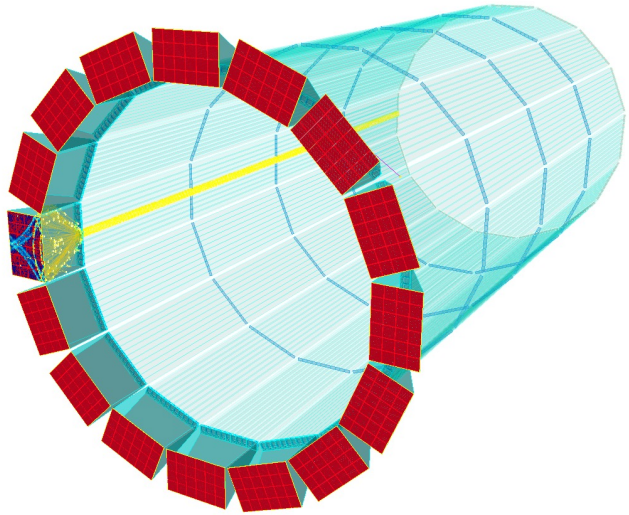
The High-Performance DIRC for the EIC



Greg Kalicy

CUA

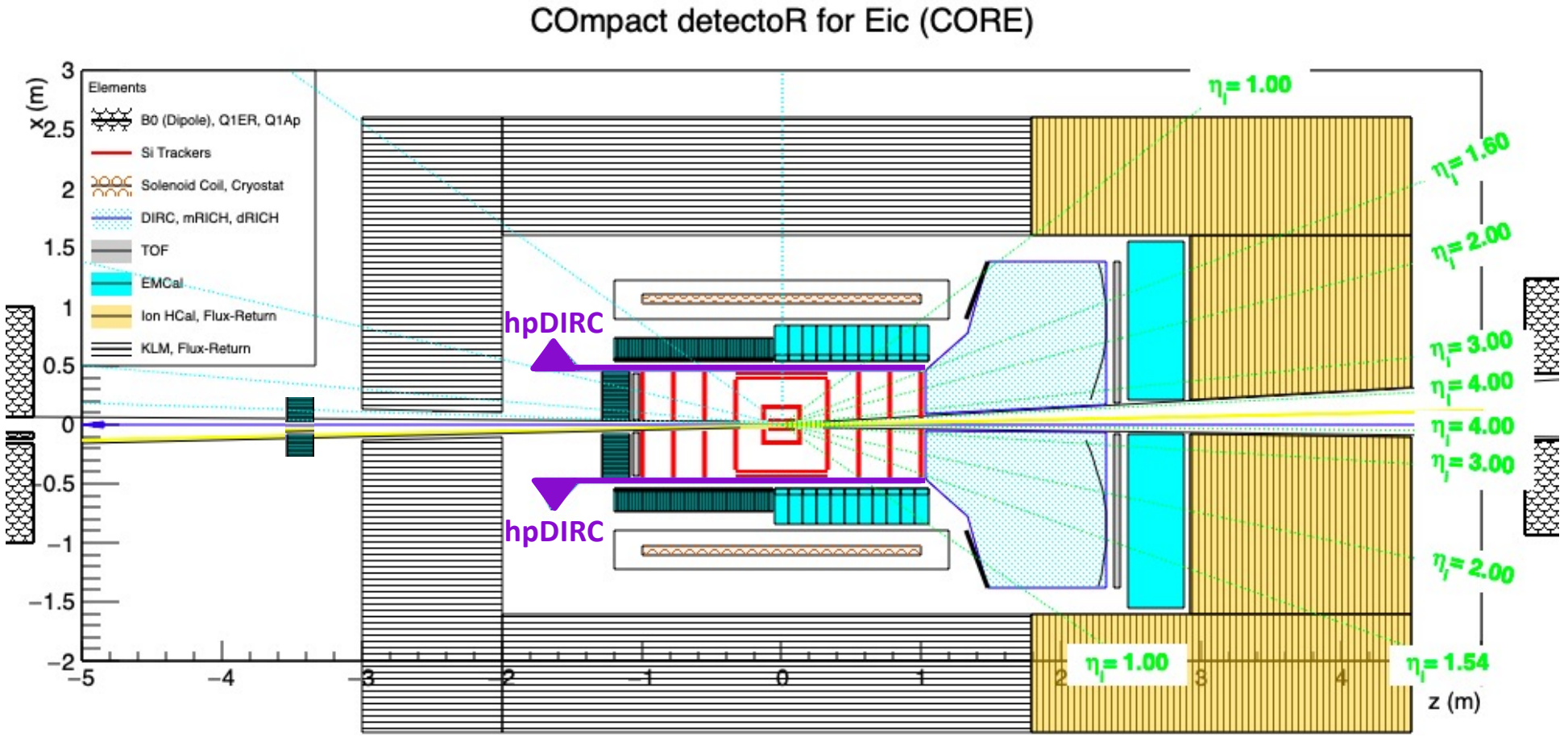
CORE kick-off Meeting, March 29, 2021

eRD14 hpDIRC Group

R. Dzhygadlo, Y. Ilieva, T. Hartlove, C. Hyde, G. Kalicy, A. Lehmann, P. Nadel-Turonski, M. Patsyuk, K. Peters, C. Schwarz, J. Schwiening, N. Wickramaarachchi, C. Zorn

CUA FAU GSI Jefferson Lab Old Dominion University South Carolina Stony Brook University University of Hawai'i Manoa

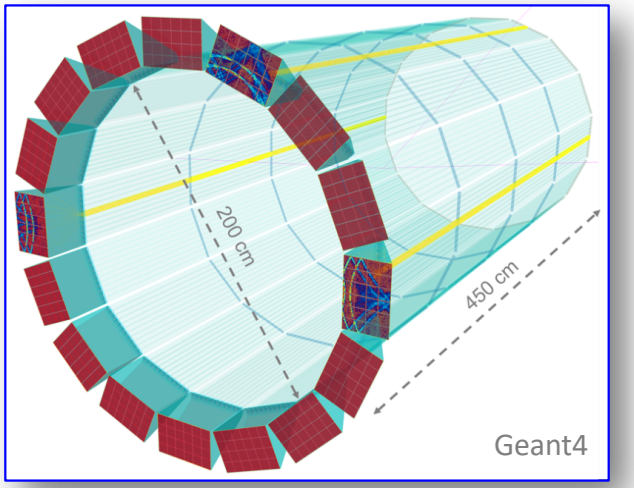
HPDIRC IN CORE PROPOSAL



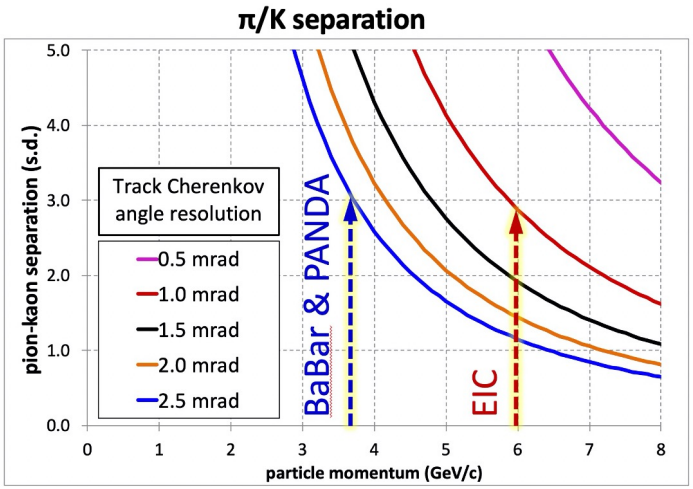
HPDIRC

High-Performance DIRC Goal:

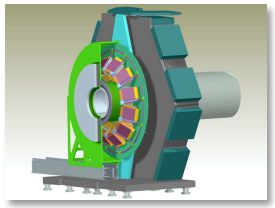
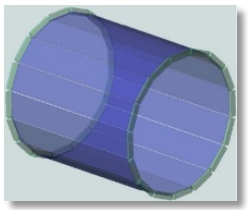
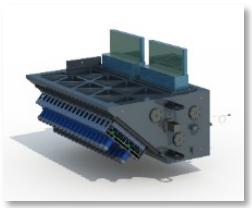
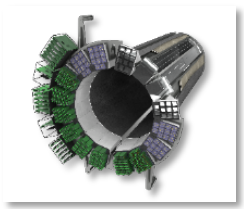
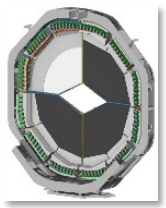
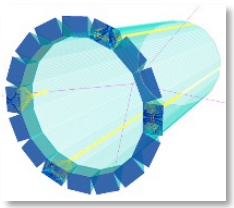
- To develop a very compact barrel EIC PID detector with momentum coverage reaching 6 GeV/c for π/K, pushing the performance well beyond the state-of-the-art for DIRC counters.



