Measurement of charged radiation with HEPD-02 onboard CSES-02

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CSES LIMADOU

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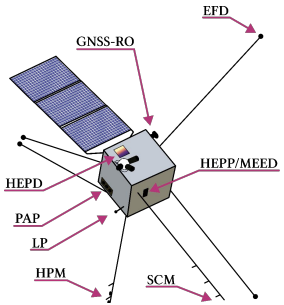
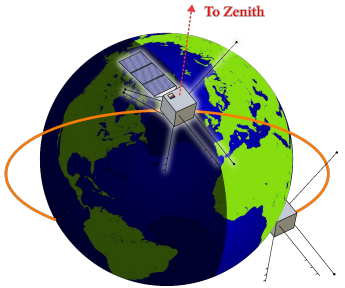
CSES-LIMADOU MISSION

CSES-02 Mission

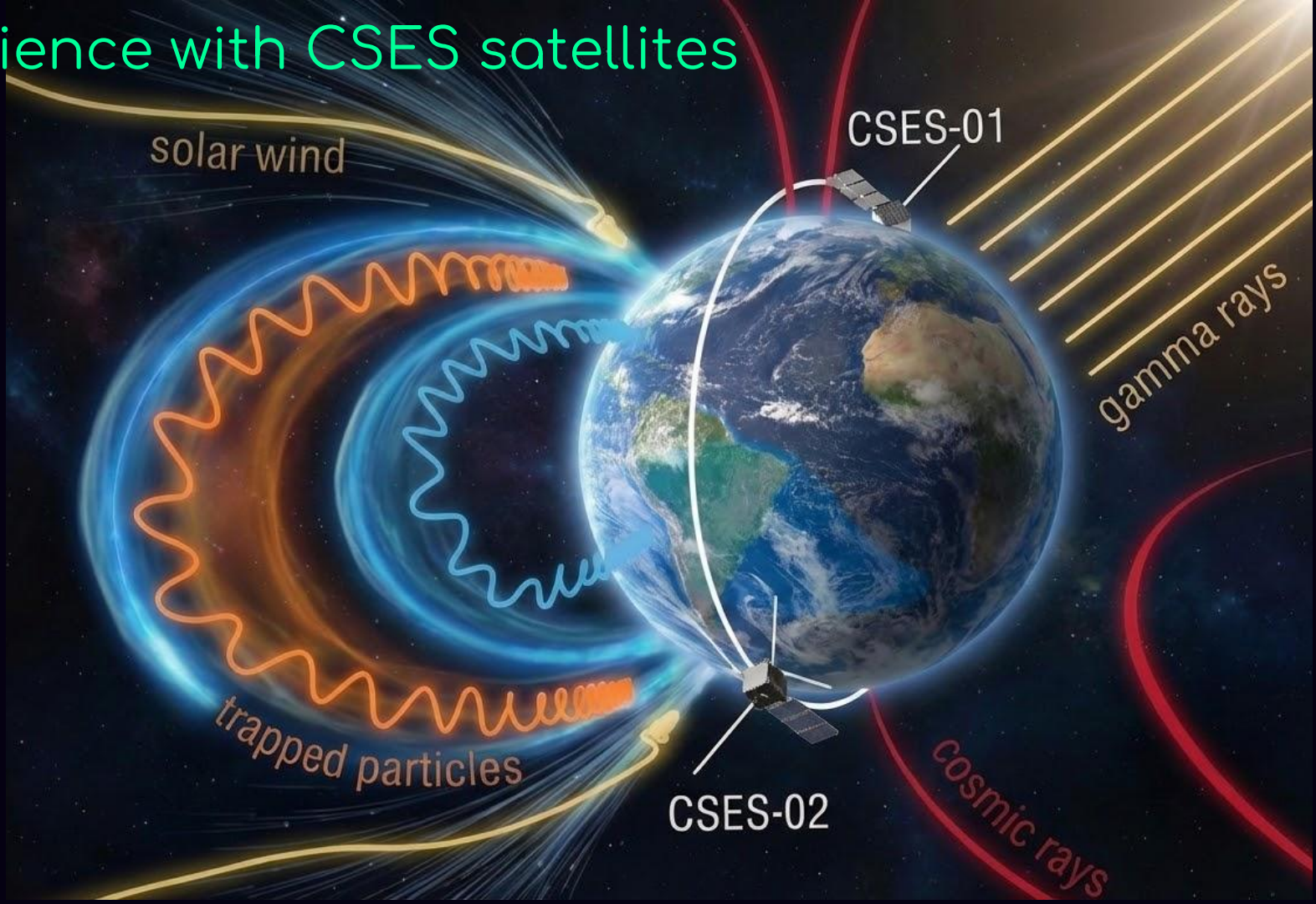
China Seismo-Electromagnetic Satellite is a collaboration between **Italy** and **China**. CSES-02 has been launched in June 2025. Its objectives:

- Monitoring of the electromagnetic near-Earth space environment
- Analysis of the ionospheric and plasmaspheric fluctuations
- Measurements of iono-magnetospheric perturbations of seismic origin
- Study of fluxes of charged particle precipitating from the Inner Van Allen radiation belt
- Measurements of magnetospheric and solar activity
- Monitoring of the e.m. anthropic effects at low Earth orbit altitude
- Observations of e.m. transient phenomena caused by tropospheric activity

