Modular RICH (mRICH) Detector Development for the Future Electron Ion Collider (EIC) Experiment

Deepali Sharma and Xiaochun He

Georgia State University

On behalf of the **EIC eRD14** and **eRD101** Collaboration

Georgia State University: Xiaochun He, Murad Sarsour, Deepali Sharma, Sawaiz Syed, and Xu Sun (former postdoc)

Duke University: Bishnu Karki and Zhiwen Zhao

INFN: Marco Contalbrigo, Marco Mirazita and Luca Barion

JLab: Sergey Furletov, Carl Zorn, Alex Eslinger, and Benedikt Zihlmann

South Carolina University: Yordanka Ilieva

University of Virginia: Kondo Gnanvo (GEM tracking)

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Outline

- mRICH for EIC
- mRICH design features
- mRICH prototype studies

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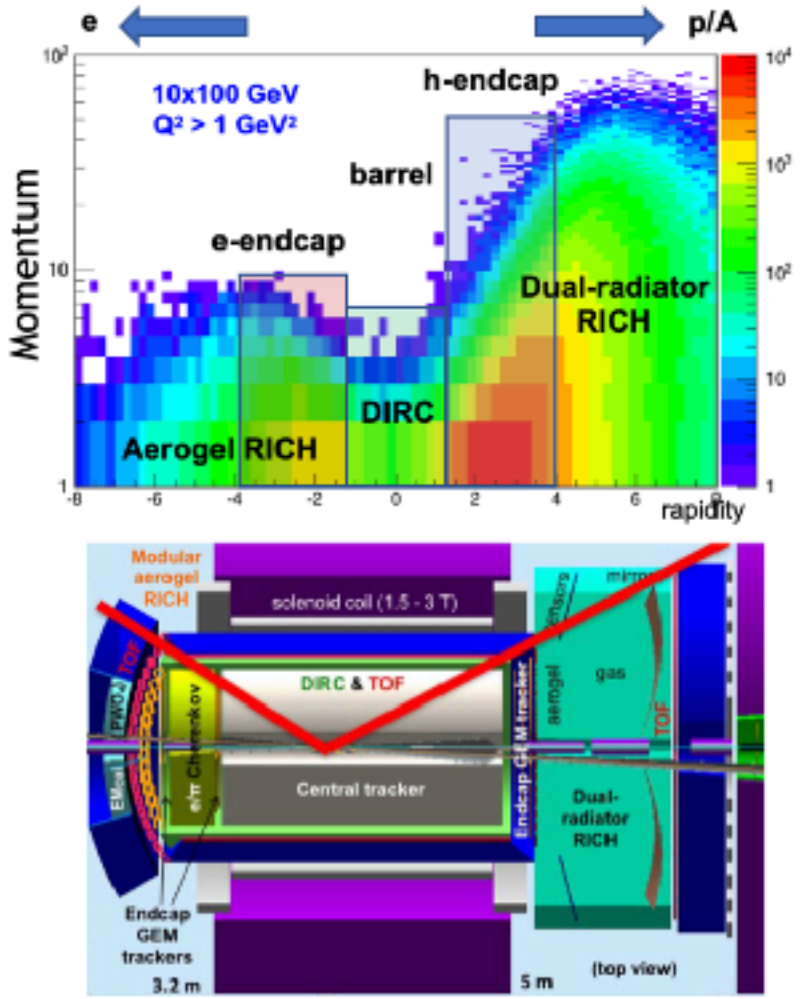
Past Presentation of mRICH at RICH Workshop



EIC PID Strategies for EIC

- **h-endcap**: A RICH with two radiators (gas + aerogel) is needed for
  π/K separation up to ~50 GeV/c **dRICH**
- **e-endcap**: A compact aerogel RICH which can be projective
  π/K separation up to ~10 GeV/c **mRICH**
- **barrel**: A high-performance DIRC provides a compact and cost-effective way to cover the area.
  π/K separation up to ~6-7 GeV/c **DIRC**

- **TOF (and/or dE/dx in TPC)**: can cover lower momenta.
- **Photosensors and electronics**: need to match the requirements of the new generation devices being developed – both for the final systemand during the R&D phase

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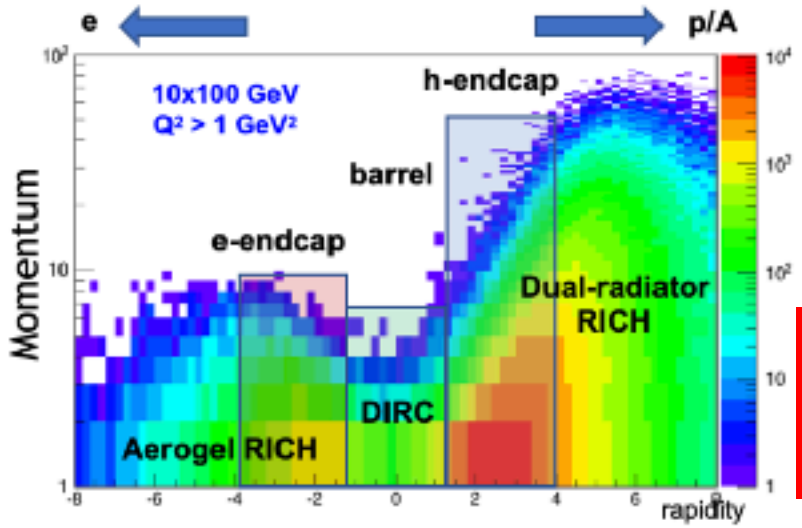

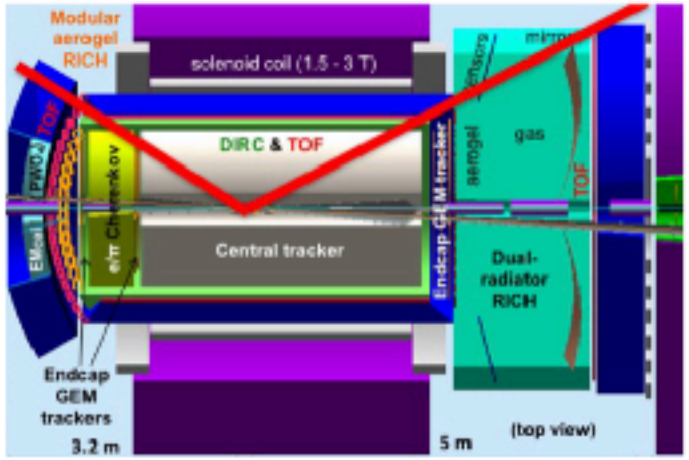

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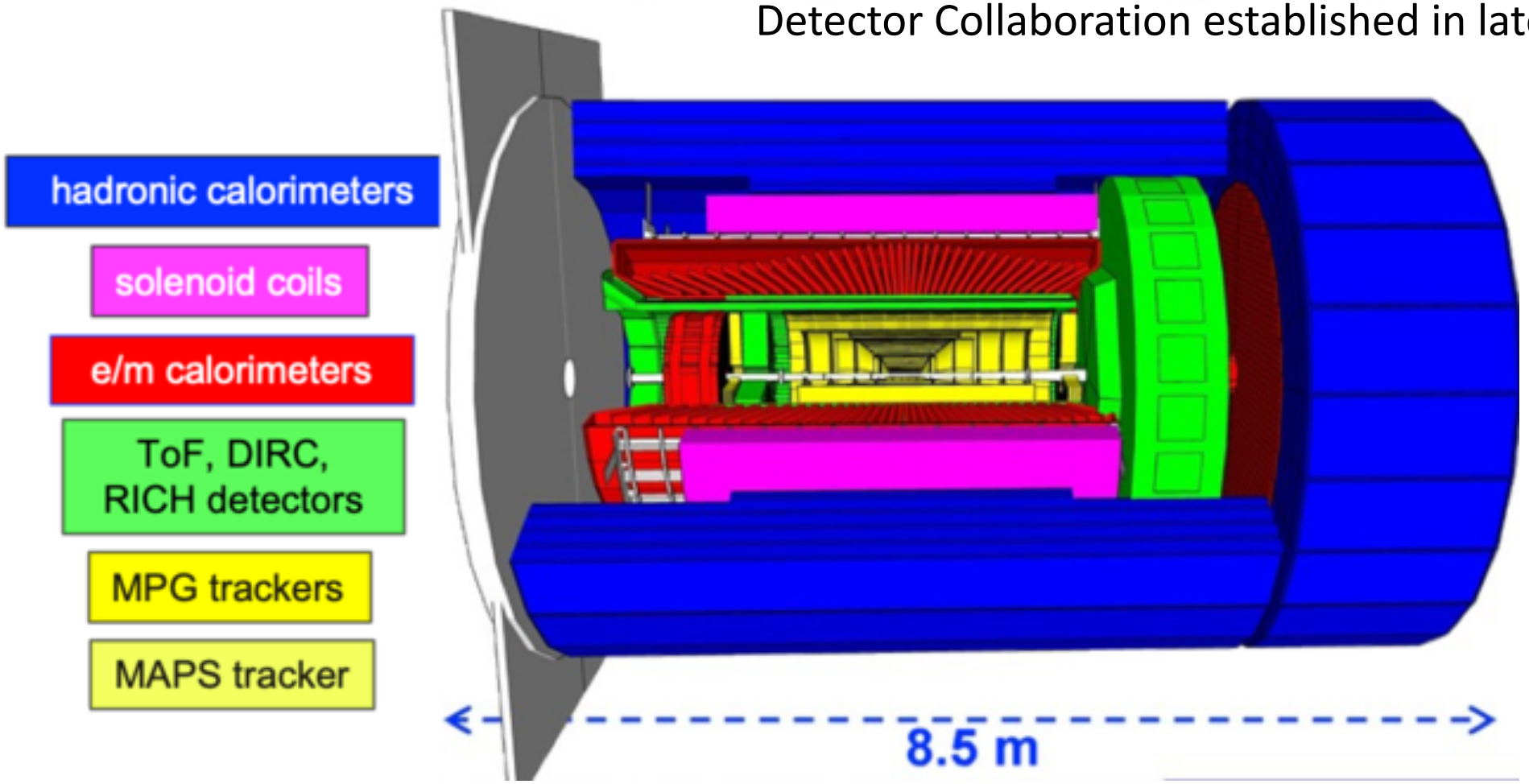
mRICH in ePIC

ePIC is the brand-new name of the EIC Project Detector Collaboration established in late July of 2022



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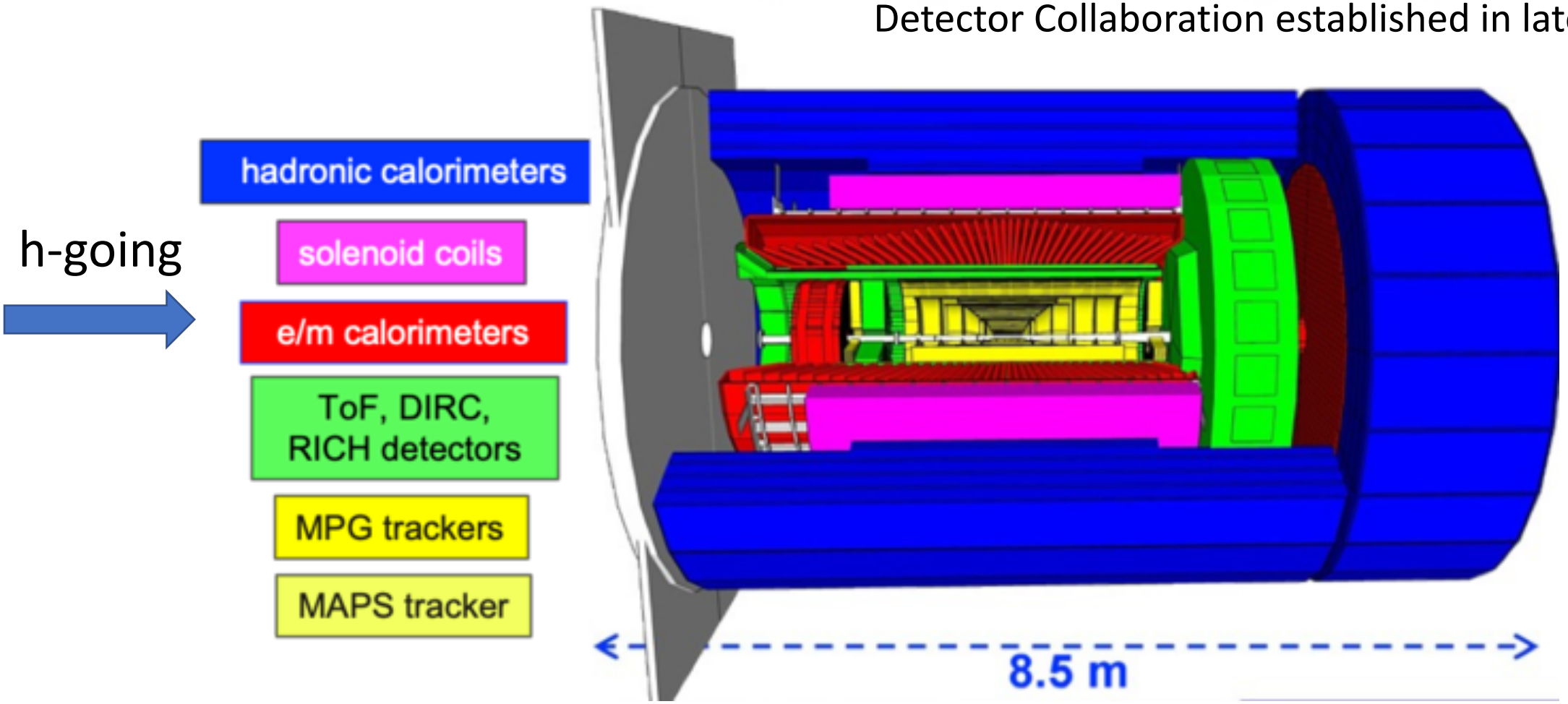

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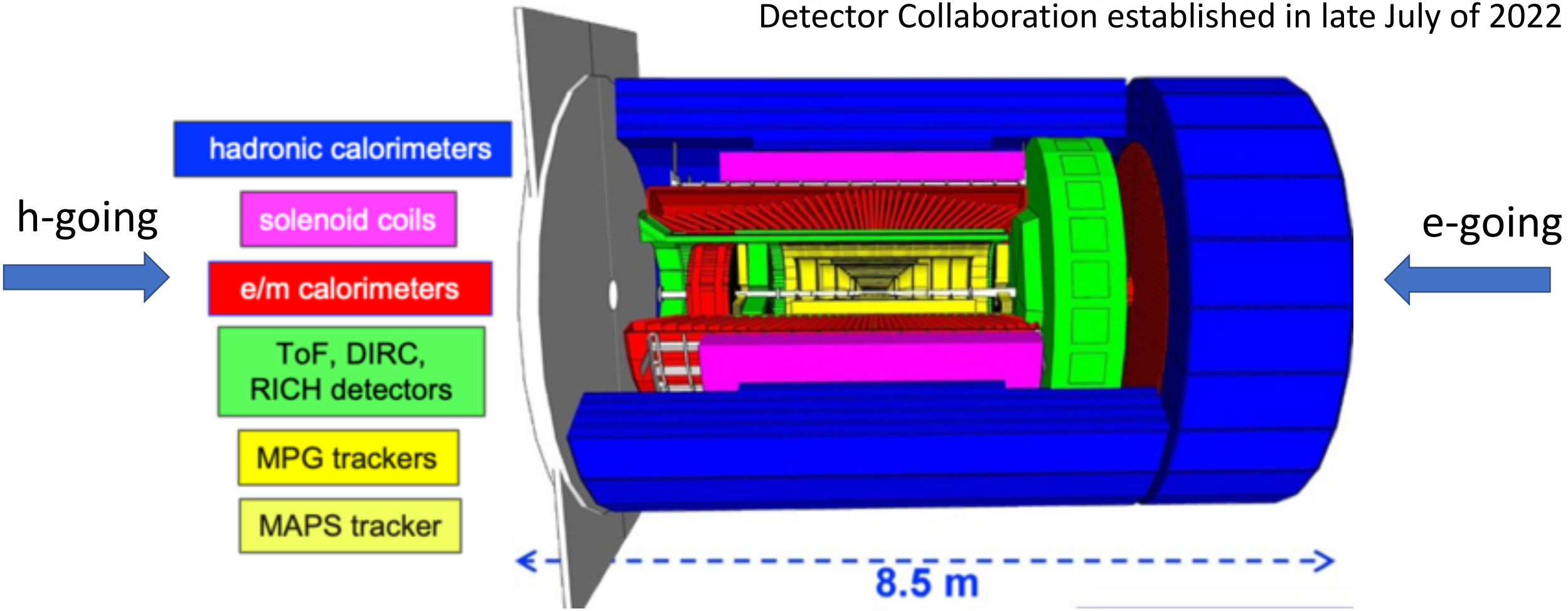

