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UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

[INFN Workshop on Future Detectors]

INFN BARI
Istituto Nazionale di Fisica Nucleare
Sezione di Bari

ALICE

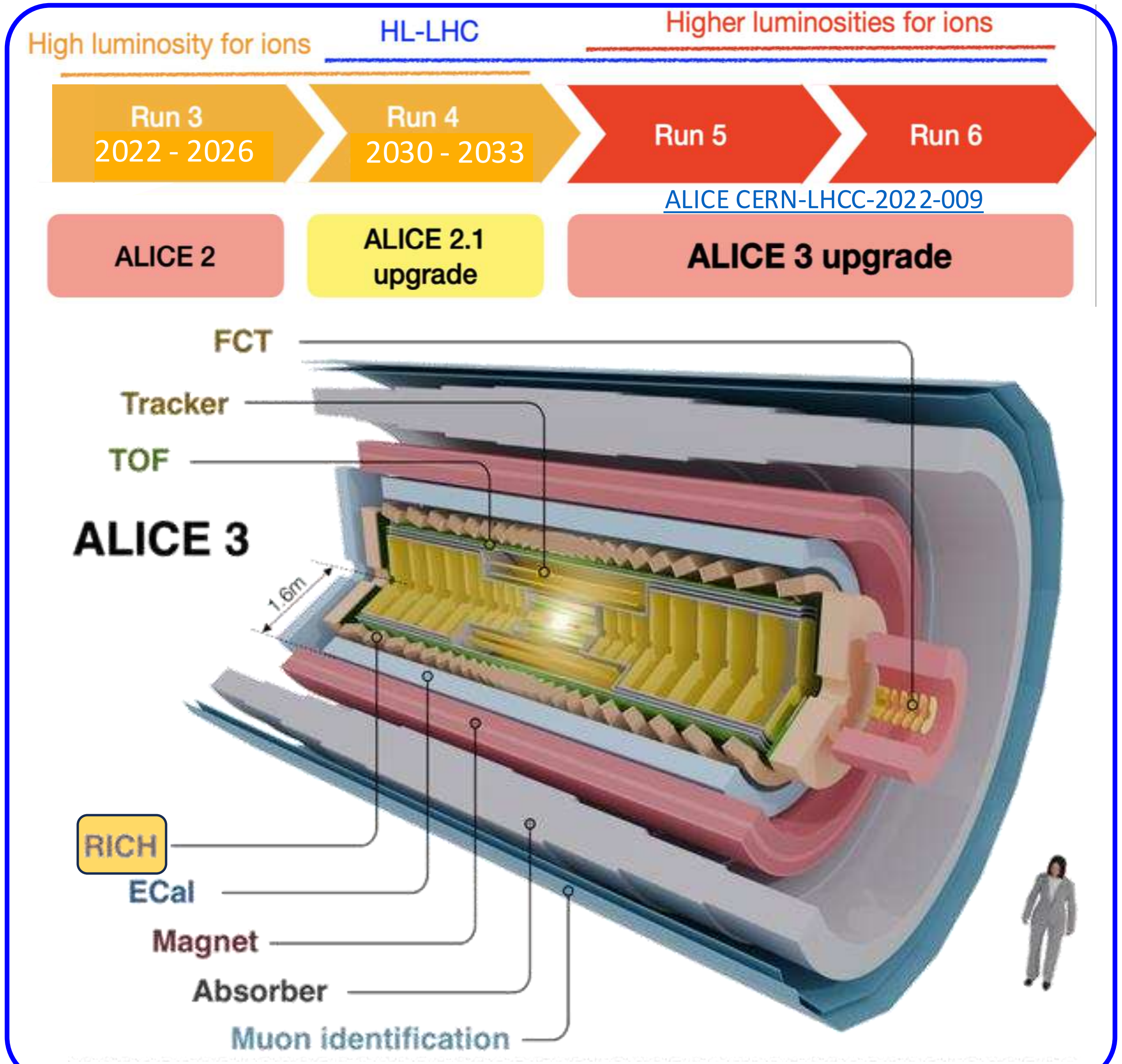
Development of a SiPM-based RICH detector for the future ALICE 3 experiment at LHC

Nicola Nicassio (CERN, University and INFN Bari)

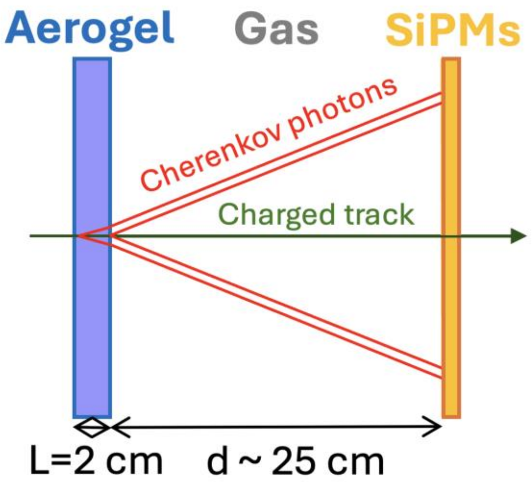
for the ALICE Collaboration

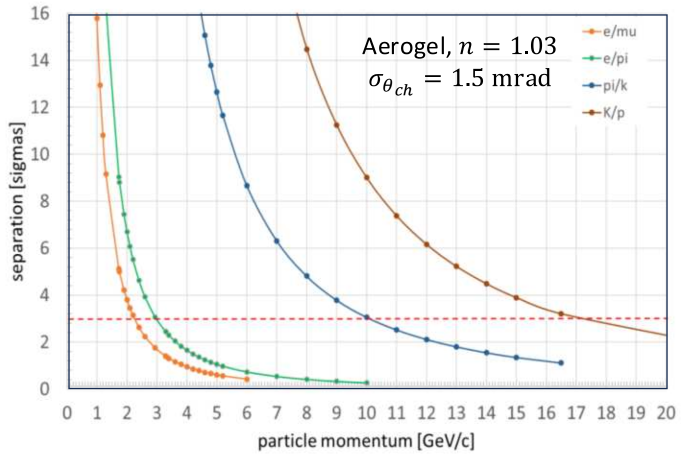
IFD 2025 – March 17-19, 2025

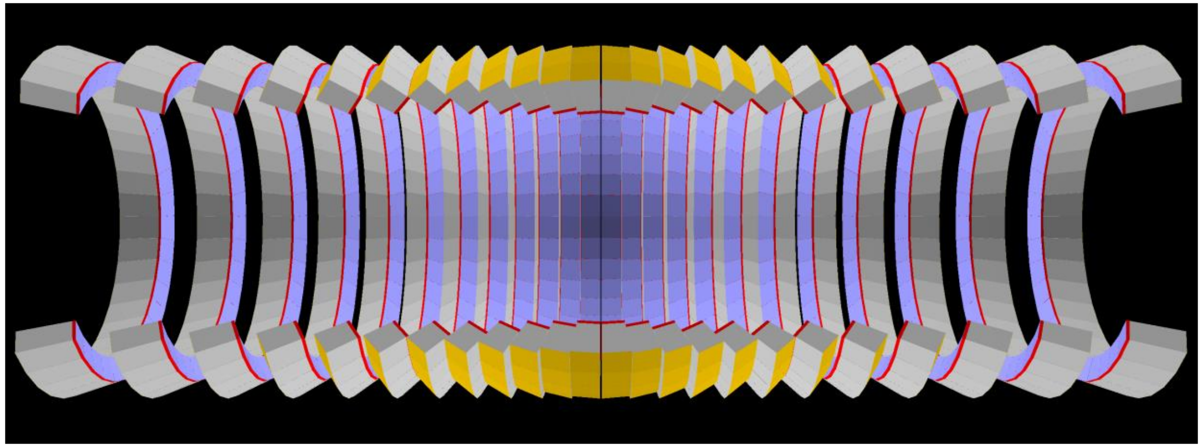
The ALICE 3 bRICH detector



bRICH: Proximity-focusing RICH based on aerogel+SiPMs in a projective geometry







2024 beam test set-up@PS-T10

Aerogel radiator: 2 cm thick tile with n=1.03, $\Lambda \approx$5.5 cm @ 400 nm

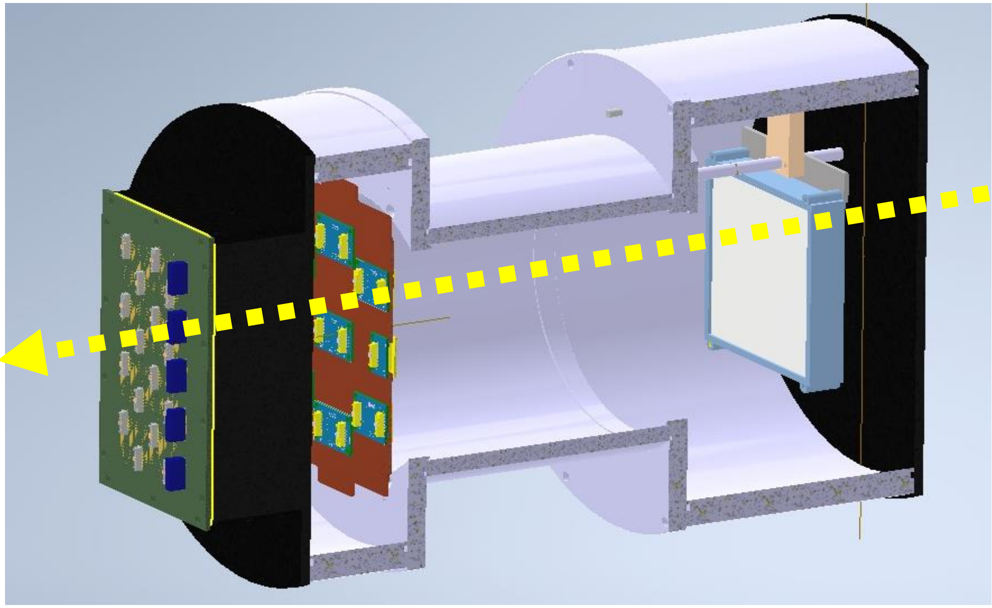
Central array: 1 HPK SiPM S13361-3050AE-08 (64 3x3 mm^2 SiPMs)

Ring arrays: 7 HPK SiPM S13361-2050AE-08 (64 2x2 mm^2 SiPMs)

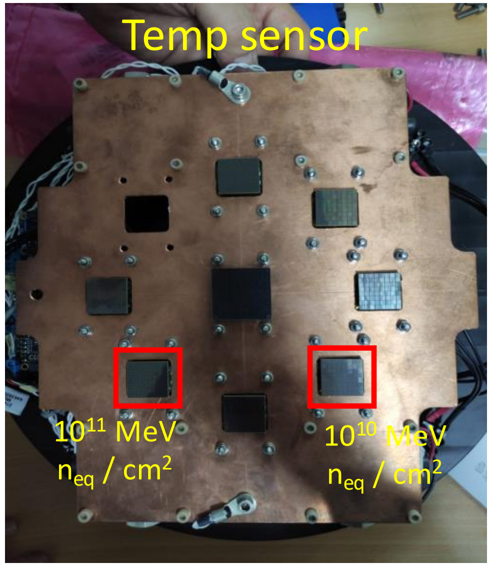
SiPM cooling: Down to -5 °C using water chiller + Peltier Cells

