Introduction on the PID Detectors at EicC

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SCNT

Outline

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

EicC Spectrometer Overview

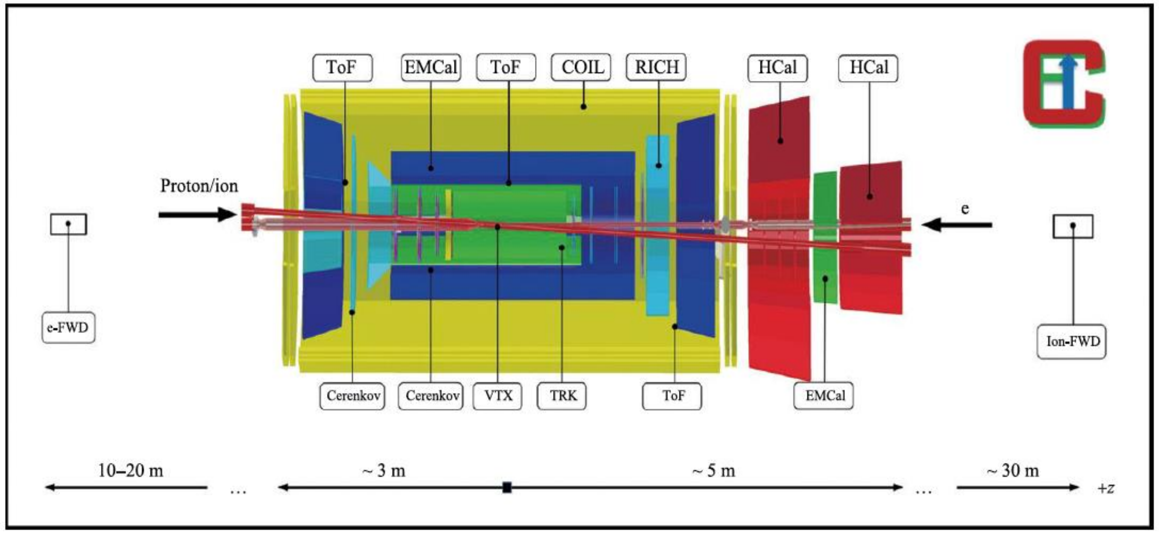
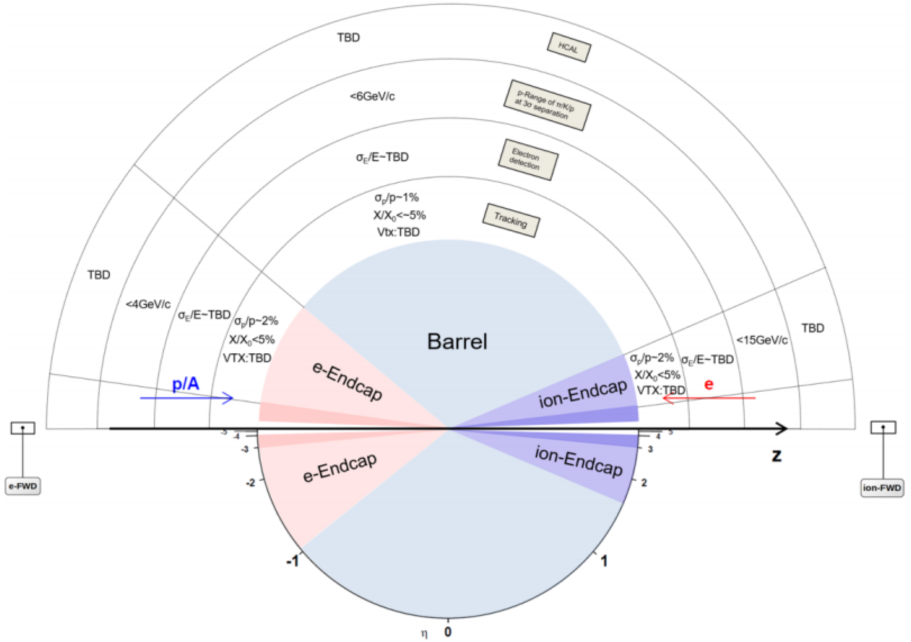


Fig. 4.10 Conceptual design of the EicC detector.



- 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

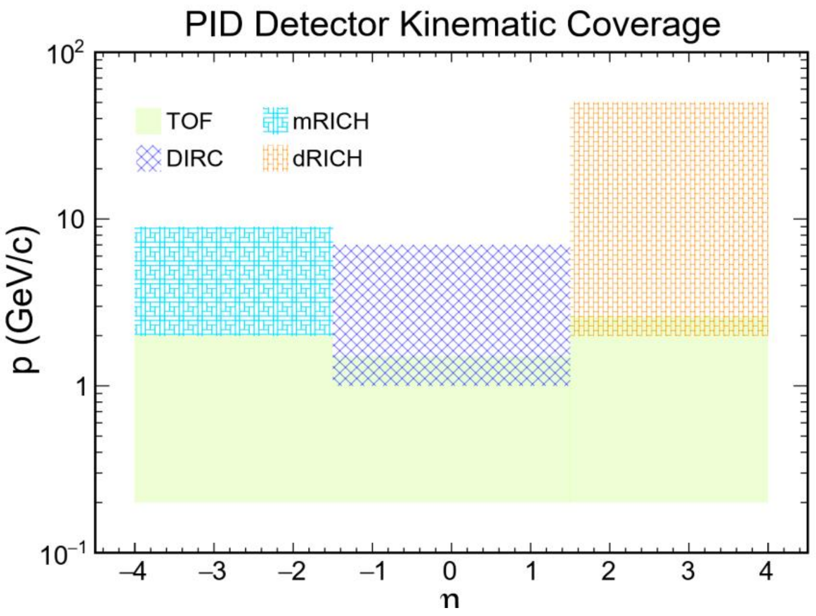
General requirements:

- Large rapidity (-4 ≤ η≤ 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

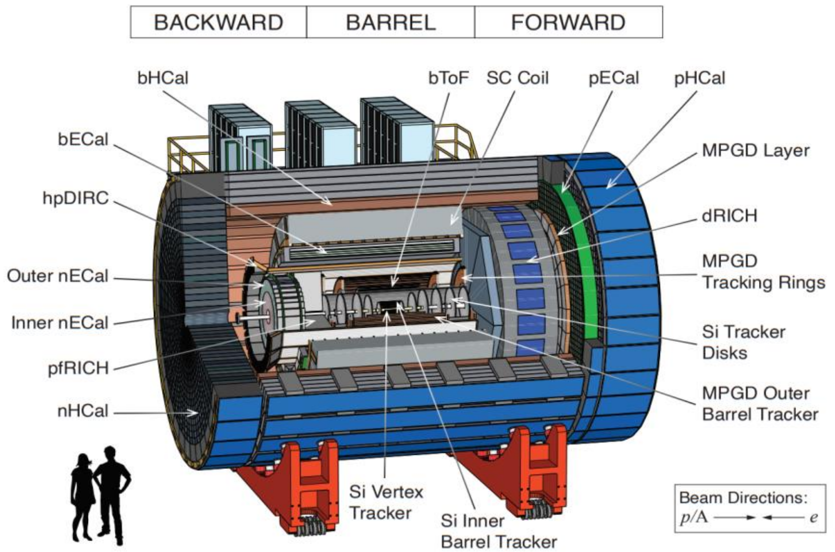
- ➢ Fast response and ultra-high resolution
- ➢ Compact structure and radiation resistant
- ➢ PID power with large momentum coverage:

  ≤ 4 GeV/c at e-Endcap;
  ≤ 15 GeV/c at ion-Endcap ;
  ≤ 6 GeV/c at Barrel.