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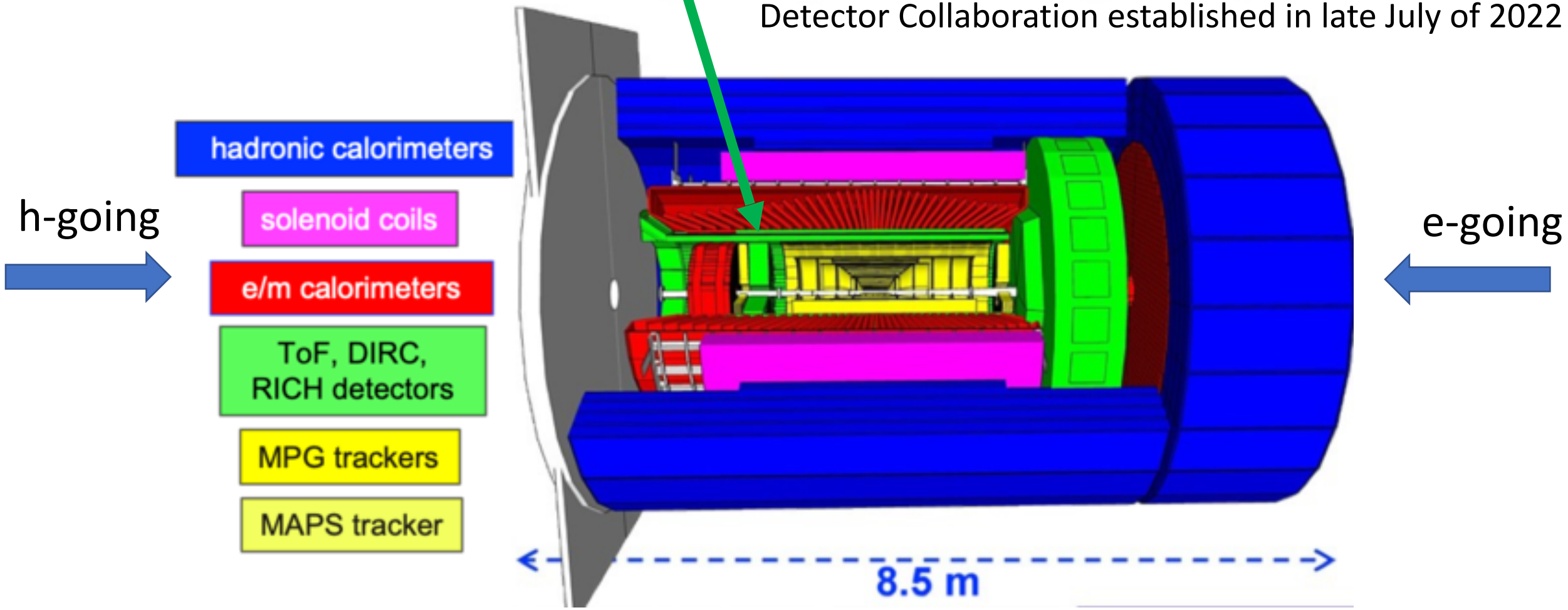
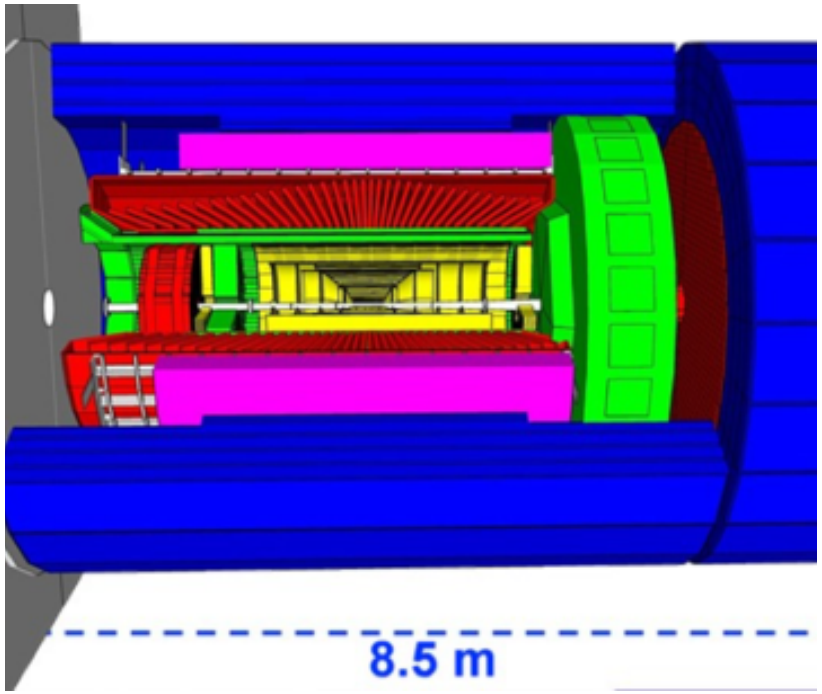


mRICH Array Implementation in ePIC



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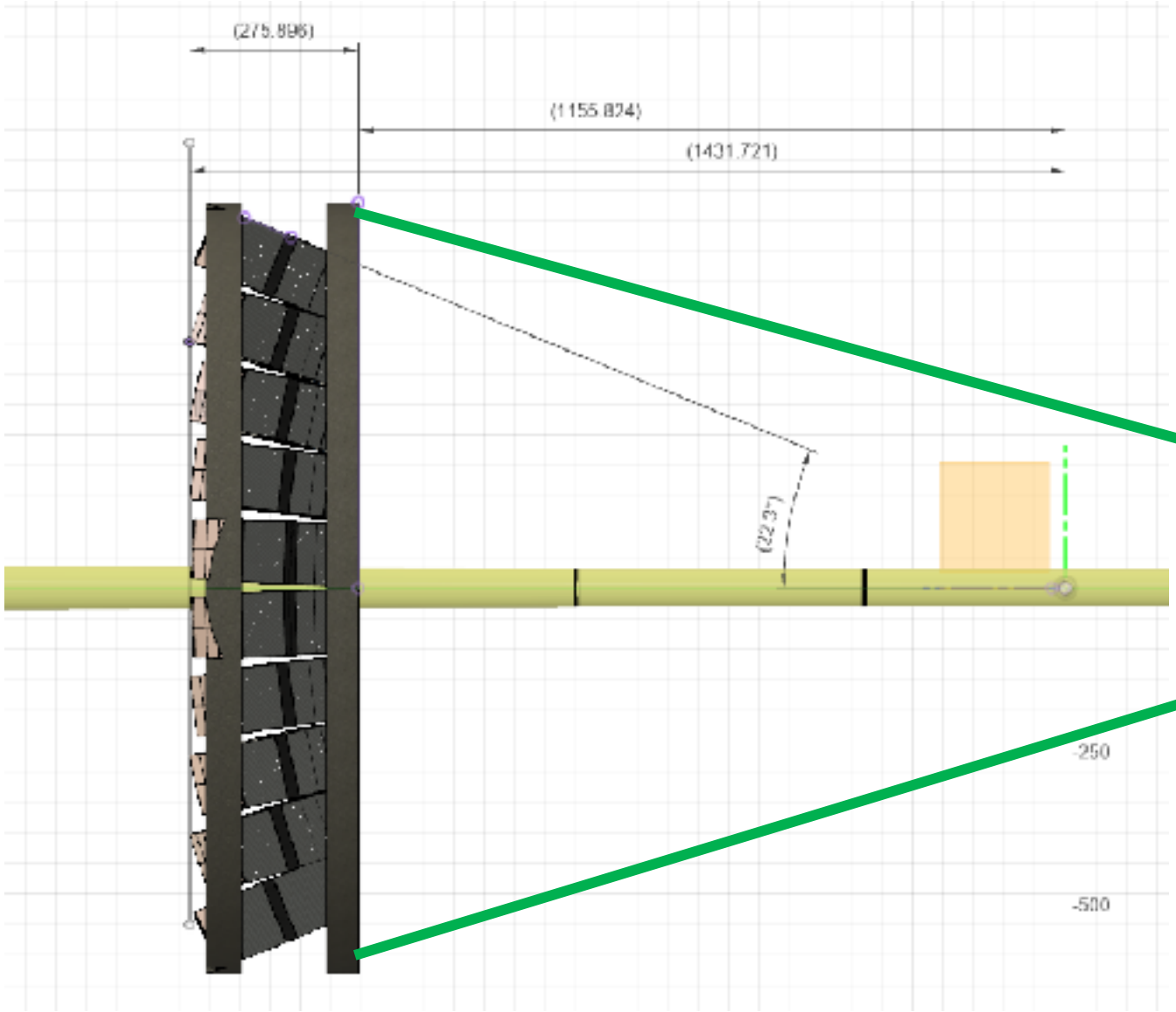
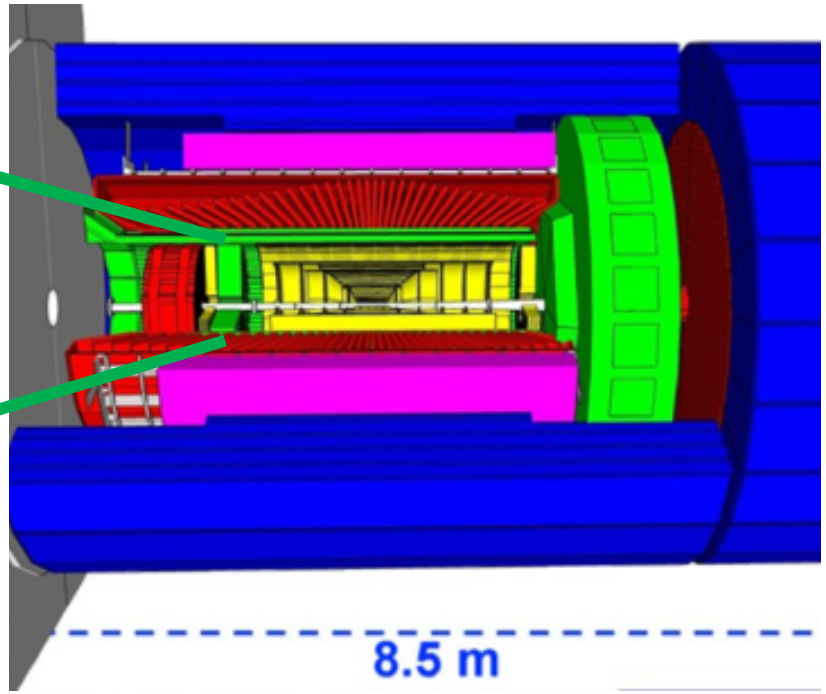
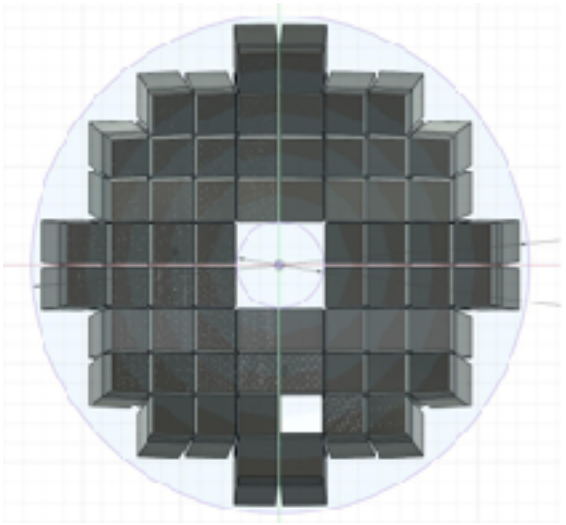
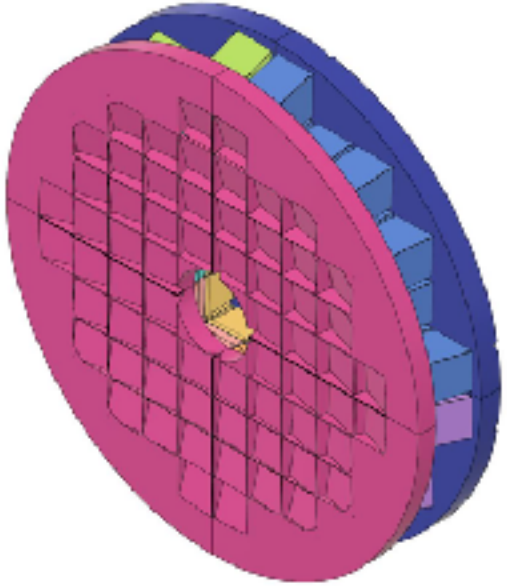
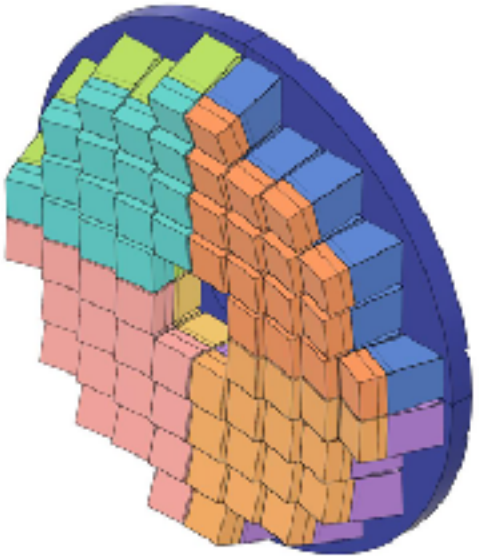


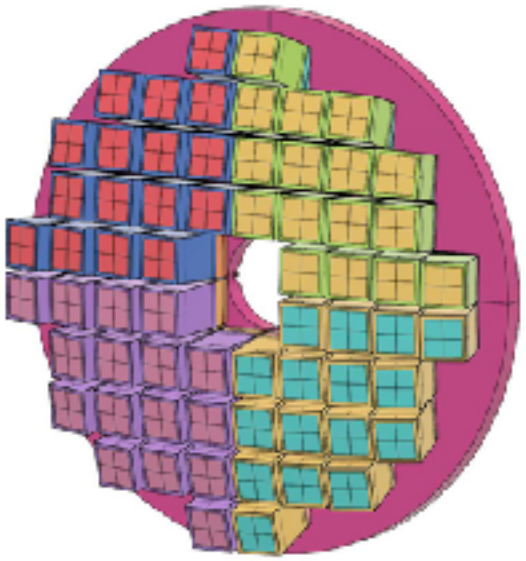








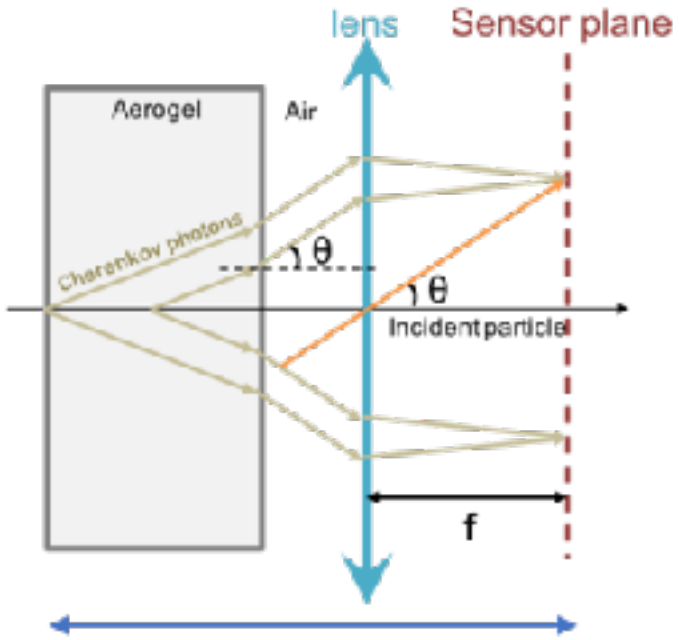
Front



Back

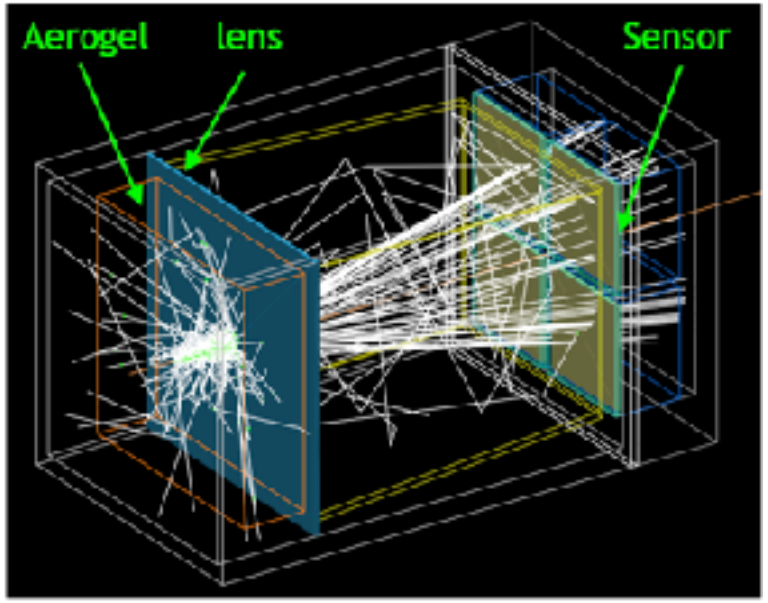
mRICH Array and the Support Structure in EIC Experiments

mRICH Optics – Working Principle & Prototyping



~ (aerogel thickness + lens focal length)

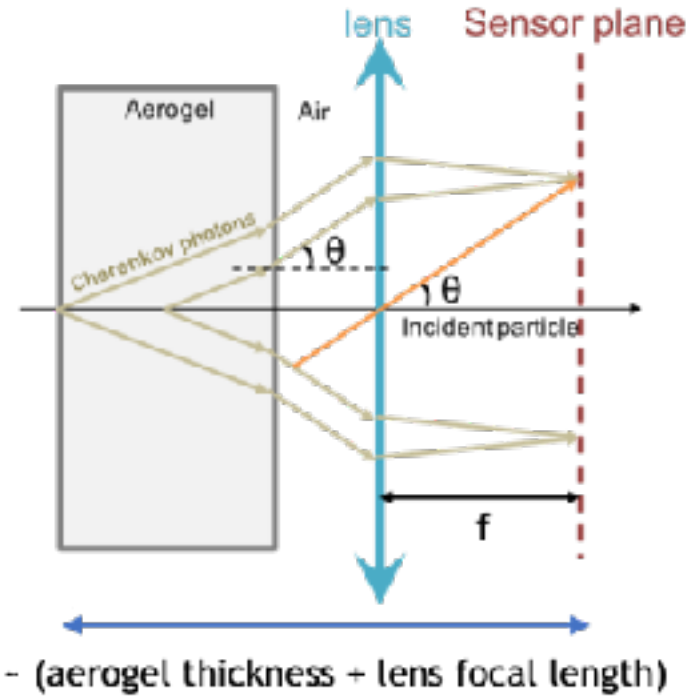
(Not to scale, for illustration purpose only)



Geant4 Simulation

With realistic material optical properties

mRICH Optics – Working Principle & Prototyping



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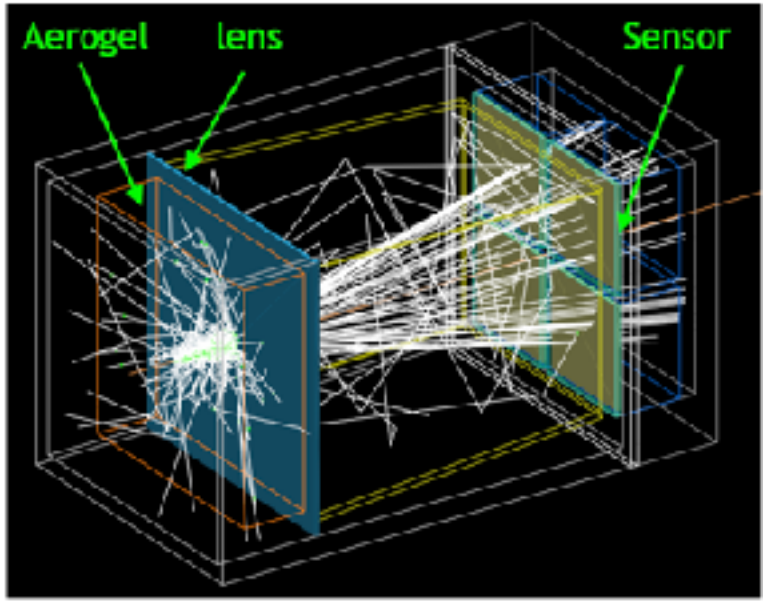

