A Modular Ring Imaging Cherenkov Detector (mRICH) for Future Electron Ion Collider Experiments

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Outline

Motivation for mRICH

EIC mRICH – Working Principle and Design

Prototypes and Beam Tests

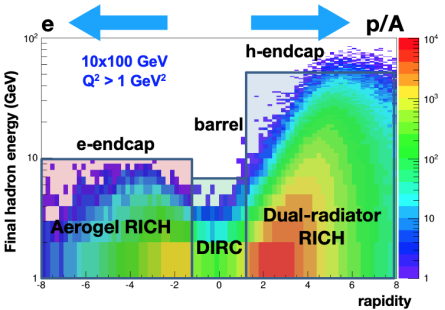
2nd Beam Test

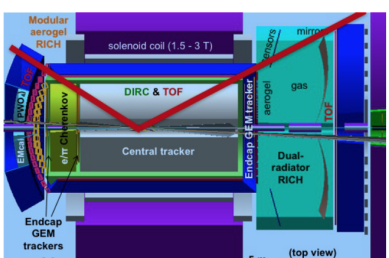
3rd Beam Test

Status of Simulations and Design

mRICH R&D Activities and Outlook

A PID Solution for the EIC



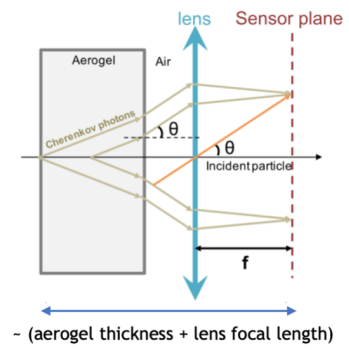


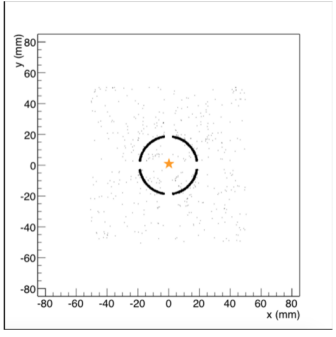
- Three RICH-based detector designs proposed by eRD14 consortium for particle identification (PID) for three different kinematic regions.
- A dual RICH detector in the **h-endcap** region for $\pi/K/p$ separation of upto $\sim$50 GeV/c.
- A compact and cost-effective high-performance DIRC in the **barrel** with a $\pi/K/p$ separation of $\sim$6-7 GeV/c
- A compact aerogel RICH in the **e-endcap** that will provde K/π separation of upto 10 GeV/c and e/π separation up to 2 GeV/c and above.

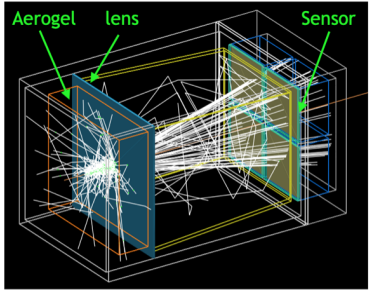
EIC mRICH – Working Principle

Compact, Modular and Projective

mRICH stands for compact and modular Ring Imaging Cherenkov detector, which is designed for K/π separation up to 10 GeV/c, and an e/pi separation of up to 2 GeV/c or more for the future EIC experiment







Geant4 Simulation

With realistic material optical properties

(Not to scale, for illustration purpose only)

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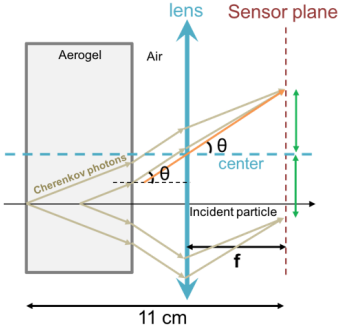
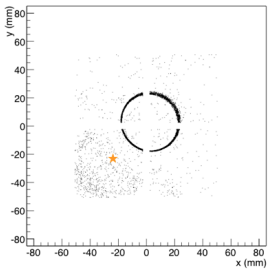
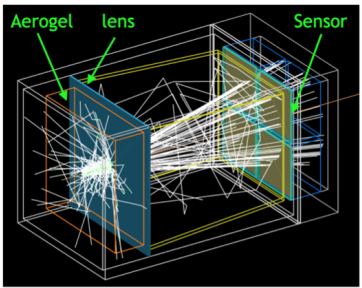