- **Key Features:**
  - **Excellent performance over wide angular range** (≥ 3 s.d. π/K up to 6 GeV/c, contribution to low momentum e/π)
  - **Radially compact** (<8cm; impact on cost of post-DIRC systems)
  - **Flexible design** (to deal with sensor in B-field and detector integration)
  - **Low demand on detector infrastructure** (no cryogenic cooling, no flammable gases)
  - **Advanced stage** (PID performance estimate based on test beam results, excellent agreement between simulation and prototype data)



DIRC Concept

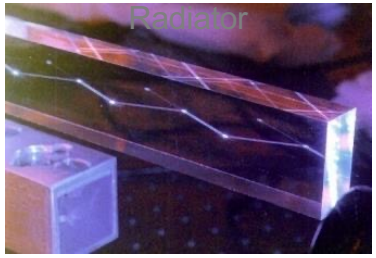








BaBar SuperB Belle II GlueX panda panda Electron Ion Collider

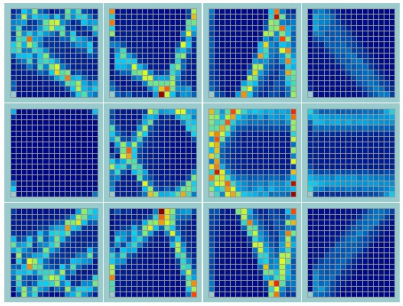
Detection of Internally Reflected Cherenkov Light

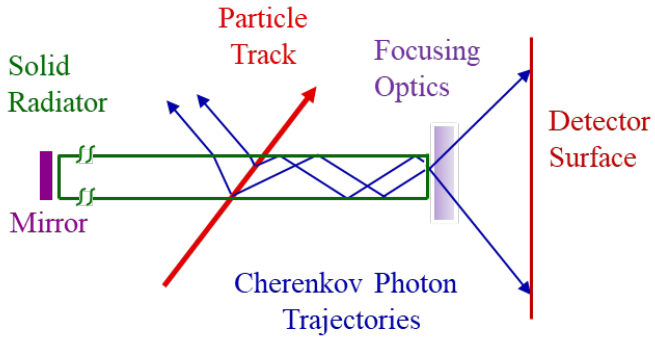
- Pioneered by the BaBar experiment at SLAC National Accelerator Laboratory
- Fused silica radiator is used also as light guide
- Detector surface is outside active volume
- Cherenkov angle is conserved during internal reflections and reconstructed from detected photons
- Ultimate Deliverable: PID likelihoods

Synthetic Fused Silica Radiator



Example Detector Surface hpDIRC simulation

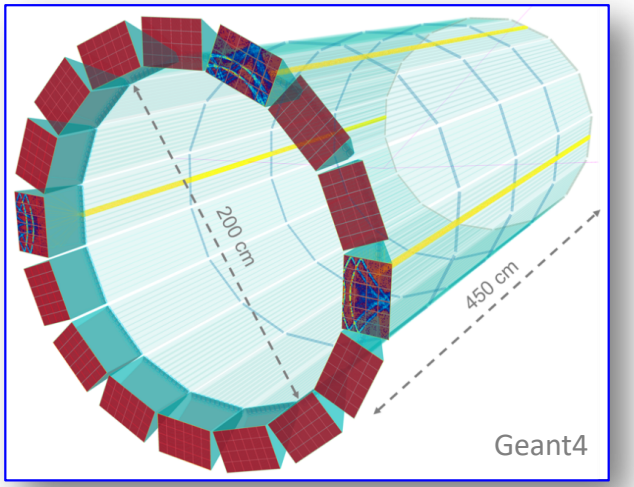


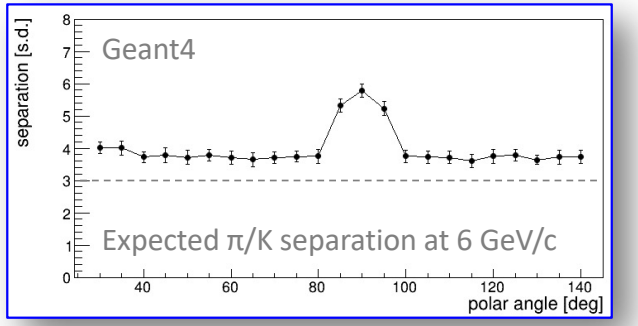


HPDIRC OVERVIEW

Concept:

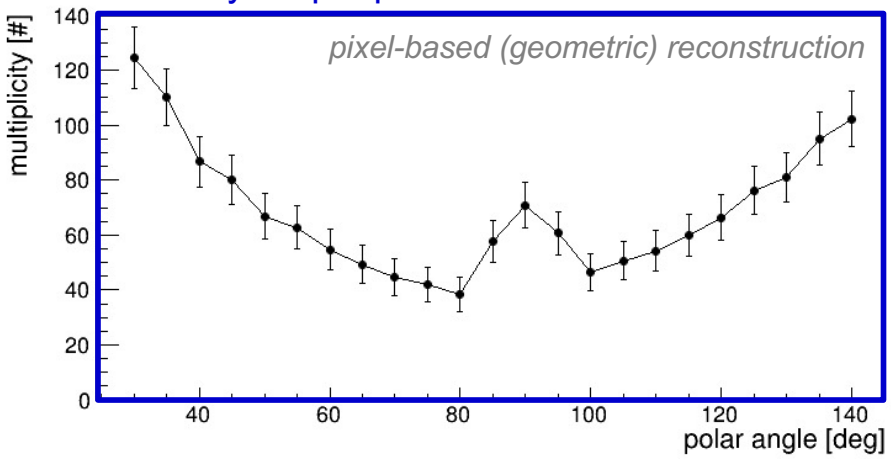
- Fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction
- Initial generic design (based on BaBar DIRC, R&D for SuperB FDIRC, PANDA Barrel DIRC): narrow fused silica bars, 1m barrel radius, 4.5m barrel length
  (barrel length and radius to be optimized for detector integration - no impact on DIRC PID)
- Innovative 3-layer spherical lenses, compact fused silica expansion volumes
- Fast photon detection using small-pixel MCP-PMTs *(eRD14)* and high-density readout electronics *(eRD14)*
- Detailed Geant4 simulation:
  40-120 detected photons per particle, ≥ 3 s.d. π/K separation at 6 GeV/c



