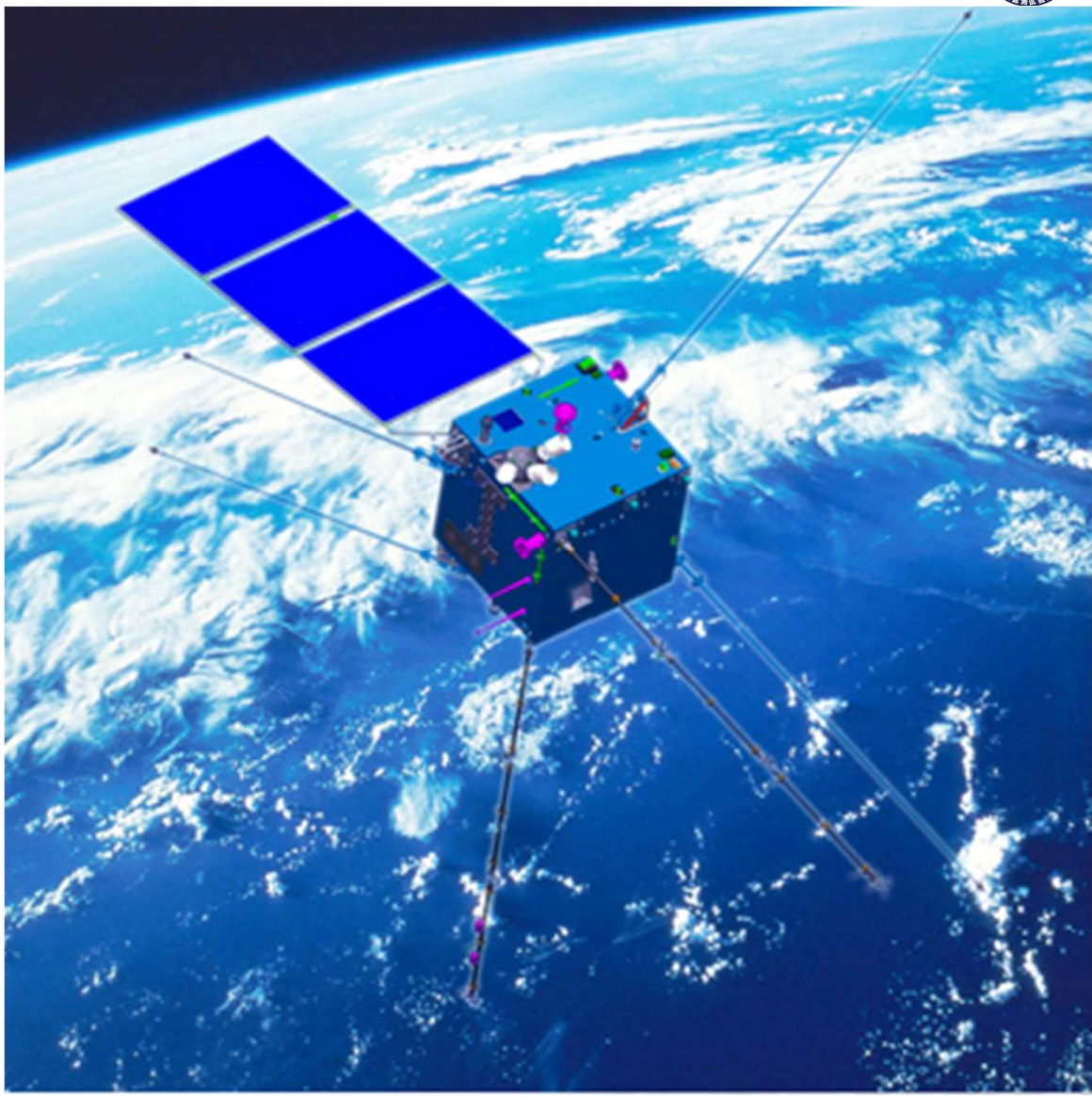
Characteristics of the HEPD-02 detector for the CSES-02 space mission

