INFN BARI
Istituto Nazionale di Fisica Nucleare
Sezione di Bari

XIV International Conference on New Frontiers in Physics
17-31 July 2025, OAC, Kolymbari, Crete, Greece

Beam test campaign of the SiPM-based RICH detector for the future ALICE 3 experiment

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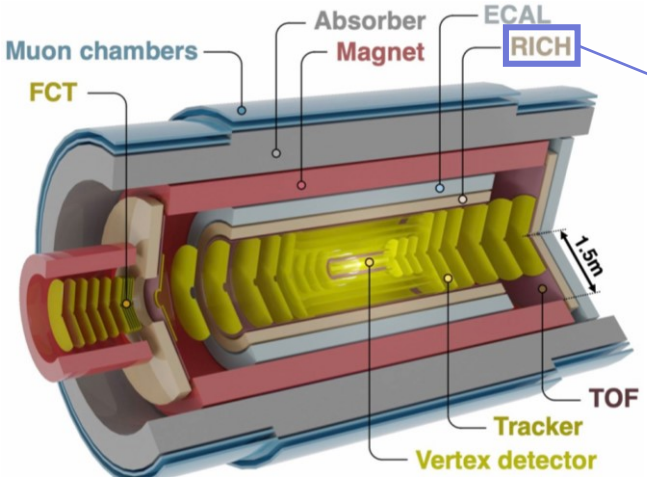
ALICE 3 RICH detector

The ALICE Coll. is proposing a new apparatus (ALICE 3) for LHC Run 5 and beyond in order to study the properties of QGP formed in ultra-relativistic heavy-ion collisions



Barrell RICH (Area~25 m^2) for the ID of charged particles:

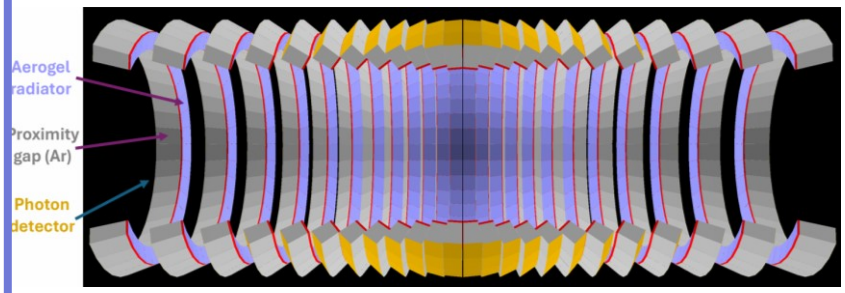
e/π separation in the p range 0.5 - 2 GeV/c

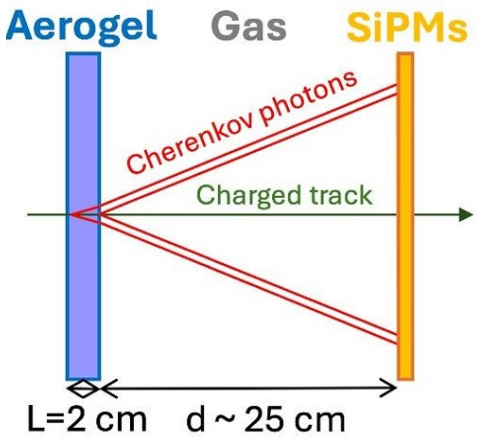
π/K separation in the p range 2 - 10 GeV/c

K/p separation in the p range 4 - 16 GeV/c

Radiator tiles with n=1.03 and thickness 2 cm + Photon detector in a **proximity focusing layout**

Projective geometry: modules oriented towards nominal collision vertex

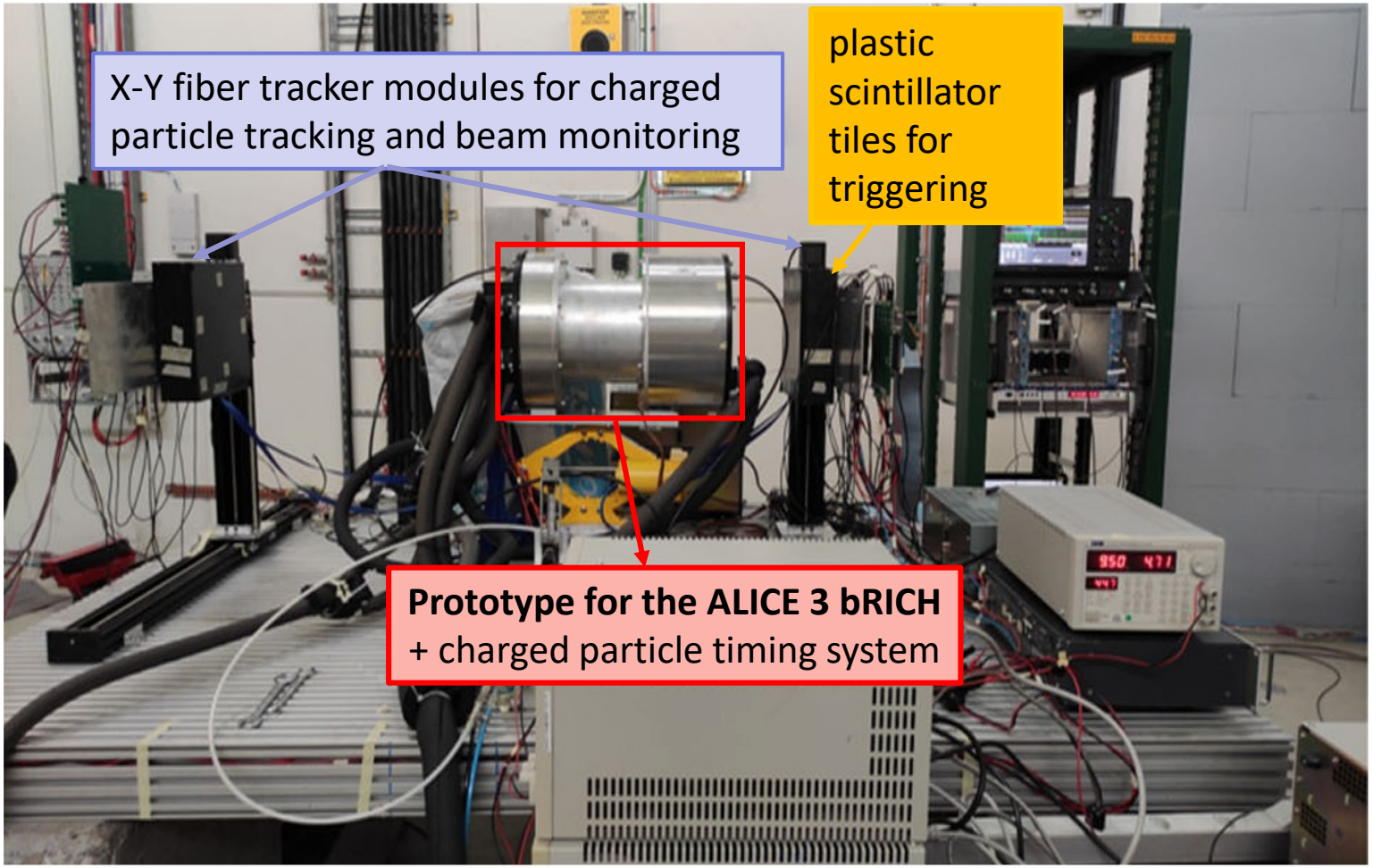




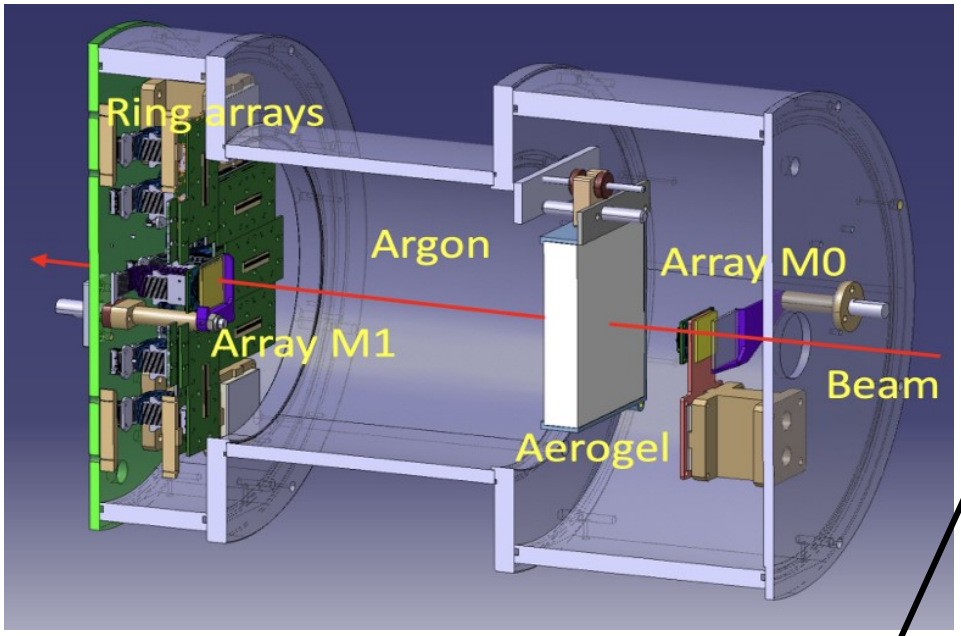
- Pixel size ~2x2mm^2
- PDE > 40% at 400nm
- Angular res. < 1.5mrad
- Readout electronics with **SPTR of ~100ps** to disentangle signal hits from background

2023 beam test - setup

A first small-scale prototype for the RICH has been tested in 2023 at CERN PS T10 beam line with pions and protons [2025 Eur. Phys. J. C 85].



