The simulation of DIRC detector at the Electron-ion collider in China

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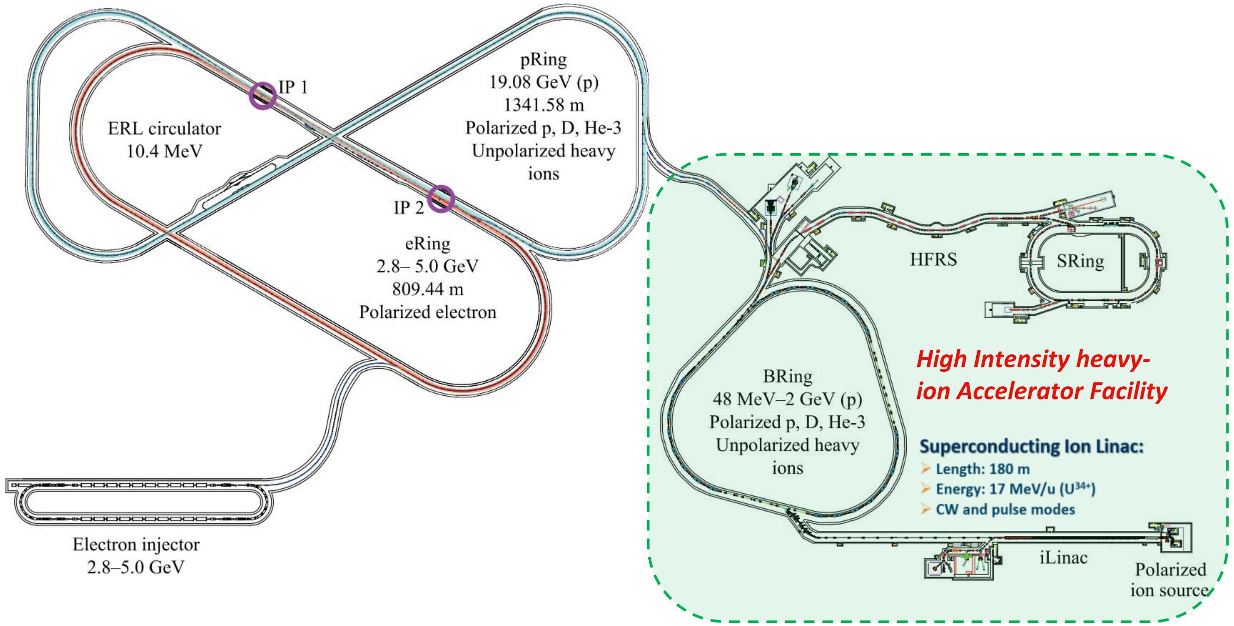
Outline

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

Introduction on EicC

- As a future high energy nuclear physics project, the 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 a high luminosity of (2–3) × 10^{33} $cm^{-2} \cdot s^{-1}$.
- The main focus of the EicC will be precise measurements of the nucleon structure 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

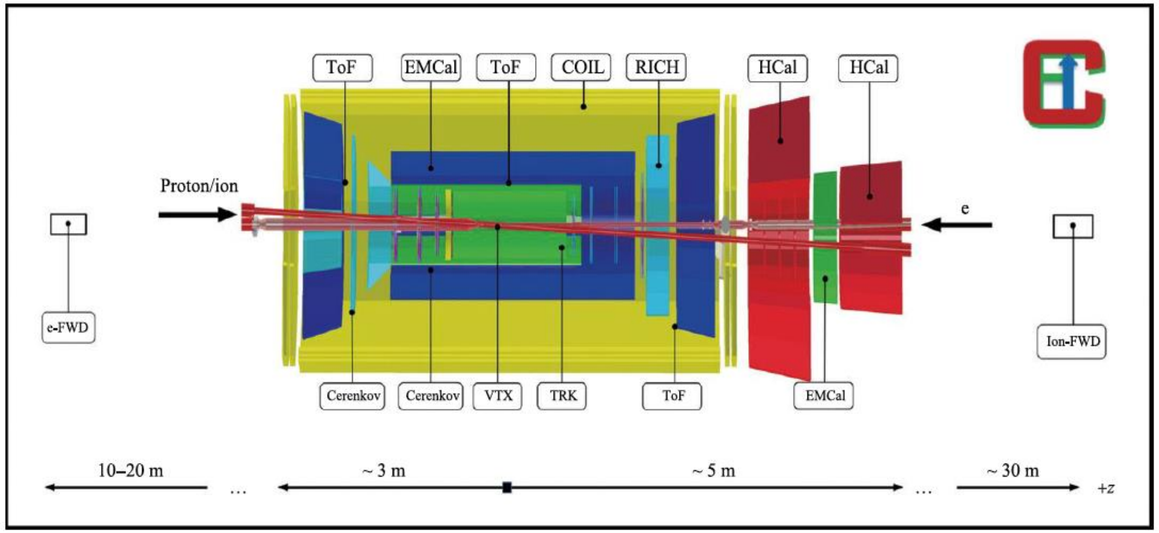
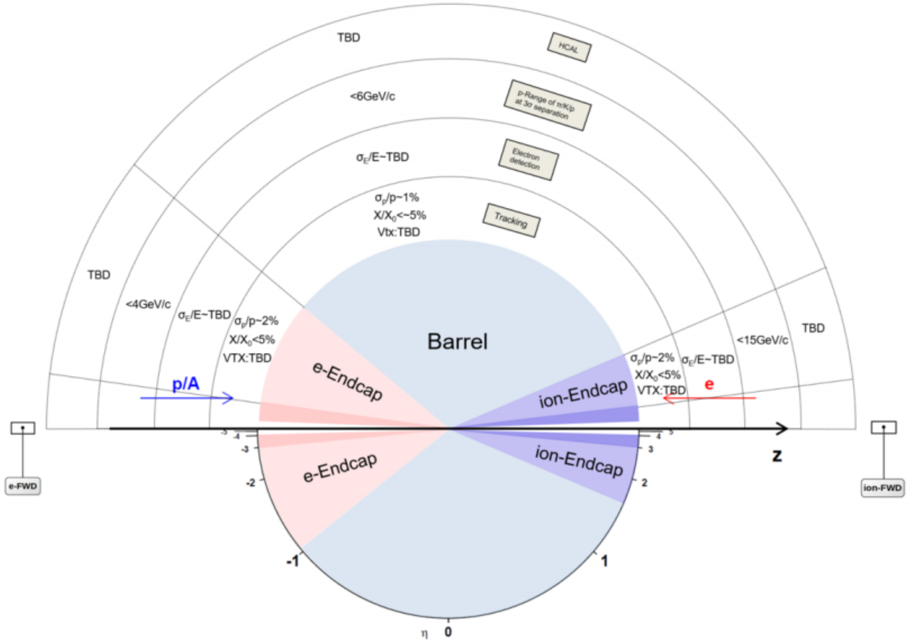


