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To cite this article: Beatrice Panico *et al* 2020 *J. Phys.: Conf. Ser.* **1342** 012124

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Time dependence of the proton and helium flux measured by PAMELA

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Abstract. The energy spectra of galactic cosmic rays carry fundamental information regarding their origin and propagation, but, near Earth, cosmic rays are significantly affected by the solar magnetic field which changes over time. The time dependence of proton and electron spectra were measured from July 2006 to December 2009 by PAMELA experiment, that is a balloon-borne experiment collecting data since 15 June 2006. These studies allowed to obtain a more complete description of the cosmic radiation, providing fundamental information about the transport and modulation of cosmic rays inside the heliosphere. The study of the time dependence of the cosmic-ray protons and helium nuclei from the unusual 23rd solar minimum through the following period of solar maximum activity is presented.

1. Introduction

During propagation through the interstellar medium to the Earth cosmic rays undergo interactions with gas atoms and suffered the solar wind interactions. The solar activity modulates cosmic rays with its cycle which lasts 11 years on average, producing a temporal variation in their intensity and in their energy as a function of the position inside the heliosphere. This process is known as the solar modulation of cosmic rays [1]. Precise measurements of cosmic-ray spectra over a wide rigidity range and over a long period of time provide fundamental data to understand the basic features of the heliosphere. PAMELA was launched in June 2006 and was taking data up to the beginning of 2016, covering a long part of the last solar cycle. This gives the possibility to study the influence of the solar modulation in different conditions and also as a function of the rigidity up to a range where it is ineffective. Therefore, it is possible with only one detector to cover a wide range of energy and a temporal period which goes from the solar minimum towards to the maximum.

2. The PAMELA experiment

PAMELA is a Payload for Antimatter-Matter Exploration and Light-nuclei Astrophysics. It is a space-based cosmic-ray detector hosted on the Russian Resurs-DK1 satellite. It was launched on June 15th of 2006 from the Baikonur cosmodrome (Kazakhstan).

Its layout was optimized for precision study of light particles and antiparticles in the energy range between tens of MeV and hundred of GeV. Study on the spectra of antiprotons, protons, helium, electrons, positrons and light nuclei have been performed. But PAMELA also has different scientific objectives, like the study of solar physics, the spectrum of Solar Energetic Particles, the study of solar modulation and the study of terrestrial magnetosphere. PAMELA is composed by different detectors: a Time of flight system (ToF), a Magnetic spectrometer, an Anticoincidence system, an Electromagnetic calorimeter and a Neutron detector [2]. A schematic view of the entire apparatus is showed in Fig.1.

3. The analysis

The last solar cycle has been uncommon; it was expected that the new cycle would begin in 2008, but the minimum has finished only in the end of 2009. For this analysis data taken in the period June 2006 - September 2014 have been used. Therefore, it is possible with only one detector to cover a wide range of energy and a temporal period which goes from the solar minimum towards to the maximum.

In the analysis reported in [3], the aim is to maximize the spectrometer performances and minimize the systematic uncertainties. Here, as a crucial role is played by statistics, the tracking requirements were relaxed and the fiducial volume was enlarged, while the selection cuts were narrowed.

