Particle Identification for the EIC Detector

Development of a Compact, Projective and Modular Ring Imaging Cherenkov Detector

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on behalf of the EIC PID Collaboration (eRD14)

Work supported by the BNL program for

Generic Detector R&D for an Electron Ion Collider

Jan 9, 2020: DOE Announcement
Mission Need (CD-0) and Site Selection

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Department of Energy

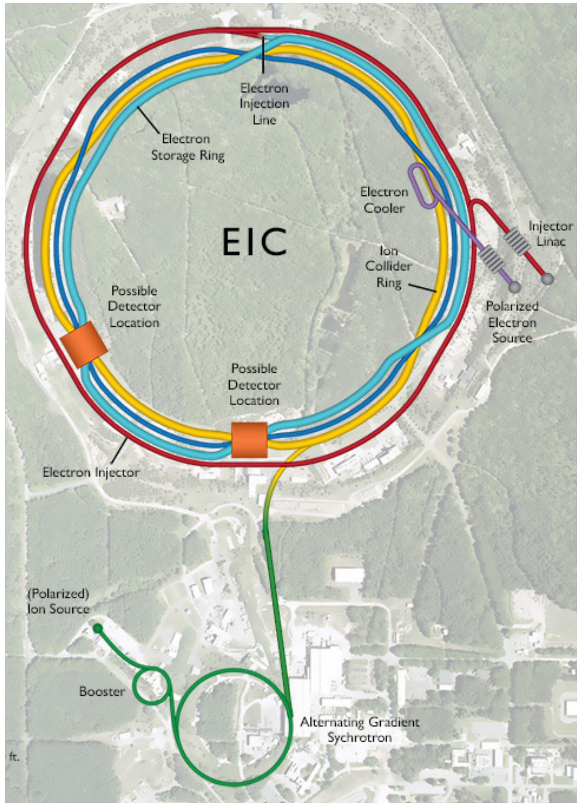
U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

Home » U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

WASHINGTON, D.C. – Today, the **U.S. Department of Energy (DOE)** announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

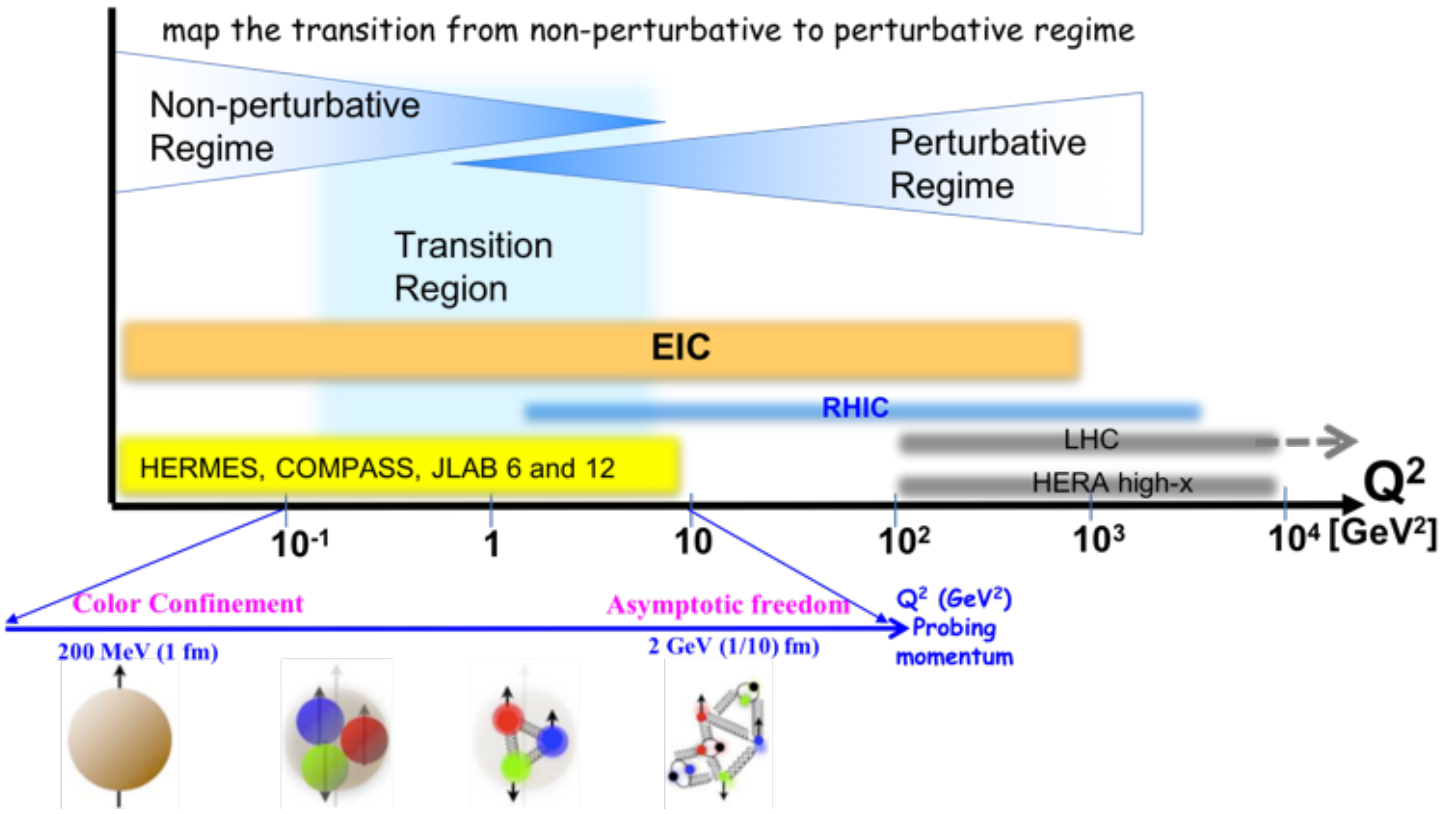
The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will smash electrons into protons and heavier atomic nuclei in an effort to penetrate the mysteries of the "strong force" that binds the atomic nucleus together.

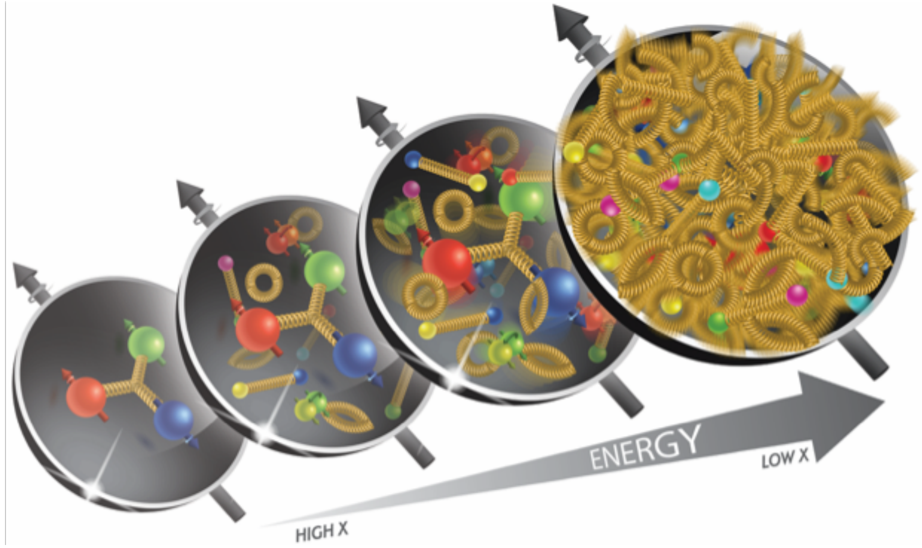


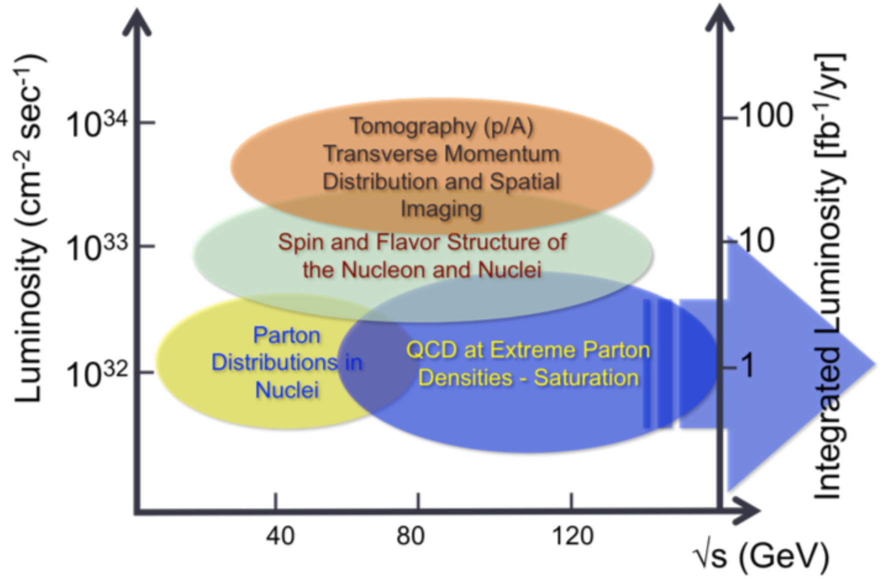
EIC@BNL concept

Physics needs EIC

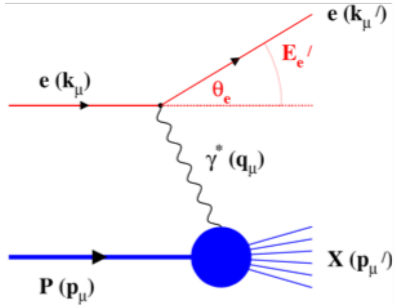
An inclusive and collective effort in the broader community of nuclear and particle physics





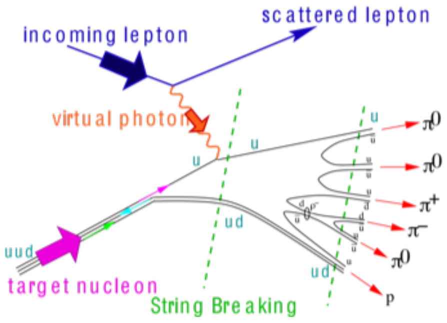


EIC needs PID



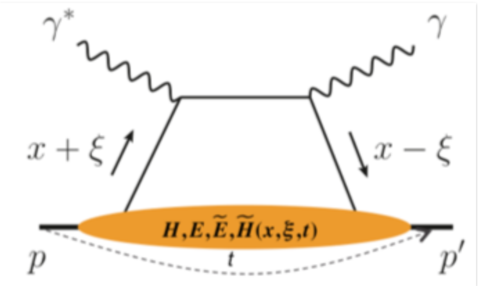
inclusive DIS
- fine multi-dimensional binning
  → x, Q^2

Critical to detect scattered e with high precision



semi-inclusive DIS
- 5-dimensional binning
  → x, Q^2, z, p_T, Θ
- to reach p_T > 1 GeV

Detect the scattered leptons & final state hadrons, jets.



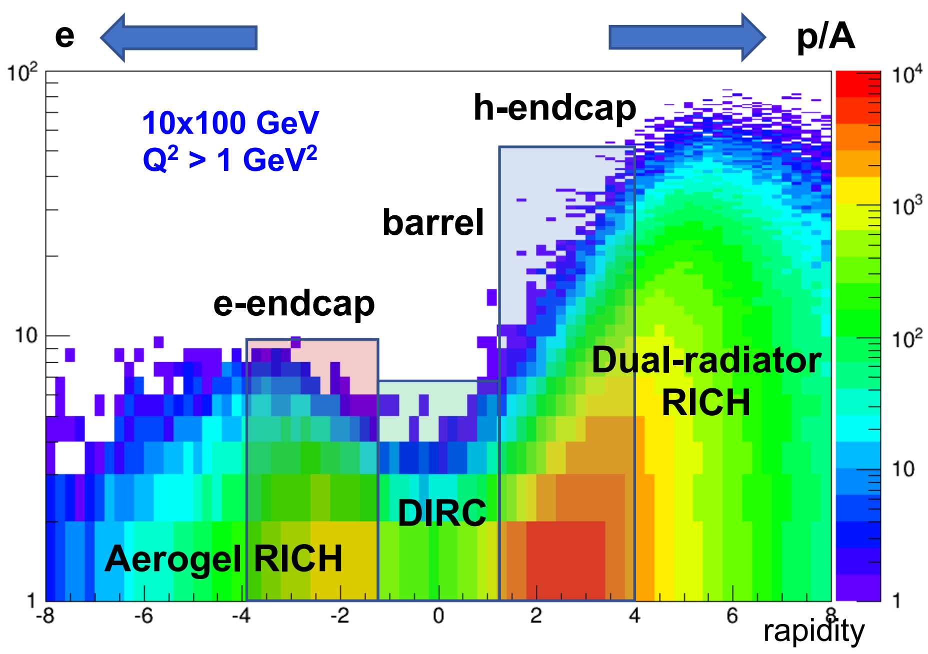
exclusive processes
- 4-dimensional binning
  → x, Q^2, t, Θ
- to reach |t| > 1 GeV^2

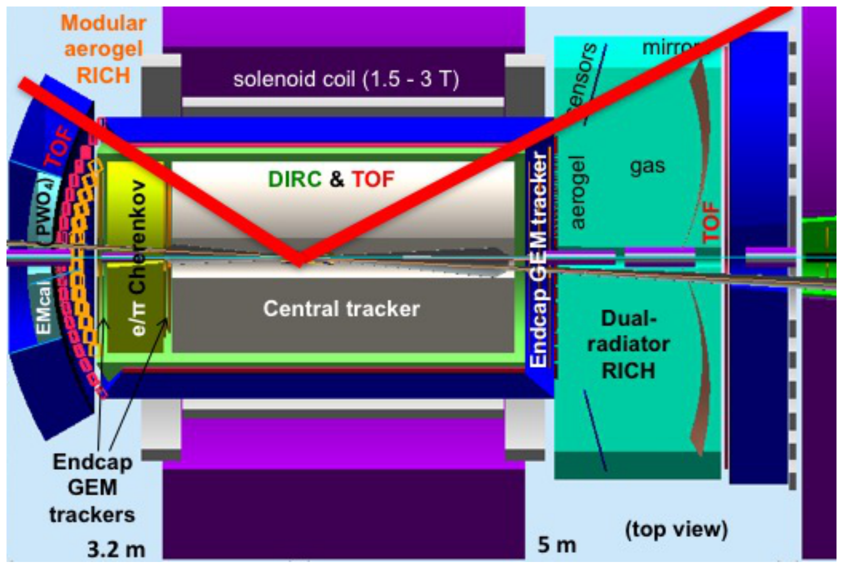
All particles needs to be measured

EIC PID needs are more demanding then your normal collider detector

EIC needs absolute particle numbers at high purity and low contamination

PID Needs RICH Detectors



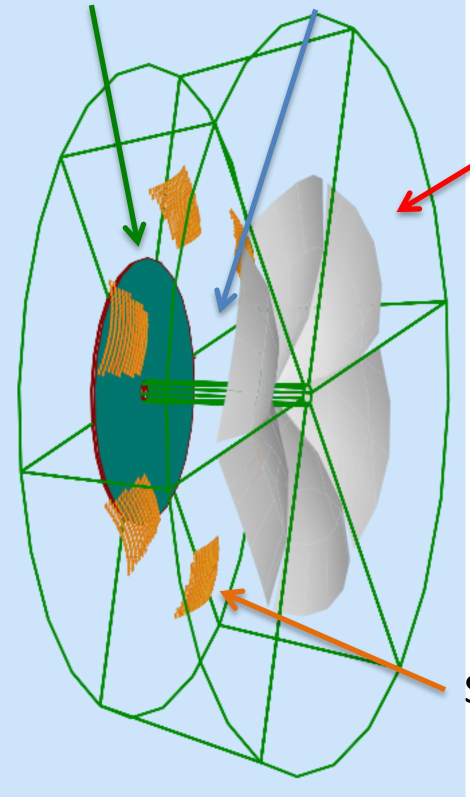


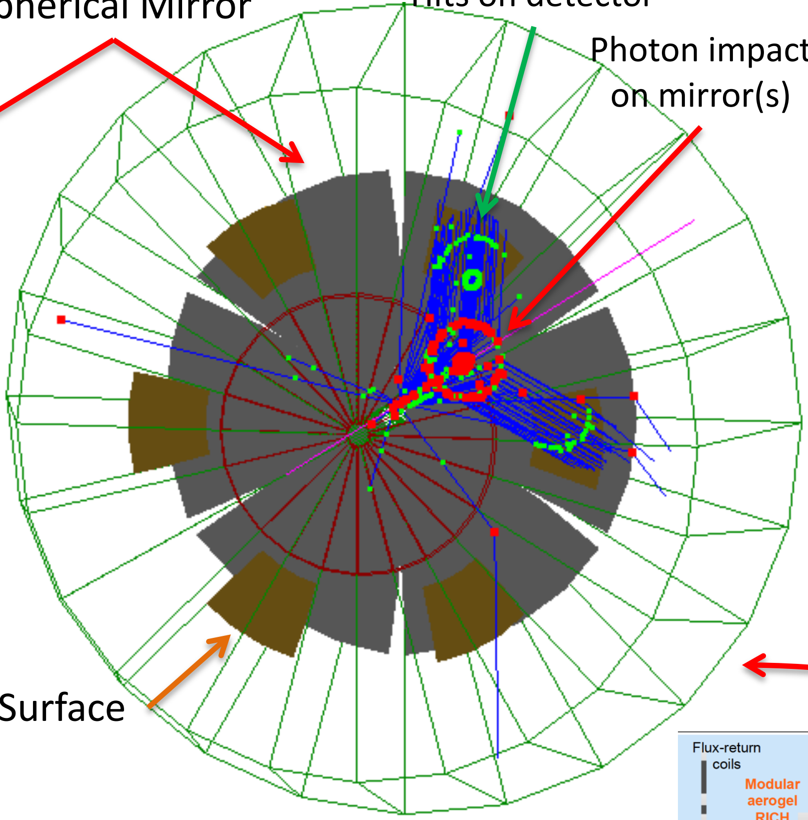
- **h-endcap**: A RICH with two radiators (C_2F_6 gas + aerogel) proposed for continuous PID coverage (dRICH)
  π/K separation up to ~50 GeV/c
- **e-endcap**: A compact modular aerogel RICH (**mRICH**) which can be projective ***π/K separation up to ~10 GeV/c***
- **barrel**: A high-performance DIRC provides a compact and cost-effective way to cover the angular range (hpDIRC)
  π/K separation up to ~6-7 GeV/c

