mRICH for EIC - past, present and future

Xiaochun He from Georgia State University

on behalf of the EIC PID Consortium (eRD14)

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Modular, Compact and Projective

Abstract

In this short presentation, I will briefly describe the mRICH design principle, its GEANT4 simulation and prototyping studies. A plan for future tasks will also be presented.

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- Technology used: spell out clearly any risk associated, if any

- Momentum range covered: p versus theta and Nsigma vs. p

- Robustness of the design (e.g. sensitivity to magnetic field) and has a prototype been built?

- Are the electronics considerations clear (channel count, data size, rate, background)

- Time needed to complete the R&D and available workforce

- Status of Simulation and Reconstruction

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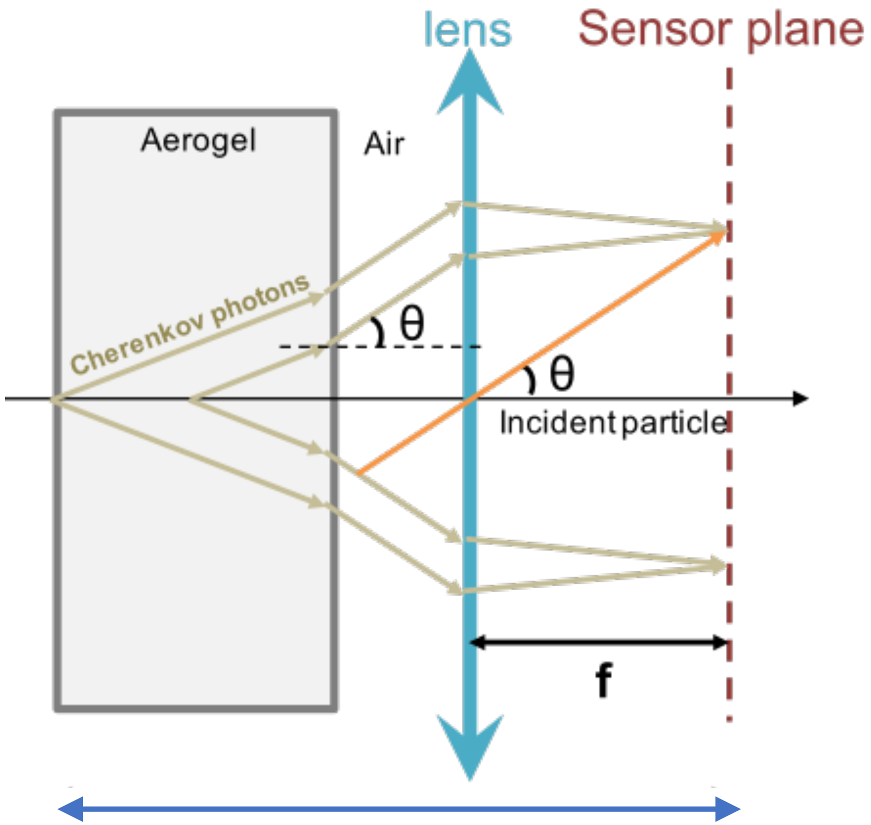
Following points will be addressed to the best of my knowledge

- Technology used: spell out clearly any risk associated, if any — **Aerogel + fresnel lens. NO tech risks!**
- Momentum range covered: p versus theta and Nsigma vs. p — **3 - 10 GeV/c k/pi, <2 GeV/c e/pi**
- Robustness of the design (e.g. sensitivity to magnetic field) and has a prototype been built? — **YES**
- Are the electronics considerations clear (channel count, data size, rate, background) — **YES**
- Time needed to complete the R&D and available workforce — **YES, mainly to quantify the performance**
- Status of Simulation and Reconstruction — **Well advanced GEANT4 simulation for the standalone mRICH**

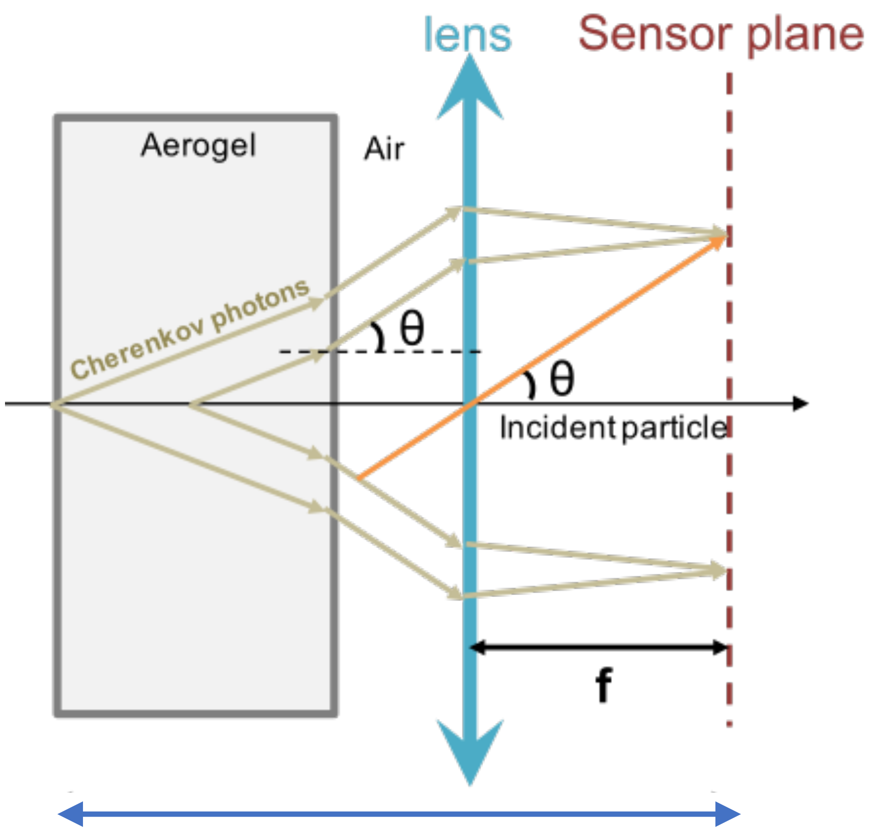
EIC mRICH – Working Principle



~ (aerogel thickness + lens focal length)

(Not to scale, for illustration purpose only)

EIC mRICH – Working Principle



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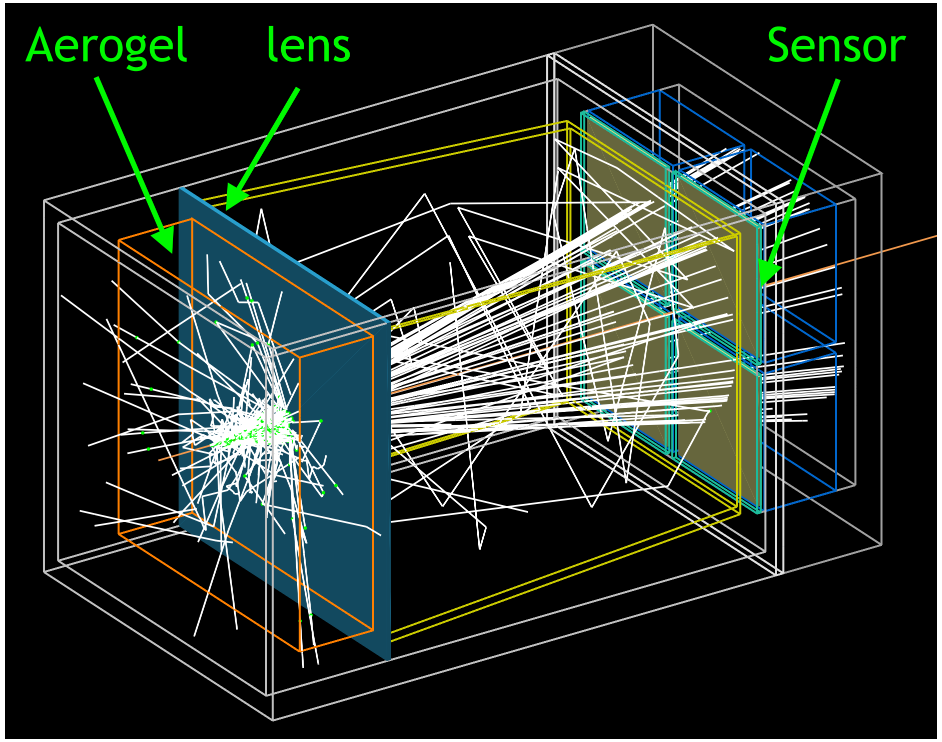
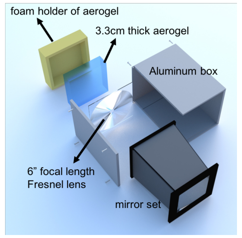


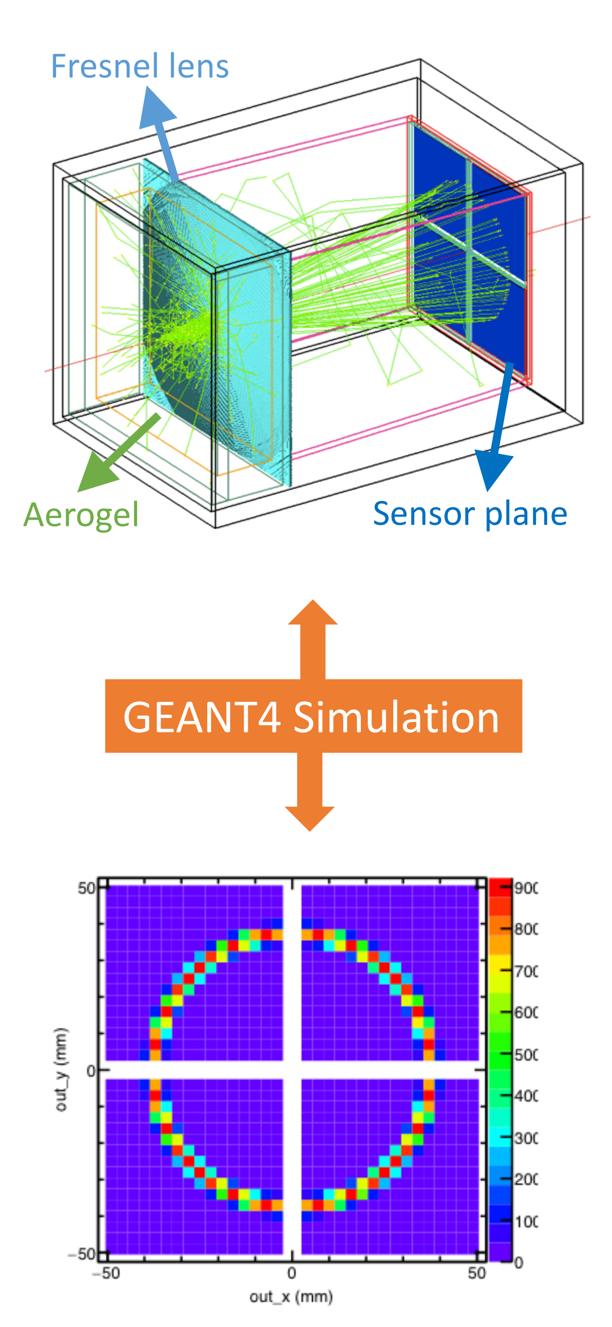
Geant4 Simulation

With realistic material optical properties

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





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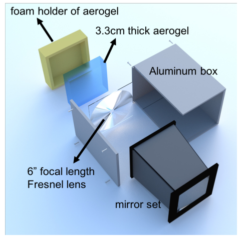
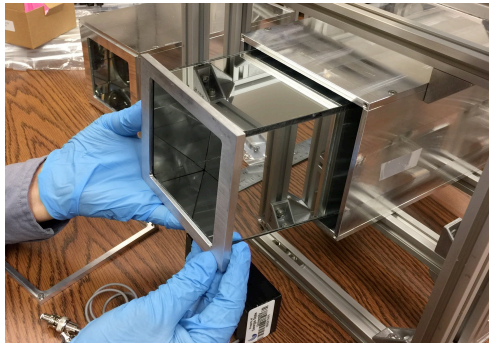
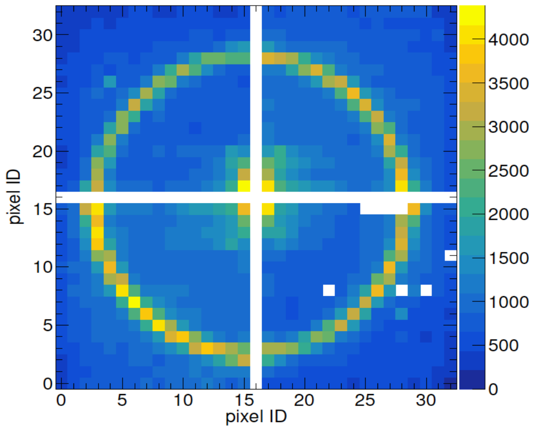


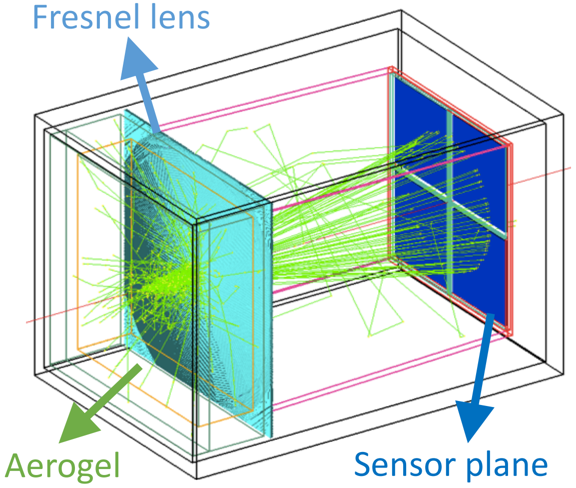
New features: a) separation of optical and electronic components; b) longer focal length (6”); c) 3mm x 3mm photosensors.