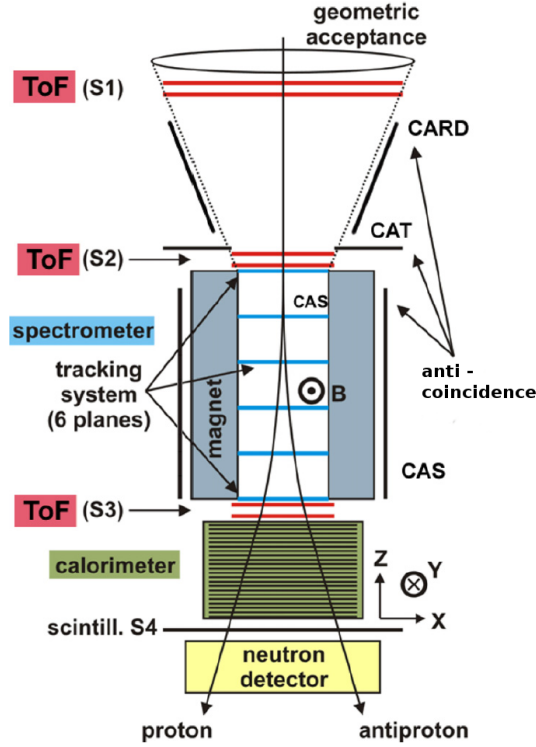


Figure 1. Pamela experiment

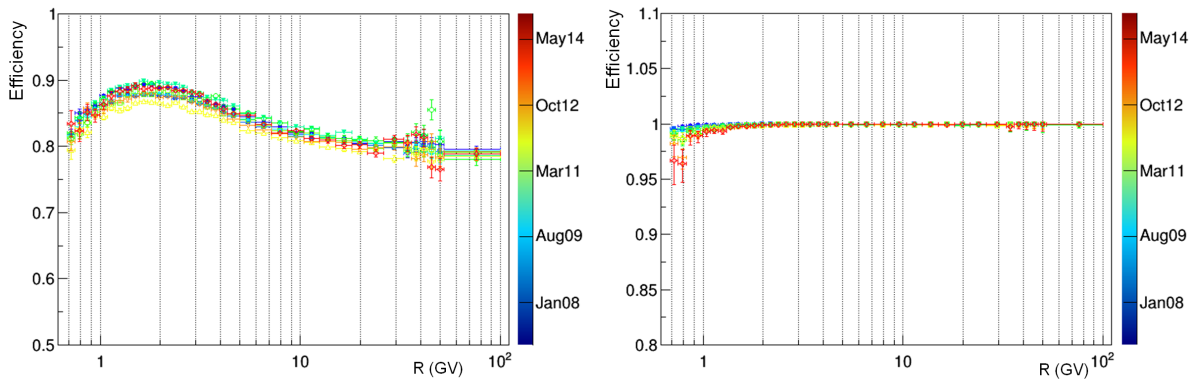


Figure 2. TOF efficiency (left) and tracker efficiency (right) obtained for the selection of helium nuclei. The temporal interval is 1 year.

3.1. TOF cuts

Thanks to the different detectors which composed PAMELA, we have a redundancy of information. To select a pure sample of events the TOF information have been used. Starting from the dE/dx for each layer of the TOF as a function of $1/\beta$, narrow cuts have been determined to select separately protons and helium. To minimize the contamination, cuts have been required on all 6 TOF planes. The efficiency for helium nuclei is reported in Fig.2(left); the dataset has been divided into 1 year temporal bins.

3.2. Tracker cuts

The fiducial area in the tracker is bounded 1.5 mm from the magnet cavity walls; a track quality cut requiring at least 3 hits on both X and Y view and a track lever-arm of at least 4 silicon planes has been applied.

Finally, also a cut based on the dEdx read by the silicon layers has been applied. The dEdx in the X and Y views is reported in Fig.3. It can be clearly seen that different particles identify different bands. As an example the boundaries set to select helium are reported; in this case the contamination due to protons is less than $5 \cdot 10^{-4}$. The efficiency obtained for helium samples is reported in Fig.2(left) considering temporal bins equal to 1 year.

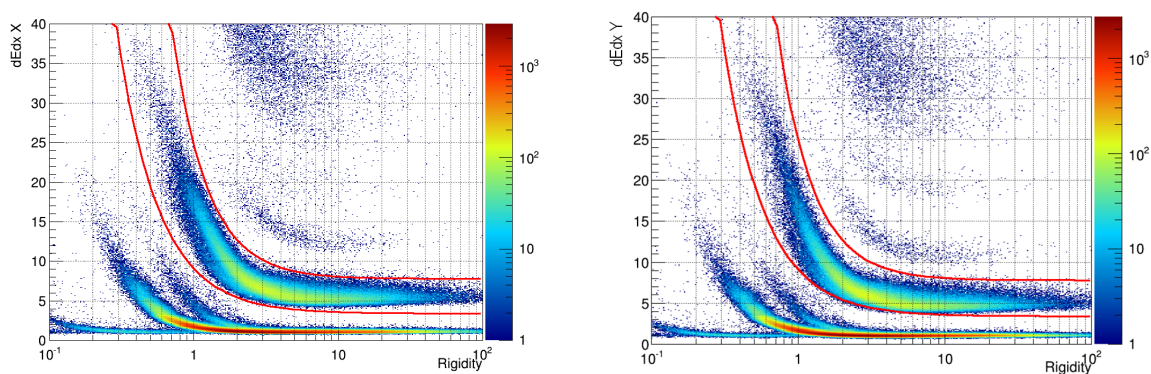


Figure 3. dEdx on the X (left) and Y (right) view in the tracker. As example the boundaries set to select helium are reported (red lines).

4. Conclusions

PAMELA has the possibility to study the solar modulation of proton and helium nuclei on a very long time from the unusual 23rd solar minimum through the following period of solar maximum activity. A preliminary analysis on the selection of events has been reported in this proceeding. To obtain the absolute fluxes in the spectrometer, the measured energy spectrum must be divided by the acquisition time, the geometrical acceptance and the selection efficiency. The effects of rigidity displacement due to finite spectrometer resolution and particle slow-down by ionization energy loss must be taken into account. The fluxes must be evaluated as a function of time binning data according to the Carrington rotations, to highlight the solar modulation effects.

5. Acknowledgments

The Italian authors acknowledge the partial financial support from the Italian Space Agency (ASI) under the program ‘Programma PAMELA - attività scientifica di analisi dati in fase E’.

6. References

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