Zouleikha Sahnoun on behalf of the LIMADOU Collaboration



The CSES Space Missions

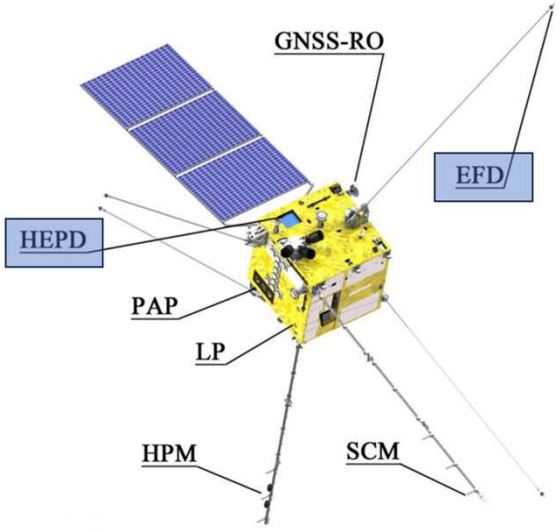
The **China Seismo-Electromagnetic Satellite** (CSES) is a space program in collaboration between China and Italy, dedicated to the monitoring of the near-Earth environment to investigate the lithosphere-magnetosphere coupling.

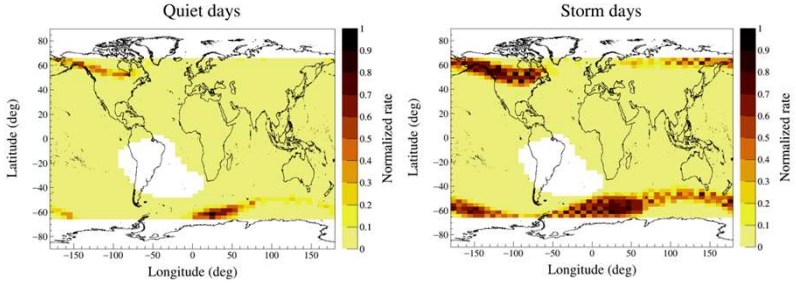
Scientific Objectives:

- Analysis of the **ionosphere, magnetosphere** and **plasma** in the near-Earth environment;
- Measurements of ionospheric and magnetospheric **perturbations** possibly correlated to strong seismic events;
- Measurement of the **flux** of charged particles and their **precipitation** from the Inner van Allen radiation belt;
- Monitoring electromagnetic anthropic effects at low-Earth orbit altitude
- Study Solar-terrestrial interactions **CMEs**, **SEPs, solar physics;**
- Measurement of the low-energy spectrum of **galactic cosmic rays**;

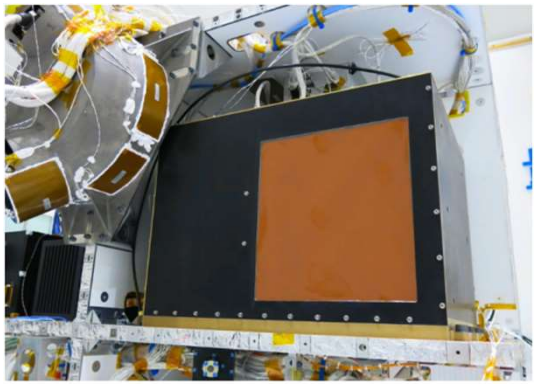
HEPD-01 onboard CSES-01

- CSES-01 was launched in February 2018.
  - Sun-synchronous circular orbit, 507 km (LEO), pointing to Zenith
  - 9 instruments, among which the **H**igh **E**nergy **P**article **D**etector (**HEPD-01**) developed by the Italian **LIMADOU** collaboration





