Space-Weather capabilities and preliminary results of the High Energy Particle Detector (HEPD) on board the CSES-01 satellite

Dr. Matteo Martucci
on behalf of the CSES-Limadou Collaboration

INFN Sezione di Roma Tor Vergata

36th International Cosmic Ray Conference - Madison (WI), USA
July 30, 2019

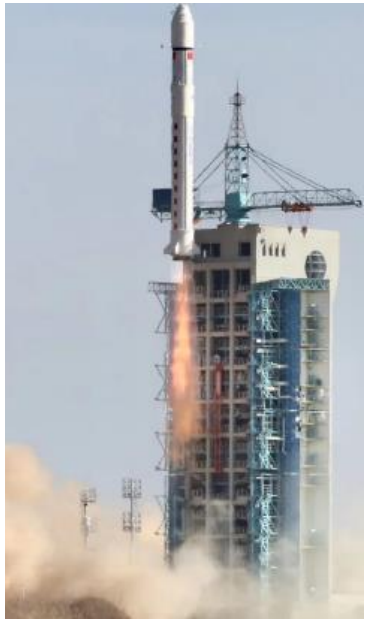
Mission objectives

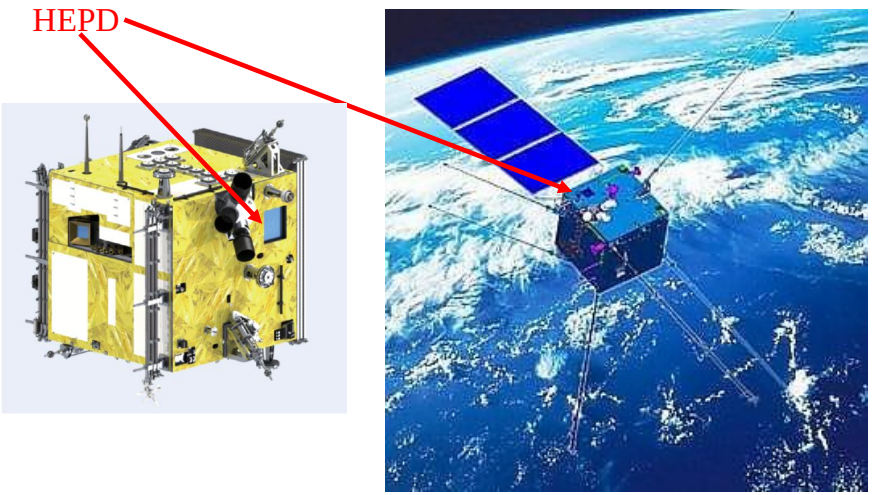
- Monitoring electromagnetic near-Earth space environment
- Measuring iono-magnetospheric perturbations possibly due to seismo-electromagnetic phenomena
- Monitoring EM man-made effects at LEO altitude
- Studying spectra of charged particles precipitating from Van Allen radiation belts
- Observing changes in solar activity

The CSES-01 satellite

Platform	Mass	$\simeq$ 700 kg
Orbit	Type	Sun-Synchronous
	Altitude	507 km
	Inclination	97°
	Period	94 min
	Local time descending node	14:00
	Revisit period	5 days
Mission	**Life Span**	**$\geq$ 5 years**

CSES-01 Launched by CZ-2D Vehicle on Feb 2. (15:51)
@Jiuquan Sat. Launching Center



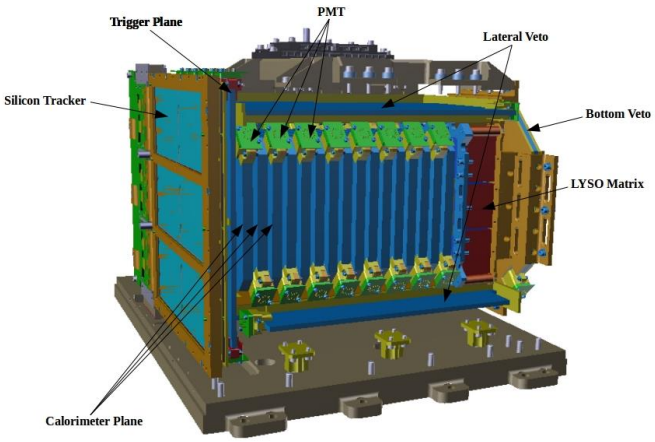


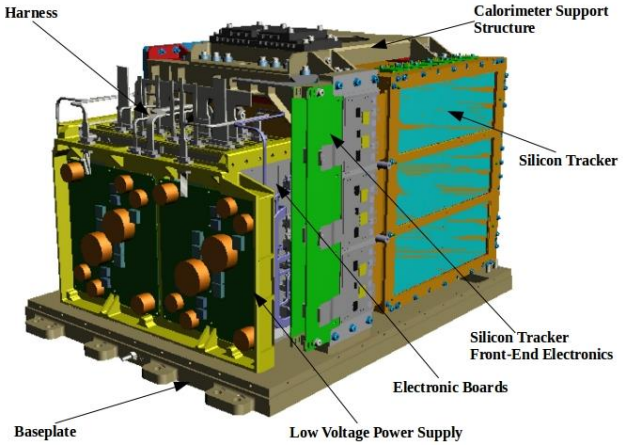
CSES-Limadou Collaboration

Limadou refers to the Italian contribution to the CSES-01 mission Several Italian institutes and universities involved:

- Italian Space Agency (ASI)
- INFN - Roma Tor Vergata, Bologna, Perugia, LNF, Naples, TIFPA
- University of Rome Tor Vergata
- University of Trento
- National Institute for Astrophysics - Institute for Space Astrophysics and Planetology (INAF-IAPS)
- Uninettuno University
- National Institute of Geophysics and Volcanology (INGV)

High-Energy Particle Detector (HEPD)

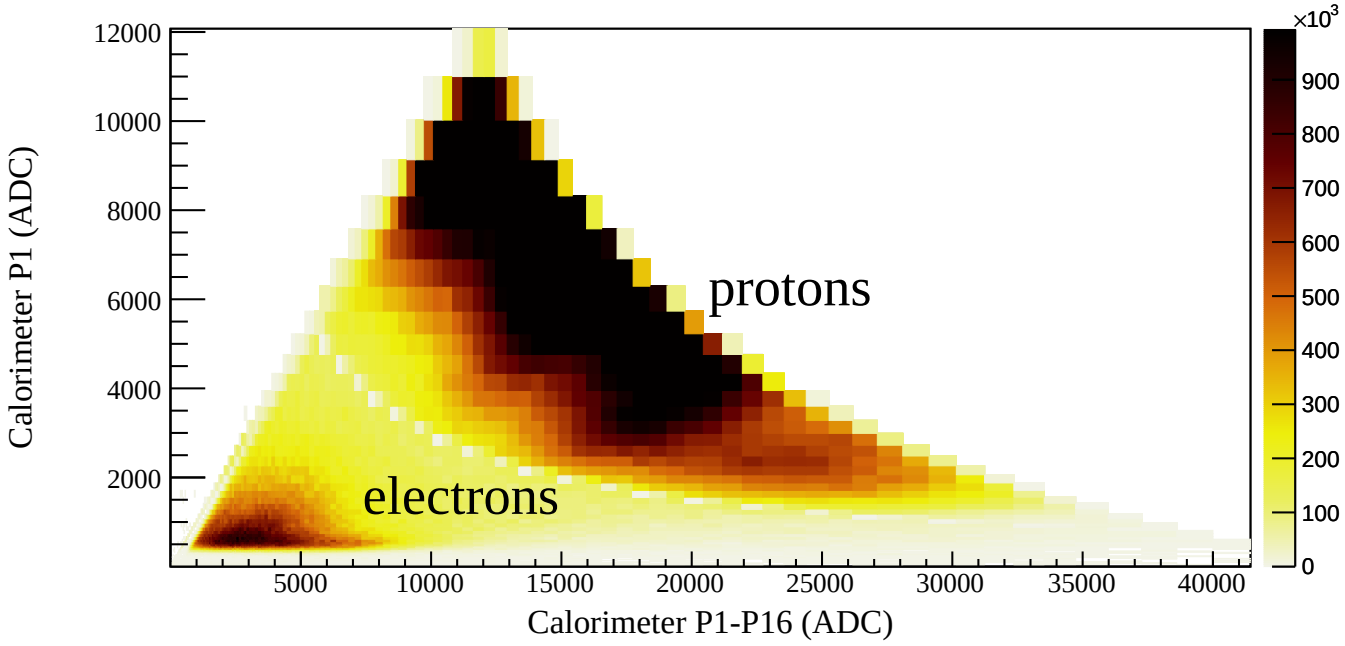




- 2 planes of double-sided Si microstrip sensors (tracker) → track-related information
- 1 layer of plastic scint. → trigger
- range calorimeter comprising:
  - 16 layers of plastic scint. planes ($15\times15\times1$ cm^3) read out by PMTs → energy deposit
  - 3×3 matrix of inorganic scint. LYSO crystals read out by PMTs → increase range
- 5 (5 mm-thick) plastic scint. planes → veto[1]

