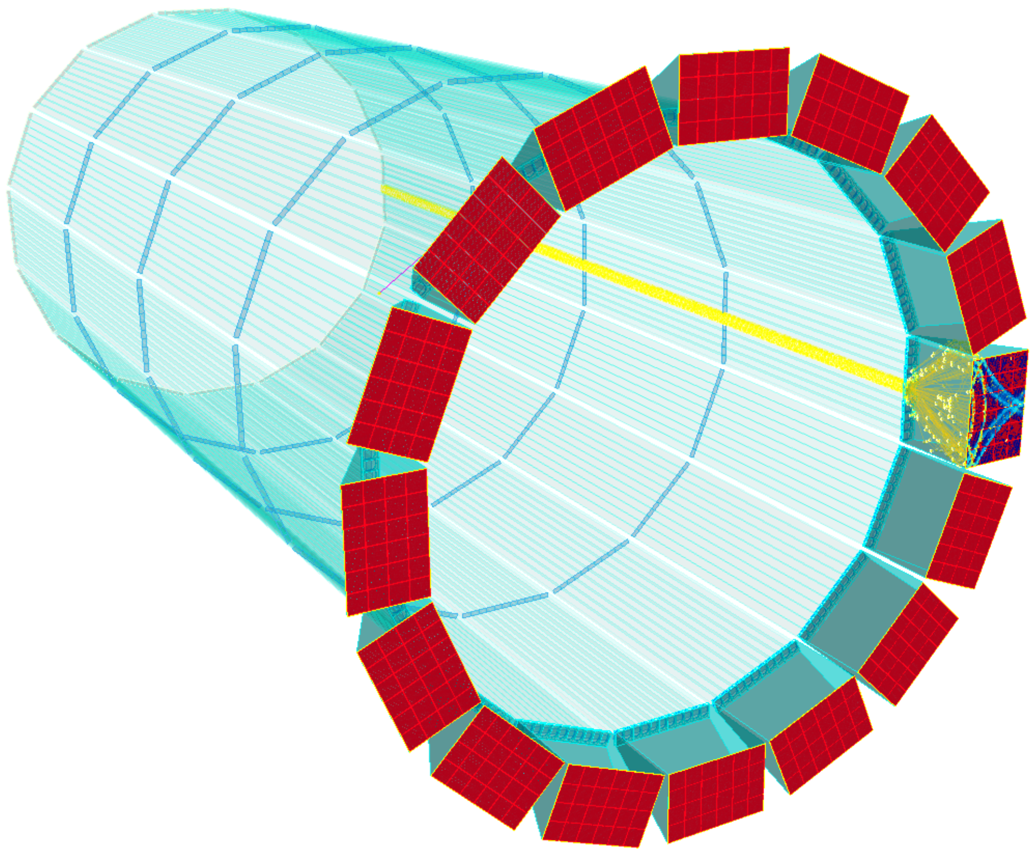
High-performance DIRC detector for the future Electron-Ion Collider



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EIC early career workshop

07/29/2021

Introduction

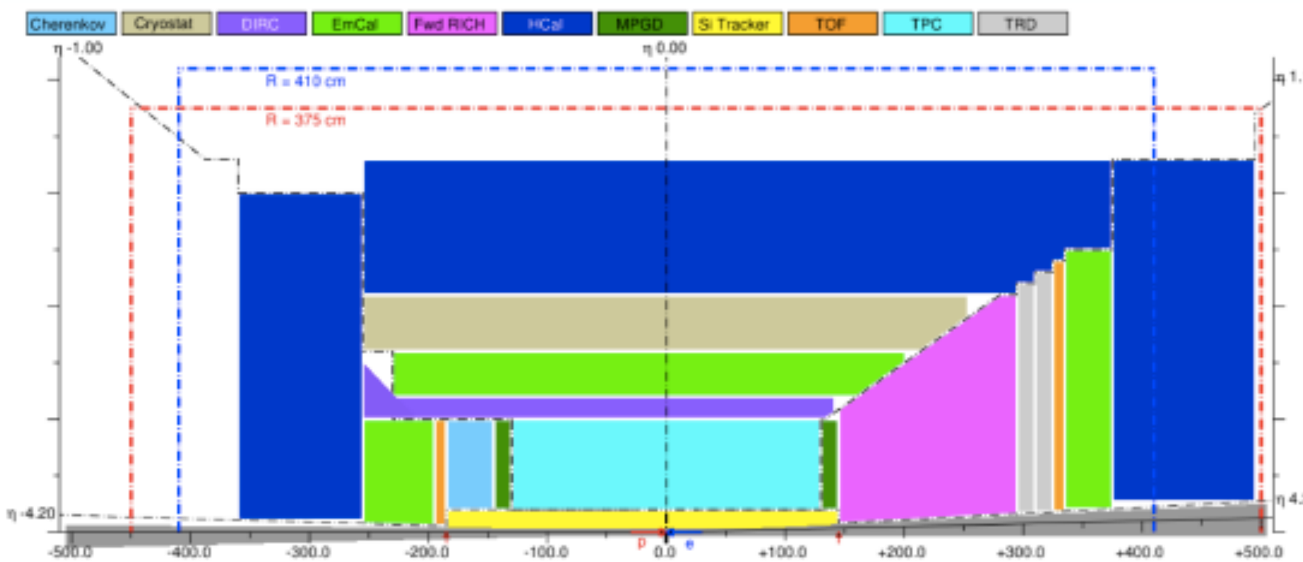
- **The EIC physics require a hermetic detector with collection of sub detectors that allows precise measurement and identification of particles**

- **The collision kinematics are very asymmetric, requiring different technologies in different parts of the detector**

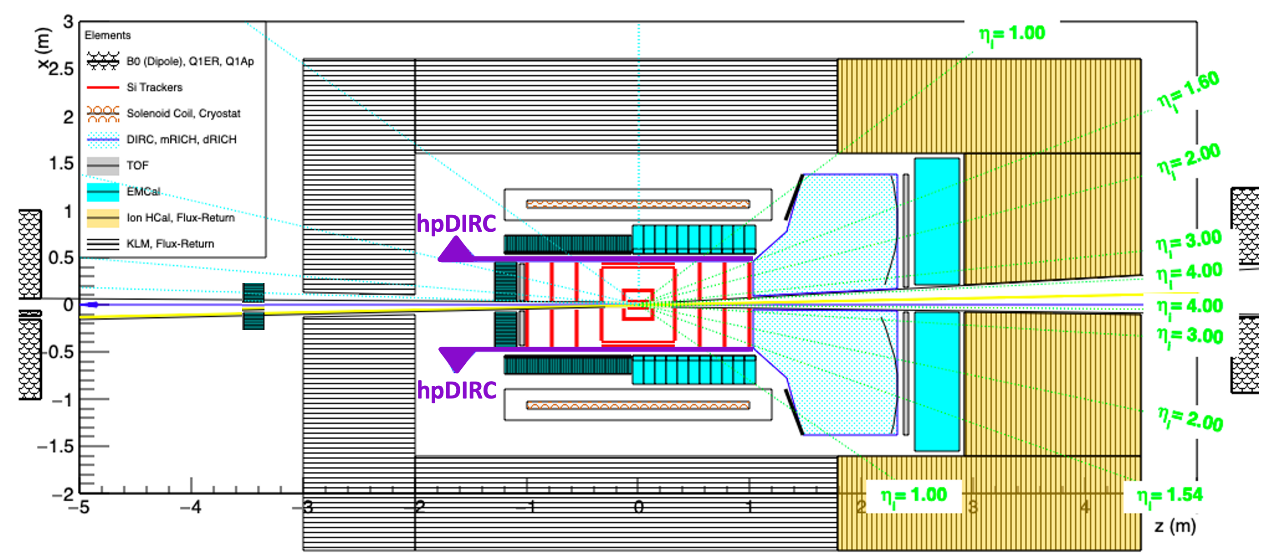
- **Limited space in the barrel region needs a compact option for PID**

- **All current detector concepts consider hpDIRC as PID system for barrel section**

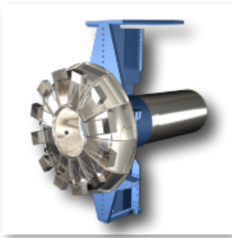
Yellow Report “Reference Detector”

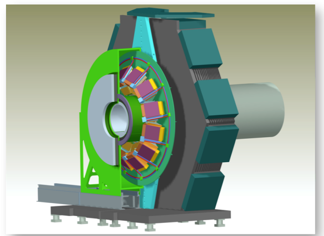


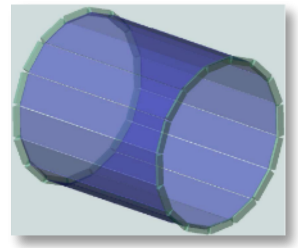
COmpact detectoR for Eic (CORE)

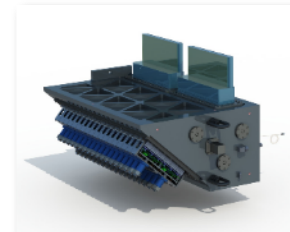


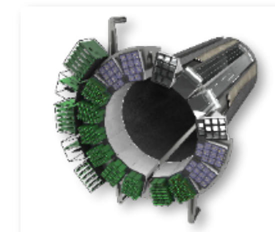
DIRC (Detection of Internally Reflected Cherenkov Light)