Electron count enhancement during Geomag. storm of 26/08/2018



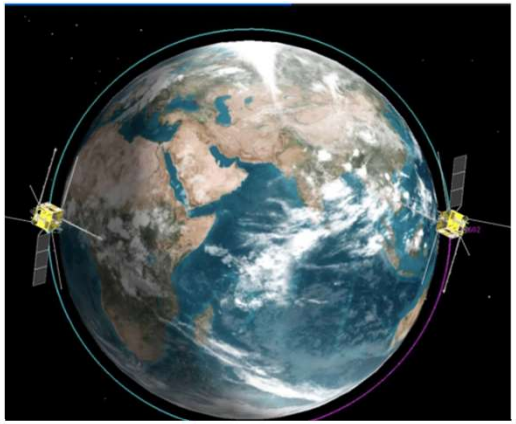
HEPD-01 onboard the CSES-01 satellite

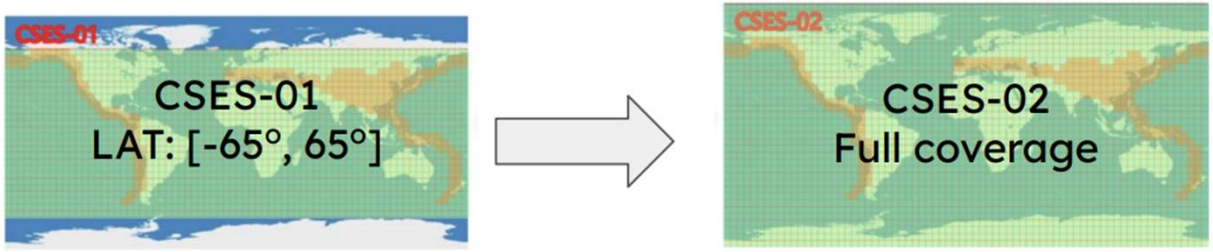
Talks HEPD-01 @ TeVPA:

- "Galactic cosmic rays results from HEPD-01 detector on board CSES-01 satellite", Dr. B. Panico, this session
- "Gamma-Ray Burst observations by HEPD-01 space detector on board CSES-01 as an anticipation of future ones by HEPD-02 on CSES-02", Dr. F. Palma, tomorrow session Gamma Ray Astronomy

HEPD-02 onboard CSES-02

- CSES-02 launch foreseen in 2024.
  - Sun-synchronous circular orbit, 500 km altitude
  - Same orbital plane of CSES-01, with a phase shift of 180°
    → **multi-satellite approach**
  - Complementary orbit with CSES-01