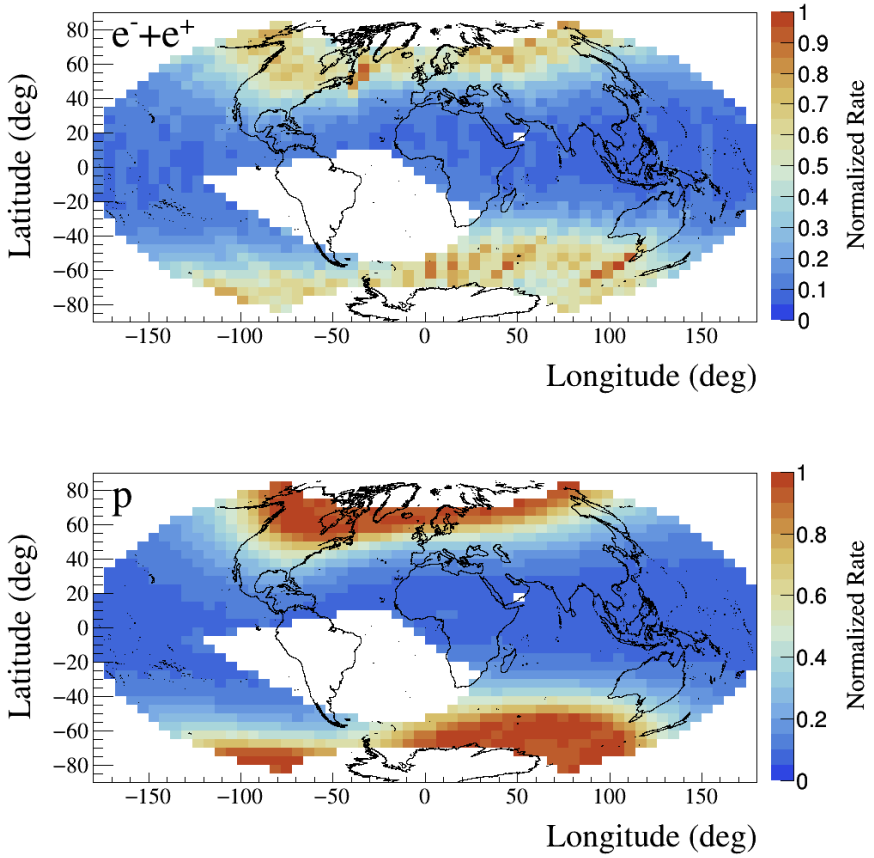
En. range (e^-)	3 MeV-100 MeV
En. range (p)	30 MeV-200 MeV
Angular resol.	$< 8^\circ$ @ 5 MeV
Energy resol.	$< 10\%$ @ 5 MeV
Acceptance	$\sim$400 cm^{2}sr
Mass (+ el.)	$\sim$44 kg

Particle Identification with HEPD



- Both tracking pl. and calorimeter measure the energy loss per unit length → good separation of species (>90%)
- 16 planes used for Range comparison (for protons)
- Check with MC simulations
- Dedicated configuration for light-nuclei ID (not shown in the figure)

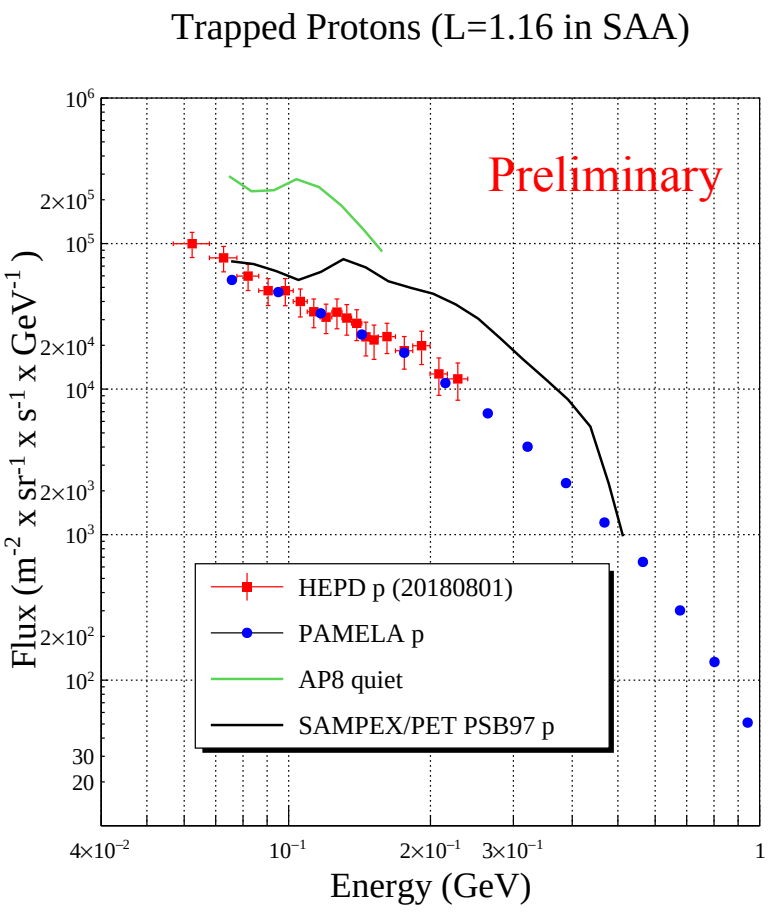
Particle populations along CSES-01 orbit



