Particle Identification

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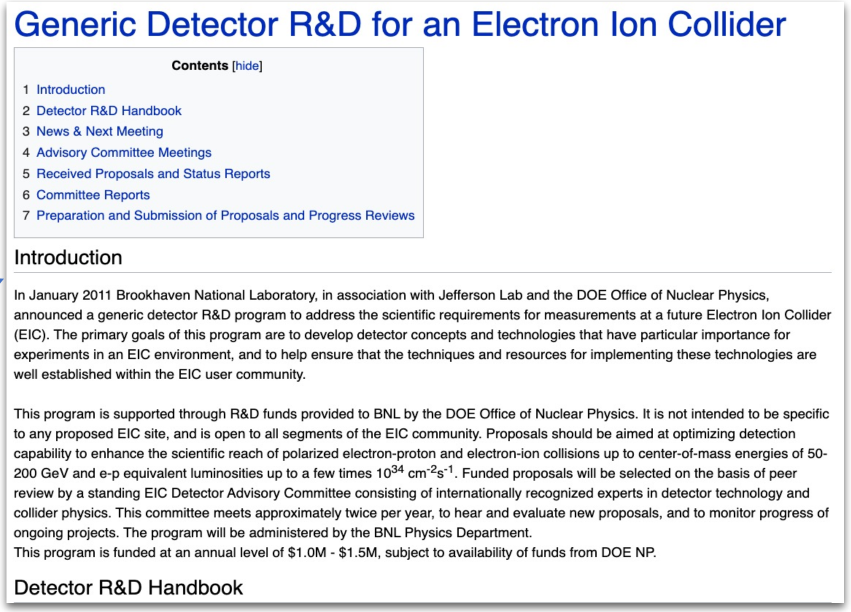
Bases of ECCE PID Technology Choices

- Closely follow the knowledge from a decade development of Generic EIC Detector R&D, especially from eRD14 (EIC PID Consortium)
- Closely follow the community effort documented in the EIC Yellow Report
- Rely on the experts who know the technology and can lead the effort
- Realize that the EIC project schedule is very aggressive, leaving limited room for new R&D

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D



Generic Detector R&D for an Electron Ion Collider

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1 Introduction
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3 News & Next Meeting
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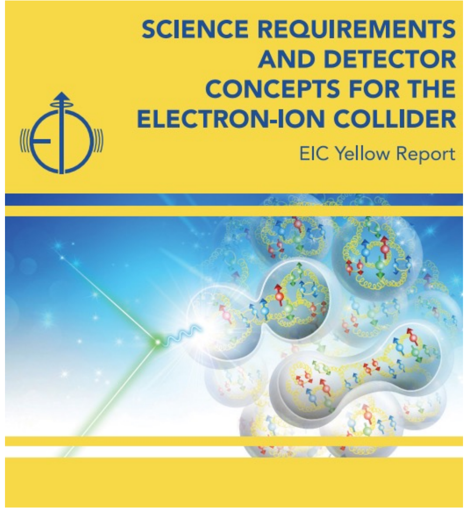
Introduction

In January 2011 Brookhaven National Laboratory, in association with Jefferson Lab and the DOE Office of Nuclear Physics, announced a generic detector R&D program to address the scientific requirements for measurements at a future Electron Ion Collider (EIC). The primary goals of this program are to develop detector concepts and technologies that have particular importance for experiments in an EIC environment, and to help ensure that the techniques and resources for implementing these technologies are well established within the EIC user community.

This program is supported through R&D funds provided to BNL by the DOE Office of Nuclear Physics. It is not intended to be specific to any proposed EIC site, and is open to all segments of the EIC community. Proposals should be aimed at optimizing detection capability to enhance the scientific reach of polarized electron-proton and electron-ion collisions up to center-of-mass energies of 50-200 GeV and e-p equivalent luminosities up to a few times 10^{34} $cm^{-2}s^{-1}$. Funded proposals will be selected on the basis of peer review by a standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology and collider physics. This committee meets approximately twice per year, to hear and evaluate new proposals, and to monitor progress of ongoing projects. The program will be administered by the BNL Physics Department.
This program is funded at an annual level of $1.0M - $1.5M, subject to availability of funds from DOE NP.

Detector R&D Handbook



http://www.eicug.org/web/sites/default/files/Yellow_Report_v1.1.pdf

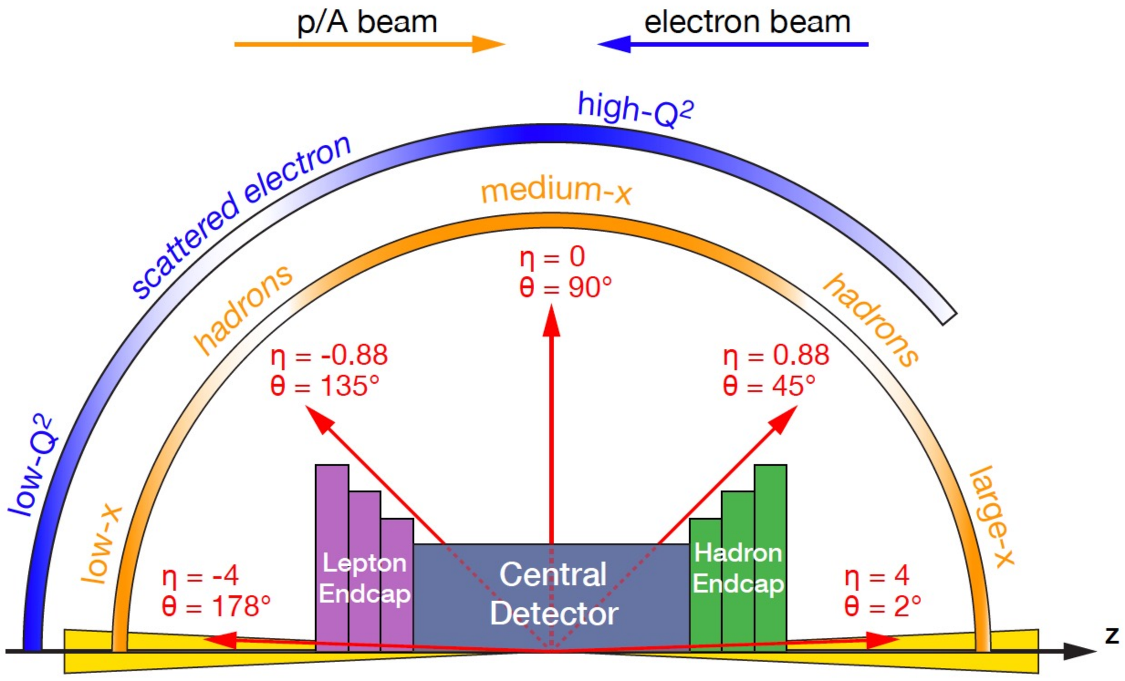


Figure 2.2: Schematic showing the distribution of the scattered lepton and hadrons for different $x - Q^2$ regions over the detector polar angle / pseudorapidity coverage.

