EicC探测器设计与预研

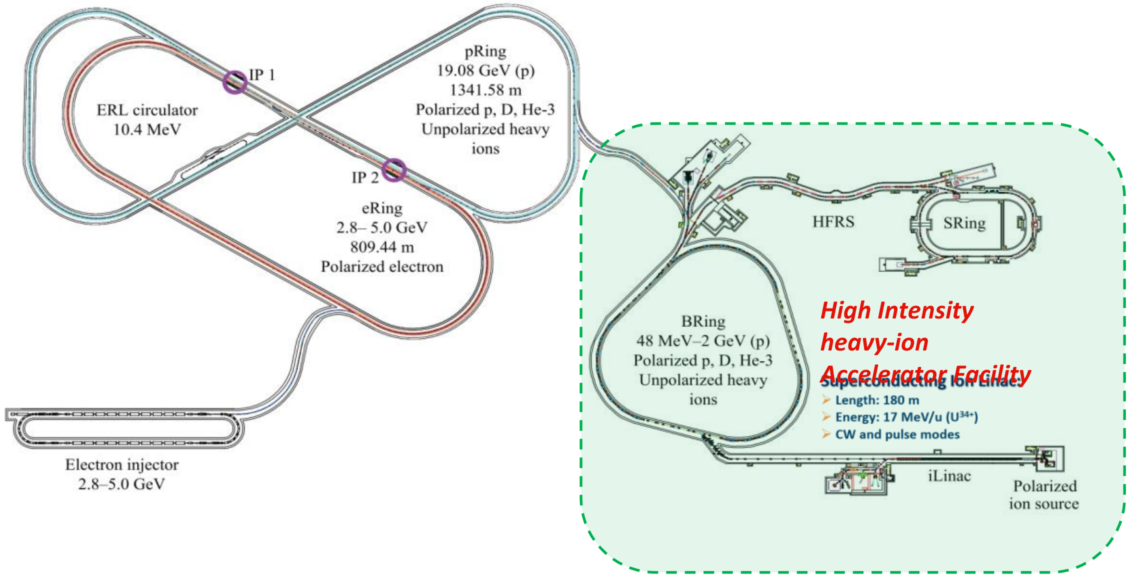
李昕
中国科学院近代物理研究所
2025/07/02

2025 年超级陶粲装置研讨会

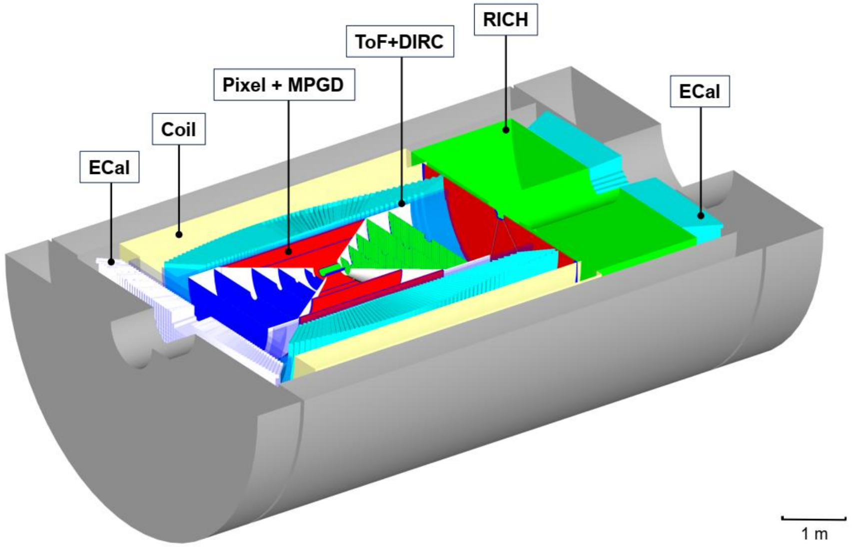
Introduction on EicC

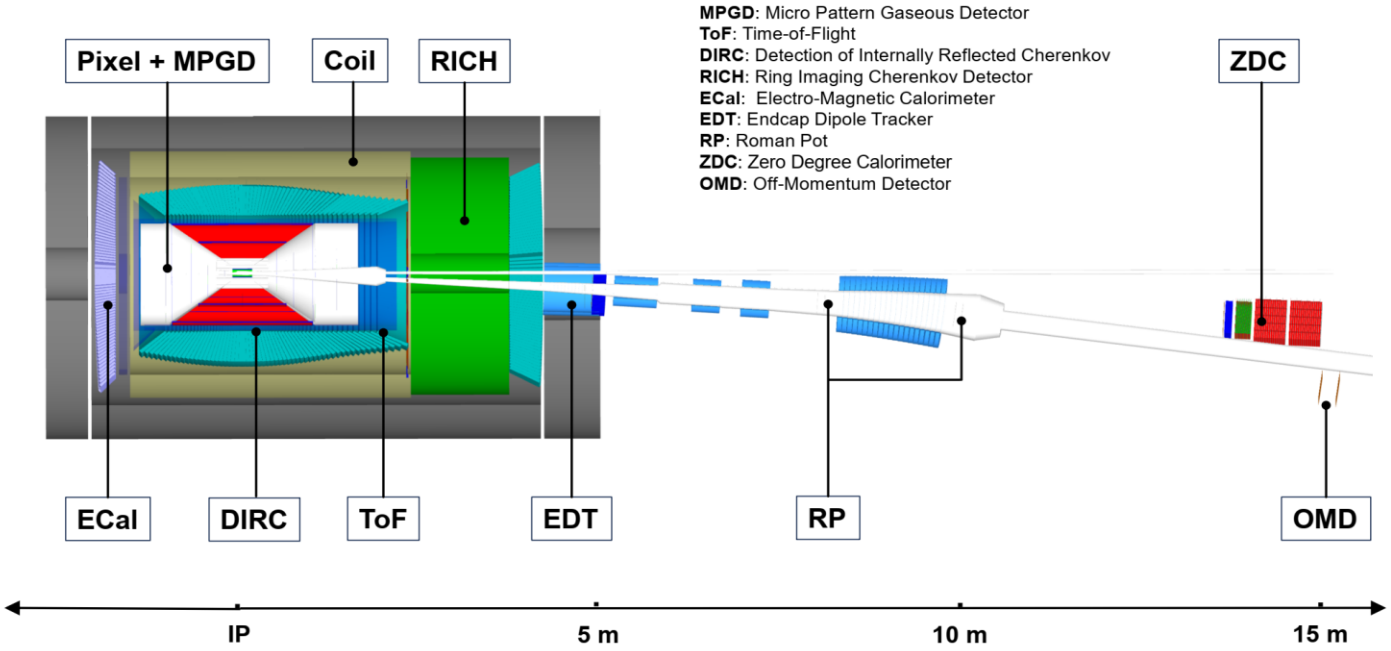
As a future high energy nuclear physics project, an Electron-ion collider in China (EicC) has been proposed based on High Intensity heavy-ion Accelerator Facility (HIAF), a heavy-ion accelerator currently under construction. The proposed collider will provide highly polarized electrons (with a polarization 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





The central EicC spectrum consists of the barrel part and two Endcaps, and it will be constructed around a solenoid. Subsystems include:

- Vertex and Tracking detectors, silicon and MPGD (Micro-Pattern Gaseous Detector)
- Particle identification detectors, Time-of-Flight (TOF) and Cerenkov detectors
- Calorimeter

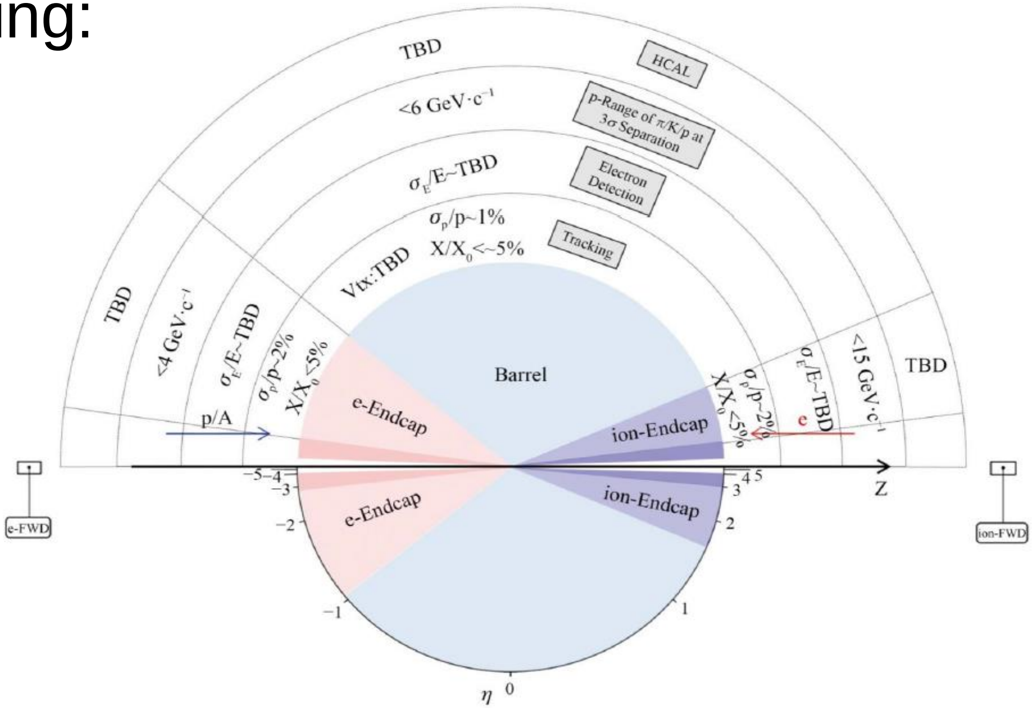
In the EicC baseline design, the electron beam momentum is 3.5 GeV/c, proton beam 20 GeV/c, which results in a center of mass energy of 16.7 GeV and a cross-section of 20.8 μb. The luminosity is expected to be $L = 4 \times 10^{33}$ $cm^{-2}s^{-1}$ with an interaction rate of 83.2 kHz. The PYTHIA simulation shows that the final state particles are dominated around $\eta = 1$, with a particle density of $dN/d\eta dt = 8 \times 10^4/s$.

1. Vertex and tracking detector

Yuming Ma, Aiqiang Guo, Yutie Liang, Yuxiang Zhao (IMP)

- Physics requirements for EicC tracking:

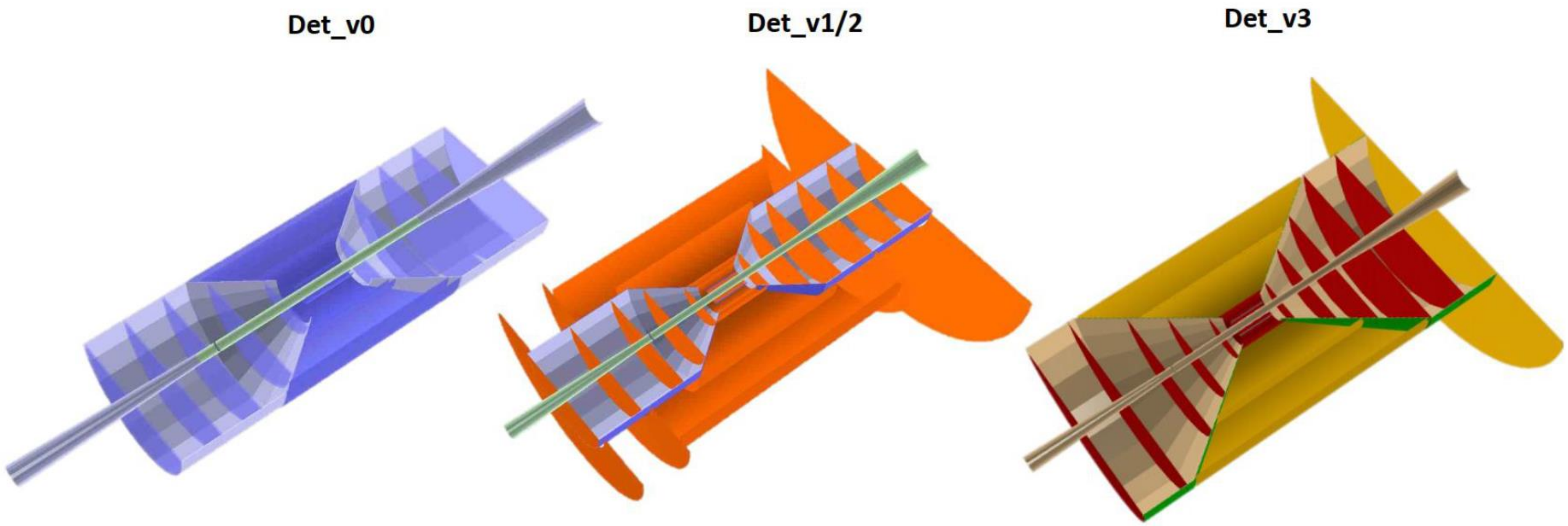
  - Assume B ~ 1.5 T
    - Barrel ($-1 < \eta < 1.6$):
      - σ(p)/p ~ 1% @ 1GeV; X/X0 <5%
    - E-endcap ($-3 < \eta < -1$):
      - σ(p)/p ~ 2% @ 1GeV; X/X0 <5%
    - P-endcap ($1.6 < \eta < 3$):
      - σ(p)/p ~ 2% @ 1GeV; X/X0 <5%



