PROCEEDINGS OF SCIENCE

The Low Energy Module (LEM) of the Zirè payload on board the NUSES space mission

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Time-resolved measurements of differential fluxes of low energy charged particles, trapped in the magnetosphere, are interesting for Space Weather characterization and to study the coupling between the lithosphere and magnetosphere, allowing the investigation of the possible correlations between seismic events and particle precipitations from Van Allen Belts. The project of a compact (10x10x10cm^3) particle spectrometer, the Low Energy Module (LEM) as part of the Zirè instrument on board the NUSES space mission is shown. The LEM will be able to perform measurements of energy, direction, and composition of low energy charged particles down to 0.1 MeV kinetic energy. The particle identification capability of the LEM relies on the ΔE-E technique performed by thin silicon detectors. To fulfill the size and mass requirements of the whole mission, the particle direction measurement is based on the "active collimation" technique. The detection concept and the expected LEM performances will be summarized.

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1. Introduction

NUSES is a planned space mission aiming to test innovative observational and technological approaches related to the study of low energy cosmic rays, gamma rays and high energy astrophysical neutrinos. The satellite will host two payloads, named Terzina [1, 2] and Zirè [3–5]. While Terzina will focus on space based detection of ultra high energy extensive air showers, Zirè is a particle detector performing the measurement of electron, proton and light nuclei fluxes from few up to hundreds MeV, also testing new tools for the detection of γ-rays. With the aim to extend the measurements to lower energies, a Zirè Low Energy Module (LEM), will be attached to the external structure of the NUSES satellite (see fig. 1).

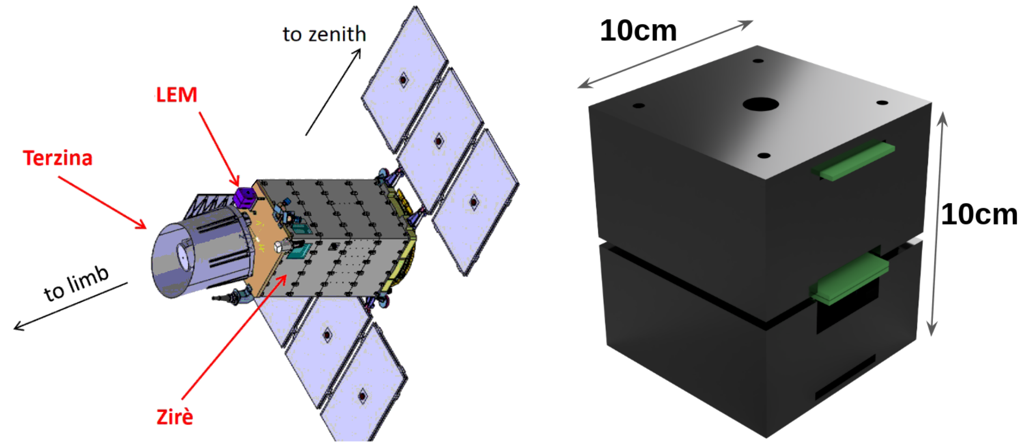

Figure 1: [Left panel] Schematic view of the NUSES mission satellite. The Terzina optical telescope will observe the night side of the Earth limb, the Zirè detector will measure charged particles and γ-rays, and the LEM spectrometer will measure low energy charged particles arriving from the zenith. [Right panel] The LEM detector inside the passive aluminium shield. The flux of charged particles crossing the top central hole is measured.

The Low Energy Module will be a compact spectrometer (10x10x10cm^3) able to perform an event-based measurement of energy, direction and composition of low energy charged particles, in particular down to 0.1 MeV for electrons. The main goal of this detector is the monitoring of the magnetosphere and ionosphere environment. It is known that the measurement of the fluxes of trapped charged particles can improve the models of the coupling between the lithosphere, atmosphere, ionosphere, and magnetosphere [6]. In particular, statistical evidences of temporal correlation between particle precipitations from Van Allen Belts and strong seismic events has been pointed out [7]. These observations, motivate the interest in further, detailed, measurements of electron fluxes in the energy window $0.1 - 7$ MeV that could be a promising channel to identify hypothetical seismic precursors.

