# PID with ePIC at the EIC

Roberto Preghenella
Istituto Nazionale di Fisica Nucleare, Sezione di Bologna

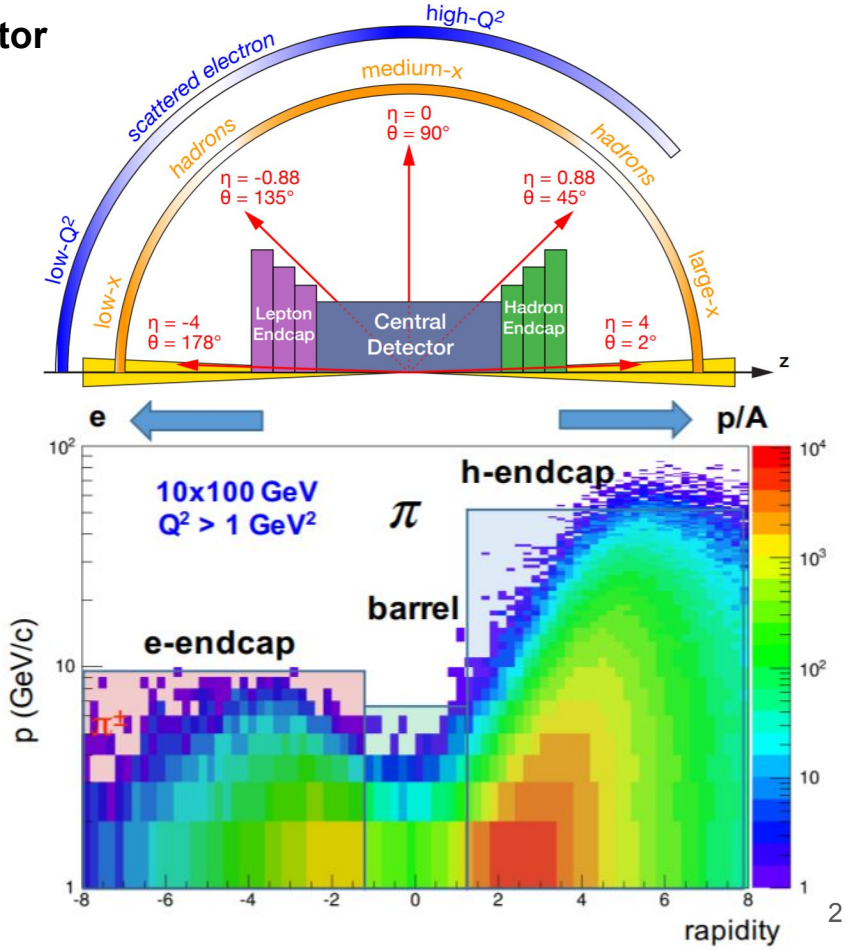
on behalf of the ePIC Collaboration

DIS2023
XXX International Workshop on Deep-Inelastic Scattering and Related Subjects
March 27–31 2023, East Lansing, Michigan, USA

# Particle identification at EIC

**one of the major challenges for the detector**

- **physics requirements**
  - pion, kaon and proton ID
  - over a wide range |η| ≤ 3.5
  - with better than 3σ separation
  - significant pion/electron suppression
- **momentum-rapidity coverage**
  - forward: up to 50 GeV/c
  - central: up to 6 GeV/c
  - backward: up to 10 GeV/c
- **demands different technologies**

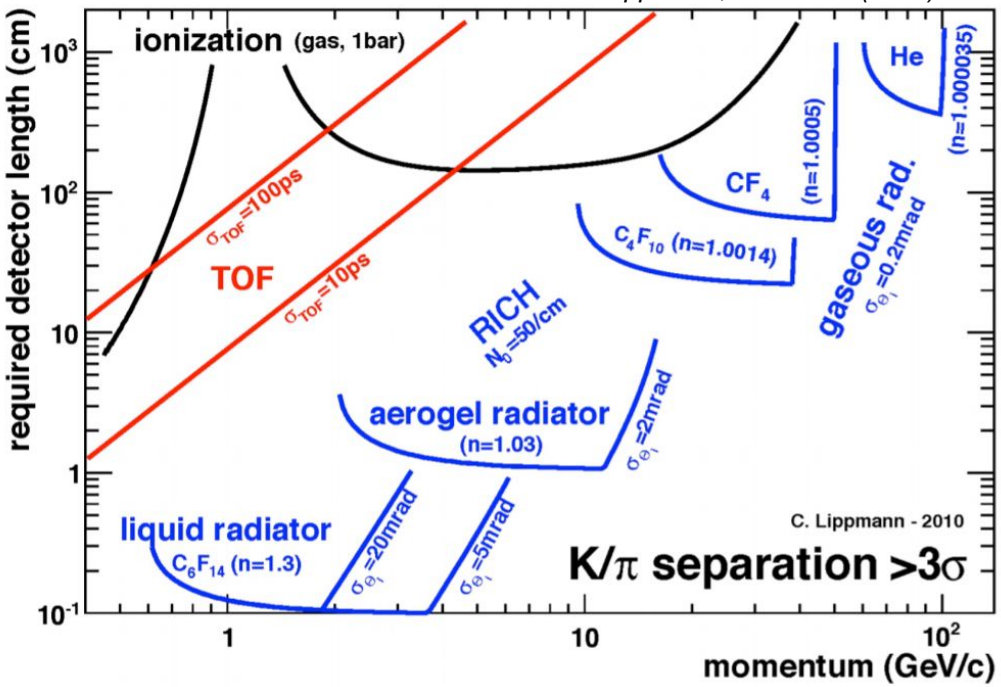


# Particle identification techniques

**EIC detector need more than one technique to cover the entire momentum ranges**

- **central (< 6 GeV/c)**
  - TPC, TOF, DIRC
- **backward (< 10 GeV/c)**
  - aerogel RICH
- **forward (< 50 GeV/c)**
  - gaseous RICH

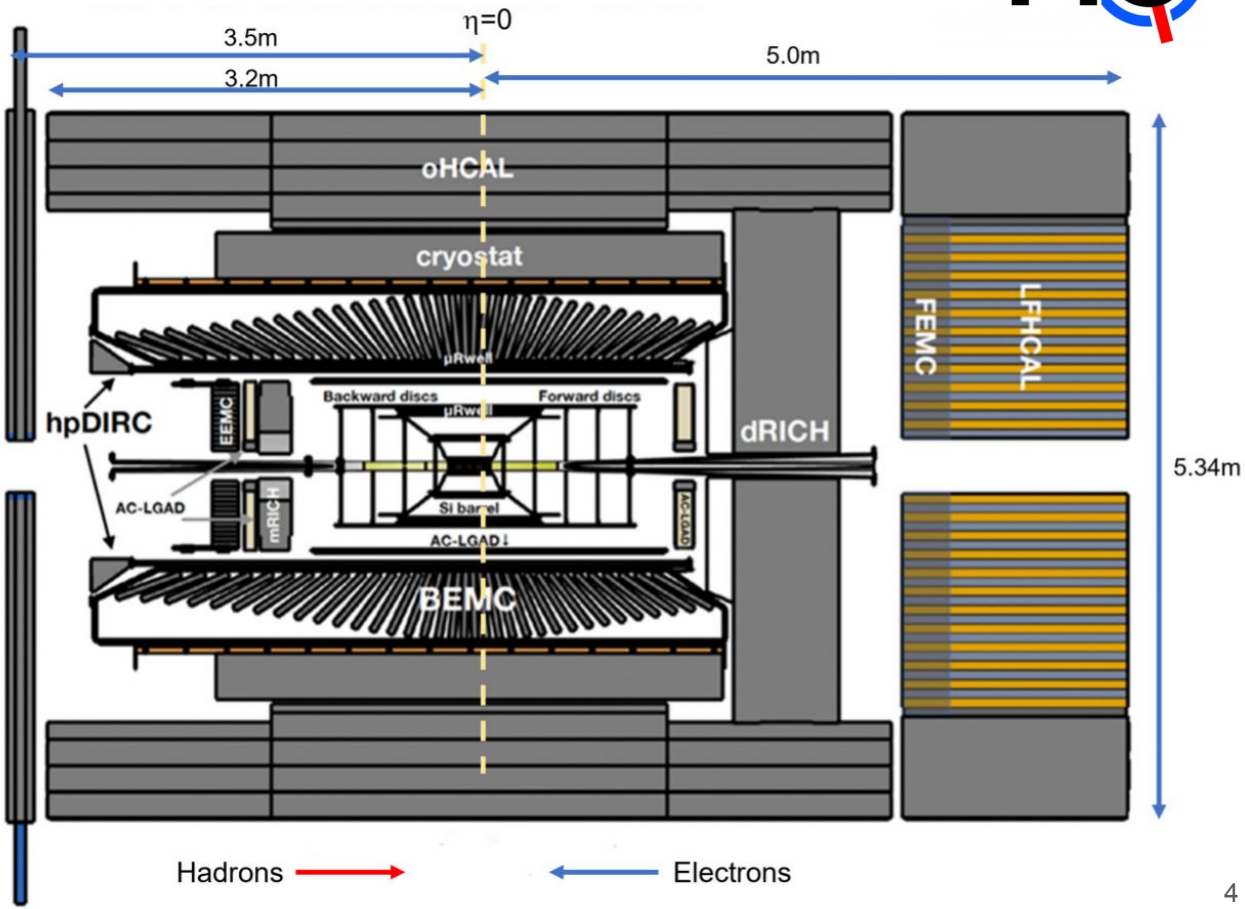
*C.Lippmann, NIMA 666 (2012) 148*



Tue 09:00
R Milner

# The ePIC barrel detector

- **tracking**
  - new 1.7 T magnet
  - Si-MAPS + MPGDs
- **calorimetry**
  - e-side: $PbWO_4$ EMCal
  - barrel: SciGlass / imaging
  - h-side: finely segmented
  - outer barrel HCal
- **particle ID**
  - AC-LGAD TOF
  - mRICH / pfRICH
  - hpDIRC
  - dRICH



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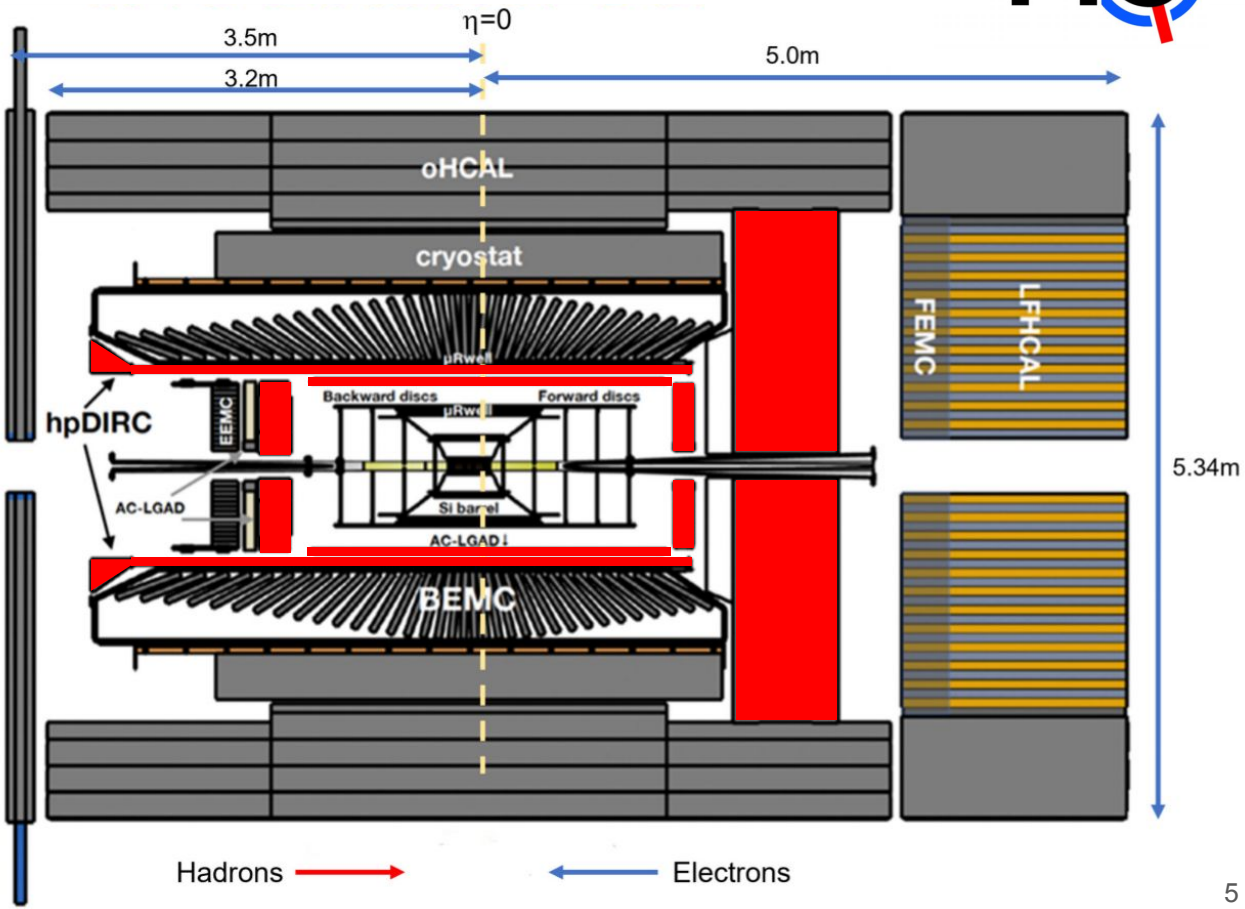
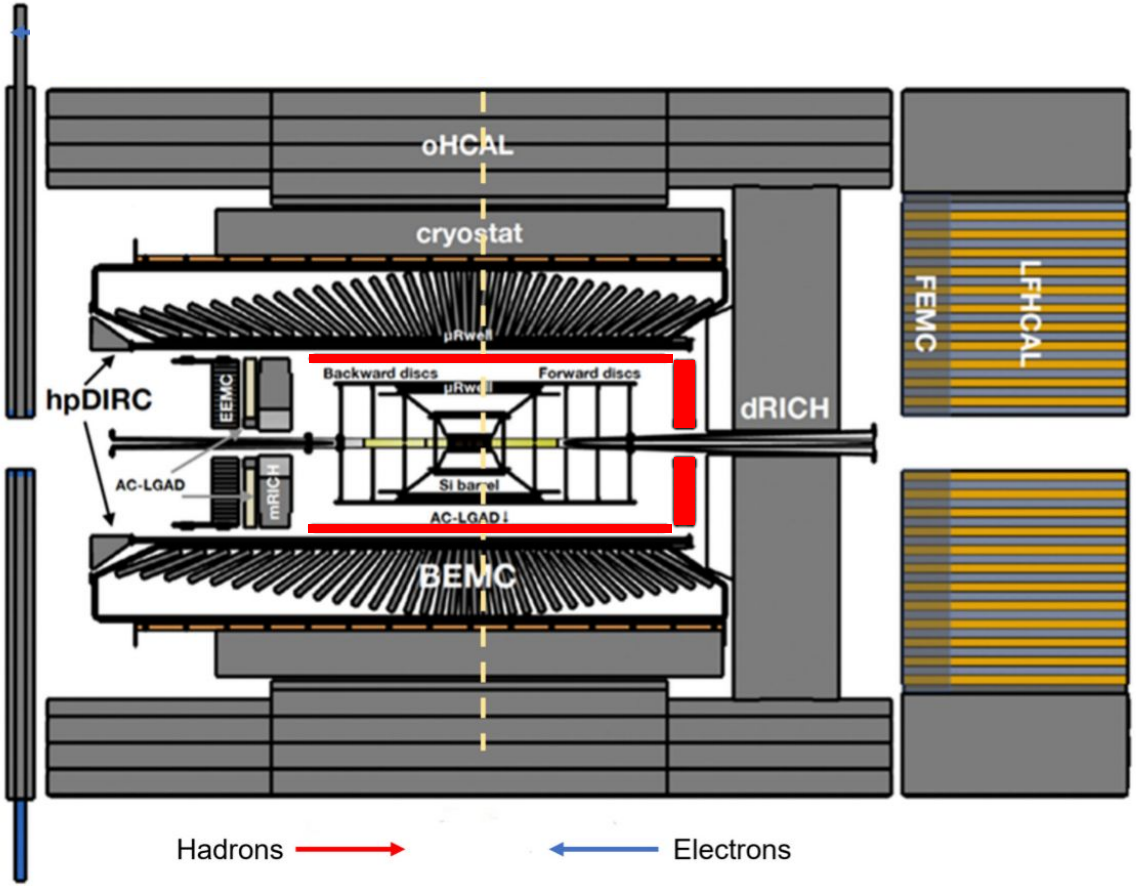