PID detectors:

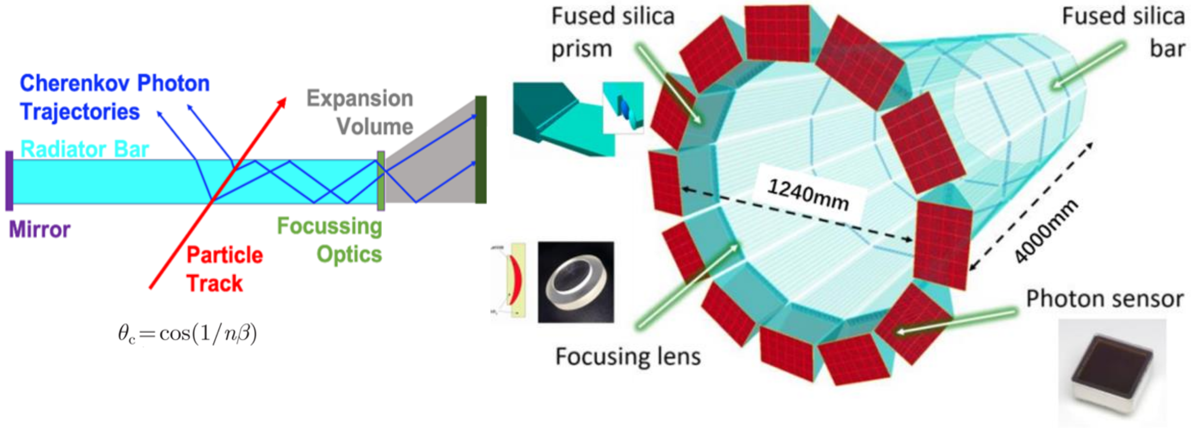
- Barrel PID: High performance Detector of Internal Reflection Cherenkov lights（hpDIRC）
- Endcap PID: Ring Imaging Cherenkov (RICH) detectors, dRICH for ion-endcap, mRICH for e-endcap
- Low Momentum PID（< 2GeV/c): MPRC, LGAD



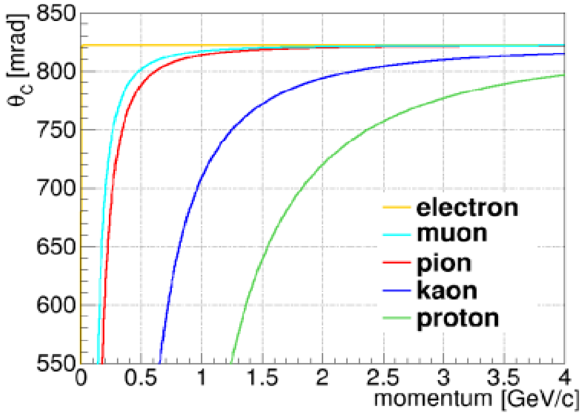
Barrel DIRC for PID

Detector of Internal Reflection Cherenkov lights (DIRC):

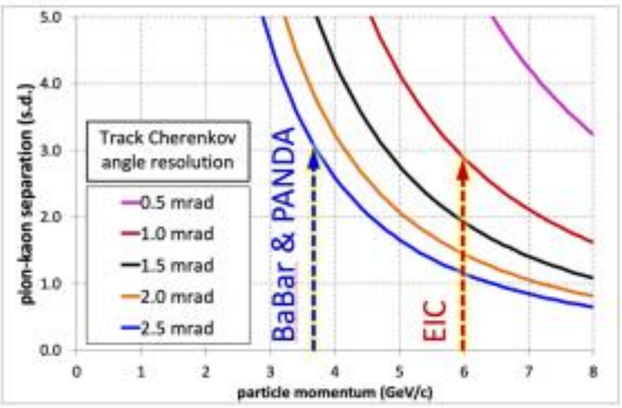
Different charged particles induce Cherenkov radiation with different Cherenkov angles, DIRC achieve PID through reconstructing their Cherenkov angles, by measuring the transit time and exit position/angle of Cherenkov photons induced by different particles.



- 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

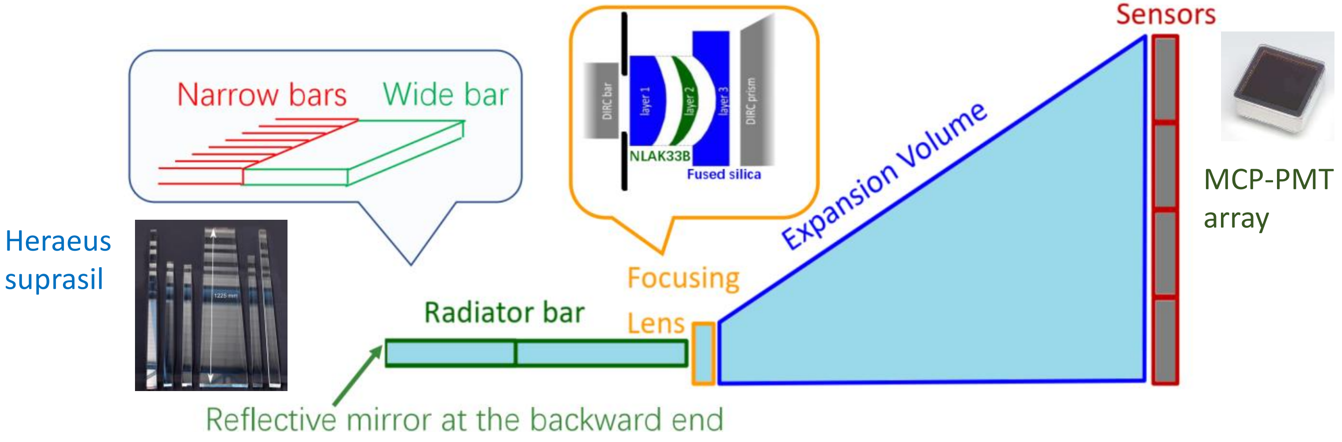


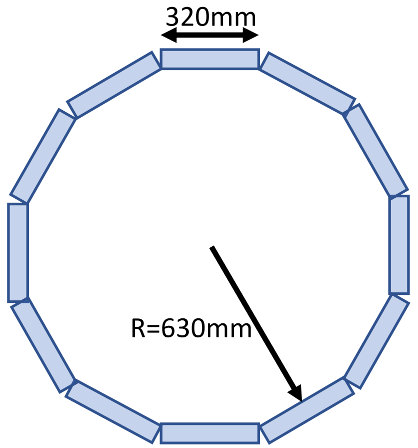
refractive index of synthetic fused silica **with n = 1.47**



Reference from PANDA & EIC

DIRC Module Design





- Quartz radiator bar: 15mm x 51mm x 3300mm
- Expansion volume(EV): 208mm x 312mm x 300mm
- MCP-PMT: Hamamatsu R10754 (pixel size: 5.2mm x 5.2mm) or Photonis XP85122 (pixel size: 3mm x 3mm)
- Tray box size: 50mm x 320mm x 4000mm with 6 bar+EV
- 12 trays forms a barrel detector with a minimum radius R = 0.63m
- Focusing: spherical 3-layer lens (Fused silica N-LAK33B) curvature radius: 30cm, Thickness: 10mm

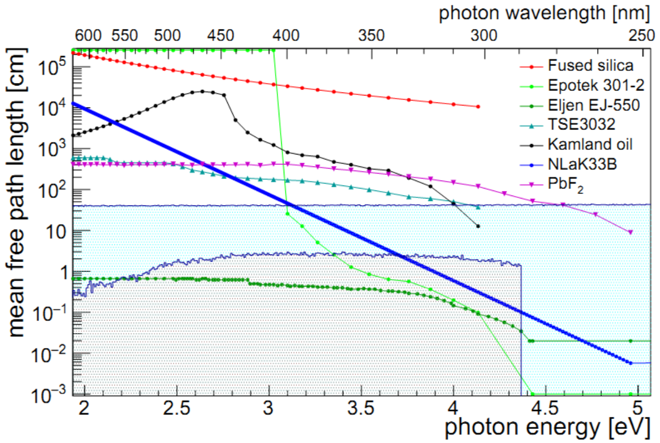
Definition of measured DIRC angular resolution:

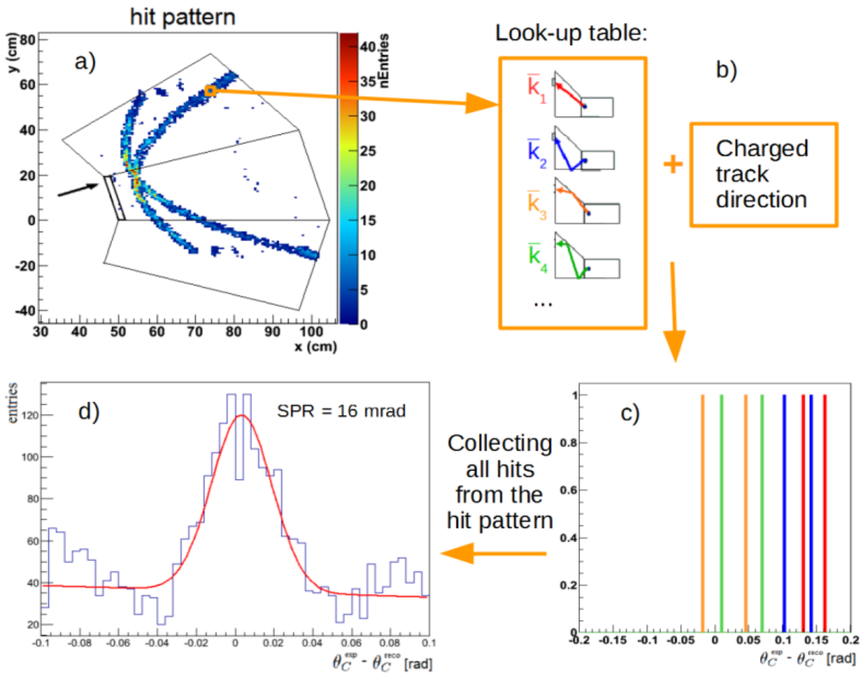
$$\sigma_{\theta_c}(\mathrm{photo}) = \sqrt{\sigma_{chrom}^2 + \sigma_{foc}^2 + \sigma_{bar}^2 + \sigma_{trans}^2 + \sigma_{rec}^2}$$

