Introduction on the PID Detectors at EicC

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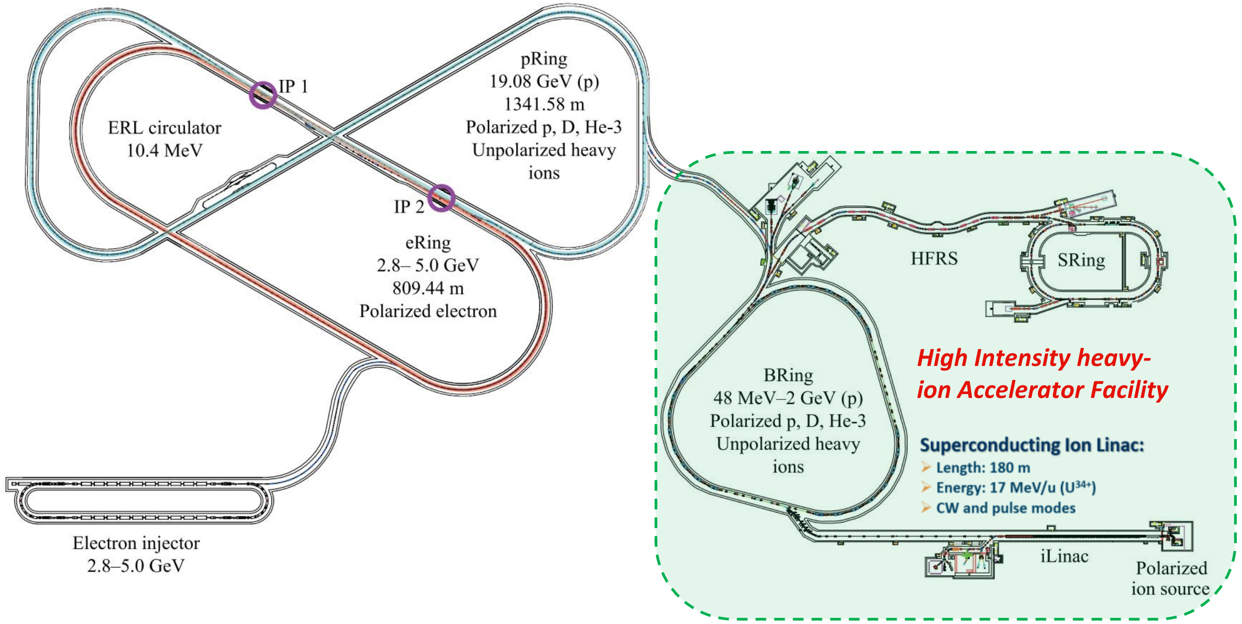
Outline

- EicC spectrometer overview and its PID requirements
- PID detectors: DIRC, RICH, LGAD, MRPC
- Summary

Introduction on EicC

As a future high energy nuclear physics project, an Electron-ion collider in China (EicC) has been proposed based on High Intensity heavy-ion Accelerator Facility (HIAF), a heavy-ion accelerator currently under construction. The proposed collider will provide highly polarized electrons (with a polarization of ~80%) and protons (with a polarization of ~70%) with variable center of mass energies from 15 to 20 GeV and the luminosity of (2–3) × 10^{33} $cm^{-2} \cdot s^{-1}$.

The main focus of the EicC will be precision measurements of the structure of the nucleon in the sea quark region, including 3D tomography of nucleon; the partonic structure of nuclei and the parton interaction with the nuclear environment; the exotic states, especially those with heavy flavor quark contents; and the origin of mass by measurements of heavy quarkonia.



EicC Spectrometer Overview

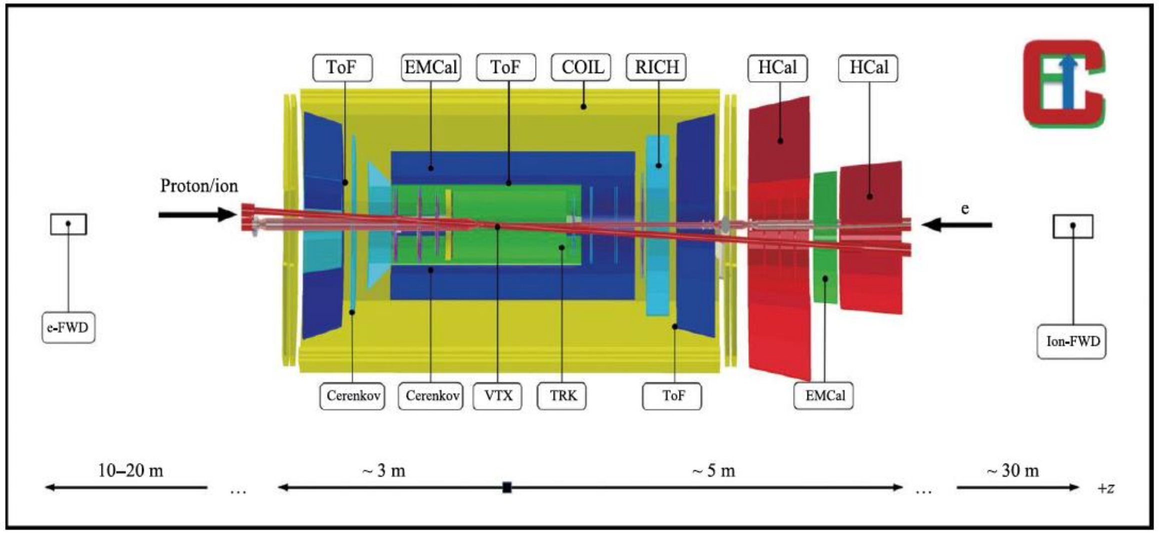
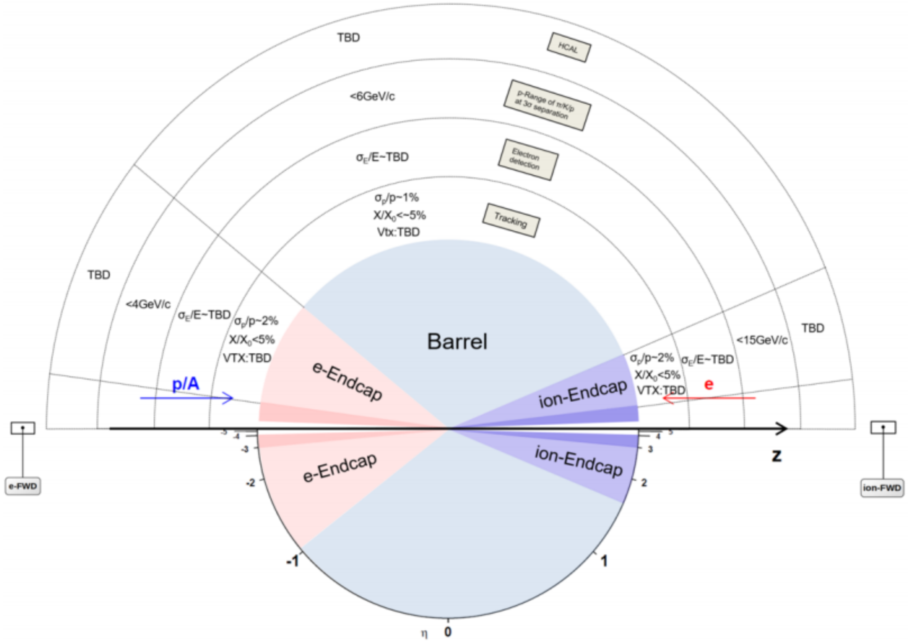


Fig. 4.10 Conceptual design of the EicC detector.