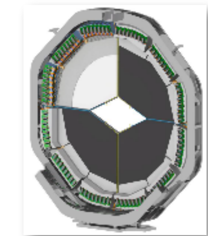


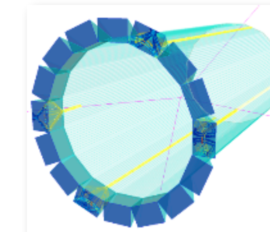


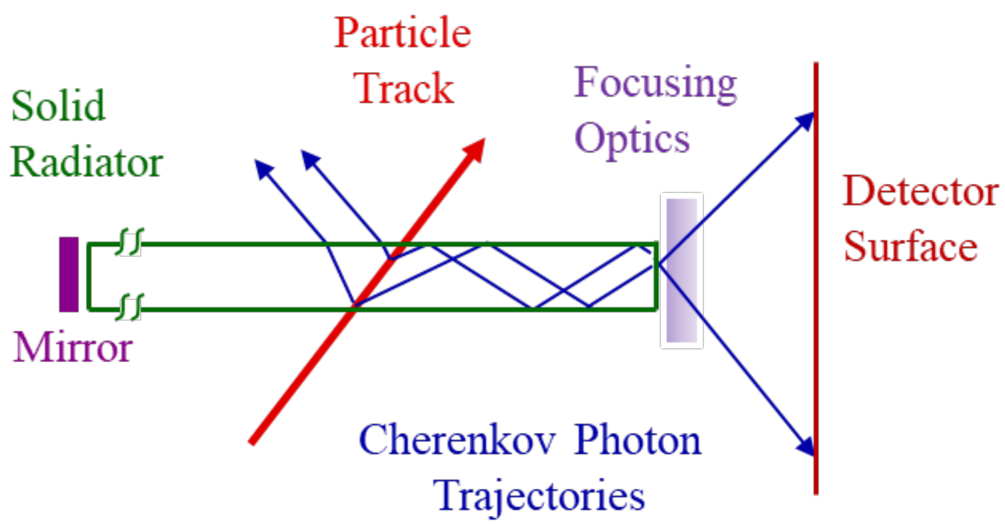


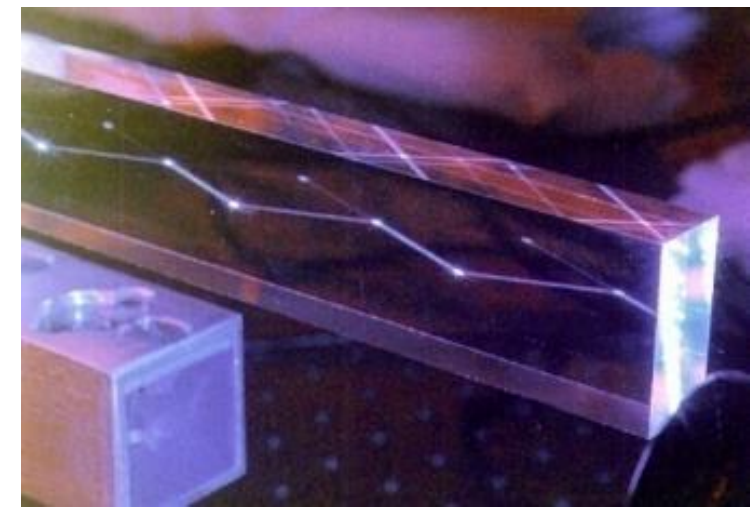












- Pioneered by the BaBar experiment at SLAC
- Synthetic fused silica solid bars act as radiators and light guides
- Cherenkov angle of photons conserved during total internal reflections in the bar
- Mirror to reflect photons originally propagated away from the readout detector
- Photons are focused onto an array of readout sensors
- Readout sensors provide measuring position (x, y) and arrival time of photons

Detection of Internally Reflected Cherenkov Light

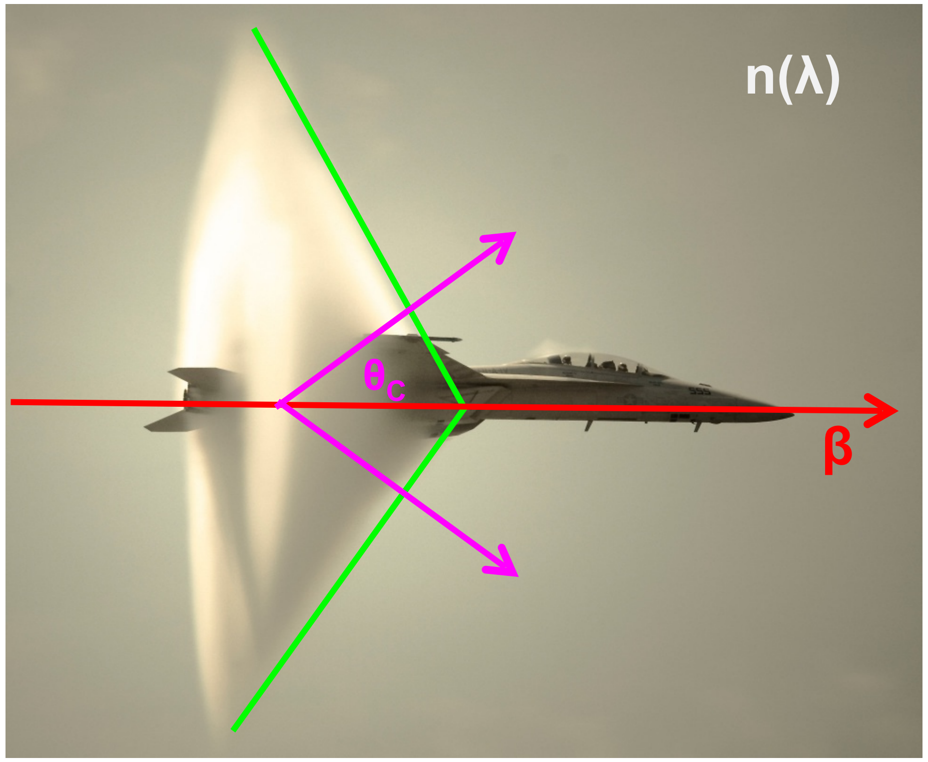
- Generated by charged particles traveling faster than the light in that medium
- Photons will be on a cone with half opening angle θ_c (Cherenkov angle)

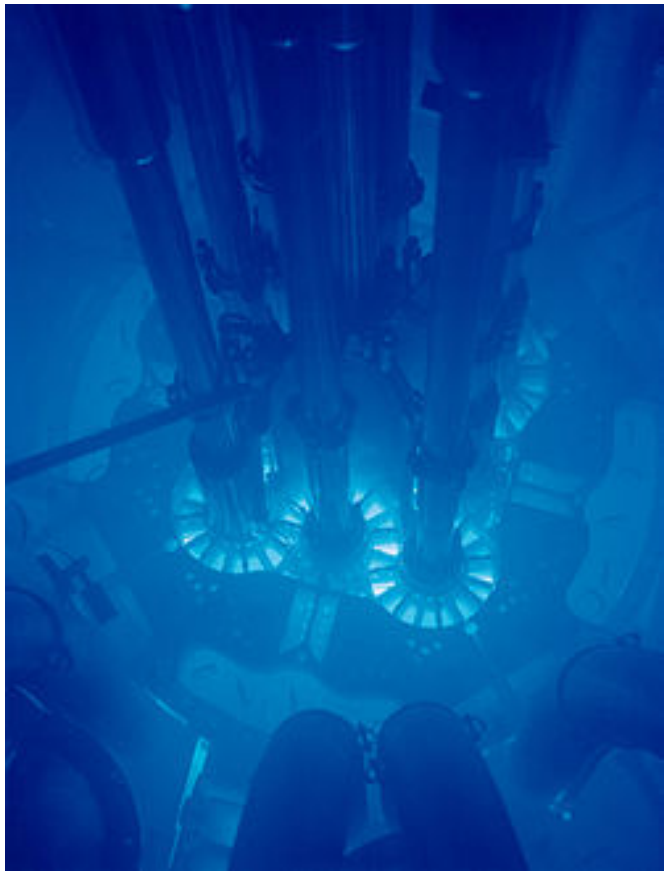
$$\cos\theta_C = \frac{1}{n(\lambda)\beta}$$

$$\beta = v/c$$

n - refractive index of the medium (function of wavelength λ)