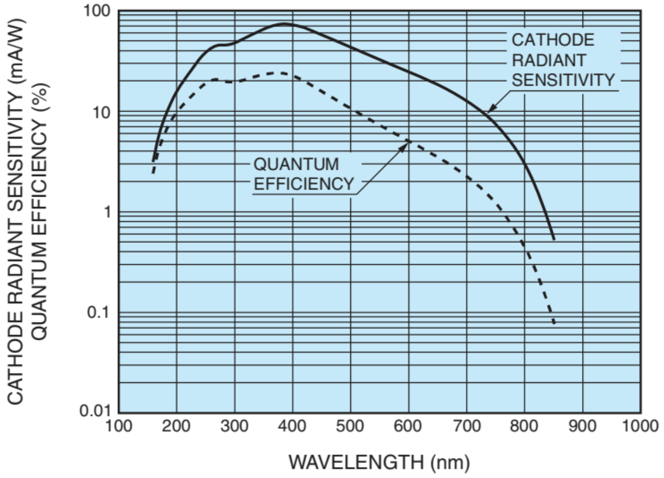
- σ_{chrom}~5.4mrad, is the dispersion contribution of the quartz radiator (wavelength: 300-700 nm)
- σ_{foc}: error from the optical focusing lens and the pixel size of photosensors
- σ_{bar}: the influence of radiator thickness (flatness) on photon yield and transmission efficiency;
- σ_{trans}: transit fluctuation due to the roughness of the radiator
- σ_{rec}: error from incident particle tracking

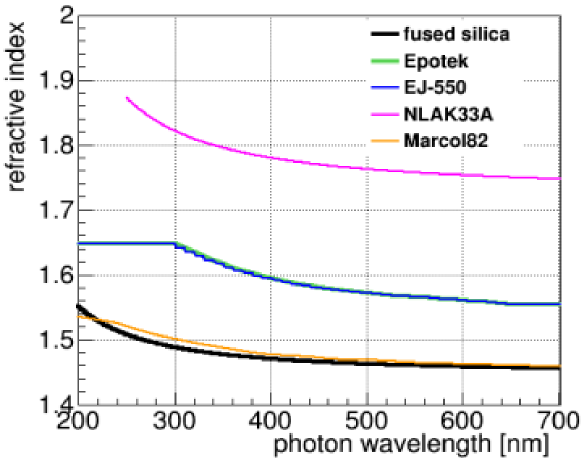
DIRC Simulation

Simulation Input & process:



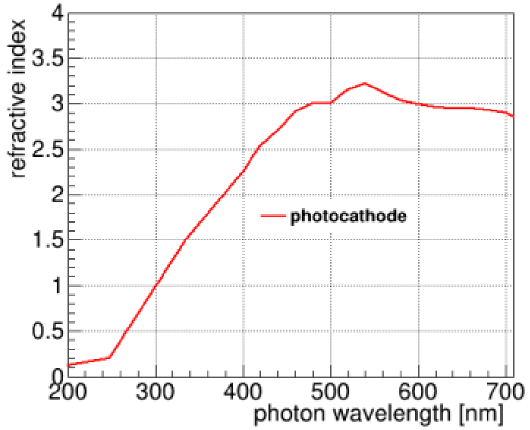




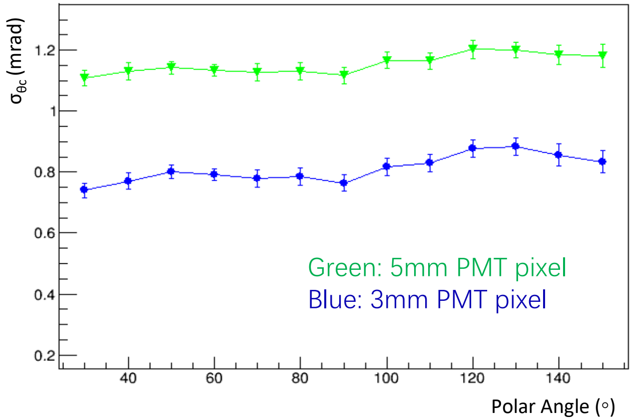


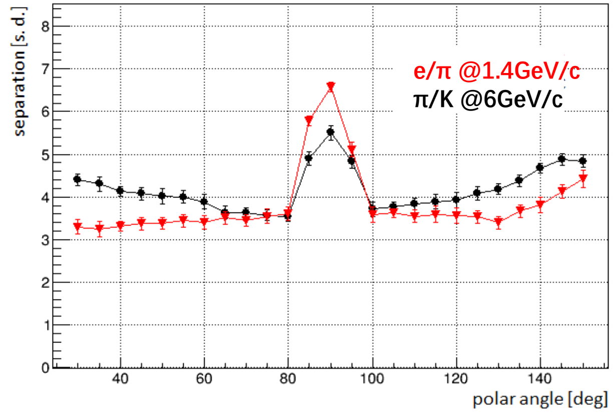
Reference from “Simulation, Reconstruction, and Design Optimization for the PANDA Barrel DIRC”, 2016

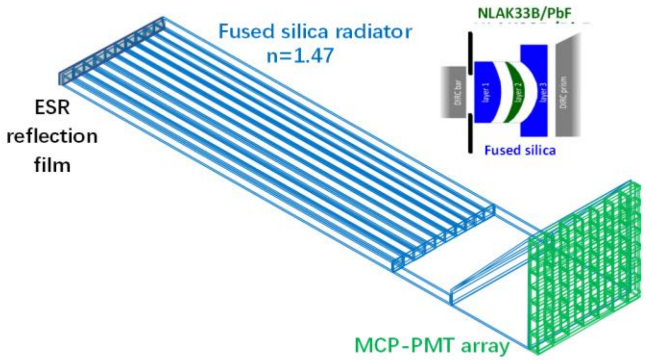
Wavelength [nm]	Bulk transmission [1/m]	# faces	Reflection coefficient	Surface roughness [Å]
406	$0.994 \pm 3.2 \cdot 10^{-4}$	49	$0.99984 \pm 1.6 \cdot 10^{-5}$	4.9 ± 1.3
532	$0.997 \pm 2.7 \cdot 10^{-4}$	49	$0.99991 \pm 1.4 \cdot 10^{-5}$	4.7 ± 1.3
635	$0.9994 \pm 8.0 \cdot 10^{-5}$	49	$0.99996 \pm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