➤ Sub detectors to realize the EicC physics goals:

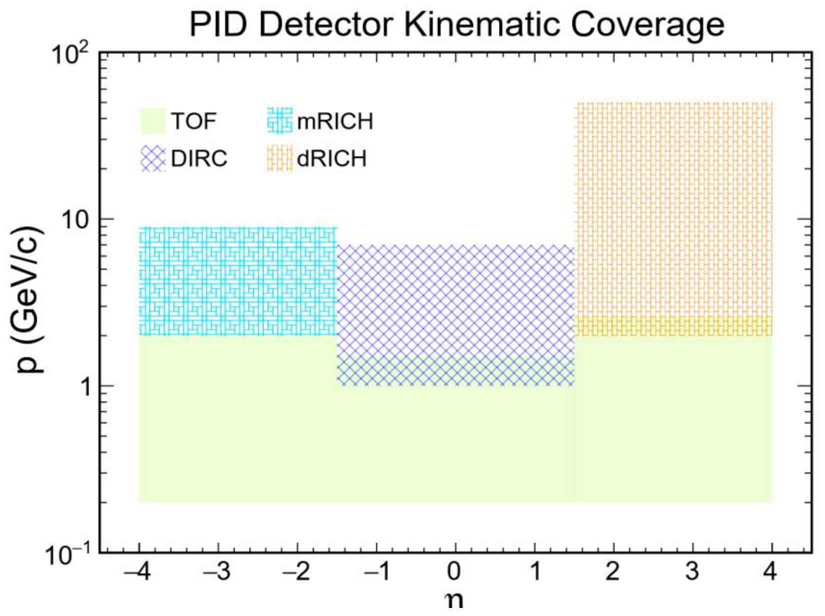
1) Vertex & tracking detectors
2) PID detectors (Cherenkov + ToF)
3) Calorimeters
4) Far Forward detectors
5) Luminosity monitor & Polarimetry
6) DAQ

General requirements:

- Large rapidity ($-4 \leq \eta \leq 4$) coverage;
- High precision & fast tracking in high luminosity
- Electromagnetic and Hadronic Calorimetry with large momentum coverage
- Accurate PID to separate π, K, p in large momentum range
- Large acceptance for diffraction, tagging, neutrons
- Strict control of spectrometer's background and systematic errors

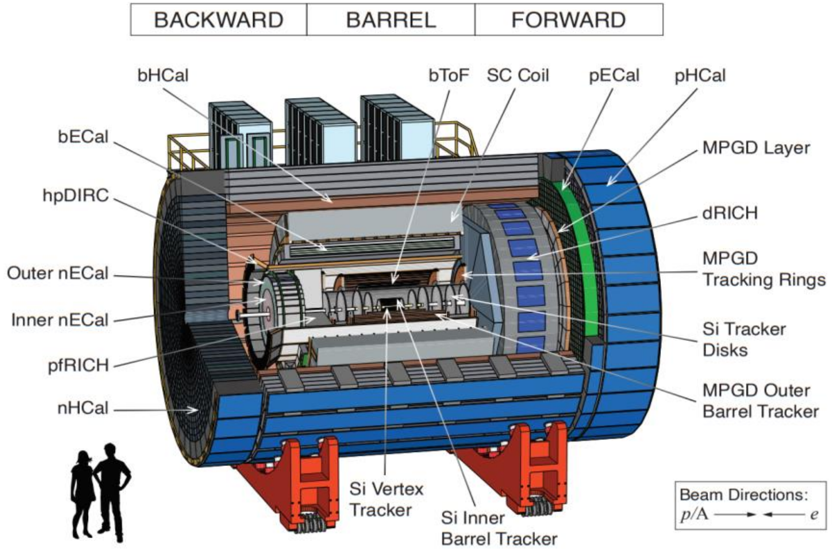
Detector Requirements for PIDs

- Fast response and ultra-high resolution
- Compact structure and radiation resistant
- PID power with large momentum coverage:
  - ≤ 4 GeV/c at e-Endcap;
  - ≤ 15 GeV/c at ion-Endcap ;
  - ≤ 6 GeV/c at Barrel.



PID detectors:

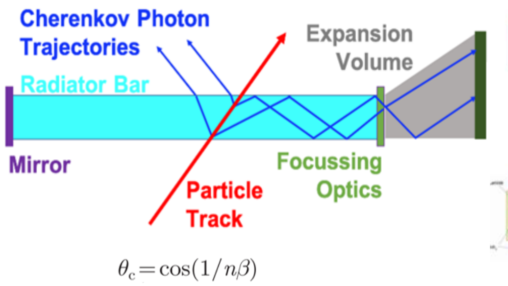
- Barrel PID: High performance Detector of Internal Reflection Cherenkov lights（hpDIRC）
- Endcap PID: Ring Imaging Cherenkov (RICH) detectors, dRICH for ion-endcap, mRICH for e-endcap
- Low Momentum PID（< 2GeV/c): MPRC, LGAD

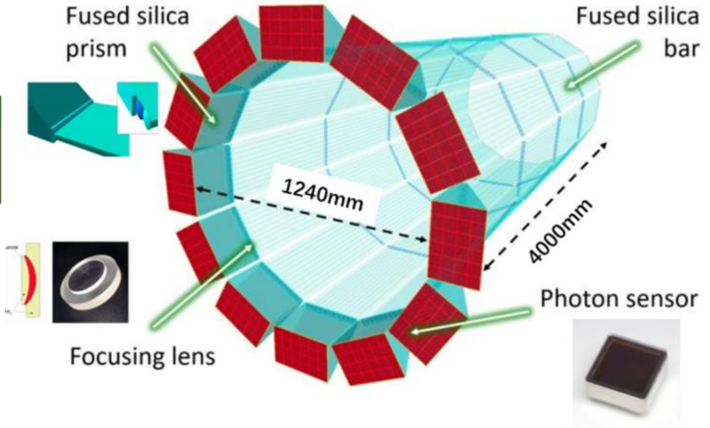


Barrel DIRC for PID

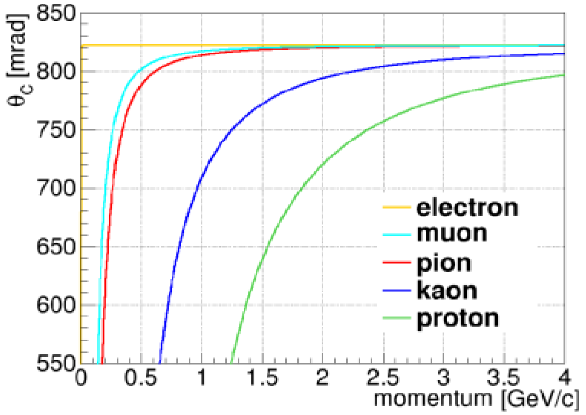
Detector of Internal Reflection Cherenkov lights (DIRC):

Different charged particles induce Cherenkov radiation with different Cherenkov angles, DIRC achieve PID through reconstructing their Cherenkov angles, by measuring the transit time and exit position/angle of Cherenkov photons induced by different particles.

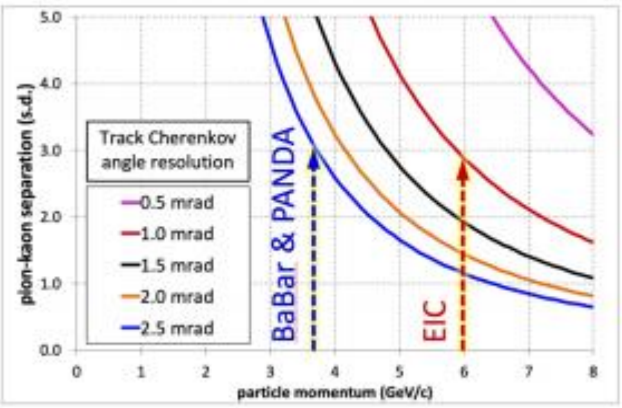




- Consisted of fused silica(n=1.47) as Cherenkov radiator and MCP-PMTs as photosensor array
- Compact structure as barrel detector
- Achieve 3σ π/K separation up to 6 GeV/c with angle resolution ~ 1mrad

