A large-area prototype SiPM readout plane for the dRICH detector of ePIC at the EIC: test at the CERN-PS facility

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for the ePIC Collaboration

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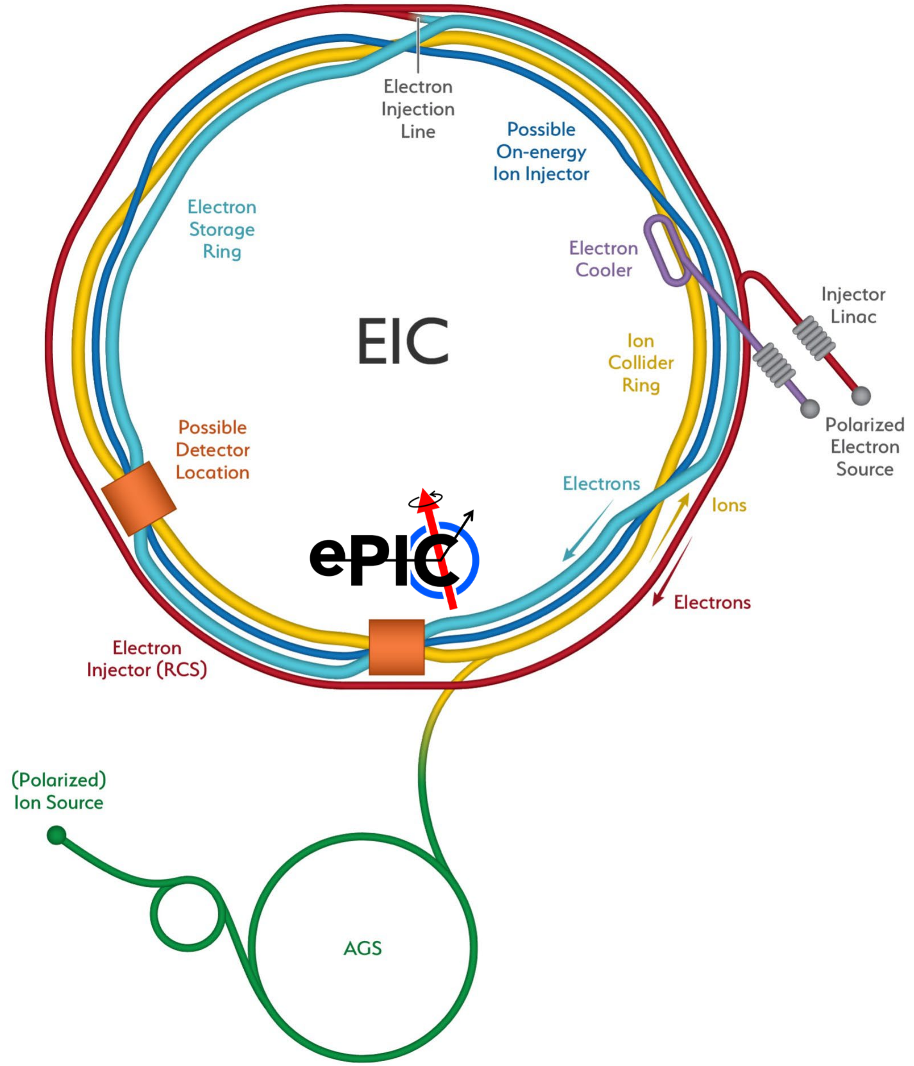
Outline

- The experiment
  - EIC
  - ePIC detector
  - dRICH
- Prototype
  - Photo-Detection Unit (PDU)
  - Readout Box
  - dRICH module
- CERN-PS test beam
  - Setup
  - Signal extraction
  - MC comparison
  - Results

EIC and the ePIC experiment

- Electron-Ion Collider (EIC) is a future accelerator at the Brookhaven National Lab
  - High Luminosity
  - Polarised beams
  - 20 < Collision energy < 140 GeV
  - Various ion species

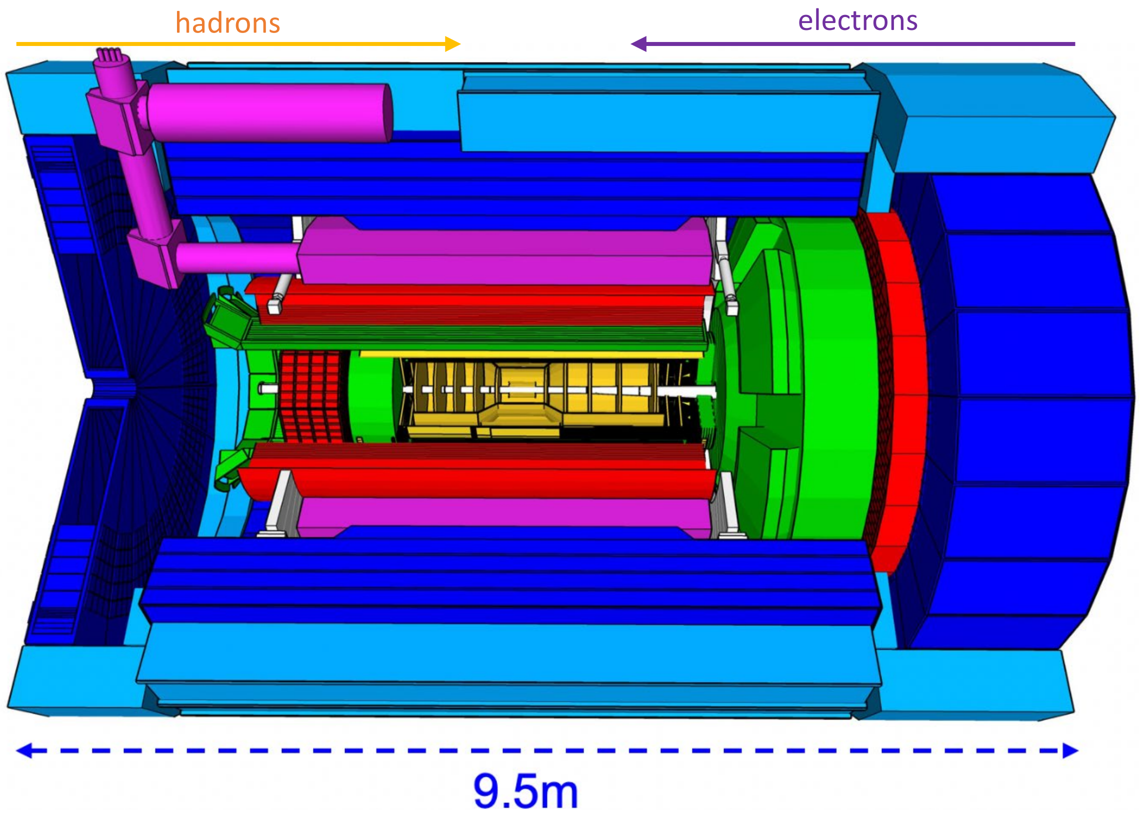
- Multiple physics targets and studies
  - Distribution of sea quarks and gluons
  - Origin of nucleon mass and spin
  - Gluon density in nuclei
  - Existence of Color Glass Condensate
  - In-depth study of strong nuclear force



EIC and the ePIC experiment

- Electron-Proton/Ion Collider is the first approved EIC detector
  - Collaboration of 171 institutions and 24 countries

- It will feature a 1.7 T superconducting magnet and various detectors
  - Tracking:
    - MAPS + MPGDs
  - PID:
    - AC-LGAD TOF
    - pfRICH
    - hpDIRC
    - dRICH
  - Calorimetry:
    - e-endcap: $PbWO_4$ EMCal
    - Barrel: imaging EMCal
    - outer barrel: HCal
    - h-endcap: finely segmented calorimeter



Hadronic calorimeters

Solenoidal magnet

Electromagnetic calorimeters

Time-of-flight, DIRC and RICH detectors

Tracking detectors (MAPS and MPGD)