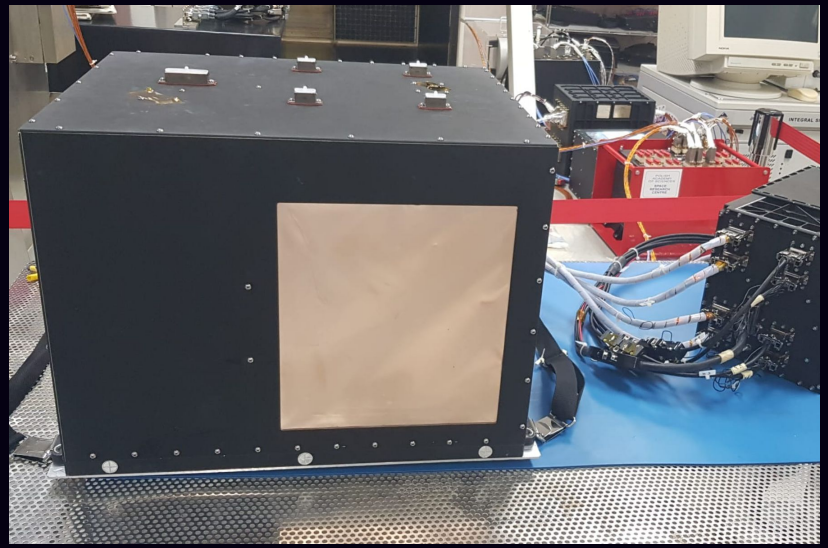




Science with CSES satellites

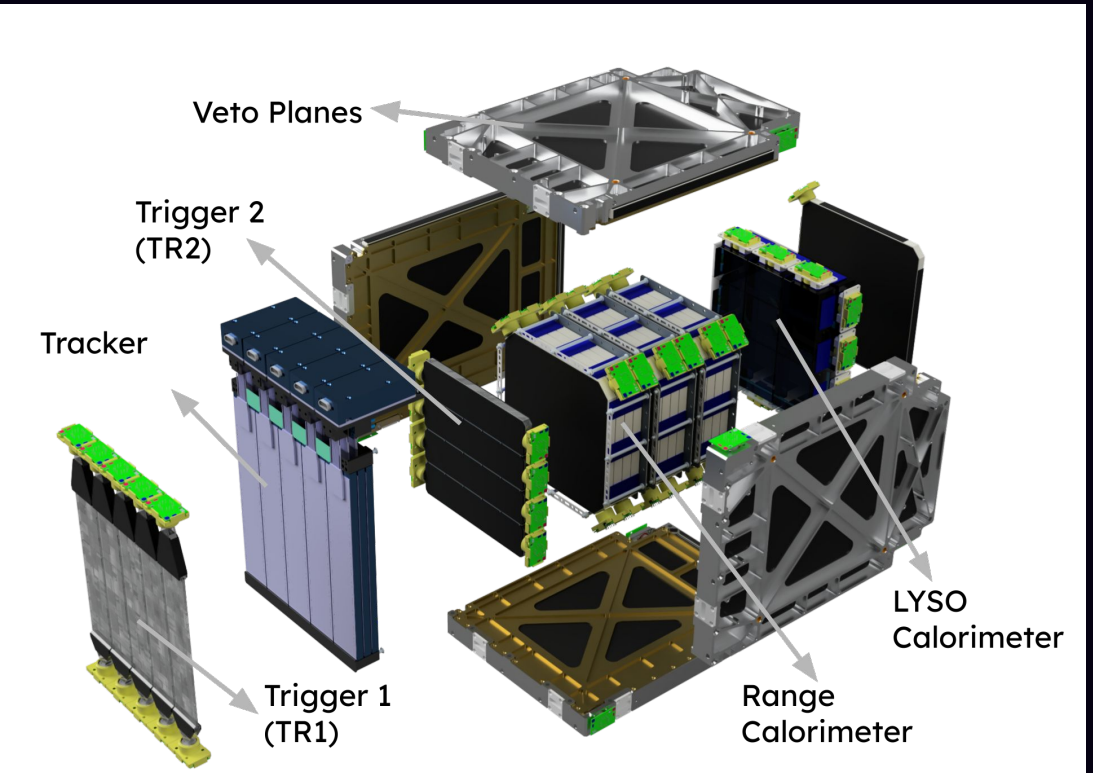


Section I: HEPD-02 Instrument



HEPD-02 Payload on CSES-02

The High Energy Particle Detector (HEPD-02) has been developed by the Italian Limadou collaboration lead by ASI and INFN. It covers the highest energy region of sensitivity of CSES-02.



HEPD-02 lowers the energy thresholds of PAMELA and AMS-02.
Unique opportunities for sub-GeV cosmic ray Physics.

- Event-based Particle Identification
- Sensitivity to GRBs down to the MeV

Target energy ranges:

- electrons: 3 - 100 MeV
- protons: 30 - 200 MeV

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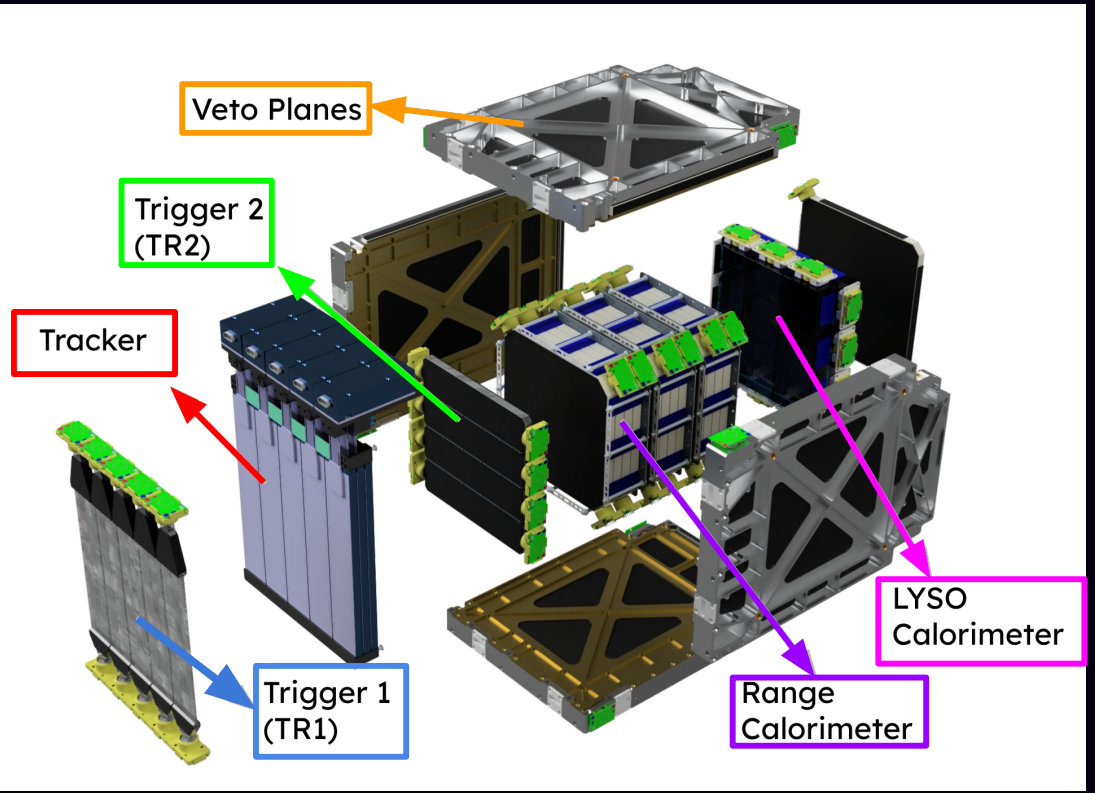