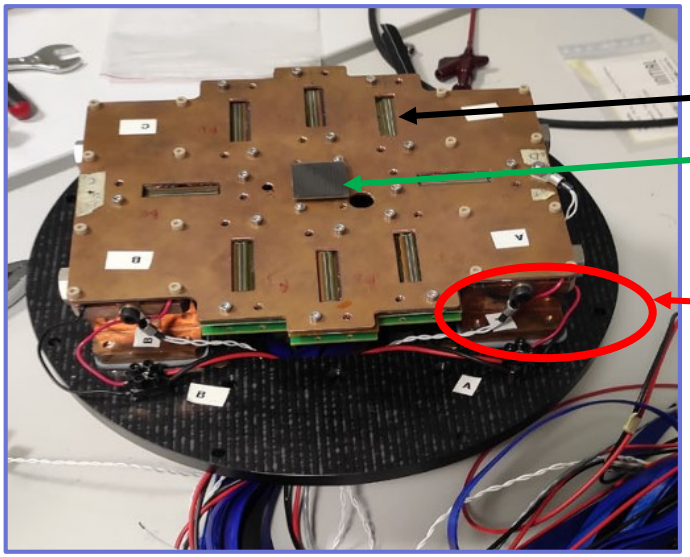
2023 beam test - setup

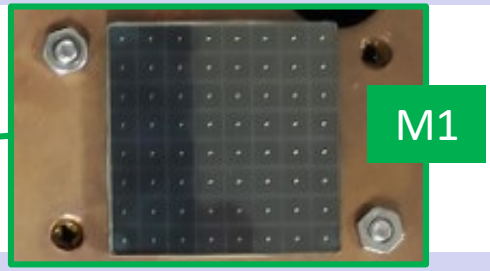


bRICH prototype

- Aerogel tile (n=1.03) with thickness of 2 cm separated by a 23 cm gap filled with Ar to keep RH < 2.5%
- **8 SiPMs** located at ~6.5 cm of radius with a readout pitch of 1 × 1.625 mm^2

Charged particle timing system (M0 and M1):
Cherenkov quartz radiator directly coupled to SiPMs (8×8 channels with 3x3 mm^2 pitch)

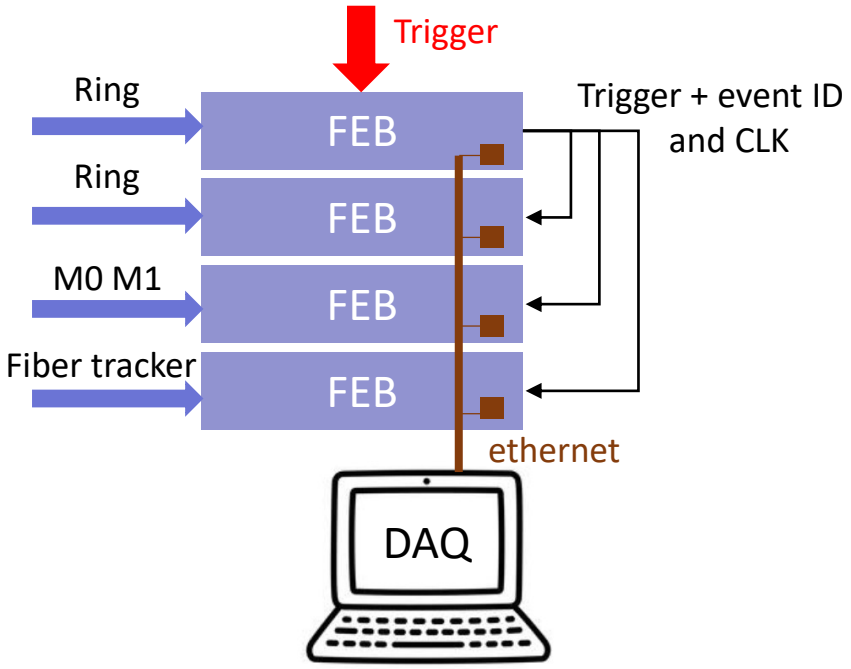


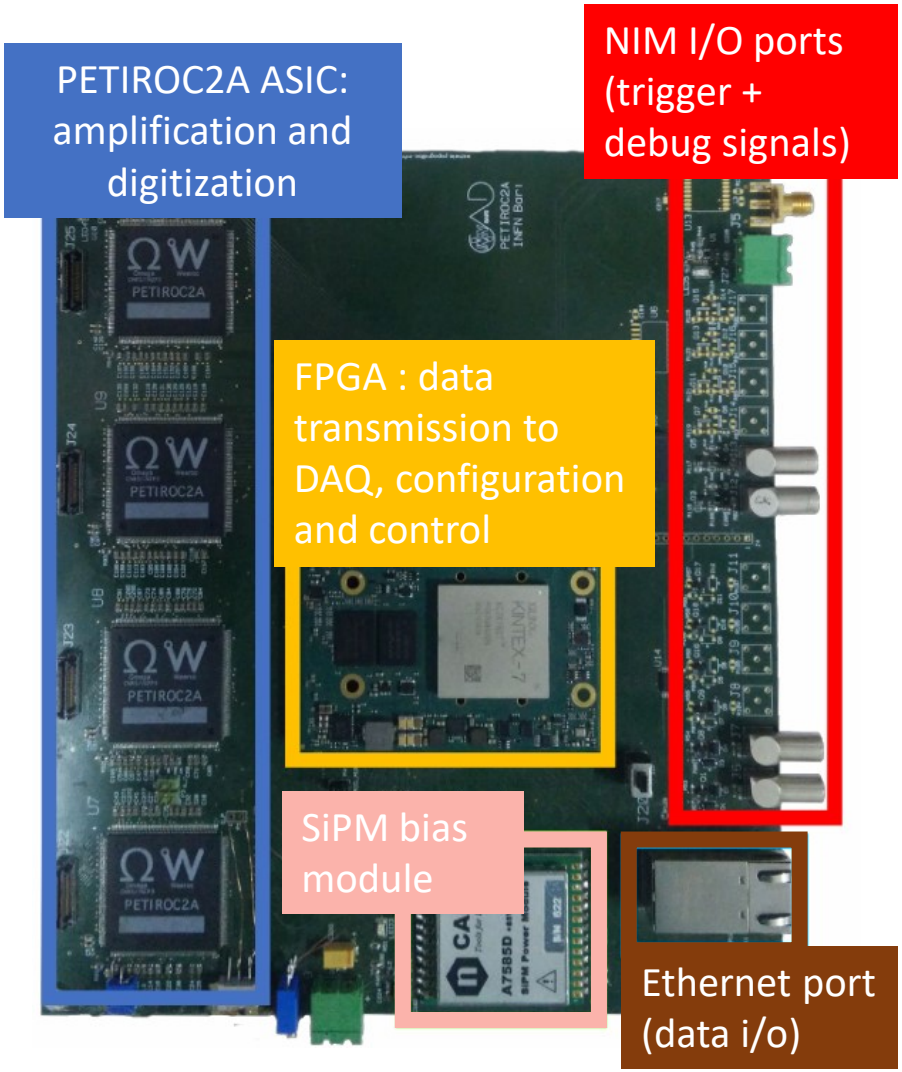


- SiPMs cooled at < 0◦C to reduce the DCR using Peltier cells interfaced to water chiller
- Analog temperature sensors and humidity sensors assembled

2023 beam test - electronics

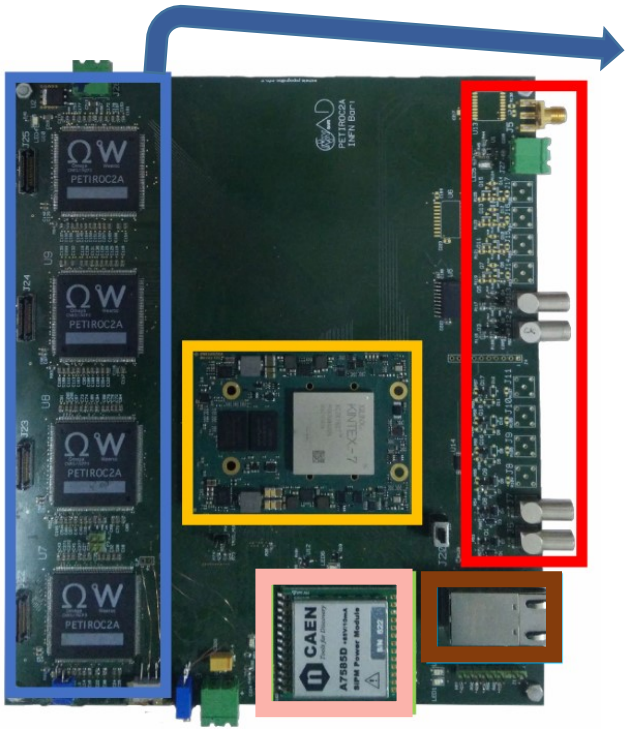
SiPMs readout by a custom FE boards developed by INFN-Bari.



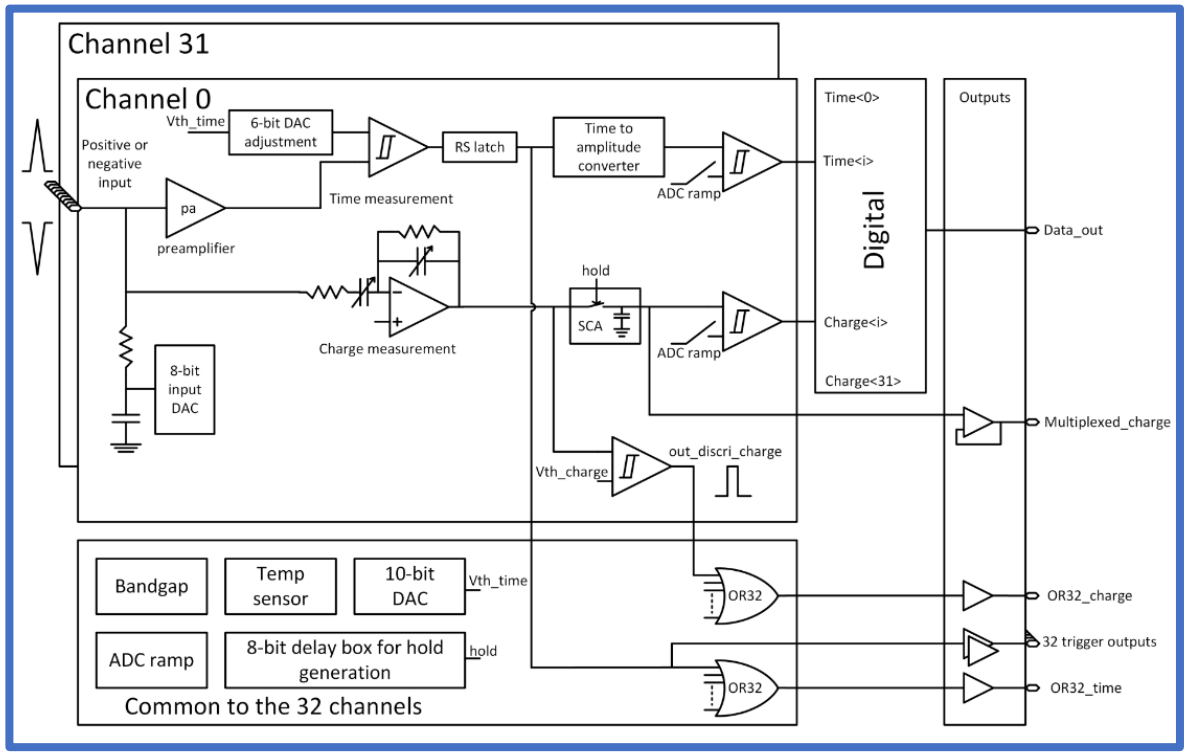


- One FEB acts as controller, providing a common 40 MHz clock, trigger signal and event id to the other FEBs.
- For each trigger event, a 550 ns time window is opened for data acquisition.

