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# The High Energy Particle Detector ready to fly onboard CSES-02

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**Abstract.** The China Seismo-Electromagnetic Satellite (CSES) space mission foresees a constellation of satellites devoted to the study of plasma, electromagnetic fields and particles perturbations potentially correlated with the occurrence of seismic events. Like the first satellite, launched in February 2018, CSES-02 hosts several payloads, among which the Italian High Energy Particle Detector (HEPD-02), with major improvements with respect to the first one. Key upgrades include the Control & Housekeeping system, with increased detector configurability and active monitoring, the advanced Trigger system, providing trigger prescaling and concurrent trigger configurations, and gamma rays detection capabilities in the 2–20 MeV range.
HEPD-02, after a large test campaign for the space qualification and calibration, has been installed on satellite with the other payloads and has currently undergone the tests at satellite level before launch, foreseen for 2025. In this contribution the instrument, with its improved design, and the test campaign are described.

## 1 Introduction

The China Seismo-Electromagnetic Satellite (CSES) space mission aims to study, by means of a constellation of satellites, the electromagnetic, plasma and particles perturbations of atmosphere, ionosphere, magnetosphere and Van Allen belts, with special focus on potential correlation with the occurrence of seismic events [1]. The first satellite was launched on February $2^{nd}$, 2018 from the Jiuquan Satellite Launch Center (Inner Mongolia, China), while the second one (CSES-02) will be launched in 2025. Both satellites, based on the same Chinese CAST2000 platform, have a sun-synchronous orbit at an altitude 507 km with $97.4^o$ inclination and $180^o$ phase difference, with the second one operating along the full orbit. Like the first satellite, CSES-02 hosts several payloads, among which the High-Energy Particle Detector (HEPD-02), developed and integrated at Clean rooms of INFN Roma Tor Vergata by the Italian CSES-Limadou collaboration, devoted to the observations of electrons and protons in the range 3-100 MeV and 30-200 MeV, respectively. The HEPD-02 instrument and its main improvements with respect to its predecessor are described in §2, while the test campaign for space qualification and calibration is given in §3.

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## 2 HEPD-02 instrument

The HEPD-02 (Fig.1) is designed to identify and measure energy and direction of electrons and protons crossing the instrument.

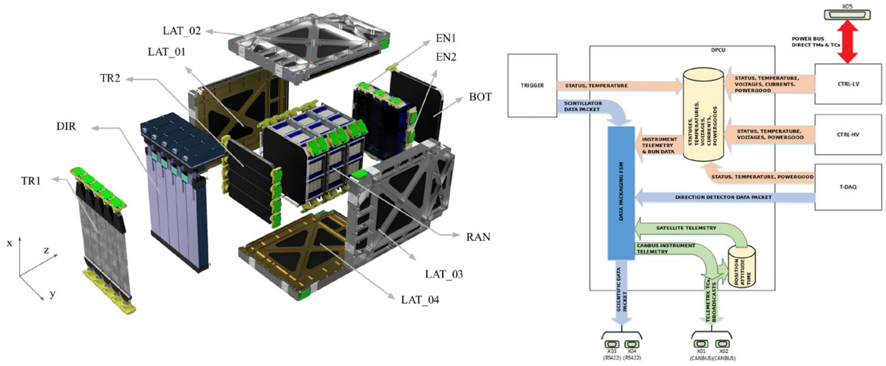


**Figure 1.** HEPD-02 detector subsystems (left): the 2 layers of the Trigger Detector (TR1, TR2) enclosing the 5 turrets of the Direction Detector (DIR), the calorimeter plastic scintillator counters (RAN) and LYSO layers (EN1, EN2) and the Lateral and Bottom counters (LAT, BOT) surrounding the calorimeter, are shown. Schematics of HEPD-02 electronics and power supply subsystems (right): communication between the boards and toward the satellite are shown.

The Direction Detector (DIR), one of the innovation of HEPD-02, is based on Monolithic Active Pixel Sensors (ALTAI CMOS pixel chip) [3], a challenge for space application due to power budget, heat dissipation and mechanical issues, providing improved tracking resolution (4 $\mu m$ single-hit resolution). It consists of 5 independent turrets, each one made of 3 planes, which sensitive area is composed by 10 ALTAI chips controlled and read-out by means of an ultra-thin (180 $\mu m$) flexible printed circuits.
The Trigger system [2] makes use of the Trigger Detector, 2 crossed layers of plastic scintillator counters enclosing the Direction Detector; the first plane (TR1), segmented in 5 counters matching the DIR turrets, is 2 *mm* thick to minimize multiple scattering, while the second one (TR2), segmented orthogonally in 4 bars, is 8 *mm* thick in order to provide good measurement of the energy loss of charged particles and particle discrimination.
Energy measurements are provided by the calorimeter, a tower of 12 plastic scintillator counters 10 *mm* thick (RAN) followed by 2 crossed layers of LYSO inorganic scintillator (EN), each one segmented in 3 bars (25 *mm* thick), enlarging the dynamic range of the Calorimeter and exploited for gamma detection (§2.2). Four 8 *mm* thick lateral scintillator planes (LAT), surrounding the calorimeter up to TR2, and a bottom one (BOT) provides the Veto system.
Each plastic scintillator (EJ-200) and LYSO counter is read-out by two PMTs R9880U-210 Hamamatsu placed at opposite sides.

The electronic subsystem (ELS) (Fig.1) comprises all front-end electronics and 3 boards: the T-DAQ board, responsible for Direction Detector (Tracker) data acquisition, the TRIGGER board, responsible for PMT data acquisition and Trigger generation, and the Data Processing and Control Unit (DPCU) board, responsible for the whole management of the detector and for Data and Satellite Communications.