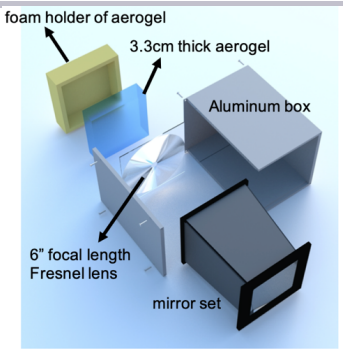


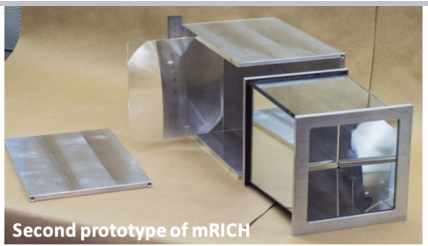


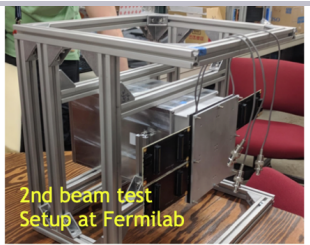
Geant4 Simulation

With realistic material optical properties

mRICH-Optical Component Design







Different photosensors and readout can be attached at the back of mRICH.

2nd and 3rd beam tests have same mRICH design

- Radiator: Aerogel, Length 3 *cm* and $n = 1.03$
- Focussing: 6″ Fresenel lens
- Dimensions (one module): $11 \times 11 \times 25$ *cm*

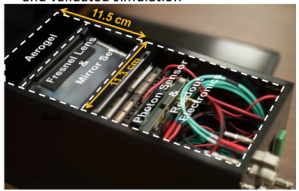
mRICH Beam Tests

We have carried out three Beam tests: 2016, 2018 and 2021

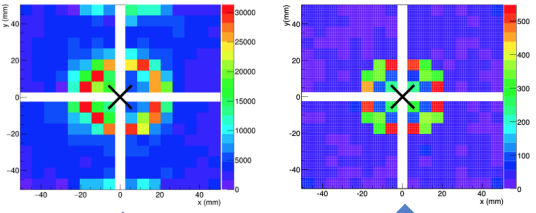
- **Ist Beam test**- Done at Fermilab and verified mRICH working principle and validated simulation (*C.P. Wong et al. NIM 871, 13-19 (2017)*)
- **2nd Beam Test** - Done at Fermilab to test mRICH performance with improved optical design, and to test SiPM sensors.
- **3rd Beam Test** - Done at JLab with the goal to compute the single photon resolution with tracking provided by two GEM trackers.

mRICH Prototype Evolution between 1st and 2nd Beam Tests

verified mRICH working principle and validated simulation



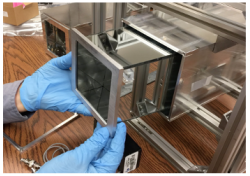
1st mRICH prototype was tested at Fermilab Test Beam Facility in April 2016



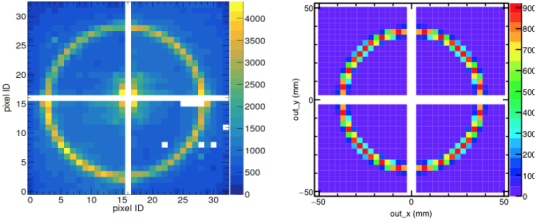
Images from 120 GeV Proton beam

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



2^{nd} Beam Test Data Analysis

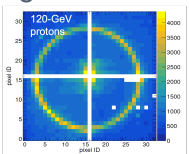
The 2^{nd} prototype test was carried out at FNAL in 2018. Data was taken with H13700 sensors and SiPM matrices.

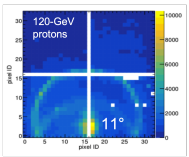
- Took a variety of data with H13700 sensors
  - Beam position scan with 120 GeV proton (mRICH working principle)
  - Threshold scan with 120 GeV proton (Hamamatsu modules testing)
  - Angle run with 120 GeV proton (simulations calibration)
  - Some runs with meson beams (check for K/π separation capability)
- Two datasets were taken with three SiPM arrays
  - Beam position scan with 120 GeV proton
  - Temperature, threshold and bias voltage scan with 120 GeV proton

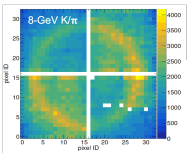
No particle tracking was available and so it was challenging to extract precise beam position.

