mRICH for EIC YR

Xiaochun He and Murad Sarsour

Georgia State University

on behalf of the EIC PID Consortium (eRD14)

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YR progress report on April 15, 2020

General Comments

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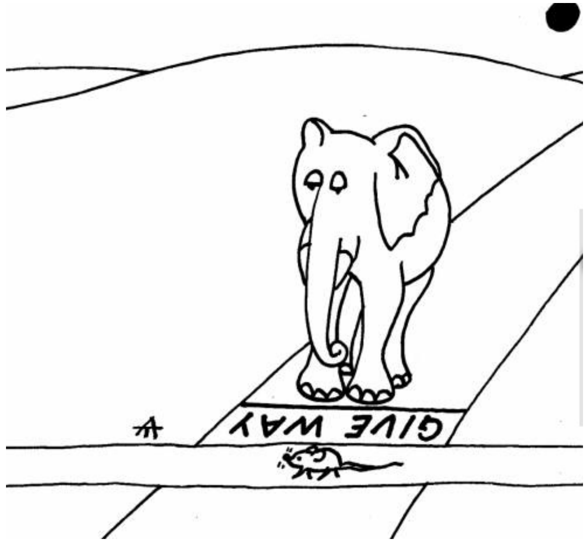
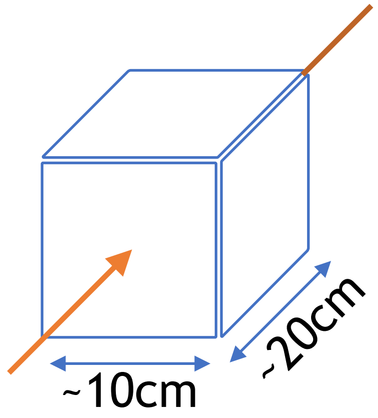
As Tom said a couple of times already, someone must make the first move. It is fair that we need to specify the tracking requirements for PID purposes relatively soon and to compare the requirements imposed by reconstructing the resonant states (D^0 as an example), etc.



To a first order estimation of the external requirement (i.e. tracking) for achieving the mRICH performance, our discussion will be mainly focused on a special case which will allow us to calculate the mRICH properties analytically.

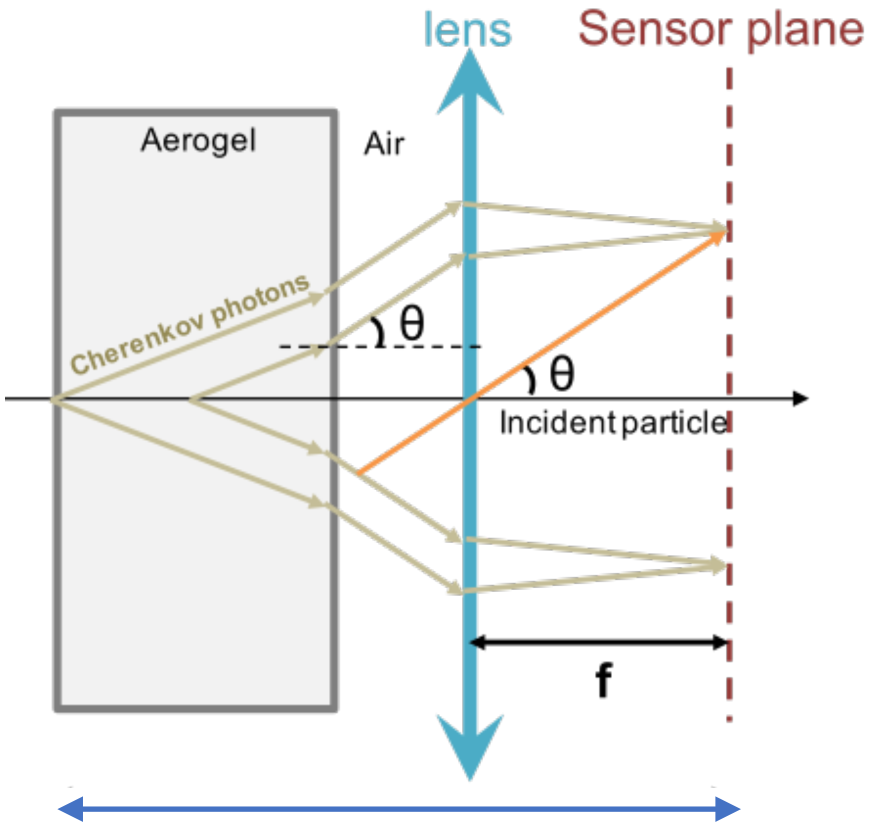


This special case is that the particle is incident normal to the front of mRICH at the center. The mRICH performance with varying momentum direction and magnitude are part of the ongoing work which includes GEANT4 simulation and prototyping studies.

mRICH
Internal Characteristics

Design tooling: analytical calculation, GEANT4 simulation and prototyping

EIC mRICH – Working Principle (Recap)



~ (aerogel thickness + lens focal length)

(Not to scale, for illustration purpose only)

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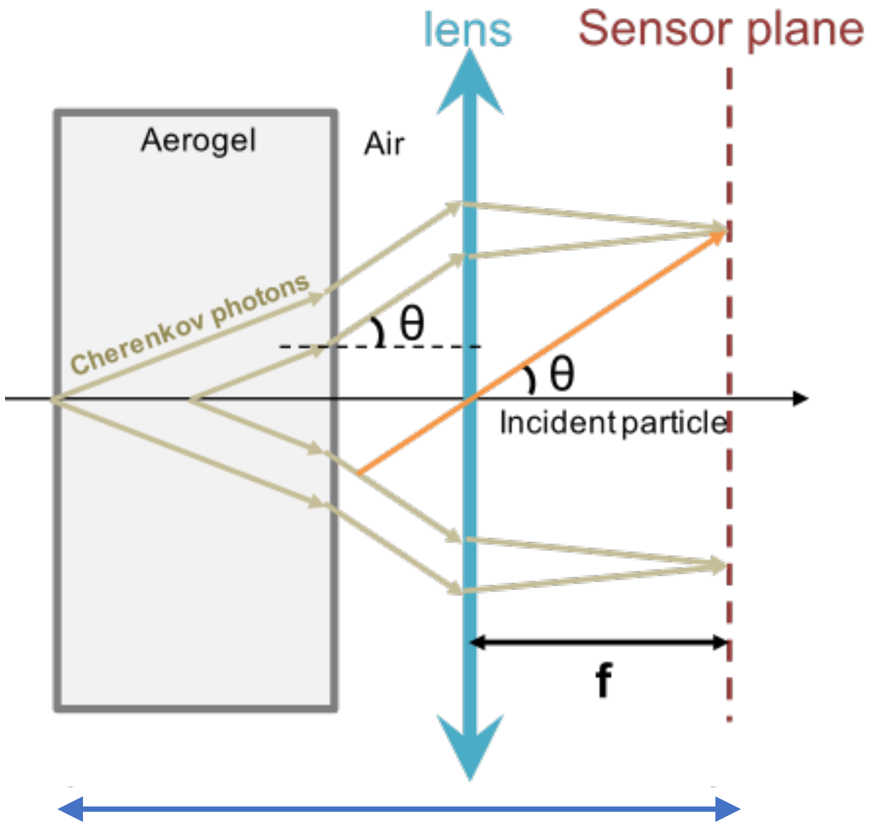

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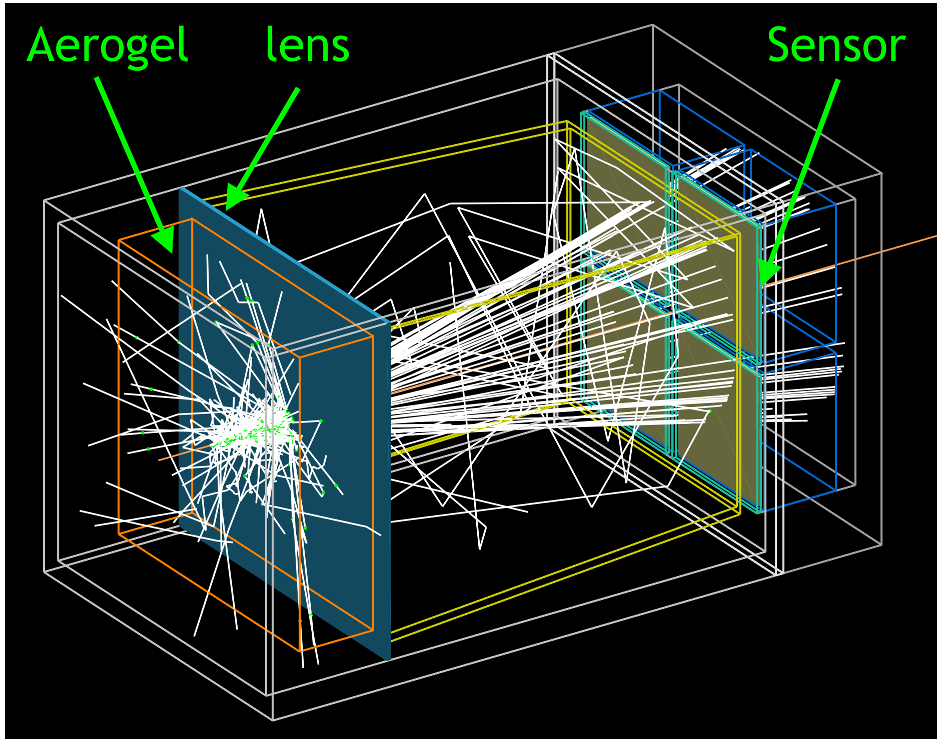


Geant4 Simulation

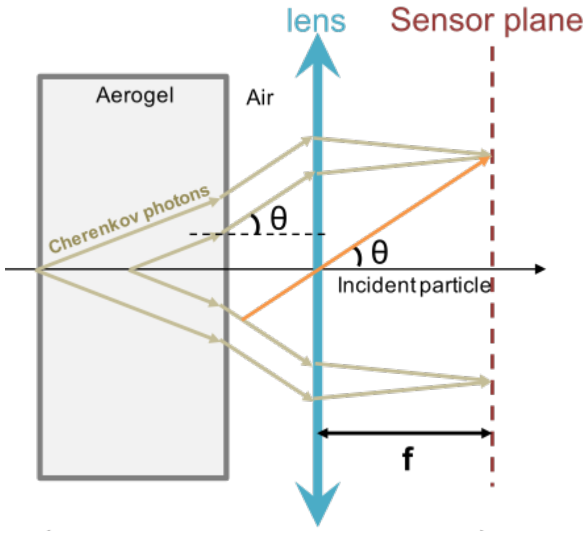
With realistic material optical properties

Analytical Calculation (A special case)

When particle is incident perpendicular at the center of mRICH, one can obtain the ring radius and the number of Cherenkov photons analytically. The details can be found in the appendix of the published mRICH NIM paper.

$$r = f \cdot \tan\theta = f \cdot \sqrt{\frac{n^2\beta^2 - 1}{1 - (n^2 - 1)\beta^2}}.$$

$$N_\gamma = 2\pi\alpha L \left(1 - \frac{1}{\beta^2 n^2}\right) \times \int_{\lambda_1}^{\lambda_2} QE(\lambda) \cdot T_{aerogel}(\lambda) \cdot T_{lens}(\lambda) \cdot T_{glass\ window}(\lambda) \frac{d\lambda}{\lambda^2}.$$



Nuclear Inst. and Methods in Physics Research, A 871 (2017) 13–19

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

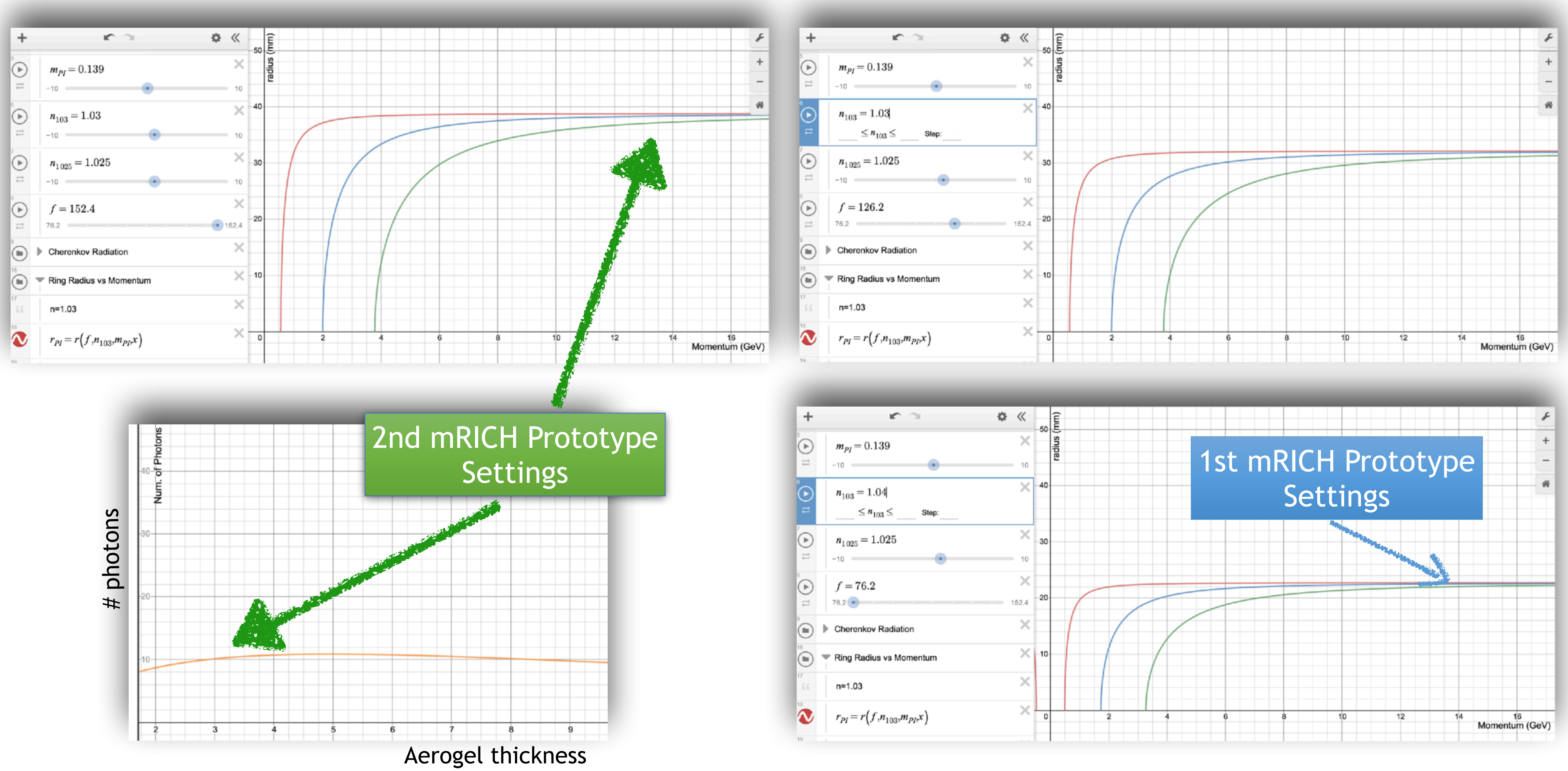
journal homepage: www.elsevier.com/locate/nima