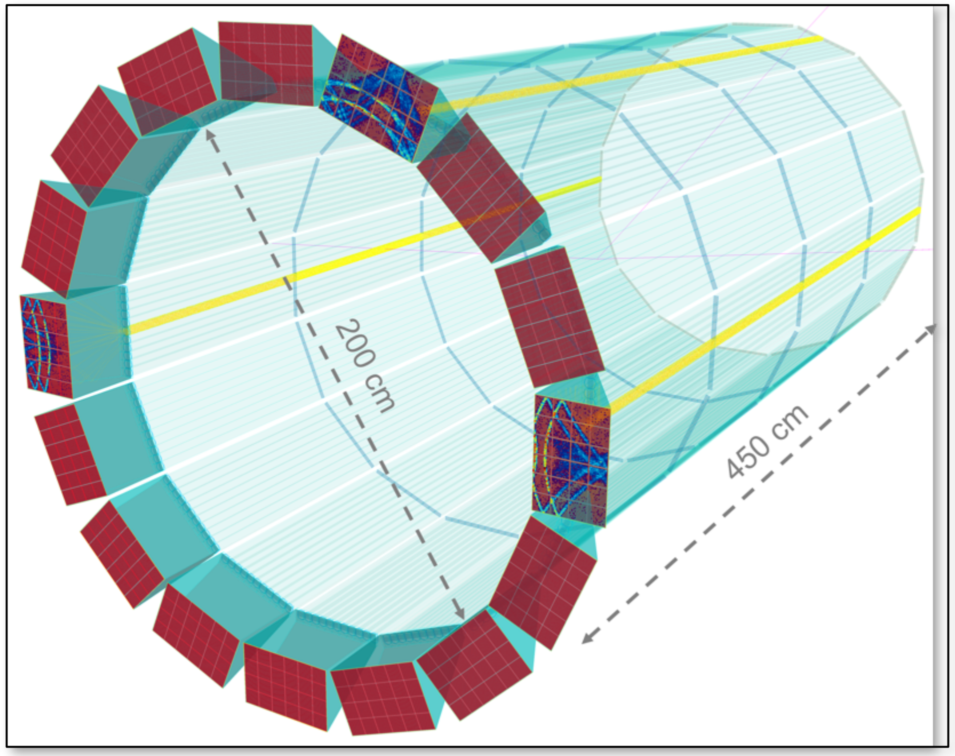
v - particle velocity



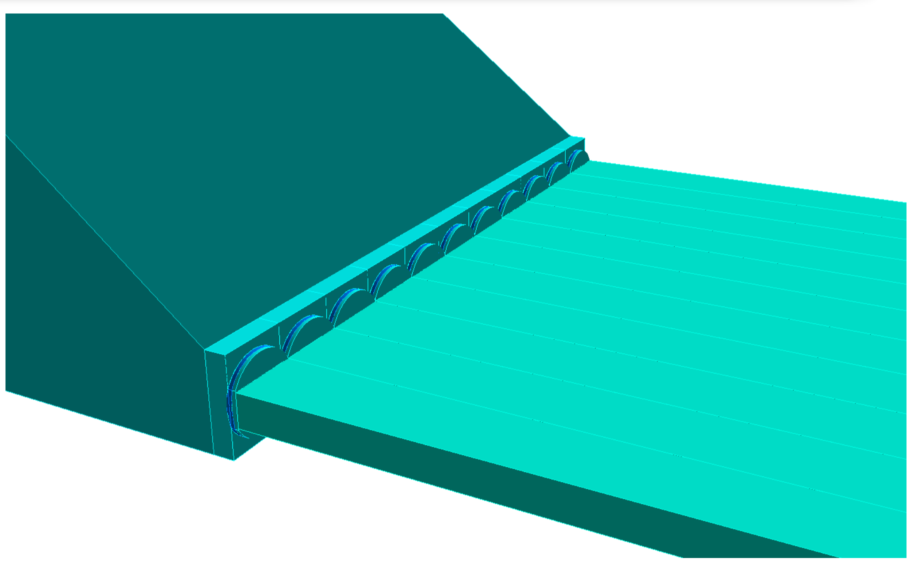


Analogous to the sonic boom !

hpDIRC Design

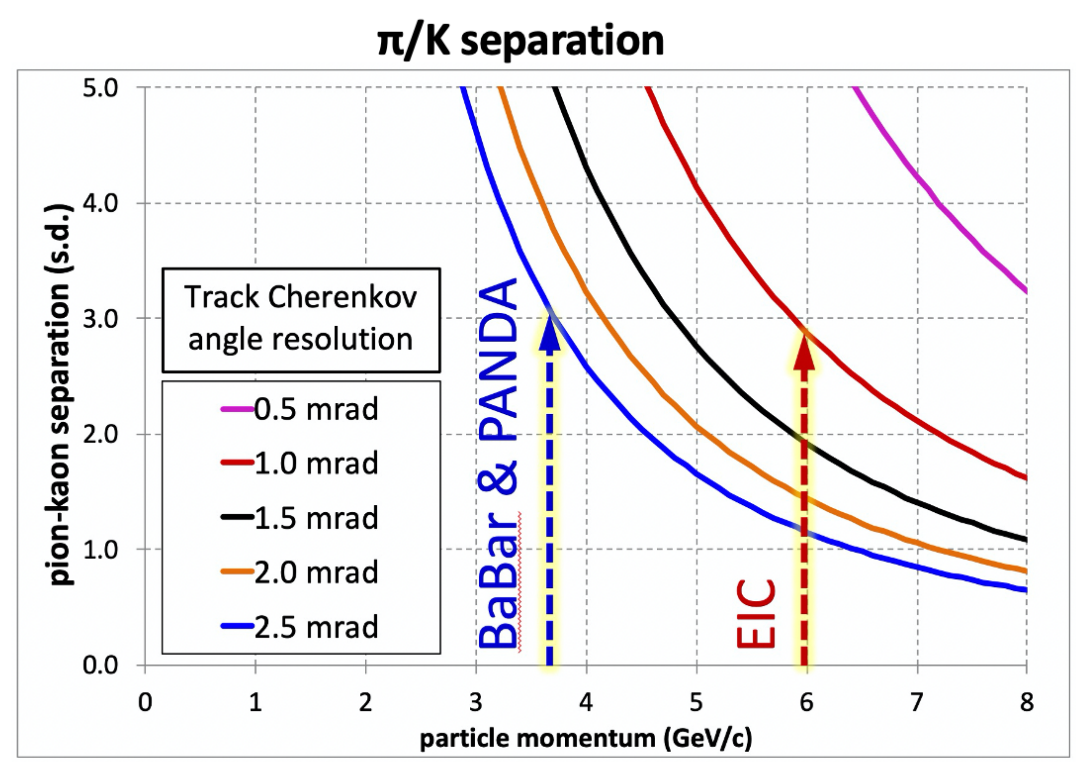


- 1 m barrel radius
- 16 sectors (bar boxes) with each having 11 bars (synthetic fused silica)



- Spherical 3-layer lens attached to each bar
- Other side of lens attached to a solid fused silica prism
- Prism as expansion volume

- Photons detected by MCP-PMT's (Micro-Channel Plate Photomultiplier Tubes)
- 256 pixels (3 mm x 3 mm) in each MCP
- 100 ps timing precision in high B-fields

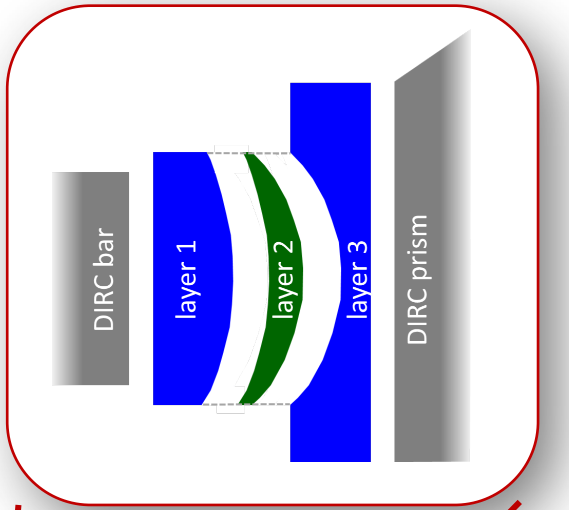


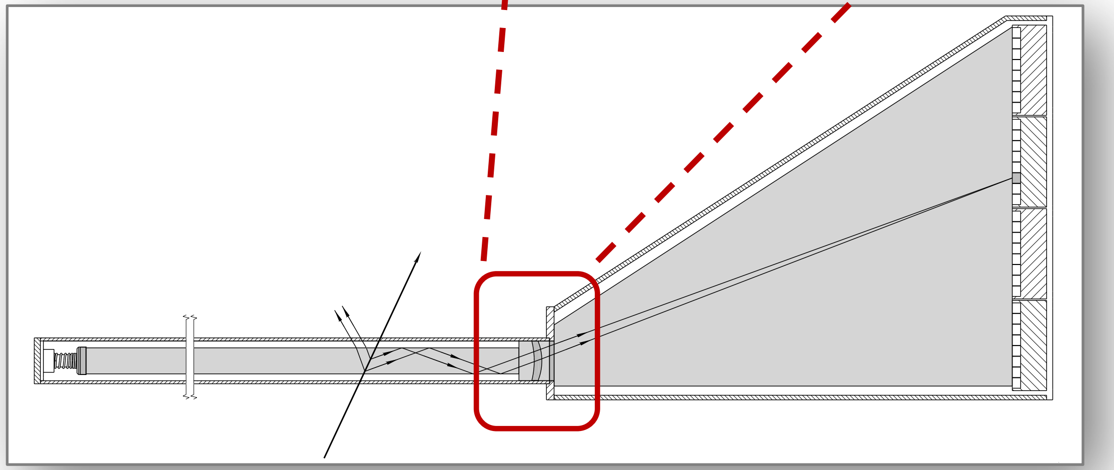
3-layer lens

- 3-layer compound lens (without air gap) is key element of hpDIRC design:

