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The High-Energy Particle Detector (HEPD) on Board the CSES Mission

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Abstract. The High-Energy Particle Detector (HEPD) will measure electrons, protons and light nuclei fluxes, in low Earth orbit. This detector consists of a high precision silicon tracker, a versatile trigger system, a range-calorimeter and an anti-coincidence system. It is one of the instruments on board the China Seismo-Electromagnetic Satellite (CSES). HEPD can detect multi-MeV particles trapped within the geomagnetic field. When operated at large latitudes HEPD can also detect un-trapped solar particles and low energy cosmic rays. A detailed description of the HEPD will be given.

1. Introduction

The High-Energy Particle Detector (HEPD) is a space experiment for the detection of electrons from 3 to 100 MeV, protons from 30 to 300 MeV and light nuclei up to few hundreds of MeV. HEPD will be flown on the CSES satellite (Shen *et al.* 2011), together with several other instrument, for the study of the low Earth orbit (LEO) electromagnetic environment (ionosphere, magnetosphere and Van Allen belts). The CSES satellite will have a 98 degrees inclination Sun-synchronous circular orbit, an altitude of 500 km and an expected lifetime is 5 of years. At low latitude HEPD will detect particles which are trapped within the geomagnetic field, while when operated at large latitudes, with a lower geomagnetic cutoff, HEPD will be able to access also un-trapped particles, such as solar energetic particles (SEPs).

SEPs consist of electrons, protons and nuclei with larger Z, with energies from tens of keV to a few GeV. They might be accelerated via magnetic reconnection during flaring events, or by shocks related to coronal mass ejections (CME). The following SEPs transport within the heliosphere washes out the characteristic imprints of the acceleration process, making more difficult to determine which one is at work. SEPs are a major factor in determining the radiation environment outside Earth. During intense events, solar particles can also penetrate the magnetosphere and reach the atmosphere, also due to sudden variations of the ionospheric currents. Then SEPs are an hazard factor for space (and high altitude) activities. Rarely, solar particle emission is intense enough to cause ground level enhancement (GLEs) of the radiation on Earth.

Solar activity effects on the Earth magnetosphere can be studied with the HEPD, which can also obtain SEPs fluxes and spectra. HEPD will work in a peculiar energy range, below the one covered by ground-based instruments and at the lower end of the energy range of the space borne cosmic ray detectors. Operating at similar energies (>80 MeV), the PAMELA experiment performed observations of the 2012 May 17 SEP (Adriani *et al.* 2015), which was associated to GLE. The PAMELA team reported two distinct SEP protons populations: - a first one below 1GeV, which undergoes important scattering effectes; - another one above 1GeV, which reaches the Earth without strong disturbances

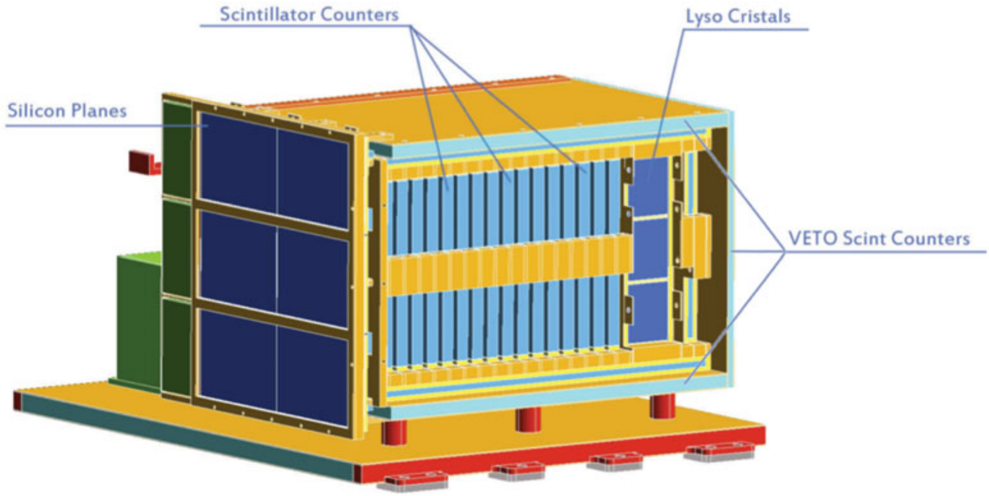

Figure 1. A detailed view of the High-Energy Particle Detector and its sub-systems. Starting from the left we see the the silicon tracker, in blue. Then it is located the trigger plane (not seen here because it is covered by the other elements). In light blue are drawn the 16 plastic scintillators of the upper calorimeter. Then going to the right, there are three of the LYSO crystals. Around the calorimeter three counters of the VETO can be seen. The power supply and electronics are drawn in green.

and is well consistent with neutron monitor measurements. Further PAMELA measurement of low energy protons, both trapped and solar particles, are reported in Bruno *et al.* (2017).