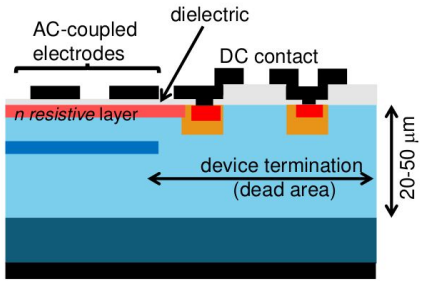
# Time of Flight

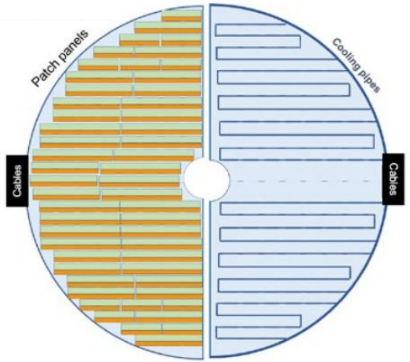


# TOF – Time of Flight

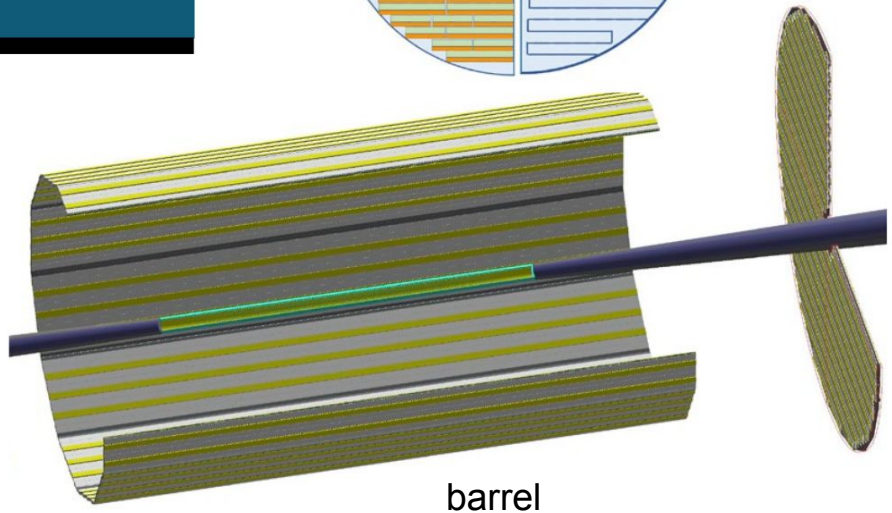
**based on AC-LGAD technology, also used in far forward ePIC instrumentation**

- **two AC-LGAD layers**
  - barrel, $|\eta| < 1.4$
  - forward, $1.5 < \eta < 3.5$
- **barrel**
  - 500 μm x 1 cm strips
  - 1% $X_0$
- **forward**
  - 500 μm x 500 μm pixels
  - 8% $X_0$
- **performance**
  - space resolution: 30 μm
  - time resolution: $\sigma \sim 25$ ps



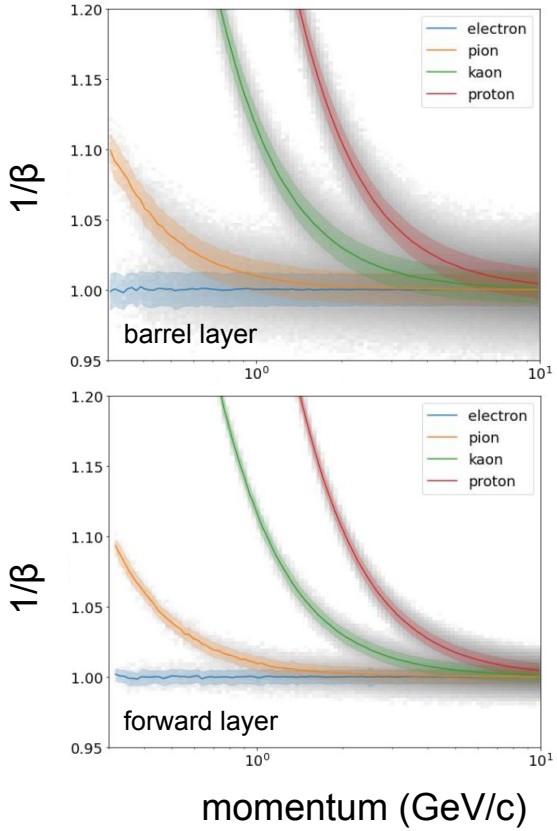

forward



barrel

# TOF performance simulation

**detector geometry implemented in Geant, digitisation and integration in tracking software**

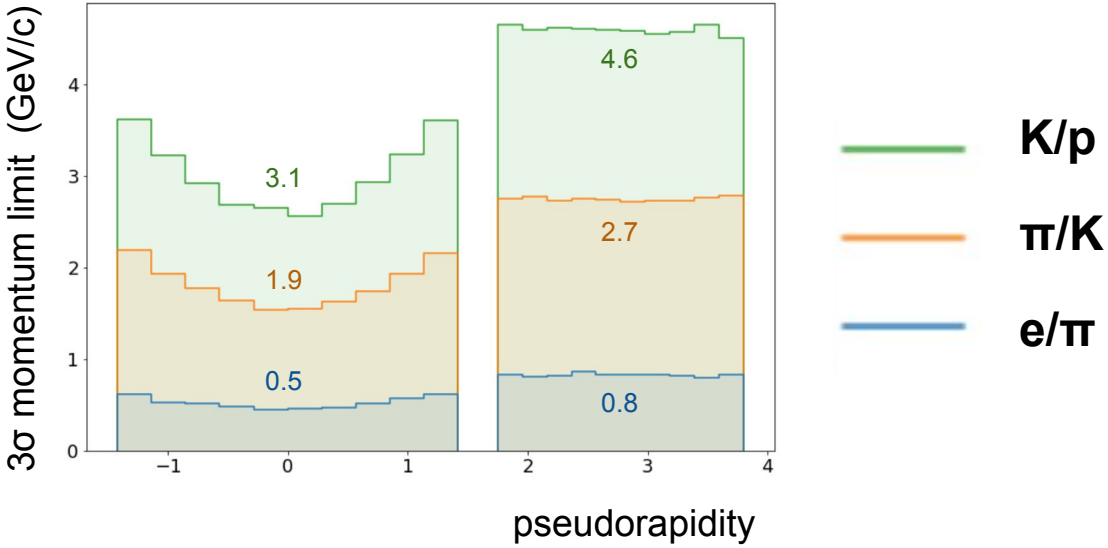


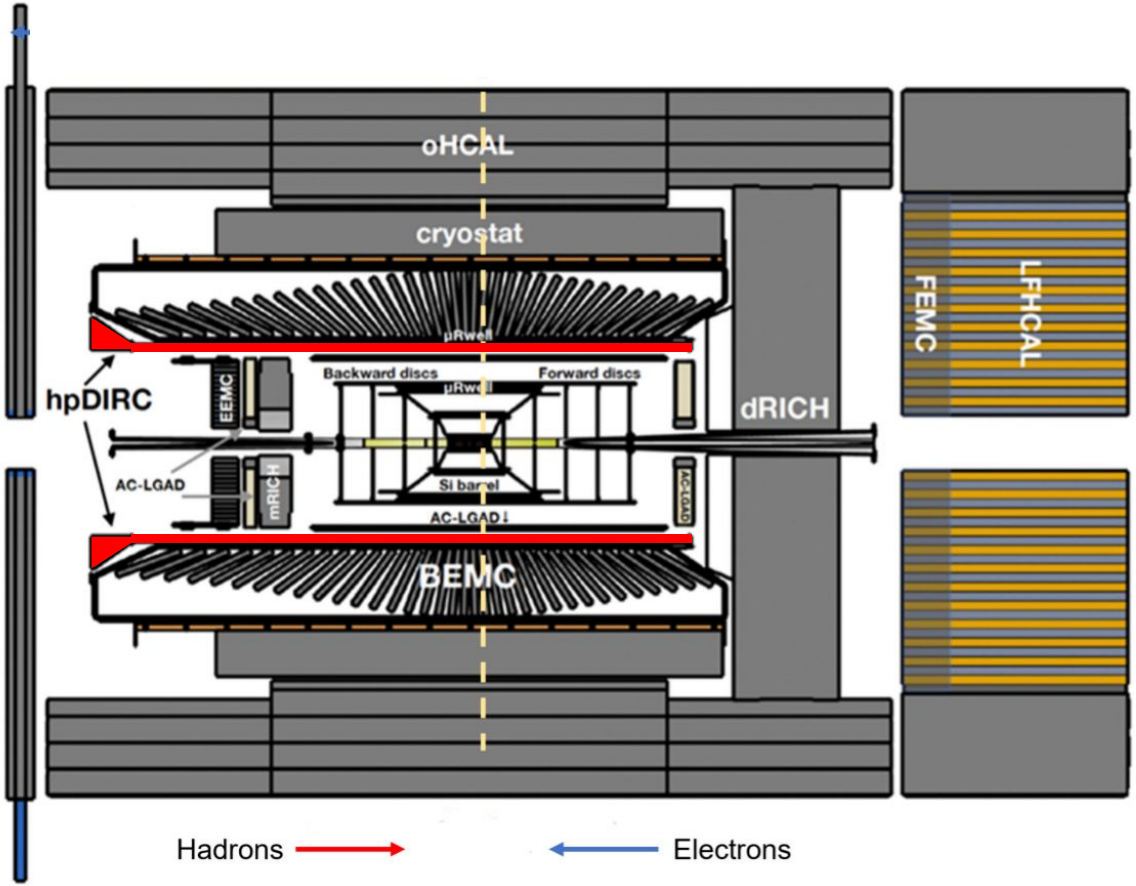

**barrel layer**

- e/pi up to 0.5 GeV/c
- pi/K up to 1.9 GeV/c
- K/p up to 3.1 GeV/c

**forward layer**

- e/pi up to 0.8 GeV/c
- pi/K up to 2.7 GeV/c
- K/p up to 4.6 GeV/c




oHCAL
cryostat
μRwell
Backward discs
Forward discs
μRwell
hpDIRC
EEMC
AC-LGAD
mRICH
Si barrel
AC-LGAD
AC-LGAD
dRICH
FEMC
LFHCAL
BEMC
Hadrons
Electrons