- First Tracker in space based on Monolithic Active Pixel Sensors (MAPS)

- Two trigger planes:
  TR1 5 bars; plastic scintillator
  TR2 4 bars; plastic scintillator

- Range detector (RAN):
  12 planes; plastic scintillator

- LYSO calorimeter
  2 planes of 3 bars each (5 x 15 x 2.4 cm^3)

- 5 Veto planes, plastic scintillator

HEPD-02 Tracker

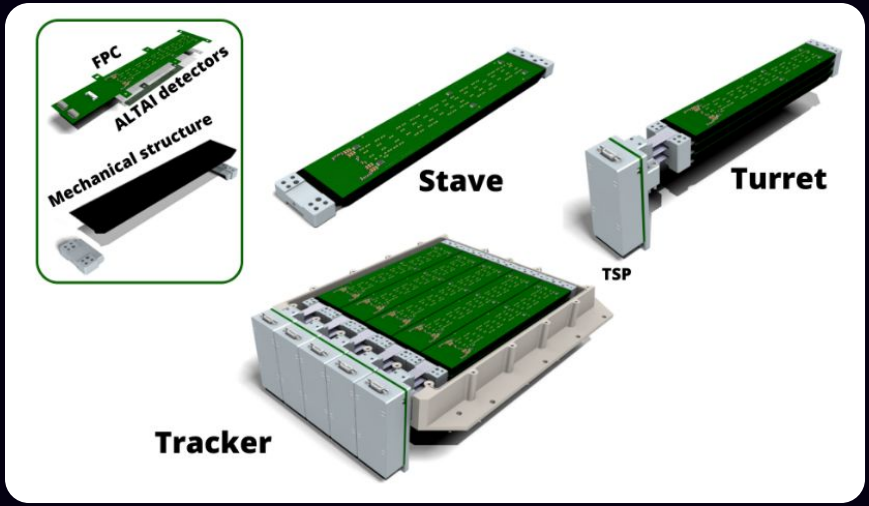
First Space Pixel Tracker

HEPD-02 is the pioneer space experiment employing a silicon pixel detector for precise tracking capabilities.

Technology: MAPS (Monolithic Active Pixel Sensors). ALTAI sensor derived from ALPIDE architecture.

Structure & Granularity:

- 5 modules (turrets) with 3 layers (staves) each
- Each stave hosts 10 ALTAI detectors (2x5 layout)
- ALTAI Sensor: 512 × 1024 pixel matrix