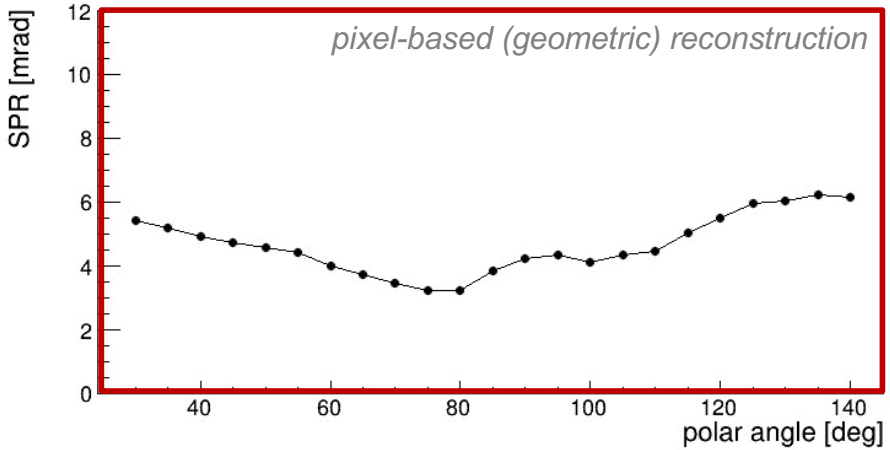


HPDIRC PERFORMANCE IN GEANT4

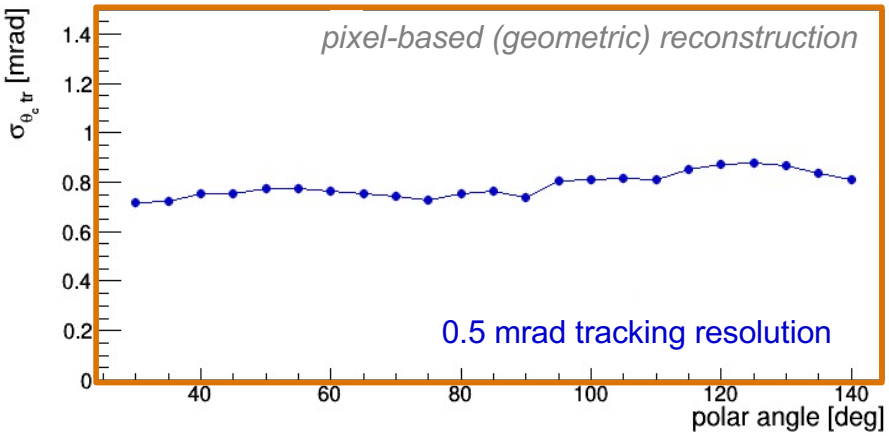
Photon yield per particle



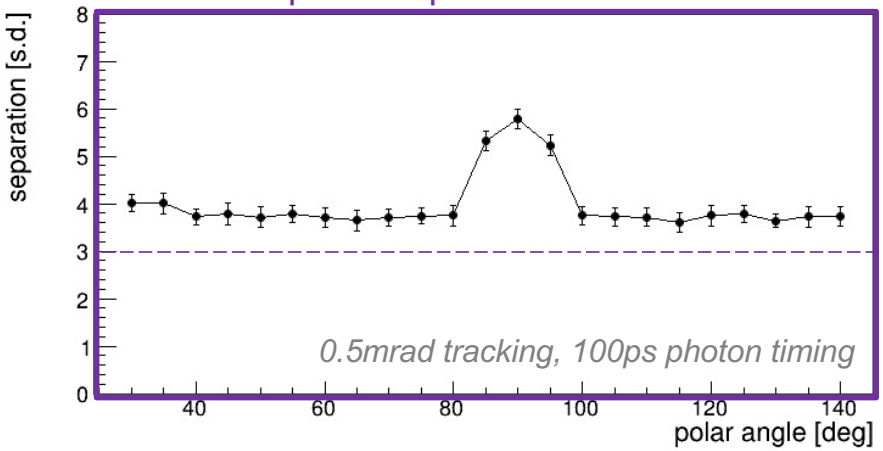
Cherenkov angle resolution per photon (SPR)



Cherenkov angle resolution angle per particle



π/K separation power at 6 GeV/c



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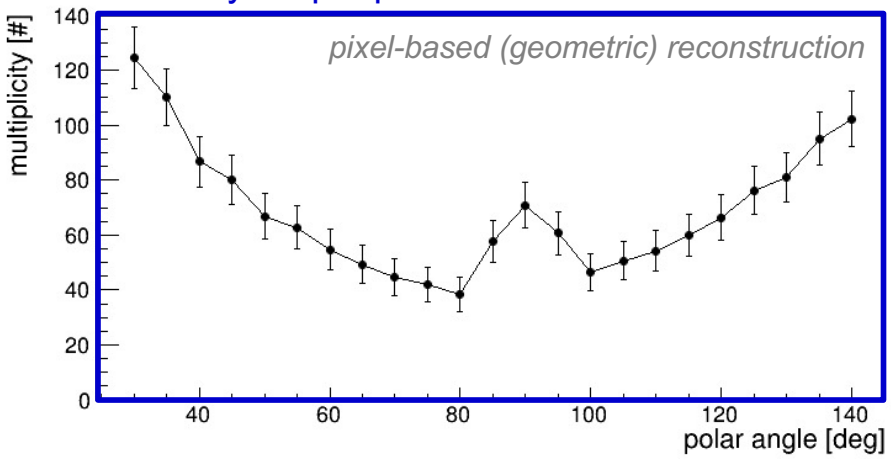

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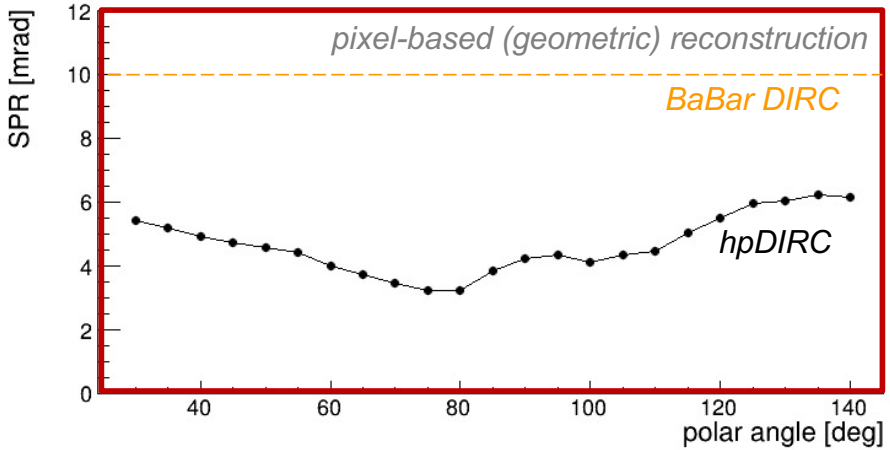
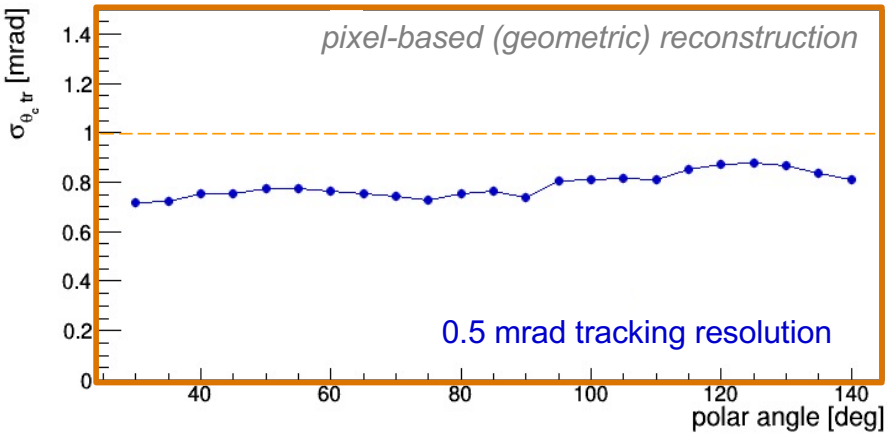


Cherenkov angle resolution angle per particle



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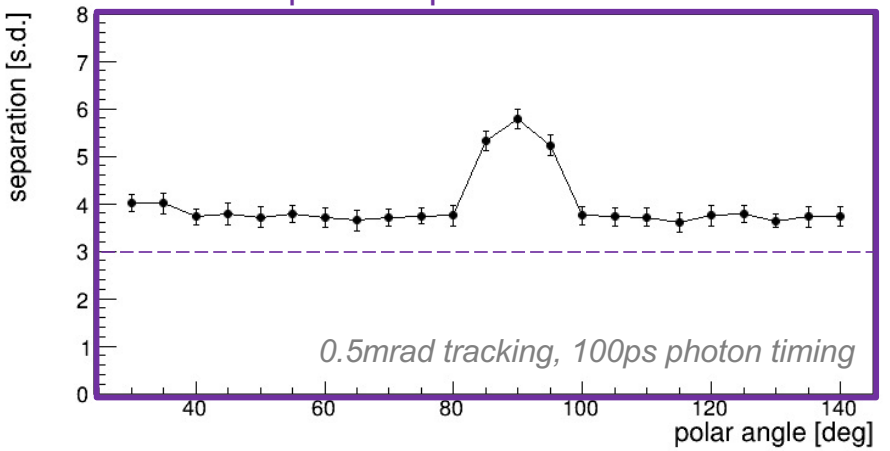

HPDIRC PERFORMANCE IN GEANT4

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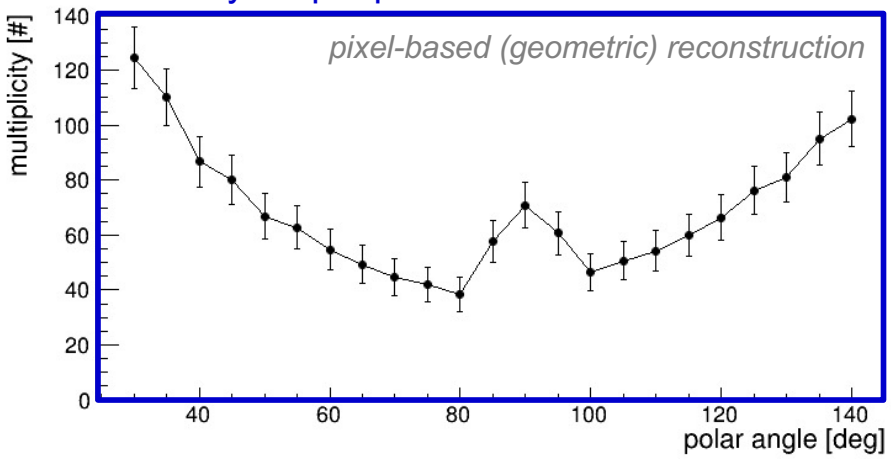