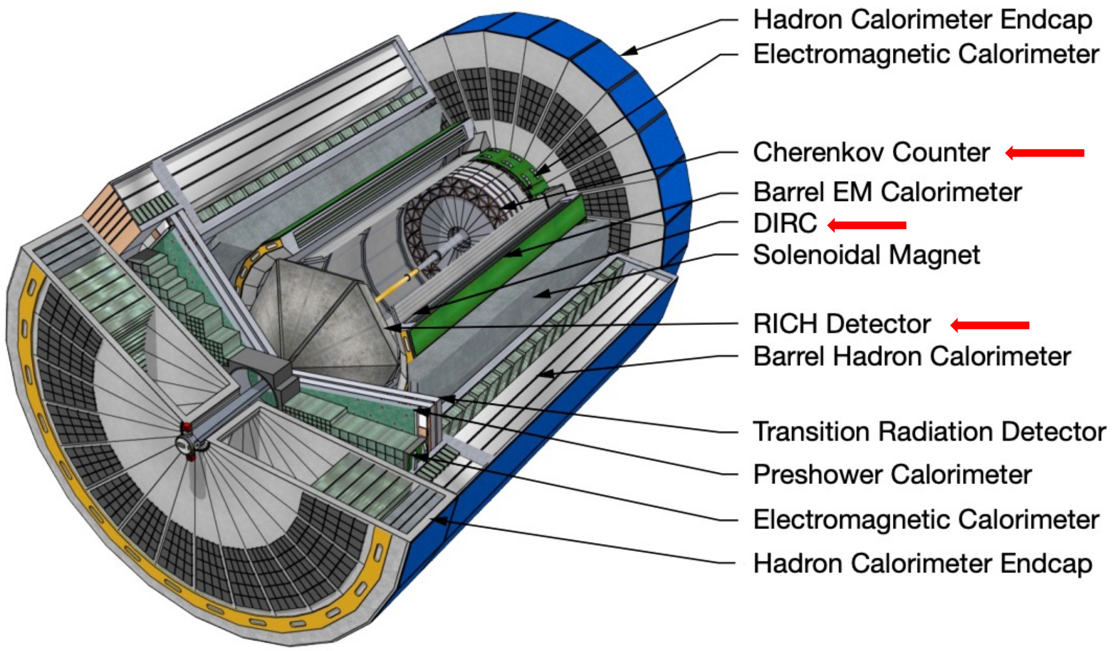


Figure 9.2: A cutaway illustration of a generic EIC concept detector.

From EIC Yellow Report

Table 8.20: Summary of the Physics Working Group detector requirement

η	Nomenclature			Tracking				Electrons and Photons			π/K/p PID		HCAL		Muons
				Min p_T	Resolution	Allowed X/X_0	Si-Vertex	Min E	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Min E	Resolution σ_E/E	
-6.9 — -5.8			low-Q^2 tagger		$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2										
...	↓ p/A	Auxiliary Detectors													
-4.5 — -4.0			Instrumentation to separate charged particles from γ												
-4.0 — -3.5														~50%/√E+6%	
-3.5 — -3.0									2%/√E+(1-3)%						
-3.0 — -2.5					$\sigma_p/p \sim 0.1\% \times p + 2.0\%$		$\sigma_{xy} \sim 30\mu m/p_T + 40\mu m$								
-2.5 — -2.0			Backwards Detectors											~45%/√E+6%	
-2.0 — -1.5					$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		$\sigma_{xy} \sim 30\mu m/p_T + 20\mu m$				≤ 7 GeV/c				
-1.5 — -1.0									7%/√E+(1-3)%	π suppression up to 1:10^4					
-1.0 — -0.5															
-0.5 — 0.0		Central Detector		100 MeV π		~5% or less		50 MeV					~500 MeV		
0.0 — 0.5			Barrel		$\sigma_p/p \sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ μm, $d_0(z) \sim d_0(r\varphi) \sim 20/p_T$ GeV μm + 5 μm				≤ 10 GeV/c	≥ 3σ		~85%/√E+7%	Useful for bkg, improve resolution
0.5 — 1.0				135 MeV K							≤ 15 GeV/c				
1.0 — 1.5									(10-12)%/√E+(1-3)%		≤ 30 GeV/c				
1.5 — 2.0					$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		$\sigma_{xy} \sim 30\mu m/p_T + 20\mu m$								
2.0 — 2.5			Forward Detectors							3σ e/π	≤ 50 GeV/c			~35%/√E	
2.5 — 3.0							$\sigma_{xy} \sim 30\mu m/p_T + 40\mu m$				≤ 30 GeV/c				
3.0 — 3.5					$\sigma_p/p \sim 0.1\% \times p + 2.0\%$		$\sigma_{xy} \sim 30\mu m/p_T + 60\mu m$				≤ 45 GeV/c				
[illegible]			Instrumentation to separate charged particles from γ												
4.0 — 4.5															
...	↑e	Auxiliary Detectors													
> 6.2			Proton Spectrometer		$\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c										

