eRD14 – EIC PID consortium

- An integrated program for particle identification (PID) for a future Electron-Ion Collider (EIC) detector.

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

Contacts:
P. Nadel-Turonski <turonski@jlab.org>,
Y. Ilieva <jordanka@physics.sc.edu>

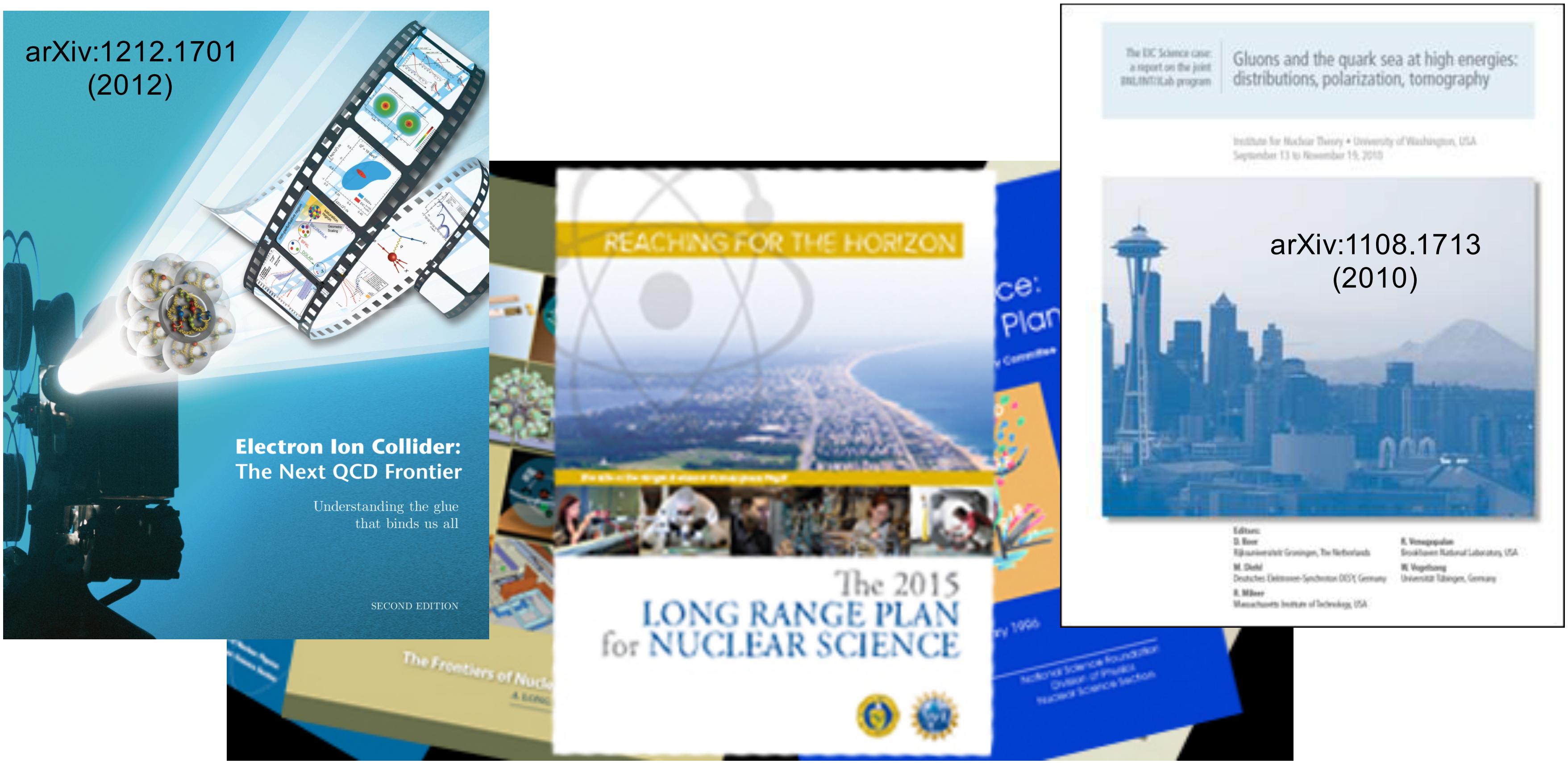
Generic Detector R&D for an Electron Ion Collider

Advisory Committee Meeting, ANL, July 6-7, 2016

Participating institutions

- Abilene Christian University (ACU)
- Argonne National Lab (ANL)
- Brookhaven National Lab (BNL)
- Catholic University of America (CUA)
- Duke University (Duke)
- Georgia State University (GSU)
- GSI Helmholtzzentrum für Schwerionenforschung, Germany (GSI)
- Howard University (HU)
- Istituto Nazionale di Fisica Nucleare, Sezione di Ferrara, Italy (INFN-Ferrara)
- Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy (INFN-Rome)
- Istituto Superiore di Sanità, Italy (ISS)
- Jefferson Lab (JLab)
- Los Alamos National Lab (LANL)
- Old Dominion University (ODU)
- Universidad Técnica Federico Santa María, Chile (UTFSM)
- University of Illinois Urbana-Champaign (UIUC)
- University of New Mexico (UNM)
- University of South Carolina (USC)
- Yale University (Yale)

PID – an essential part of the EIC physics program



- The physics program for a generic EIC is outlined in the 2015 NSAC LRP, the 2012 White Paper, the 2010 INT report, etc.
- Excellent PID is crucial for achieving these physics goals!

eRD14: an integrated program for PID at an EIC

1. Develop a suite of detector systems covering the full angular- and momentum range required for an EIC detector

- Different requirements and technologies in different parts of detector
- Initial focus is on hadron ID, but electron ID is a natural extension

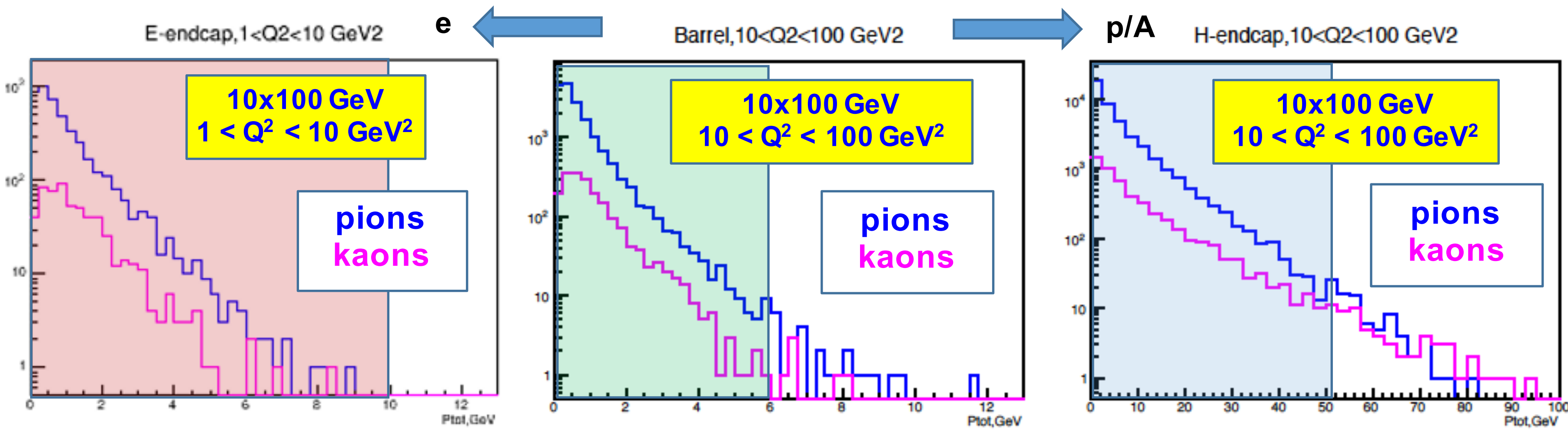
2. Find a cost-effective sensor and electronics solution

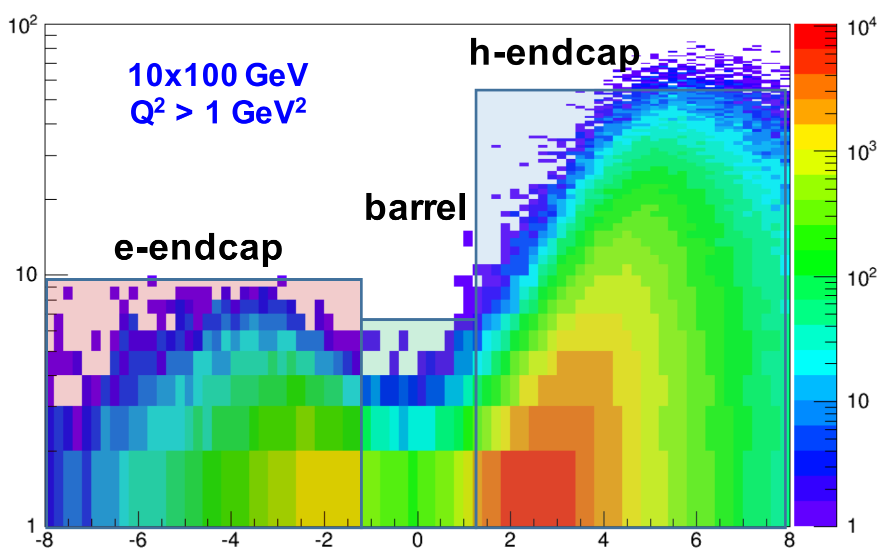
- Requirements and development of photosensors
- Provide a road map for the electronics needed for the readout

3. Maximize synergies and minimize cost of R&D

- Collaboration and sharing of support systems (sensors, electronics, etc)

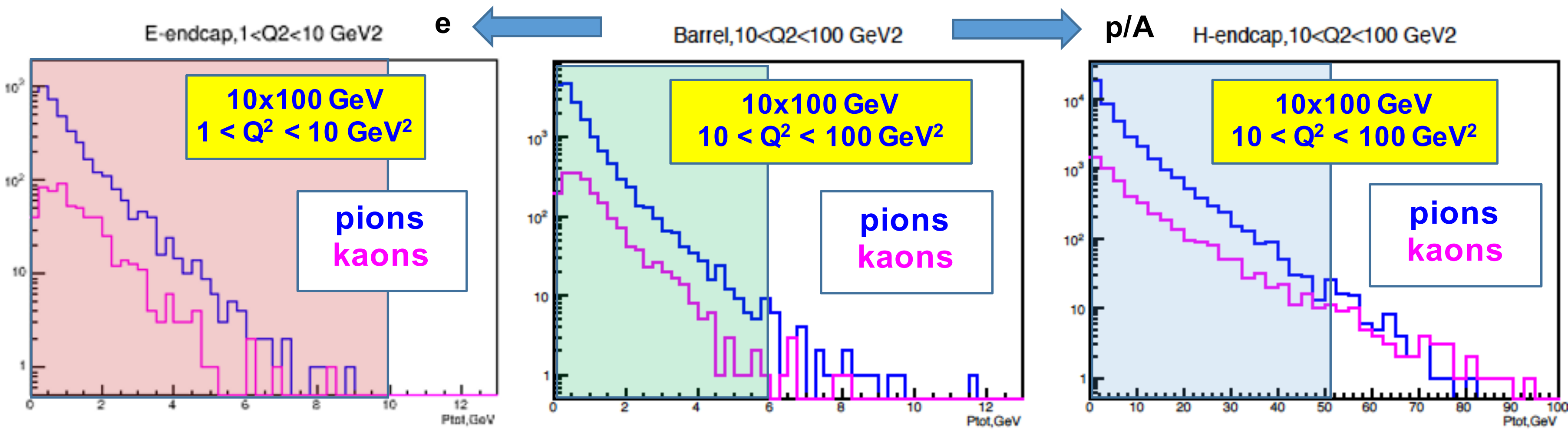
Hadron ID – kinematics

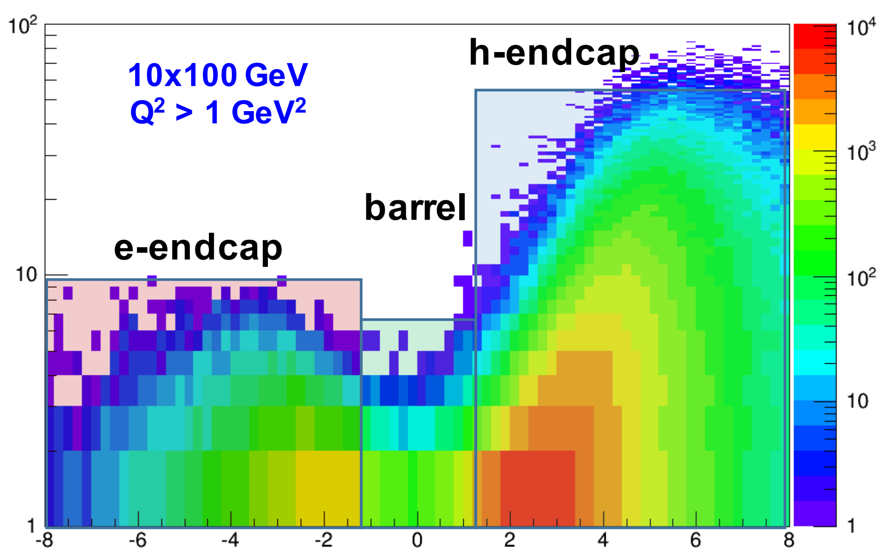




- 10 GeV e on 100 GeV p is a common BNL/JLab accelerator energy setting
- The maximum energy at BNL (and for stage II at JLab) is 20 x 250 GeV.
- In the endcaps, the maximum hadron energy is close that of the e/ion beam
- In the barrel, the high-p distribution is suppressed by the cross section ($p \sim p_T$)

