Forward Particle Identification at the EIC with the ePIC dRICH Detector

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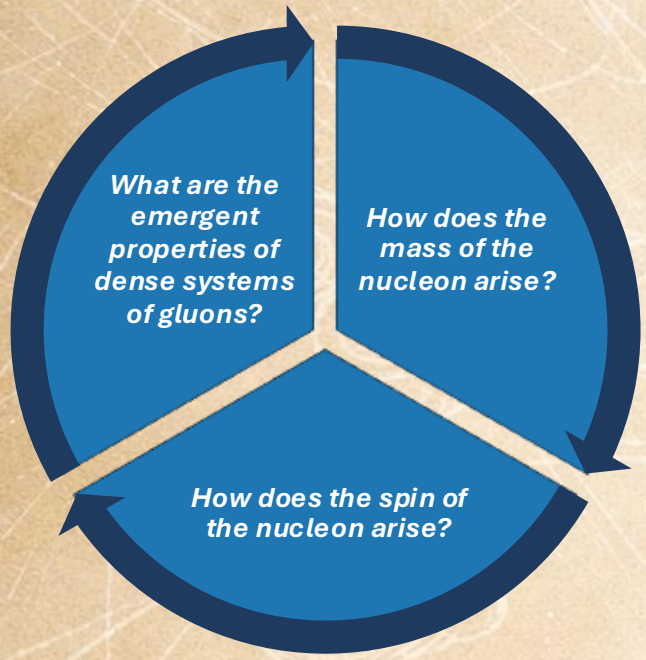
INFN Genova, on behalf of ePIC dRICH group

DIS2026

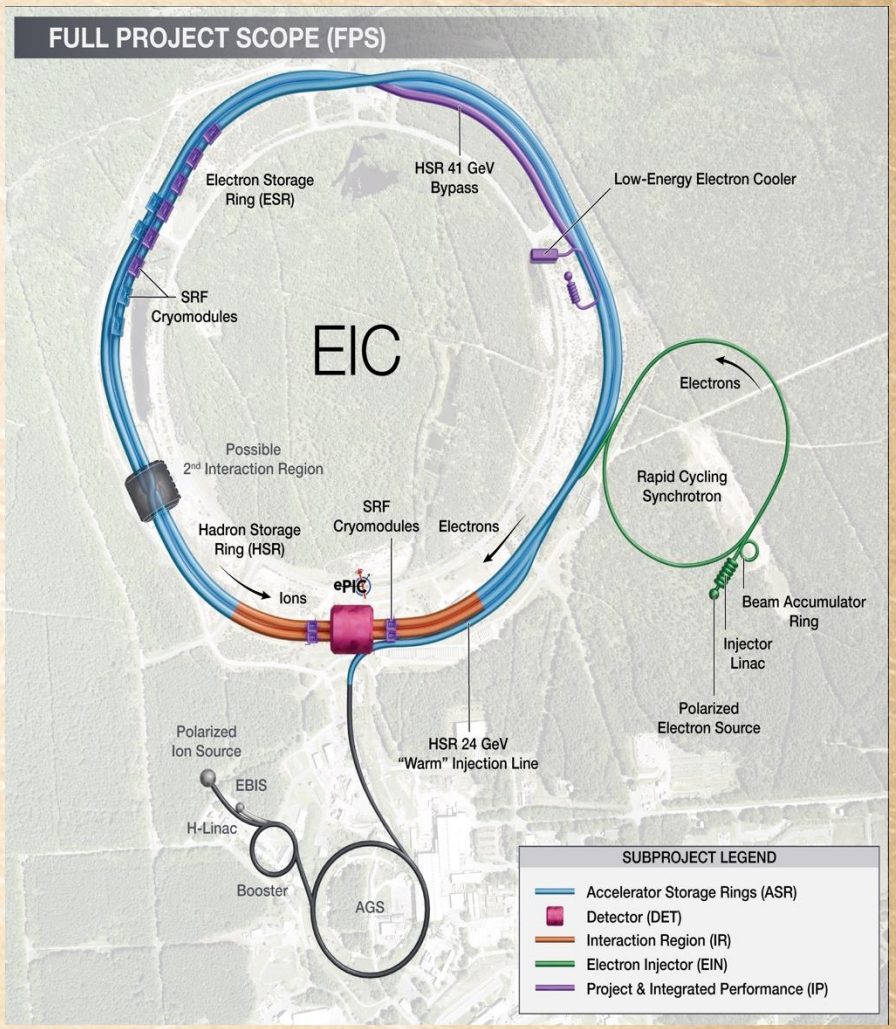
May 5th, 2026, Bologna

The Electron-Ion Collider

See A. Tricoli talk this morning and J. Lajoie talk on Friday

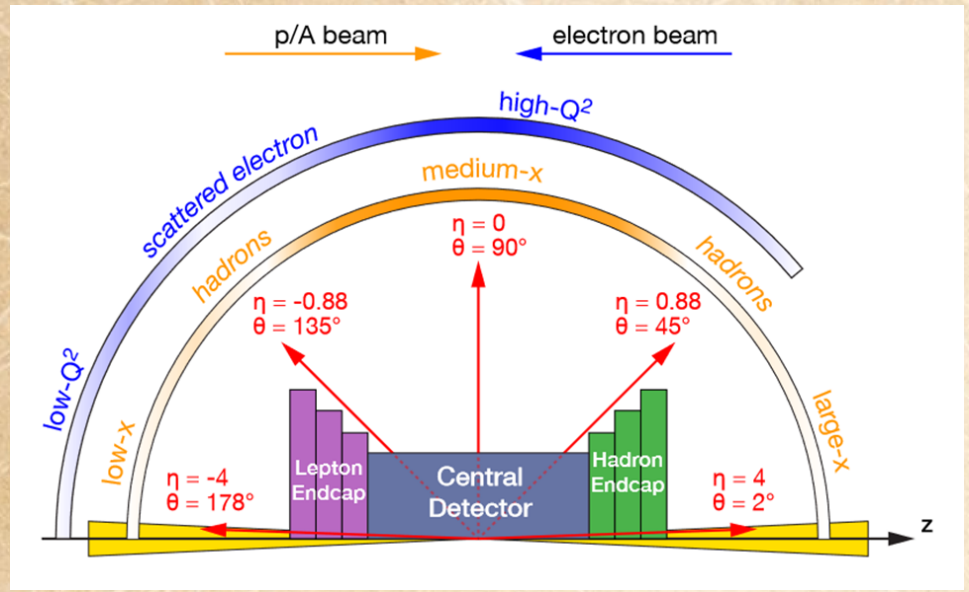


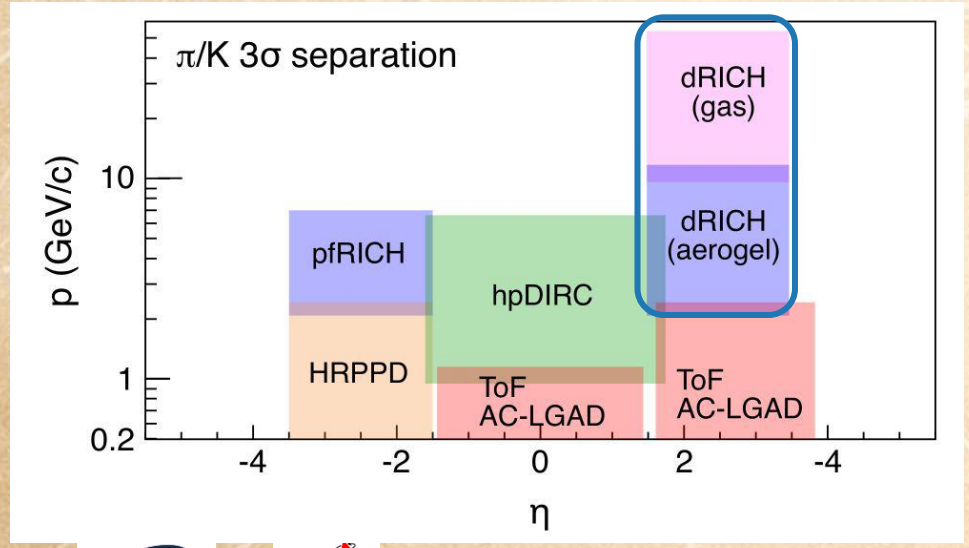
Electron-Ion Collider: The new asymmetric collider to investigate the nature of non-perturbative QCD.



- Collision with a broad range of ion species, from protons to uranium;
- Highly polarized beams: ~70%;
- Variable e+p center-of-mass energy: 28 – 140 GeV;
- High luminosity: 10^{33} cm^{-2} s^{-1};
- The Electron-Proton/Ion Collider experiment: ePIC

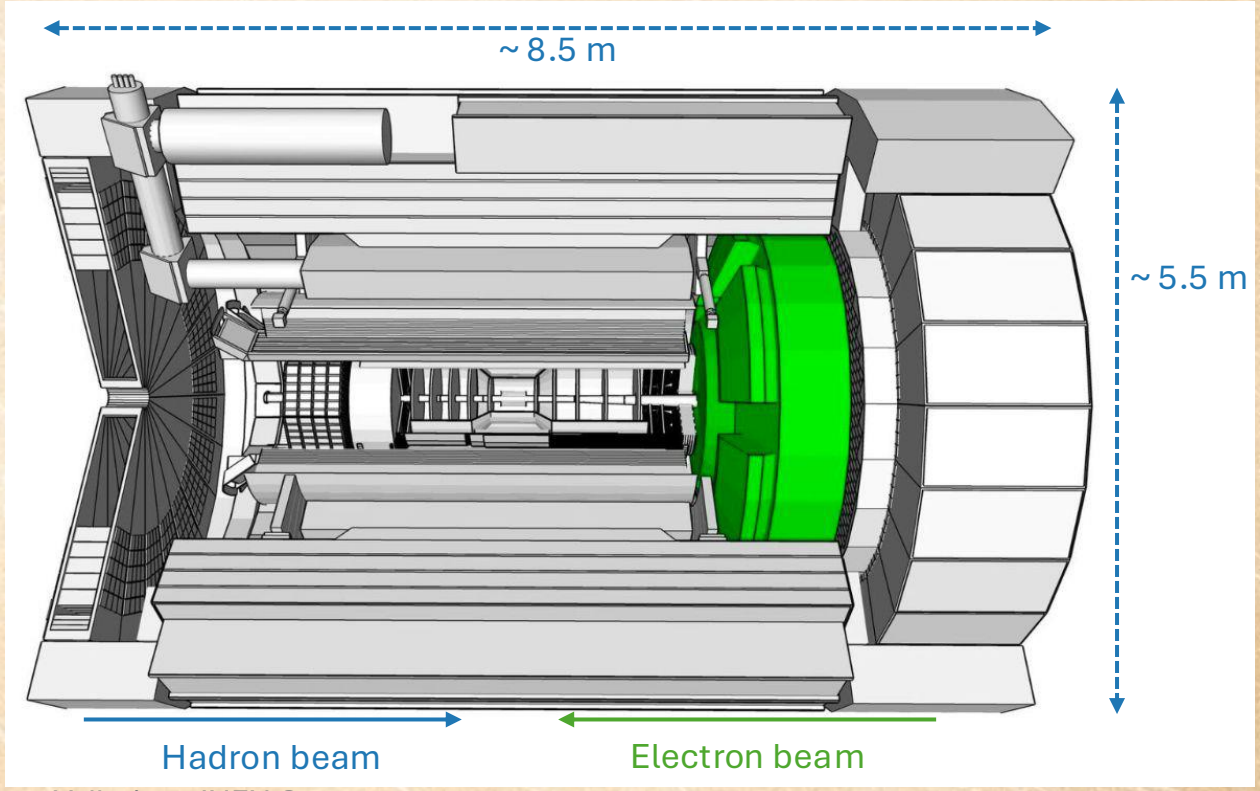
The Electron-Proton/Ion Collider experiment ePIC





It is built around a 1.7 T solenoidal magnetic field and consists of three different regions:

- the Central Detector, surrounding the interaction region;
- the Lepton Endcap, in the backward direction;
- the Hadron Endcap in the forward direction.

