eRD11 Modular RICH Detector R&D

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for the eRD11 Collaboration

eRD11 Project Overview

- Hardware R&D current status
  - *The first sample of LAPPD larger area photon sensor has been tested in Lab.*
  - *HBD GEM for visible photon detection not funded yet, will seek funding in July.*

- Detector concept and GEANT4 simulation status
  - *Modular aerogel RICH will be presented in this talk*
  - *A focusing / proximity focusing aerogel RICH will be next in line*
  - *A new post-doc is found for dual-radiator RICH study*

https://userweb.jlab.org/~yqiang/files/eic_rich/20140627_EIC_RICH_RnD_final.pdf

Outline

- Modular RICH detector has been constructed and studied in JLab GEant4 Monte-Carlo (GEMC) framework.
- Analysis framework has been developed for analyzing GEMC simulation data.
- Hough transform rings finder algorithm and likelihood analysis technique were developed for particle identification.
- All software publicly available on github

https://github.com/EIC-eRD11

Modular RICH In GEMC

1) A block of aerogel.

- SiO_2, 0.02 g/cm3
- Refractive index: n=1.025

2) Fresnel lens

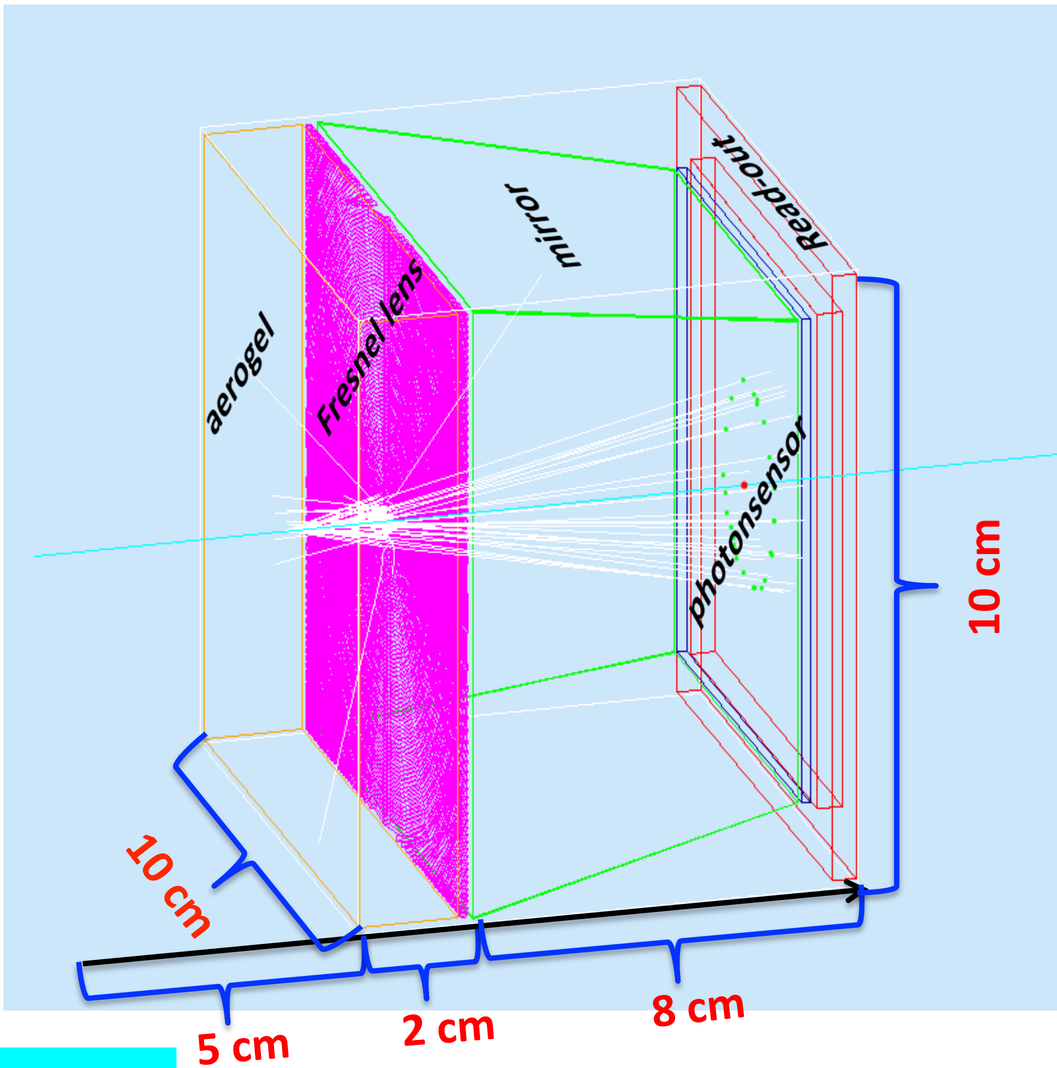
- Acrylic, $C_5H_8O_2$, 1.19 g/cm3
- Four sections, G4Polycon
- 100 grooves, good focusing