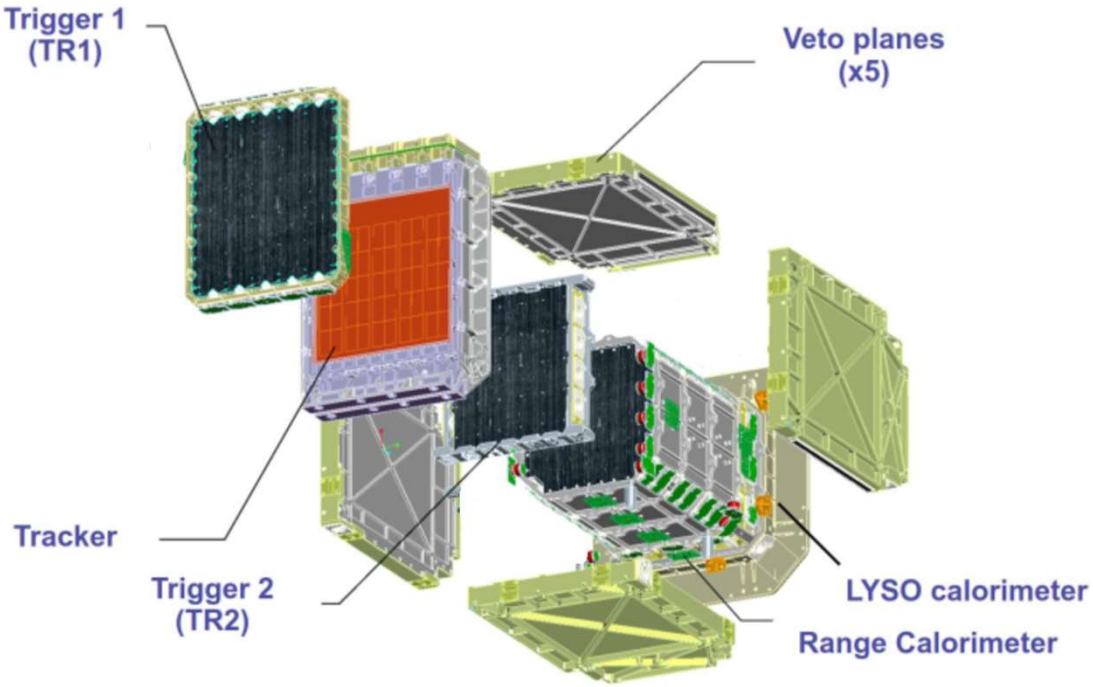


Kin. energy range (electron)	3 MeV to 100 MeV
Kin. energy range (proton)	30 MeV to 200 MeV
Angular resolution	≤10° for E_{kin} > 3 MeV electrons
Energy resolution	≤10% for E_{kin} > 5 MeV electrons
Particle selection efficiency	> 90%
Detectable flux	up to 10^7 $m^{-2}s^{-1}sr^{-1}$
Operating temperature	-10 °C to +35 °C
Operating pressure	≤ $6.65 \cdot 10^{-3}$ Pa ("vacuum")
Mass budget	50 kg
Power Budget	45 W
Data budget	≤ 100 Gb/day

The Limadou collaboration developed 2 of the 11 instruments on board: the High Energy Particle Detector (**HEPD-02**) and the Electric Field Detector (**EFD-02**). HEPD covers the highest energy region of sensitivity of CSES.

The High Energy Particle Detector (HEPD-02)

HEPD-02 is designed to measure fluxes of electrons, protons and heavy nuclei in a wide range of energies , from 3 to 100 MeV for electron, and 30 to 200 MeV/n for protons and heavy nuclei.

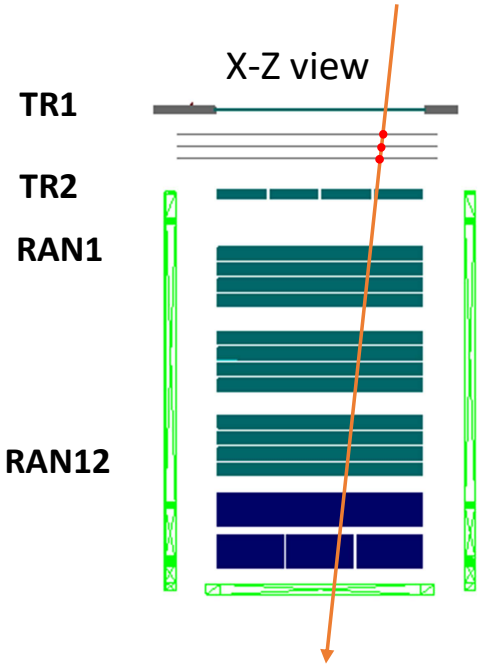


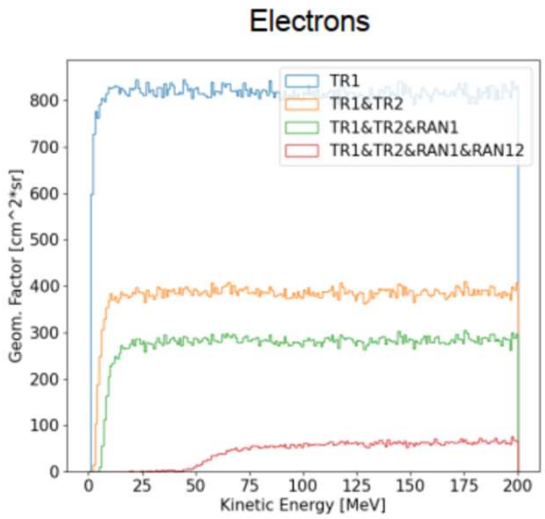
- Two orthogonal trigger planes **TR1** (2 mm thick) and **TR2** (8 mm thick), composed of segmented plastic scintillators
- Direction detector (Tracker) based on 3 layers of Monolithic Active Pixels.
- Energy detector composed of:
  - a tower of 12 plastic scintillators (**RAN**), 150 × 150 × 10 mm^3
  - Two orthogonal planes of segmented LYSO:CE crystals 50 × 150 × 25 mm^3 (**EN**)
- five plastic scintillator panels, covering the sides and bottom , composing the containment detector (**CD**).

