42ND INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

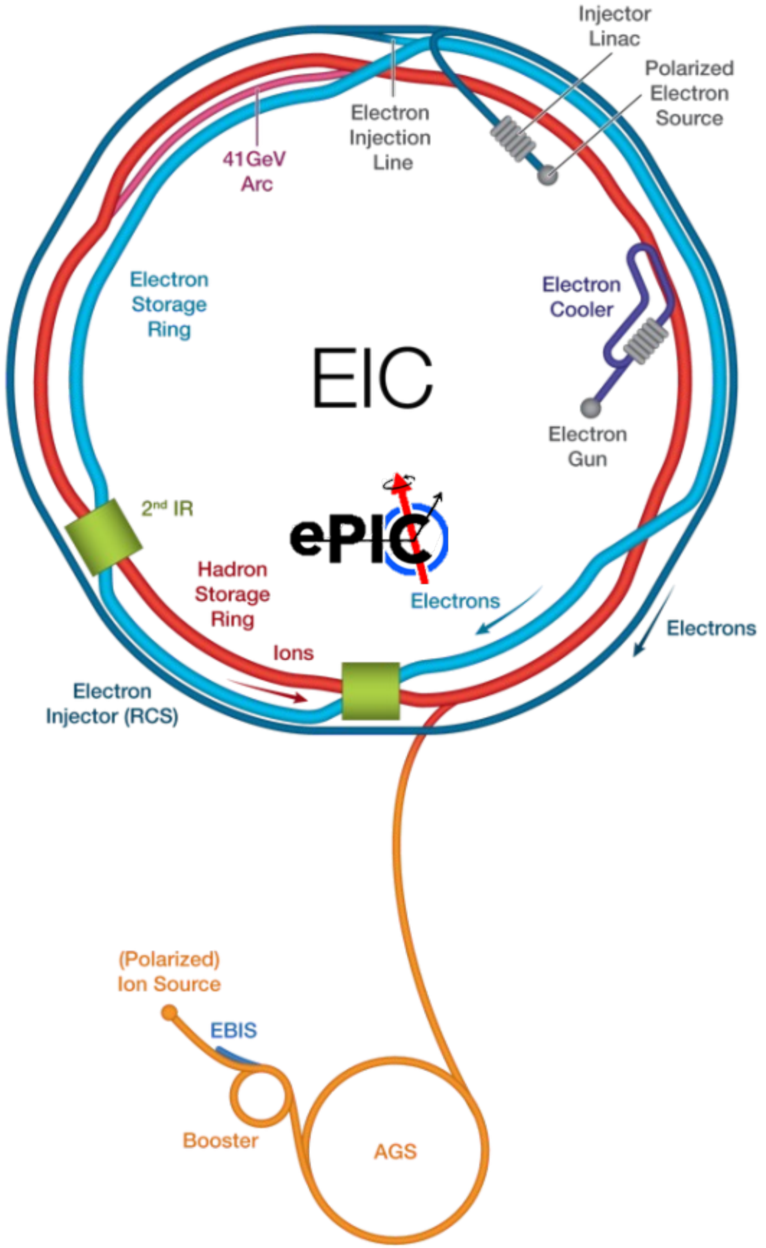
18-24 July 2024

A large-area prototype SiPM readout plane for the ePIC-dRICH detector at the EIC

Luigi Rignanese on behalf of the **ePIC dRICH** collaboration

Outline:

- The **Electron-Ion Collider** and the **ePIC detector**
- **SiPMs** and **radiation damage**
- **Prototype**
- **Test beam** results



The Electron-Ion Collider

Brookhaven National Laboratory
www.bnl.gov/eic

The major US project in the field of nuclear physics

- Operating in the early '30s

The world's first collider for

- Polarized electron-proton (and light ions)
- Electron-nucleus collisions

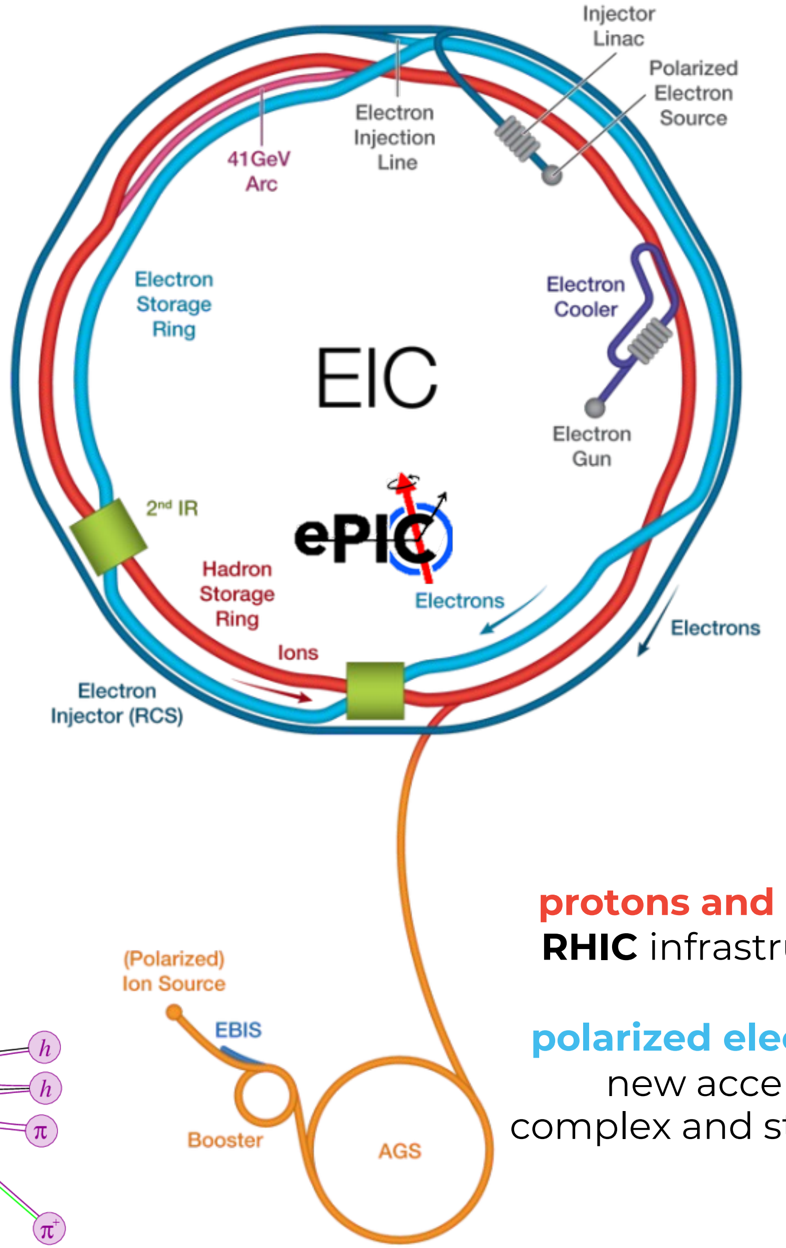
High Luminosity: 10^{34} cm^2s^{-1}

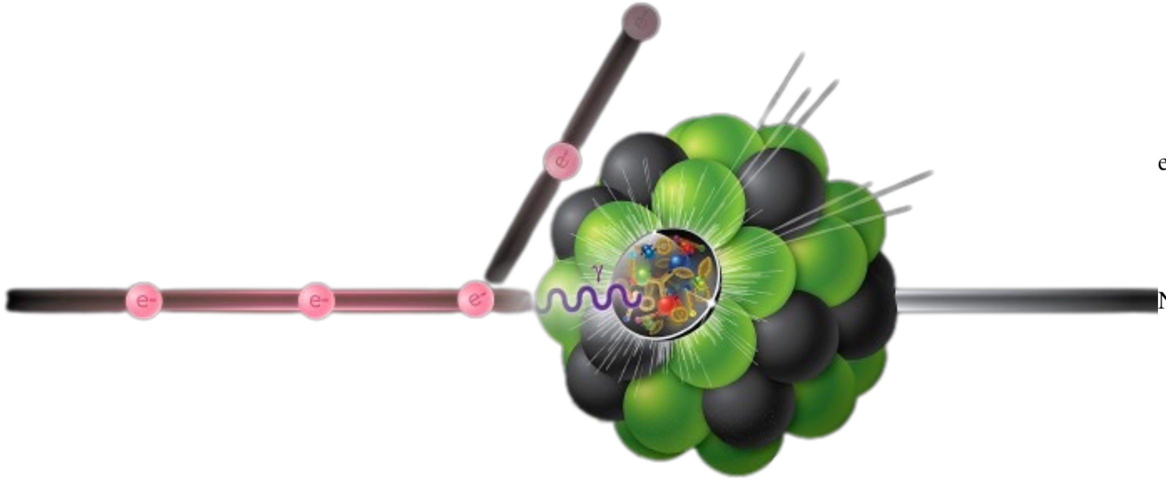
Wide energy span → 20-140 GeV

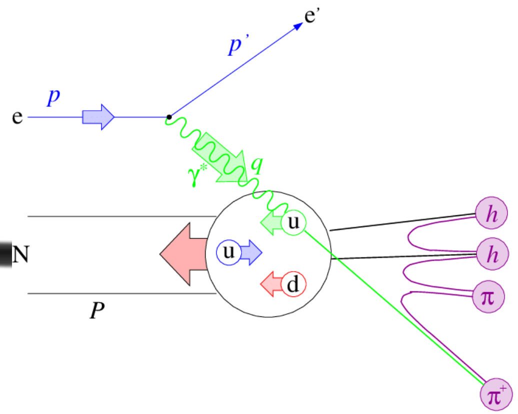
Inclusive/semi-inclusive DIS

- understand origin of mass & spin of the nucleons

3D images of the nuclear structure (GPD)







protons and nuclei
RHIC infrastructure

polarized electrons
new accelerator complex and storage ring

ePIC

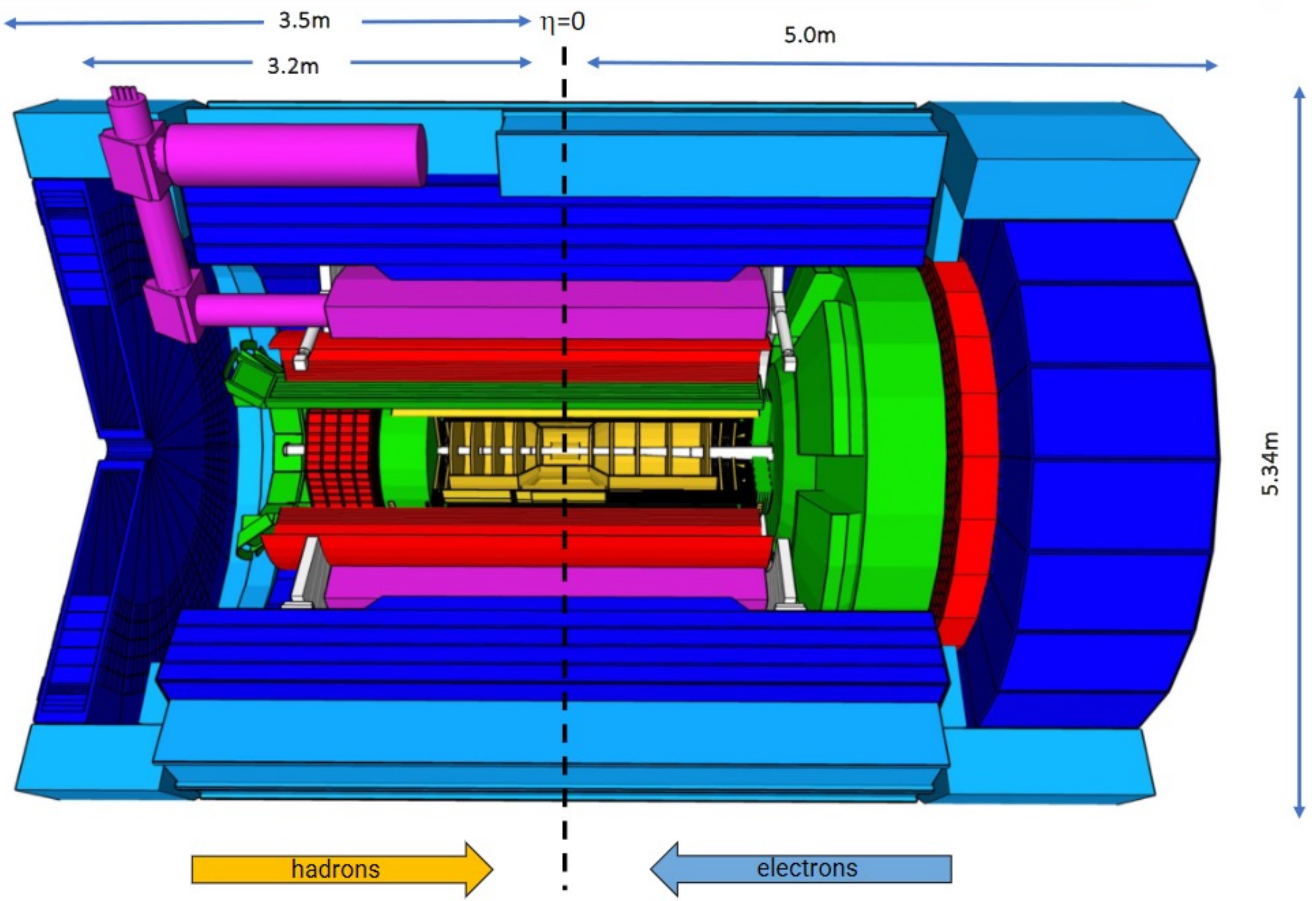
Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



ePIC

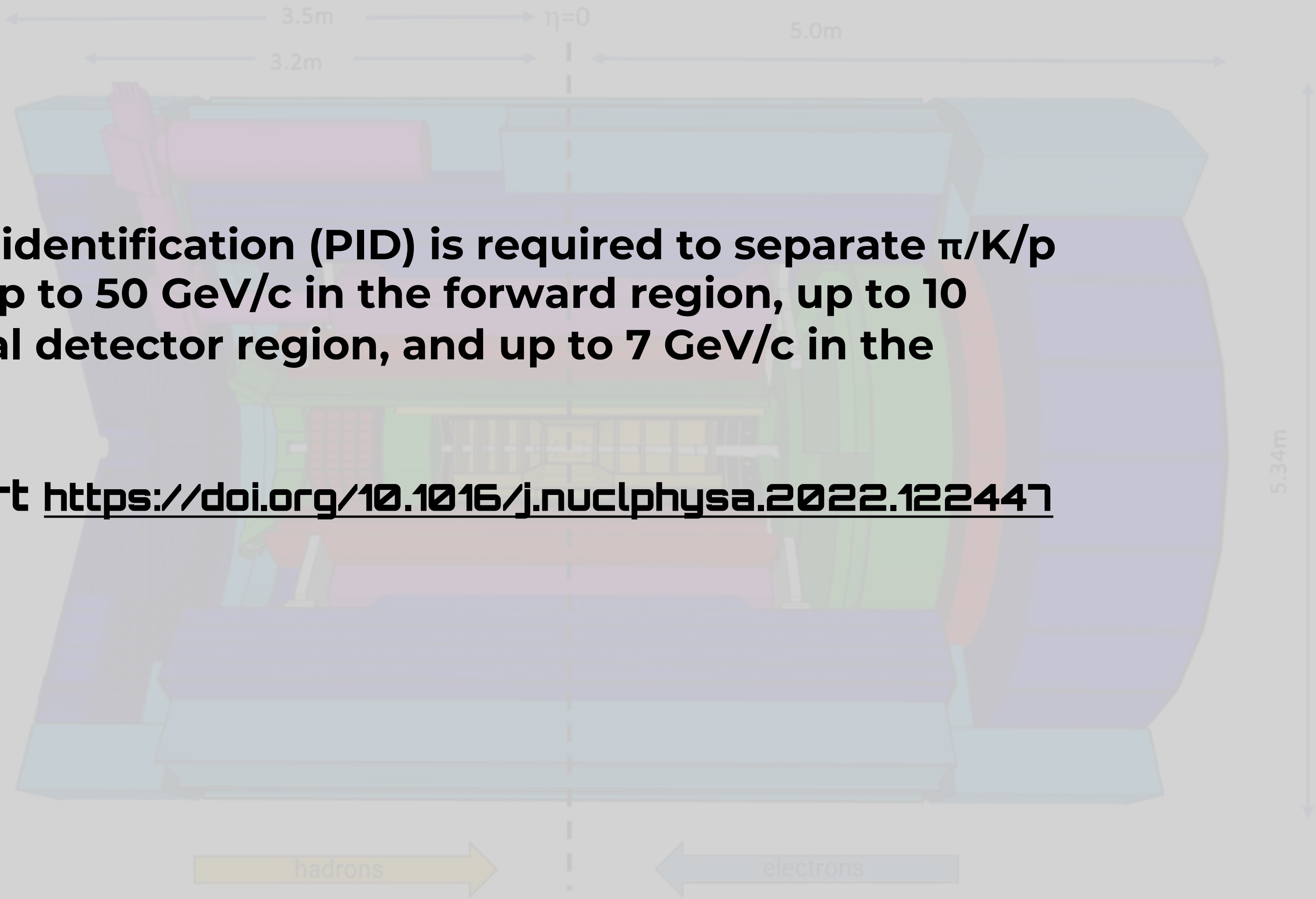
Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous trackers: MPGDs (µRWELL, MMG) cylindrical and planar

PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

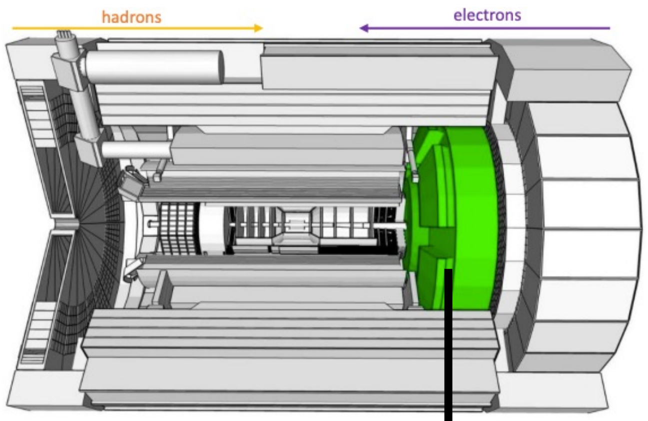
Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



"Excellent particle identification (PID) is required to separate π/K/p at the level of 3 σ up to 50 GeV/c in the forward region, up to 10 GeV/c in the central detector region, and up to 7 GeV/c in the backward region"

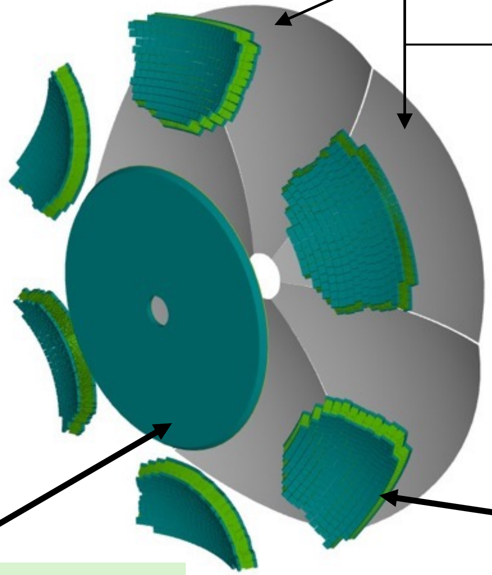
EIC yellow report https://doi.org/10.1016/j.nuclphysa.2022.122447

The dual-radiator (dRICH)

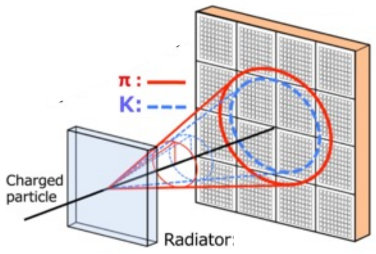


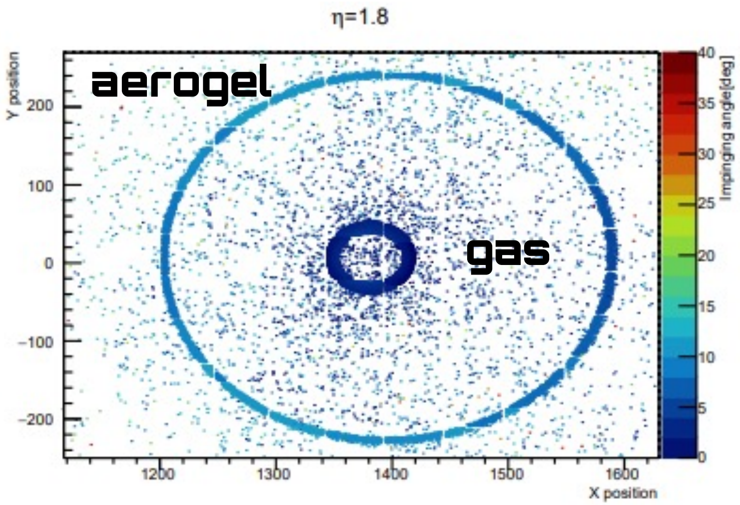
Compact and **cost-effective** solution for **broad momentum** (3-50 GeV/c) coverage at forward rapidity **π/K 3σ separation at 50 GeV/c** and **wide acceptance** (+- 300 mrad/ 1.5 < η < 3.5)

Gas volume 120 cm
C_2F_6 (n ~ 1.0008)



6 spherical mirrors
Backward-reflecting
Radius = 220 cm



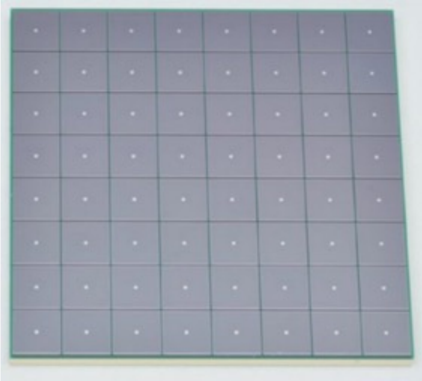


Aerogel (n ~ 1.02) **4 cm**
Radius = 110 cm

Photosensors 3x3 mm² pixels 0.5 m² per sector in 1 T magnetic field and radioactive environnement for low light levels.

SiPMs are the best candidates

- **Small** and **cheap**
- **Insensitive** to **magnetic field**
- **High** photo-detection efficiency (**PDE**)
- High gain-**single photon** detection
- **Low voltage** operation
- Excellent **timing** performance

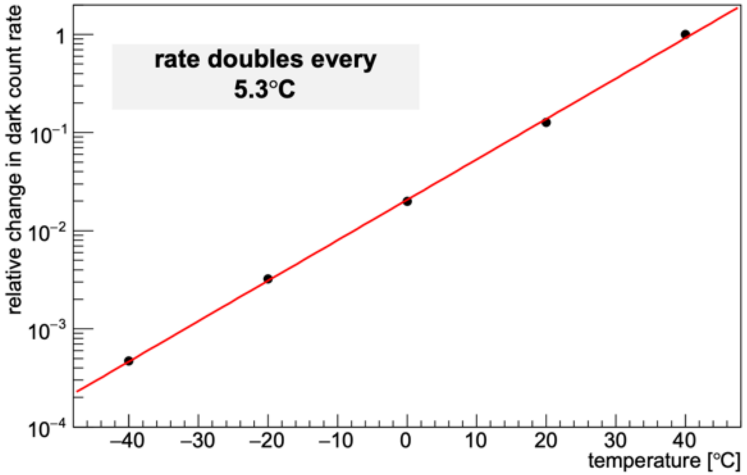


But:

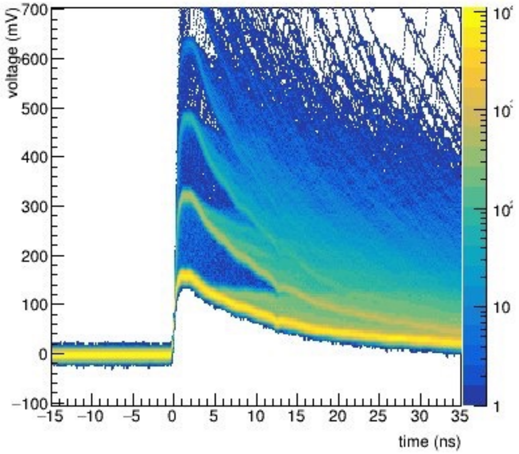
x **High DCR** @ room temperature

x **Low** radiation **tolerance**

DCR increases with **dose**



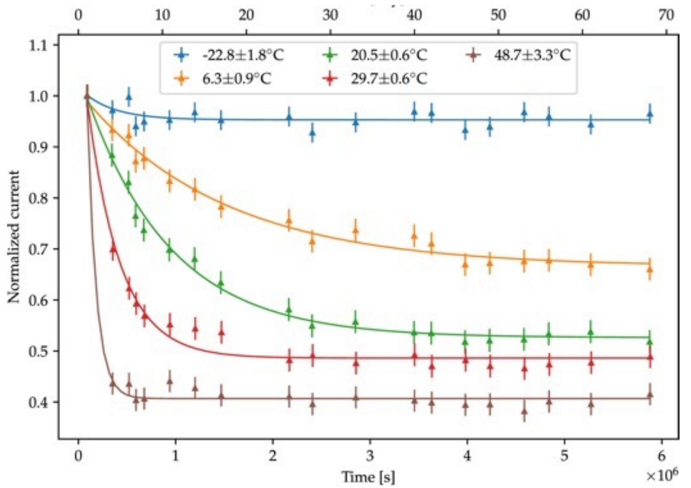
A. N. Otte et al., Nucl.Instrum.Meth.A 846 2016



Sub ns time resolutions allow **coincidence** cuts that greatly reduces **DCR** contribution in the measurements

Annealing techniques (**high temperature process**) to recover **DCR** performance loss

Cooling the sensors down to **– 30° C reduces** the **DCR** by a factor **~ 100**

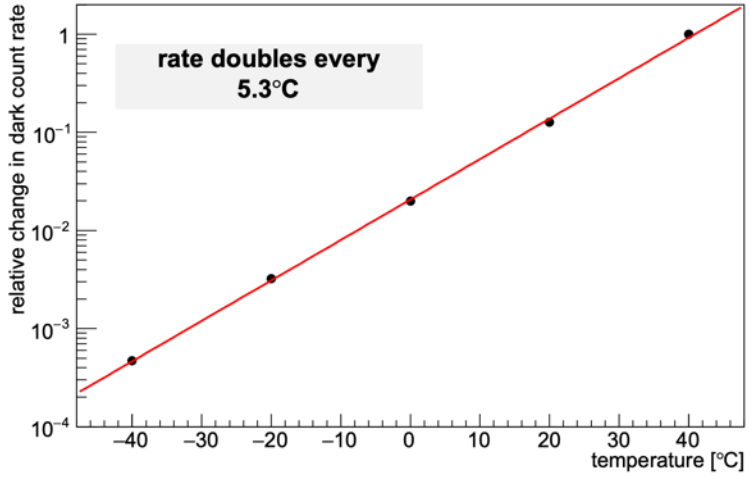


N. De Angelis et al., Nucl.Instrum.Meth.A 1048 2023

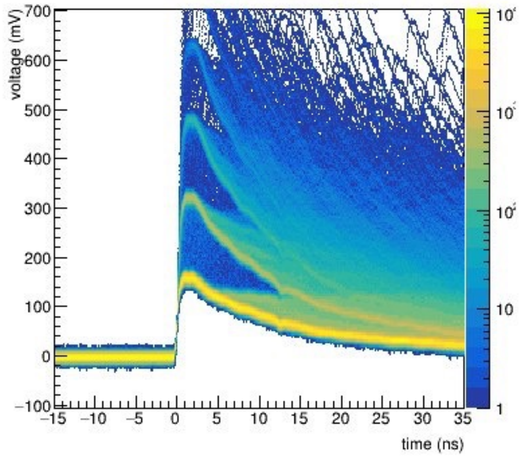
But:

