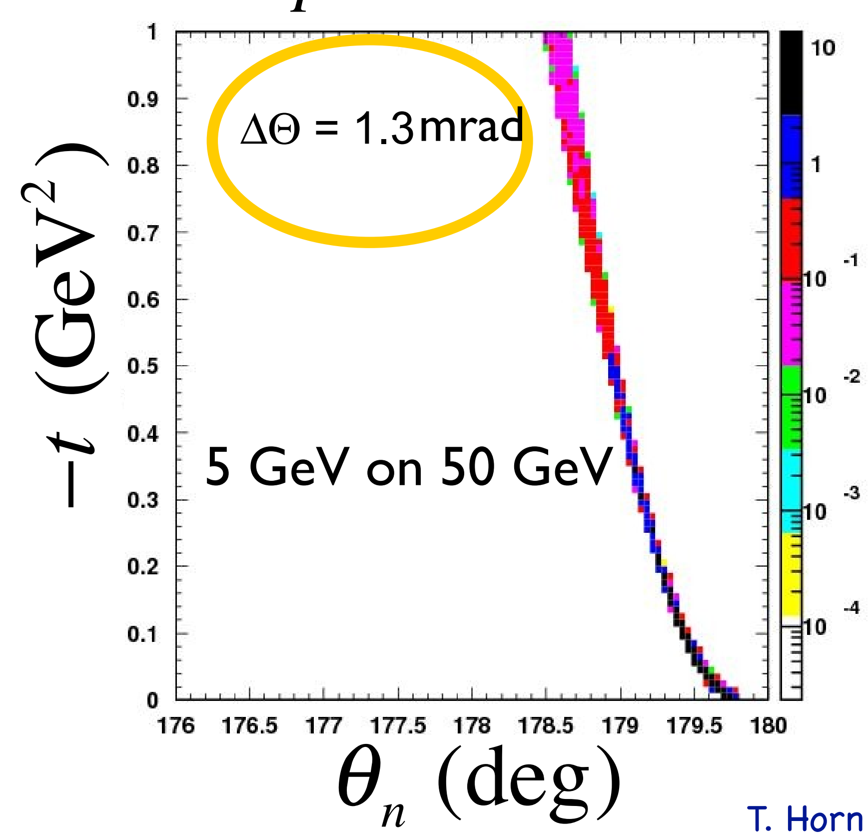


- Detection of all scattered particles
  - hermeticity
  - large kinematic coverage
  - forward baryon detection capabilities
  - excellent π/K/p separation in a wide momentum range
  - photon detection (EM calorimetry required over a wide rapidity range)
  - high momentum and angular resolutions

$\gamma^* p \rightarrow \gamma p,\ 1 < Q^2 < 100\ \mathrm{GeV}^2,\ 10^{-5} < x < 0.7,\ 0 < t < 2\ \mathrm{GeV}^2$



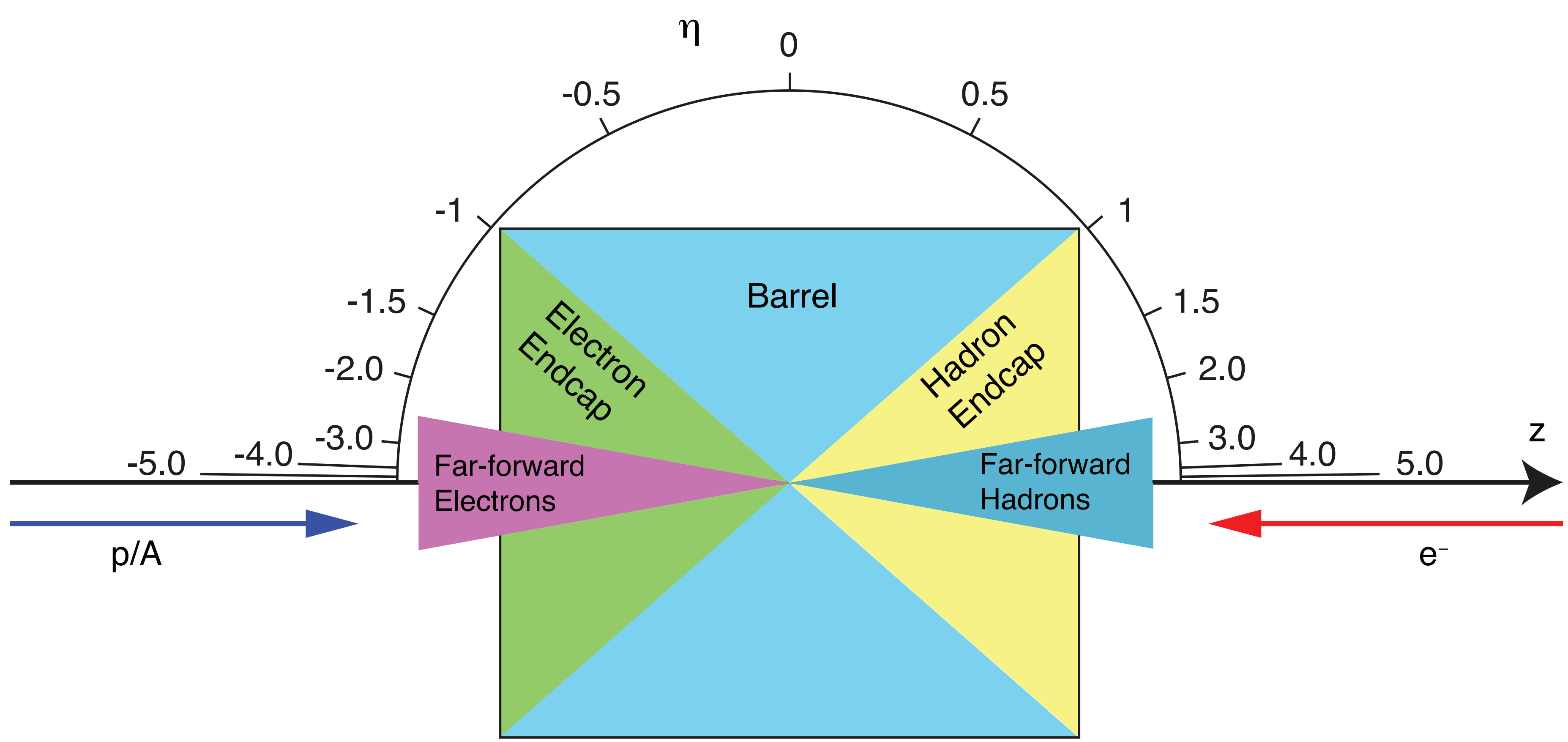
$ep \rightarrow e'\pi^+ n$



Electron Ion Collider: The Next QCD Frontier, arXiv:1212.1701 (2014)

T. Horn

The EIC Detector: Overview



Electron Ion Collider: Detector Requirements and R&D Handbook (A. Kiselev and Th. Ullrich, Eds.), in preparation

- Close to 4π acceptance: central detector, ion endcap, electron endcap, small-angle detectors on both sides
- Central Solenoid Field: 1.5 – 3 T
- Tracking momentum resolution: few %
- Good electron ID
- Hadron PID
- Vertex resolution: < 20 μm

The EIC Generic R&D Program (2011 - present)

Peer-reviewed program to:

- develop detector concepts and technologies of importance in the EIC environment
  - new concepts and technologies
  - adaptation of existing technologies
  - new design and simulation tools
  - new computing/analysis techniques
- help ensure that the techniques and resources to implement these technologies are well established within the EIC user community

Administered by Brookhaven National Lab, Program Manager: Thomas Ullrich (BNL)

Call for proposals:

Spring of each year

Open to everyone

EIC Detector R&D Advisory Committee

- January meeting: evaluation of progress of ongoing projects
- July meeting: merit review of new proposals and funding recommendations

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

The EIC Generic R&D Program (2011 - present)

Current and recently completed projects

- eRD1: Calorimeter Development
- eRD2: Magnetic-Field Cloaking Device
- eRD3: Fast and Lightweight Forward Tracking
- eRD6: The EIC Tracking and PID Consortium
- eRD12: Polarimeter, Luminosity Monitor and Low Q2-Tagger for Electron Beam
- eRD14: An Integrated Program for Particle Identification for an EIC Detector
- eRD15: R&D for a Compton Electron Detector
- eRD16: Forward Silicon Tracking
- eRD18: Precision Central Silicon Tracking and Vertexing for the EIC
- eRD17: BEAGLE: A tool to Refine Detector Requirements for eA Collisions
- eRD20: Developing Simulation and Analysis Tools for the EIC
- eRD21: EIC Background Studies and Impact on the IR and Detector design
- eRD22: GEM based Transition radiation detector and tracker