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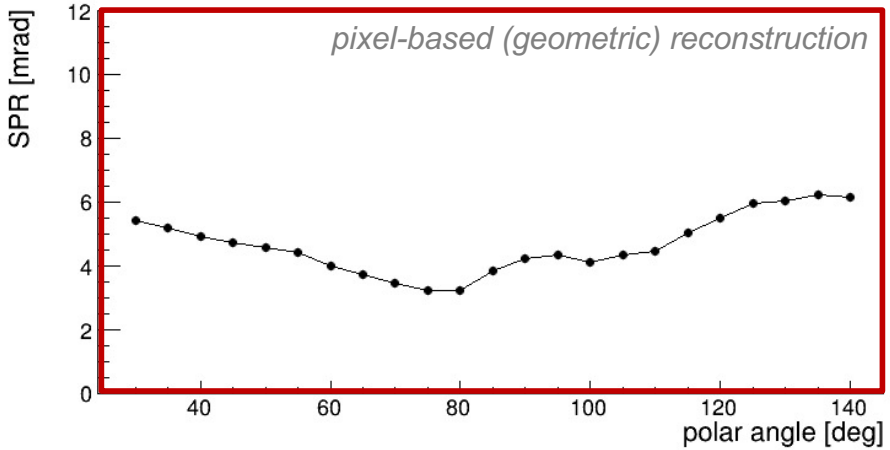
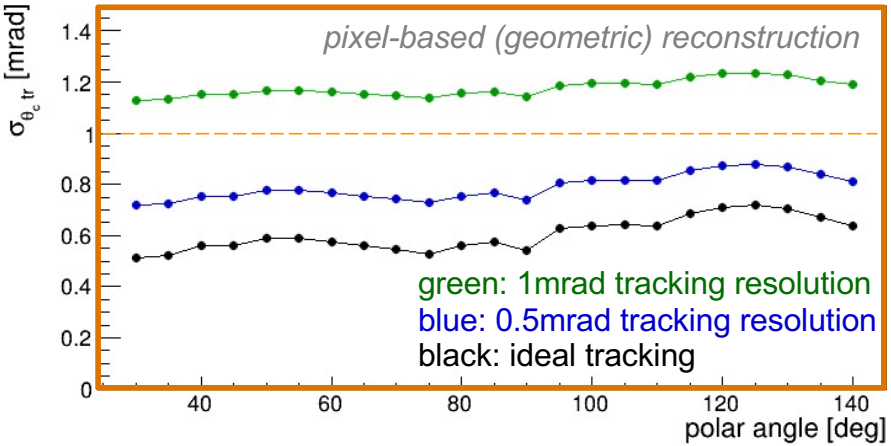
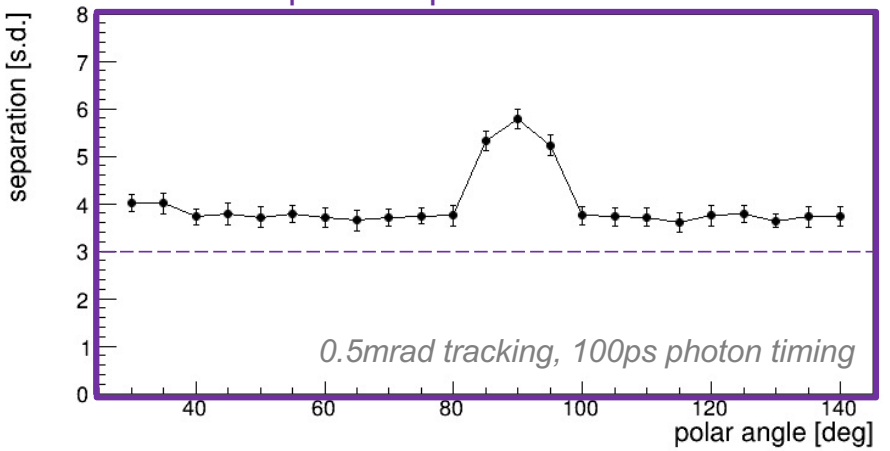


Cherenkov angle resolution angle per particle



π/K separation power at 6 GeV/c



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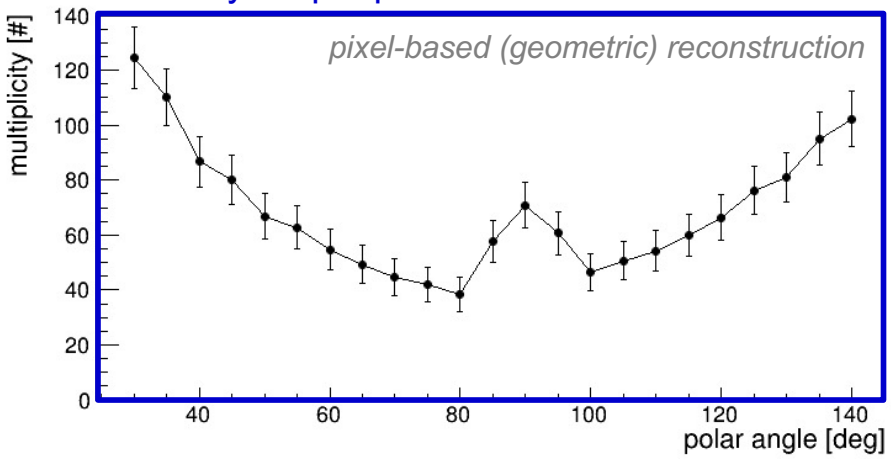

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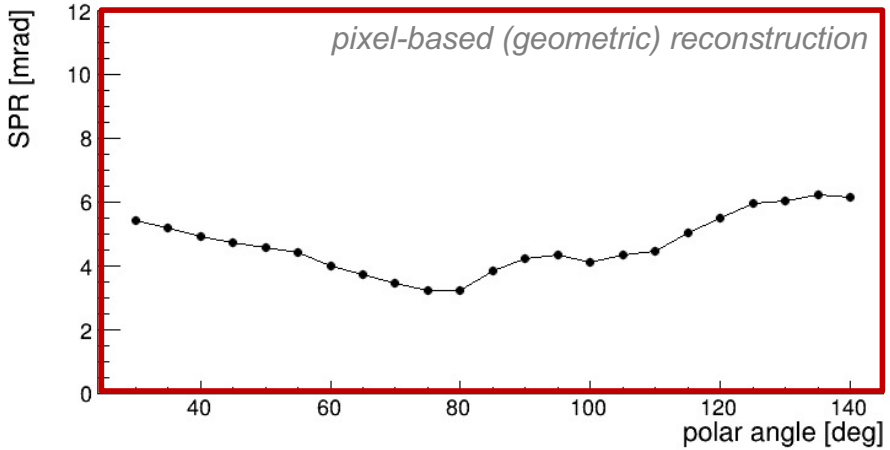

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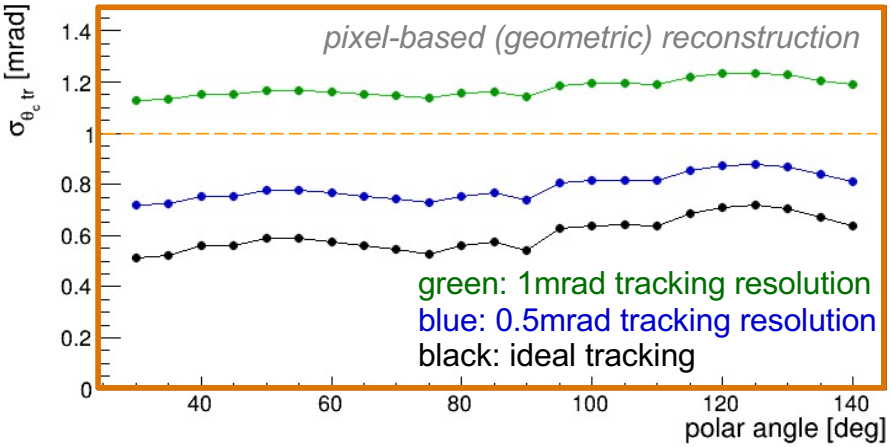
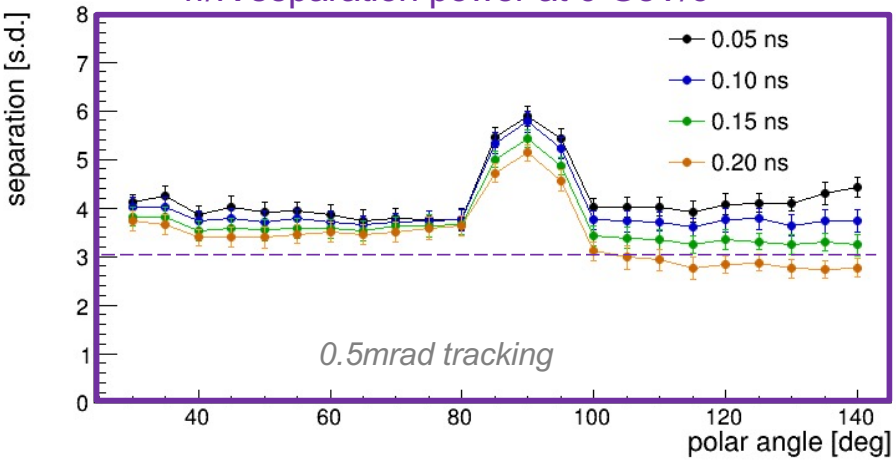


