Trigger and data acquisition system of the High Energy Particle Detector on board the CSES-02 satellite

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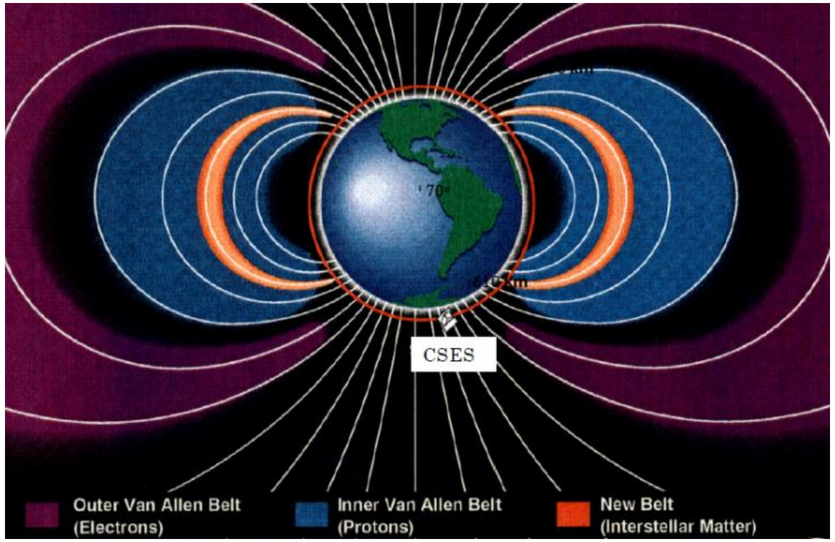
LIMADOU 利瑪竇

Outline

电磁监测卫星计划
China Seismo-Electromagnetic Satellite Program

- ❑ The CSES-02 satellite
- ❑ The High Energy Particle Detector (HEPD-02)
- ❑ The electronics of the HEPD-02
- ❑ The trigger and data acquisition system: requirements and capabilities
- ❑ Status and outlook

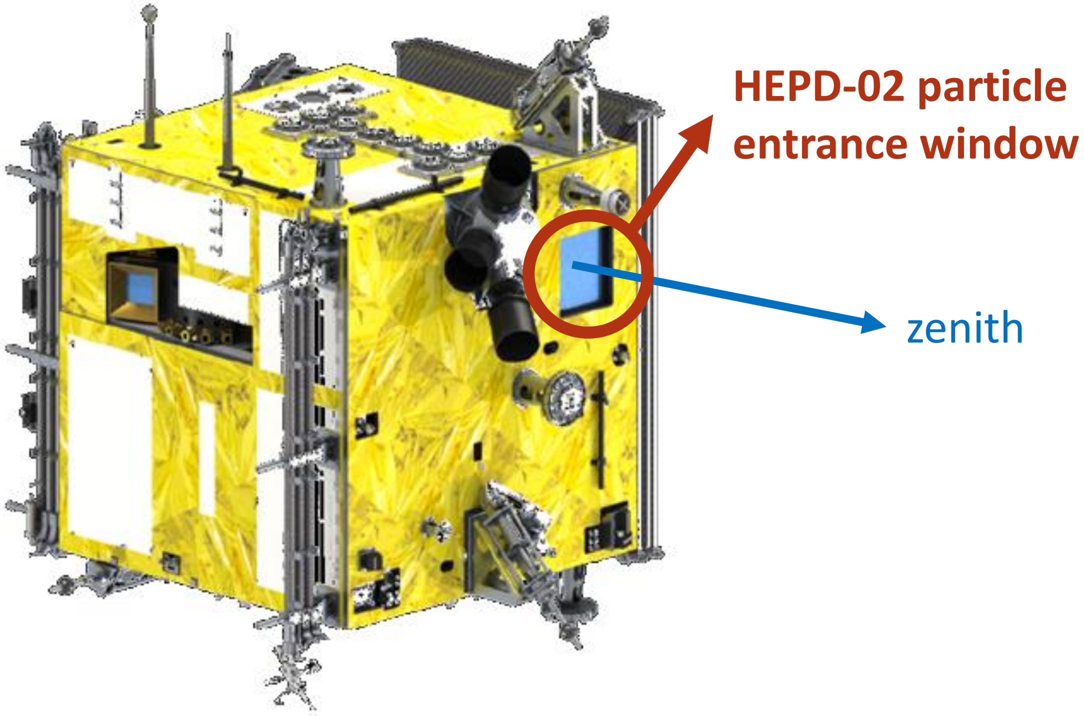


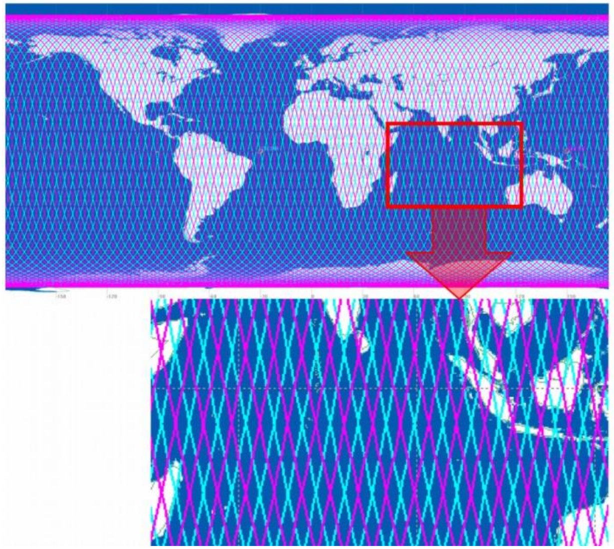
CSES-02 satellite

CSES-02: China Seismo-Electromagnetic Satellite

- Total Mass: 900 kg
- Orbit: 500 km, sun-synchronous, 97° inclination
  - Same as CSES-01 (launched in 2018), 180°phase difference
  - Orbit maneuver capability
  - Earth-oriented stabilization system
- Design life cycle > 6 years
- Launch expected in 2023
- Equipped with several payloads for electromagnetic and plasma measurements in the Van Allen belts

➢ **HEPD-02**: payload for (relatively) High-Energy Particle Detection
- Main target: energy spectrum of electrons and protons in the Van Allen belts
- Full time operational





HEPD-02

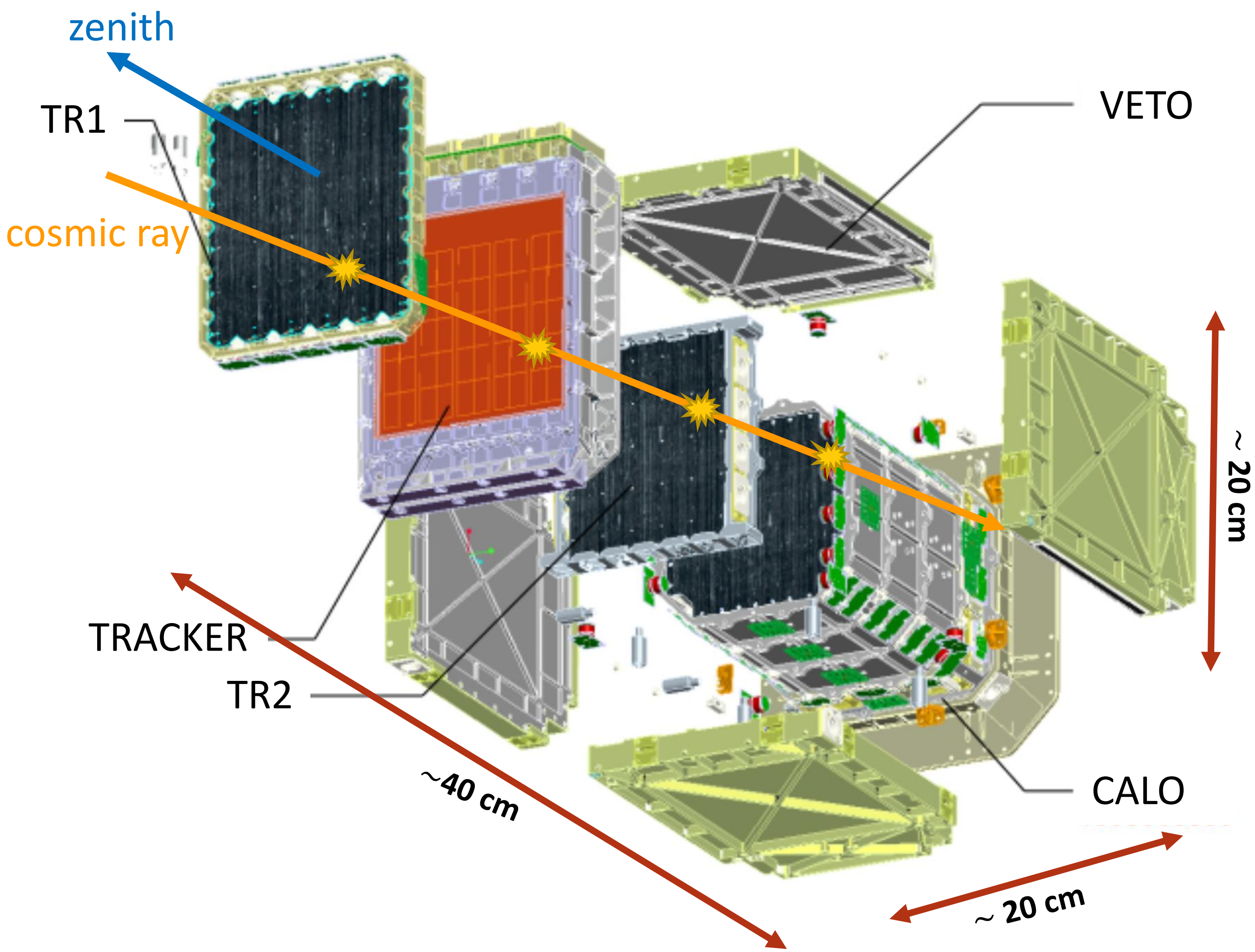
Low energy Cosmic Rays with energy 3 ÷ 300 MeV

