Modular Ring Imaging Cherenkov Detector for Particle Identification in the Electron-Ion Collider (EIC) Experiments

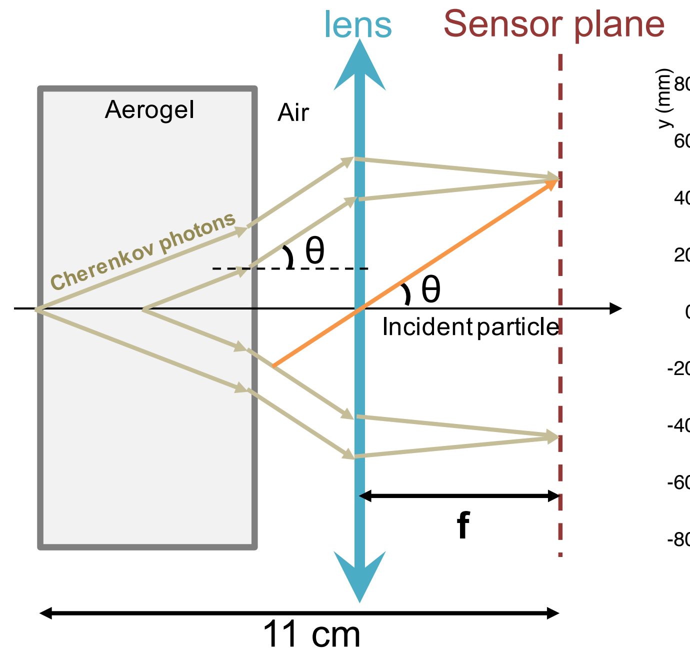
Xu Sun
Georgia State University

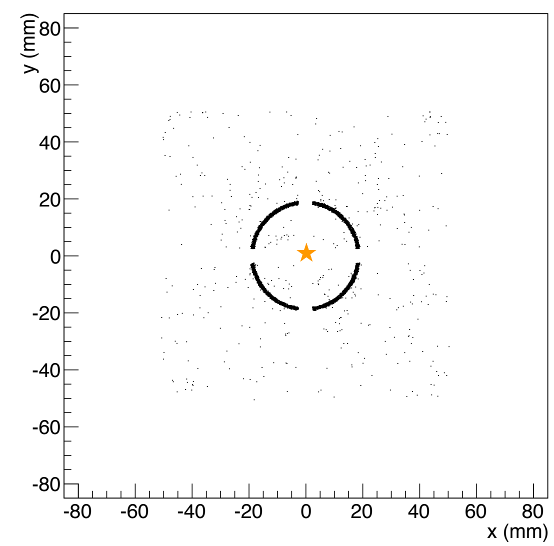
mRICH

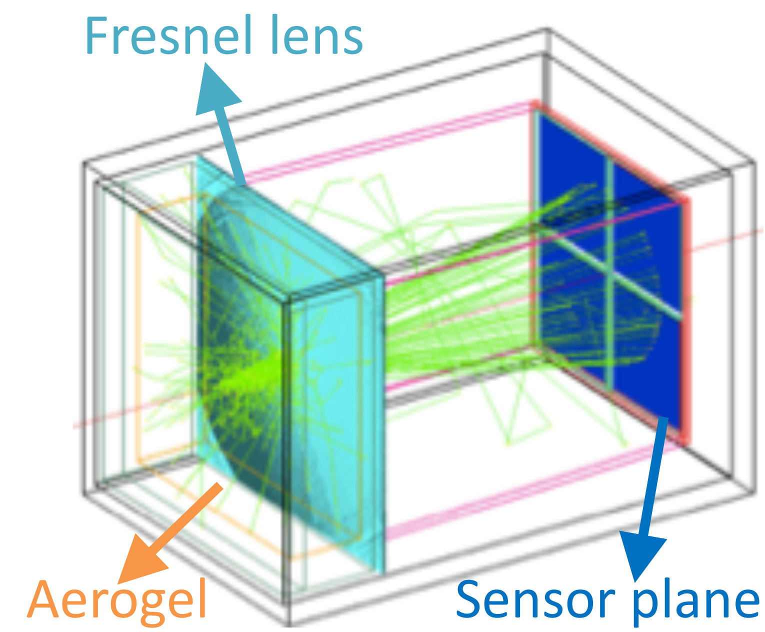
Lens-based Focusing Aerogel Detector Design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

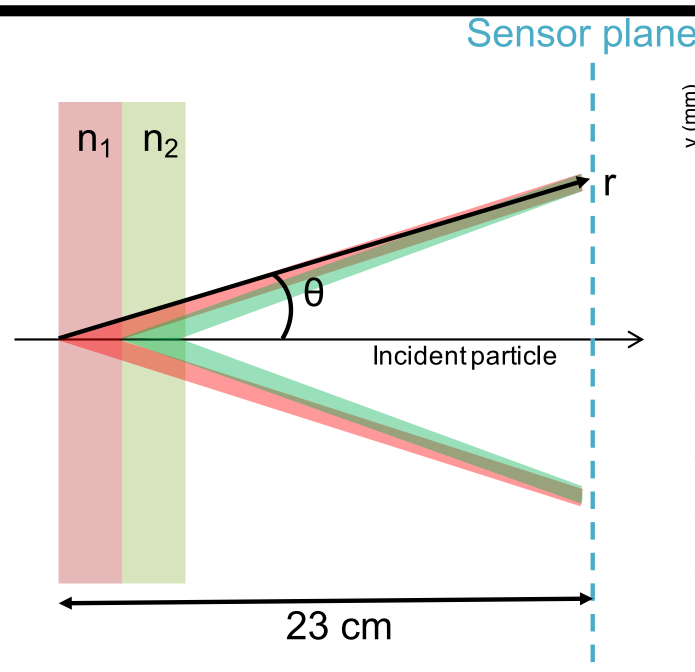


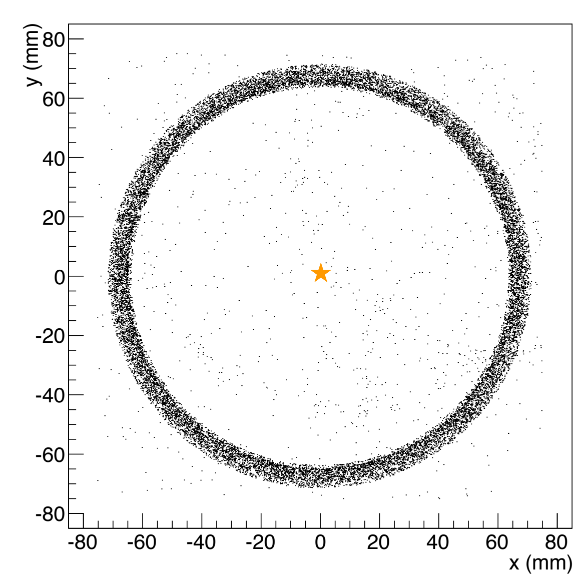




9 GeV/c pion beam launched at the center of xy plane in simulation

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**

Lens-based Focusing Aerogel Detector Design

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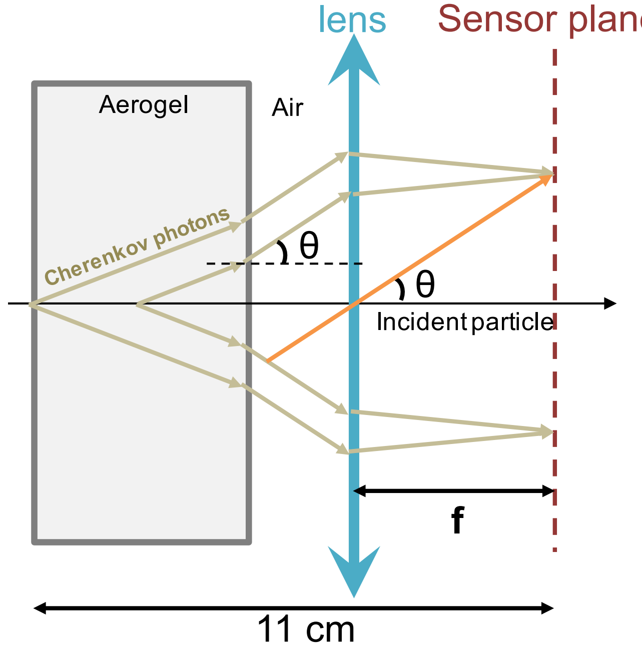
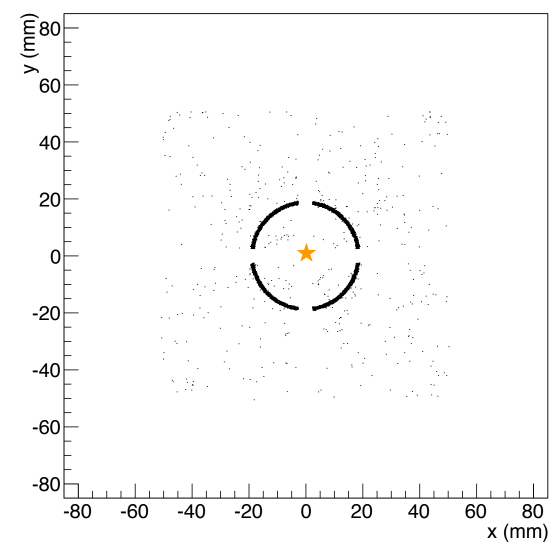
Lens-Based mRICH Design

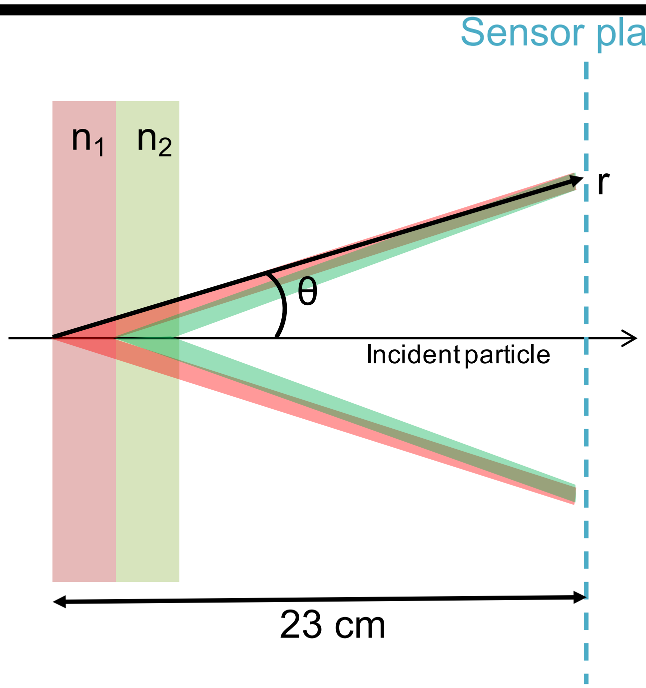


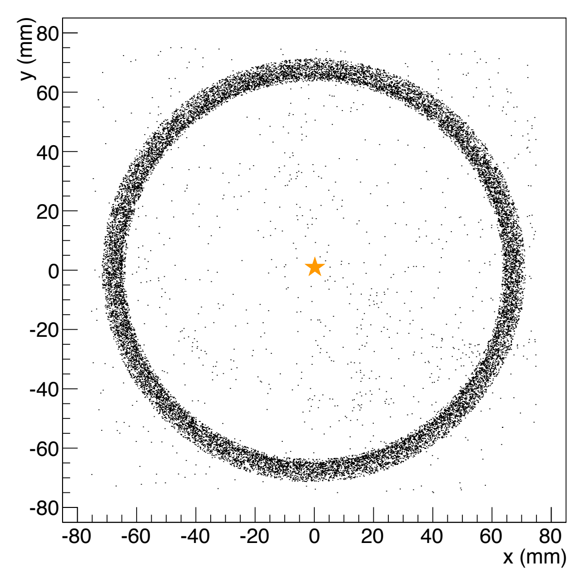


- **9GeV/c pion beam launched at the center of xy plane in simulation**
- **Smaller and thinner ring image**

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

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





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Lens-based Focusing Aerogel Detector Design

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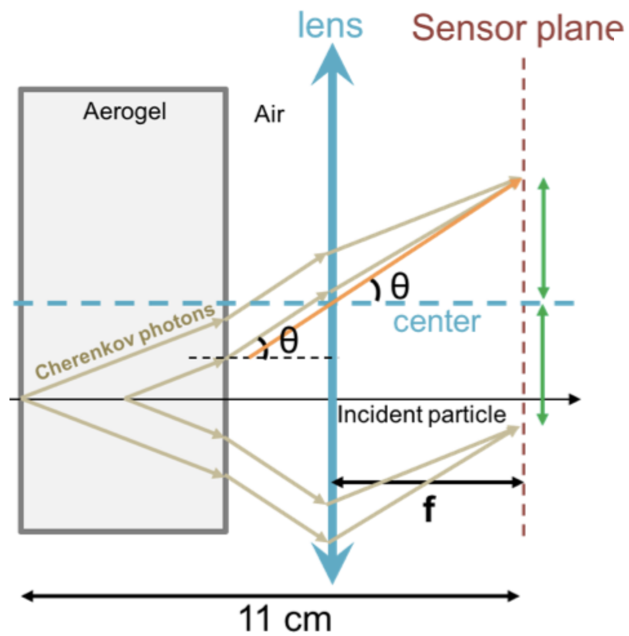
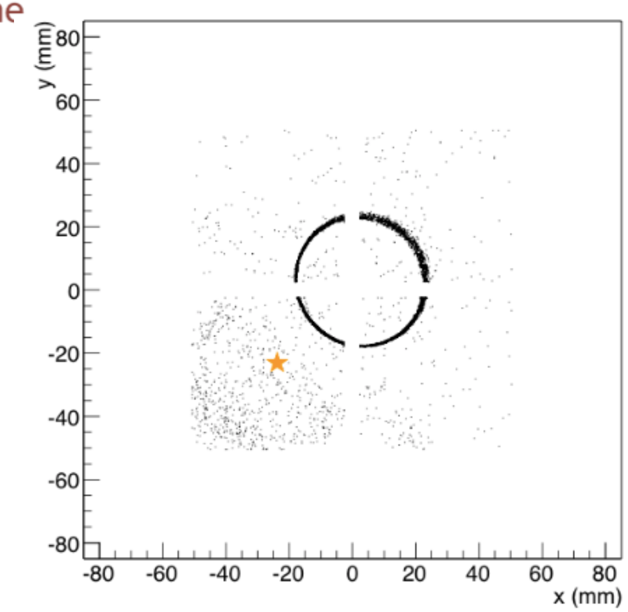
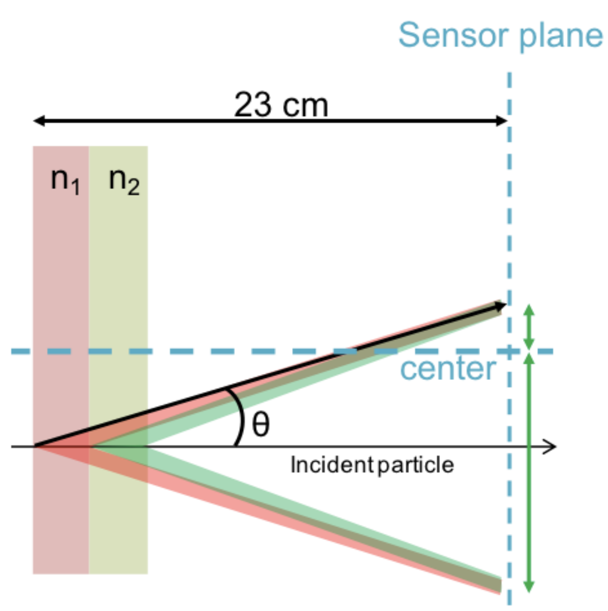
Lens-Based mRICH Design

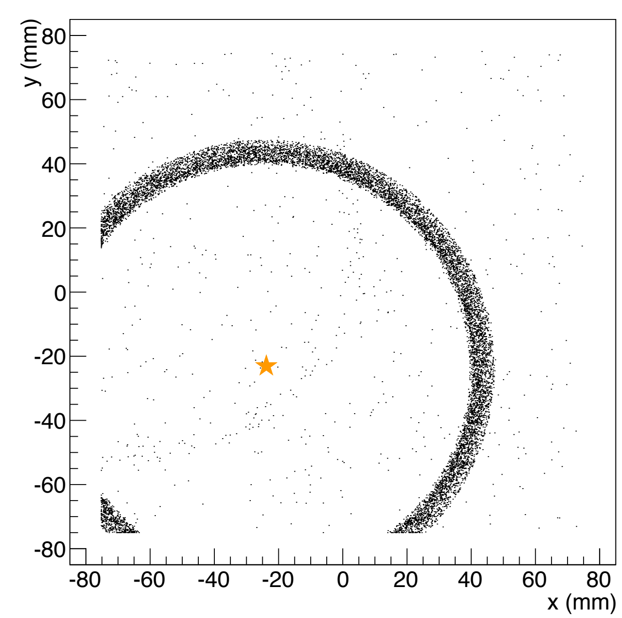




- **9 GeV/c pion beam incident at third quadrant (star) in simulation**
- **Ring image is center on the middle of the sensor plane**

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



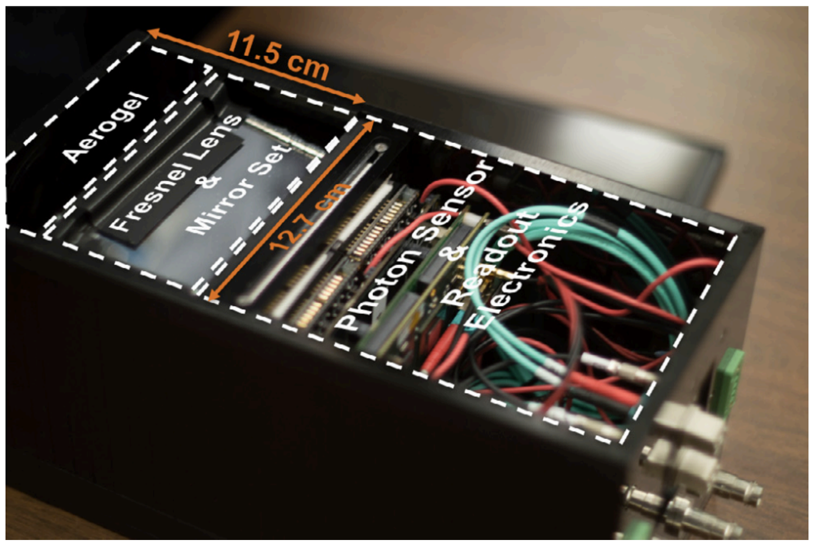


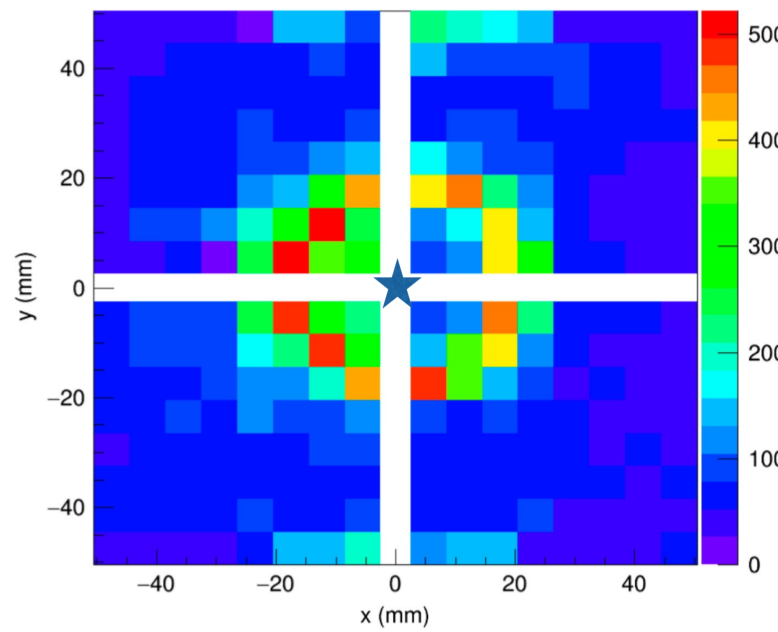
- **9 GeV/c pion beam incident at third quadrant (star) in simulation**
- **Ring is centered at point of incidence**