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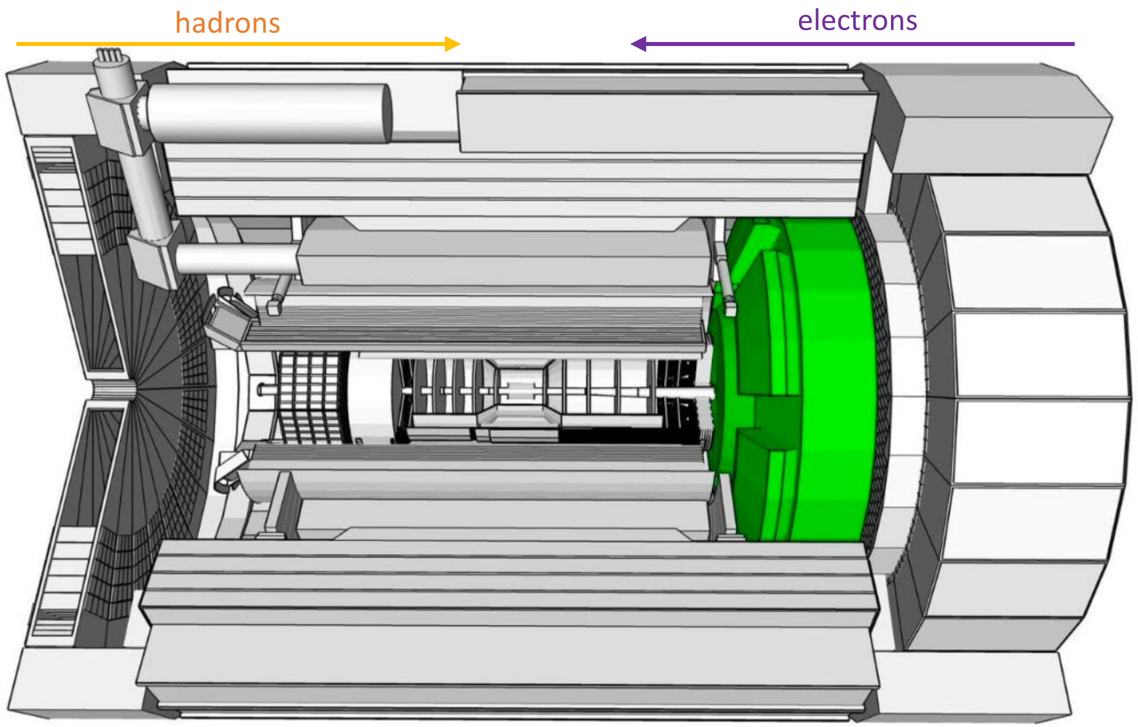


dRICH

dRICH

- Dual-radiator RICH (dRICH) is a compact and cost-effective solution for broad momentum coverage at forward rapidity
  - 3 - 60 GeV/*c* and $1.5 < \eta < 3.5$
- 6 open sectors with large mirrors for Cherenkov light outward reflection
  - Light generated from particles passing through aerogel (n ~ 1.02) and C_2F_6 (n ~ 1,0008)
- Photosensors based on SiPM:
  - 3x3 mm^2 pixels
  - 0.5 m^2 per sector

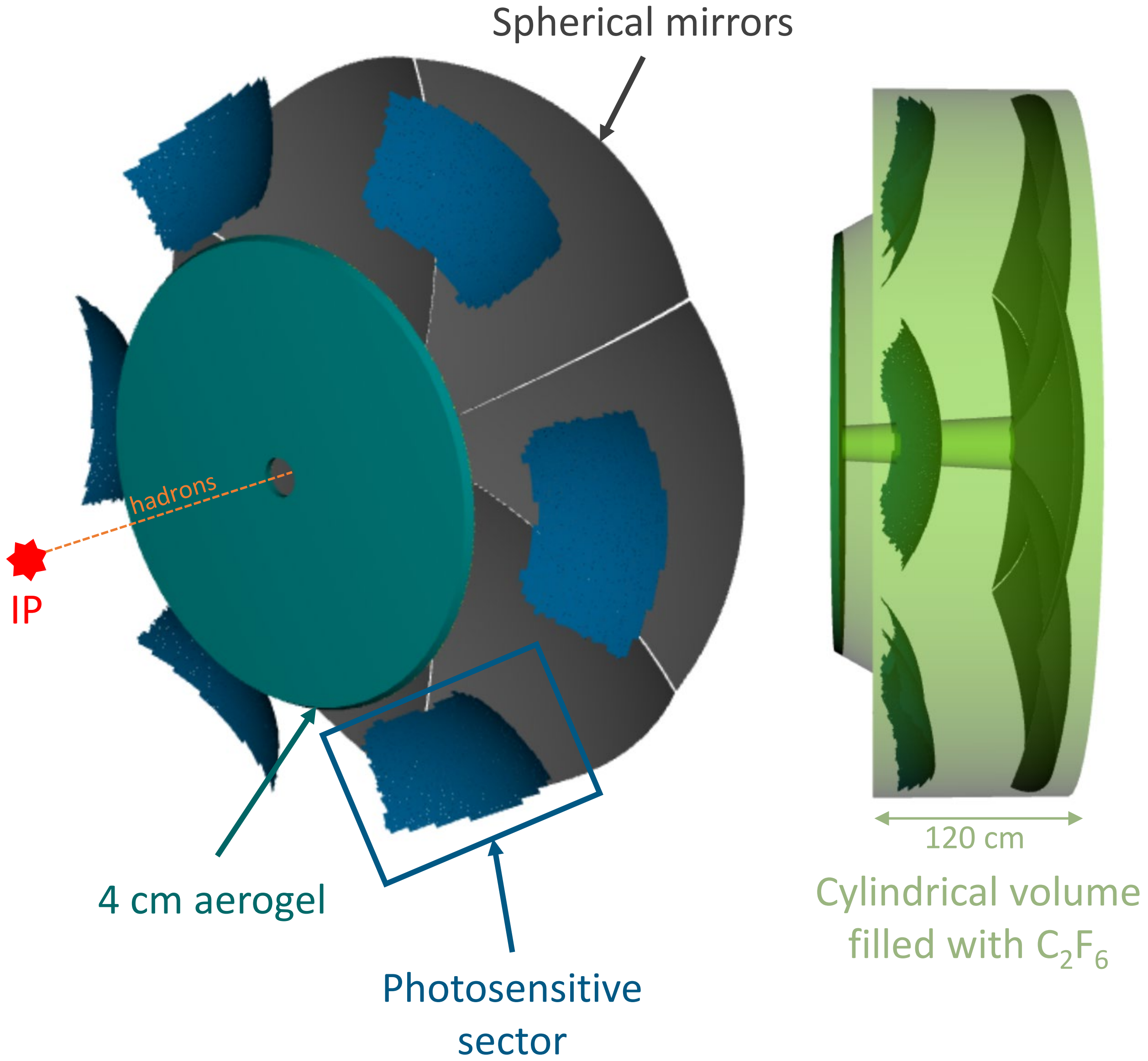
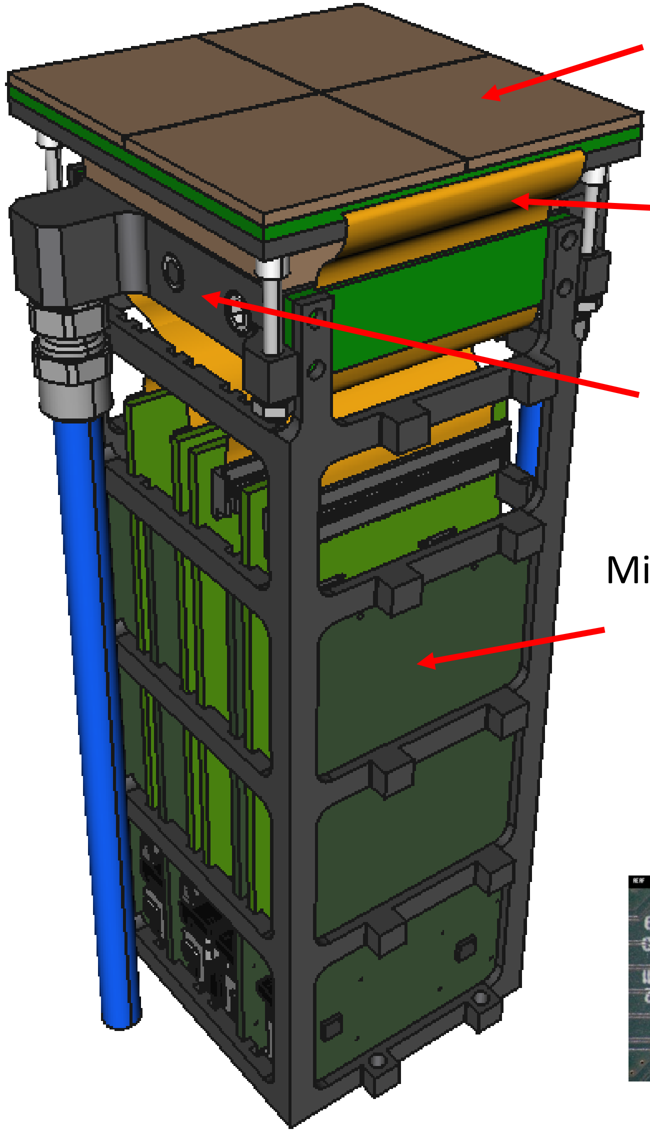
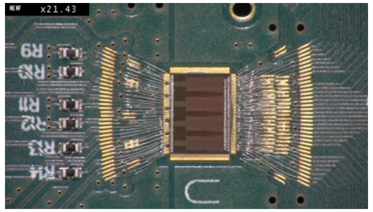
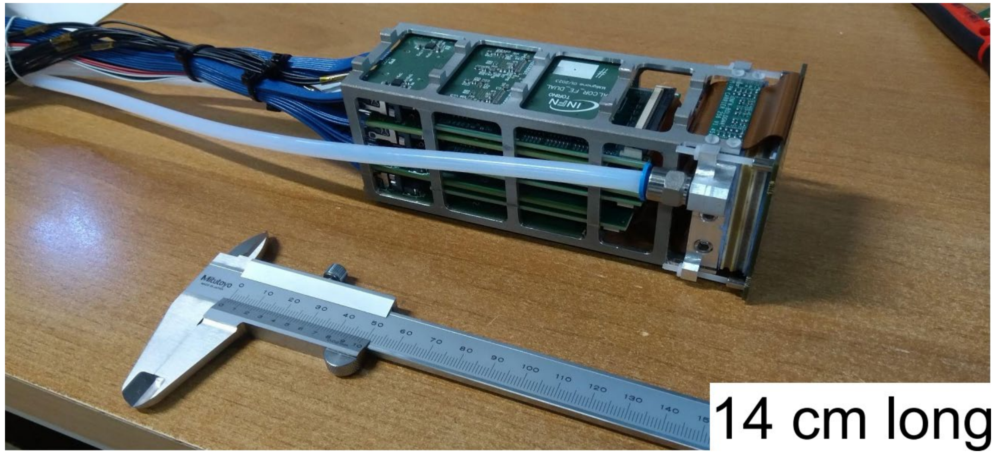