For each particle:

- ✓ identification (proton, electron, nucleus)
- ✓ energy
- ✓ pitch angle

Goal: **maximize the geometrical acceptance**
according to weight and power budgets constraints

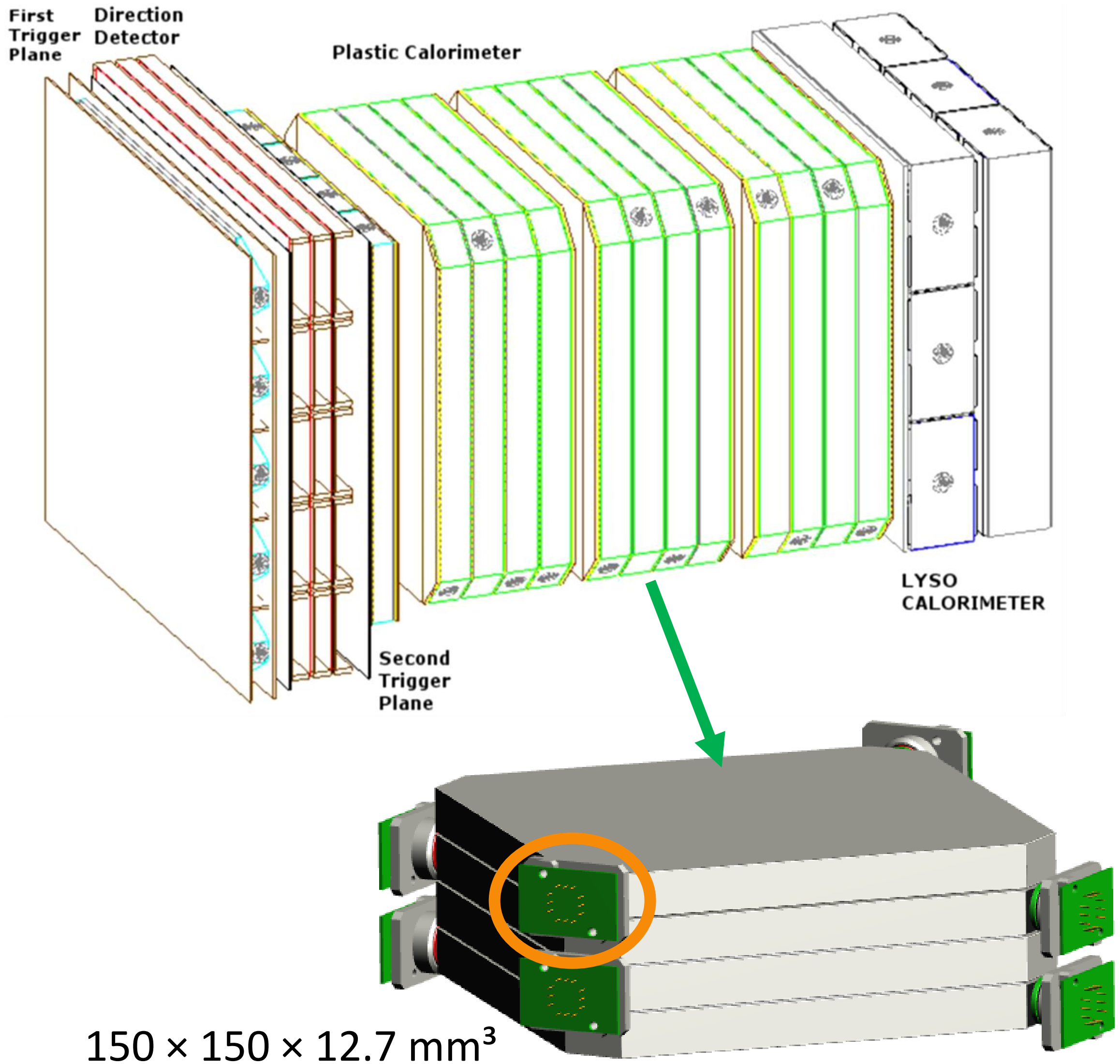
Parameter	Value
Energy Range	Electrons: 3-100 MeV Protons: 30-200 MeV
Angular resolution	Electrons: $< 10°$ with $E > 3$ MeV
Energy resolution	Electrons: $< 10\%$ with E>5 MeV
Pointing	Zenith
Operative temperature	-10°+35°
Mass	< 45 kg
Power Consumption	< 45 W
Data budget	< 100 Gb/day



The instruments

- **Trigger:** 2 crossed layers of plastic scintillators [18 PMT]
- **Tracker:** - 3 layers of CMOS **Monolithic Active Pixel Sensor**
  - after the 1st trigger plane to limit the effect of multiple scattering on the direction measurement
- **Calorimeter**: - **12 layers** of 12 mm thick **plastic scintillator** (EJ-200) planes [24 PMT]
  - **2** crossed **layers** segmented into 3 bars of **LYSO** scintillator crystals (high LY, slower) [12 PMT]
- **Veto:** (not shown) 4 lateral + 1 bottom planes of 8 mm-thick plastic scintillators, surrounding the calorimeter [10 PMT]

