Particle Identification for a Future EIC Detector

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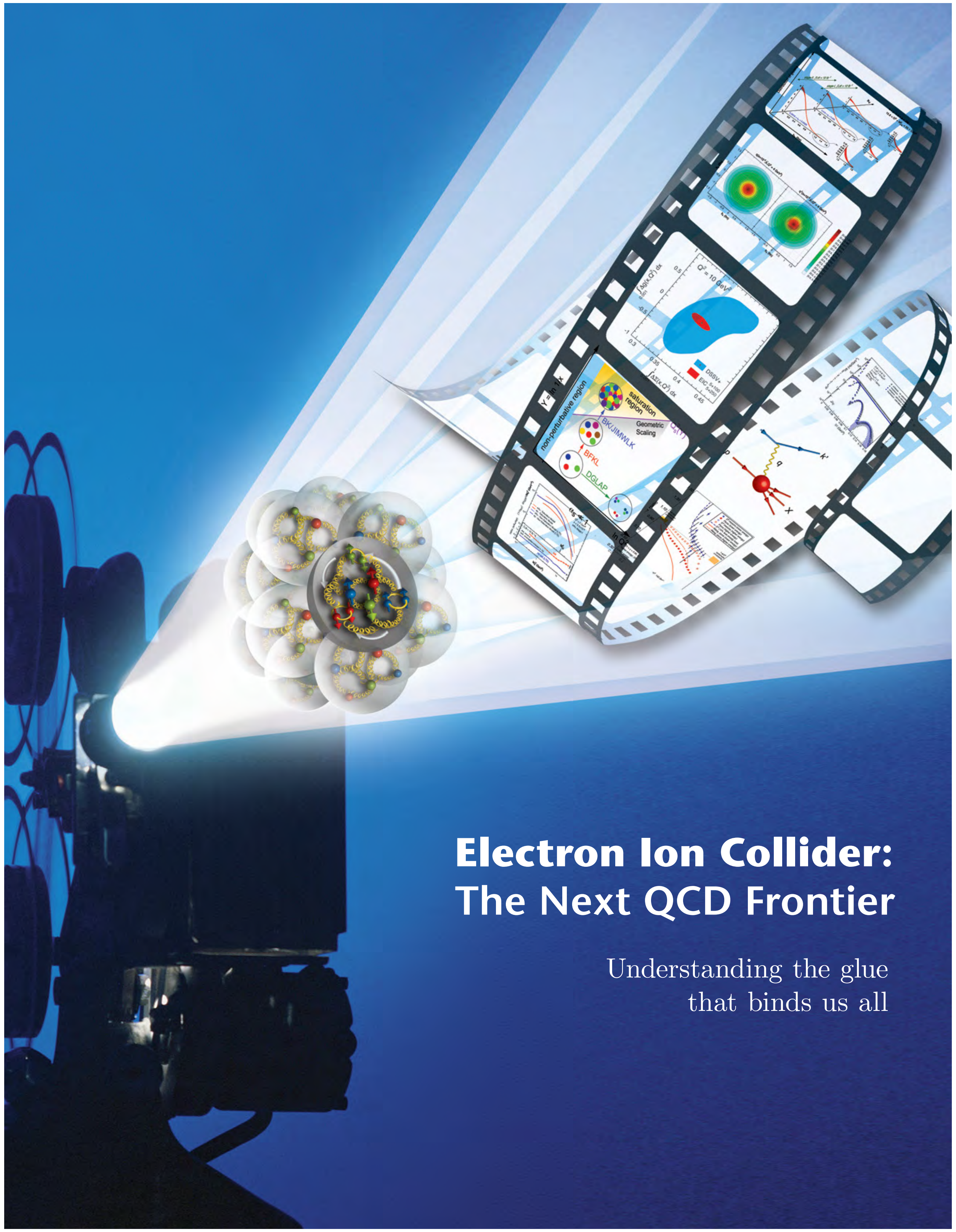
University of South Carolina
the EIC-PID Consortium

DIRC2017 Workshop, 7 - 9 August 2017

The U.S. Electron-Ion Collider Project



Scientific Objectives

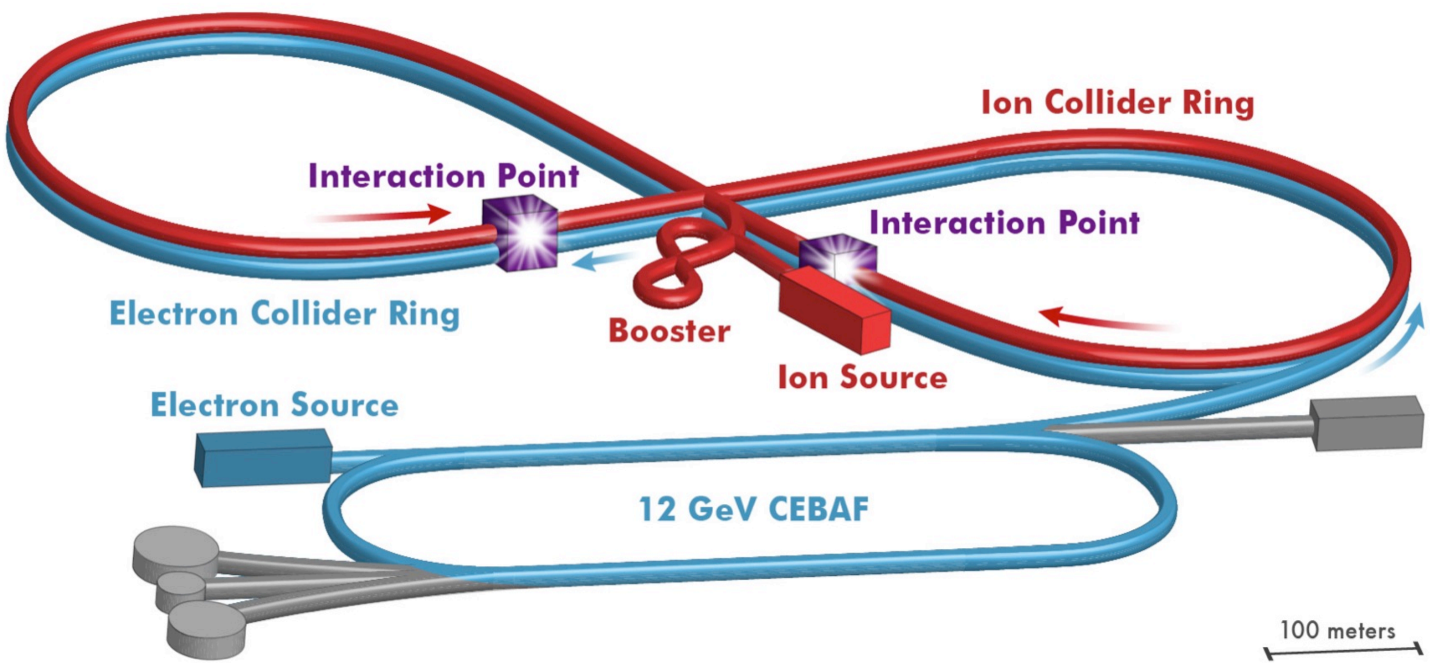
- to map the gluon and sea quark distributions in space and momentum space
- to study gluon and sea quark polarizations
- to study quark and gluon distributions in nuclei
- to study parton propagation in nuclei

Features

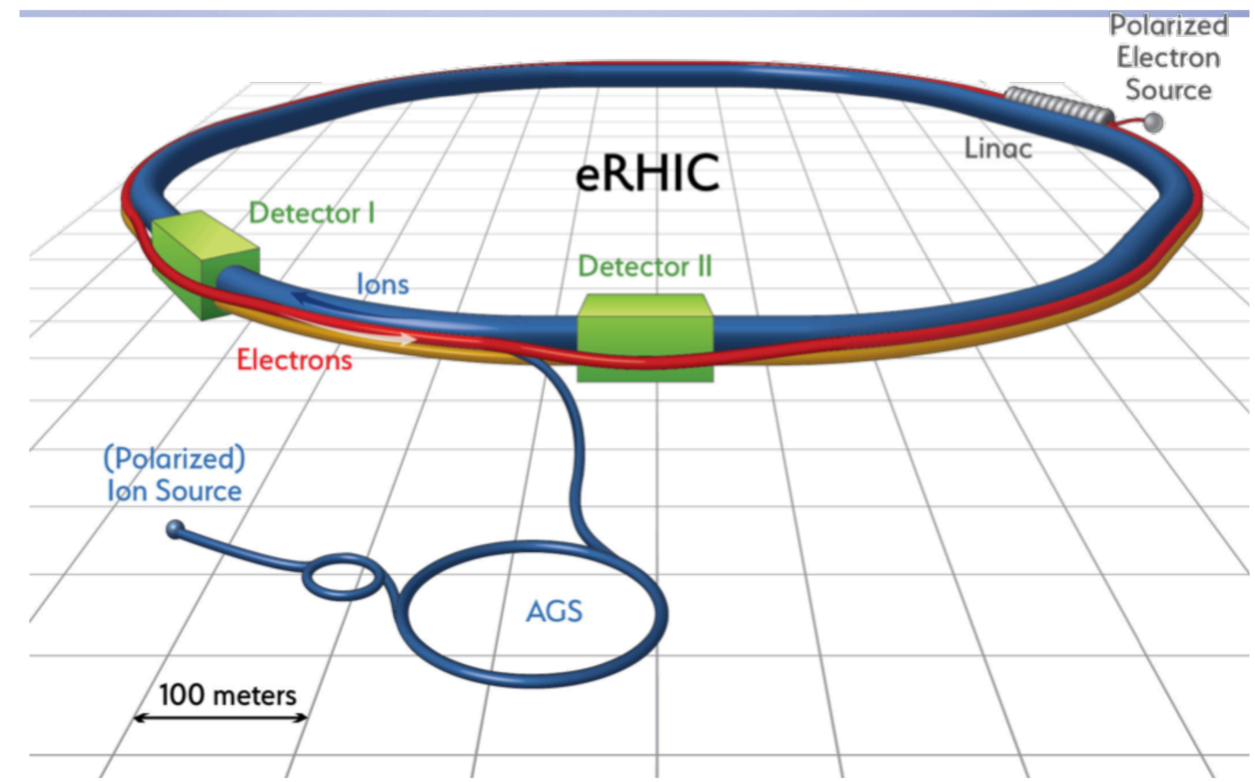
- polarized electron, proton, and light ion beams
- $L=10^{33-34}$ $cm^{-2}s^{-1}$ (ep)
- variable CM energy

The U.S. Electron-Ion Collider Project

JLab (JLEIC) Design



BNL (eRHIC) Design

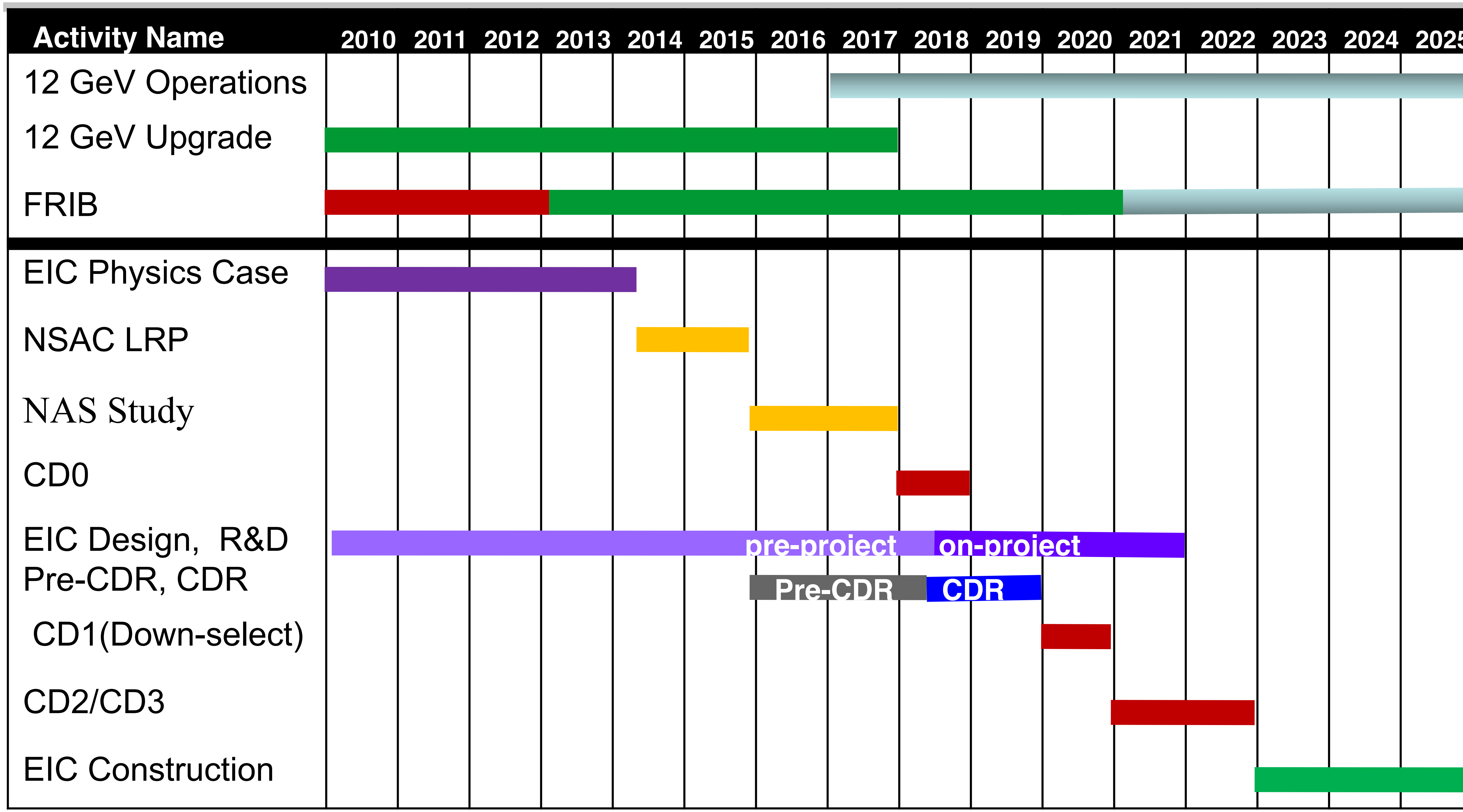


Developments:

- Two possible sites explored: Jefferson Lab, Brookhaven National Lab
- DOE-NP established EIC Accelerator R&D program in FY2016
- EIC Users Group (http://www.eicug.org/web)
    - 2107 EIC UG Meeting, Trieste (Italy): 17 - 22 July 2017
- EIC Science Assessment by U.S. National Academy of Sciences Underway (report expected in 2017/18)