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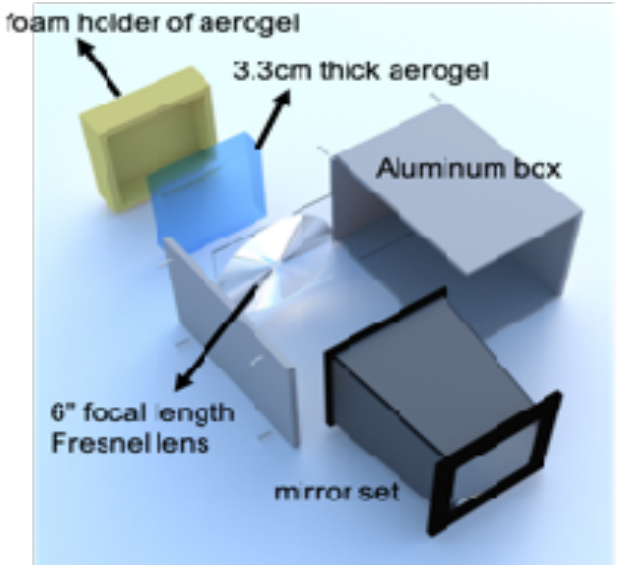
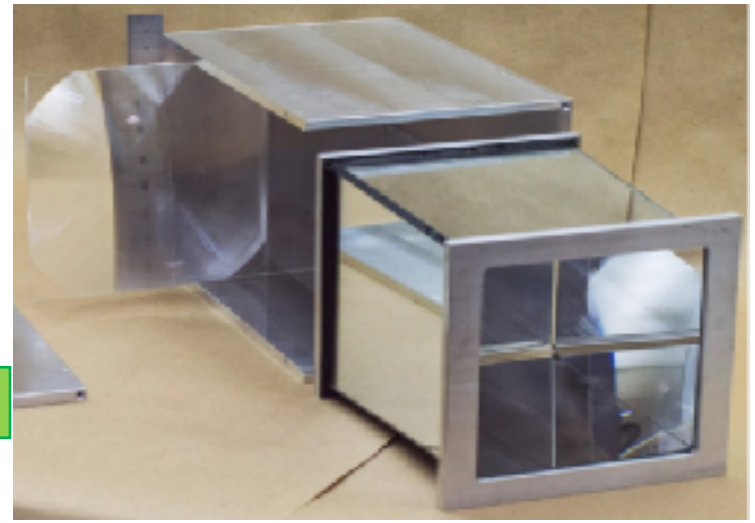


2nd version



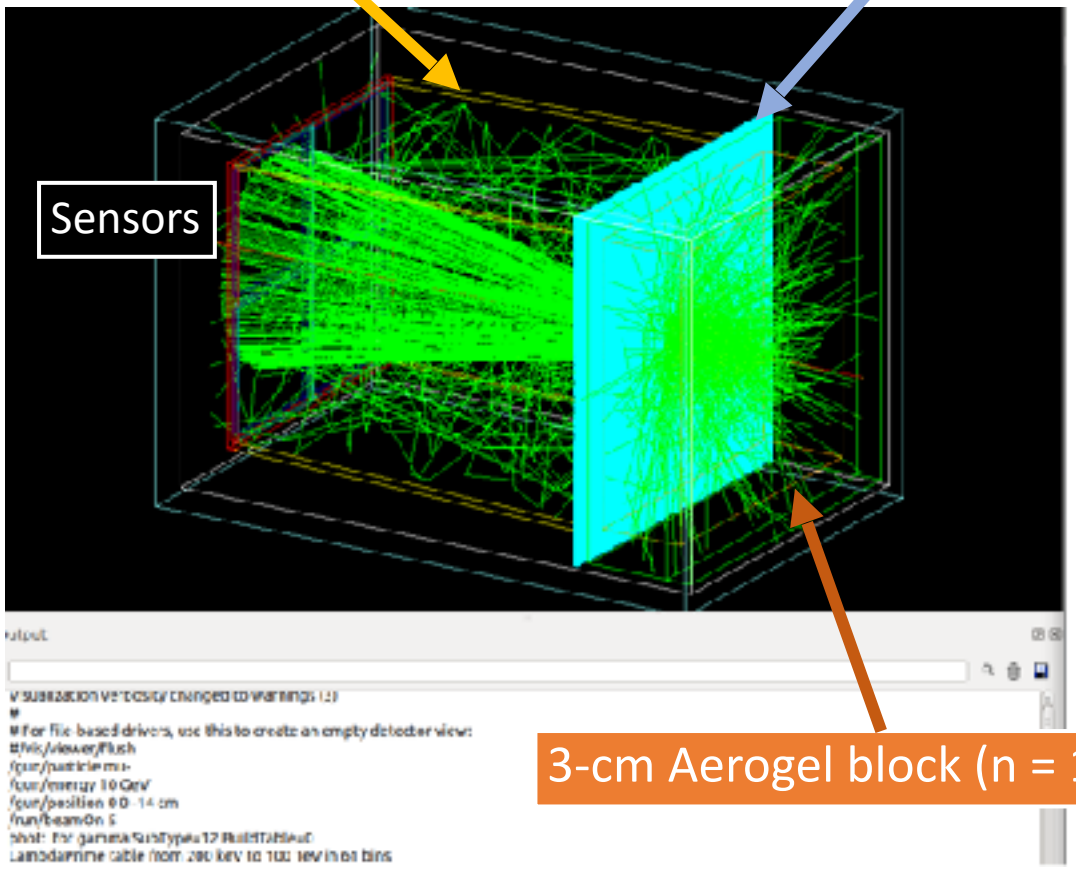
We are working on the 3rd version of mRICH prototype which will be closer to the final design of mRICH for the EIC Project Detector I, called ePIC.

mRICH Key Features

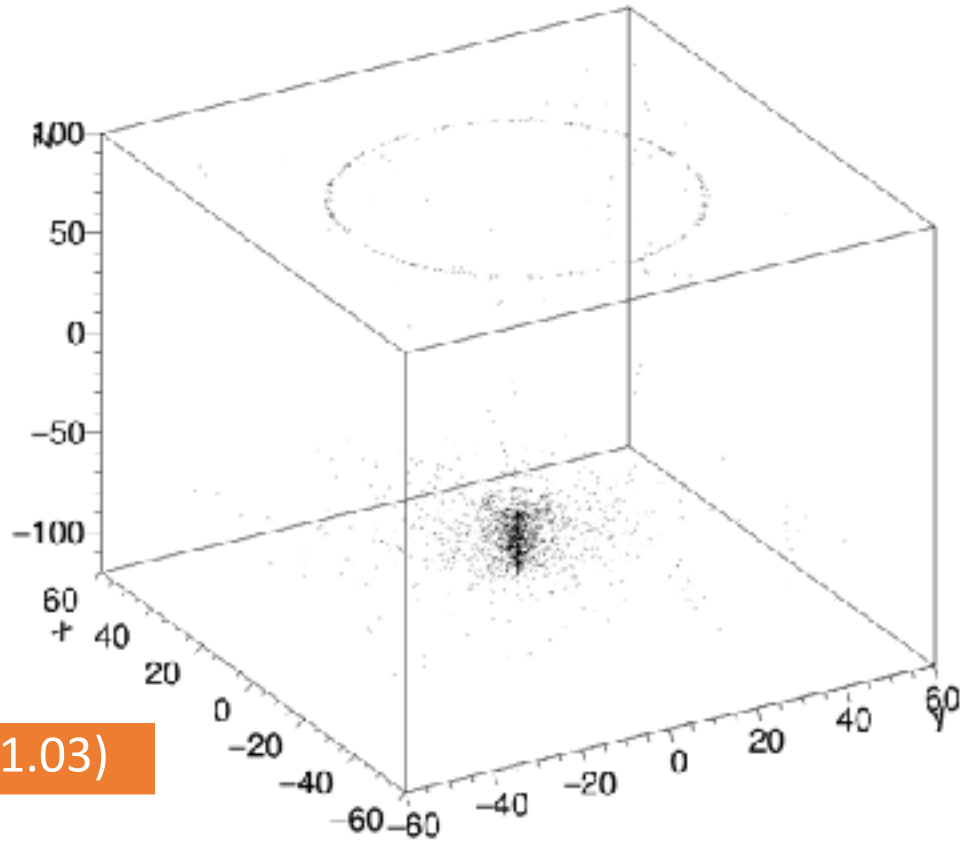
Mirror wall

6” acrylic Fresnel lens

Sensors

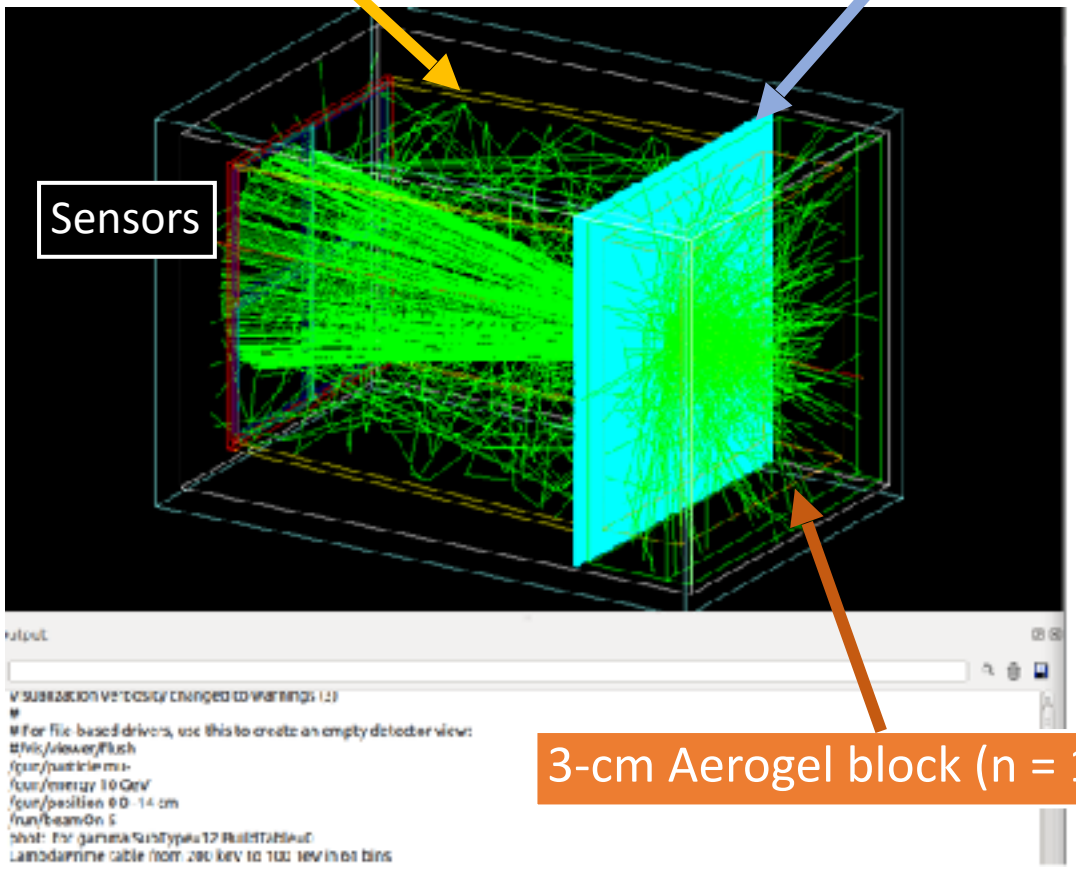


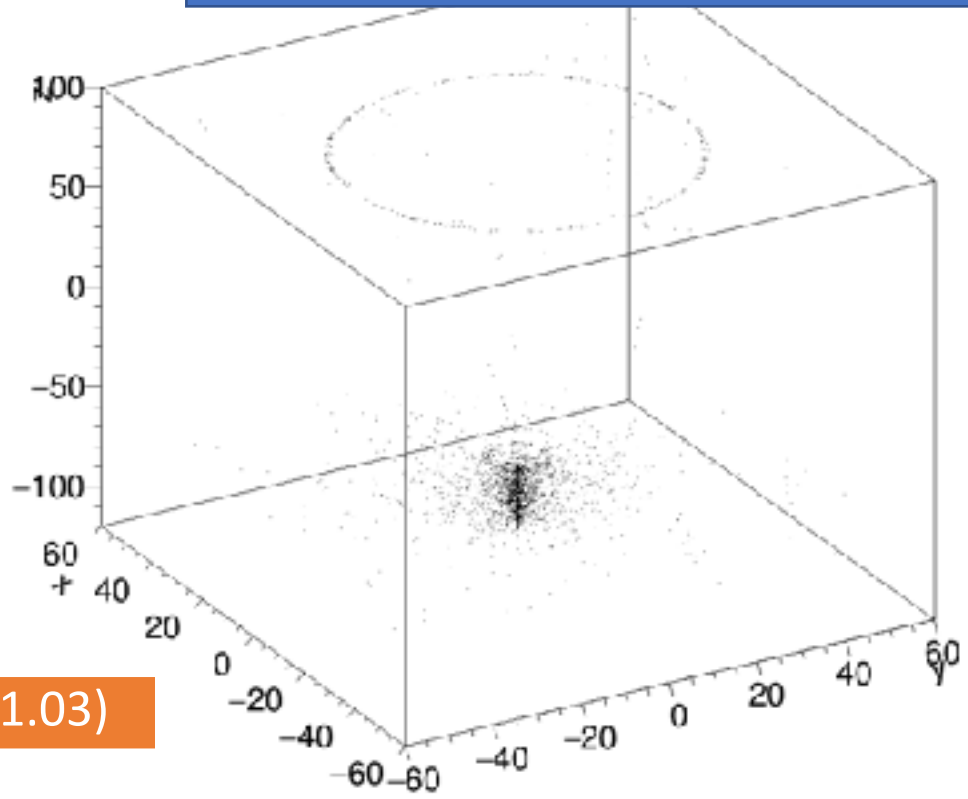
3-cm Aerogel block (n = 1.03)



mRICH Key Features

- **Sharper & small ring image in comparison to proximity focusing**
- **Compact, projective, and modular (confining signal photons within one module)**





mRICH Prototyping Studies

Objectives of Prototyping Studies

The first mRICH prototype was developed in 2015 and tested at Fermilab in 2016. The goal was to verify its working principle. The results were published in 2017 in NIM A.

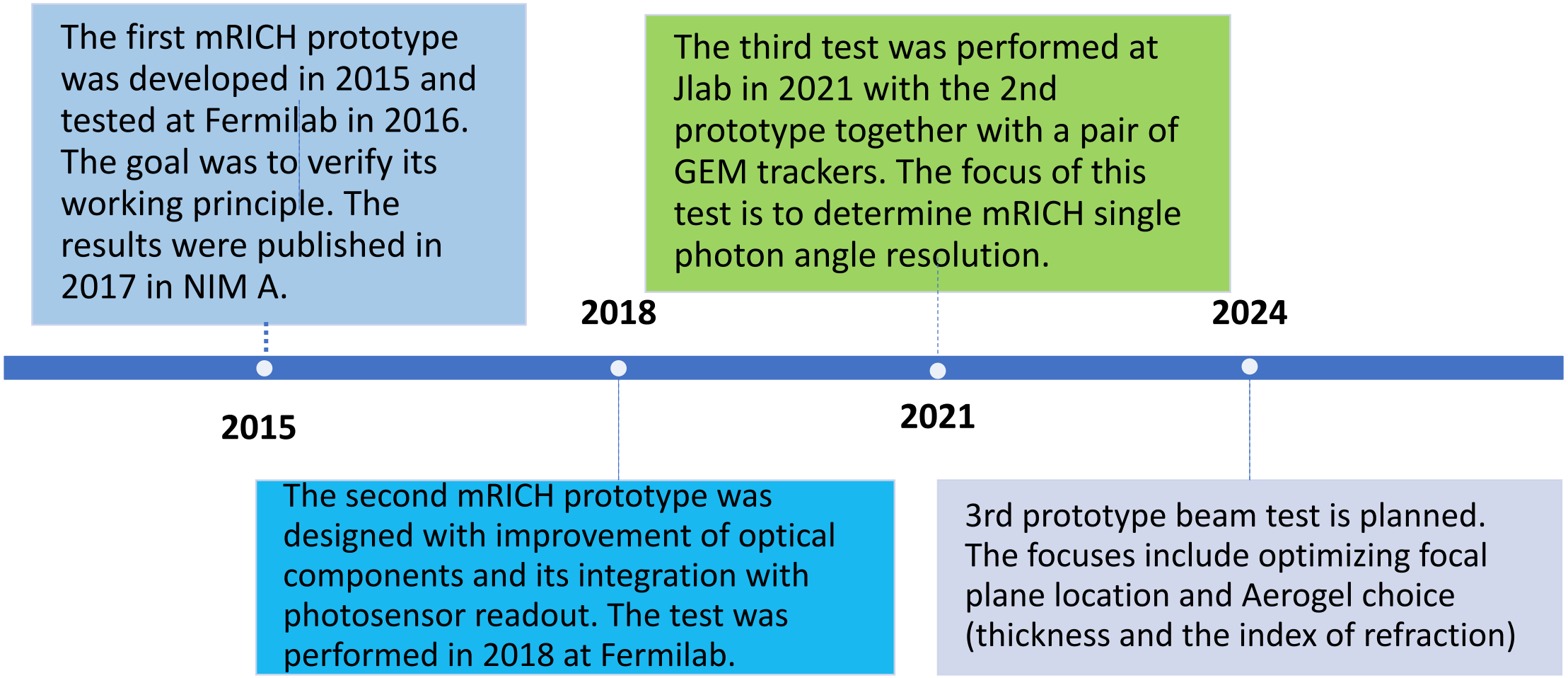
The third test was performed at Jlab in 2021 with the 2nd prototype together with a pair of GEM trackers. The focus of this test is to determine mRICH single photon angle resolution.

The second mRICH prototype was designed with improvement of optical components and its integration with photosensor readout. The test was performed in 2018 at Fermilab.