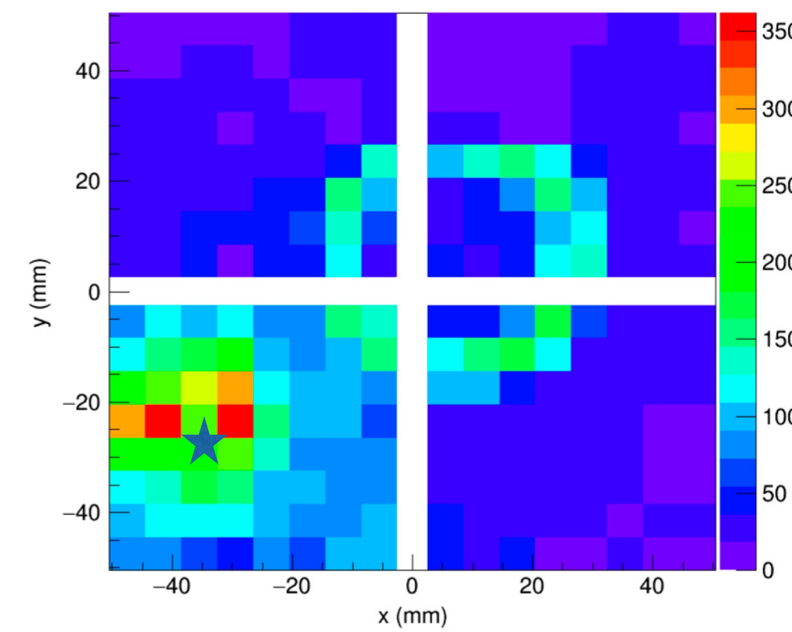
Beam Test of 1st Prototype

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

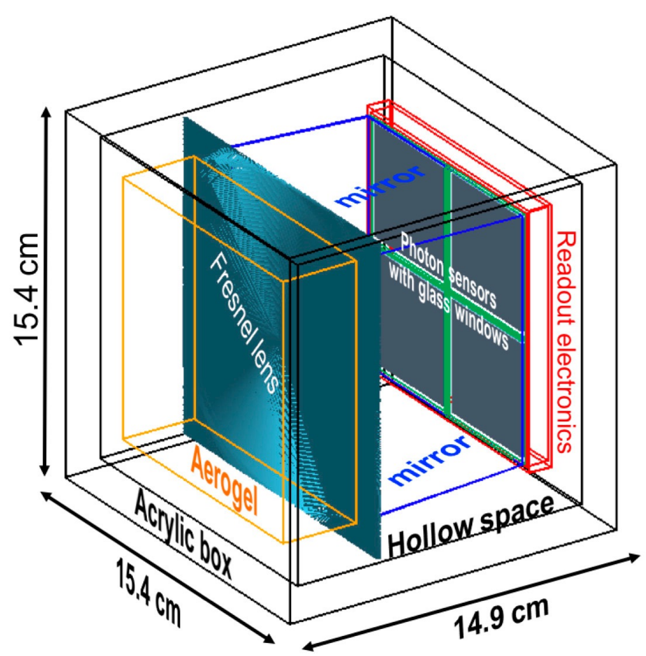
real data

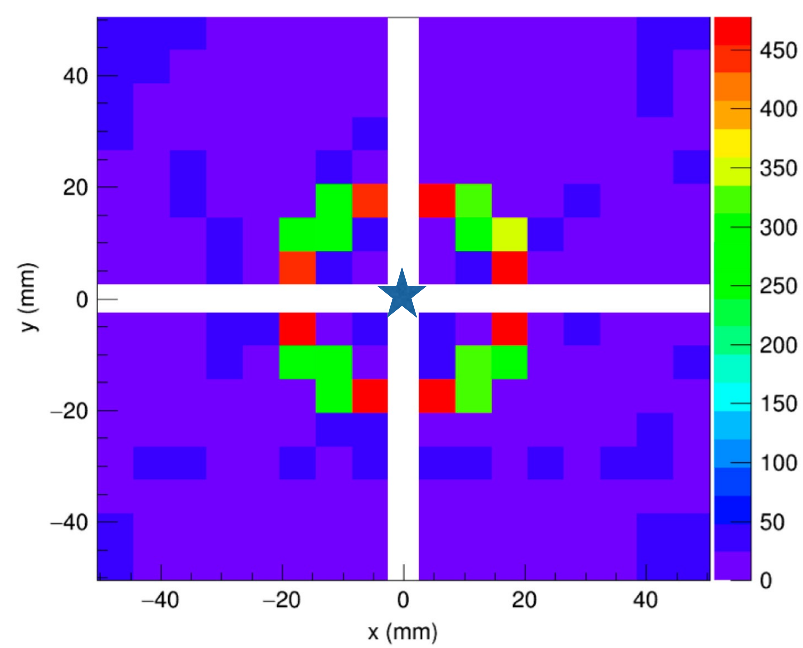


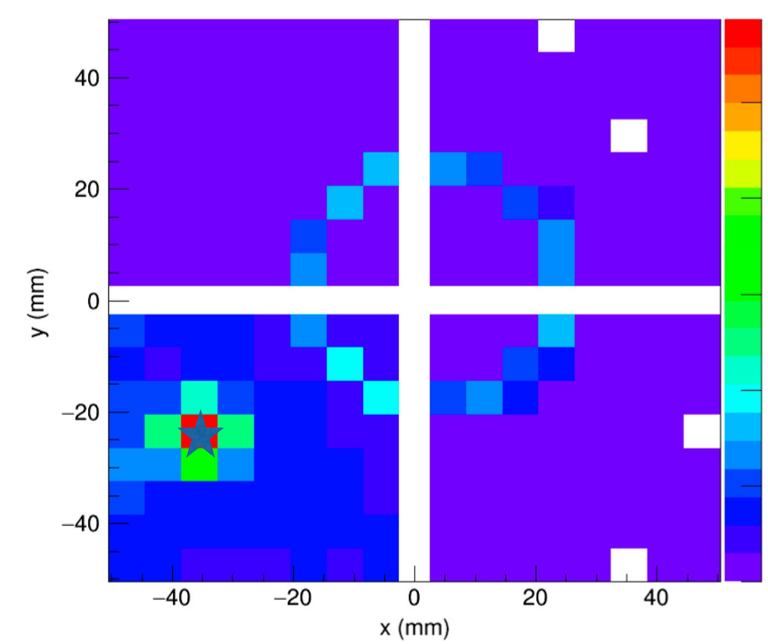




simulation

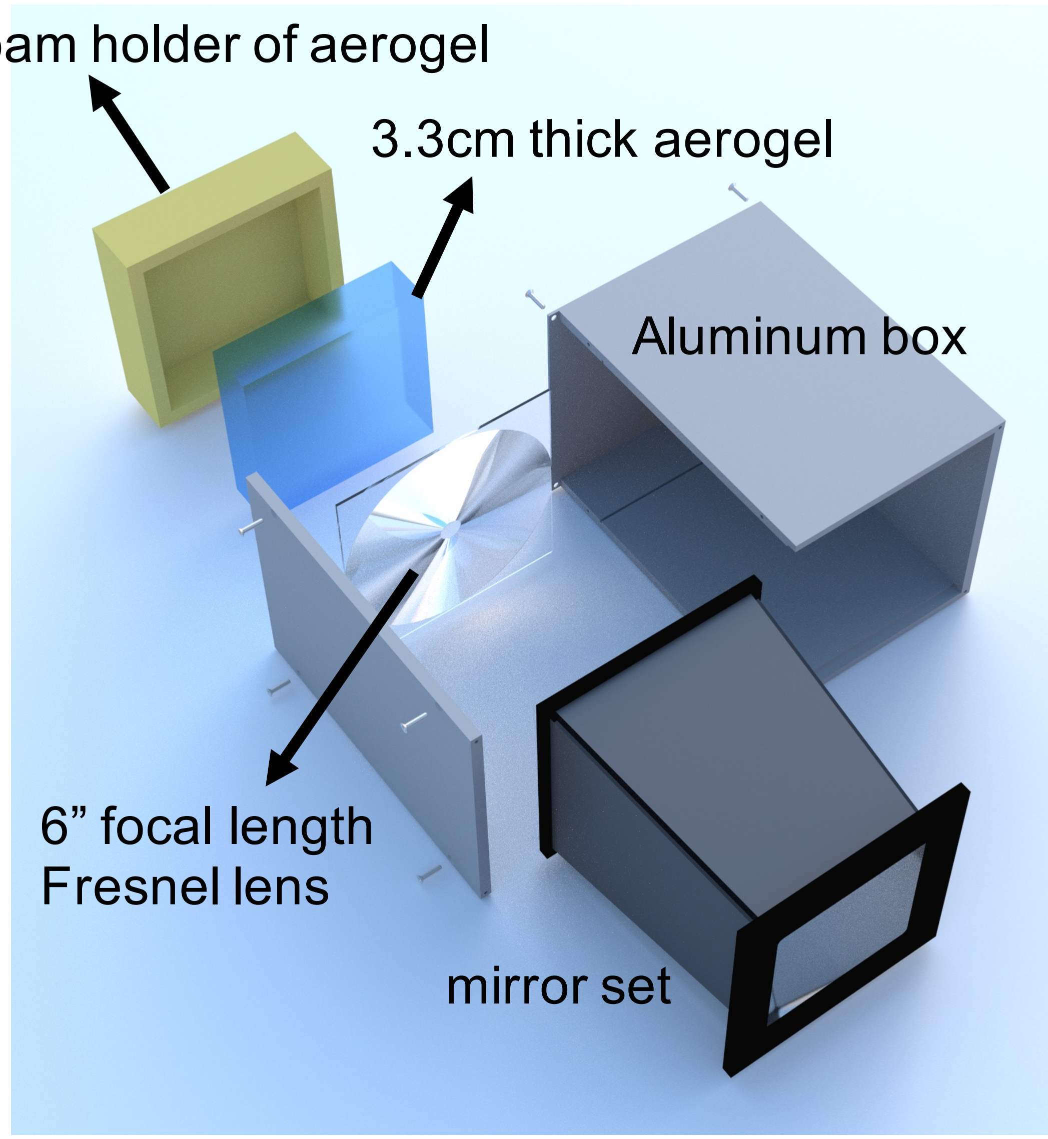


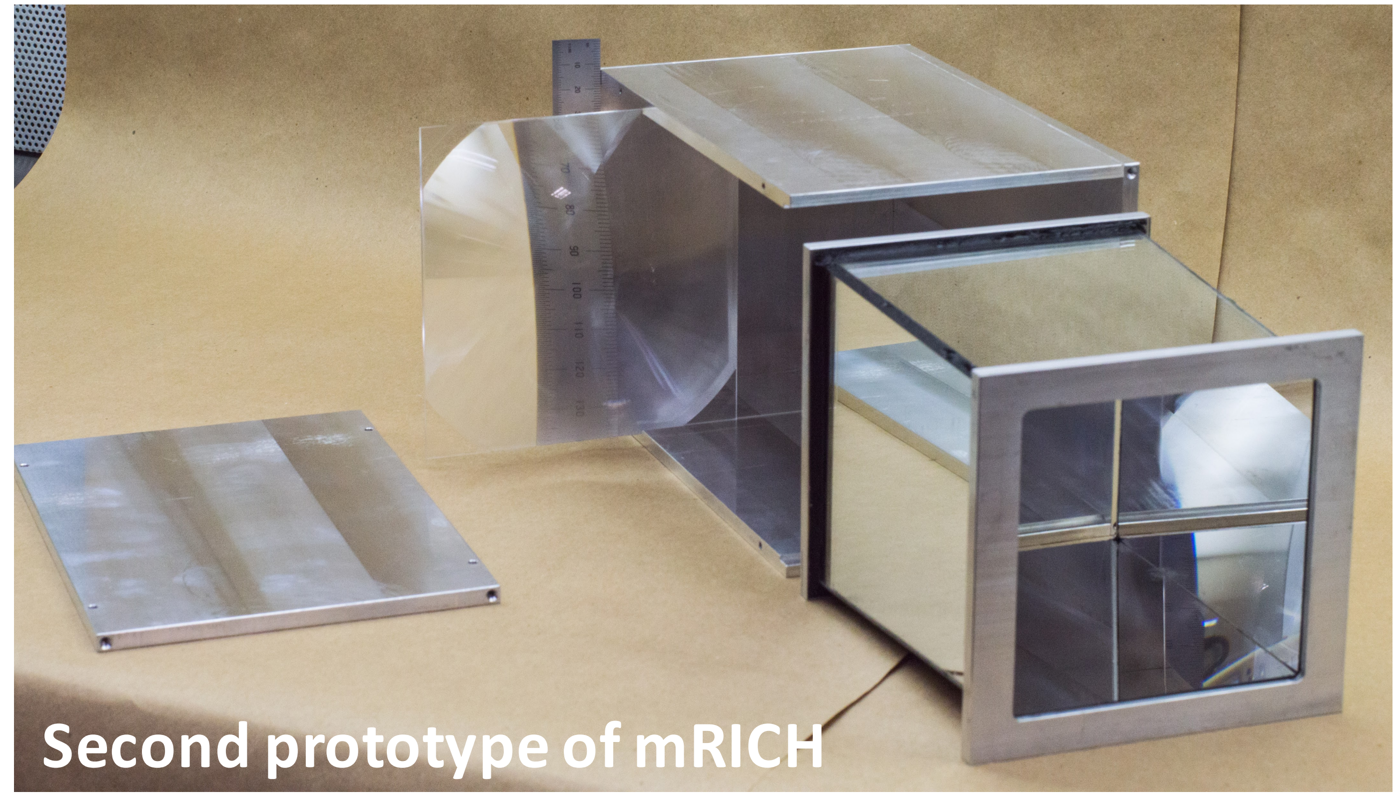


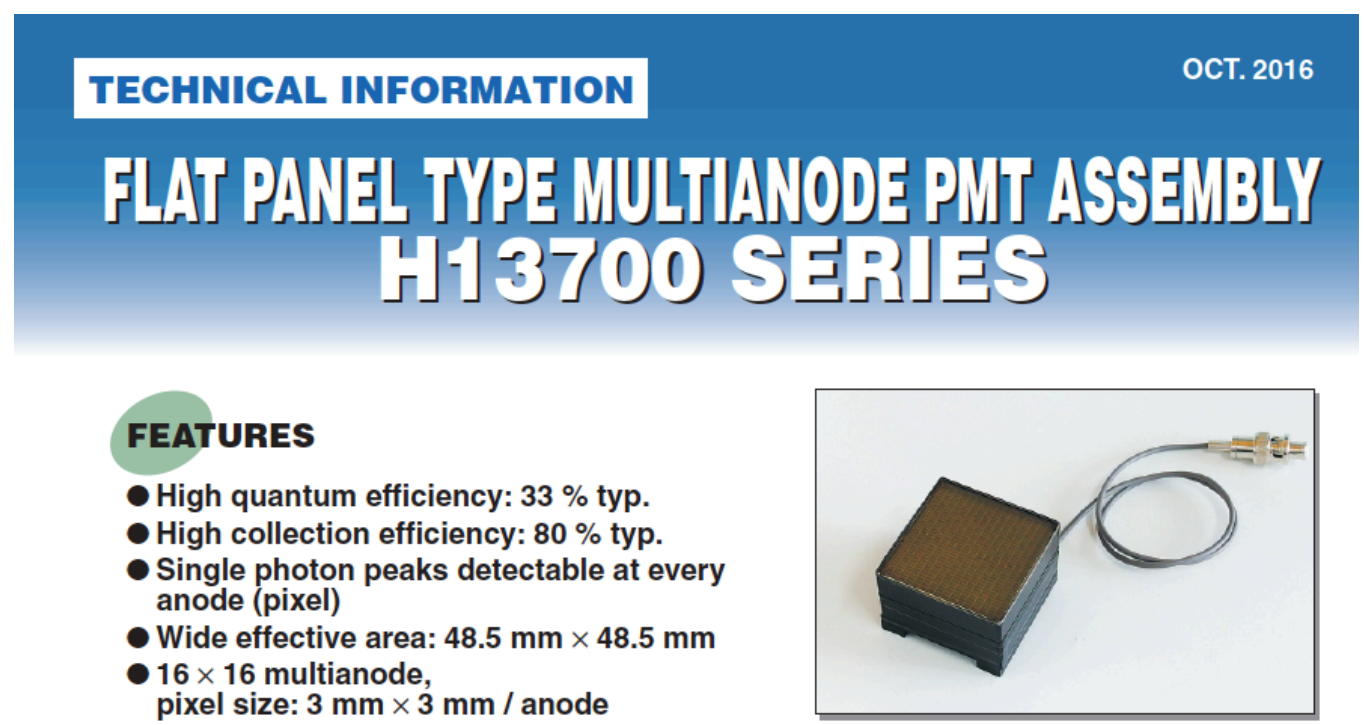


- 120 GeV proton beam test simulation matched with data perfectly
- Ring finder algorithm & 3” focal length & 6*6 mm pixel size
- Cheuk-Ping Wong et al., NIM A871 (2017) 13-19

2nd mRICH Prototype






TECHNICAL INFORMATION

OCT. 2016

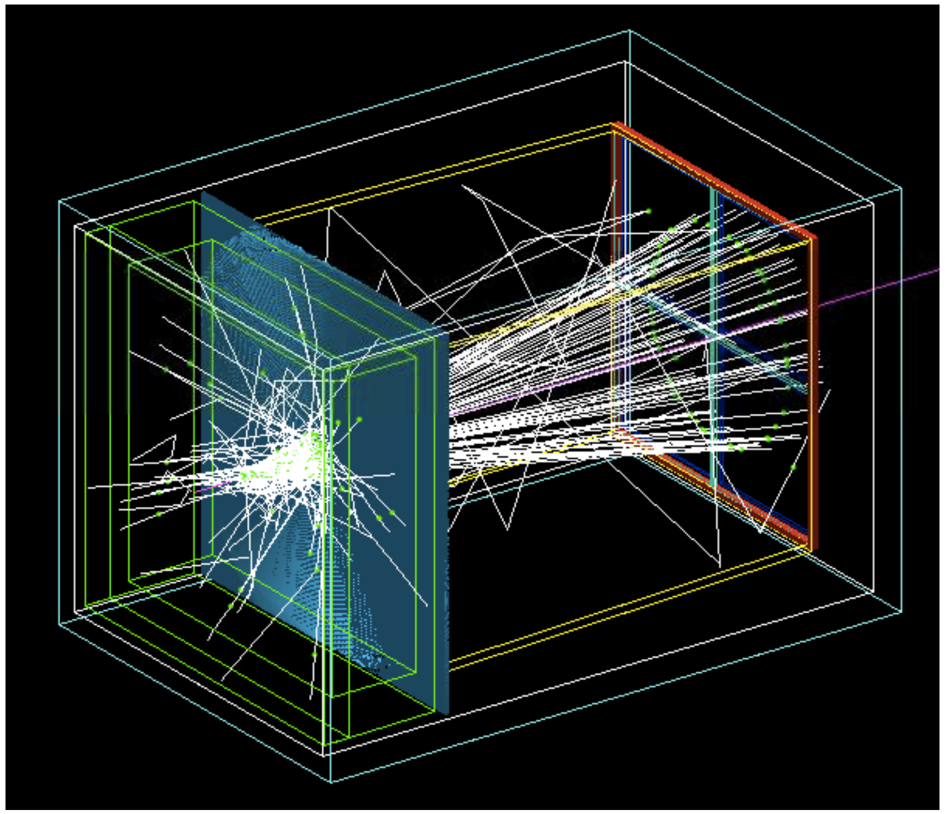
FLAT PANEL TYPE MULTIANODE PMT ASSEMBLY
H13700 SERIES

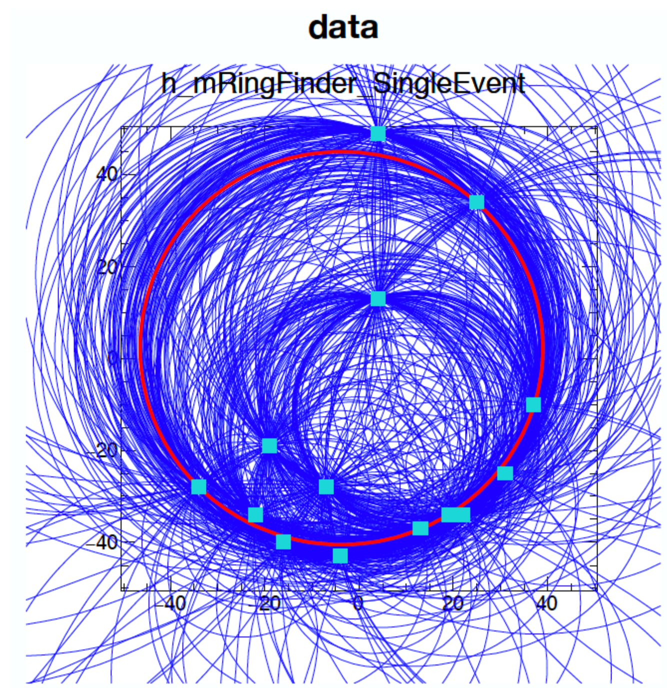
FEATURES

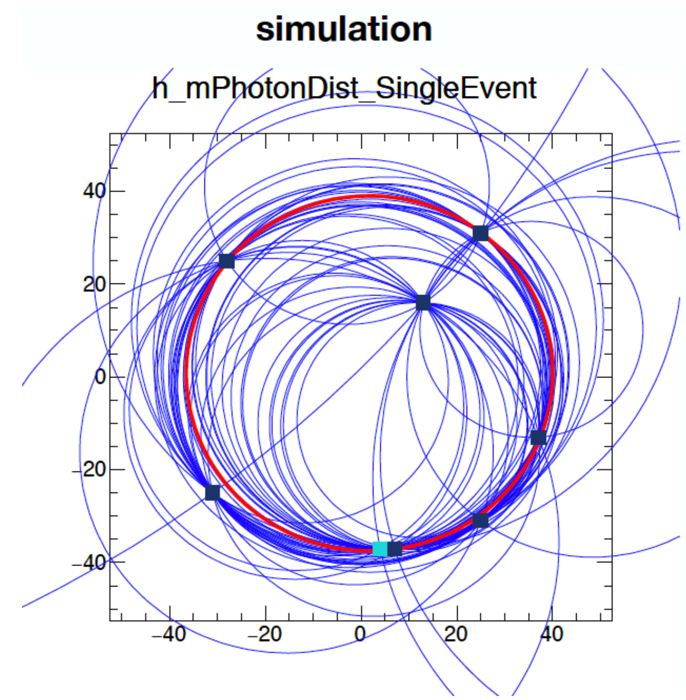
- High quantum efficiency: 33 % typ.
- High collection efficiency: 80 % typ.
- Single photon peaks detectable at every anode (pixel)
- Wide effective area: 48.5 mm × 48.5 mm
- 16 × 16 multianode, pixel size: 3 mm × 3 mm / anode

- **Longer focal length (6” Fresnel lens)**
- **Smaller pixel size sensors**
- **Test PID capability**