- HEPD is switched off above 65° to monitor the satellite attitude and manage the orbit control system
- The tilt angle of the Earth magnetic field allows HEPD to collect data in regions with magnetic latitude values of c.a 75°
- Here the geomagnetic rigidity cutoff is low, and charged particles, coming from outside the magnetosphere, can penetrate and be easily detected
- IGRF-12[2] and Tsyganenko-89[3] models are used to describe both internal and external mag. fields

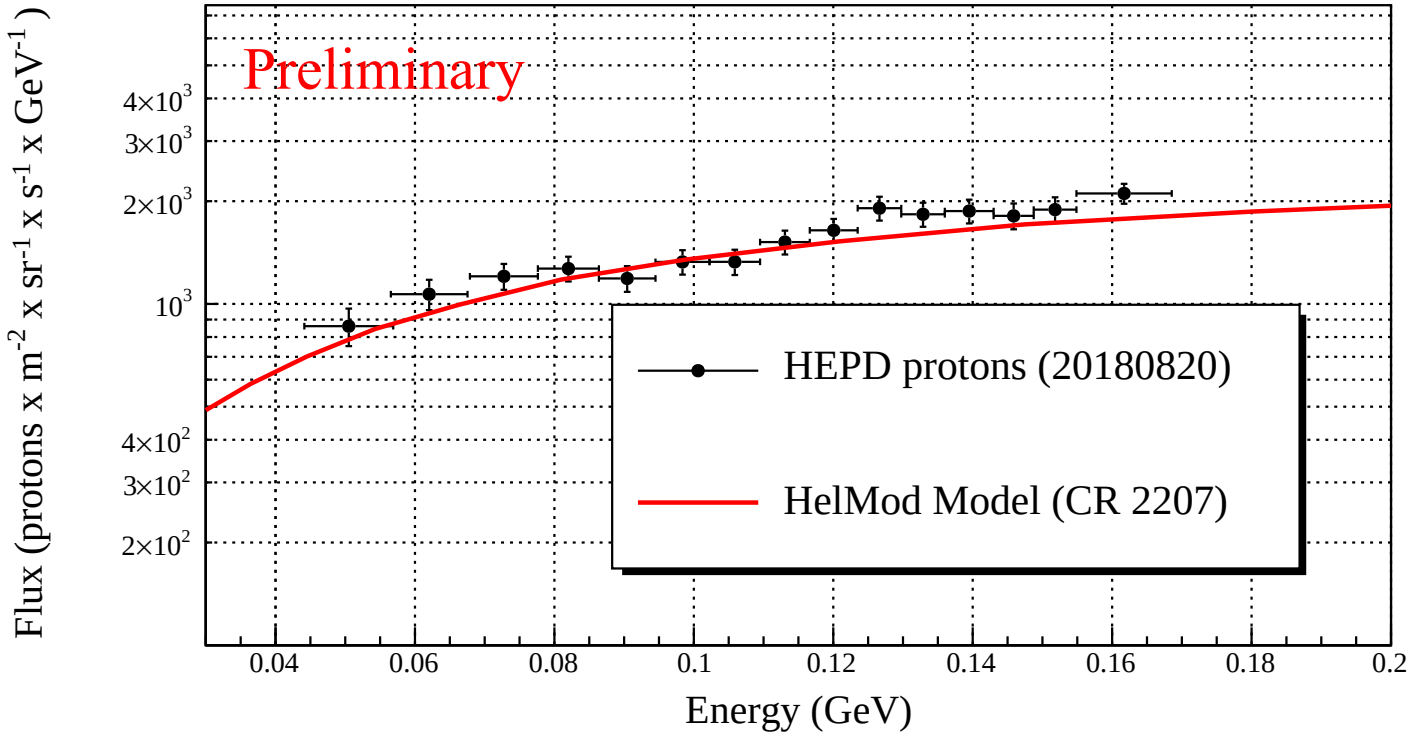
Preliminary results by HEPD: SAA protons

- Geomagnetically trapped protons
- Originated from β-decay of free neutrons produced in the interaction of GCRs with the Earth's atmosphere (CRAND) mechanism[4]
- Good agreement with PAMELA (2006-2009)
- HEPD could place important constraints on the trapping and interaction processes
- HEPD data could also be used to validate current trapped particle radiation models



