The scintillating fiber tracker of the NUSES-ZIRÈ pathfinder satellite

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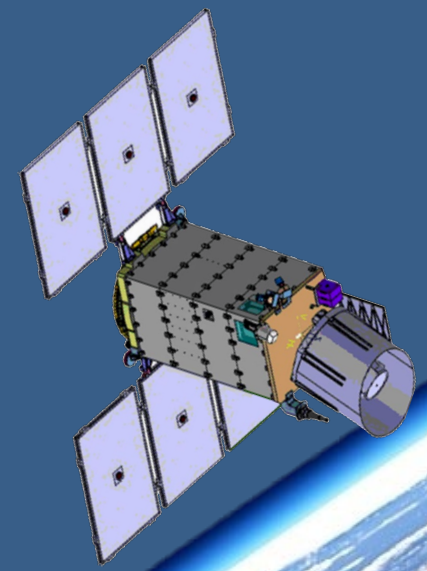
on behalf of the **NUSES** Collaboration

INFN
Istituto Nazionale di Fisica Nucleare

30th June – 4th July 2024
Lisbon, Portugal

International Workshop
25th iWoRiD
on Radiation Imaging Detectors



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THE NUSES MISSION

A small pathfinder satellite for new technologies

- Development of new observational techniques, sensors (e.g. SiPMs) and related electronics/DAQ for space missions;
- Scientific collaboration among GSSI-INFN and TAS-I
- Italian lead mission
- Funded by Italian government and ASI
- Two payloads:
  - Terzina
  - Ziré
- Payload delivery: end 2025
- Launch: 2026

GRAN SASSO SCIENCE INSTITUTE

Istituto Nazionale di Fisica Nucleare

Agenzia Spaziale Italiana

ThalesAlenia Space

Industrial Partners:

OFFICINASTELLARE OUR WORLD, YOUR SPACE

Nuclear Instruments

FONDAZIONE BRUNO KESSLER

AGE SCIENTIFIC

SOPHIA HIGH TECH

THE NUSES COLLABORATION

60+ persons from many institutions.
Large expertise (and synergies) from space missions/R&D:
AMS, DAMPE, eASTROGAM, Fermi, LIMADOU, GAPS, HERD, PAMELA, POEMMA, SPB2, …

Italian Institutes:

- Gran Sasso Science Institute
- Laboratori Nazionali del Gran Sasso
- Università dell'Aquila
- Università di Roma "Tor Vergata" and INFN-Roma2
- Università di Torino and INFN Torino
- Università di Trento and INFN-TIFPA
- Università di Bari and INFN Bari
- Università di Padova and INFN Padova
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN Lecce

Other Institutes:

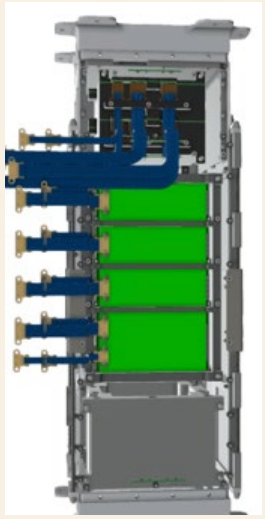
- University of Geneva
- University of Chicago
- Interests from other US institutions, …

THE PAYLOADS

Science goals

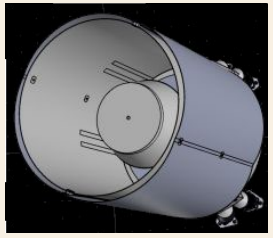
Zirè

- Measure the **flux (E<300 MeV) of cosmic e-, p and light nuclei** of solar/galactic origin;
- Study of the **cosmic radiation variability** (Van Allen belt system);
- Possible correlations with seismic activity due to Magnetosphere-Ionosphere-Lithosphere Coupling (MILC);
- Detection of **0.1 - 30 MeV photons** for study of transient and stable **gamma sources**;
- Monitoring of near-Earth space environment



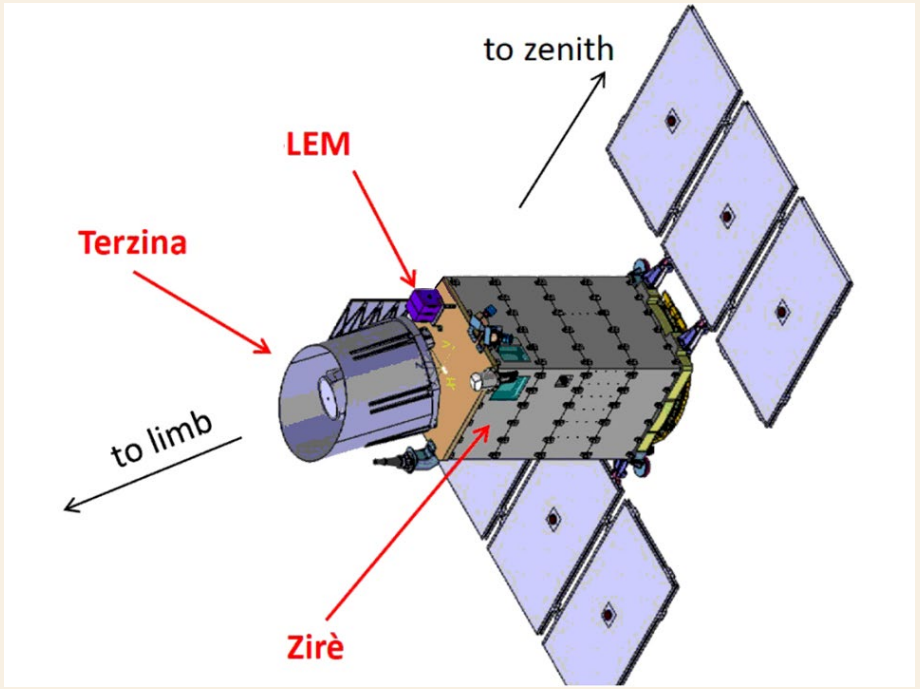
Terzina

Pathfinder for future missions committed to the UHE cosmic rays and neutrino astronomy through space-based atmospheric Cherenkov light detection.