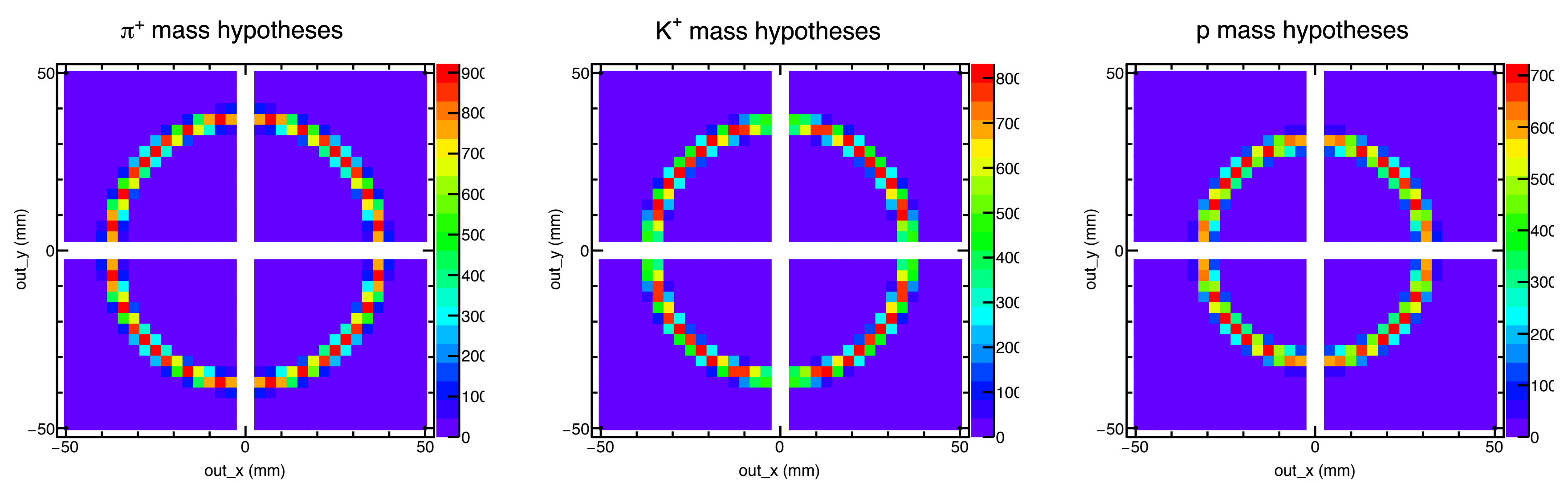
Particle Identification Algorithm Development



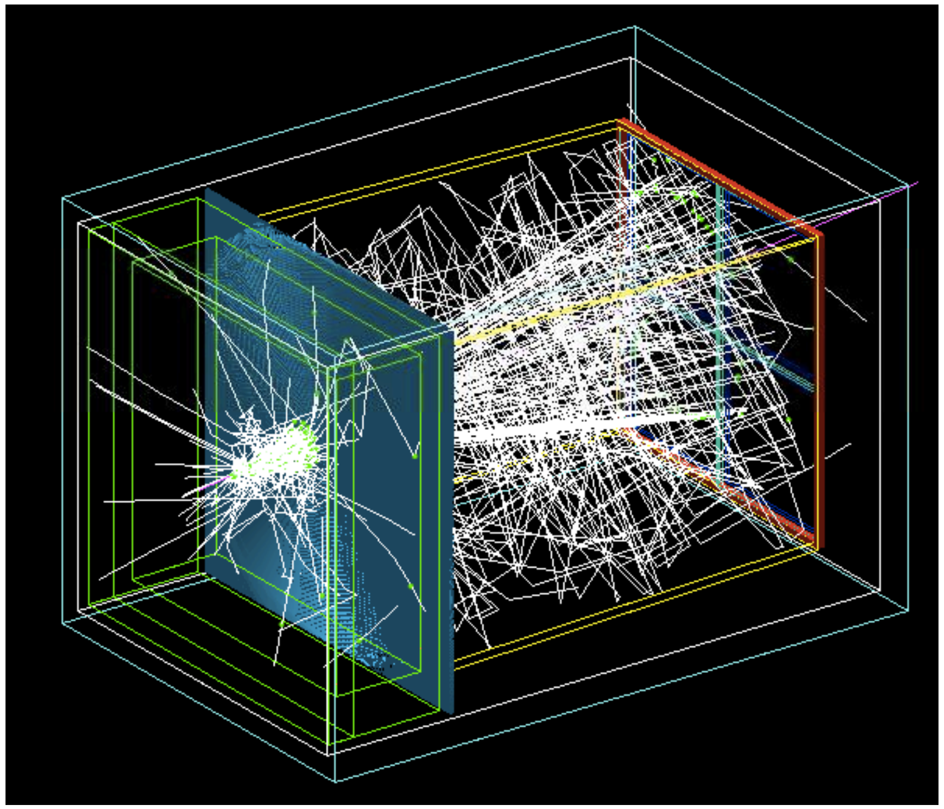




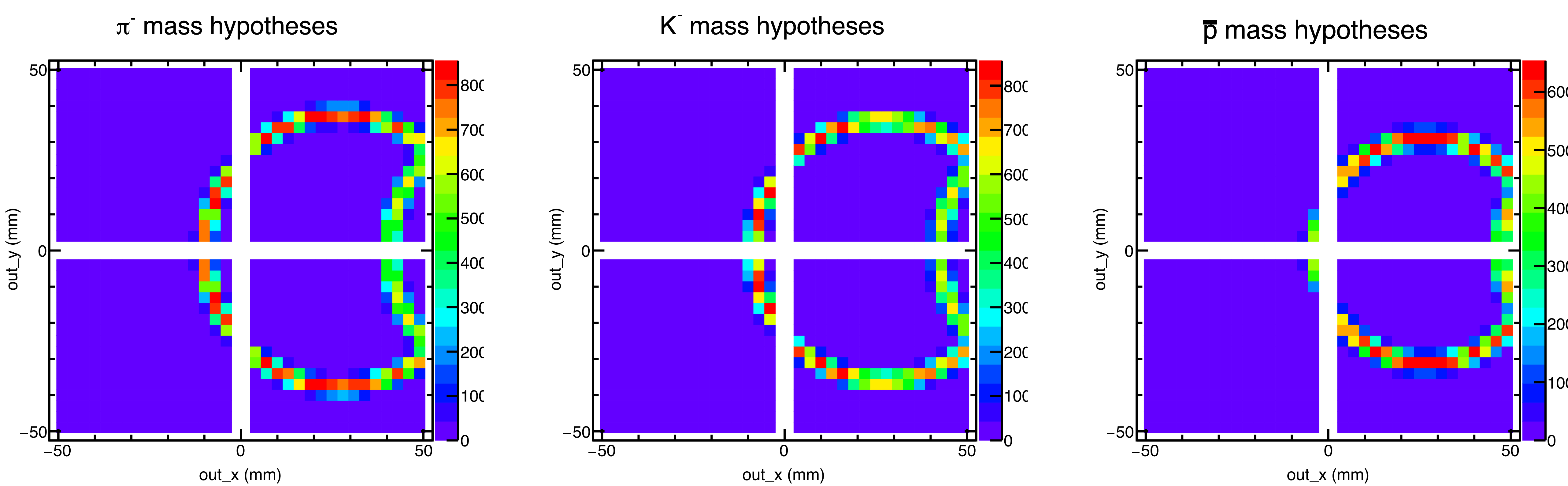
1. Perfect circle image exists only when beam hit at the center. Used Hough transformation to find the ring image and provided the baseline for consistency checks on GEANT4 simulation and analytical results.



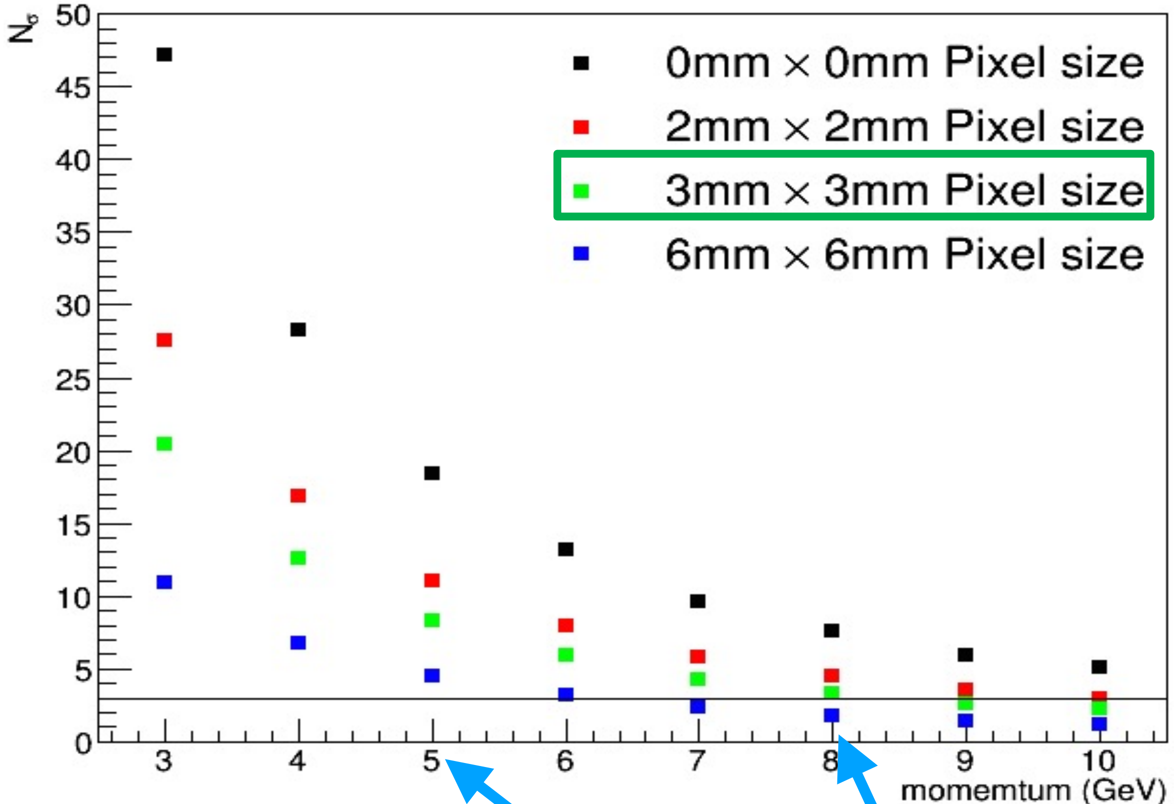
Particle Identification Algorithm Development



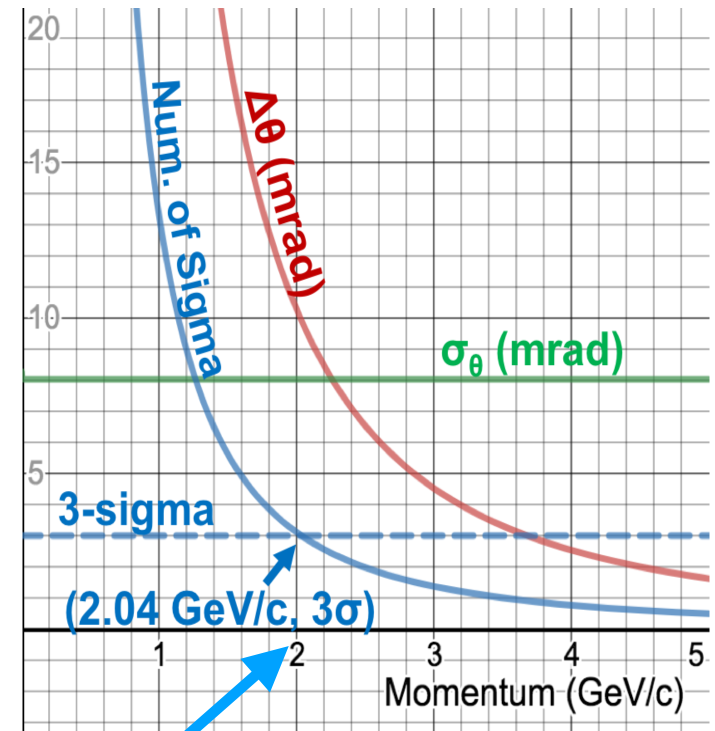
2. For other ring image forms (i.e., particles entering at off-center positions and angles), one needs to use log-likelihood method for determining ring image formation. Extensive simulation is required for generating image template database.



Projected mRICH Performance



- 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

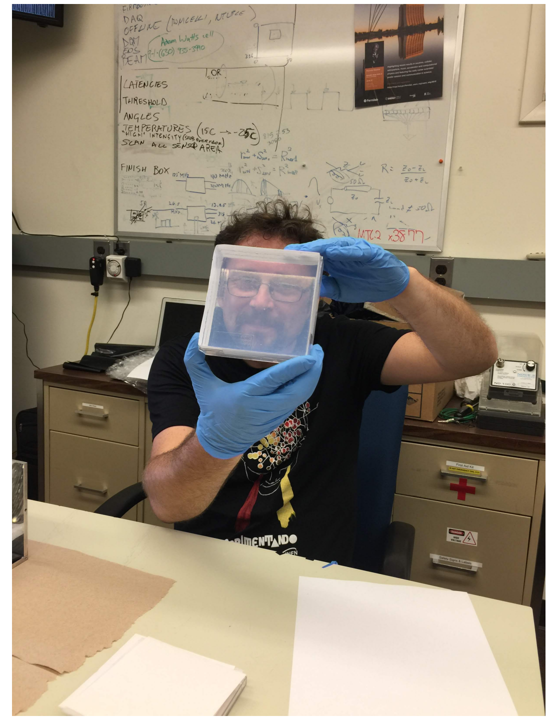


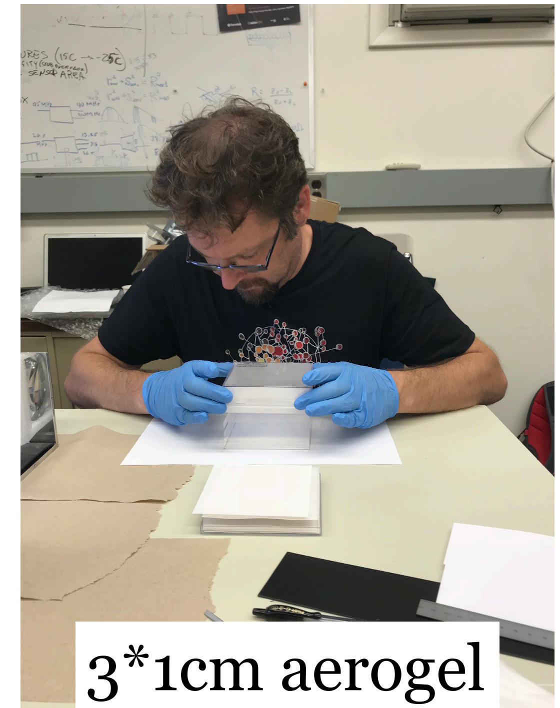
- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c

Data sets taken during the second mRICH beam test at Fermilab in June/July 2018

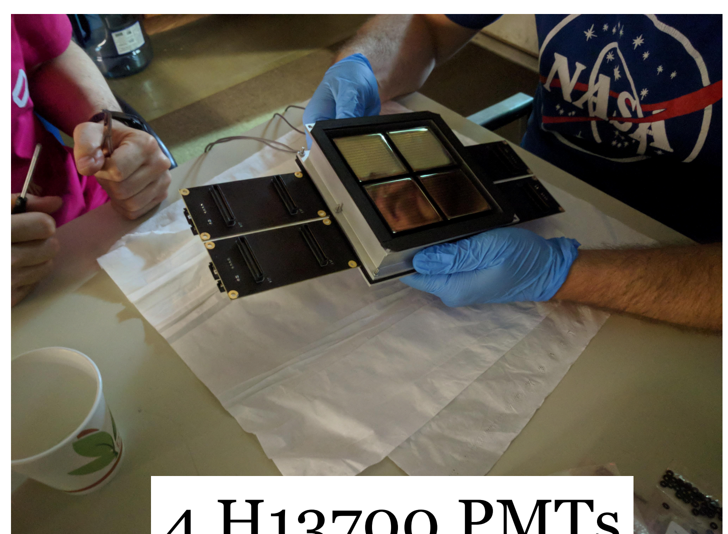
The major goal of the 2nd mRICH beam test data analysis is to **verify the PID performance at 2, 5 and 8 GeV/c**

