Conceptual Design of PID Detectors for the EicC Spectrometer

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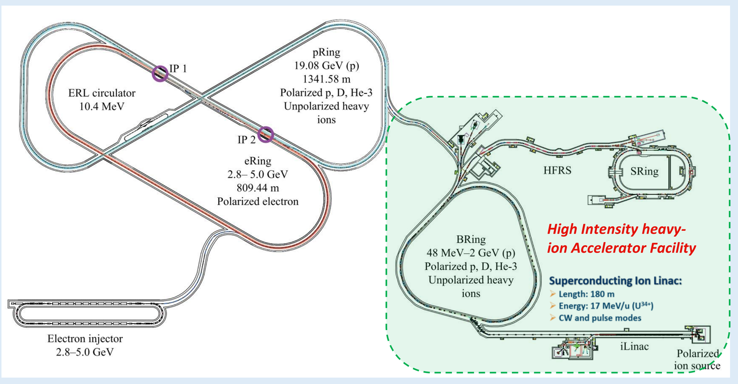
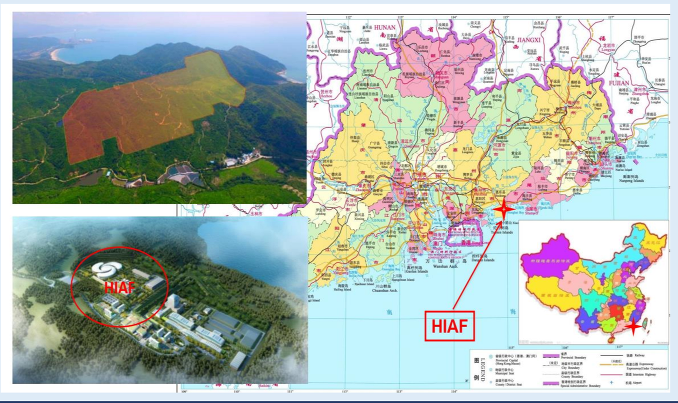
Abstract

The Electron-ion collider in China (EicC) is a proposed future electron-ion collider with a high luminosity above 2.0 × 10^{33} $cm^{2}\cdot s^{-1}$ and center-of-mass energy ranging from 15 to 20 GeV. Accurate particle identification (PID) with large momentum coverage is crucial for investigating exclusive and semi-inclusive processes, as well as enabling precise 3D imaging of the nucleon structure in the EicC experiment. One significant challenge of EicC spectrometer is to achieve precise PID capability with large momentum coverage: up to 6 GeV/c in the barrel region and 15 GeV/c in the ion-endcap region for 3σ π/K separation. To meet these PID requirements, the EicC Collaboration has proposed the conceptual design of various Cherenkov detectors, including DIRC in the barrel region, dRICH in the ion-endcap region, and mRICH in the electron-endcap region. To study and optimize their performance, GEANT4 simulation involving advanced optical transmission and image reconstruction algorithms has been conducted.

