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

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on behalf of the CSES-Limadou Collaboration

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UNIVERSITÀ DI TRENTO

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CSES MISSIONS – SCIENTIFIC OBJECTIVES

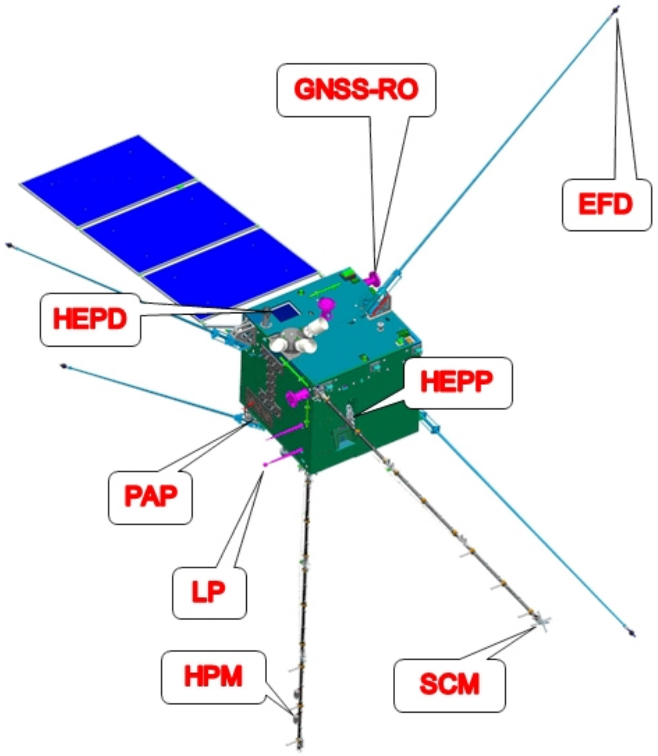
- Monitoring of the electromagnetic near-Earth space environment
- Analysis of the ionospheric and plasmaspheric fluctuations
- Measurements of iono-magnetospheric perturbations possibly due to seismo-electromagnetic phenomena
- Study of fluxes of high & low energy charged particles precipitating from 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 MISSION – CSES-01

Launched into a sun-synchronous circular orbit (97.4°) on February 2nd, 2018 at an altitude of 507 km in the upper ionosphere [*Shen, X.et al., Science China Technological Sciences, vol. 61, no. 5, pp. 634-642, May 2018*]

Payload working zone: −65° ÷ +65° latitude

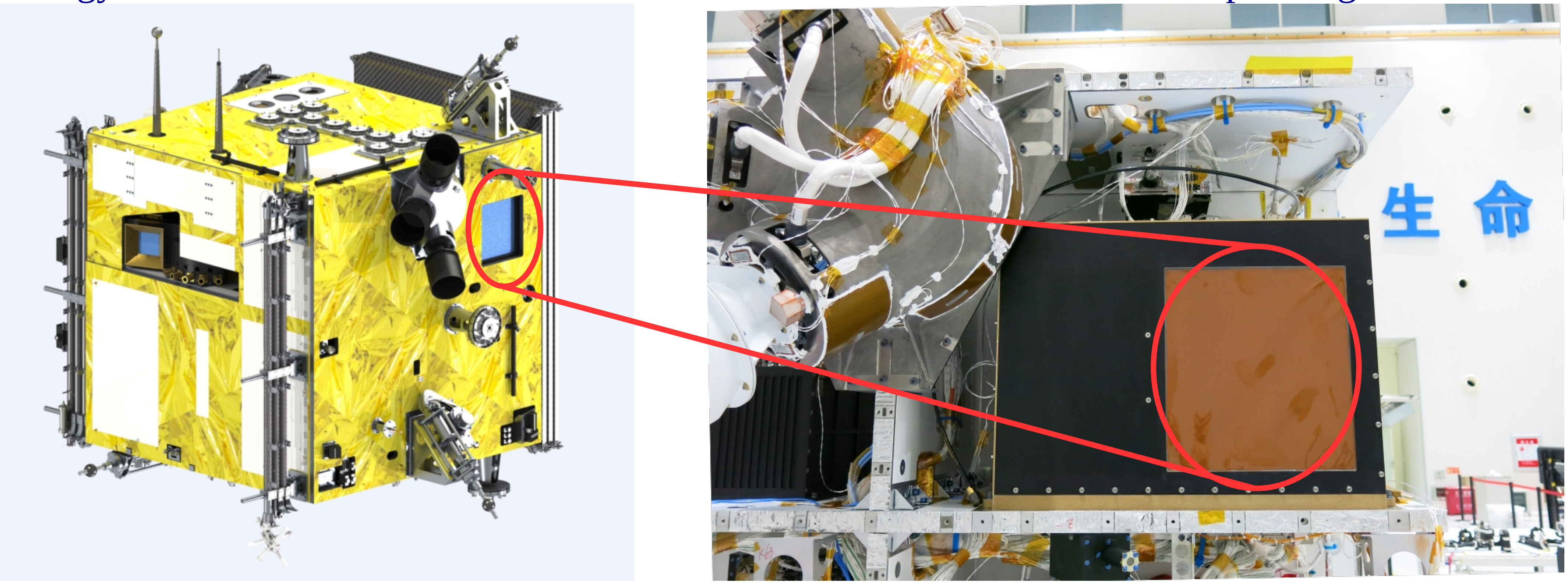
Payloads	Parameters	Status
High Precision Magnetometer (HPM): Two flux gate + one coupled dark state magnetometer (CDSM)	DC to 16 Hz	Good health condition Excellent performance
Search-Coil Magnetometer (SCM)	10 Hz ~20 kHz	Good health condition and performance
Electric field detector (EFD)	DC~3.5 MHz	ULF/ELF/VLF good, HF band with high noises
Plasma analyzer package（PAP）	Ion density : 10^2~10^7 cm^{-3} Ion temperature: 500~10000 K Ion content: H^+、He^+、O^+ Ion drift velocity: Vxyz	Contamination mechanism and cause of contamination still in evaluation
Langmuir probe (LAP)	Electron density：10^2~10^7 cm^{-3} Electron temperature： 500~10000K	Good health condition and performance
GNSS Occultation Receiver (GOR)	TEC、Ne Profile Air Refraction index, Profile of air temperature and pressure Ionospheric scintillation index	Good health condition and performance
Tri-Band Beacon (TBB) : Three bands：50/400/1066MHz		400 MHz band malfunction data processing algorithm and ground receivers not finished
Energetic particle detector (HEPP-H, L, X ray）	Proton flux：1.5MeV～200MeV Electron flux：≥100keV Pitch angle：5° HEPP-X：0.9–35 keV	Good health condition and performance
Italian **Energetic particle detector (HEPD)**	Proton flux: 30- 100 MeV Electron : 30 – 200 Mev；	Good health condition



