The dRICH at ePIC: first SiPM based Cherenkov detector for frontier QCD studies at the EIC

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on behalf of the ePIC dRICH working group

EuNPC2025, MoHo, Caen (Fr)

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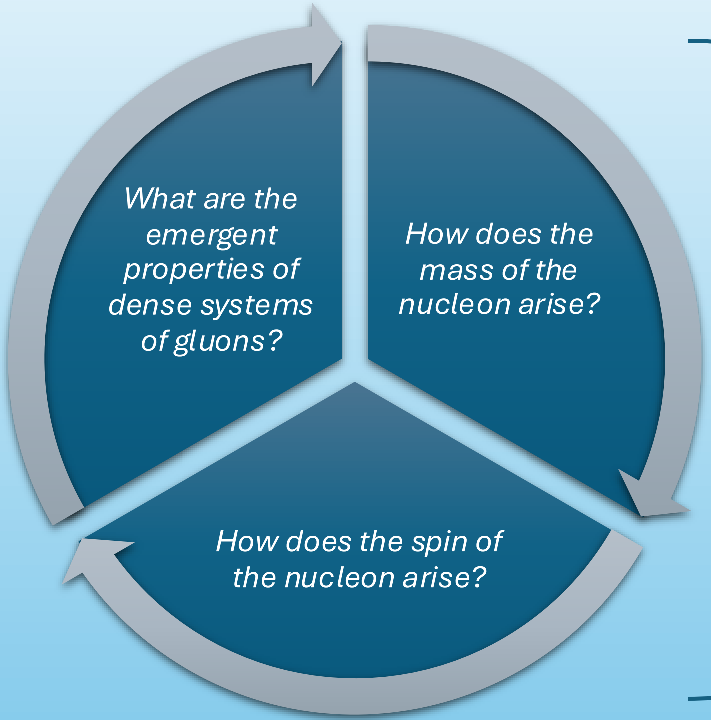
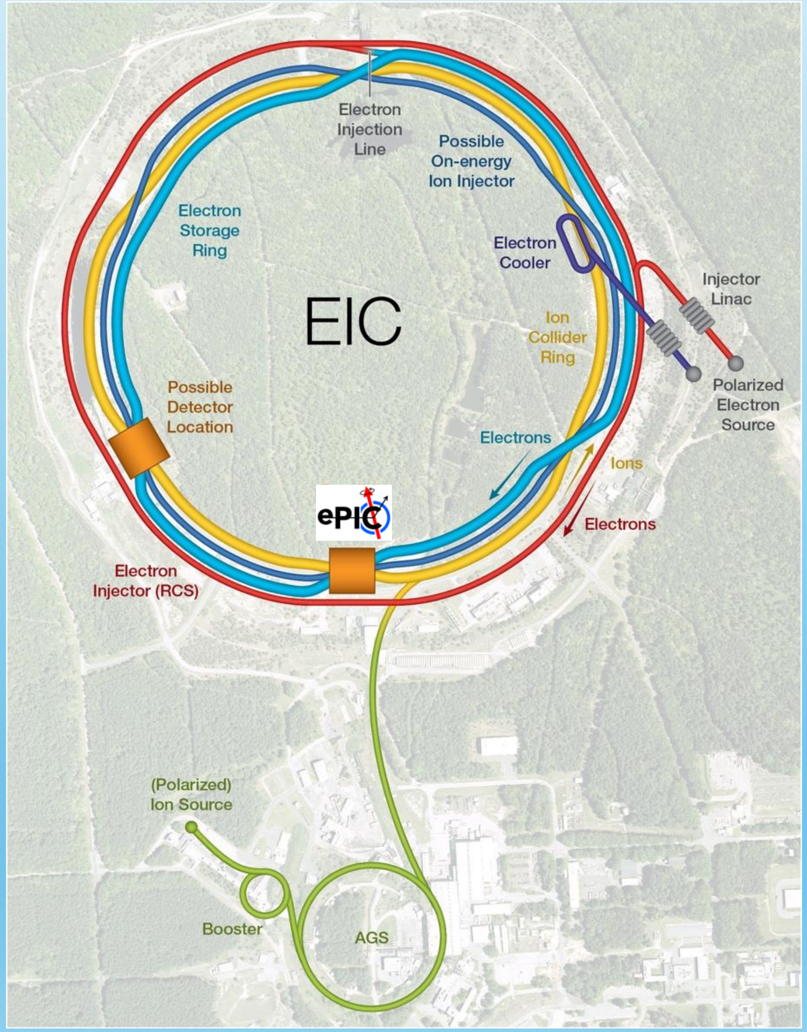
The Electron-Ion Collider (EIC) @ BNL

Brookhaven National Laboratory

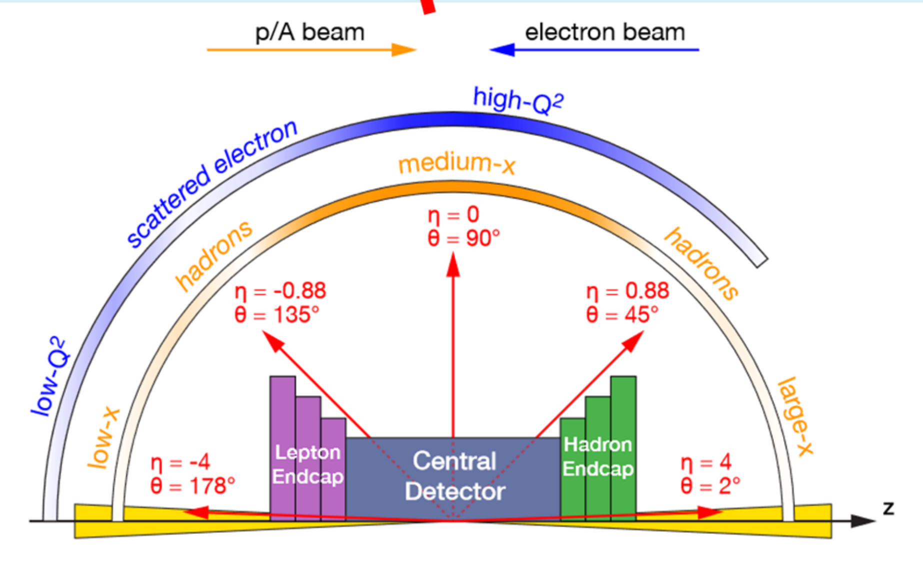


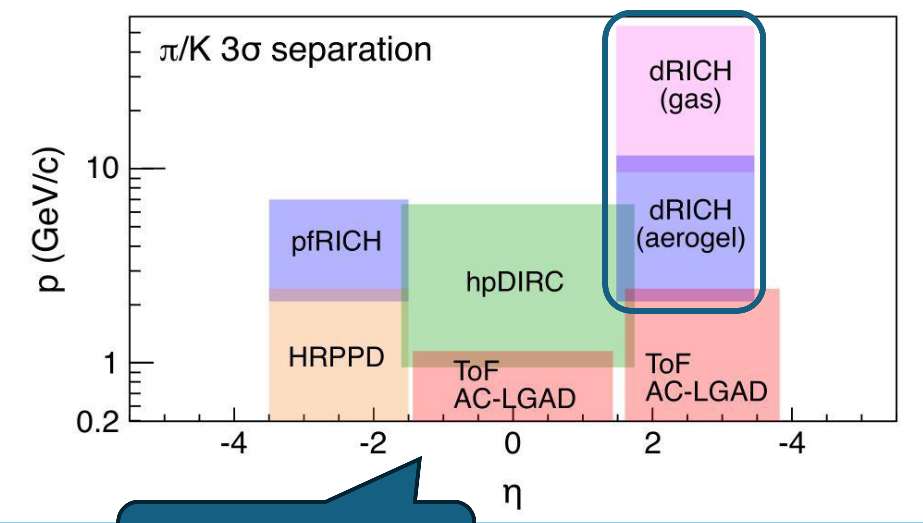
Electron-Ion Collider: The new asymmetric collider to investigate the nature of non-perturbative QCD.



- Beams of various ion species: from proton to uranium;
- Highly polarized beams: ~70%;
- Variable *e+p* center-of-mass energy: 20 – 140 GeV;
- High luminosity: 10^{33} cm^{-2} s^{-1};
- The electron–Proton/Ion Collider experiment: ePIC

The ePIC experiment

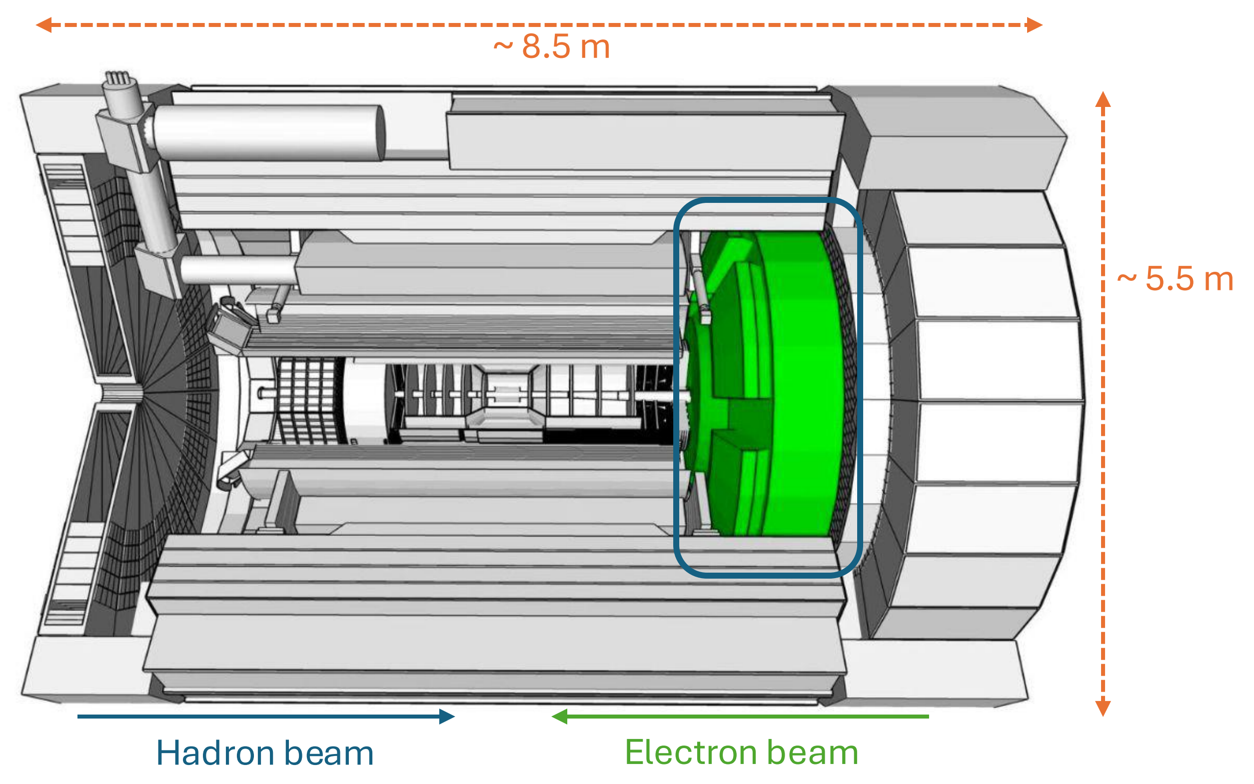




ePIC PID detectors

It is built around a ~ 2 T magnetic field along the beamline and three different regions:

- The Central Detector, surrounding the beamline;
- The Lepton Endcap, in the backward direction;
- The Hadron Endcap in the forward direction.

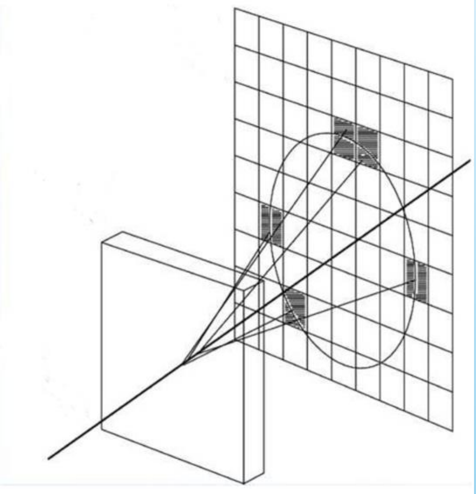


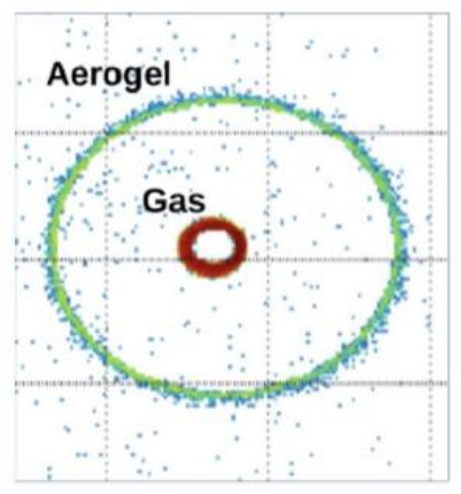
The Ring Imaging Cherenkov detector

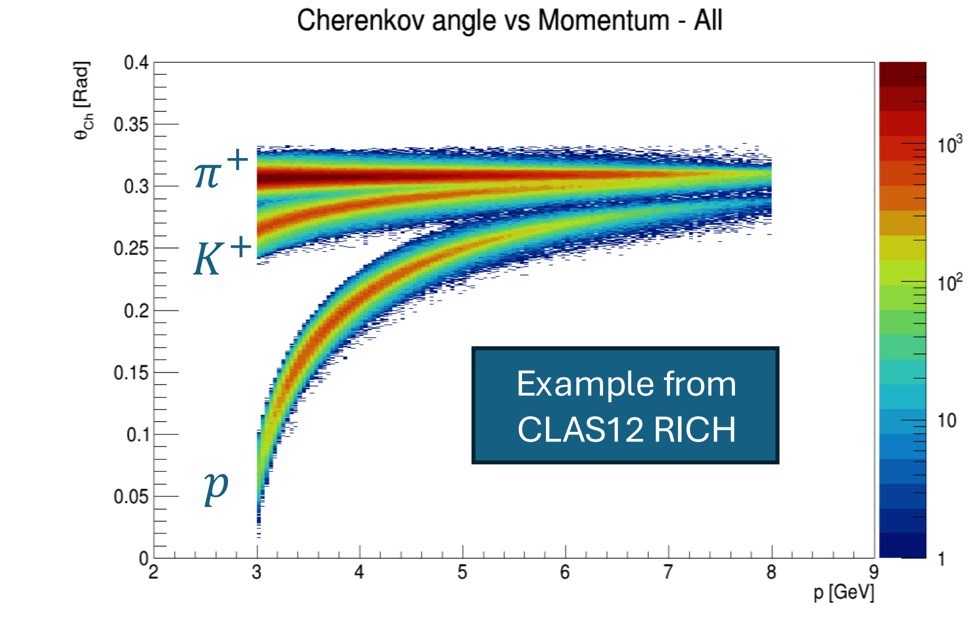
- The Ring Imaging Cherenkov detector exploits the Cherenkov effect to identify charged particles

