Particle Identification

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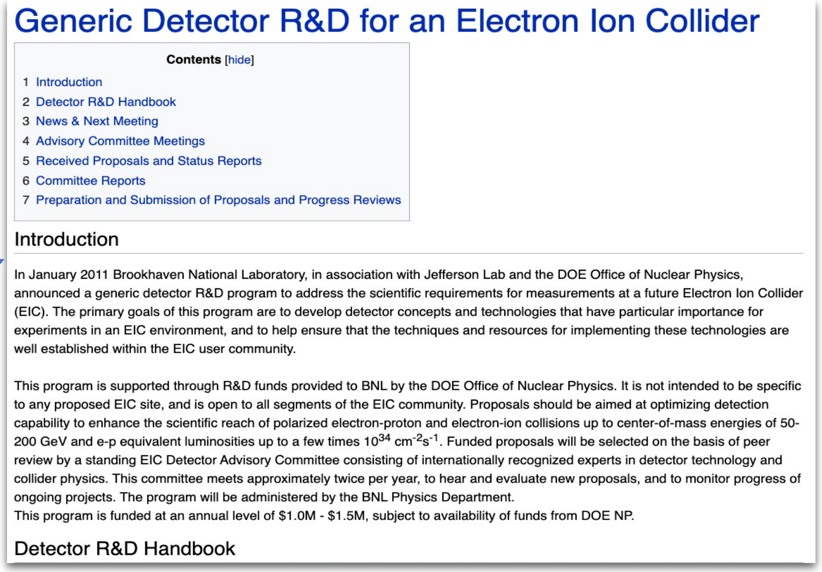
Bases of ECCE PID Technology Choices

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



Generic Detector R&D for an Electron Ion Collider

Contents [hide]

1 Introduction
2 Detector R&D Handbook
3 News & Next Meeting
4 Advisory Committee Meetings
5 Received Proposals and Status Reports
6 Committee Reports
7 Preparation and Submission of Proposals and Progress Reviews

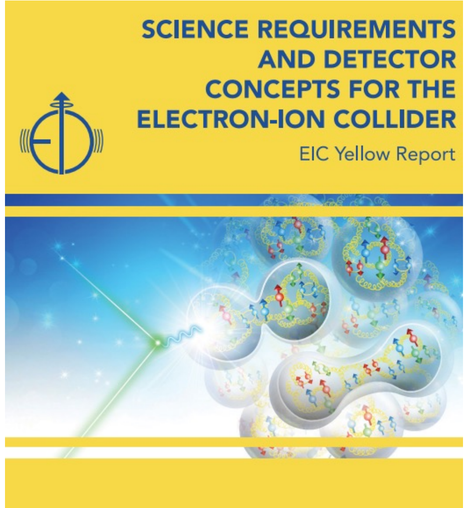
Introduction

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

- 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



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

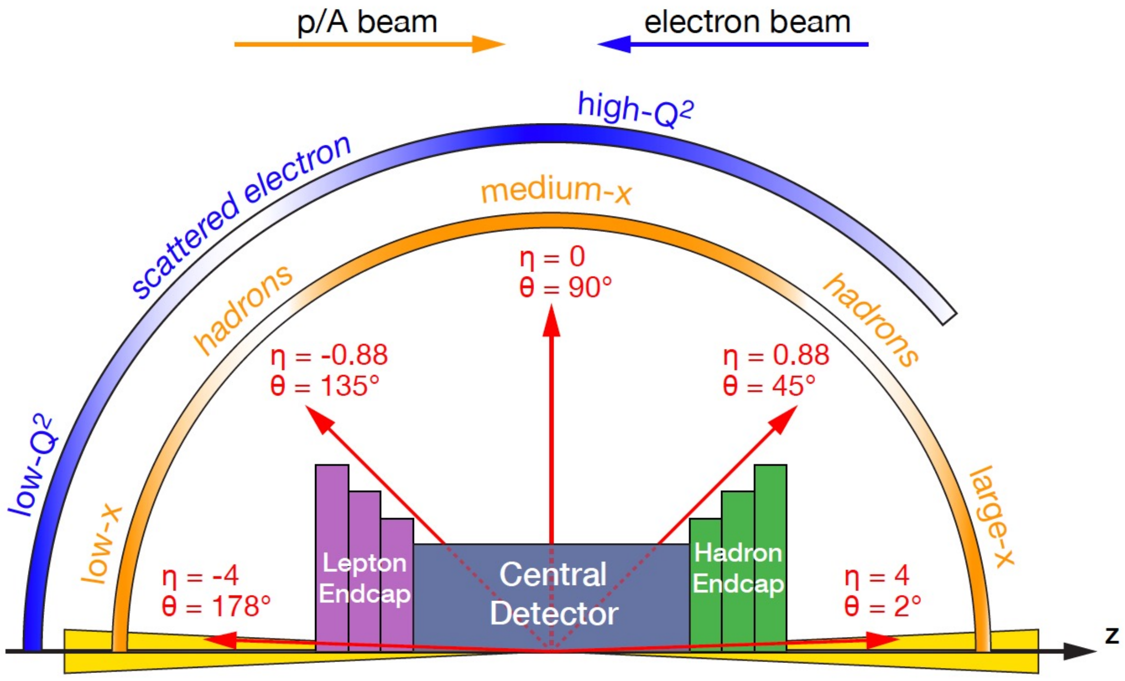


Figure 2.2: Schematic showing the distribution of the scattered lepton and hadrons for different $x - Q^2$ regions over the detector polar angle / pseudorapidity coverage.

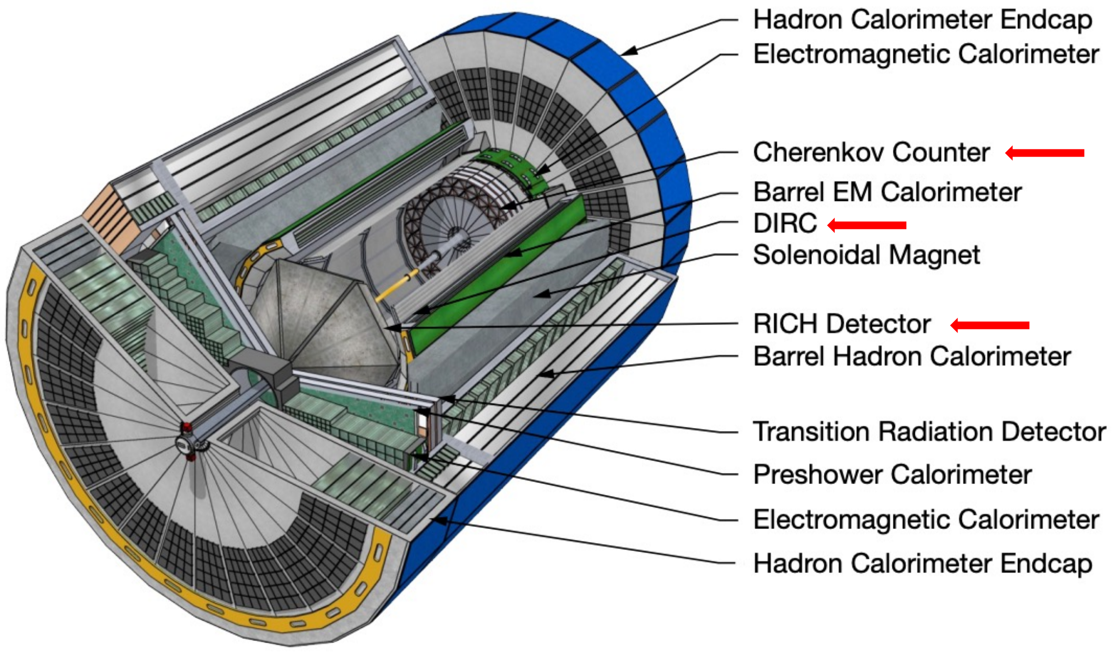


Figure 9.2: A cutaway illustration of a generic EIC concept detector.