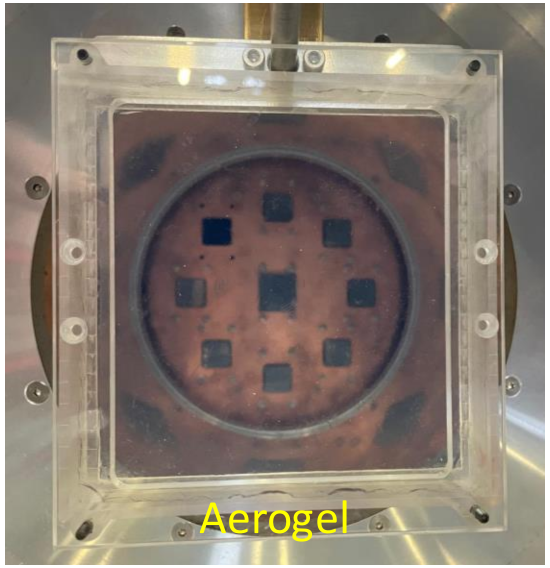
Proximity gap: 23.4 cm between aerogel and SiPMs flushed with Ar

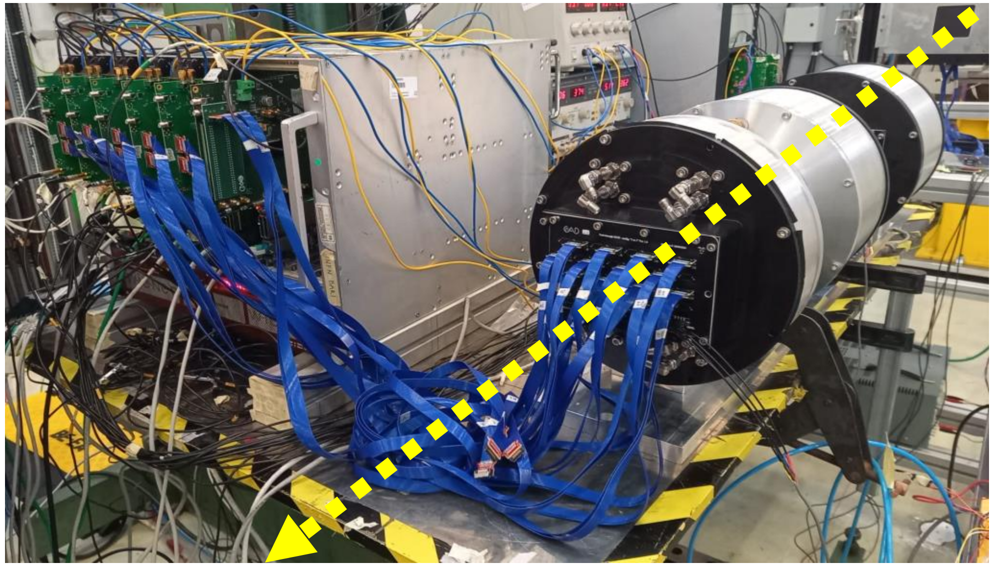
Front-end: Custom board based on Radioroc 2 FE ASIC and picoTDC



Additional vessel equipped with 2 extra HPK SiPM S13361-2050AE-08 for charged particle timing studies ⇒ See contribution by Bianca Sabiu