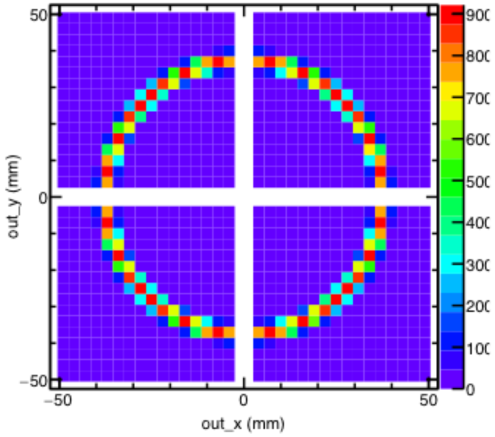
2nd mRICH prototype was tested at Fermilab Test Beam Facility in June/July 2018

Beam Test at Fermilab





GEANT4 Simulation



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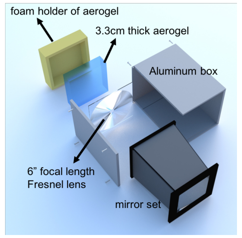
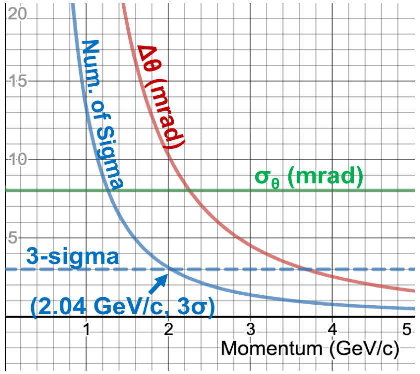
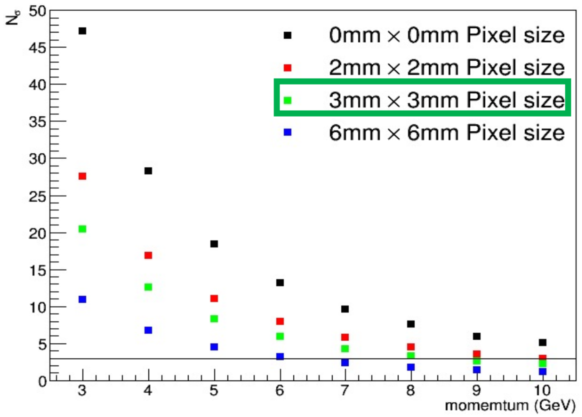




- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c



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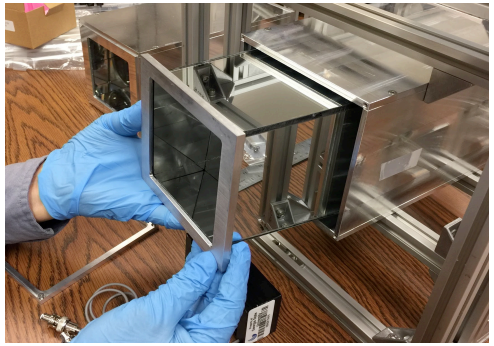

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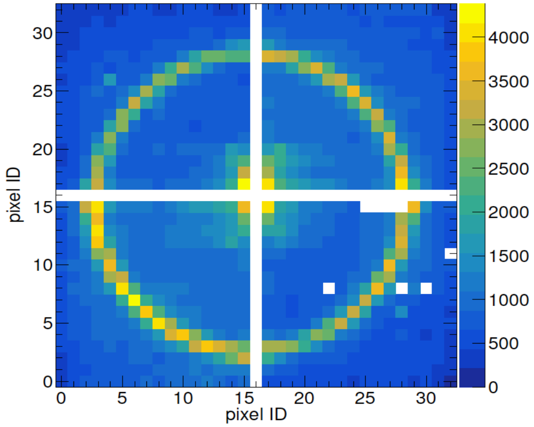
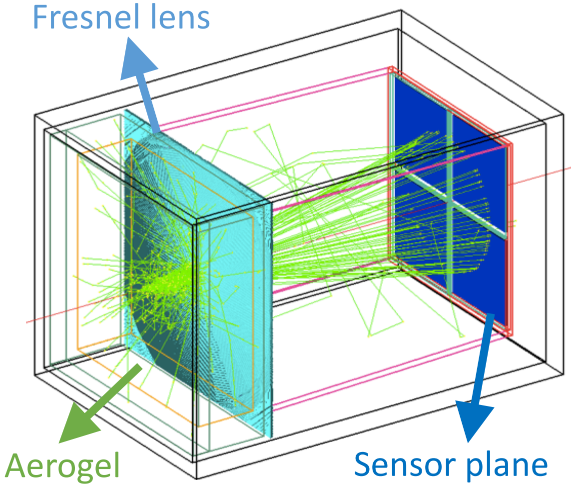
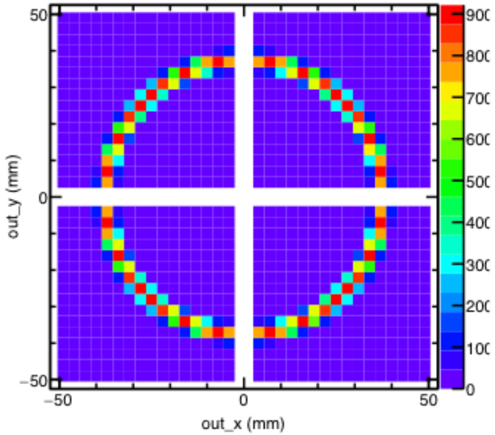




GEANT4 Simulation



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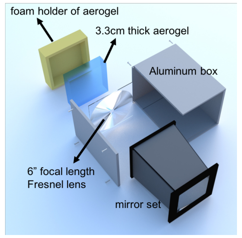

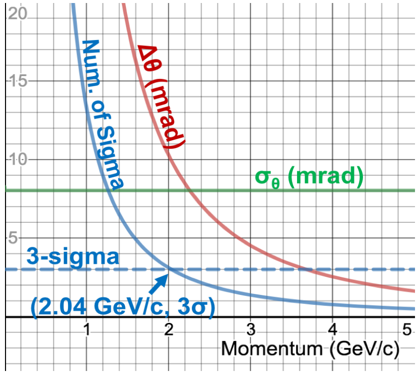

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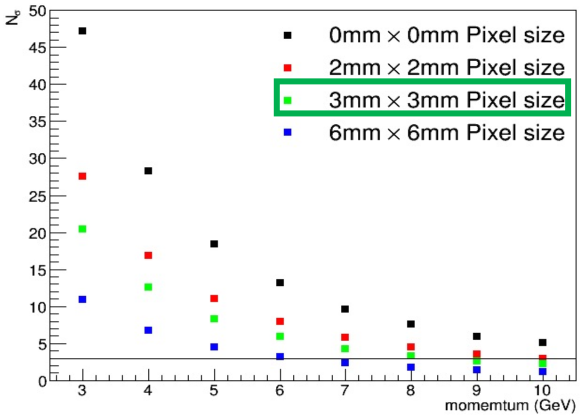

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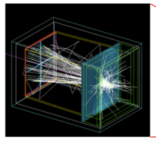
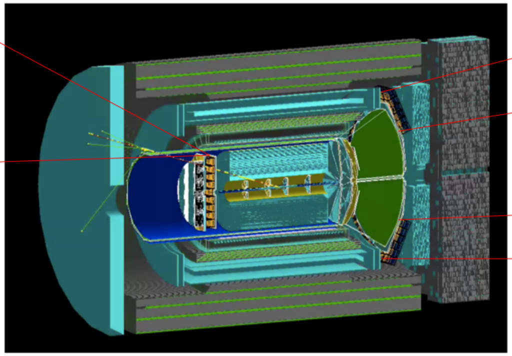
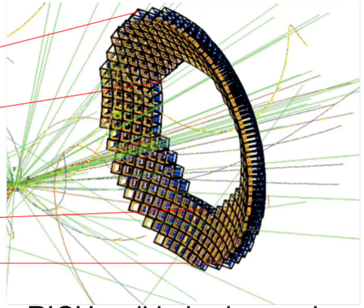


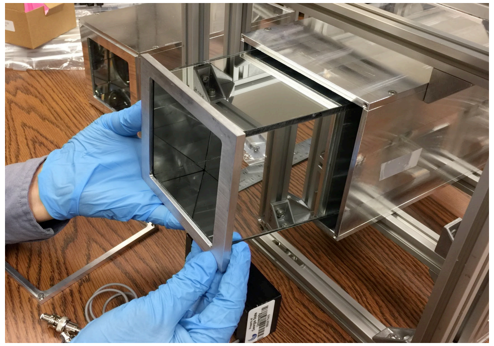


mRICH wall e/π separation



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.



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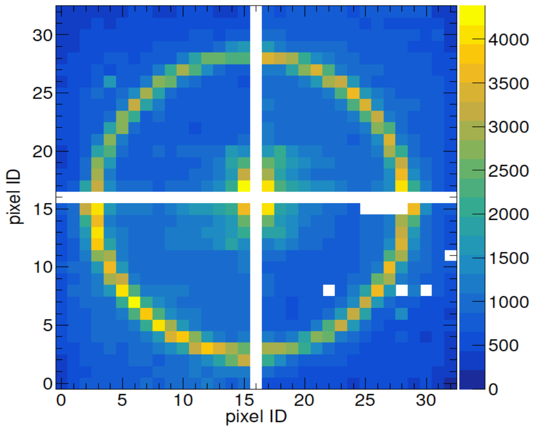
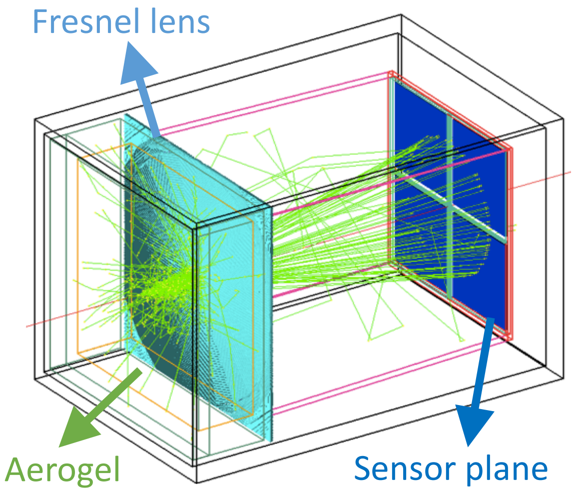
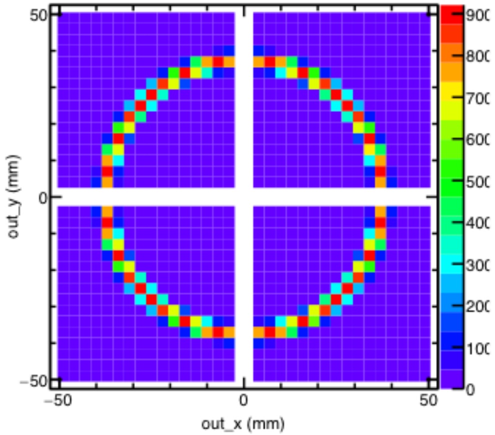




GEANT4 Simulation

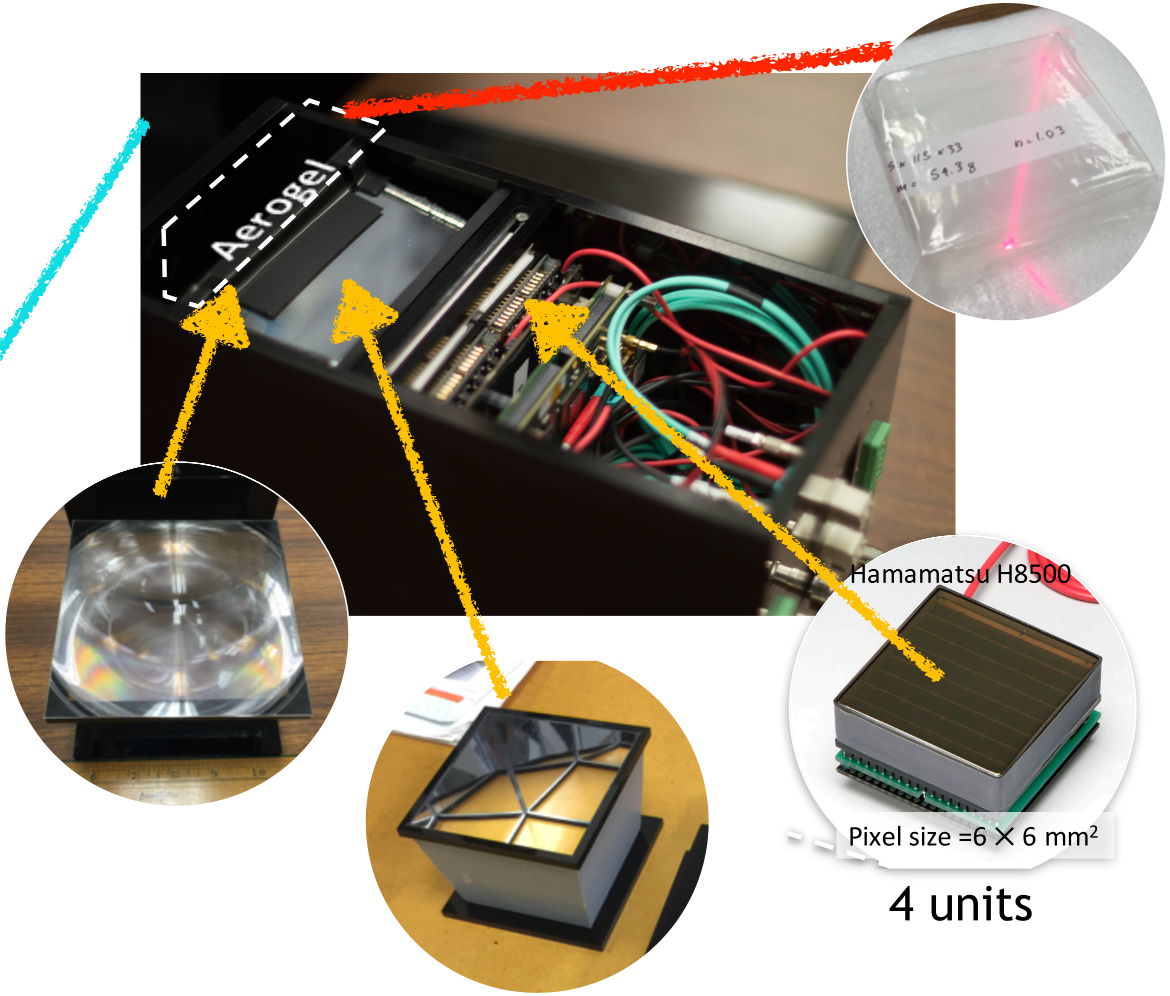


Beam Test Studies

We had two beam tests already and are preparing for a third test at Lab in early May 2020.