Fig. 4.10 Conceptual design of the EicC detector.



➢ Sub detectors to realize the EicC physics goals:

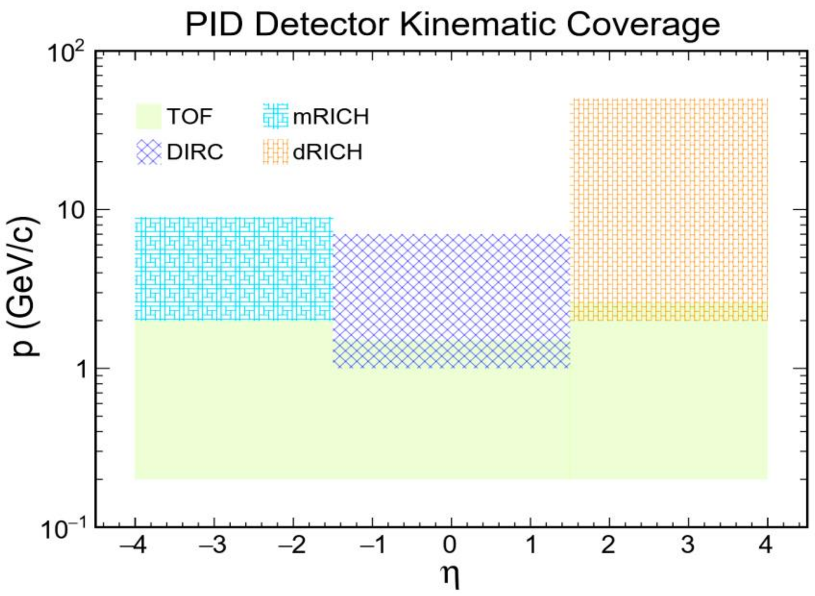
1) Vertex & tracking detectors
2) PID detectors
3) Calorimeters
4) Far Forward detectors
5) Luminosity monitor & Polarimetry
6) DAQ

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

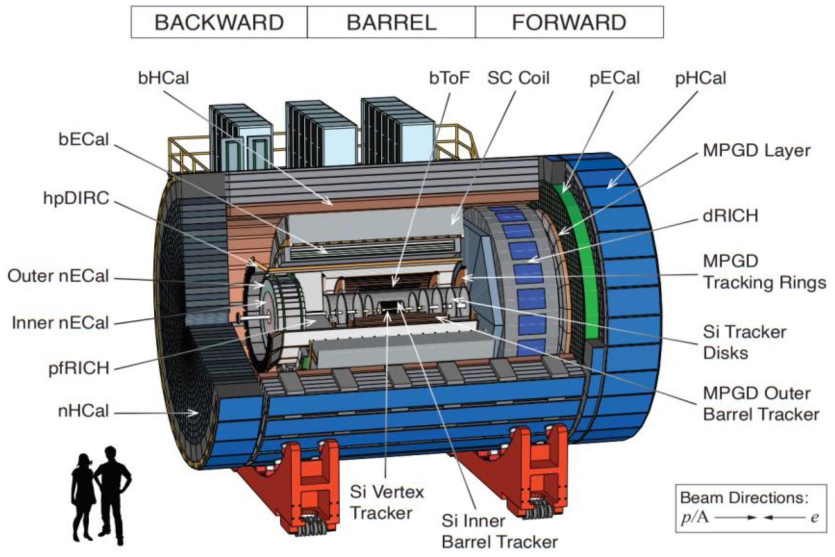
Detector Requirements for PIDs

- Fast response and ultra-high resolution
- Compact structure and radiation resistant
- PID power with large momentum coverage:
  ≤ 5 GeV/c at e-Endcap;
  ≤ 15 GeV/c at ion-Endcap ;
  ≤ 6 GeV/c at Barrel.