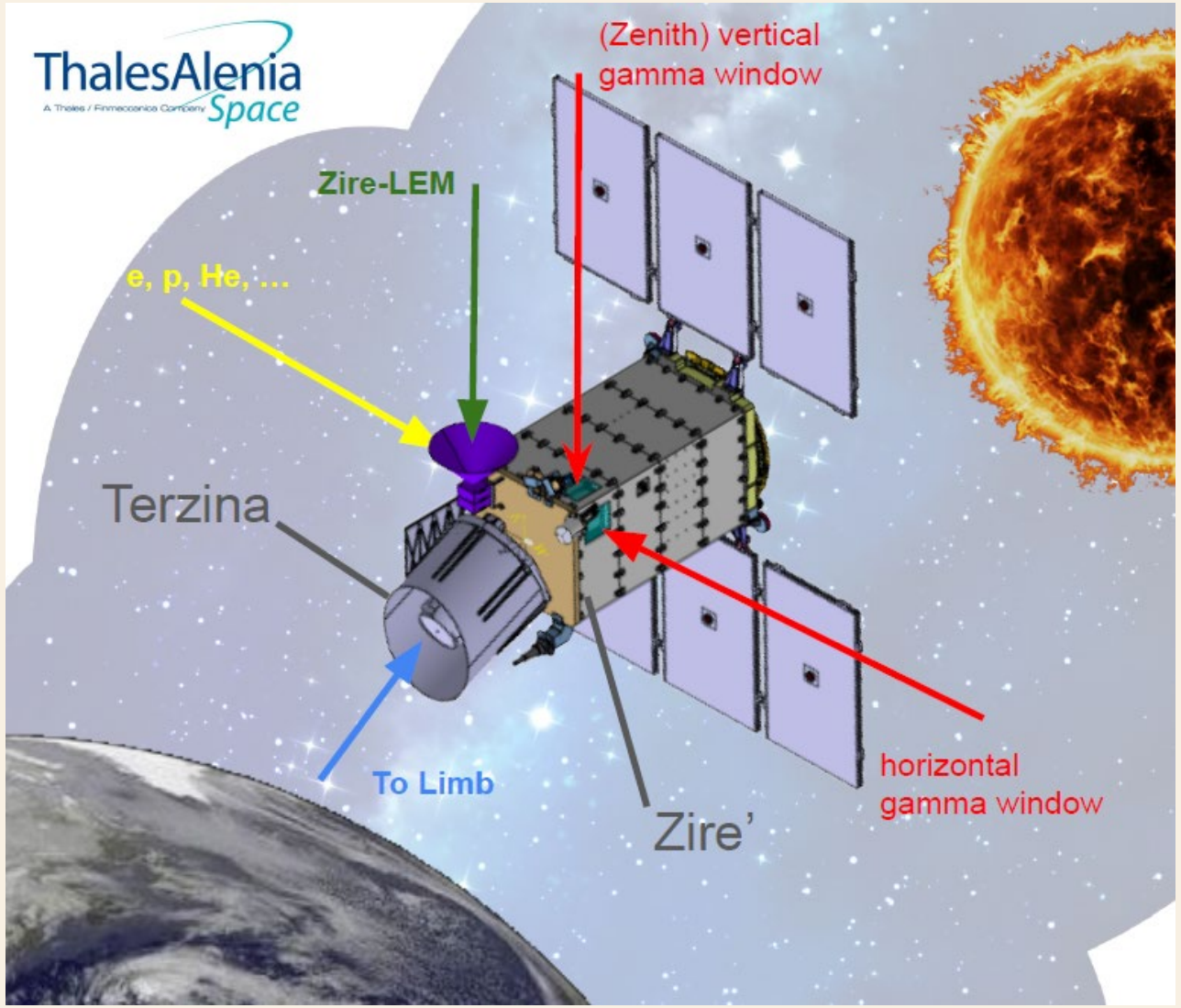


New Technologies and approaches

Development of new observational techniques, testing new sensors (e.g. **SiPM**) and related electronics/DAQ for space missions. New solutions for satellite platforms.

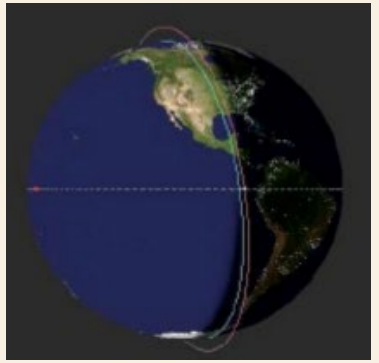


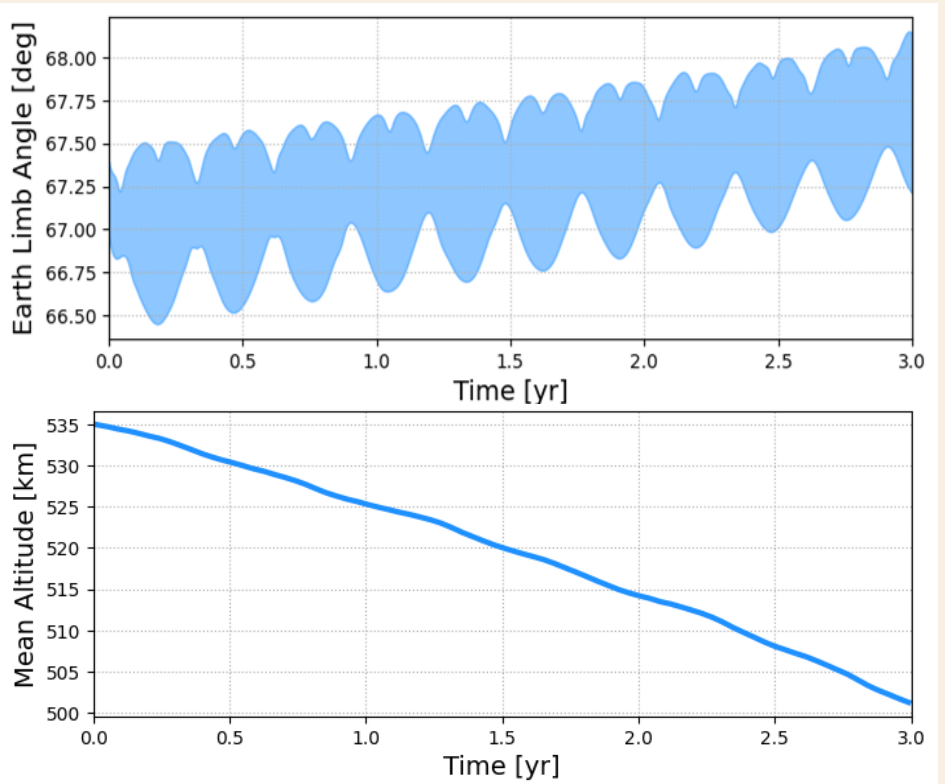
THE SATELLITE ORBIT



Ballistic Low Earth Orbit (LEO) with high inclination, sun-synchronous dusk-dawn orbit

