THE HIGH ENERGY PARTICLE DETECTOR (HEPD-02) FOR THE SECOND CHINA SEISMO-ELECTROMAGNETIC SATELLITE (CSES-02)

Cristian De Santis (INFN)
on behalf of the CSES-Limadou Collaboration

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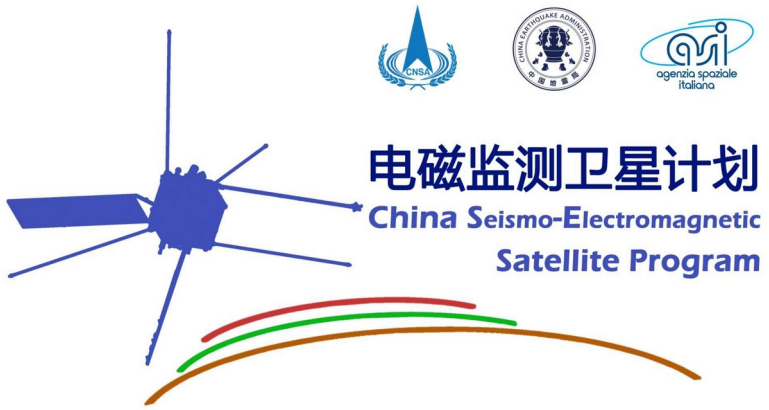
Agenzia Spaziale Italiana
Istituto Nazionale di Fisica Nucleare
UNIVERSITÀ DI TRENTO
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA
UNIVERSITÀ DEGLI STUDI DI TORINO

CSES MISSIONS – SCIENTIFIC OBJECTIVES

- Monitoring of the electromagnetic near-Earth space environment
- Analysis of the ionospheric and plasmaspheric fluctuations
- Measurements of iono-magnetospheric perturbations possibly due to seismo-electromagnetic phenomena
- Study of fluxes of high & low energy charged particles precipitating from the Inner Van Allen radiation belt
- Measurements of magnetospheric and solar activity
- Monitoring of the e.m. anthropic effects at LEO altitude
- Observations of e.m. transient phenomena caused by tropospheric activity



CSES-01 - HIGH ENERGY PARTICLE DETECTOR (HEPD)

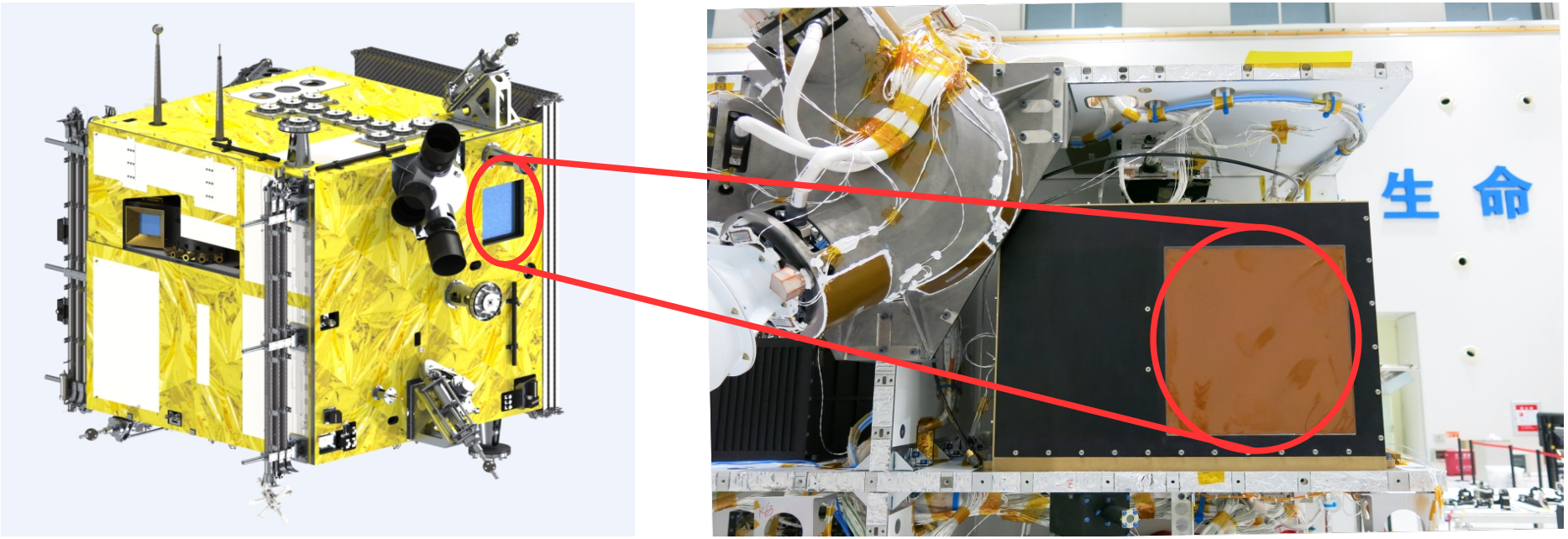
CSES-01: launch February 2nd, 2018 (97.4° sun-synchronous circular orbit, altitude 507 km)

The High-Energy Particle Detector (HEPD) on board CSES-01 can:

- measure the increase of the electron and proton fluxes due to short-time perturbations of the radiation belts caused by solar, terrestrial and anthropic phenomena
- detect different particle populations (solar, trapped, galactic, etc.) according to the satellite position and energy

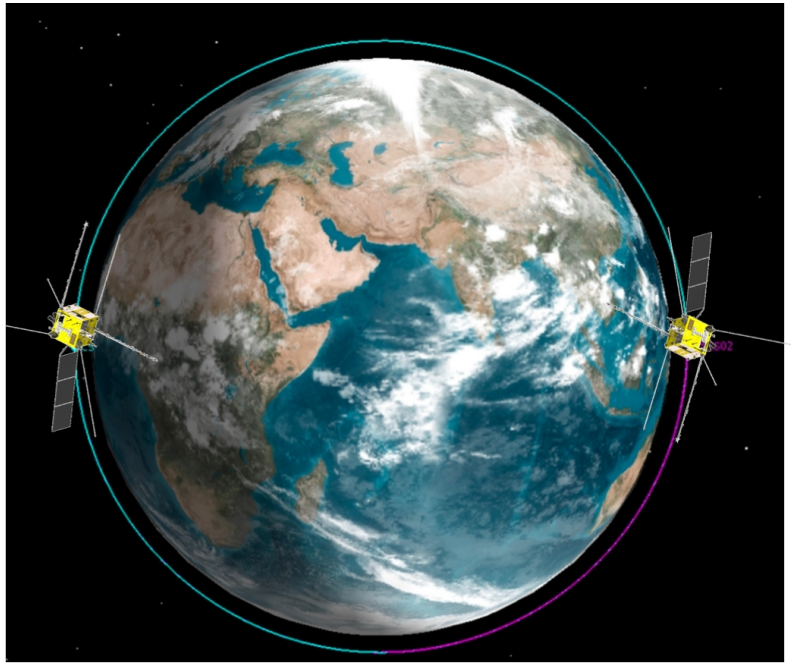
The energy range explored is 3 - 100 MeV for electrons and 30 - 200 MeV for protons

HEPD-01 is installed on board the satellite with its entrance window pointing to the zenith



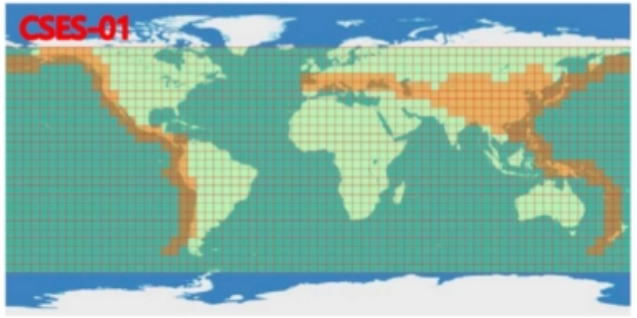
HEPD-01 installed on-board CSES-01 (Credits: DFH)