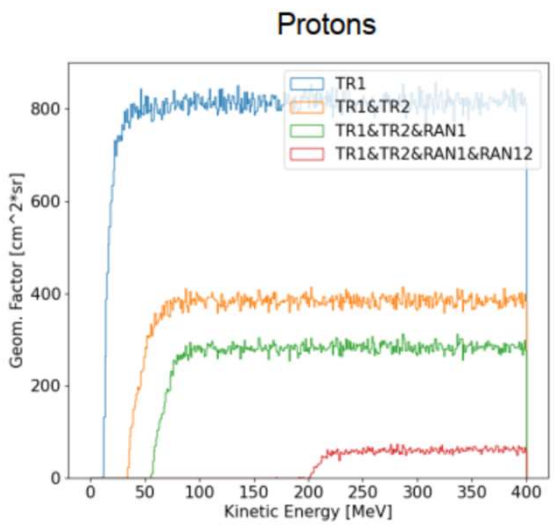
Geometrical factor

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

- Max **6 concurrent trigger** masks; (default TR1&TR2)
- 4 trigger masks can be **pre-scaled**;



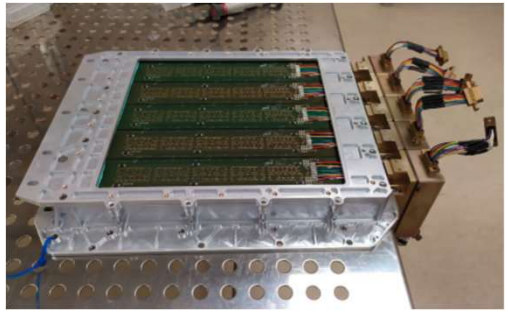




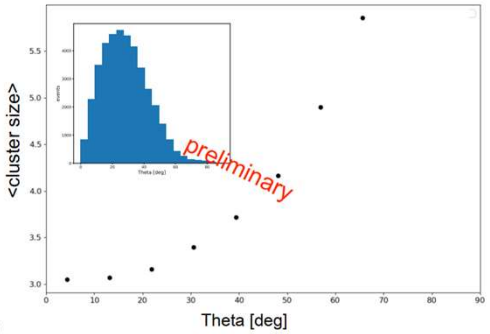
Innovative Design

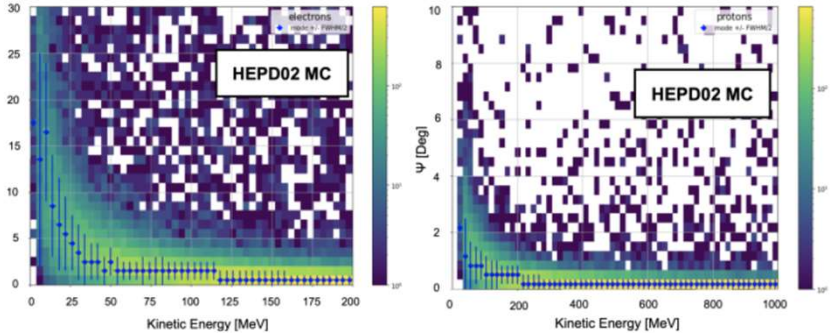
HEPD-02 first use in space of:

- **ACTIVE MONOLITHIC PIXEL SENSORS** based on MAPS development for ALICE experiment at CERN
- **Large size LYSO:CE crystals** (50 × 150 × 25 mm^3)



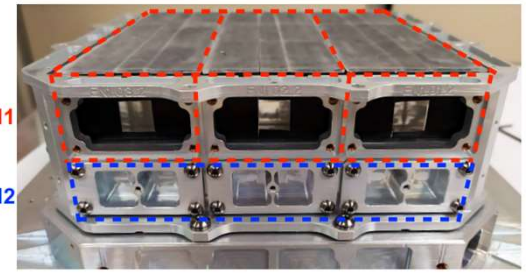
3 layers of 5 independent modules (staves)



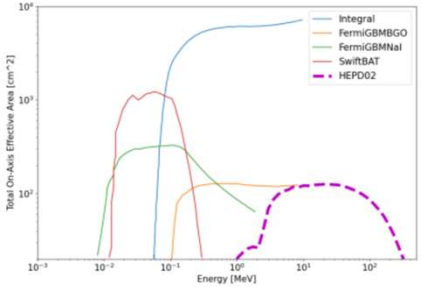


Angular resolution vs energy from MC

→ high density
→ high light yield



The module made of LYSO crystals will be sensitive to Gamma-Ray Bursts of energy larger than 2 MeV. (courtesy F. Follega and A. Lega, ICRC 2023, 116 and 758)