- Altitude ~550 km
- Inclination = 97,8°
- LTAN = 18:00





THE ZIRÉ DETECTOR

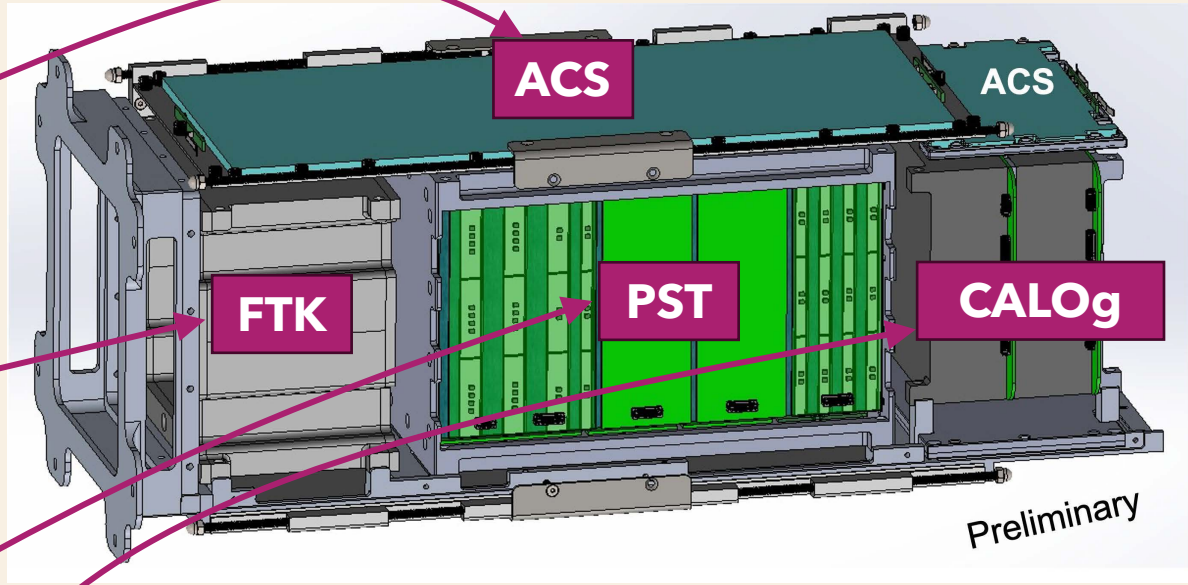
Completely based on **scintillators & SiPMs**

ACS (Anticoincidence System)
- Charged background rejection
- Plastic scintillators

FTK Fiber TracKer
- Fast trigger
- Particle tracking
- PID/energy loss measurement

PST (Plastic Scintillator Tower)
- PID
- Partial energy measurement

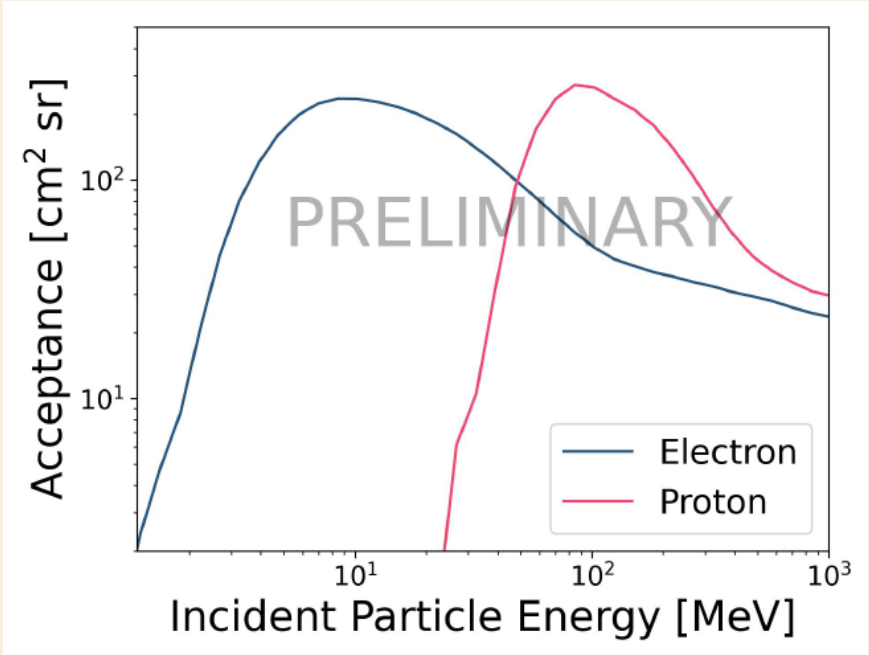
CALOg (Calorimeter gamma)
- Energy measurement
- LYSO/GAGG scintillator crystals



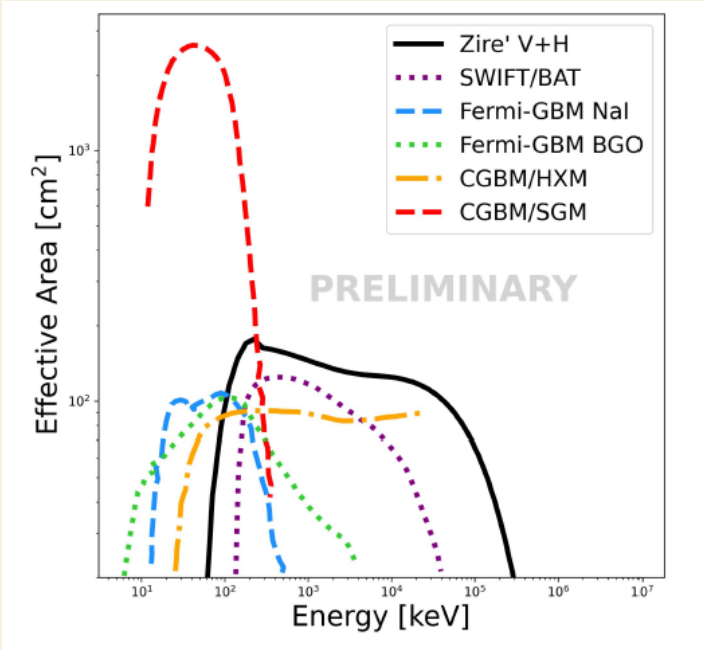
Fiber Tracker module (FTK) Astroparticle Physics Bari Research group (INFN, Poliba, Uniba)

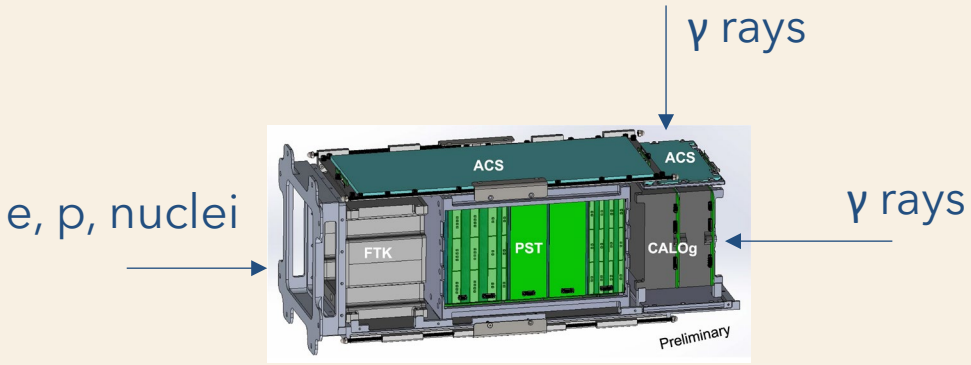
ZIRÉ EXPECTED PERFORMANCE

e & p acceptance



γ-ray effective area





- CALOg will be also used for the study of low-energy γ rays between 10 keV and 30 MeV.
- **Two entrance windows** surrounding the CALOg for this purpose.