- x **High DCR** @ room temperature
- x **Low** radiation **tolerance**

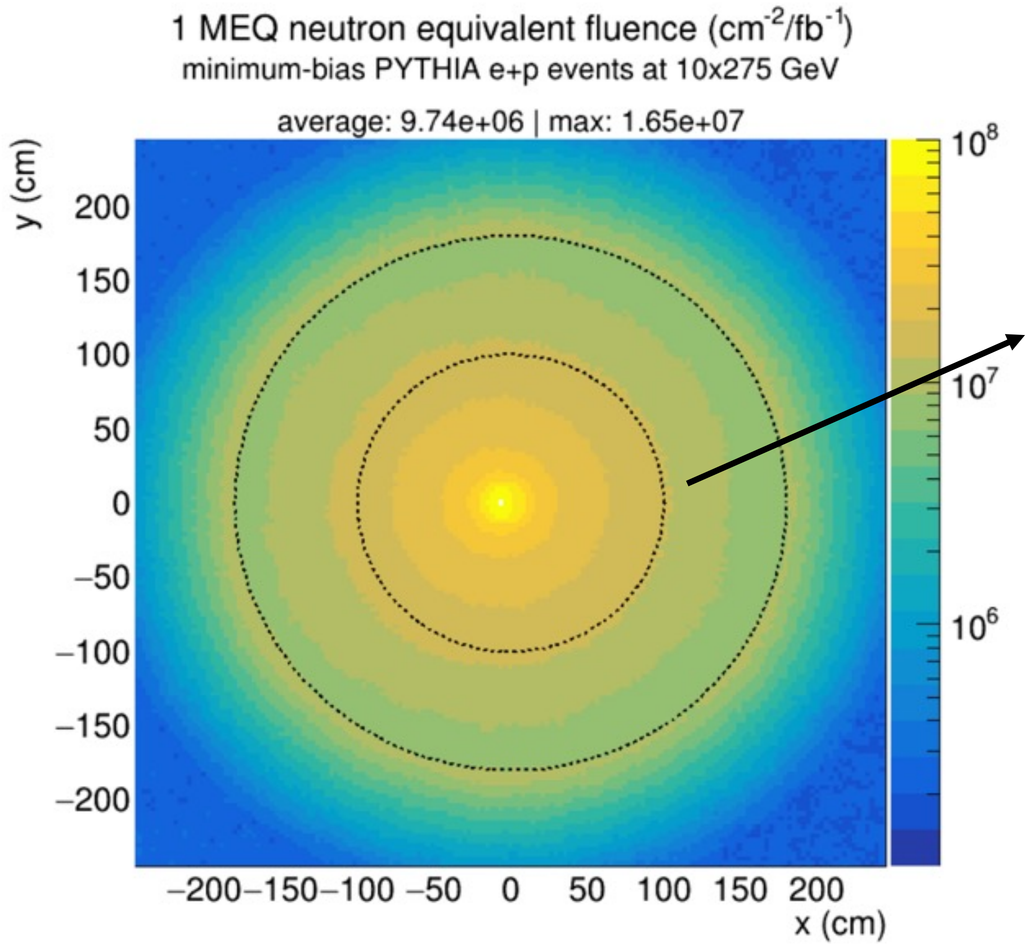
  DCR increases with **dose**



A. N. Otte et al., Nucl.Instrum.Meth.A 846 2016



Radiation levels on the dRICH



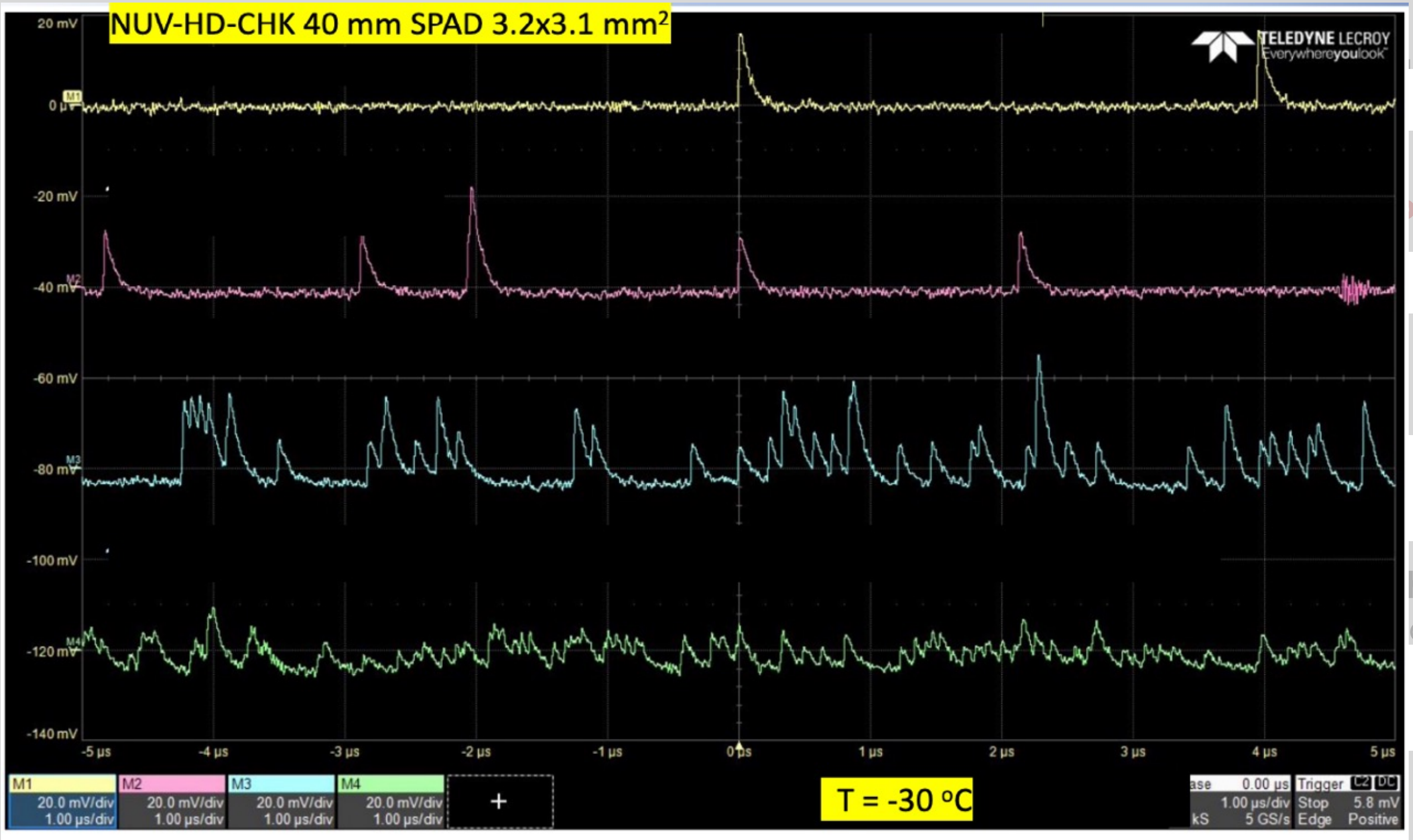
$\mathbf{n_{eq}}$ = 1-MeV neutron equivalent (NIEL model)

dRICH photosensors location:
mean ≈ 9.7 10^6 n_{eq}/cm^2 per fb^{-1}
max ≈ 1.7 10^7 n_{eq}/cm^2 per fb^{-1}
(including bkg)

Integrated luminosity and **radiation levels**

- 10 fb^{-1} for **most** of the **physics topics** — **<10^9 n_{eq}/cm^2**
- 10^2 fb^{-1} **GPD** and statistically eager topics — **<10^{10} n_{eq}/cm^2**
- 10^3 fb^{-1} may **never** be reached — **<10^{11} n_{eq}/cm^2**

Radiation levels on the dRICH



uivalent (NIEL model)

new

cation:

10^9 n_{eq}/cm^2

10^{10} n_{eq}/cm^2 (SP affected)

ation levels

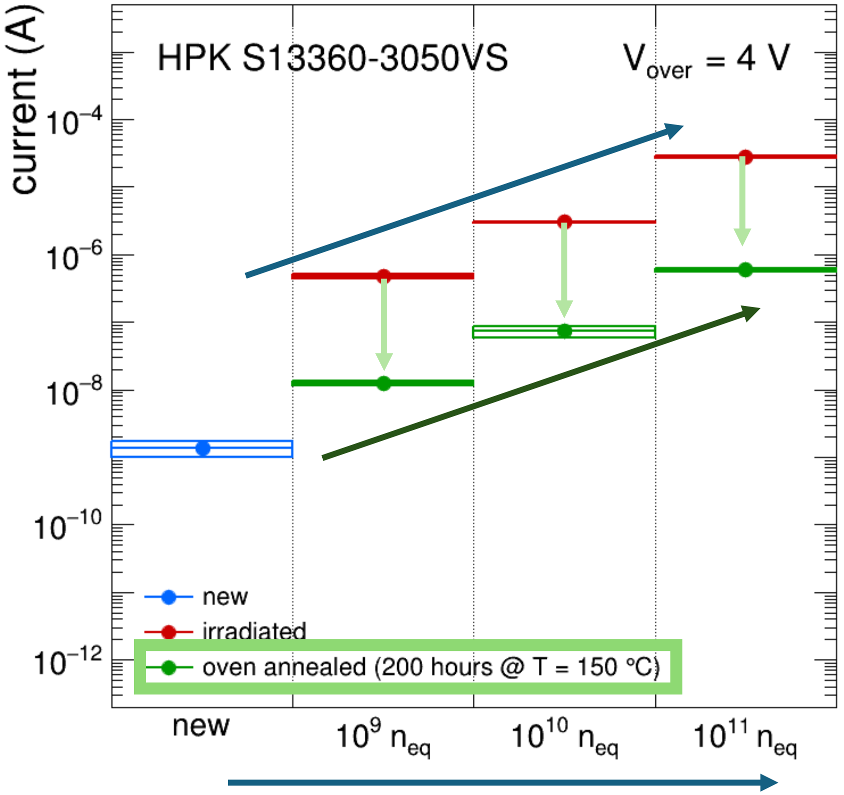
hysics topics $<10^9$ n_{eq}/cm^2

cally eager topics $<10^{10}$ n_{eq}/cm^2

10^{11} n_{eq}/cm^2 (baseline affected)

SiPMs radiation damage studies and annealing (2021)

Irradiation campaigns with protons at TIFPA (TN)

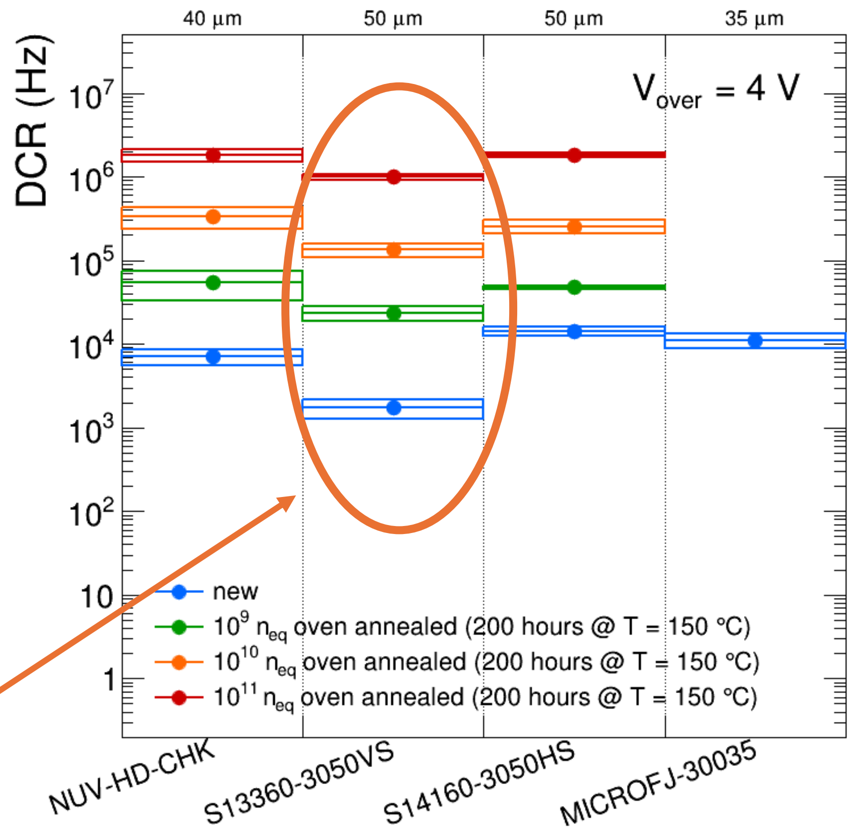


Linear **increase** of dark current/**DCR** with the dose

~50x reduction of dark current/**DCR** with **150° C** oven **annealing**

Residual increase in **DCR** is **proportional** to the dose

All sensors behave similarly but **HAMATSU s13360-3050** shows the **lowest DCR** and **best PDE**

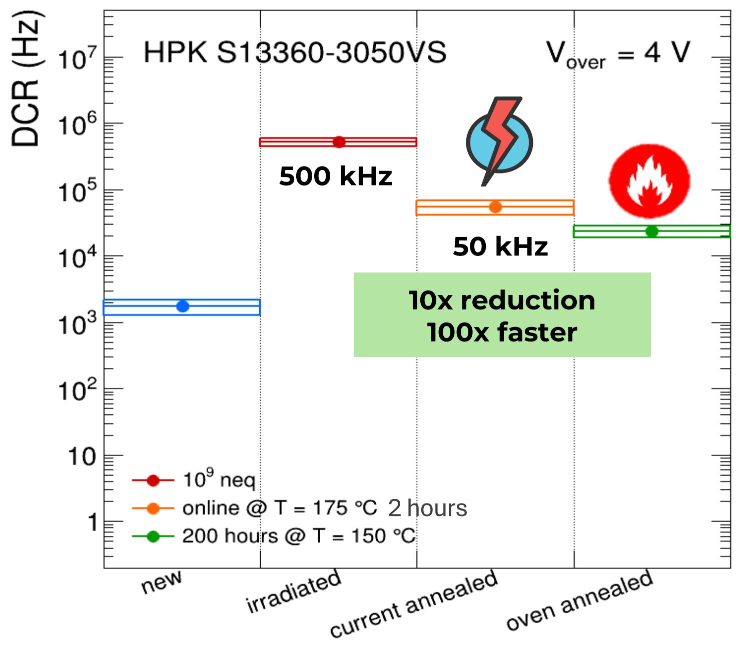


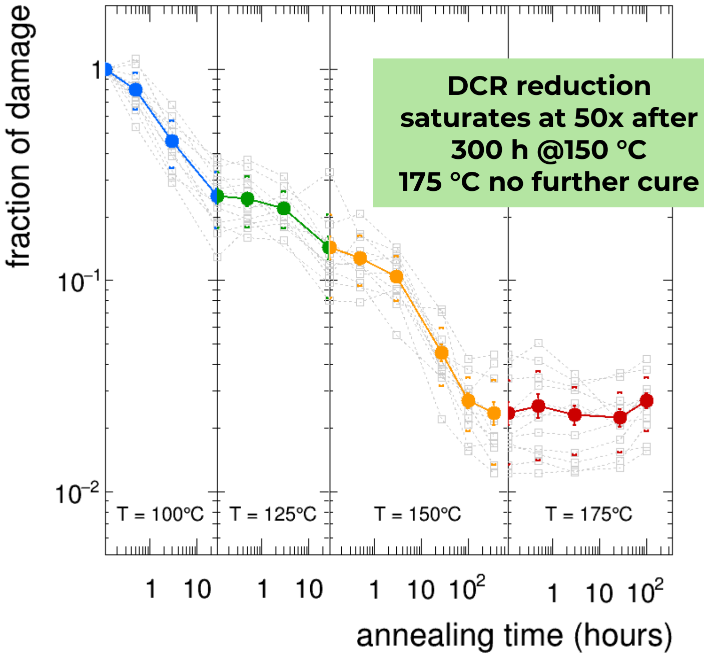
R. Preghenella et al., Nucl.Instrum.Meth.A 1056 2023

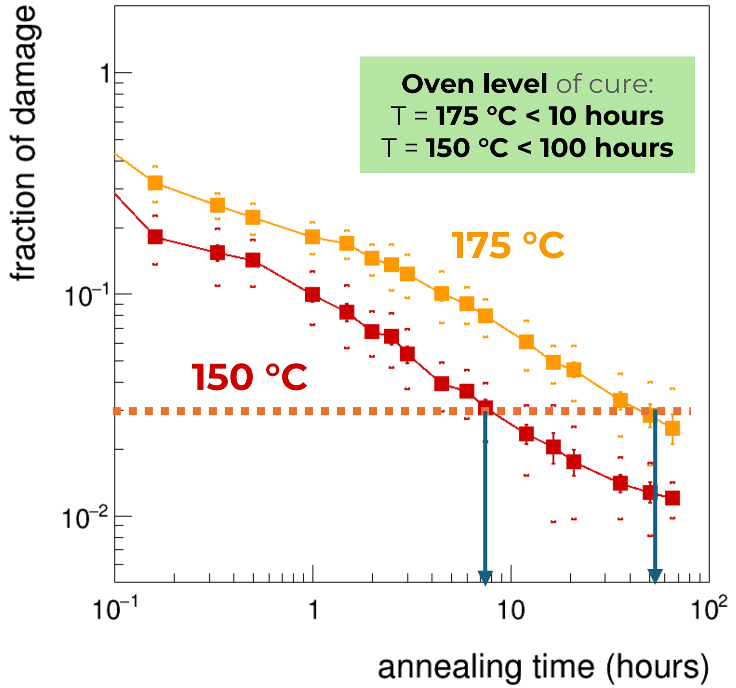
Measurements taken @ -30° C

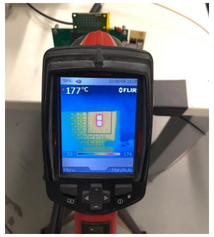
SiPMs current annealing

Annealing by heating up the sensors. Direct polarized “high” current flowing into the SiPM. 175° C with 10 V and ~100 mA (**~ 1 W**) per sensor.

