# *Modular Ring Imaging CHerenkov Detector (mRICH)*


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Deepali Sharma
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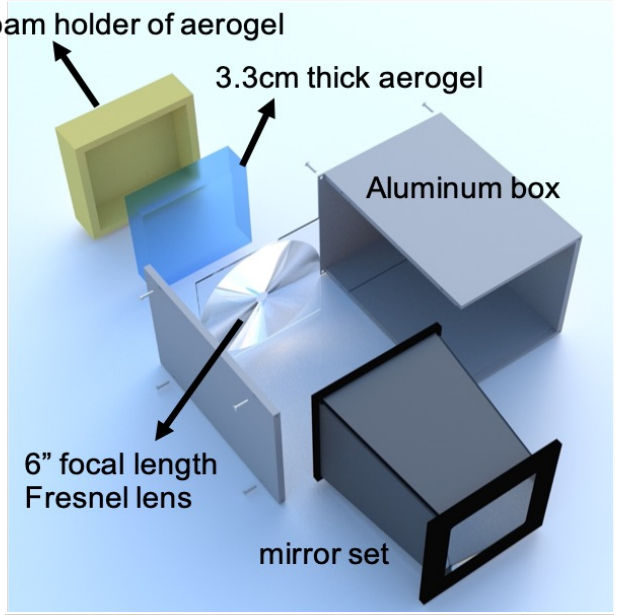
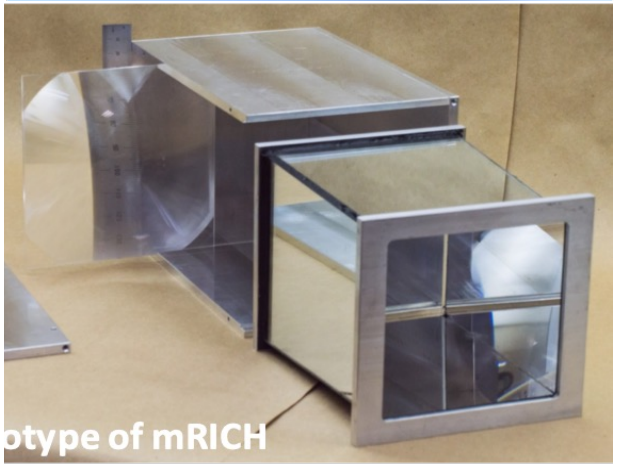
Institutions involved

- Georgia State University
- INFN @ Ferrara and @ LNF
- Duke University
- University of Hawaii
- University of South Carolina
- Brookhaven National Lab
- Jefferson Lab
- Argonne National Lab
- Los Alamos National Lab

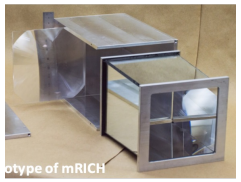
***eRD14: PID consortium***

***mRICH R&D project: eRD101***

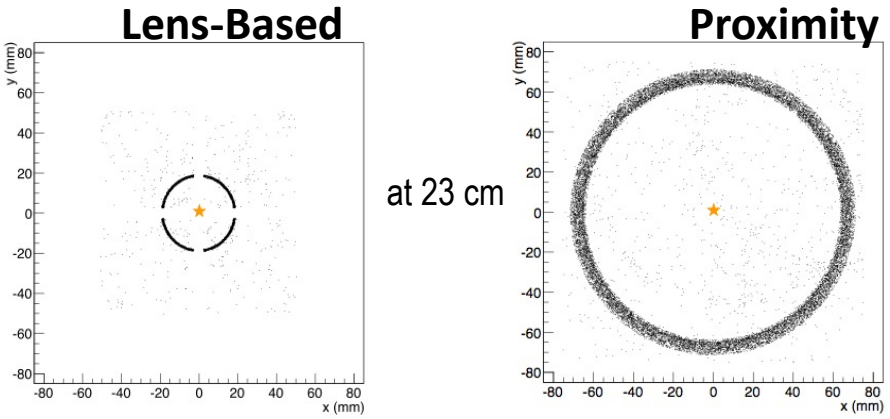


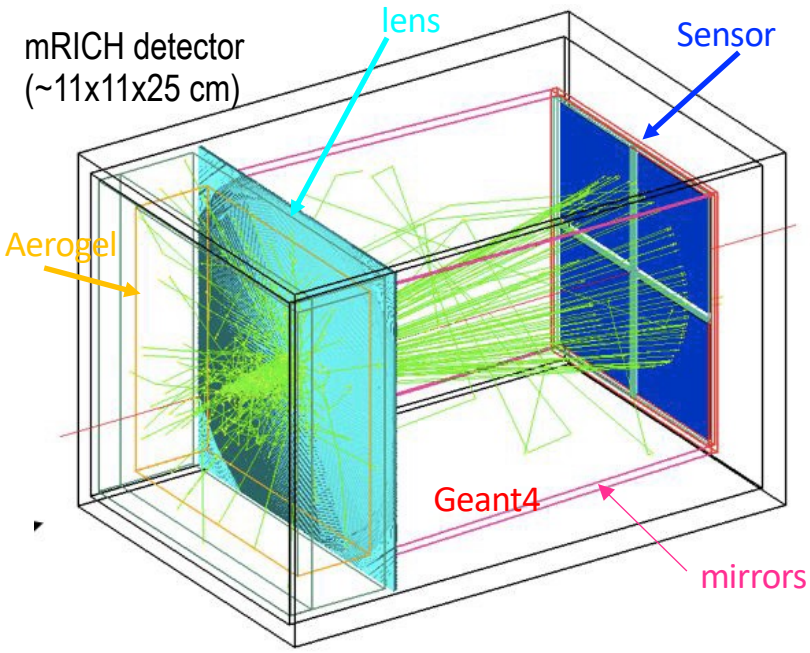



# EIC mRICH – Working Principle



- *Compact, modular and projective*
  - Radiator: Aerogel, L~3 cm and n=1.03
  - Focusing: 6” Fresnel lens



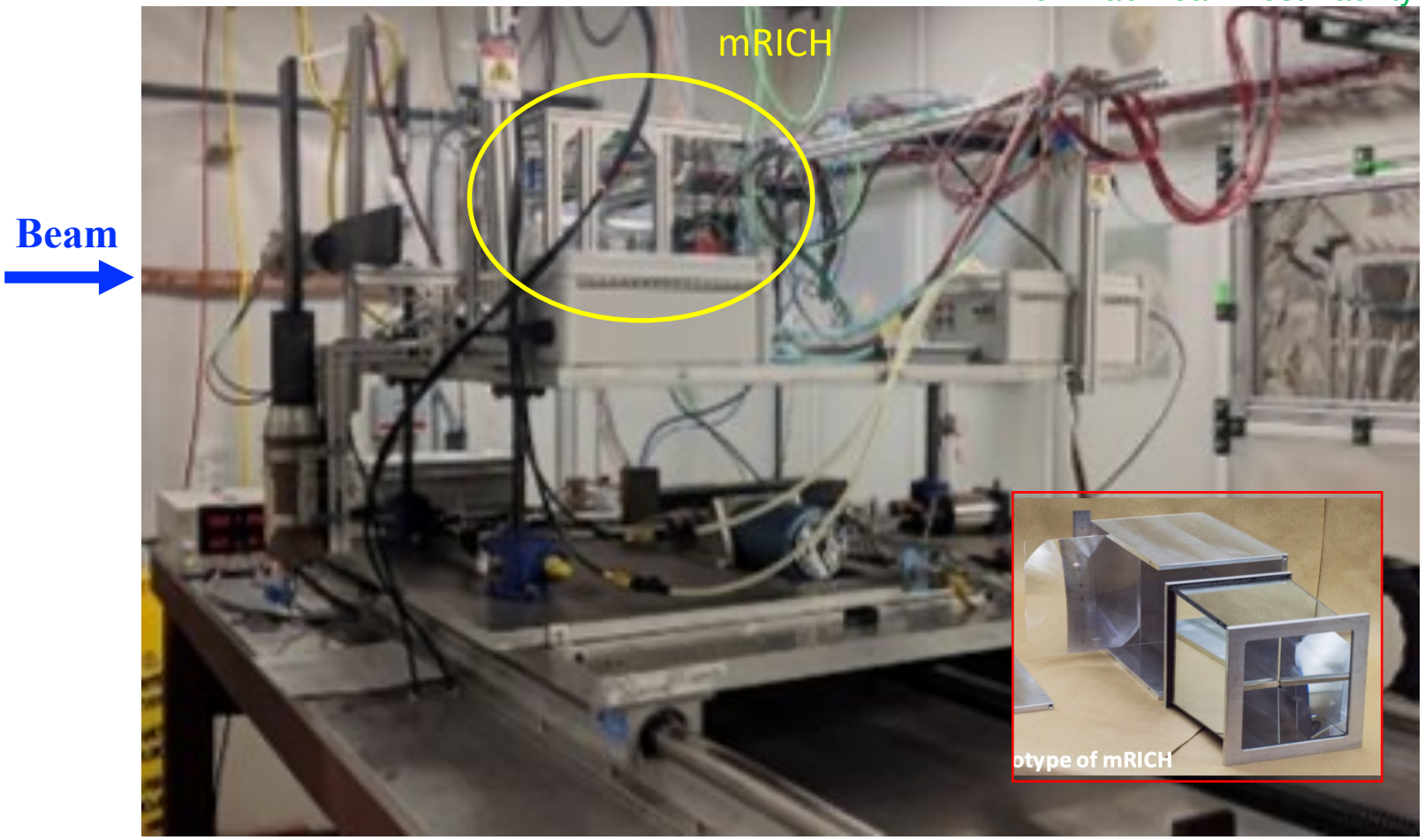




- Compact PID device with momentum coverage up to 10 GeV/c for $\pi$/K and e/$\pi$ up to 2 GeV/c or more.
- The emission point error is minimized at the lens focal plane, and chromatic dispersion error is reduced by UV filtering (acrylic).
- R&D is at very advanced stage – 3 beam tests already!

# Prototyping & Beam Tests

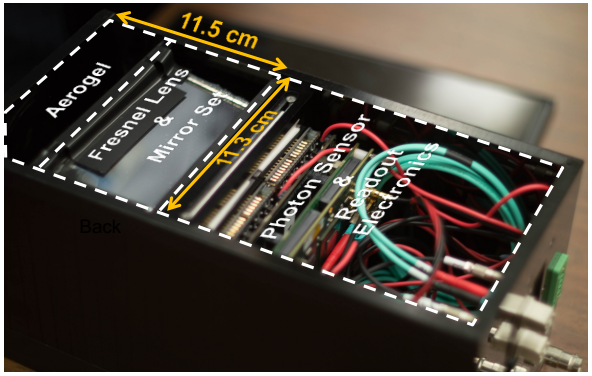
- Two beam tests: 2016 and 2018.
  - **1st beam test** - verified mRICH working principle and validated simulation
  - **2nd beam test –** test mRICH performance with improved optical design, and test SiPM sensors.