$$\cos\theta_{Ch} = \frac{1}{n\beta}$$

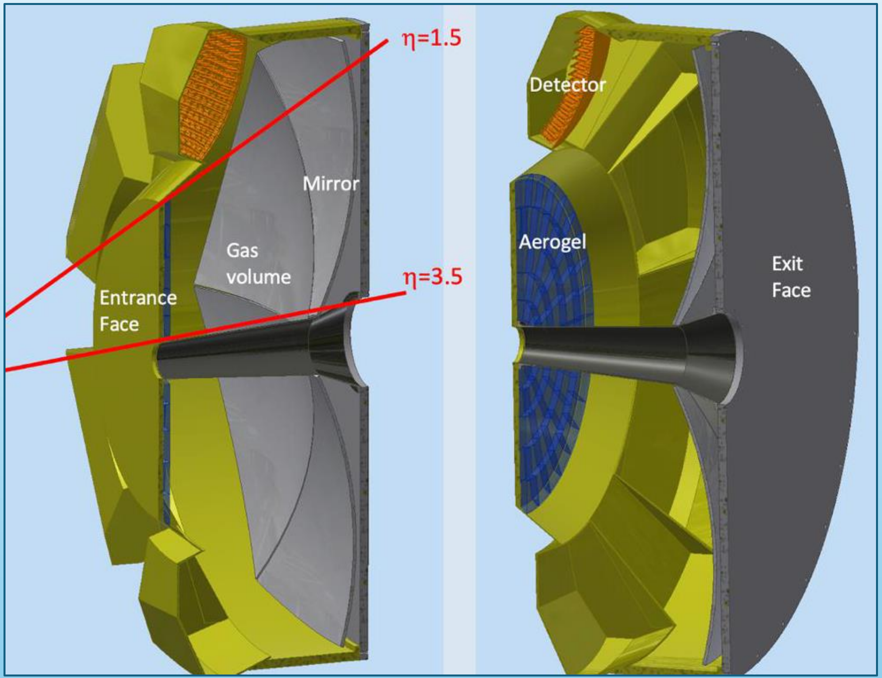
- The Cherenkov-photon cone is projected on the photodetection plane as a ring.
- The number of optical photons is typically in the order of tens, so the photo-sensor must be sensitive to the single optical photon.
- By combining the Cherenkov angle reconstructed from the ring, and the momentum of the particle is possible to identify it.

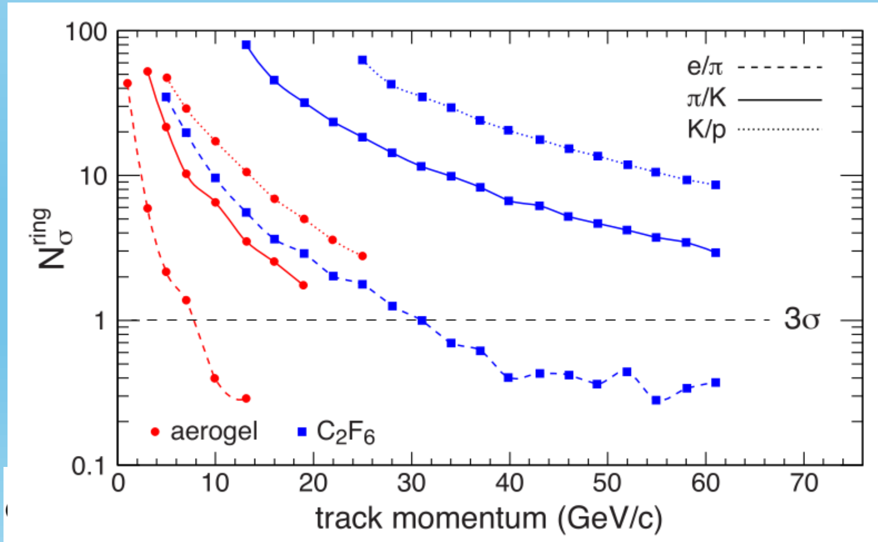






The ePIC dual-radiator RICH





Experiment requirements for the dRICH
$\pi^\pm/K^\pm/p^\pm$ 3σ separation from 3 to 50 GeV/c;
To improve $e^\pm$ PID up to 15 GeV/c
To cover the $1.5 < \eta < 3.5$ region

The dRICH must face two main challenges:

- To cover a wide momentum range, which crosses the typical regions of refractive index for liquid and gaseous radiators;
- To operate in a high (~1T) magnetic field.

The two radiators, aerogel (n≃1.026) and gas (n≃1.0085) will allow for combining their information to identify hadrons over the full momentum range.

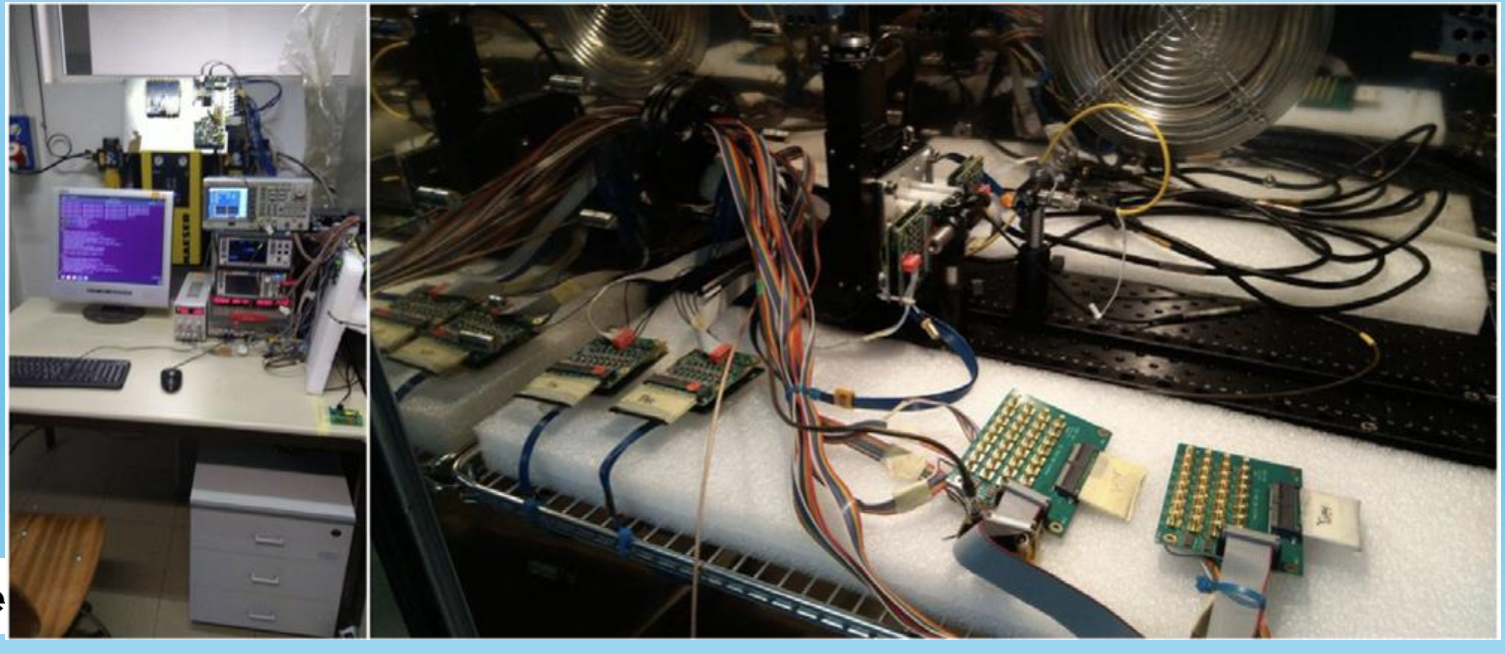
The **Silicon Photomultiplier (SiPM)** will be used as magnetically insensitive photosensor, for the first time in a Ring Imaging Cherenkov detector.

The dRICH SiPM

Silicon Photomultiplier

The SiPM is a solid-state photo-sensor. It is made of a matrix of APD micro-cells operating in Geiger mode, and the signal produced is the sum of the activated pixels.

Pros	Cons
Good single photon sensitivity; Good timing performance; Insensitive to magnetic field; Cheap.	High Dark Count Rate (DCR) at room temperature; Sensitivity to radiation damage, increasing the DCR.

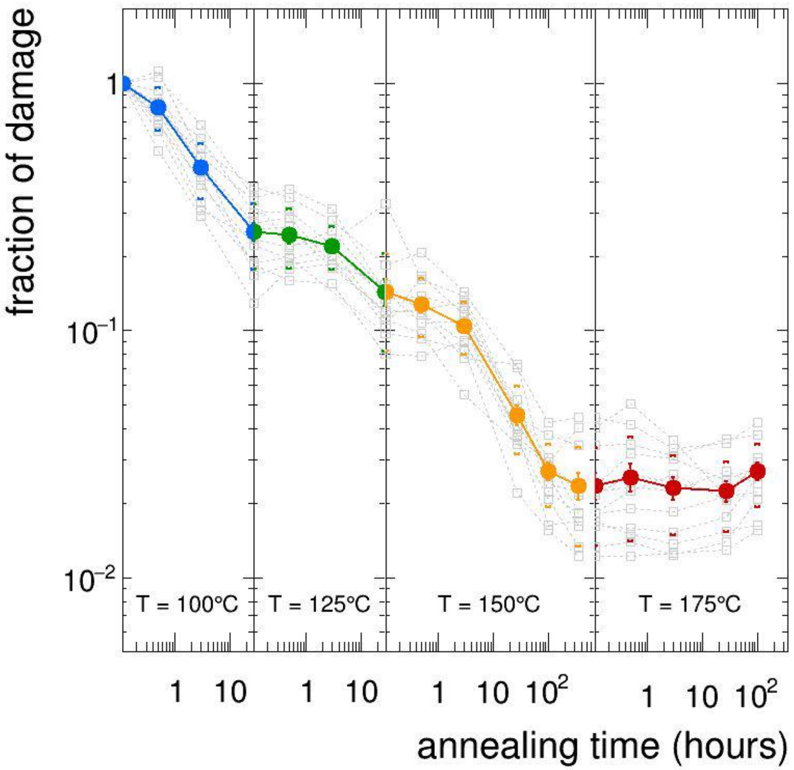


Cons mitigation strategies:

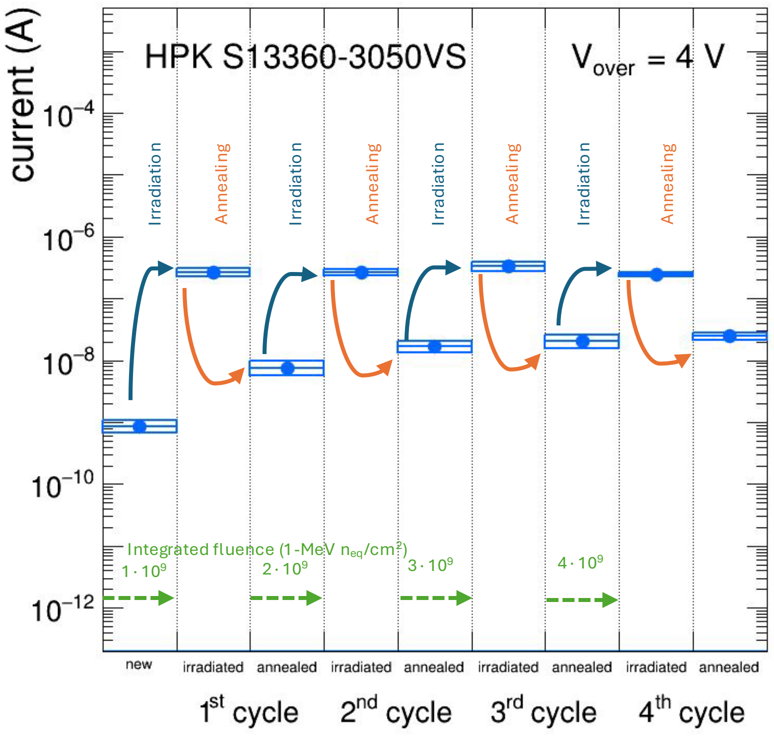
- Cooling the sensors to -40°C
- Curing the radiation damage through annealing
- Gating with high-precision TDC