3rd prototype beam test is planned. The focuses include optimizing focal plane location and Aerogel choice (thickness and the index of refraction)

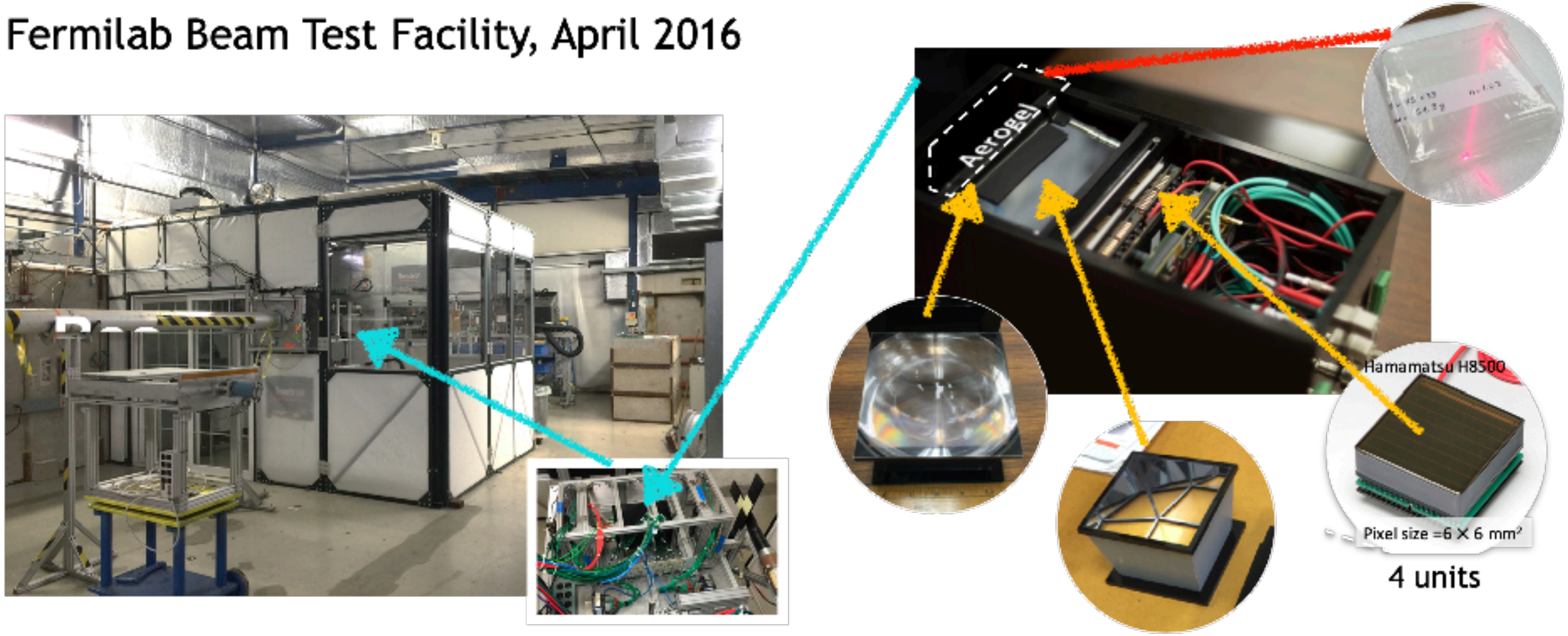
Objectives of Prototyping Studies

Technology evolution



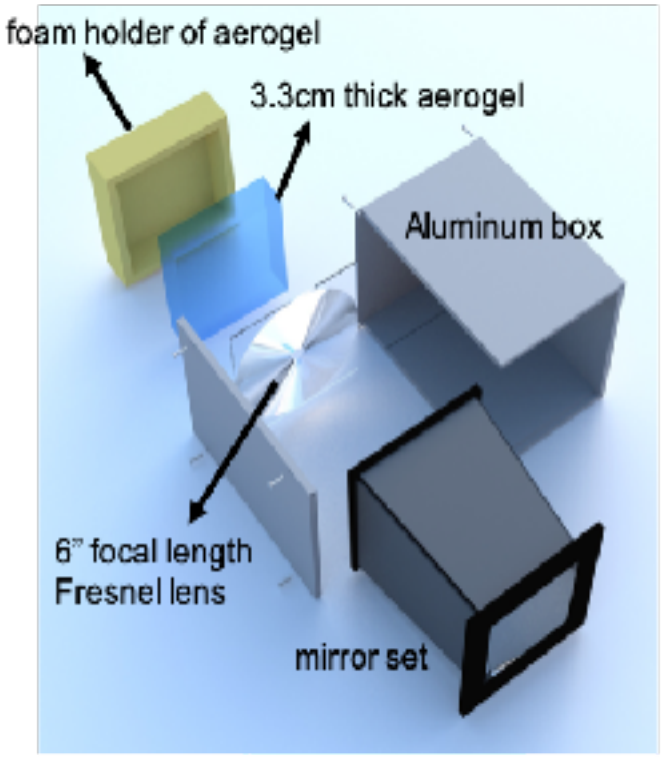
1st mRICH Prototype Beam Test – Proof of Working Principle

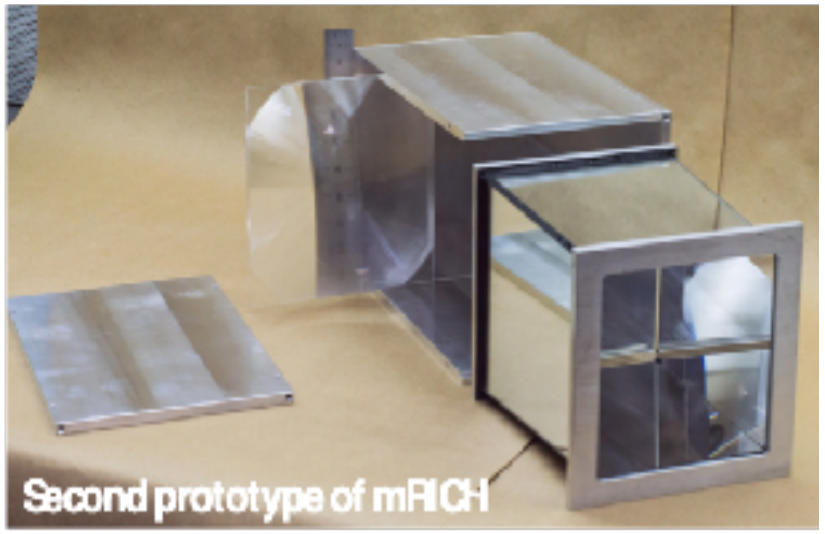
Fermilab Beam Test Facility, April 2016



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

2nd mRICH Prototype
New Optical Component Design





- ✓ Longer Fresnel focal length
- ✓ Photosensors with smaller pixel size

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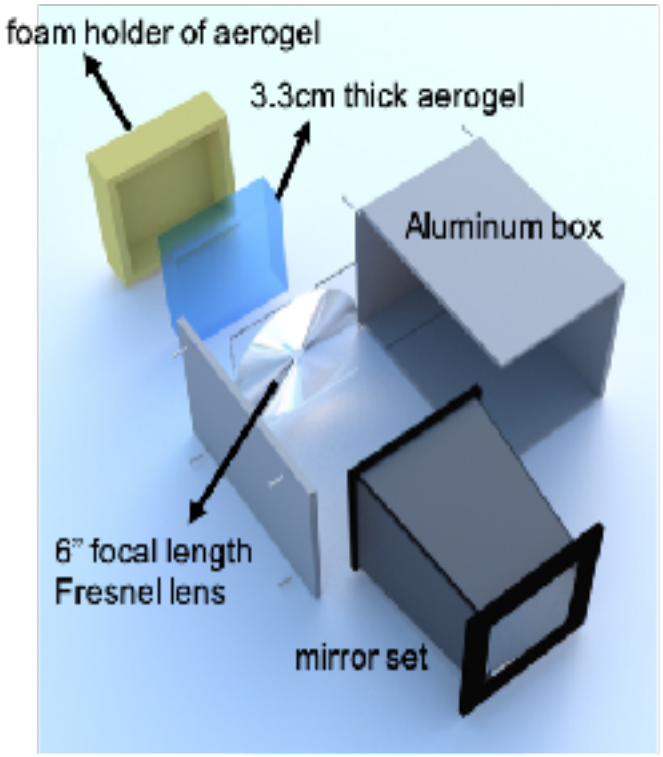

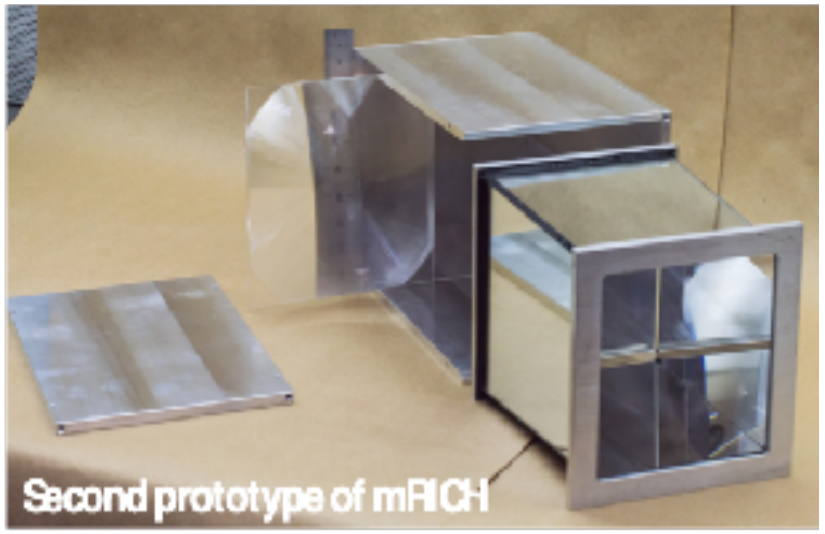

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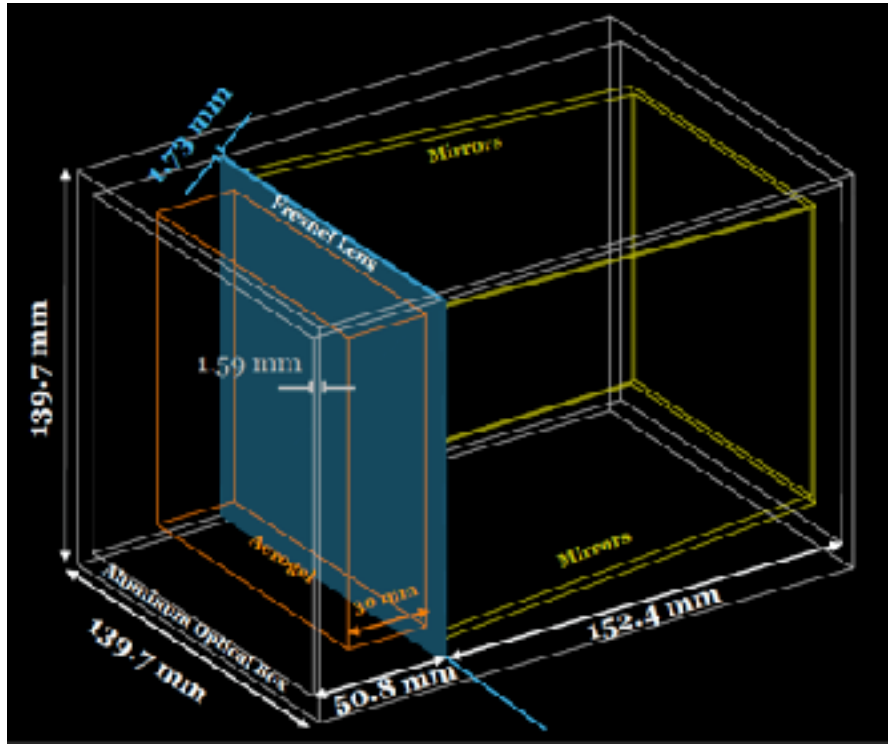
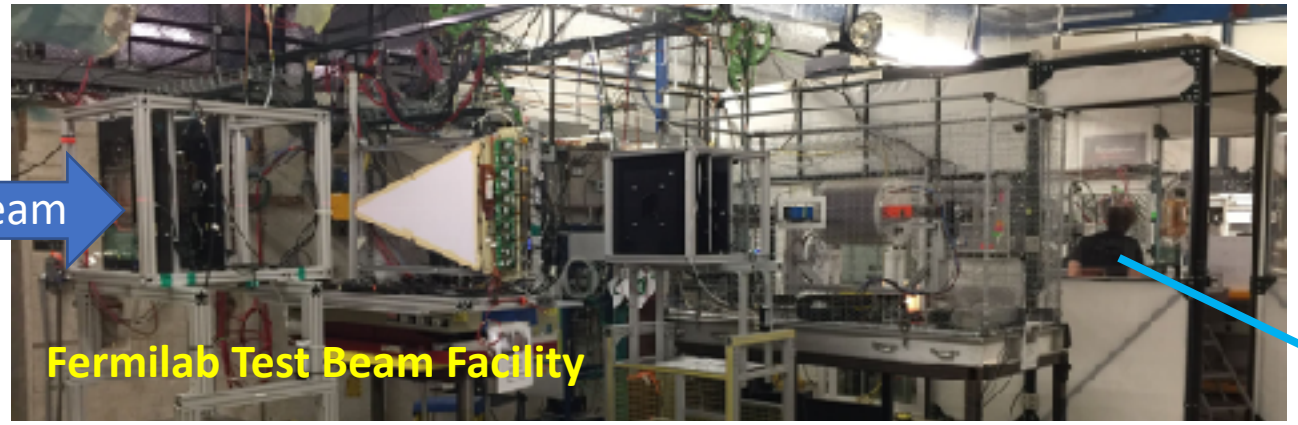
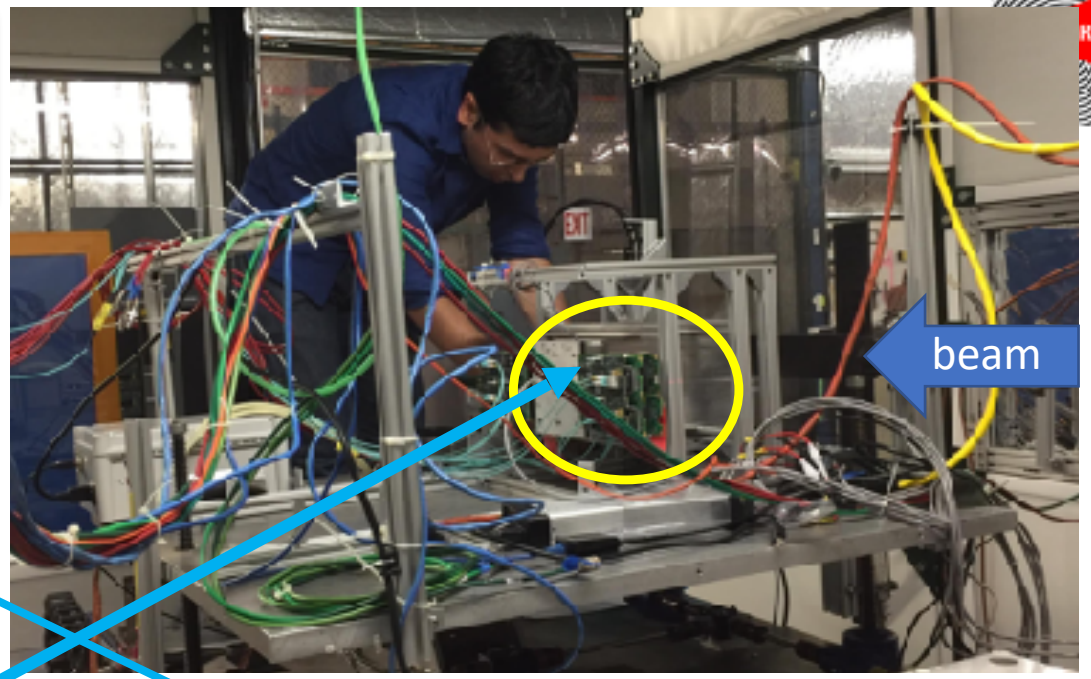
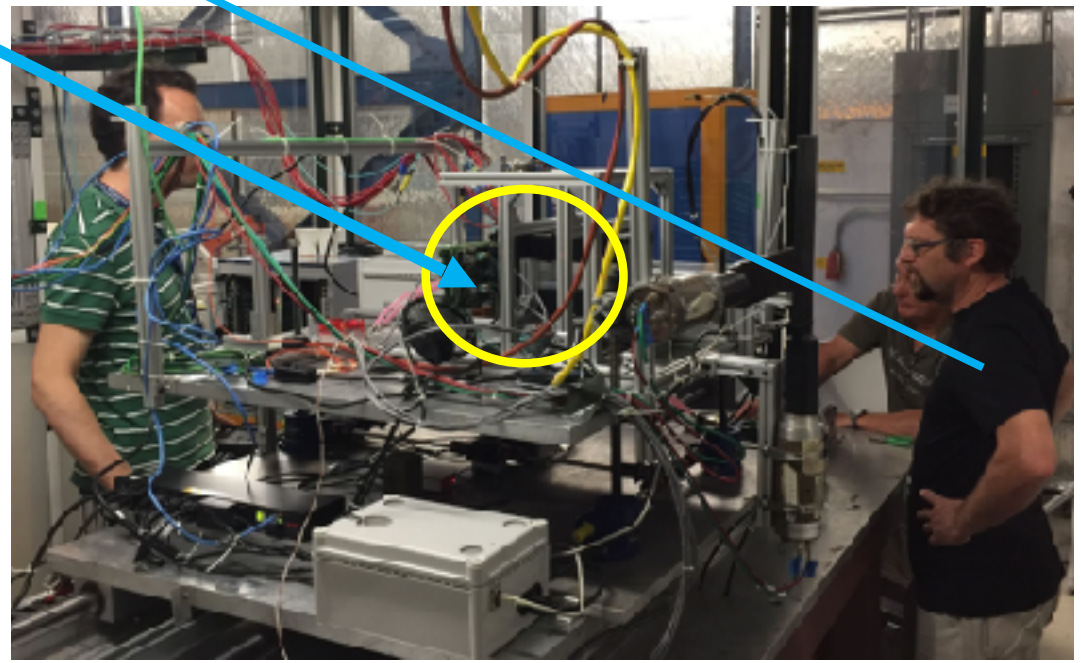


mRiCH was mounted in a test frame assembled with extruded aluminum bars. The frame was put on a motion table. No tracking detectors were available during this beam test.





