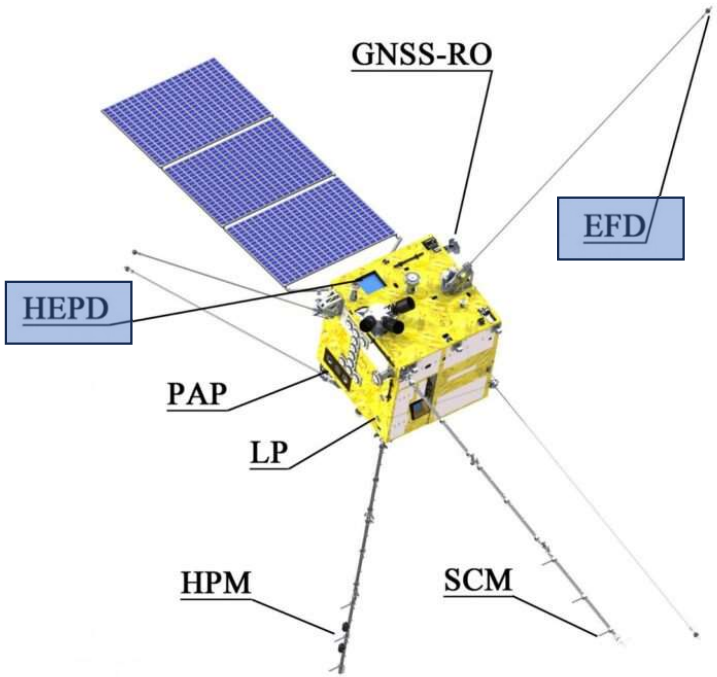
The High Energy Particle Detector (HEPD-02) onboard the CSES-02 Satellite

Z. Sahnoun on behalf of the LIMADOU Collaboration

The CSES Missions



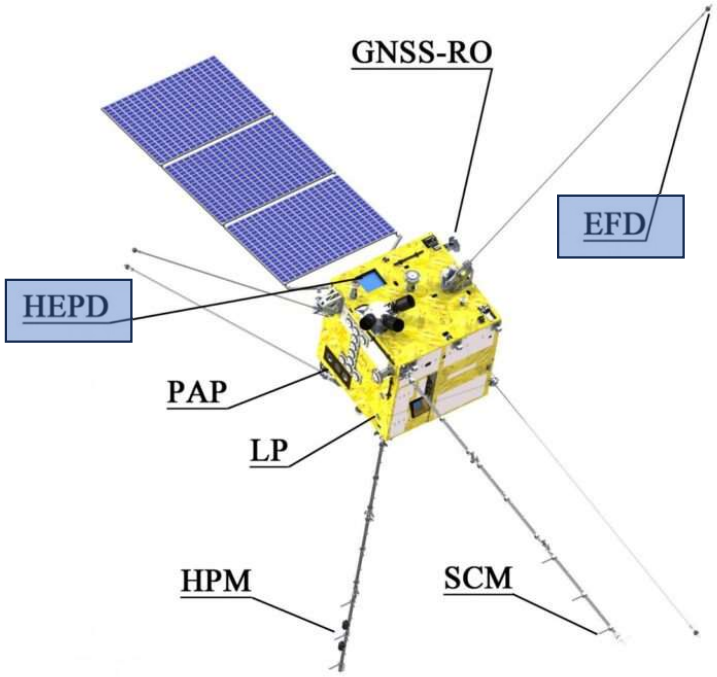
The **China Seismo-Electromagnetic Satellite** (CSES) is a space program dedicated to the monitoring of the near-Earth environment.

Collaboration between China and Italy.

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 (lithosphere-to-magnetosphere coupling)
- Measurement of the **flux** of charged particles and their **precipitation** from the Inner van Allen radiation belt
- Study Solar-terrestrial interactions (**CMEs**, **SEPs**)
- Measurement of the low-energy spectrum of galactic cosmic rays.
- …

The CSES Missions

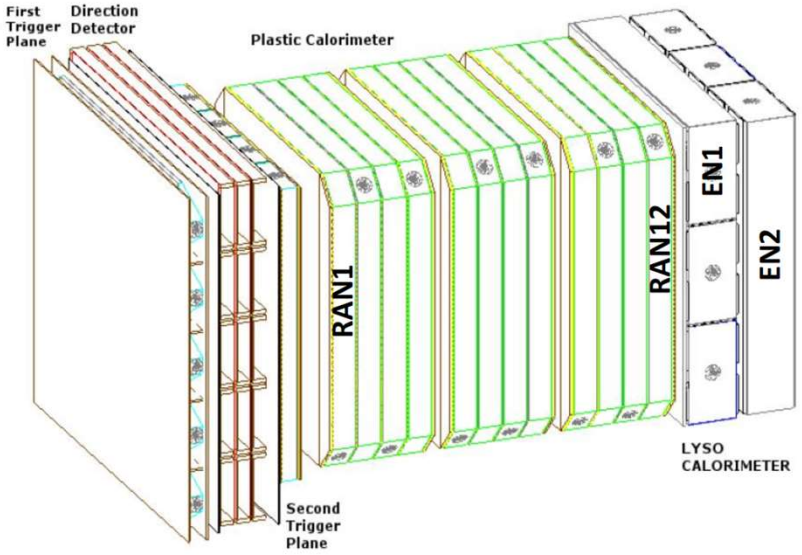


- CSES-01 was launched in February 2018.
  - Sun-synchronous circular orbit, 507 km (LEO)
  - 9 instruments, among which the **H**igh **E**nergy **P**article **D**etector (**HEPD-01**) developed by the Italian **LIMADOU** collaboration
- CSES-02 launch foreseen in 2024.
  - Sun-synchronous circular orbit, at about 500 km altitude
  - Same orbital plane of CSES-01, with a phase shift of 180° → **multi-satellite approach**
  - Upgraded version of HEPD (**HEPD-02**)

