Trento Institute for Fundamental Physics and Applications

UNIVERSITÀ DI TRENTO

Status and future prospects of the Limadou HEPD on board the CSES satellite

Advances in Space AstroParticle Physics - ASAPP, 19-23 June 2023

F.M.Follega[1,2] on behalf of the CSES-Limadou collaboration

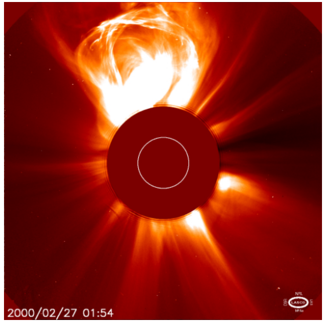
(1) *University of Trento*
(2) *INFN-TIFPA*

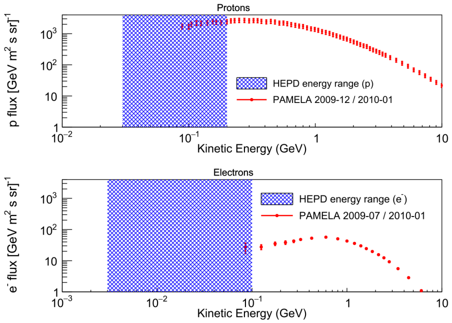
The CSES scientific mission

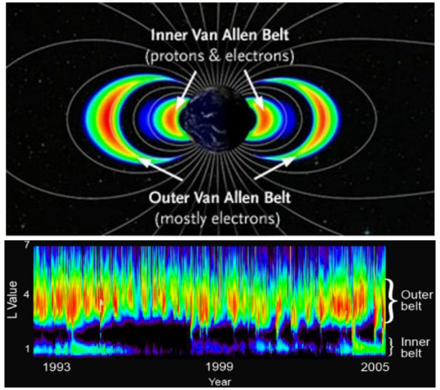
The **CSES mission** is a scientific collaboration between Italy and China.

Scientific goals:

- **Investigate the ionosphere** and gather world-wide data;
- Measure the particles and plasma **perturbations in the ionosphere and magnetosphere:** natural sources (EQs) and anthropic emitters;
- Study solar-terrestrial interactions and solar physics: CMEs, SEPs, solar flares;
- Study and extend **low energy spectrum of cosmic rays;**

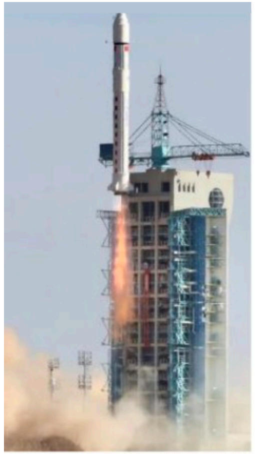






The CSES-01 Satellite

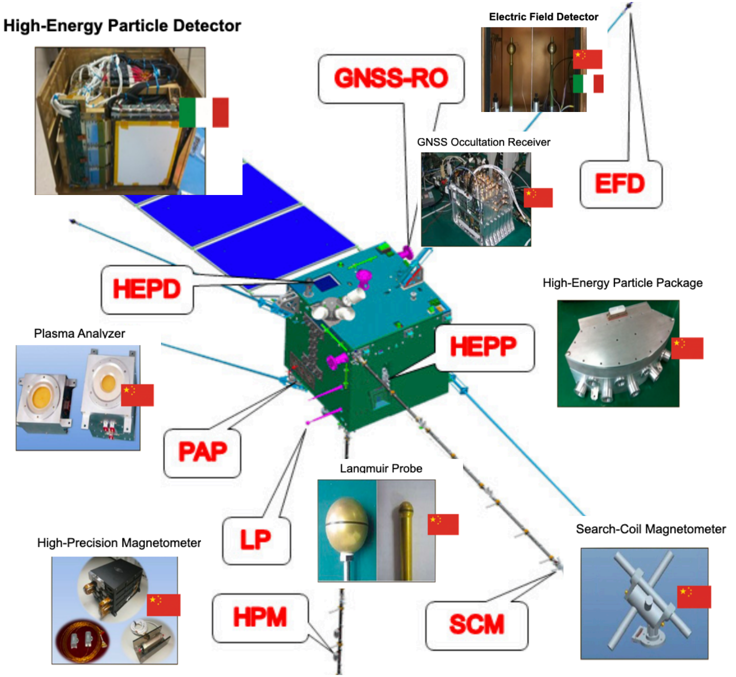
CSES-01 was launched on 02/02/2018



- Sun-Synchronous orbit at 500 km;
- Equipped with 9 instruments, among them the **High-Energy Particle Detector (HEPD-01)**
- Payload operation range -65°/65° lat

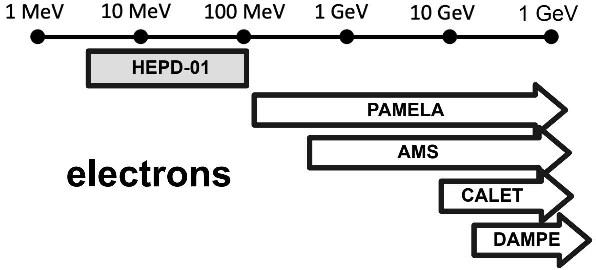
Category	Payload Name	Observation Targets
Electro-Magnetic Field	*Electric Field Detector*	*Electric Field: DC ～3.5MHz*
	High Precision Magnetometer	*Magnetic Field: DC ～15Hz*
	Search Coil Magnetometer	*Magnetic Field: 10Hz ～20kHz*
Energetic Particle	*Italian HEPD(INFN Prod.)* *High Energy Particle Package*	*Proton：2MeV~200MeV* *Electron：100keV~100MeV*

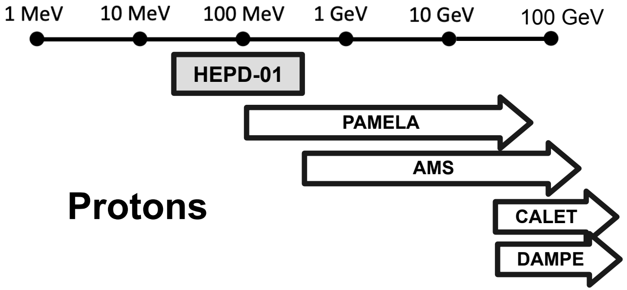
CSES-01: is a sophisticated space observatory.



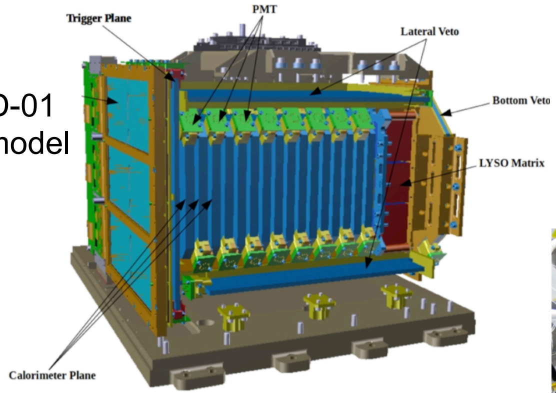
The High Energy Particle Detector HEPD-01

HEPD-01 is designed to measure fluxes of charged particles: electrons (3-100 MeV) and protons (30-200 MeV).

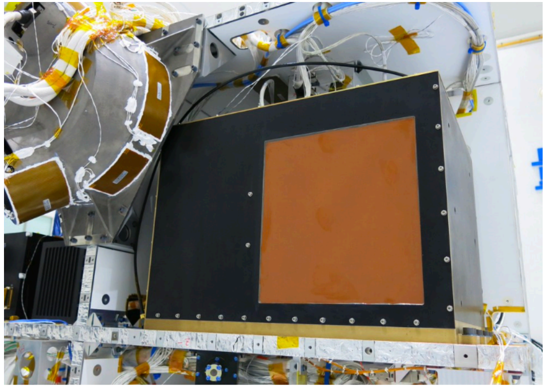


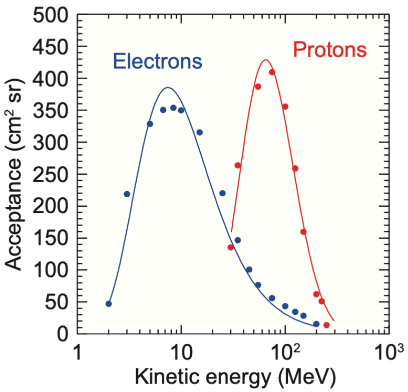


HEPD-01
CAD model



Limadou HEPD-01 integrated on CSES



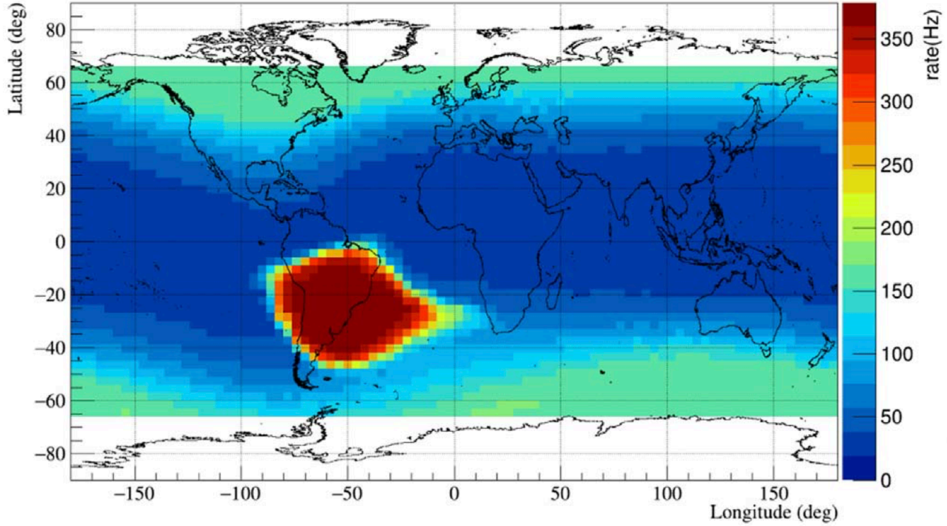


Acceptances for contained particles
Peak ~ 400 cm^2 sr

[Sci. China Technol. Sci. 61, 643–652 (2018)]