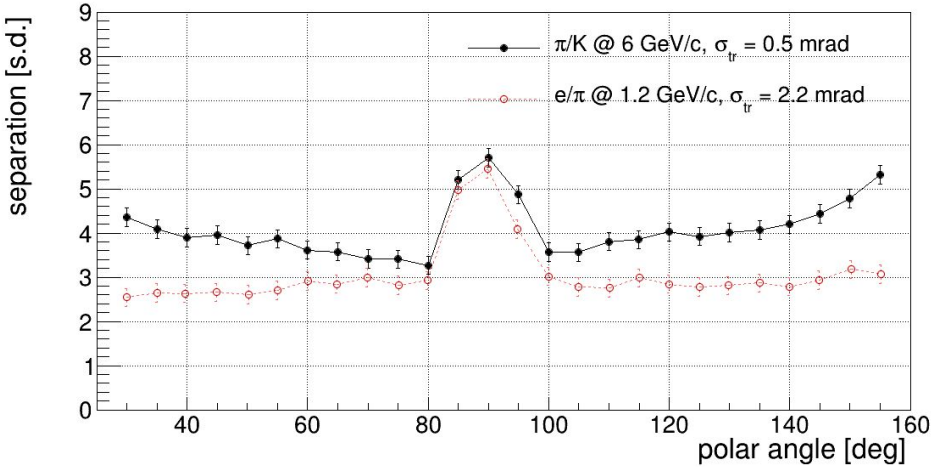
ePIC
hp DIRC

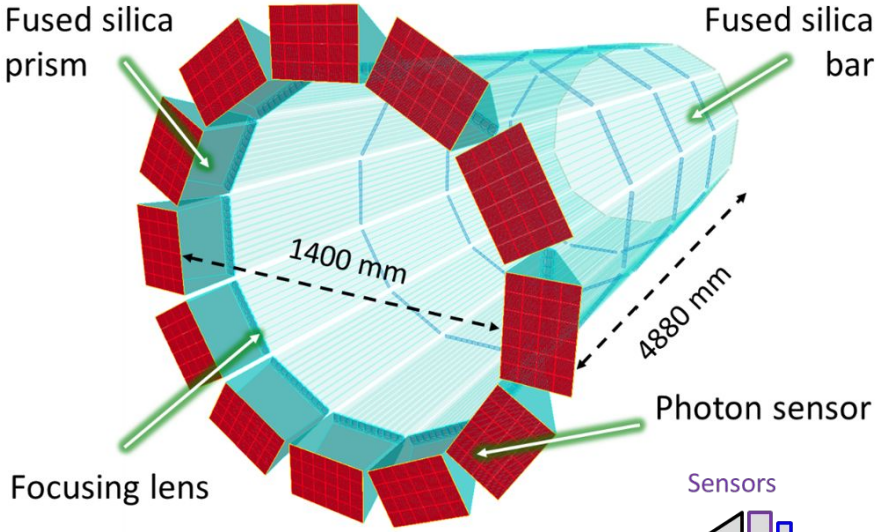
Tue 09:40
N Wickramaarachchi

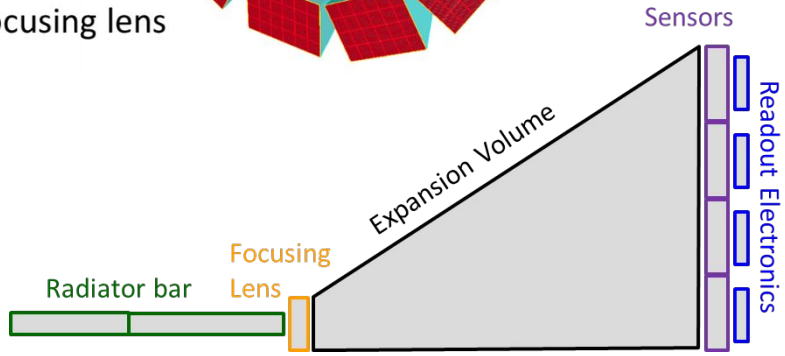
# hpDIRC – high-performance DIRC

**fast focusing DIRC with high-resolution 3D (x,y,t) reconstruction**

- **crucial components**
  - innovative 3-layer spherical lenses
  - compact fused silica expansion volumes
  - fast photodetection, small pixel MCP-PMT
- **hpDIRC creates focused images**
  - significantly improved resolution

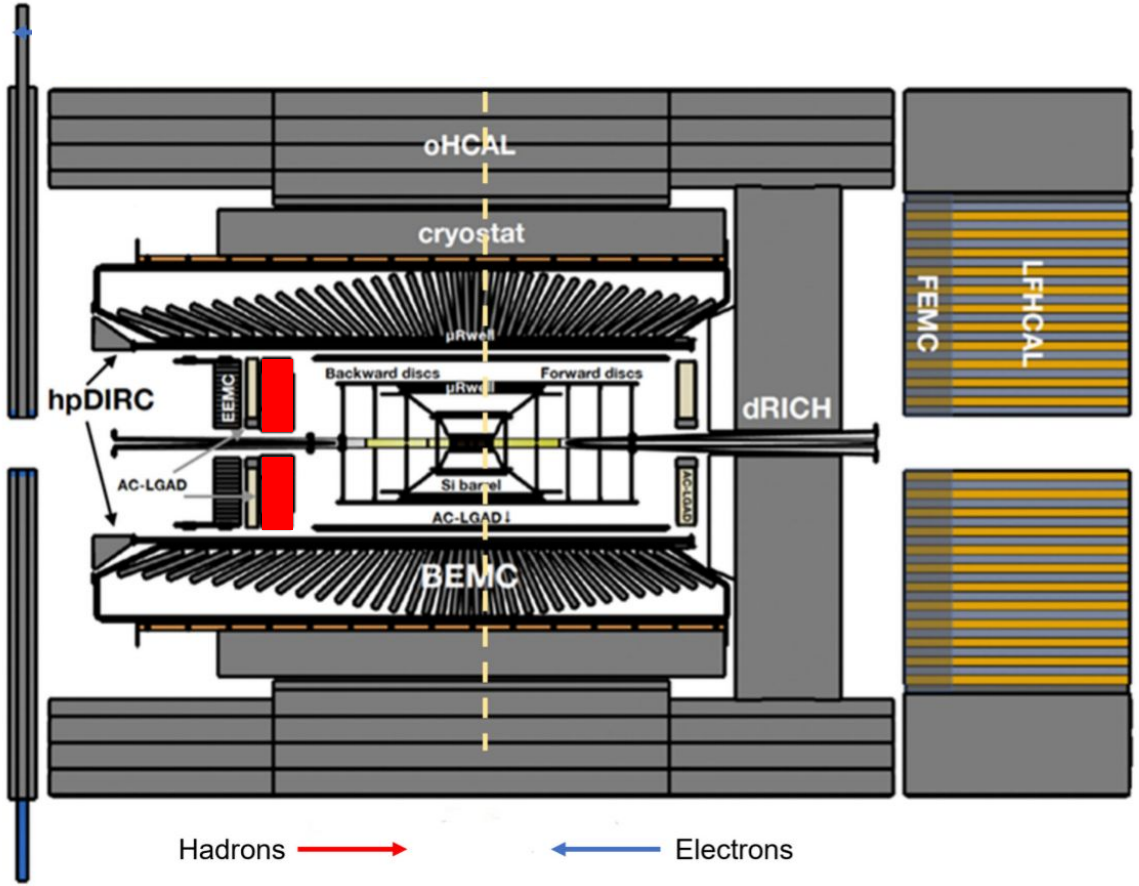


ePIC

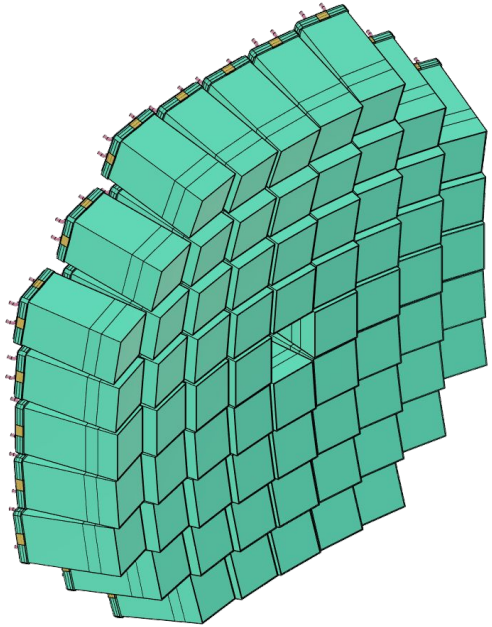
backward RICH

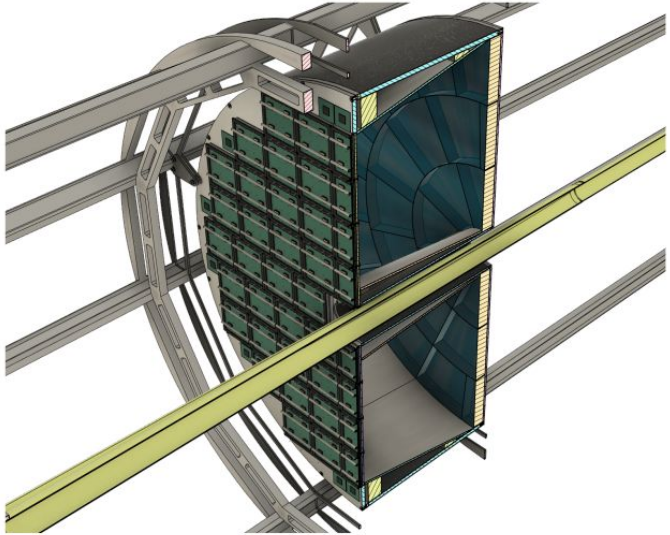


# Backward RICH selection

**two candidate technologies for PID in the electron-side direction**

**mRICH**





**pfRICH**

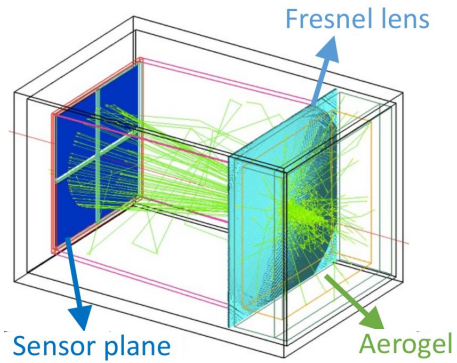
technologies under review (ePIC review on 20-21 March 2023)

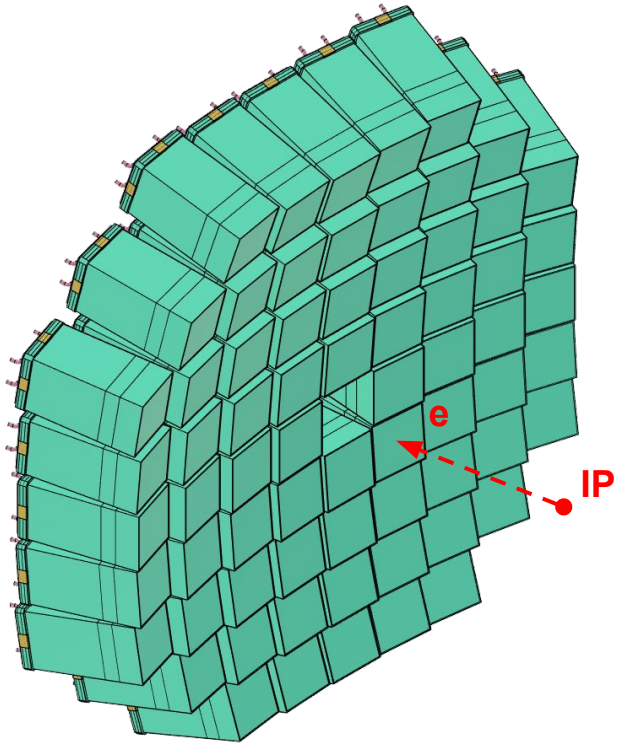
# mRICH – modular RICH

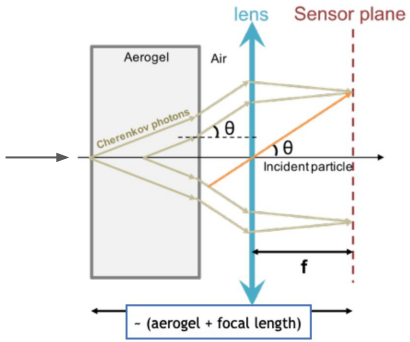
**a compact, projective and modular RICH detector**

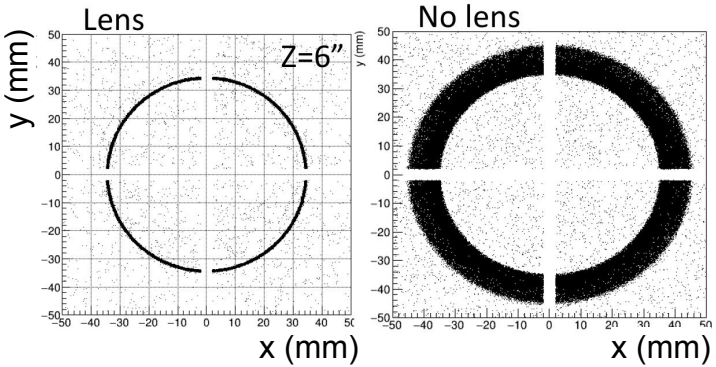
- **key components of a module**
  - 3-cm aerogel radiator (n = 1.03)
  - 6'' acrylic Fresnel lens
  - mirror wall set
  - photosensor surface
- **smaller and sharper rings**