π/K separation power at 6 GeV/c

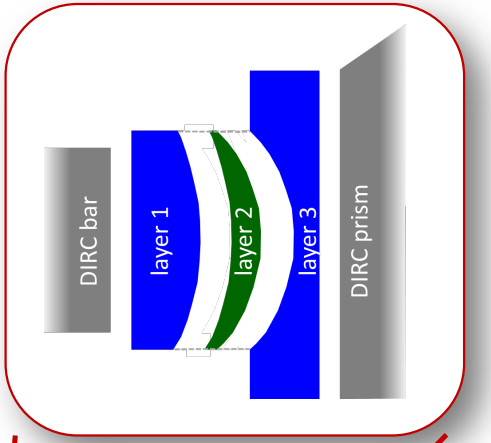


HPDIRC FOCUSING

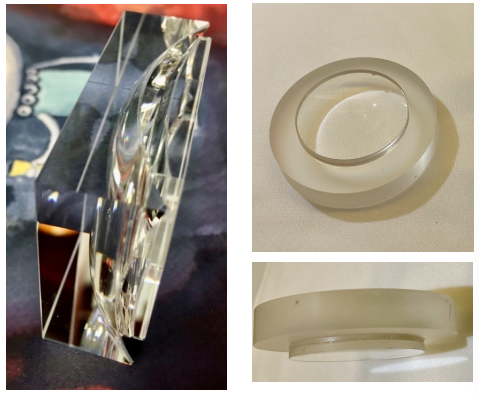
- 3-layer compound lens (without air gap) is key element of hpDIRC design:

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

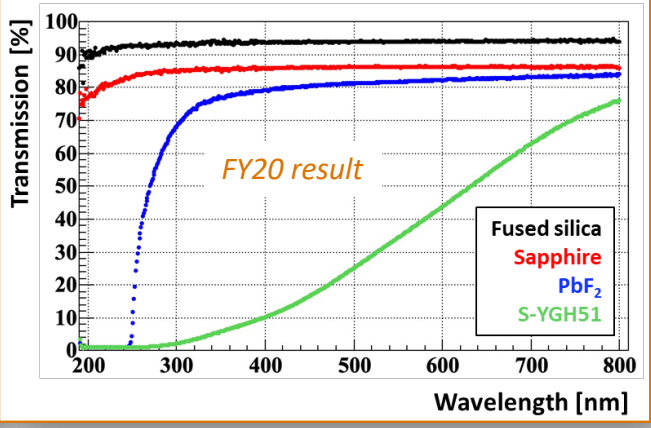
- Creates flat focal plane – matched to fused silica prism shape
- Avoids photon loss and barrel PID gap
- Successfully produced prototype lenses and validated performance in PANDA Barrel DIRC prototype with particle beams at CERN and GSI

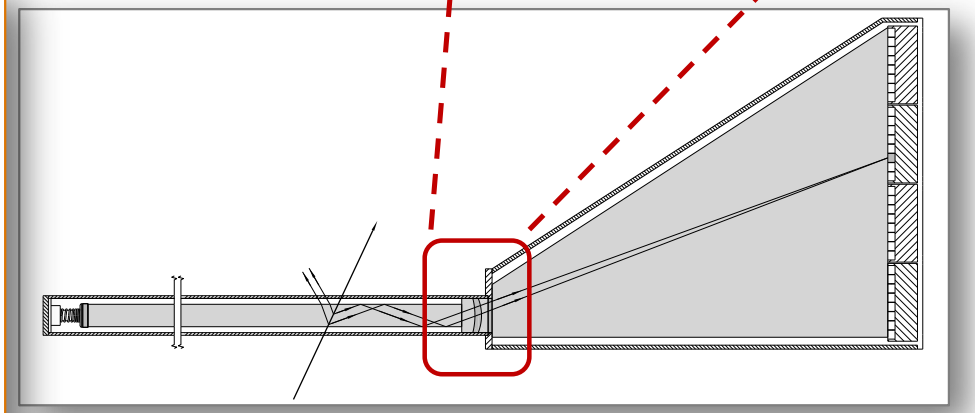


Sapphire (RMI, USA) **PbF_2 (HIT, China)**



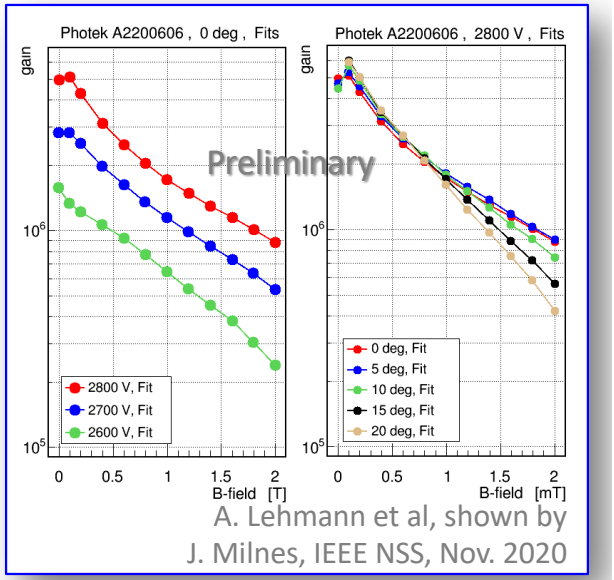
Transmission after 2Mrad dose (^{60}Co source)



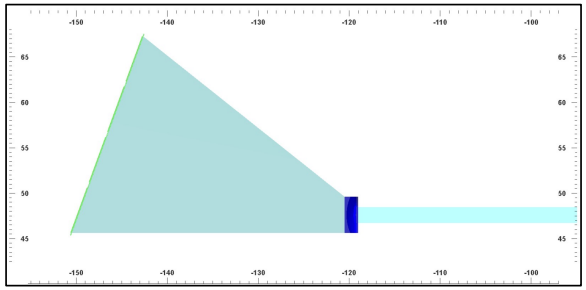


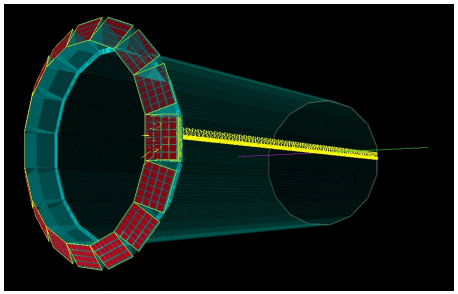
HPDIRC SENSORS

- Commercially available MCP-PMTs (Photonis Planacon or Photek MAPMT) and HRPPD LAPPD are the leading candidates
- Some of the detector proposals plan to use a new 3 T magnet, other proposals favor magnets with 1.5—2 Tesla fields
- Waiting for field maps for to determine local field strength and direction at location of DIRC sensors
- Ongoing effort within eRD14, studying LAPPD/commercial MCP-PMT in high B-fields
- Small-pore MCP-PMTs shown to be OK for fields up to 2 Tesla (see recent result from A. Lehmann et al. for 6µm-pore 2'' Photek AuraTek MCP-PMT)
- If expected fields are much higher or as an upgrate: investigate SiPM as alternative (dark noise, radiation damage, cooling, annealing, integration issues)



A. Lehmann et al, shown by J. Milnes, IEEE NSS, Nov. 2020

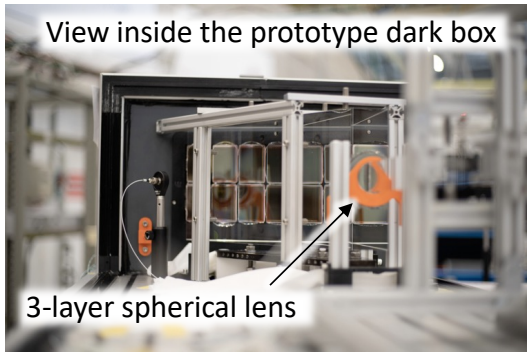


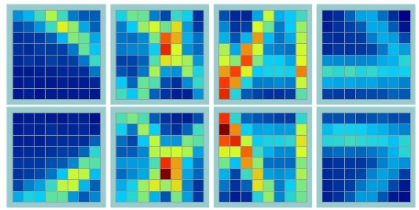


HPDIRC VALIDATION

hpDIRC PID design validation

- Resolution and PID performance of system prototype
- PANDA Barrel DIRC prototype tested with particle beams at CERN (2015-18)
  (included 3-layer spherical lens – but older MCP-PMTs, larger pixels, slower electronics)
- Up to 5 s.d. p/π separation at 7 GeV/c (equivalent to 5.2 s.d. π/K at 3.5 GeV/c)
- Excellent agreement with simulation (same simulation used for hpDIRC)