Front. Phys. 16(6), 64701 (2021)

Evolution of the EicC tracker design

-Yuming Ma (IMP)



- All-silicon based on ITS2

- Silicon+MPGD Hybrid design
- Silicon: vertex ITS3 + tracker ITS2
- Only the pixel size is different for v1/v2

- Silicon+MPGD Hybrid design
- Silicon: ITS3
- Geometry is Optimized

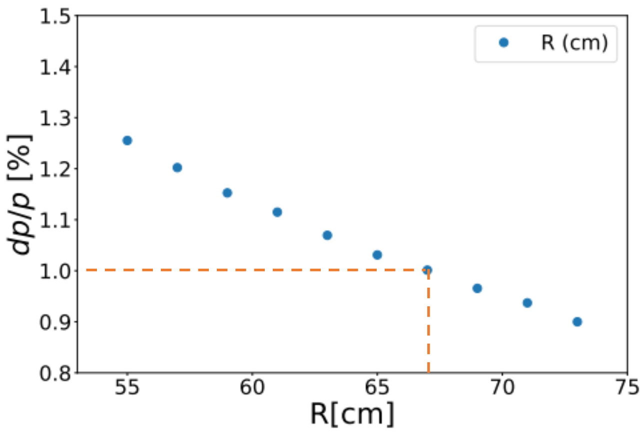
2

✓ Further dedicated optimization of the scale and structure recently based on Det_v3

Optimization on tracking design

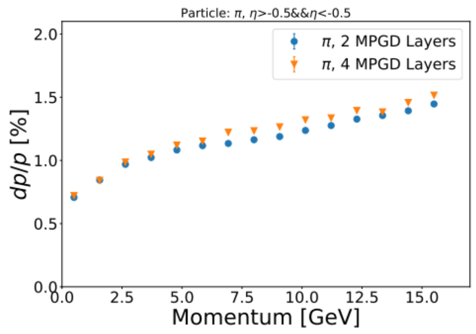
Barrel Radius

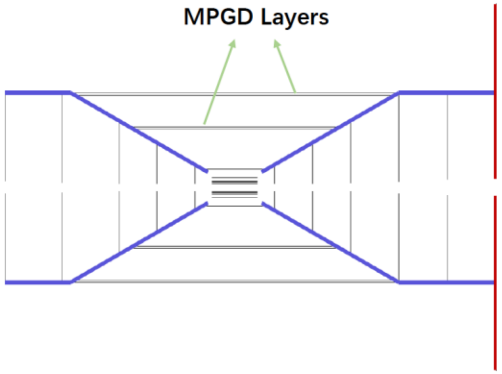
- Optimized based on **Vertex(ITS3*3)+Barrel(ITS2*2+MPGD*2),**
- Using tracks with **p = 4 GeV**



Number of Barrel MPGD Layers

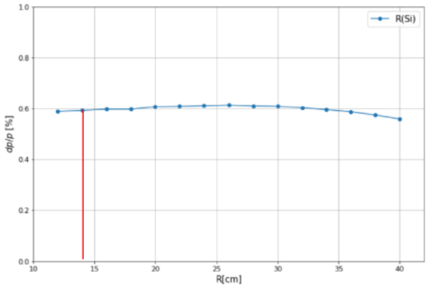
- Comparison of detector with 2+2 MPGD Layers and 2 MPGD Layers:
  - **Performances are almost the same for tracks with p<4 GeV;**
  - **Therefore, we keep only 2 MPGD Layers.**

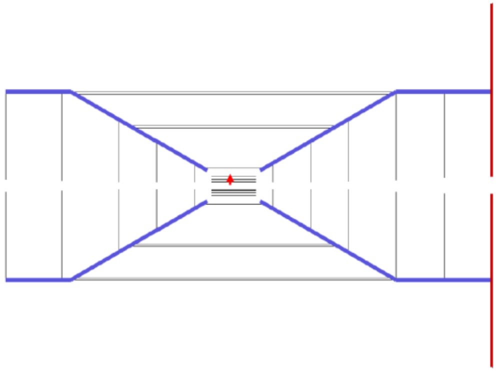




Radius of Barrel Si Layers

- Optimization with **Inclusive MC sample,**
- The distance of 2 Si layers is fixed to 4 cm,
- The radii are set to 14 cm and 18 cm.

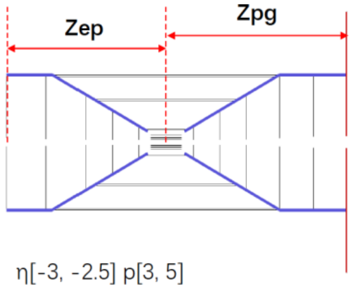


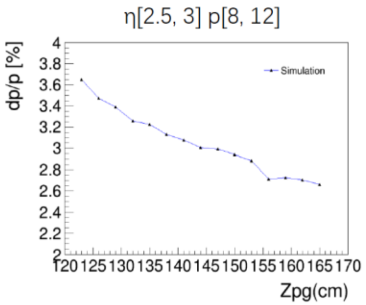


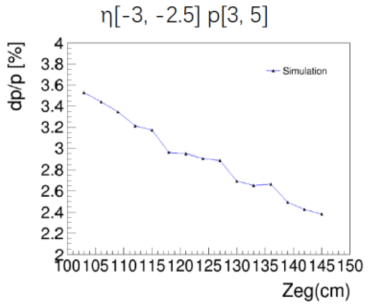
Performance changes according to the radius of inner Si layer.

Optimization of Endcaps

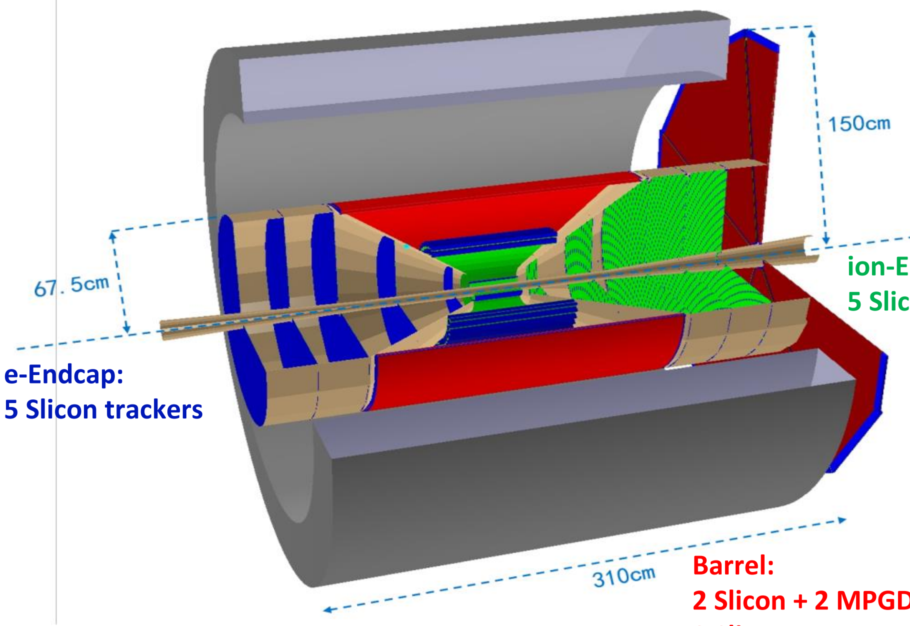
Optimized based on:
e going direction (ITS2*5)
p going direction (ITS2*5+MPGD*1)