Credits: Z. Zhima (NINH)

CSES-01 - HIGH ENERGY PARTICLE DETECTOR (HEPD)

- The High-Energy Particle Detector (HEPD) onboard CSES-01 measures the increase of the electron and proton fluxes due to short-time perturbations of the radiation belts caused by solar, terrestrial and anthropic phenomena [*Picozza, P. et al., Astrophys. J. Suppl. 2019, 243, 16*]
- The energy range explored is 3 - 100 MeV for electrons and 30 - 200 MeV for protons
- High Energy Particle Detector is installed on the satellite with its entrance window pointing to the zenith



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

A PARTICLE DETECTOR FOR IONOSPHERE-LITHOSPHERE COUPLING STUDIES

INOSPHERE-LITHOSPHERE COUPLING

- The lithosphere may produce EM perturbations that can propagate in the ionosphere and inner magnetosphere
- An earthquake is a sudden perturbation that can induce e.m. and particle signals in the ionosphere/lower magnetosphere

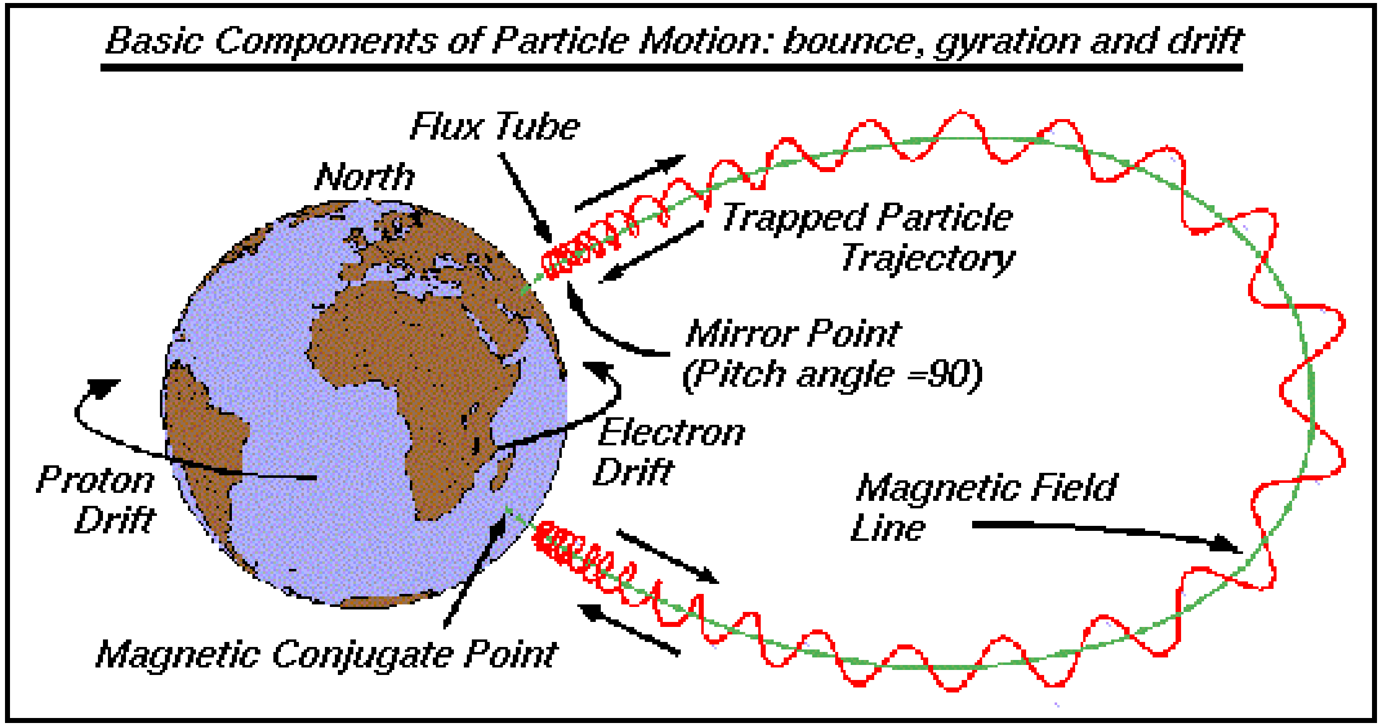
IONOSPHERIC-MAGNETOSPHERIC PERTURBATIONS