ELSEVIER

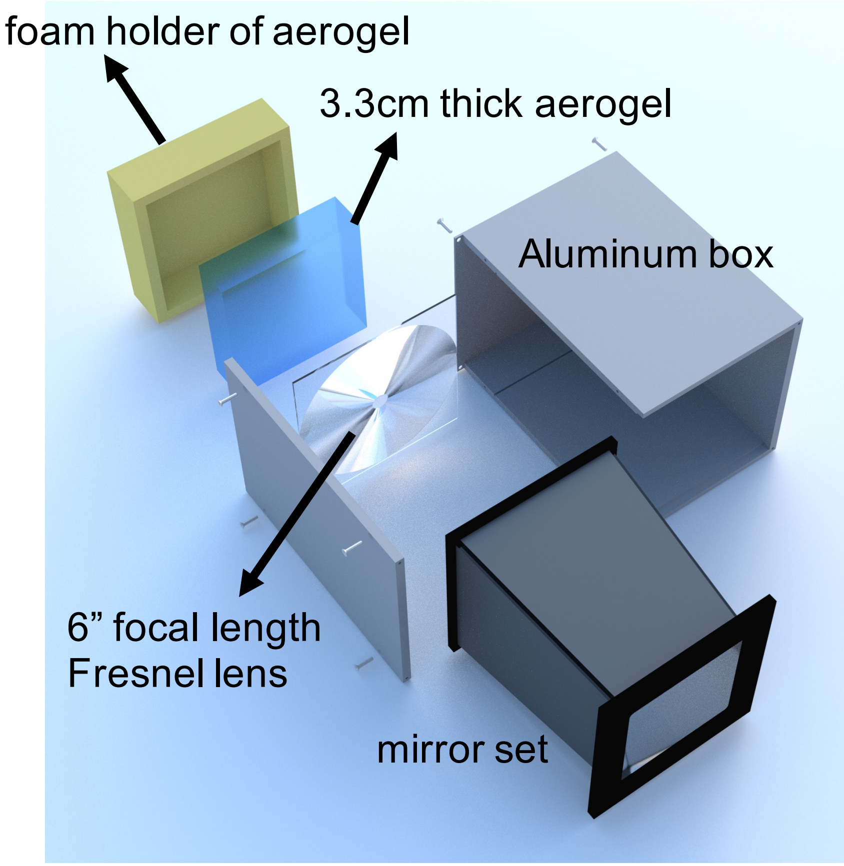
Modular focusing ring imaging Cherenkov detector for electron–ion collider experiments☆

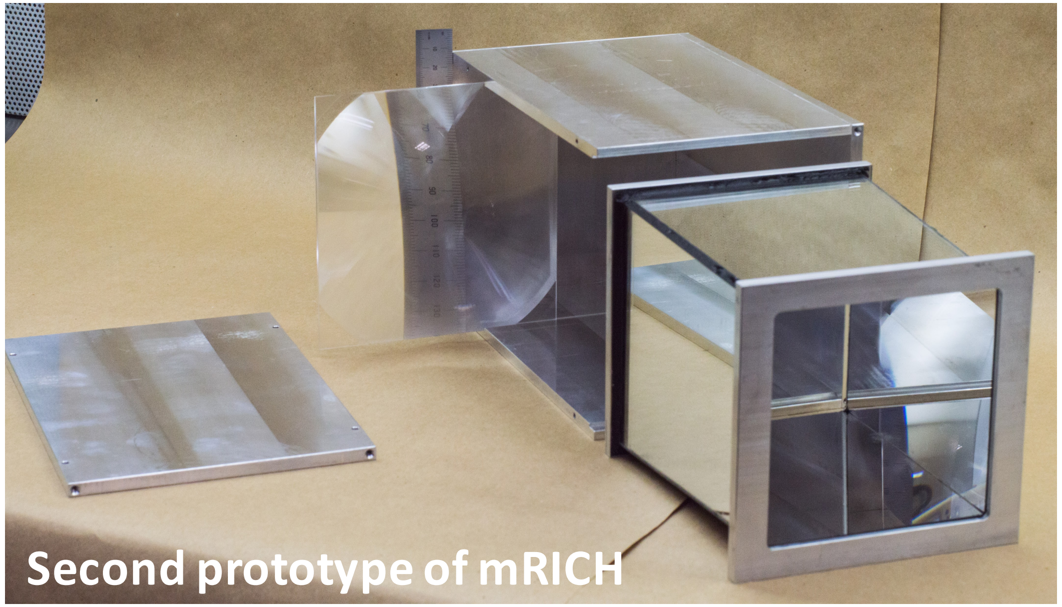
C.P. Wong[g,*], M. Alfred[i], L. Allison[o], M. Awadi[i], B. Azmoun[c], F. Barbosa[m], L. Barion[j,r],

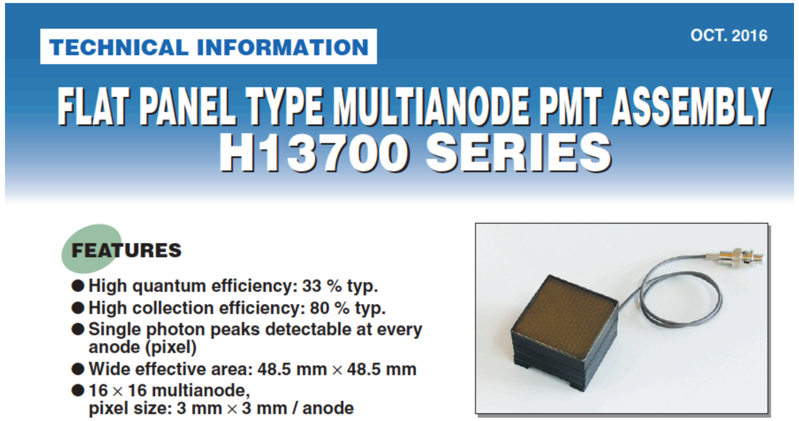
Examples from Analytical Calculations (perfect tracking!)



2nd mRICH Prototype (Recap)






TECHNICAL INFORMATION

OCT. 2016

FLAT PANEL TYPE MULTIANODE PMT ASSEMBLY
H13700 SERIES

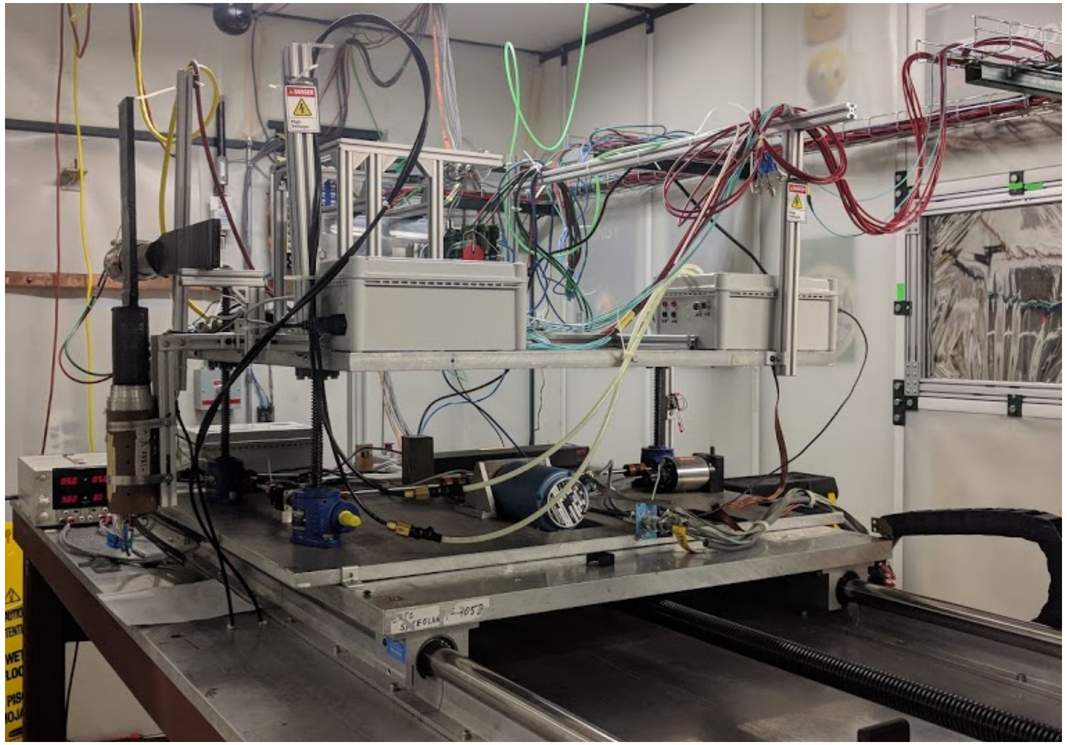
FEATURES

- 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

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

mRICH 2nd Beam Test at Fermilab

120 GeV/c
proton



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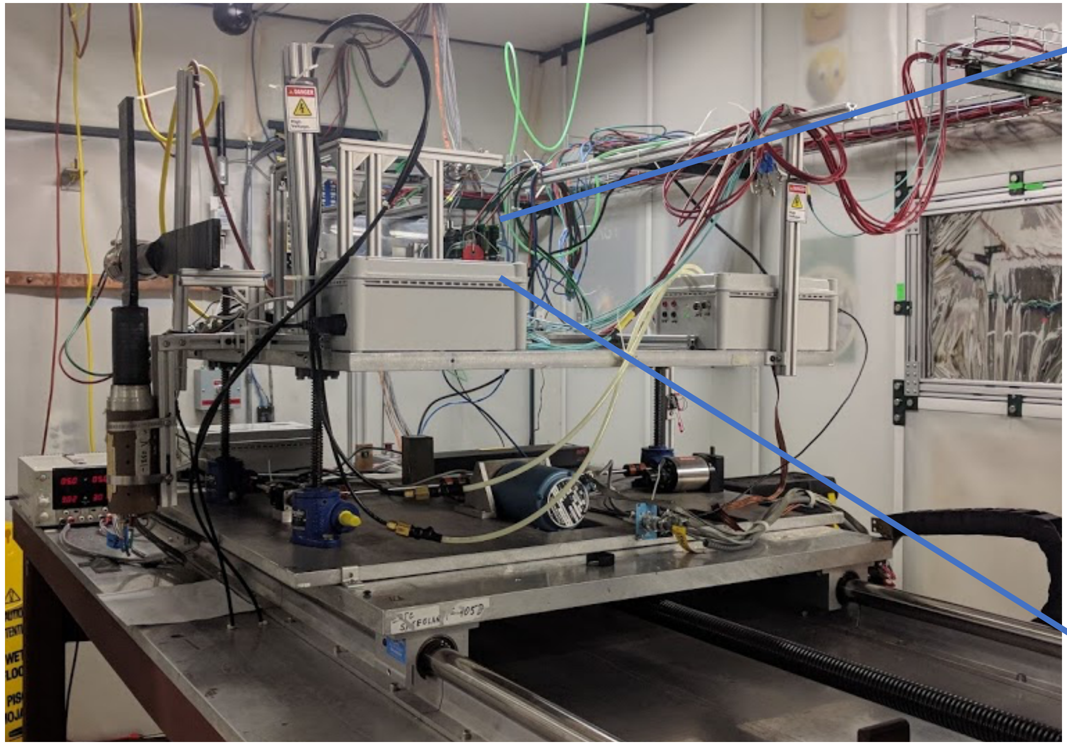
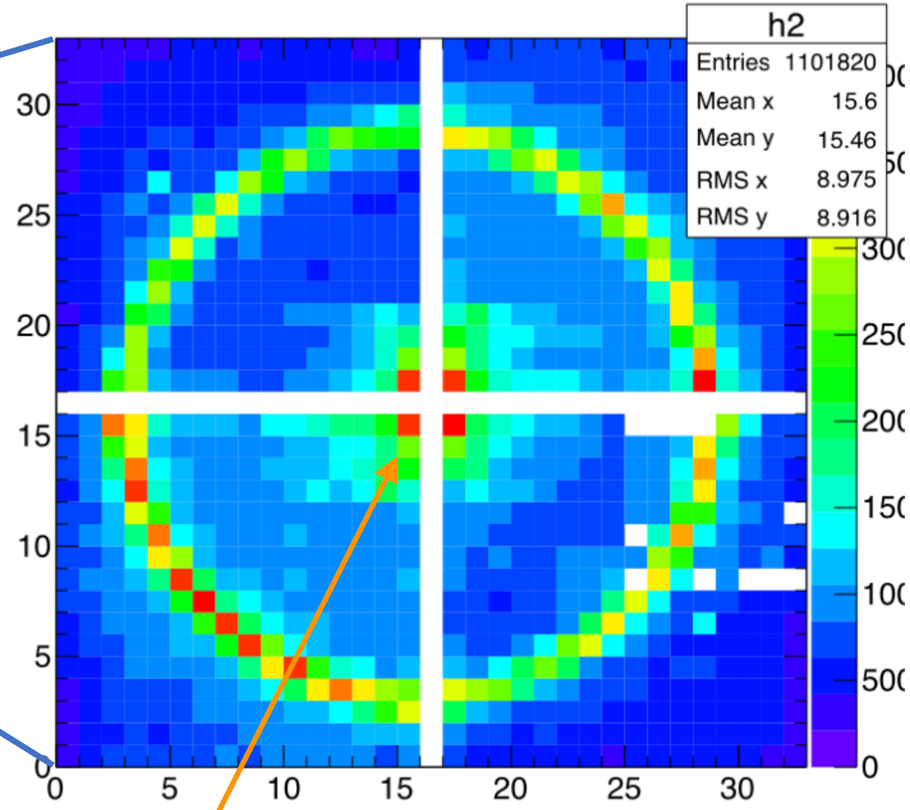