CSES-02 SATELLITE

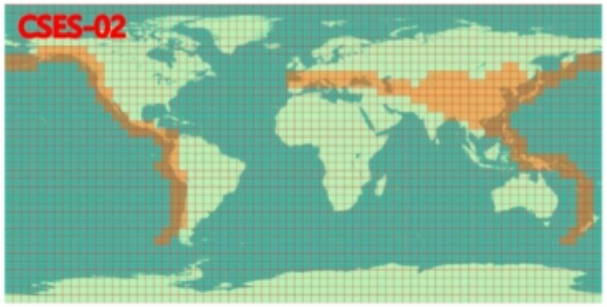


- The second CSES satellite (CSES-02) is expected to be launched in 2024
- CSES will be a sophisticated multi-satellite space observatory (*F. M. Follega The CSES mission: a sophisticated multi-point space observatory, 27/09 11:50*)
- Same DFH CAST-2000 platform of CSES-01 with some upgrades
  - Earth oriented 3-axis stabilization system with orbit maneuver capability
  - X-Band Data Transmission 120Mbps → **150Mbps**
  - Storage 160Gb → **512Gb**
  - Total Mass: 730kg → **900kg**
  - Peak Power Consumption: ~900W
  - Design Life-span: 5 years → **6 years**
- Complementary Ground Track wrt CSES-01
  - Identical Orbit Plane **with 180° Phase Difference**
  - Track interval: 5° → **2.5°**
  - Return cycle: 5 days → **2.5 days**
- Operation mode: Full time operational

Operation area between lat [-65,65]



Full coverage at extreme latitudes



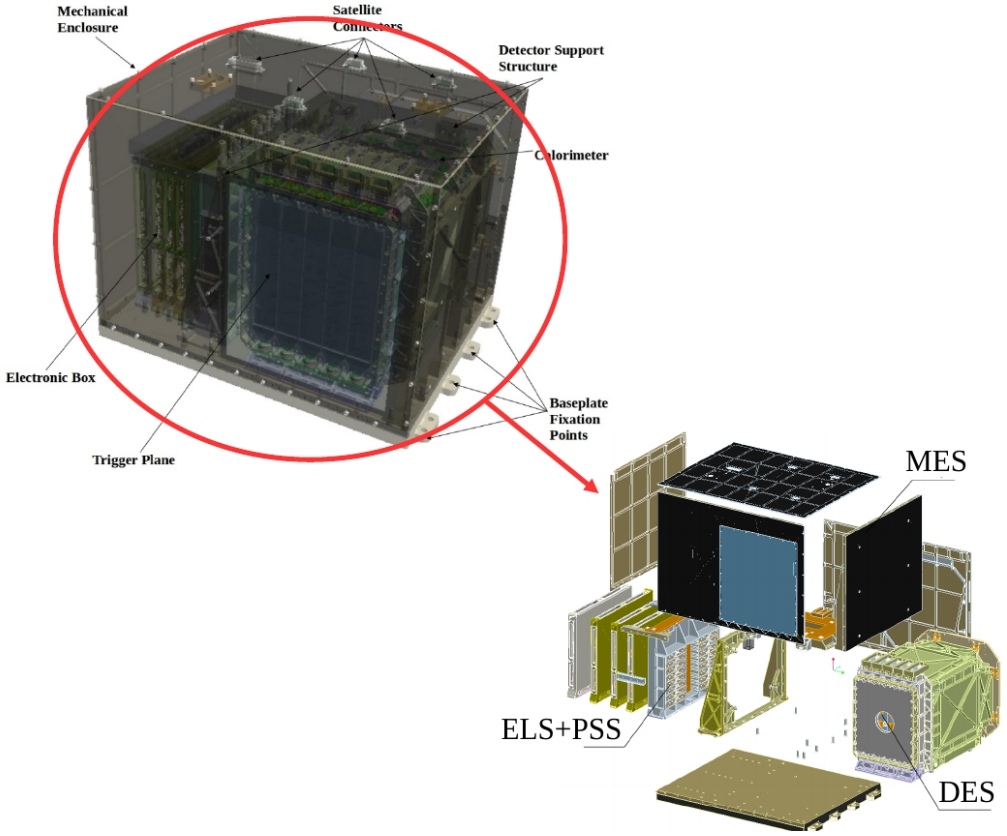
CSES-02 – PAYLOAD CONFIGURATION

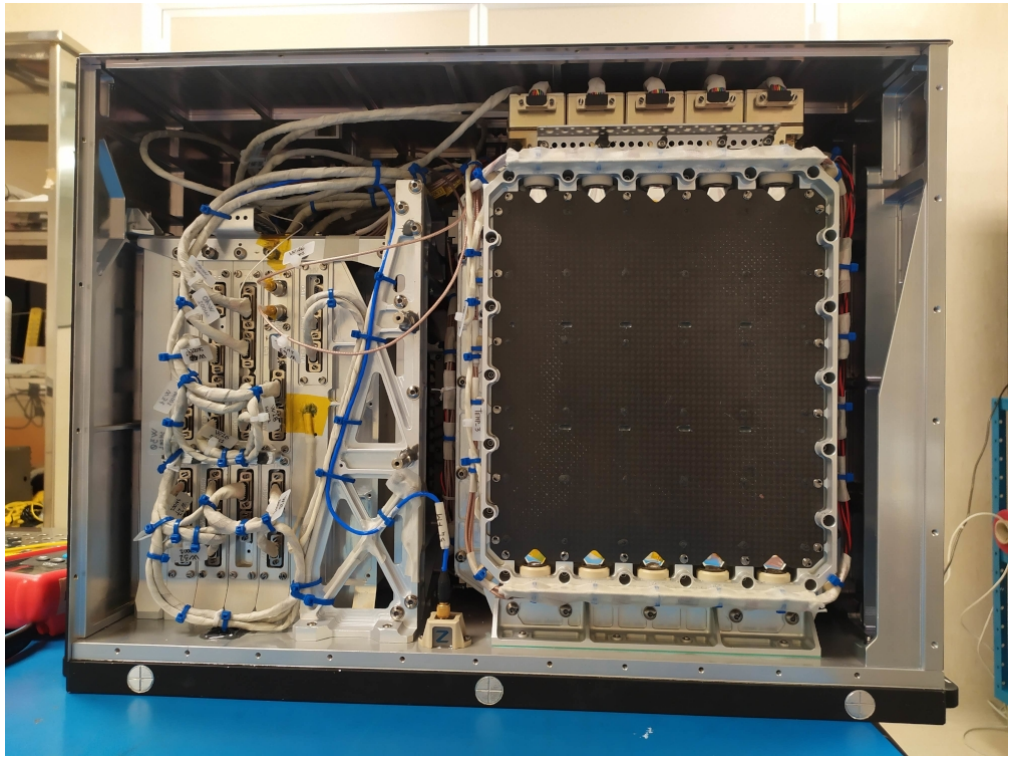
Category	*Payload Name*	*Observation Targets*
Energetic Particle	***High Energy Particle Detector (HEPD) Italy*** ***Medium Energetic Electron Detector (MEED)***	*Proton： 2MeV~200MeV* *Electron： 30keV~50MeV*
Electro-Magnetic Field	***Electric Field Detector (EFD) Italy***	*Electric Field: DC ～3.5MHz*
	High Precision Magnetometer (HPM): *FGM1, FGM2, CDSM **Austria***	*Magnetic Field: DC ～15Hz*
	Coherent Population Trap (CPT)	*Magnetic Field: DC ～15Hz*
	Search Coil Magnetometer (SCM)	*Magnetic Field: 10Hz ～20kHz*
In Situ Plasma	*Plasma Analyzer Package (PAP)*	*Composition： H^+, He^+, O^+* *N_i： 5×10^2~$1\times10^7 cm^{-3}$* *T_i： 500K~10000K*
	Langmuir Probe (LP)	*N_e： 5×10^2~$1\times10^7 cm^{-3}$* *T_e： 500K~10000K*
Plasma Profile	*GNSS Occultation Receiver*	*TEC by GNSS Occultation Signal*
	Tri-Band Beacon (TBB)	*TEC by transmit VH/U/L Signal*
	Ionospheric Photometer (IP)	*135.6nm and N_2LBH airglow*

