The electronics of the HEPD of the CSES experiment

Valentina Scotti - INFN Napoli

Outline of the talk

- *The China Seismo Electromagnetic Satellite mission*
- *The High Energy Particle Detector of CSES*
- *Description of the instrument and its electronics*
- *Status and plans*

XXV European Cosmic Ray Symposium - 4-9 September 2016 -Torino

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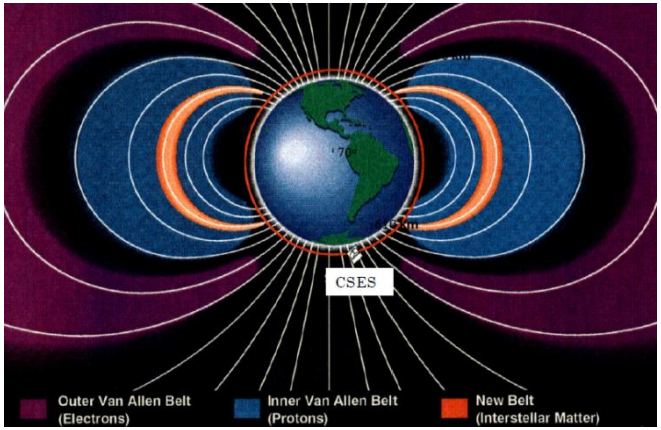

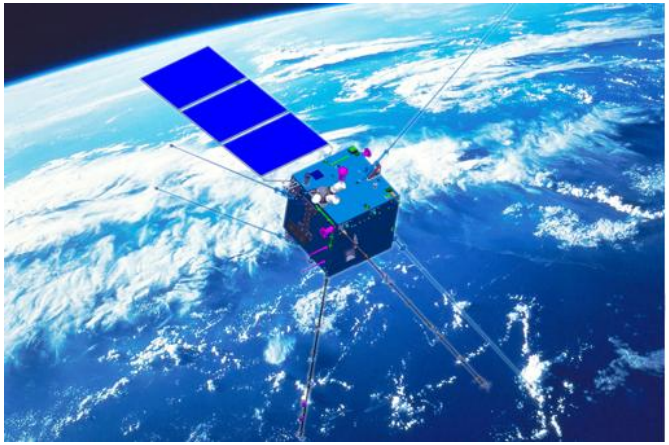

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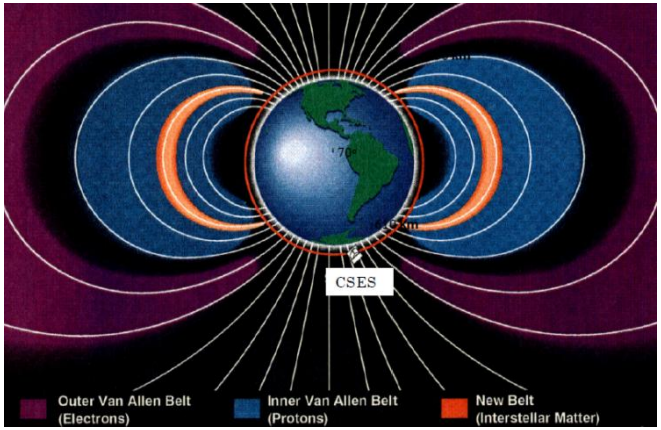

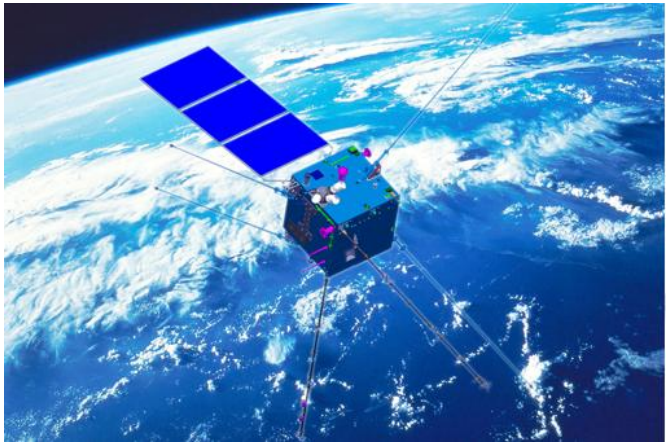

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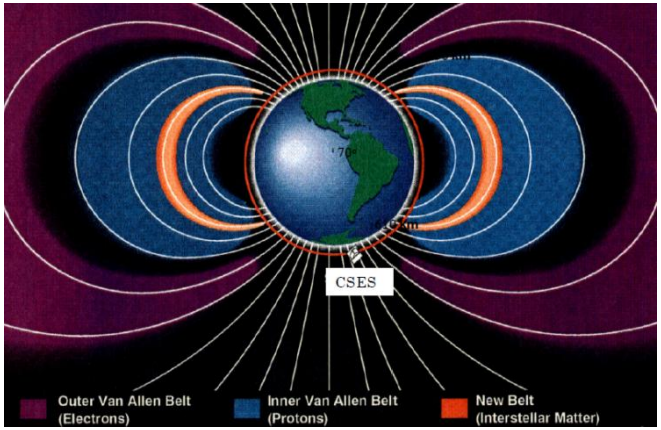
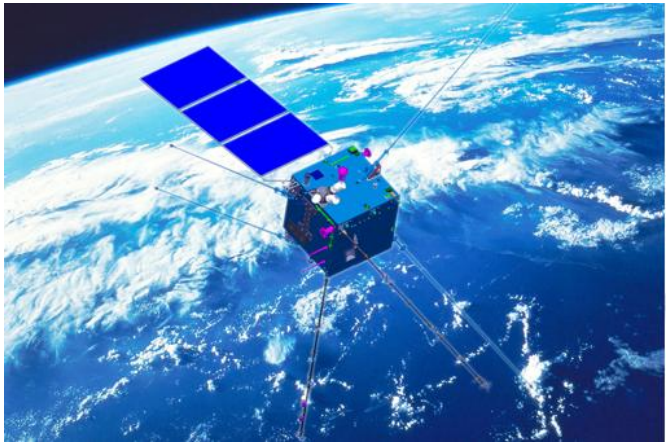
98° Sun-synchronous circular orbit at 500 km of altitude with two different orbital working zones:
• payload operating zone: instruments will collect measurements in the latitude range of ± 65°
• platform adjustment zone: at higher latitudes all detectors will be switched off, in order to perform activities of satellite attitude and orbit control system





3-axis attitude stabilized satellite based on CAST2000 platform
Mass = 730 kg
Peak power consumption = 900 W

Project Objectives of CSES

SCIENTIFIC

- to study the ionospheric perturbations possibly associated with earthquakes
- to explore new approaches for short-term prediction and theoretic studies on the mechanism of earthquake preparation processes
- to measure Cosmic Ray (CR) in an energy range below the one which has been studied so far by current CR space missions (PAMELA, AMS-02)

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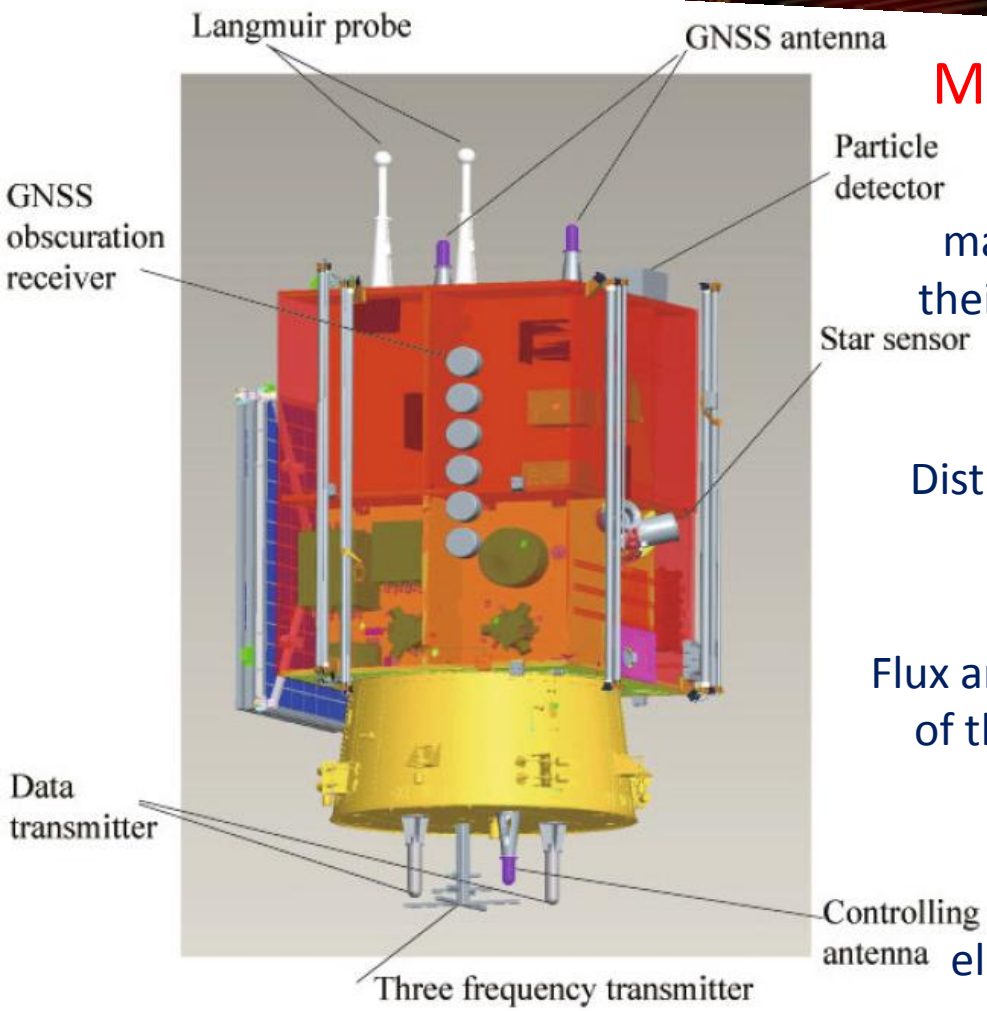
ENGINEERING

- to check the reliability of the electromagnetic satellite earthquake monitoring system by using new techniques and equipments
- to obtain world-wide data of the electromagnetic field, plasma and energetic particles in space environment
- to provide a good basis for a space-ground system in earthquake monitoring in the near future in China