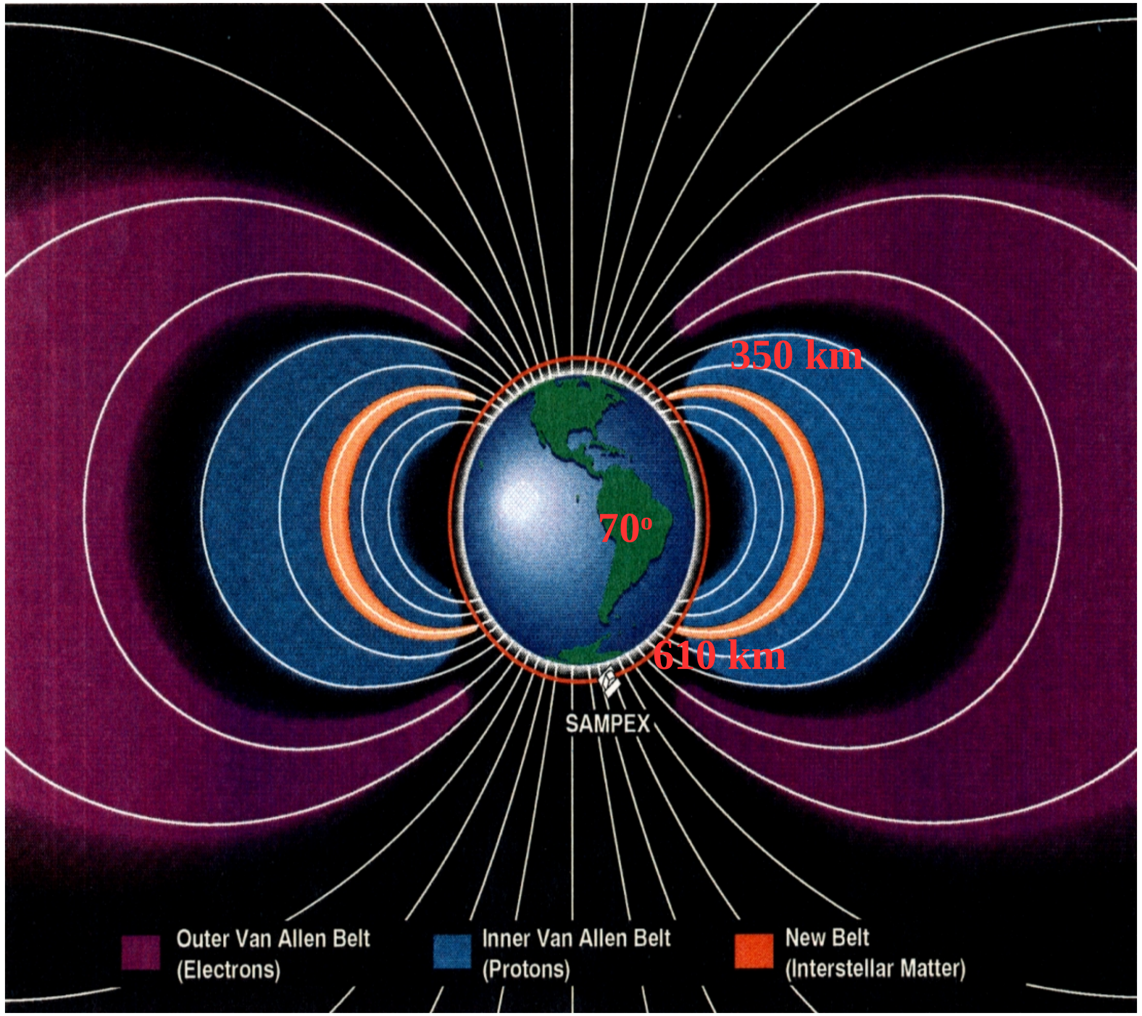
Electro-Magnetic Emission (EME)

- **Natural emissions (earthquakes and volcanic eruptions)**
- **Anthropogenic emissions (PLHR, VLF & HF transmitters)**

ULF EME: wave-trapped particle interaction?