The U.S. Electron-Ion Collider Project

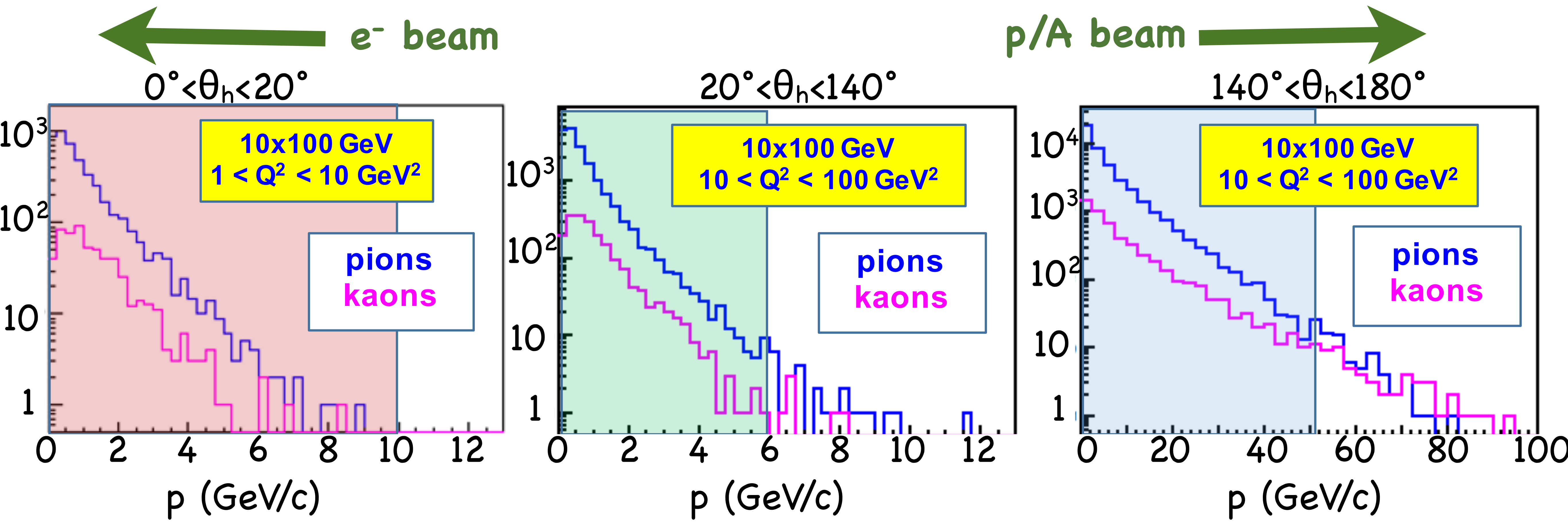
Timelines (JLEIC)



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

EIC Detector Hadron PID Requirements

10 × 100 GeV SIDIS Hadron Kinematics



EIC Program: wide CM energy range; different combinations of beam energy and particle species; inclusive, semi-inclusive, exclusive processes.

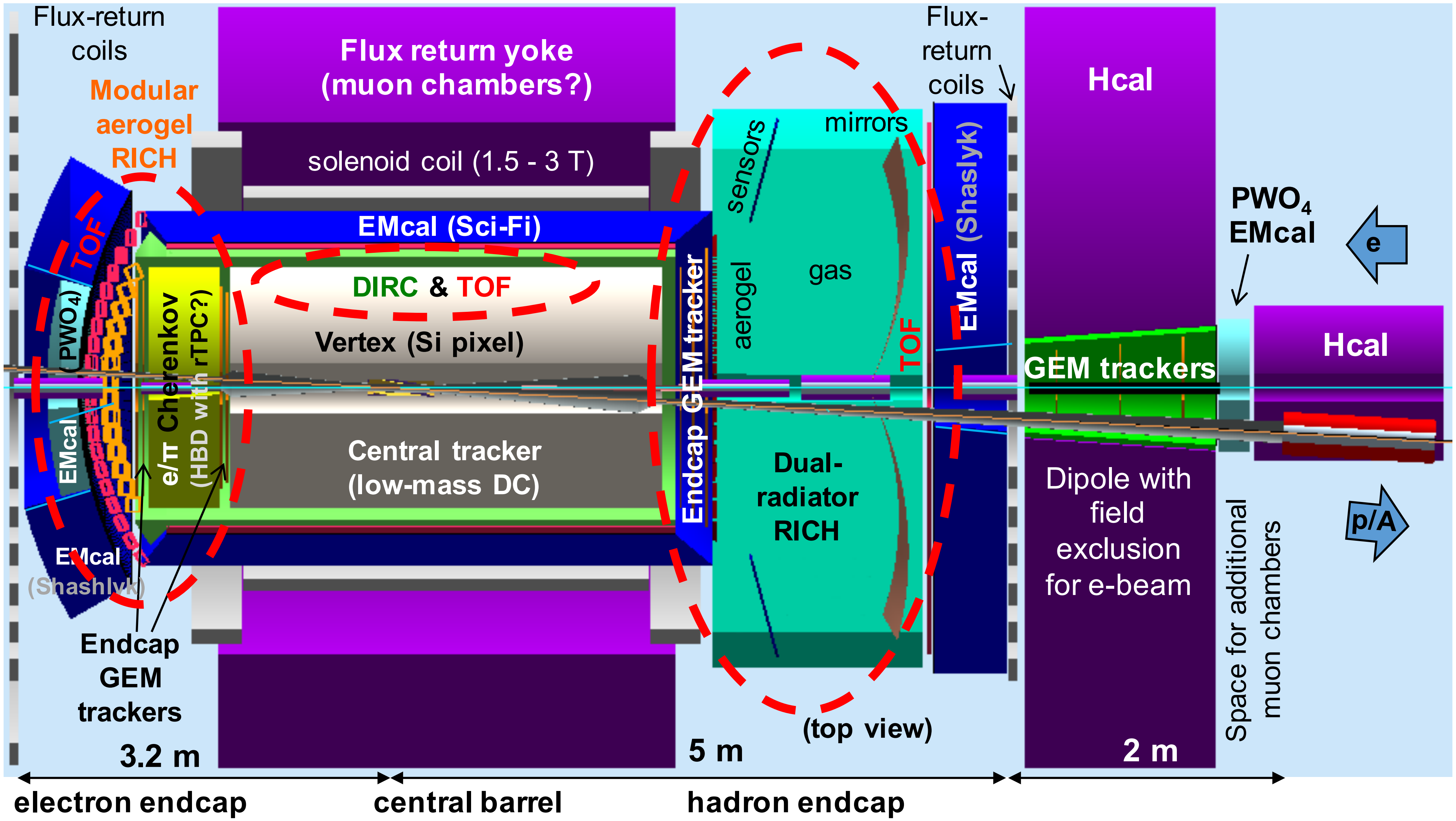
- Maximum hadron momentum at small and large angles close to the electron and ion beam energies, respectively.
- Momentum range at mid-angles depends weakly on beam energies, determined by specific kinematics (Q^2).
- High-momentum tails contain important physics.

JLEIC Central Detector and Hadron PID Systems

EIC PID Consortium

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

JLEIC Central Detector and Hadron PID Systems



- e-endcap: compact aerogel RICH for p/π/K separation up to 10 GeV/c.
- barrel: high-performance DIRC for p/π/K separation up to 6-7 GeV/c.
  - see Greg Kalicy's talk in the afternoon today
- h-endcap: dual-radiator RICH for p/π/K separation up to 50 GeV/c.

Outline

- Dual-Radiator RICH (dRICH)

A. Del Dotto et al., Design and R & D of RICH detectors for EIC experiments, NIM A (2017), in press

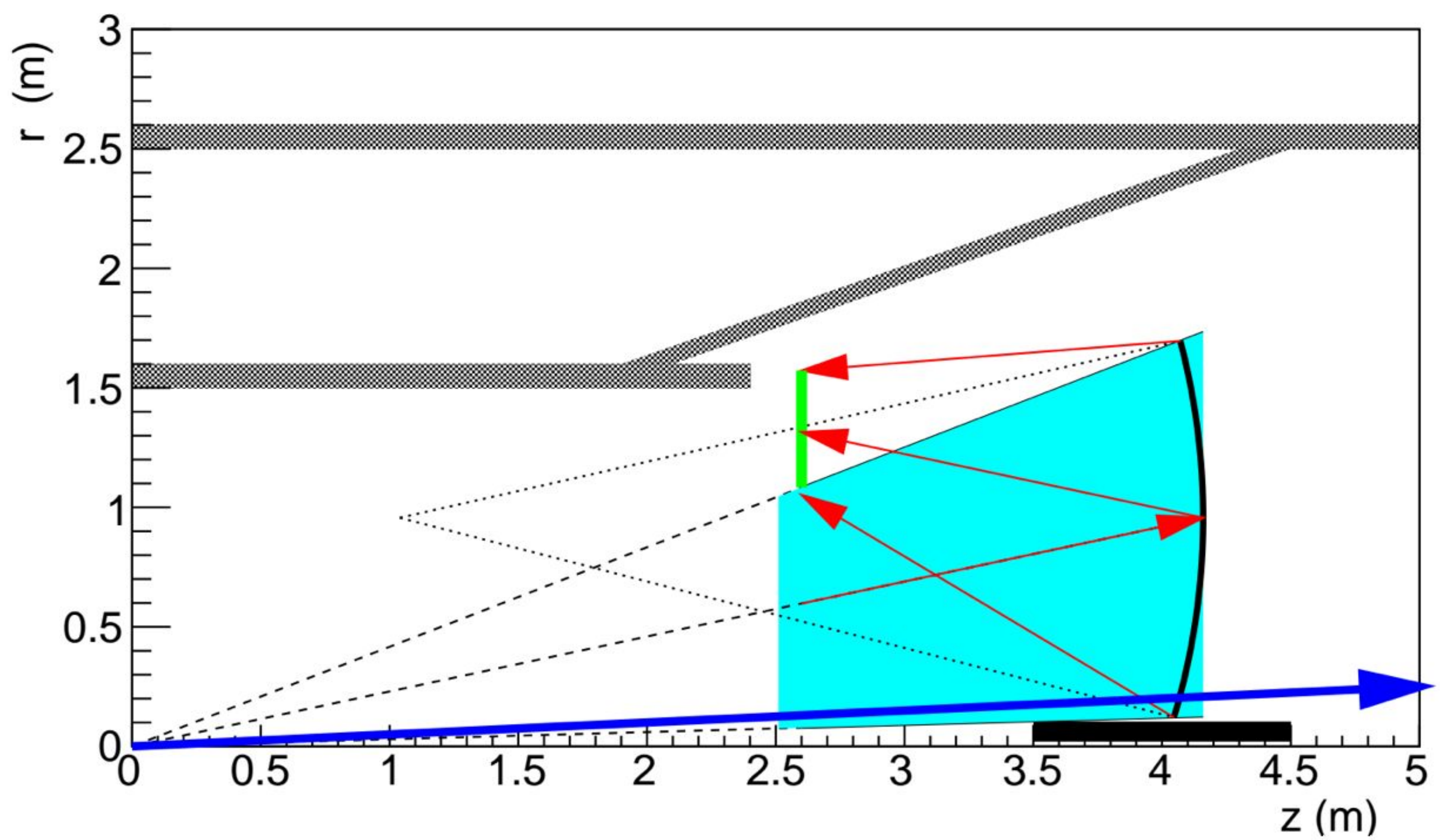
- Modular RICH (mRICH)

C.P. Wong et al., Modular focusing ring imaging Cherenkov detector for electron-ion collider experiments, NIM A 871, 13 (2017)