Momentum-driven Technology Choices

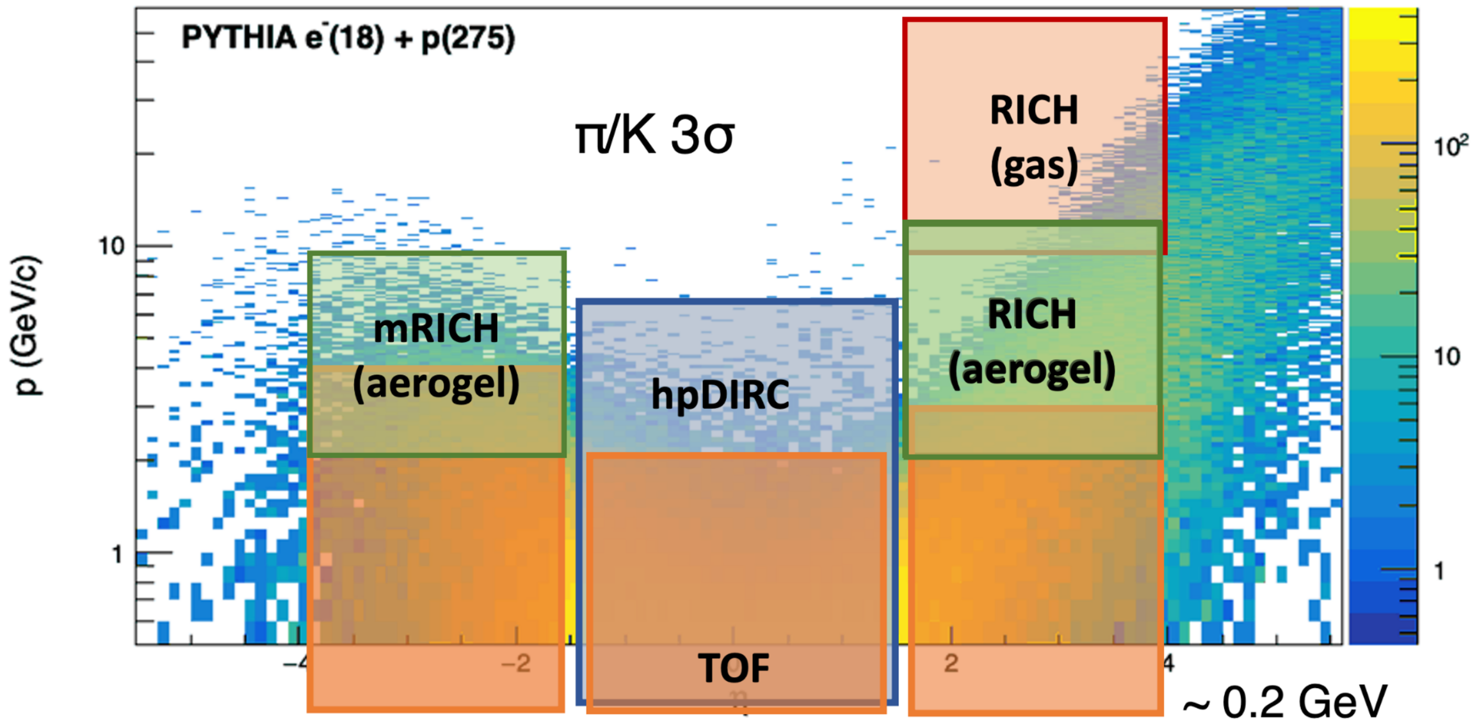


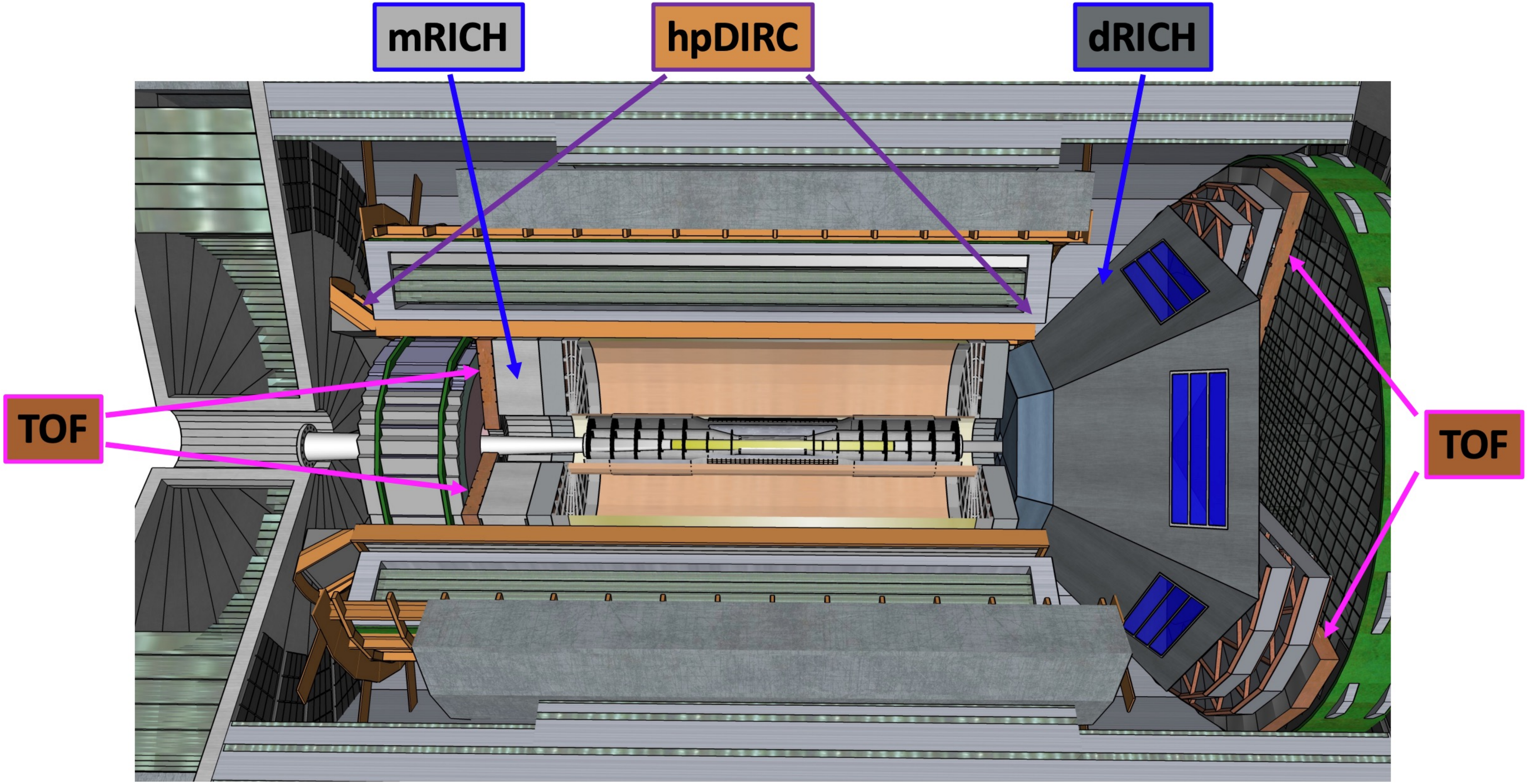
Table 8.6 Requested PID momentum coverage for 3σ pion/kaon separation. (Yellow Report)

Pseudorapidity Range	Momentum Range
$-3.5 < \eta < -1.0$	≤ 7 GeV/c
$-1.0 < \eta < 0.5$	≤ 10 GeV/c
$0.5 < \eta < 1.0$	≤ 15 GeV/c
$1.0 < \eta < 1.5$	≤ 30 GeV/c
$1.5 < \eta < 2.5$	≤ 50 GeV/c
$2.5 < \eta < 3.0$	≤ 30 GeV/c
$3.0 < \eta < 3.5$	≤ 20 GeV/c