- **TOF (and/or dE/dx in TPC)**: can cover lower momenta
- **Photosensors and electronics**: cost-effective solutions to match the requirements of the next-gen PID systems

➔ eRD14 – EIC PID consortium (BNL R&D funding)
An integrated program for particle identification (PID) for a future Electron-Ion Collider (EIC) detector

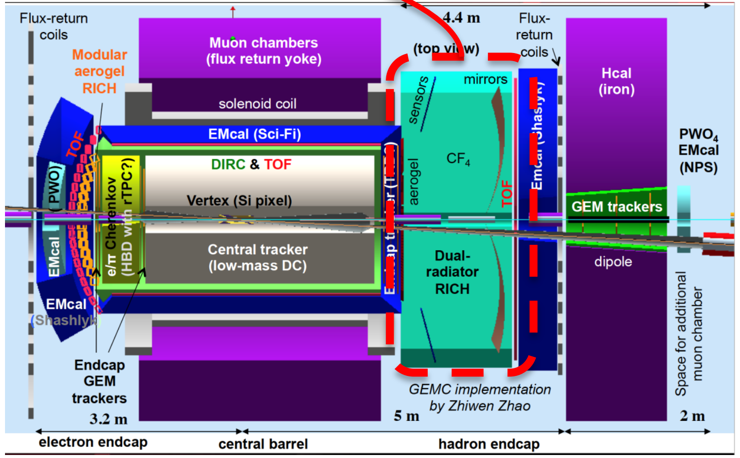
Dual radiator RICH in the EIC hadron endcap





Advantages:
- Full momentum, continuous coverage 3-50 GeV/c
- Relatively simple geometry/optics
- Expected to be Cost Effective (respect to 2 x detectors solution)

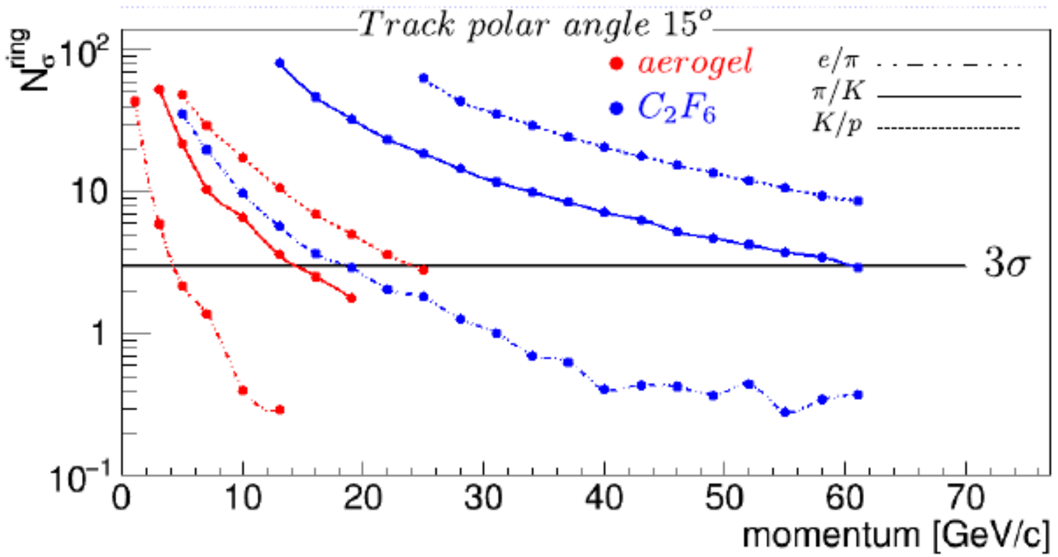
➔ for more detail see E. Cisbani, DIRC2019 workshop



- Radiators: Aerogel (4 cm, $n_{(400nm)}$~1.02) + 3 mm acrylic filter, Gas (1.6 m, n_{C2F6}~1.0008)
- 6 Identical Open Sectors (Petals):
  - Large Focusing Mirror with R ~2.9 m
  - Optical sensor elements: ~4500 cm^2/sector, 3 mm pixel size, UV sensitive, out of charged particles acceptance

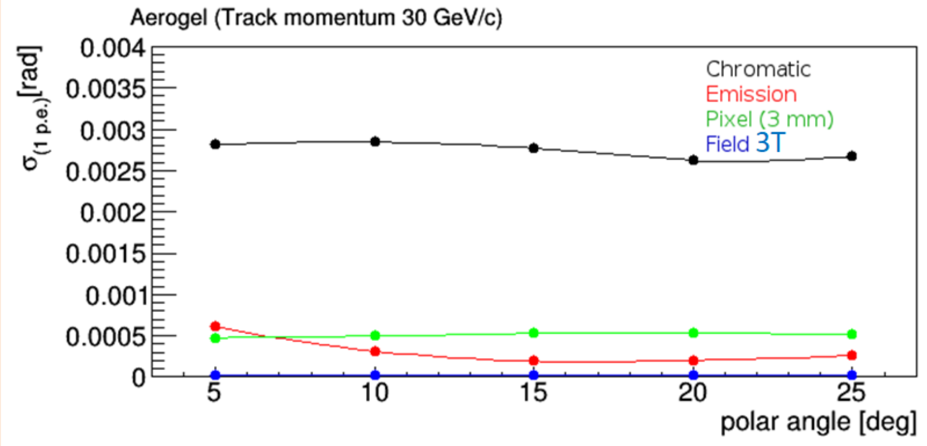
dRICH Geant4 expected performance

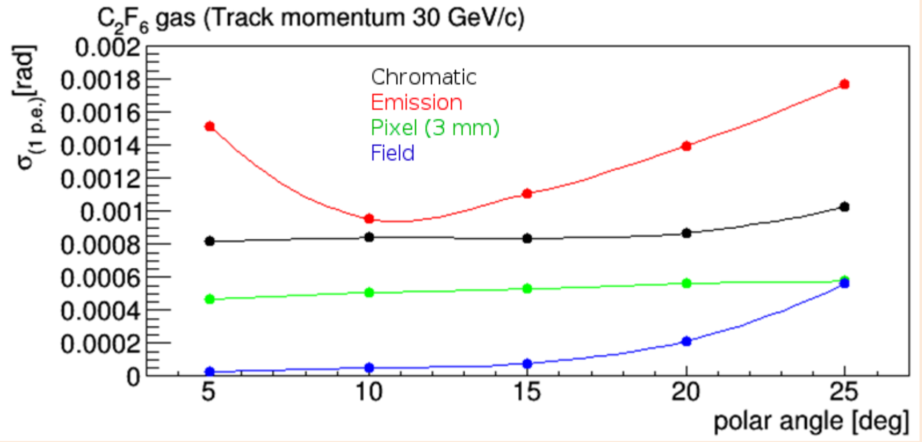
- Acrylic Filter (<300nm) after the aerogel to minimize Rayleigh scattering
- Include 3T central magnetic field
- Tracking accuracy 0.5 mrad
- QE from realistic CLAS12/PMT measurements (200-500 nm)
- Cherenkov Angle reconstruction based on Inverse Ray Tracing
- Prototype beam test in preparation



Hadron identification (π/K/p, better than 3 sigma from ~3 up to ~50 GeV/c for π/K

Single Photon Angular resolution





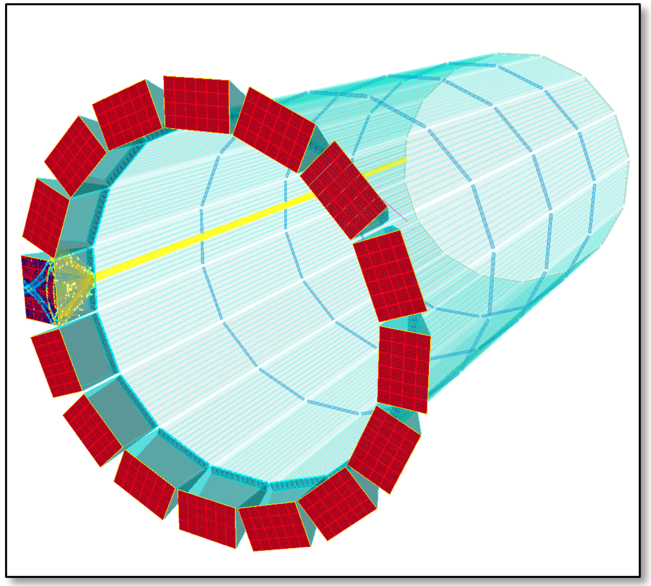
High-Performance DIRC

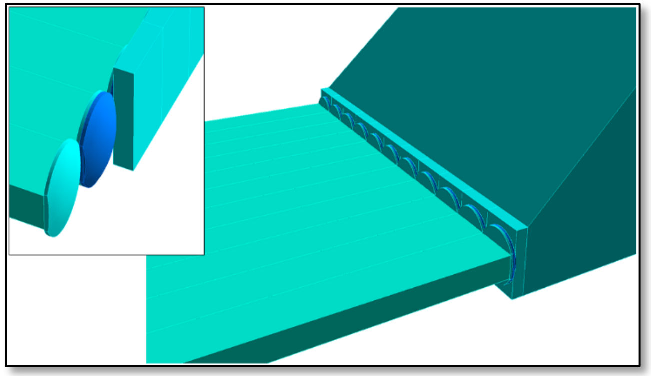
➔ for more detail see poster #49 this afternoon or G. Kalicy, DIRC2019 workshop

Concept: fast focusing DIRC

Inspired by design elements from BaBar, SuperB, Belle II, and PANDA

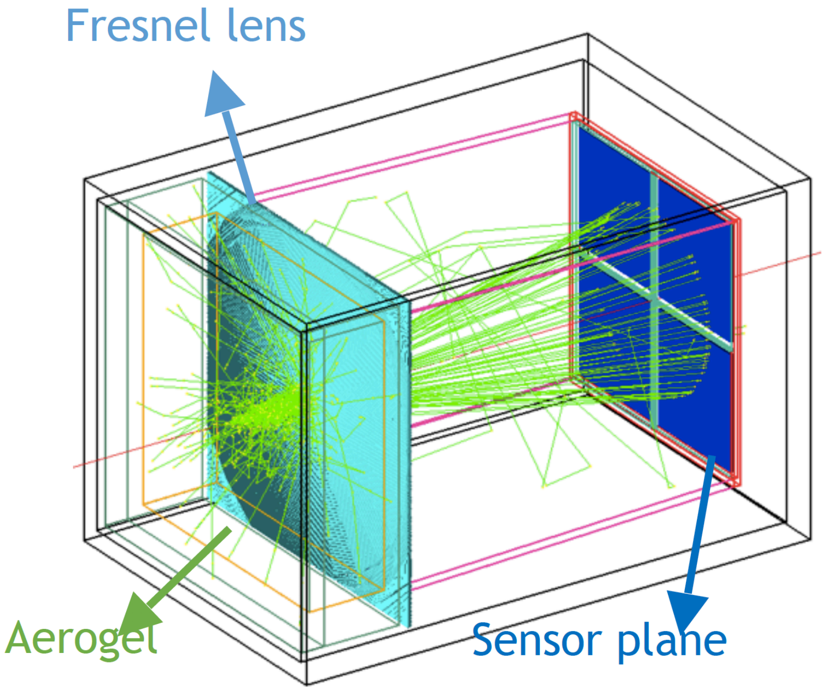
- Initial design based on PANDA: 1m barrel radius, 16 sectors
- 176 radiator bars (11 per sector), synthetic fused silica,
  17mm (T) × 35mm (W) × 4200mm (L)
- Focusing optics: innovative rad-hard 3-layer spherical lens
- Compact photon camera:
  30cm-deep solid fused silica prisms as expansion volumes
  lifetime-enhanced MCP-PMTs with 3x3mm^2 pixels
  fast readout electronics (~100,000 channels , <100ps single photon timing)
- Expected performance (Geant4 simulation):
  30-100 detected photons per particle, ≥ 3 s.d. π/K separation at 6 GeV/c
- Prototype beam test in preparation (reusing PANDA Barrel DIRC prototype)



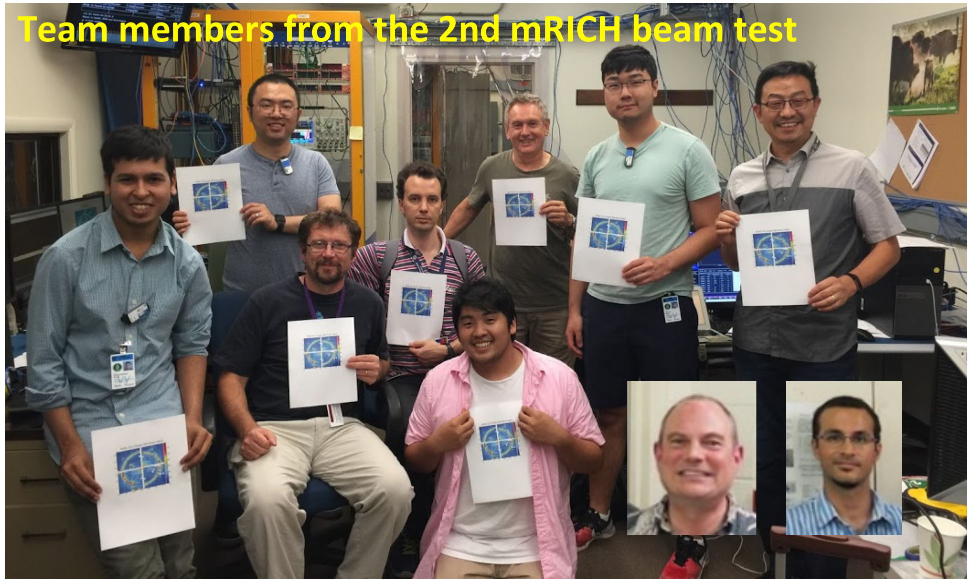


Modular aerogel RICH - mRICH

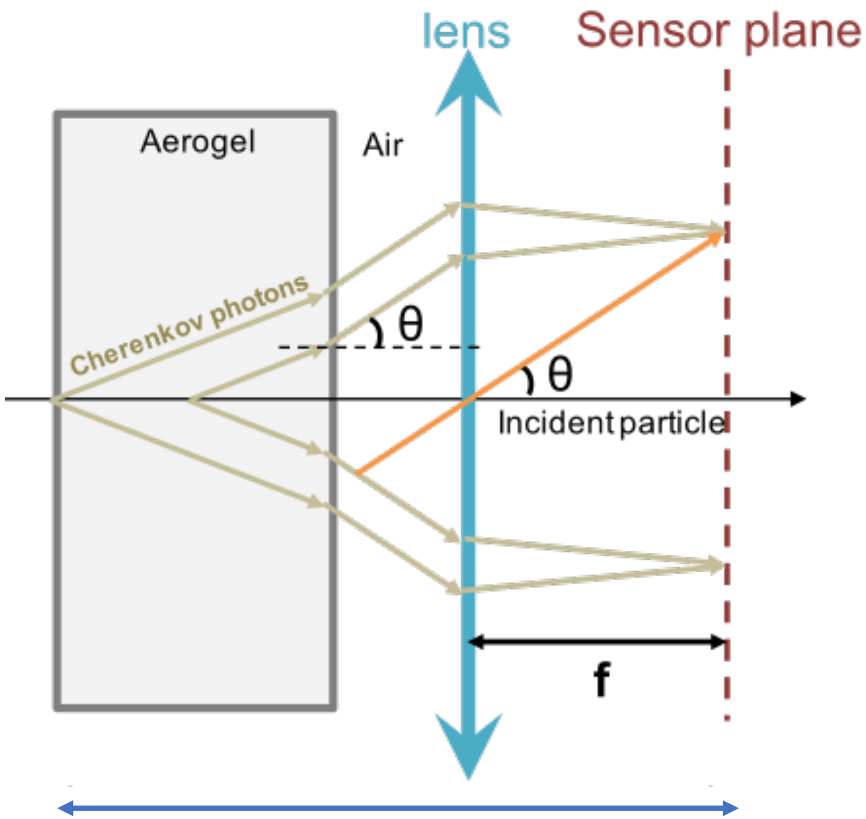
mRICH stands for compact and modular Ring Imaging CHerenkov detector, which is designed for K/pi separation in a momentum range of 3 to 10 GeV/c and e/pi separation below 2 GeV/c for the future EIC experiments.