HEPD-02

- Compact and lightweight payload (40.36x53x38.15 cm^3, 47.2 kg)
- Low power consumption (~43 W)
- Acceptance and calibration campaign completed
- To be delivered to China October/November 2023

Operating temperature	-10 °C ÷ +35 °C
Operating pressure	≤ $6.65 \cdot 10^{-3}$ Pa
Data budget	≤ 100 Gb/day
Mass budget	≤ 50 kg
Power budget	≤ 45 W
Electron kinetic energy range	3 MeV ÷ 100 MeV
Proton kinetic energy range	30 MeV ÷ 200 MeV
Angular resolution	≤ 10° for e^- with E > 3 MeV
Energy resolution	≤ 10% for e^- with E > 5 MeV
Pointing	Zenith
Scientific data bus	RS-422
Data handling bus	CAN 2.0
Life cycle	> 6 years





HEPD-02 DETECTOR LAYOUT AND UPGRADES WRT HEPD-01

TRigger plane TR1 (200x180 mm^2) segmented in 5 plastic scintinllator bars (2 mm thick) → *upgrade wrt HEPD-01: additional trigger plane, decrease energy threshold and increase redundancy*

Direction Detector DD ("tracker") made of five standalone tracking modules ("turrets"), each composed of three sensitive planes ("staves")

TRigger plane TR2 (150 x 150 mm^2)

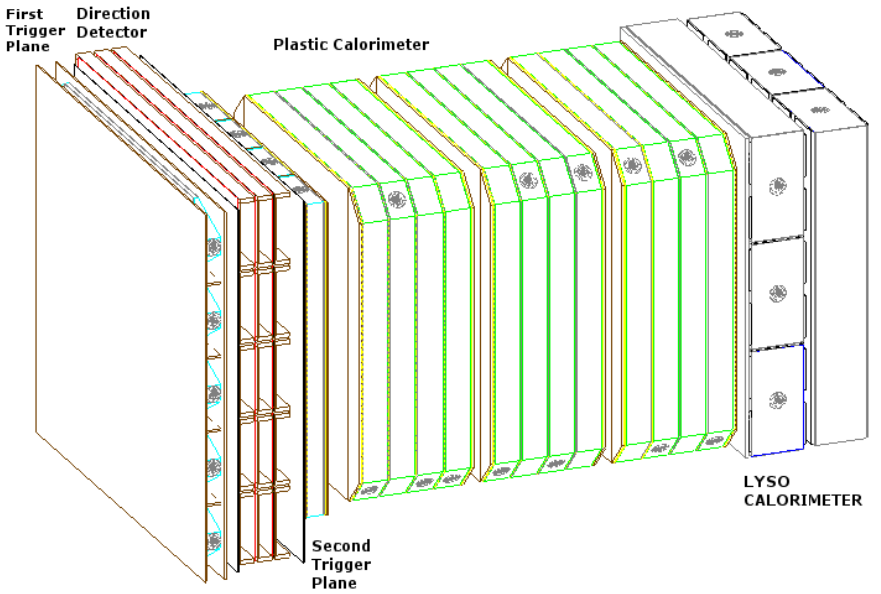
Energy Detector ED ("calorimeter") composed of:

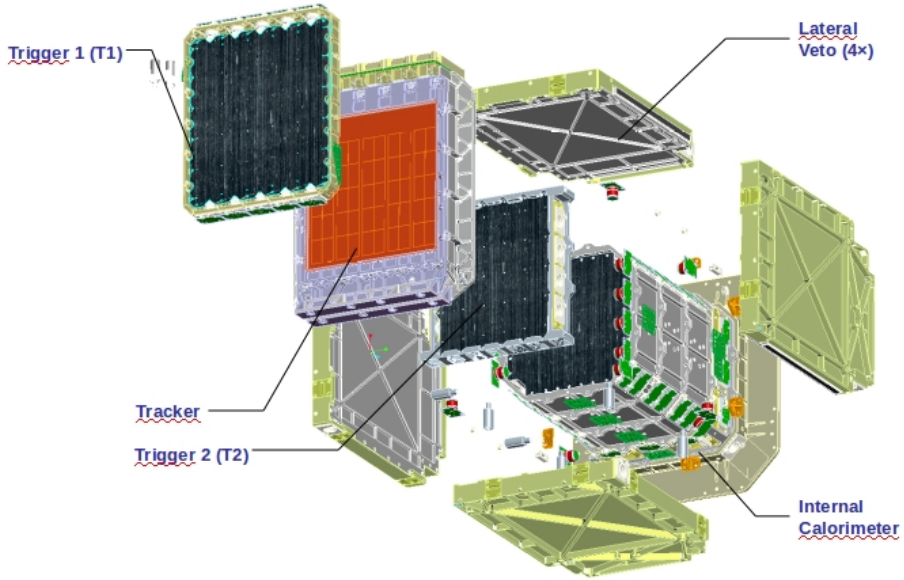
12 plastic scintillator planes (150 x 150 x 10 mm^3) → *16 planes in HEPD-01*

2 crystal (LYSO) scintillator planes (150 x 150 mm^2 segmented in 3 bars (50 mm thick) → *upgrade wrt HEPD-01: 6 bars instead of 9 cubes, increase energy range, position sensitivity and redundancy.*

Containment Detector CD surrounding the calorimeter on 5 sides, made of plastic scintillator planes (4 lateral and 1 bottom plane), 8 mm thick.

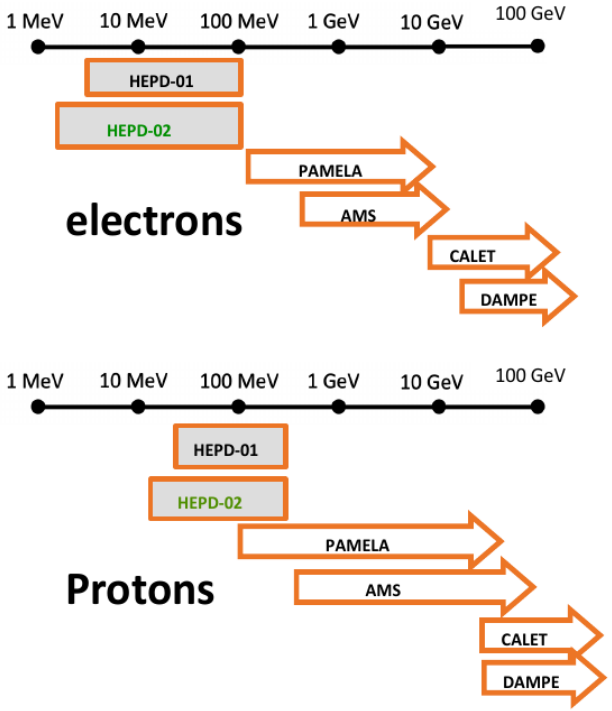
Plastic scintillators: Eljen EJ-200; PMTs: Hamamatsu R9880-210