TRAPPED PARTICLE MOTION IN THE VAN ALLEN RADIATION BELTS

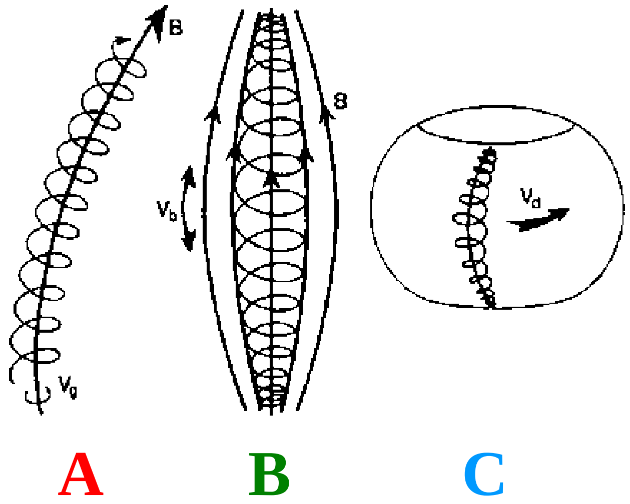




A. Gyro

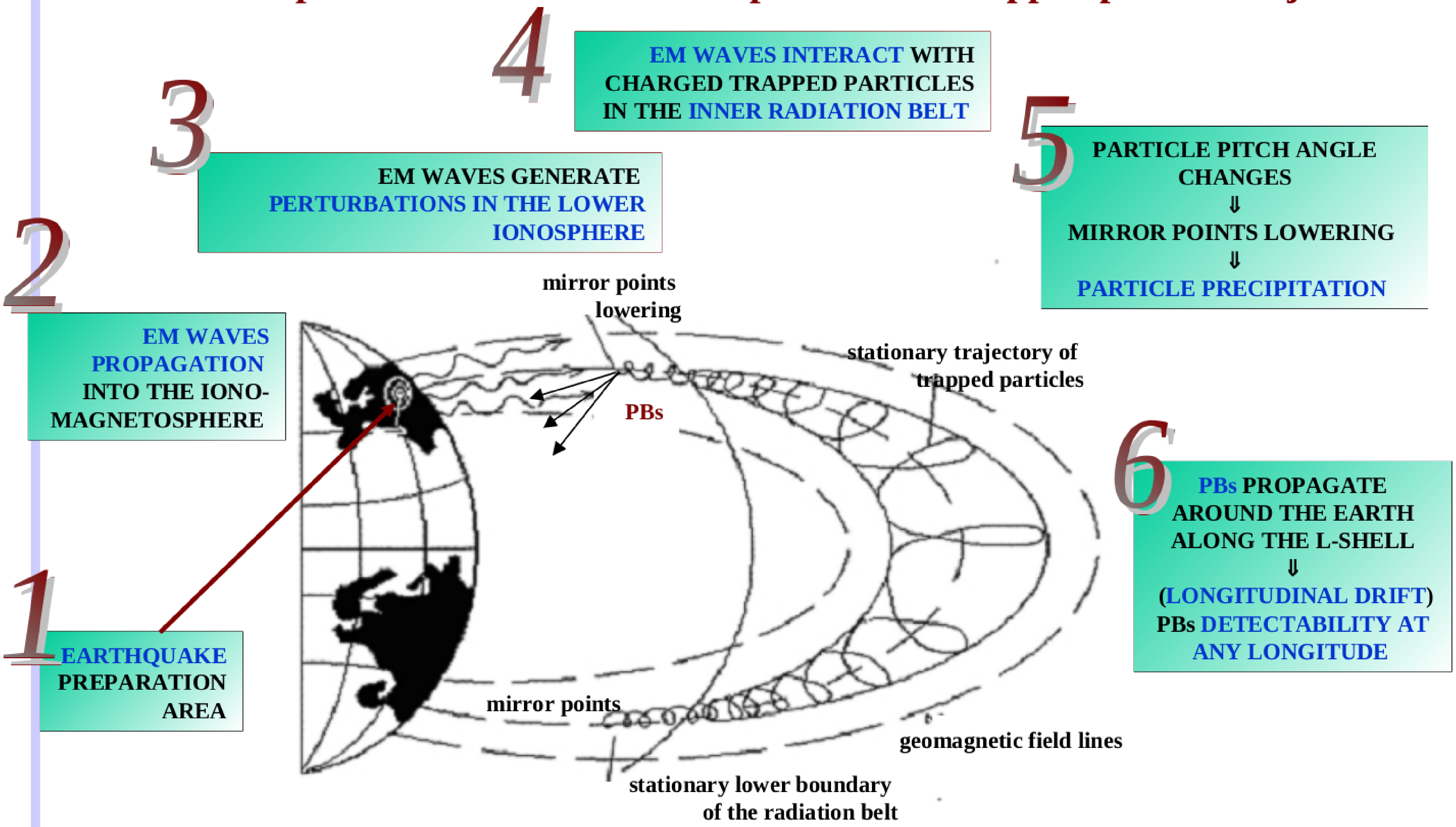
B. Bounching

C. Longitudinal drift

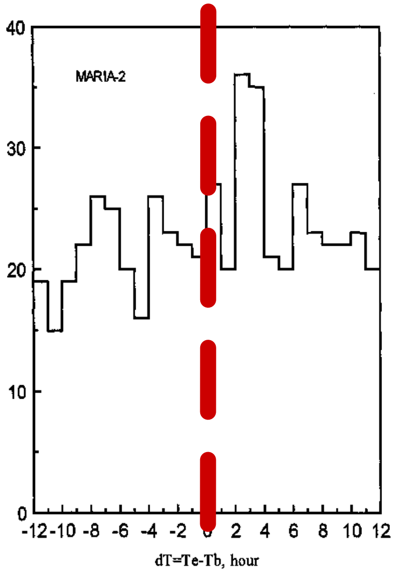


WAVE-PARTICLES INTERACTION MECHANISM

Schematic representation in a meridian plane of the trapped particle trajectories



CORRELATIONS BETWEEN EQ AND PB: $\Delta T_{EQ\text{-}PB}$ DISTRIBUTION



MIR mission

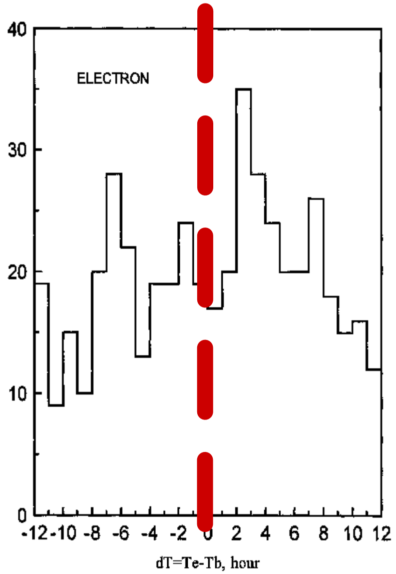
1985-2000

Altitude: 400 km

Inclination: 51°

E_e: 20-200 MeV

E_p: 20-200 MeV



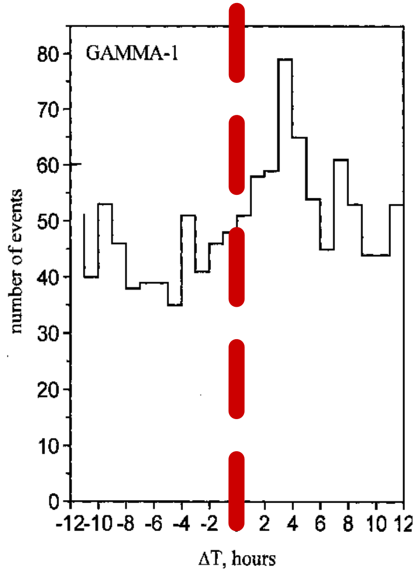
METEOR-3 mission

1985-1986

Altitude: 1250 km

Inclination: 82°

E_e: ≤ 30 MeV



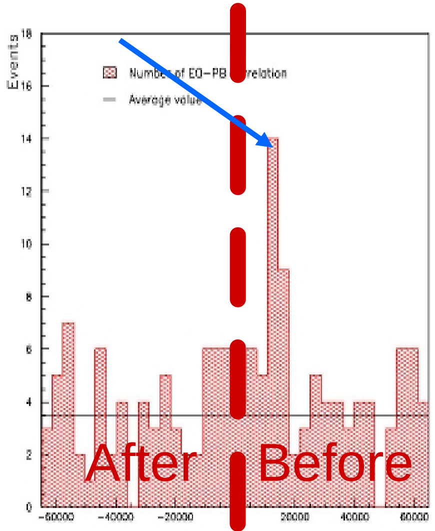
GAMMA-1 mission

1990-1992

Altitude: 350 km

Inclination: 51°

E_e: > 50 MeV



ORR

(Orbit Rate Rotation;
July 1992 - May 1994)

SAMPEX/PET mission

1992-1999

Altitude: 520-740 km

Inclination: 82°

4 ≤ E_e ≤ 15 MeV

CSES-02 MISSION

CSES-02 SATELLITE

- Launch scheduled by the end of 2022
- 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**