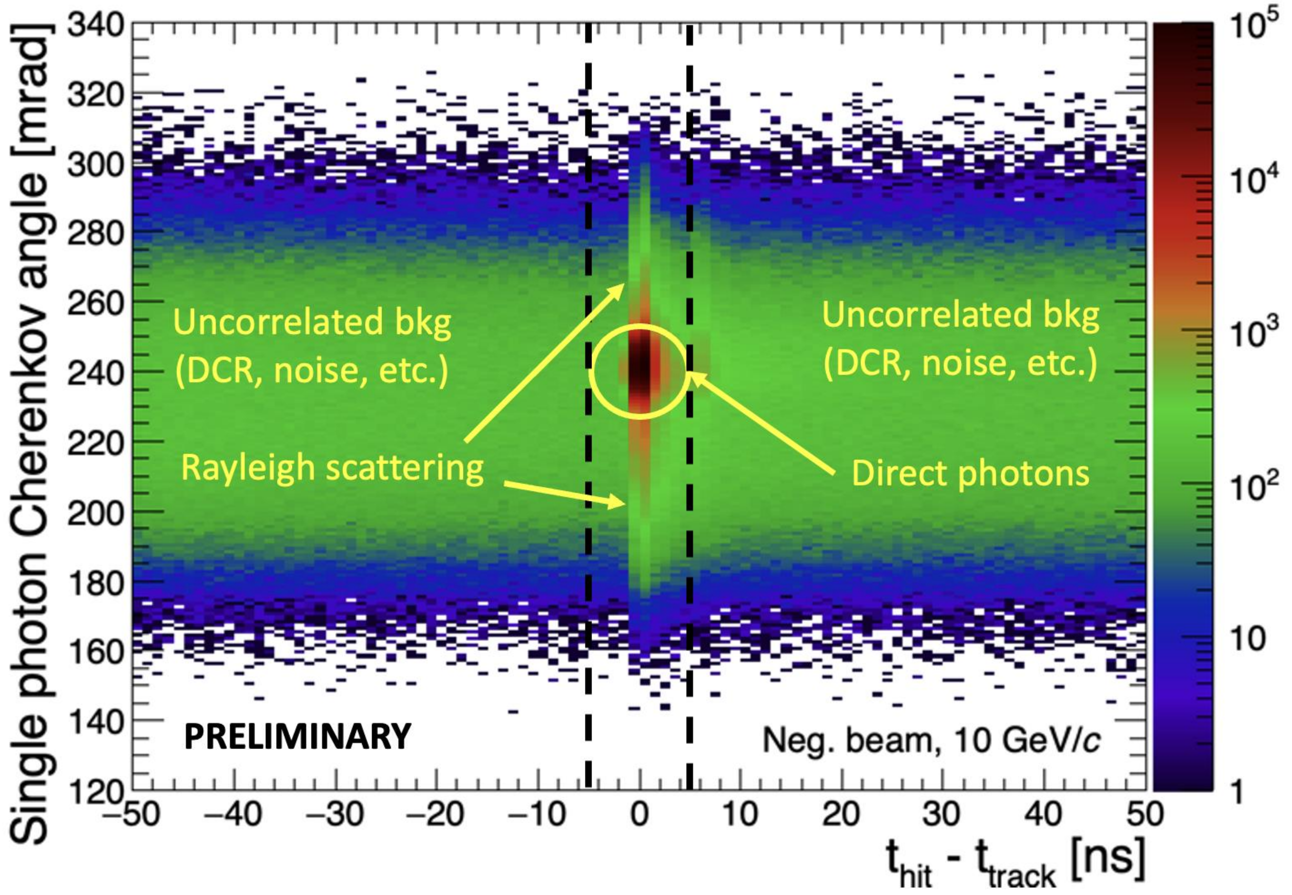


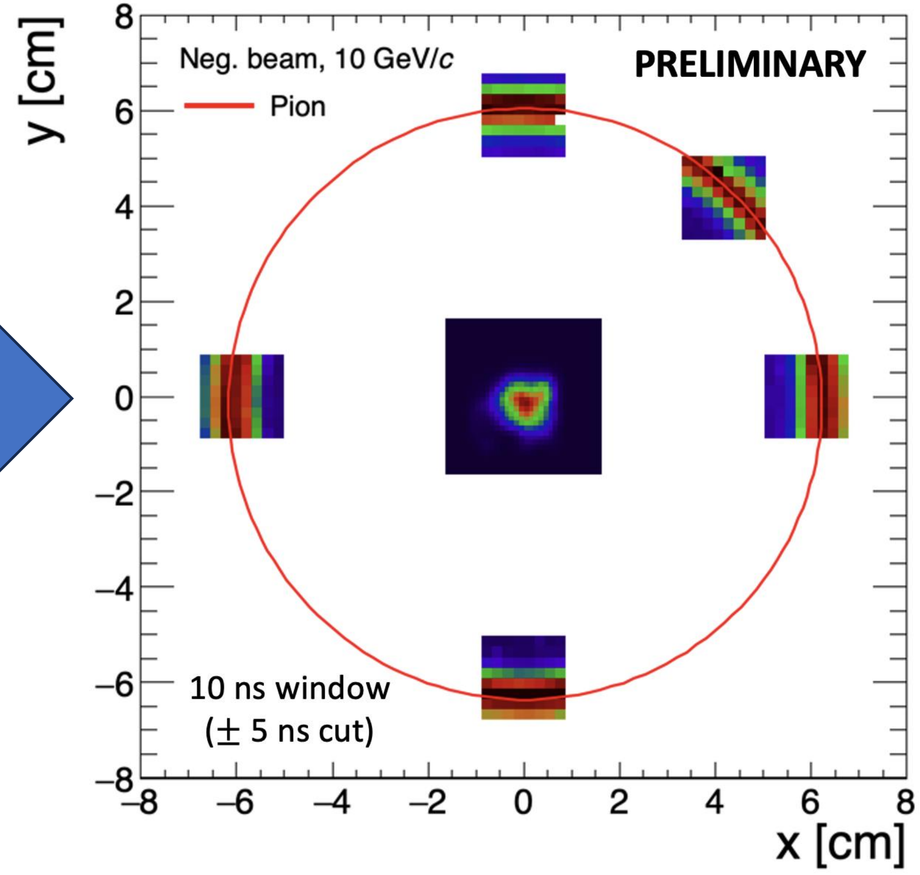




DCR bkg suppression using timing

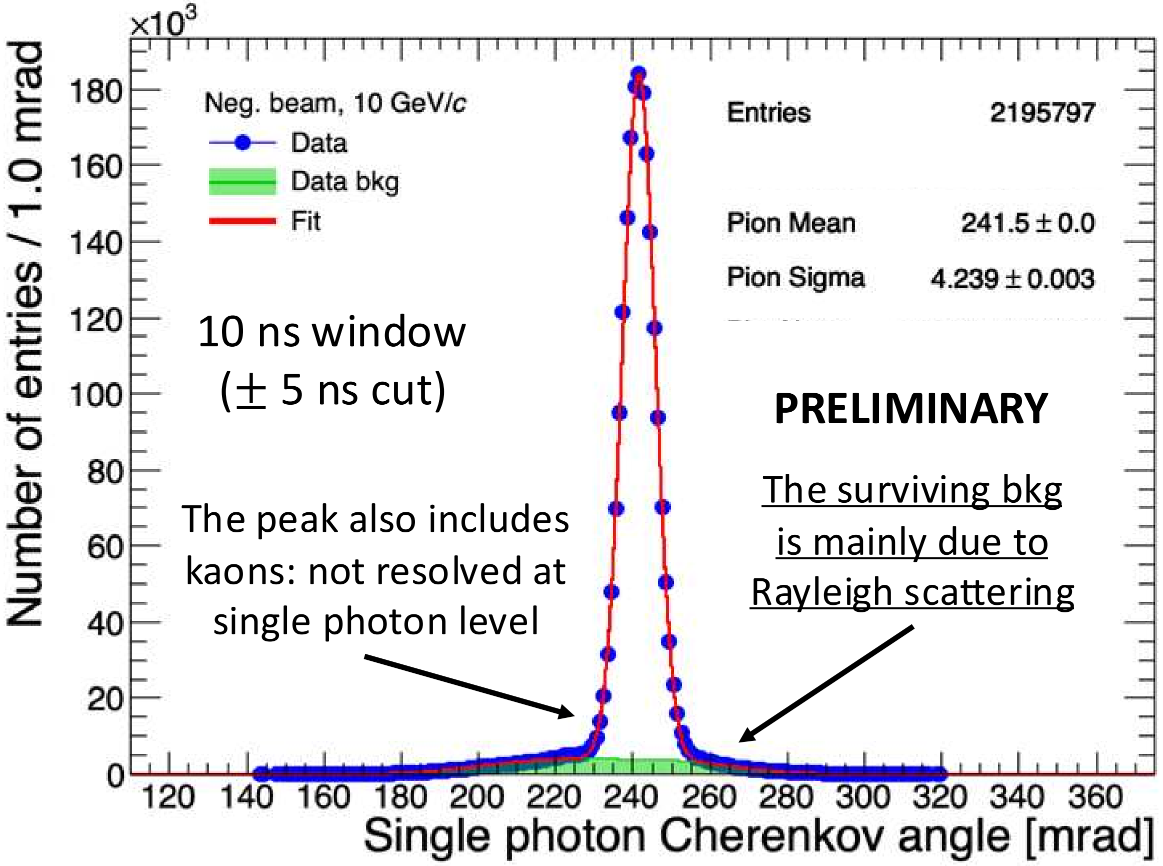
- Assuming all hits at candidate Cherenkov photon for ring reconstuction
- Signal hits fall in a few ns window wrt track on top of Rayleigh / DCR bkg
- Possibility to significantly suppress uncorrelated DCR bkg using timing

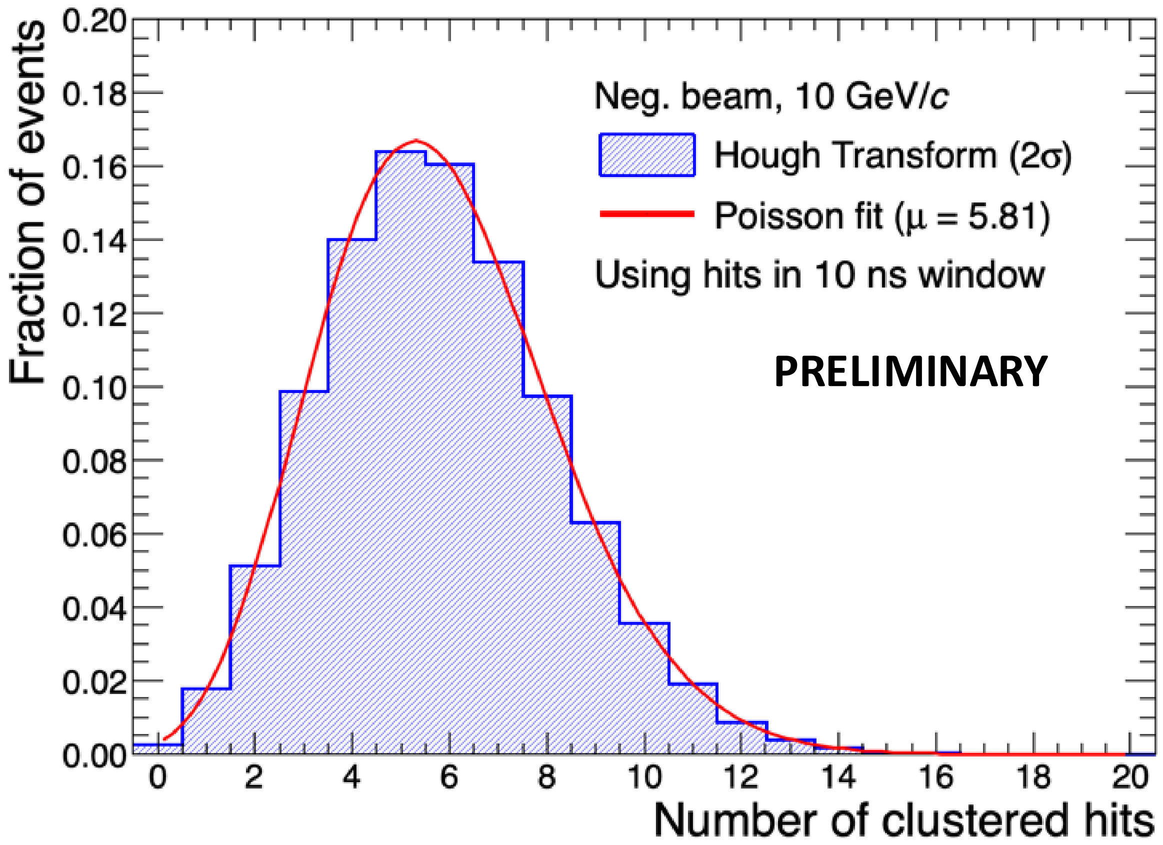




Cherenkov angle recostruction

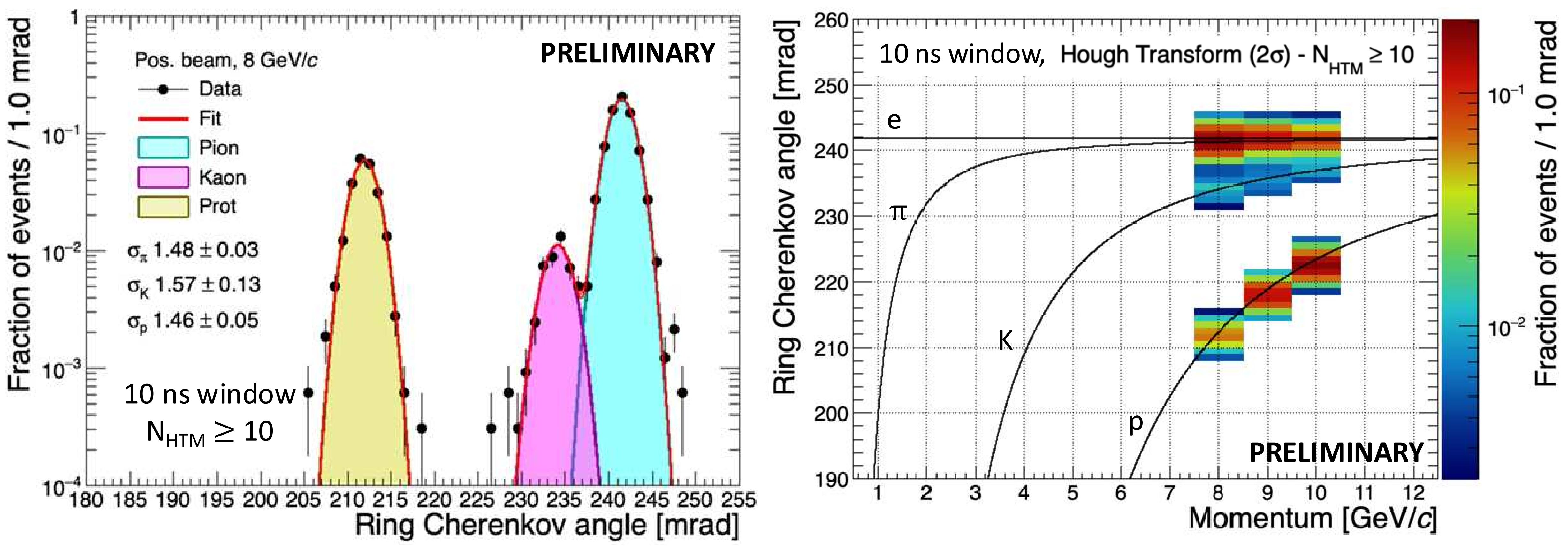
- **Single photon angular resolution at angle saturation of about 4.2 mrad**
- **Background level consistent with expectations @ operation T and V_{ov}**
- **Approximately 6 selected hits per track at saturation with 25% acceptance**





Separation power vs momentum

- Comparing results with positive beam @ 8,9,10 GeV/c with $N_{HTM} \geq 10$
- Reconstructed ring angles follow the expected scaling with momentum
- Separation of π, K and p beyond 3σ, with π/K limit at 10 GeV/c as required



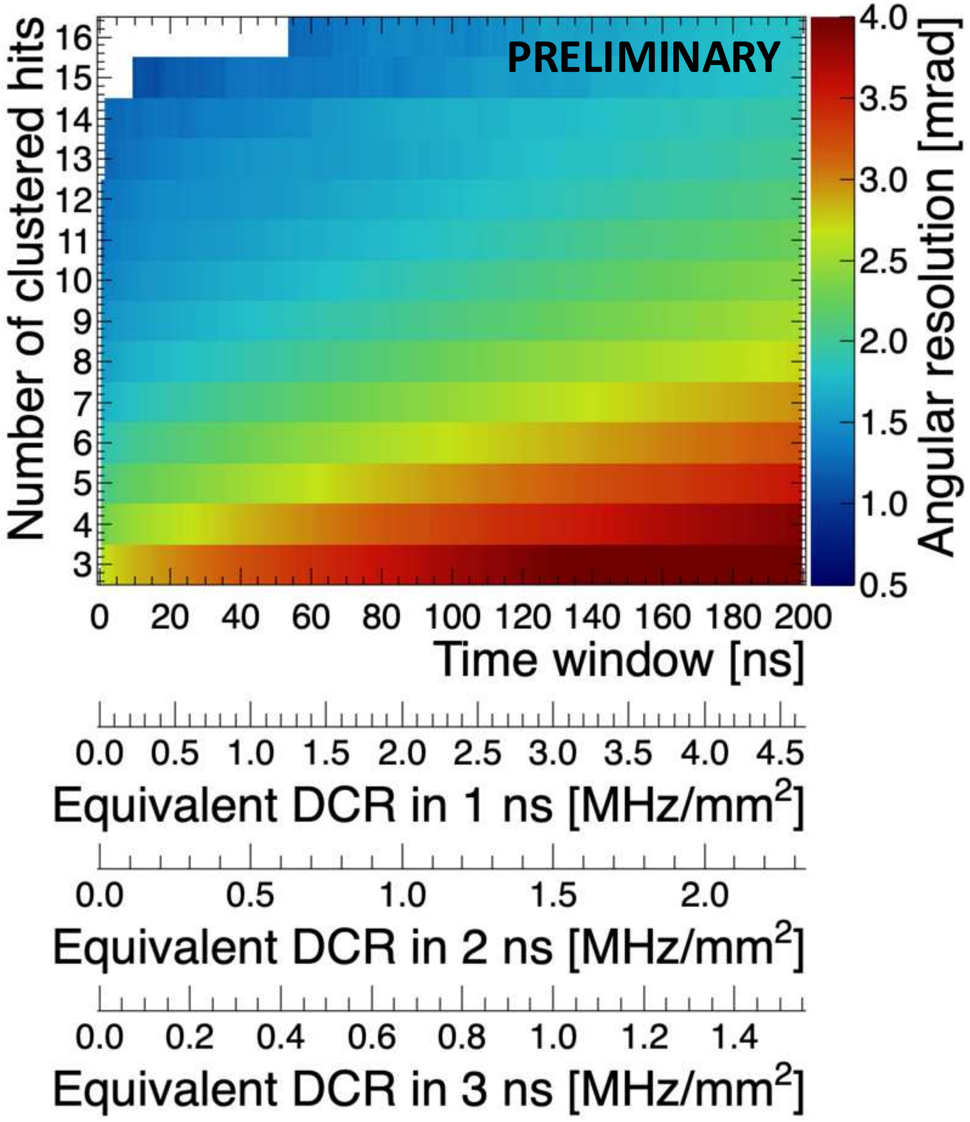
Stability with increasing background

Performance vs time window and DCR

- We studied the pattern recognition stability considering wider and wider windows with the nominal 23.3 kHz/mm^2
- We scaled the resulting mean number of background hits in terms of the **equivalent DCR bkg** we would have in the target **1-2-3 ns acquisition window** for the ALICE 3 RICH