3) Mirrors

- Four sections: front, back, top and bottom
- Reflectivity index : 0.95

4) Photosensor and read-out

- Block of aluminum



Fully implemented in GEMC framework

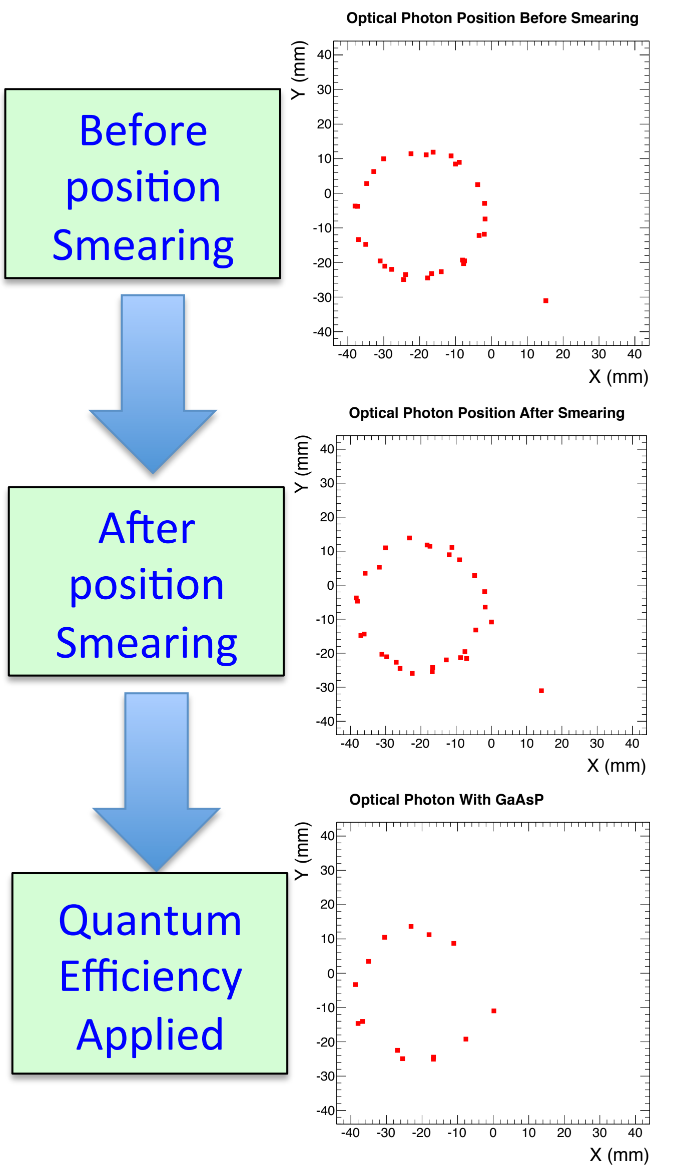
Detector Effects Implemented

- For 5 GeV μ-, ~76 photons produced by aerogel, ~28 photons arrive at the photonsensor, ~11 photons left after quantum efficiency applied for GaAsP. Less optical photons for other particles.

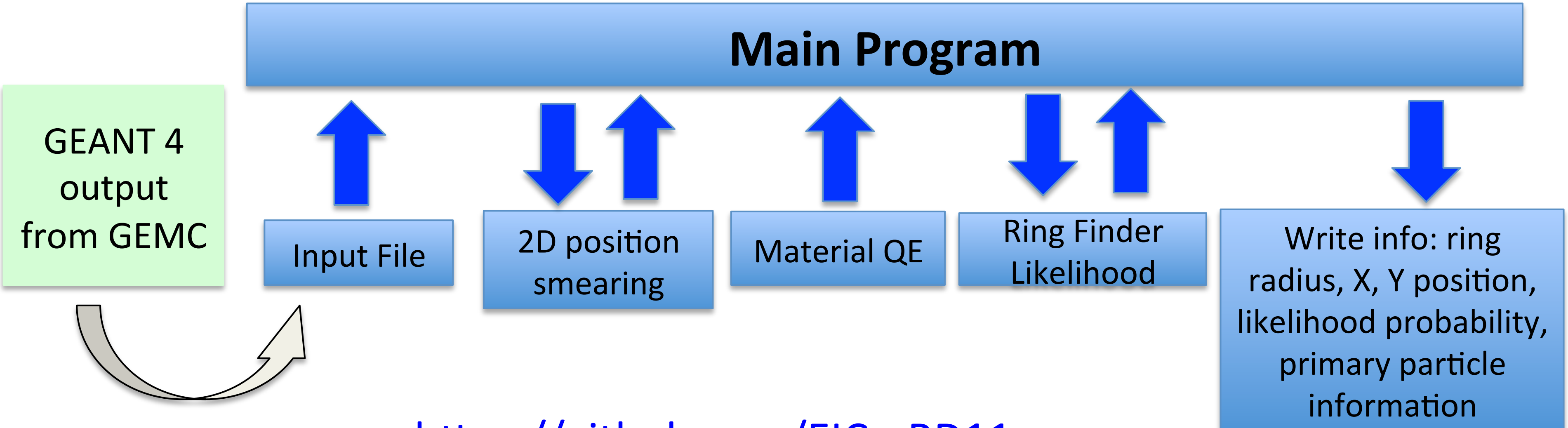
- Perfect rings on photonsensor with photon reflected by fresnel lens.

- Photon position (2D gaussian) on photonsensor are smeared to mimic the "non-uniformity effect" of the aerogel and fresnel lens.

- Residual photons are used for PID analysis (rings finder, likelihood analysis).



Analysis Framework



https://github.com/EIC-eRD11

include/:

event.h hit.h material.h ntuple.h ring.h

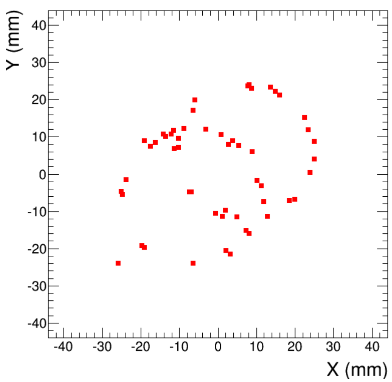
src/:

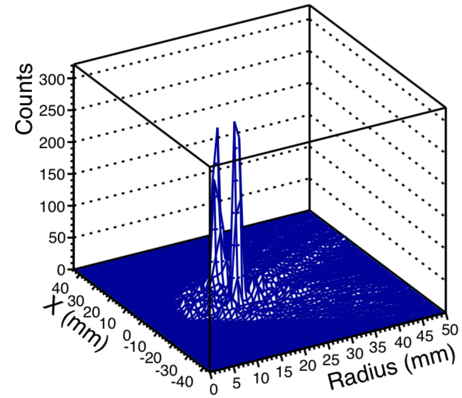
event.cxx hit.cxx main.cxx material.cxx ntuple.cxx ring.cxx

Read GEANT4 hit information from GEMC, do photon position smearing, implement quantum efficiency, find rings with "rings finder" or do likelihood analysis, write information for further analysis.