PMT: Hamamatsu R9880-210



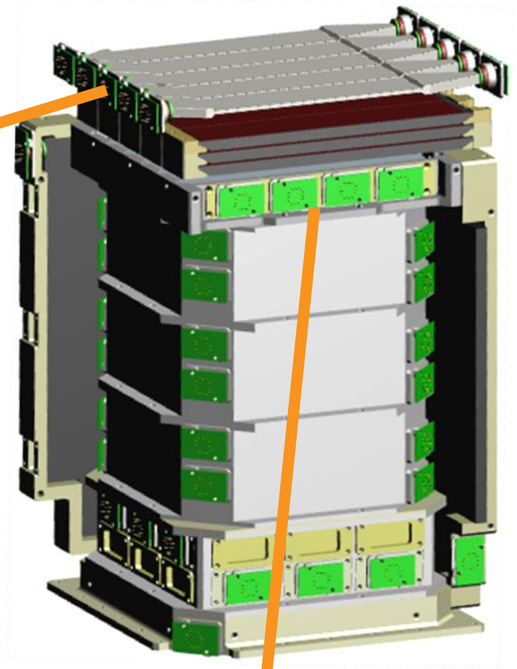
$150 \times 150 \times 12.7$ mm^3

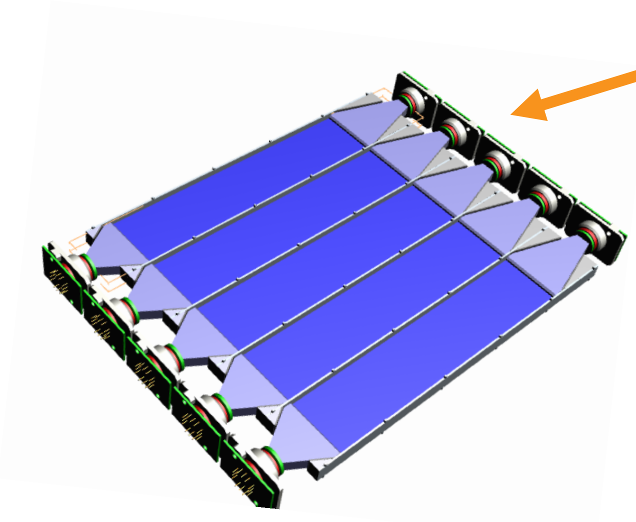
The trigger detector

2 crossed layers of scintillator planes
EJ-200 enclosing the tracker

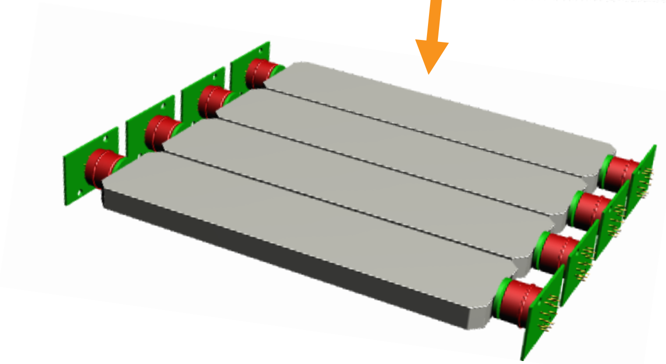
TR1:
- segmented into 5 counters read out by light-guides connected to PMTs: to match the tracking modules
- 2 mm thick: to minimize multiple scattering and allow for a low threshold

TR2:
- segmented into 4 ticker bars: to give a good measure of the energy loss of charged particles





TR1: $200 \times 180 \times 2$ mm^3



TR2: $150 \times 150 \times 8$ mm^3

- All counters are covered with a reflective coating and read out by two PMTs

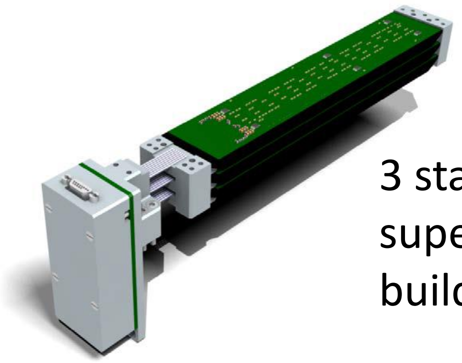
Trigger logic:
- **Flexible:** combinations of signals from TR1, TR2 and CALO planes form HEPD trigger configuration which can be selected during the flight
- **Strong**: to cope with increased fluxes of particles at polar orbits

The tracker

3 sensitive planes of 5 independent tracking modules Monolithic Active Pixel Sensor (MAPS):

- based on the MAPS developed for ALICE experiment at LHC
- ✓ reduces systematic uncertainties on tracking: up to 6x single-hit resolution
- ✓ no multi-hit degeneracy

- Each plane has 10 sensors of 512x1024 pixels in 15x30 mm^2
- Control and read-out based on ultra-thin (180 mm) flexible printed circuits



3 staves are superimposed to build a turret

Challenges for use in Space:

- Light support (to avoid multiple scattering)
- Support must withstand launch acceleration and vibrations
- Heat dissipation and material outgassing in vacuum
- Limited power budget

The whole tracker is formed by 5 turrets:

- 15 staves
- 150 MAPS
- 80 Mpixel in 3 planes

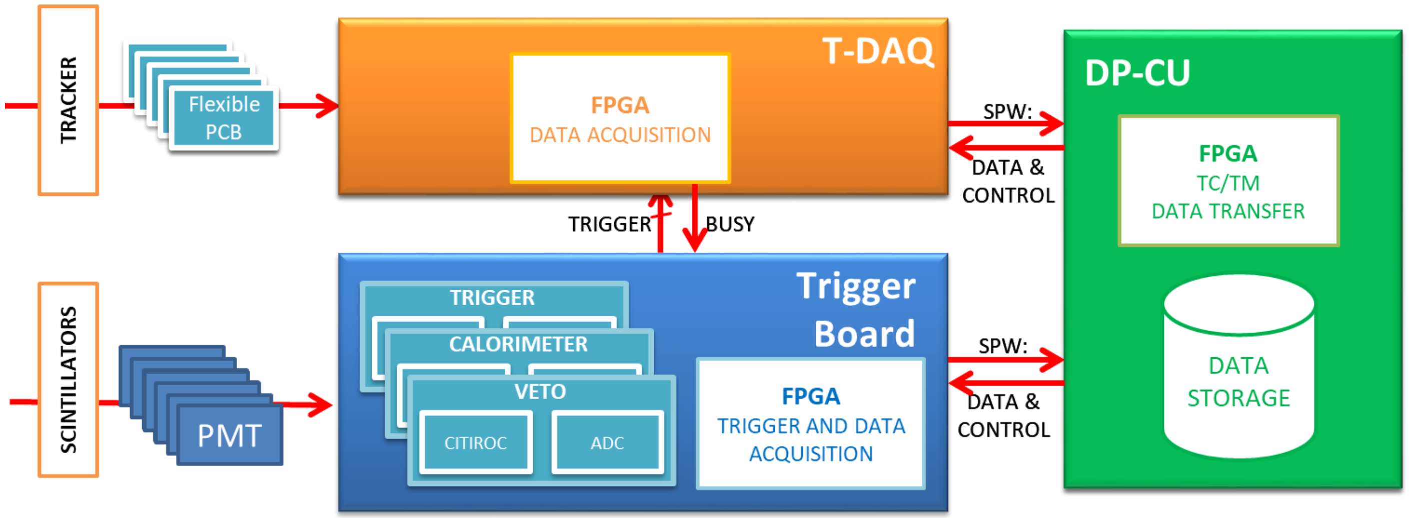
The electronics

Data acquisition:

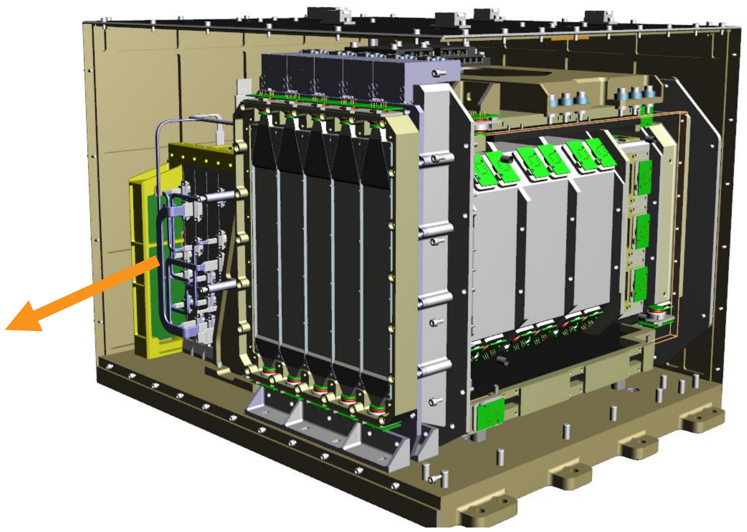
1. Tracker detector (T-DAQ)
2. Scintillator detectors: trigger, calorimeter and veto (Trigger Board)