2nd Beam Test Data Results

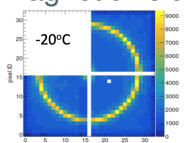
Demonstrated mRICH working principle again.

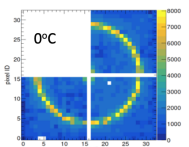


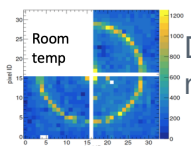




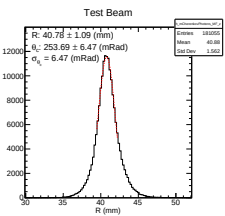
Took data with SiPM sensors as well since H13700 will not work in high magnetic field.

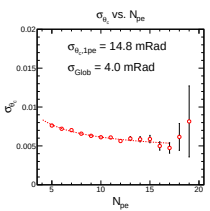






- Prelim calculation of number of photoelectrons and single photon resolution.

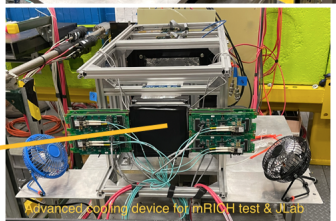




Data analysis full potential limited due to no tracking available.

3rd Beam Test Set-up at JLab

Area view of the setup



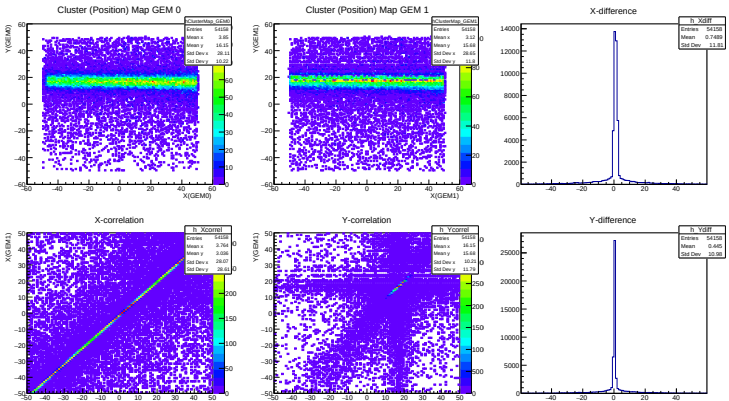
Viewed from back

GEM Trackers

3^{rd} Beam Test Data Analysis

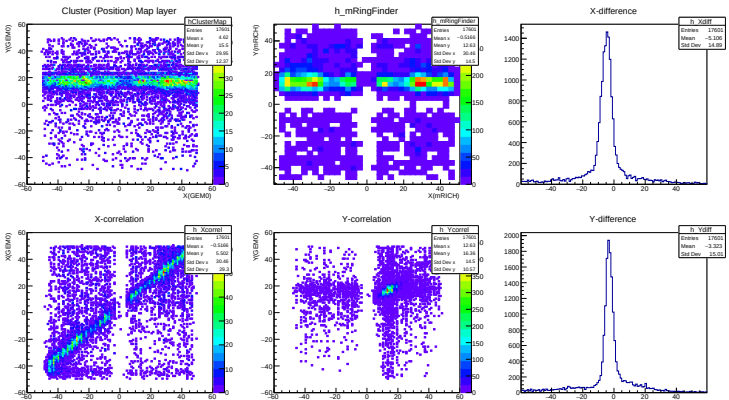
- Major goal of the beam test is to determine the single photon resolution.
- The pair spectrometer sent an electron beam (1-6 GeV/c) downstream towards the mRICH set-up.
- In the set-up we had two GEM trackers as well, analogous of a small section of EIC experiment for tracking and particle ID .
- Two GEM trackers provide the track information that is crucial to extract mRICH single photon resolution.
- Collected a good amount of data ($\sim$ 470 M triggered events).
- Softwares/Analysis codes to read GEMs and mRICH data, and generate correlations have been developed and are ready.