Other goals of the LEM detector will be the study of the Space Weather, monitoring the flux of low energy protons, and the investigation of the particle composition within the harsh environment of the South Atlantic Anomaly (SAA), measuring the isotopic abundances of H, He and eventually the fraction of heavier nuclei.

2. The LEM detection concept

In a particle spectrometer (like e.g. Zirè) the measurement of the particle direction is usually performed by tracking technique; however for low energetic particles, the standard tracking approach fails due to large multiple Coulomb scattering within the first detector layer. For the measurement of the arrival direction of low energy particles, a collimation technique must be adopted [8]. In the collimation technique, a shaped passive shield must be thick enough to stop energetic particles hitting the collimator from "unknown"/random directions. To avoid bulky and heavy passive shields, the technique of "active collimation" is developed for the LEM spectrometer, it relies on the use of shaped plastic scintillators as a veto, tagging the particles that are crossing the relatively light passive shield. To limit the occupancy of the veto detectors in the SAA, permitting a reliable measurement of the particle composition there, a 0.8 cm thick aluminium shield is considered for the LEM. The particle identification capability of the LEM relies on the ΔE-E spectrometric technique, performed by five pairs of thin Passivated Implanted Planar Silicon (PIPS) detectors placed in a telescopic configuration. Typical resolution of the PIPS detector is ≃10 keV.

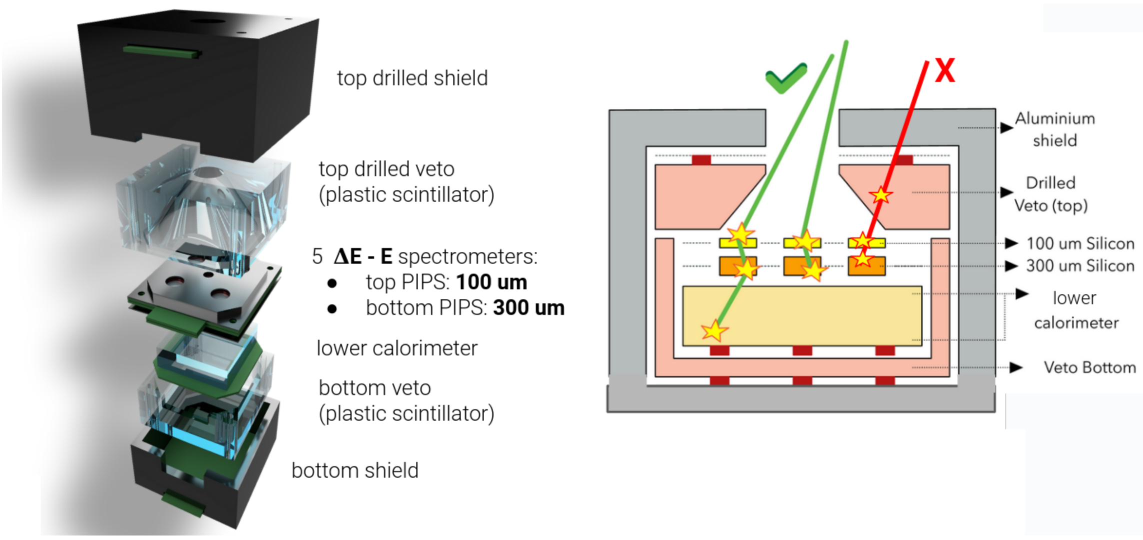

Figure 2: [Left panel] Exploded view of the LEM detector.
[Right panel] Schematics of the LEM detection approach; green lines are examples of accepted events, red line is an example of rejected event.