Results

- $\approx$ **0.5 mrad worsening** up up to **1 - 4 MHz/mm^2 equivalent** depending on the considered acquisition time window
- **This study proves the stability of the reconstruction and physics performance up to the considered DCR levels**



Conclusions

Measured RICH performance

- Measured photon yield, single photon angular resolution and ring angular resolution consistent with ALICE 3 target
- Excellent signal efficiency signal-to-background ratio achieved in time matching windows shorter than 5 ns
- Performance scaling vs momentum in agreement with expectations (e.g. > 3σ π/K separation up to ≈ 10 GeV/c)
- Stable reconstruction performance beyond MHz/mm^2 DCR values considering proper DAQ / time matching windows

Thank you for your attention

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The ARC compact RICH detector concept: design, simulations and prototype development

Serena Pezzulo

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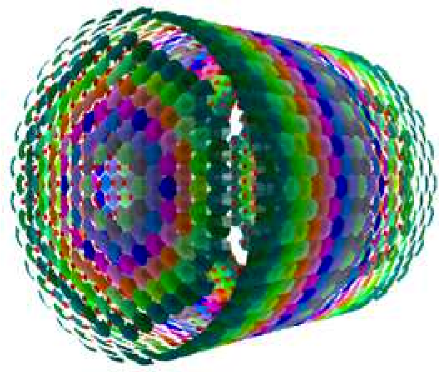
March 18, 2025

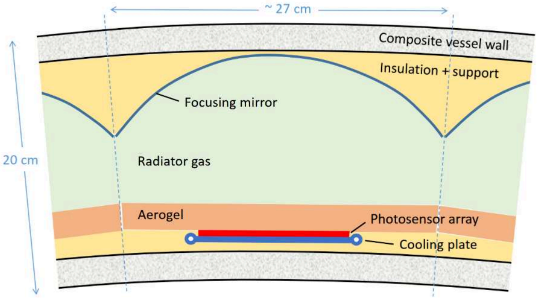
The ARC concept

ARC (**A**rray of **R**ich **C**ells) is a proposed RICH detector for the FCC (or another Higgs factory)

- First presented by R. Forty at FCC week 2021
- Lightweight and compact solution for PID
- Specifically adapted for the CLD experiment, occupying 10% of the tracker volume:
  - Dimensions: 20 cm radial depth, 2.1 m radius, 4.4 m length
  - Material budget targeted below $0.1X_0$
- Cellular in design, with each cell functioning as an independent RICH detector cell



ARC single cell geometry



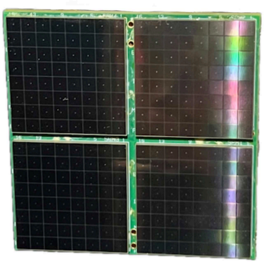
- Two radiators: $\mathbf{C_4F_{10}}$ (or a more eco-friendly alternative) + **Aerogel** (for low **p** tracks)
- Spherical focusing mirror
- Photosensor array: most suitable candidates are Silicon Photomultipliers (SiPMs) arrays with cooling plates
- Aerogel also as thermal insulator between SiPM array and gas radiator

Goal: Construct prototype of single cell in 3 years (fostered by DRD4 Collaboration)

Silicon Photomultipliers

SiPMs: compact, highly sensitive light detectors capable of detecting single photons

- SiPM array with 0.5 mm $\times$ 0.5 mm pixel
- PDE from FBK curve (at Overvoltage=10V) is considered



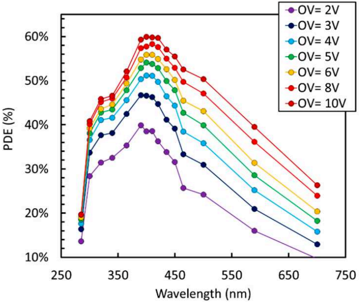
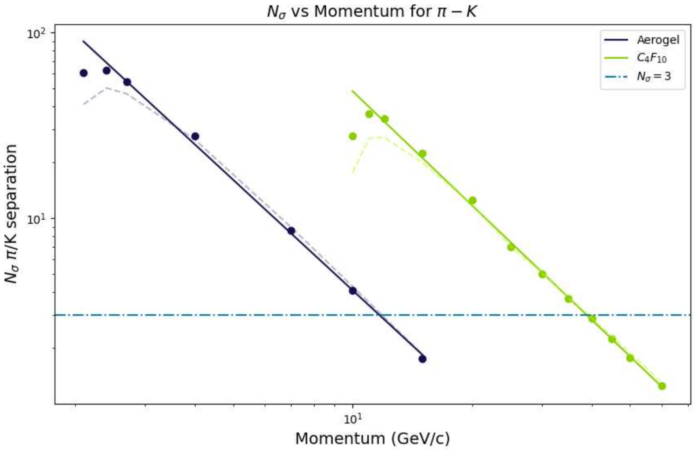


Figure: PDE vs Wavelength for FBK SiPMs
doi.org/10.3390/s19020308

π/K particle separation - C_4F_{10} + aerogel



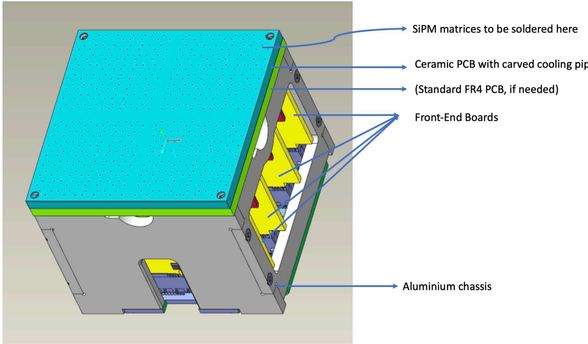
Separation above the threshold ($N_\sigma = 3$) up to 13 GeV/c for aerogel and 40 GeV for C_4F_{10}

Localized Cooling for SiPM Sensors

Active Cooling: A new housing board design integrates a ceramic PCB with fluid coolant circulation, in order to achieve sensor temperatures of -60°C to -80°C

Compact and High-Performance Design:

- SiPMs directly soldered onto metalized pads on the ceramic surface
- Hollow PCB structure enables coolant flow
- Optimized signal routing through PCB vias minimizes analog signal length, preserving integrity and timing performance



Synergies with **LHCb/RICH** upgrade II, **ALADDIN**, **DRD4** WP 3 and 4

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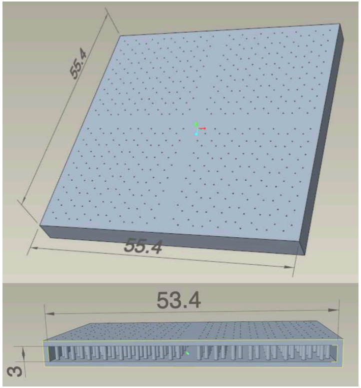
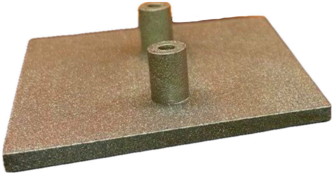


Synergies with **LHCb/RICH** upgrade II, **ALADDIN**, **DRD4** WP 3 and 4

Prototype development

We have multiple contacts for the ceramic cooling PCB, with prototypes expected in the coming months. Meanwhile, we are testing 3D-printed plastic and **metal prototypes**, using hot water to test the thermal properties of the cooling plate



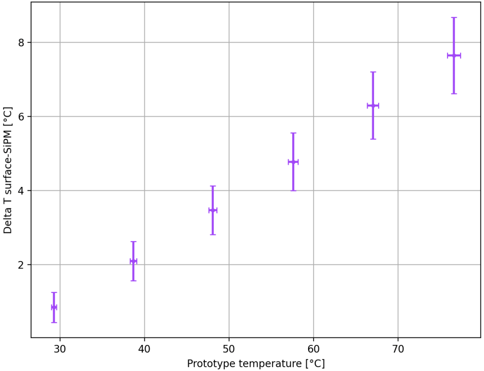


Figure: Temperature gap between the surface of the prototype and a glued SiPM.

Conclusions

- Particle separation power was studied for C_4F_{10} and aerogel, showing good performance in the 2-40 GeV/c range for $\pi - K$ separation
- Alternative **environmentally friendly** radiators have been explored [ECFA '24]
- **SiPMs** are promising photosensors due to their high sensitivity and compact design. A **new cooling prototype** is under development, with initial tests on 3D-printed plastic and metal models
- **Next Steps**:
    - Extend simulations to the entire ARC detector, include the **magnetic field**, develop a global **PID likelihood approach**
    - Evaluate prototype thermal behavior at low temperatures (-60°C to -80°C) using silicon oil
    - Plan to conduct a **test beam** in autumn for a photodetector module with integrated active cooling
- More details on the simulations in the **supporting note**: [10.17181/6g0gs-7kw30]

Thank you for the attention!

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March 18, 2025

The modular SiPM photodetector for the ePIC-dRICH detector at the EIC

B Rajesh Achari (University and INFN Bologna)
On behalf of ePIC-dRICH collaboration

IFD 2025
Mar 18, 2025

Overview of ePIC-dRICH detector of the EIC

World's first collider for polarised electrons with protons and ions.

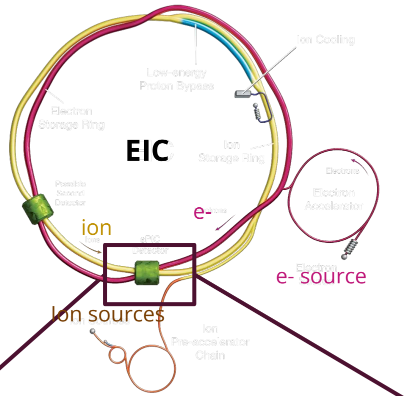
Major US Project in nuclear physics and going to be one of the important future facilities in the world, going to be constructed in **Brookhaven National Laboratory (USA)**.

will allow to explore the secrets of QCD

- Origin of mass & **spin** of the nucleons
- **3D images** of the nuclear structure

The collider is expected to start at the early 2030s.