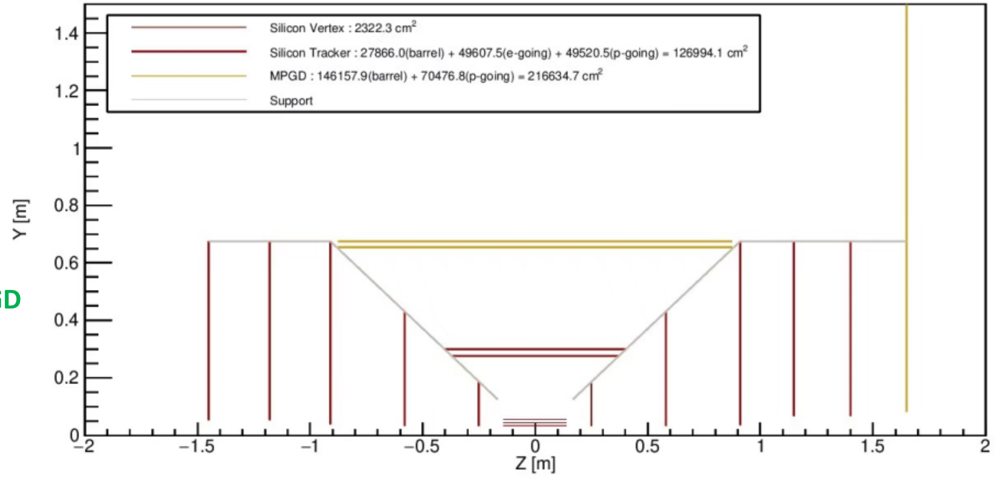




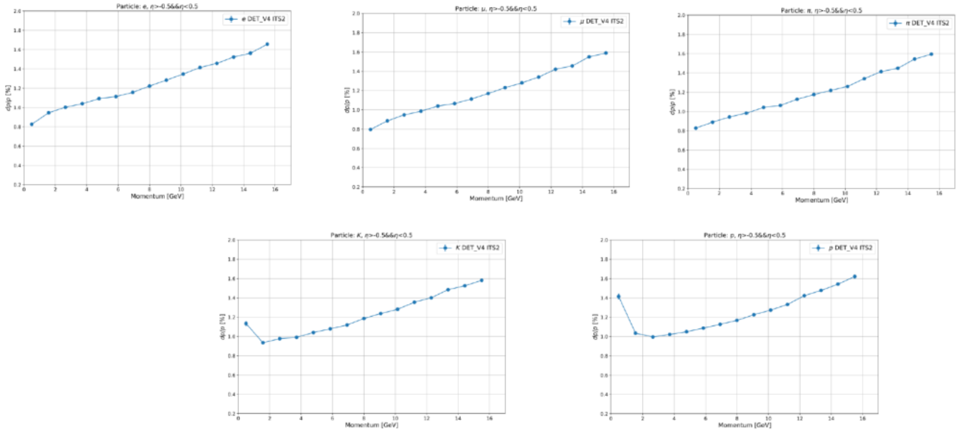


Simulated Performance with optimized tracking design

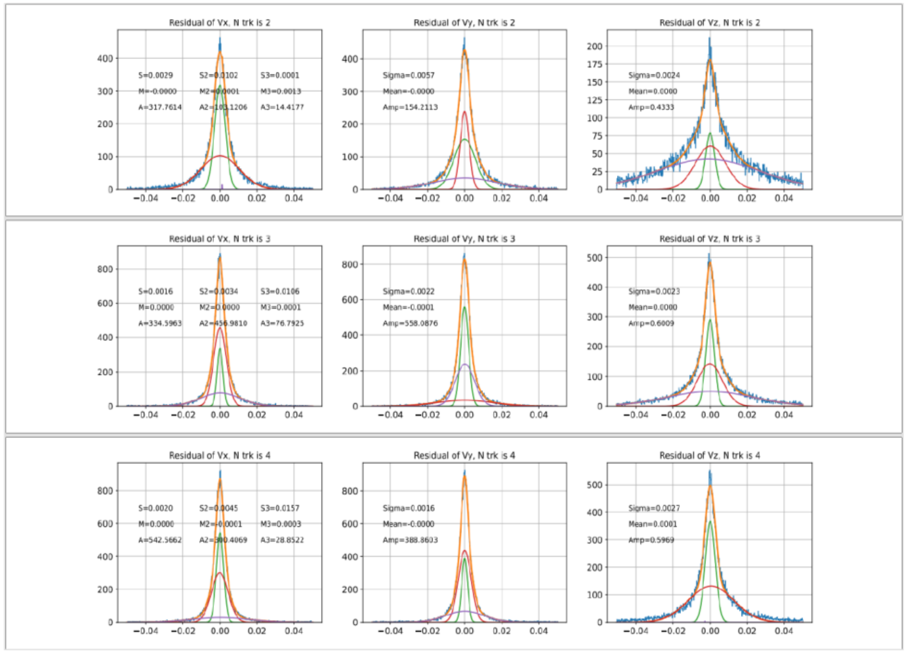




Performance

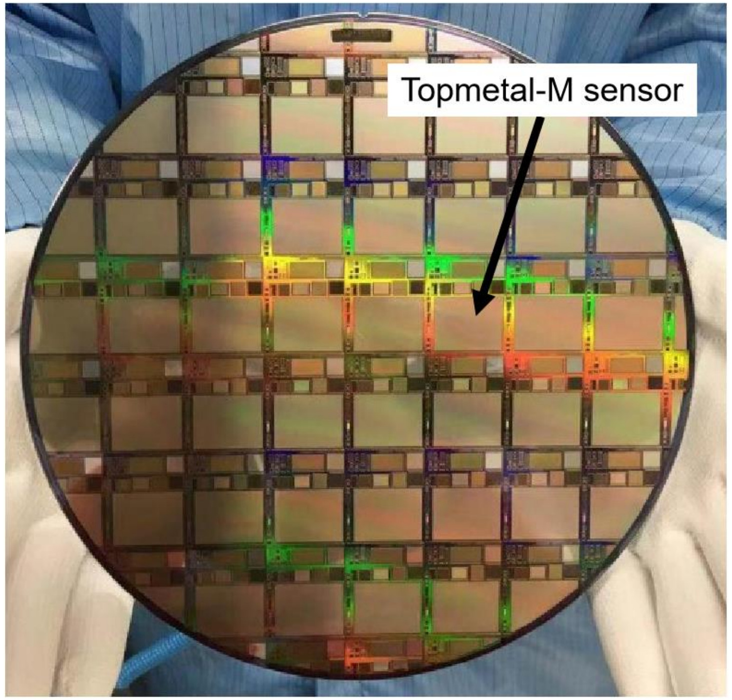


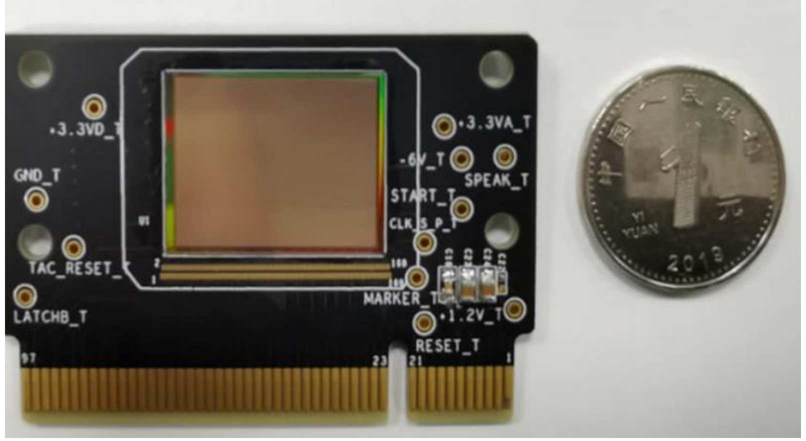
Vertex resolution



2023/5/03

Silicon technology development





Chengxin Zhao (**IMP**), Yaping Wang(**CCNU**), Aiqiang Guo (**IMP**)

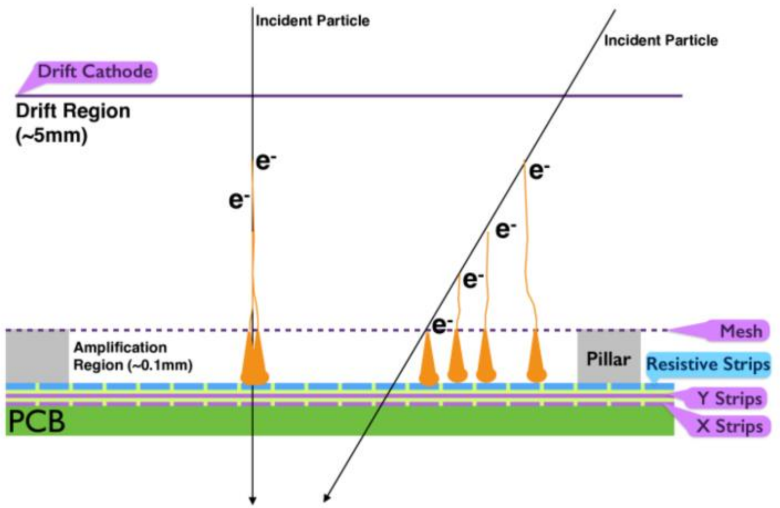
- 第一款基于国内工艺的MAPS(Monolithic Active Pixel Sensors)芯片 - Topmetal-M

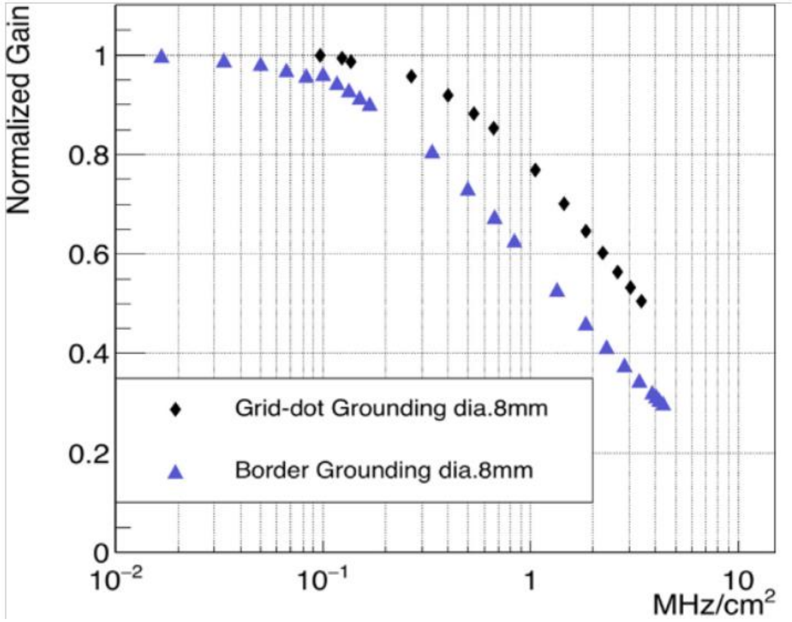
中科院战略先导B"核物质相结构与重元素合成研究"专项支持

- 近物所IMP SLIMP & 华师CCNU PLAC
- 基于国内四阱高阻衬底工艺
- 2018.05 - 2019.12设计制造
- 2020.01 - 2021.12测试验证
- 像素阵列 512 x 400 Pixels
- 40umx 40um
- Time, Energy and Position Measurement
- Thinned to 100um from backsid
- 兼具电荷搜集型Topmetal和MAPS

Micromegas technology development

A large-area prototype of the Micromegas detector module will be developed using the thermal bonding technique (TBM) a novel resistive anode with a germanium film and grid-dot grounding technique and auto microfluidic technology for EicC. The detector performance parameters aim to reach the position resolution <100 microns, and the counting rate is ~100 kHz/cm^2. A 40cm × 40cm Micromegas prototype based on above new developed techniques has been tested, detector demonstrating a performance efficiency exceeding 95% (represented by diamond-shaped points) at a counting rate of approximately 200 kHz/cm^2.

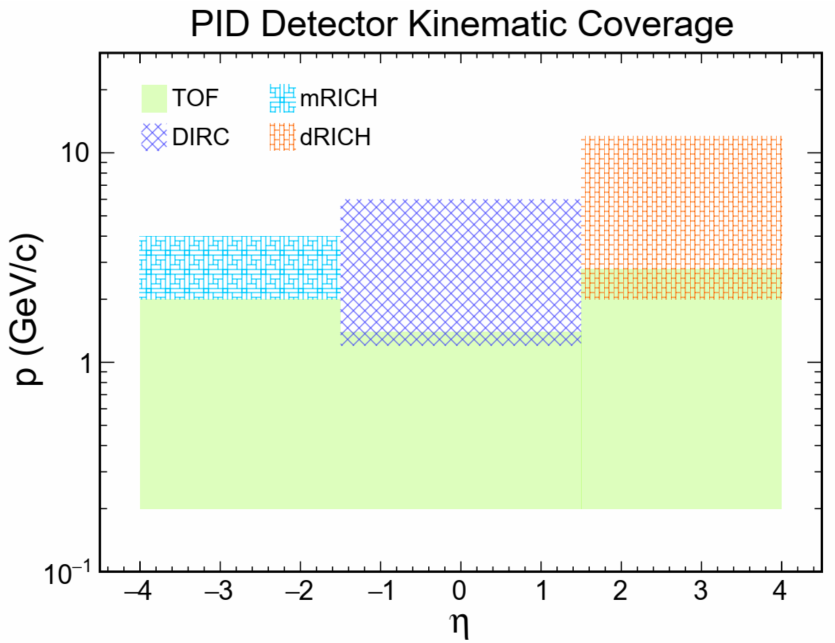




Left: Cross sectional view of micromegas detector. Right: Comparison of counting rates for different grounding techniques

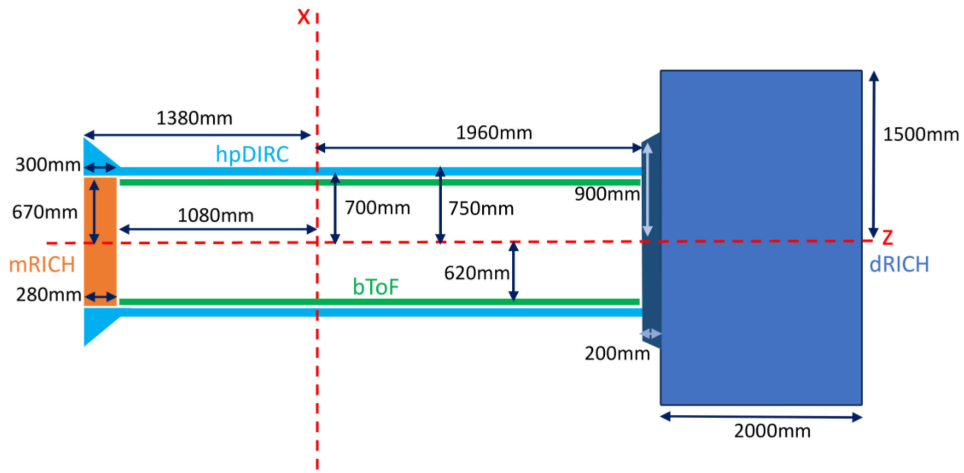
2. PID Detectors

- 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 ($-1 < \eta < 1.6$)



PID detectors:

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

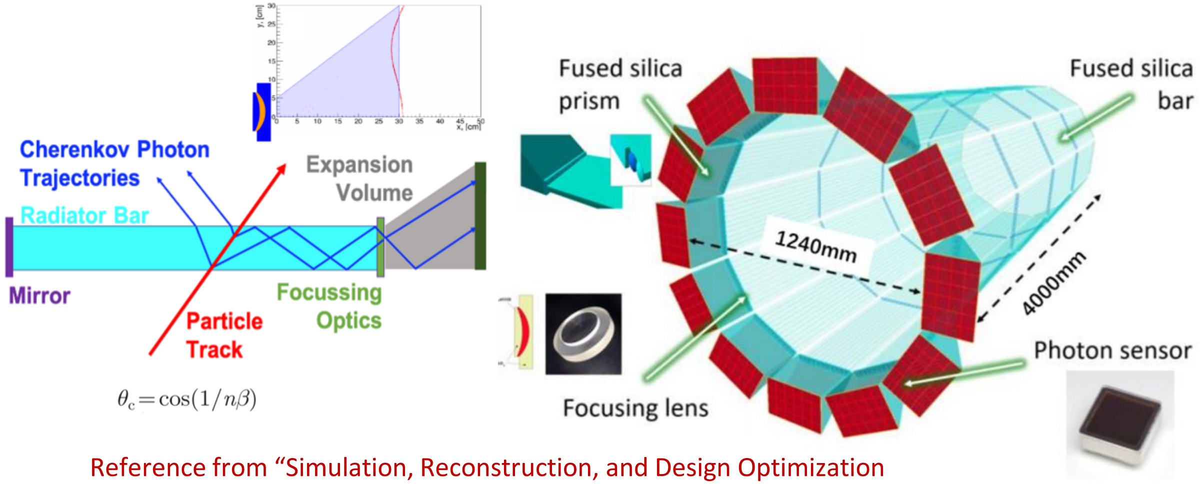


Barrel DIRC for PID

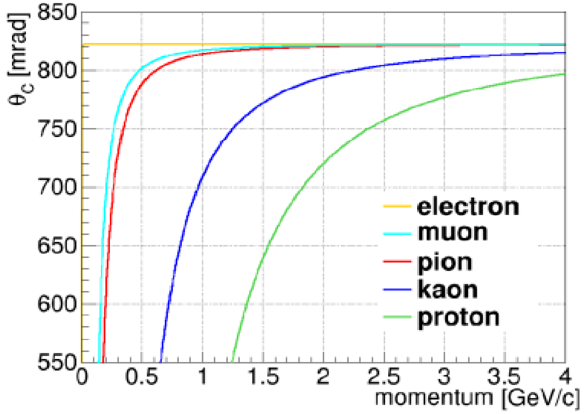
Detector of Internal Reflection Cherenkov lights (DIRC):

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.