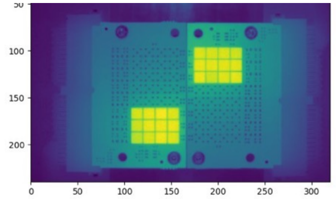








Preliminary studies in 2022 demonstrated the feasibility



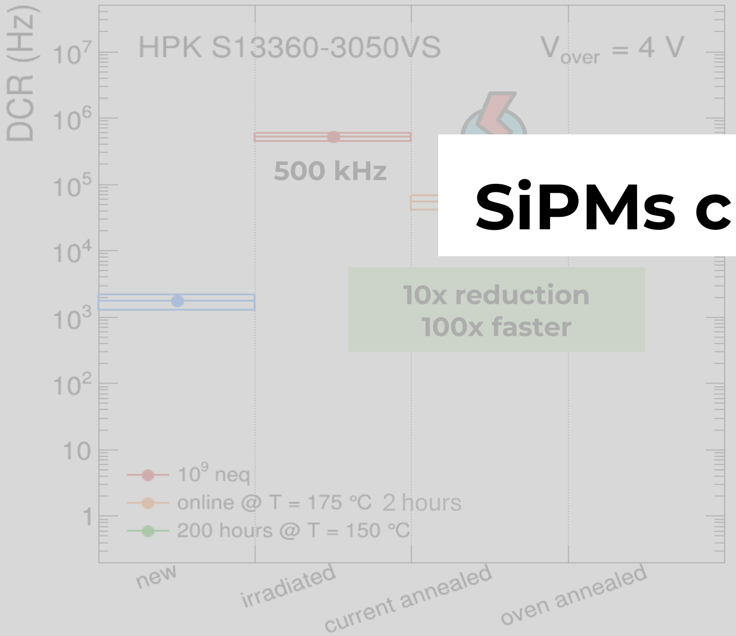
2023/24 test on a large number SiPM. Automated test at different temperatures and time intervals

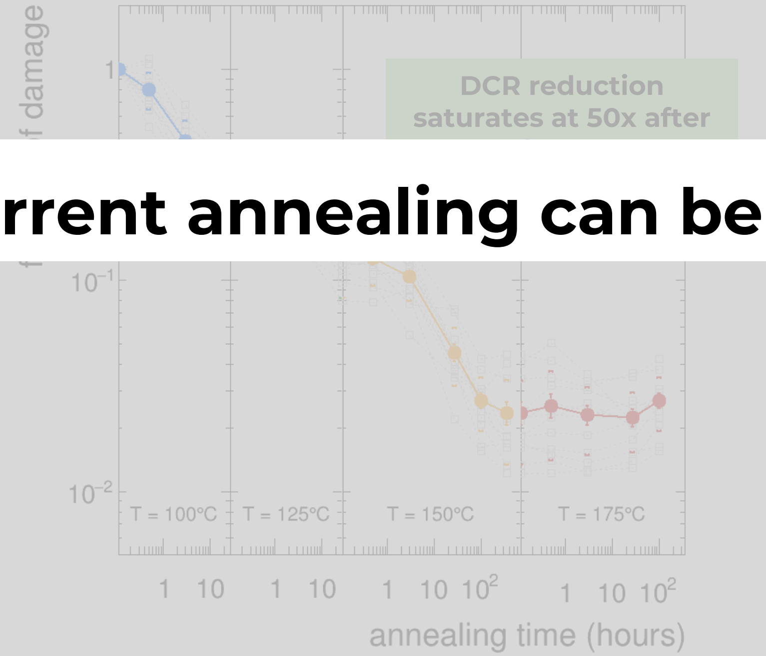
R. Preghenella et al., Nucl.Instrum.Meth.A 1056 2023

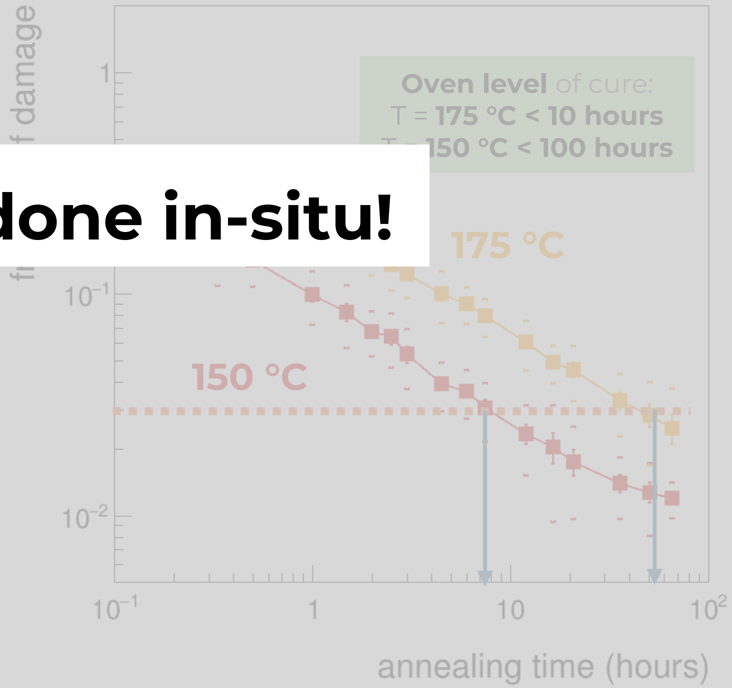
SiPMs current annealing

Annealing by heating up the sensors. Direct polarized “high” current flowing into the SiPM. 175° C with 10 V and ~100 mA (**~ 1 W**) per sensor.

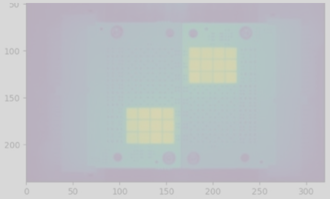
SiPMs current annealing can be done in-situ!







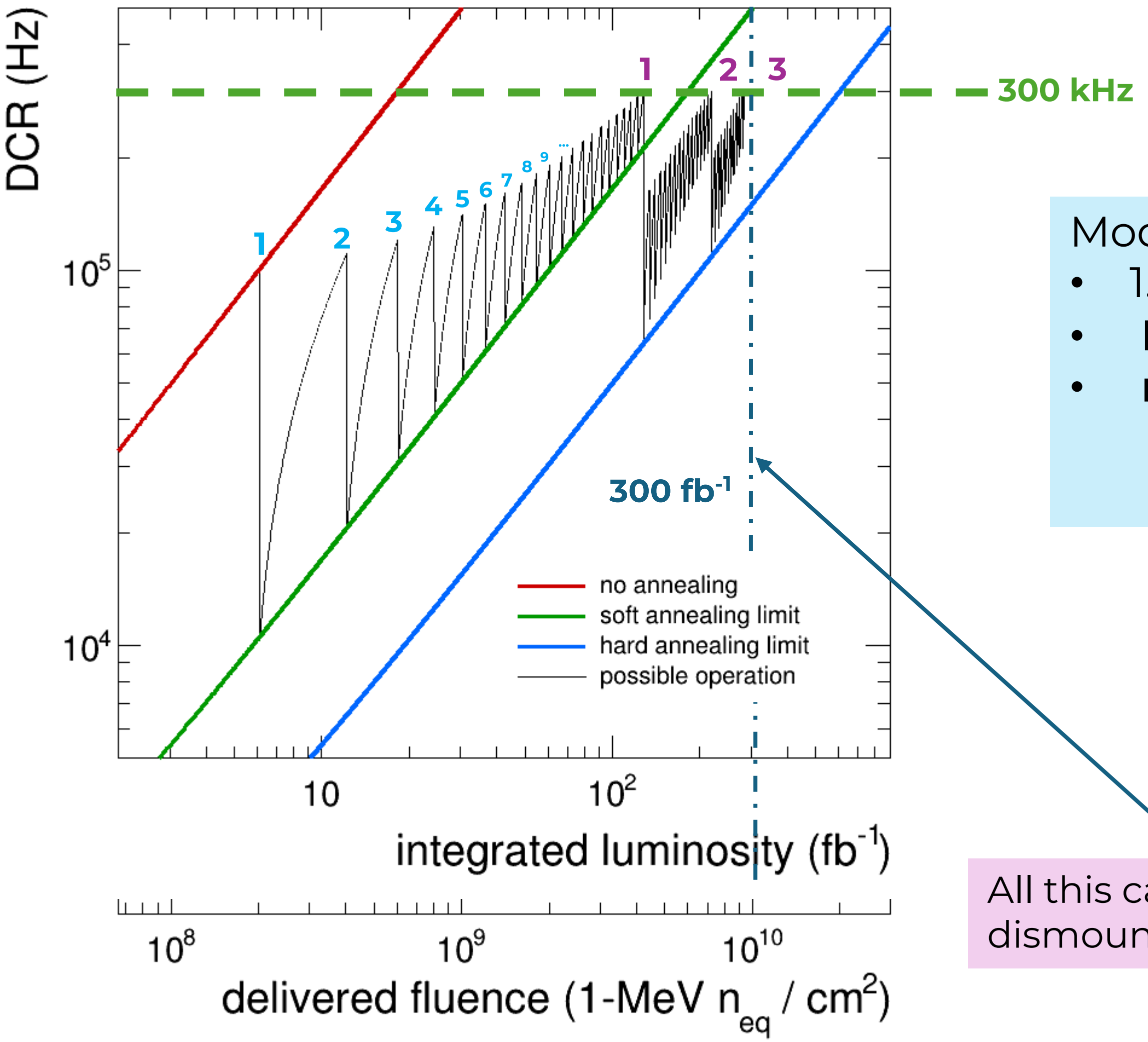
Preliminary studies in 2022 demonstrated the feasibility



2023/24 test on a large number SiPM. Automated test at different temperatures and time intervals

SiPMs aeging model

Hamamatsu S13360-3050 @ Vover = 4 V, T = -30 C



DCR limit per **sensor**
SNR and **physics program**

Model parameters:

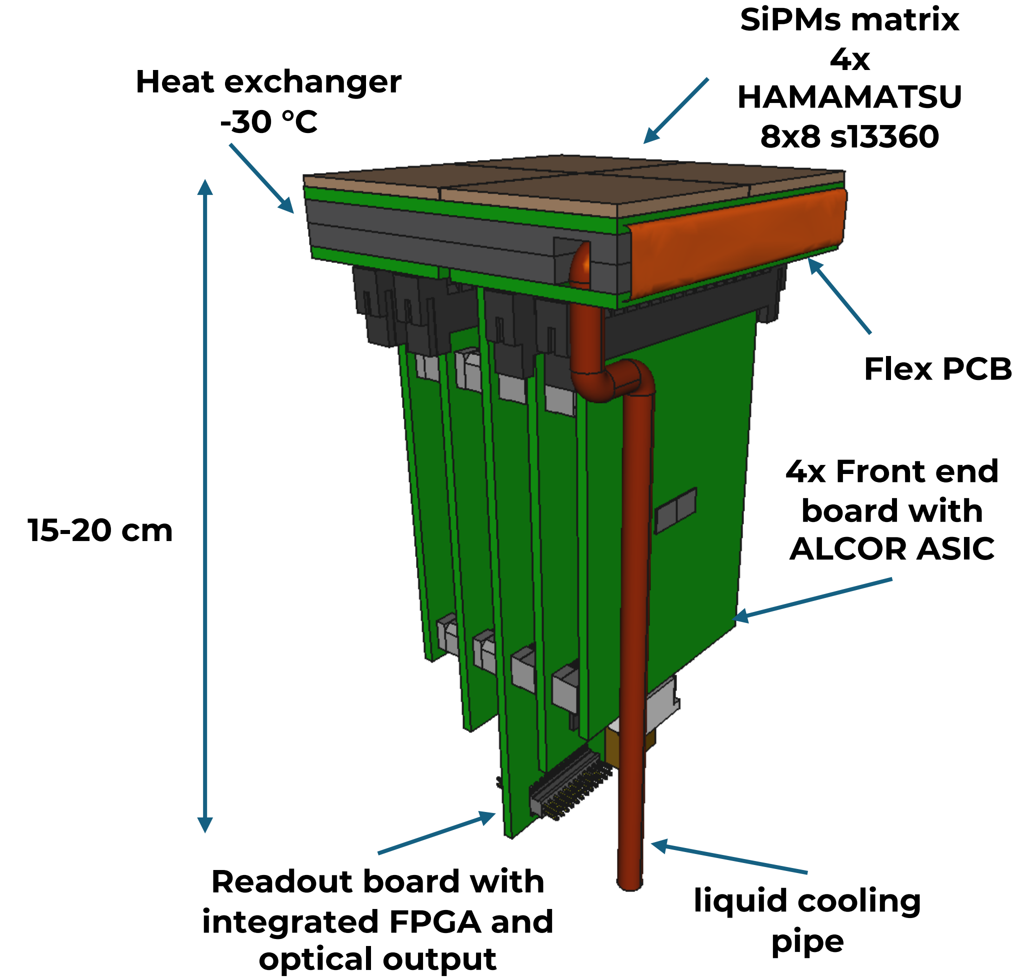
- 1.75 10^7 n_{eq} /cm^2 / fb^{-1} + **2x safety factor**
- **DCR increase (F_d)**: 500 kHz/10^9 n_{eq} /cm^2
- **residual DCR (F_a)**:
  - **soft** 2 h@150C annealing = 50 kHz/10^9 n_{eq}/cm^2
  - **hard** 100 h@150C annealing = 15 kHz/10^9 n_{eq} /cm^2

$DCR(K)=DCR_0+F_d-(K-1)F_a$
K-1= number of annealing cycles
K soft = 44
K hard = 3

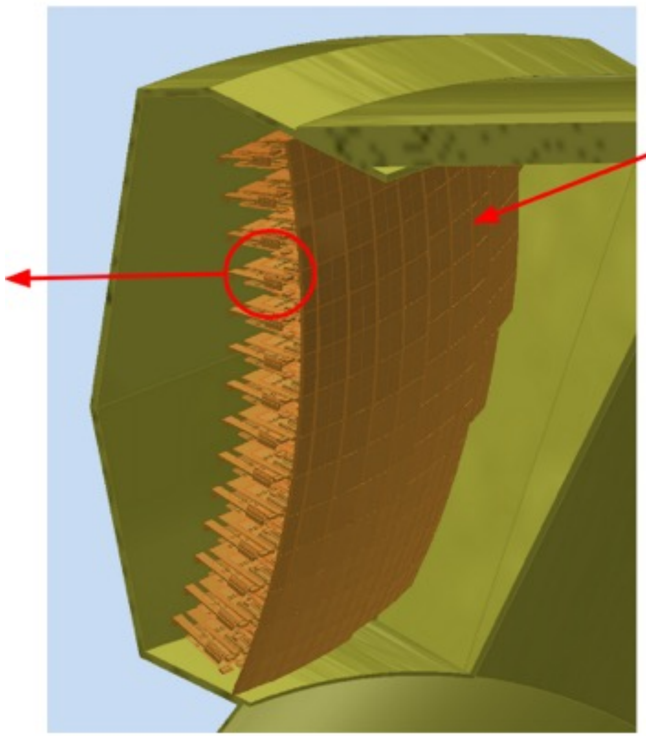
All this can be done **in-situ**. From here we we'll need to dismount the detector (**10 yr** operation)

Photodetector design and layout

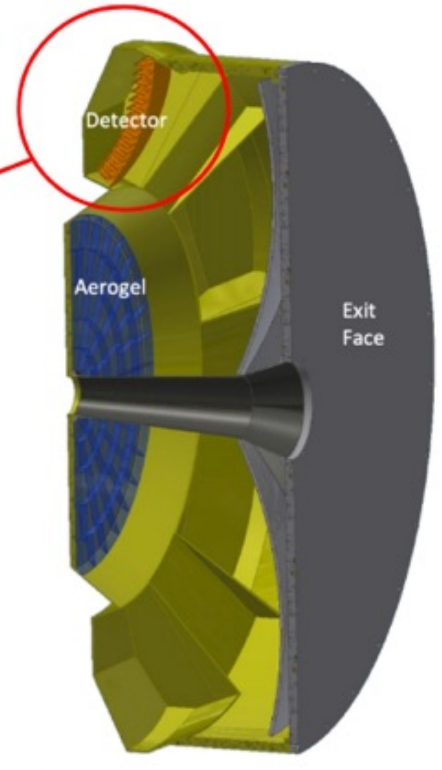
PDU



Curved SiPM readout plane (sector)