Managing and control

1. Global control and data managing (DP-CU)
2. LV-PS and HV-PS



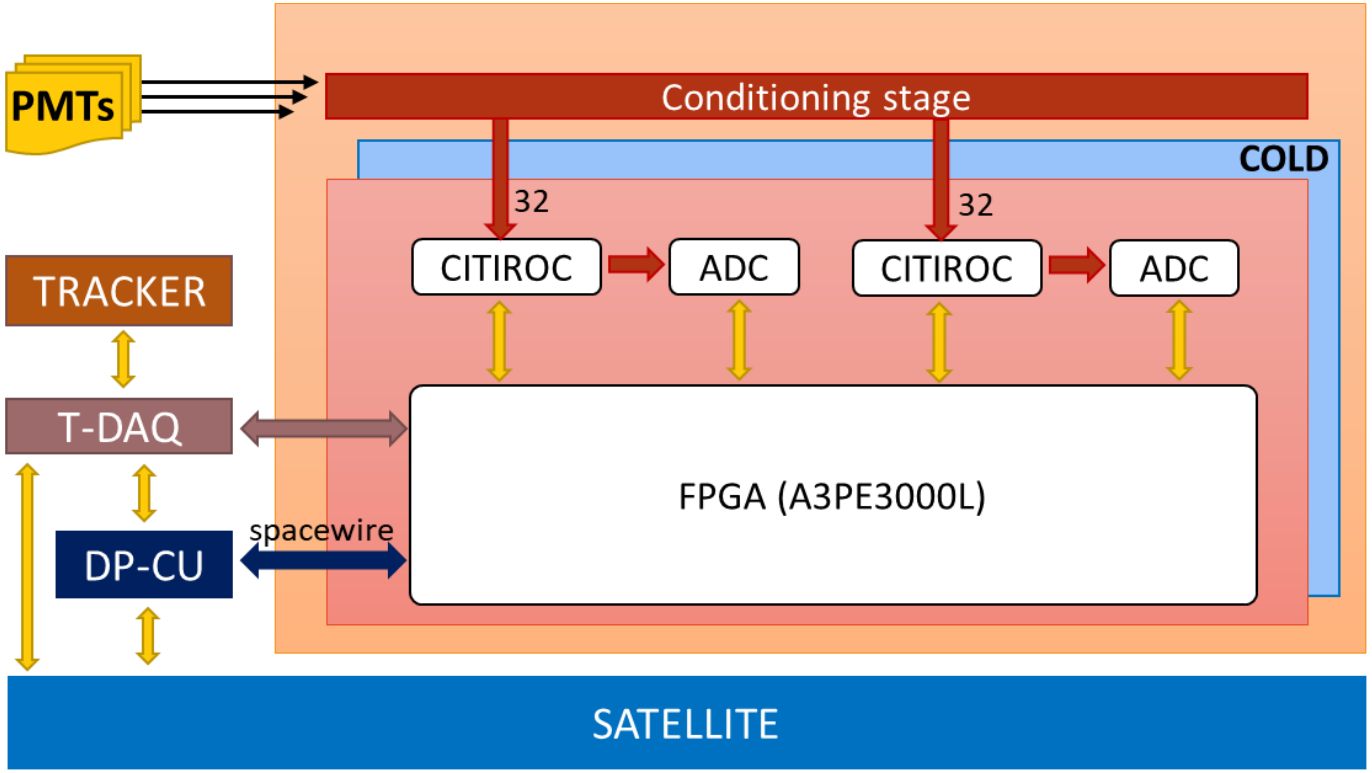
- Dedicated mechanics that allow anchoring to the HEPD-02 base plate and heat dissipation
- Communication via SpaceWire Light protocol
- Embedded “HOT/COLD” redundancy
- -30°C to +50°C qualification temperature range
- Max data transfer rate from satellite = 100 Gb per day



The trigger board

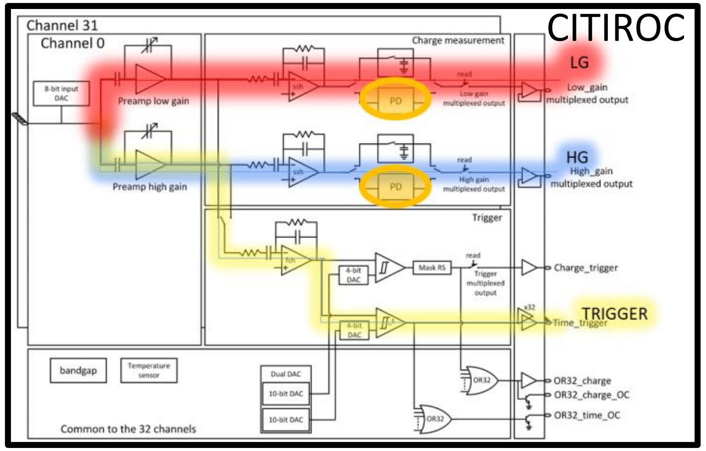
Functionalities:

- Readout of 64 PMT: 2×32-channel ASICs CITIROC (Weeroc)
- Digitalization of PMT signals
- Configurable gain/trigger threshold to optimize the acceptance
- Two different configurable gain chain
- Different trigger configurations to match different orbital zones and particles
- Rate meters for each PMT and trigger configuration



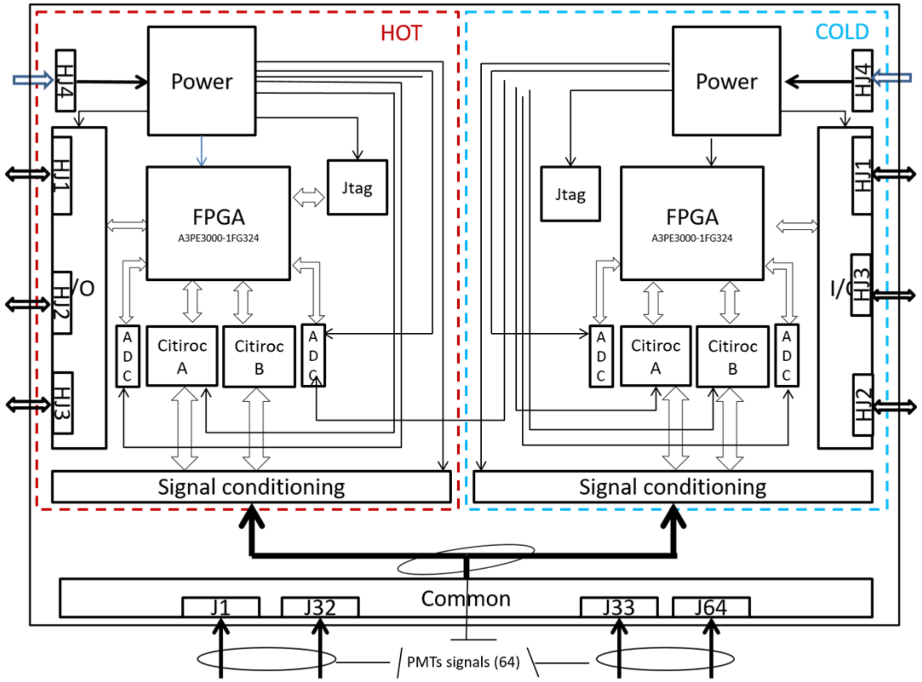
From HEPD-01 to HEPD-02:

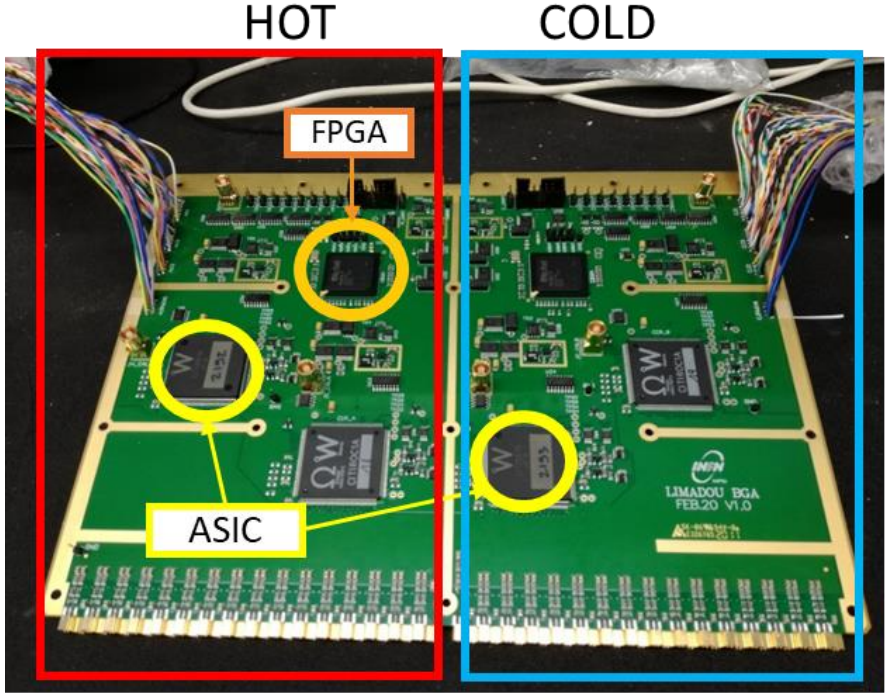
- High trigger rate at polar regions: improved trigger logic and pre-scaling
- Larger amount of acquired data: mass memory on board for buffering