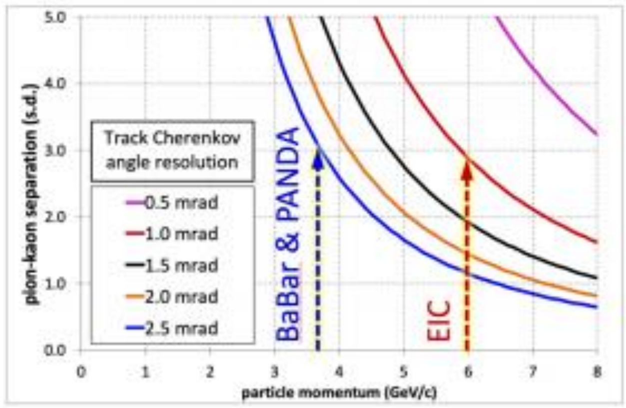
- Consisted of fused silica(n=1.47) as Cherenkov radiator and MCP-PMTs as photosensor array
- Compact structure as barrel detector
- Achieve 3σ π/K separation up to 6 GeV/c with angle resolution ~ 1mrad



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

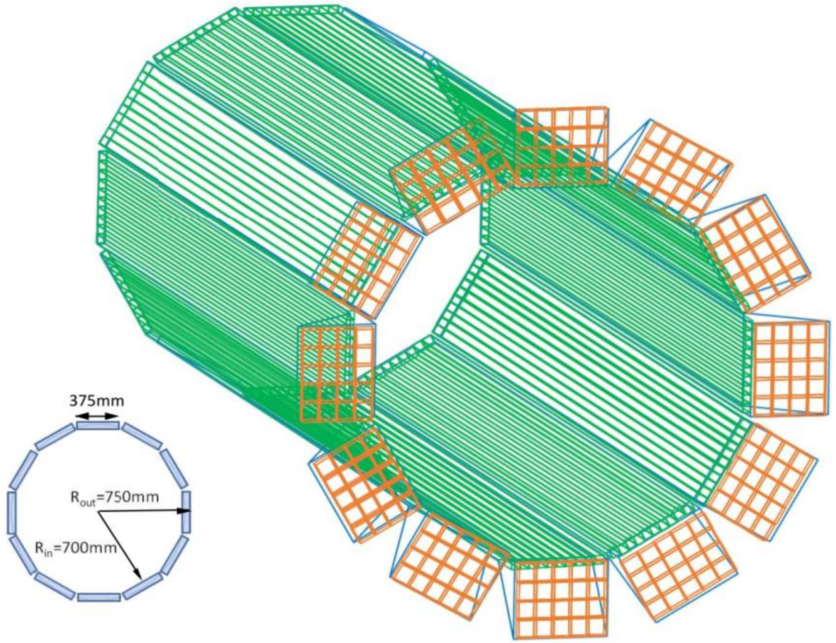


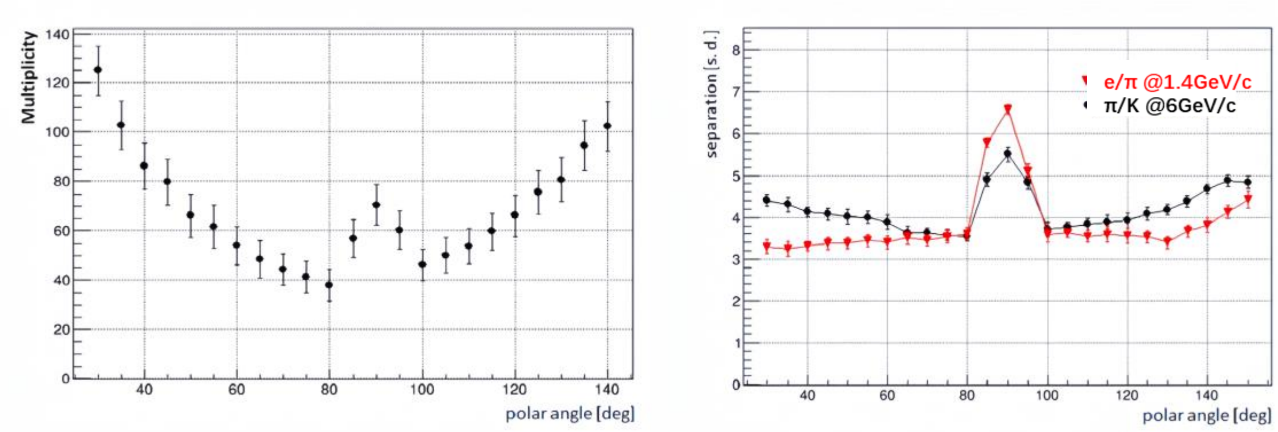
refractive index of synthetic fused silica **with n = 1.47**



Reference from PANDA & EIC

Barrel DIRC Concept Design





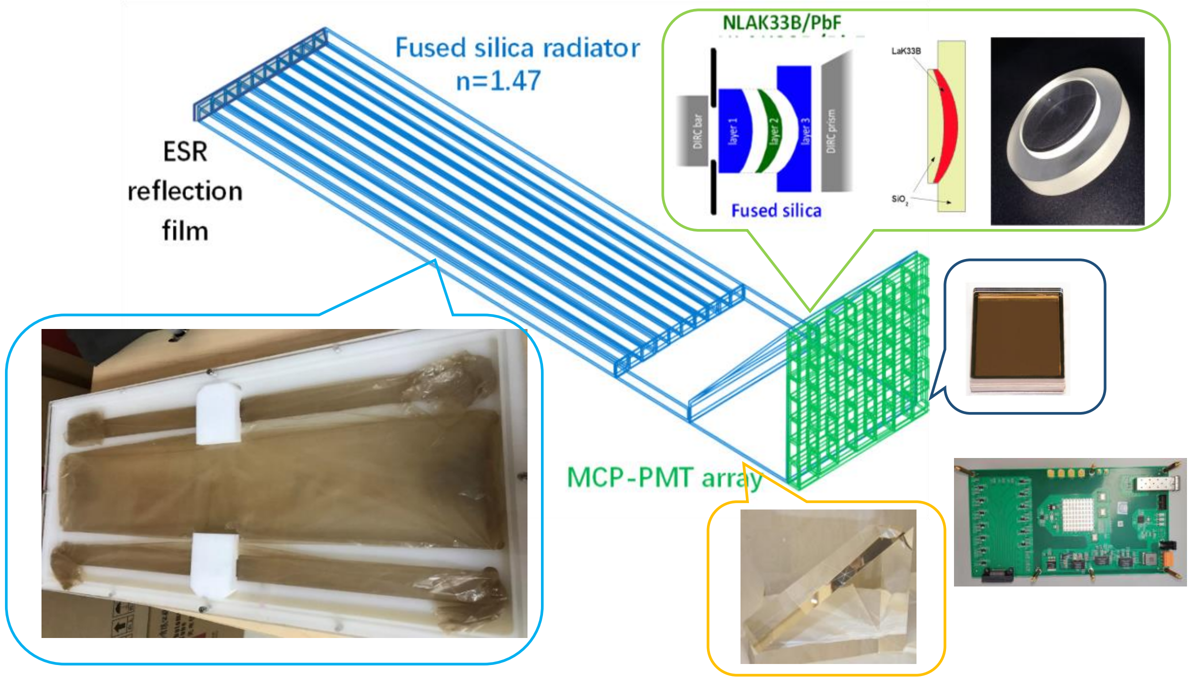
- Quartz radiator bar: 15mm x 17mm x 3300mm
- Expansion volume(EV): 208mm x 340mm x 300mm
- MCP-PMT: Hamamatsu R10754 (pixel size: 5.2mm x 5.2mm) or Photek MAPMT253 (pixel size: 1.6mm x 1.6mm)
- Tray box size: 50mm x 320mm x 4000mm with 6 bar+EV
- 12 trays forms a barrel detector with a minimum radius 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 Prototype setup



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 × 23	mm
Dynode	Dynode structure	2 stages Microchannel plate	—
	Channel diameter	10	μm
Number of anode pixels		16 (4 × 4 matrix)	—
Anode pixel size		5.28 × 5.28	mm
Operating ambient temperature (A)		-30 to +45	°C
Storage temperature (A)		-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) (B)	—	75	—	ps

北方夜视 N6021

N6021		Min.	Typ.	Max.	Unit.
阴极参数Cathode parameters	光谱范围/Spectral response		280-650		nm
	量子效率峰值波长/Quantum efficiency peak wavelength		380		nm
	积分灵敏度/Luminous sensitivity		70		μ A/lm
	量子效率@410nm/QE @410nm		22		%
	辐射灵敏度/Radiant sensitivity@410nm		72		mA/W
阳极参数Anode parameters	工作电压/Supply voltage		2500	3200	V
	增益/Gain		2×10^6		
	暗计数/Dark count rate@0.2pe(单阳极)		500	5000	Hz
	能量分辨率/Charge resolution		35		%
	单光电子谱峰谷比/Peak to valley ratio		3		
时间参数Time Response	上升时间/Rise time		300		ps
	脉冲宽度/Pulse width		650		ps
	下降时间/Fall time		800		ps
	渡越时间弥散/TTS@σ(SPE)		50		ps
	渡越时间弥散/TTS@σ (MPE)		15		ps

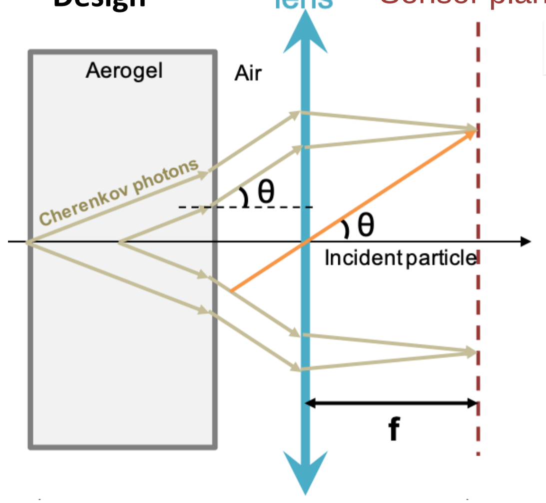
DIRC protype consisted of fused silica radiator (HERAEUS SUPRASIL) , optical focus system, and MCP-PMT array (transit time spread < 50ps, pixel size ~ 5mm, candidate: R10754, N6021).

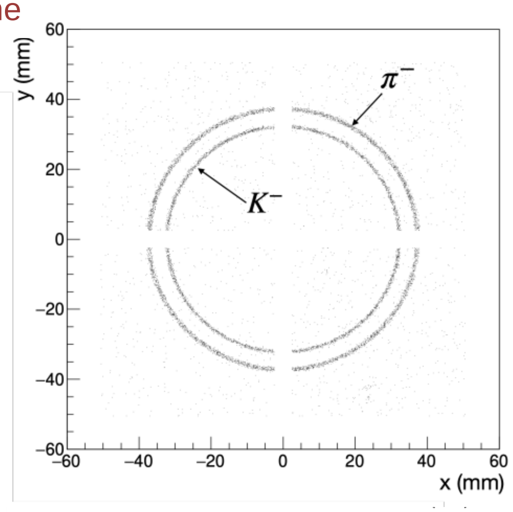
Muti-channel readout electronics coupled with MCP-PMT, timing resolution ~ 10ps, developed by USTC-STCF group.

mRICH: Lens-based Focusing Aerogel Detector Design

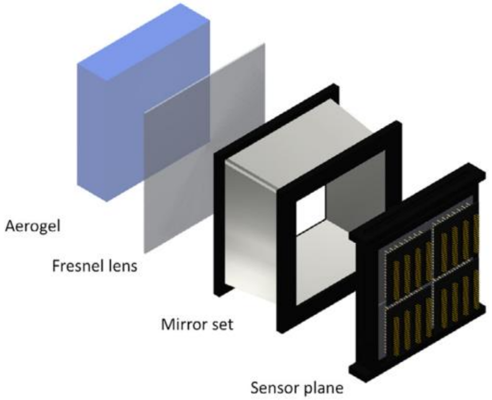
Modular RICH is a Cherenkov detector based on aerogel radiator. It uses a Fresnel lens to generate focusing effect to improve position resolution (Fresnel lens limit the wavelength range of transmission light, which can reduce Rayleigh scattering effect). It has compact and flexible structure, and PID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