2. HEPD Components and Measurement Methods

The sub-systems composing the HEPD instrument are: (a) a **Tracker** (TRK) which is located on the top of the HEPD and consists of two silicon detector planes (213×213 mm^2). Si detectors have 192 micron read-out (p and n) for a resultant resolution of 40-50 micron; (b) a **Trigger System** (TS), which consists of one thin plane of 6 counters (dimension 200×30×5mm^3), dubbed bars, made of plastic scintillator EJ-200 and read out by PMTs Hamamatsu R9880U; (c) a **Range-Calorimeter** (CALO), which is divided in two sections. Its upper part is a tower made of 16 plastic scintillator EJ-200 planes while the lower part is a 3×3 matrix of an inorganic scintillator LYSO, located on the bottom of the tower. Each plane measures 150×150×10 mm^3 , and is read out by two PMTs at two opposite corners. The lower calorimeter consists of 9 crystals. Each crystal has dimensions 48×48×40 mm^3 and is read out by one PMT located on the bottom face; (d) a **Veto System** (Veto), which consists of 5 plastic scintillator counters (four lateral and one at the bottom of the instrument) similar to those of the CALO. (e) the **Electronics and Power Supply Sub-System** is composed by the Electronics Subsystem (ELS), made by all front-end electronics and four boards, which are the DAQ board, the PMT/Trigger board, the CPU board and the Power Control board and the Power Supply Subsystem (PWS), which is made with the Low Voltage Power Supply (LVPS) and High Voltage Power Supply (HVPS). An illustration of the HEPD sub-systems is given in Figure 1.

The instrument dimensions are 530 ×382×404 mm^3 with a mass budget of 45 kg and a power consumption limited to 27 W. HEPD reaches a geometrical acceptance of few hundreds cm^2sr, relatively large for this type of instruments. Preliminary indications of the effective acceptance for electrons and protons were given in Sparvoli *et al.* (2015),

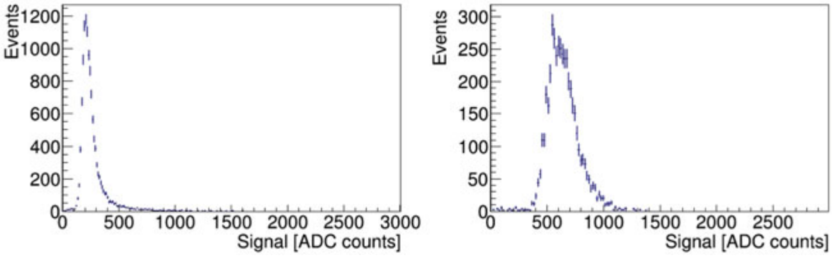

Figure 2. Energy loss within the Trigger System: on the left atmospheric muons; on the right 228 MeV protons acquired during a dedicated beam test.

with peak acceptance in the order of hundred of cm^2sr, depending on the particle type and trigger conditions. In facts the trigger logic is a key factor in defining the instrument effective acceptance. The main trigger logic requires to have in coincidence: (a) a signal within one of the trigger bars; (b) a signal from one of the calorimeter planes, usually the first from above. The acceptance and the energy threshold can be modulated by changes in the trigger logic: - the acceptance can be reduced by allowing only one or few of the trigger bars to form the main trigger, or by requiring no signal in the lateral veto; - the energy threshold can be raised by associating to the trigger logic a calorimeter plane which is closer to the instrument bottom, so that a particle needs more energy to reach it.

This instrument can achieve a good particle identification. In the energy range of interest while electrons are always relativistic, protons are much slower. Then it is possible to used the ΔE vs E_{total} method for the electron vs. proton discrimination. The ΔE is the energy loss within a thin detector layer, and can be obtained with the silicon tracker measurement, or the with the trigger bars and the individual calorimeter planes. An example of energy loss within the trigger bars is in Figure 2. The E_{total} is the particle energy and can be measured by the calorimeter, for particles which are fully contained within the detector. Discrimination of higher Z particles can be achieved also with the energy release within the silicon tracker.

3. Conclusions

The HEPD, a space detector for particles up to few hundred of MeV, is scheduled to be launched during late 2017-early 2018. For large part of the 24th solar cycle, it will be able monitor SEPs and the effects of solar activity on the Earth magnetosphere.†

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