The Italian Limadou collaboration developed 2 of the 11 instruments on board: the High Energy Particle Detector (**HEPD-02**) and the Electric Field Detector (**EFD-02**)

The High Energy Particle Detector (HEPD-02)

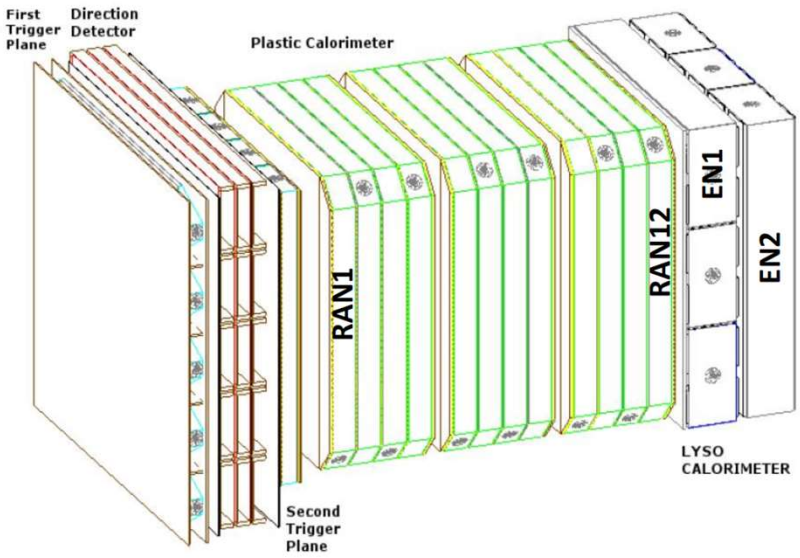
The High Energy Particle Detector has been developed by the Italian Limadou collaboration lead by ASI and INFN. It covers the highest energy region of sensitivity of CSES.



HEPD-02 detector layout.

- Energy range:
  - electrons: 3 – 100 MeV
  - Protons: 30 – 200 MeV
  - Light ions: up to 200 MeV/nucleon
- detect particles on an event-by-event basis
- Sensitive to gamma with energy > 2 MeV

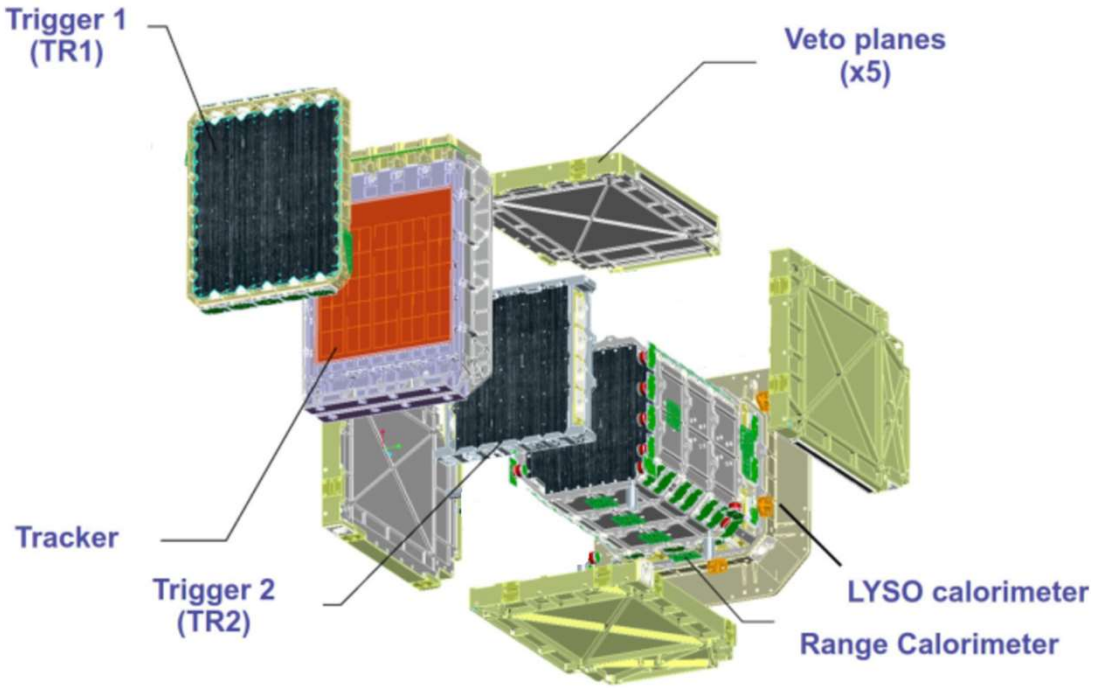
The High Energy Particle Detector (HEPD-02)



HEPD-02 detector layout.
The containment panels are not shown

- Two orthogonal trigger planes **TR1** and **TR2**, 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**), $150 \times 150 \times 10$ mm^3
  - Two orthogonal planes of segmented LYSO:CE crystals $50 \times 150 \times 25$ mm^3 (**EN**)
- five plastic scintillator panels, covering the sides and bottom , composing the containment detector (**CD**).