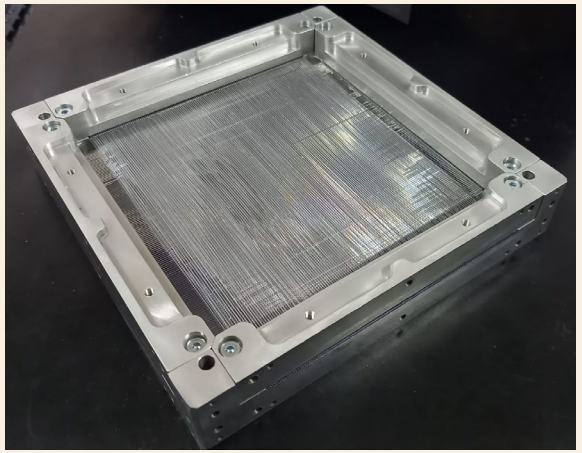
THE FIBER TRACKER

THE ZIRÉ FIBER TRACKER

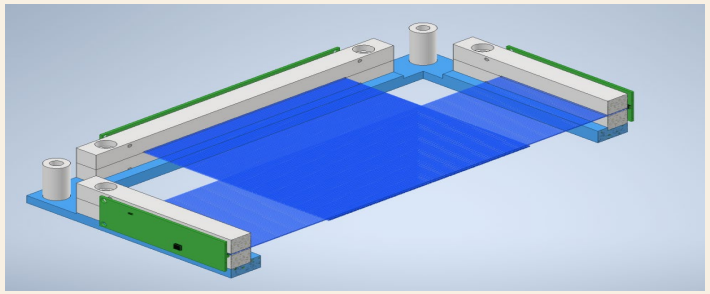
Plastic scintillator fibers with SiPM array readout

Fiber tracker tasks

- provide a fast and efficient trigger
- measure the particle entry point
- measure the deposited charge
- contribute to PID

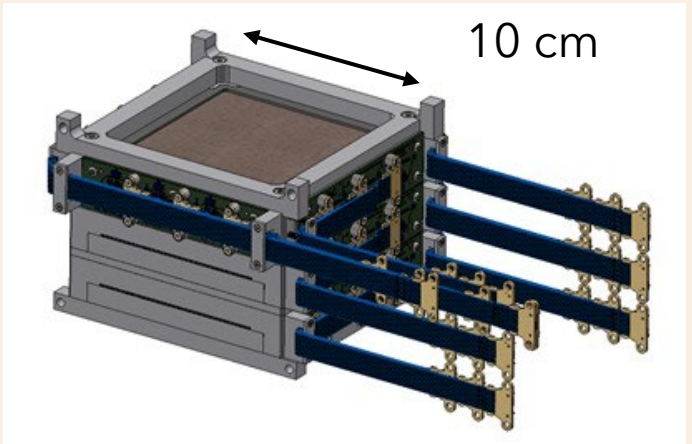


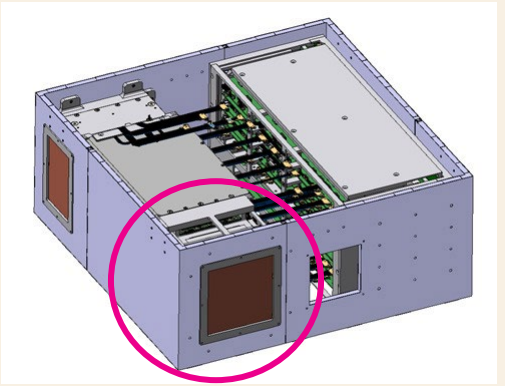
Single X-Y plane section



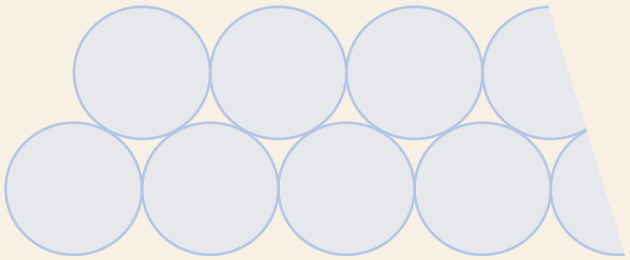
FTK layout

- 3 X-Y planes
- One plane with double-sided readout for trigger and redundancy
- Layer surface: ~10 cm x 10 cm





FIBER TRACKER PROTOTYPES

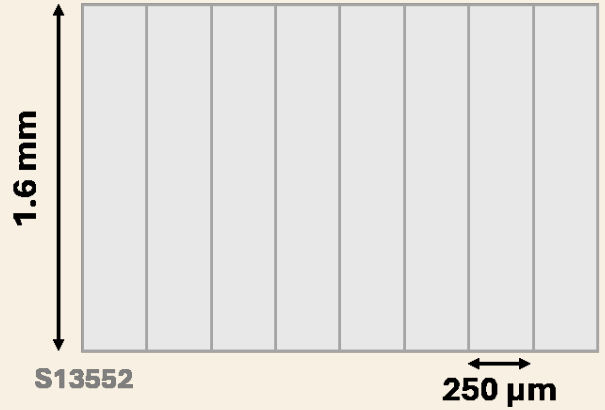


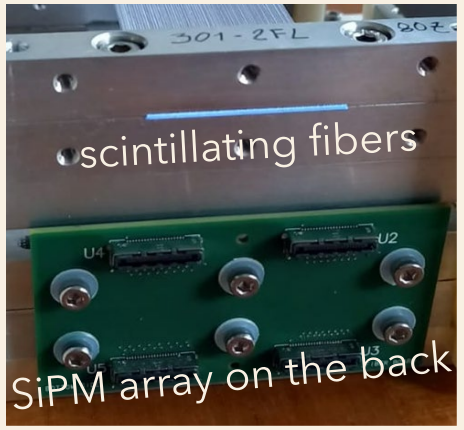
Fiber tracker prototype for the NUSES-Ziré detector