Geant4 Simulation

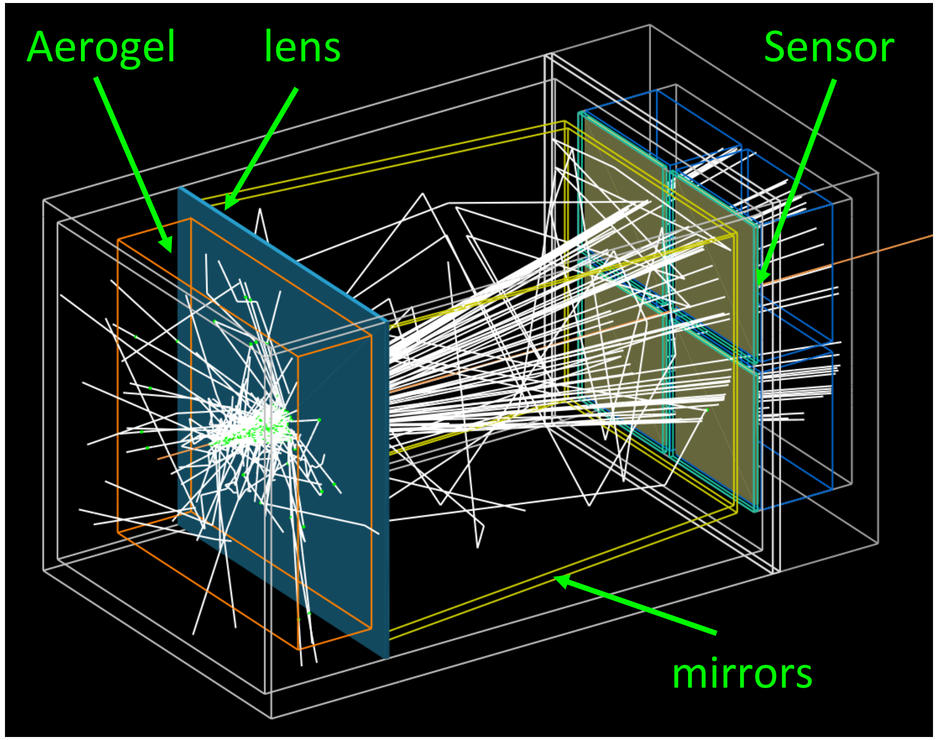


EIC mRICH – Working Principle



~ (aerogel thickness + lens focal length)

(Not to scale, for illustration purpose only)



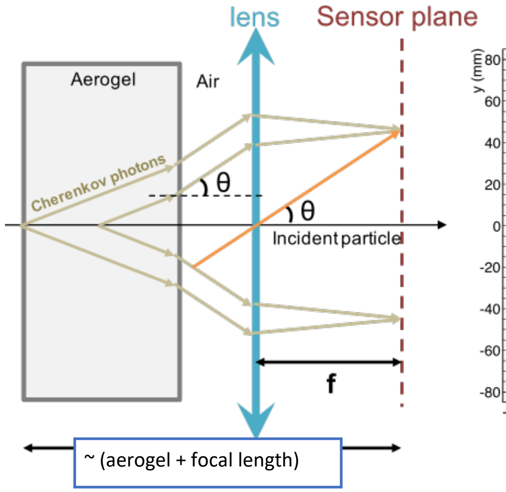
Geant4 Simulation

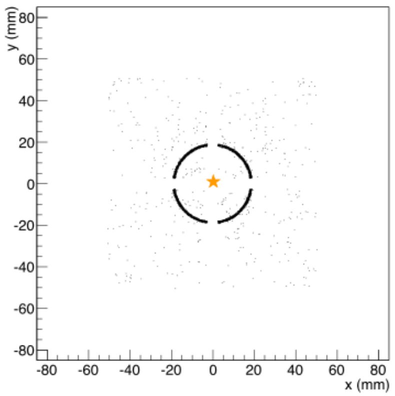
With realistic material optical properties

mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based
mRICH Design

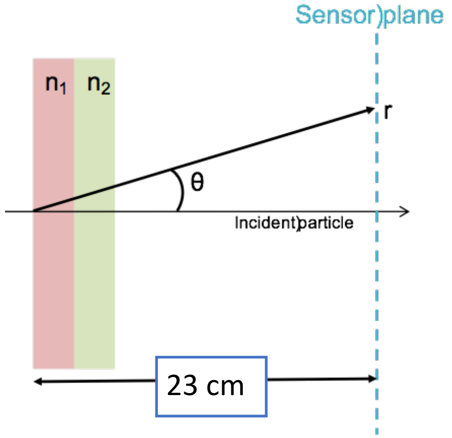


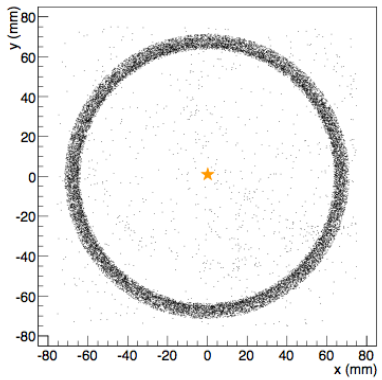


- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner ring image**

9 GeV/c pion beam launched at the center of xy plane in simulation

Two-Layer Proximity
Focusing Design
(BELLE-2 ARICH,
PANDA FRICH)



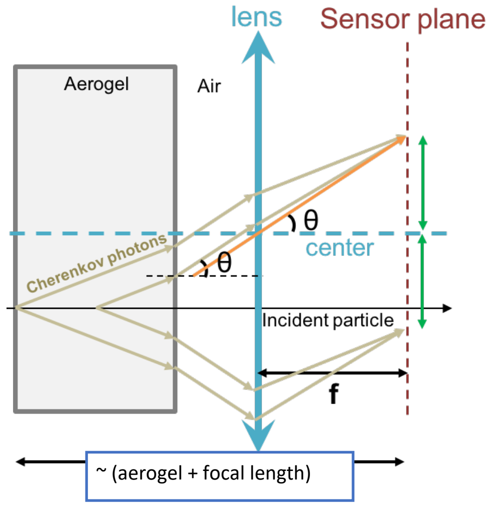


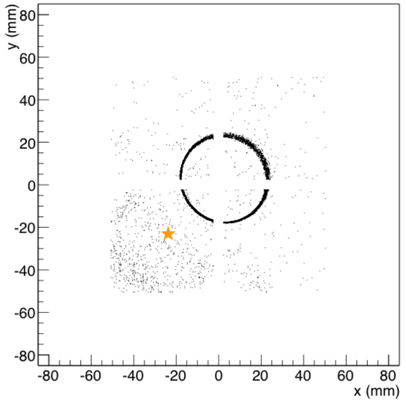
- EIC mRICH designed for K/pi ID up to 9 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

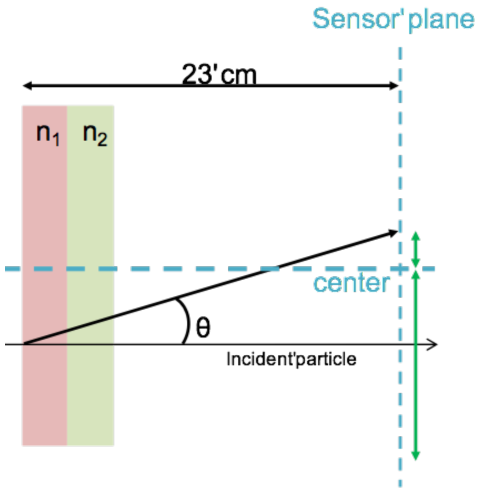
Lens-Based mRICH Design

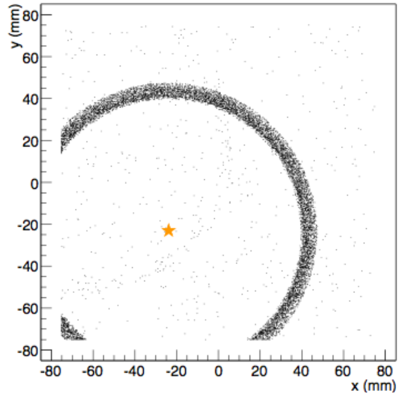




- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring image is **shifted toward the central region** on the sensor plane

Two-Layer Proximity Focusing Design (BELLE-2 ARICH, PANDA FRICH)

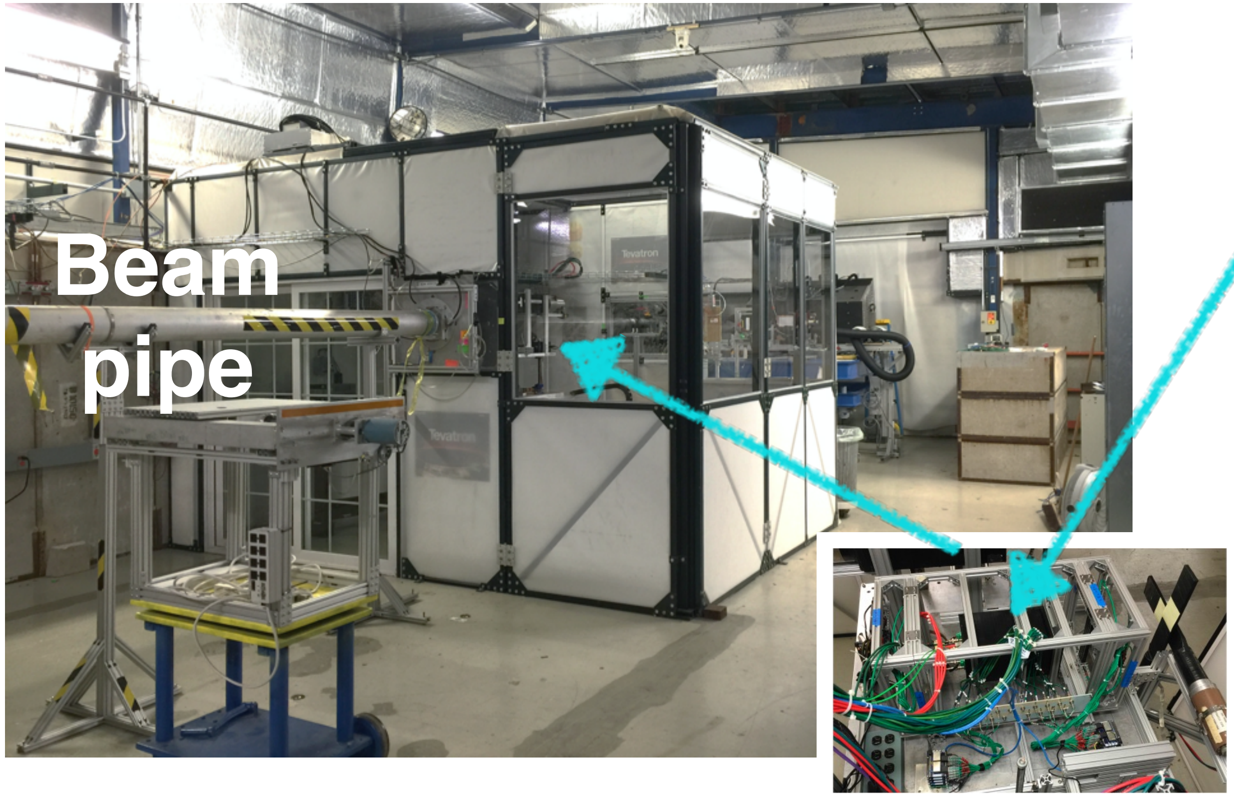


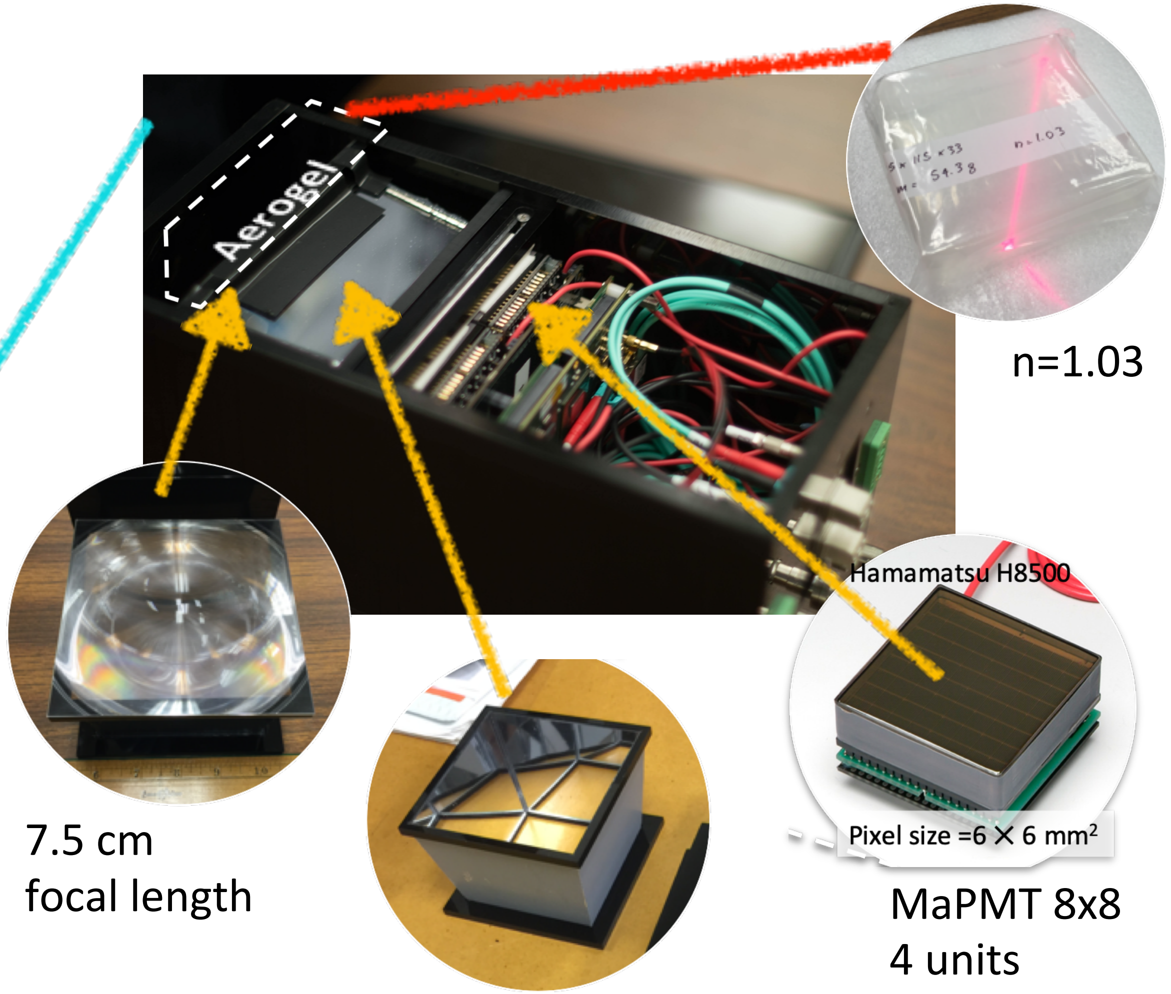


- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring is centered at point of incidence