1st mRICH Prototype Beam Test - Proof of Working Principle

Fermilab Beam Test Facility, April 2016



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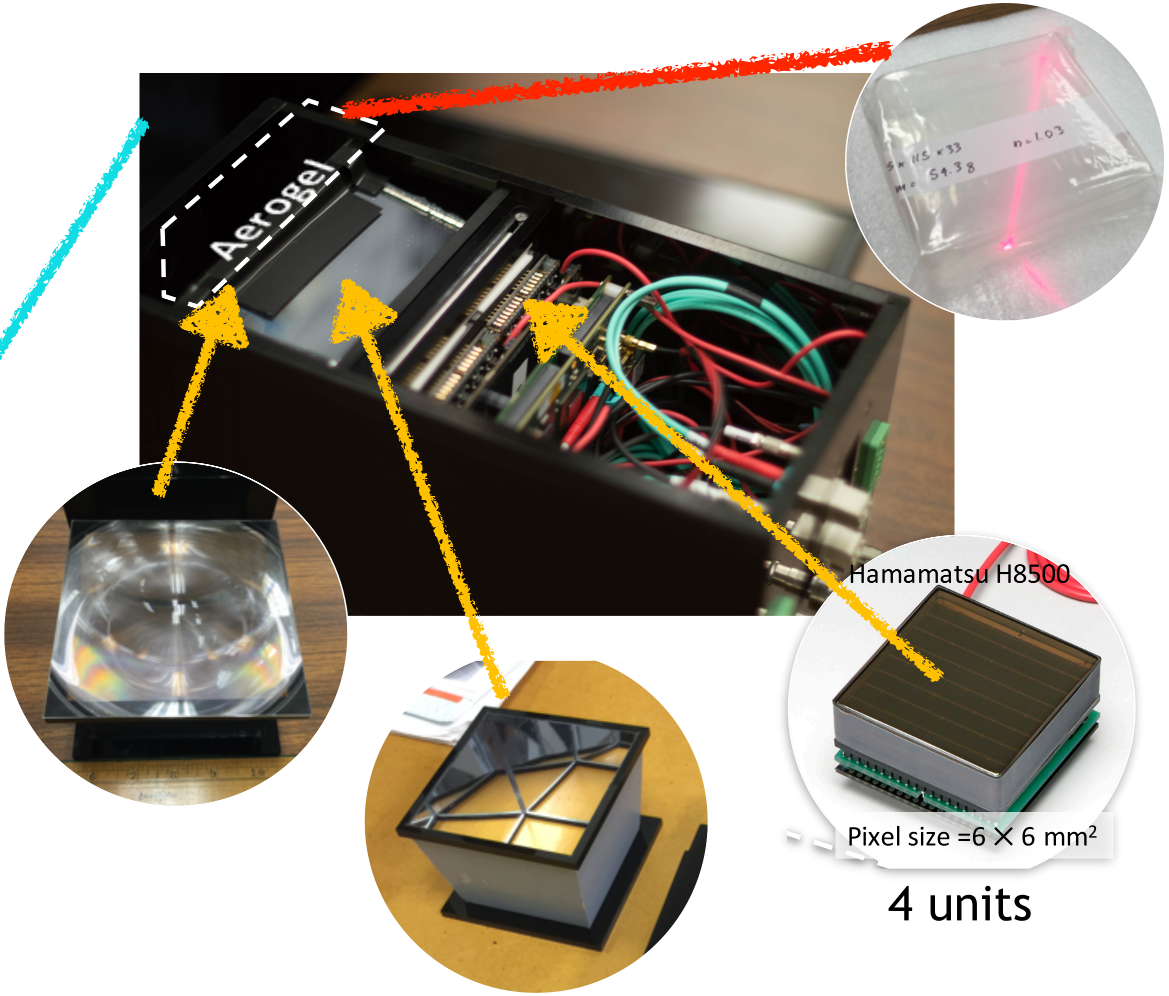
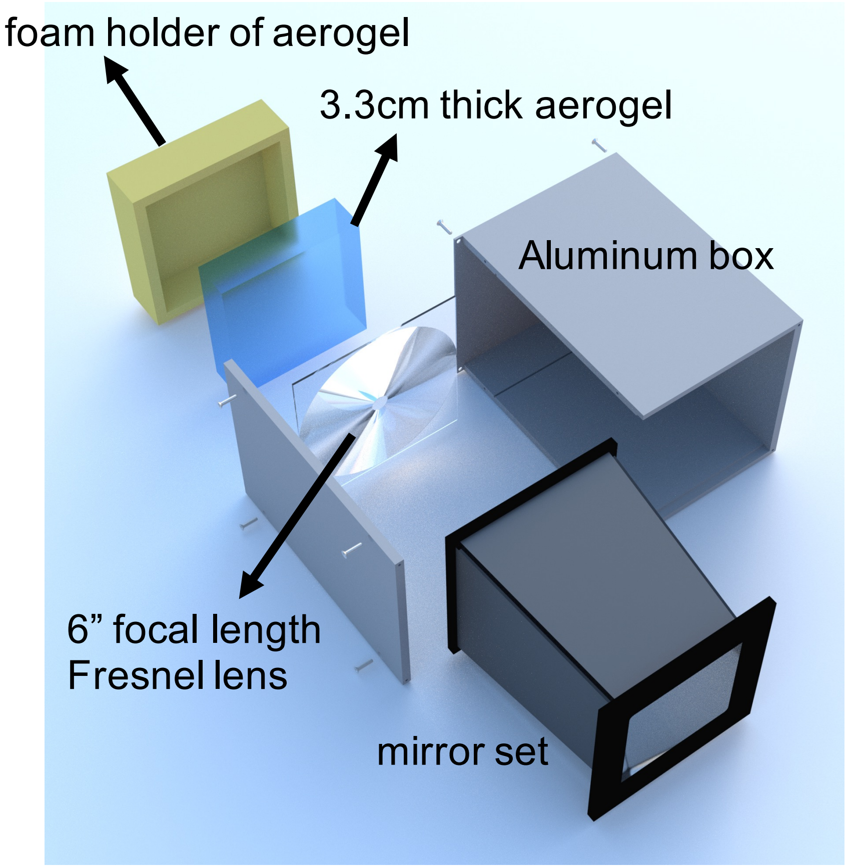
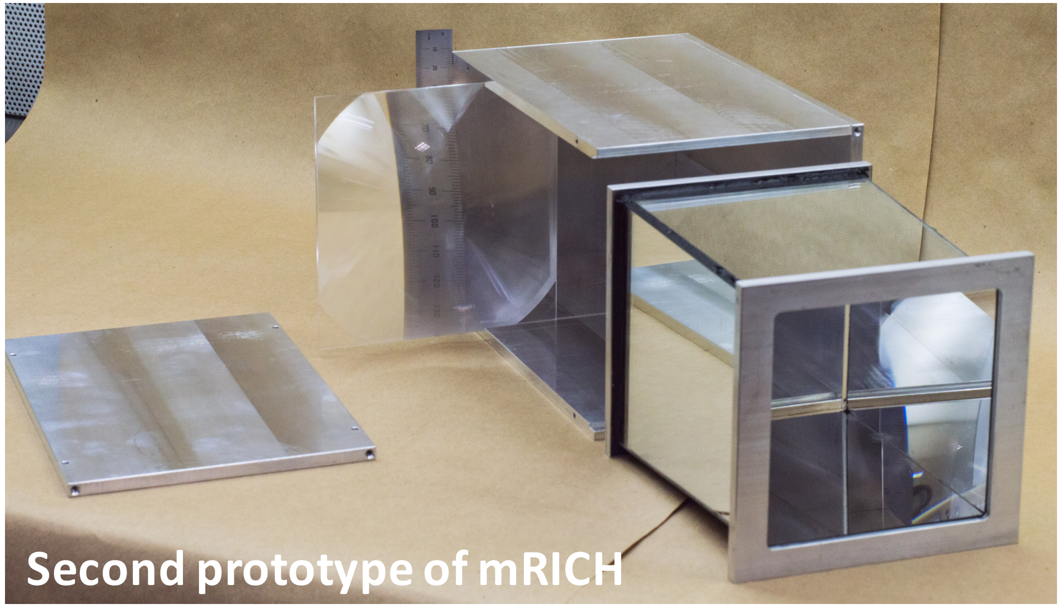


C.P. Wong et. al. NIM A871 (2017) 13-19

2nd mRICH Prototype - Improved Optical Component Design





1. Longer focal length (Fresnel lens)
2. Smaller pixel size sensors

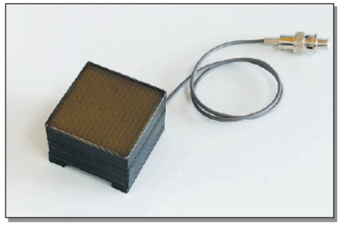
TECHNICAL INFORMATION

OCT. 2016

FLAT PANEL TYPE MULTIANODE PMT ASSEMBLY
H13700 SERIES

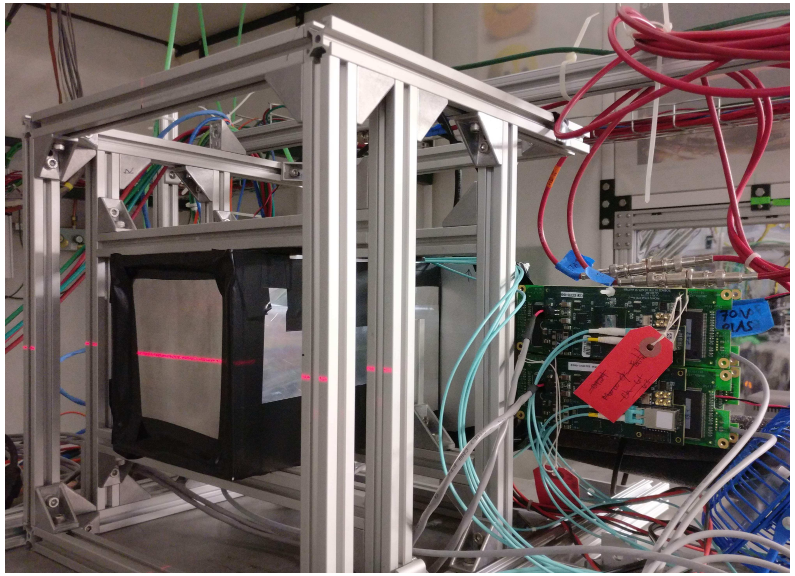
FEATURES

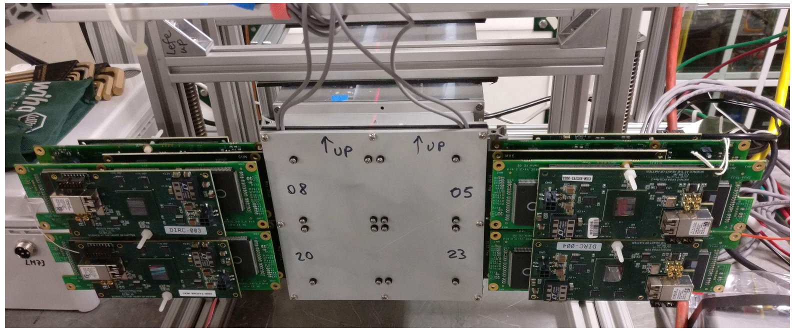
- High quantum efficiency: 33 % typ.
- High collection efficiency: 80 % typ.
- Single photon peaks detectable at every anode (pixel)
- Wide effective area: 48.5 mm × 48.5 mm
- 16 × 16 multianode, pixel size: 3 mm × 3 mm / anode



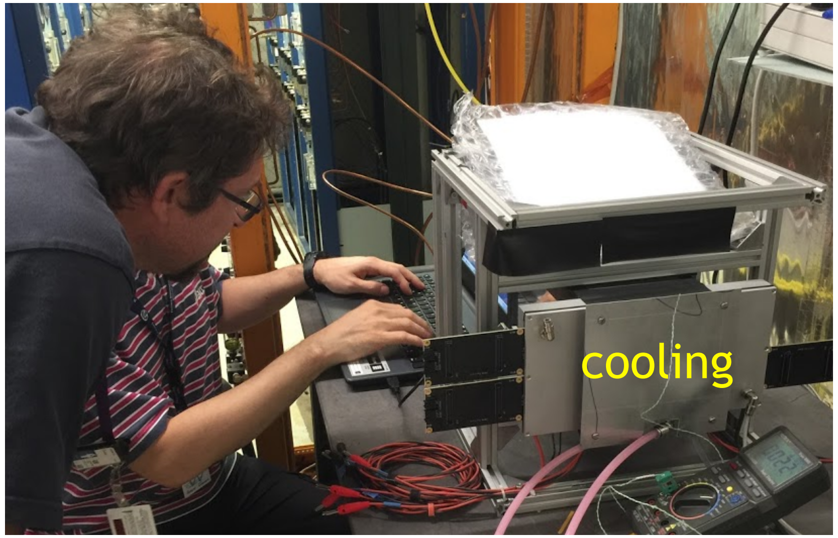
The separation of the optical and electrical components in the improved mRICH design allows us to test different photosensors

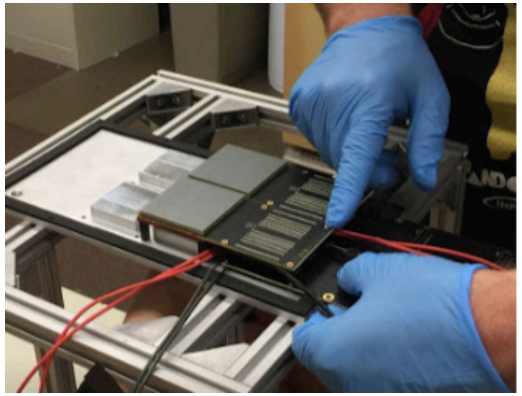
Using four H13700 Multi-anode PMTs

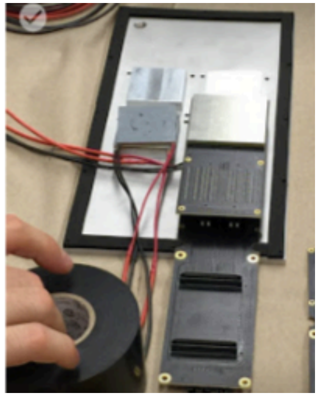




Using three Hamamatsu SiPM Matrices







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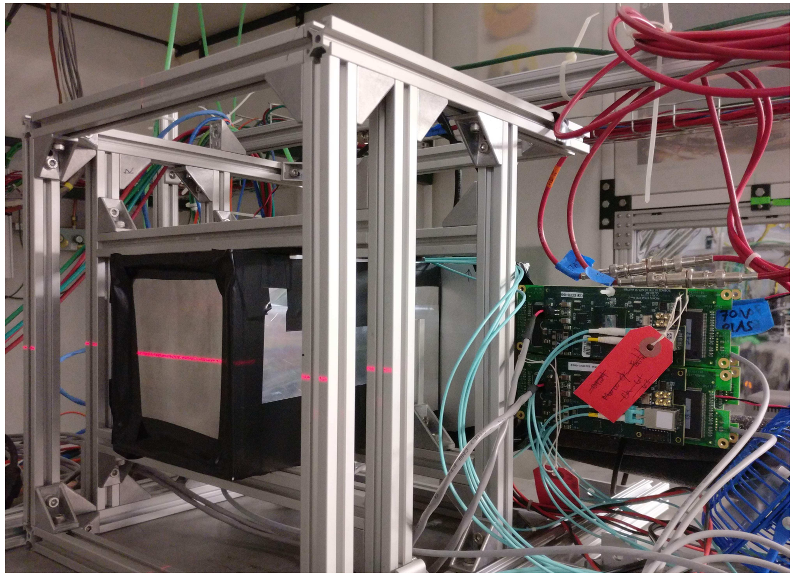
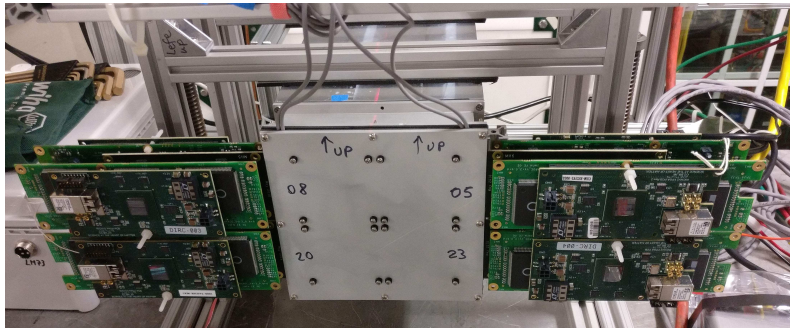
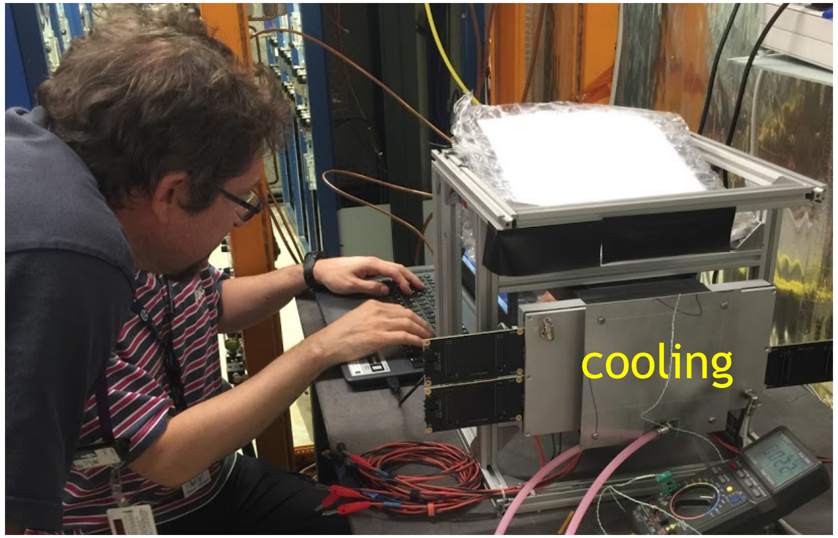


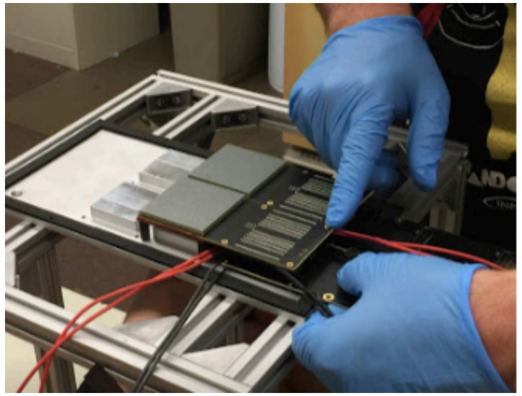


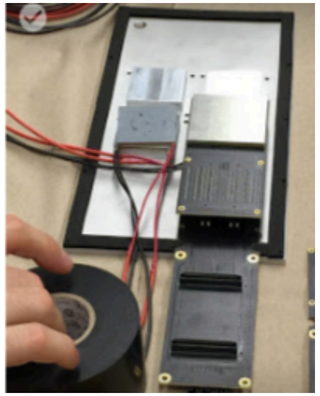
To achieve the required PID separation power, the pixel size of photosensors should be 3mm x 3mm or smaller.