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	↓ p/A	Auxiliary Detectors	low-Q^2 tagger		$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2										
…															
-4.5 — -4.0			Instrumentation to separate charged particles from γ						2%/√E+(1-3)%						
-4.0 — -3.5														~50%/√E+6%	
-3.5 — -3.0		Central Detector	Backwards Detectors	1[illegible]0 MeV π 1[illegible]5 MeV K	σ_p/p ~ 0.1%×p+2.0%	~5% or less		50 MeV		π suppression up to 1:10^4	≤ 7 GeV/c	≥ 3σ	~500 MeV	~45%/√E+6%	Useful for bkg, improve resolution
-3.0 — -2.5							σ_{xy}~30μm/p_T+ 40μm								
-2.5 — -2.0					σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+ 20μm								
-2.0 — -1.5									7%/√E+(1-3)%						
-1.5 — -1.0															
-1.0 — -0.5			Barrel		σ_p/p ~ 0.05%×p+0.5%		σ_{xyz} ~ 20 μm, $d_0(z)$ ~ $d_0(r\varphi)$ ~ 20/p_T GeV μm + 5 μm		(10-12)%/√E+(1-3)%		≤ 10 GeV/c			~85%/√E+7%	
-0.5 — 0.0															
0.0 — 0.5															
0.5 — 1.0											≤ 15 GeV/c				
1.0 — 1.5			Forward Detectors		σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+ 20μm			3σ e/π	≤ 30 GeV/c			~35%/√E	
1.5 — 2.0											≤ 50 GeV/c				
2.0 — 2.5															
2.5 — 3.0					σ_p/p ~ 0.1%×p+2.0%		σ_{xy}~30μm/p_T+ 40μm				≤ 30 GeV/c				
3.0 — 3.5							σ_{xy}~30μm/p_T+ 60μm				≤ 45 GeV/c				
3.5 — 4.0	↑e	Auxiliary Detectors	Instrumentation to separate charged particles from γ												
4.0 — 4.5															
…															
> 6.2			Proton Spectrometer		$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c										