1st mRICH Prototype Beam Test - Proof of Working Principle

Fermilab Beam Test Facility, April 2016

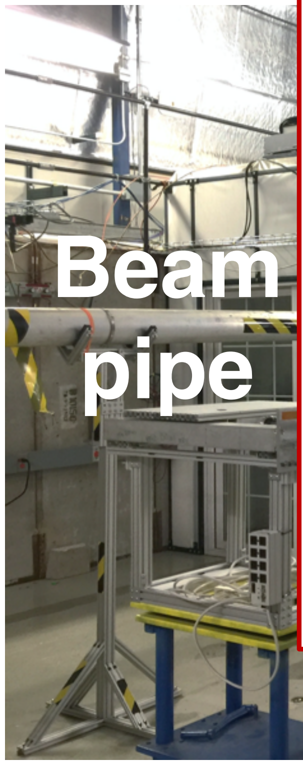


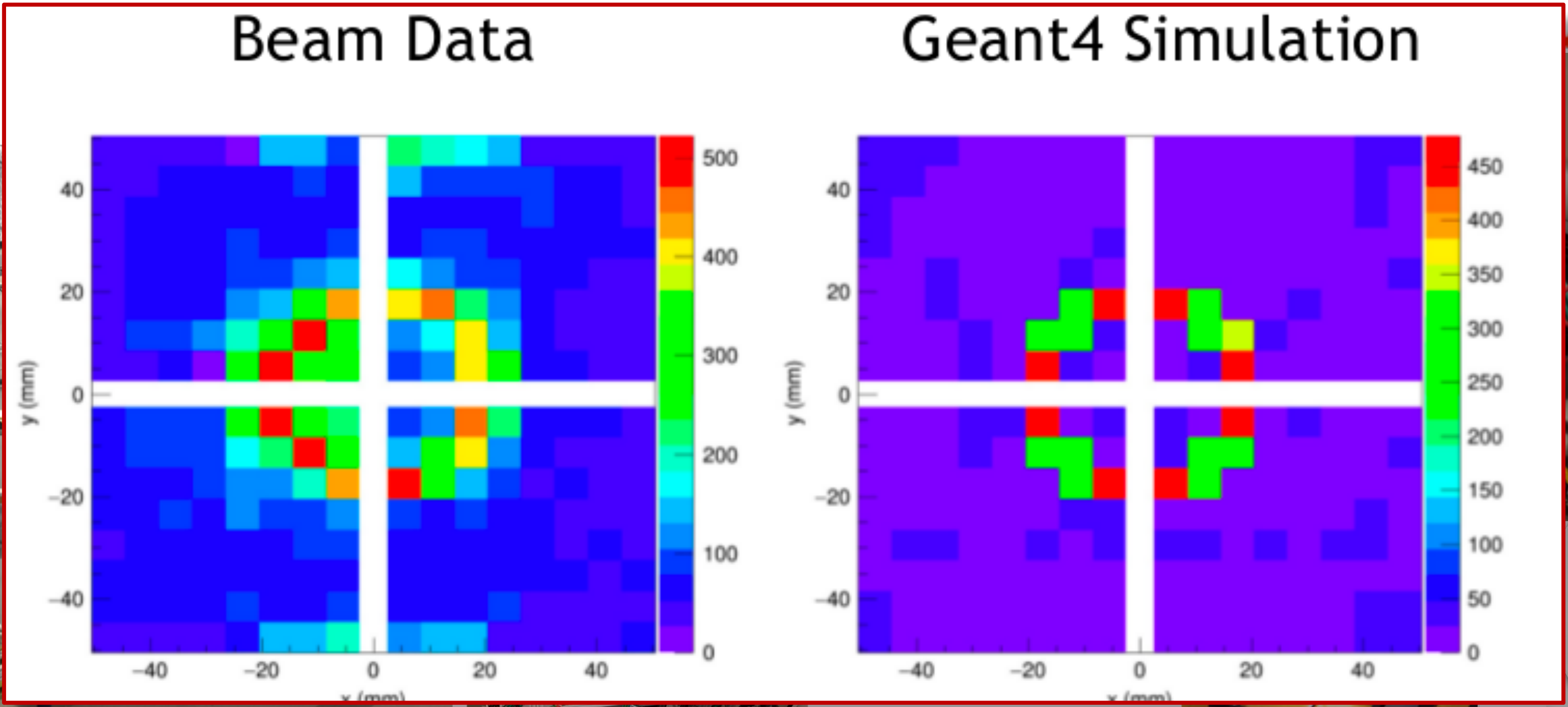


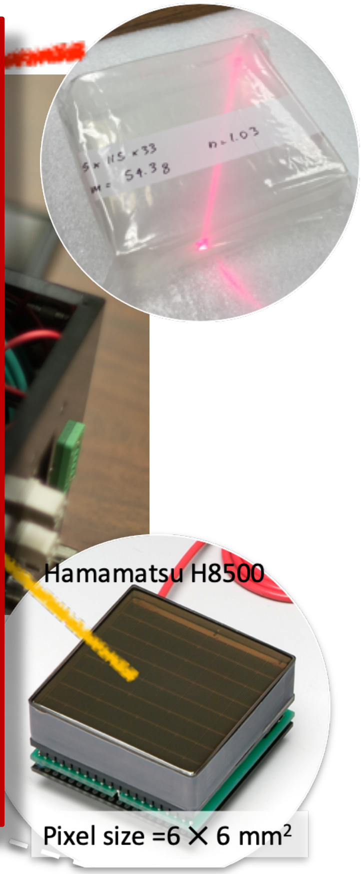
MAROC-based readout system
(CLAS12, GlueX)

1^{st} mRICH Prototype Beam Test - Proof of Working Principle

Fermilab B



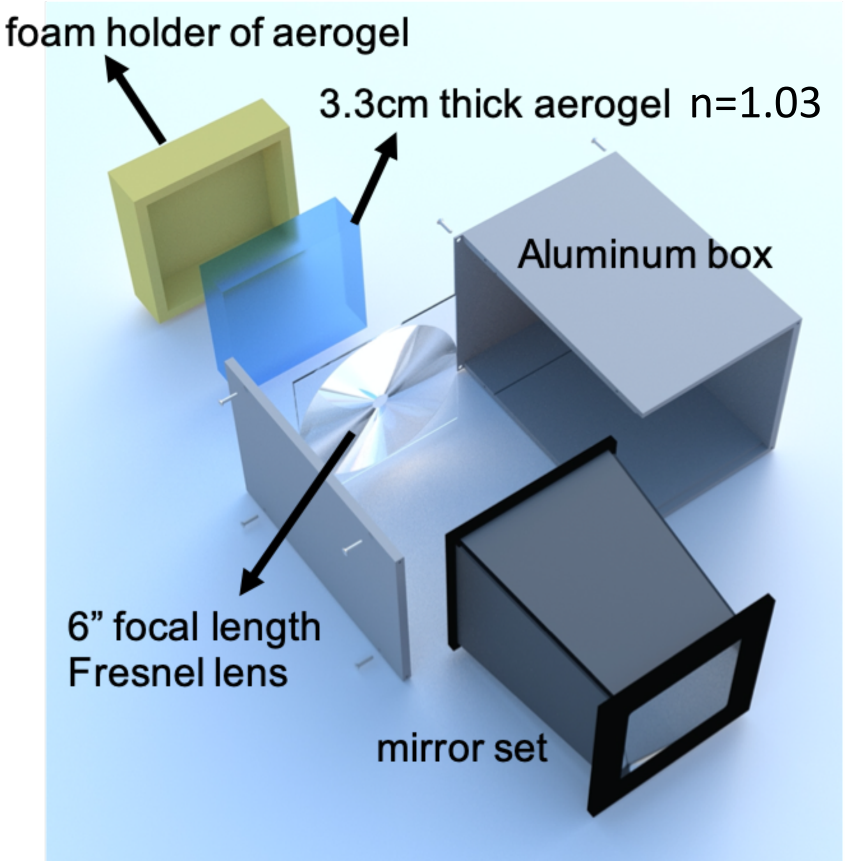


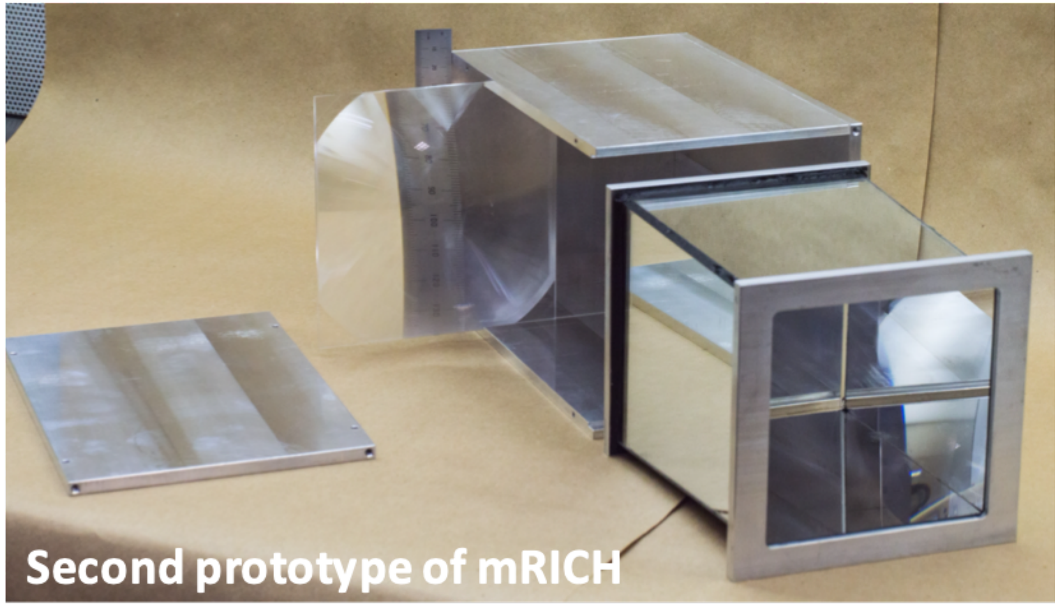


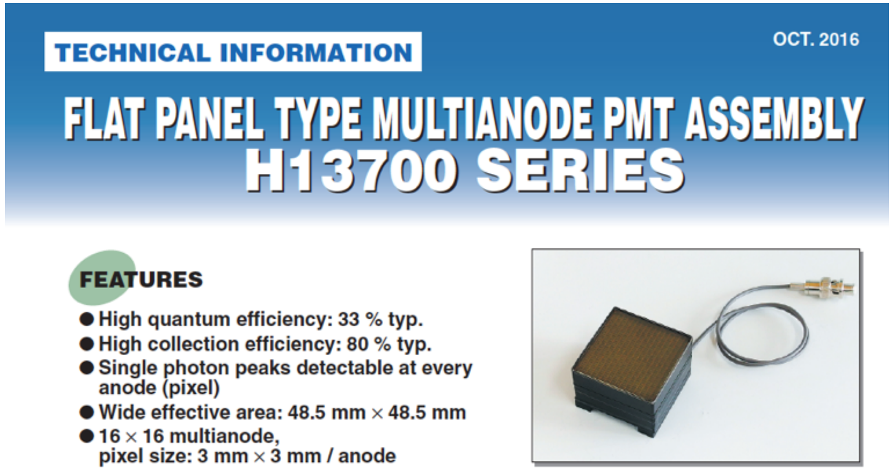
4 units

C.P. Wong et. al. NIM A871 (2017) 13-19

2nd mRICH Prototype - Improved Optical Component Design



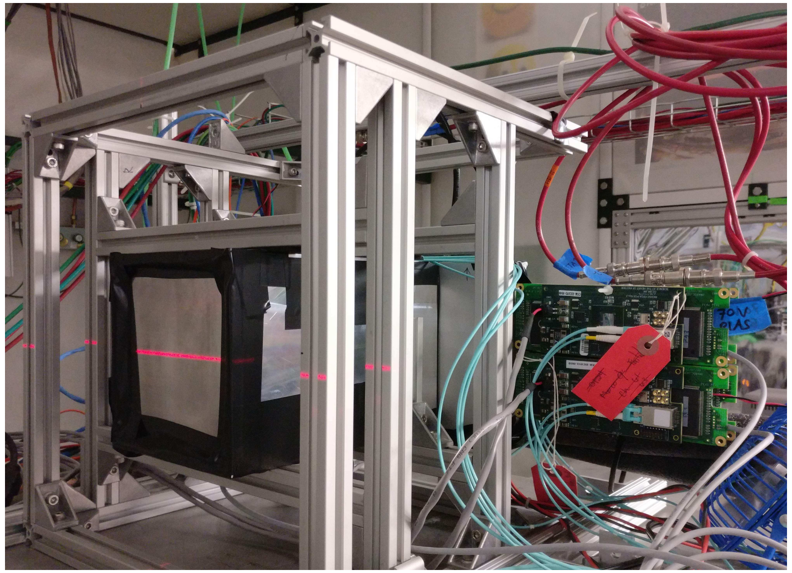


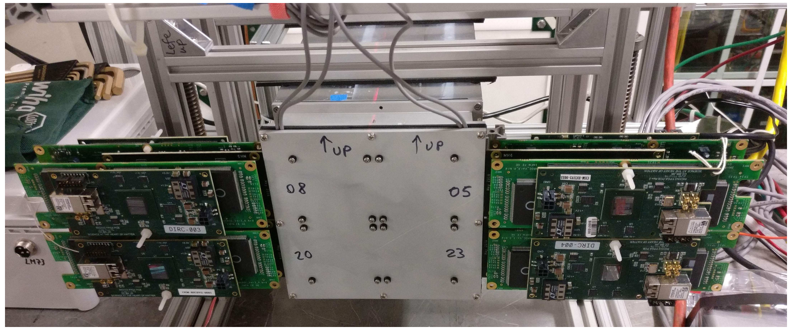


1. Longer focal length (Fresnel lens)
2. Smaller pixel size sensors (3mm)
   16x16 pixels, 4 units

The separation of the optical and electrical components in the improved mRICH prototype design allowed us to test different photosensors

Using four H13700 Multi-anode PMTs

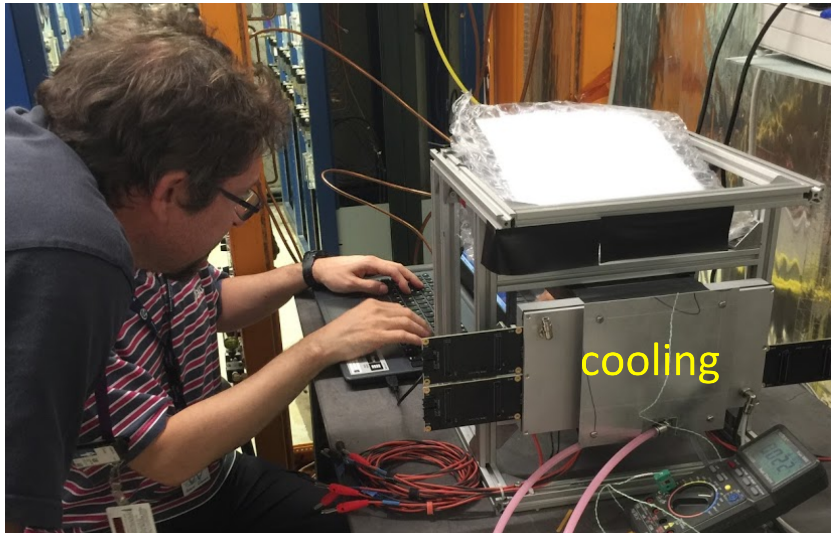


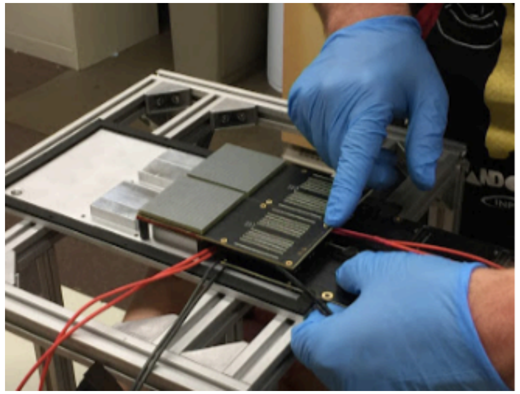


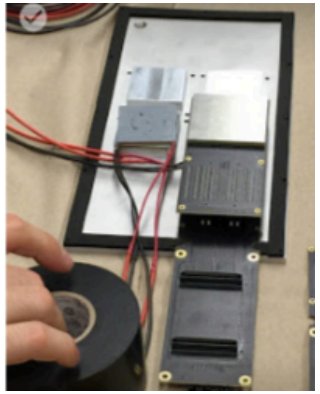
To achieve the required PID separation power, the pixel size of photosensors should be 3mm x 3mm or smaller.

