PROCEEDINGS OF SCIENCE

The PMT acquisition and trigger generation system of the HEPD-02 calorimeter for the CSES-02 satellite.

Marco Mese,[a,b,*] **Antonio Anastasio,**[b] **Alfonso Boiano,**[b] **Vincenzo Masone,**[b] **Giuseppe Osteria,**[b] **Francesco Perfetto,**[b] **Beatrice Panico,**[b] **Valentina Scotti**[a,b] **and Antonio Vanzanella**[b] **on behalf of the CSES-Limadou collaboration**

[a] *University of Naples Federico II, Department of Physics, via Cintia 21, Naples, Italy*
[b] *National Institute for Nuclear Physics (INFN), via Cintia 21, Naples, Italy*

E-mail: marco.mese@unina.it, mese@na.infn.it

The HEPD-02 calorimeter, realized by the Italian collaboration for the CSES-02 mission, will be equipped with a redesigned electronic board for the acquisition and digitization of signals from the PMTs and the generation of the trigger signal for the detector.
The board represents an improvement of the previous version used for HEPD-01, onboard of the CSES-01 satellite. The enhancements include the utilization of a new generation ASIC (CITIROC) for the amplification, shaping and memorization of signals from PMTs.
The new ASIC features several improvements, including the peak detection mode, which optimizes the acquisition of signals with different temporal characteristics, such those produced by plastic scintillators and LYSO.
In addition to this, additional features will be implemented: trigger prescaling, concurrent trigger masks and Gamma Ray Burst detection.
Using prescaled concurrent triggers, it will be possible to use different masks per orbital zone at the same time, avoiding the saturation of the available bandwidth.
Concurrent triggers will also be used for the detection of rare events (such as GRBs) while monitoring particle bursts.
In this contribution, I will present the progress status of this work and the measurements and tests made to finalize the Flight Model of the board.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

*Speaker

PoS(ICRC2023)111

1. The CSES-Limadou mission

The CSES (China Seismo-Electromagnetic Satellite) space mission is dedicated to study the upper ionosphere and its interaction with seismic events [1].

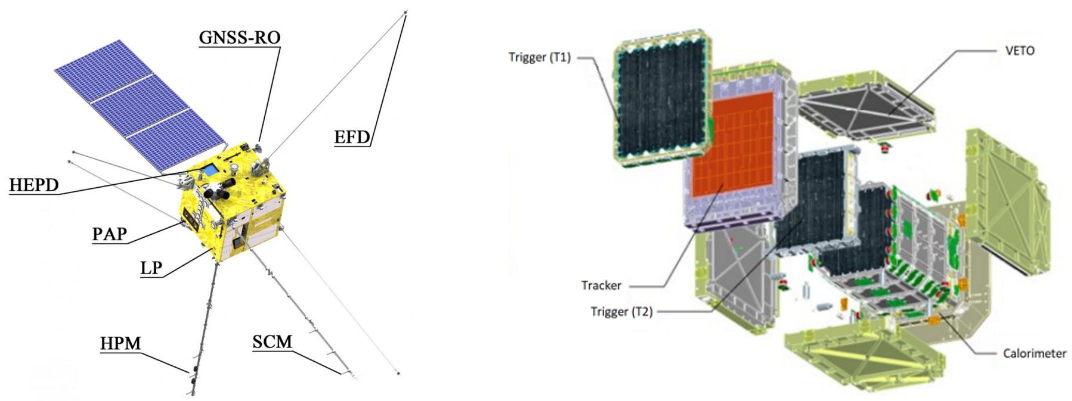
This mission is part of the Limadou project: a collaboration between the China National Space Administration (CNSA) and the Italian Space Agency (ASI) and foresees the realization of a constellation of satellites, which will monitor variations in ionospheric parameters that are supposed to be related to earthquakes.

The CSES satellites will be equipped with various instruments used for the following measurements:

- the electric and magnetic field components;
- the plasma composition and density;
- the plasma total electron content;
- the flux of particles precipitating from Van Allen belts and their energies.

The first satellite (CSES-01) is in orbit since February 2nd 2018 and obtained various results in the field of earthquake observation and in the study of cosmic rays [2].

The CSES-02 satellite will be launched in early 2024 and the detectors on board will feature several improvements. The second model of the High Energy Particle Detector (HEPD-02) [3] and the Electric Field Detector (EFD-02) will be entirely developed by the italian collaboration.