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



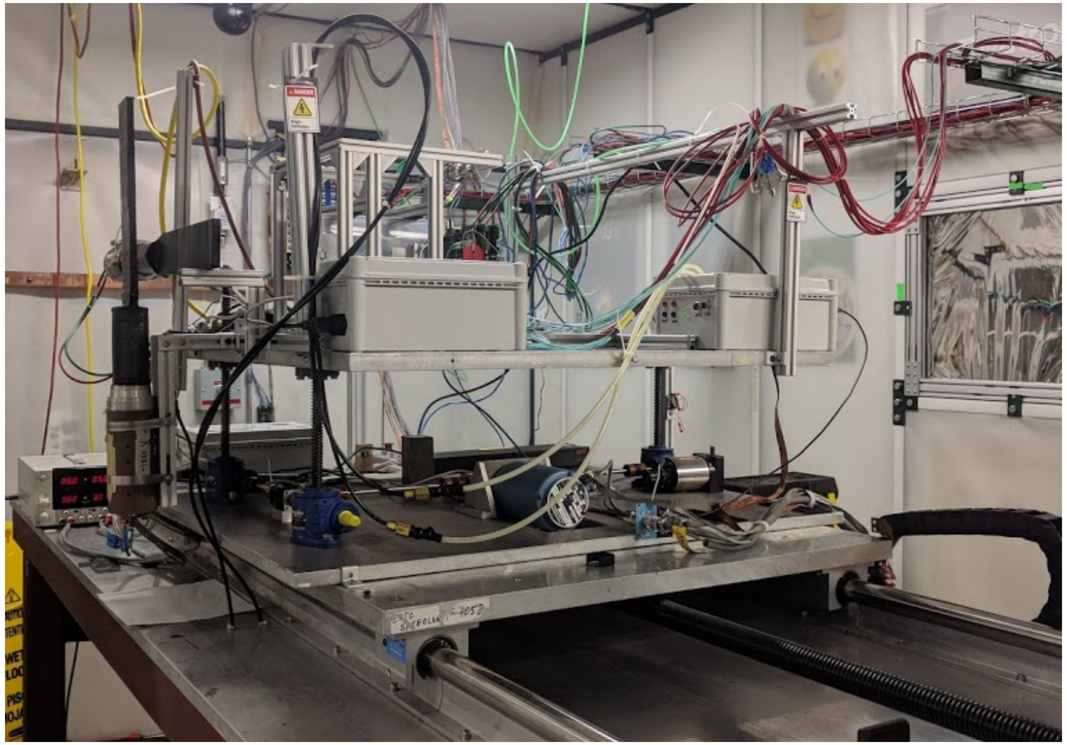




2nd mRICH Beam Test - Verify the PID Capability

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

120 GeV/c proton



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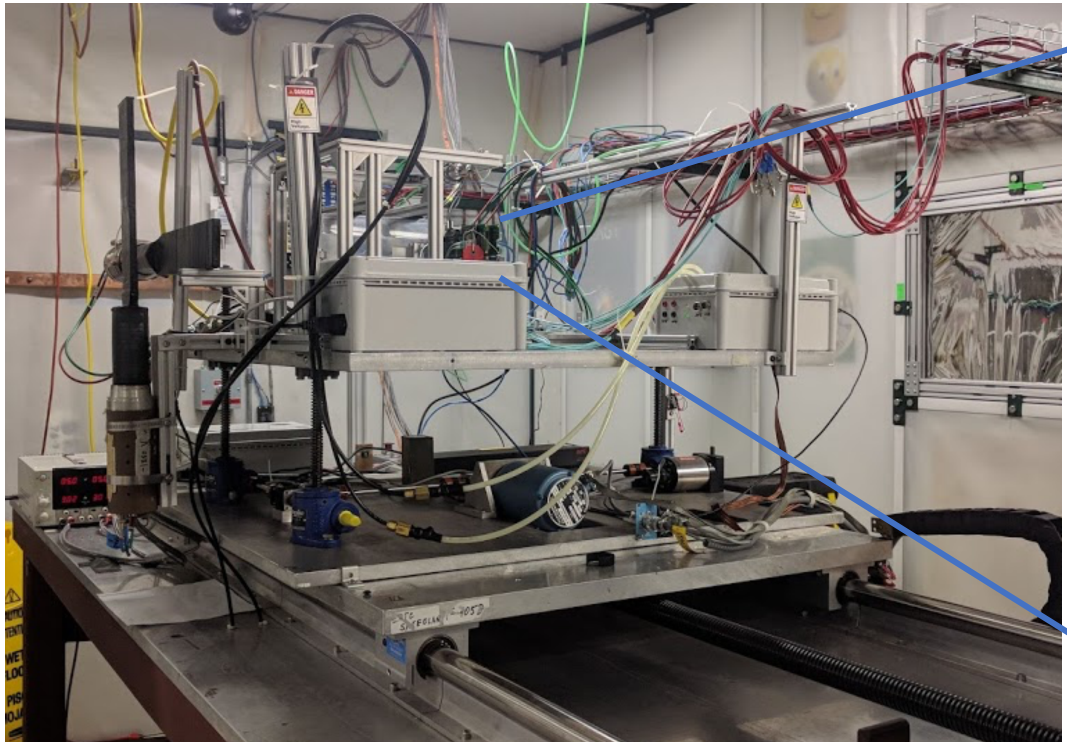

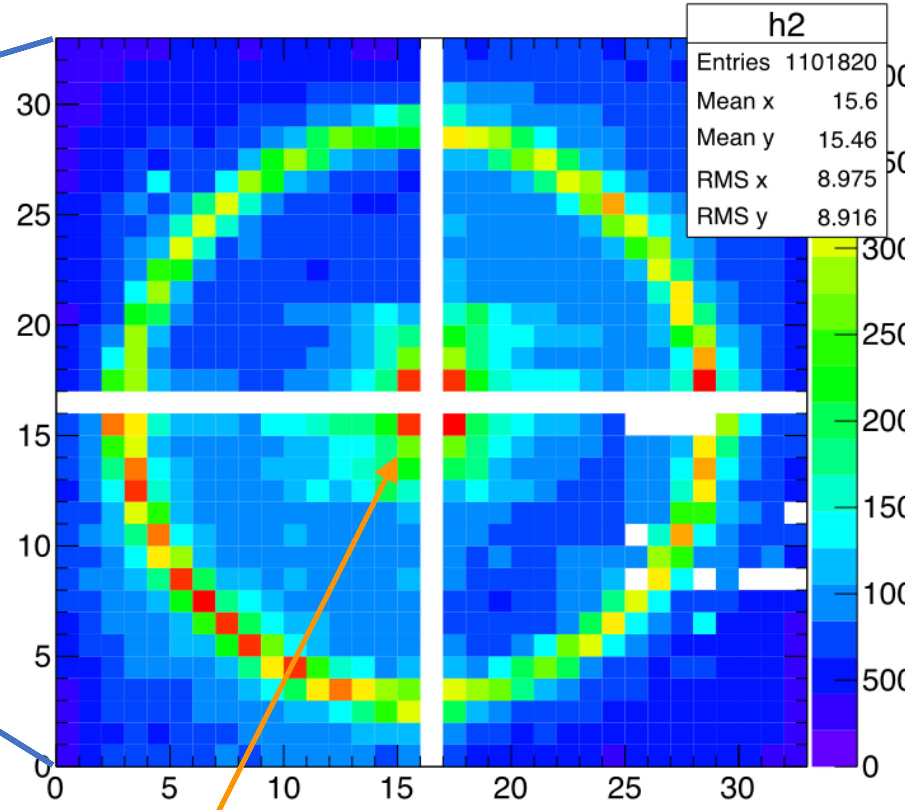

Beam spot

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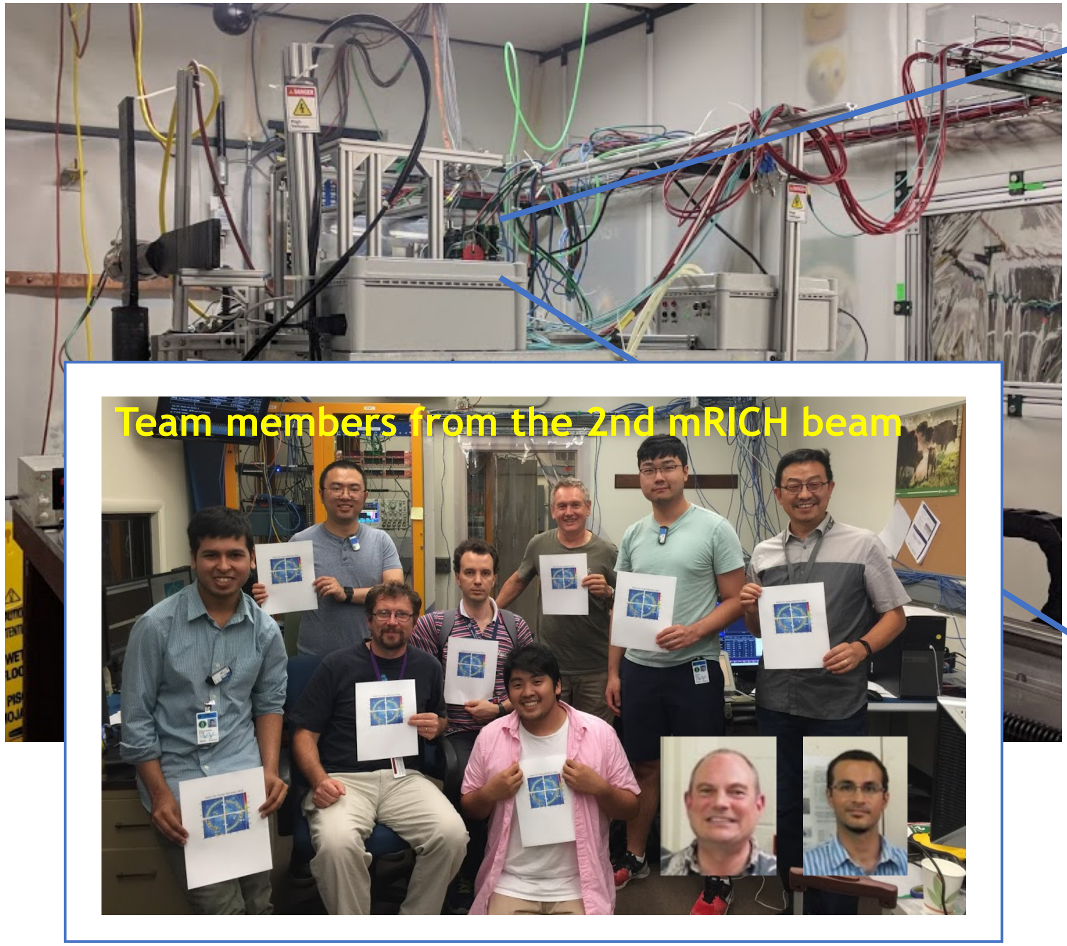
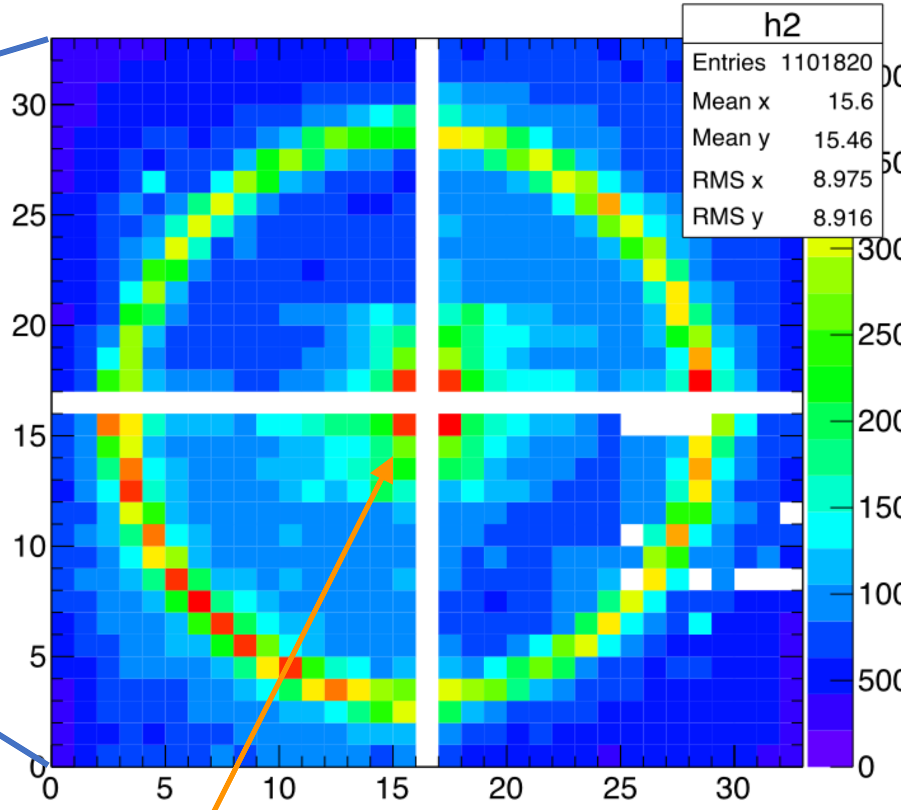
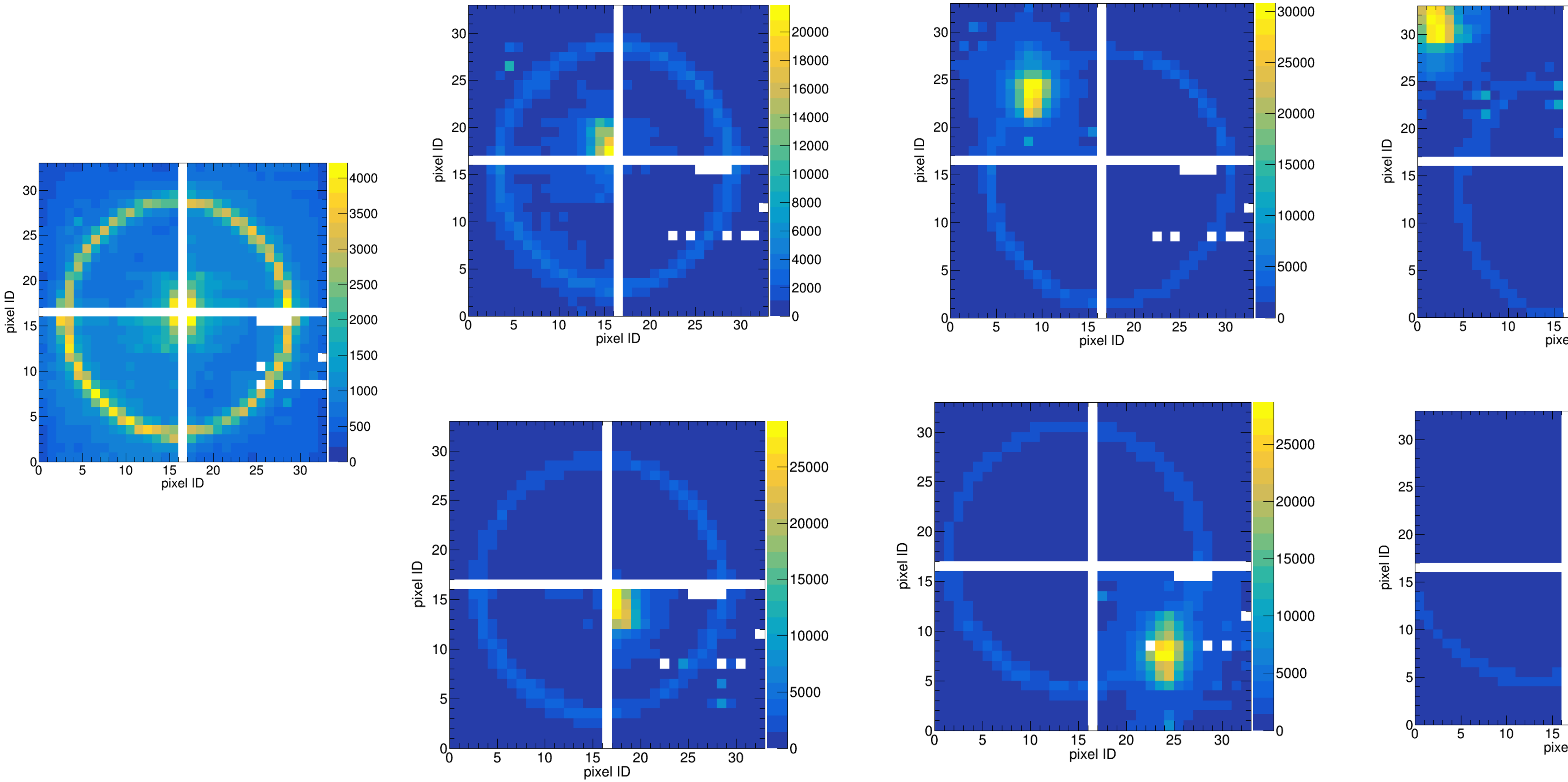