Photo-detection unit (PDU)



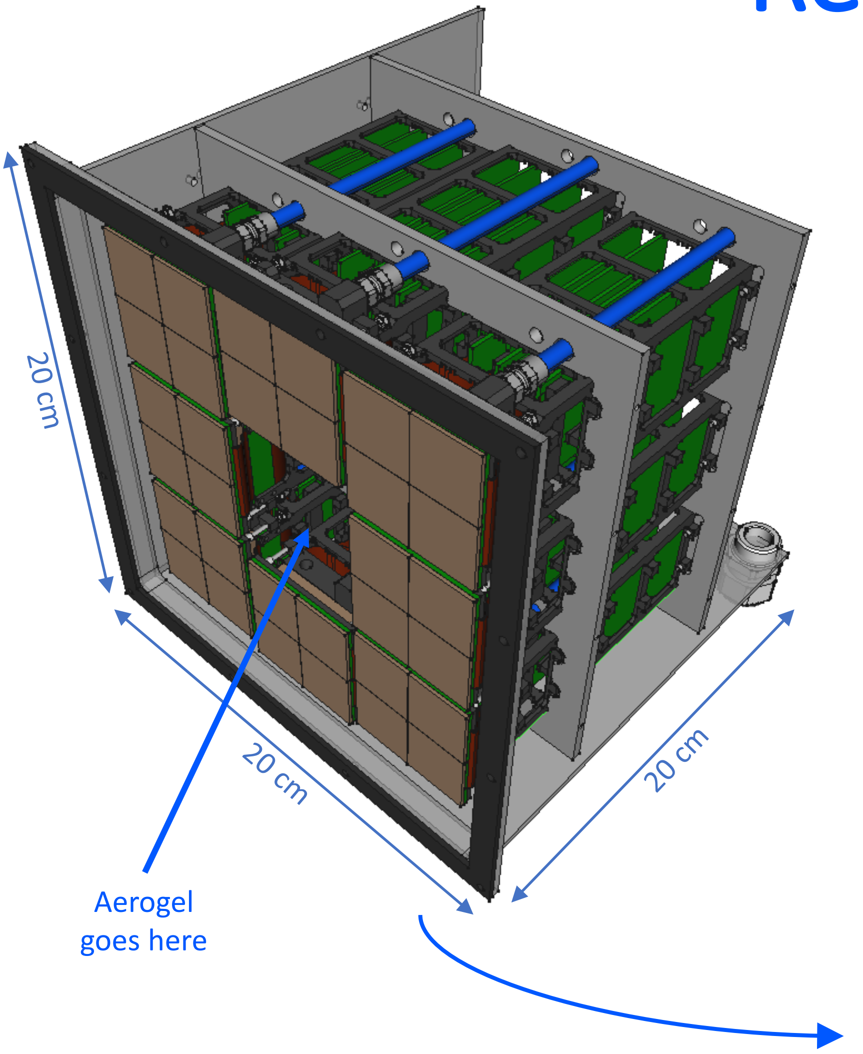


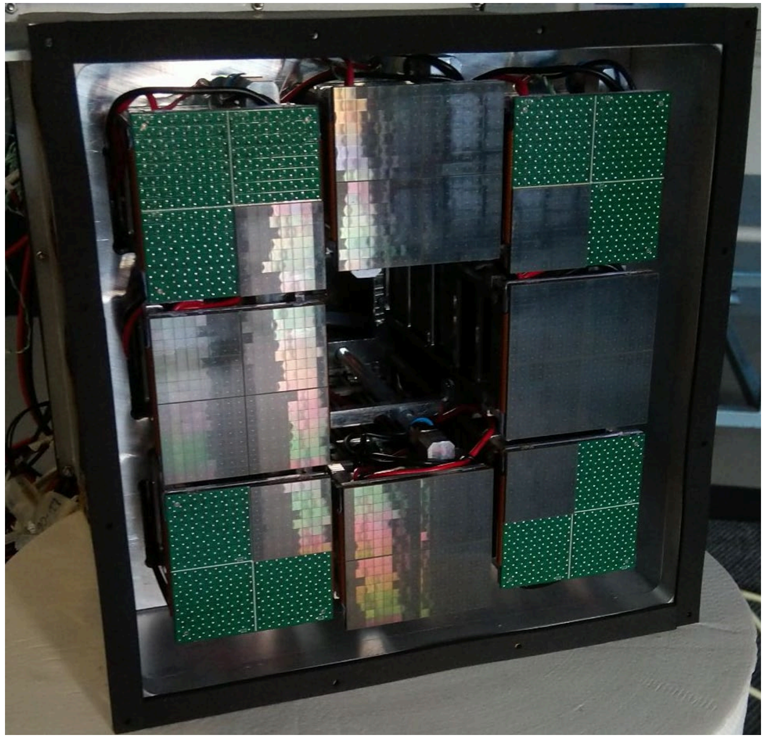
- PDUs are the fundamental detection components of our prototype
- 8x8 SiPM matrices (Hamamatsu*) → 256 channels in total per PDU
- Sub-zero operating temperatures reached with 2 Peltier modules
- Lightweight aluminum structure hosts front-end electronics based on ALCOR chips



