The Ziré instrument onboard the NUSES space mission

Giuliana Panzarini[a,b], Adriano Di Giovanni[c,d], Mario Nicola Mazziotta[a], Riccardo Nicolaidis[e,f], Francesco Nozzoli[e,f], Roberta Pillera[a,b] On behalf of the NUSES Collaboration

[a]INFN – Sezione di Bari, [b]Dipartimento Interateneo di Fisica del Politecnico e Università di Bari, [c]Gran Sasso Science Institute,[d]INFN LNGS, [e]Università di Trento,[f]INFN TIFPA

Abstract

The Ziré experiment is an instrument onboard of the NUSES (NeUtrino and Seismic Electromagnetic Signals) space mission dedicated to test new techniques for the study of loa energy cosmic radiation, astrophysical neutrinos, Sun-Earth environment, space weather and magnetosphere-ionosphere-lithosphere coupling (MILC). Ziré will consist of a fiber tracker, a stack of plastic scintillators, an array of LYSO crystals and an anticoincidence system. A dedicated Low Energy Module (LEM) will extend the sensitive energy range down to the MeV scale for charged particles as well. In this work, a general overview of the Ziré payload will be given, together with a focus on the design activities, and the review of dedicated tests on the first prototypes.

1. The NUSES space mission

NUSES is a technological pathfinder for exploration of innovative observational approaches for satellite-borne particle detectors [1].

▶ Science Goals:
- Study of sub-GeV cosmic rays and gamma rays
- Study of astrophysical neutrinos
- Study of the Magnetosphere-Ionosphere-Lithosphere coupling (MILC)

▶ New solutions for satellite platforms: NIMBUS (New Italian Micro BUS).
- New Platform concept involving modular approach
- Low Earth Orbit at high inclination, Sun-synchronous orbit on the day-night border
- Ballistic mission (no propulsion for orbital elevation corrections)
- Orbit optimization for Cherenkov light detection

▶ The NUSES satellite will host two payloads:
- Terzina: pathfinder for future space missions devoted to the exploration of Ultra High Energy Cosmic Rays (UHECRs) and neutrino astronomy [2]
- Ziré: devoted to the monitoring of low energy photons and cosmic rays (CRs)

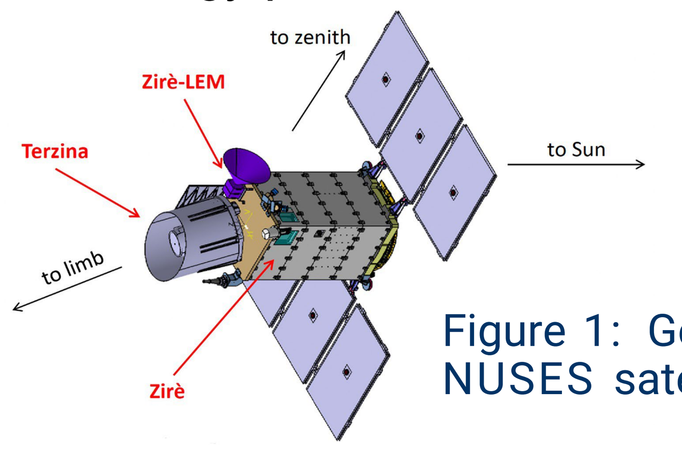


Figure 1: General scheme of the NUSES satellite design.

2. The Ziré instrument

▶ Full Silicon Photomultiplier (SiPM) technology for all system readouts

▶ Subdetectors:
- Fiber TracKer (FTK)
- Plastic Scintillator Tower (PST)
- Calorimeter (CALOg)
- AntiCoincidence System (ACS)
- Low Energy Module

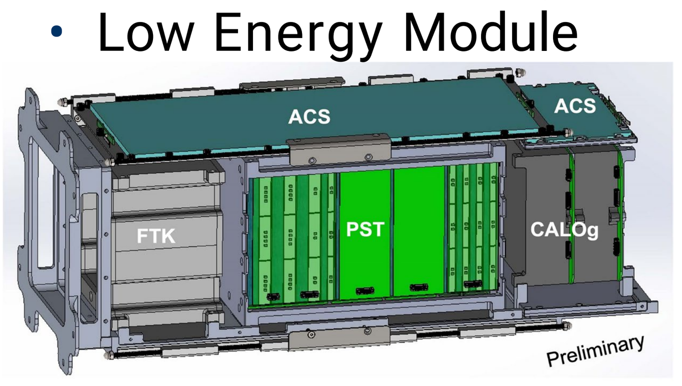


Figure 2: Preliminary mechanical design of the Ziré detector.