In fig. 2 an exploded view of the detector and an example of the LEM detection approach is shown. Coming from the zenith, a particle can enter inside the LEM through the hole drilled in the top shield avoiding to be tagged by the drilled top veto. Depending on the particle direction, the nature of the charged particle is identified by one of the five ΔE-E spectrometers. Each spectrometer is composed by a 100μm thin silicon detector superimposed to a 300μm thick silicon detector. To extend the energy range capability for the LEM particle identification, a lower calorimeter is placed below the PIPS. A lower calorimeter made by 2 cm thick plastic scintillator allows a flux measurement up to 10MeV for electrons, thus a reasonable overlap is expected with the Zirè flux measurements[4]. Finally a bottom veto is identifying particles of relatively large energy, that are not contained by the lower calorimeter. A good particle identification capability is expected for contained particles that are crossing one of the 100μm top PIPS (see left plot of fig. 3).

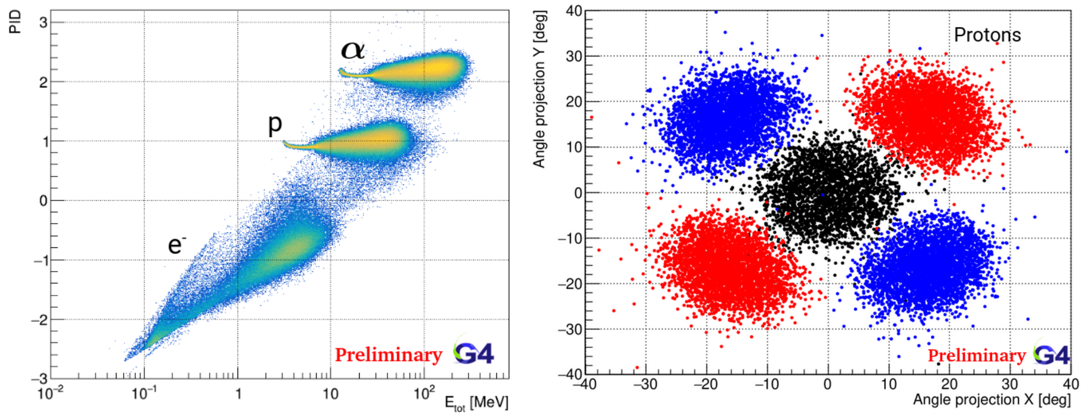

Figure 3: [Left panel] Particle identification capability for events crossing the top 100μm "thin" PIPS and contained in the LEM.
[Right panel] Field of view and angular resolution of the LEM detector for protons, the different colors are encoding which pair in the ΔE-E spectrometer detects the particle.

Assuming a low energy non-relativistic charged particle passing through the thin PIPS detector, both the energy deposited, $\Delta E \propto \frac{Z^2}{\beta^2}$, and the total kinetic energy, $E_k \approx \frac{1}{2}m(\beta c)^2$, are velocity dependent. Combining these quantities, a particle classifier can be defined: PID $= \log_{10}(\Delta E \cdot E_k) \approx \log_{10}\left(Z^2 m\right) + const.$, that is mainly dependent on the particle mass, m, and charge, Z, but is almost energy independent. The PID classifier is shown in the left plot of fig. 3. Despite the non-relativistic approximation fails for electrons, they still are recognized from protons thanks to the very low mass. The poor energy resolution expected by the plastic scintillator calorimeter ($\sim 30\%$) is responsible for the PID performance degradation at relatively large energy where the particles are crossing the thick PIPS stopping in the plastic calorimeter.

In the right plot of fig. 3, the example of the LEM Field of View (FoV) and angular resolution for protons is shown. The overall LEM FoV is $\approx 45°$, the color of the points is encoding the five different PIPS pairs that detected the particles. The obtained angular RMS is $\approx 6°$ for proton and α particles while a worst resolution ($\approx 12°$) is expected for electrons due to interactions with the inner fringe of the LEM aperture.

The overall LEM geometrical factor is ≈ 0.1 cm^{2}sr; it is almost constant for electrons in the range 0.2-5 MeV, for protons in the range 3-50 MeV and for α particles in the range 20-200 MeV. Knowing the expected orbit parameters of the NUSES mission (Sun-synchronous, 97.8deg, LEO 535km) a preliminary map of the expected rates of the LEM can be evaluated using the IRENE-AE9/AP9 model [9]. In fig. 4 it is shown that the LEM will experience an high acquisition rate (≈ 50 kHz) in the SAA, thus a twofold data transmission approach is in preparation ("event-based" for rates below 1kHz and "histogram based" for larger rates) to fulfill the data bandwidth assigned to LEM in the NUSES mission.