➢ **Storage 160Gb/512Gb**

➢ **Total Mass: 730kg/900kg**

➢ **Peak Power Consumption: ~900W**

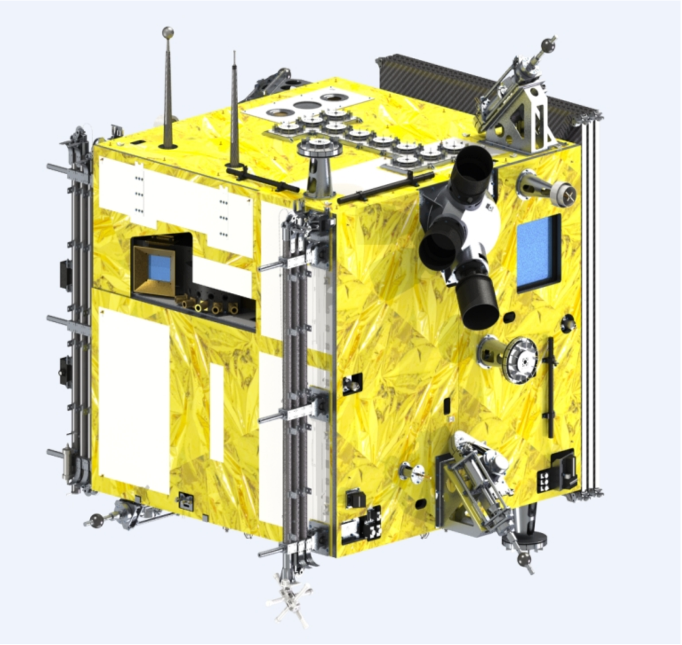
➢ **Design Life-span: 5 Years/6 Years**

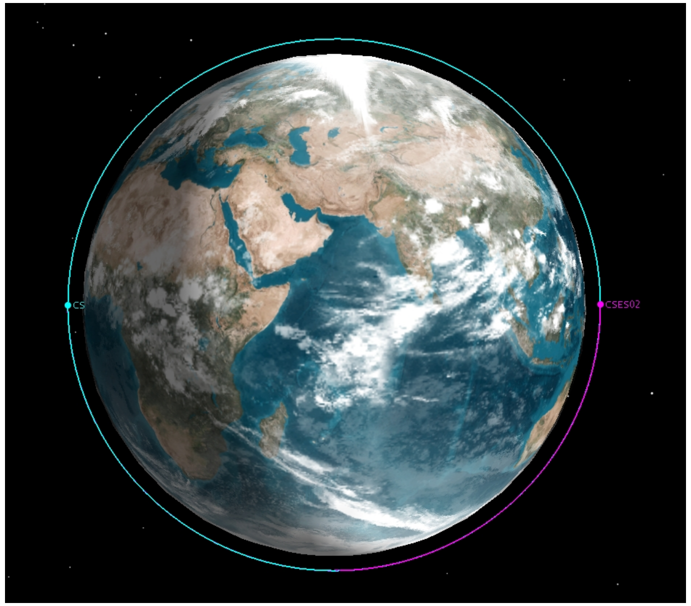
- Complementary Ground Track wrt CSES-01

➢ **Identical Orbit Plane**

➢ **180°Phase Difference**

- Operation mode: Full time operational





Credits: Z. Zhu (DFH)

CSES-02 – PAYLOAD CONFIGURATION

Category	*Payload Name*	*Observation Targets*
Energetic Particle	***High Energy Particle Detector (Italy)*** ***Low Energy Electron Spectrometer***	*Proton：2MeV~200MeV* *Electron：30keV~50MeV*
Electro-Magnetic Field	***Electric Field Detector (Italy)***	*Electric Field: DC ～3.5MHz*
	High Precision Magnetometer	*Magnetic Field: DC ～15Hz*
	Search Coil Magnetometer	*Magnetic Field: 10Hz ～20kHz*
In Situ Plasma	*Plasma Analyzer Package*	*Composition：* H^+, He^+, O^+ N_i ： 5×10^2~$1\times10^7 cm^{-3}$ T_i ： *500K~10000K*
	Langmuir Probe	N_e ： 5×10^2~$1\times10^7 cm^{-3}$ T_e ： *500K~10000K*
Plasma Profile Construction	*GNSS Occultation Receiver*	*TEC by GNSS Occultation Signal*
	Tri-Band Beacon	*TEC by transmit VH/U/L Signal*
	Ionospheric Photometer	*135.6nm and* N_2*LBH airglow*

Credits: Z. Zhu (DFH)