Beam Test of 2nd Prototype

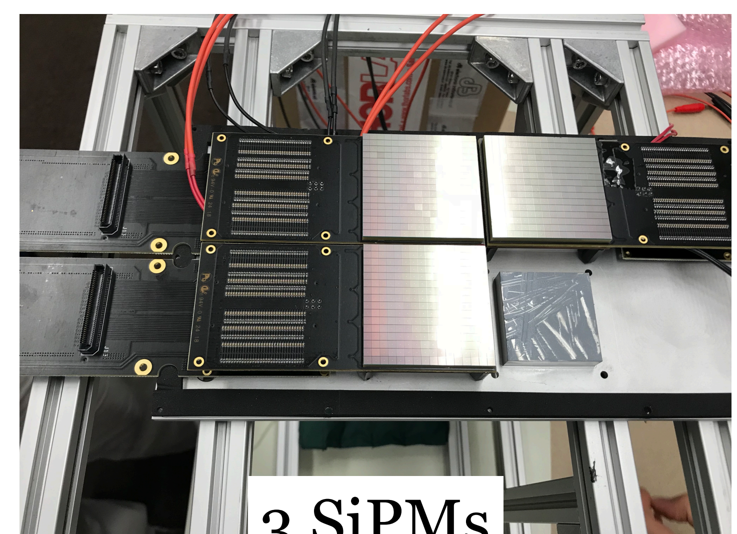



3*1cm aerogel

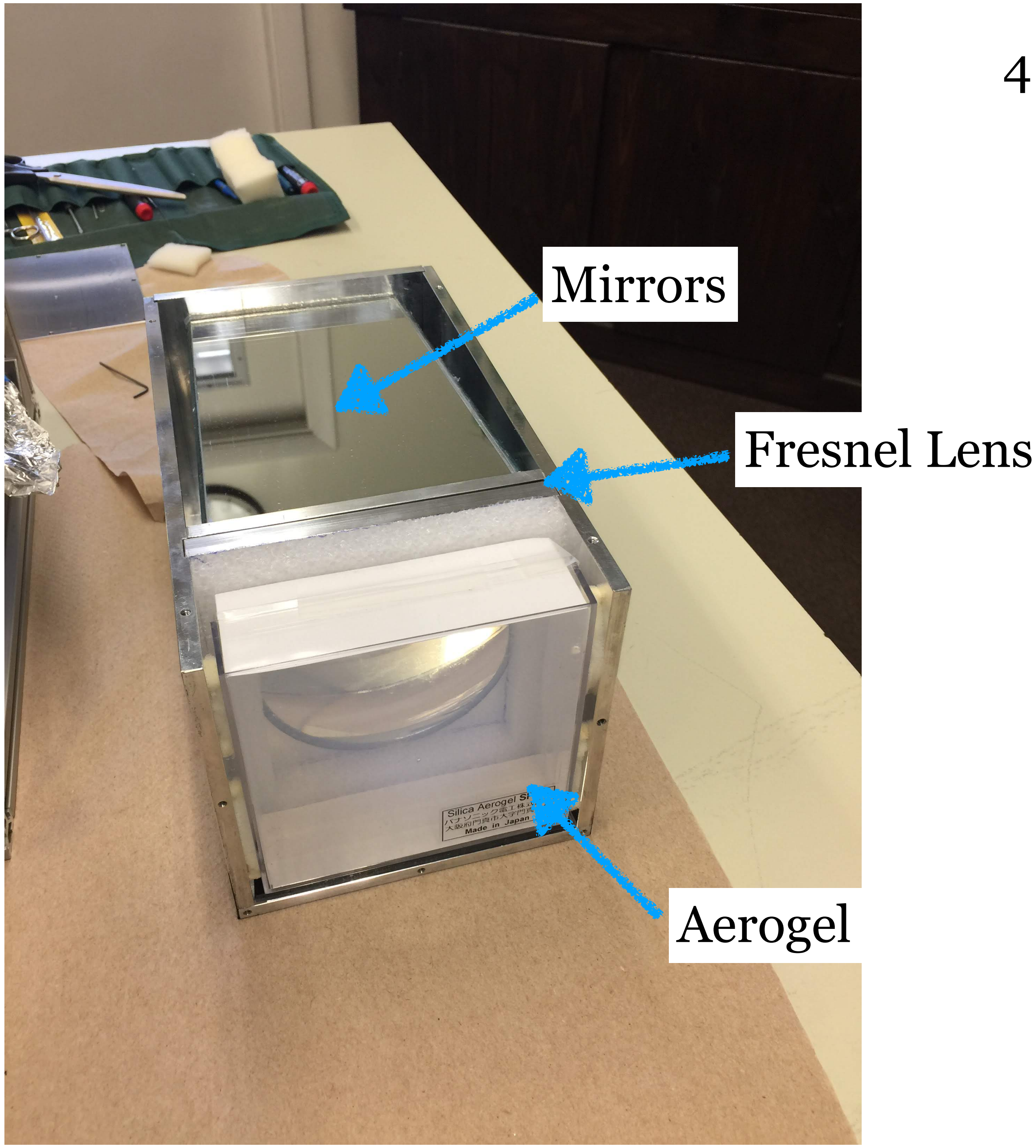

Fresnel Lens

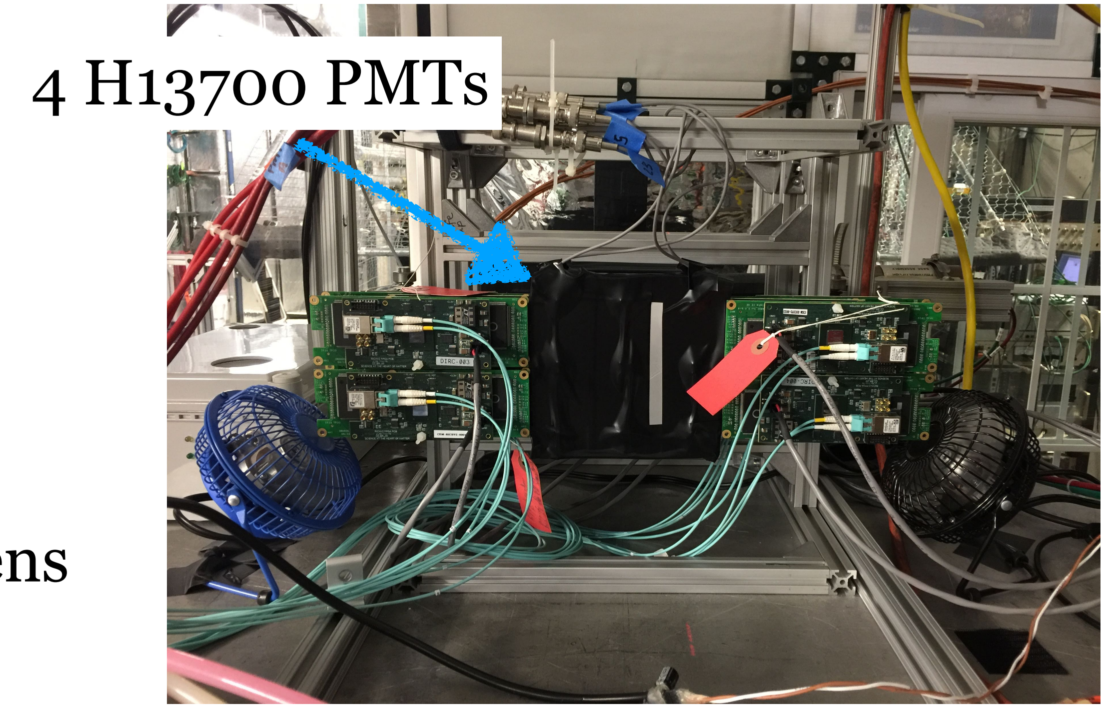


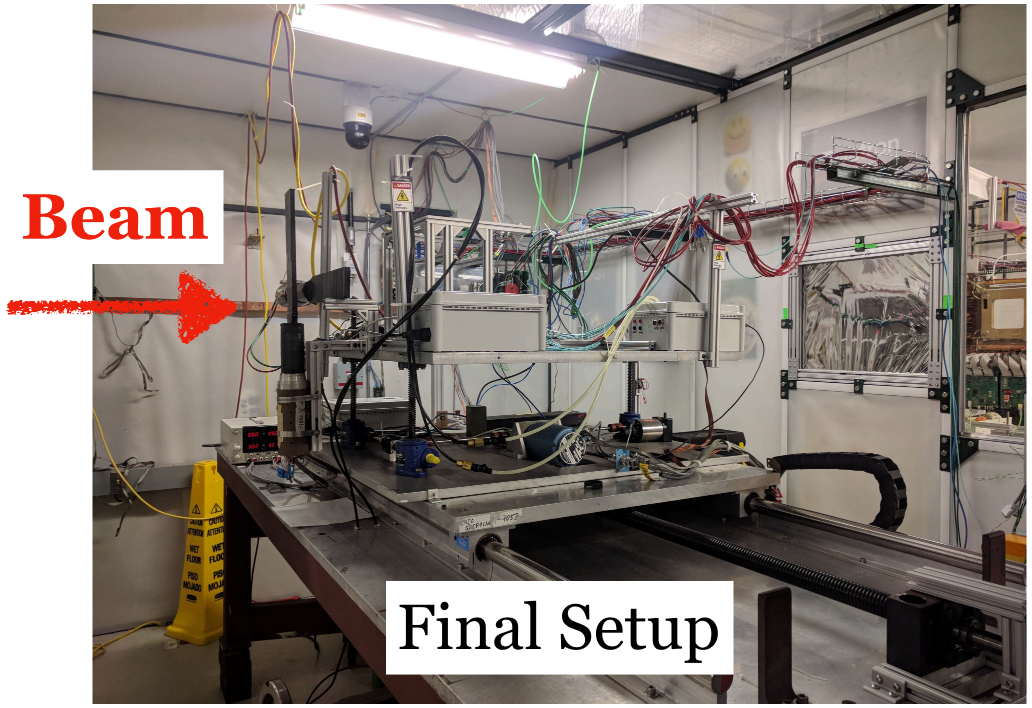
4 H13700 PMTs


3 SiPMs

Beam Test of 2nd Prototype

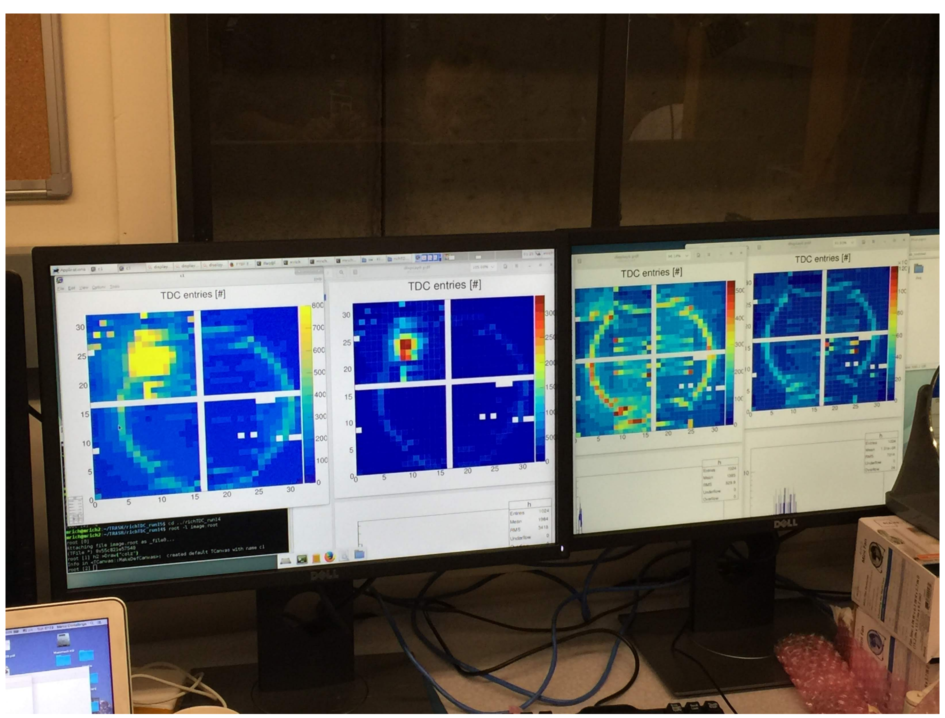


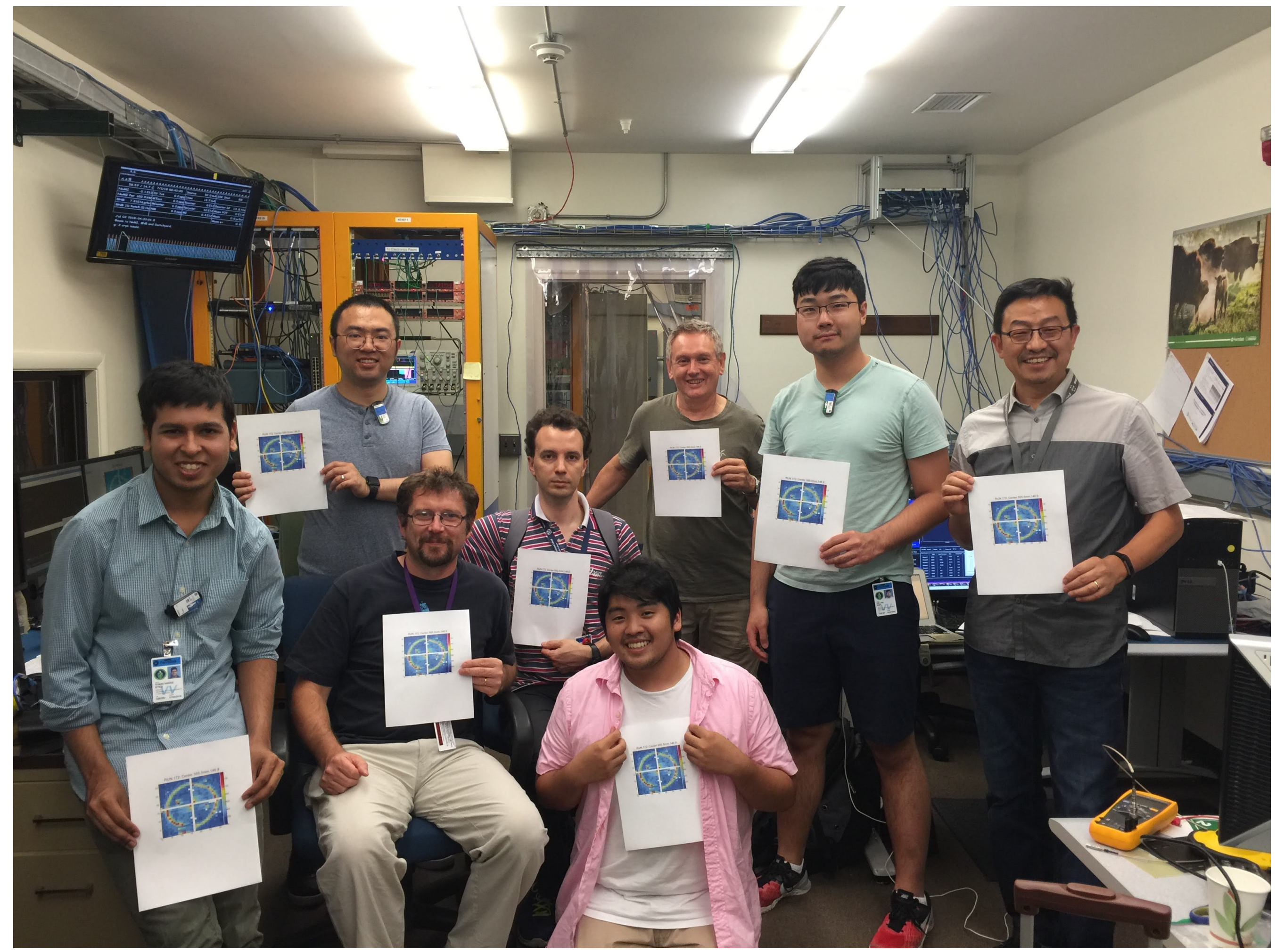




Beam Test of 2nd Prototype

First Ring

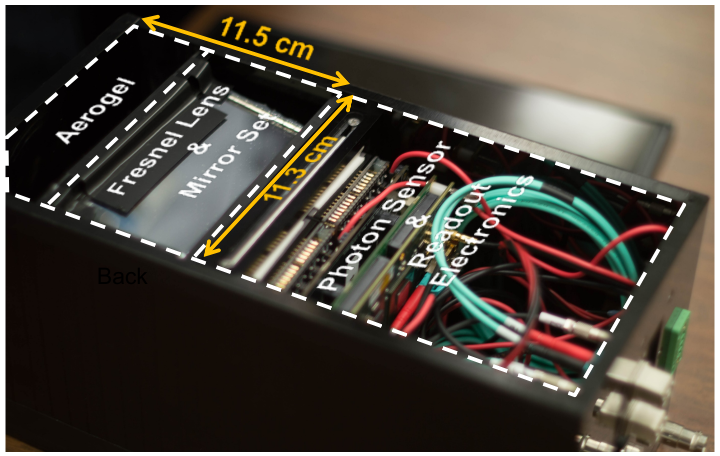




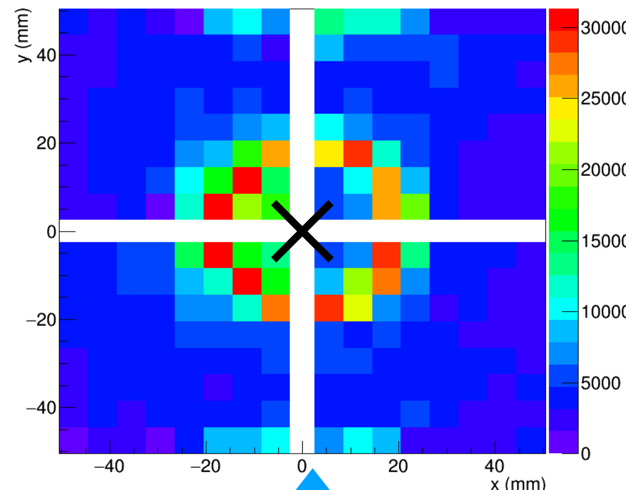
Beam Test Team

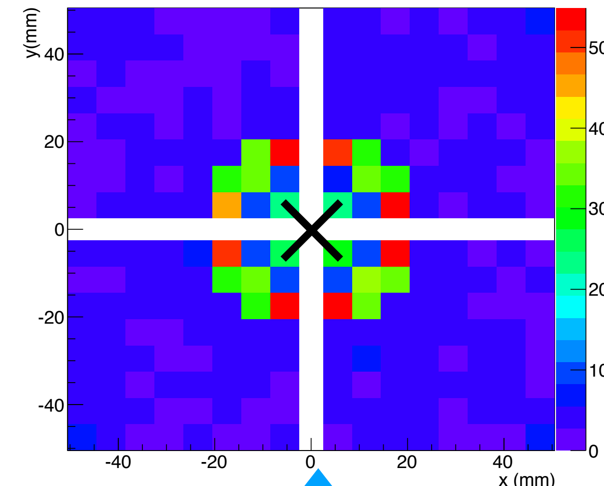
1st and 2nd Beam Test Comparison (120 GeV Proton Beam)

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

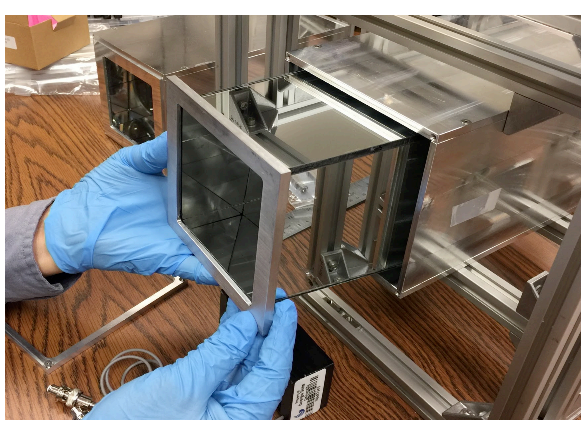




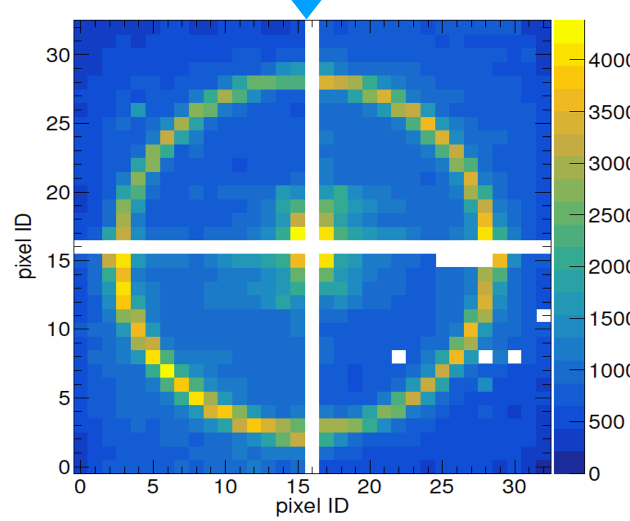
Images from 120 GeV Proton beam

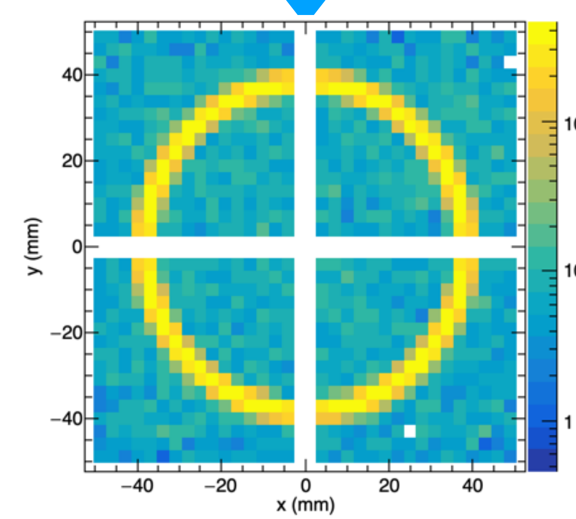
Simulated Images Using GEANT4

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

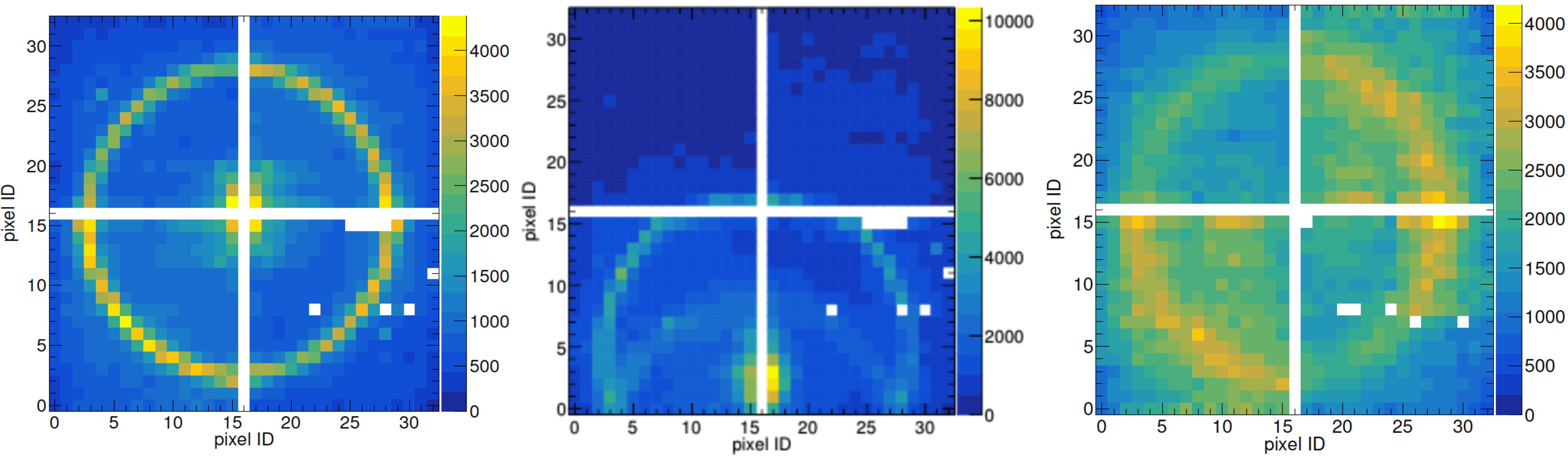




- 1st prototype 3” focal length & 6*6 mm pixel size
- 2nd prototype 6” focal length & 3*3 mm pixel size

mRICH Ring Images from PMTs

Examples of cumulative ring images from the second mRICH prototype beam test



Left: ring images formed by 120-GeV primary proton beam incident on the center of mRICH. White gaps are the PMT frames.

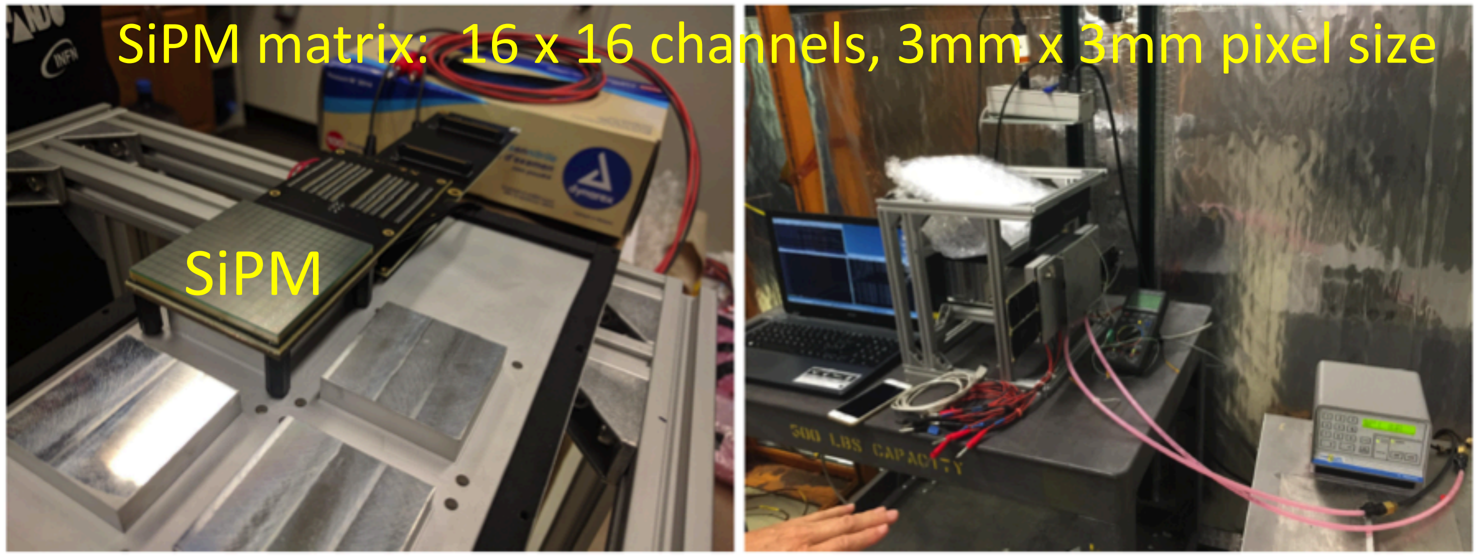
Middle: ring images from 120-GeV primary proton beam incident at an angle of 11° toward the lower section of mRICH.

Right: images from an 8-GeV meson run. The challenge of this analysis is to determine the beam position since the beam hodoscope readout was not ready for this test.