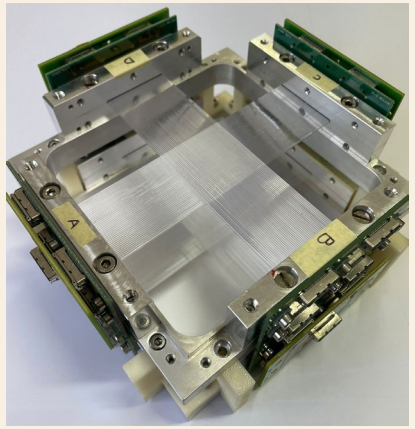
- Several modules: X-Y fiber views
- Each view: two staggered round scintillating fiber ribbons
  - **Kuraray**/Saint-Gobain
  - 500 μm and 750 μm diameter
- SiPM array readout: Hamamatsu S13552, 128 channels
- Layer width: about 3.25 cm
- Designed and assembled @INFN Bari

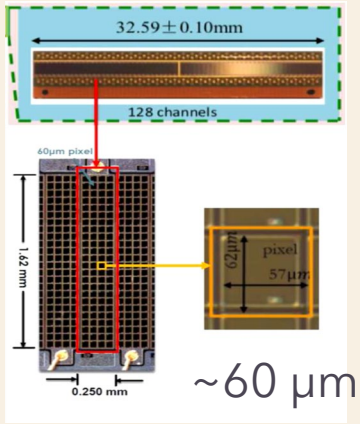
Tests and characterization with custom Front End Board designed @INFN Bari

- Weeroc/Omega ASIC **PETIROC2A** as front-end electronics









Ziré preliminary choice

- **OR-4** readout
- **1 mm pitch** equivalent
- **32** readout **channels**/array

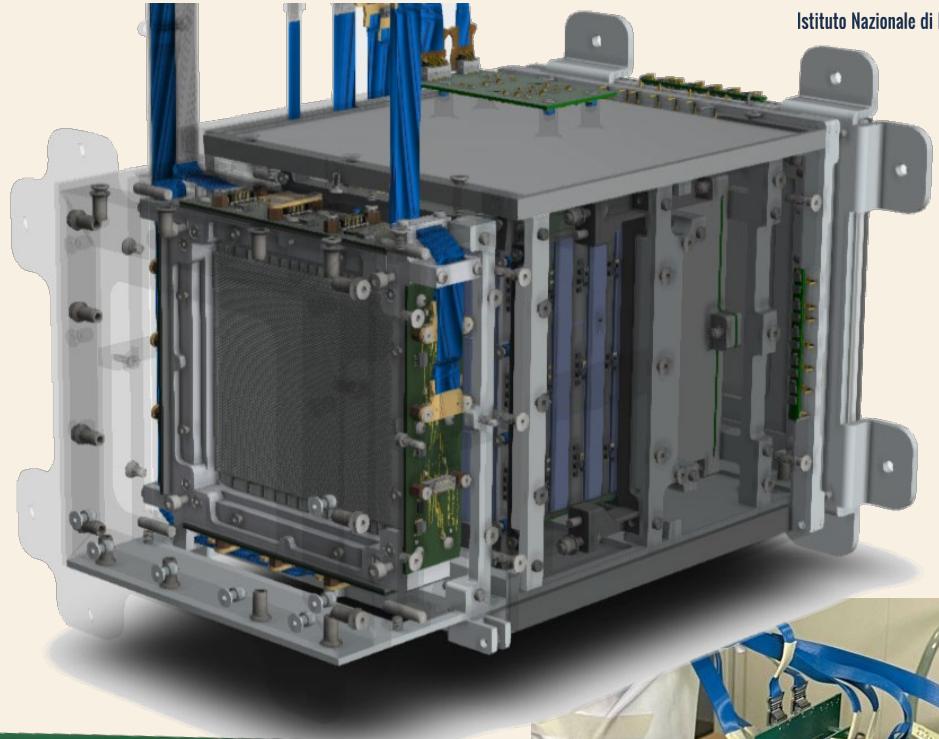
~60 μm cell pitch

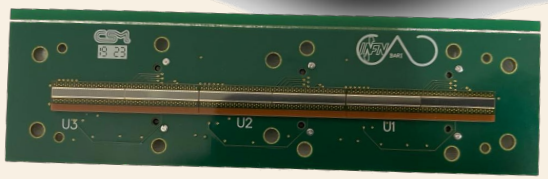
Pillera R. et al, *Characterization of a light fiber tracker prototype with SiPM array readout*, 2023 9th IWASI), IEEE DOI 10.1109/IWASI58316.2023.10164306

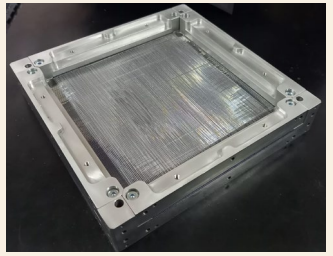
ZIRETTINO PROTOTYPE

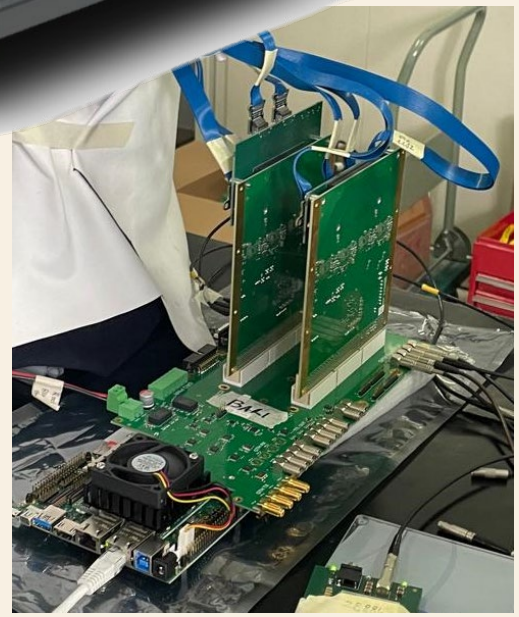
Reduced scale Ziré prototype

- Layout
  - **1 fully equipped FTK plane** (750 μm fiber Ø)
  - 8 PST layers
  - 8 CALOg cubes (4 LYSO / 4 GAGG)
  - 5 ACS tiles
- FTK mechanics designed by SOPHIA based on FTK prototypes
- Flight model electronics prototype developed by Nuclear Instruments
  - SiPM readout with **CITIROC** ASIC by Omega/Weeroc