All the voltages required by HEPD-02 are provided by the Low/High Voltage Power Supply (LV/HV-PS), consisting of DC/DC converters and relative Control boards (LV-CTRL and HV-CTRL) for low voltages generation and distribution to ELS and DIR turrets and for PMTs bias, respectively.

### 2.1 Control & Housekeeping System

The DPCU board is in charge of the control and monitoring of the whole apparatus, of data acquisition and transmission via RS422 link and of communication with the satellite via CAN Bus link. Communication with other boards, for both housekeeping and configuration purposes and scientific data acquisition, makes use of the SpaceWire Light connections. The DPCU manages the detector power-on and the automatic execution of scientific data acquisition: depending on the orbital position (provided by the regular satellite broadcasts) and on its internal run scheduler, the DPCU configures and executes automatically calibration or event acquisitions. During the power-on phase and following operations, the complete detector status is monitored and reported periodically by the Control & Housekeeping system within Scientific data and partially in the Telemetry data via CAN Bus link. Several independently disableable diagnostic routines are implemented in order to monitor ELS and PS statuses, temperatures, power-goods, voltages and currents monitors; the diagnostics recognizes an anomalous behavior and reports the subsystem involved, the error type and its severity. Depending on the specific case, an automatic action is undertaken to restore the correct working; in case of an unrecoverable error precluding acquisition, all subsystems are powered-off, except of LVPS and DPCU board, and Internal Status Error is asserted towards the satellite waiting for external actions.

### 2.2 Trigger System & Gamma-Ray Detection

The HEPD-02 Trigger System makes use of different logic combinations of signals from scintillator counters to form 9 predefined trigger configurations (called Trigger Masks) which can be selected during the flight. For the event trigger generation the system has been improved allowing to use up to 6 trigger masks in concurrence, 4 of which with configurable prescaling factors; the Trigger Masks are optimized on the nature of particles impinging in HEPD-02 with prescaling settings suitably adjusted along the orbit according to the expected flux, the amount of processable data and the available satellite data budget. Setting the concurrent trigger patterns and relative prescaling factors for each one of the 128 orbital zones defined on DPCU board allows HEPD-02 to measure efficiently the different population dominating different zones (re-entrant and cosmic protons, trapped electrons and protons, etc).

Among the predefined trigger masks, two dedicated trigger configurations, exploiting signals from LYSO crystals and plastic scintillator planes in a NOT logic, and relative counters (200 Hz resolution), have been specifically designed to extend HEPD-02 trigger capability to Gamma Ray Burst (GRB) detection in the 2-20 MeV energy range (with a similar effective area of the Fermi Gamma-Ray satellite). The GRB algorithm, implemented on DPCU board, uses those counters to evaluate the average counts and to trigger the GRB detection when the counters, summed over different time intervals, significantly deviate from it. Once triggered, the DPCU board collects the GRB counters and event data until the trigger condition is not longer satisfied. The GRB detection can be enabled independently in each orbital zone in order to avoid gamma ray acquisition in those zones, such as South Atlantic Anomaly and polar zones, where spurious signals could activate the acquisition at the expense of charged particle detection and available data budget.

## 3 Test Campaign and Status

For the CSES mission, two identical models of HEPD-02 have been constructed, the Qualification model (QM) and the Flight Model (FM), which have been subjected to an extensive test campaign for Qualification and Acceptance, respectively, with the former one requiring extreme stress conditions in order to assess its compliance with space requirements. The pyroshock tests were conducted only on HEPD-02 QM, exposing it to pyrotechnic shocks with a shock frequency ranging from 600 to 4000 Hz and an acceleration up to 1000 g along its 3 directions, while both models underwent vibrations, thermal cycling and Thermal vacuum tests. For Vibration tests, sinusoidal and random vibration tests were performed along the 3 axes in the frequency range from 20 to 100 Hz corresponding to a 12g/8g acceleration (QM/FM) and from 10 to 2000 Hz, respectively. The operational temperature range requirement ($-10\,^oC\ \div\ +35\,^oC$) was successfully tested in thermal and thermal vacuum chambers with temperature cycles at ambient pressure and at pressure $< 6.65 \times 10^{-3}\ Pa$ in the range $-30\,^oC \div +50\,^oC/-20\,^oC \div +45\,^oC$ (QM/FM).

Besides the environmental tests, conducted successfully at SERMS Laboratory in Terni, the HEPD-02 FM has been subject to a test beam campaign in order to characterize the detector response and to verify the required performances. Protons and electrons beams were exploited for energy calibration and to assess and characterize the particle detection and discrimination performances, while detection of light ions and gamma rays has been tested with Carbon nuclei and X-rays.
After the test campaign, HEPD-02 FM has been shipped to China and installed on the satellite on January $10^{th}$, 2024; from January to September 2024 it underwent test at satellite level, functional tests and environmental tests similar to the acceptance tests. The satellite is now ready to be transferred to the Jiuquan Satellite Launch Center for the last tests before launch, foreseen for 2025.

## 4 Conclusion

The High Energy Particle Detector (HEPD-02) for the second China Seismo-Electromagnetic Satellite has been developed and integrated with some improvements with respect to the first one: the Direction Detector, the first silicon-pixel tracker ever designed for space, the Control & Housekeeping System, with its active diagnostics, the Trigger System, with its concurrent trigger configurations and prescaling capability, and the sensitivity to gamma rays.
After an extensive test campaign for Qualification and Acceptance, HEPD-02 has been installed on satellite and successfully tested at satellite level. CSES-02 will be launched in 2025 from Jiuquan Satellite Launch Center.

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