Fermilab Beam Test Facility

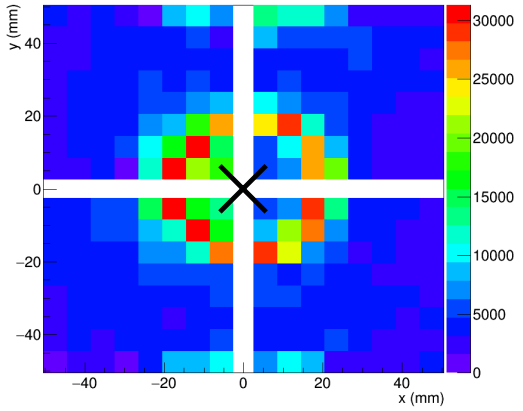


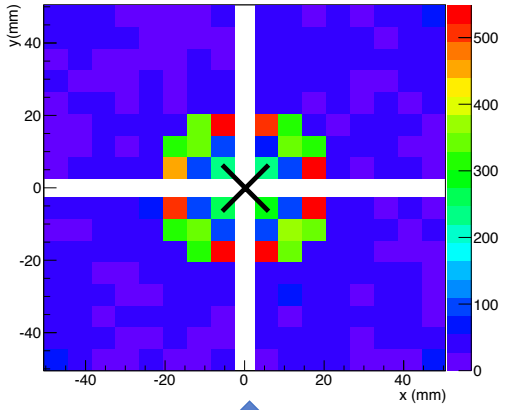
# 1st and 2nd Beam Test Comparison (120 GeV Proton Beam)

Verified mRICH working principle and validated simulation




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

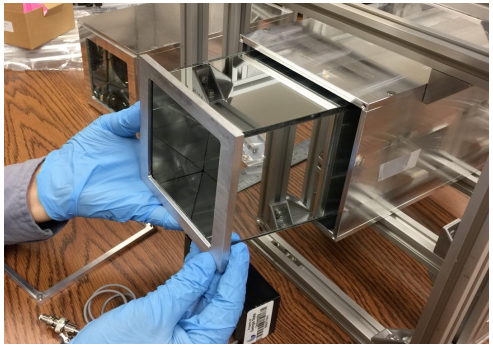


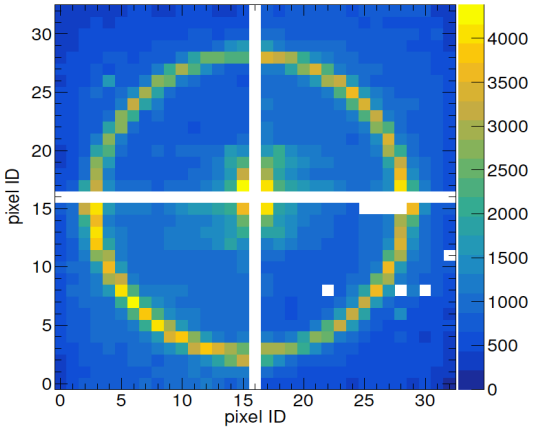

Images from 120 GeV Proton beam

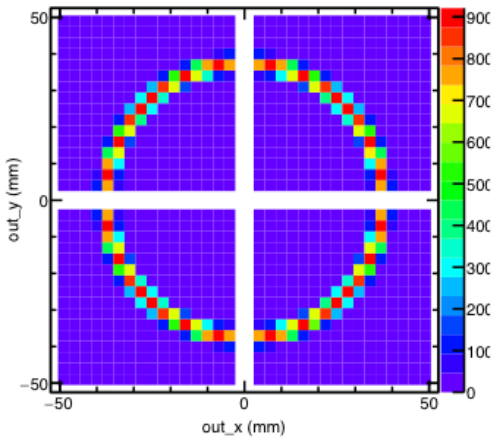
Simulated Images Using GEANT4

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

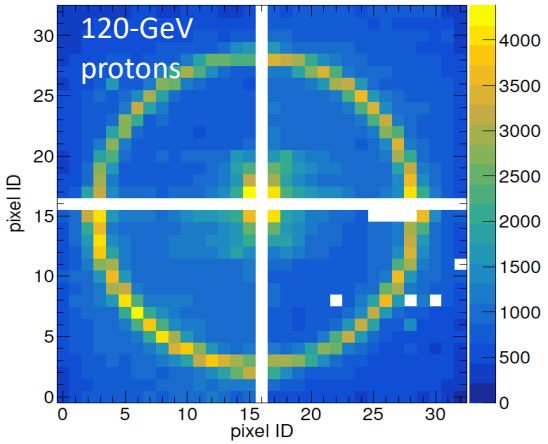


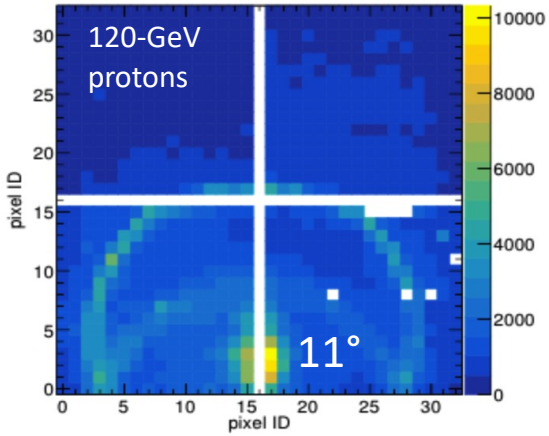
2nd mRICH prototype was tested at Fermilab Test Beam Facility in June/July 2018

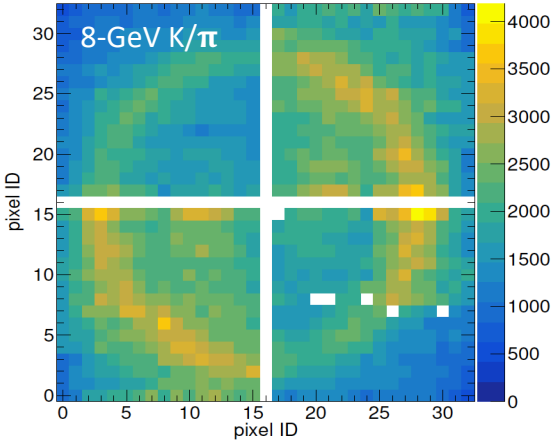


# Completed Data QA Analysis for the 2nd Beam Test



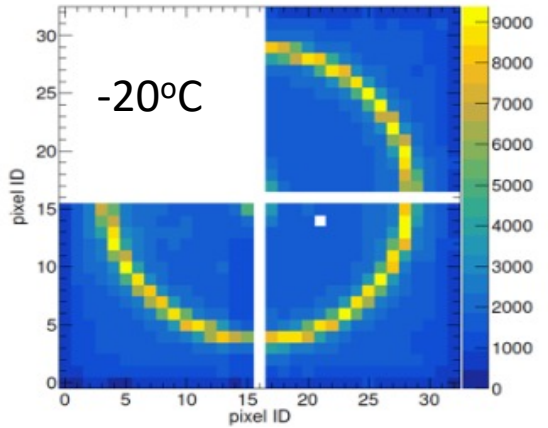



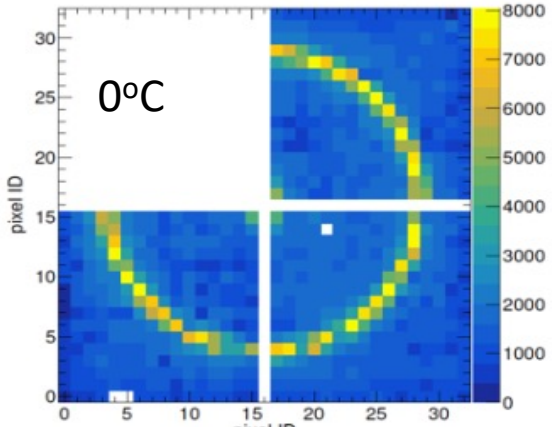



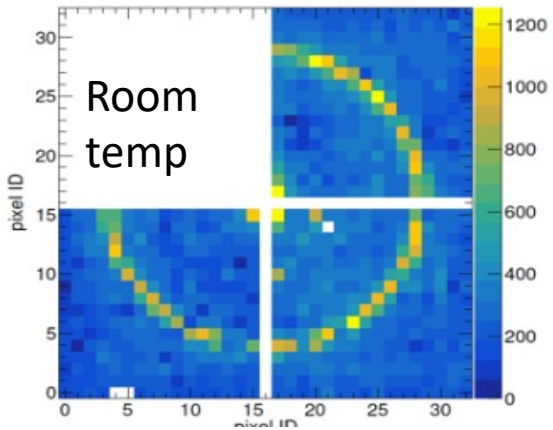

- The challenge of this analysis is to determine the beam position since the beam hodoscope readout was not ready for this test.

Four Hamamatsu H13700 PMTs (3mm x 3mm pixel size; 16x16 channels) were used in these test runs. These sensors will NOT work in high magnetic field!!!

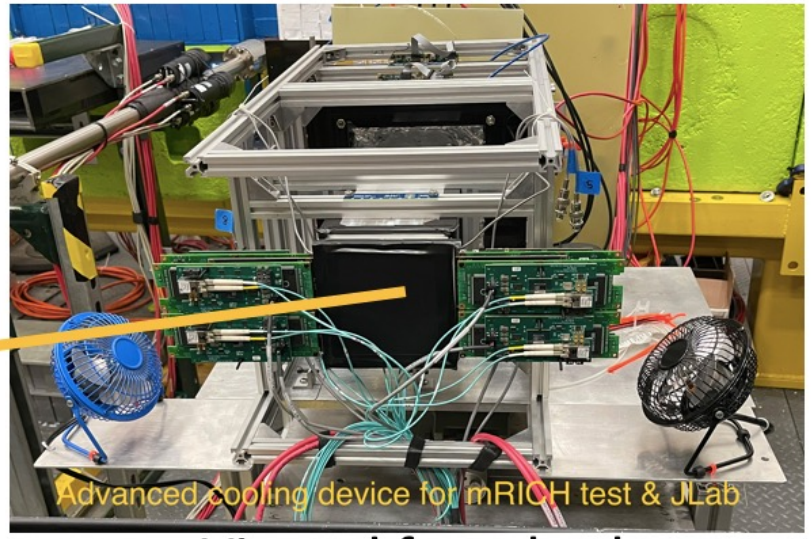
SiPM?



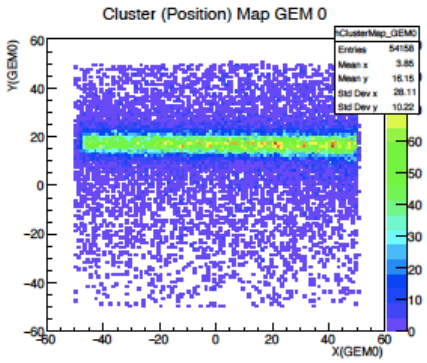



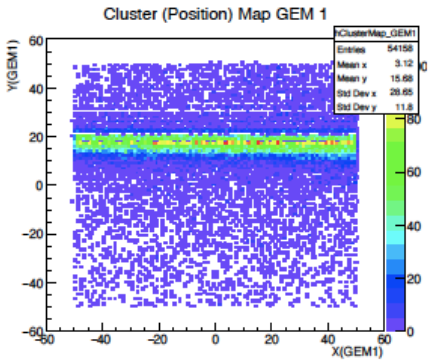
# JLab Beam Test (1-6 GeV/c Secondary Electron Beam)