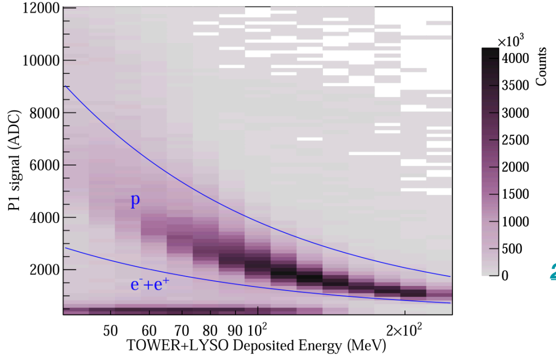
HEPD-01 event acquisition and reconstruction

Data acquisition performed in several modes/with different trigger masks:
- T ⟶ rate studies @ low energies
- T & (P1&P2) ⟶ standard DAQ mask

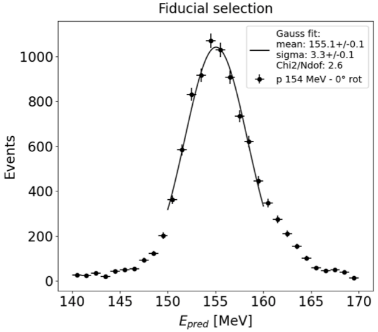


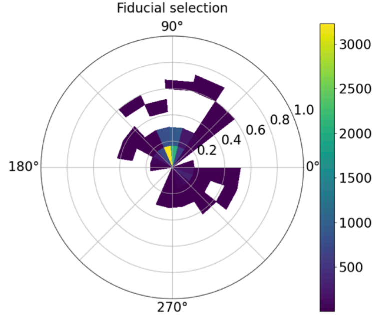
Event acquired also in SAA (saturation effects)

Event reconstruction strategy



2020 ApJ 901 8

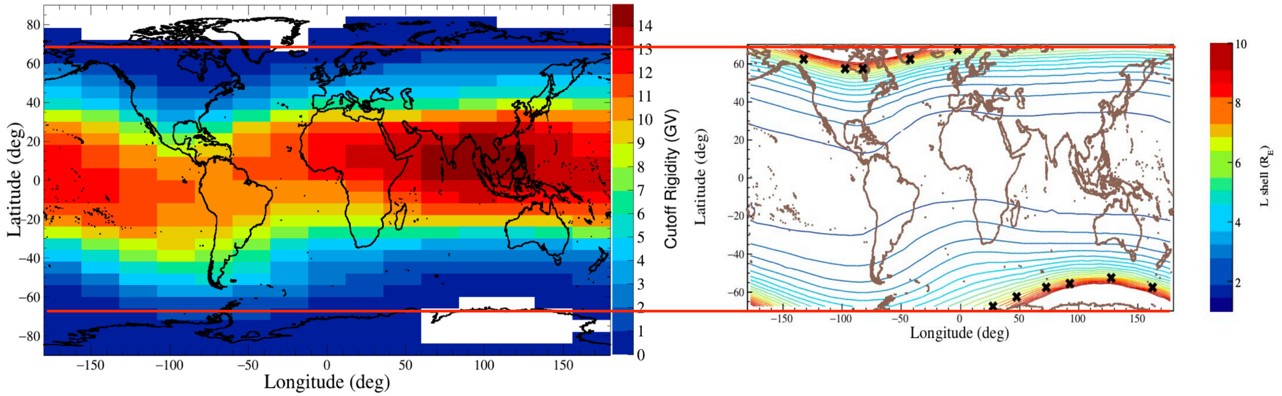


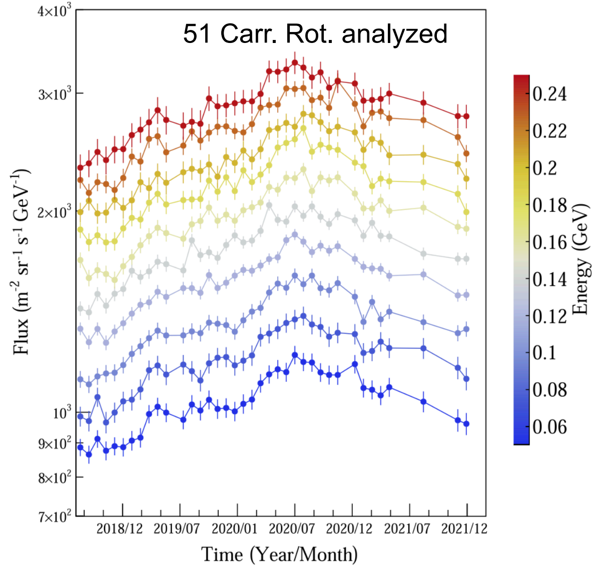


Phys. Rev. D 105, 022004

Galactic Cosmic-Ray Hydrogen Spectra

HEPD-01 demonstrated excellent capabilities to measure protons and the possibility to study the solar modulation.

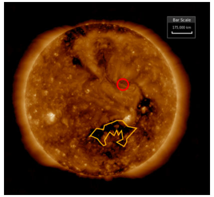




- To separate primary cosmic ray protons from albedo protons, a rigidity cut-off/ L-shell map (L-shell>7) was used;
- Residual contamination, due to high-energy electrons is below 10%.

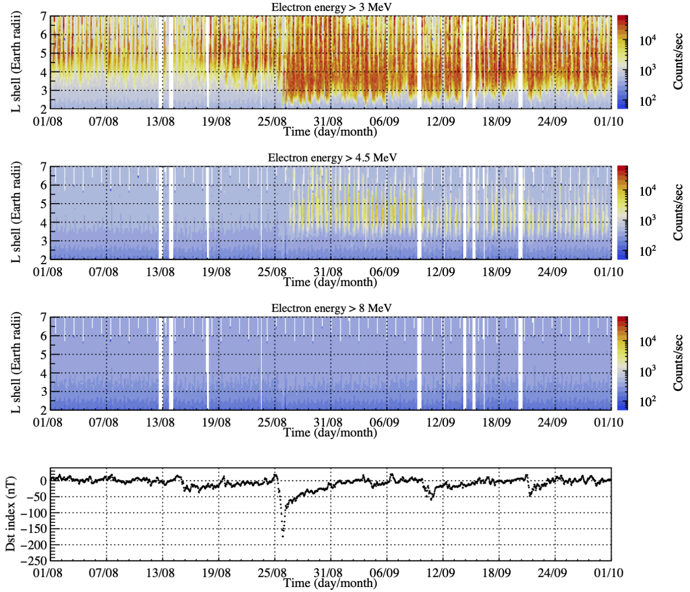
ApJL 945 L39 (2023)

Observation of Space Weather phenomena

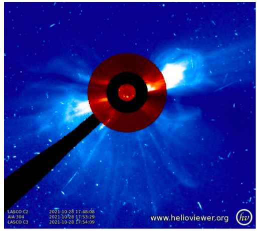


Geomagnetic storm of 26/08/2018

- A clear enhancement of HEPD-01 count rate for electrons @ L > 3
- Other geomagnetic storms under study



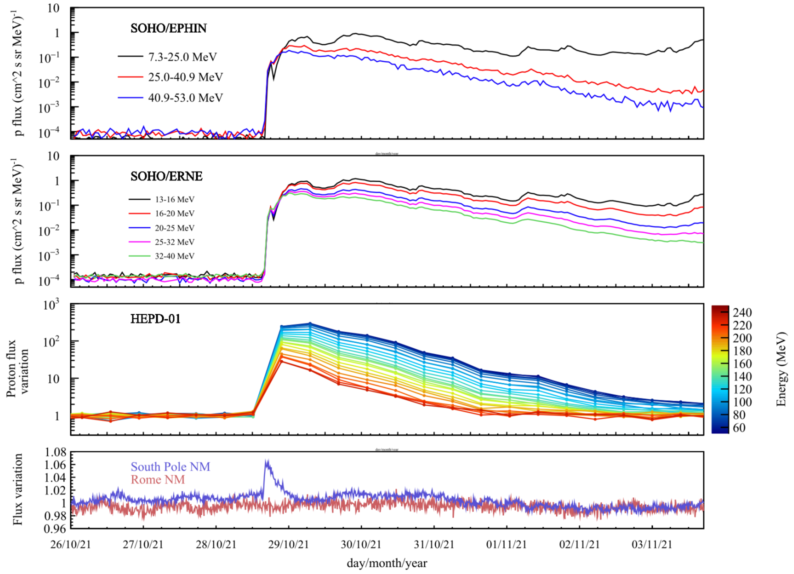
Appl. Sci. 2021, 11(12), 5680



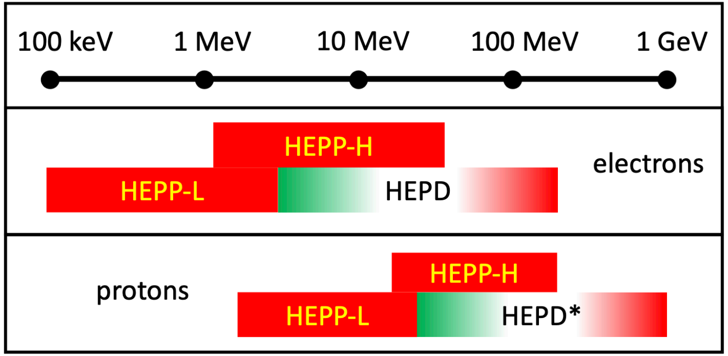
SEP/Ground-Level Enhancement (2021)