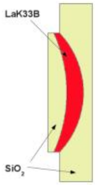
DIRC simulation and prototype setup

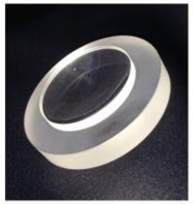






Silica radiaor





Focusing lens and EV

Hamamastu R10754

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

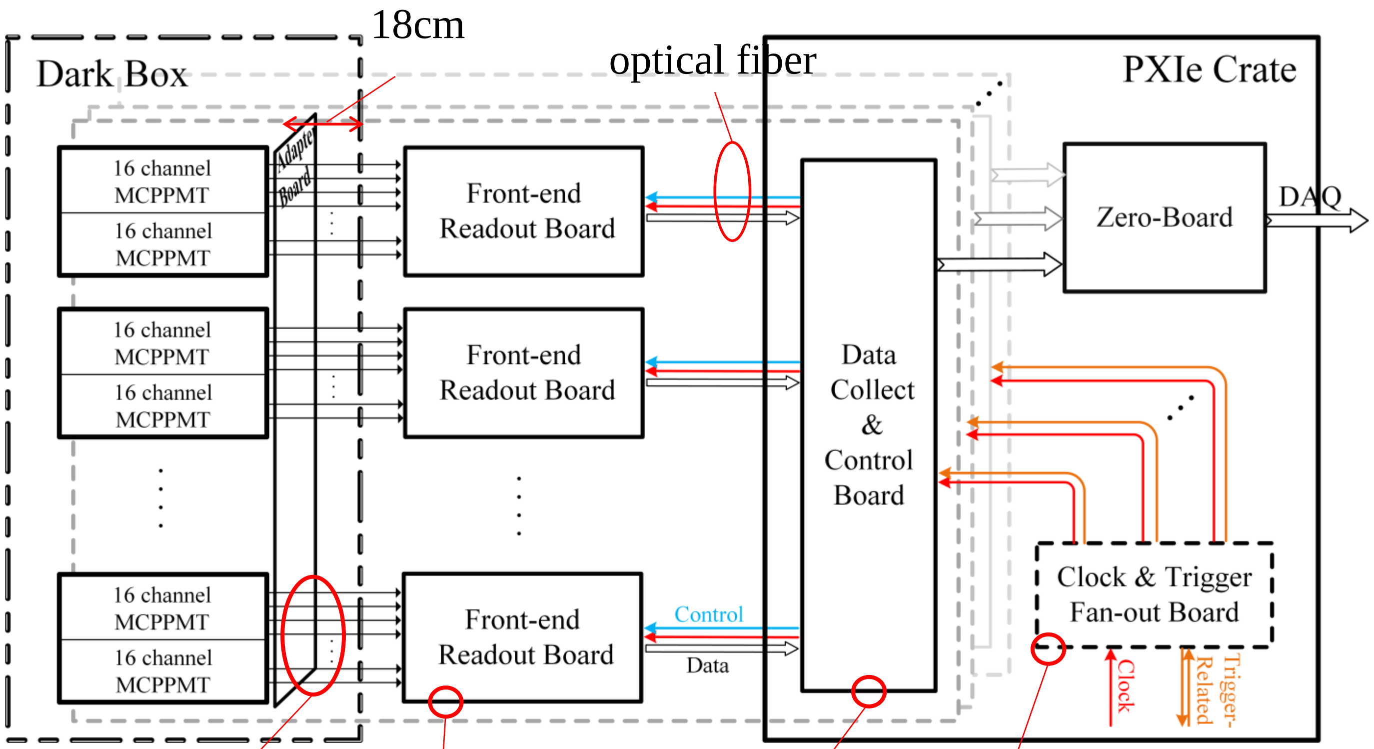
The AuraTek-Square has an active area of 53 mm x 53 mm with packaged anode configurations of 32 x 32 with 1.656mm pitch, 16 x 16 with 3.312mm pitch, and 8 x 8 with 6.624mm pitch. A non packaged version with anode confirguration of 64 x 64 with 0.828mm pitch is also available. Custom readout configurations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

North night vision 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 Readout Electronics



- 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 are finished
- 1 data control board coupled with 12 front-end readout, the bandwidth of the front-end readout is 320mb/s
- 1 slot controller can have up to 17 data control boards, and supports up to 17 × 12 × 32 = 6528 channels

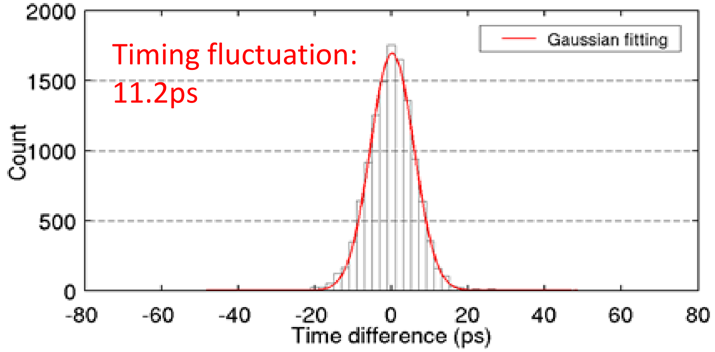
Flexible readout backpanel

Front end readout board

Data control board

Clock fan-out board

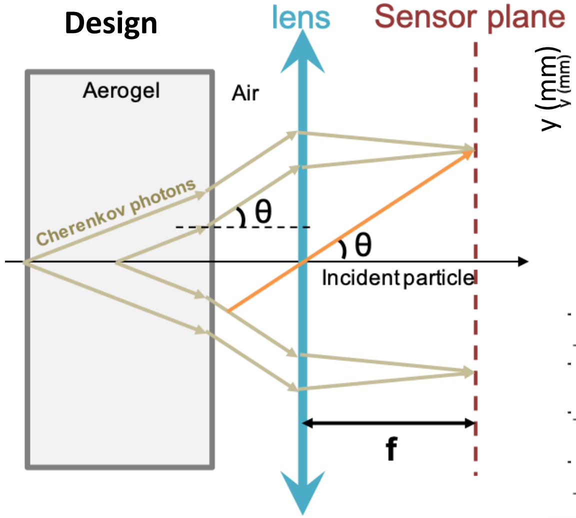
slot controller



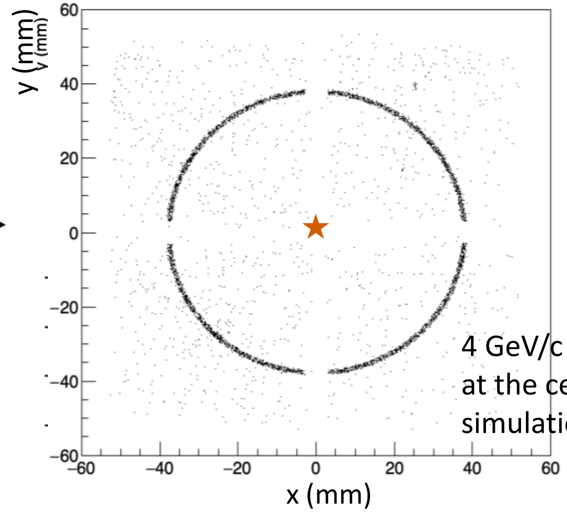
mRICH: Lens-based Focusing Aerogel Detector Design

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

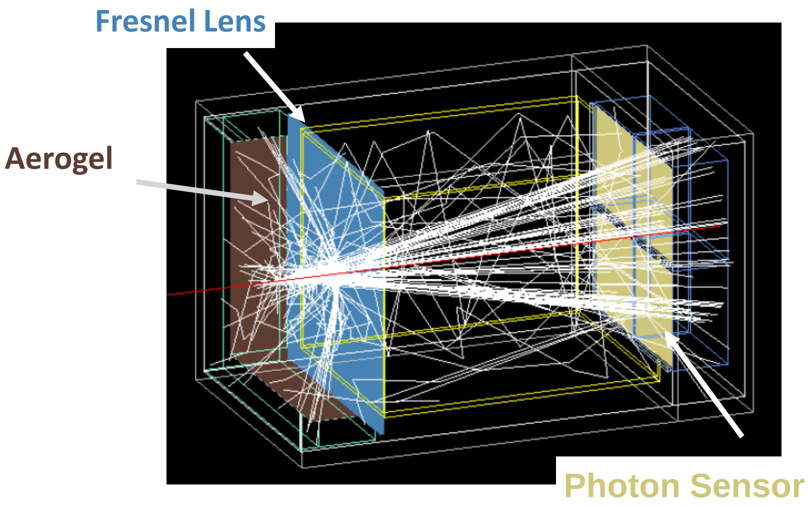


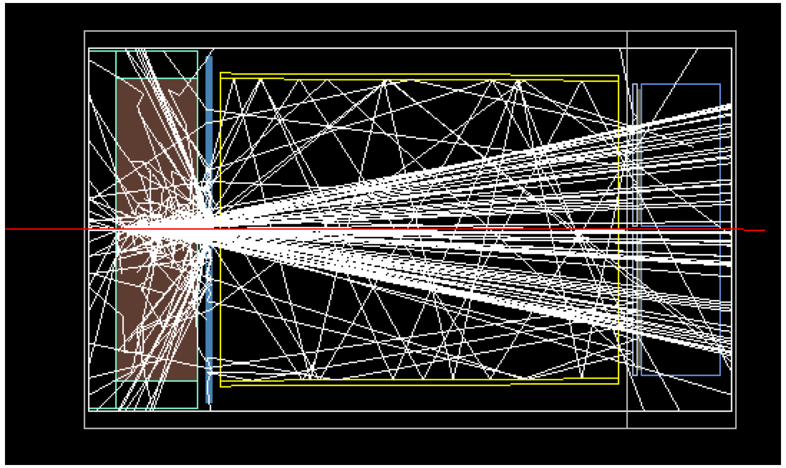
focal length 15.24cm (6”)