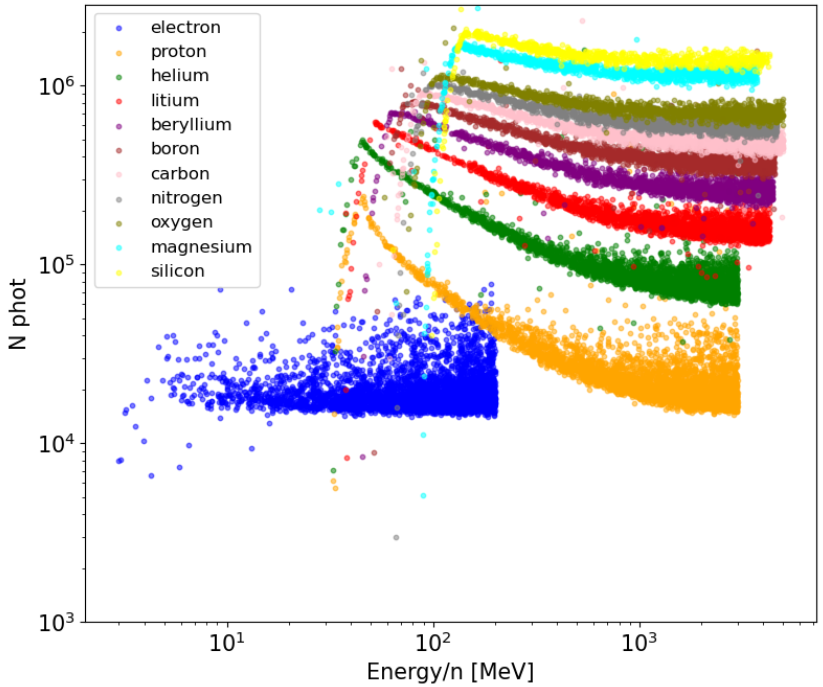


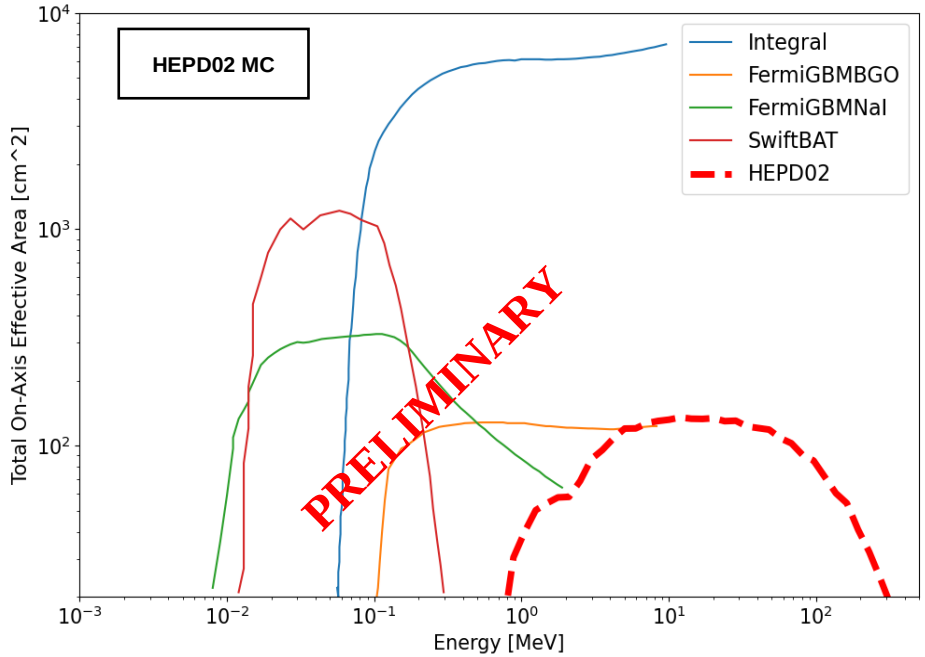


HEPD-02 DETECTOR CAPABILITIES

- Designed to measure fluxes of electrons, protons and nuclei in a wide energy range
- Implements a logic to trigger on sudden increases of GRB masks counts, integrated @ 200 Hz (*V. Scotti, The DAQ and trigger of the High Energy Particle Detector (HEPD-02) for the CSES-02 space satellite, 26/09 18:00*)