INFN Group provided readout



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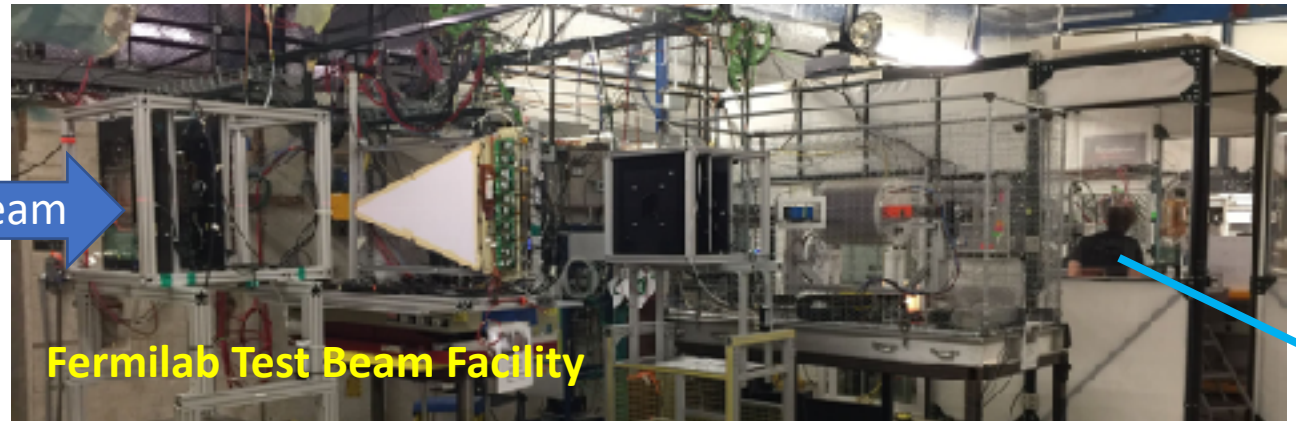

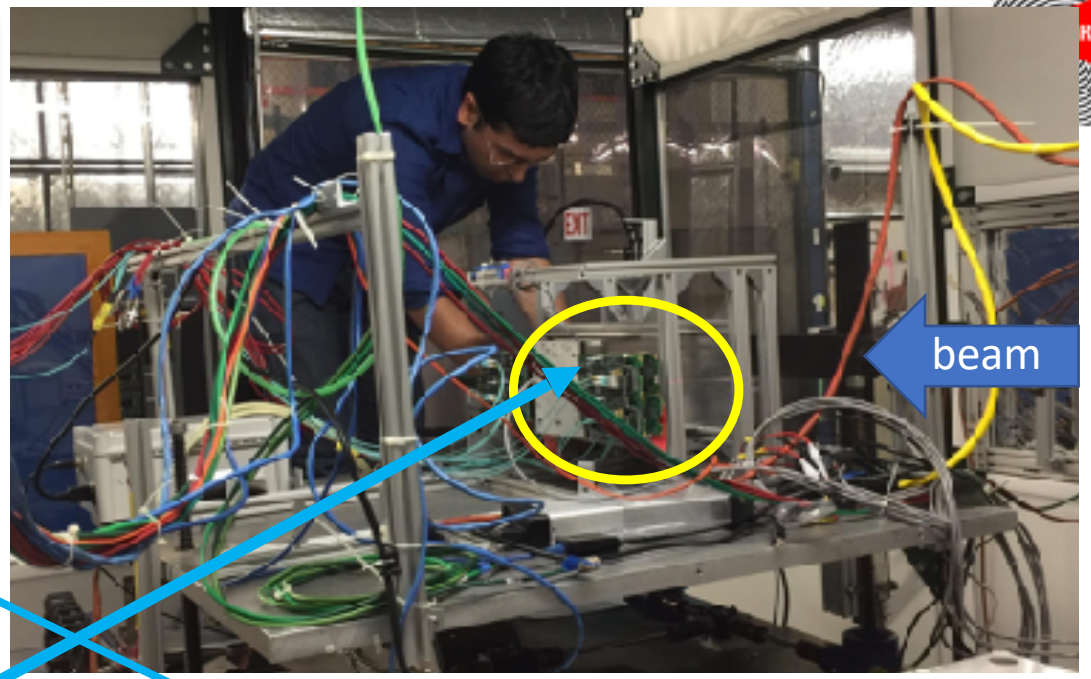

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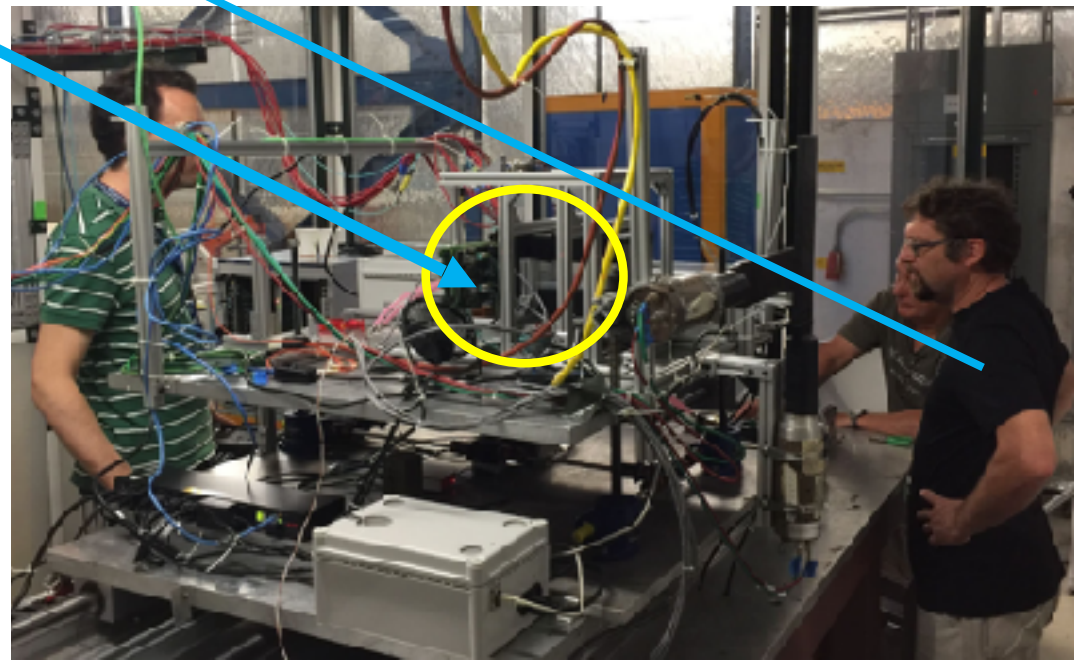
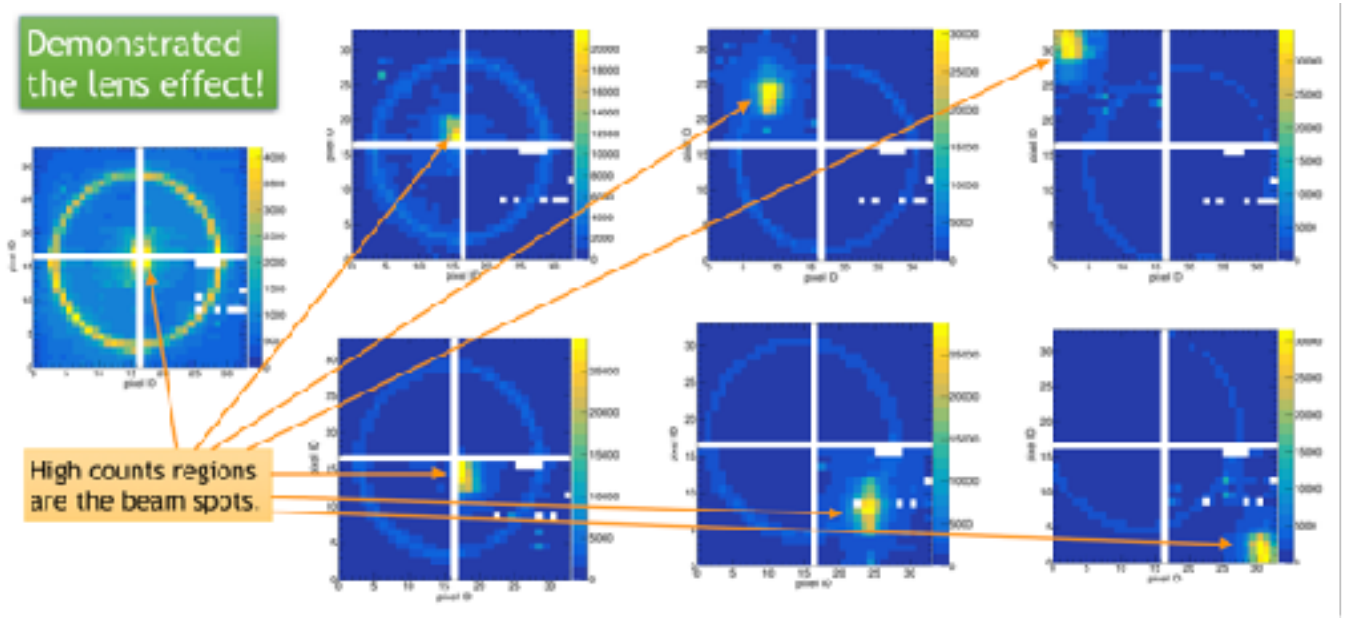
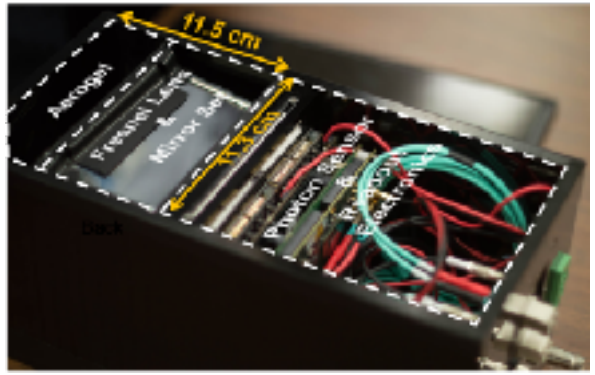


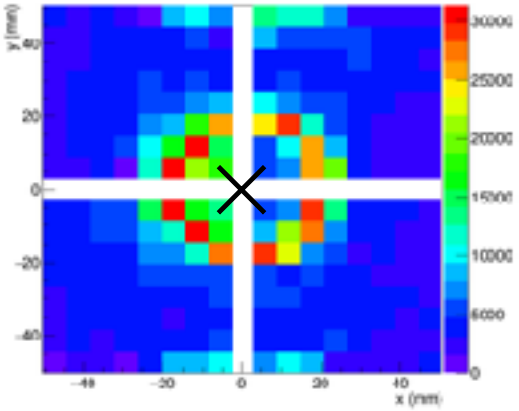


1st & 2nd Beam Test Comparison (120 GeV Proton Beam)

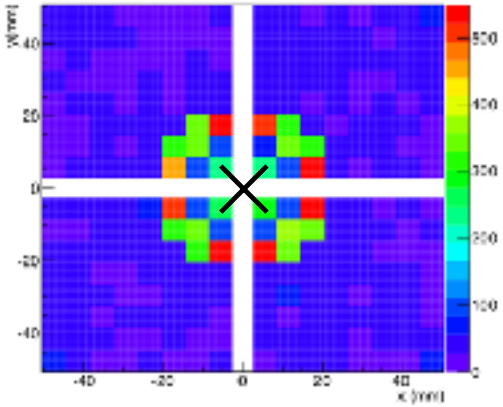
The 1st test beam result verified mRICH working principle and validated simulation



1st mRICH prototype was tested at Fermilab Test Beam Facility in April 2016



Images from 120 GeV Proton beam



Simulated Images Using GEANT4

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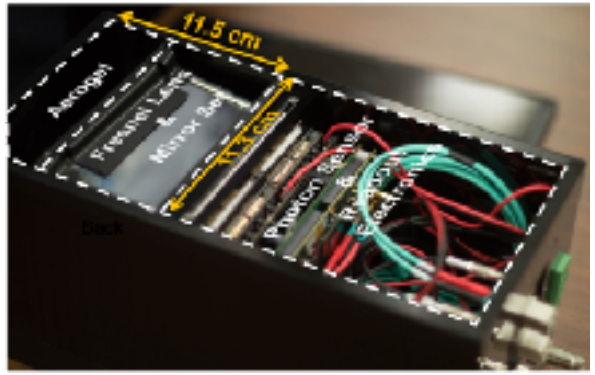

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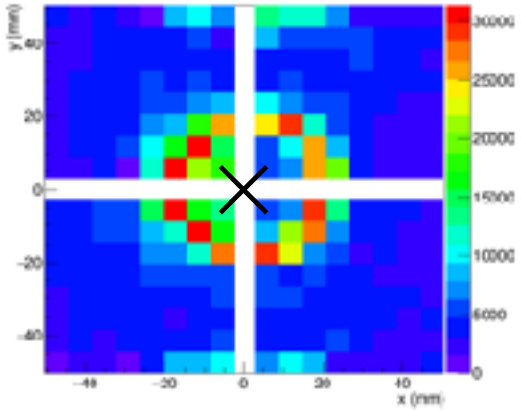
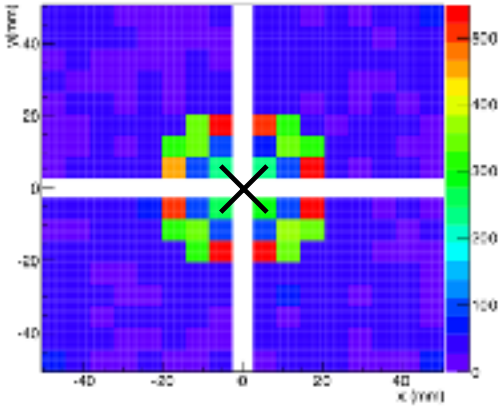
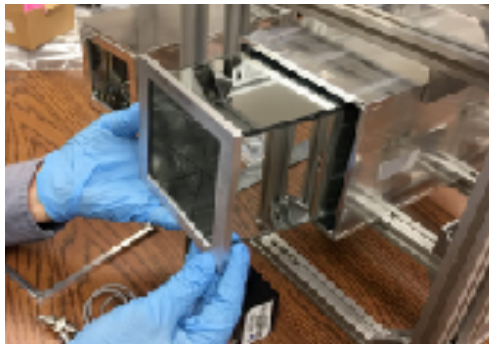




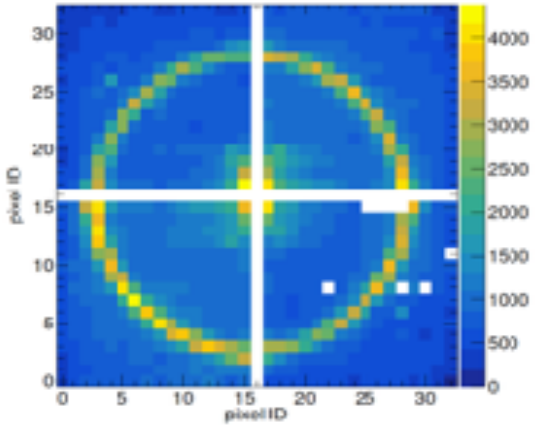
Images from 120 GeV Proton beam

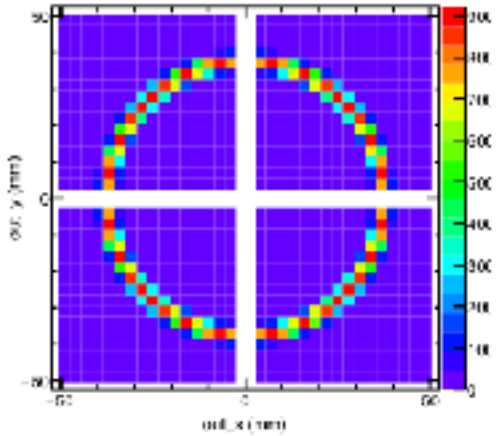
Simulated Images Using GEANT4

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





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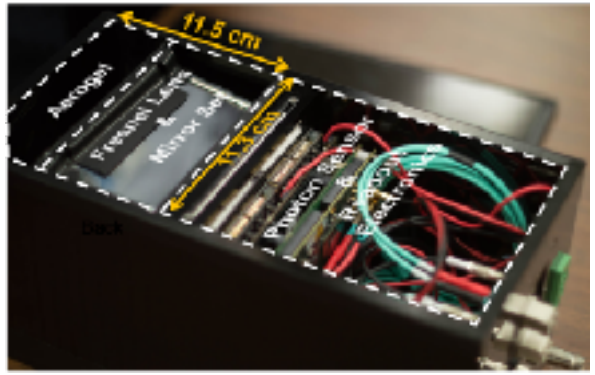
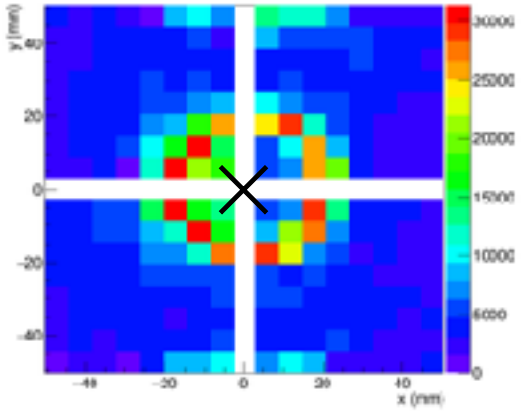
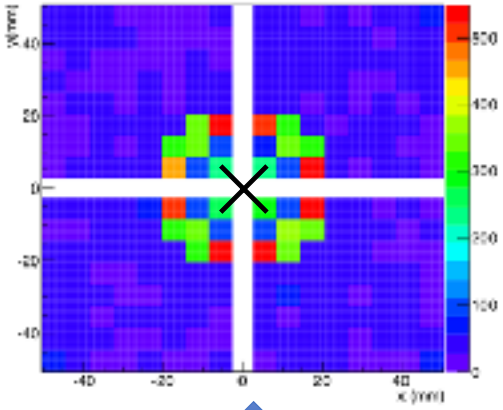


