Istituto Nazionale di Fisica Nucleare
Sezione di Roma Tor Vergata

Low-Energy Cosmic-ray Measurements with HEPD

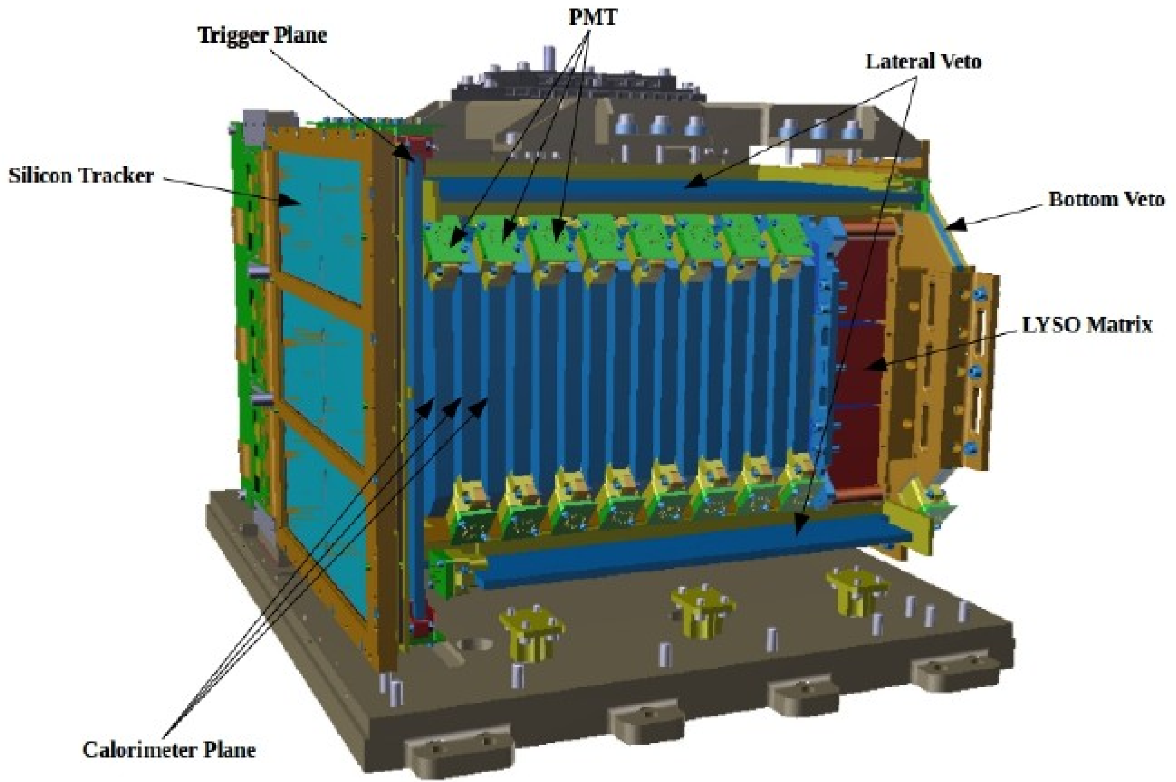
Vincenzo Vitale for the CSES-Limadou Collaboration

Outline

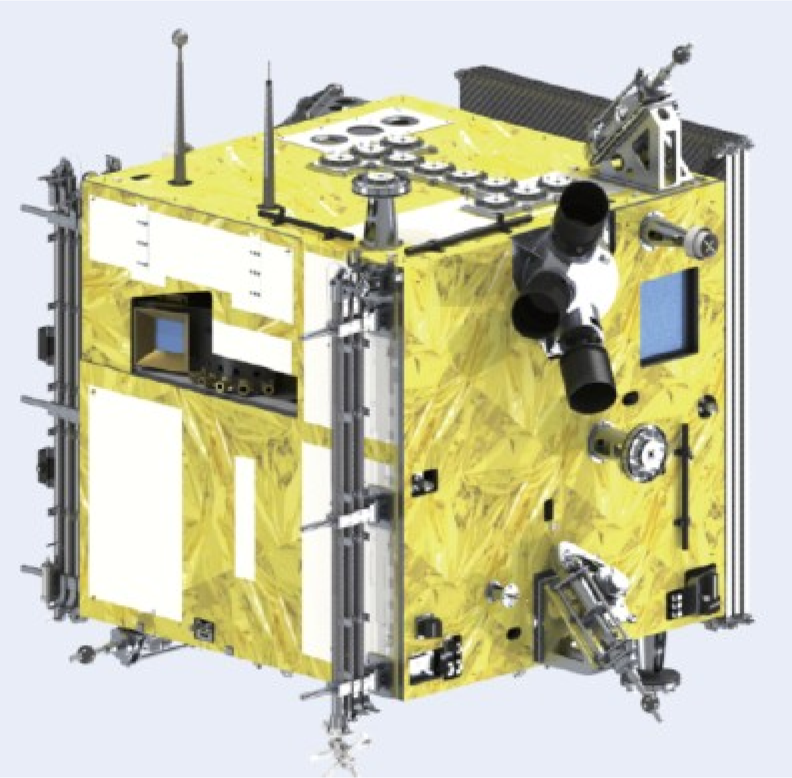
- High Energy Particle Detector
  on board of the CSES satellite
- HEPD components
- Early operations
- Fully contained events analysis
- Passing through events analysis
- Early results with passing through events

The High Energy Particle Detector

- A space particle detector
- Light-weighting (45kg) - low power consuming (27W)
- For electrons, protons and light nuclei (He to C)
- Energy ranges electrons [3-100MeV], protons [30-300MeV], nuclei [few tens-few hundres MeV/n.]
- Developed and build by the Italian CSES-*Limadou* collaboration (Roma Tor Vergata, Univ and INFN, Trento Univ. and INFN (TIFPA), Perugia INFN, Napoli Univ. and INFN, IFAC-CNR, Uninettuno University, Bologna Univ. and INFN, LNF, Italian Space Agency.)
- One of the payload of the CSES satellite



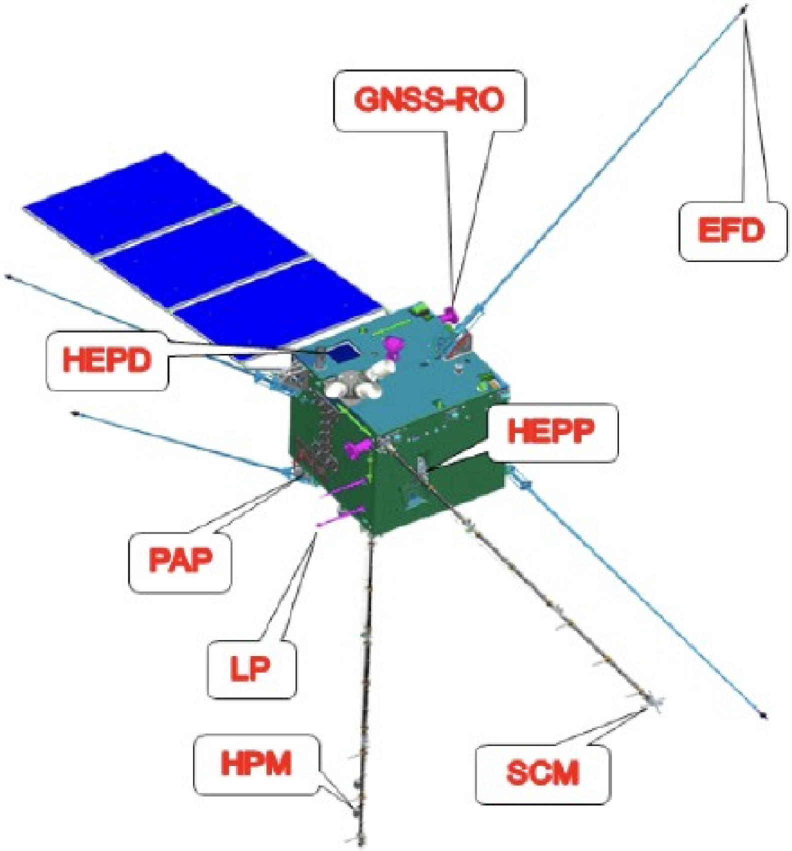
The China Seismo-Electromagnetic Satellite (CSES)