Hadron ID – physics

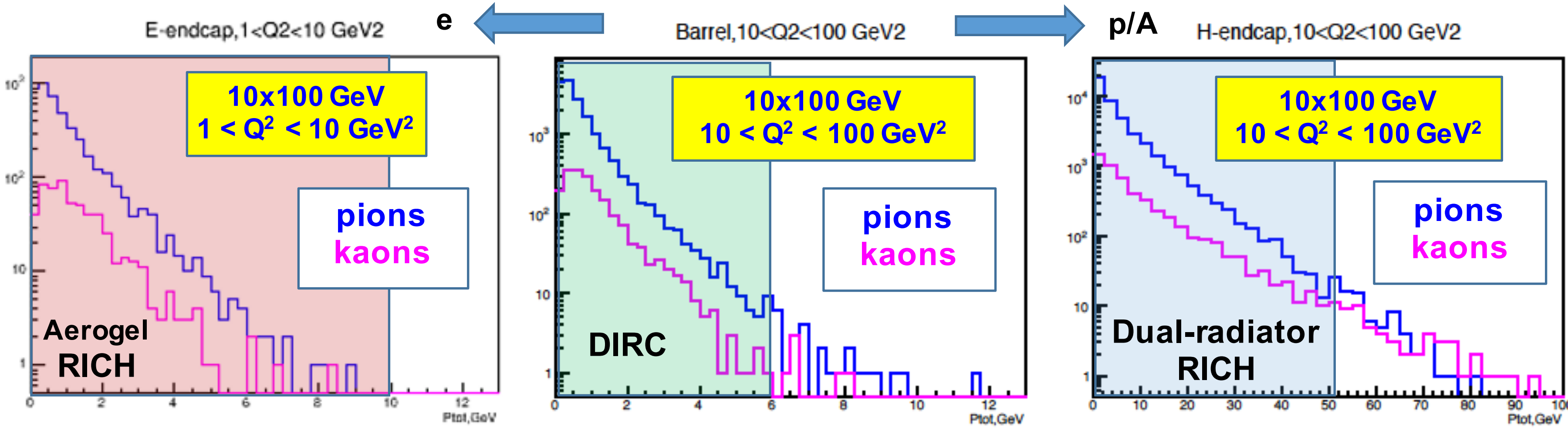


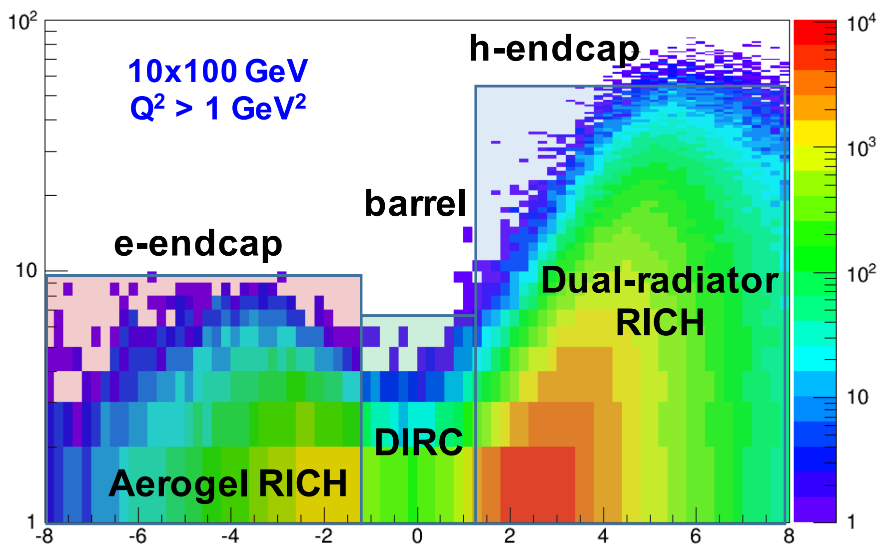


The high-momentum tails contain important physics, including:

- High p_T, and z in SIDIS
- Exclusive limit (z=1) for 3D tomography
- Particles decaying into kaons, e.g.
  - phi-mesons (diffraction/saturation)
  - open charm (probe of gluons)

Hadron ID – technology options

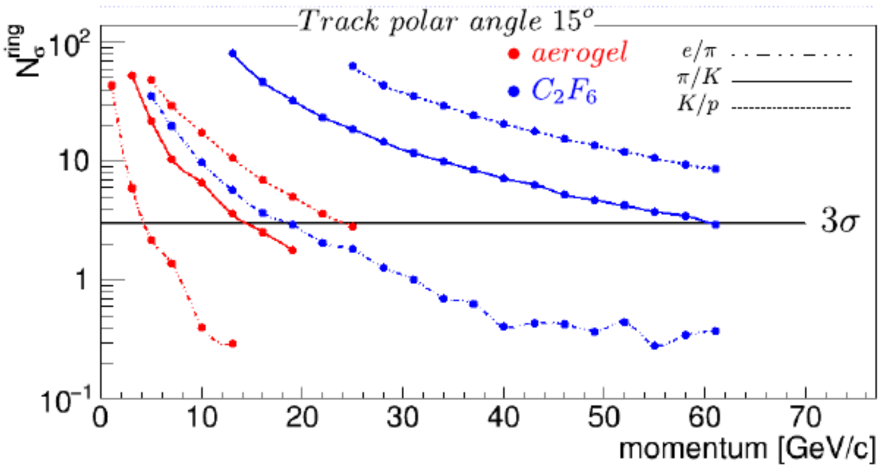




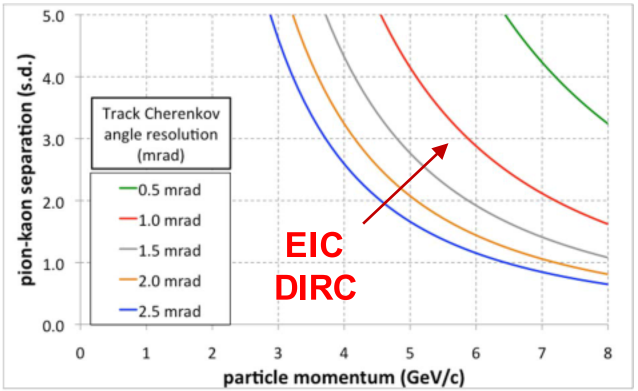
- **e-endcap**: aerogel RICH with TOF (or dE/dx) for lower momenta
- **h-endcap**: combined gas and aerogel RICH to cover the full range with TOF
- **barrel**: a DIRC is the most compact and cheapest way to cover the full momentum range for the barrel area.

PID performance summary for eRD14 systems

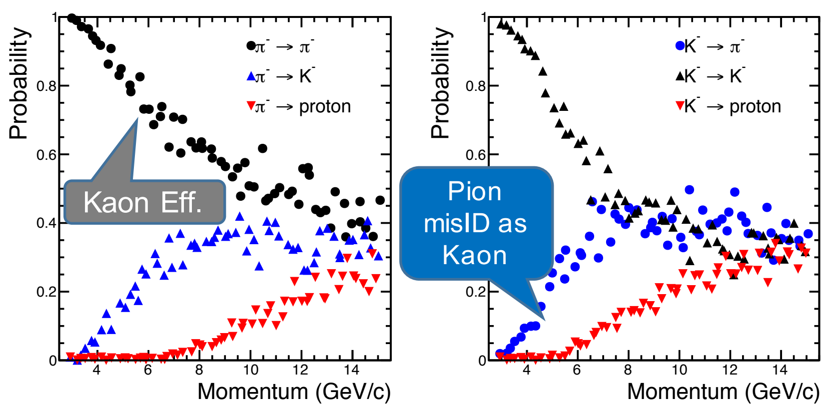
h-endcap: dual-radiator RICH (dRICH)



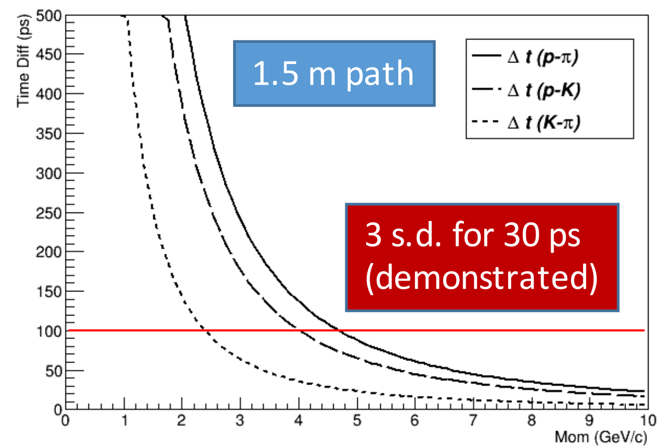
barrel: high-performance DIRC



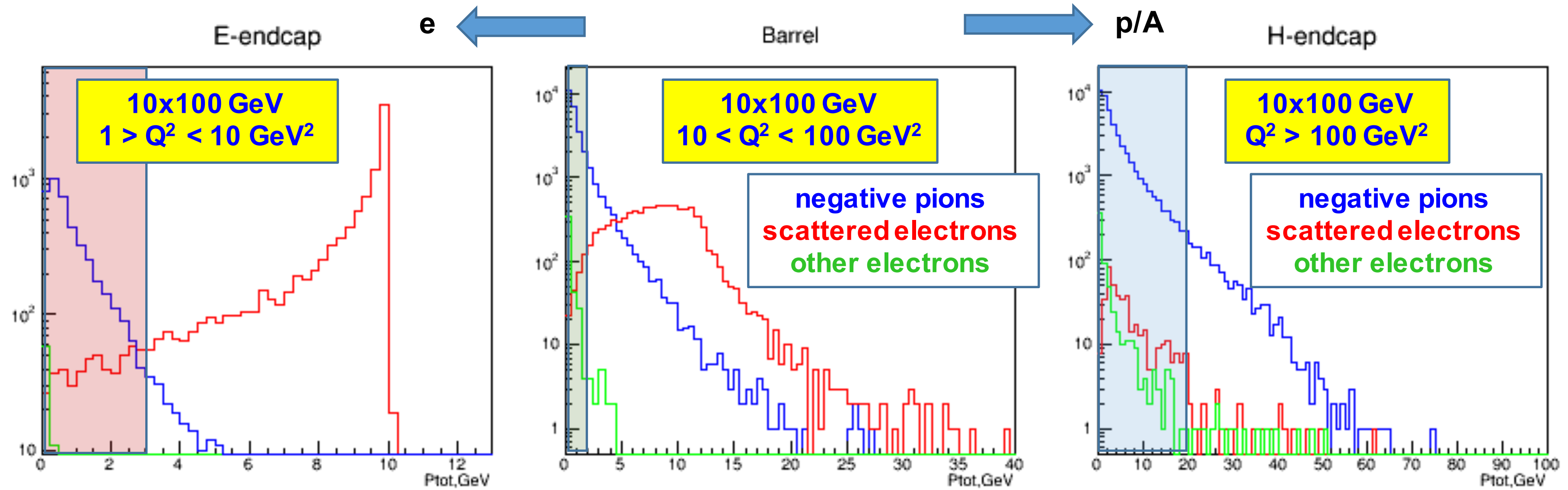
e-endcap: modular aerogel RICH (mRICH)



High-resolution mRPC TOF



Electron identification



- Basic e/pi ID is provided by the EM cal (but only about 1:100 pion suppression)
- The Cherenkov detectors developed by eRD14 provide **supplementary e/pi ID**
- **h-endcap**: needed for all momenta. dRICH can cover up to 20 GeV
- **e-endcap and barrel**: needed for low momenta. DIRC and mRICH can cover up to about 2 GeV

- In the future, R&D on dedicated e/pi systems could follow
- **e-endcap**: Fast e/pi Cherenkov based on the PHENIX HBD, but in a reversed configuration (also possible radial TPC)
- **h-endcap**: a TRD could replace some of the GEM trackers
- Collaboration with eRD6?

eRD14 detector systems: key FY17 R&D goals

Dual-radiator RICH (dRICH) for h-endcap

- Finalize design with C_2F_6 for continuous coverage (2.5-60 GeV for pi/K)
- Refine simulations and prepare for validation through prototyping

Modular aerogel RICH (mRICH) for e-endcap (flexible use)

- Improve simulation and optimize design
- Prepare for 2nd beam test with small pixels to validate PID performance

High-performance DIRC for barrel

- Further improve performance through time-based reconstruction
- Purse cost reduction by using wide bars (plates) with new optics
- Long-term GSI involvement – prepare to use PANDA prototype at Fermilab

High-resolution mRPC TOF

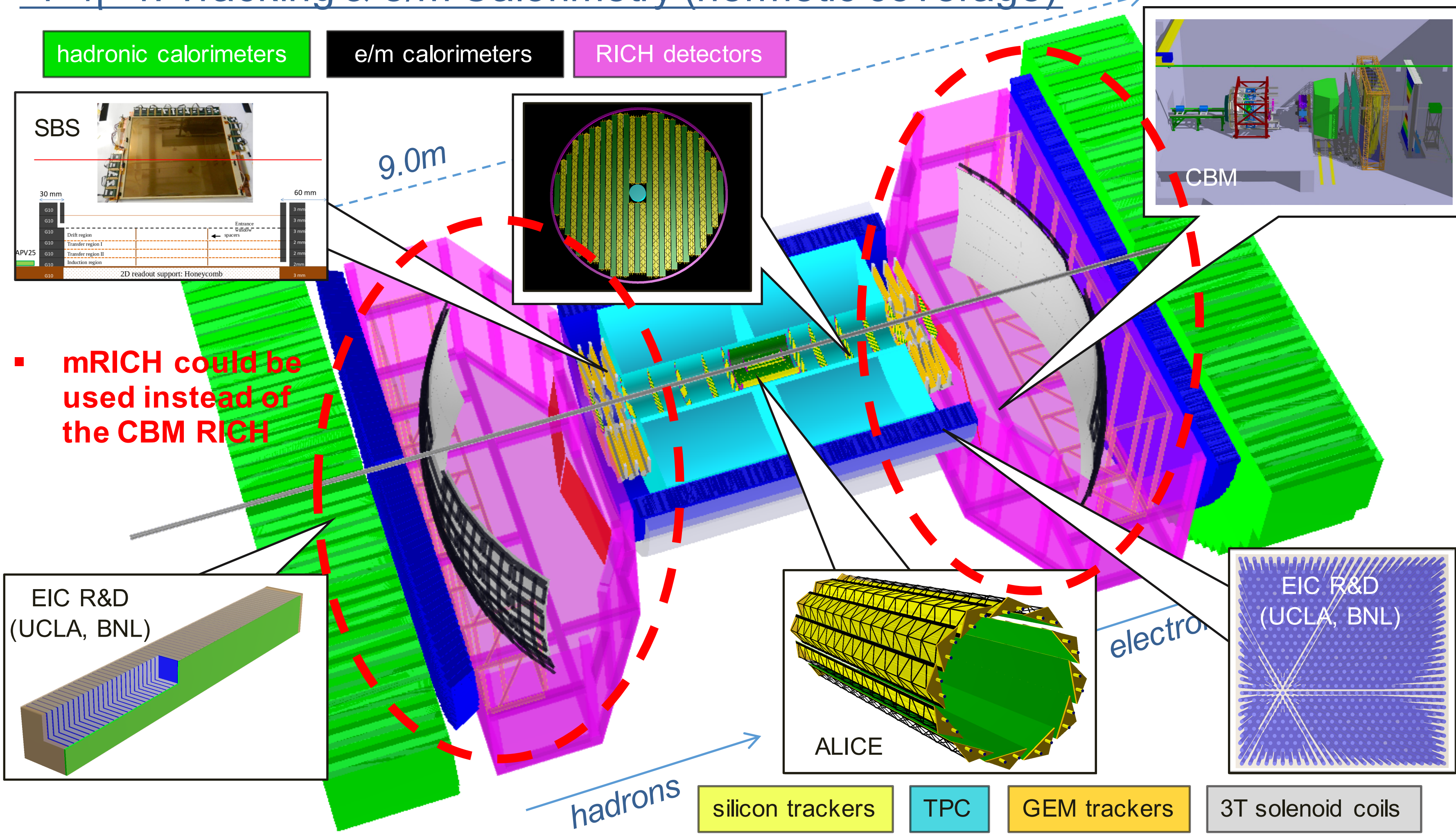
- Reduce cost through new manufacturing methods
- Explore performance limits under experimental conditions