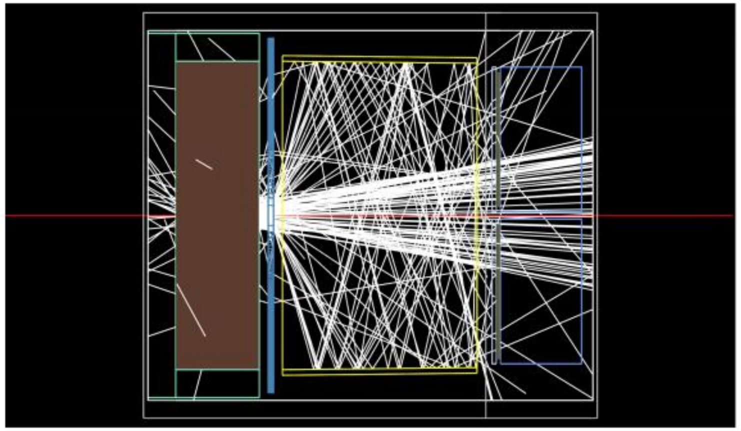
Lens-Based mRICH Design

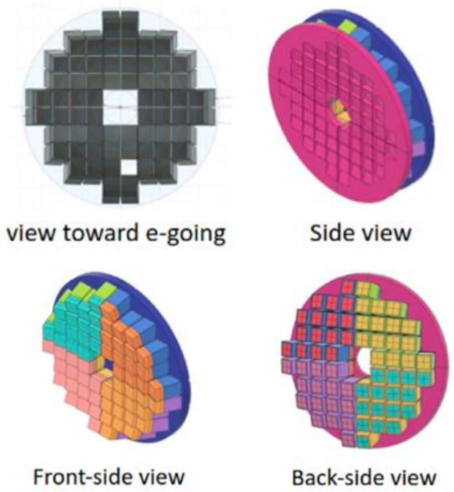




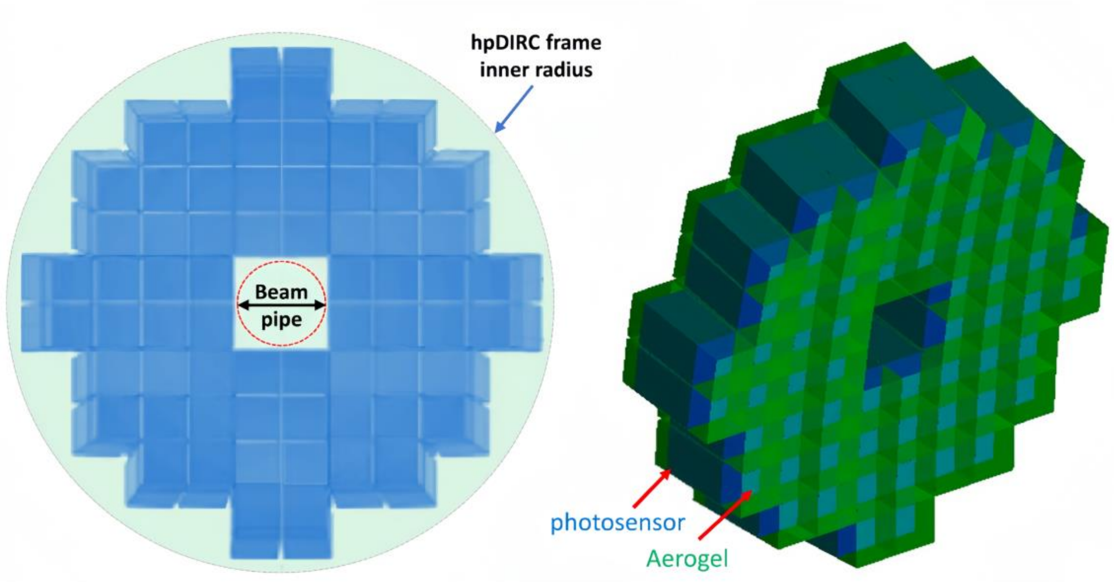
focal length 7.62cm (3")





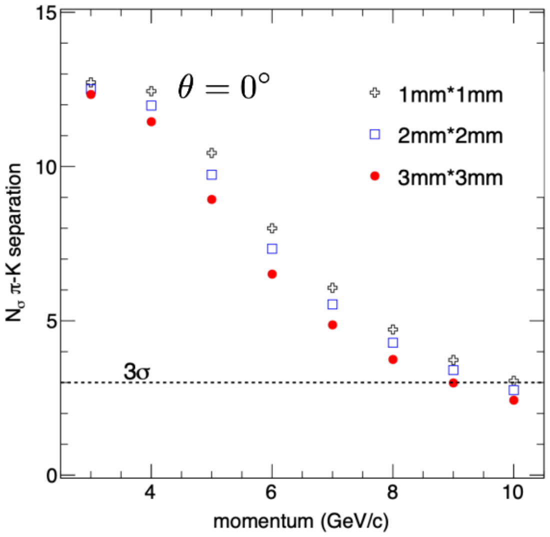


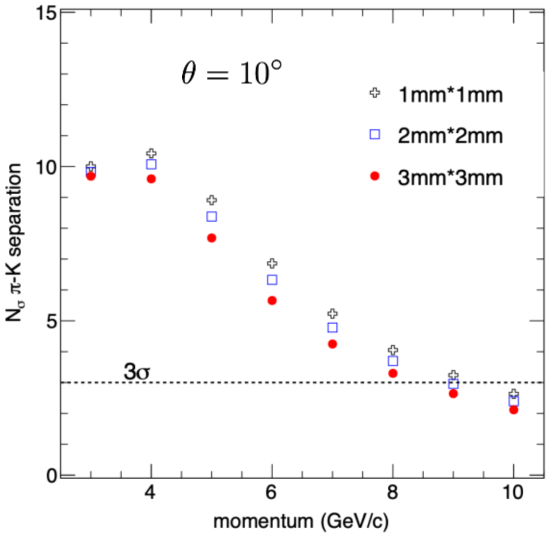
mRICH Design and Simulation

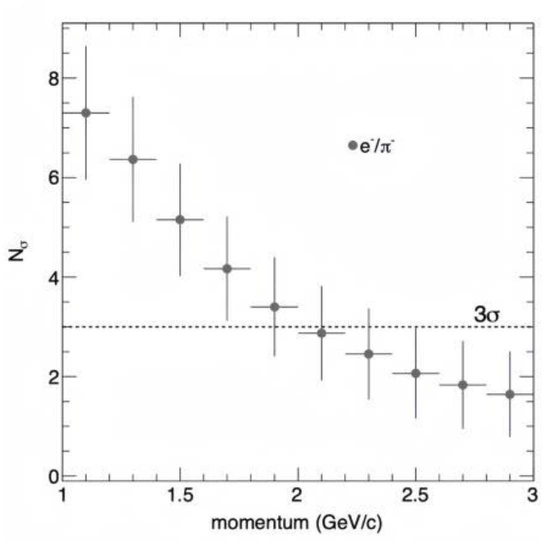


- Composed of 64 aerogel modules (located at z=1080 ~ 1380 mm, radius 100 ~ 670 mm);
- The cross section of each module is 108 × 108 mm^2, with a thickness of 25 ~ 35 mm;
- The center of each module is at z=-1230 mm and tilted towards the collision center point;
- Fresnel lens focal length L=76.2 mm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

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



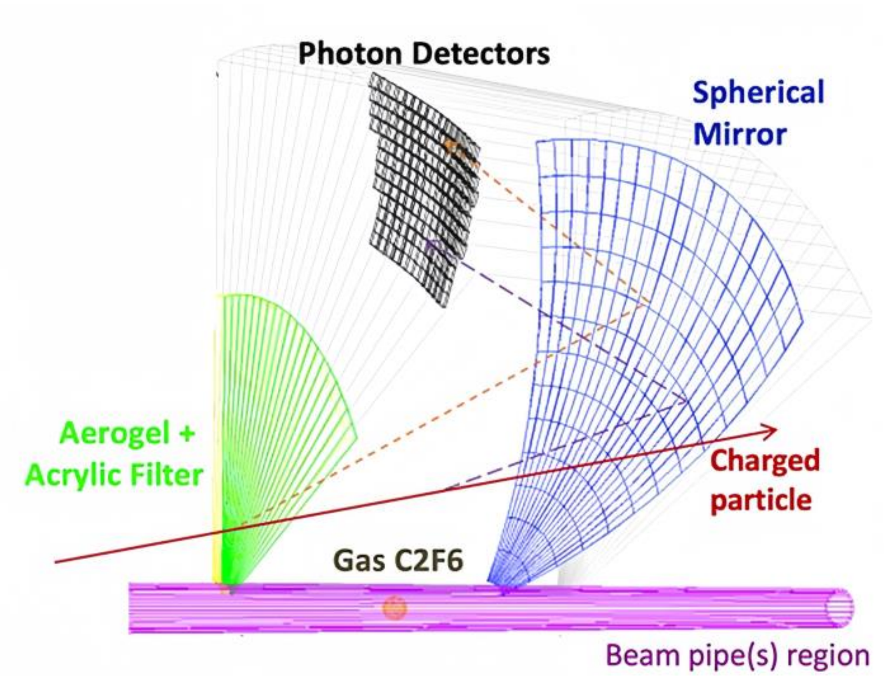


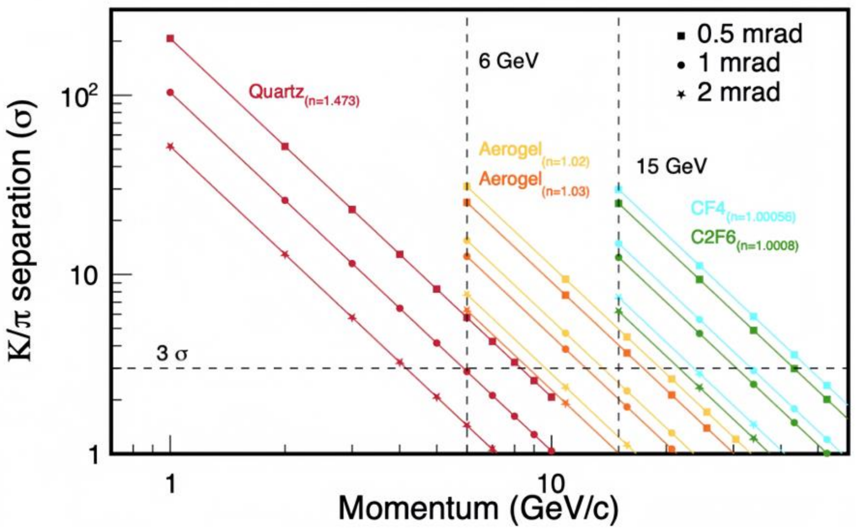


- Separation power decrease with increasing polar angle
- 3 sigma separation up to 9 GeV/c when particle launched at the center of aerogel
- 3 sigma separation up to 8 GeV/c when particle launched at 10 degrees

dRICH: RICH with "dual" radiators

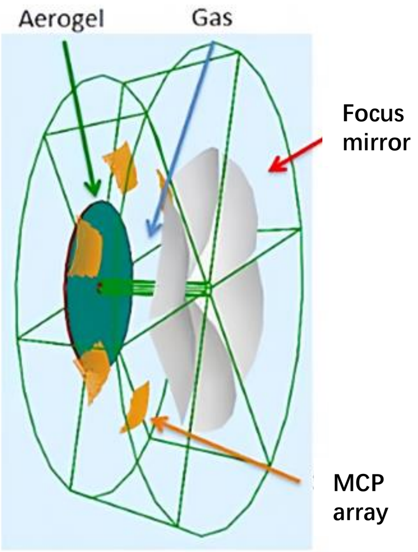
Dual RICH contains "dual" radiators with different refractive index, which largely expands its PID momentum coverage. The C_2F_6 gas and aerogel are ideal dual radiator options for the π/k identification in large momentum region. The particle passes through the aerogel and the gas sequentially, the induced Cherenkov radiation is focused by the spherical reflector (gray) and forms a halo image at the focal plane, finally readout by the photosensor array. "dual" radiators.

