Heliospheric and Magnetospheric Physics with the CSES/LIMADOU mission

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The China Seismo-Electromagnetic Satellite (CSES) has the purpose to measure electromagnetic wave emissions, plasma properties and particle fluxes in the Earth ionosphere and magnetosphere, to investigate the possible correlation with seismic events. Phenomena related to the solar-terrestrial interactions, such as Coronal Mass Ejections (CMEs), and the study of low-energy cosmic rays in the magnetosphere are also fundamental scientific issues of this mission. CSES, prepared by a Chinese-Italian collaboration, is scheduled to be launched in the first half of 2017 and has an expected lifetime of 5 years. The satellite will have a circular Sun-synchronous orbit with 98° inclination and 500 km altitude. A series of instruments will be used to investigate the many aspects of the electromagnetic environment: two magnetometers, an electric field detector, a plasma analyser, a Langmuir probe and the High-Energy Particle Detector (HEPD).The HEPD is built by the Italian collaborators. It includes a silicon tracker for the precision measurement of the particle pitch angle and a segmented (plastic scintillator and LYSO) calorimeter for the particle identification and the energy measurement. The HEPD will measure electrons and protons up to few hundreds of MeV, as well as light nuclei. A description of the HEPD and its characteristics are reported in this poster.

The CSES Mission

The China Seismo-Electromagnetic Satellite (CSES) [1] is a space mission dedicated to the monitoring of the perturbations originated by electromagnetic emissions in the atmosphere, ionosphere, magnetosphere and in the Van Allen belts. The satellite is based on the Chinese CAST2000 platform. It is a 3-axis attitude stabilized satellite and will be placed in a 98° inclination Sun-synchronous circular orbit, at an altitude of 500 km. The launch is scheduled for the first half of 2017 and the expected lifetime is 5 years.

CSES hosts several instruments on board:(i) a Search-Coil Magnetometer, a High Precision Magnetometer and Electric Field Detector for measuring the magnetic and electric fields; (ii) a Plasma Analyser Package and a Langmuir Probe for measurements of local plasma disturbances; (iii) a GNSS Occultation Receiver and a three frequency (VHF/UHF) Transmitter for the study of profile disturbance of plasma; (iv) the High-Energy Particle Package and High-Energy Particle Detector (HEPD) for the measurement of the flux and spectrum of energetic particles.

HEPD has a rich science program:

- measurement of electron and proton fluxes, within short time scale, as well as the precipitation of Inner Van Allen radiation belt particles, in view of seismic physics.
- cosmic ray measurements in an energy range up to few hundreds of MeV, below the one which has been studied so far by current cosmic ray space missions (PAMELA, AMS). The HEPD will contribute to the study of the solar-terrestrial environment (heliosphere and magnetosphere) and will be a fundamental instrument for the Space Weather.

