The new High Energy Particle Detector (HEPD-02) on board the CSES-02 satellite

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Summary. — The China Seismo-Electromagnetic Satellite (CSES) is a multi-payload space observatory aimed at monitoring the near-Earth environment through the observation of the Van Allen Belts dynamics, the study of solar-terrestrial interactions and the extension at low energies of Cosmic Ray measurements. The first satellite (CSES-01) has been in orbit since February 2018, hosting on board the High Energy Particle Detector (HEPD-01) developed by the Italian LIMADOU collaboration. The launch of the second satellite (CSES-02) is expected at the end of 2024. It will carry HEPD-02, a new high-energy particle detector optimized to detect charged particles, mostly electrons in the 3-100 MeV energy range and protons between 30 and 200 MeV, with good capabilities for identifying light nuclei and detecting Gamma Ray Bursts. The instrument is quite compact (40.36 cm $\times$ 53.00 cm $\times$ 38.15 cm) and presents important upgrades with respect to its predecessor. It will be the first instrument in space carrying a CMOS pixel tracker designed to achieve 5-micron resolution; and the largest LYSO crystals (15.0 cm $\times$ 4.9 cm $\times$ 2.5 cm) ever used, as part of the electromagnetic calorimeter. This contribution provides a synthetic description of the HEPD-02 detector on board the CSES-02 mission and summarizes its main characteristics and performance.

1. – Introduction

The China Seismo-Electromagnetic Satellite (CSES) is a space program in collaboration between China and Italy aimed at monitoring the near-Earth environment with the purpose of correlating perturbations observed in the ionosphere and magnetosphere with strong seismic events [1, 2]. The first satellite CSES-01, was launched in February 2018 and is currently taking data. A second satellite CSES-02 will be launched at the end of 2024. It will fly in the same orbital plane as CSES-01 with a 180° phase shift allowing a multi-satellite approach.

Among the instruments hosted by both satellites is a High Energy Particle Detector (HEPD) developed by the Italian collaboration LIMADOU. It is able to measure the flux of electrons in the energy range between 3 MeV to 100 MeV, and protons and nuclei in

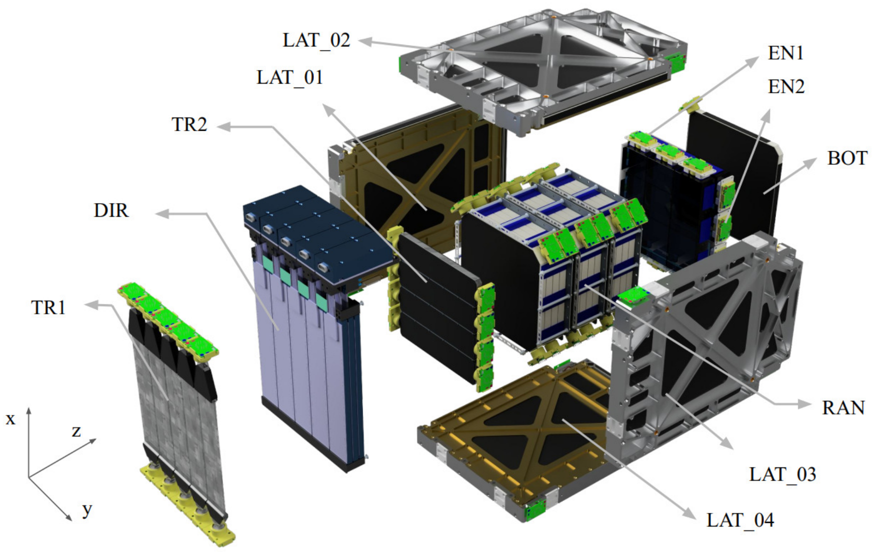

Fig. 1. – An exploded view of the HEPD-02 detector, from left to right: the two trigger planes (TR1 and TR2) with the direction detector (DIR) in between, the plastic scintillators tower (RAN), the two LYSO crystal planes (EN) and the bottom containment panel (BOT). The system is surrounded by four lateral containment panels (LAT).

the energy range between 30 and 200 MeV/nucleon. It is dedicated to look for particles precipitating from the Van Allen belts (i.e. sudden increases in the particle counts), and to study possible correlations with solar or terrestrial phenomena. HEPD-01, on board CSES-01, already demonstrated its capability in characterizing the radiation environment around the Earth, such as, the trapped component in the South Atlantic Anomaly [3], the proton component of galactic cosmic rays [4, 5] and also in the detection of Solar Energetic Particles [6], and Gamma-Ray Bursts (GRBs) [7].