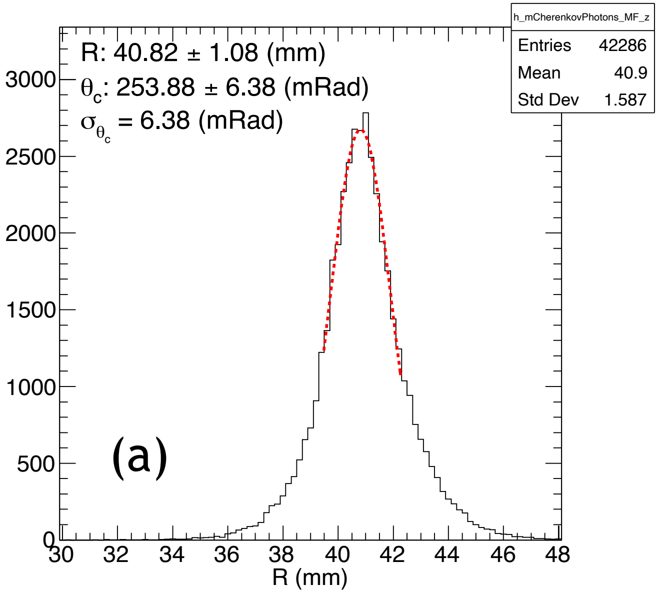


Beam spot

Ring Radius and Number of Cherenkov Photons

Data

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

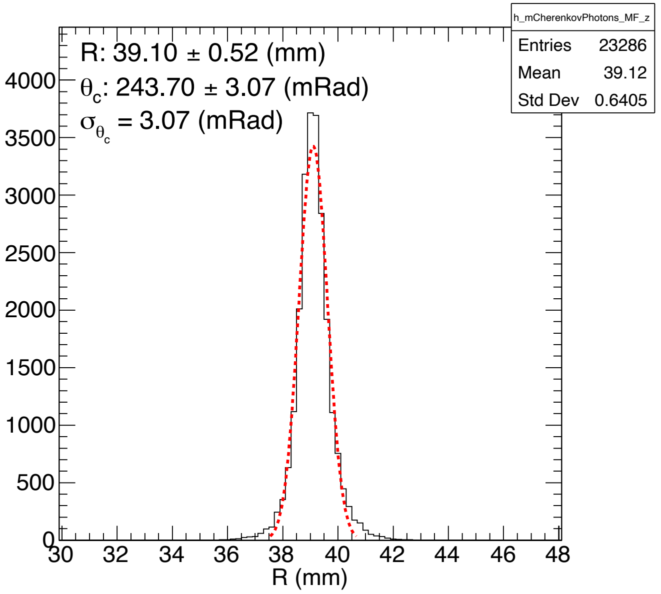


(a)

(b)

(c)

GEANT4 Simulation



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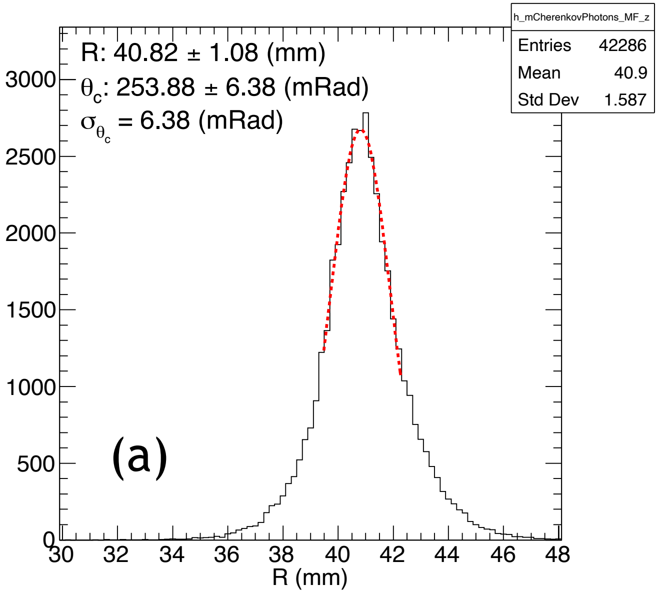
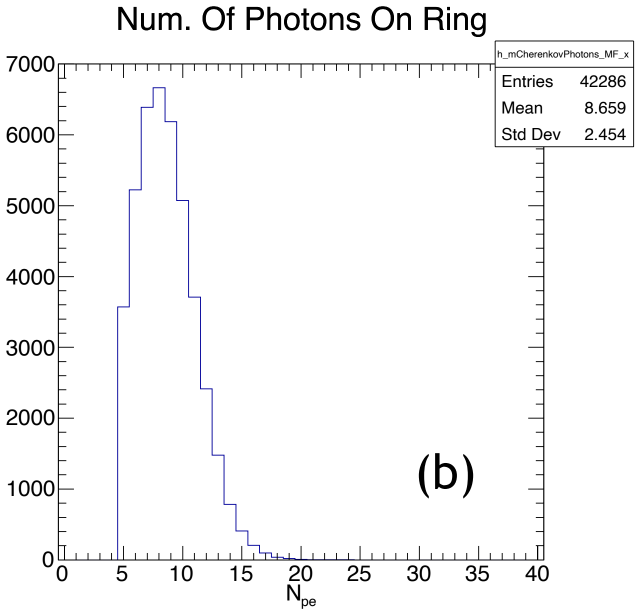


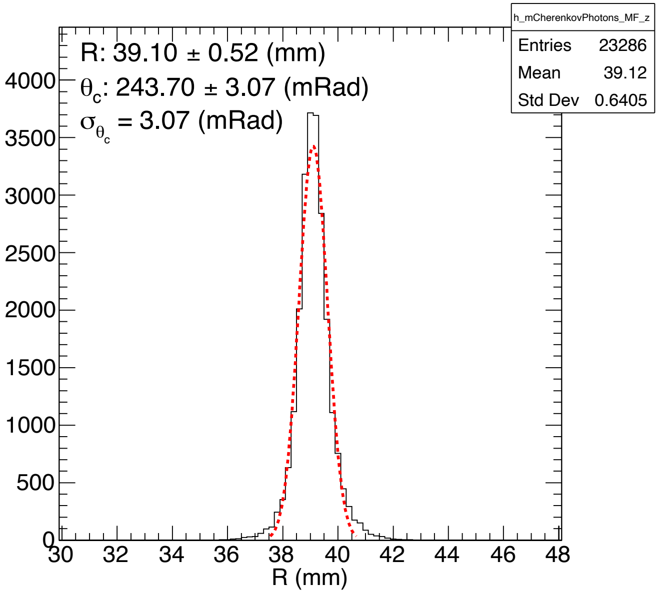
(a)

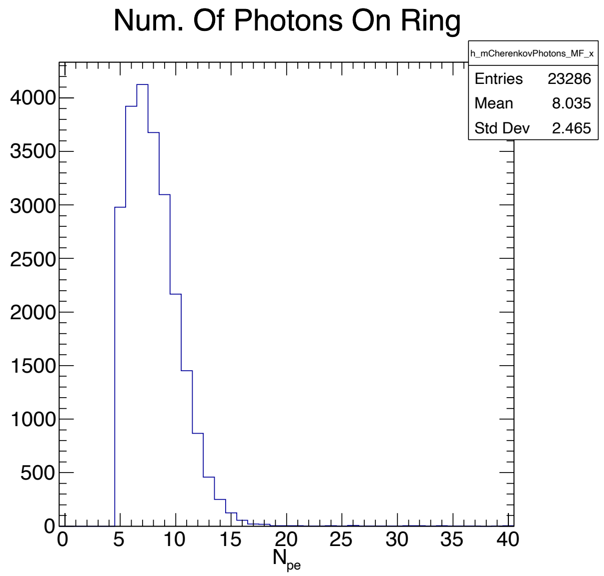


(b)

(c)

GEANT4 Simulation





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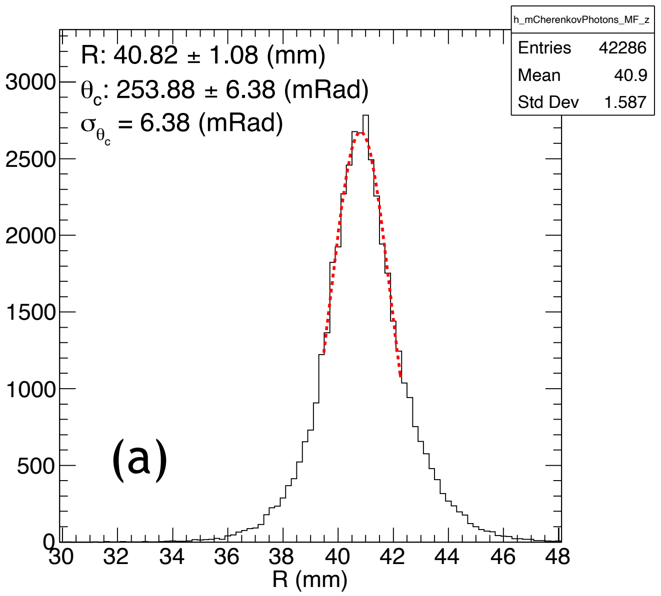

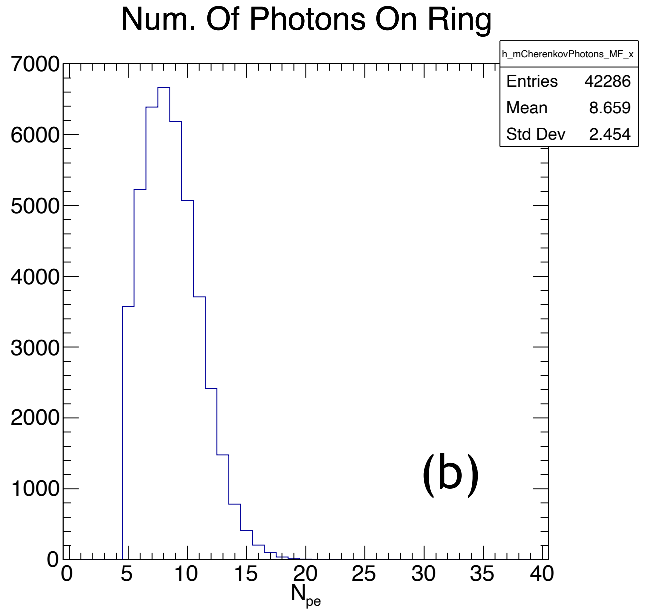

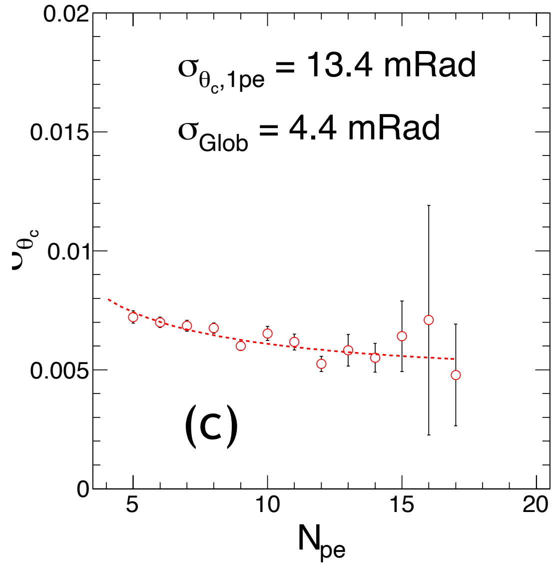

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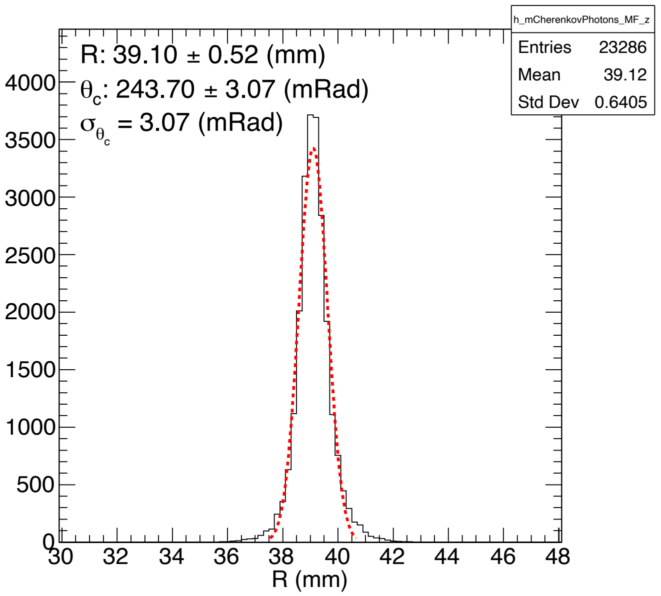