Beam Position Determination Using Two GEMs



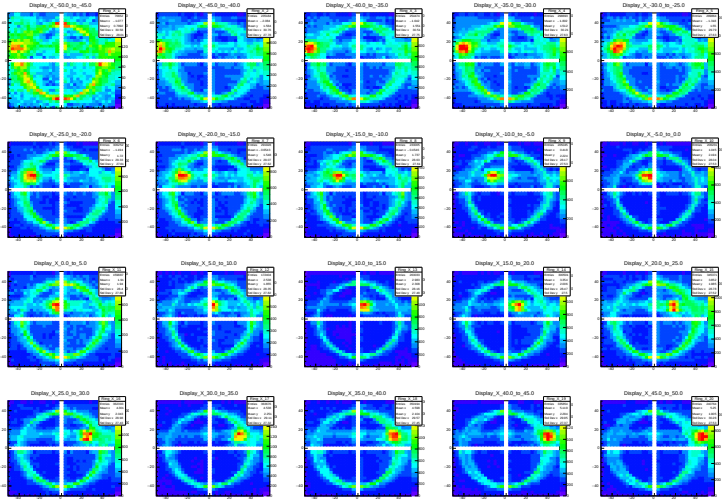
- Clear nice correlation seen between the hit positions in the two GEMs, both in X and Y directions.
- Band seem between 10 to 25 mm corresponds to the incident electron beam.

Correlation between mRICH and GEMs

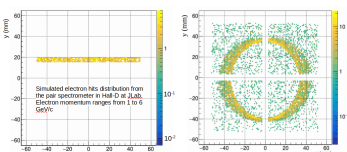


- Clear nice correlation can be seem between the electron position as seen by GEMs with that seen in mRICH determined via clustering.

Rings as a Function of Hit Position

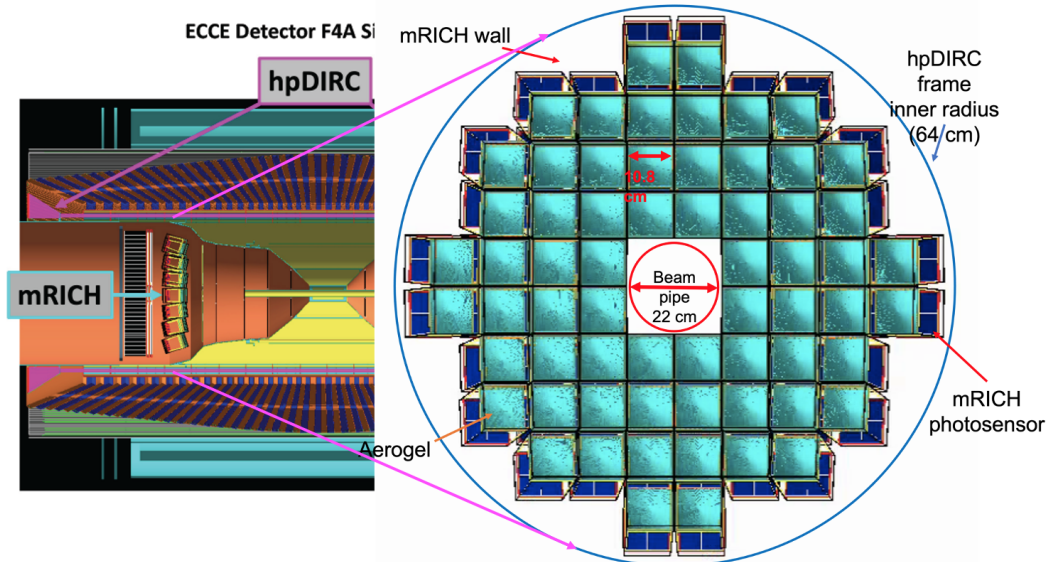


- One can see the shifts in the ring as the electron hit position moves from left to right!
- Shown below is the simulated electron beam and cumulative ring pattern!



mRICH in ECCE

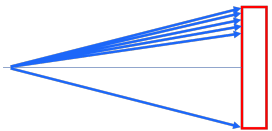
GEANT4 simulation/full implementation in Fun4All!