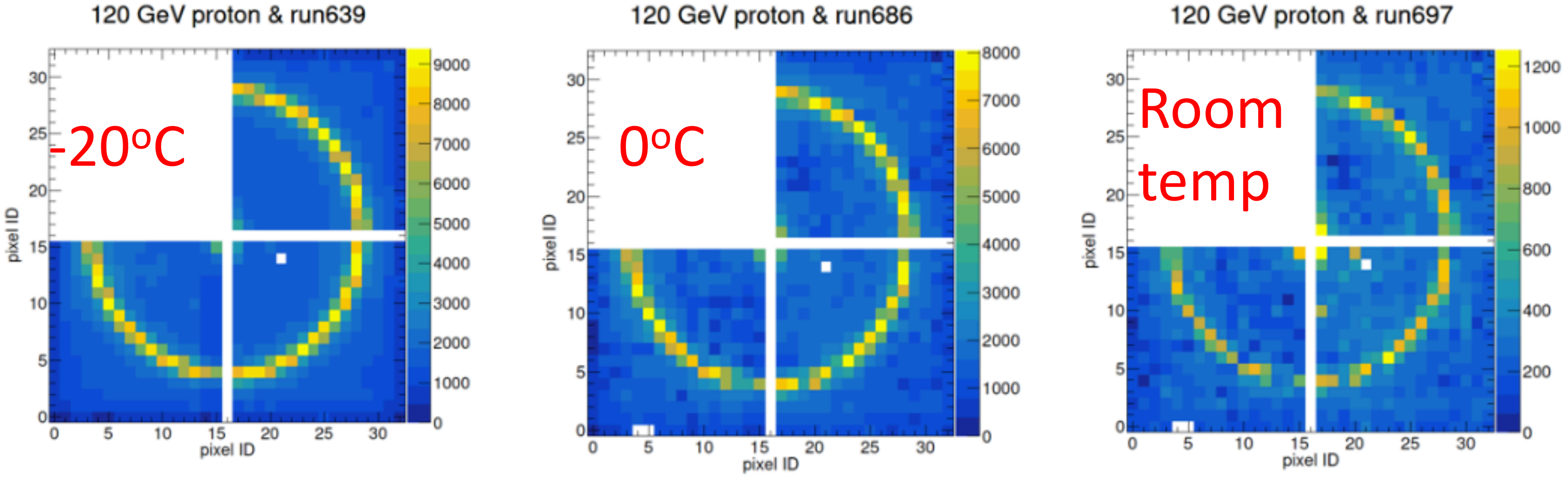
Four Hamamatsu H13700 PMTs (3mm x 3mm pixel size; 16x16 channels) were used in these test runs. Each costs ~$5k. These sensors will NOT work in high magnetic field!!!

mRICH Ring Images from SiPM Sensors (a FIRST!)

To meet the requirement of operating photosensors in high magnetic field in EIC experiment, we successfully demonstrated ring imaging construction using mRICH in the 2nd beam test. There were only three Hamamatsu SiPM matrices available at the time of this test. Given the limited beam time, we only took data with the primary proton beam at 120 GeV with cooling temperature settings at -30°C, -20°C, -10°C, 0°C and room temperature.



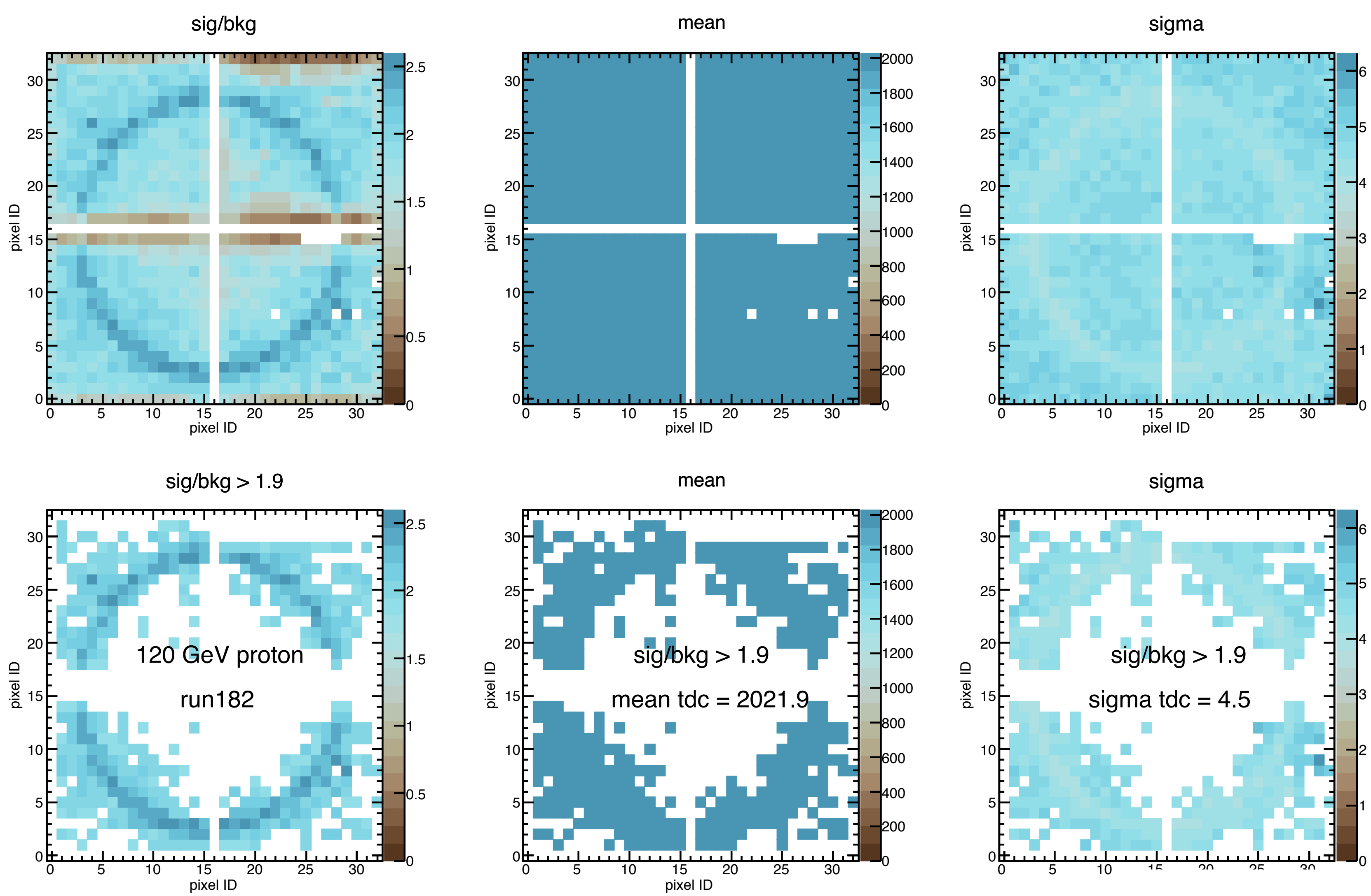
SiPM matrix assembly and Cooling setup



Cumulative ring images from 120 GeV/c proton beam at center

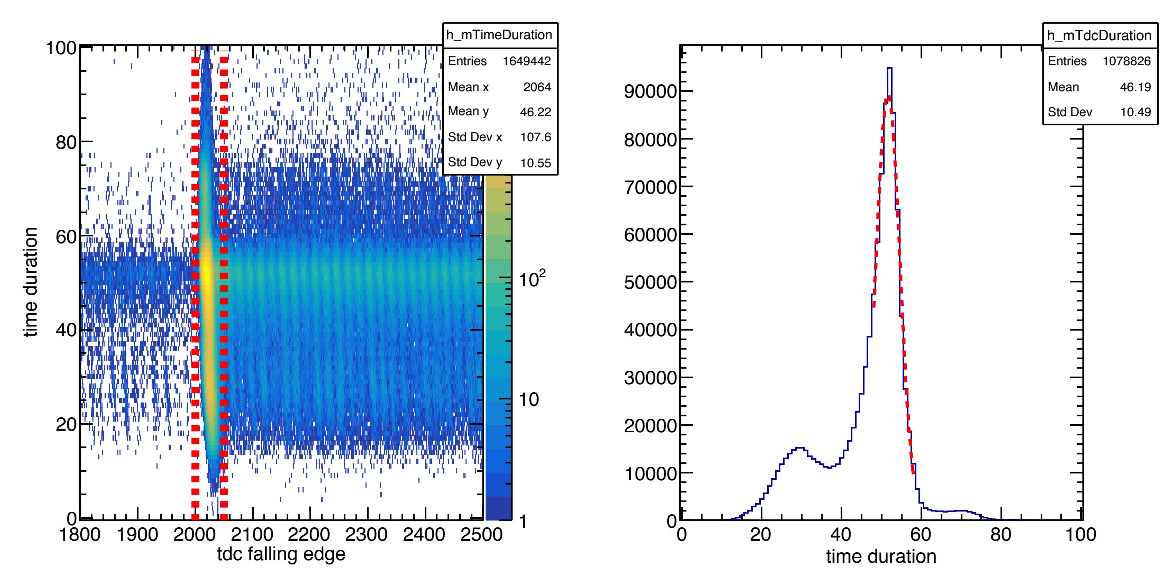
Ongoing effort: (a) photon hit timing structure; (b) noise level study; and (c) event-by-event ring image construction and fine tuning simulation.

TDC Signal Selection for Test Beam Analysis

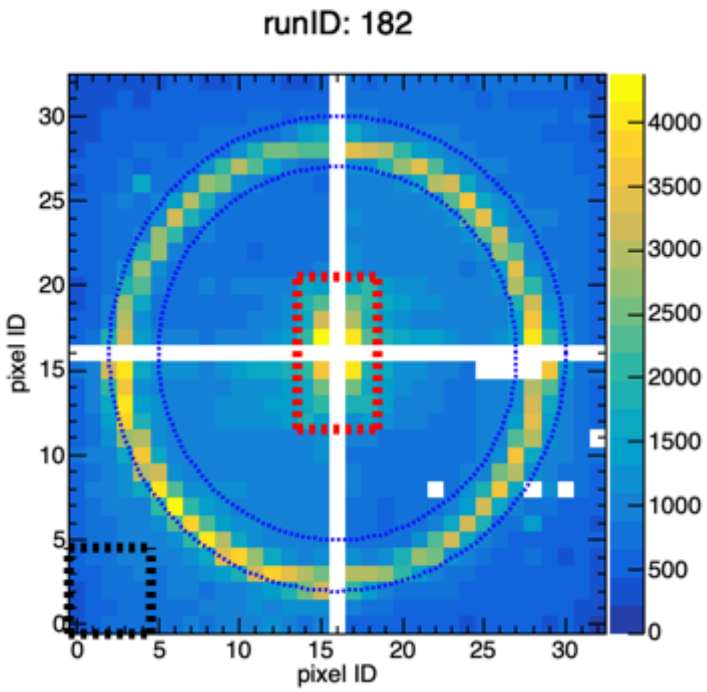


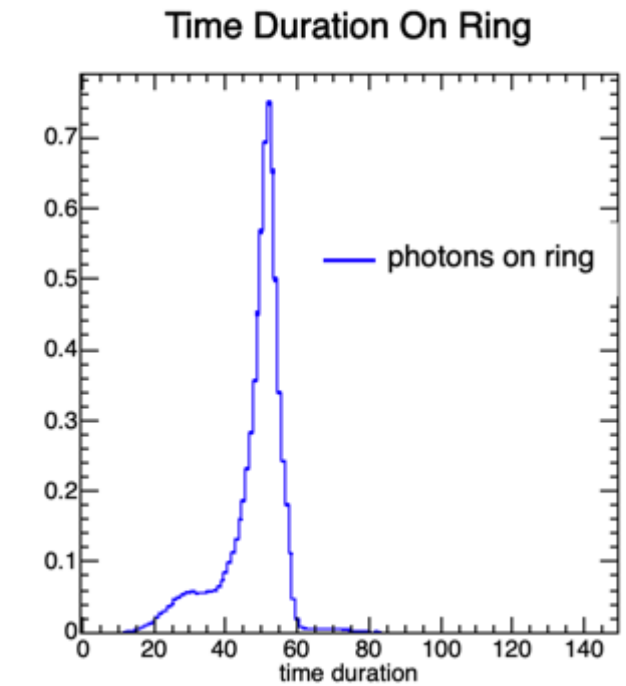
- save mean & sigma of tdc
- tdc cuts set to 2 sigma

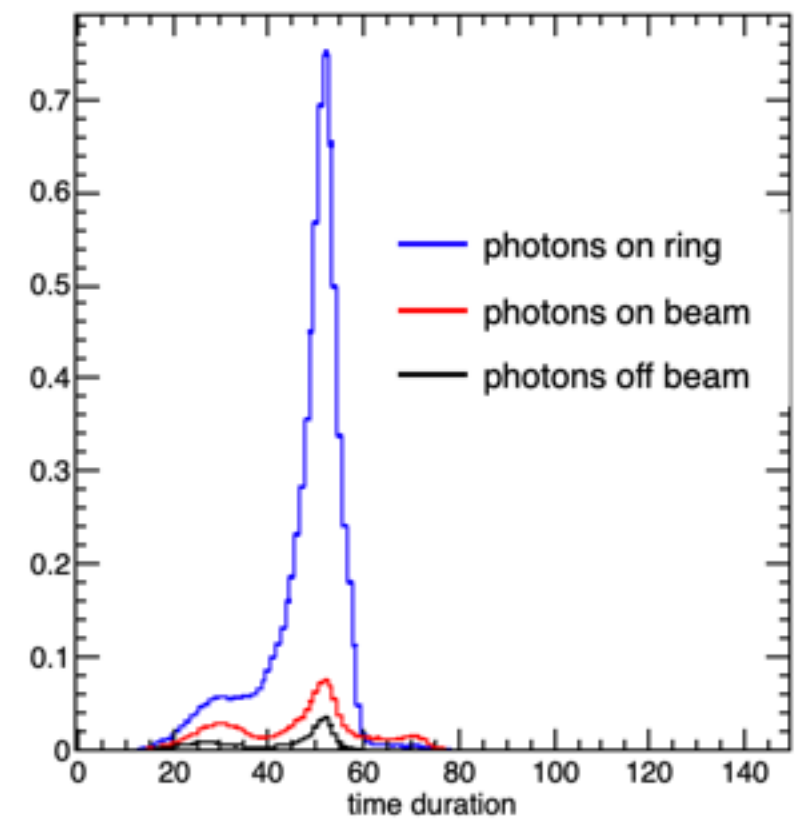
- time = tdc_raising - tdc_falling
- projection range is under investigation
- 2 sigma cut applied to test beam data

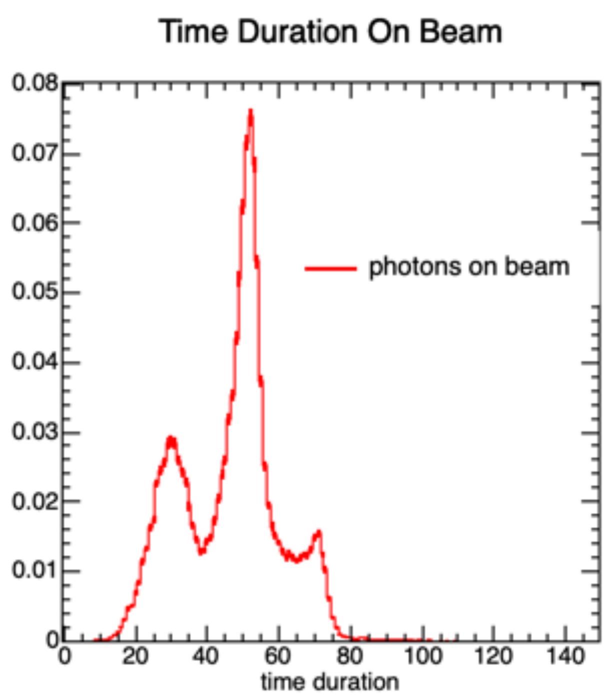


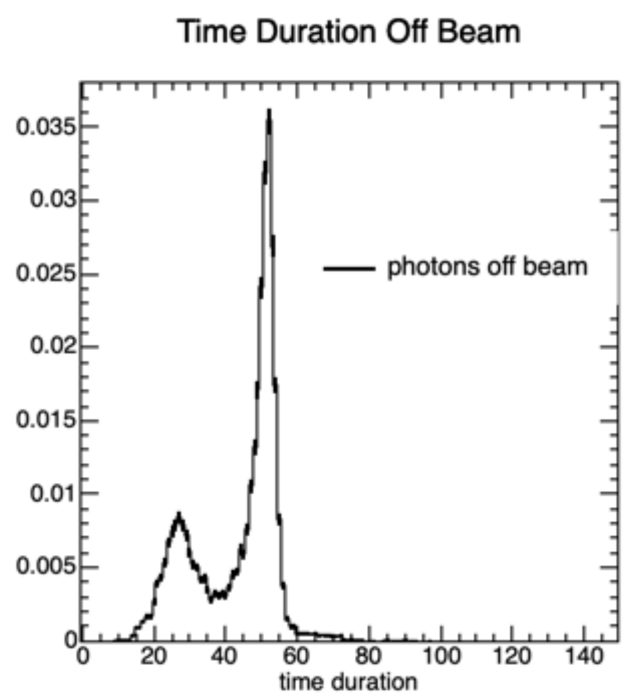
Time Duration for Test Beam Analysis







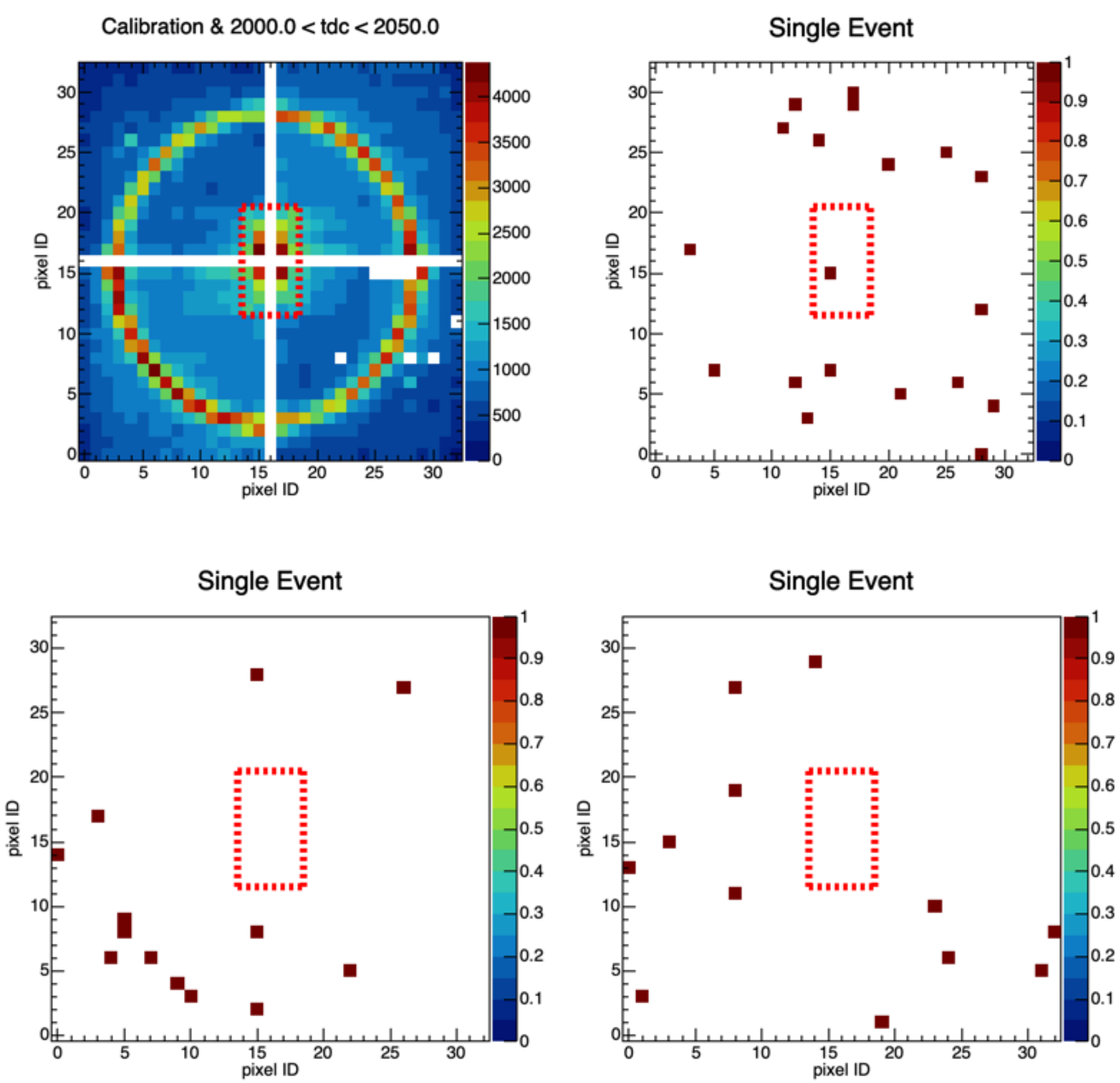




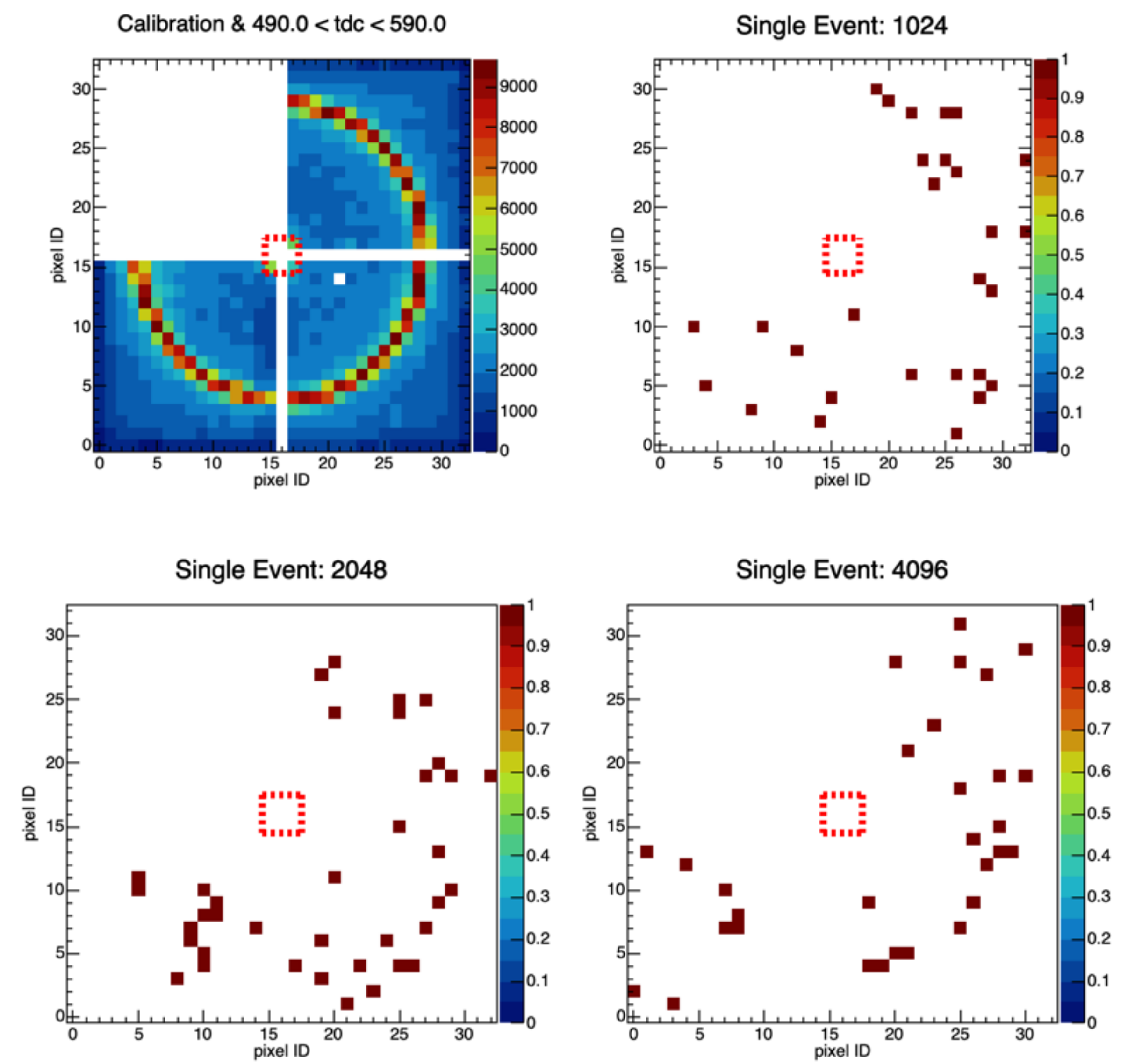
- time duration signal shows different patterns
- but hard to select on event level