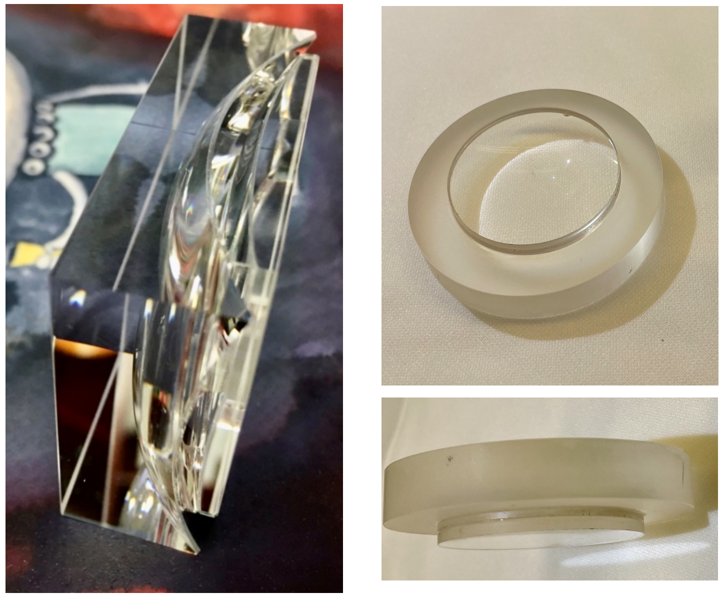
  layer of high refractive index material (focusing / defocusing) sandwiched between two layers of synthetic fused silica

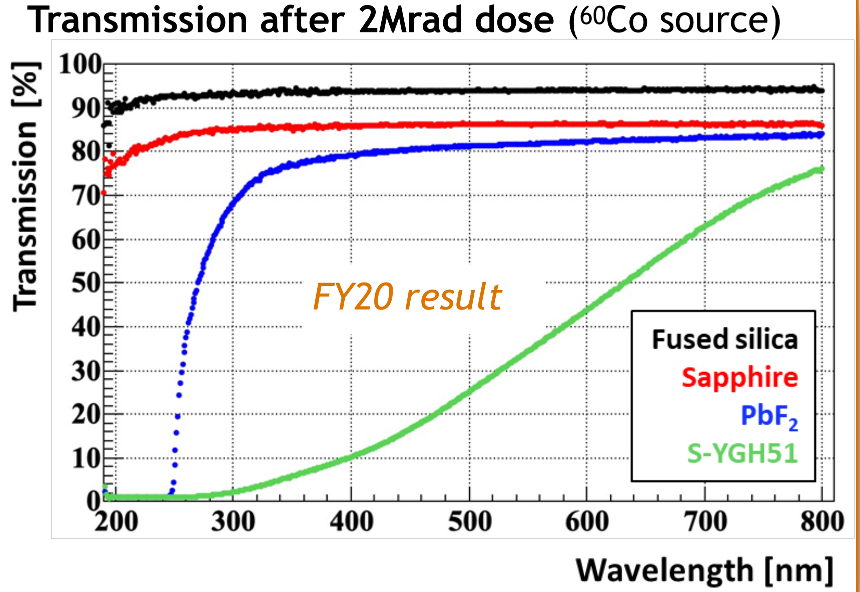
- Creates flat focal plane – matched to fused silica prism shape
- Avoids photon loss and barrel PID gap
- Successfully produced prototype lenses and validated performance in PANDA Barrel DIRC prototype with particle beams at CERN and GSI





Sapphire (RMI, USA) | PbF_2 (HIT, China)

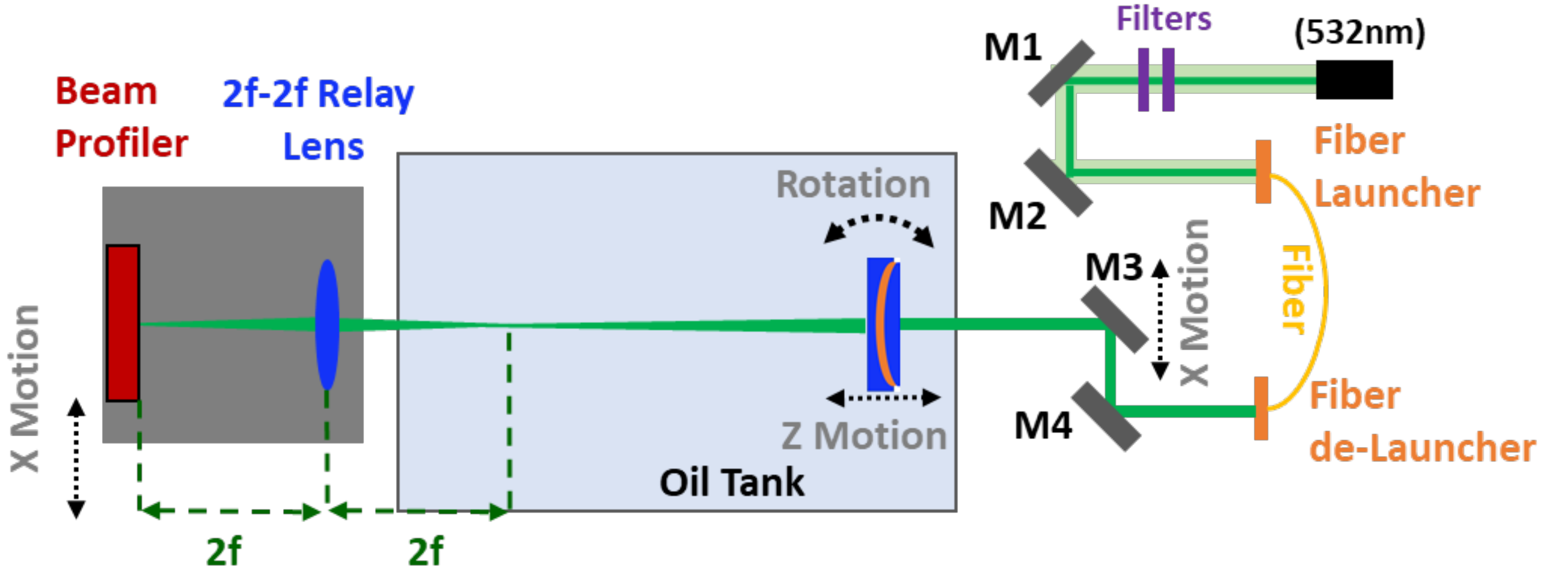




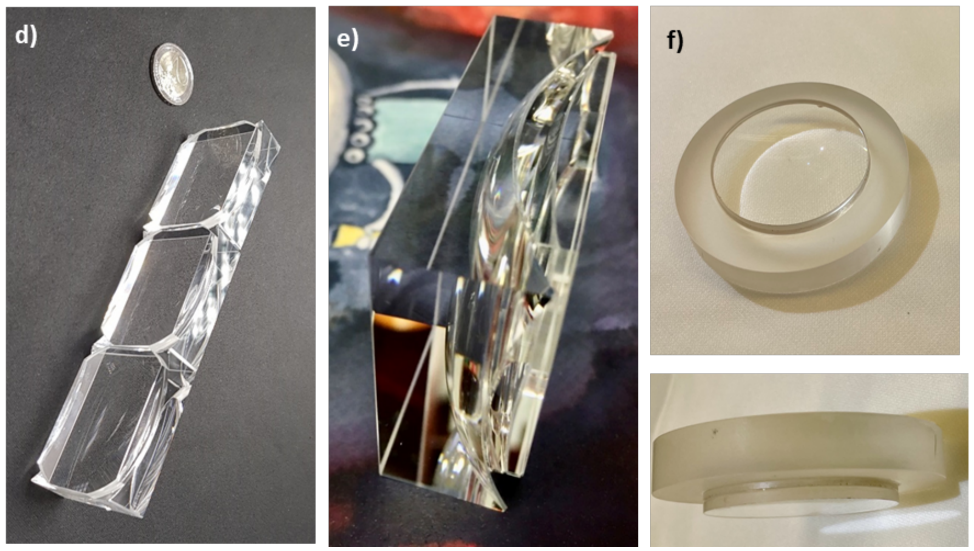
Radiation hardness study for lens materials (at BNL)

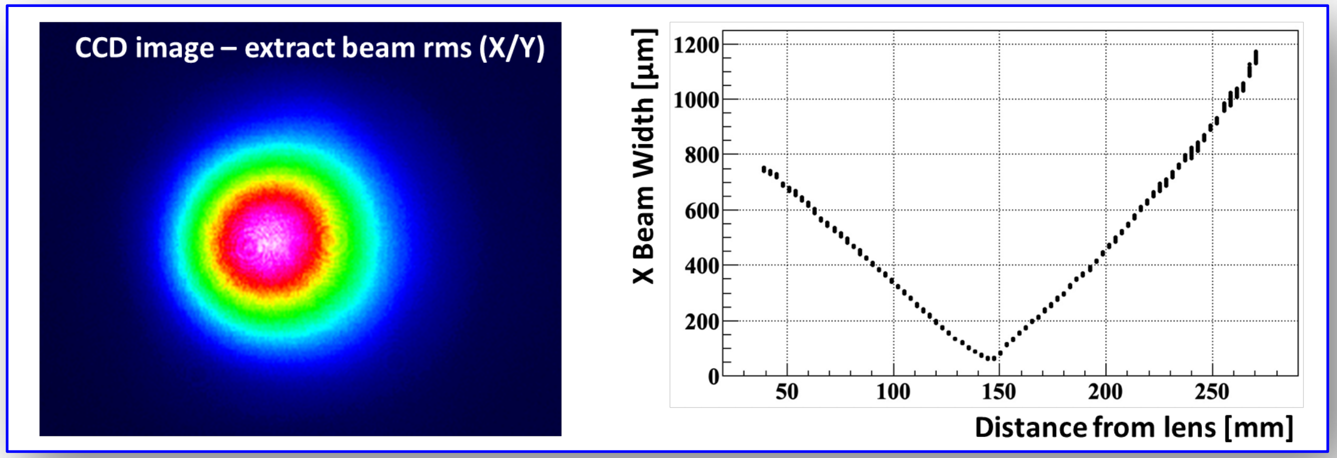
Lens measurements

Laser setup at ODU



Spherical (LaK33) Spherical (Sapphire) Spherical (PbF_2)