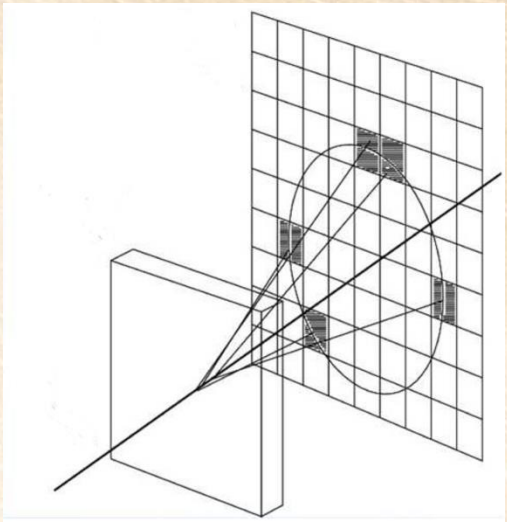


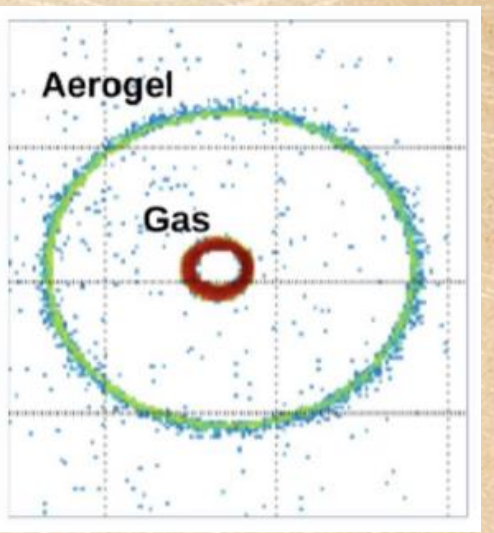
Ring Imaging Cherenkov Detector

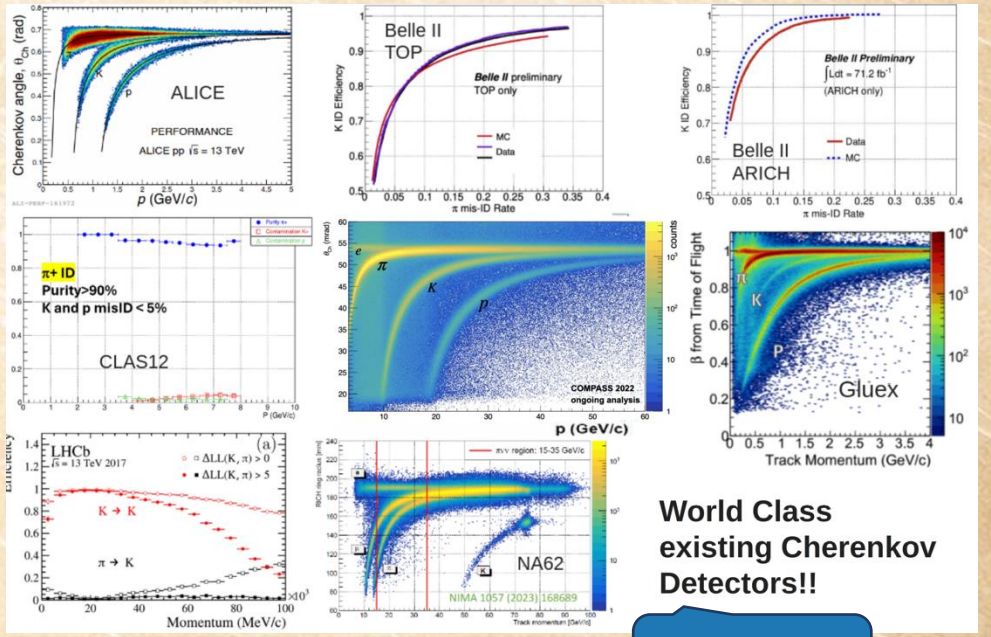
- Ring Imaging Cherenkov (RICH) detector exploits the Cherenkov effect to identify charged particles

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

- The Cherenkov photon cone is projected onto the photodetection plane as a ring.
- By combining the Cherenkov angle reconstructed from the ring with the particle momentum allows the particle mass to be determined.

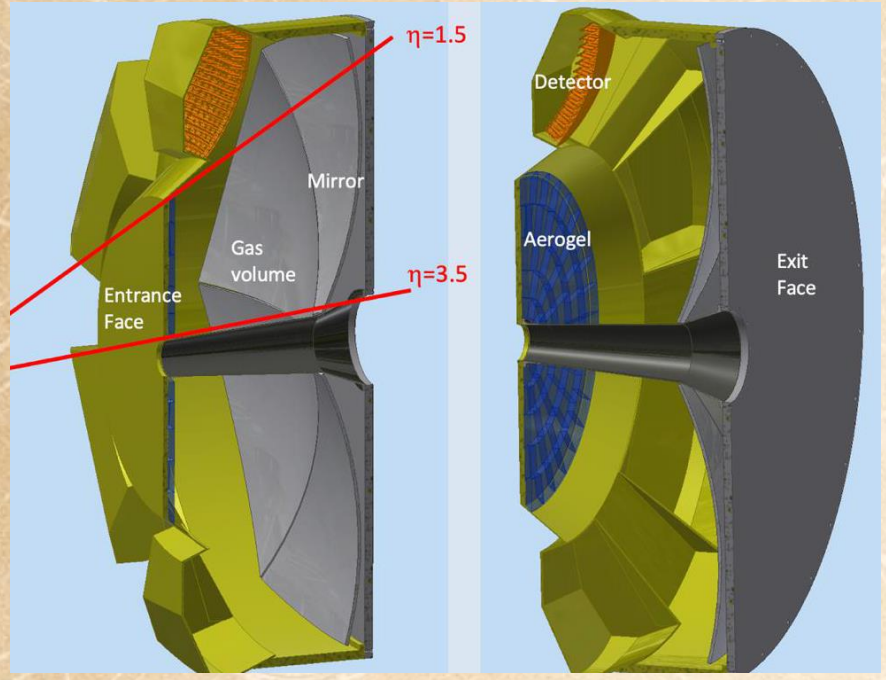


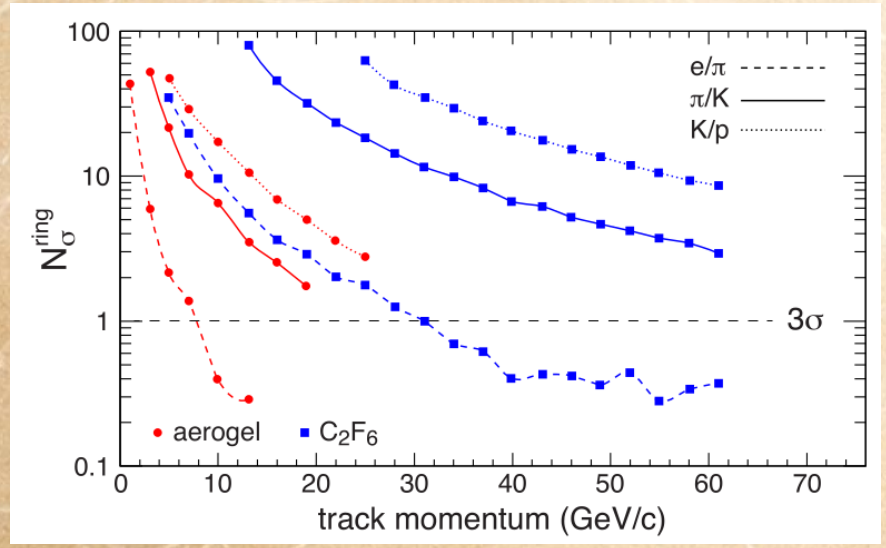




Courtesy of C. Chatterjee

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 address main challenges:

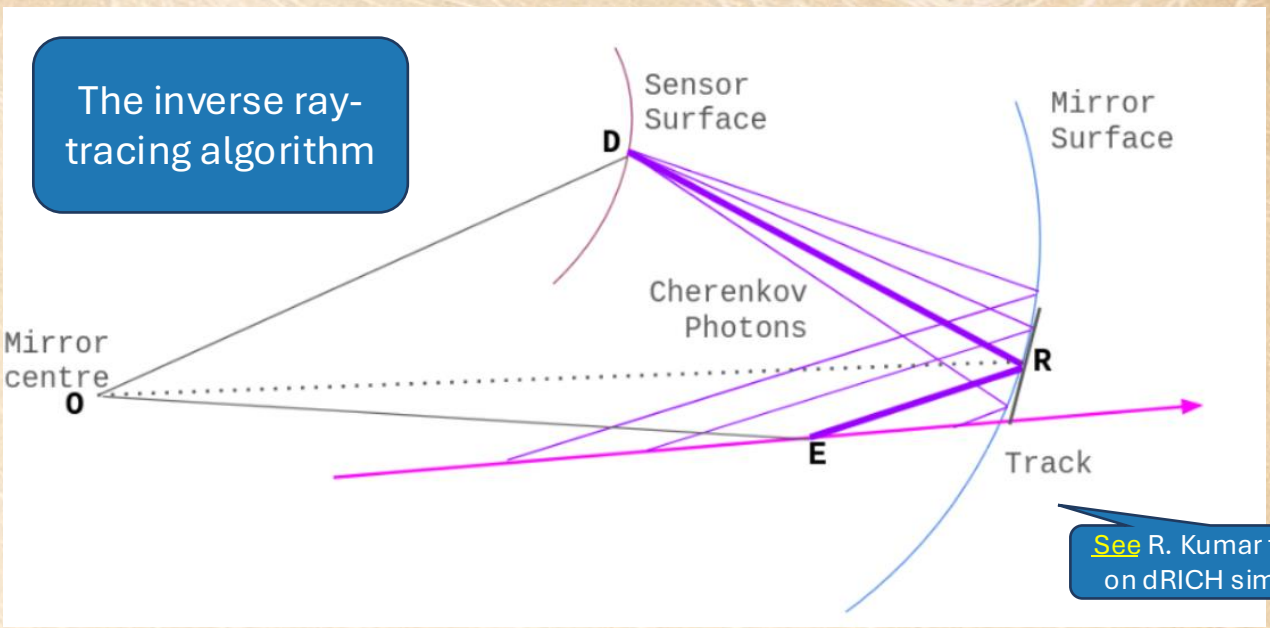
- covering a wide momentum range, which crosses the typical regions of refractive index for liquid and gaseous radiators;
- operating in a high magnetic field (~1T).

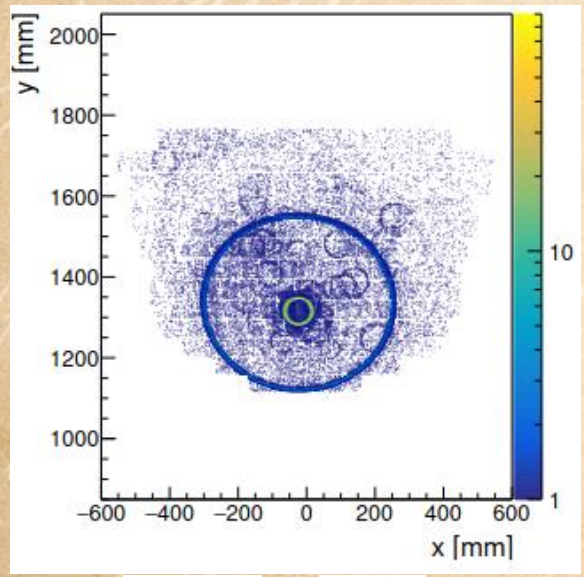
The two radiators, aerogel ($n \simeq 1.026$) and gas ($n \simeq 1.0085$), will provide complementary information for hadron identification over the full momentum range.