PID detectors:

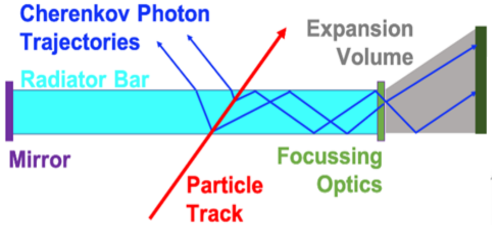
- Barrel PID: High performance Detector of Internal Reflection Cherenkov lights（hpDIRC）
- Endcap PID: Ring Imaging Cherenkov (RICH) detectors, pfRICH for ion-endcap, dRICH for e-endcap
- Low Momentum PID（< 2GeV/c): MPRC, LGAD

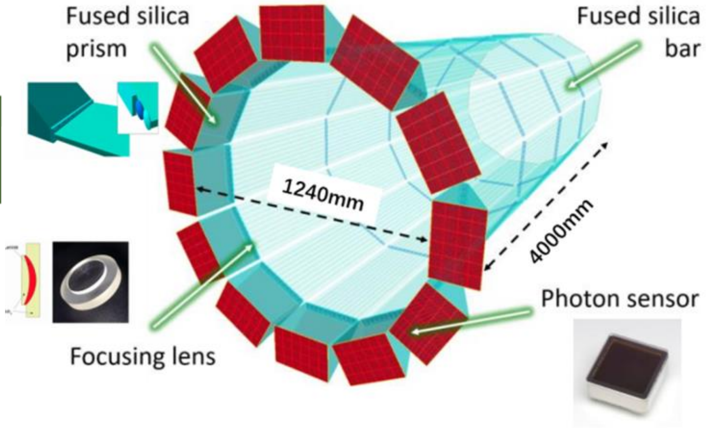


Barrel DIRC for PID

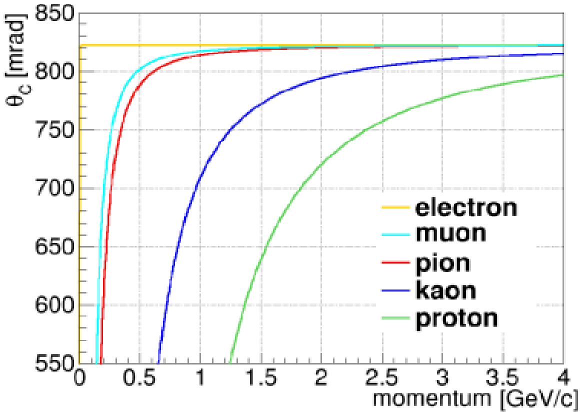
Detector of Internal Reflection Cherenkov lights (DIRC):

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.

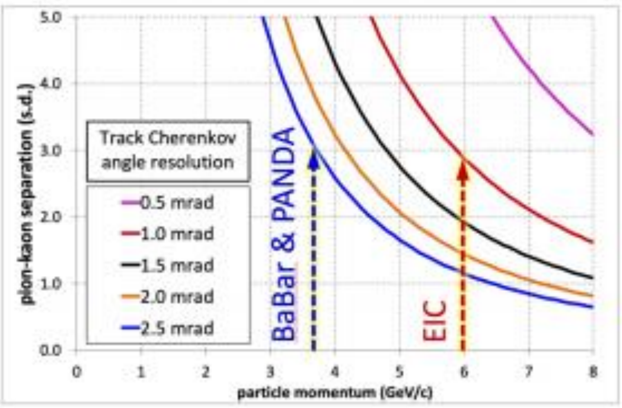




- ➢ Consisted of fused silica(n=1.47) as Cherenkov radiator and MCP-PMTs as photosensor array
- ➢ Compact structure as barrel detector
- ➢ Achieve 3σ π/K separation up to 6 GeV/c with angle resolution ~ 1mrad

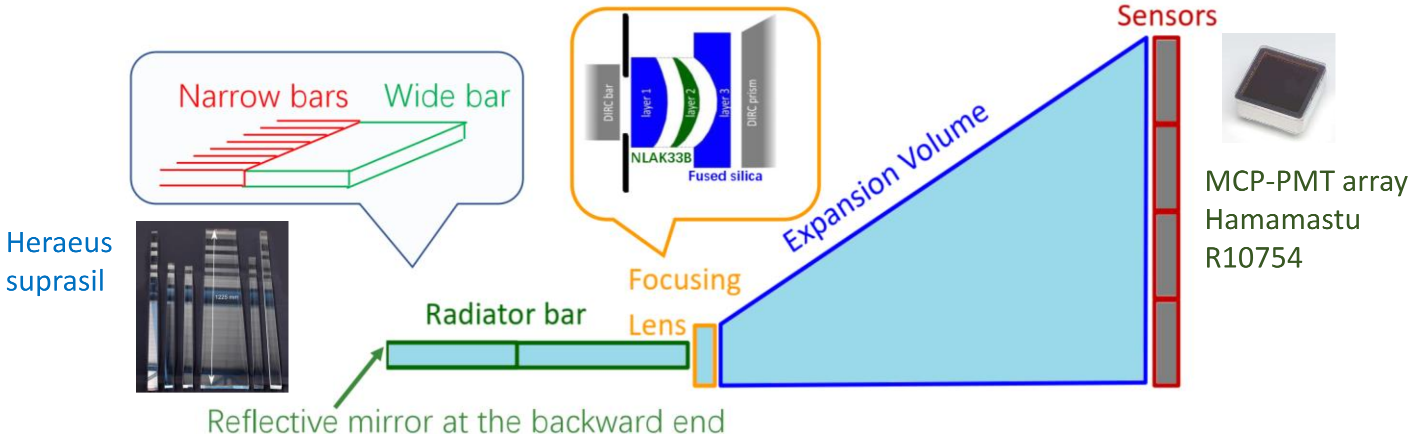


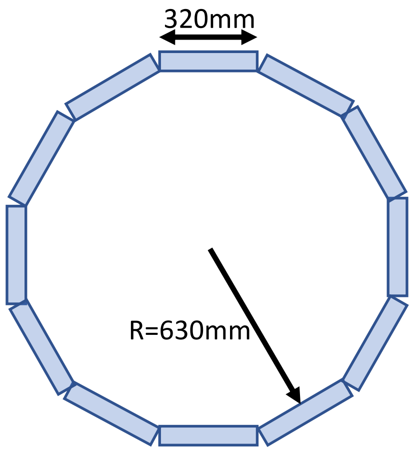
refractive index of synthetic fused silica **with n = 1.47**