Momentum-driven Technology Choices

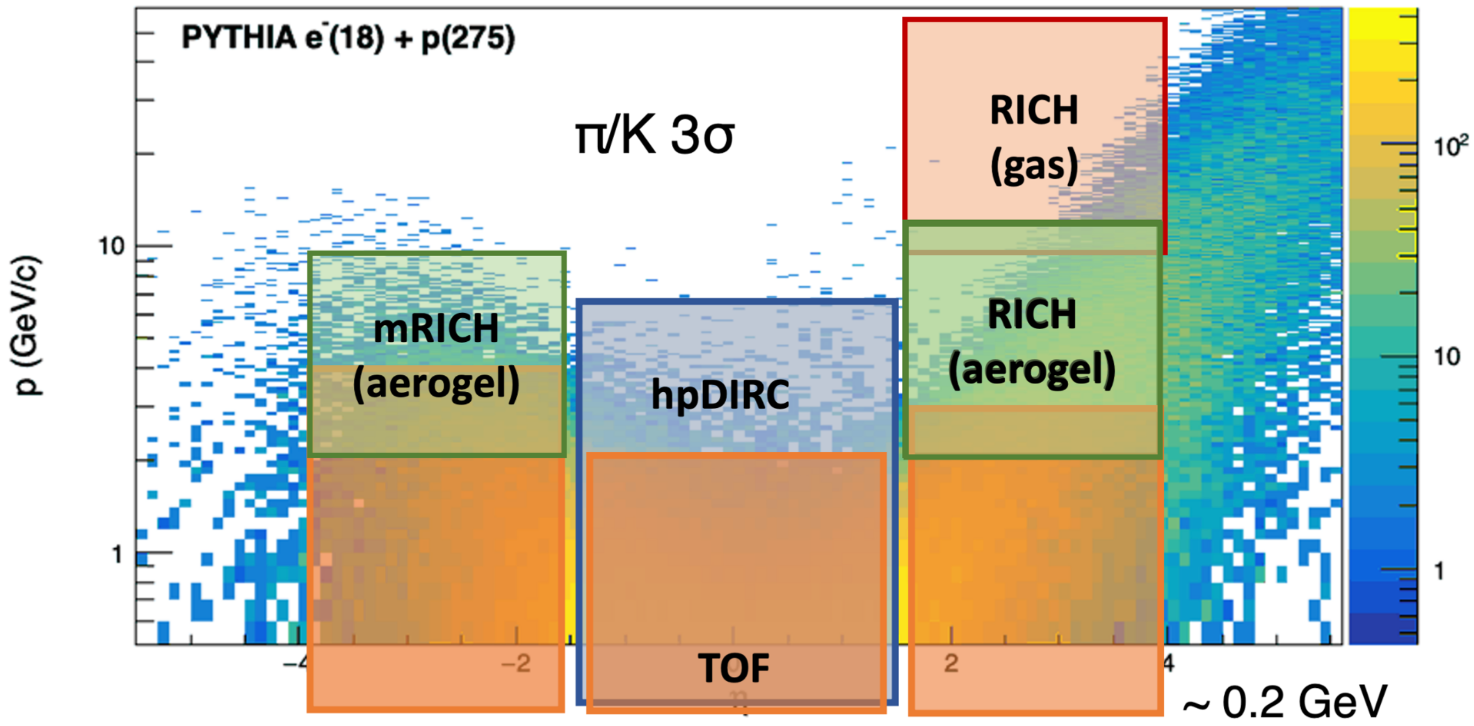


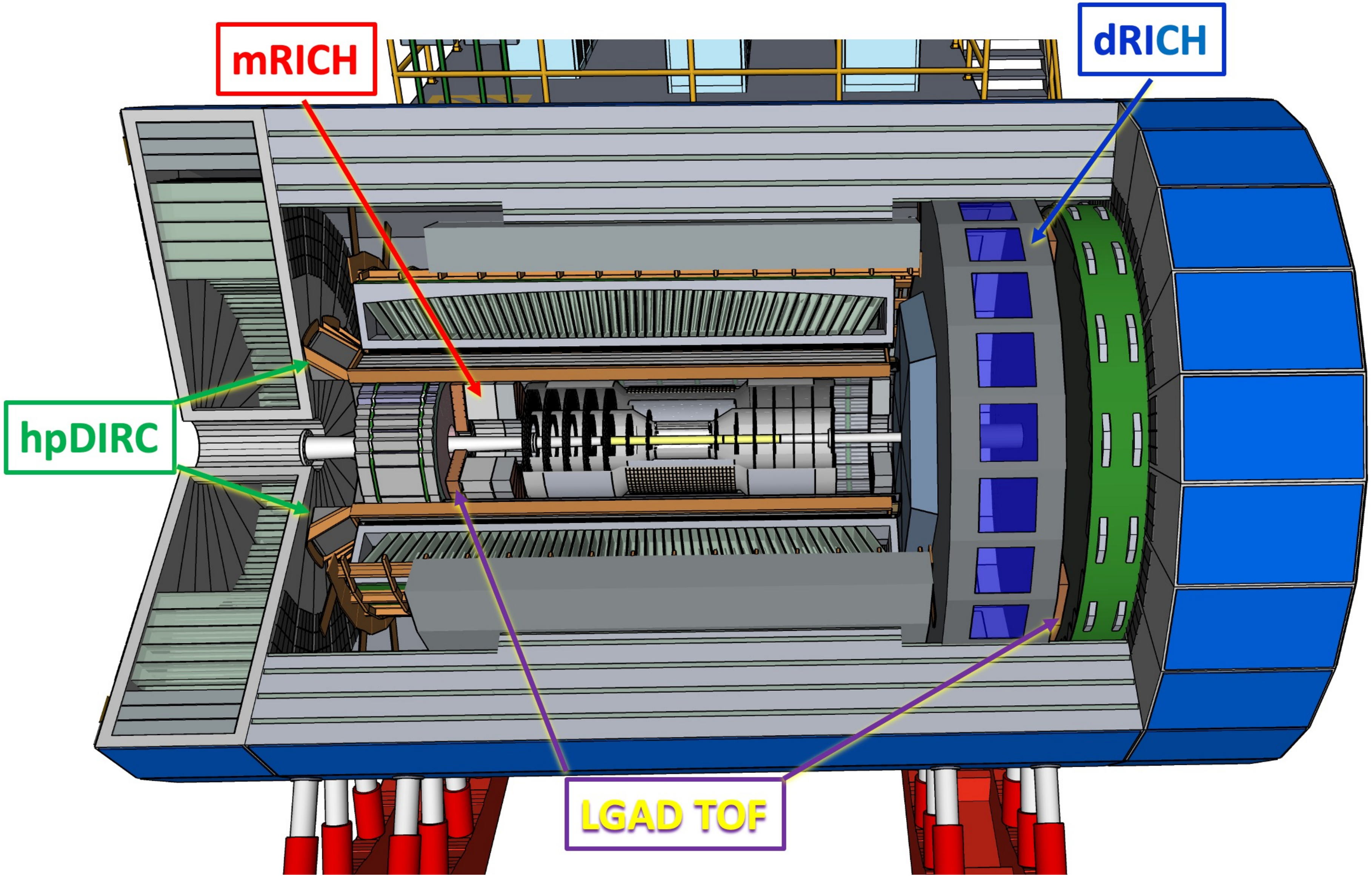
Table 8.6 Requested PID momentum coverage for 3σ pion/kaon separation. (Yellow Report)