- Photosensors

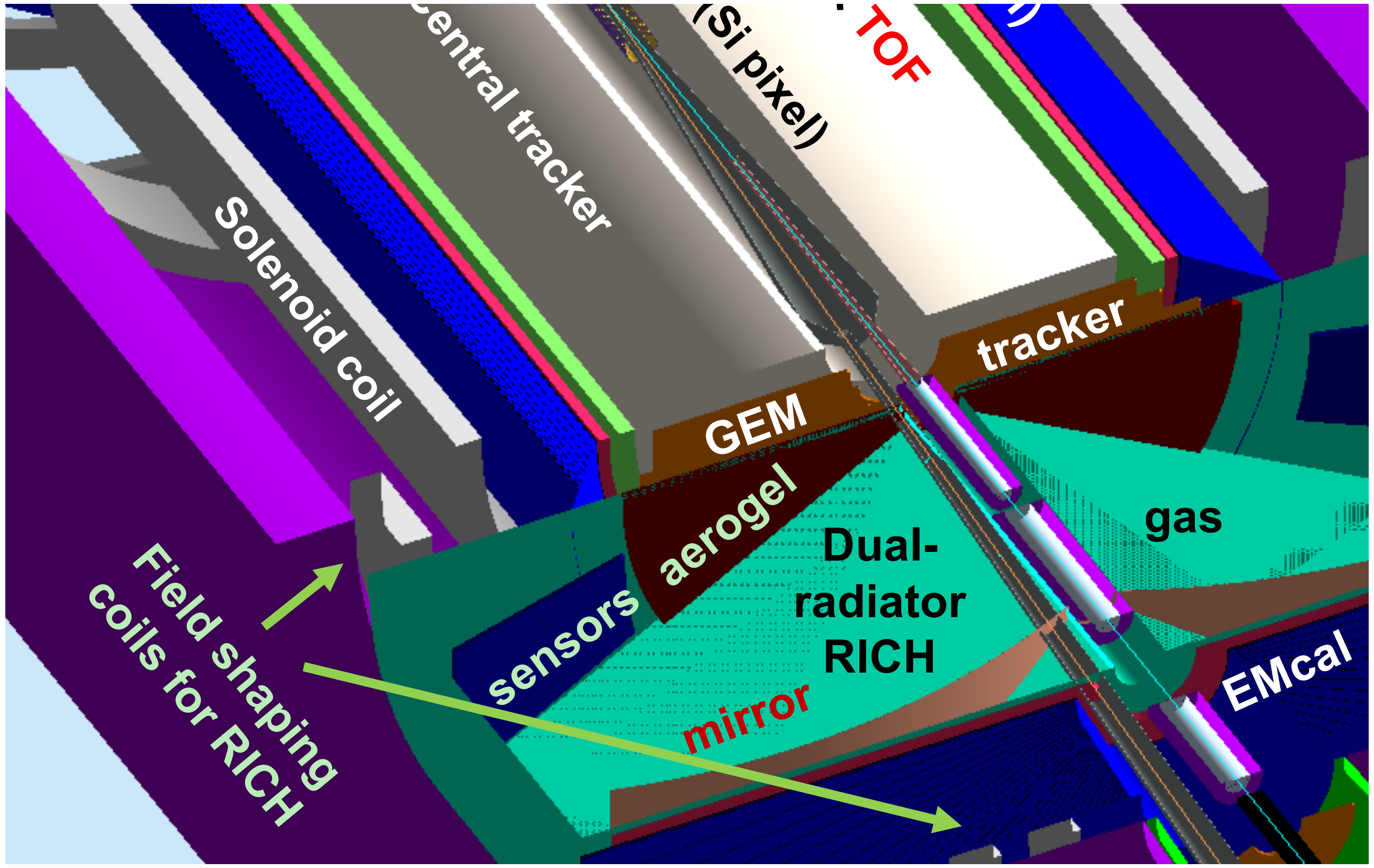
Dual-Radiator RICH

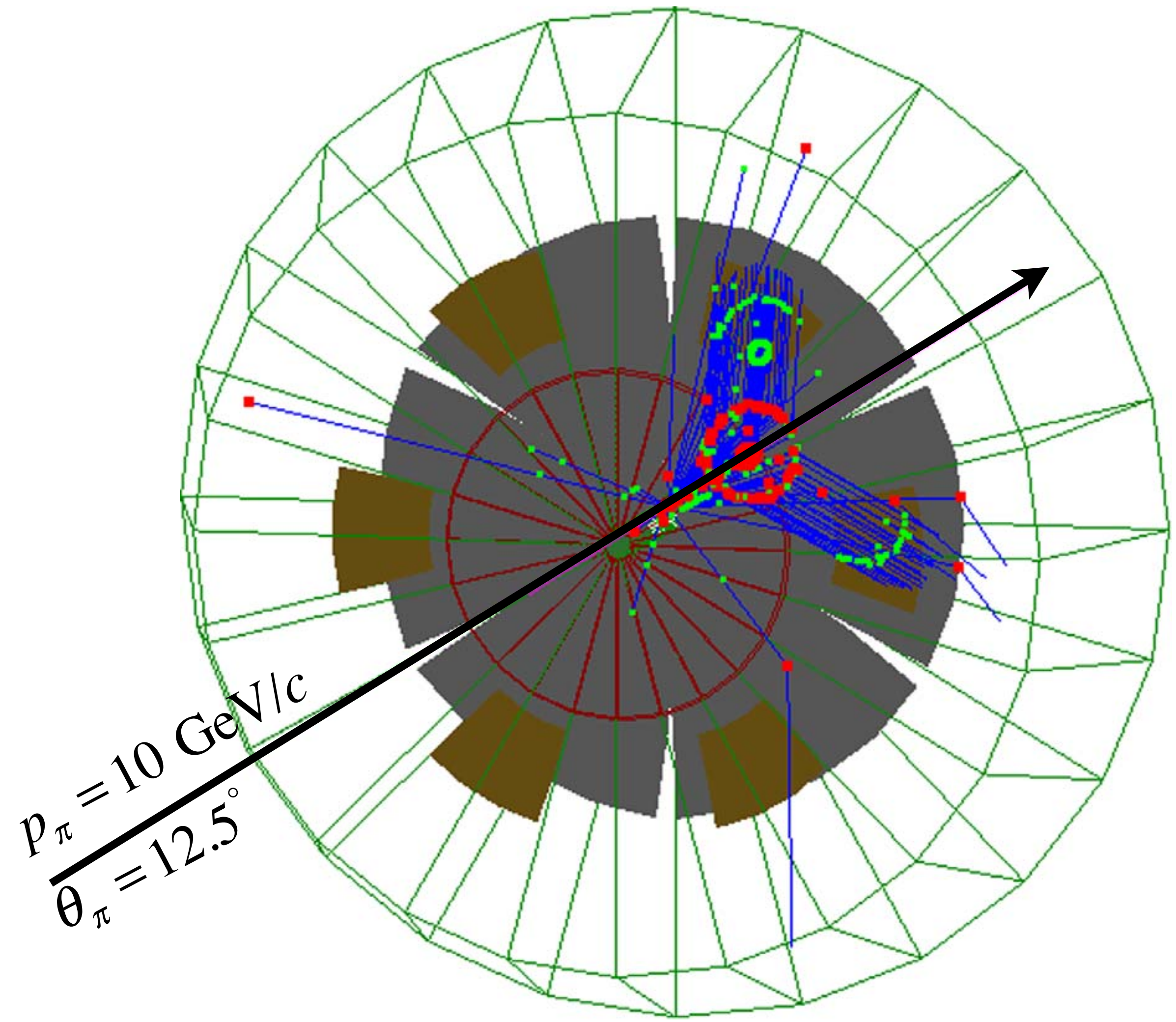
Alessio Del Dotto (USC, INFN-Rome)
Evaristo Cisbani (INFN-Rome)
Pawel Nadel-Turonski (Stony Brook University)
Zhiwen Zhao (Duke Uni)



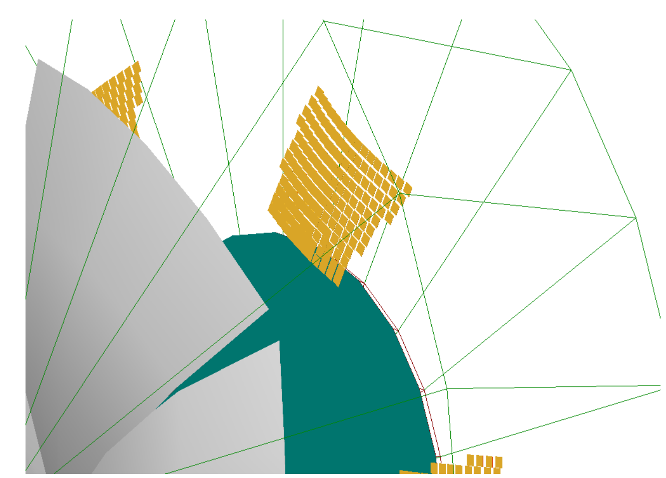
- Mirror-based focusing system.
- Compact read-out area located in the shadow of the barrel calorimeter.
- JLEIC Constraint: approx. 160 cm length

Dual-Radiator RICH: JLEIC Implementation



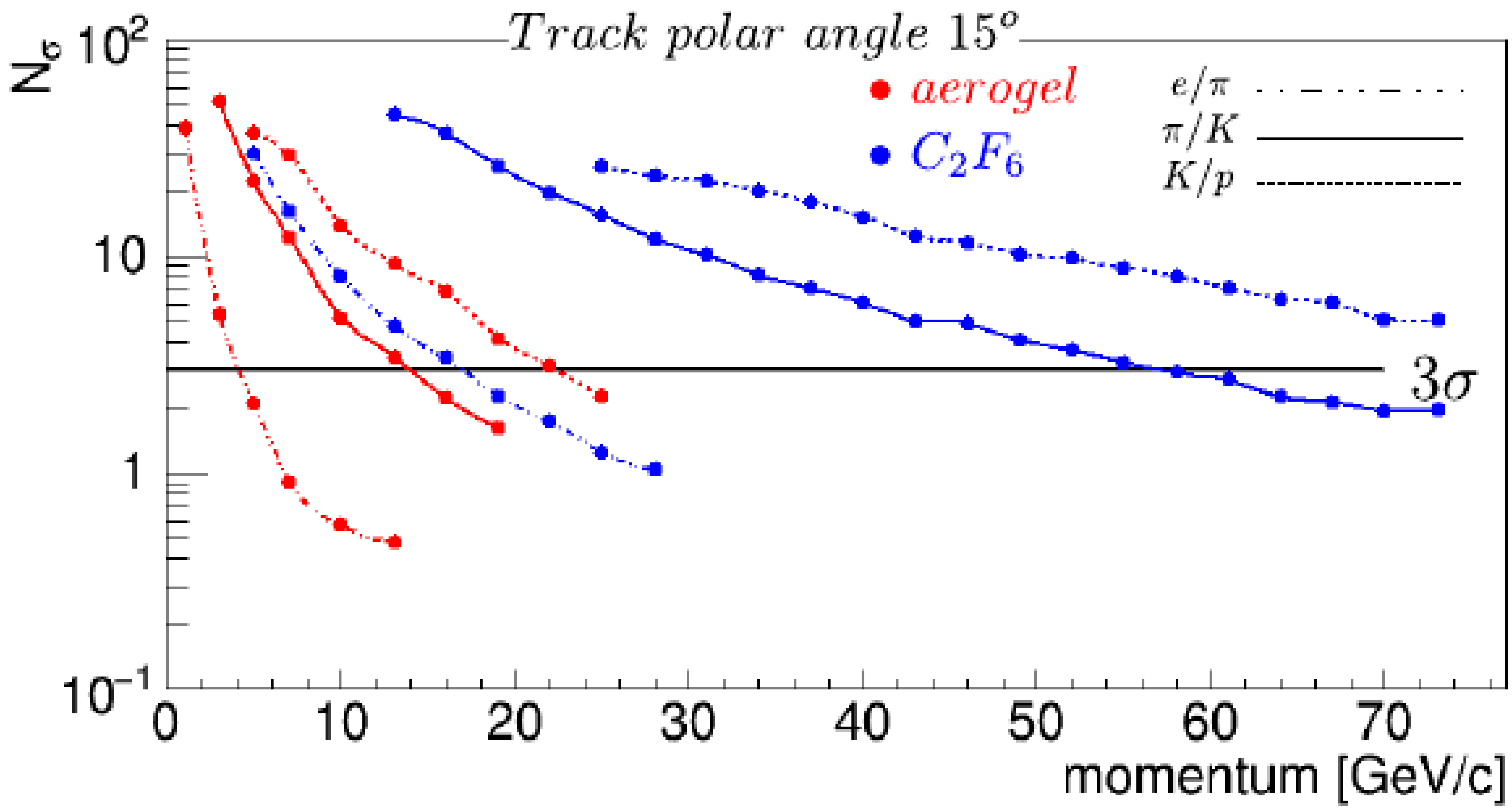


- 6-sector layout, polar-angle acceptance: 5° - 25°
- Aerogel (n=1.02, 4-cm thickness) and C_2F_6 gas tank (n=1.00082, 160-cm length)
- Outward reflecting mirrors (R = 2.9 m) - sensors away from beam; no scattering in aerogel
- 3D focusing - reduced sensor area
- Acrylic filter in front of aerogel: minimization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