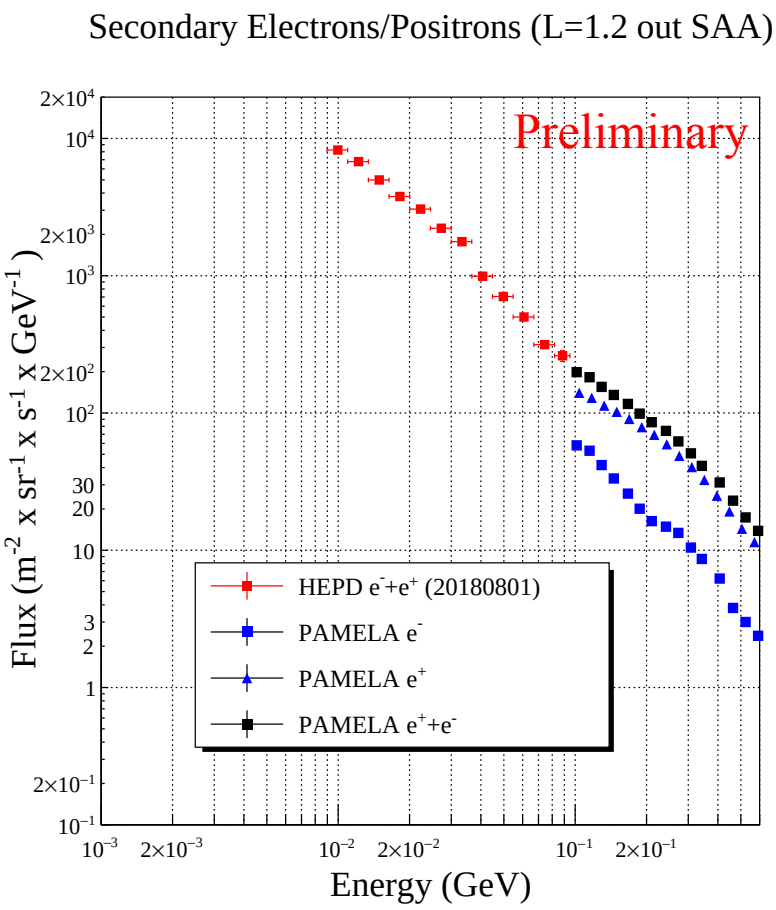
HEPD data collected in a single day (August 1, 2018)

Preliminary results by HEPD: cosmic ray protons



- Galactic protons (>50 MeV) can be observed with high statistics thanks to the wide HEPD acceptance
- Cutoff selection applied to reject sub-cutoff protons
- Good agreement with HelMod model in CR 2207[5]

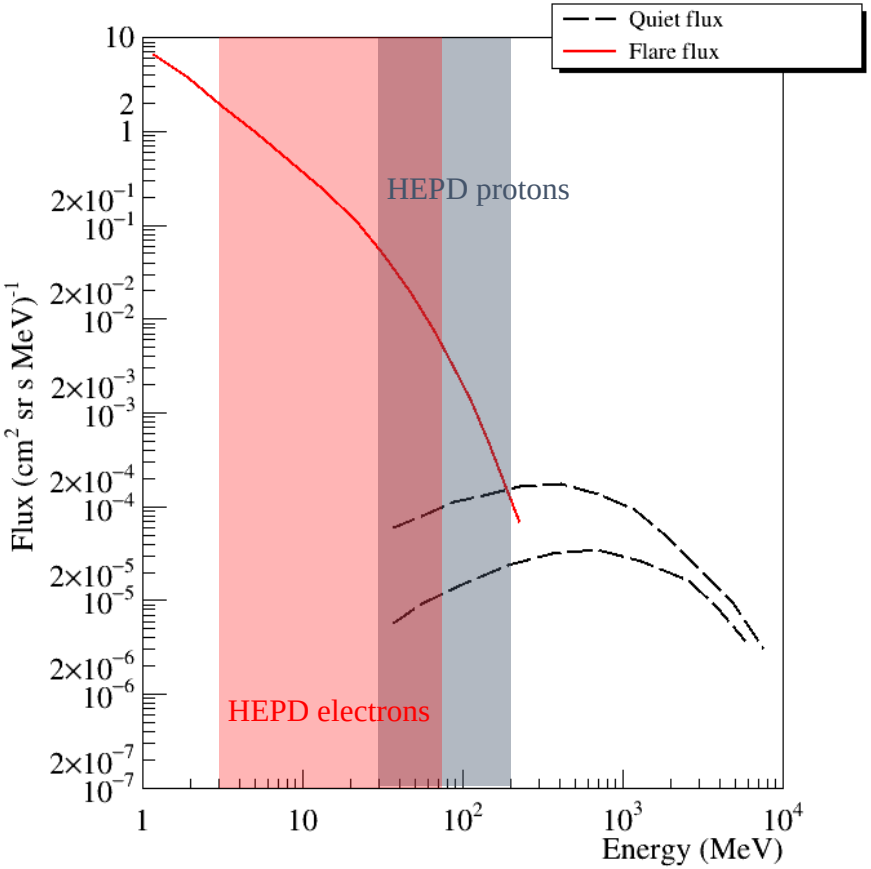
Preliminary results by HEPD: re-entrant electrons



- e^-, e^+ largely produced by nuclear component GCRs in reaction with atmosphere - decay chains: $\pi^\pm \rightarrow \mu^\pm \rightarrow e^\pm$
- e^-, e^+ produced in roughly equal numbers
- e^-, e^+ propagate back to ToA and along field lines to their field-conjugate location
- HEPD is not able to distinguish between e^- and e^+ $\rightarrow$ all-electron spectrum
- Agreement with PAMELA e^-+e^+ is very good even in a single day of data (August 1, 2018)