HEPD-02 ON-BOARD CSES-02

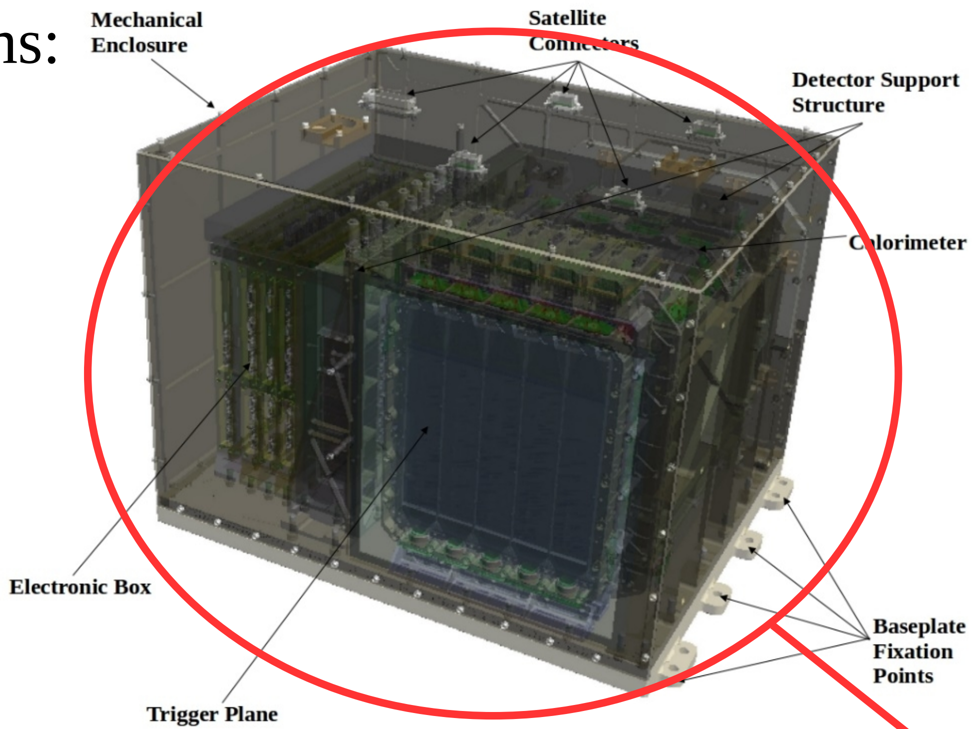
HEPD-02 MAIN REQUIREMENTS

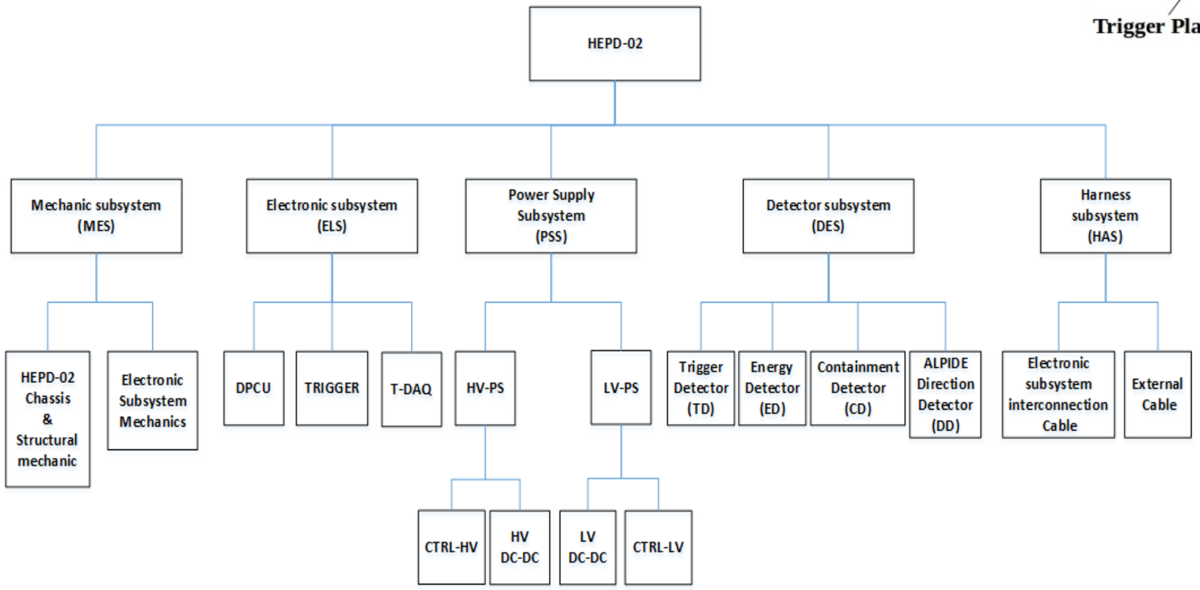
Operating temperature	-10 °C ÷ +35 °C
Operating pressure	$\leq 6.65 \cdot 10^{-3}$ Pa
Data budget	$\leq$ 100 Gb/day
Mass budget	$\leq$ 50 kg
Power budget	$\leq$ 45 W
Electron kinetic energy range	3 MeV ÷ 100 MeV
Proton kinetic energy range	30 MeV ÷ 200 MeV
Angular resolution	$\leq 10°$ for e^- with E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

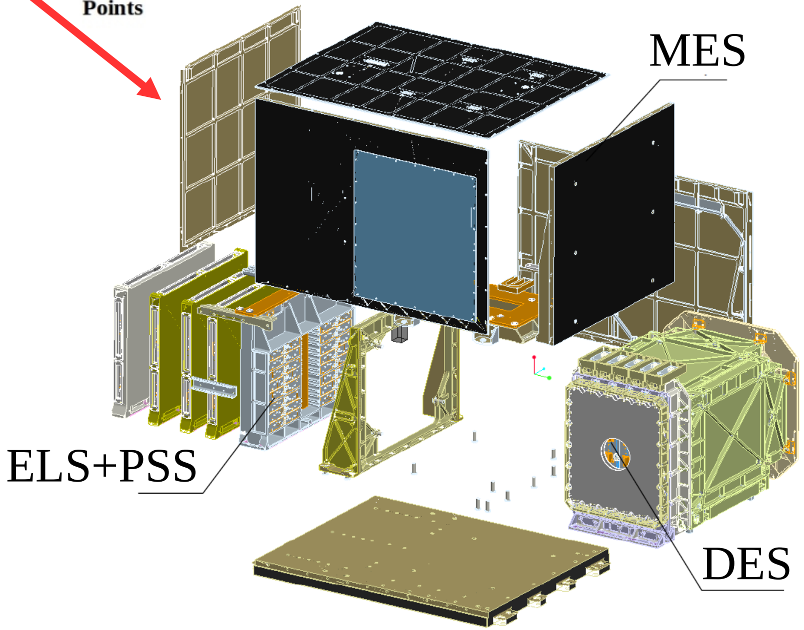
HEPD-02 SYSTEM ARCHITECTURE

HEPD-02 consists of five subsystems:

- Detector (DES)
- Mechanics (MES)
- Electronics (ELS)
- Power-Supply (PSS)
- Harness (HAS)







HEPD-02 DETECTOR LAYOUT

TRigger plane TR1 (overall dimensions 200x180 mm^2) segmented in 5 plastic scintinllator bars (2 mm thick);

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

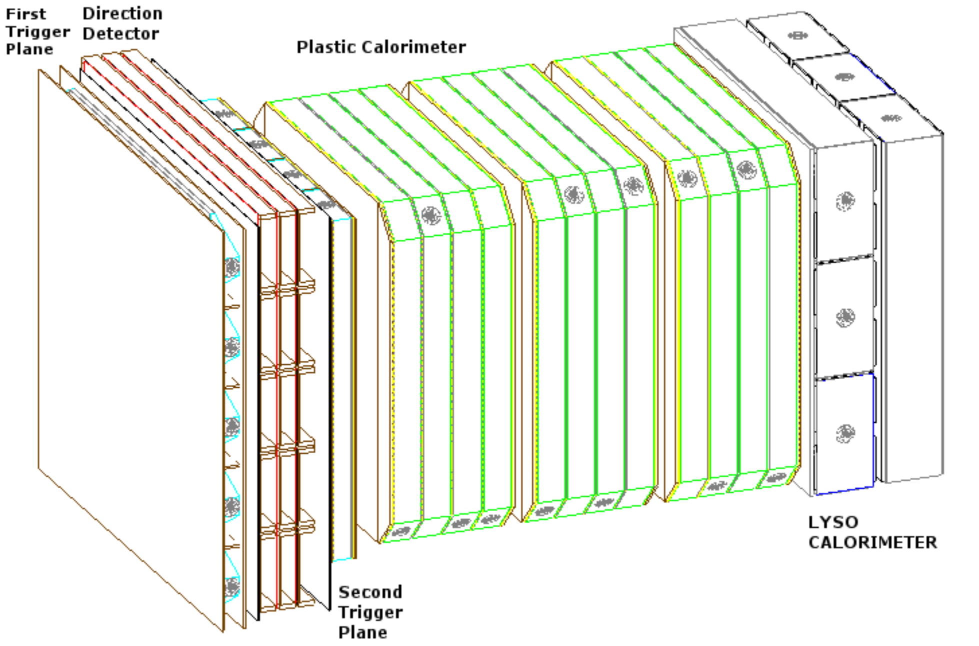
TRigger plane TR2 (overall dimensions 150 x 150 mm^2)