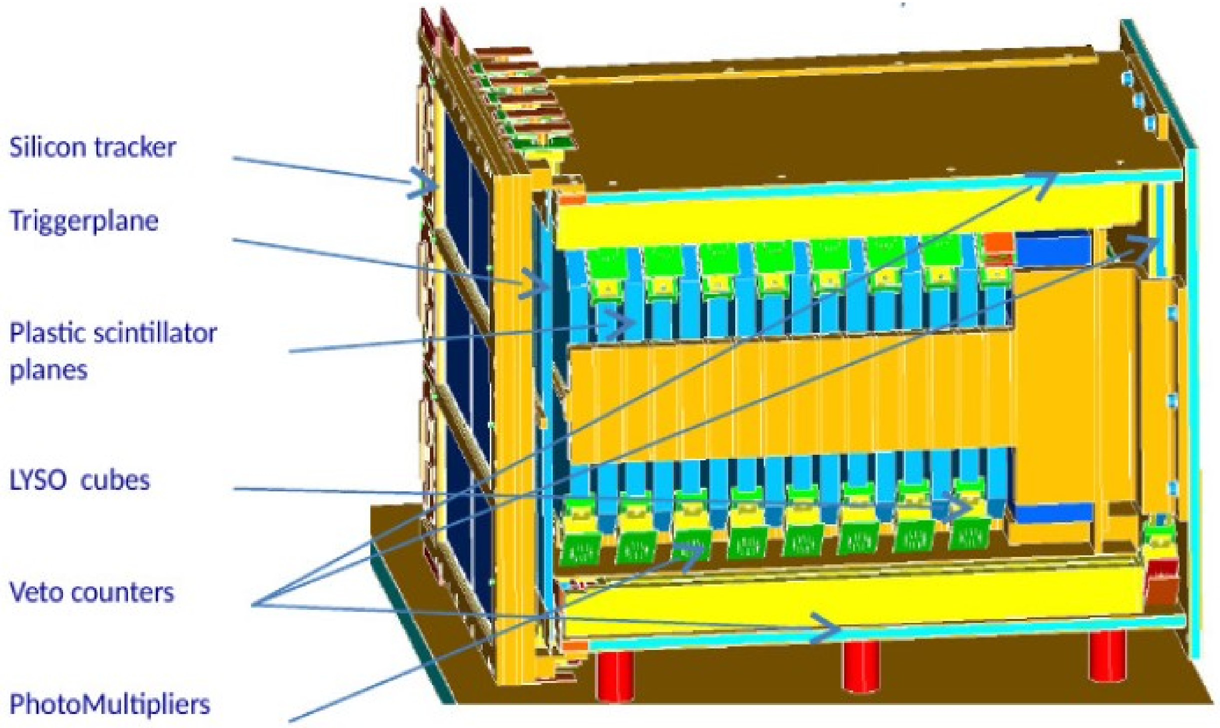
- Collaboration between the Chinese and Italian Institutions (China National Space Administration (CNSA), Italian Space Agency (ASI), China Earthquake Administration (CEA), Italian National Institute for Nuclear Physics (INFN), several Chinese, Italian and Austrian universities and institutes.)
- Lunched from the Jiuquan Launch on Feb 2, 2018
- 500 km altitude, sun-sinchronous orbit, with at least 5 years life span.
- **First of a series of satellites.** An agreement for the collaboration on CSES-II has been signed by Italian and Chinese institution during spring 2019

CSES Science

- Search for possible **electro-magnetic seismic precursor** (waves, plasma, particles);
- characterize orbit e.m environment;
- study of solar-terrestrial interactions, also in the Space-Weather context
- Study of the **low energy cosmic rays**.
- Multi-disciplinary detector set:
  - a High-Precision Magnetometer (HPM)
  - a Search-Coil Magnetometer (SCM)
  - an Electric Field Detector (EFD)
  - a Plasma Analyzer Package (PAP)
  - a Langmuir Probe (LP)
  - a GNSS Occultation Receiver
  - three frequency (VHF/UHF) beacon transmitter
  - two particle detectors the Chinese HEPP and the Italian **High-Energy Particle Detector (HEPD)**



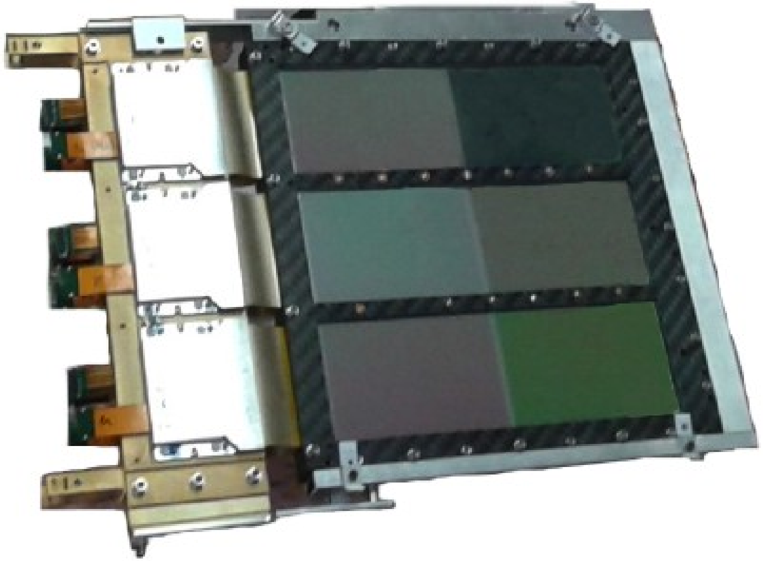
HEPD Components



- **Trigger**: 6 bars,with dimensions 20X3X0.5 cm^3 each, read by 2 Hamamatsu R9880-210 PMTs
- Tracker: two layers of FBK Si sensors
- Range-Calorimeter:
  - **plastic counters tower**: 16 counters, Each plane with dimensions 15X15X1 cm^3, read out by two PMTs
  - **LYSO matrix**: 3X3 matrix of LYSO crystal with dimensions 4.8X4.8X4 cm^3 each, read out by a PMT. (LYSO density = 7.3)
- Veto System: 5 counters similar to those of calorimeter:
  -4 **lateral counter**
  -1 **bottom counter**