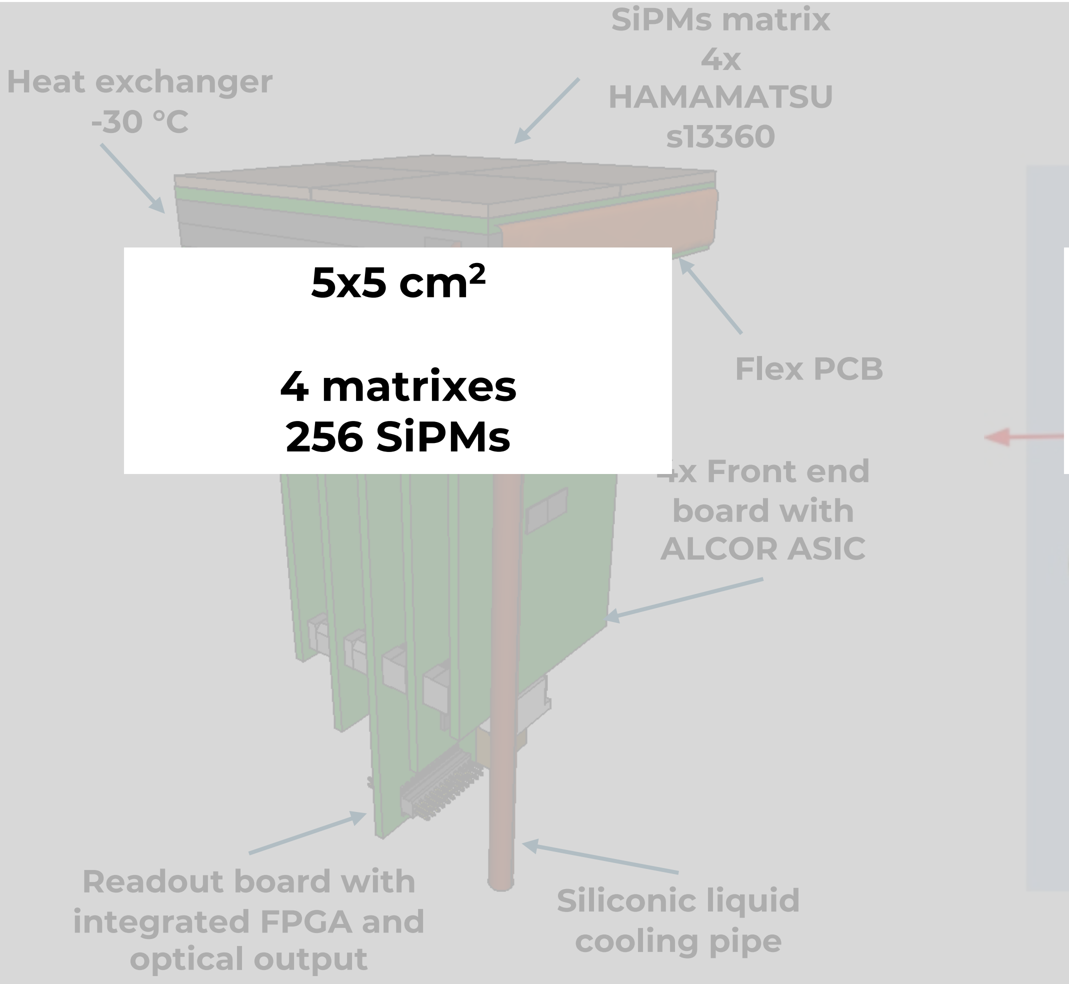


dRICH



Photodetector design and layout

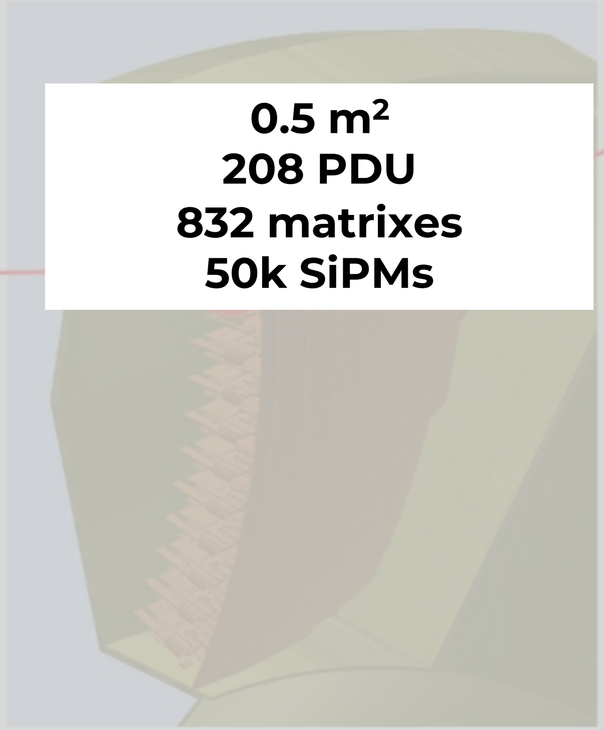
PDU



5x5 cm²

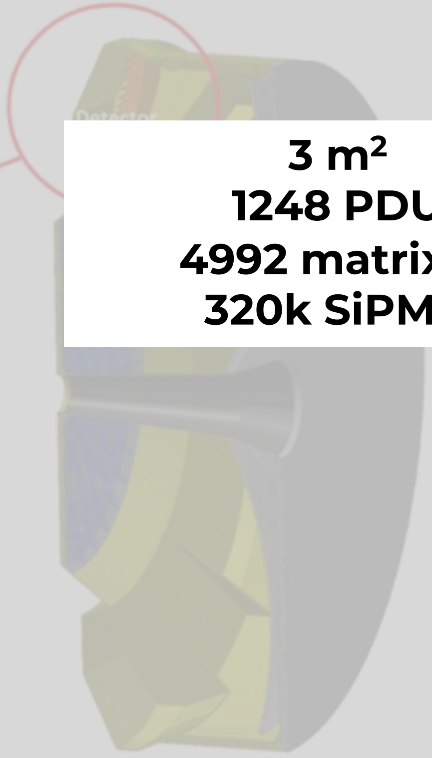
4 matrixes
256 SiPMs

Curved SiPM readout plane (sector)



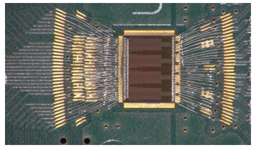
0.5 m²
208 PDU
832 matrixes
50k SiPMs

dRICH



3 m²
1248 PDU
4992 matrixes
320k SiPMs!

ALCOR ASIC by INFN-To



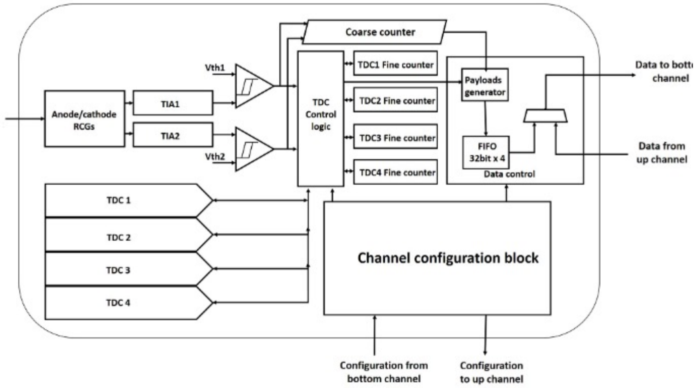
32-pixel matrix mixed signal **ASIC** initially foreseen for **SiPMs** in **cryogenics**

The chip performs **amplification**, **signal conditioning** and **event digitization** with a fully **digital I/O**

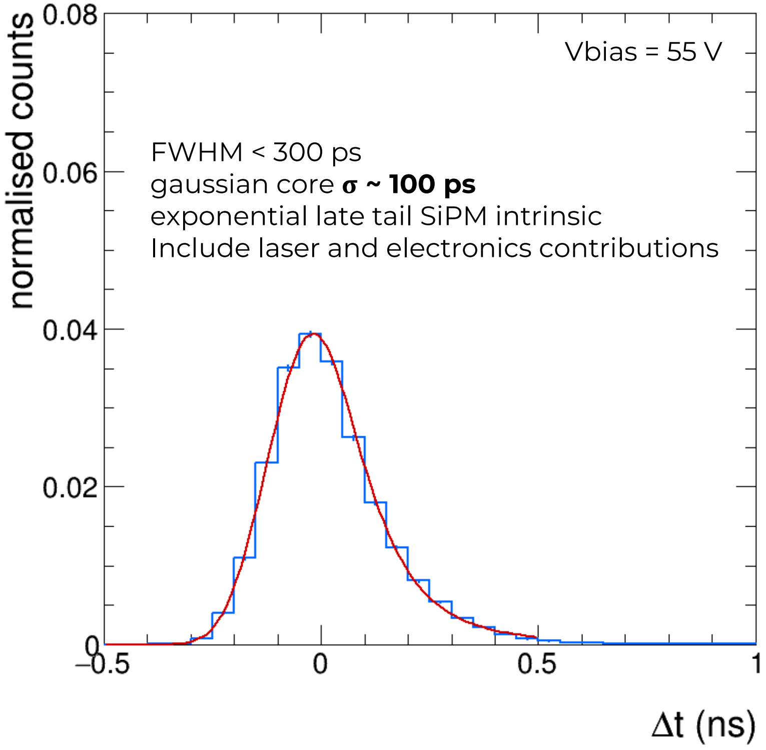
Each **pixel** features

- Regulated common gate **amplifier** (10 Ω impedance)
- Post amp TIA for **4 gain settings**
- 2 **leading-edge discriminators** with independent **threshold** settings
- 4 **TDCs** based on analogue interpolation with **50 ps LSB** (@ 320 MHz)
- 3 **triggerless operation** modes:
    - **LET** leading edge threshold measurement, high-rate time-stamp
    - **ToT** Time-over-Threshold
    - **Slew rate**

Fully **digital output** on **4 LVDS TX** data links
SPI-based chip configuration
64-bit event and **status** data

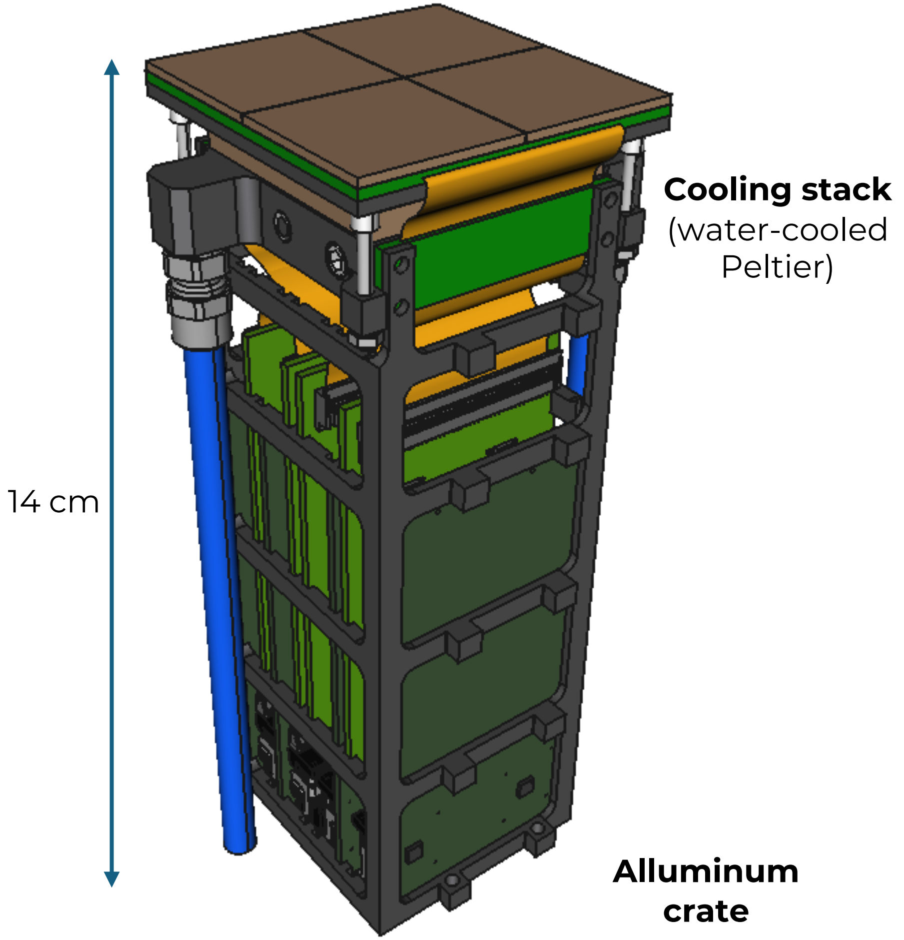


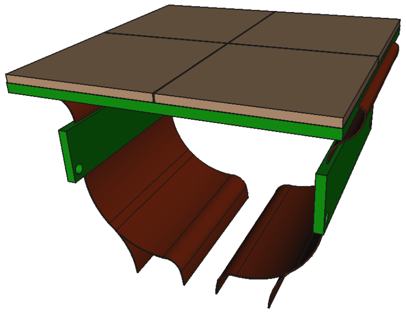
SPTR ALCOR +Hamamatsu s13360-3075



R. Kugathasan PoS TWEPP2019 (2020) 011

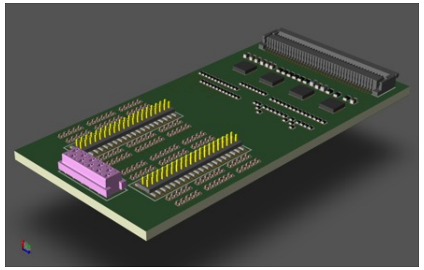
PDU prototype





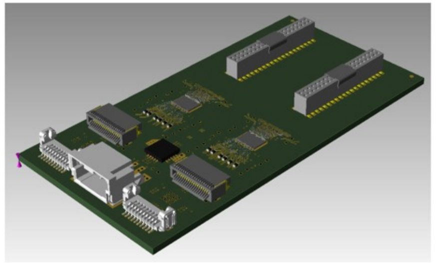
carrier board

4 matrixes of **8x8**
Hamamatsu S13650 **SiPMs**
(256) on rigid-flex pcb
4 **ntc** sensors on the back