One experiment foreseen till now **ePIC**

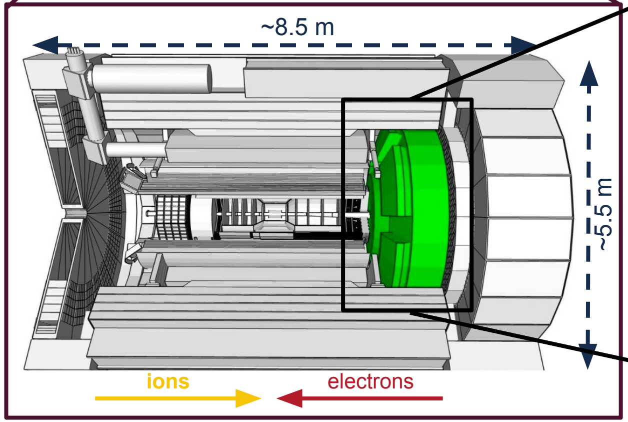


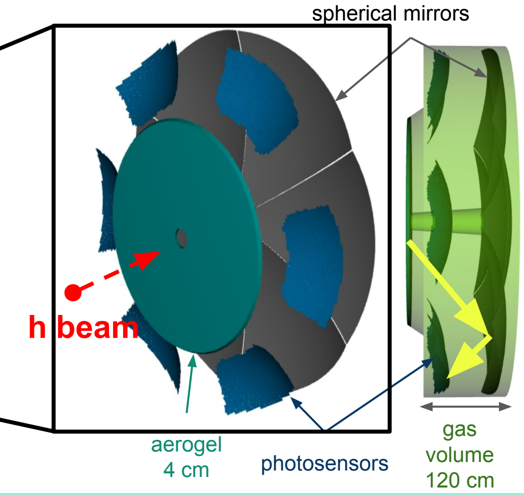
- **Radiators: aerogel (n ~ 1.02)** and **C_2F_6 (n ~ 1.0008)**
- **Mirrors:** large outward-reflecting, 6 open sectors
- **Sensors: 3x3 mm² pixels of SiPM, ~ 3 m² of photodetectors**
- Pros:
  - Single photon sensitivity
  - Good timing performance
  - Resistive to high B field (~ 1 T)
  - Compact and cost effective
- Cons:
  - High dark count rate at room temperature
  - Not radiation tolerant

A **dual-radiator (dRICH)** is in-charge for the forward **P**article **Id**entification **(PID)**.

It is a compact and cost-effective solution for a broad momentum coverage range **(3-50 GeV/c)**.

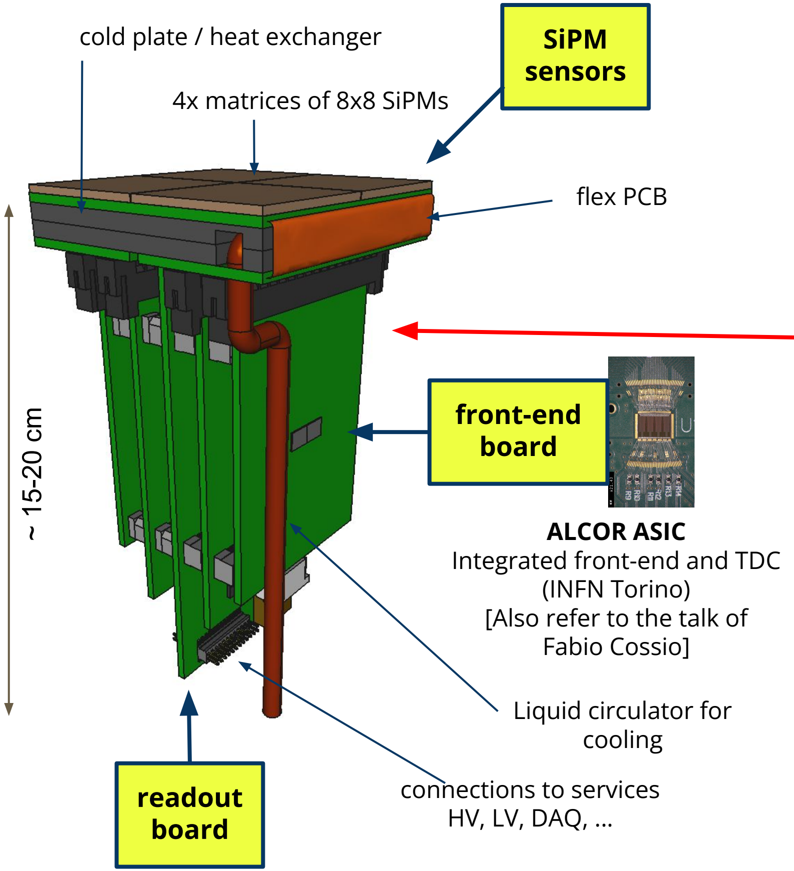
p ~ 3-50 GeV/c
η ~ 1.5-3.5 GeV/c
e ~ up to 15 GeV/c





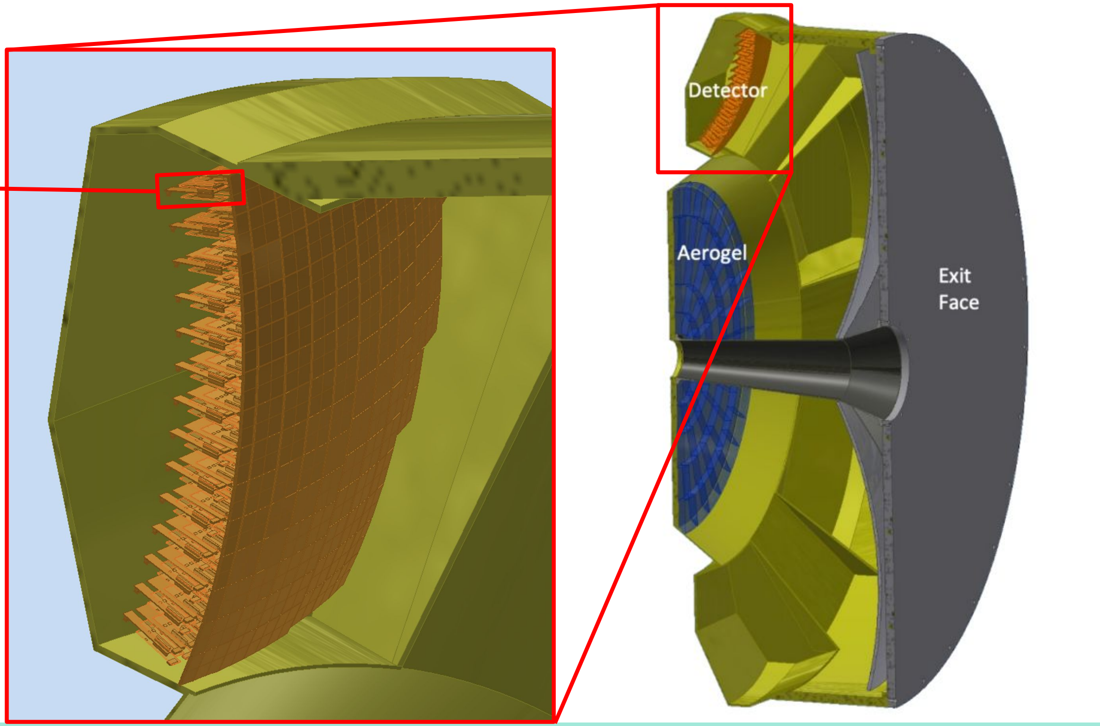
Detector integration and Electronics

Conceptual photodetector unit



SiPM sensor matrices mounted on carrier PCB board

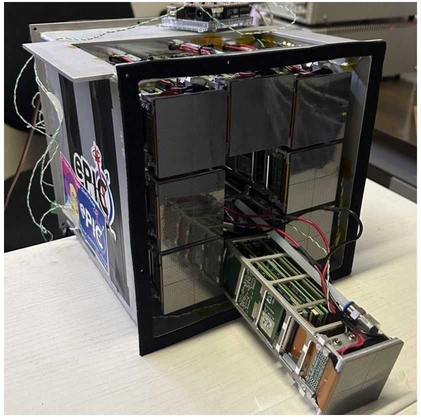
- 4x 64-channel SiPM array device (256 channels) for each unit
  - need **modularity to realise curved readout surface**
- 1248 photodetector units for full dRICH readout
  - 4992 SiPM matrix arrays (8x8)
  - 319488 readout channels



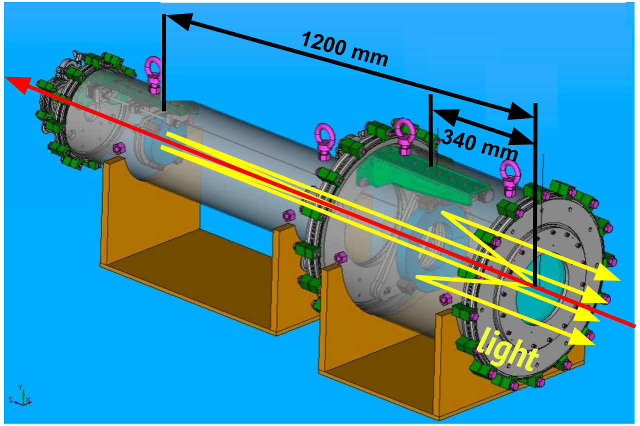
dRICH Prototype 2k24 and experimental set up at CERN-PS

Full PDU

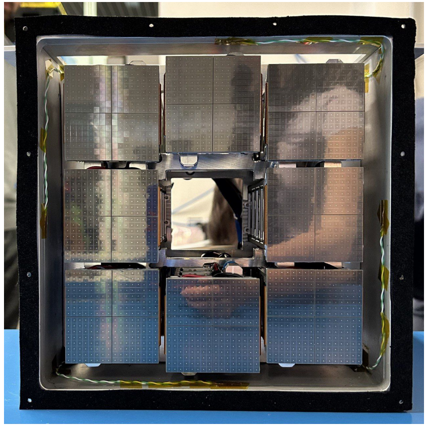
Prototype readout box



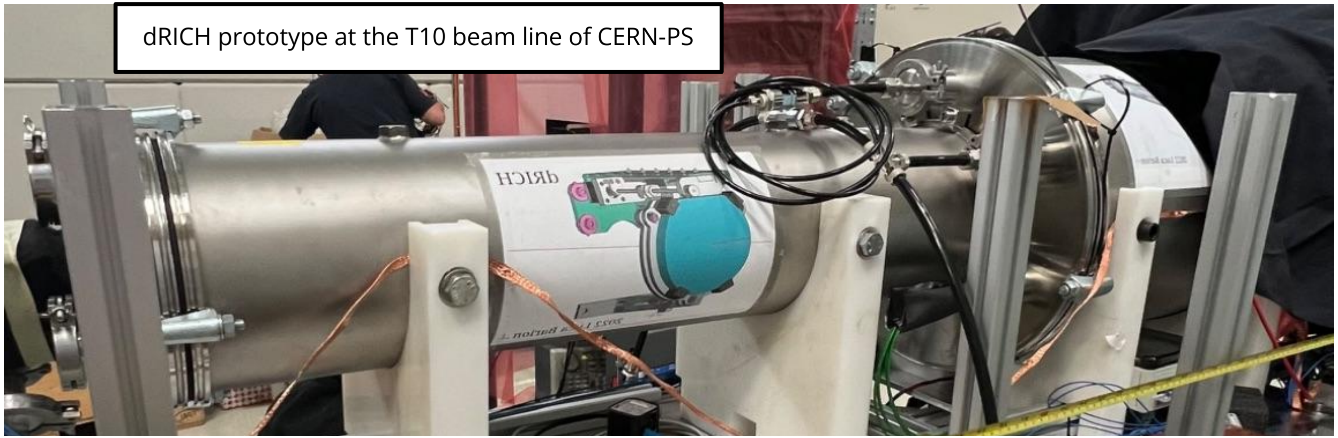
Schematic of the dRICH prototype



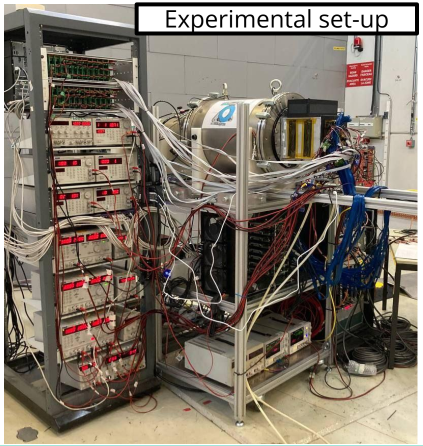
Fully equipped over 2k SiPM photo sensors