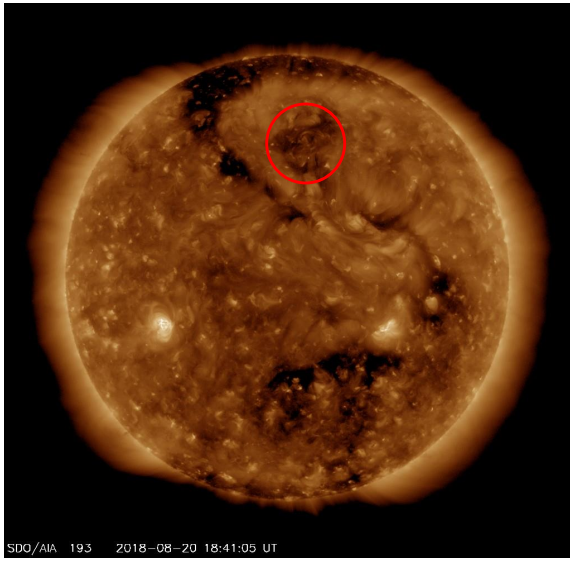
Solar Particle Events with HEPD

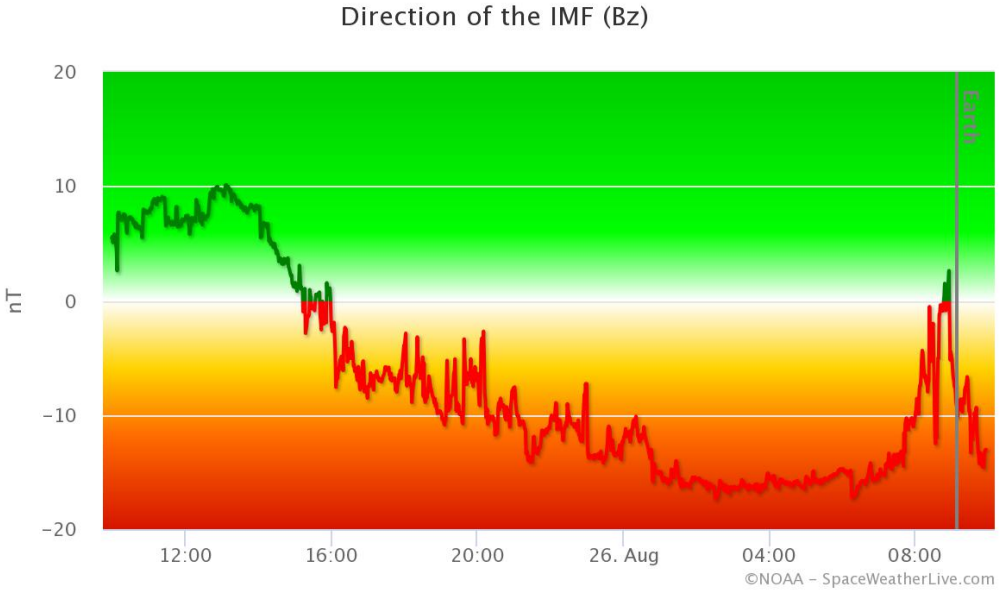
- Solar Particle Events accelerate particles close to the Sun (*flare*) or in interplanetary space (*CME shocks*)
- p, He or HZE ions are produced
- Spectral shape/time-evolution could shed more light on acceleration site/mechanism
- Un-disturbed heliosphere could help disentangle transport effects
- Last SEP on 2017 Sep. 10 (X8)
- Catalog different events with common characteristics
- HEPD could fill the gap between *in situ* observations and Neutron Monitors data on ground