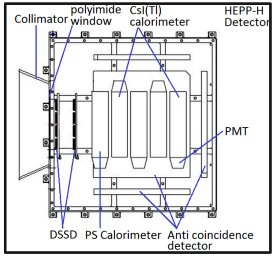
- 200x flux variation for ~50 MeV proton flux
- Rapid increase for energies up to 250 MeV

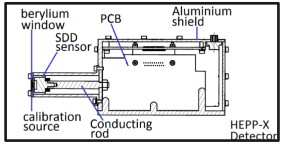
10.1029/2022SW003191

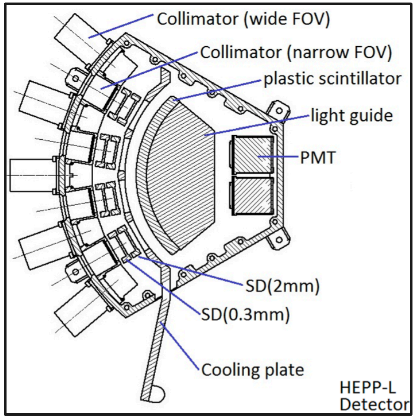


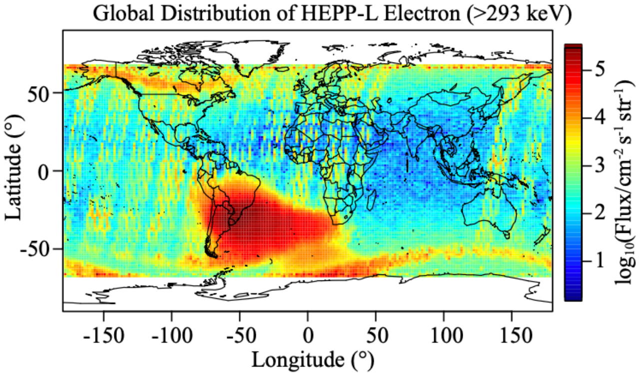
Other particle detectors on board CSES-01



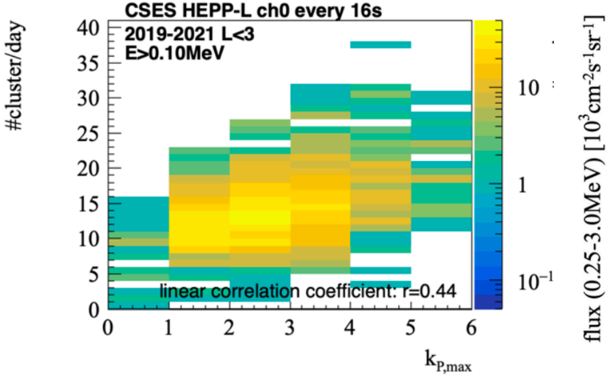




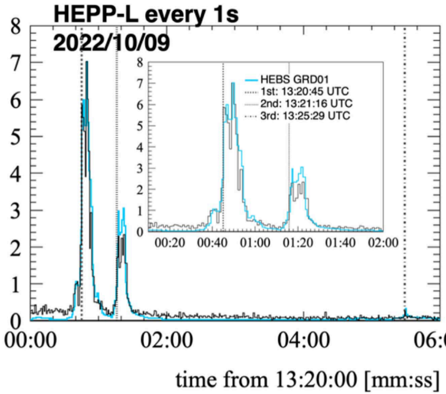




Remote Sens. 2023, 15(2), 411



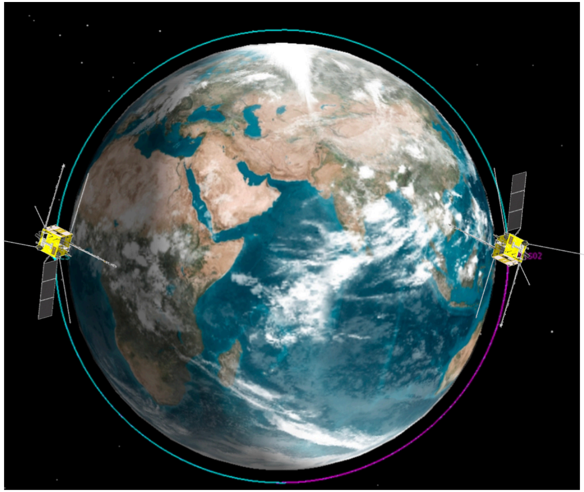
ApJL 946 L29 (2023)



The future of the mission with CSES-02

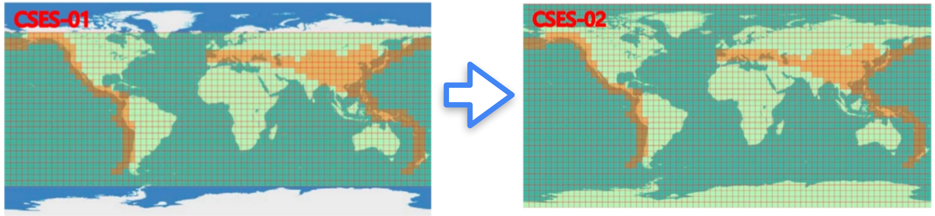
The launch of the second satellite CSES-02 will lead to a new era for the project, **making CSES a sophisticated multi-satellite space observatory:**

- Same platform of CSES-01 with some upgrades
  - system with orbit manoeuvre capability
  - X-Band Data Transmission 120Mbps →150Mbps
  - Total Mass: 730kg→900kg
  - Peak Power Consumption: ~900W
  - Design Life-span: 5 years→6 years
- Complementary Orbit with CSES-01
  - Same Orbit Plane but shifted by 180°;
  - Return cycle: 5 days→2.5 days
- Operation mode: Full time operational



Operation area between lat [-65,65]

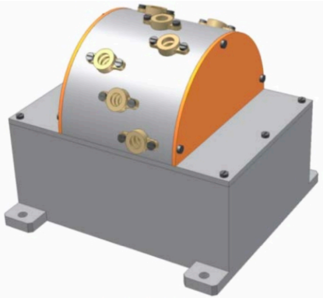
Full coverage at extreme latitudes



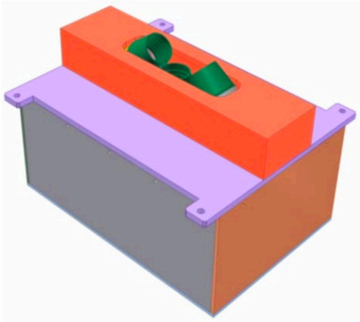
The Limadou Collaboration committed to build HEPD-02

Particle detectors on-board CSES-02

MEED-L



MEED-H

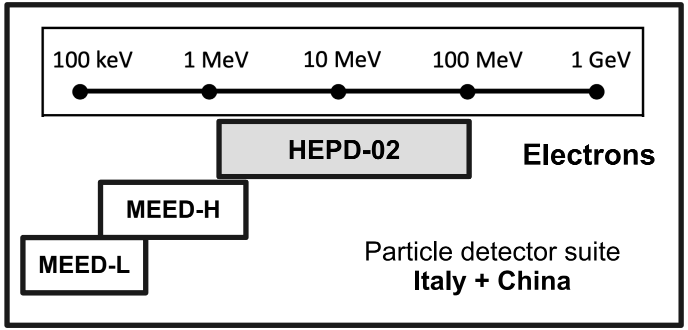


<u>In situ measurement of electrons:</u>

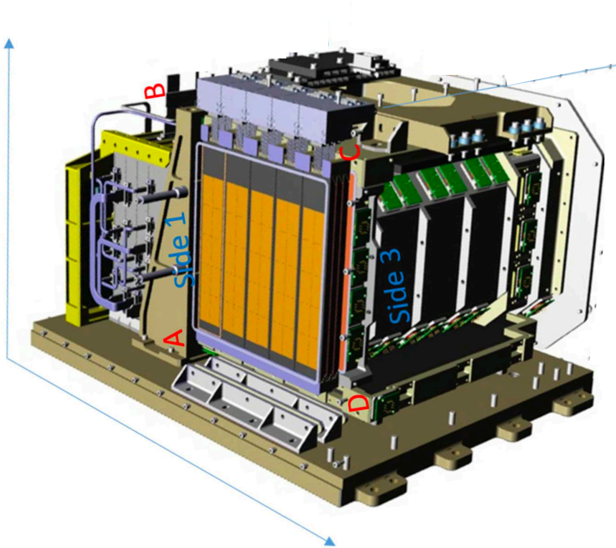
- MEED-L: 9 silicon sensors, energy range 25 keV to 400 keV