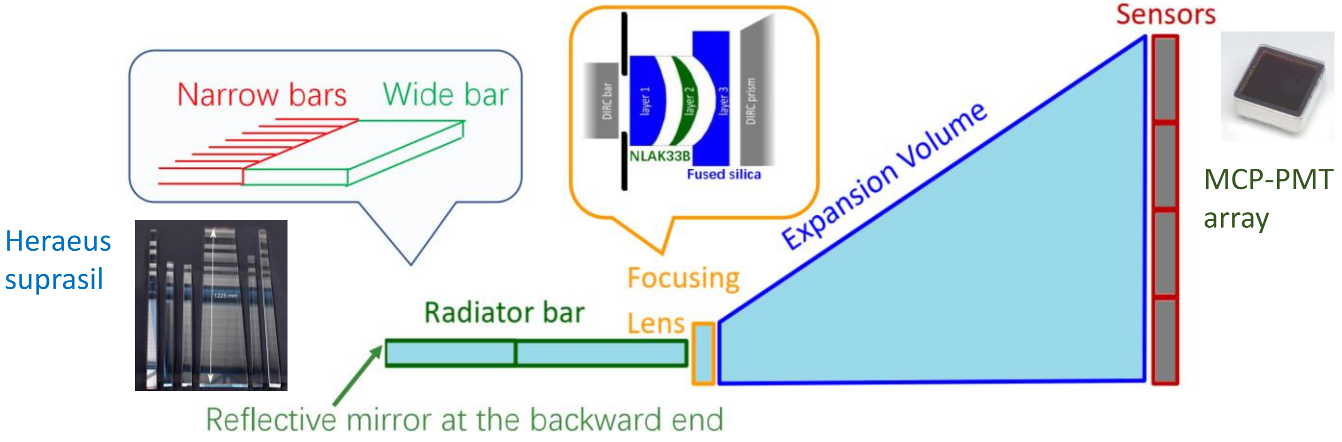


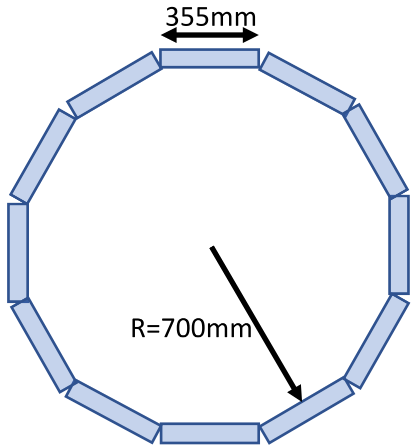
refractive index of synthetic fused silica **with n = 1.47**



Reference from PANDA & EIC

DIRC Module Design





- 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) or Photek MAPMT253 (pixel size: 1.6mm x 1.6mm)
- 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

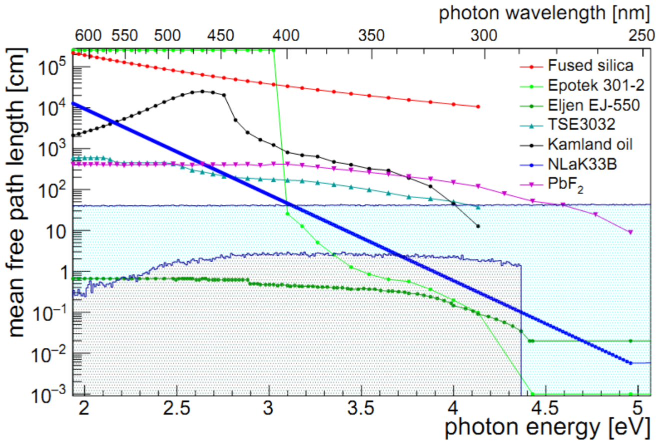
Definition of measured DIRC angular resolution:

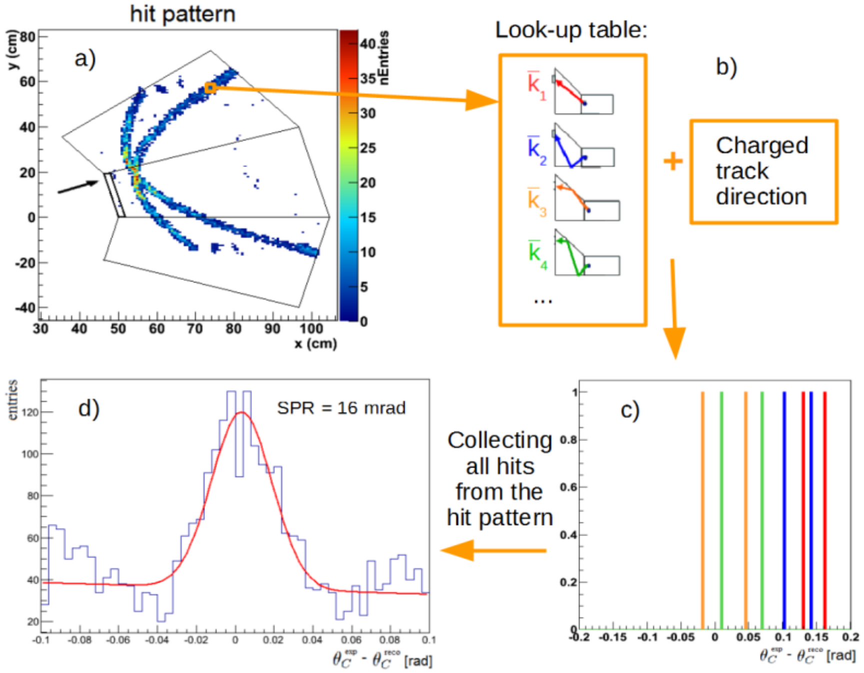
$$\sigma_{\theta_c}(\text{photo}) = \sqrt{\sigma_{chrom}^2 + \sigma_{foc}^2 + \sigma_{bar}^2 + \sigma_{trans}^2 + \sigma_{rec}^2}$$

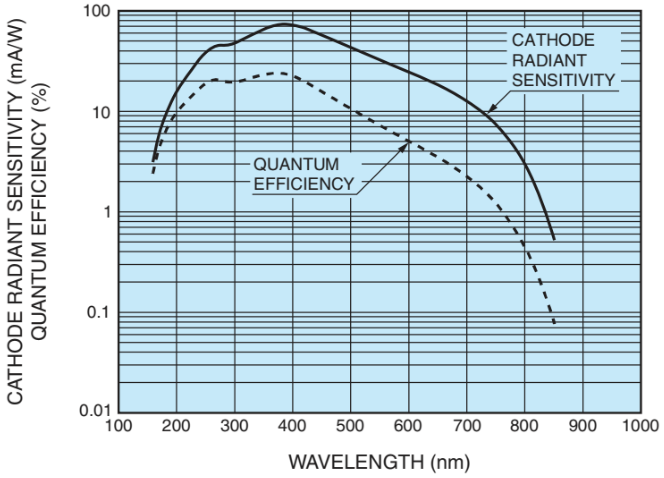
- σ_{chrom}: the dispersion contribution of the quartz radiator (wavelength: 300-700 nm)
- σ_{foc}: error from the optical focusing lens and the pixel size of photosensors
- σ_{bar}: the influence of radiator thickness (flatness) on photon yield and transmission efficiency;
- σ_{trans}: transit fluctuation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

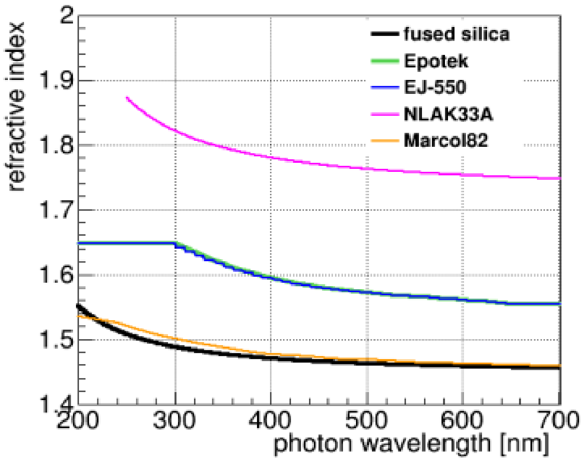
DIRC Simulation

Simulation Input & process:



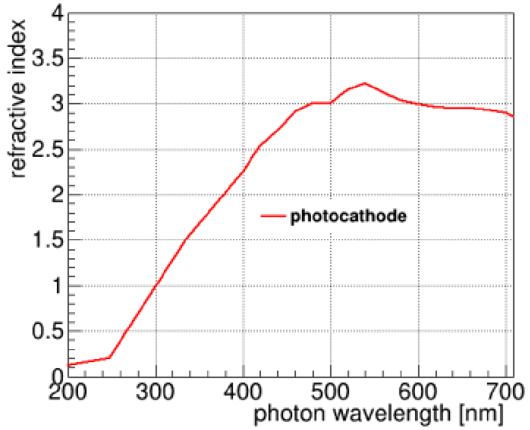




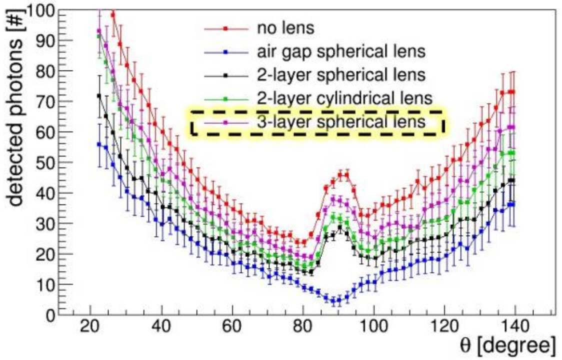


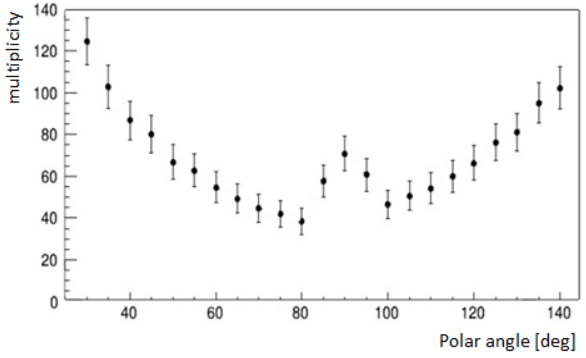
Reference from "Simulation, Reconstruction, and Design Optimization for the PANDA Barrel DIRC", 2016

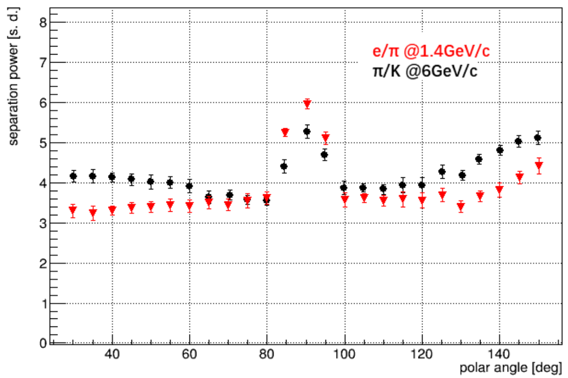
Wavelength [nm]	Bulk transmission [1/m]	# faces	Reflection coefficient	Surface roughness [Å]
406	$0.994 \pm 3.2 \cdot 10^{-4}$	49	$0.99984 \pm 1.6 \cdot 10^{-5}$	4.9 ± 1.3
532	$0.997 \pm 2.7 \cdot 10^{-4}$	49	$0.99991 \pm 1.4 \cdot 10^{-5}$	4.7 ± 1.3
635	$0.9994 \pm 8.0 \cdot 10^{-5}$	49	$0.99996 \pm 1.5 \cdot 10^{-5}$	3.7 ± 3.0

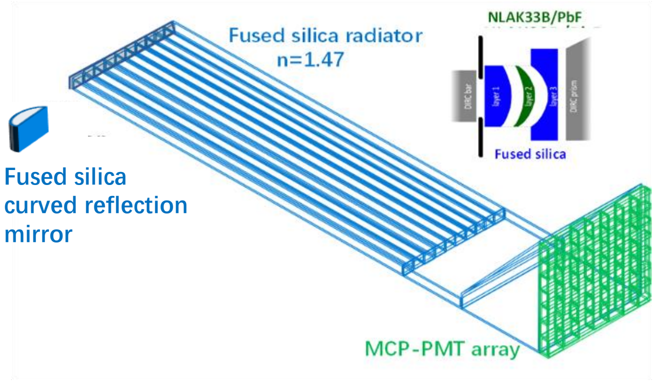


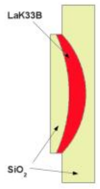
DIRC simulation and prototype setup

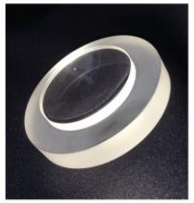












under processing

Hamamastu
R10754 (available)

GENERAL

Parameter		Description / Value	Unit
Spectral response		160 to 850	nm
Wavelength of maximum response		380	nm
Window material		Synthetic silica	—
Photocathode	Material	Multialkali	—
	Minimum effective area	23 x 23	mm
Dynode	Dynode structure	2 stages Microchannel plate	—
	Channel diameter	10	μm
Number of anode pixels		16 (4 x 4 matrix)	—
Anode pixel size		5.28 x 5.28	mm
Operating ambient temperature Ⓐ		-30 to +45	°C
Storage temperature Ⓐ		-30 to +50	°C

MAXIMUM RATINGS (Absolute maximum values)

Parameter		Value	Unit
Supply voltage	Between anode and cathode	2700	V
Average anode current		2	μA

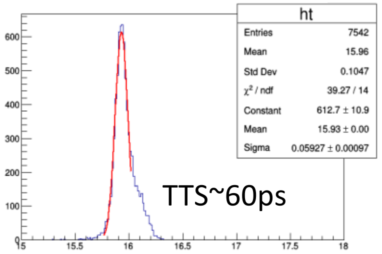
CHARACTERISTICS (at 25 °C, 2200 V)

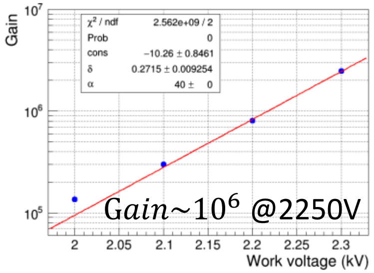
Parameter		Min.	Typ.	Max.	Unit
Cathode sensitivity	Luminous (2856 K)	80	110	—	μA/lm
	Blue sensitivity index	—	7.5	—	—
Anode luminous sensitivity		22	110	—	A/lm
Gain		—	1×10^6	—	—
Dark current (After 30 minutes storage in darkness)		—	5	30	nA
Time response	Rise time	—	195	—	ps
	Fall time	—	310	—	ps
	Width	—	400	—	ps
	T.T.S. (FWHM) Ⓑ	—	75	—	ps

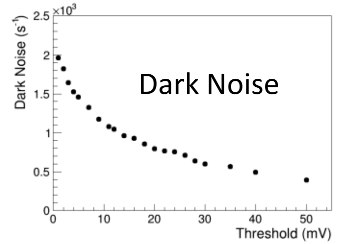
Photek MAPMT253
(within months)

The AuraTek-Square has an active area of 53 mm x 53 mm with packaged anode configurations of 32 x 32 with 1.656mm pitch, 16 x 16 with 3.312mm pitch, and 8 x 8 with 6.624mm pitch. A non packaged version with anode confirguration of 64 x 64 with 0.828mm pitch is also available. Custom readout configurations with different anode pitch and signal connectors can be considered.