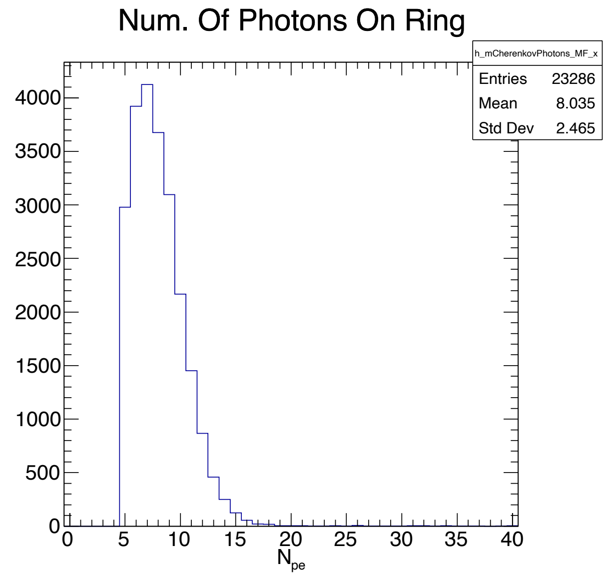

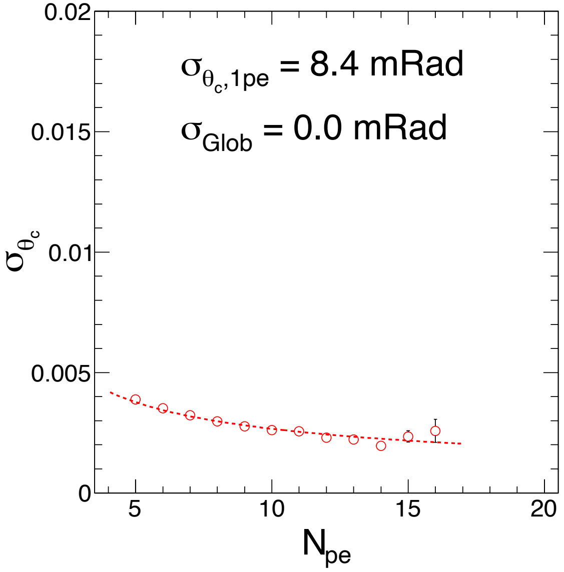

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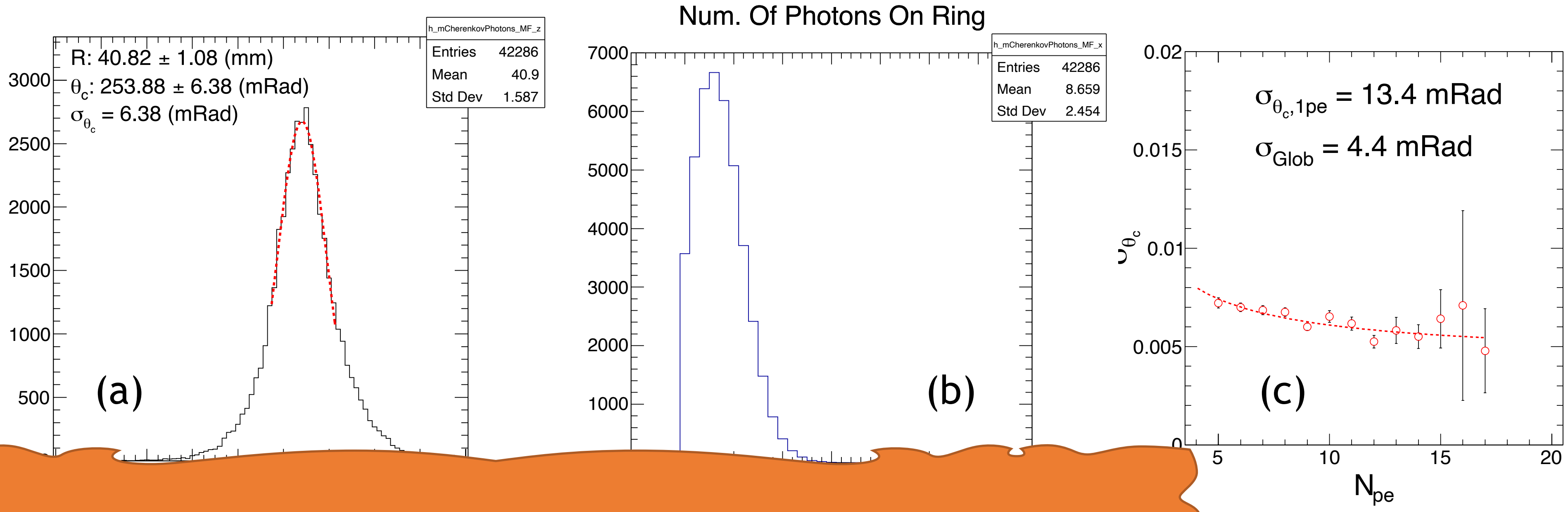
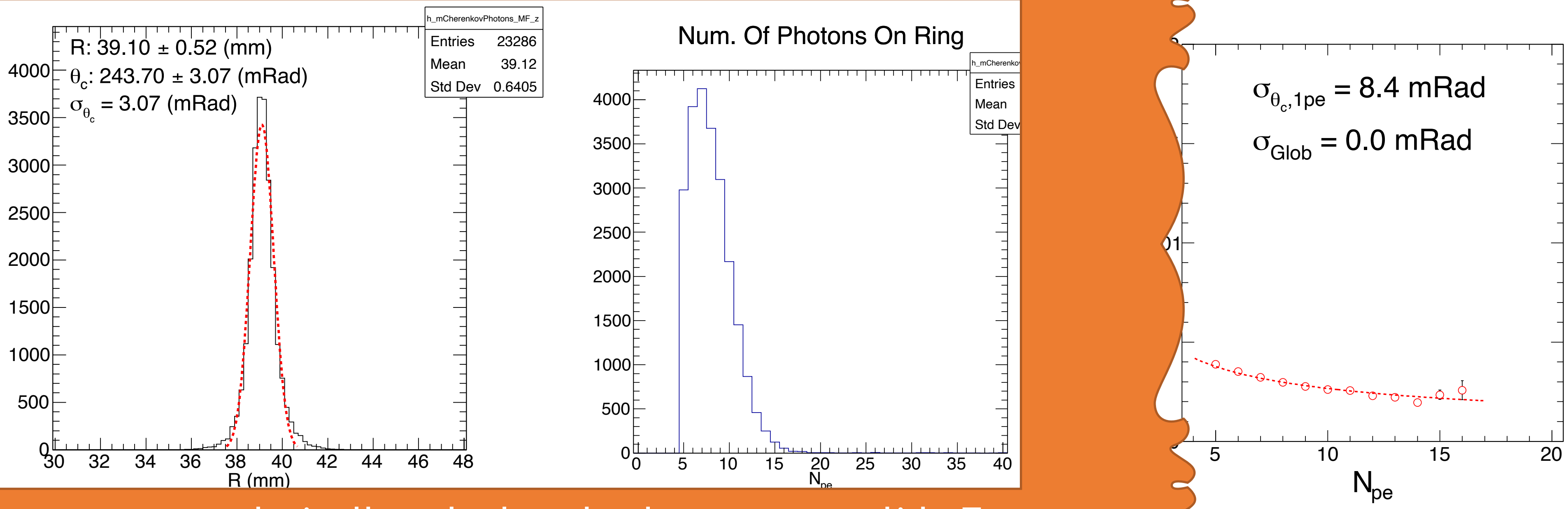


GEA Sim



Comparison: analytically calculated values on slide 7

mRICH
External Input Requirements

Particle momentum vector and the entry point at the front of mRICH

An Excellent Reference

Nuclear Instruments and Methods in Physics Research A 666 (2012) 148–172

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journal homepage: www.elsevier.com/locate/nima

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Review

Particle identification

Christian Lippmann

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Resolution, Resolution, and Resolution

From $p = \gamma m v$ one gets, $m = p/(c\beta\gamma)$ and $\left(\frac{dm}{m}\right)^2 = \left(\frac{dp}{p}\right)^2 + \left(\gamma^2 \frac{d\beta}{\beta}\right)^2$.

In most cases, since γ is large, the mass resolution is determined mainly by the accuracy of the velocity measurement. The velocity measurement is given by

$$\frac{\sigma_\beta}{\beta} = \tan(\theta_C)\sigma_{\theta_C}$$

With the average angular resolution for the angle photon σ_{θ_i}, the total resolution becomes

$$\sigma^2_{\theta_C} = \left(\frac{\sigma_{\theta_i}}{\sqrt{N_{pe}}}\right)^2 + \sigma^2_{\theta_{Glob}}$$

The term $\sigma_{\theta_{Glob}}$ combines all contributions that are independent of the single photon measurement.

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The 2nd term is similar to Tom's equation, which depends the external effects (background hits, tracking Parameters, etc). One of the goals here!

The term $\sigma_{\theta_{Glob}}$ combines all contributions that are independent of the single photon measurement.

Single photon angular resolution of mRICH

$$\sigma_{\theta_i} = \sqrt{\sigma_{EP}^2 + \sigma_{Chro}^2 + \sigma_{Det}^2}$$

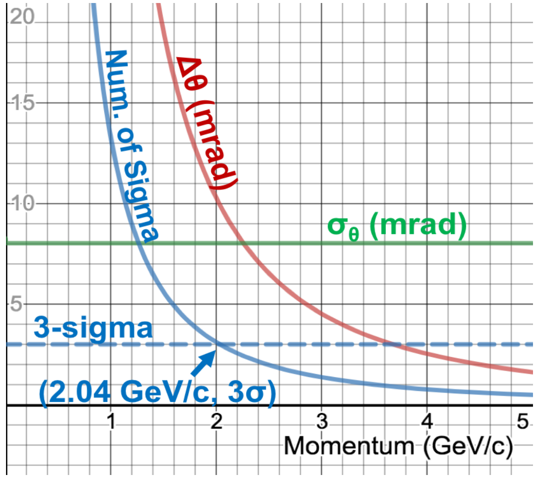
In the lens based mRICH design, σ_{EP} is minimized at the lens focal plane, σ_{Det} can be controlled with the lens focal length, and σ_{Chro} is reduced by selecting the lens transmittance in the near-UV region. As a consequence, the lens insertion improves the RICH performance at high momenta even in a compact device. Preliminary studies show that a 3σ kaon–pion separation is achievable at 10 GeV/c momentum with an aerogel of refractive index $n = 1.03$, a focal length of $6''$ and a detector pixel of 2 mm.