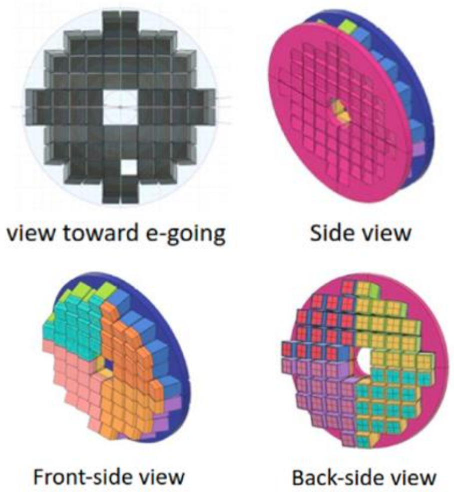


4 GeV/c pion beam launched at the center of xy plane in simulation

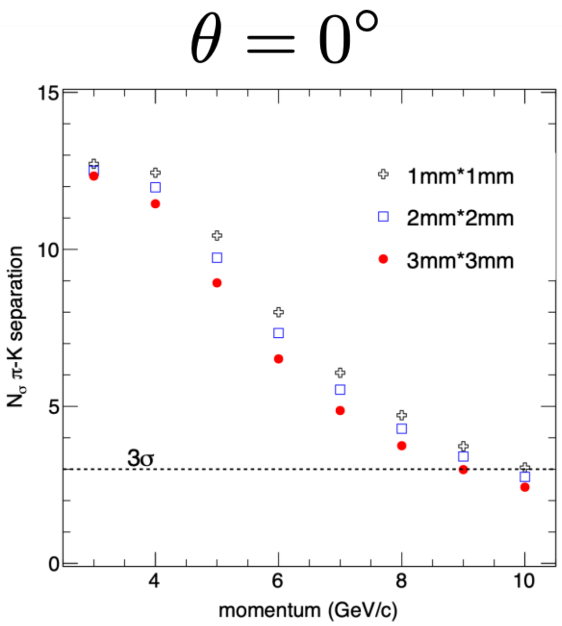
Focus length: 7.62cm & 15.24cm (3” & 6”)

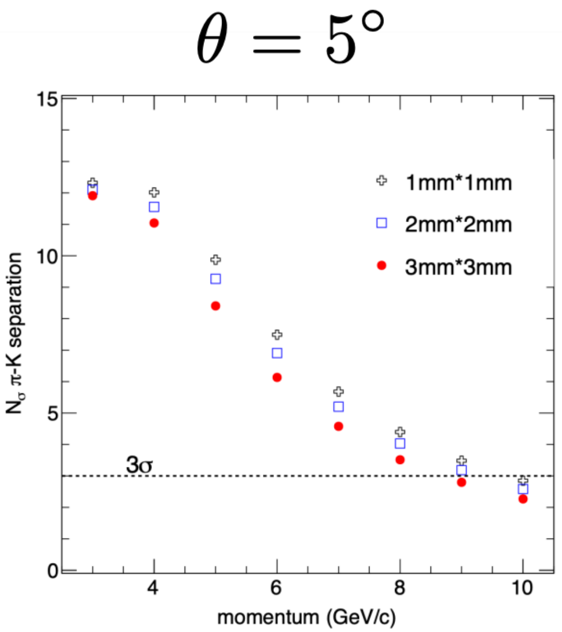


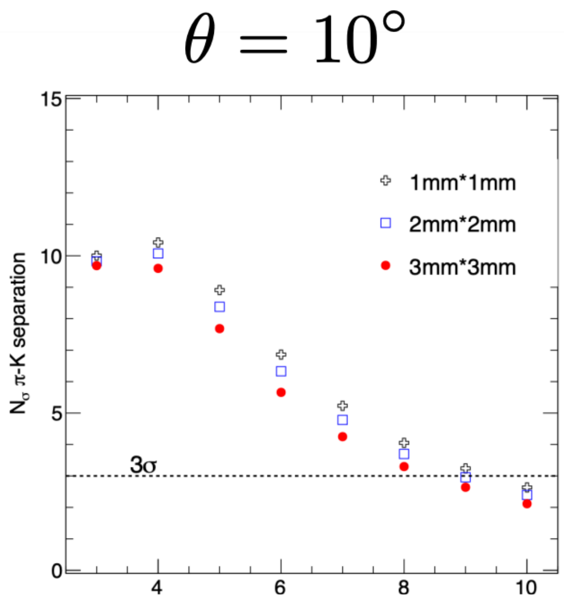




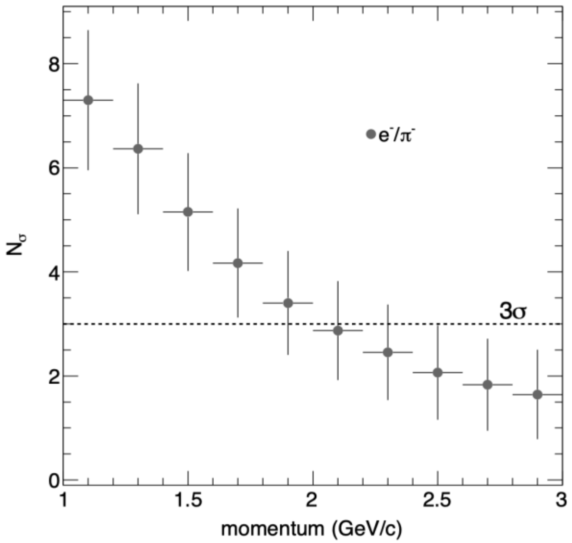
Separation Power for 6” mRICH



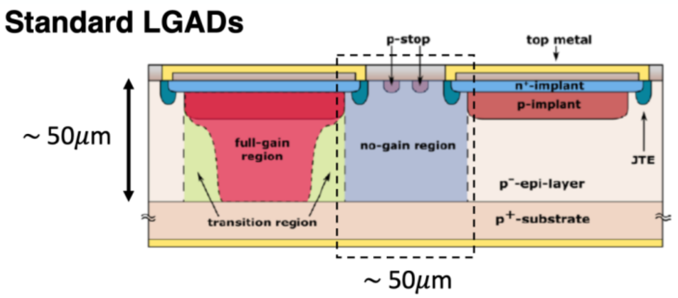


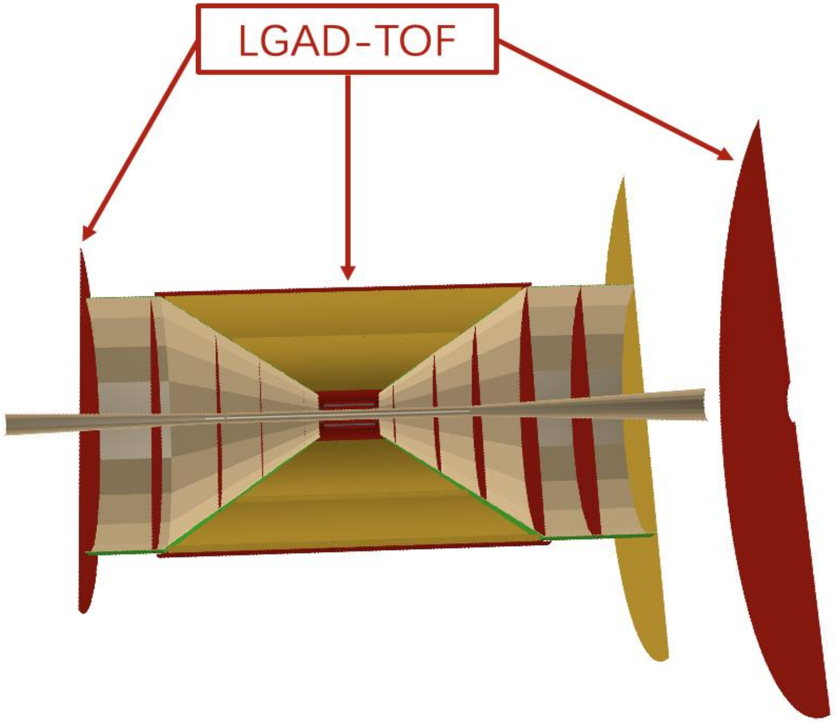


- Separation power decrease with increasing polar angle
- 3σ π/K separation up to 9 GeV/c when particle incident at the center of aerogel
- 3σ π/K separation up to 8 GeV/c when particle incident at 10 degrees
- e/pi separation low to 2 GeV/c