Beam spot

Position scans with 120 GeV/c proton beam



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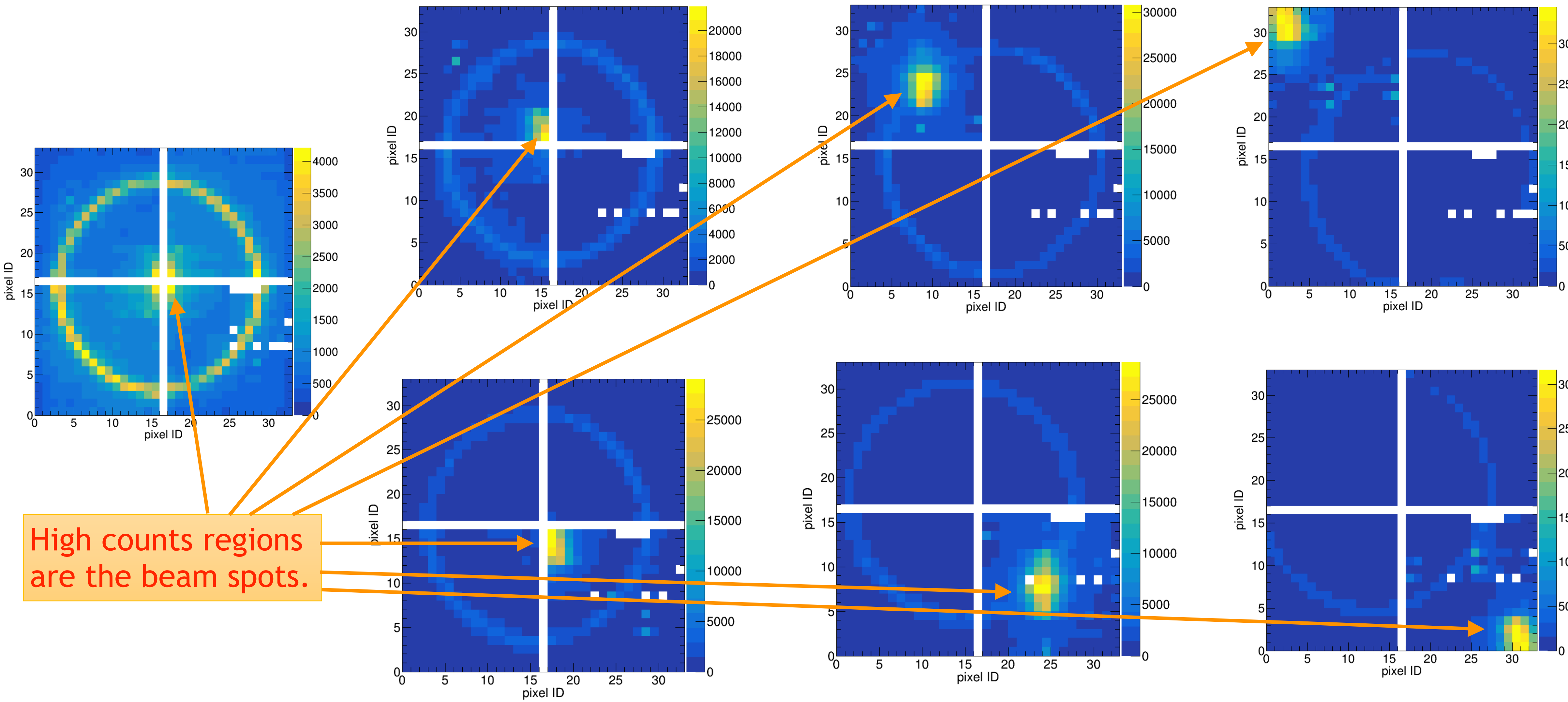
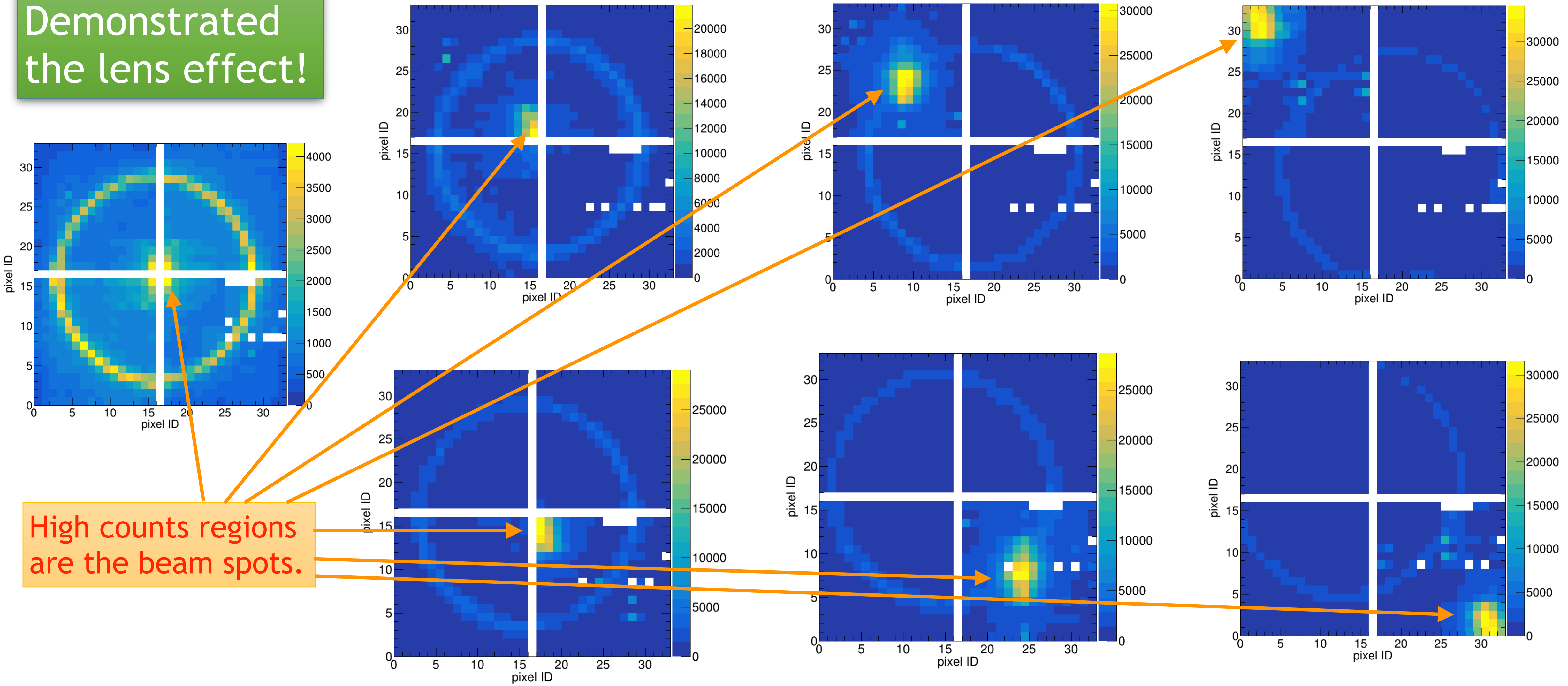


Position scans with 120 GeV/c proton beam

Demonstrated the lens effect!



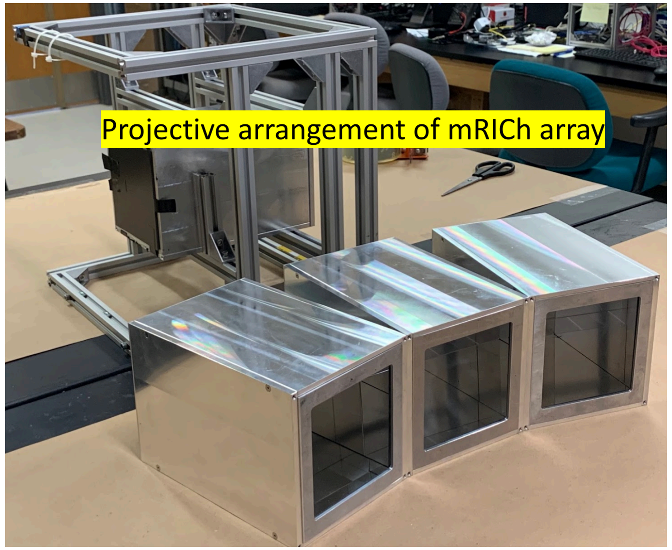
High counts regions are the beam spots.

Outlook

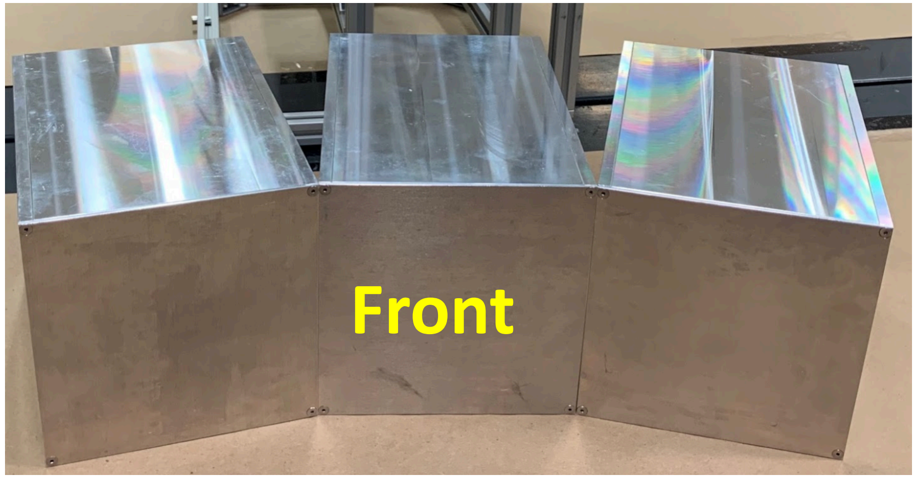
Construct more mRICH modules for performance test

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

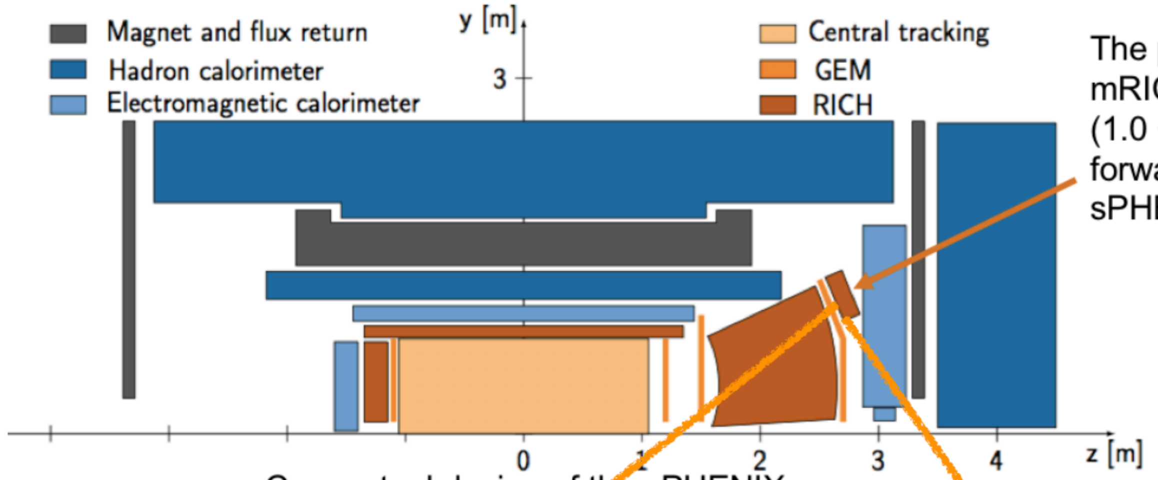


- Preparing for a beam test at Jefferson Lab in early May of 2020 using secondary electrons.
- Plan to have another beam test at Fermilab once a tracking system is identified.
- Starting on mechanical design optimization.



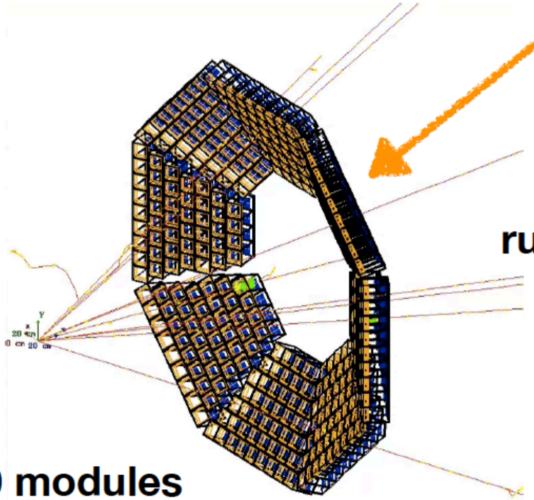
- Modular
- Compact
- Projective

mRICH modules in sPHENIX



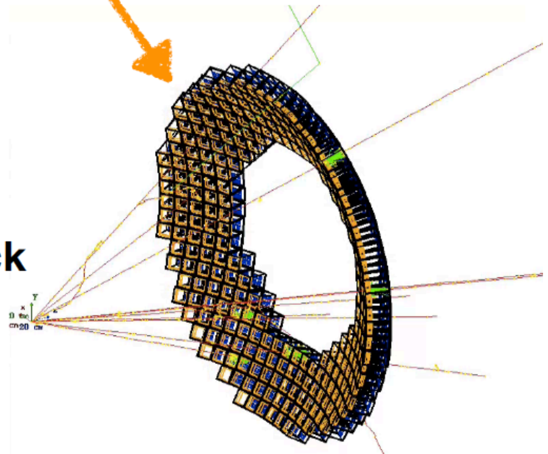
Conceptual design of the sPHENIX

The proposed mRICH coverage (1.0 < y < 2.0) in the forward region of sPHENIX.