mRICH PID Parameterization

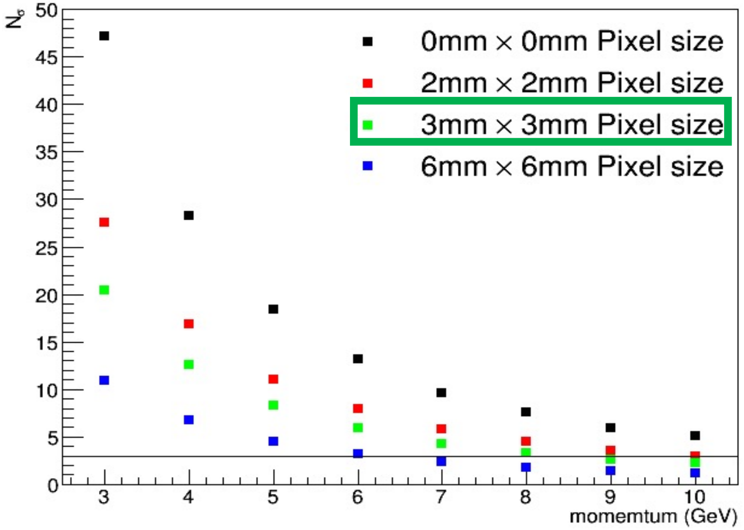
- We have implemented the pid performance (for particles entering mRICH perpendicularly as a starter) parameterization following Tom Hemmic's virtual PID base class: <mRICH.h>. This will be revised with more accurate results from GEANT4 simulations.

```
#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

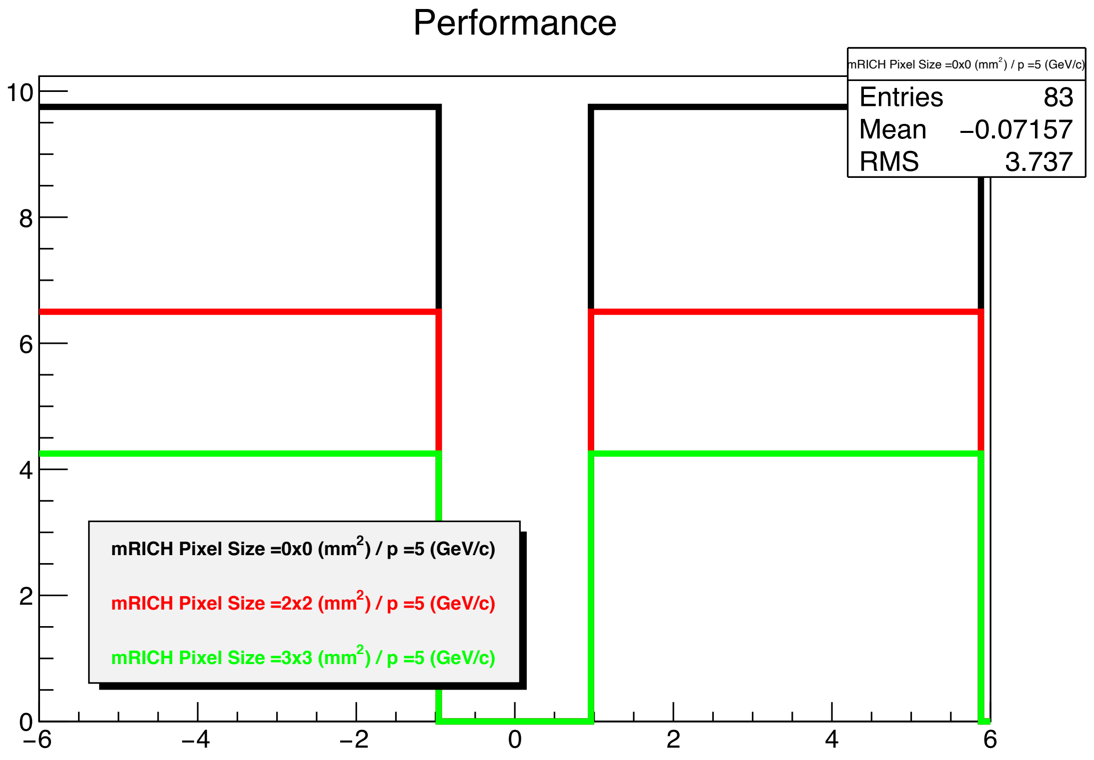


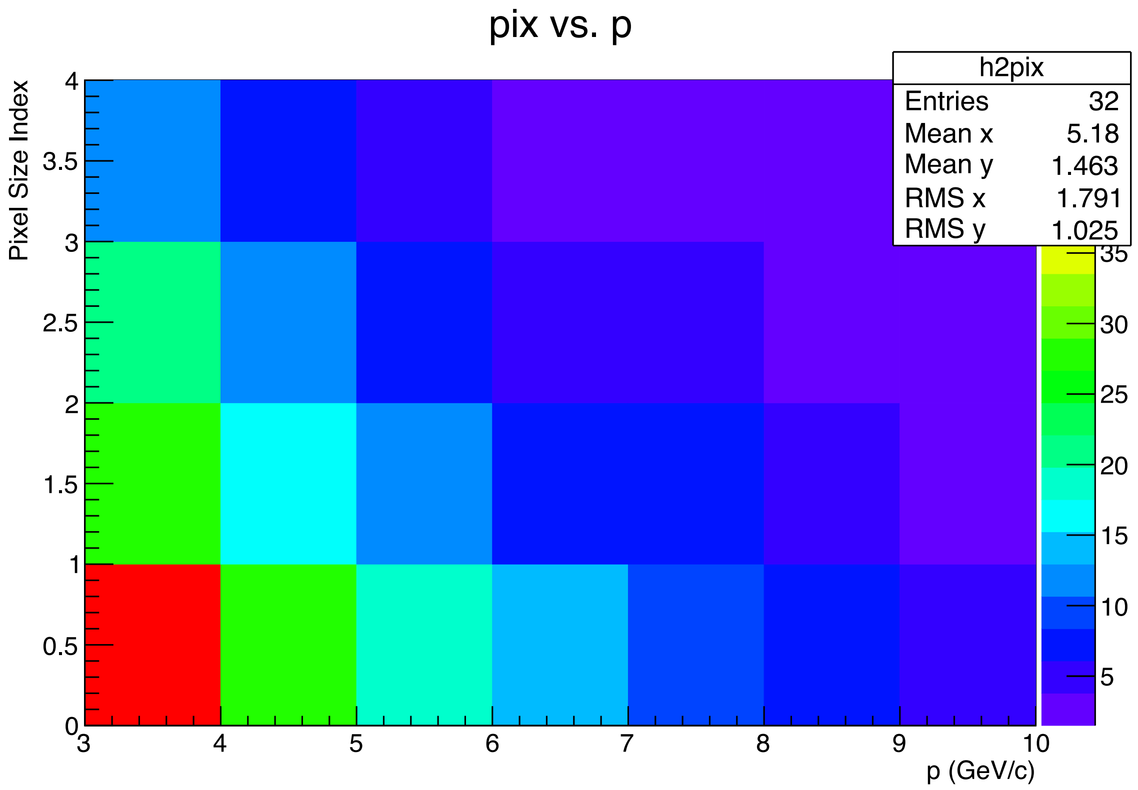
- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c



- 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

Example Output from the Fast Parameterization

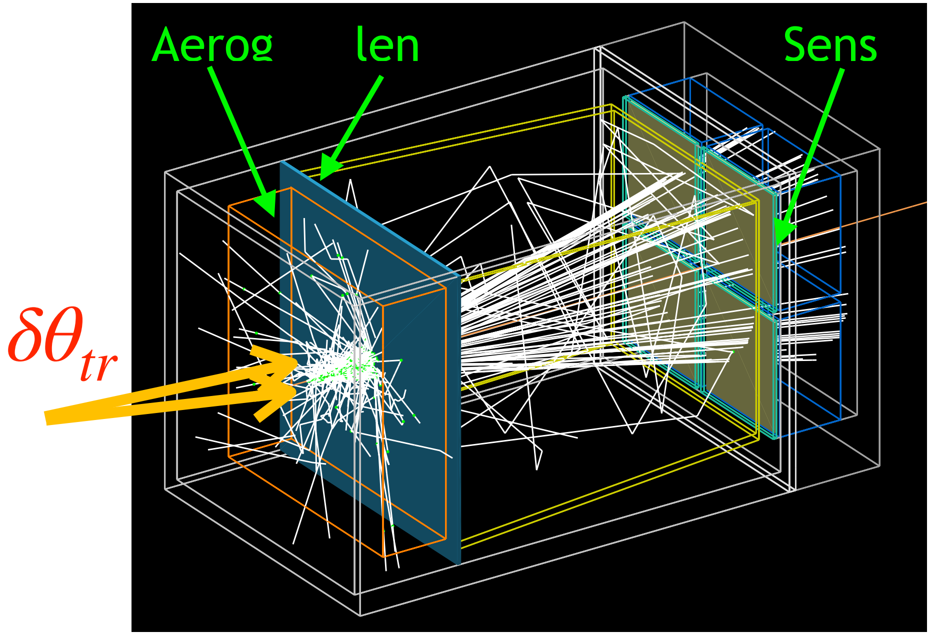




Tracking Requirement - Follow Tom's Example

- At any $|\vec{p}|$, there exists a "1-sigma" resolution in $\delta\theta_C$ which we'll call $\delta\theta_{C1}$
- Physics will demand that our full uncertainty follows: $\frac{\delta\theta_{C1}}{N}$.
- If we take the detector performance with a perfect tracker to be $\delta\theta_{C0}$.