- MEED-H: 3 sensors, energy range: from 200 keV to 3.2 MeV

Designed to have a small overlap with Limadou HEPD-02



Limadou HEPD-02



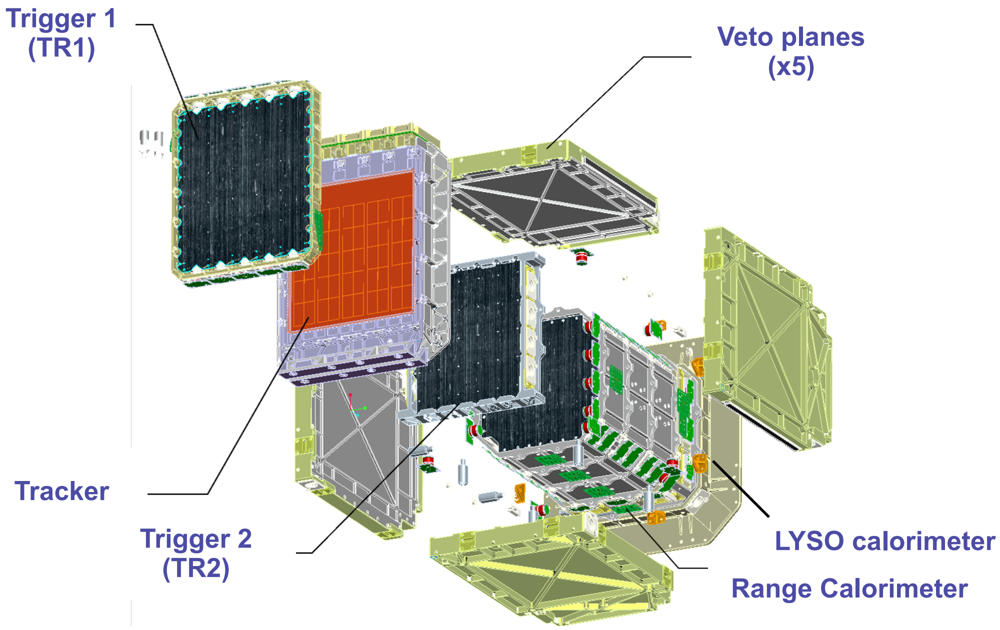
Major Changes with respect to HEPD-01

1. **Pixel tracker (MAPS modules)**
   -> 28 um pixel pitch

2. **Trigger doubled** (2 planes):
   - TR1 is 5 bars 0.2 cm thick
   - TR2 is 4 bars 0.8 cm thick (opposite direction w.r.t. TR1)
   -> Decrease energy threshold and increase redundancy.

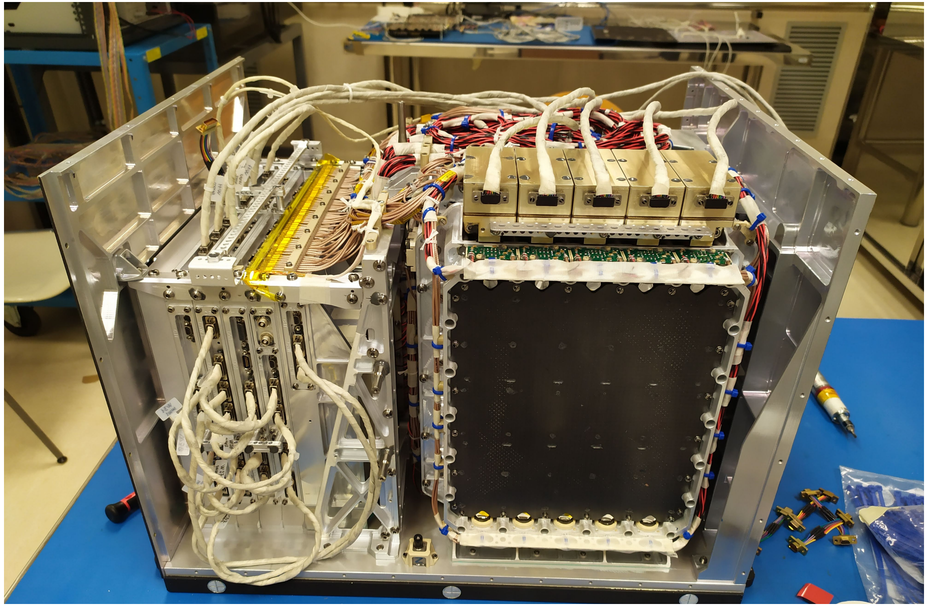
3. **Range calorimeter planes reduced** from 16 to 12 (15x15x1 cm^3 thick);

4. **Lyso**: from 9 cubes to **6 bars** (5x15x2.5 cm^3);
   -> Increase energy range, position sensitivity and redundancy.

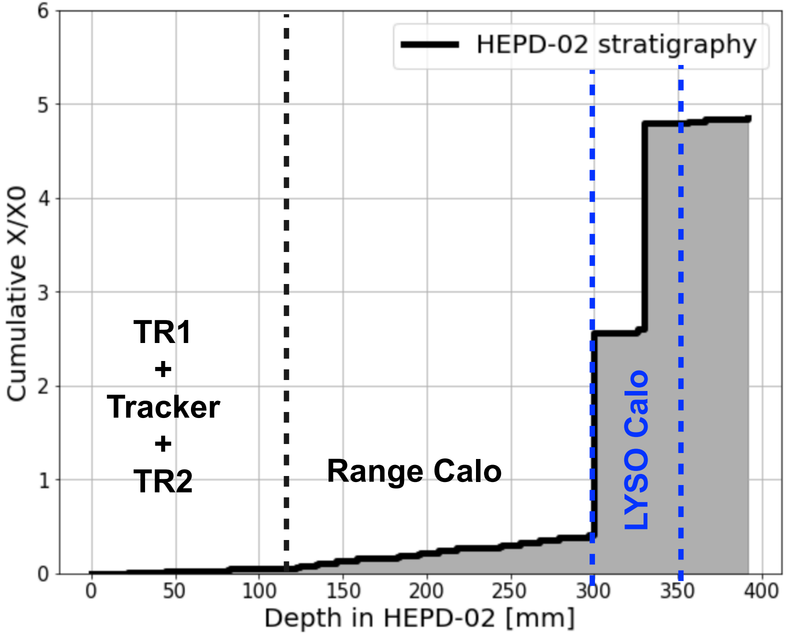


Major upgrades with HEPD-02

Assembled HEPD-02 FM

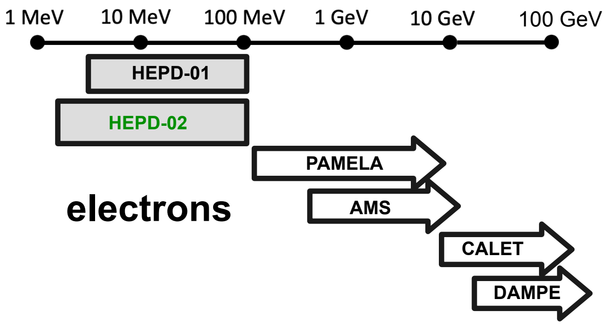


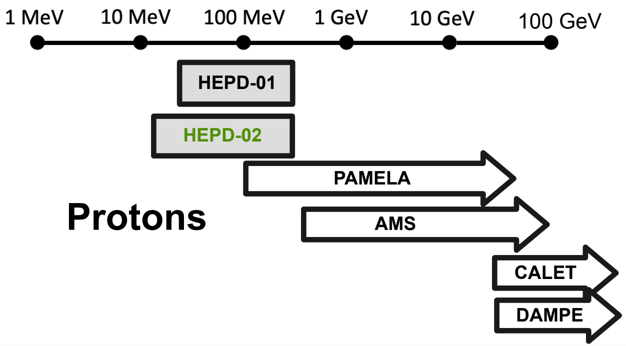
HEPD-02 thickness in X/X_0



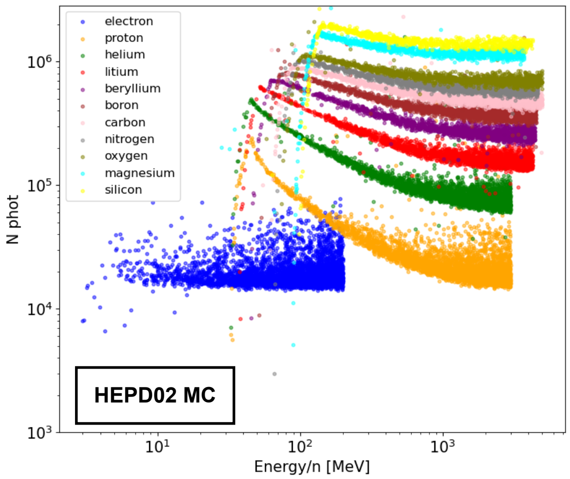
Limadou HEPD-02 on board CSES-02

HEPD-02 is designed to measure fluxes electrons, protons and heavy nuclei in a wide range of energies and it has sensitivity to Gamma Ray Burst down to the MeV level