4x adapters

HV regulation
AC coupling to ALCOR

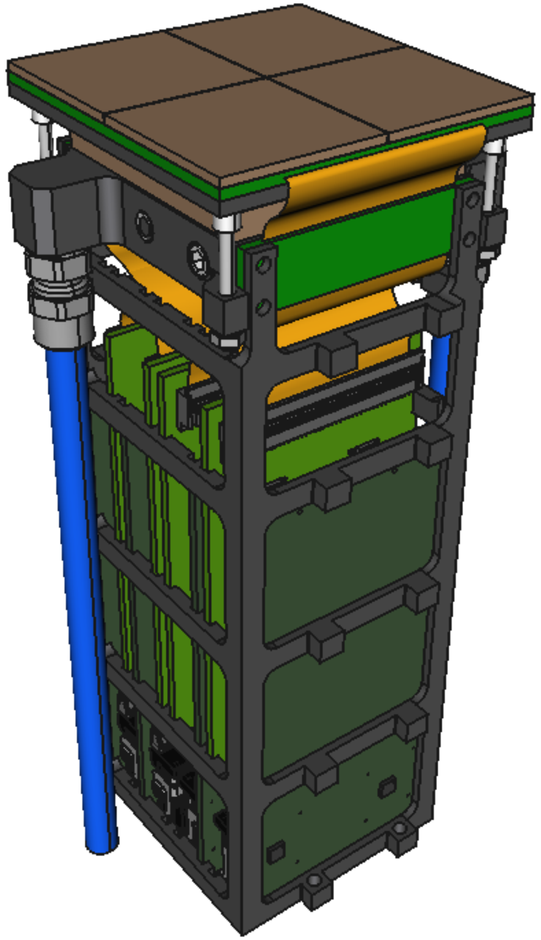


4x FE boards

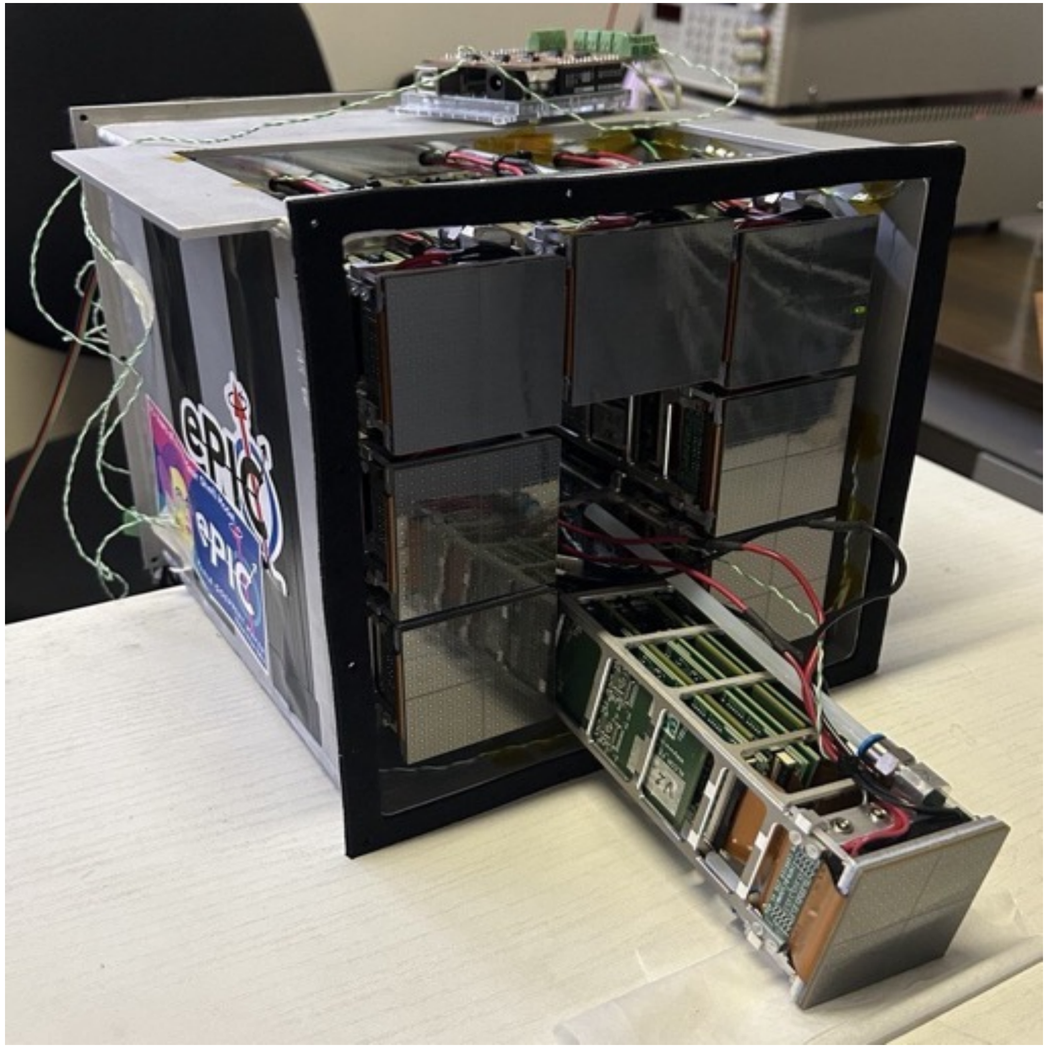
2x ALCOR-v2 (8 total)
2x Firefly connectors

L. Rignanese et al., JINST 19 (2024) 02, C02062

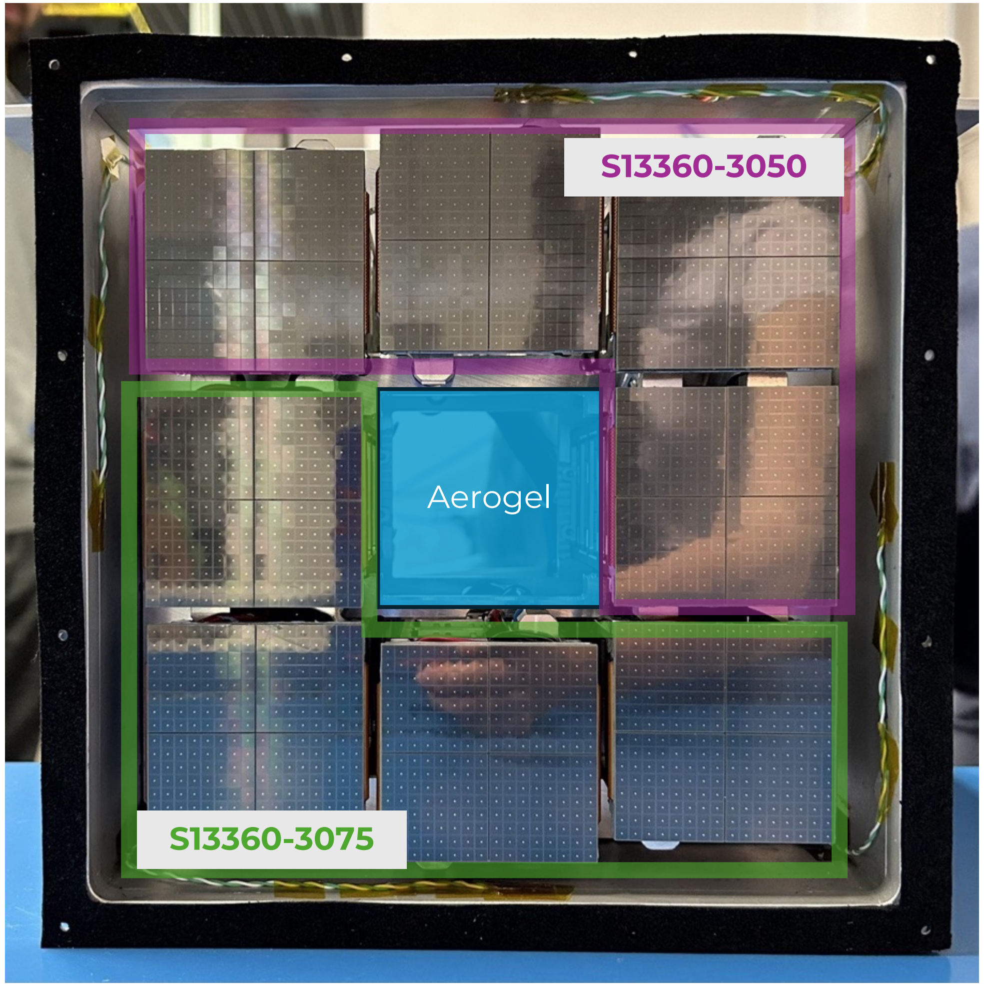
Detector box prototype



8x



Detector box prototype



20x20x20 cm^3

≈**400** cm^2 optical surface (1/10 of a dRICH sector)

2048-Hamamatsu S13360 SiPMs

2 different SPAD sizes (**50** and **75** um)

2 mm dead layer between PDUs

64 ALCOR v2 ASICS

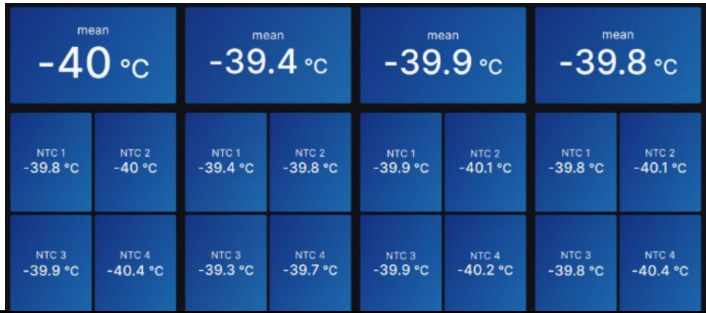
2048 TDC channels electronics

800 Mb/s data rate

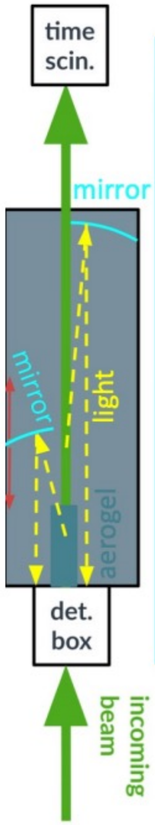
TEC active cooling (≈400 W)

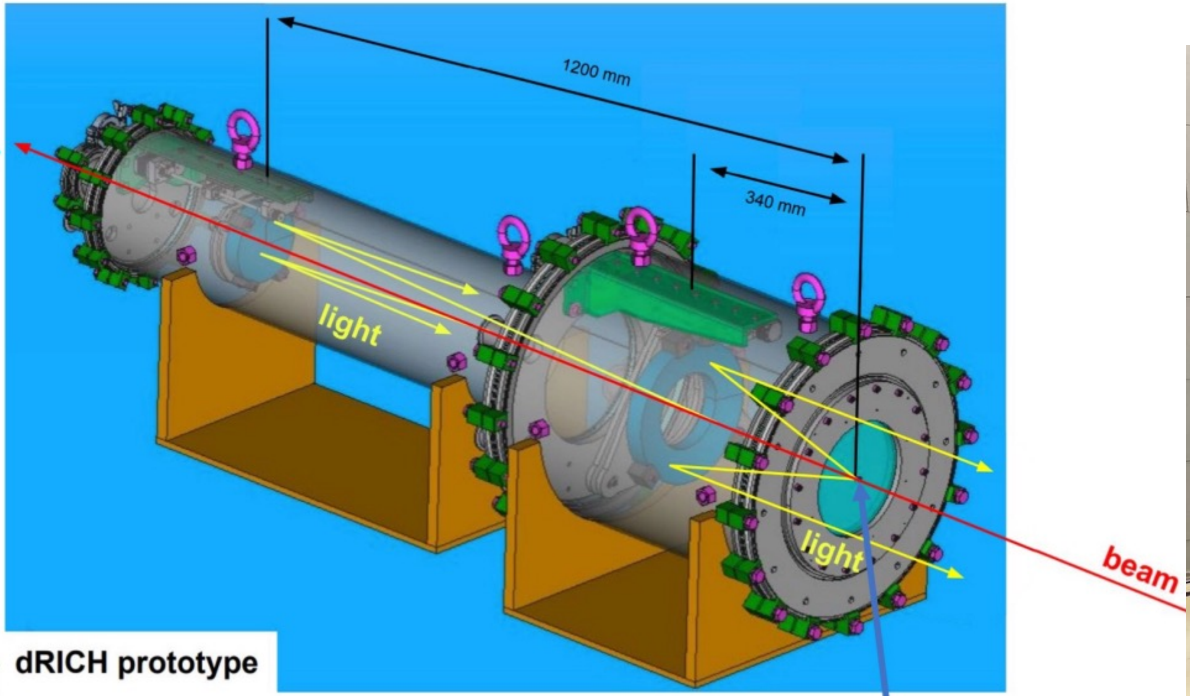
Automatically controlled temp down to **-40 °C**

10 °C water cooling

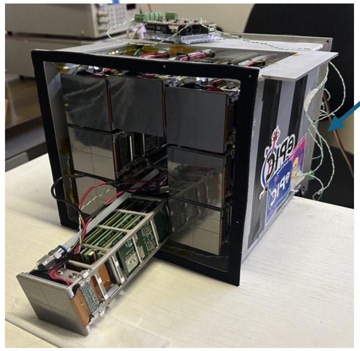


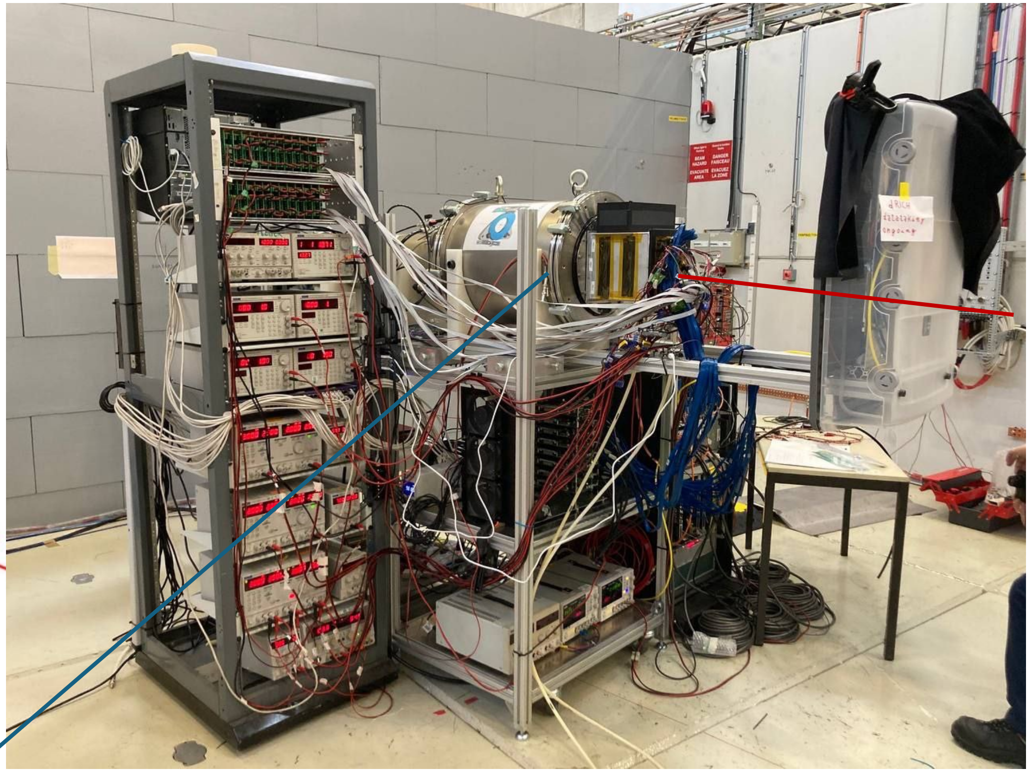
2024 test beam at CERN PS (ended 5 June)