2.1. The Ziré FTK

▶ Task: fast trigger; particle tracking and energy loss measurement.

▶ Three X-Y scintillating fiber planes
- Double-cladding 750 μm round Kuraray SCSF78-MJ fibers [3] (light yield ~ 8000 photons/MeV)
- Read out by 128-channel HPK S13552 SiPM arrays with 250 μm pitch [4]
- Read out pitch 1 mm obtained OR-ing 4 adjacent SiPM strips groups

▶ Two X-Y modules with single side readout

▶ One X-Y module with double side readout for trigger and redundancy

Figure 3: FTK X-Y layer view prototype.

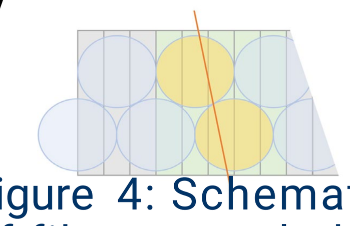


Figure 4: Schematic view of fibers coupled with SiPM strips.

2.2. The Ziré PST

- Task: coarse tracking; partial energy measurement and particle identification
- 32 layers of 12 cm x 3 cm plastic scintillator bars read-out by SiPM
- Three bars for each layer in X-Y hodoscopic configuration
- The front 6 layers 1 cm thick; those in the other 26 layers with 0.5 cm thick bars

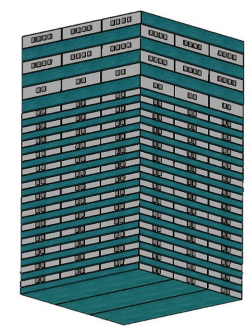


Figure 5: PST CAD view.

2.3. The Ziré CALOg

- Task: study of gamma rays in the energy range 0.1 MeV – 50 MeV and charged particle energy measurement
- Two layers of 4 × 4 matrices of LYSO(Ce) scintillating crystals of 2.5 cm × 2.5 cm × 3.0 cm
- Readout by 5 SiPMs

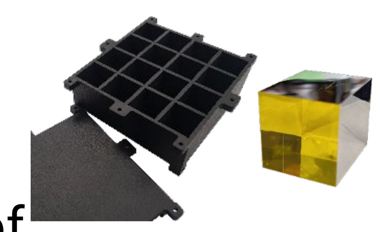


Figure 6: CALOg matrix frame and LYSO crystal.

2.4. The Ziré LEM

▶ Task: detection of electrons < 5 MeV from the zenith and study of correlations with seismic activity
- 5 independent silicon detectors
- plastic scintillator calorimeter
- top and bottom veto systems

▶ **Good event**: particle confined within the thin layer and the veto

▶ **Rejected event**:
- Undefined direction = Veto activated
- Energy too large = Veto activated

