The fiber tracker of the Ziré instrument on board NUSES

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ABSTRACT

NUSES is a low Earth orbit pathfinder satellite for innovative particle detectors dedicated to the study of cosmic radiation, astrophysical neutrinos, Sun-Earth environment, space weather and magnetosphere-ionosphere-lithosphere coupling (MILC). The satellite will host two instruments: Terzina and Zirè. While Terzina will focus on space based detection of ultra high energy extensive air showers, Zirè will perform measurements of electrons, protons and light nuclei from a few up to hundreds MeV, also testing new tools for the detection of MeV gamma rays, and monitoring possible MILC signals.
Zirè will consist of a scintillating fiber tracker, a stack of plastic scintillator counters and an array of LYSO crystals. An active veto system and a Low Energy Module (LEM) are also part of the payload. In this work we present the design of a novel tracker prototype based on plastic scintillating fibers coupled with SiPM linear arrays. The preliminary results obtained in a beam test with a concept module will be illustrated.

1. THE ZIRÈ INSTRUMENT ON BOARD THE NUSES MISSION (NeUtrino and Seismic Electromagnetic Signals)

- NUSES is a pathfinder for technologies for future space-based detectors [1]
- Full Silicon Photomultiplier (SiPM) technology for all system readouts

Ziré physics goals:

- Measurement of energy spectra of Cosmic Rays (CR) from a few up to hundreds MeV
- Detection of gamma rays from hundreds keV up to 10 MeV
- Observation of changes in counting rates of low-energy particles near the Earth's Van Allen Belts and study of their potential connection to geophysical phenomena
- Monitoring low-energy CRs for understanding solar activity and space weather
- Detection of low-energy electrons (<5 MeV), to provide further insights into MILC models

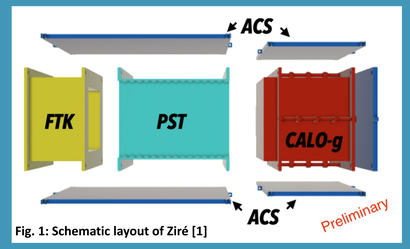


Fig. 1: Schematic layout of Ziré [1]

Ziré subdetectors:

- Fiber TracKer (FTK)
- Plastic Scintillator Tower (PST)
  - tracking
  - partial energy measurement
  - particle identification
- Calorimeter (CALOg)
  - γ-ray energy measurement
- AntiCoincidence System (ACS)
  - charged particle identification
- Low Energy Module (LEM, not shown in Fig. 1)

4. CHARACTERIZATION AND LAYOUT CHOICE

- Single layer irradiated with a ^{90}Sr electron source (end point 2.2MeV) coupled with a 2mm diameter hole collimator

Larger fiber diameter
Larger readout pitch
→ More p.e. collected
→ Higher efficiency
→ Larger efficiency plateau

$V_{op} = 4.5$ V @25°C

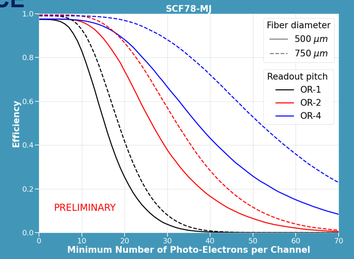


Fig. 6: Efficiency studies

- 750 µm fibers with larger readout pitch (OR-4) generally more efficient than 500 µm fibers with smaller pitches
- 750 µm fibers with OR-4 exhibit larger dynamic range in the discriminator threshold
- Flexibility in threshold adjustment to compensate for SiPM aging and extend the detector's lifetime (see [6] and refs therein)

2. THE ZIRÈ FIBER TRACKER (FTK)

FTK tasks:

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

Design:

- 3 X-Y modules:
  - 2 modules with single side readout
  - 1 module with double side readout for trigger and redundancy

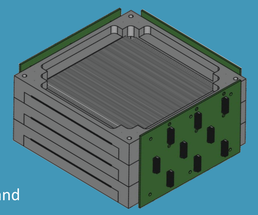


Fig. 2: Layout of the FTK

5. TRIGGER EFFICIENCY TESTS

- Threshold scan at different overvoltages with ^{90}Sr placed on top of the 750µm module
- External trigger given by the 500µm fiber diameter module placed below
- Both views for each plane of all modules are readout with an OR-4 pitch
- Trigger condition:
  - FTK plane (X or Y) trigger: coincidence of any pair of adjacent strips from the two sides (to take into account possible array misalignments)
  - FTK trigger: AND of X-Y FTK planes
  - Coincidence window: 25 ns (1 DACu)