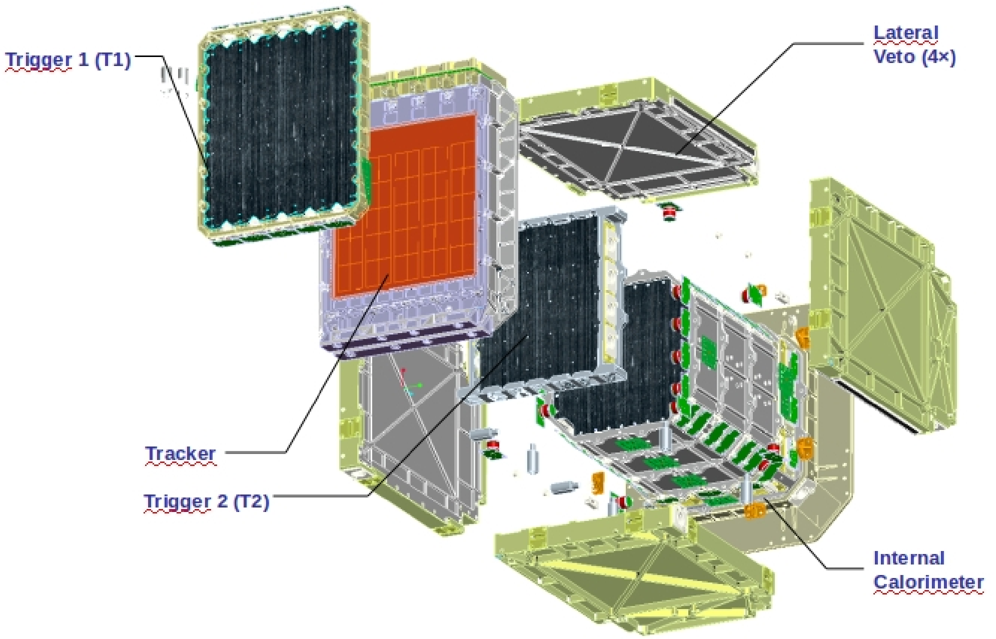
Energy Detector ED ("calorimeter") composed of:

- 12 plastic scintillator planes (150 x 150 x 10 mm^3);
- 2 crystal (LYSO) scintillator planes (overall dimensions 150 x 150 mm^2 segmented in 3 bars (50 mm thick);

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

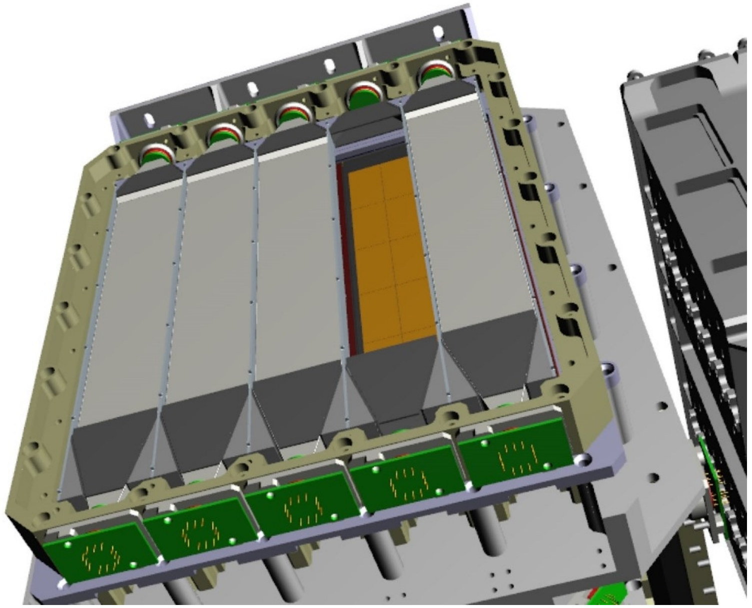
Plastic scintillators: Eljen EJ-200; PMTs: Hamamatsu R9880-210



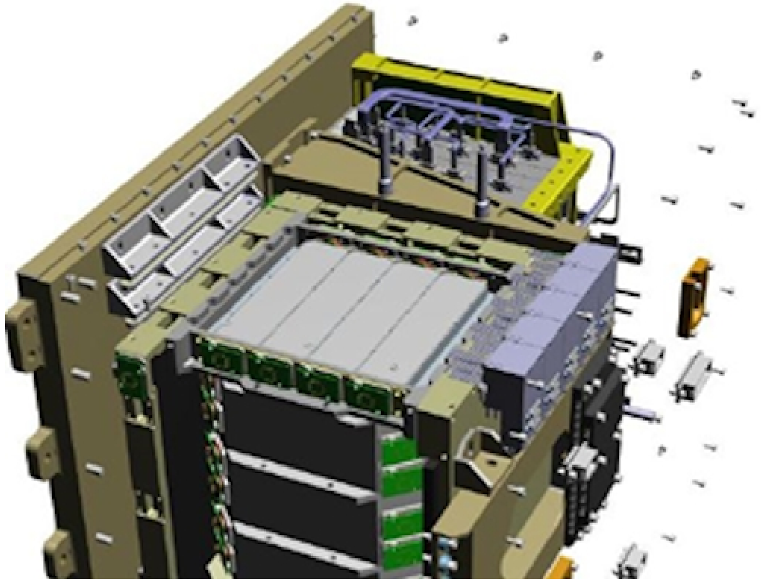


HEPD-02 DETECTOR DESIGN

- HEPD-02 designed to meet the scientific requirements (energy range, energy and angular resolution)
- Particular attention paid to the electron and proton angular and energy resolution in the explored energy range
- Given the demanding mechanical constraints, the detector has been carefully studied to obtain an optimal trade-off between active materials and support structures along the vertical axis



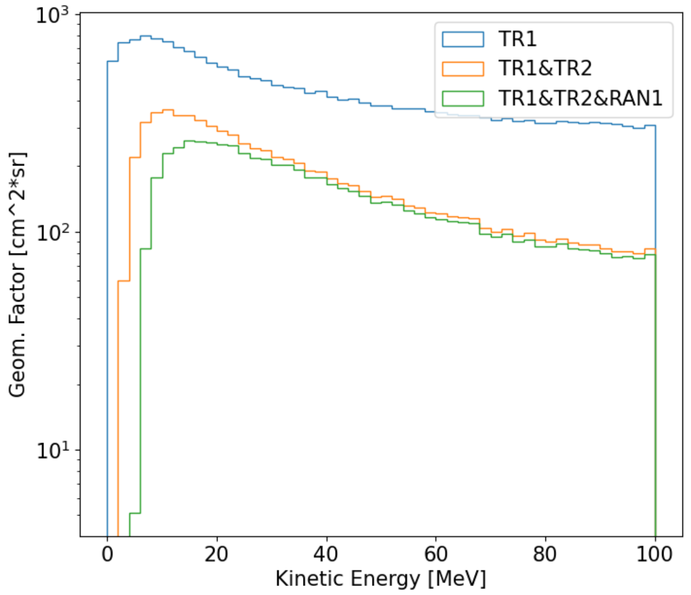
Superposition between a TR1 bar (removed from figure) and the underlying DD ALPIDE stave