HEPD Components

the segmented trigger plane

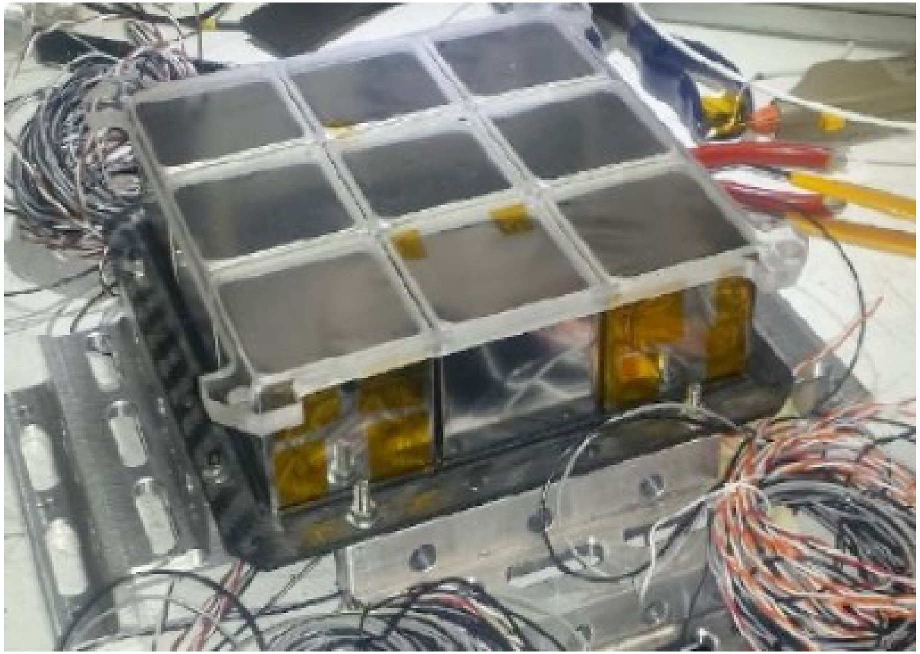


An assembled plane of silicon tracker

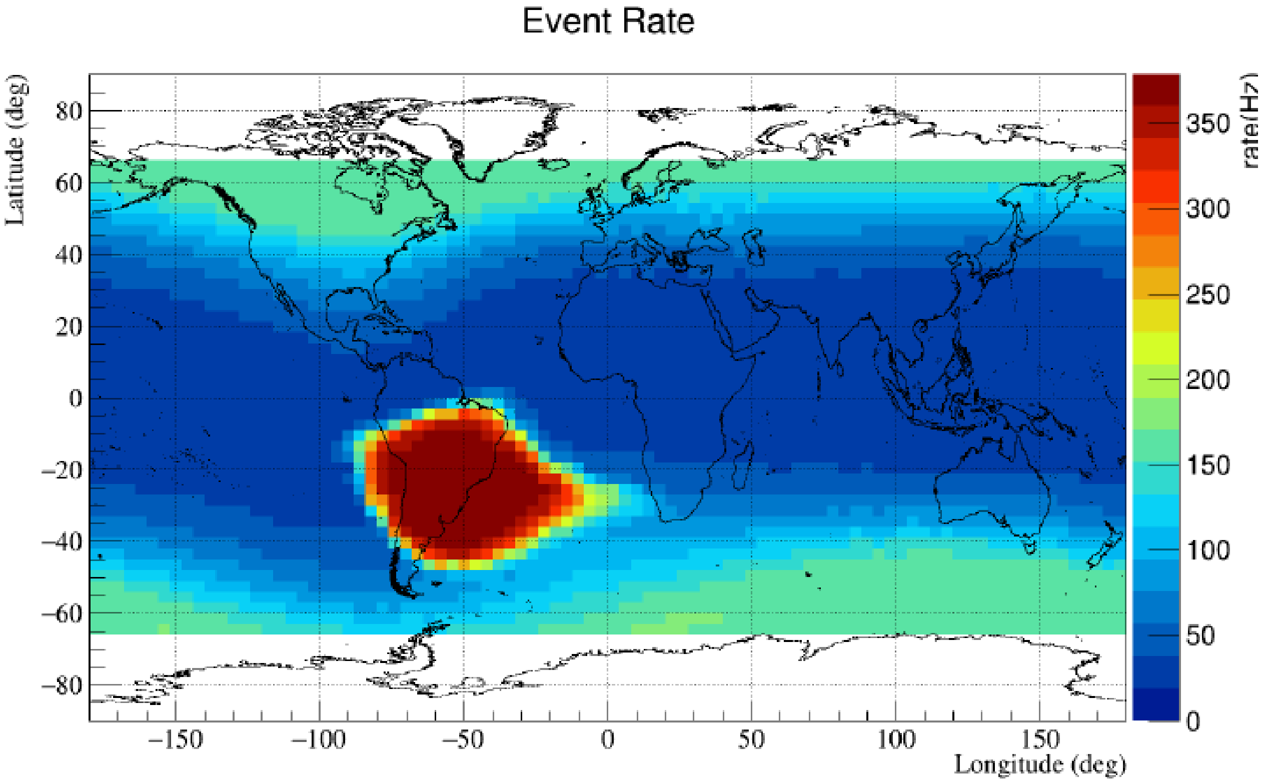
HEPD Components

on the left the assembled scintillator tower

the LYSO matrix plane

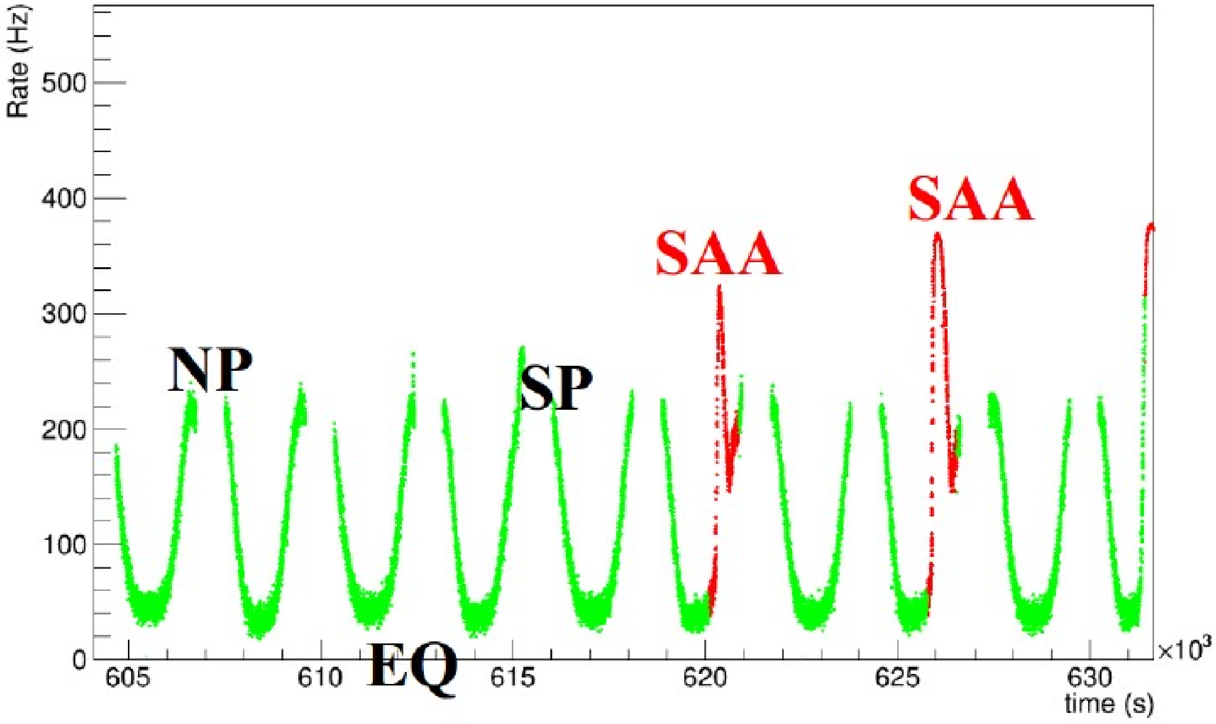


HEPD Early Operations



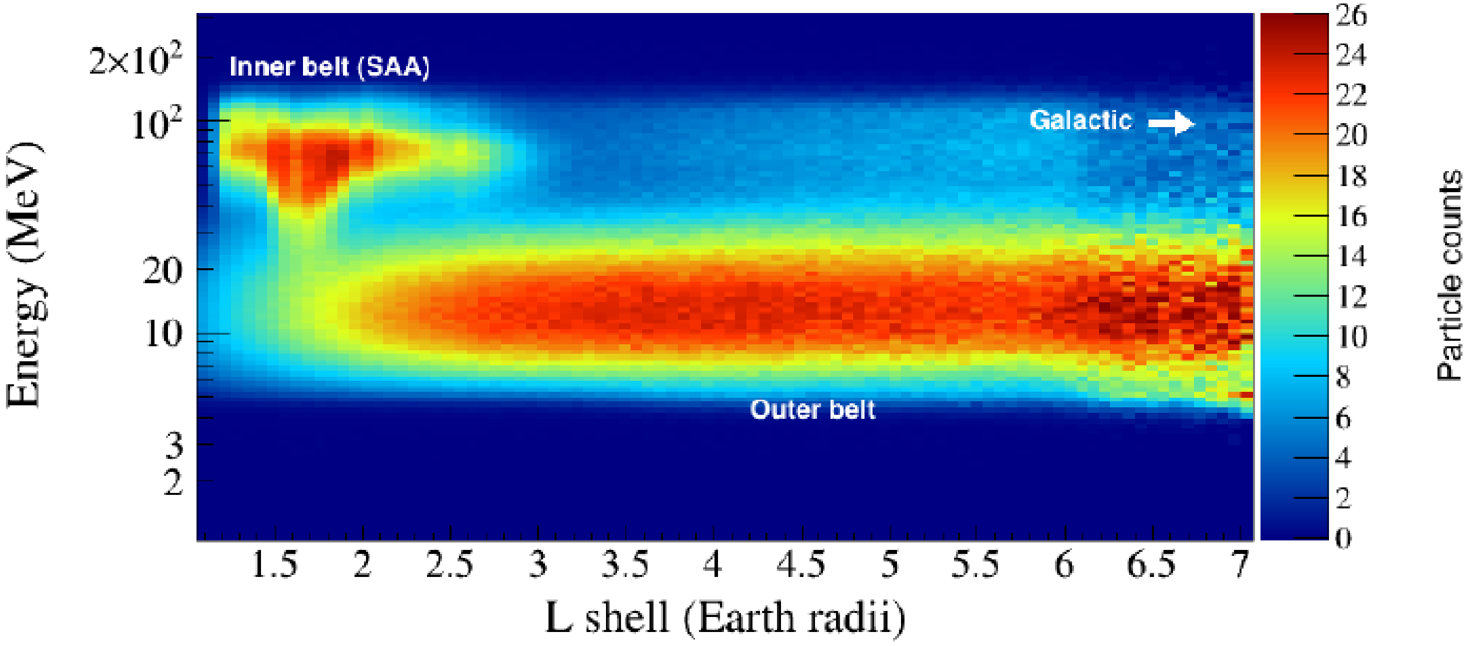
Commissioning phase: average event-rate map (May 14- June 11, 2018). The red spot is given to the South Atlantic Anomaly.

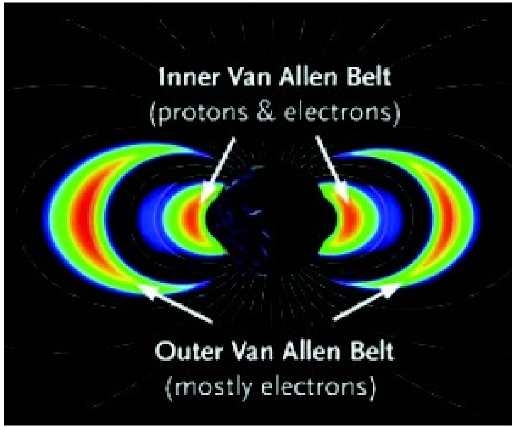
HEPD Early Operations



Commissioning phase: Trigger rate as a function of on-board time for a few orbits. Orbital segments are marked (SAA = South Atlantic Anomaly, NP and SP = North and South Pole, EQ = equatorial region).