Generic detector technologies that could be applied both at JLab and BNL

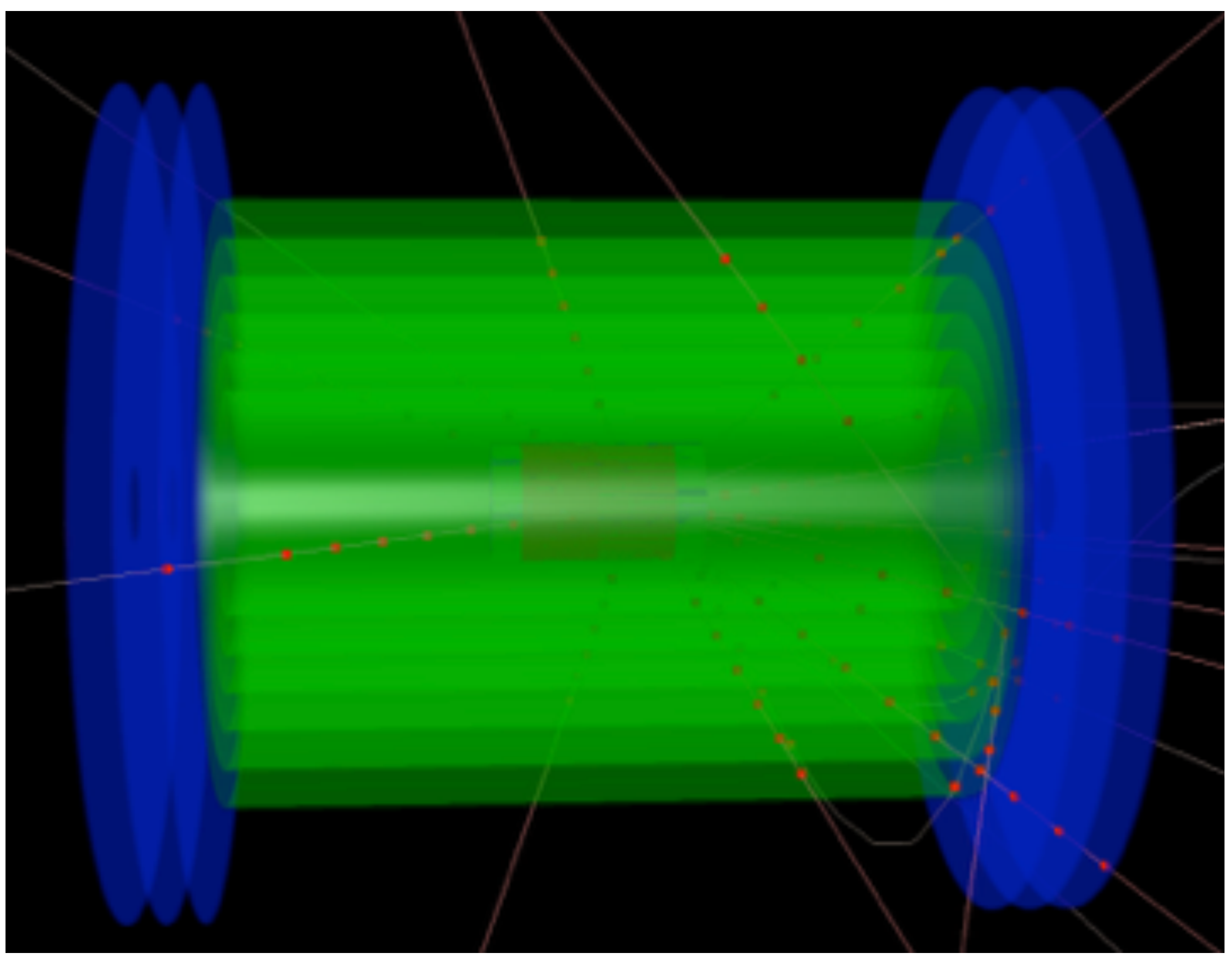
https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

Tracking Detectors

eRD3: Fast and Lightweight EIC Integrated Tracking System

Franck Sabatie, Maxence Vanderbroucke, Bernd Surrow, Matt Posik

Satisfies the requirement for a very low material budget: < 5% of r.l.



- **Barrel tracking system:** Micromega detectors in the form of cylindrical shell elements (similar to CLAS12), 100-μm position resolution
- **Rear/Forward Tracking System:** Triple GEM detectors in the form of planar segments

M. Posik

Tracking Detectors

eRD6: Tracking Consortium

- **Brookhaven National Laboratory (BNL)**
  - People: E.C Aschenauer, B. Azmoun, A. Kiselev, M. L. Purschke, C. Woody
  - R&D: Mini-Drift detector; TPC/Cherenkov prototype (TPC-C); zigzag pad development.
- **Florida Institute Of Technology (FIT)**
  - People: M. Bomberger, M. Hohlmann
  - R&D: Large & low mass GEM with zig-zag readout structures.
- **INFN Trieste**
  - People: S. Dalla Torre, S. Dasgupta, G. Hamar, S. Levorato, F. Tessarotto
  - R&D: Hybrid MPGD for RICH applications.
- **Stony Brook University (SBU)**
  - People: K. Dehmelt, A. Deshpande, N. Feege, T. Hemmick
  - R&D: Short radiator length RICH; Large mirror coating, TPC-IBF
- **University Of Virginia (UVa)**
  - People: K. Gnanvo, S. Jian, N. Liyanage, J. Matter
  - R&D: Large & low mass GEM with u-v readout; Chromium-GEM (Cr-GEM).
- **Yale University**
  - People: D. Majka, N. Smirnov
  - R&D: 3-D-coordinate GEM readout; hybrid gain structure.

Calorimeters

eRD1: Calorimeter Development

S. Ali, E. Aschenauer, V. Berdnikov, S. Boose, M. Carmignotto, A. Denisov, L. Dunkelberger, A. Durum, S. Fazio, Y. Fisyak, D. Griggs, A. Hernandez, T. Horn, H.Z. Huang, J. Huang, G. Hull, W. Jacobs, M. Josselin, Y. Kim, K. Landry, L. Leon, I. Pegg, M. Purschke, A. Kiselev, E. Kistenev, S. Kuleshov, C. Lauer, C. Munoz-Camacho, H. Mkrtchyan, C. Pinkenberg, S. Roustom, E. Rozas, H. San, M. Sergeeva, A. Sickles, S. Stoll, V. Tadevosyan, S. Trentalange, R. Trotta, P. Ulloa, A. Vargas, G. Visser, R. Wang, S. Wissink, C. Woody, L. Zhang, R. Zhu

A.I. Alikhanyan National Science Laboratory/Yerevan, Catholic University of America, The Vitreous State Laboratory, Indiana University, Institut de Physique Nucleaire d'Orsay/France, Jefferson Laboratory, Brookhaven National Laboratory, Caltech, University of Illinois, University of California Los Angeles, Federico Santa Maria Technical University, MEPHI