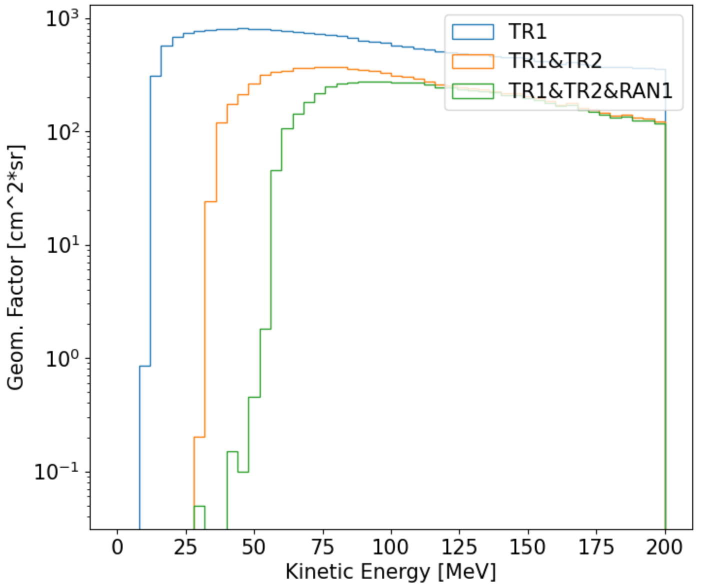
Second trigger plane TR2 on top of the ED calorimeter

HEPD-02 PERFORMANCE - ENERGY RANGE

- The scientific performance of HEPD-02 has been evaluated by means of a Geant4 simulation for an isotropic incoming flux of electrons and protons on top of the instrument
- The energy range requirement is met both for electron (3 MeV ÷ 100 MeV) and proton (30 MeV ÷ 200 MeV)
- The low energy threshold is limited by the mechanical constraints on the stiffness of the detector support layers, given by the structural requirements to sustain mechanical stresses at launch



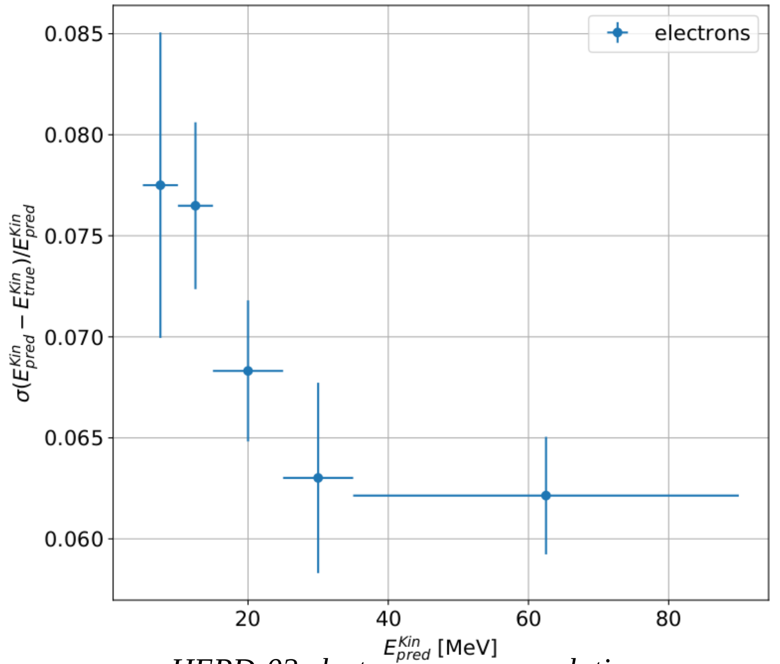
HEPD-02 electron geometric factor



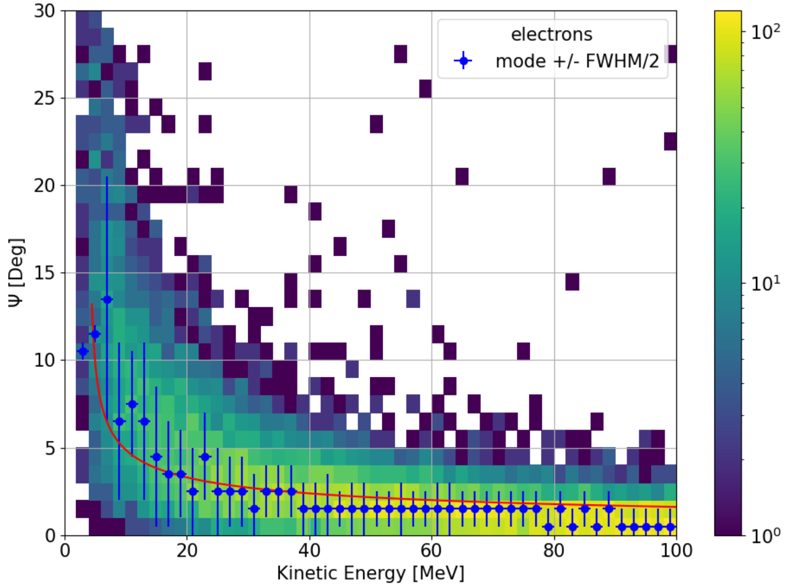
HEPD-02 proton geometric factor

HEPD-02 PERFORMANCE – ENERGY AND ANGULAR RESOLUTION

- Energy resolution: relative difference between true initial kinetic energy and reconstructed kinetic energy (selected sample)
- Electron energy uncertainty <10% for kinetic energies >5 MeV in compliance with the mission requirement
- Angular resolution: distribution of the angle between incoming electron direction reconstructed in the DD and true direction (selected sample)
- Angular resolution better than 10° for the larger part of the electron events with kinetic energies above 5 MeV in compliance with the mission requirement



HEPD-02 electron energy resolution



HEPD-02 electron angular resolution

CONCLUSIONS

- The High Energy Particle Detector (HEPD-02) is being developed to be launched on-board of the second China Seismo-Electromagnetic Satellite (CSES-02) by the end of 2022
- HEPD-02 will be capable of detecting individual incident particles and:
  - identifying type (proton, electron, nucleus)
  - measuring energy
  - determining pitch angle
- HEPD-02 main purpose: identifying particle burst from the stability bands of the Van Allen internal belt to find possible temporal correlations with terrestrial seismic events
- HEPD-02 architecture is the result of an optimized trade-off between scientific objectives of the mission and technical requirements for high-reliability operation in space environment
- Simulation demonstrate that HEPD-02 performance is expected to meet the mission requirements