dRICH prototype at the T10 beam line of CERN-PS



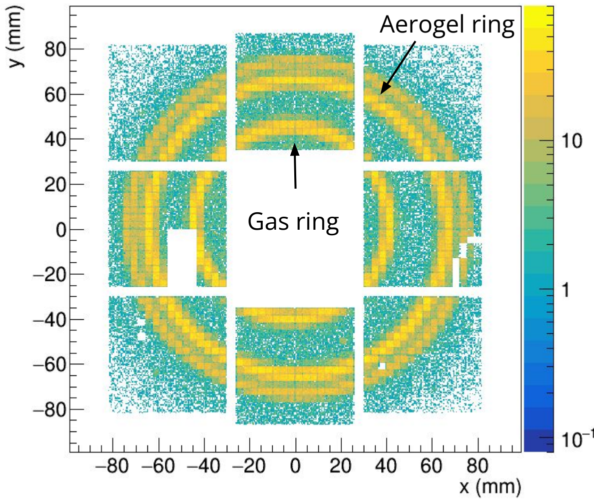
Experimental set-up



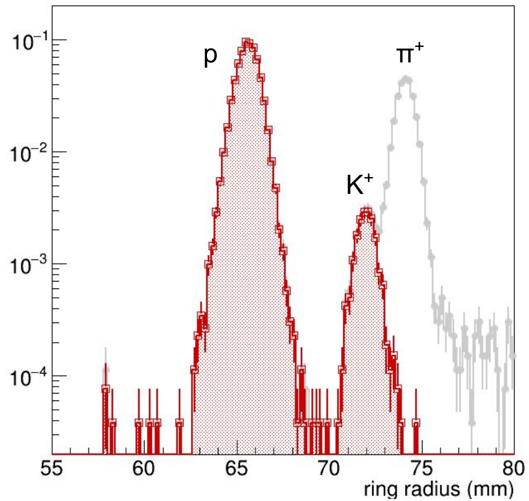
Beam Test Results

- Clear Cherenkov rings were detected by the modular SiPM-based optical readout plane with more than 2000 channels. Unfortunately one ASIC chip (32 channels) has some front-end issue where photons were not detected.
- Reconstructed ring radii shows clear identification of protons, kaons and pions at 10 GeV/c momentum.
- A positive beam momentum from 2 to 11 Gev/c in 1 GeV/c momentum steps allowed us to identify the Cherenkov rings produced from proton, kaons, pions and positron.

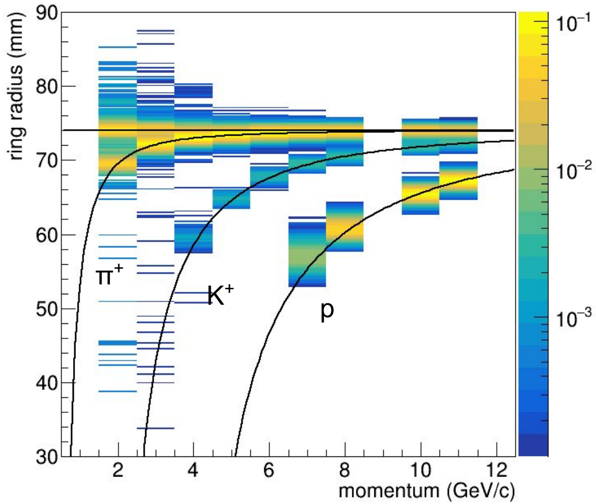
Cherenkov rings from 10 GeV/c positive beam



reconstructed radii at 10 GeV/c with gas veto applied



reconstructed radii vs. beam momentum



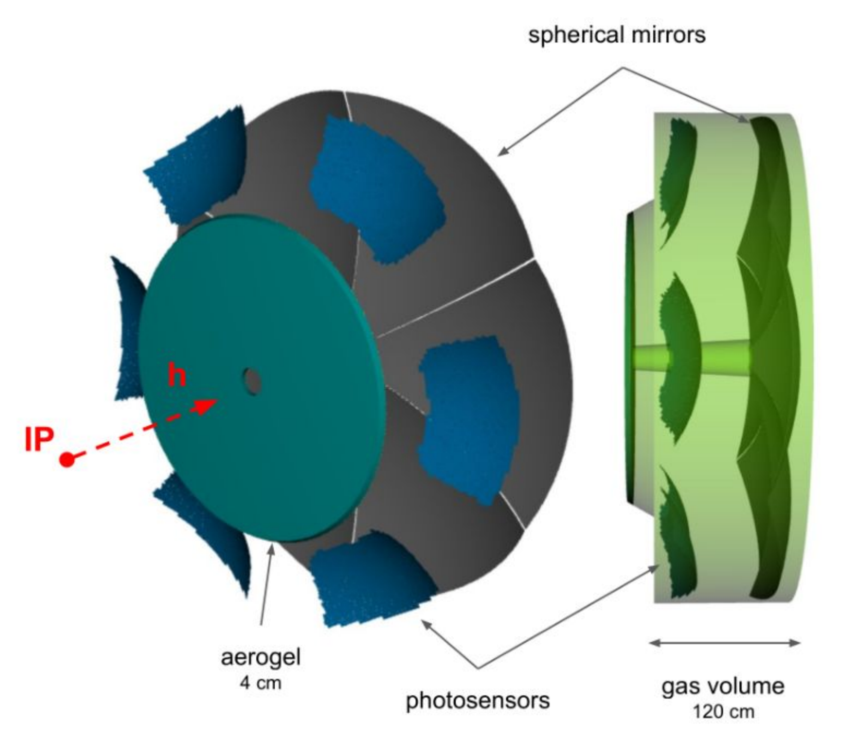
Conclusion: The beam test validated the performance of the Photo Detection Unit. Successful beam test with **working over 2k SiPM photosensors**. The dRICH detector meets the performance requirements for the ePIC experiment at the EIC.

Thank you!

The Interaction Tagger for the ePIC dRICH

Simone Vallarino
INFN Genova
on the behalf of the
ePIC dRICH WG
March 18, 2025

The ePIC dual Radiator Ring Imaging Cherenkov

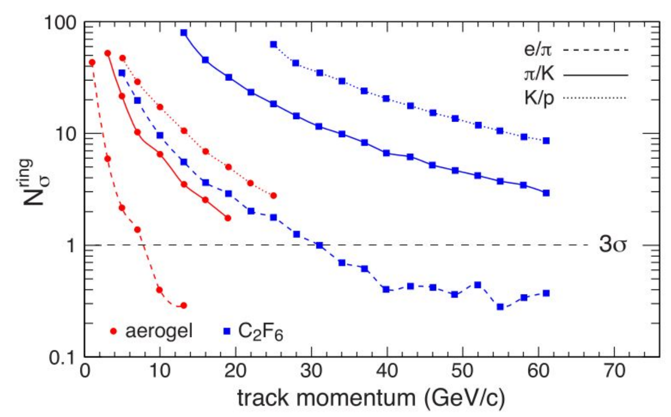


The identification of charged particles with momenta larger than 3 GeV/c in the hadronic endcap will face two major challenges:

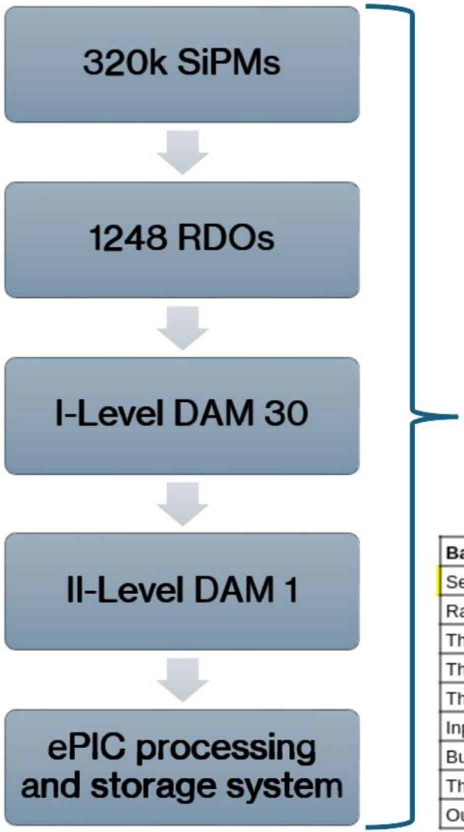
- to cover a wide momentum range (up to 50 GeV/c);
- to operate in a high (~1T) magnetic field.

The two radiators, aerogel (n≈1.020) 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 magnetic-insensitive photosensor.



The dRICH data throughput issue



dRICH DAQ parameters	
RDO boards	1248
ALCOR64 x RDO	4
dRICH channels (total)	319488
Number of DAM L1	27
Input link in DAM L1	47
Output links in DAM L1	1
Number of DAM L2	1
Input link to DAM L2	27
Link bandwidth [Gb/s] (assumes VTRX+)	10
Interaction tagger reduction factor	1
Interaction tagger latency [s]	2,00E-03
EIC parameters	
EIC Clock [MHz]	98,522
Orbit efficiency (takes into account gap)	0,92

Bandwidth analysis		Limit
Sensor rate per channel [kHz]	300,00	4.000,00
Rate post-shutter [kHz]	55,20	800,00
Throughput to serializer [Mb/s]	34,50	788,16
Throughput from ALCOR64 [Mb/s]	276,00	
Throughput from RDO [Gb/s]	1,08	10,00
Input at each DAM I [Gbps]	50,67	470,00
Buffering capacity at DAM I [MB]	12,97	
Throughput from DAM I to DAM II [Gbps]	50,67	10,00
Output to each DAM II [Gbps]	1.368,14	270,00

Sensors Dark Count Rate: 3 - 300 kHz (increasing with radiation damage → with experiment lifetime).

Detector throughput: 14 - 1400 Gbps.

