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The Limadou-HEPD Segmented Calorimeter

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Abstract. The core of the High-Energy Particle Detector (HEPD) on board of the China Seismo-Electromagnetic Satellite (CSES) is a segmented calorimeter, which is composed with an upper tower of plastic scintillator counters and a bottom array of LYSO large crystals. Electrons with energy below 100 MeV, protons and light nuclei, below few hundreds of MeV/nucleon are fully contained within this calorimeter. Mainly the LYSO array (density 7.3 g/cm^3, thickness around 29.2 g/cm^2) extends the HEPD energy range, allowing those measurements (solar energetic particles, low-energy cosmic rays) which are more related to astroparticle physics topics. Two identical copies of HEPD, and then of its calorimeter, exist: the Flight (FM) and the Qualification (QM) models. While the FM has achieved the orbit on board of the CSES satellite in February 2018, the Qualification Model, is used, at ground, for tests and calibrations. A report on the characterization of this compact particle space detector and on preliminary studies and results, will be given.

1 HEPD

The High-Energy Particle Detector (HEPD, [1]) is a space detector for high-energy particles (electrons from 3 to 100 MeV, protons from 30 to 300 MeV, light nuclei up to hundreds of MeV/n), developed and built by a consortium of Italian institutions. Figure 1 it is shown a model of the entire High-Energy Particle Detector with its sub-detectors, obtained with a GEANT4 based MC code, and a picture of the apparatus. HEPD is one of the instruments on board of the Chinese Seismo-Electromagnetic Satellite (CSES, [2]). This is a CNSA (Chinese National Space Administration) and ASI (Italian Space Agency) mission, focused to study the near-Earth electromagnetic, plasma and particle environment, to search for electromagnetic seismo associated disturbances. Two HEPD copies were built: the Qualification Model (QM) and the Flight model (FM). These had intense test and qualification campaigns with proton and electron beam tests (INFN-LNF-BTF and ProtonTerapy Center in Trento), space qualification tests (thermo-vacuum, pyro-shock, thermal cycles, SERMS lab. in Terni). CSES was successfully launched February the 2nd 2018. HEPD FM completed its commissioning phase in June 2018. HEPD QM is used, at ground, for further characterization of the detector, such as a beam test with light nuclei (H, He, C, O, at 62MeV/n) performed during July 2018 at INFN-LNS. Apart from the searches for Geo-space anomalies related to powerful seismic events, with HEPD several astroparticle topics can be addressed. The main are: - the study of the solar energetic particles [3]; - the measurement of the low-end of the Galactic Cosmic Rays spectrum [4]; - the characterization of the orbit radiation environment [5].

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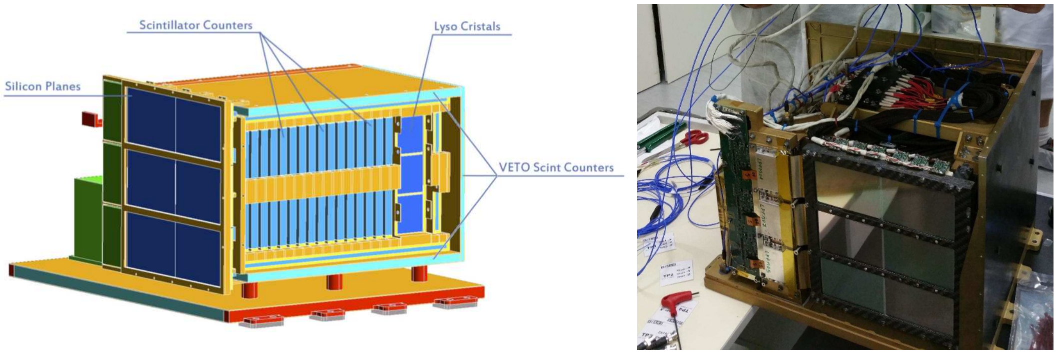