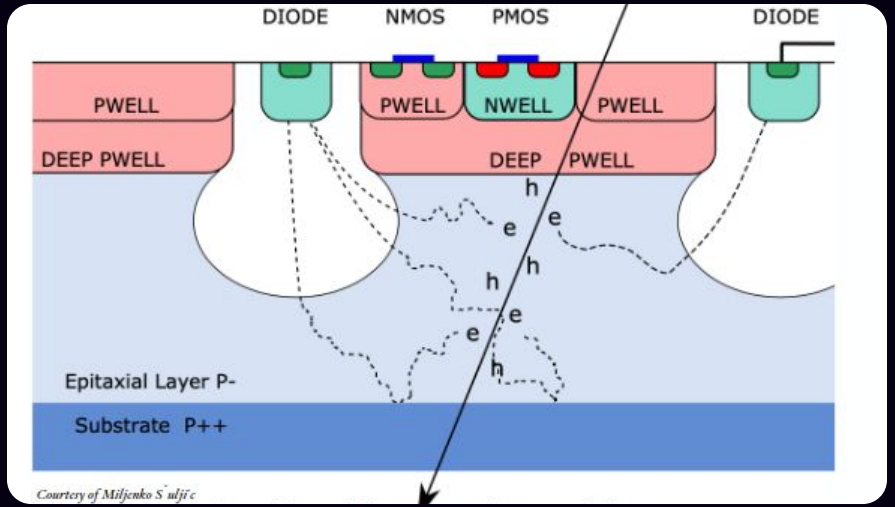


Performance & Silicon Integration

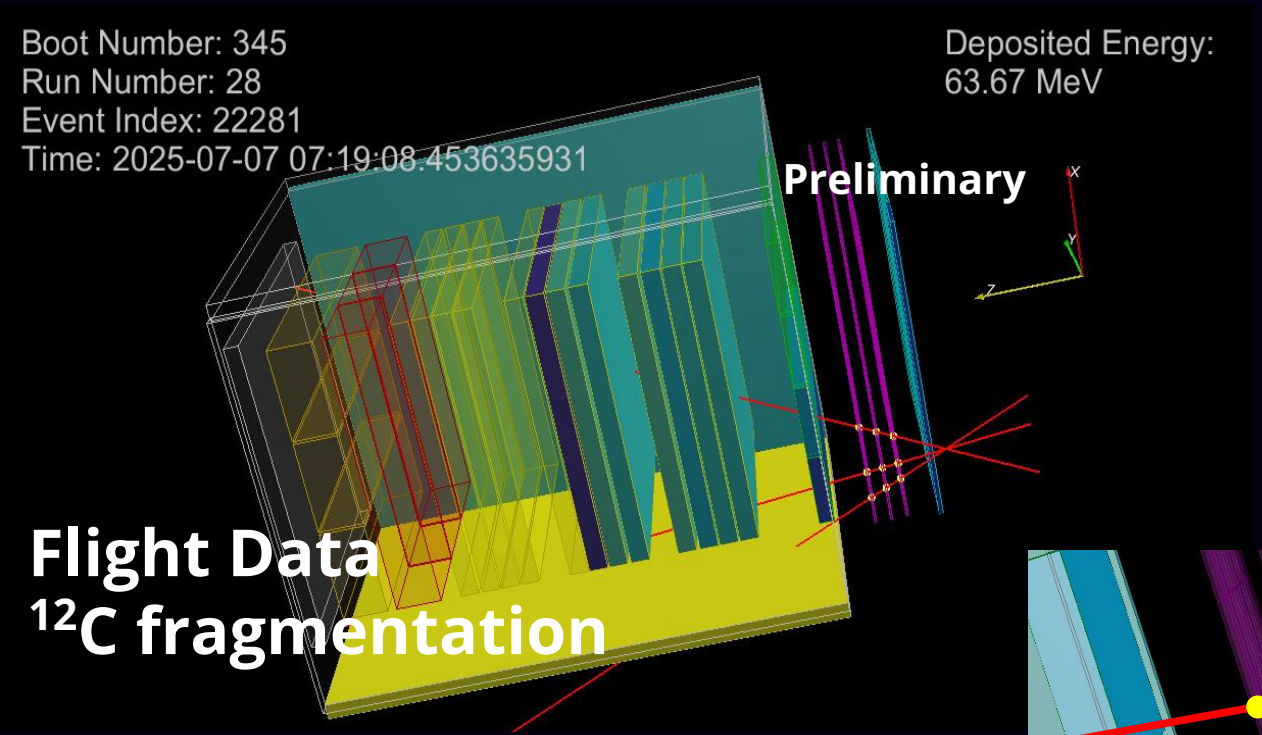
Resolution: 5 µm | Thickness: 50 µm
Efficiency: >99% | Integration Time: ~2 µs

Monolithic Advantages (Same Silicon Substrate):

- **High Resolution & Low Noise:** Optimized signal detection
- **Low Power Consumption:** Ideal for space flight constraints
- **Minimal Material Budget:** Reduces particle scattering

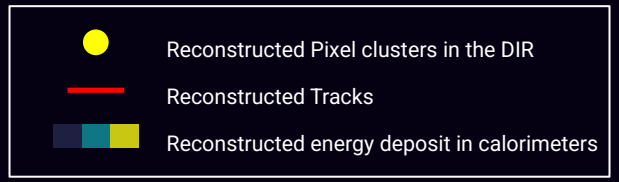


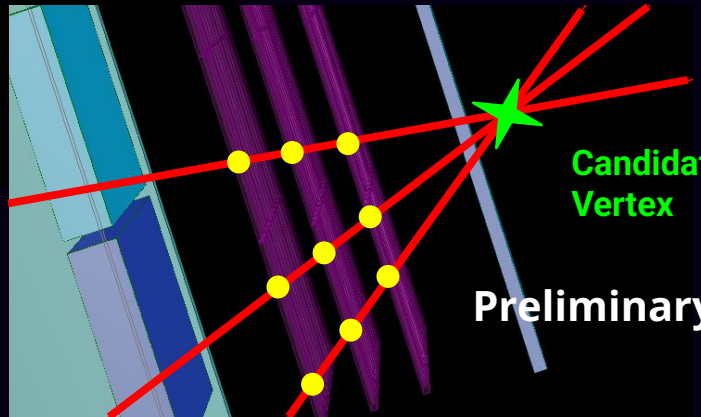
Vertexing for Flight Data



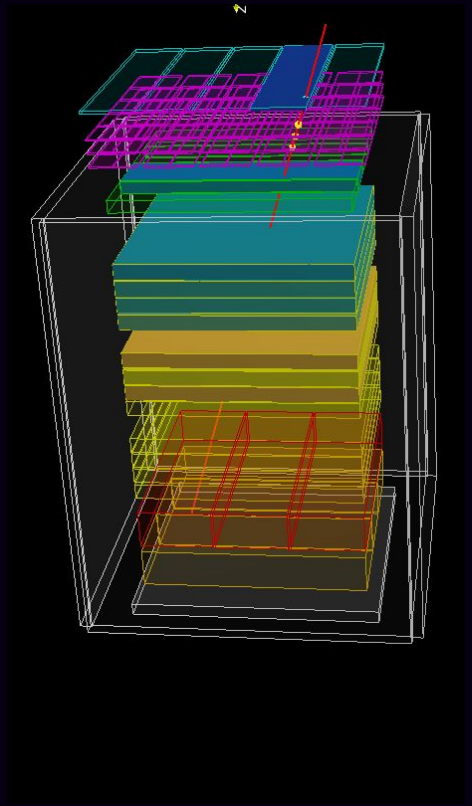
Flight Data
^{12}C fragmentation

- The yellow dots are clusters measured by the tracker
- Red lines represent the reconstructed tracks
- We see here **physical observables.**
- Vertex is the expected frag./ann. point