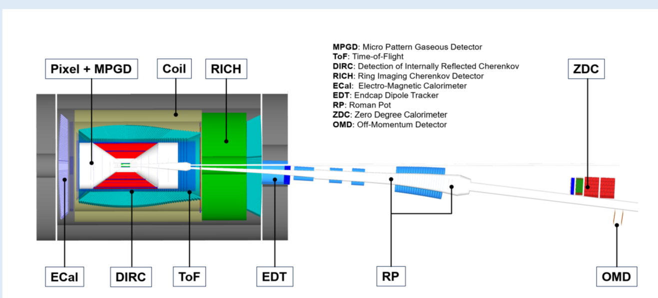
Introduction on EicC

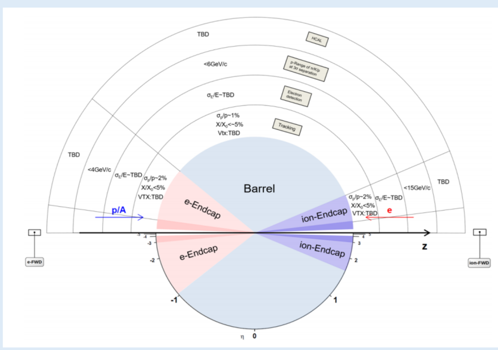
A proposed high-energy nuclear physics project in China, the Electron-Ion Collider (EicC) based on the High Intensity Heavy-Ion Accelerator Facility (HIAF), which is currently under construction in Huizhou, China. This collider will provide highly polarized electrons (approximately 80% polarization) and protons (approximately 70% polarization) at variable center-of-mass energies ranging from 15 to 20 GeV, with a high luminosity of 2.0 × 10^{33} $cm^{2}\cdot s^{-1}$. The primary goals of EicC include precise measurements of nucleon structure in the sea quark region, such as 3D tomography of nucleons, the partonic structure of nuclei, interactions between partons and the nuclear environment, exotic states particularly those containing heavy flavor quarks, and the origin of mass through measurements of heavy quarkonia.

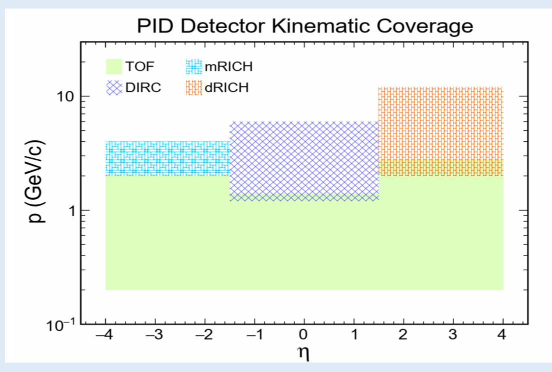




EicC Spectrometer and PID requirements





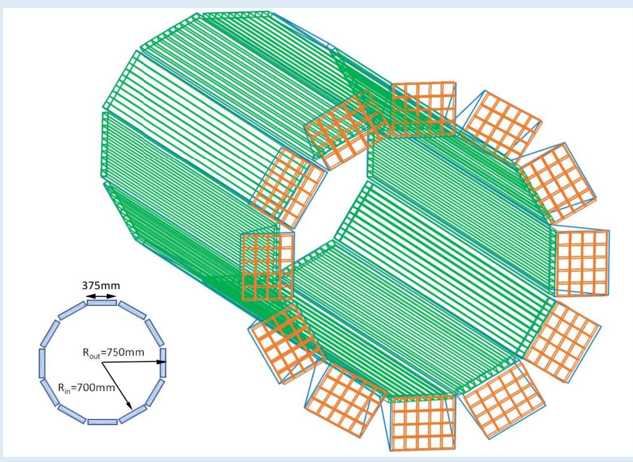


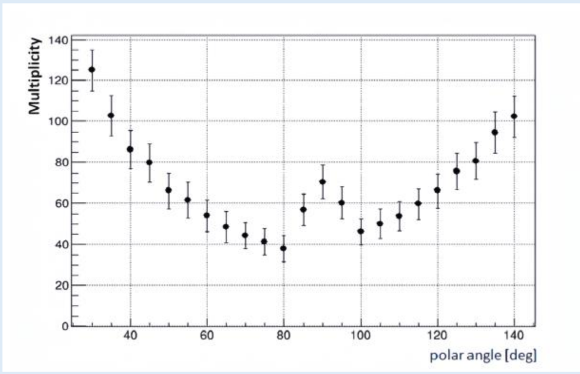
- **Sub detectors to realize the EicC physics goals:**
  1) **Vertex & tracking detectors**
  2) **PID detectors (Cherenkov + ToF)**
  3) **Calorimeters**
  4) **Far Forward detectors**
  5) **Luminosity monitor & Polarimetry**
  6) **DAQ**