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

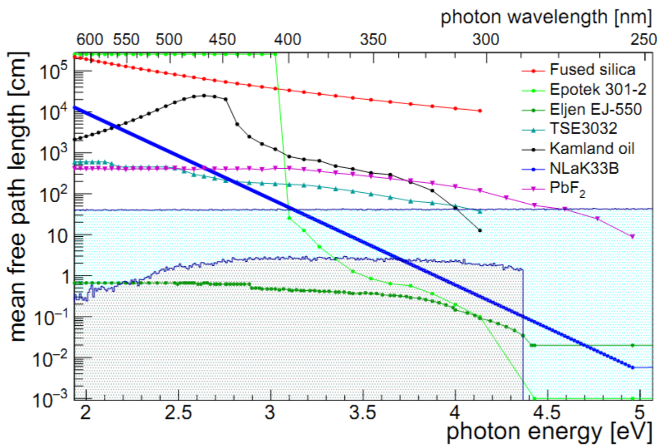
Definition of measured DIRC angular resolution:

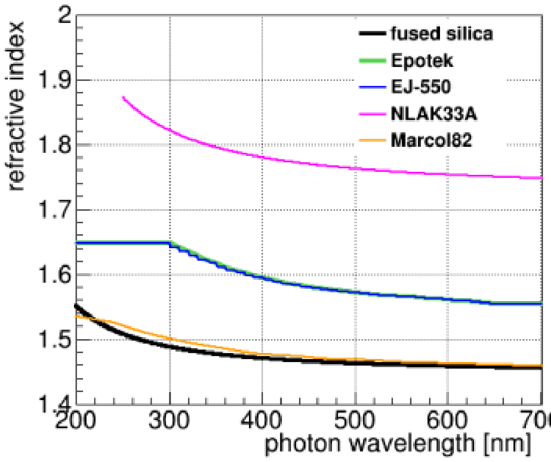
$$\sigma_{\theta_c}(\text{photo}) = \sqrt{\sigma_{chrom}^2 + \sigma_{foc}^2 + \sigma_{bar}^2 + \sigma_{trans}^2 + \sigma_{rec}^2}$$

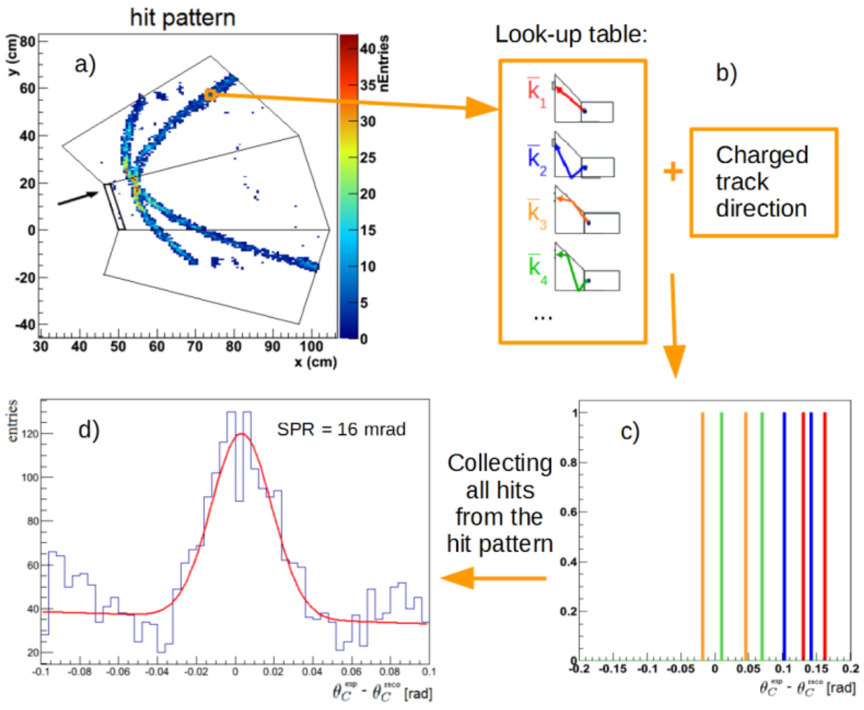
- σ_{chrom}~5.4mrad, is the dispersion contribution of the quartz radiator (wavelength: 300-700 nm)
- σ_{foc}: error from the optical focusing lens and the pixel size of photosensors
- σ_{bar}: the influence of radiator thickness (flatness) on photon yield and transmission efficiency;
- σ_{trans}: transit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

DIRC Simulation

Simulation Input & process:

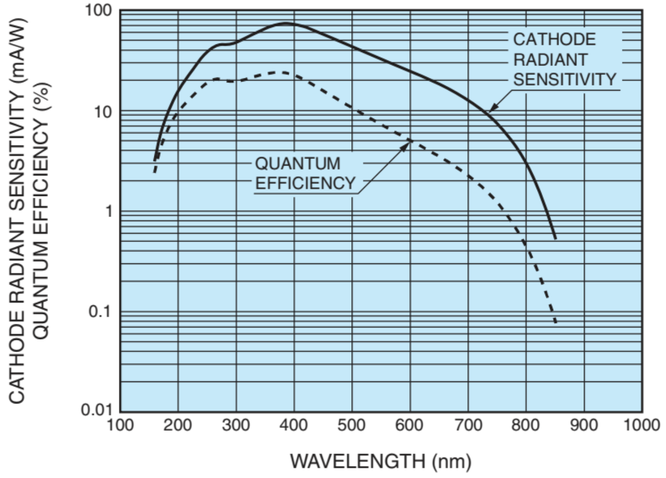


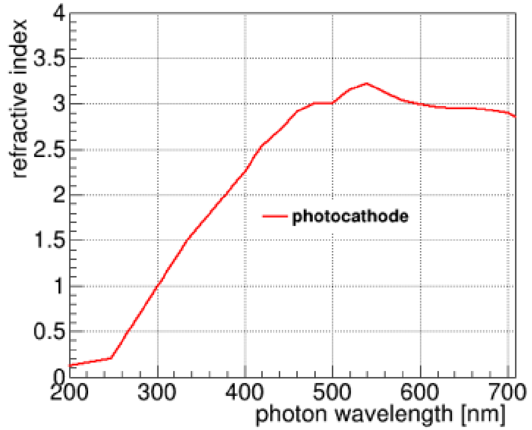




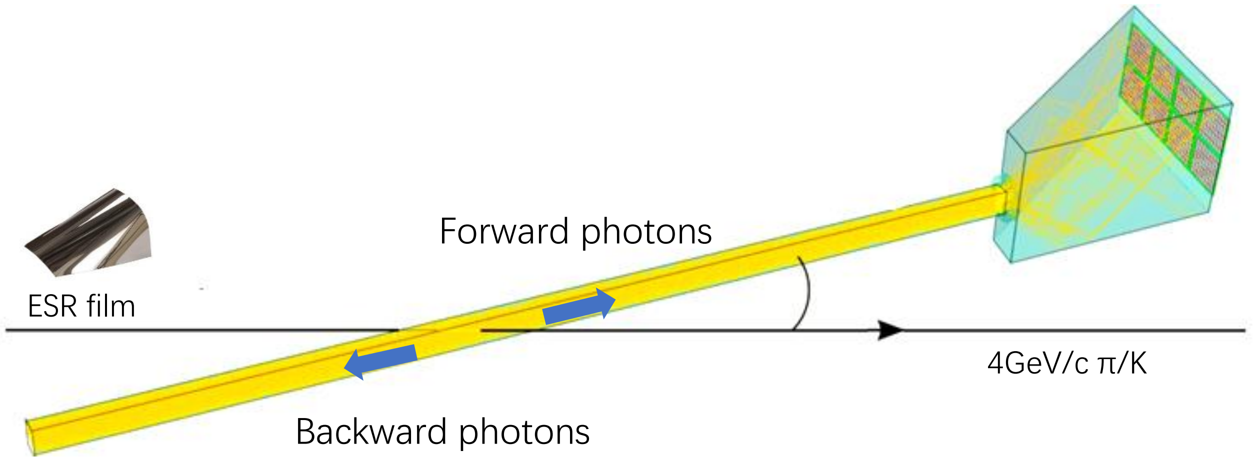
Reference from "Simulation, Reconstruction, and Design Optimization for the PANDA Barrel DIRC", 2016

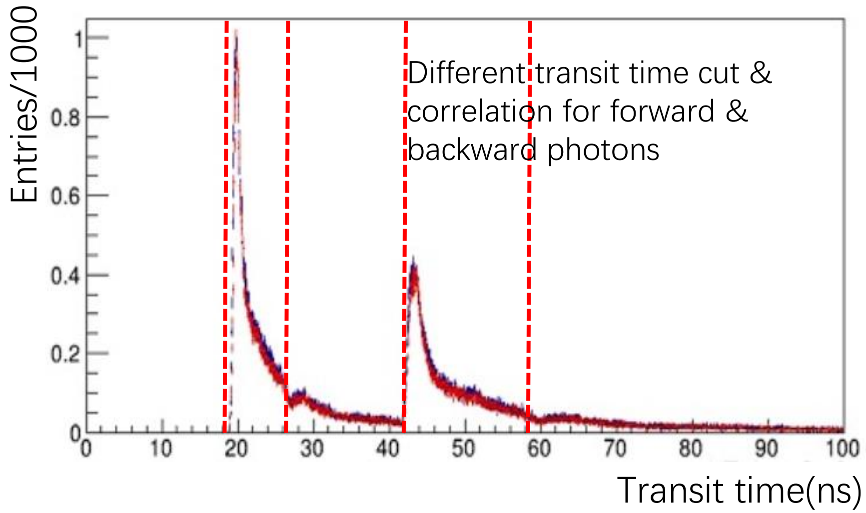
Wavelength [nm]	Bulk transmission [1/m]	# faces	Reflection coefficient	Surface roughness [Å]
406	$0.994 \pm 3.2 \cdot 10^{-4}$	49	$0.99984 \pm 1.6 \cdot 10^{-5}$	4.9 ± 1.3
532	$0.997 \pm 2.7 \cdot 10^{-4}$	49	$0.99991 \pm 1.4 \cdot 10^{-5}$	4.7 ± 1.3
635	$0.9994 \pm 8.0 \cdot 10^{-5}$	49	$0.99996 \pm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