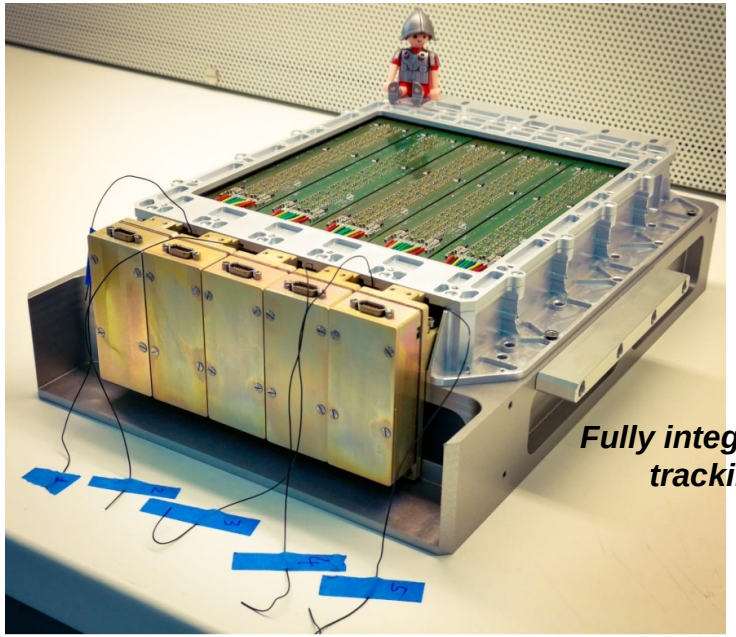






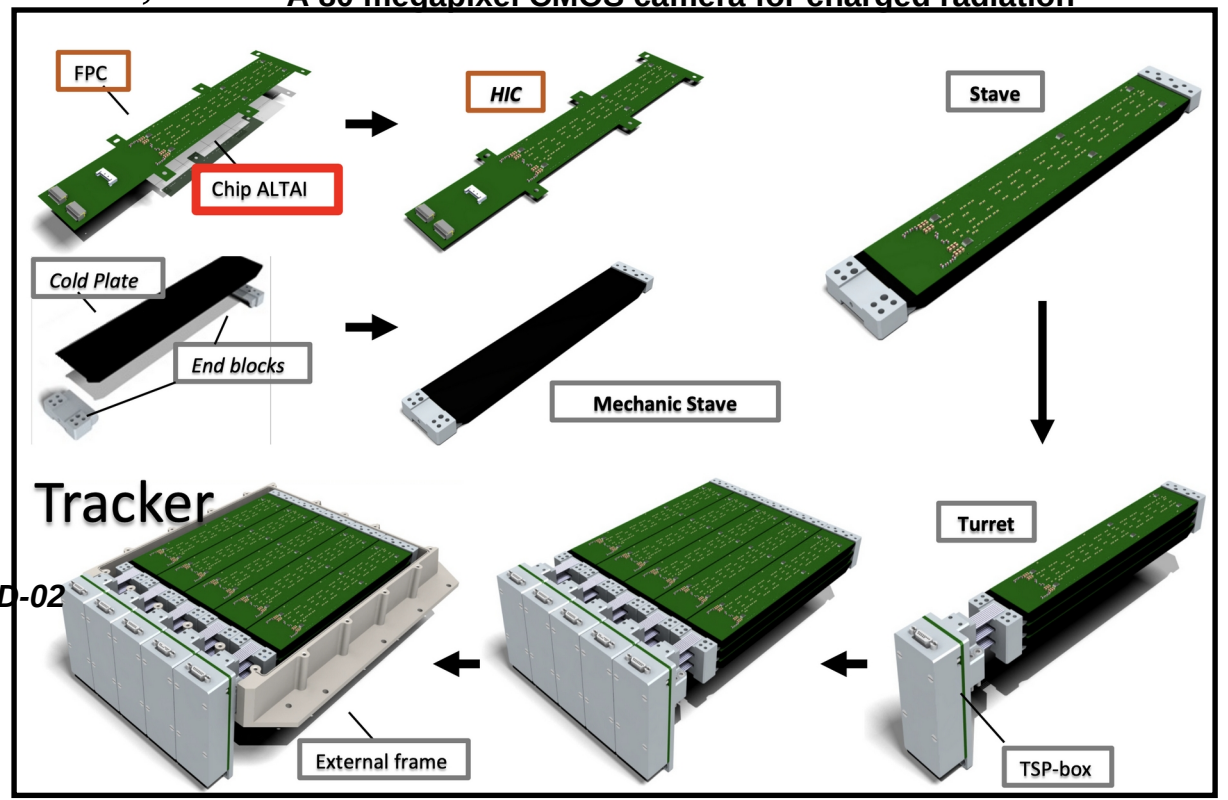
HEPD-02 DIRECTION DETECTOR

- Based on the MAPS developed for the ALICE experiment at CERN (*E. Ricci, Design and characterisation of the HEPD-02 MAPS-based tracker for operations in space, 25/09 09:50*)
- 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 cm^2 each;



Fully integrated HEPD-02 tracking system

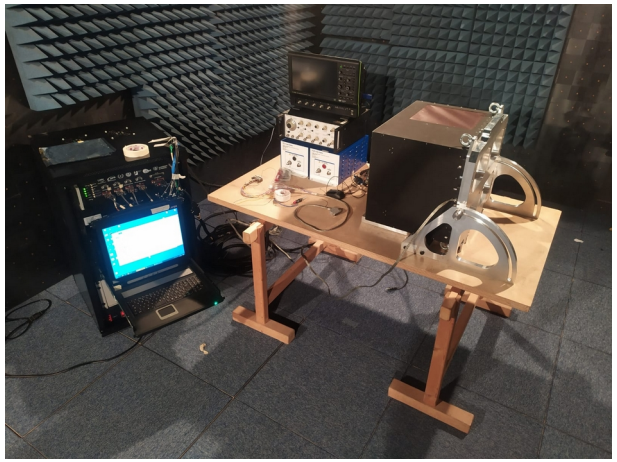
A 80 megapixel CMOS camera for charged radiation



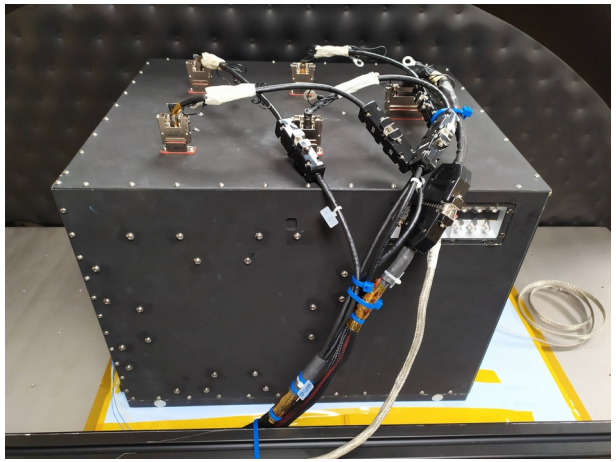
HEPD-02 ACCEPTANCE TEST CAMPAIGN

Environmental test campaign February-July 2023

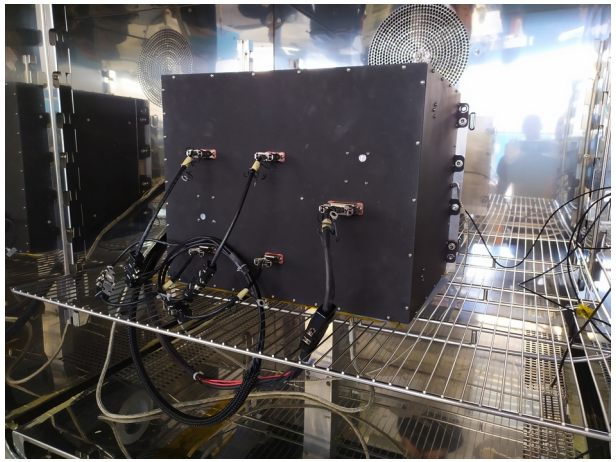
- Vibration Test (sine 8 g & random 7.55 GRMS)
- Thermal Cycling Test (14.5 cycles, -20 °C ~ + 45 °C)
- EMC Test (CE102, CS101, CS114, RE102, RS103)
- Thermal Vacuum Test (3.5 cycles, -20 °C ~ + 45 °C)



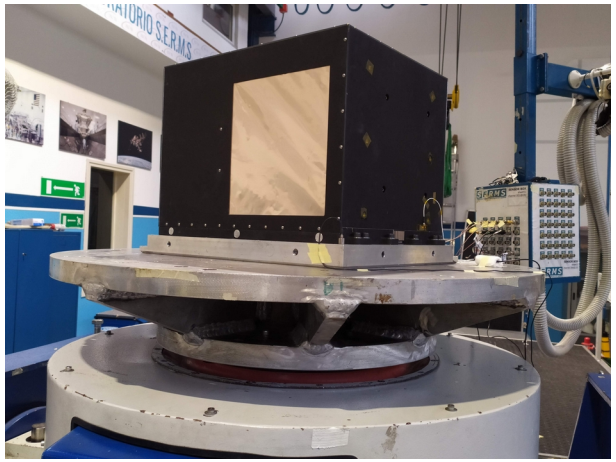
HEPD-02 FM EMC test @IFAC-CNR



HEPD-02 FM in thermal vacuum chamber @SERMS



HEPD-02 FM in thermal chamber @SERMS

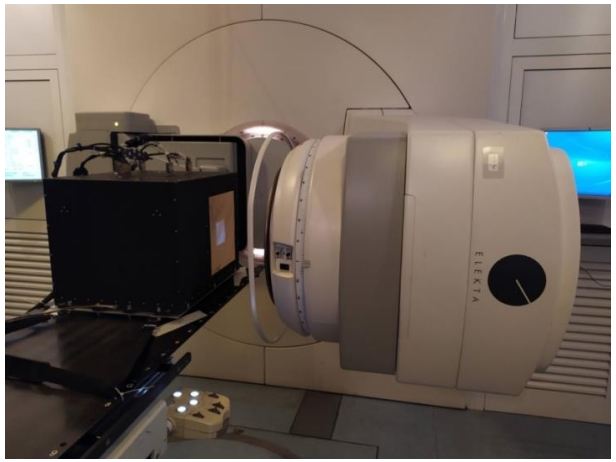


HEPD-02 FM vibration test @SERMS

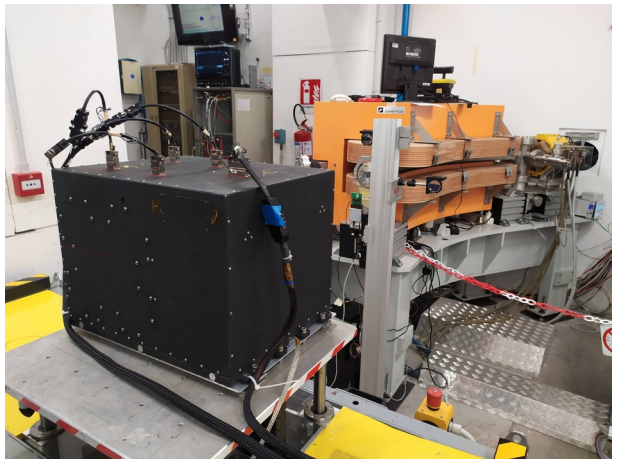
HEPD-02 BEAM TEST CAMPAIGN

Beam test campaign June-July 2023

- e^- (6-12 MeV)/gamma @ LINAC S. Chiara (Trento, Italy)
- e^- (>30 MeV) @ BTF (Frascati, Italy)
- Proton (70-230 MeV) @ APSS (Trento, Italy)
- Carbon/proton (115-398 MeV/amu) @ CNAO (Pavia, Italy)

