



# XIV International Conference on New Frontiers in Physics

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## The scintillating fiber tracker of the Ziré detector onboard the NUSES satellite

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Collaboration

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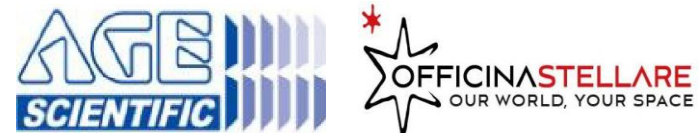
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# Outline

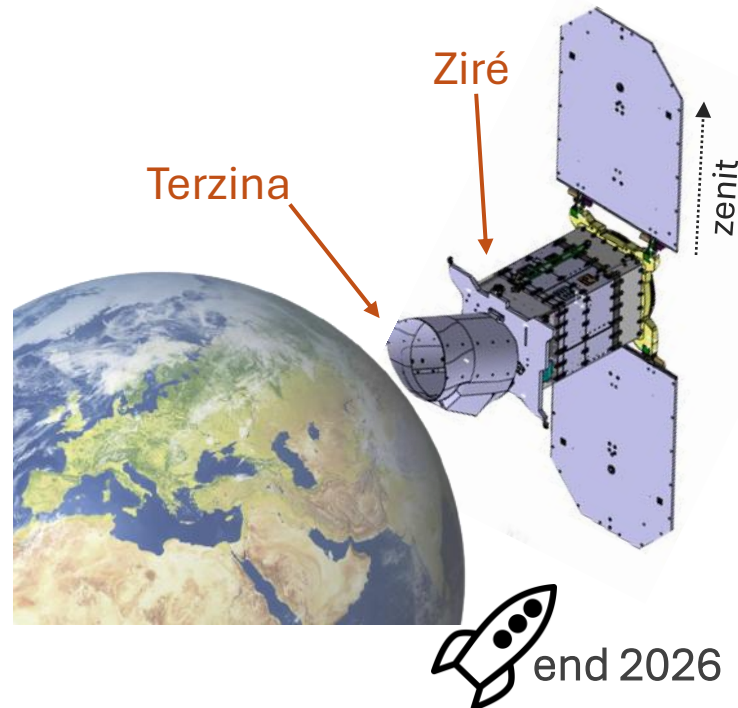
- The Ziré instrument onboard the NUSES mission
- The Fiber Tracker of Ziré (FTK)
- Reduced FTK prototypes developed at Bari INFN
- Zirettino: a reduced Ziré prototype
- Zirettino FTK characterization:
  - Beam test results
- Structural model and qualification tests:
  - Dynamic tests and thermal cycles
- Overview on the next planned activities



# The Ziré instrument onboard NUSES

NUSES (NeUtrino and Seismic Electromagnetic Signals) → a technological pathfinder for future space-based detectors

- Read-out system based on Silicon Photo-Multiplier (SiPM) technology.



## Ziré

### Scientific goals:

- measurement of the fluxes of cosmic ray (CR) electrons, protons and light nuclei with energies up to hundreds of MeV
- gamma-ray telescope in the MeV energy range (below 30 MeV)
- Search for correlations of the  $e^-$  and p fluxes with seismic activities through the magnetosphere-ionosphere-litosphere coupling (MILC effect)
- Space weather

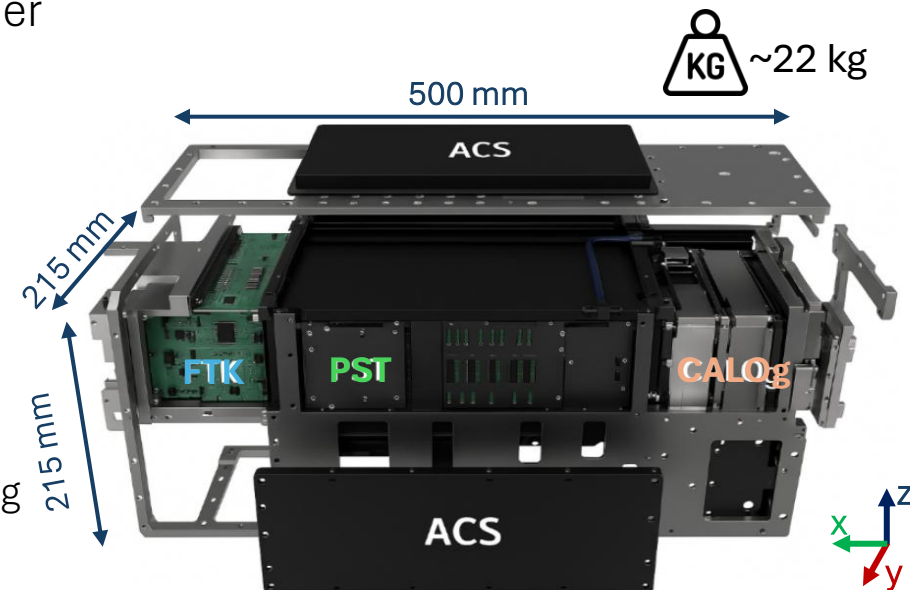
see G. Panzarini's talk

### ACS

- Charged background rejection

### FTK

- Fast trigger
- Particle tracking
- PID and  $dE/dx$



### PST

- PID
- Coarse tracking
- Energy meas.

### CALOg

- Energy meas.