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

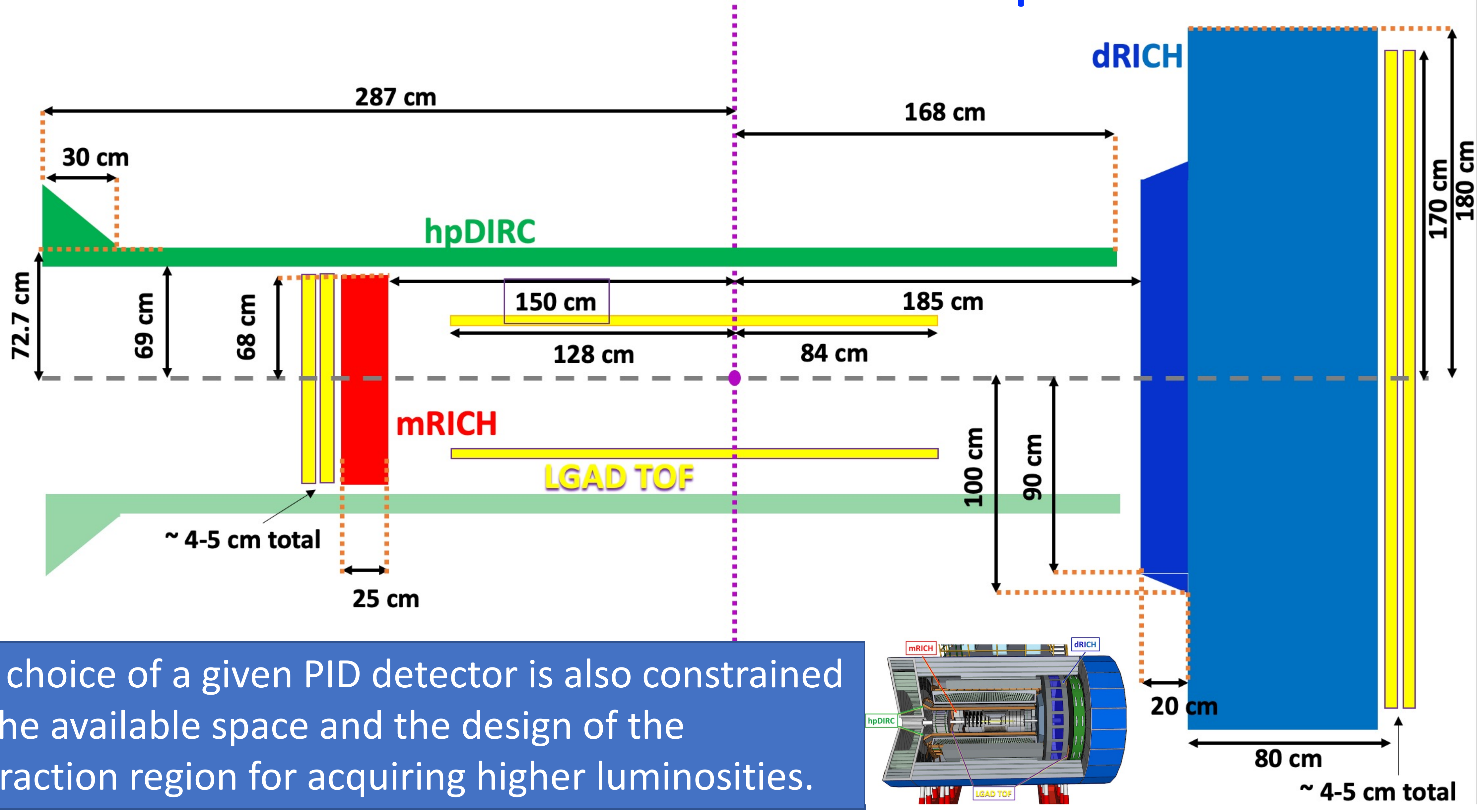
TOF

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

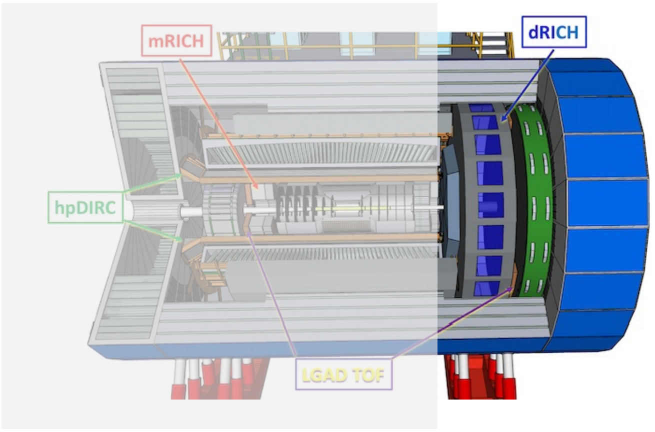


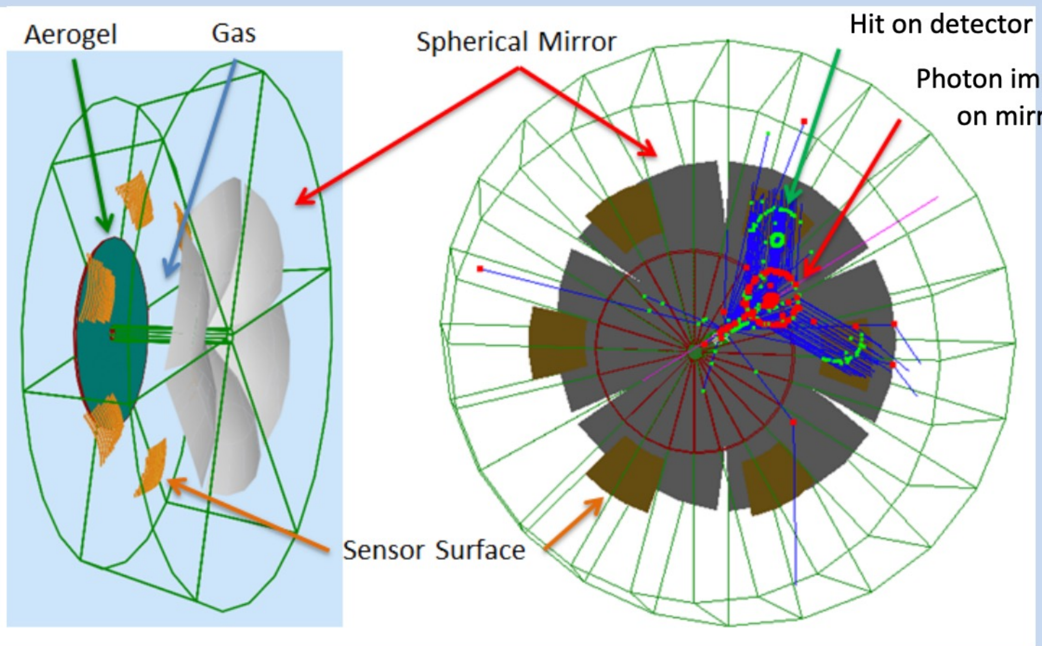
Overall Dimension and the Allocated Space



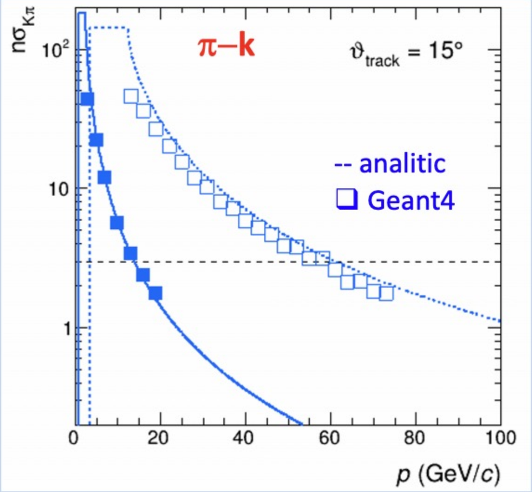
The choice of a given PID detector is also constrained by the available space and the design of the interaction region for acquiring higher luminosities.

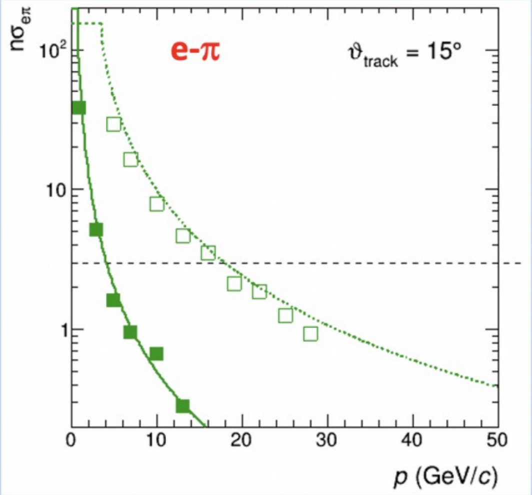
dRICH in Hadron Endcap (Forward)





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





dRICH: effective solution, part of reference detector

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

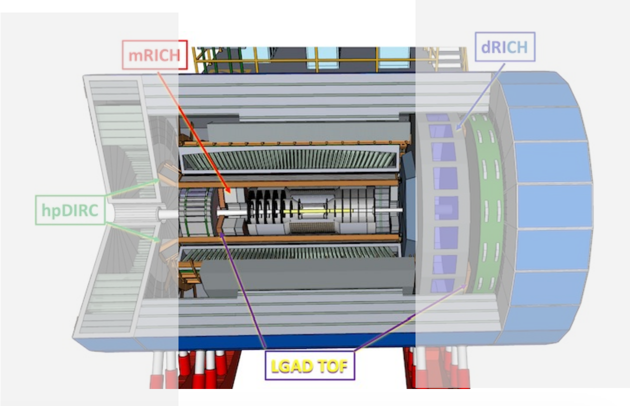
Detector: 0.5 m^2/sector , 3x3 mm^2 pixel

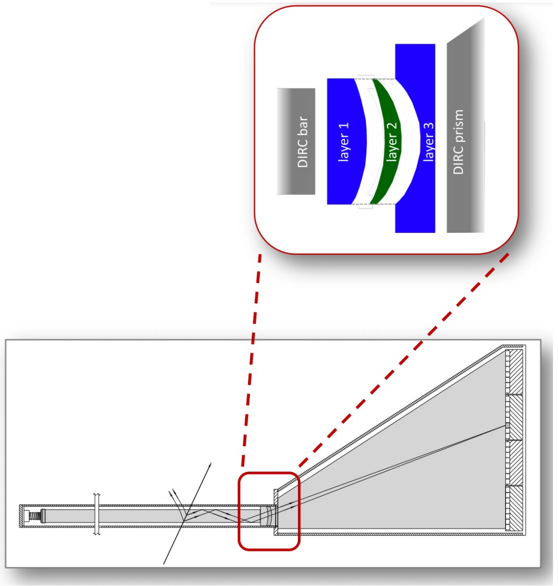
Single-photon detection in ~1T magnetic field