- Then our external requirement on the tracker system is:

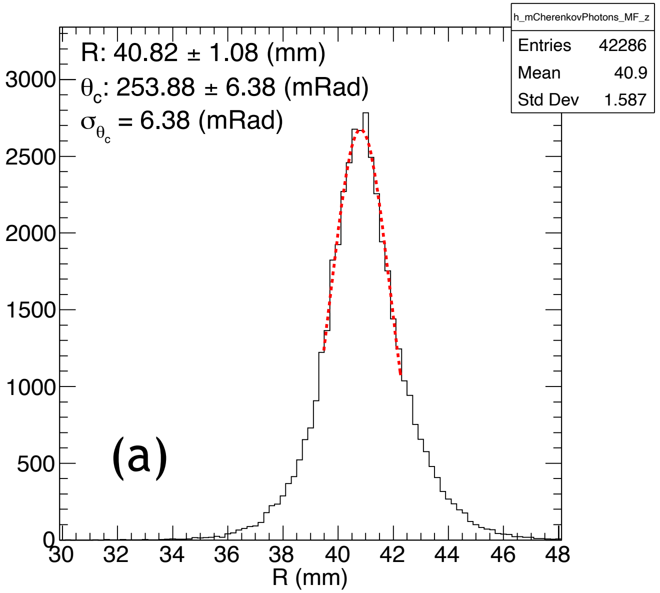
$$\left(\frac{\delta\theta_{C1}}{N}\right)^2 \leq (\delta\theta_{C0})^2 + (\delta\theta_{tr})^2$$



We already have some knowledge of poor tracking effects in the 2nd mRICH test

Data

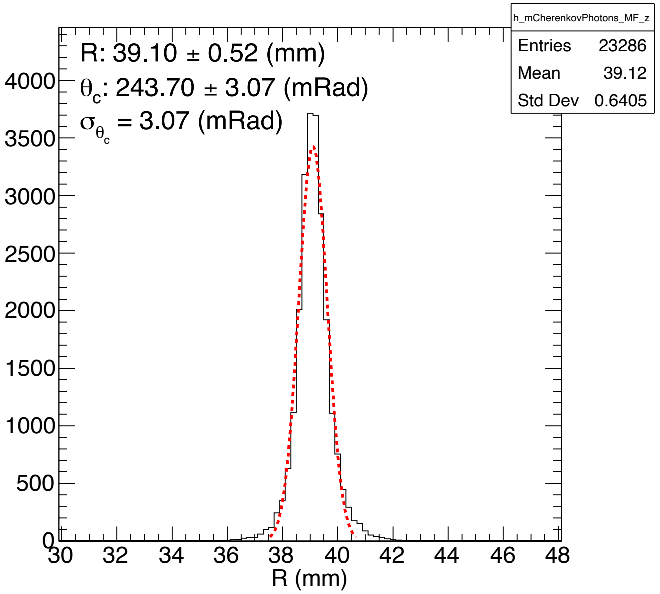
No precision tracking was available. Beam size is ~6mm in radius.



(b)

(c)

GEANT4 Simulation



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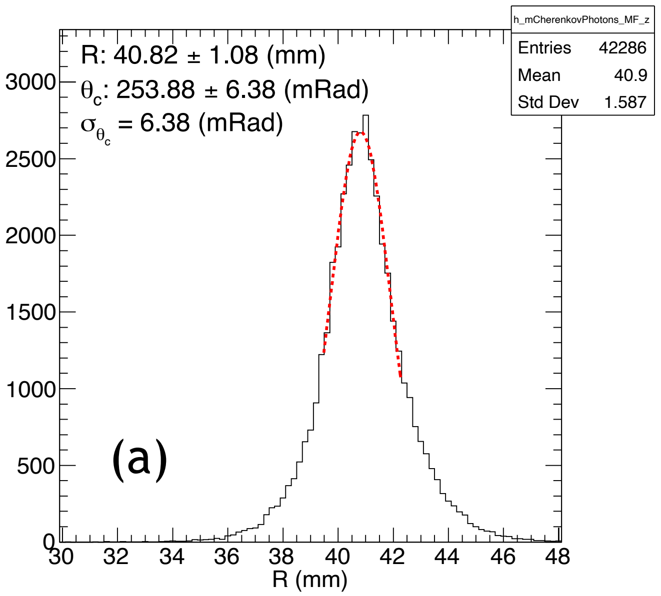
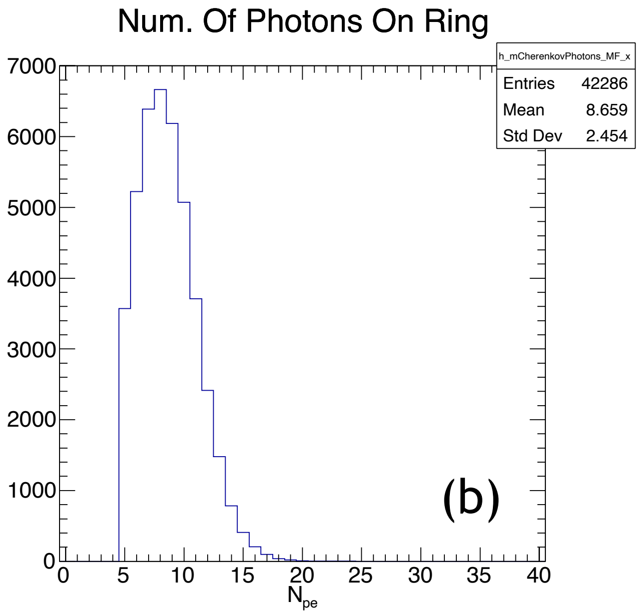
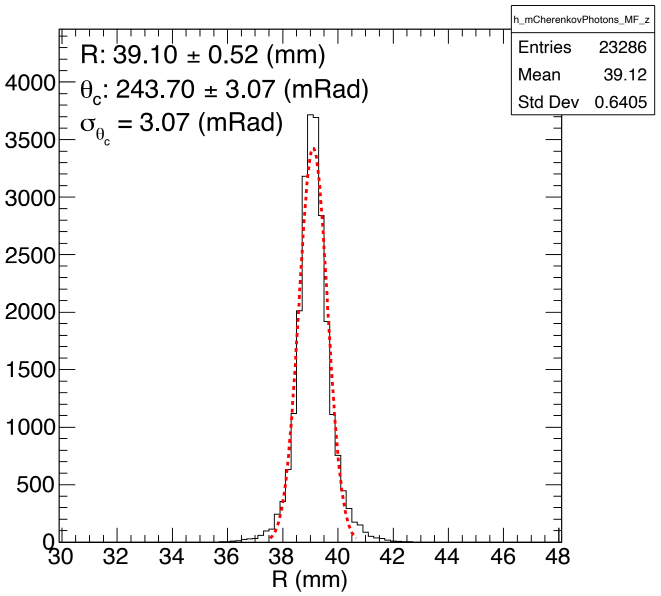
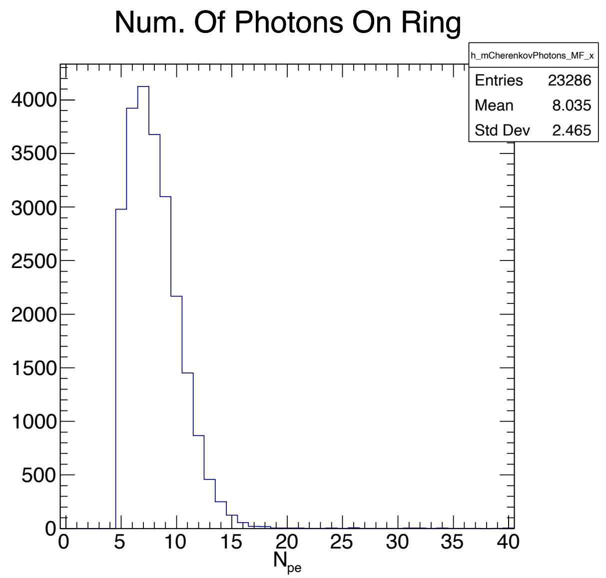




(c)

GEANT4 Simulation





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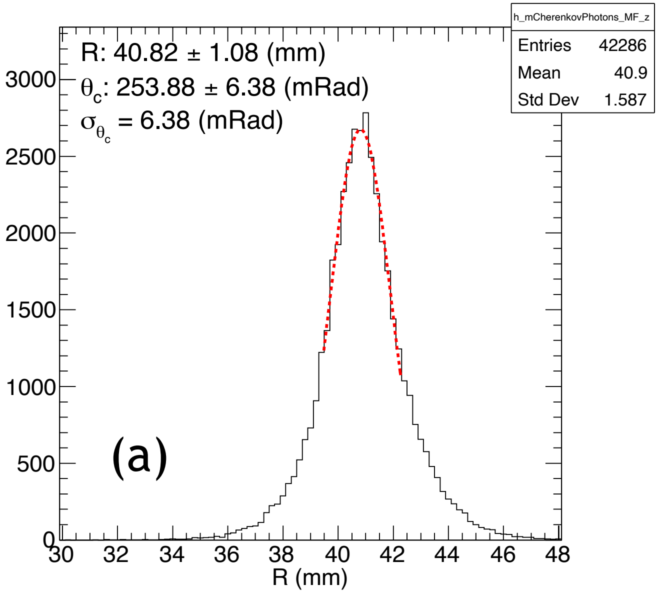

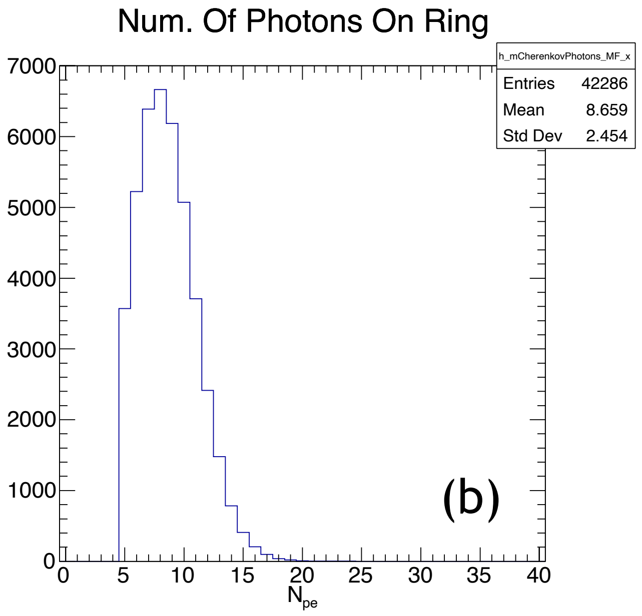

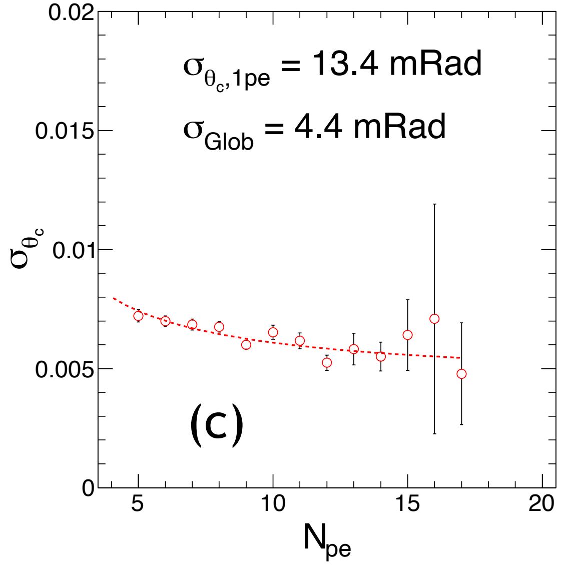

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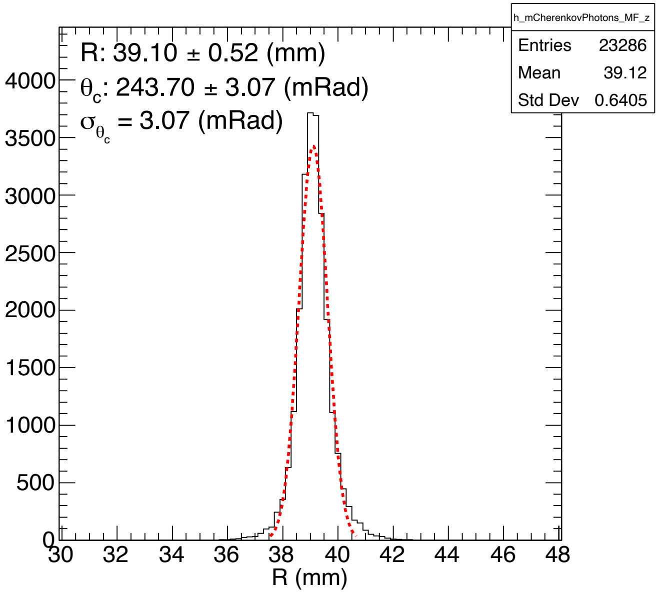

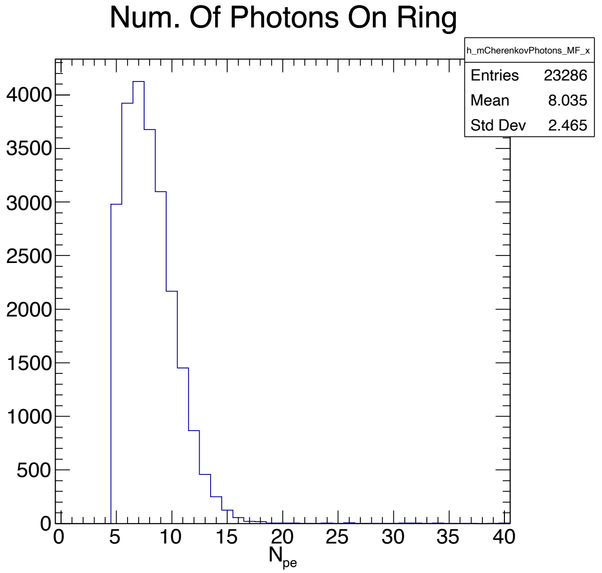

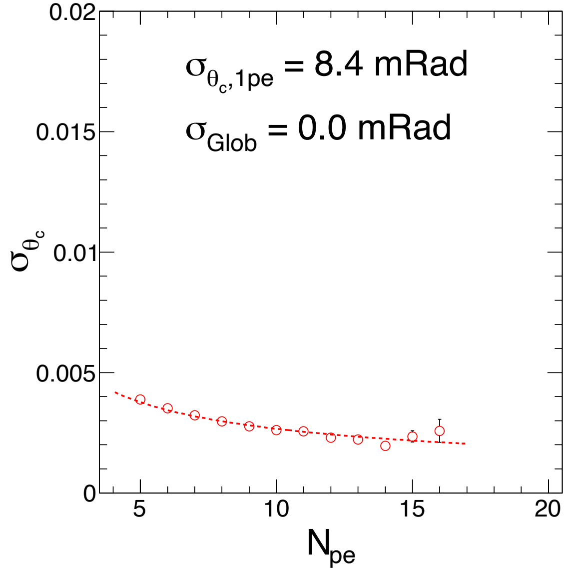