Hit pattern

CERN 2018

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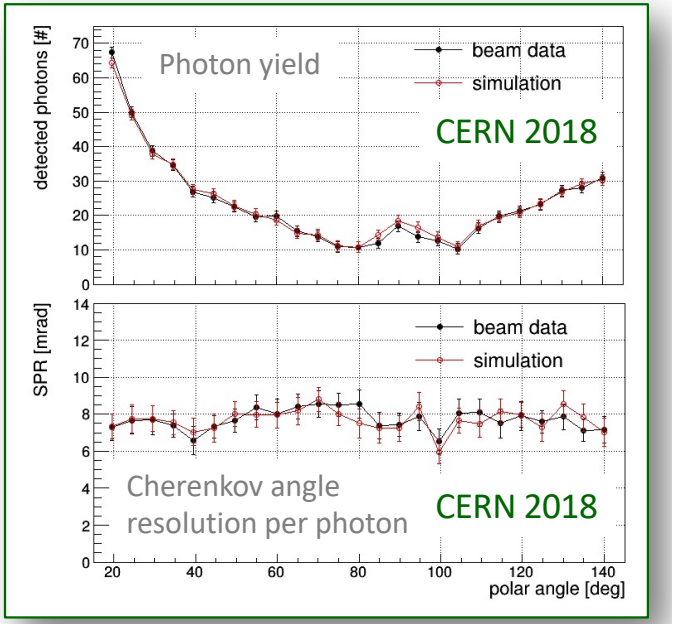

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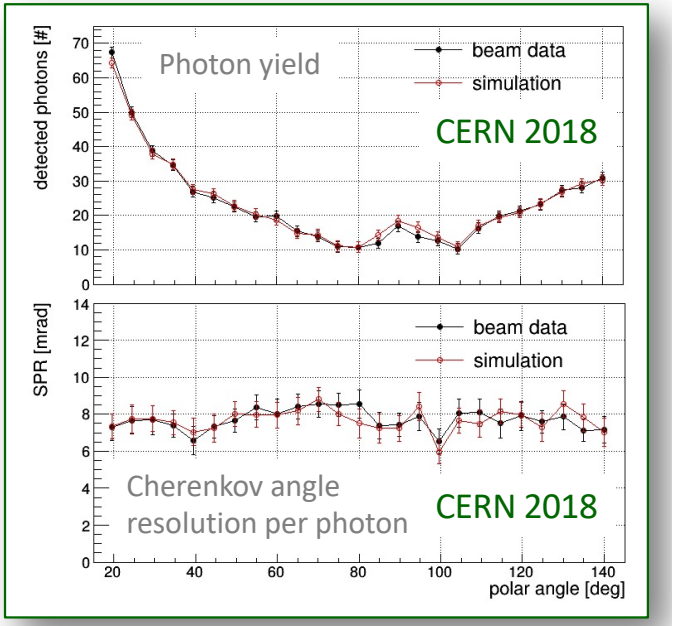
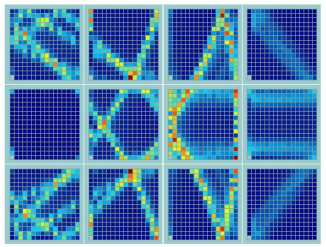
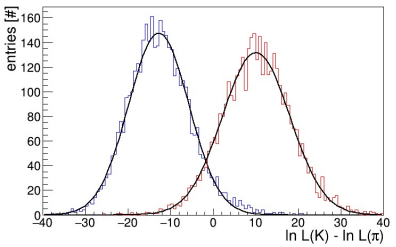


- Used this simulation to predict PID performance of upgraded prototype
  (new MCP-PMTs and electronics, 3mm pixels, improved PDE, 100ps timing)
- Expected π/K separation at 6 GeV/c at 20°: 3.1 s.d.
- Upgraded PANDA Barrel DIRC prototype (new sensors, new electronics) capable of hpDIRC PID performance validation in particle beams

Geant simulation of upgraded prototype

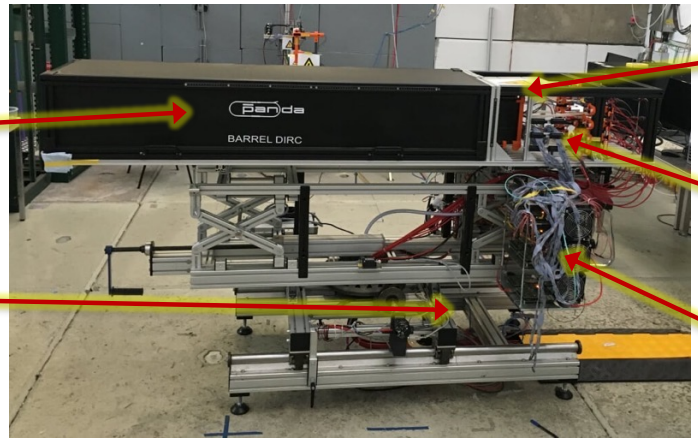




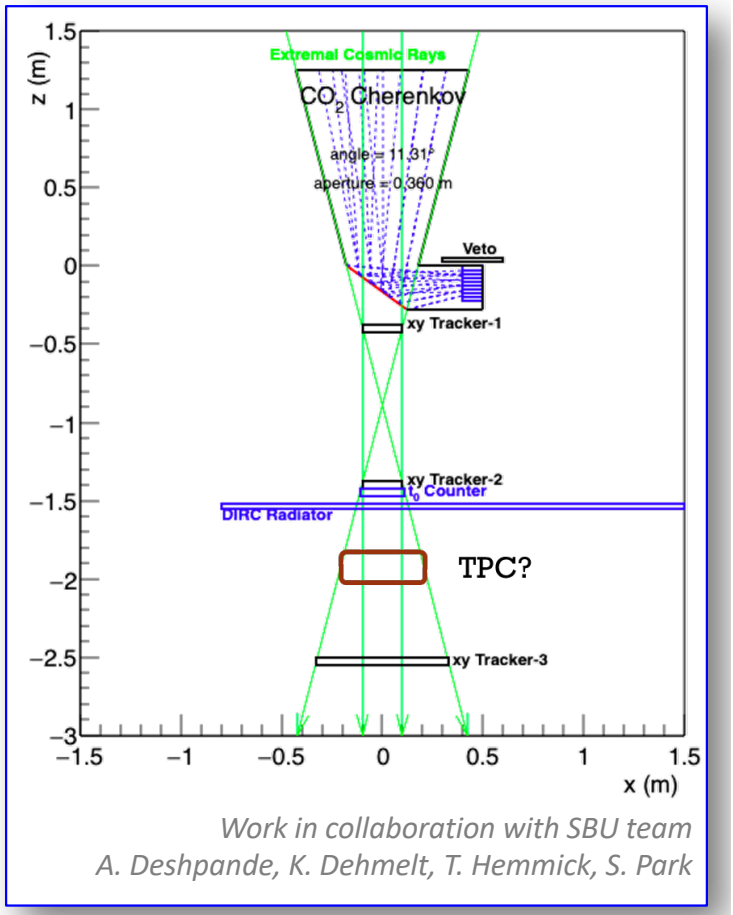
HPDIRC VALIDATION

- 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 beamtest at Fermilab in 2023

PANDA Barrel DIRC Prototype



Preliminary CRT arrangement at SBU



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

HPDIRC VALIDATION

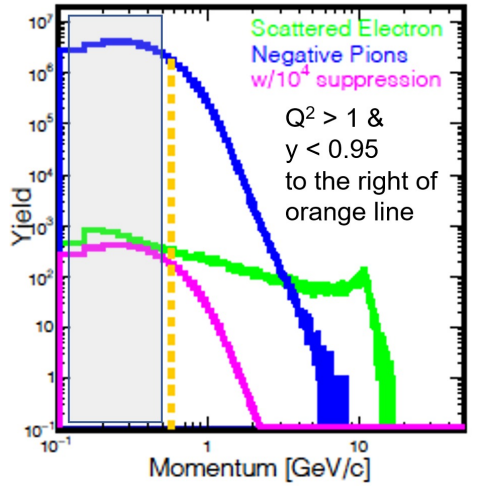
Performance opportunity: improve e/π separation at low momentum