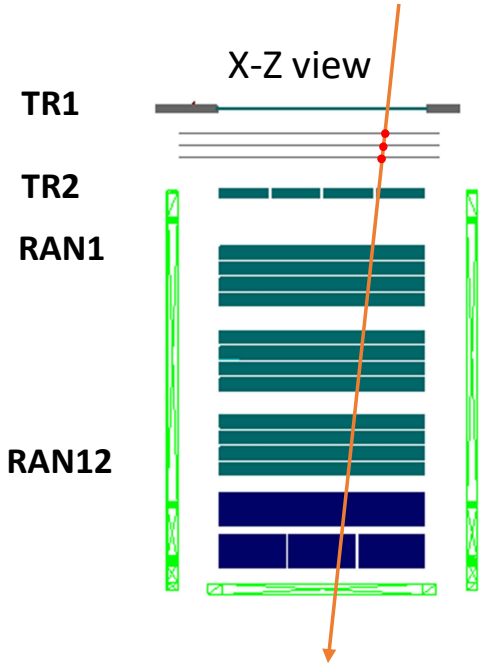
The High Energy Particle Detector (HEPD-02)

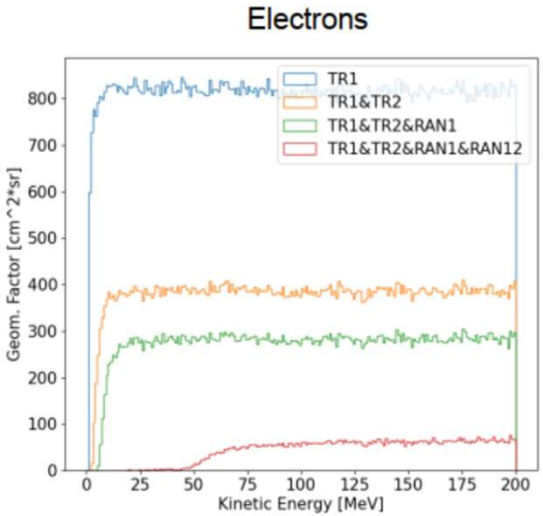


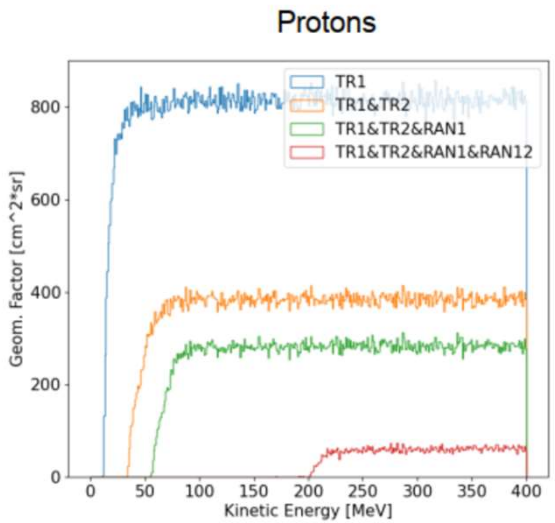
Geometrical factor

- Depends on the trigger mask

Several masks have been implemented and can work in concurrent mode.



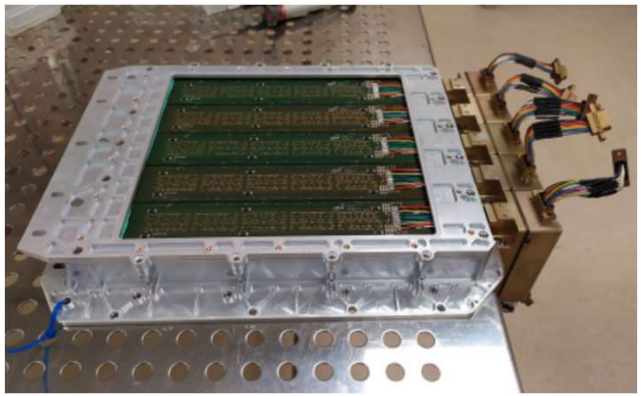




HEPD-02 Innovation

HEPD-02 first use in space of:

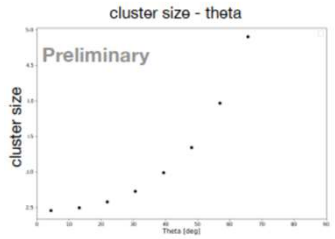
- **ACTIVE MONOLITHIC PIXEL SENSORS** based on MAPS development for ALICE experiment at CERN



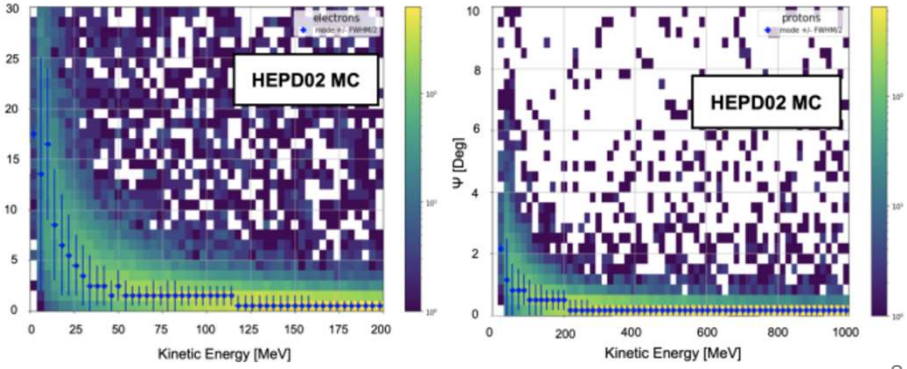
3 layers of 5 independent modules (staves)

Talk yesterday : Umberto Savino Univ. & INFN Turin

cluster size increasing with track inclination



MC angular resolution for electrons and protons as a function of the kinetic energy. ~ 10° for low energy electrons, ~ 1° for low energy protons.