Study of annealing procedure

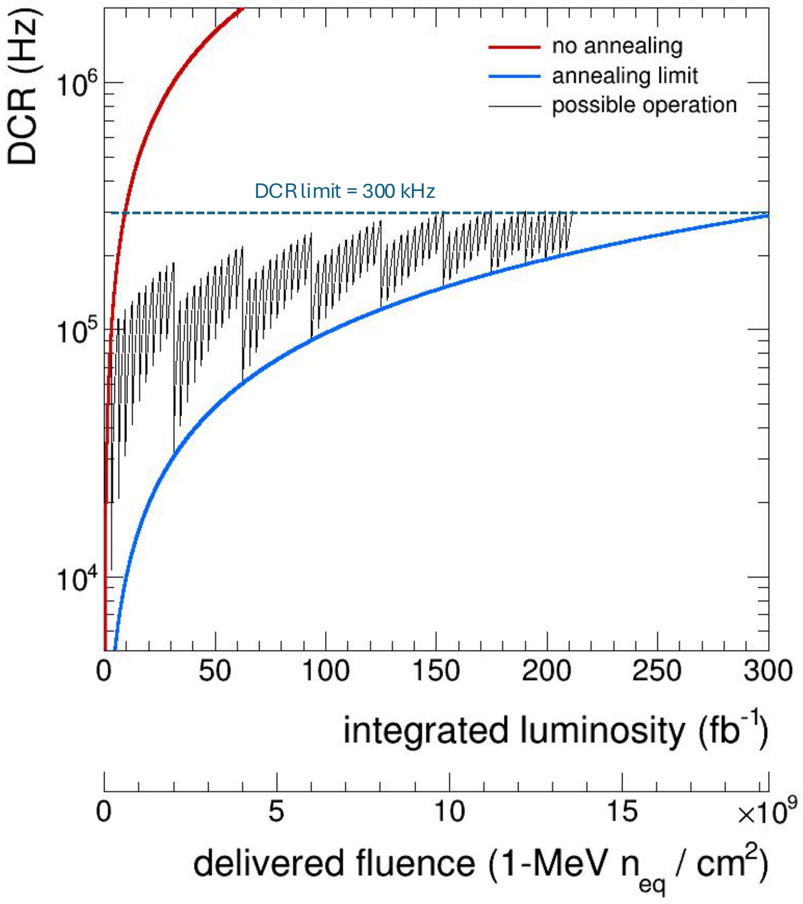
Fraction of residual irradiation damage after forward bias annealing



Dark current on SiPM after repeated irradiation-annealing cycles



Projected increase of DCR as a function of luminosity

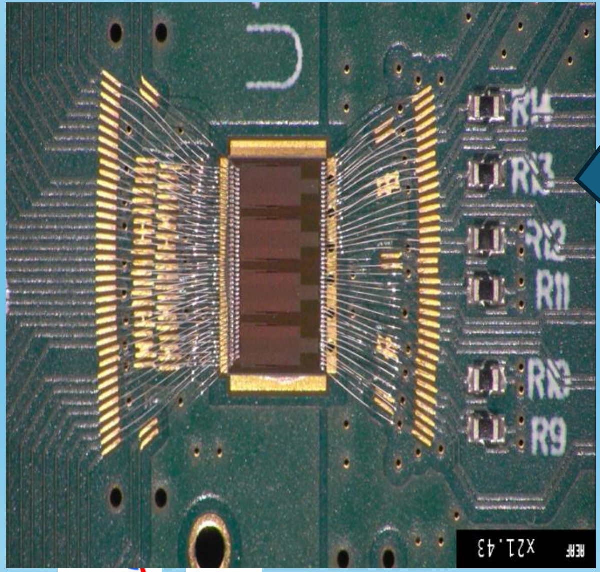


The Photo-Detection Unit

The dRICH SiPMs will be divided in 6 sectors, each one composed by 208 Photo-Detection Unit (PDU).

One PDU hosts 256 SiPMs (3x3 mm^2) arranged in 4 matrices, 4 Front-End Boards for power distribution and the ALCOR chip, 1 readout board.

The cooling system is made of Peltier cells and a liquid heat exchanger to thermally stabilize the PDU.

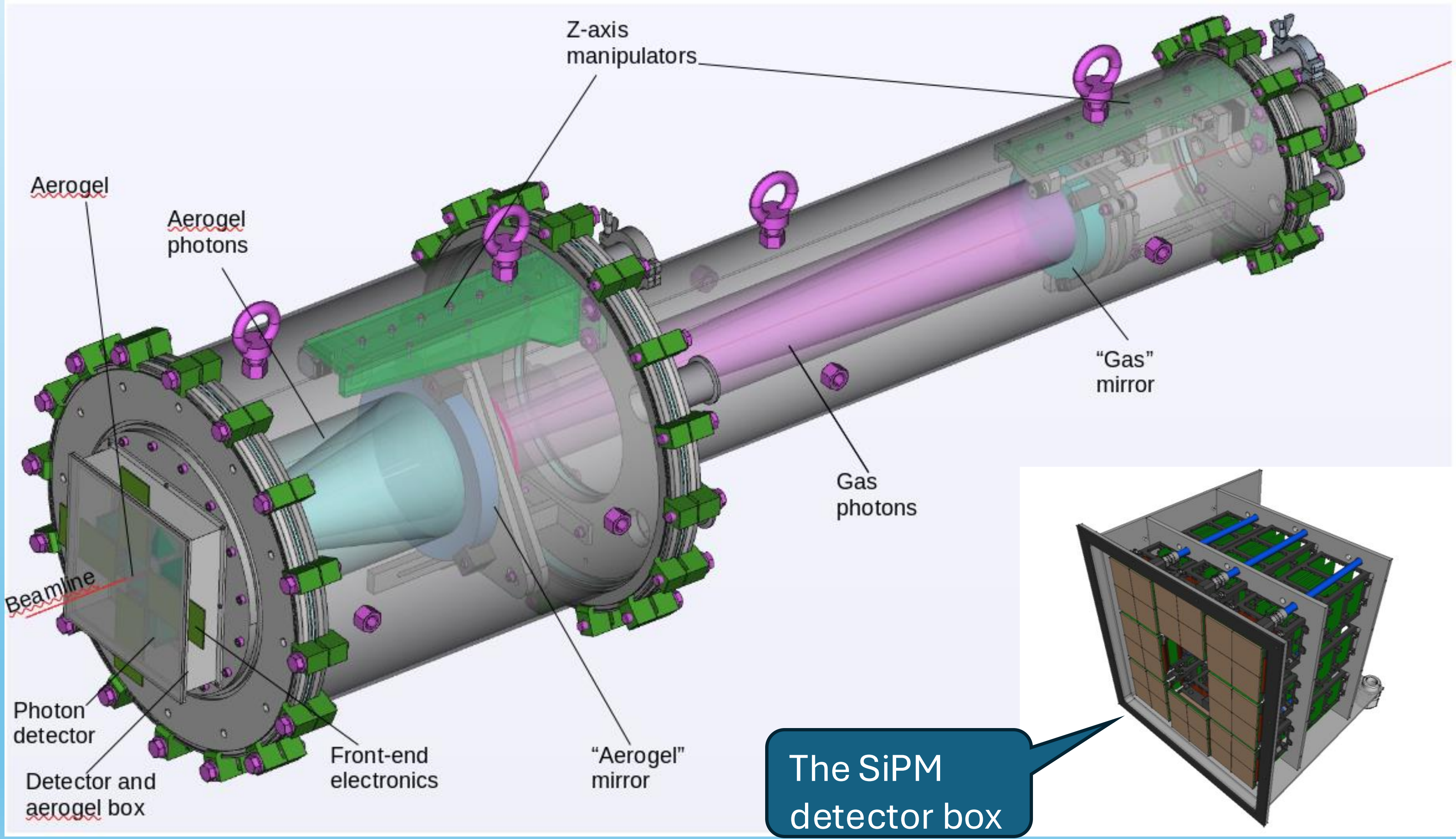


The ALCOR ASIC, a 64-channel mixed-signal developed by INFN Torino:

- Signal amplification, conditioning and event digitization;
- 2 leading-edge discriminators;
- 4 TDCs with analog interpolation;
- Digital shutter to allow TDC digitization;
- Continuous readout;
- Time-over-Threshold mode.

The dRICH prototype performance

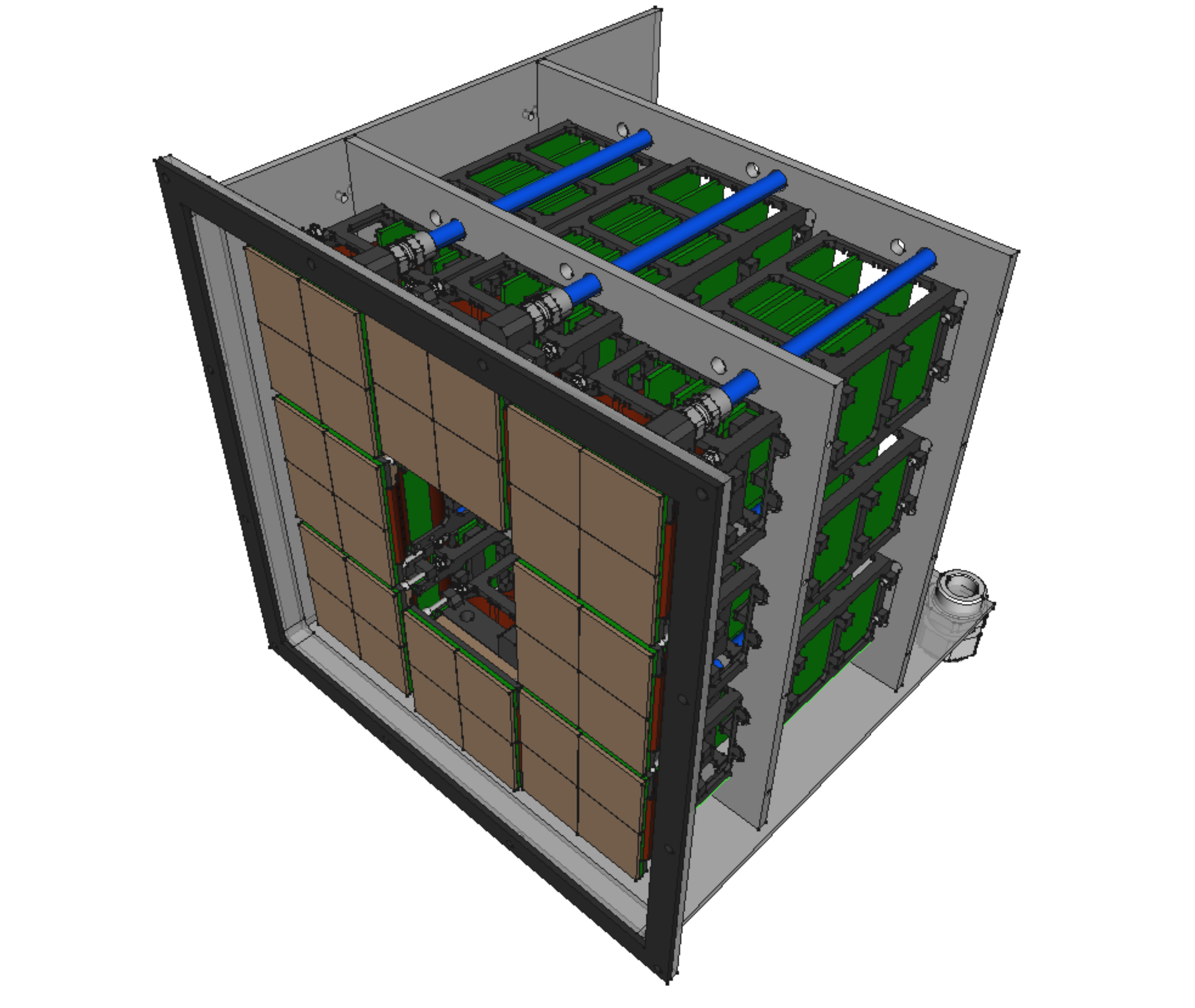
The dRICH prototype



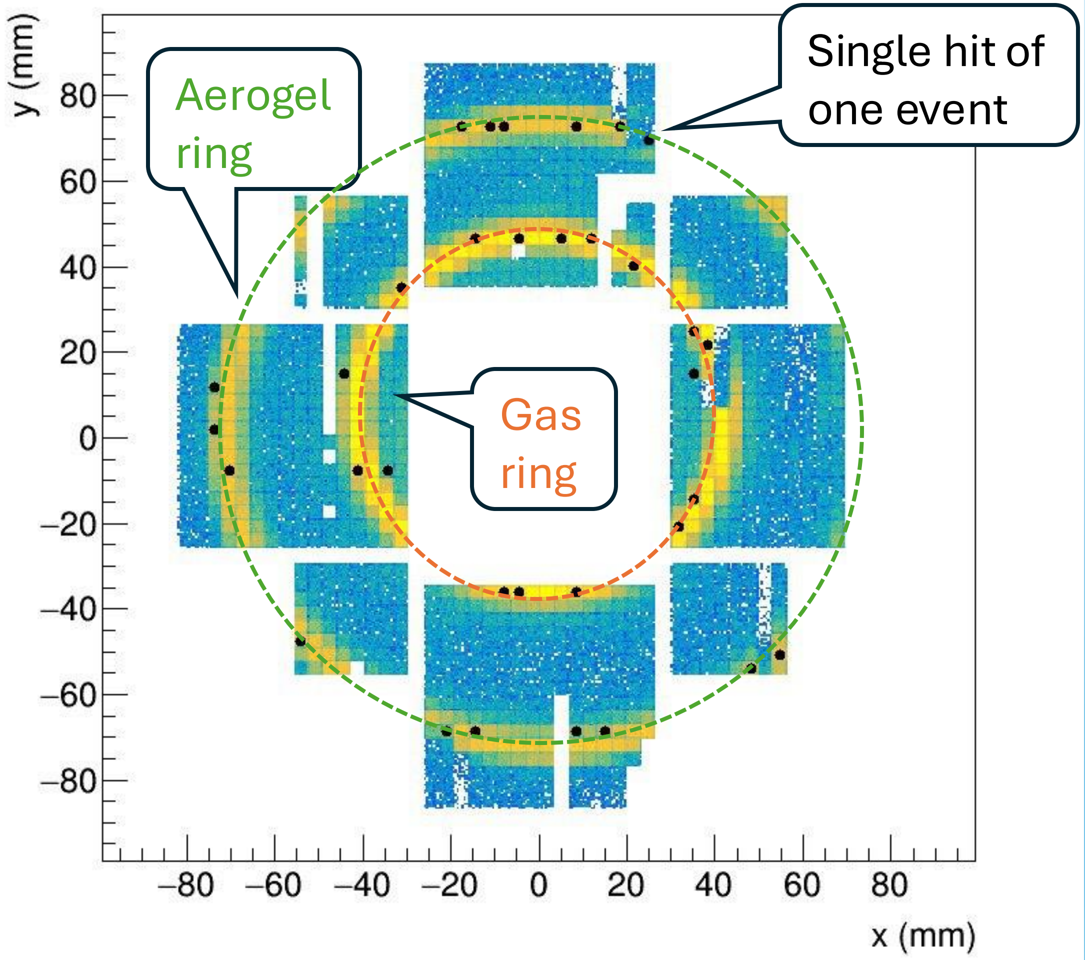
A prototype has been under development since 2021:

- Characterized using MAPMT as reference photosensor;
- Evaluation of the aerogel and gas radiators performance;
- Study of mirrors positioning;
- Testing the SiPM as a photo-sensor in a noisy environment.

