Proton fluxes inside the South Atlantic Anomaly measured by the High-Energy Particle Detector (HEPD) on board the CSES-01 satellite during the 2018-2020 period.

M. Martucci[1,2] on behalf of the Limadou/HEPD-01 Collaboration

[1]INFN-Sezione di Roma "Tor Vergata", V. della Ricerca Scientifica 1, I-00133 Rome, Italy;
[2]Department of Physics, University of Rome "Tor Vergata", V. della Ricerca Scientifica 1, I-00133 Rome, Italy;

Correspondence to: matteo.martucci@roma2.infn.it

Despite notable improvements made in the last decades, the characterization of the near-Earth proton radiation environment is incomplete, with major uncertainties affecting the description of high-energy particles (>40 MeV) in the South Atlantic Anomaly (SAA) region. The High-Energy Particle Detector (HEPD) on board the China Seismo-Electromagnetic Satellite (CSES-01), launched on February 2018 on a Low-Earth Orbit and with an altitude of about 507 km, is a light and compact payload suitable for measuring electrons (3-100 MeV), protons (30-300 MeV), and light nuclei (up to a few hundreds of MeV) with a high energy resolution and a wide angular acceptance. Thanks to its good identification performance, it can carry out precise and comprehensive measurement of particle fluxes, including angular information. The observations of HEPD could be fundamental not only for space weather purposes, but because they could help set important constraints on trapping and interaction processes in the Earth's atmosphere and magnetosphere. Furthermore, they enable the testing and validation of current theoretical and empirical models of the inner radiation belt, like the NASA AP9. In this contribution, we report a preliminary analysis of >40 MeV protons detected inside the SAA region between 2018 and 2020.

Introduction

It is well-known that galactic cosmic ray (GCR) protons, above several hundreds of MeV, permeate the interplanetary space. The majority of this particles are likely produced inside our Galaxy from Supernovae and they are believed to be the main source of the Cosmic Ray Albedo Neutron Decay (CRAND) mechanism. In this process, >GeV cosmic protons interact with the neutral molecules in the upper atmosphere, generating energetic albedo neutrons which will consequently decay into protons (together with electrons and antineutrinos). Such protons become geomagnetically trapped and form the so-called inner radiation belt [3]. The region where the inner belt comes the closest to the Earth's surface - approximately located over the South Atlantic Ocean - is known as South Atlantic Anomaly (SAA) and it is characterized by an extremely low intensity of the geomagnetic field. The scientific community has been considerably involved in modeling such space radiation environment with the aim of better assessing the significant radiation hazard to spacecraft and human crews [1]. The NASA AE9/AP9 set of models for high-energy electrons and protons, respectively, is the most complete and recent one. Despite their success in describing the radiation environment, both AE9 and AP9 are partly incomplete and often their predictions are not based on a statistically sufficient sample of direct measurements. It is of key importance to test such models and, above all, to provide new and reliable data-sets from in-flight instruments to improve their output and accuracy.

High-Energy Particle Detector

The China Seismo-Electromagnetic Satellite (CSES-01) is the first of a series of multi-instrument monitoring satellites, scheduled for launch in the next few years. CSES-01 - put in orbit on February 2, 2018 - is currently flying on a sun-synchronous polar orbit at a ∼507 km altitude, with a 5-day revisiting periodicity. Among various scientific payloads, the High-Energy Particle Detector (HEPD), depicted in Fig.1, has been designed and built by the Limadou team, the Italian branch of the CSES Collaboration. It is a light and compact (40.36 cm × 53.00 cm × 38.15 cm, total mass ∼45 kg) payload, designed for electrons (3-100 MeV) and protons (35-250 MeV) measurements, and made up of a series of sub-detectors: a double-sided silicon microstrip tracking system, a plastic scintillator layer providing trigger and a range calorimeter - composed of a stack of 16 plastic scintillator in the upper portion (TOWER) and a 3×3 matrix of Lutetium-Yttrium Oxyorthosilicate (LYSO) inorganic scintillator crystals in the lower portion. The whole apparatus is surrounded by a total of 5 plastic scintillators (VETO) which reject particles not entirely contained in the detector. More technical details on the instrument can be found in [2].