# The Ziré Fiber Tracker (FTK)

## ➤ Plastic scintillator fibers with SiPM array readout

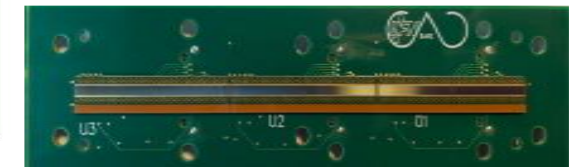
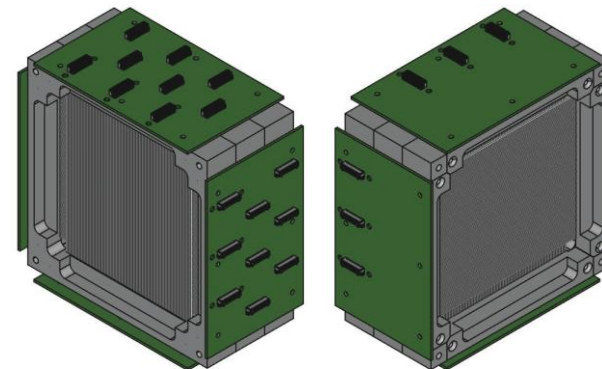
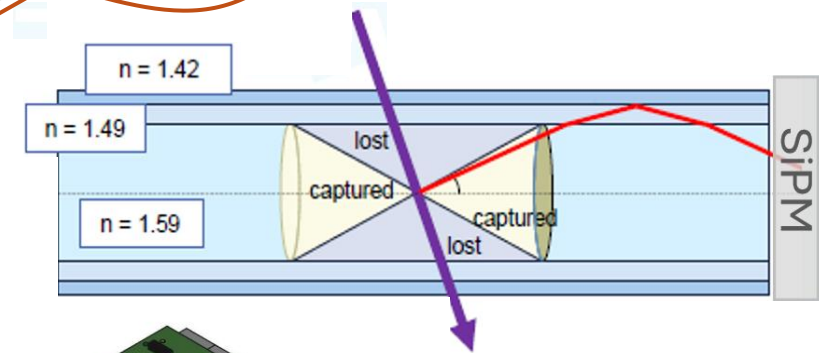
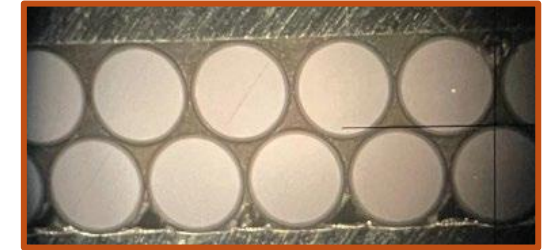
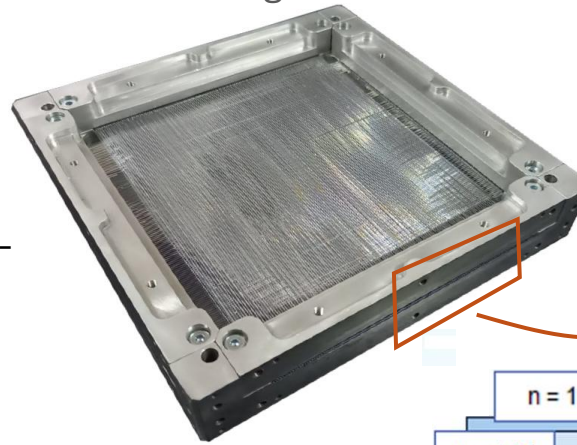
### Layout

- 3 X-Y modules ( $9.6 \times 9.6 \text{ cm}^2$ ) spaced 2.5 cm apart
- Each module → two perpendicular layers
  - Each layer → two staggered ribbons of double-cladding 750  $\mu\text{m}$  round Kuraray SCSF78-MSJ fibers (light yield  $\sim 8000$  photons/MeV)

### Read-out system

- 128-channel S13552 SiPM arrays with 250  $\mu\text{m}$  pitch
- One module (the closest to the PST) with double-sided read-out for trigger and redundancy
- 4 Front-End Boards (FEBs): 6 CITIROC 1A ASICs + analog-to-digital chip + FPGA each.
  - connected with a motherboard with a proper FPGA to manage the data acquisition system

single X-Y module

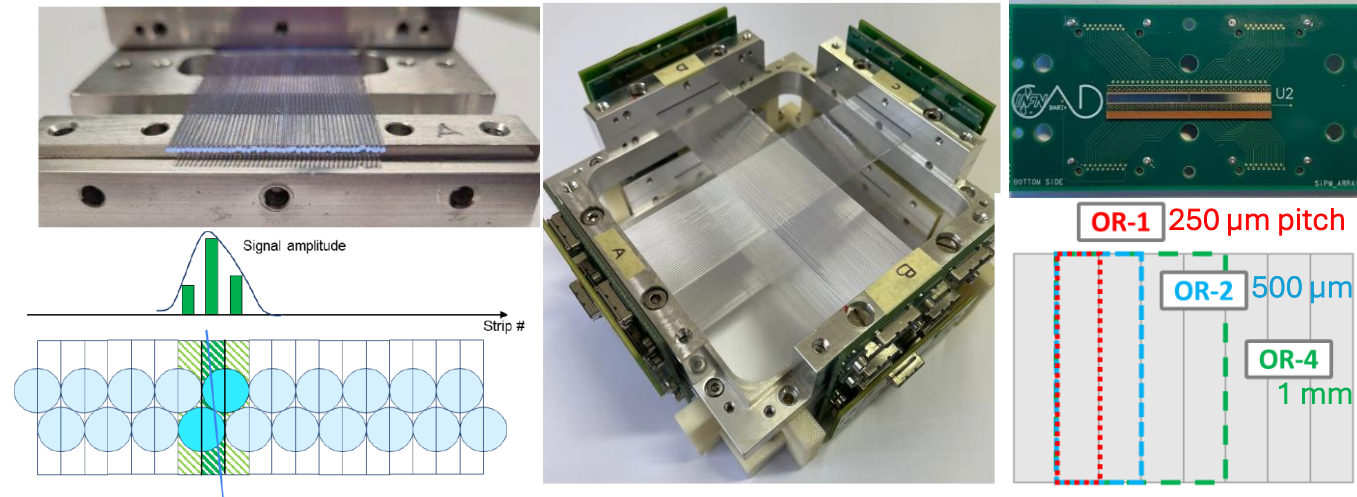


# The FTK prototypes (1/2)

➤ The Ziré FTK detector is based on detailed studies performed on reduced scale modules.

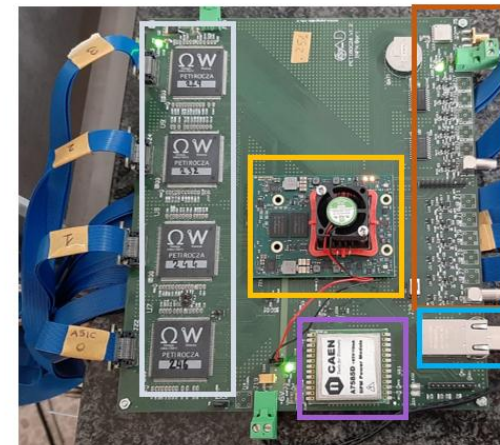
## Layout

- Several X-Y modules ( $3,25 \times 3,25 \text{ cm}^2$ ) of two perpendicular layers
- Each layer → two staggered scintillating fiber round ribbons:
  - Saint-Gobain/Kuraray
  - 500  $\mu\text{m}$  and 750  $\mu\text{m}$  diameter