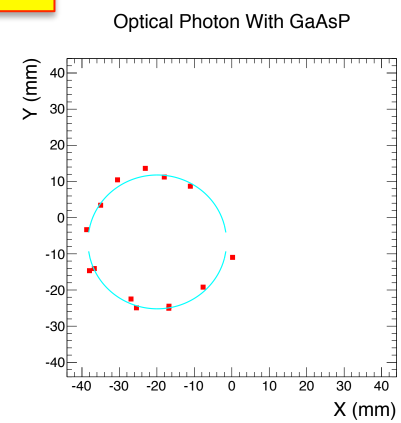
Hough Transform Rings Finder

Position Smearing
Ring Finder w/o QE



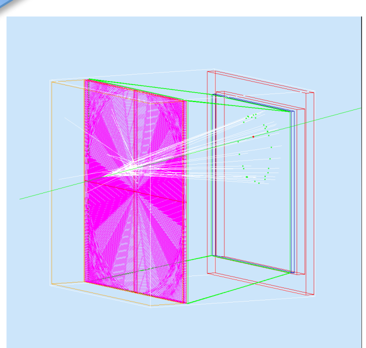


Ring Finder
with QE

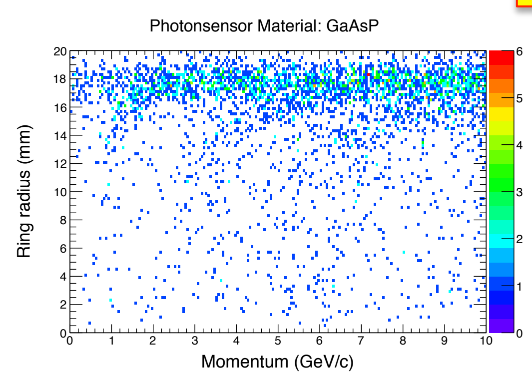


- Combinatorial hough transform is used to identify Cherenkov rings on the photonsensor detector.
- Detector PID performance is studied by correlating ring radius and momentum.

GEANT4 Data
Production



Detector
Optimization



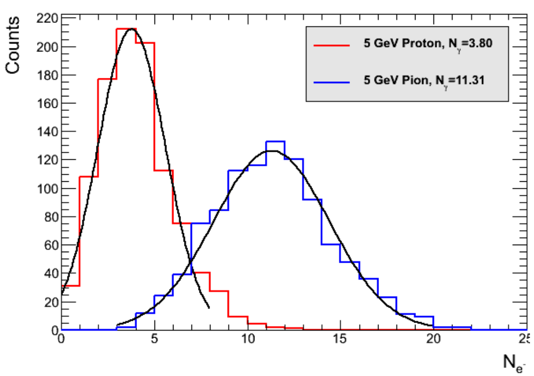
Single
Particle PID
Performance

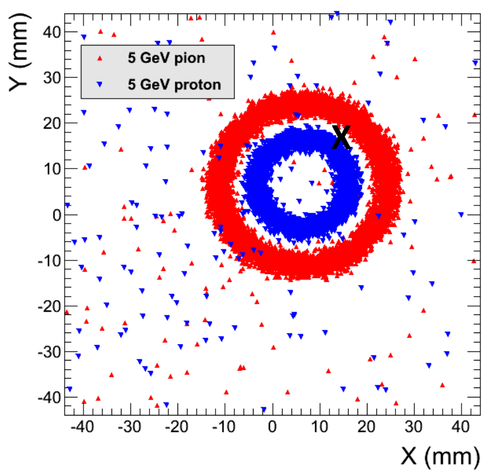
Likelihood Analysis

Analysis Procedure:

- Given momentum, the detector responses (N_{e-}, photon position, etc) for different particle species are different.
- Calculate the detector responses for each particle (π, K, proton) at particular momentum in GEANT4 simulation. Construct probability density function (PDF) base on detector response, and build PDF database as a function of the momentum and detector position.
- Given unknown incoming particle, do particle identification by comparing it PDF to be different particle species.

Modular RICH Detector Responses:





1st Probability Density Functions:

$$P(N_{e^-}; p, H\}) = \frac{1}{\sqrt{2\pi}\sigma(p,H)} \exp[-\frac{1}{2}(\frac{N_{e^-}-\mu(p,H)}{\sigma(p,H)})^2]$$

and

$$P(R; p, H\}) = \frac{1}{\sqrt{2\pi}\sigma(p,H)} \exp[-\frac{1}{2}(\frac{R-\mu(p,H)}{\sigma(p,H)})^2]$$

where

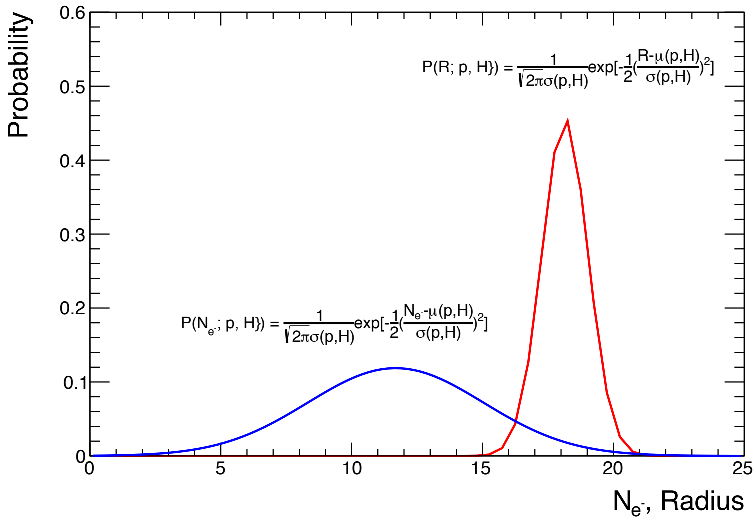
$$R = \frac{1}{N_{e-}} \sum_{i=1}^{N_{e-}} \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}$$