APPLICATION

- to extract electromagnetic information associated possibly with the earthquakes of $M_s \geq 6$ in Chinese territory and that of $M_s \geq 7$ in the global scale
- to analyze seismo-ionospheric perturbations in order to test the possibility for short-term earthquake forecasting with satellite observation

Instruments onboard CSES



Measurements	Instruments
Electrical and magnetic fields and their perturbations in ionosphere	Search-Coil magnetometer Fluxgate magnetometer Electrical field detector
Disturbance of plasma in ionosphere	Plasma analizer Langmuir probe
Flux and energy spectrum of the particles in the radiation belts	High Energy Particle Detector (HEPD)
Profile of electronic content	GPS occultation receiver Tri-frequency transmitter

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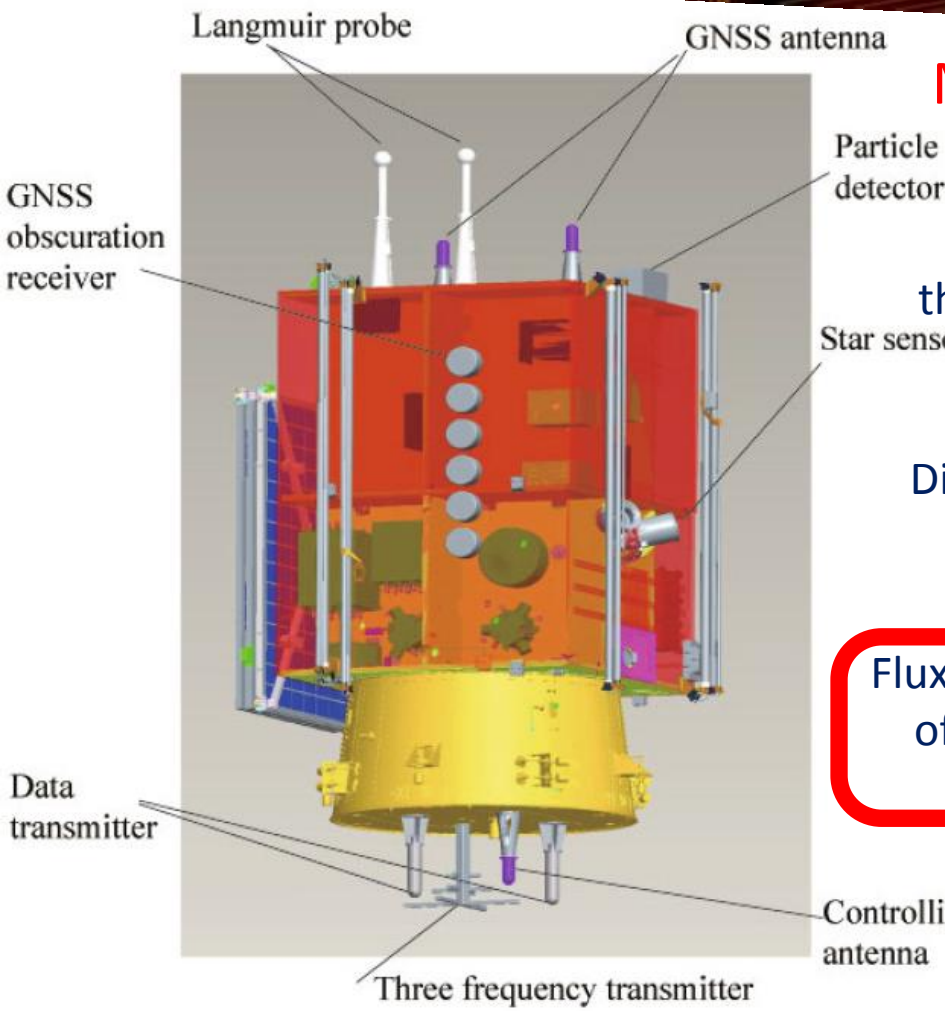

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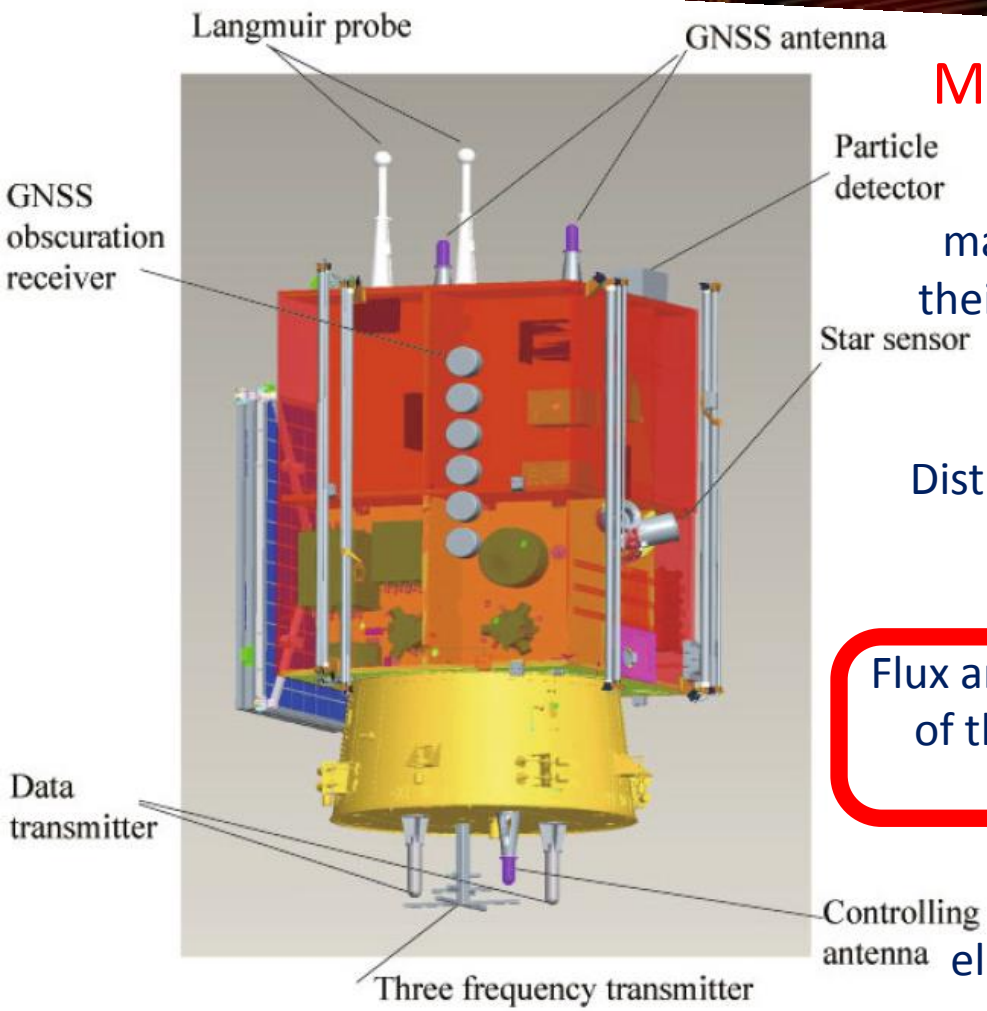

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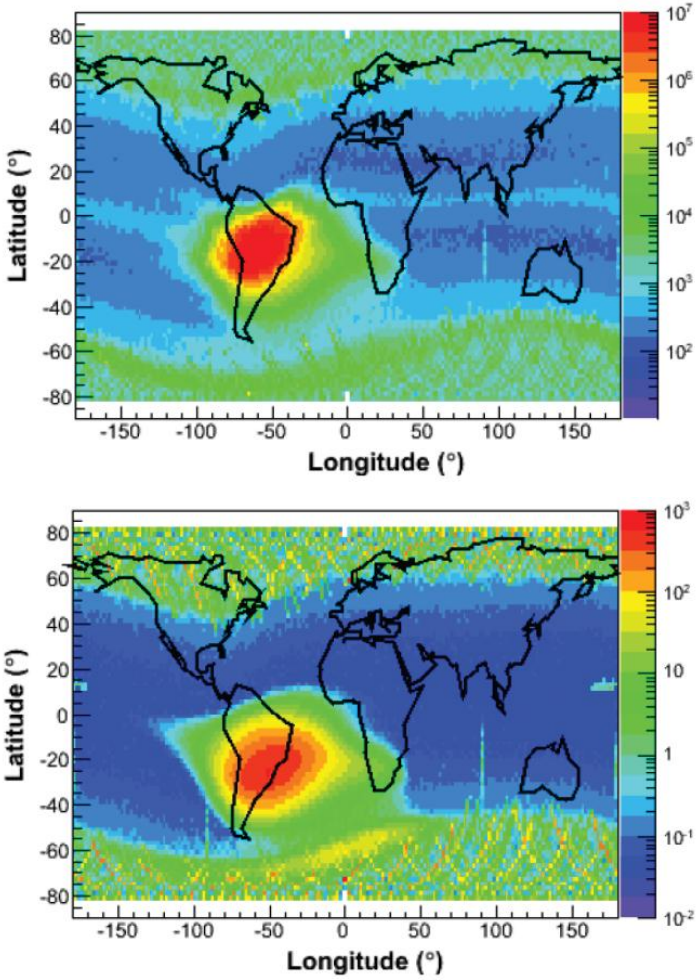
HEPD space physics:
- composition and energy spectra of galactic and solar particles
- solar-terrestrial environment (heliosphere and magnetosphere), fundamental for Space Weather