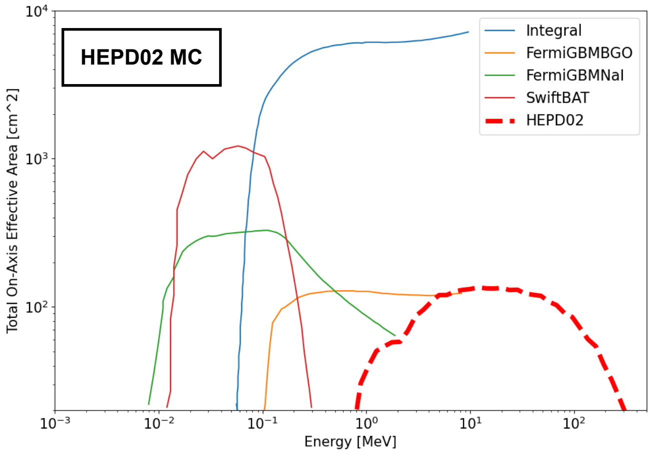




Nuclei



Sensitivity to Gamma Ray Burst



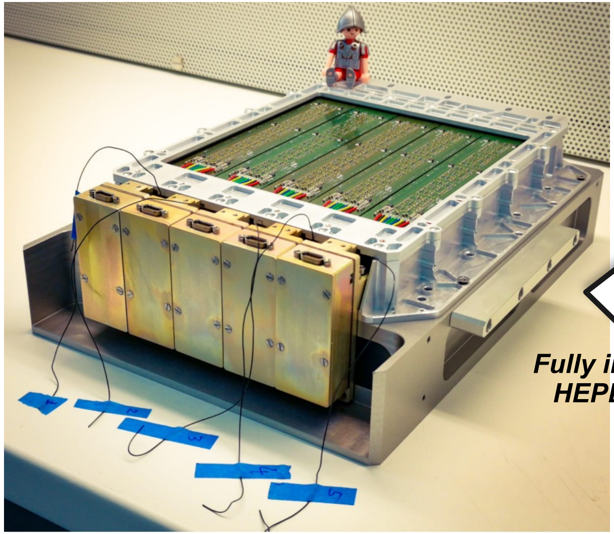
For details on MAPS
talk by M. Mager
talk by T.Kugathasan

First MAPS pixel tracker in space

LIMADOU 利瑪竇

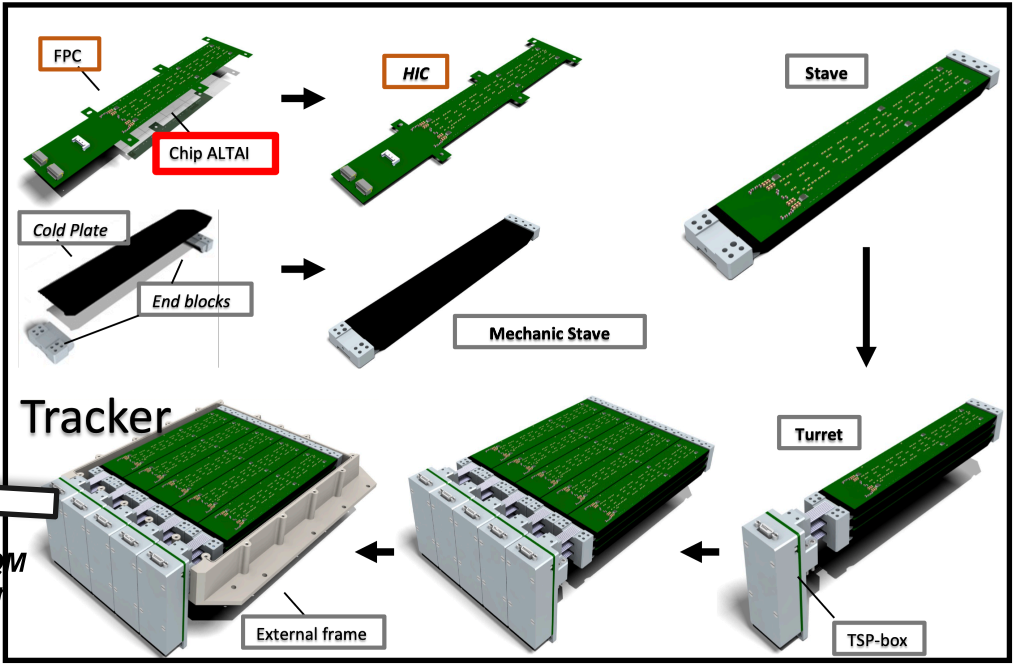
Based on the MAPS developed for ALICE experiment

- Pixel size 29.24 µm x 26.88 µm (~ 4 µm single-hit resolution)
- ALTAI: 512x1024 pixels -> 10 chips per stave;
- 5 turrets, each made of 3 staves with active area 15 x 3 cm² each;
- Low material budget ~ 0.015 X_0;



Fully integrated QM HEPD-02 tracker

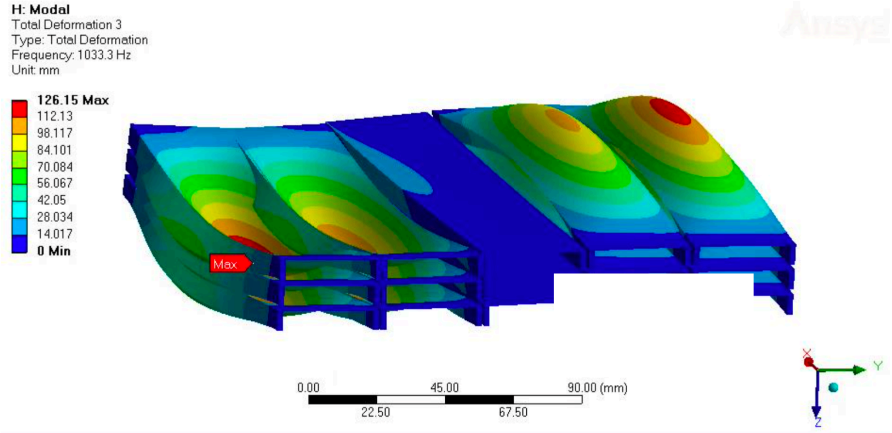
Tracker integration steps



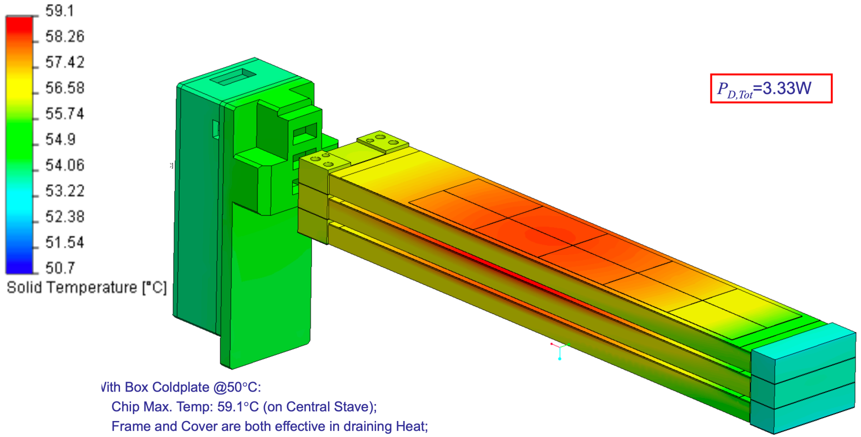
A 80 megapixel CMOS camera for charged radiation

Mechanical and thermal models

Modal analysis of tracker mechanics (sustain structural stresses > 10 G)



Thermal analysis of a turret at high temperatures (thermal cycling between -30°C and +50 °C)



Tracker Readout (TDAQ)

Customized ALTAI readout for HEPD-02 space application

- Designed to respect the power **consumption limit of the full tracker**.

- manage tracker configuration and full DAQ and data reduction.

- Implement a hot/cold design to increase overall reliability during flight.

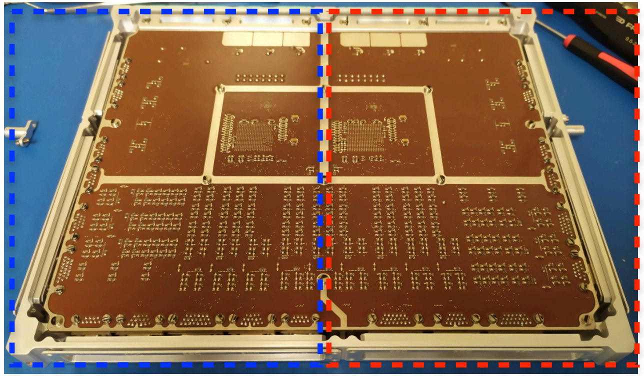
TDAQ implementation

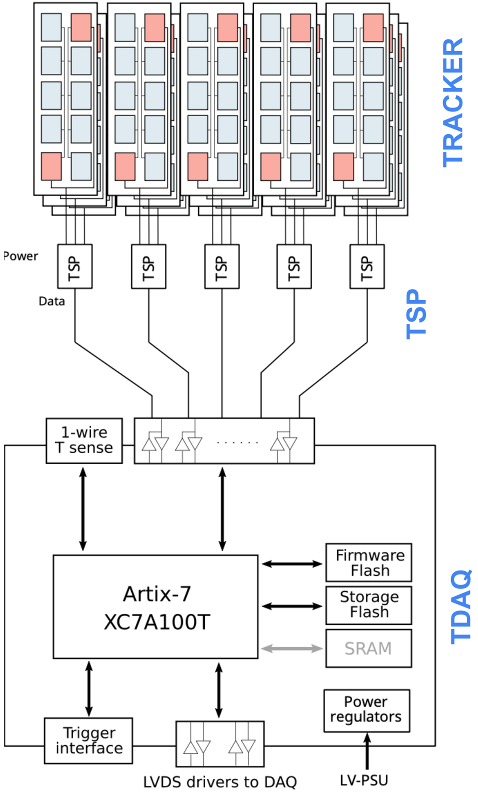
- Xilinx Artix7 in the low-power version.

