CMOS-SPAD:
Cherenkov and scintillator counter applications

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ASPIDES kick-off meeting

Bologna – Jan 30-31, 2025

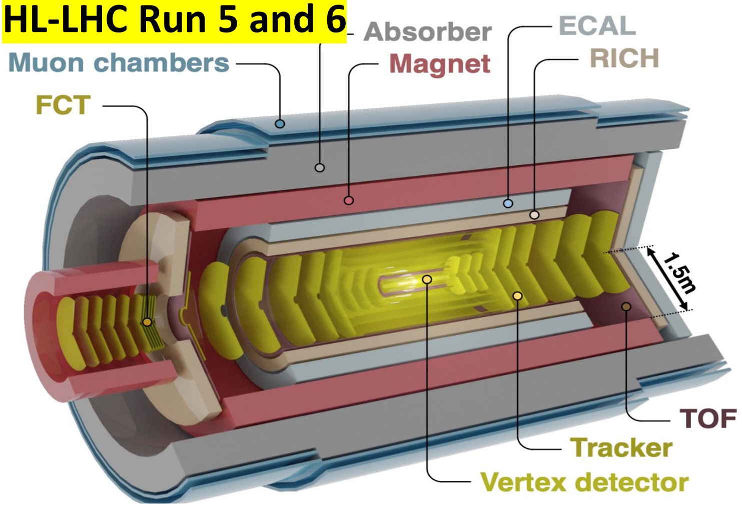
Outline

- ALICE 3 RICH layout proposal
- Scintillator counters

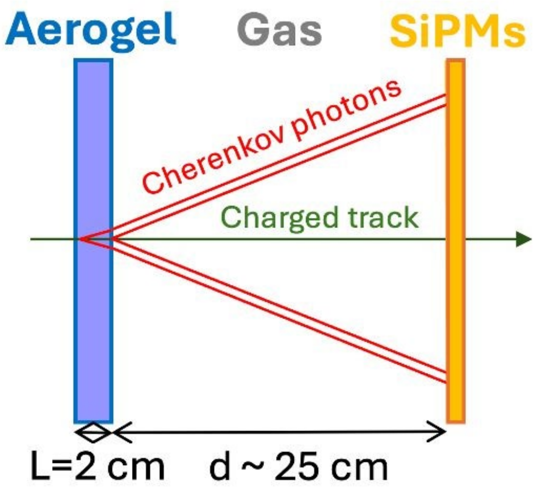
ALICE 3 proximity-focusing RICH detector

- PID goals
  - e/π separation in the *p* range 0.5 - 2 GeV/*c*
  - π/K separation in the *p* range 2 - 10 GeV/*c*
  - K/p separation in the *p* range 4 - 16 GeV/*c*
- Design concept: proximity-focusing geometry
  - Aerogel radiator tiles
    - n = 1.03, thickness = 2 cm
    - Transmission length > 6-7 cm at 400 nm
  - Photon detector based on SiPMs
    - Pixel size of 2x2 mm^2
    - PDE > 40% at 400 nm
    - BoL DCR < 50 kHz/mm^2 at RT
    - Expected NIEL of about 10^{12} MeV neq /cm^2
  - Fast front-end with SPTR < 100 ps
- R&D ongoing with on-the-shelf components
  - Hydrophobic aerogel from Aerogel Factory & co.
  - HPK SiPM S13361-* (+ thin quartz window for Cherenkov based charged track timing and better pattern recognition)
  - Petiroc 2A and Radioroc 2 Omega/Weeroc FEs + CERN pTDC

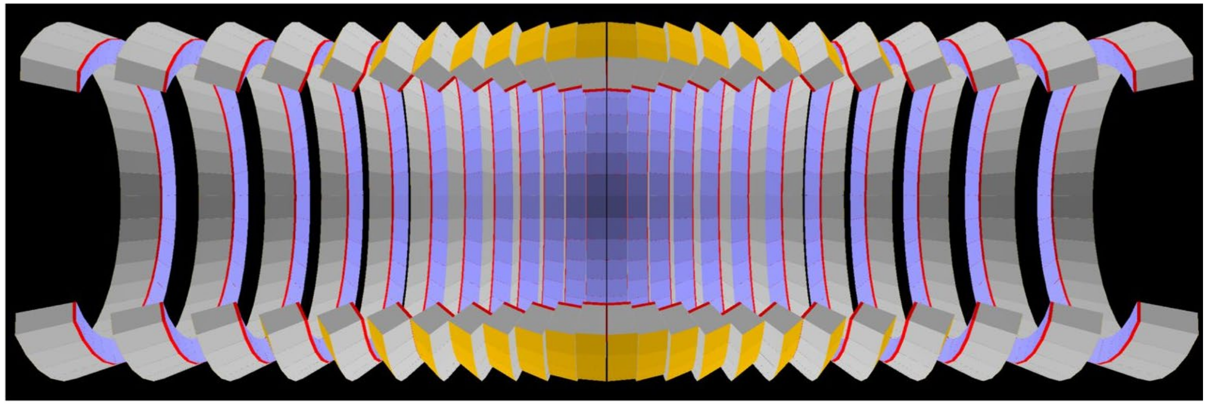
ALICE 3 baseline (LoI) B = 1-2 T
HL-LHC Run 5 and 6



Proximity-focusing geometry

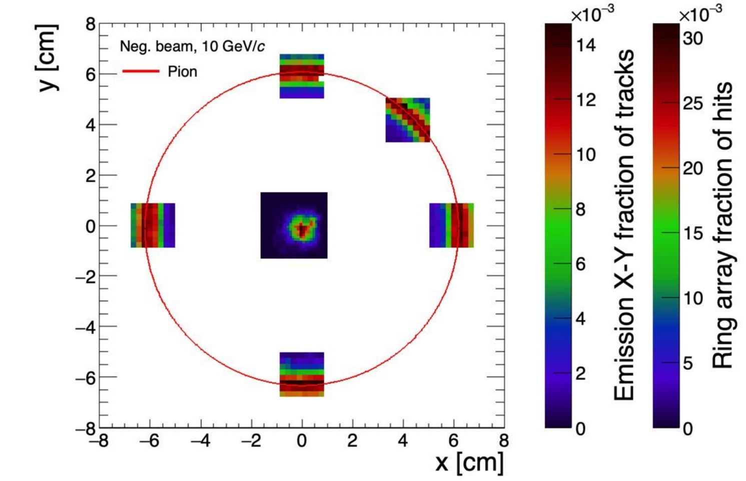


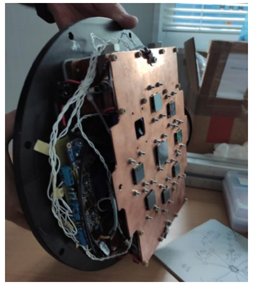
Projective geometry: modules oriented towards nominal collision vertex
24 sectors x 36 modules, sensor area ≈ 30.7 m^2, total N channels ≈ 7M

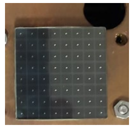


Proximity-focusing RICH detector

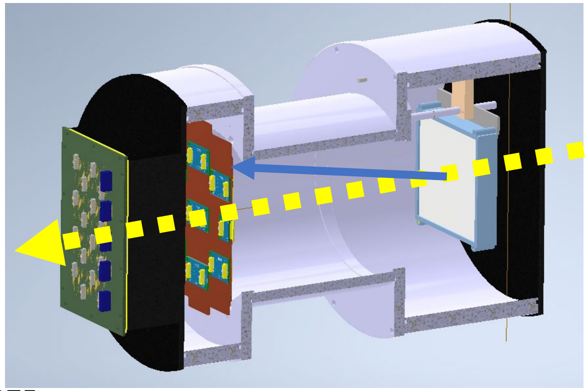
- Single hit angular resolution of about 4.3 mrad as expected with 2x2 mm^2 SiPM pixel size
- At the saturation Cherenkov angle the total expected PE is about 20-25 → Angular resolution is of about 1 mrad or better