1st mRICH prototype was tested at Fermilab Test Beam Facility in April 2016

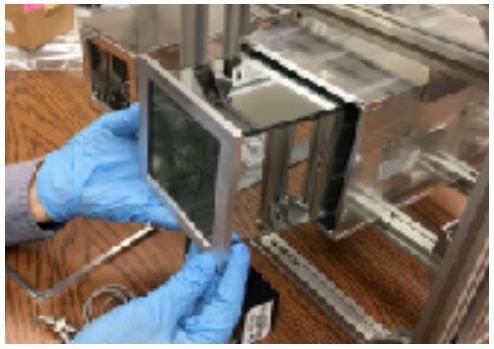




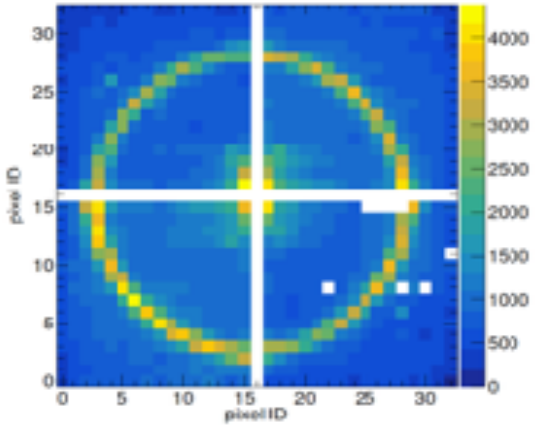
Images from 120 GeV Proton beam

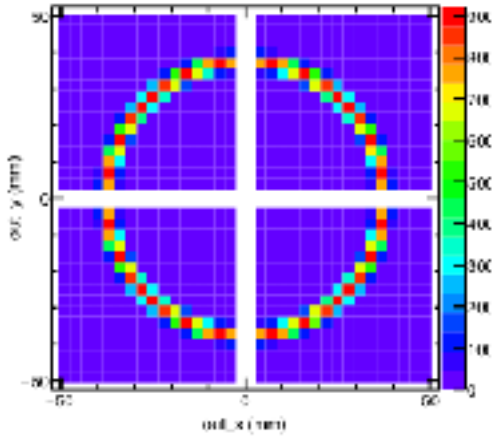
Simulated Images Using GEANT4

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

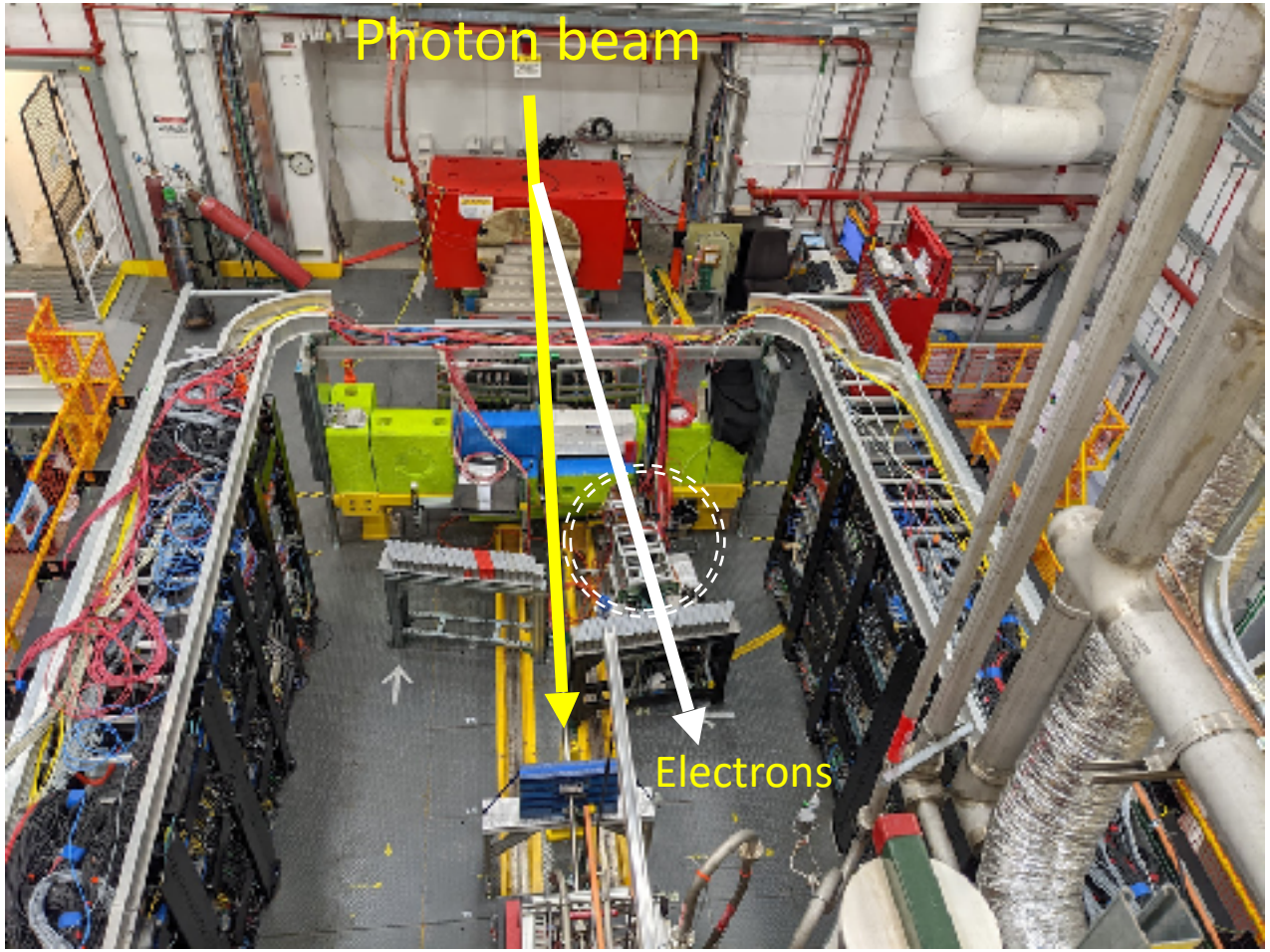




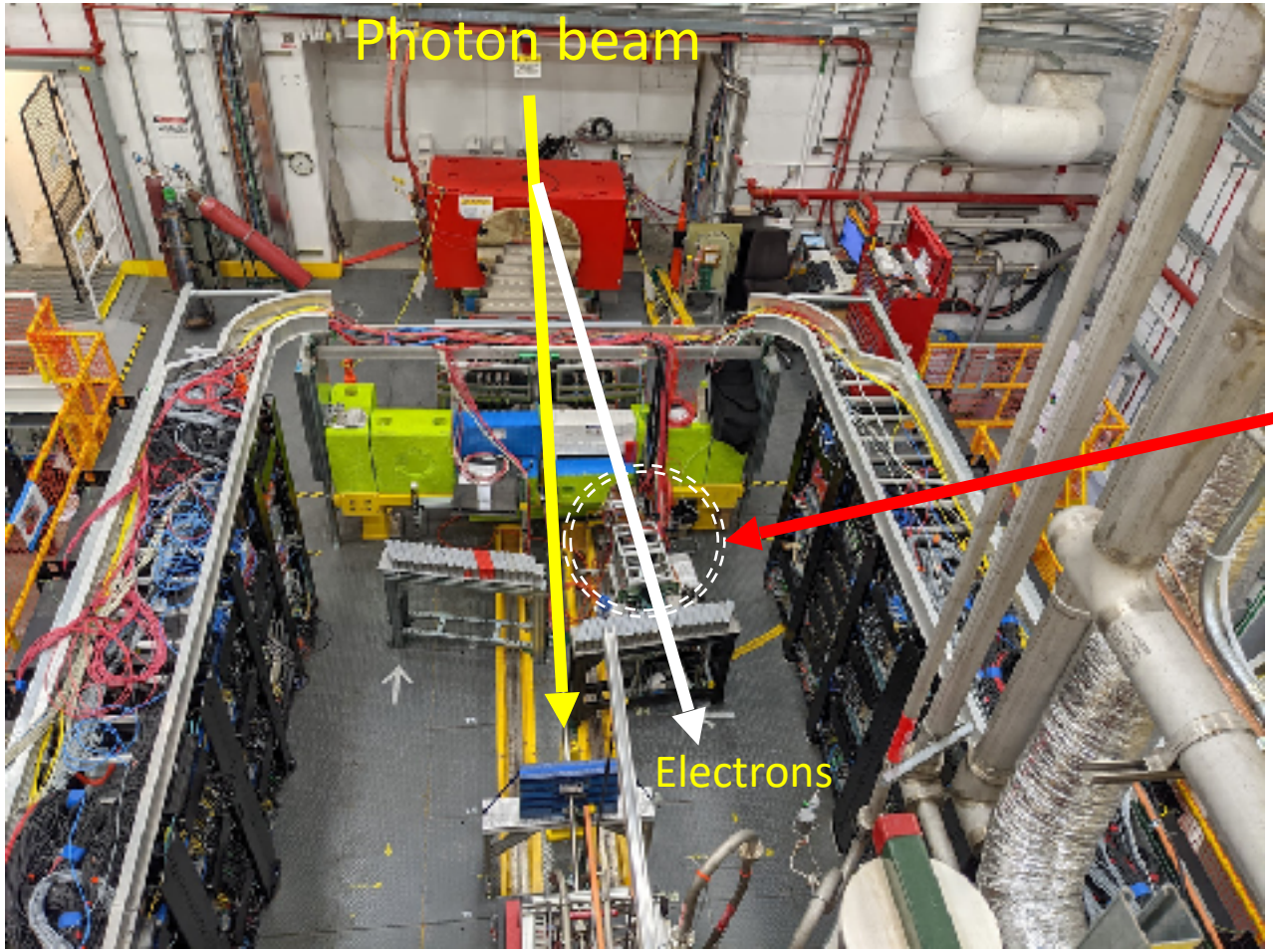
mRICH Test at JLab

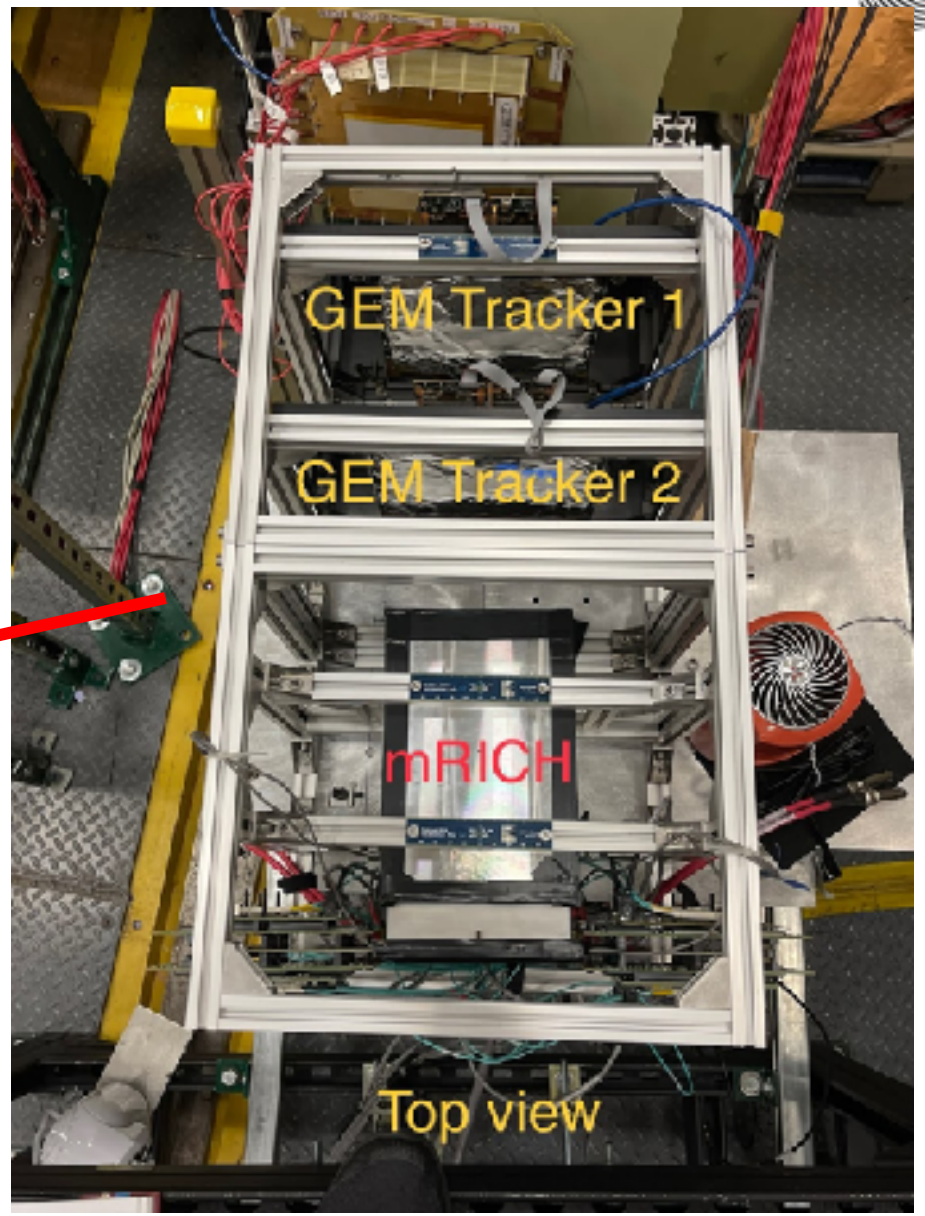
To quantify single photon angle resolution and Aerogel edge effects