## Read-out system

- 128-channel S13552 SiPM arrays with 250  $\mu\text{m}$  pitch
- Study with different read-out pitches for the SiPM strips (250  $\mu\text{m}$ , 500  $\mu\text{m}$  and 1 mm)
- Test and characterization with a custom FEB designed by INFN Bari



PETIROC 2A (32 channel chip): 32 ADC, TDC and digital outputs for triggering

Kintex-7 FPGA module: data management, trigger, coincidence

CAEN A7585D SiPM voltage module

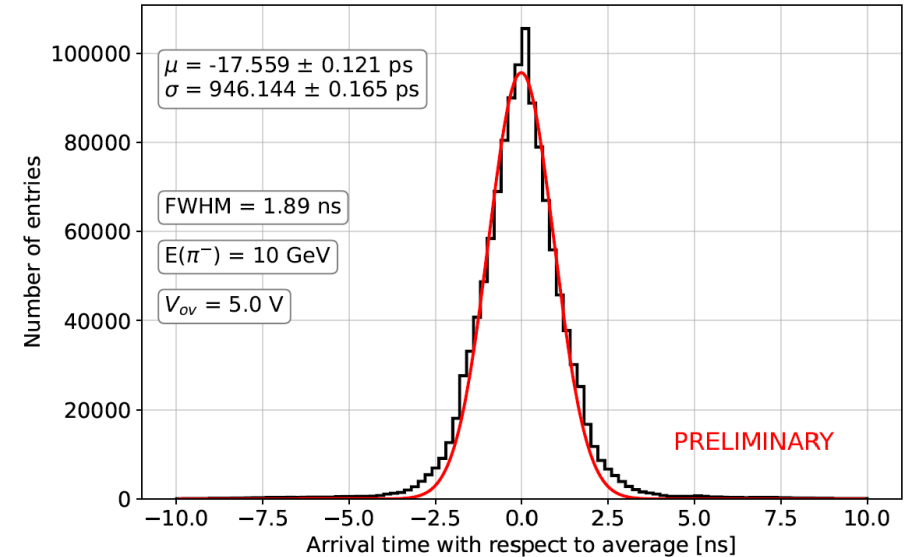
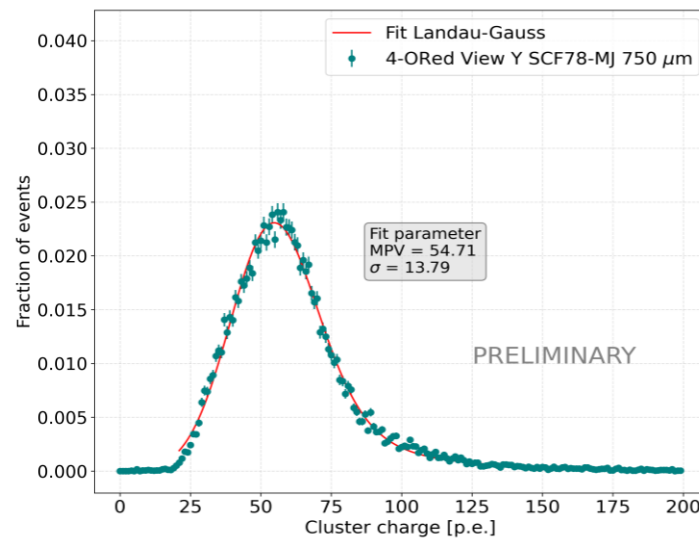
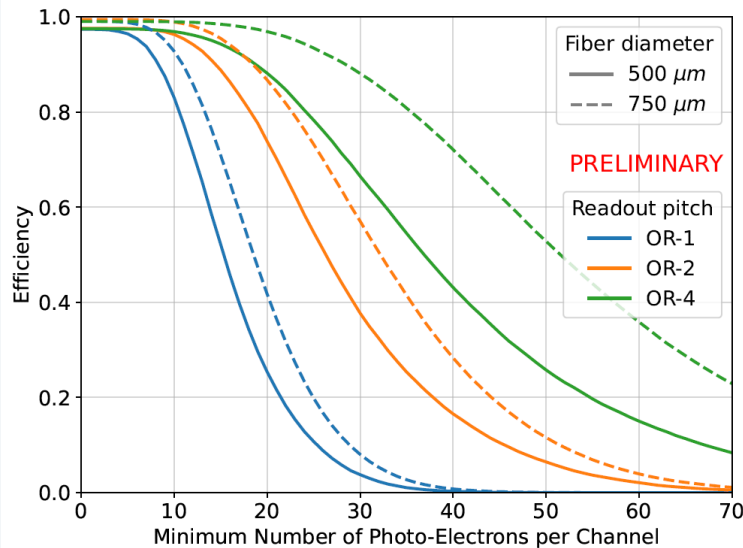
NIM I/O for ext trigger

Ethernet

# The FTK prototypes (2/2)

➤ The Ziré FTK detector is based on detailed studies performed on reduced scale modules.

## Some results



- larger fiber diameters → larger readout pitch → more photoelectrons collection → higher efficiency & larger efficiency plateau

- the yield for the 750 μm fiber plane is almost twice than 500 μm fiber plane.
- the yield for the 750 μm fiber is slightly affected by OR-ing 2 or 4 channels.

- A narrow coincidence window can be set to reduce the dark noise false coincidences even at the level of a single FTK view, providing a fast trigger for other FTK planes and the other Ziré subsystems.

# Zirettino prototype

➤ A reduced scale Ziré prototype, to validate the performance of the whole detector

## Layout

	Zirettino	Ziré
FTK	1 X-Y module	3 X-Y modules
PST	8 X-Y layers	32 X-Y layers
CALOG	2 x 4 x 1 matrix of 4 LYSO cubes and 4 GAGG cubes	4 x 4 x 2 matrix of GAGG cubes
ACS	5 tiles	9 tiles

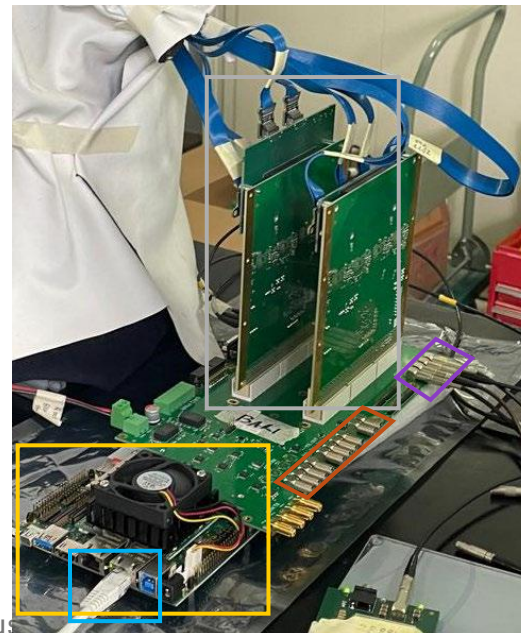
FTK mechanics designed by SOPHIA High Tech, based on FTK prototypes developed by INFN Bari.