*HPK S13360-3050VS

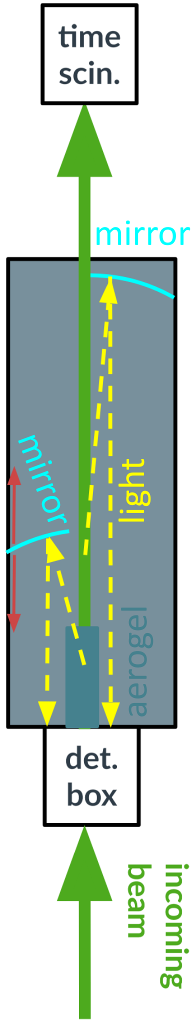
Readout prototype box

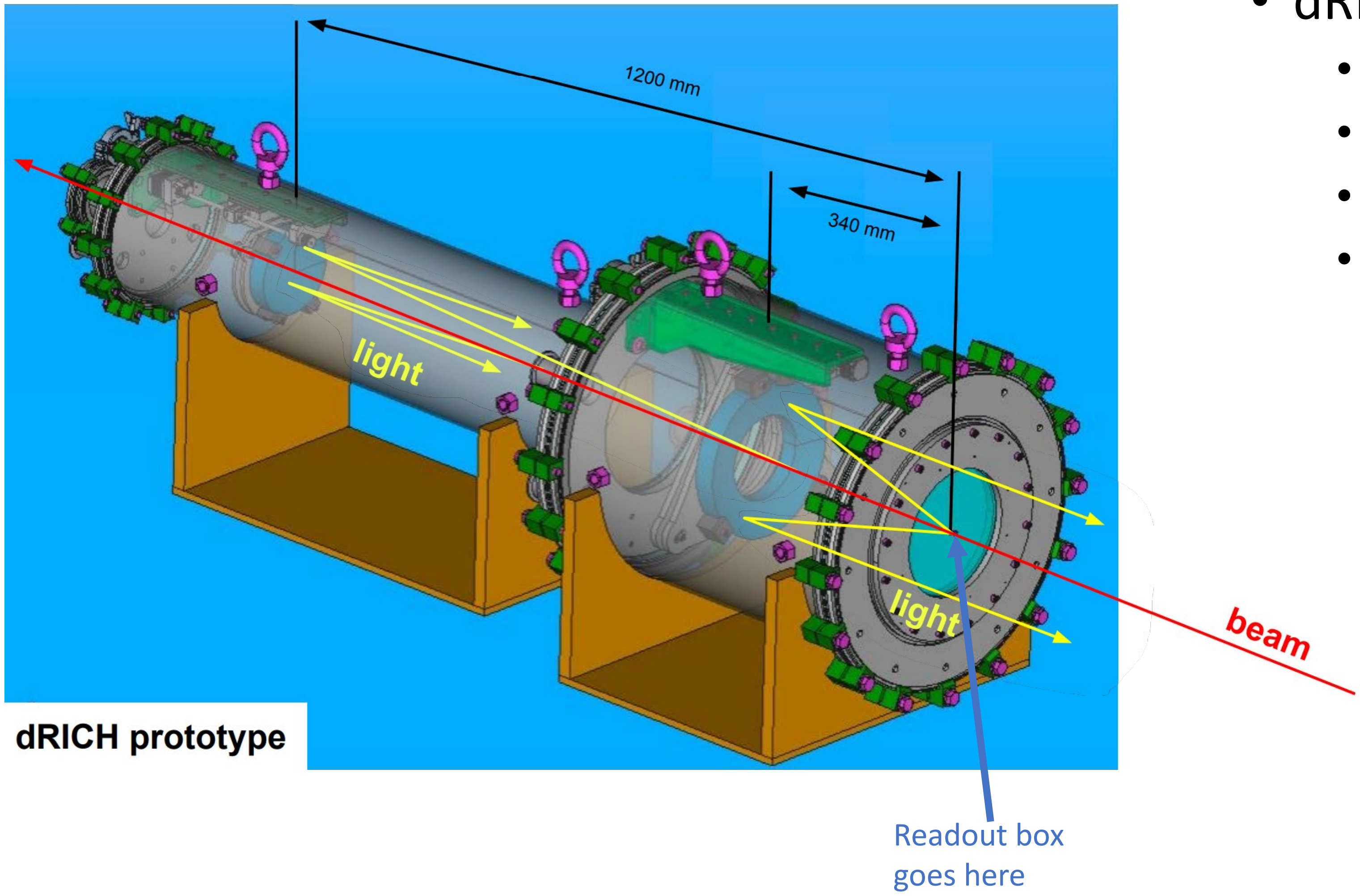




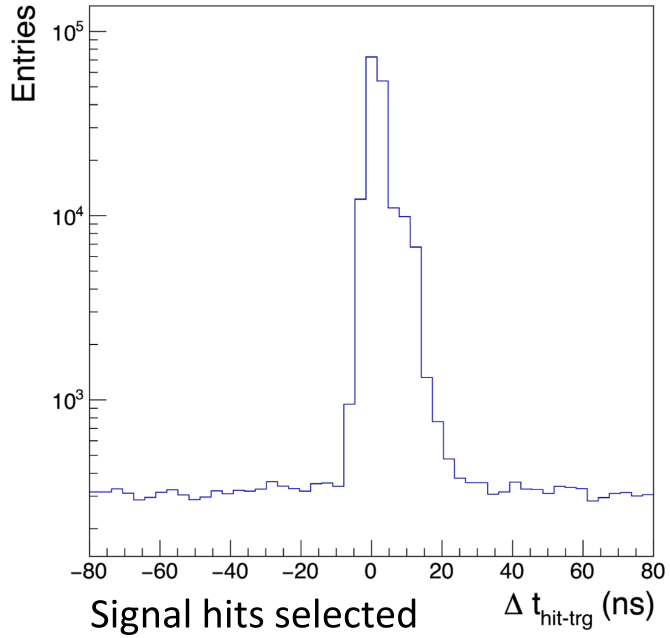
- 8 PDUs operated for the readout prototype:
  - Design used for test beam contains 4 incomplete PDUs at the corners
  - Total of 1280 channels
- Box attached to beam receiving side of dRICH prototype

Test beam setup (October 2023)



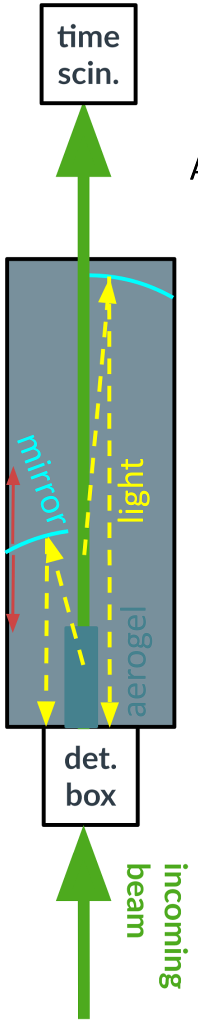


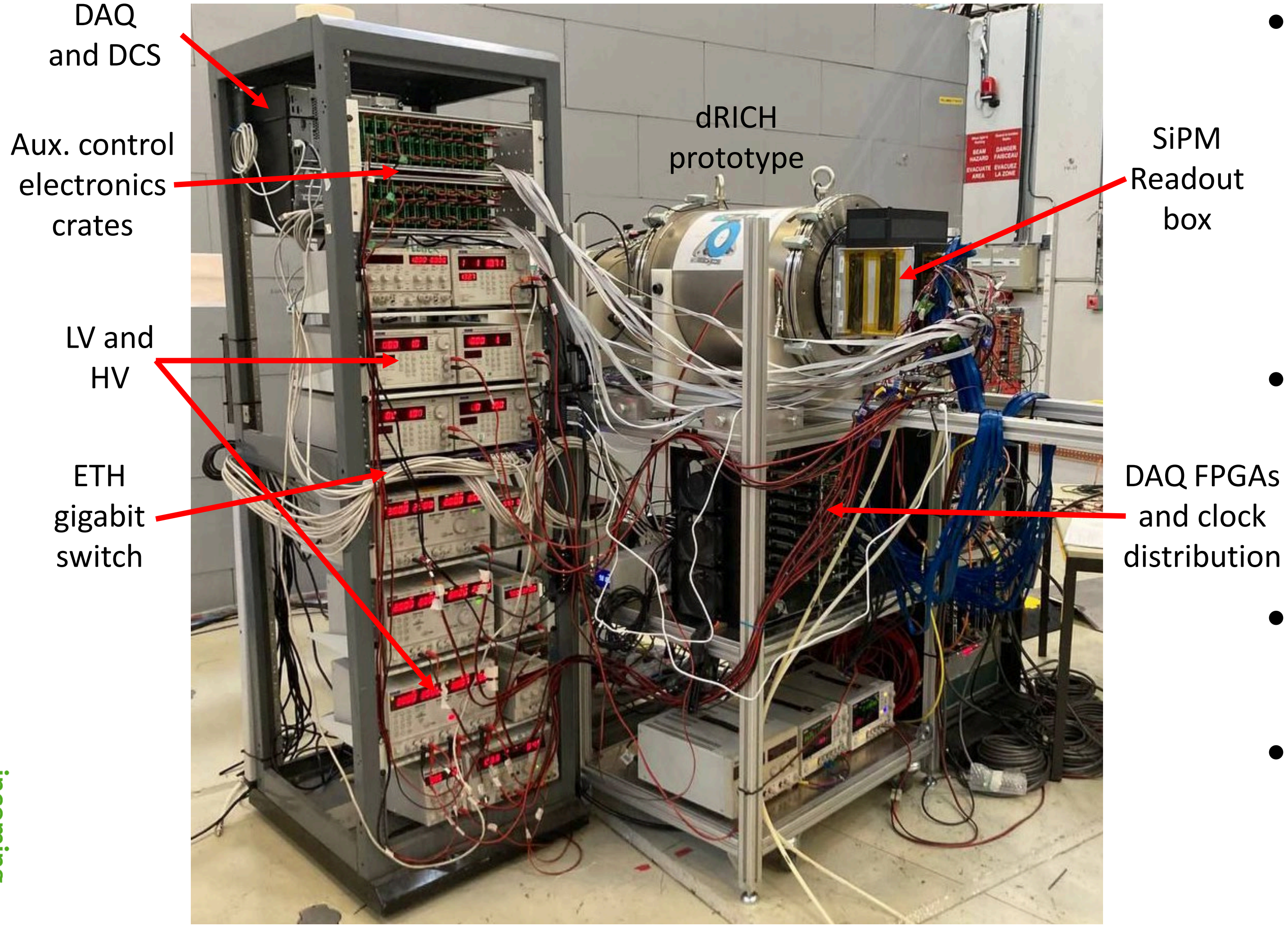
- dRICH prototype comprises:
  - Readout box
  - Gas chamber
  - Two mirrors focusing Cherenkov γ
  - Triggerless system (continuous readout) ⟶ scintillator for timing