2023 beam test - electronics

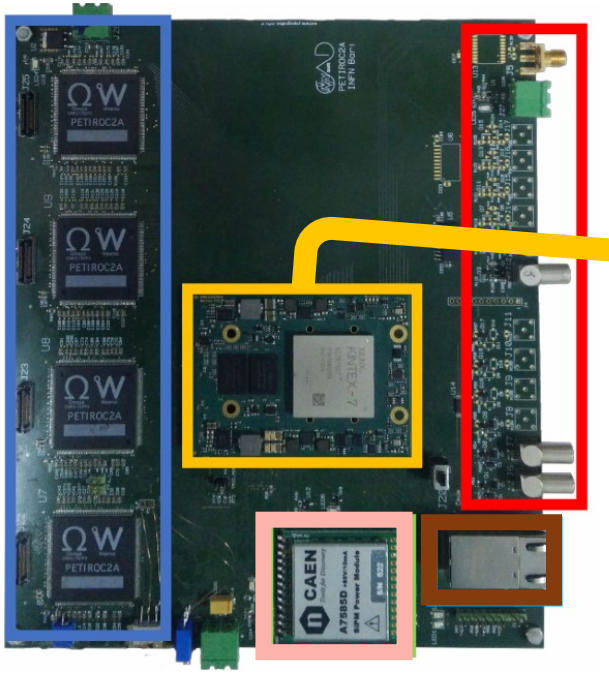


PETIROC2A by Weeroc

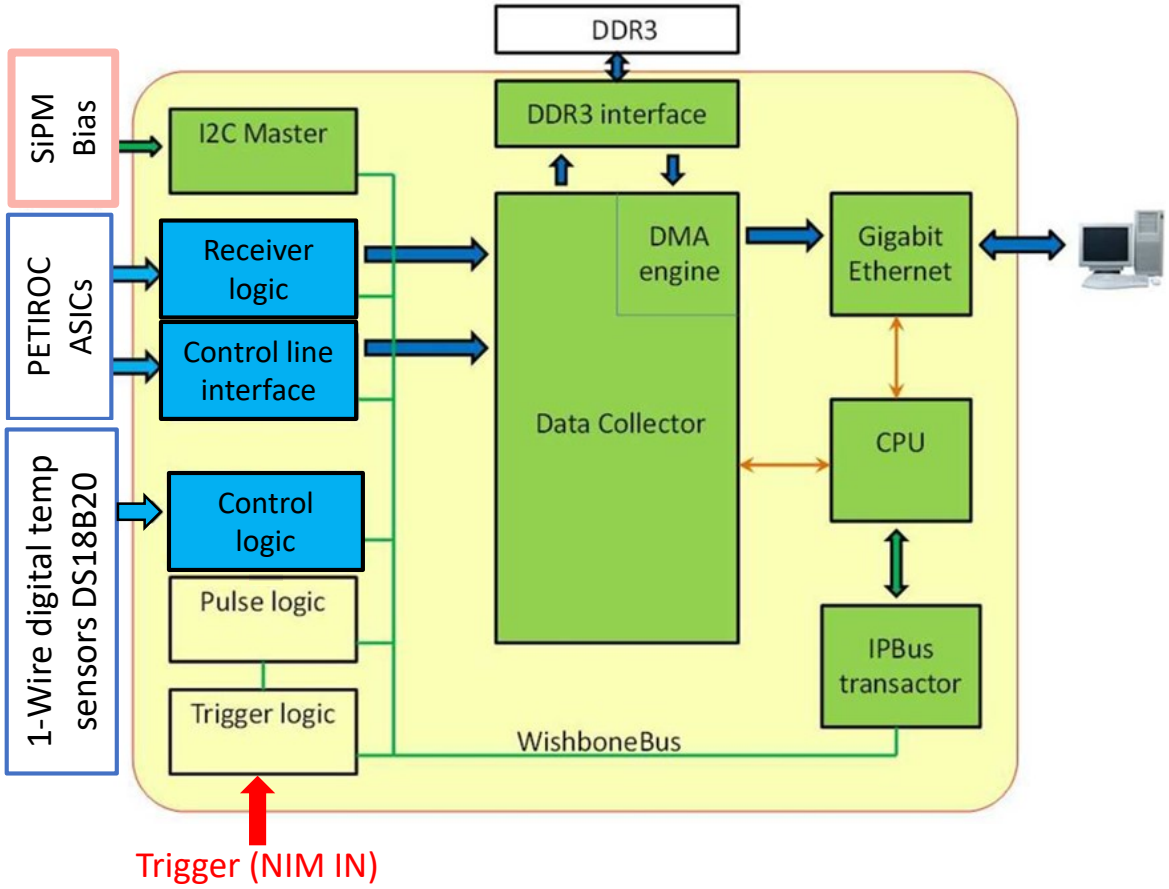


- Signal acquisition from SiPM- 32 input channels – positive or negative polarity
- Charge measurements (10-bit ADC) and time measurements (resolution~37 ps)
- Time-of-arrival: Coarse-time (CT) counter with a 40MHz used as reference + Fine time between two 40MHz edges obtained by a ramp based Time-to-Amplitude converter

2023 beam test - electronics



Kintex-7 FPGA mounted on a Mercury+KX2 module - Modular System for Acquisition, Interface and Control (MOSAIC) firmware



«Flexible» structure:

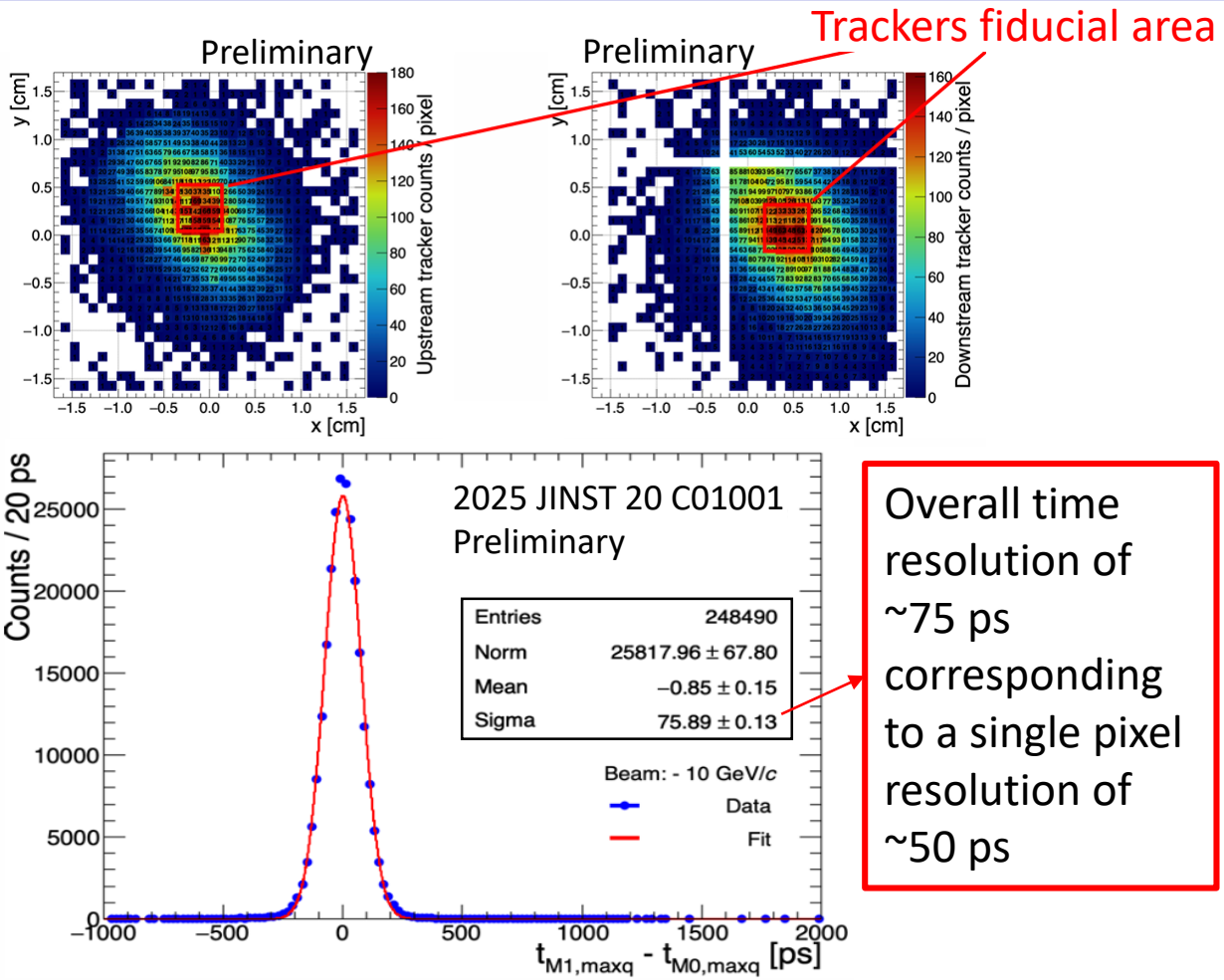
- **Infrastructure:** Wishbonebus for configuration and monitoring + interface for DDR3 memory
- **Hardware-dependent modules**

2023 beam test - results

A good timing-particle match helps in discarding uncorrelated hits due to the SiPM DCR, crucial for ALICE 3 since the DCR increases at high-radiation environment.
Timing performance studied through the time differences between M0 and M1.

