Conceptual design of the DIRC detector for EicC experiment

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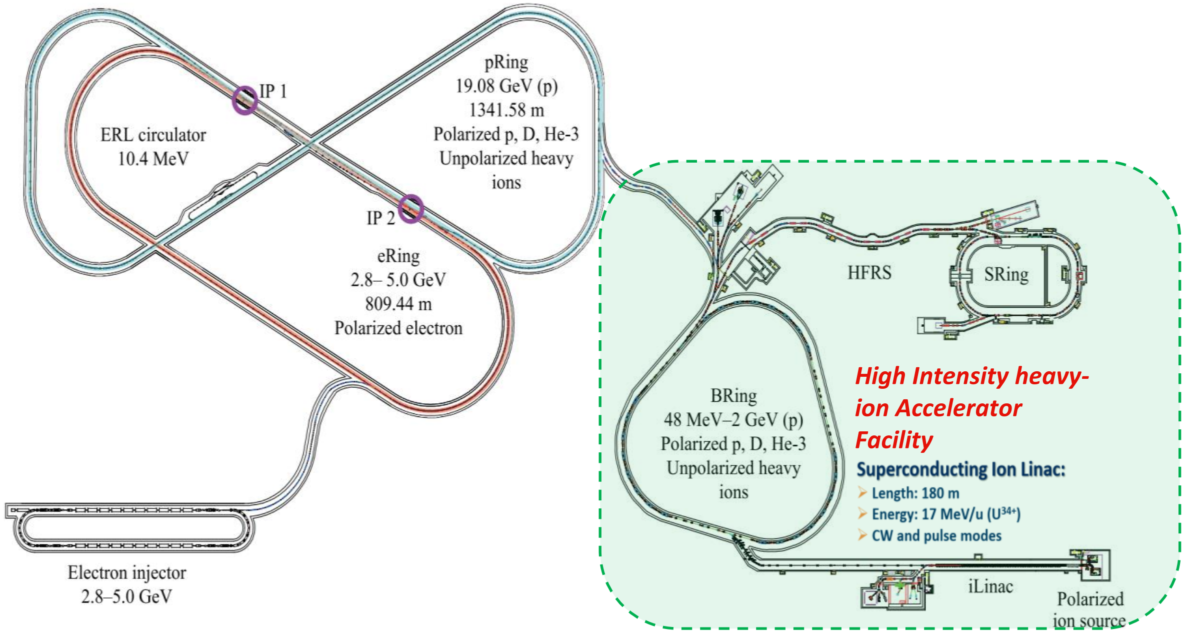
Outline

- Introduction on Electron-ion collider in China (EicC)
- EicC spectrometer overview and its PID requirements
- DIRC Concept design & simulation
- Summary