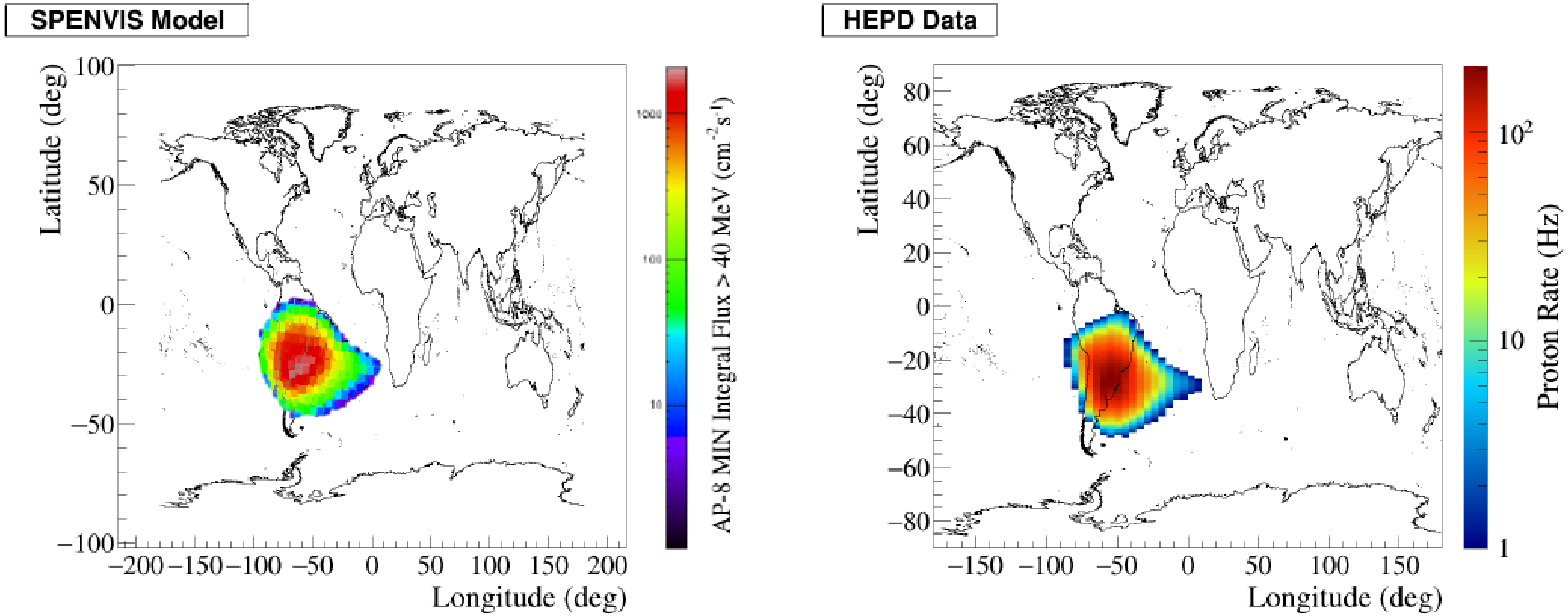
HEPD Early Operations





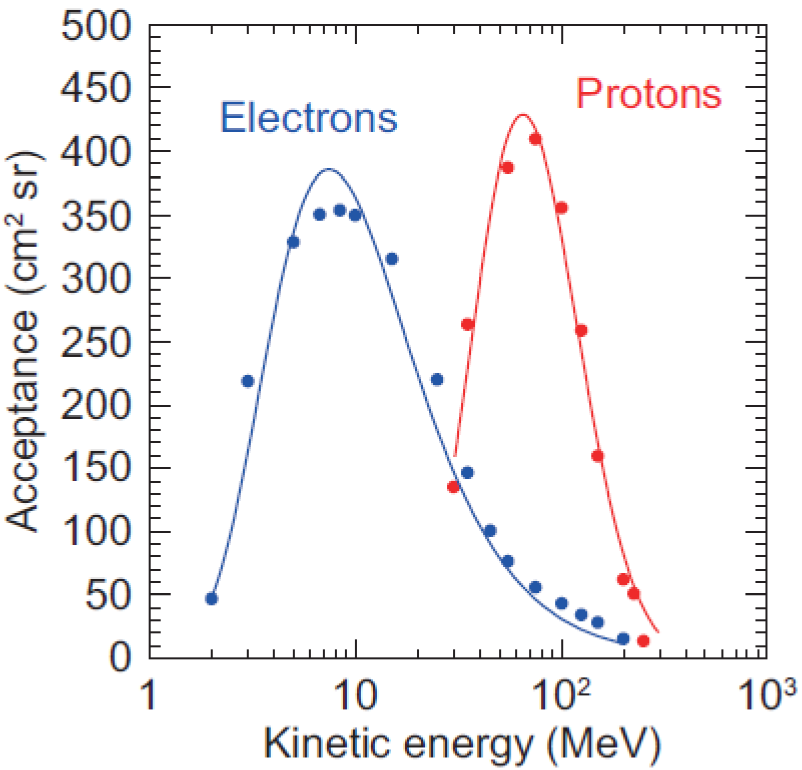
Particle populations detected by HEPD as a function of L-shell and energy

HEPD Early Operations



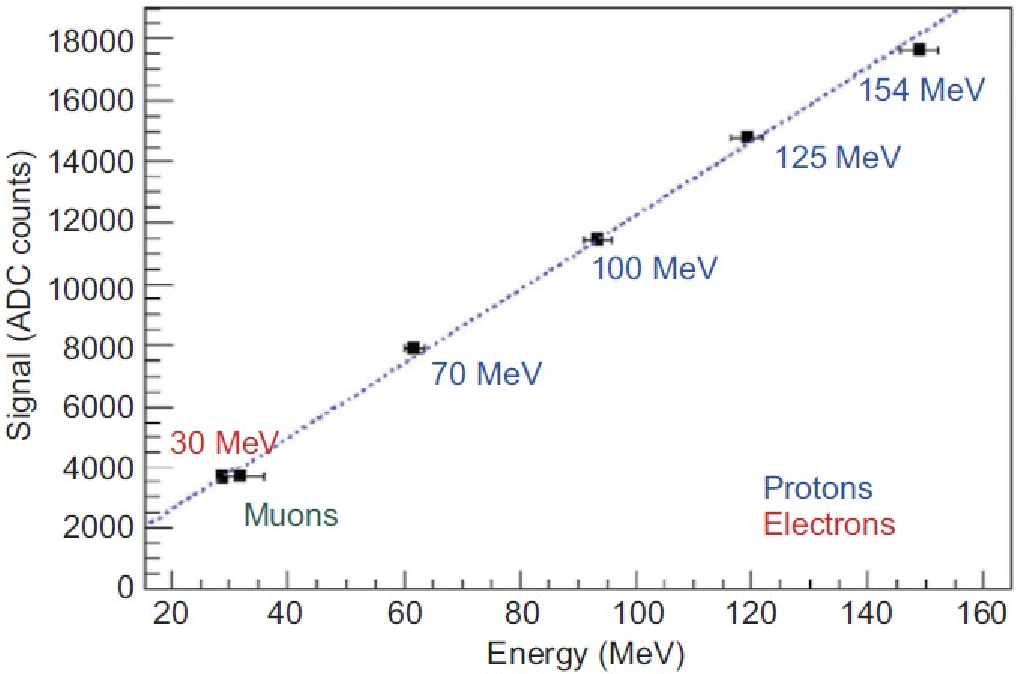
Comparison between trapped-protons geographical distribution obtained through SPENVIS model and HEPD data (August 2018) inside the South Atlantic Anomaly.