Outside acceptance, reduced constraints

→ best candidate for SiPM option

hpDIRC for Central Barrel



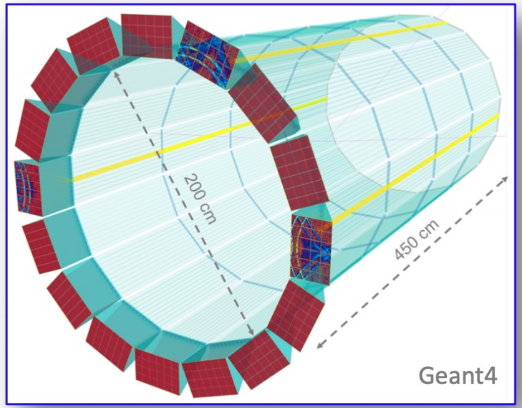


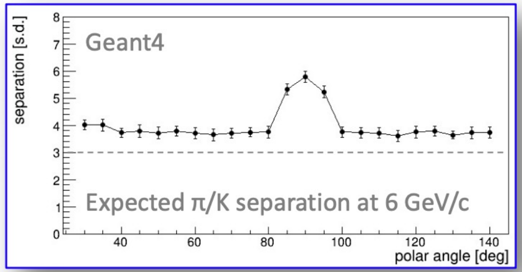
High-Performance DIRC Goal:

- 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

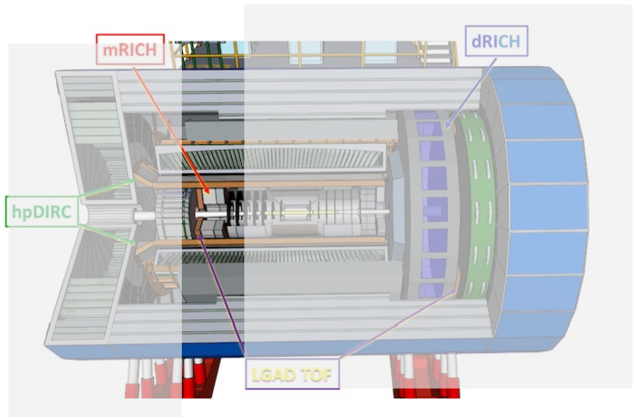




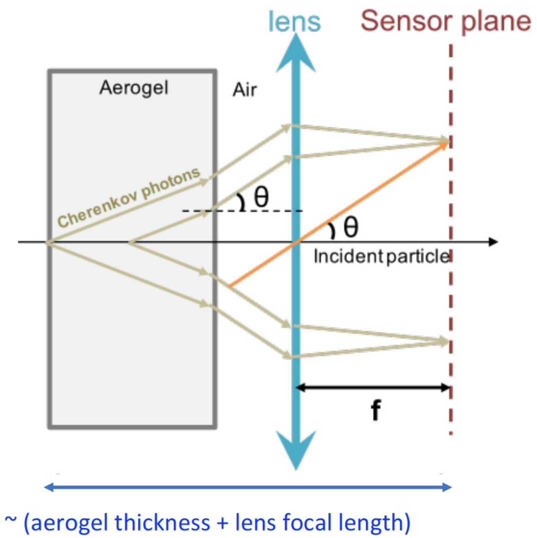
3-layer compound lens creates flat focal plane (matched to the fused silica prism shape.

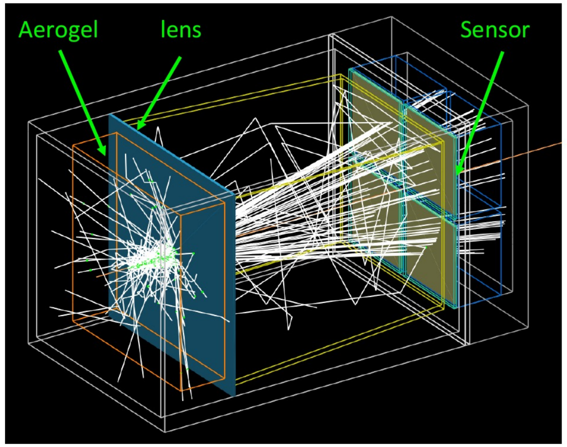
Successfully produced prototype lenses and validated performance in PANDA Barrel DIRC prototype.

mRICH in Electron Endcap (Backward)



EIC mRICH – Working Principle

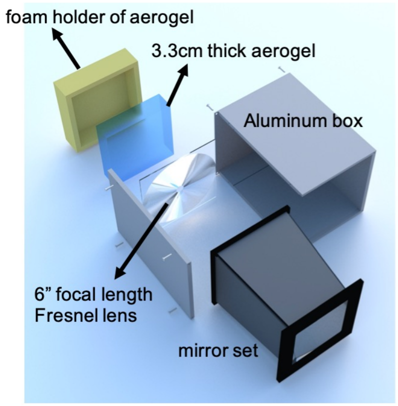


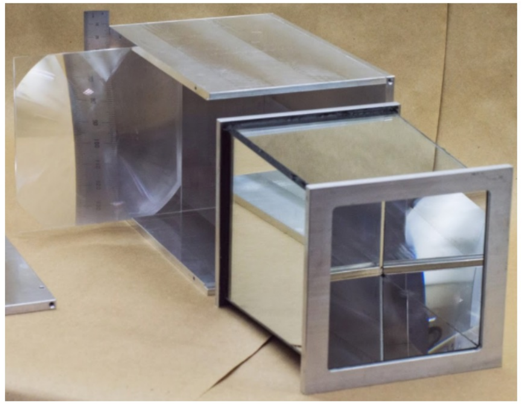


Geant4 Simulation

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.

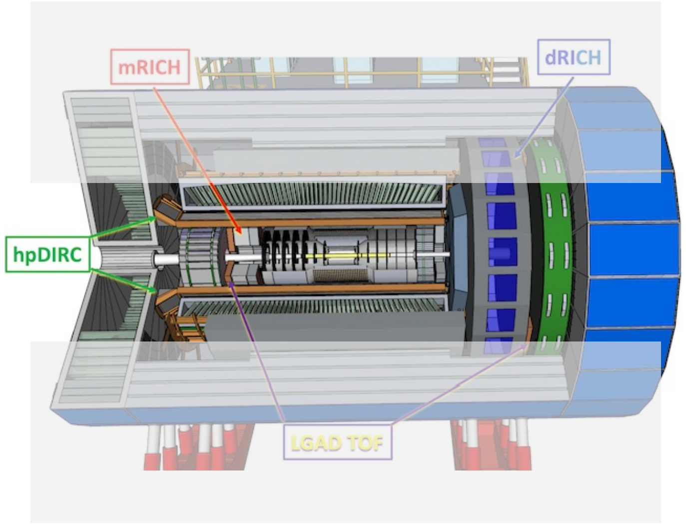




Beam tests in 2016 and 2018 at Fermilab for verifying mRICH working principle and performance; 2021 test at Fermilab with LAPPD photosensor (characterization!); Another test is planned in late August at Jlab with GEM tracker.