- Yellow report effort identified need for supplemental e/π suppression from PID systems to support EM calorimeter at lower momentum
- Simulation shows that ID of scattered electron requires $O(10^4)$ suppression of large pionic background

- Detail simulation in progress
- Recent result, without special measures: > 3 s.d. e/π separation at 1.2 GeV/c (caveat: long non-Gaussian tails)
- Even "out-of-the-box" hpDIRC capable of very useful background suppression

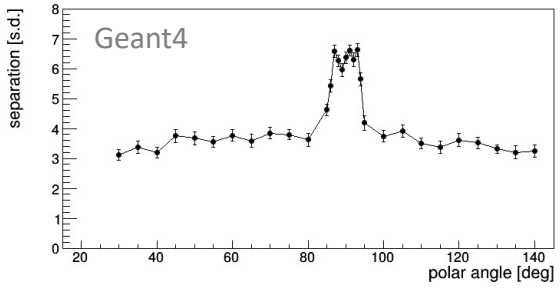
- Better performance possible, study use of post-DIRC tracking, "ring center fit", optimized DIRC geometry (bar width/thickness, bar/plate hybrid), etc.
- Post-DIRC tracking expected to further improve π/K separation at high momentum

-1.0 < η < 0.0 (half of DIRC Barrel)



Simulation by B. Schmookler

hpDIRC e/π separation at 1.2 GeV/c momentum



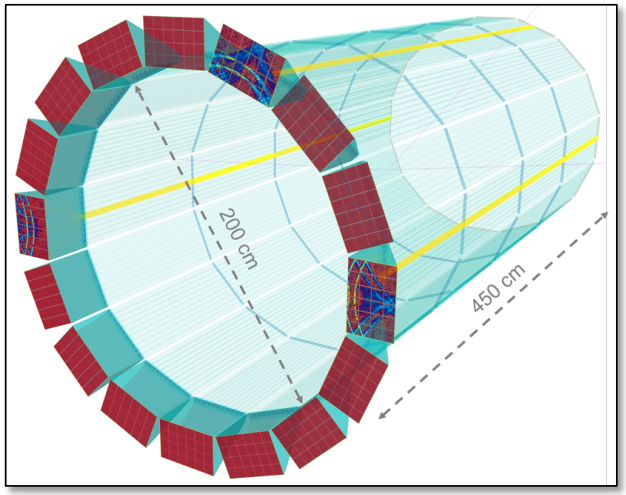
EIC HPDIRC DESIGN FACTS

EIC High-Performance DIRC (hpDIRC)

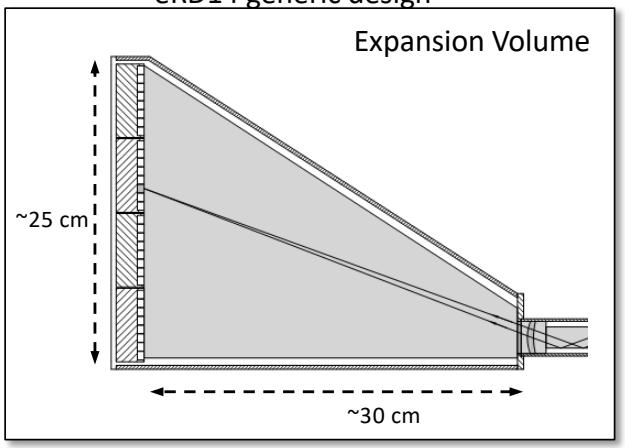
Expected performance: ≥ 3 s.d. π/K separation up to 6 GeV/c

- Generic reference design:
  16 sectors, one bar box and one expansion volume per sector
- Focusing optics:
  Radiation-hard 3-layer spherical lens
- Expansion volume:
  Solid fused silica prism: 24 x 36 x 30 cm^3 (H x W x L)
  Additional longitudinal space for MCP-PMTs, readout cards, cables: ~20cm
- Number of sectors, barrel radius and bar length can be optimized for integration, PID performance largely independent of barrel radius and bar length
- Expansion volume shape can be optimized for MCP-PMT magnetic field performance (tilted backplane) but length is directly related to performance

eRD14 generic design



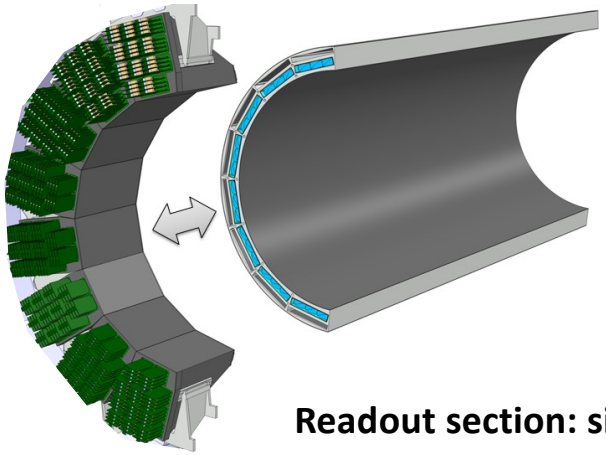
eRD14 generic design



DIRC Integration Example

Readout section

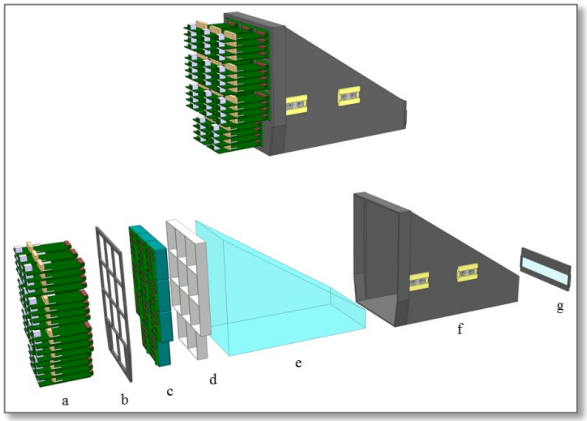
Bars section

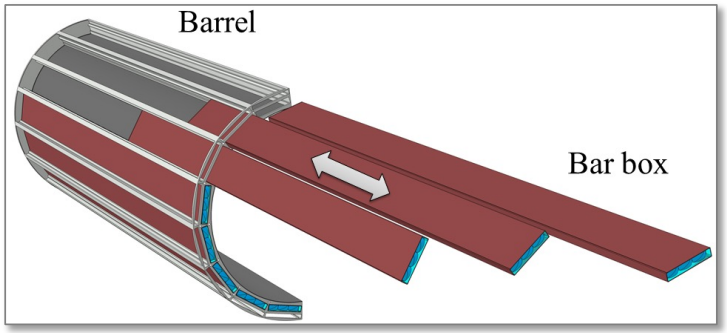


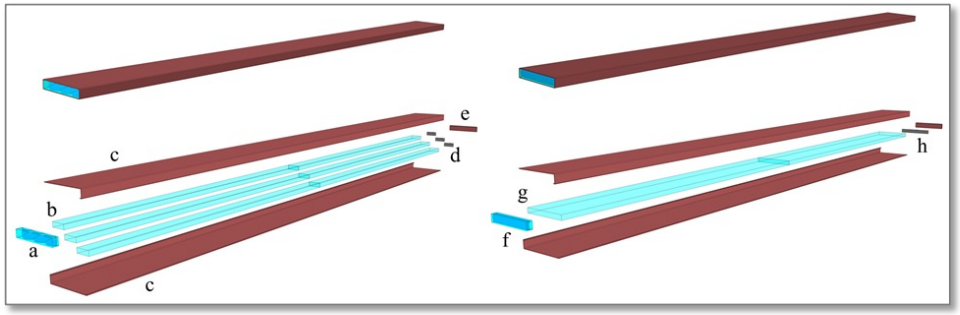
Example: Barrel DIRC in PANDA (smaller radius, shorter bars than hpDIRC)

- bars long enough to guide light to prism located outside crowded central region
- prism (30cm) inside B field, all mech. components aluminum alloy or CFRP
- modular design, bar boxes/prism boxes can be installed later or removed