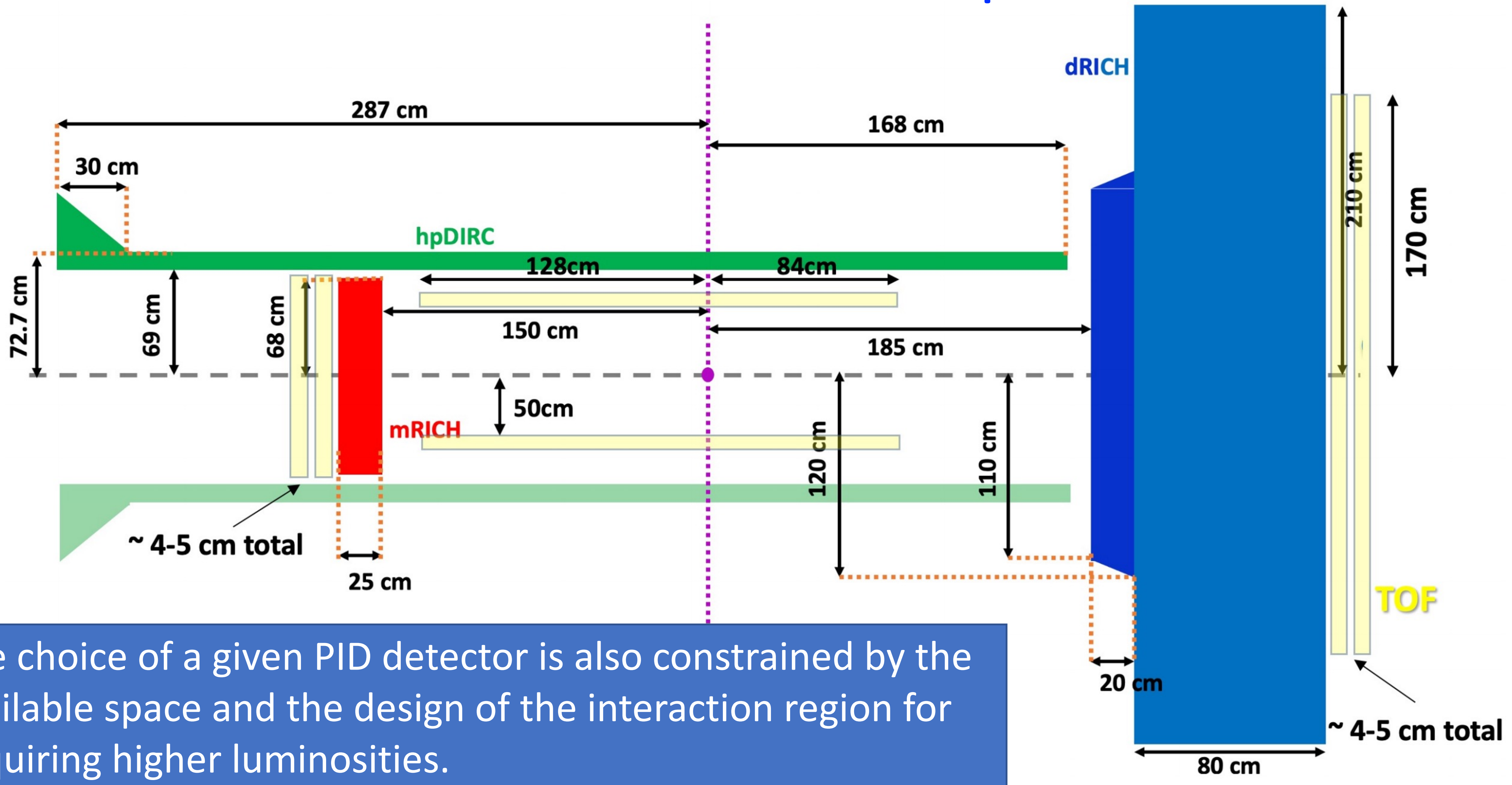
TOF

Extends PID coverage to lower momentum range and complements the RICH-based PID coverage. In the barrel region, hpDIRC and TOF provide an overlapping coverage from ~200 MeV/c to 2 GeV/c.

PID Detectors in ECCE

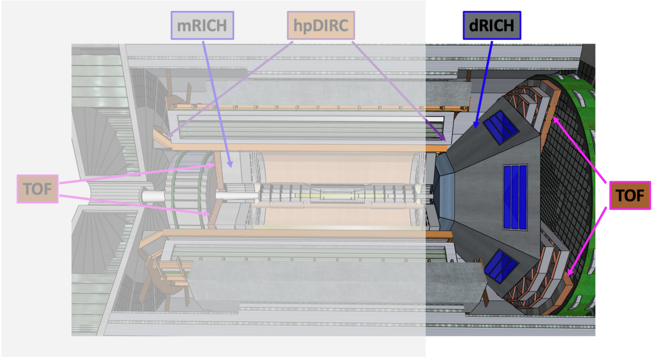


Overall Dimension and the Allocated Space

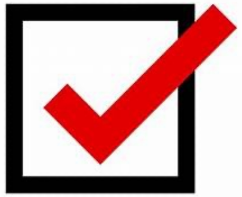


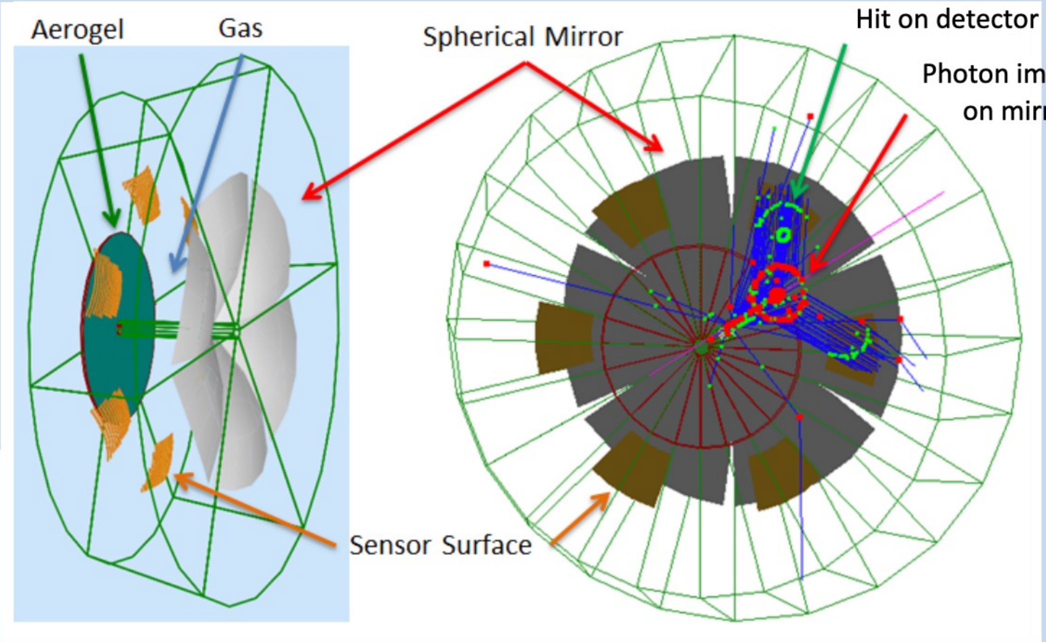
The choice of a given PID detector is also constrained by the available space and the design of the interaction region for acquiring higher luminosities.

dRICH in Hadron Endcap (Forward)



ECCE





INFN Duke University Georgia State University Stony Brook University

dRICH: effective solution, part of reference detector

Radiators: Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6}~ 1.0008)

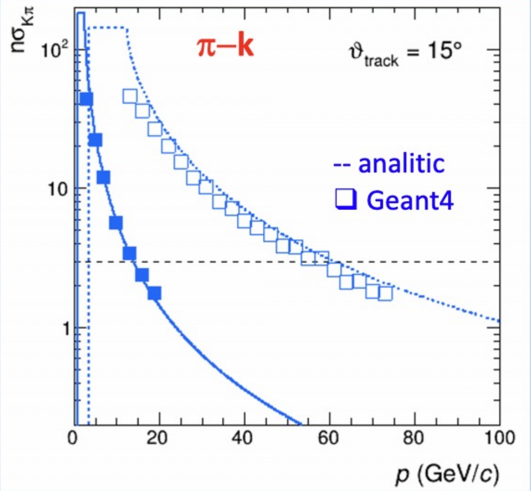
Detector: 0.5 m^2/sector , 3x3 mm^2 pixel

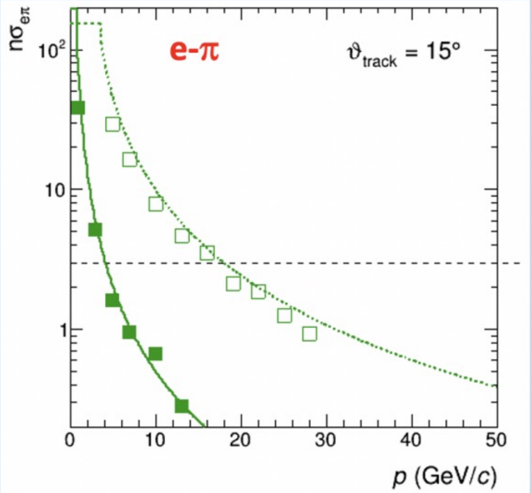
Single-photon detection in ~1T magnetic field