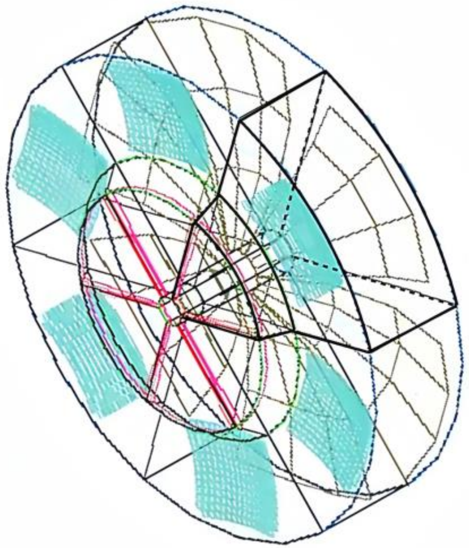




Radiator	Index	Threshold (GeV/c) e	π	k	P
Fused Silica(DIRC)	1.473	0.00047	0.13	0.46	0.87
Aerogel(mRICH)	1.03	0.00213	0.58	2.06	3.92
Aerogel(dRICH)	1.02	0.00254	0.69	2.46	4.67
C_2F_6(dRICH)	1.00080	0.0128	3.49	12.34	23.45
CF_4(dRICH)	1.00056	0.0153	4.17	14.75	28.03
C_4F_{10}(RICH)	1.00014	0.0305	8.34	29.50	56.07

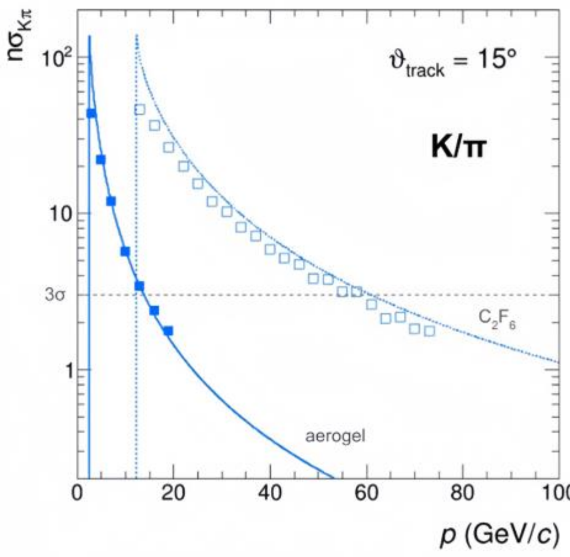
dRICH Design and Simulation

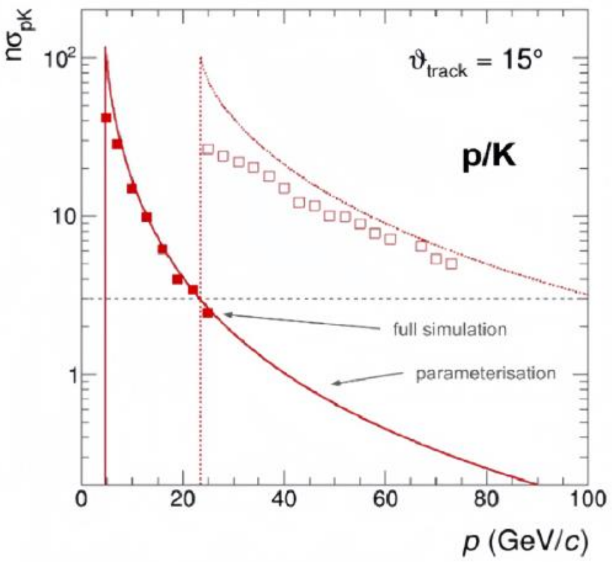




Geometric:
– Length: 2160 mm
– Inner radius: 100 mm
– Outer radius: 1500 mm
– Coverage angle 5-25 degrees

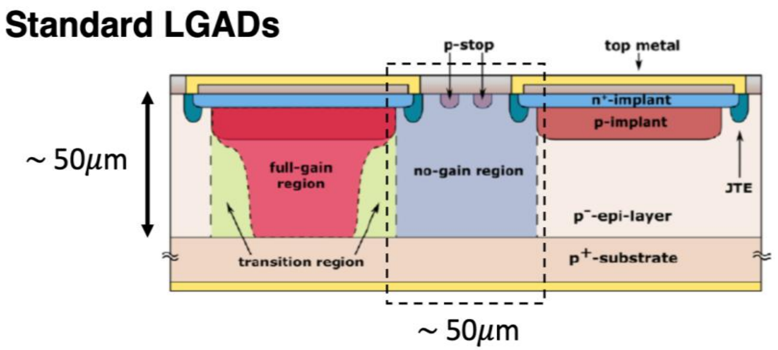
Cherenkov radiator:
– Refractive index: n = 1.03/1.02 (aerogel, 400 nm); n = 1.0008 (C_2F_6)
– Thickness of radiant body: L = 40-50 mm (aerogel), 1600-2000 mm (C_2F_6)



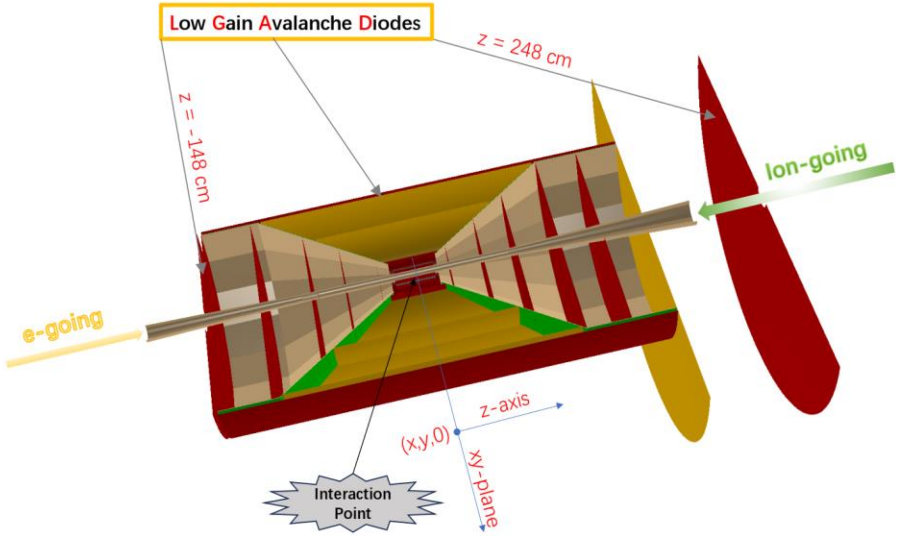


In GEANT4 simulation, the reflectivity of the spherical mirror is set to be 50%, the quantum efficiency of the photosensor is 20%, and its pixel size is 3mm × 3mm. Approximately 60 photons are generated by the aerogel radiator per track. Considering the detection efficiency of the photosensor array,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

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).

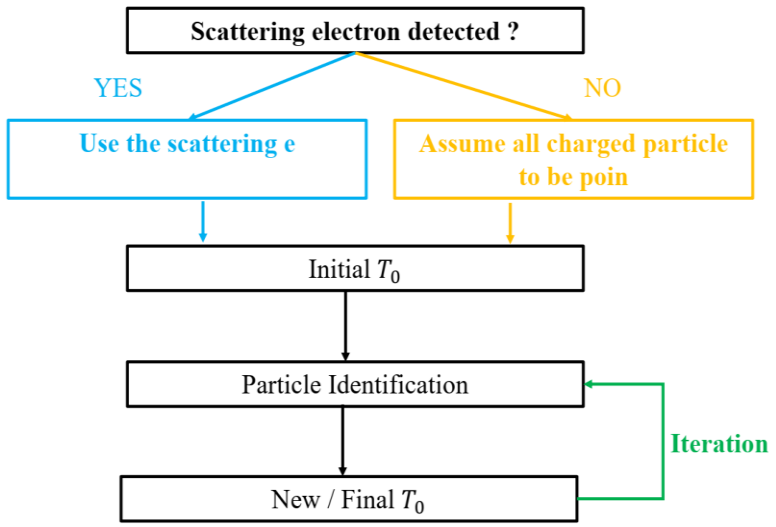
- Barrel TOF: right after the tracker system
- Ion-endcap TOF: right after the RICH system
- E-endcap TOF: right after the calorimeter system

LGAD-TOF configuration

	R^{barrel} (cm)	Length (cm)	Z location (cm)	R_{in}^{endcap} (cm)	R_{out}^{endcap} (cm)	η coverage
Backward			-148	5.4	110.81	[-4.0, -1.1]
Barrel	67	214				[-1.1, 1.1]
Forward			248	12.3	185.7	[1.1, 3.7]

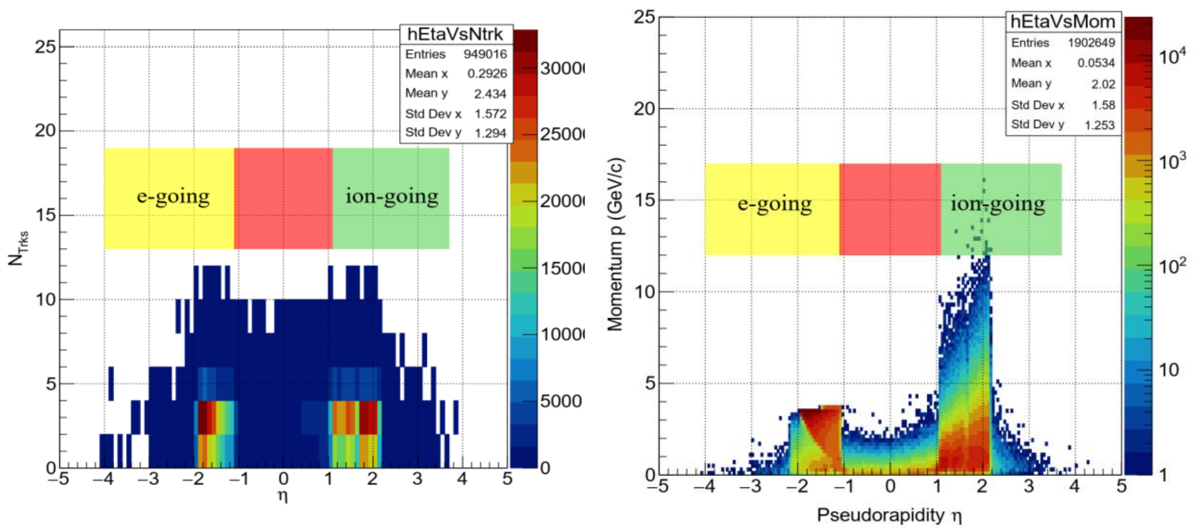
- Current configuration fits to the tracking system well
- Timing resolution: 20-30 ps / layer
- Spatial resolution: ~30 μm

LGAD: Pythia Simulation

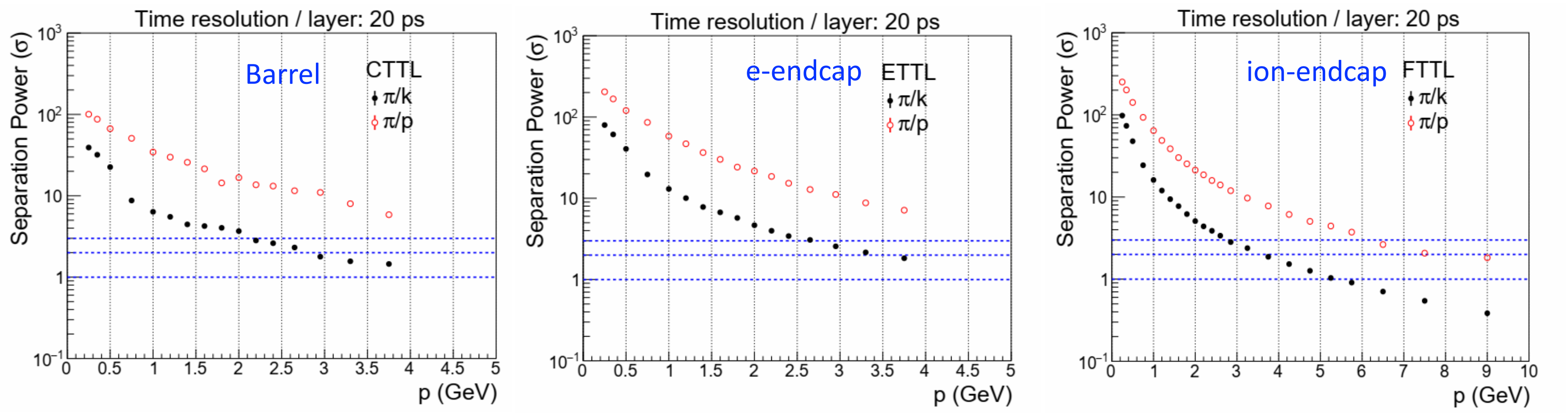


Pythia: e(3.5 GeV) + p(20.0 GeV)

Acceptance



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



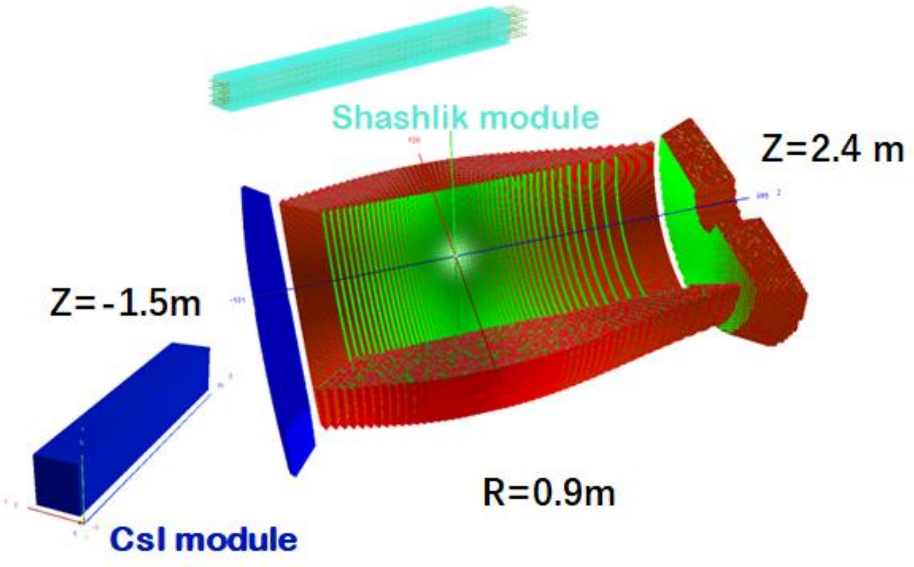
3. Calorimeter system for EicC

Ye Tian, Dexu Lin/ (IMP)