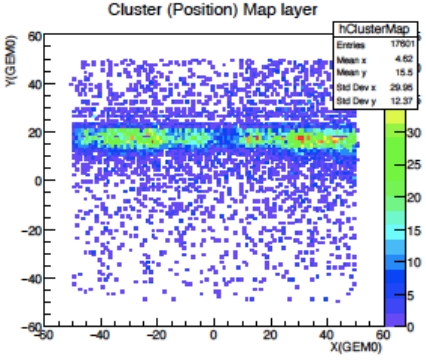



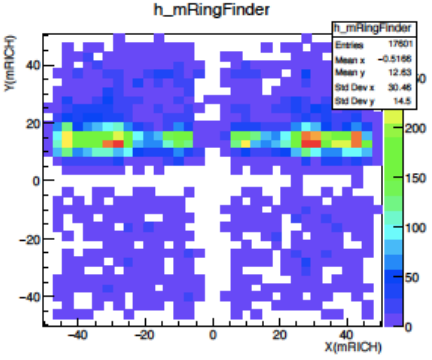

Viewed from back

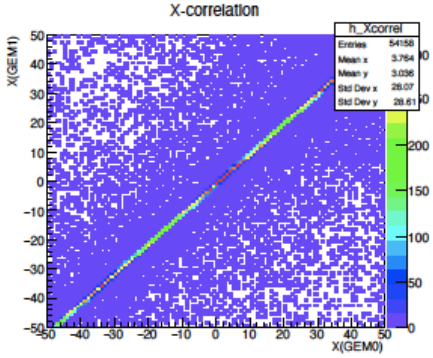
# JLab Beam Test: Data Analysis

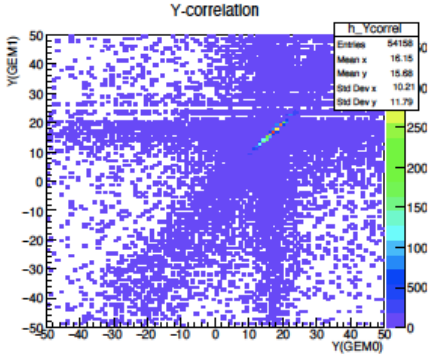


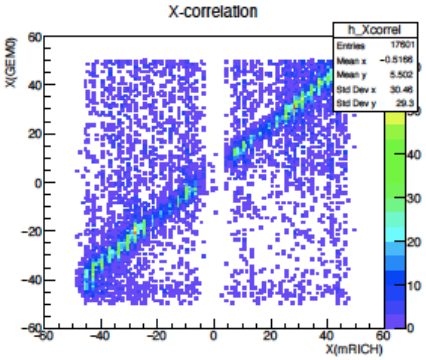



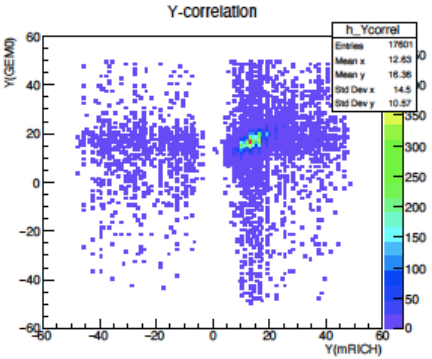



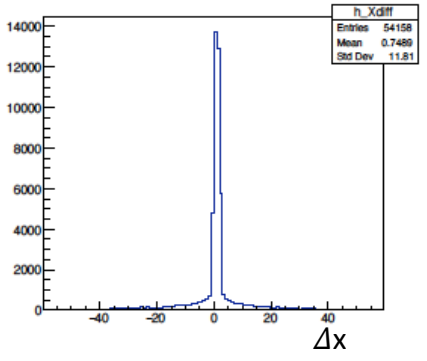



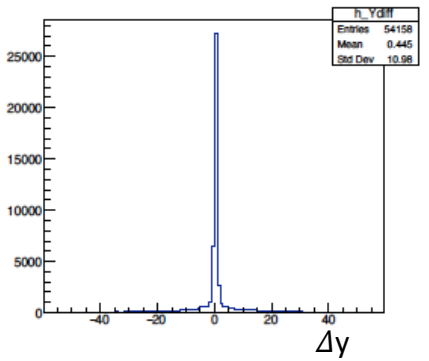



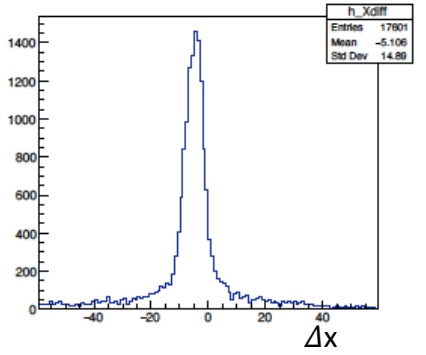



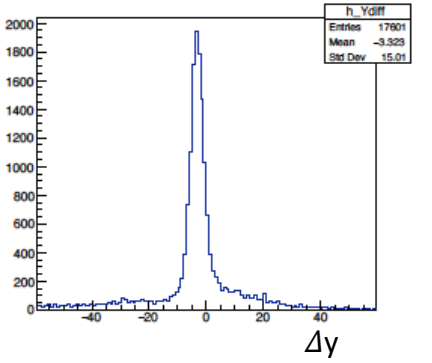



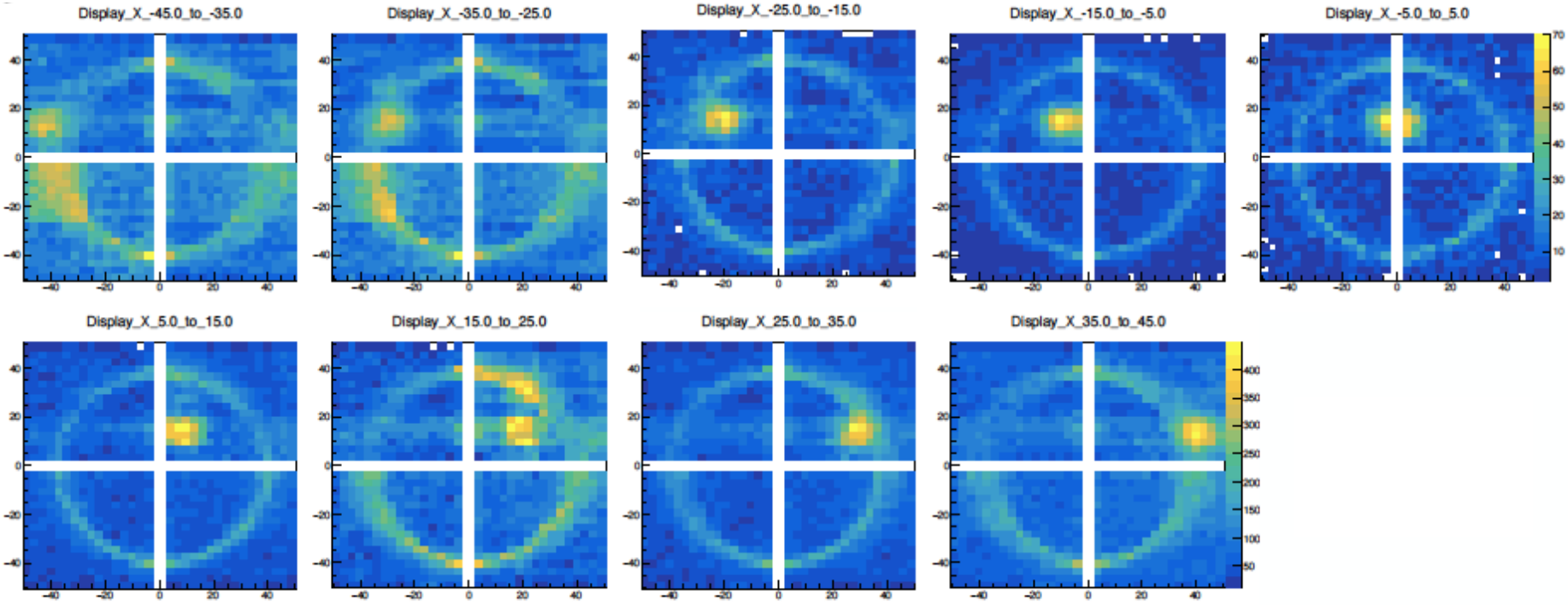



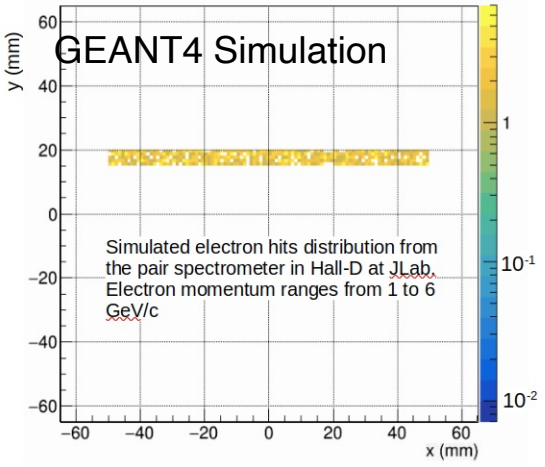



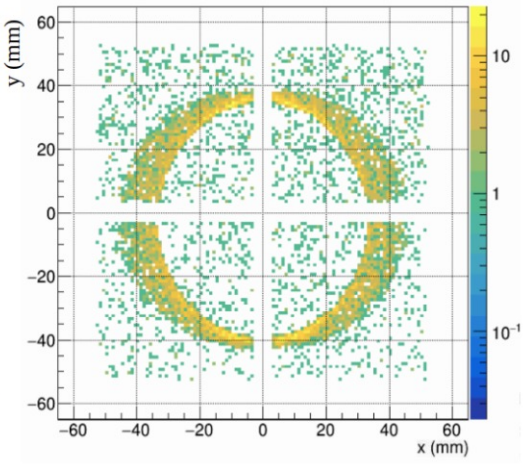



# JLab Beam Test: Rings as a Function of Incident Beam Position



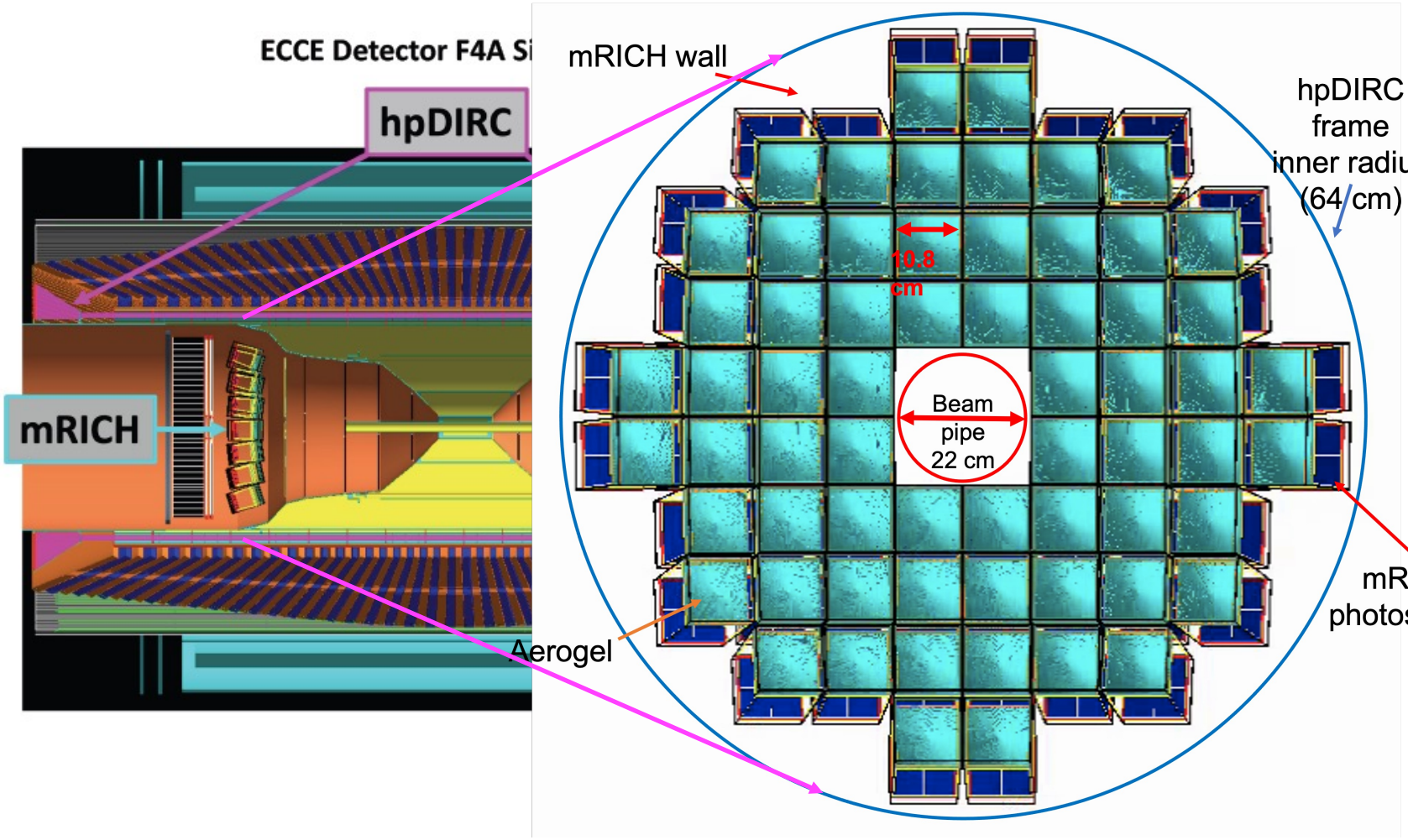




Next steps:

- Determination of mRICH and GEMs efficiencies as a function of different cuts
- Calculate the number of photons, ring radius and single photon angular resolution

