Deuteron spectrum measurements with PAMELA instrument in radiation belt

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Abstract: The results of measurements of deuteron uxes in the radiation belt region and out of it are presented. Measurements were carried out by PAMELA satellite borne experiment designed to study spectra of cosmic ray particles. Different detectors of PAMELA allow measuring the rigidity, velocity, energy losses and other characteristics of particles. This gives the possibility to determine the kinds of particles and to identify the isotopes of light nuclei and specically of deuterons in the energy range from 60 MeV/nucleon till 700 MeV/nucleon.

Keywords: icrc2013, deuteron, radiation belt, under radiation belt.

1 Introduction

The PAMELA detector [1] is a magnetic spectrometer equipped with a time-of-flight (TOF) system and a calorimeter. The experimental setup also contains a scintillation shower leakage detector (shower tail catcher) and a neutron detector. The active volume of the spectrometer is covered with an anticoincidence system (figure 1). The magnetic spectrometer consists of a permanent magnet and a tracking system (tracker) composed of semiconductor detectors. The permanent magnet produces an uniform magnetic field of 0.43 T inside the spectrometer working volume of 13.1 $\times$ 16.1 $\times$ 43.7 cm^3 [2]. Tracker is installed in the magnetic field volume. It consists of six position-sensitive detectors in the form of thin (300 μm thick) double-sided microstrip silicon wafers used to measure both the particle trajectory in the magnetic field and ionization losses dE/dx. The coordinate accuracy is 3.0 μm for the bending view and 12 μm for the perpendicular view. Based on the measured curvature of the particle trajectory in the magnetic field, the particle rigidity is reconstructed. Rigidity is the ratio of particle momentum to its charge. The TOF system consists of three scintillator detectors: S1 is at the top of the instrument, S2 is above the magnetic spectrometer, and S3 is at the top of the calorimeter. Each detector includes two detecting planes consisting of paddles by such a way that the paddles of adjacent planes are orthogonal. The end faces of the paddles are viewed by photomultiplier tubes. The thicknesses of detectors S1 and S3 is 7 mm, the thickness of S2 is 5 mm, and the distance between detectors S1 and S3 is 77.3 cm [1]. The TOF system is used to measure the time of flight and arrival direction of particles in the instrument, and its time resolution is 250 ps. Each scintillator detector is capable to measure the ionization losses of particles traversing through it. The anticoincidence system rejects the events when particle passes beyond the magnetic spectrometer aperture. Detection of particles and recording of data into the memory are triggered by the signal produced when the signals of three TOF detectors coincide. The detectors of the PAMELA spectrometer are described in more detail in [1, 2, 3].

In this paper, deuteron identification method and results of deuteron measurements in the radiation belt and under it in the energy range from 50 to 500 MeV/nucleon are described.

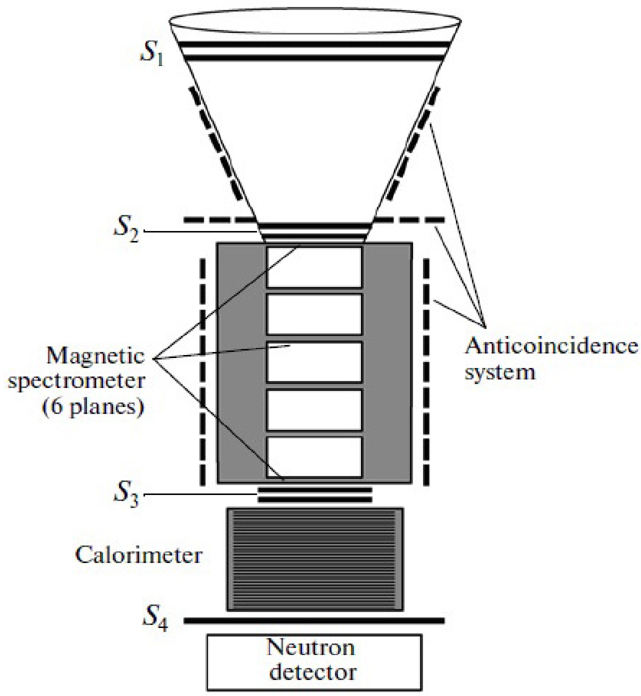

Figure 1: Schematic view of PAMELA apparatus.

2 Particle identification

Responses of various detectors, which depend on the characteristics of detected particles, are used in PAMELA experiment to separate deuterons from other particles. This method is shortly described below. First, the special set of cuts (so called basic cut) was applied to Monte-Carlo simulation and real date. For example, this basic cut includes a measured positive speed of particle, no signal in anticoincidence system, a set of attributes of good trajectory approximation in tracker etc. Basic cut allow us to distinguish events with correctly measured characteristics of passed particles from ones, where we cant trust the quality of data. At the second stage, energy deposited in the time-of-flight system and in the tracker was analyzed. For TOF six different values were used. For tracker truncated mean value for12 layers was used. Different particles with different en-

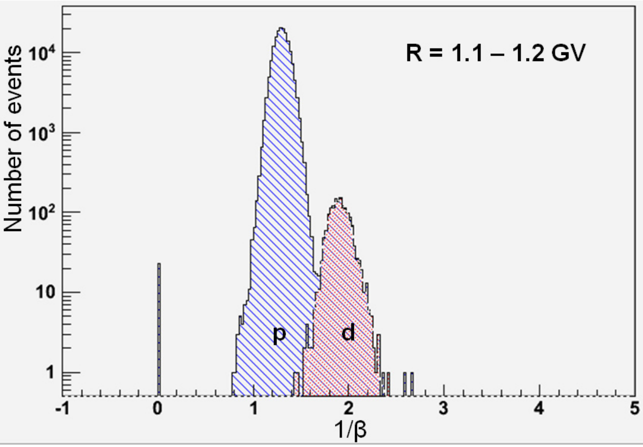

Figure 2: Deuteron counting at lower energies when direct counting is possible for rigidity interval 1.1 - 1.2 GV.