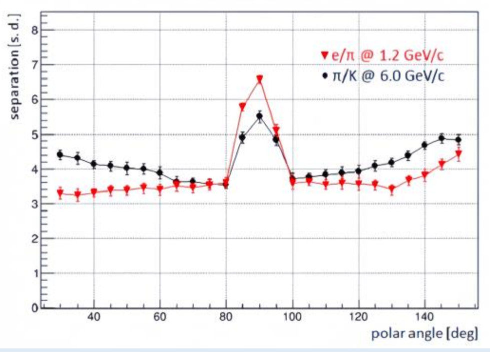
PID detectors：

- **Barrel PID: High performance Detector of Internal Reflection Cherenkov lights (hpDIRC). momentum coverage up to 6 GeV/c**
- **Endcap PID: Ring Imaging Cherenkov (RICH) detectors, dRICH for ion-endcap (up to 15 GeV/c) , mRICH for e-endcap (up to 4 GeV/c)**
- **Low Momentum PID（< 2GeV/c): MPRC, LGAD**

Barrel DIRC: Design and Simulation







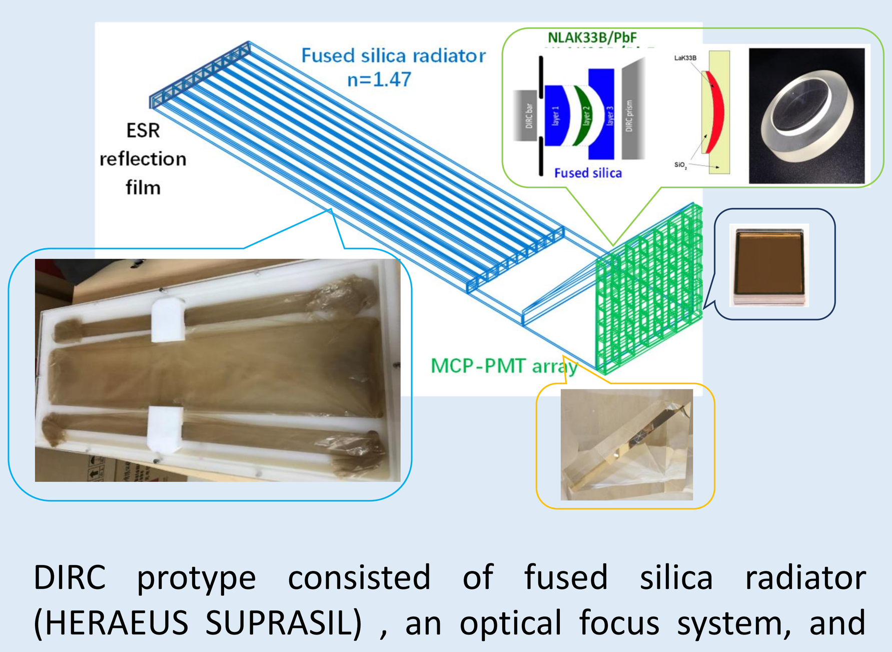
- Quartz radiator bar: 15mm x 17mm x 3300mm
- Expansion volume(EV): 208mm x 340mm x 300mm
- MCP-PMT: Hamamatsu R10754 (pixel size: 5.2mm x 5.2mm)
- Tray box size: 50mm x 320mm x 4000mm with 6 bar+EV
- 12 trays forms a barrel detector with a minimum radius R = 0.7m
- Focusing: spherical 3-layer lens (Fused silica N-LAK33B) curvature radius: 30cm, Thickness: 10mm

Definition of measured DIRC angular resolution:

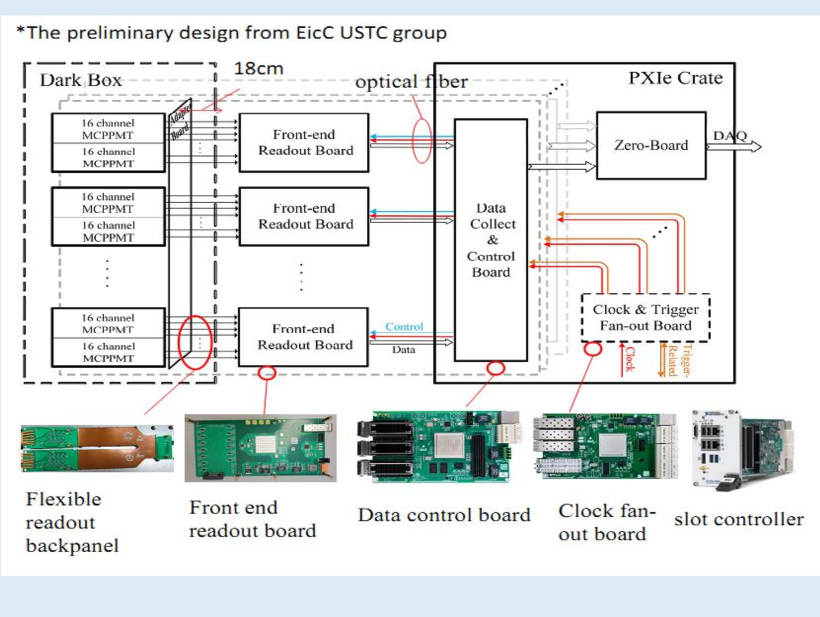
$$\sigma_{\theta_c}(\text{photo}) = \sqrt{\sigma_{chrom}^2 + \sigma_{foc}^2 + \sigma_{bar}^2 + \sigma_{trans}^2 + \sigma_{rec}^2}$$

- σ_{chrom}: Dispersion contribution of the quartz radiator (wavelength: 300-700 nm)
- σ_{foc}: Error from the optical focusing lens and the pixel size of photosensors
- σ_{bar}: Influence of radiator thickness (flatness) on photon yield and transmission efficiency;
- σ_{trans}: Transit fluctuation due to the roughness of the radiator
- σ_{rec}: Error from incident particle tracking

Barrel DIRC Prototype



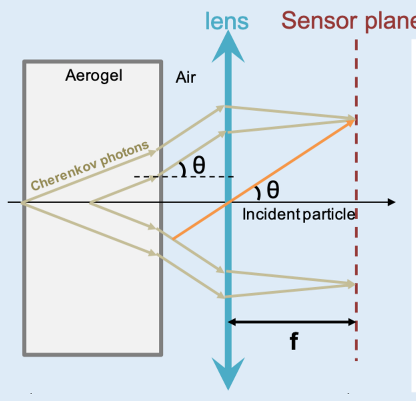
DIRC protype consisted of fused silica radiator (HERAEUS SUPRASIL) , an optical focus system, and MCP-PMT array (transit time spread < 50ps, pixel size ~ 5mm, candidate: R10754, N6021). The muti-channel readout electronics coupled with MCP-PMT, timing resolution of approximately 10ps, developed by USTC-STCF group.