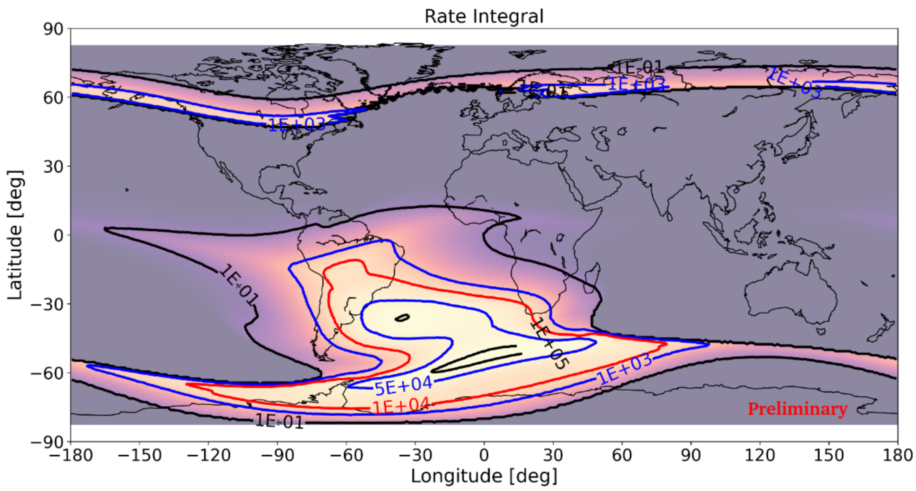

Figure 4: Expected rate map considering the satellite polar orbit and the $\simeq 0.1$ cm^{2}sr acceptance.

3. Preliminary test on PIPS sensors.

The heart of the LEM detector is composed by the PIPS spectrometer. The spectrometer will use four circular PIPS with area 150mm^2 surrounding a central one with area 50mm^2 (see fig. 5). The central PIPS diameter is smaller to equalize the geometrical acceptance among the five channels. The five top sensors, with thickness 100μm, will be the R-series (ruggedized) PIPS manufactured by ORTEC/AMETEK [10].

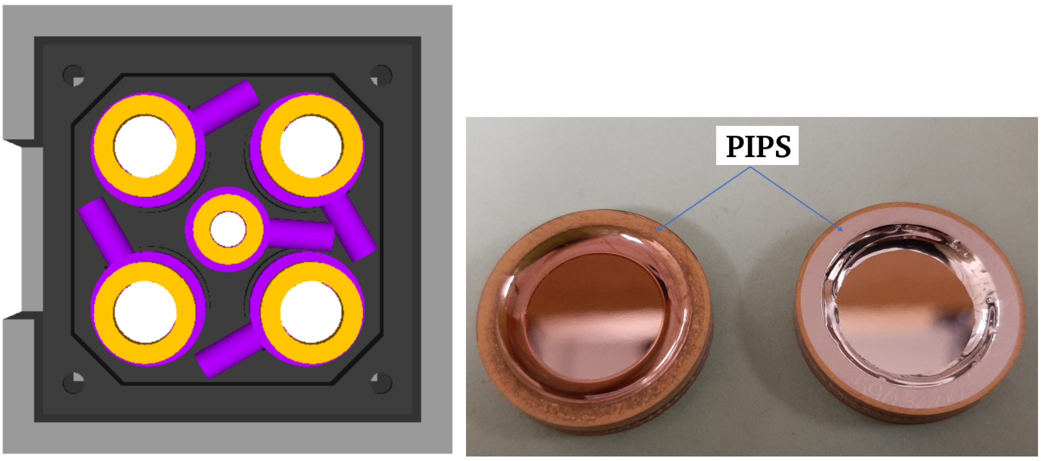

Figure 5: [Left panel] Mounting arrangement of the PIPS in the LEM spectrometer.
[Right panel] A picture of the 100μm thin PIPS manufactured by ORTEC/AMETEK.