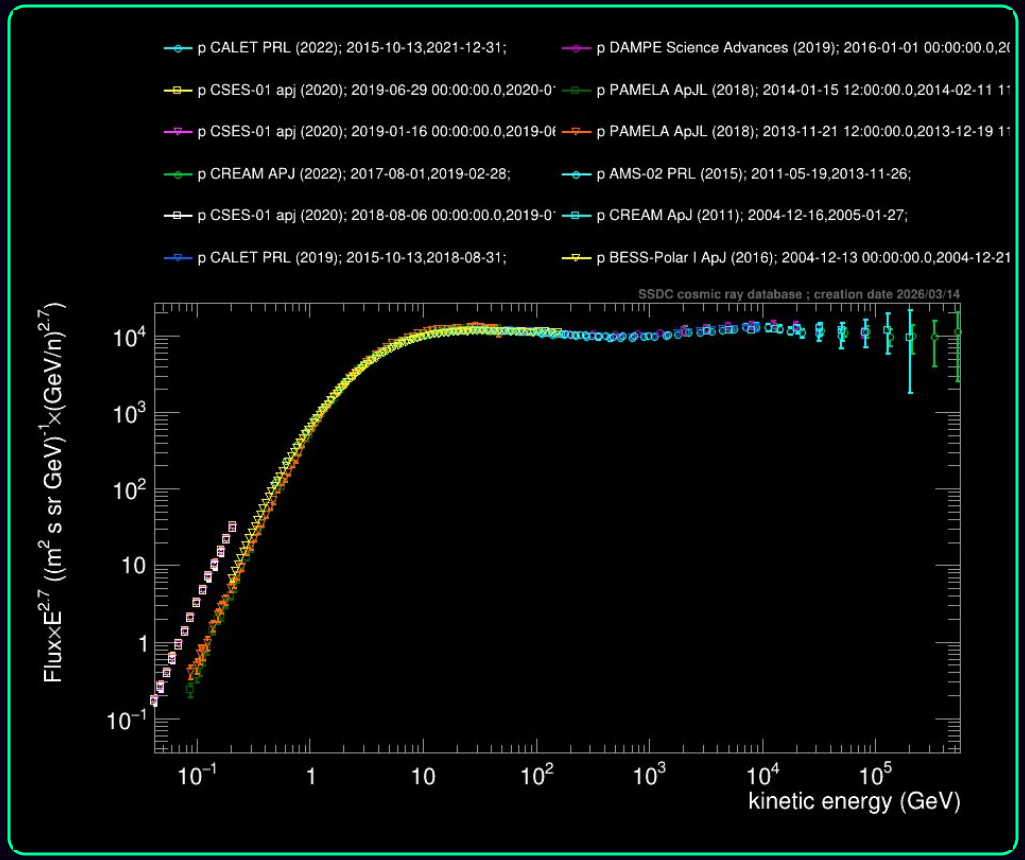




Section II: Charged Radiation with HEPD-02



Existing measures on proton GCR



Existing/Past Cosmic Ray Detectors

AMS-02:
1 GeV - 3 TeV

CALET:
50 GeV - 10 TeV

PAMELA:
100 MeV - 1 TeV

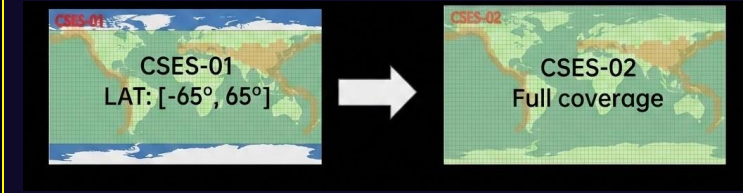
BESS:
200 MeV - 100 GeV

DAMPE:
40 GeV - 100 TeV

HEPD-01:
30 - 200 MeV

HEPD-02 Upgrades

Sensitive in the same energy range of HEPD-01, but features increased statistics and improved silicon tracker technology.