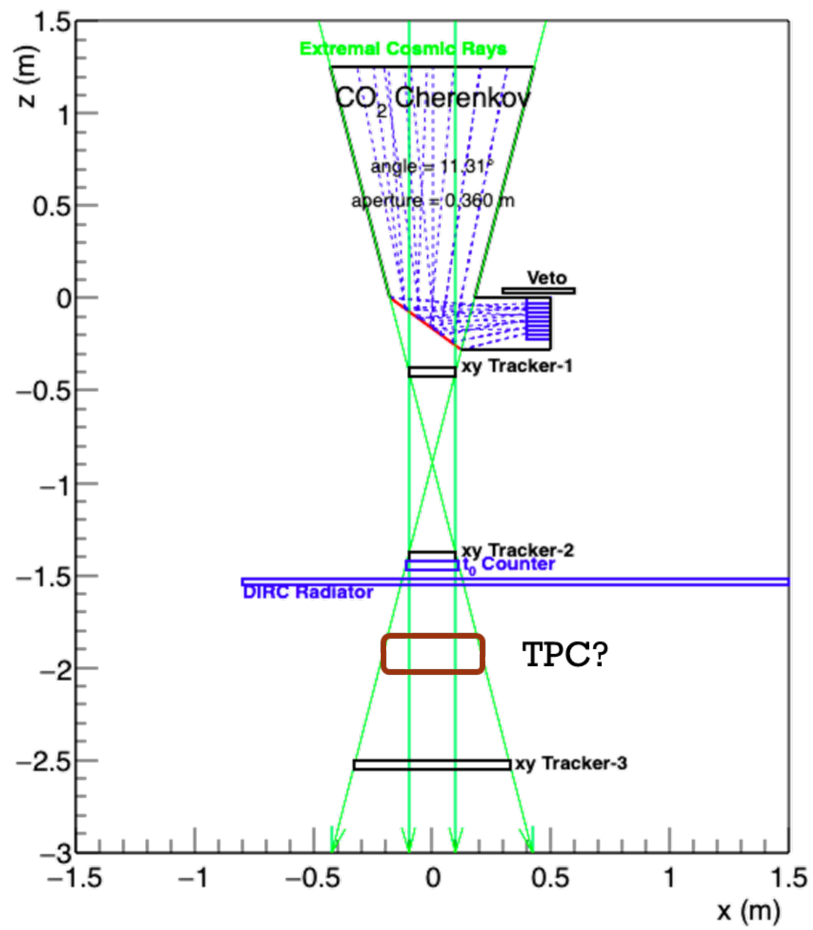




- Measurements of focal length of lens are ongoing with an upgraded setup
- Several compound lens prototypes available

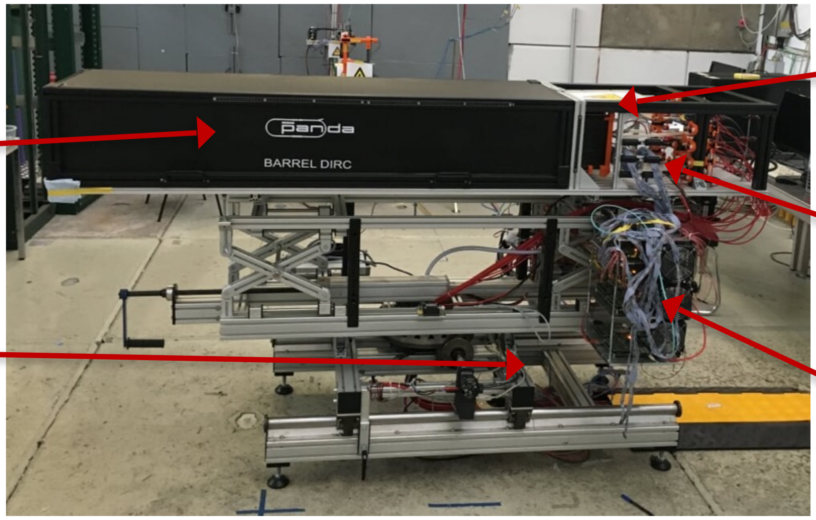
hpDIRC validation

- PANDA Barrel DIRC prototype being transferred from GSI to U.S. (CUA/SBU) to start the hpDIRC prototype
- Development of cosmic ray telescope (CRT) at Stony Brook by CUA – GSI – ODU – SBU groups
- Performance tests in SBU hpDIRC lab starting this fall, potential beam test at Fermilab in 2023



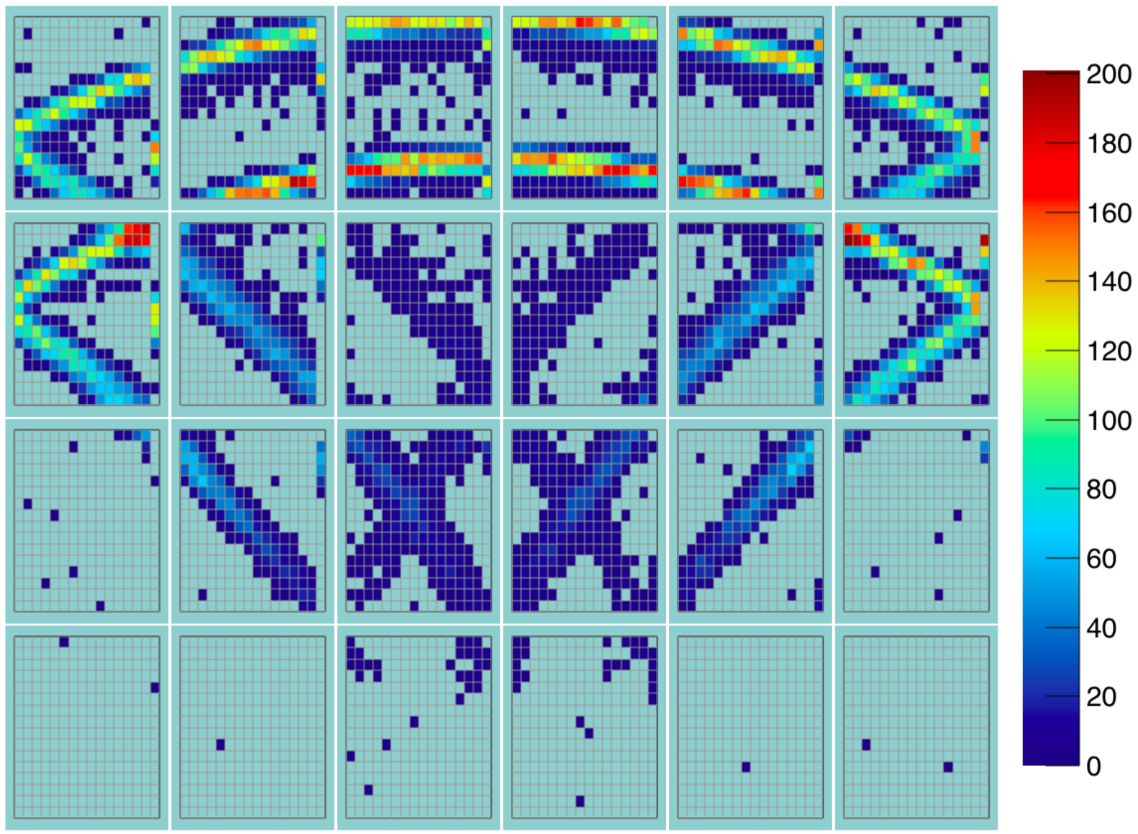
Work in collaboration with SBU team
A. Deshpande, K. Dehmelt, T. Hemmick, S. Park