The two sides of the 100μm PIPS are covered by an aluminium and a gold layer with a thickness of $\approx$50μg/cm^2 and $\approx$40μg/cm^2, respectively. These layers ensure that the PIPS detectors are light tight and "ruggedized". The five bottom sensors, with thickness 300μm, will be manufactured by Canberra/MIRION [11]. The two sides of the 300μm PIPS are covered by aluminium with a thickness of $\approx$70μg/cm^2 and $\approx$250μg/cm^2, respectively, to ensure the detector is light tight.

A preliminary set-up for the measurement of the performances of a PIPS detector was tested in the INFN-TIFPA laboratory, the depletion voltage of the PIPS sensor was 60V and preliminary measurement of the power budget of the used charge amplifier is below 100mW/ch. The sensor was tested acquiring atmospheric muons in telescopic configuration, γ-rays from ^{176}Lu source and α-particles and γ-rays from from ^{241}Am source. A very good linearity of the energy scale was obtained, moreover the PIPS response to particles with very different specific ionization (muons, recoiling electrons and α) has found to be compatible within few %, as expected.

Two key requirements for the LEM project is to guarantee a low energy threshold and a relatively fast response. In left plot of fig. 6 the measured 59.5 keV γ-line from from ^{241}Am source is compared with the background spectrum from the tested PIPS detector. This measurement verify the feasibility of the 40 keV energy threshold adopted in the LEM simulations as well as the 10 keV energy resolution.

Another important factor for the LEM is the measurement of the signal decay time; this is related to the detector occupancy that could be an issue in the harsh environment of the SAA. In the right plot of fig. 6 some waveforms obtained measuring few MeV α-particles from from ^{241}Am source are shown. The $\approx$ 100 ns measured signal decay time prevents issue of the possible pile-up of overlapping signals from different particles in the SAA.

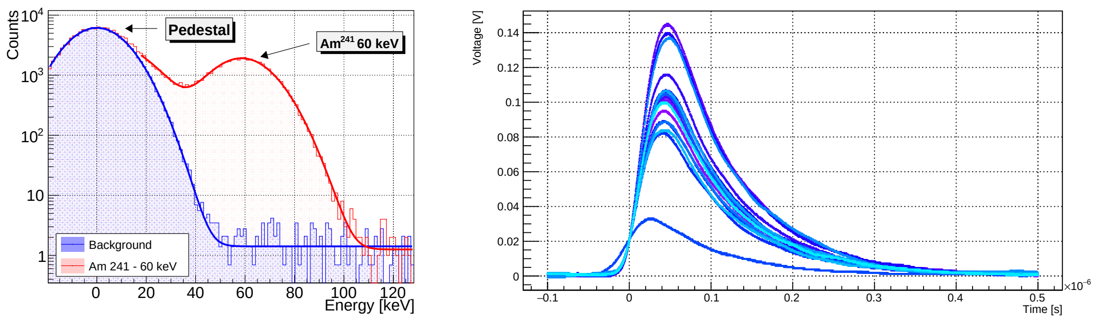

Figure 6: [Left panel] PIPS calibration with 59.5 keV γ-line from from ^{241}Am source. [Right panel] Waveforms collected measuring few MeV α-particles from from ^{241}Am source.

4. Conclusion

The project of a compact (10x10x10cm^3) particle spectrometer, the Low Energy Module (LEM) as part of the Zirè instrument on board the NUSES space mission is in construction and testing phase. Prototypes of PIPS detector readout has been tested in the INFN-TIFPA laboratory, confirming $\approx$ 10 keV energy resolution and $\approx$ 100 ns signal decay time. The LEM will be able to perform measurements of energy, direction, and composition of low energy charged particles down to 0.1 MeV kinetic energy, studying the coupling between the lithosphere and magnetosphere, measuring the particle fluxes in the SAA and monitoring the Space Weather.

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