Signal hits selected coherently with beam arrival

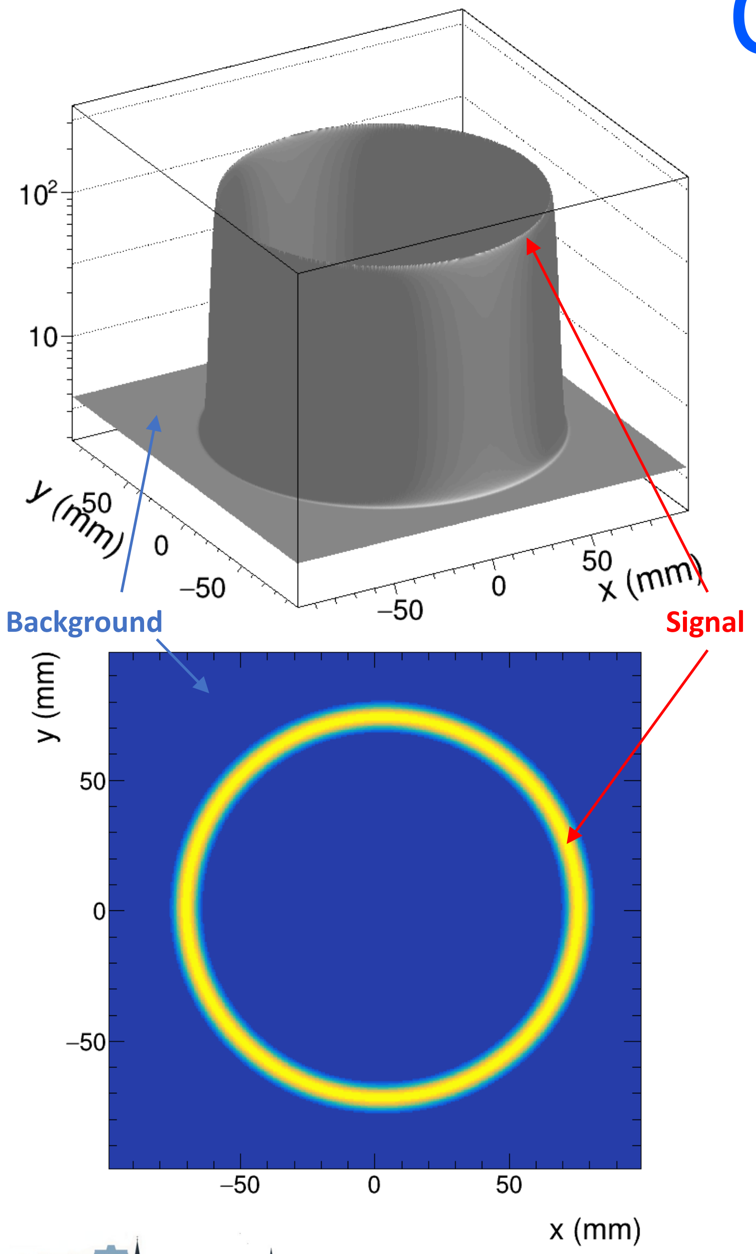
Test beam setup (October 2023)





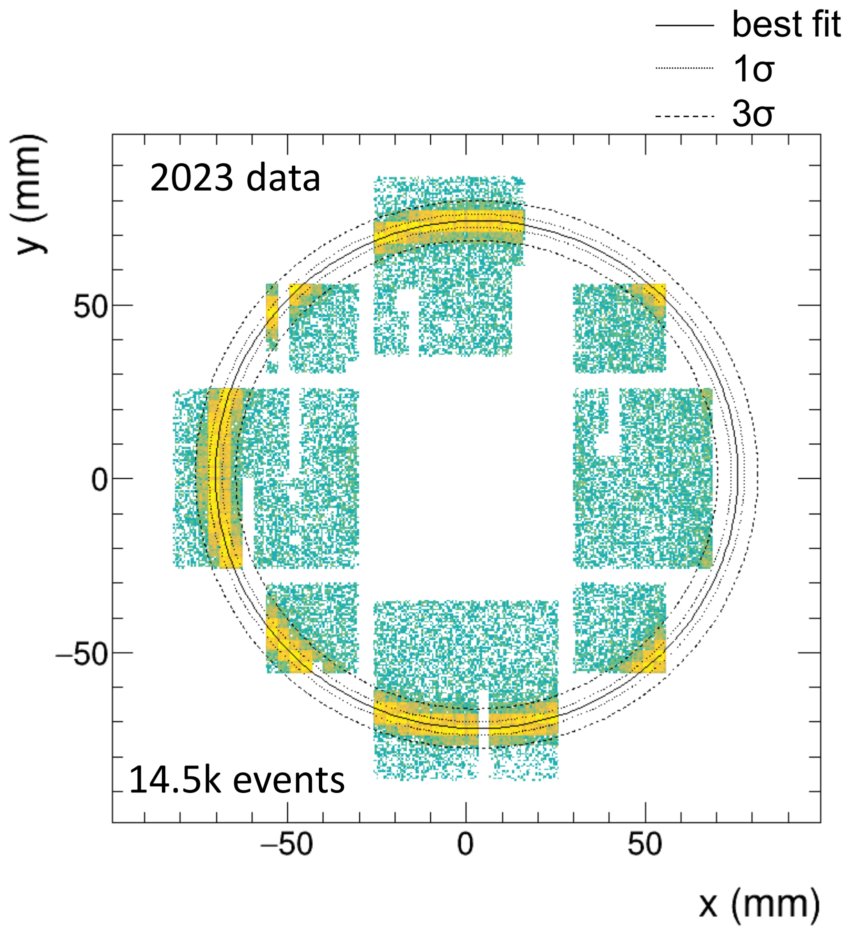
- dRICH prototype comprises:
  - Readout box
  - Gas chamber
  - Two mirrors focusing Cherenkov γ
  - Triggerless system (continuous readout) ⟶ scintillator for timing
- Data acquired via FPGAs connected to front-end
  - 1 gigabit ETH connection to DAQ machine
- Masterlogic boards used for auxiliary electronic control
- CERN-PS Beam settings could be tweaked to change particle abundances

Cherenkov ring fitting



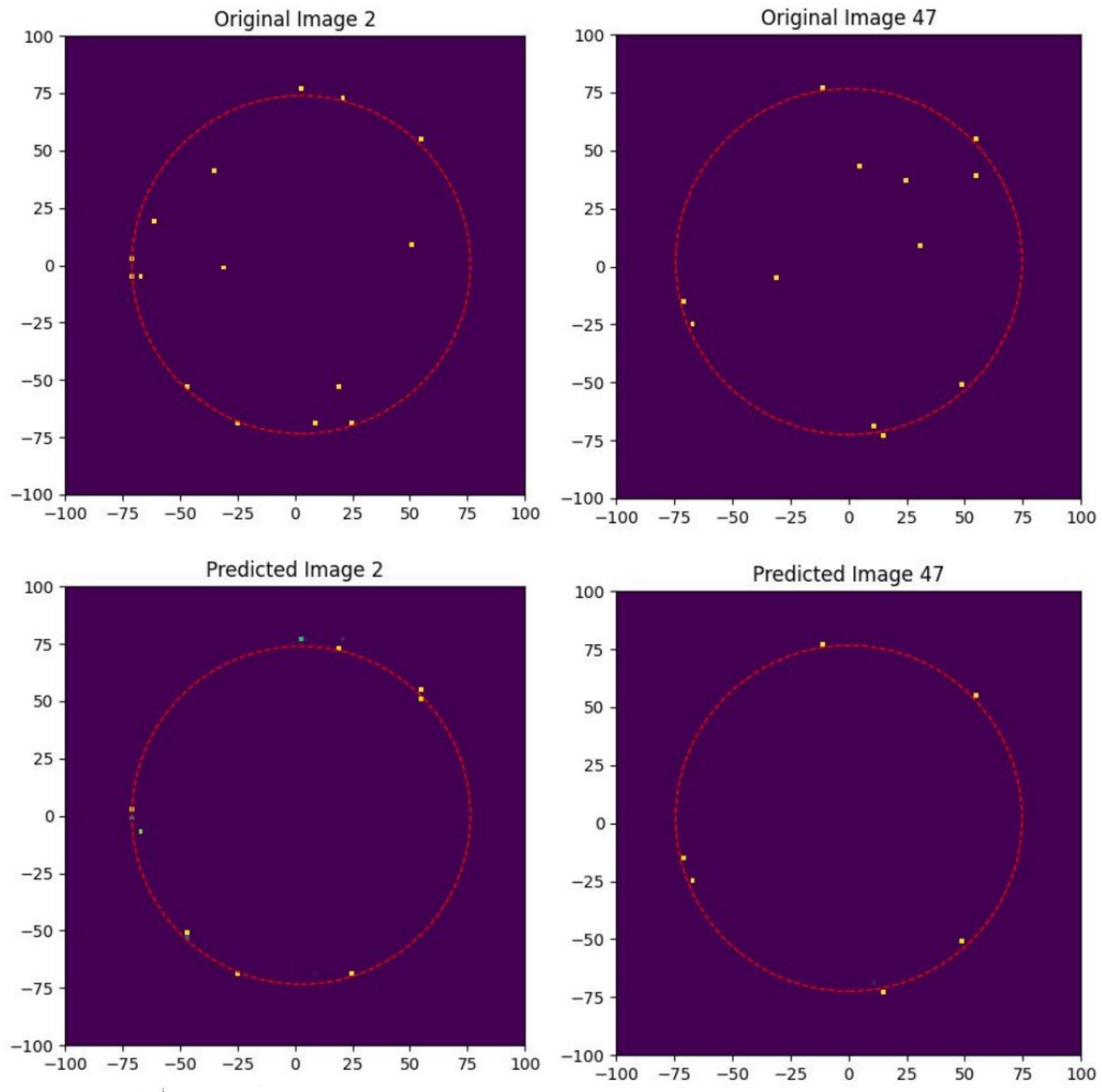
- 2D fit function:
  - signal: circle with gauss smearing
  - background: flat
- χ^2 minimization applied:
  - integrates function to properly consider SiPM active area
  - proper errors computation

