Particle Identification with the ePIC detector at the EIC exploiting Cherenkov radiation

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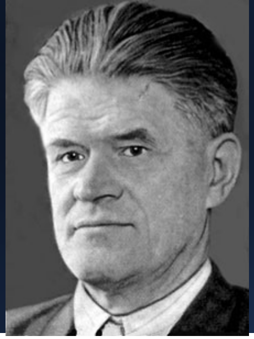
On behalf of ePIC collaboration

Cherenkov radiation



Invariant mass of a relativistic particle

$$m = \frac{p}{c\beta\gamma}$$

$$\left(\frac{dm}{m}\right)^2 = \left(\gamma^2\frac{d\beta}{\beta}\right)^2 + \left(\frac{dp}{p}\right)^2$$

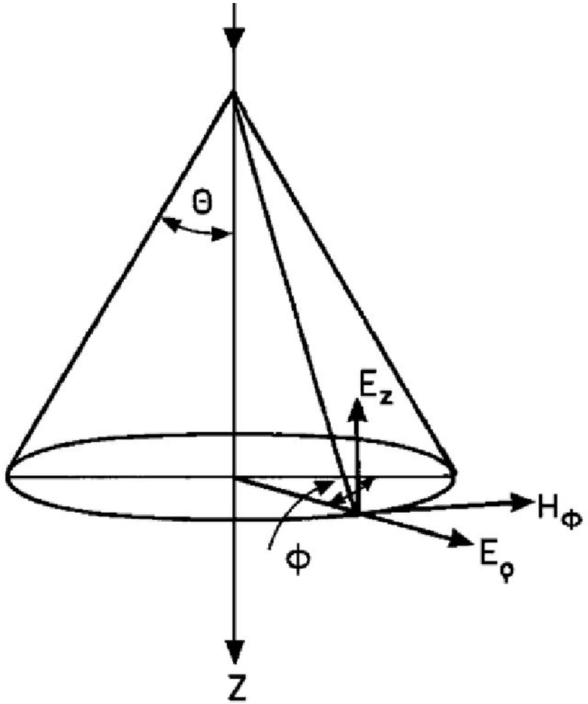
β resolution:

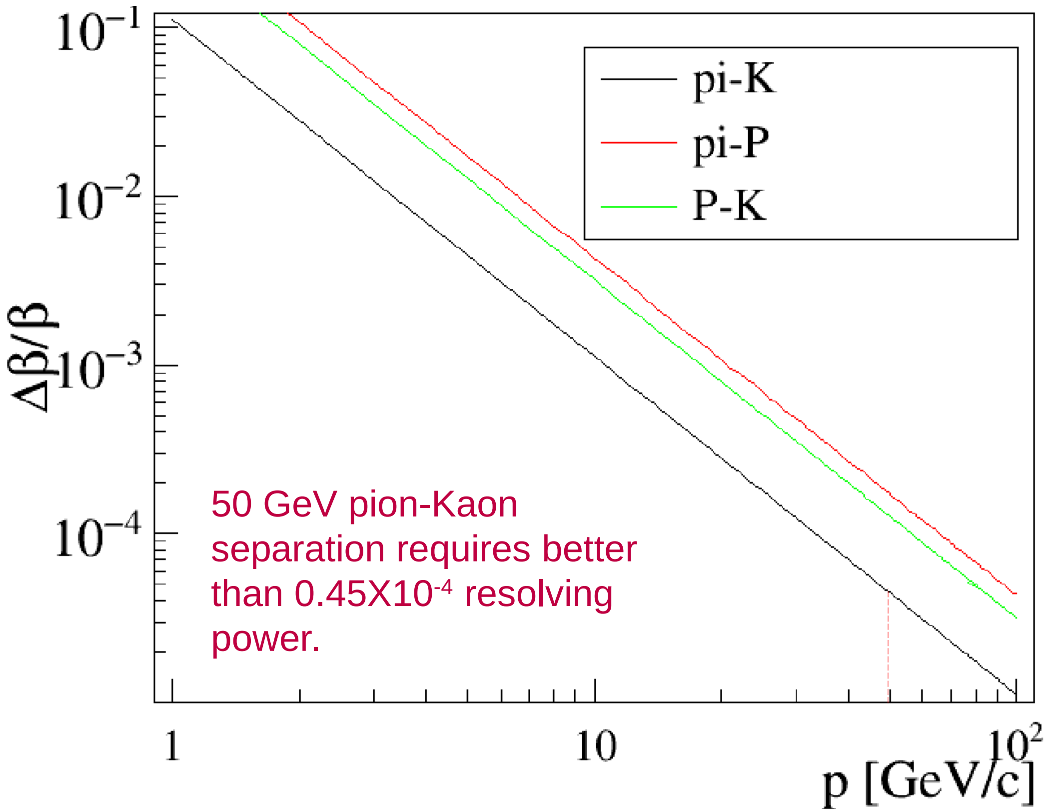
$$\frac{\Delta\beta}{\beta} = \frac{(m_1^2 - m_2^2).c^2}{2p^2}.$$

Exploiting Cherenkov equation

$$\cos\theta_C = \frac{1}{n\beta}$$

$$\left(\frac{\sigma_\beta}{\beta}\right)^2 = (\tan\theta_C\sigma_{\theta_C})^2 + \left(\frac{\sigma_n}{n}\right)^2$$

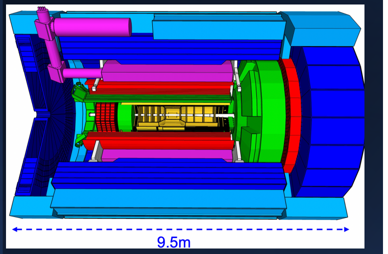


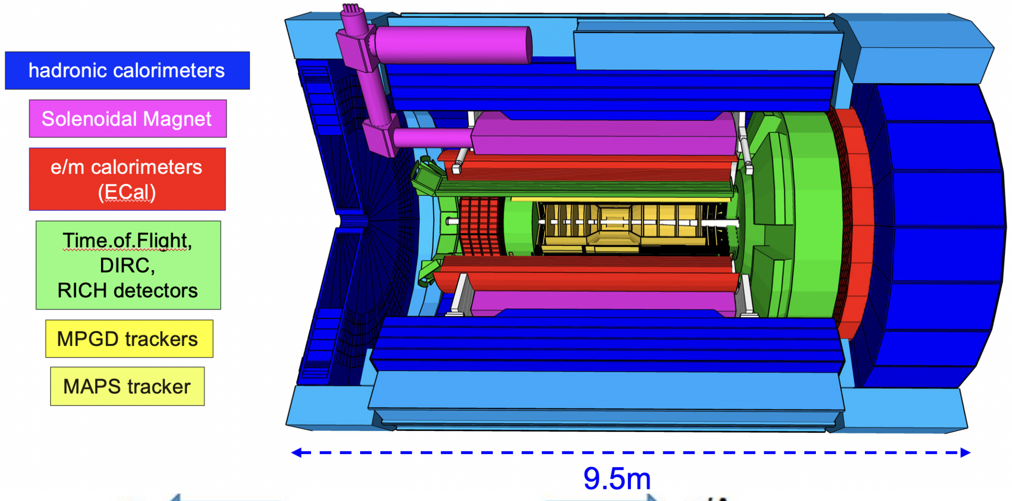


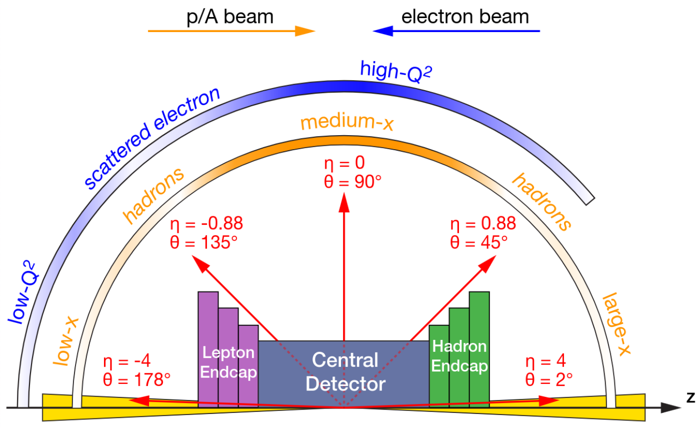
Excellent angle reconstruction!!
High number of Cherenkov photons.

Introduction: ePIC in EIC

Talk by Silvia Dalla Torre about ePIC detector







PID subsystems

Backward

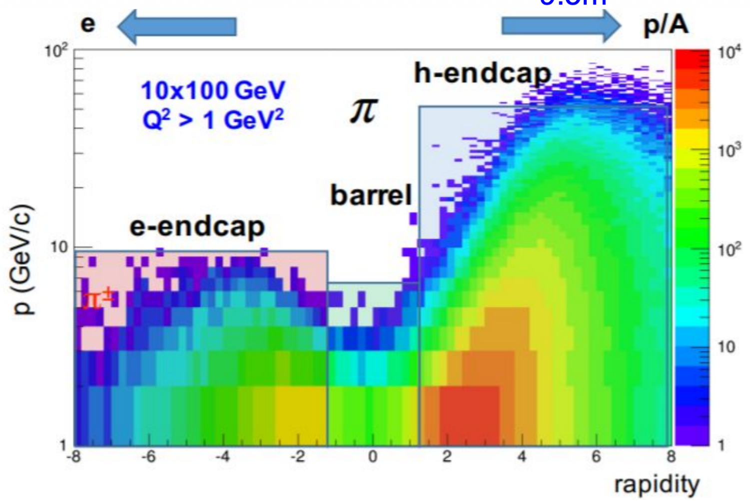
Proximity focusing RICH (aerogel RICH + peripheral conical mirrors + HRPPD)

Central

Time Of Flight (AC LGAD), DIRC (fused silica bar with novel lensing and MCP-PMT based readout)

Forward

Time Of Flight (AC LGAD) and Dual radiator RICH (aerogel + C2F6 gas + spherical mirrors + SiPM sensors)



