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The High-Energy Particle Detector on board of the CSES mission

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Abstract.
The High-Energy Particle Detector (HEPD) is a range-calorimeter for the near-Earth measurement of electrons, protons and light nuclei fluxes up to few hundreds of MeV. HEPD will fly on board of the China Seismo-Electromagnetic Satellite (CSES), scheduled to be launched in July/August 2017. This mission will investigate possible correlations between geomagnetic properties (electromagnetic wave emissions, plasma properties and particle fluxes in the ionosphere and magnetosphere) and seismic events. The study of the solar-terrestrial environment, Coronal Mass Ejections (CMEs), Solar Energetic Particles (SEPS) events and low-energy cosmic rays are also within the scientific objectives of this mission. A detailed description of the HEPD and its characteristics will be reported.

1 Introduction

The China Seismo-Electromagnetic Satellite (CSES) [1] is a space mission dedicated to the monitoring of the electromagnetic (e.m.) perturbations in atmosphere, ionosphere, magnetosphere and Van Allen belts, and to investigate possible correlations with seismic events. The satellite is based on the Chinese CAST2000 platform. It is a 3-axis attitude stabilized satellite and will be placed in a 98 degrees inclination Sun-synchronous circular orbit, at an altitude of 500 km. The launch is scheduled for July/August 2017 and the expected lifetime is 5 years.

There will be several instrument systems on board of CSES: (i) a Tri-Band Beacon and GNSS Occultation Receiver for the study of profile disturbance of plasma; (ii) a Langmuir Probe and Plasma Analyzer for measurements of local plasma disturbances; (iii) a High-Precision Magnetometer, an Electric Field Detector and a Search-Coil Magnetometer for the measurement of electromagnetic field; (iv) a High-Energy Particle Package, which has three components (H, L and X) and measures electrons (few keV to 50 MeV) and protons (20 MeV to 200 MeV) with acceptance of some tens of $cm^2 sr$; (v) the High-Energy Particle Detector (HEPD), which is discussed in this article.

Then CSES science program can cover several fields and topics. In the field of the e.m. wave emissions, we list the monitoring of the e.m near-Earth space environment, of the e.m. man-made

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effects at low Earth orbit altitude and the observations of e.m. transients caused by tropospheric activity, as also to search for direct correlation of e.m. wave emission and earthquakes. For the Ionosphere and plasma-sphere studies, the measurement of plasma perturbations is considered, while for the energetic charged particles, there are the measurements of electron and proton fluxes, the study of short time scale variability and precipitation of inner Van Allen belt particles. When at large latitudes, the HEPD detector can also perform measurements of not-trapped low-energy charged particles up to few hundreds of MeV. This allows the study of several topics related to the solar-terrestrial environment and the lower end of the cosmic-ray spectrum.

1.1 Van Allen Belts and Cosmic Rays

At low and intermediate magnetic latitudes the HEPD detector can access particles, which are trapped or significantly influenced by the geomagnetic field. Trapped charged particles constitute two (and sometimes more [2]) radiation belts. Different species (electrons and protons) have maximum intensities at different values of the McIlwain L-parameter (L defines a specific set of geomagnetic field lines). In the energy range of interest, particle fluxes within the belts are orders of magnitude larger than outside. A detailed characterization of the charged particle fluxes within the geomagnetic field is difficult for several reasons: - the departure of the geomagnetic field structure from a pure dipole and the presence of anomalies such as the South Atlantic Anomaly (SAA); - the time variation of the particle fluxes on several time scales; - the existence of few particle populations (particle albedo, likely produced with collisions of cosmic rays with the atmosphere gas, quasi-trapped component with limited lifetime and low flux); - the "penumbra" region, where both cosmic rays and trapped charged particles are found. Inner and outer belts have a different degree of flux stability, and likely different particle sources. Protons within the inner belt are thought to be produced via the CRAND process [3] by the decay of albedo neutrons. At large magnetic latitudes the solar particles and the low-energy component of cosmic ray might be measured. Coronal mass ejections (CME), emitted by the Sun, propagate through solar magnetic field and inter-planetary plasma. When directed along the proper trajectory CMEs can reach the Earth, and cause geomagnetic storms and other important perturbations of the Earth's magnetosphere. CMEs, as also powerful solar flares, can accelerate Solar energetic particles (SEPs), which carry unique information on the impulsive phenomena in the Sun atmosphere. An intense SEP event can also determine significant changes in the fluxes of trapped particles, The effects of intense SEP events can even reach the planetary ground as shown by the increase of the neutron flux measured by ground-based neutron monitors during the so-called ground-level enhancements (GLEs). A wide investigation program on low-energy cosmic rays and solar particles was pursued with the PAMELA satellite experiment. This included the study of trapped, albedo and solar energetic particles [4], of SEP events [5] and also the discovery of anomalously high fluxes of trapped anti-protons [6] in the kinetic energy range between 60 and 750 MeV. At lower energies, the measurements cited above can be complemented with the HEPD.