PID in the EIC concept detectors and integration of eRD14 systems

BNL BeAST EIC central detector

- **dRICH could be used instead of the CBM RICH**

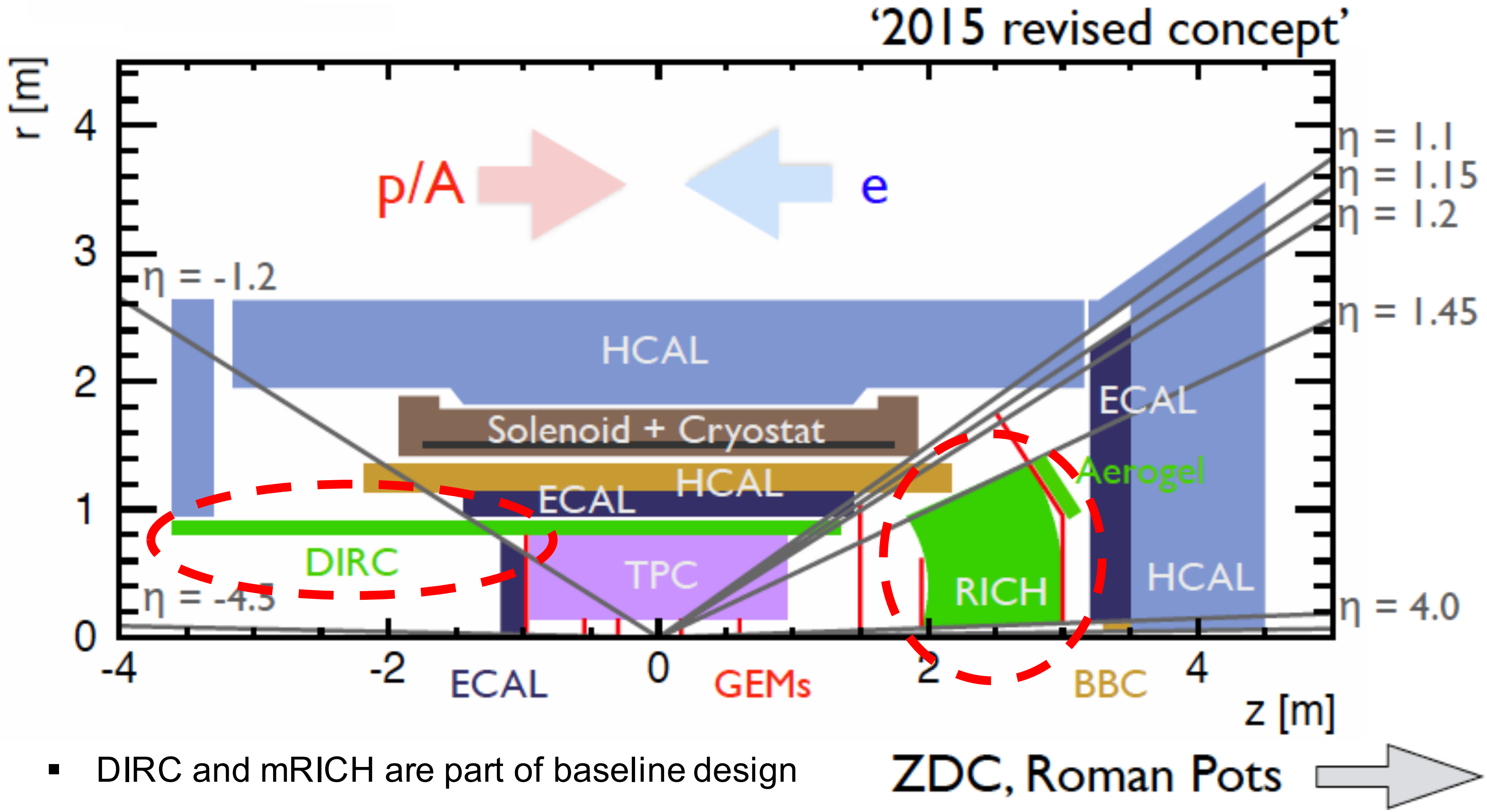
-4<η<4: Tracking & e/m Calorimetry (hermetic coverage)



- **mRICH could be used instead of the CBM RICH**

- **DIRC could be added to barrel**

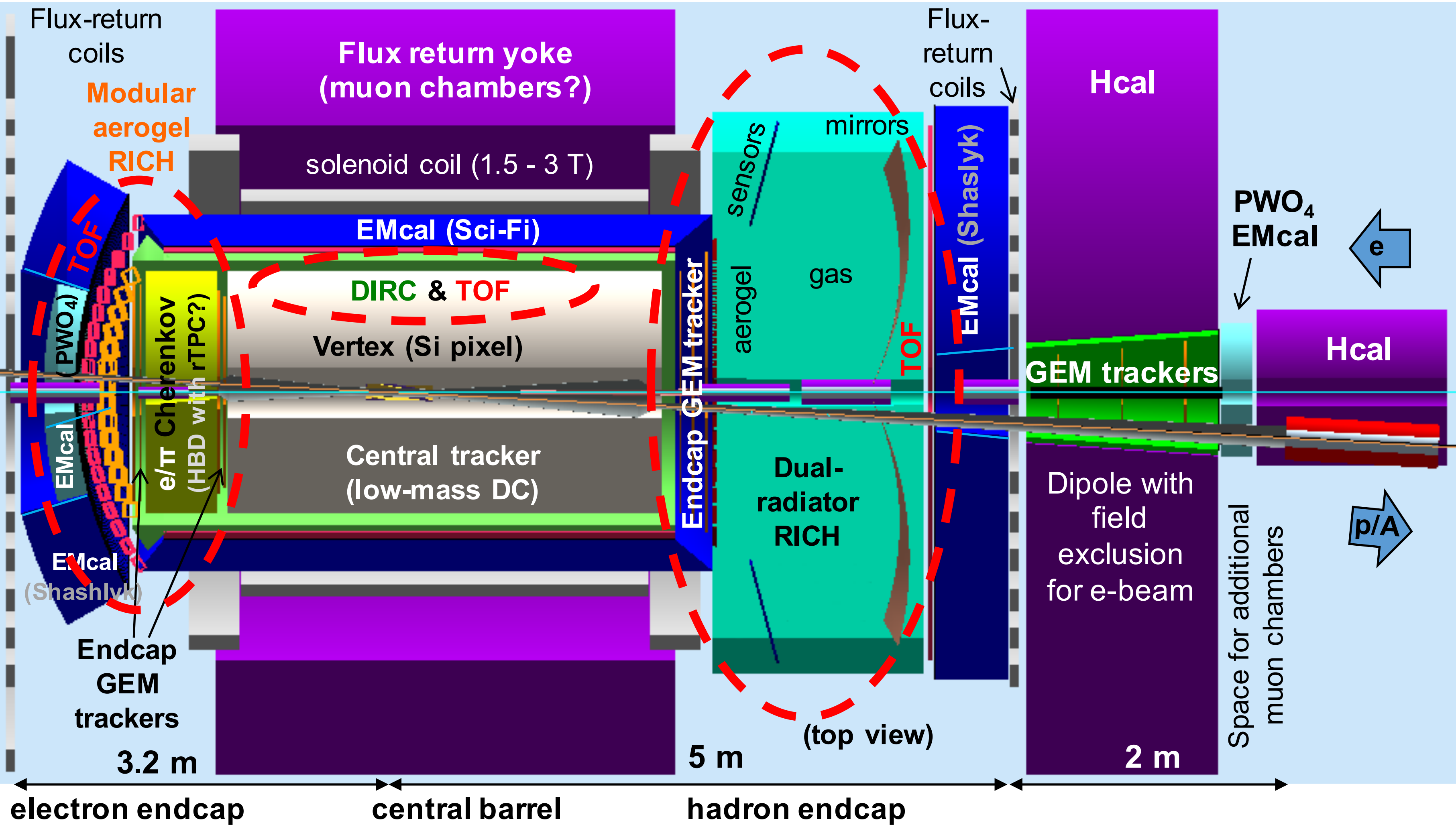
BNL ePHENIX/Celeste EIC central detector



- DIRC and mRICH are part of baseline design
- dRICH and TOF are options for ePHENIX
- mRICH could also be used on e-endcap

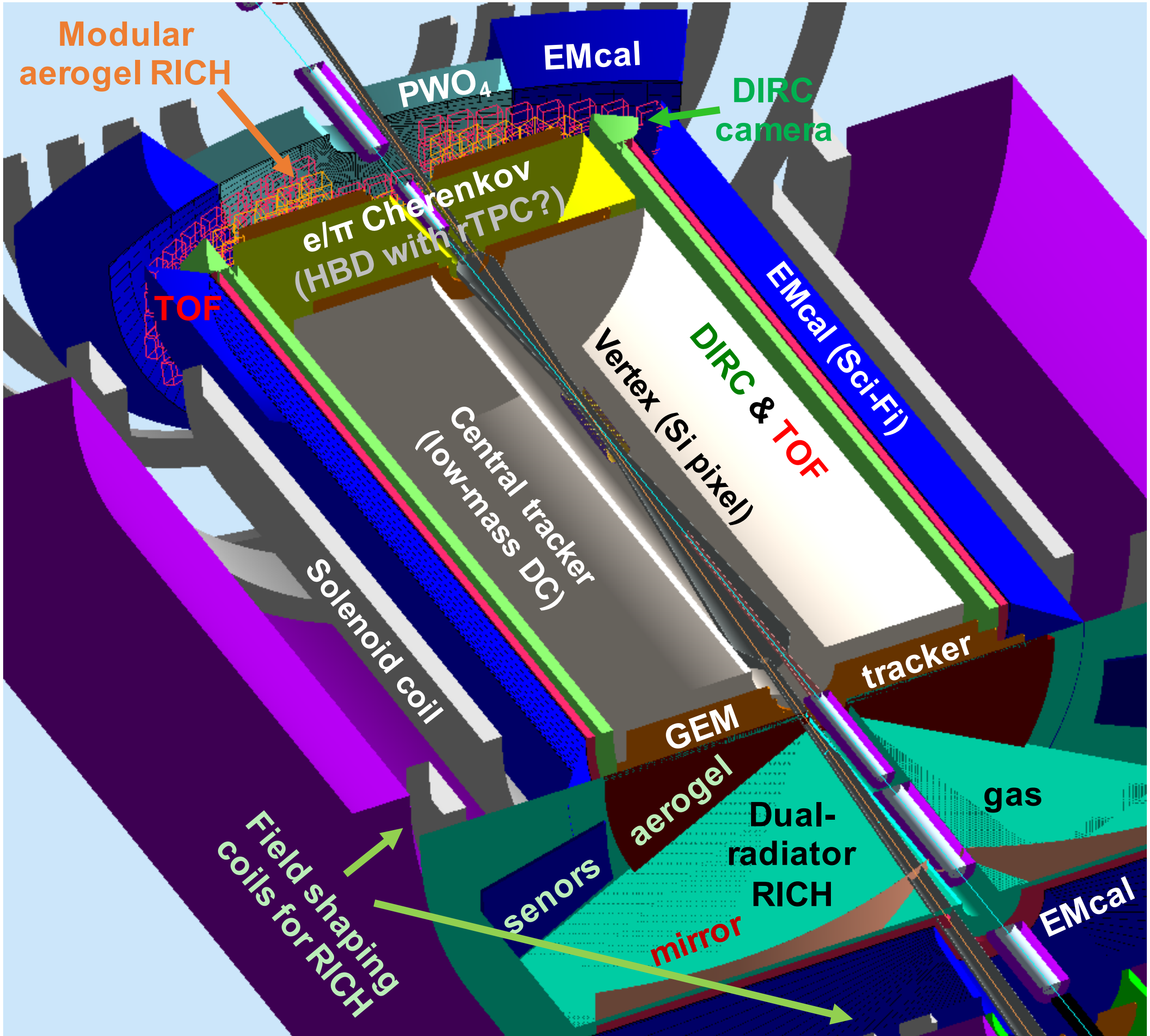
N. Feege, EIC UG meeting, Jan 2016

JLab EIC central detector



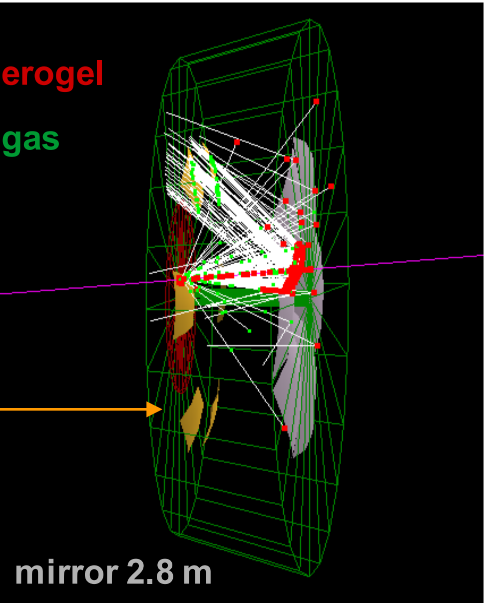
- All eRD14 technologies (mRICH, dRICH, DIRC, TOF) are part of baseline design

PID integration (JLab EIC central detector example)