  wrt proximity focusing
  - better resolution, less sensor area



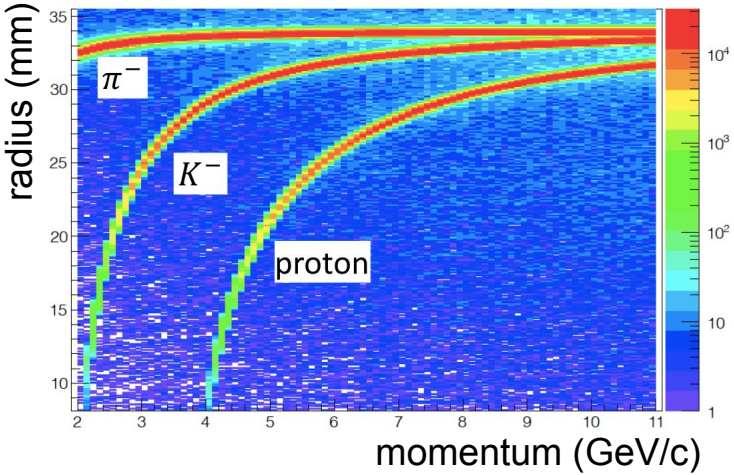



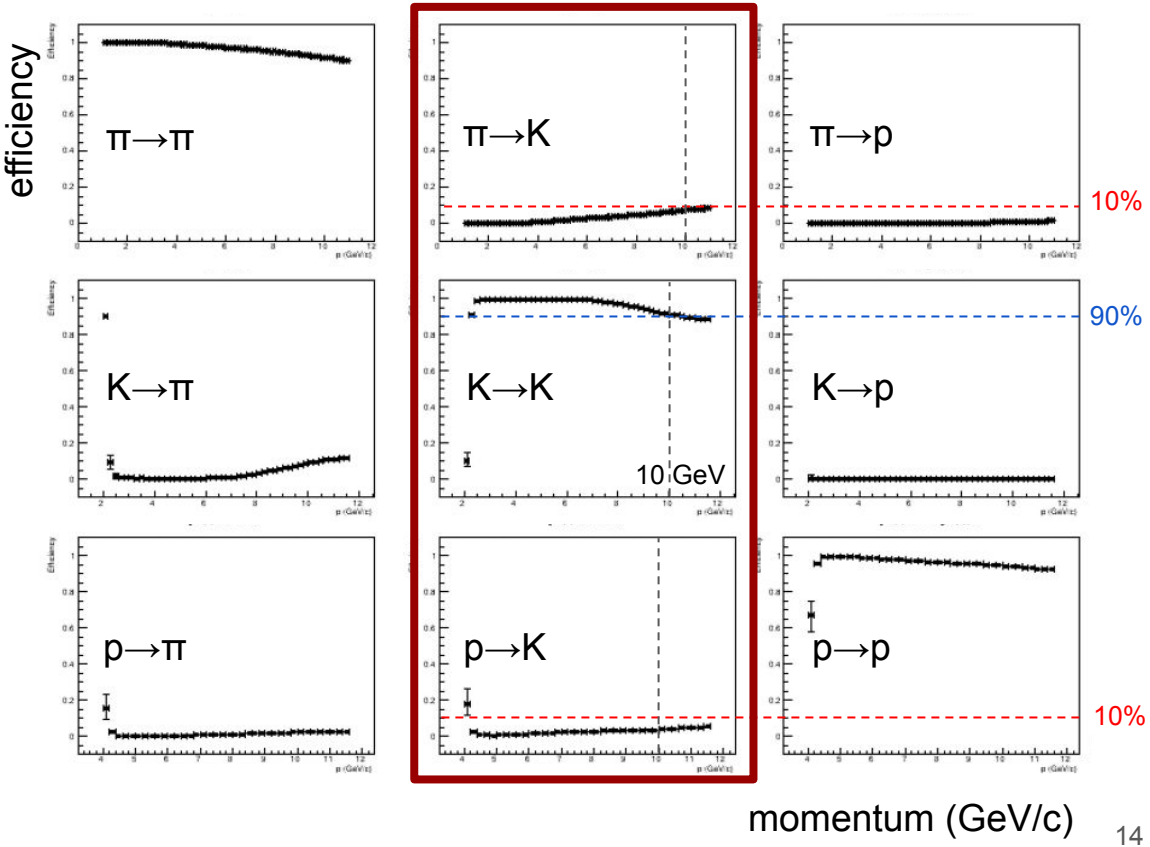



# mRICH performance simulation

**full Geant4 simulation and reconstruction (single particle events)**

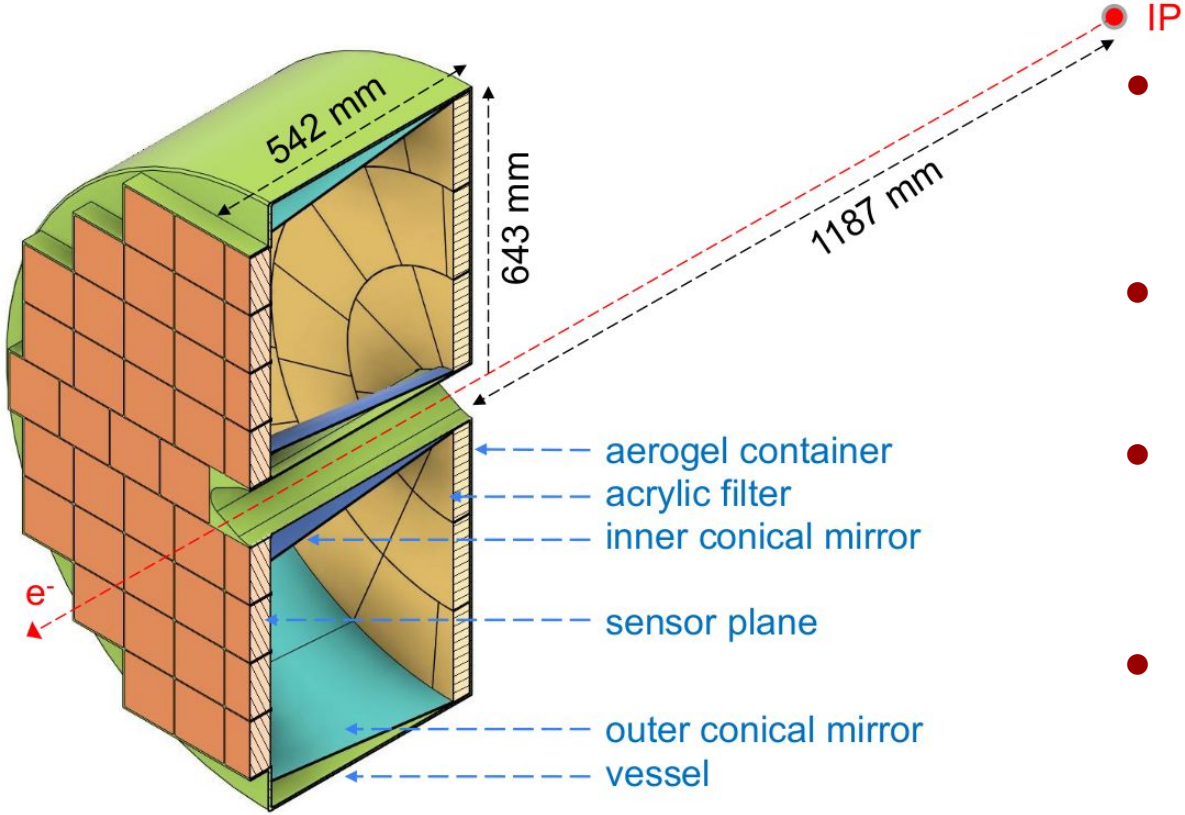



- **kaon-ID efficiency**
  - K→K
  - better than 90% up to 10 GeV/c
- **kaon mis-ID probability**
  - π→K
  - lower than 10% up to 10 GeV/c

# pfRICH – proximity focusing RICH

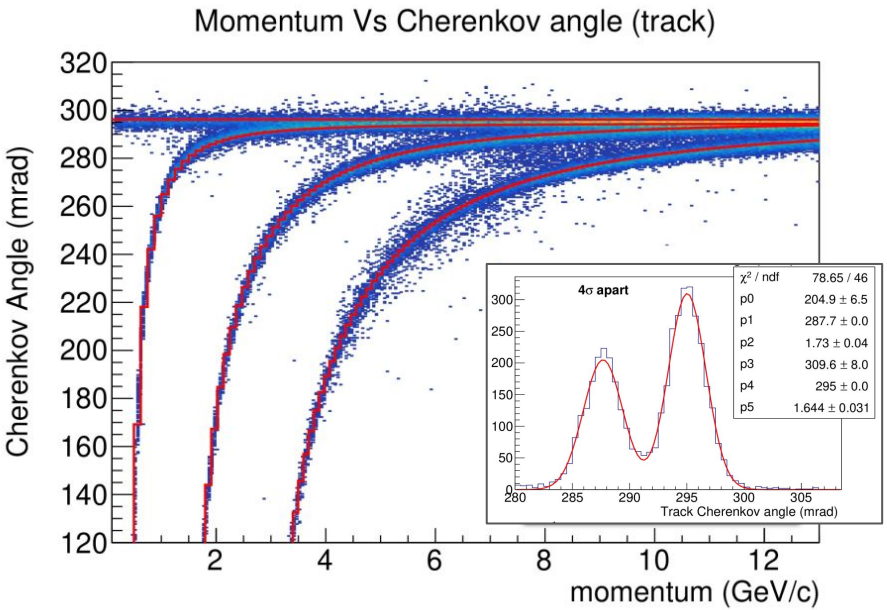
**a classical proximity focusing RICH with timing capability for MIPs**

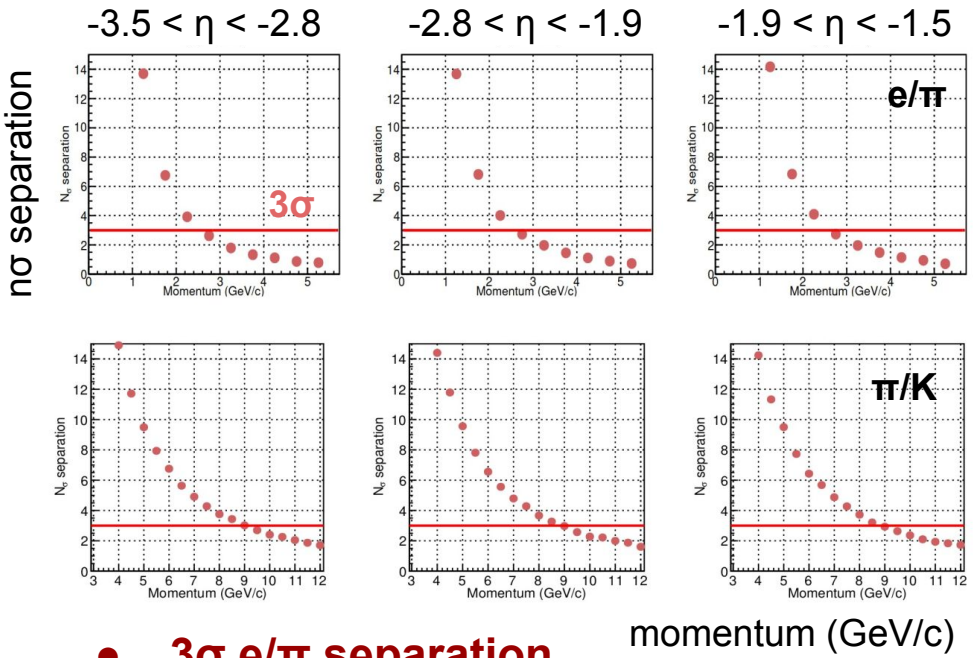



- **Cherenkov radiator**
  - 2.5 cm thick aerogel (n = 1.04-1.05)
  - with 300 nm acrylic filter
  - $\langle N_{pe} \rangle \sim 11\text{-}12$
- **proximity gap**
  - 45 cm long
  - nitrogen filled
- **HRPPD photosensors**
  - 120 x 120 mm tiles
  - pixelation: 32 x 32 pads
  - DC-coupled
- **timing capability**
  - MIP produces UV light (dozens of pe) in the HRPPD window
  - provide time with $\sigma < 20$ ps

# pfRICH performance simulation

**complete Geant4 simulation, event-level digitisation and reconstruction**



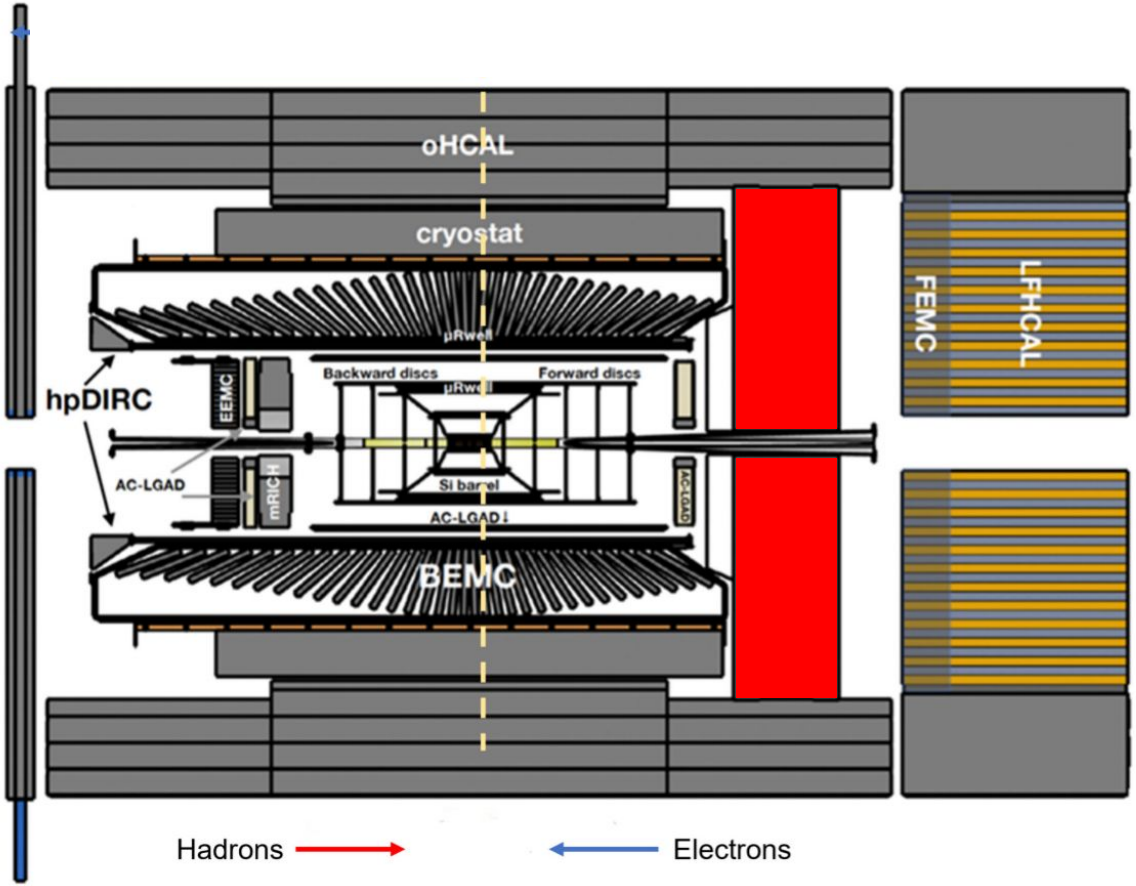




- **direct and reflected photon hits**
  - reconstruction algorithm capable of handling complex categories
  - angles in agreement with expectations