2 The HEPD Detector

HEPD, developed and built by the Italian members of the CSES mission, is designed for detecting electrons in the energy range between 3 and 100 MeV, protons between 30 and 300 MeV, and light nuclei. Being a space detector the HEPD mass budget is limited to 45 kg, while power to 43 W, and despite the small dimensions (20x20x40) cm^3 it reaches a relatively large geometrical acceptance of hundreds of $cm^2 sr$. The HEPD includes four sub-detectors: - the **tracker** (TRK), made of two planes of double-sided silicon micro-strip sensors. Each plane includes 3 ladders made of 2 modules, each module with an area of (10.7x7.2)cm^2, and read out by twelve VLSI chips; - the **trigger system** (TS), consisting of 6 plastic scintillator paddles, each with dimensions (20x3x0.5) cm^3 and read out by two Hamamatsu PhotoMultiplier Tubes (PMTs). The paddles fully cover the entrance of the detector and are placed below the tracker and above the calorimeter; - the **range-calorimeter** (CALO), divided in two sections. The top part consists in 16 plastic scintillator counters, each of which with dimensions (15x15x1) cm^3 and read out by two PMTs. The PMTs are placed at the ends of a counter diagonal and the instrumented diagonal alternates for even and odd counters. The lower calorimeter section is made of 9 LYSO crystals,which are arranged in a layer. A crystal has a height of 4 cm and a side of 5 cm and is read out by a PMT; - the **veto system** (VETO), made of five plastic scintillator counters, 5 mm thick, read out by two PMTs. Four counters are at the sides of the CALO, while the fifth one is below the LYSO layer.

The HEPD associated electronics (sub-system ELS) is inside a box placed at one side of the detector. The ELS includes: the CPU, the silicon detector DAQ, the PMT trigger and acquisition, the LV Control Board, the High Voltage Power Supply (HVPS), the Main power DC/DC converter (LVPS) and 6 mechanical modules. A scheme of the HEPD sub-systems can be seen in Fig. 1. The HEPD

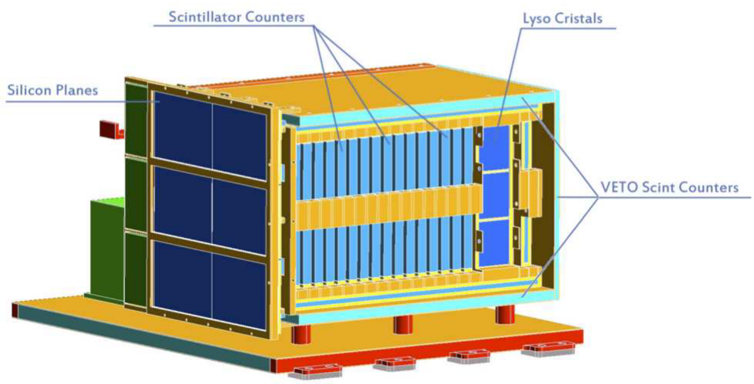

Figure 1. A scheme of the HEPD:- in blue, the silicon tracker, labeled as "Silicon Planes"; - below the tracker there is the trigger plane (not seen here), composed of 6 paddles; - in light blue 16 plastic scintillators which compose the upper part of the calorimeter, labeled as "Scintillation Counters"; - on the right, the LYSO cubes (3 of them are visible), which compose the lower part of the calorimeter, labeled as "LYSO Crystals"; - above, below and on the right of the calorimeter 3 counters of the VETO are visible, labeled as "VETO Scint Counters" ; - in green the power supply and electronics.