Dual-radiator RICH (dRICH)

dRICH – FY16 report



Goal pi/K/p ID from 2.5 to 50 GeV/c

e/pi ID up to 20 GeV/c

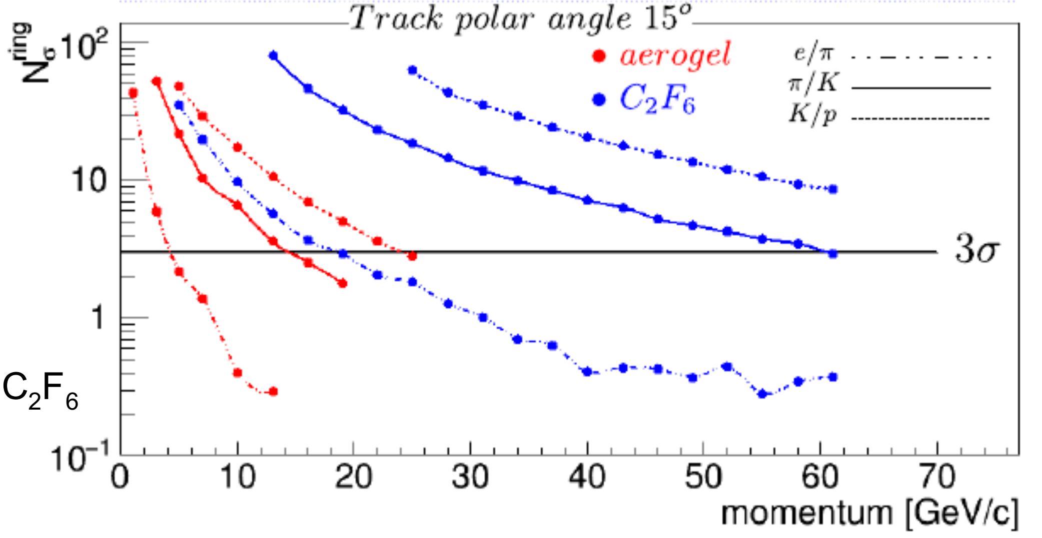
6 sectors of 60° in azimuthal angle

Radiators: aerogel (1.02) & C_2F_6 (or CF_4) gas

photondetector, spherical shape *8500 cm²* (per sector)

Layout: Outward reflecting mirrors
(focal plane sensors away from the beam, light not reflected back through aerogel, 3D focus reduces sensor area)

Discrimination power for particles species



Simulation:

- Angular coverage 5°-25°
- MC data by Geant4 (GEMC)
- Reconstruction using Inverse Ray Tracing (IRT)

- Software cut at 300 nm on aerogel light
- Errors for 3T solenoid field
- Focal plane position not yet optimized for C_2F_6

dRICH – FY16 report

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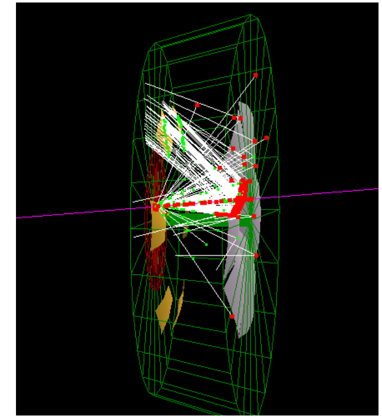

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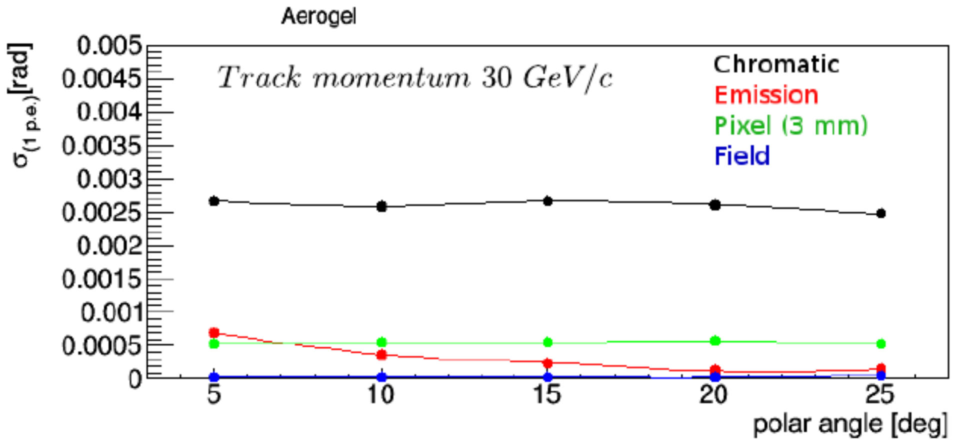
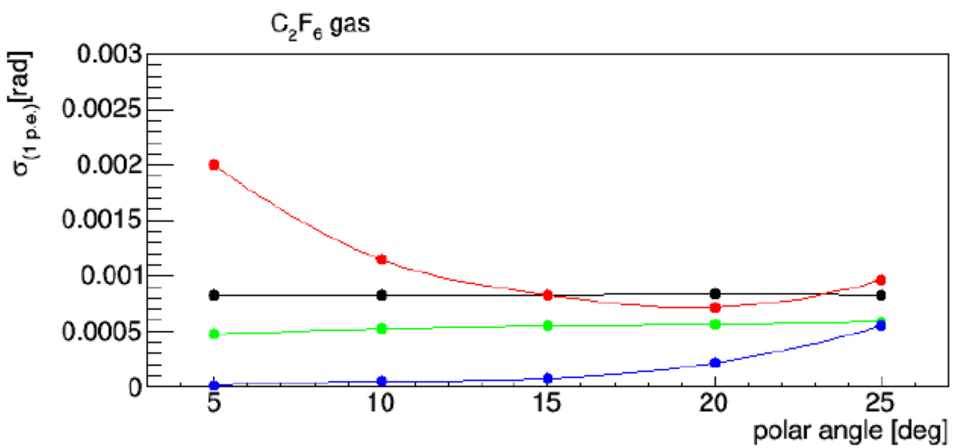
1 p.e. error contributions





dRICH – proposed FY17 activities

FY17 (simulation):

- Study of the background, with acrylic shield separating the aerogel from the gas.

- Comparison and improvement of reconstruction algorithms, is expect to reduce some sources of error (emission error, magnetic field error)

- GEMC based digitalization of the photodetector

- Formulation of requirements on the EIC detector for optimal RICH performance (magnetic field, track reconstruction, etc)

- Adapt the dual-radiator RICH to better fit the (smaller) BNL versions of the EIC detector

FY17 (toward a prototype):

- Identification of baseline photon detector candidates

- Study and definition of a small scale prototype

FY18:

- Study of performance with physical background in the EIC detector

- Configuration and simulation of a small scale version of the dual-radiator RICH

- Realization of the prototype, beam test, data analysis, and MC validation

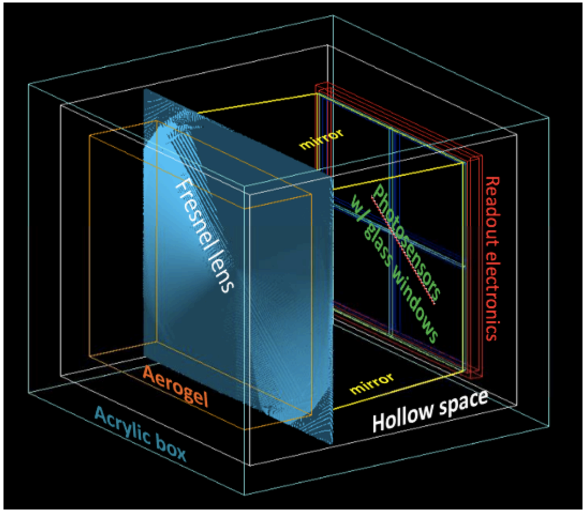
Modular aerogel RICH (mRICH)

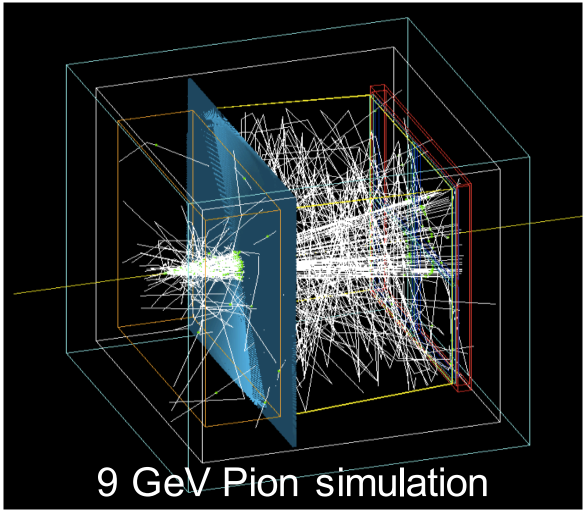
mRICH – FY16 report

mRICH is designed for hadron identification covering a momentum range of 3-10 GeV/c.

Improved mRICH detector simulation using GEMC

- **Using realistic optical properties of aerogel (based CLAS12 aerogel blocks) and Fresnel lens, including Rayleigh scattering and absorption length.**
- Adding borosilicate glass windows at the photosensor plane to match the optical material of the H12700A PMT used for the beam test.
- Continued PID feasibility studies by analyzing the Geant4 simulated data using the maximum likelihood method.





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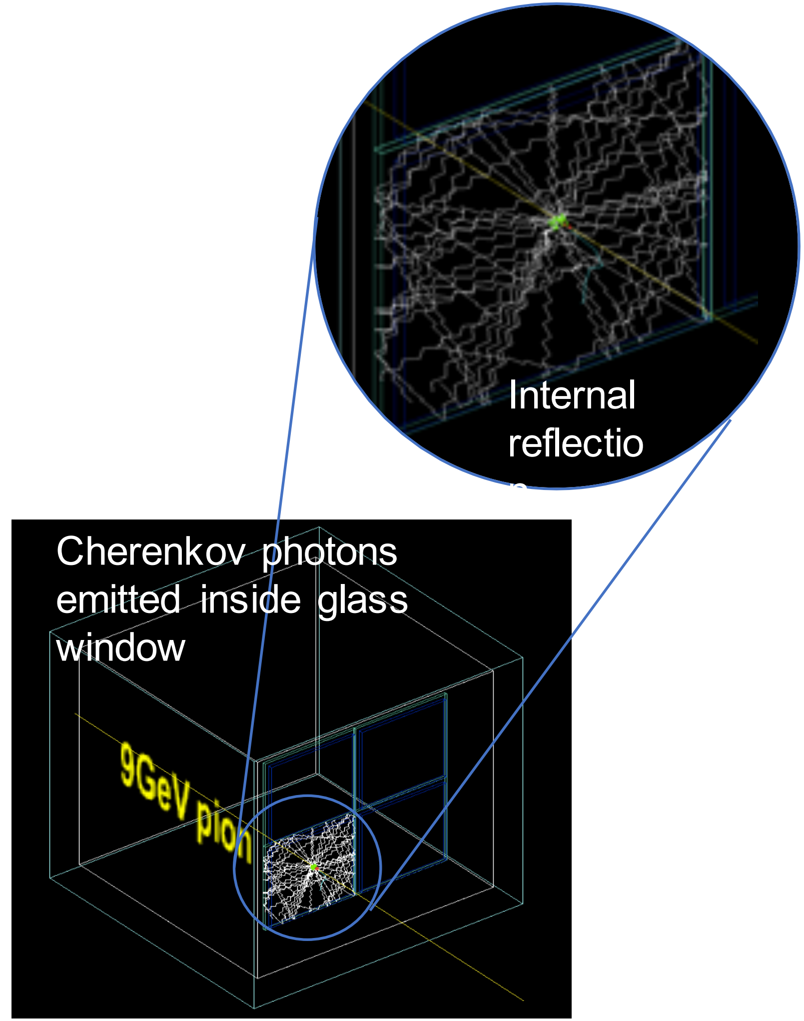

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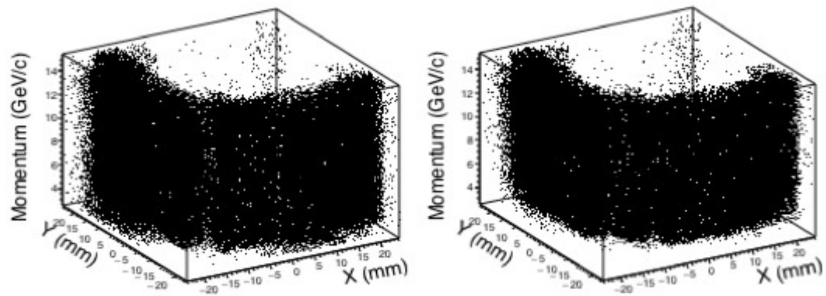
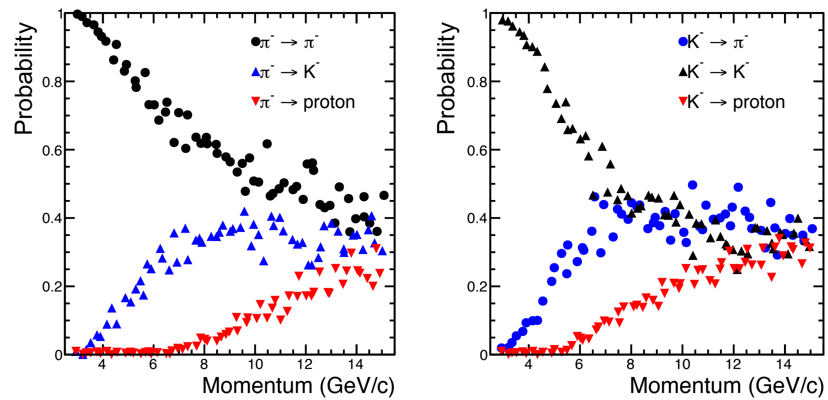
π, angle (θ,ϕ) =(5°,45°) K, angle (θ,ϕ) =(5°,45°)



Particle response distribution generated from simulation.



PID performance from the maximum likelihood method using the response distributions shown above.

mRICH – FY16 report

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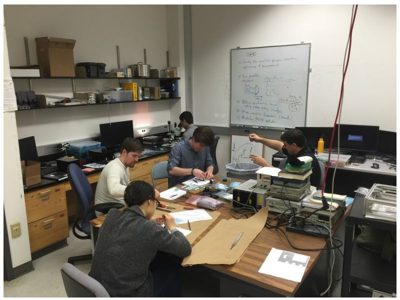
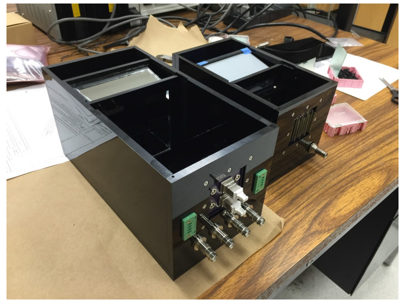
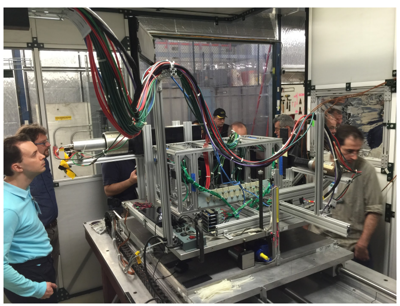

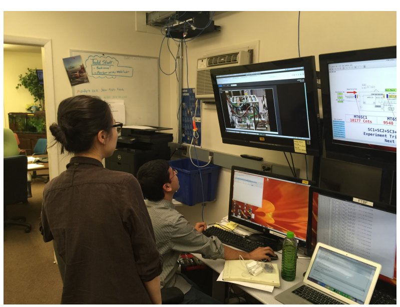


mRICH prototype development and beam test at Fermilab

- **A prototype was successfully built by GSU group (with GSU internal funding).**
- **Tested at Fermilab, April 18-29, 2016 with a proton beam at 120 GeV/c and pion beams at 4 and 8 GeV/c.**
- **The principle of the mRICH was demonstrated and the data analysis is ongoing.**
- The plots show the comparison of Cherenkov rings from 120 GeV/c primary proton beam between the test beam results and the simulated results.