Calorimeters

eRD1: Calorimeter Development

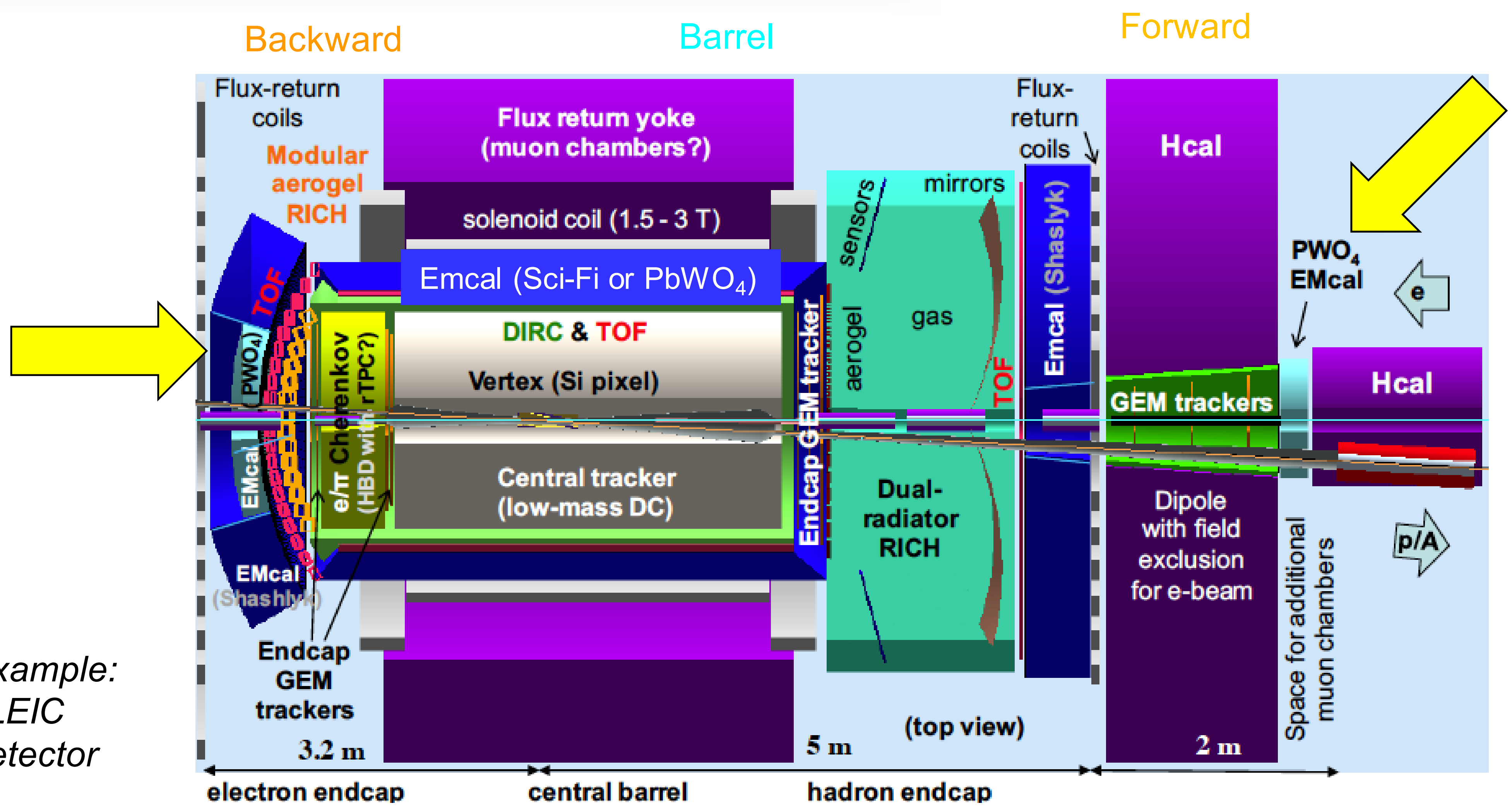
Electron Endcap:

High Resolution Inner Calorimeter: $2\%\sqrt{E}$

Outer Calorimeter: $10\%\sqrt{E}$

Hadron Endcap and Barrel:

$10-12\%\sqrt{E}$



Example: JLEIC detector

Calorimeters

eRD1: Calorimeter Development

Various technologies explored

- **Compact W-powder/Scintillating Fiber EM calorimeter**
  - good energy/timing resolution: $15.6\% / \sqrt{E} + 4.3\%$ achieved in a beam test with an sPHENIX prototype
- **High-resolution Shashlyk Calorimeter**
  - goal resolution of $10\% / \sqrt{E}$
- **High-Resolution Endcap EM Calorimeters**

- goal resolution: $1 - 1.5\% \sqrt{E} + 0.5\%$
- timing resolution: < 2 ns
- small-angle detection (at least 1 deg)

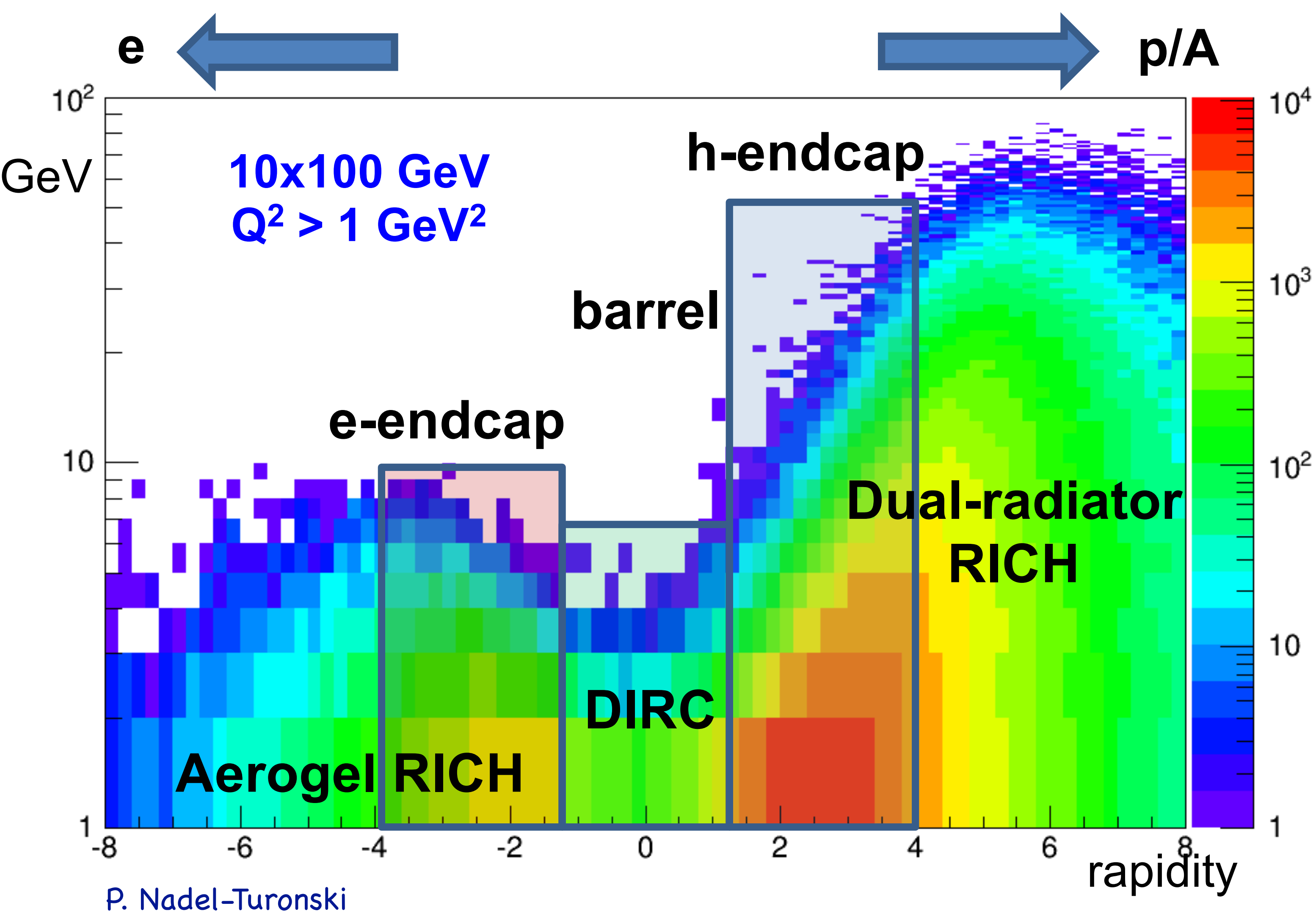
Particle Identification

eRD14: An Integrated Program for Particle Identification for an EIC Detector

M. Alfred, L. Allison, M. Awadi, B. Azmoun, F. Barbosa, M. Boer, W. Brooks, T. Cao, M. Chiu, E. Cisbani, M.Contalbrigo, S. Danagoulian, A. Datta, A. Del Dotto, M. Demarteau, A. Denisov, J.M. Durham, A. Durum, R. Dzhygadlo, D. Fields, Y. Furletova, C. Gleason, M. Grosse-Perdekamp, J. Harris, X. He, H. van Hecke, T. Horn, J. Huang, C. Hyde, Y. Ilieva, G. Kalicy, A. Kebede, B. Kim, E. Kistenev, Y. Kulinich, M. Liu, R. Majka, J. McKisson, R. Mendez, P. Nadel-Turonski, K. Park, K. Peters, T. Rao, R. Pisani, P. Rossi, M. Sarsour, C. Schwarz, J. Schwiening, C.L. da Silva, N. Smirnov, J. Stevens, A. Sukhanov, S. Syed, J. Toh, R. Towell, T. Tsang, G. Varner, R. Wagner, C. Woody, C.P. Wong, W. Xi, J. Xie, Z.W. Zhao, B. Zihlmann, C. Zorn