Contained Particles - Acceptance



- Two main classes of events:
  - fully contained particles
  - passing through particles
- Particle containment: no signal in lateral and bottom vetos
- Electrons contained up to 100MeV, protons up to 300 MeV
- Energy threshold and containment condition determine acceptance for contained particles
- Peak acceptance of several hundreds of cm^2sr

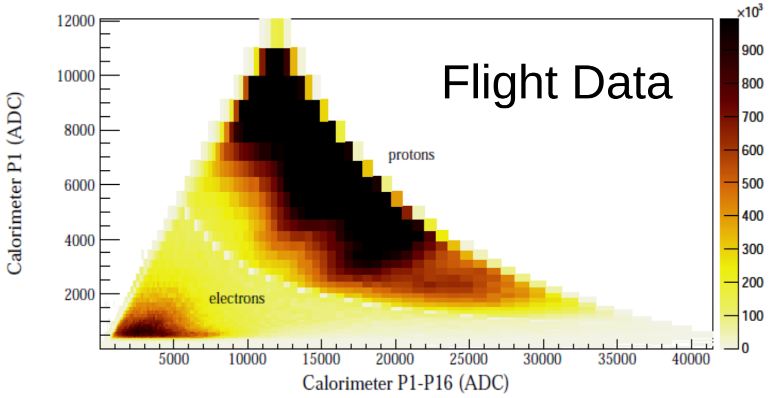
Contained Particles - Energy

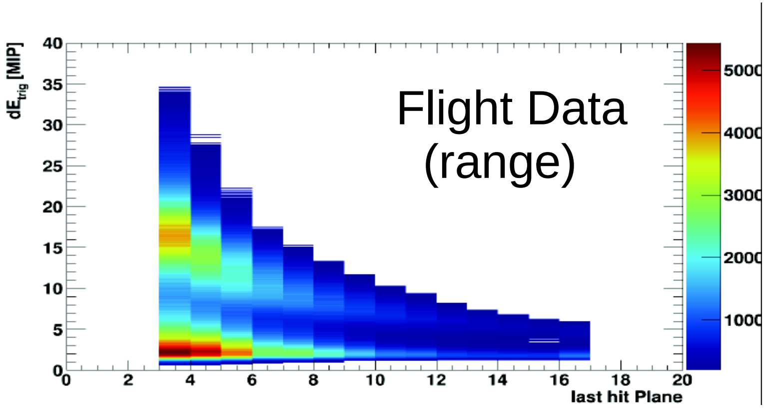


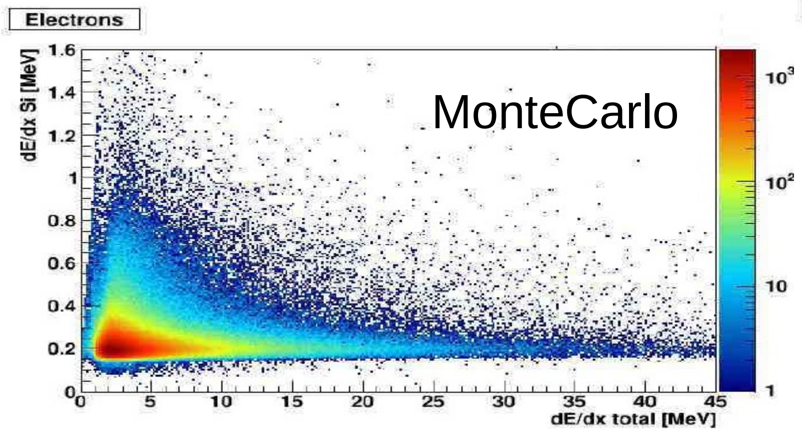
- For contained particles full energy measurement is possible
- Three methods:
  - measurement of energy loss;
  - measurement of the range (protons);
  - Deep Learning (NN, under development)

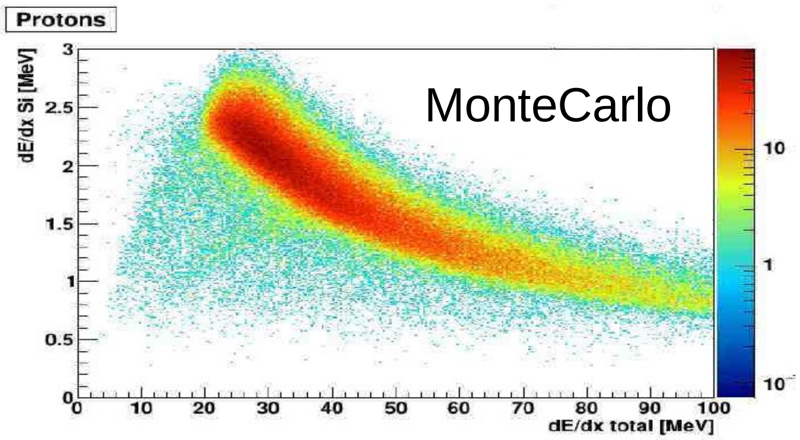
Contained Particles - PID

- For contained particles Particle-Identification with the ΔE vs E method
- ΔE obtained from trigger, or first tower planes
- Alternative method with NN under development