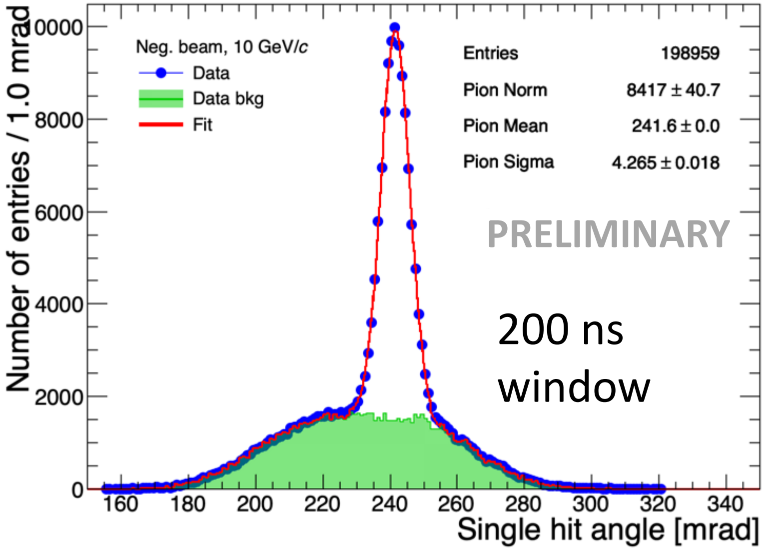


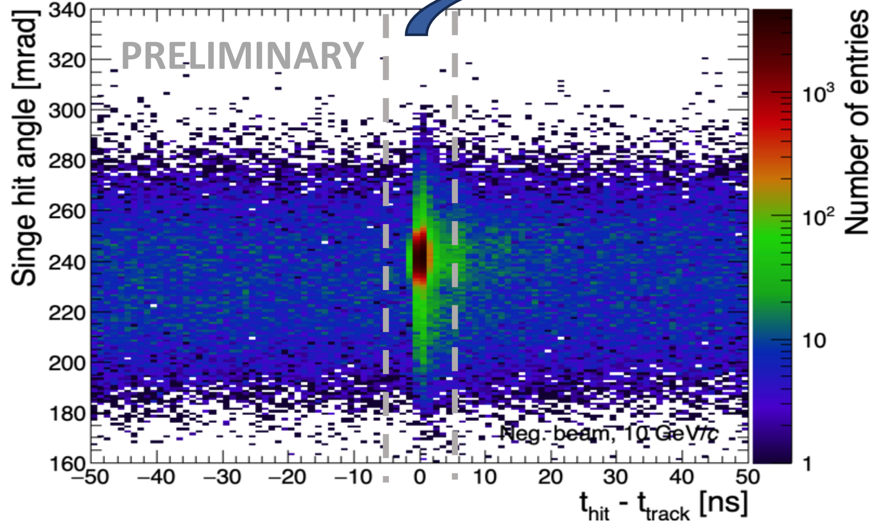


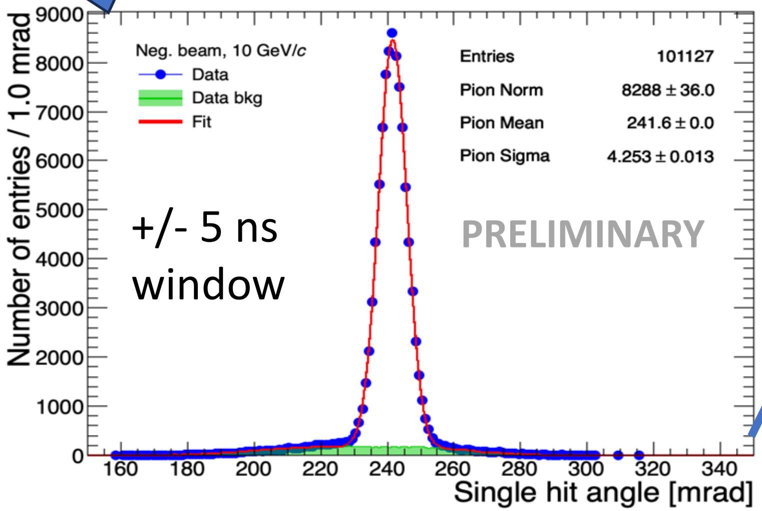


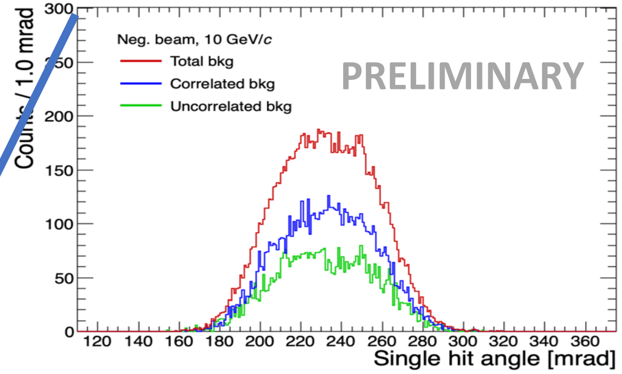
S13361-3075 array
With 1 mm of SiO2











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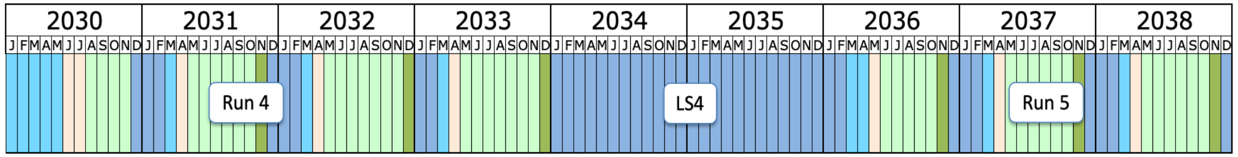
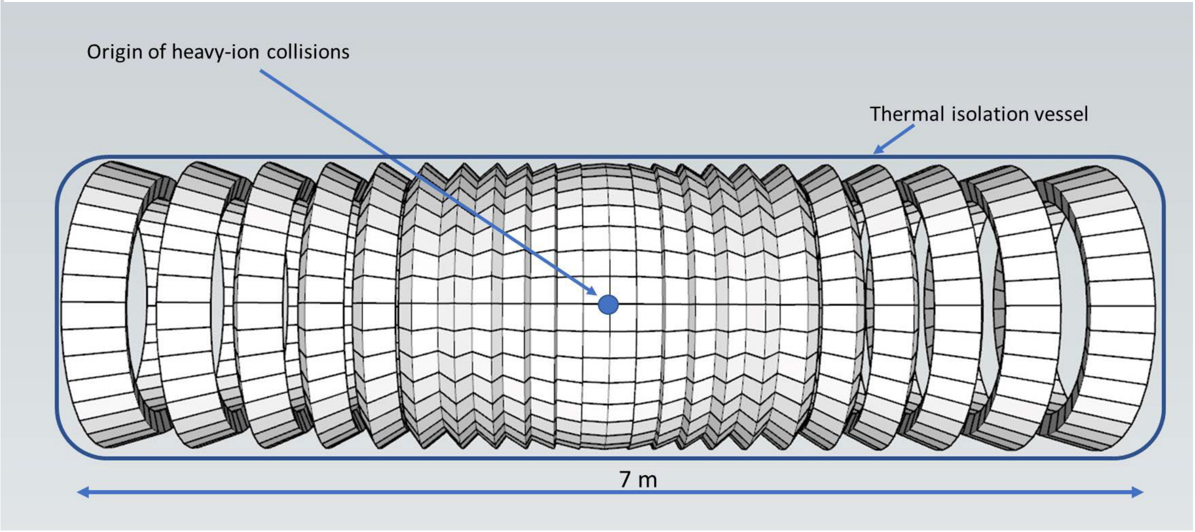
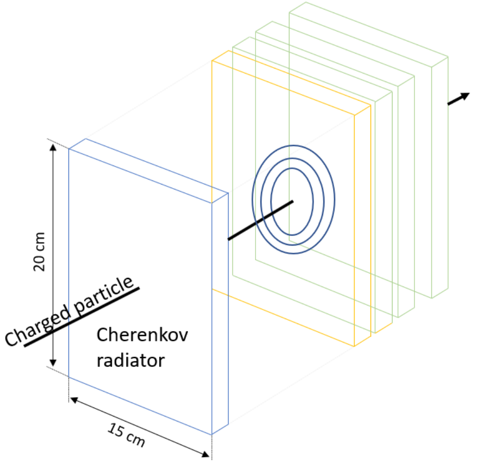
ALICE 3 layout







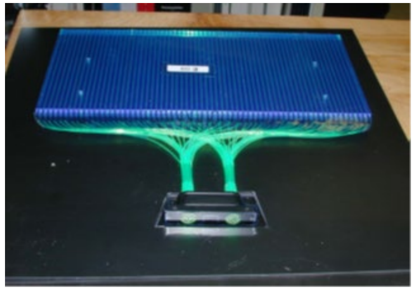
24 rings with 36 segments/sectors
SiPM area of 15-17 cm x 18-20 cm

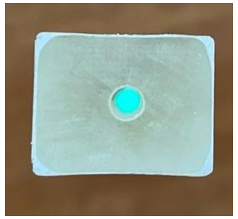
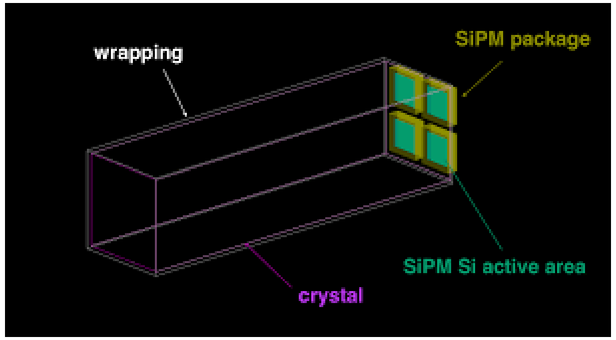
- Results achieved so far with SIPM:
  - Pion and proton Cherenkov <u>single photon angle resolution</u> of about 4-5 mrad in 8 - 10 GeV/c beam <u>momenta</u>
    - 2 cm aerogel with n=1.03 and a proximity gap of about 23 cm
    - SiPM pixel pitch of 2 mm
    - Background suppression achieved using timing information
      - A good timing particle Cherenkov hits match helps in the pattern recognition and discarding uncorrelated hits due to the SiPM DCR
        - Crucial for long term operation in ALICE 3, with the DCR increasing with the radiation
- Towards ALICE 3 RICH
  - Compact SiPM + electronic layout, i.e. vertical integration with cooling (interposer)
  - Dedicated rad-hard SiPM and CMOS SPAD sensors
  - Dedicated front-end ASICs
    - Currently we are investigating to use the ALCOR chip developed by INFN Torino
  - Read-out based on the LpGBT ASIC and VTRX+ optical links
    - No local FPGAs due to the high radiation environment
  - TDR Q3-Q4 2027

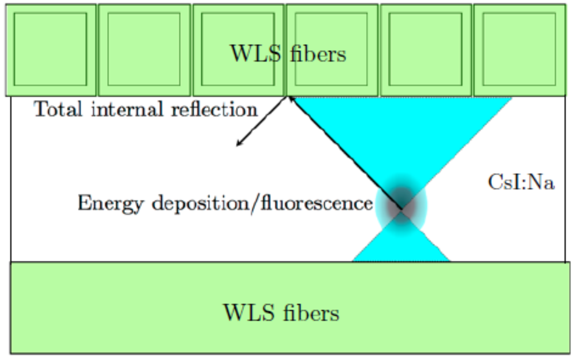
Scintillator counters

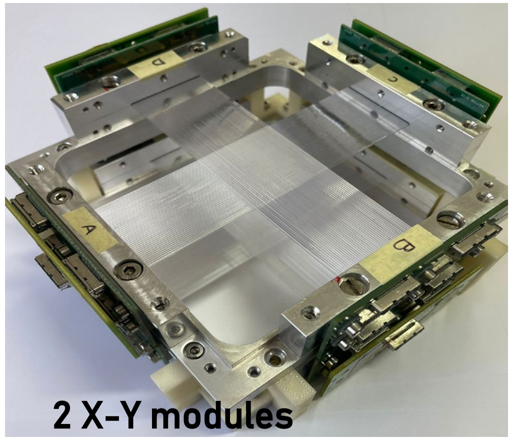
- Plastic scintillator
  - LY of about 10000 ph/MeV
  - Ion identification (Z-charge) dE/dx $\propto Z^2$
  - ToF application
  - Fiber tracker
  - Read-out by means of wavelength shifting (WLS) fibers
    - Extruded plastic scintillator with a hole
- Inorganic (crystal) scintillator
  - LY of 30000-40000 ph/MeV
  - Low energy spectroscopy with low noise sensors
  - Calorimeter
    - Read-out by means of WLS fibers