Particle Identification

eRD14: An Integrated Program for Particle Identification for an EIC Detector

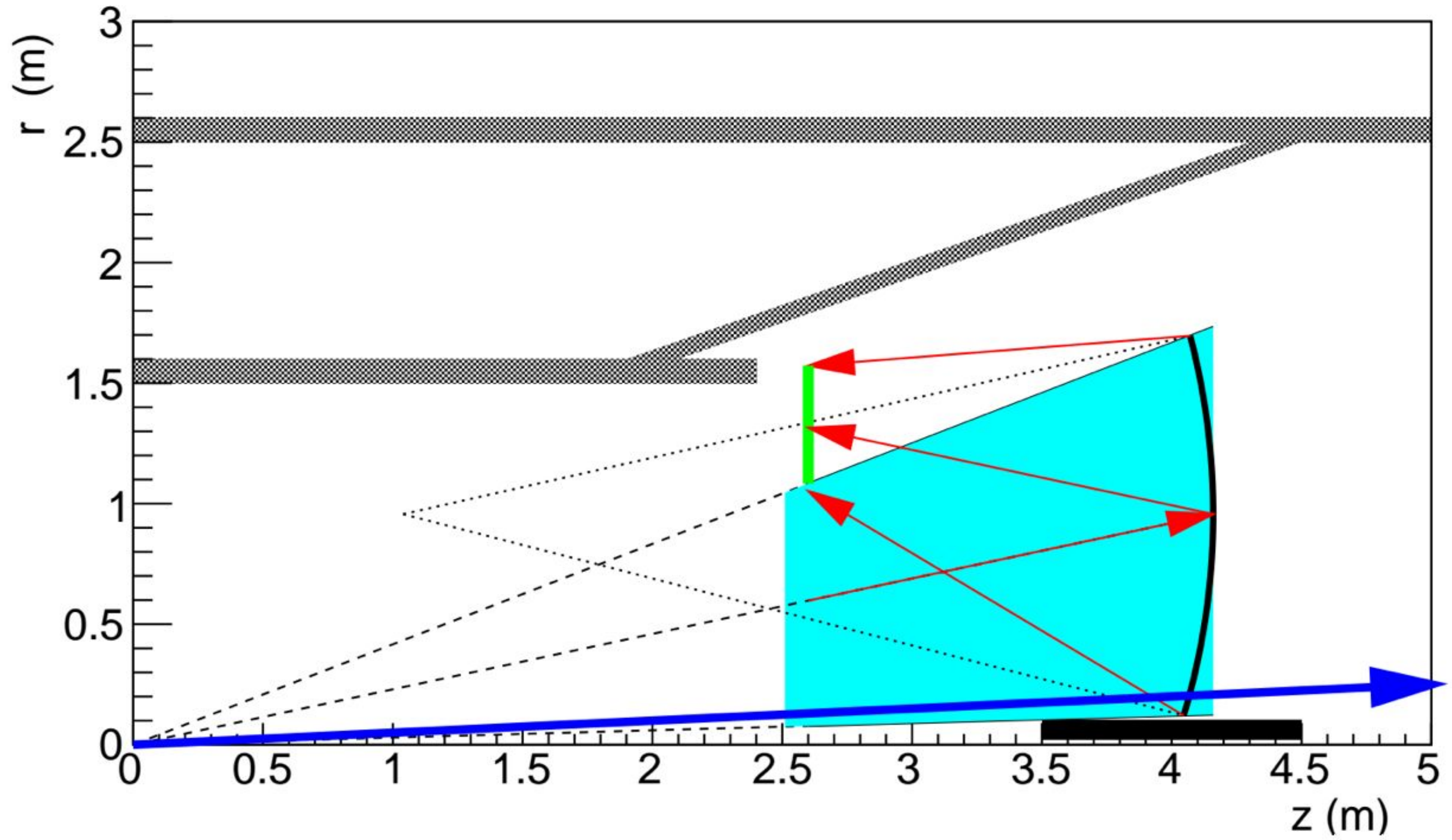


Hadron PID

- **electron endcap:** compact aerogel modular RICH (mRICH)
  π/K/p separation: up to 10 GeV/c
- **barrel:** high-performance DIRC
  π/K/p separation: up to 6 - 7 GeV/c
- **ion endcap:** dual-radiator RICH (gas and aerogel)
  π/K/p separation: up to 50 GeV/c
- TOF: coverage at lower momenta