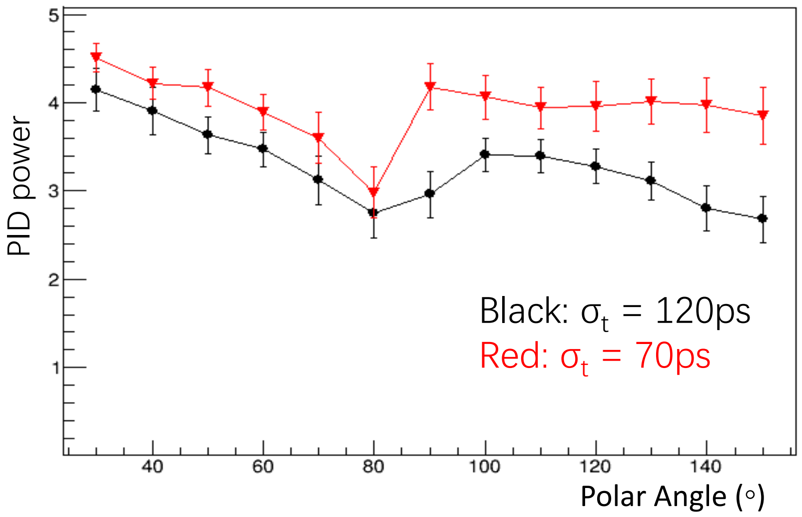


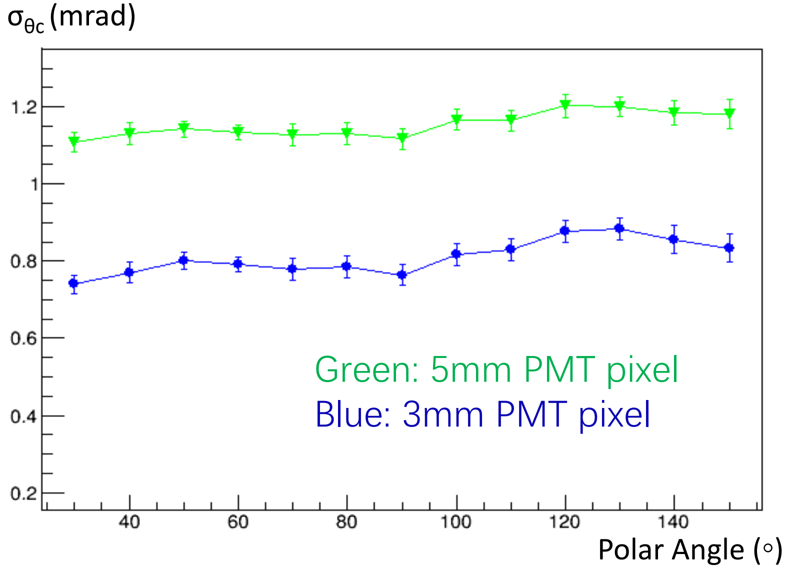


Simulated DIRC performance







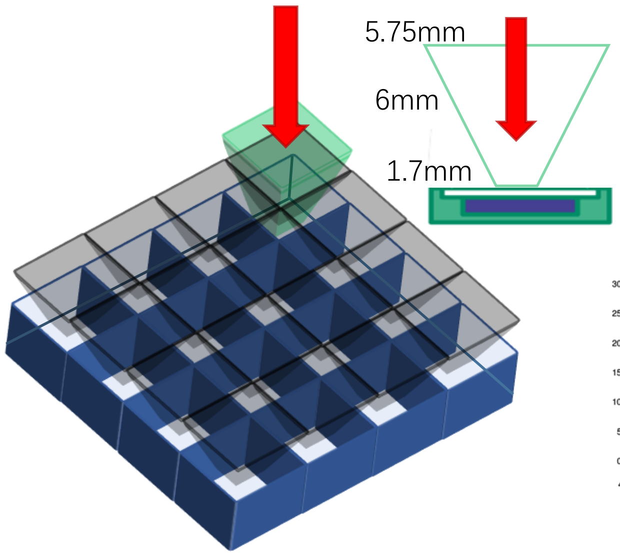


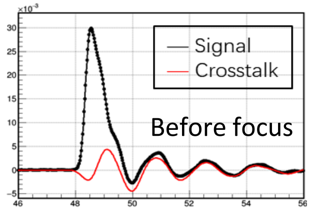
Up: separate transmission time cut for forward and backward photons

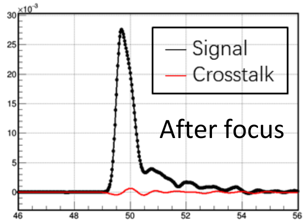
Low: Influence of PMT on DIRC PID performance

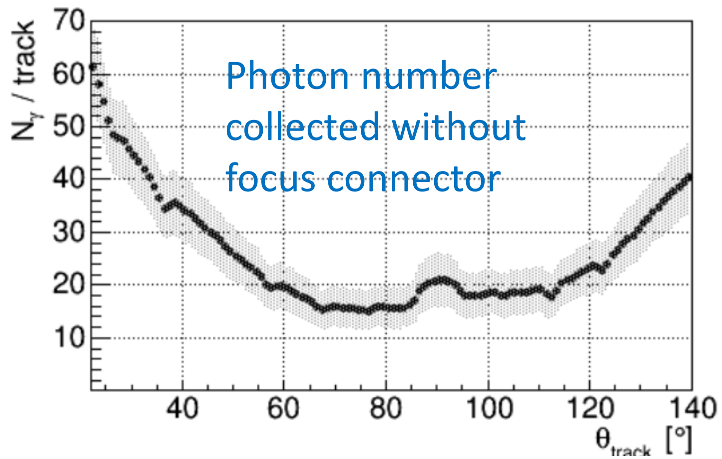
- Right: DIRC angular resolution for PMTs with different pixel size (3mm/5mm);
- Left: 6 GeV/c π/k separation power versus PMTs with different time resolution at angular resolution ~1mrad.