Figure 1. On the left panel is shown the High-Energy Particle Detector: - in blue, the silicon tracker (two silicon planes of 213×213 mm^2), with 192 micron read-out (p and n) and resolution of 40-50 micron); - below the tracker there is the trigger plane (one thin plane of 6 counters with dimen-sion 200×30×5 mm^3 of plastic scintillator EJ-200 and read out by PMTs Hamamatsu R9880U.); - in light blue 16 plastic counters of the upper calorimeter and on the right are visible three of the LYSO crystals of the lower calorimeter (see text for details); - around the calorimeter three counters of the VETO can be seen (the VETO has four lateral and one bottom counters similar to the CALO ones; - in green the power supply and electronics. On the right panel a picture of the HEPD FM during the detector integration.

2 The Detector

The core of HEPD consists of a segmented calorimeter, which is divided in two sections. Its upper part is a tower made of 16 plastic scintillator EJ-200 counters. Each counter measures 150×150×10 mm^3 , and is read out by two PMTs at two opposite corners.The lower calorimeter consists of an array of 3×3 crystals of heavy inorganic scintillator (LYSO, density 7.3 g/cm^3). Each crystal has dimensions 48×48×40 mm^3 and is read out by one PMT. This array is located at the bottom of the tower. In Figure 2 pictures of the tower and LYSO array are shown. These two devices constitute two different radiator homogeneus layers. The main departures from homogeneity are given by the mechanical structures, which had to be included between each pair of tower counters, to the gaps (few mm) between the LYSO crystals, as also to the mechanical structure between tower and array. A fraction of the incident particles will be fully contained within the calorimeter. For them it is possible to measure the total energy (to have which also the energy release within the trigger should be included). The particle identification can be obtained with the dE/dX vs E_{Tot} method, using the energy release within the trigger (or the tracker) as dE/dX. For contained events, the particle range can also be obtained. Another fraction of particles pass through the calorimeter and exit from the bottom veto. For these passing through particles it is possible to measure the differential energy loss within each calorimeter element, and then a study of the event is possible with a comparison with an energy deposition model (passing through analysis).

3 Energy Calibration

A preliminary energy calibration of the plastic tower was performed by means of the electron (30 MeV) and proton (51, 70, 100 and 125 MeV) irradiations. For each of the PMT channels, the pedestal and the associated rms were determined with special runs, during which a high-frequency artificial

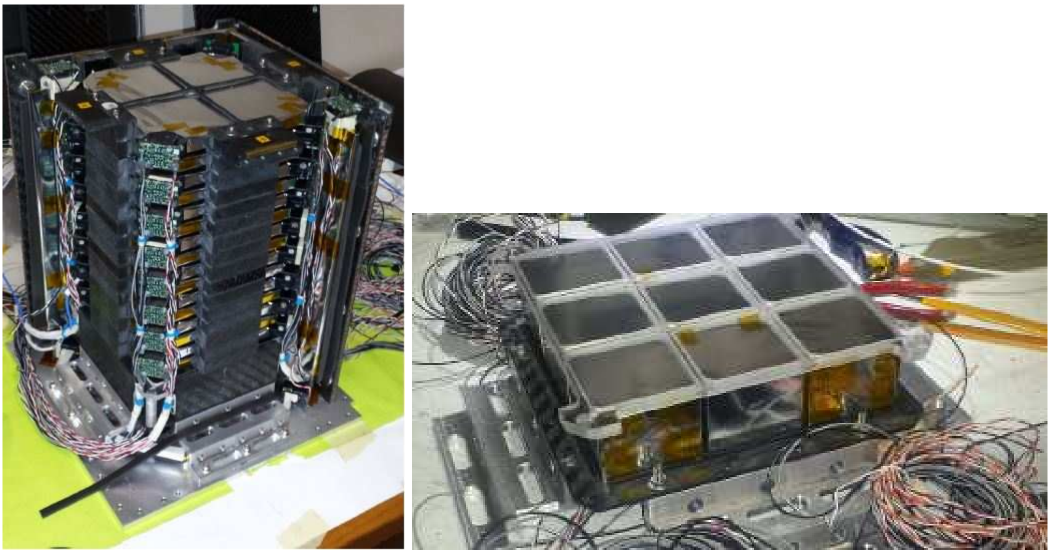

Figure 2. On the right panel: the HEPD-QM calorimeter. The tower of 16 plastic scintillator counters is visible. On the bottom is located the 9 LYSO crystals array. On the left panel: the HEPD-QM LYSO array. In both pictures also a part of the mechanical structures are visible)