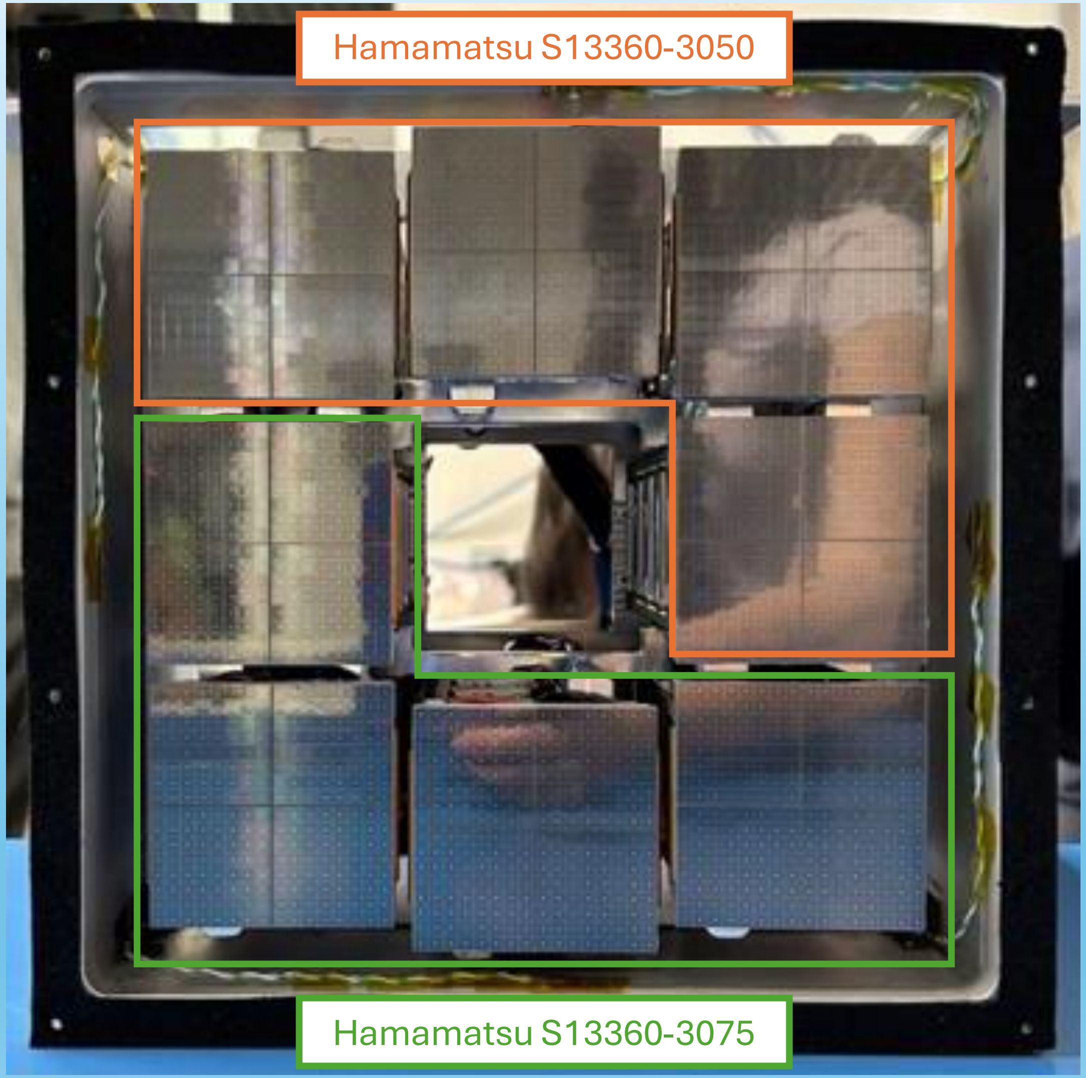
The dRICH detector box

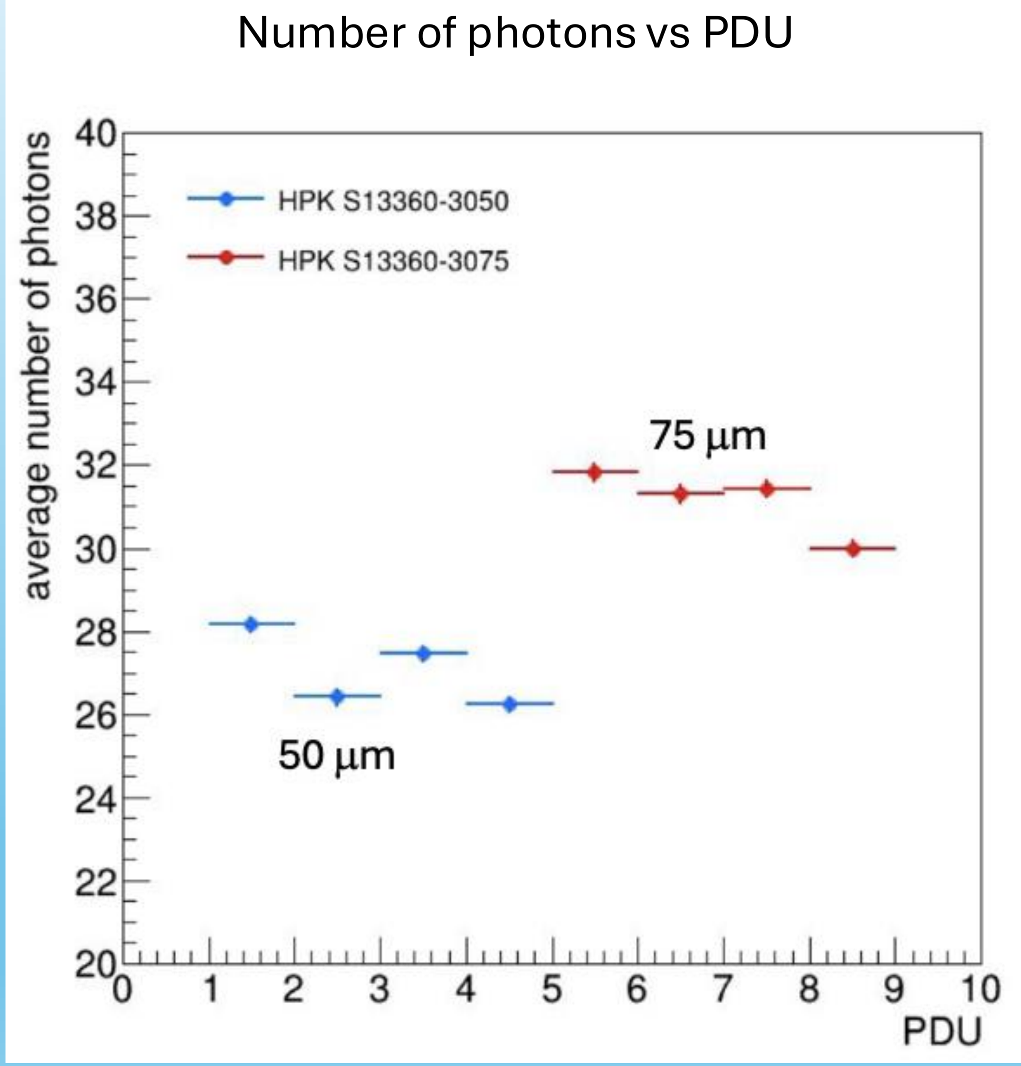


Preliminary image of the two rings



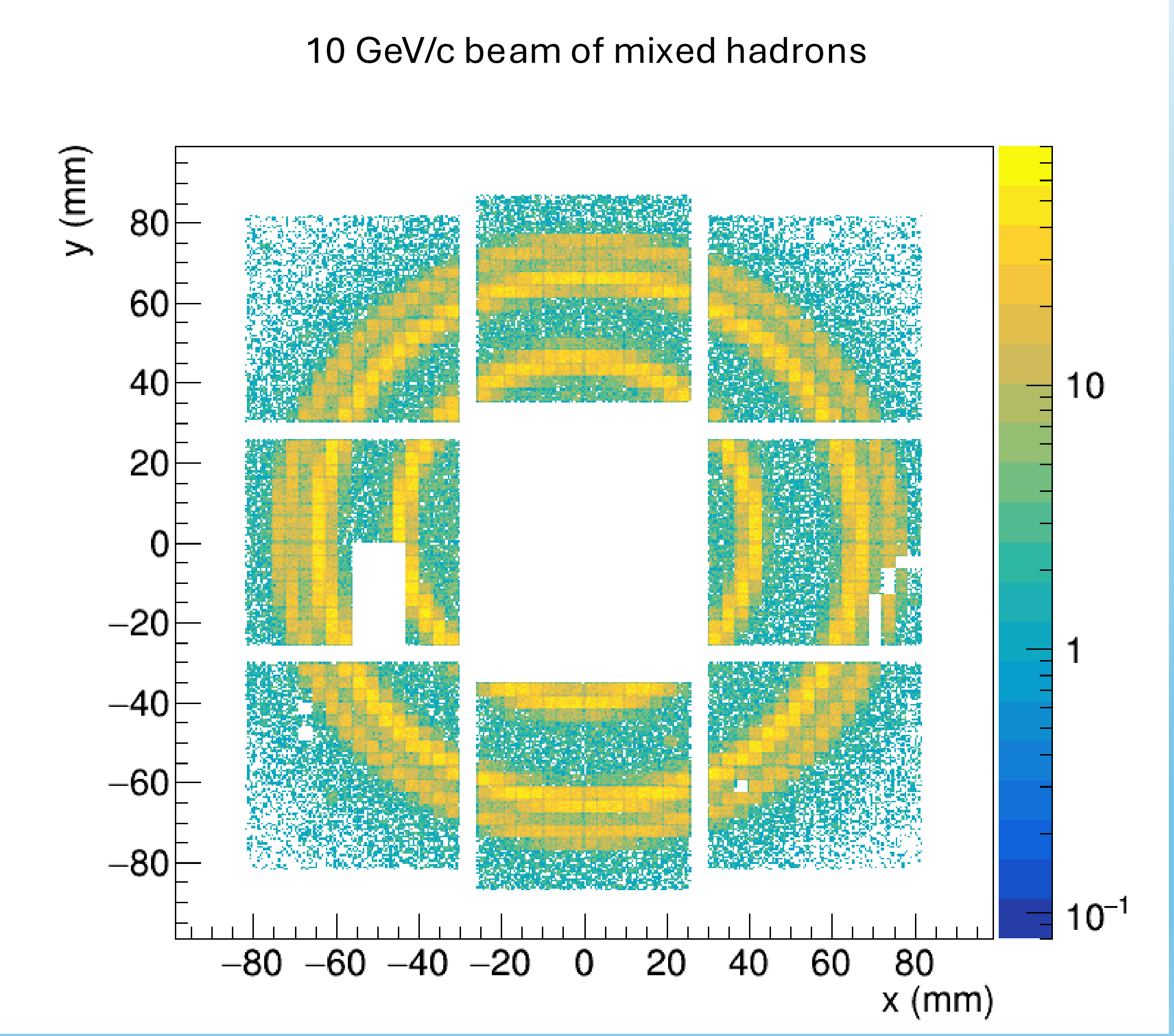
The dRICH test beam – 2024 setup





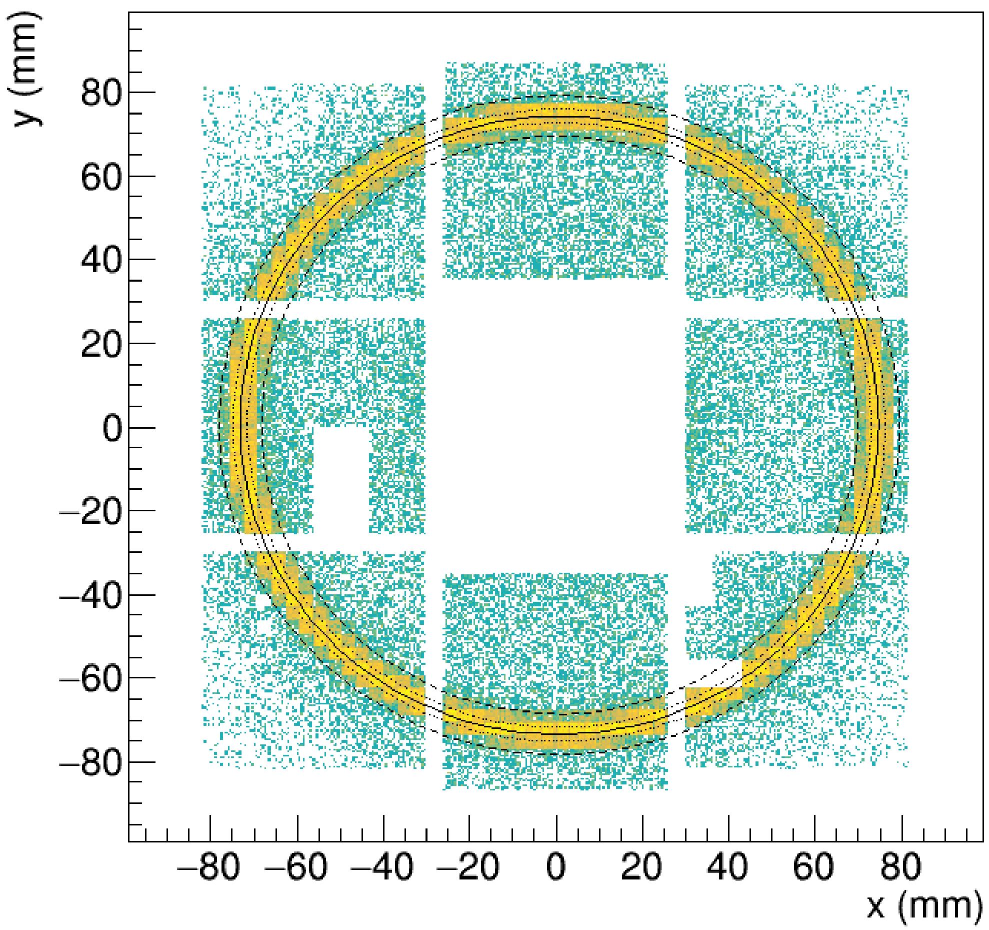
dRICH test beam results

- Photon position distribution of a full run with a 10 GeV momentum beam of mixed positive hadrons (~45/5/50% of $\pi^+/K^+/p$)
- Each pixel of the histogram corresponds to one SiPM.
- The gas (inner) and aerogel (outer) rings are visible and well separated.
- The proton aerogel-ring is separated from the pion aerogel-ring, qualitatively showing the capability to distinguish the two particles.