## Read-out system (by Nuclear Instrument)

- 2 FEBs for a total of 16 CITIROC 1A ASIC
- 1 concentrator for FEB

### FTK

- 750  $\mu\text{m}$  fibers
- 1 mm readout pitch
- 3 SiPM arrays to readout a single FTK side  $\rightarrow$  384 channels



2 DAQ units, hosting: 4 CITIROC 1A and an FPGA for controlling the DAQ of the individual unit

1 concentrator hosting a central FPGA to coordinate the two DAQ units

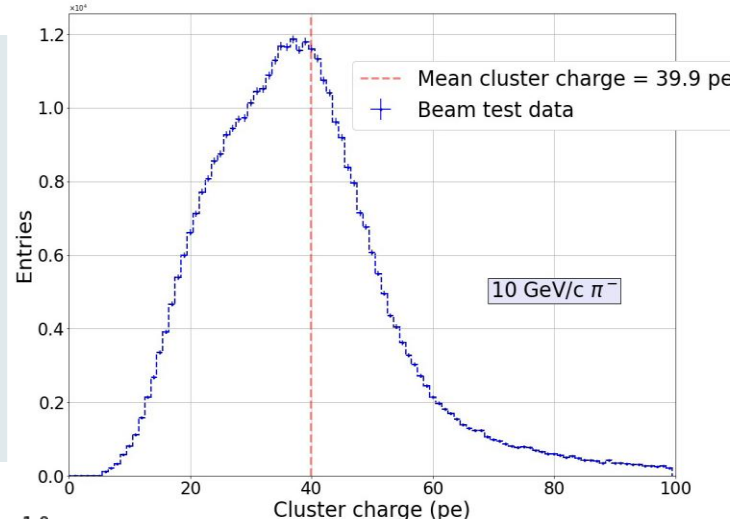
8 SiPM voltage LEMO connectors

NIM I/O for external trigger and validation

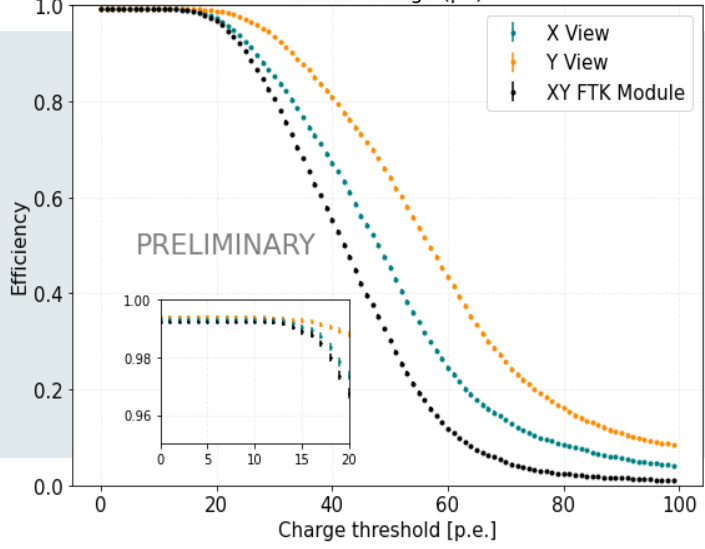
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# FTK characterization @ CERN-PS

➤ Beam: negative pions of 10 GeV/c



**Yield**  
FTK cluster charge distribution in p.e. units for X view: ~ 40 p.e. @ 4 V overvoltage.



**Trigger efficiency**

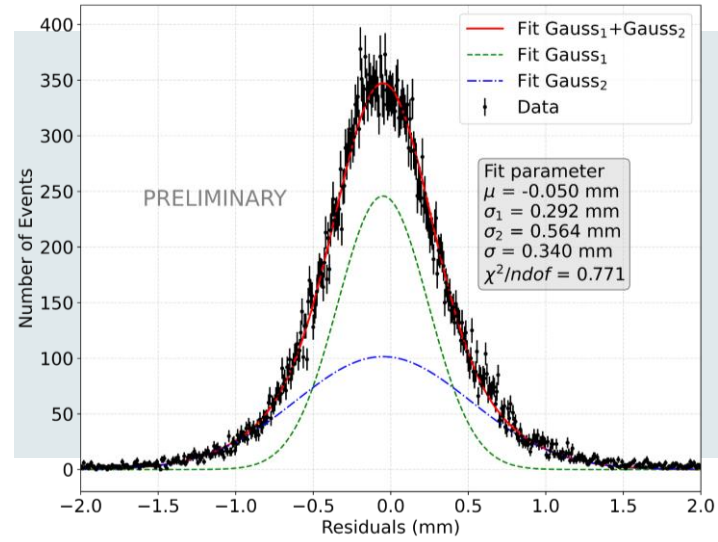
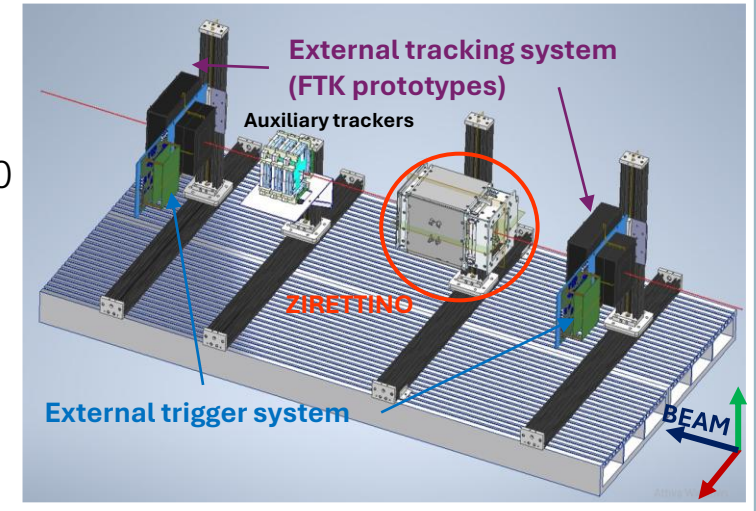
- For each view:

$$\epsilon(q_{th}) = \frac{N(q > q_{th})}{N}$$

- A plateau above 99% is found up to almost 15 p.e

## Setup

- External tracking system:**
- 2 X-Y planes of 500/750  $\mu\text{m}$  round fibers
- External trigger system:**
- 10 cm square tile
  - 2 fingers (1 cm)
  - 1 veto tile (2 cm hole)