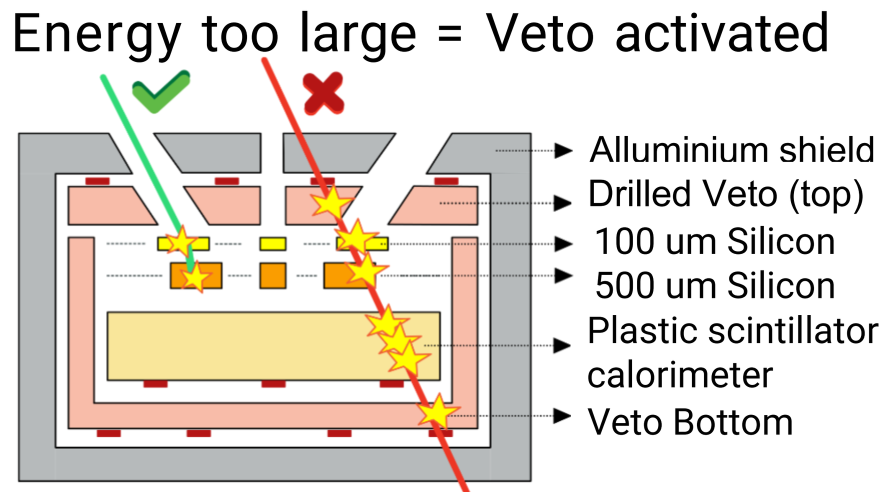


Figure 7: Event selection in LEM

2.5. The Ziré ACS

- Task: provide a veto system for lateral or not fully contained incoming charged particles
- 9 plastic scintillator tiles, 0.5 cm thick surrounding the sides of the instrument and the bottom side of CALOg

Figure 8: ACS tile.

3. Geant4 simulation studies

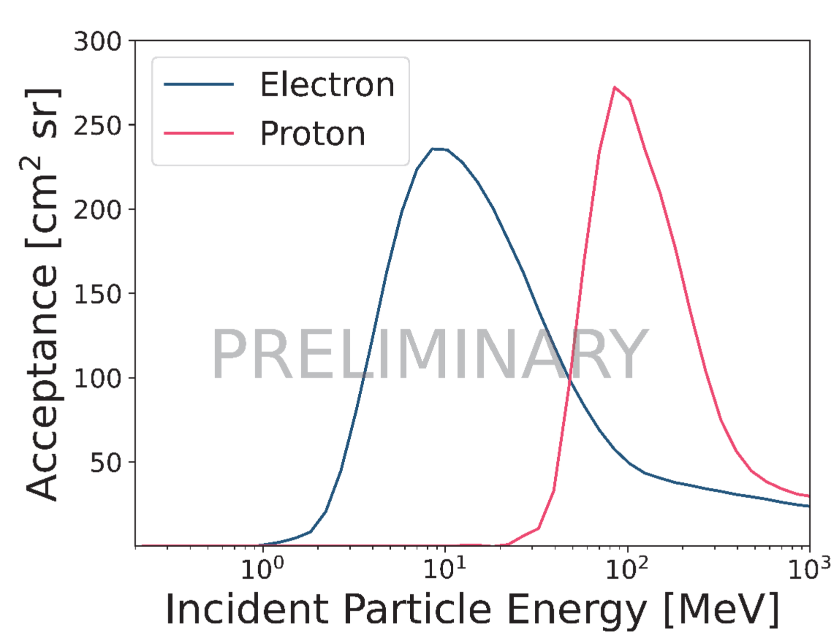


Figure 9: Detector acceptance. Trigger condition: energy deposit > 0.1 MeV and 0.3 MeV in FTK and in PST first layer (PST0).