Event-by-Event Analysis (example)

With 4 H13700 – PMT's



With 3 Hamamatsu SiPM matrices (-30^{o}C)

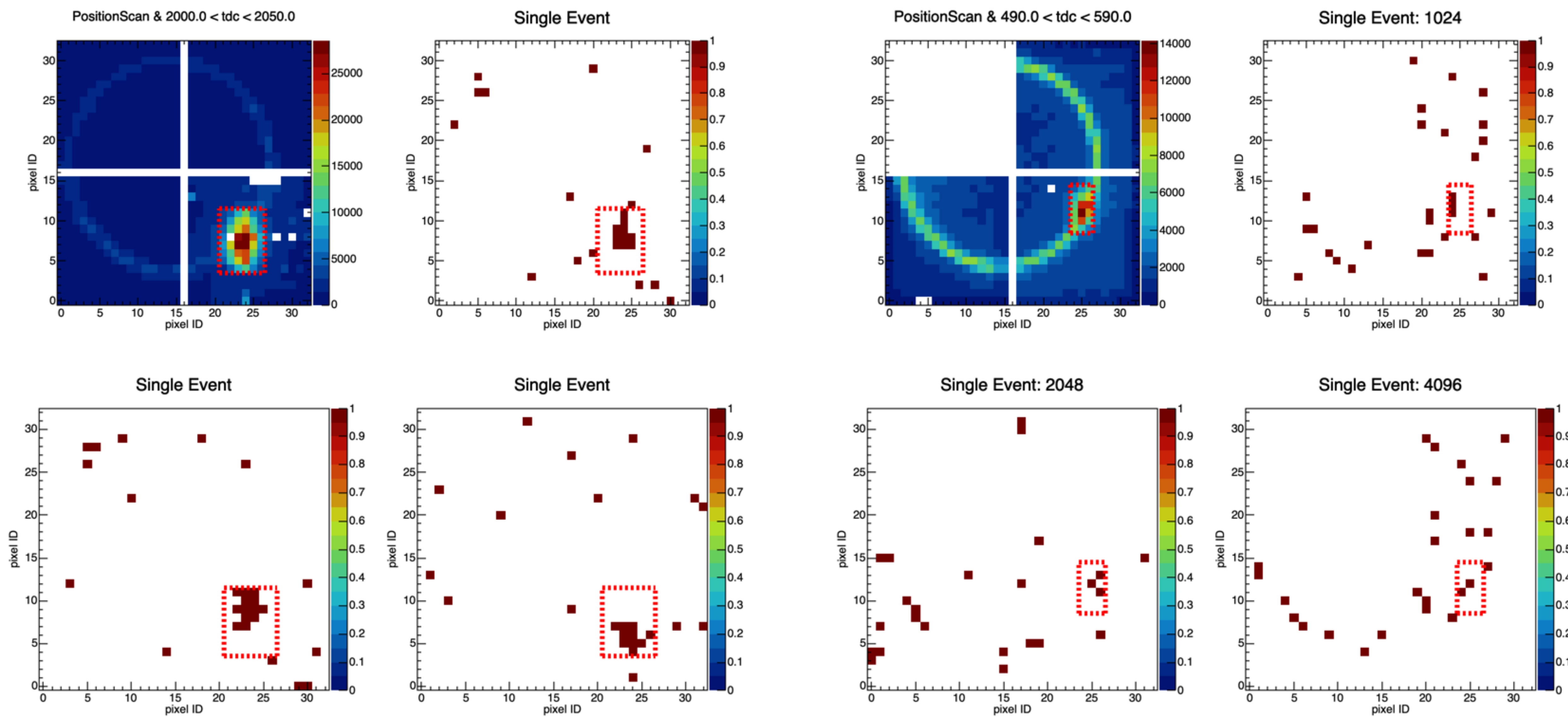


120 GeV/c proton beam incident at the center of mRICH - baseline analysis

Event-by-Event Analysis (example)

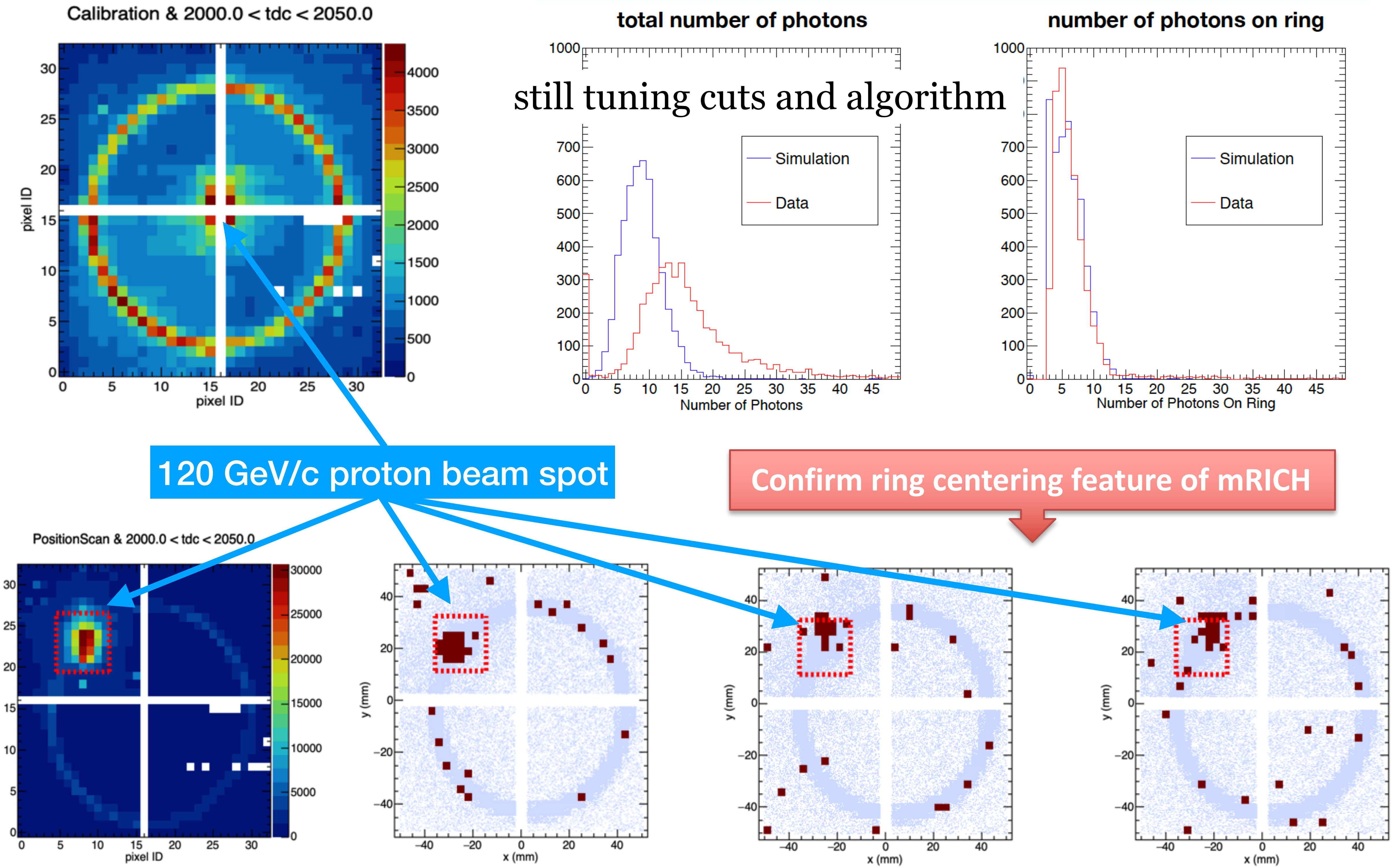
With 4 H13700 – PMT's

With 3 Hamamatsu SiPM matrices (-30°C)



- beam spot can be identified with a group of fired pixels in PMTs
- beam spot in SiPMs is less significant than PMTs

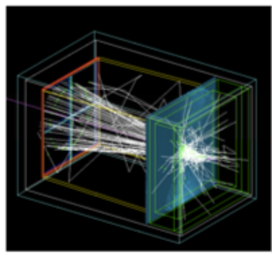
Baseline Performance as Expected

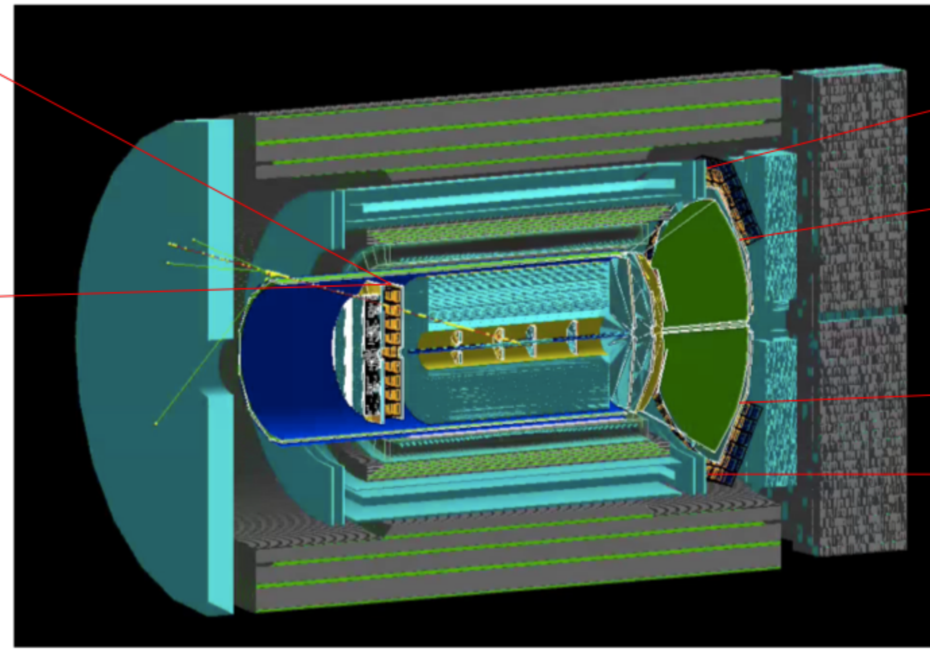


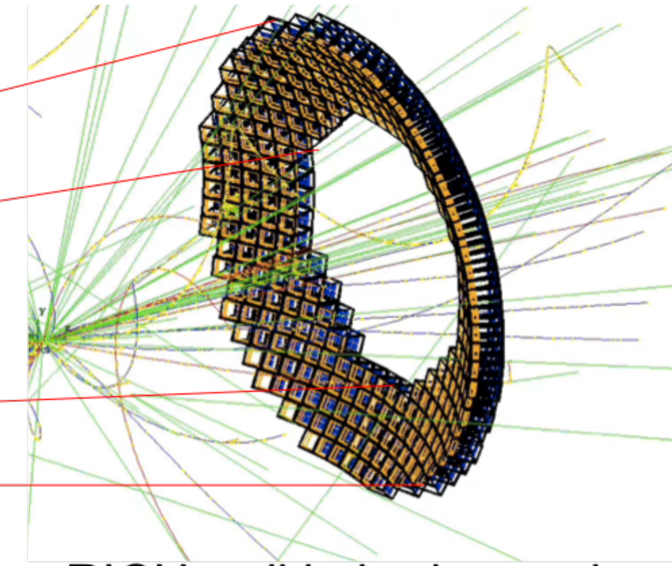
Cumulative image

Single event samples (shaded ring images are from simulation)

mRICH in an EIC Detector Built Around the sPHENIX Solenoid







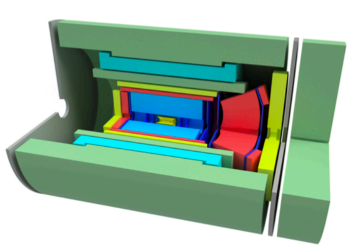
mRICH wall
e/π separation

mRICH wall in hadron-going direction for hadron PID

sPHENIX-note sPH-cQCD-2018-001

An EIC Detector Built Around The sPHENIX Solenoid

A Detector Design Study



Christine Aidala, Alexander Bazilevsky, Giorgian Borca-Tasciuc, Nils Feege, Enrique Gamez, Yuji Goto, Xiaochun He, Jin Huang, Athira K V, John Lajoie, Gregory Matousek, Kara Mattioli, Pawel Nadel-Turonski, Cynthia Nunez, Joseph Osborn, Carlos Perez, Ralf Seidl, Desmond Shangase, Paul Stankus, Xu Sun, Jinlong Zhang

For the EIC Detector Study Group and the sPHENIX Collaboration

October 2018

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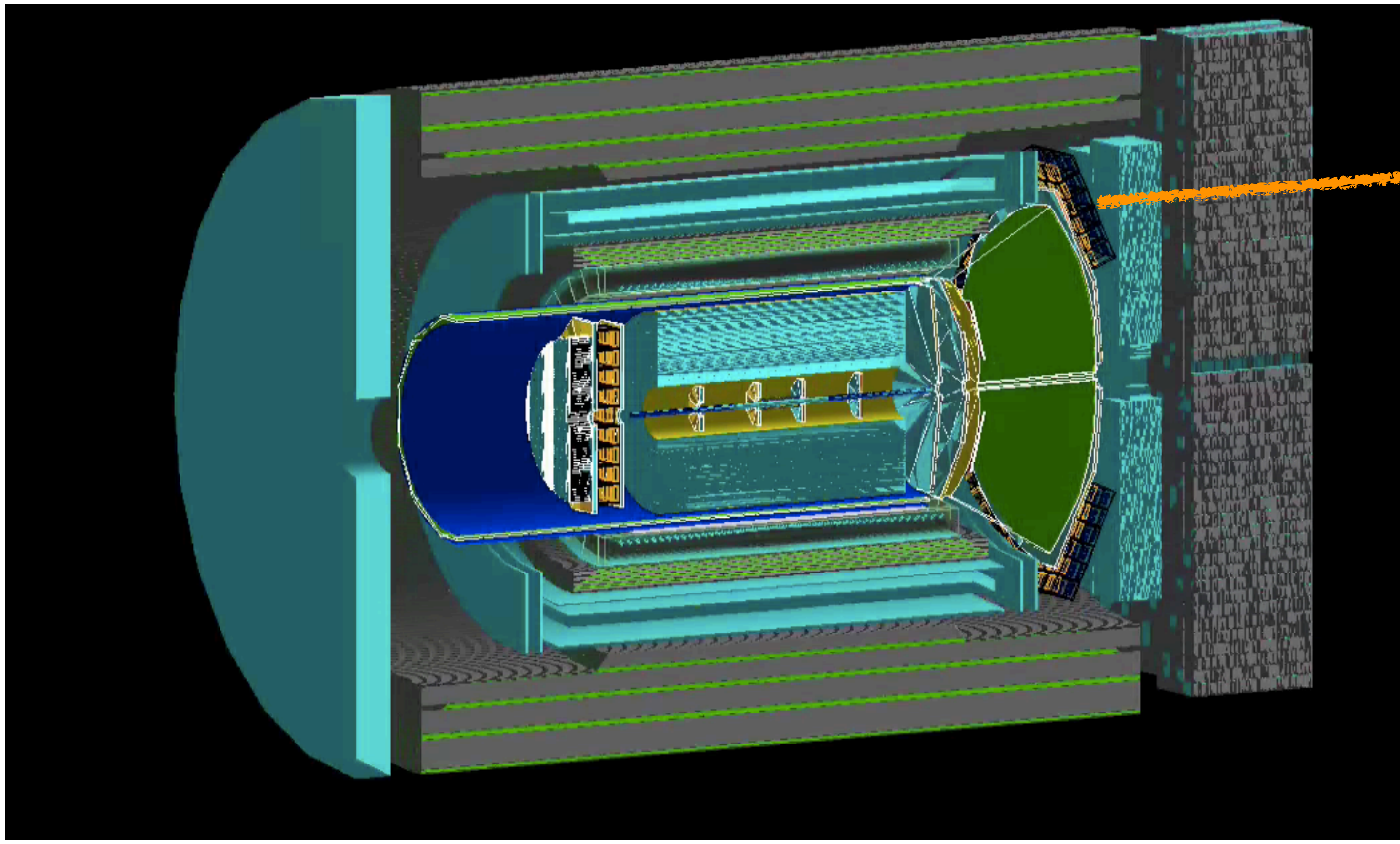
Summary and Outlook

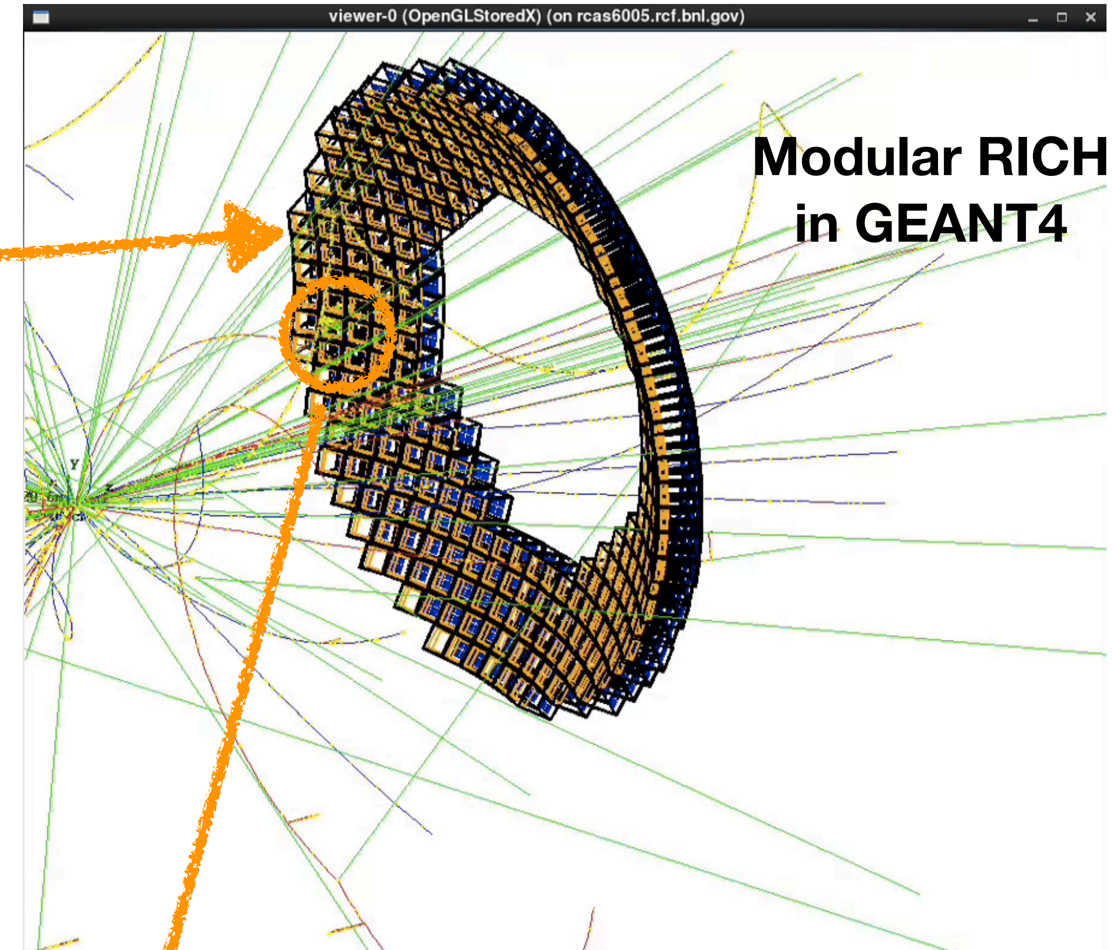
- The 1st test beam result verified mRICH working principle while the second established the PID capability
- Data analysis of the second mRICH beam test (ongoing effort).
- Study of radiation hardness of Fresnel lens.
- Simulation study of mRICH performance in the electron endcap of JLEIC and in the Forward sPHENIX experiments at BNL (ongoing effort).
- Organize a joint dRICH/mRICH beam test. Plan for an electron beam (~2 GeV/c) test.
- Optical characterization of Fresnel lens and aerogel block properties.