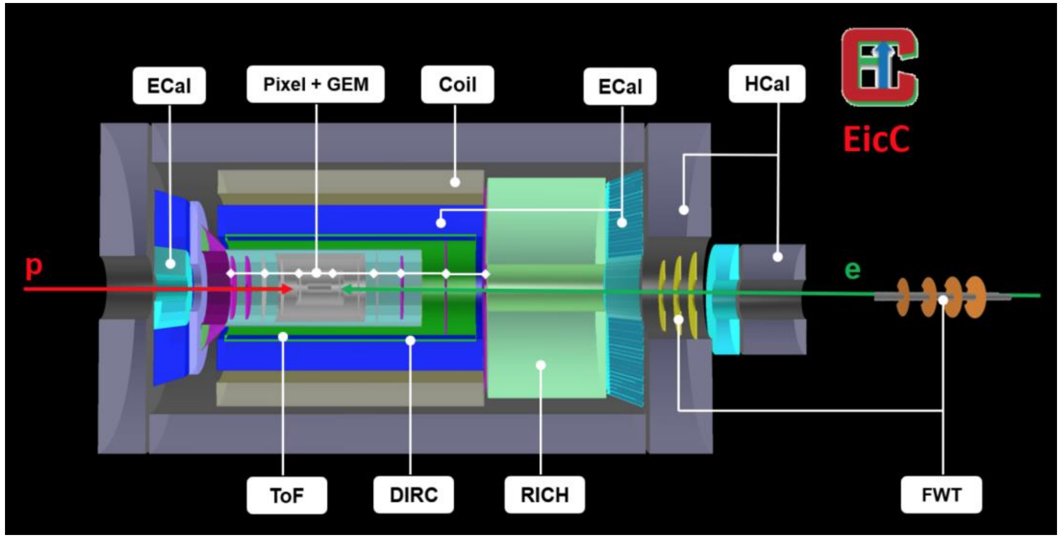
Introduction on EicC

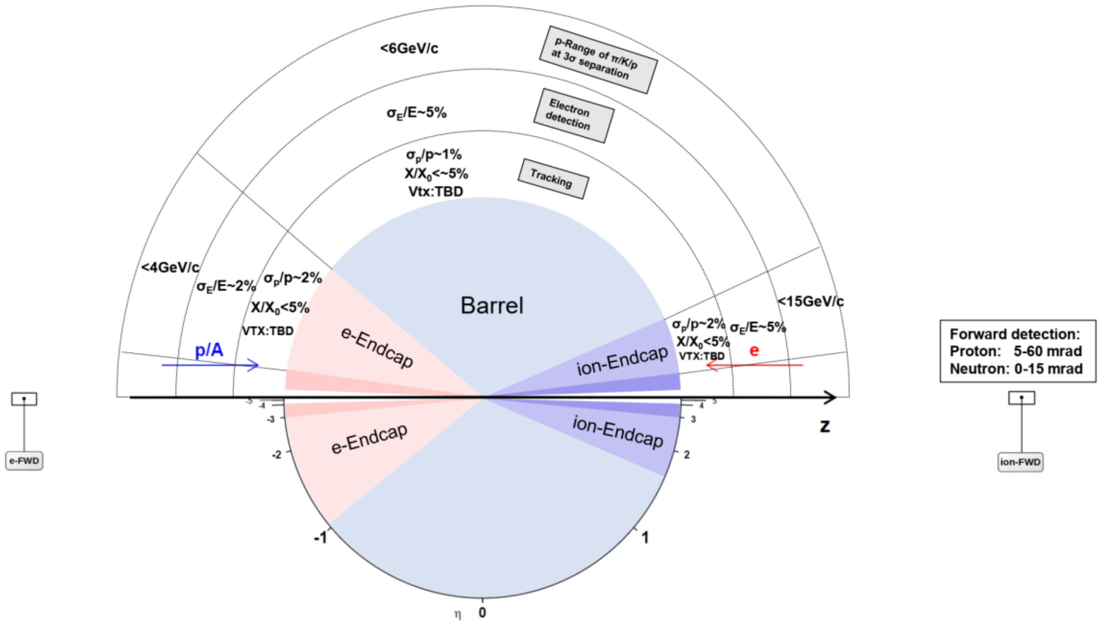
As a future high energy nuclear physics project, an Electron-ion collider in China (EicC) has been proposed based on High Intensity heavy-ion Accelerator Facility (HIAF), a heavy-ion accelerator currently under construction. The proposed collider will provide highly polarized electrons (with a polarization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





- Sub detectors to realize the EicC physics goals:

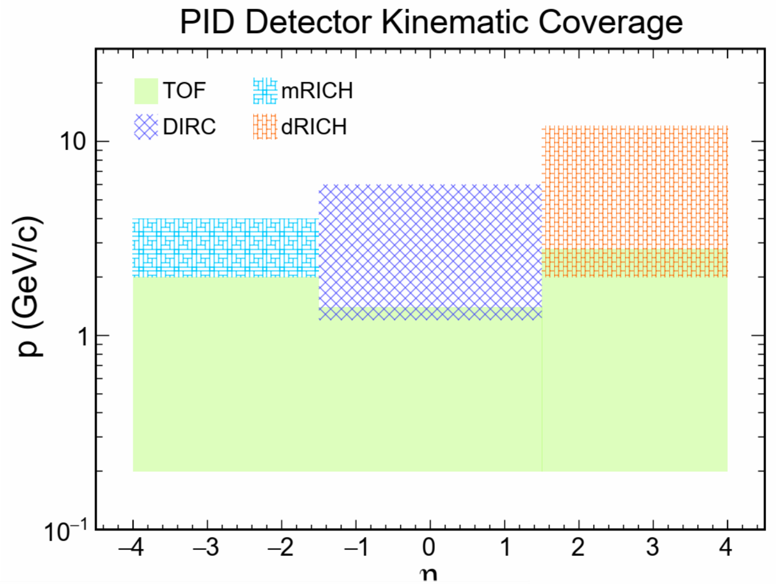
  1) Vertex & tracking detectors
  2) PID detectors (Cherenkov + ToF)
  3) Calorimeters
  4) Far Forward detectors
  5) Luminosity monitor & Polarimetry
  6) DAQ