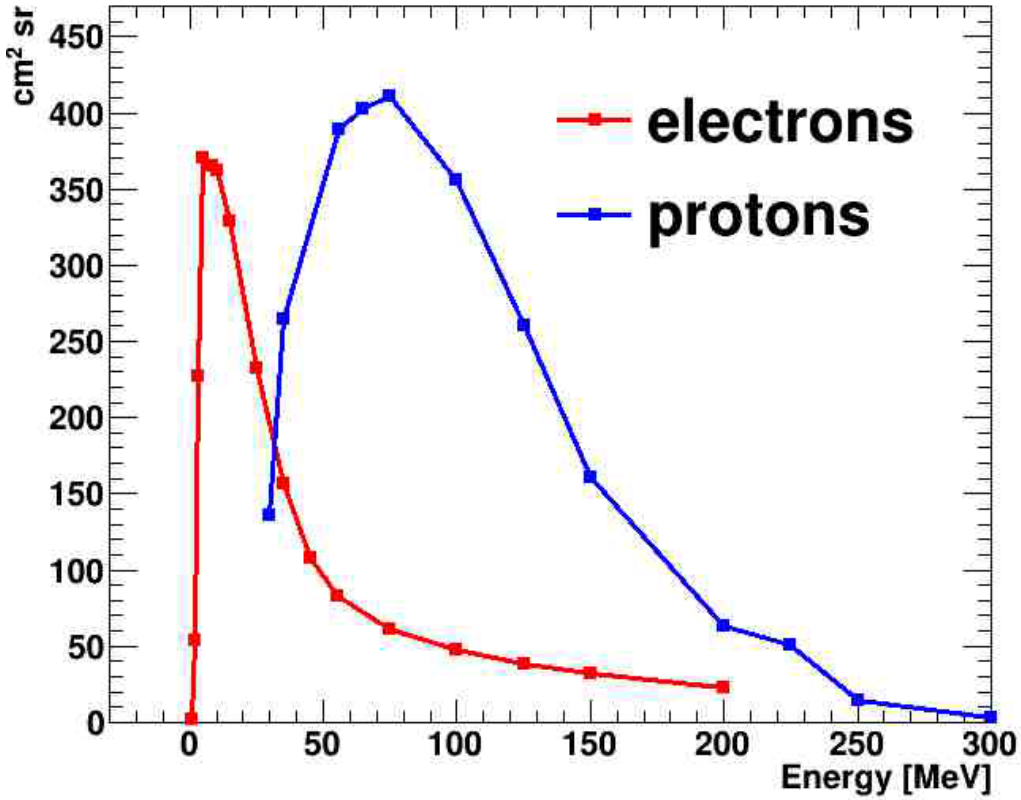
Scientific objectives of HEPD

The HEPD will study low energy Cosmic Rays (CR) in the energy range 3 - 300 MeV



Expected count rates for electrons (3- 200 MeV) and protons (30 – 300 MeV) along the CSES orbit

- **separate electrons and protons** identifying electrons within a proton background (10^{-5}-10^{-3})
- **identify nuclei up to Iron**



Expected acceptance for protons and electrons

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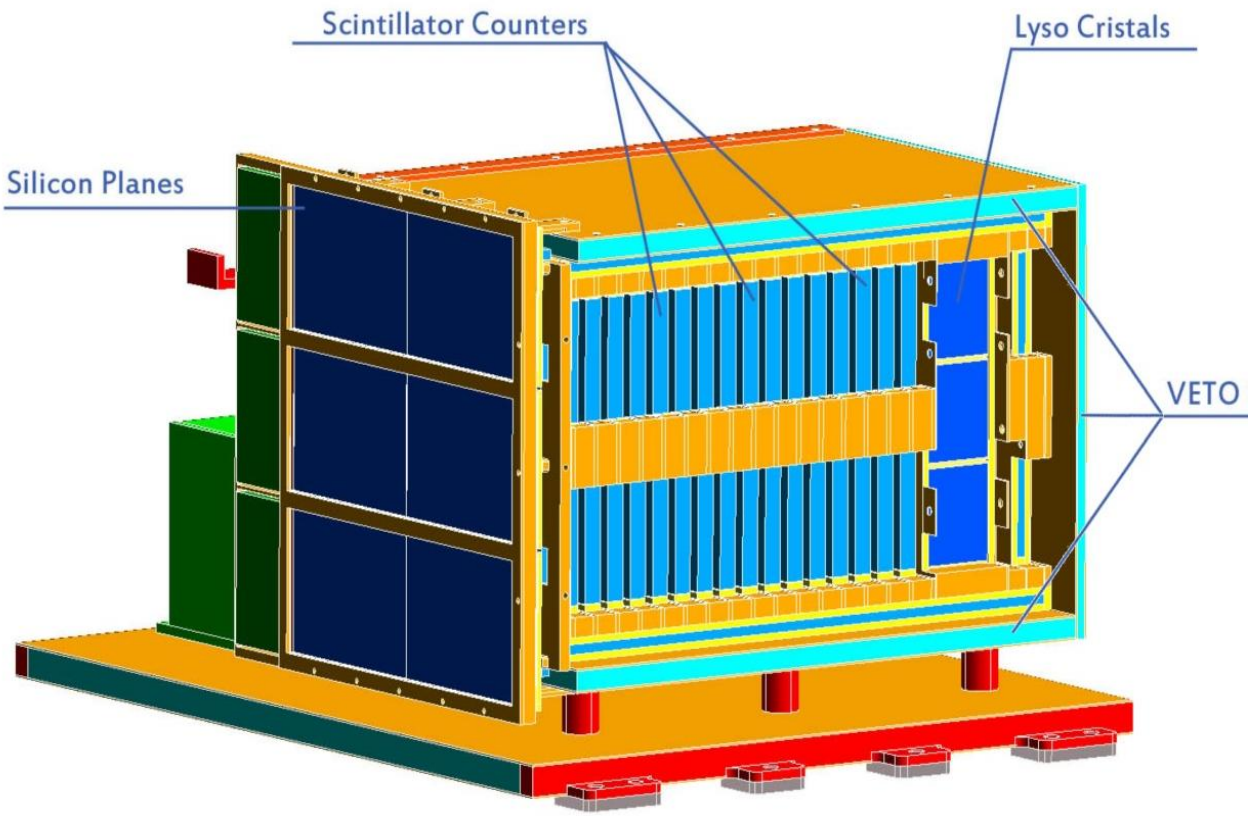
- **identify nuclei up to Iron**

The high-inclination orbit allows the telescope to detect particles of different nature during its revolution: galactic CR, Solar Energetic Particles, particles trapped in the magnetosphere.

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

The HEPD components



Silicon tracker: two planes of double-side **silicon micro-strip detectors** placed on the top of the detector in order to provide the direction of the incident particle limiting the effect of Coulomb multiple scattering on the direction measurement

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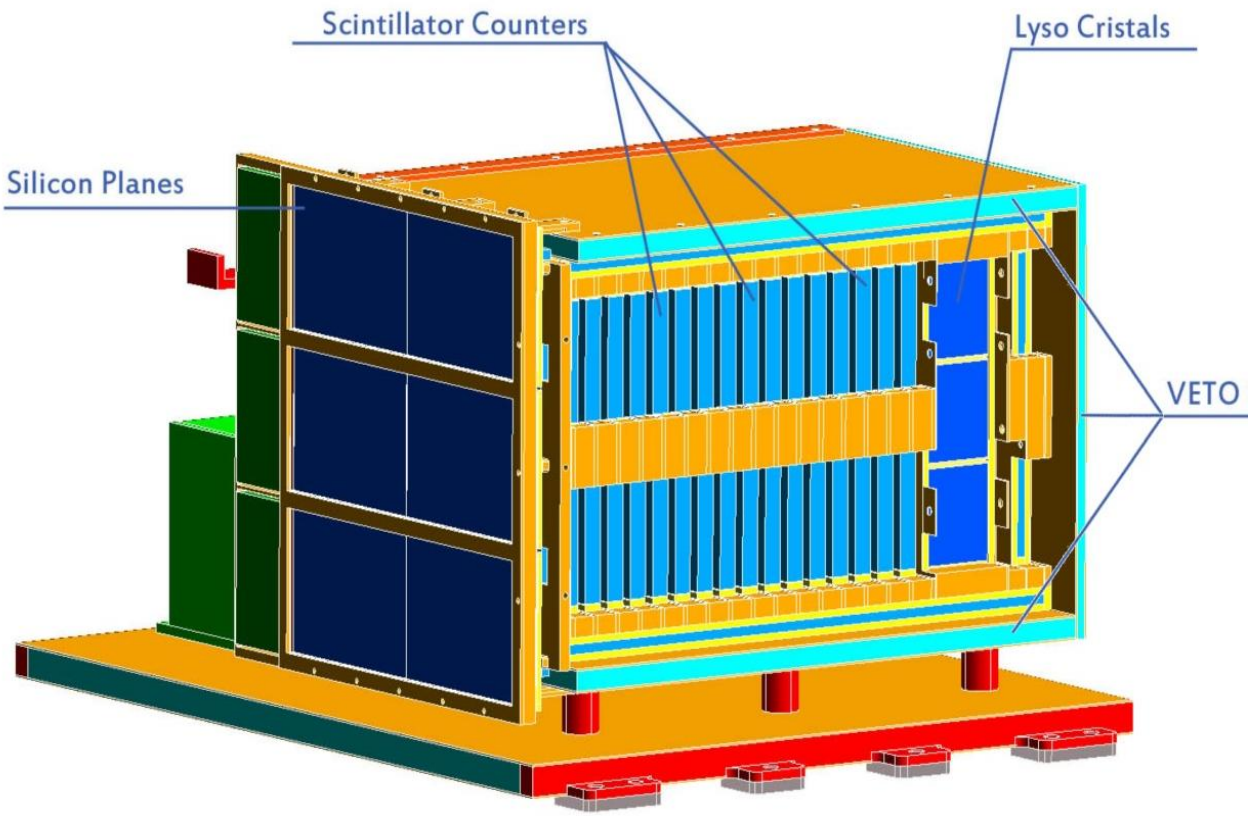