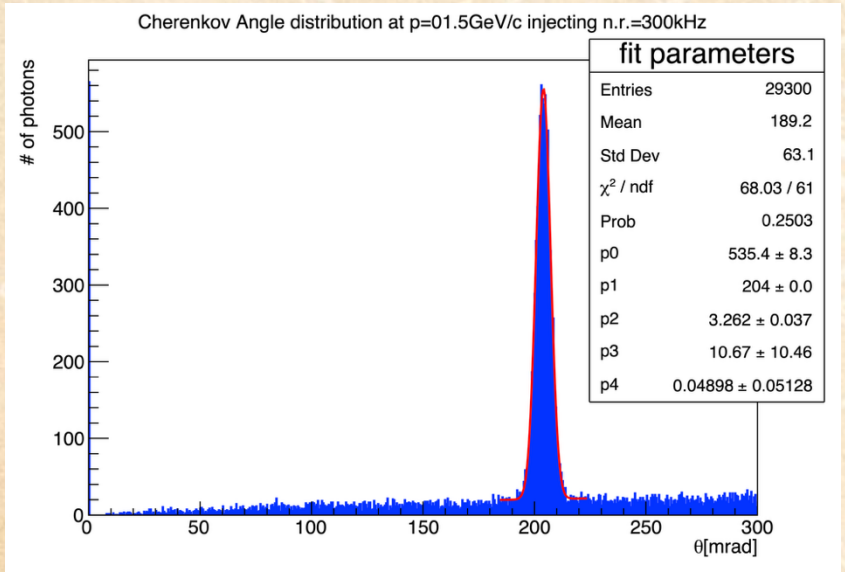
Silicon Photomultipliers (SiPMs) will be used as magnetically insensitive photosensors, for the first time in a RICH detector.

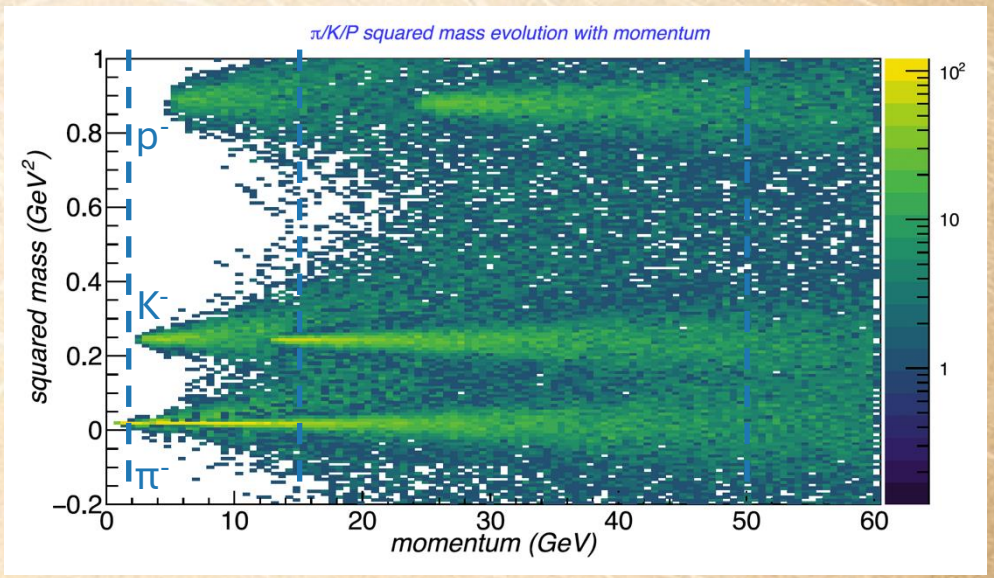
Simulation

- The dRICH simulation is implemented in the ePIC dd4hep framework and accounts for tracking, material budget, and magnetic bending.
- The detector response is modeled using laboratory characterization and test-beam data for the individual components.
- An inverse ray-tracing algorithm is implemented to associate photons with the reconstructed ring.









The dRICH components

Aerogel

Requirements: π/K separation up to 15 GeV/c, more than 10 photons from a 4 cm-thick radiator, single photon resolution approaching 2 mrad.

Baseline solution: n = 1.026, $dn/d\lambda = 6 \times 10^{-6}$ nm^{-1}, scattering length > 50 mm.

Gas

Requirements: π/K separation up to 50 GeV/c, more than 20 photons from a 1 m-depth radiator, single photon resolution approaching 1 mrad.

Baseline solution: C_2F_6 with n = 1.00086, $dn/d\lambda = 0.2 \times 10^{-6}$ nm^{-1}, absorption length > 100 m.

Mirror

Requirements: Cherenkov light focalization, Cherenkov information preservation, low material budget.

Baseline solution: Carbon fiber structure, roughness of a few nm, angular precision < 0.3 mrad.

Mechanics

Requirements: acceptance maximized in 1.5-3.5 pseudorapidity range, material budget minimized, Compatibility with barrel maintenance operations.

Baseline solution: Composite material, single open volume, detector in barrel shadow.

Photosensor

Requirements: Single-photon detection capability in a high magnetic field, excellent PDE in the visible range, marginal contribution to angular resolution, few 10^{10} 1-MeV neq/cm^2 fluence.

Baseline solution: Spatial resolution of 3x3 mm^2, time resolution O(100 ps), operation at -30 °C, annealing.

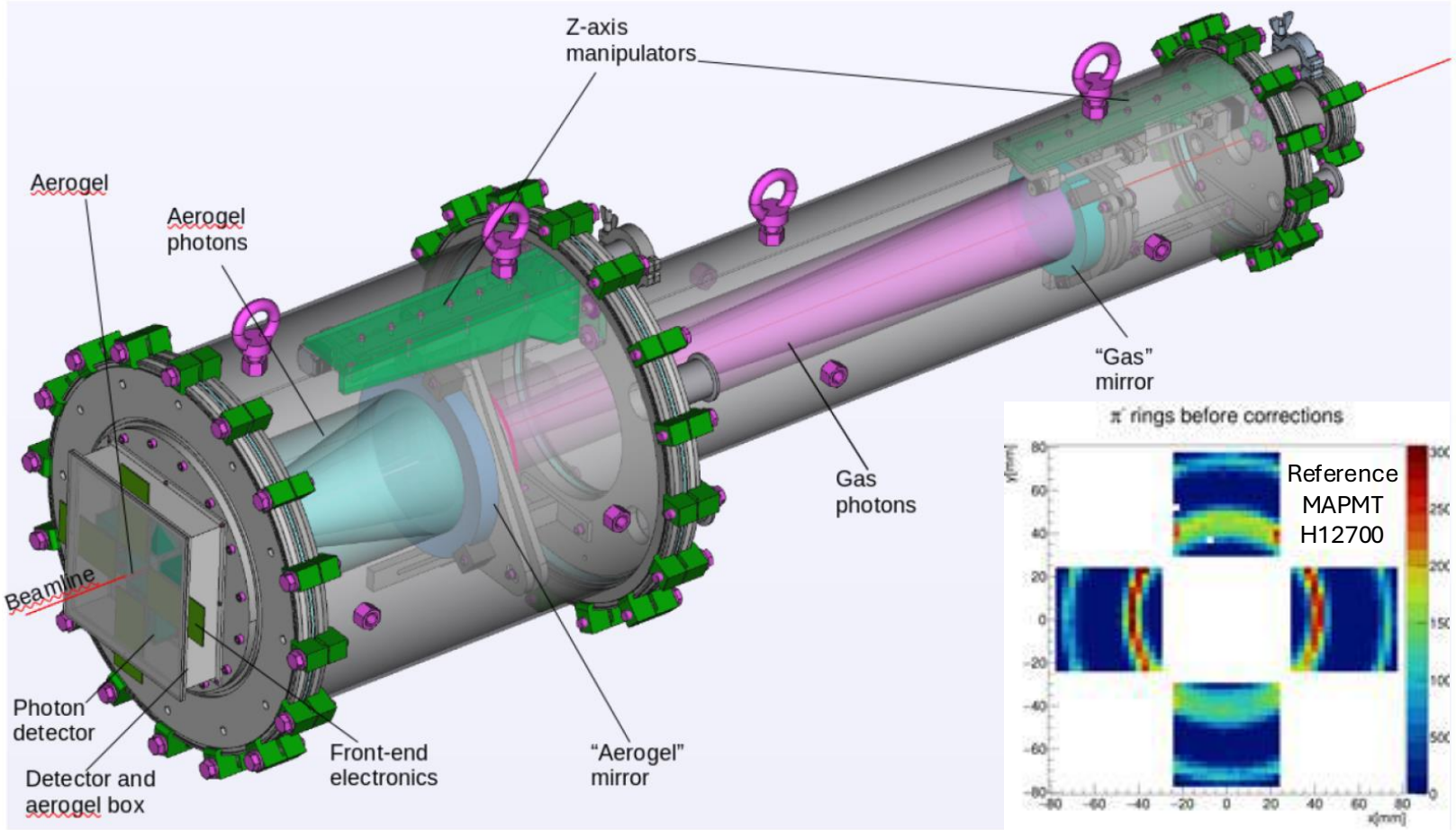
Readout

Requirements: Below 1 p.e. threshold capability, preserve sensor time resolution, more than 300 kHz/ch rate capability, streaming readout with suppression of no-interaction frames.

Baseline solution: ALCOR chip, time resolution < 200 ps, rate > 300 kHz/ch

Radiators study

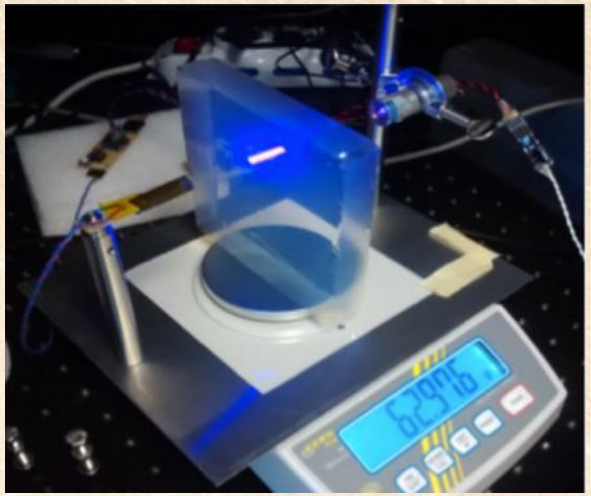
The dRICH prototype

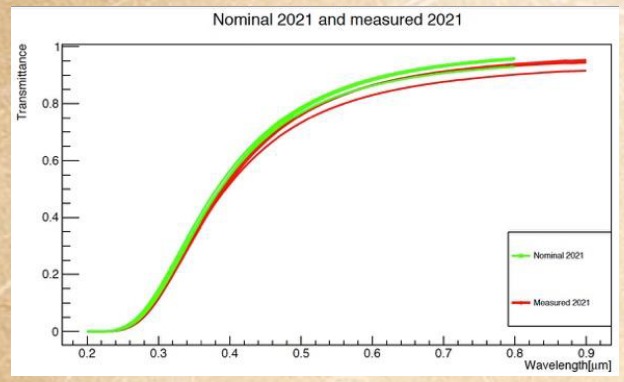


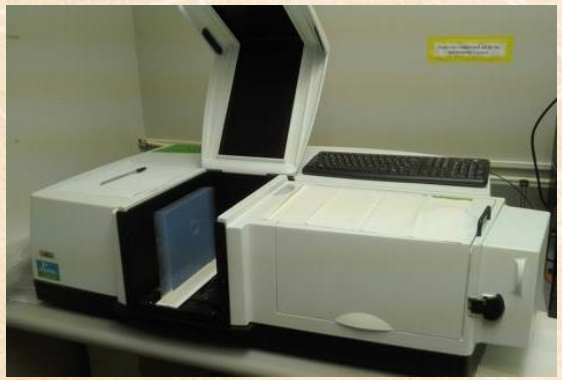
- Designed in 2021 to assess the achievable performance of the dual-radiator design;
- Two on-axis optics to minimize the photodetection surface;
- Vacuum and gas recovery system;
- Detector boxes equipped with MAPMTs as reference sensors and SiPMs for photodetector study.