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

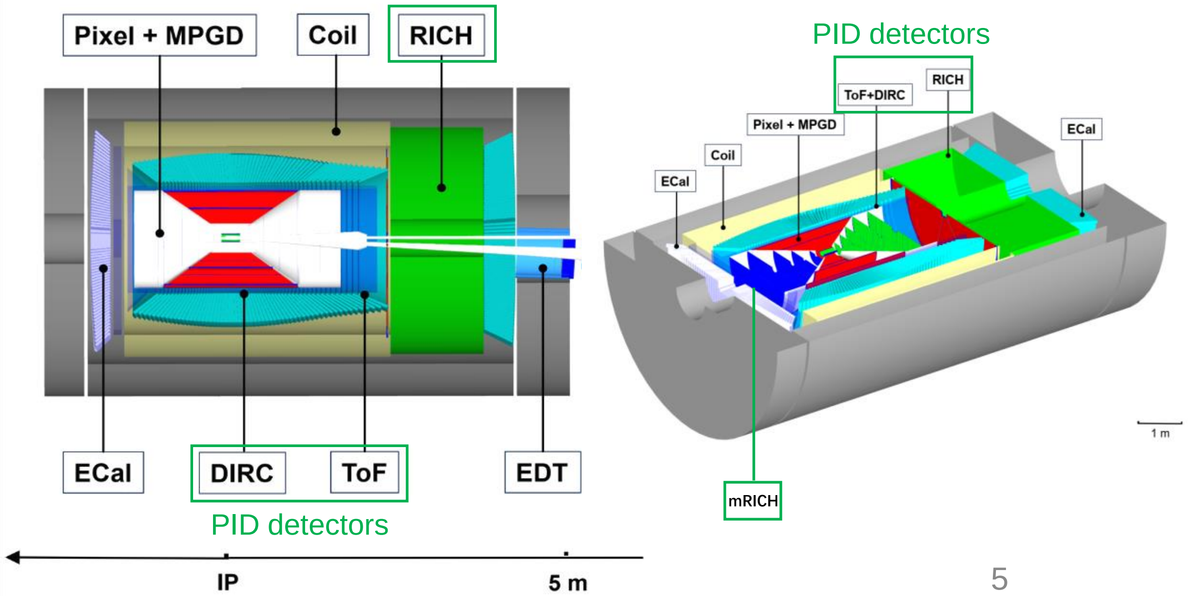
Detector Requirements for PIDs

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



PID detectors：

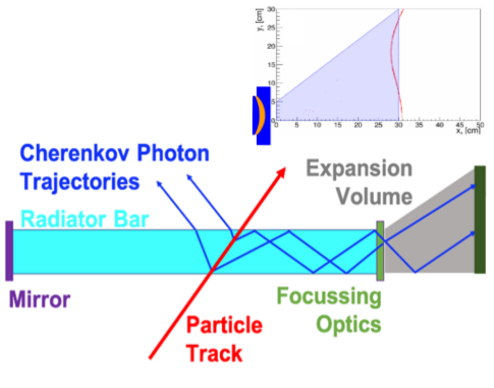
- Barrel PID: High performance Detector of Internal Reflection Cherenkov lights (DIRC)
- Endcap PID: Ring Imaging Cherenkov (RICH) detectors, dRICH for ion-endcap, mRICH for e-endcap
- Low Momentum PID（< 2GeV/c): LGAD as ToF



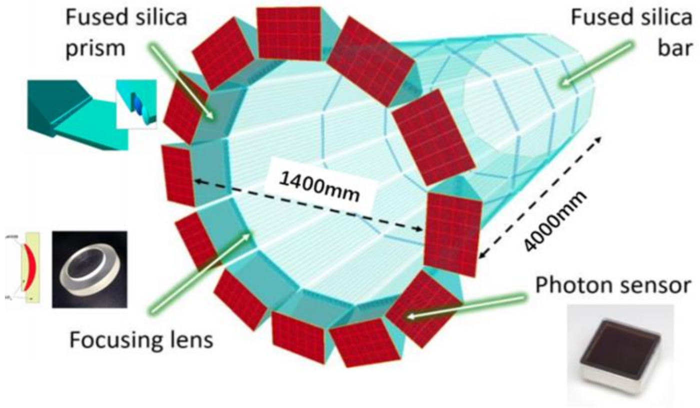
Barrel DIRC for PID

Detector of Internal Reflection Cherenkov lights (DIRC):

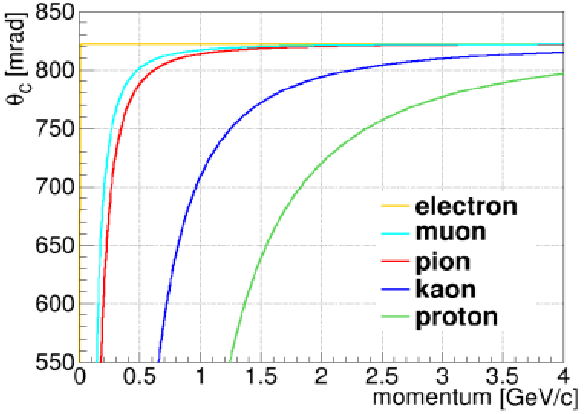
Different charged particles induce Cherenkov radiation with different Cherenkov angles, DIRC achieve PID through reconstructing their Cherenkov angles, by measuring the transit time and exit position/angle of Cherenkov photons induced by different particles.



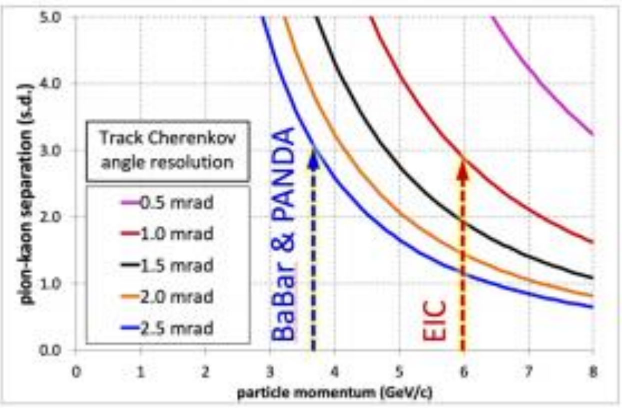
$\theta_c = \cos(1/n\beta)$



- 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



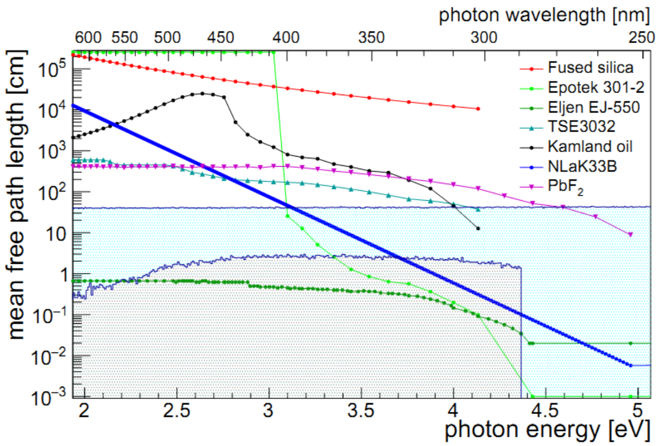
refractive index of synthetic fused silica **with n = 1.47**