- **3σ e/π separation**
  - up to ~ 2.5 GeV/c
- **3σ π/K separation**
  - up to ~ 9.0 GeV/c

ePIC

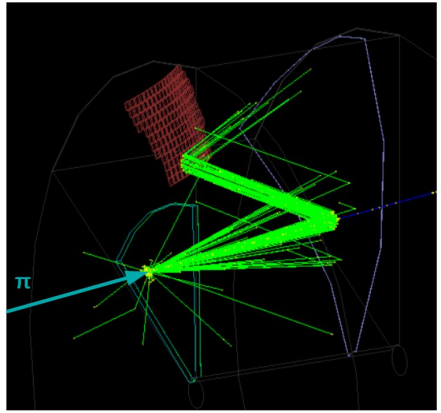
dual RICH



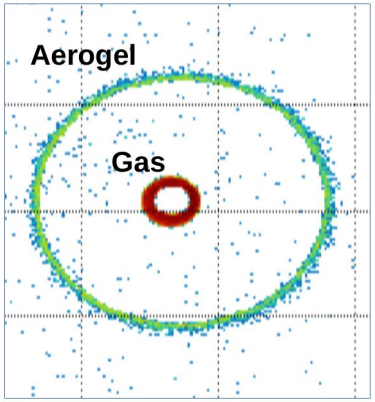
# dRICH – dual-radiator RICH

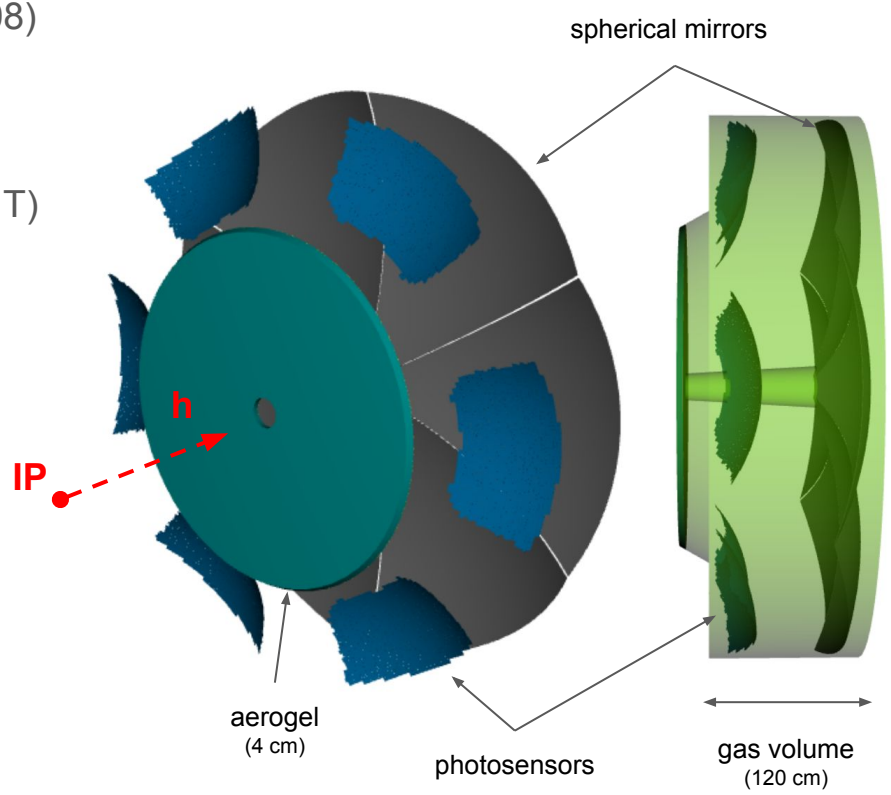
**compact and cost-effective solution for broad momentum coverage at forward rapidity**

- **radiators:** aerogel (n ~ 1.02) and $C_2F_6$ (n ~ 1.0008)
- **mirrors:** large outward-reflecting, 6 open sectors
- **sensors:** 3x3 $mm^2$ pixel, 0.5 $m^2$ / sector
  - single-photon detection inside high B field (~ 1 T)
  - outside of acceptance, reduced constraints
  - best candidate for SiPM option




example event (accumulated hits)

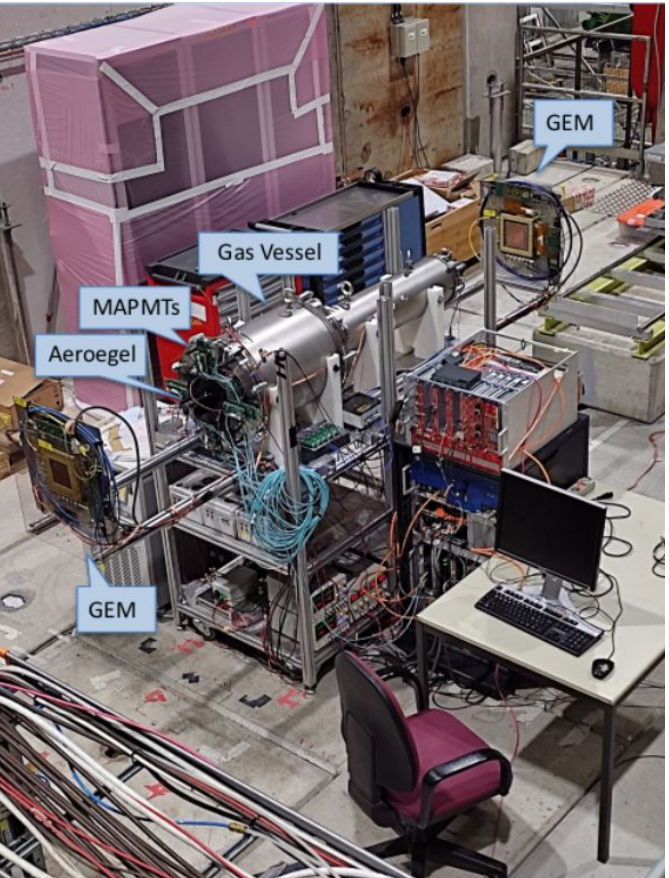


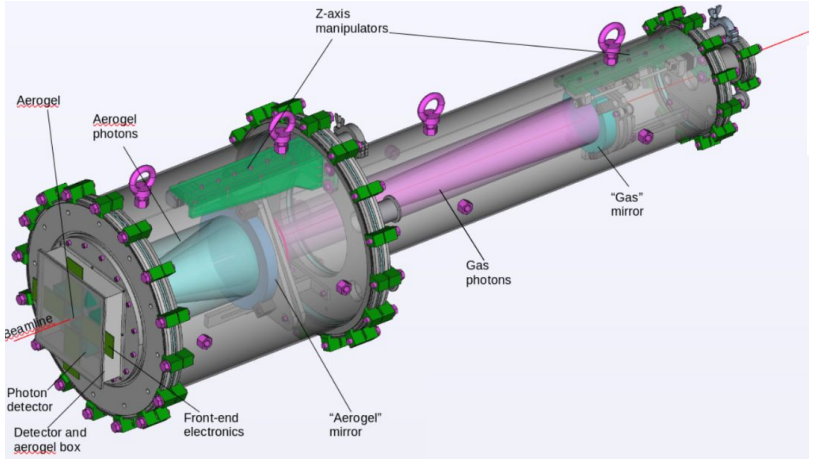



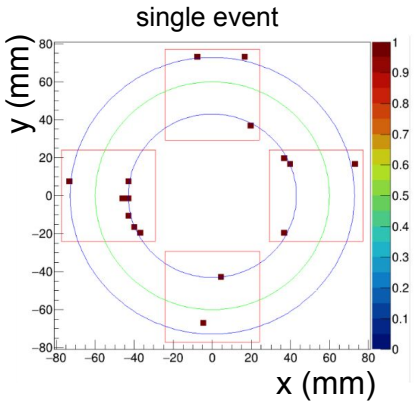
# dRICH beam tests

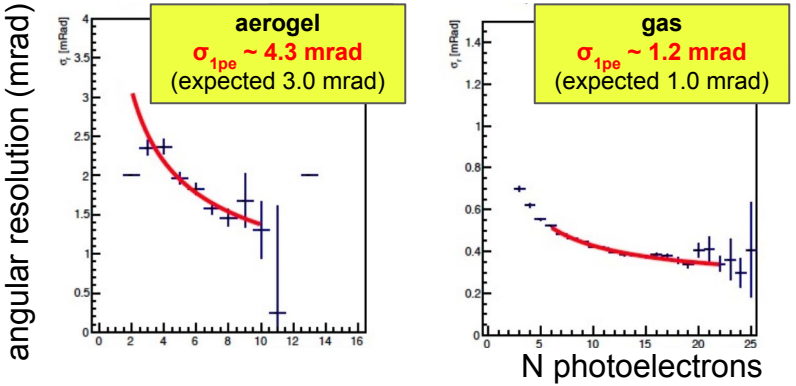
CERN SPS

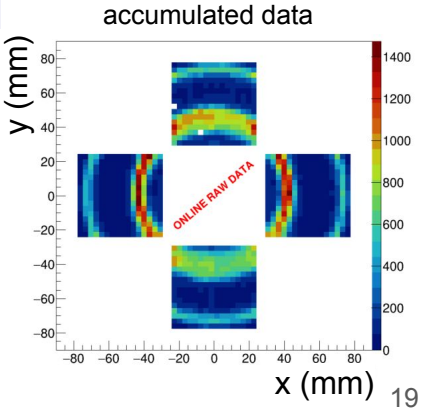
**detector prototype to study dual radiator performance and interplay**