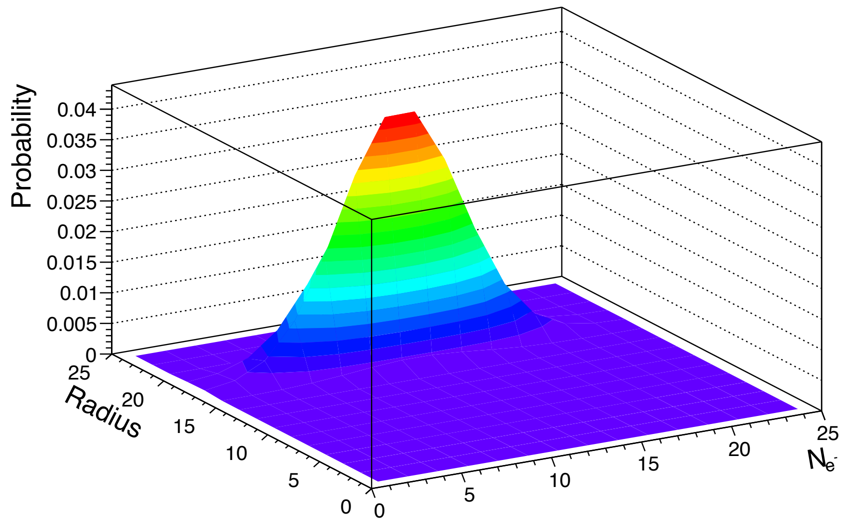
x_0, y_0 are the primary projected position, x_i, y_i are the photon positions.

A photon level likelihood technique capable of handling complex imaging for modular RICH, focusing / proximity focusing RICH, dual-radiator RICH, DIRC will be developed next.

Combined Probability Density Function

5 GeV π, K, proton, lanuch from (0,0,0) with theta 5°, phi 45°





- To utilize both **photon electron production** and the **ring position** information. A combined PDF is defined as:

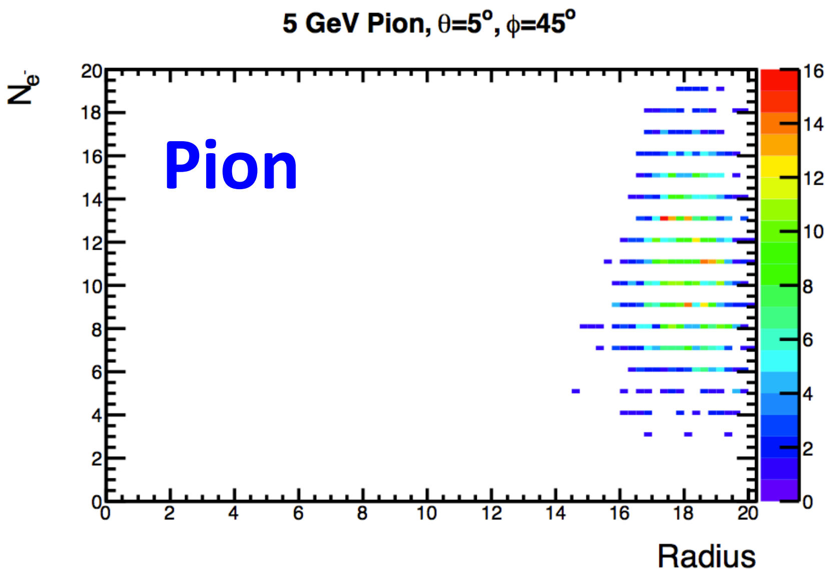
$$P(N_{e^-}, R; p, H) = P(N_{e^-}; p, H) \times P(R; p, H)$$

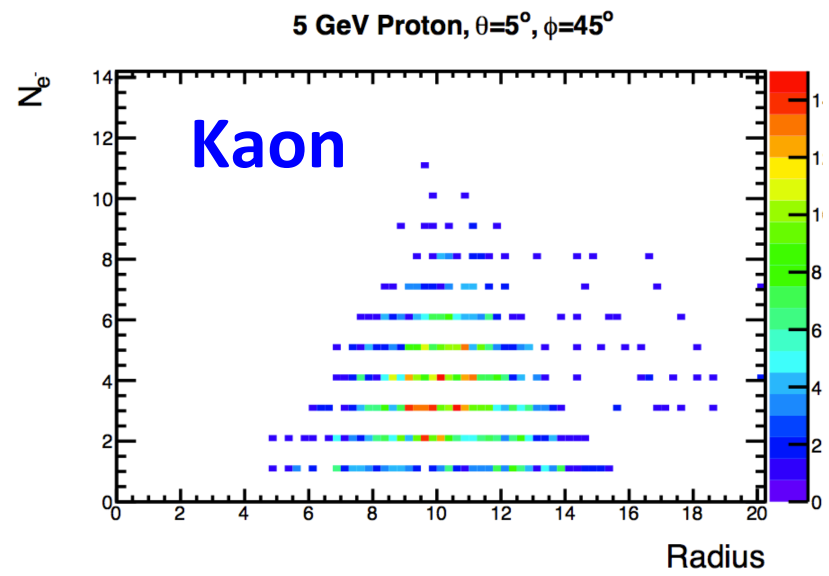
$$= \frac{1}{\sqrt{2\pi}\sigma_1(p,H)} exp[-\frac{1}{2}(\frac{N_{e^-} - \mu_1(p,H)}{\sigma_1(p,H)})^2] \times \frac{1}{\sqrt{2\pi}\sigma_2(p,H)} exp[-\frac{1}{2}(\frac{R - \mu_2(p,H)}{\sigma_2(p,H)})^2]$$