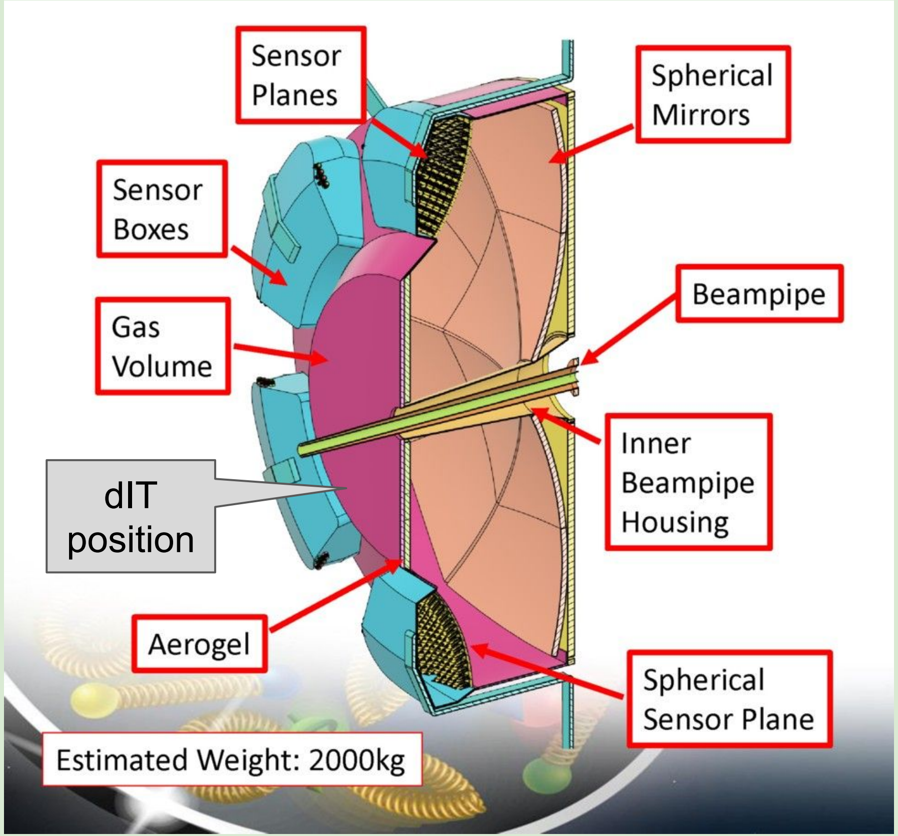
EIC bunch crossing: bunch crossing rate of 100 MHz.

Physicsl relevant interaction: one every ~ 200 bunch crossing → interaction rate of 500 kHz.

A system tagging the interacting bunches can solve the throughput issue.

An ML-guided data reduction system is being developed by INFN RM1 as a complementary option to solve the issue.

The dRICH Interaction Tagger



The dRICH Interaction Tagger (dIT) will be a scintillating detector-based component of the dRICH, designed to tag events in which at least one charged particle with sufficient energy passes through.

Requirements:

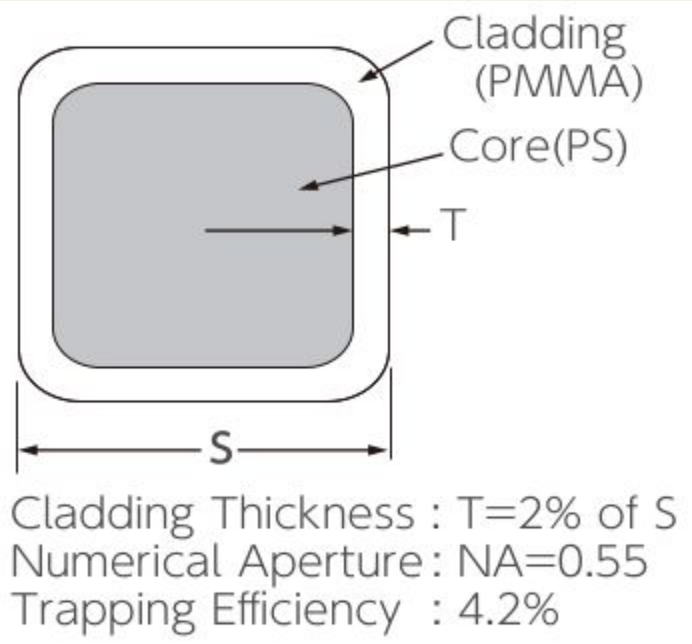
- High efficiency (no false negative);
- Good timing ~1 ns;
- Reduction factor > 10;
- Thin due to strict geometrical constraints.

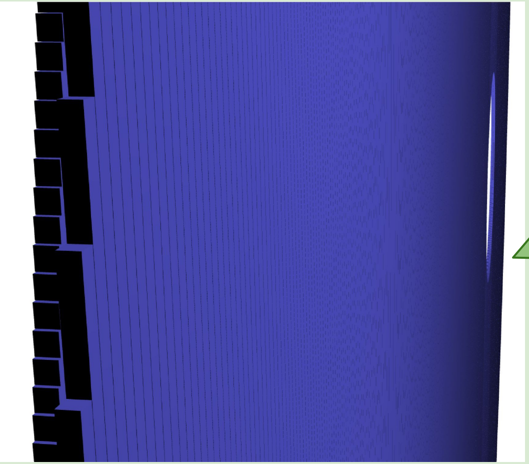
We are developing a hodoscope based on Scintillating Fibers (SciFi) to meet these requirements. It consists of two layers of square-shaped SciFi, rotated by 90°.

The dIT simulation

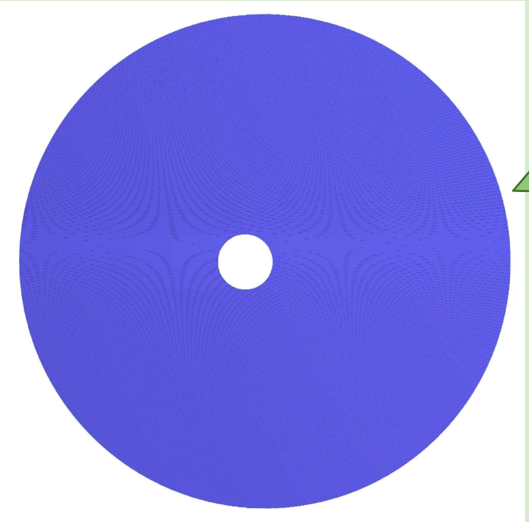
The SciFi simulation

- Two layers of 2 mm wide scintillation fibers, 2% cladding thickness
- XY-directions, 956 fibers/layer, 1.23 km of fiber length/layer;





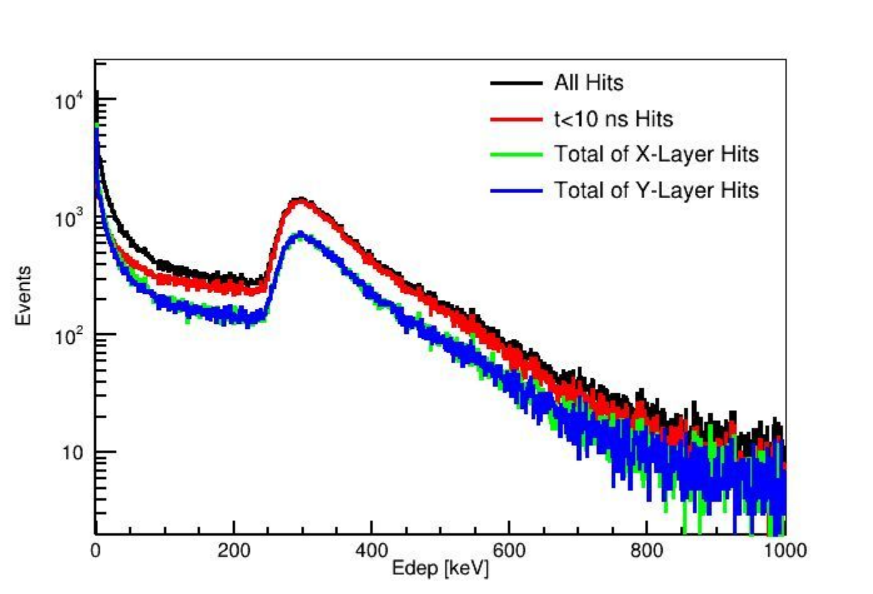
The 2-mm-wide squared-shape SciFi

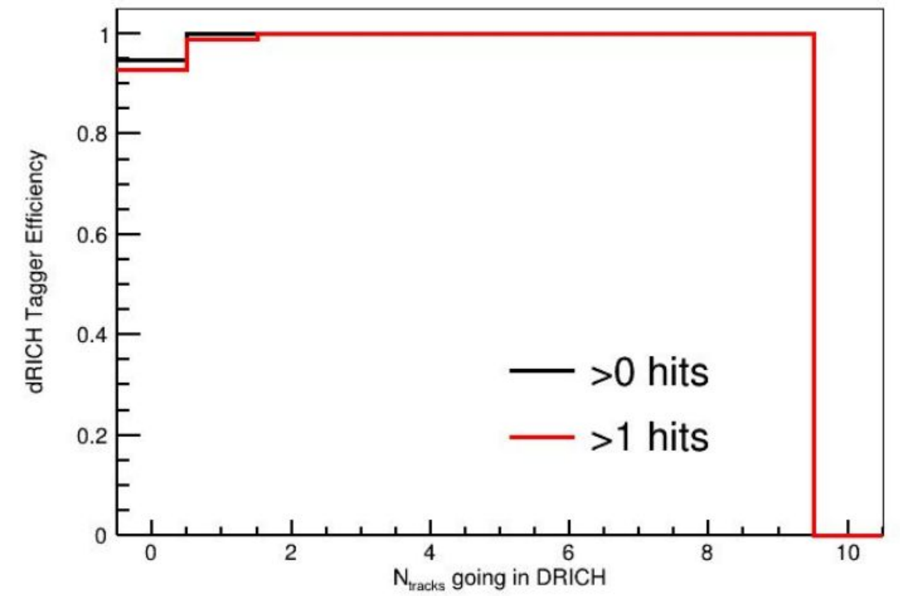


The dIT implementation. The beam pipe hole has an offset of ~ 25 mRad

The SciFi expected performance

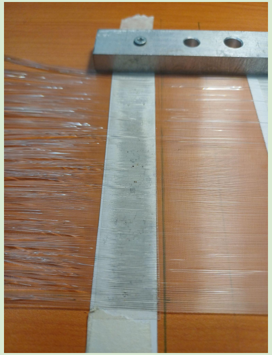
- E_{MPV} = 300 keV/layer = 2400 photons ≊ 20 p.e./SiPM;
- The threshold could be set at 100 keV ≊ 7 p.e./SiPM → expected Poisson inefficiency < 0.1 %;
- Efficiency is estimated as the ratio of events with charged tracks having dIT over the number of events with dRICH hits.
- Overall expected efficiency 99.97%, if there is at least one track from the interaction point in the dRICH.