Hadron Identification

Backward

- Up to 9 GeV/c

Central

- Up to 6 GeV/c

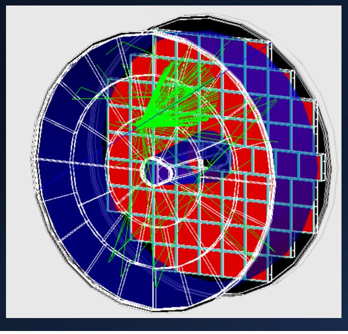
Forward

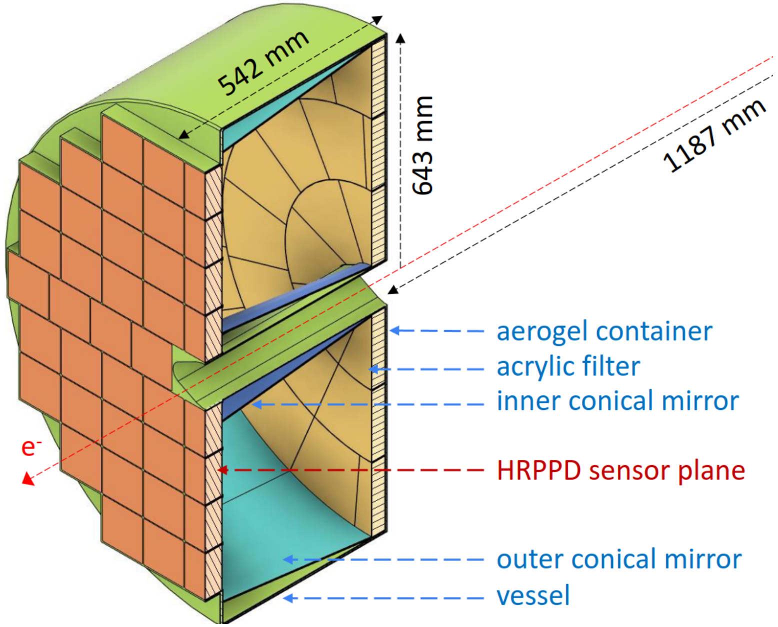
- Up to 50 GeV/c

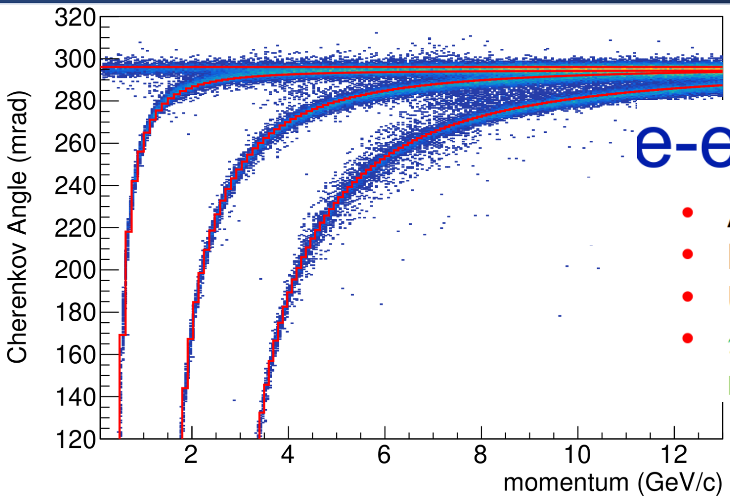
Provide electron-pion separation to boost calorimeter performance!

Diverse phase-space.
Multiple PID Detectors. Cherenkov detectors play central role.

Backward PID



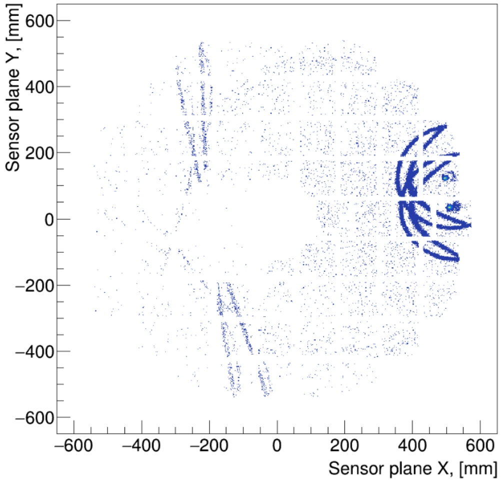


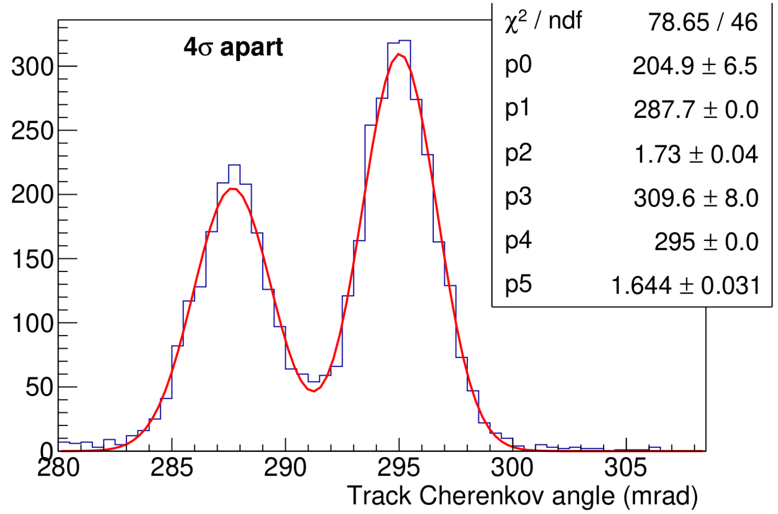


e-endcap RICH for ePIC detector

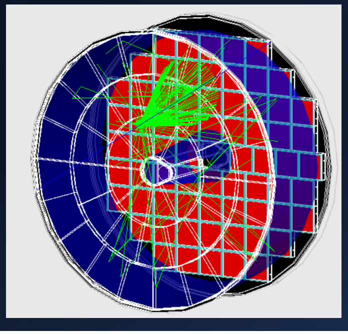
- A classical proximity focusing RICH
- Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- Uniform performance in the whole $\{\eta,\phi\}$ range
- π/K separation above 3σ up to ~ 9.0 GeV/c and ~10-20ps t_0 reference with a ~100% geometric efficiency in one detector

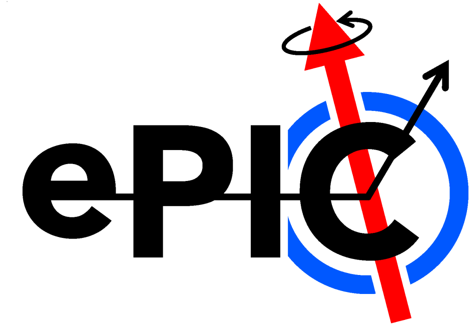
Large proximity gap(~50 cm), 4 mrad SPE resolution, 11-12 Npe at saturation, sophisticated chi-squared analysis capable of performing efficient pid with complicated event topologies.

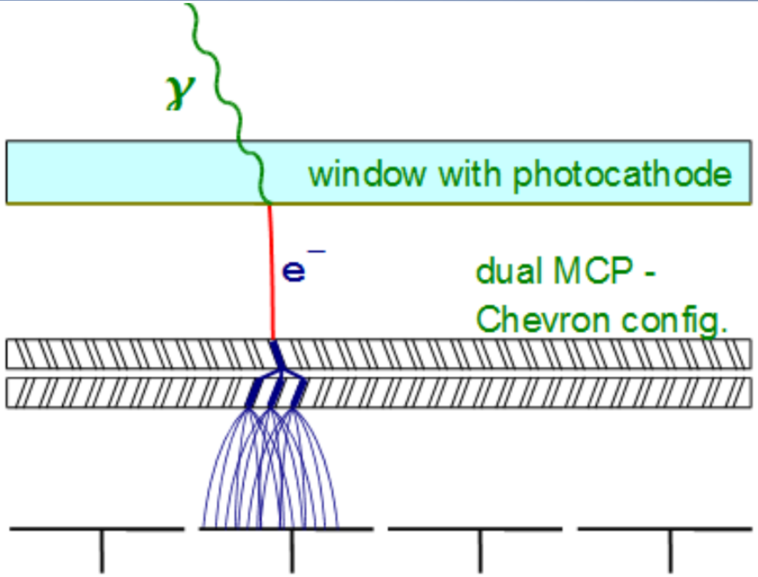


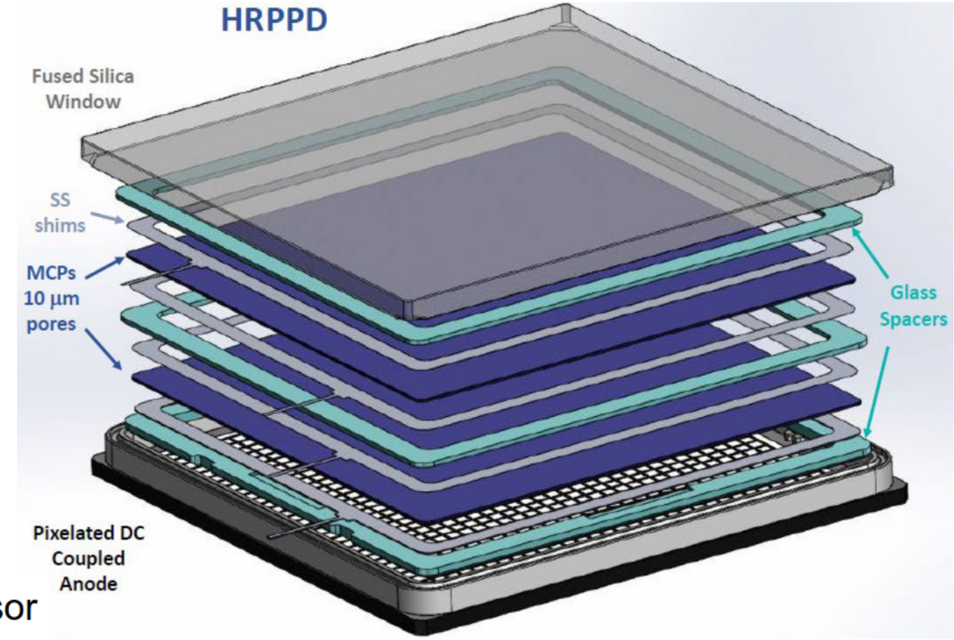


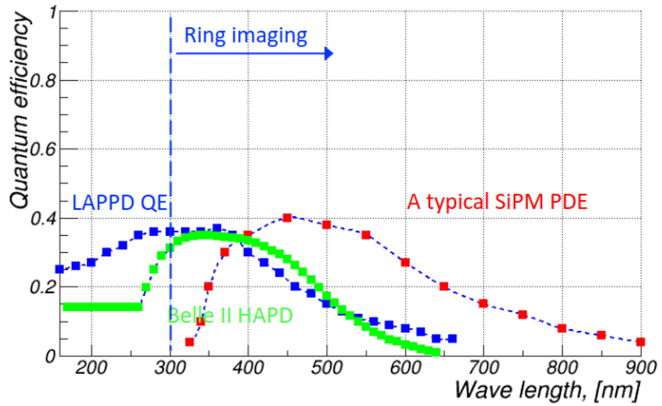
Backward PID: Hardware activities and prototype