trigger is formed with the coincidence of signals from one of the TS paddles and from the upper CALO counter (P1). In order to vary the acceptance, when needed, other trigger combinations can be formed, using the other CALO counters, or requiring only a specific paddle to be hit. The dE/dX and incidence direction of the charged particle can be obtained with the TRK measurements, and a further dE/dX measurement is obtained with the TS paddles. Charged particles with trajectories fully inside the calorimeter can be selected by asking no signals from the lateral and the bottom VETO counters. In such a case the total energy can be measured with the CALO. For particles stopping in the upper CALO a range measurement can also be obtained. The lower CALO (LYSO layer) is designed to provide a larger matter thickness and to increase the operational energy range. Within the energy range of interest electrons are always relativistic, while protons are slower and not relativistic.

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Then for fully contained particles, the electron/proton separation can be achieved with the dE/dX vs E_{tot} method. Two examples of electrons, which are stopped within the CALO, are in Fig. 2.

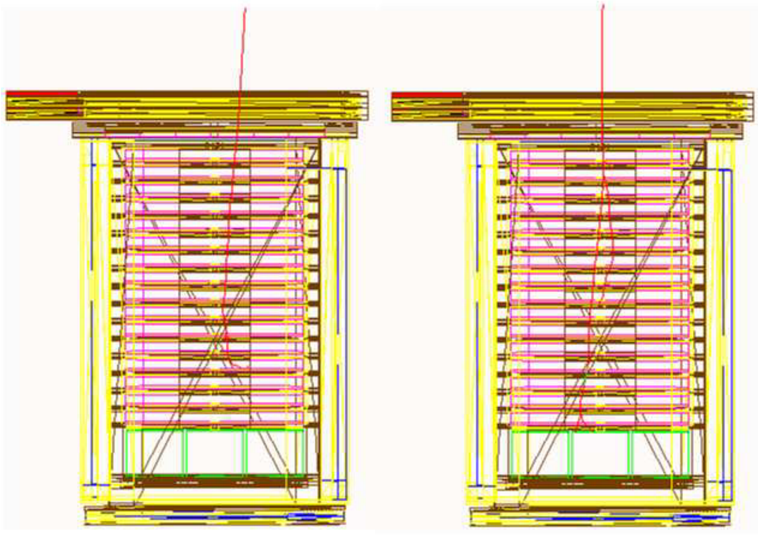

Figure 2. Monte Carlo simulations of electron measurement with the HEPD apparatus. On the right a 60 MeV electron, on the left a 30 MeV one, incident on HEPD from above. In red are the electrons trajectories, the apparatus elements are drawn as solids in color. While the 30 MeV electron is contained in the upper plastic scintillator CALO, the 60 MeV electron reaches the LYSO layer. These simulations are based on Geant4 [7].

2.1 Status of the project

Four HEPD versions were built, as required by Chinese space procedures: the Electrical Model (EM), the Structural and Thermal Model (STM), the Qualification Model (QM), the Flight Model (FM). During Spring-Summer 2016 a test and qualification campaign was performed on the QM, to assess the compliance of the HEPD to the space operation requirements, and to study the detector performances. The campaign included: -a beam test, carried on at Beam Test Facility (BTF) of the "Laboratori Nazionali di Frascati" of INFN, with electrons in the 30-150 MeV energy range; -a full set of thermo-vacuum-vibrational tests, performed at SERMS laboratory in Terni. At the end of Summer the FM model was also integrated, and at the beginning of Fall a test campaign started on the FM.

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