Dual-Radiator RICH

EIC PID Consortium

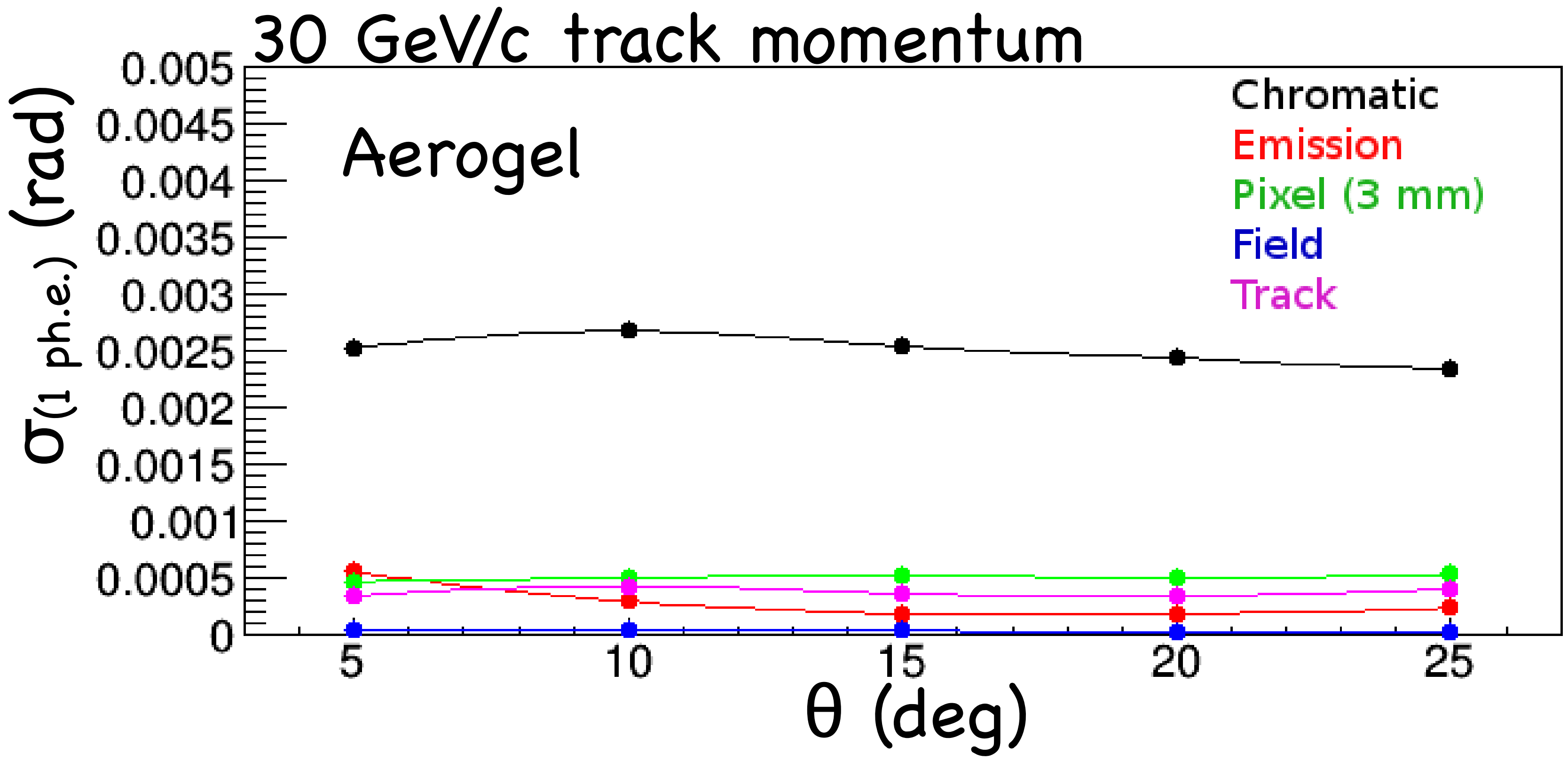


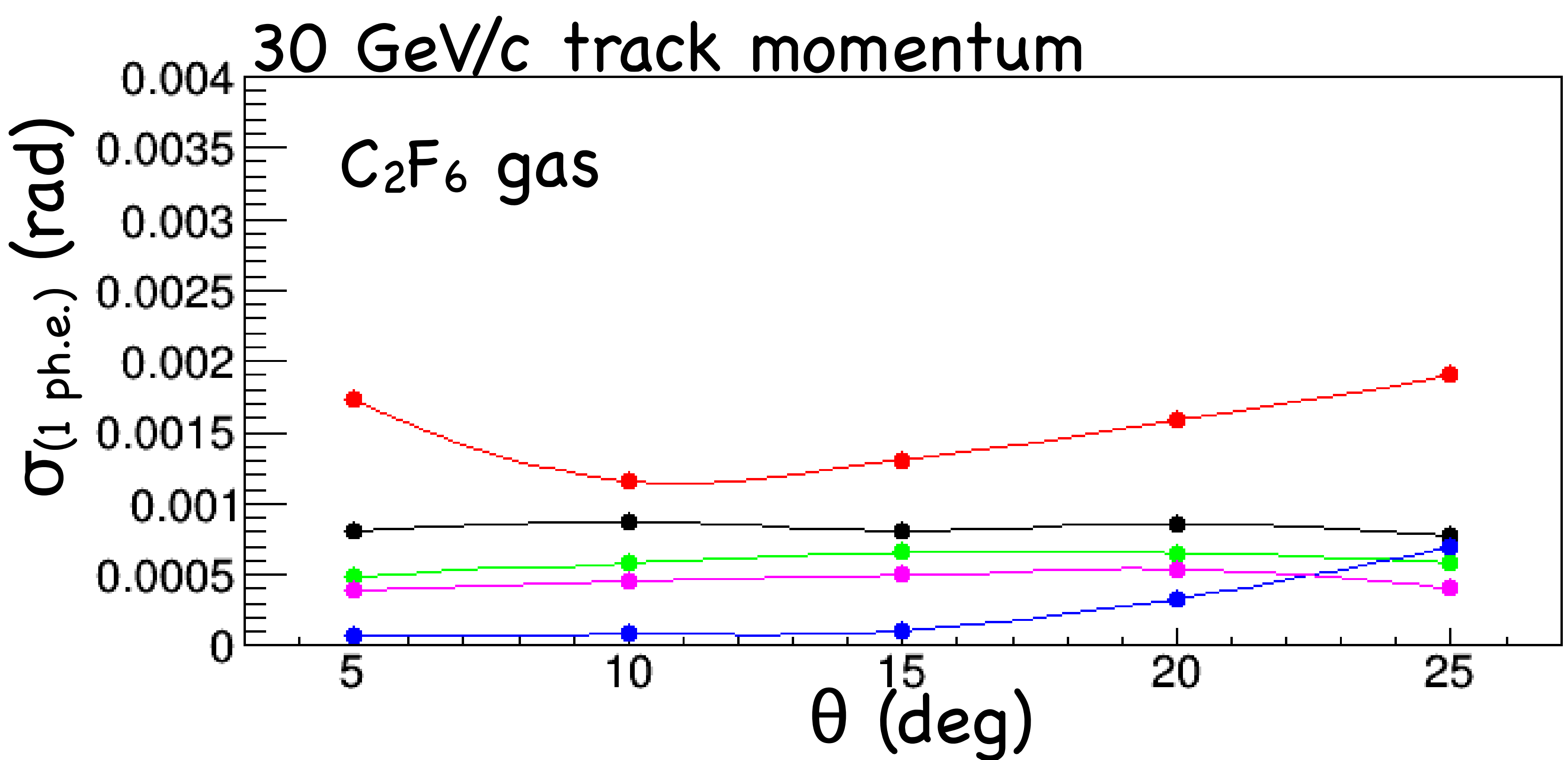
Continuous coverage

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

Dual-Radiator RICH

Contributions to the Cherenkov-angle resolution





Studied with GEANT4 simulated data:

- dRICH placed in magnetic field (3-T central field)
- optical properties of aerogel inferred from CLAS-RICH studies
- Cherenkov angle reconstruction based on the *indirect ray tracing algorithm* used by HERMES
- minimum of emission error for C_2F_6 corresponds to a maximum in momentum coverage.

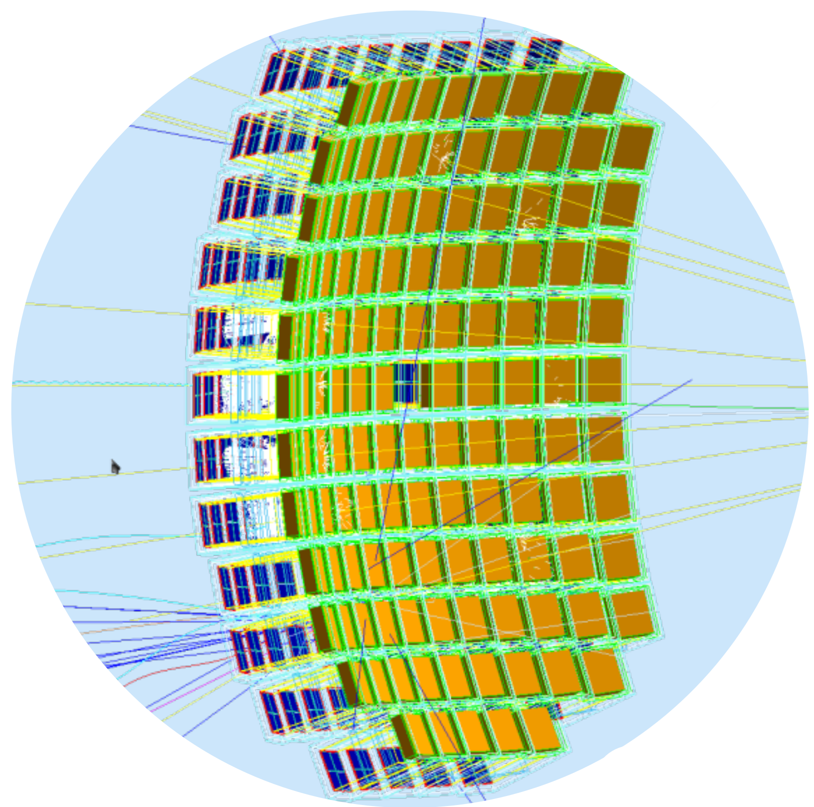
Dual-Radiator RICH: Summary

- Dual-Radiator RICH advantages (aerogel and C_2F_6 gas)
  - continuous coverage (up to ~50 GeV/c for π/K and K/p)
  - cost-effective (common set of photosensors for both radiators)
  - outward mirror focusing: improved resolution, sensors away from beam
  - photosensor spherical planes: reduce cost, improve resolution
- dRICH has been fully implemented in JLEIC detector
- Prototype Design completed
- Under Development
  - tessellation of sensor planes
  - implement dRICH in BNL ePHENIX and BeAST detectors and study performance
  - study dRICH performance for a specific physics channel in presence of backgrounds

Modular RICH

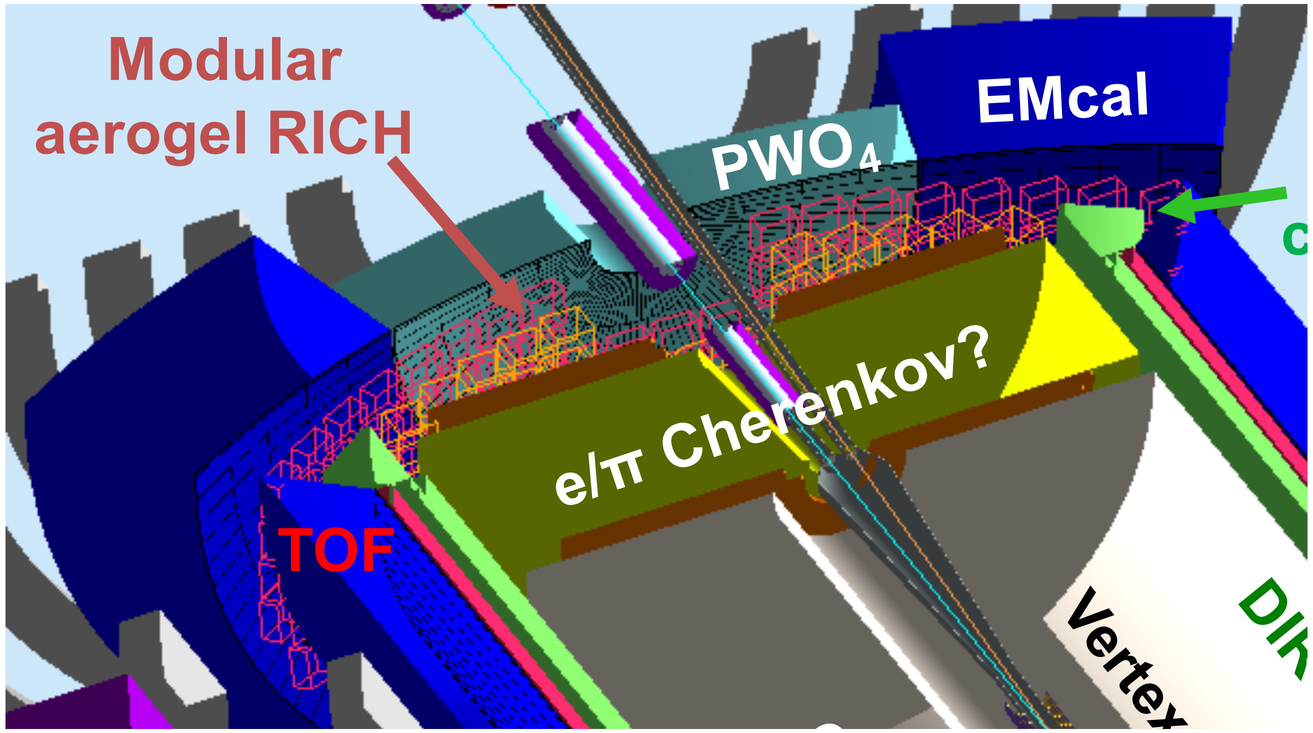
Herbert van Hecke (Los Alamos National Lab)

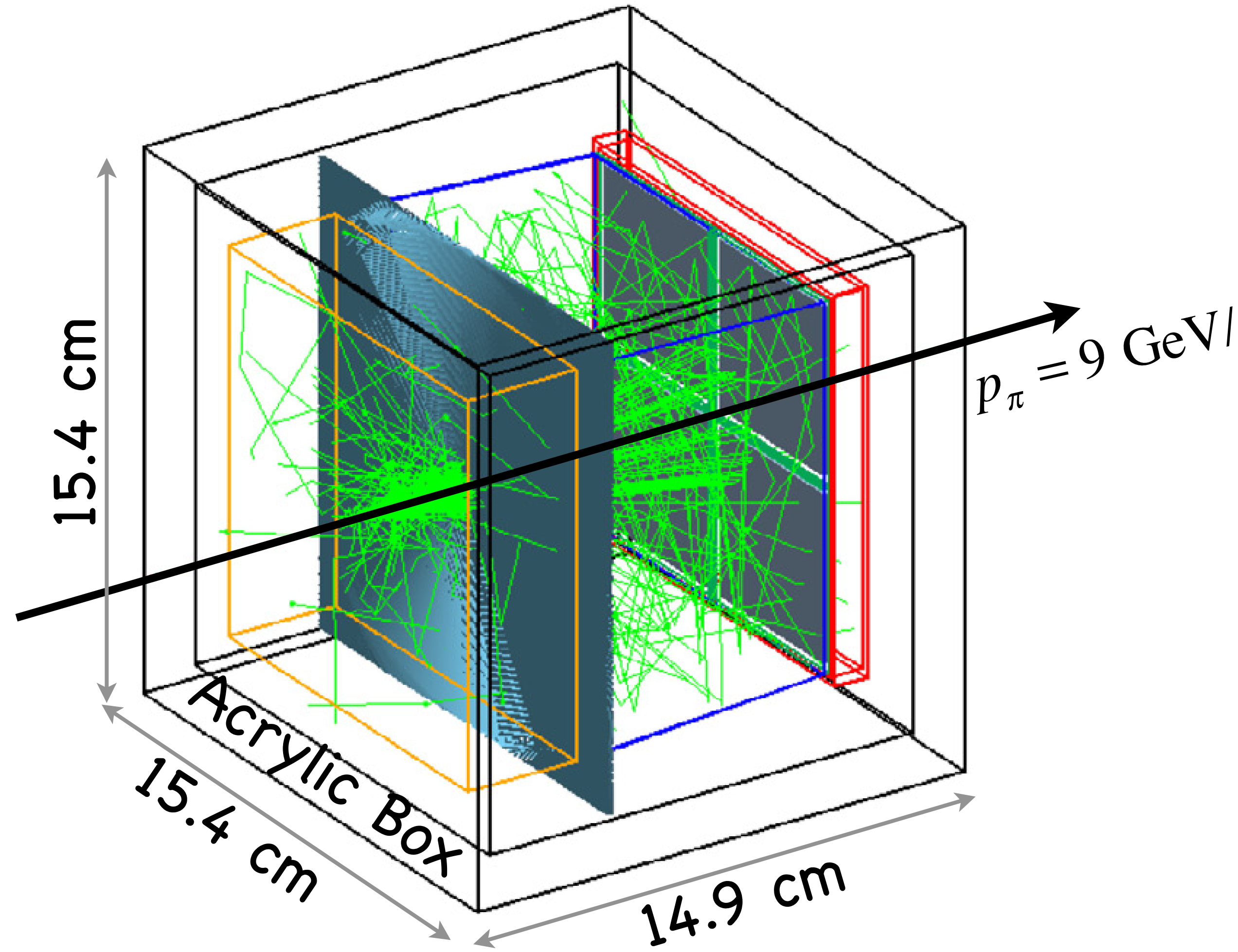
Xiaochun He, Cheuk-Ping Wong (Georgia State Uni)