Each H13700 & SiPM matrix have 16 x 16 pixels (3mm x 3mm). Four sensors are needed to cover the imaging plane of mRICH. This leads to 1024 readout channels per module.

Using three Hamamatsu SiPM Matrices



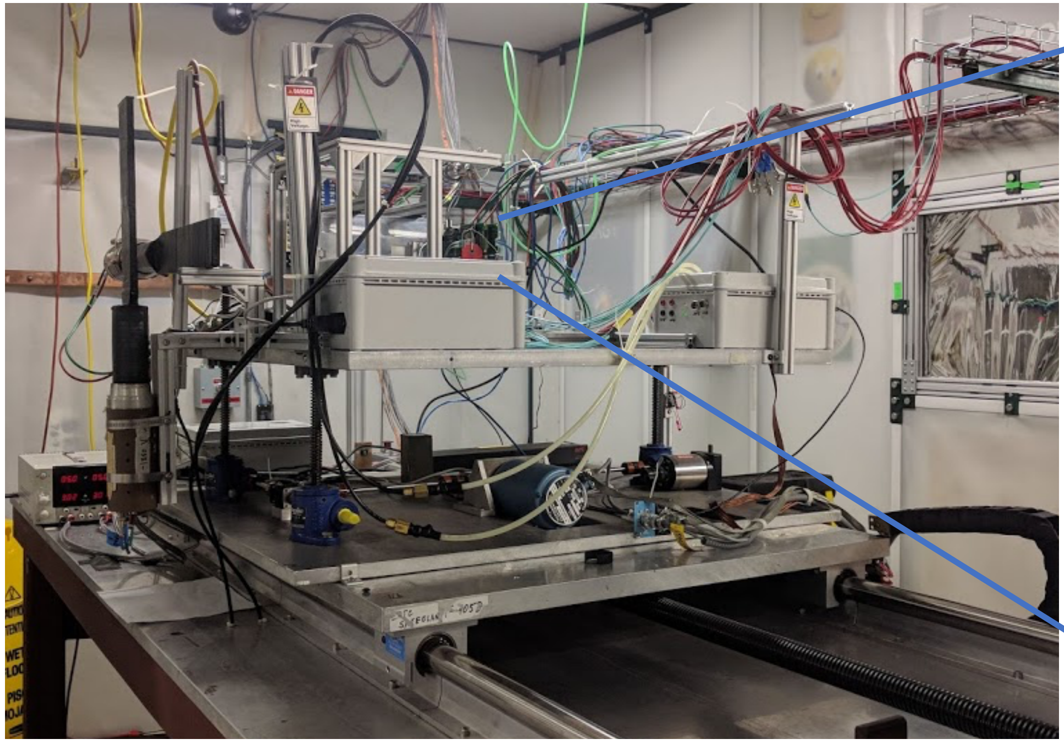


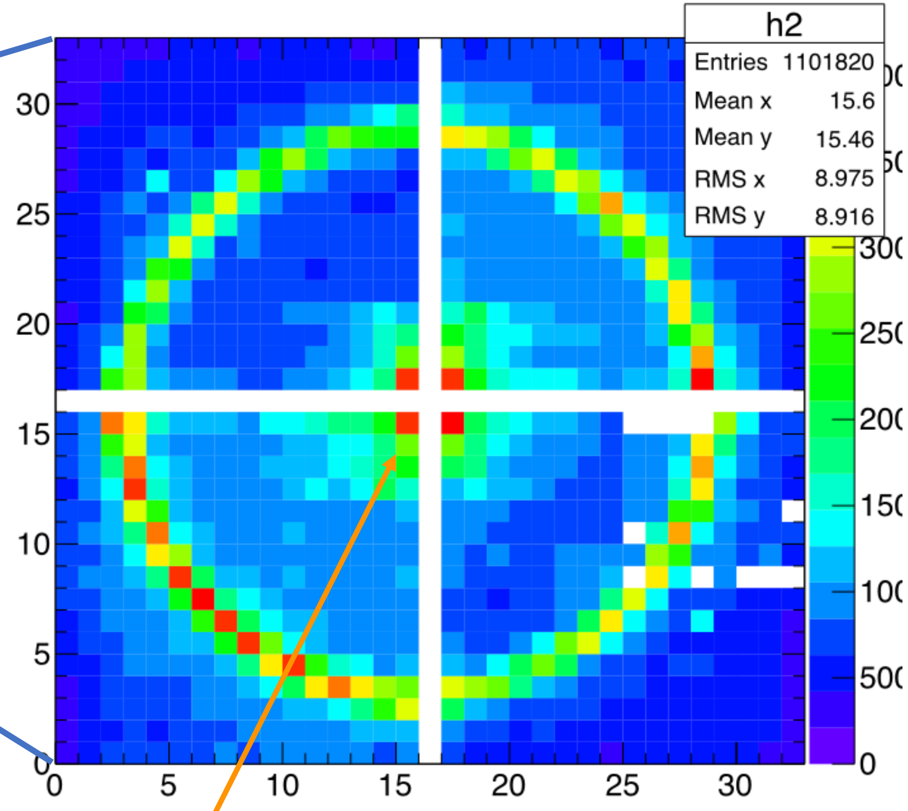


2nd mRICH Beam Test - Verify the PID Capability

Fermilab Beam Test Facility, from July 25 to August 6, 2019

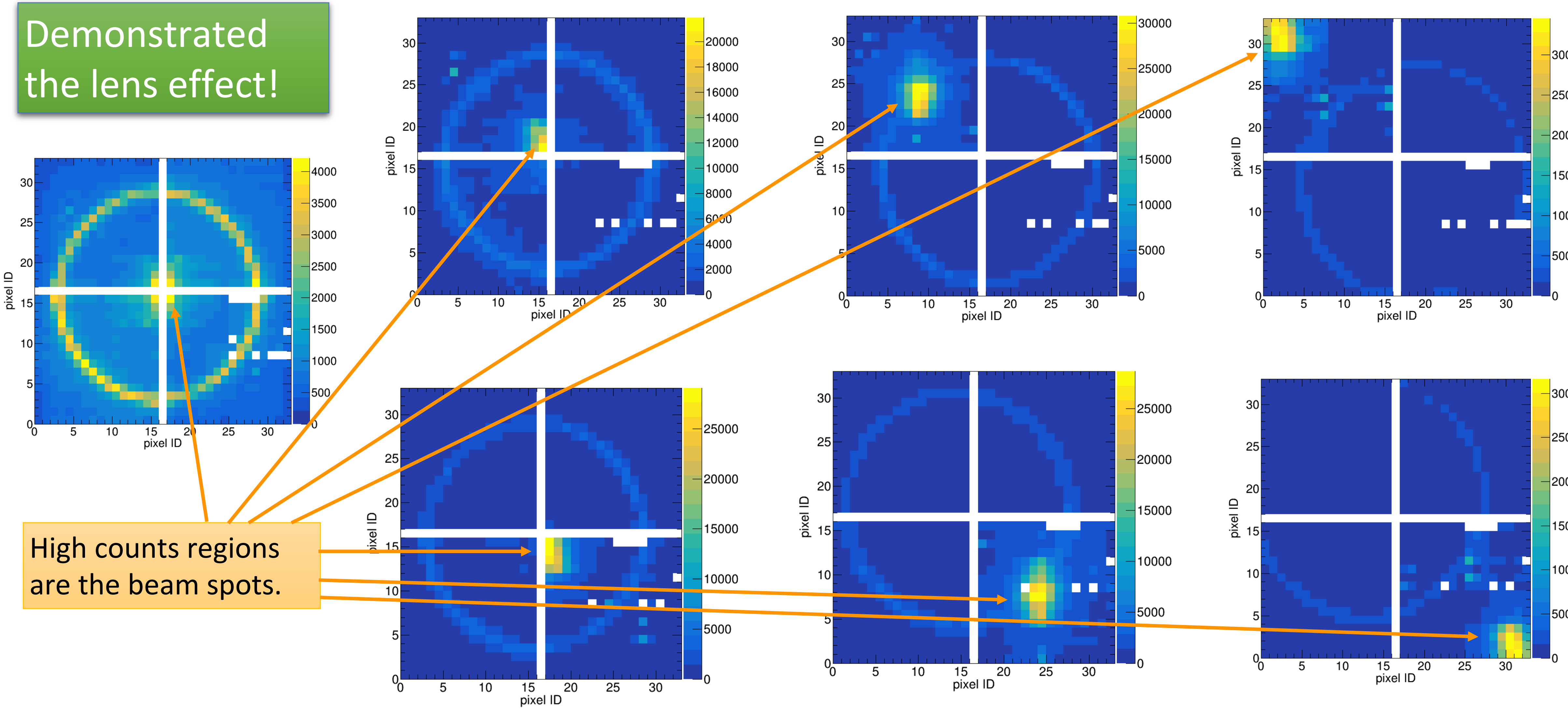
120 GeV/c proton



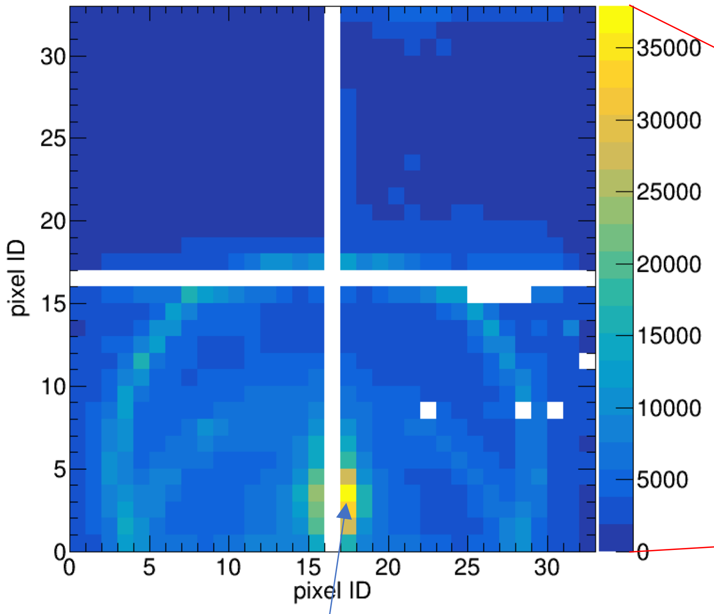


Beam spot

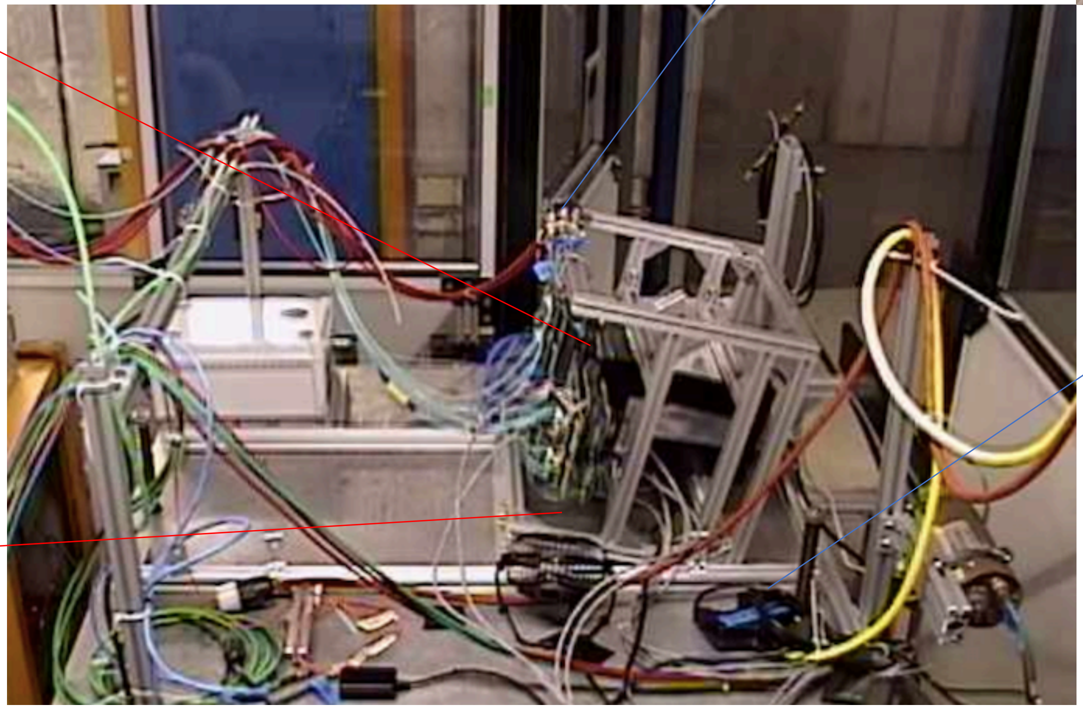
Position scans with 120 GeV/c proton beam

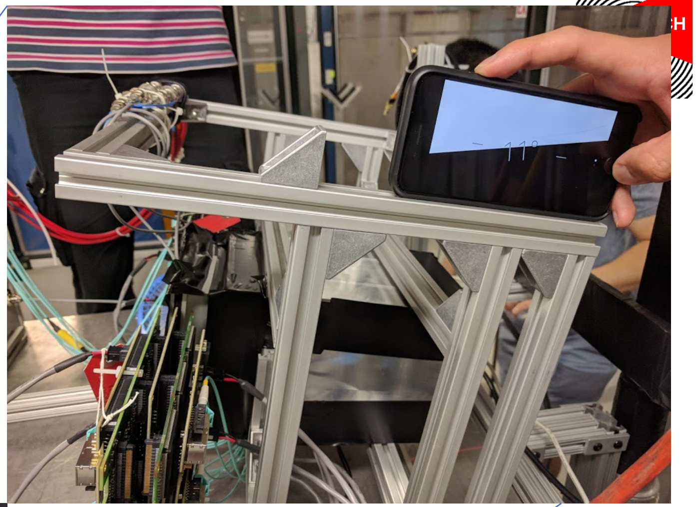


Ring image from proton beam at an angle (11^0)