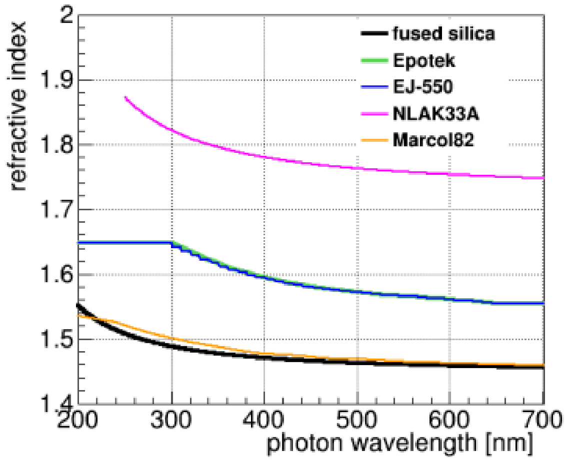


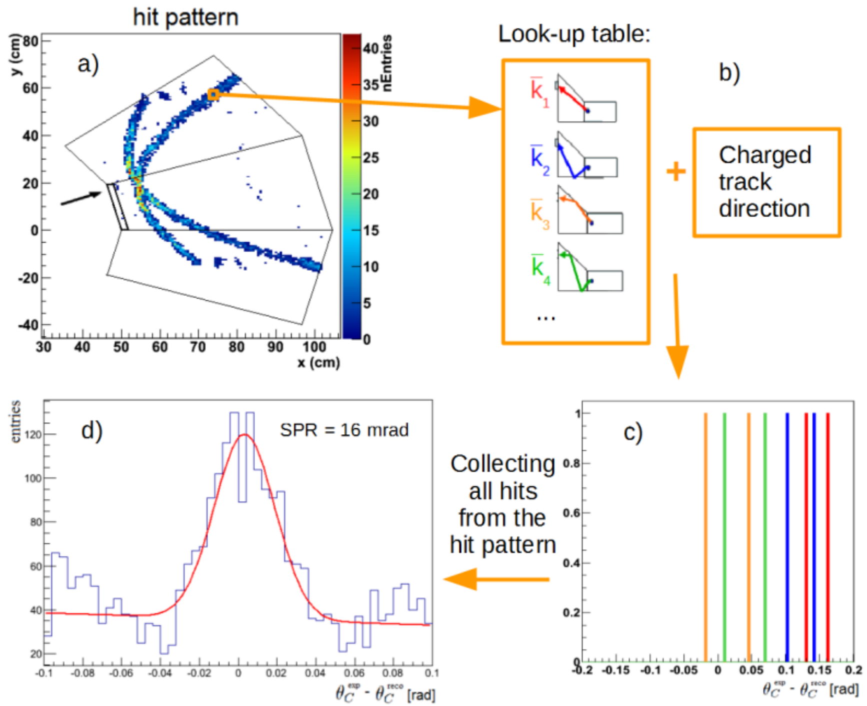
Reference from PANDA & EIC

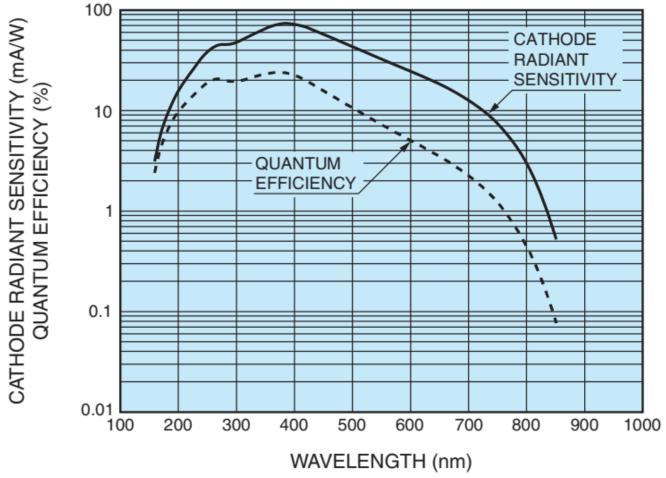
DIRC Simulation

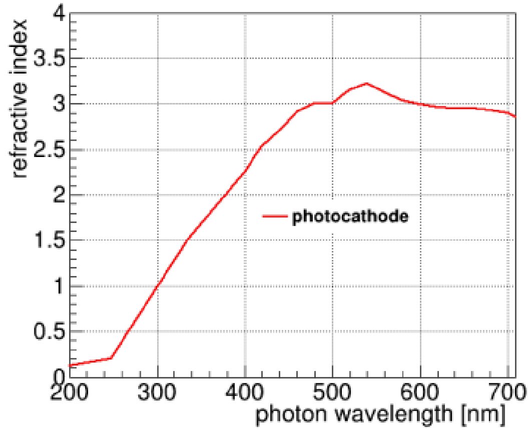
Simulation Input & process:







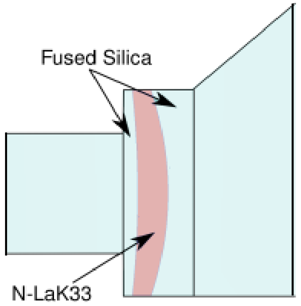


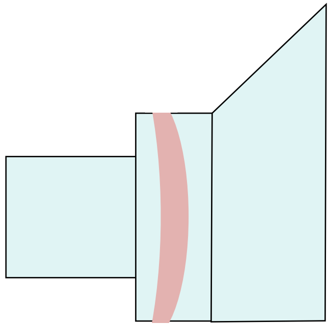


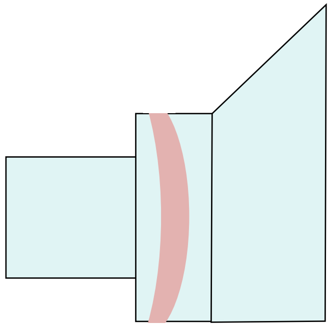
Reference from "Simulation, Reconstruction, and Design Optimization for the PANDA Barrel DIRC", 2016