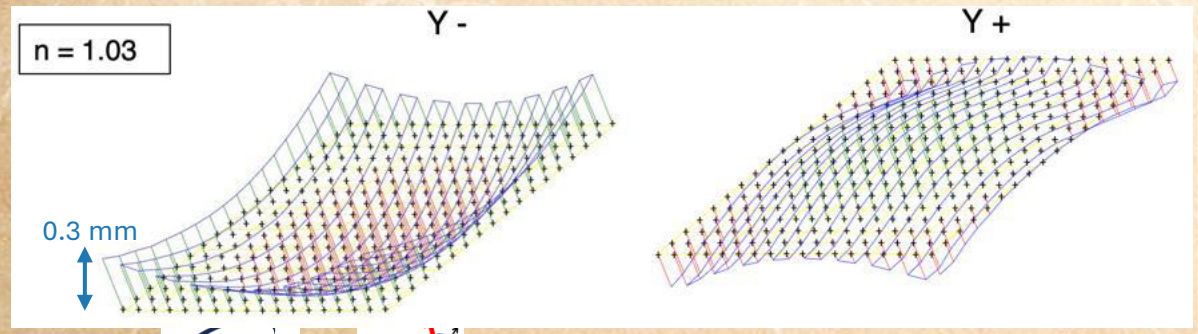
Aerogel characterization

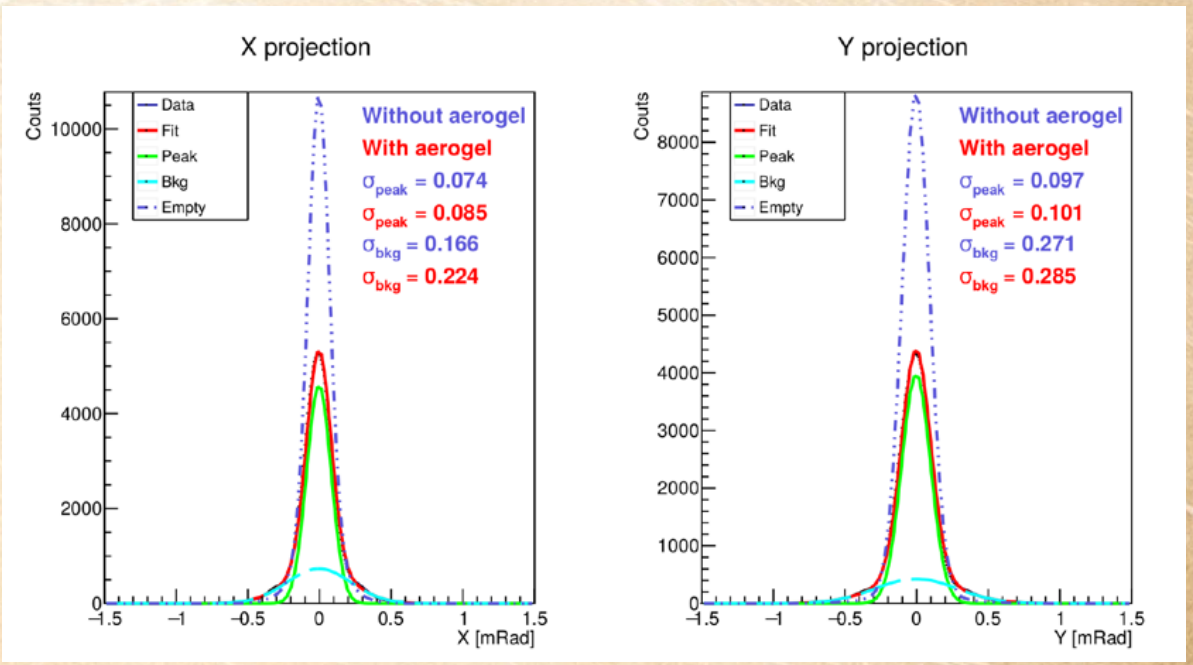
- Reproducibility study on small samples from Aerogel Factory (Chiba University, Japan), in synergy with ALICE;
- Transmittance and transflectance measurement with a spectrophotometer;
- Touch-probe measurements: planarity and thickness of a 10x10x2 cm^3 ALICE tile;
- Laser spot broadening measurement with a 3x2 cm aerogel sample.







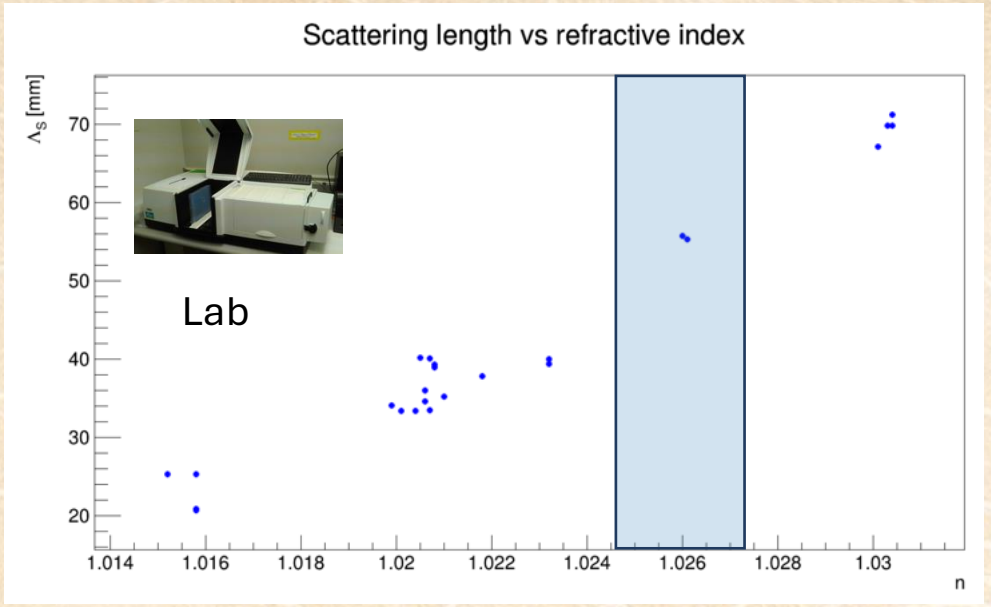


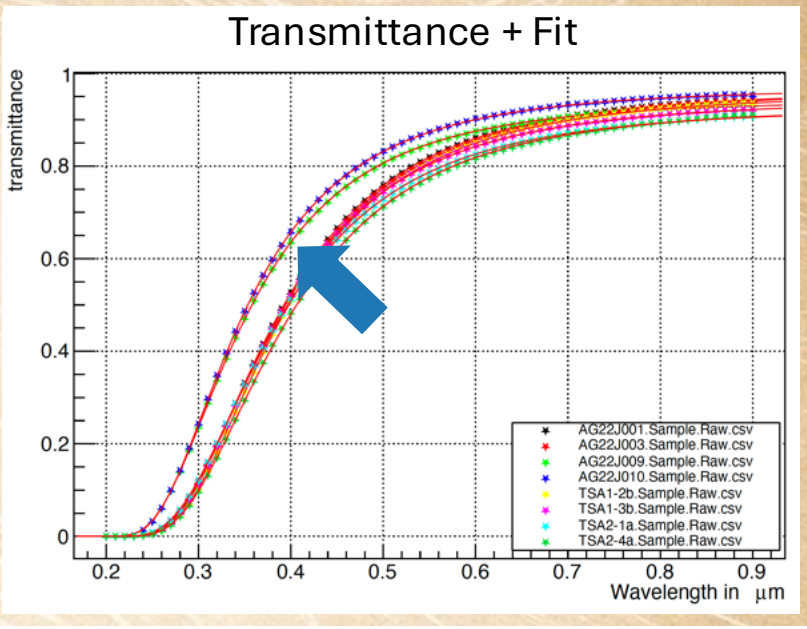


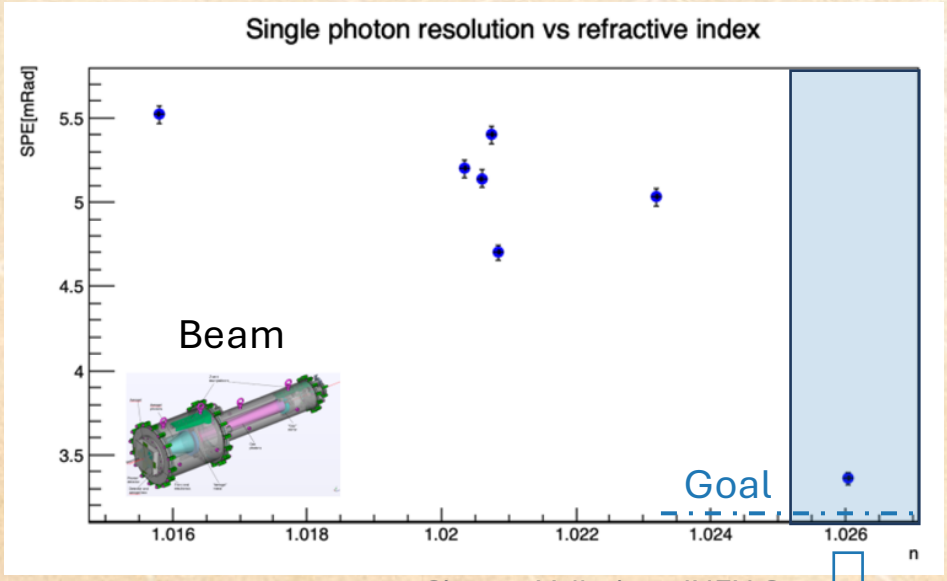
Aerogel performance

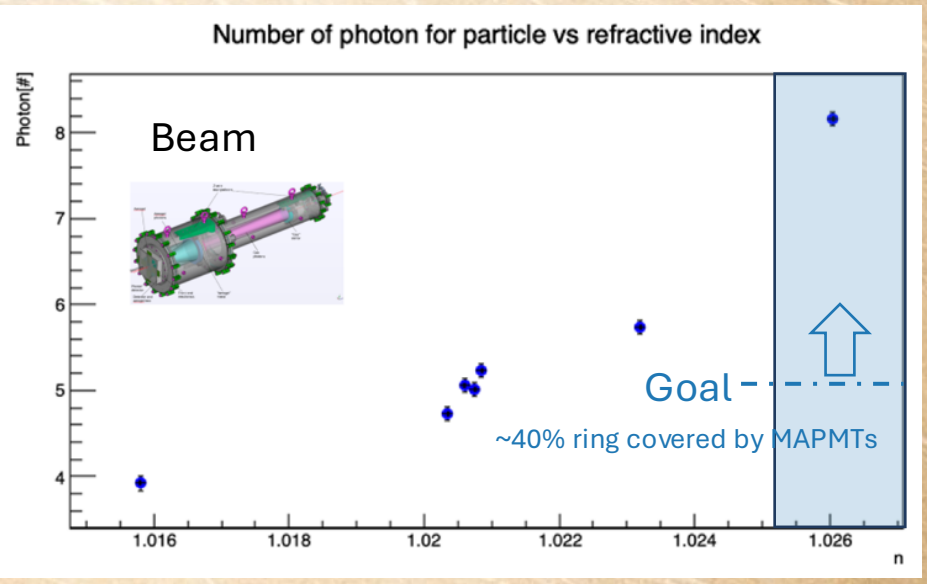
- n = 1.026 meets single-photon resolution requirement;
- Scattering length > 50 mm;
- Match with the TOF endpoint (2.5 GeV/c);
- Overlap with gas (12 GeV);
- Photon yield > 10/particle with MAPMTs.