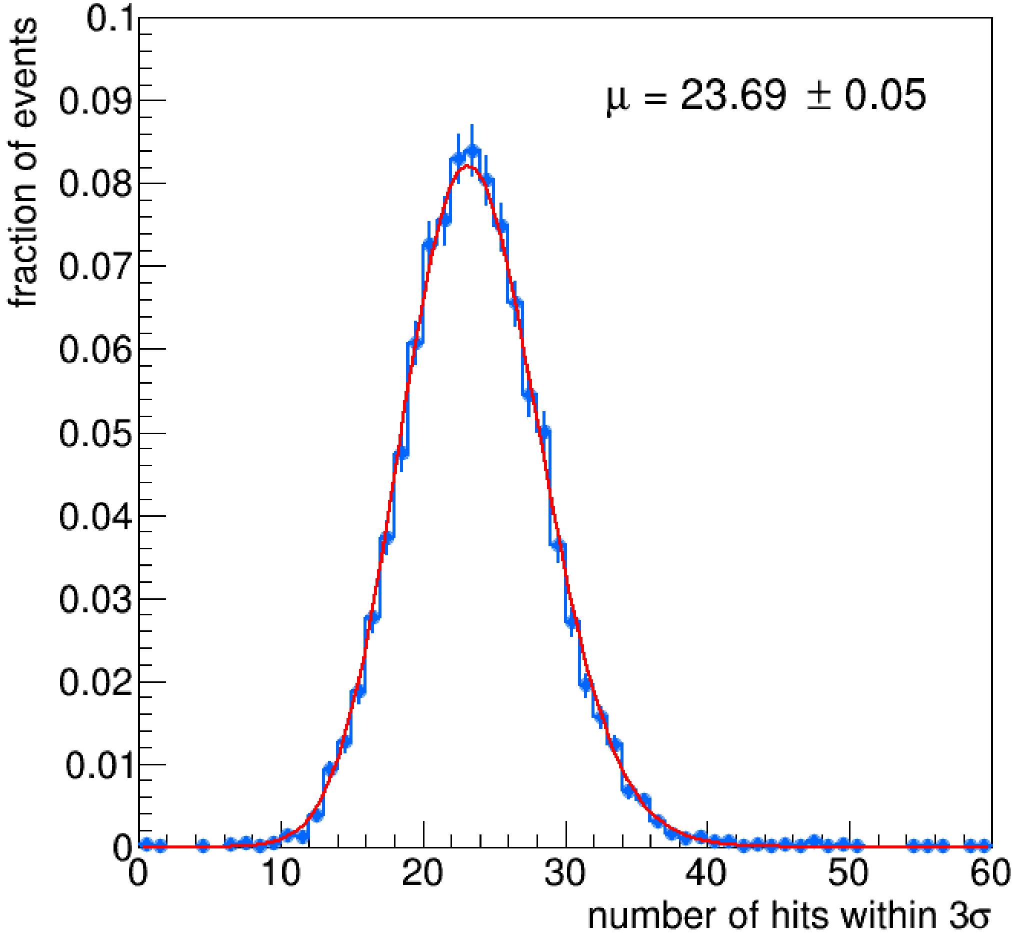


dRICH test beam results

11.5 GeV/c negative beam (>95% π^-), no gas.

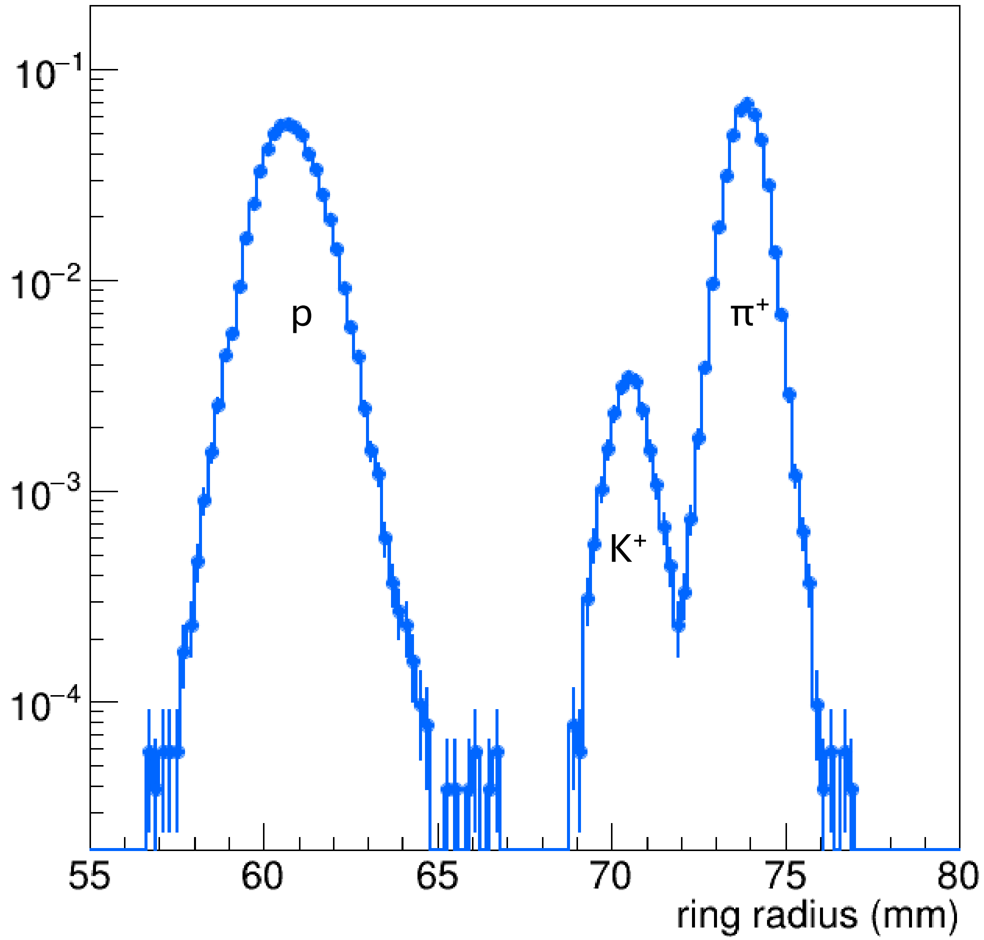


Number of photons per ring - aerogel

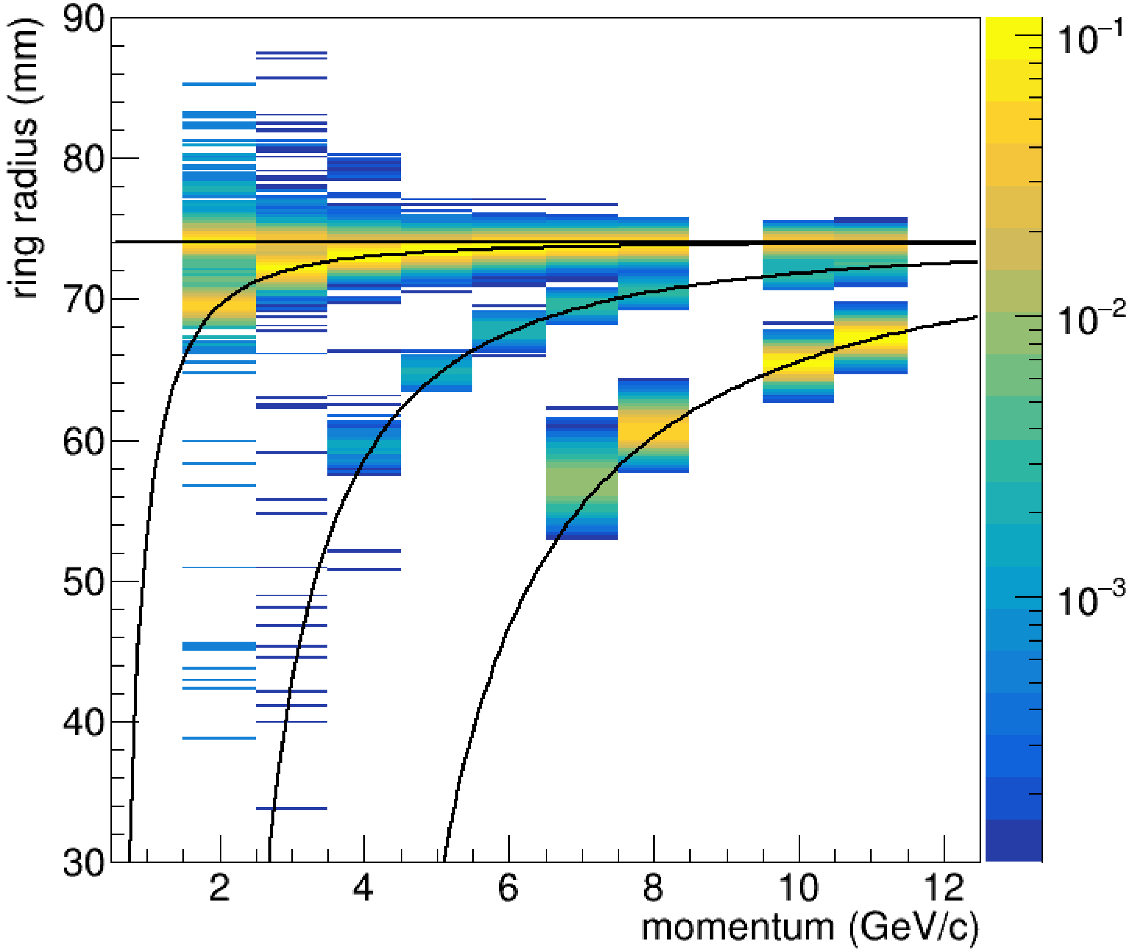


dRICH test beam results

Reconstructed radii at 8 GeV/c beam of mixed positive hadrons

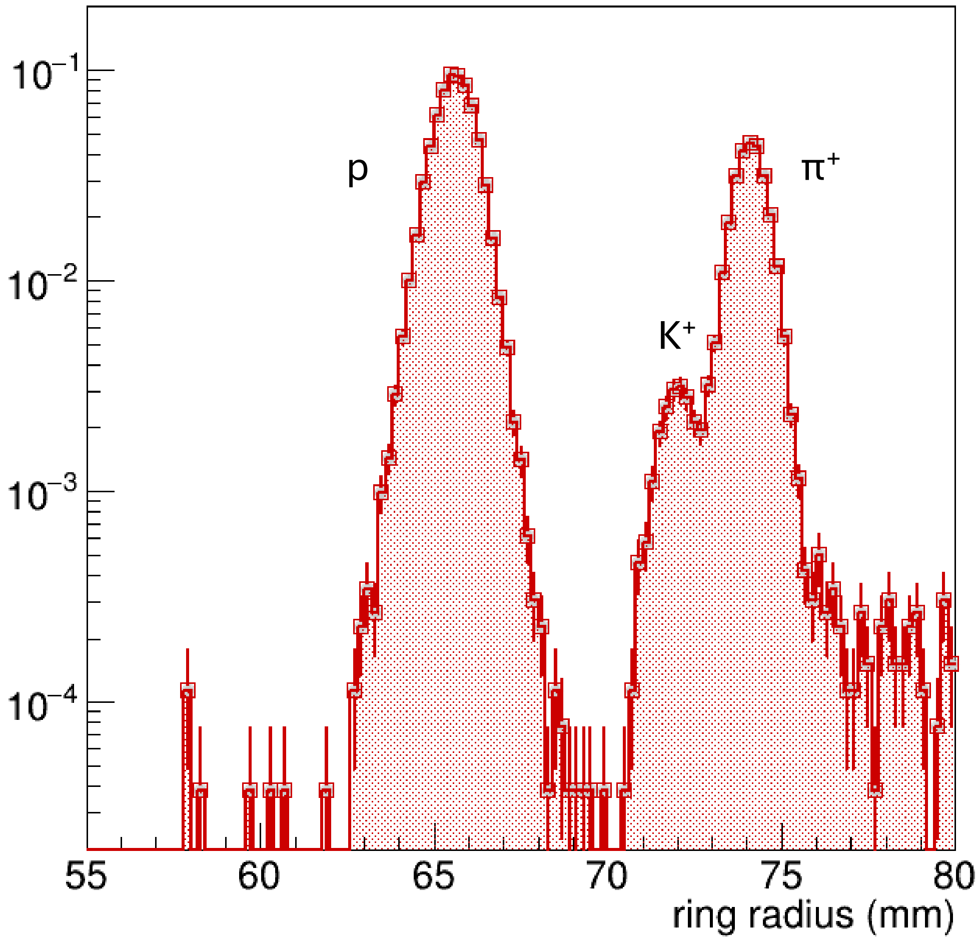


Reconstructed radii vs beam momentum

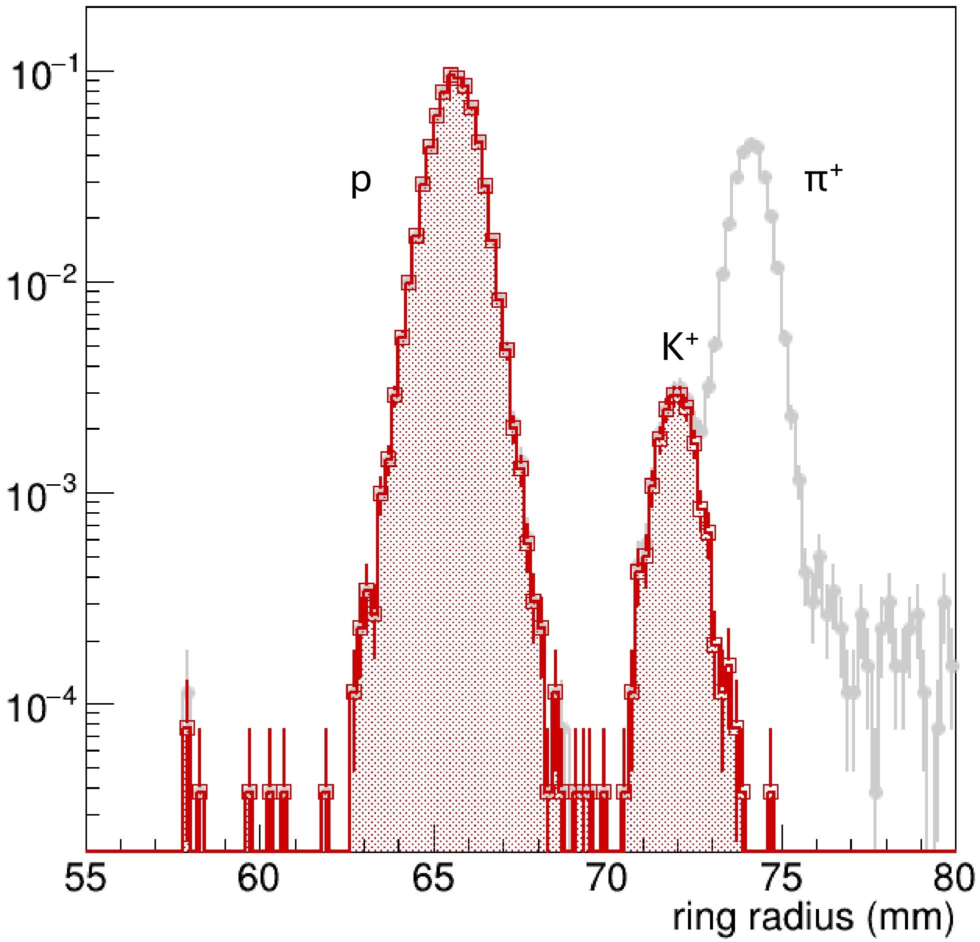


dRICH test beam results

Reconstructed radii at 10 GeV/c beam without selection



Reconstructed radii at 10 GeV/c beam with pion tagged



Conclusion and outlook

- The dual-radiator Ring Imaging Cherenkov will be a key component of the ePIC experiment at the Electron-Ion Collider;
- The dRICH will be the first RICH detector using the Silicon Photomultiplier as photo-sensors.
- The test performed on the annealing procedure showed the capability of curing most of the radiation damage. The online annealing through direct bias will allow curing them without having to dismount the whole detector.
- The Photo-Detection Unit design is complete. Each PDU will operate data acquisition and annealing for 256 photo-sensors, and they will combine to ~320k channels.
