Measurement of the Low-Energy Charged Particle Background with HEPD

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Abstract

Space borne gamma-ray telescopes are operated within a dominant background of charged particles, mainly primary Cosmic Rays and Earth albedo particles. Dedicated anti-coincidence devices and on-board rejection techniques are needed, to reject this background, as also the best available background models. The High-Energy Particle Detector (HEPD) is a space experiment for high-energy particles, which can identify electrons, protons and light nuclei, in the energy range from few MeV to many hundreds of MeV and measure their fluxes. It consists of a high precision silicon tracker, a versatile trigger system, a range-calorimeter and an anti-coincidence system and will fly on-board of the China Seismo-Electromagnetic Satellite (CSES). HEPD will extend PAMELA and the AMSII measurements to lower energies and characterize the orbital radiation environment, then providing very useful data for the future gamma-ray missions development, specially for the optimization of the on-board background rejection

Introduction

The High-Energy Particle Detector (HEPD) is a space experiment for high-energy particles (electrons from 3 to 100 MeV, protons from 30 to 300 MeV, light nuclei up to many hundreds of MeV/n). It reaches a geometrical acceptance of few hundreds cm^2 sr, relatively large for its class of instruments, despite the small dimensions (530 × 382 × 404 mm^3), a mass budget of 45 kg and a power consumption limited to 27 W. HEPD is one of the instruments to be flown with the Chinese Seismo-Electro-magnetic Satellite (CSES, see [1]), which main purposes are the study of the Low Earth Orbit (LEO) electromagnetic environment (ionosphere, magnetosphere and Van Allen belts), and the search for correlation between seismic events and electromagnetic observables. CSES will have a 98 degrees inclination Sun-synchronous circular orbit, with an altitude of 500 km and an expected lifetime is 5 of years (launch in late summer 2017). With HEPD several topics can be addressed: (i) searches for Geo-space anomalies related to powerful seismic events; (ii) study of the energetic solar particles; (iii) measurement of the low-end of the Galactic Cosmic Rays spectrum; (iv) characterization of the orbit radiation environment.

Charged Particle Background Model

A realistic model of the charged particle background is instrumental to develop and optimize the on-board background rejection for space-borne gamma-ray satellites. For the Fermi/LAT detector, which is operated between 20 MeV and 300 GeV, a similar background model was composed (see Figure 1 and ref. [2]). It included the most up to date measurements of protons, helium nuclei and electrons, from few tens of MeV up to many hundreds of GeV. It also had neutral secondaries such as the Earth albedo neutrons and gamma rays. The model used for the LAT was a stationary one, no time evolution or transients were considered. Furthermore its purpose is to reproduce the radioactive environment outside the the Van Allen belts and the South Atlantic Anomaly (SAA). Several different measurements were needed to build such a model in order to cover the large energy range of interest and the different particle types. In Table 1 are the measurements used for the Fermi/LAT particle background model. The HEPD detector will provide new and precise measurements from 10 MeV to few hundreds of MeV, for protons, electrons and light nuclei. Together with the steady fluxes HEPD will also provide time resolved measurements, because of its relatively large acceptance.

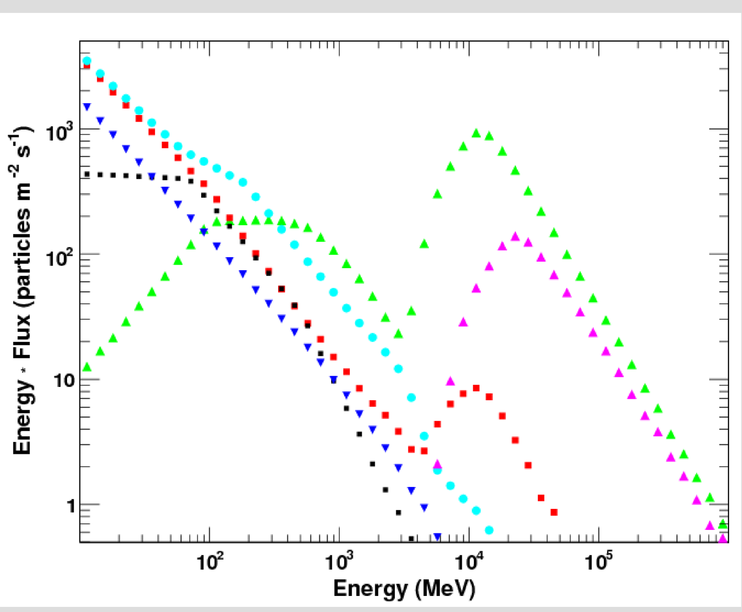

FIGURE 1.Fermi/LAT particle background model. Are shown protons (green triangles), He (purple triangles), electrons (red squares), positrons (blue squares), Earth albedo neutrons (black squares), and Earth albedo gamma-rays (dark blue triangles).