Samples from Aerogel Factory



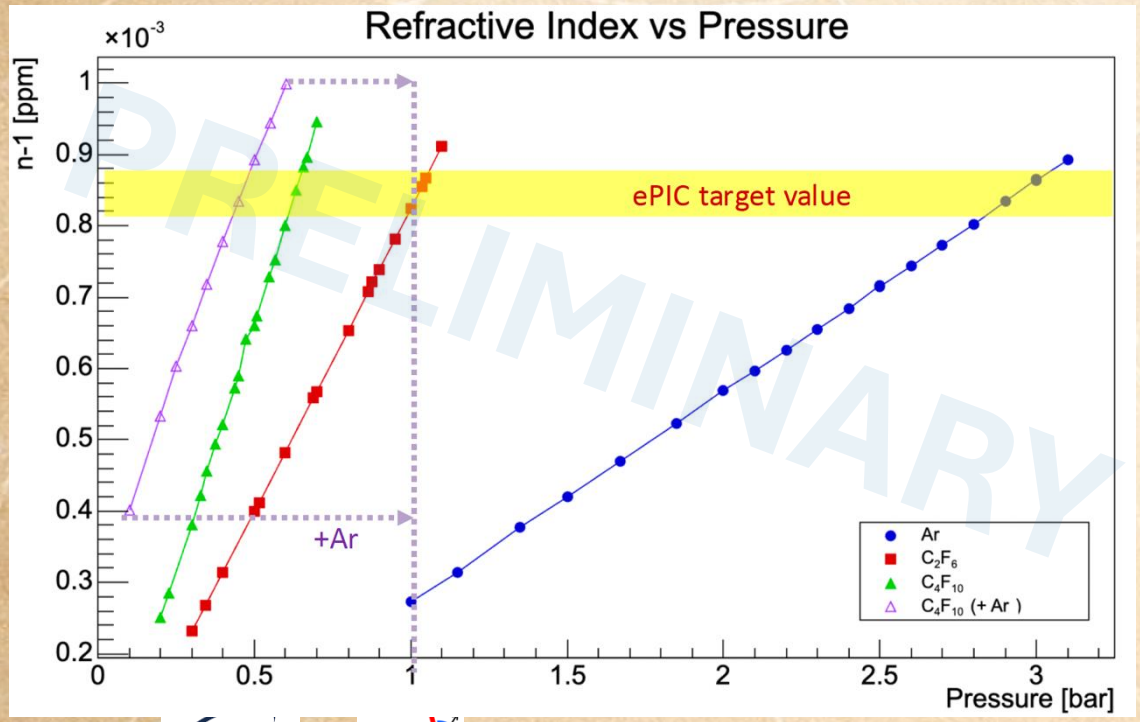


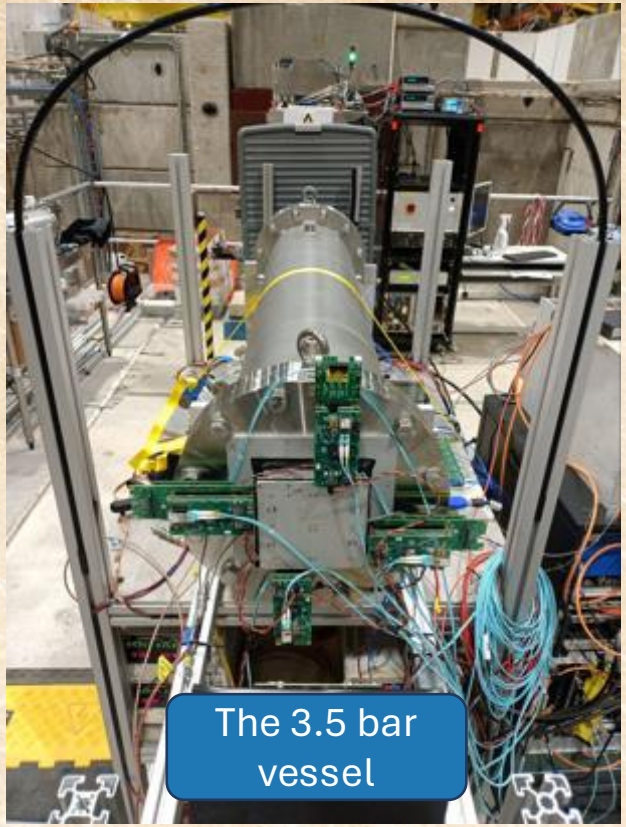


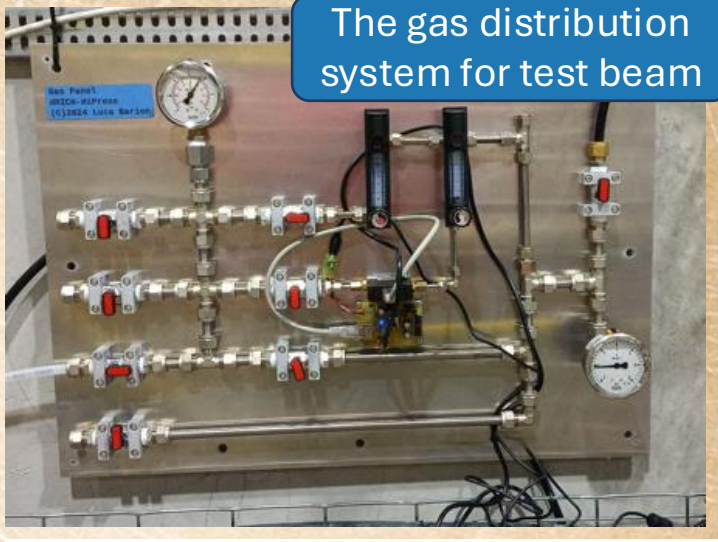


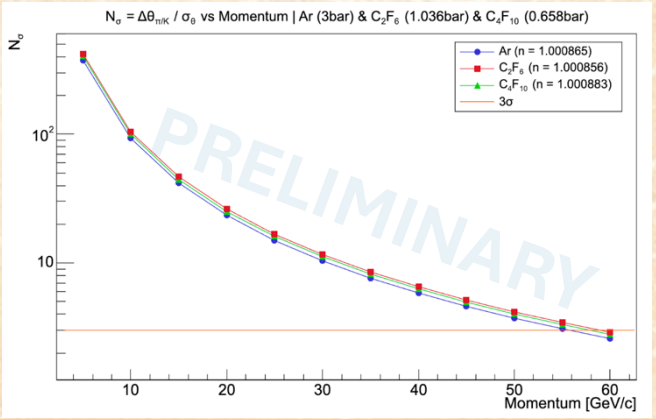
Gas performance

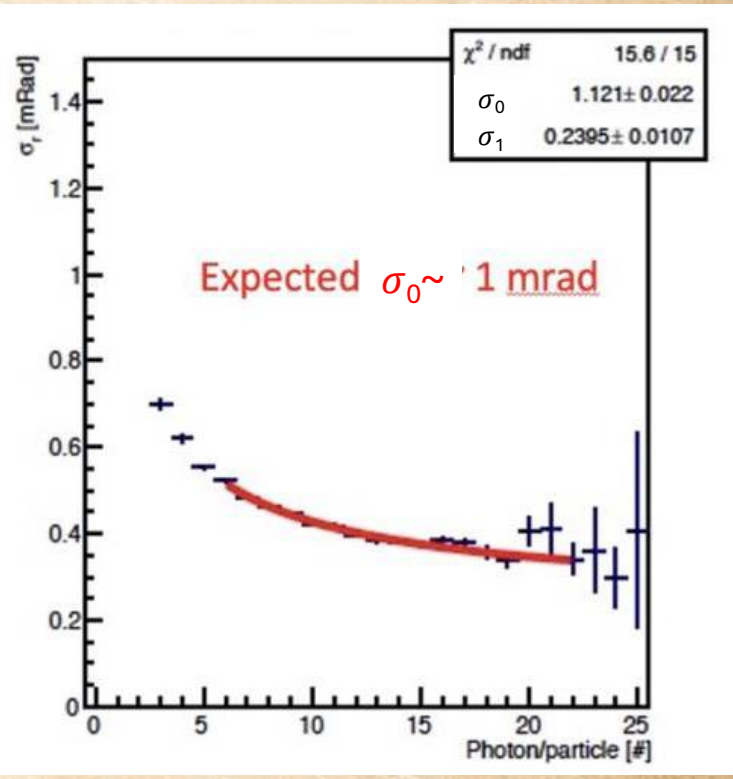
- The reference gas, C_2F_6, match detector requirements;
- C_2F_6 is a greenhouse gas; therefore, alternative based on pressurized gas are under study;
- Preliminary performance from C_4F_{10} and pressurized Ar is comparable with reference gas.











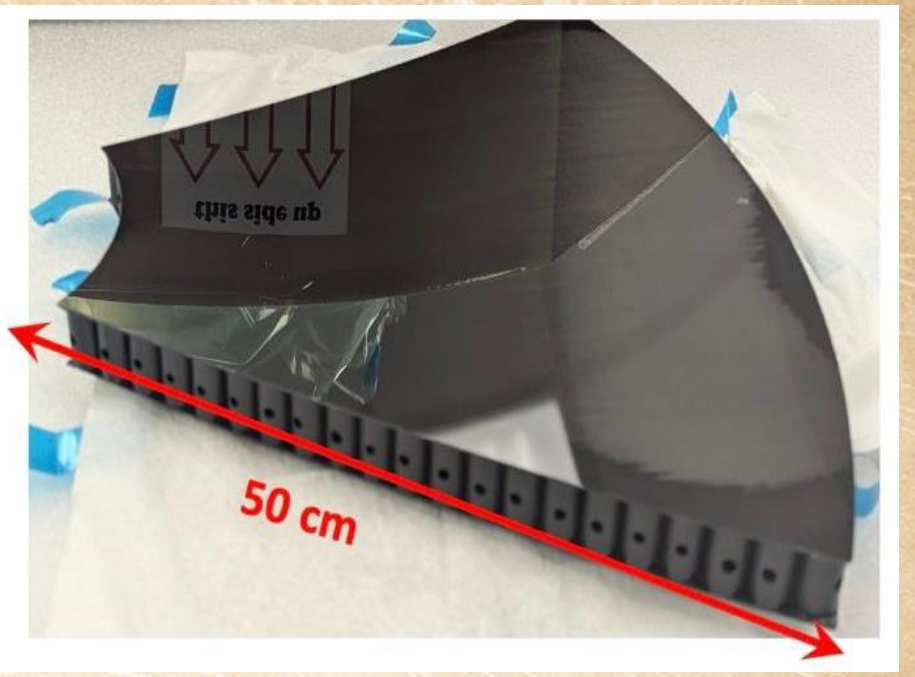
Mechanics design

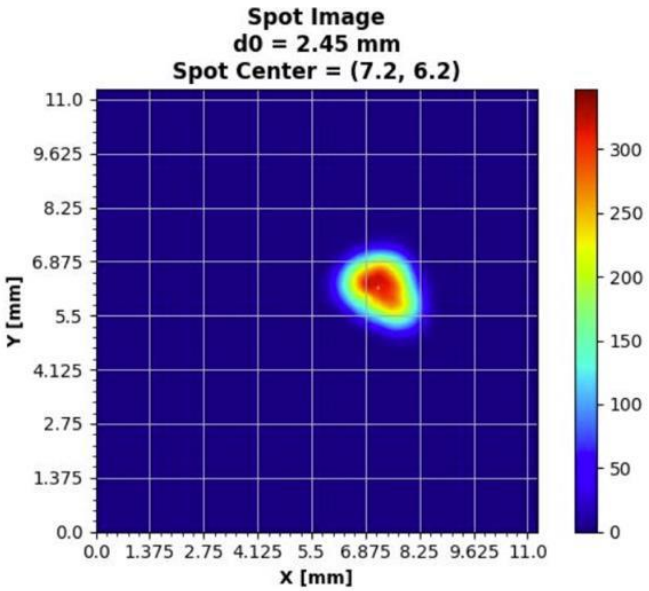
Mirrors

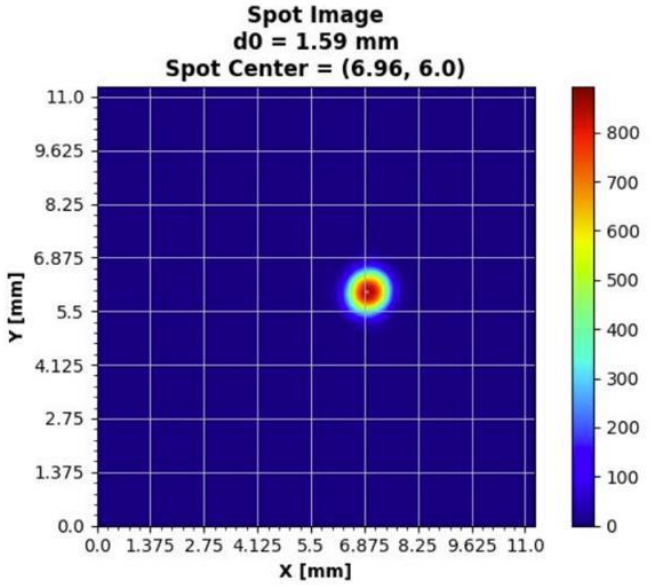
Mid-size CFRP-substrate demonstrator (~50 cm side) was validated with laboratory tests before coating;