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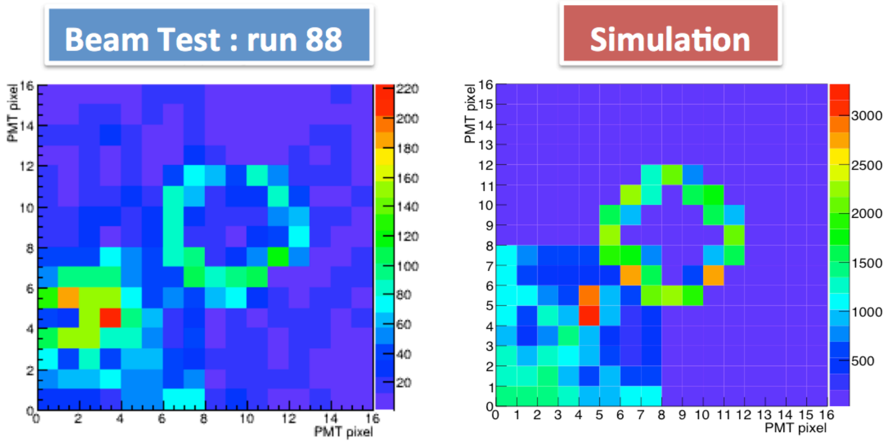
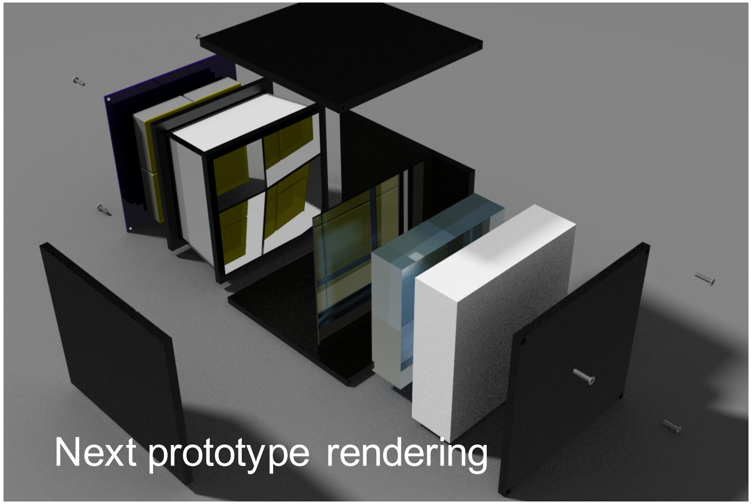


The 120 GeV/c proton beam was incident toward the lower left quadrant of the detector. The produced Cherenkov ring was shifted toward the central region of the sensor plane.

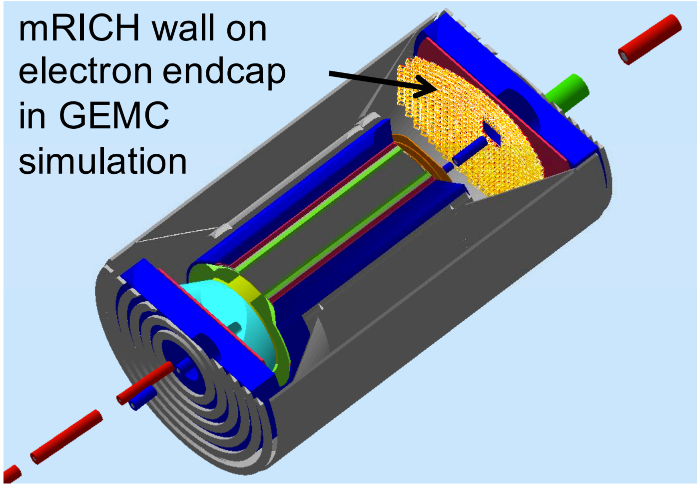
mRICH – proposed FY17 activities

- Preparation of the second prototyping test
  - Decouple the optical and readout components for easy integration and avoiding overheating the electronics.



  - Need to use finer photosensors (3mm x 3mm or smaller) in order to stablishPID capability

- First prototype data analysis and publication
- Continued Geant4 simulation
  - Systematic simulation studies of Aerogel and Fresnel lens to optimize the Cherenkov ring image on the sensor plane.
  - Performing systematic mRICH simulation studies within the EIC detector configuration.



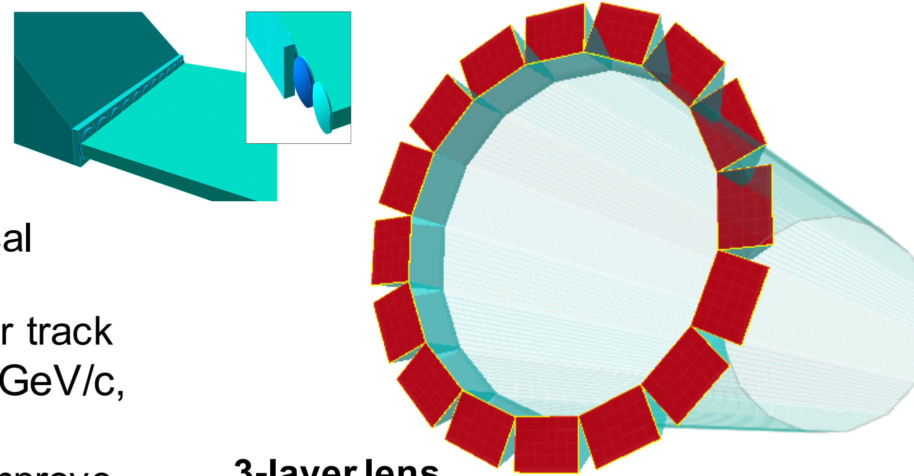
High-performance DIRC

DIRC – FY16 report

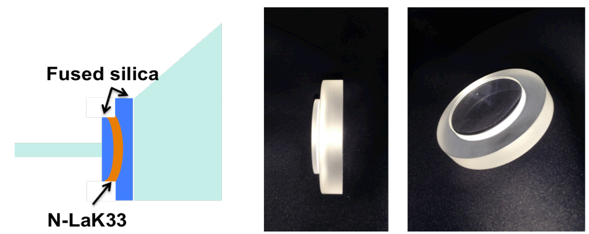
High-performance DIRC simulations

- DIRC@EIC with 3-layer lens using geometrical reconstruction:
  - 1 mrad Cherenkov angular resolution per track
  - 3σ separation of p/K@10GeV/c, π/K@6GeV/c, and e/π@1.8GeV/c
- Time-based reconstruction has potential to improve significantly momentum coverage and lower the cost
- General paper on high-performance DIRC published in JINST

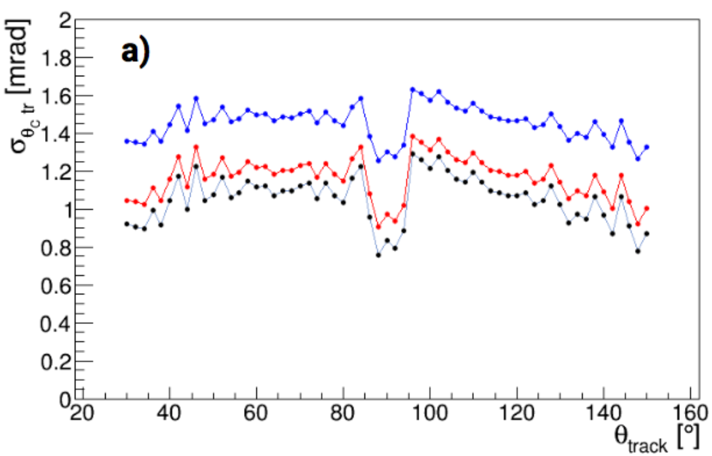
High-performance DIRC in Geant4



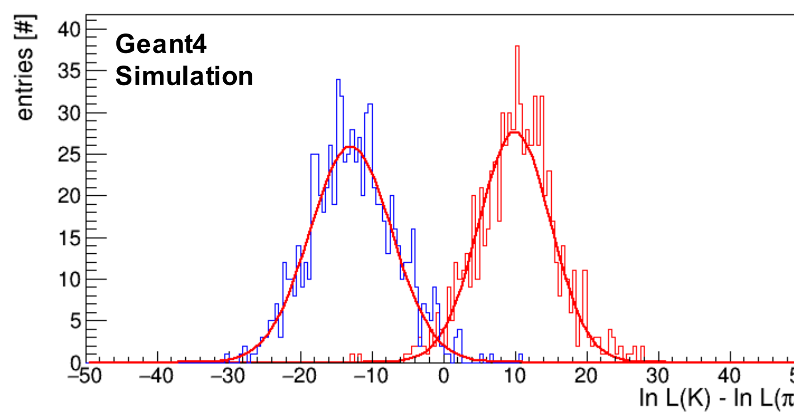
3-layer lens



Per-track Cherenkov angle resolution using geometrical reconstruction



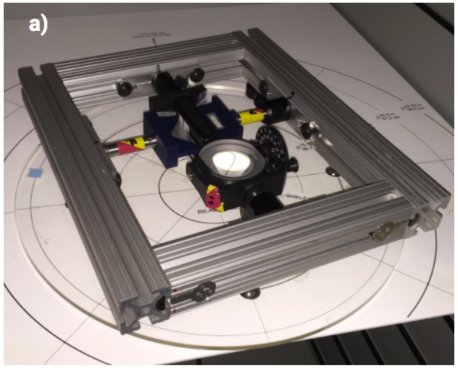
Demonstrated 4.3σ π/K separation at 6 GeV/c using time-based reconstruction



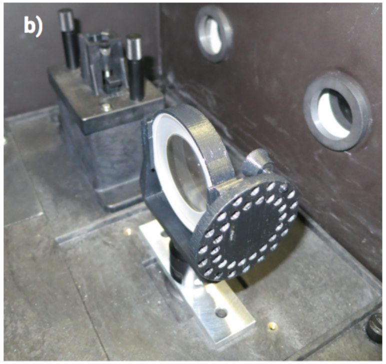
DIRC: validation of 3-layer lens

Experimental tests with 3-layer lens:

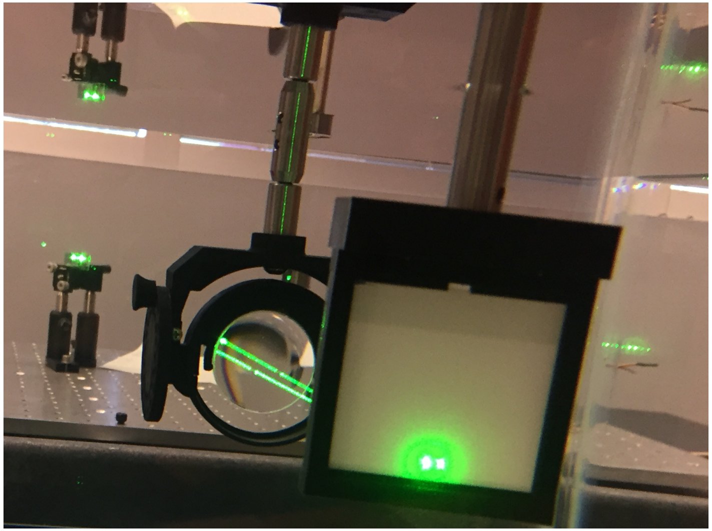
- Radiation hardness test at CUA – setup ready, calibration of X-Ray setup in progress
- Mapping focal plane at ODU – measured, analysis in progress



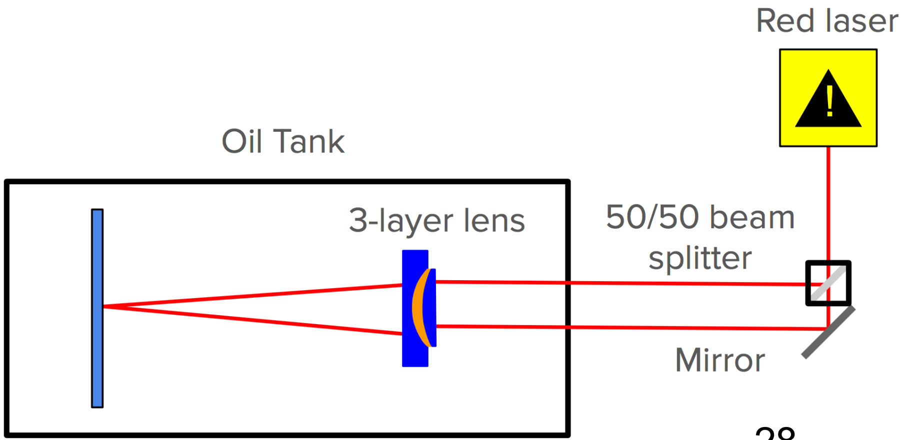
X-Ray setup at CUA



Monochromator at CUA



Laser setup at ODU



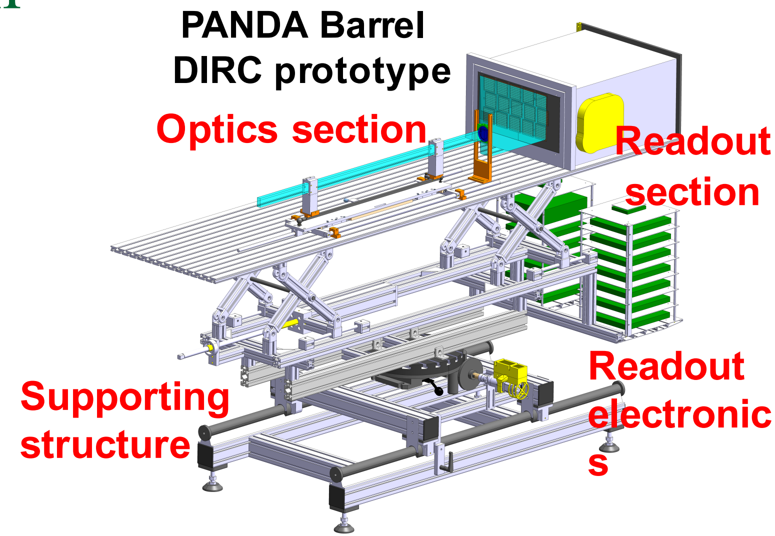
G. Kalicy, L. Allison and T. Hartlove

DIRC: validation of simulation

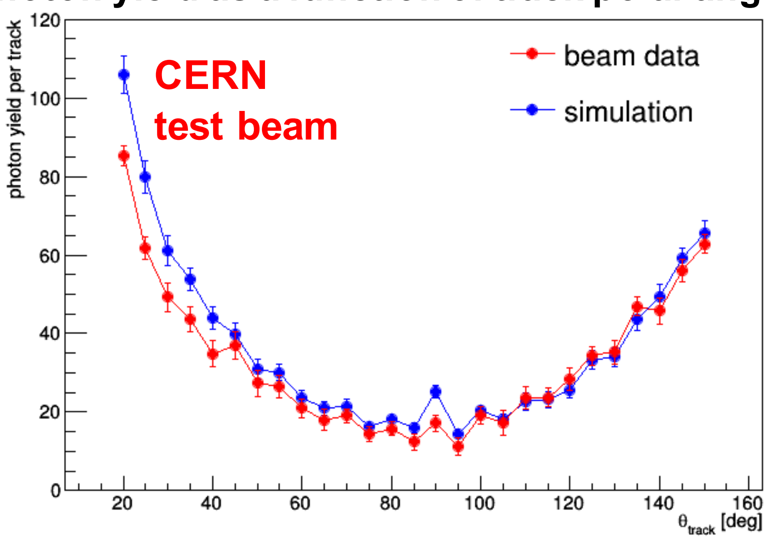
Experimental tests of 3-layer lens:

- Performance in prototype in test beam at CERN
  test beam data analyzed
  detector simulation validated!