LGADs-Based TOF for ECCE

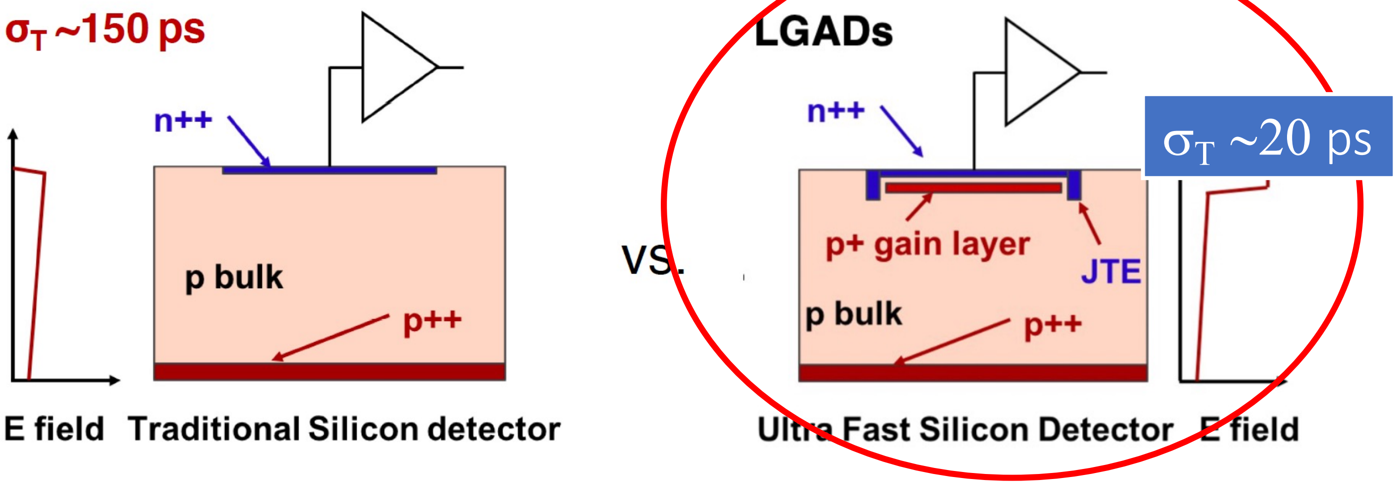
From Wei Li at Rice University



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

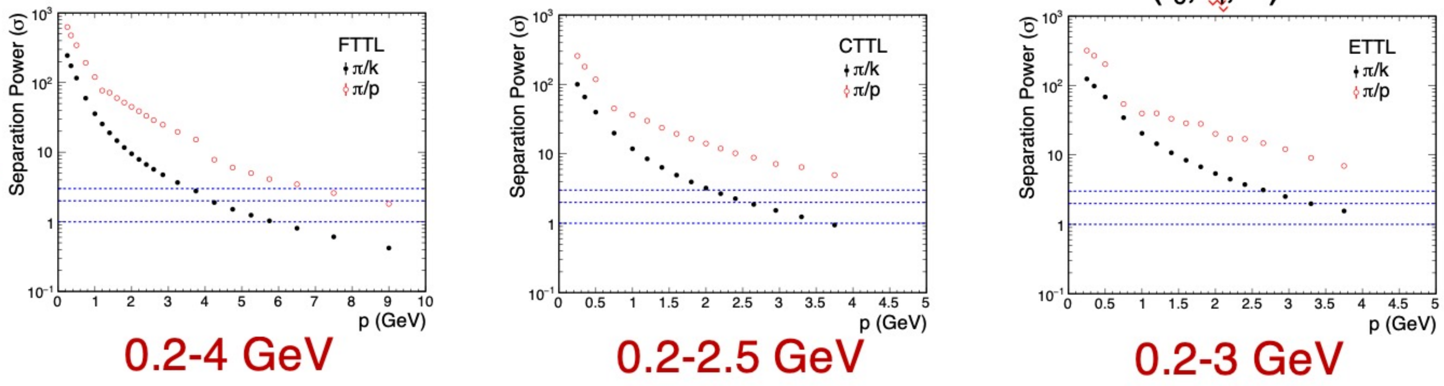
Low Gain Avalanche Diodes (LGADs)

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



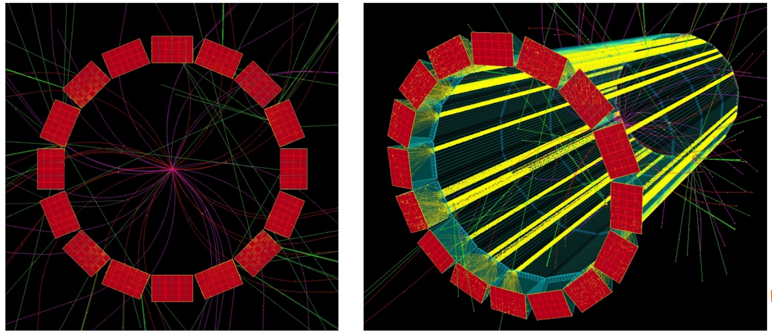
Adding an extra doping layer (E ~ 300 kV/cm, close to breakdown)