- Following variable and criteria will be used for PID

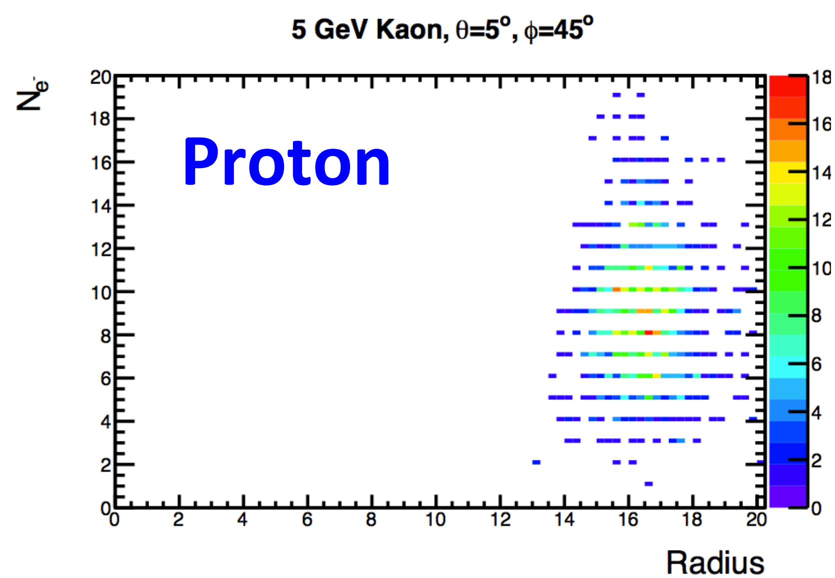
$$L(H; p, N_{e^-}, R) = P(N_{e^-}, R; p, H) \qquad \mathcal{L}(K^+; p_{\rm obs}, x_{\rm obs}) / \mathcal{L}(\pi^+; p_{\rm obs}, x_{\rm obs})$$

Detector Responses Difference





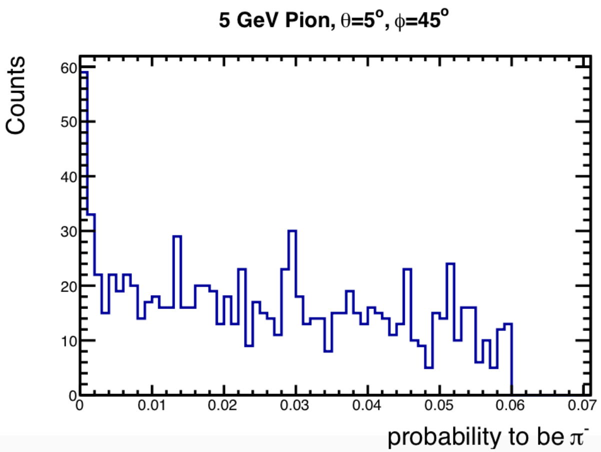
- Based on the detector responses distribution, likelihood PID seems working for pion, Kaon and proton at 5 GeV.

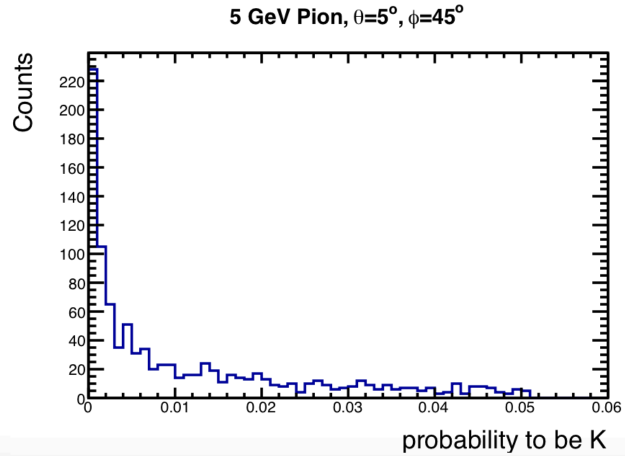


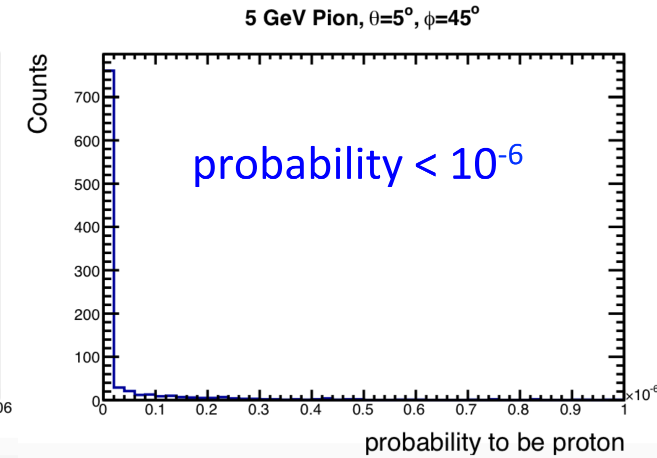
Separate π- from other Particles

1000 π^- launched from (0,0,0) theta 5°, phi 45°.