- True noiseless photon counting
- < 860 ps FWHM pulse width
- Transit time spread of < 40 ps rms



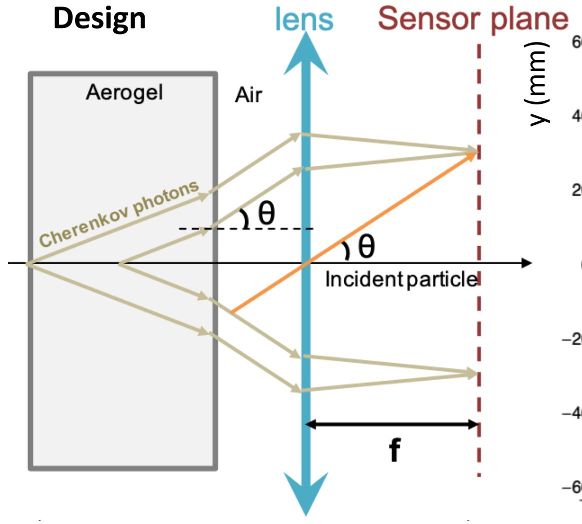




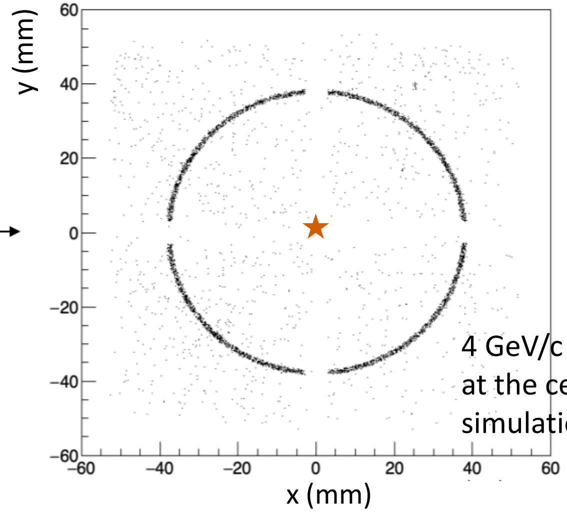
mRICH: Lens-based Focusing Aerogel Detector Design

Modular RICH is a Cherenkov detector based on aerogel radiator. It uses a Fresnel lens to generate focusing effect to improve position resolution (Fresnel lens limit the wavelength range of transmission light, which can reduce Rayleigh scattering effect). It has compact and flexible structure, and PID power with large momentum coverage.

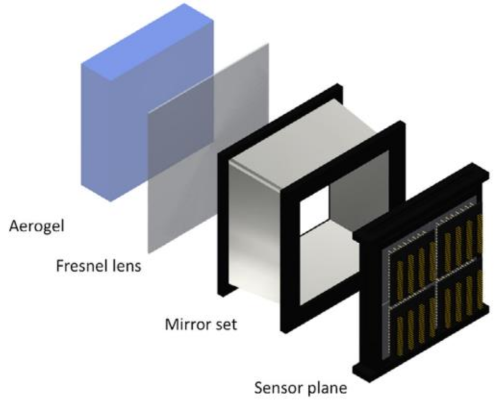
Lens-Based mRICH Design



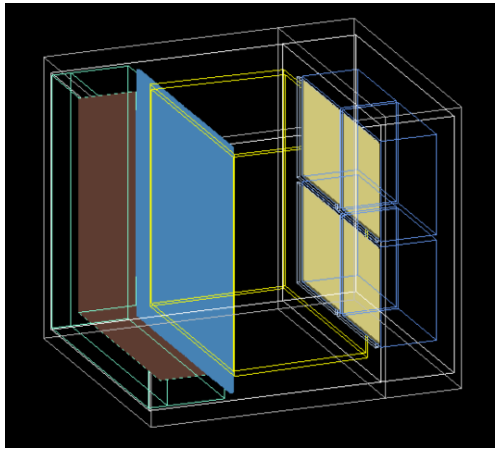
focal length 15.24cm (6")



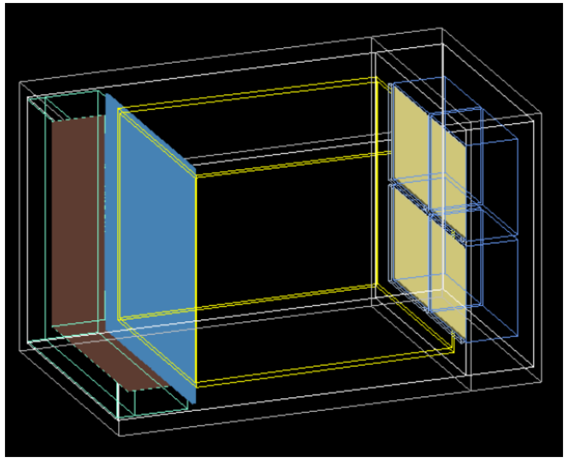
4 GeV/c pion beam launched at the center of xy plane in simulation

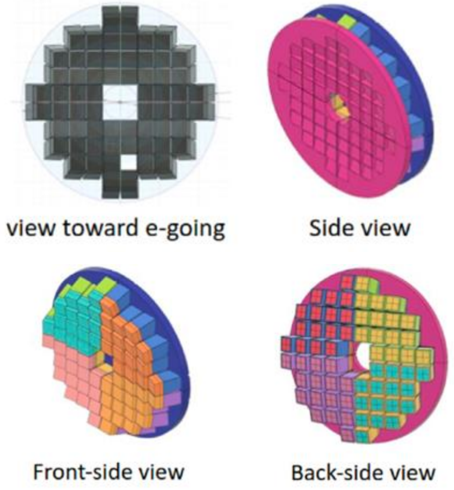


focal length 7.62cm (3")

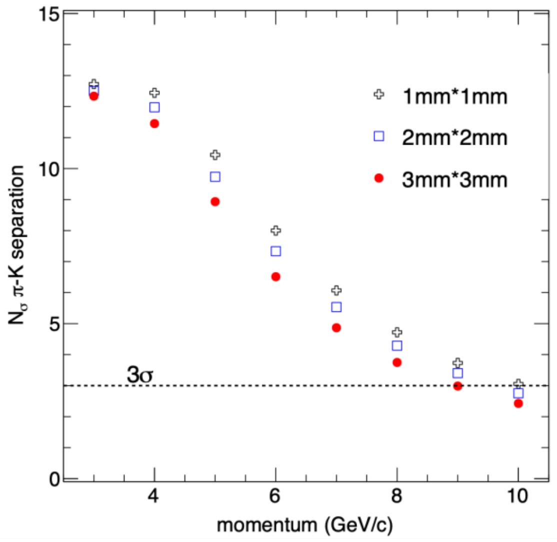


focal length 15.24cm (6")