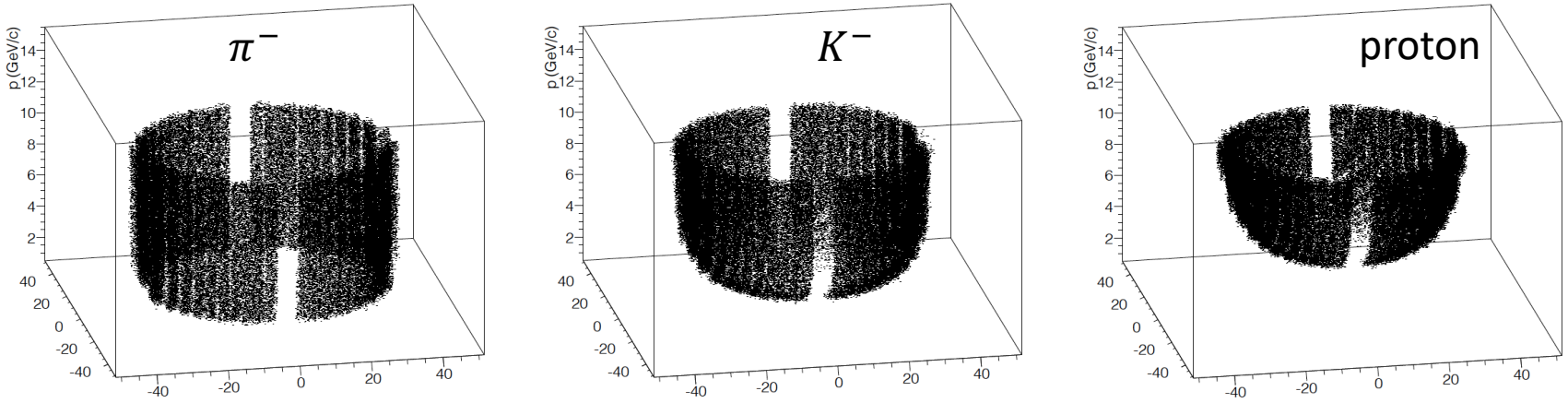
# mRICH in ECCE

- GEANT4 simulation / full implementation in Fun4All!

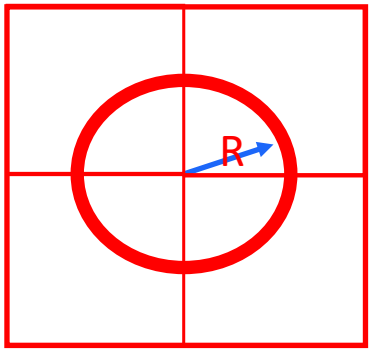


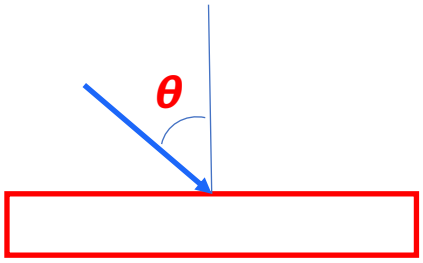
# mRICH Performance: Analysis Code / PID

- Use Likelihood method
  - Establish a DB and match patterns based on Likelihood!



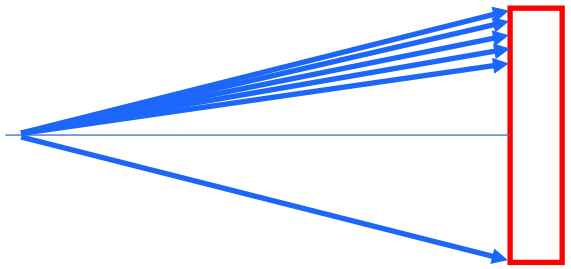

- Position resolution:
  **Δ**R, binned with assumption of 3 mm pixel size
- Angular resolution:
  **Δ*θ***, binned with optimal angular resolution of 1.5 mrad