Outside acceptance, reduced constraints

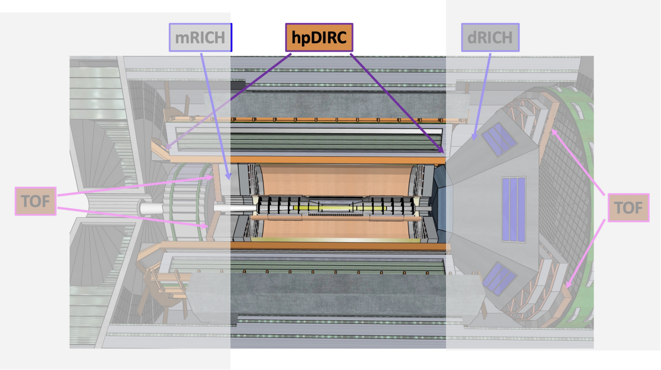
→ best candidate for SiPM option

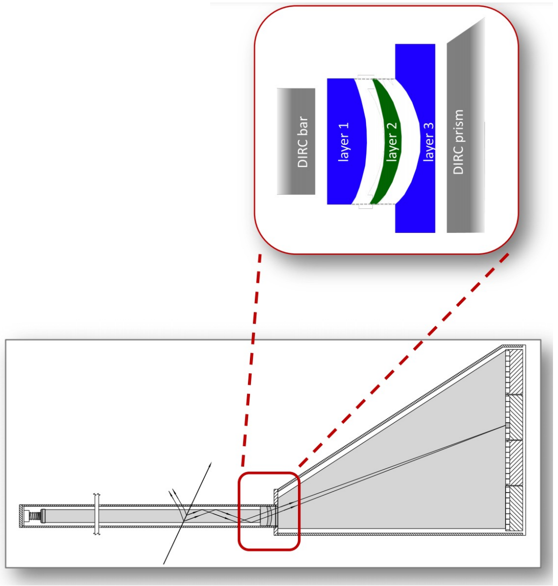
- Polar angle: 5-25 deg
- Momentum: 3-60 GeV/c
- Magnet: 3T Solenoid





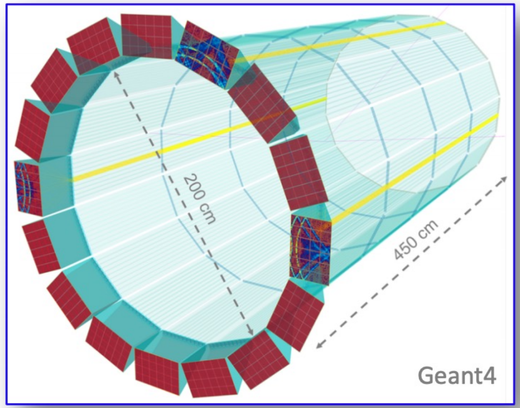
hpDIRC for Central Barrel





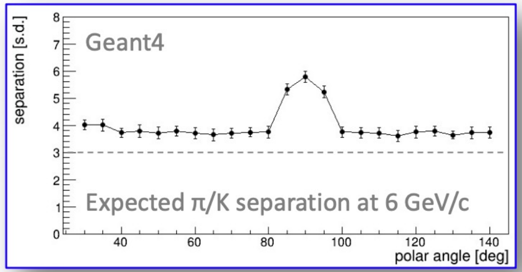
High-Performance DIRC Goal:

- 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.



Concept:

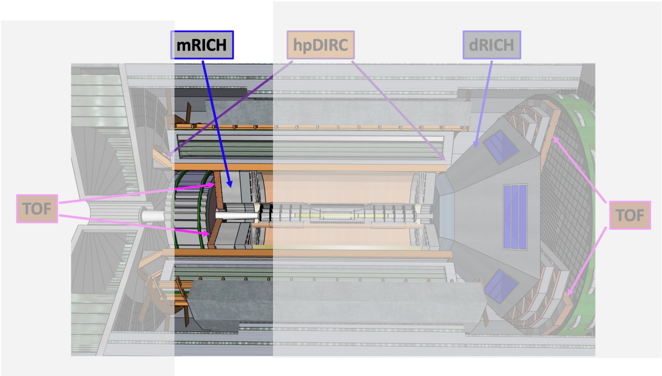
- Fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction
- Initial generic design (based on BaBar DIRC, R&D for SuperB FDIRC, PANDA Barrel DIRC): narrow fused silica bars, 1m barrel radius, 4.5m barrel length *(barrel length and radius to be optimized for detector integration - no impact 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



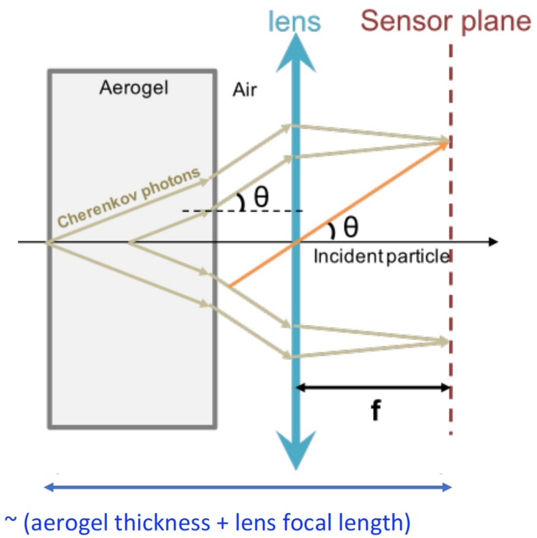
3-layer compound lens creates flat focal plane (matched to the fused silica prism shape.

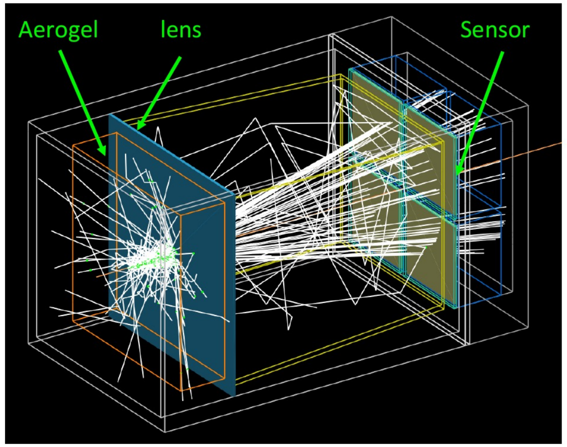
Successfully produced prototype lenses and validated performance in PANDA Barrel DIRC prototype.

mRICH in Electron Endcap (Backward)