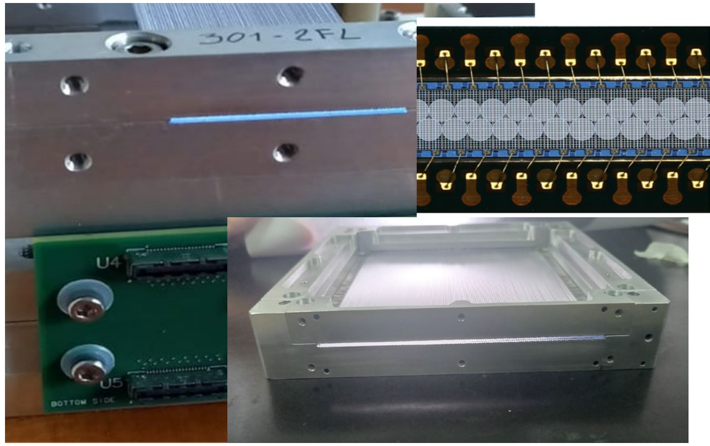






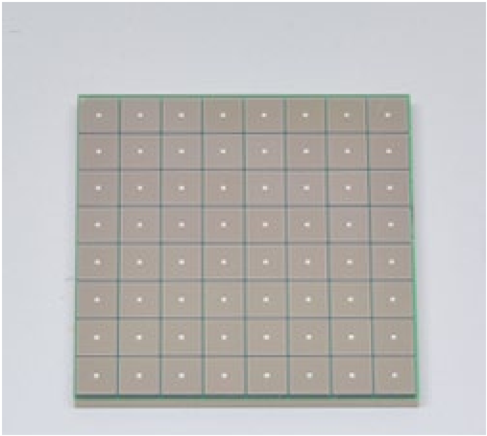


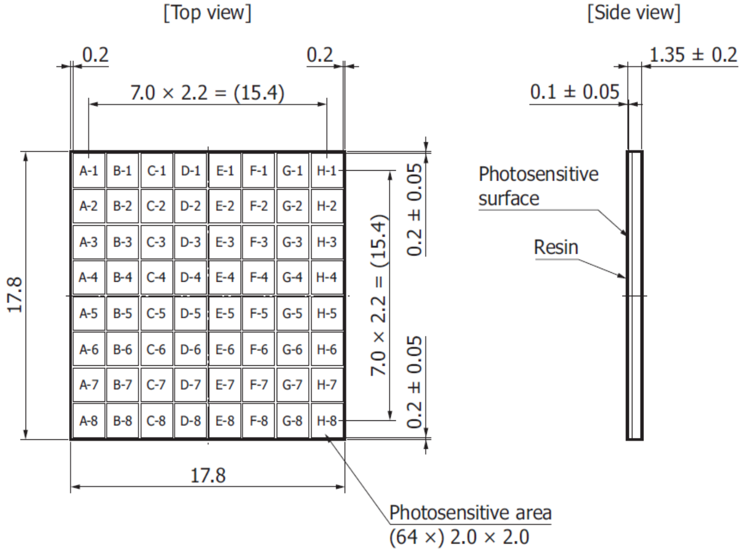


Conclusion

- Cherenkov application (e.g. RICH) requires large sensitive area, single photon threshold, good timing performance and high PDE
  - Potential issue with filling factor and loss sensitive area due to digital zone, but standard SiPM tile show some dead zones even with the TSV technology
- Scintillator counters
  - No issue with loss of filling factor
  - Good timing for ToF application
  - Large dynamic range
  - Low noise sensor for spectroscopy application
  - Large pitch read-out with many "single" sensors

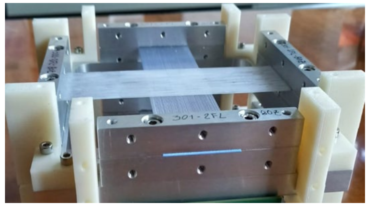
SiPM S13361-2050AE-08



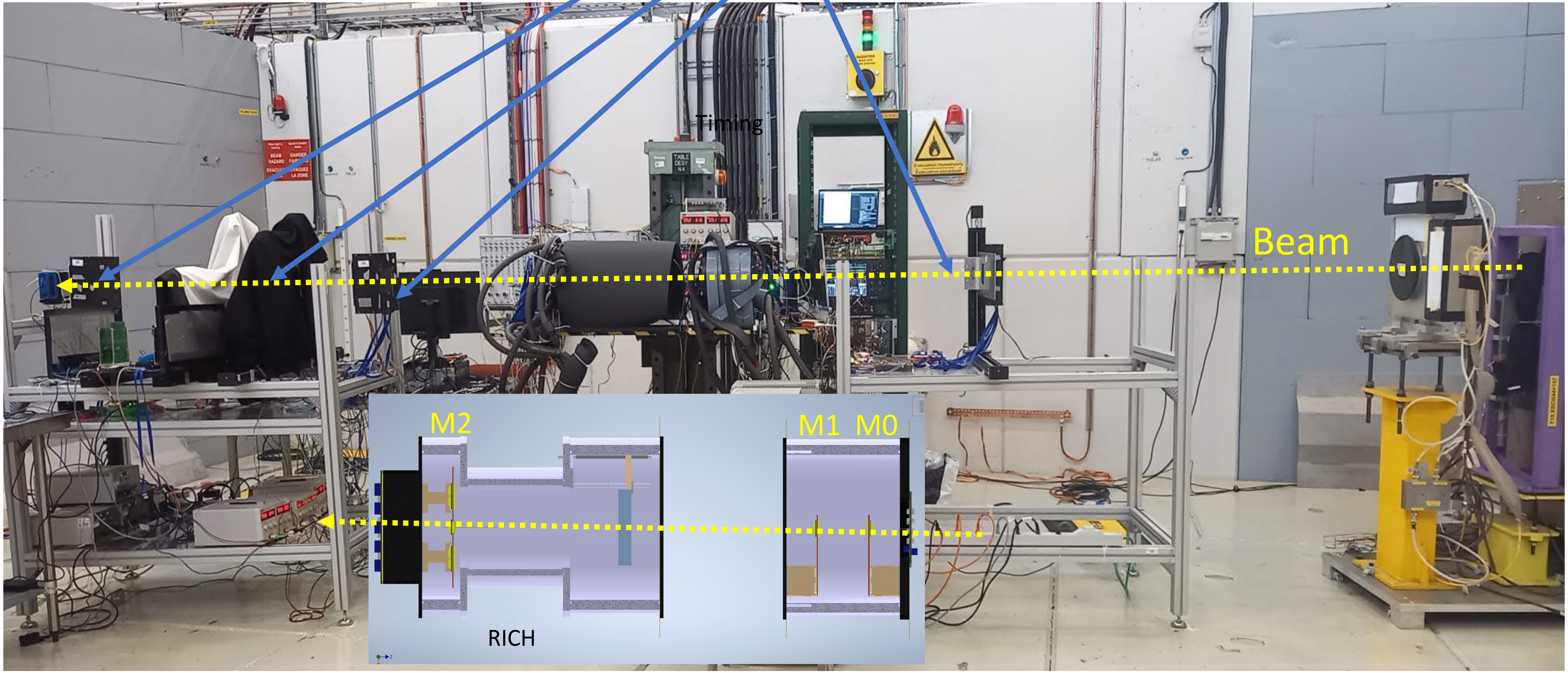


BACKUP

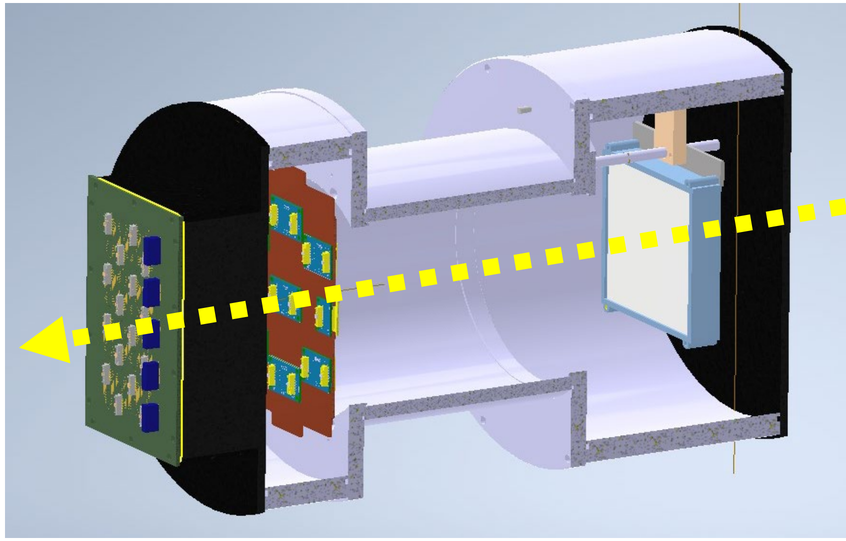
2024 Beam test set-up@T10



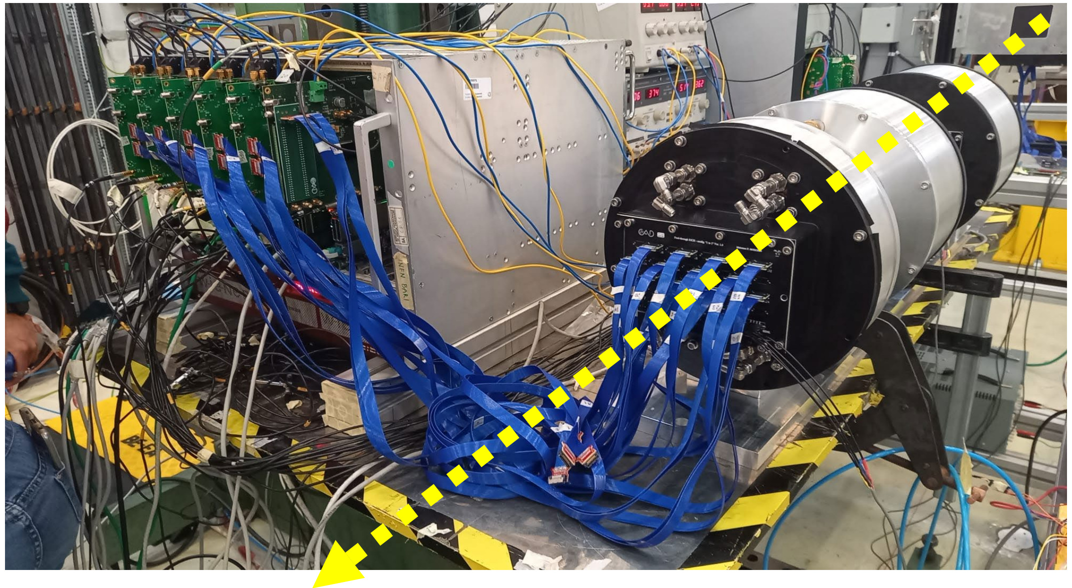
X-Y fiber tracker module: beam trigger and particle tracking