trigger was sent to the detector. The PMTs light responses to a MIP-like particle were set to a conventional value, by means of acquisitions of atmospheric muons. Beam tests data were required: a) to give signal only in one trigger bar (trigger multiplicity = 1); b) to be contained within the upper calorimeter (no hit in the veto counters and no hit in the LYSO crystals); c) to have more than a minimum number of hit planes, to reject events with anomalous low energy loss. Then we calculated the sum of the signal of trigger and tower as $S_{Tot} = S_{Tower} + \frac{1}{2}\, S_{Trigger}$, with S_{Tower} the sum of the signals of all the tower PMTs, $S_{Trigger}$ the sum of the signal of the trigger PMTs over threshold. The trigger bars have half of the thickness of a tower counter. An energy response function was built, by associating the S_{Tot} peak-position to the related particle energy. The energy losses of the particles before arriving to the trigger (air, tracker, etc) were taken into account, by means of MC simulations. The LYSO array calibration was performed with a different method, because all the beam particles which reach the LYSO array have already interacted with the HEPD elements above it (tracker, trigger, tower, structures). To build the energy response function S_{Tot} peak-position was associated to the expected energy deposition within the LYSO crystals. This deposition was estimated with Monte Carlo simulations. The LYSO array was calibrated with 60 and 90 MeV electrons, 174, 202 and 228 MeV protons. The obtained energy response functions for the tower and the LYSO array are shown in Figure 3, together with an example of energy reconstruction, e.g. BTF 60 MeV electrons, which loose energy both in tower and LYSO array.

4 Outlook

A preliminary energy calibration of the HEPD calorimeter has been performed with the use of the electron and proton beams data. Studies of secondary effects such as larger charges, mechanical structures effects, etc, are ongoing. After the calibration, further data analysis steps are possible, as

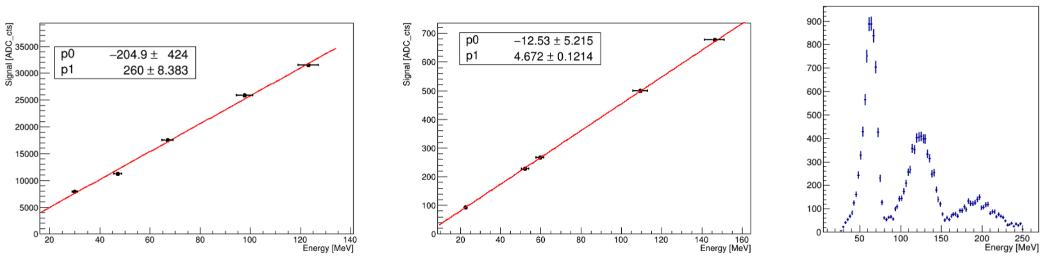

Figure 3. On the left: tower Energy Repsonse Function. The peak position of the signal distribution is associated with the beam energy minus the losses in the tracker and air. On the centre : LYSO array Energy Response Function.The peak position of the signal distribution is associated to the expected energy deposition within the LYSO array, obtained with MC simulations. On the right: Energy Reconstruction for the BTF 60 MeV electrons. Events were required to have more than 15 active tower counters. These particles reach both tower and array, The second and third peaks are produced by the pile-up of 2 or 3 simultaneous electrons.

the implementation of the particle identification methods (dE/dX vs E_{Tot}, passing through particles analysis).

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