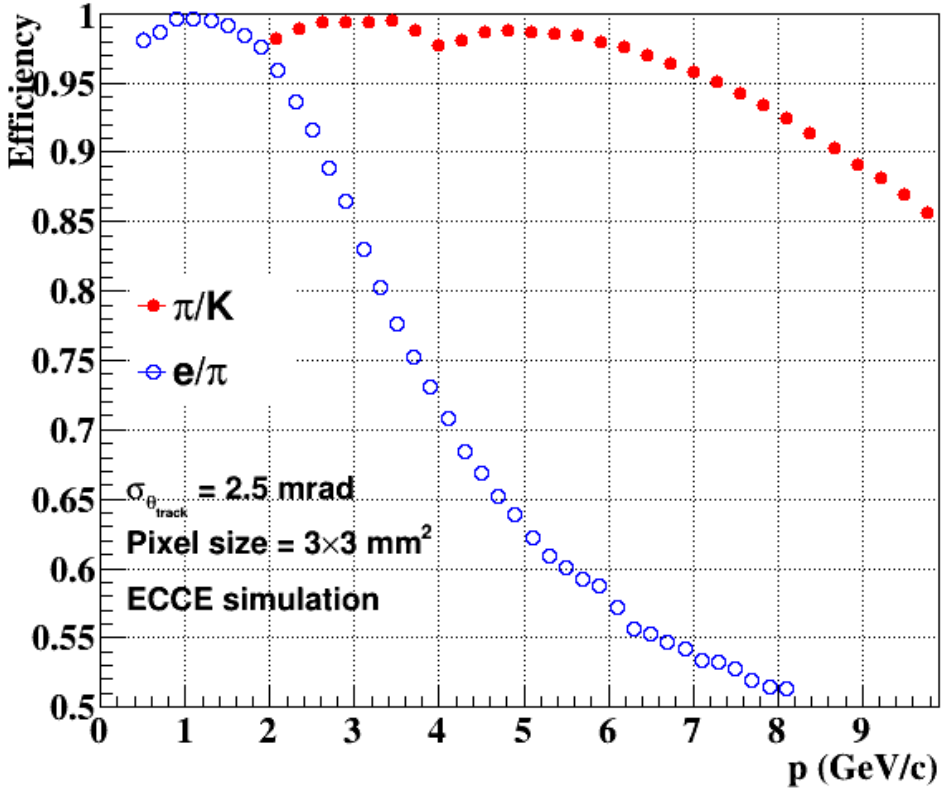


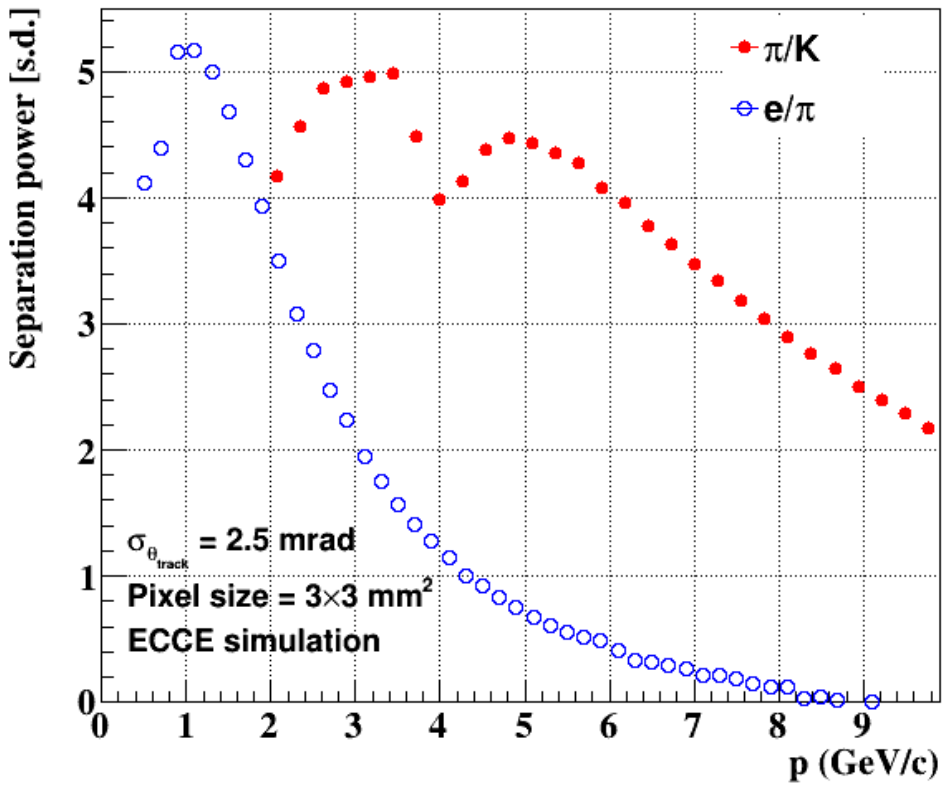



# mRICH PID Performance

- Focus on extreme cases to test performance

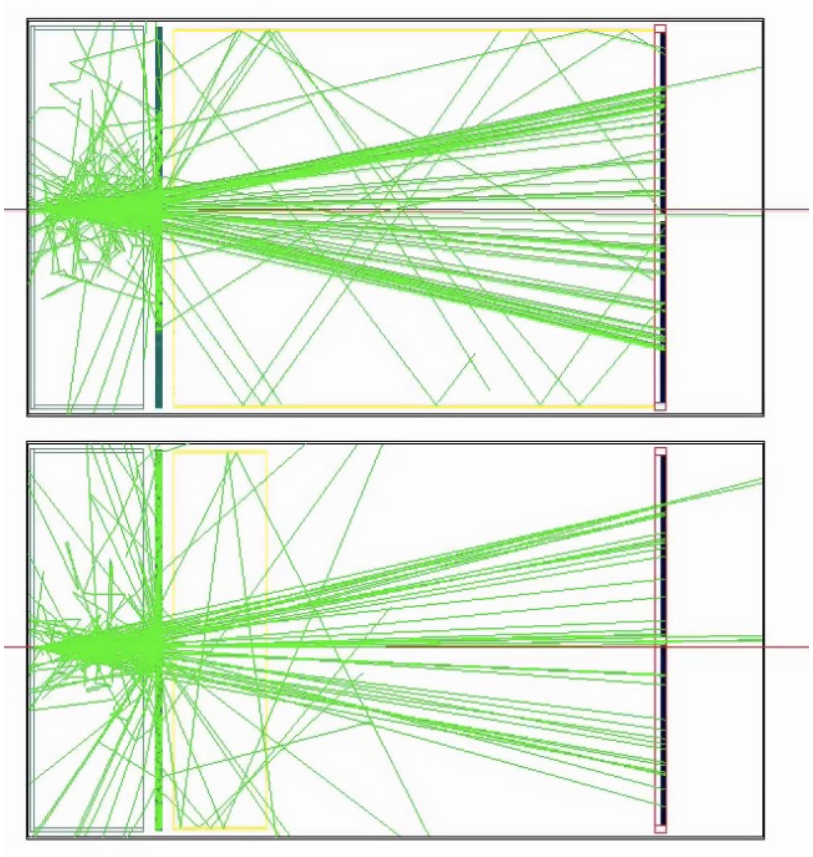


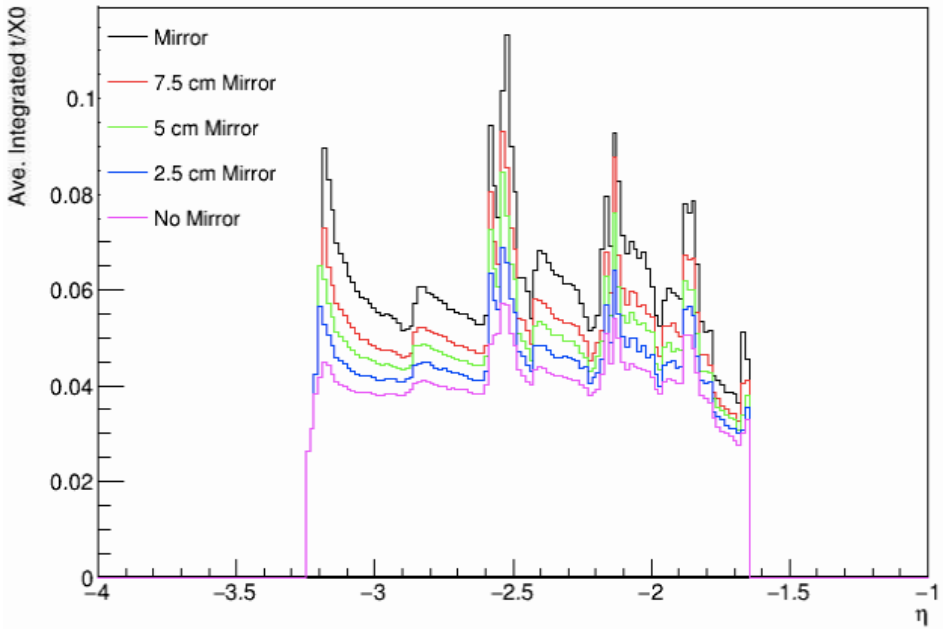


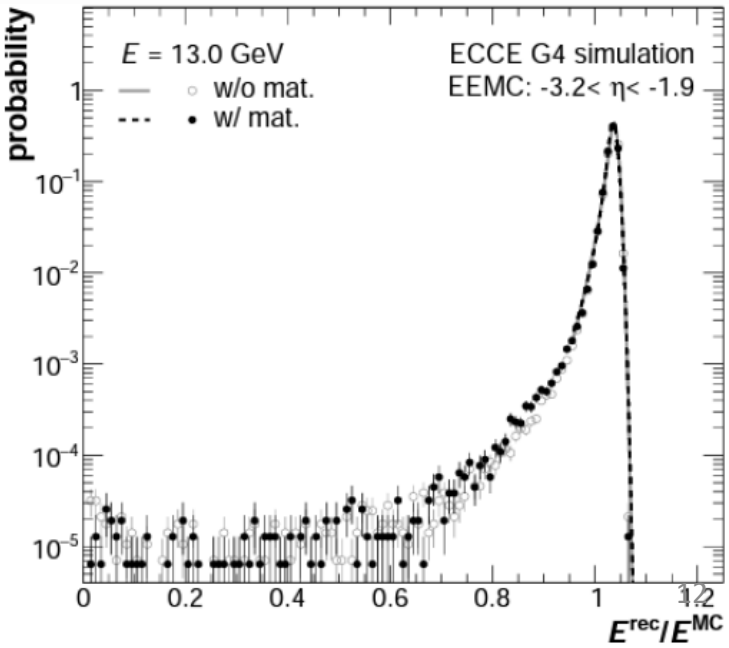



# **mRICH R&D:** *Material Scan*

- Mirrors: 15.34 cm x 10.4 cm
  @ 0.5 mm thickness / Al
- Frame: 10.8 cm x 20.45 cm
  @ 0.5 mm thickness / carbon fiber

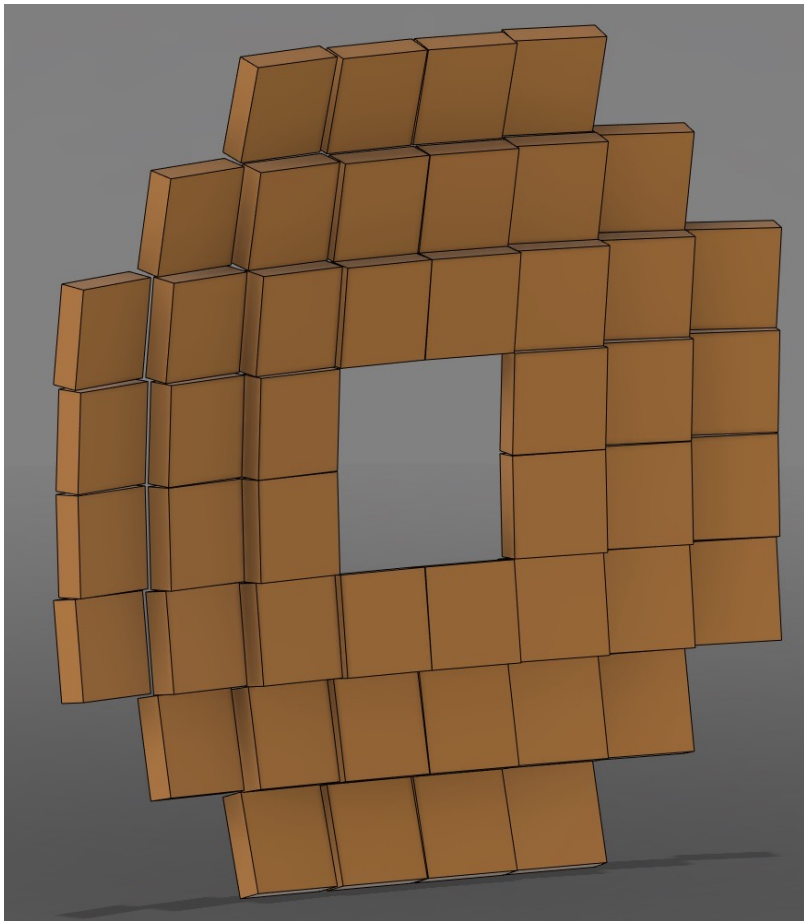


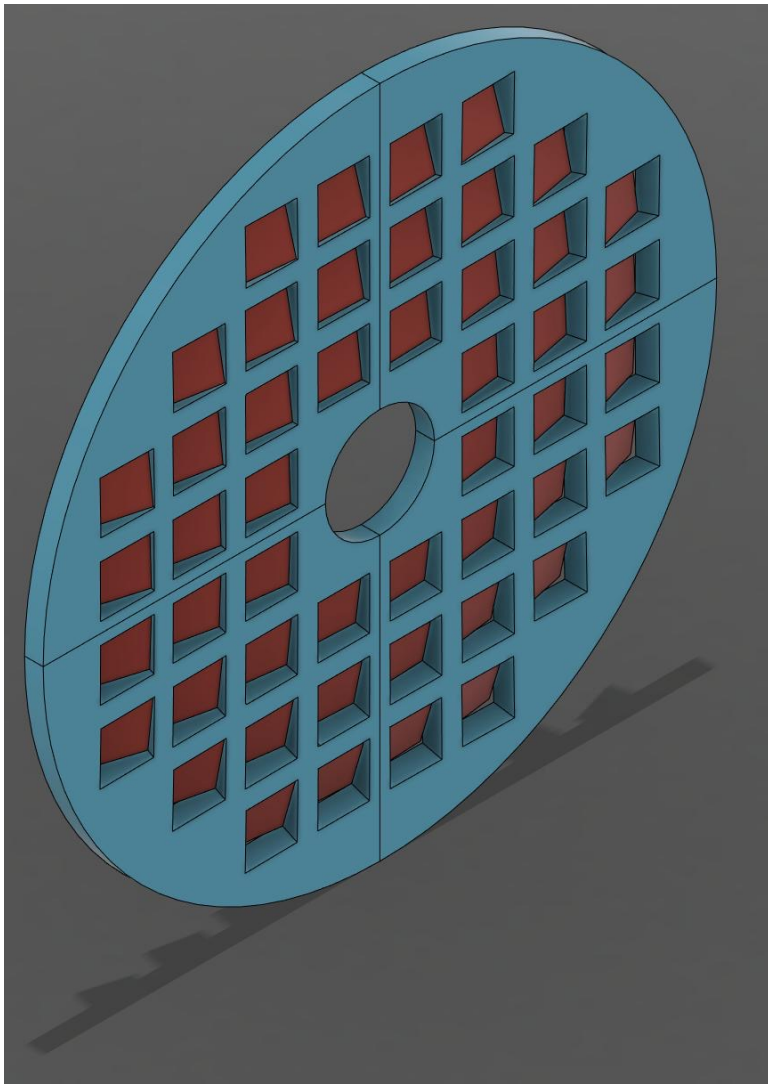


# **mRICH R&D:** *Support Frame Design*

- Alexander Barnyakov (Russia)
- Alex Eslinger (Jlab)
- Edward Kistenev (BNL)





# mRICH R&D Activities and Outlook

Ongoing activities …

- mRICH JLab test data analysis for extracting single photon angle resolution – eRD101
- Fine tuning mRICH GEANT4 simulation to match performance from test data – eRD101
- FermiLab June 2022 LAPPD beam test
- Engineering design: optimizing detector coverage and optical components & assembly

Outlook

- Build new prototype toward its final design for array installation
- mRICH performance tests with the new prototype
- mRICH tests with new photosensors

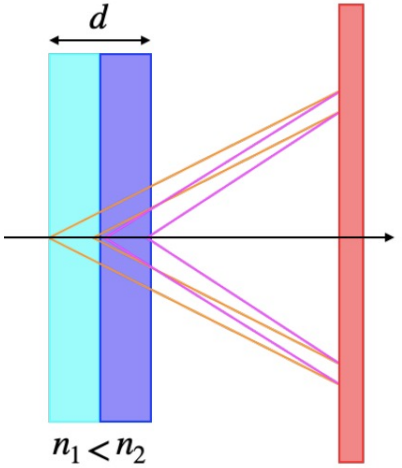
*Thank You*

# BELLE-II ARICH

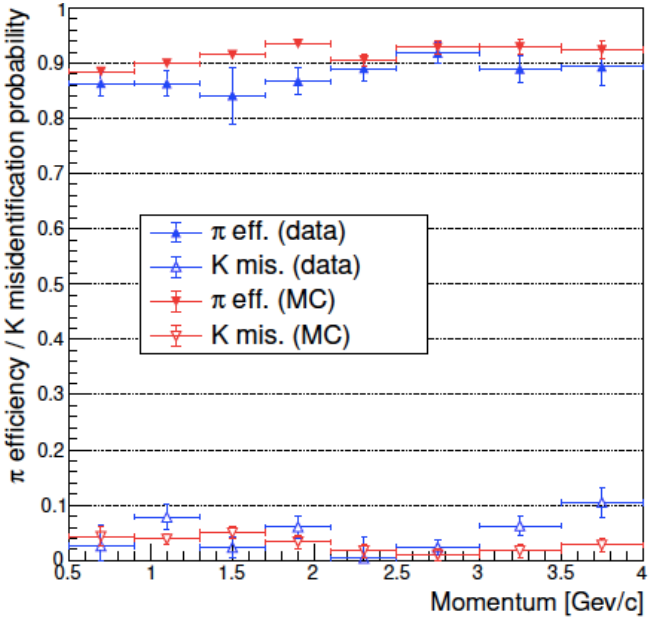
L. Burmistrov *et. al*, NIMA **958**, 162232 (2020)

I. Adachi et al., NIMA **907,** 46–59 (2018)

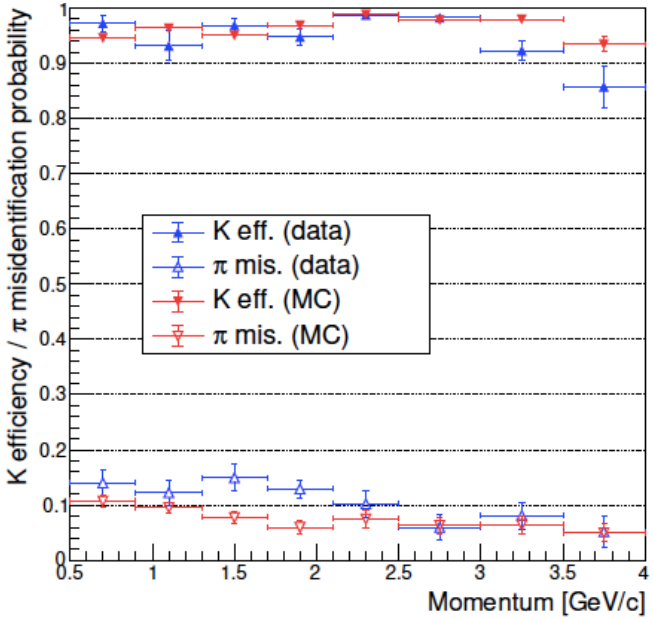
Good separation of pions and kaons up to about 4 GeV/$c$, it should also be able to separate electrons, muons and pions at momenta below 1 GeV/$c$.