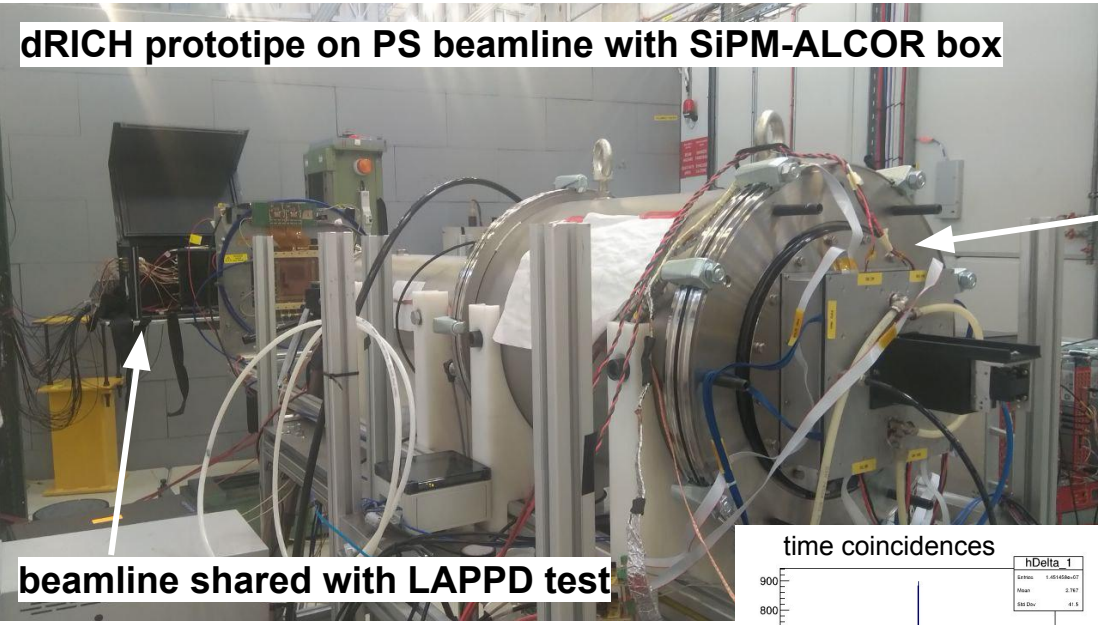



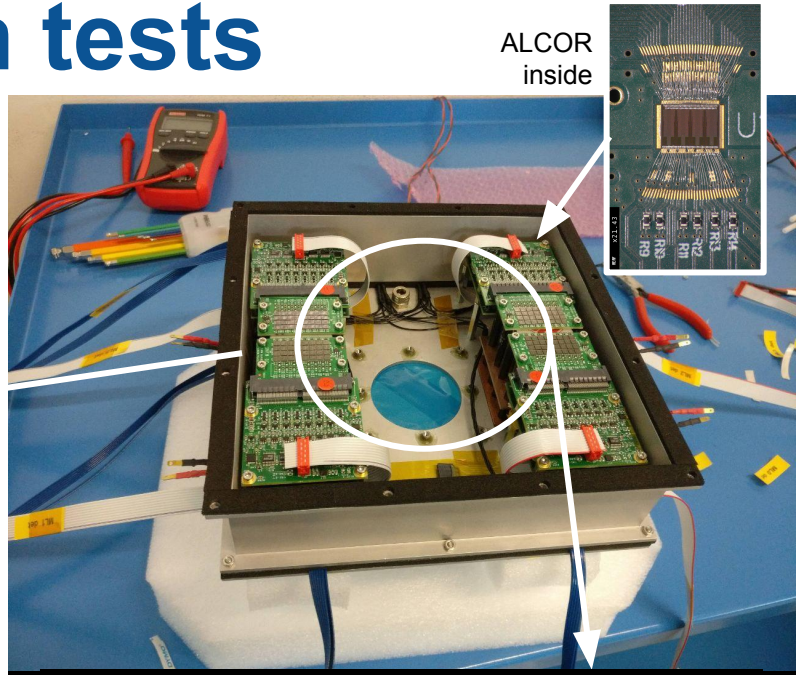



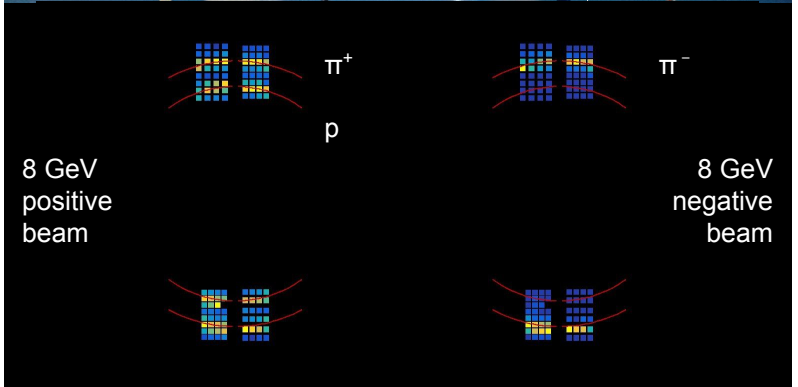



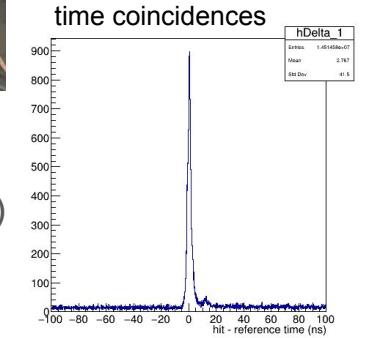
# dRICH beam tests

**successful operation of SiPM with complete readout chain**



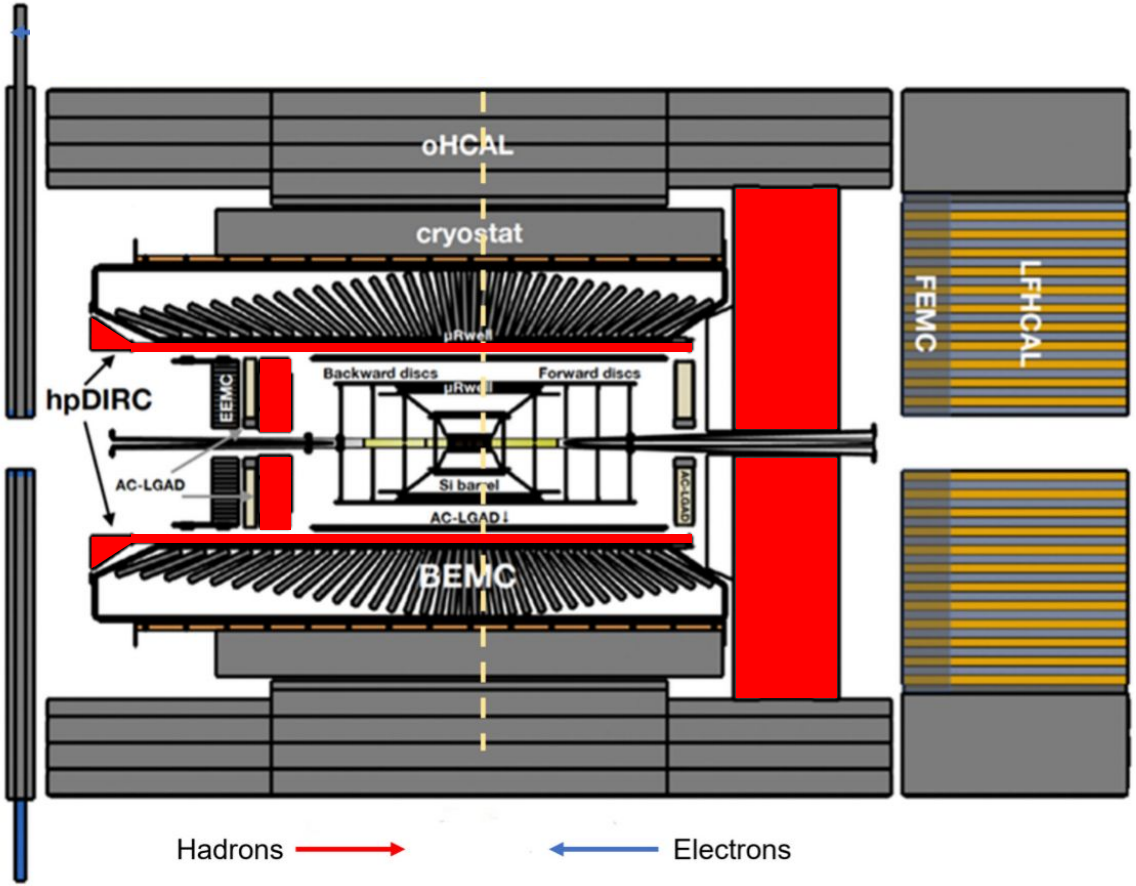




SiPM sensors were **irradiated** (up to $10^{10}$) and **annealed** (150 hours at T = 150 C)

ePIC

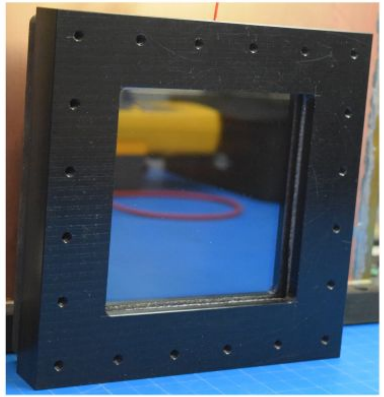
photosensors

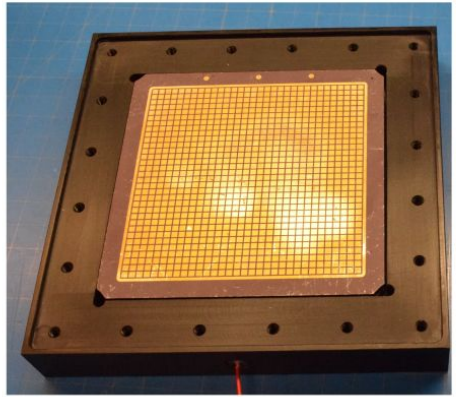


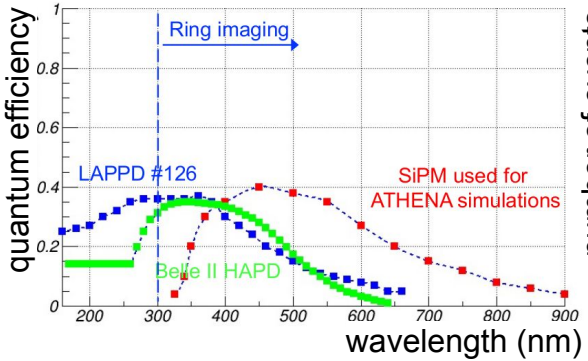
# Photosensors – HRPPD

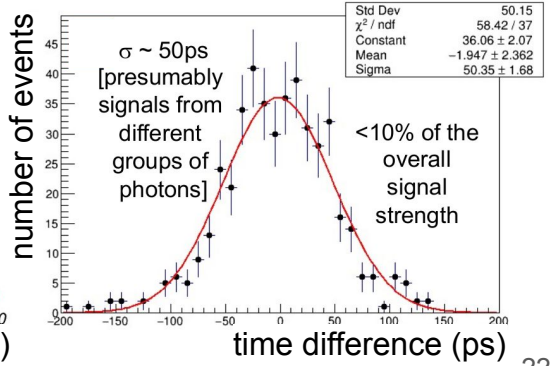
**smaller version of LAPPD MCP-PMT technology, being developed with Incom Inc.**

- **DC-coupled HRPPD**
  - choice for backward RICH detector
    - for both mRICH and pfRICH layout
  - 108 x 108 $mm^2$ active area (120 x 120 $mm^2$ total)
  - high intrinsic time resolution
  - low DCR (compared to SiPM) ~ 1 $kHz/cm^2$
  - low cost (compared to other MCP-PMT)
    - possible application for DIRC
- **ongoing R&D**
  - optimisation of QE and pixelation
  - characterisation in B field
    - gain and time resolution
  - mechanical / electrical interface
    - with direct pixel readout





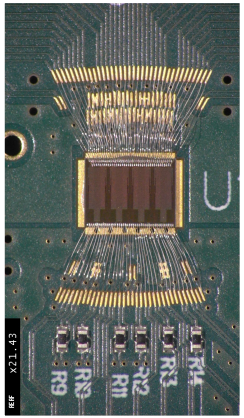


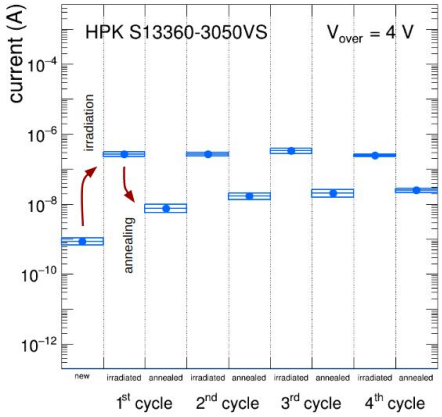



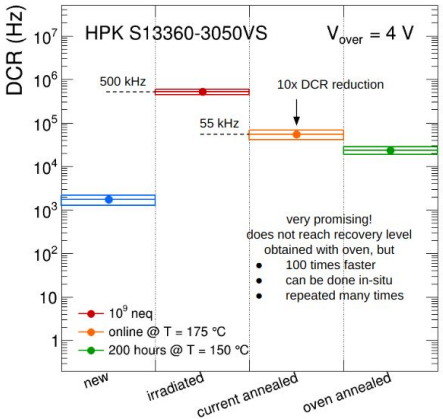
# Photosensors – SiPM

**magnetic-field insensitive and cheap solution for the dRICH**

- **pros**
  - cheap
  - high photon efficiency
  - excellent time resolution
  - insensitive to B field
- **cons**
  - large DCR, ~ 50 kHz/mm$^2$ @ T = 24 °C
  - not radiation tolerant
    - moderate fluence < $10^{11}$ $n_{eq}$/cm$^2$
- **R&D on mitigation strategies**
  - reduce DCR at low temperature
    - operation at T = -30 °C (or lower)
  - recover radiation damage
    - in-situ high-temperature annealing
  - exploit timing capabilities
    - with ALCOR (INFN) front-end chip

# Summary

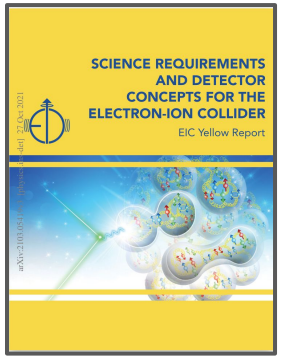
**ePIC meets EIC PID needs with advanced detector technology**

- **PID is one of the major challenges for the ePIC detector at the EIC**
  - physics requires high-purity π K p over large phase-space
  - multiple techniques needed
    - time-of-flight, ring imaging Cherenkov
    - calorimetry for e (μ) identification
- **selected detector technologies meet the requirements**
  - AC-LGAD TOF
  - high-performance DIRC
  - dual-radiator RICH
  - currently reviewing technologies for the backward RICH (mRICH / pfRICH)
- **ongoing R&D activities**
  - risk reduction
  - optimisation of technologies

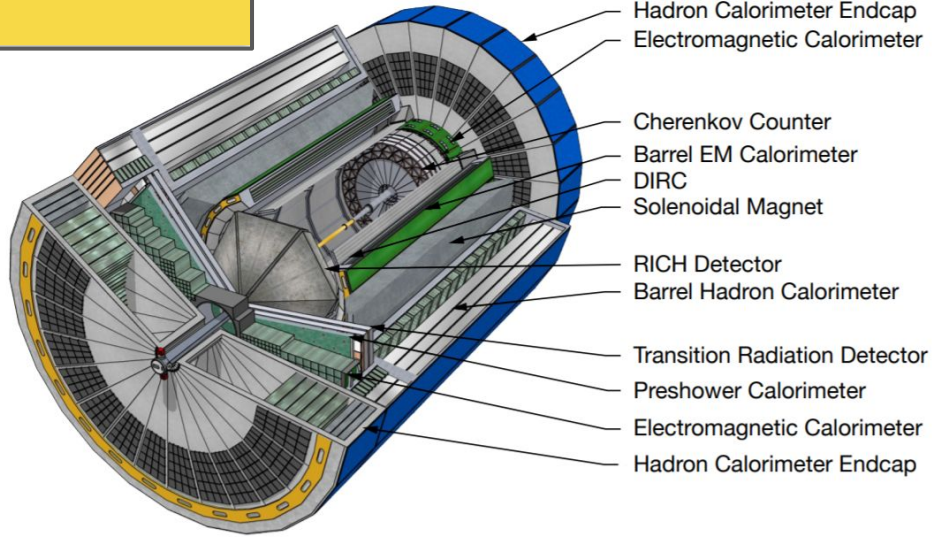
END

# Detector requirements for PID

**definition of requirements in the Yellow Report**




- **generic all-purpose detector and performance matrix**
  - summarises the detector requirements for the diverse physics program at EIC
  - focus on the PID-relevant subset of the detector matrix




| η | θ | Nomenclature | | | Electrons and Photons | | | π/K/p | |
|---|---|---|---|---|---|---|---|---|---|
| | (mrad) | | | | Resolution $\sigma_E/E$ | PID | min E photon | p-Range (GeV/c) | Separation |
| -4.0 to -3.5 | | | | | not accessible | | | | |
| -3.5 to -3.0 | | | | | | | | | |
| -3.0 to -2.5 | | | | | 1%/E⊕2.5%/√E⊕1% (for 40 cm space) | π suppression up to 1:1E-4 | 20 MeV | | |
| -2.5 to -2.0 | | | | | | | | | |
| -2.0 to -1.5 | | | | | | | | | |
| -1.5 to -1.0 | | | | Backward Detector | 2%/E⊕(4-8)%/√E⊕2% (Upper limit achievable with 50 cm space *Better resolution requires ~65 cm space allocated ) | π suppression up to 1:(1E-3 - 1E-2) | 50 MeV | ≤ 10 GeV/c | |
| -1.0 to -0.5 | | | | | | | | ≤ 6 GeV/c | |
| -0.5 to 0.0 | | | Central Detector | | 2%/E⊕(12-14)%/√E⊕(2-3)% for 30 cm space A better stochastic term can be achieved with more space: 2.5% with crystals 35cm 10% sampling 40cm 4% SciGlass 65cm *Better resolution requires ~65 cm space allocated ) | π suppression up to 1:1E-2 | 100 MeV (50 MeV if higher resolution) | | ≥ 3 σ |
| 0.0 to 0.5 | | | | Barrel | | | | | |
| 0.5 to 1.0 | | | | | | | | ≤ 6 GeV/c | |
| 1.0 to 1.5 | | | | | | | | | |
| 1.5 to 2.0 | | | | | | | | | |
| 2.0 to 2.5 | | | | | | | | | |
| 2.5 to 3.0 | | | | Forward Detectors | 2%/E⊕(4*-12)%/√E⊕2% Upper limit achievable with 40cm space *Better resolution requires ~65 cm space allocated | 3σ e/π up to 15 GeV/c | 50 MeV | ≤ 50 GeV/c (worse approaching 3.5) | |
| 3.0 to 3.5 | | | | | | | | | |

*arXiv:2103.05419 [physics.ins-det]*

# Generic R&D projects since 2014

PID

| Project | Topic | | |
|---|---|---|---|
| eRD1 | EIC Calorimeter Development | eRD18 | Precision Central Silicon Tracking & Vertexing |
| eRD2 | A Compact Magnetic Field Cloaking Device | eRD19 | Detailed Simulations of Machine Background Sources and the Impact to Detector Operations |
| eRD3 | Design and assembly of fast and lightweight forward tracking prototype systems | eRD20 | Developing Simulation and Analysis Tools for the EIC |
| **eRD6** | **Tracking and PID detector R&D towards an EIC detector** | eRD21 | EIC Background Studies and the Impact on the IR and Detector design |
| **eRD10** | **(Sub) 10 Picosecond Timing Detectors at the EIC** | **eRD22** | **GEM based Transition Radiation Tracker R&D** |
| **eRD11** | **RICH detector for the EIC'S forward region particle identification - Simulations** | eRD23 | Streaming Readout for EIC Detectors |
| eRD12 | Polarimeter, Luminosity Monitor and Low Q2-Tagger for Electron Beam | eRD24 | Silicon Detectors with high Position and Timing Resolution as Roman Pots at EIC |
| **eRD14** | **An integrated program for particle identification (PID)** | eRD25 | Si-Tracking |
| eRD15 | R&D for a Compton Electron Detector | eRD26 | Pulsed Laser System for Compton Polarimetry |
| eRD16 | Forward/Backward Tracking at EIC using MAPS Detectors | eRD27 | High Resolution ZDC |
| eRD17 | BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing/Saturation Regime | eRD28 | Superconducting Nanowire Detectors |
| | | **eRD29** | **Precision Timing Silicon Detectors for for combined PID and Tracking System** |