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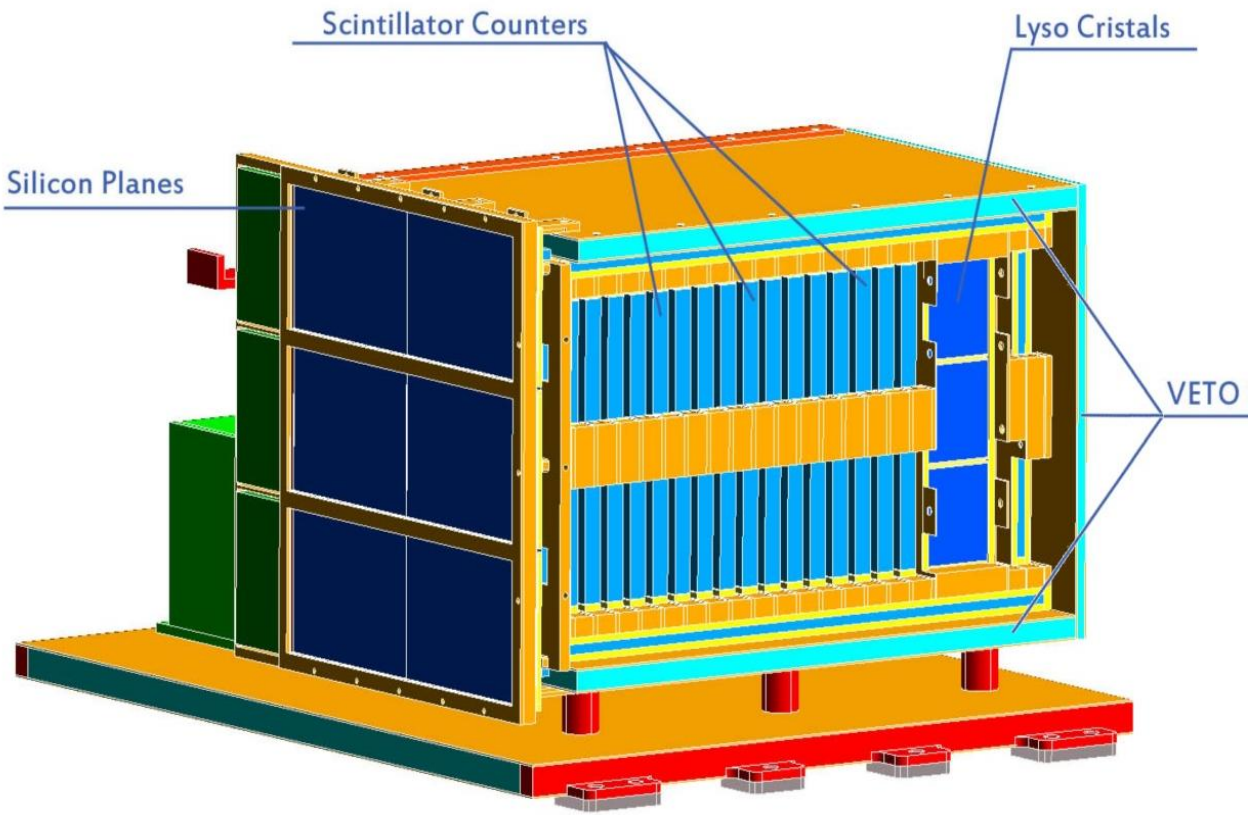

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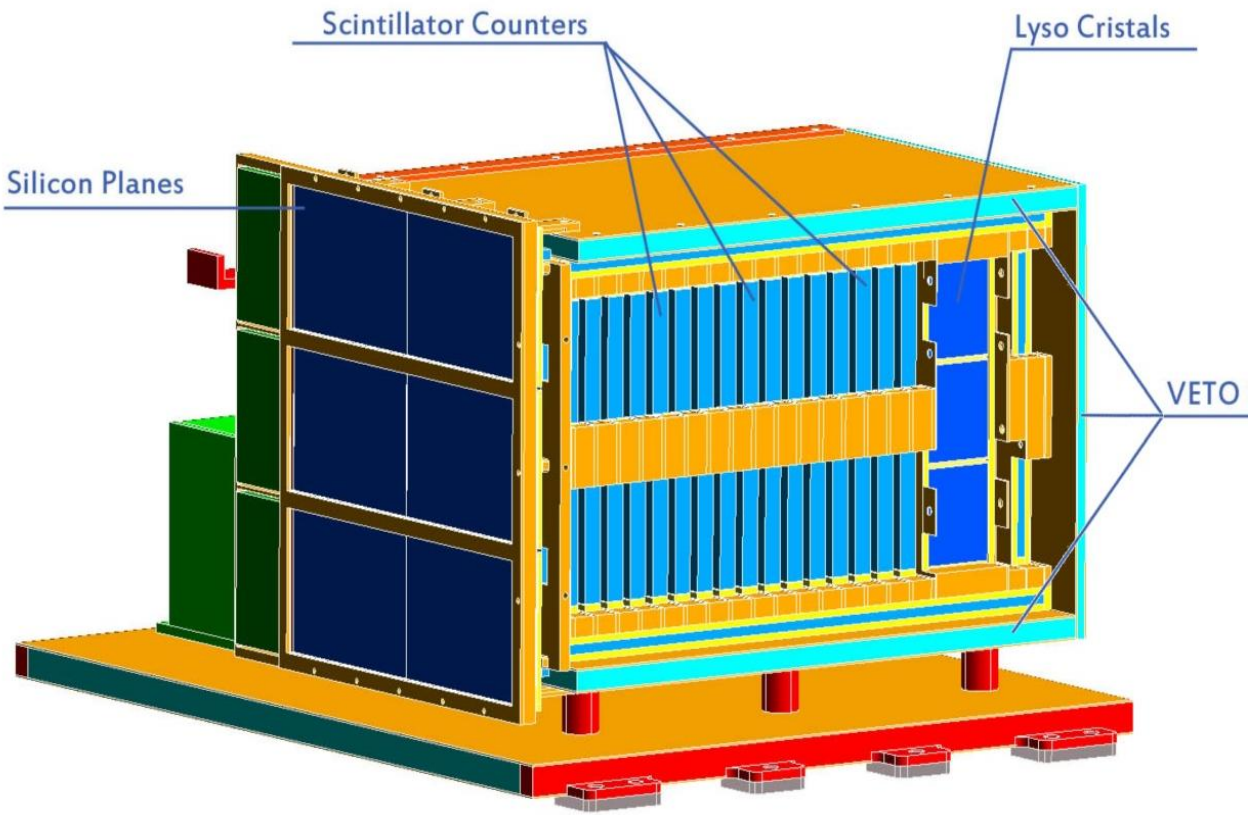

The calorimeter volume (about 20×20×40 cm^3) is surrounded by 5mm thick plastic scintillator planes: **VETO** .

All the scintillator detectors (trigger, calorimeter and VETO) are read out by photomultiplier tubes (PMTs).

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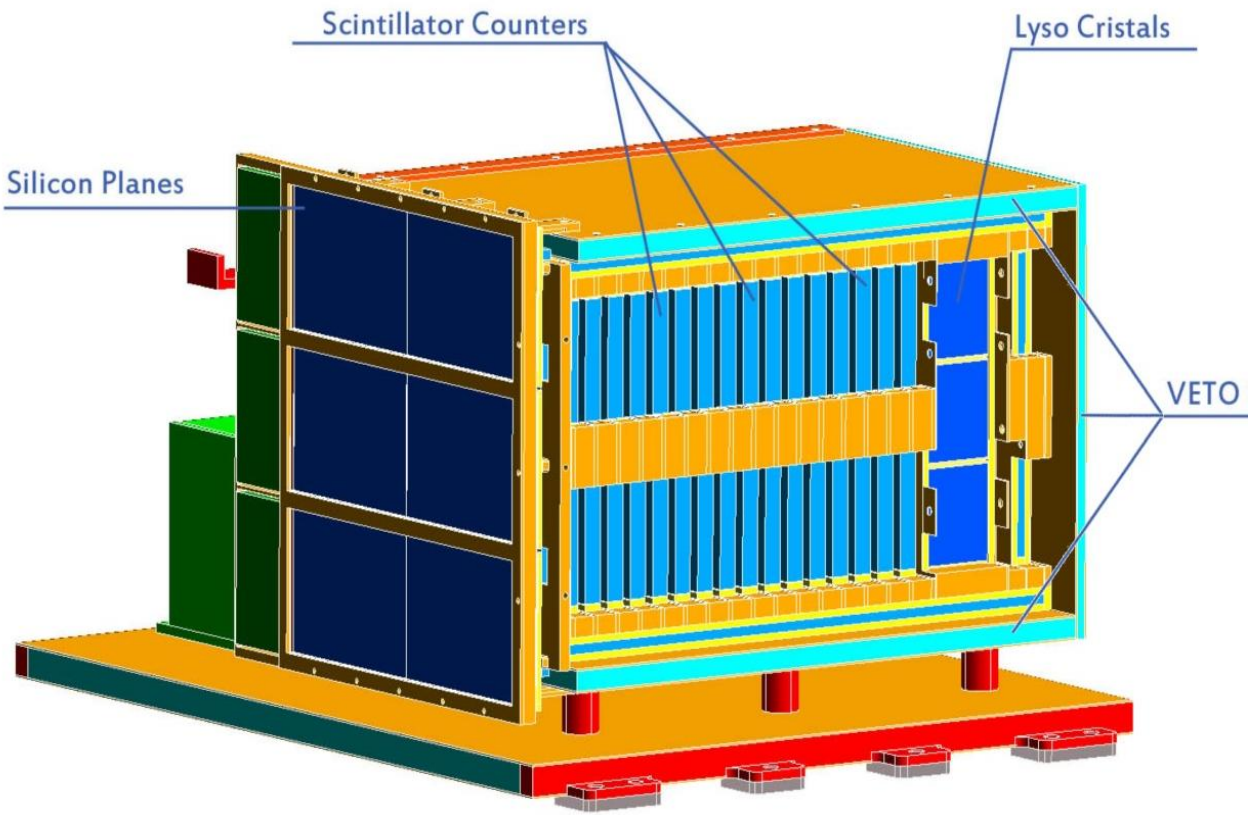

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4 HEPD models: Electrical, Mechanical&Thermal, Qualification (QM) and Flight Models (FM).

The HEPD electronics

The electronics can be divided in three blocks:

1. **Tracker**
2. **Scintillator detectors**
3. **Global control and data managing**

Each block includes power chain for bias distribution and a data acquisition and processing chain. The main power supply provides the low voltages to the detector electronics and the high voltages to PMTs and silicon modules.