HEPD-02 Innovation

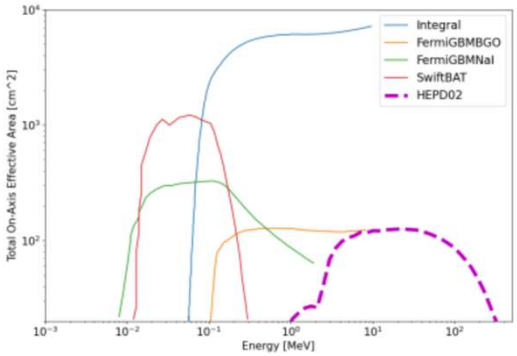
HEPD-02 first use in space of:

- ACTIVE MONOLITHIC PIXEL SENSORS (MAPS)
- **Large size LYSO:CE crystals** (50 × 150 × 25 mm^3)

→ fast decay time
→ high density
→ high light yield

Density [g/cm^3]	7.1
Attenuation length for 511 keV (cm)	1.2
Decay time [ns]	36
Energy resolution @ 662 keV	8.0
Light output, photons per keV	33
Average temperature coefficient 25 to 50°C (%/°C)	-0.28

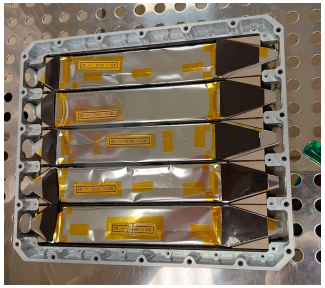
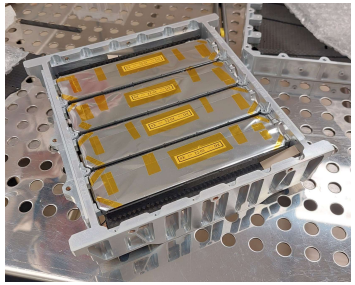
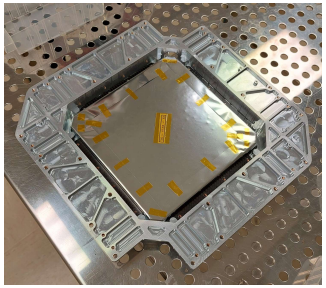
The module made of LYSO crystals, and its relative acquisition system will be sensitive to Gamma-Ray Bursts of energy larger than 2 MeV. (courtesy F. Follega and A. Lega, ICRC 2023, 116 and 758)

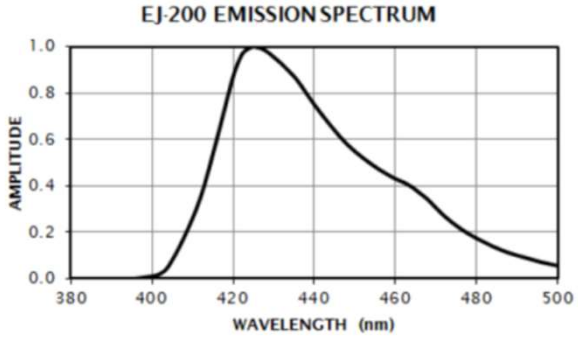


on-axis effective area

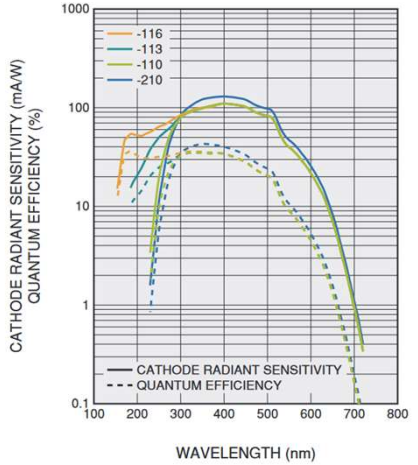
Plastic Scintillators

Trigger Planes (**TR1, TR2**), range calorimeter (**RAN**) and containment panels are EJ-200 (Eljen) plastic scintillators.



→ TR1 thin paddles, 2mm, couples to PMTs through light guides
→ All counters are read by **2** PMTs, R9880-210 Hamamatsu, at opposite sides.
→ Efficient light collection.



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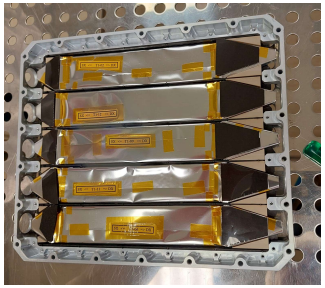
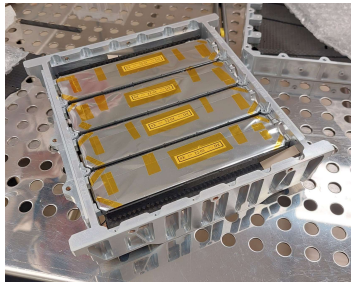
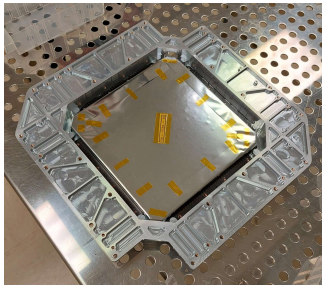
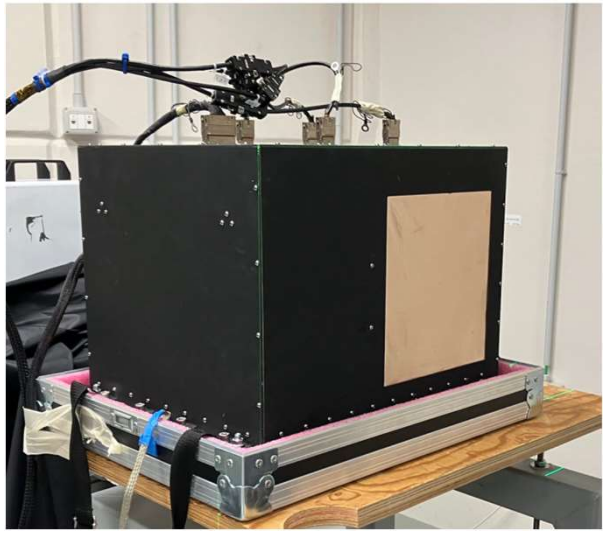






→ HEPD-02 FM is fully integrated and has passed all the space-qualification tests.