LGAD-TOF in full simulation





Thanks to Aiqiang and Yuming

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

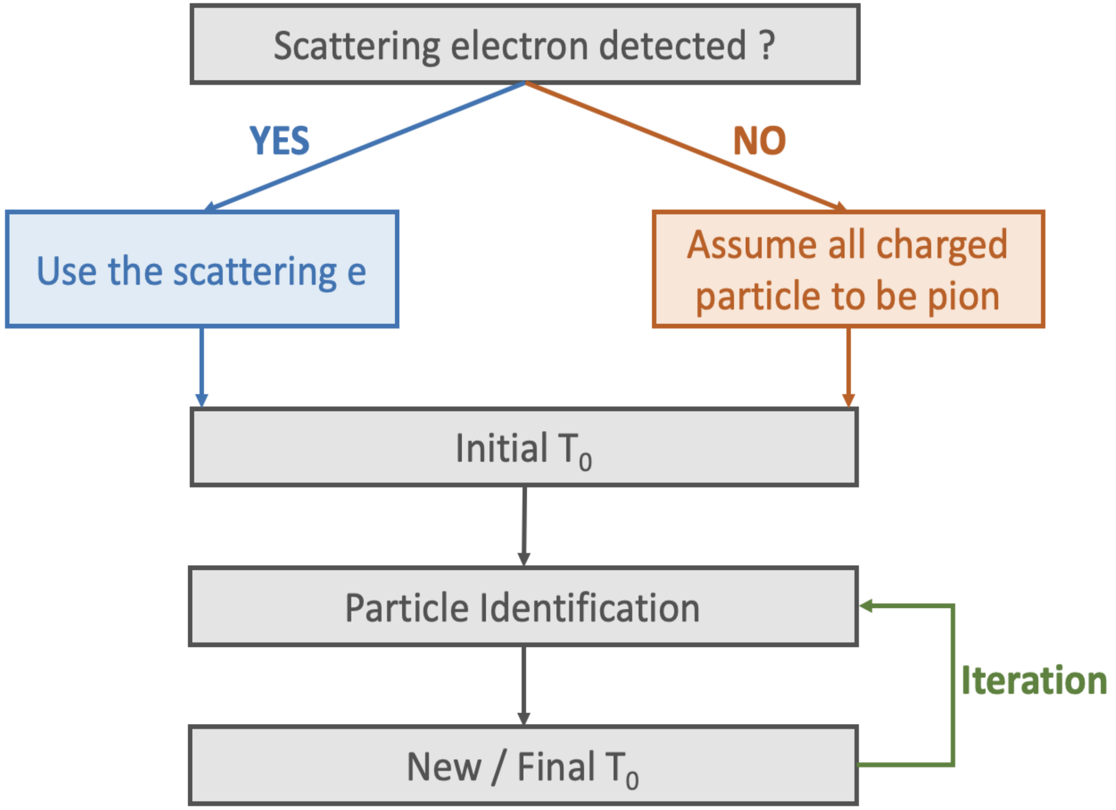
	R^{barrel} (cm)	Length (cm)	Z location (cm)	R^{endcap}_{in} (cm)	R^{endcap}_{out} (cm)	η coverage
Backward			-148	5.4	110.81	[-4.0, -1.1]
Barrel	80 (trying to achieve 60cm)	214				[-1.1, 1.1]
Forward			248	12.3	185.7	[1.1, 3.7]

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

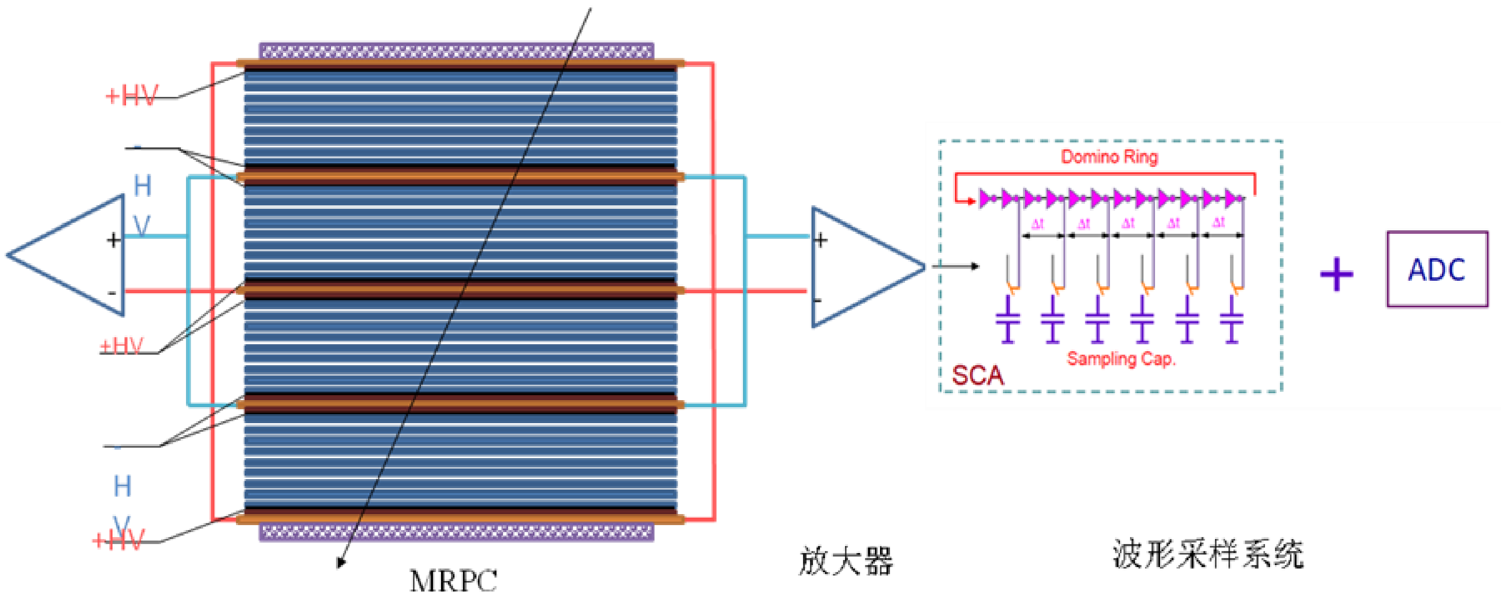
Start time determination (ongoing)