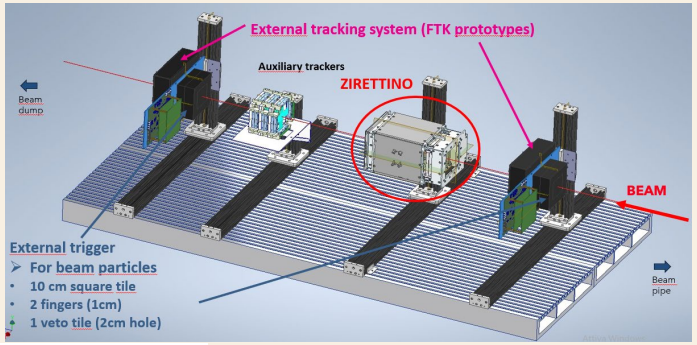
Beam tests @CERN

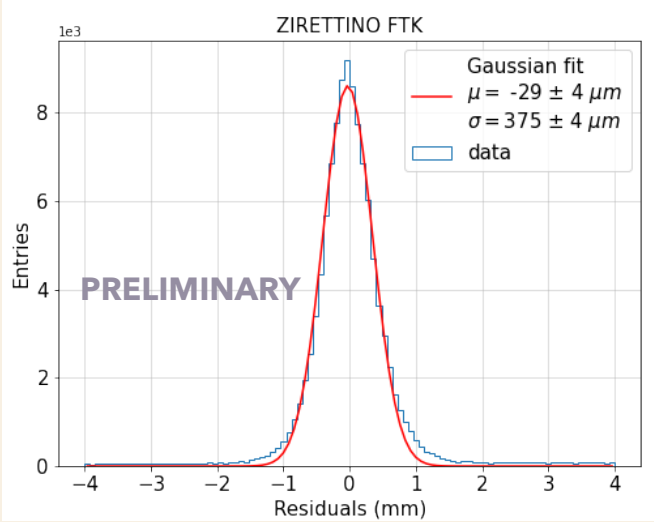
1. PS pions 10 GeV/c
   - all FTK views equipped with S13552 (~60 μm cell pitch)
2. SPS Pb 150 GeV/c/A – A/Z=2
   - 2 views S13552-10 (10 μm cell pitch)

FTK CHARACTERIZATION

Spatial resolution

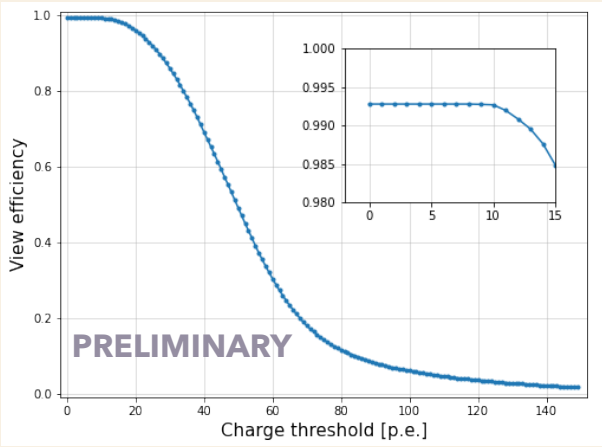
- External FTK modules used for tracking and alligment
- Residuals in Zirettino-FTK computed with respect to tracks





Efficiency

- External FTK modules used for Zirettino-FTK efficiency evaluation



Timing

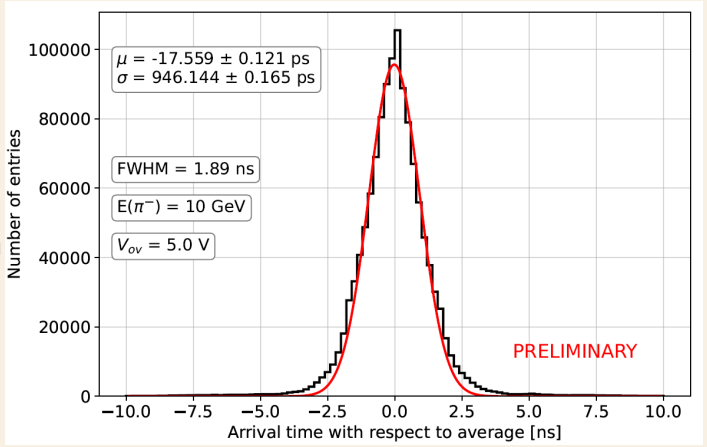
One of FTK tasks: fast trigger

FTK prototype with PETIROC-FEB readout

- PETIROC -> single channel TDC with 40 ps time resolution

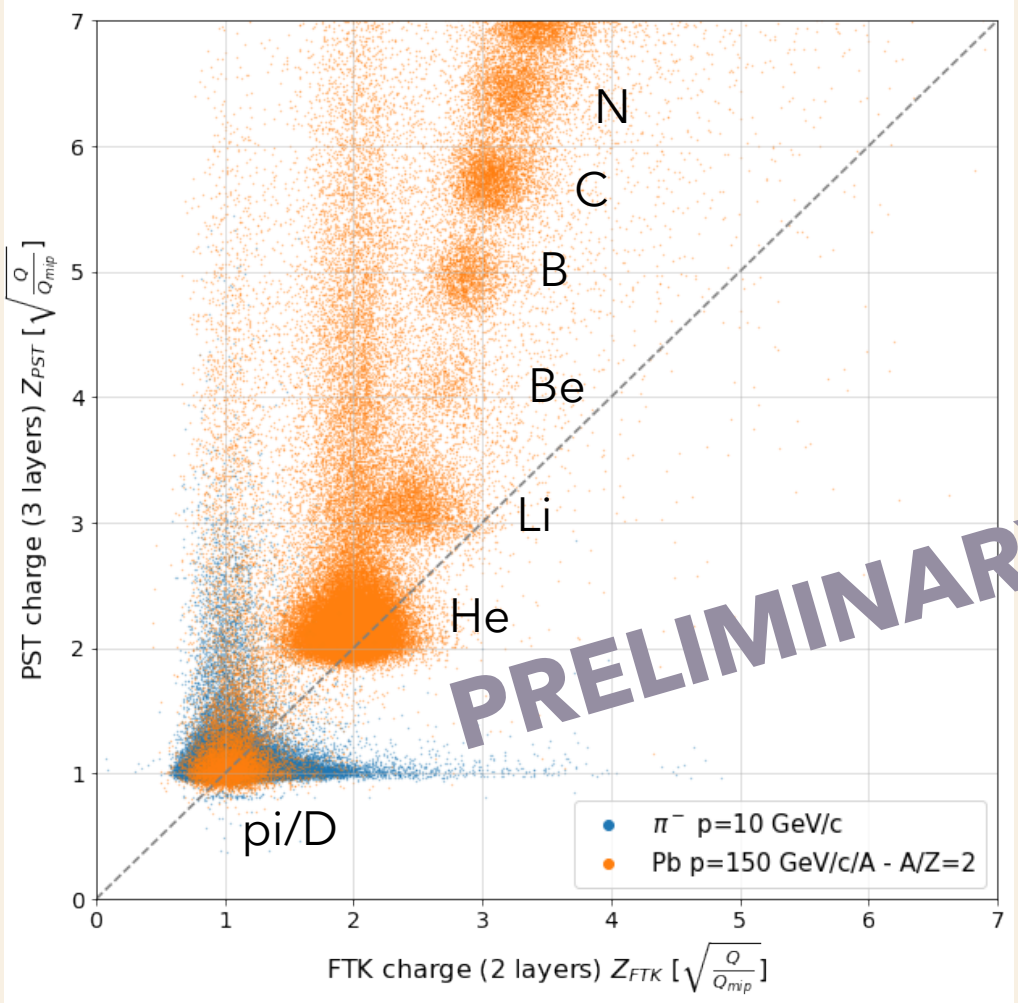
Timing measurements with 10 GeV/c pion beam at CERN PS