The new HEPD-02 detector on board the CSES-02 mission introduces two main innovations ever used in a space-based experiment: (i) Monolithic Active Pixel Sensors (MAPS) for particle tracking [8], and (ii) the largest ever employed LYSO (Lutetium Yttrium Oxyorthosilicate doped with Cerium) crystals (15.0 cm × 4.9 cm × 2.5 cm). In this paper, a brief description of HEPD-02 is provided, focusing on its innovative design and performance.

2. – The High Energy Particle Detector

The High Energy Particle Detector (HEPD-02) is mainly composed of two trigger planes, a tracking system and a calorimeter tower combining plastic and crystal scintillators. A detailed view of the instrument is displayed in Fig. 1, from left to right, are shown:

- **Trigger Detector, TR1**: consisting of five 2-mm thick, plastic scintillator counters of 32×154 mm^2 coupled at both ends to flat, 6-mm thick, light guides ensuring a correct coupling to the PMT active areas.

- **Direction Detector, DIR**: made of five standalone tracking modules, each composed of three layers of MAPS [8] of total dimensions of 150×150 mm^2.
- **Trigger Detector, TR2**: the second trigger plane is composed of four 8-mm thick plastic scintillators, with dimensions 36×150 mm^2, orthogonal to TR1 counters.
- **Range Detector (RAN)**: made of a tower of twelve 10-mm thick plastic scintillators with dimension 150×150 mm^2.
- **Energy Detector (EN)**: composed of two orthogonal layers, EN1 and EN2, of three 25-mm thick LYSO crystals of 49×150 mm^2.
- **Containment Detector**: made of five 8-mm thick plastic scintillator panels enclosing the detection volume. They allow to reject particles not completely absorbed into the calorimeter or entering from the side.

The plastic scintillators are made of EJ-200. All scintillators are wrapped in aluminized Mylar and coupled to two Hamamatsu R9880U-210 Photomultipliers (PMTs), on the opposite sides. The details on the detector design can be found in [9].

Two models of HEPD-02, a Flight Model (FM) and a Qualification Model (QM), were developed. Both models were fully characterized in the laboratory using cosmic muons and during test beam campaigns at beam facilities. They also successfully passed all qualification tests in compliance with space requirements.

3. – The Tracker System

The design of a tracker system for a space-borne experiment is challenging due to the need for low power consumption, good thermal control, and mechanical stability, along with low material budget and high spatial resolution. The LIMADOU collaboration worked on developing a tracking system for HEPD-02 that combines all of these requirements. It is based on 5 independent modules, each one with three sensitive layers, hosting 10 ALTAI sensors containing 512×1024 rectangular pixels. The pixel dimensions are $29.24 \times 26.88\,\mu\text{m}^2$. A picture of the tracking system integrated into its mechanical structure is shown in Fig. 2. The tracker system was fully tested and characterized in the laboratory. It was found to achieve better than $\sim 5\mu$m spatial resolution. The derived angular resolution at low energies, estimated from simulations, is around 10° for electrons and $\sim 1^\circ$ for protons [10], as shown in Fig. 3. More details on the tracker assembly and performance can be found in [8] and [11].

4. – The Energy Detector

HEPD-02 Energy Detector subsystem includes two layers composed of 3 bars of large dimension crystals (15.0 cm $\times$ 4.9 cm $\times$ 2.5 cm) made of LYSO ($Lu_{2(1-x)}Y_{2x}SiO_5$:Ce). These crystals are characterized by a high density ($7.1\,\text{g/cm}^3$) and a very high light yield ($> 3 \times 10^4$ photons/MeV). The detector material budget in terms of energy release amounts to $4X_0$. Each bar is wrapped in aluminized Mylar, and light is collected from opposite ends along the longest dimension by R9880U-210 Hamamatsu PMTs, ensuring good uniformity and efficiency in triggering. By combining the energy detector with the range detector, the HEPD-02 achieves an energy resolution better than 10% and can reach less than 5% at the highest energies. Finally, the use of LYSO crystals allows for excellent energy measurements with good linearity and capabilities in GRB detection [12, 13]. In

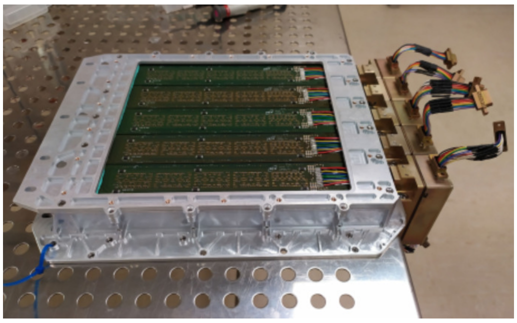

Fig. 2. – A picture of the HEPD-02 tracker system.