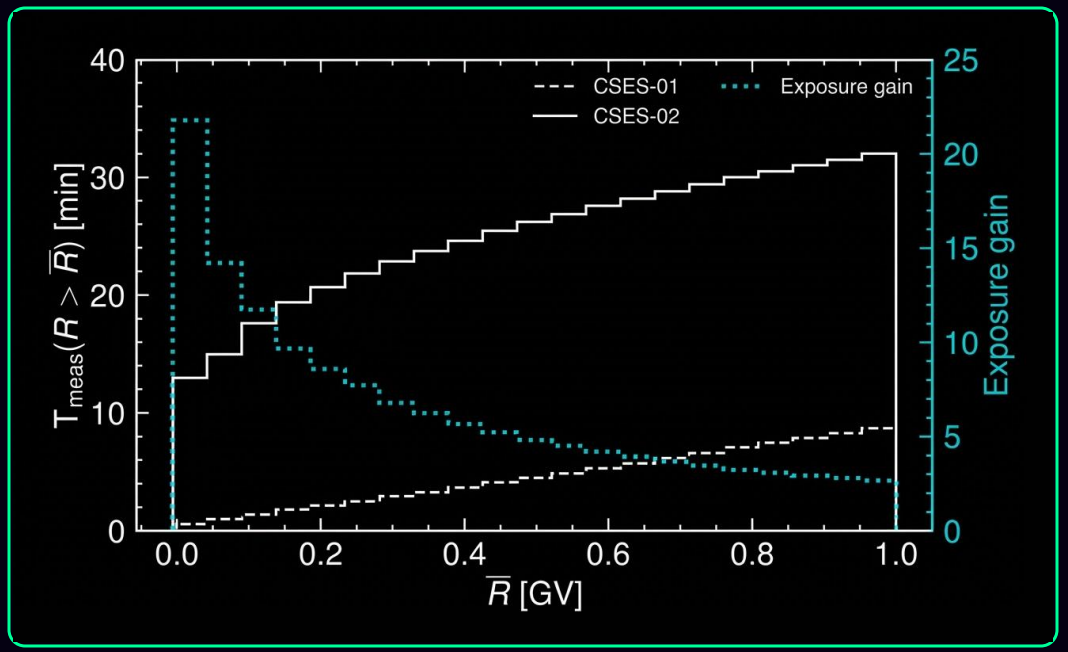


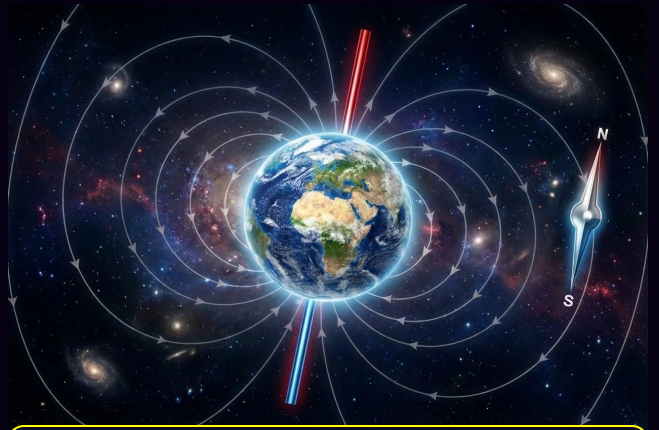
From HEPD-01 to HEPD-02

The rigidity cutoff is the minimum rigidity required by a particle to reach a region magnetic diffusion.

At the poles particle arrive parallel to the magnetic field lines, lower deflection.

$$\vec{F} = q\vec{v} \times \vec{B}$$

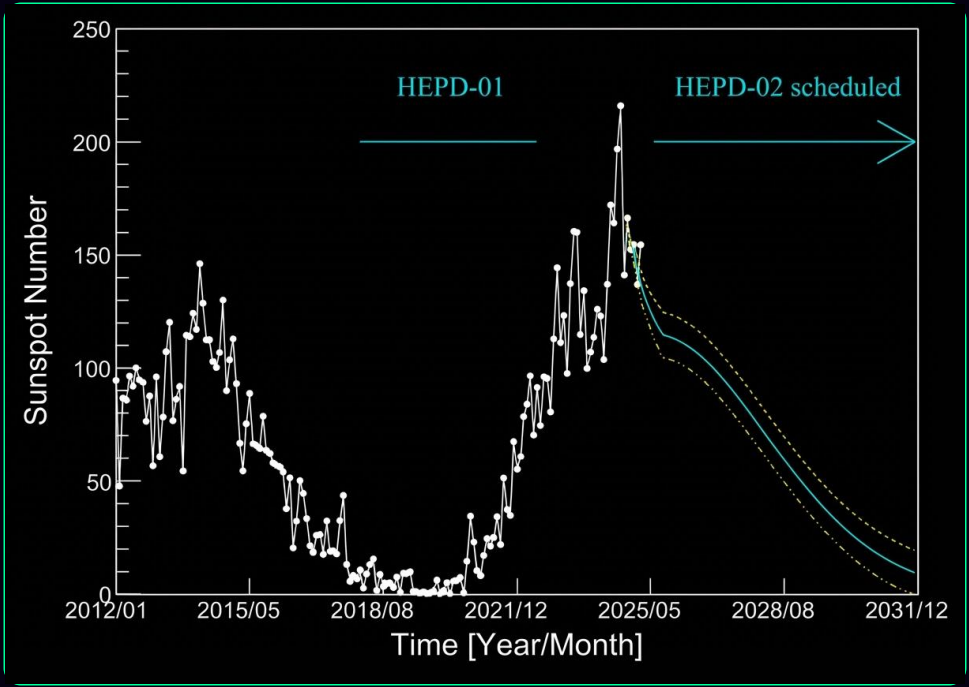




Fraction of time above geomagnetic cut-off increases from a factor 3 up to 35.

HEPD-02 can provide precision measurements of low-energy cosmic radiation thanks to its high exposure time.

From HEPD-01 to HEPD-02 II



01. Solar Cycle 25 Peak

Investigation of the peak phase of solar cycle 25 to understand high-activity behavior.

02. Descent & Cycle 26 Start

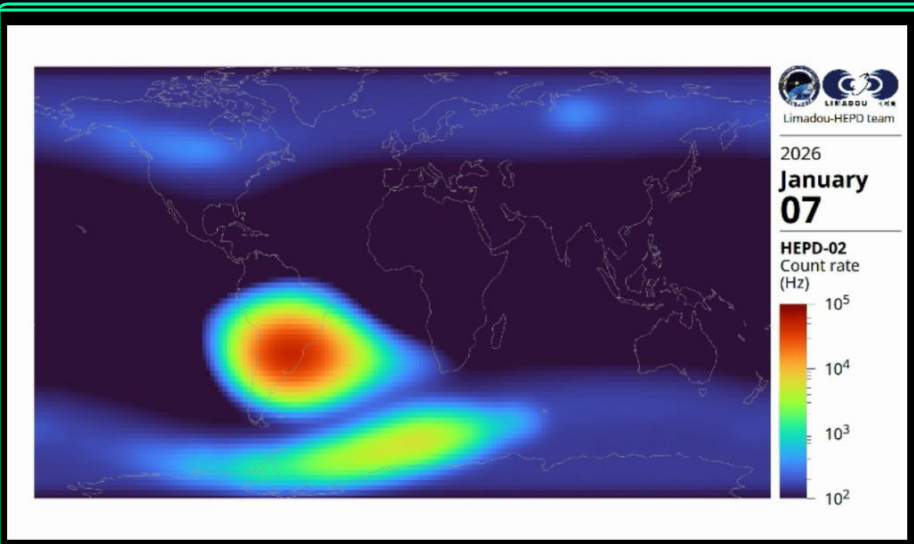
Tracking the descent towards the minimum setting the start of solar cycle 26 and beyond.