- Modular structure to implement a sparse readout to achieve high throughput rate.

- MicroBlaze soft processor manage lightweight in-flight calibration procedures.

Cold Hot

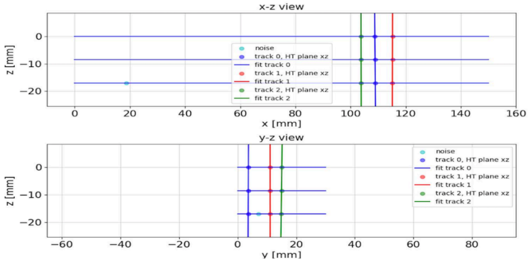


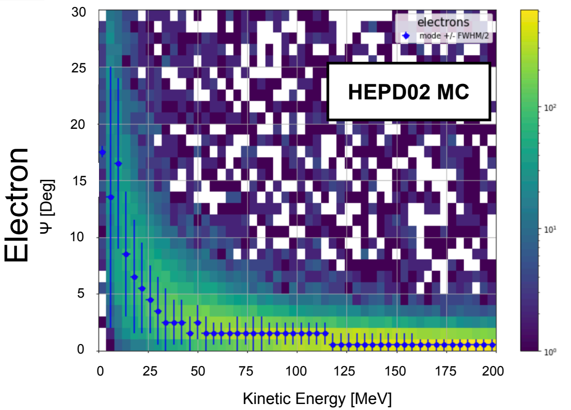


HEPD-02 tracker capabilities

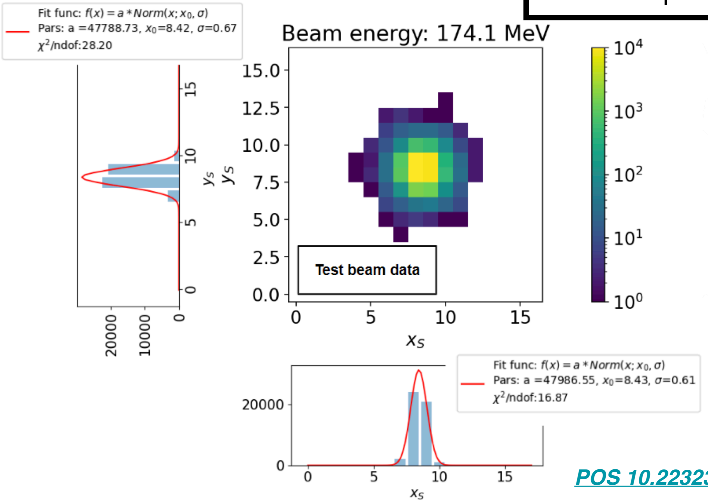
HEPD-02 tracking capabilities

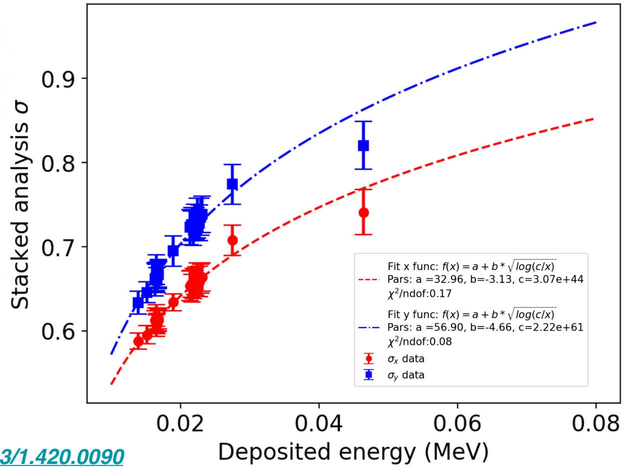
- Good correlation between cluster size and deposited energy;
- Energy resolution limited by multiple scattering at low energies;
- Digital output makes room for online tracking.



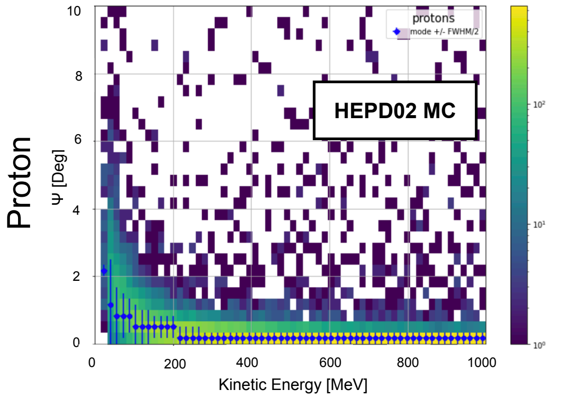


Data from proton test beam





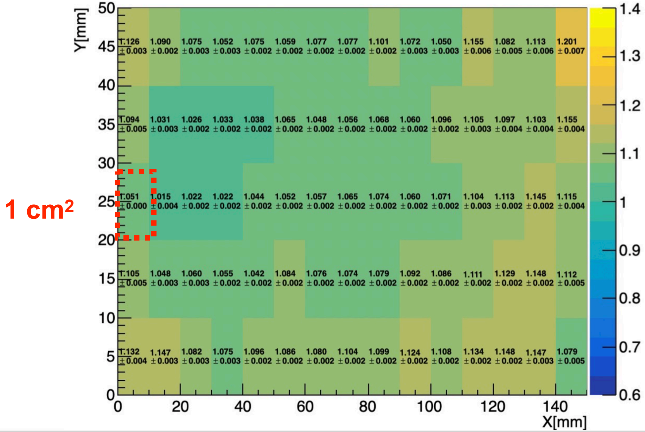
POS 10.22323/1.420.0090

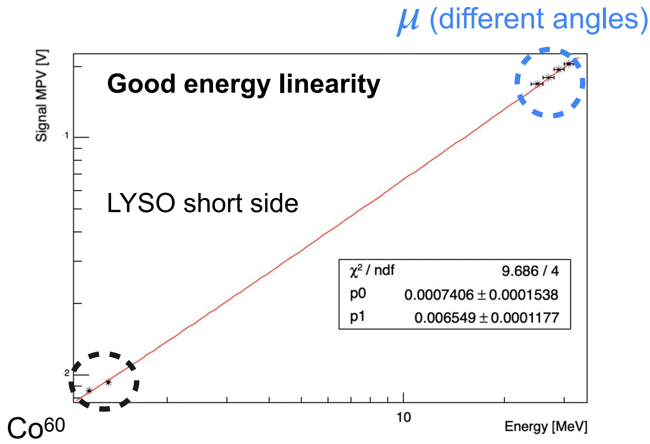


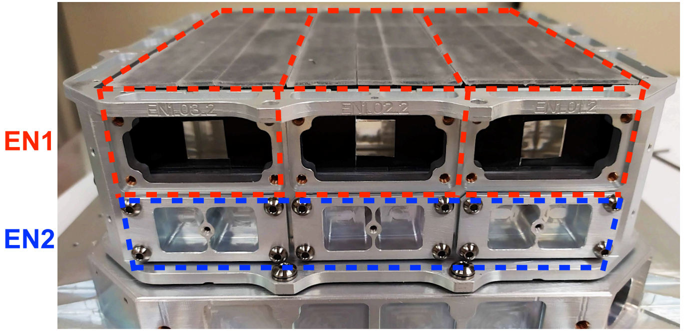
HEPD-02 LYSO calorimeter

LYSO calorimeter structure:

- Among the largest LYSO crystal ever fabricated 15x5x2.5 cm^3;
- Two layers of LYSO bars and a layer contains three bars (read-out by two PMTs each) ~ 4.3 X_0
- Optical features and light propagation properties compatible within 5%.