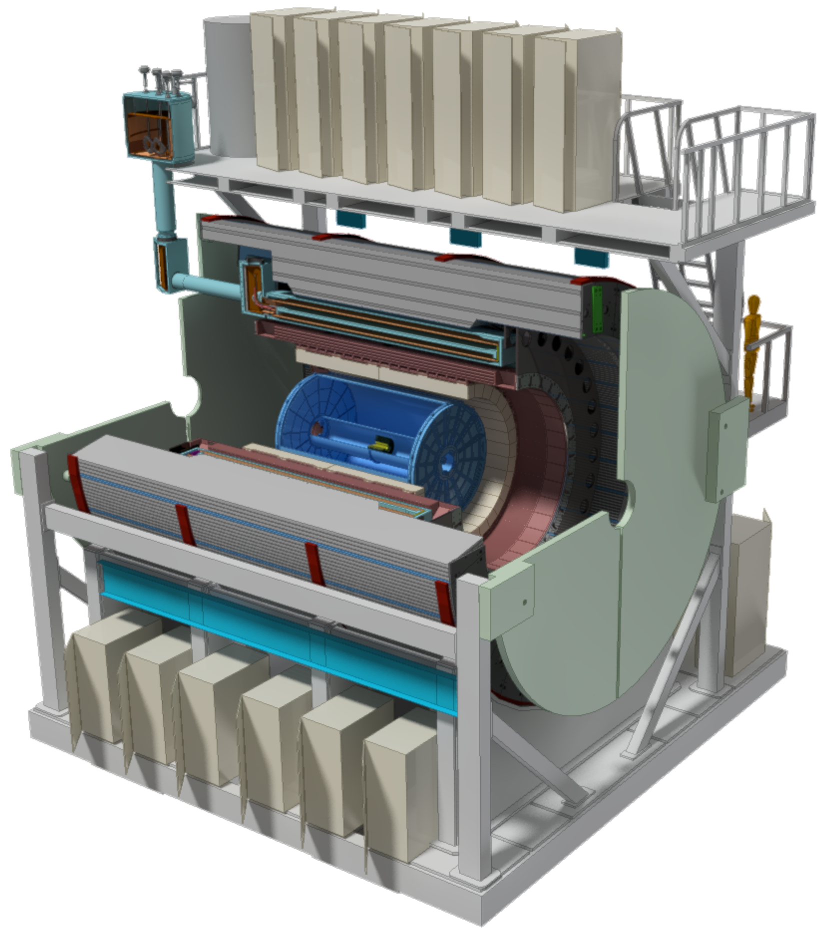


340 modules

running overlap check



284 modules



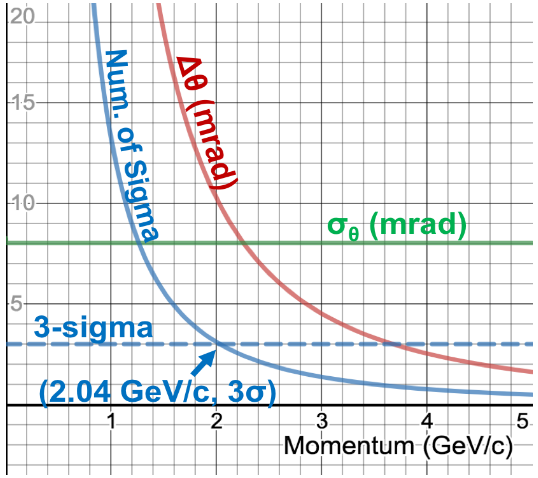
sPHENIX

mRICH PID Parameterization

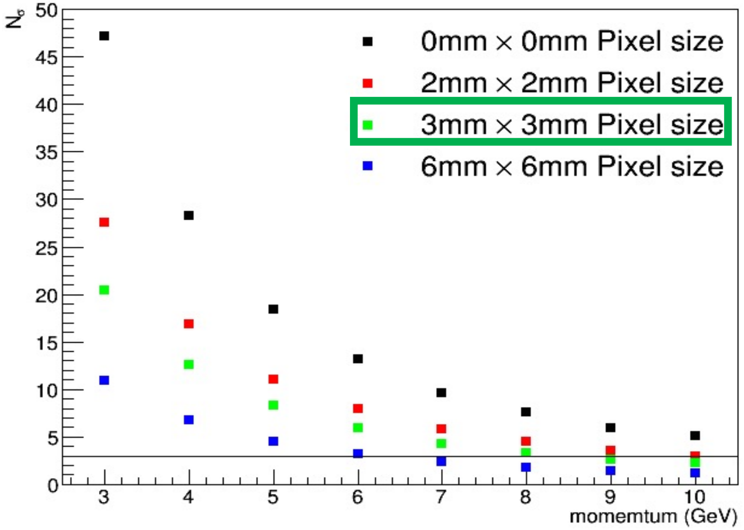
- We are very close to implement the pid performance (see the plots on right) parameterization following Tom Hemmic's virtual PID base class: <mRICH.h>

```
#ifndef __MRICH_H__
#define __MRICH_H__

// History
// Created on 3/15/2020 by Xiaochun He at Georgia State University
// for the EIC Yellow Report

// Wrapper class for mRICH (fast PID for the EIC mRICH)
//

#include "PID.h"
#include "mRICHPidFast.cxx"

class mRICH: public PID
{
public:
  mRICH(double trackResolution=0.5, double timePrecision=1.0, double pLow=3.0, double pHigh=10.0);
  virtual ~mRICH() {}

  bool   valid    (TVector3 p) {return (p.Mag() > pLow && p.Mag() < pHigh);}
  double numSigma(TVector3 p, PID::type PID);
  double maxP     (double numSigma, PID::type PID);
  double minP     (double numSigma, PID::type PID) {return 3.0;}
  string name     () {return myName;}
  void   description ();

protected:
  std::string myName;

  mRICHPidFast pid;
  mRICHPidInfo info;

  double fTrackResolution; // resolution of the traker [mrad]
  double fTimePrecision;   // time precision of the MCP-PMT [ns]
  double pLow;
  double pHigh;
  double fSensorQMefficiency;  // photon sensor quantum efficiency
  int mRICH_ID;     //
};
```

mRICH Performance based on GEANT4 simulation



- 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

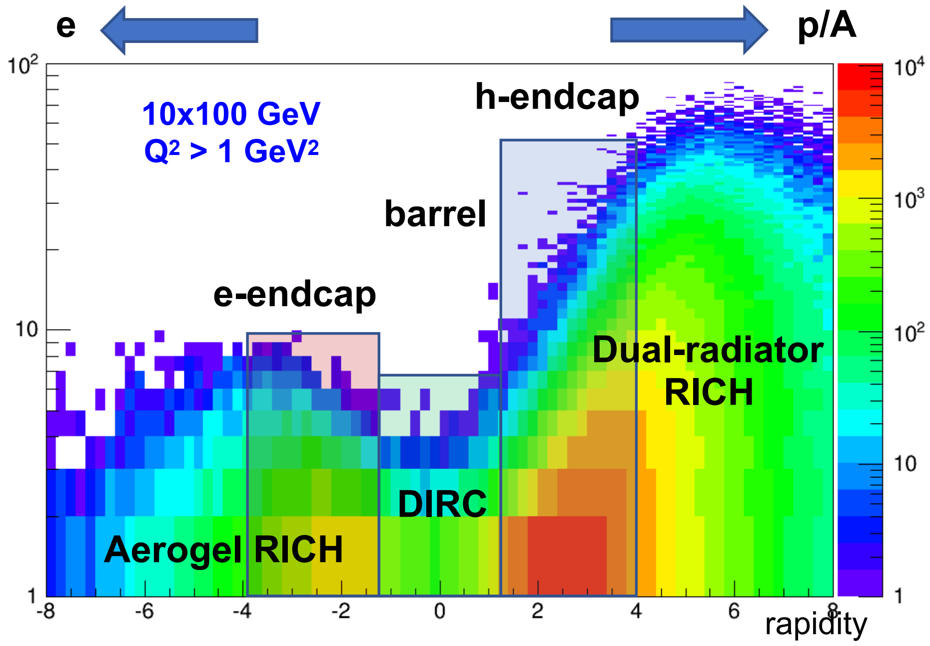
Summary

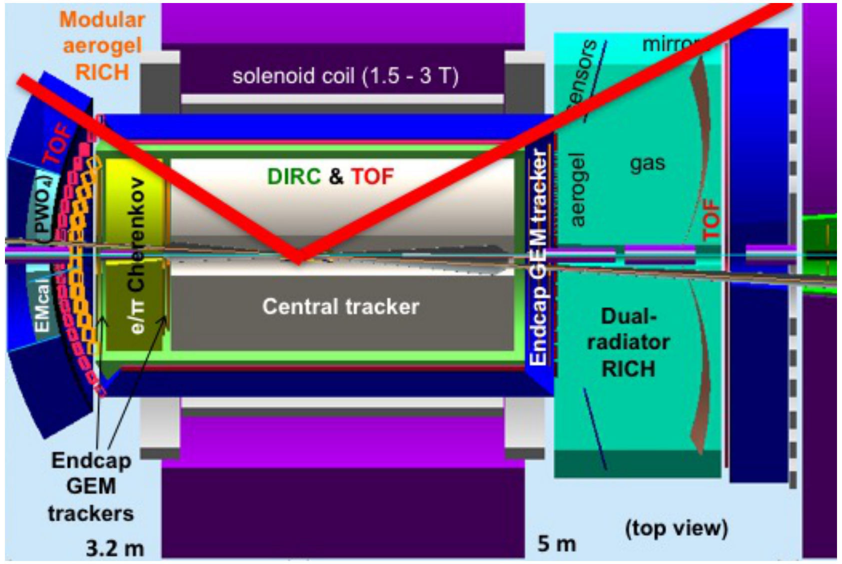
- First of all, I would like to take this opportunity to thank the members of the EIC Detector R&D Committee for their continued support of the eRD14 PID Consortium on developing RICH-based PID detector technologies.
- Two successful beam tests of the mRICH prototypes demonstrated the mRICH working principles and validated the realistic implementation of mRICH in GEANT4 simulation.
- Further beam tests are needed in order to quantify the PID performance with improved detector design (including feasible photosensors and readout) and tracking capability.
- A array of mRICH modules have been implemented in the simulation framework of the sPHENIX experiment.

THANKS!

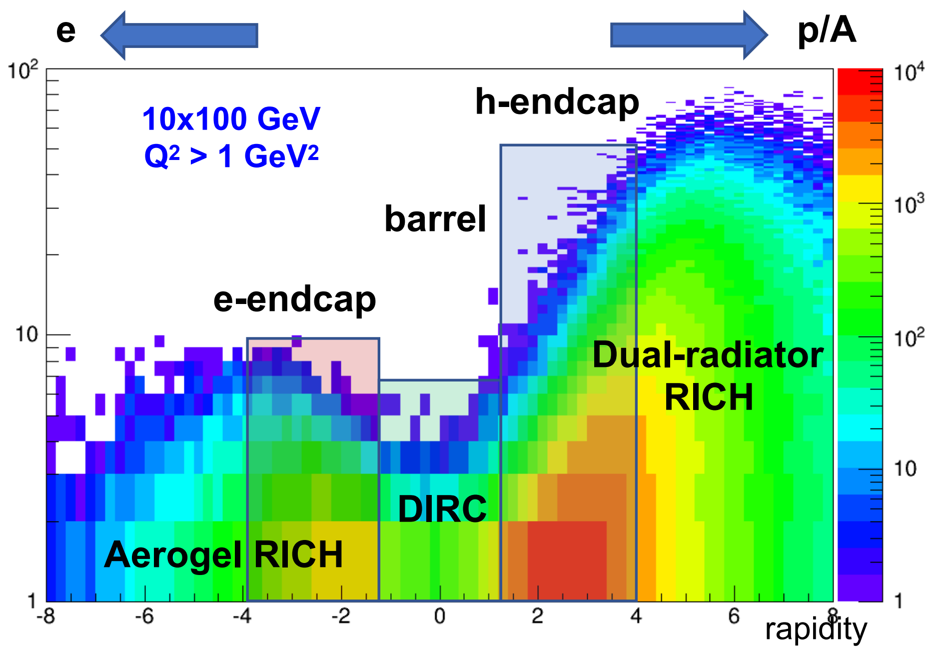
Backup slides

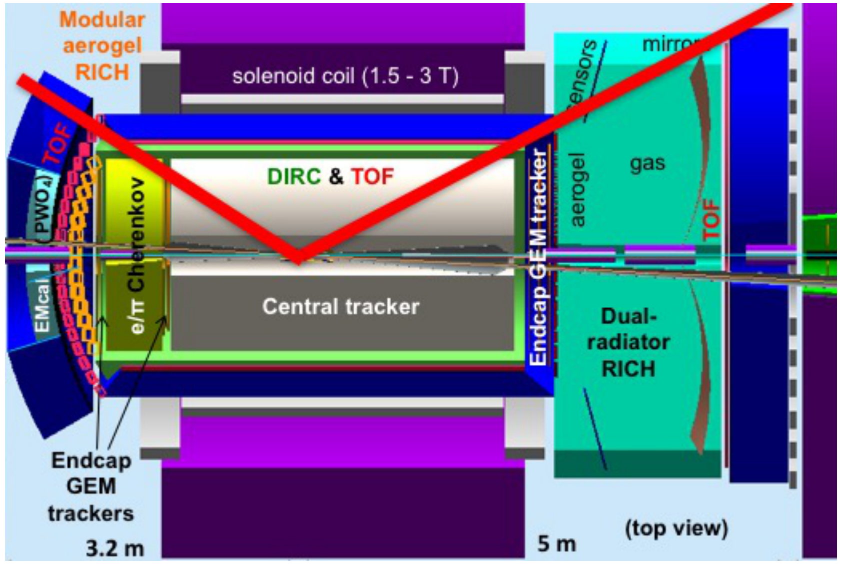
PID Needs RICH Detectors





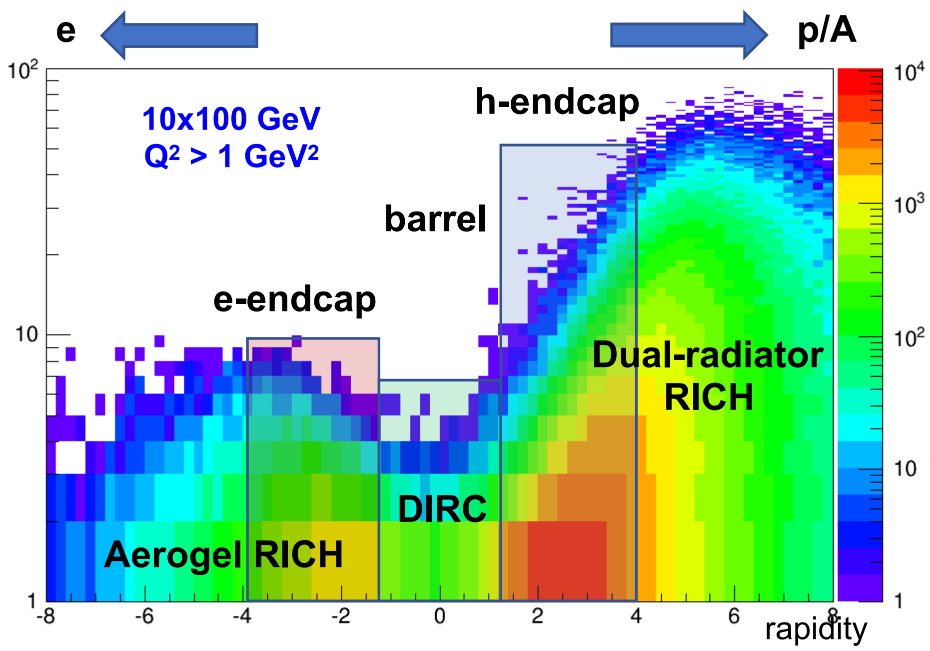
PID Needs RICH Detectors

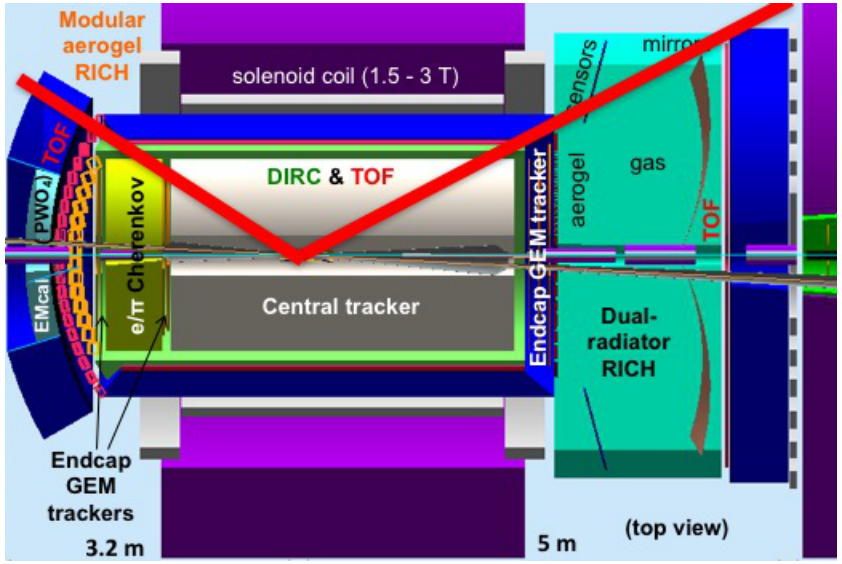




- **h-endcap**: A RICH with two radiators (gas + aerogel) is needed for
  π/K separation up to ~50 GeV/c
- **e-endcap**: A compact modular aerogel RICH (**mRICH**) which can be projective *π/K* ***separation up to ~10 GeV/c***
- **barrel**: A high-performance DIRC provides a compact and cost-effective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