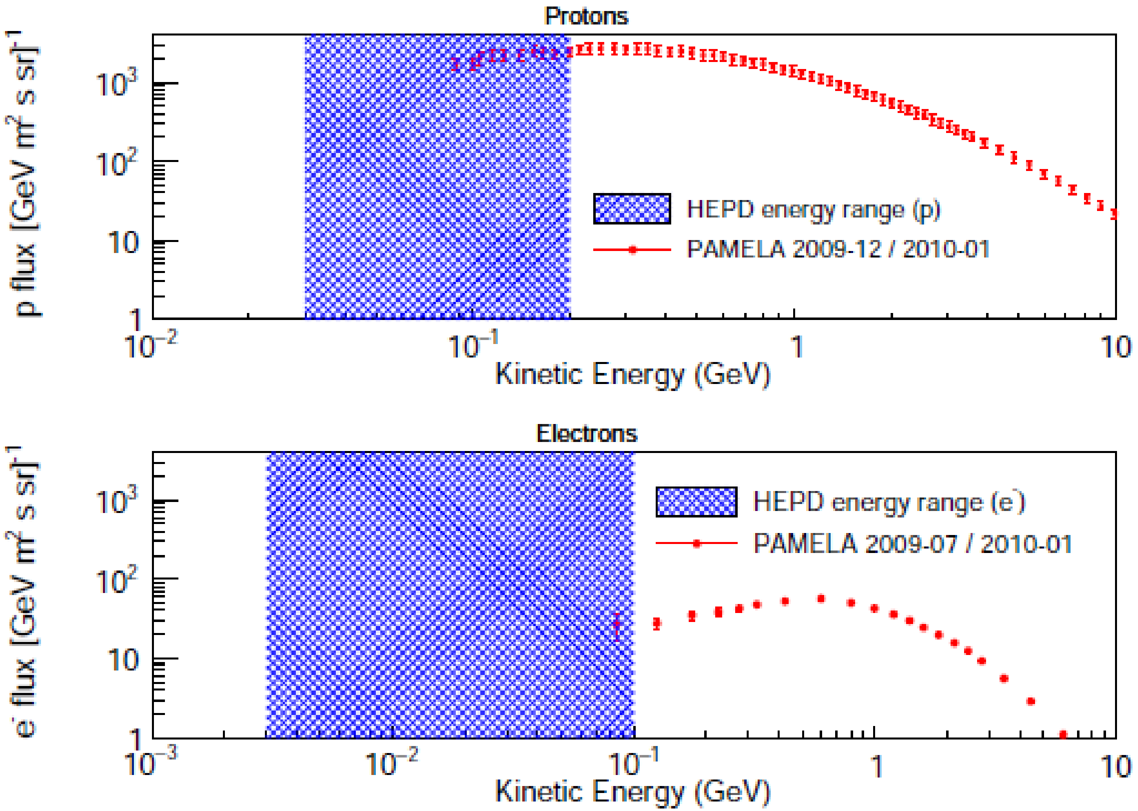


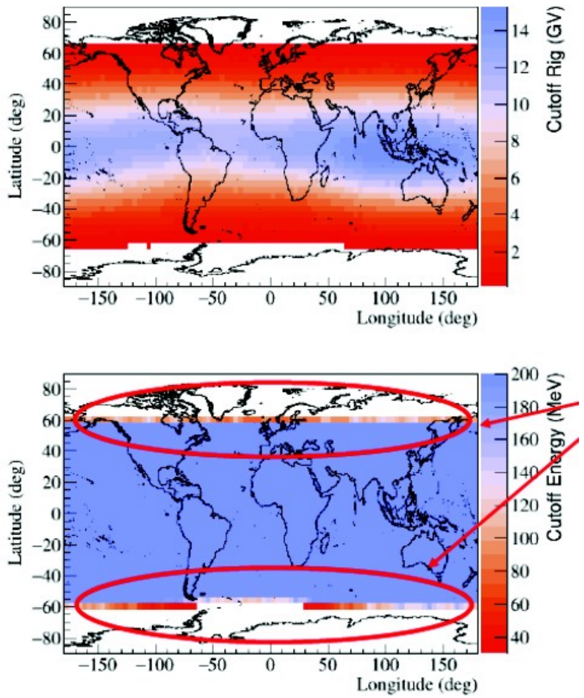






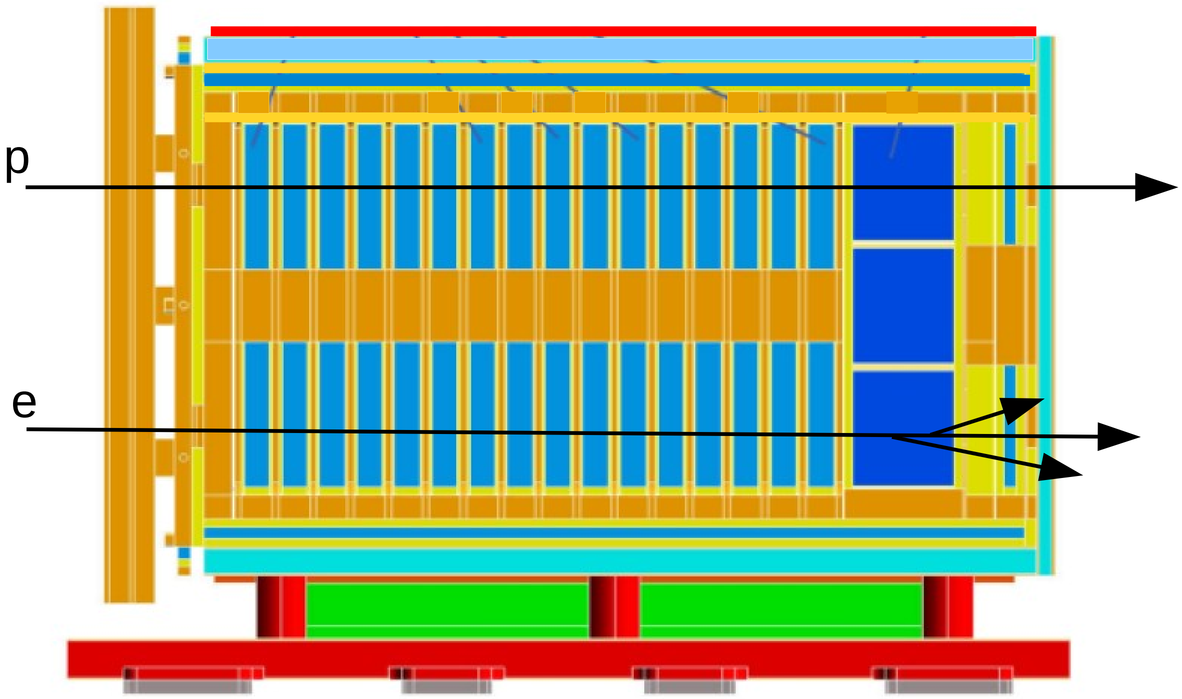
Cosmic Rays and contained events





6% orbit

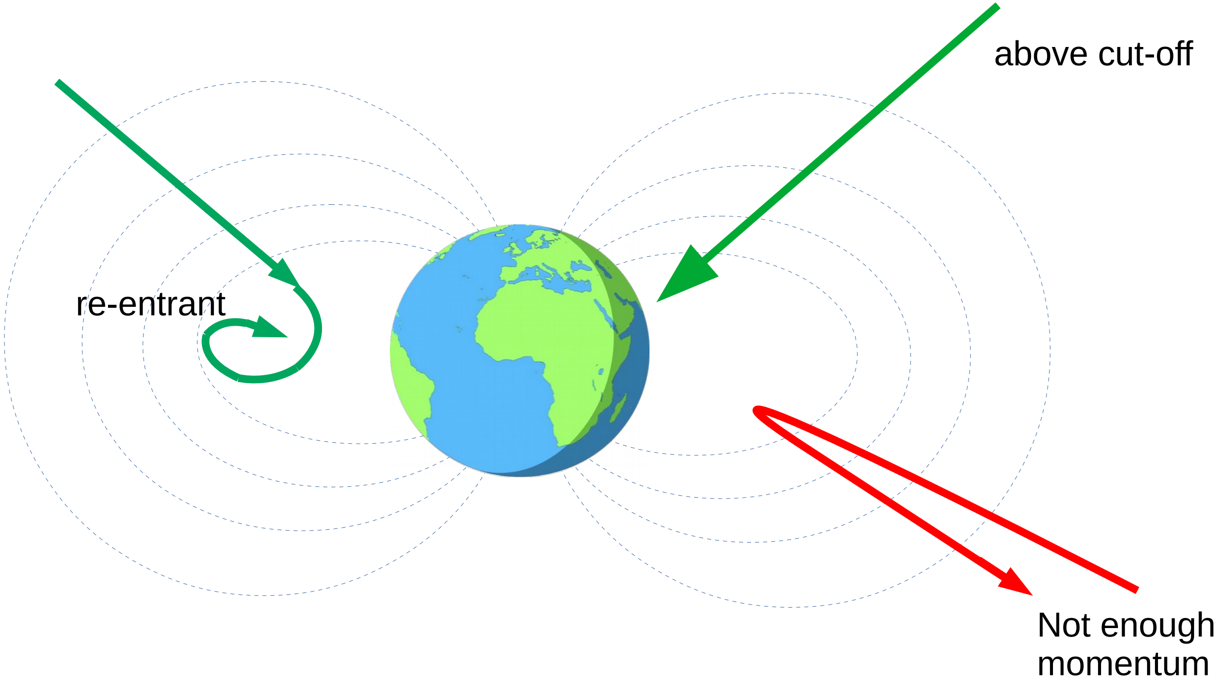
Passing Through Particles



- Passing through particles transverse the whole apparatus
- They are either electrons > 120 MeV or protons >350 MeV
- Protons above 2-3GeV are also minimum ionizing particles (MIPs), their energy loss is minimal
- Energetic electrons also are MIPs but loose more energy in the bottom segments via radiative losses.

CR Relativistic Protons

- At a given latitude HEPD integrates all the CR proton flux above cut-off (but it can’t measure the energy >300MeV)
- For cut-off rigidity >2-3GV all CR protons that reach HEPD area passing through MIPs
- Contamination of **re-entrant albedo protons (other ?)** should be considered.



Re-entrant Albedo Component

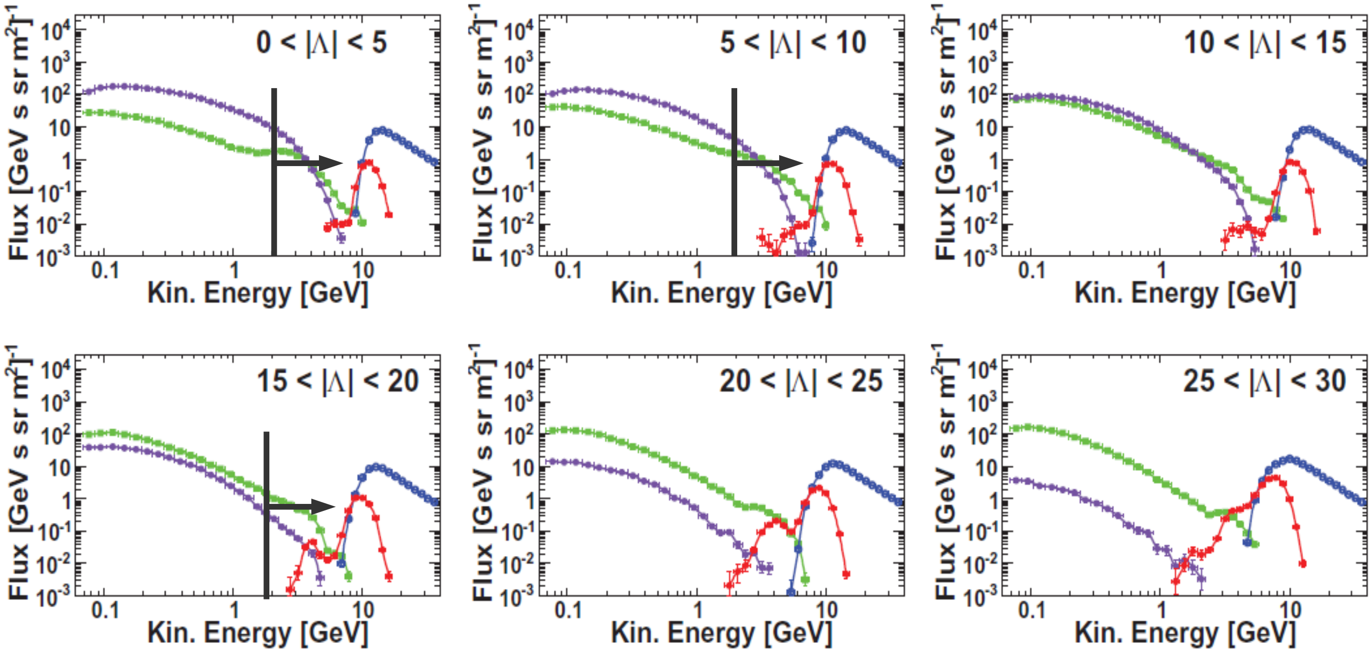
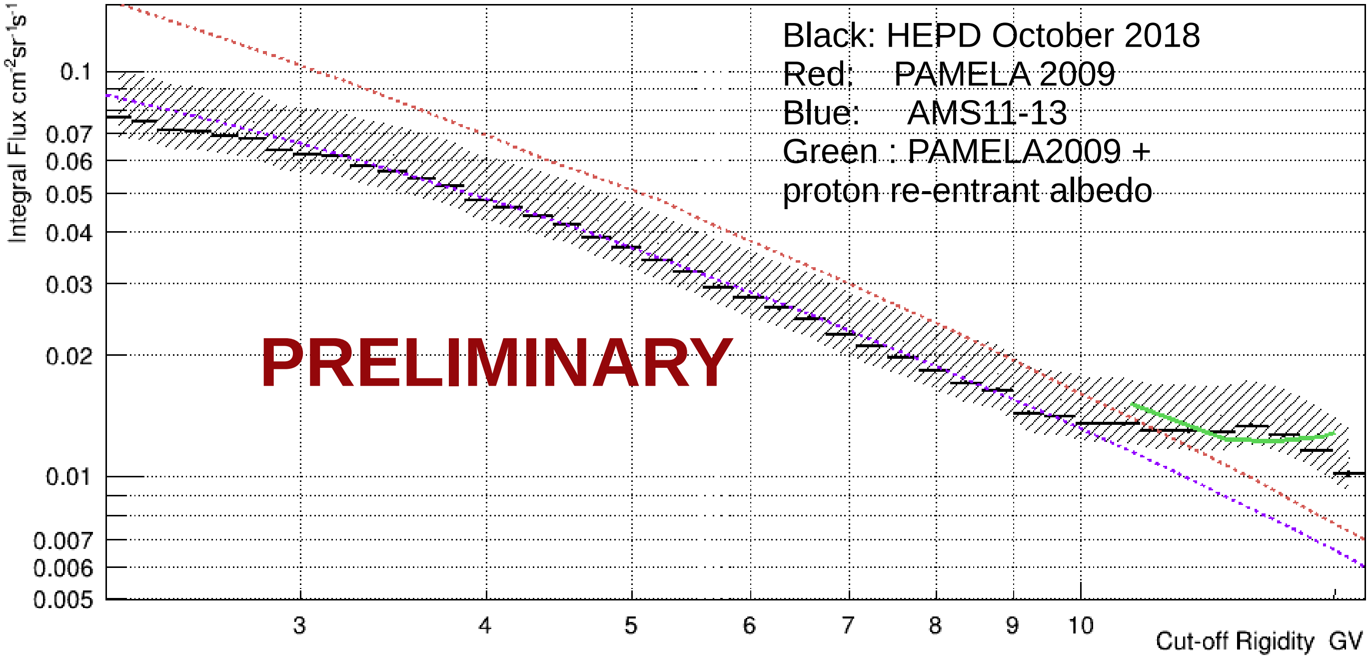