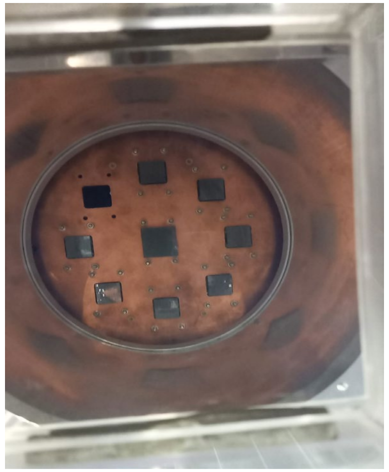


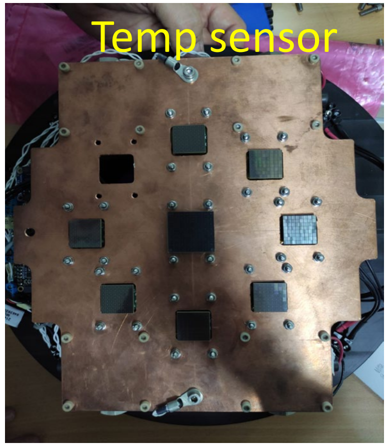
2024 RICH set-up

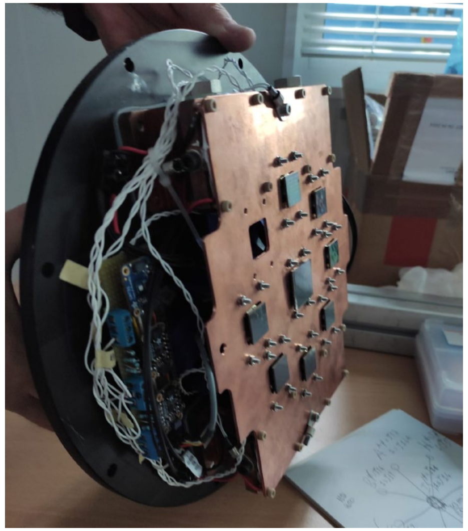


- SiPM RICH camera with a feedthrough board (SiPM signals, Peltier bias and environmental sensor signals)
  - Flushed with Argon or CO_2
- Central array: HPK SiPM S13361-3050AE-08 with 3 mm pitch and 1 mm thick quartz window (M2)
- Ring array: HPK SiPM S13361-2050AE-08 matrices
- Aerogel radiator:
  - Single tile 2 cm thick with n=1.03 (single layer)
  - Focusing aerogel tile with 1 cm n=1.030 (upstream) + 1 cm n=1.033 (downstream) (two layers aerogel)



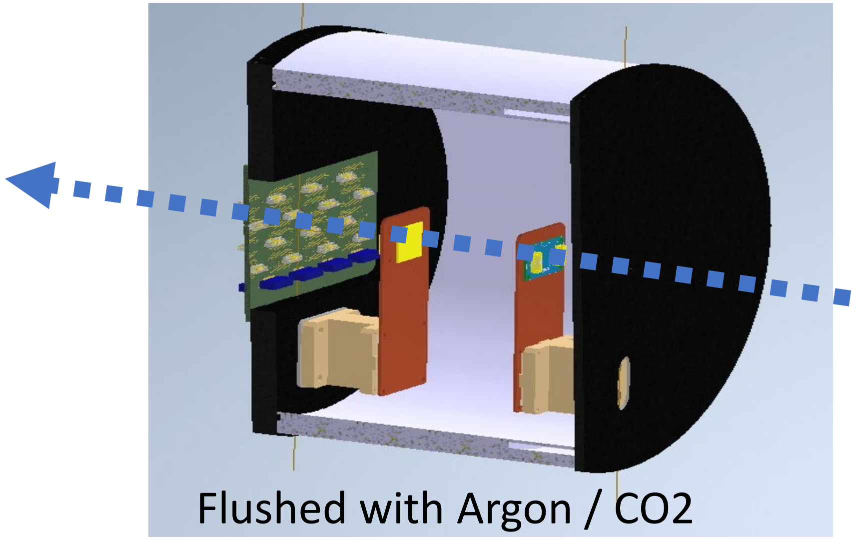


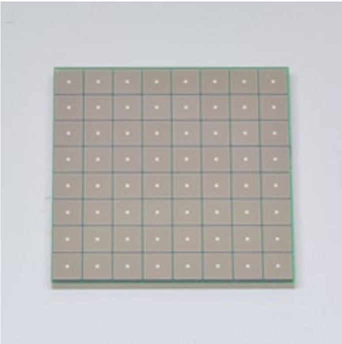


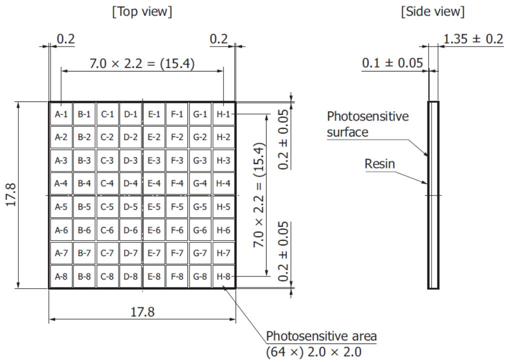


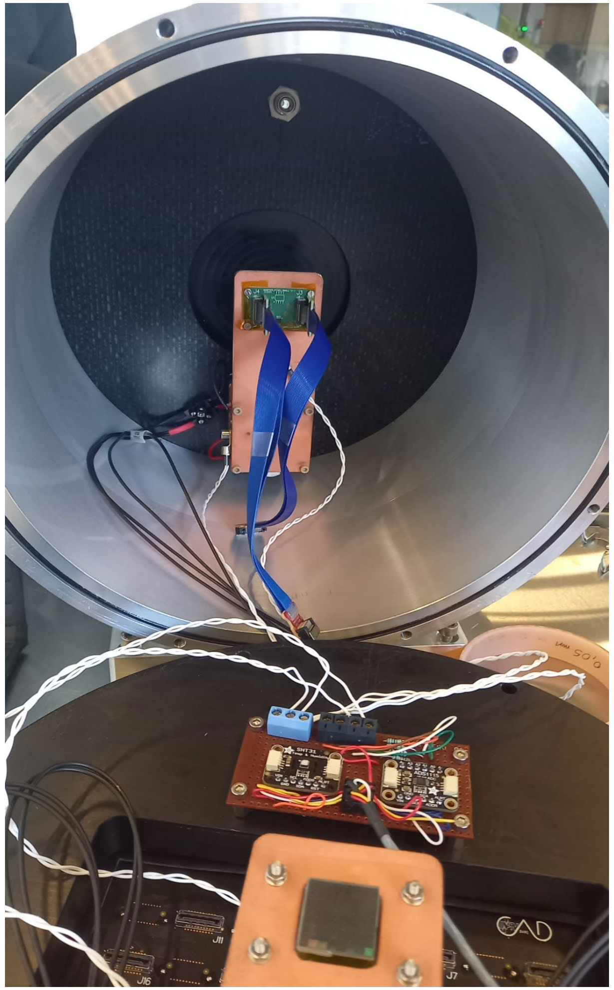
2024 - Timing set-up

- Two Hamamatsu SiPM S13361-2050AE-08 arrays (M0 and M1) with 2 mm pitch and 1 mm thick quartz window to produce a cluster of Cherenkov photons

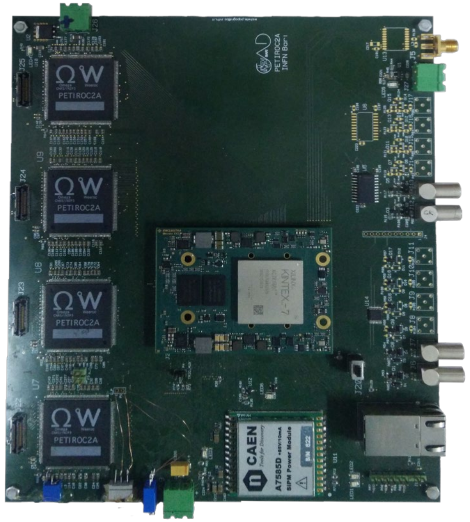




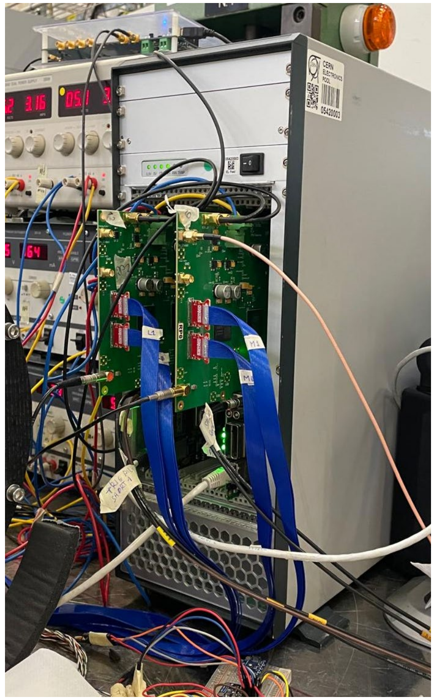


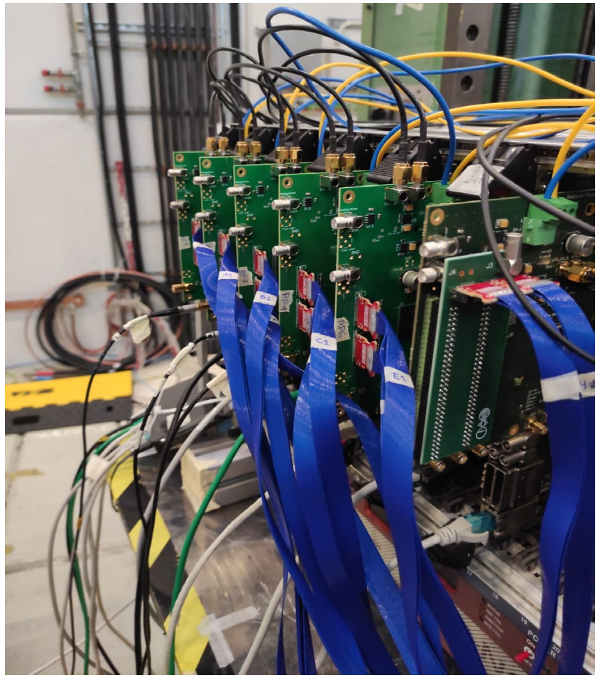


2024 - Front-end and DAQ boards



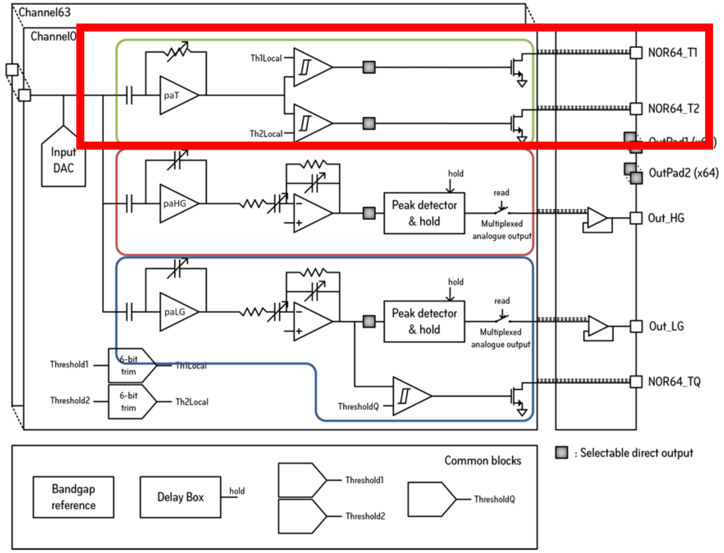
- RICH and timing systems
  - Custom board based on the Radioroc 2 FE ASIC with picoTDC (LSB ≈ 3 ps) and read-out by MOSAIC boards
  - picoTDC in multihit configuration with ToA and ToT
- Fiber tracker modules:
  - Custom boards based on the PETIROC2A FE ASICs with TDC (LSB ≈ 37 ps) and ADC and FPGA on board
    - As beam test in 2023
  - Beam particle trigger and tracking