Basical ECal special requirement:

- **E-endcap:** good low energy resolution
- **Barrel:** short radius, good position& time resolution
- **Ion-endcap:** π^0 reconstruction, PID

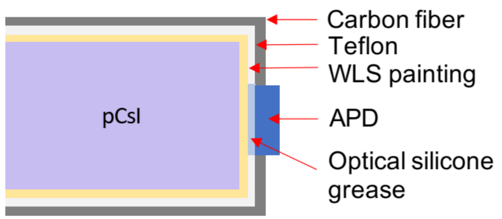
Particle	Performance	Segment e-Endcap $\eta(-3, -1)$	Segment Barrel $\eta(-1, 1.5)$	Segment ion-Endcap $\eta(1.5, 3)$
Electron & gamma	Energy resolution ($/\sqrt{E}$)	2.5%	5%	
	Position resolution ($/\sqrt{E}$) [mm]		6	
	Time resolution [ns]		<1	
Electron	Momentum range [GeV/c]	0.2 - 4	0.2 - 13	0.2 - 15
	π suppression (>1 GeV)	>1000:1	1000:1	100:1
Gamma	Momentum range [GeV/c]	0.01 - 4	0.025 - 10	0.025 - 15
π^0	Momentum range [GeV/c]	<4	<10	<15

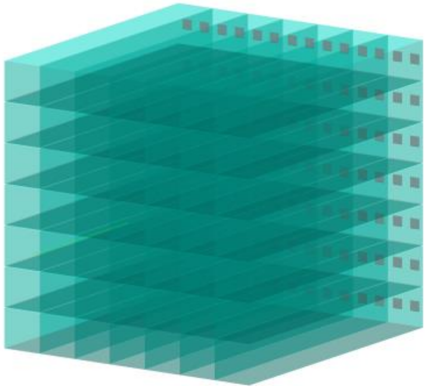


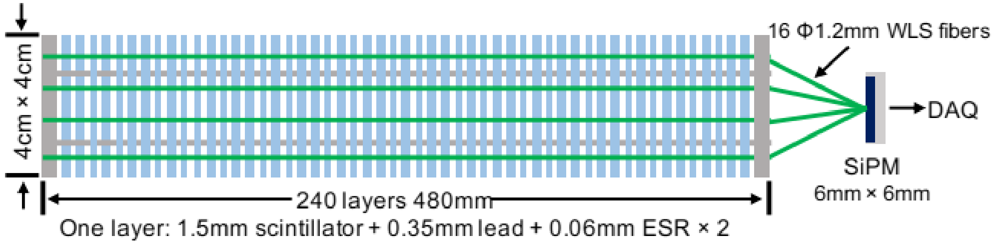
Detector	Pseudorapidity	Angle(degree)
Ion-Endcap	3	5.7
	1.5	25.2
Barrel		
	-1	139.6
e-Endcap		
	-3	174.3

Ecal Design in Simulation

- CsI is applied in e-endcap, Shashlik style is applied in both barrel and ion-endcap: The e-Endcap is designed as a homogeneous calorimeter by using pure Cesium Iodide (pCsI) crystal, optimized specifically for detecting scattered electrons with high energy and position resolutions. For the barrel and ion-Endcap, which primarily detect secondary hadrons, a Shashlik-type sampling calorimeter is employed, balancing physics performance and budget.





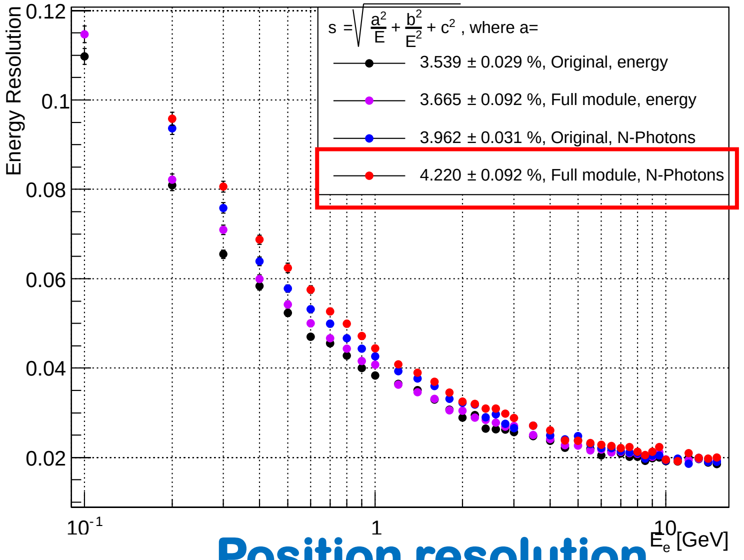


Parameter	**e-Endcap**	**Barrel**	**ion-Endcap**
Material	pCsI	Shashlik	
Distance to IP [m]	1.8	0.9 (radius)	3
η acceptance	[-3, -1]	[-1, 1.5]	[1.5, 3]
Inner radius [cm]	18	90	30
Outer radius [cm]	153	150	145
Length [cm]	30 + 5 (readout)	49 + 11 (readout)	
Radiation length [X_0]	16	16	
Molière radius [cm]	3.5	5.02	
Front size [cm^2]	4×4	4×4	
Rear size [cm^2] (max)	4.67×4.67	5.8×6.1	4.6×4.6
N layers	-	240	
Scintillator thickness [mm]	-	1.5	
Lead thickness [mm]	-	0.35	
Reflector thickness [mm]	-	0.075	
Sampling ratio	-	0.33	
N fibers (front)	-	16	
Photon detector	APD or SiPM	6×6 mm^2 SiPM	
Total modules	~3900	~8000	~3900