(a) Rendering of the CSES-02 satellite

(b) HEPD-02 structure

Figure 1

2. The High-Energy Particle Detector (HEPD-02)

The HEPD-02 energetic ranges will be slightly different from HEPD-01: for electrons will be 30 to 200 MeV and for protons 3 to 100 MeV.

The redesigned detector presents an improved structure to detect very low-energy particles and provide segmentation for additional information on the particle trajectory.

The structure is showed in figure 1b and described below:

- the **trigger system** is composed by two segmented planes of plastic scintillator (EJ-200), surrounding the tracker system. The segments of the first plane are arranged perpendicularly with respect to the segments of the second plane;
- the **tracker system** is composed by five segments of three overlapping layers of MAP sensors (ALTAI);
- the **range calorimeter** is made by twelve planes of plastic scintillator, followed by two segmented planes of inorganic scintillator (LYSO);
- the **veto system** is realized by five planes of plastic scintillator surrounding the whole calorimeter.

Two photomultiplier tubes (PMTs) are coupled with each scintillator for a total of 64 PMTs.

3. Electronics architecture

The electronics of the detector is composed by five main boards [4][5]:

- the **PMT acquisition and trigger generation system** (TRIG), that acquires and digitizes signals from PMTs and produces the trigger signal for the detector [8];
- the **Tracker Data Acquisition** board (TDAQ), that acquires data from the tracker [6];
- the **Data Processing and Control Unit** board (DPCU) that collects data from the TDAQ and the trigger board and communicates with the satellite [7];
- the **High Voltage Control** board (HV-CTRL), that controls the power supply for the PMTs;
- the **Low Voltage Control** board (LV-CTRL), that controls the power supply required by the boards.

The communication between the boards is made by SpaceWire protocol. The communication between the satellite and the DPCU is made by CANBUS and RS-422 protocols.

All the boards follows design requirements that ensure low power consumption, passive heat dissipation, radiation hardeness and redundant design. The redundancy consists in the realization, for each board, of two identical and independent sections: if a critical failure occurs on the active section of the card (HOT), it is possible to disable it to use the second one (COLD).

4. The PMT acquisition and trigger generation system

The PMT readout and trigger system is based on CITIROC read-out integrated circuits by Weeroc and on Microsemi A3PE3000L FPGA and its operation is described in figure 2.

The signals from the detector are collected from the last PMT's dynodes, in such a way as to match the input polarity of CITIROCs and avoiding the use of inverters, effectively reducing the consumption of the board.

A stage of attenuators, made of resistive voltage dividers, are also used to adapt the input range of the CITIROCs, in order to exploit the full dynamics of the ASIC.

CITIROCs have 2 independent preamplifiers:

- the **High Gain** preamplifier can be configured with gain from 10 to 600

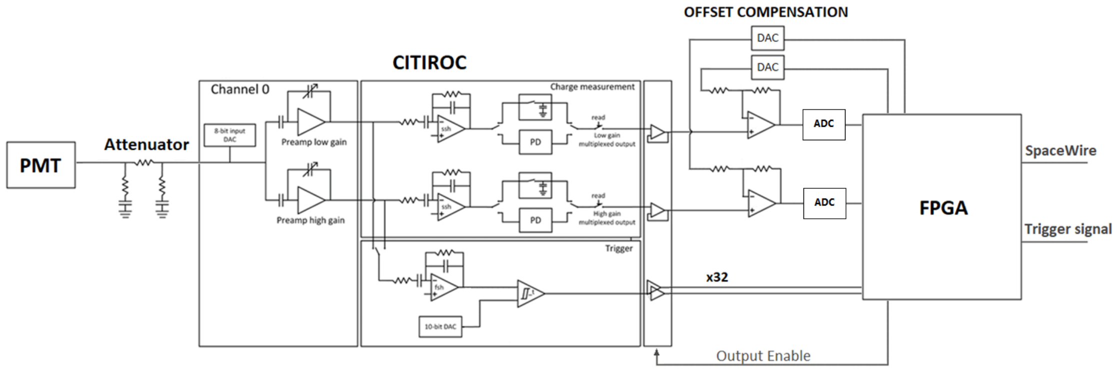


Figure 2: Operation of the trigger and PMT readout board

- the **Low Gain** with gain from 1 to 60

This ensures a wide dynamical range, required for the acquisition of signals from different type of scintillators, produced by particles in a wide energy range.