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

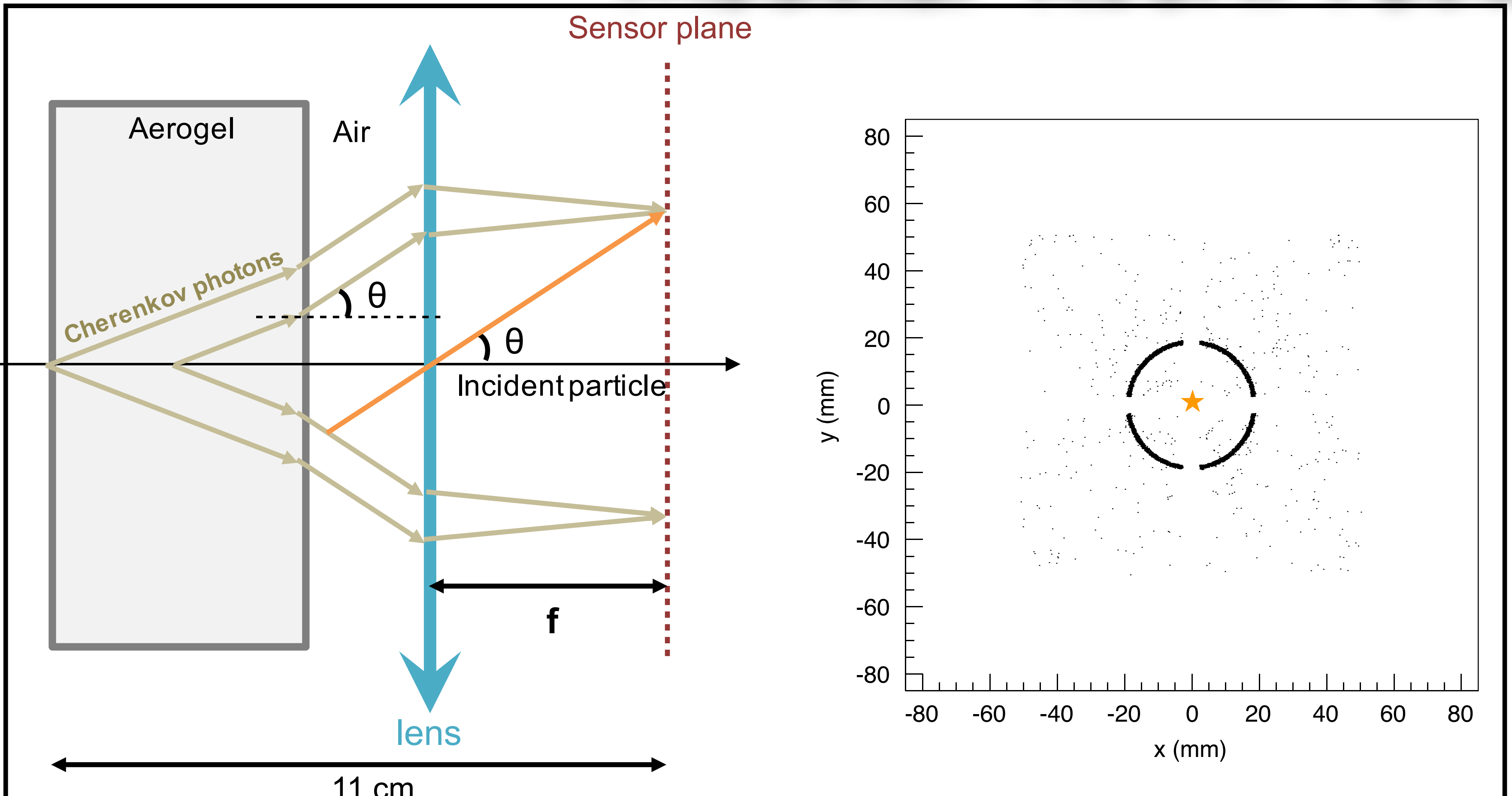
Modular RICH: JLEIC Implementation

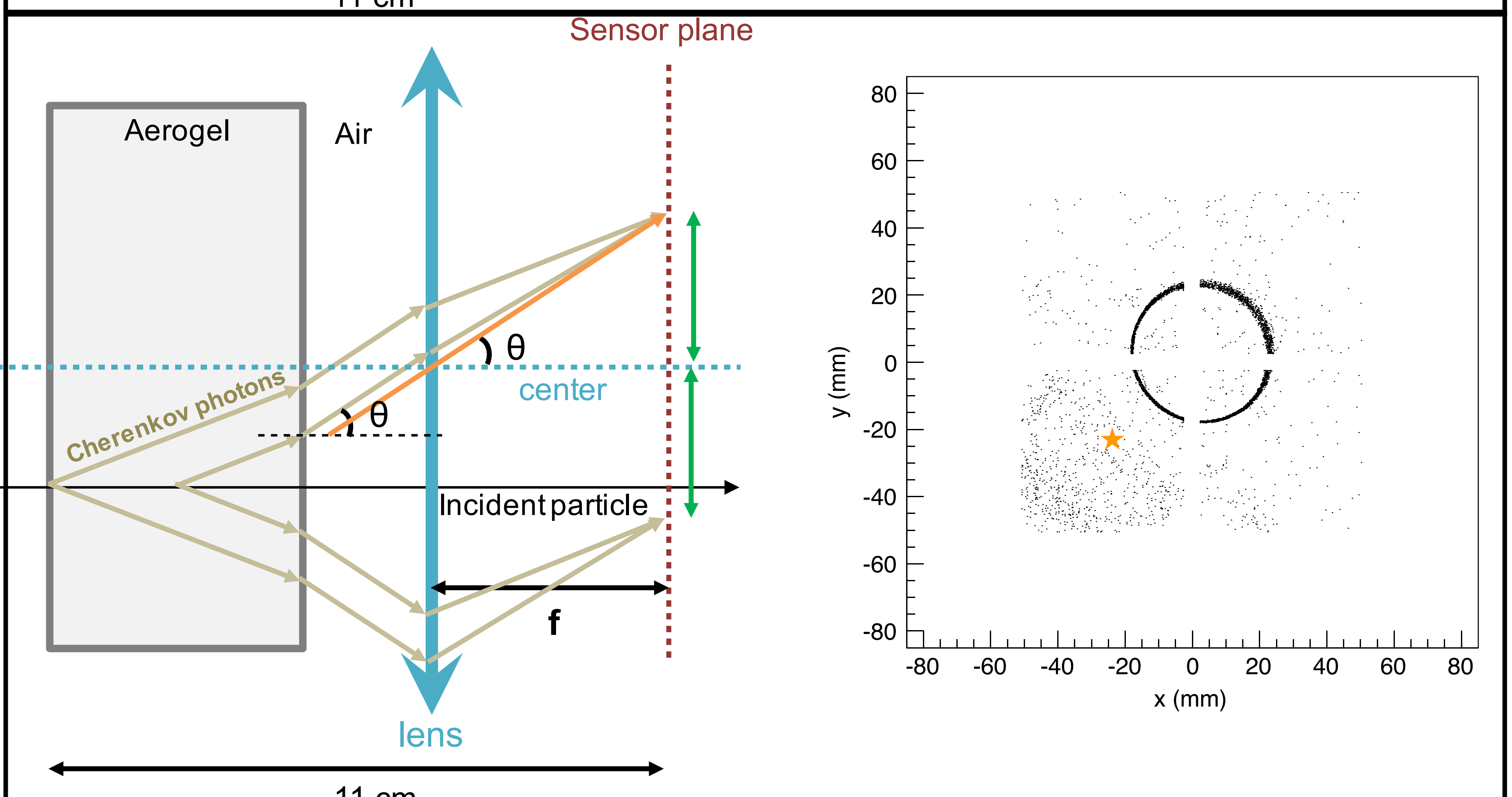




- Aerogel block (3.3-cm thick)
- Acrylic Fresnel Lens (focusing, UV filter)
- Pixelated photon sensor plane (4 square sensitive areas), readout electronics
- Gap lens-image plane is bounded by 4 flat mirrors, **$L = f_{Lens} = 7.6$ cm**
- **Geant 4 Simulation:** transmission, Rayleigh scattering, index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

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.

Optimization of single ph.e. Cherenkov-angle resolution

- emission-point source minimized at lens focal plane
- chromatic dispersion reduced by lens transmittance in the near-UV

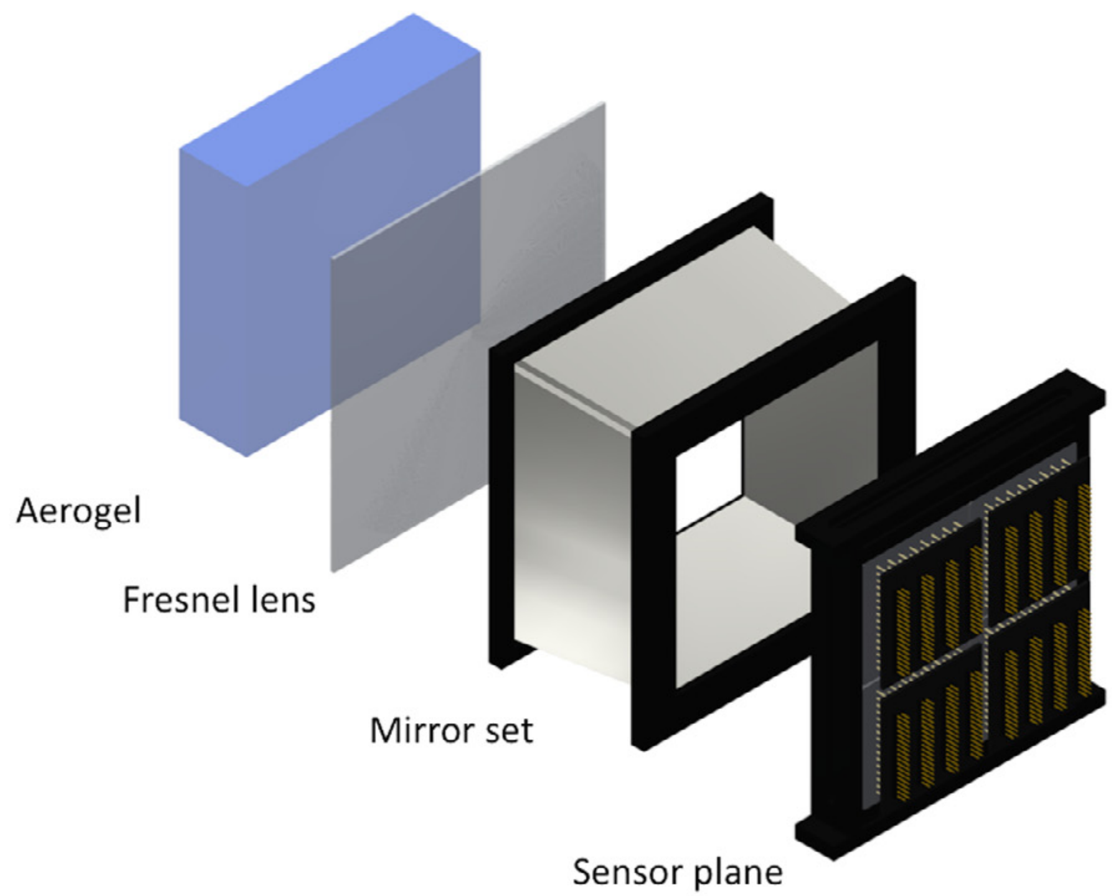
π/K separation at 10 GeV/c:

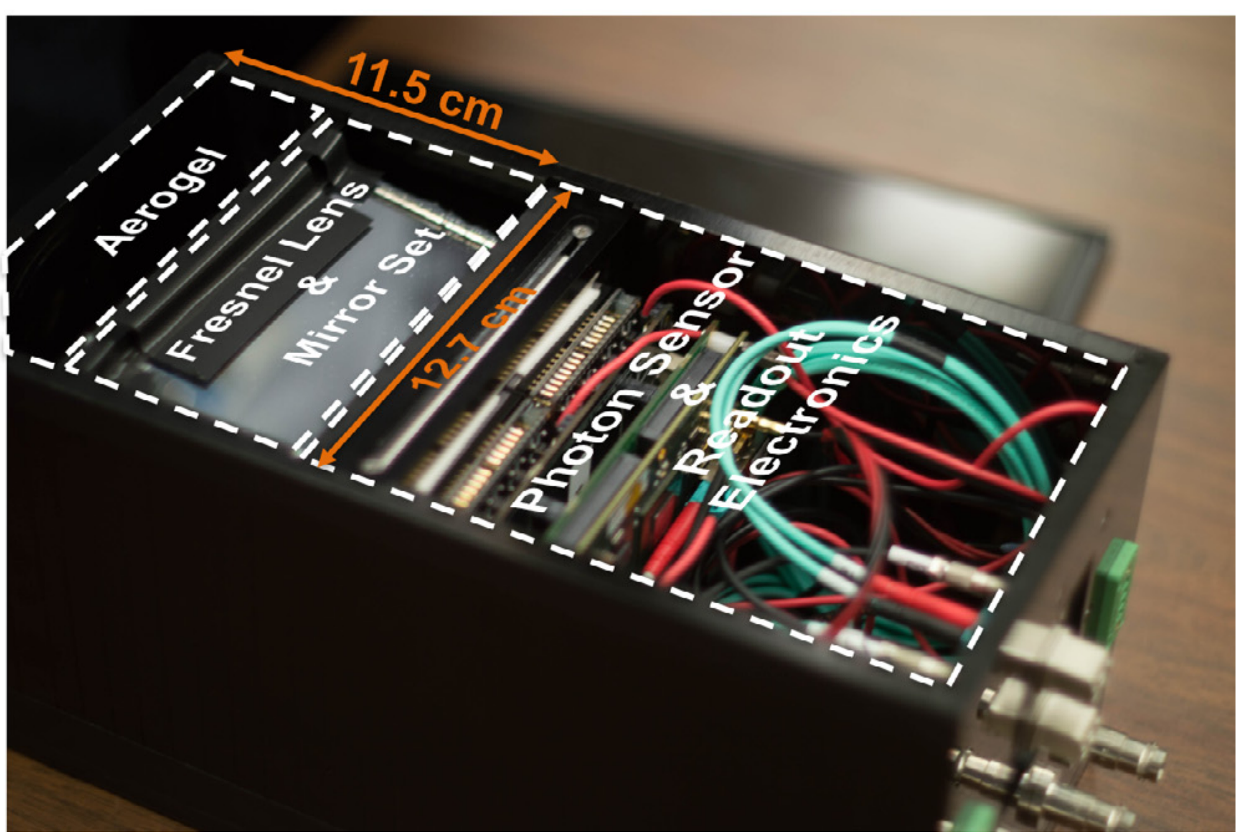
$n = 1.03$

$f = 6''$

pixel size: 2 mm

Modular RICH: Prototype and Beam Test





Prototype

Aerogel: 3.3-cm thick, n = 1.03

Fresnel Lens: f = 3″

Sensors: four H8500 MaPMT, 6x6 mm^2 pixel size

Beam Test

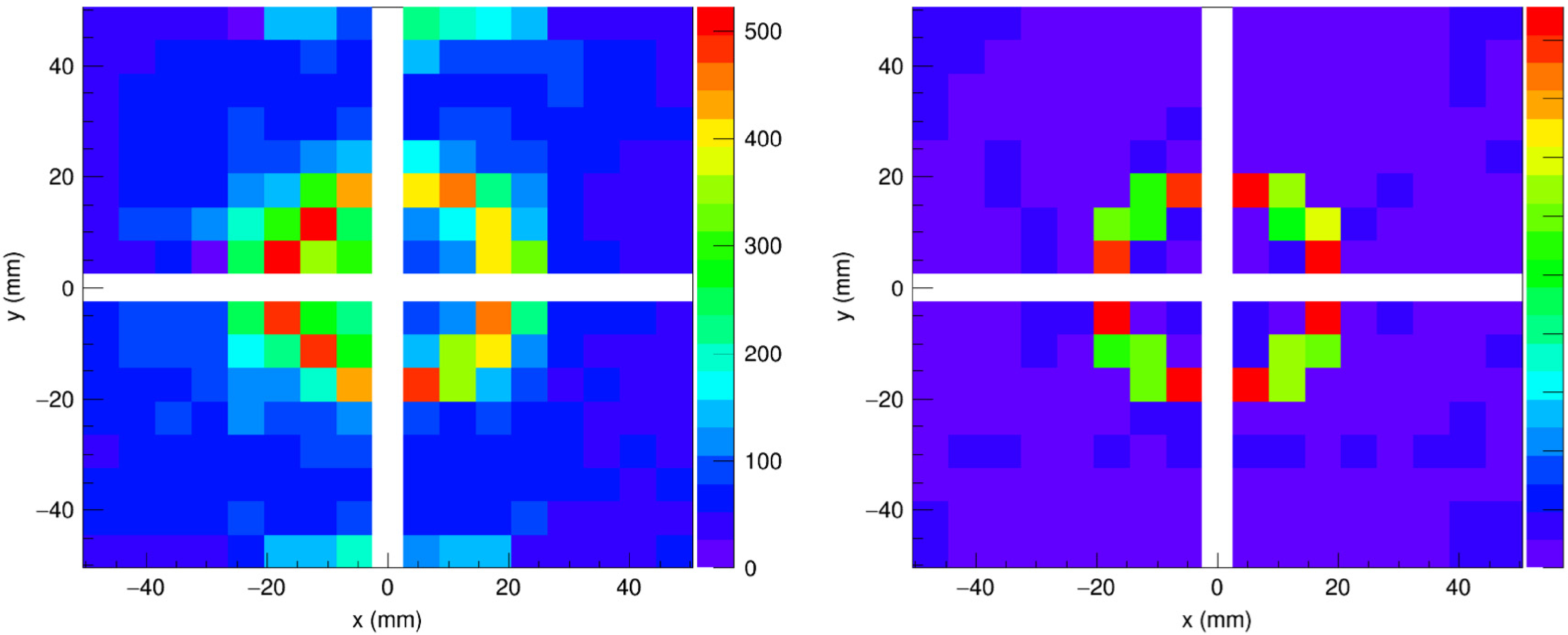
Fermi Lab, with 120 GeV/c proton beam

Incident particle position: two sets of hodoscopes in front and in back of prototype