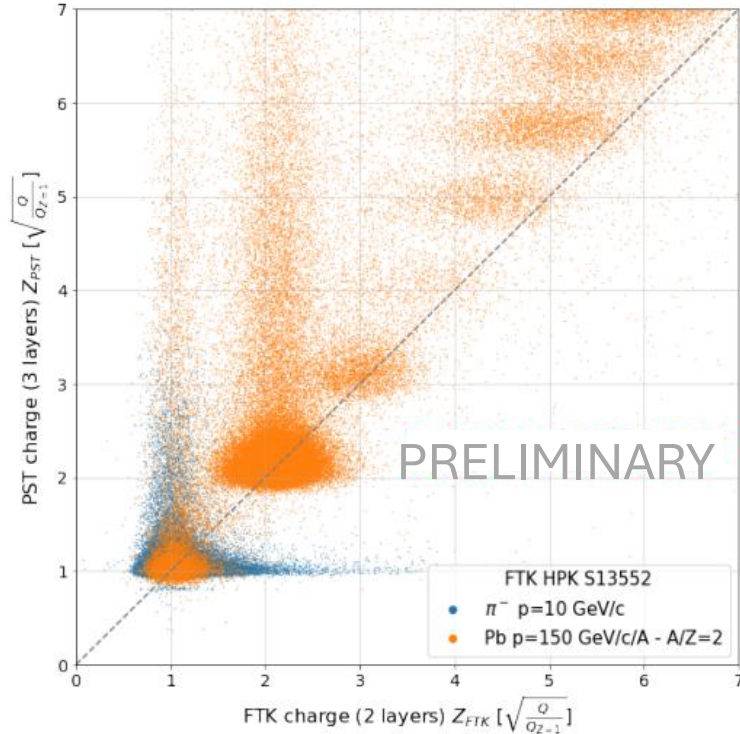
**X view spatial resolution**  
Fitted with a double gaussian:  $\sigma = 340 \mu\text{m}$ .

- Comparable with expected value

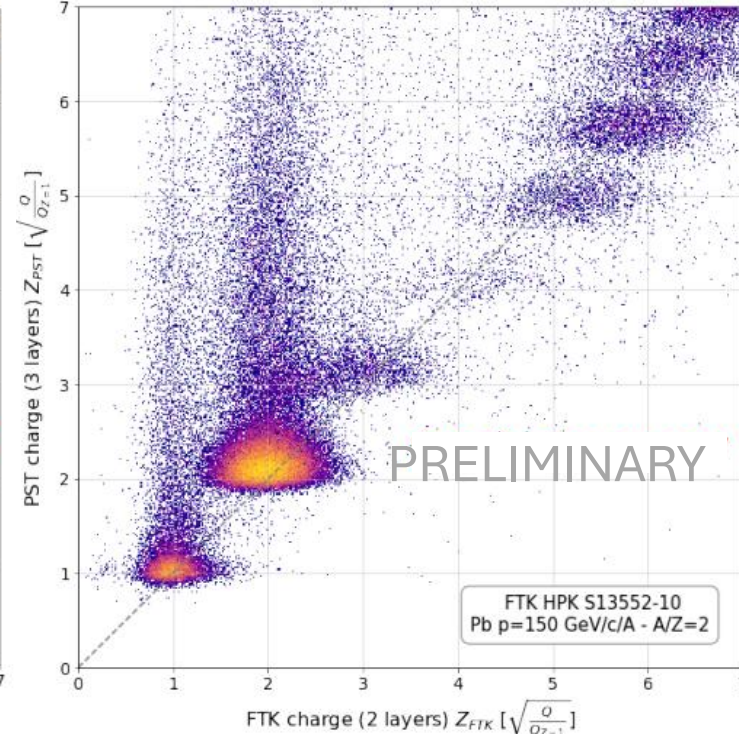
# FTK characterization @ CERN-SPS

- Beam: Pb 150A GeV/c on Be target – selected nuclei with  $A/Z = 2$
- FTK one X-Y views equipped with S13552-10 SiPM arrays

### FTK HPK-S13552



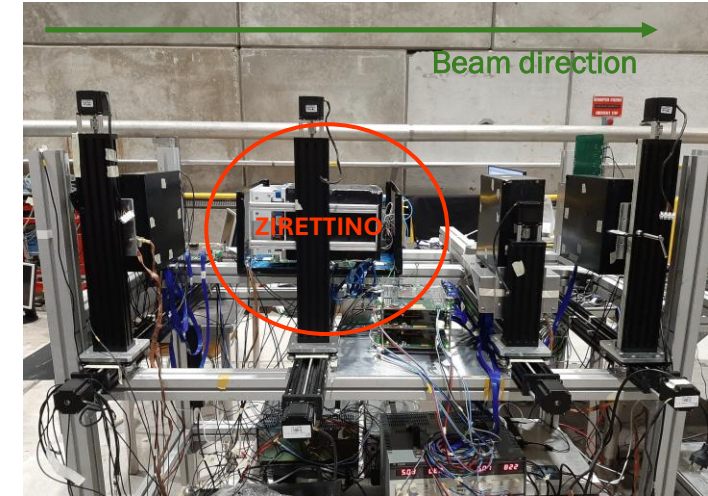
### FTK HPK-S13552-10



- X axis: the square root of the charge measured with the FTK and normalized to  $Z = 1$ , evaluated as the average over the two X-Y views
- Y axis: charge measured by the first three PST layers in the same units