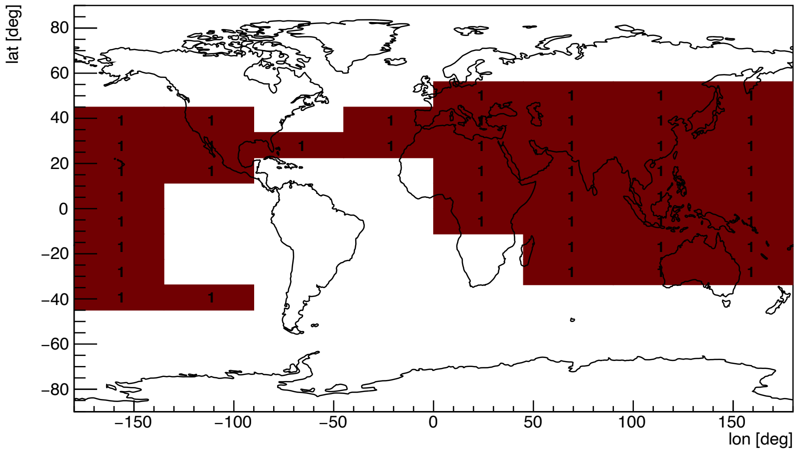


For other details see
next talk by M.Mese

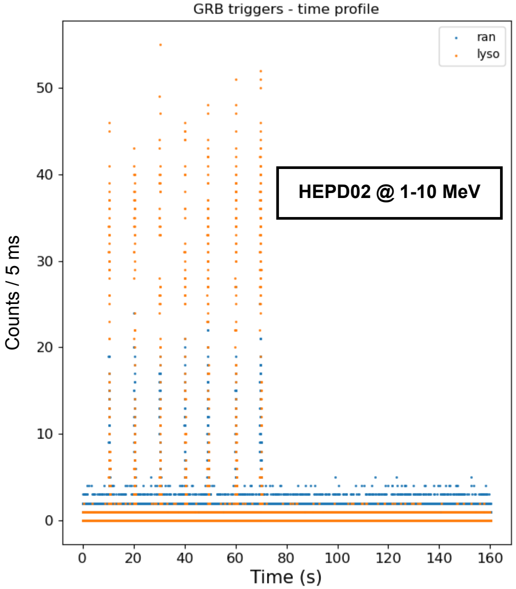
Gamma Ray Burst with HEPD-02

Dedicated GRB trigger has been designed for HEPD-02, exploiting both EJ-200 plastic scintillators (for low energy gammas) and LYSO crystals (for high energy gammas). **Tests of the GRB ongoing @ LINAC** - Trento.

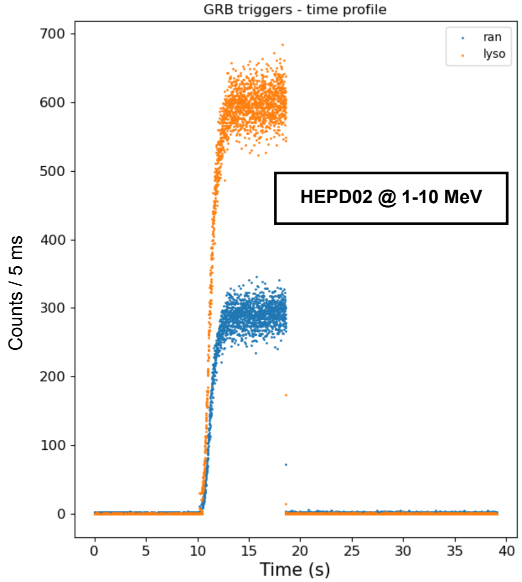
GRB acquisition region



7 consecutive <1 sec gamma pulses



Single ~10 second pulse



For other details see **next talk by M.Mese**

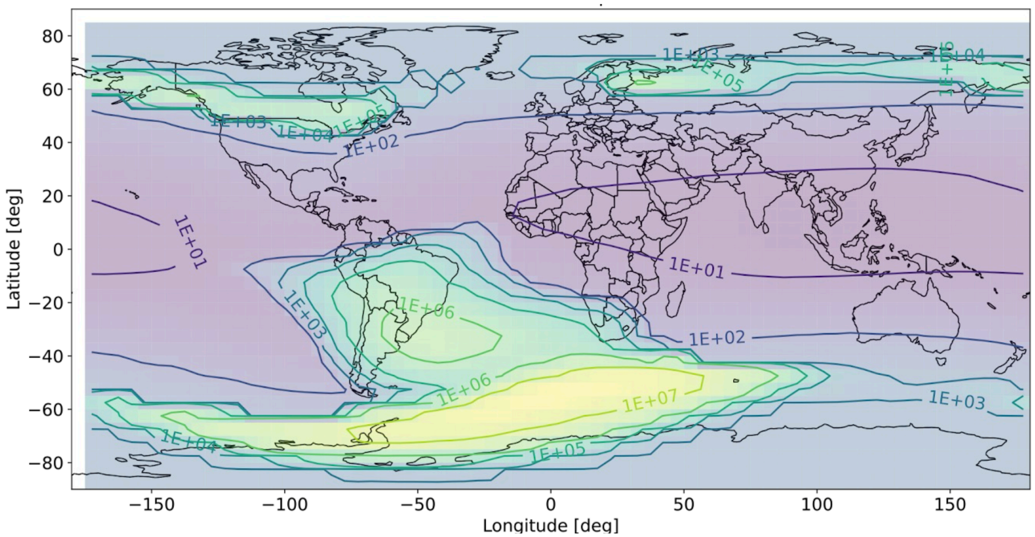
Upgraded trigger capabilities

LIMADOU 利瑪竇

Depending on the zone along the orbit, different trigger masks can be used at the same time.

- Max **6 concurrent trigger** masks;
- 4 trigger masks can be **pre-scaled**;

Galactic + Trapped (AE9/AP9)

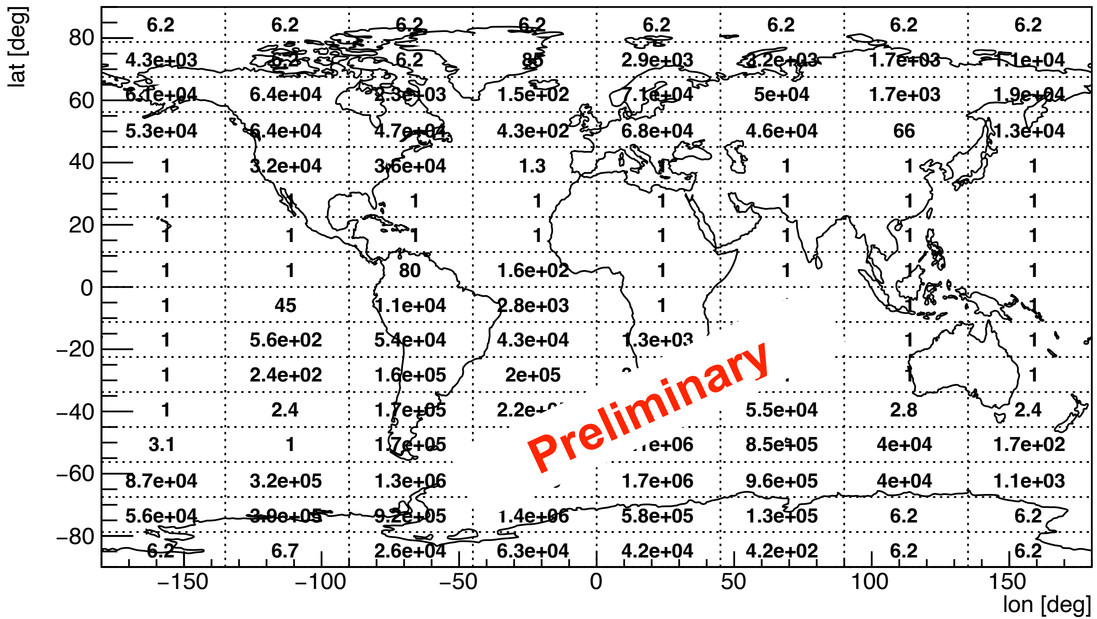


For other details see
next talk by M.Mese

Upgraded trigger capabilities

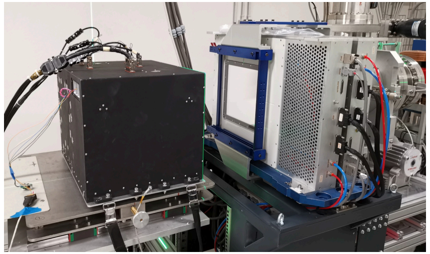
Depending on the zone along the orbit, different trigger masks can be used at the same time.