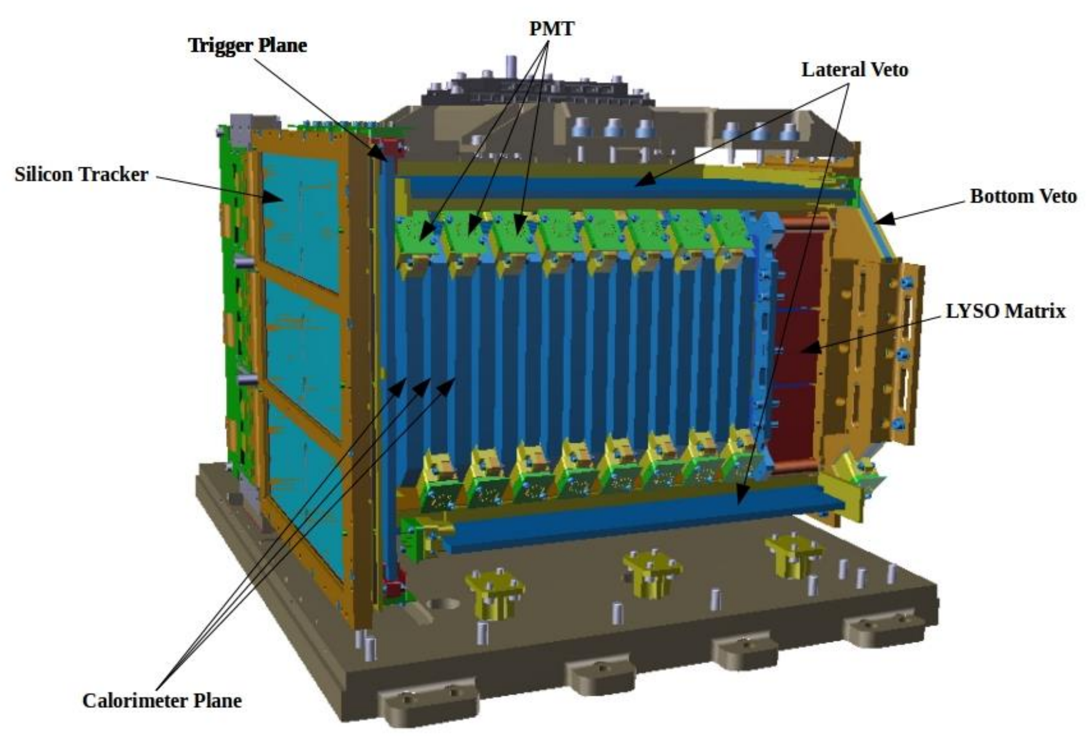

Fig.1: Schematic view of the HEPD detector

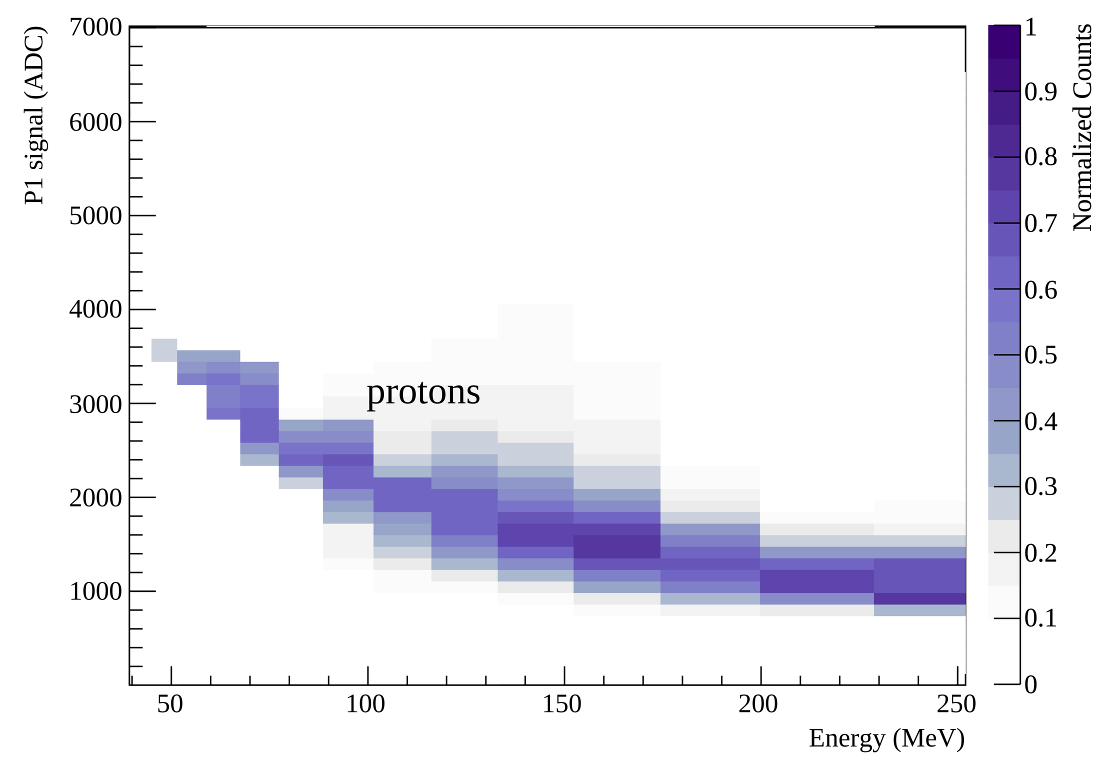

Fig.2: Protons ADC signal on plane P_1 as a function of the total energy deposited inside the calorimeter (TOWER+LYSO). To better visualize the distribution in the plot, only vertical particles (θ<15°) have been selected.

Data analysis and results

For protons inside the SAA - recognised by their characteristic signal deposited on the first scintillator plane (P_1) as a function of the total deposited energy (see Fig.2 - the presence of trapped electrons is restricted to the <8 MeV energy range, thus not affecting the 35-250 MeV energy range analyzed in this work. Contamination from anti-protons (HEPD is unable to discriminate particles from their antiparticles) is negligible and no attempt was made to discriminate between pseudo-trapped, quasi-trapped and precipitating protons or hydrogen isotopes.

From a geographical/geomagnetic point of view, a selection on both the magnetic field B<20500 (reconstructed using the IGRF-13 routines) and McIlwain parameter L-shell<1.3 (calculated using IRBEM libraries) is performed to operatively define the SAA region in which to collect the proton sample. Due to the extreme anisotropy of trapped protons inside the anomaly, flux estimation is properly performed using a multi-dimensional matrices approach.

Fig. 3 compares HEPD results and the predictions from the NASA AP9 model at 95% C.L. (red dashed lines). Both experimental and model spectra are obtained averaging over the entire period between August 2018 and December 2020. Vertical bars account for both statistical and systematic errors.