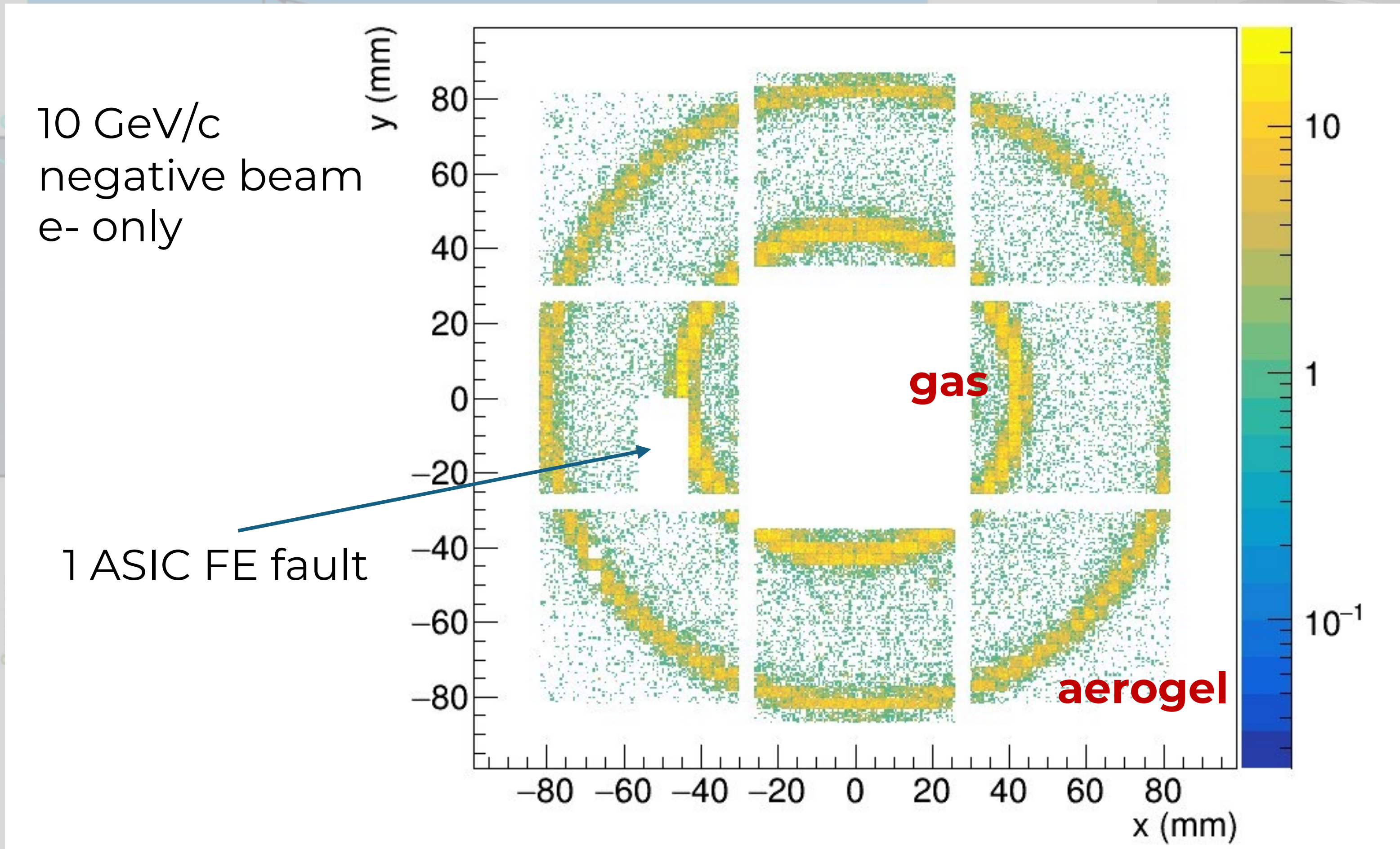


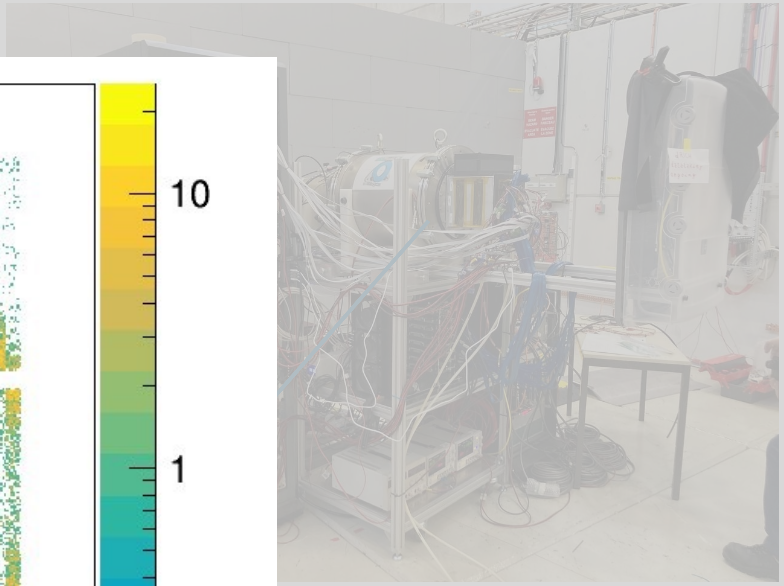
S. Vallarino et al., Nucl.Instrum.Meth.A 1058 2023





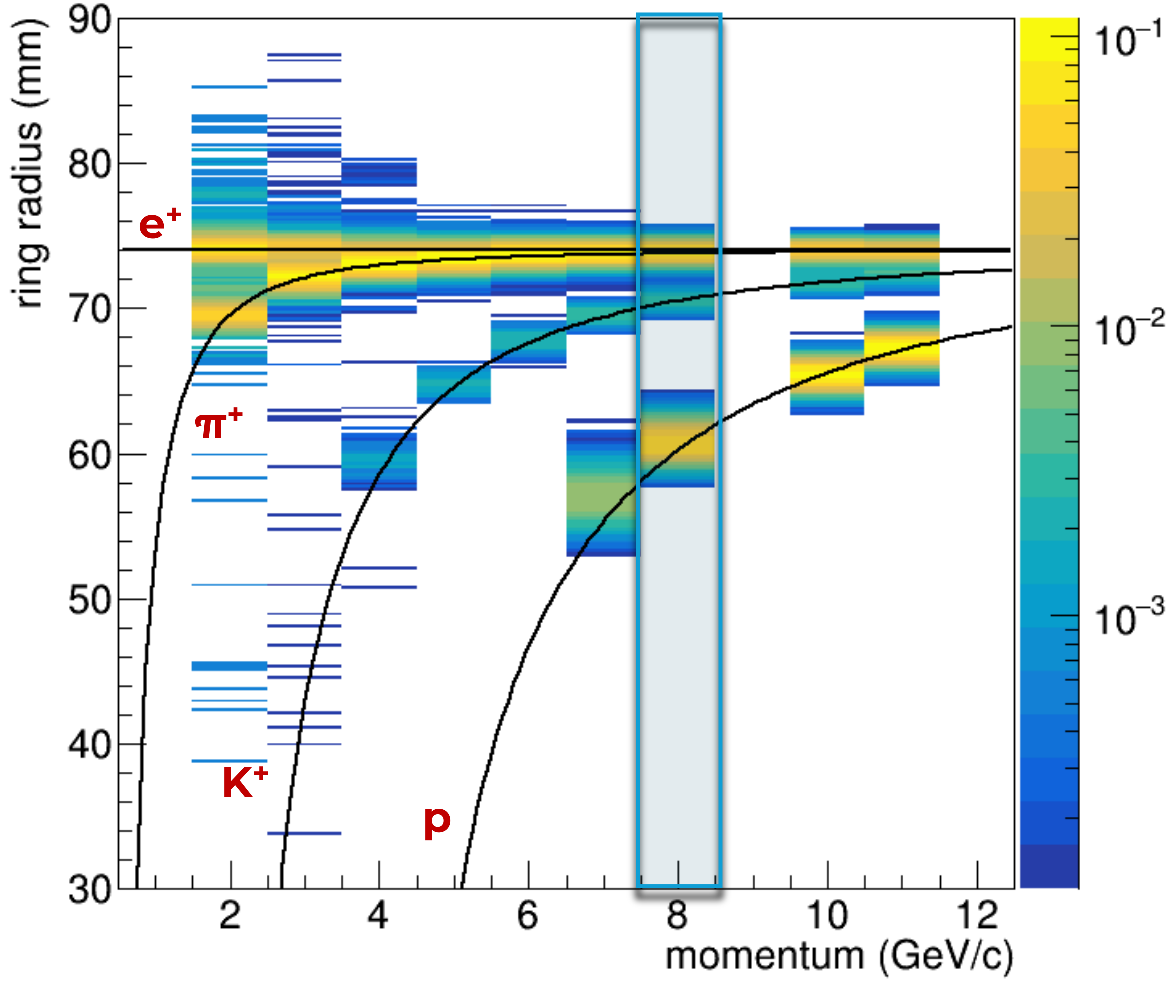
2024 test beam at CERN PS (ended 5 June)