Fig. 4, the total effective area on-axis for gamma detection of HEPD-02 is compared to other experiments. It can be seen that the module made of LYSO crystals, and its relative acquisition system, will be sensitive to GRBs of energies larger than 2 MeV up to ~ 500 of MeV.

5. – Conclusions

The HEPD-02 is the first space-borne experiment with a tracking system hosting a MAPS technology and large LYSO crystals. The use of MAPS allows the reconstruction of tracks with an angular resolution better than $10°$ for electrons and $1°$ for protons. The use of LYSO crystals of unprecedented dimensions in space opens new perspectives in detecting GRBs with energies ranging from 2 to hundreds of MeV. The calibration and performance of the subsystems were studied with cosmic muons, and with electrons, protons, and ion beams at the beam test facilities. The two models, FM and QM, realized were fully characterized and passed all space qualification tests. The FM is now integrated into the CSES-02 satellite, scheduled for launch at the end of 2024.

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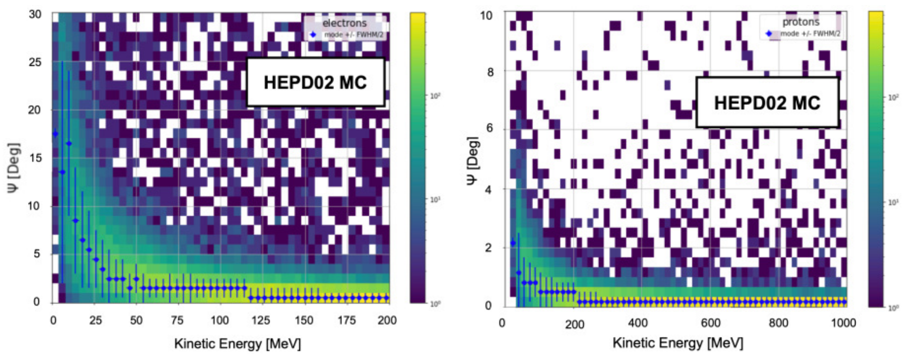

Fig. 3. – The angular resolution for electrons (left) and protons (right) as a function of the kinetic energy of the incoming particle as given from simulation (courtesy F. Follega [10]).

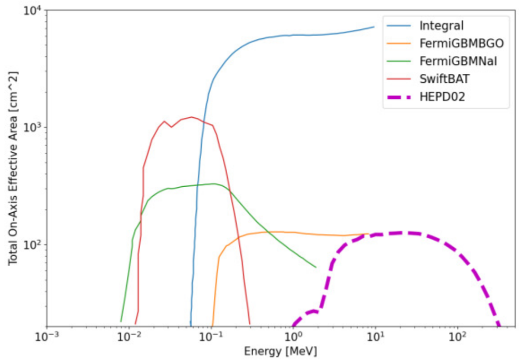

Fig. 4. – The total effective area on-axis for gamma detection (courtesy F. Follega [10]).

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REFERENCES

[1] Shen X. *et al.*, *Sci. China Tech. Sci.*, **61** (2018) 634.
[2] Picozza P. *et al.*, *Astrophys. J. Supp. Ser.*, **243** (2019) 16.
[3] Martucci M. *et al.*, *Applied Sciences*, **11(8)** (2021) 3465.
[4] Bartocci S. *et al.*, *Astrophys. J.*, **901** (2020) 8.
[5] Martucci M. *et al.*, *Astrophys. J. Letters*, **945** (2023) L39.
[6] Martucci M. *et al.*, *Space Weather*, **21** (2023) 1.
[7] Palma F. *et al.*, *Astrophys. J.*, **960** (2024) 21.
[8] Ricci E. *et al.*, *Proc. of the 38th Int. Cosmic Ray Conf.*, **PoS ICRC2023** (2023) 058.
[9] De Santis C. *et al.*, *Proc. of the 37th Int. Cosmic Ray Conf.*, **PoS ICRC2021** (2021) 058.
[10] Follega F. *et al.*, *Proc. of the 38th Int. Cosmic Ray Conf.*, **PoS ICRC2023** (2023) 116.
[11] Iuppa R. *et al.*, *Proc. of the 37th Int. Cosmic Ray Conf.*, **PoS ICRC2021** (2021) 070.
[12] Lega A. *et al.*, *Proc. of the 38th Int. Cosmic Ray Conf.*, **PoS ICRC2023** (2023) 758.
[13] Lega A. *et al.*, *Il Nuovo Cimento C*, **46** (2023) 118.