- Arrival time FWHM 1.89 ns
- Tight coincidence window can be set to provide a fast trigger for other Ziré subsystems.



PARTICLE IDENTIFICATION (1)

Beam tests @ CERN PS and SPS



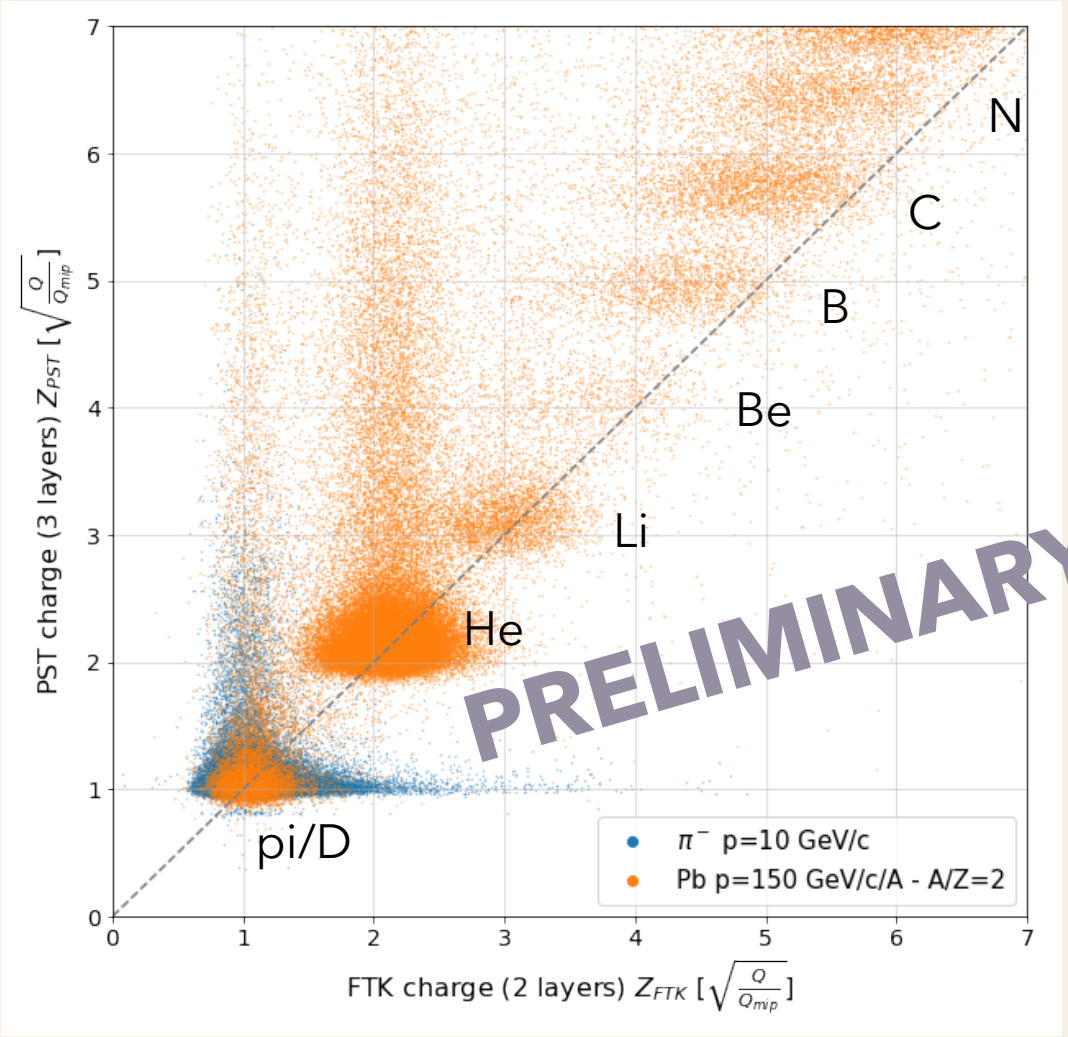
FTK HPK-S13552
Pixel pitch: 57.5 × 62.5 µm

Caveats:

- Calibration not perfect
- SiPM saturation effects
- Electronics saturation effects
- Birks for higher Z
- Different beam tests in 2023:
  - different facilities and setups
  - different ASIC configurations
  - different V_{bias}
  - different Temperature

PARTICLE IDENTIFICATION (2)