- The test beam performed in 2024 showed the ability to reconstruct the gas and aerogel rings using the SiPM and the capability to distinguish different hadrons.
- A new real-scale 1-sector prototype is under construction and will be tested in fall 2025.

Thank you for your kind attention

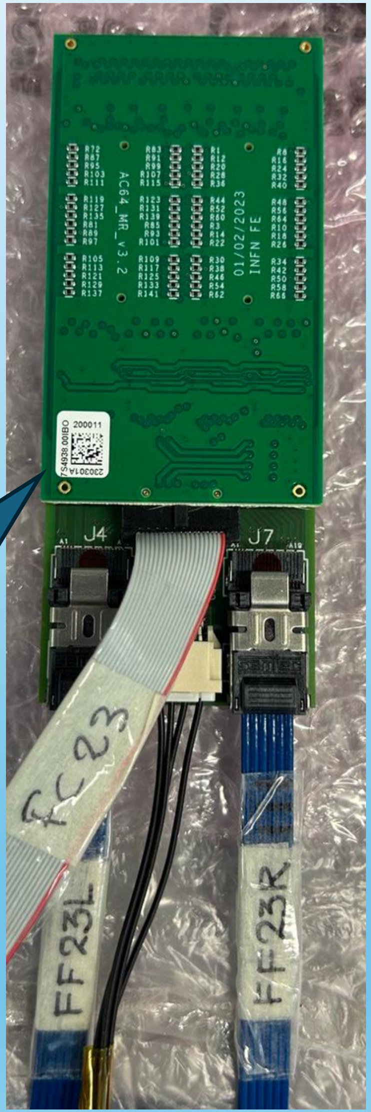
References and backup slides

References

- EIC Yellow report
- dRICH project update at the last ePIC Italy national meeting occurred in June 2025. Other details are available in sub-system dedicated presentation at the same meeting.
- SiPM annealing study
- SiPM photo-detection plane desing
- dRICH prototype design
- dRICH prototype performance

The Photo-Detection Unit

A single readout unit



SiPM matrices

Flex PCB

Peltier cells

Liquid vessel

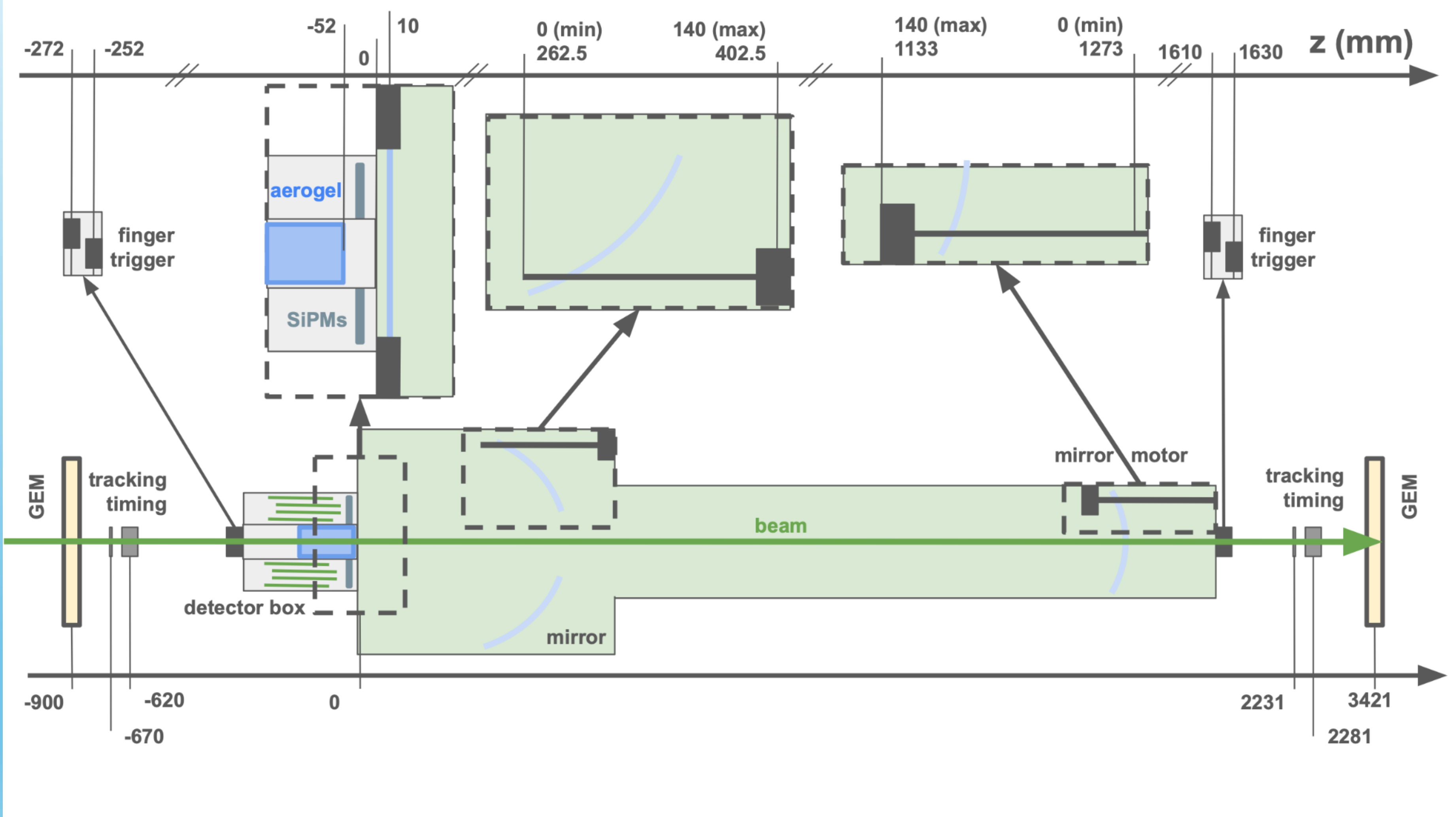
Aluminum frame

Full PDU

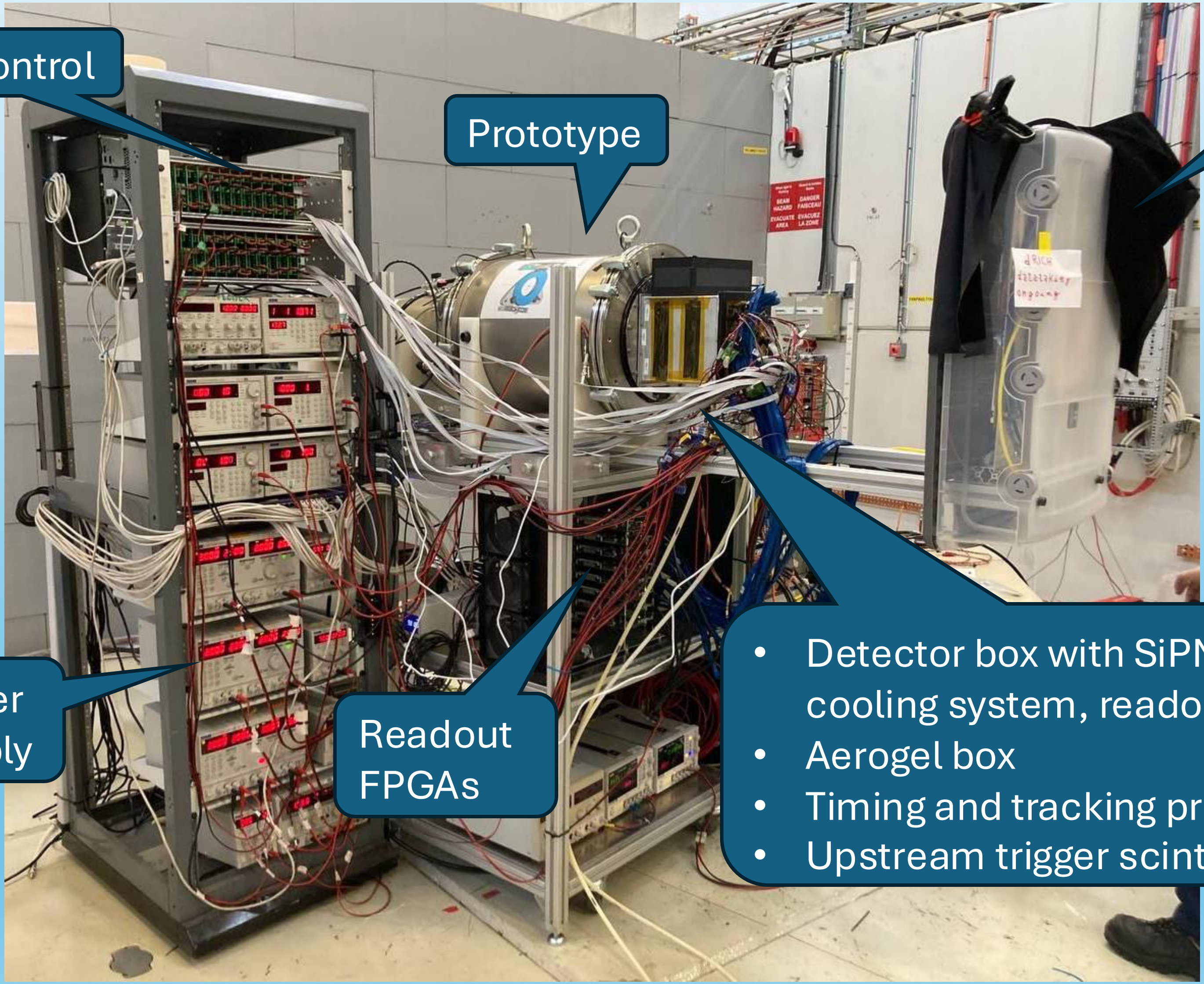
The dRICH test beam – 2024 setup

The test beam setup includes:

- The dRICH prototype;
- A tracking system based on GEM detectors;
- A prototype of tracking and timing system based on SiPMs and on-resin Cherenkov radiator;
- A trigger system based on two 2x1 cm^2 plastic scintillators.