EIC mRICH – Working Principle

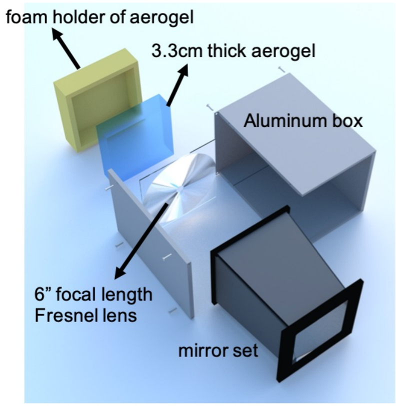


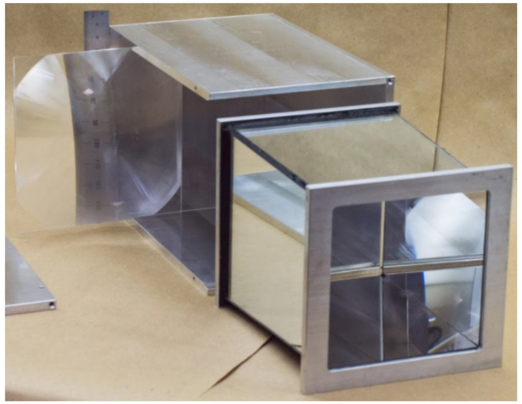


Geant4 Simulation

Compact, modular and projective

mRICH is designed for K/π separation in a momentum range from 3 to 10 GeV/c and e/π separation below 2 GeV/c.

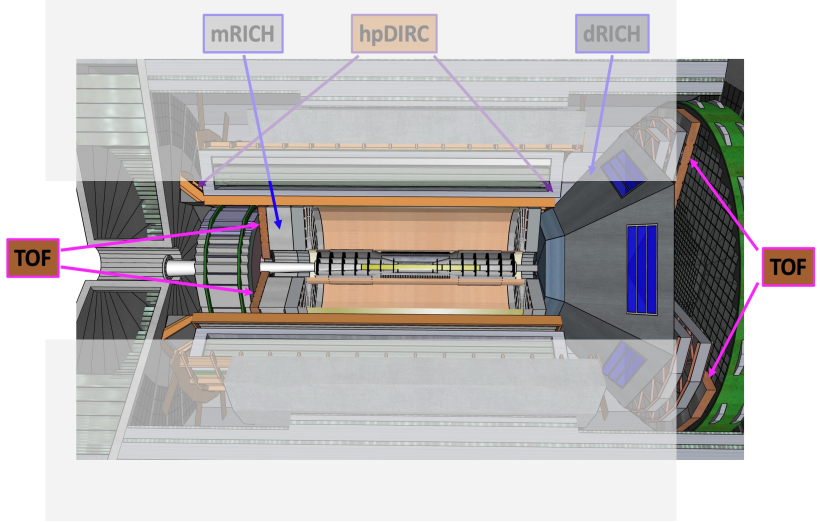




Beam tests in 2016 and 2018 at Fermilab for verifying mRICH working principle and performance; 2021 test at Fermilab with LAPPD photosensor (characterization!); Another test is planned in late August at Jlab with GEM tracker.

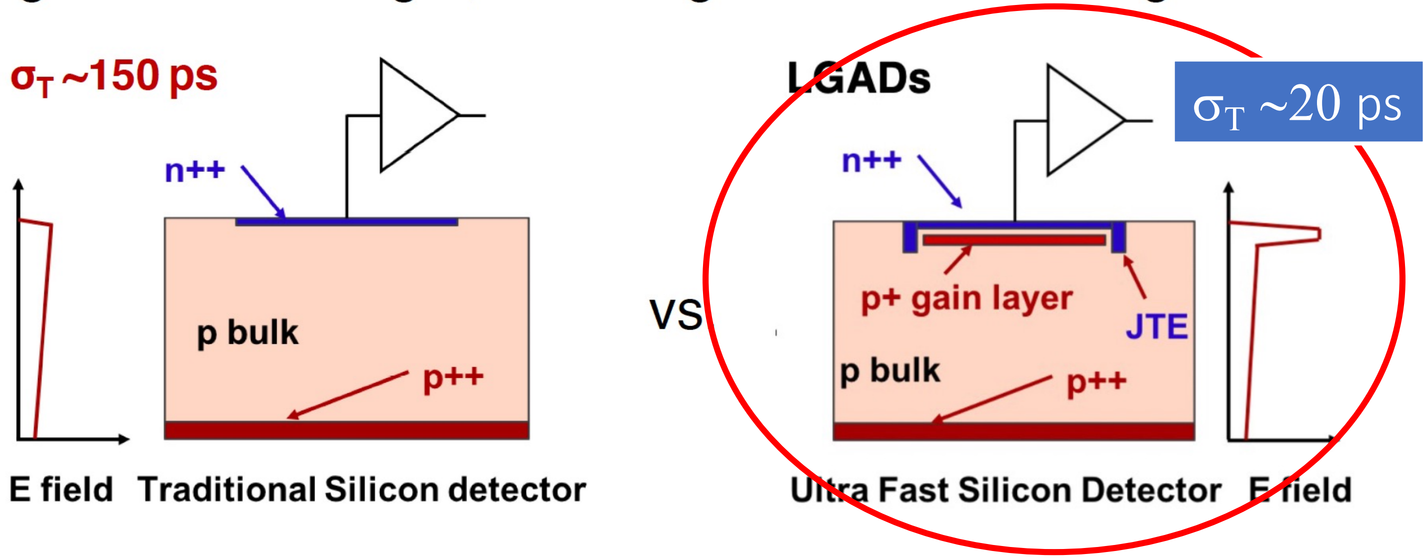
LGADs-Based TOF for ECCE

From Wei Li at Rice University



Low Gain Avalanche Diodes (LGADs)

High E field → larger, faster signal → better timing resolution



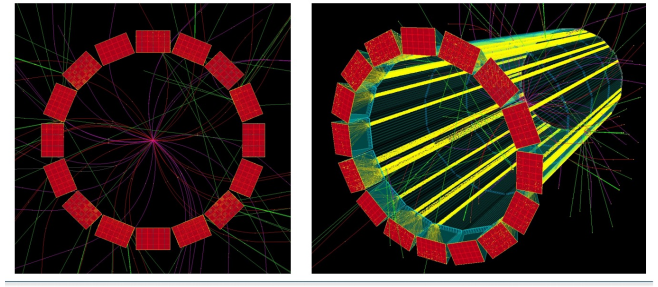
Adding an extra doping layer (E ~ 300 kV/cm, close to breakdown)

LGADs potentially provide both PID at low momentum and a space point for particle tracking.

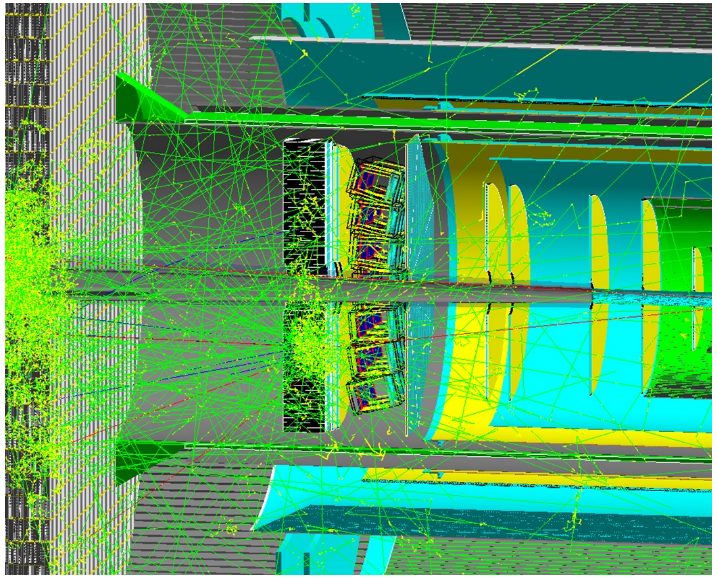
Mechanical construction for ECCE? Need help from Wei Li
And other experts!!!