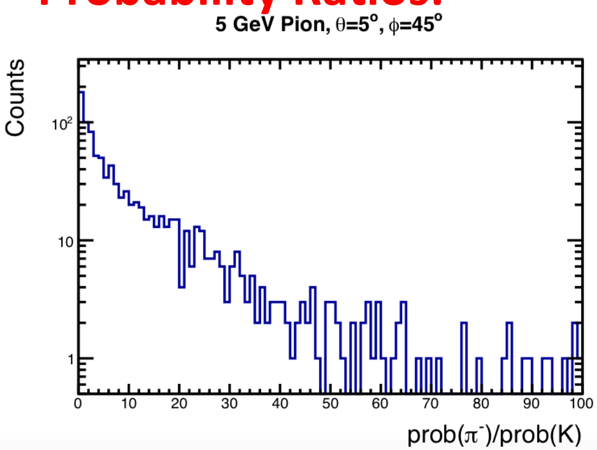
Probability Distributions:

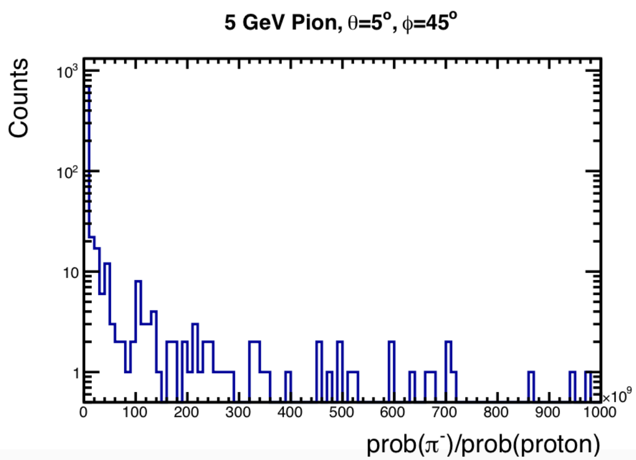






Probability Ratios:





π- sample mixed together with muon and e- and 5 GeV, however, still can be separated from K- and protons

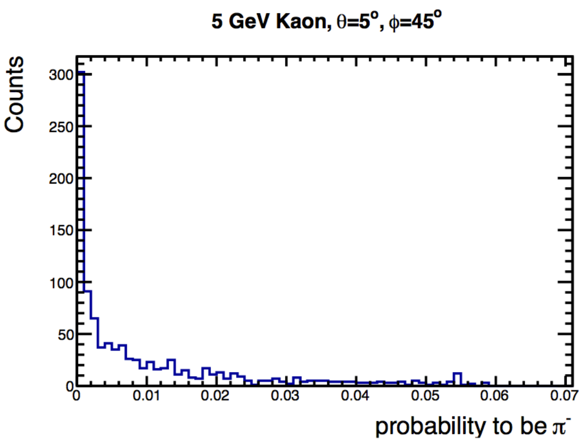
π- PID efficiency and mis-identification rate:

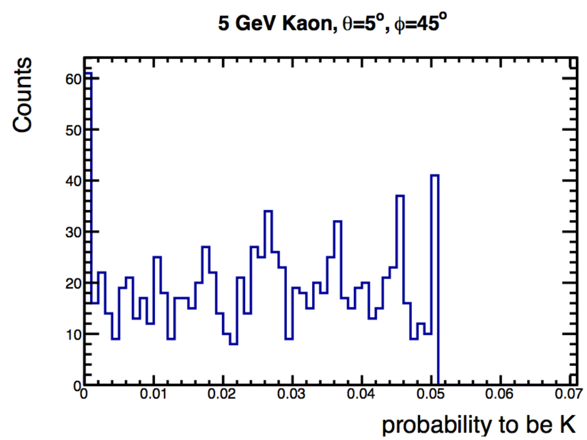
Cuts:	Frac:
pion -> pion L(π-)/L(others)>1.	82.0%
pion -> Kaon L(K-)/L(others)>1.	18.0%
pion -> proton L(proton)/L(others)>1.	0.0%

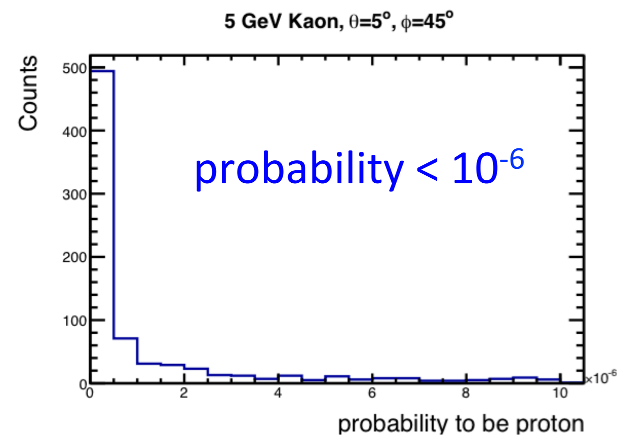
Separate K from other Particles

1000 K^- launched from (0,0,0) theta 5°, phi 45°.

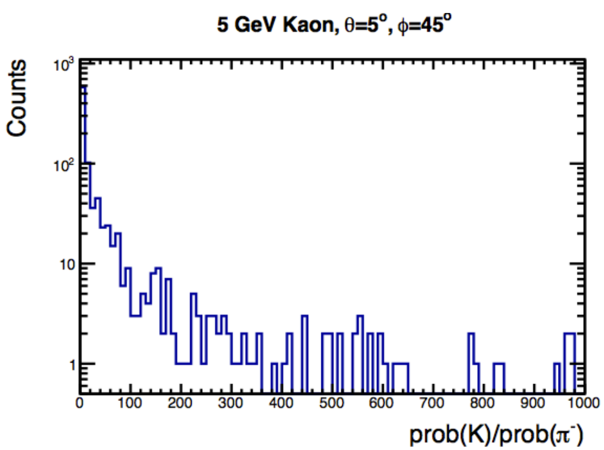
Probability Distributions:

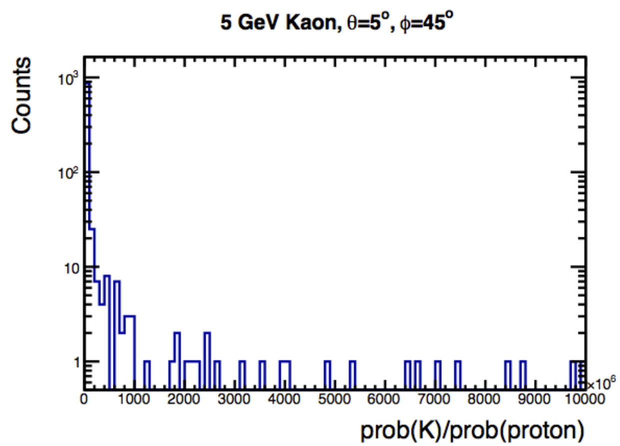






Probability Ratios:





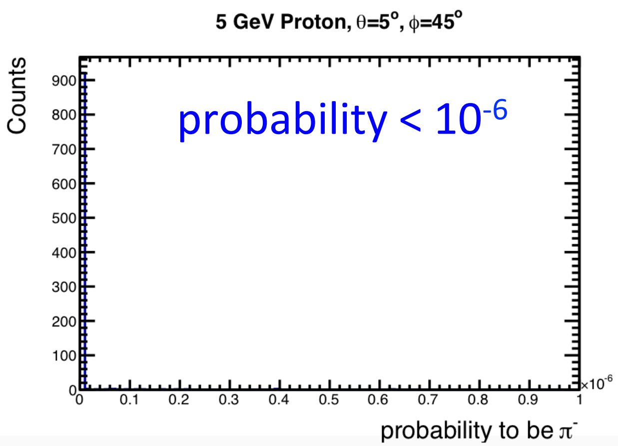
Kaon PID efficiency and mis-identification rate:

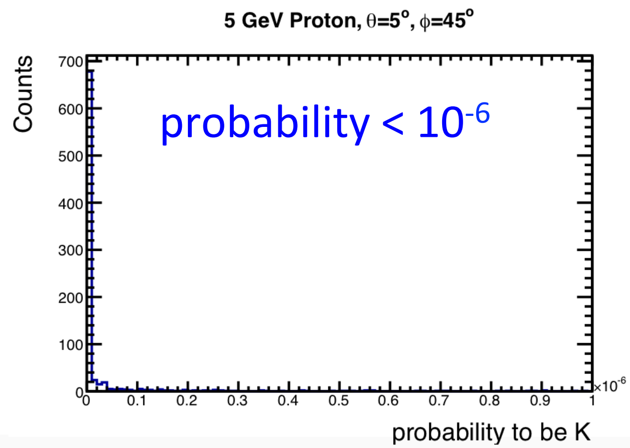
Cuts:	Frac:
K -> K L(K-)/L(others)>1.	79.1%
K -> pion L(pion)/L(others)>1.	19.7%
K -> proton L(proton)/L(others)>1.	1.2%

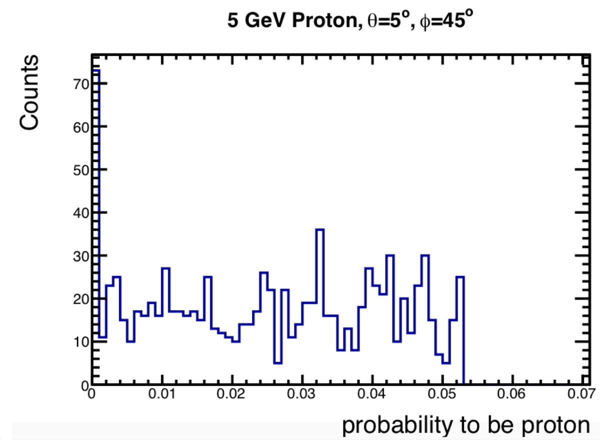
Separate proton from other Particles

1000 K^- launched from (0,0,0) theta 5°, phi 45°.

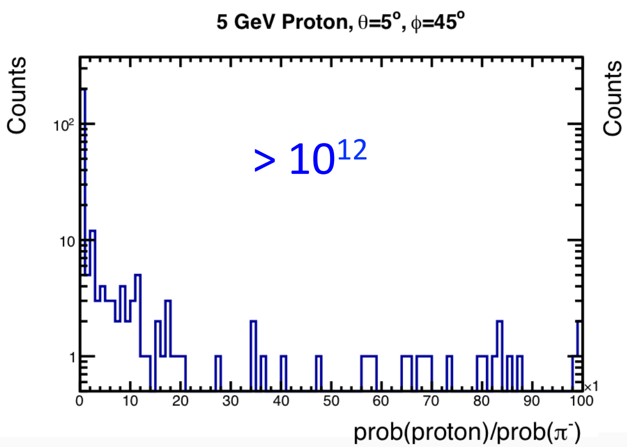
Probability Distributions:

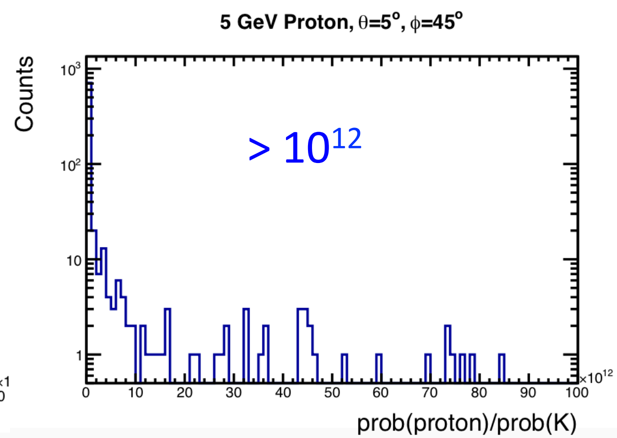






Probability Ratios:





Proton PID efficiency and mis-identification rate:

Cuts:	Frac:
proton -> proton L(proton)/L(others)>1.	94.5%
proton -> pion L(pion)/L(others)>1.	1.7%
proton -> K L(K)/L(others)>1.	2.4%

Summary & Next

- Modular RICH detector has been constructed and studied in JLab GEant4 Monte-Carlo (GEMC) framework.
- Hough transform rings finder algorithm is used to study the PID performance of modular RHIC detector.
- Likelihood technique is under develop to study the PID performance for modular RHIC detector.
- Using likelihood method, at 5 GeV with 1000 single particle sample:
  - 82% π- identified as ture π-, 18% π- identified as K-, 0% of π- identified as proton.
  - 79.1% K- identified to be true K-, 19.7% of K- identified as π-, 1.2% of K- to be proton.
  - 94.5% proton identified as proton, 1.7% proton identified as π-, 2.4% proton identified as K-.
- Photon level likelihood technique capable of handling complex imaging for modular RICH, focusing / proximity focusing RICH, dual-radiator RICH, DIRC will be developed next.
- Different aerogel refractive index (n=1.01 to n=1.04), and momentum dependent particle identification performance study will be done next.

BACKUP

Quantum Efficiency

- The wavelength range of interest for unscattered Cherenkov photons produced in aerogel, ~ 300 - 500 nm.
- The eRD11 collaboration are interested in "bialkali crystals (SbCsK)", as well as semiconductor material such as GaAs, which have relatively high QE.

QE definition:

$$EQE = \frac{N_{e^-}}{Incident\ N_\gamma}$$

$$IQE = \frac{N_{e^-}}{Absorbed\ N_\gamma}$$

Quantum efficiency is extracted for bialkali crystals, GaAsP, and GaAs and used for photosensor study.

http://www.hamamatsu.com/jp/en/technology/innovation/photocathode/index.html

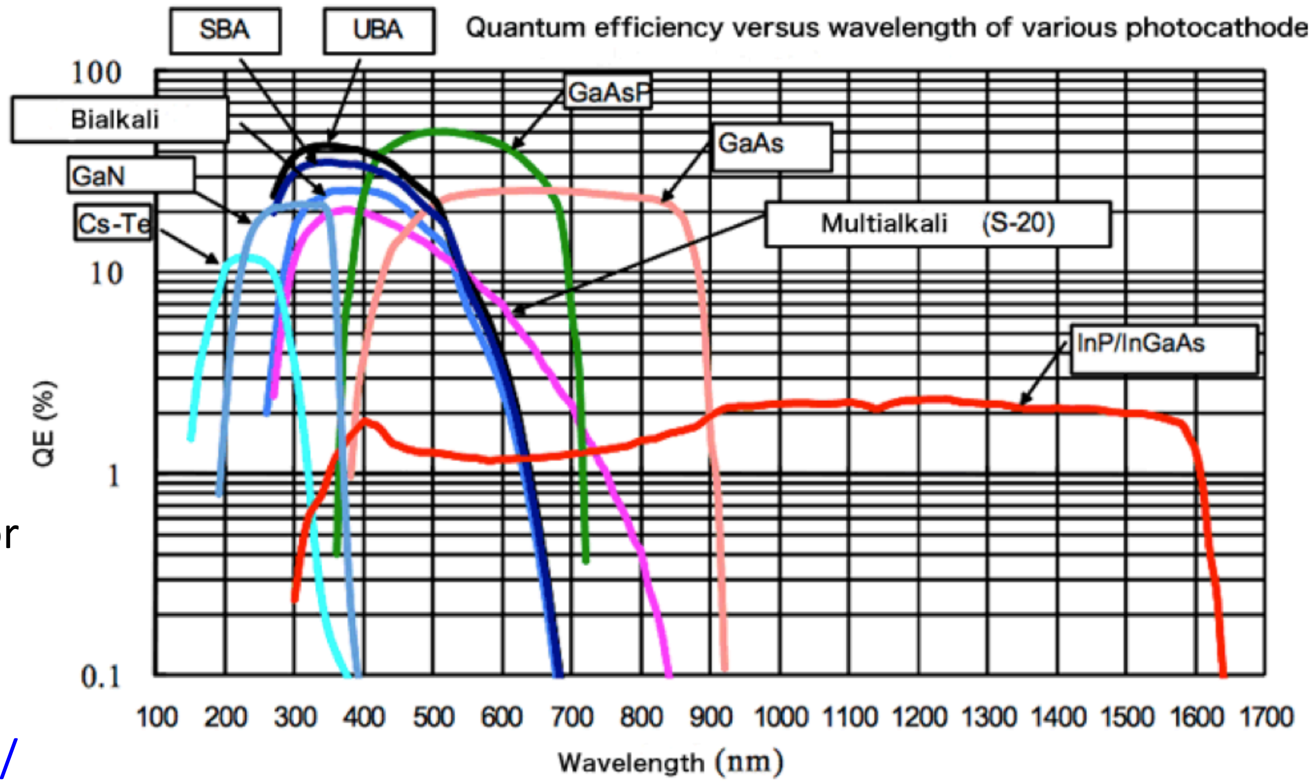


Figure 17. Comparison of quantum efficiency curves with various photocathode materials from Hamamatsu Photonics Corporation.