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

Simulation on DIRC with different optical geometry



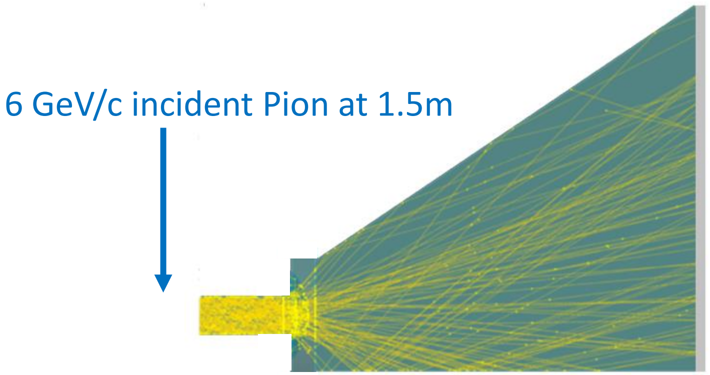




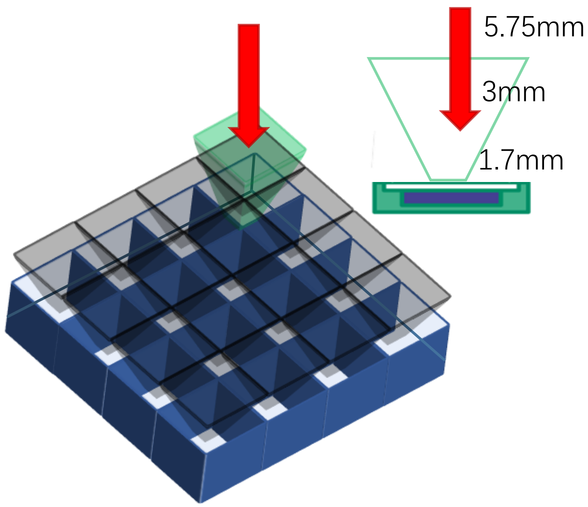
Optical Focus	Size (cm)	Photon number	SPE Angle resolution (mrad)
3-layer lens	40°, 30/7.5	15 ~ 60	10 ~ 12
3-layer lens	30°, 30/7.5	13 ~ 51	9 ~ 12
3-layer lens	25°, 30/7.5	11 ~ 48	7 ~ 11

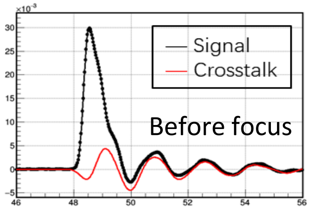
Radiator width	Photon number	SPE Angle resolution (mrad)
1.4cm	12 ~ 51	7 ~ 11
1.7cm	12 ~ 50	7 ~ 11
2.0cm	11 ~ 48	8 ~ 11
2.3cm	11 ~ 47	8 ~ 12
2.5cm	10 ~ 45	10 ~ 13

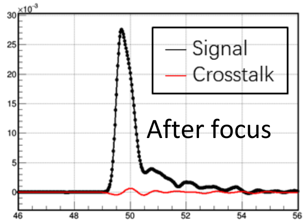
Radiator thickness	Photon number	SPE Angle resolution (mrad)
1cm	5 ~ 27	7 ~ 10
1.3cm	9 ~ 38	7 ~ 12
1.5cm	12 ~ 48	7 ~ 12
1.7cm	15 ~ 60	8 ~ 15
2cm	17 ~ 74	8 ~ 17