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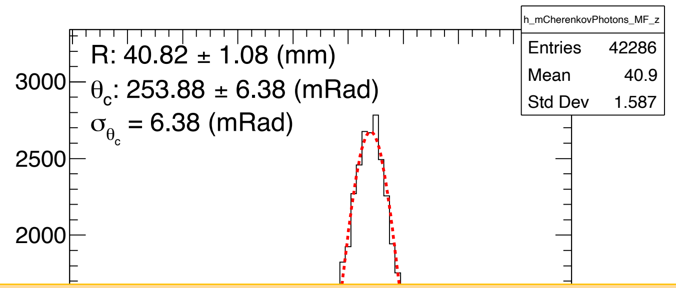
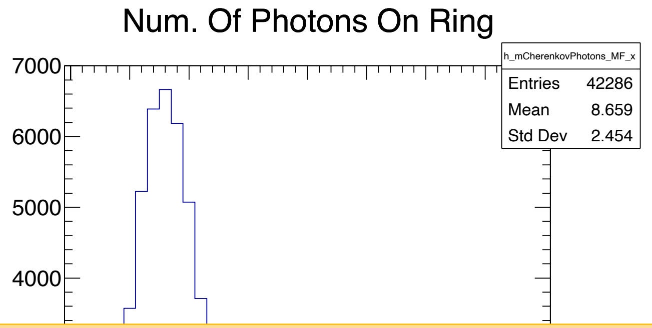
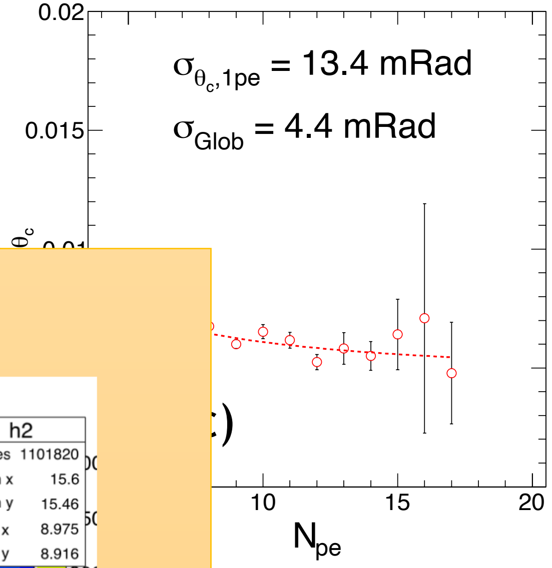


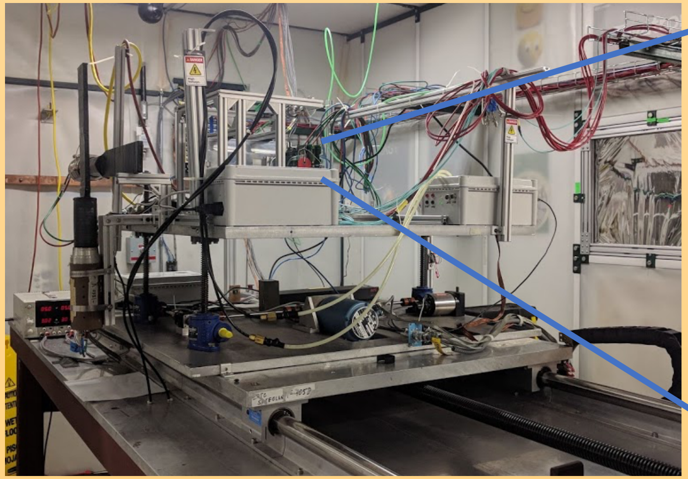


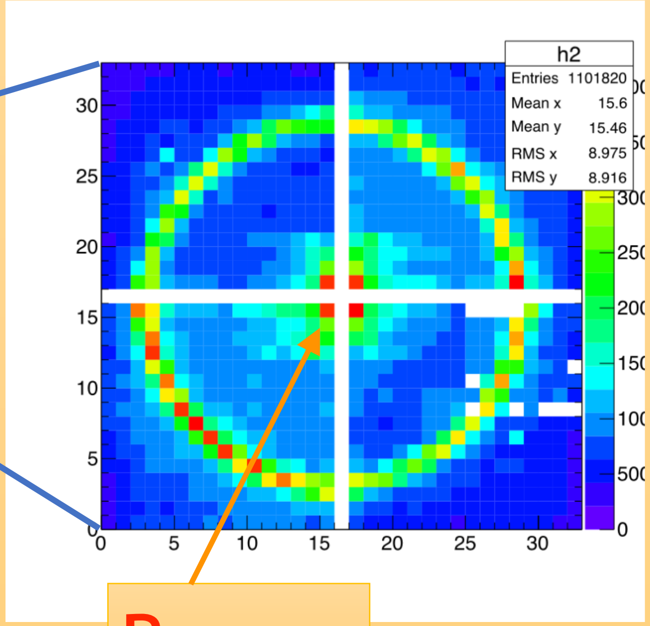


Data

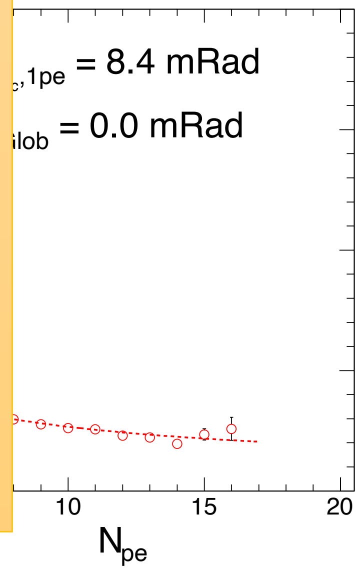
No precisio
tracking wa
available.
size is ~6m
radius.

120



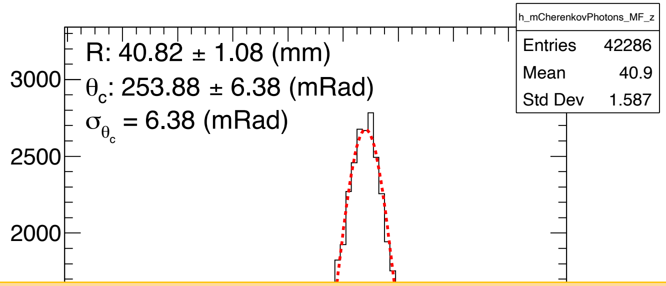


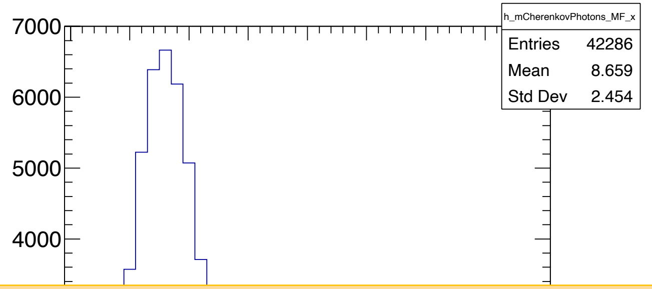
GEANT4
Simulati

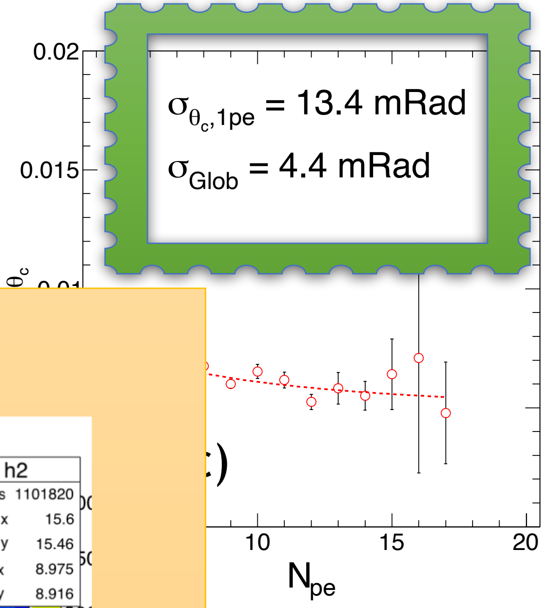


We already have some knowledge of poor tracking effects in the 2nd mRICH test

Data

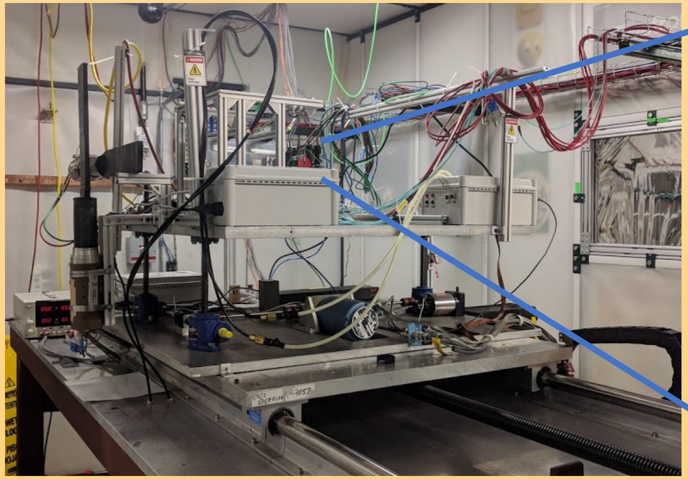


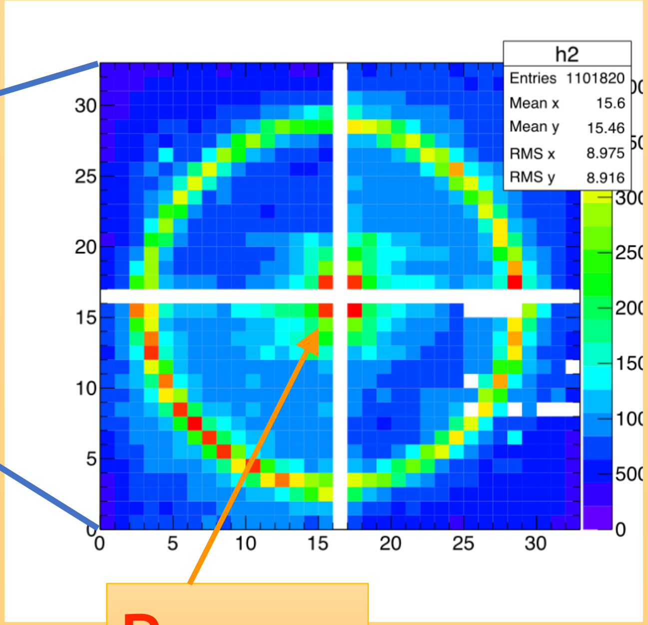




No precisio
tracking wa
available. I
size is ~6m
radius.

120





Beam

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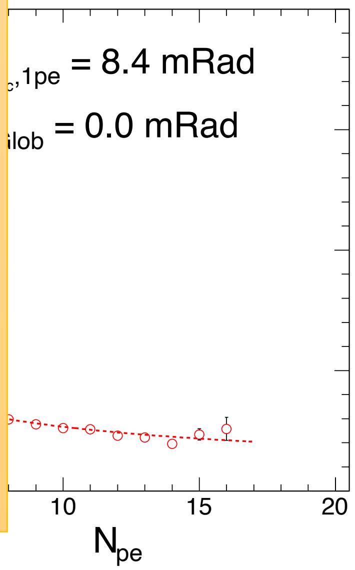
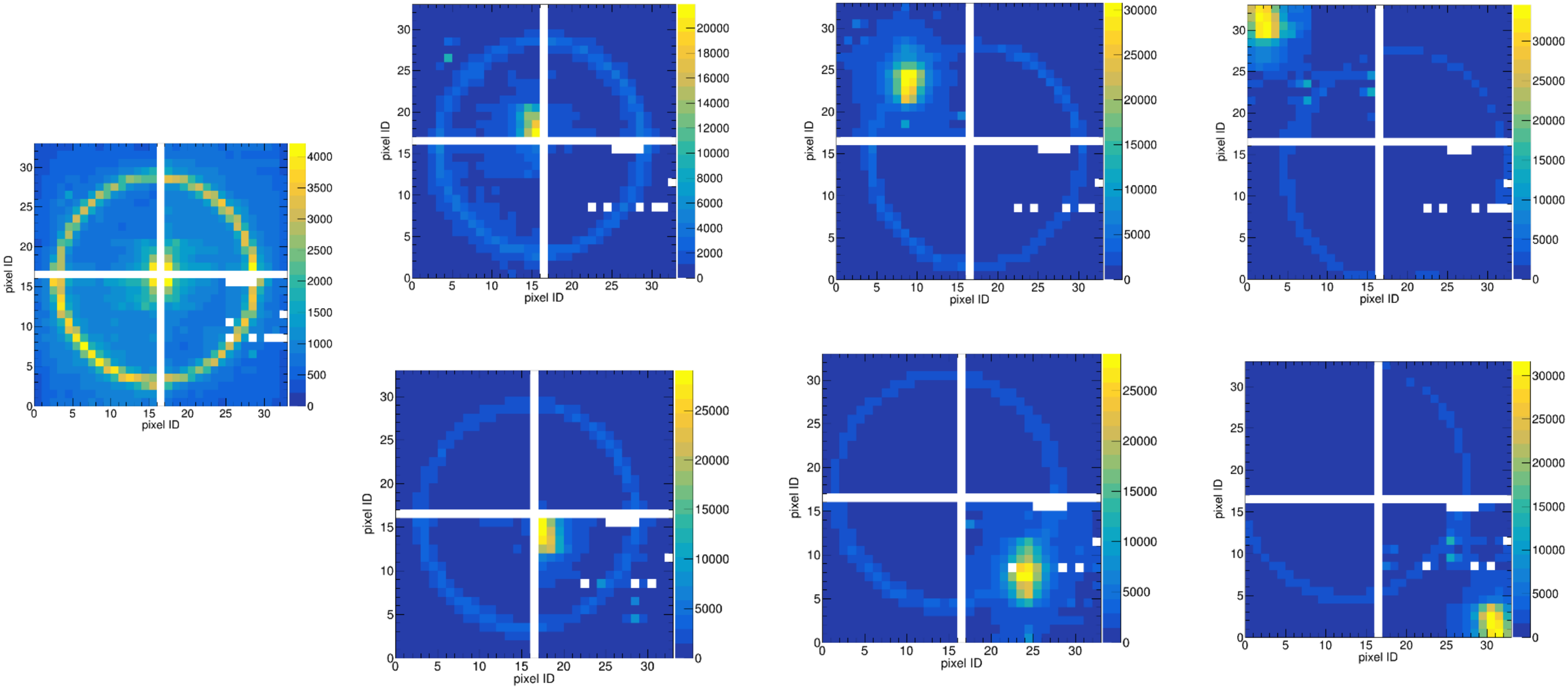


R (mm)

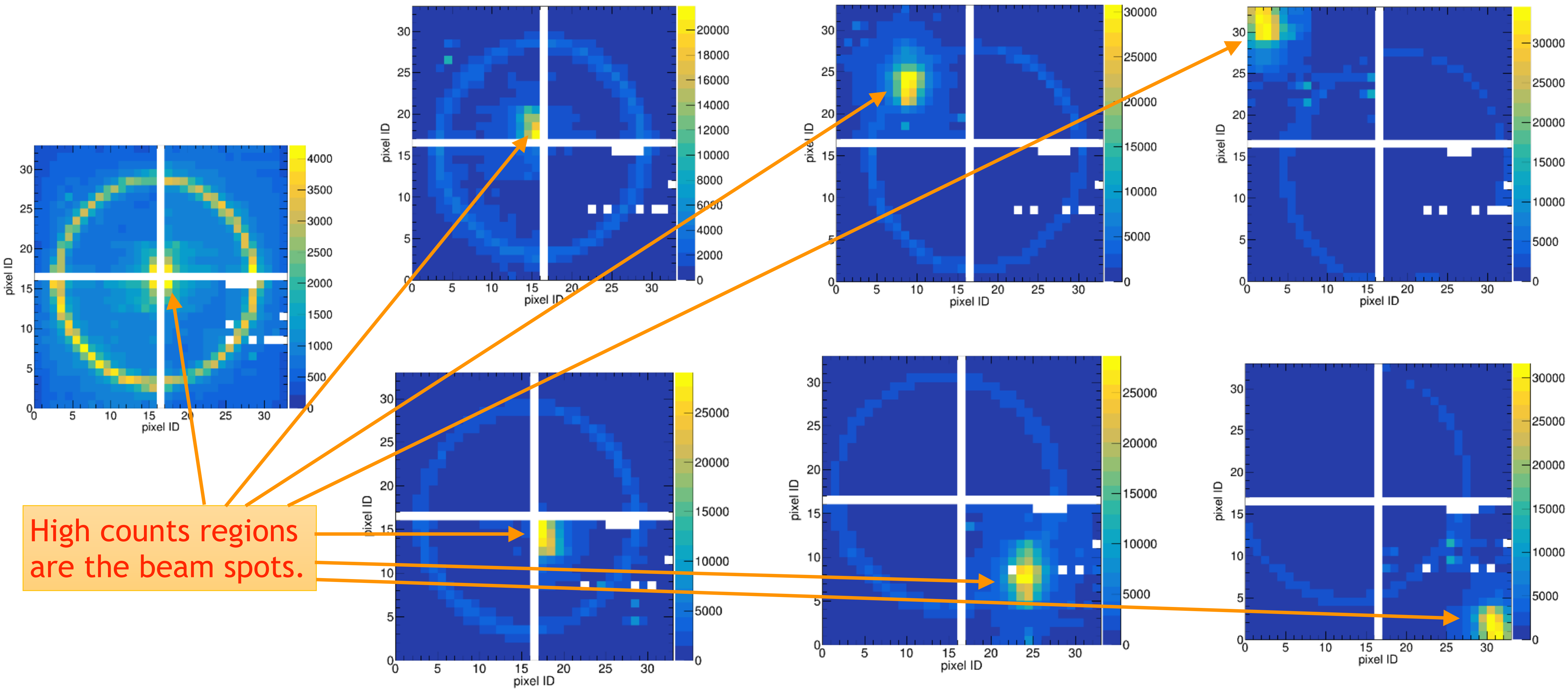
We plan to give another update in two weeks.

Backup slides