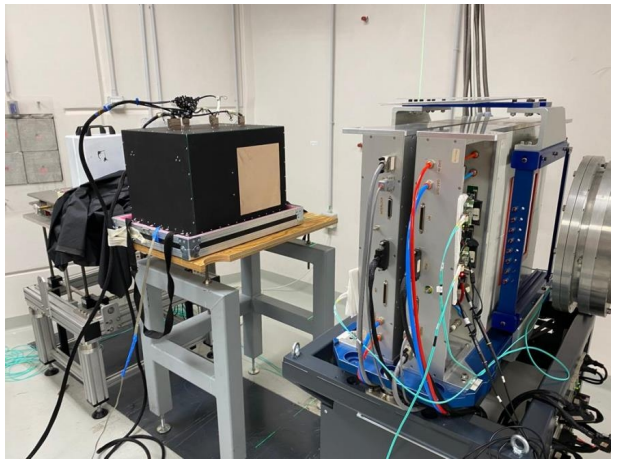


HEPD-02 FM beam test w/ electrons and gammas @LINAC S. Chiara



HEPD-02 FM beam test w/ electrons @BTF

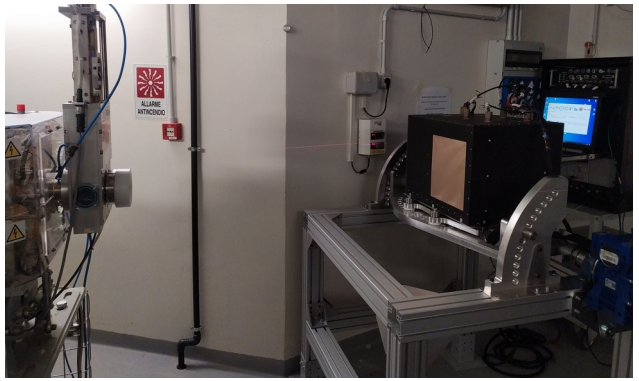
HEPD-02 FM beam test w/ protons @Proton Therapy Trento

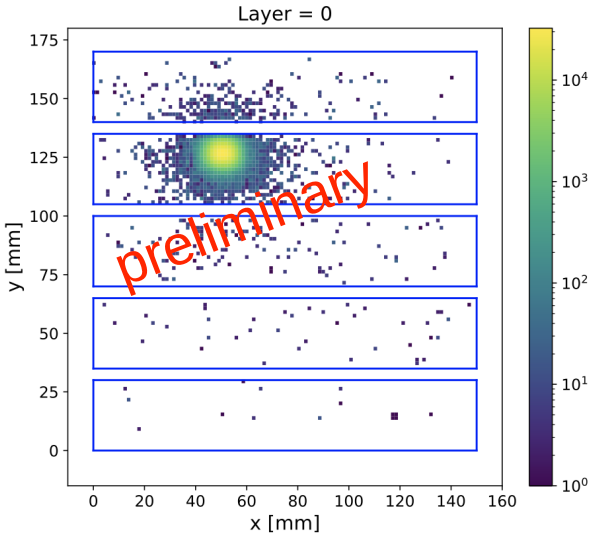


HEPD-02 FM beam test w/ protons+carbon nuclei @CNAO

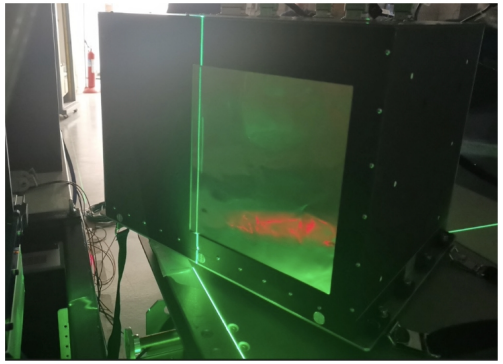
HEPD-02 TEST BEAM RESULTS - POSITION AND TRACKING