HEPD

The High-Energy Particle Detector is composed of the following sub detectors, arranged as shown in Figure 2: (i) tracker; (ii) trigger plane; (iii) range-calorimeter; (iv) veto system; (v) power-supply and electronics. **The Tracker** (TRK) is located on the top of HEPD and consists of two silicon detector planes (213x213 mm^2).Si detectors have 192 micron read-out (p and n) for a resultant resolution of 40-50 micron. The **Trigger System** (TS) covers the entrance of the detector. The TS consists of one thin plane of 6 counters (dimension 200×30×5 mm^3), dubbed bars, made of plastic scintillator EJ-200 and read out by PMTs Hamamatsu R9880U. The **Range-Calorimeter** (CALO) 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 150x150x10mm^3 , and is read out by two PMTs at two opposite corners. The lower calorimeter consists of a matrix of 3×3 crystals. Each crystal has dimensions 48×48×40 mm^3 and is read out by one PMT. located on the bottom face. The **Veto** detector consists of 5 plastic scintillator counters (four lateral and one at the bottom of the instrument) similar to those of the CALO. 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; - the Power Supply Subsystem (PWS), which is made with the Low Voltage Power Supply (LVPS) and High Voltage Power Supply (HVPS). The main HEPD design parameters are listed in Table 2. An estimate of the HEPD acceptance for electrons and protons was obtained with a MC study in [3] and is reported in Figure 3.

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 2. HEPD design parameters

	Energy range > local geomagnetic cutoff	150 MeV to geomagnetic cutoff	10 MeV – 150 MeV
Galactic Cosmic Rays			
protons + antiprotons	AMS		
electrons	AMS		
positrons	AMS		
He	AMS		
$Z > 2$ nuclei	HEAO–3		
Splash Albedo			
protons		AMS	Nina
electrons		AMS	Mariya
positrons		AMS	Mariya
Re-entrant Albedo			
protons		Nina	
electrons		Mariya	
positrons		Mariya	
Earth albedo γ-rays	10 MeV – 100 GeV, EGRET		
Neutrons	10 MeV – 1 TeV, various sources		

TABLE 1. An example of particle background model (the Fermi/LAT collab. [2]). Data sources are: AMS: Aguilar et al. (2002); Nina: Bidoli et al. (2002); Mariya: Voronov et al. (1991), Mikhailov et al. (2002); EGRET: Petry (2005); HEAO–3: Engelmann et al. (1990); neutrons: Selesnik et al. (2007), see also [2].