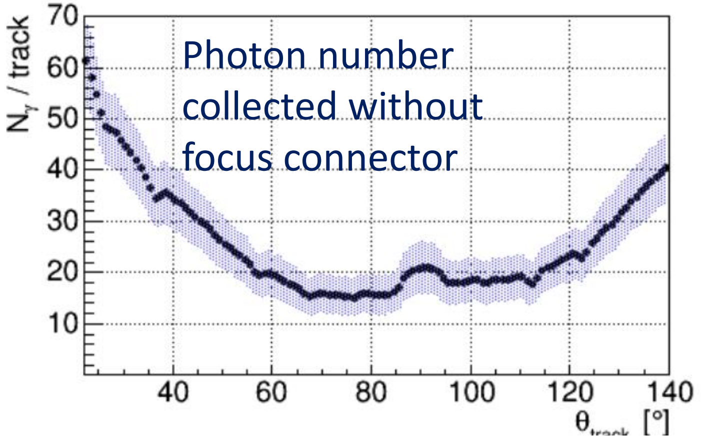


Simulation on DIRC w/o fucus connector

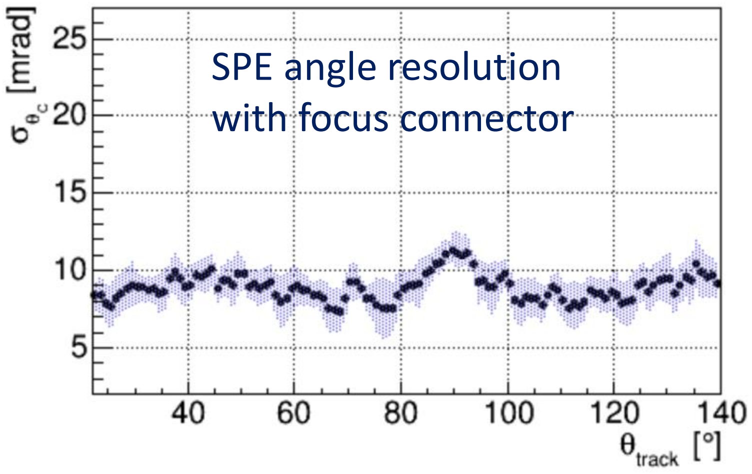


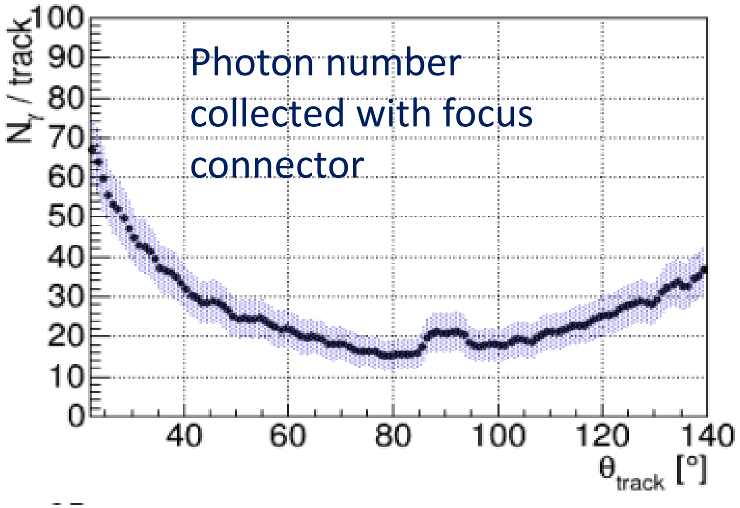






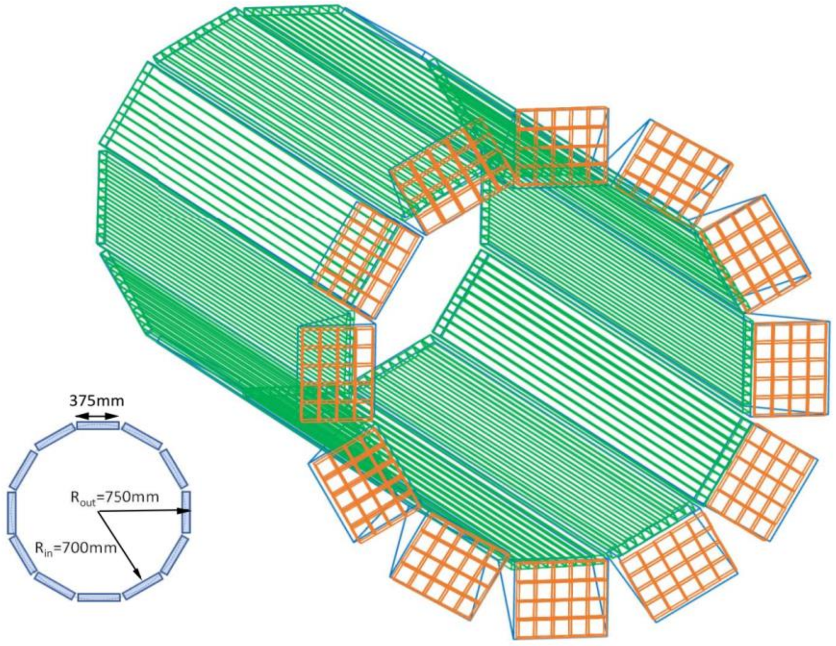
Optical Connector	Photon number	SPE Angle resolution (mrad)
None	14 ~ 62	9 ~ 12
3mm	16 ~ 68	6 ~ 10
5mm	16 ~ 66	7 ~ 11

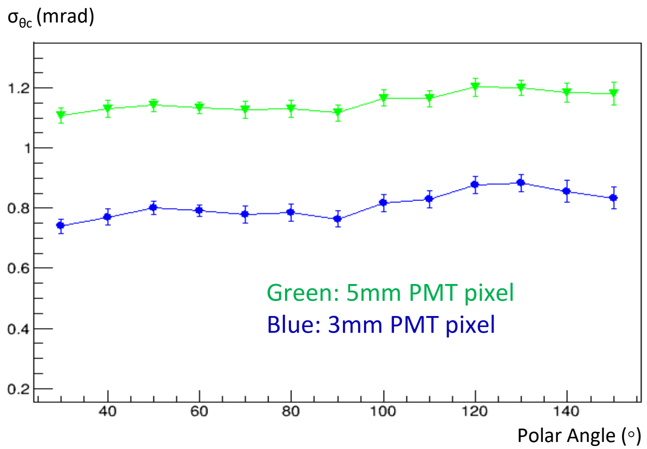


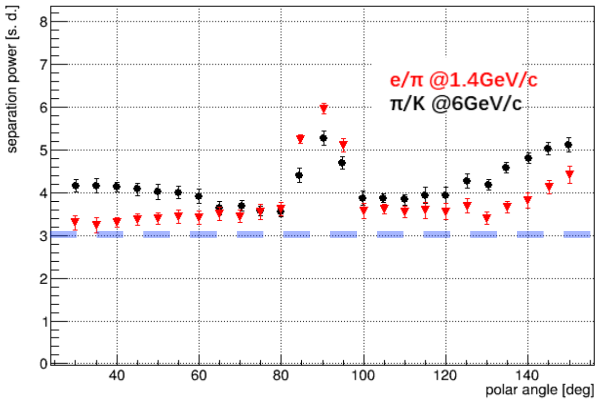


- Dead area caused by PMT frame: 10% - 20%, which can be eliminated by focusing light through light connector.
- Crosstalk occurs when the photons hit near the boundary of pixel units, and the crosstalk effect can be significantly reduced by focusing the light to the center of each pixel unit.