PID Needs RICH Detectors





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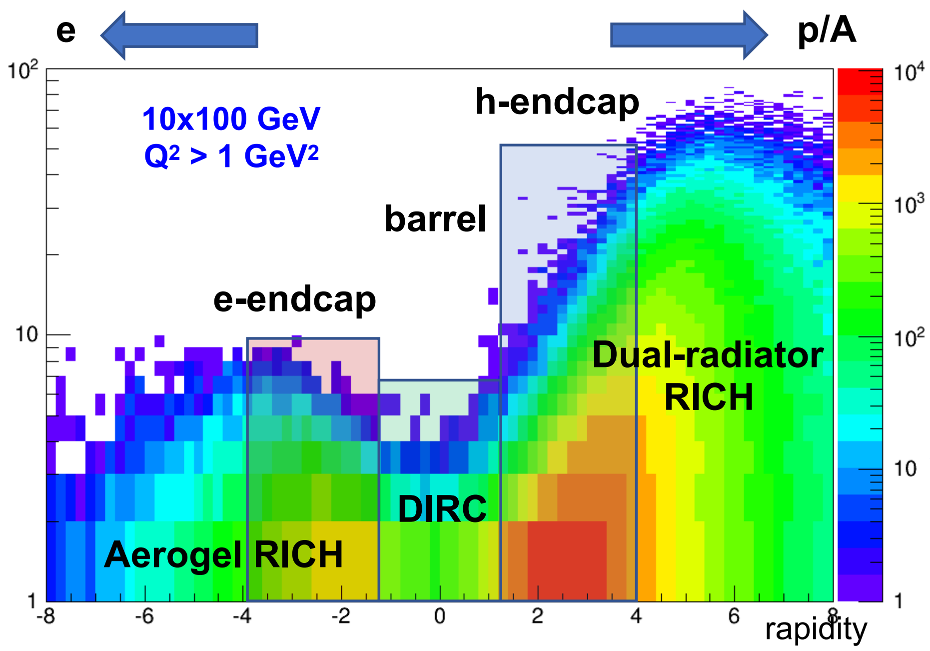

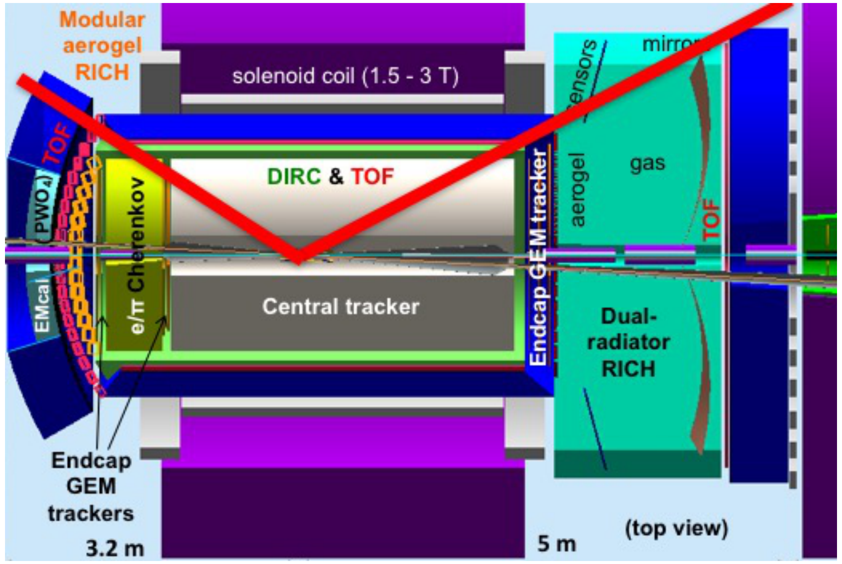

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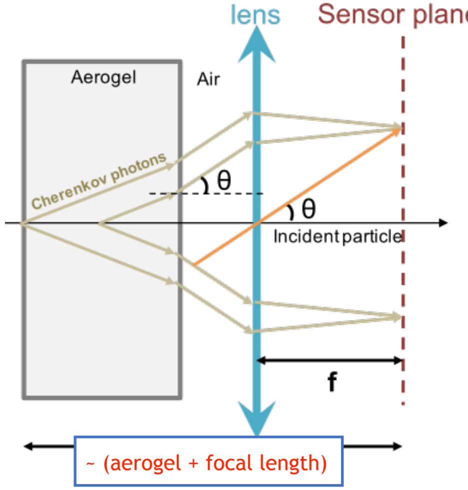
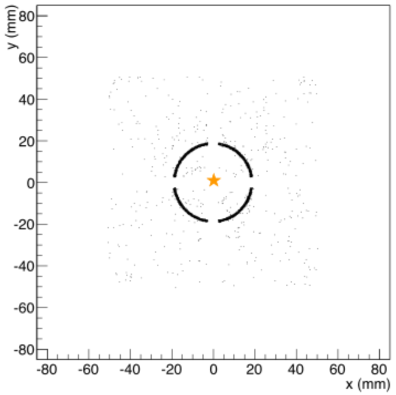
mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

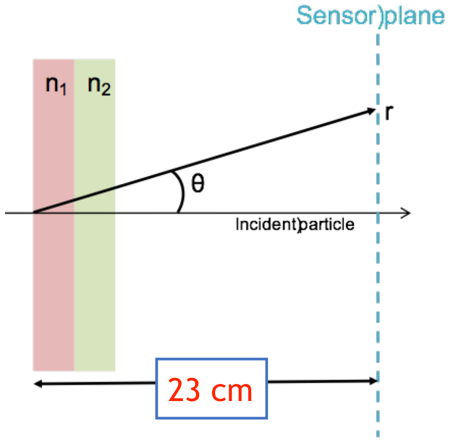


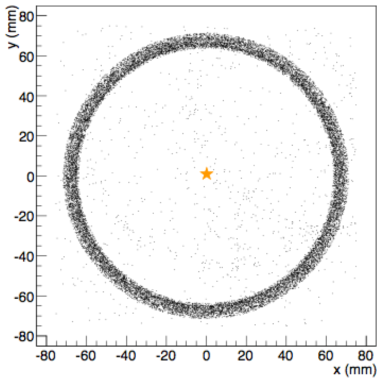


- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner ring image**

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

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



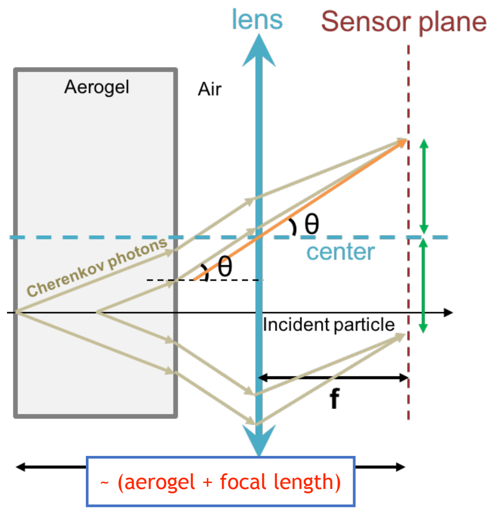


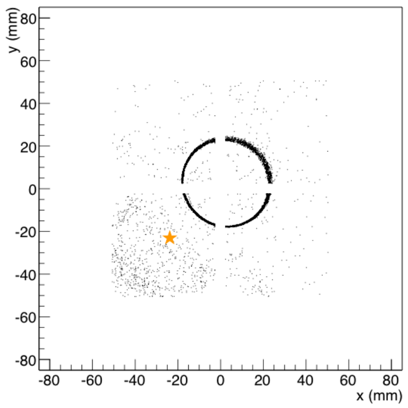
- EIC mRICH designed for K/pi ID up to 9 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

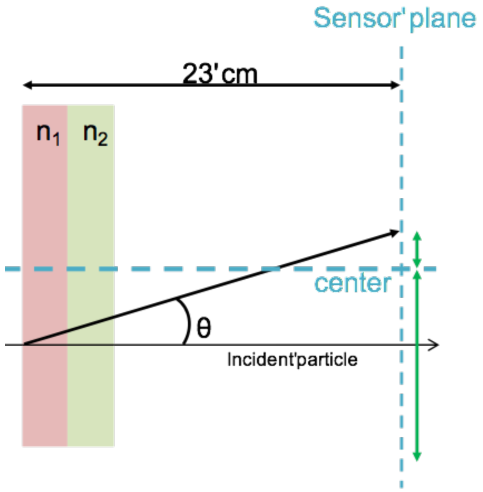
Lens-Based mRICH Design

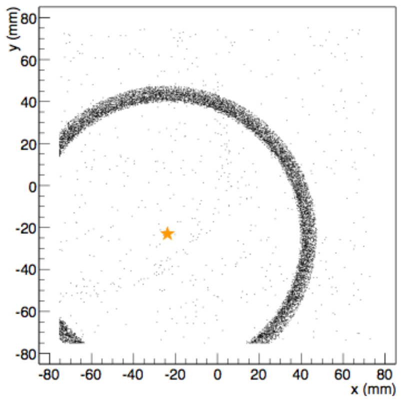




- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring image is **shifted toward the central region** on the sensor plane

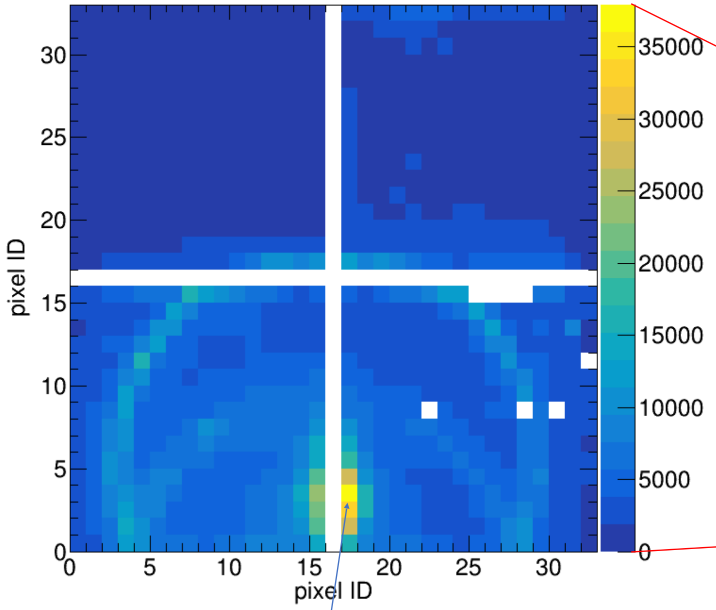
Two-Layer Proximity Focusing Design (BELLE-2 ARICH)



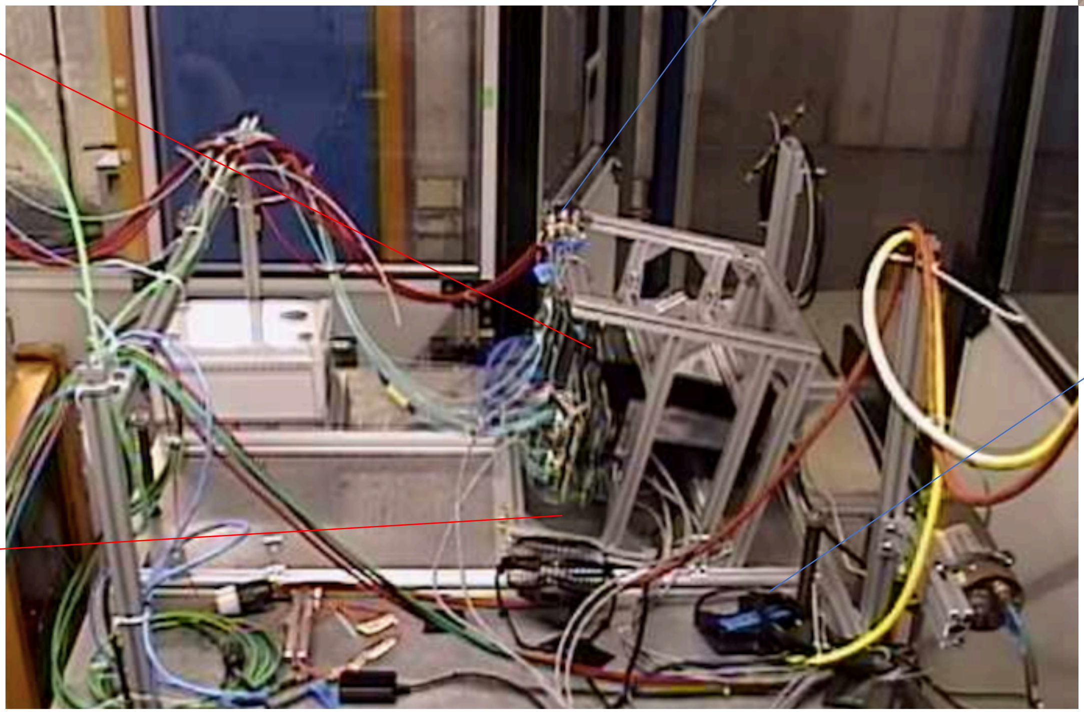


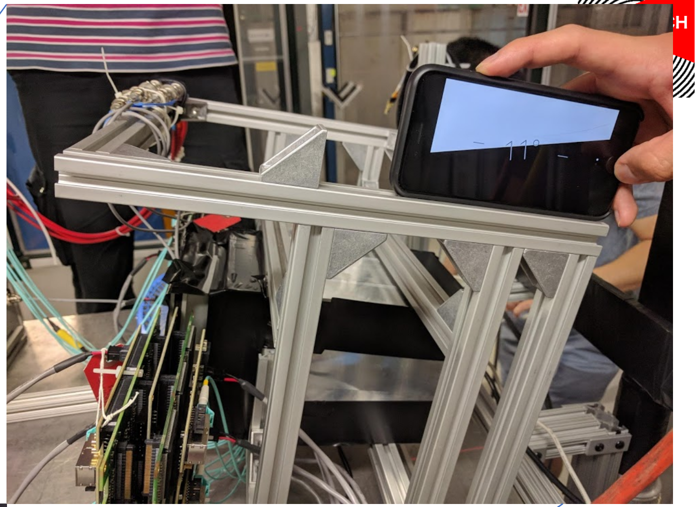
- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring is centered at point of incidence