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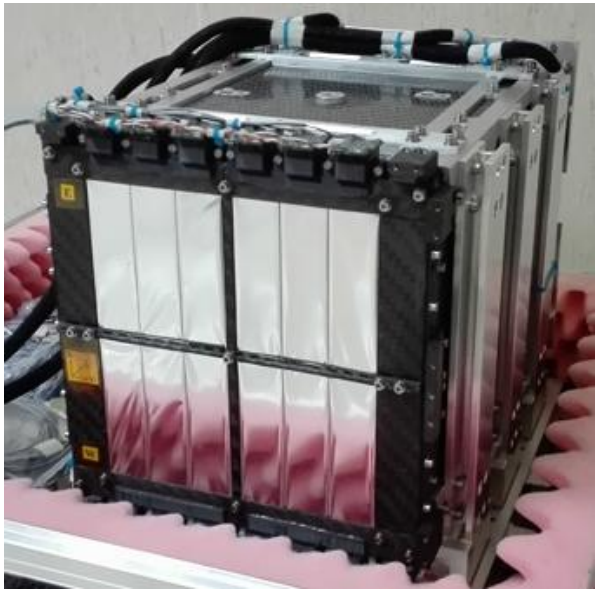
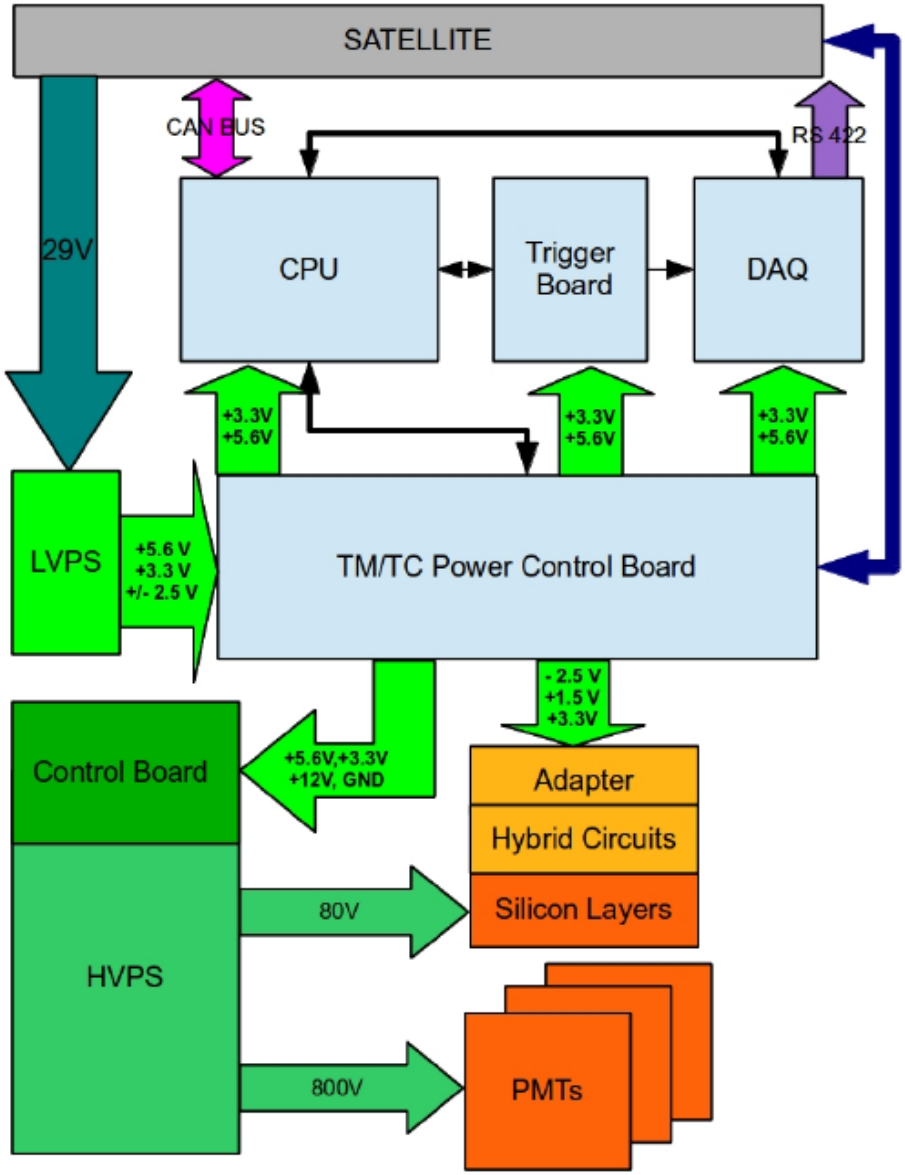
- embedded "Hot/Cold" redundancy
- -40°C to +85°C operating range
- max data transfer rate from satellite = 50 GB per day



Front view of the QM: the trigger system with its six segments is visible.

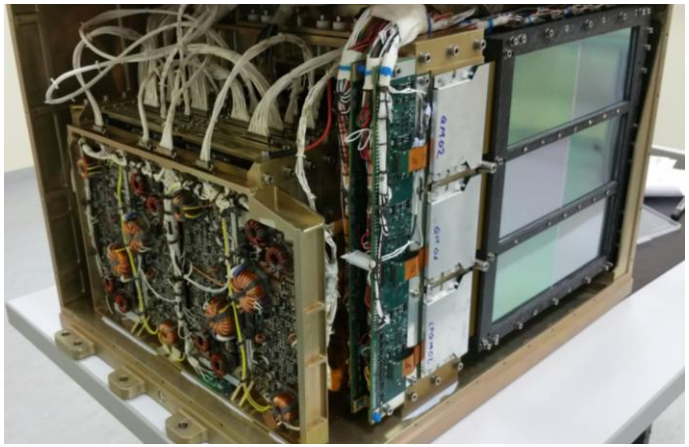
Side view of the QM calorimeter which shows the plastic scintillator planes. The PMTs are at the corners of each calorimeter plane.

The electronics components



The system is composed by front-end electronics and **four main boards**:

- Data Acquisition (DAQ) : manages all the scientific data of the HEPD
- Trigger Board: manages the analog signals coming from the PMTs and generates trigger signals needed for data acquisition
- CPU: controls the detector and communicates with the platform of the satellite via CAN BUS interface
- Telemetry/Telecommand (TM/TC) Board



The electronics and the silicon detector

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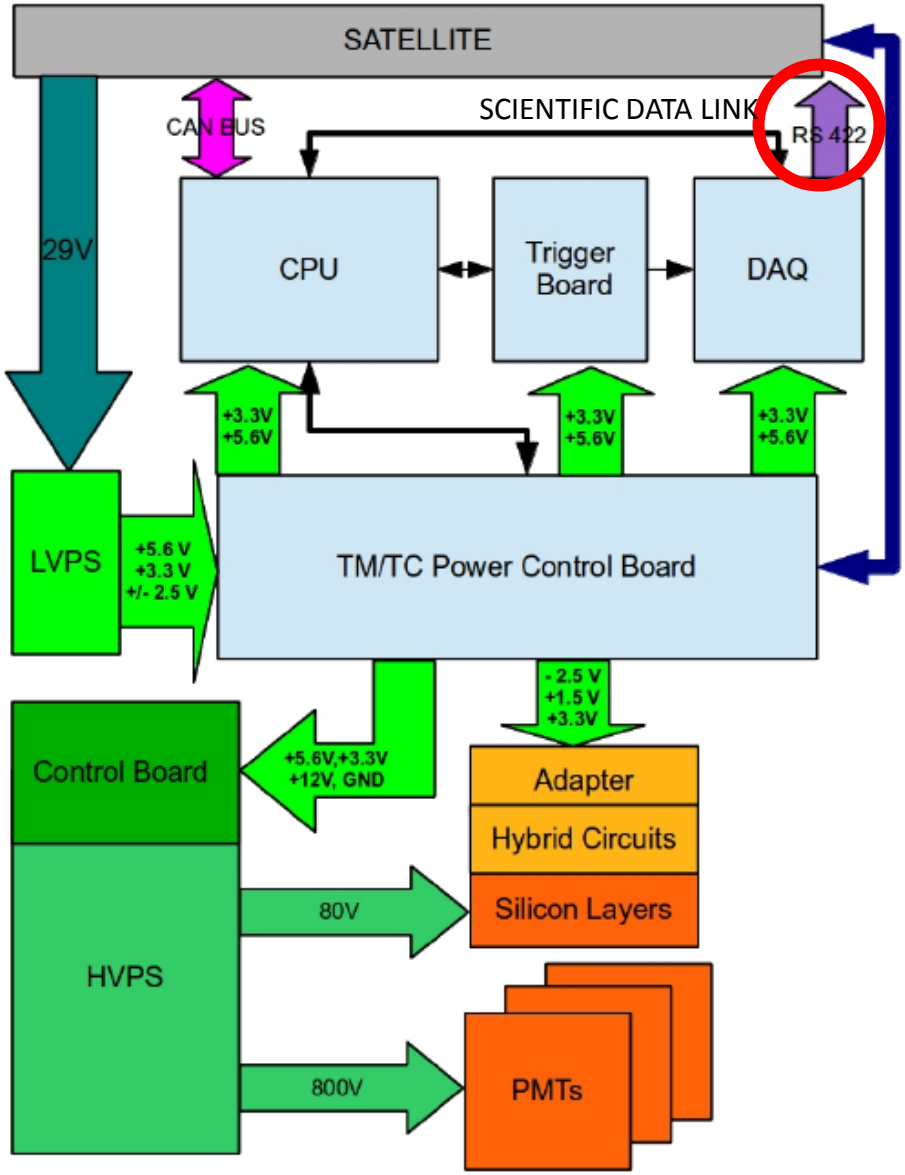

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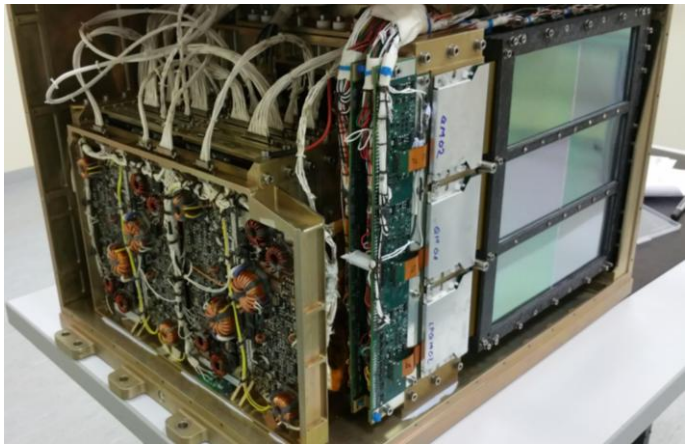