Simulation on DIRC w/o focus connector

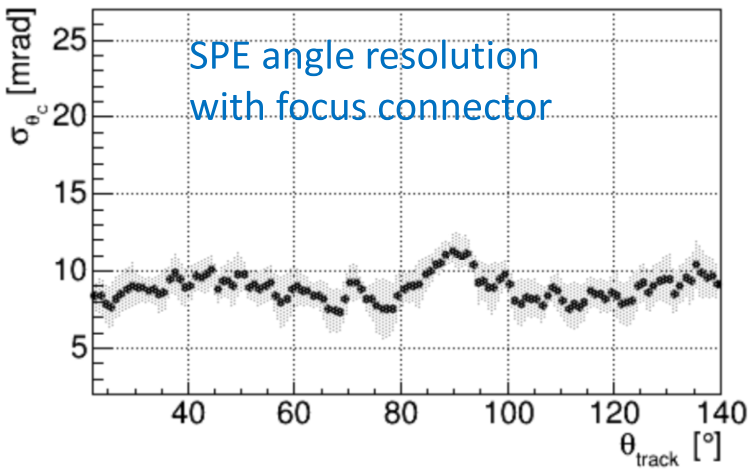


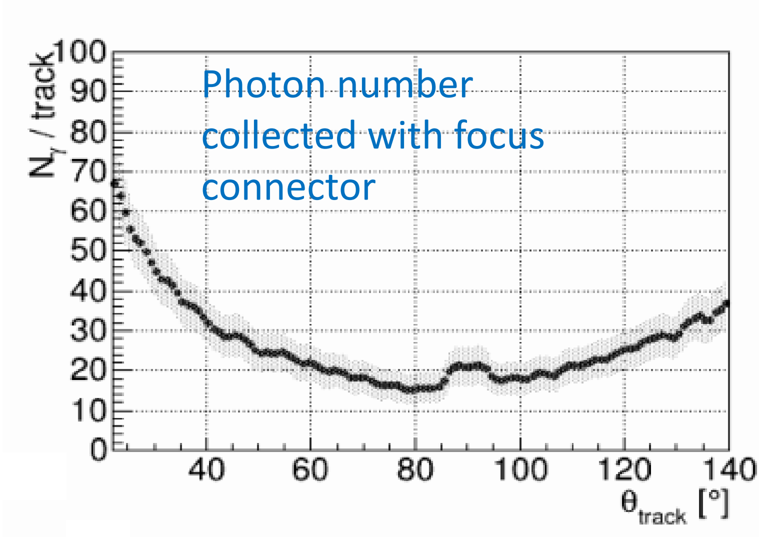






Optical Connector	Photon number	SPE Angle resolution (mrad)
None	14 ~ 62	9 ~ 12
6mm	16 ~ 68	6 ~ 10
8mm	16 ~ 66	7 ~ 11



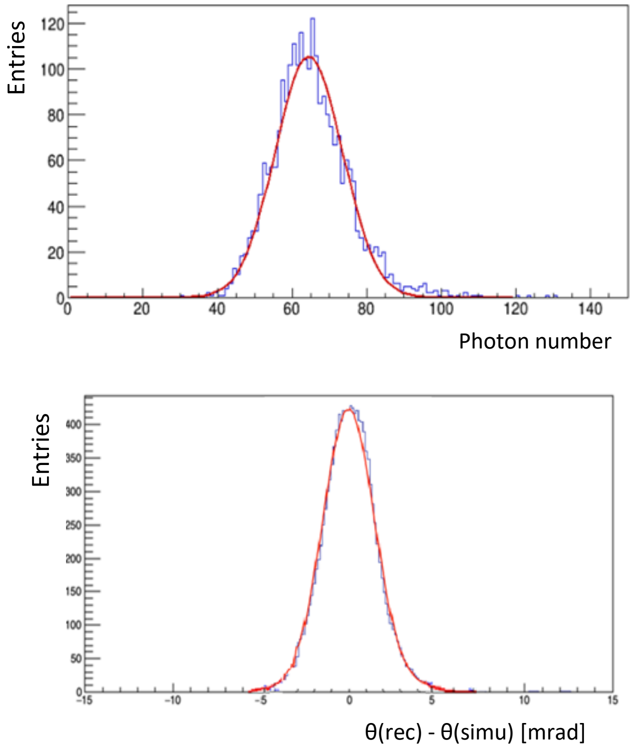


- Dead area caused by PMT frame: 10% - 20%, which can be eliminated by focusing light through focus connector.
- Crosstalk occurs when the photons hit near the boundary of pixel units, and the crosstalk effect can be significantly reduced by focusing the light to the center of each pixel unit.

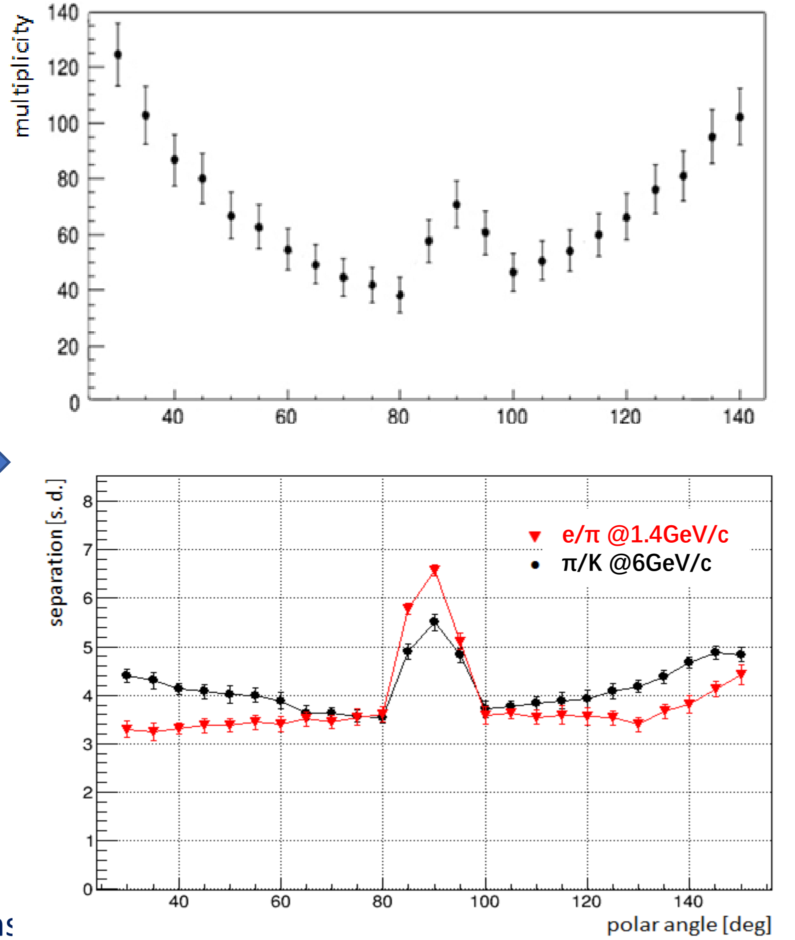
Optimized DIRC performance in simulation