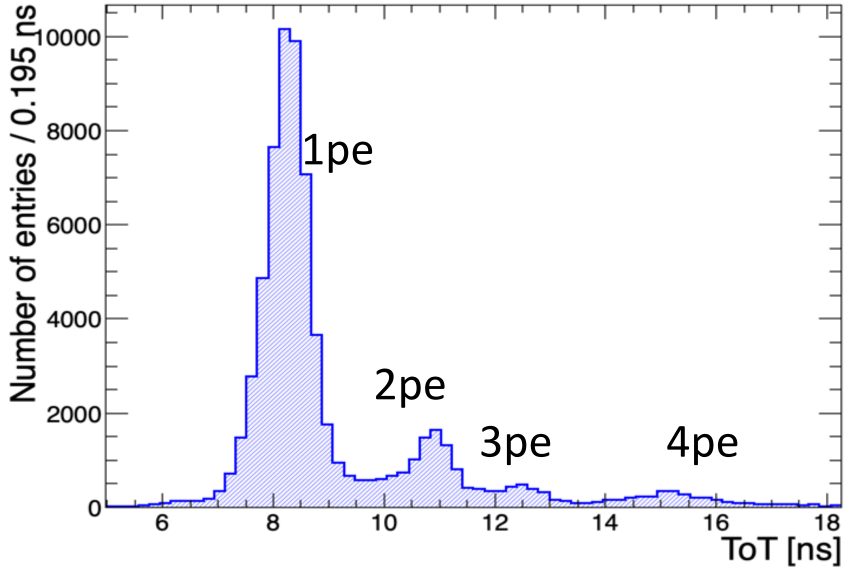




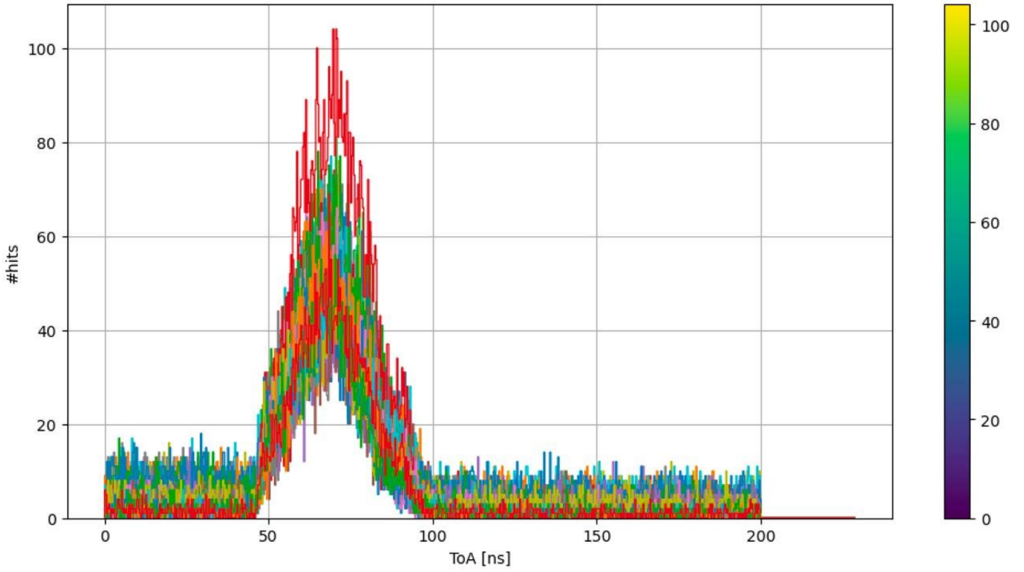
Radioroc2+pTDC board
(in collaboration with Weeroc)
+ MOSAIC

2024 - Radioroc 2 and picoTDC





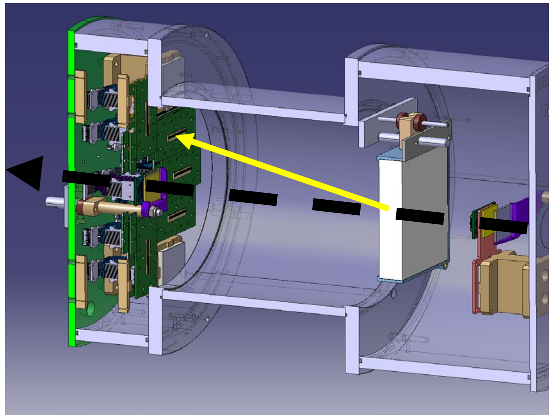
- Radioroc 2 - Weeroc
  - ToT proportional to the number of photoelectrons (P.E.)
  - Threshold at single P.E. level
- picoTDC - CERN
  - ToA LSB ≈ 3.05 ps
  - ToT LSB ≈ 195 ps
  - Acquisition window of 200 ns



RICH with timing capability

- A good timing-particle match helps aerogel pattern recognition by allowing us to discard uncorrelated hits due to the SiPM DCR
  - Crucial for long term operation in ALICE 3, with the DCR increasing with the radiation
- First, we consider the time differences between the SiPM arrays (M0, M1 and M2) with thin window (Č radiator in front) to study the timing performance of the system
  - All time offsets removed as well (including the time-of-flight)
- Then, we consider the time difference between the RING arrays and the central matrix to remove the dark counts hit in the signal region
  - A Č photons – particle hit arrival time within a narrow interval, i.e. +/- 5 ns

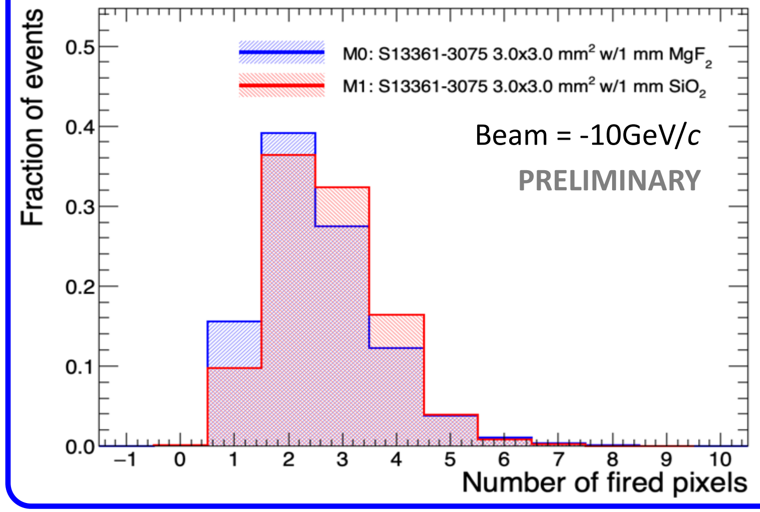
Cherenkov angle reconstruction method

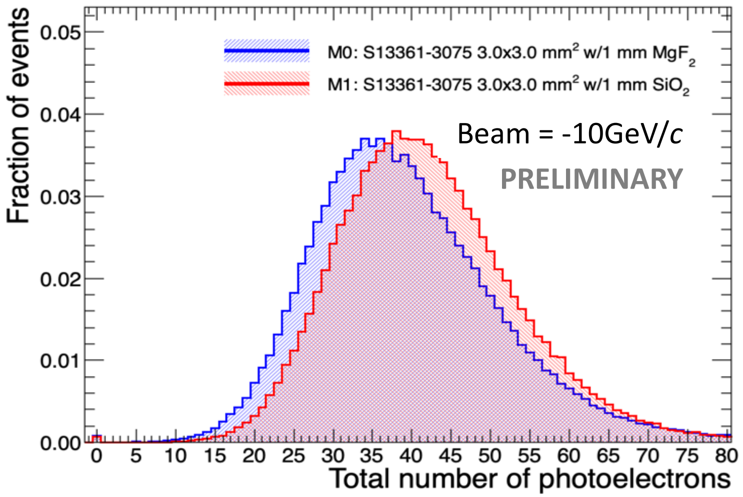


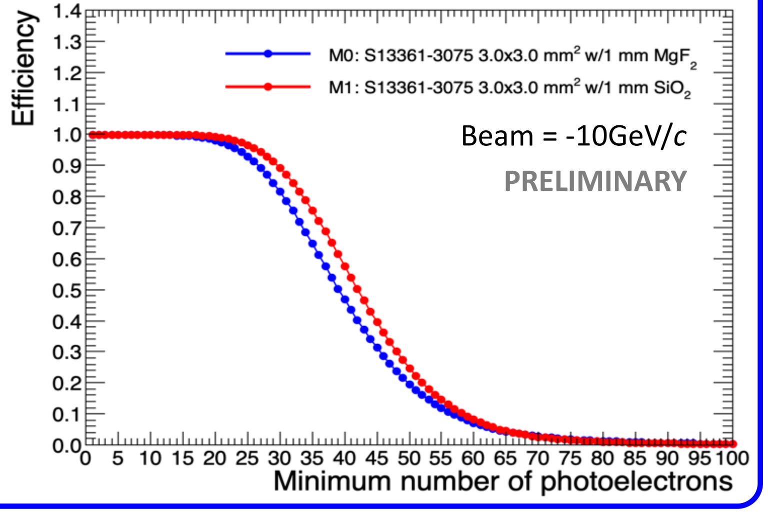
- All hits in the ring SiPM assumed as candidate Cherenkov photons
  - Emission position in the middle of the aerogel tile by means of particle track parameters
- Cherenkov angle reconstruction
  - Analytical backpropagation:
    - Pixel hit $\leftrightarrow$ Radiator by including Snell's law (at the areogel-argon surface)
- Angle resolution
  - Data fitted with $Gaus(\pi)$ (+ $Gaus$(p)) + background template
    - Background due to random coincidences, dark count rate hits, optical cross-talk, wrong tracking, …
    - The background hits template looking ToA values outside the signal region

2023 - M0 and M1 performance with 10 GeV/c pions

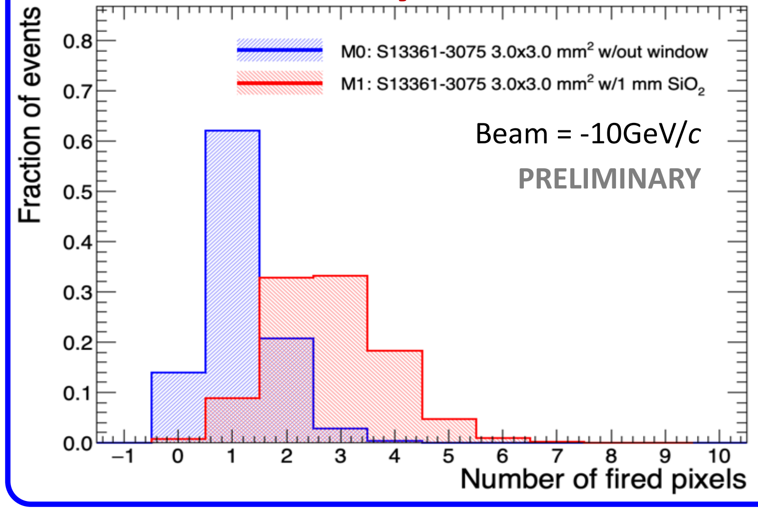
Efficiency of ≈ 100% with clusters with $N > 20$ p.e. coupling thin window to the SiPMs