Beam tests @ CERN PS and SPS



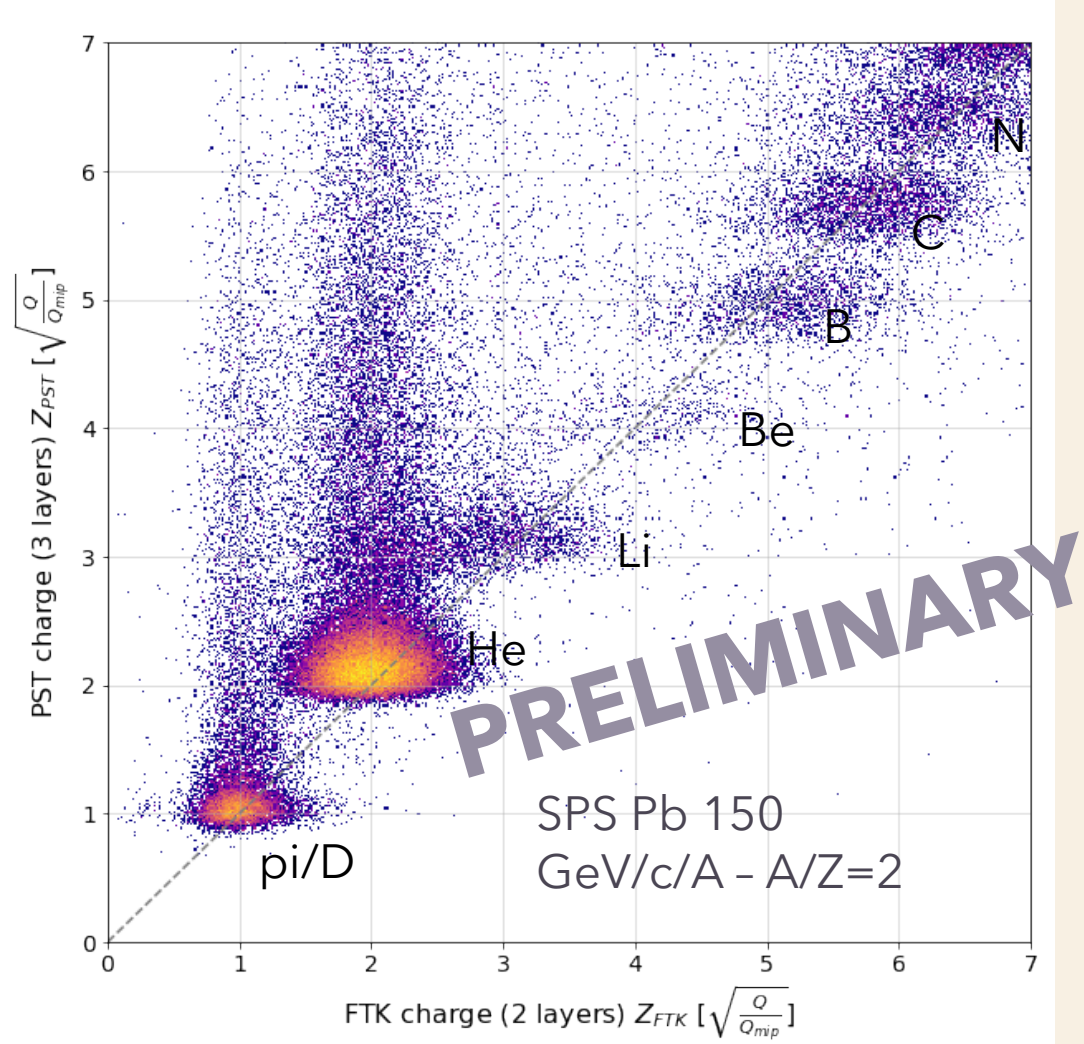
FTK HPK-S13552
Pixel pitch: 57.5 × 62.5 µm

Caveats:

- Calibration not perfect
- **SiPM saturation effects correction**
- Electronics saturation effects
- Birks for higher Z
- Different beam tests in 2023:
  - different facilities and setups
  - different ASIC configurations
  - different V_{bias}
  - different Temperature

PARTICLE IDENTIFICATION (3)

Beam test @ CERN SPS



FTK HPK-S13552-10
Pixel pitch: 10 µm

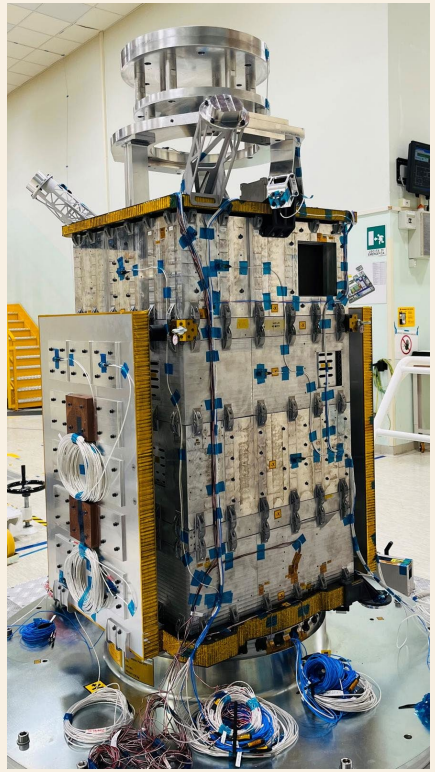
Caveats:

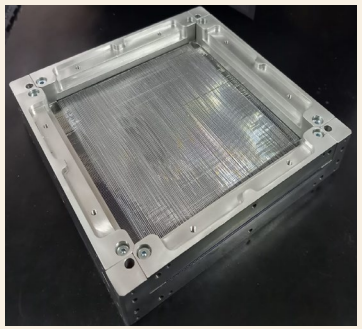
- Calibration not perfect
- SiPM saturation effects
- Electronics saturation effects
- Birks for higher Z
- Different beam tests in 2023:
  - different facilities and setups
  - different ASIC configurations
  - different V_{bias}
  - different Temperature

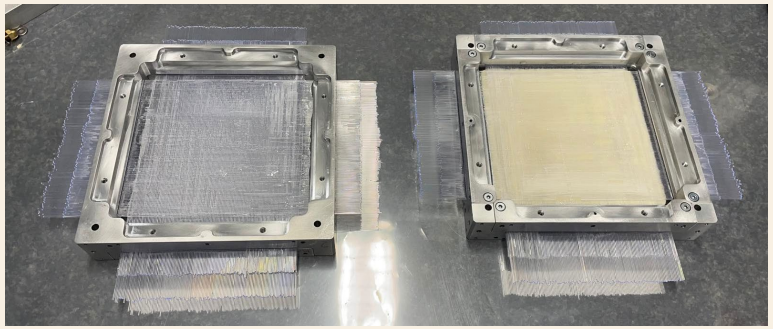
VIBRATIONAL TESTS

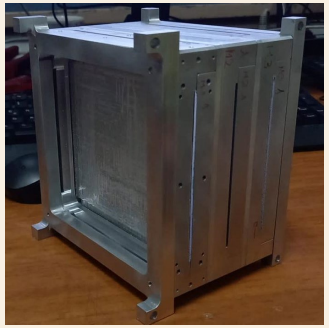
Ziré structural model (SM)

- Zirettino FTK (1module/plane)
  - Fibers glued at module frame, no glue on other parts
- SM FTK (3 modules/planes)
  - 1 module with glue all over the fibers
  - 1 module with additional airex panel for more stability
  - 1 empty frame
  - PWBs without sensors









Vibrational tests of the whole spacecraft performed at Thales-Alenia in April 2024

FTK accelerometers put on top of fiber plane and on frame

- ➢ No visible damage on the fibers
- ➢ Post vibration functional tests in progress

CONCLUSIONS

- NUSES will allow a test in orbit of a fiber tracker with SiPM readout
- Tests on FTK prototypes give promising results
  - High efficiency
  - Good space resolution
  - Excellent PID
- NUSES launch foreseen in 2026
  - Fiber tracker technology space-qualification