

The method of deuteron spectra reconstruction in the PAMELA experiment

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Abstract. The method of reconstruction of the cosmic ray deuteron spectra is presented in this work. The data from the international space-born PAMELA experiment was analyzed. Deuterons in the energy range from 100 to 600 MeV/nucleon were selected by modified multiparameter correlation technique. This method can be used for obtaining the instrumental energy spectrum of deuterons.

1. Introduction

Deuterons of galactic cosmic rays (GCR) along with other light nuclei are born as a result of the interactions of the primary cosmic rays (mainly protons and alpha-particles) with the interstellar nuclei [1]. After generation these light nuclei propagate and diffuse inside interstellar medium and finally reach the heliosphere where they can be registered by different space-born cosmic-ray experiments and balloon ones as well. Differential energy spectrum of deuterons registered in near Earth space is not constant over the time, because the GCR flux is influenced strongly by solar activity. Solar activity changes the parameters of particle transport processes in the heliosphere due to changes in the corresponding solar parameters, such as the solar wind speed or the angle of the heliospheric current sheet [2]. This leads to the effect of solar modulation of the GCR spectrum.

The model capable to describe all the processes of the solar modulation of galactic cosmic rays completely does not exist today. The simplest model used to calculate the unmodulated spectrum was presented by Gleesson and Axford in 1968 [3]. This model, which is called a simplified force field model uses only one parameter describing the modulation phenomenon namely the potential of solar modulation ϕ .

It is extremely important to measure the CR particles spectra at different times, i.e. with various solar parameters, and to do it for different GCR components because it is expected [2] that these components will be modulated by different ways, depending on the sign of charge, mass and type of particles. These measurements will lead to a better understanding of the GCR solar modulation processes and possibly will allow to create a theory that could describe the whole diversity of the processes taking place inside the heliosphere with GCR. And this in turn will allow to reconstruct the unmodulated spectrum of the GCR accurately, that is necessary to improve the models of the generation and propagation of cosmic rays in Galaxy.

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Over the past two decades, measurements of the galactic deuterons spectrum were performed in energy range from 0.1 to 1.0 GeV/nucleon by several experimental groups, including the BESS collaboration [4], the AMS-01 team [5] and the PAMELA collaboration [6, 7]. Because of different observation periods the absolute values of the spectra does not coincide one with other. The BESS collaboration experimental apparatus assembled by a magnetic spectrometer with a number of additional detectors placed inside was mounted as payload on a balloon. This balloon-borne experiment was able to perform the first long-term measurements of the deuteron spectrum for the time period from 1992 to 2000 [8]. PAMELA experiment which have both long-term (from 2006 to 2016) out-of-atmosphere measurements and high statistical reliability of results can open a new page in studying of Sun induced variations of GCR particles spectra, including the deuteron one.

This paper presents the modification of deuteron selection method presented earlier [10–12] and the preliminary results on the measurement of GCR deuterons instrumental spectra for the period from mid-2006 to the end of 2012 with PAMELA experimental data.

2. PAMELA experiment

PAMELA experiment [9] was developed by collaboration of scientists from Russia, Italy, Germany and Sweden. The main objectives of the experiment were to search for antimatter in cosmic rays as well as to perform the high-precision measurements of cosmic ray particles spectra in a wide energy range. The experimental equipment was mounted on board of an artificial Earth satellite "Resurs DK1", which was launched into Earth's orbit June 15, 2006. The "heart" of the PAMELA experimental equipment is a magnetic spectrometer, the assembly of 12 (6 X-projection and 6 Y-projection) strip semiconductor detectors (tracker) placed inside the working volume of the permanent magnet. This detector allows to separate positive and negative charged particles and to reconstruct their magnetic rigidity with high precision. The apparatus includes a time of flight (ToF) system consisting of three two-layer scintillation detectors, electromagnetic calorimeter, scintillator shower leak detector S4 and neutron detector. The workspace of a magnetic spectrometer is surrounded by scintillation counters operating in anti-coincidence mode (AC system). AC system is used for the "rejection" of events when the particles enter the spectrometer outside the aperture.

3. Reconstruction of deuteron spectrum

To reconstruct a differential energy spectrum of deuterons it is mandatory to count the number of detected particles in the narrow energy intervals and to know the efficiencies of their registration and selection.

The special method was used, which is discussed in detail in works [10–12]. The main feature of this method is the multivariable correlation analysis of data from different detectors of PAMELA experimental apparatus. The necessity of using of a complex analysis is caused by presence of significant background of proton flux which exceeds the deuteron one by two orders of magnitude, so the part of proton events can be very similar with deuteron ones with the same rigidity and velocity due to finite energy and time resolutions of detectors. Only the simultaneous analysis of several parameters allows to identify reliably the deuterons in the rigidity range 0.5 – 2.7 GV, which corresponds to the kinetic energy of deuterons from 100 to 600 MeV/nucleon.