- 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



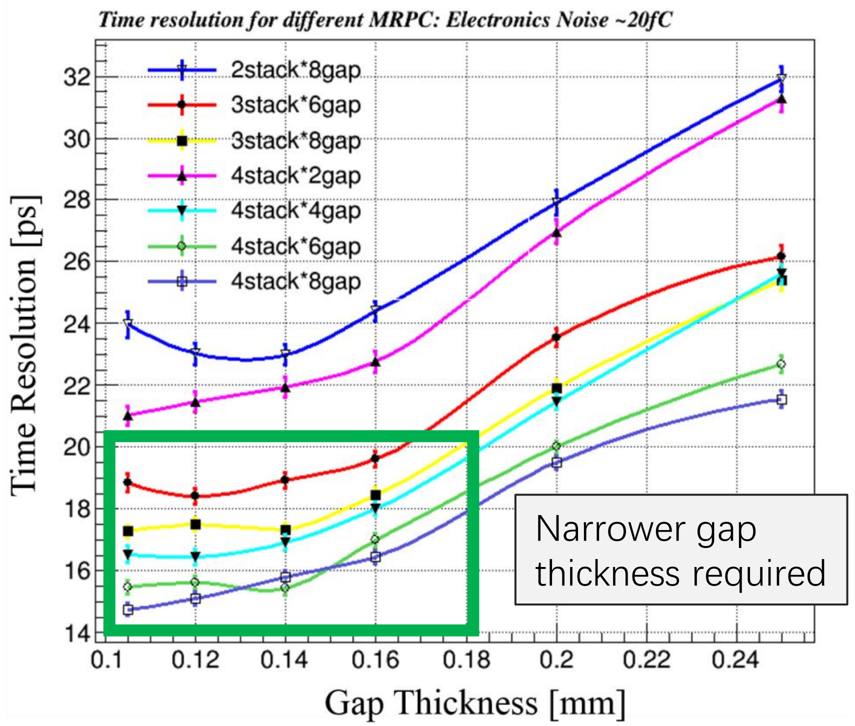
Narrow gap MRPC: toward 20ps resolution



$$\sigma_{TOF} = \sqrt{\sigma_{MRPC}^2 + \sigma_{electronics}^2}$$

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

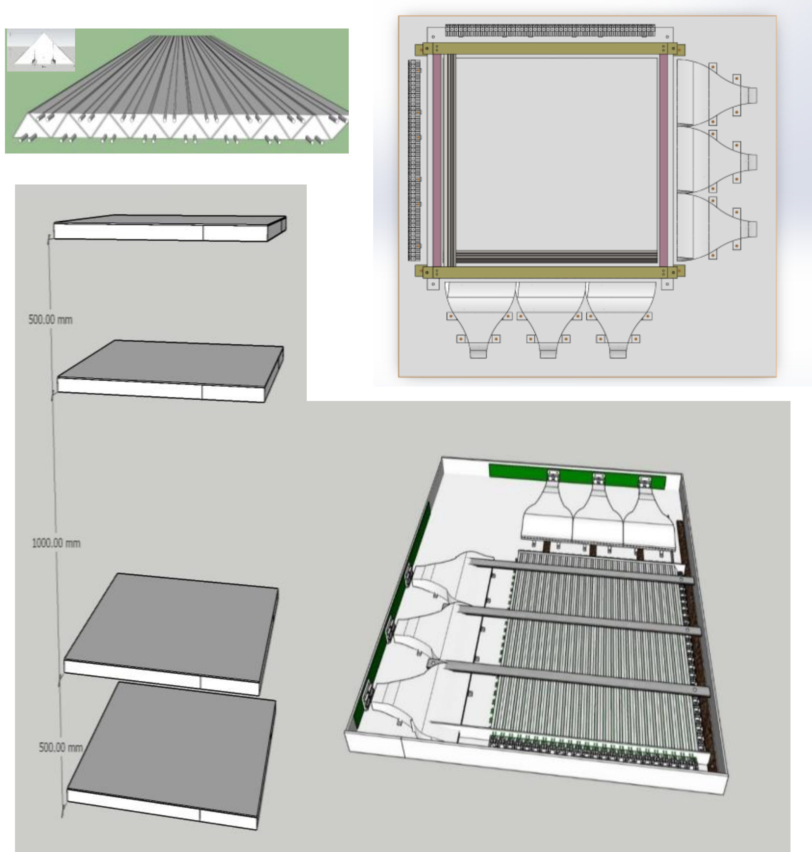
- Simulation indicates proper ways to design the gap thickness and arrange the stacks

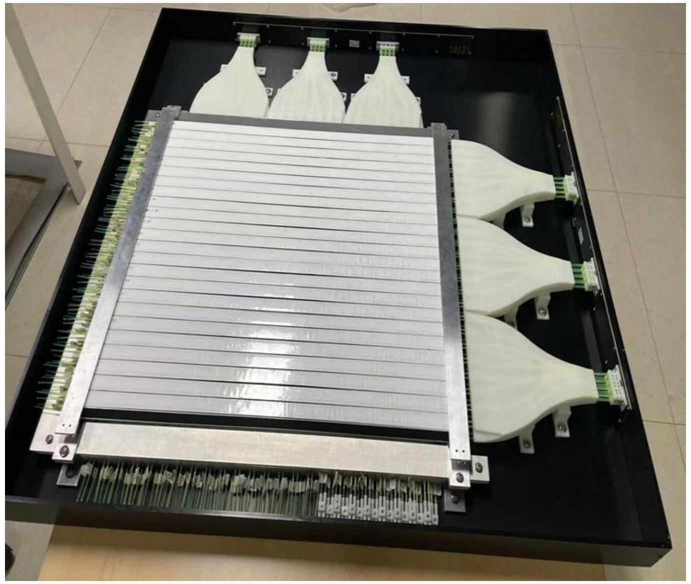


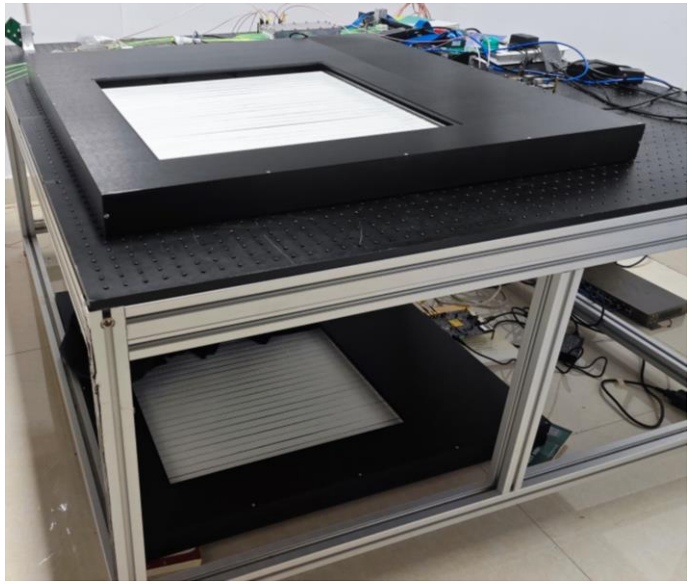
σ_{MRPC} <20 ps, the gas gap: <0.18mm

gap number: >16

Cosmic ray platform: design







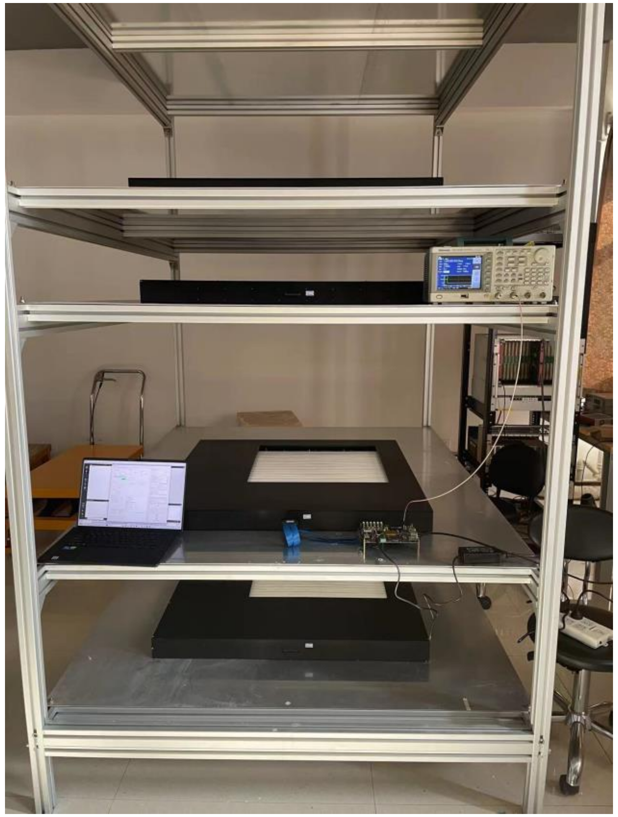
2-D position cosmic ray detector:

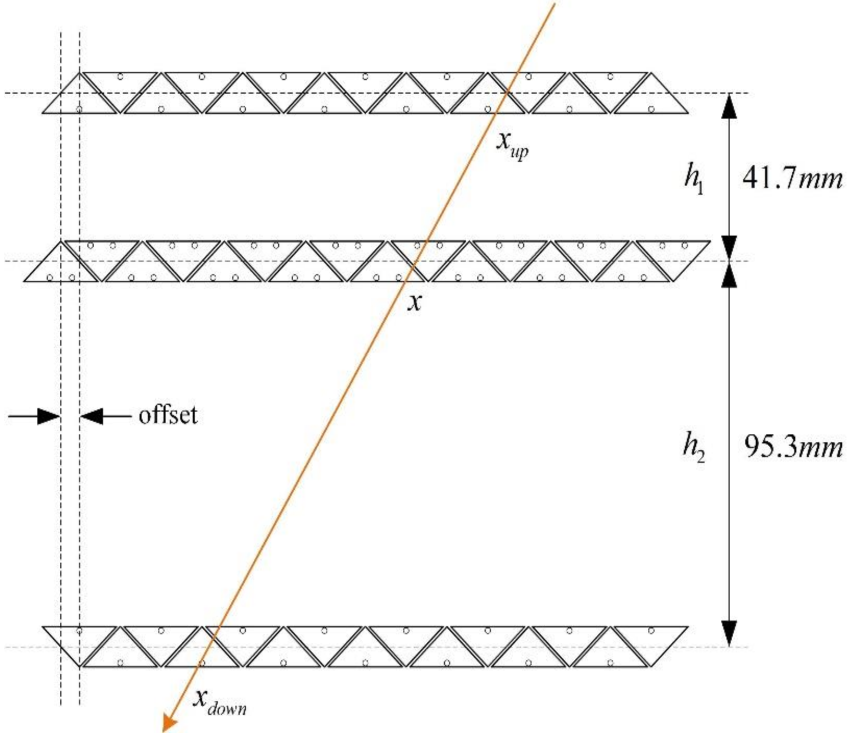
- Installed in 80cm x 80cm dark box
- 2 layers (x-y) consist of 6 modules, 96 strips, 192 fibers, and 2 electronic boards
- Position resolution ~ 1mm