Masanobu YONENAGA, PhD thesis, "PID using the ARICH at the Belle II Experiment". Fig.6.10 / page 65




(a) $\pi$ eff. and $K$ mis.

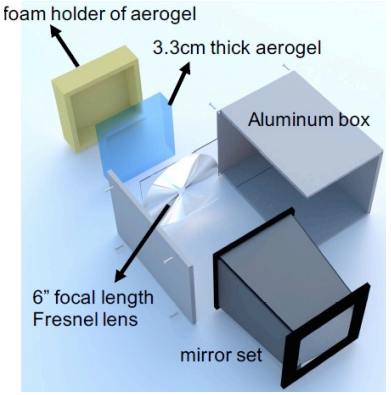



(b) $K$ eff. and $\pi$ mis.

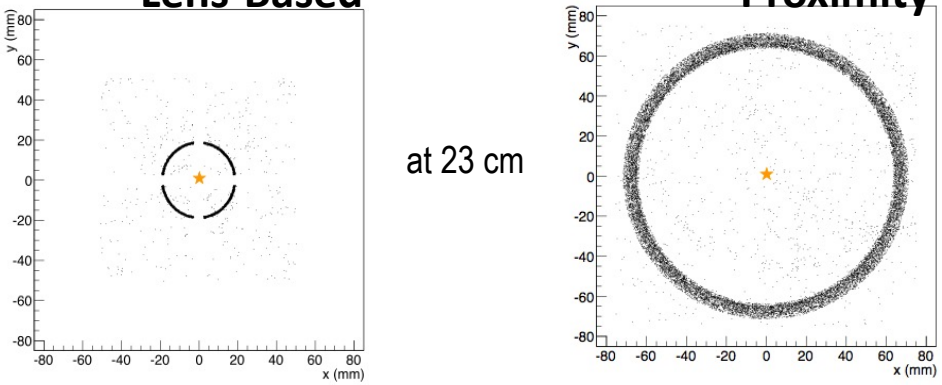
# mRICH Concept

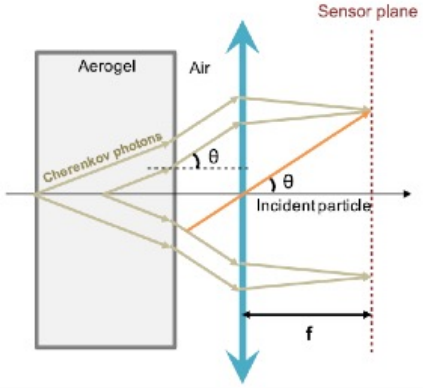
## Overview:

- Modular and compact RICH detector (~11x11x25 cm)
- Radiator: Aerogel, L~3 cm and n=1.03
- Focusing: 6” Fresnel lens




**Lens-Based** at 23 cm **Proximity**

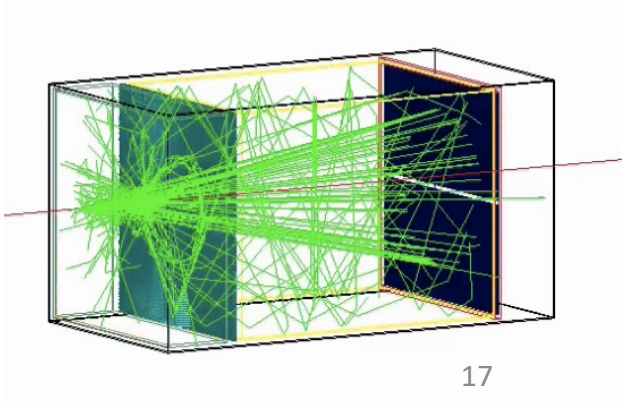



- π/K separation up to 10 GeV/c and e/π separation up to 2 GeV/c.

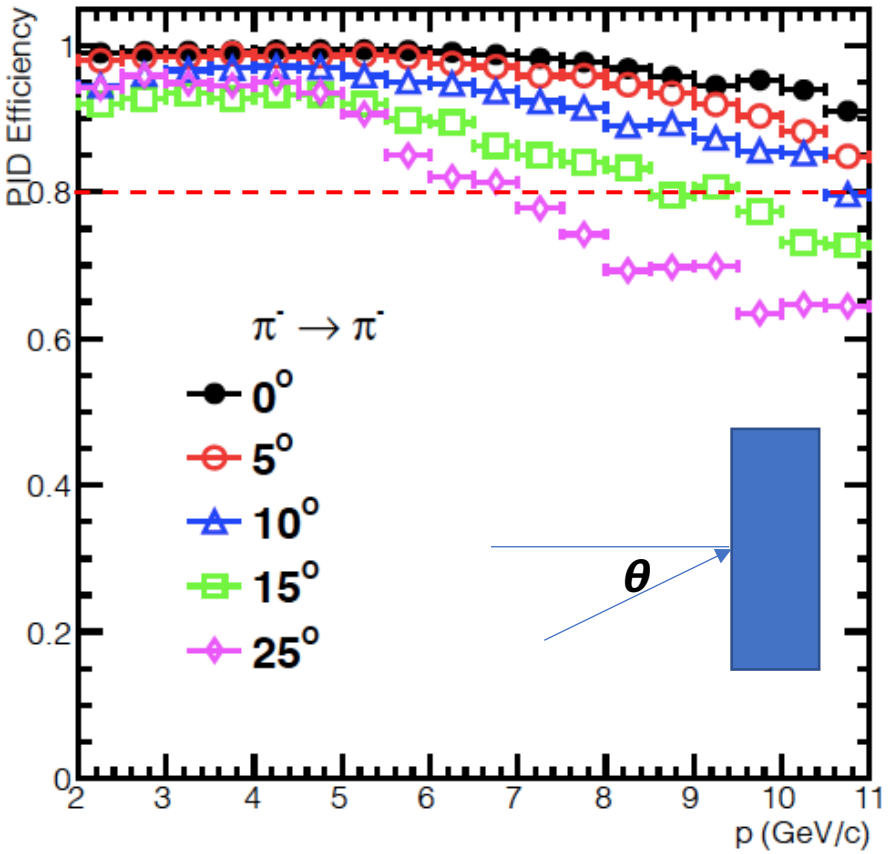
## Systematic effects

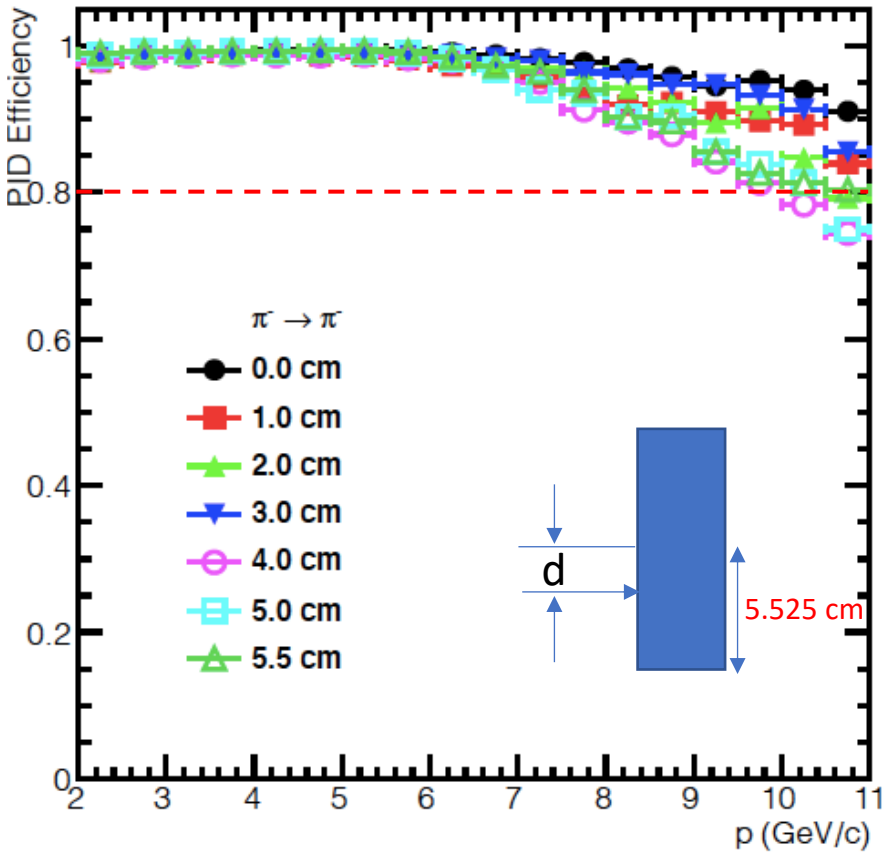
- Emission point error: minimized at the lens focal plane
- Chromatic dispersion error: reduced by UV filtering (acrylic).
- Pixel size error: the uncertainty raised by pixel size, $a$, error



# mRICH PID Performance: $\pi^-/_{K^-}$

- Construction code output: $\mathcal{L}_\pi, \mathcal{L}_K, \mathcal{L}_p$
- $\pi^- \to \pi^-$: $\mathcal{L}_\pi - \mathcal{L}_K > 0 \&\& \mathcal{L}_\pi - \mathcal{L}_p > 0$



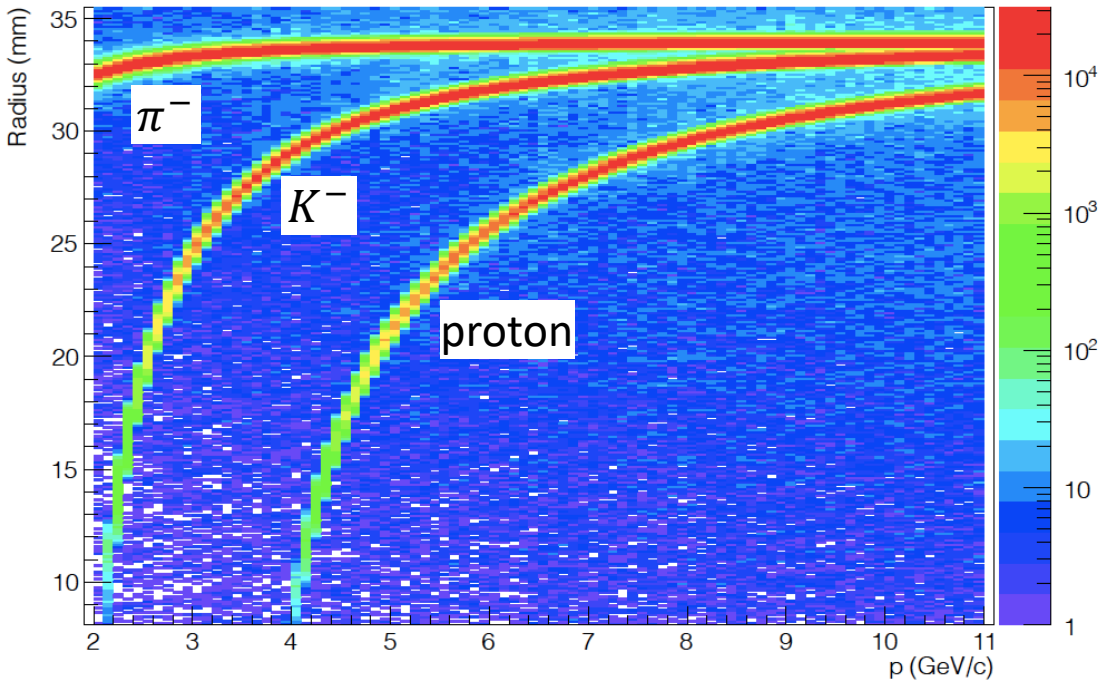

- Efficiency drops beyond 15°
- When incident perpendicular no impact even at the edge of the Aerogel

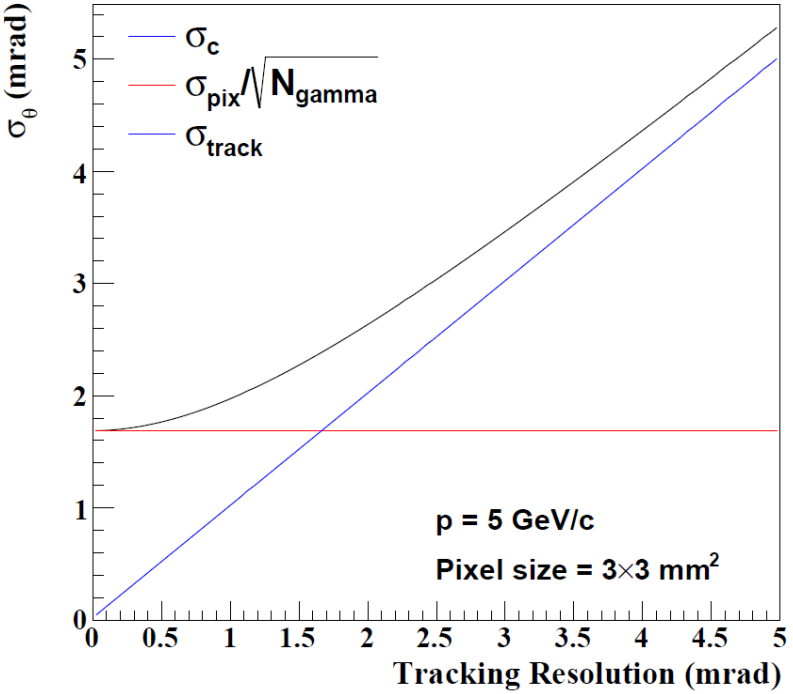
➠ Projective setup if preferable!