# Project R&D

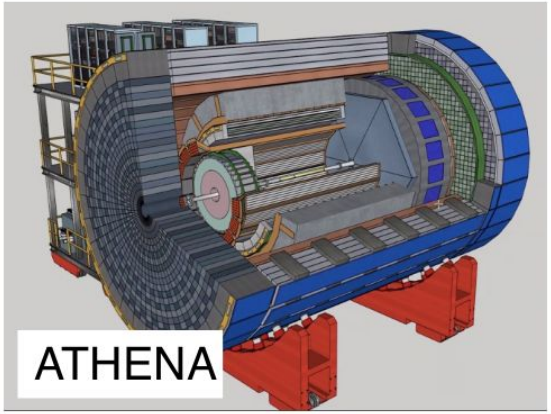
PID

**Generic R&D program ended in September 2021**
**focus on projects targeted for the EIC detector**

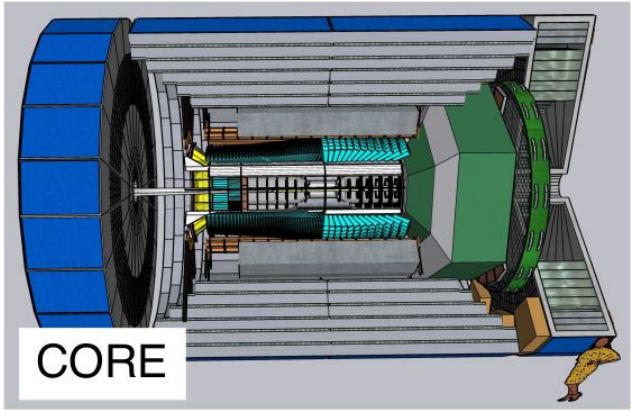
- **Project driven R&D scope**
  - reflects reference detector as defined in CD-1
  - encapsulate Project and detector systems
  - reduce risk, ensure feasibility, optimisation

| Project | Topic |
|---|---|
| **eRD101** | **Modular RICH / aerogel RICH** |
| **eRD102** | **Dual-radiator RICH** |
| **eRD103** | **High-performance DIRC** |
| eRD104 | Silicon service reduction |
| eRD105 | SciGlass |
| eRD106 | Forward EMCAL |
| eRD107 | Forward HCAL |
| eRD108 | Cylindrical / planar MPGD |
| eRD109 | ASICs / electronics |
| **eRD110** | **Photosensors** |
| eRD111 | Silicon tracked (excluding electronics) |
| **eRD112** | **AC-LGAD (including ASIC)** |

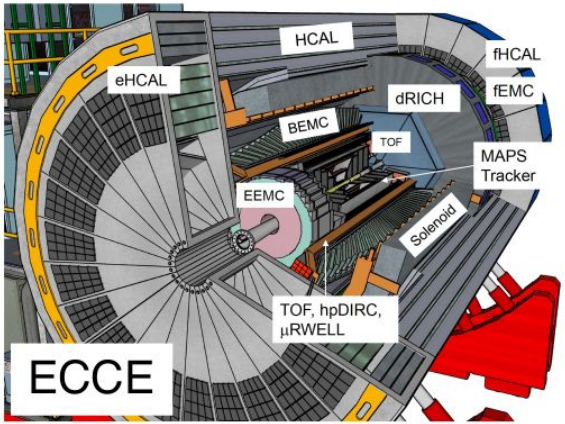
# PID in detector proposals



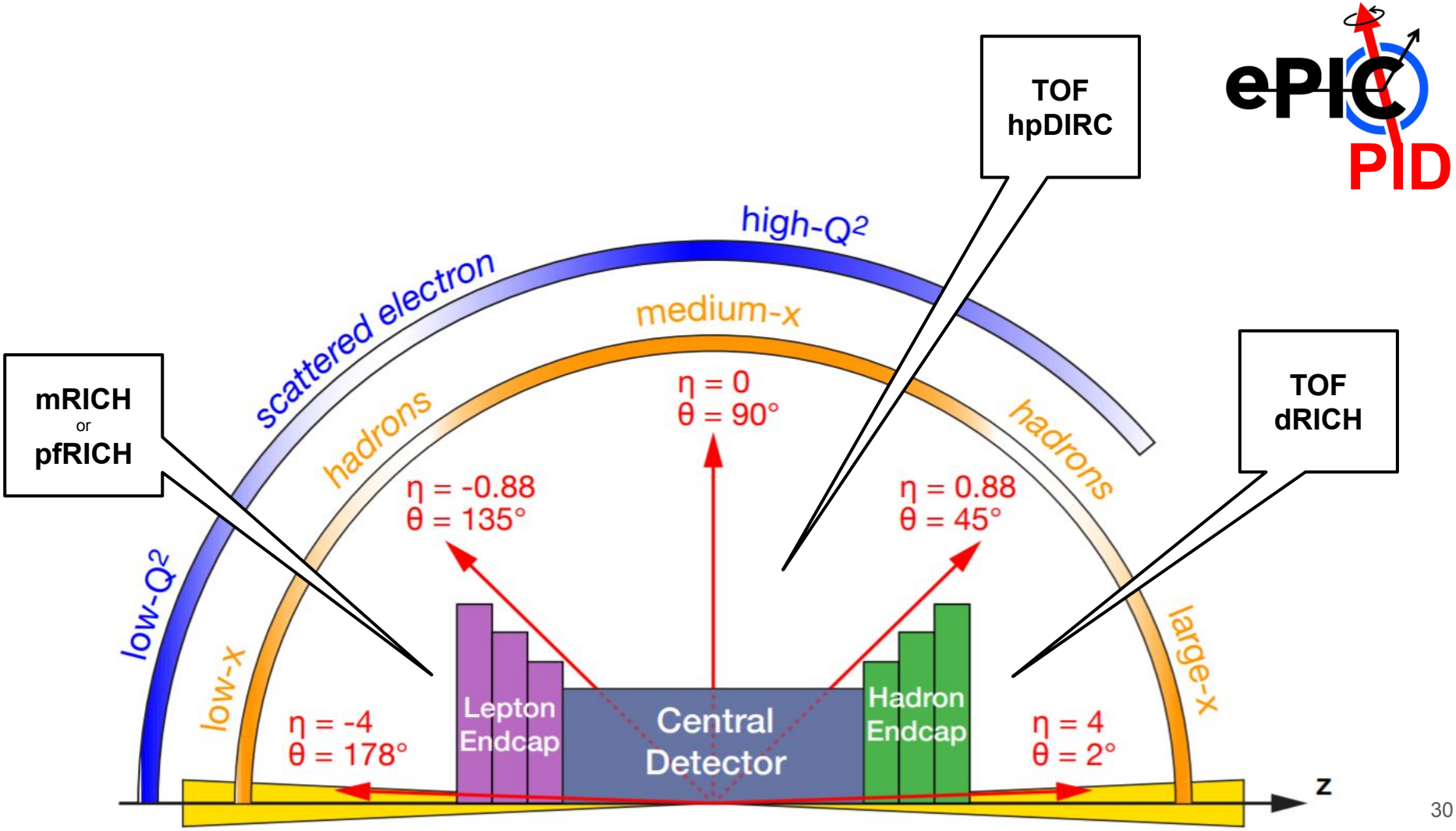

- **backward**
  proximity-focus RICH
- **central**
  high-performance DIRC
  AC-LGAD TOF
- **forward**
  dual-radiator RICH




- **backward**
  AC-LGAD TOF
- **central**
  high-performance DIRC
- **forward**
  dual-radiator RICH



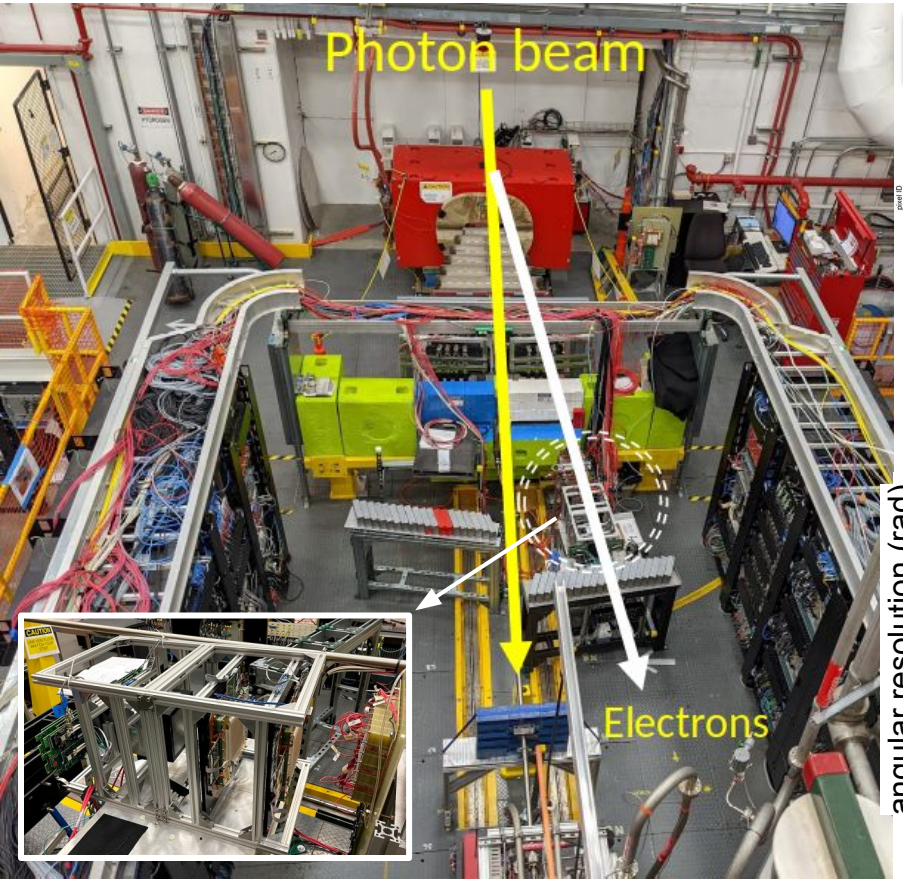

- **backward**
  modular RICH
  AC-LGAD TOF
- **central**
  high-performance DIRC
  AC-LGAD TOF
- **forward**
  dual-radiator RICH
  AC-LGAD TOF

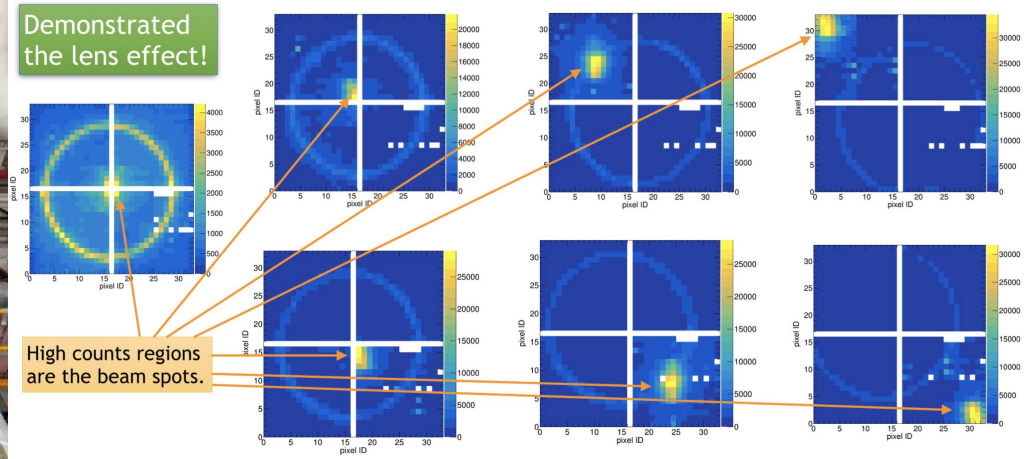

ePIC PID
TOF
hpDIRC
mRICH
or
pfRICH
TOF
dRICH
high-Q²
scattered electron
medium-x
hadrons
hadrons
low-Q²
low-x
large-x
η = 0
θ = 90°
η = -0.88
θ = 135°
η = 0.88
θ = 45°
η = -4
θ = 178°
η = 4
θ = 2°
Lepton
Endcap
Central
Detector
Hadron
Endcap
z