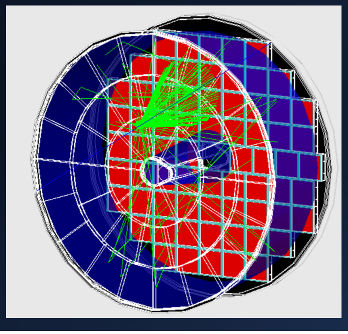






- An affordable large area vacuum photosensor
  - Up to ~3 times more cost efficient in $$ per mm² than other commercially available MCP-PMTs
- 10x10 cm² active area
- DC-coupled square pads
- Quantum efficiency above 30%
- SPE timing resolution ~50 ps level or higher
- EICROC based ASIC for readout system: meets requirements and available in 256+ channel configuration.

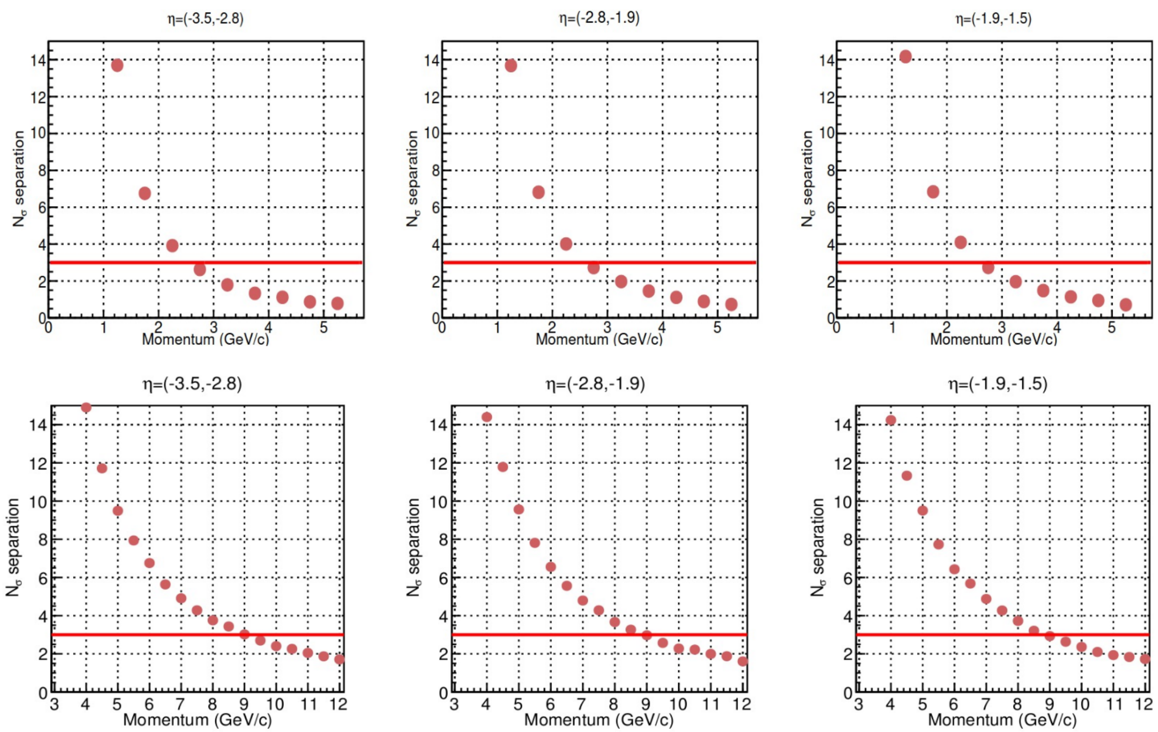
Backward PID



Performance: e/π & π/k separation

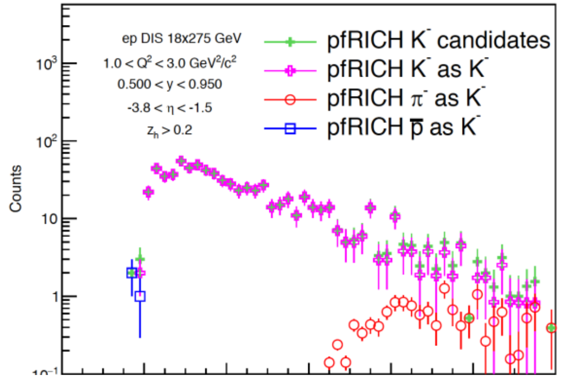
e/π

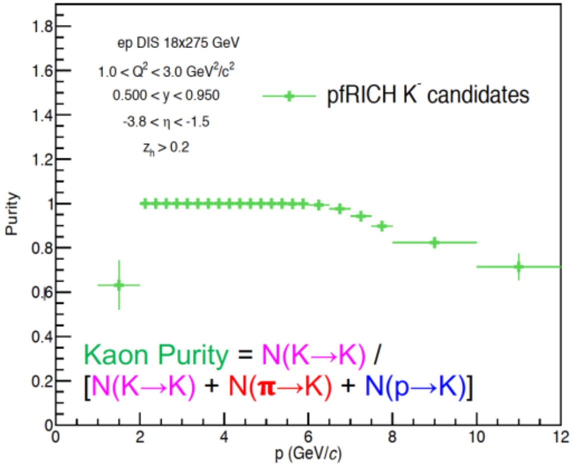
π/k

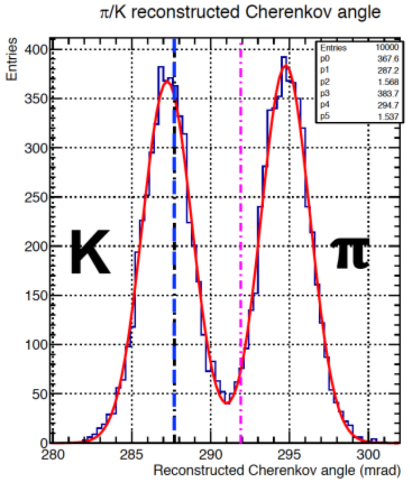


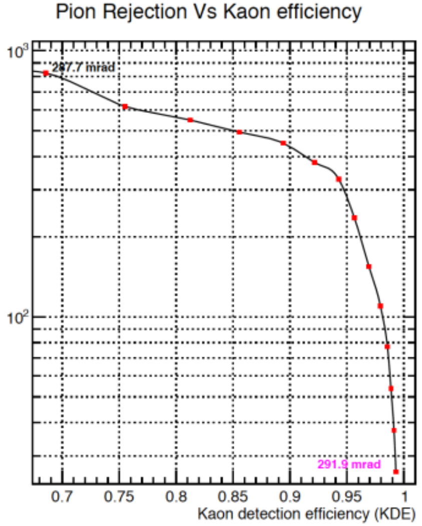
SIDIS Performance

- PYTHIA 18 x 275 GeV simulation
- Parameterized pfRICH hadron PID response, assuming 100% kaon detection efficiency

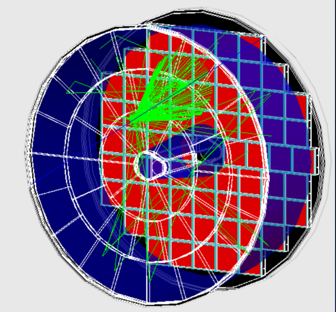




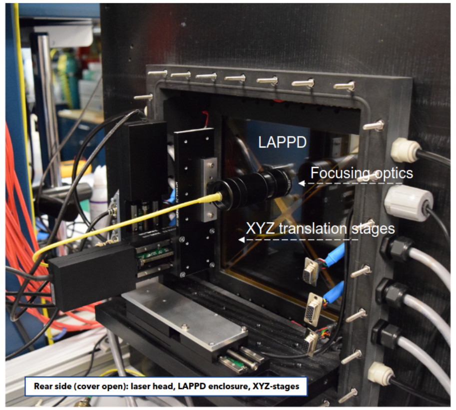


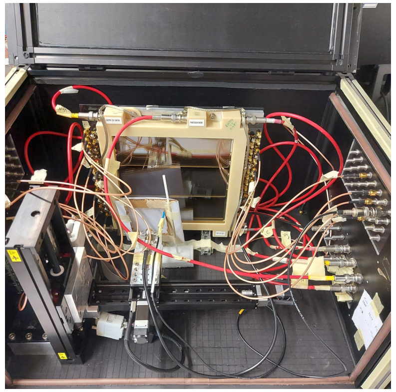


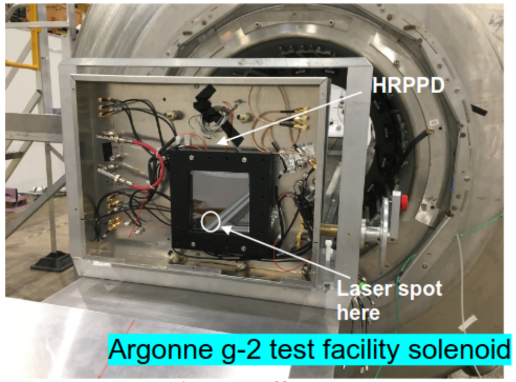
Backward PID:
Hardware activities and prototype