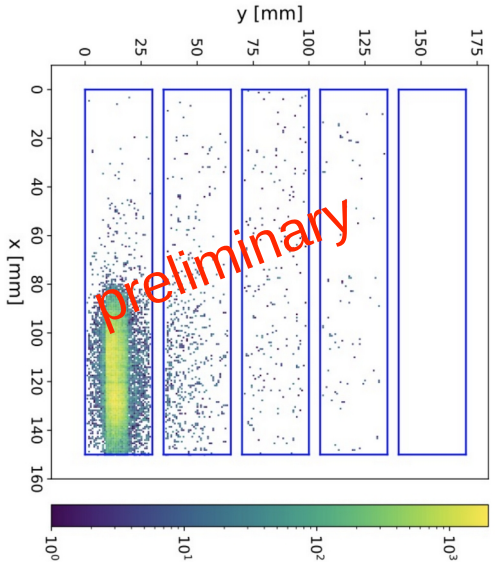
Proton beam



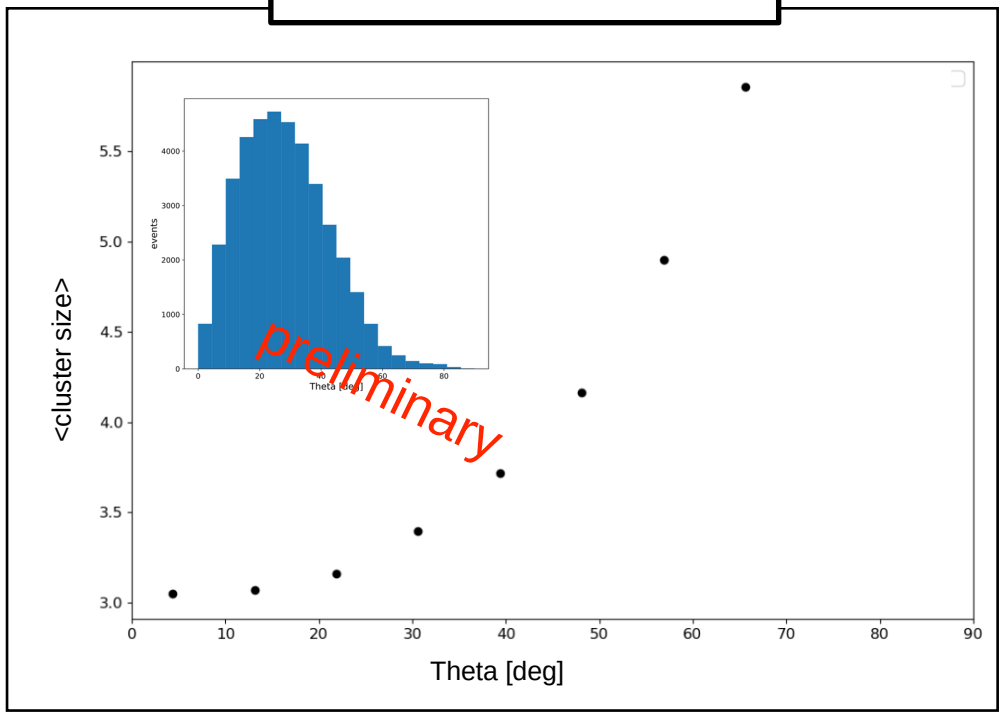


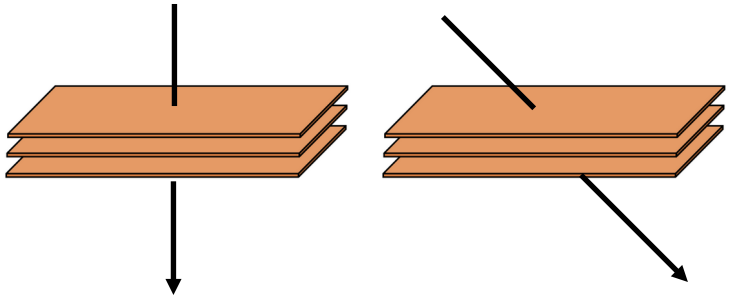
Carbon beam





Atmospheric muon data



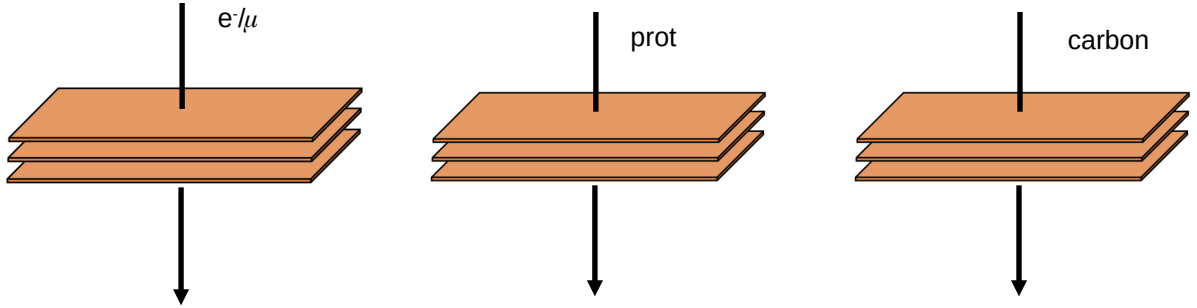


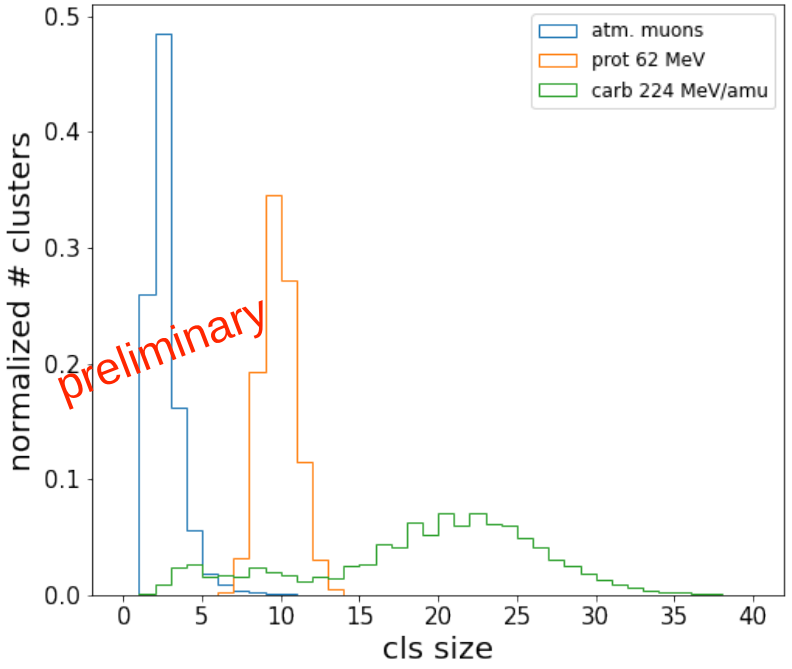
Inclined μ-tracks fires more pixels

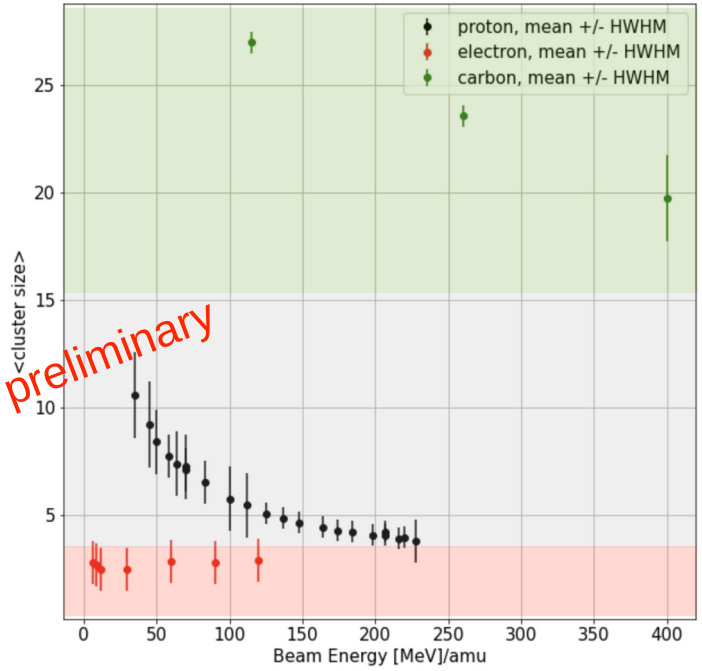
Credits: F. M. Follega

HEPD-02 TEST BEAM RESULTS – PARTICLE IDENTIFICATION

Particle identification using cluster size (Tracker information)

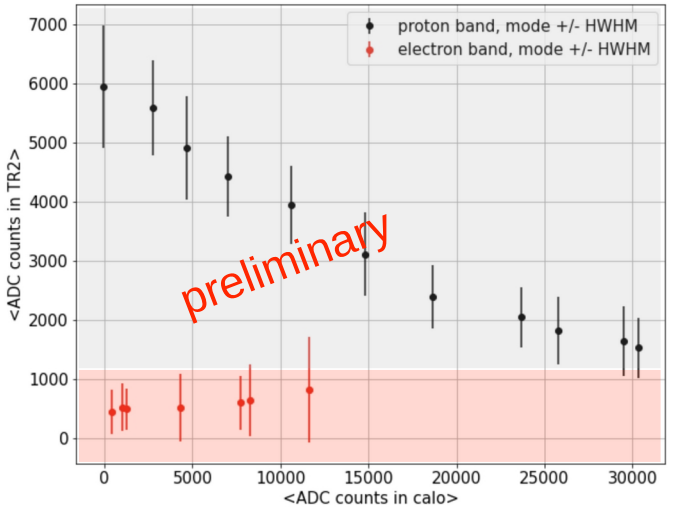




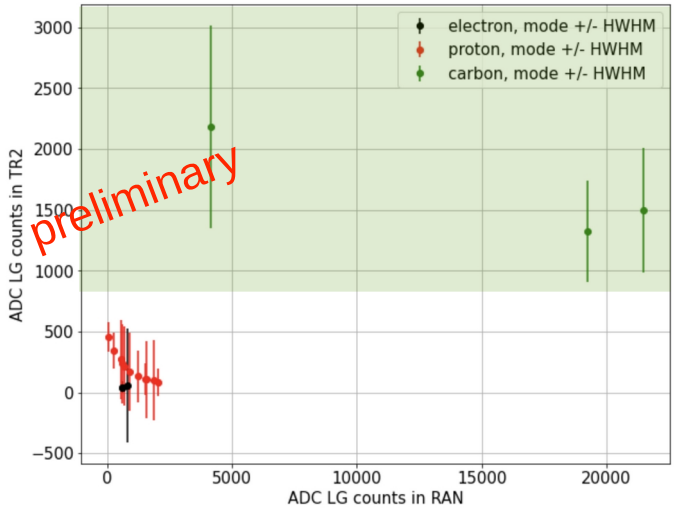


Particle identification calo signal

HG ADC scale (e-/p)