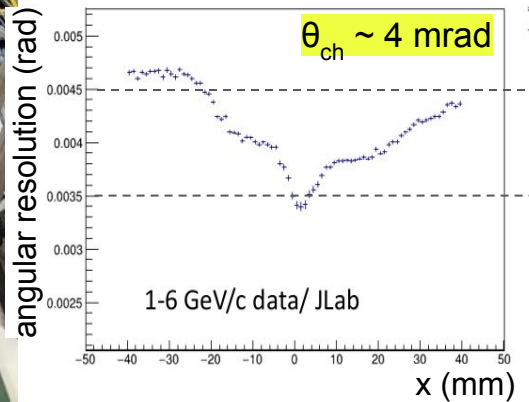
# mRICH beam tests

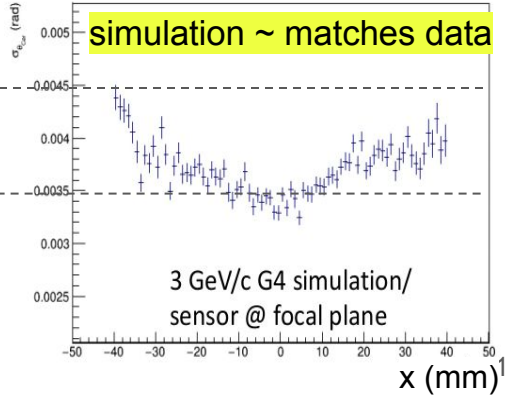
JLab Hall D

**verified working principle and validated simulation**

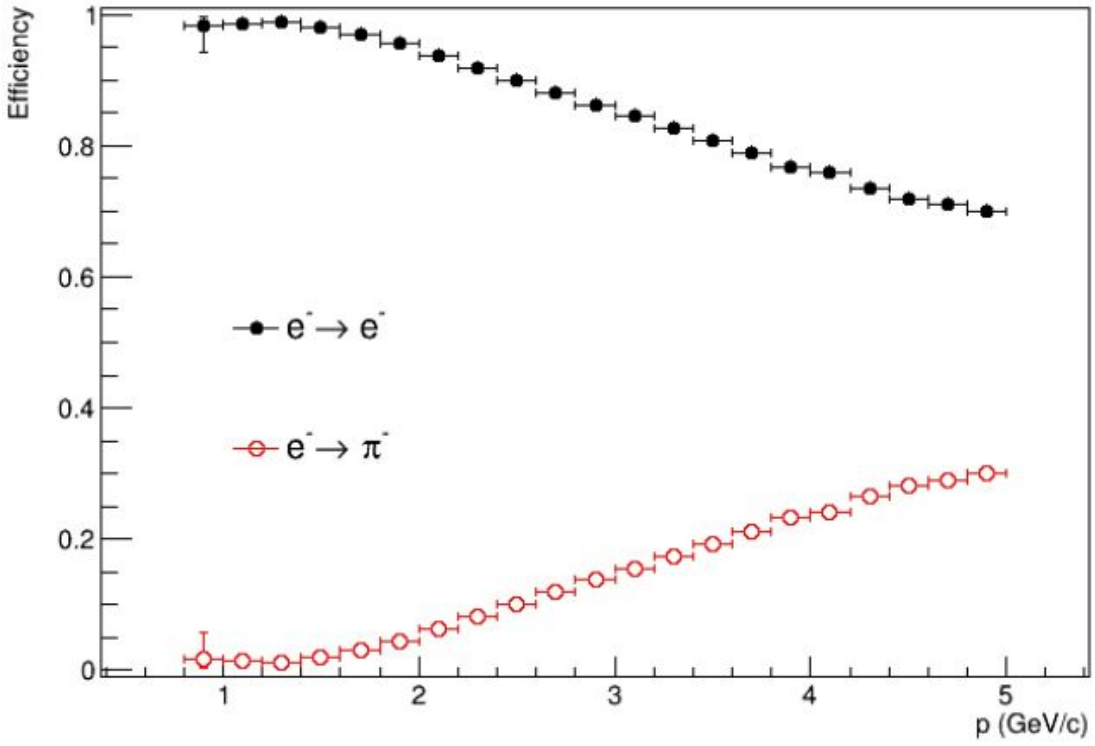


# mRICH electron-ID

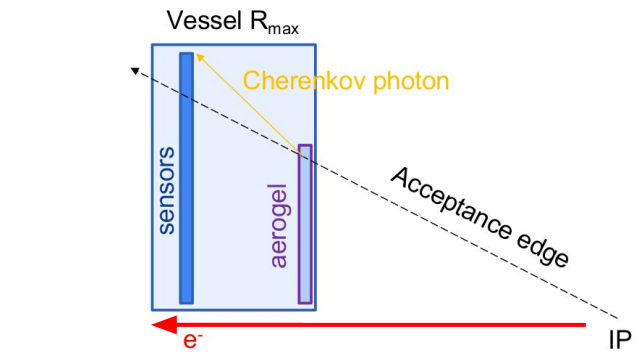


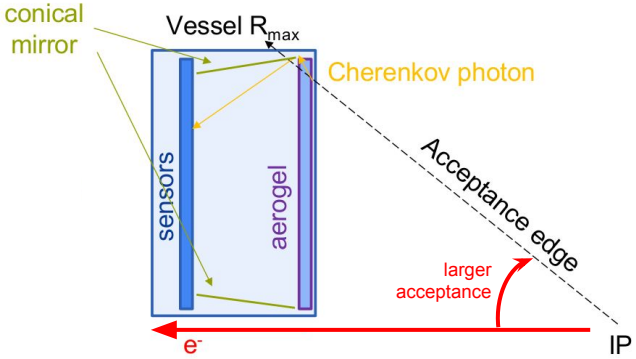

Murad Sarsour

# pfRICH acceptance optimisation

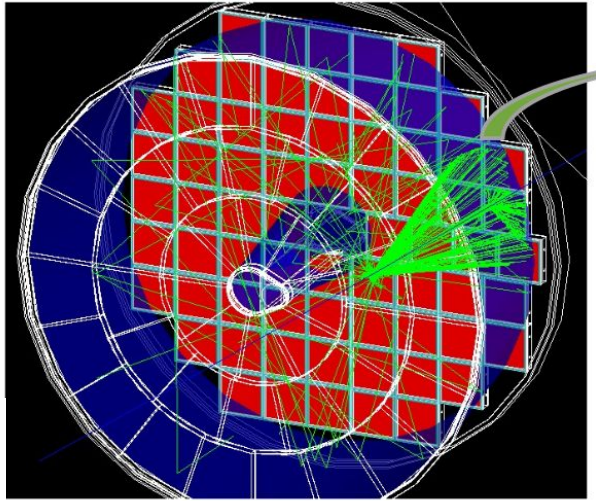
**use side wall mirrors to increase pseudorapidity acceptance**

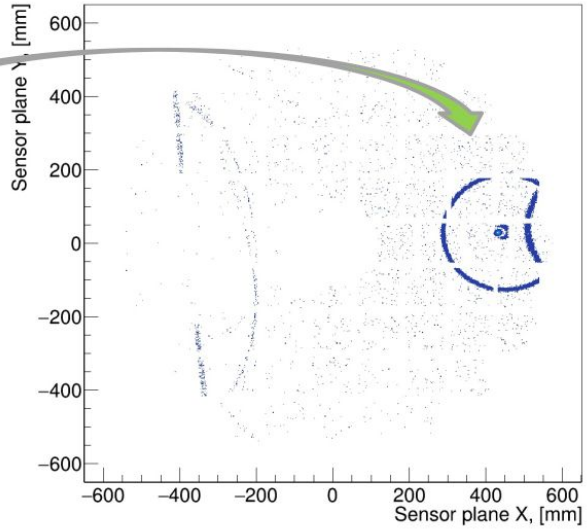
without wall mirrors



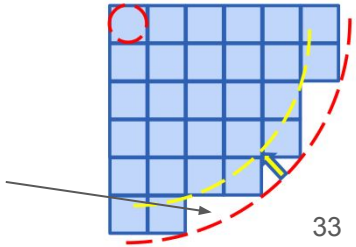

with wall mirrors





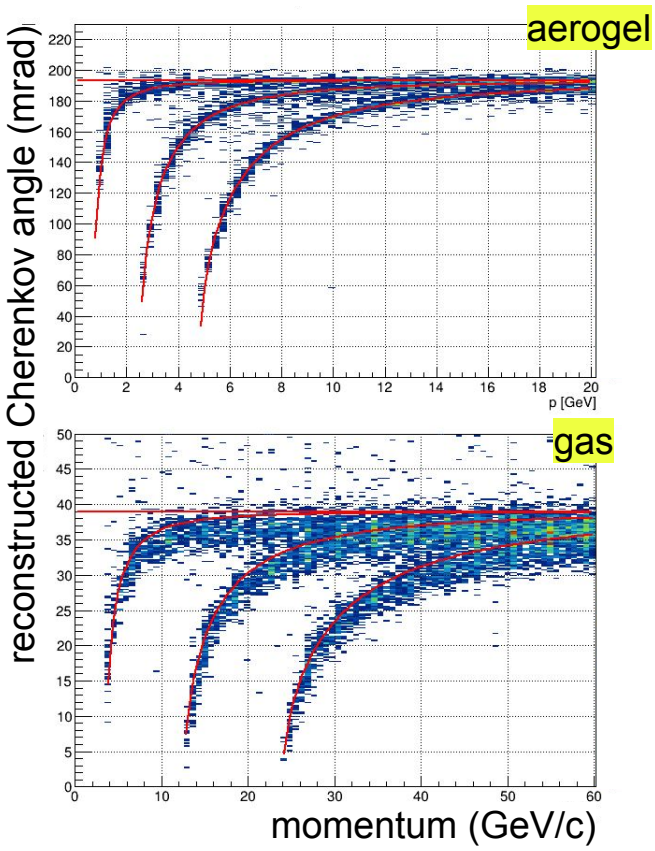

**achieve -3.5 < η < -1.5 acceptance**

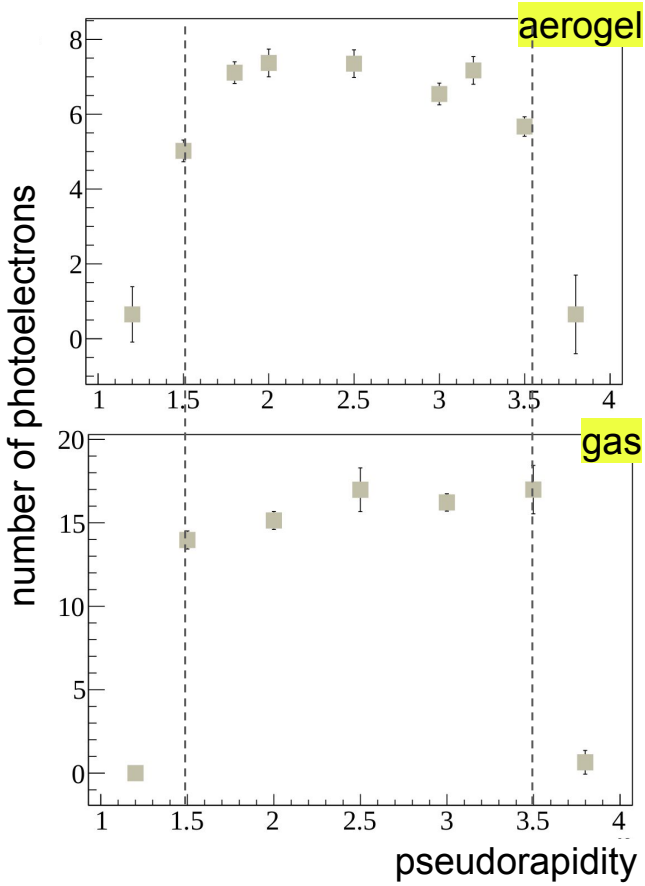
conical mirrors to avoid inefficiency of the sensor plane



# dRICH performance simulation

**inverse ray-tracing reconstruction algorithm shared with pfRICH**

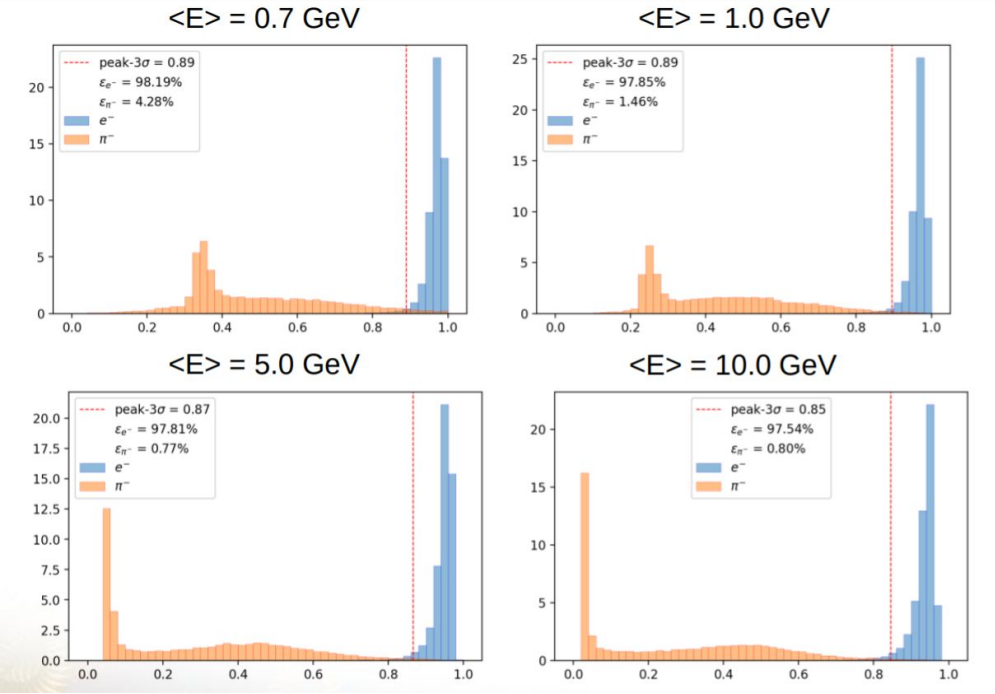


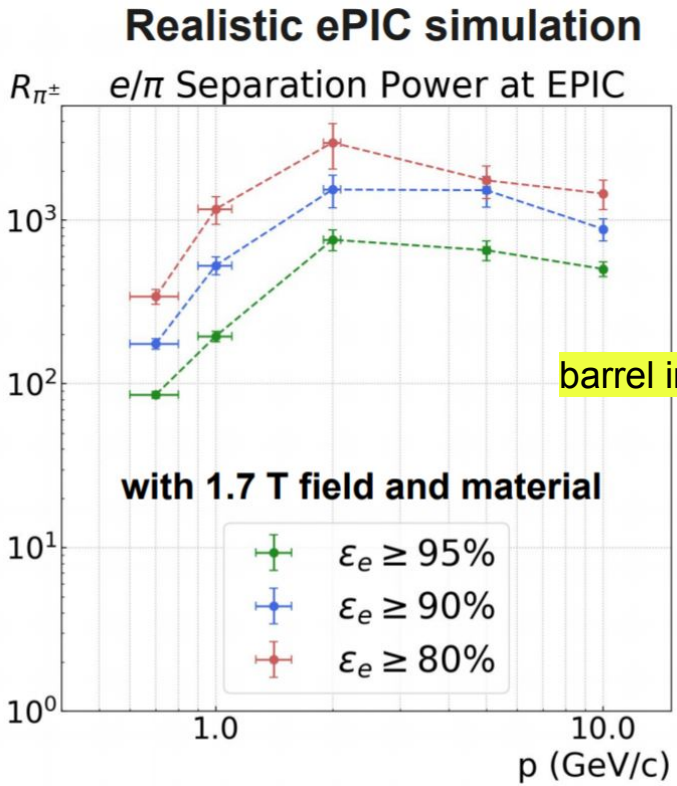



# EMCal e/π separation power

**excellent, up to $10^4$ pion suppression**

barrel SciGlass




barrel imaging

# Muon identification

**muon ID using a combination of EM and Hadron calorimetry**

Total hadron interaction length:
6-7 $\lambda_0$ for central and 7-8 $\lambda_0$ for forward
Pion punch through probability: $10^{-2}$ to $10^{-3}$ level

- Utilizing central track, barrel EMCal, EMCal active support and barrel HCal
- Pion rejection starting at $10^{-1}$ at low p and saturate above 100:1 above a few GeV/c