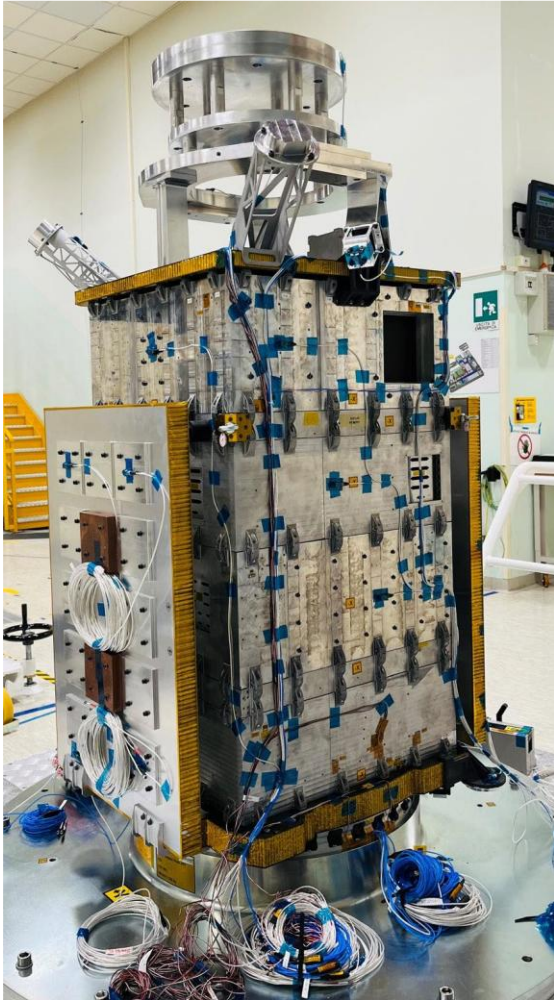
## Setup

External tracking system + External trigger system



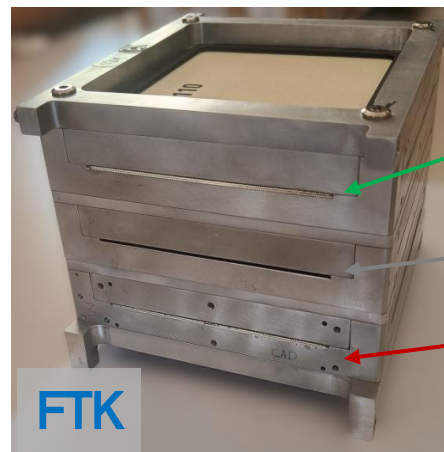
- The spots identify the different ion species: Z identification
- FTK saturation effects are almost negligible with 10  $\mu\text{m}$  cell pitch SiPMs
  - their coupling with the CITIROC 1A ASIC results into a non-linearity of the low-gain ADC of the ASIC with respect to the high gain one

# The Ziré Structural Model (SM)



Ziré SM of the whole satellite assembled by SOPHIA High Tech at the beginning of 2024:

- structurally equivalent to the flight model (FM)
- non-functional photodetectors and electronic modules



1 X-Y plane with AIREX panels to increase the stiffness

1 empty plane

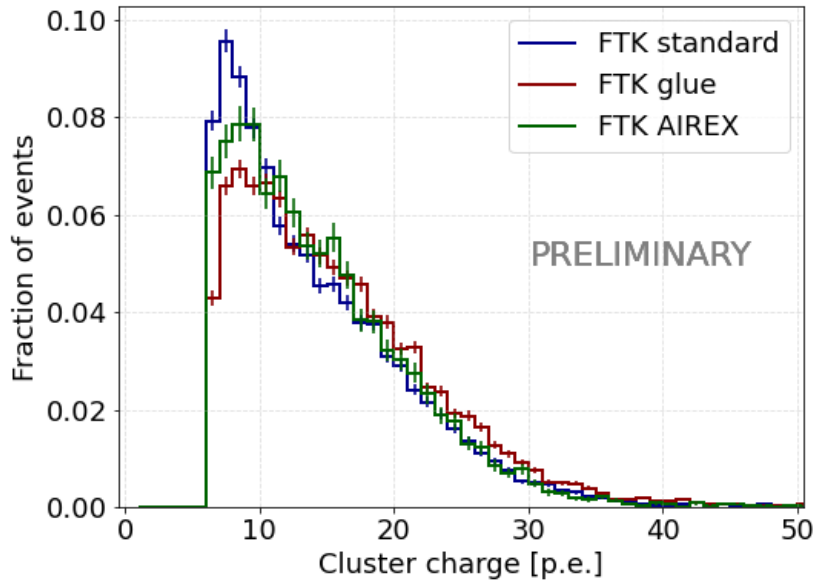
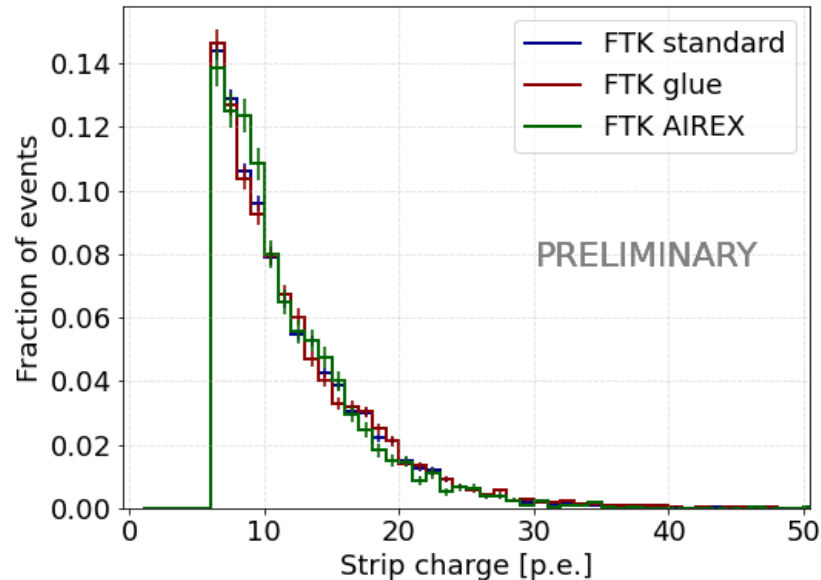
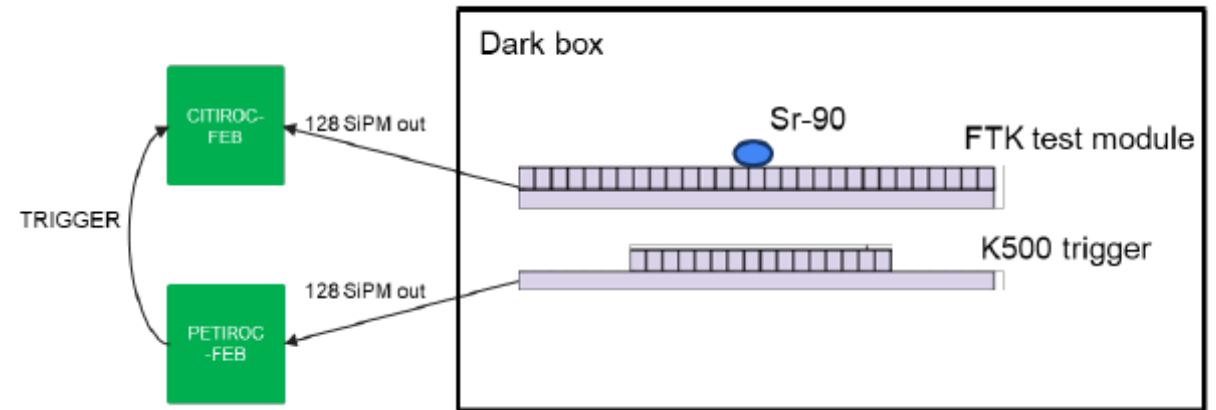
1 X-Y plane with epoxy glue all over the fibers