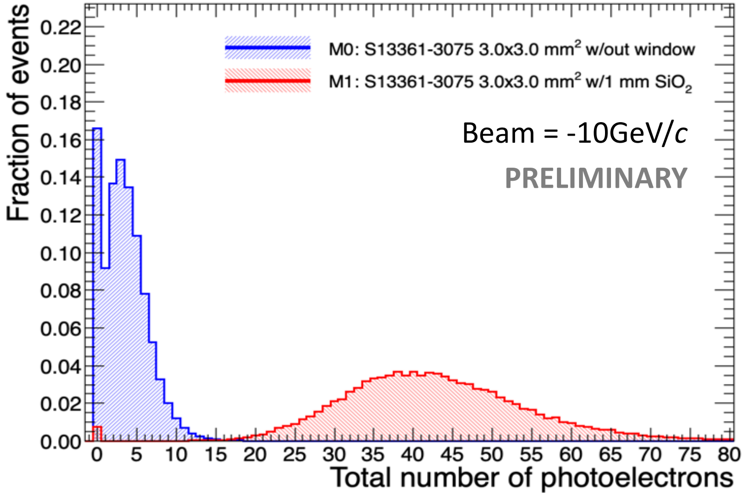


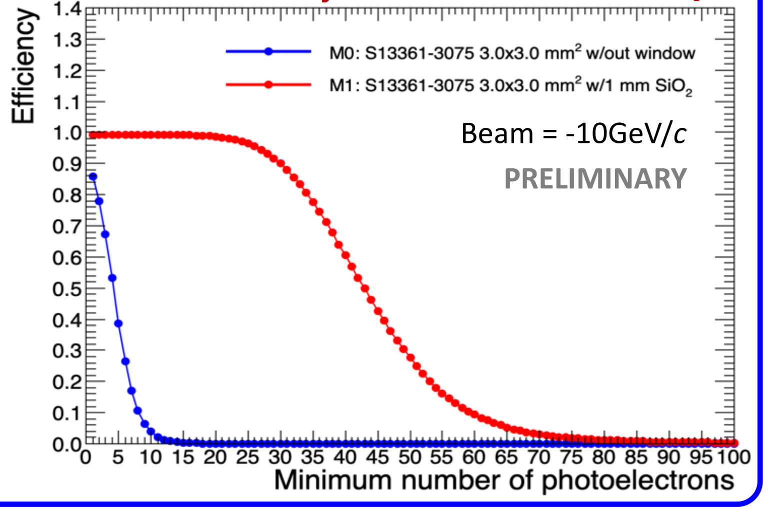




Lower efficiency without window (only direct MIP interactions or photons from ≈ 100 μm built-in resin)



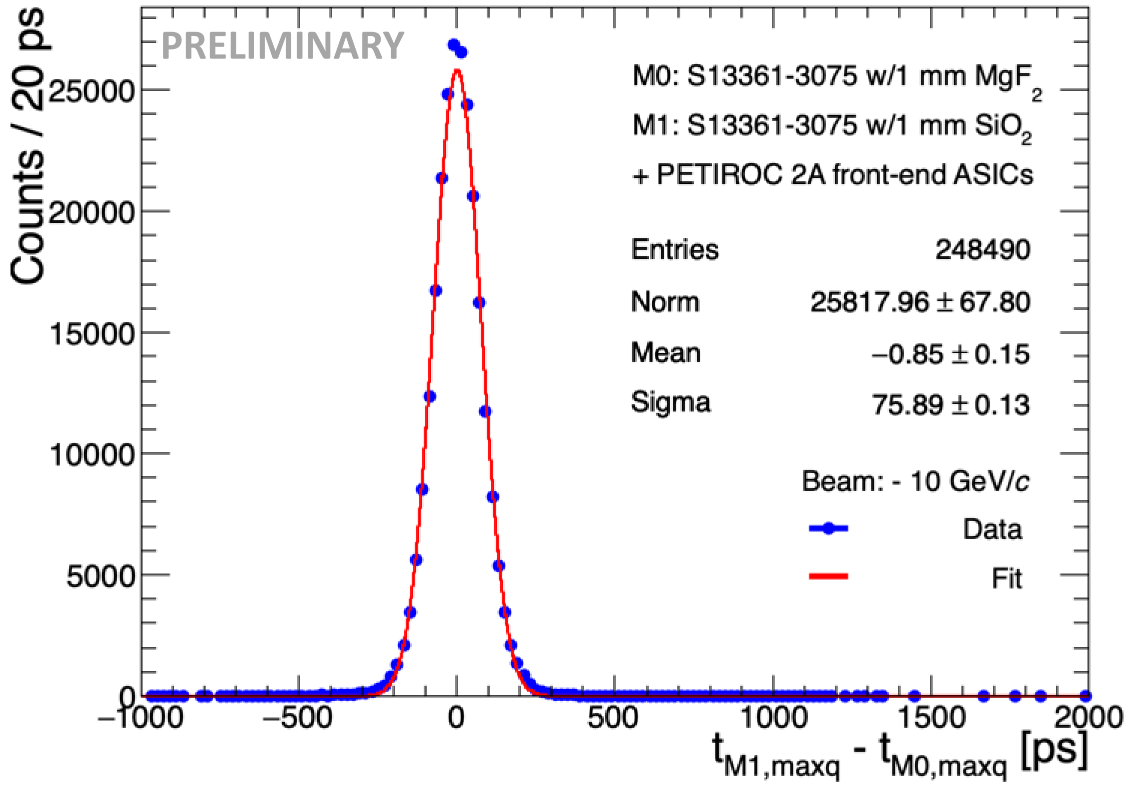




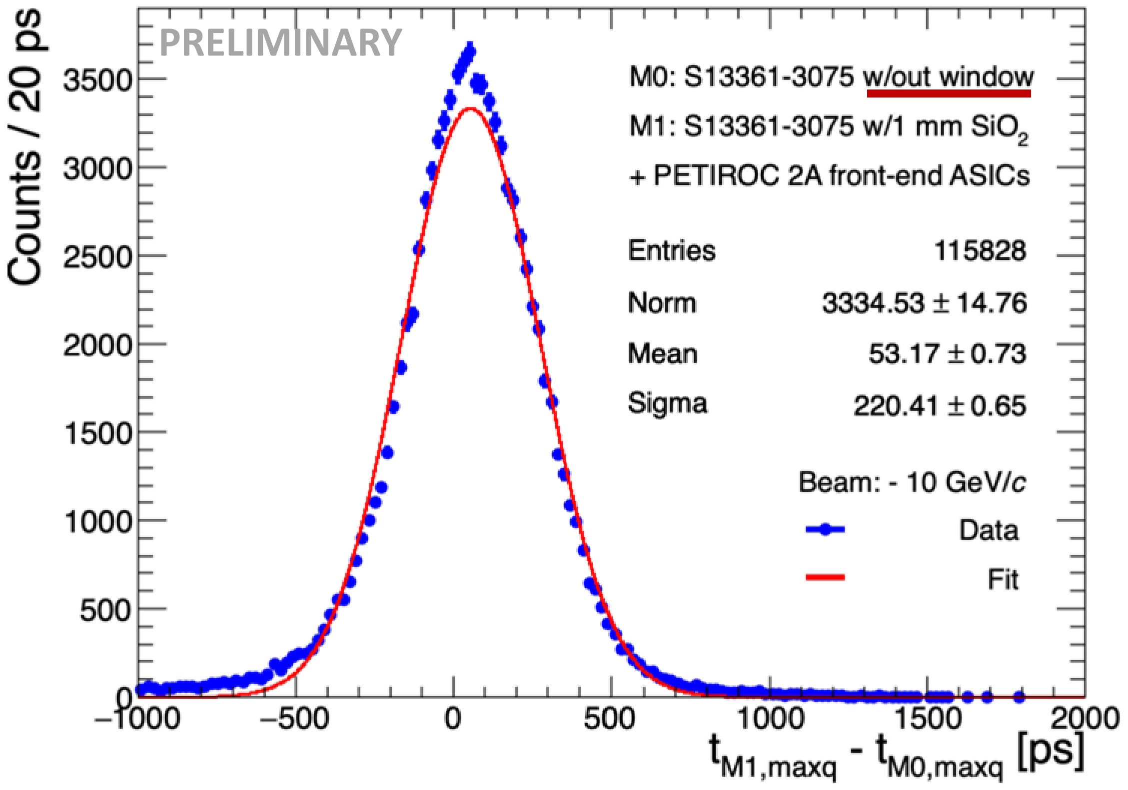
2023 - Time resolution with/without window

- Selecting tracks in fiducial area requiring hits both in the two tracker planes and in the two central arrays
- Including time walk and channel by channel offset corrections and subtracting the nominal Time-of-Flight offset at the actual beam momentum

We measured an overall resolution down to ≈ 75 ps (i.e. $\approx 50\ ps$ single pixel resolution) adding thin window radiator with the SiPM arrays