Each preamplifier is connected to a shaper with a configurable shaping time that goes from 12.5 to 87.5 ns with steps of 12.5 ns. The shaper outputs are connected to an analog memory circuit that can be used in Track&Hold mode or Peak Detection mode.

Trigger signals for the 32 channels of the CITIROC are generated by a fast shaper and a discriminator with configurable threshold.

The trigger signals produced by the CITIROCs are acquired by the FPGA, which produces a global trigger if logic conditions, called “trigger masks”, are met.

The global trigger signal enables the CITIROCs analogue outputs and starts the ADC conversion and is also sent to the TDAQ to start the tracker acquisition.

5. Scientific data and boards interwork

The ADC values produced by the board, are stored in a FIFO along with counters and other data used for the reconstruction of the event.

The interwork with the other boards is depicted in the timing diagram of figure 3 and described below:

- when a trigger occurs, the data produced by the trigger board are stored in a FIFO. The trigger signal is also sent to the TDAQ to start its acquisition;
- if the BUSY signal from the DPCU is not asserted, the first packet in the FIFO is written in a series of SpaceWire registers;
- the total length of the data itself is stored in a separate register (DATALEN);
- a DATA_READY signal is asserted by the trigger board;
- when the DATA_READY is asserted, the DPCU reads the DATALEN register and starts the reading of all the data registers;
- the DATALEN register is erased by the DPCU;

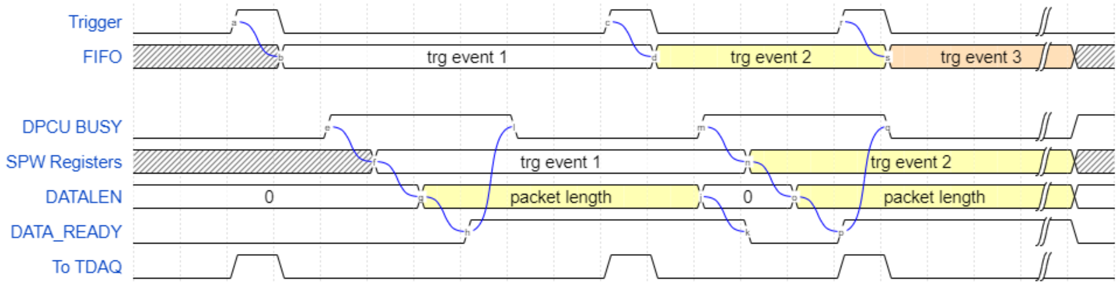


Figure 3: HEPD-02 boards interwork

- when the BUSY signal is deasserted, the next packet in the FIFO (if present) is moved to SpaceWire registers.

6. Trigger masks

The PMT readout and trigger system implements three classes of trigger masks:

- **Event acquisition** masks, that validate the acquisition of the event;
- **Event monitor** masks, which provide information about the efficiency of the detector;
- **GRB detection** masks, specifically designed for the detection of Gamma Ray Bursts.

An additional trigger mask, the "generic trigger mask", can be configured to put in AND a selection of the calorimeter layers.

The description of the trigger masks of these classes is reported below, the figure 4a can be used as reference for the nomenclature.

The masks in the **event acquisition class** can be used to select particles entering the detector with increasing energies, satisfying the following logical conditions:

1. $TR1$
2. $TR1 \cdot TR2$
3. $TR1 \cdot TR2 \cdot RAN2$

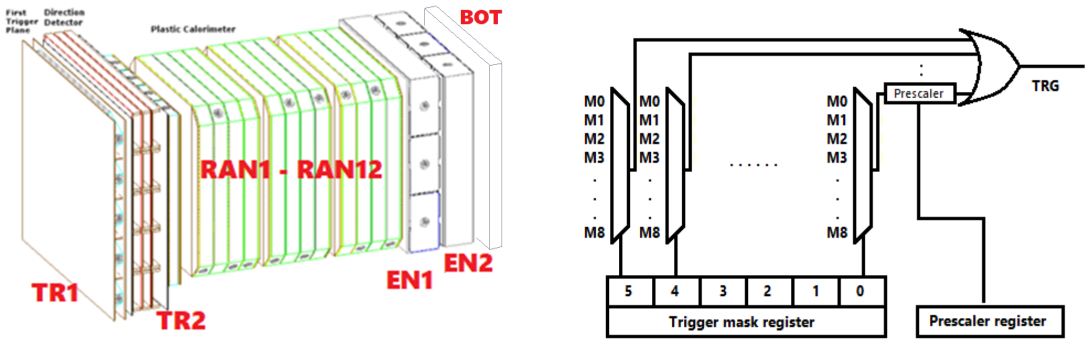
Event monitor masks are used to monitor particles that are not contained in the calorimeter, or enters from the bottom or the side of the calorimeter:

4. $RAN1 \cdot RAN7 \cdot RAN12$
5. $TR2 \cdot BOT$
6. $BOT \cdot EN1 \cdot EN2 \cdot (\overline{TR1 + TR2 + LAT})$
7. $(RAN5 + RAN6 + RAN7 + RAN8) \cdot (\overline{RAN4 + RAN9})$

The mask (4) can be used for measuring the efficiency of the trigger system of the detector, if compared with the event acquisition masks.

The ability to detect Gamma Ray Bursts, in an energy range between 2 to 20 MeV, is one of the improvements made to HEPD-02.

The trigger masks that made this feature possible are the **GRB detection masks**:



(a) HEPD-02 scintillators

(b) Concurrent prescaled triggers

Figure 4

8. $EN1 + EN2 \cdot (\overline{RAN12 + LAT + BOT})$
9. $RAN5 + RAN6 + RAN7 + RAN8 + (\overline{RAN4 + RAN9 + LAT})$

The first mask exploits the high density of the LYSO layers of the calorimeter to detect photons with relatively high energies. The second mask is implemented for photons with lower energies.

7. Prescaled concurrent triggers

The trigger masks allows to study different physics cases depending on the oribital zone of the satellite and four orbital zones are defined for this purpose:

1. the **South-Atlantic Anomaly** (SAA) region, where trapped electrons (dominant at 1 MeV) and protons (dominant above 8 MeV) are expected;
2. the **Equatorial** region, for re-entrant and cosmic protons;
3. the **Outer belt** region, to study low energy trapped electrons (below 10 MeV);
4. the **Polar regions**, where primary particle fluxes are expected.

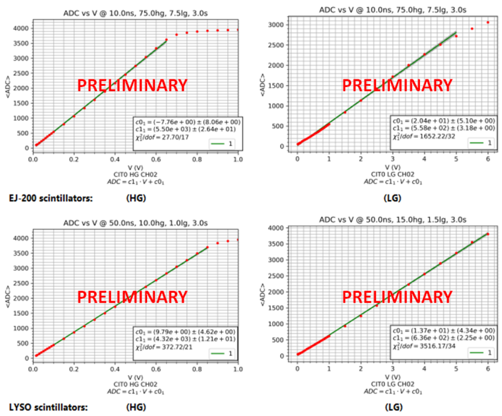
To enrich the physics program of the mission, HEPD-02 will not be limited to select a single trigger mask per orbital zone but it will be able to use 6 of the predefined trigger masks in concurrency.

Since low-energies particle rate, in some regions such as the SAA, can reach rates around 100 MHz, the sharing of data troughput among different physics channels is controlled by trigger prescaling, to not saturate the available bandwidth.

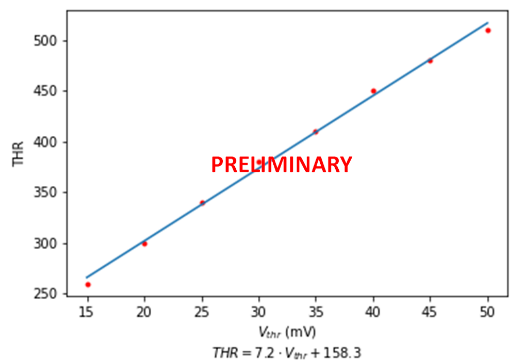
To achieve these functionalities, the trigger masks are connected to six multiplexers whose outputs are selected by a SpaceWire register. The OR of these multiplexers produces the trigger signal and each multiplexer output is also registered to identify which mask produced the event trigger. The first four multiplexer are also connected to four configurable prescalers (see figure 4b).