→ It was extensively tested under cosmic muons and at beam test facilities.

Electrons, 30-450 MeV @ BTF, Frascati (Italy) and 6-12 MeV @ Medical LINAC, S. Chiara Hospital, Trento (Italy)

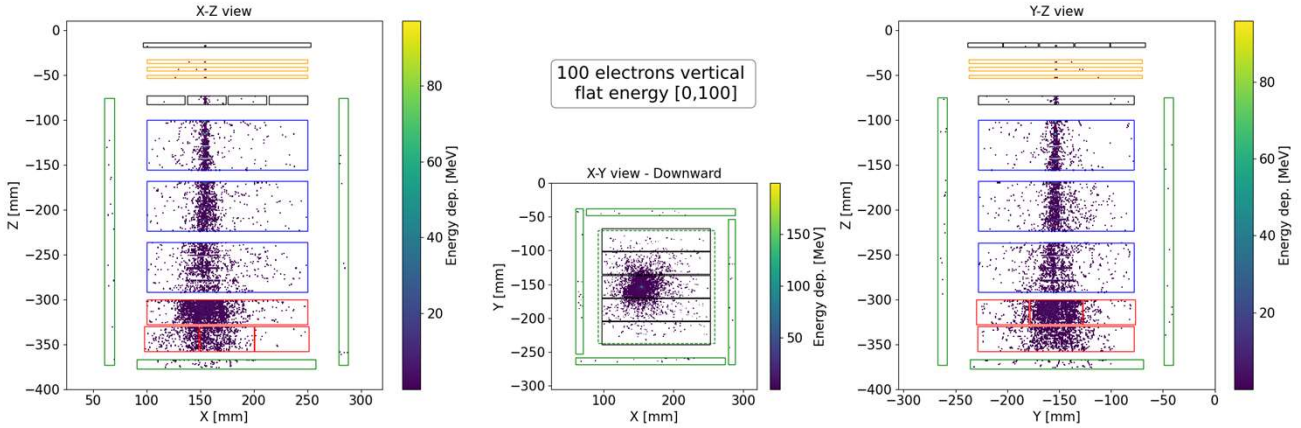
Protons, 20-230 MeV @ Trento Proton Therapy Centre

Carbon ions, 115-400 MeV/amu @ CNAO, Pavia (Italy)

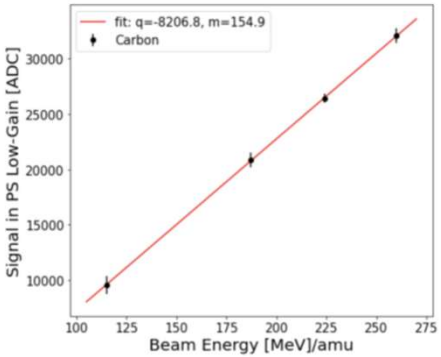
Energy Reconstruction

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

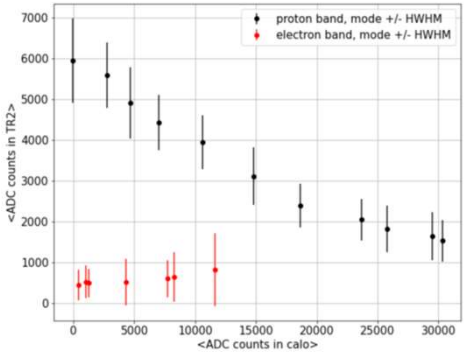
→ corrections for the energy lost in the inert materials using MC



DATA

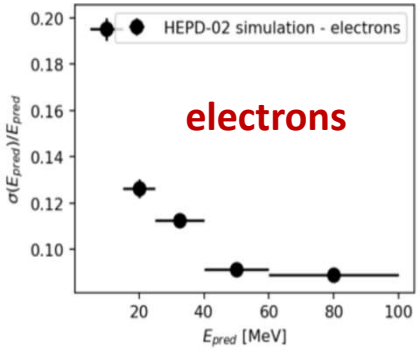


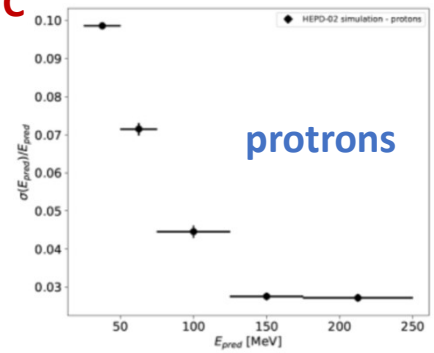
Signal linearity with energy



Particle identification

MC





(courtesy F. Follega, ICRC 2023, 116)