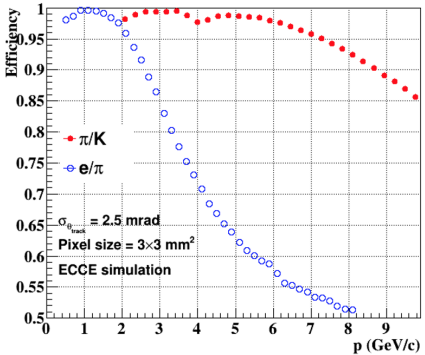


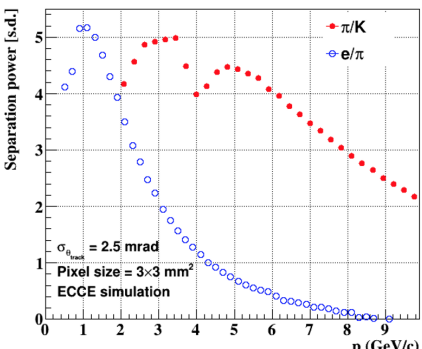
mRICH Performance

Results on e/π and K/π separation as seen in simulation in ECCE framework. Focus on extreme cases to test performance:

- Particles hitting the modules at outward angles and in the outer area of Aerogel
- Tracking resolution of 2.5 mrad at which tracking effect competes with the sensor resolution



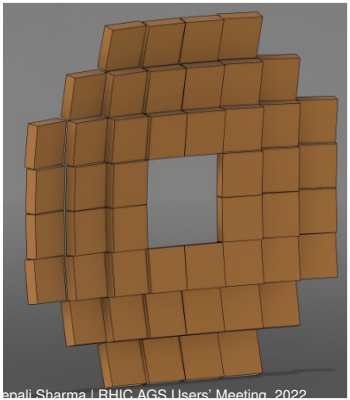


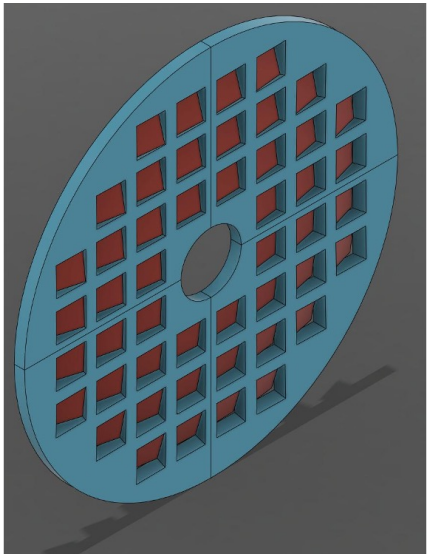


mRICH R&D: Support Frame and Design

A few experts are working on the design of mRICH support frame:

- 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 resolution, number of photons and ring radius.
- Fine tuning mRICH GEANT4 simulation to match performance from test data.
- Engineering design: optimizing detector coverage and optical components and assembly.

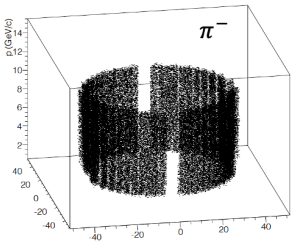
Outlook:

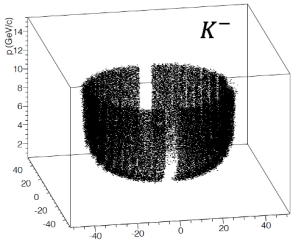
- Build new protype towards its final design for array installation.
- mRICH performance tests with the new prototype
- mRICH tests with new photosensors.

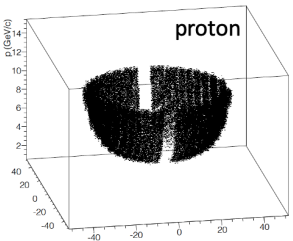
Back-Ups

mRICH Performance: Analysis Code/PID

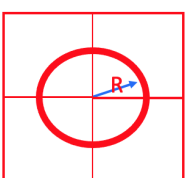
- Use Likelihood method
  - Establish a DB and match patterns based on Likelihood!