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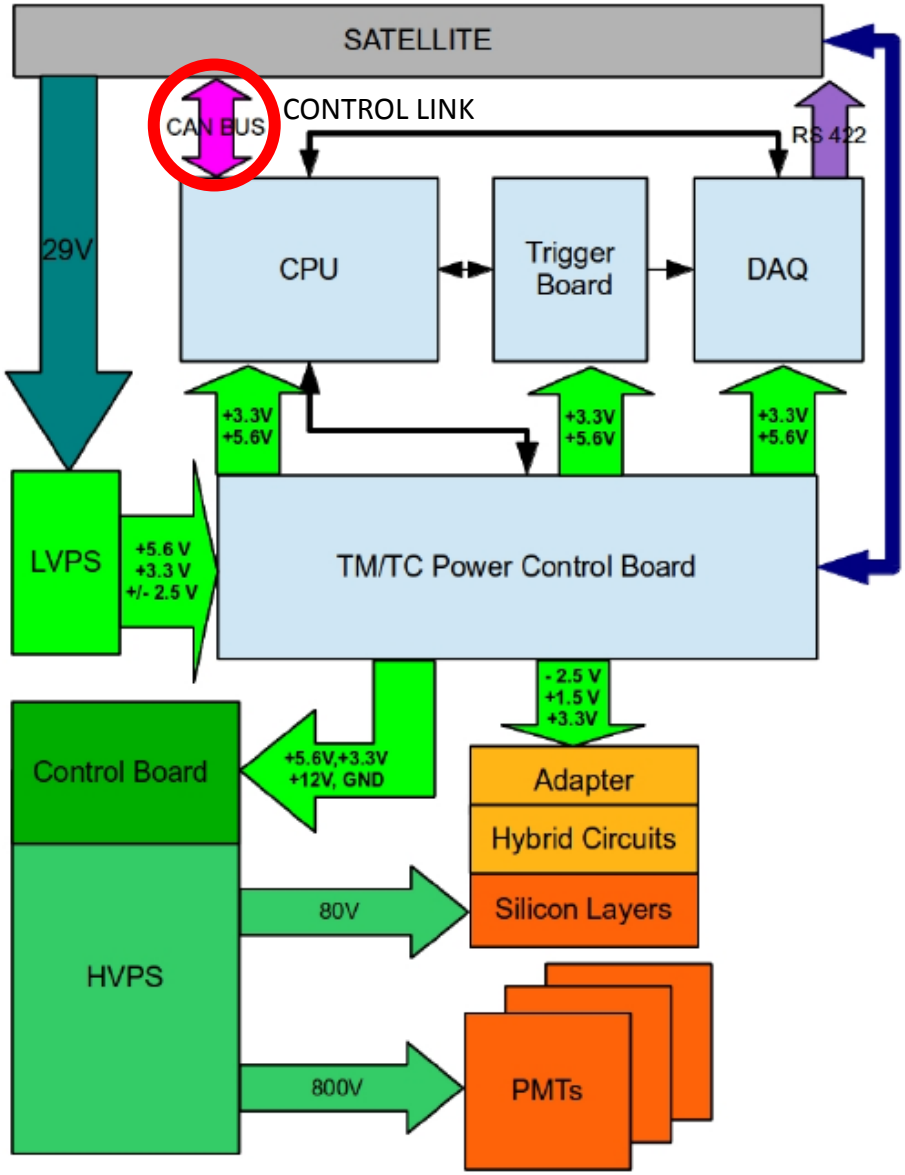

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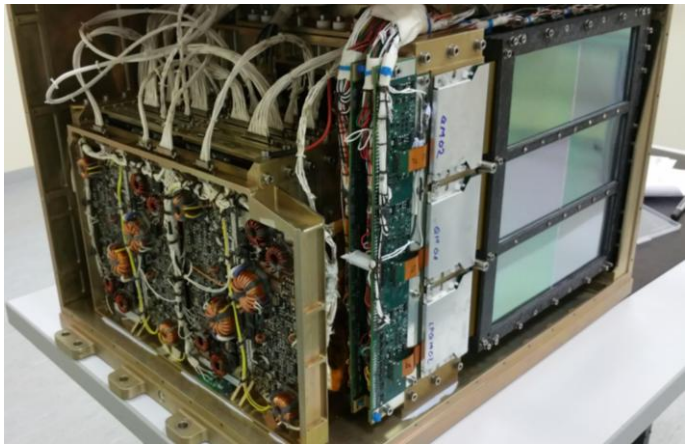
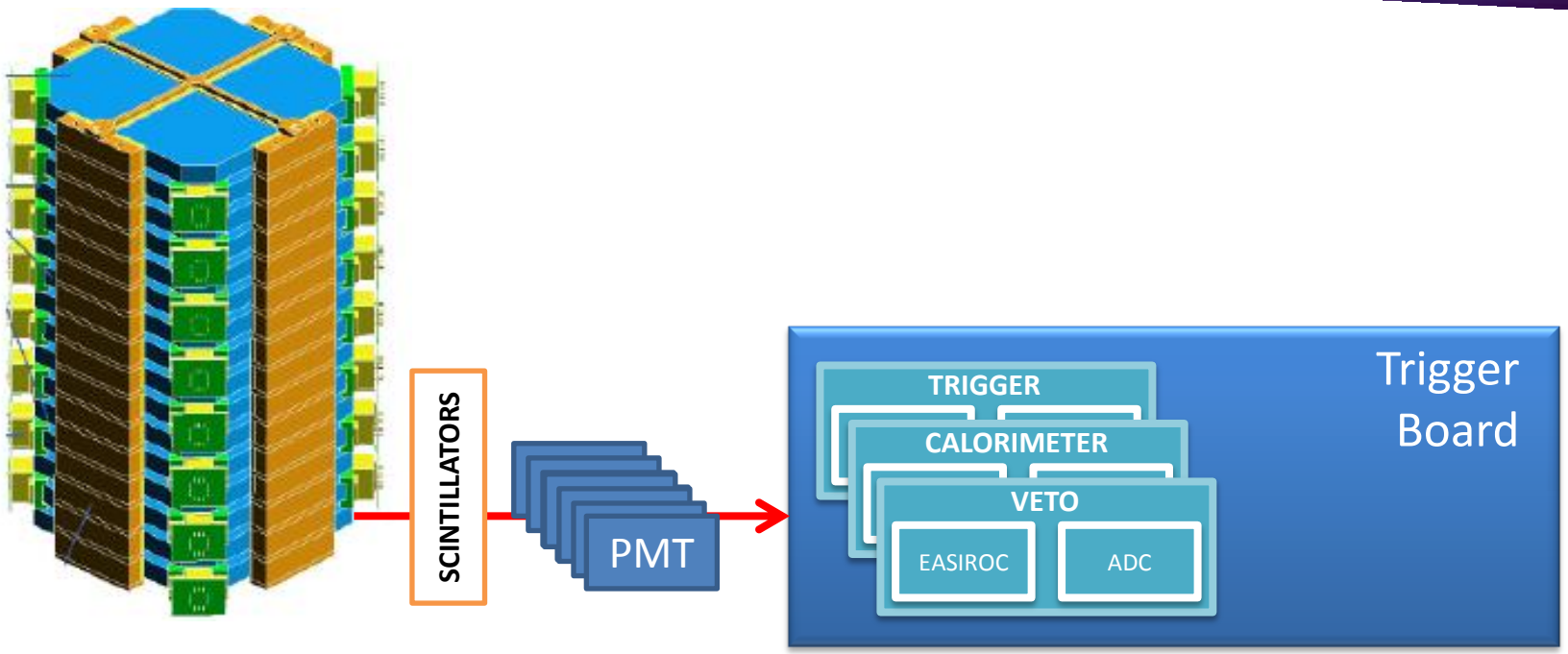


The electronics and the silicon detector

The electronics working principle



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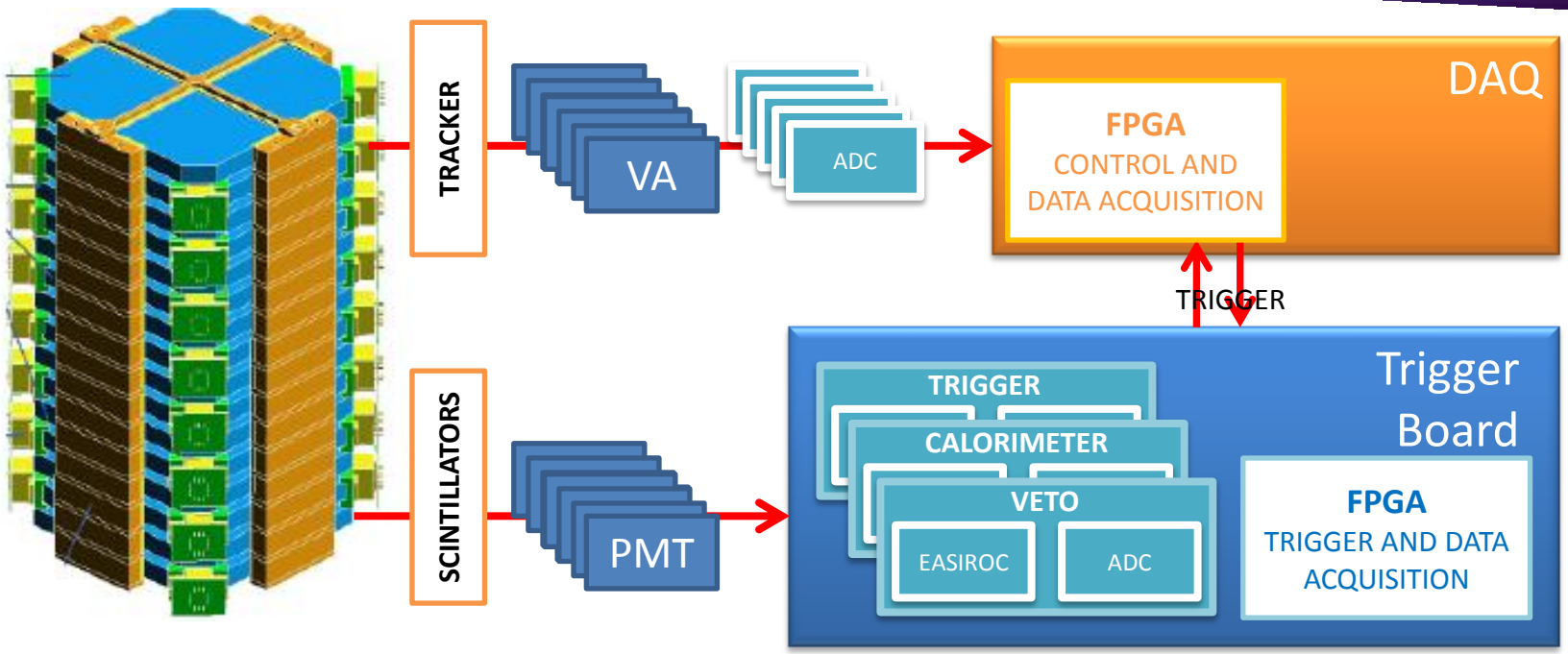