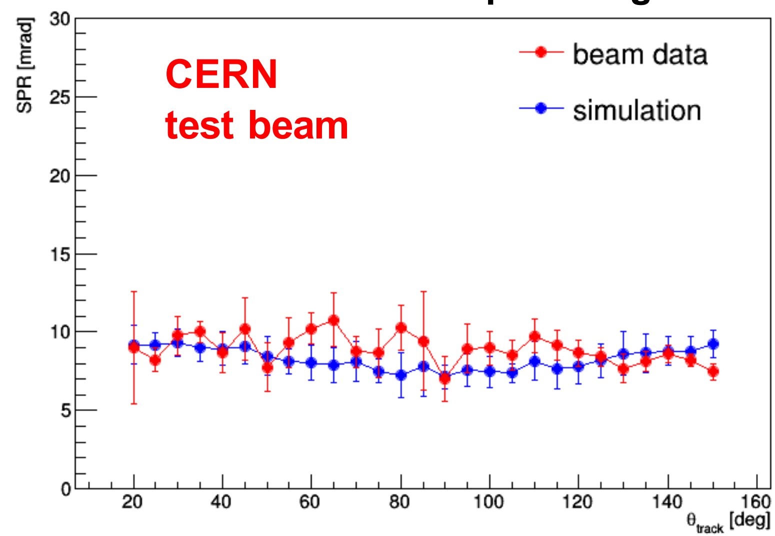
- PANDA geometry with DIRC@EIC 3-layer lens
  synergy with PANDA DIRC group



Photon yield as a function of track polar angle



Single-photon resolution as a function of track polar angle



G. Kalicy, L. Allison and PANDA Barrel DIRC group

DIRC – proposed FY17 activities

Simulation

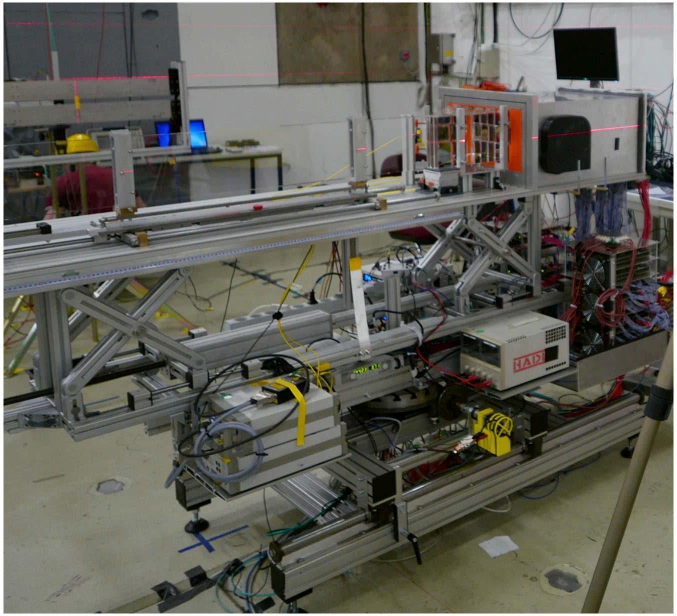
- Optimize sensor and electronics requirements for high-performance DIRC using both geometrical and time-based reconstruction.
- Prepare cost optimized baseline design of high-performance DIRC.

Hardware

- Design and build prototype of cylindrical 3-layer lens and measure it in lab and in particle beam.
- Finish radiation hardness test at CUA.
- Investigate possibility of building 3-layer lens made of PbF_2.
- Write paper on properties and performance of 3-layer lens.

- **Preparation to move PANDA DIRC prototype to the U.S. after PANDA finishes its R&D program (in FY18?).**

PANDA Barrel DIRC prototype



High-resolution mRPC TOF

TOF – FY16 report

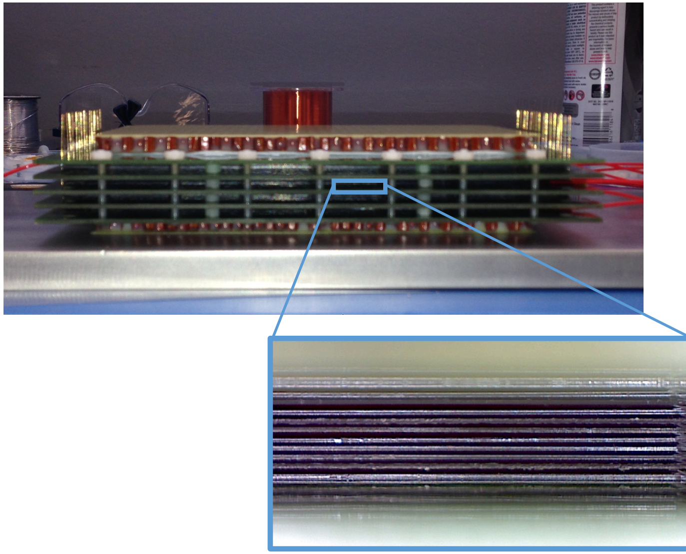
Goal: TOF PID with 5-10 ps resolution

- Developing mRPC and MCP-PMT options
- 3σ separation capability (assuming 10 ps):
  - Barrel: π/K@3.5, K/p@6 GeV/c
  - Forward: π/K@6.5, K/p@11 GeV/c
- Compact (only ~10 cm radial space required)
- Very cost effective PID detector

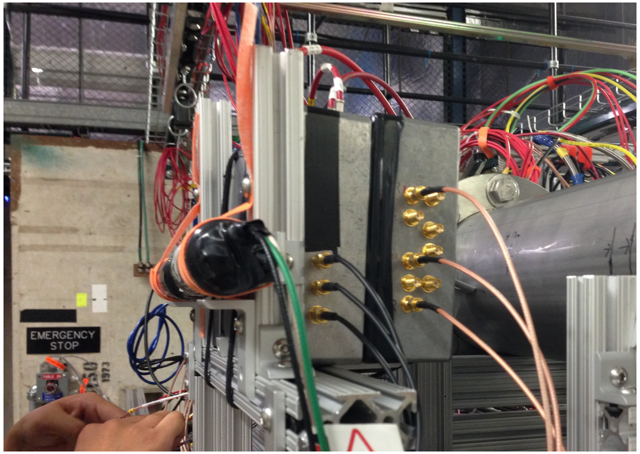
Accomplishments To Date

- Established 36 gap glass mRPCs have 18-25 ps resolution and tested up to ~80 Hz/cm^2/s
- Built and testing 3D printed mRPC
- Built mechanically stable 48 gap mylar mRPC
  - Unstable electrically due to static buildup
- Built UV sensitive MCP-PMT (fused silica) at ANL, under testing
- Built fast preamp with 8GHz TI LMH5401

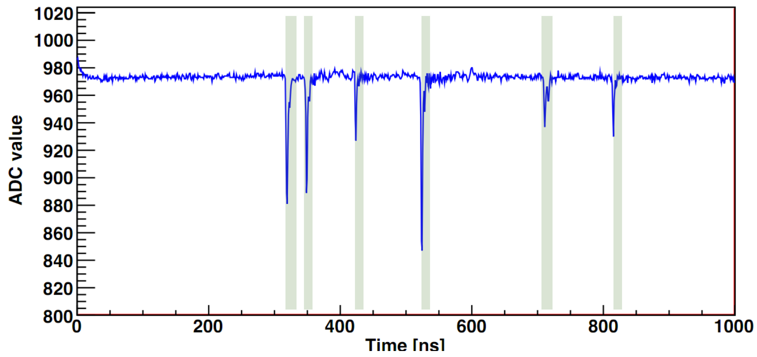
Mylar mRPC



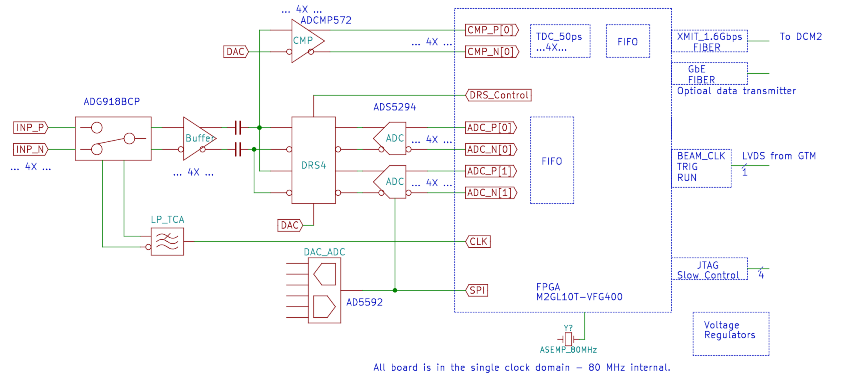
ANL UV MCP-PMT test @ FTBF



TOF – proposed FY17 activities



Block diagram for DRS4 prototype board using windowed readout for EIC



- Electronics Development
  - DRS4 prototype digitization board using self-triggered window-readout
    - Capable of working at the EIC (long trigger latency allowed)
    - Possible synergy with high energy, e.g., 10 ps at the HL-LHC
  - Further Preamp Development after more testing
- Evaluate best dielectric option for mRPC going forward
  - Anti-static mylar, 3D printed plastic, or glass mRPCs?
    - With mylar, can have much thinner mRPCs (48 gaps!)
  - Comparative tests between all in cosmic rays and test beam
- UV sensitive MCP-PMT from ANL for TOF
  - Characterize in detail for its timing capabilities with lasers, and tested with cosmics rays and test beam
- Simulation: Garfield++ model of mRPCs will continue to be developed

Photosensors and Electronics

Photosensors and Electronics – overview

Objectives

- To identify and assess suitable photosensor and electronics solutions for the readout of the EIC Cherenkov detectors.
- To support development if photosensor technologies for the EIC Cherenkov detectors (LAPPD, GEM).

Expected Outcome: A cost-efficient readout solution, ideally, a common to several of the detectors within the EIC-PID consortium. The short-term focus is on the RICH and DIRC prototypes.

Sensor Requirements

Parameter	DIRC	Modular RICH	Dual RICH
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	≤ 1 kHz/cm^2	≤ 5 MHz/cm^2	≤ 5 MHz/cm^2
Radiation Hardness	Yes	Yes	Yes
Single-photon mode?	Yes	Yes	Yes
Magnetic-field Resistance?	Yes (1.5 – 3 T)	Yes (1.5 – 3 T)	Yes (1.5 – 3 T)
Photon Detection Efficiency	≥ 20%	≥ 20%	≥ 20%
Sensor Candidates	MCP-PMT, LAPPD	GEM, SiPM, LAPPD, MCP-PMT	GEM, SiPM, LAPPD, MCP-PMT

Photosensors and Electronics – overview

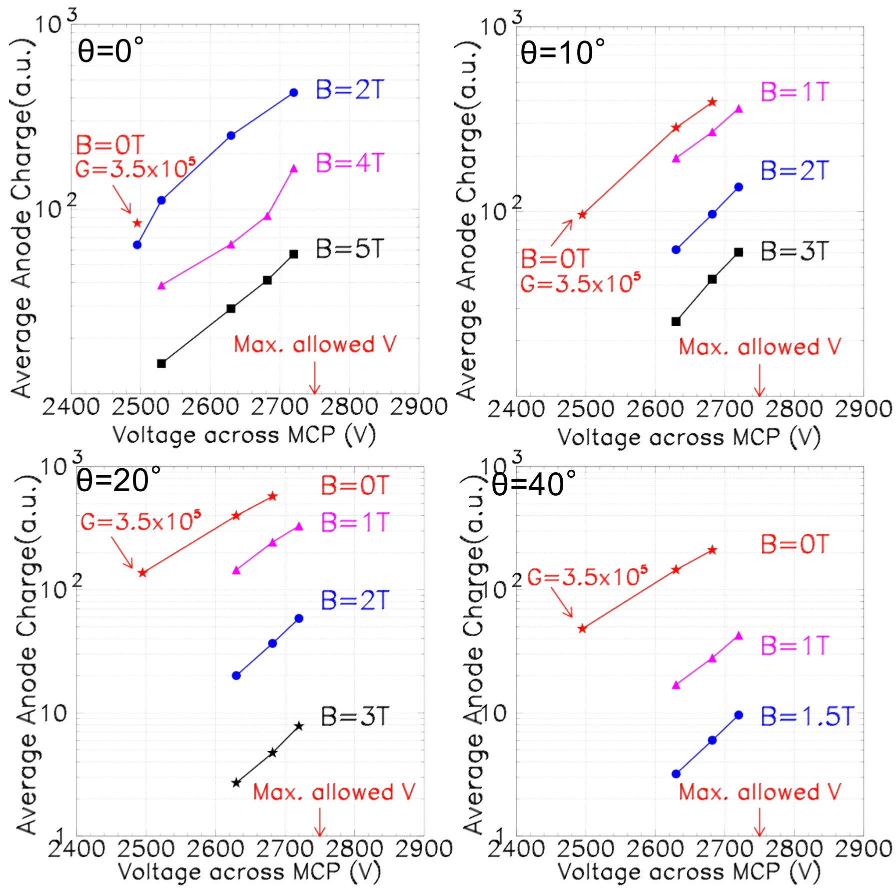
- **Sensors in High-B Field**
  - To assess the gain and timing performance of commercially available MCP PMTs (Photonis, Photek, Hamamatsu) in high magnetic fields and for various relative orientations of the sensor and the B-field.
  - To achieve an MCP-PMT design and operational parameters that are optimized for successful application in the high magnetic field (1.5–3 T) of the EIC detector.
- **LAPPDs**
  - To create a pixelated MCP-PMT that has similar performance to existing MCP-PMTs, but at a lower cost.
  - To optimize the design for operation in high magnetic fields
- **Photosensors and Electronics for Detector Readout**
  - Assess and identify the most cost-efficient option to instrument the RICH and DIRC prototypes with readout sensors and electronics. Ideally, the readout would be common and shared among the three prototypes (FY17)
  - Develop electronics readout solution to instrument the prototypes (FY18)

Photosensors and Electronics – FY16 report

Sensors in High-B Fields

- **Studied gain recovery by increasing HV across individual MCP-PMT stages**
- The HV across the micro-channel plates has the largest effect on gain recovery.
- **Results and Findings published: JINST 11, C03061 (2016)** http://dx.doi.org/10.1088/1748-0221/11/03/C03061 (Conference proceedings of DIRC2015 workshop).
- Design and construction of a universal HV divider and power supply allowing to control the voltages across the internal MCP-PMT stages independently:
- Will serve further measurements of multi-anode MCP-PMTs (Hamamatsu, Photonis, Photek).