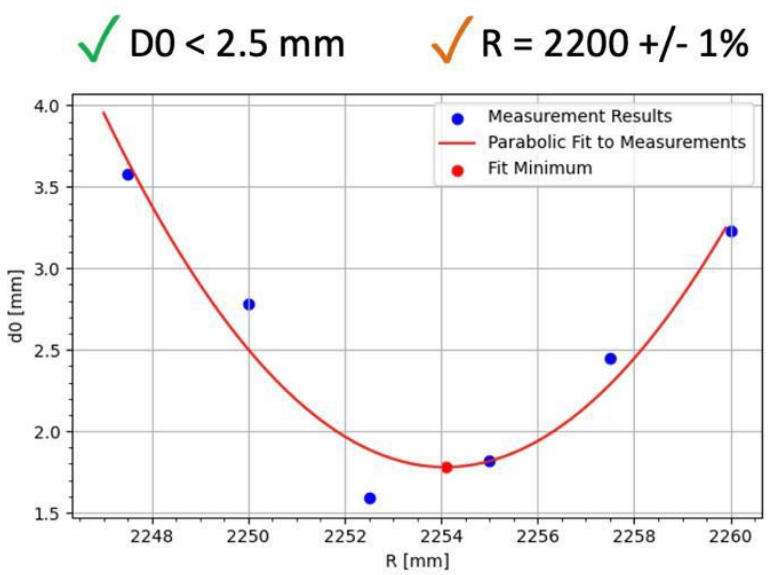
Mirror requirements for manufacturer include:

- radius within 1% of nominal RoC;
- roughness < 2 nm;
- point-like image spot size d0 < 2.5 mm;
- compatibility with fluorocarbon C_2F_6;
- compatibility with SiO_2 reflective coating.

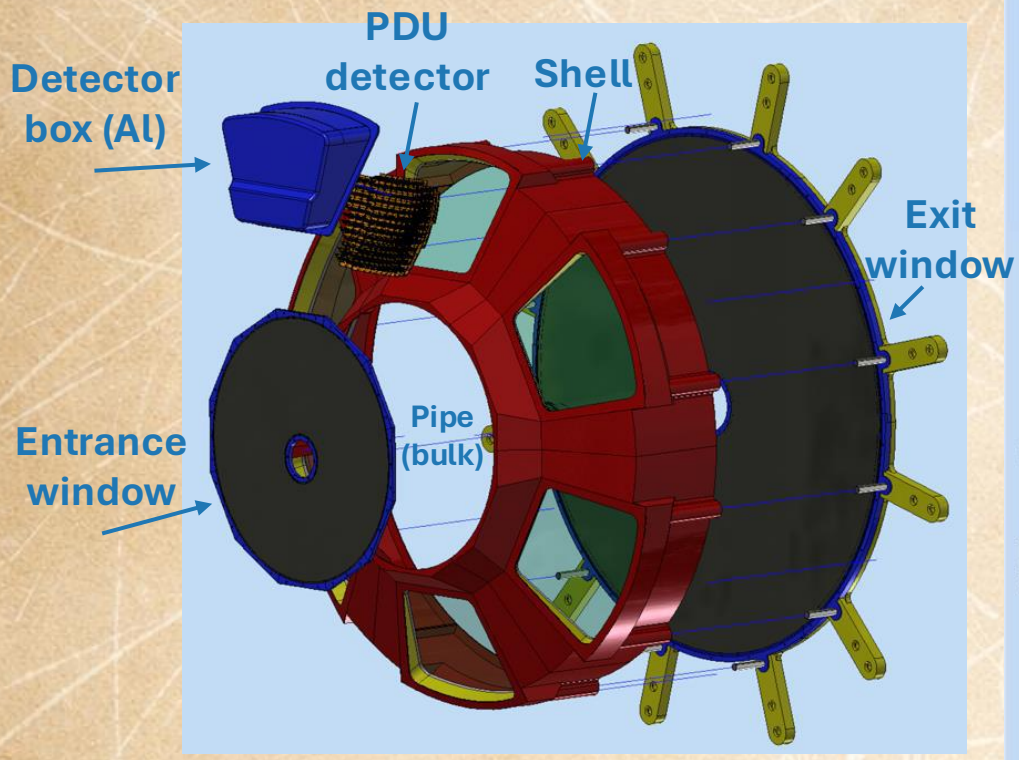


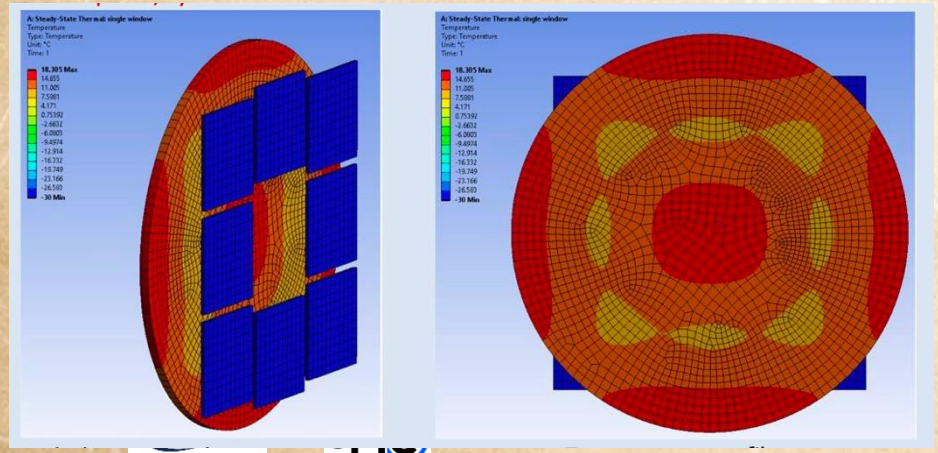


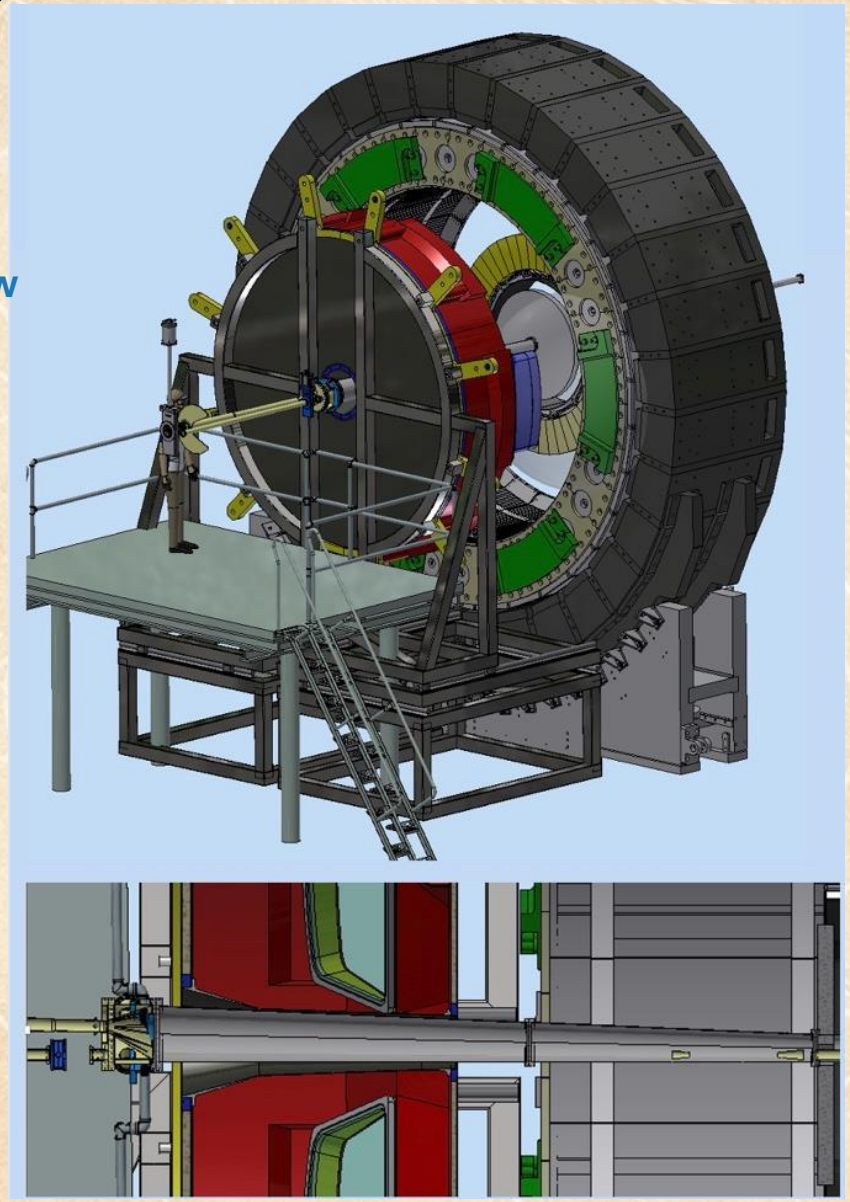




Mechanical design

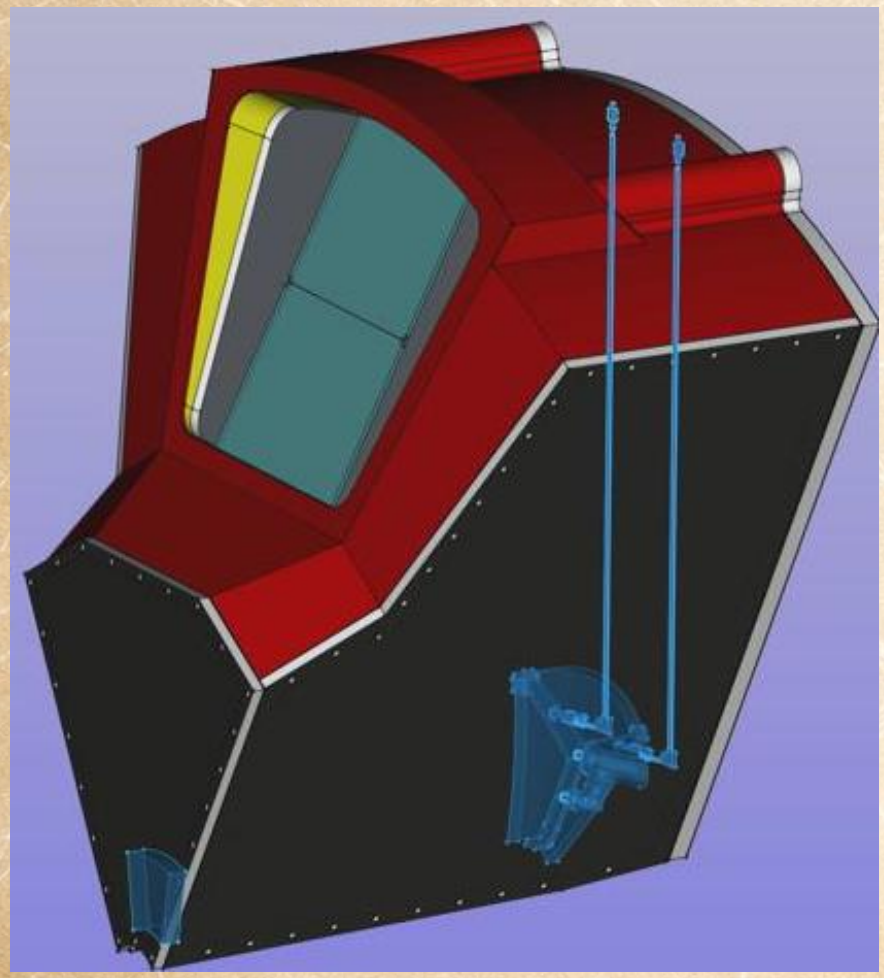






- The dRICH structure allows on-site maintenance without breaking the beam vacuum;
- Total weight: ~ 2 ton;
- Thermal simulation is ongoing to evaluate the impact of the thermal gradient between photosensors (-30 °C) and the gas volume.