Fig. 2. Differential energy spectra outside the SAA for different bins of AACGM latitude |Λ|. Results for the several proton populations are shown: quasi-trapped (violet), precipitating (green), pseudo-trapped (red) and galactic (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

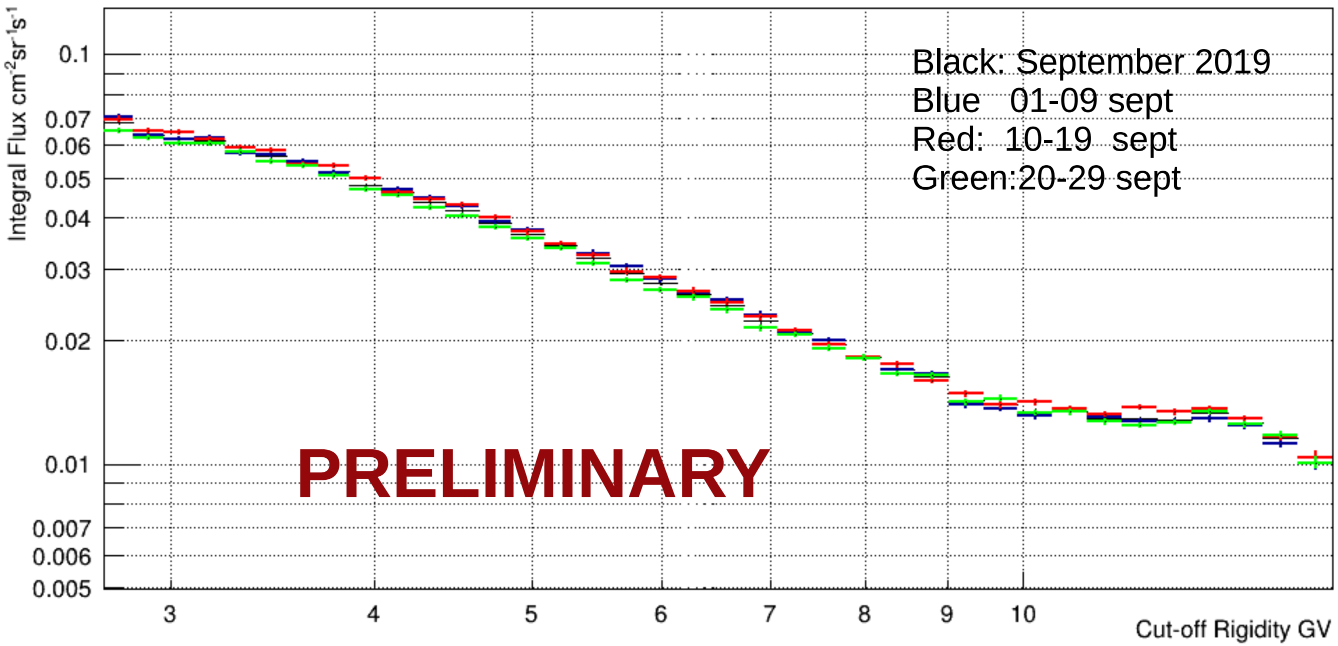
Measured re-entrant protons (Adriani, et al. Advances in Space Research 60 (2017) 788–795)

MIP Integral Flux



- Integral MIP flux as function of the rigidity cut-off.
- It is compared to CR proton integral fluxes
- The cut-off value is obtained from the satellite position and a geo-magnetic field model
- Shadowed band represents -10%+30% systematic uncertainties.
- Main syst. unc. Sources are:
  - the missing correction for East-West angle dependence of the cut-off;
  - magnetic field model without external component.

Flux vs Time

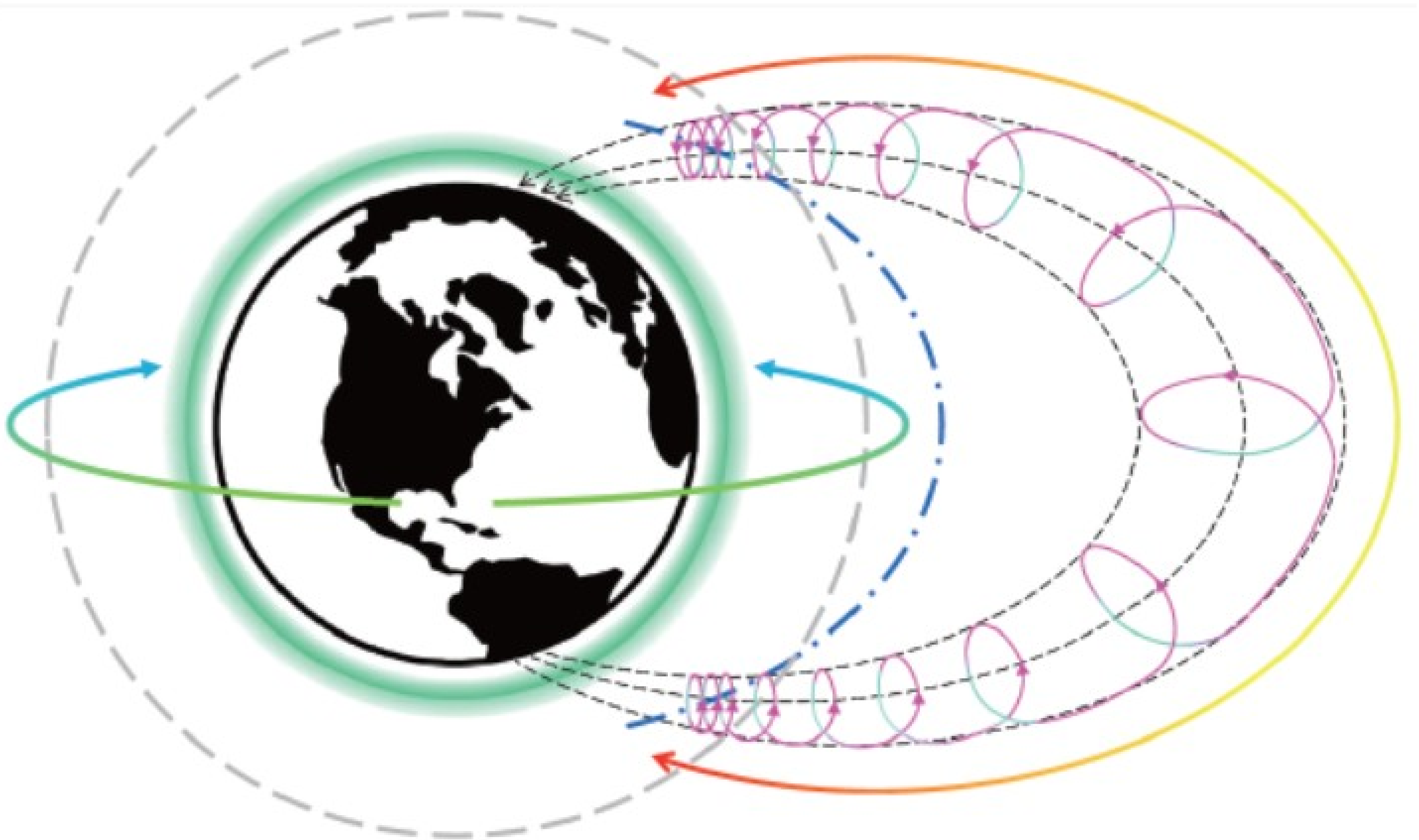


- Integral MIP flux as function of the rigidity cut-off, for four different time periods
- Only statistical errors are shown
- During september about 850k events after selection were found