Thanks for your attention!

Backups

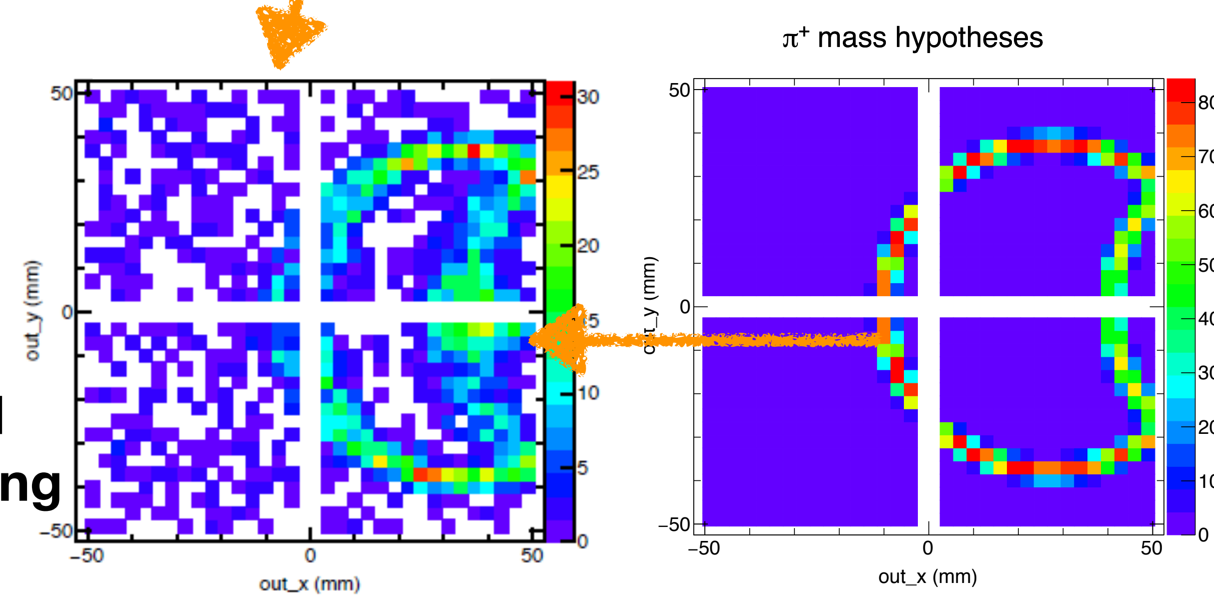
mRICH in EIC



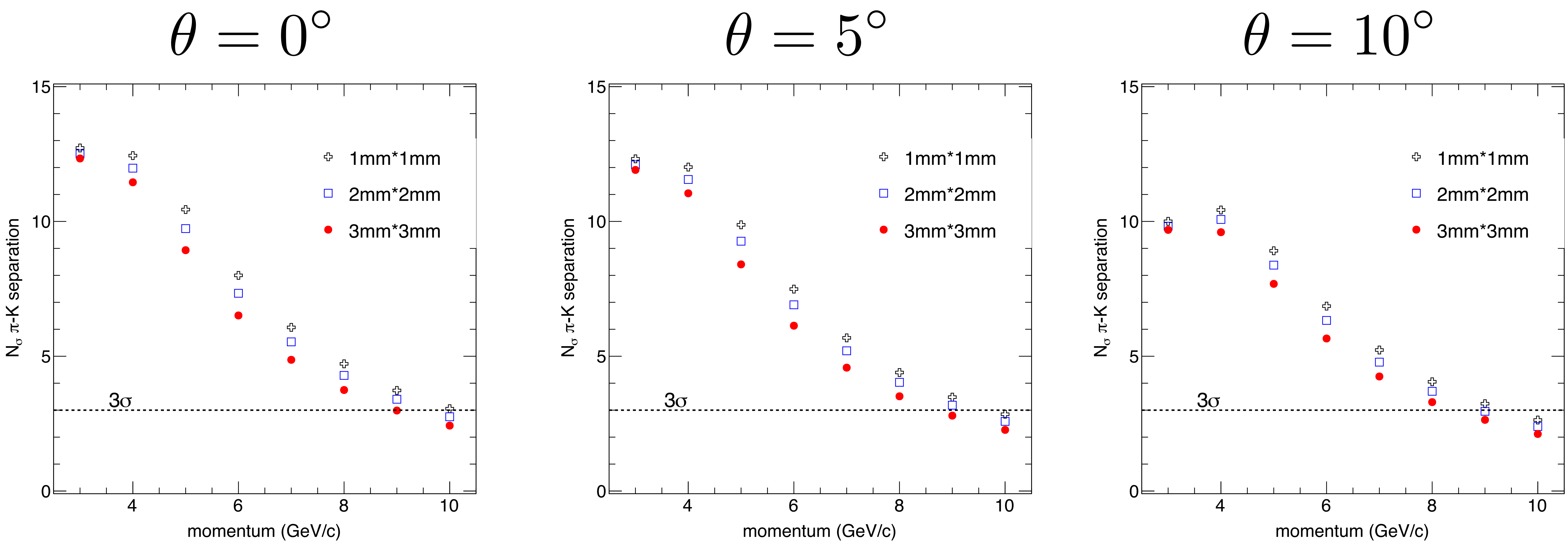


- validate in PYTHIA simulation
- likelihood method is available for PID

Modular RICH reconstructed ring

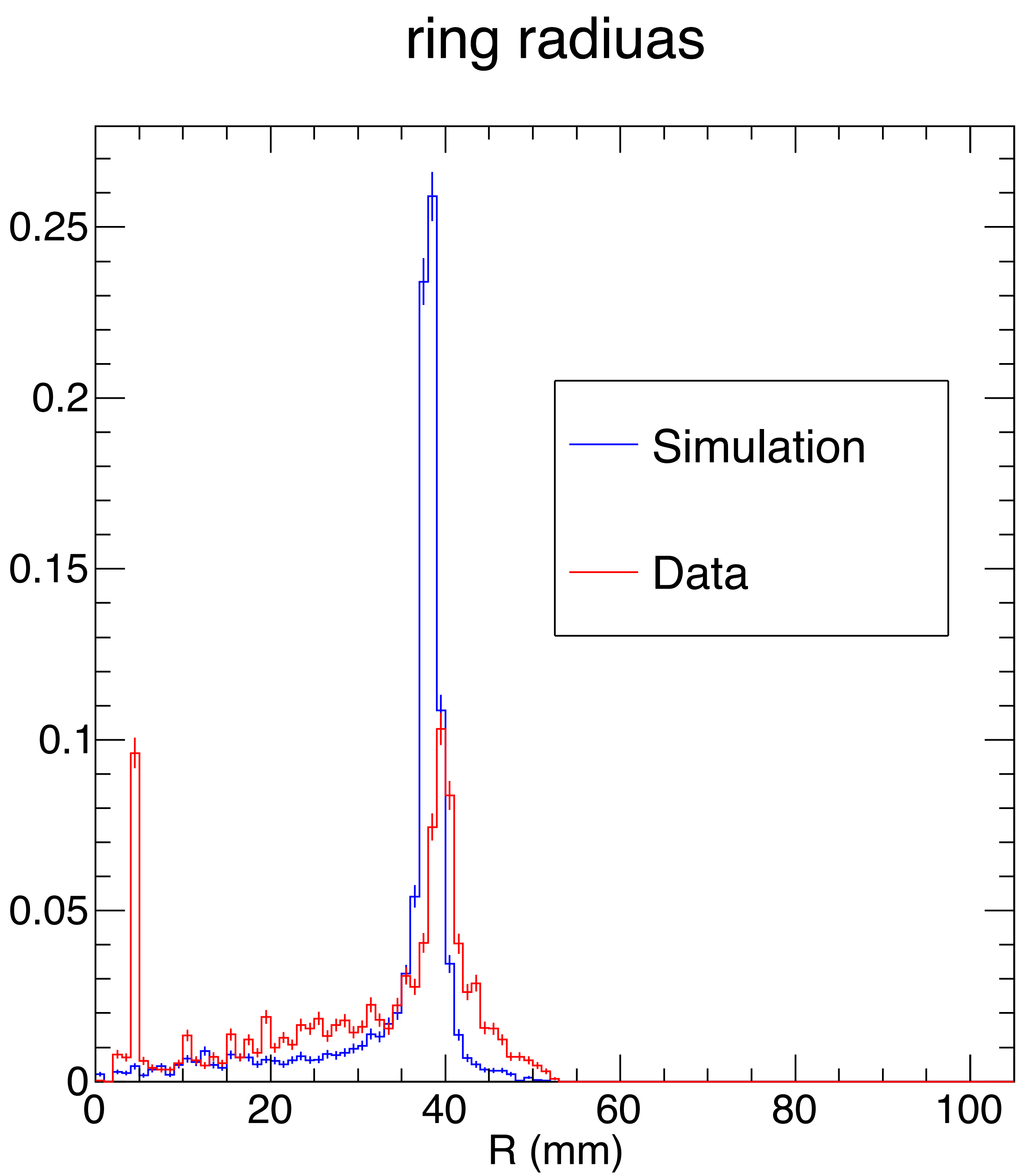


Separation Power



- 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

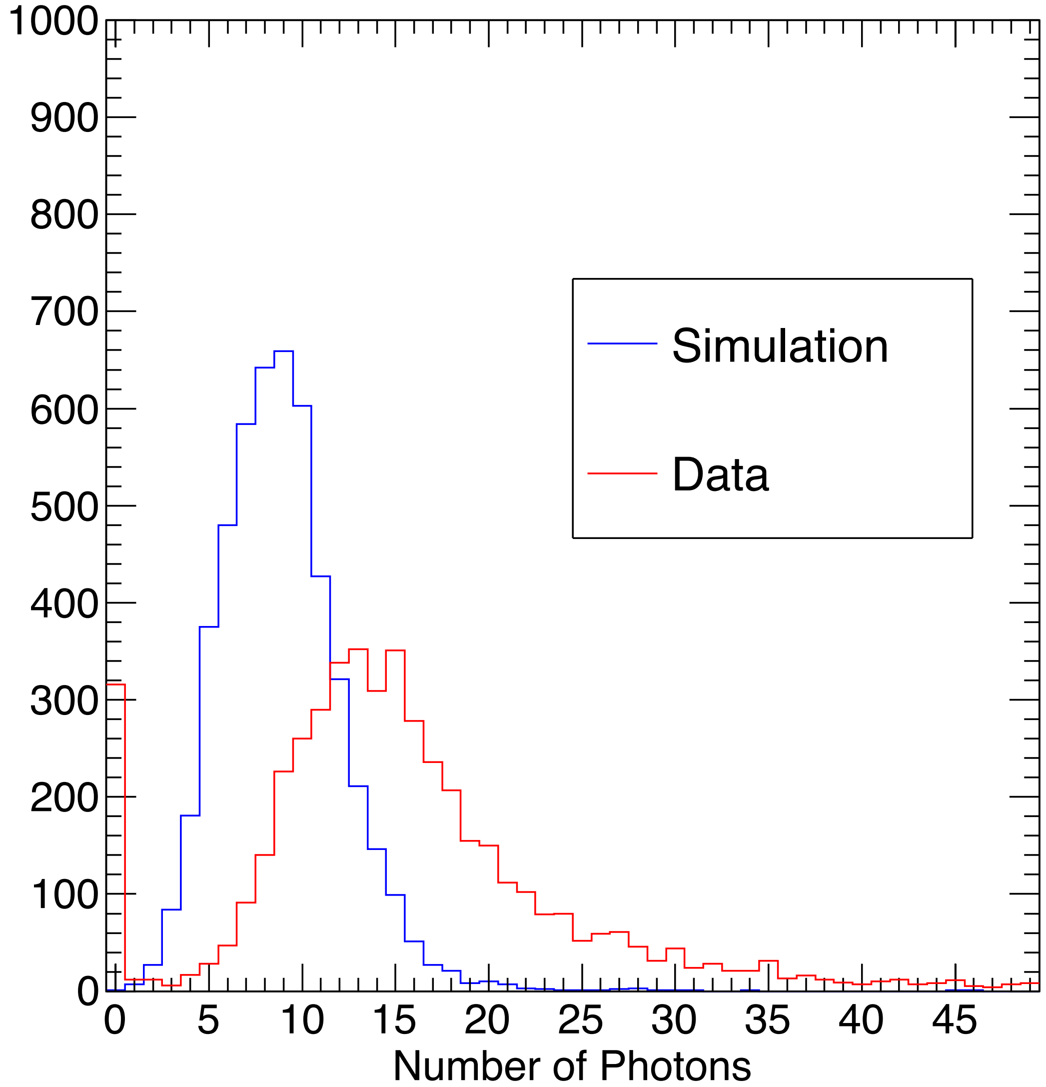
Ring Radius



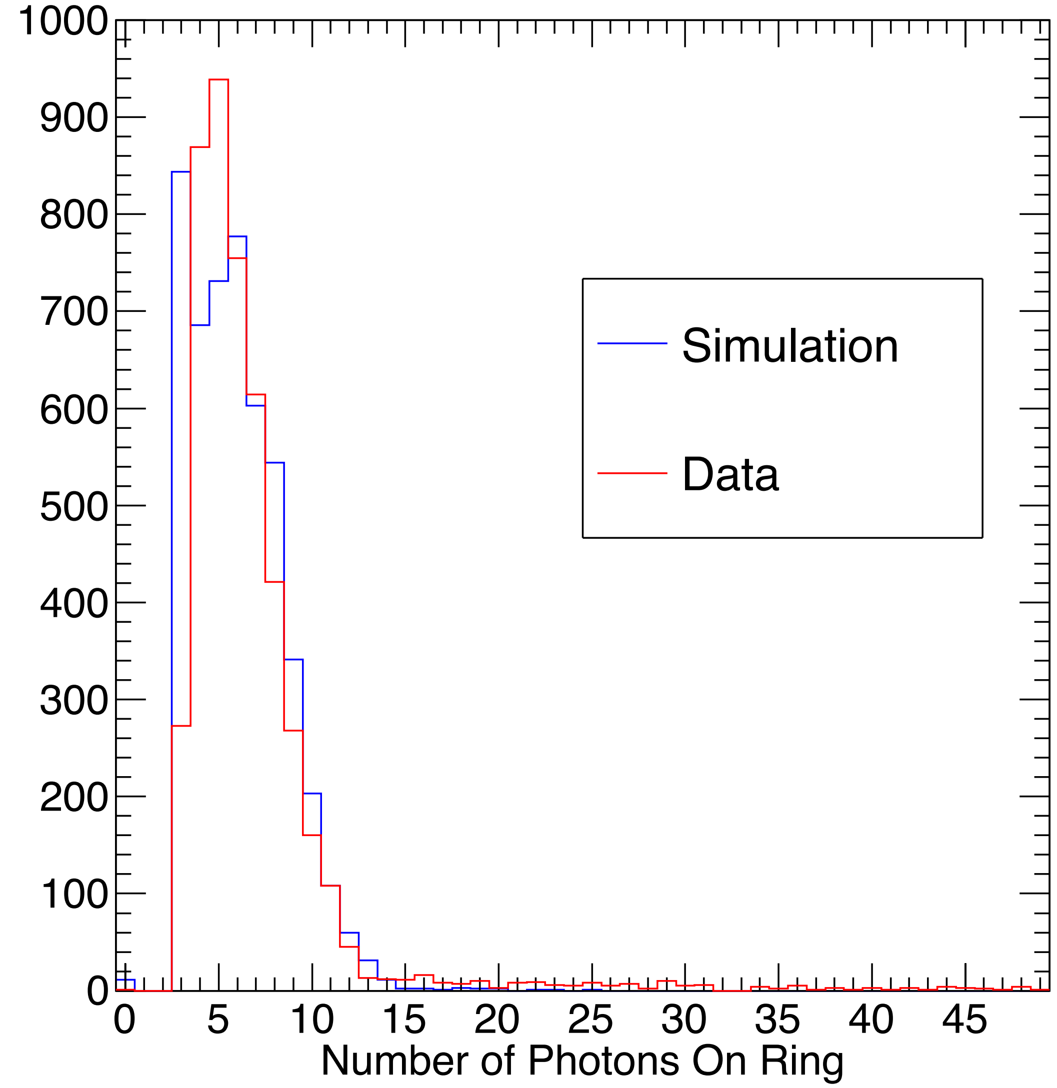
- **Radius in data is slightly larger than simulation => due to sensor geometry**

Number of Photons

total number of photons

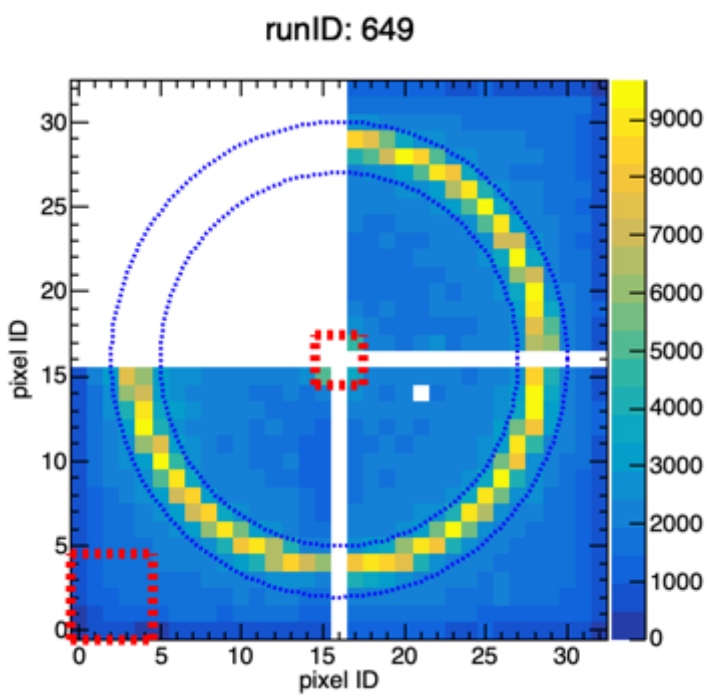


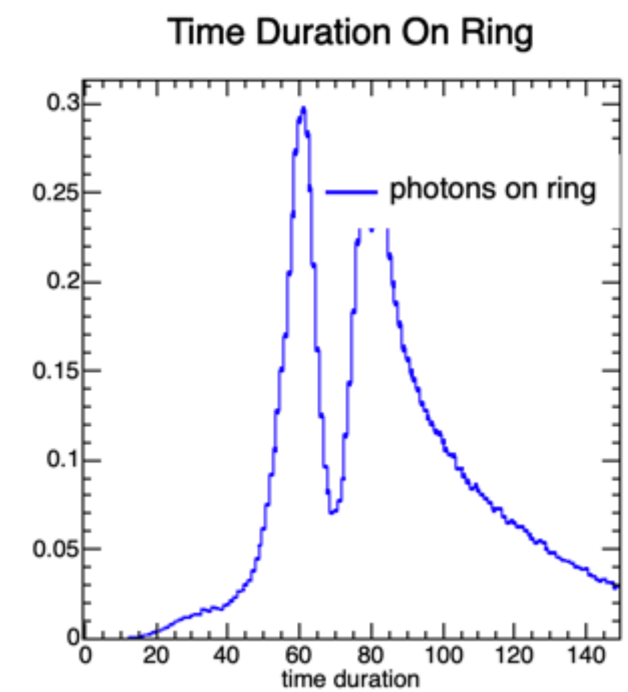
number of photons on ring

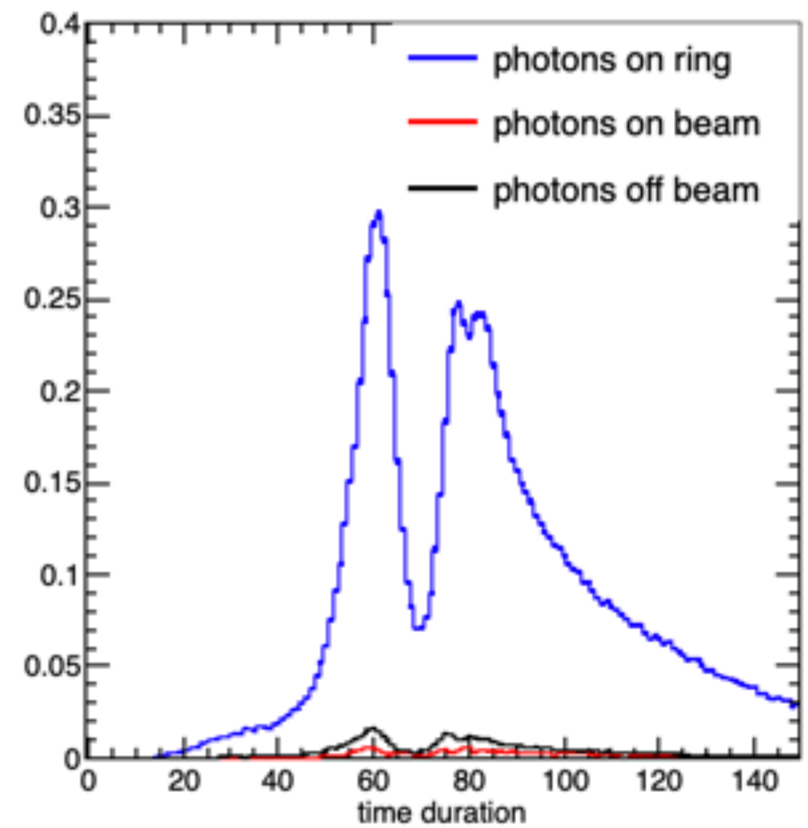


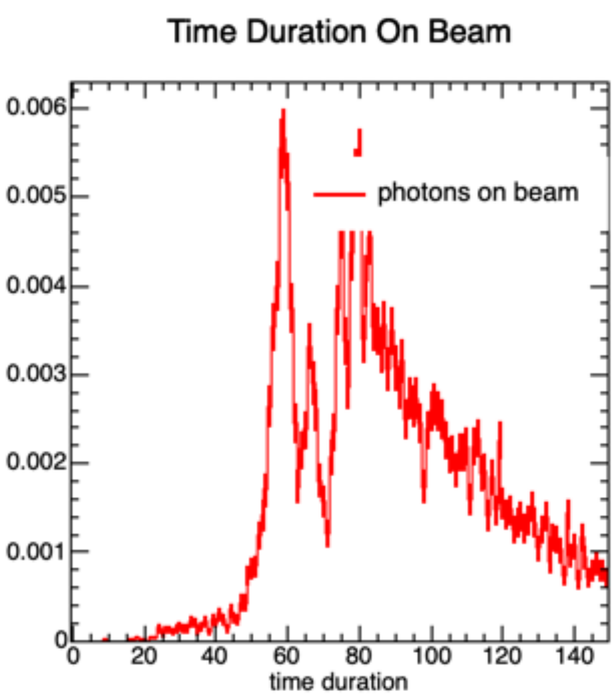
- **data shows more total photons**
- **photons on ring matched with simulation**
- **more photons from noise?**