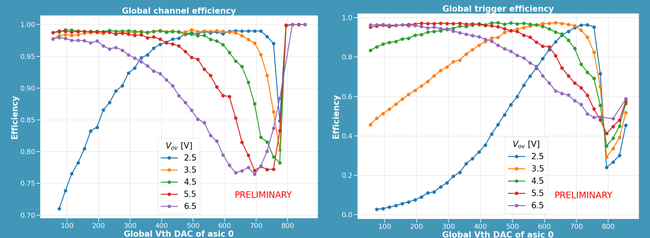
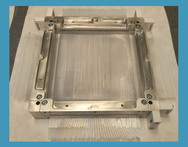
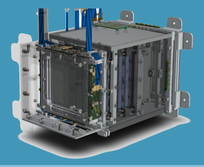


Fig. 7: Left panel: Single channel efficiency (fraction of events with at least one active channel) as a function of the threshold in DAC units (DACu); Right panel: FTK trigger efficiency (fraction of events satisfying the FTK trigger condition). Larger DACu correspond to thresholds closer to the pedestal. The efficiency plateau increases with the overvoltage.

7. COMING SOON: *ZIRETTINO*, A REDUCED SCALE ZIRÈ PROTOTYPE

Following the results obtained on the single subdetector prototypes, a reduced scale prototype of the entire Ziré has been designed. A full 10x10 cm FTK plane with 750 µm fibers and OR-4 readout pitch will be fully equipped. Tests @ CERN PS and SPS are planned.





3. THE FTK PROTOTYPES

- 2 X-Y modules with scintillating fiber planes and SiPM arrays
- Double-cladding Kuraray SCSF78-MJ [2] fibers of 500µm and 750µm diameters
- Light yield ~8000 photons/MeV
- Scintillation photons collected by 250 µm pitch HPK S13552 128-channel SiPM array [3]
  - $V_{bd} = 51.5$ V @25°C
- PWB interfaces enable different read-out pitches by combining multiple SiPM strips
  - Tested configurations with pitches labeled as OR-1, OR-2, and OR-4
- Readout with custom front-end board (FEB) using PETIROC2A ASIC [4,5,6]

Fig. 3: Schematic view of the 500µm (left) and 750µm (right) diameter fibers coupled with the SiPM strip. The trajectory of a particle is also shown and the hit strips are highlighted.

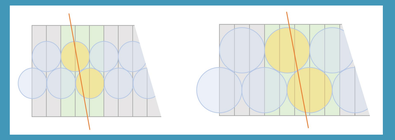
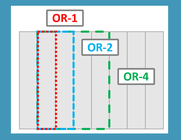


Fig. 3: Schematic of the different readout configurations.



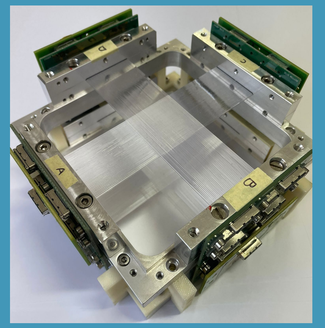


Fig. 3: FTK prototype

6. BEAM TEST RESULTS AT THE PS FACILITY @ CERN

Single view of a 750µm fiber diameter plane with OR-4 readout pitch configuration

Timing studies

- Arrival times within a few ns consistent with scintillator decay time of 2.8 ns [2]
- A tight coincidence window can be set to provide a fast trigger for other FTK planes and the other Ziré subsystems

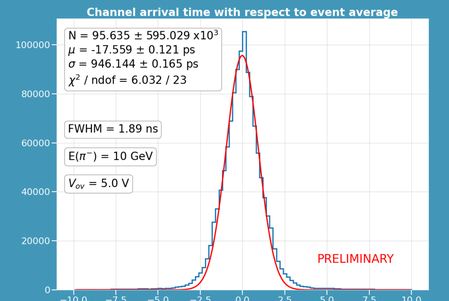


Fig. 9: Single channel arrival time distribution

Light yield

- Adjacent hit strips grouped in clusters
  - Cluster position evaluated as the charge-weighted average of the channel nominal positions
- The maximum charge cluster is selected
- From geometry and nominal yield MPV is compatible with expectations

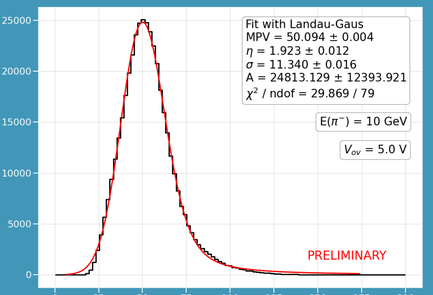


Fig. 10: Cluster charge distribution

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