Real-scale prototype



In May and June 2026, a real-scale prototype will be tested at CERN in two test-beam campaigns.

- Large-size aerogel demonstrator;
- Mechanical structure;
- Mirror mounting and holder;
- SiPM detector box;
- MAPMT detector box for reference measurements.

Readout system

Photo Detection Unit (PDU)

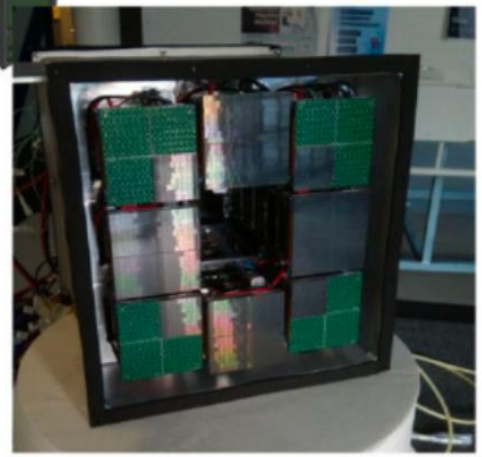
towards construction

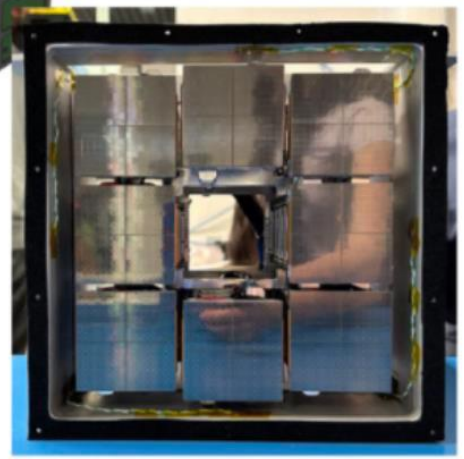
2022
electronics v1

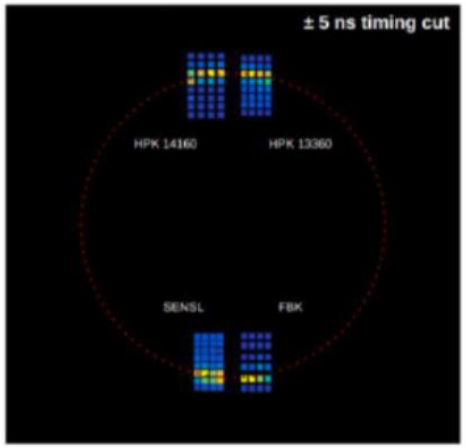
2023
electronics v2

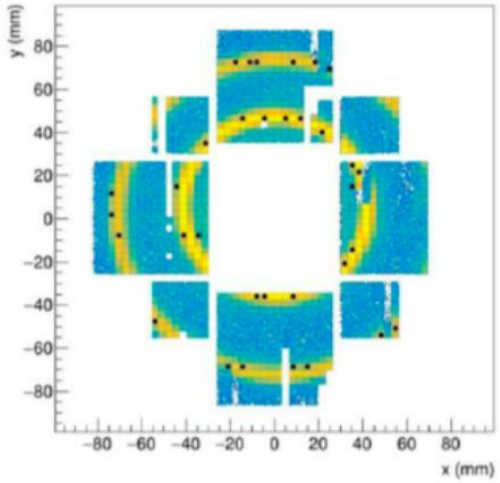
2024
electronics v2.1

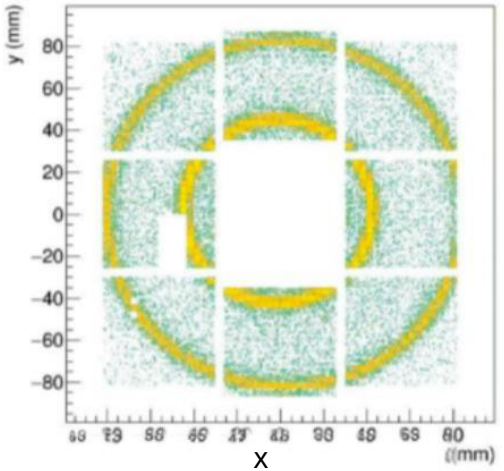
2025
electronics v3
final prototype









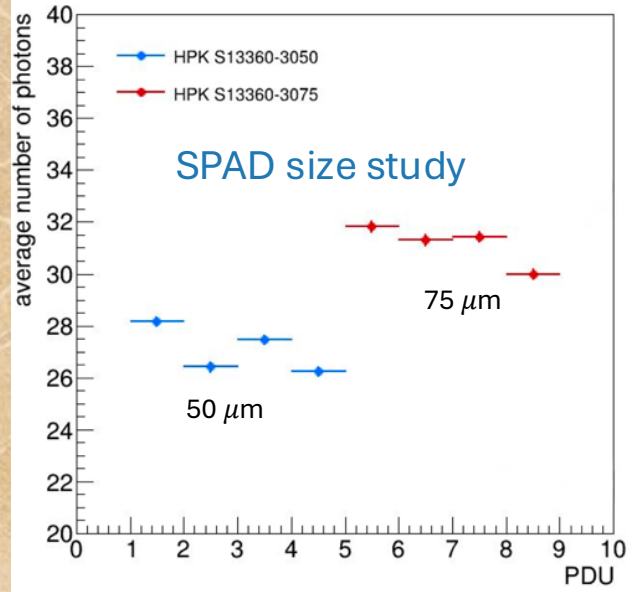


Courtesy of P. Antonioli, R. Preghenella, and the PDU development group

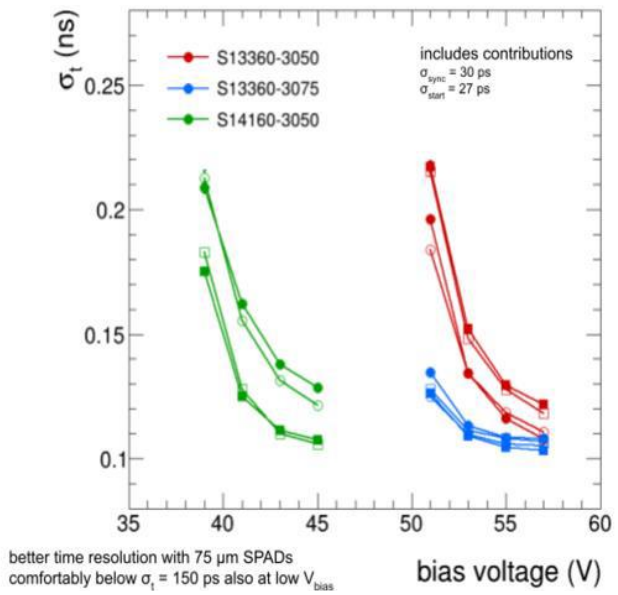
See S. Geminiani talk for more details

SiPM studies

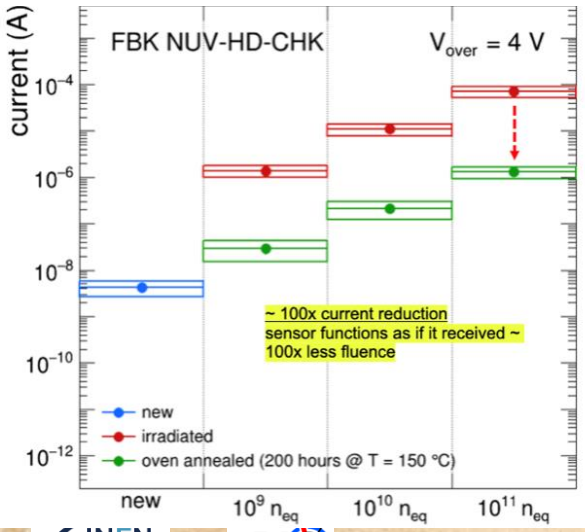
Photon yield



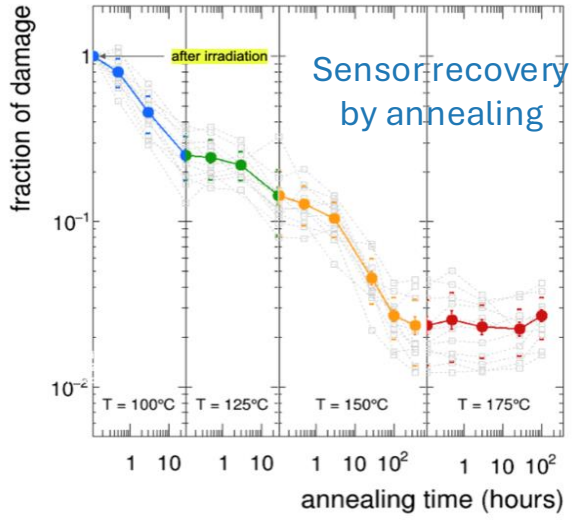
Time resolution with ALCOR readout

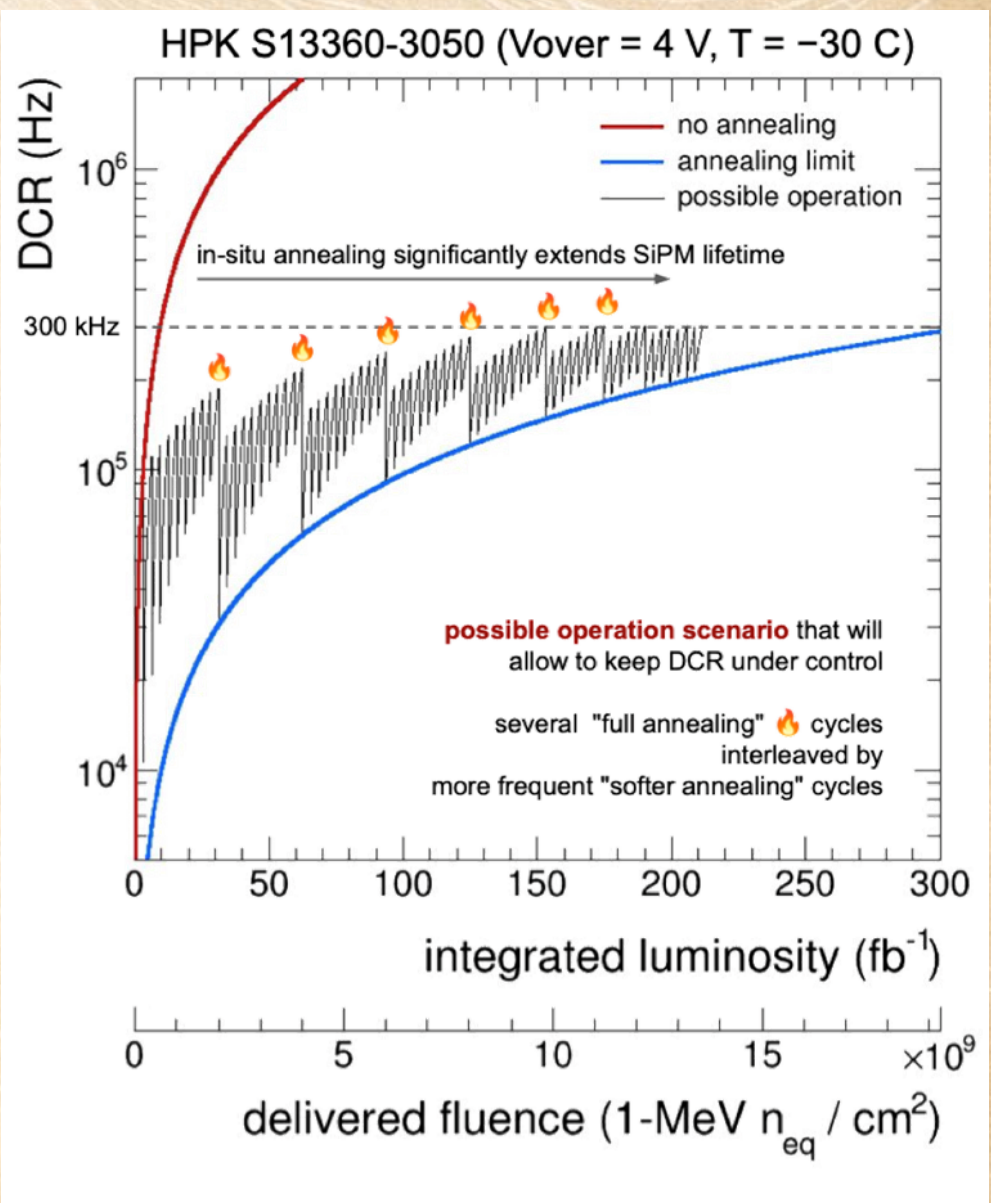


Dark current



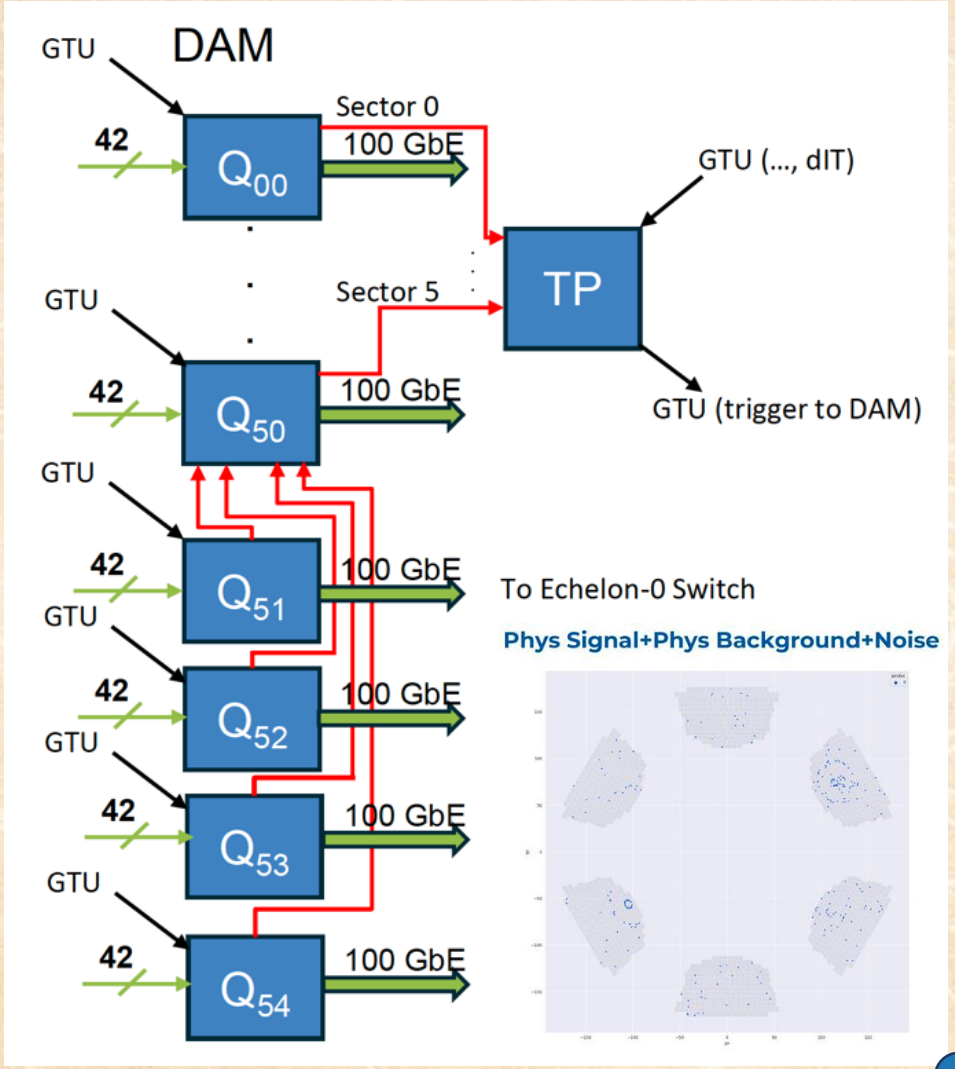
Dark count rate

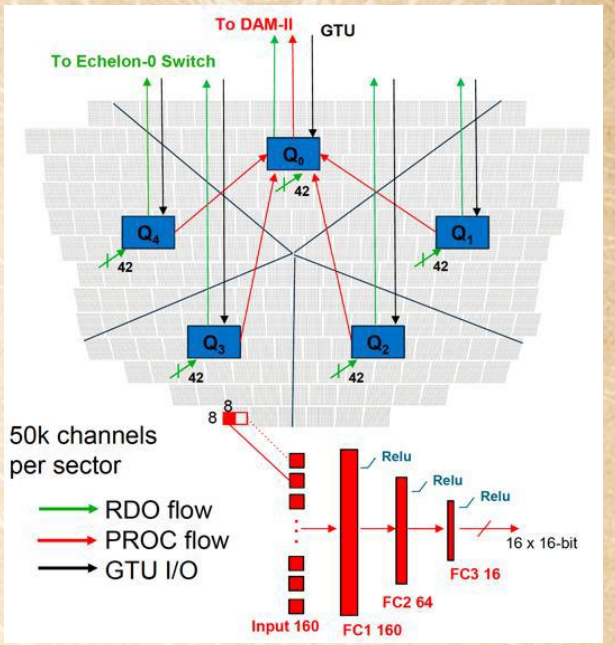


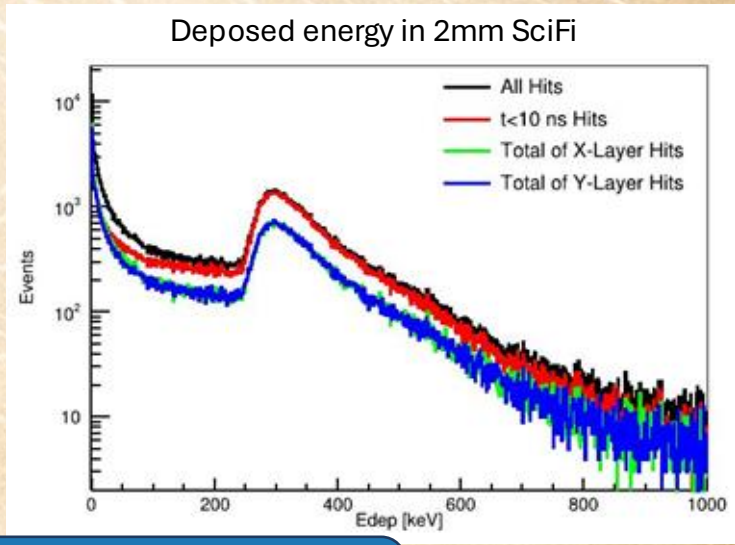


Online data reduction

- With annealing, the SiPM DCR is expected to be kept below 300 kHz/channel, corresponding to a full-detector throughout of ~1.3 Tbps;
- Online data reduction is required to fit within the available bandwidth;
- For DIS the expected interaction rate is ~1 MHz, while the EIC bunch crossing rate will be 100 MHz;