Barrel DIRC Concept Design







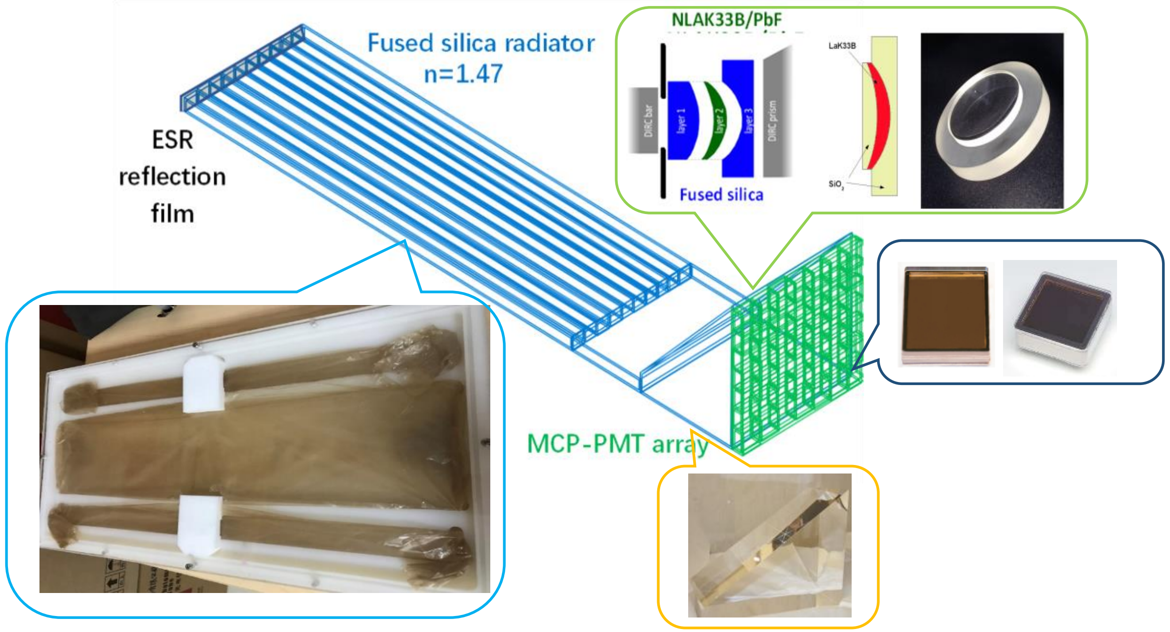
- Quartz radiator bar: 15mm x 17mm x 3300mm
- Expansion volume(EV): 208mm x 340mm x 300mm
- MCP-PMT: Hamamatsu R10754 (pixel size: 5.2mm x 5.2mm) or MCP under R&D at Xi'an Institute of Optics and Mechanics (pixel size: 3mm x 3mm)
- Tray box size: 50mm x 320mm x 4000mm with 6 bar+EV
- 12 trays forms a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

Definition of measured DIRC angular resolution:

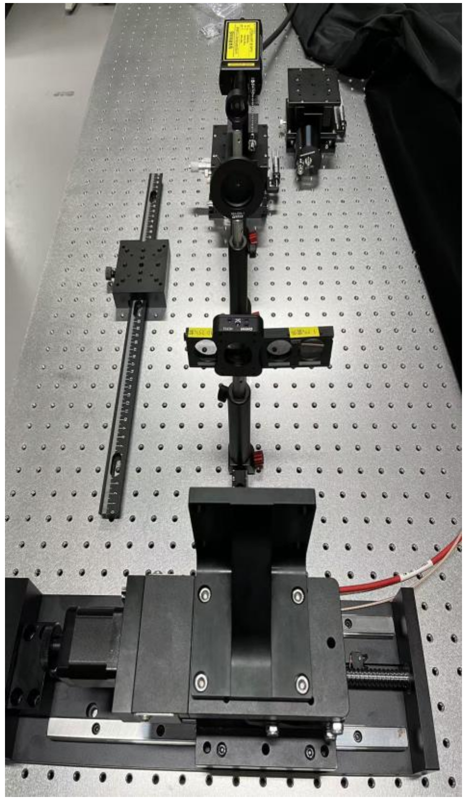
$$\sigma_{\theta_c}(\text{photo}) = \sqrt{\sigma_{chrom}^2 + \sigma_{foc}^2 + \sigma_{bar}^2 + \sigma_{trans}^2 + \sigma_{rec}^2}$$

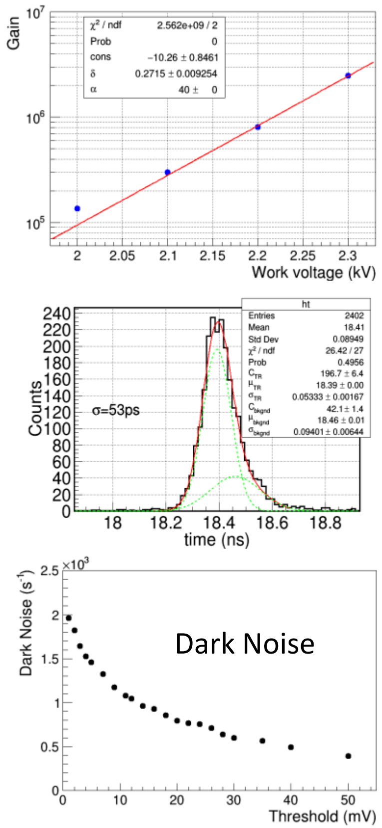
- σ_{chrom}: the dispersion contribution of the quartz radiator (wavelength: 300-700 nm)
- σ_{foc}: error from the optical focusing lens and the pixel size of photosensors
- σ_{bar}: the influence of radiator thickness (flatness) on photon yield and transmission efficiency;
- σ_{trans}: transit fluctuation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