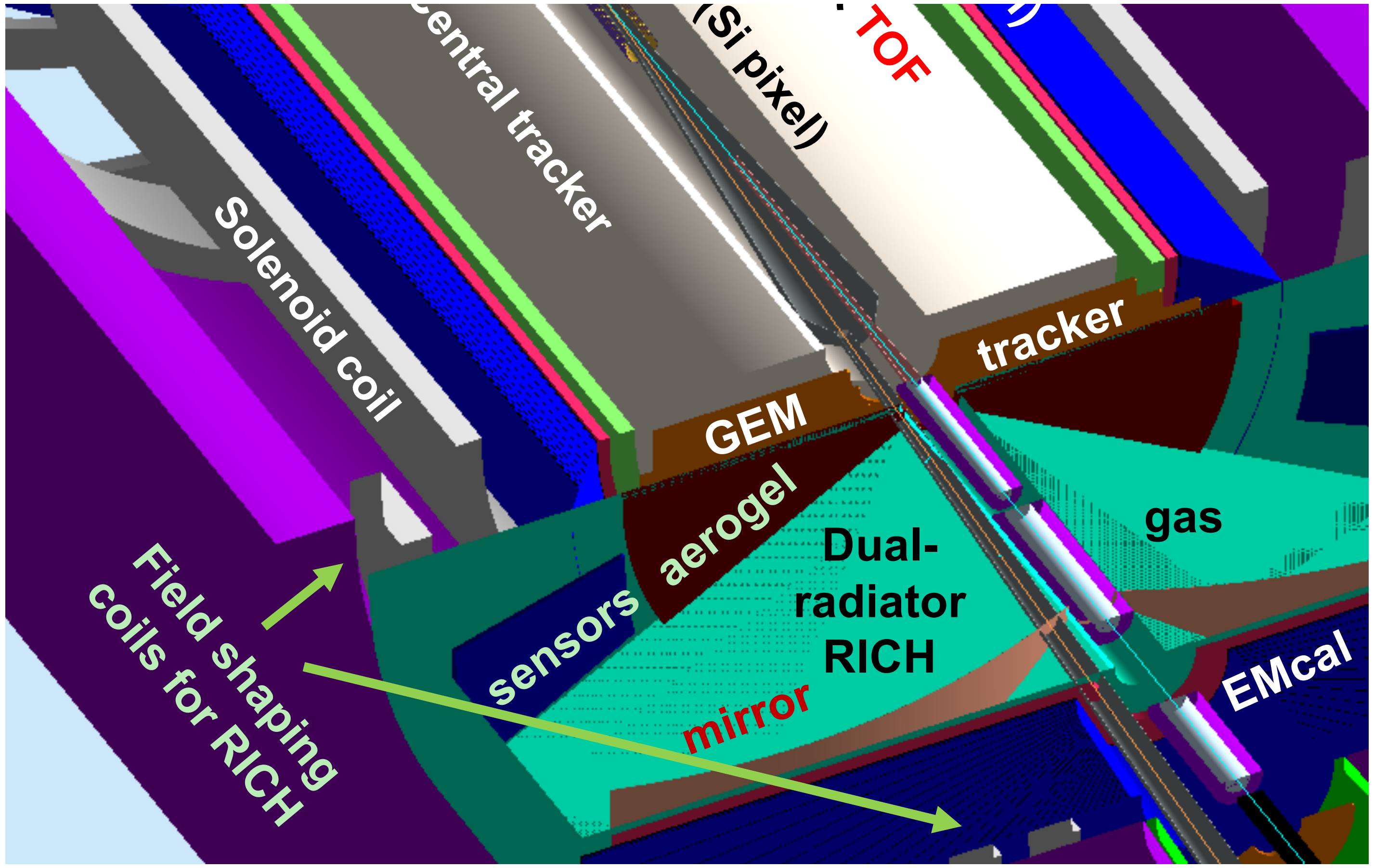
eRD14: Dual-Radiator RICH

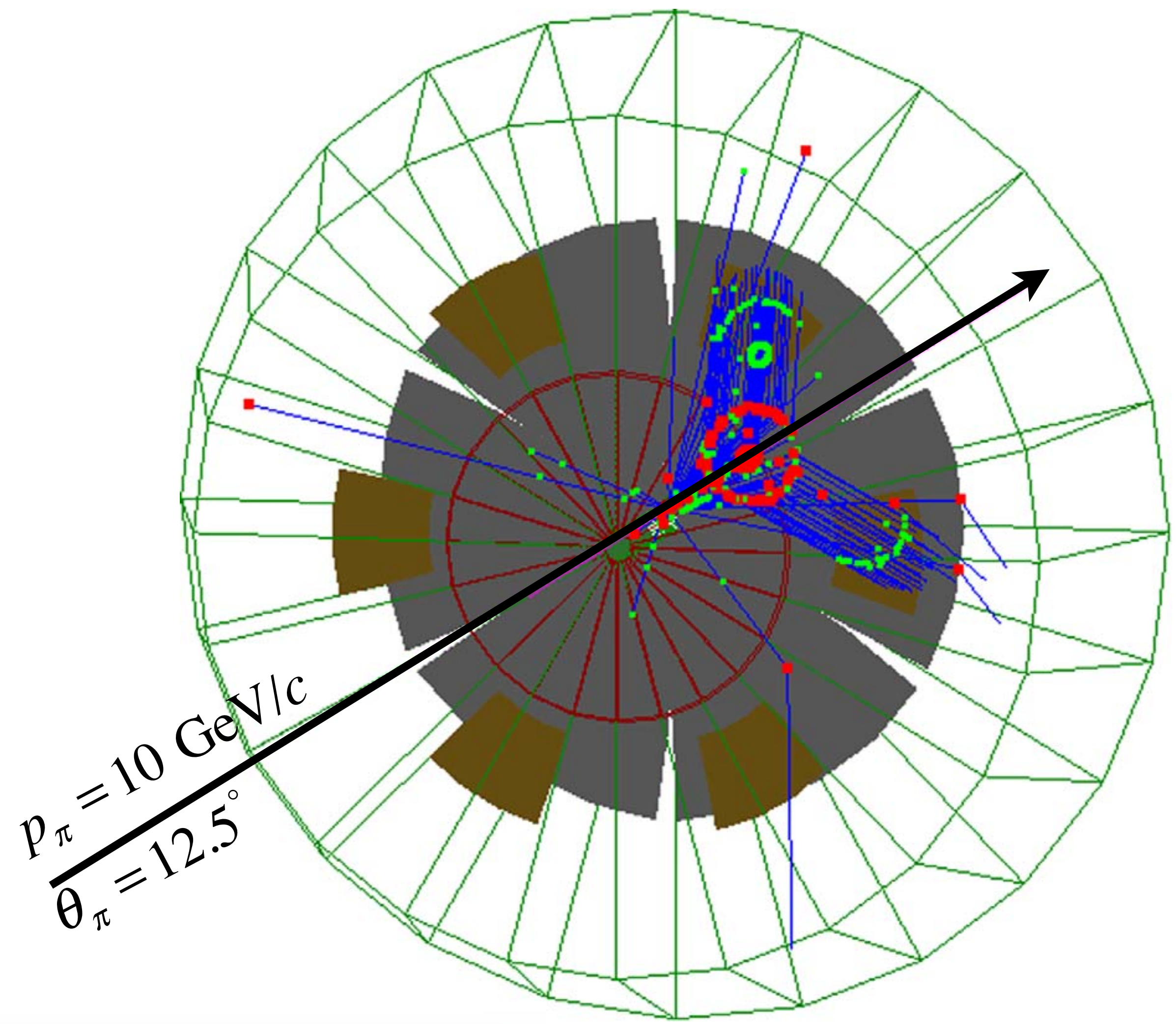
Alessio Del Dotto (USC, INFN-Rome)
Evaristo Cisbani (INFN-Rome)
Pawel Nadel-Turonski (Stony Brook University)
Zhiwen Zhao (Duke Uni)



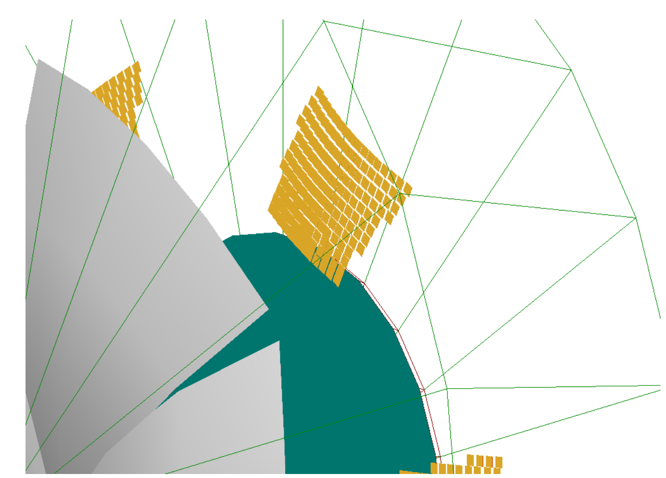
- Mirror-based focusing system.
- Compact read-out area.

eRD14: Dual-Radiator RICH

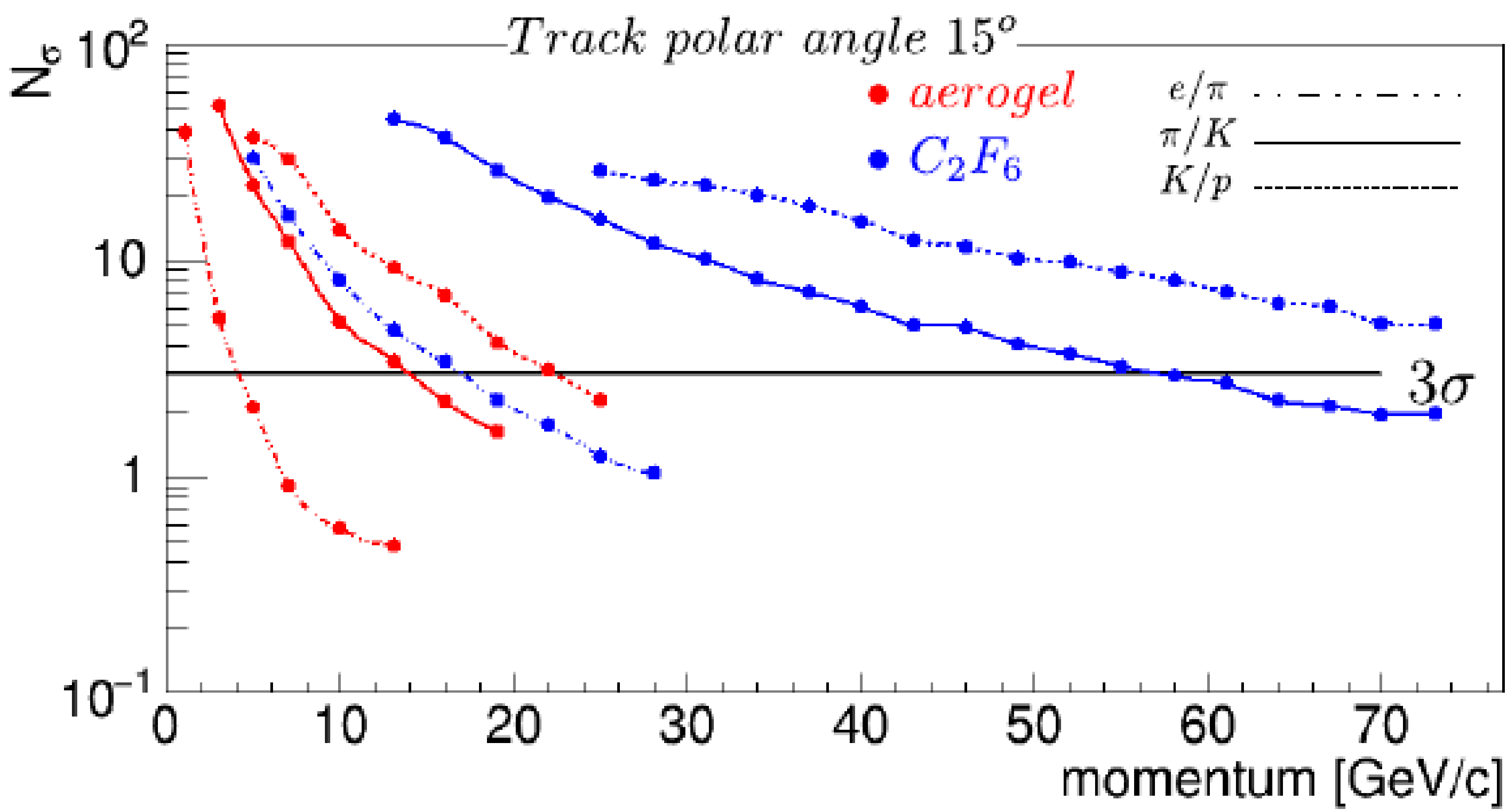




- 6-sector layout, polar-angle acceptance: 5° - 25°
- Aerogel (n=1.02, 4-cm thickness) and C_2F_6 gas tank (n=1.00082, 160-cm length)
- Outward reflecting mirrors (R = 2.9 m) - sensors away from beam; no scattering in aerogel
- 3D focusing - reduced sensor area
- Acrylic filter in front of aerogel: minimization of Rayleigh scattering