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



Beam spot

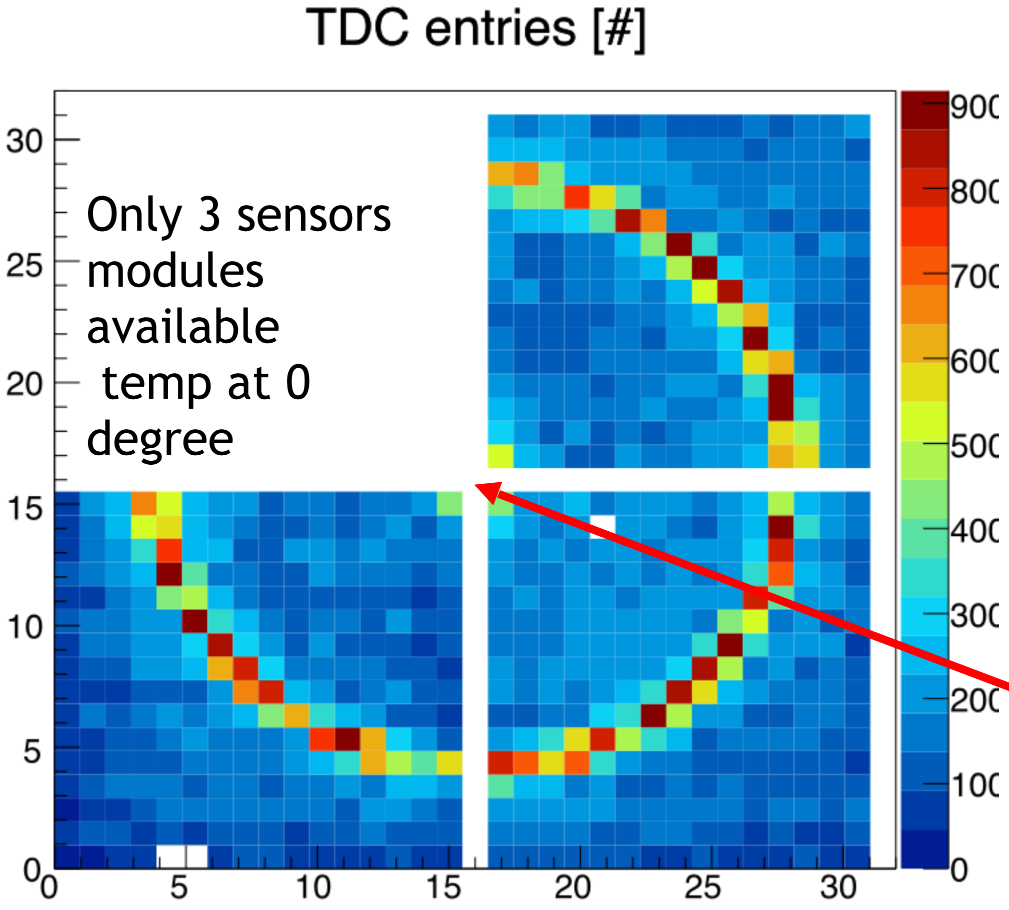


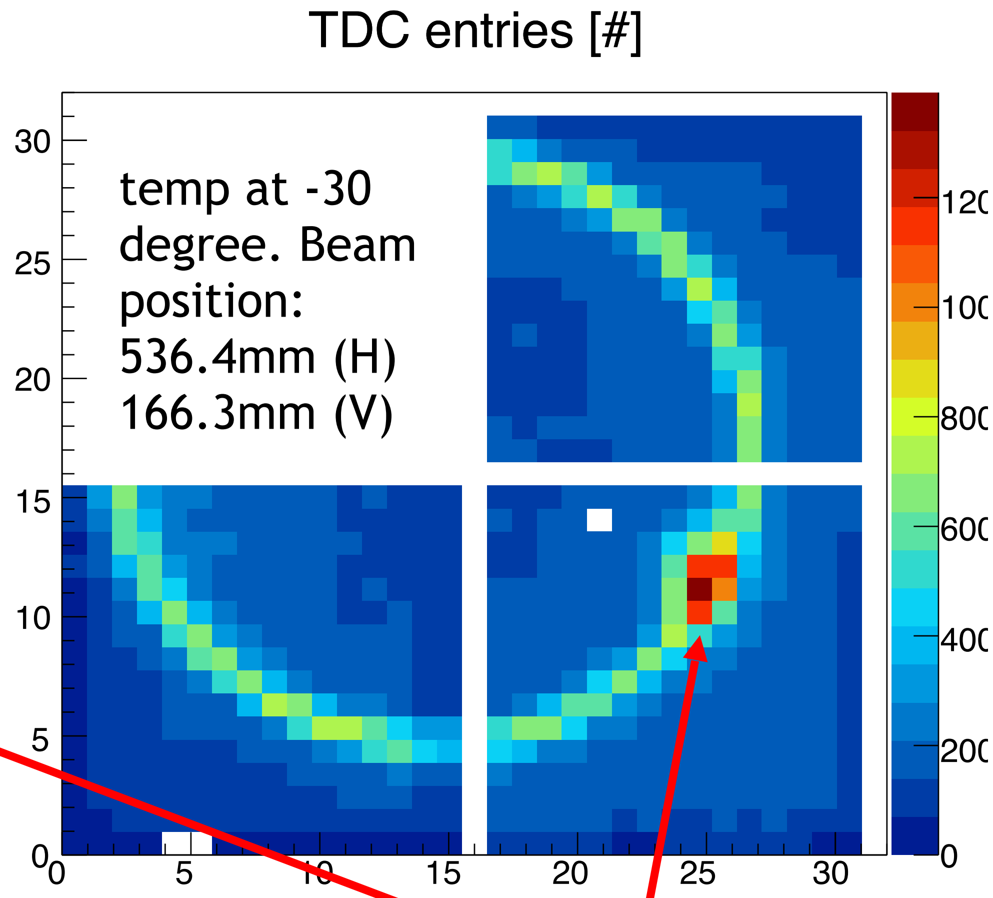


11 degree tilt downward

120 GeV/c proton beam

mRICH readout with SiPM matrix sensors





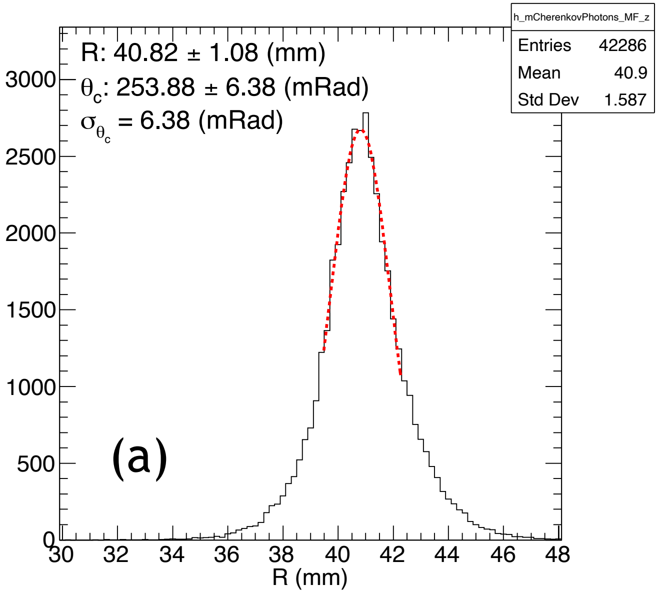
120 GeV/c proton Incident at center

Beam spot

Ring Radius and Number of Cherenkov Photons

Data

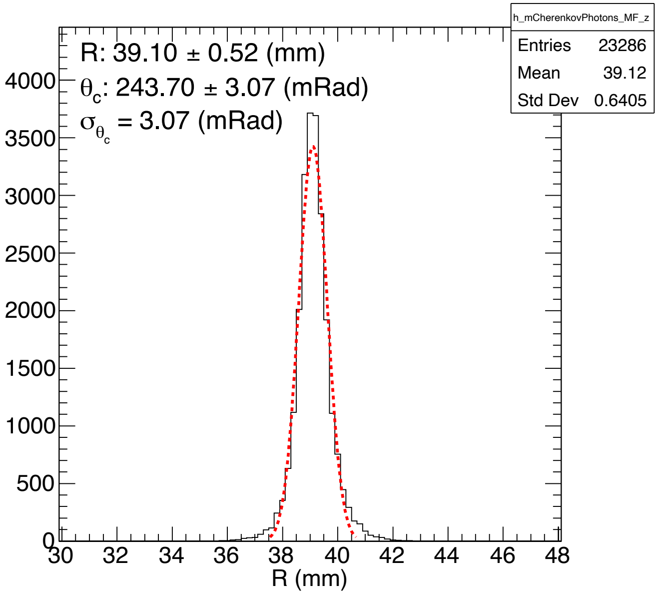
No precision tracking was available. Beam size is ~6mm in radius.



(b)

(c)

Simulation



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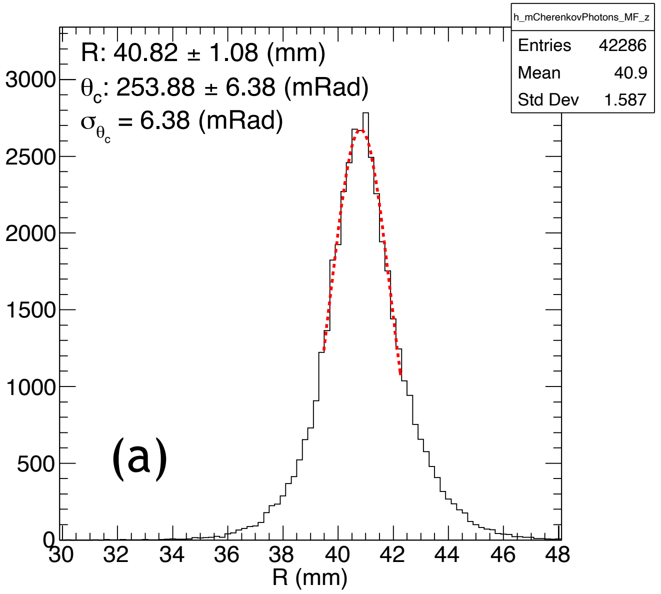
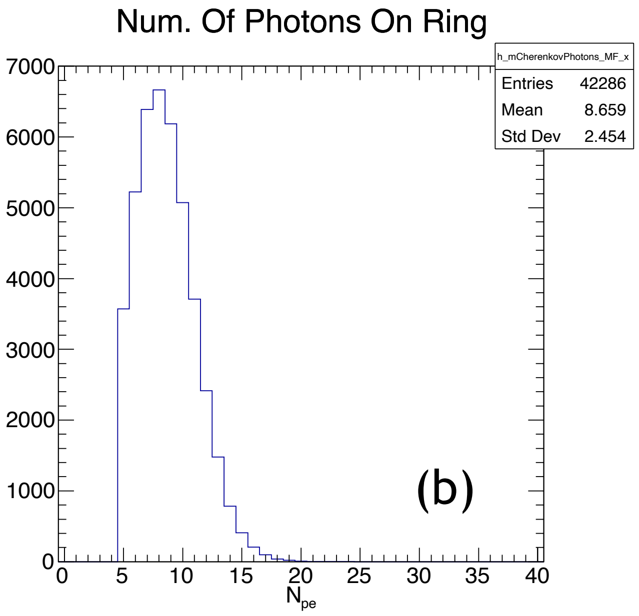
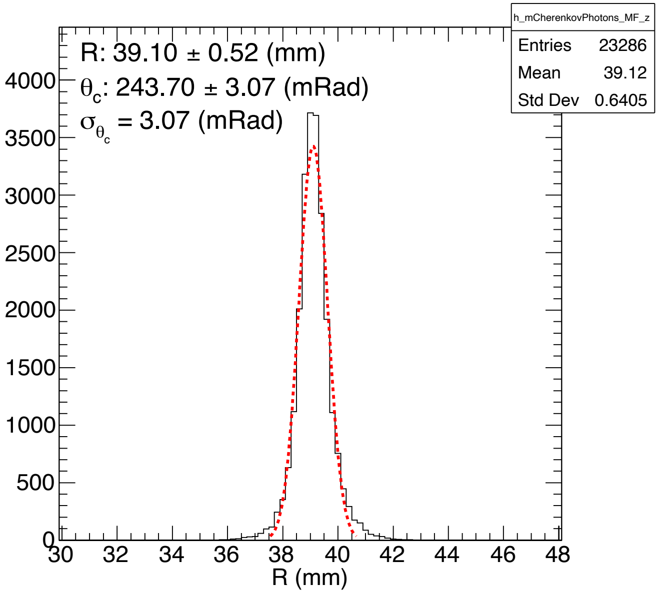
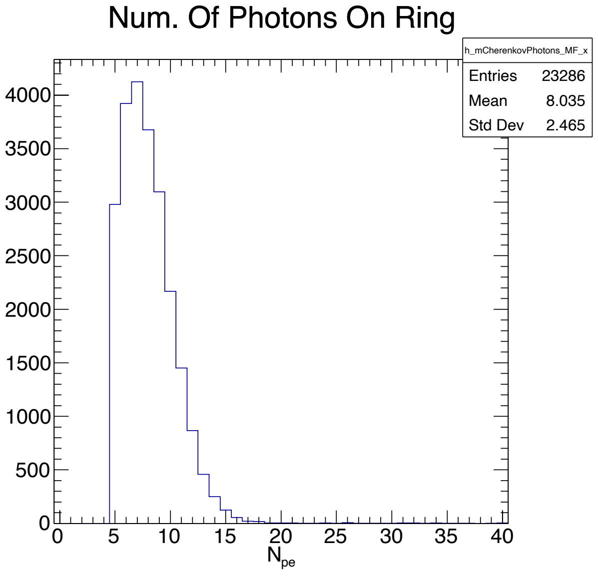




(c)

Simulation





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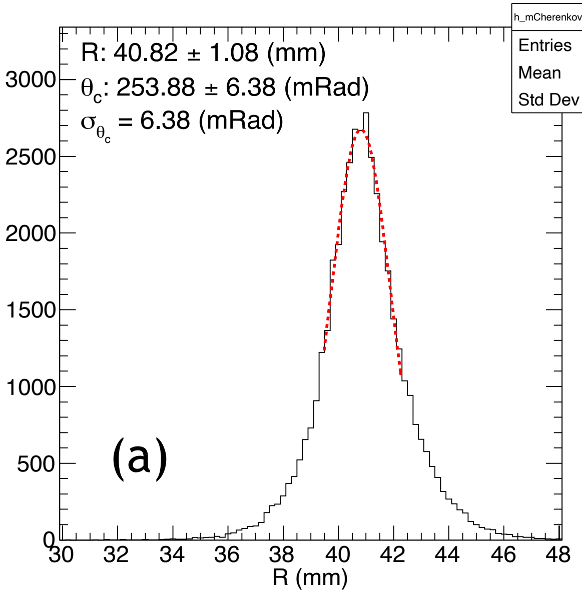

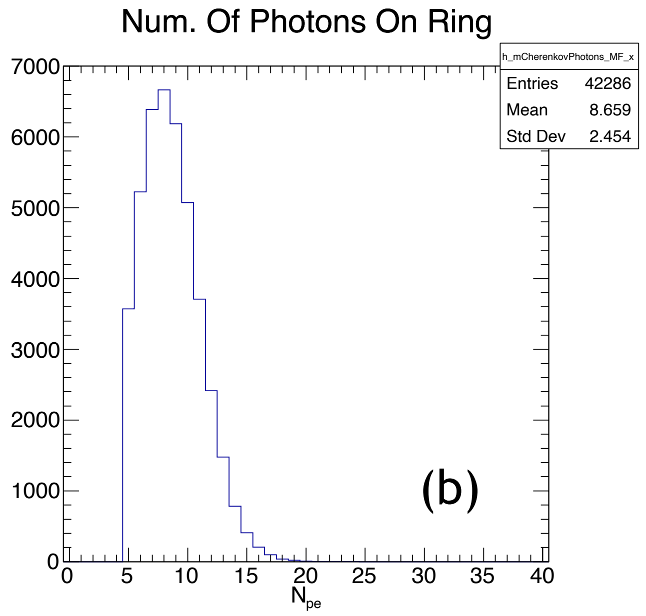

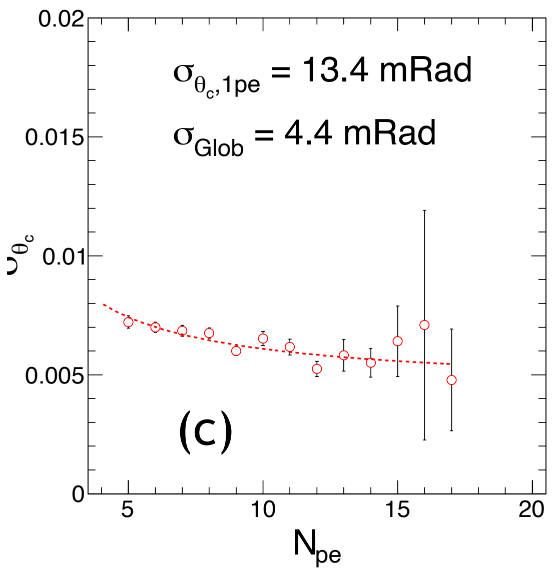

Simulation