DIRC prototype and test platform setup



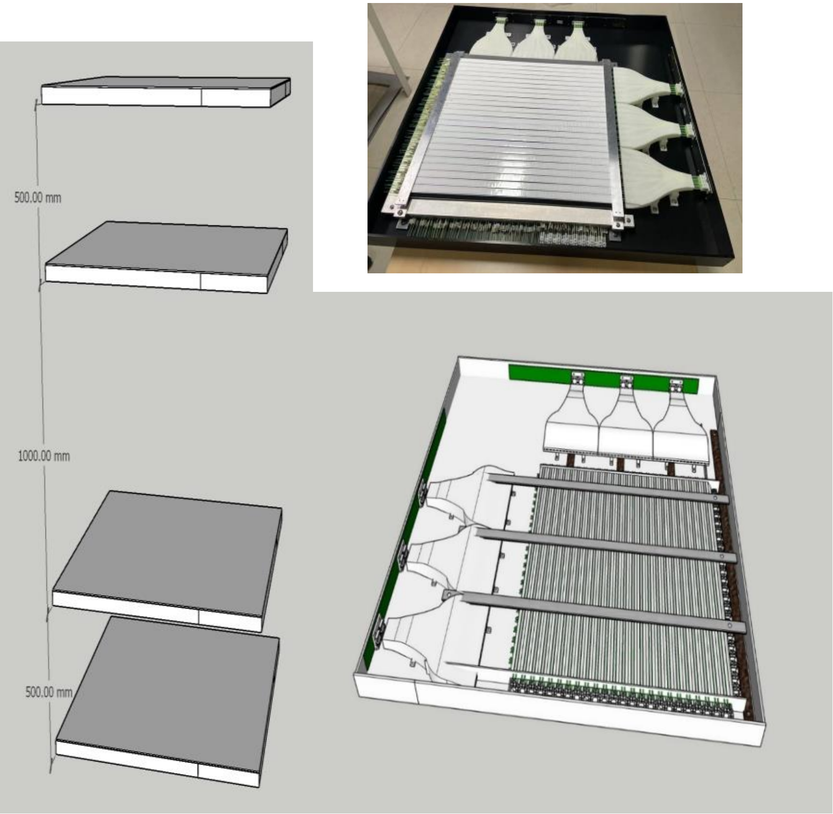
DIRC protype consisted of fused silica radiator (HERAEUS SUPRASIL) , optical focus system, and MCP-PMT array (transit time spread < 50ps, pixel size ~ 5mm, candidate: Hamamastu R10754, NVT N6021).

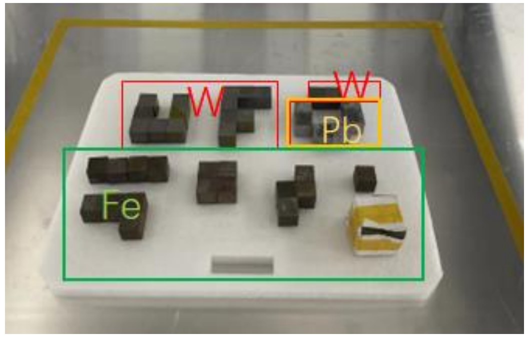


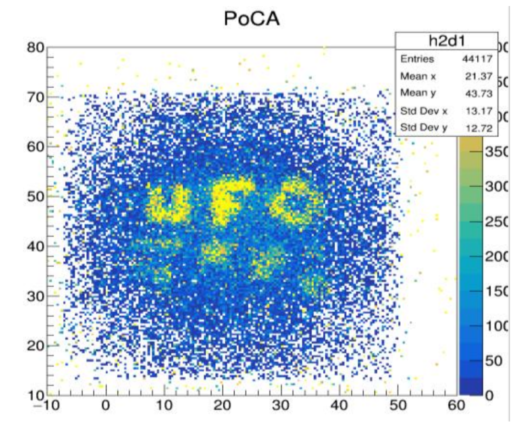


An Optoelectronic test platform with laser source to conduct performance tests on MCP-PMT candidates, including signal gain, transit time fluctuations, dark noise, etc

Cosmic ray test platform setup







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

- 4 layers, size of 55cm x 55cm, each layer composed of 8 modules (each 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.

Summary & Outlook

- The simulation results show that hpDIRC can achieve the 3σ π/K separation power required by EicC. Table below shows the expected performance of the barrel hpDIRC module based on the simulation and PANDA test data.

- It is worth noting that the simulation analysis did not include the effect of magnetic field. On the other hand, the reconstruction algorithm does not utilize the information from external tracker layers to reduce the impact of multiple scattering, especially for lower momentum particles. These will be done in further sophisticated detector simulations.

- Further improvement of angular resolution requires more detailed study, including simulation and cosmic ray test, and image reconstruction method based on artificial intelligence algorithms

Chromatic dispersion of quartz radiator	Optical focusing lens and MCP-PMT pixel size	Thickness & width of quartz radiator	Surface properties of quartz radiator	Angle of the incident particles and image reconstruction
σ_{chrom}~5.4mrad	σ_{foc}<10mrad	$\sigma_{bar}\leq$2mrad	$\sigma_{trans}\leq$3mrad	$\sigma_{rec}\leq$1mrad

Thank you!