Readout section: single unit







HPDIRC SUMMARY

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

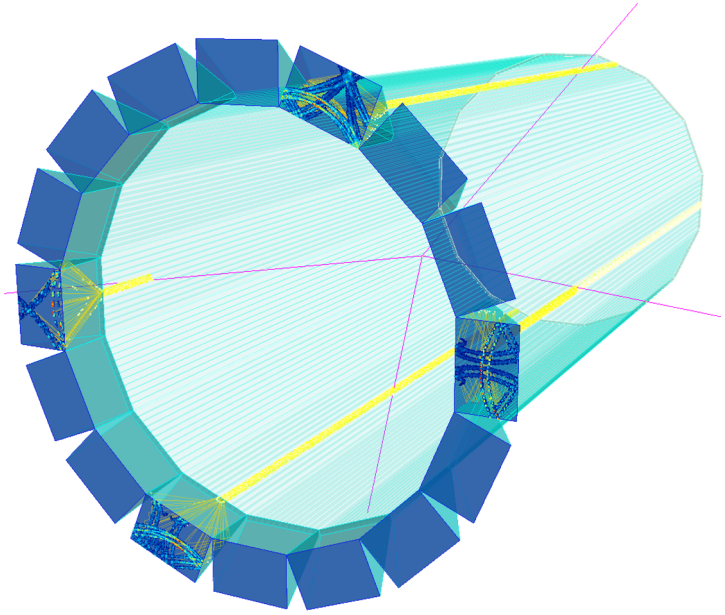
- Simulations show **excellent performance over wide angular range** (≥ 3 s.d. π/K up to at least 6 GeV/c, contribution to low momentum e/π)

- **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 the CORE concept**



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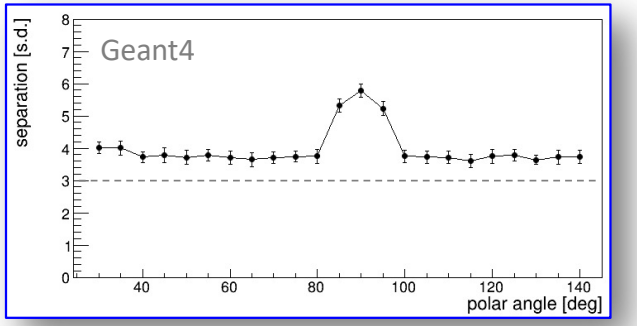
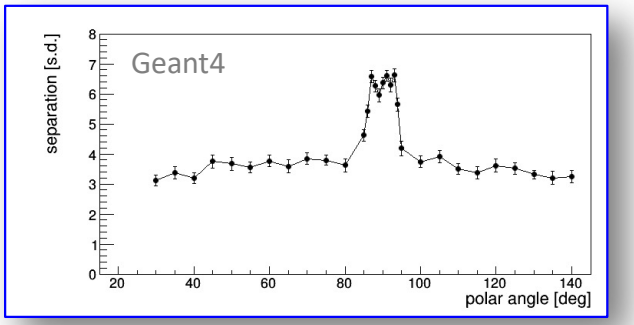
Expected π/K separation at 6 GeV/c



Expected e/π separation at 1.2 GeV/c



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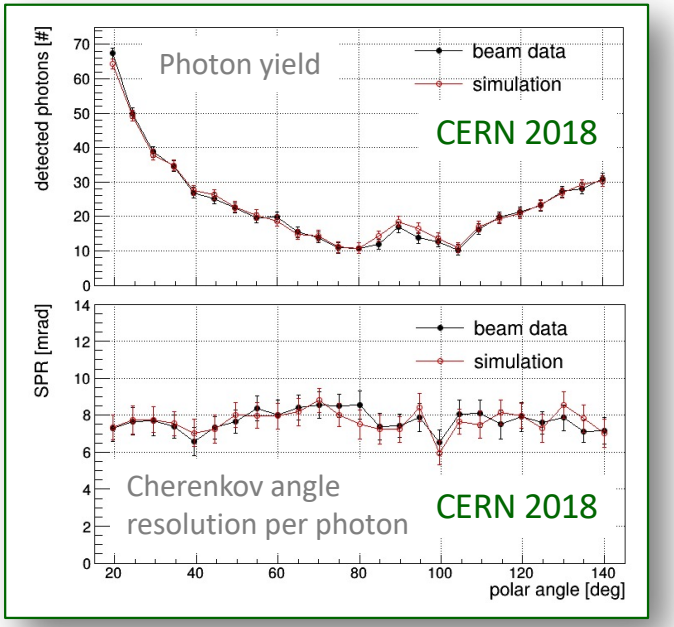

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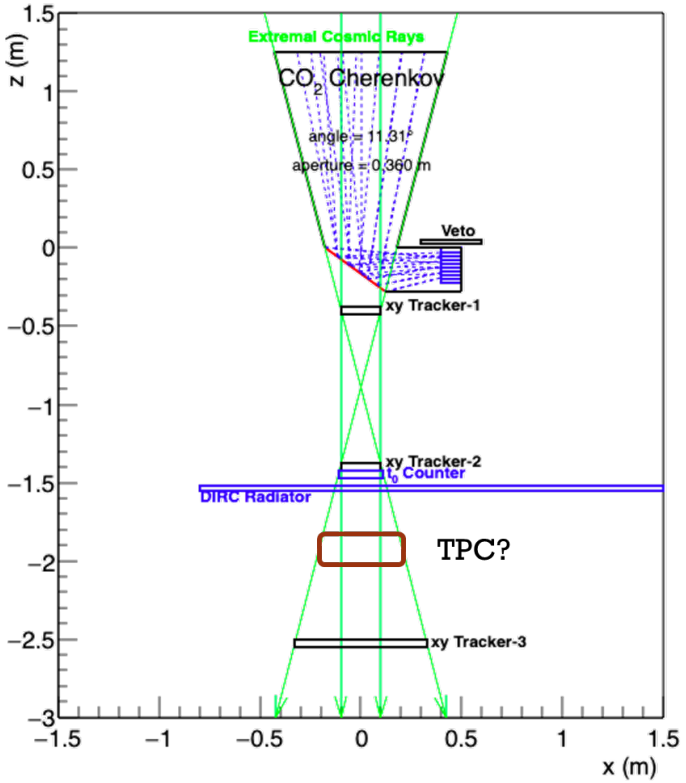

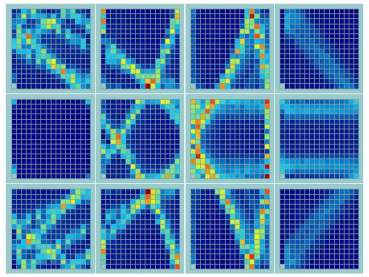

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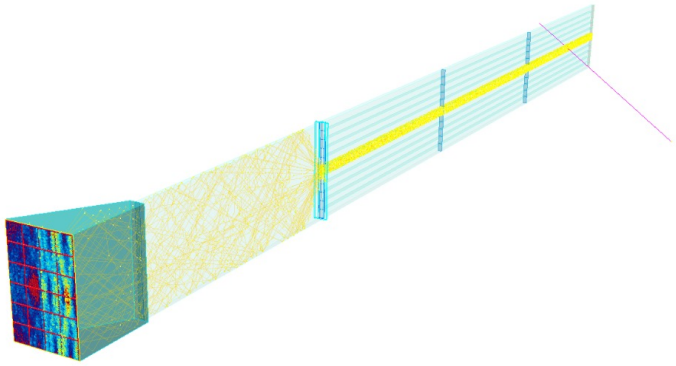
Hybrid of bars and plate in each sector



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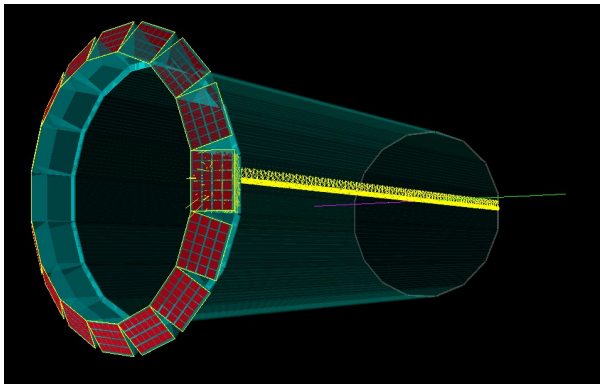

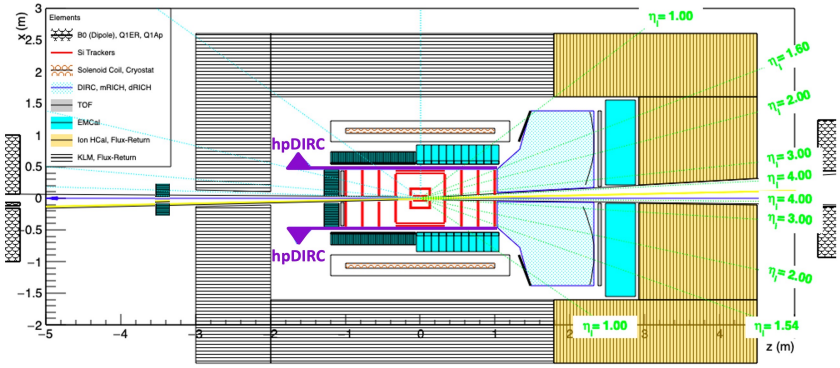

Thank you for your attention!