Track selection in fiducial area and hits required both in the two tracker planes and in the two central arrays

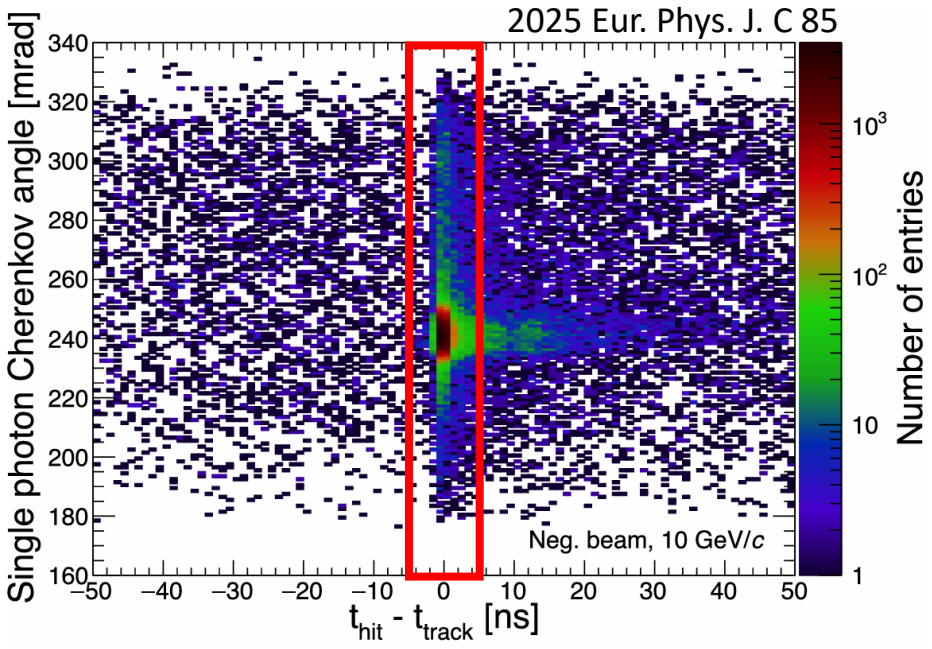
N.B. Nominal Time-of-Flight at the actual beam momentum is subtracted;
time walk and channel by channel offset corrections are applied.



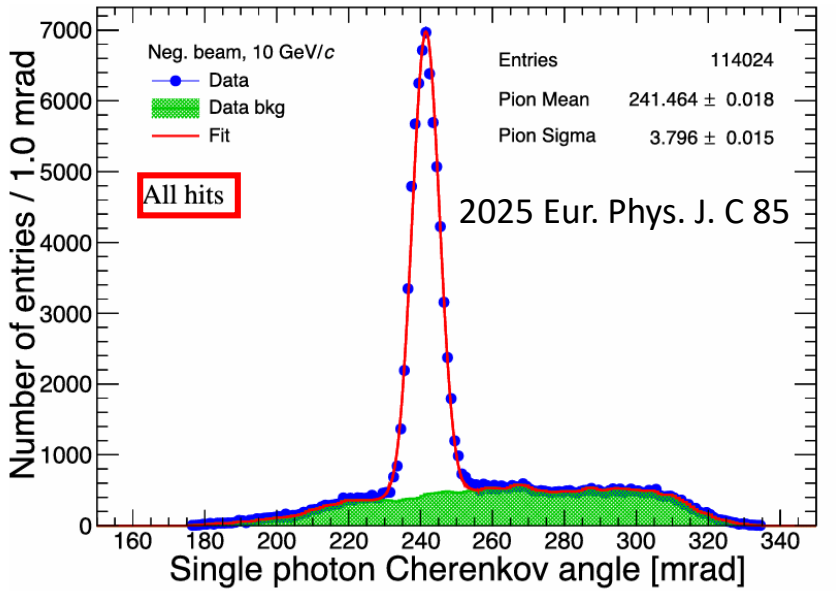
Overall time resolution of ~75 ps corresponding to a single pixel resolution of ~50 ps

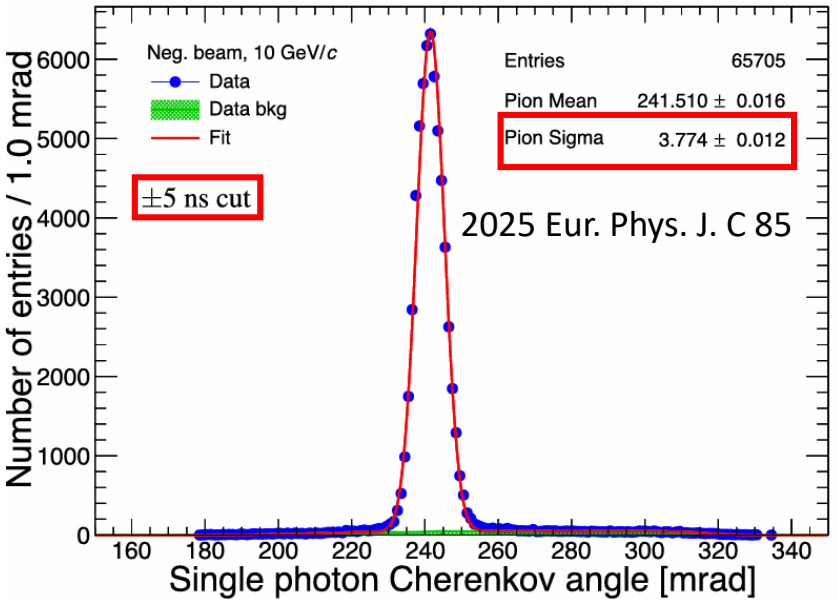
2023 beam test - results

Time difference between the RING arrays and the central matrix

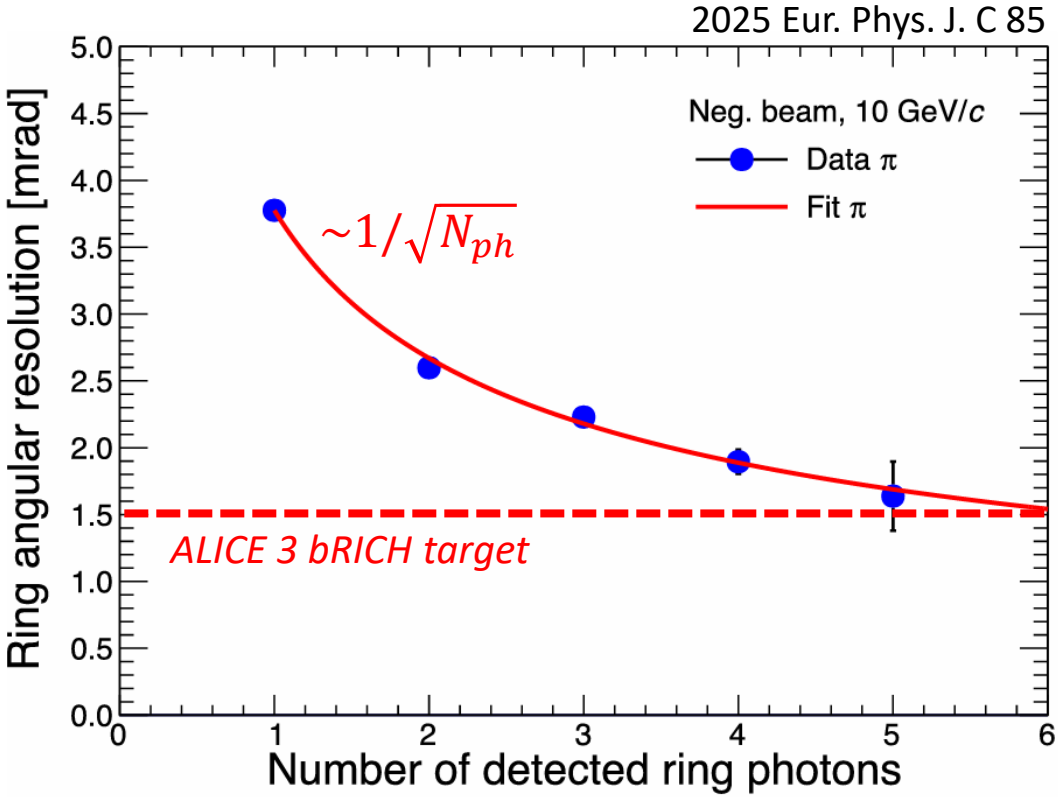


Timing information critical to reach a good background suppression





2023 beam test - results

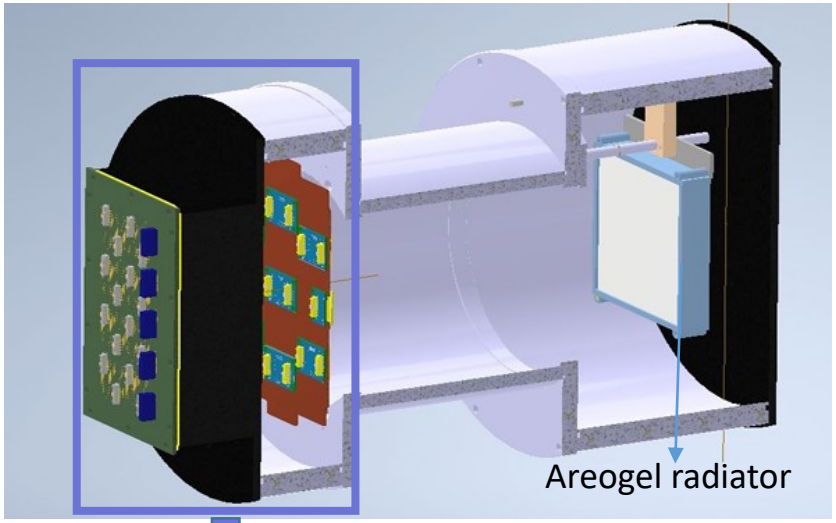


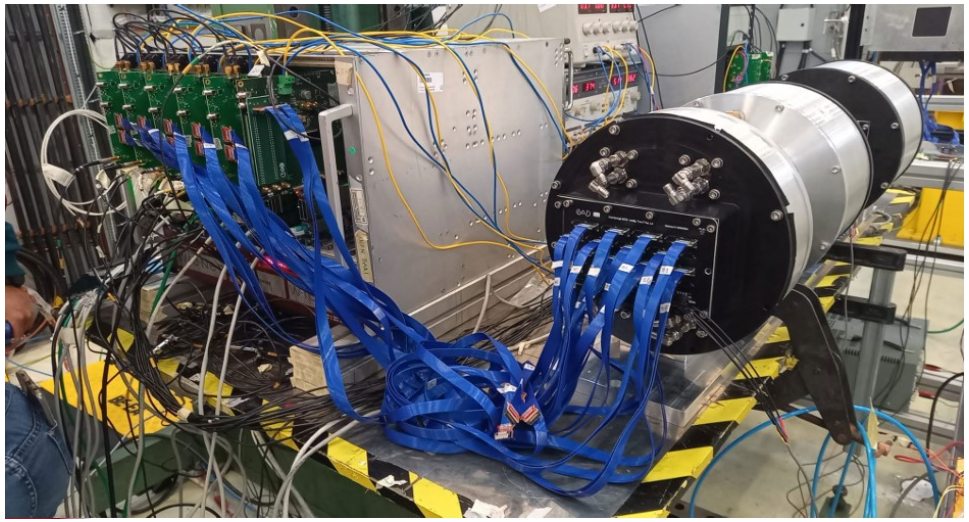
- An angular resolution <1.5mrad (ALICE 3 bRICH target) is reached for a $N_{ph} > 6$.
- For a photosensitive surface fully covered by SiPMs the average N_{ph} is expected to be about 28.