Direction “complementary” reconstruction

Make use of the trigger planes and energy detector segmentation

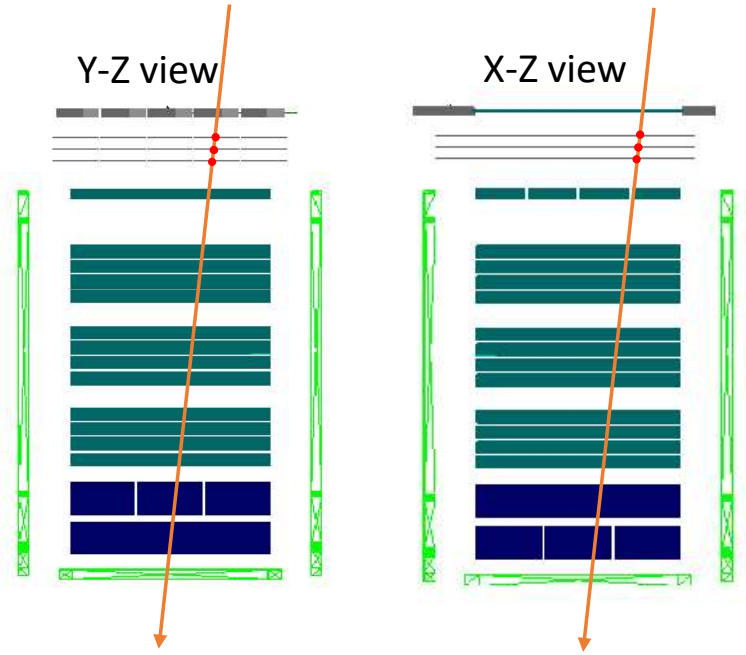
→ **TR1**, 5 bars, orthogonal to **TR2** , 4 bars.

→ **EN** two orthogonal planes of 3 bars.

→ Efficient in selecting normal incident particles

→ almost trough-going particles

→ Resolution on position limited by geometry.



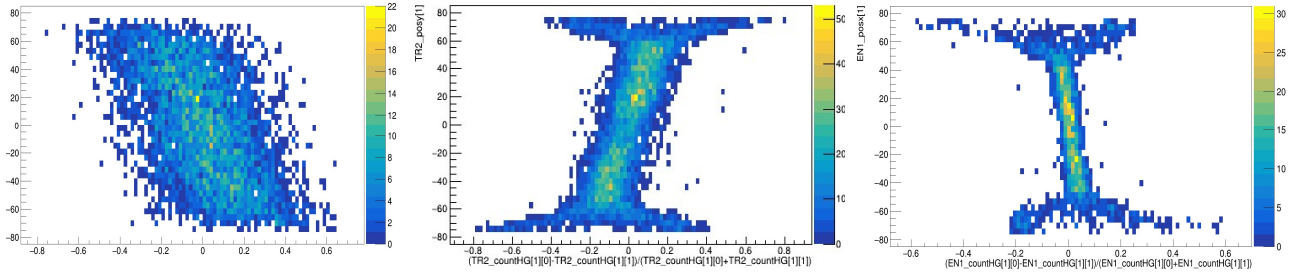
→ Make use of the two PMT signals for each counter ...

Light collection sensitivity to position

Investigate the asymmetry in light collection by the 2 PMTs versus impact position.

→ PMTs need to be equalized, as best as possible.

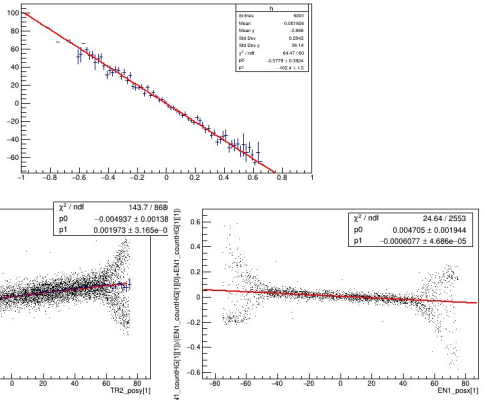
Position versus estimator



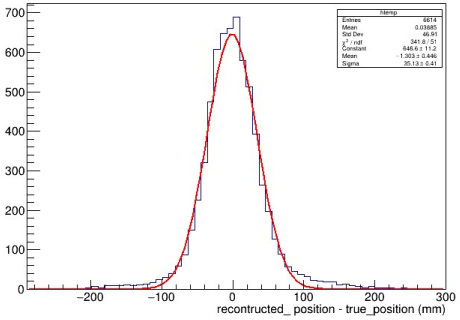
TR1 **TR2** **EN**

→ **Estimator : (ADC_PMT1 - ADC_PMT2) /(ADC_PMT1+ADC_PMT2)**

Preliminary parametrization

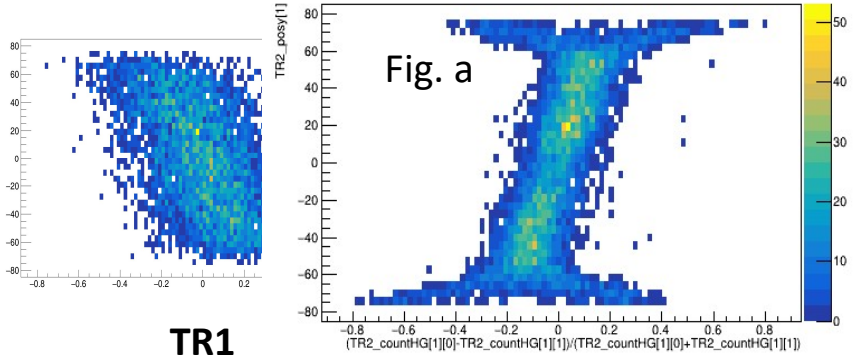


Individual counter resolution ~ 3cm

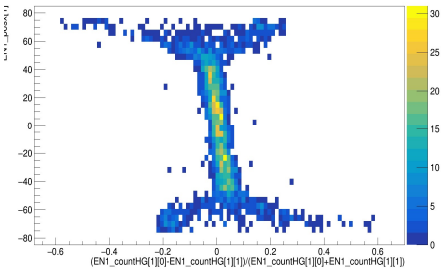


Light collection sensitivity to position

One can also make use of interesting features.