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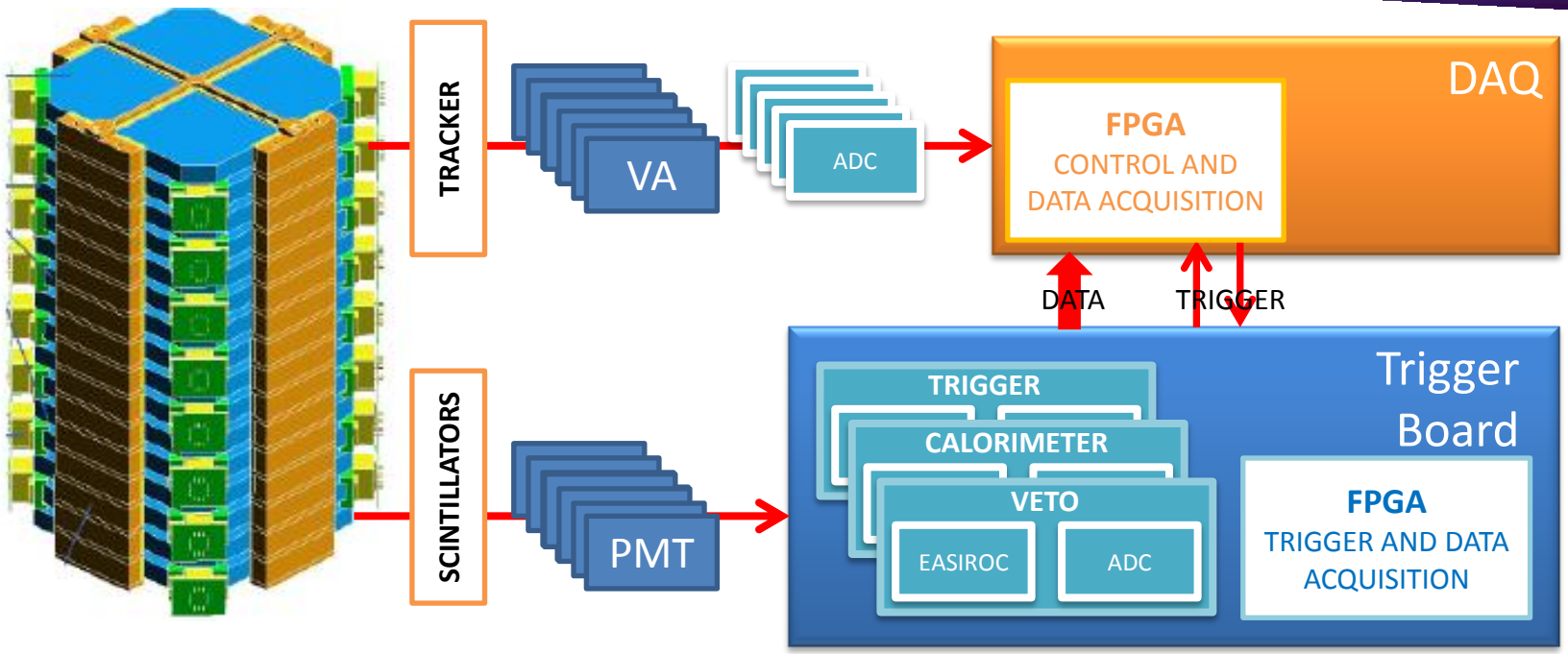

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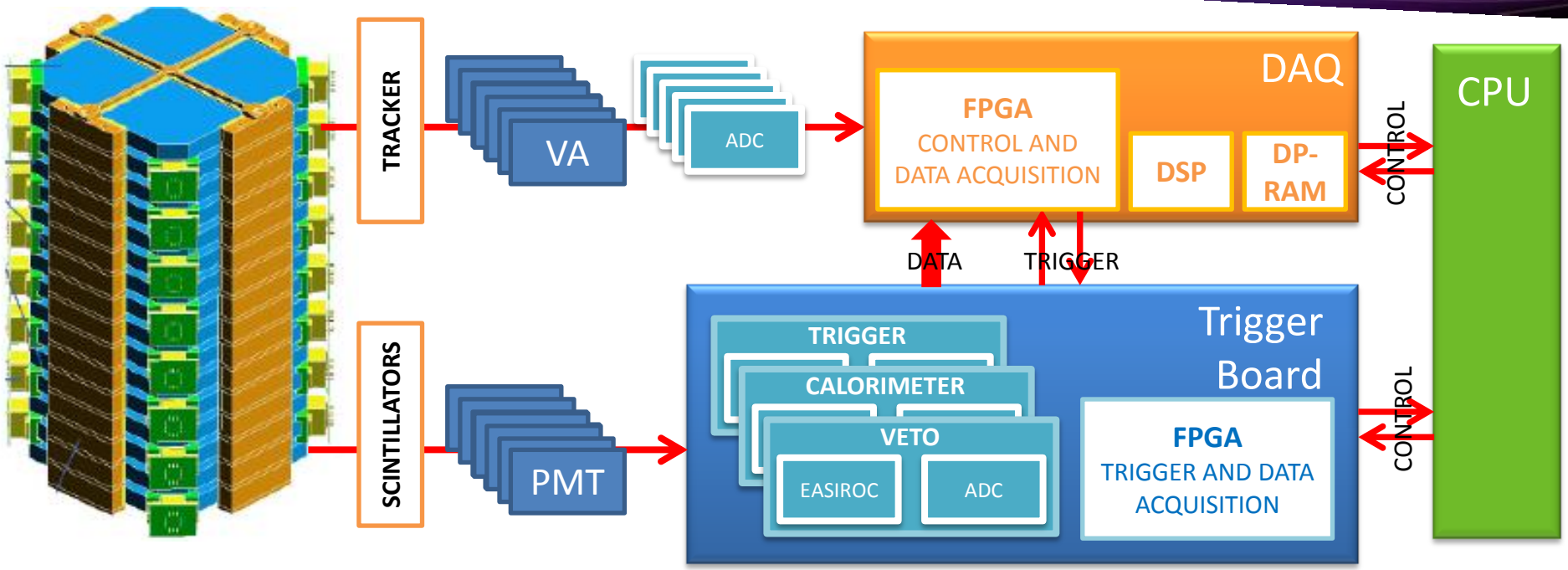

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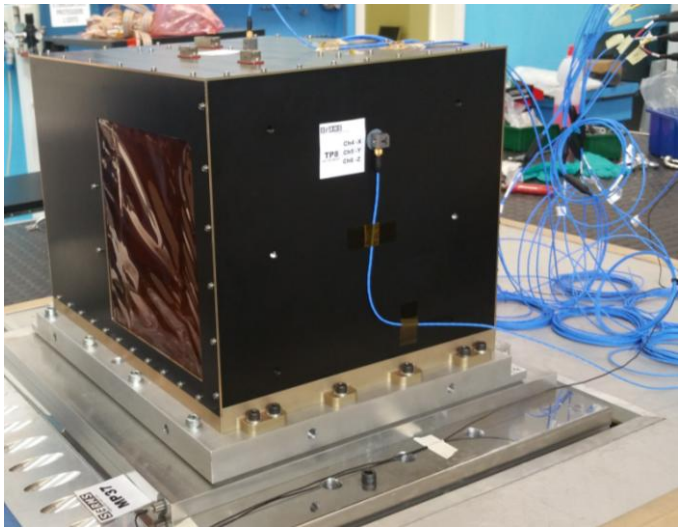
4. Scintillators and Tracker data are processed by a dedicated DSP and the results are written on a DP-RAM waiting to be transferred to satellite via RS-422 on a CPU command.

Test and qualification campaign

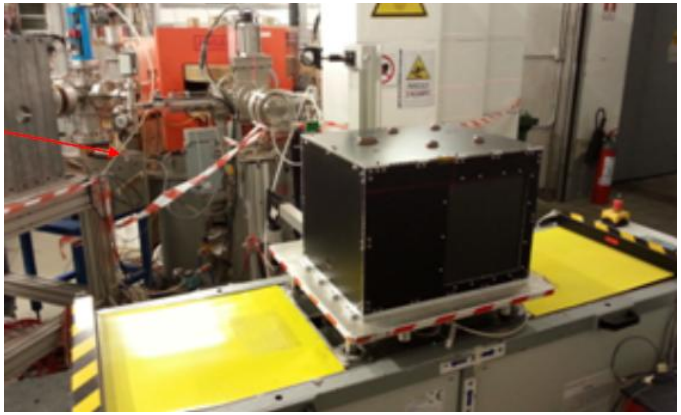


The QM during vibration test at SERMS.
The detector is housed within the black box.

Spring 2016: start of test and qualification campaign with the HEPD Qualification Model (QM)

Vibration test at SERMS laboratory in Terni (PG) simulating launch and flight

Thermal and vacuum test at SERMS laboratory simulating space environment



The QM of the HEPD during the beam test at the BTF. The end of the beam pipe is visible in front of the HEPD.

Beam test carried out at Beam Test Facility of the "Laboratori Nazionali di Frascati" of INFN: electrons and positrons from 30 to 150 MeV
Objective: 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.
Beam test data are under analysis.