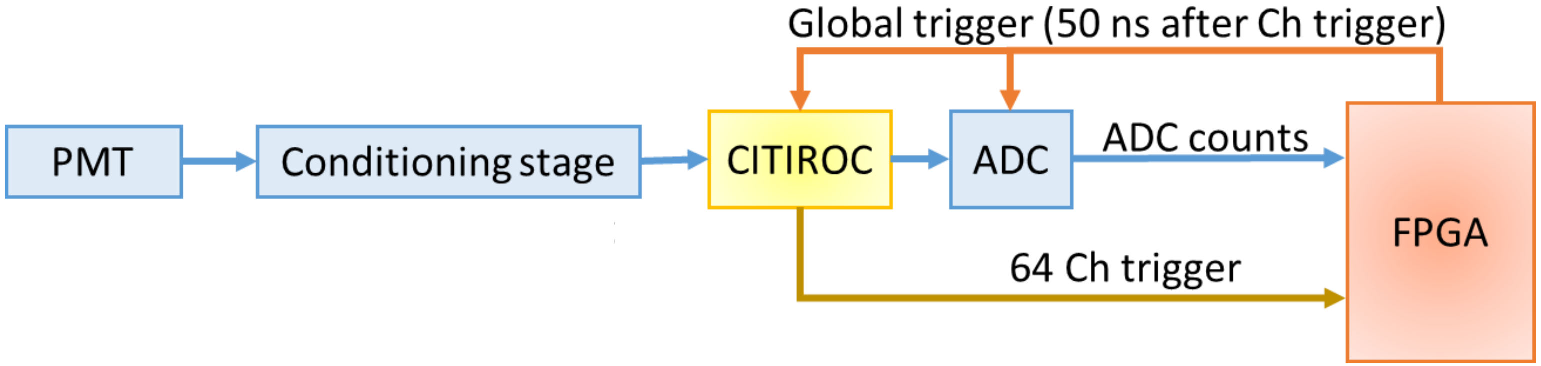
Trigger board architecture

- Custom designed
- 64 channels in common for HOT and COLD sides
- On each side (H&C):
  - FPGA: MicroSemi ProASIC A3PE3000
  - 2 ASIC: CITIROC 1A Weeroc
  - 4 ADC: AD7274 (12 bits, 24 MHz)
- Signals coming from the last dinode of PMTs
  - Reduce power consumption
  - Simplify design (no inverters)
- Coaxial cables RG178 to improve noise immunity

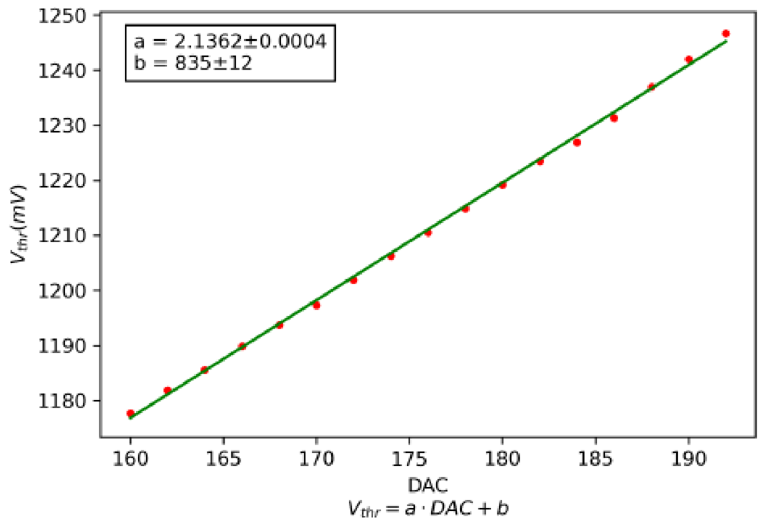


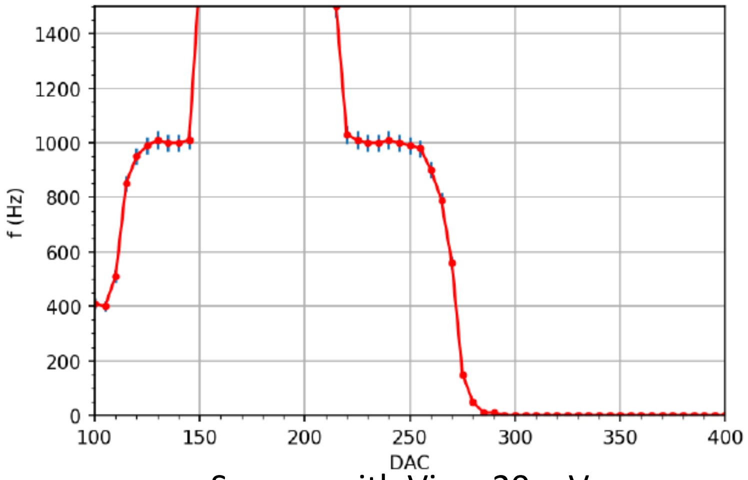


Trigger/PMT board (EM)

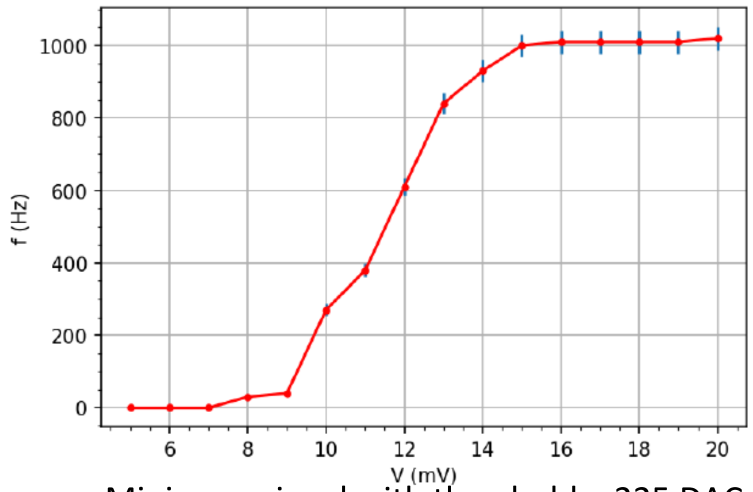


Characterization of the read-out chain





S-curve with Vin = 20 mV



Minimum signal with threshold = 225 DAC

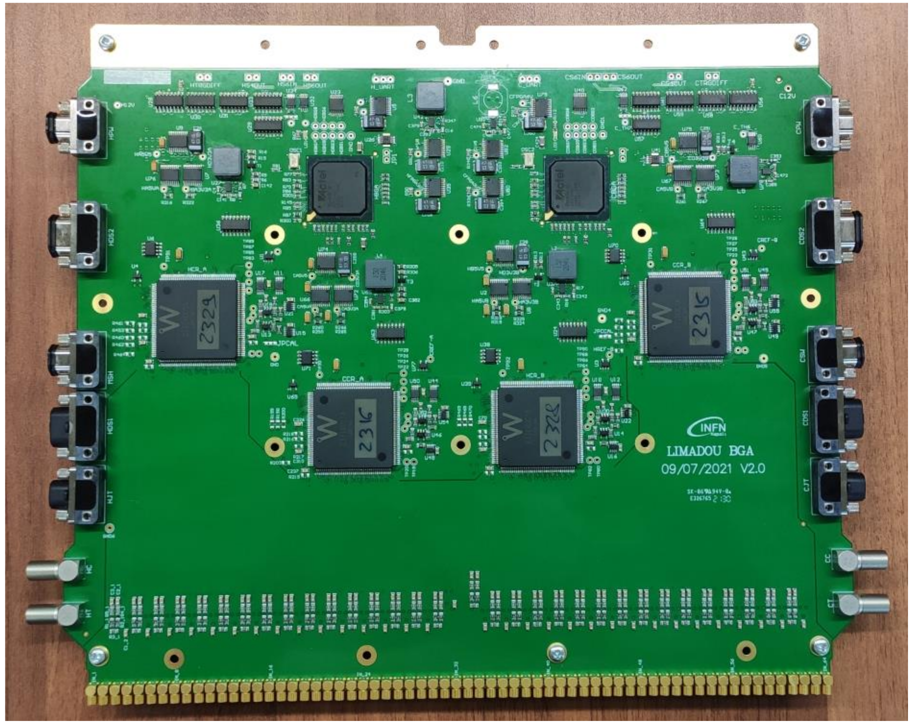
Attenuation factor	Threshold	Minimum amplitude (mV)
3	250	12
6	225	15
20	210	35