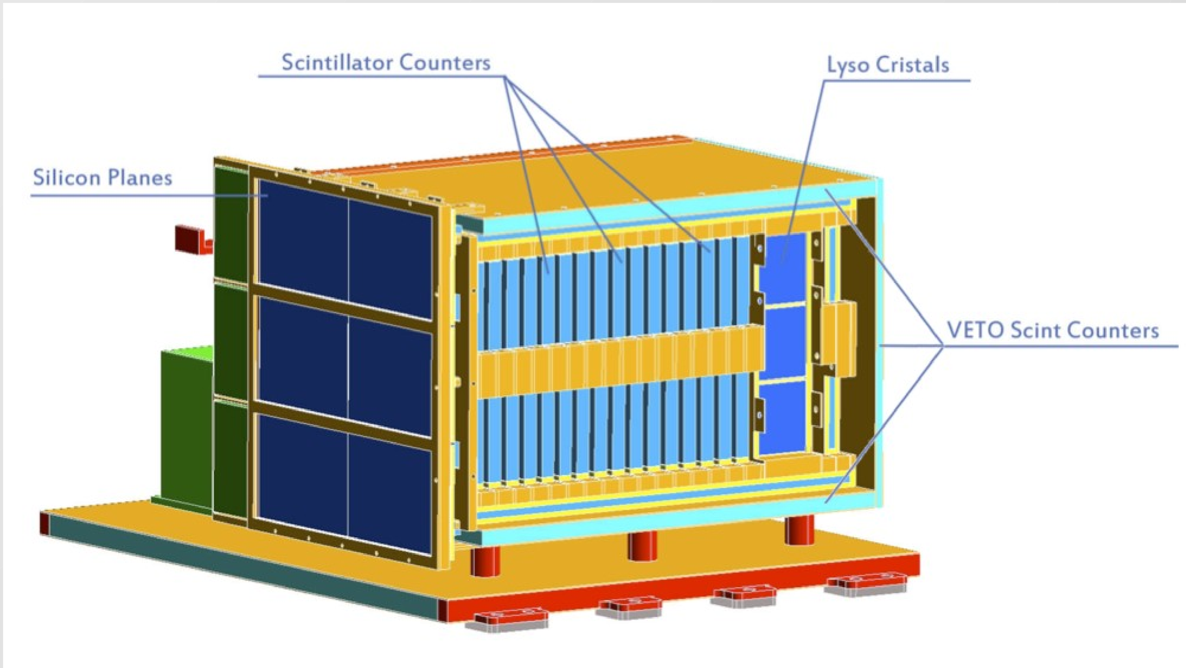

FIGURE 2. A schematic draw of the High-Energy Particle Detector:- in blue, the silicon tracker; - below the tracker there is the trigger plane (not seen here); - in light blue 16 plastic scintillators of the upper calorimeter; - on the right are visible three of the LYSO cubes of the lower calorimeter; - around the calorimeter three counters of the VETO can be seen; - in green the power supply and electronics.

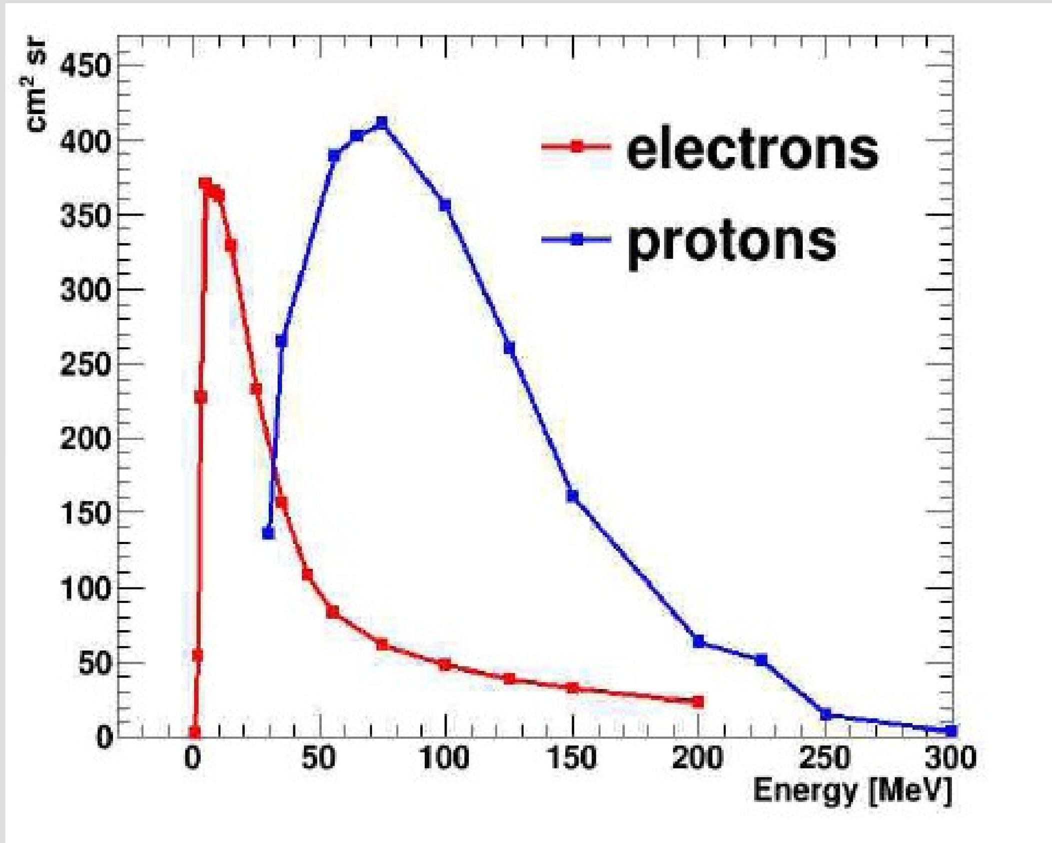

Figure 3: Expected acceptance for electrons and protons [3].

Outlook

At the end of summer 2016 the HEPD flight model (FM) was integrated. It underwent a comprehensive qualification and calibration campaign, which included: -several space qualification tests at SERMS laboratory in Terni, - an electron beam test, carried on at Beam Test Facility (BTF) of the "Laboratori Nazionali di Frascati" of INFN, with electrons in the 30-120 MeV energy range; -a proton beam test, carried on at the "Centro di Proton Terapia" of Trento APPS, with protons from 37 to 228 MeV. Since beginning of 2017 an important effort is ongoing to prepare the reduction and analysis software, as also to perform the analysis of the collected beam test data. HEPD is scheduled to be launched during early 2018 and ready to start operations.

References:
[1] X. Shen et al,Earthq Sci (2015) 28(4):303–310
[2] Atwood W.B., et al, 2009, ApJ 697, 1071
[3] Sparvoli R., for the CSES/HEPD Collab., proceedings 34th ICRC