Fit performed on full run data



Nsig	=	23.6048	+/-	0.0154101
X0	=	2.87125	+/-	0.00255149
Y0	=	1.18834	+/-	0.00193679
R	=	73.0013	+/-	0.00166626
sigmaR	=	1.88591	+/-	0.00123206
Nbkg	=	10.3538	+/-	0.0133316

A preliminary ML alternative for reconstruction



Prompt

ML ring selection

As a possible alternative to standard methods a machine learning algorithm was explored

↓

The ring pattern recognition of hits is promising → background events are correctly discarded

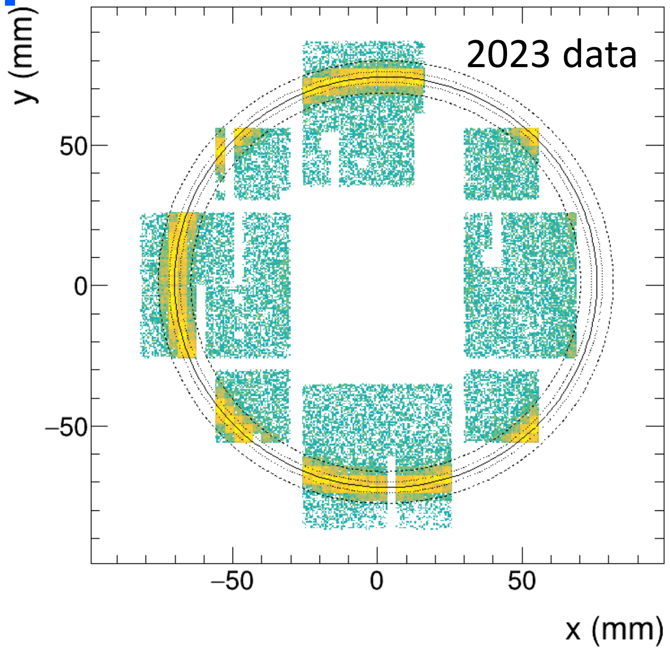
↓

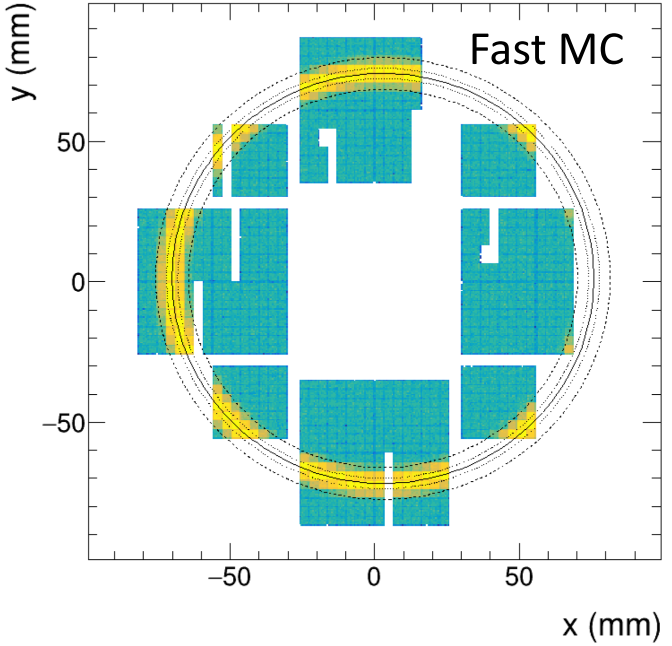
More complete studies will be performed to understand implementation feasibility

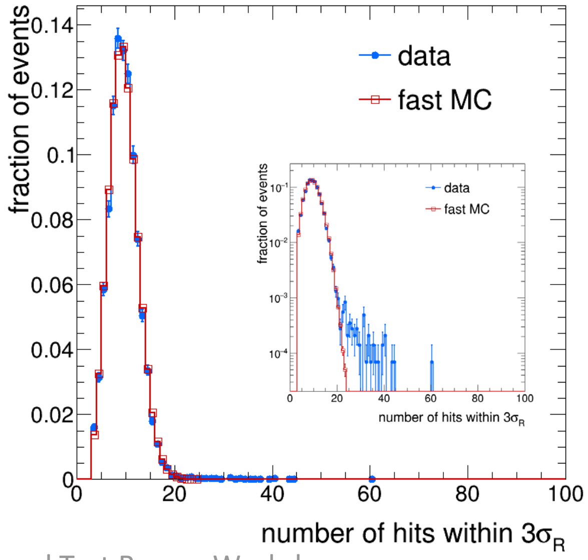
Extraction of n_γ and MC comparison

- n_γ extracted event-by-event within 3σ of the globally-fitted ring radius
- Gaussian fit performed on n_γ distribution

$\langle n_\gamma \rangle = 9.056 \pm 0.025$







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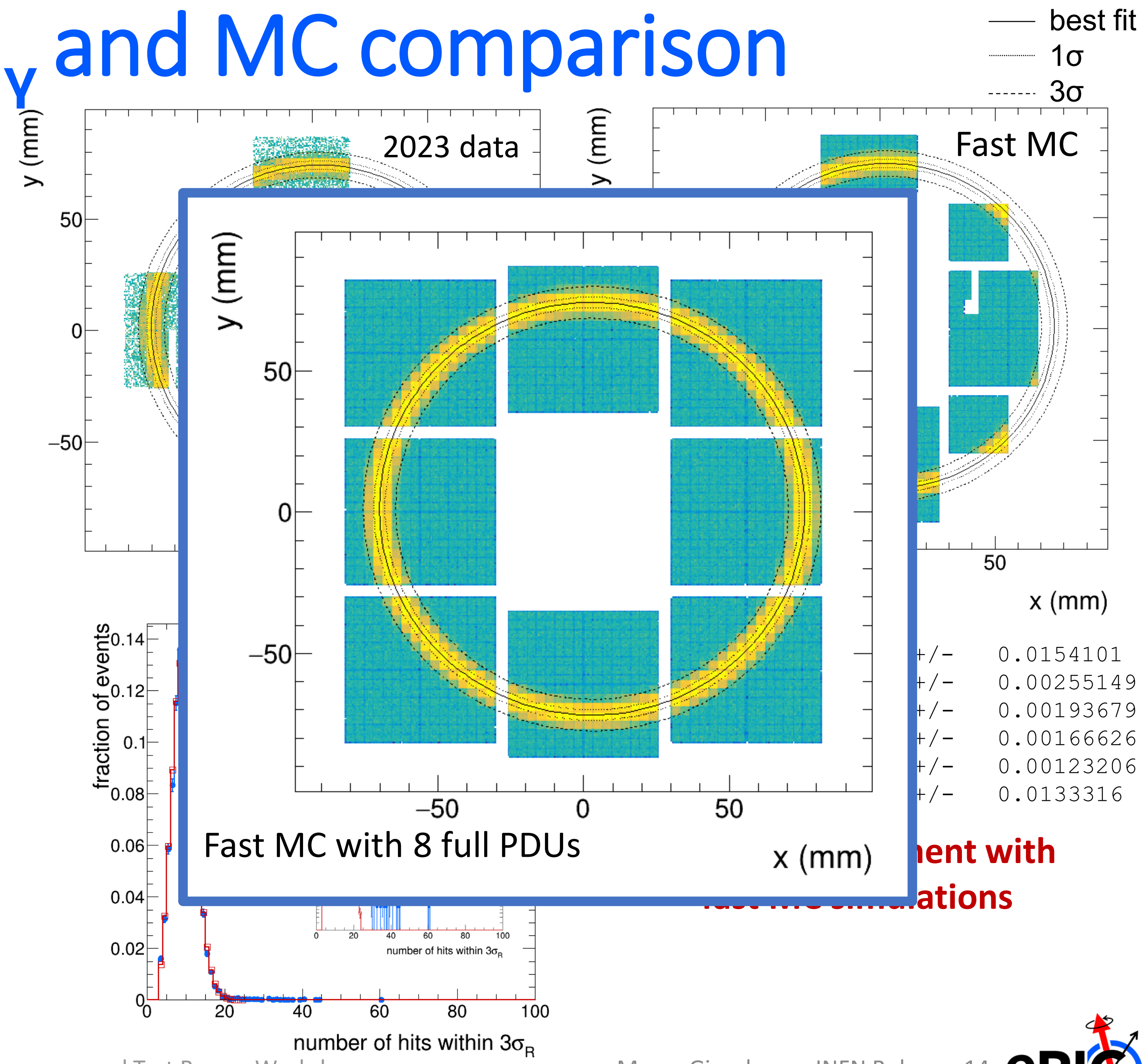
Accurate agreement with fast MC simulations