The simulation shows that hpDIRC's PID performance can meet the 3σ (s.d.) π/K separation required by EicC.

Within the measurable polar angle range, the PID coverage of π/K can reach above 6 GeV/c, while e/π can reach 1.4 GeV/c.



Average number distribution of collected photons (65.2/track)and reconstructed angular resolution (θc = 1.67 mrad) for 6GeV/c pion at 50 deg



The average number of collected photons and the estimated PID power versus charged particles' incidence angle

Summary & Outlook

- The simulation results show that hpDIRC can achieve the 3σ π/K separation power required by EicC. Table below shows the expected error contributions 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, and the resolution of incident tracking is simply assumed to be 1mrad. These will be done in further simulations.

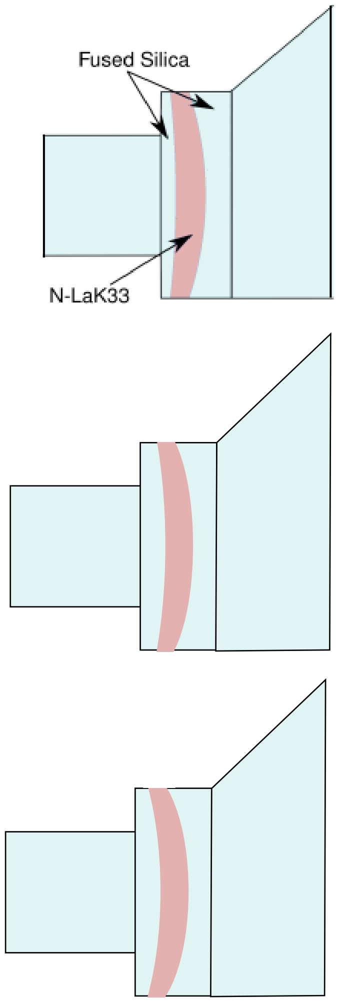
- Further improvement of hpDIRC's optical geometry and image reconstruction method based on artificial intelligence algorithms and cosmic ray tests.

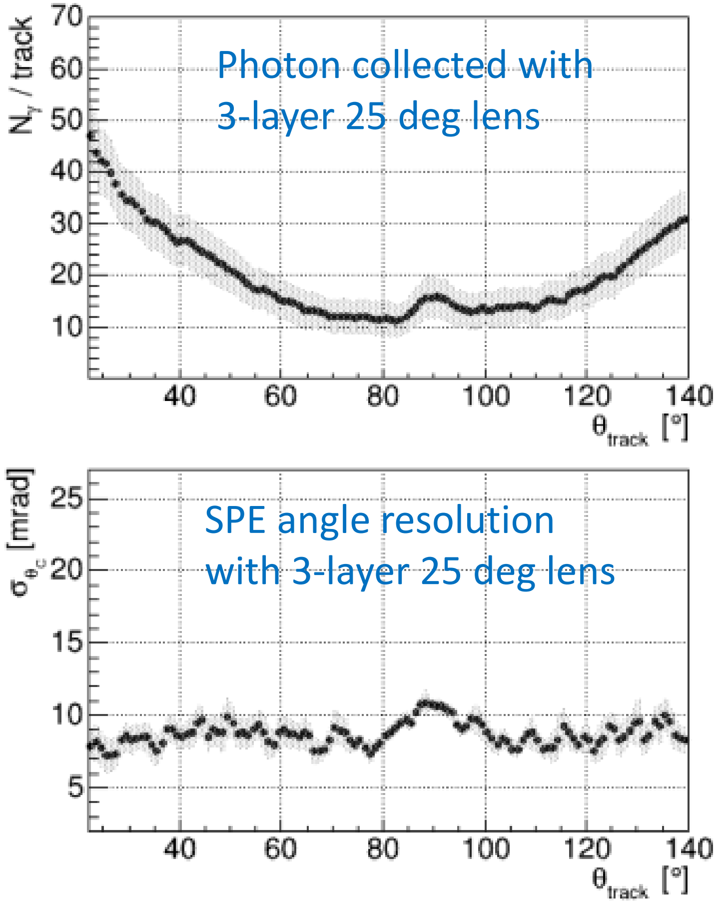
Chromatic dispersion of quartz radiator	Optical focusing lens and MCP-PMT pixel size	Thickness & width of quartz radiator	Surface properties of quartz radiator	Angle of the incident particles and image reconstruction
σ_{chrom}~5.4mrad	σ_{foc}<10mrad	$\sigma_{bar}\leq$2mrad	$\sigma_{trans}\leq$3mrad	$\sigma_{rec}\leq$1mrad

Thank you!

Backup Slide

Simulation on DIRC with different focusing lenses





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

6 GeV/c incident Pion at 1.5m