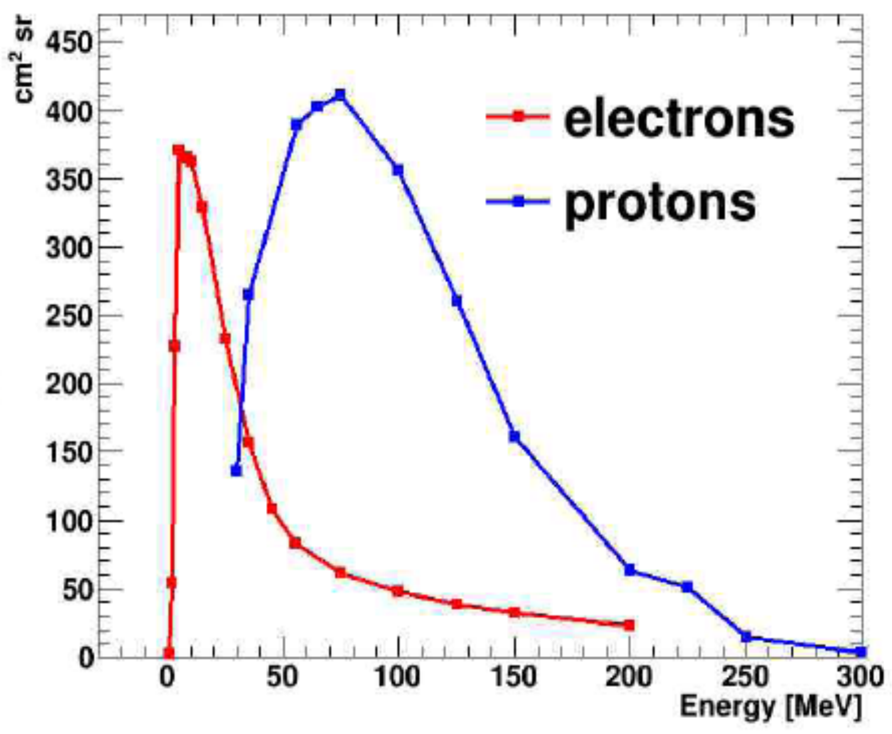
Earthquakes and Particle Bursts

Sudden increases of energetic electrons (E>MeV) count rates have been measured beneath the lower boundary of the inner radiation belt, with several instruments in the past . These changes in the electron flux can be originated by the interaction of the trapped electrons with low-frequency (ULF/ELF) e.m. waves. The interaction results in a modification of the particles pitch angle and a lowering of their mirror point, up to the particle precipitation into the atmosphere. These particle bursts have been observed also few hours before strong Earthquake. A major scientific topic of the mission is the search for a correlation between the seismic phenomena, which are potential sources of low-frequency (ULF/ELF) e.m. waves, and particle bursts. For a review of past studies see [2] .

Expected Performance

Preliminary estimates of the detector performance were obtained by a Monte Carlo simulation, which was developed with the Geant4 tool-kit. All the HEPD active components (silicon tracker, trigger planes, calorimeter and veto scintillators), the mechanical structure, the top HEPD box and the front satellite wall were included into the simulations. Then the detector response to electrons and protons was simulated. Five million particles were simulated at fixed energy bins (from 30 to 500 MeV for protons and from 1 to 200 MeV for electrons) and hundred million particles were generated according to a power law spectrum, originating from a large rectangular surface, above the satellite wall, and reaching the detector with an inclination between 0 and 90 degrees. We obtained estimates of the electron and proton operational range, of the energy and angular (pitch angle) resolutions. These are reported in Table 2 (see also [3] for details). The same data were also used to estimate the HEPD acceptance vs energy, both for electrons and protons (Fig. 2). The acceptance was studied as a function of the different trigger conditions which can be achieved by requiring a particle hit on one of the trigger scintillator segments, and on the counters at top of the calorimeter. The electron acceptance is one of the largest obtained so far with detectors for magnetosphere particles. Within the HEPD operational energy range, e.g. up to few hundreds of MeV per particle, is possible to exploit the dE vs E method to identify the particle type. With HEPD the dE can be obtained with the two layers of silicon tracker, while E, which is the total energy of the particle, can be measured with calorimeter for fully contained events. Estimates of proton contamination for selected electron samples are shown in Table 3.

Figure 2: Expected acceptance for electrons and protons [3].



Item	Value
Energy range (electrons)	3 MeV ± 200 MeV
Energy range (protons)	30 MeV ± 300 MeV
Angular resolution	8° at E ≥ 5 MeV
Energy resolution (electrons)	≤ 10% at E ∼ 5 MeV

Table 2: Monte Carlo simulation estimates of HEPD performance [3].

E [MeV]	p/e (90% cut)	p/e (95% cut)	p/e (99% cut)
2-3	$< 2.5 \cdot 10^{-5}$	$< 2.3 \cdot 10^{-5}$	$< 2.3 \cdot 10^{-5}$
5-6	$< 9 \cdot 10^{-5}$	$< 8 \cdot 10^{-5}$	$< 1 \cdot 10^{-4}$
6-10	$< 5 \cdot 10^{-5}$	$< 5 \cdot 10^{-5}$	$< 1 \cdot 10^{-4}$
10-15	$< 1.5 \cdot 10^{-4}$	$< 1.7 \cdot 10^{-4}$	$< 4 \cdot 10^{-4}$
15-40	$< 2.7 \cdot 10^{-4}$	$< 3.4 \cdot 10^{-4}$	$< 7 \cdot 10^{-3}$

Table 3: Proton contamination of selected electron samples, as a function of cut hardness [3].