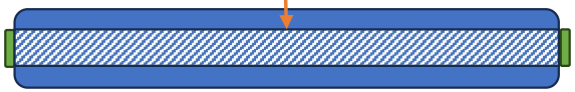
TR1

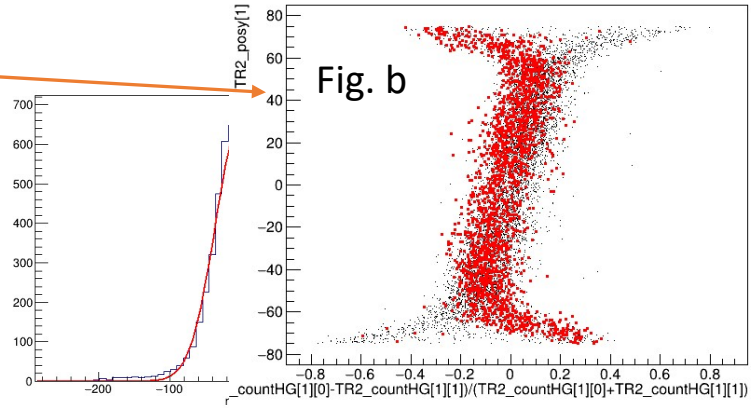


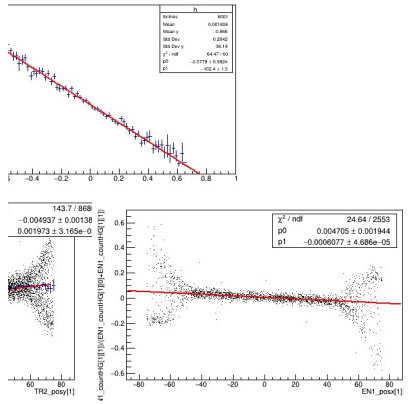
EN

ry parametrization

Red dots in Fig. b, are signals along the band joining PMTs

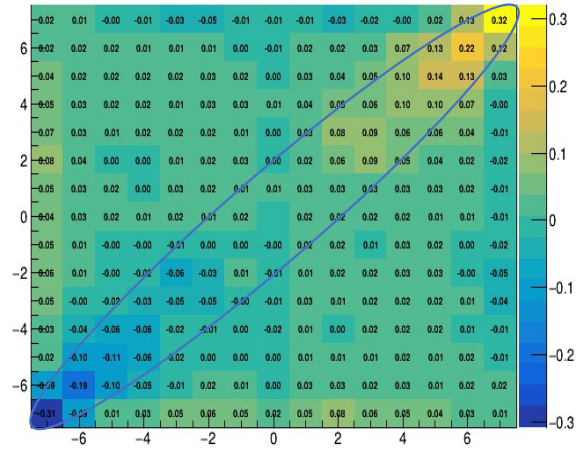






Light collection sensitivity to position

Investigate the asymmetry in light collection by the 2 PMTs versus impact position.

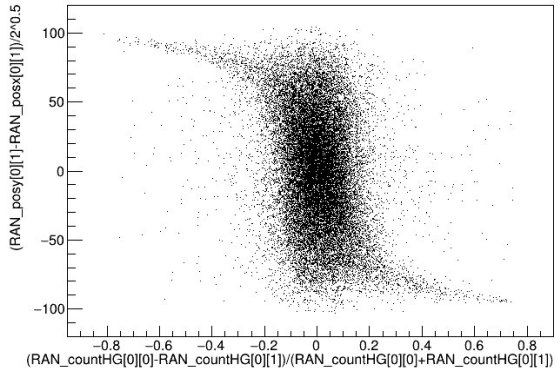


→ trickier for the calorimeter tile (**RAN**) : very uniform response ! As was expected

→ rotate coordinates : OX' along the diagonal 

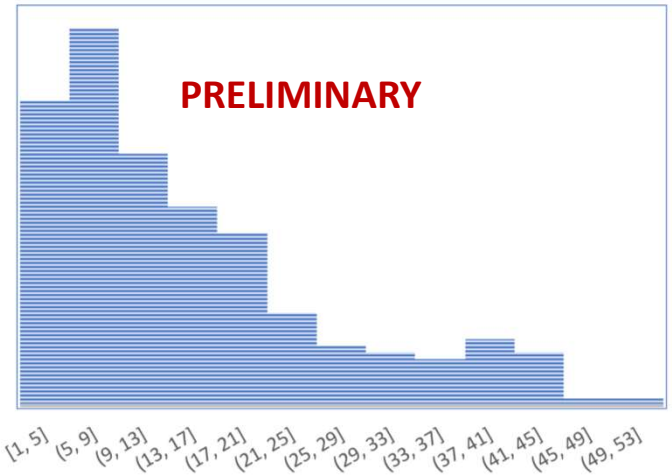
→ Use of orthogonality of PMTs line between two consecutive RAN planes.

Still under development !