# Reconstruction/ PID

Focusing on a single module for performance studies!

- Ring radius without considering the sensor pixelization!

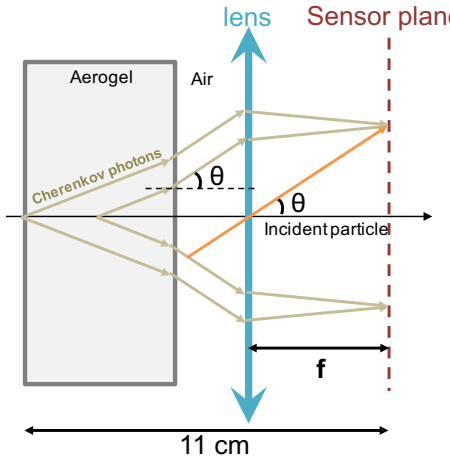


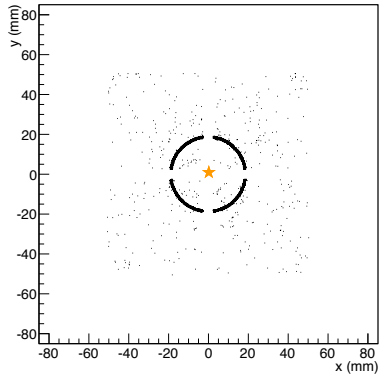



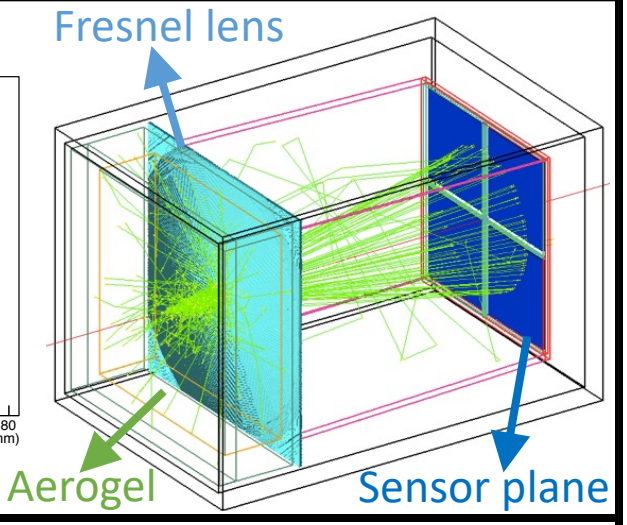
# mRICH – lens-based focusing aerogel detector design

**Smaller, but thinner ring improves PID performance and reduces length**

**Lens-Based mRICH Design**

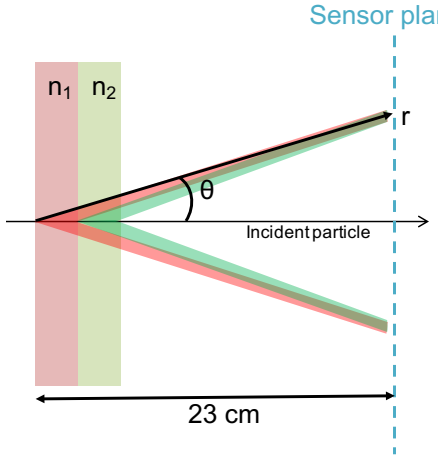


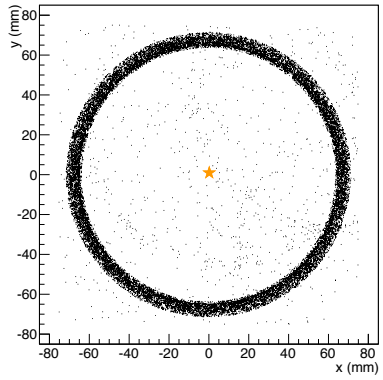




9 GeV/c pion beam launched at the center of xy plane in simulation

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



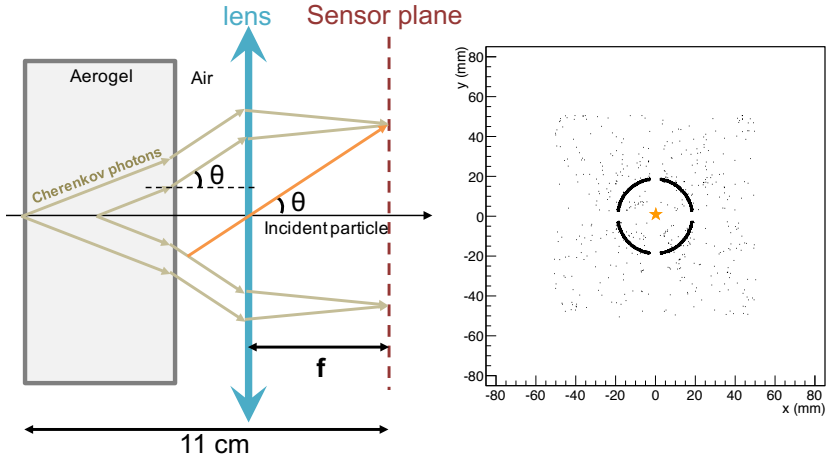




- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

# mRICH – lens-based focusing aerogel detector design

**Smaller, but thinner ring improves PID performance and reduces length**

**Lens-Based mRICH Design**



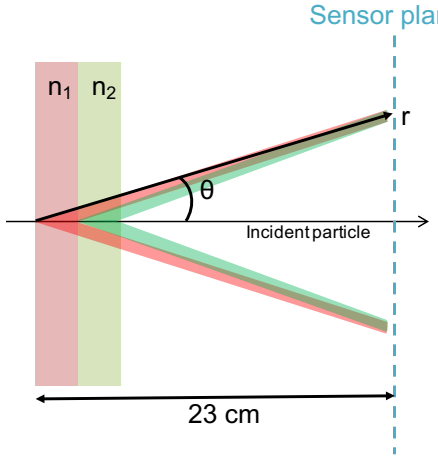


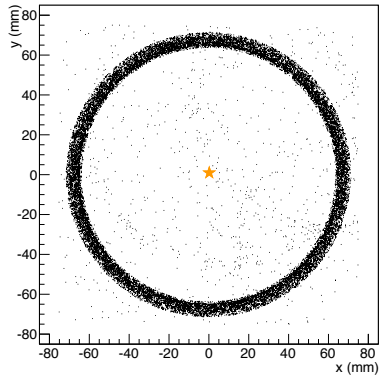


- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner** ring image

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

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



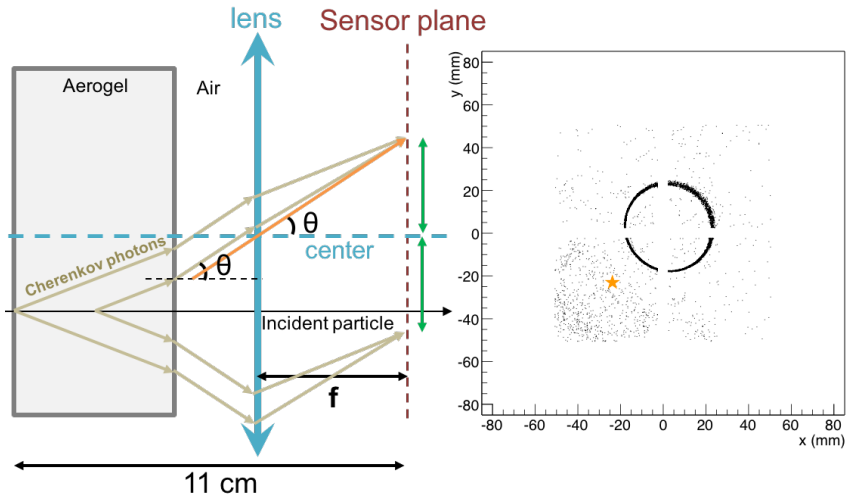




- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

# mRICH – lens-based focusing aerogel detector design

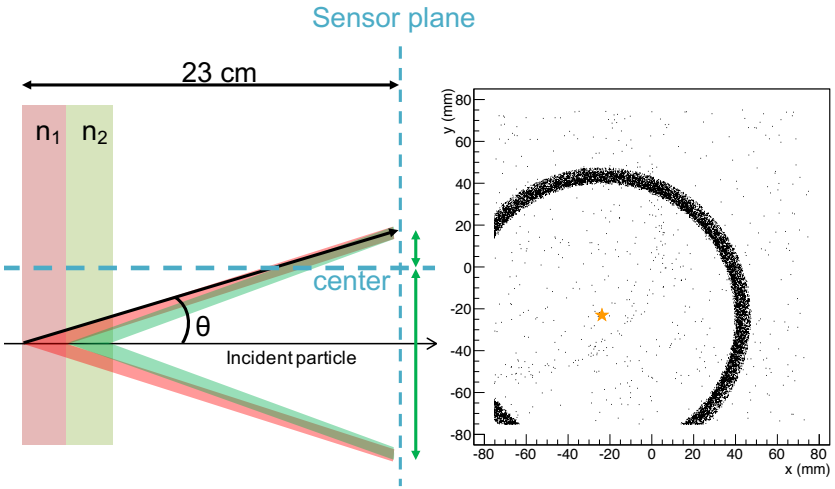
**Ring centering of lens-based optics reduces sensor area (main cost driver)**