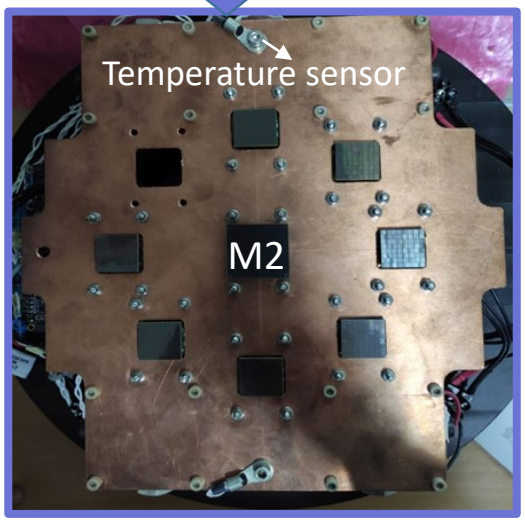
The result obtained with this bRICH prototype equipped with SiPMs having $1 \times 1.625 mm^2$ pitch fulfill the ALICE 3 requirements.

2024 beam test - setup

A new prototype with larger pixel size has been assembled and tested in 2024 at T10



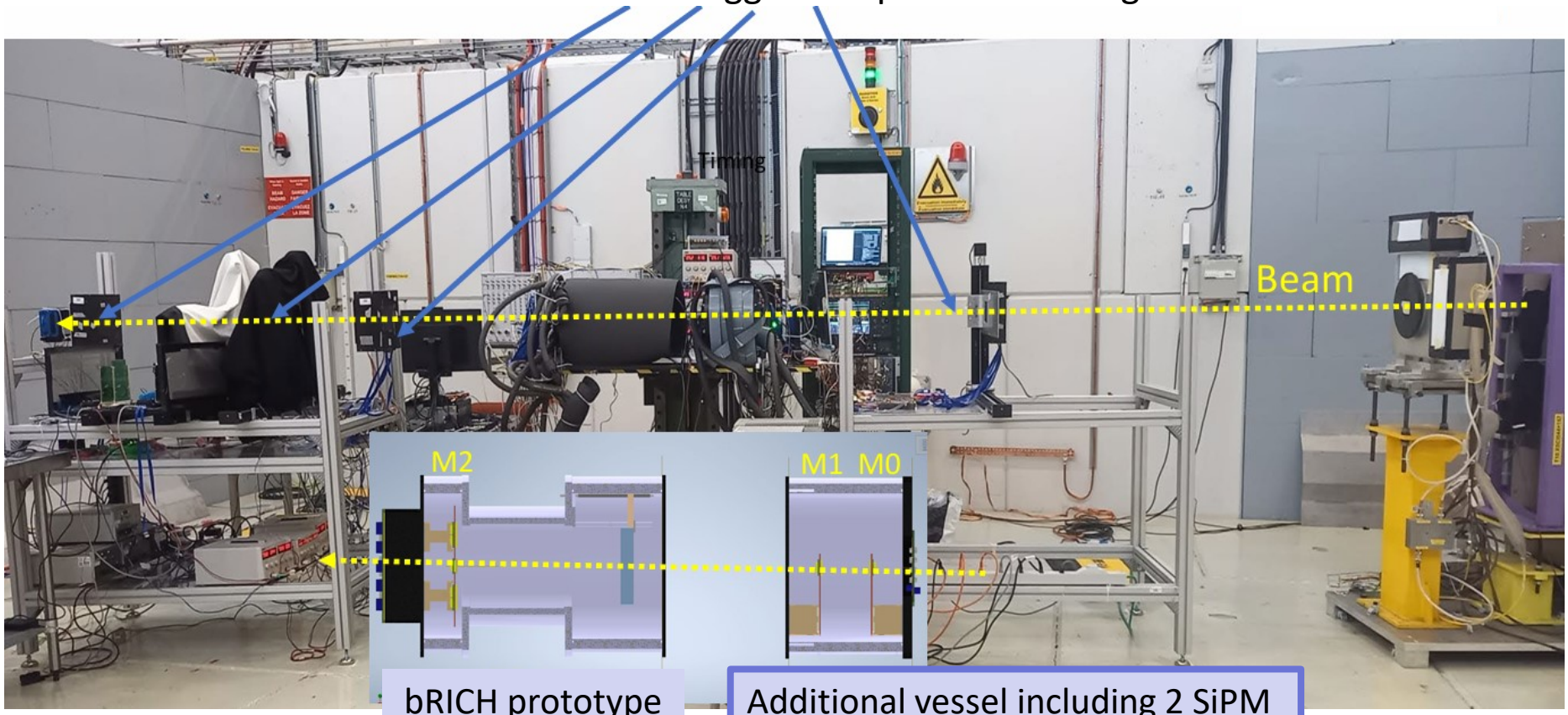




- **Ring array**:
  SiPMs with 8×8 channels having a pitch of 2.2x2.2 mm^2 (baseline for the ALICE3 bRICH) arranged along a circumference with radius 5.9 cm
- **Central SiPM array** (M2) with 3 mm pitch and 1 mm thick quartz window for charged particle timing
- **New redout electronics** for SiPM with improved time resolution to enhance the single-photon capabilities

2024 beam test - setup

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

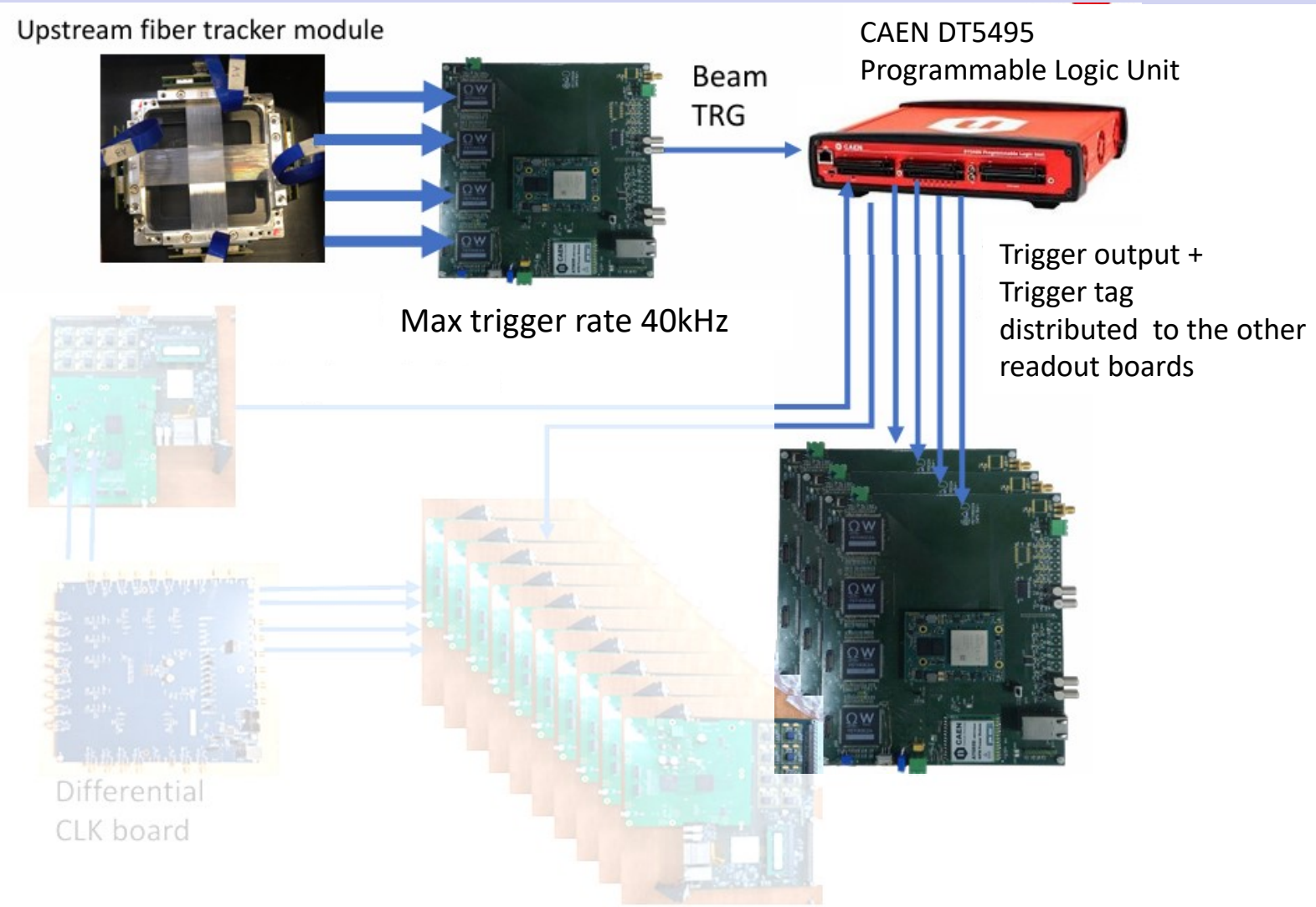


bRICH prototype

Additional vessel including 2 SiPM arrays (M0 and M1) for timing purposes with 2 mm pitch glued on a 1 mm thick quartz radiator