Cosmic ray module:

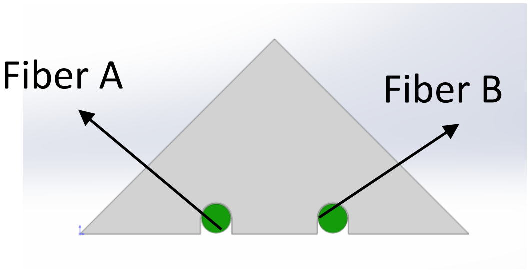
- 16 scintillator strips & 32 fibers in the same encoding group
- Couple with 8 SiPMs & readout electronic channels

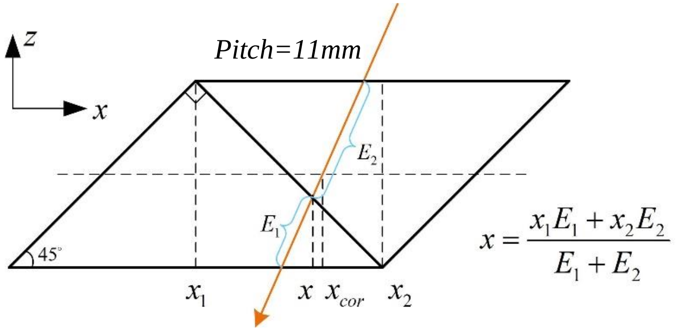
Cosmic ray test



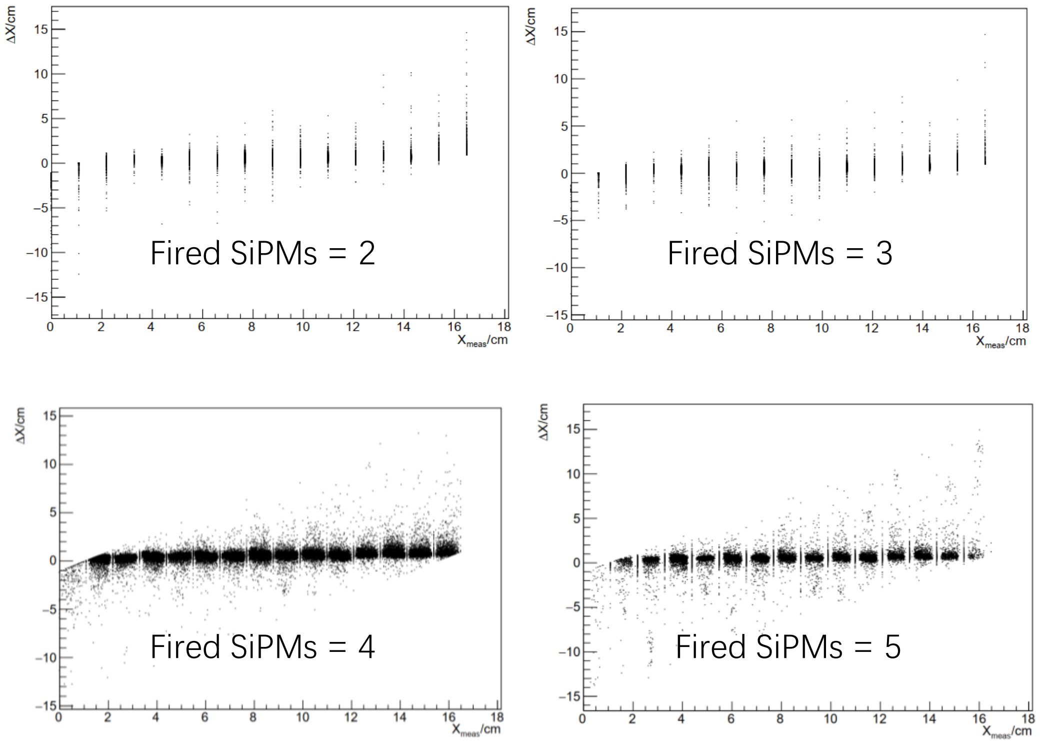


- 4 module completed, has been tested by cosmic ray:
  55 x 55cm sensitive area total
- 1 test module, another 2 modules as trigger & tracker
- Cosmic ray detection efficiency ~ 97%





Performance test results

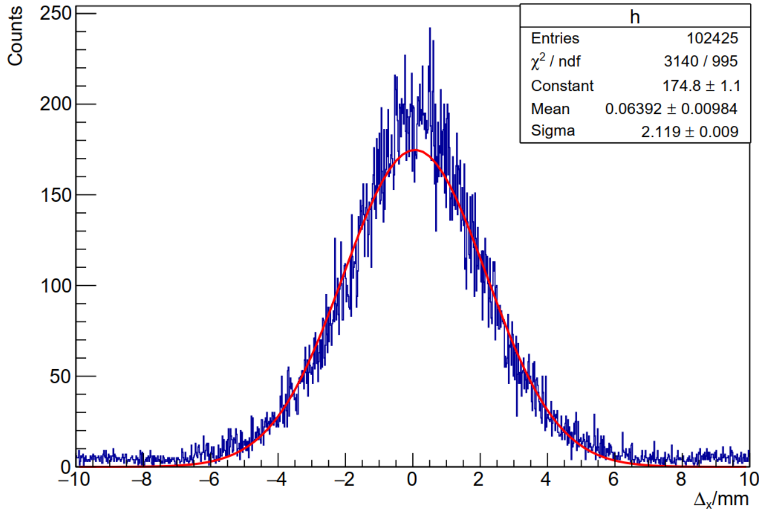


Positioning fluctuation with different fired SiPM counts

- Photon collection efficiency increase 40% with ESR film
- single module's spatial resolution at x, y plane:

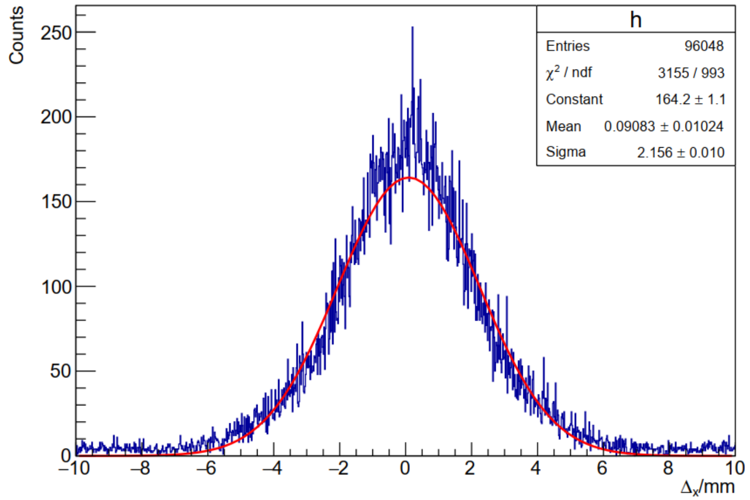
  2.119/√1.5 = 1.73mm, 2.156/√1.5 = 1.76mm
- Estimated overall spatial resolution for 4 modules: $\sigma_{x,y} \sim 0.8$ mm

Status: 4 modules completed, performance as expected, improving 4-layer tracking algorithm.



Measurement fluctuation Δx in x direction

$$\Delta x = \frac{(x_0+x_2)}{2} - x_1$$



Measurement fluctuation Δy in y direction

Summary

- DIRC: improving optical design & imaging reconstruction algorithm by simulation, developing small prototype & readout electronics
- RICH, LGAD, MRPC: under simulation, setup R&D platform
- Cosmic ray test platform: 4-layer platform (position resolution ~1mm), improving tracking algorithm

Thank you!