Status and plans

DONE

- The Electrical Model and the Structural and Thermal Model of the HEPD are in China and passed all the tests
- The Qualification Model (QM) of the HEPD has been built, assembled and integrated
- The HEPD QM was tested with electron beams at different energies
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2016

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- Delivery in China of QM (September) and FM (November)
- Test of QM in China

2017

- Pre-flight test in China
- Launch campaign starting in June
- Commissioning post launch at CSES Ground Segment in Beijing
- Beam test of the QM after the redelivery

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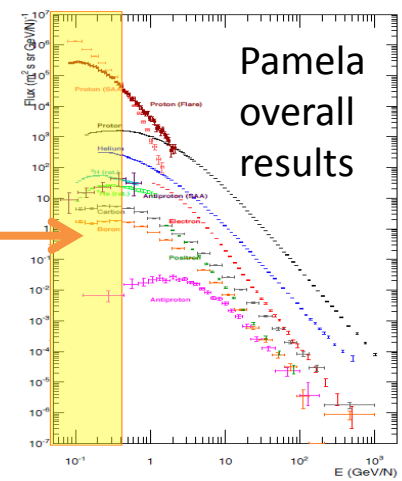
Scientific outcome from HEPD:

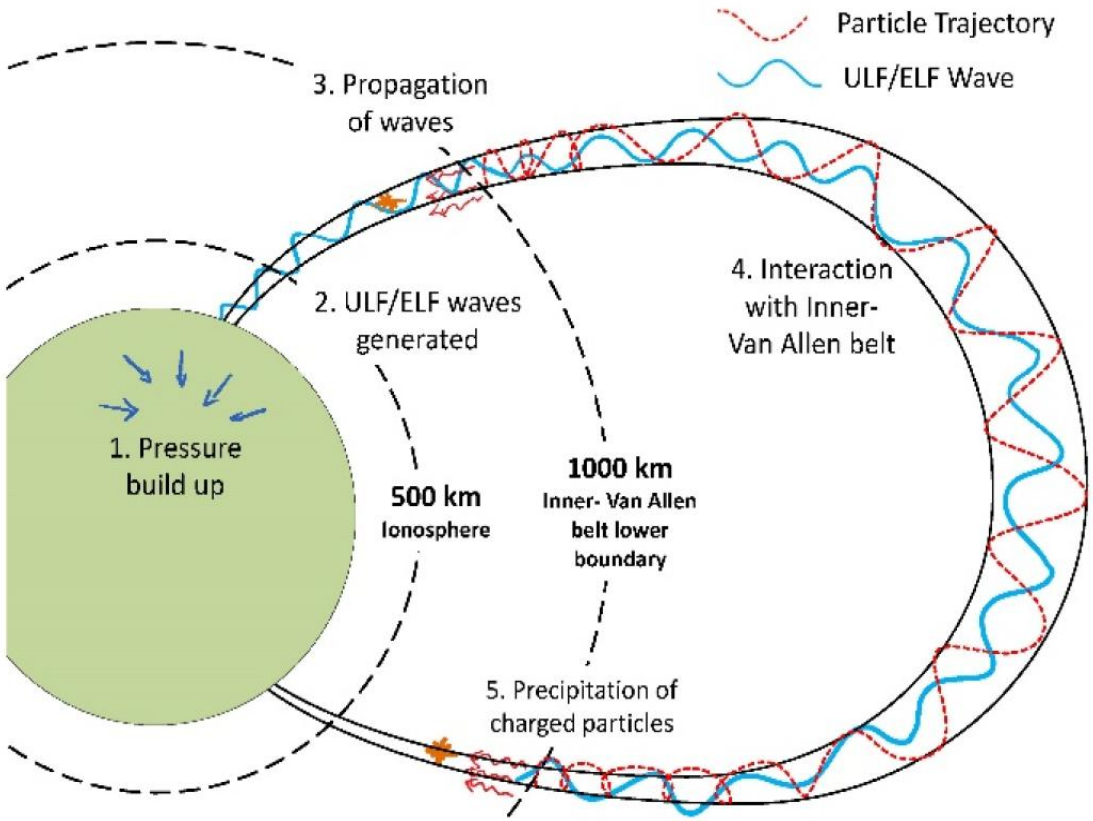
1. **Radiation belt physics**
2. **Solar physics**
3. **EM field and plasma of Ionosphere**
4. **Seismo-associated phenomena**

Limadou energy window



Spare slides

Physics of CSES

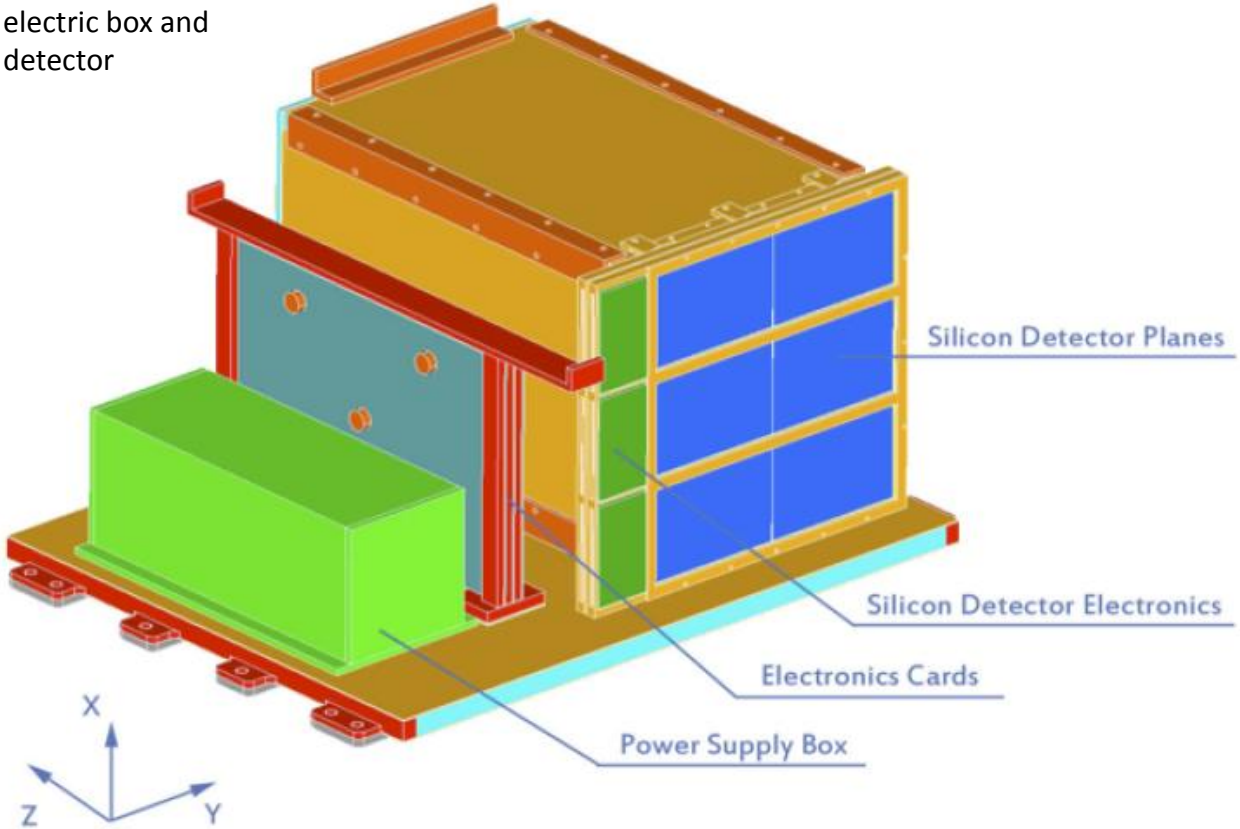


Among the possible anomalies generated by a seismic event, bursts of Van Allen belt electron fluxes in the magnetosphere have been repeatedly reported in literature by various experiments, though a statistical significance was always difficult to claim [1, 2, 3]. A recent study [4] presented a new search for correlation between the precipitation of low energy electrons (E > 0.3 MeV) trapped within the Van Allen Belts and earthquakes with magnitude above 5 Richter scale. The authors used 13 years of electron data measured by the NOAA POES satellites corresponding to about 18 thousands M>5 earthquakes registered in the NEIC catalog of the U.S. Geological Survey, and found a correlation peak with significance of 5.7 standard deviations.

[1] X. Shen et al, Earthq Sci (2011) 24: 639A ¸S650.
[2] X. Zhang et al, Nat. Hazards Earth Syst. Sci., 13, 197 ¸S209, 2013
[3] V. Sgrigna, , et al 2005, Journal of Atmospheric and Solar-Terrestrial Physics, 67 1448S.
[4] S. Y. Alexandrin et al 2003, Annales Geophysicae 21, 597.

Physics of HEPD

View of the HEPD electric box and detector



The HEPD will study the temporal stability of the inner Van Allen radiation belts, investigating precipitation of trapped particles induced by magnetospheric, ionosferic and tropospheric EM emissions, as well as by seimo-electromagnetic disturbances. The HEPD scientific scope, besides monitoring the precipitation of trapped particles in the magnetospere, is studying the low energy component of cosmic rays.

CSES/Limadou will repeat the measurements of the two WIZARD/NINA missions (similar orbit, same energy window), which flew over the years 1998 – 2003, in a different period of the solar cycle, and will complement the cosmic ray measurements of PAMELA and AMS-02 at low energy. For its specific nature, CSES will be a powerful instrument for the Space Weather in the incoming solar cycle.

Main electronics boards

Data Acquisition (DAQ) : manages the scientific data of detector.

- Acquires of Trigger signal from PMT/Trigger board
- Manages hybrid circuits on the silicon planes
- Acquires silicon planes data
- Computes of PMTs data & Silicon planes data
- Data compression
- Transmits scientific data on the scientific data link

Trigger Board: manages the analog signals coming from the PMTs and generates trigger signals needed by other boards.

- Acquires the PMTs analog signal using EASIROC Integrated Circuits
- Converts the EASIROC readout signals into digital signals
- Allows the DAQ board to read the EASIROC digital output
- Allows the CPU to configure the EASIROC
- Generates and transmits “slow” event trigger signals manipulating the “fast” trigger signals coming from EASIROC
- Allow the CPU to configure the “slow” trigger generation algorithm

CPU : controls the detector and communicates with the platform of the satellite via CAN BUS interface.

- Communicates with Satellite OBDH computer via CAN bus
- Stores non volatile information
- Manages, via internal slow control links bus of TM/TC and LVPS control board, Trigger Board and DAQ
- Manages system diagnostic routines
- Manages system configuration
- System monitor