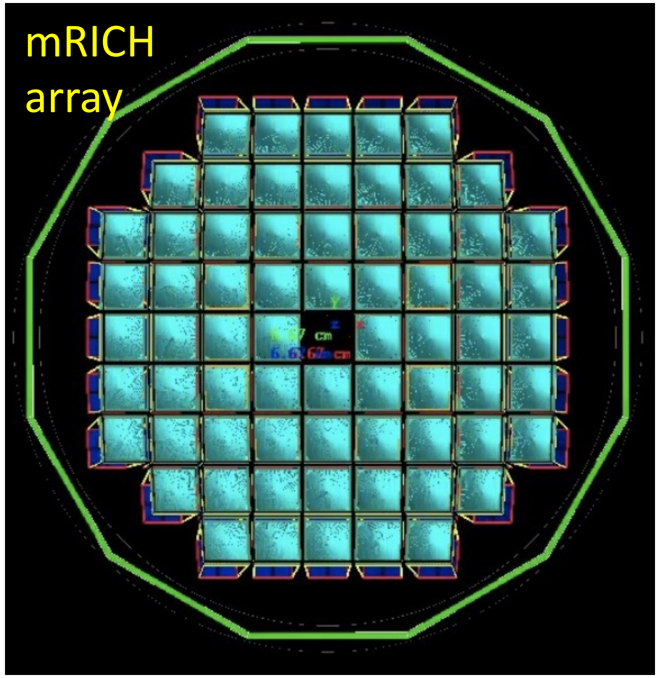
Full GEANT4-based Simulation (Fun4All Framework)

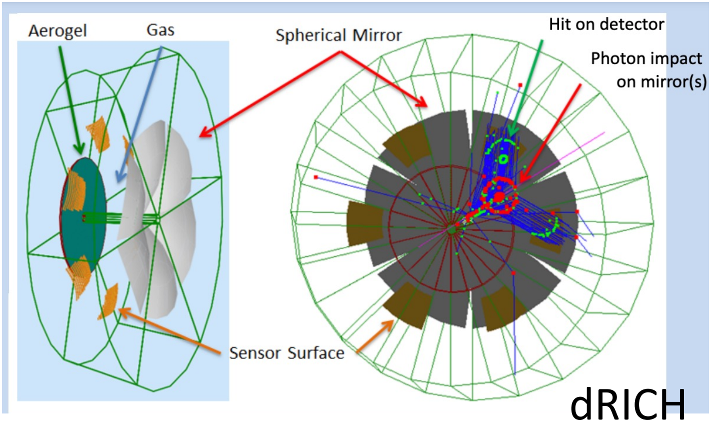
hpDIRC



Integrated ECCE GEANT4 Simulation







Integrated Performance Tests via Simulation

A plot from each of the PID detector

Work in progress

Photosensors and Readout Electronics

- There has been a parallel effort in eRD14 for searching/testing/developing single-photon sensors and the associated readout electronics for RICH-based PID detectors. The ultimate sensors need to be functioning well inside magnetic field.
  - ANL group led the effort of MCP-PMT and LAPPD development.
  - Hawaii and INFN group led the readout electronics development.
- The pixel-size is 3mm x 3mm or smaller in order to achieve the required single-photon angular resolution for 3σ K/π separation.
- We have tested a few commercially available sensors: Hamamatsu H13700, S12642 MPPC (SiPM matrix), and a LAPPD (development version from Incom).
- More study continues.

Summary

- The choices of the ECCE PID technology are based extensively on the knowledge from the EIC Generic Detector R&D project – eRD14.
- ECCE PID strategy is closely aligned with the reference design documented in the EIC Yellow Report for achieving its scientific goals.
- All PID detectors (dRICH, hpDIRC, mRICH and TOF) have been implemented in full GEANT4 simulation with realistic material (i.e., optical) properties in ECCE simulation framework.
- The PID detector performance at the integrated system level (e.g. tracking quality) has started.

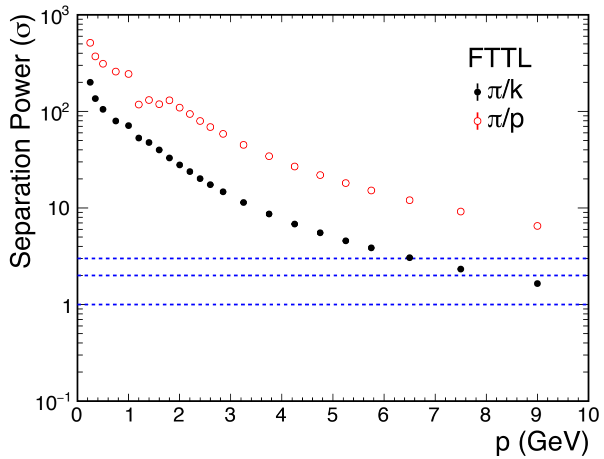
Physics -> EIC -> ECCE -> PID

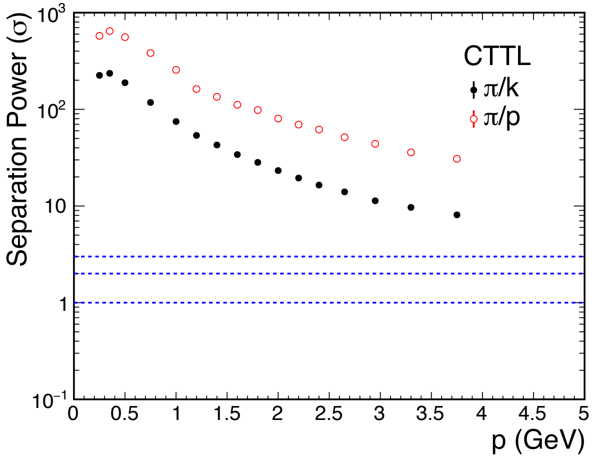
PID Realization in ECCE

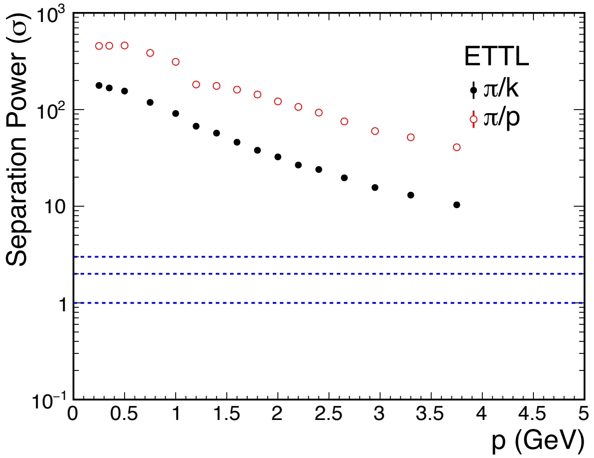
ECCE TOF PID Performance

Forward ($1<\eta<3.5$) | Central ($|\eta|<1$) | Backward ($-3.5<\eta<-1$)