**Lens-Based mRICH Design**

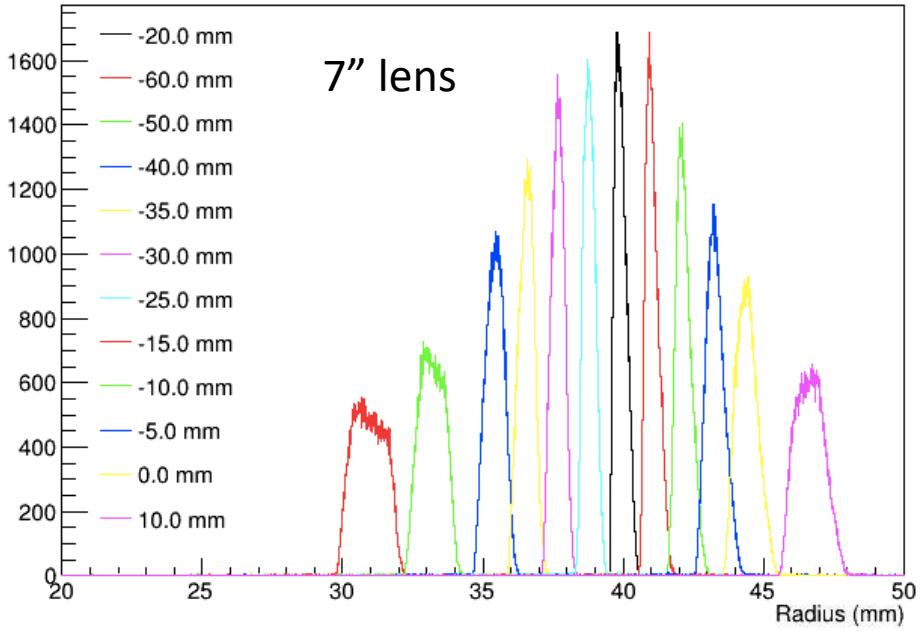


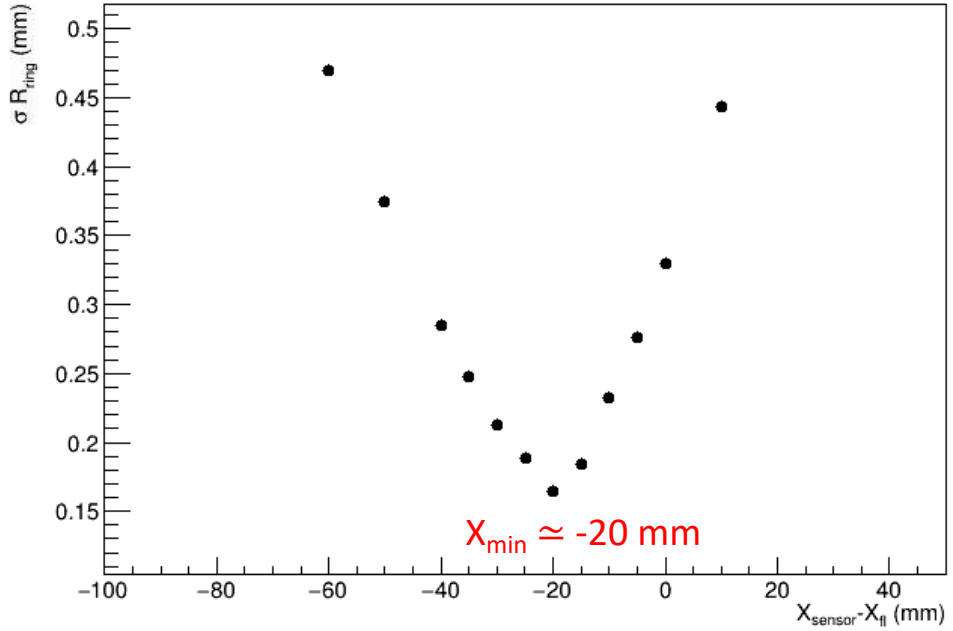

- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring image is **center** on the middle of the sensor plane

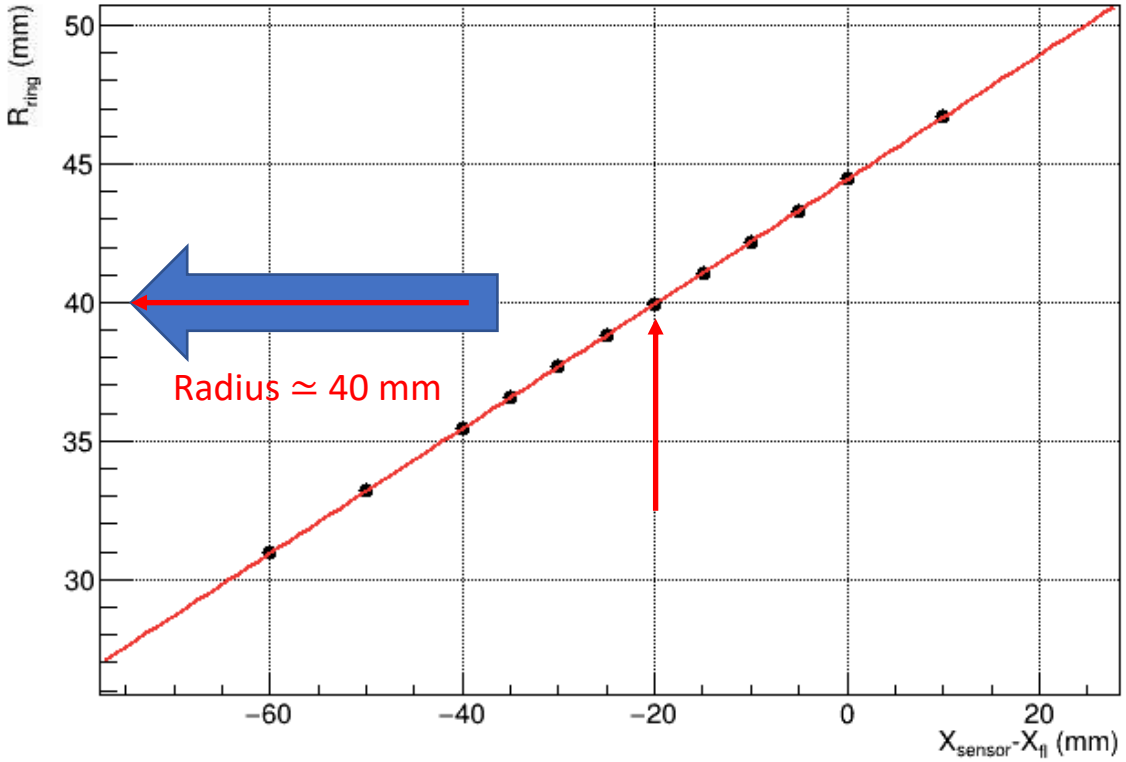
**Two-Layer Proximity Focusing Design (BELLE-2 ARICH)**



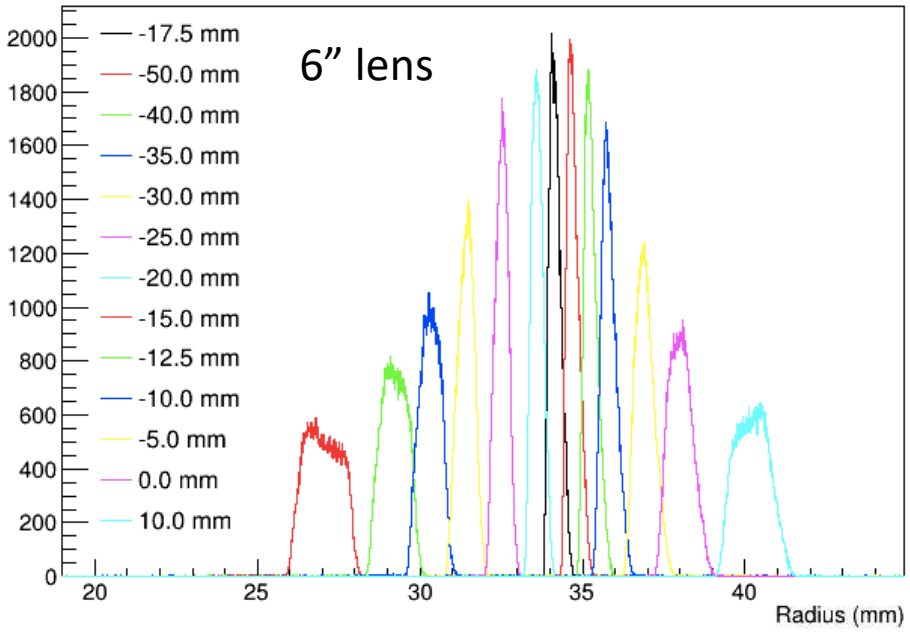

- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring is centered at point of incidence

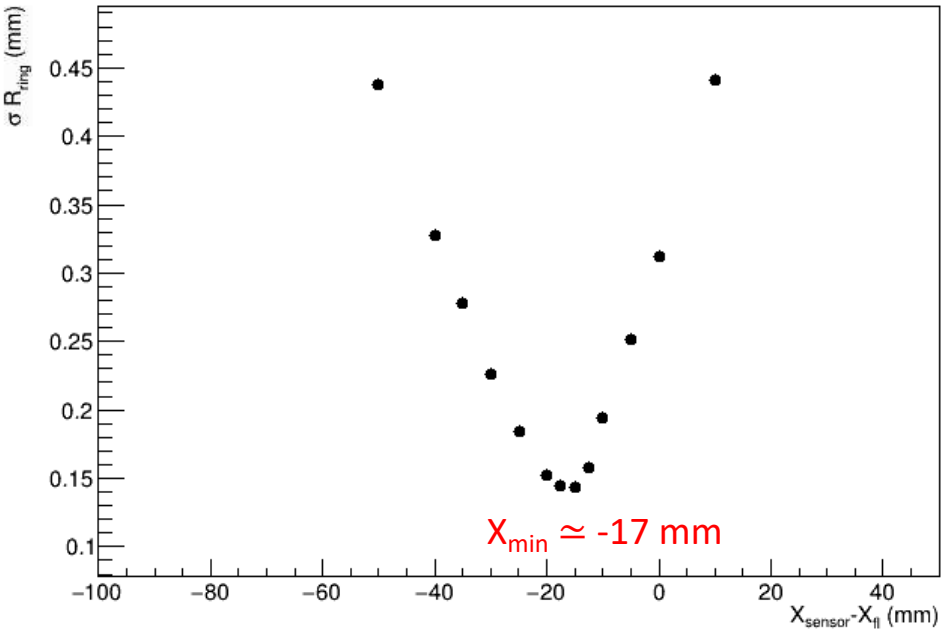


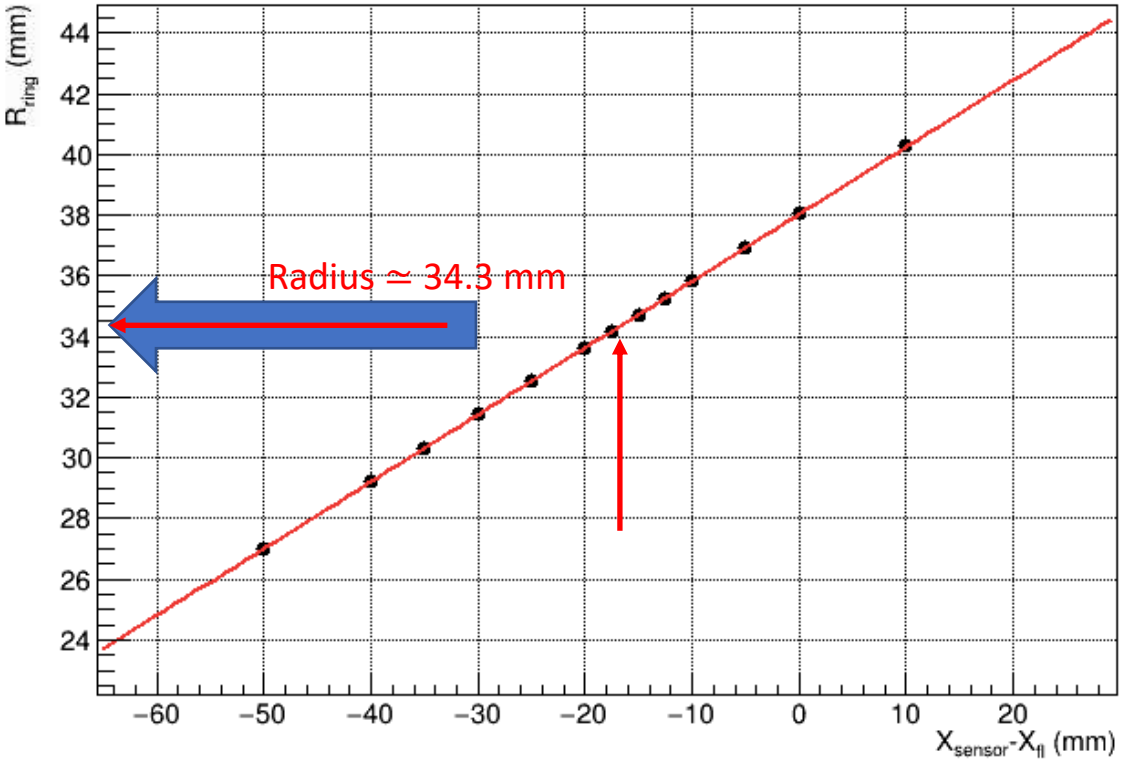




For 7” lens the optimal sensor location is at 40 ± 2 mm




For 6” lens the optimal sensor location is at 34.3 ± 1 mm