Extraction of n_γ and MC comparison

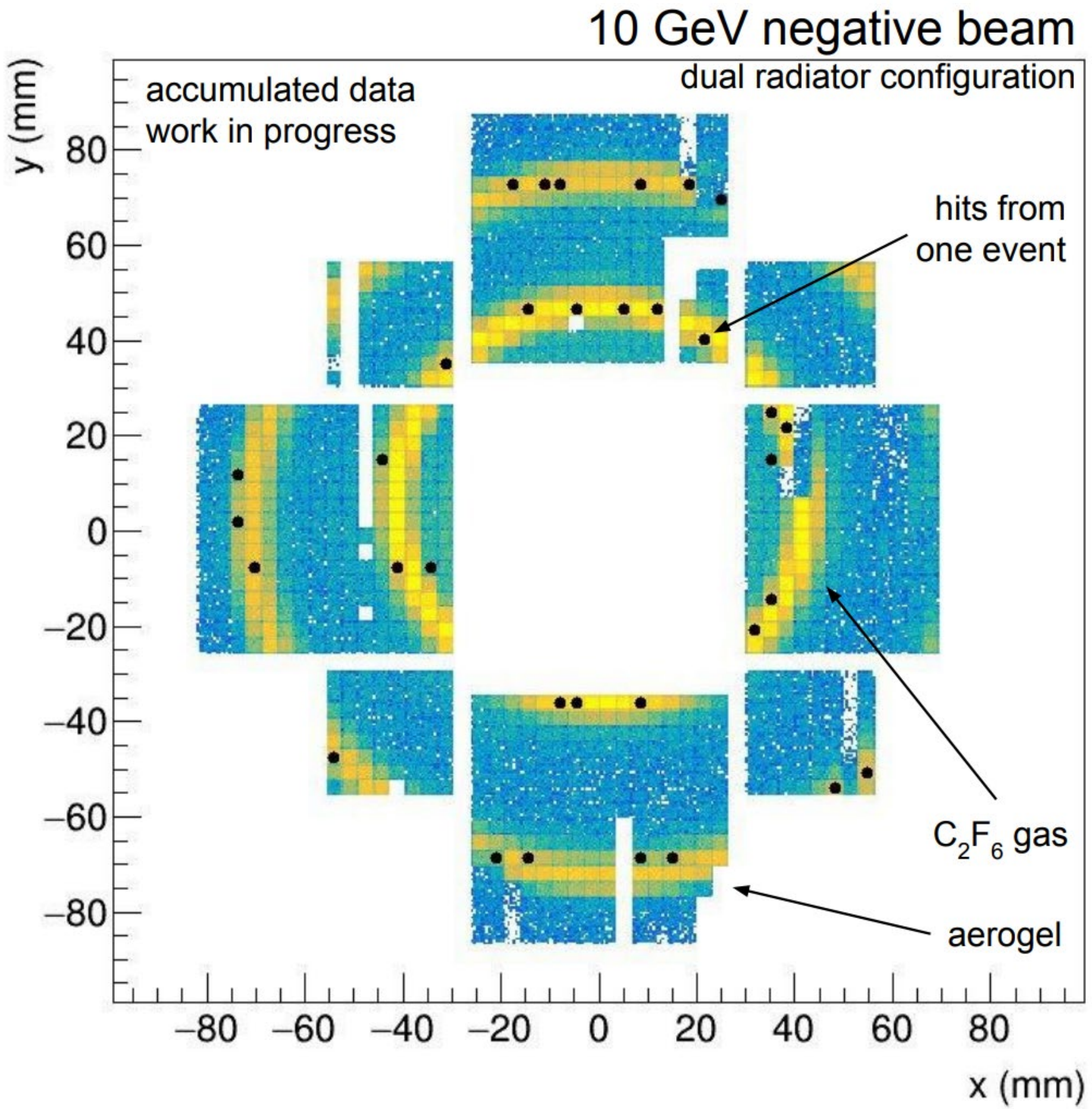
- n_γ extracted event-by-event within 3σ of the globally-fitted ring radius
- Gaussian fit performed on n_γ distribution

$$\langle n_\gamma \rangle = 9.056 \pm 0.025$$

- Fast MC estimates with 8 full PDUs show >18 photons for aerogel ⟶ will be acknowledged in 2024 test beam
- A study with GEANT4 with the ePIC SiPM parameters might be introduced in the future



Results of test beam at CERN PS



- Data were collected from CERN Proton-Synchrotron facility → T10
- Accumulated data plot shows two rings from Cherenkov light coming from the two different radiators

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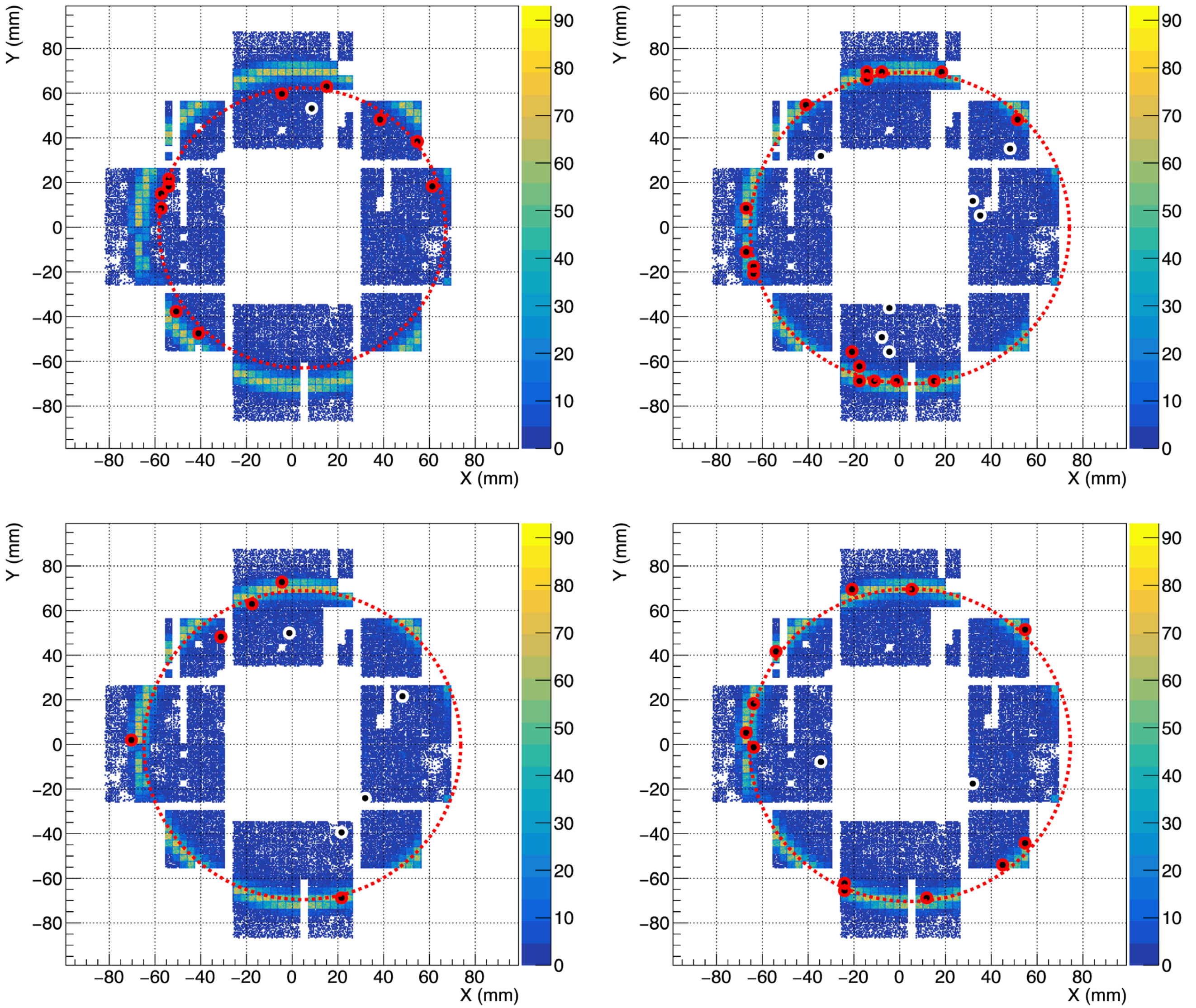
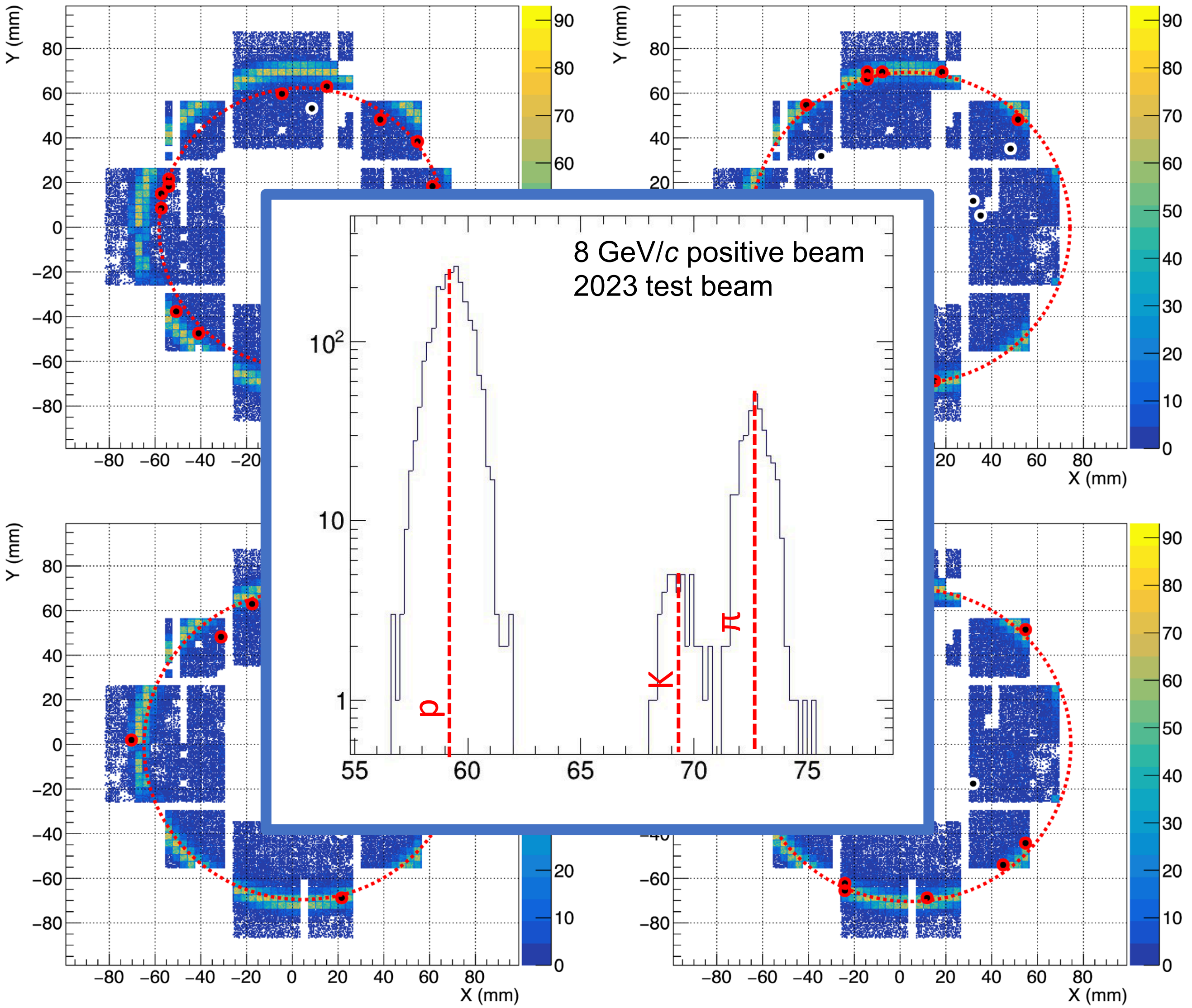