Summary

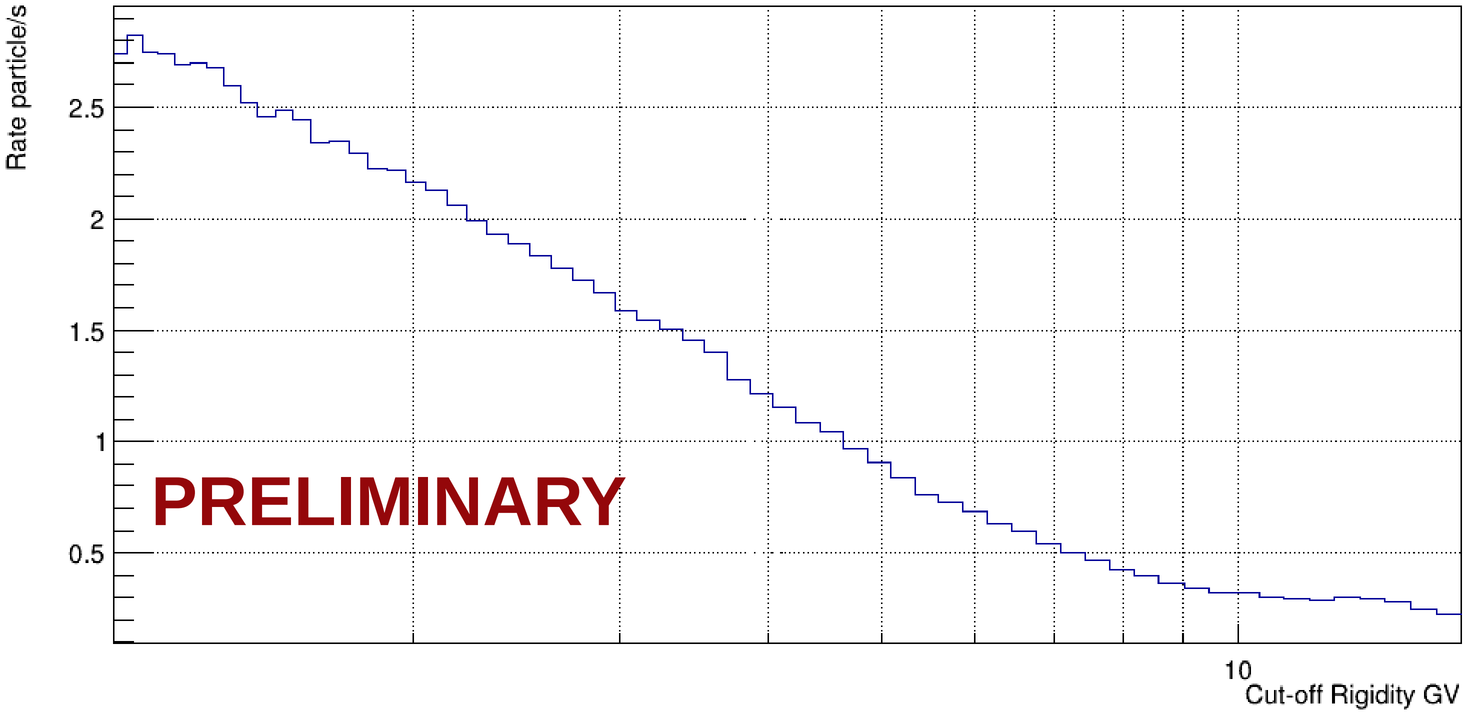
- The CSES satellite has been successfully launched on Feb 2, 2018
- Since then the HEPD performed the commissioning phase, and started the nominal data taking
- Early operations provided first results on trapped particles and space radiation environment
- Multidisclinary studies together with team of other payloads are going on
- Development of analysis tools for the astroparticle related measurement are also in development
- Early results with passing through events were shown.
- For these we can profit of adequate statistics. Systematics are under consideration.

Litho-Magneto-sphere Coupling

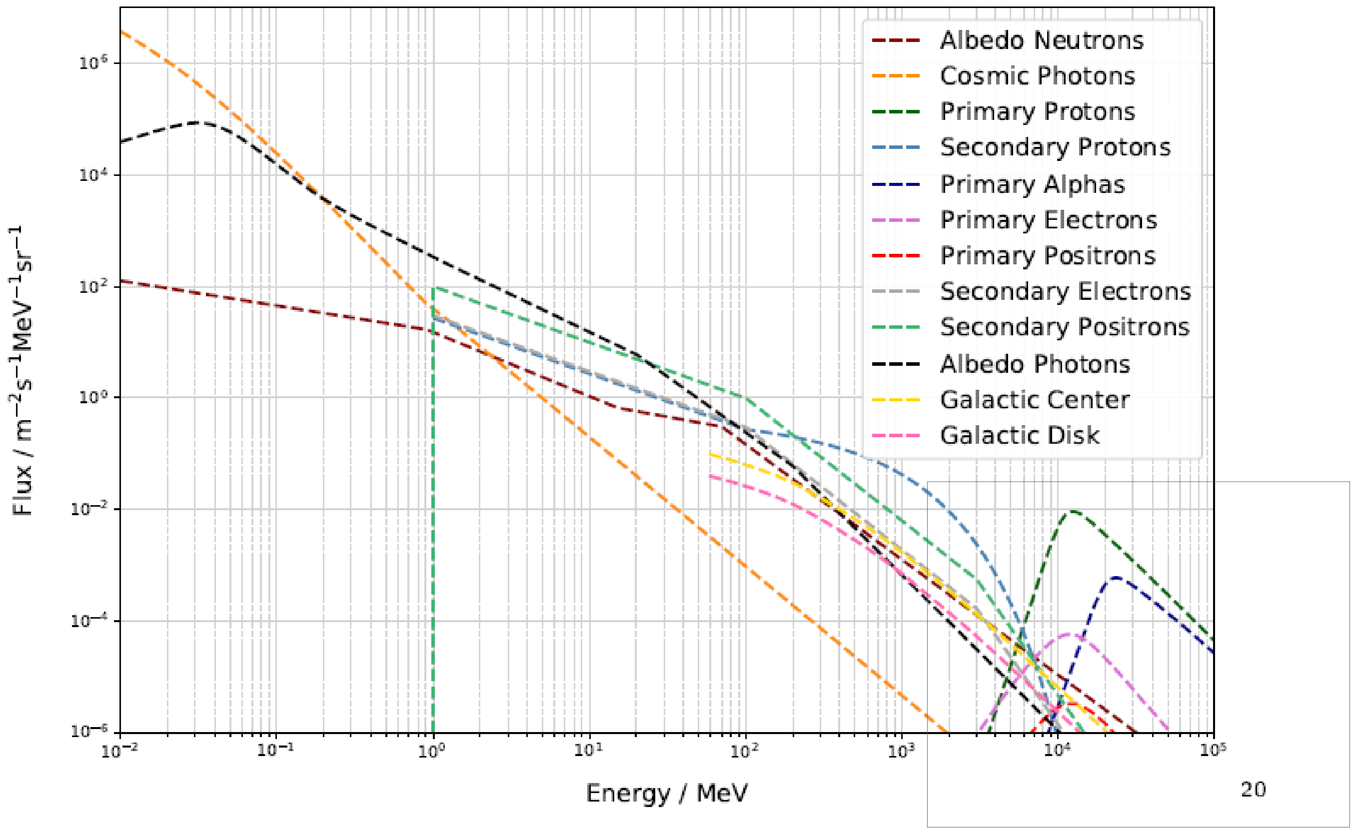


CSES Launch

Rate


Rate particle/s
2.5
2
1.5
1
0.5
10
Cut-off Rigidity GV
PRELIMINARY

Re-entrant Albedo Component



Expected radiation at LEO orbit (P.Cumani, AHEAD 2nd progress Meeting, April 2018, Coimbra)