Beam spot

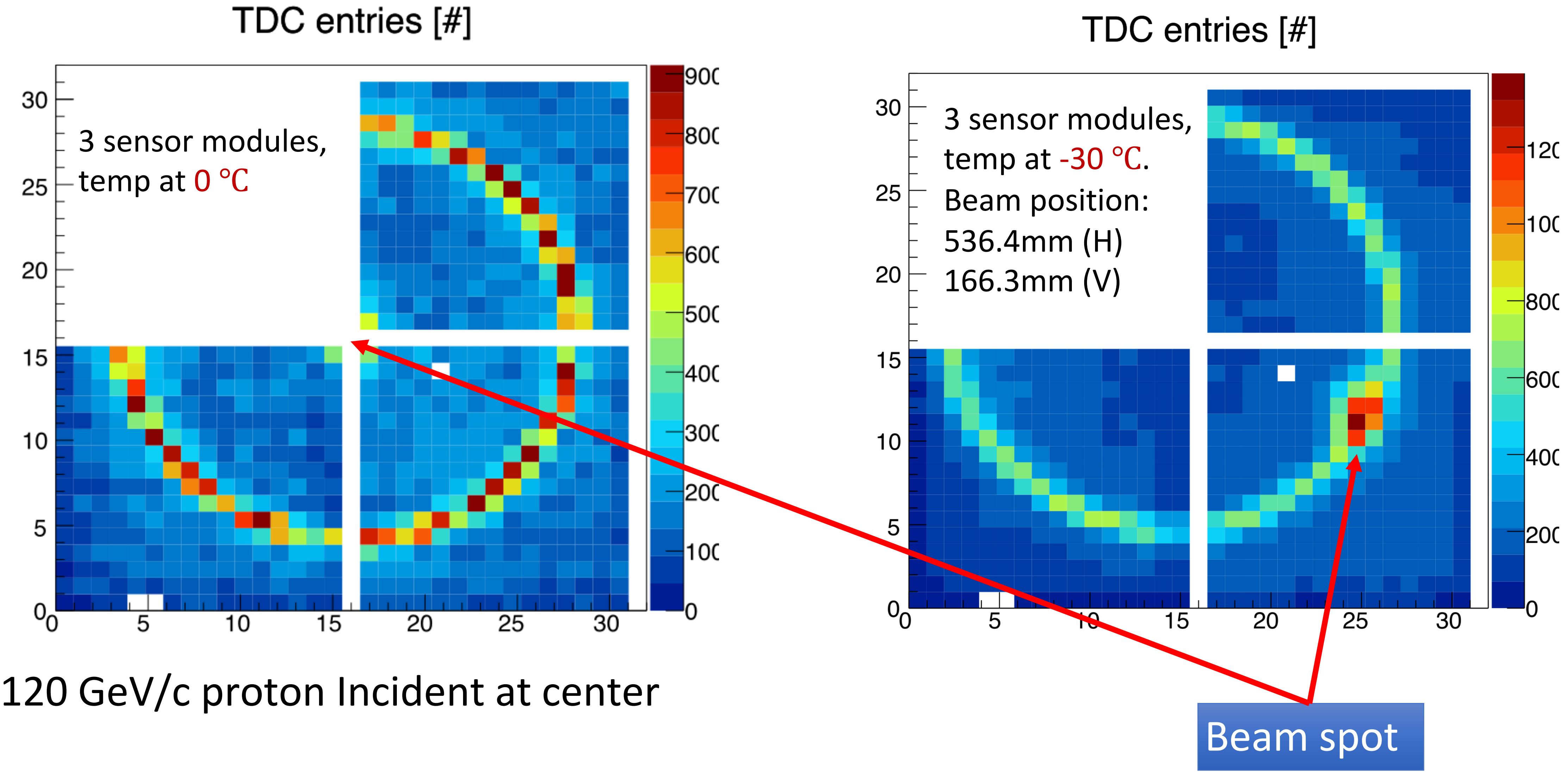




11 degree tilt downward

120 GeV/c proton beam

mRICH readout with SiPM matrix sensors



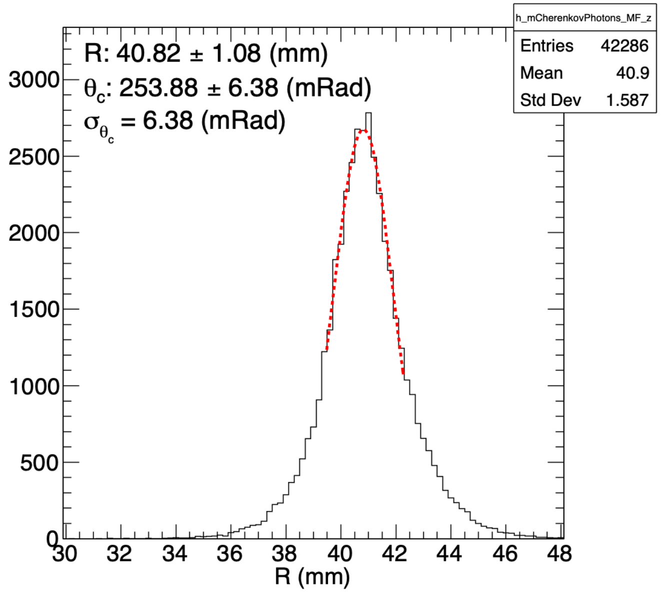
120 GeV/c proton Incident at center

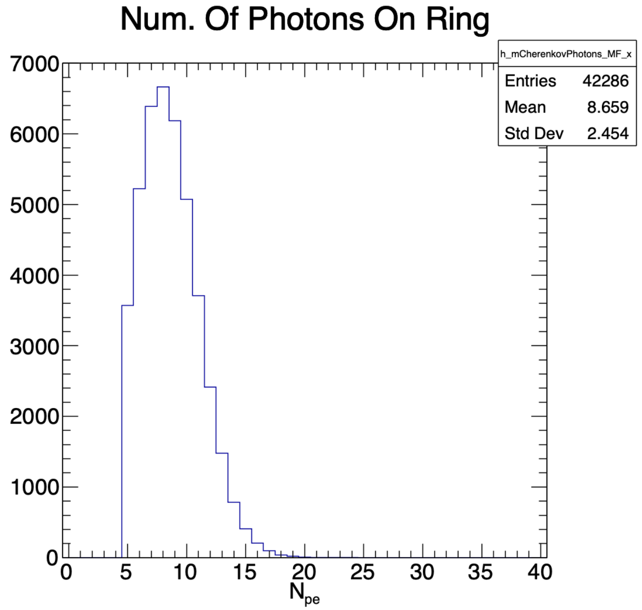
Ring Radius and Number of Cherenkov Photons

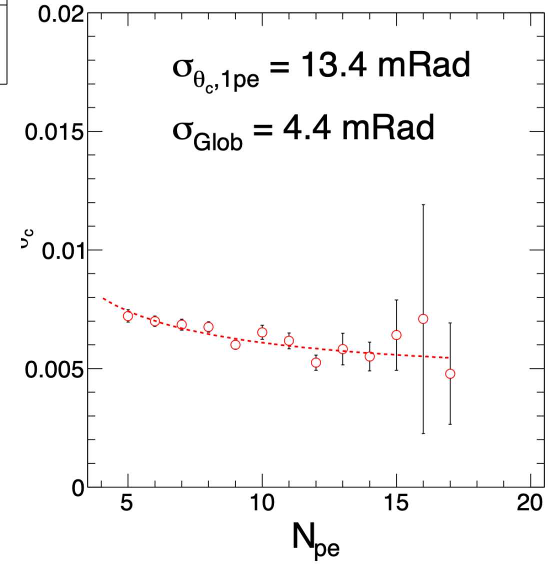
Data

No precision tracking was available.

Beam size is ~6mm in radius.



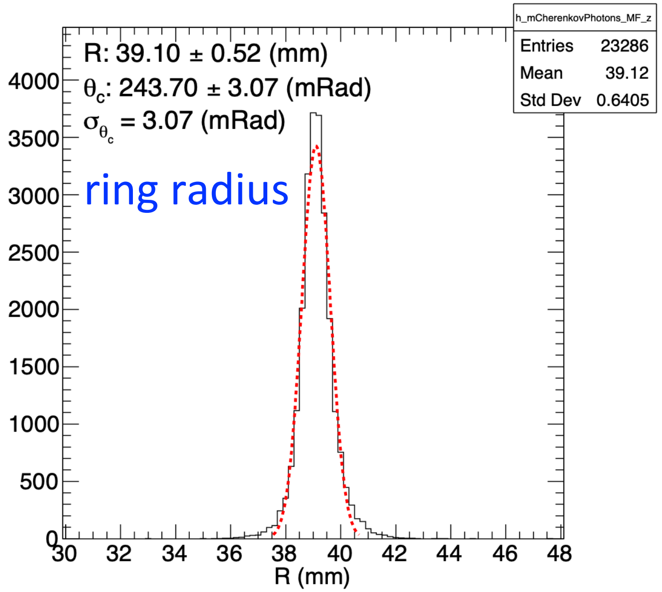


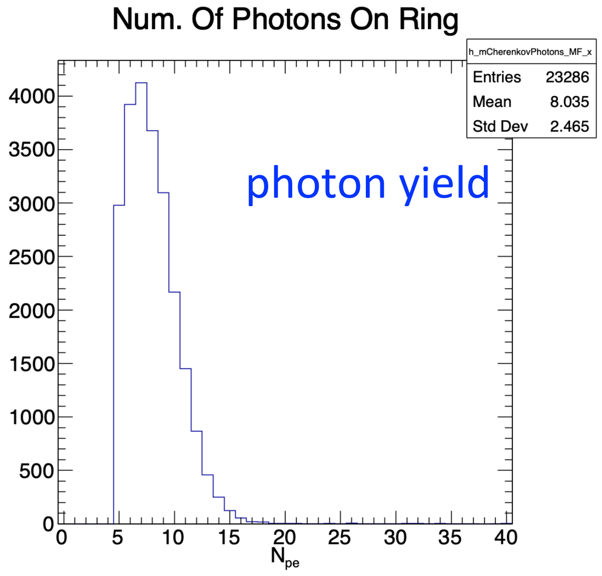


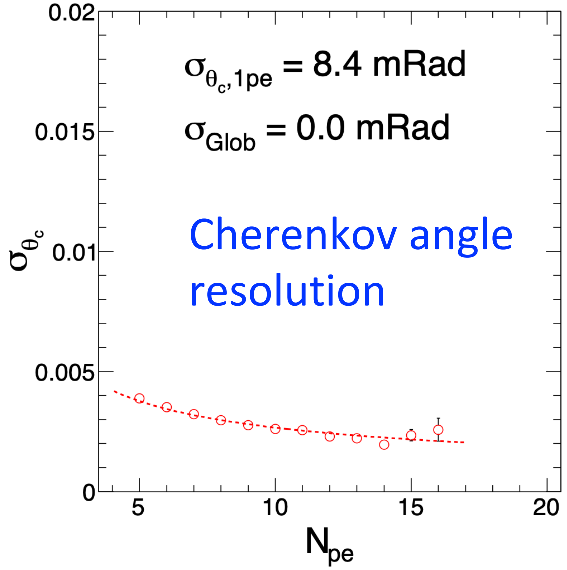
resolution affected by

- sub-optimal internal alignment and positioning
- incomplete aerogel tile characterization

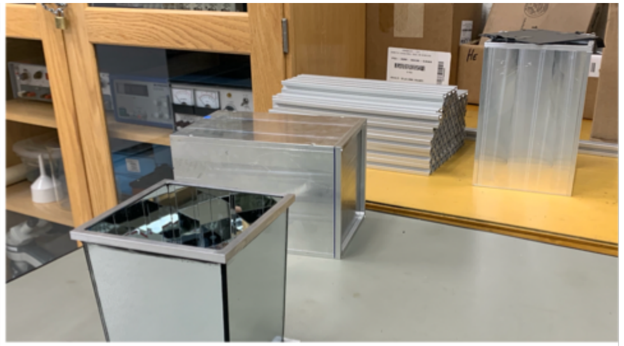
Simulation





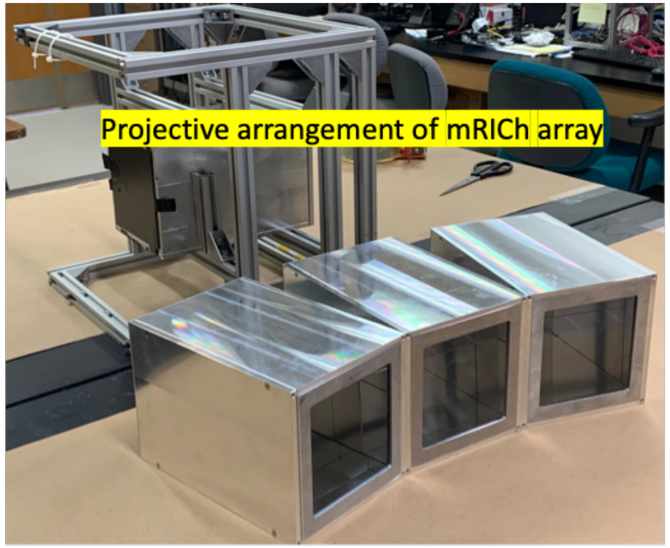


Outlook: Construct more mRICH modules for performance test

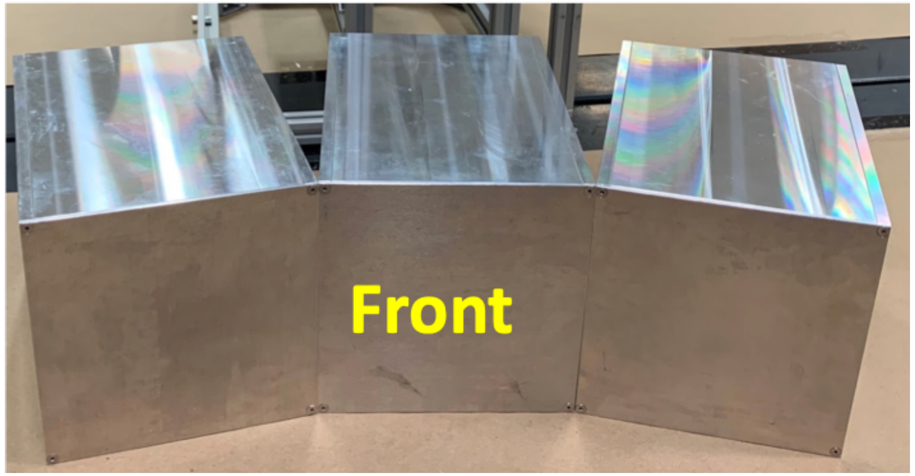


MRICH TEST PLANNING AT JLAB

CONSTRUCT 3 MORE MRICH OPTICAL UNITS AT GSU TO BE IDENTICAL TO THE ONE USED IN THE 2ND BEAM TEST

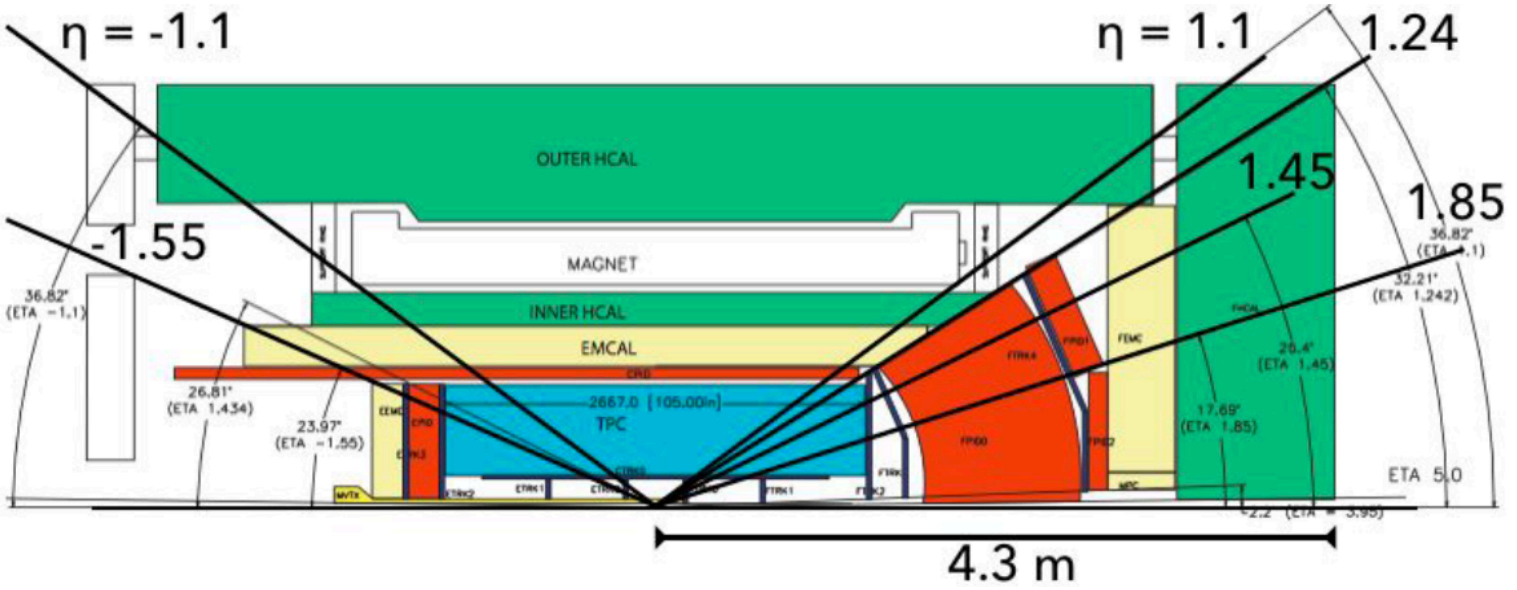


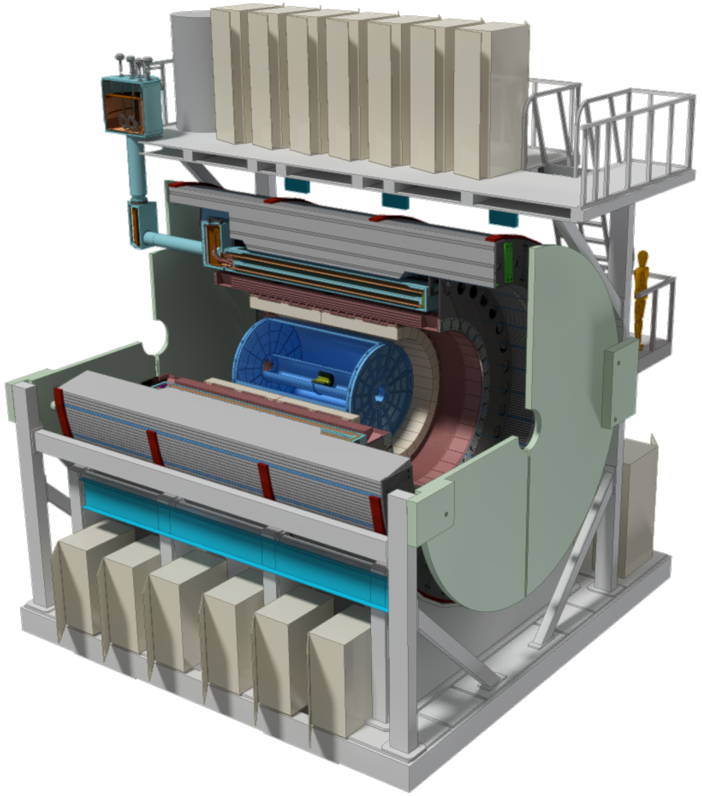
- Working on a potential beam test at Jefferson Lab using secondary electron beam.
- Plan to have another beam test at Fermilab once a tracking system is identified.
- Starting on mechanical design optimization.