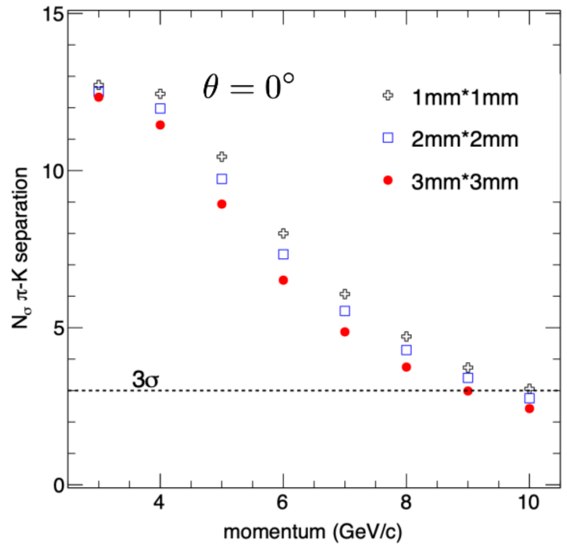


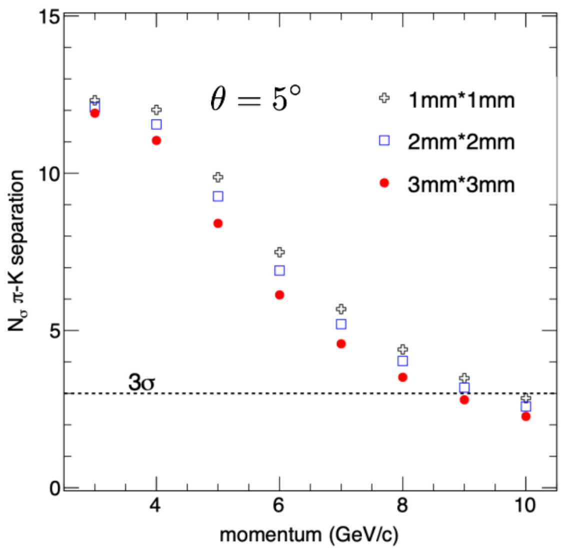


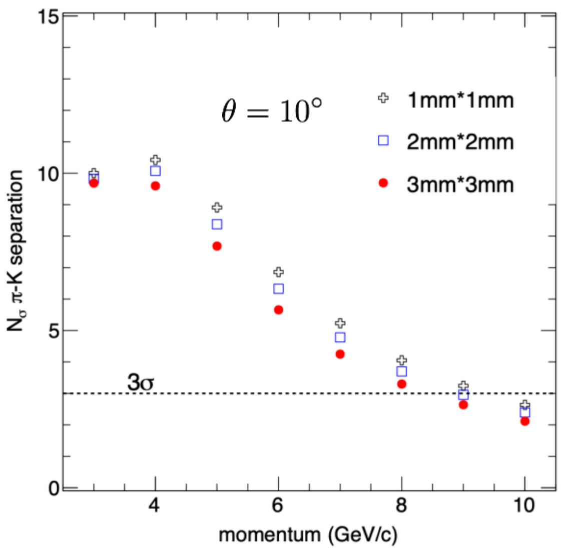
mRICH Simulation: PID Separation Power



- pi/K separation up to 9 GeV/c
- e/pi separation up to 2 GeV/c

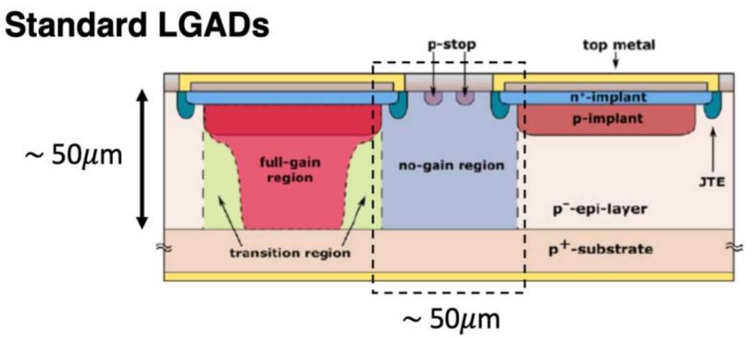




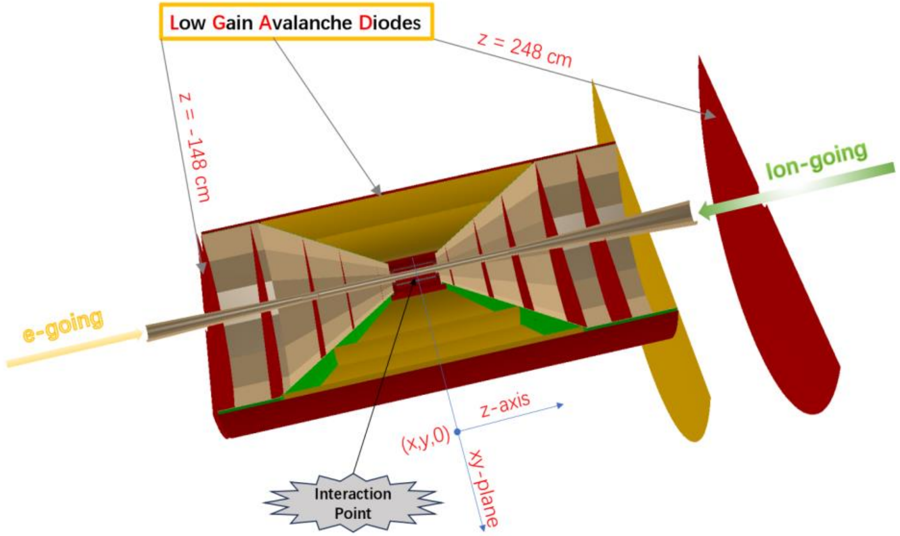


- Separation power decrease with increasing polar angle
- 3 sigma separation up to 9 GeV/c when particle launched at the center of aerogel
- 3 sigma separation up to 8 GeV/c when particle launched at 10 degrees

LGAD: Low gain avalanche detector



Low Gain Avalanche Diodes (LGAD)



Low gain avalanche detector (LGAD): Silica TOF achieves low momentum PID (<2GeV/c) by generating signal pulses with fast rising edges through local avalanche amplification in semiconductors. It has compact pixel structure and can provide high resolution (um) tracking information besides measuring ToF (ps).

- Barrel TOF: right after the tracker system
- Ion-endcap TOF: right after the RICH system
- E-endcap TOF: right after the calorimeter system

LGAD-TOF configuration

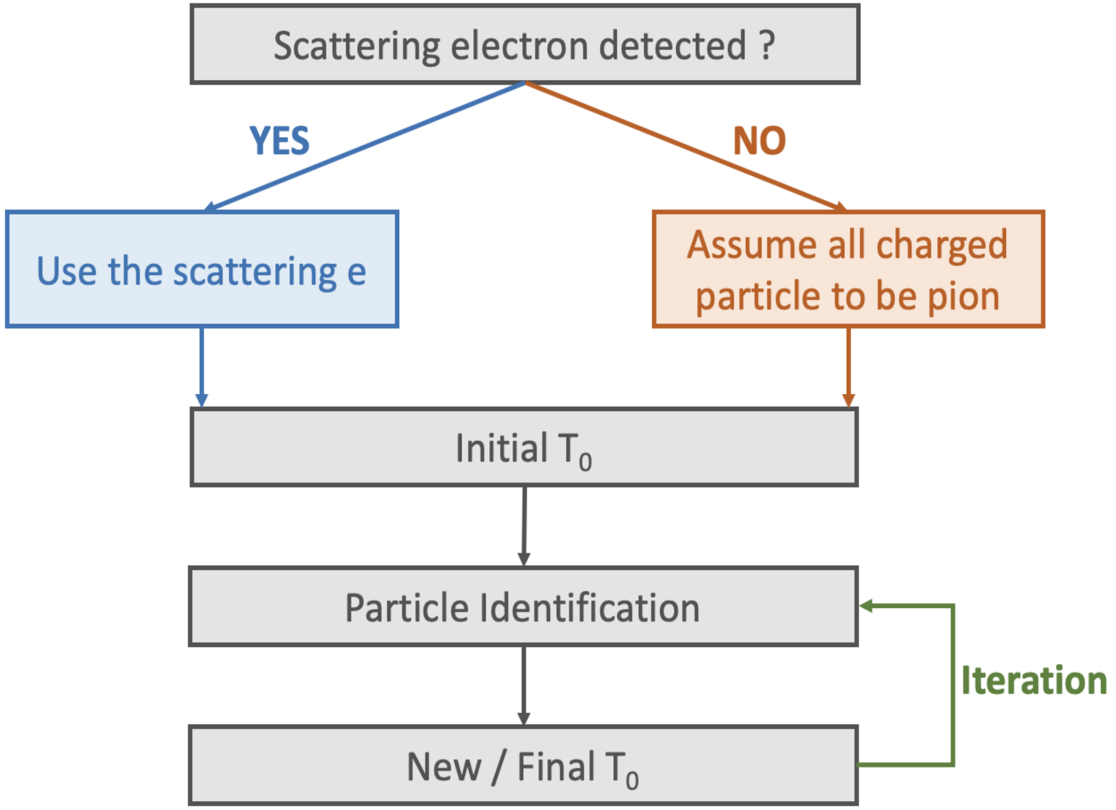
	R^{barrel} (cm)	Length (cm)	Z location (cm)	R^{endcap}_{in} (cm)	R^{endcap}_{out} (cm)	η coverage
Backward			-148	5.4	110.81	[-4.0, -1.1]
Barrel	80 (trying to achieve 60cm)	214				[-1.1, 1.1]
Forward			248	12.3	185.7	[1.1, 3.7]

- Current configuration fits to the tracking system well
- Timing resolution: 20-30 ps / layer
- Spatial resolution: ~30 μm

LGAD: Pythia Simulation

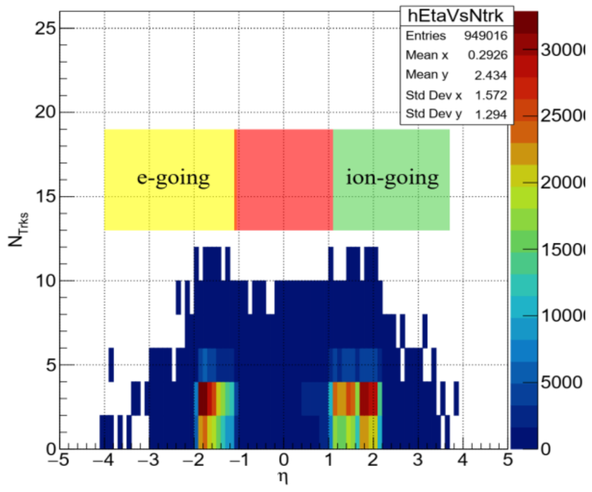
- Event generator: Pythia
- e (3.5GeV) + p (20 GeV)
- Generate 1M e+p event, simulate the performance of LGAD-TOF correlated to tracking detector
- Simulation ongoing