Trigger: pair of 7-cm wide scintillator paddles

Modular RICH: Beam Test Results

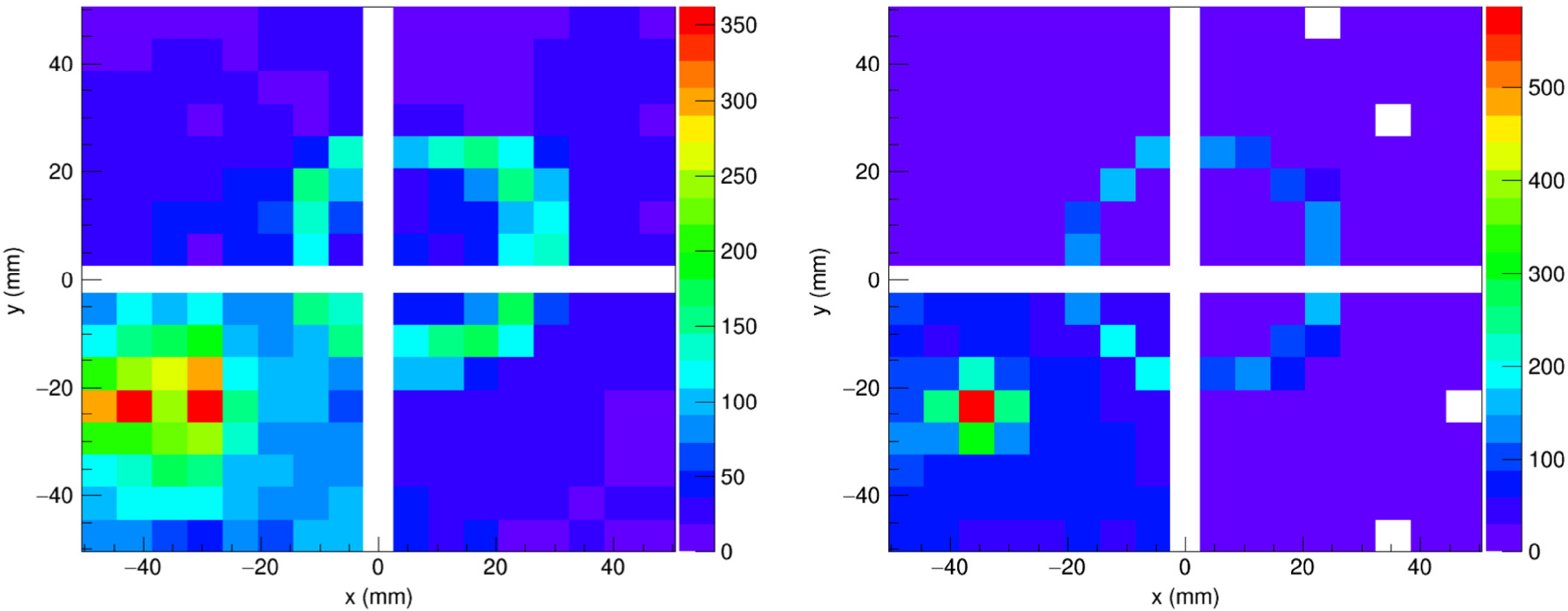
120-GeV protons incident on the central axis of prototype



	Analytical calculation	Test beam data	Simulation
Radius (mm)	19.4	19.0 ± 1.3	18.9 ± 1.0
Total number of photons	10.4	11.0 ± 2.9	11.1 ± 2.9
Number of photons on the ring		5.9 ± 1.8	5.8 ± 1.5

Modular RICH: Beam Test Results

120-GeV protons incident off axis of prototype



	Test beam data	Simulation
Radius (mm)	20.8 ± 1.5	21.6 ± 0.9
Total number of photons	17.6 ± 3.5	17.0 ± 3.4
Number of photons on the ring	4.4 ± 1.0	4.4 ± 1.4

Modular RICH: Summary

- Lens-based mRICH advantages
  - smaller and thinner ring than in proximity-focusing RICH
  - image centered on photo-sensor plane
  - compact and modularized design

- Initial mRICH Wall implementation in JLEIC and sPHENIX Detectors

- First prototype construction and beam test: proof of detector principle

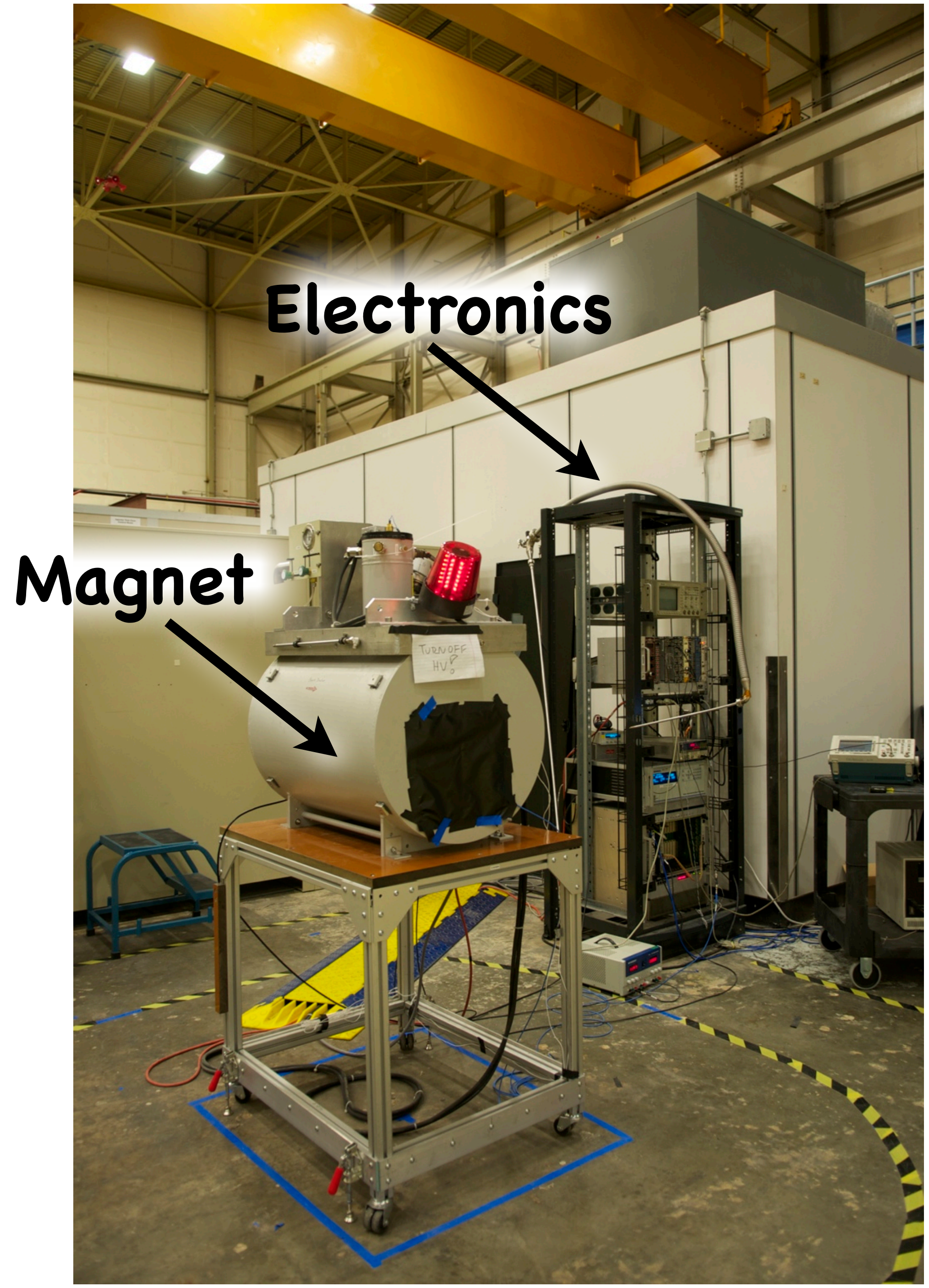
- Second prototype under construction: to test PID performance
  - Fresnel Lens: f=6"
  - Sensors: 3x3 mm^2 pixel size H13700
  - separation of optical components from readout electronics
  - Measure π/K separation power up to 8 GeV/c
  - Measure e/π separation power up to 2 GeV/c

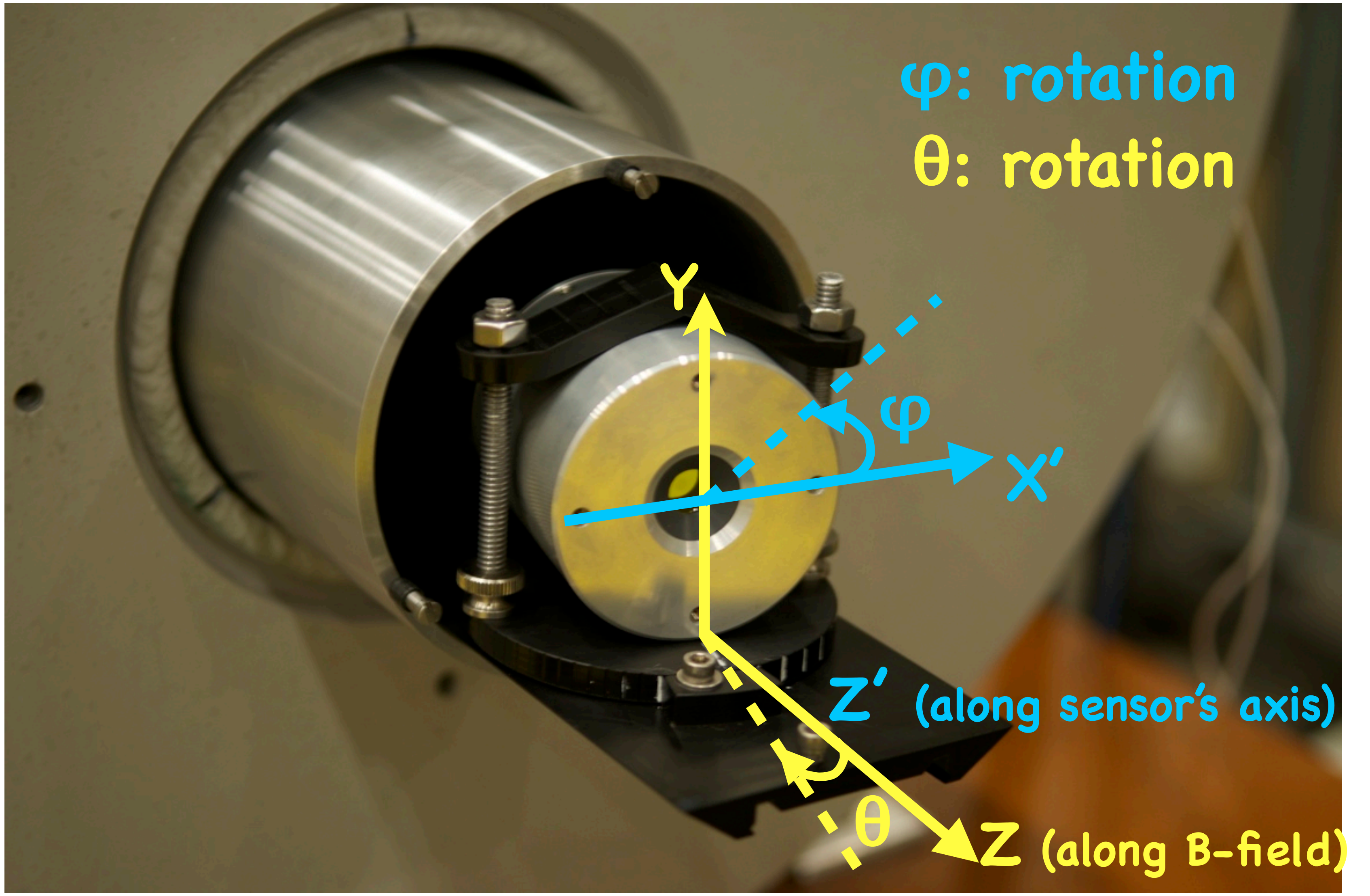
Studies of Photosensors in B-Field

YI, C. Gleason, T. Cao (USC); C. Zorn, J. McKisson, K. Park (JLab); G. Kalicy (CUA); P. Nadel-Turonski (SB); C. Schwartz, J. Schwiening (GSI); Ch. Hyde, L. Alison (ODU)

Parameter	DIRC	mRICH	dRICH
Gain	$\sim 10^6$	$\sim 10^6$	$\sim 10^6$
Timing Resolution	≤ 100 ps	≤ 800 ps	≤ 800 ps
Pixel Size	2–3 mm	≤3 mm	≤ 3 mm
Dark Noise	≤ 1kHz/cm^2	≤ 5MHz/cm^2	≤ 5MHz/cm^2
Radiation Hardness	Yes[14]	Yes[14]	Yes[14]
Single-photon mode operation?	Yes	Yes	Yes
Magnetic-field immunity?	Yes (1.5–3 T)	Yes (1.5–3 T)	Yes (1.5–3 T)
Photon Detection Efficiency	≥ 20%	≥ 20%	≥ 20%