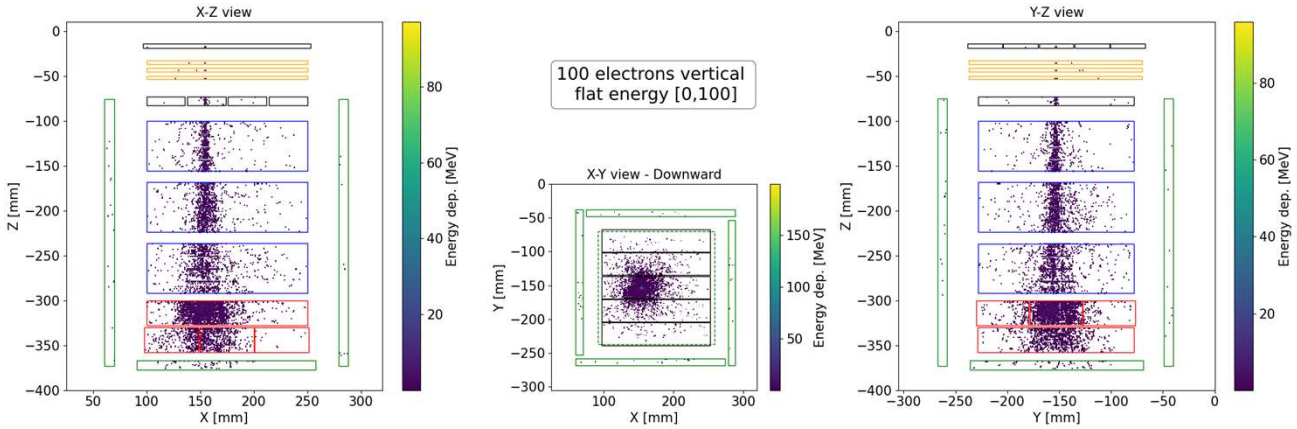


on-axis effective area

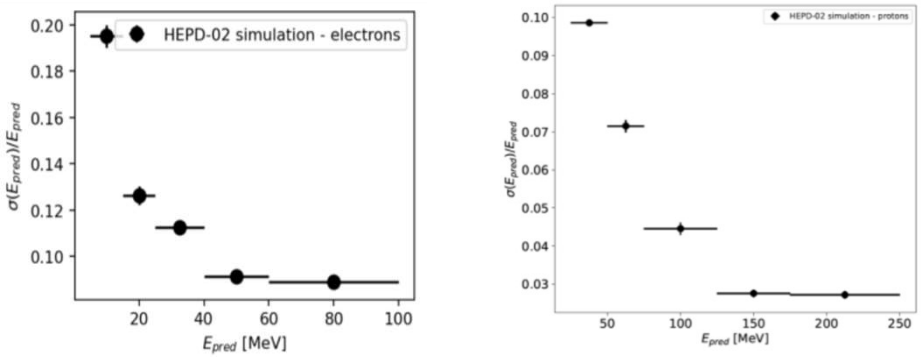
Energy Reconstruction

ADC signals from the calorimeter and the particle impact position and direction
→ reconstruct the deposited energy.

→ corrections for the energy lost in the inert materials using MC



Energy resolution limited by multiple scattering at low energies;

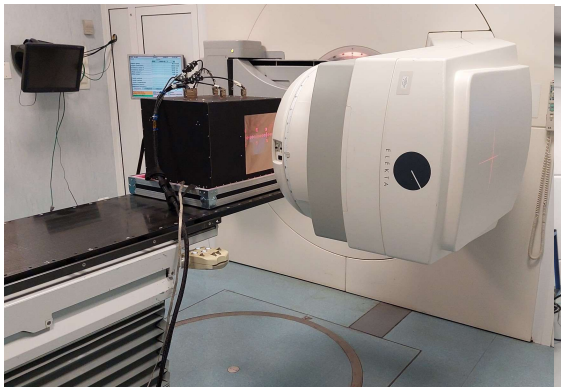


Resolution in energy from MC
(courtesy F. Follega, ICRC 2023, 116)