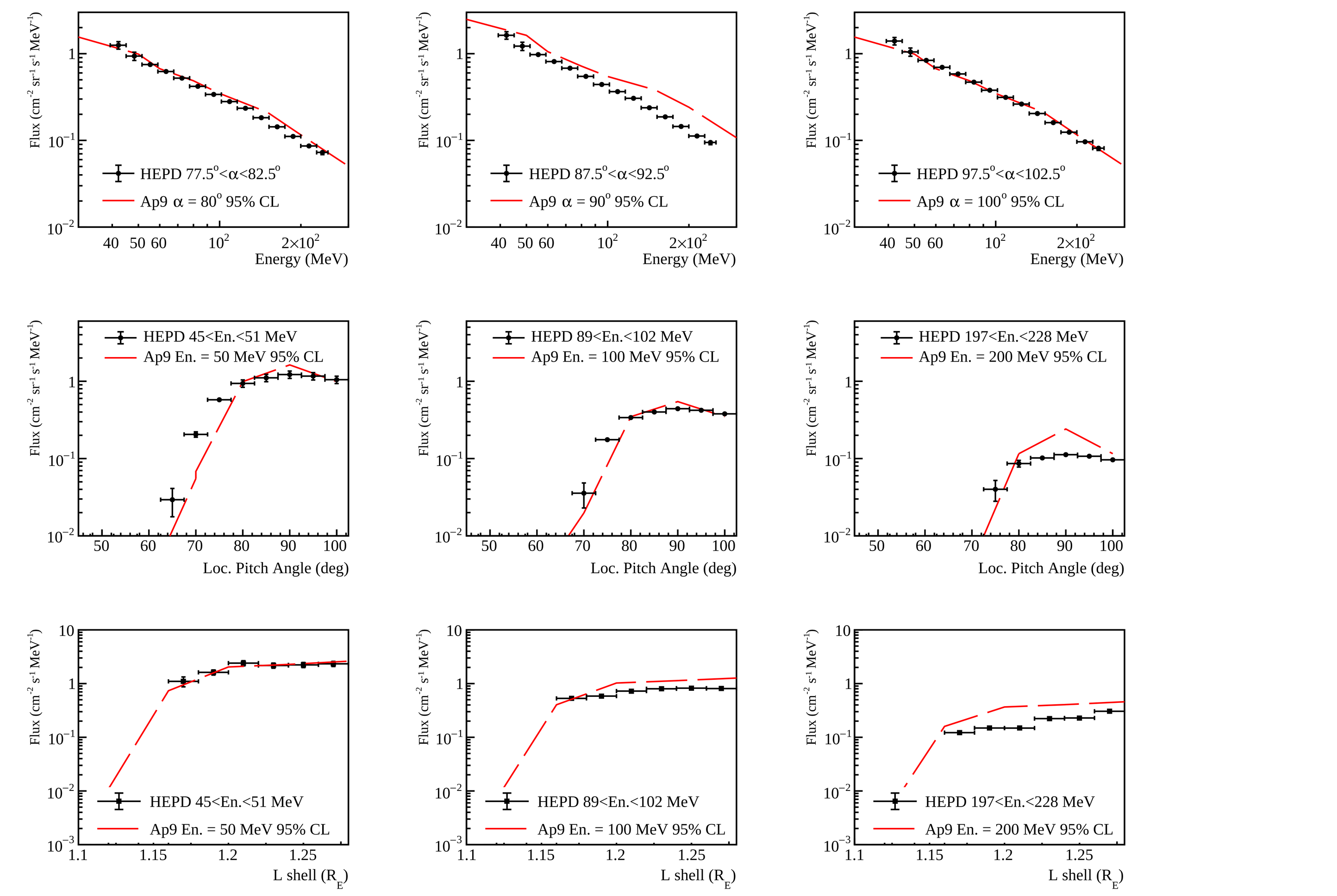

Fig.3: South Atlantic Anomaly proton energy spectra (top panels), pitch angle profiles (middle panels) and L-shell profiles (bottom panels) obtained by HEPD between August 2018 and December 2020, and compared with predictions from AP9 model at 95% C.L. - red dashed line - in the same period.

Conclusions

In conclusion, HEPD can provide excellent cross-calibration for radiation environment models at Low-Earth Orbit, such as the NASA AP9. Moreover, after the end of the Van Allen Probe mission, new data are necessary to continue validation and to explore higher energy ranges with more statistics. HEPD could be able to cover this role, performing measurements with precision and stability; besides, new CSES missions - with more HEPD-like particle detectors - are already planned for the next years, possibly expanding the data-taking period by several years into the 2020s.

References

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