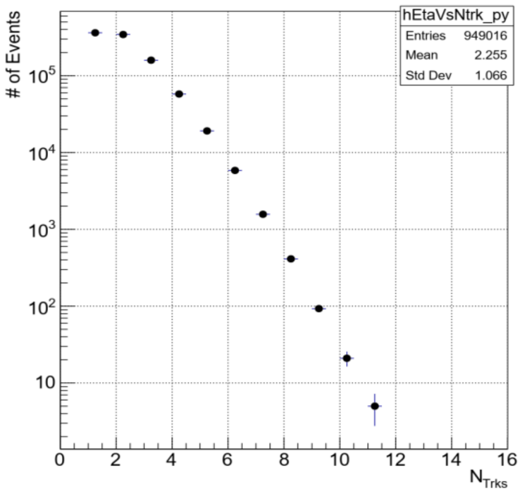
Start-time determination strategy



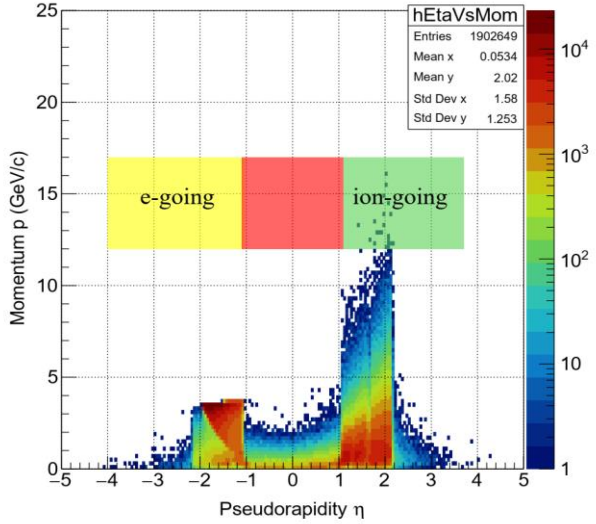
LGAD: Pythia Simulation

Pythia: e(3.5 GeV) + p(20.0 GeV)

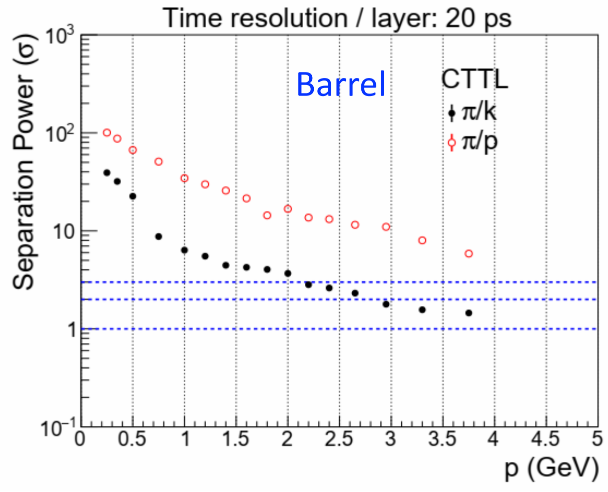


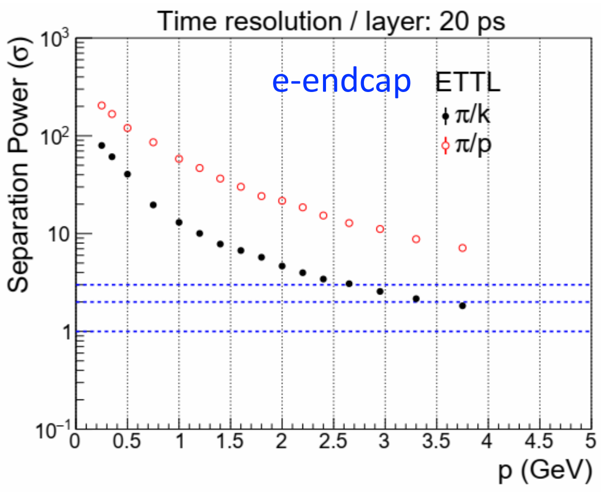


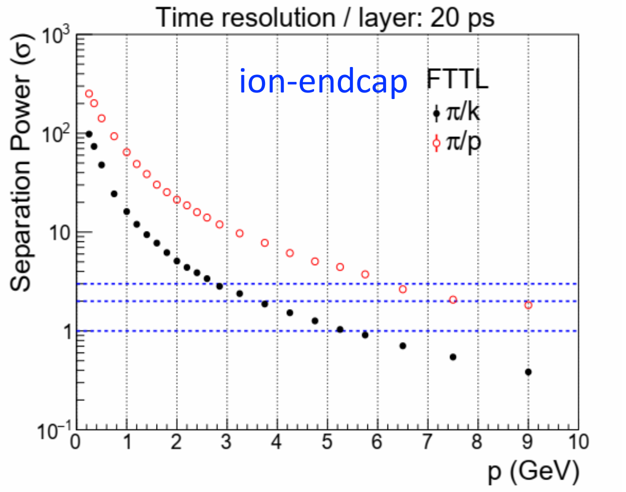
Acceptance



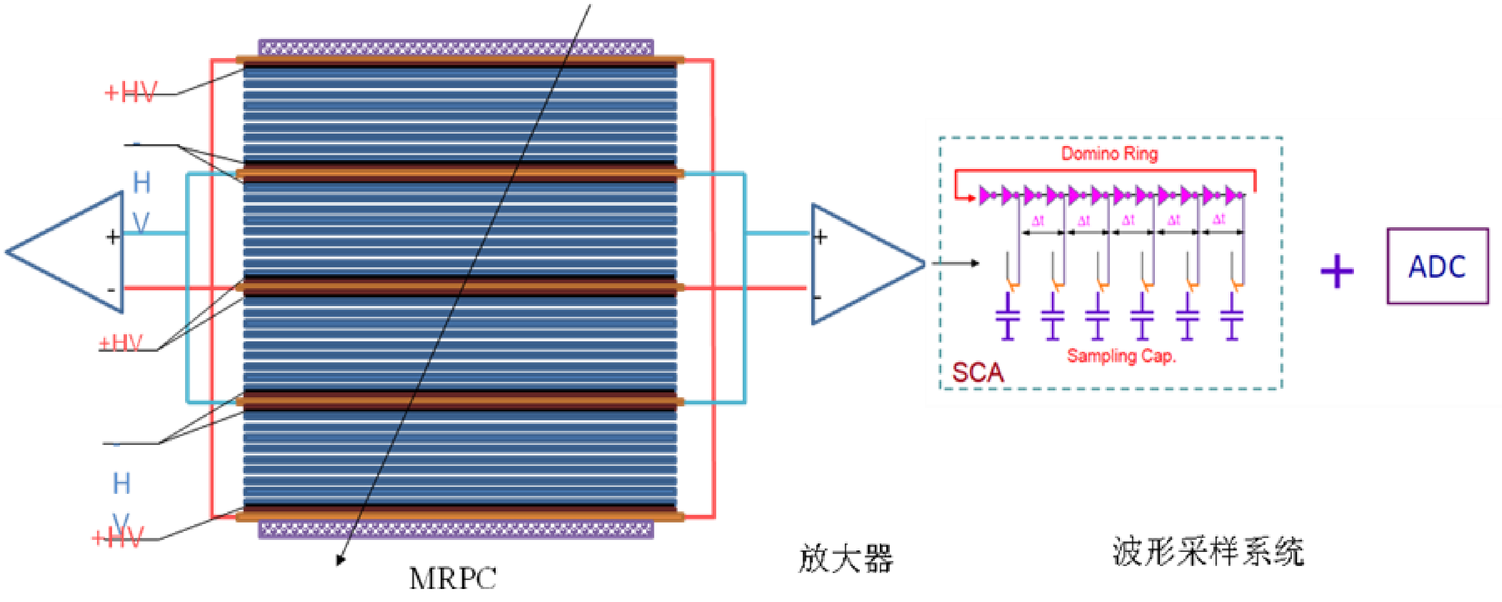
- N_{Trks} includes Electron (Positron), π^- (π^+), k^+ (k^-), and Proton ($\bar{p}$)
- N_{Trks} with vertex detector