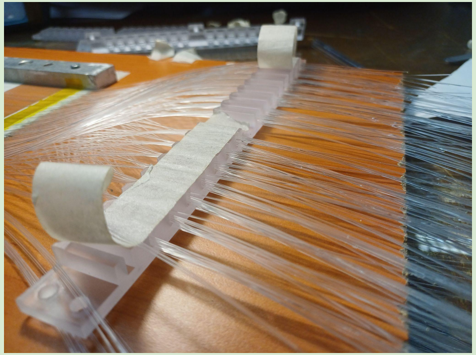




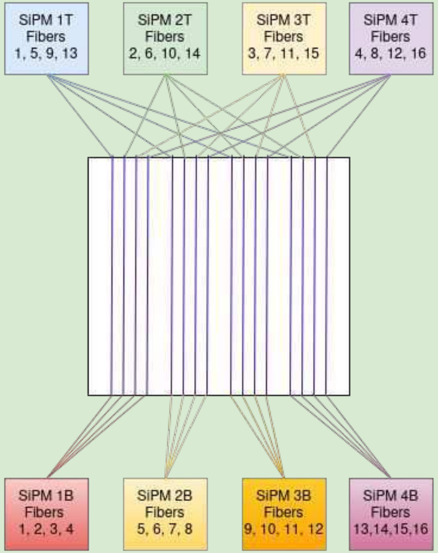
Lab activity status

The SciFi tagger-tracker prototype





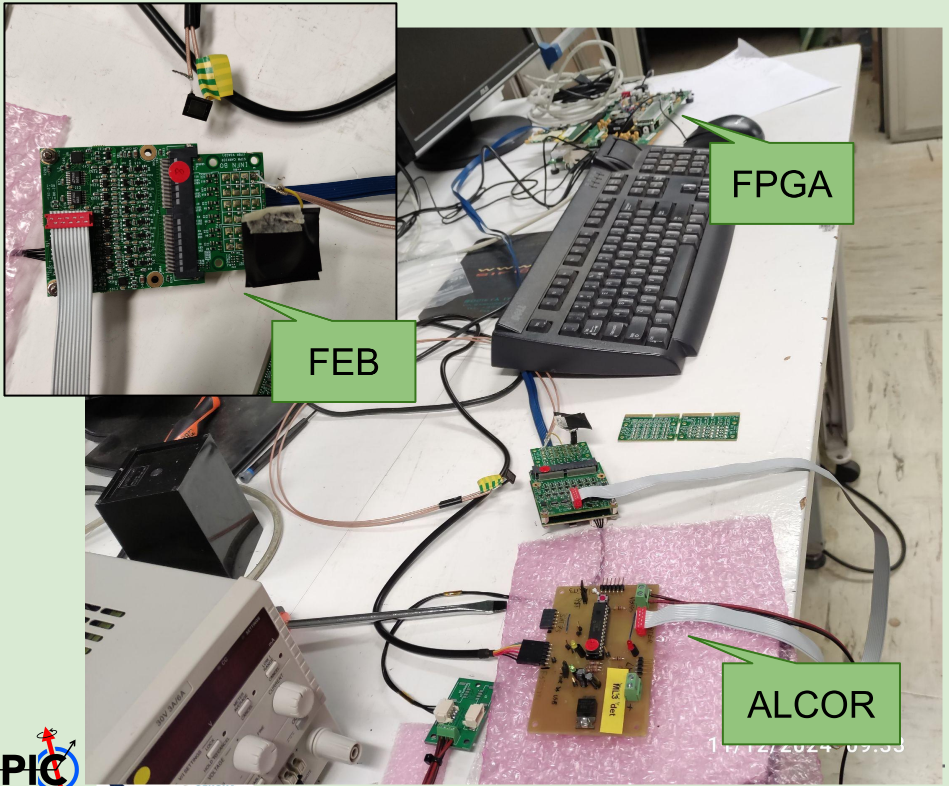
- 1 layer of tracker prototype based on 0.5 mm ∅ SciFi;
- 10 cm →200 fibers;
- 32 channels;
- Designed to identify the exact fiber that fired;
- A new 2 mm ∅ fiber sample was ordered from Luxium. It will be used to measure the performance of this large-diameter fiber.

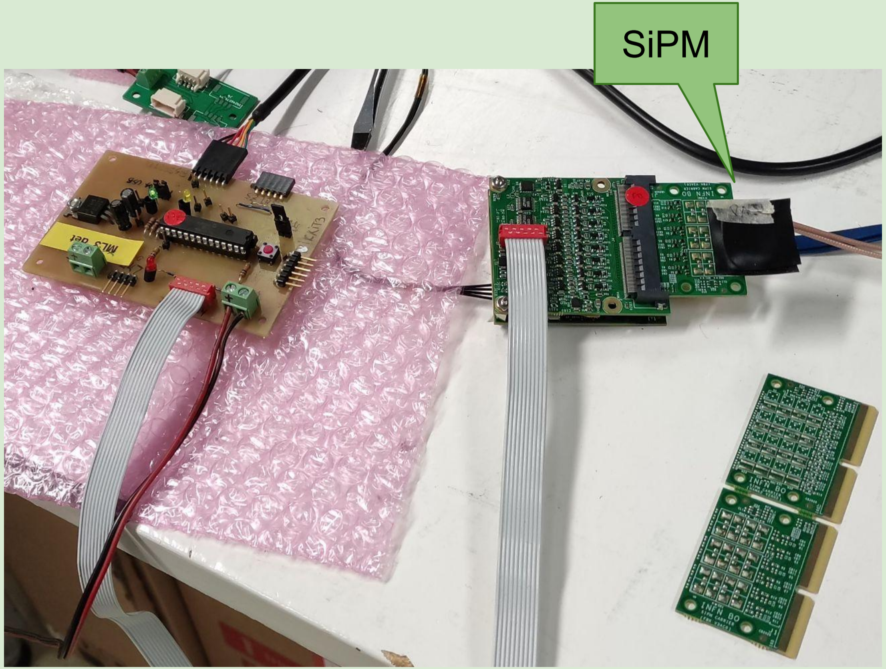


ALCOR DAQ chain

The ePIC dRICH DAQ is based on ALCOR (talk by F. Cossio).

This readout station will be used to test the new SciFi, which are currently being delivered.





Thanks for your attention

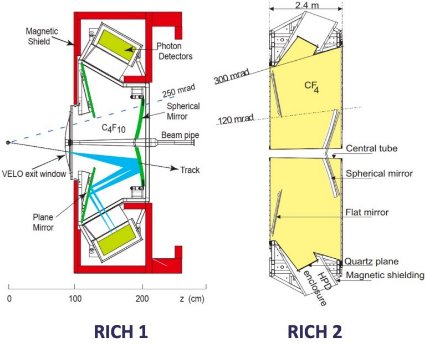
Silicon PhotoMultiplier (SiPM) characterization for LHCb RICH Upgrade II

Simon Ghizzo

University & INFN Genova

18/03/2025

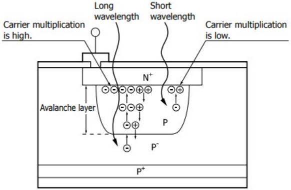
LHCb RICH detectors and Upgrade II



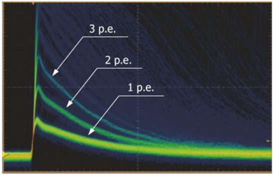
https://lhcb.web.cern.ch

- Single photon angular resolution of less than 0.5 mrad
- Maintain the occupancy below 30%
- Increase spatial granularity with 1 - 3 mm^2 pixel size
- Introduce timing information with < 100 ps resolution per channel
- Replace MaPMTs; SiPMs are considered as an option

Silicon PhotoMultiplier



https://www.hamamatsu.com



https://www.hamamatsu.com

Solid-state single photon sensors.

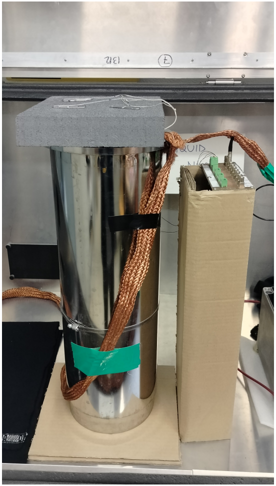
Formed by a grid of many Single Photon Avalance Diode (SPAD) $\rightarrow$ proportional behaviour.

High photon detection efficiency (PDE), high gain, insensitivity to magnetic fields, low bias voltage, and good timing resolution.

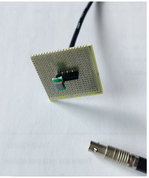
High dark count rate (DCR) at room temperature, which increases significantly with irradiation.

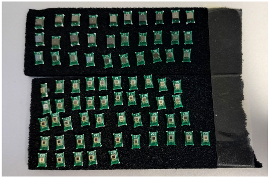
Mitigation by operating SiPMs at sufficiently low temperatures, radiation shielding, and annealing during detector maintenance periods.

SiPM characterization in lab

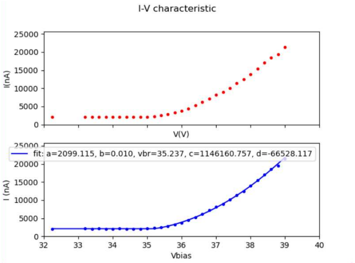


- Joint effort of all LHCb/RICH INFN institutes (MiB, FE, PG, PD).
- Preliminary measurements to validate the methodology.
- Full characterization before and after irradiation (and annealing), starting with measurements of V_{br} and DCR, using a cryostat with liquid nitrogen (from +25℃ to $\sim$ -190℃).
- Characterization of 75 SiPMs of 5 different models.

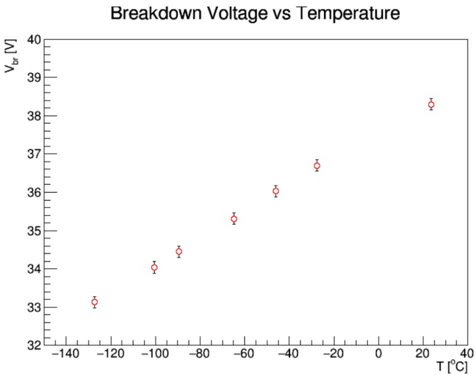




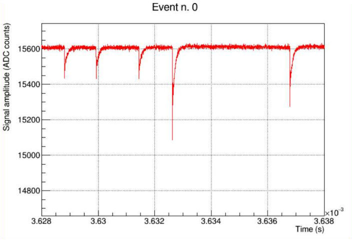
Preliminary results - V_{br}

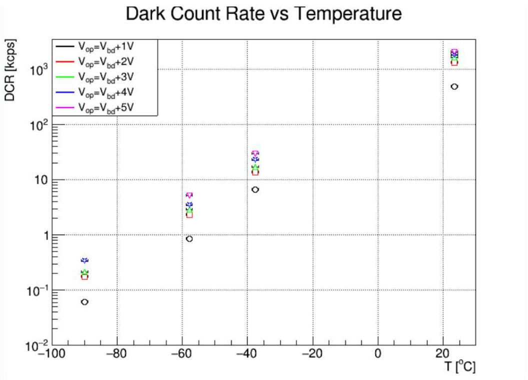


The temperature dependence of V_{br} is linear.



Preliminary results - DCR





The temperature dependence of DCR is exponential-like.

Conclusion and Future Outlooks

- Preliminary evaluation of the temperature dependencies of V_{br} and DCR is consistent with expectations.
- Perform other measurements:
  - Gain
  - Photon Detection Efficiency (PDE)
  - Time resolution

  To do this, integrate a laser into the setup.
- Plan to use the amplifier designed by MiB (see D. Trotta talk) to characterize all the 75 SiPMs.
- Use a bigger LN2 cryostat to have access to a finer gradient in temperature.
- Perform characterization after irradiation and annealing.

THANK YOU FOR YOUR ATTENTION