The dRICH test beam – 2024 setup



HV control

Prototype

Upstream GEM tracker

In the back of the picture: downstream trigger scintillators, downstream GEM

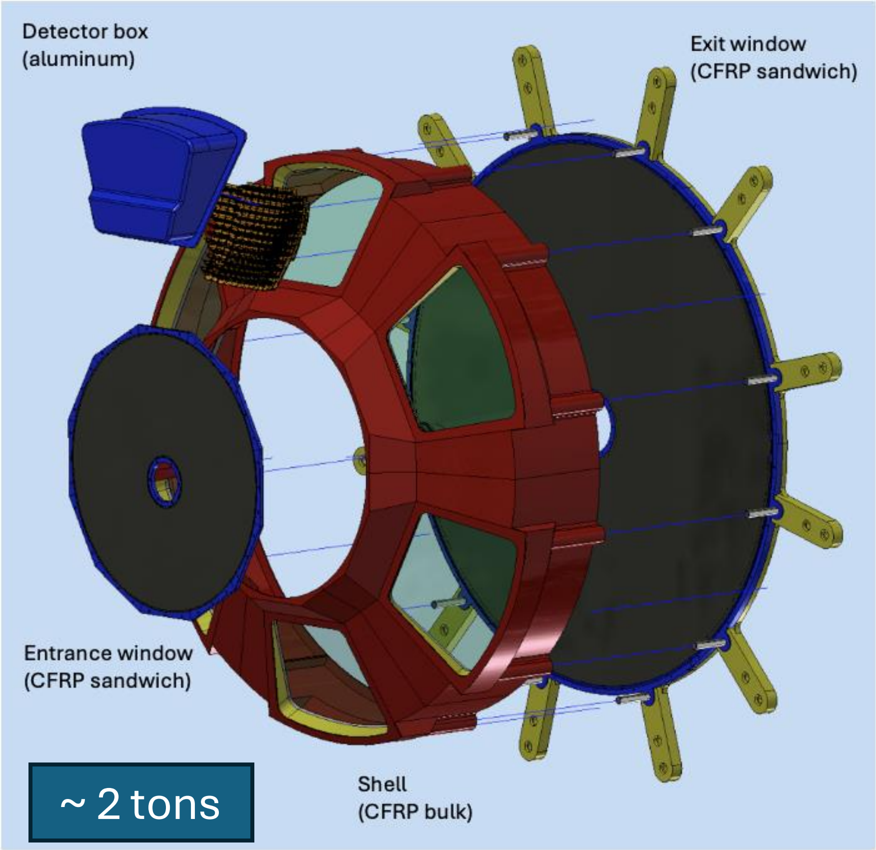
Upstream: Beam Cherenkov detector, providing an independent PID

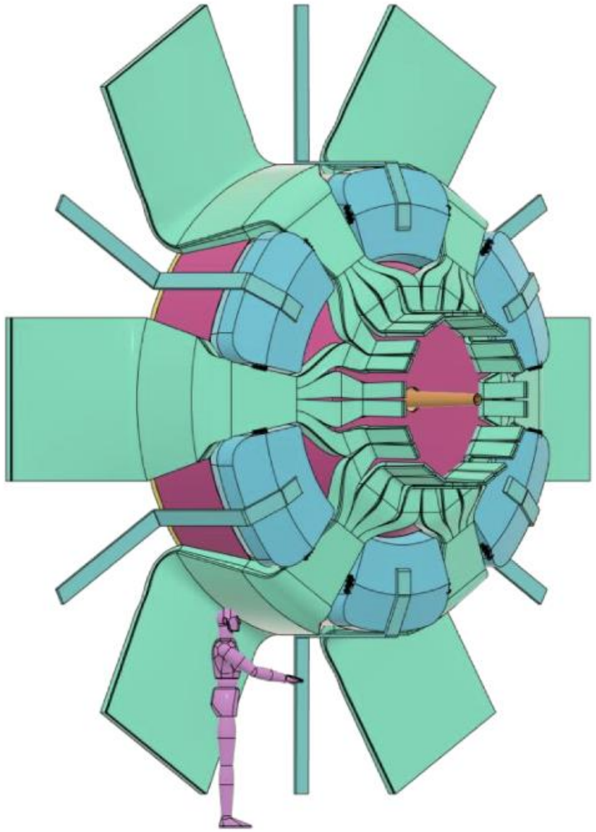
Power supply

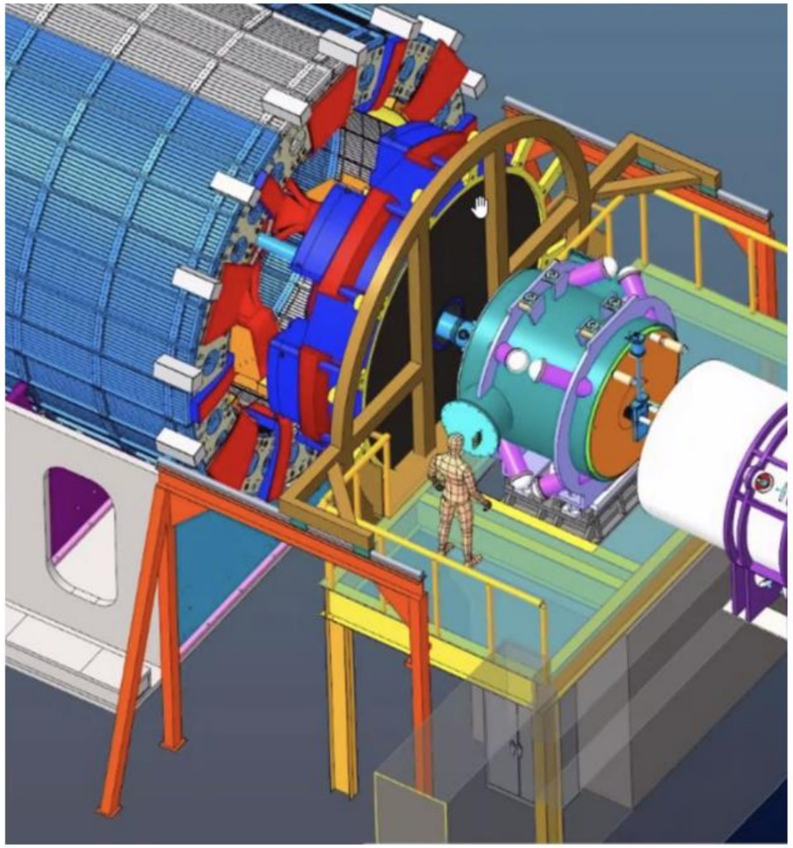
Readout FPGAs

- Detector box with SiPMs, cooling system, readout board
- Aerogel box
- Timing and tracking prototype
- Upstream trigger scintillators

The mechanical structure

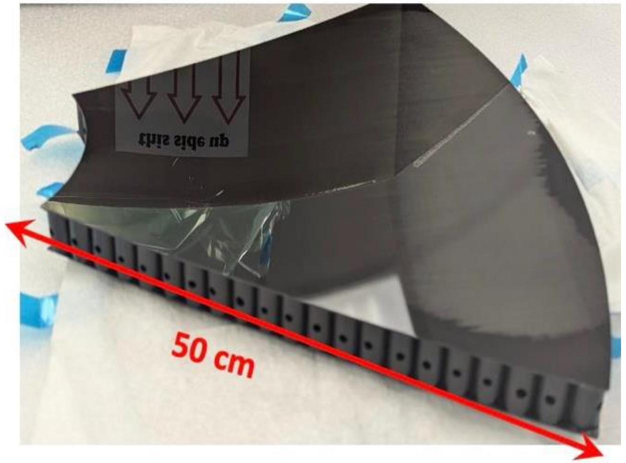


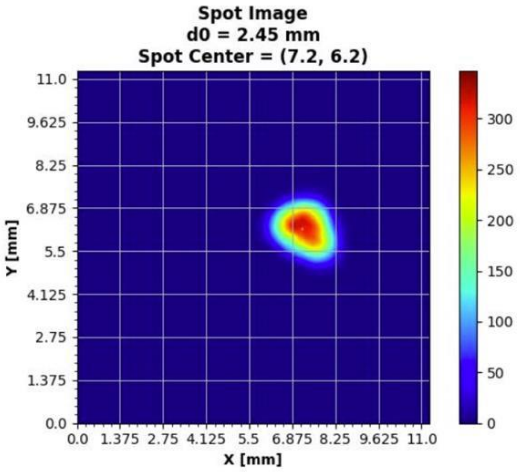


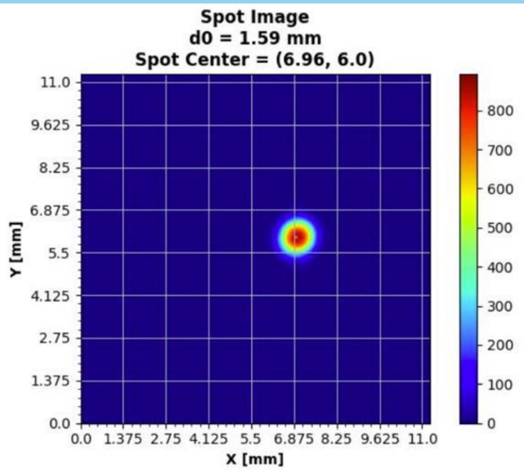


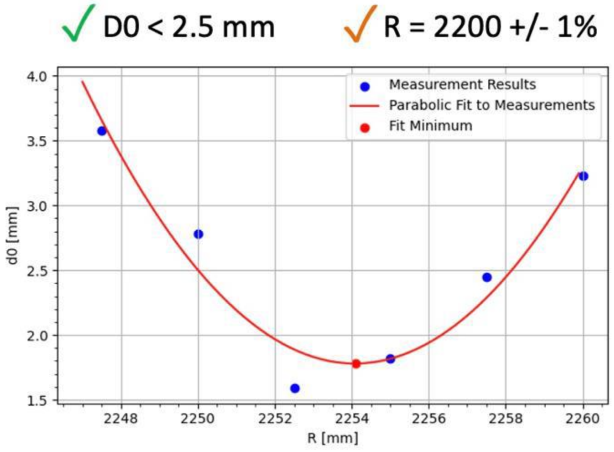
The mirror

- The spherical mirrors are designed to focalize the Cherenkov photons on the limited area of the photosensors.
- Mirror requirements includes radius within 1% of nominal RoC, roughness < 2 nm, point-like image spot size d0 < 2.5 mm, compatibility with fluorocarbon C2F6, compatibility with SiO2 reflective coating.