8. Measurements and tests on the Flight Model

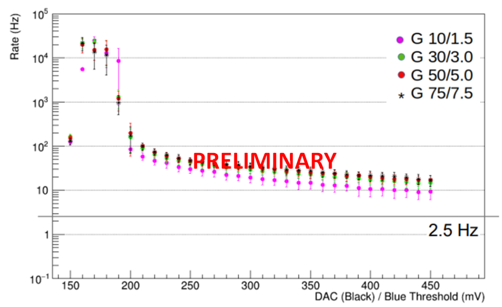
A first set of measurements, involving a limited set of channels of the board, has been carried out using a pulse generator to test different configuration for the CITIROC's preamplifiers and



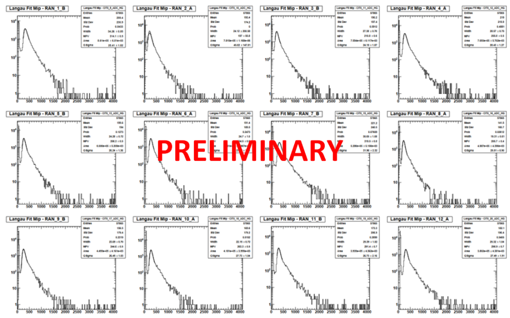
(a) Calibration curves for different type of signals



(b) Threshold calibration



(c) Threshold scan



(d) Fine tuning of the MIP's ADC value

Figure 5

shapers and to get the best linearity for plastic scintillators and LYSO crystals. The calibration curves obtained are reported in figure 5a, while figure 5b shows an example plot of the threshold calibration.

After the integration of the system, threshold scans have been conducted using cosmic muons (figure 5c). Different values of the preamplifiers gain were used, in order to find a suitable value for all the scintillators.

The ADC value for MIPs has been tuned for all the channels of the detector, changing the gain of PMTs and of CITIROC's preamplifiers (figure 5d).

9. Conclusions

The PMT readout and trigger board, developed for HEPD-02, brings improvements on the flexibility of the instrument and allows the detector to operate in regions such as SAA and poles, extending the scientific significance of the mission.

Concurrent and prescaled trigger allows to use different masks per orbital zone and also made possible Gamma Ray Bursts detection.

The added functionalities have been intensively tested and work as expected.

References

[1] S. Pulinets and K. Boyarchuk. “Ionospheric Precursors of Earthquakes". Springer, 2004

[2] CSES-Limadou website: https://cses.web.roma2.infn.it/

[3] C. De Santis, S. Ricciarini, “The High Energy Particle Detector (HEPD-02) for the second China Seismo-Electromagnetic Satellite (CSES-02)", 2021, *Proceeding of Science* vol. ICRC2021, p. 58, doi: 10.22323/1.395.0058

[4] Scotti, V., Osteria, G., “The electronics of the HEPD of the CSES experiment”, (2017) Nuclear and Particle Physics Proceedings, 291-293, pp. 118-121, doi: 10.1016/j.nuclphysbps.2017.06.024

[5] G. Ambrosi, S. Bartocci, L. Basara et al., “The electronics of the High-Energy Particle Detector on board the CSES satellite”, Nuclear Instruments and Methods in Physics Research, A (2021) 165639, doi: 10.1016/j.nima.2021.165639

[6] R. Iuppa, S. Ricciarini, S. Coli, S. Beole, L. De Cilladi, G. Gebbia, E. Ricci, P. Zuccon, “The innovative particle tracker for the HEPD space experiment onboard the CSES-02”, 2021, *Proceeding of Science* vol. ICRC2021, p. 70, doi: 10.22323/1.395.0070

[7] G. Masciantonio, C. De Donato, A. Sotgiu, “The HEPD-02 Data Processing and Control Unit for the CSES-02 mission", 2021, *Proceeding of Science* vol. ICRC2021, p. 59, doi: 10.22323/1.395.0059

[8] V. Scotti, M. Mese and G. Osteria, “A Versatile Readout and Trigger System for the High Energy Particle Detector Onboard the Satellite CSES-02", 2019 IEEE NSS/MIC, 2019, pp. 1-3, doi: 10.1109/NSS/MIC42101.2019.9059936.

[9] CITIROC 1A. Rev. 2.52. Weeroc. Mag. 2019, https://www.weeroc.com/my-weeroc/download-center/citiroc-1a/16-citiroc1a-datasheet-v2-5/file

[10] V. Scotti and G. Osteria, “The high energy particle detector onboard the CSES satellite," 2016 IEEE NSS/MIC/RTSD, 2016, pp. 1-8, doi: 10.1109/NSSMIC.2016.8069878.