mRICH Test Setup in Hall D at JLab

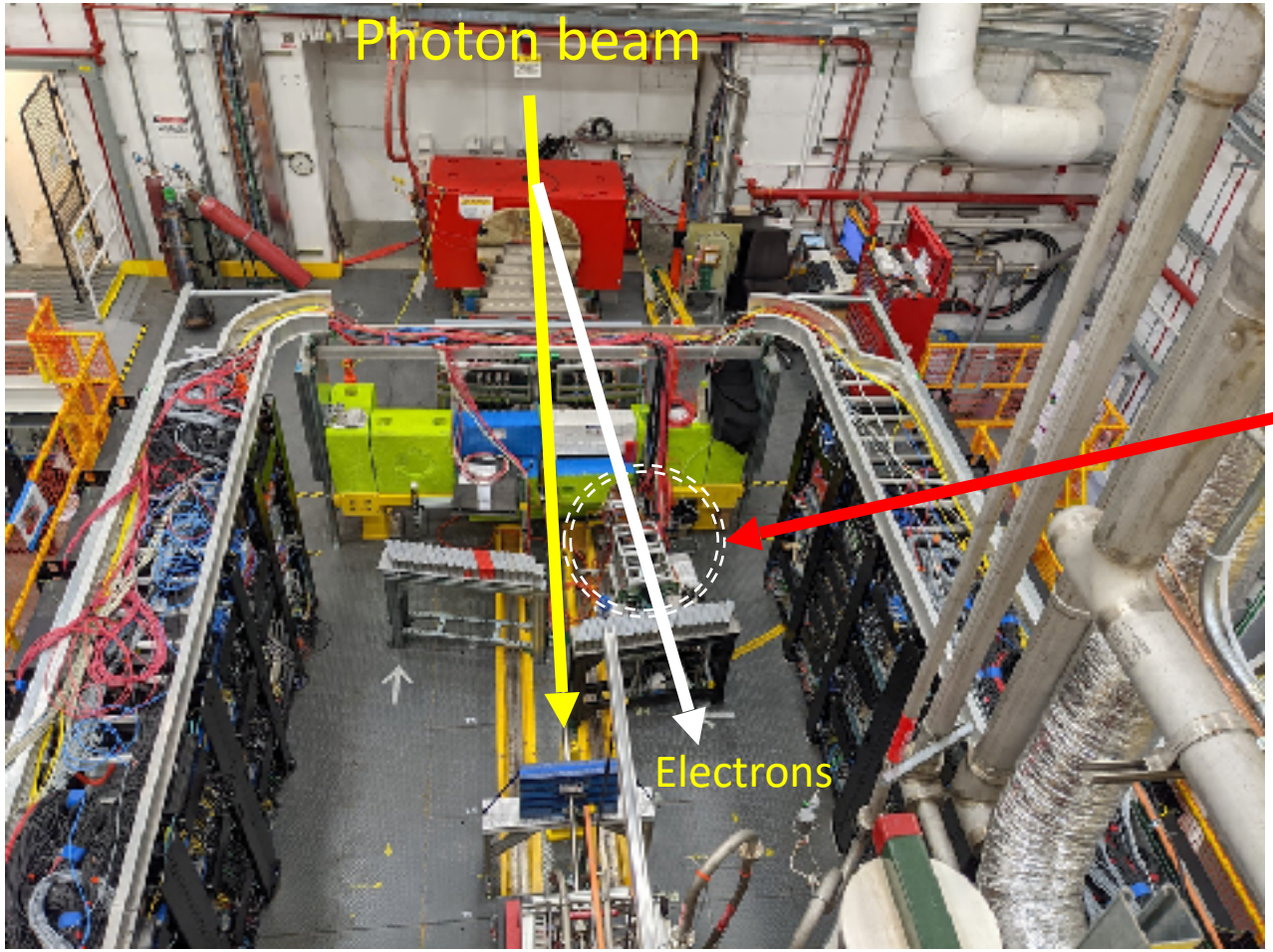


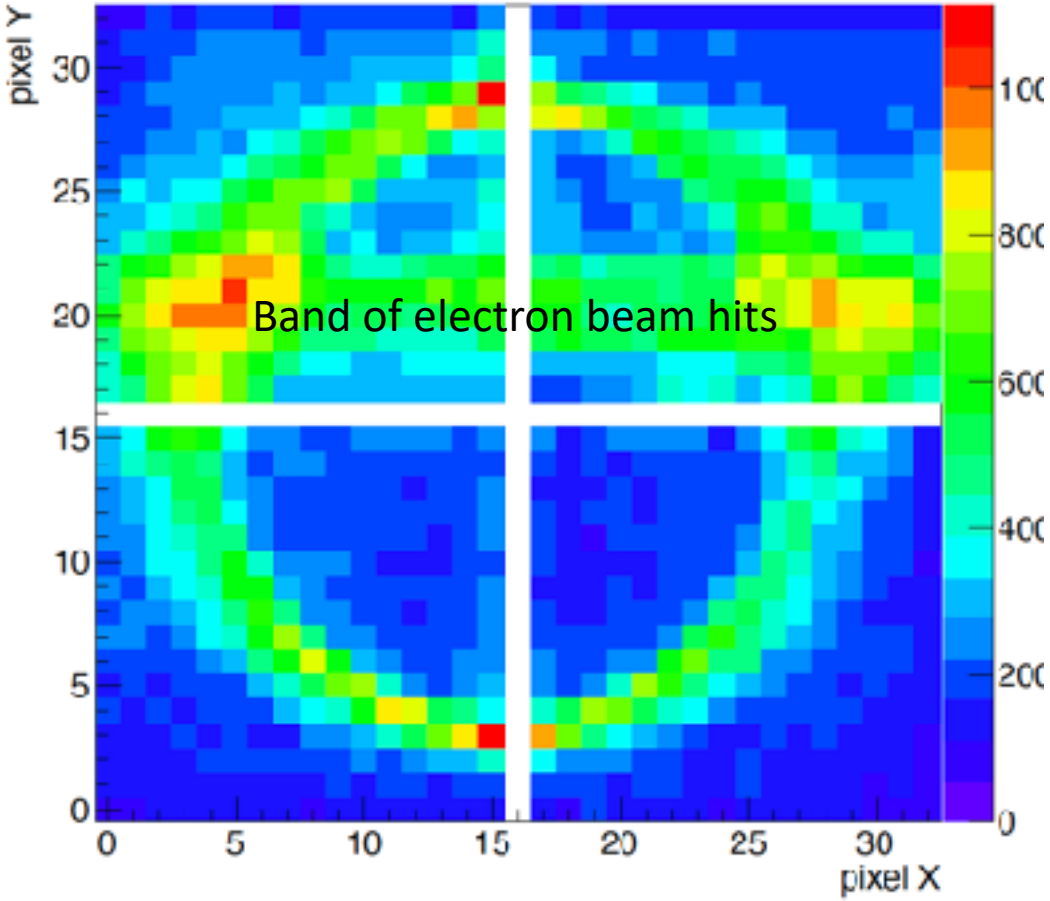
mRICH Test Setup in Hall D at JLab





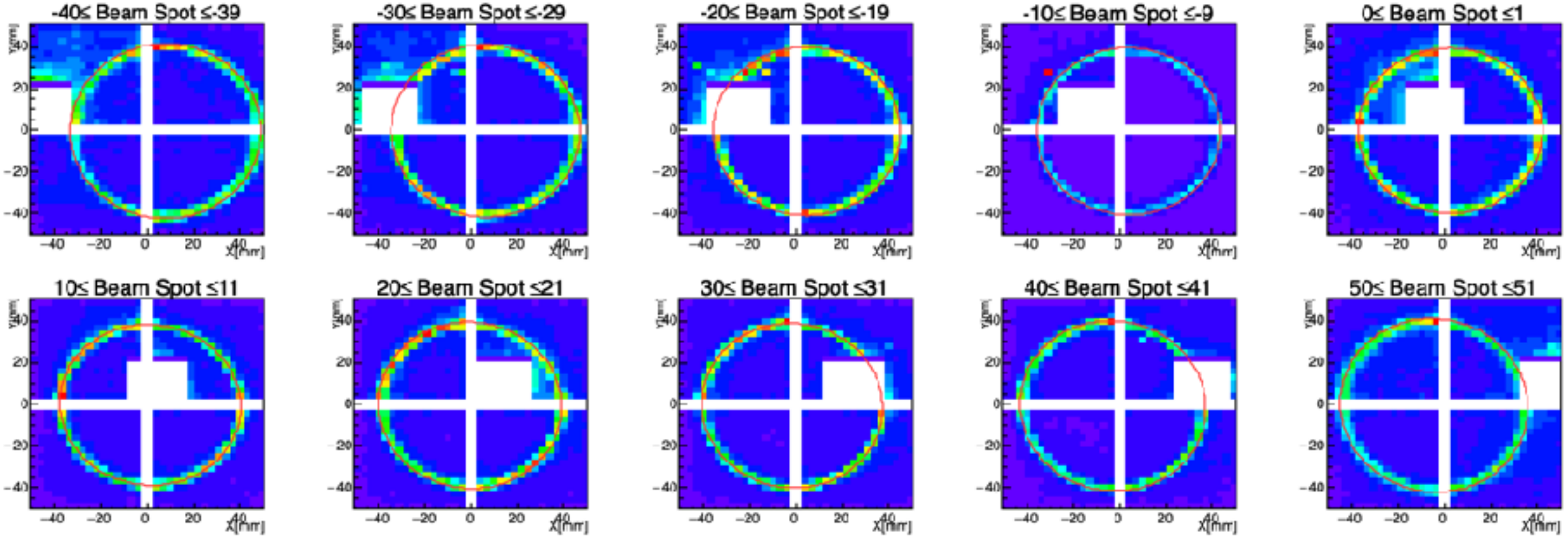
mRICH Test Setup in Hall D at JLab





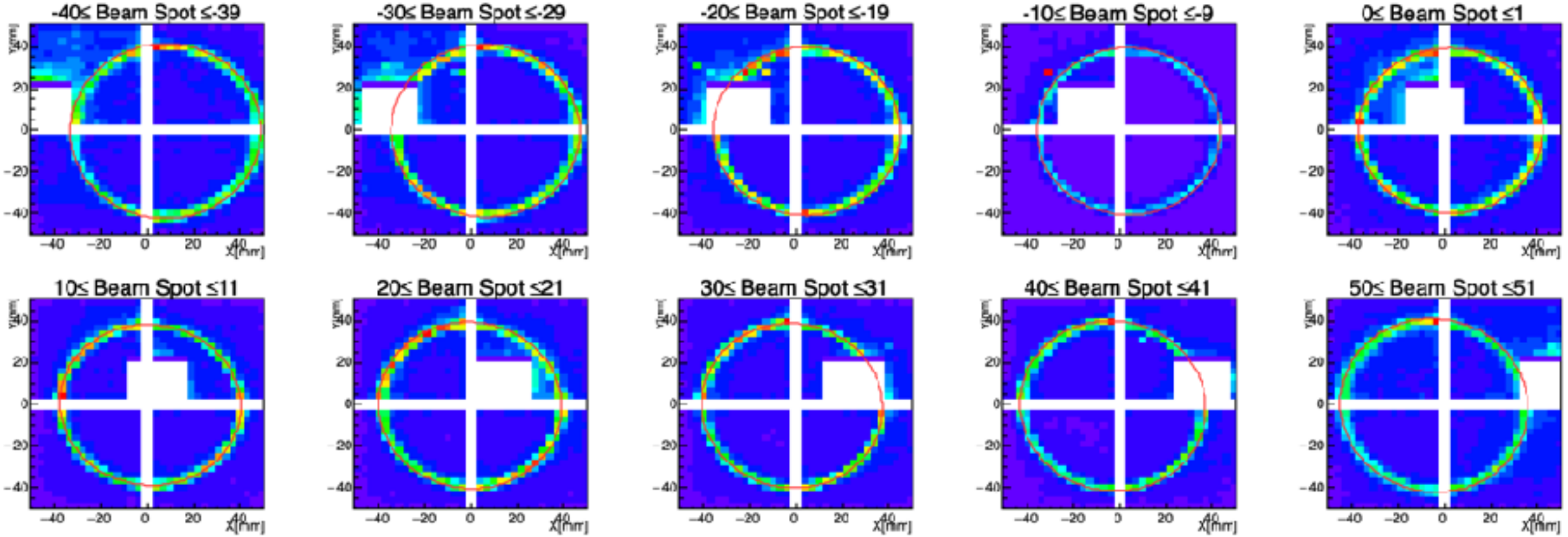
Cumulative Ring Patterns vs Beam Spots

Test Data (with excellent statistics)



Cumulative Ring Patterns vs Beam Spots

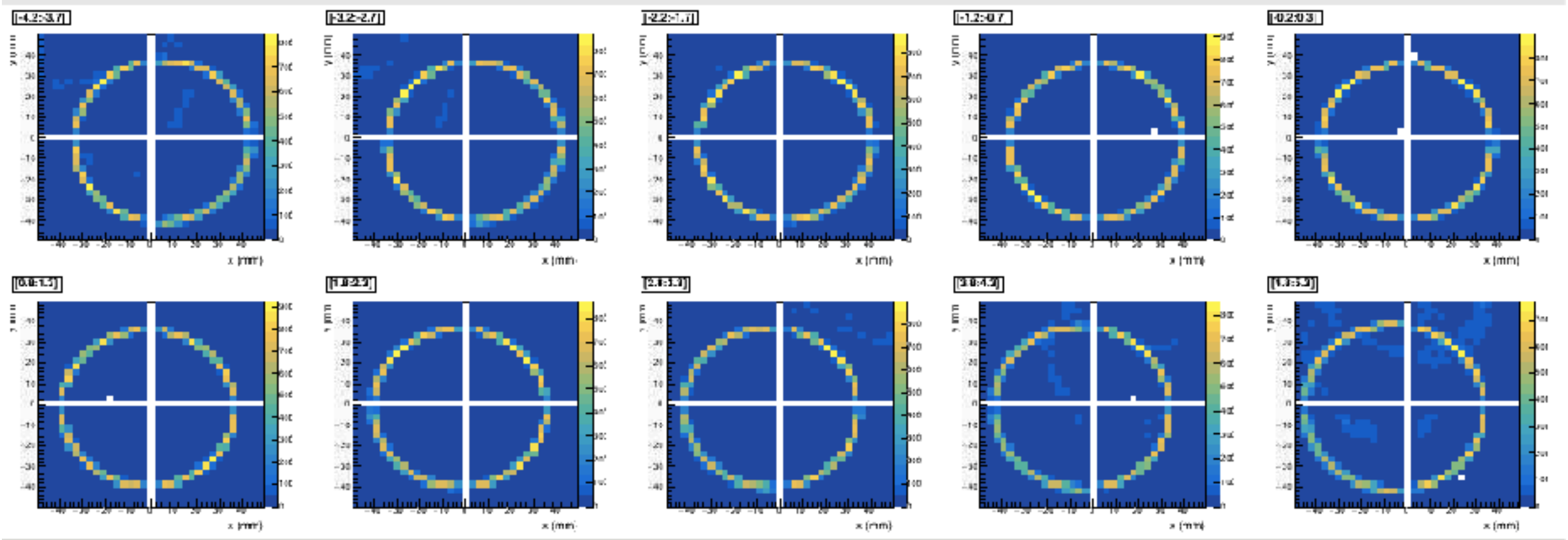
Test Data (with excellent statistics)



Solid rings in red are fitted ellipses

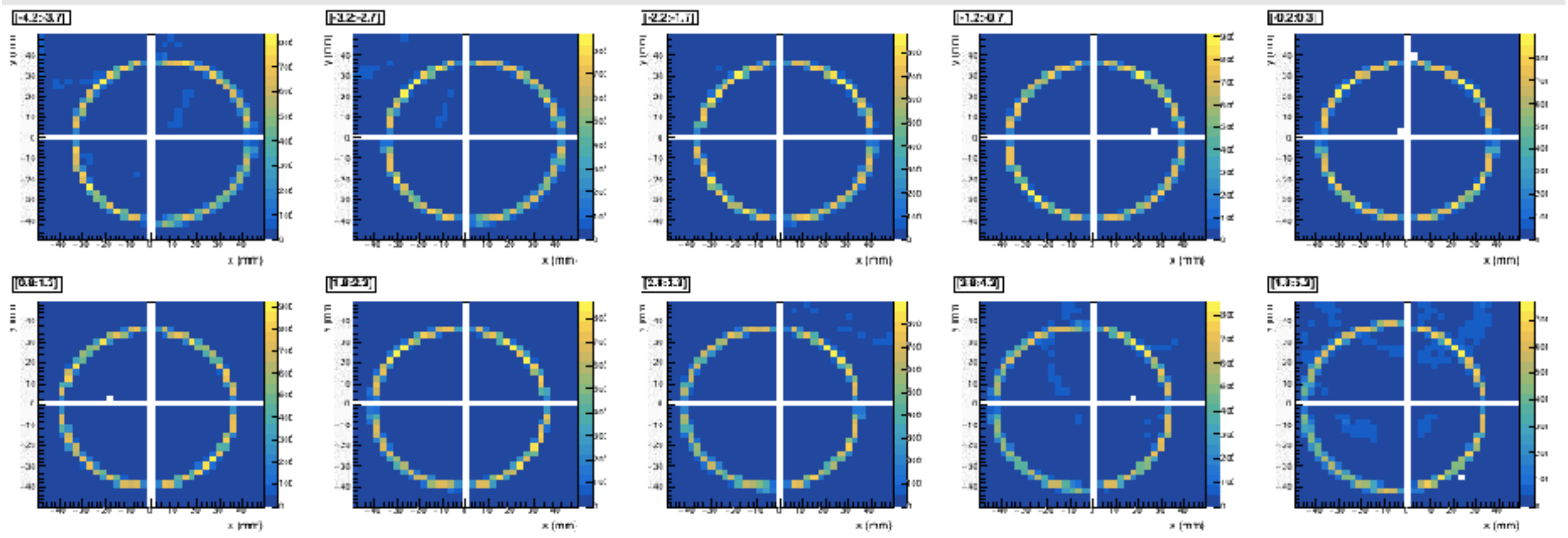
Cumulative Ring Patterns vs Beam Spots

Simulated Image Pattern Using GEANT4



Cumulative Ring Patterns vs Beam Spots

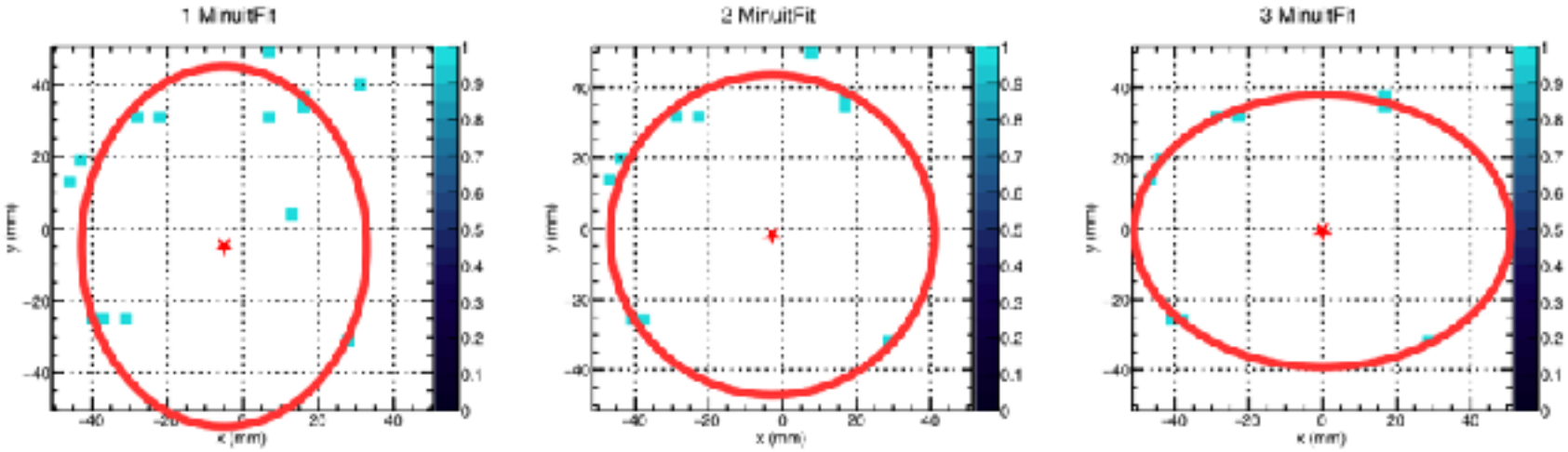
Simulated Image Pattern Using GEANT4



With the same beam spot as shown in data

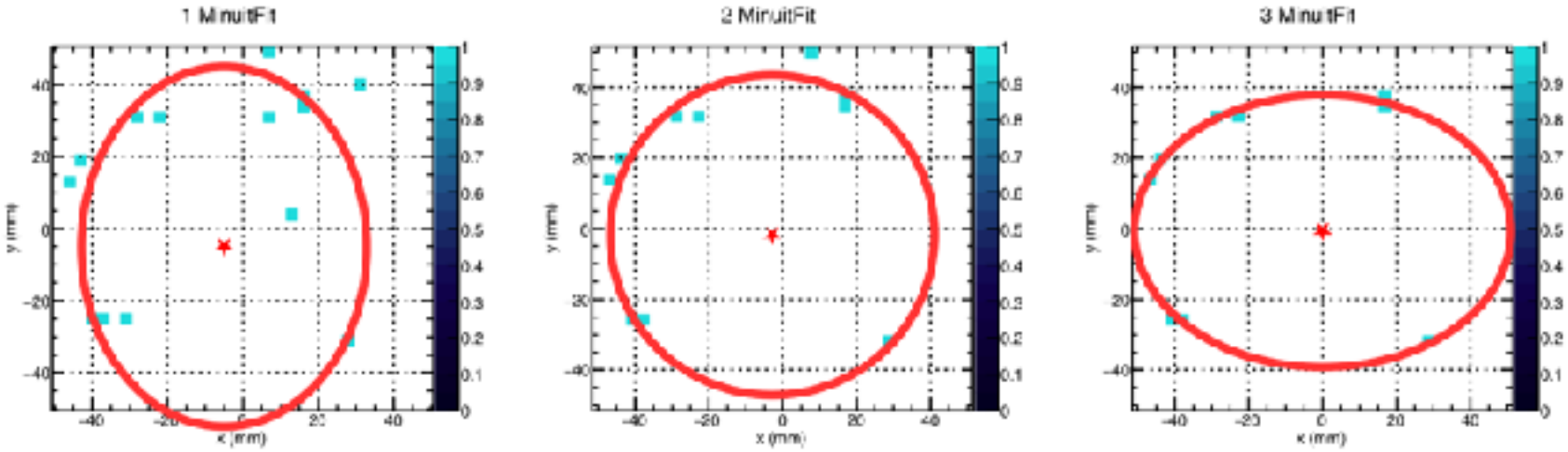
Fitting Ring Image Pattern on Event-by-Event Basis

Unconstraint fit with an ellipse function with all hits on sensor plane. The results are not converging and unstable.

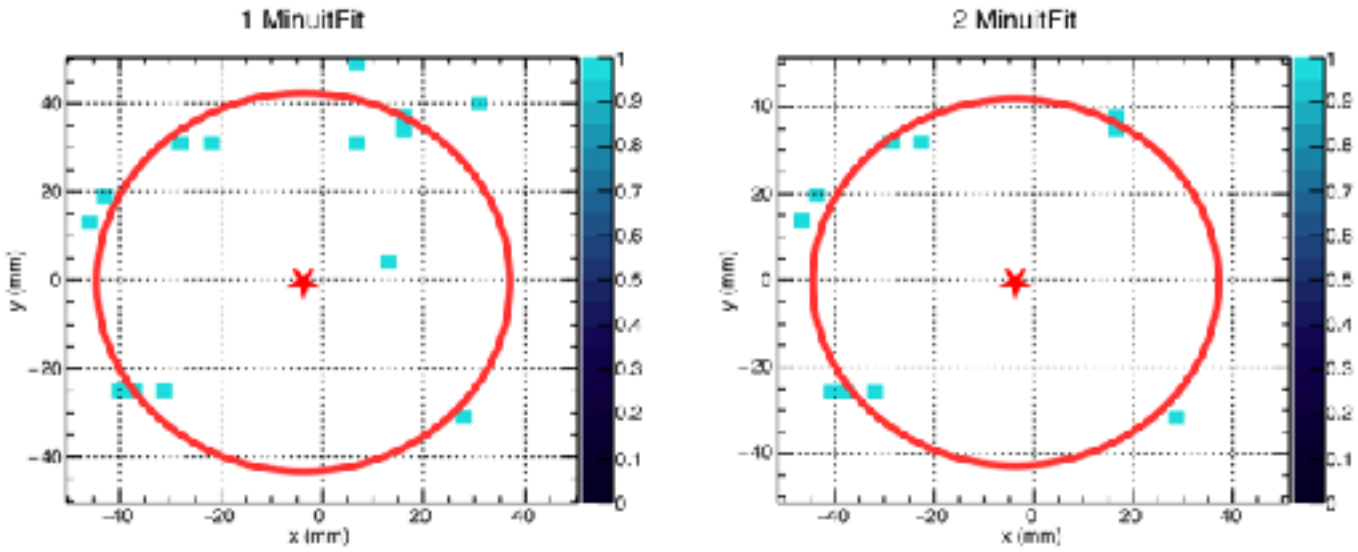


Fitting Ring Image Pattern on Event-by-Event Basis

Unconstraint fit with an ellipse function with all hits on sensor plane. The results are not converging and unstable.



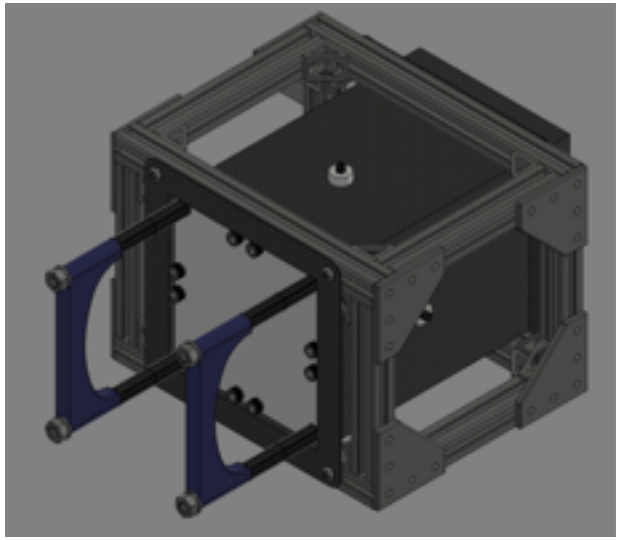
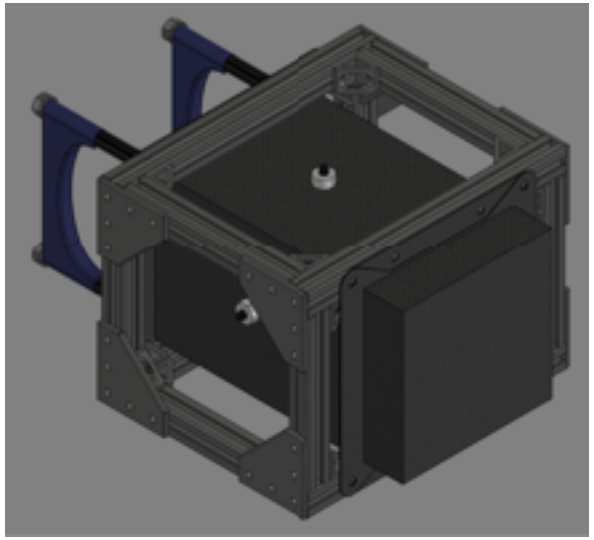
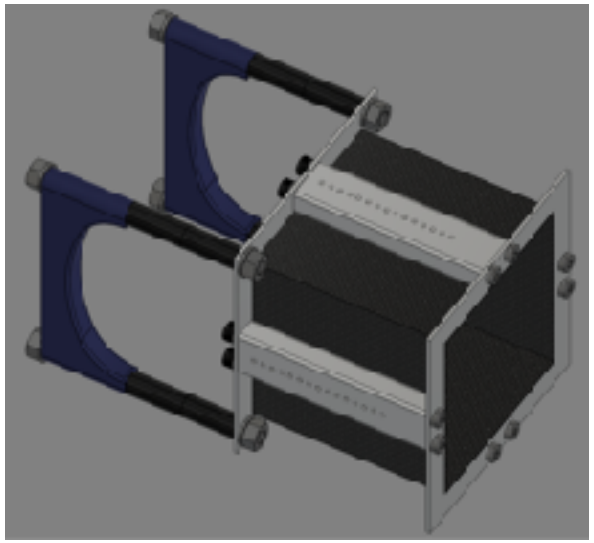
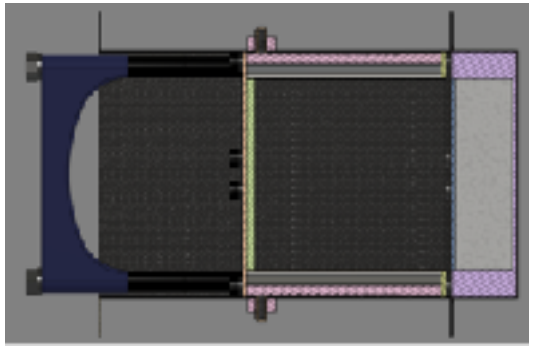
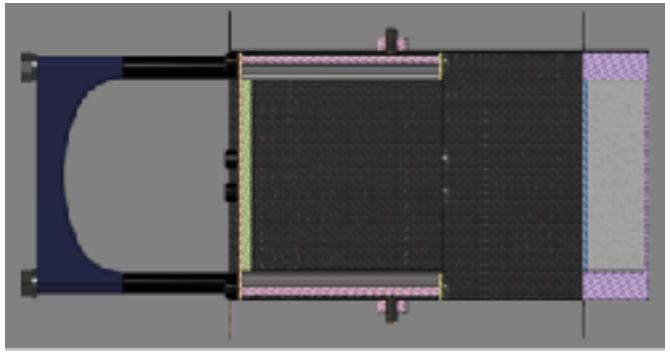
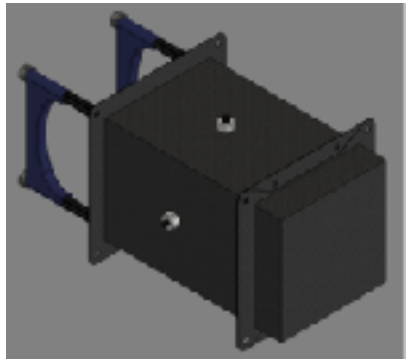
Constraint fit with an ellipse function by initializing the fitting parameter based on expected ring pattern.