Minimum amplitude to get 100% trigger efficiency

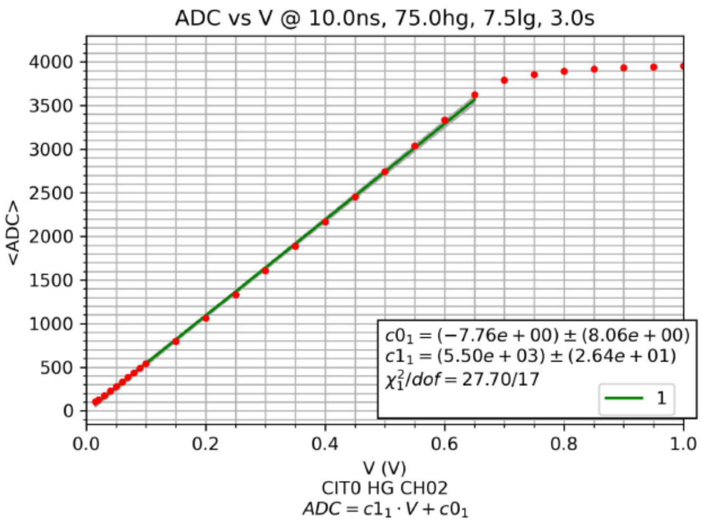
- Smallest detectable input signal (square signal of 10 ns) (3% 1/3 MIP on TR1)= 17mV corresponding to pC (about 3 pe @ 10^6 PMT gain) → 2.3 mV @Citiroc

- Min DAC threshold = 220-240
- Trigger from the HG chain
- Use of the peak detector

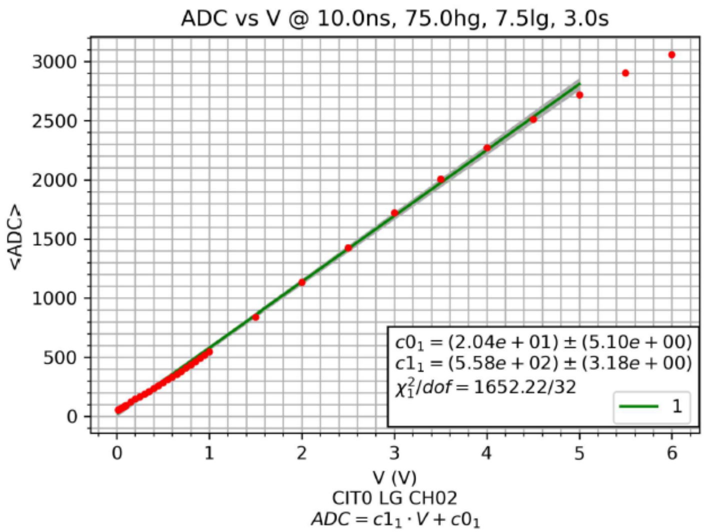
EM board response



HG = 75



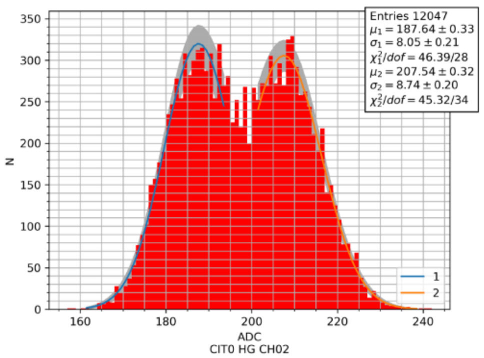
LG=7.5



S/N ratio (10 ns square pulse)

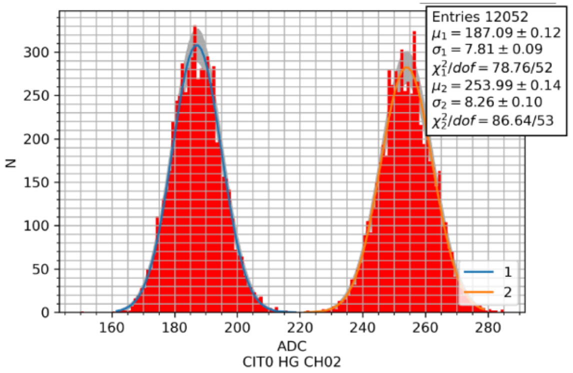
V_{imp} (mV)	μ_{sig}	μ_{pdst}	σ_{pdst}	S/N
15	207.5	187.6	8.1	2.45
30	231.1	186.9	7.9	5.59
45	254.0	187.1	7.8	8.58

1/3 MIP



(a) $V_{imp} = 15\,\mathrm{mV}$ (1/3MIP)