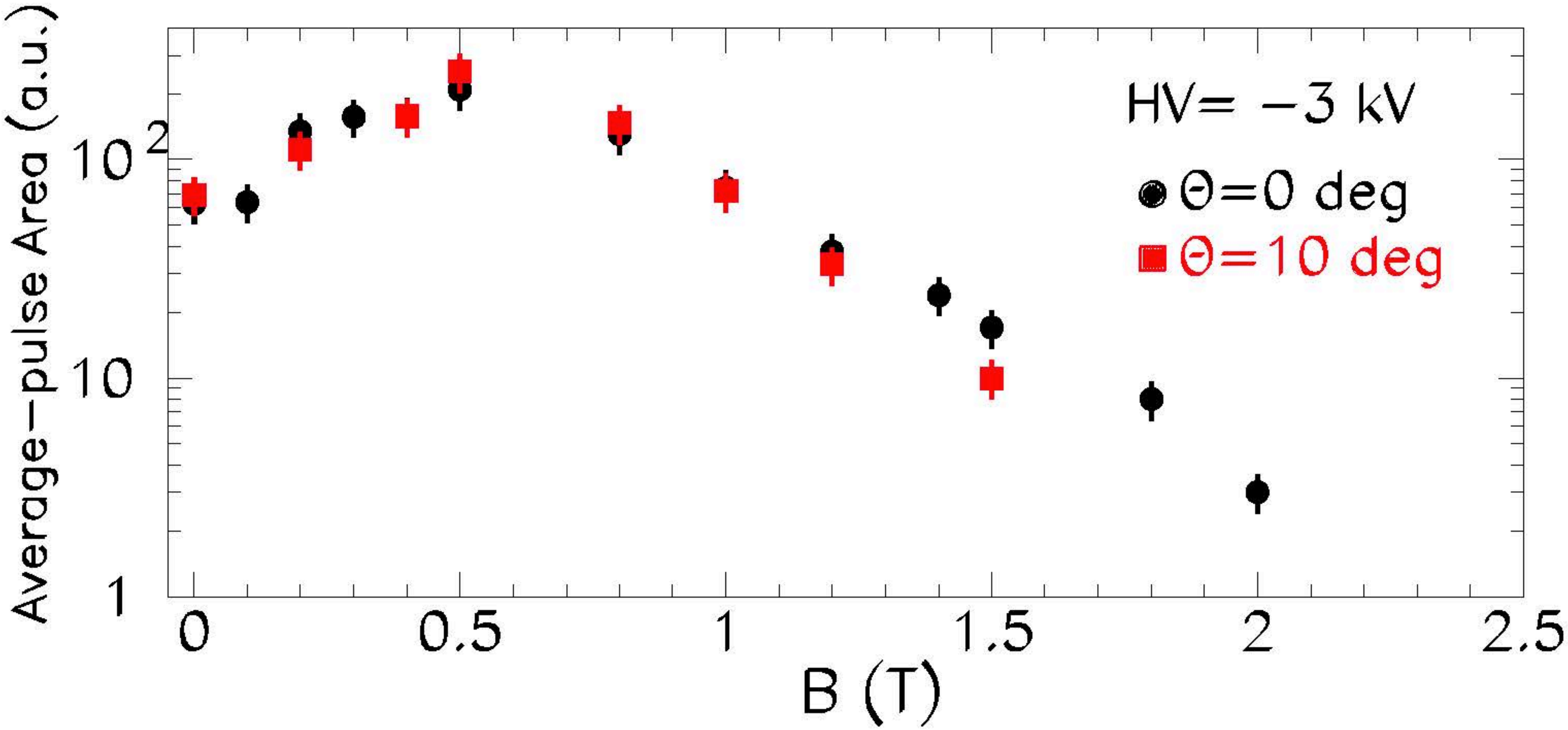
High-B Sensor-Testing Facility at JLab





Gain Evaluation of 10-μm Pore-Size MCP-PMT

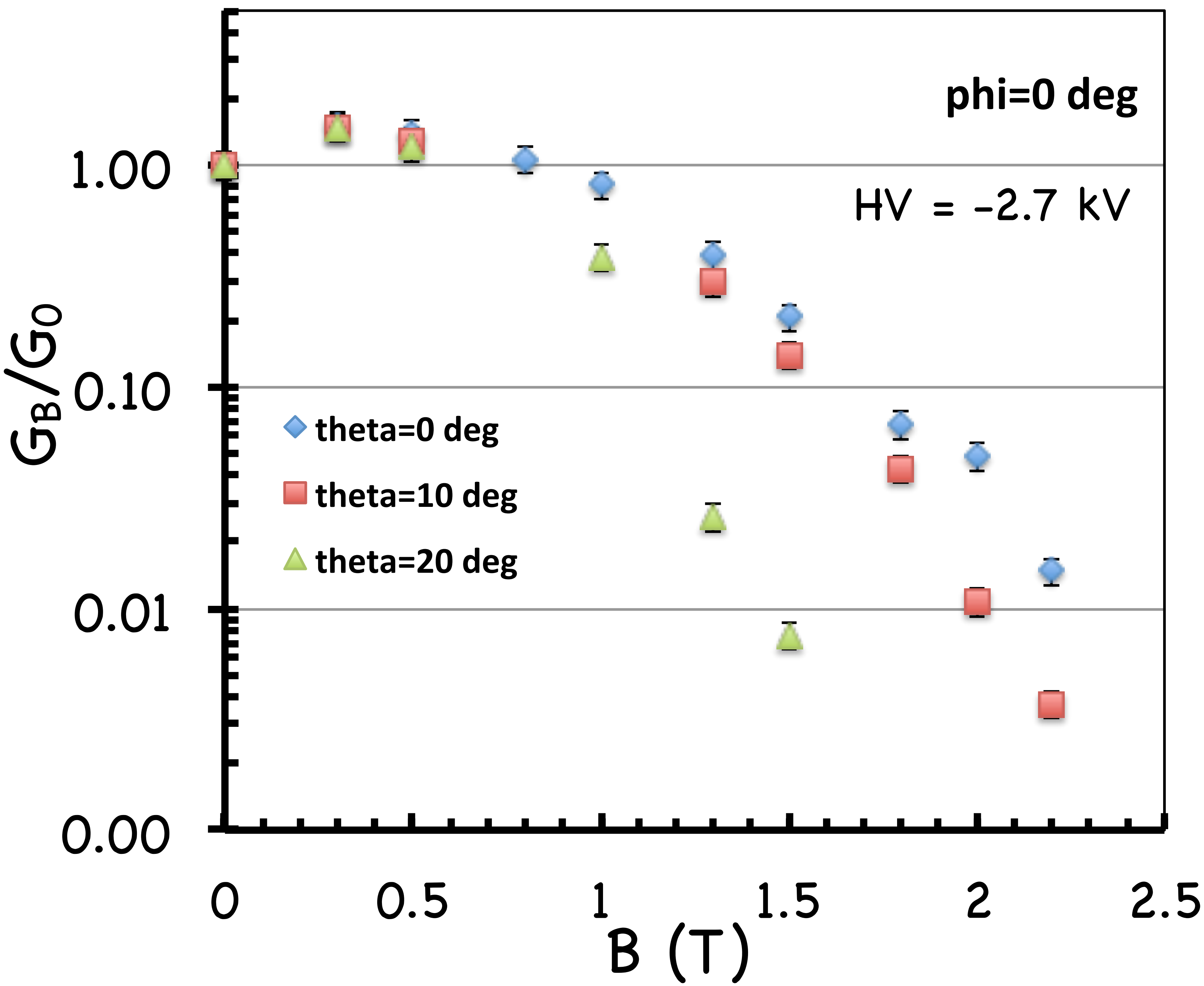
Hamamatsu R10754-07-M16X



- Measurements performed at 96% of maximum allowed high voltage.
- Data
  - Gain maximum at 0.5 T
  - Can be operated up to about 2 T at standard orientation.
  - Can be operated up to about 1.5 T at 10 deg.

Gain Evaluation of 10-μm Pore-Size MCP-PMT

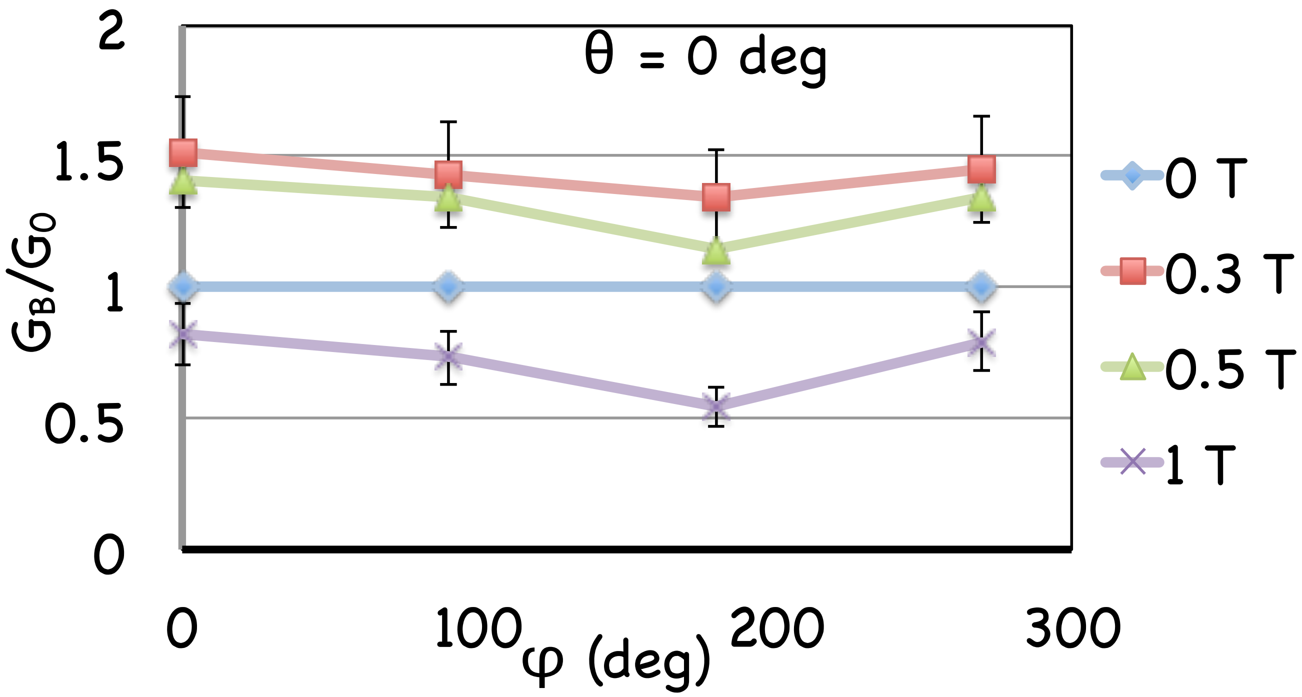
Photonis XP85112

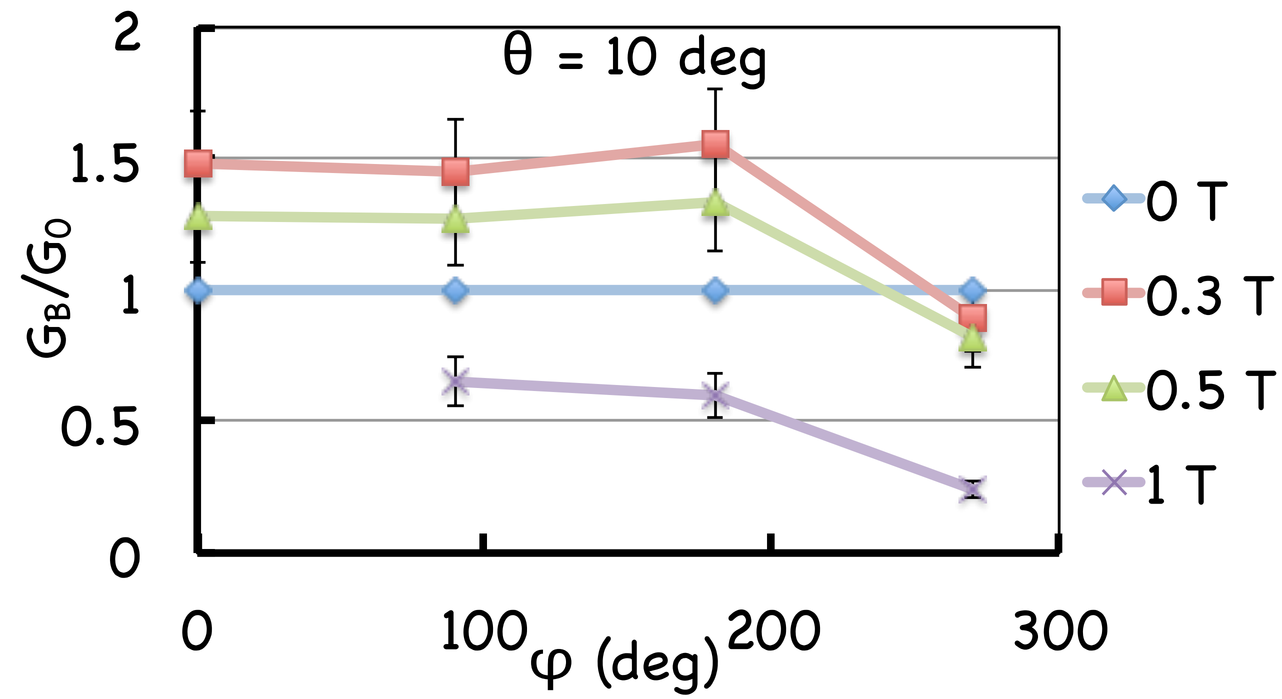


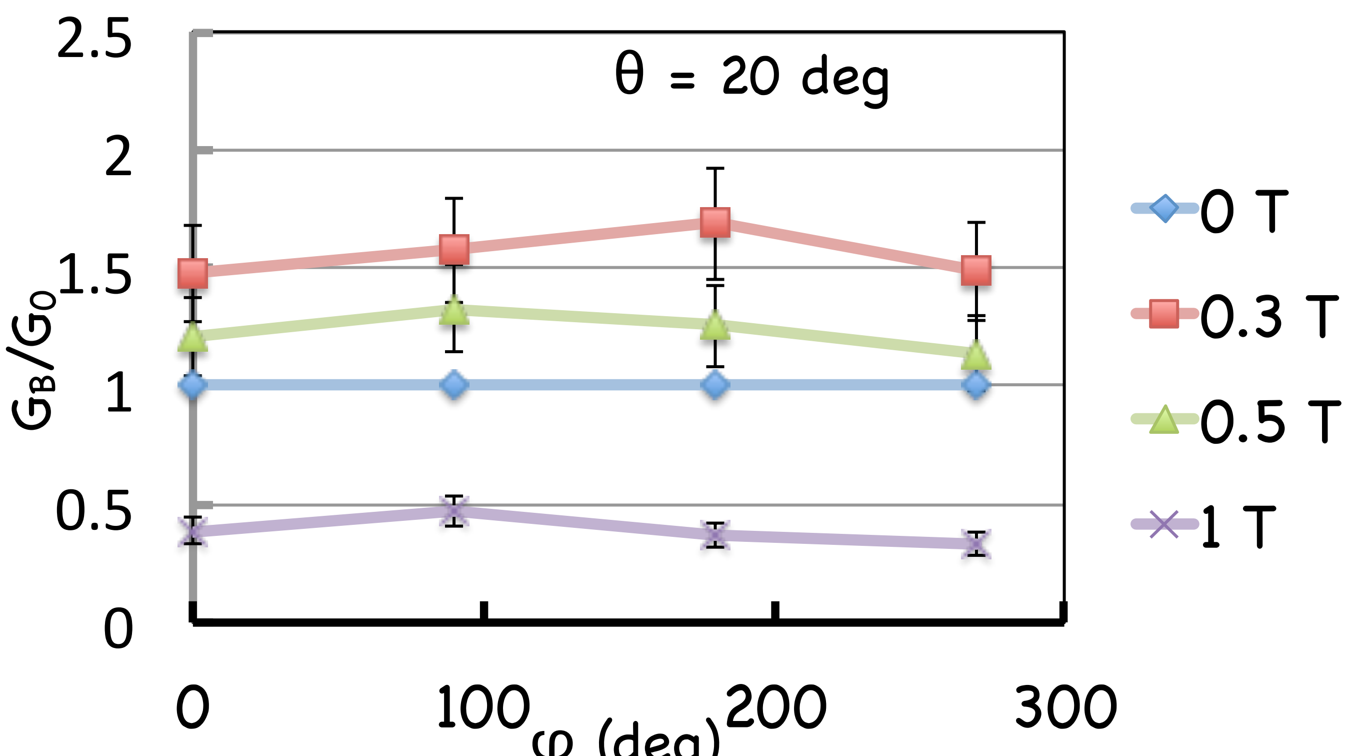
- Measurements performed at 96% of maximum allowed high voltage.
- Data
  - Maximum gain at 0.3 T.
  - B_{max} = 2.2 T.
  - Value of B_{max} strongly depends on orientation.
  - The larger the polar angle, the lower B_{max}.