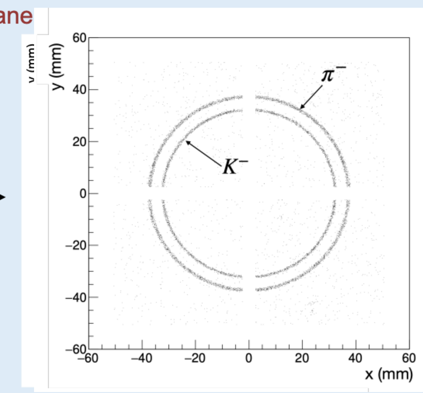


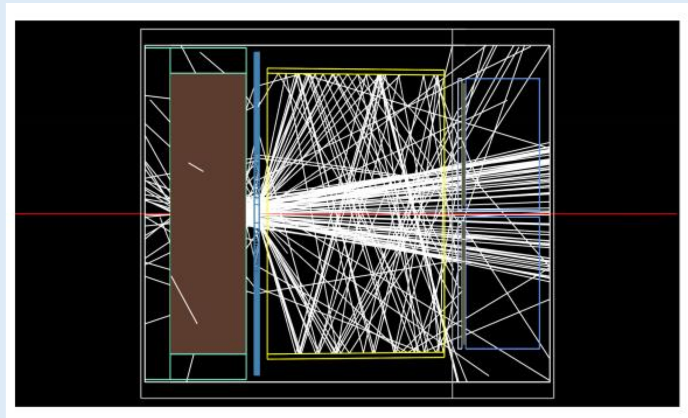
- 672 channels, 21 front-end boards and flexible boards, 1 T0 timing board, 2 data control boards, 1 clock fanout board, and 1 slot controller.
- 1 data control board coupled with 12 front-end readout, the bandwidth of the front-end readout is 320MB/s
- 1 slot controller can accommodate up to 17 data control boards, supporting up to 17 × 12 × 32 = 6528 channels

mRICH: Lens-based Focusing Aerogel Detector Design

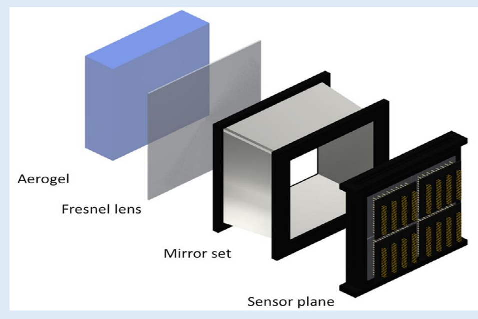
Modular RICH is a Cherenkov detector that employs an aerogel radiator. It utilizes a Fresnel lens to create a focusing effect, enhancing position resolution by limiting the wavelength range of transmitted light and reducing Rayleigh scattering. It features a compact and flexible design, along with powerful particle identification capabilities in a wide momentum range.

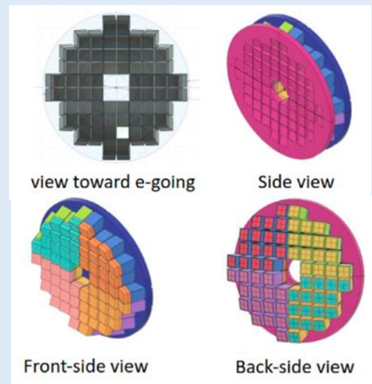




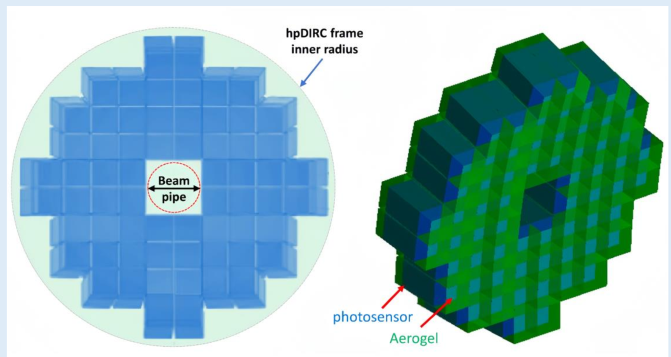


focal length 7.62cm (3")