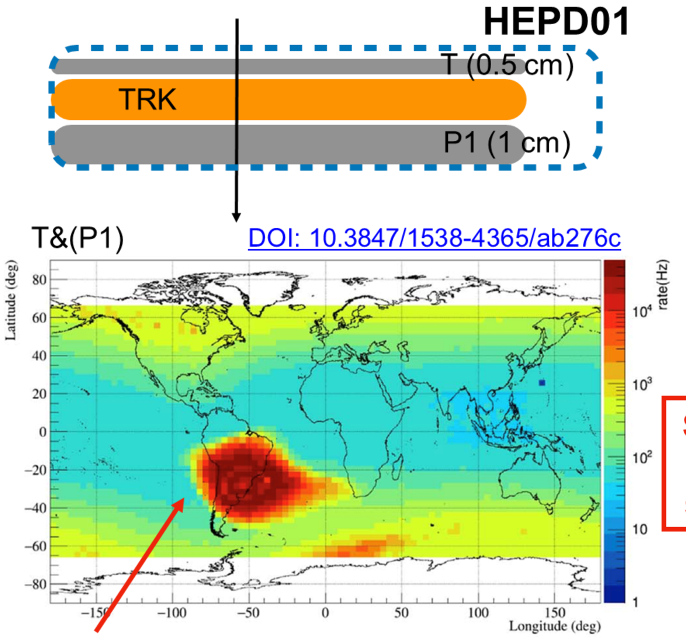
1 MIP

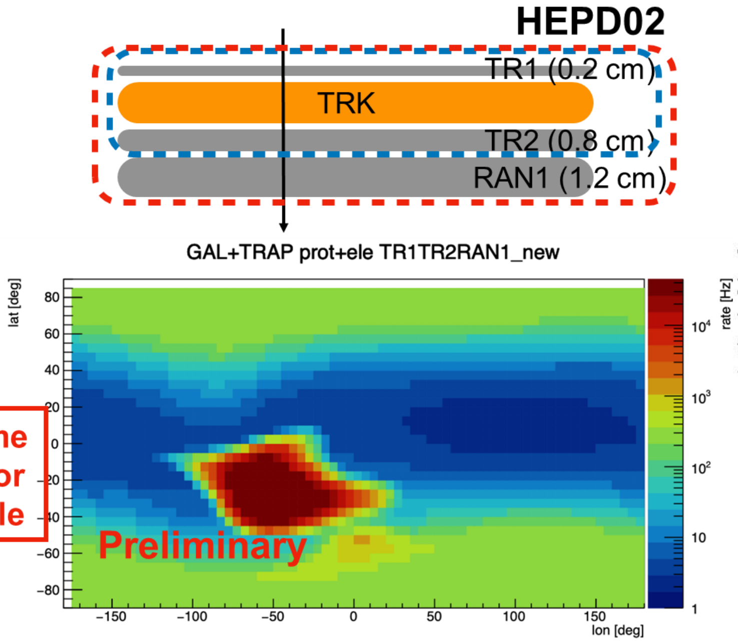


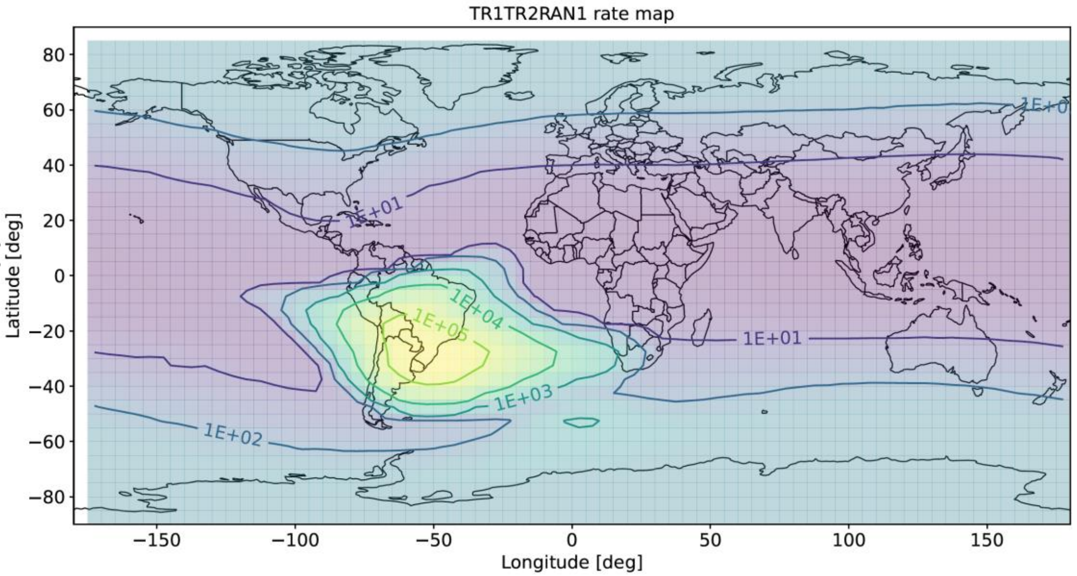
(c) $V_{imp} = 45\,\mathrm{mV}$ (1MIP)

Trigger capabilities

- Along the orbit of CSES-02 particle fluxes span several orders of magnitude
- Data acquisition must guarantee the measurement of energy spectra with a high duty cycle
- Capability to acquire data on the SAA by selecting appropriate trigger configurations





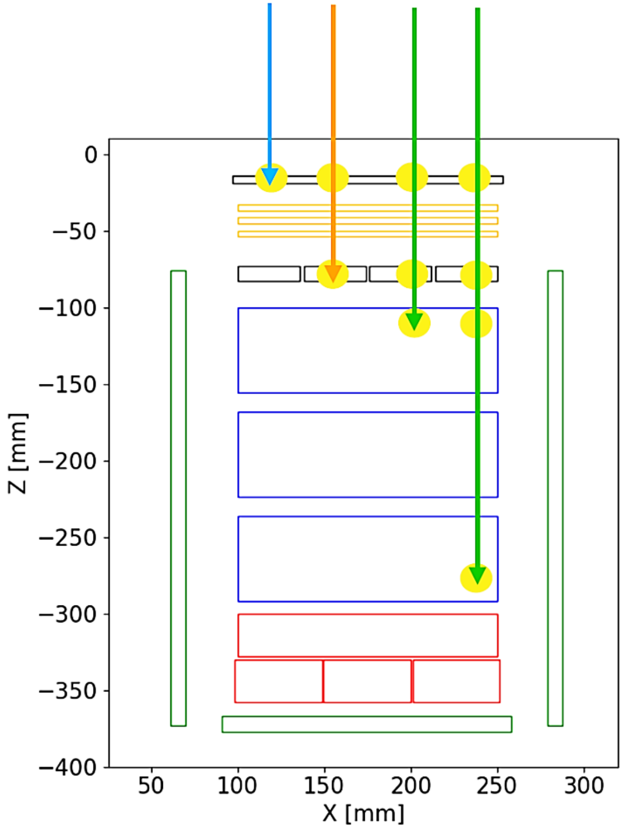


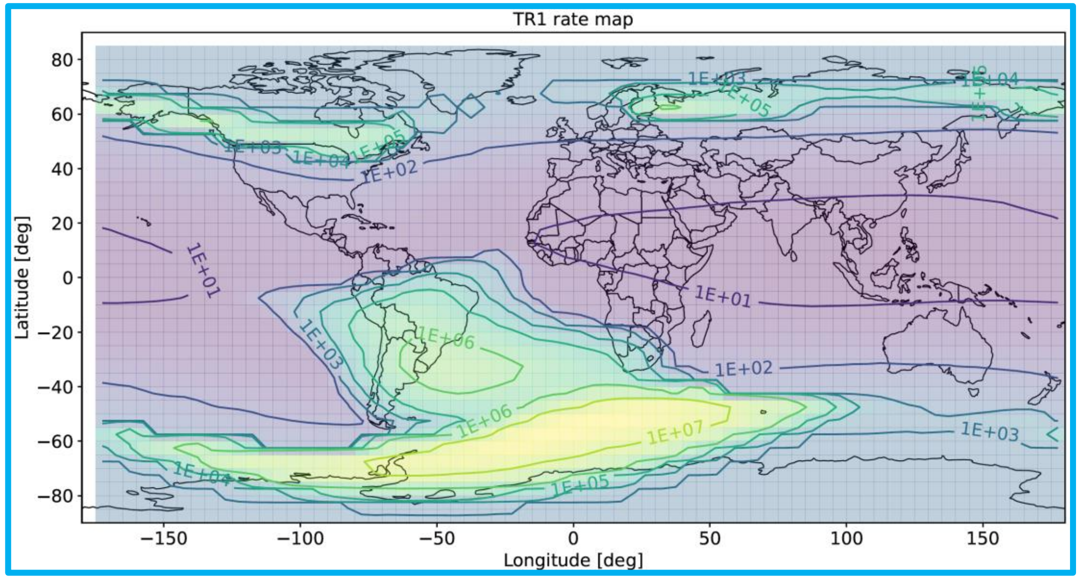
SAA Sat

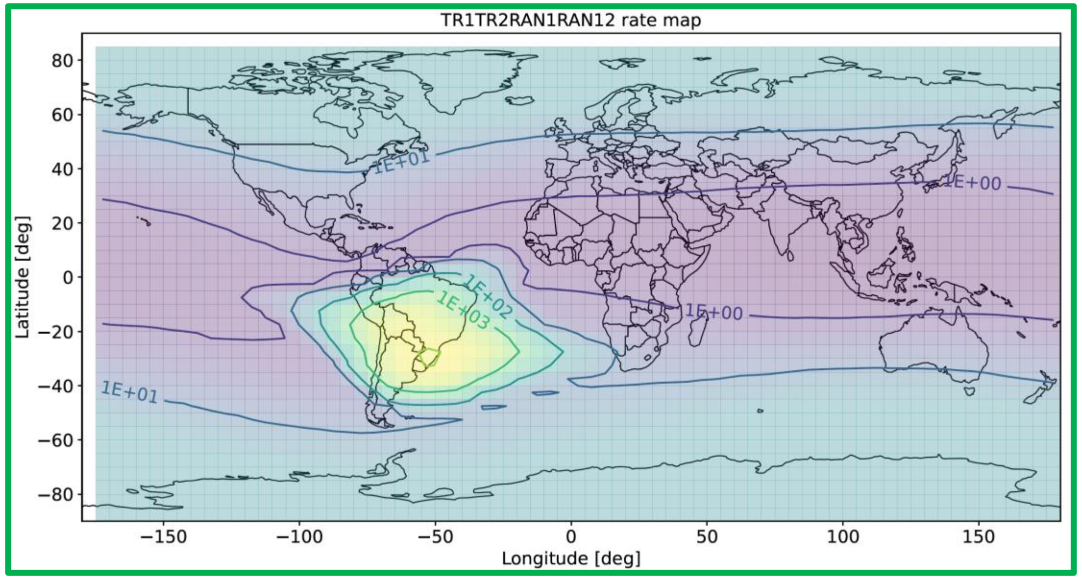
T&P1(HEPD01) is in between TR1&TR2 and TR1&TR2&CALO1 (HEPD02)