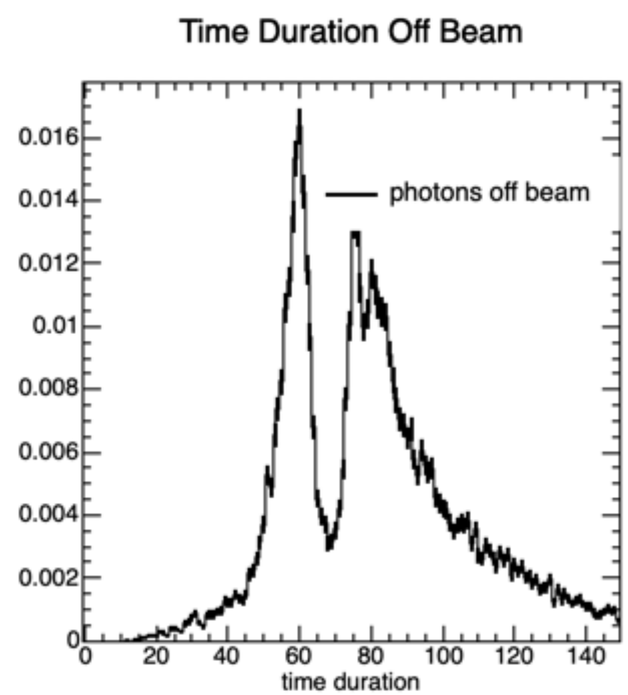
Time Duration for SiPMs





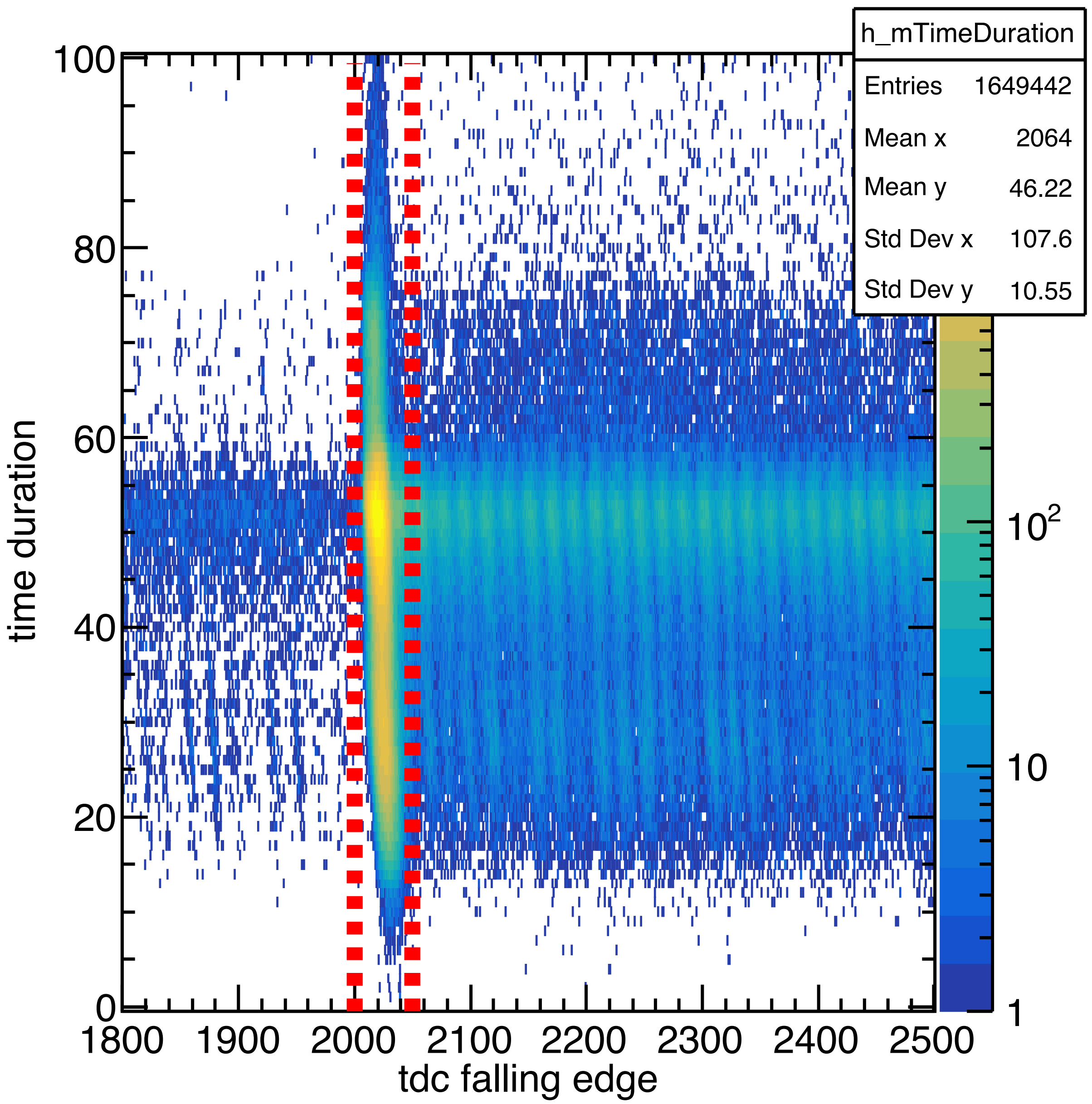


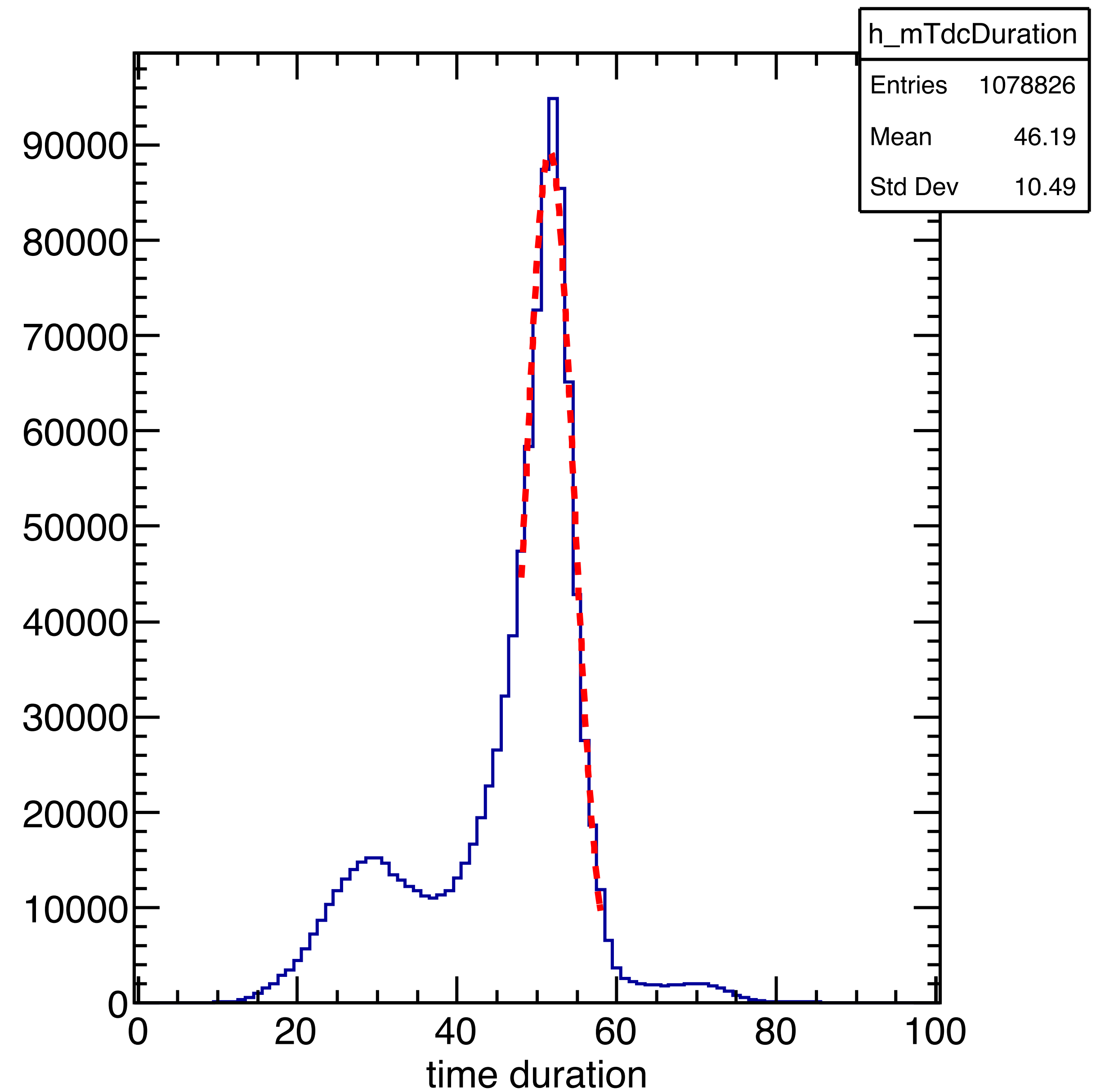




- time duration signal shows different patterns
- but hard to select on event level

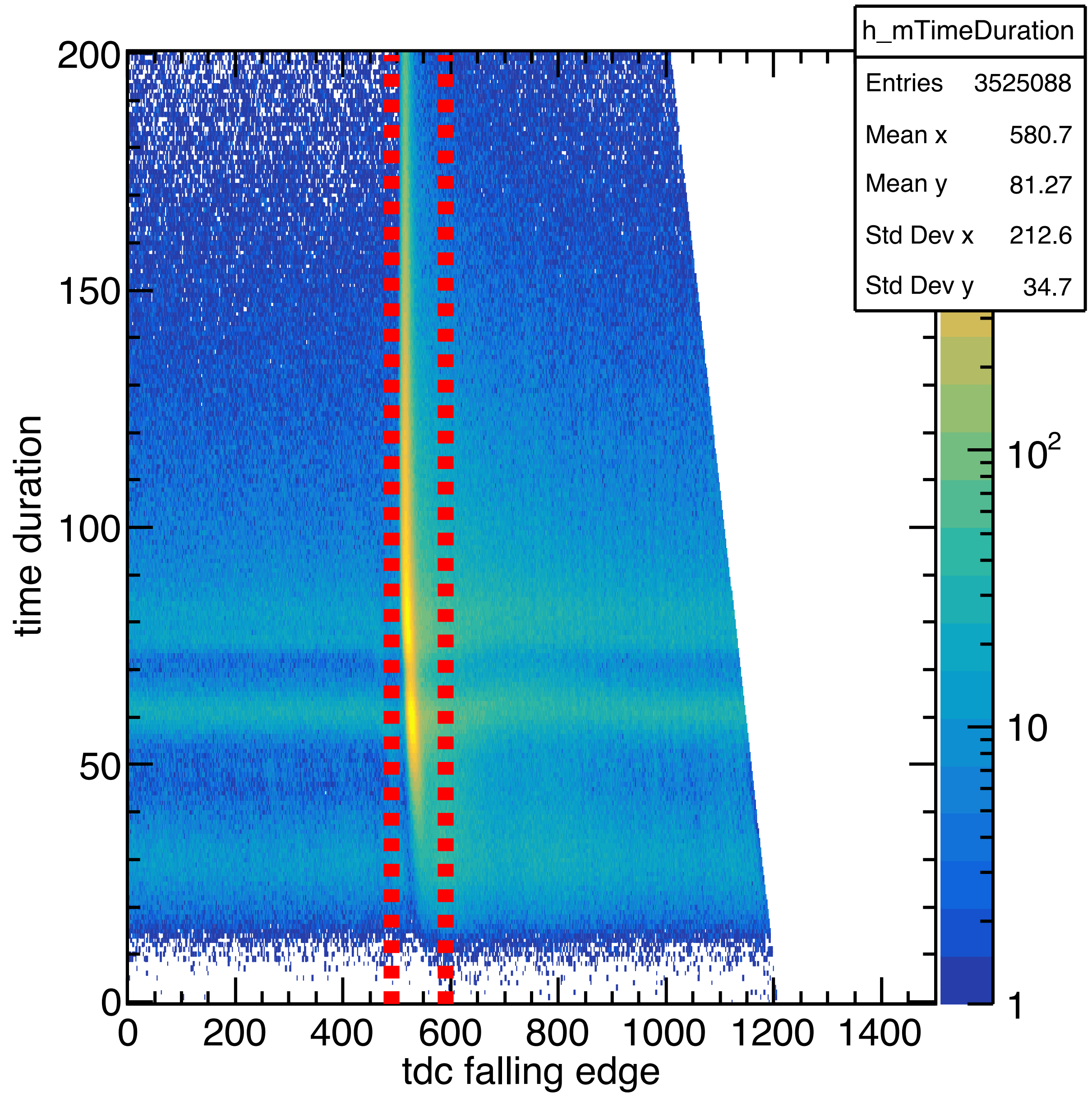
Time Duration Cut for PMTs

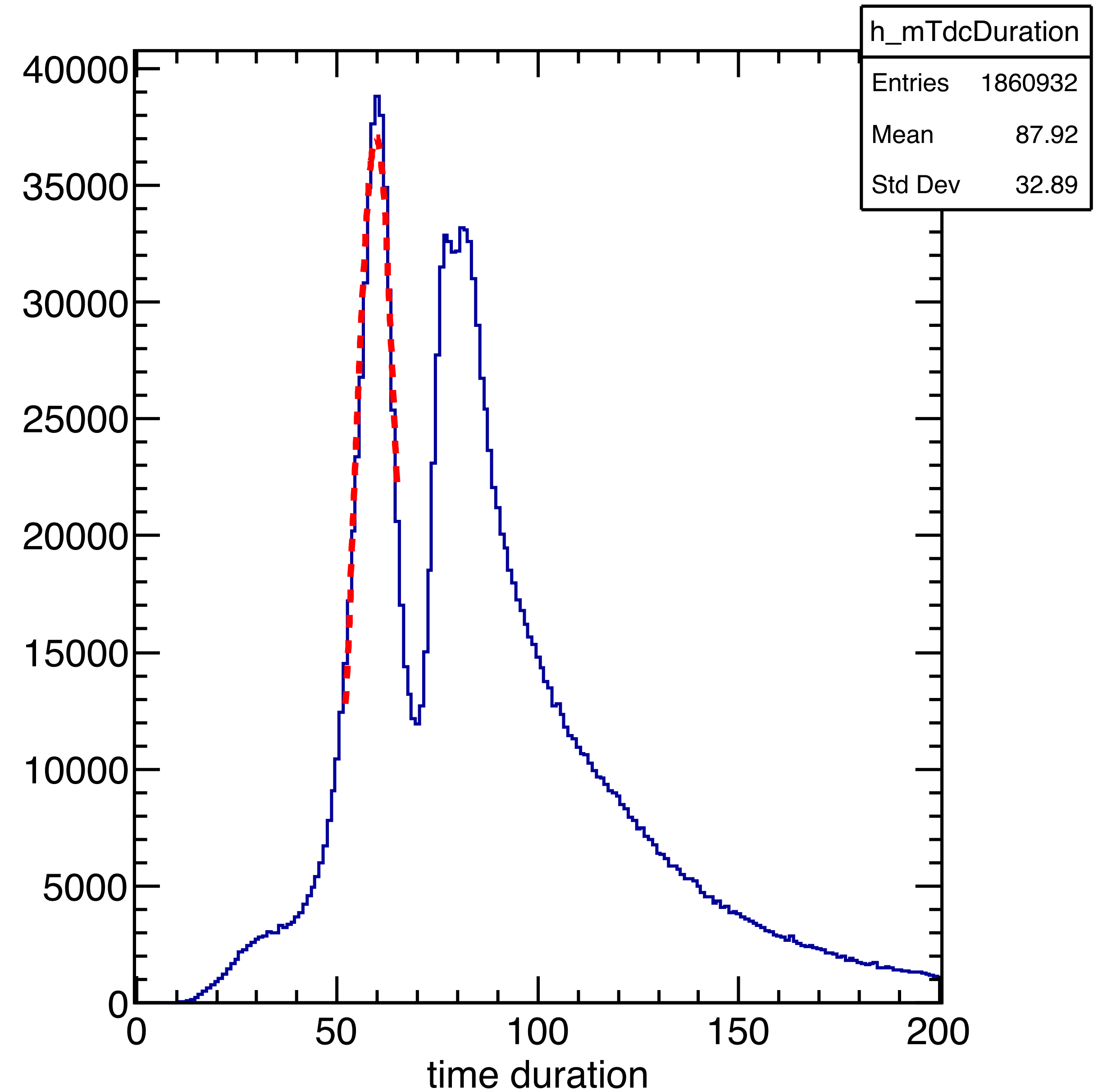




- time = tdc_falling - tdc_raising
- projection range is under investigation
- 2 sigma cut applied to test beam data

Time Duration Cut for SiPMs





- time = tdc_falling - tdc_raising
- projection range is under investigation
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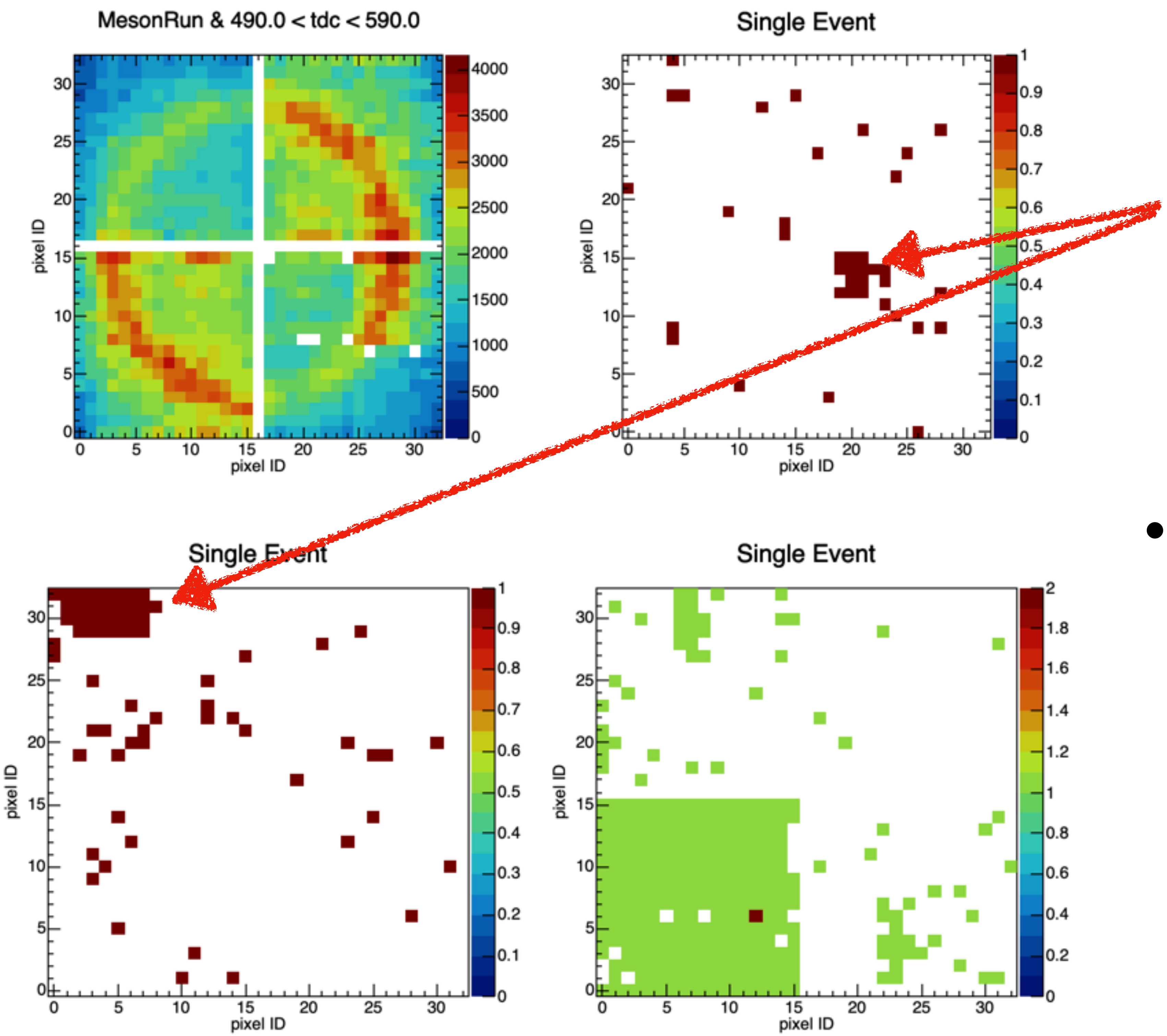
Ring Image for Meson Run



seems like beam?

- hard to tell where beam hits