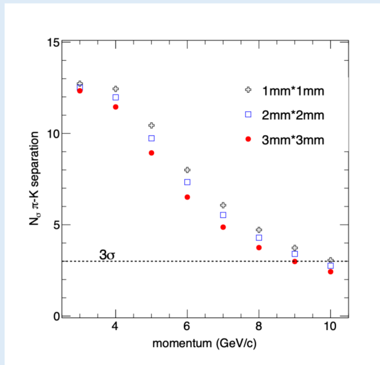


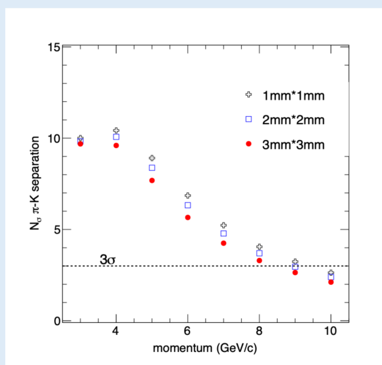


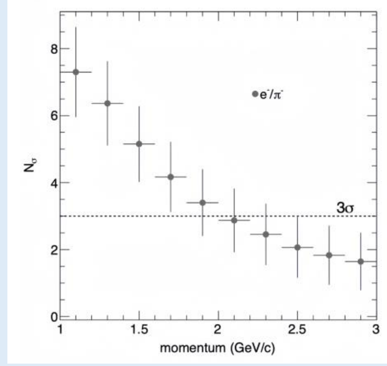
mRICH: Design and Simulation



- Composed of 64 aerogel modules (located at z=1080 ~ 1380 mm, radius 100 ~ 670 mm);
- The cross section of each module is 108 × 108 mm^2, with a thickness of 25 ~ 35 mm;
- The center of each module is at z=-1230 mm and tilted towards the collision center point;
- The Fresnel lens focal length L=76.2 mm (3 inches, n=1.47, Edmund Optics).



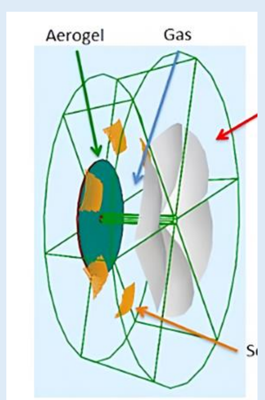


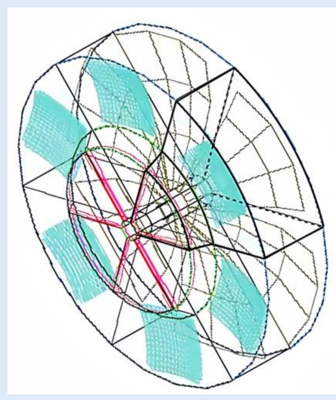


- Separation power decrease with increasing polar angle
- 3 sigma separation up to 9 GeV/c when particle launched at the center of aerogel
- 3 sigma separation up to 8 GeV/c when particle launched at 10 degrees

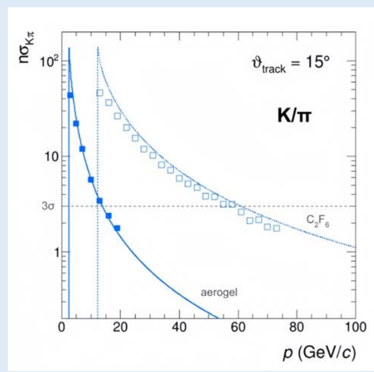
pi/K separation up to 9 GeV/c at best, e/pi separation up to 2 GeV/c at best

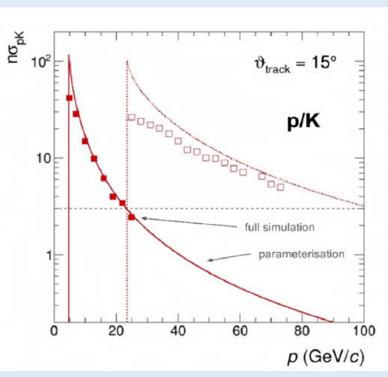
dRICH: Design and Simulation





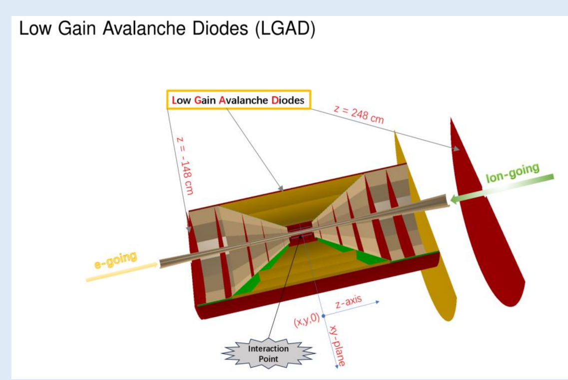
Geometric:
– Length: 2160 mm
– Inner radius: 100 mm
– Outer radius: 1500 mm
– Coverage angle 5-25 degrees
Cherenkov radiator:
– Refractive index: n = 1.03/1.02 (aerogel, 400 nm); n = 1.0008 (C_2F_6)
– Thickness of radiant body: L = 40-50 mm (aerogel), 1600-2000 mm (C_2F_6)