HEPD-02 Test Beam Campaign

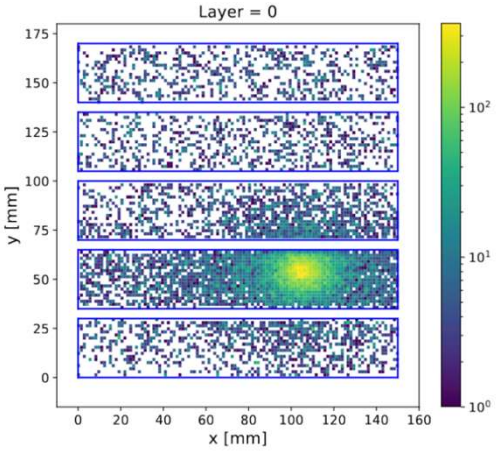
validation of HEPD-02 performance

Electrons, 30-450 MeV @ BTF, Frascati (Italy)
Electrons 6-12 MeV /gamma @ Medical LINAC, S. Chiara Hospital, Trento (Italy)
Protons, 20-230 MeV @ Trento Proton Therapy Centre
Carbon ions, 115-400 MeV/amu @ CNAO, Pavia (Italy)

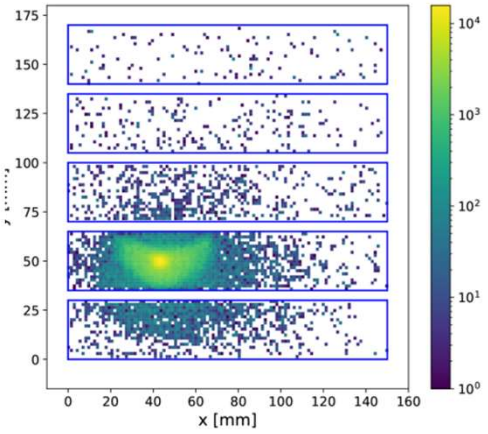


Electron test beam at **Linac** Santa Chiara

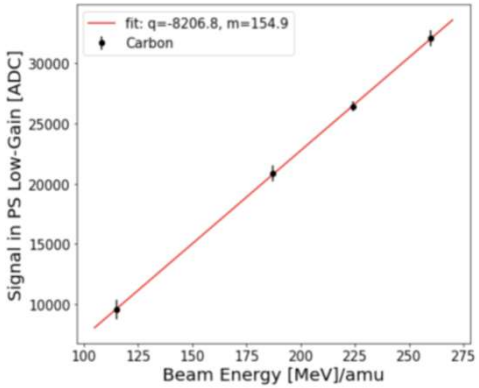
Carbon test beam at **CNAO**, Pavia.



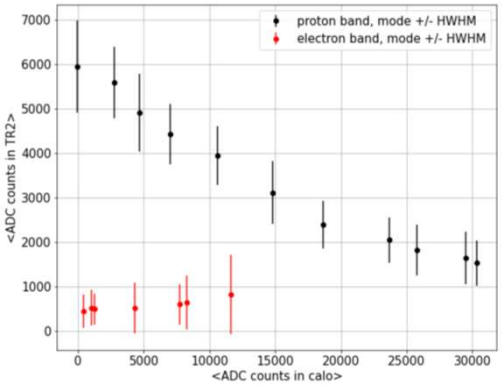
12 MeV electron beam @ Linac, Santa Chiara (Italy)



Carbon beam @ CNAO, Pavia (Italy)