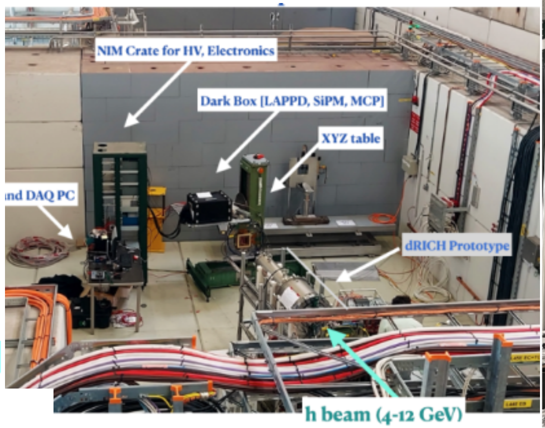


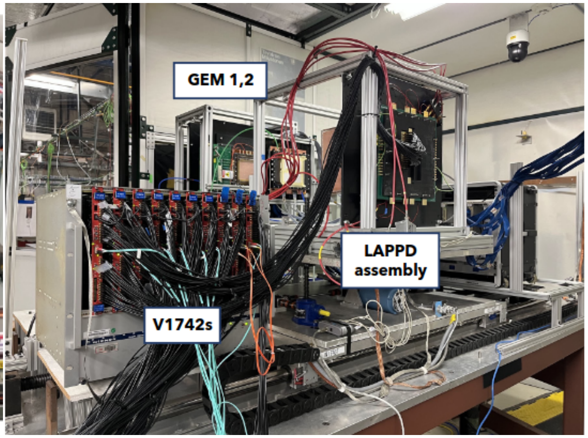
Test bench setup at BNL **Test setup at INFN Trieste**

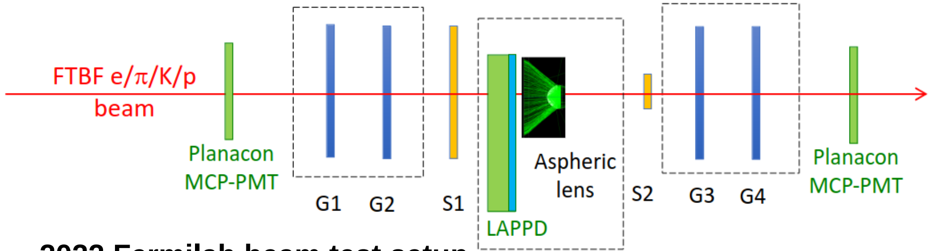




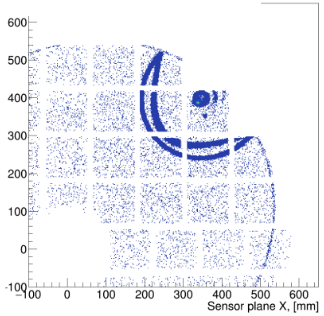


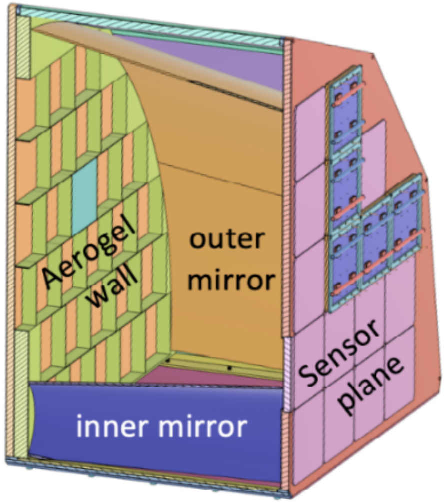






2022 Fermilab beam test setup





USA-Europe joint beam test effort!!

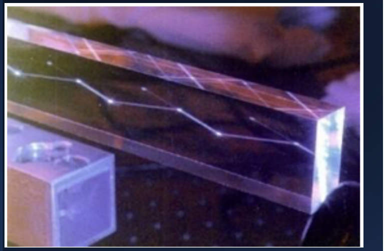
Evaluate prototype at Fermilab Test Beam Facility in FY24

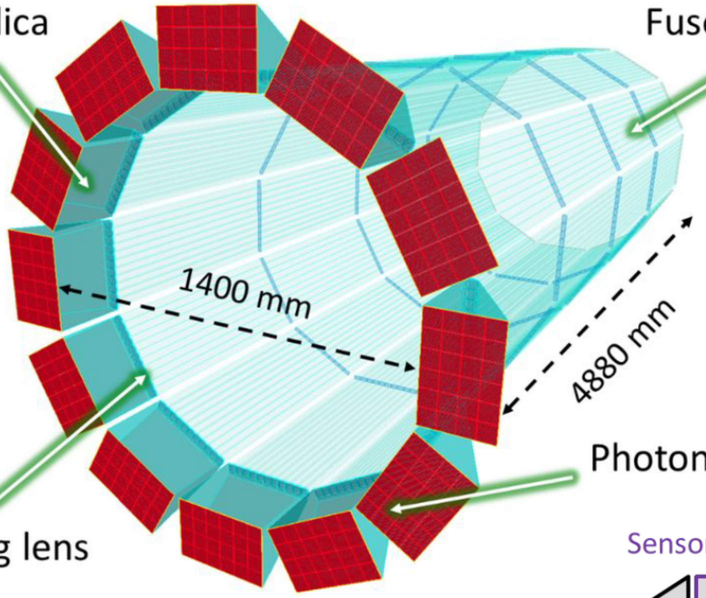
- Quantify π/K separation performance
- Verify single and multi-photon timing performance
- Evaluate Chiba Aerogel Factory tiles for pfRICH usage
- Make use of the first five HRPPDs produced by Incom, in a fully Integrated ASIC configuration.
- Evaluate conical mirror performance
- Check detector component integration

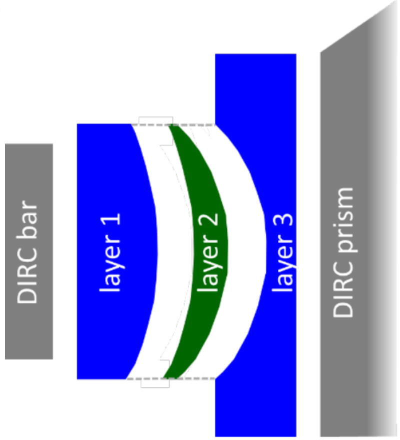
Evaluate LAPPD performance in magnetic field

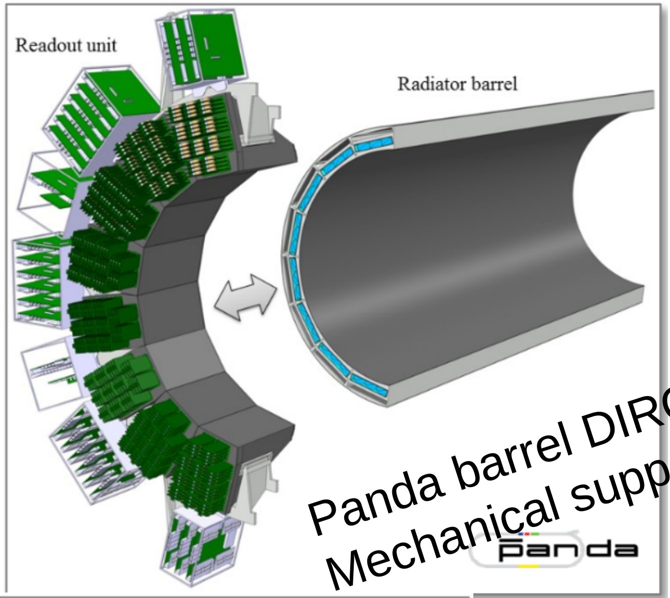
- Timing performance of LAPPD in magnetic field.

Central PID
hpDIRC

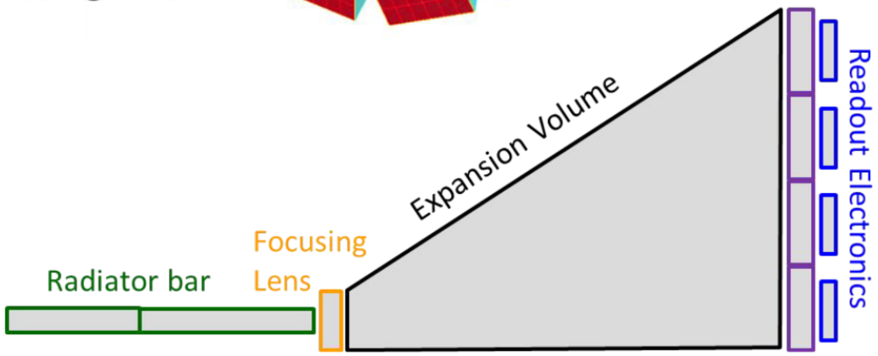


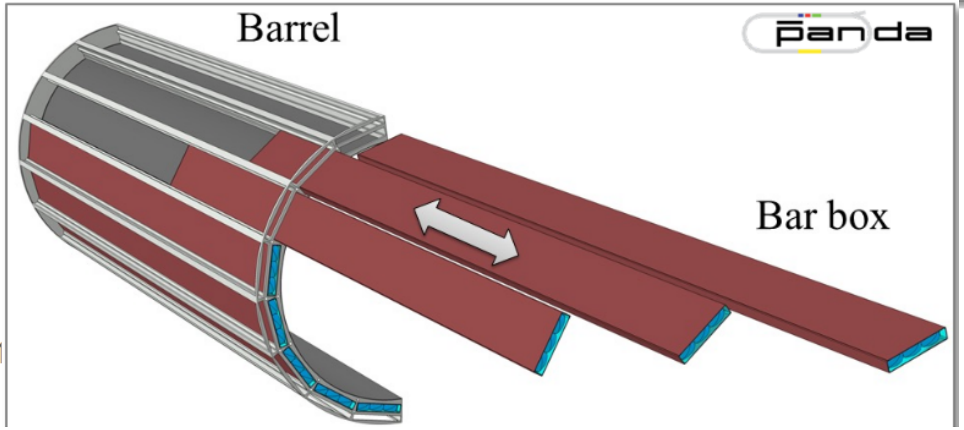






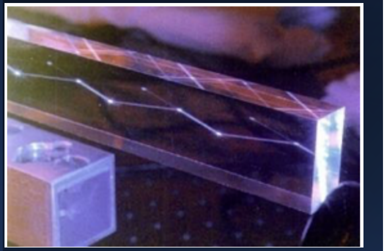
Panda barrel DIRC an example for EIC
Mechanical support