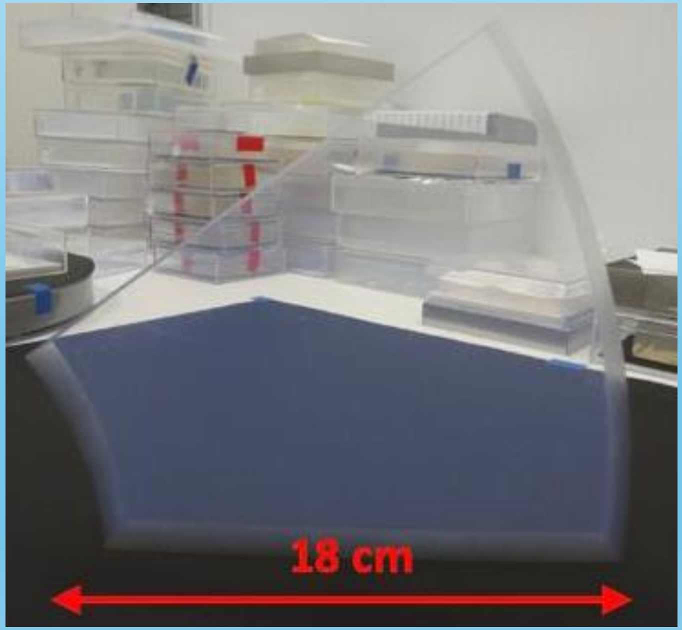


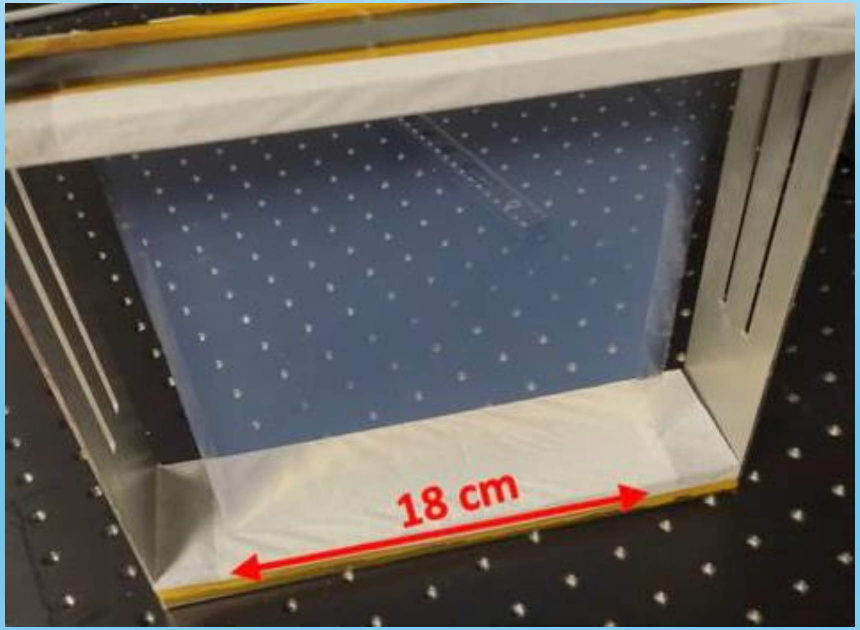




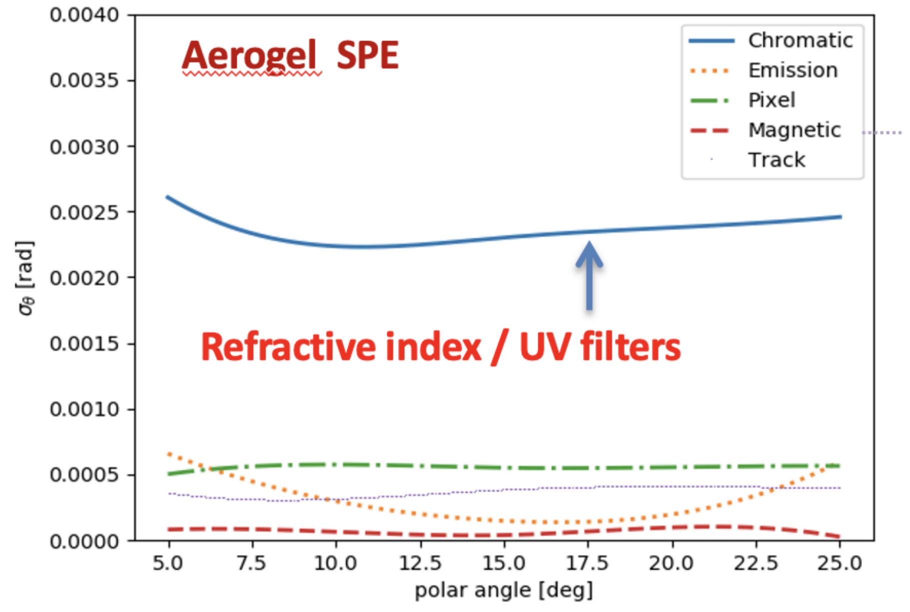
The aerogel radiator

- The aerogel is an amorphous solid network of SiO_2 nanocrystals, shaped in 20-cm tiles;
- Attenuation length Λ_{400nm} > 50 mm;
- Refractive index n_{400nm} = 1.026;





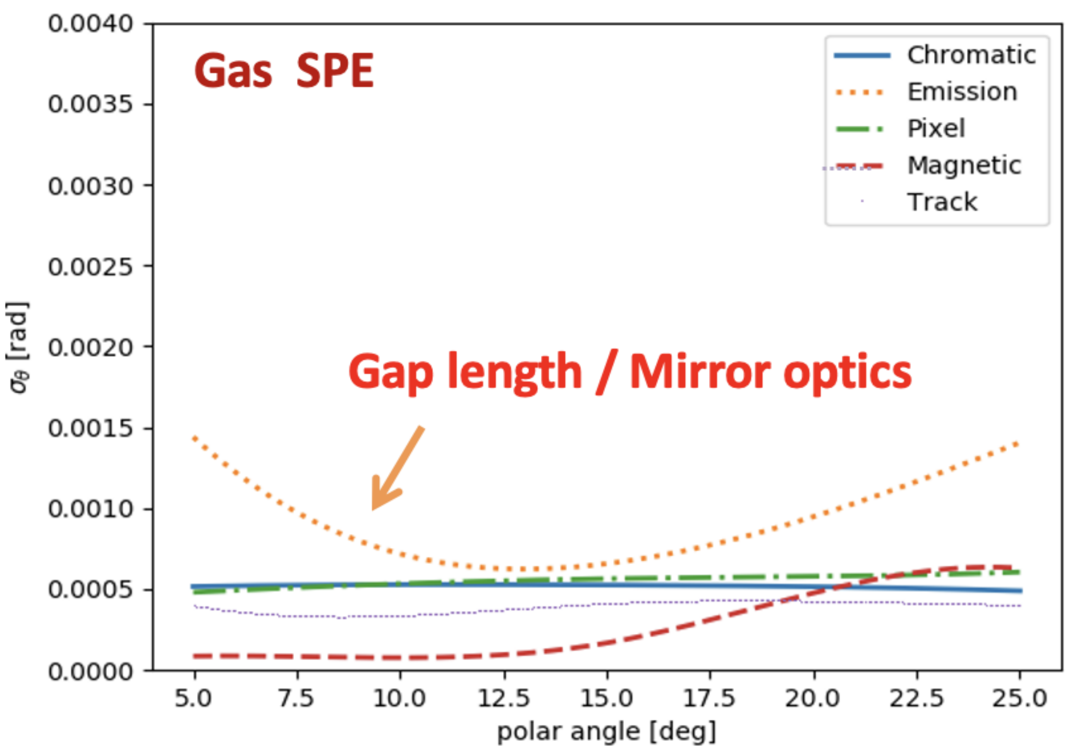
Contribution to resolution for aerogel ring

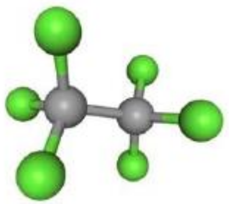


The gas radiator

- The gas radiator is hexafluoroethane C_2F_6;
- Refractive index n = 1.0085;
- C2F6 is greenhouse gas, alternative and risk mitigation strategies are being studied.

Contribution to resolution for gas ring



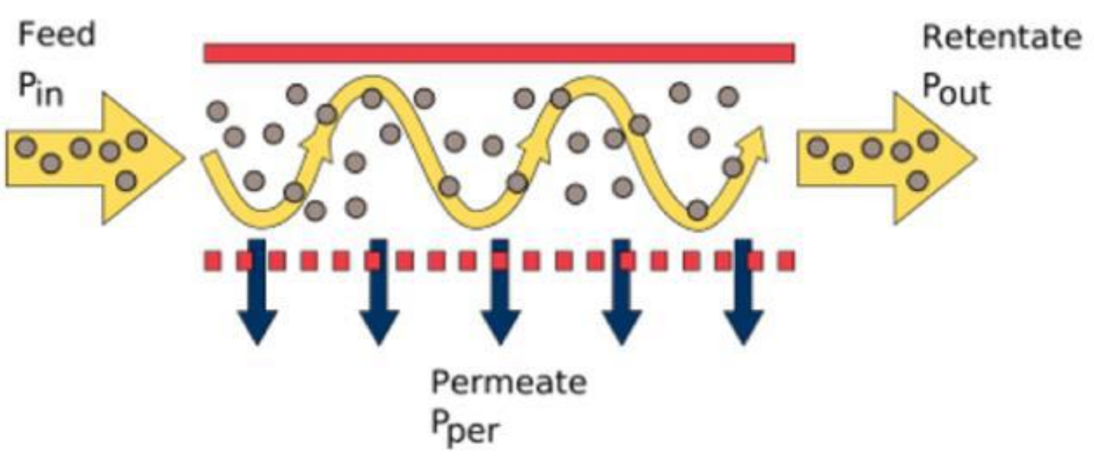


C_2F_6 molecular weight: 138.01 g/mol
boiling point: -78.1 °C
melting point: -100.6 °C
density: 5.734 kg/m³ at 24 °C
density: 16.08 kg/m³ at -78 °C

1 covalent + 6 hydrogen bonds

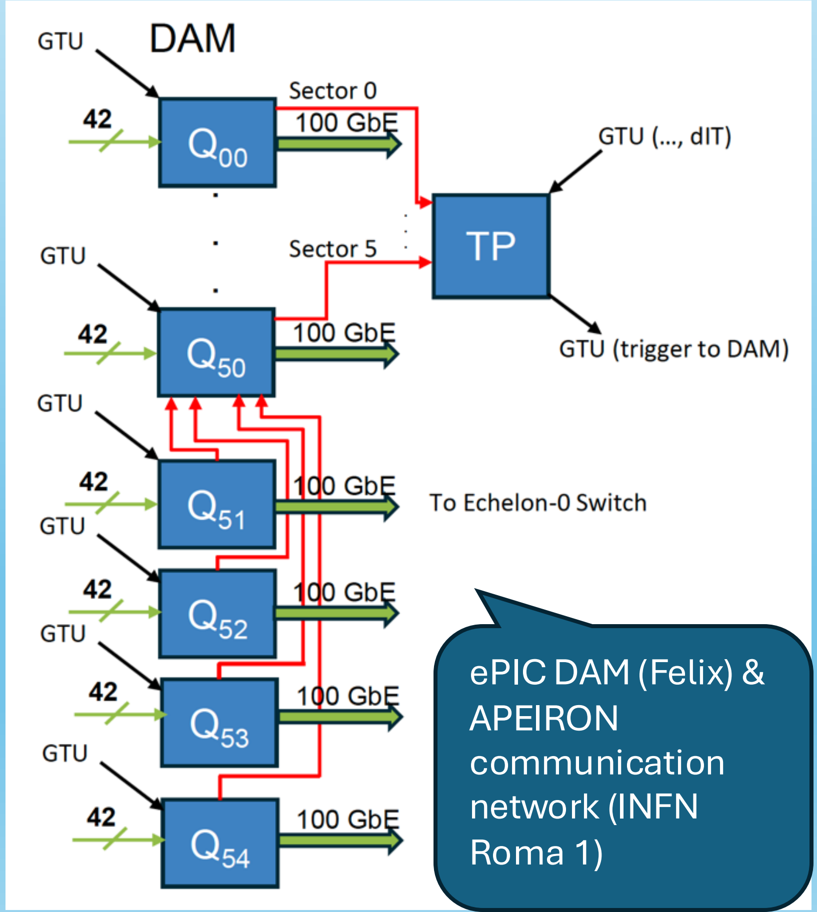
Gas	Npe(π/K)	θ_π	θ_K	σ_π	σ_K	N_σ	ρ = Δθ/θ (λ = 300 nm)
C_2F_6	16.0/14.9	36.8	35.7	0.32	0.33	3.5	1.8 %
C_4F_{10}	24.8/23.8	48.6	47.8	0.29	0.30	2.8	2.4 %

R. Guida, B. Mandelli, M. Corbetta

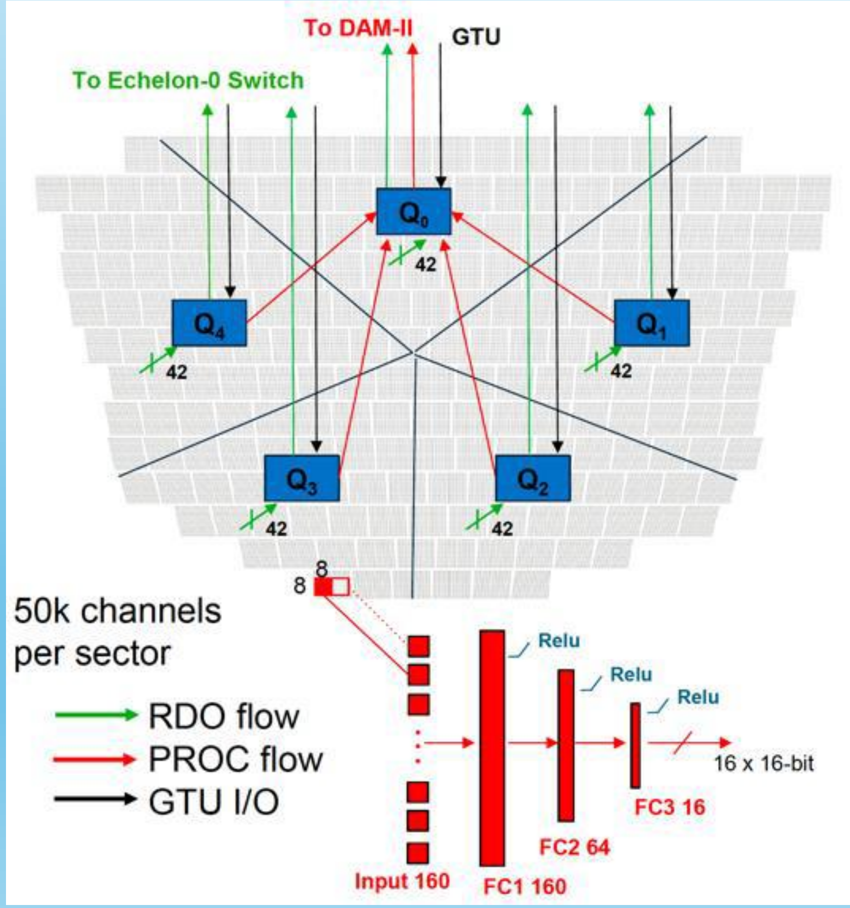


dRICH online filtering

- The dRICH will produce a huge amount of background signal (up to 1.4 Tb/s). Two complementary strategies are being developed to reduce it.



ePIC DAM (Felix) & APEIRON communication network (INFN Roma 1)



dRICH Interaction Tagger based on two layer of Scintillating Fiber placed in front of the detector entrance window.