$\sigma_t = 0$ ps

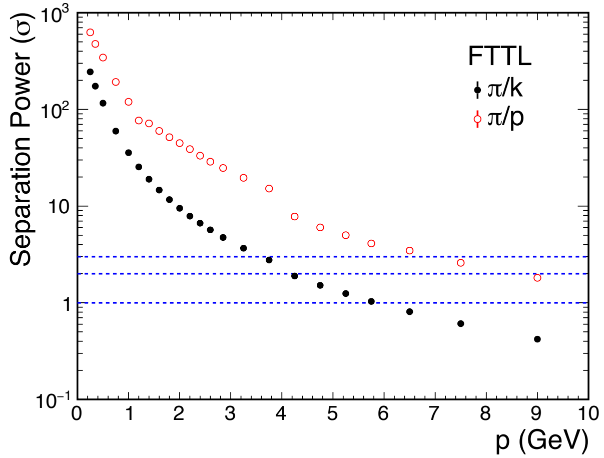




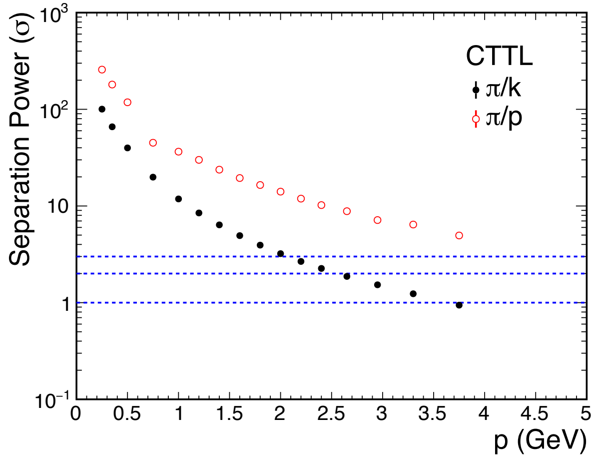


all uncertainties (t_0, t_f, L) included

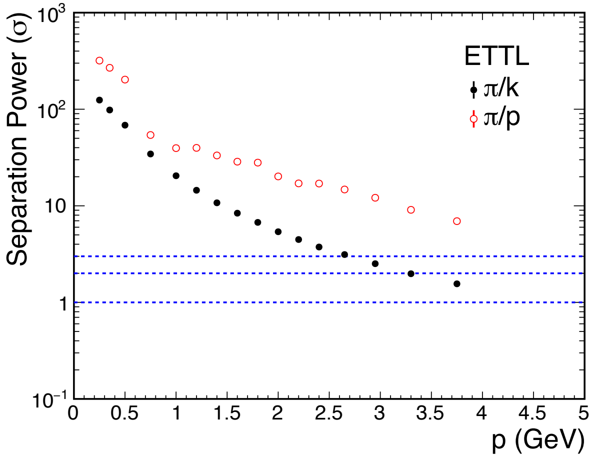
$\sigma_t = 20$ ps



0.2-4 GeV



0.2-2.5 GeV



0.2-3 GeV

Radiation Dose Level Distribution

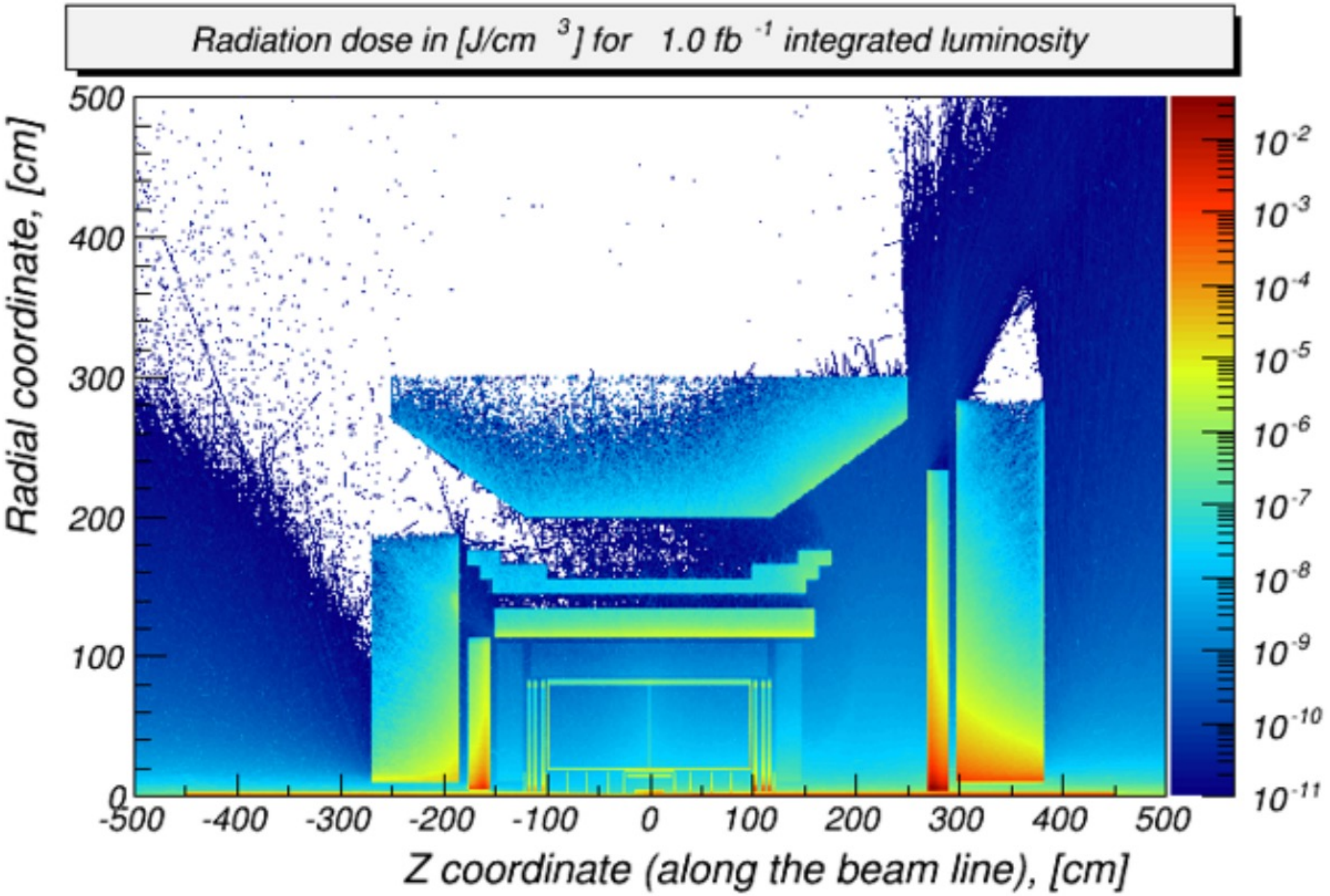


Figure 10.7: Ionizing radiation energy deposition from e+p collision at $\sqrt{s_{ep}}$ = 140 GeV studied using the BeAST detector concept, which also applies to the reference EIC detector as in this report.