The High Energy Particle Detector

The High-Energy Particle Detector (HEPD), developed by the Italian Collaboration, is aimed to measure electrons (3 to 100 MeV), protons (30 to 200 MeV) and light nuclei. The HPED mass is 35 kg, the power consumption lower than 38 W and mechanical dimensions (20x20x40) cm^3. The HEPD components are:

a **tracker**, made of two planes of double-side silicon micro-strip sensors, at the top of the instrument, to provide the direction of the incident particle;

the **trigger system**, e.g. two layers of plastic scintillators read by PMTs, an upper thin one divided into 6 segments;

a **calorimeter**, composed by 16 plastic scintillators (15x15x1)cm^3 and a layer (15x15x4)cm^3 of 9 LYSO cubes, all of which read by PMTs.

a scintillator **veto system**, 5 mm thick, at sides and at the bottom of the instrument;

the **power supply and electronics**, which are inserted in a box placed at one side of the detector.

The detector components can be seen in Fig 1.Three models (Electrical Model (EM), Structural and Thermal Model (STM) and Qualification Model (QM)) were built to assess the compliance of the HEPD characteristics to the space operation requirements.

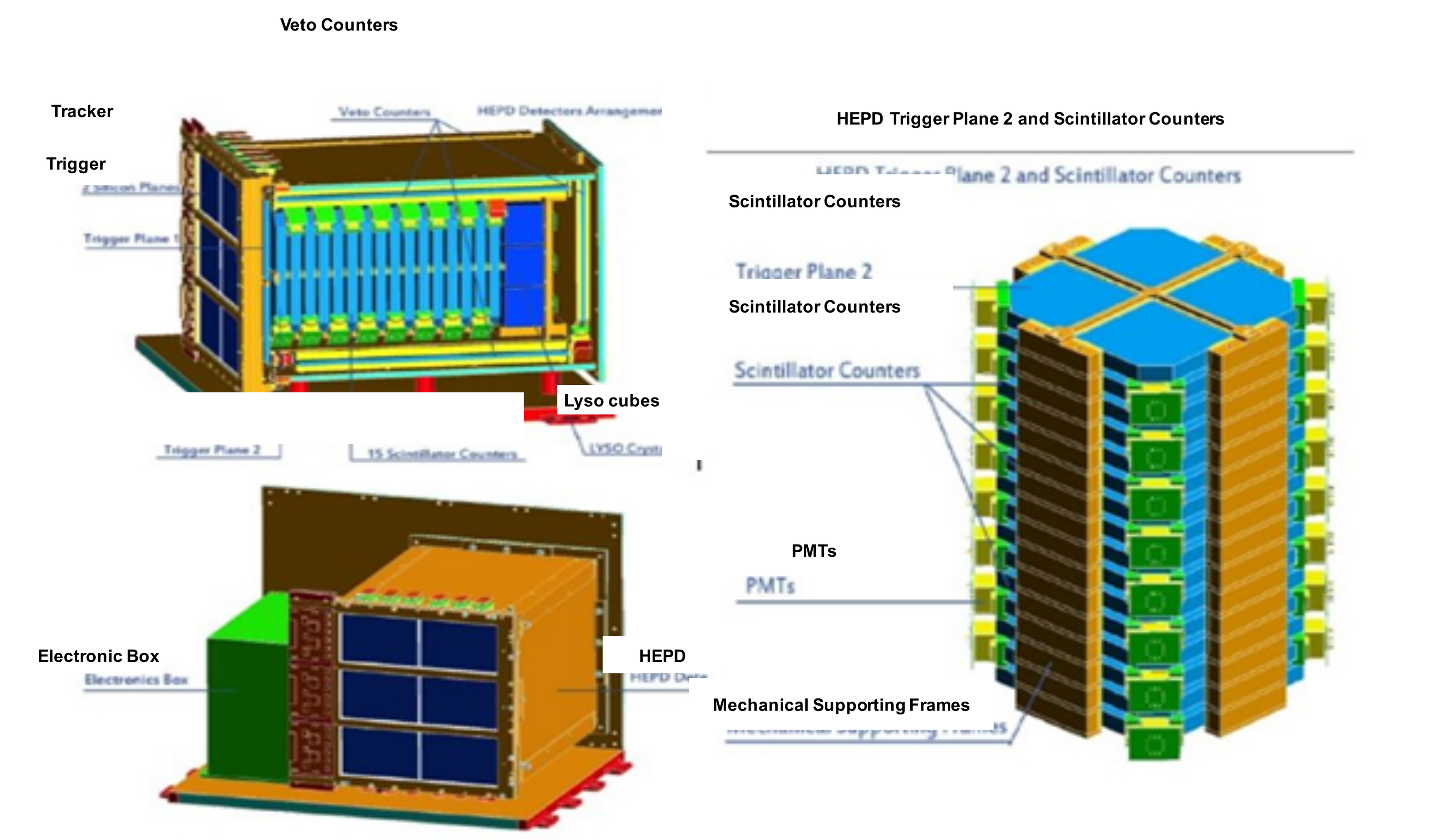


Figure 1. An illustration of the main components of HEPD. On the top a side view with the position of the sub-detectors; on the right the plastic counters of the calorimeter; bottom-left, HEPD, the electronic box and other structural Components.

Parameter	Value
Energy range	Electron: 3-100 MeV
	Proton: 30-200 MeV