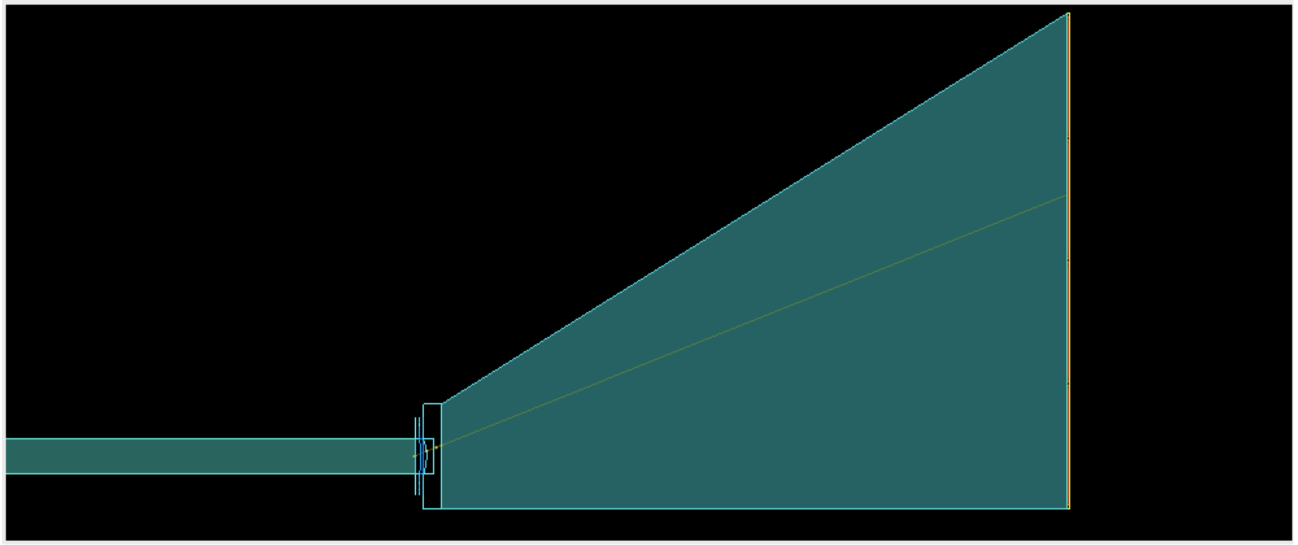
PANDA Barrel DIRC Prototype

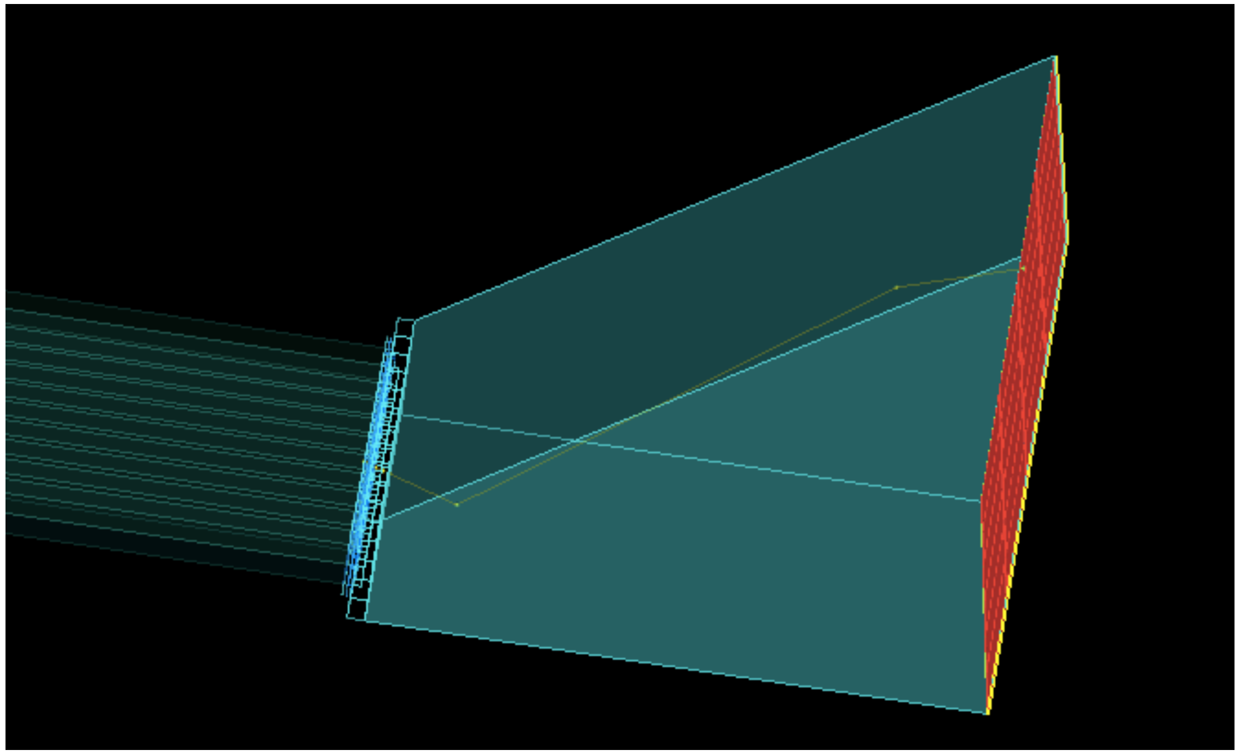


DIRC photon detection

Example hit pattern for $\theta = 90^{\circ}$, 1k π^{+}events

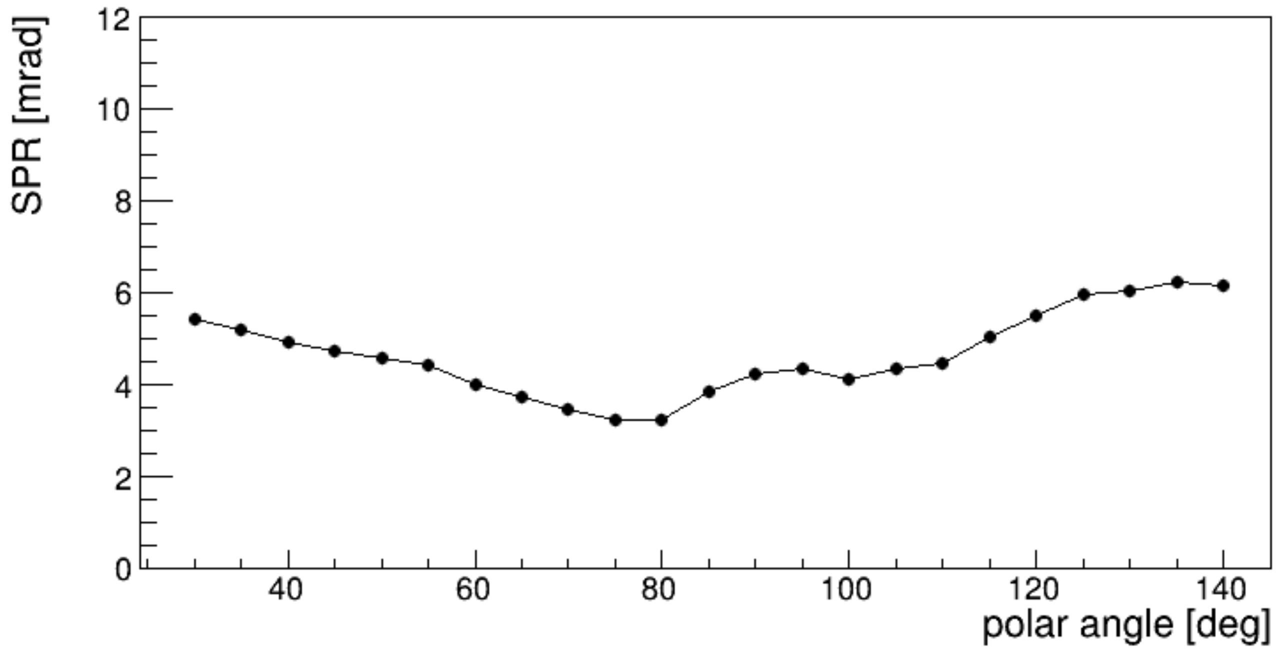


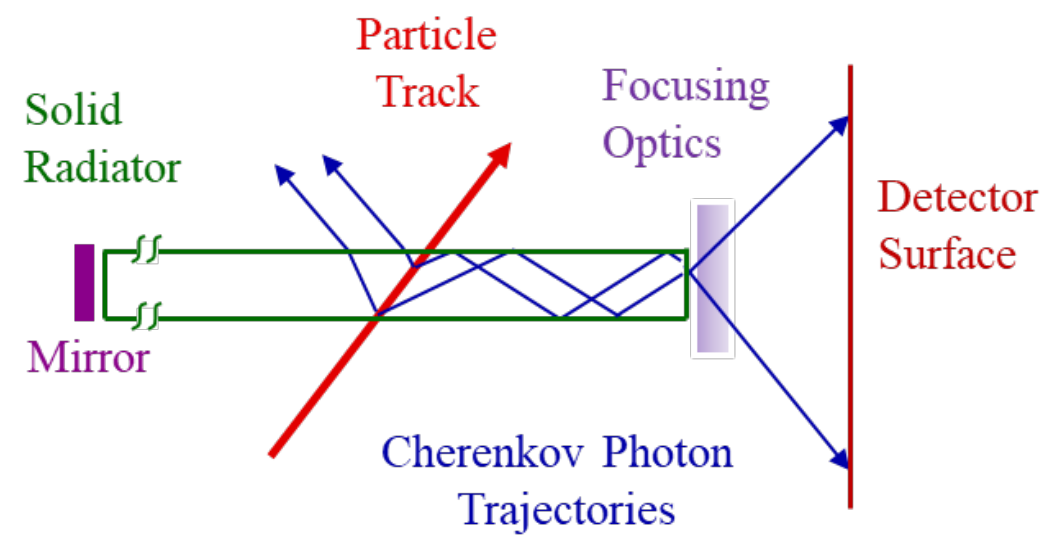




- **Photons arrive to the sensors at different times due to reflections within the bar and prism**
- **Produces ring segments on the sensor plane**

Cherenkov angle resolution per photon (Single photon resolution)