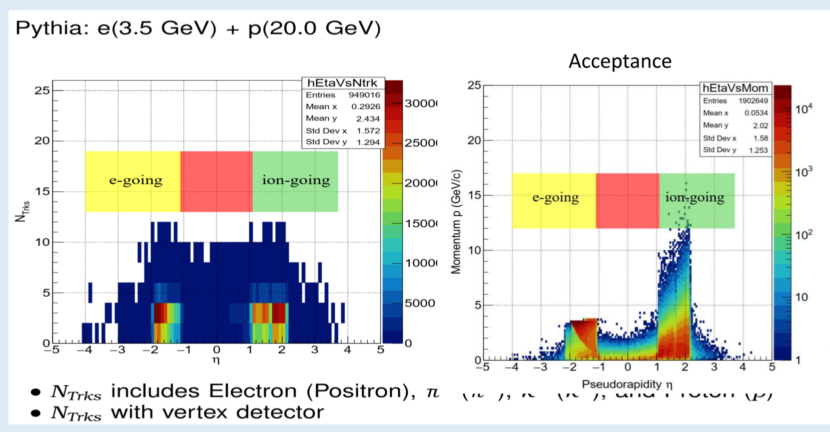


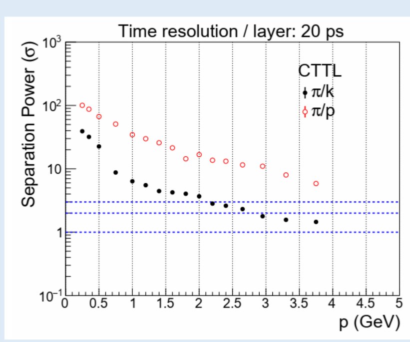


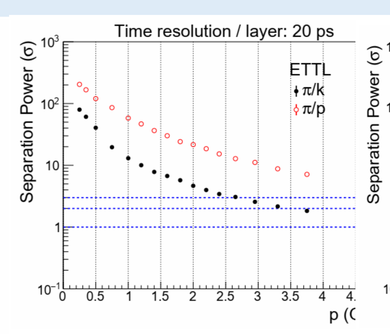
In GEANT4 simulation, the reflectivity of the spherical mirror is set to be 50%, the quantum efficiency of the photosensor is 20%, and its pixel size is 3mm × 3mm. Approximately 60 photons are generated by the aerogel radiator per track. Considering the detection efficiency of the photosensor array, the actual measured number is 3 ~ 5pe. Meanwhile, approximately 200 photons are generated in the gas, with an actual measured count of 30 ~ 40 pe.

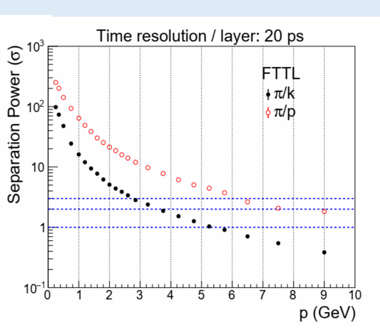
LGAD: Design and Simulation











Low Gain Avalanche Detector (LGAD): Silica TOF achieves low momentum PID (<2GeV/c)

Barrel TOF: right after the tracker system

Ion-endcap TOF: right after the RICH system

E-endcap TOF: right after the calorimeter system

Timing resolution: 20-30 ps / layer, Spatial resolution: ~30 μm

Summary

Based on simulations and analysis above, it is proposed to use mRICH, hpDIRC, dRICH and TOF as EicC PID detectors to meet its PID requirements with high precision and large momentum coverage up to 15 GeV/c.

Special thanks for all help and supports from EicC and USTC colleagues!