event-by-event ring fit examples

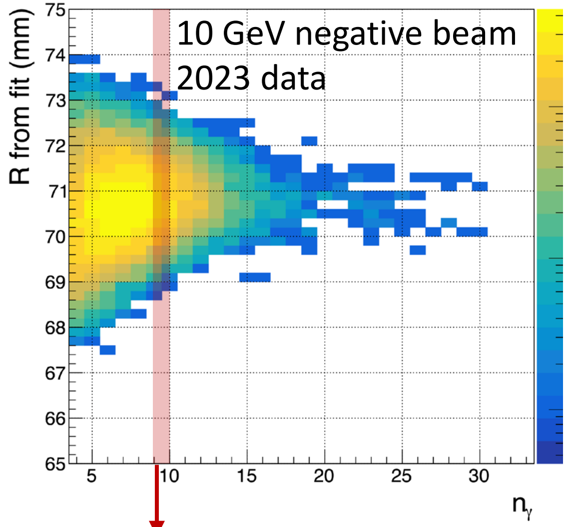
- Data were collected from CERN Proton-Synchrotron facility → T10
- Accumulated data plot shows two rings from Cherenkov light coming from the two different radiators
- Analysis is performed on aerogel produced photons

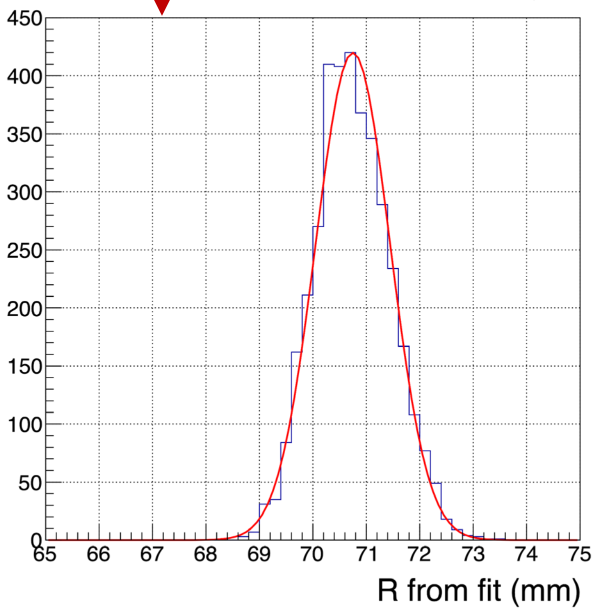
Results of test beam at CERN PS



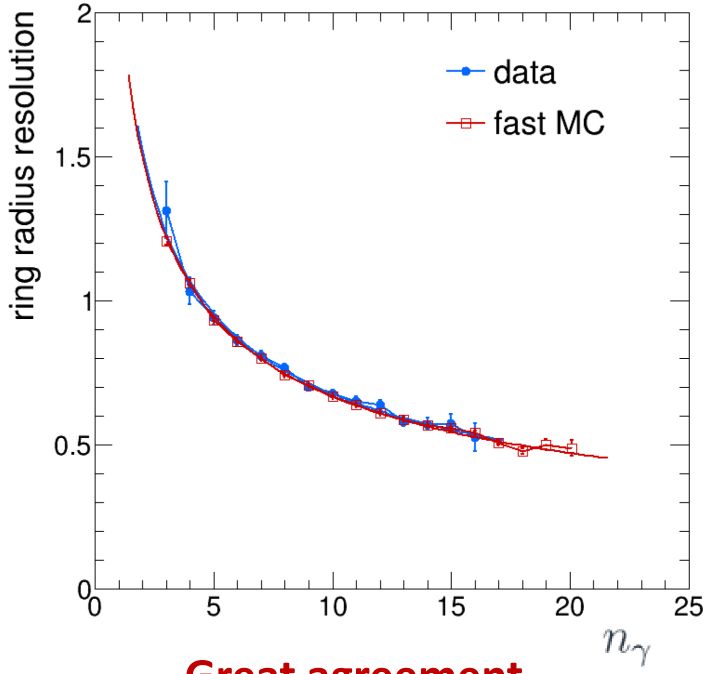
- Data were collected from CERN Proton-Synchrotron facility → T10
- Accumulated data plot shows two rings from Cherenkov light coming from the two different radiators
- Analysis is performed on aerogel produced photons
- Fit obtained radii show a distribution from which particles species can be distinguished → protons, kaons and π peaks

Measurement of single photon resolution





$$\sigma(n_\gamma) = \frac{\sigma_{\mathrm{SPR}}}{\sqrt{n_\gamma}}$$



Great agreement data/MC

- Radius distribution can be projected in slices of n_γ
- A Gaussian fit of the projection let us find the radius resolution per number of participating photons
- The resolution per single photon is then computed with one last n_γ dependent fit

$\sigma_{SPR} = 2.141 \pm 0.014$ mm

Summary

- A full data acquisition test under radiation on a dRICH prototype was performed in October 2023 $\longrightarrow$ the setup did not show any radiation related issues and triggerless data were recorded smoothly by our DAQ

- Double rings were seen in the accumulated data plots $\longrightarrow$ coherent with dual radiator configuration of our detector

- A standard method for the ring reconstruction has been used, but a ML algorithm has also been studied for the ring reconstruction $\longrightarrow$ possible implementation with future results

- Rings distributions show a clear distinction between protons, kaons and π peaks

- The resolution per single participating photon has been computed: 2.141 ± 0.014 mm

- Simulations show >18 hits per event for 2024 test beam using 8 full PDUs readout system

Thank you for your **ePIC** attention

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