- Max **6 concurrent trigger** masks;
- 4 trigger masks can be **pre-scaled**;

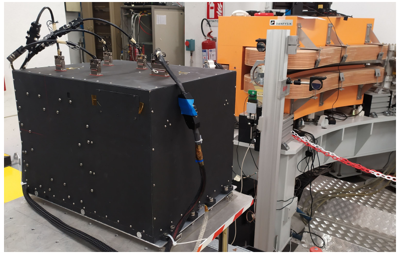


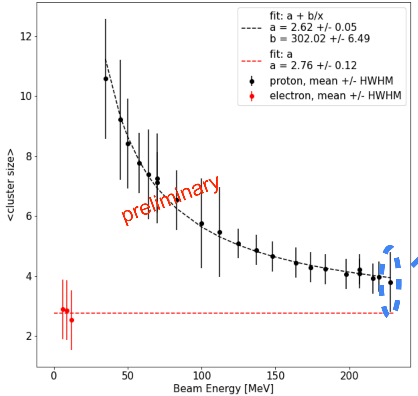
HEPD-02 Test Beam campaign

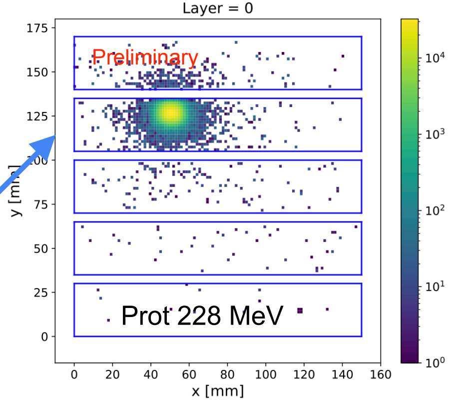
Carbon/proton @ CNAO
Dec 2022 - Jan 2023



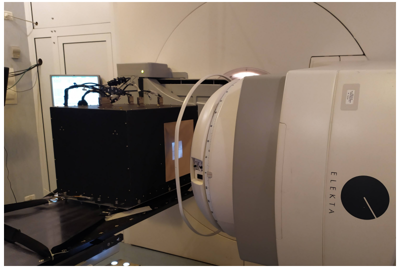
e- (>30 MeV) @ BTF April 2023



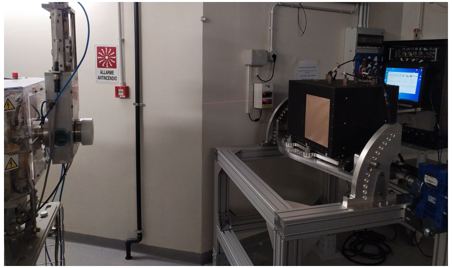


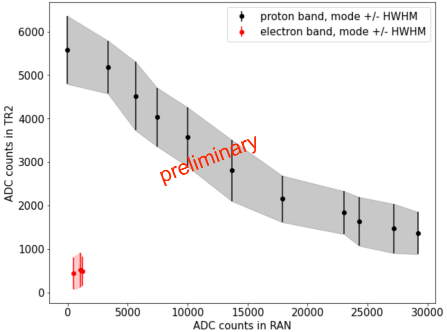


e- (6-12 MeV)/gamma @ (Trento)
Last week June 2023

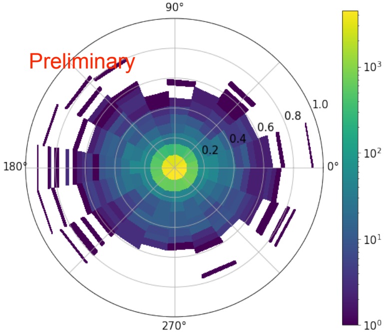


Proton @ APSS (Trento)
Last week June 2023

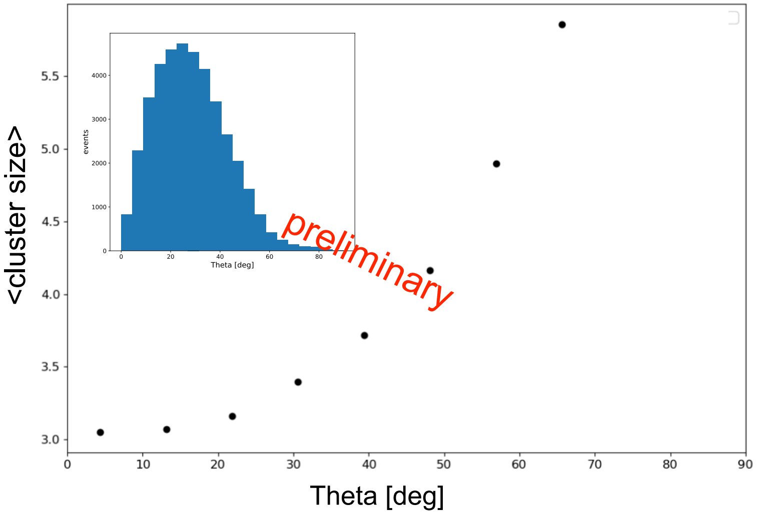




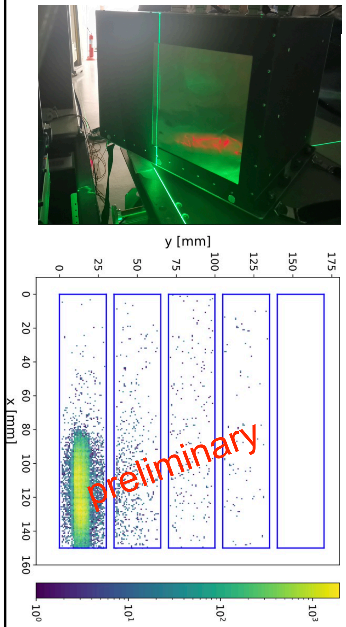
Vertical beam e- 120 MeV

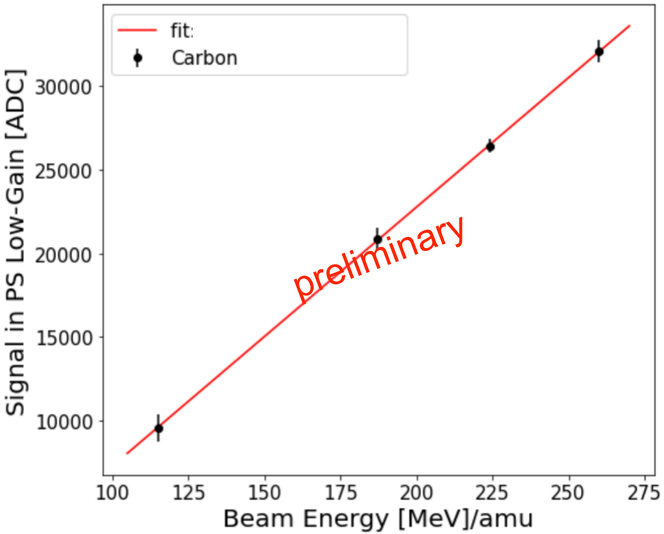


Atmospheric muon data



Carbon Beam





Summary and perspectives

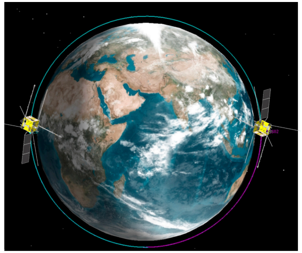
In this talk we reviewed the status of the CSES mission:

- **The Limadou HEPD-01 detector and activities;**
  - **Solar modulation** of galactic cosmic rays;
  - Observation of impulsive phenomena;

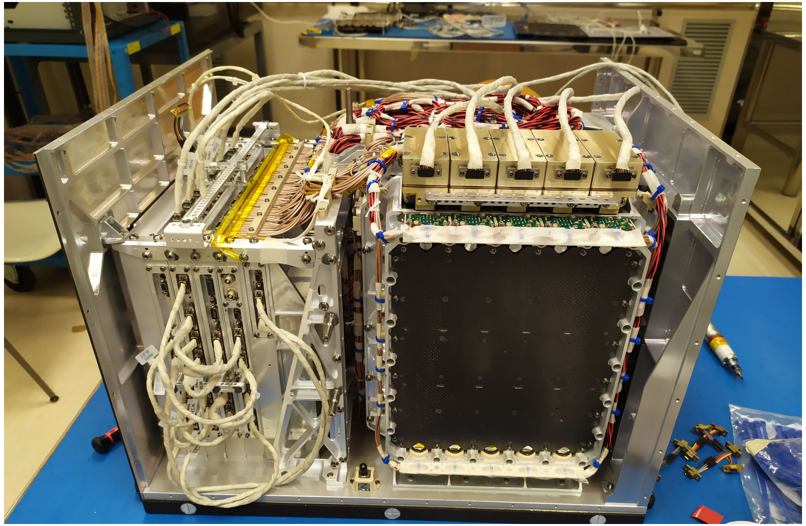
- **The Limadou HEPD-02 detector;**
  - Design and upgrades with respect of HEPD-01;
  - MAPS tracker and LYSO calorimeter;
  - Improved trigger capabilities;

The new phase of the CSES mission will start with launch of the second satellite, during 2024. An exciting phase will start!

CSES as a new multi-point space observatory



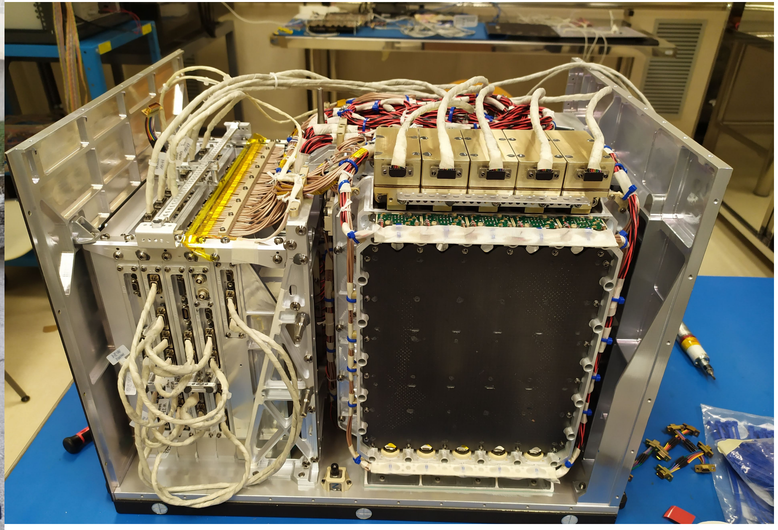
Shipment to Beijing for integration at the end of July



Launch early 2024

Summary and perspectives

Shipment to Beijing for integration at the end of July



Launch early 2024