Gain Performance as a Function of $V_{MCP-MCP}$ for single-anode 3-µm pore-size sensor (Photek PMT210)



θ: angle between sensor and B-field axes

Photosensors and Electronics – FY16 report

Sensors in High-B Fields

- Studied gain recovery by increasing HV across individual MCP-PMT stages

- The HV across the micro-channel plates has the largest effect on gain recovery.

- Results and Findings published: JINST 11, C03061 (2016) http://dx.doi.org/10.1088/1748-0221/11/03/C03061 (Conference proceedings of DIRC2015 workshop).

- **Design and construction of a universal HV divider and power supply allowing to control the voltages across the internal MCP-PMT stages independently**

- Will be used for measurements of multi-anode MCP-PMTs (Hamamatsu, Photonis, Photek).

Universal HV Power Supply and Divider for High-B Tests, June 2016

People: J. McKisson (JLab), J. Defazio (Photonis), T. Hartlove (ODU), G. Kalicy (ODU),

Photosensors and Electronics – proposed FY17 activities

Sensors in High-B Fields

- MCP-PMT gain measurements of multi-anode MCP-PMTs from different manufacturers for various operational parameters (B, θ, φ, HV) in B-fields up to 5 T.
- Development of GEANT simulation of MCP-PMT for studies of MCP-PMT performance in high B-fields for various design parameters.
- Design and construction of laser optics box for timing measurements.
- Submission of results for publication.

LAPPDs

- QE studies of the UV-sensitive MCP-PMT produced by ANL will be completed at BNL. A measurement of the QE, as well as the TTS, will be done vs. wavelength down to 170 nm.
- ANL will produce a modified MCP-PMT with a much smaller gap between the two MCPs. This will then be tested to see if this enhances their capabilities in a magnetic field.
- ANL will produce a version of the MCP-PMT with a pixelated readout, using either a ceramic base with feed-through pins, or via capacitive pickup through a resistive anode.
- If possible, a 20x20 cm^2 MCP-PMT will be procured from Incom, and initial studies of the time resolution, position resolution, and magnetic field susceptibility will be done. Due to the large size, the high B-field tests will need to be done at ANL in the g-2 magnet test facility.

Photosensors and Electronics – proposed FY17 activities

Readout Sensors and Electronics for Detector Prototypes

- Instrument the mRICH prototype for the next test beam (3-mm pixel-size PMT is critical)
  - Sensors: procure one unit H13700 MaPMT with 3-mm pixel size (256 channels) and borrow 3-mm pixel-size SiPMs from the JLab detector group to partially cover the prototype sensor area with small-pixel readout.
  - Electronics: modify the CLAS12 RICH electronics to read out above sensors (INFN group).
- Investigate the best sensor solution(s) for the RICH and DIRC prototypes.
- Investigate the most cost effective way to develop readout electronics for the RICH and DIRC prototypes.
  - Workshop on electronics solutions for RICH and DIRC prototypes: limitations of current solutions, possible adaptations, needs for development.
  - Formulate a staged plan (proposed activities and budgets for FY18 and the following years).

Publications and Presentations

List of publications and presentations (1-10)

- C. Nickle, *Experimental Setup for Magnetic-Field Tests of Small-Size Light Sensors at Jefferson Lab*, poster presentation at the Conference Experience for Undergraduates at the 2013 Fall Meeting of the APS Division of Nuclear Physics, October 23–26, 2013, Newport News, VA; BAPS.2013.DNP.EA.121.
- E. Bringley *et al.*, *Experimental Setup and Commissioning of a Test Facility for Gain Evaluation of Microchannel-Plate Photomultipliers in High Magnetic Field at Jefferson Lab*, poster presentation at the Conference Experience for Undergraduates at the 4th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, October 7–11, 2014, Waikoloa, Hawaii; BAPS.2014.HAW.GB.140.
- H. Hamilton, *Time of Flight Detector Development for Future Heavy Ion Experiments*, poster presentation at the Conference Experience for Undergraduates at the 4th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, October 7–11, 2014, Waikoloa, Hawaii; BAPS.2014.HAW.GB.149.
- C. Towell, *Developing a High Precision Cosmic Test Stand for PHENIX Research and Development*, poster presentation at the Conference Experience for Undergraduates at the 4th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, October 7–11, 2014, Waikoloa, Hawaii; BAPS.2014.HAW.GB.147
- H. Hamilton, *Improved Timing Instruments for Particle Identification*, oral presentation at the Abilene Christian University Undergraduate Research Festival, March 31, 2015, Abilene, TX.
- C. Towell, *Building Detectors to Study a New Phase of Matter*, oral presentation at the Abilene Christian University Undergraduate Research Festival, March 31, 2015, Abilene, TX.
- E. Bringley *et al.*, *Experimental Setup and Commissioning of a Test Facility for Gain Evaluation of Microchannel-Plate Photomultipliers in High Magnetic Field at Jefferson Lab*, poster presentation at the University of South Carolina Discovery Day, 24 April 2015, Columbia, SC.
- C. Barber, *Gain Evaluation of Micro-Channel-Plate Photomultipliers in the Upgraded High-B Test Facility at Jefferson Lab*, poster presentation at the Conference Experience for Undergraduates at the 2015 Fall Meeting of the APS Division of Nuclear Physics, October 28–31, 2015, Santa Fe, NM; BAPS.2015.DNP.EA.37.
- H. Hamilton, *Testing of multigap Resistive Plate Chambers for Electron Ion Collider Detector Development*, poster presentation at the Conference Experience for Undergraduates at the 2015 Fall Meeting of the APS Division of Nuclear Physics, October 28–31, 2015, Santa Fe, NM; BAPS.2015.DNP.EA.9.
- C. Towell, *Cosmic Test Stand Development for Electron Ion Collider Detector R&D*, poster presentation at the Conference Experience for Undergraduates at the 2015 Fall Meeting of the APS Division of Nuclear Physics, October 28–31, 2015, Santa Fe, NM; BAPS.2015.DNP.EA.20.

List of publications and presentations (11-21)

- H. Hamilton, *Testing of Advanced Particle Detectors for the Next Generation Particle Collider*, oral presentation at the Abilene Christian University Undergraduate Research Festival, 5 April 2016, Abilene, TX.
- C. Towell, *Development of an Electron Ion Collider Detector Test Stand*, oral presentation at the Abilene Christian University Undergraduate Research Festival, 5 April 2016, Abilene, TX.
- Y. Ilieva for the EIC DIRC Collaboration, *MCP-PMT Studies at the High-B Test Facility at Jefferson Lab*, invited talk at the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.
- Y. Ilieva *et al.*, *MCP-PMT Studies at the High-B Test Facility at Jefferson Lab*, JINST **11**, 2016; http://dx.doi.org/10.1088/1748-0221/11/03/C03061. Proceedings of the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.
- A. Del Dotto for the EIC PID consortium, *Design and R&D of RICH detectors for EIC experiments*, accepted for RICH 2016, 9th International Workshop on Ring Imaging Cherenkov Detectors, Slovenia on September 5-9, 2016 (proceedings will be published in NIMA).
- Z.W. Zhao for the EIC PID consortium, EIC RICH R&D, presentation at EIC User Group Meeting, January 2016.
- G. Kalicy for the EIC DIRC Collaboration, High-performance *DIRC detector for Electron Ion Collider*, invited talk at the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.
- L. Allison for the EIC DIRC Collaboration, *Studies of prototype 3-component lens in CERN test beam and on a test bench at ODU*, invited talk at the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.
- L. Allison for the EIC DIRC Collaboration, *Particle ID with DIRC Detectors*, invited talk at ODU Nuclear Group Seminar, March 17, 2016.
- G. Kalicy *et al.*, High-performance *DIRC detector for Electron Ion Collider*, submitted to JINST, 2016; Proceedings of the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.
- G. Kalicy *et al.*, High-performance *DIRC detector for Electron Ion Collider*, submitted to JINST, 2016; Proceedings of the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.

List of publications and presentations (22-30)

- G. Kalicy for EIC DIRC Collaboration , *DIRC@EIC*, presentation at EIC User Group Meeting, January 2016.
- G. Kalicy for EIC DIRC Collaboration, *DIRC detectors*, presentation for seminar in JLab, December 2015.
- G. Kalicy for EIC DIRC Collaboration, *Photosensors tests at high B facility in JLab*, presentation on meeting with Photonis in Lancaster, PA,October 2015.
- G. Kalicy for EIC DIRC Collaboration, *Photosensors tests at high B facility in JLab*, presentation on meeting with Hamamatsu at JLab, September 2015.
- G. Kalicy for EIC DIRC Collaboration, *Developing DIRC Technology*, presentation at ODU Colloquium Norfolk VA, April 2015.
- C.P. Wong, *Simulation Study of RICH Detector for Particle Identification in Forward Region at Electron-Ion Collider*, oral presentation at APS April Meeting 2015, April 11-14, 2015, Baltimore, MD.
- J. Xie *et al.*, *Planar microchannel plate photomultiplier with VUV-UV-Vis full range response for fast timing and imaging applications*, accepted for RICH 2016, 9th International Workshop on Ring Imaging Cherenkov Detectors, Slovenia on September 5-9, 2016 (proceedings will be published in NIMA).
- J. Xie *et al.*, *Development of a low-cost fast-timing microchannel plate photodetector*, Nucl. Instrum. Meth. A 824 (2016) 159-161.
- J. Wang *et al.*, *Development and testing of cost-effective, 6cm × 6cm MCP-based photodetectors for fast timing applications*, Nucl. Instrum. Meth. A 804 (2015) 84-93.

Budget Request

Budget request by activity

	FY17	FY18	*Total*
dRICH	**$55k**	$75k	*$130k*
mRICH	**$85k**	$85k	*$170k*
DIRC	**$98k**	$87k	*$185k*
TOF	**$40k**	$40k	*$80k*
High-B	**$55k**	$60k	*$115k*
LAPPDs	**$90k**	$56k	*$146k*
Electronics	**$21k**	$112k	*$133k*
Total	***$443k***	*$515k*	*$958k*

All numbers include overhead.

Budget request by institution

	FY17	FY18	*Total*
ANL	**$90k**	$56k	*$146k*
BNL	**$40k**	$40k	*$80k*
CUA and GSI	**$72k**	$142k	*$214k*
Duke	**0**	$20k	*$20k*
GSU	**$91k**	$85k	*$176k*
INFN (JLab)	**$55k**	$55k	*$110k*
JLab	**$42k**	$84k	*$126k*
ODU	**$25k**	$5k	*$30k*
USC	**$28k**	$28k	*$56k*
Total	***$443k***	*$515k*	*$958k*

All numbers include overhead.