Position scans with 120 GeV/c proton beam

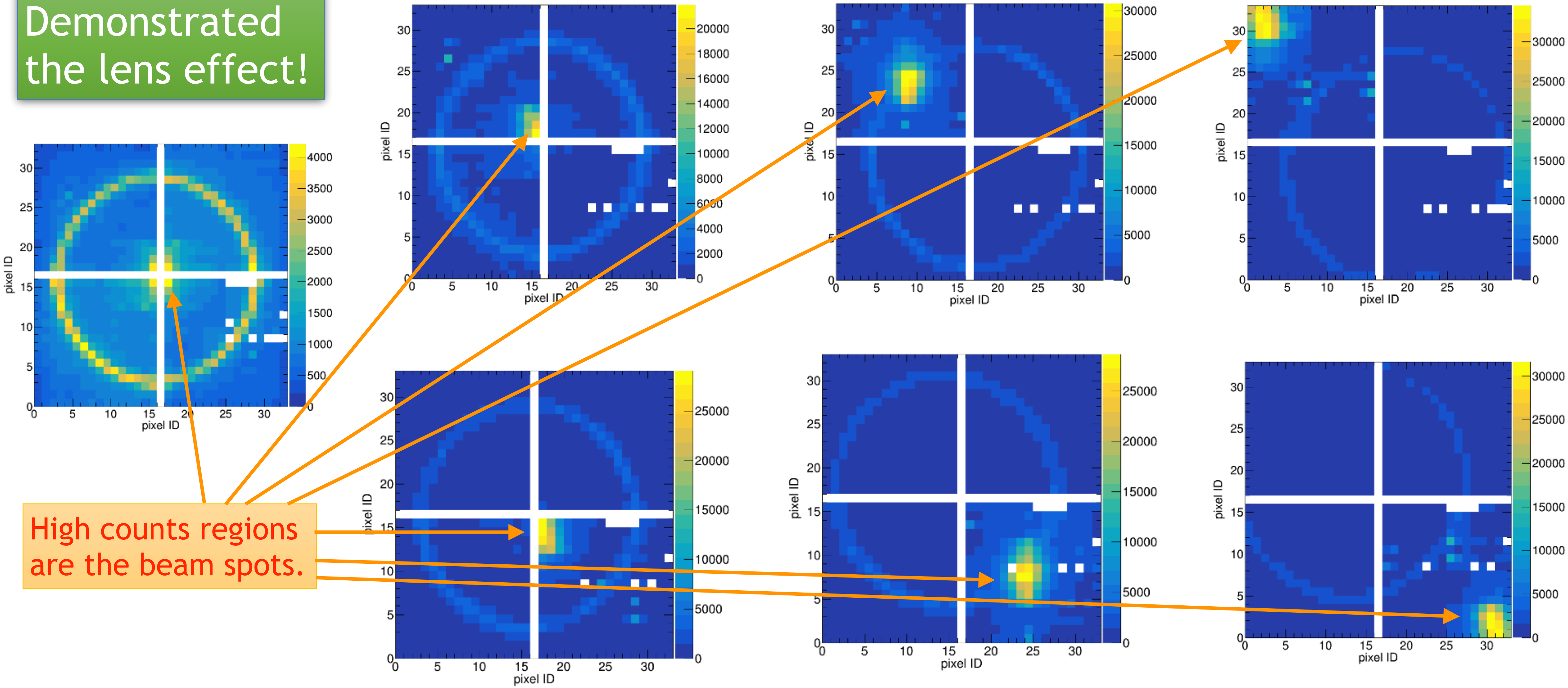


Position scans with 120 GeV/c proton beam



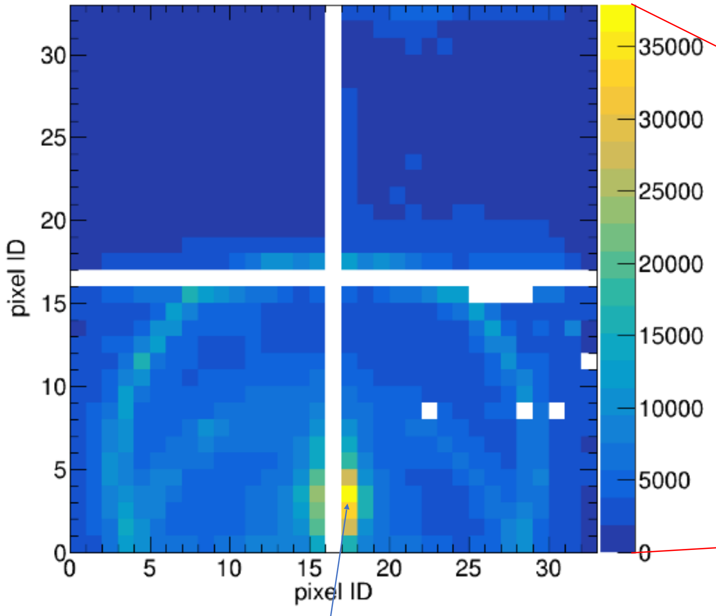
Position scans with 120 GeV/c proton beam

Demonstrated the lens effect!

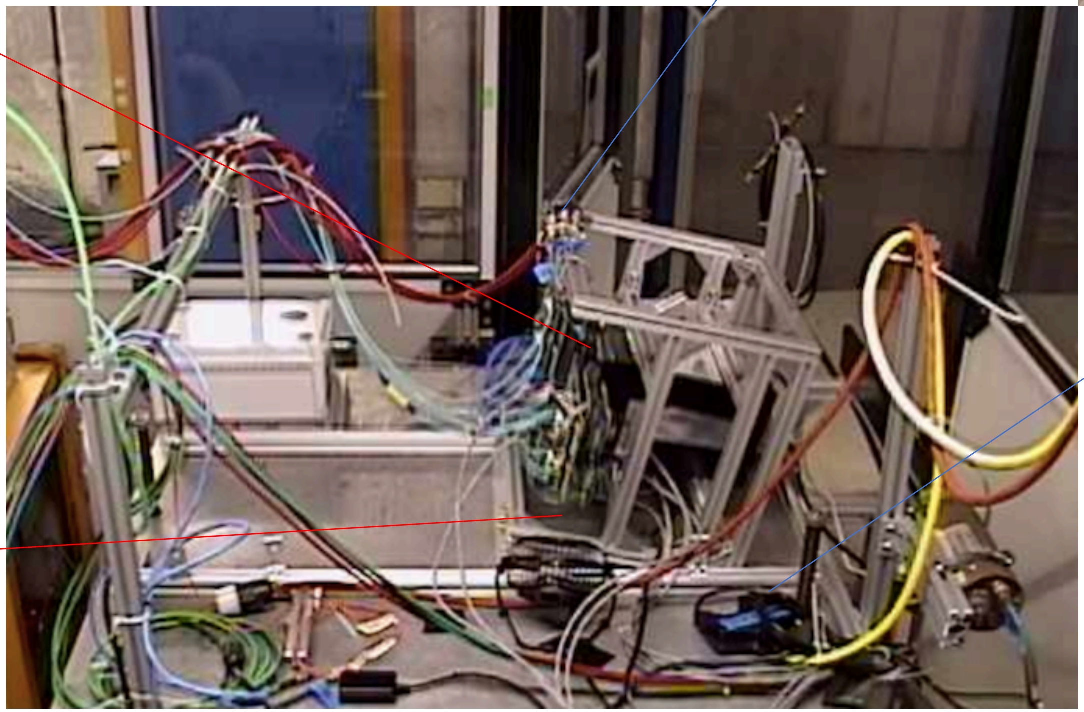


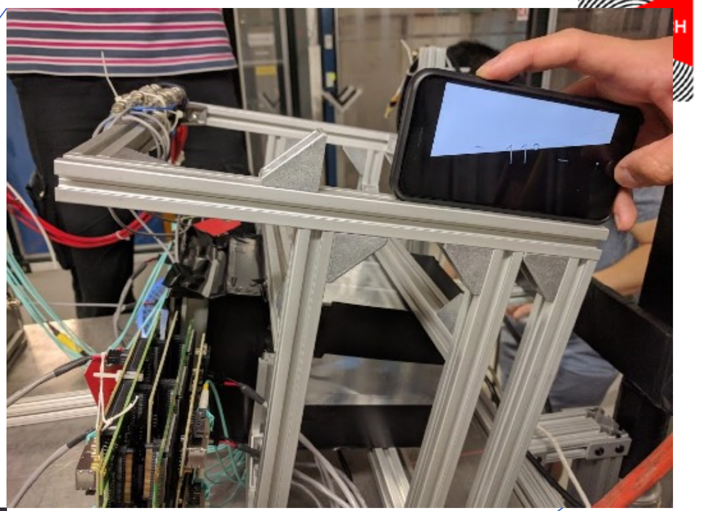
High counts regions are the beam spots.

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



Beam spot

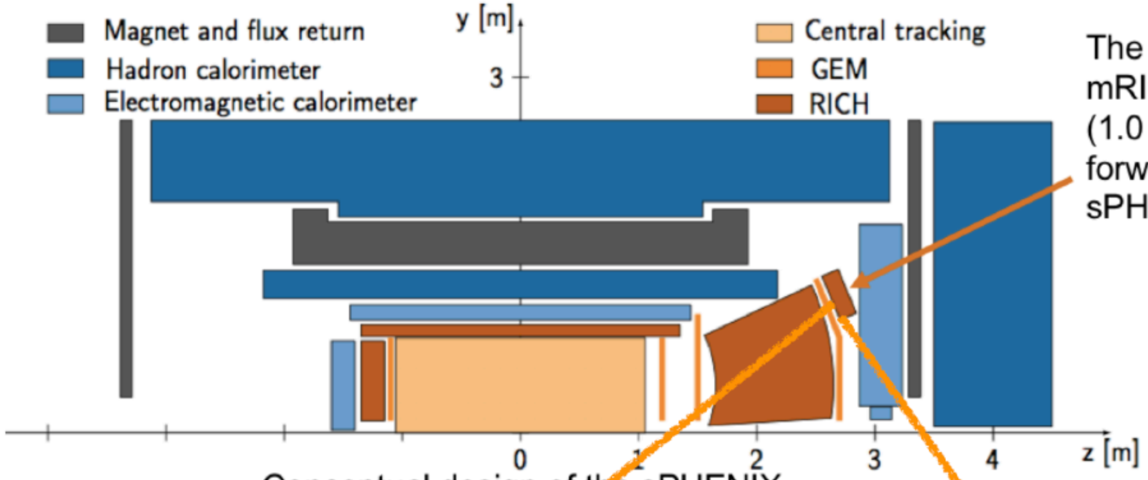




11 degree tilt downward

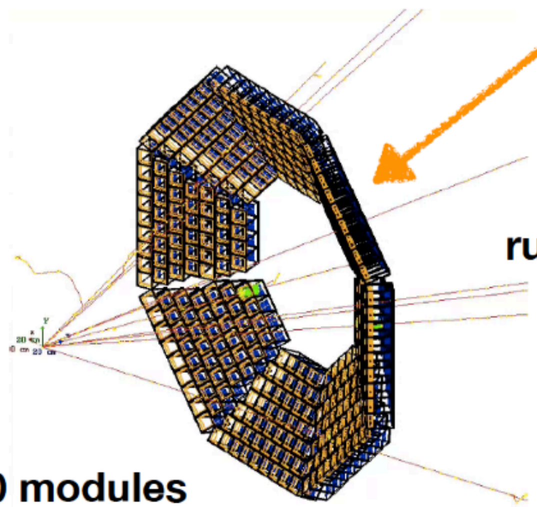
120 GeV/c proton beam

Modular, Compact and Projective (Recap)



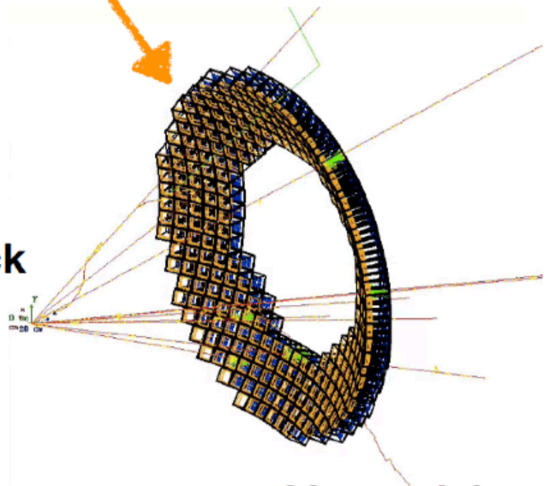
Conceptual design of the sPHENIX

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

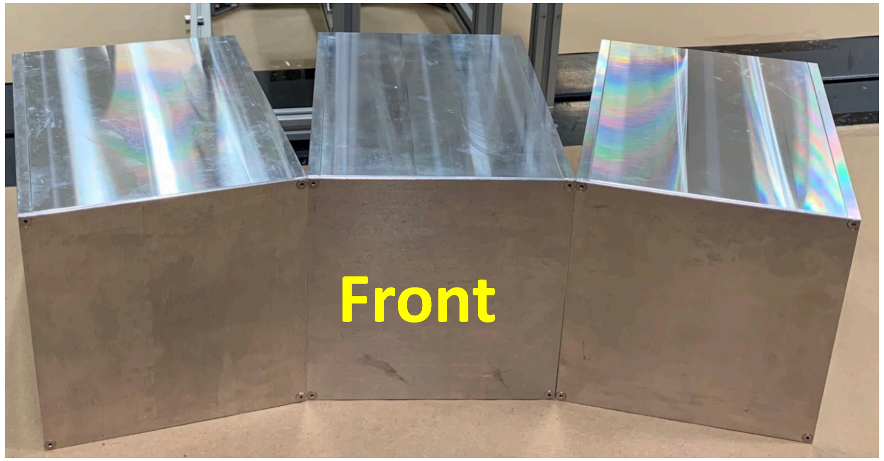


340 modules

running overlap check



284 modules



Following points will be addressed to the best of my knowledge

- 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

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**