But this method worked without modifications only for the time period till the end of year 2009, when selection efficiency was more or less stable. After this timemark the parameters of PAMELA spectrometer framework changed so the presented method need to be improved. The main goal of this was to increase the number of selected deuterons and to save the energy range of deuteron simultaneously. To satisfy these requirements all 6 dE/dx values in ToF and 12 dE/dx values of tracker were considered and these values were analyzed to find those of

them, which would not decrease significantly the rate of event registration during the flight. For example, in the figure 1 energy losses in six scintillation detectors of ToF system versus time in months of PAMELA experiment are shown for particles with rigidities from 0.9 to 1.0 GV. Proton and helium "lines" are clearly visible in amplitudes 1.5 and 10, respectively. This figure shows that values of all 6 dE/dx measurements in ToF are stable in time so all of them can be used for further analyses and deuteron selection because they don't have a significant decrease in month's number of registered events. Similar analysis was performed for values of energy losses in tracker planes as well.

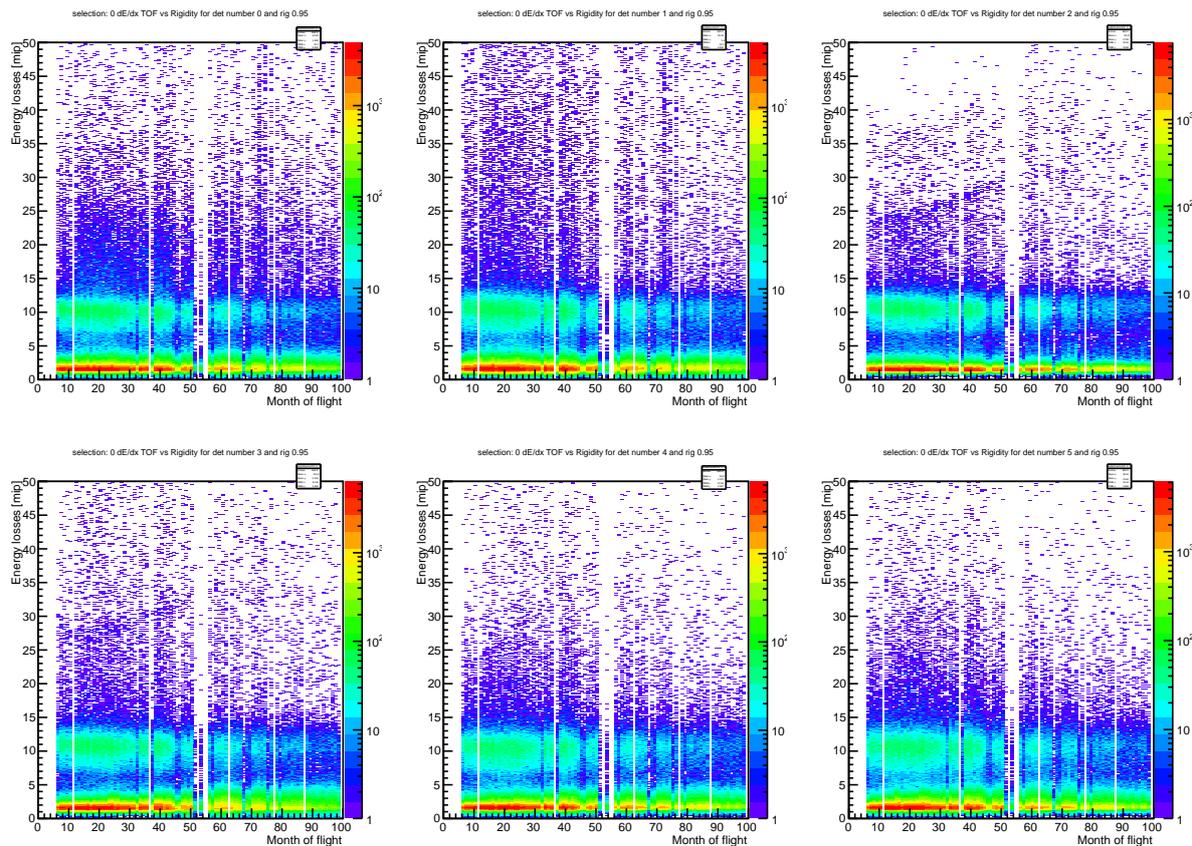


Figure 1. Energy losses in six scintillation detectors of ToF system versus time in months of PAMELA experiment for particles with rigidities from 0.9 to 1.0 GV.

As a result the new set of stable-in-time parameters was chosen. They can be used for full experimental data set from 2006 to 2015. The procedure described in details in works [10–12] was applied to these new parameters to suppress proton background and to count true deuteron event sample.

Energy and particle-dependent efficiencies of selection and detection of particles will be obtained by the method of cross-calibration when the efficiency of the selection by one detector is determined using the information from other detectors, and will be tested as well with the Monte Carlo simulation data, based on the GEANT software package [13].

4. Conclusion

The result of this work was the deuteron event selection method updating. The developed method can be used for reconstruction of GCR deuterons spectrum from PAMELA experimental

data for the time period from 2006 to 2015. In the future this spectrum and the selection efficiency will be calculated so the differential energy spectrum will be reconstructed. This will give the opportunity to study the solar modulation of deuteron fluxes during all PAMELA flight duration

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