Courtesy F. M. Follega @unitn

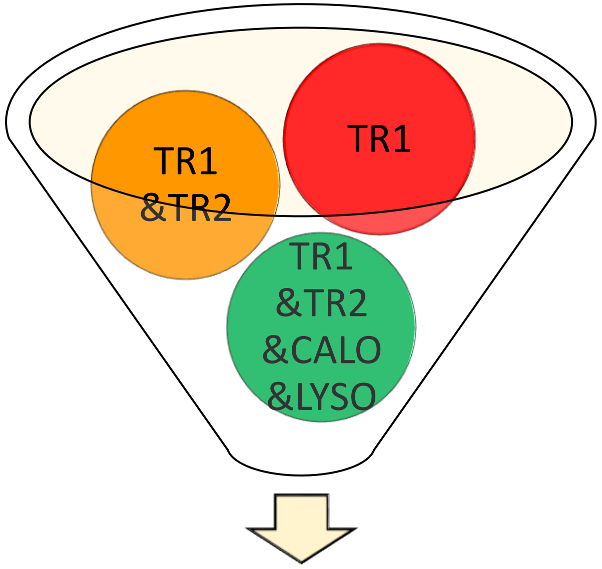
Concurrent trigger and prescaling





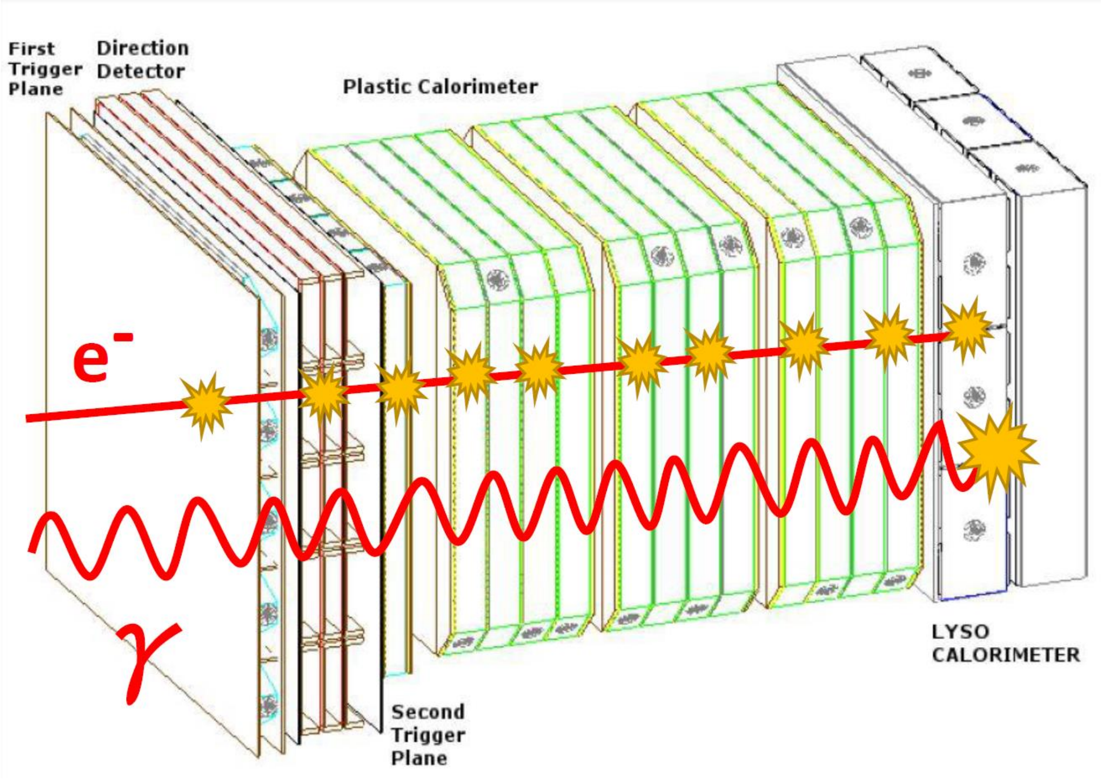


- Concurrent trigger configurations prescaled to match the amount of data the instrument can process and send to the ground
- Configurations optimized after scientific requirements about FoV and kind of particle, with prescaling suitably adjusted

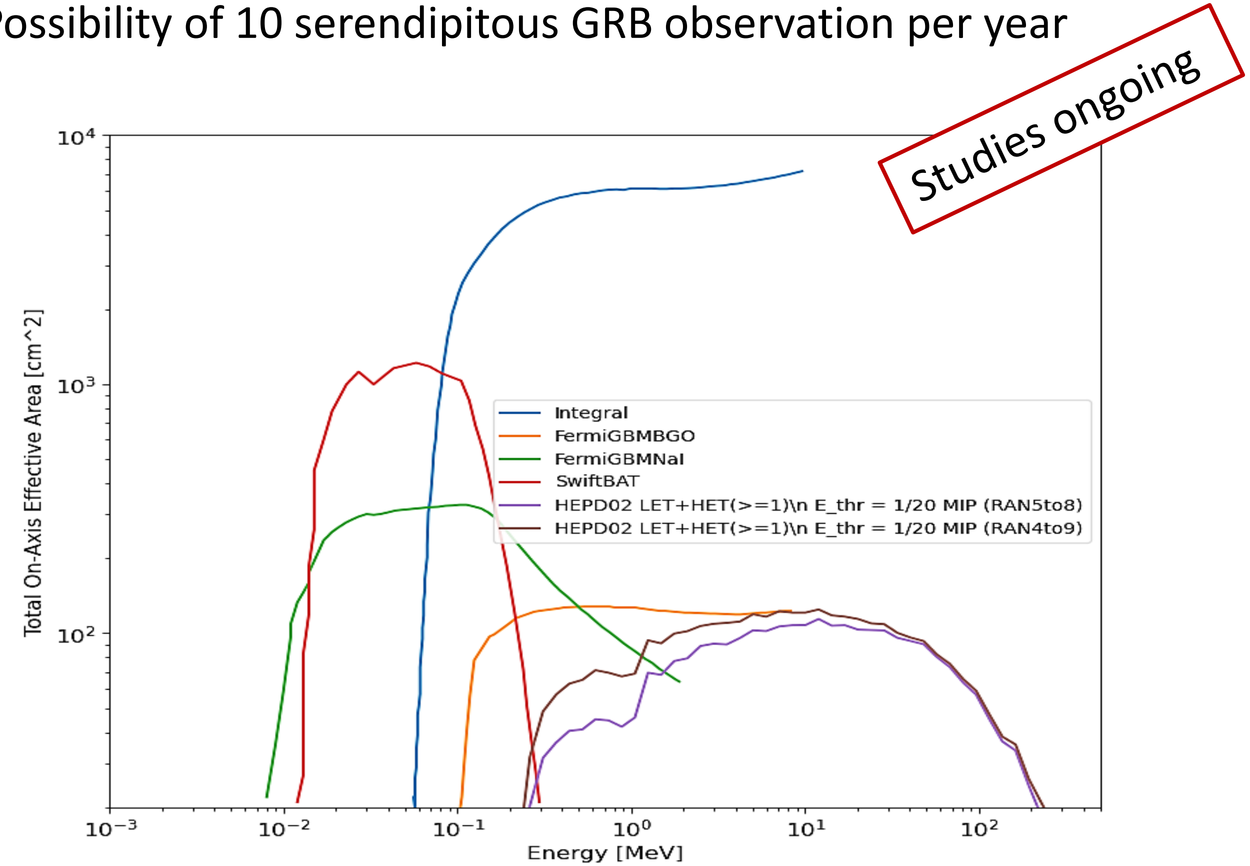


HEPD-02 trigger

Gamma-ray observation opportunity



- LYSO radioactivity background: negligible effect above 2 MeV
- HEPD-02 will be able to measure photons of energy > 2 MeV
- Trigger configuration dedicated to gamma rays tracked on a time basis of 10 milliseconds
- Possibility of 10 serendipitous GRB observation per year



Status and outlook

The 1st satellite of the CSES program was launched on February 2nd, 2018 and all 8 payloads worked smoothly since then

- Data analysis is ongoing to look for correlations of particle bursts with seismic phenomena
- Space weather physics program well developed: very low-energy galactic and trapped particles

✓ The design of the HEPD-02 Trigger Board has been finalized and the QM is under production

✓ A versatile and powerful trigger system has been designed

✓ An intense tests program has been scheduled to target the launch in 2023

2018-2022	Jul-Oct 2022	Oct 2022	2023
- Instrument concept and design - EM development and test	Thermal-vacuum, vibration, and beam test in Italy	Flight model delivery	Launch


Thank you!