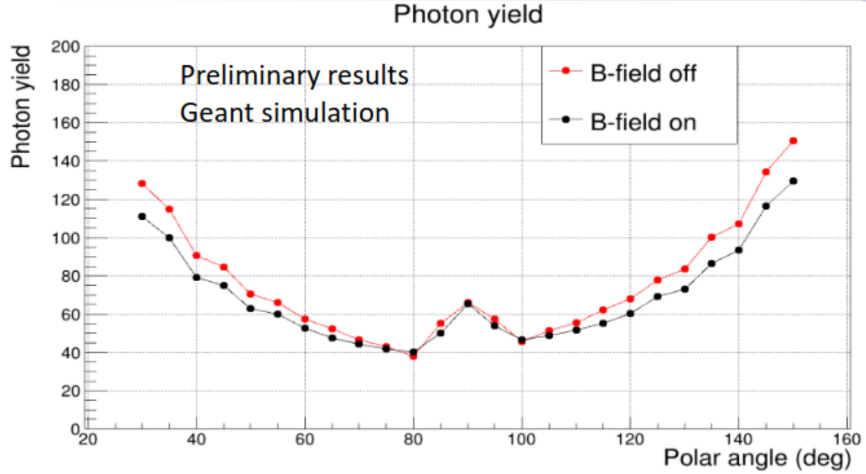


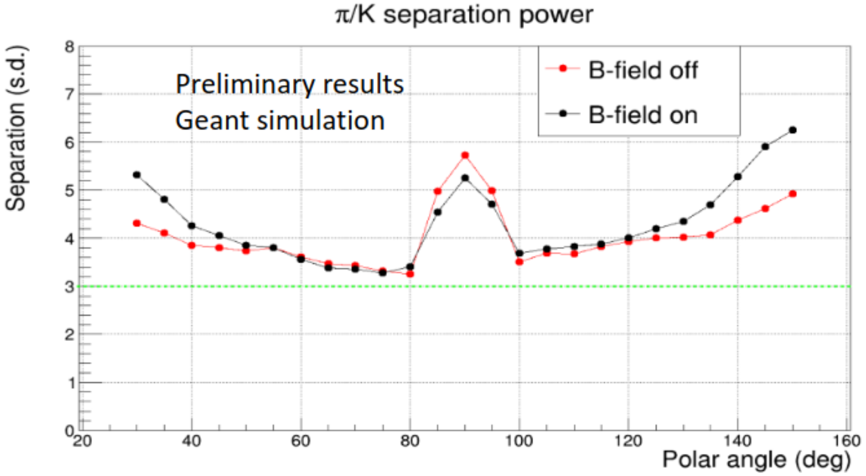


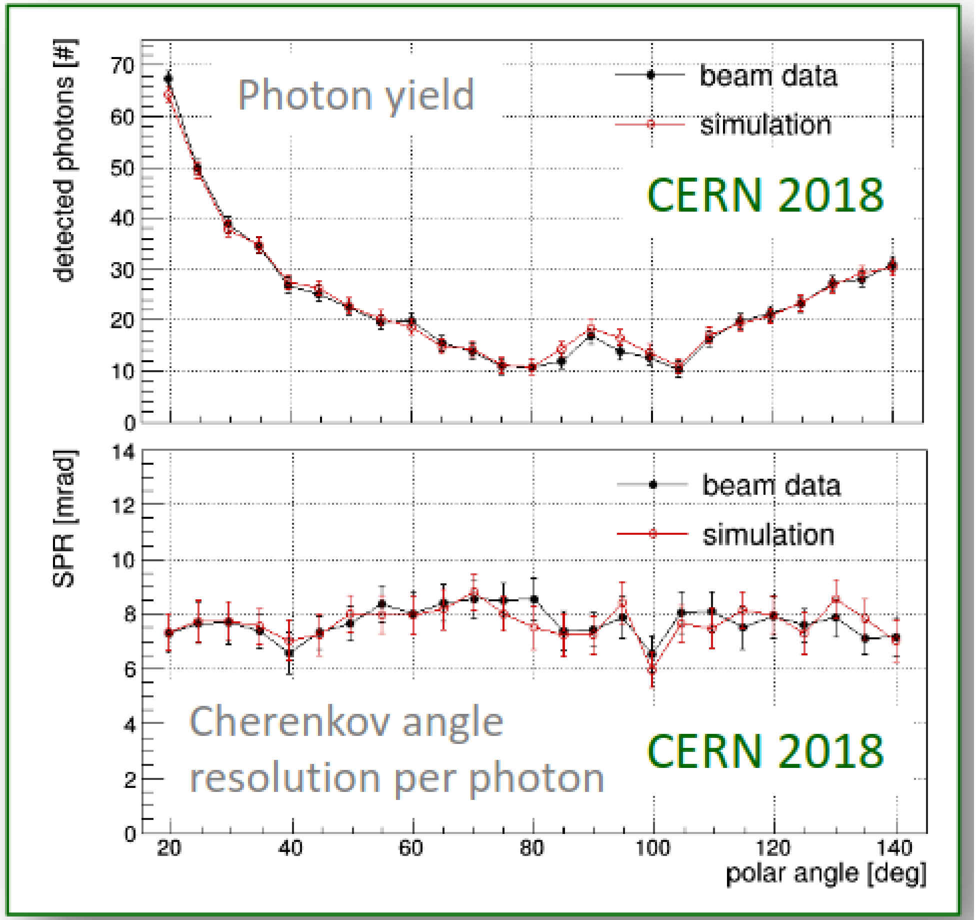
- Improved resolution.
- Key components:
  - Innovative focusing lens
  - Compact fused silica expansion.
  - Fast photon detection.

Central PID *hpDIRC*: *Simulation and Beam-tests*

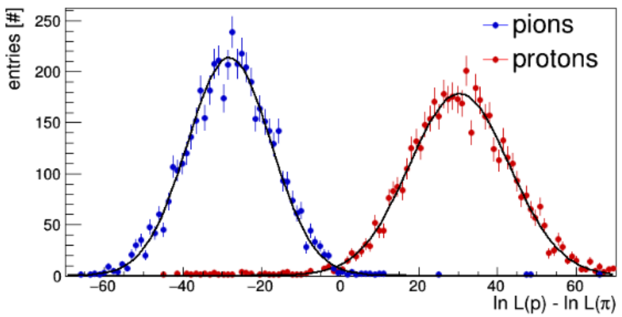








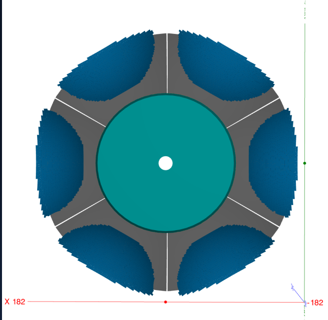
π/p separation power @ 7 GeV/c



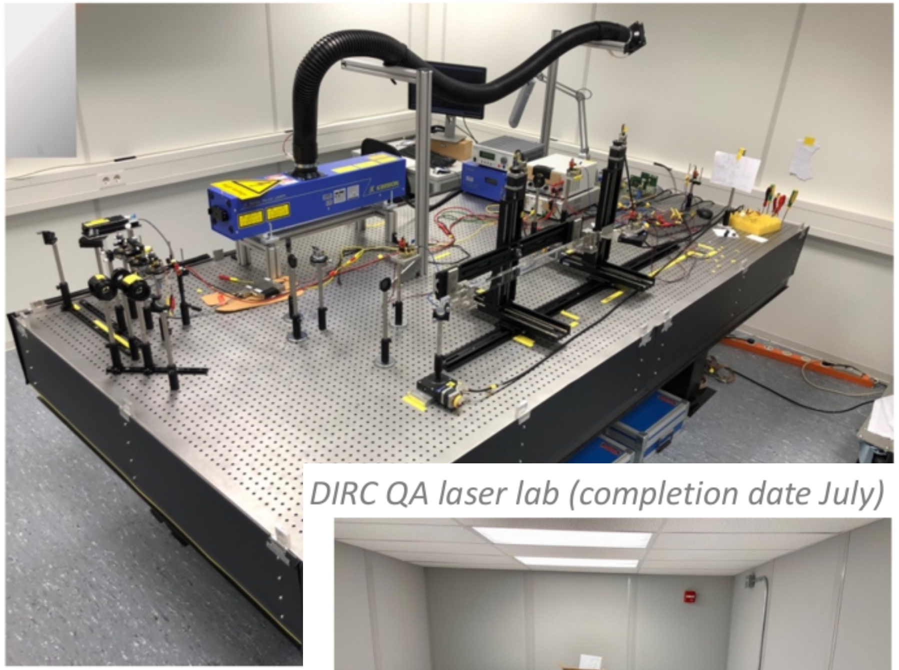
Excellent agreement between simulation and beam test results. 3 sigma pi/K separation up to 6 GeV/c (covering -1.73<eta<1.73).

3D (X,Y,t) reconstruction thanks to fast photon detection sensor. MCP PMTs are baseline photo-sensor. Potential commonality with pfRICH for using HRPPD.