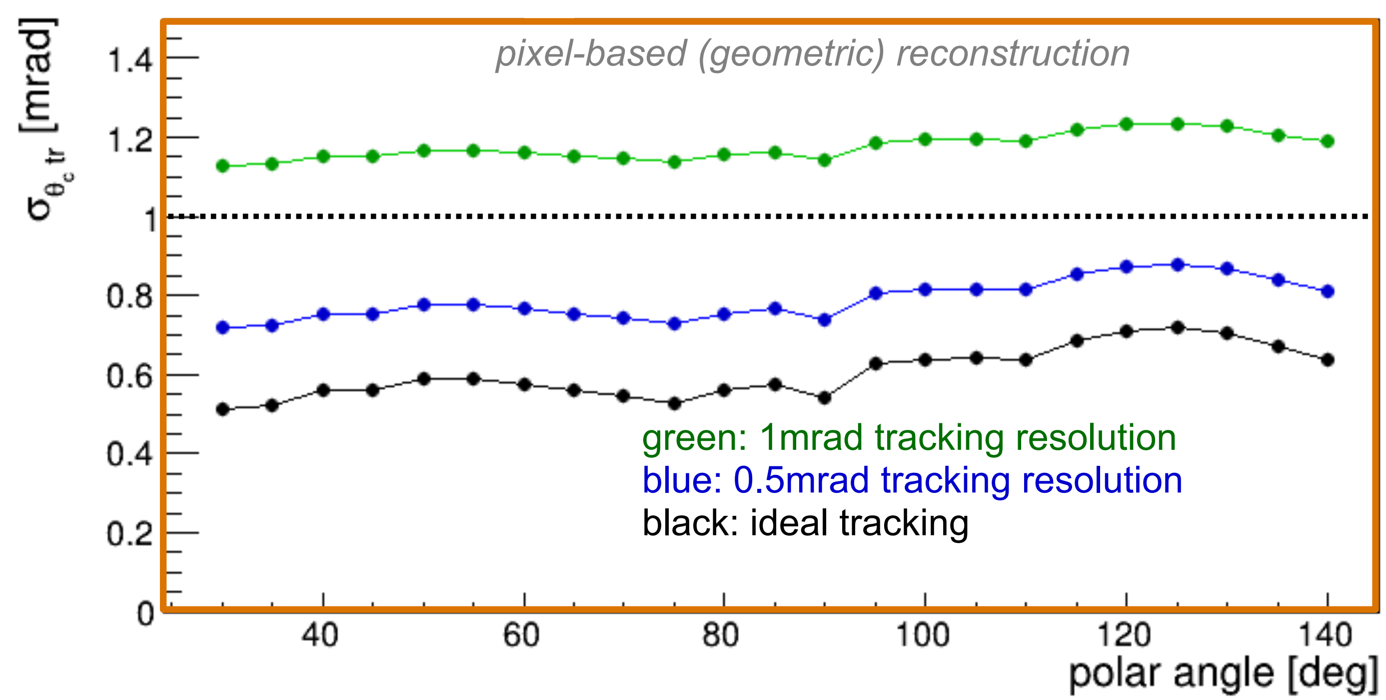
Track Cherenkov angle resolution

$$\sigma_C^2 = \frac{\sigma_{C,\gamma}^2}{N_\gamma} + \sigma_{track}^2$$

$\sigma_{C,\gamma}^2$ - single photon resolution

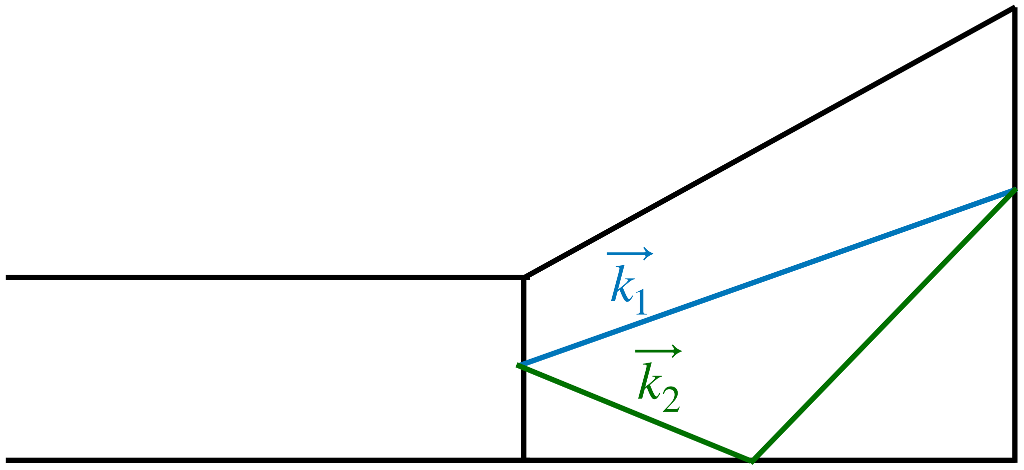
N_γ - number of photons detected per track

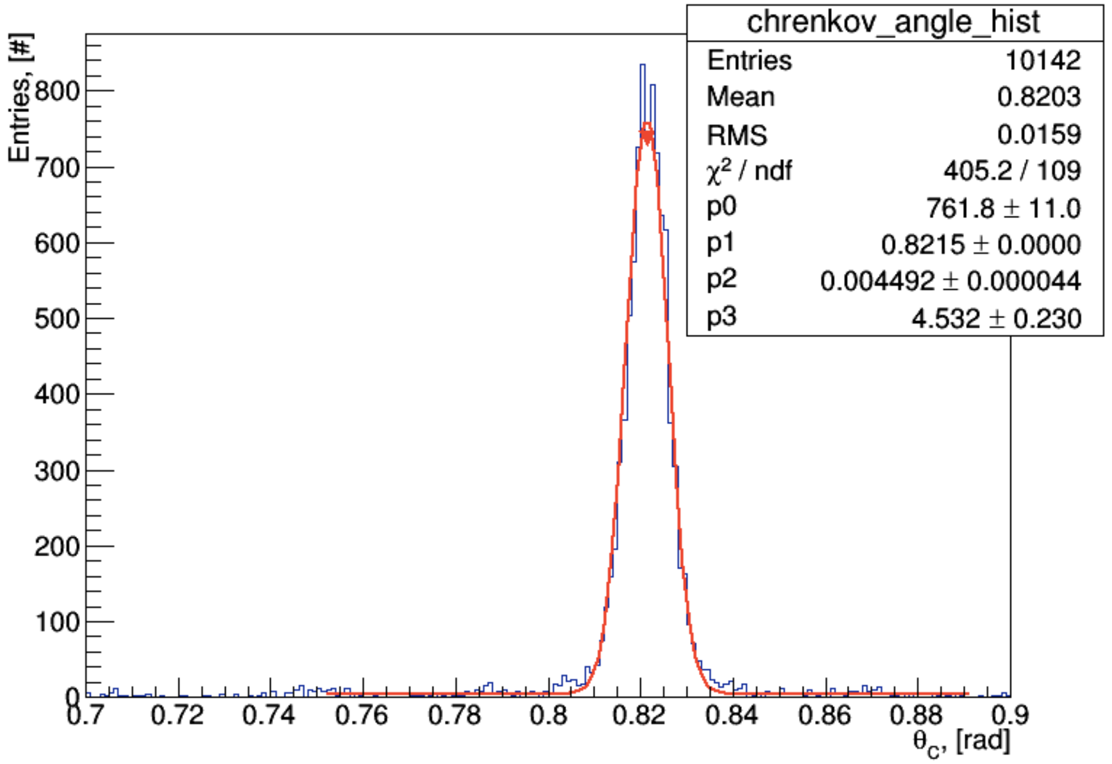
σ_{track} - uncertainty of the track direction in the DIRC



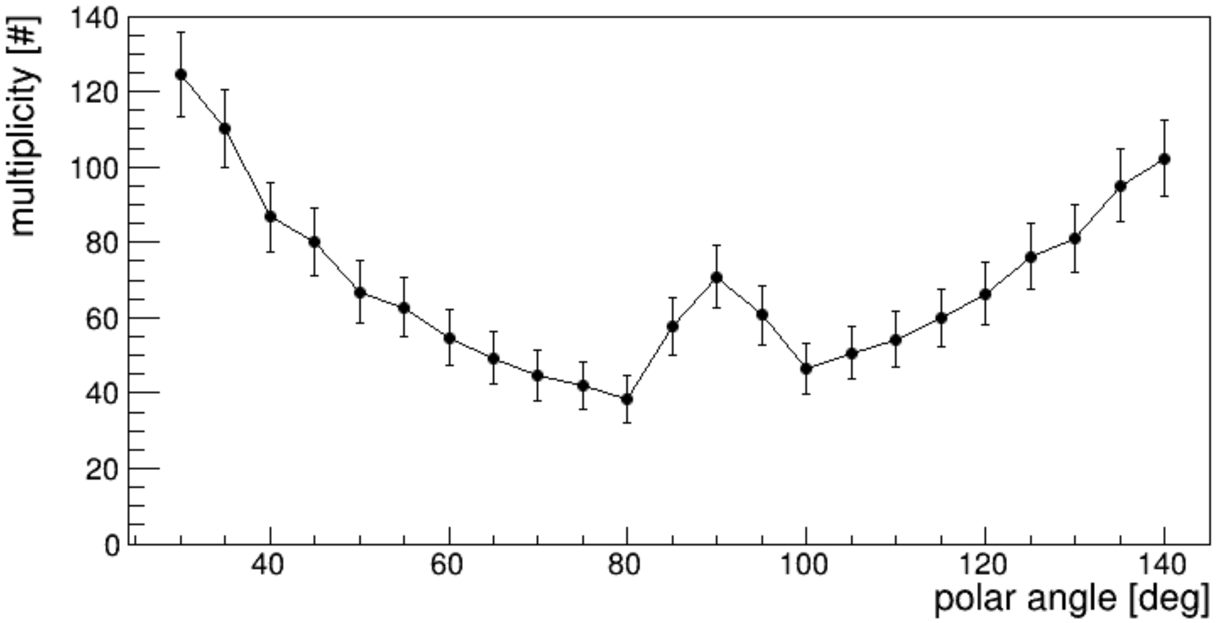
Geometric reconstruction

- Based on the method used for the BaBar DIRC
- Use Look Up Tables to determine Cherenkov angle
- For a given pixel, there are many ways the photon can propagate from the end of the bar to the pixel
- Photon direction vectors and the propagation times are stored
- Cherenkov angle is plotted for all the ambiguities of photon path