all uncertainties (t_0, t_f, L) included

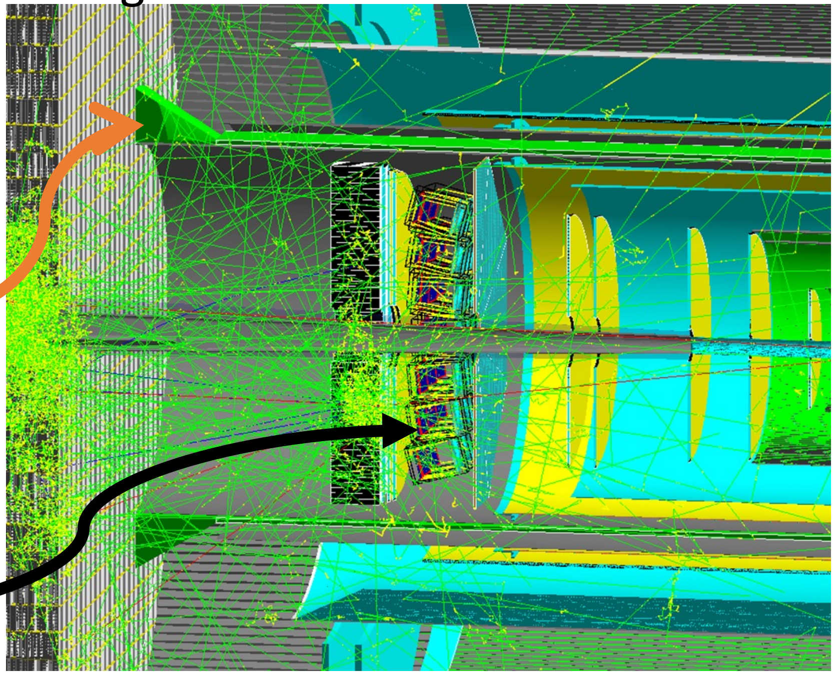


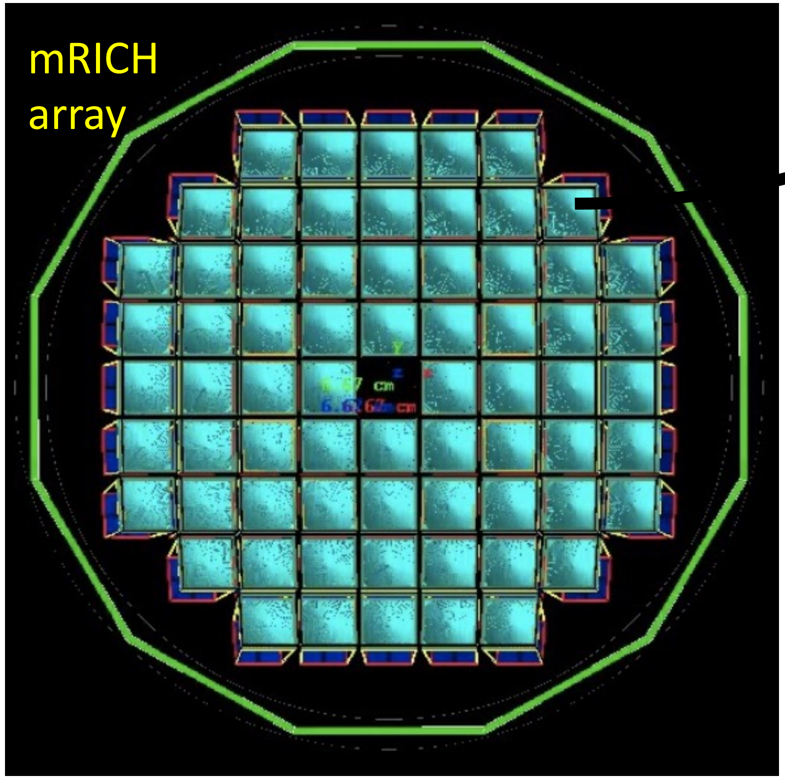
Full GEANT4-based Simulation (Fun4All Framework)

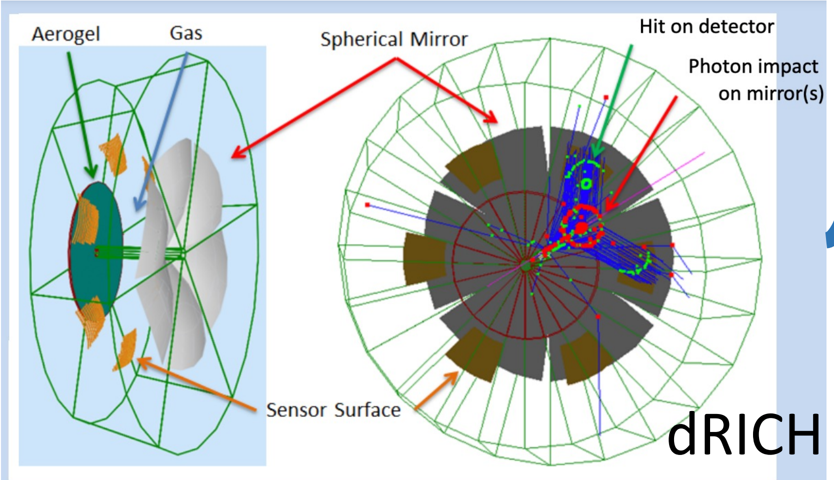
hpDIRC



Integrated ECCE GEANT4 Simulation







Integrated PID Performance Test via Full GEANT4 Simulation is Work in Progress. More to come.

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.

Welcome to Join the ECCE PID

Physics -> EIC -> ECCE -> PID

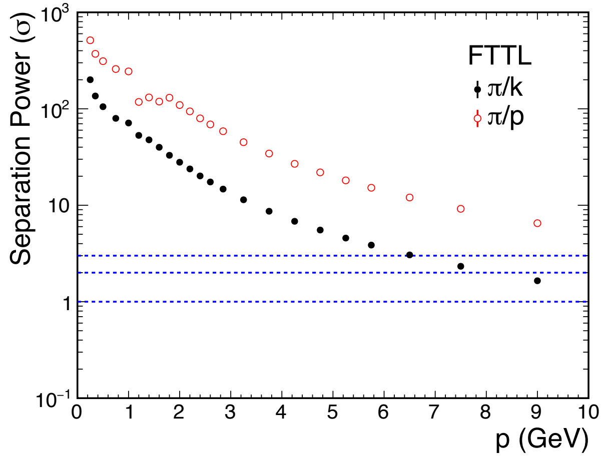
Photosensors and Readout Electronics

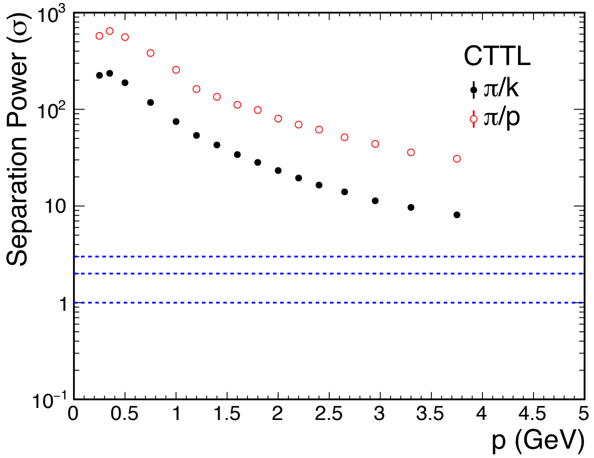
- There has been a parallel effort in eRD14 for searching/testing/developing single-photon sensors and the associated readout electronics for RICH-based PID detectors. The ultimate sensors need to be functioning well inside magnetic field.
  - ANL group led the effort of MCP-PMT and LAPPD development.
  - 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.