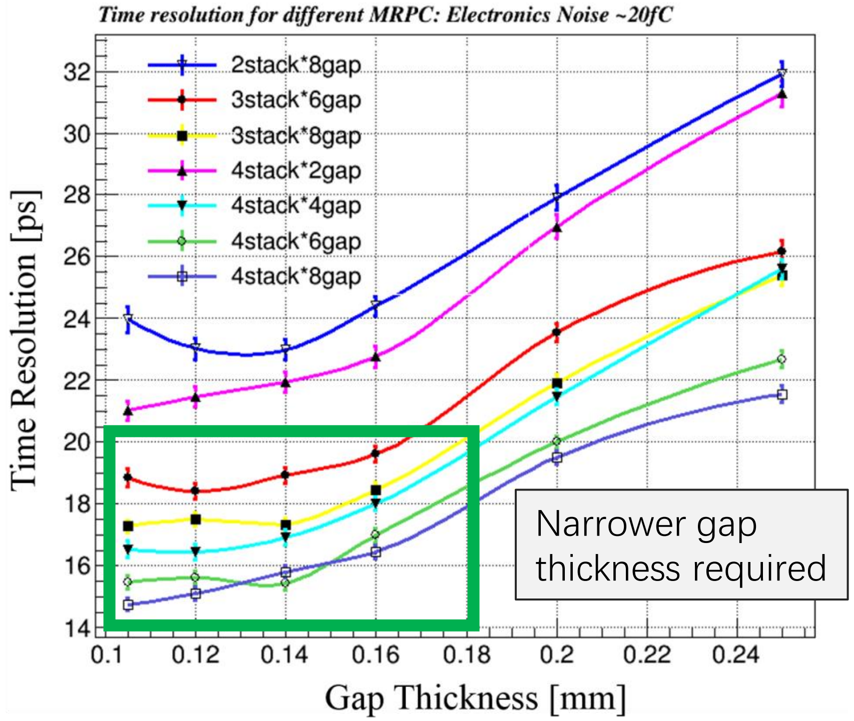
Narrow gap MRPC: toward 20ps resolution



$$\sigma_{TOF} = \sqrt{\sigma_{MRPC} + \sigma_{electronics}}$$

σ_{TOF} <20 ps, the intrinsic resolution of narrow gaps MRPC is around 15ps, and the time jitter of readout electronics <13~15 ps。

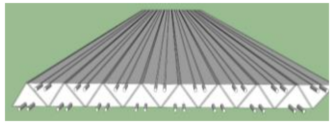
- Simulation indicates proper ways to design the gap thickness and arrange the stacks

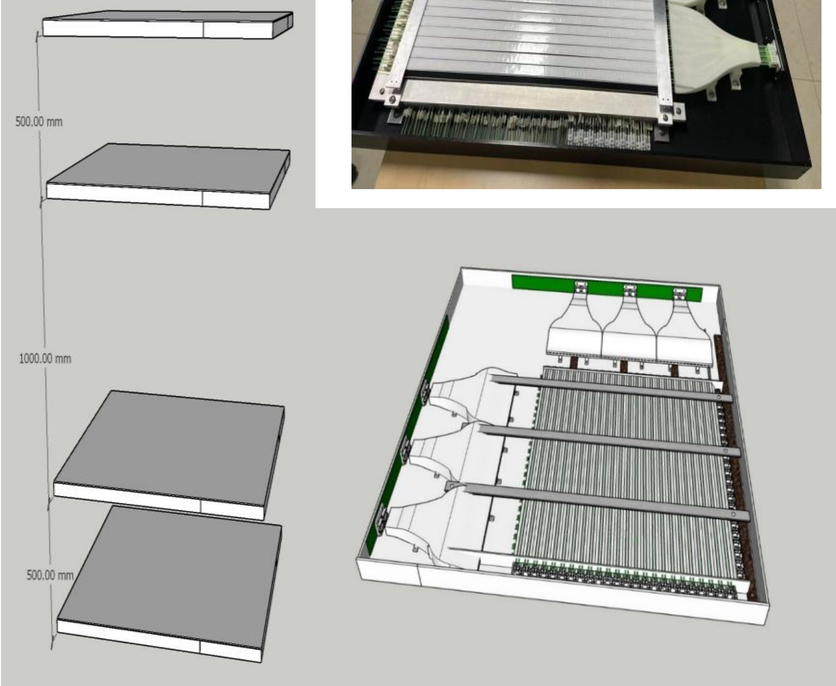


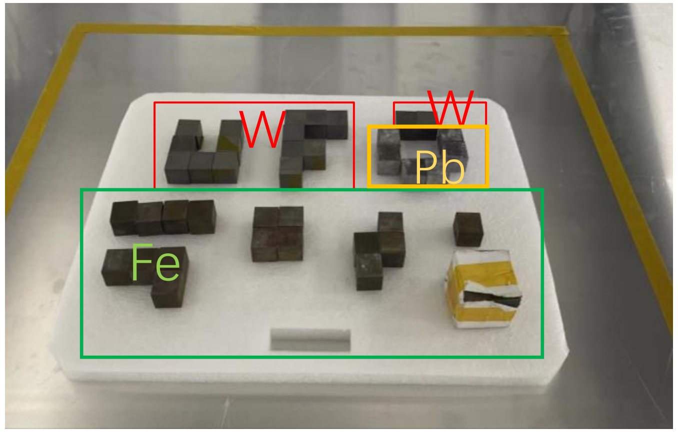
σ_{MRPC} <20 ps, the gas gap: <0.18mm

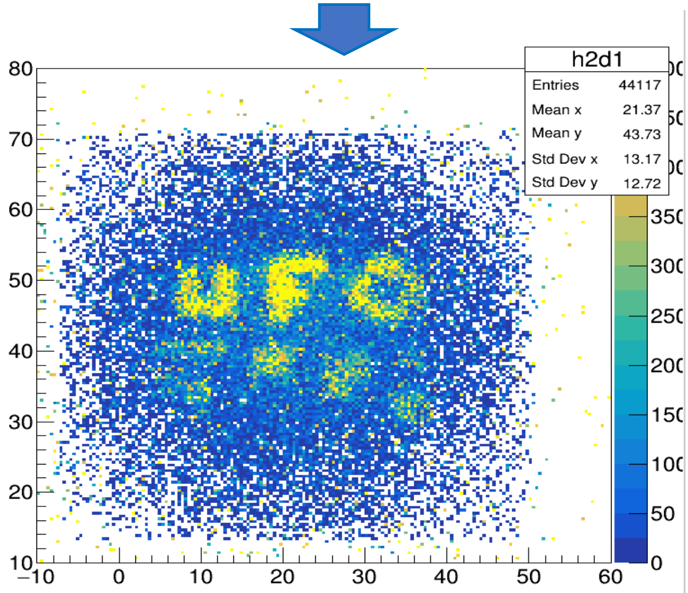
gap number: >16

Cosmic Ray Platform for Performance Tests









A two-dimensional positioning platform for cosmic ray tests on the performance of DIRC and other detectors:

- 4 layers, size of 55cm x 55cm, each layer composed of 8 modules (4 at x, y direction)
- Each module is composed of 16 triangular plastic scintillators (EJ-200), 32 optical fibers, 8 SiPMs
- Cosmic rays incident on the scintillator excite scintillation photons, which are collected by optical fibers, transmitted to SiPMs for readout. The position resolution of the platform can reach ~1mm.

Preliminary test result: 2D image reconstruction of samples of different materials (W, Pb, Fe), with higher material density resulting in better image resolution.

Summary

- DIRC: manufacturing small prototype, setup test platform
- RICH & LGAD: under simulation, setup R&D platform
- Cosmic ray platform: installed at Huizhou, testing & improving tracking algorithm

PID CDR draft link at overleaf:
https://www.overleaf.com/read/qwsrhvqxbdfp#46e543

Thank you!