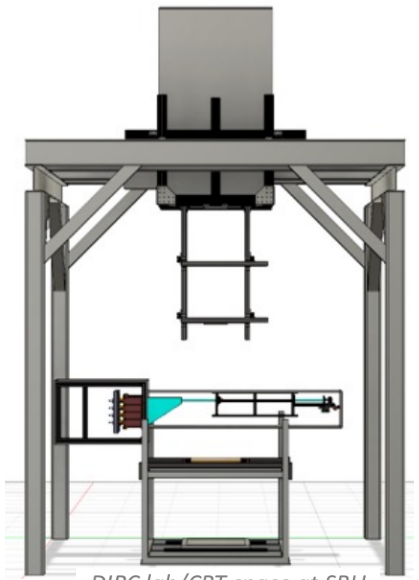
Central PID *hpDIRC :*
EIC focused hardware activities



Laser lab at GSI



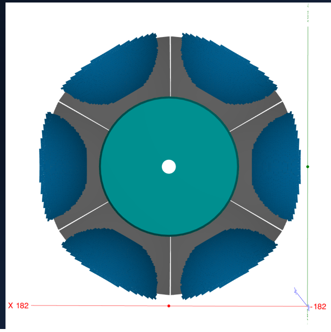
DIRC QA laser lab (completion date July)

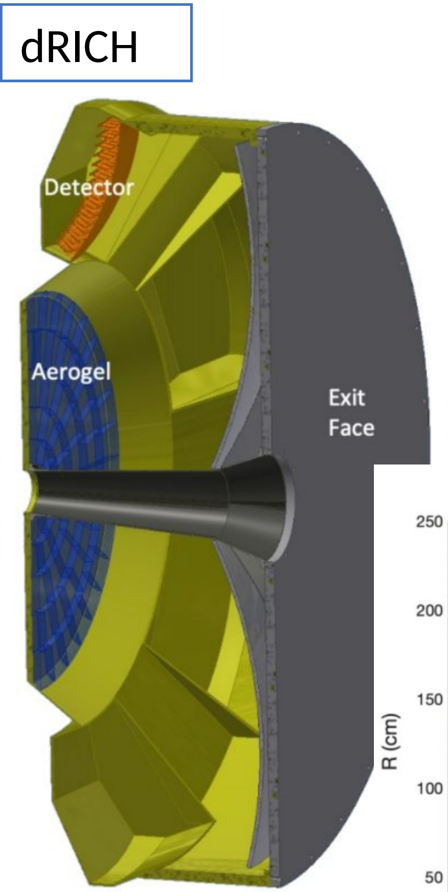


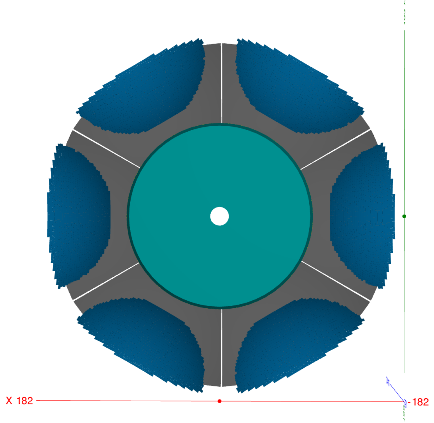
DIRC lab/CRT space at SBU

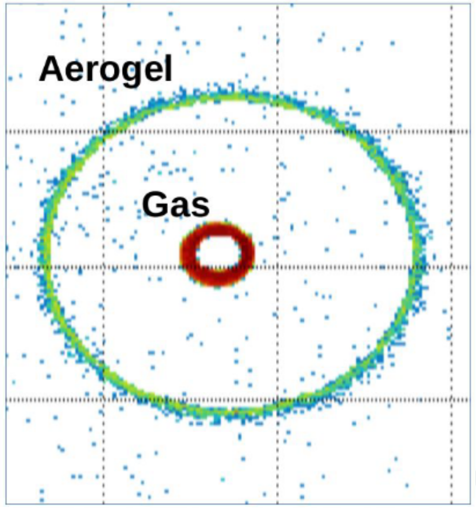
Reuse/Reference BaBar DIRC bars
Intense hardware activities @ Jlab, GSI Stonybrook ...

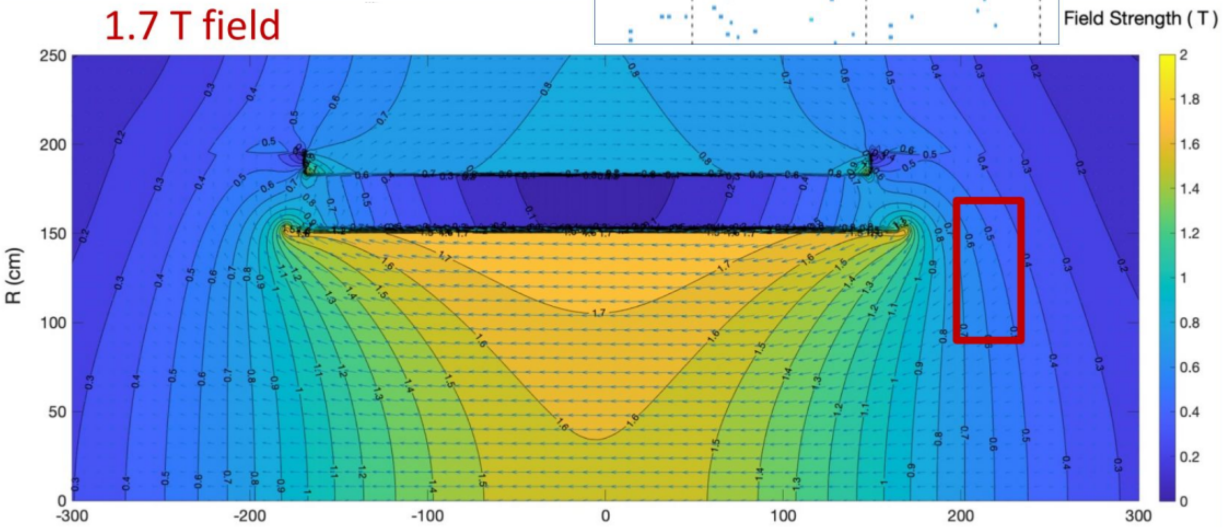
Forward particle identification









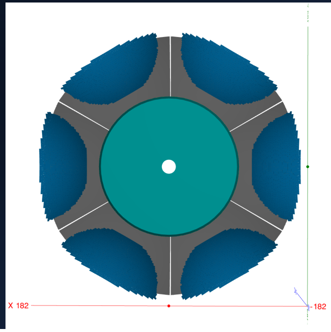


- Requirements:
  - **Wide acceptance** (*+- 300 mrad/ 1.5<η≤3.5*)
  - **High momentum coverage** up to *50 GeV/c π-K*
    - Dual radiator (**aerogel (n ~1.02)**+ **C_2F_6 gas (n~1.0008)**)
- **Compact geometry**: short radiator space available
  - Smaller number of detected photons → Critical optical tuning and control over background hits.
- **Large sensor surface to be covered in magnetic field**.
  - Limited choice of photon-sensor (**SiPM as an appealing solution**)

Simulation contains: **6 identical sectors**

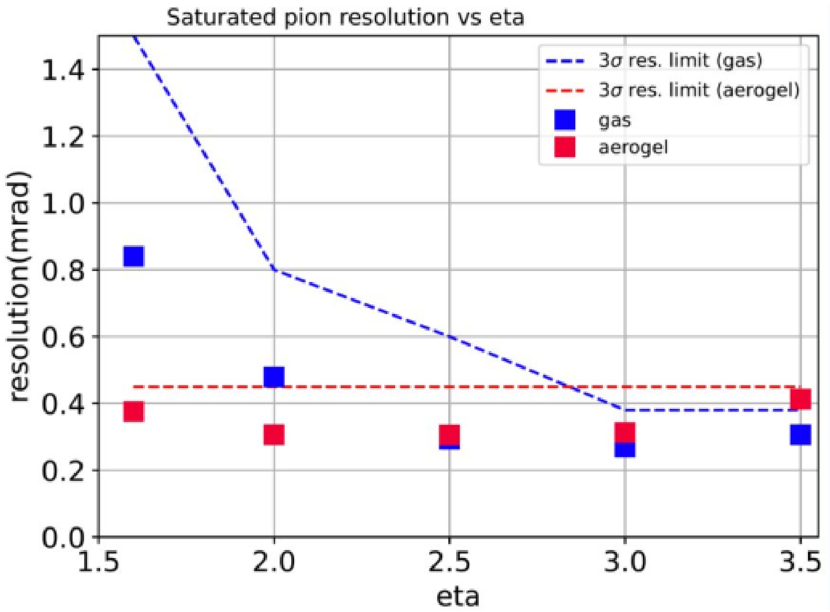
- **Spherical mirror with radius 220 cm**
- **SiPM sensors with realistic PDE and additional 70% safety factor.**
- **Realistic parameters** for **aerogel** and **C_2F_6**

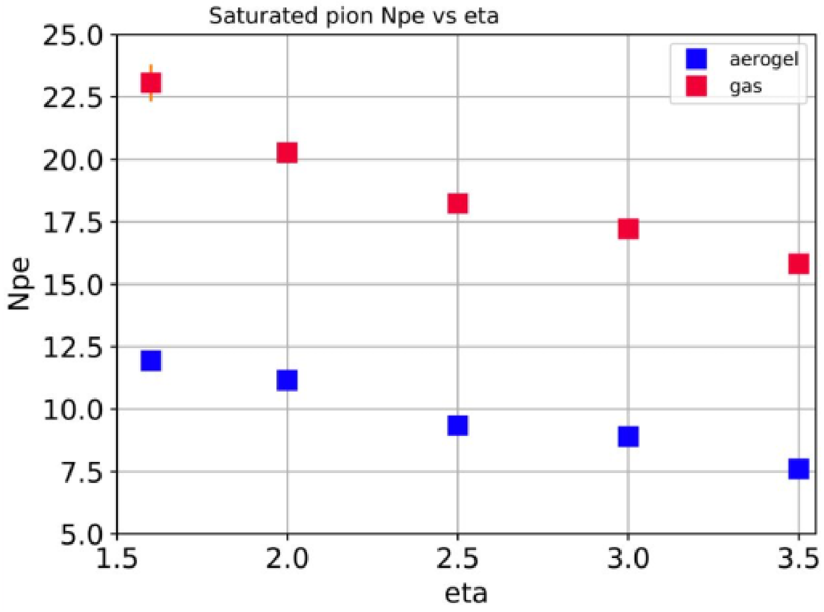
Forward particle identification
Simulation Studies