The geo-storm of August 25-26

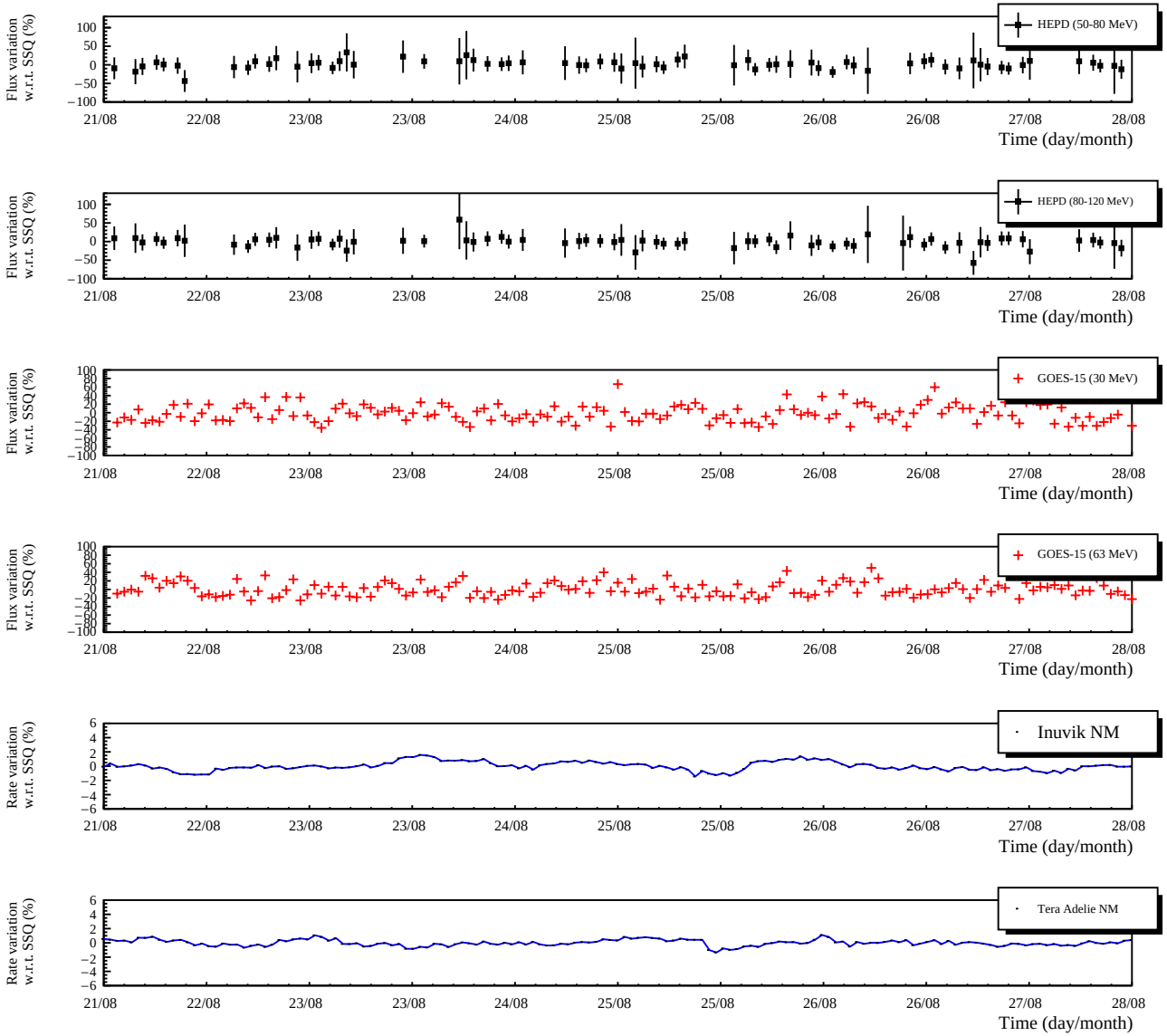
- CME from filament (N40W05) - August 20
- Slow moving
- Shock arrival August 25 (0600 UTC)[6]





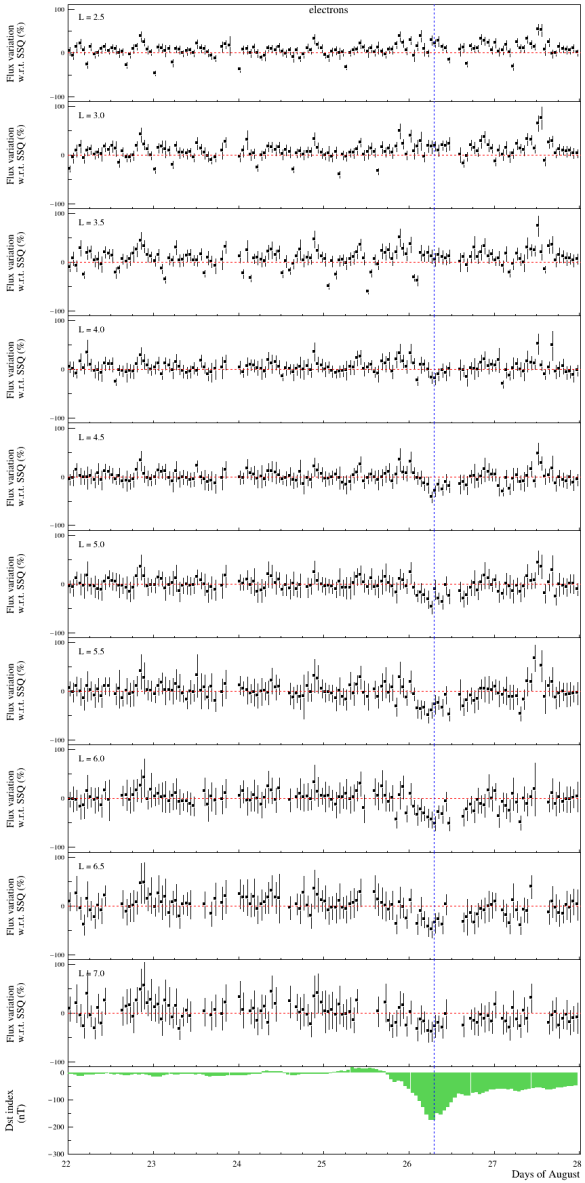
- It triggered a G3 storm
- Maximum Kp 7.0
- Minimum B_z ∼-17 nT