Backup

Budget details

Dual-radiator RICH

FY17

1.Postdoc (100%, Alessio Del Dotto, INFN/JLab): $55k

Total: $55k

FY18

1.Postdoc (100%, Alessio Del Dotto, INFN/JLab): $55k

2.Prototype (Duke): $20k (aerogel tile (n=1.02), materials & gas)

Total: $75k

Modular aerogel RICH

FY17

Postdoc (50% salary, Sawaiz Syed at GSU): $45k

Graduate student (Cheuk-Ping Wong at GSU): $30k

Travel (beam test): $10k (GSU)

Total: $85k

FY18

Postdoc (50% salary, Sawaiz Syed at GSU): $45k

Graduate student (Cheuk-Ping Wong at GSU): $30k

Travel: $10k (GSU)

Total: $85k

Budget details

DIRC

FY17

Procurement: Radiation hard, three-layer lens (for high-performance DIRC): $11k (CUA)

Postdoc (¾ of year 50%): $33k (CUA)

Undergraduate Student: $8k (CUA)

Graduate Student: $20k (ODU)

Travel: $25k (ODU 5k; CUA 20k for all other travel, including GSI)

Total: $98k

FY18

Costs associated with transport of PANDA prototype from GSI to CUA: $10k

Postdoc (50%): $44k (CUA)

Undergraduate Student: $8k (CUA)

Travel: $25k (ODU 5k; CUA 20k for all other travel, including GSI)

Total: $87k

TOF

FY17

1.Materials for Prototype Electronics + mRPC Development (BNL): $25K

2.Travel (BNL): $15K

Total: $40k

FY18

1.Materials Electronics + mRPC Development (BNL): $25K

2.Travel (BNL): $15K

Total: $40k

Budget details

Sensors in High-B Fields

FY17

1. Timing upgrade for high-B test facility (JLab):
    1. Laser Box, optics, and safety: $10k
2. Liquid Helium, high-B test facility (JLab): $12k
3. Shipping cost of MCP-PMTs on loan (JLab): $2k
4. High-B components (sensor holders, dark box cap modifications, *etc.*) (JLab): $3k
5. Undergraduate students (USC): $15k
6. Travel (USC): $13k

Total: $55k

FY18

1. Timing upgrade for high-B test facility:
    1. High-resolution TDC and Fast Constant Fraction Discriminator: $15k (JLab)
2. Liquid Helium: $12k (JLab)
3. High-B components (sensor holders, dark box cap modifications, *etc.*): $3k (JLab)
4. Shipping cost of MCP-PMTs on loan: $2k (JLab)
5. Undergraduate students (USC): $15k
6. Travel (USC): $13k

Total: $60k

Budget details

LAPPDs

FY17
1. 0.2 FTE Post-doc (ANL): $25k
2. 0.1 FTE Scientist (ANL): $25k
3. 0.1 FTE Technician (ANL): $25k
4. Materials (ANL): $5k
5. Travel (ANL): $10k

Total: $90k

FY18
1. 0.2 FTE Post-doc (ANL): $25k
2. 0.1 FTE Scientist (ANL): $25k
3. Travel: $6k

Total: $56k

Budget details

Readout Sensors and Electronics for Detector Prototypes

FY17

1.Procurement: one MaPMT H13700 (GSU): $6k

2.Adaptation of existing electronics to readout 3-mm pixel-size sensors - H13700 and SiPMs (JLab): $15k

Total: $21k

FY18

Develop a prototype electronics readout for specific sensor solution (JLab):

1.Parts & Materials (ASICs, FPGAs, components, etc): $17k

2.PCB Services (Fab & Assembly): $10k

3.Test Fixtures: $5k

4.Equipment (power supplies, etc): $20k

Sensors:

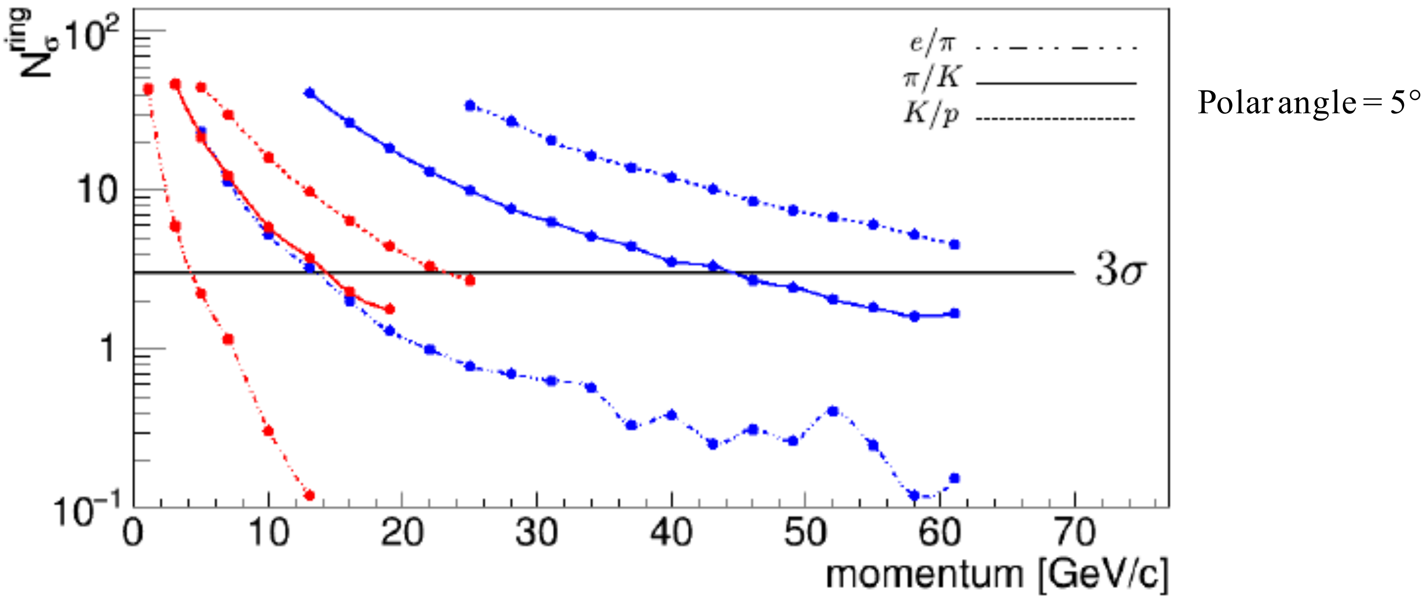
1.Specific sensors will depend on identified solution in FY17 (CUA): $60k

Total: $112K

Dual RICH@EIC FY16 – C_2F_6 at 5°

$Aerogel(n = 1.02) \mid e_{th}(GeV/c) = 0.0025 \mid \pi_{th}(GeV/c) = 0.67 \mid K_{th}(GeV/c) = 2.46 \mid p_{th}(GeV/c) = 4.89$

$C_2F_6(n = 1.00082) \mid e_{th}(GeV/c) = 0.0123 \mid \pi_{th}(GeV/c) = 3.48 \mid K_{th}(GeV/c) = 12.3 \mid p_{th}(GeV/c) = 23.4$



The focal plane for C_2F_6 gas has to be optimized to improve performances al low angles

$$N_\sigma^{ring} = \frac{(<\theta_{p2}> - <\theta_{p1}>)\sqrt{N_\gamma}}{\sigma_\theta^{tot(1p.e.)}}$$

$$N_\gamma = (N_\gamma^{p1} + N_\gamma^{p2})/2$$

$$\sigma_\theta^{tot(1p.e.)} = (\sigma_\theta^{p1} + \sigma_\theta^{p2})/2$$

QE -→H12700 maPMT

The distributions of the reconstructed angle are from IRT

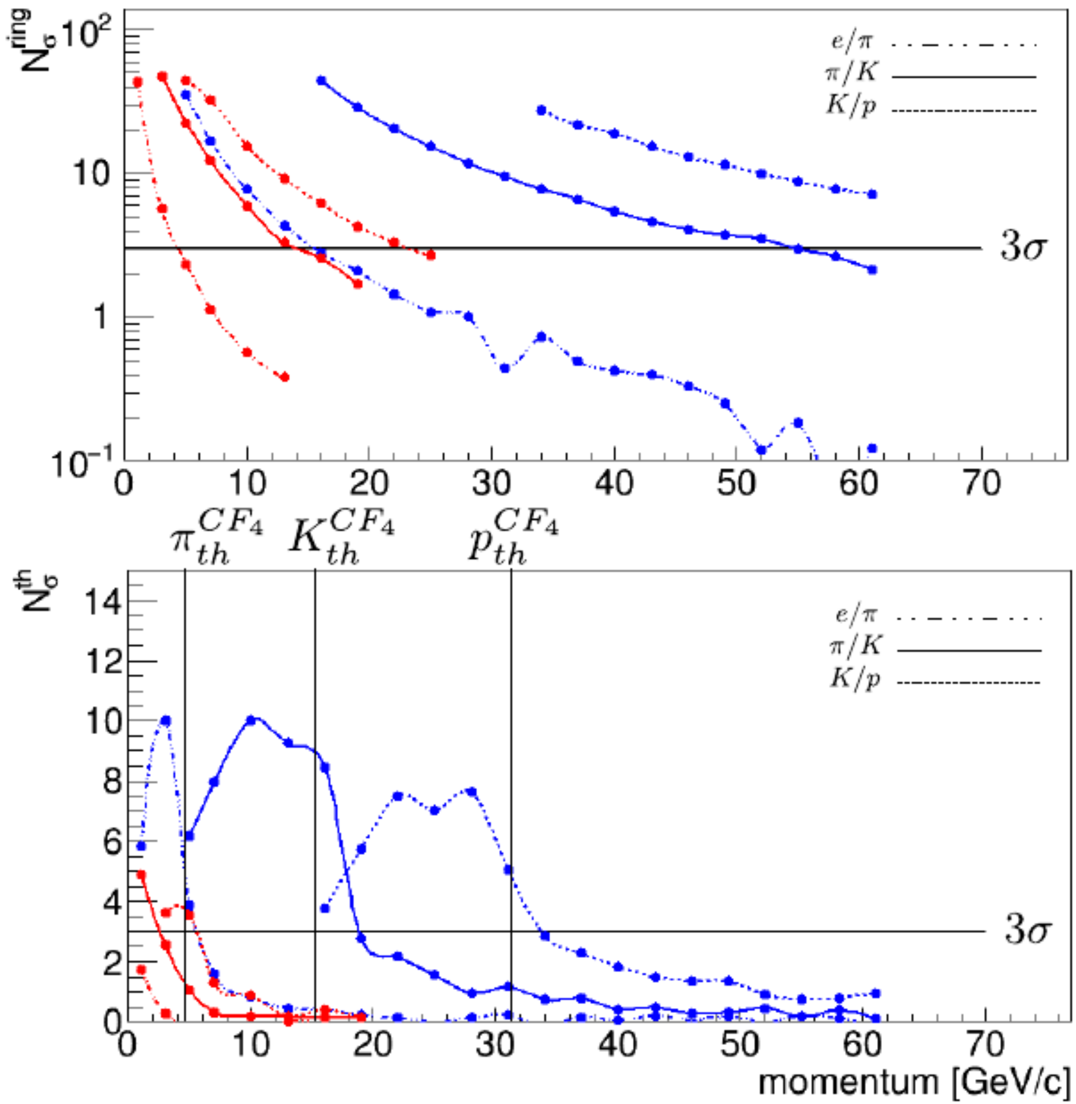
Dual RICH@EIC FY16 – aerogel & CF_4

$Aerogel \mid e_{th}(GeV/c) = 0.002542 \mid \pi_{th}(GeV/c) = 0.67 \mid K_{th}(GeV/c) = 2.46 \mid p_{th}(GeV/c) = 4.89$

$CF_4 \mid e_{th}(GeV/c) = 0.016457 \mid \pi_{th}(GeV/c) = 4.35 \mid K_{th}(GeV/c) = 15.94 \mid p_{th}(GeV/c) = 31.66$

RICH

Threshold Cherenkov



Polar angle = 5°

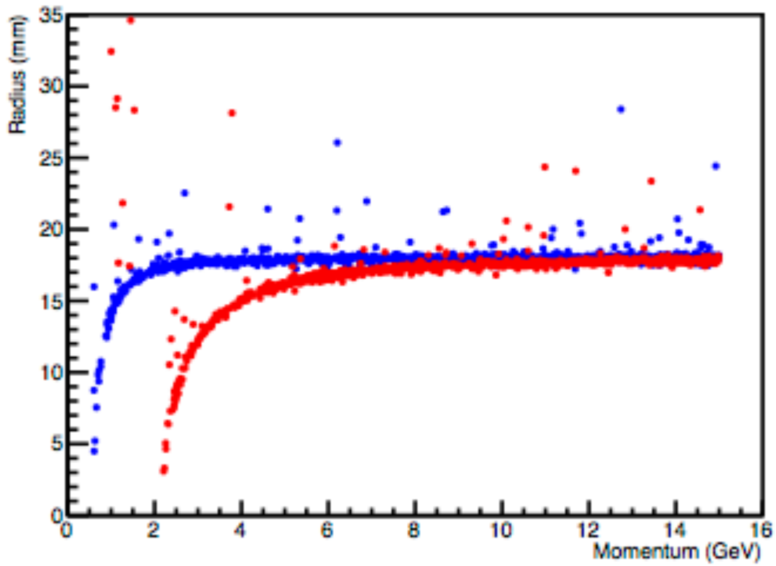
Some regions covered by threshold with CF_4:

- only *e* up to 4.3
- only *e* and *pi* up to 16
  --> pi/K region [10,16] covered in redundancy with Aerogel

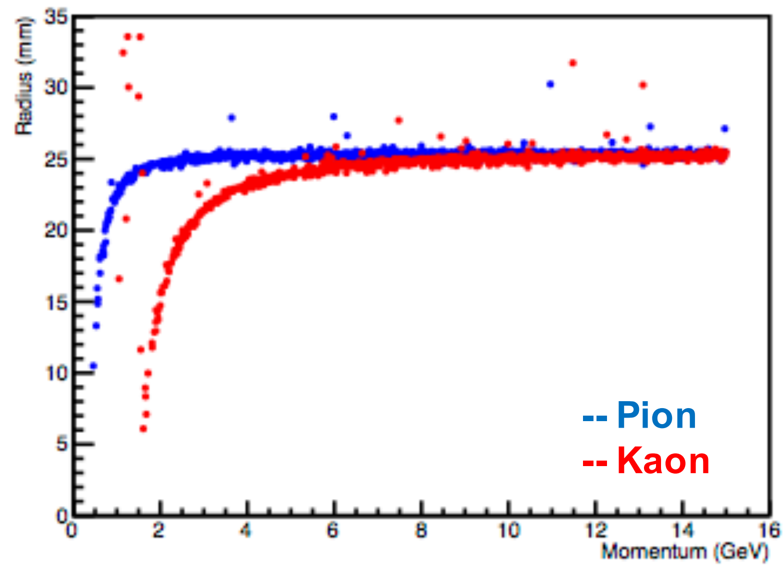
mRICH

Cherenkov ring radius from different refractive index of aerogel

Refractive index=1.02



Refractive index=1.047

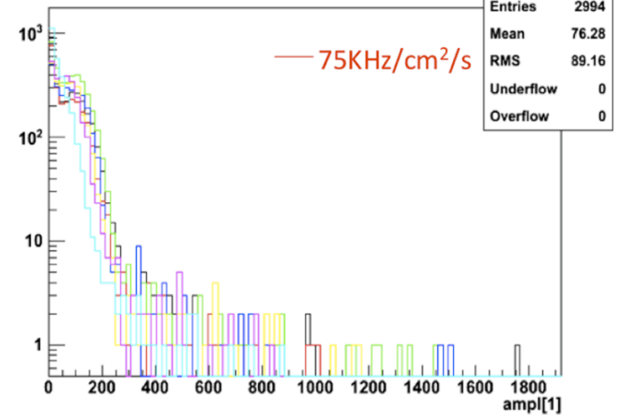


Photosensors and Electronics – FY16 report

LAPPDs

- New LAPPD samples produced.
- Rate capability study with 120-GeV protons (FTBF) for various intensities (3.3–150 kHz/cm²/s) shows that the waveform of the signal is affected only at fluxes above 75 kHz/cm²/s.
- Relative Quantum Efficiency measurement (BNL) with a borosilicate glass window suggests that replacing the window material may increase the photon yield by a factor of 2.

LAPPD output signal for various proton fluxes



LAPPD Relative QE vs wavelength