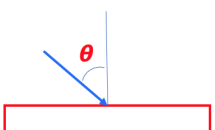






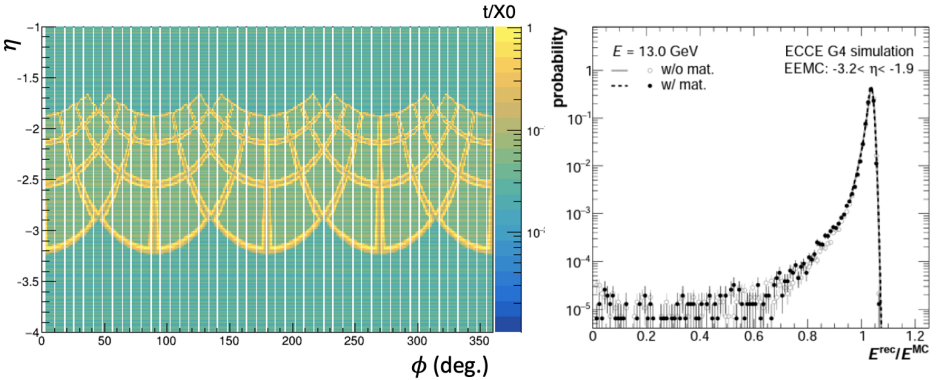
- Position resolution:
  ΔR, binned with assumption of 3 mm pixel size
- Angular resolution:
  Δ*θ*, binned with optimal angular resolution of 1.5 mrad





mRICH R&D

❖ *Material Scan*

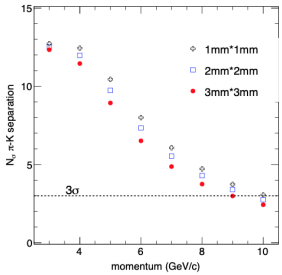


❖ *Proposed Changes*

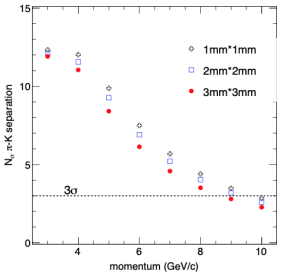
- Mirrors: 15.34 cm x 10.4 cm @ 1 mm thickness / material: G4_Al
- Frame: 10.8 cm x 20.45 cm @ 1 mm thickness / material: Carbon fiber
- Electronics & cooling are not included!

Separation Power

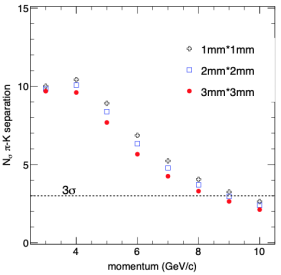
$\theta = 0°$



$\theta = 5°$

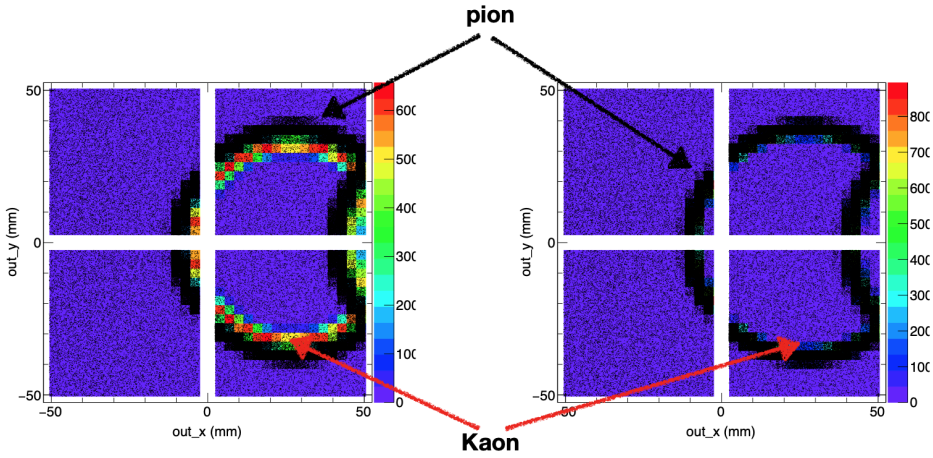


$\theta = 10°$



- **Separation power decrease with increasing polar angle**
- **3 sigma separation up to 9 GeV/c when particle launched at the center of aerogel**
- **3 sigma separation up to 8 GeV/c when particle launched at 10 degrees**
- **simulation will cover full phase space and use for future particle identification**

Database



- momentum: 3.5-4.5 GeV/c
- theta: 10°
- k/pi can be separated easily

- momentum: 9.5-10.5 GeV/c
- theta: 10°
- hard to separate K/pi