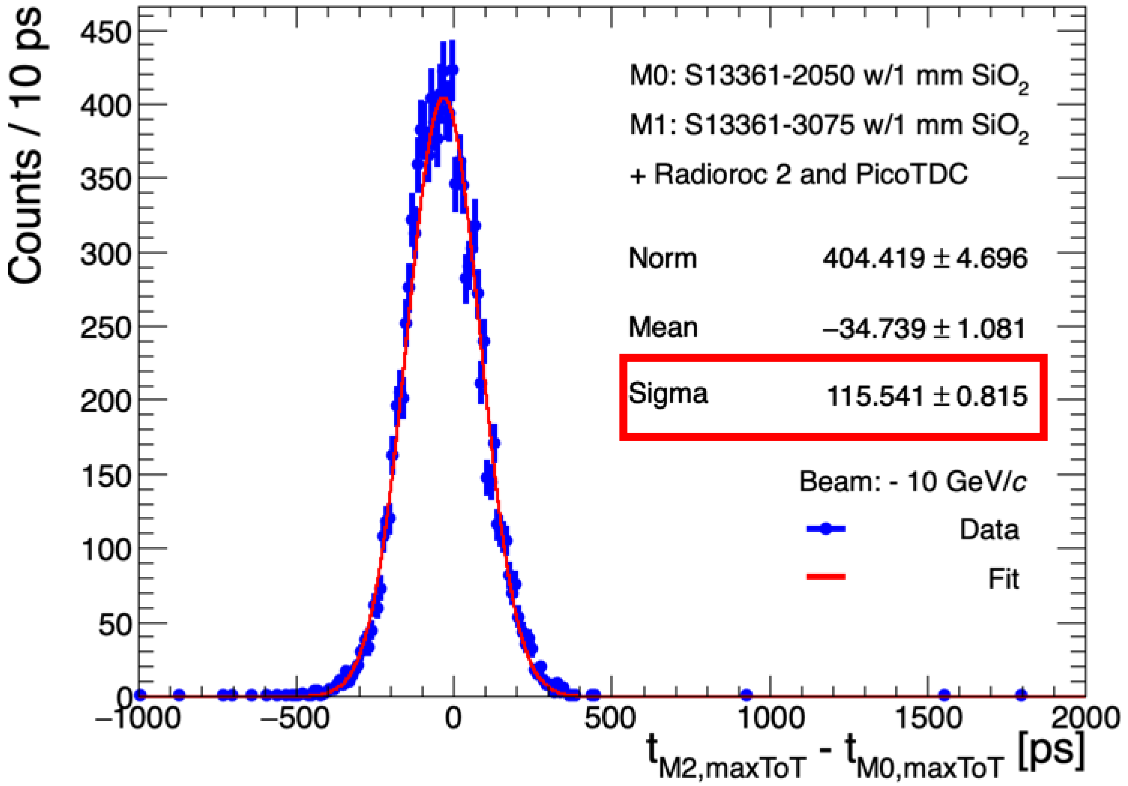
Much better performance using SiPMs coupled with radiator window w.r.t. same matrix without window



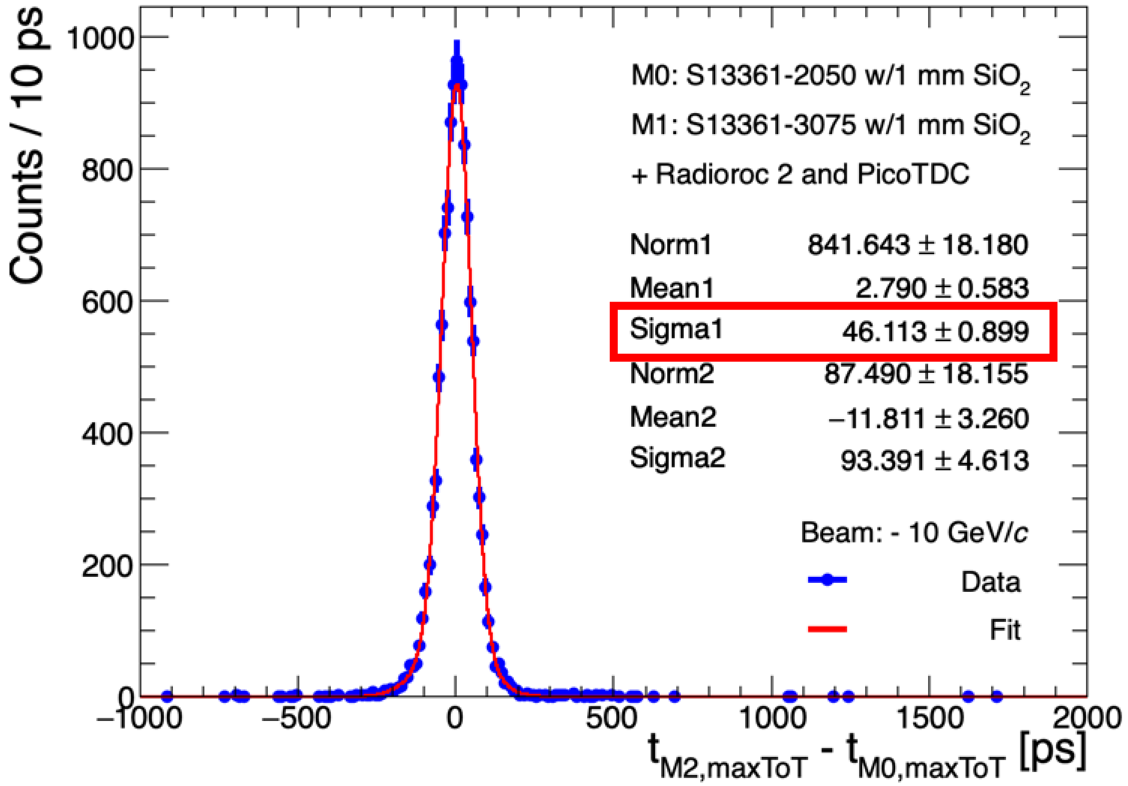
2024 - time resolution with maximum charge pixels

- Selecting tracks in fiducial area with M0 max-ToT > 20 ns, M1 max-ToT > 20 ns and M2 max-ToT > 40 ns
- Comparing results both with and without ToT-based time walk and channel by channel offset correction

We measured a Δt_{max} res. down to ≈ 120 ps with no time walk and ch by ch offset correction (but subtracting only TOF)



Correcting for time walk and ch by ch offset, a Δt_{max} res. down to ≈ 50 ps is achieved ⇒ Better than 35 ps at single SiPM level



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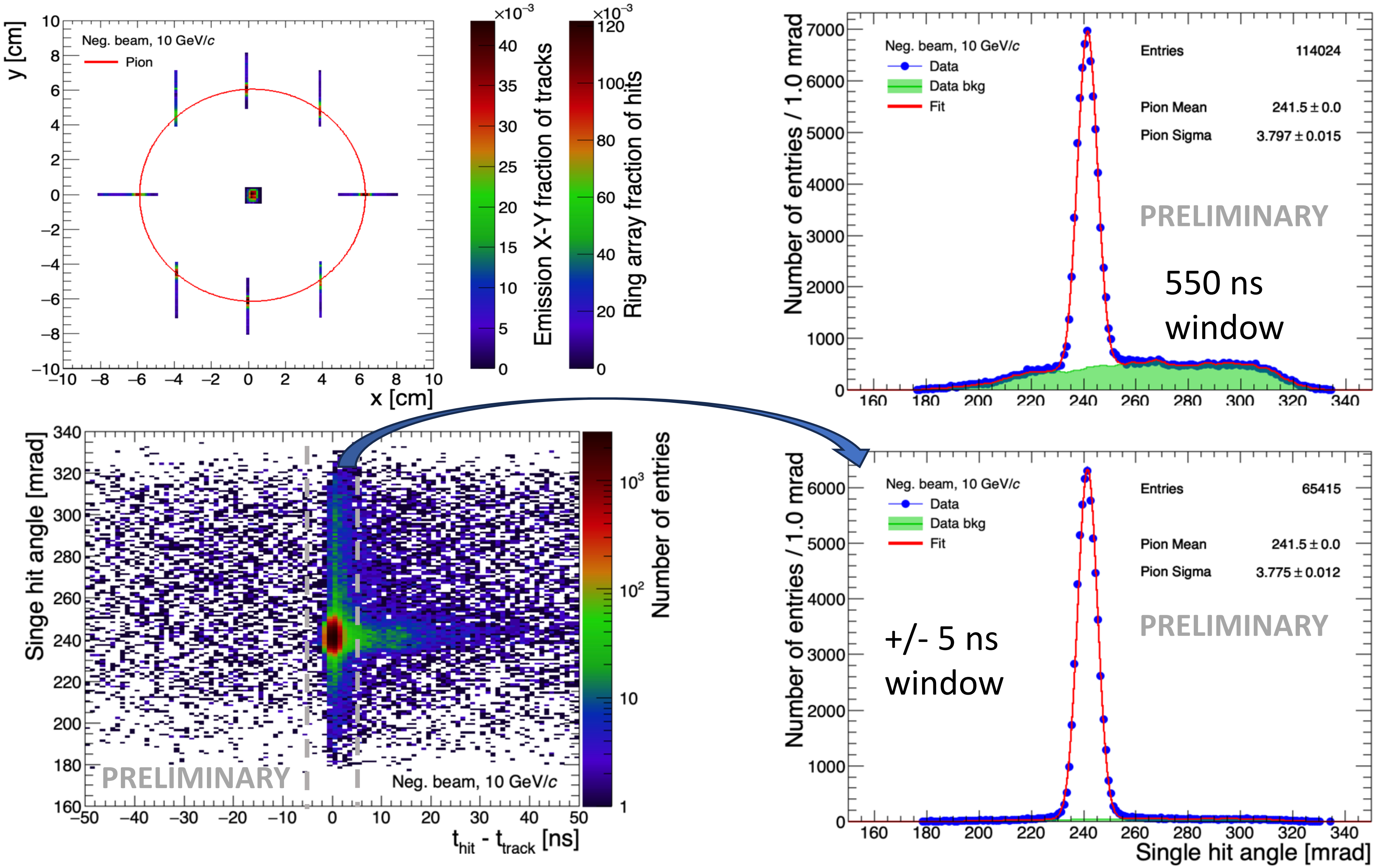
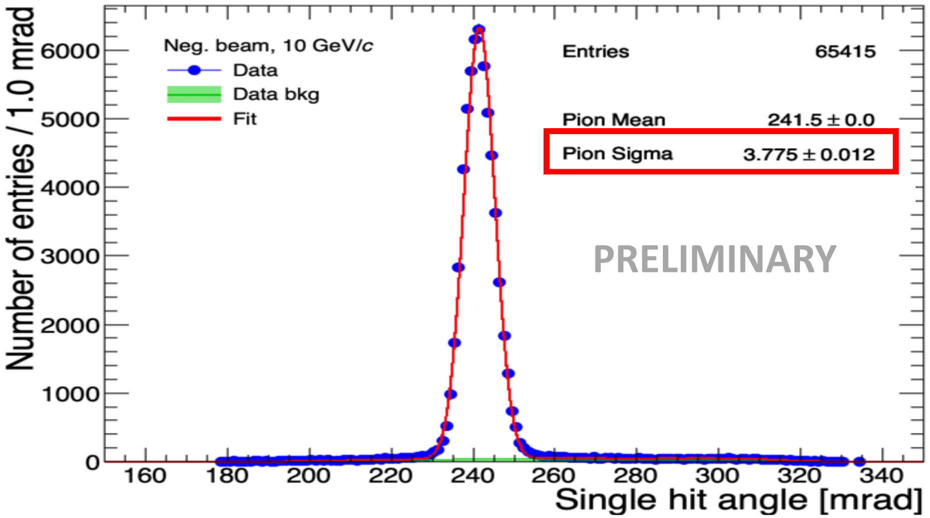
2023: Cherenkov angle and timing effects