Gain Evaluation of 10-μm Pore-Size MCP-PMT

Photonis XP85112







Azimuthal-angle dependence is correlated with the polar angle

- θ = 0° – minimum at φ = 180°
- θ = 10° – minimum at φ = 270°
- θ = 20° – no characteristic features

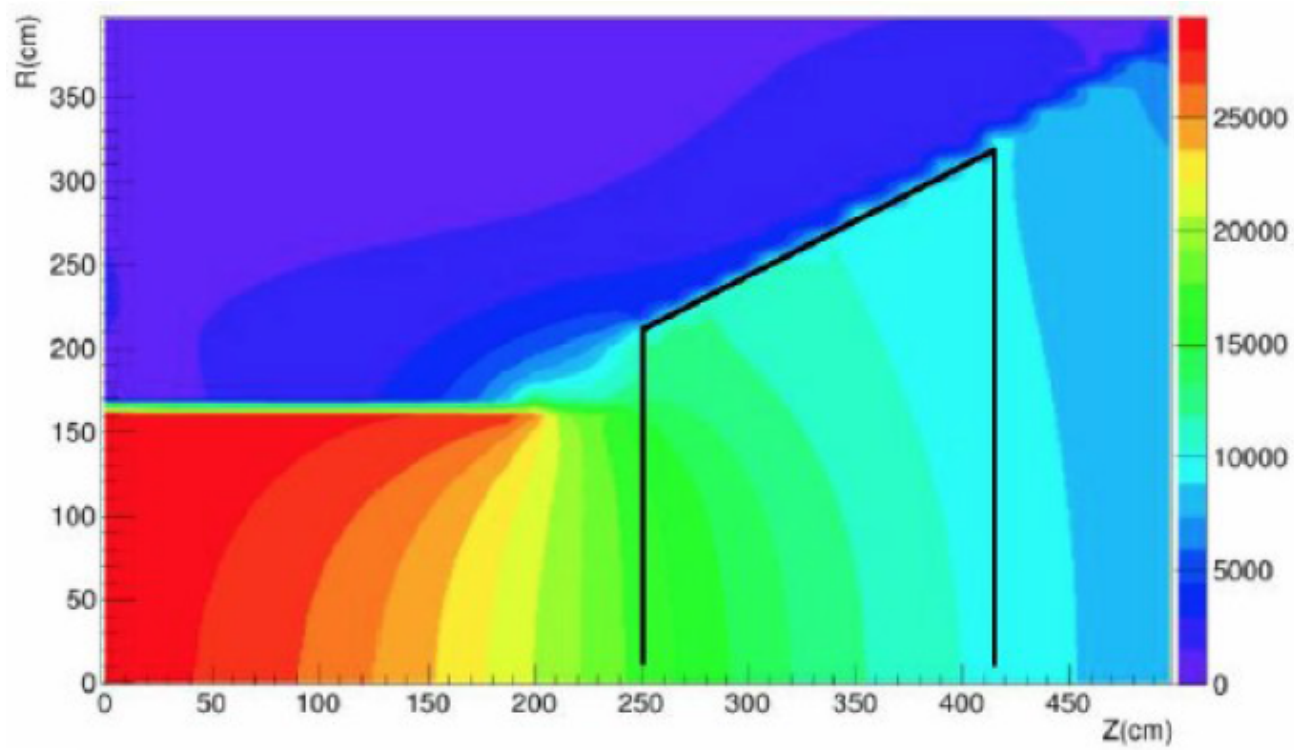
Studies of Photosensors in B-Field: Summary

- Commercially available 10-μm pore size MCP-PMT sensors.
  - Ideal range of operation is up to 1 T, where the gain is larger or equal to the gain at 0 T for various orientations.
  - Range could be extended to 2 T with increased HV and limited variation of sensor orientations to small polar angles (< 10°).
- Ongoing developments
  - Upgrade and commission facility for timing resolution evaluations.
  - Develop an MCP-PMT simulation to support design optimization in high B-field.

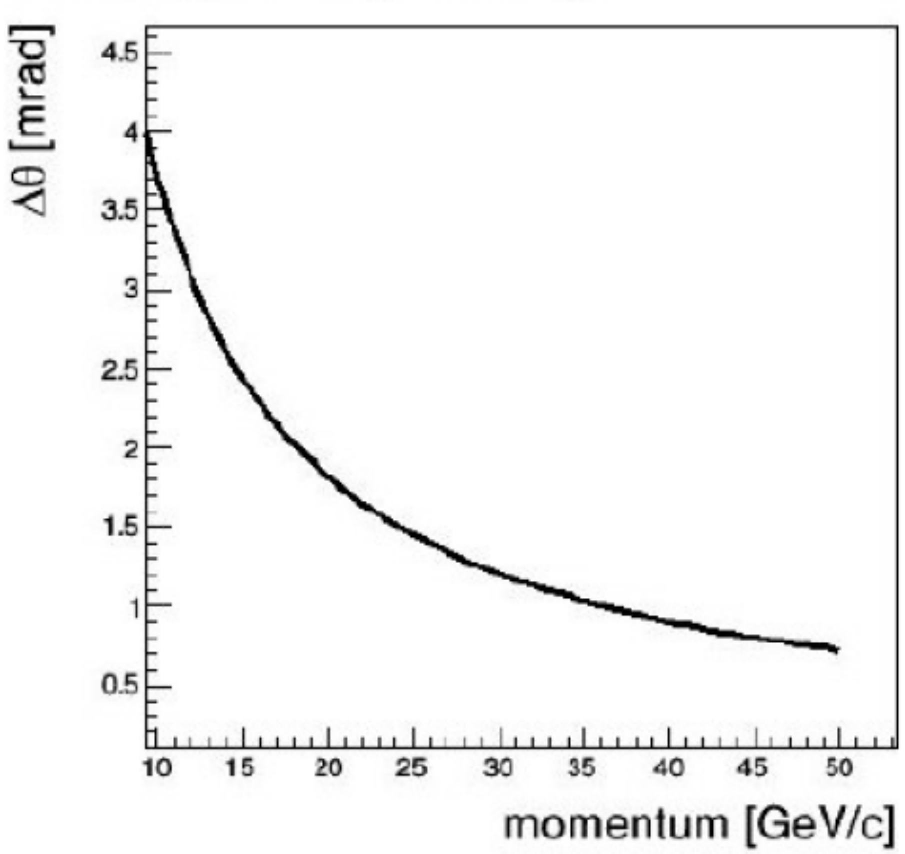
The END

Effects of magnetic field

- Field components transverse to the track smear the ring resolution
- Can be minimized by shaping the field

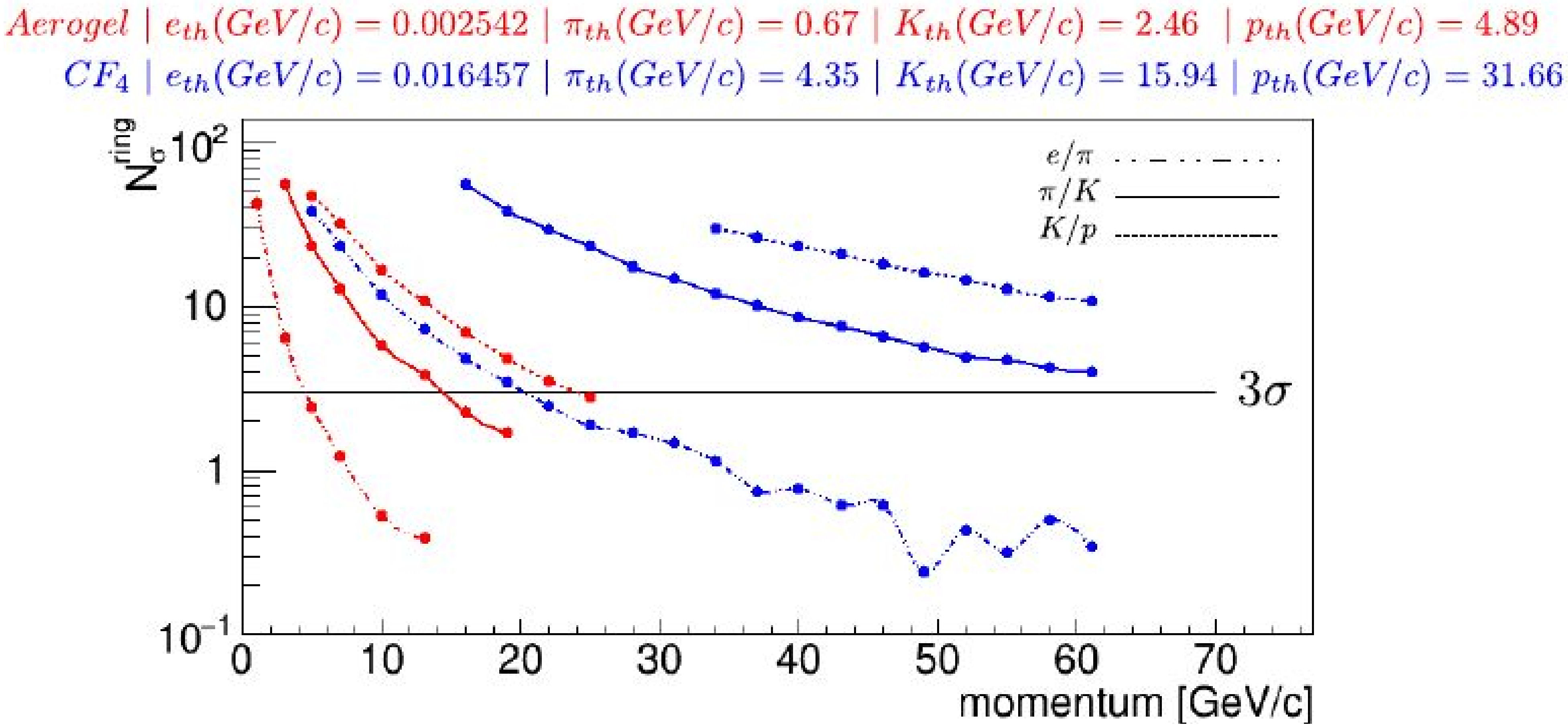


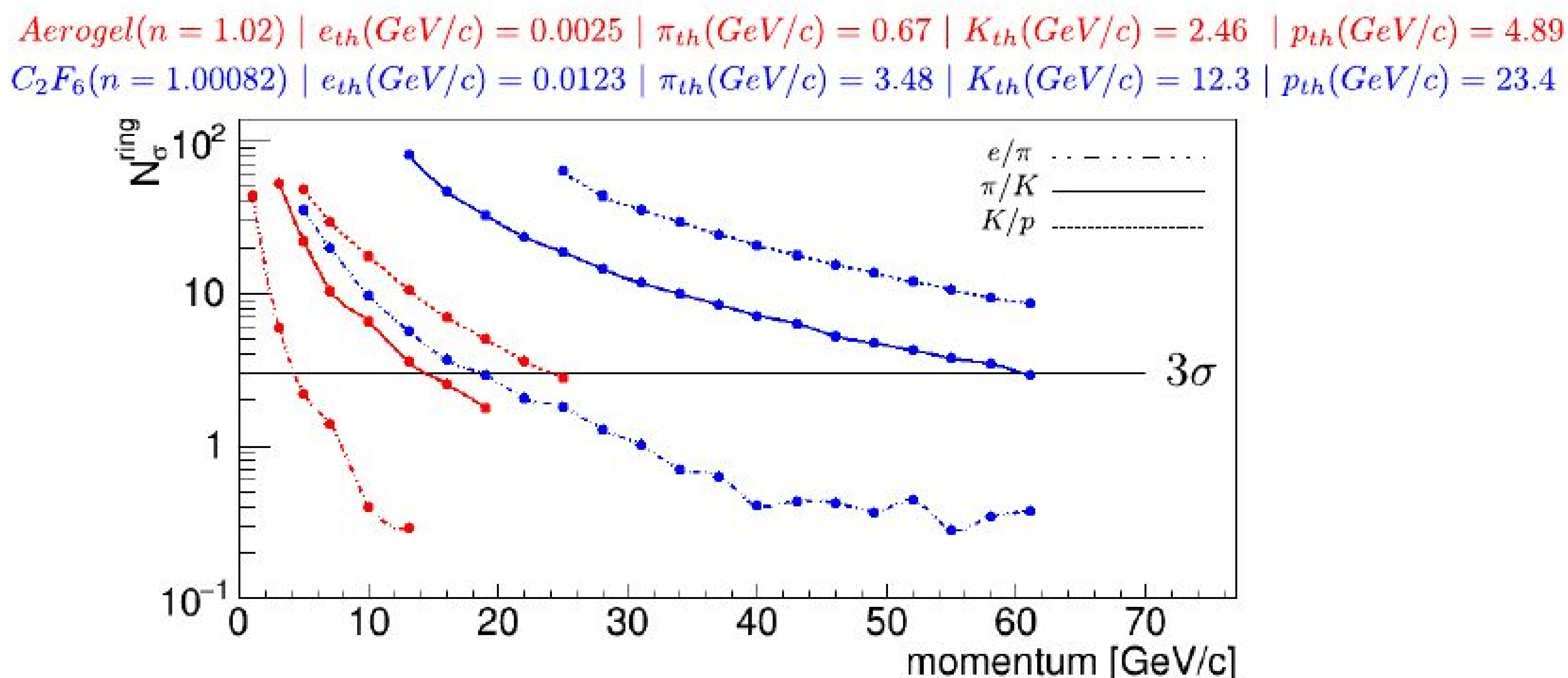
Particle polar angle 25 deg



This error is of the same order as other errors (tracking, pixel size, chromatic)

Dual-Radiator RICH: CF4 vs C2F6





Flowchart: Test Setup