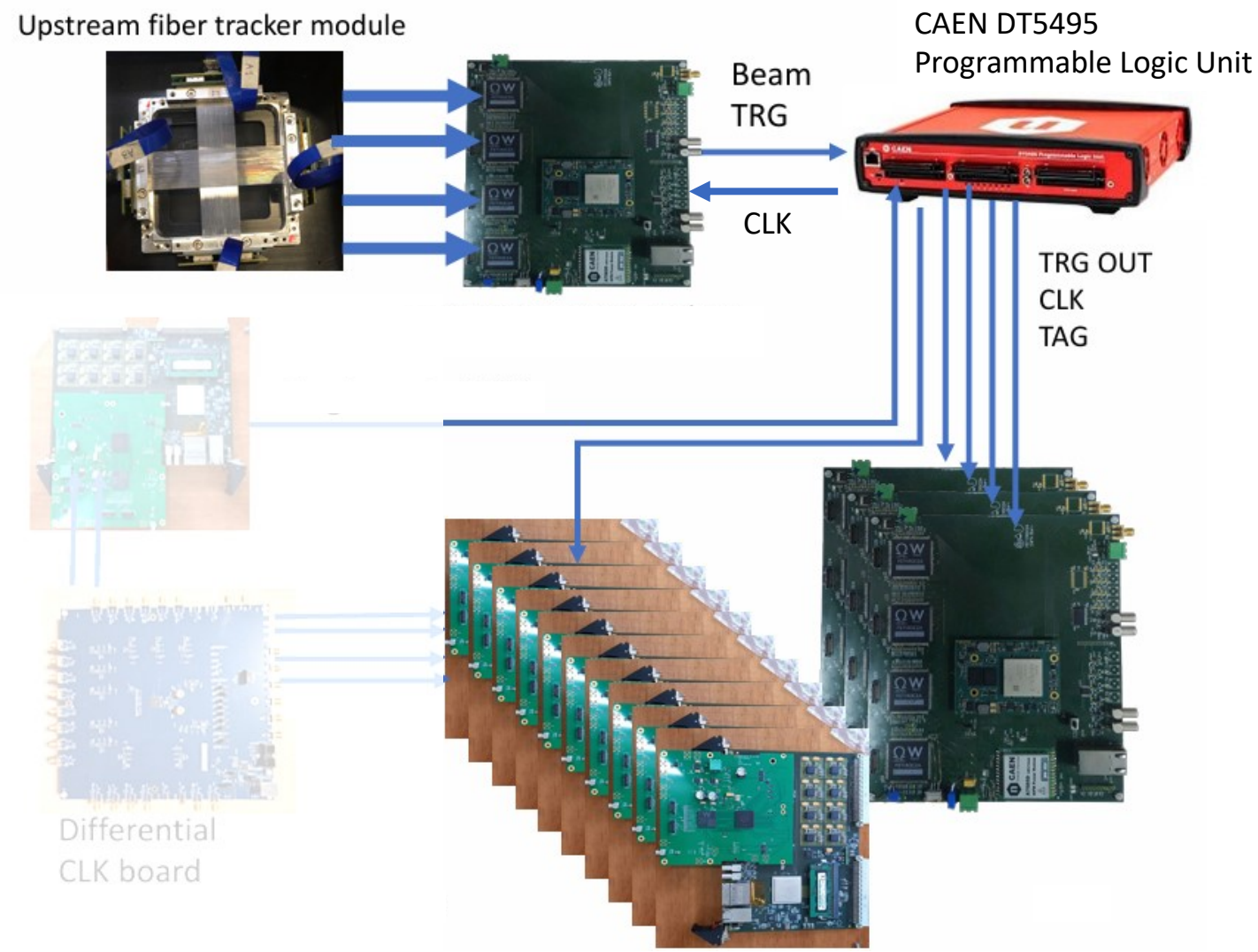
2024 beam test - electronics

Fiber tracker modules for triggering and tracking readout by the custom boards developed by INFN-Bari used in 2023



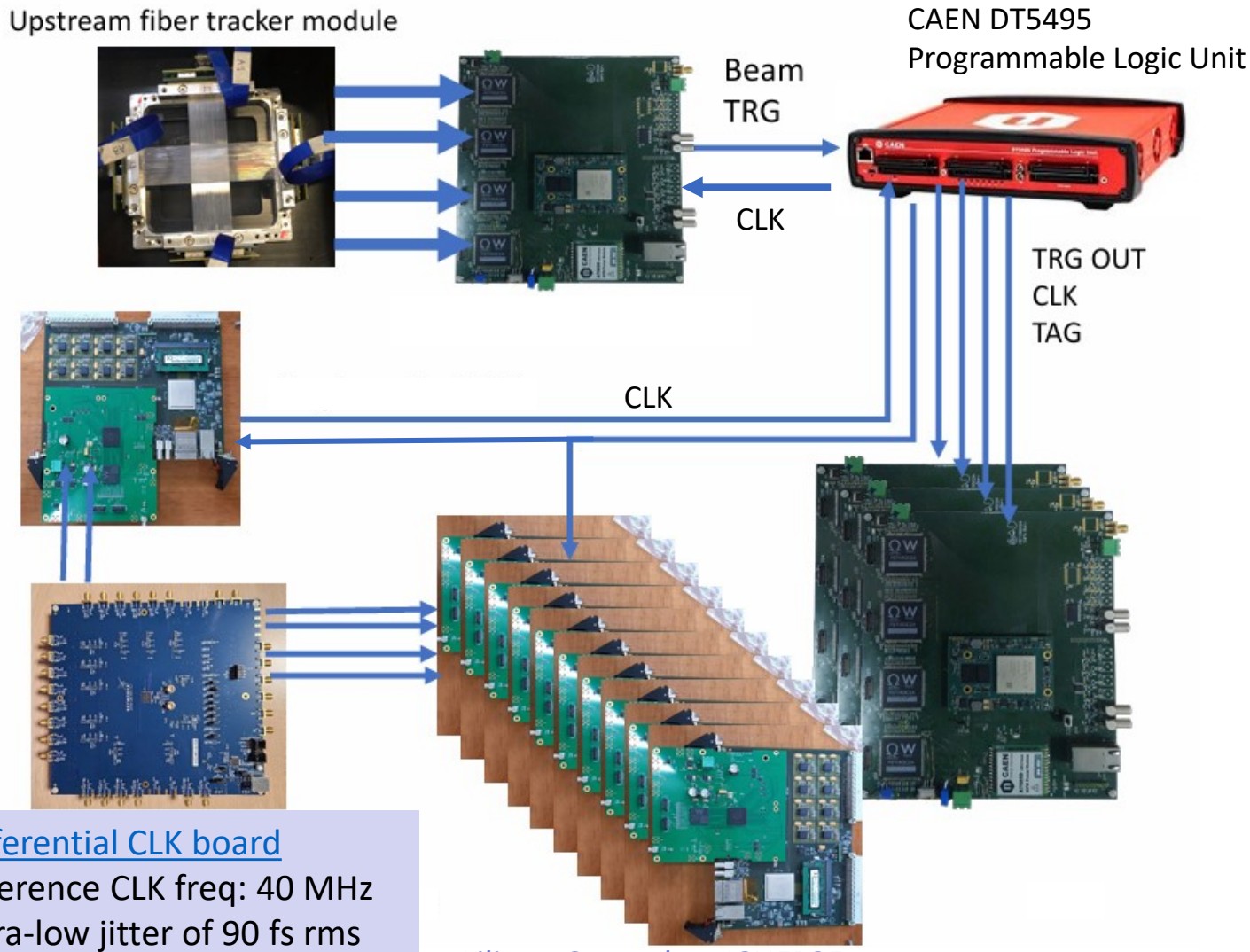
2024 beam test - electronics

RICH and timing system readout by new custom boards with improved time resolution based on the Weeroc Radioroc 2 FE ASIC with picoTDC connected to MOSAIC boards



2024 beam test - electronics

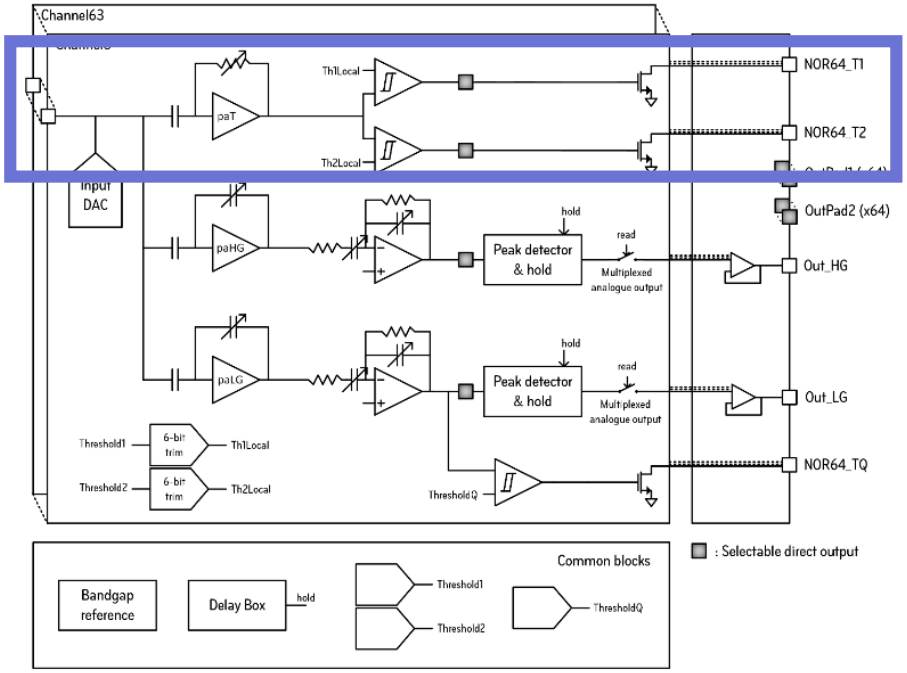
In order to improve the time resolution of the system up to few tens of ps, the clock system distributes a low-jitter and stable clock to the FEBs.