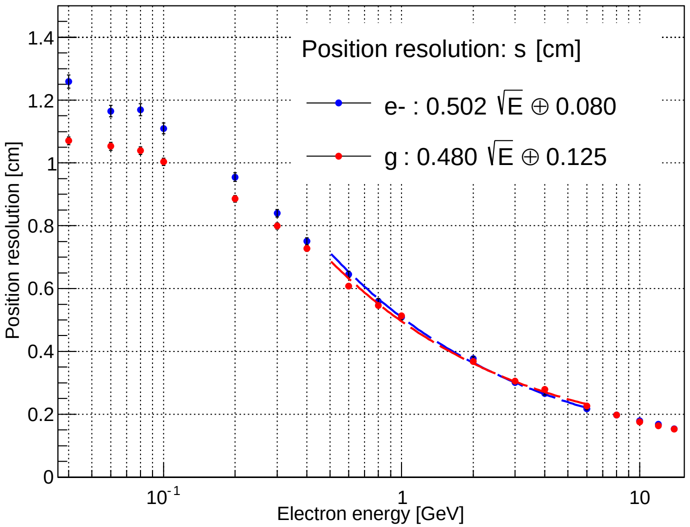
Ecal simulation result

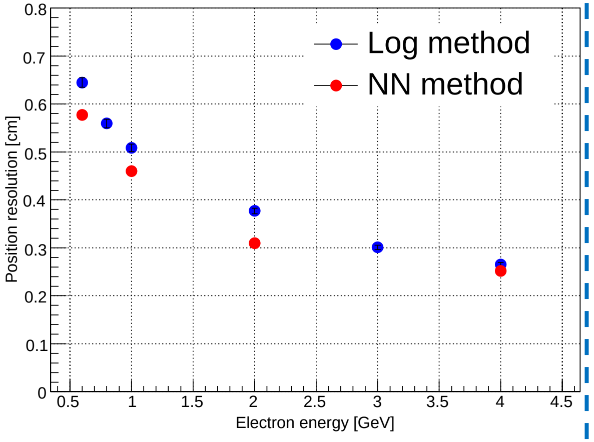
Shashlik simulation result

Energy resolution



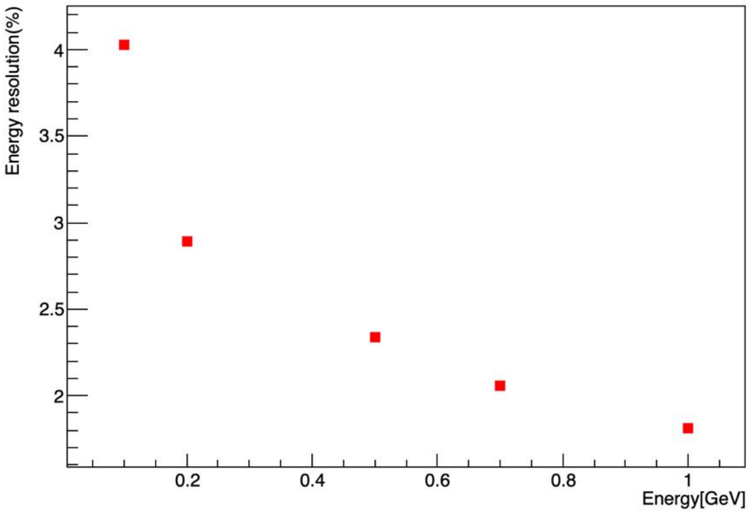
Position resolution



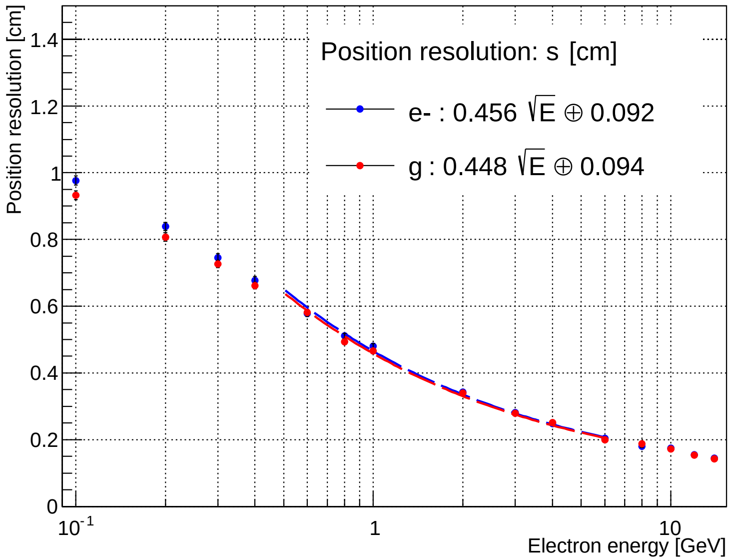


CsI simulation result

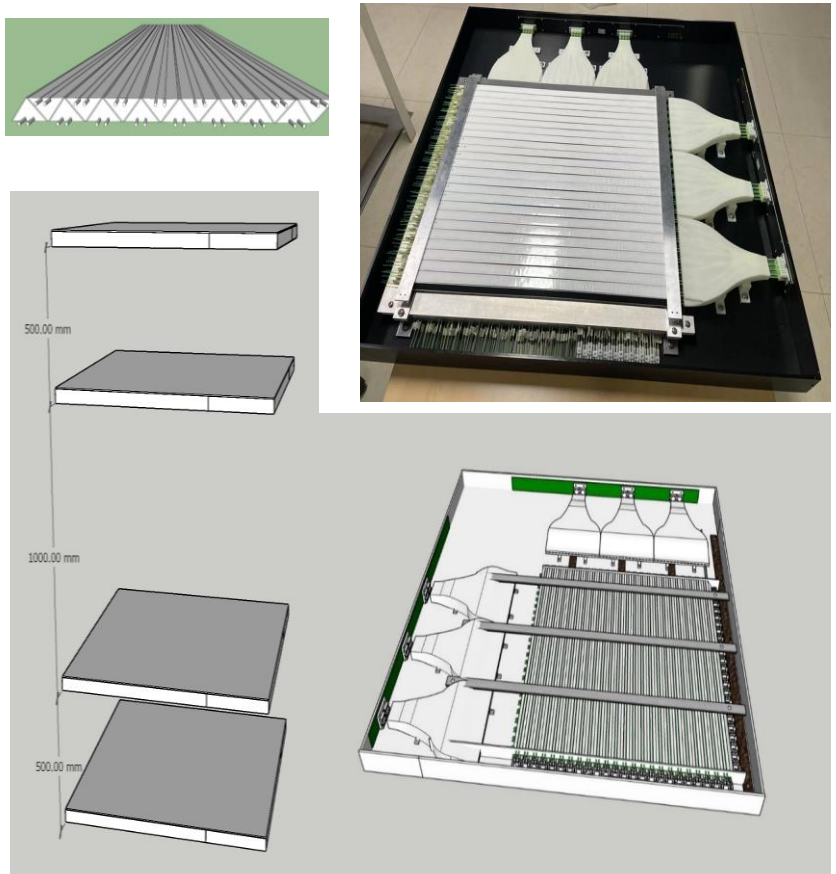
Energy resolution

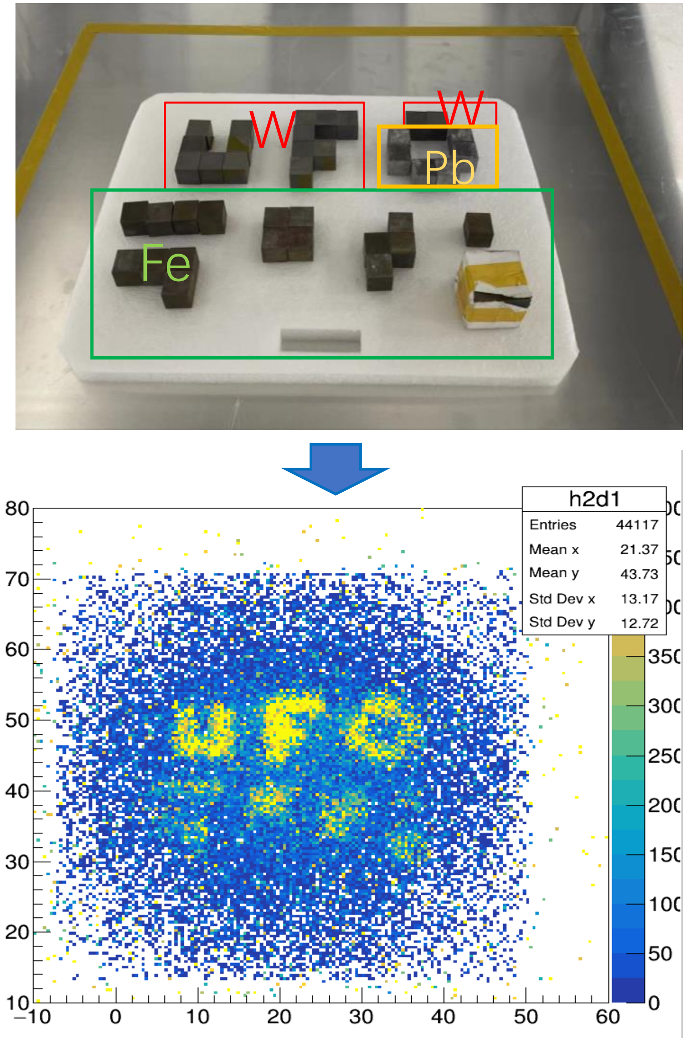


Position resolution



Cosmic Ray Platform for Performance Tests





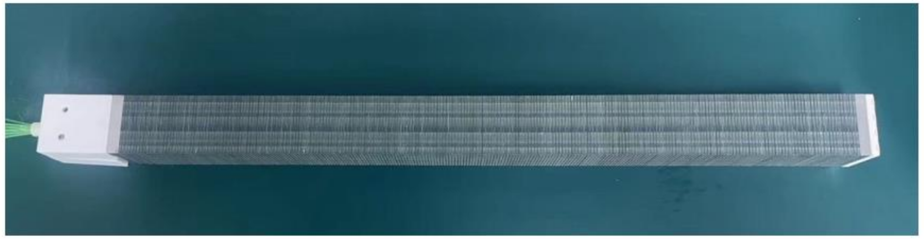
A two-dimensional positioning platform for cosmic ray tests:

- 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.

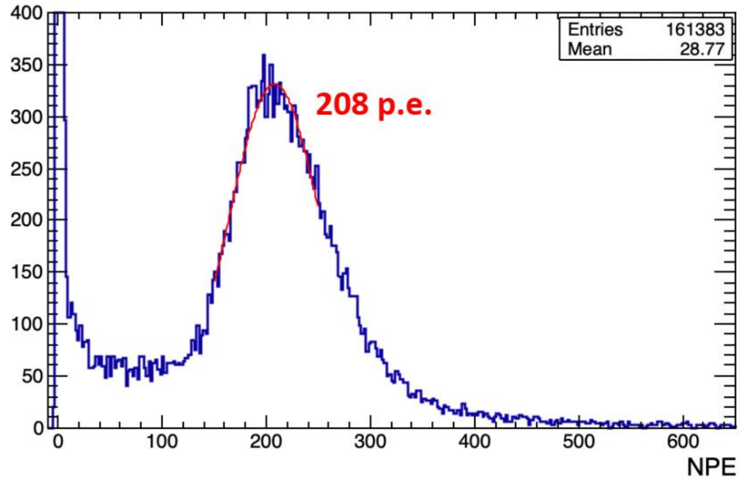
Preliminary test result: 2D image reconstruction of samples of different materials (W, Pb, Fe), with higher material density resulting in better image resolution.

Shashlik ECal cosmic ray test result

Assembled Shashlik module

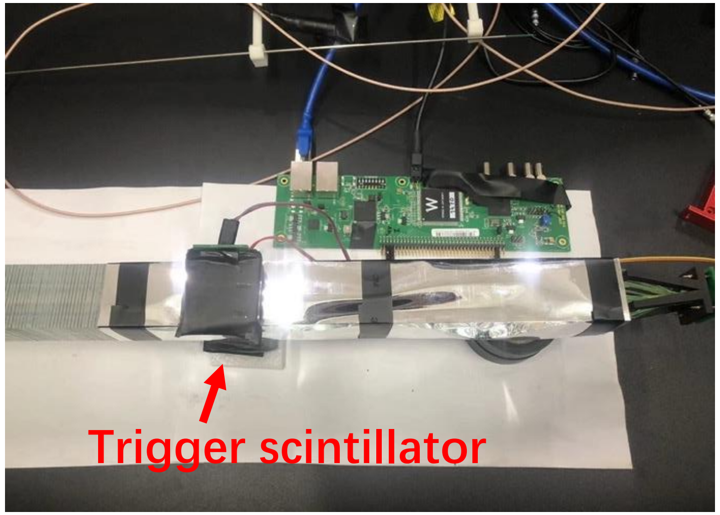


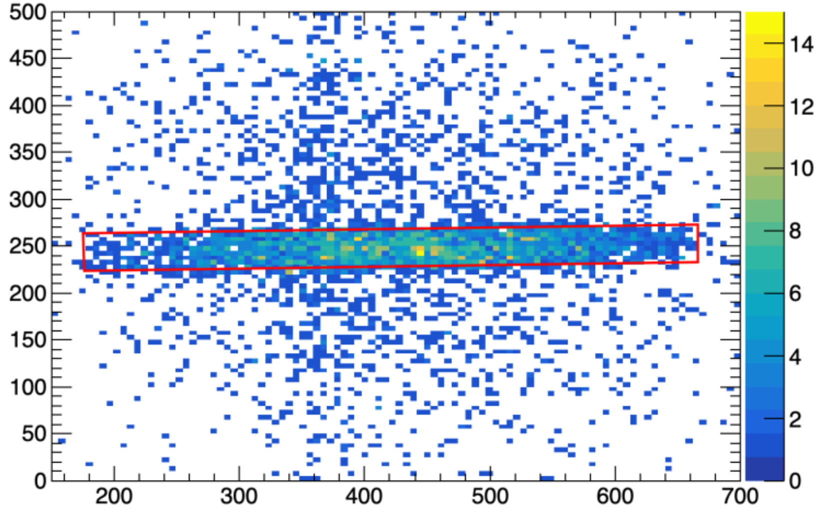
cosmic ray NPE spectrum (PMT)



Horizontal test setup

Module

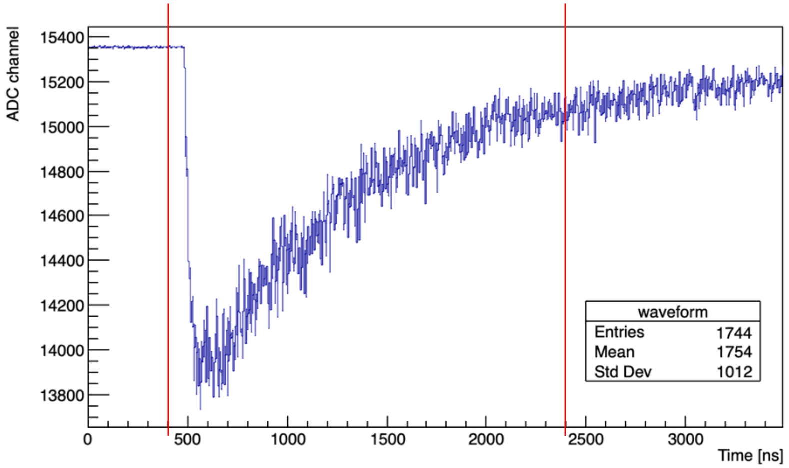


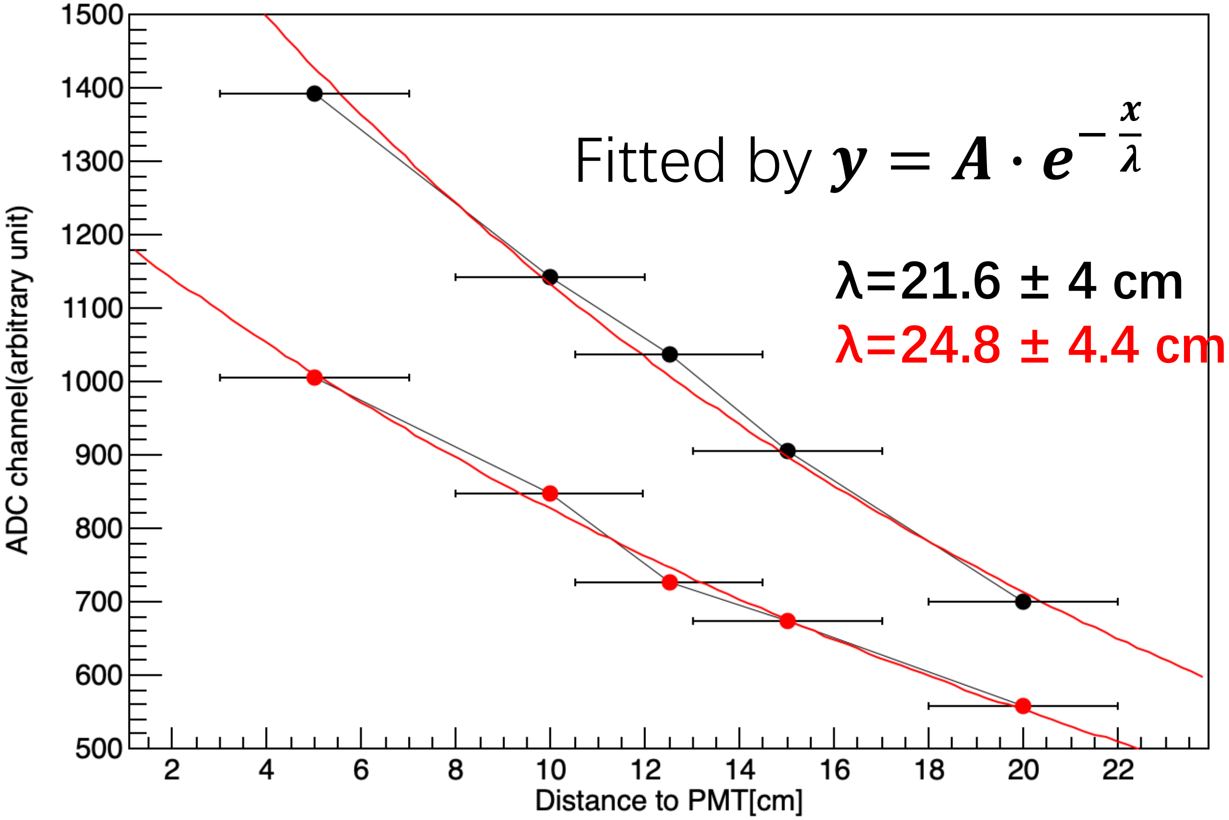


CsI(Tl) attenuation cosmic ray test

- The attenuation length is a main parameter of CsI(Tl), influence the uniformity of energy deposit
- Simulation shows muon deposit 22.3 MeV in CsI, created 1.1M photons.

Cosmic ray signal sample





Short attenuation length confirmed

Summary

- A lot of progress on detector subsystems to realize the physics goal:
  1) Vertex & tracking detectors
     - silicon+MPGD, simulation, R&D
  2) PID detectors
     - DIRC, RICH identified, simulation, R&D
  3) Calorimeters
     - CsI, Shashlik for ECal, simulation, R&D
  4) Far Forward detectors
     - EDT, FDT design available
  5) IR+Magnet: R&D
  6) Luminosity monitor & Polarimetry
     - Methodology, technology identified, simulation
  7) DAQ
     - stream readout/trigger, R&D

CDR →

- ➢ Physics requirements
- ➢ Targeted resolutions
- ➢ Technology candidates
- ➢ Simulation results
- ➢ Coordination of subsystems
- ➢ R&D activities or planning

http://cicpi.ustc.edu.cn/indico/conferenceDisplay.py?confId=6574

- Simulation & software: simulation framework available, beam background simulation is important.

Thanks for your attantion!