# FTK validation tests

## Setup and settings:

- Trigger: external tracker module ( $3 \times 3 \text{ cm}^2$  active area)
- AND\_XY trigger logic PETIROC-FEB (left and right trigger on the two views)
- FTK module ( $10 \times 10 \text{ cm}^2$  active central area) aligned above the trigger module
- Radioactive Sr-90 source



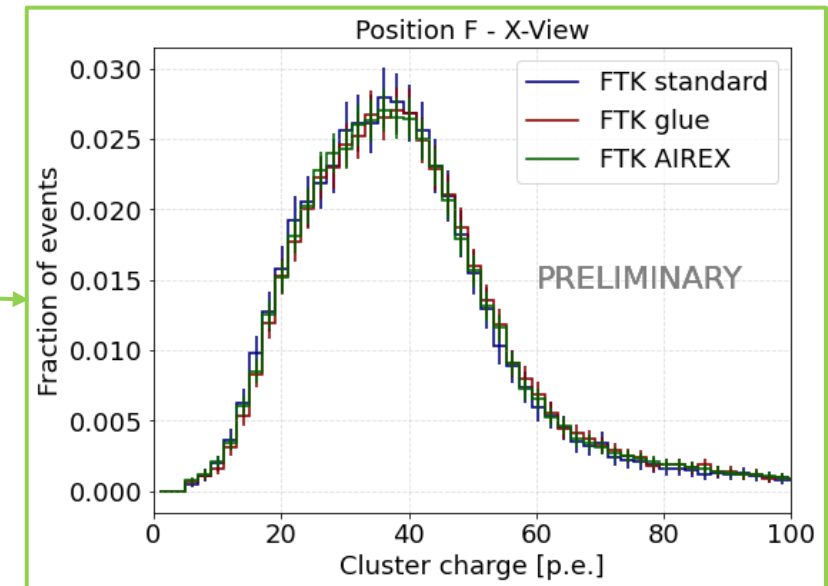
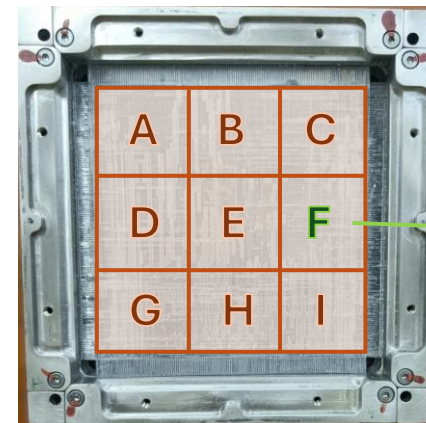
No significant inefficiencies observed

- Epoxy glue and AIREX mat do not negatively impact module performance

# FTK qualification test

## ➤ Dynamic tests

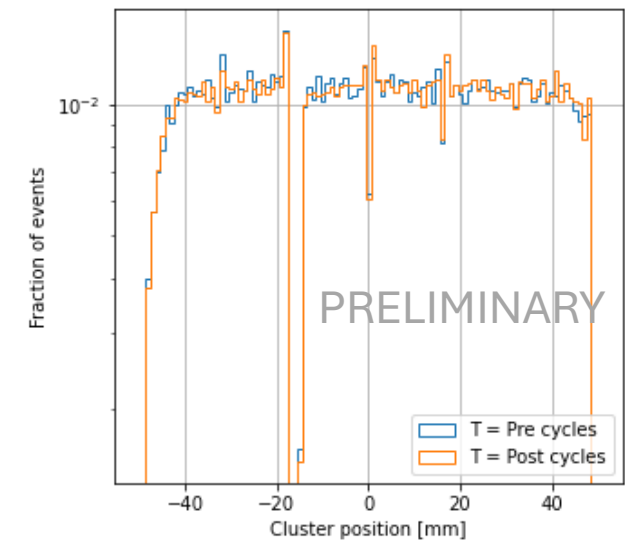
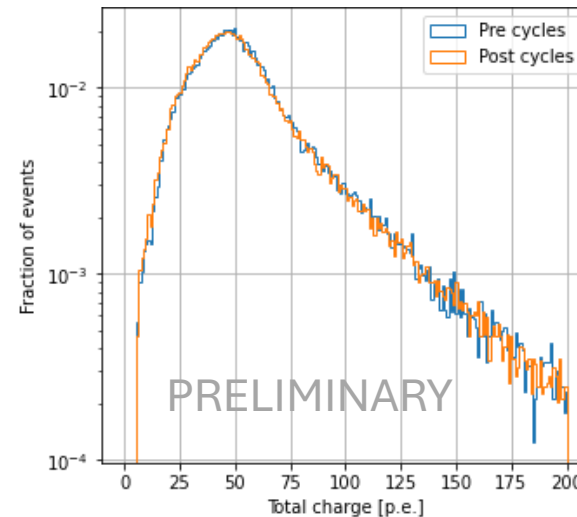
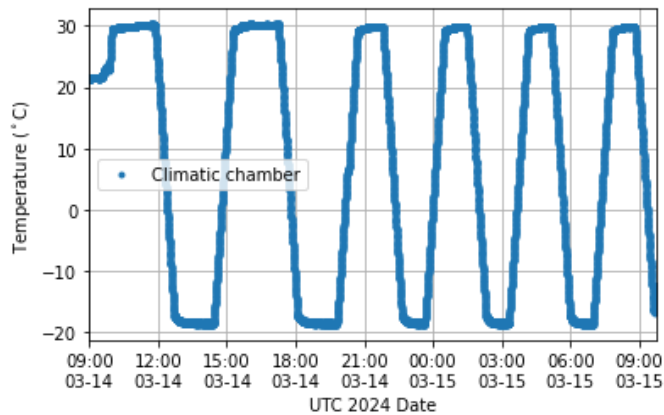
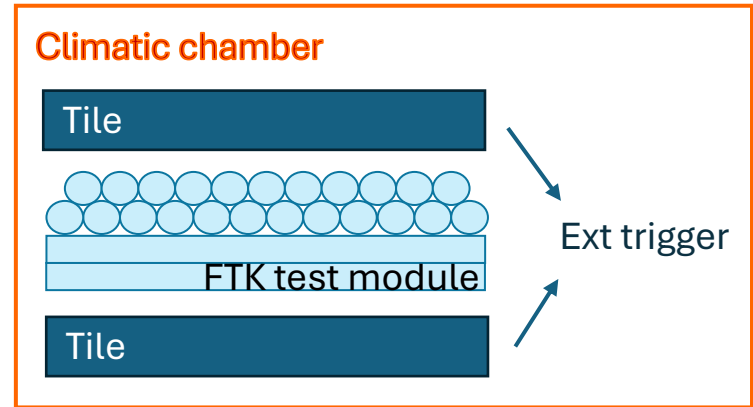
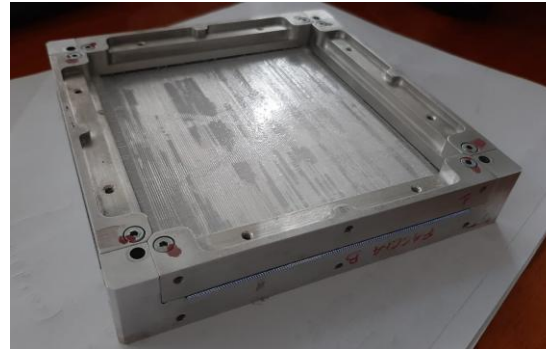
- Vibrational tests at Thales Alenia Space – Italy (April 2024):
  - **2 FTK accelerometers**: one at the center of the module with epoxy glue and one on the mechanical frame
  - Sine sweep: no significant frequency shifts
  - Random vibrations: amplified energy along the transverse plane (X-axis) at the tracker center
  - Visual inspection: no breakages
- Functionality check with 10 GeV/c negative pions:
  - no differences between vibrated and no-vibrated planes
  - no damages caused by vibrational tests