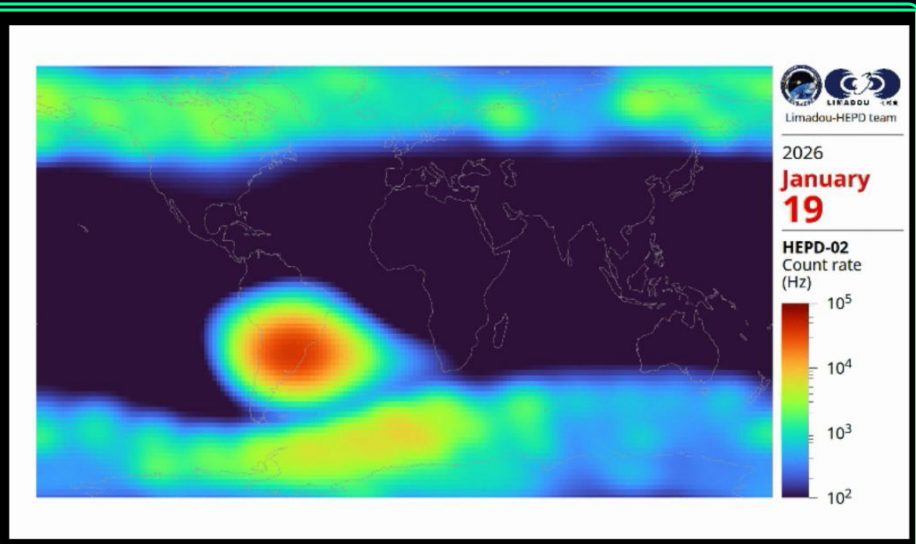
03. Polarity Reversal

Exploring the impact of magnetic field reversal from the A+ configuration of cycle 25 to the A- configuration of cycle 26 (2031)*.

*A+ (positive polarity): the magnetic field is oriented such that field lines emerge from the Sun's north pole
A- (negative polarity): the magnetic field is reversed

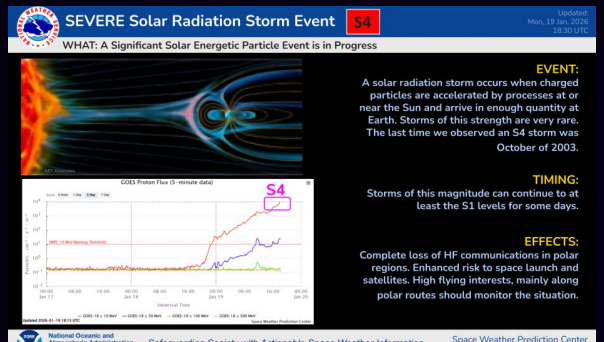
Space weather events



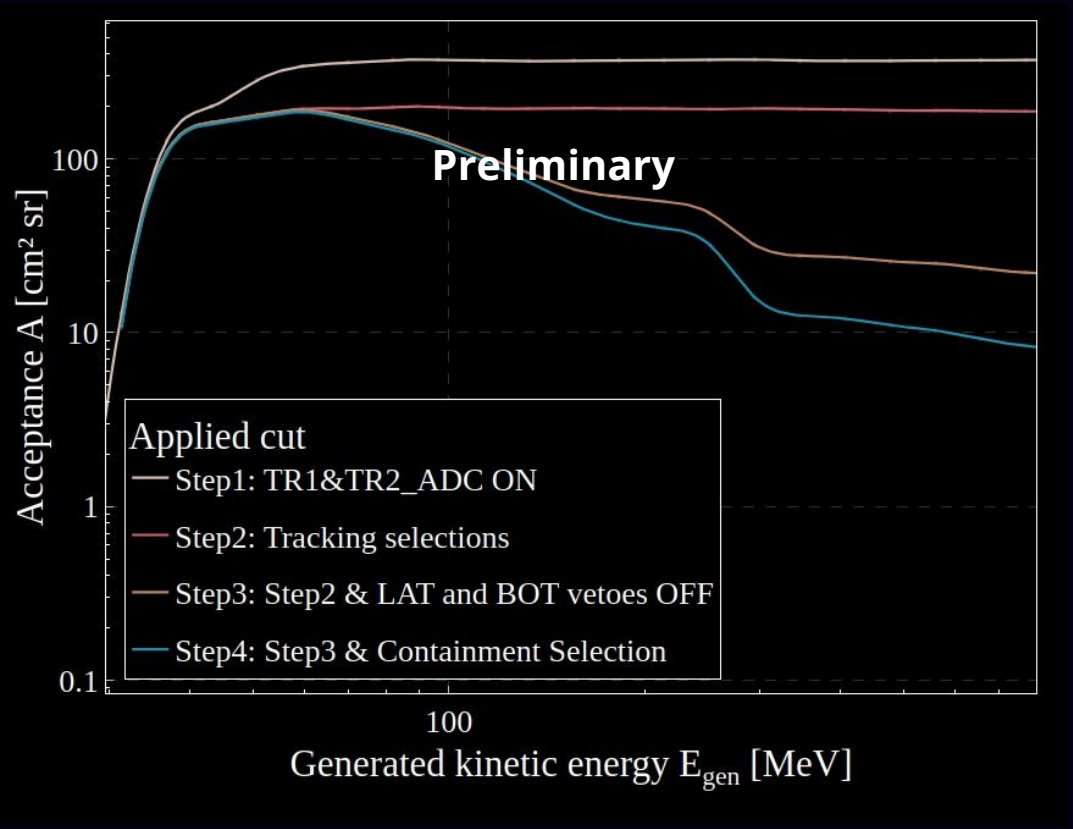


Severe solar storm

In January 2026 a solar storm event happened. HEPD-02 was able to observe it.