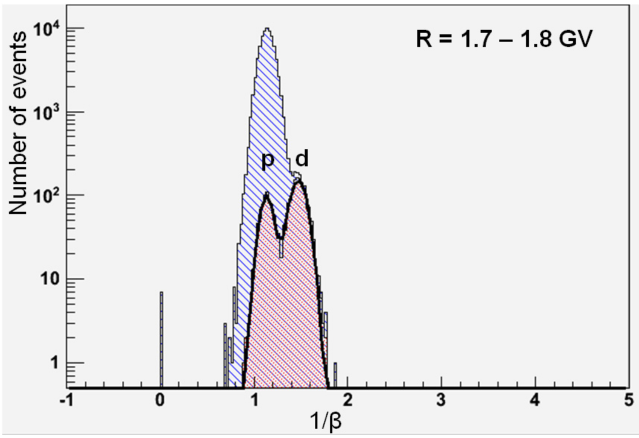

Figure 3: Deuteron counting at higher energies using approximation of two normal distributions for rigidity interval 1.7 - 1.8 GV.

ergies have a various signatures in energy deposit. It allows us to separate hydrogen isotopes from helium isotopes and to separate more heavy nuclei. Furthermore, analyzing of dE/dx values allows us to suppress protons when we are trying to calculate deuterons and vice versa. For deuterons this task is more complicated as protons are the dominant component of cosmic rays in general and they can be detected as deuterons because protons and deuterons have similar responses in different detectors. After this stage a set of rigidity-depended energy loss cuts was created to separate hydrogen isotopes from other particles and apart. At the third stage, evaluation of amount of registered deuterons and protons by means of direct counting at the low energies, rigidity less than 1.4 GV, figure 2) or by fitting of $1/\beta$ distributions by two normal distributions (at higher energies, figure 3 was performed. More detailed description of method can be found in [4, 5, 6].

3 Efficiency calculation

It is important to know the efficiency of particle selection to reconstruct spectrum of incoming particles. Efficiency was calculated using flight data by following way. Since few detectors were used for particle identification it is

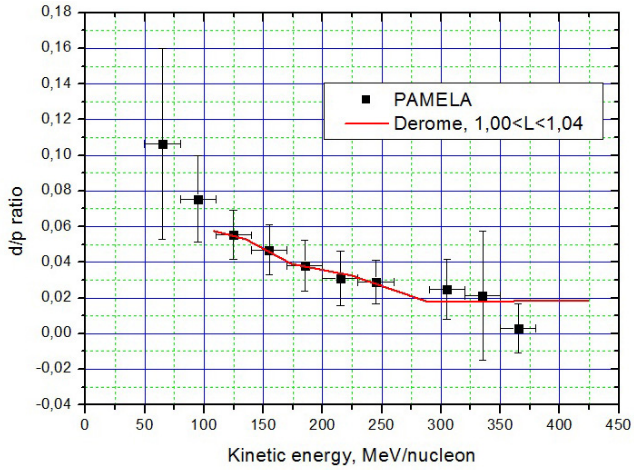

Figure 4: d/p ratio under radiation belt.

possible to use cross-detector efficiency determination. It means that, for example, the efficiency of TOF system can be calculated by analysis of tracker and AC system data. Some particles (e.g., deuterons) were selected from full data sample with help of procedure as described above, but with important addition: selection was made only by tracker and AC system, TOF system basic criteria and particle selection were discarded. The last steps were the implementation of TOF system basic separation criteria and efficiency calculation. Efficiencies of tracker system and AC system were calculated by a similar manner. Final apparatus efficiency was calculated by multiplication of AC, TOF and tracker system efficiencies.

4 Results

Finally, galactic deuteron spectrum and deuteron to proton ratio were reconstructed. These results are presented elsewhere [5, 6]. For under cutoff region (albedo particles, $1.00 < \text{L-shell} < 1.04$) deuteron to proton ratio was measured (figure 4) and compared with calculations from [7], based on AMS-01 experimental data [8]. There was a good agreement between results and calculations. Radiation belt was investigated too and deuterons were found in this zone of magnetosphere, but this is very sophisticated task to evaluate efficiency of deuteron selection in radiation belt conditions. So only the minimal ($\sim$50 MeV/nucleon, its lower threshold for deuteron registration in PAMELA apparatus) and maximal ($\sim$300 MeV/nucleon) kinetic energy for deuterons in radiation belt and corresponding rigidity interval (0.45 - 1.65 GV) were evaluated.

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