Single Photon Angle Resolution

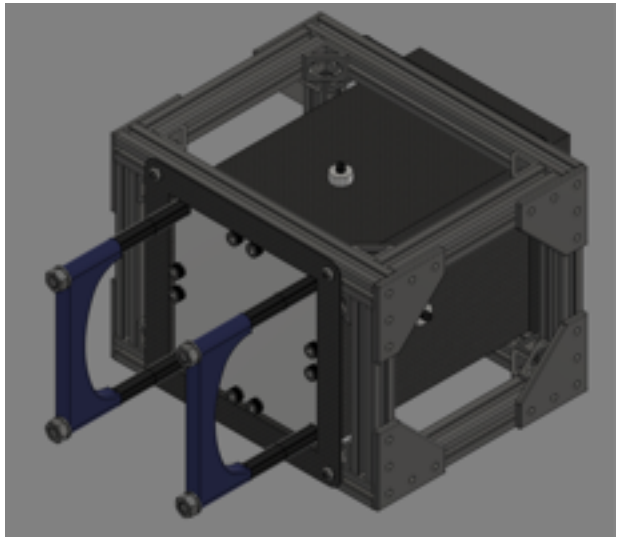
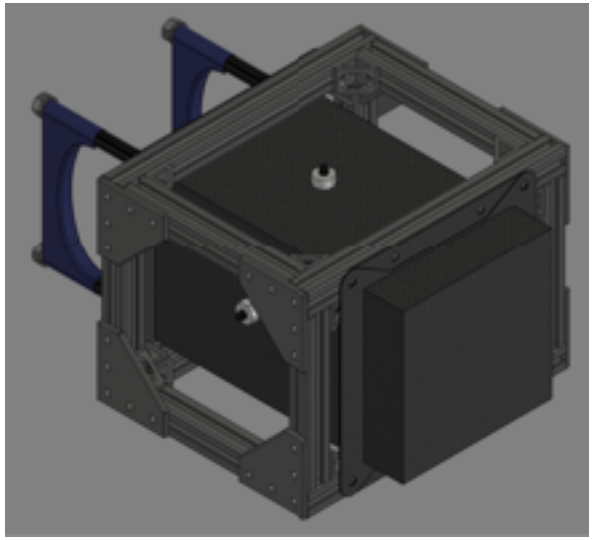
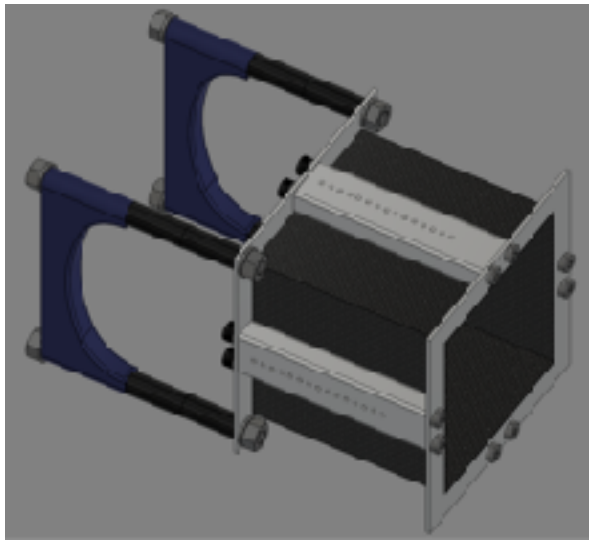
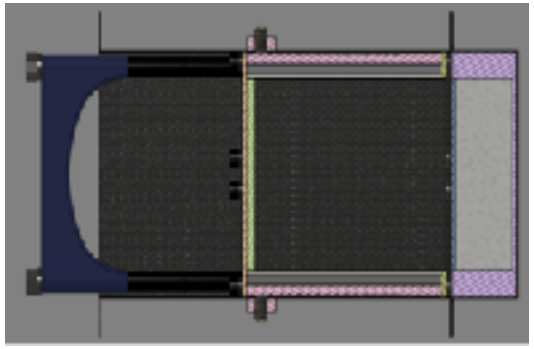
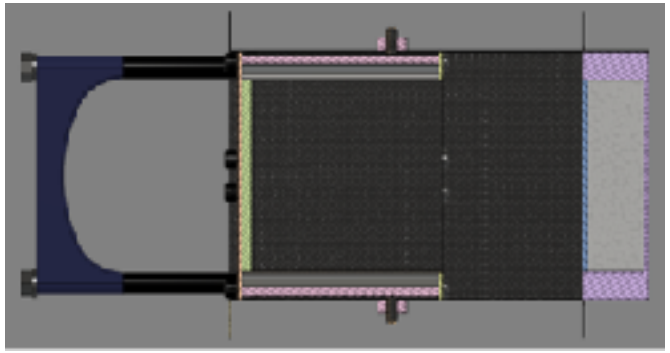
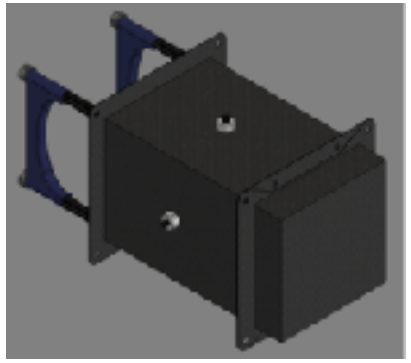
To be available soon !!!

New mRICH Prototype Design

New mRICH Prototype Design

Optimizing the focal plane location and Aerogel thickness

Photosensors and Readout Electronics

- **Two top candidates for photosensors (3mm x 3mm pixel size)**
  - LAPPD (10 cm x 10 cm form factor)
  - SiPM
- **Readout electronics**
  - 1024 channels
  - Fit to the back side of mRICH

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  - LAPPD (10 cm x 10 cm form factor)
  - SiPM
- **Readout electronics**
  - 1024 channels
  - Fit to the back side of mRICH

We are looking for groups to join the effort.

Summary & Outlook

- I hope that I have presented sufficient information about mRICH for the choice of particle identification detector in the electron-going direction, especially there is a limited space for the full EIC physics program.
- It took good eight long years as a R&D project supported by the US Department of Energy.
- We know there are several challenges ahead which include Aerogel production, photosensors choice (working in magnetic field), and readout.
- We are recruiting groups around the world to join our effort in building PID detectors for EIC experiments.

Thanks for you attention

Backup

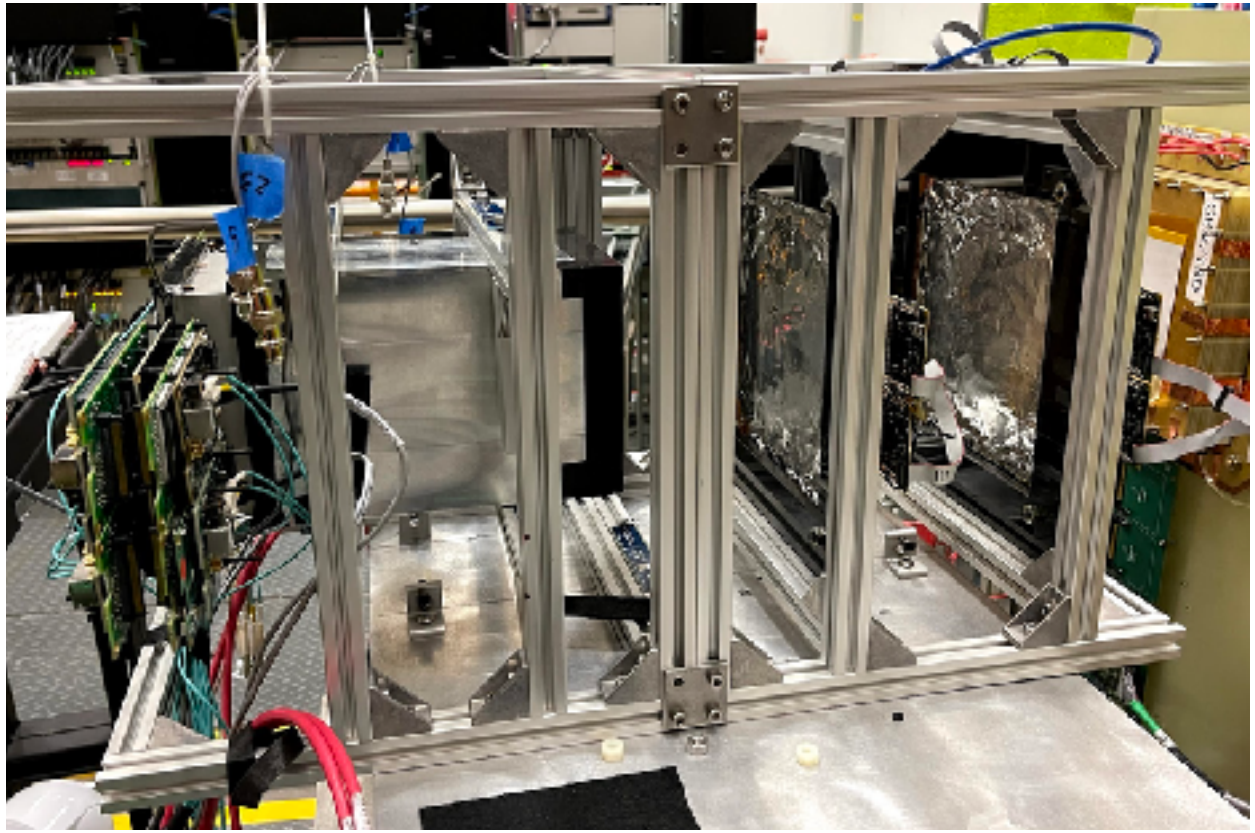
Abstract

Excellent particle identification is an essential requirement for the future Electron Ion Collider (EIC) experiment. Particle identification (PID) of the final state hadrons in the semi-inclusive deep inelastic scatteing allows the measurement of flavor-dependent gluon and quark distributions inside nucleons and nuclei. The EIC PID Consortium (eRD14 Collaboration) was formed in 2015 for identifying and developing PID detectors using ring imaging Cherenkov(RICH) and the ultra-fast time-of-flight (TOF) techniques for the EIC experiments with broad kinematics coverage.

To meet the challenge of limited confined space of electron end-cap in the EIC experiments, a compact modular ring imaging Cherenkov (mRICH) detector has been developed that provides K/π separation over a momentum coverage of 2 GeV/c to 8 GeV/c, and an e/π separation up to 2 GeV/c or more. The mRICH detector consists of an aerogel block, a Fresnel lens, photosensor plane and flat mirrors forming the sides of the space between the lens and photosensors. The first prototype of this detector was successfully tested at Fermi National Accelerator laboratory in April 2016 for verifying the detector work principles [1]. This was followed by a second prototype test in 2018 at FNAL with much improved optical design and photosensor integration, which allowed adaptation of different readout options. In September 2021, the third beam-test was carried at Jefferson Laboratory (JLAB) with the goal of testing mRICH performance with a precision tracking capability.

Two GEM Tracking Chambers Borrowed from UVA

Upstream view



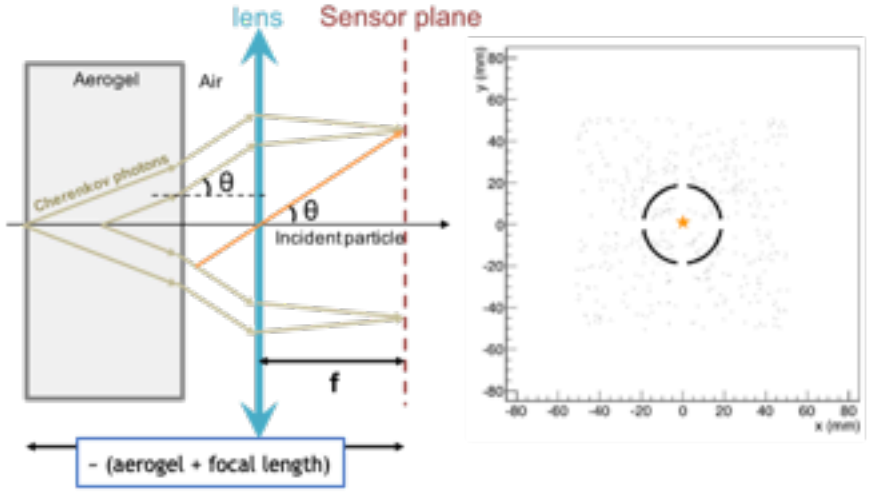
Downstream view

[Note: This is the first time that we were able to test mRICH performance with a tracking system. Big thanks go to Kondo at UVA.]

mRICH – lens-based focusing aerogel detector

Smaller, but thinner ring improves PID performance and reduces length

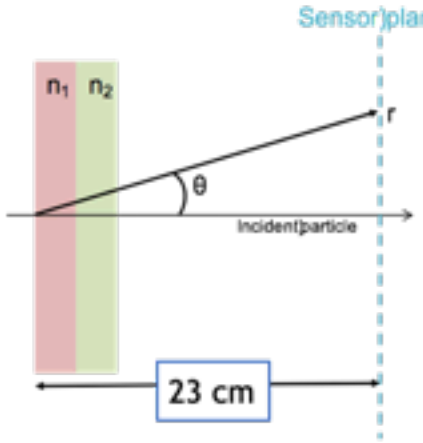
Lens-Based mRICH Design

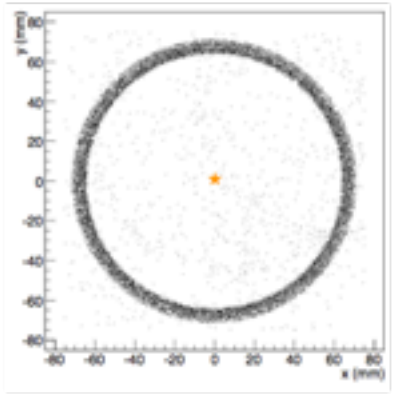


- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner ring image**

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

Two-Layer Proximity Focusing Design (BELLE-2 ARICH)

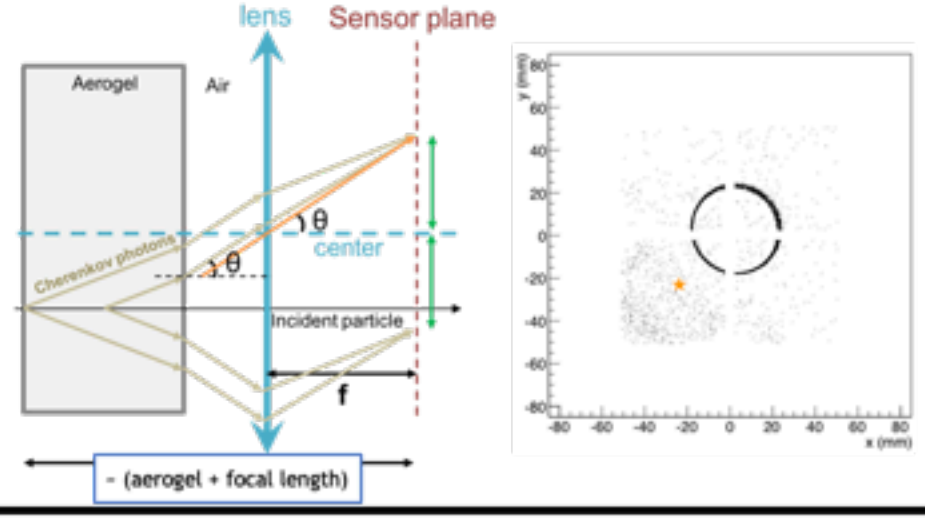




- EIC mRICH designed for K/pi ID up to 9 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

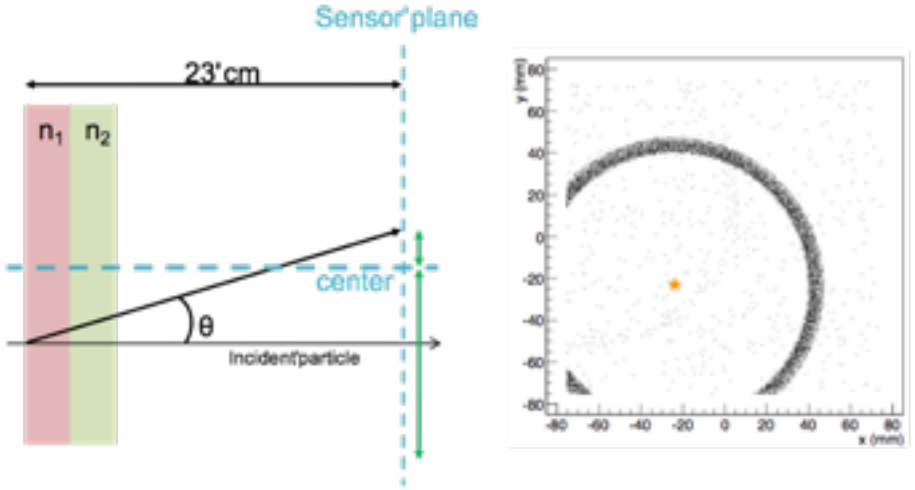
Smaller, but thinner ring improves PID performance and reduces length

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)



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