[Differential CLK board](#)
Reference CLK freq: 40 MHz
Ultra-low jitter of 90 fs rms

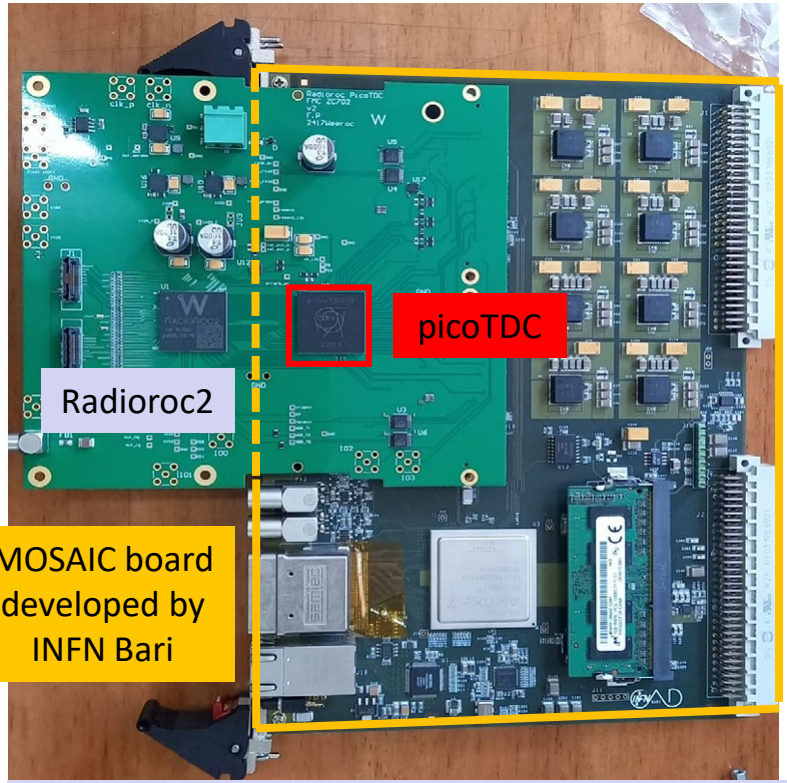
2024 beam test - electronics

Radioroc 2 FE ASIC

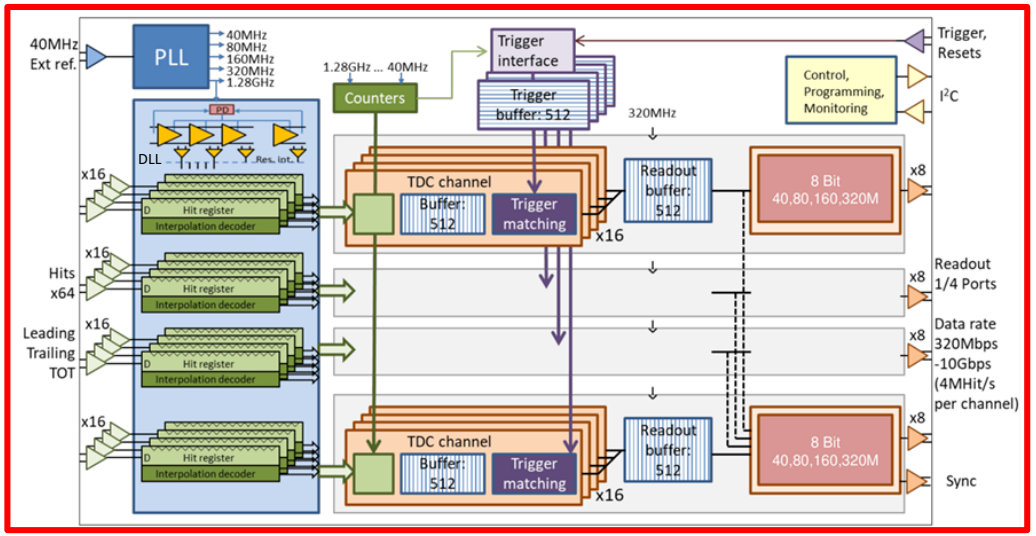


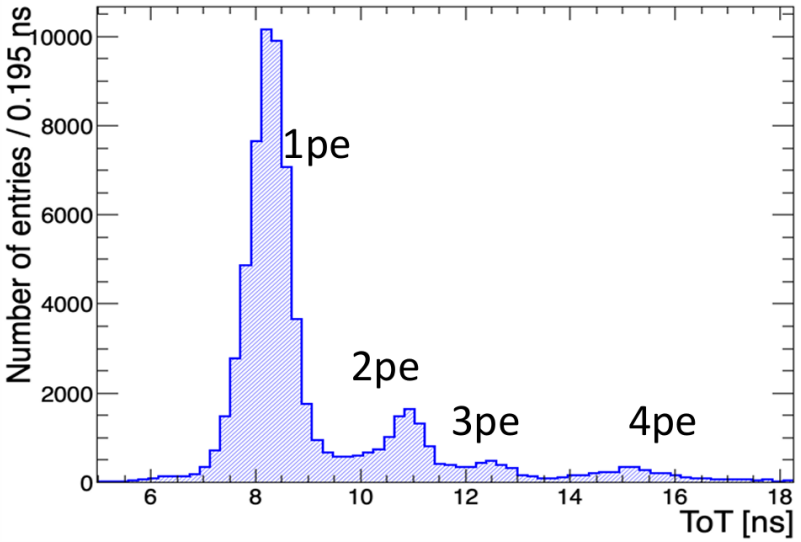
- Signal acquisition from SiPM- 64 input channels
- Signal amplification and discrimination: Threshold at single P.E. level
- LVDS output signals

2024 beam test - electronics



picoTDC developed by CERN





- ToA (LSB~3.05ps) and ToT (LSB~195ps) meas.
- Acquisition window of 200 ns
- Data transmitted in LVDS at 320 Mbps to the MOSAIC board equipped with the MOSAIC firmware updated for:
  - data acq. from picoTDC and transmission to DAQ;
  - control of Radioroc and picoTDC chips.

2024 beam test - results

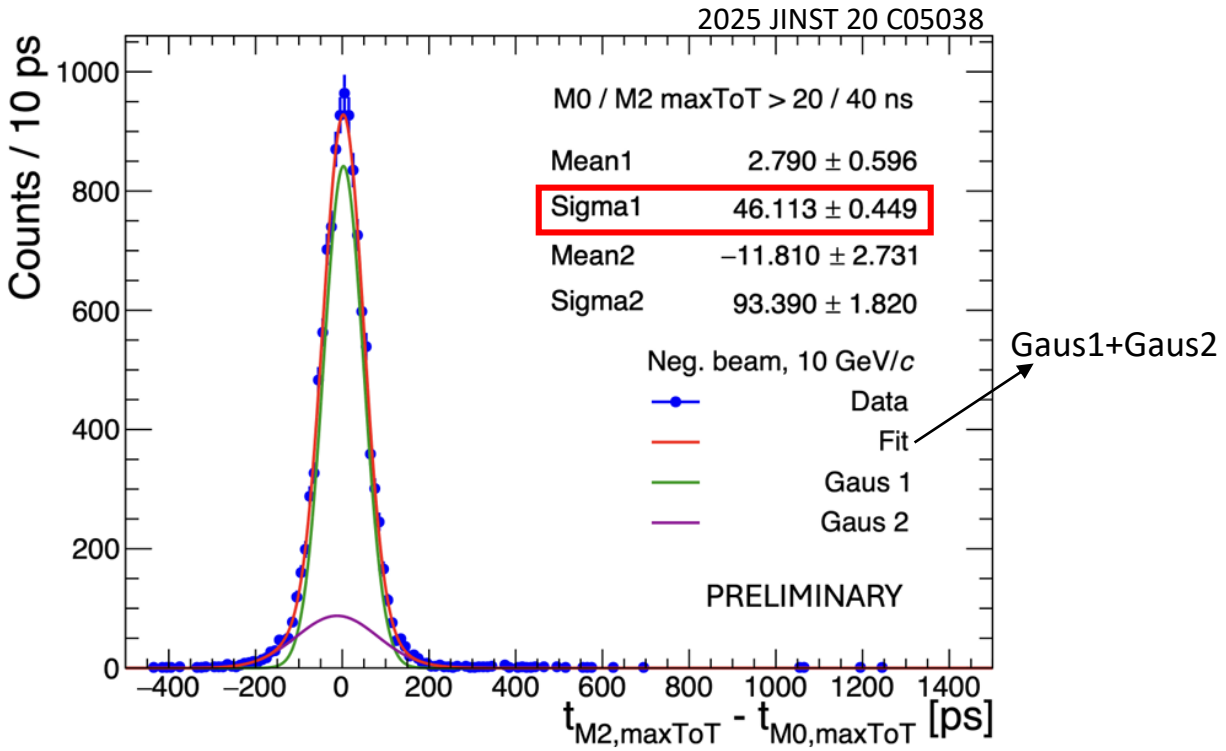
Timing performance studied through the time differences between the SiPM arrays M0,M1,M2

Selections:

- tracks in fiducial area
- M0ToT > 20 ns and M2ToT > 40 ns to limit time jitter

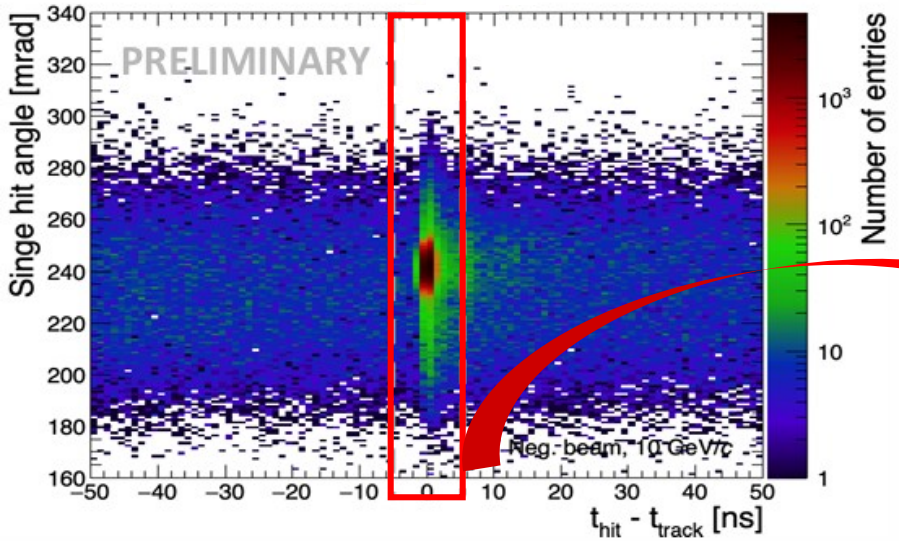
Corrections for time walk and ch by ch offset applied