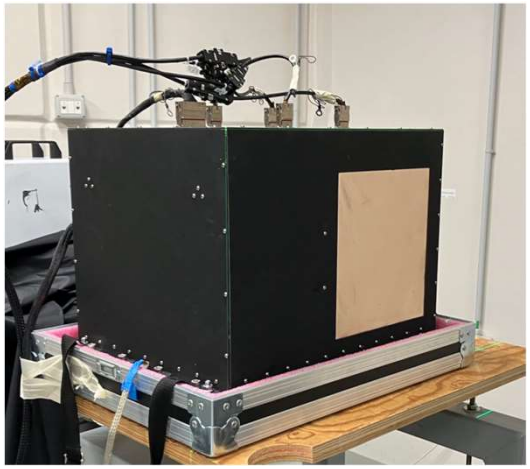
Signal linearity with energy



Particle identification

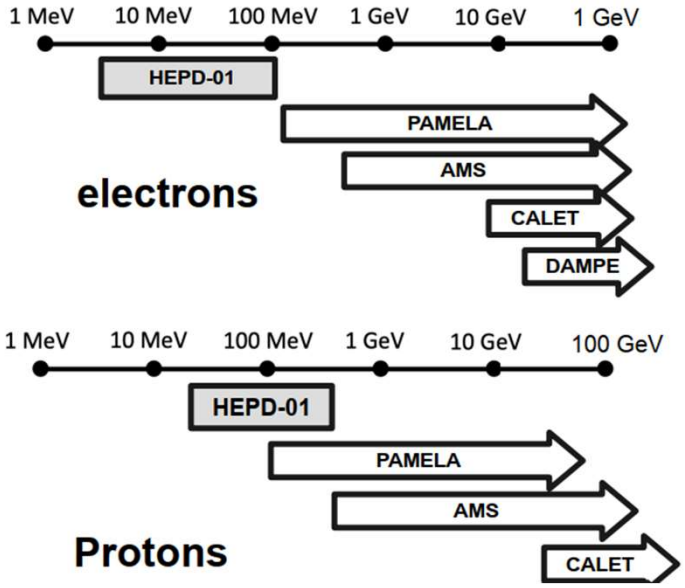
Summary and Perspective

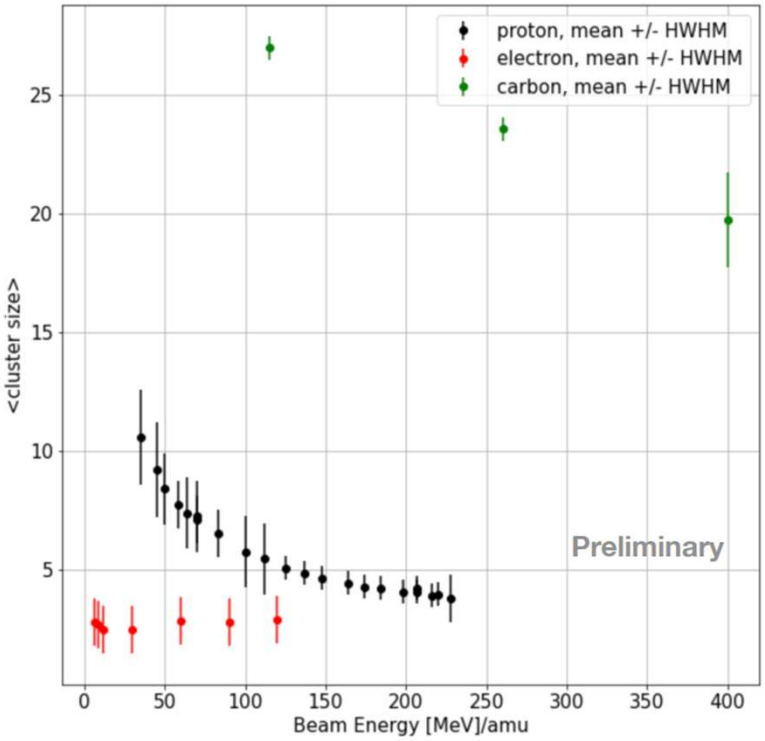
- HEPD-02 has a new design and upgrades with respect to HEPD-01;
- First use of MAPS in space and large LYSO crystals;
- It was fully integrated and passed all space qualification tests;
- Good reconstruction capabilities and improved trigger capability;
- The Flight Model (FM) is to be integrated in CSES-02 satellite with a launch foreseen in **2024.**



Thank You

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




proton, mean +/- HWHM
electron, mean +/- HWHM
carbon, mean +/- HWHM
Preliminary
<cluster size>
Beam Energy [MeV]/amu
0
50
100
150
200
250
300
350
400
5
10
15
20
25