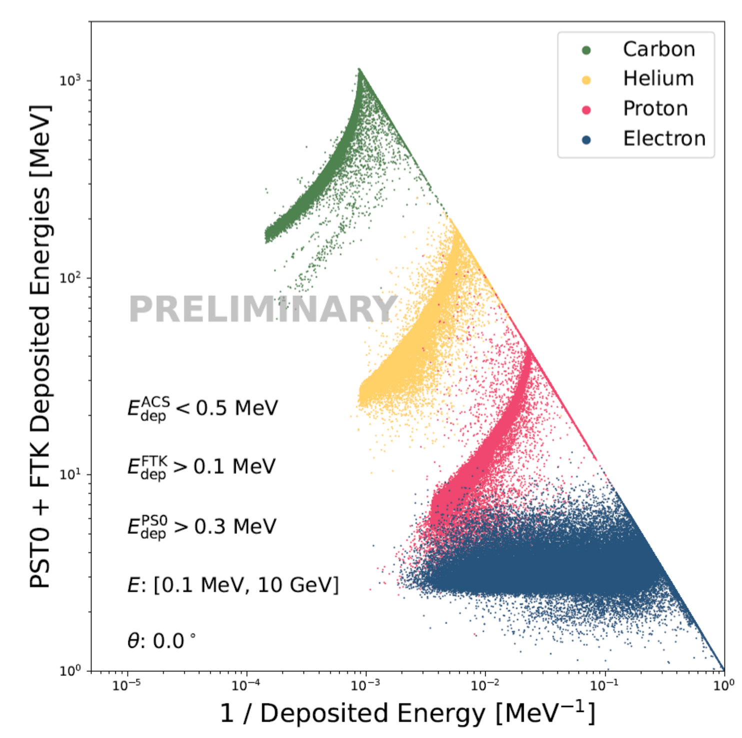


Figure 10: PID from the correlation between energy deposit inside FTK+PST0 and in the whole detector.

4. Zirettino, a reduced scale Ziré prototype

▶ Small scale Ziré prototype: one X-Y FTK layer; Eight PST layers; One 2 × 4 CALOg layer; Five ACD tiles.

▶ Particle beam test at CERN PS T10 line in September 2023

▶ Tested with flight electronics model

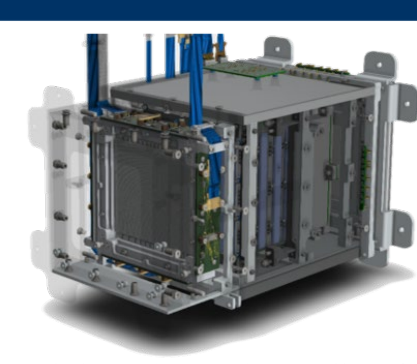
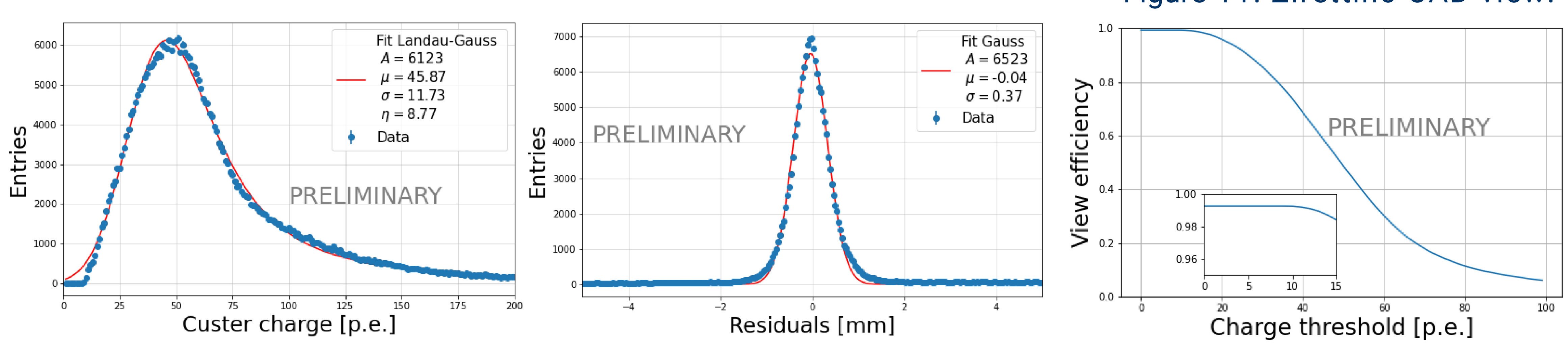


Figure 11: Zirettino CAD view.



(a) FTK Cluster Charge distribution in photoelectron units (p.e.) fitted with a Landau+Gauss distribution.

(b) FTK Residual distribution of fitted tracks. The distribution is fitted with a gaussian with σ = 370μm.

(c) Single view FTK layer trigger efficiency. A plateau above 98% is found up to almost 15 p.e.

Acknowledgements

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[3] http://kuraraypsf.jp/psf/.

[4] https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_mppc-array/S13552.html.