eRD14: Dual-Radiator RICH

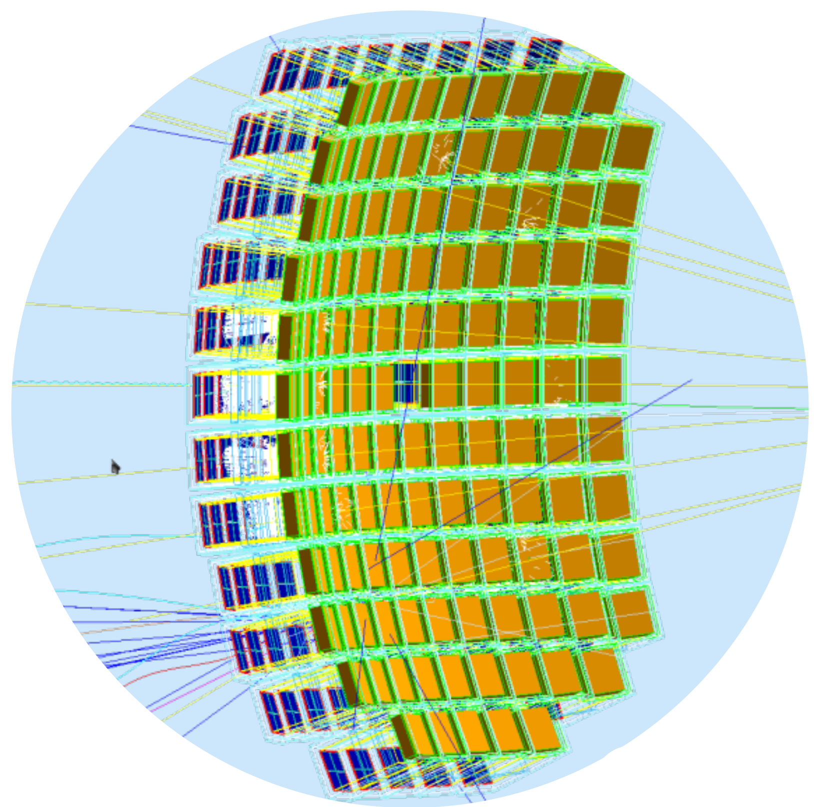


Continuous coverage

- up to ~50 GeV/c for π/K and K/p
- up to ~15 GeV/c for e/π

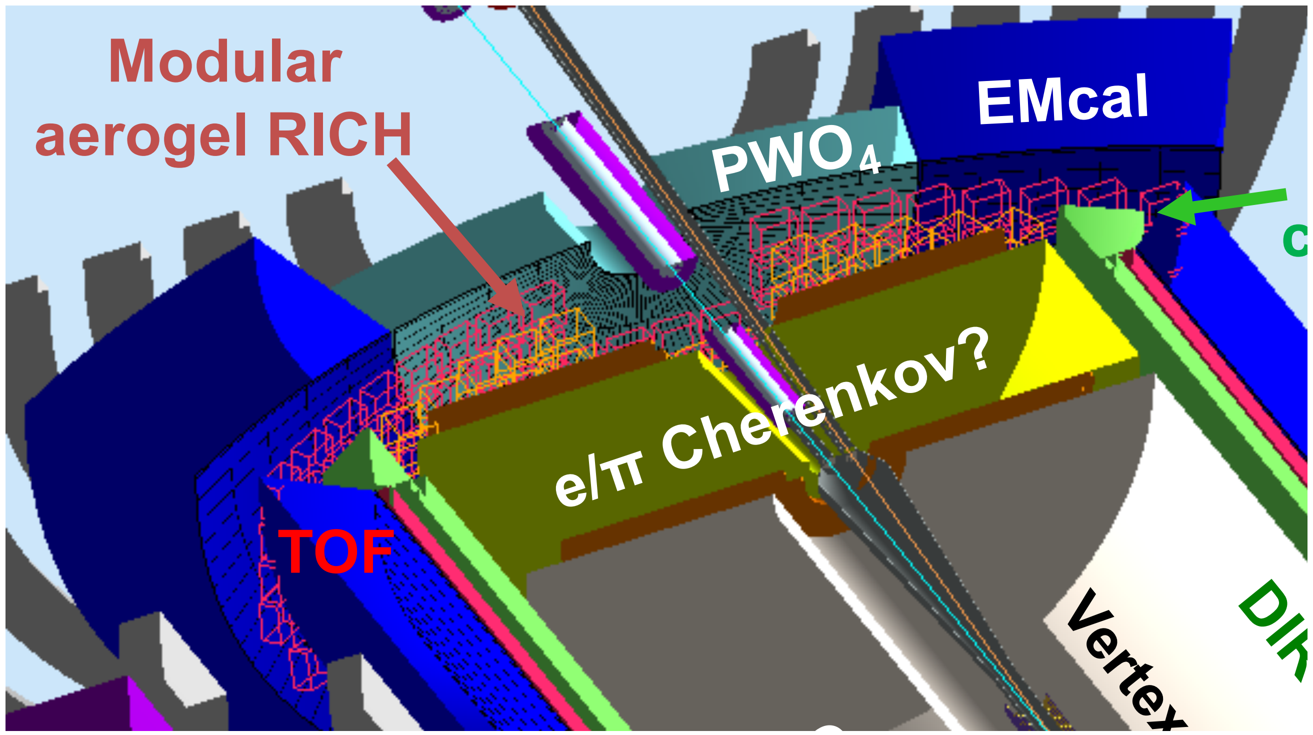
eRD14: Modular RICH

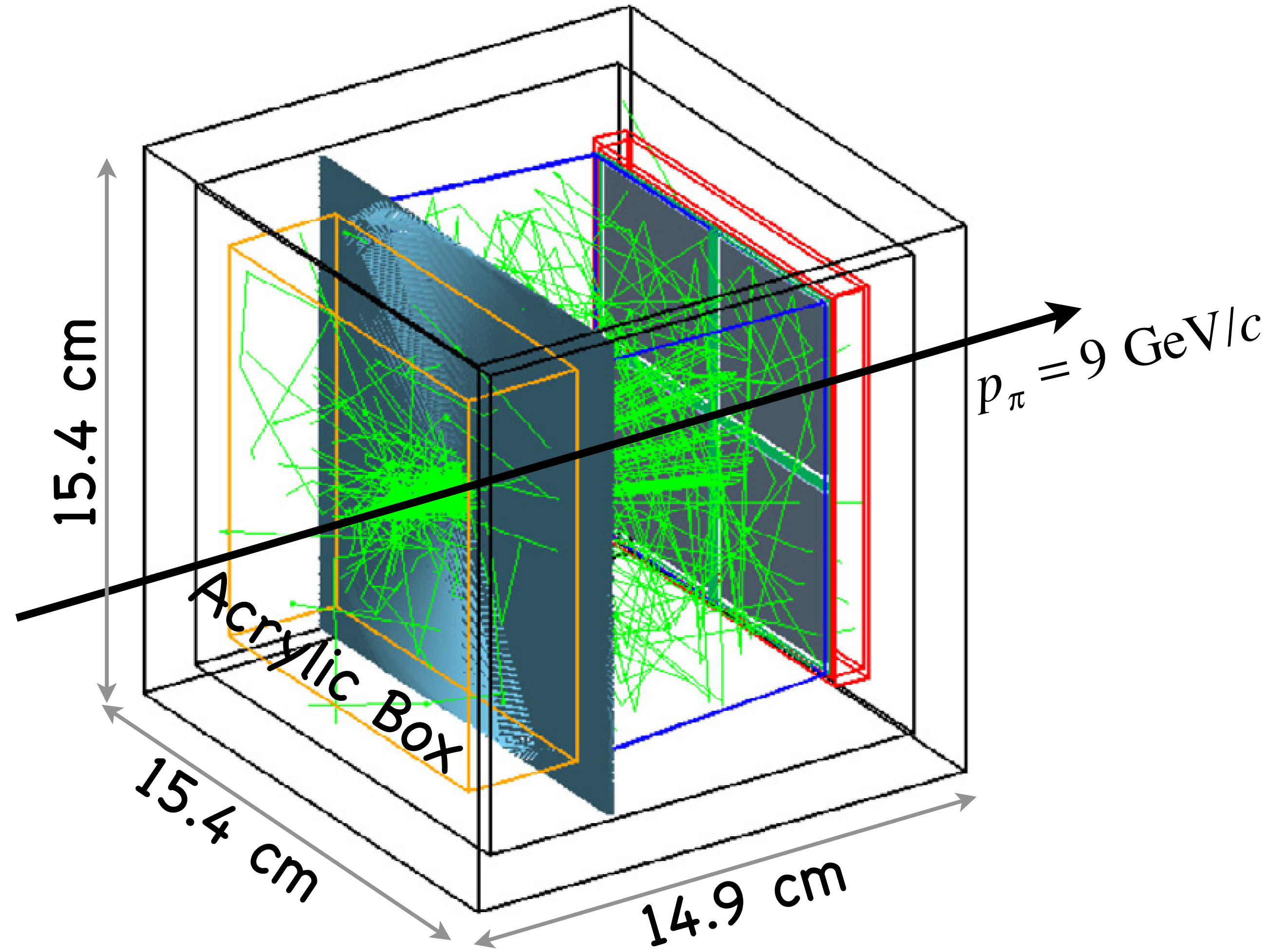
Herbert van Hecke (Los Alamos National Lab)
Xiaochun He, Cheuk-Ping Wong (Georgia State Uni)