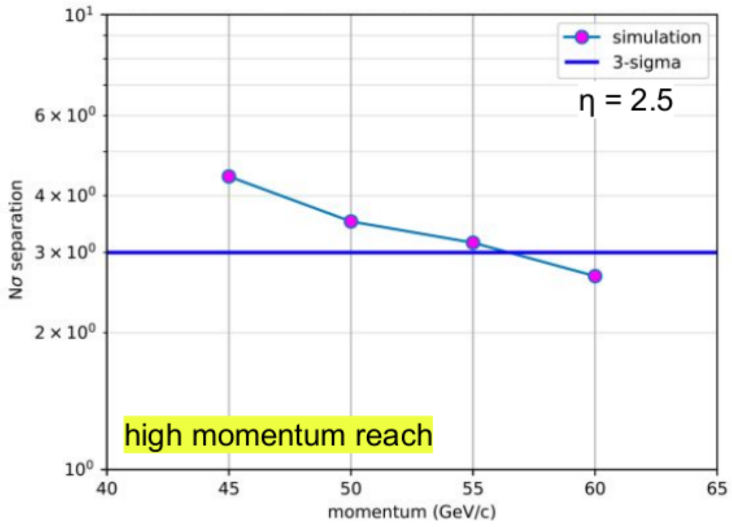


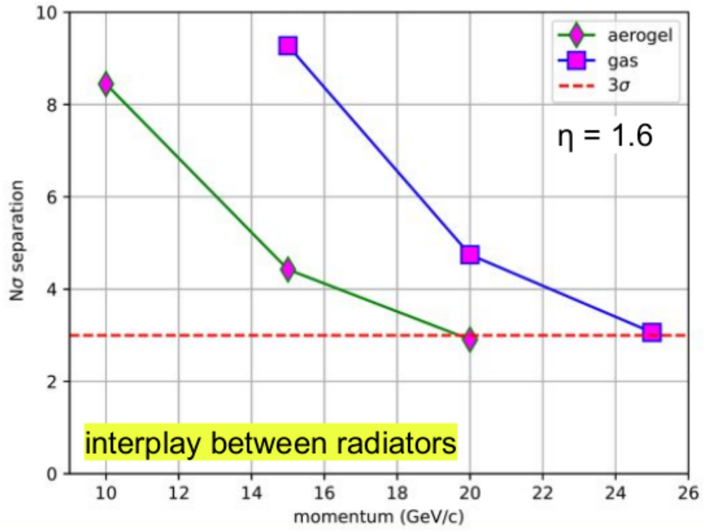
preliminary optimisation of dRICH optics within ePIC simulation framework

- single mirror configuration
- optimise focus in the most demanding region, 2.5 < η < 3.5
- target resolution of ~ 0.3 mrad

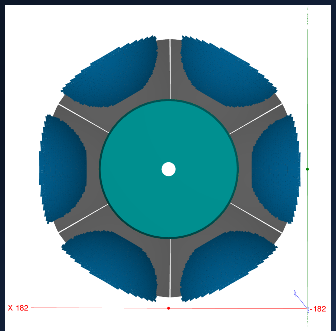


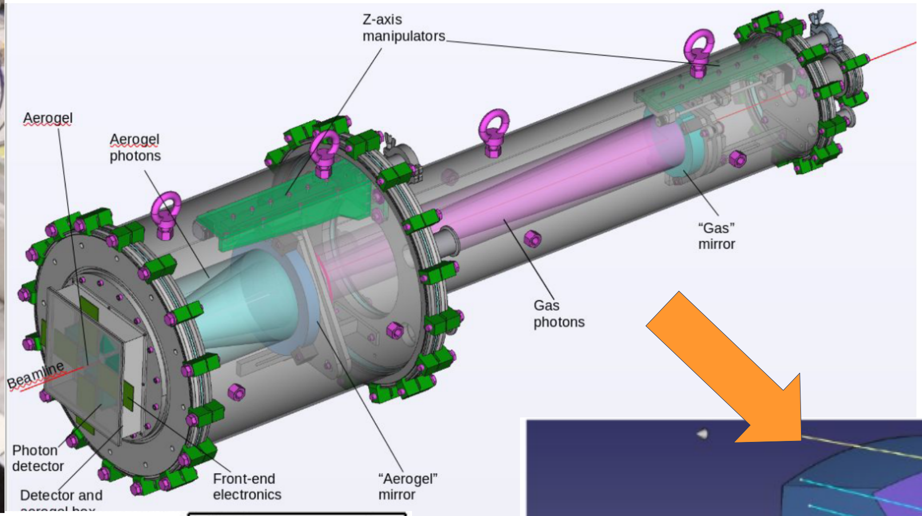


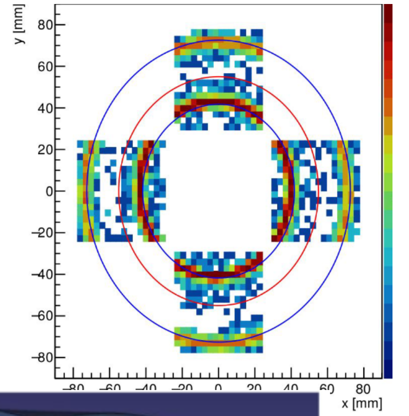


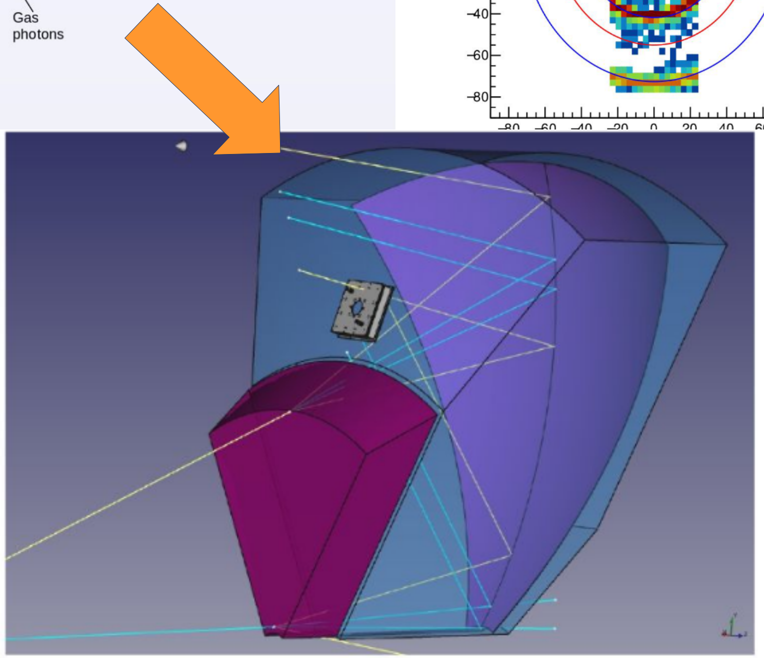


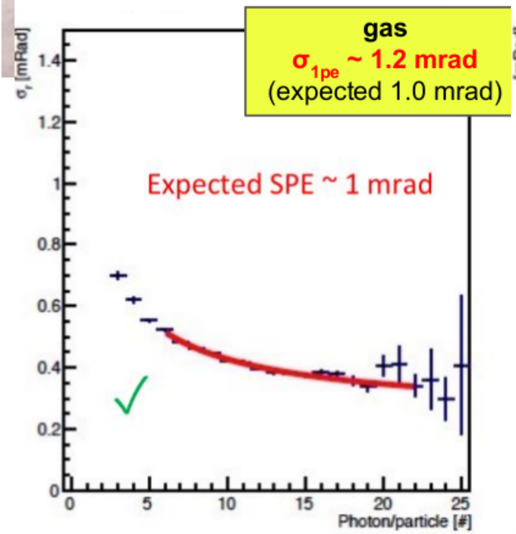
Forward particle identification:
Beam test @ CERN