Angular resolution	<8°@ 5 MeV
Energy resolution	<10% @ 5 MeV
Particle Identification	>90%
Maximum Omni-directional Flux	10^7 cm^{-2}s^{-1}sr^{-1} (accepted by trigger before pre-scaling)
Operating temperature	-10 °C - + 35 °C
Mass (including electronics)	< 43 kg
Power Consumption	< 43 W
Scientific Data Bus	RS-422
Data Handling Bus	CAN 2.0
Operation mode	Event by Event
Life span	> 5 Years

Table 1: Main design parameters of the HEPD.

Test and Qualification Campaign

During Spring 2016 a test and qualification campaign with the HEPD Qualification Model (QM, Figure 3) was started. It included a beam test, which was carried out at Beam Test Facility (BTF) of the "Laboratori Nazionali di Frascati" of INFN. The HEPD QM was irradiated with electrons and positrons from 30 to 150 MeV, in order to study the instrument response to electrons in the energy range of interest and to perform precise calibration of the calorimeter energy measurement for the QM. The beam test data are under analysis. Further tests were performed to assess the HEPD qualification to the space environment. These were performed at SERMS laboratory in Terni and consisted in exposing and operating the HEPD QM in thermal and vacuum conditions similar to those found in space environment.

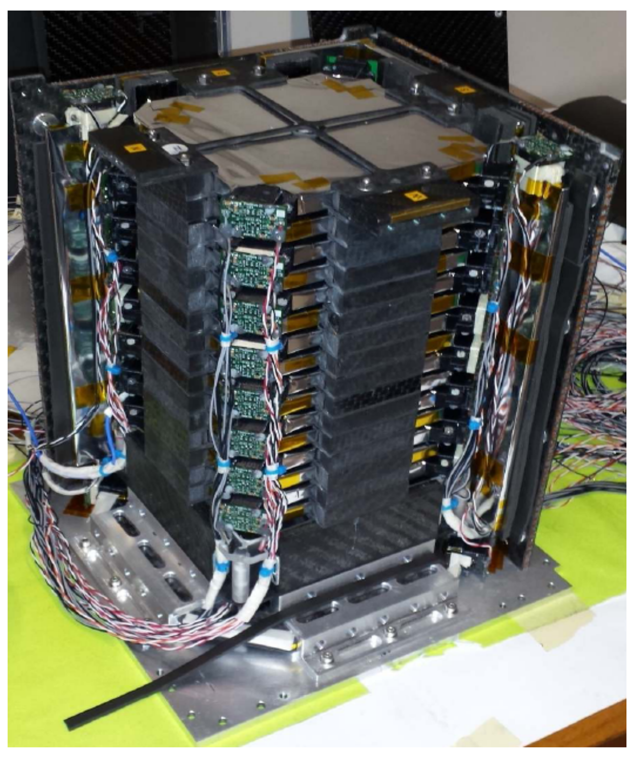


Figure 3: The HEPD Qualification Model.

References:

[1] X. Shen et al,Earthq Sci (2015) 28(4):303–310

[2] De Santis A. et al.,Physics and Chemistry of Earth 85-86(2015) 17-33

[3] Sparvoli R., for the CSES/HEPD Collaboration, proceedings to the 34th Int. Cosmic Ray Conference