- Space constraint in detector systems.
- Compact modular design.
- Easy maintenance: modules can be taken out individually.

eRD14: Modular RICH

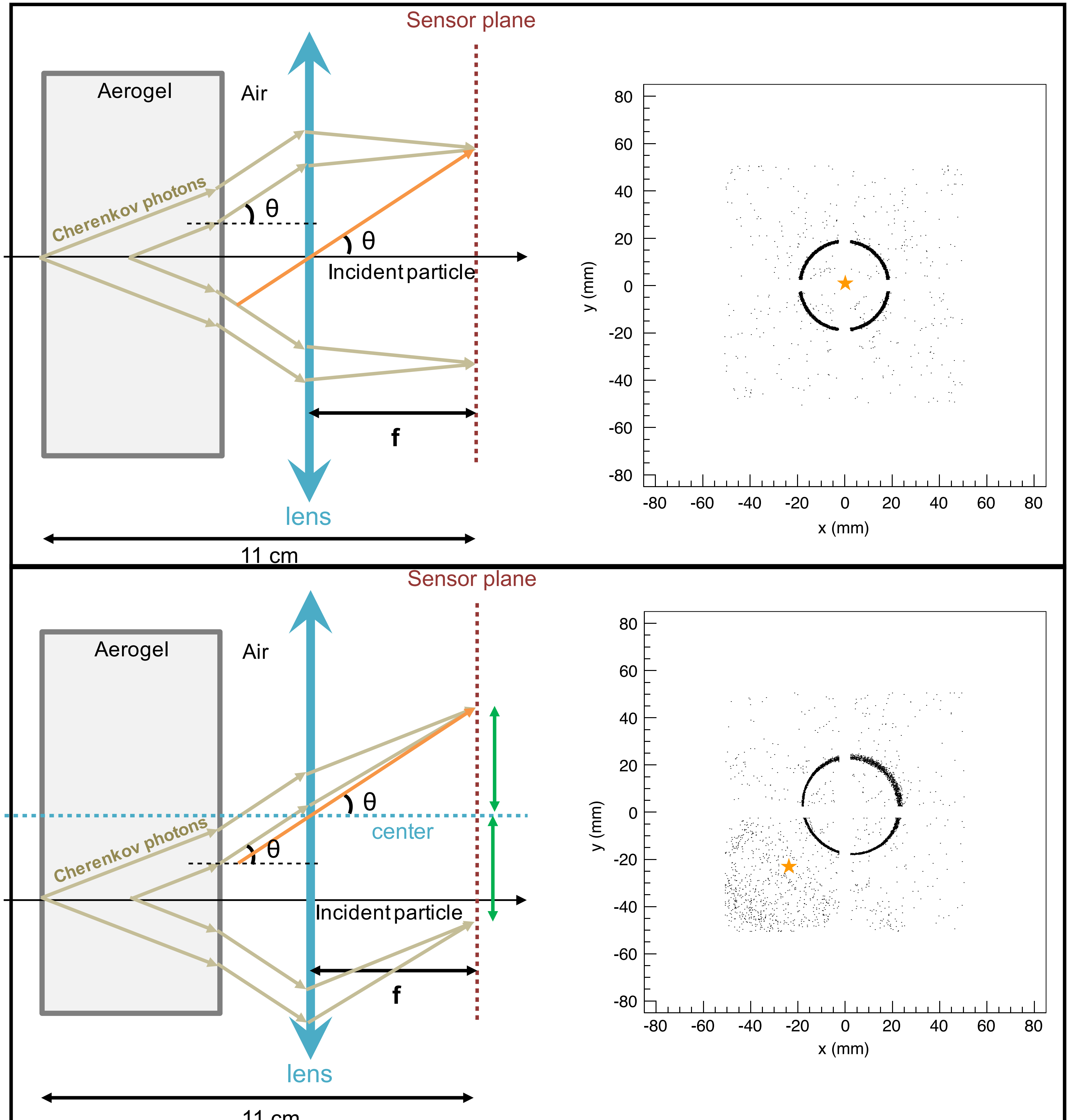




- Aerogel block (3.3-cm thick)
- Acrylic Fresnel Lens (focusing, UV filter)
- Pixelated photon sensor plane (4 square sensitive areas), readout electronics
- Gap lens-image plane is bounded by 4 flat mirrors, **L = f_{Lens} = 7.6 cm**
- **Geant 4 Simulation:** transmission, Rayleigh scattering, index of refraction for each component is implemented

C.P. Wong et al., Modular focusing ring imaging Cherenkov Detector for Electron-Ion Collider Experiments, Nucl. Instr. and Methods A871, 13 (2017).

Modular RICH: Focusing



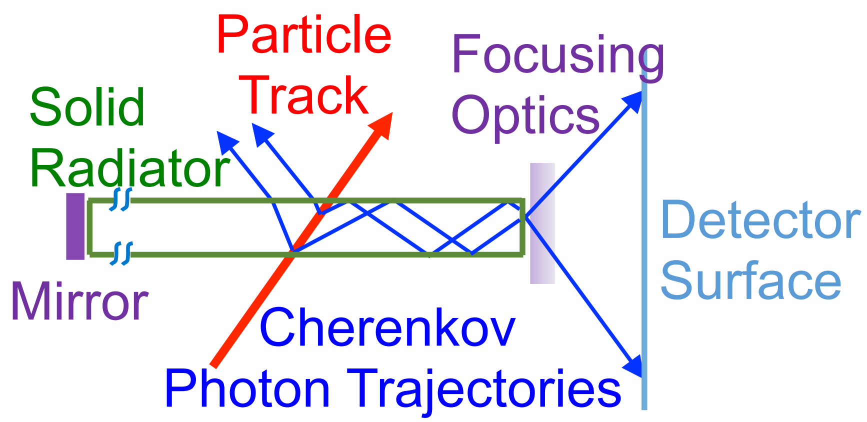
Ring image is centered on the sensor plane for both, tracks on and off the central axis.

Less active photon sensor coverage is needed compared to other RICH designs.

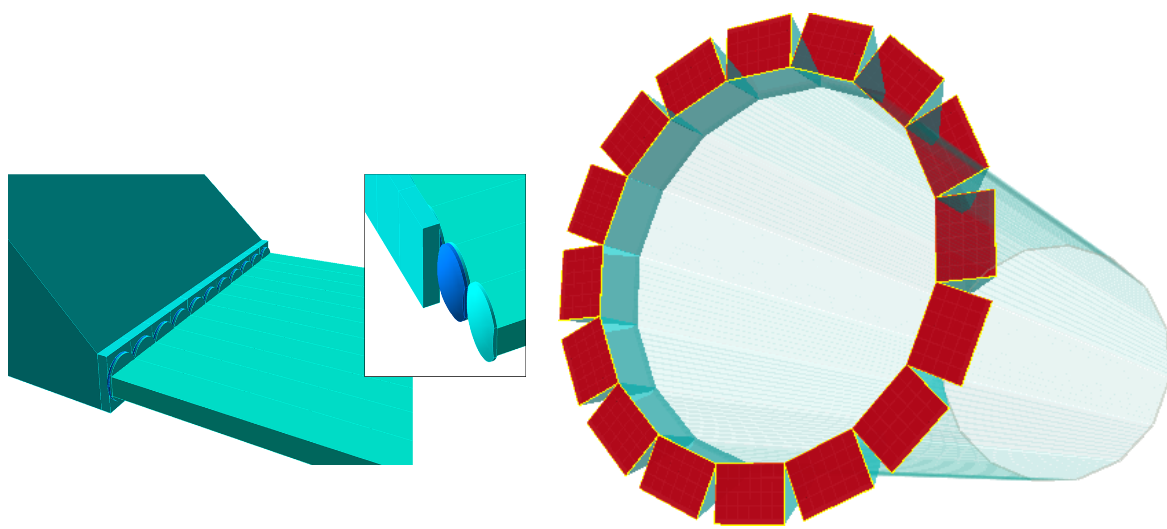
π/K separation at 10 GeV/c with:

- n = 1.03
- f = 6"
- pixel size: 2 mm

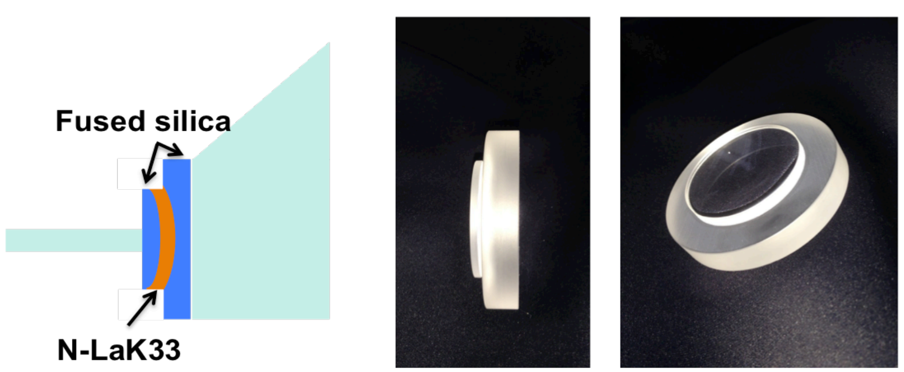
eRD14: High-Performance DIRC



High performance DIRC in Geant 4



Spherical 3-layer lens prototype



Greg Kalicy, Marie Boer (CUA)
Roman Dzhygadlo, Carsten Schwartz, Joe Schwiening (GSI)

- Radially compact detector (2-cm thick).
- Narrow synthetic fused silica bars arranged in 16 barboxes, coupled to solid prisms with custom made 3-layer lens, read out by arrays of MCP-PMTs.
- EIC R&D is pushing performance far beyond state-of-the-art (3σ at 4 GeV/c for π/K in BaBar) to 4σ at 6 GeV/c for the EIC)

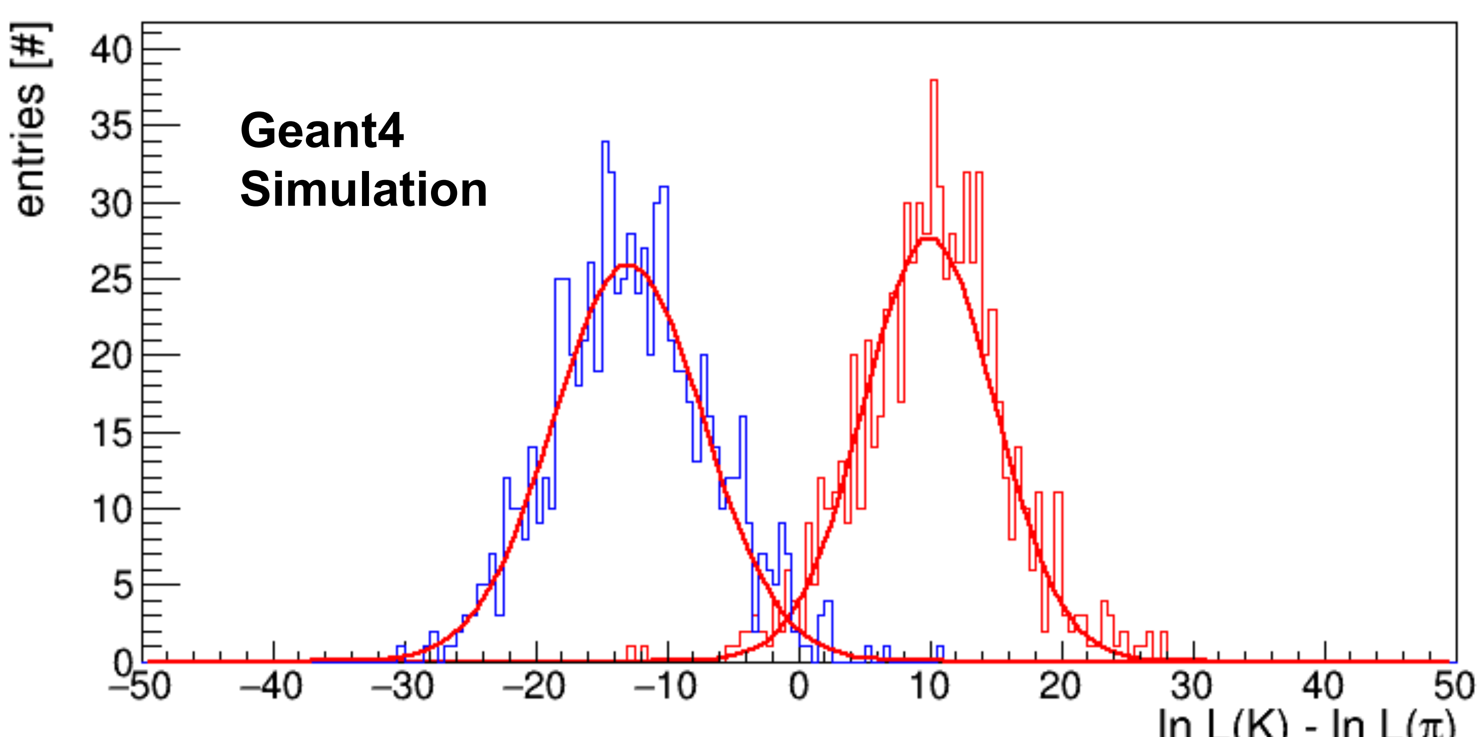
eRD14: High-Performance DIRC

- Design and performance validation with Geant4 simulation:

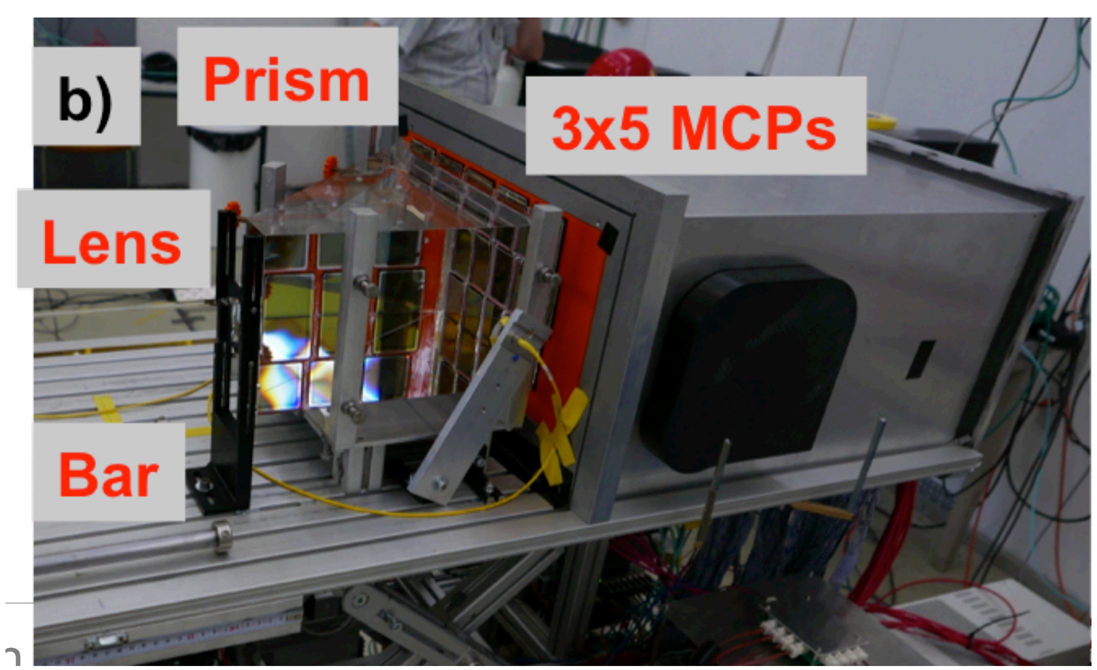
π/K separation up to 6 GeV/c; e/π separation up to 1.8 GeV/c, p/K separation up to 10 GeV/c

- Development of new algorithms for 3D imaging (spacial coordinates at focal plane and time)

- Hardware development: lens characterization, PID performance validation in beam (collaboration with PANDA DIRC)



4.3σ π/K separation at 6 GeV/c using 3D (x,y,t) reconstruction



PANDA DIRC Prototype at GSI

Summary

- The basic requirements for an EIC detector are well understood.
  - hermeticity
  - excellent tracking resolution and PID over a broad momentum range and particle spieces

- Active generic detector R&D Program since 2011 to adapt existing technology and push the state-of-the art for the needs of the EIC.
  - EM calorimetry: W-powder/scintillating fibers, crystal EM, Shashlyk
  - various technologies explored for PID: dRICH, mRICH, DIRC
  - Tracking: micromegas, GEMs, TPC, Drift Chambers
  - Much more: polarimetry, forward tagging, software, background studies, vertexing, etc.
- Topical Workshops and EIC User Group Meetings
- Electron Ion Collider: Detector Requirements and R&D Handbook (A. Kiselev and Th. Ullrich, Eds.), in preparation

The END