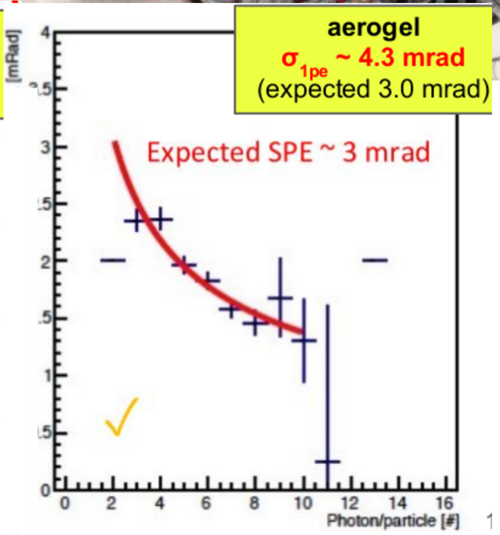


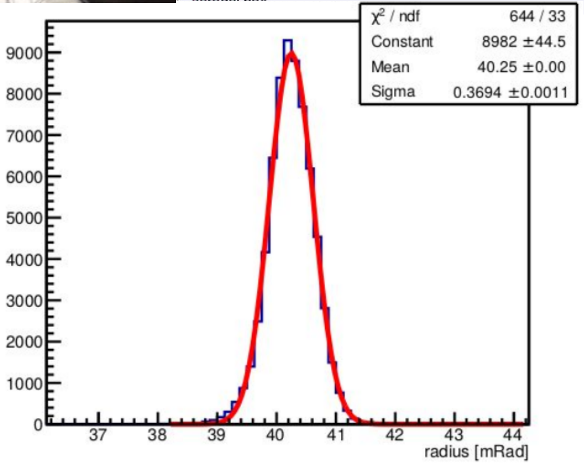










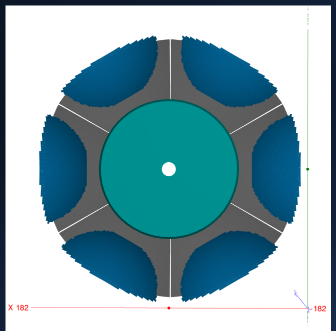


2nd August 2023

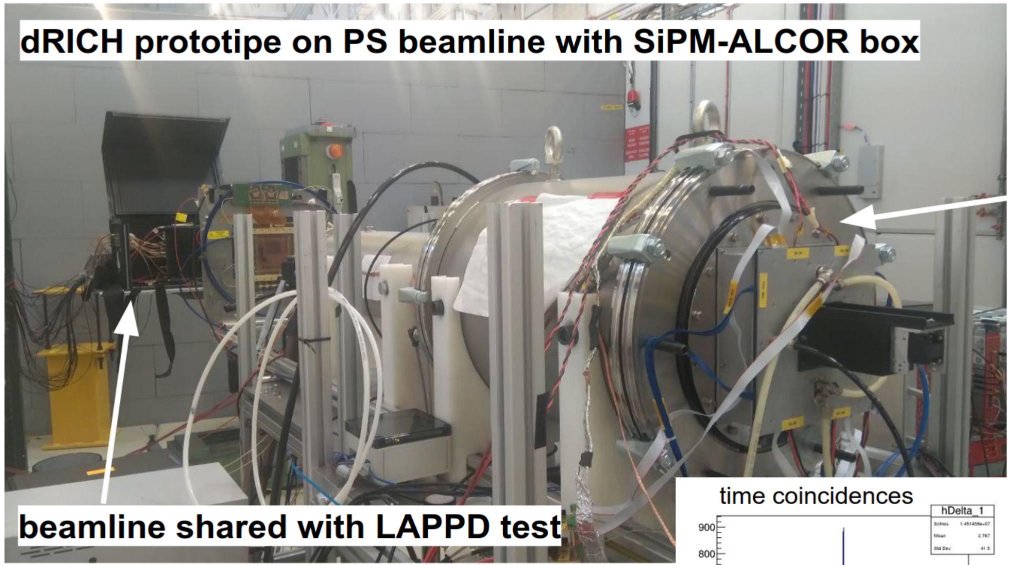
RHIC AGS Users' Meeting 2023

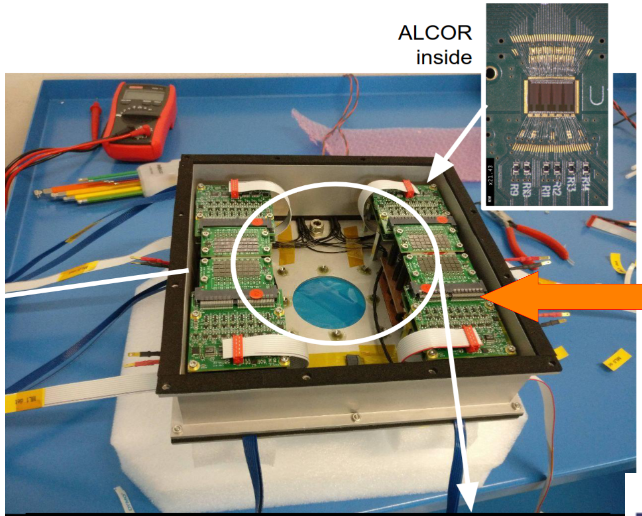
2024 Plan for building a realistic dRICH prototype

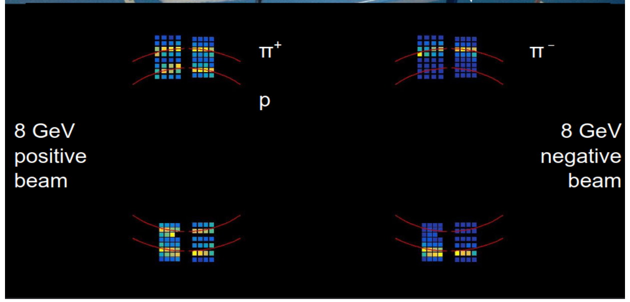
Forward particle identification:
Beam test @ CERN

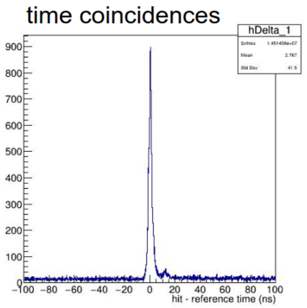


successful operation of SiPM with complete readout chain

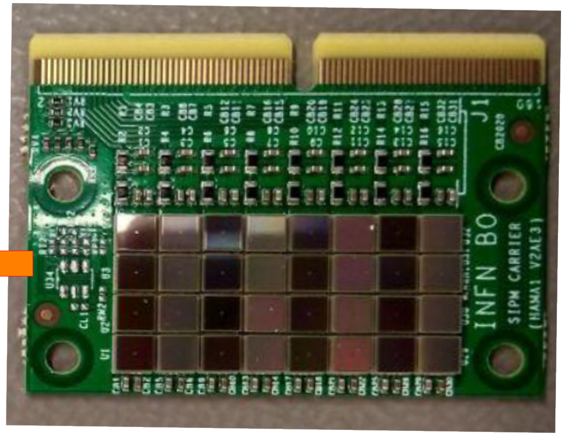


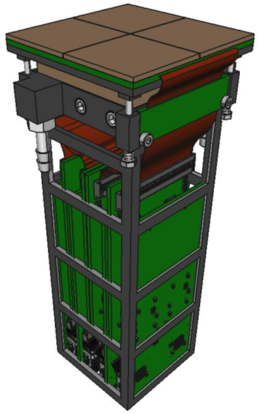






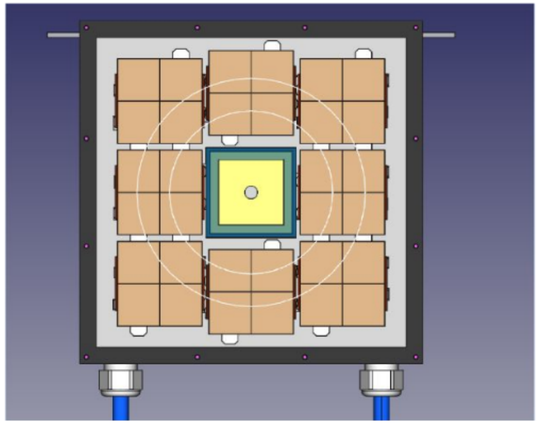
SiPM sensors were **irradiated** (up to 10^{10})
and **annealed** (150 hours at T = 150 C)

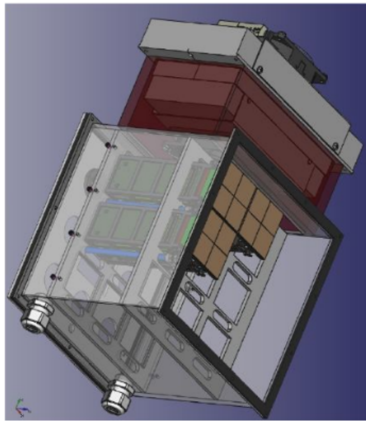




new EIC-driven readout unit

new EIC-driven detector plane and readout box for 2023 beam tests





2023: EIC-driven detector plane-→ test beams planned in August and October

Cherenkov PID @ ePIC :
Detector sub system and cross-cutting Working group

1. Each detector subsystem has formed Detector Subsystem Committee (DSC), with responsible and different contact persons.

2. Based on commonalities among different PID sub-detector systems cross-cutting PID working group is formed. Focusing mainly on unified reconstruction framework and helping in preparing reviews affecting two or more PID DSCs.

3. RICH consortium will play significant role on long term in coordination and collaboration of pfRICH and dRICH.

Possible commonalities of Cherenkov detectors:

a. Software, mirror, aerogel for pfRICH and dRICH
b. HRPPD based photon-sesnor for pfRICH and hpDIRC

...

Talk by Thomas Ullrich at EICUG Warsaw
https://indico.cern.ch/event/1238718/contributions/5433443/attachments/2691696/4671086/PID_Overview.pdf

Cherenkov PID @ ePIC : *Summary*

a. **Different Cherenkov PID technologies adopted by the ePIC collaboration to achieve desired physics goals**:

1. **h**igh **p**erformance **DIRC**
2. **p**roximity **f**ocusing **RICH**
3. **d**ual radiator **RICH**

b. **Matured simulation and test beam results have validated the conceptual designs. Ongoing R&D exercises are focusing the risk minimization and optimization.**

c. Commonalities among photo-sensor technology, software are

References:

1. *pfRICH: B.Page; EICUG 2023 https://indico.cern.ch/event/1238718/contributions/5431814/attachments/2691830/4671369/5%20epicUsersMeeting_pfRICH_2023-07_v2.pdf*
2. *DIRC: G.Kalicy EICUG 2023*
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4. *DIRC: EIC UG Meeting Januray 2023; https://indico.bnl.gov/event/17621/#sc-9-4-hpdirc*
5. *dRICH beam tests and photo-sensors: R.Preghenella at DIS 2023; https://indico.cern.ch/event/1199314/contributions/5193188/attachments/2619053/4528569/%5B20230326%5D%5BDIS%5D%20PID%20with%20EPIC%20at%20EIC.pdf S. Vallarino; https://indico.bnl.gov/event/19345/#2-prototype-data*
6. *dRICH R.Preghenella: EICUG Warsaw 2023 https://indico.cern.ch/event/1199314/contributions/5193188/attachments/2619053/4528569/%5B20230326%5D%5BDIS%5D%20PID%20with%20EPIC%20at%20EIC.pdf*

Thank You