Overall time resolution of ~50 ps corresponding to a single pixel resolution of ~35 ps

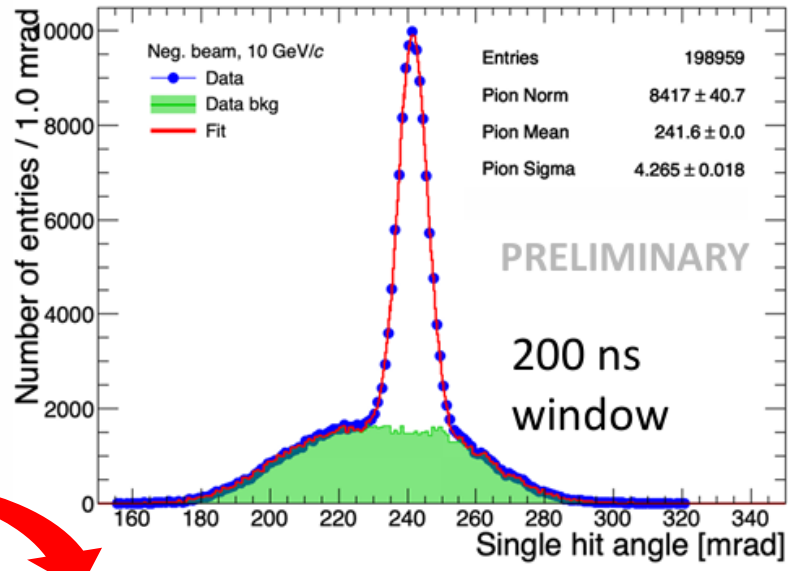


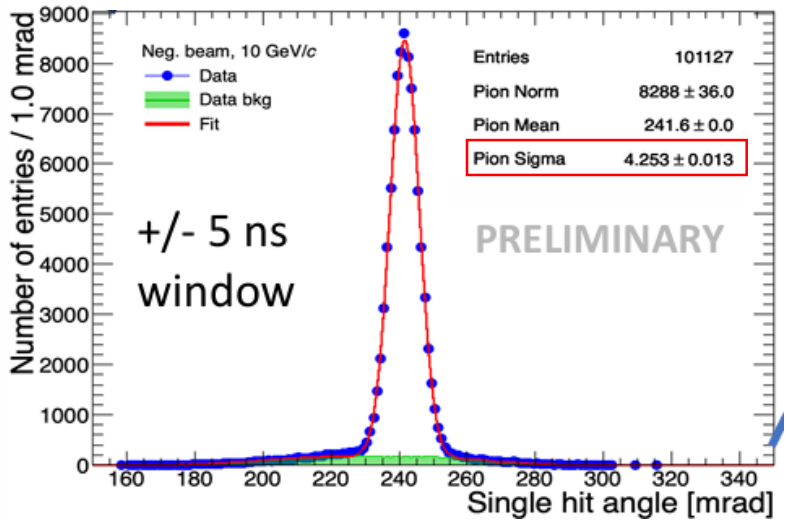
2024 beam test - results

Time difference between the RING arrays and the central matrix M2



Angular resolution of 4.3 mrad reached, only a few tenths of mrad higher w.r.t. the 2023 value, due to the larger pixel size. Compatible results are obtained with the positive beam (pions + protons).

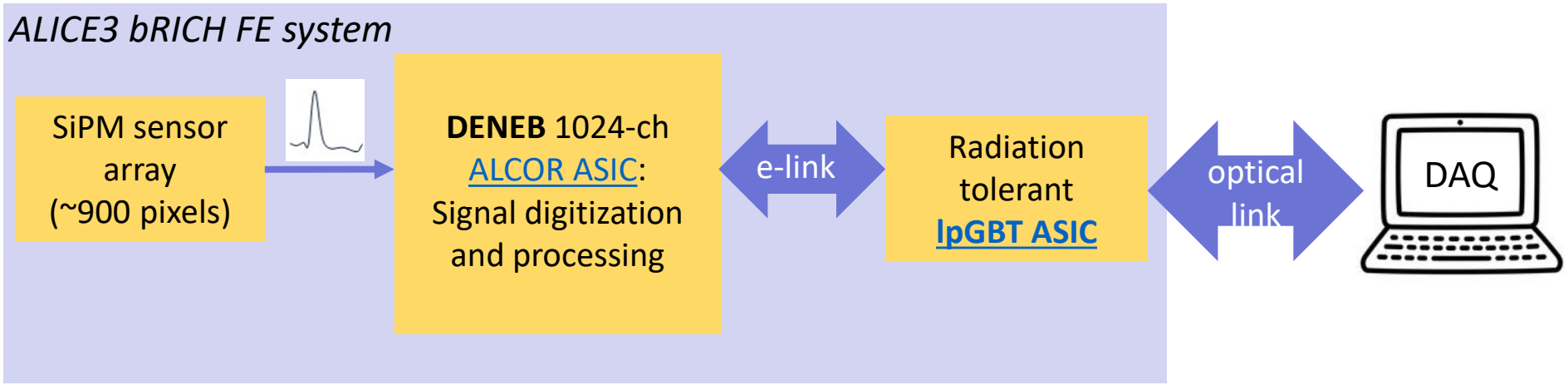




Outlook

A new front-end electronics based on the ALCOR ASIC with 1024 channels developed by INFN Torino is being investigated for the ALICE 3 bRICH.
Advantages:

- FE electronics hosted in the same PCB of the SiPMs;
- ALCOR chip equipped with a LpGBT compatible transceiver providing data transmission via optical link. No local FPGAs needed in the ALICE3 high radiation environment.

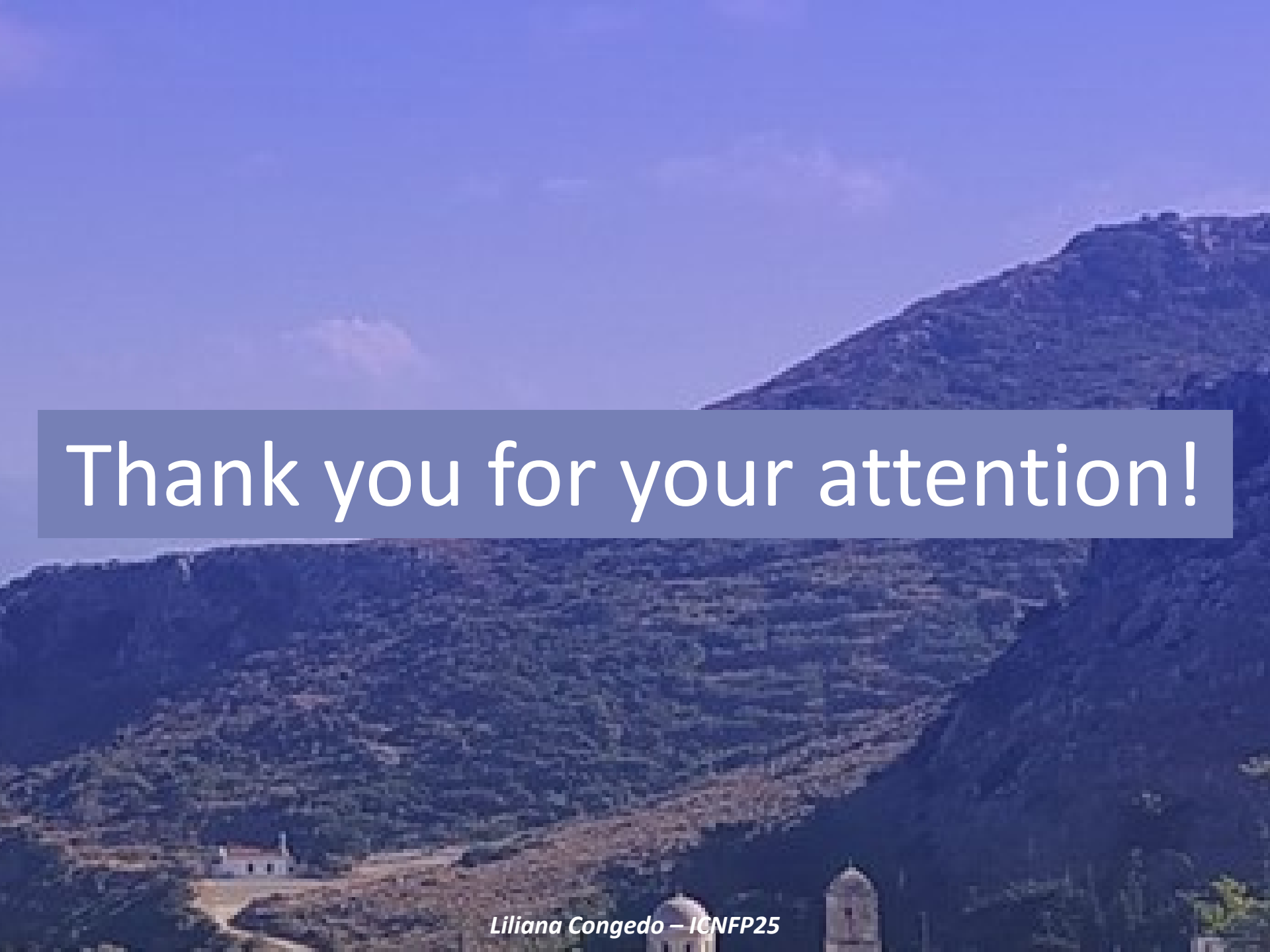


Conclusion

Prototypes of the SiPM-based RICH detector for the future ALICE 3 experiment have been produced and tested with dedicated electronics in 2023 and 2024 at T10 beam line showing:

- An overall (electronics + SiPM) single pixel timing resolution of about 35 ps with 1 mm of quartz radiator;
- Pion and proton Cherenkov single photon angle resolution of 4.3 mrad in 8-10 GeV/c beam momenta with a 2 cm aerogel (n=1.03), a proximity gap of about 23 cm and a SiPM pixel pitch of 2 mm.

A further beam line campaign is foreseen in 2025 with the new front-end ASIC ALCOR chip developed by INFN Torino which could be a candidate for the ALICE 3 bRICH front-end electronics.


Thank you for your attention!