HEPD GCRs during August storm



HEPD electrons/protons during storm

electrons (<20 MeV)



L = 2.5

L = 3.0

L = 3.5

L = 4.0

L = 4.5

L = 5.0

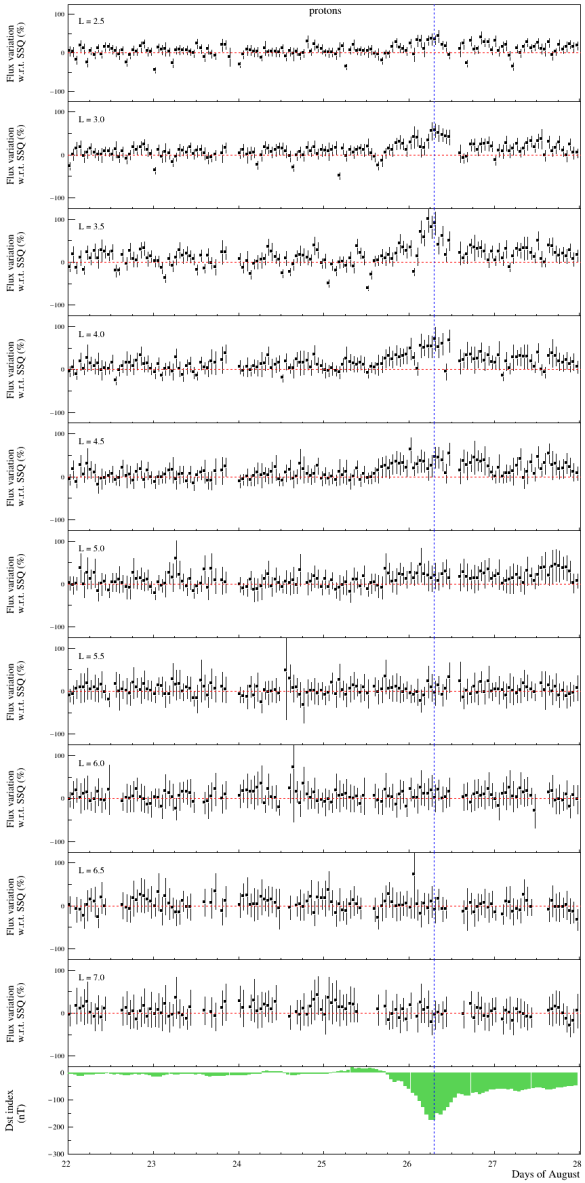
L = 5.5

L = 6.0

L = 6.5

L = 7.0

protons (<80 MeV)



Conclusions

- The large acceptance of HEPD allows high statistics
- The energy threshold is crucial to measure low-energy particles
- Polar orbit ($\pm 65^\circ$) allows to measure not only trapped populations but also galactic particles
- Sun-synchronous orbit allows to easily measure differences between night-side and day-side of the Earth's magnetosphere
- The stability of the detector together with its fixed revisiting time allow to precisely monitor small variations with respect to a background
- All the above-mentioned characteristics make HEPD very well suited for space weather purposes
- A network of satellite like CSES-01 is expected to be launched in the next years to enforce space weather studies

References

[1] P. Picozza et al. "Scientific Goals and In-orbit Performance of the High-energy Particle Detector on Board the CSES". In: *The Astrophysical Journal Supplement Series* 243.1 (July 2019), p. 16. DOI: 10.3847/1538-4365/ab276c.

[2] Erwan Thébault et al. "Evaluation of candidate geomagnetic field models for IGRF-12". In: *Earth, Planets, and Space* 67, 112 (July 2015), p. 112. DOI: 10.1186/s40623-015-0273-4.

[3] N. A. Tsyganenko. "A magnetospheric magnetic field model with a warped tail current sheet". In: *Planet. Space Sci.* 37.1 (Jan. 1989), pp. 5–20. DOI: 10.1016/0032-0633(89)90066-4.

[4] S. F. Singer. "Trapped Albedo Theory of the Radiation Belt". In: *Phys. Rev. Lett.* 1.8 (Oct. 1958), pp. 300–300. DOI: 10.1103/PhysRevLett.1.300.

[5] M.J. Boschini et al. "Propagation of cosmic rays in heliosphere: The HelMod model". In: *Advances in Space Research* 62.10 (2018). Origins of Cosmic Rays, pp. 2859–2879. ISSN: 0273-1177. DOI: https://doi.org/10.1016/j.asr.2017.04.017.

[6] *CME Scoreboard*. https://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard/. Accessed: 2019-07-21.