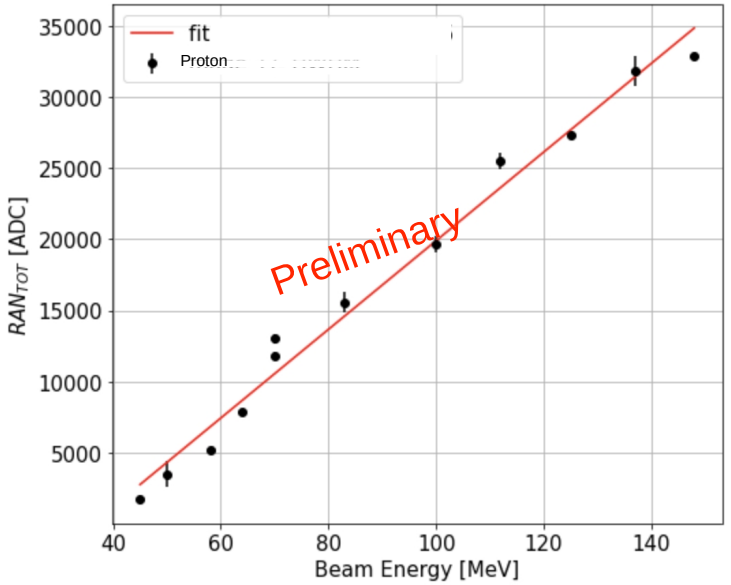
LG ADC scale (p/nuclei)



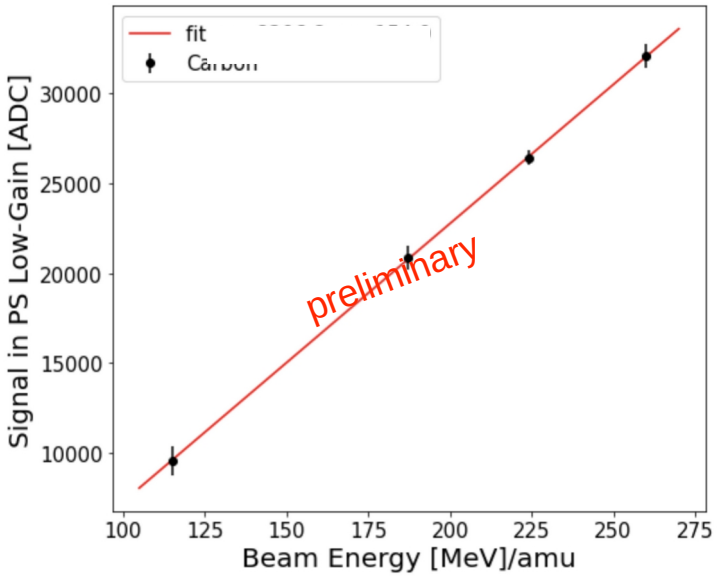
Credits: F. M. Follega

HEPD-02 TEST BEAM RESULTS – ENERGY RECONSTRUCTION

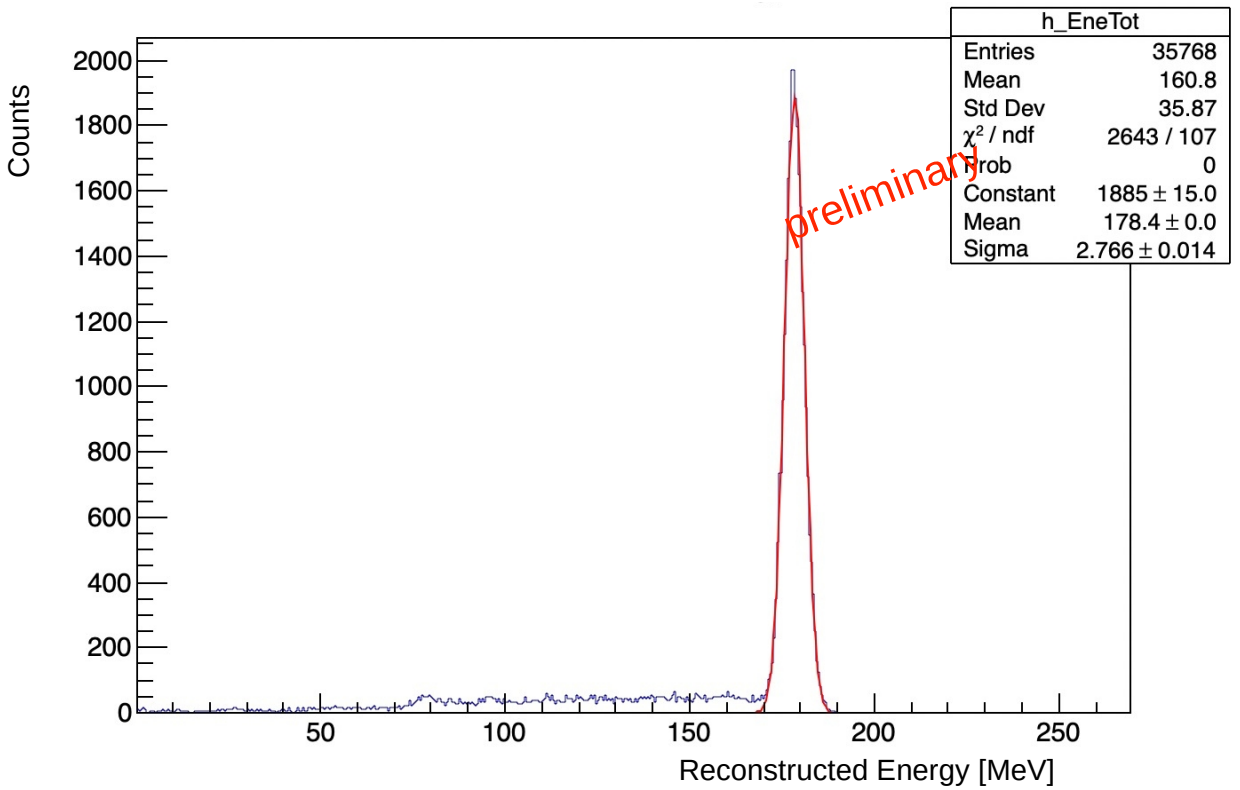
Proton beam



Carbon beam



Proton beam @ Proton Therapy Center (Trento)



< 5% resolution on high energy protons

Credits: F. M. Follega

CONCLUSIONS

- The High Energy Particle Detector (HEPD-02) has been developed to be launched on board of the second China Seismo-Electromagnetic Satellite (CSES-02) in 2024
  - Detector design and capabilities have been improved wrt HEPD-01
  - Designed to measure fluxes electrons, protons and nuclei in a wide energy range
  - A dedicated GRB trigger logic has been implemented and tested
- Acceptance and beam test campaign completed → ready for delivery to China
- Preliminary beam test analysis demonstrates that the performance is compliant with simulations and main mission requirements