Photon yield per particle



Estimation of separation power

- Use log likelihood difference for particle hypotheses

Geometric reconstruction

- Compare measured Cherenkov angle to the expected angle for different particle hypotheses (e, μ, π, K, p)

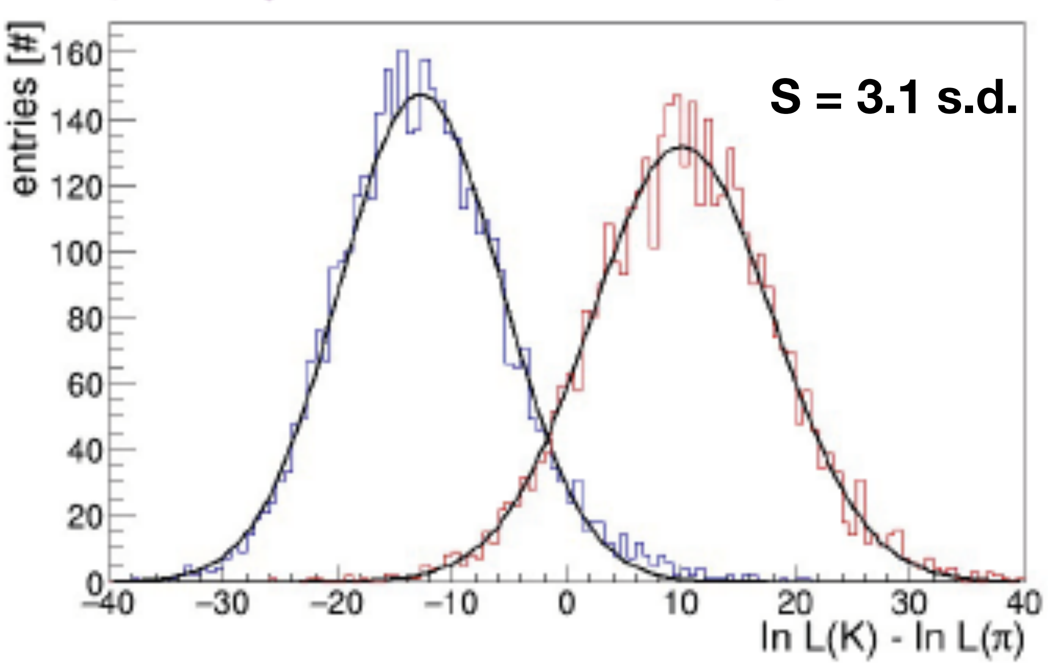
Time imaging reconstruction

- Compare measured arrival time of Cherenkov photons in each event to the expected time

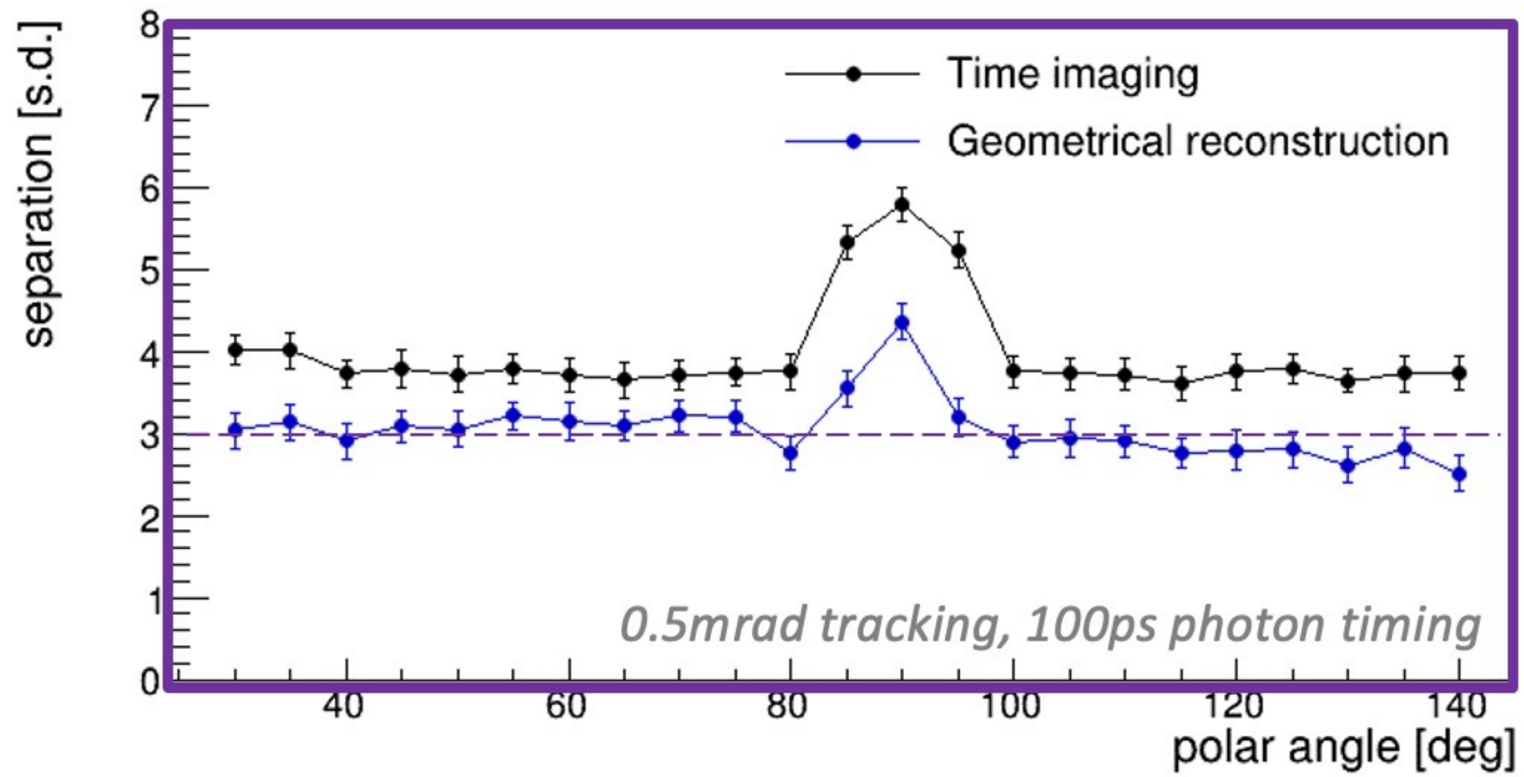
Separation calculated using mean and std. dev. of gaussians

$$S = \frac{(m_1 - m_2)}{(\sigma_1 + \sigma_2)/2}$$

π/K separation at 6 GeV/c at 20°



π/K separation power at 6 GeV/c



Summary

- The hpDIRC design is very advanced, yet flexible to fit the design of EIC central detector concepts

- Simulations show **excellent performance over wide angular range**
(≥ 3 s.d. π/K up to at least 6 GeV/c, contribution to low momentum e/π, p/K up to 10 GeV/c)

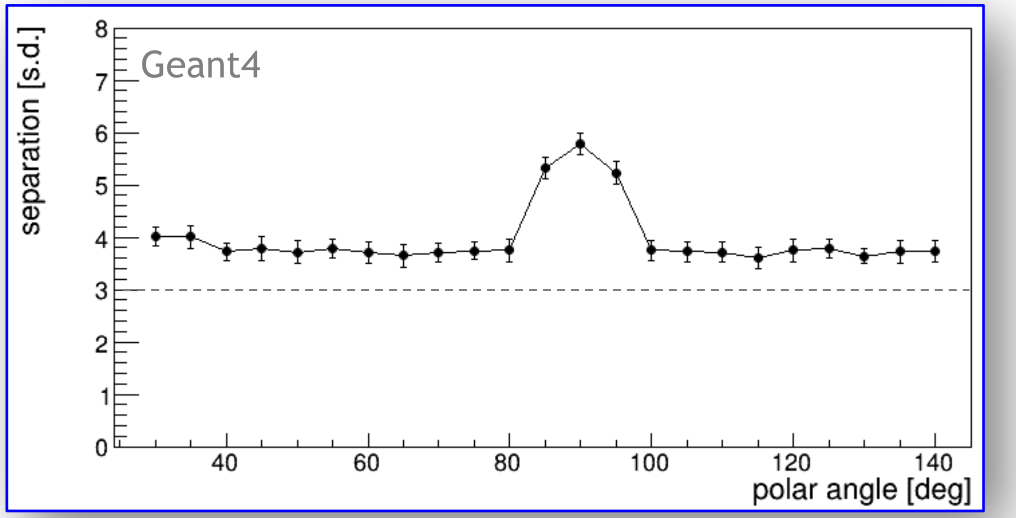
- **Geant simulation validated** with PANDA barrel DIRC prototype
(including hpDIRC components) in particle beams - excellent agreement between data and simulation

- The hpDIRC prototype upgrade and performance validation in new CRT setup at SBU are in preparation

- Still room for further design improvements

- **hpDIRC is an excellent fit to all considered EIC detector designs**

Expected π/K separation at 6 GeV/c



Expected e/π separation at 1.2 GeV/c