# Thermal validation test

➤ Thermal cycles at room pressure in climatic chamber at Bari INFN laboratories with cosmic rays (spring 2025)

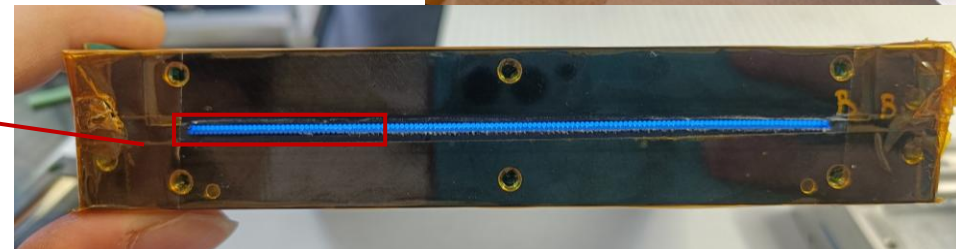
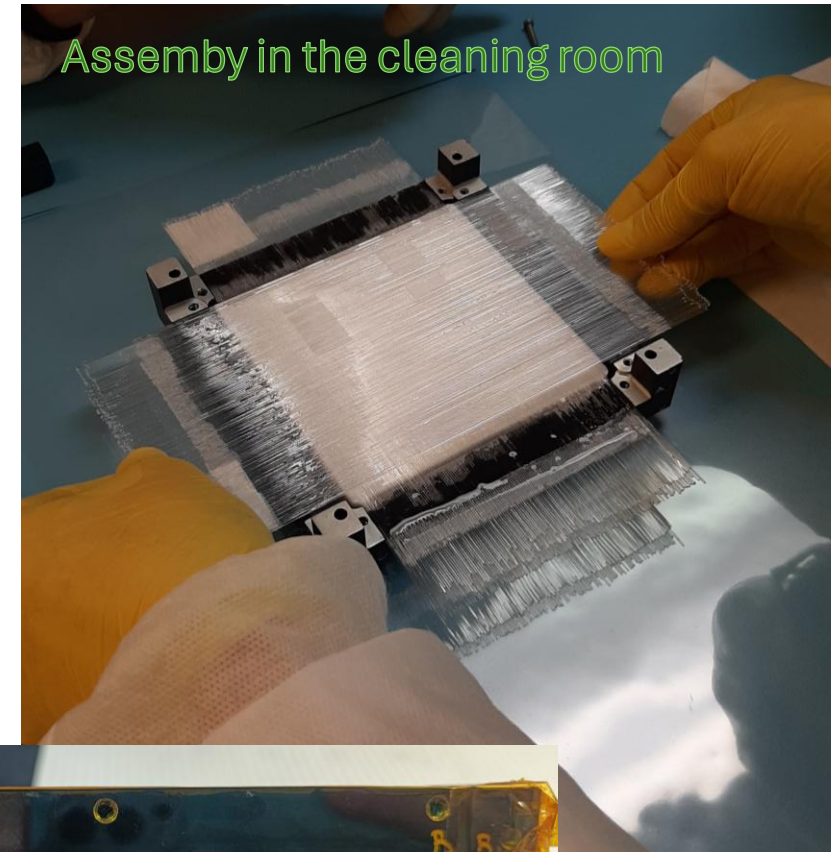
- Tested FTK: module with epoxy glue all over the fibers and assembled with a new simplified procedure
- Readout one side per view
- Rapid thermal cycles:  $[-20\text{ }^{\circ}\text{C}, +30\text{ }^{\circ}\text{C}]$  (without electronics)



- Visual inspection: no evident breakage; glue has not undergone any alterations
- Test with CRs: no deformations

# Near future activities

- To complete the FTK validation phase, vacuum test at room temperature are in progress at Bari INFN laboratories
- The engineering qualification model (EQM) is just assembled (3 EQM FTK modules):
  - Functionality check
- Assembly of 3 Flight model (FM) modules in winter 2025
  - Proto-flight model delivery expected in 2026





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**BACKUP**