- Modular
- Compact
- Projective

Near-term PID Detector Realization – BNL ePHENIX



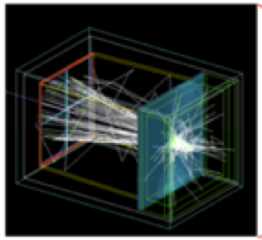


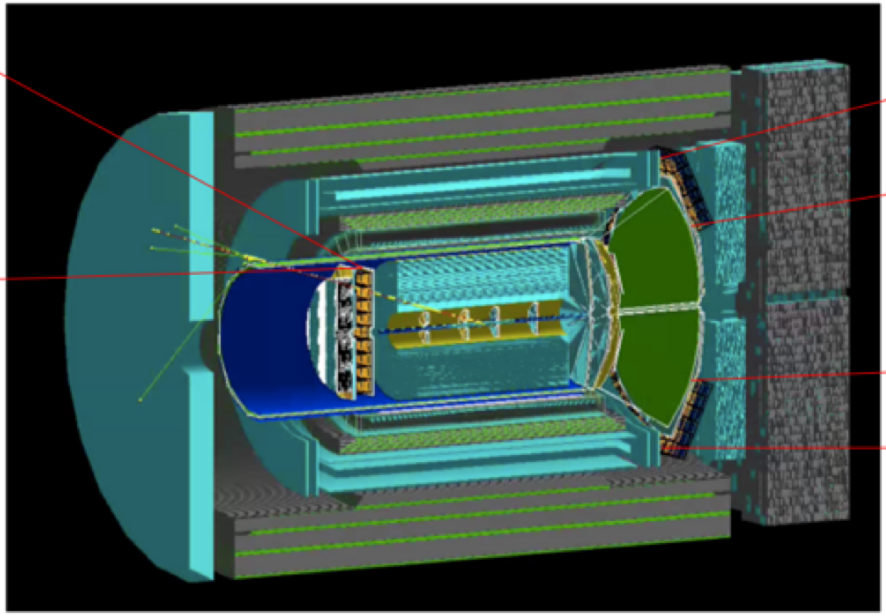
sPHENIX

- The DIRC, mRICH, and TOF systems already part of the current concept. An implementation in Geant4 (Fun4All) is ongoing.
- In addition, either the eRD14 dRICH and eRD6 gas RICH could be used. The two options have been compared in a collaborative effort.

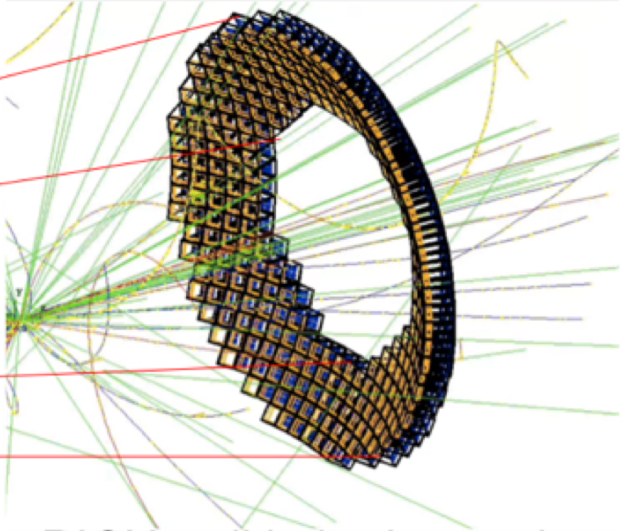
mRICH array implementation in sPHENIX

mRICH array implementation in Forward sPHENIX and JLab EIC detector concept in Geant4 simulation studies. Developed mRICH-based PID algorithms using a loglikelihood method.



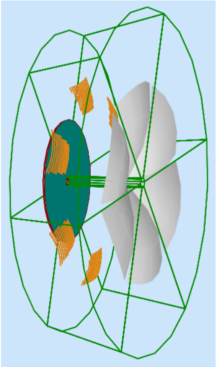


mRICH wall
e/π separation



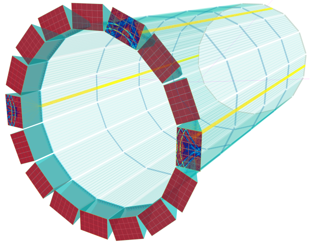
mRICH wall in hadron-going
direction for hadron PID

- Electron Ion Collider (EIC): next major facility for nuclear physics in the USA, located at BNL
- eRD14 consortium: R&D for an integrated EIC PID solution (funded by BNL)



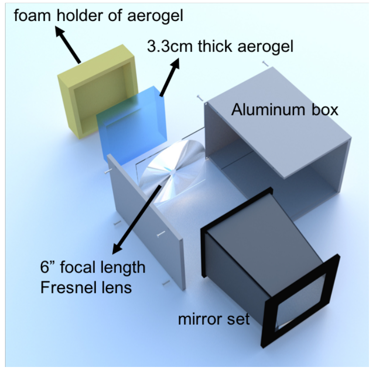
Activities: RICH/DIRC, TOF (mRPC), sensors in high B fields, fast electronics

dRICH: dual-radiator (aerogel & C_2F_6) RICH for hadron endcap
continuous momentum coverage, π/K separation for 3 – 50 GeV/c
large prototype in preparation for beam test



hpDIRC: compact fast focusing DIRC for barrel region, π/K separation up to 6 GeV/c
PANDA Barrel DIRC prototype to be transferred to US for beam tests at Fermilab

mRICH: modular aerogel RICH for electron endcap, π/K separation for 3 – 10 GeV/c
compact, projective design, Fresnel lens creates smaller, focused rings
two successful beam tests at Fermilab, proof-of-principle,
rings observed using MaPMT and SiPM arrays, MAROC readout
beam tests at JLab and Fermilab in preparation



- Goal: validate PID performance of design and components, TDR readiness in 2023

Thank you for your attention

Extra Material

eRD14 – EIC PID consortium

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

M. Alfred, B. Azmoun, F. Barbosa, L. Barion,, 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, C. Fanelli, D. Fields, Y. Furletova, C. Gleason, M. Grosse-Perdekamp, J. Harris, M. Hattawy, X. He, H. van Hecke, T. Horn, J. Huang, C. Hyde, Y. Ilieva, G. Kalicy, A. Kebede, B. Kim, E. Kistenev, A. Lehmann, M. Liu, R. Majka, J. McKisson, R. Mendez, I. Mostafanezhad, P. Nadel-Turonski, K. Peters, R. Pisani, W. Roh, P. Rossi, M. Sarsour, C. Schwarz, J. Schwiening, C.L. da Silva, N. Smirnov, J. Stevens, A. Sukhanov, X. Sun, S. Syed, R. Towell, G. Varner, R. Wagner, C. Woody, C.-P. Wong, W. Xi, J. Xie, Z.W. Zhao, B. Zihlmann, C. Zorn.

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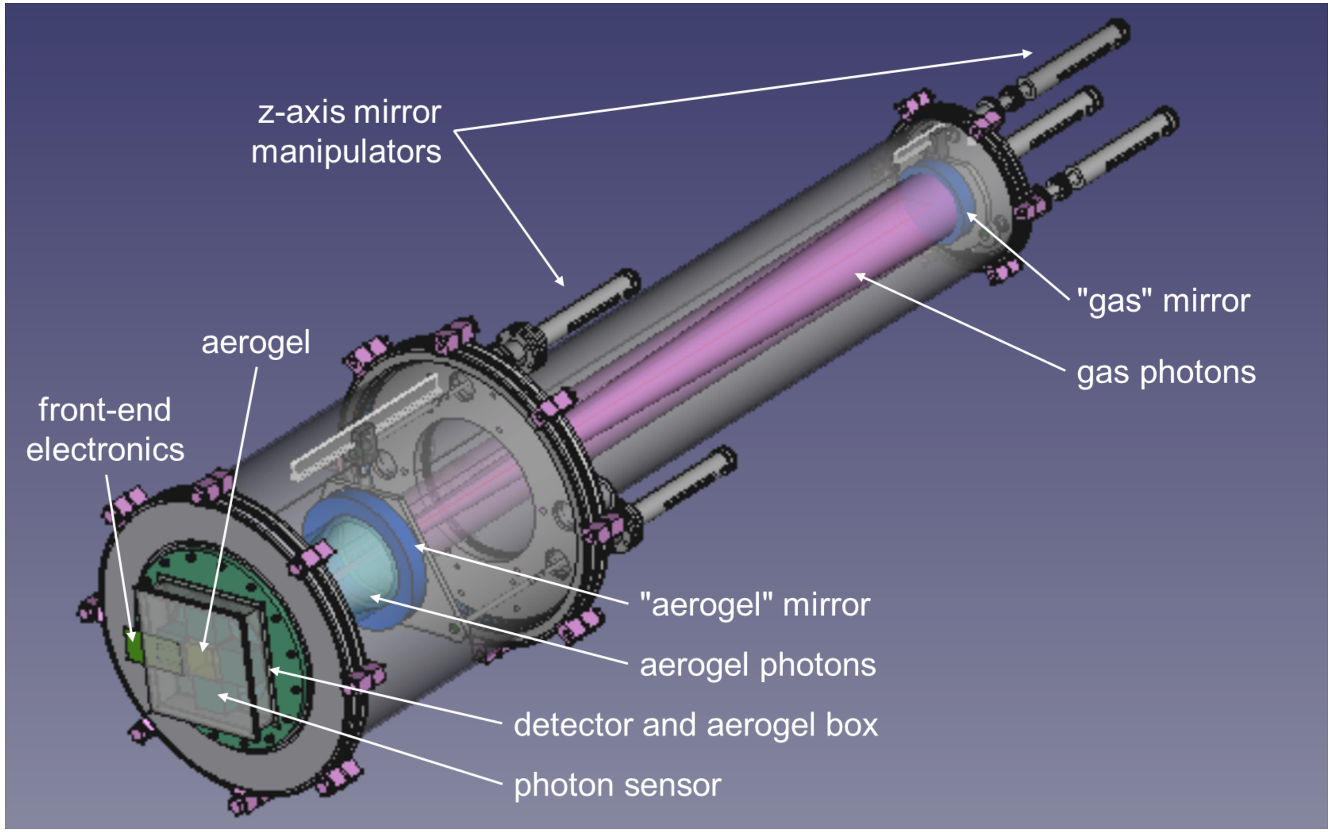
Y. Ilieva <jordanka@physics.sc.edu>

Generic Detector R&D for an Electron Ion Collider

eRD14: Participating institutions

- Abilene Christian University (ACU)
- Argonne National Lab (ANL)
- Brookhaven National Lab (BNL)
- Catholic University of America (CUA)
- City College of New York CCNY)
- College of William & Mary (W&M)
- Duke University (Duke)
- Georgia State University (GSU)
- GSI Helmholtzzentrum für Schwerionenforschung, Germany (GSI)
- Howard University (HU)
- Institute for High Energy Physics, Protvino, Russia
- 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)
- North Carolina A&T State University (NCAT)
- Old Dominion University (ODU)
- Stony Brook University (SBU)
- Universidad Técnica Federico Santa María, Chile (UTFSM)
- Universität Erlangen, Germany
- University of Hawaii (UH)
- University of Illinois Urbana-Champaign (UIUC)
- University of New Mexico (UNM)
- University of South Carolina (USC)
- Yale University (Yale)

dRICH prototype

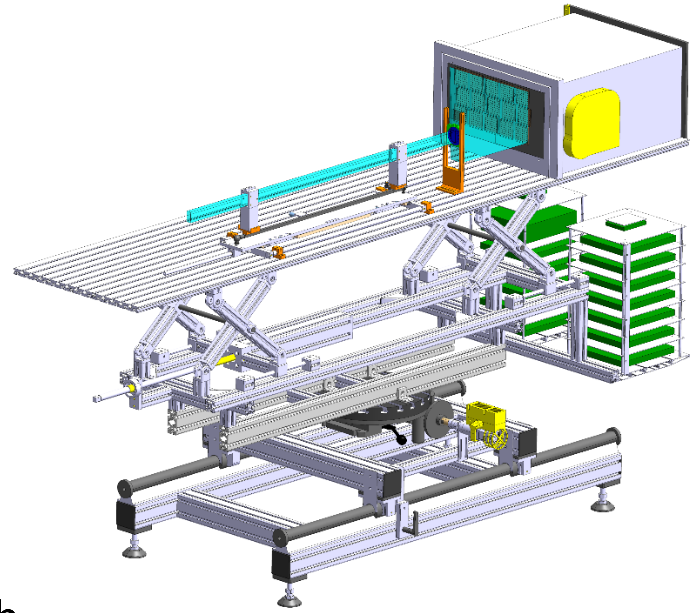


- Design in an advanced stage, mechanical details being finalized
- Standard Vacuum Technologies to optimize gas handling
- Two tunable mirrors system for using the same detector
- Common (limited) sensitive surface for both aerogel and gas photons
- Detector and aerogel box isolated from the gas tank

HPDIRC PROTOTYPE

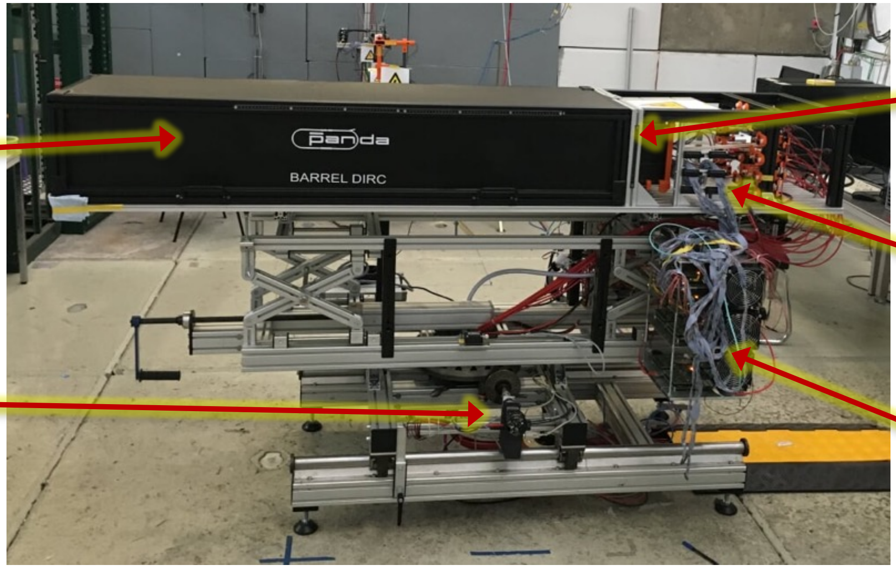
Transfer of the PANDA barrel DIRC prototype to USA (CUA/SBU)

- Modular design modified and improved over 11 years
- Achieved up to 4.8 s.d. π/K separation at 3.5 GeV/c and 20° polar angle in PANDA configuration (6mm pixels, 200ps photon timing)
- Available now due to conclusion of PANDA DIRC R&D
- Transfer will include support mechanics, bar, plate, prism, several MCP-PMTs (6mm pixels) and GSI readout electronics (~200ps photon timing)
- Start point for hpDIRC prototype, will be upgraded with sensors with smaller pixels (3mmx3mm) plus faster readout electronics and tested at SBU and Fermilab



Dark box for optics (bar, lens, prism)

Rotation stage (remote controlled)



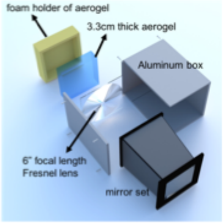
MCP-PMT array

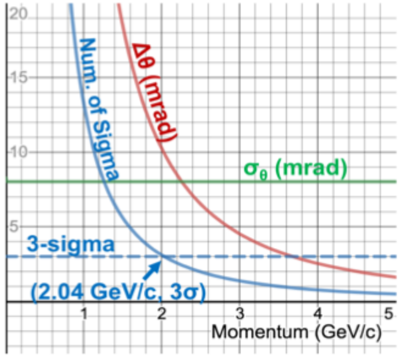
Frontend electronics (PADIWA) (air-cooled)

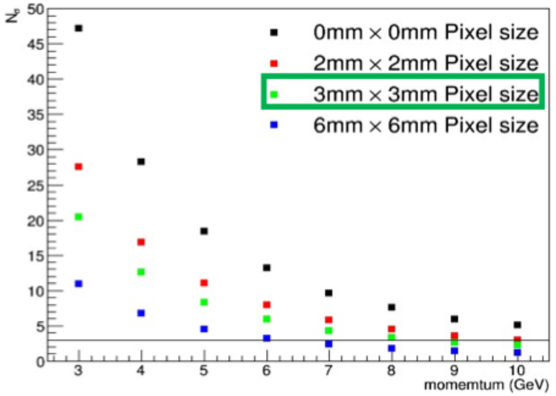
DAQ boards (TRB)