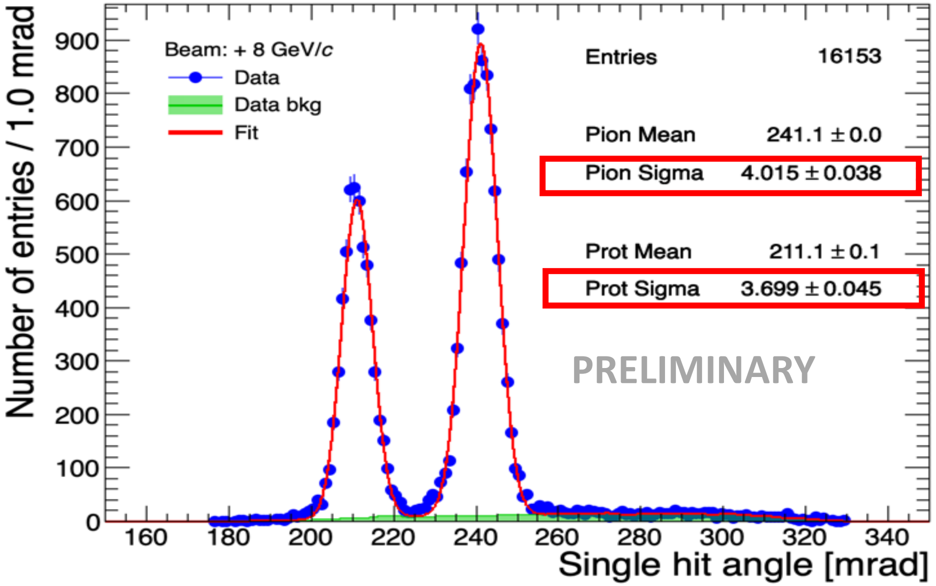
- Excellent background suppression achieved using timing information

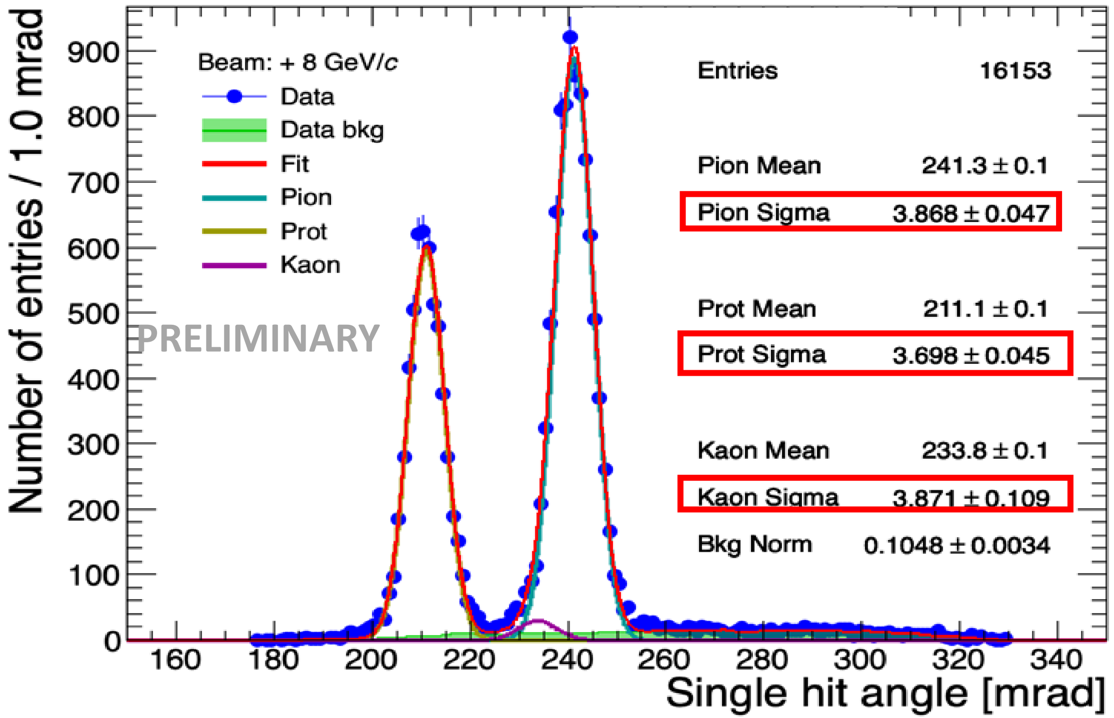


Pixel size of 1 x 1.6 mm^2

2023 Angular resolution - signal hits within a ±5 ns



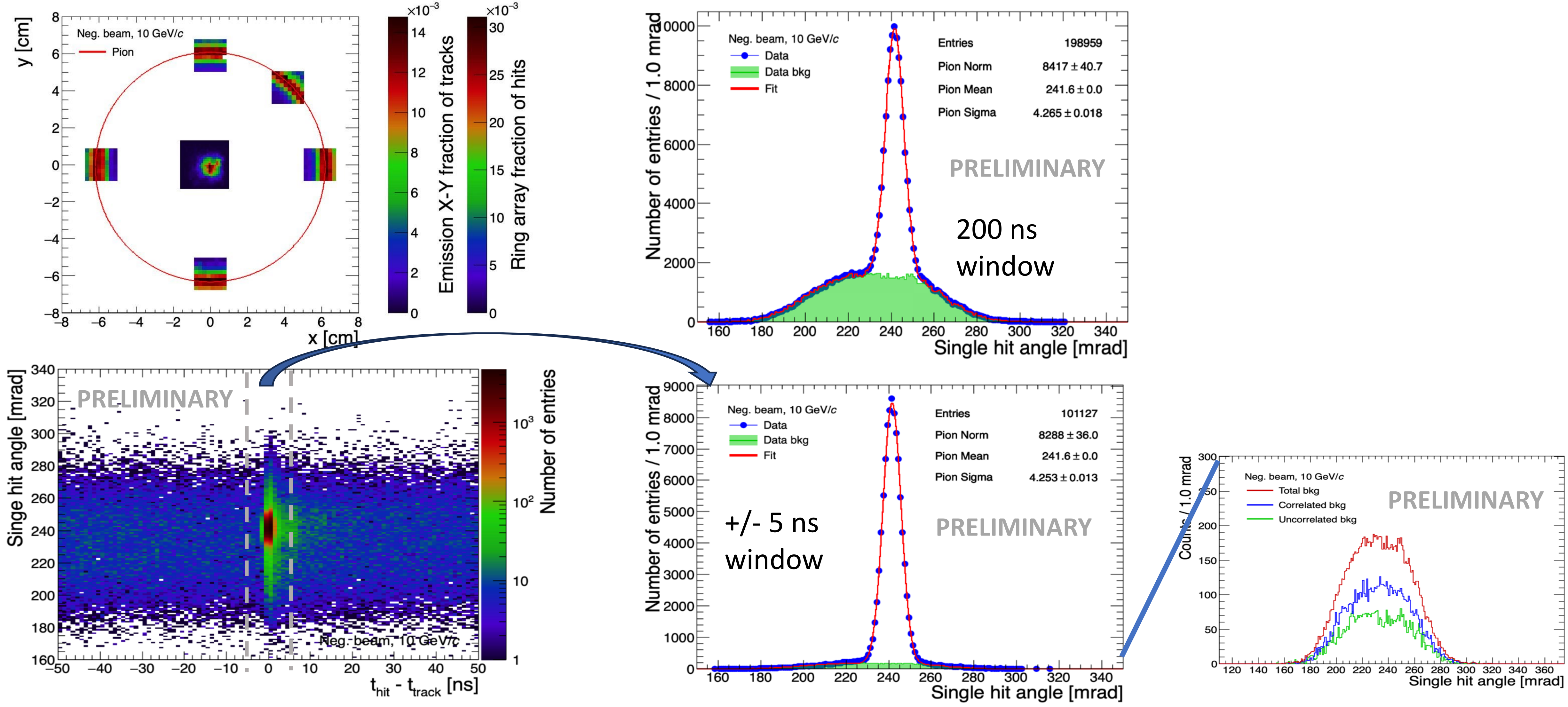




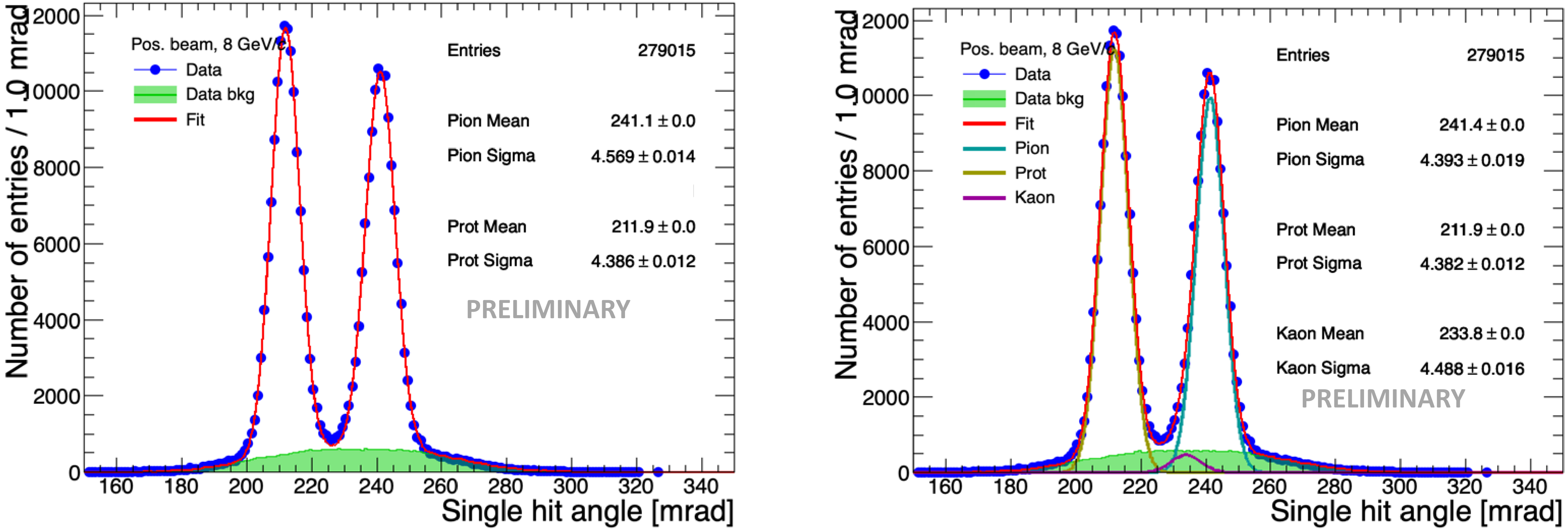
- Including kaons in the fit the pion resolution is recovered
  - The kaon fraction is compatible with the T10 particle beam composition at 8 GeV/c

2024: Cherenkov angle and timing effects

- Angular resolution of about 4.3 mrad as expected with 2x2 mm^2 pixel size



2024 - Angular resolution 8 GeV/c positive pions+protons



- Including kaons in the fit the pion resolution is recovered
  - The kaon fraction is compatible with the T10 particle beam composition at 8 GeV/c