Acceptance



Sequential cuts identified:

01 TR1 & TR2 ON

02 Single track, 3 clusters, single bar on TR1 and TR2

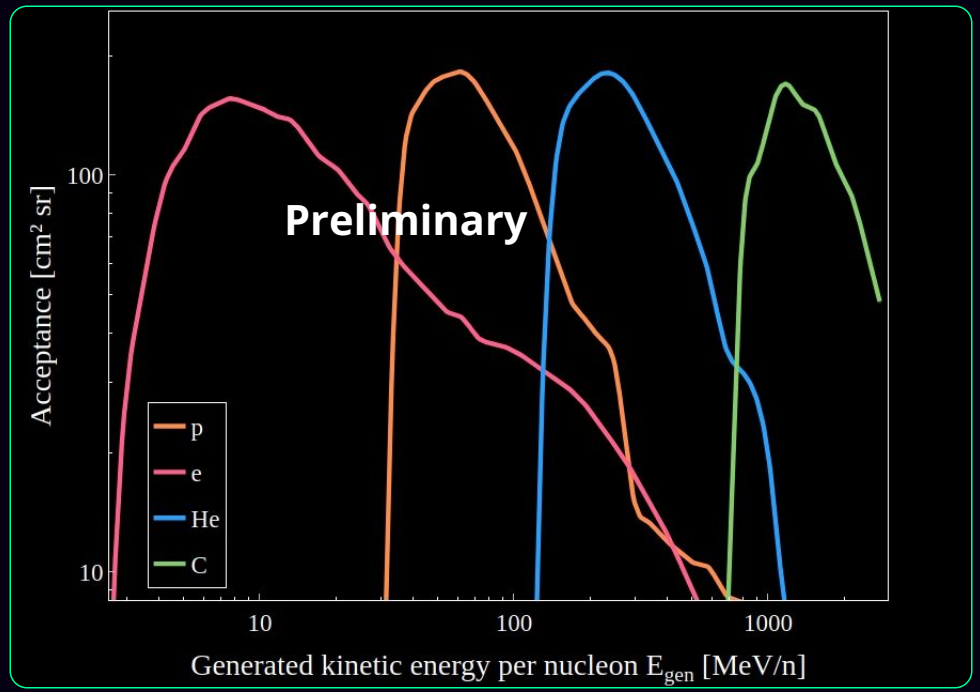
03 VETOes off

04 Geometrical containment

Key Takeaway

Essential contribution of the tracker to cut not contained particles.

Acceptance for electrons, protons and nuclei



01. Lowest Threshold

As expected, e^- have the lowest threshold (O(MeV)).

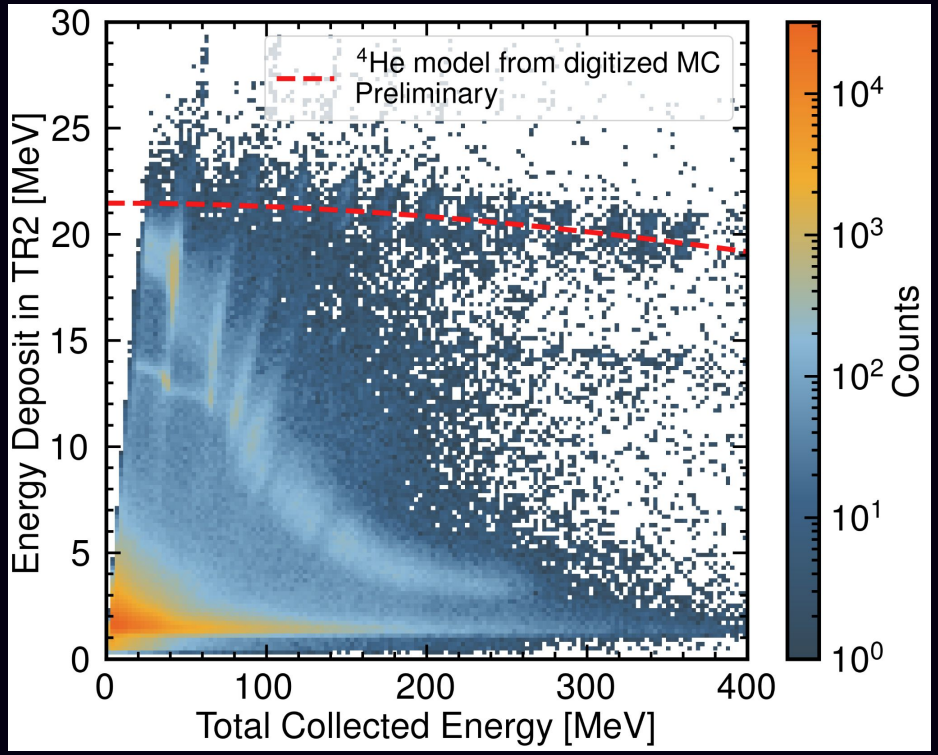
02. Energy loss effect

$dE/dX \sim Z^2 / \beta^2$: heavier nuclei lose more energy, resulting in a higher threshold.

03. Geometrical Decrease

Acceptance decreases with energy due to higher penetration and lower angular acceptance.

PID for protons and nuclei



01. Helium observed

The helium region is clearly identified

02. MC agreement

MC simulations well reproduce the helium region.

03. Proton band

The main sequence in the plot identifies protons.

Conclusions and Outlook

01. MAPS-Based Space Tracker

HEPD-02 on CSES-02 introduces the first MAPS-based space tracker (ALTAI), achieving ~5 μm spatial resolution.

02. Radiation Monitoring

HEPD-02 will provide results in the monitoring of the radiation environments.

03. GCR Measurement

The full coverage of high latitudes enables precision measurement of Galactic Cosmic Rays (GCR).

04. Particle Separation

Combination of tracking and calorimetric observable allows efficient separation between electrons, protons and light nuclei.

Bibliography: Bartocci, S., Battiston, R., Beolè, S. *et al.* The High-Energy Particle Detector on Board the CSES-02 Satellite. *Space Sci Rev* **222**, 26 (2026). https://doi.org/10.1007/s11214-026-01274-x