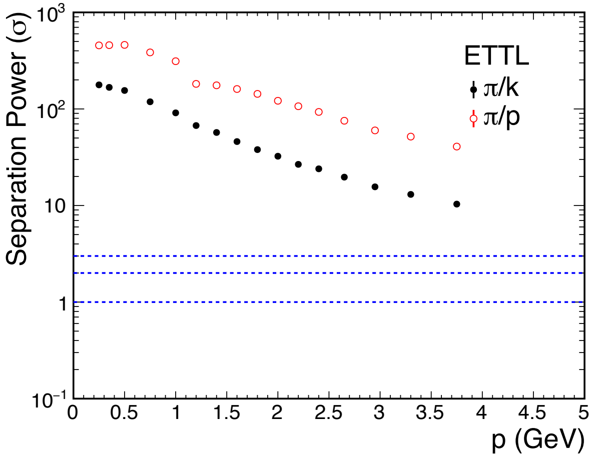
ECCE TOF PID Performance

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

$\sigma_t = 0$ ps

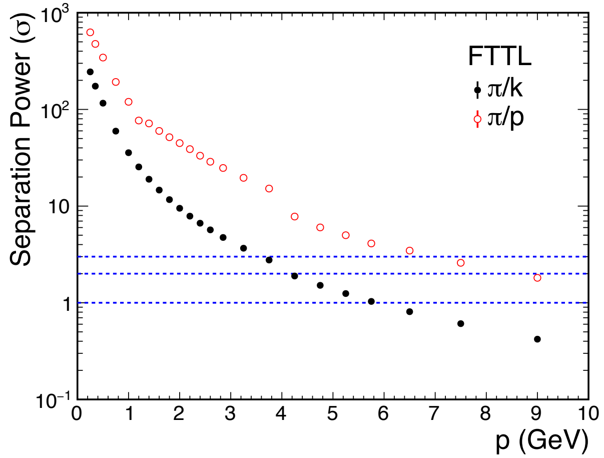


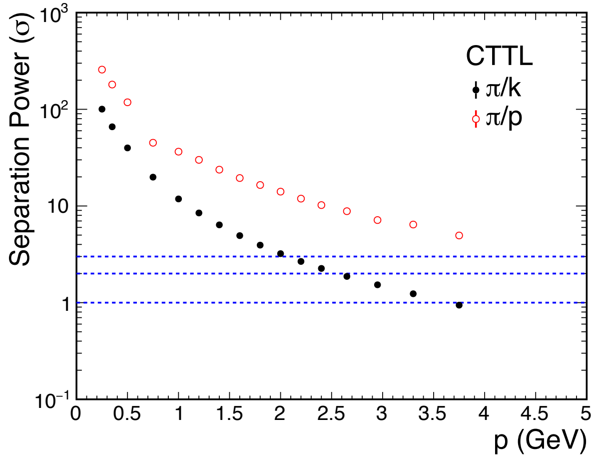


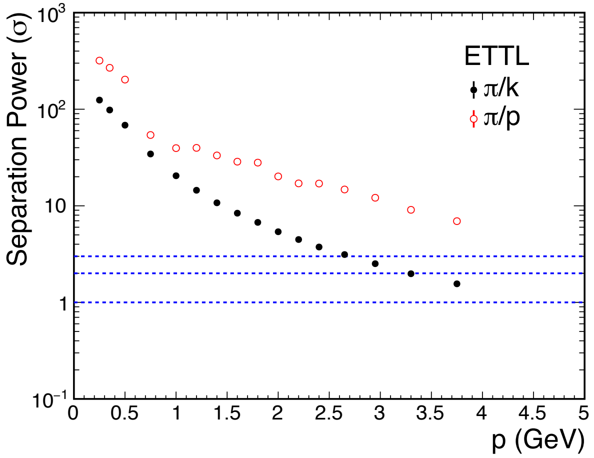


all uncertainties (t_0, t_f, L) included

$\sigma_t = 20$ ps







0.2-4 GeV | 0.2-2.5 GeV | 0.2-3 GeV

Radiation Dose Level Distribution

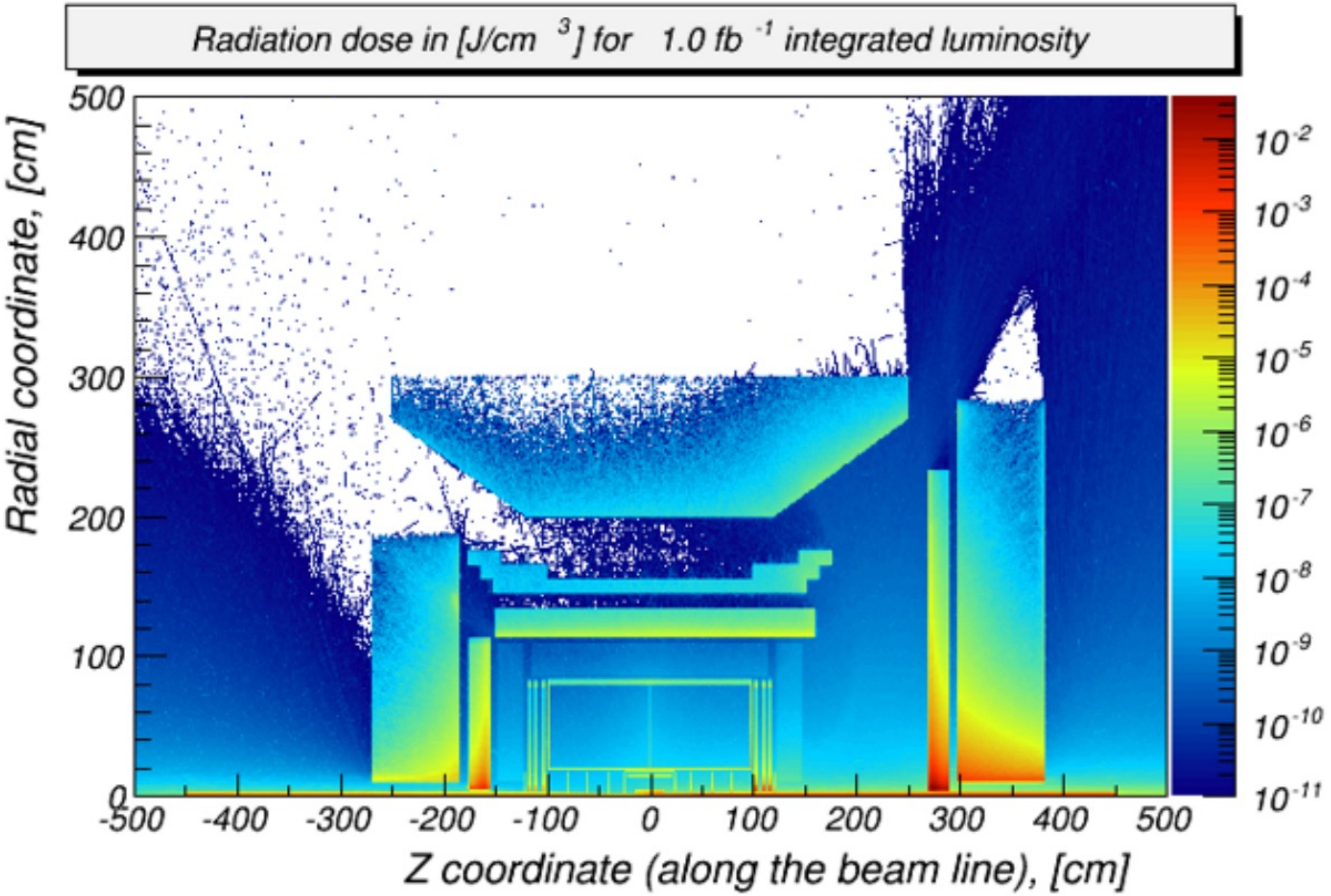


Figure 10.7: Ionizing radiation energy deposition from e+p collision at $\sqrt{s_{ep}} = 140$ GeV studied using the BeAST detector concept, which also applies to the reference EIC detector as in this report.