- An online, AI-based distributed data-reduction algorithm is being developed for FPGA implementation, based on hit-pattern recognition;
- A scintillating-fiber interaction tagger placed in front of the dRICH is under study.







100 keV threshold → 99.97% efficiency for tagging events with ≥1 particle in the dRICH

Conclusion and outlook

- The ePIC experiment at Electron-Ion Collider will investigate key aspect of non-perturbative QCD.
- The dRICH is a key detector for forward PID at ePIC.
- The dual-radiator concept provides a continuous hadron separation over a broad momentum range.
- Beam-test and laboratory studies are validating the main detector components: radiators, mechanics, photosensors, and DAQ.
- SiPM operation in a RICH requires DCR mitigation strategies and online data reduction techniques, both of which are actively addressed in the current design.
- The 2026 CERN test beams with the real-scale prototype will be a major step toward final design validation.

Thanks for your kind attention

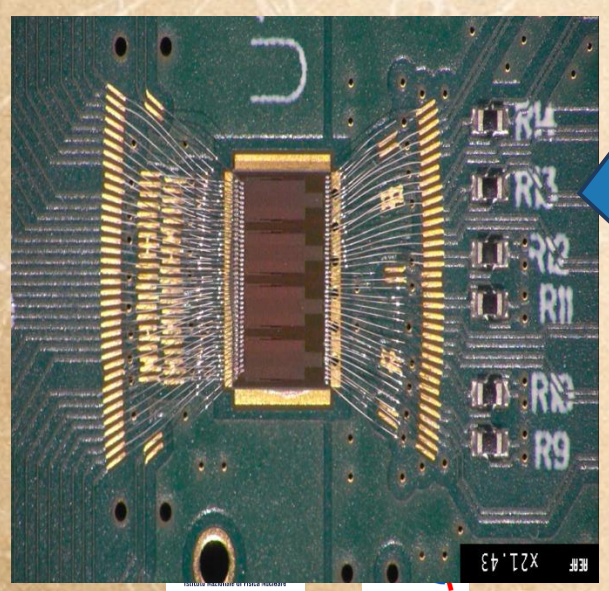
Backup

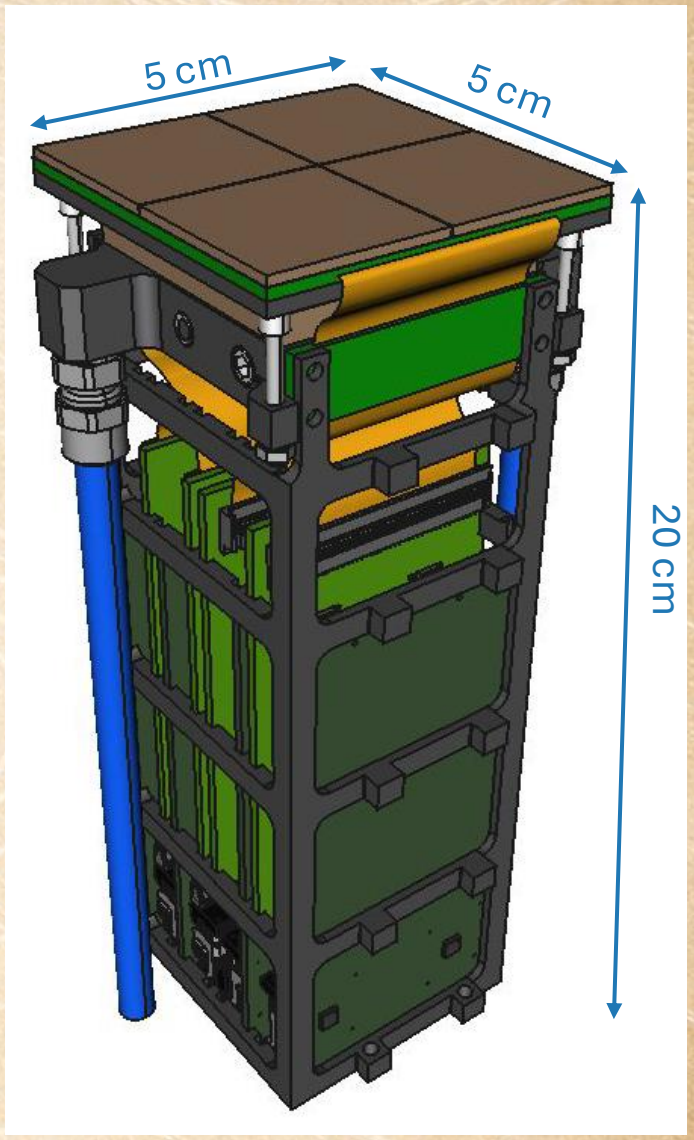
PDU details

The dRICH SiPMs will be divided in 6 sectors, each composed of 208 PDUs.

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

The cooling system consists 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, featuring:

- signal amplification, conditioning and event digitization;
- 2 leading-edge discriminators;
- 4 TDCs with analog interpolation;
- digital shutter for TDC digitization;
- continuous readout;
- Time-over-Threshold mode.