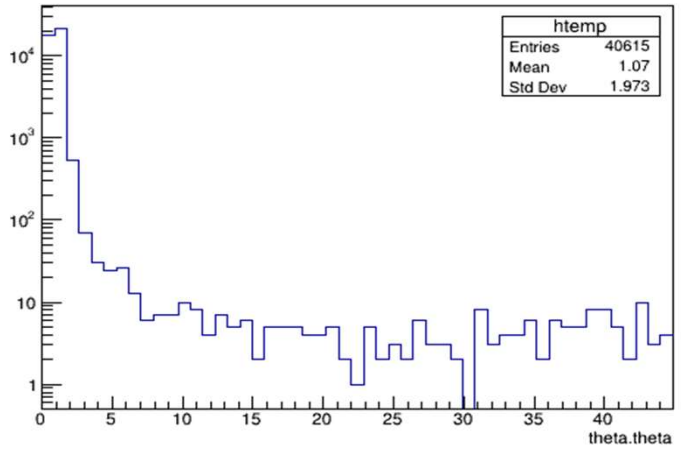


Preliminary results

Theta angle reconstruction: from a proton beam 228 MeV with normal incidence.



This work



From tracker reconstruction

Ongoing development and tests of ground data “ cosmics and beam test”.

Conclusions and perspectives

- HEPD-02 was fully integrated and passed all space qualification tests.
- First use of MAPS in space.
- Trigger counters and range calorimeter have a high detection efficiency and a good uniformity
- The Flight Model (FM) is to be integrated in CSES-02 satellite with a launch foreseen in **2024**.
- On going analysis of test beam data.
- The response of the HEPD-02 counters to the ion impact position is being investigated.
  - The combined signals and asymmetries may add new, complementary information about ions impact position and direction. → Still to be fully developed.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

INFN
Istituto Nazionale di Fisica Nucleare

LIMADOU 利瑪竇

THANK YOU

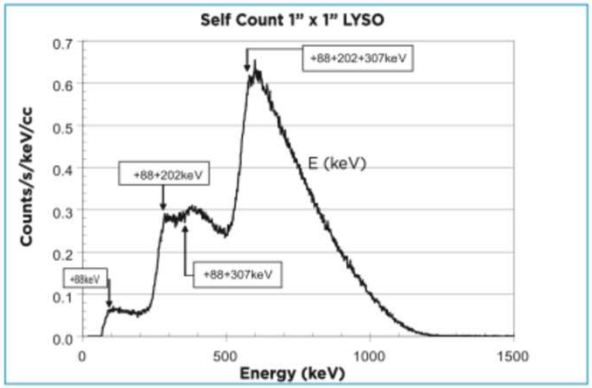
Backup

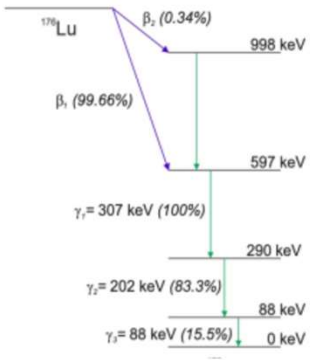
CSES-02

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

LYSO:CE

Natural radioactivity

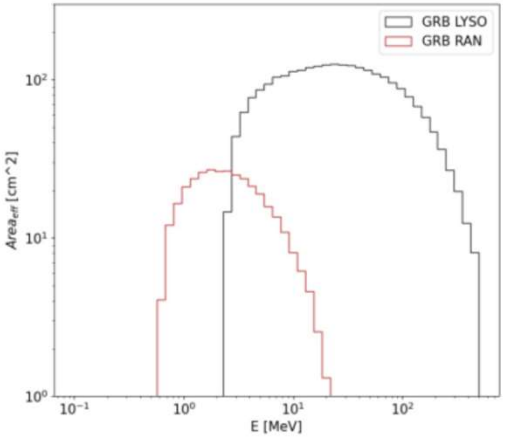




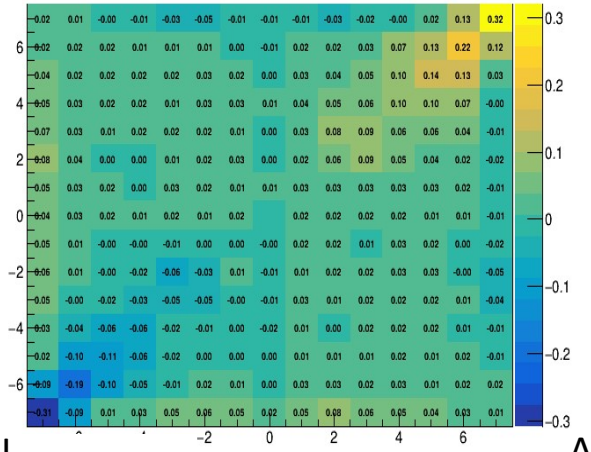
GEOMETRICAL FACTOR OF HEPD-02 FOR GRB

$$GRB_{LYSO} = \mathrm{OR}(EN1, EN2)\&\neg\mathrm{OR}(RAN12, LAT, BOT)$$

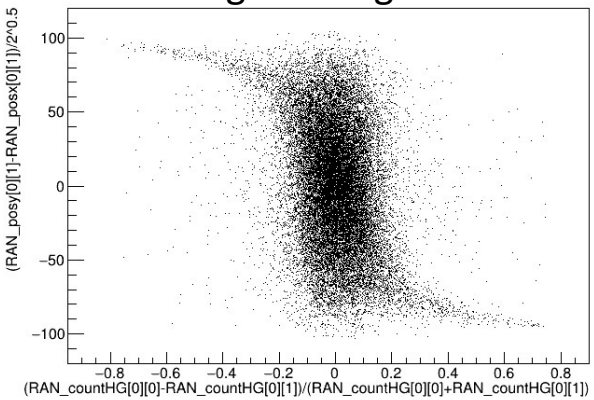
$$GRB_{RAN} = \mathrm{OR}(RAN5, RAN6, RAN7, RAN8)\&\neg\mathrm{OR}(RAN4, RAN9, LAT)$$



Calorimeter tile



Along the diagonal



Along the normal to diagonal