Prepared by X. He on 8/12/2019, EIC PID Consortium (eRD14 Collaboration)

Modular and compact ring imaging Cherenkov (mRICH) PID detector for EIC experiments

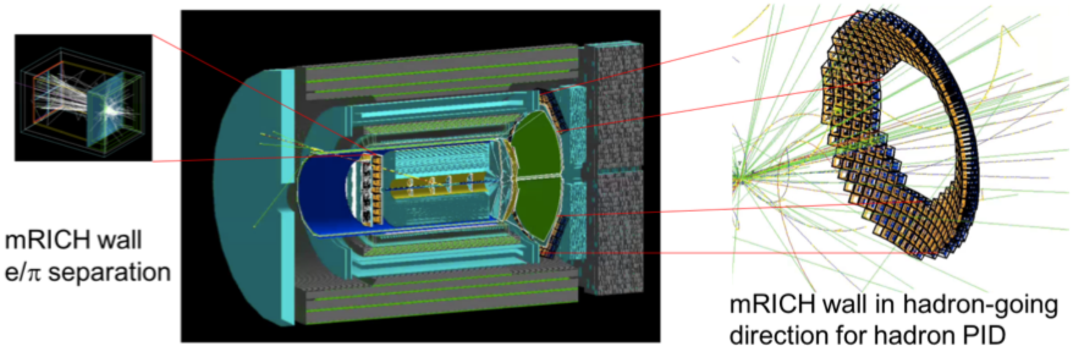






- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c

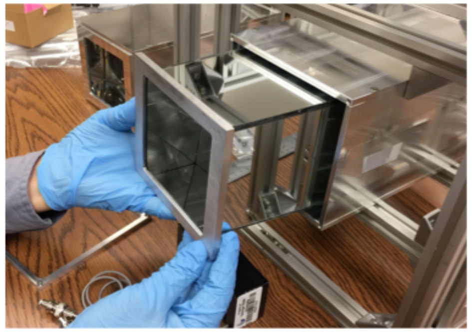
- Projected K/pi separation of mRICH 2nd prototype detector (**Green dots**)
- 2nd prototype detector can achieve 3-sigma K/pi separation up to 8 GeV/c



mRICH wall e/π separation

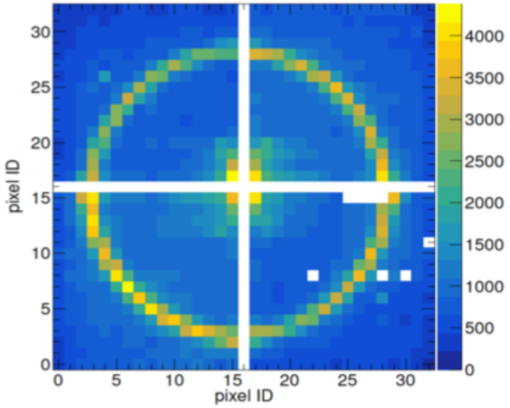
mRICH wall in hadron-going direction for hadron PID

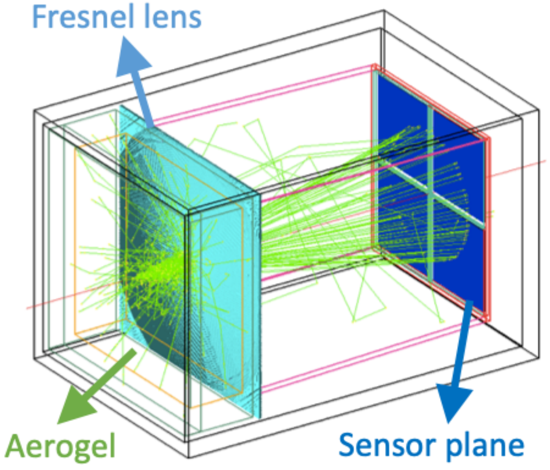
New features: a) separation of optical and electronic components; b) longer focal length (6"); c) 3mm x 3mm photosensors.



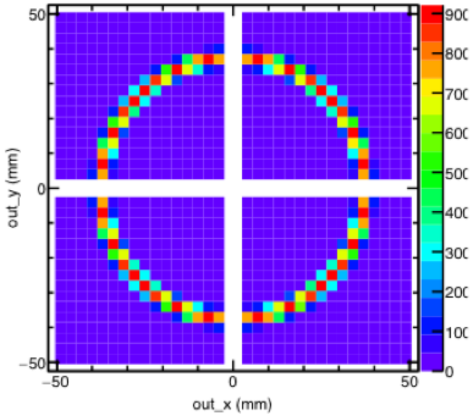
2nd mRICH prototype was tested at Fermilab Test Beam Facility in June/July 2018

Beam Test at Fermilab



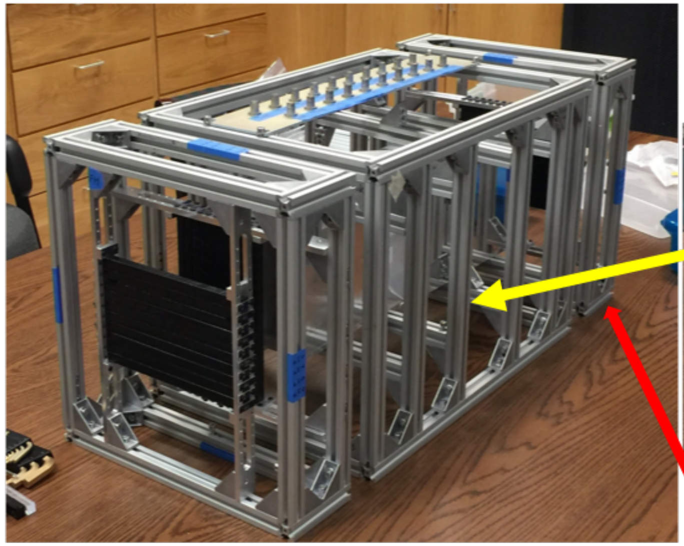


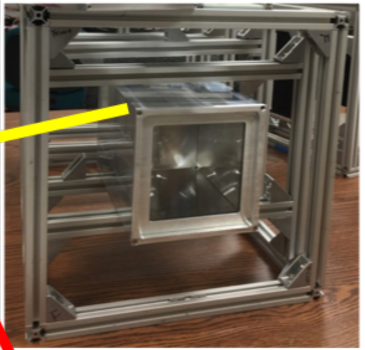
GEANT4 Simulation

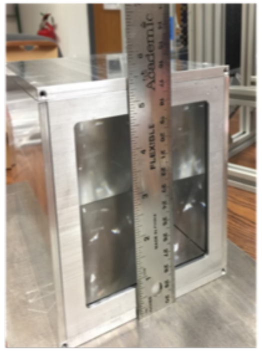


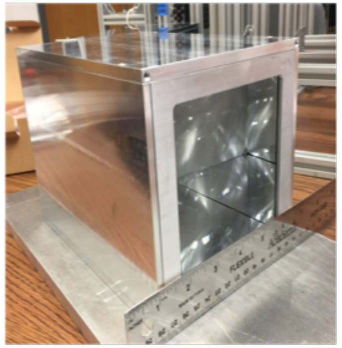
The goal of this test is to verify PID (k/pi separation) capability between 3 to 9 GeV/c and e/pi separation around 2 GeV/c.

Beam requirement: pion and kaon beams with momentum between 3 to 10 GeV/c. Electrons and pions around 2 GeV/c (or lower). Primary proton beam at 120 GeV/c for calibration, alignment, and consistency checks against the 1st test results.



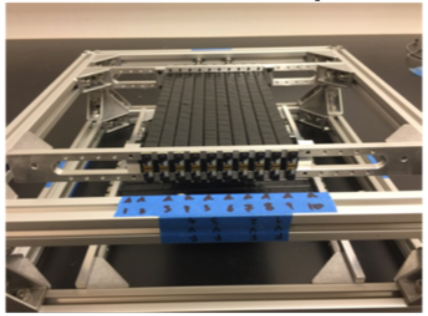






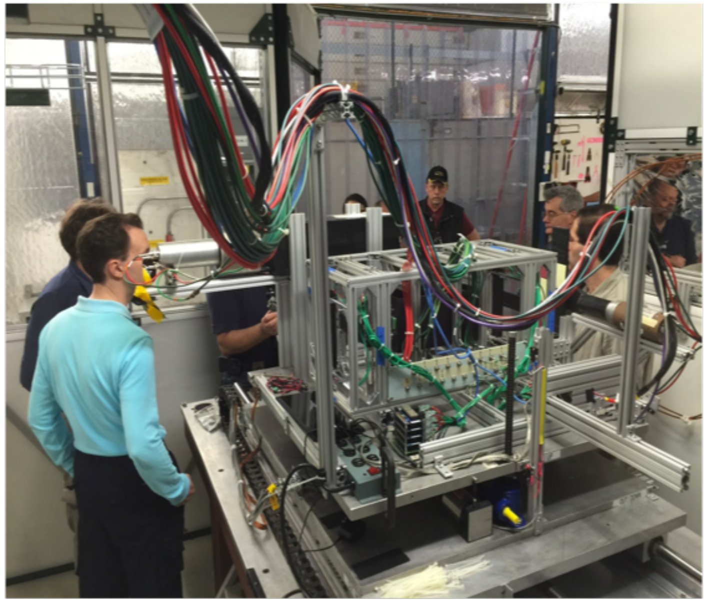
mRICH and its test stand

Beam hodoscopes



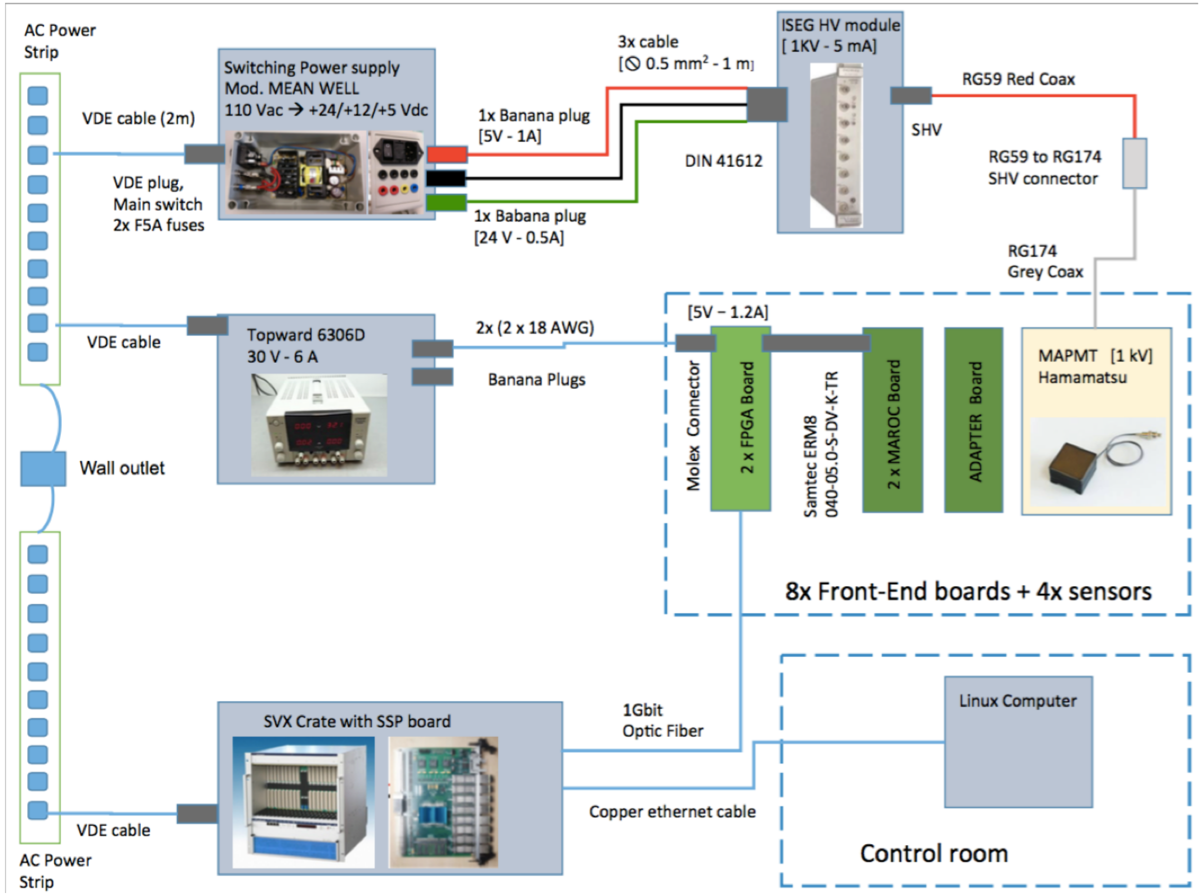
No readout electronics shown here, which are currently under development by two groups: Hawaii University and INFN, Ferrara, Italy

1st Beam Test in April 2016. Focused on testing the mRICH working principles using 120 GeV primary beam. Results have been published in NIMA in July 2017.

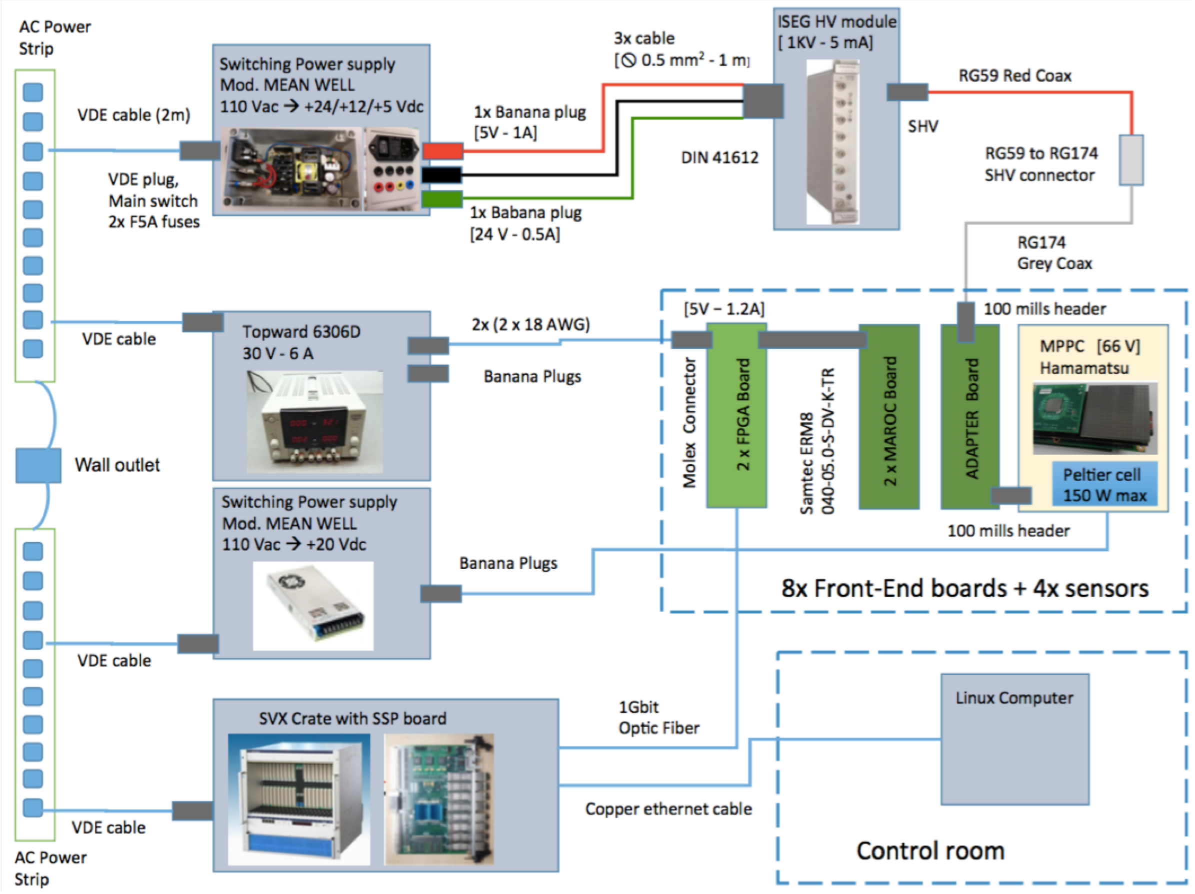


mRICH Prototype Readout Overview

Using four H13700 Multi-anode PMTs



Using three Hamamatsu SiPM Matrices



Each mRICH readout is completely independent of other modules in an mRICH array configuration.