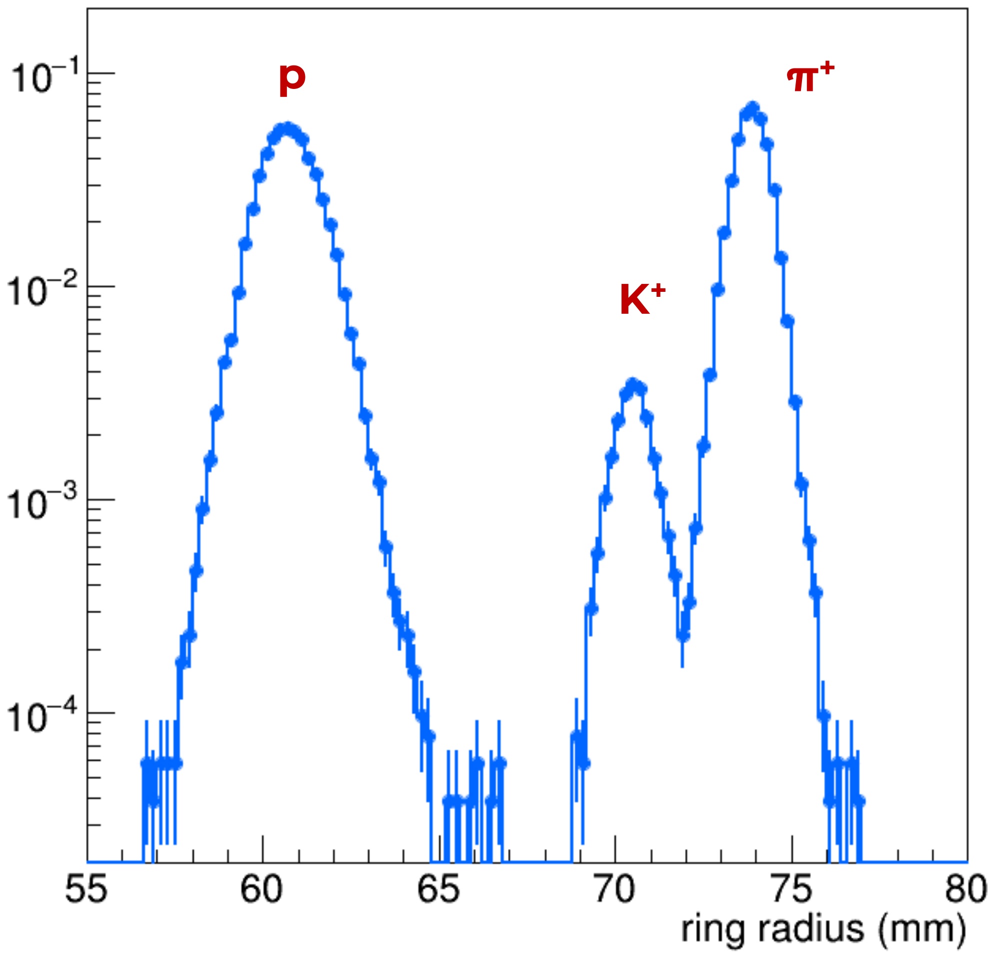


Positive beam momentum scan

Reconstructed radii vs. beam momentum

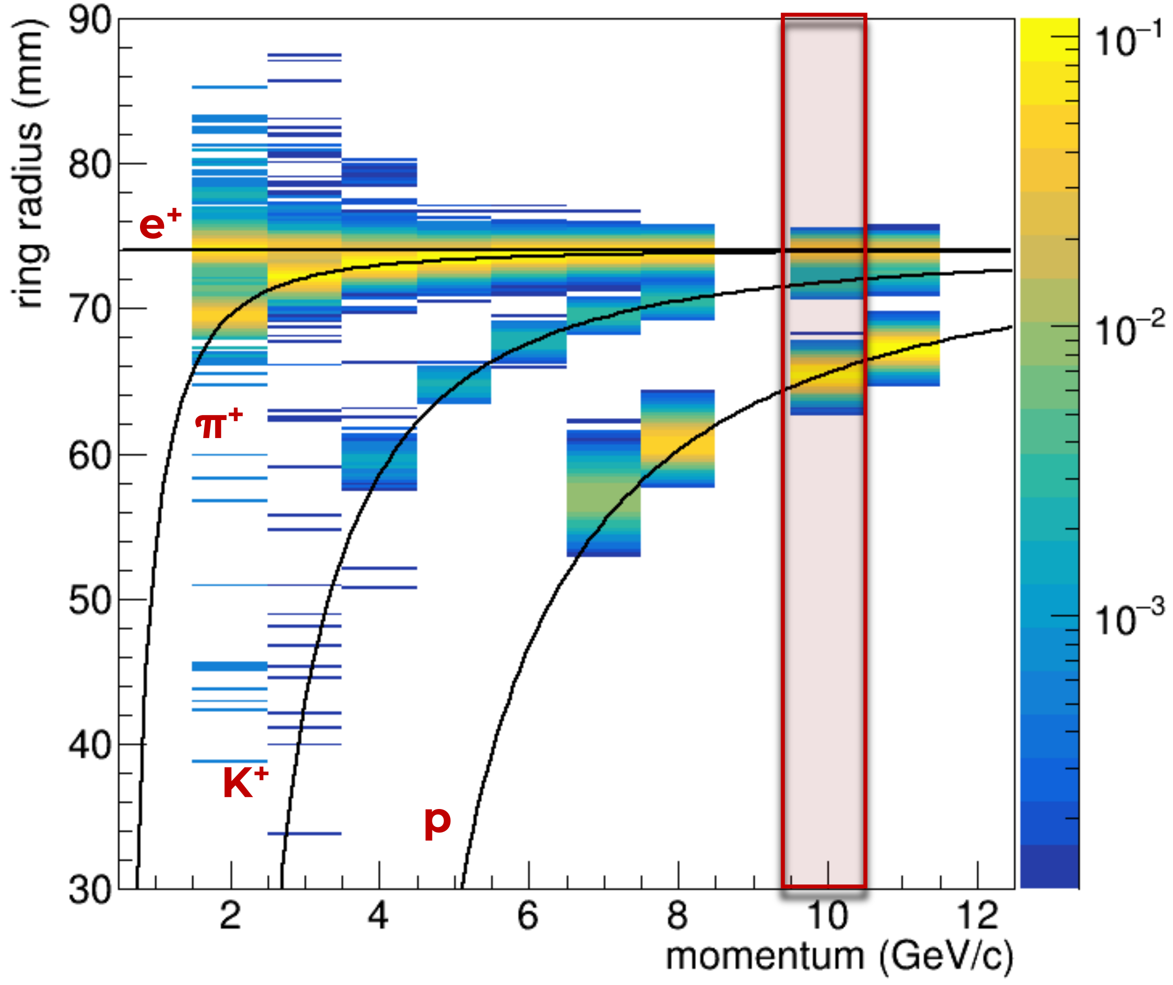


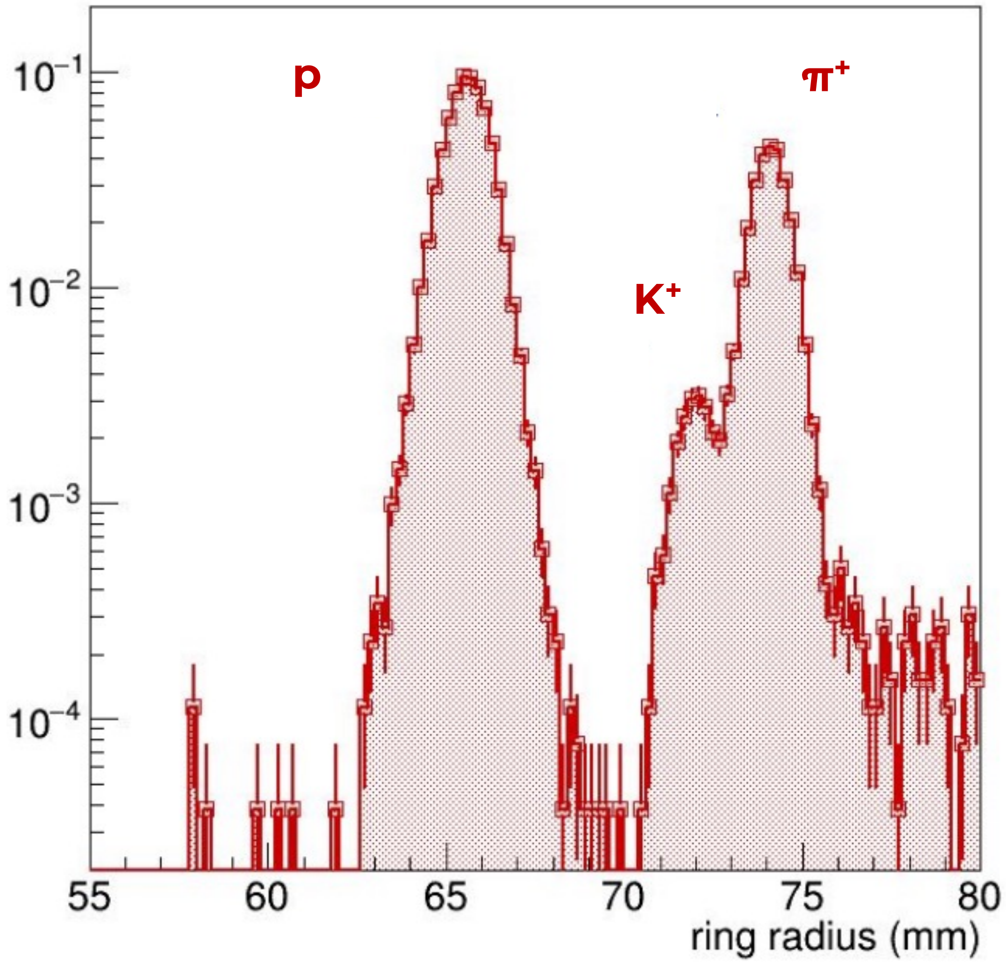
Aerogel only



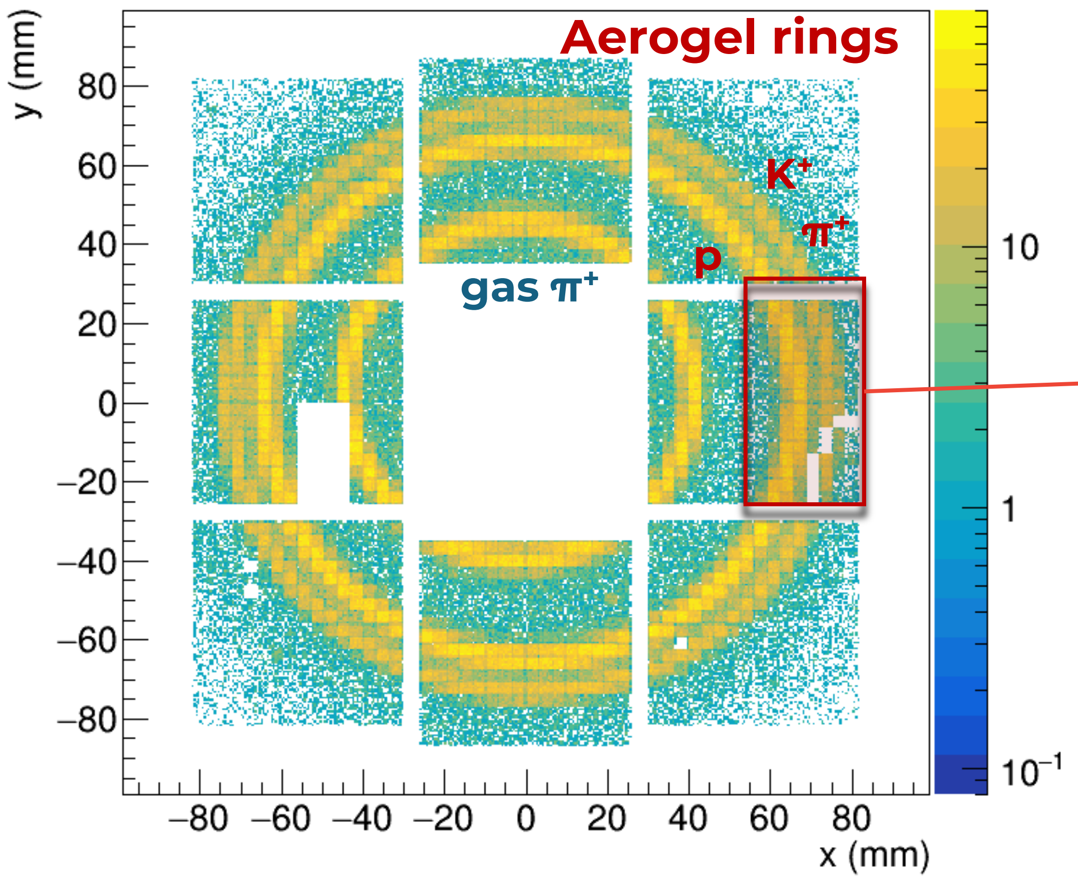
Positive beam momentum scan

Reconstructed radii vs. beam momentum

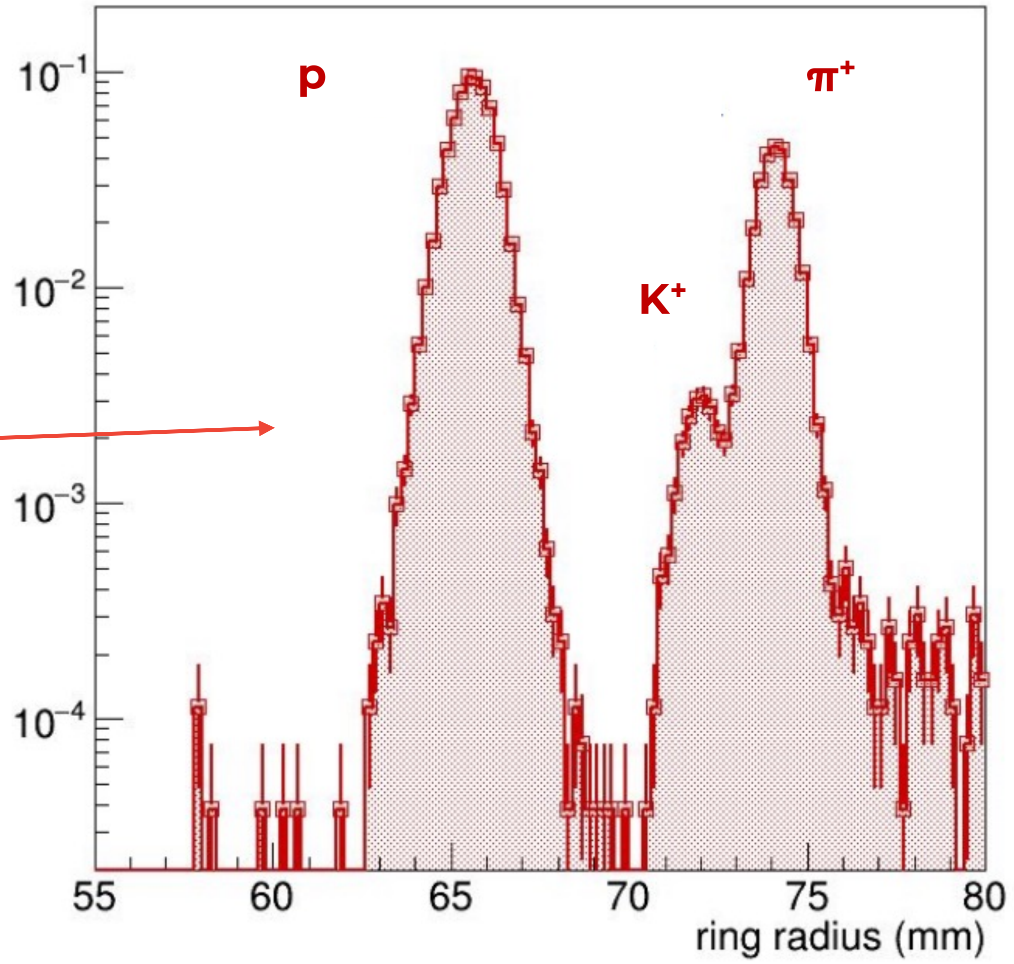




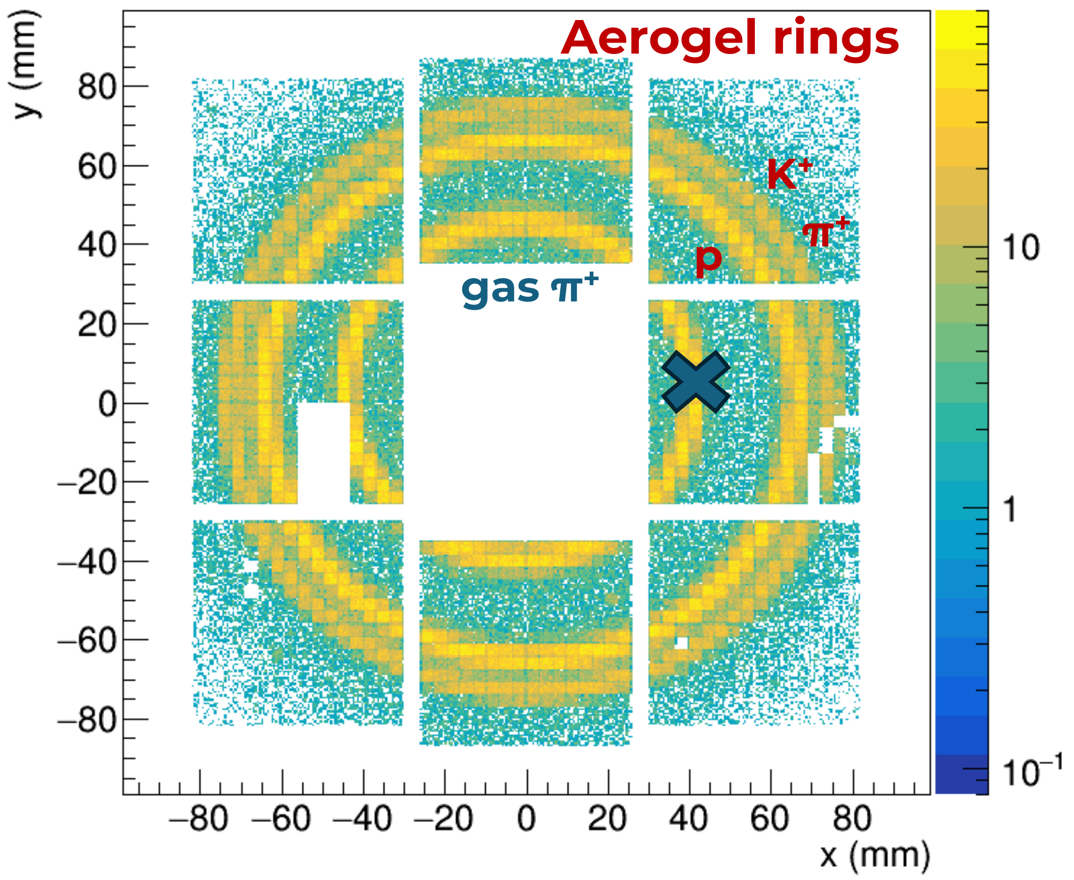
Positive beam momentum scan



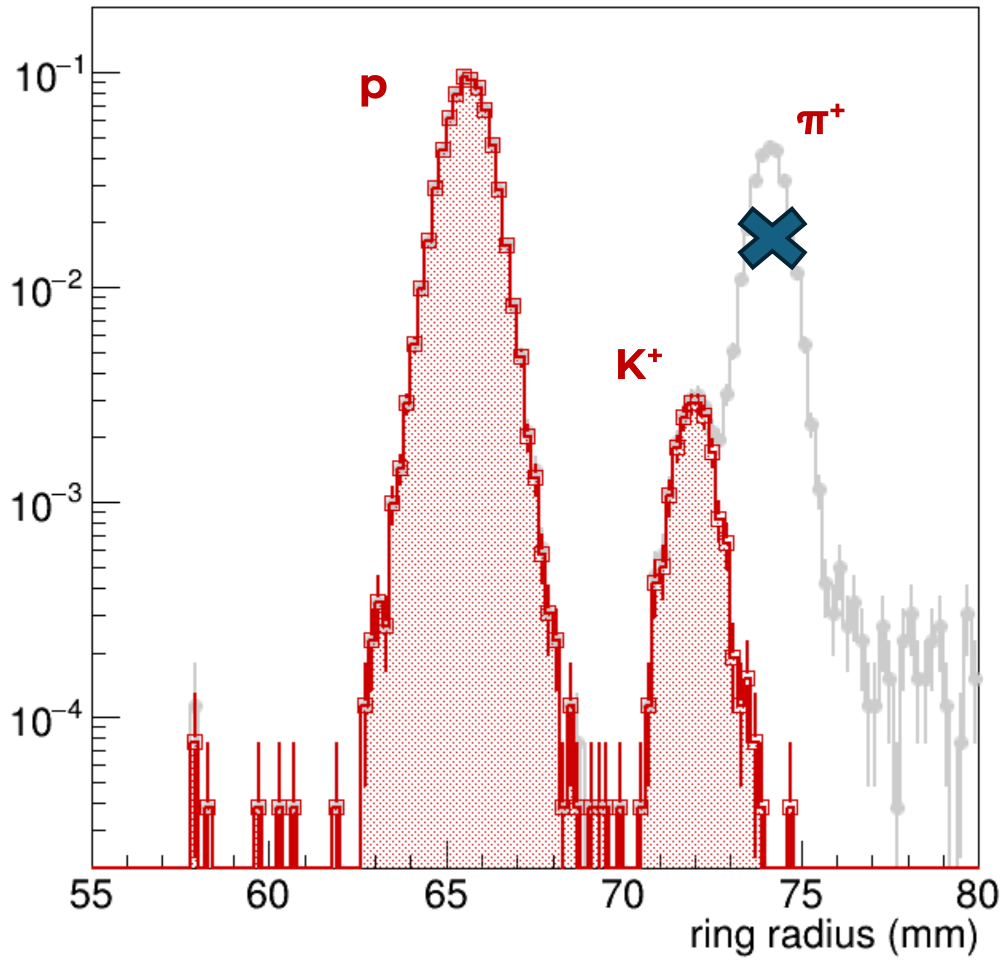
10 GeV/c positive beam with no selection applied



Positive beam momentum scan



10 GeV/c positive beam with π in gas as veto



Summary

Successfull **R&D** program to operate **SiPM** in mild **radiation** environment through **annealing**

400 cm² demonstrator with full **electronics** readout working with **dRICH prototype**

First SiPMs application for a RICH in HEP experiment

THANK YOU