

The measurement of the dipole anisotropy of protons and helium cosmic rays with the PAMELA experiment

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Abstract. In the framework of the PAMELA experiment the features of the large-scale anisotropy have been measured within the energy range 1-20 TeV/n. The measurements were carried out with the use of the calorimeter on the base of the hypothesis about the existence of a dipole anisotropy. The amplitude and phase of the dipole were obtained. The results are in agreement with the ground-based observations.

1. Introduction

All the results of the ground-based experiments [1-7] agree in the fact that there is a large-scale anisotropy and that at the first order it is a dipole, the amplitude and phase of which depend on energy. These parameters are different in the various measurements in the energy range 1-20 TeV. However, their values have a crucial role for the processes that might be involved for an anisotropy explanation. For example, in the work [8] the anisotropy is explained by a single nearby source. The same source is responsible for the positron and antiproton spectra as they are seen in the PAMELA [9,10] and AMS [11,12] experiments.

Beside to ground based measurements the satellite ones are able to measure the anisotropy in the both hemispheres and do not undergo by any atmospheric influences. But unlike the ground-based measurements, where it is possible to collect a large number of events (\sim tens of millions) to observe the effect of anisotropy (at an intensity level of 10^{-3}) in the angular distribution of the primary cosmic rays (mostly protons), the satellite PAMELA experiment provides with much lower statistics due to the small size of its aperture.

The aim of this study was to measure the phase and amplitude of the dipole anisotropy of cosmic rays on the basis of information collected in the PAMELA experiment within the energy range 1–20 TeV/n during Jun 2006 – Nov 2014.

2. The PAMELA experiment

The PAMELA magnetic spectrometer was launched in the summer of 2006 and has been operating since that time [13]. The main scientific goals of the experiment are the study of particle and antiparticle fluxes in a wide energy range. PAMELA apparatus consist of several various detectors positioned around a magnetic spectrometer. While the tracker is able to measure the deflection of particles in the magnetic field up to energies of about 1 TeV, another PAMELA subdetector, a calorimeter, could be used to extend the measured energy range. Furthermore the calorimeter allows to measure arrival particle direction over a wide range of angles. The calorimeter consists of 44 silicon planes, with 96 strips in each one; interleaved with 22 tungsten layers. In neighboring silicon planes, strips are orthogonal providing topological and longitudinal information of the shower development.

3. The data analysis

To measure the particle direction the shower axis inside the calorimeter was reconstructed. The iterative procedure allowed to restore the axis along the primary particle track throughout the 44 planes [14]. This procedure is a fit of the centres of gravity of energy released in each plane of each view. The events with reconstructed shower axis were further selected by the cuts based on the total energy deposition in the calorimeter. A cut threshold was set at the level of 180000 mips corresponding to particles within the energy range 1–20 TeV/n.

The anisotropy of cosmic rays is obtained by comparing two distributions: the reference and the experimental ones. The reference distribution of events corresponds to case when the cosmic ray direction distribution is perfectly isotropic taking into account a real exposure and a registration efficiency of the apparatus as well as its mass distribution throughout a structure. The reference distribution was simulated by a shuffling method [15] and contains of

100 times more events than the experimental one. These distributions were constructed in the equatorial coordinate system. In our case, we consider a single coordinate only: a right ascension, which varies from 0 to 360 degrees. All events distributed along a declination coordinate were summarized.

Since the existence of the dipole anisotropy based on the ground-based observations is not questioned, so far the task, as mentioned above, was to obtain its characteristics: the amplitude and phase. We have approximately 600,000 coordinate values of right ascensions, reflecting the direction of incidence of the particles in the experimental data.

The basis of the analysis is the hypothesis that there is the dipole in the experimental distribution. For this reason the size of an integration bin equal to 180 degrees was chosen. In our approach this bin reproduces an integration radius in HEALPIX method for the anisotropy study in 3D map [16]. All events within this bin were integrated. The bin centre was shifting through the entire range from 0 to 360 degrees with 5 degree step and the integration procedure was repeated at each step. Then we took an average value for each 6 bins (we had 72 values in total) and got 12 values which are shown in figure 1. The obtained dipole is demonstrated in terms of relative intensities: I_r is the experimental one and I_s is the reference one. The number of events in the reference distribution was normalized to the experimental one.

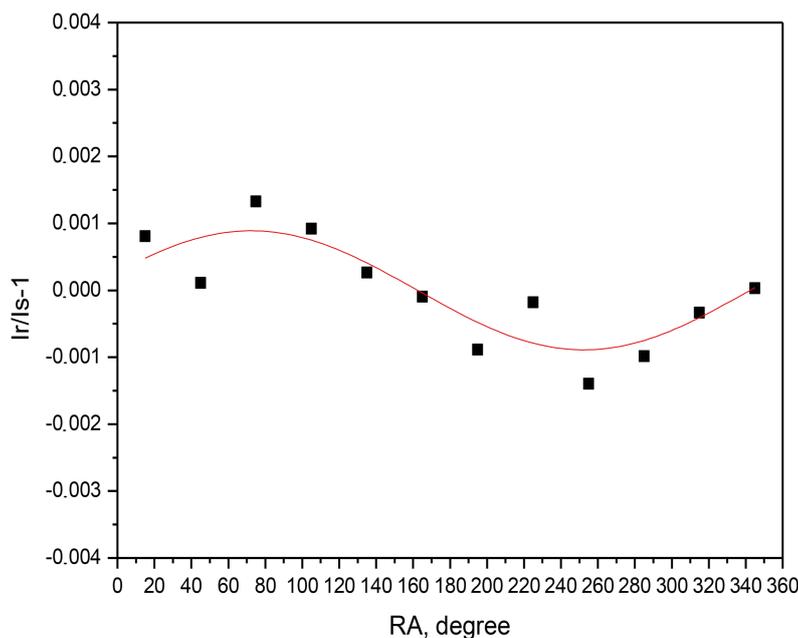


Figure 1. The I_r/I_s-1 depending on RA. I_r is the real intensity, I_s is the simulated isotropic intensity. The red line is a fit by the sine wave.

4. The results

The results were obtained by an approximation of the values in figure 1 by a sine function with the Levenberg-Marquardt algorithm [17]. The amplitude A and phase ϕ (a position of the maximum) were obtained from this approximation: $A=0.0013\pm 0.0003$, $\phi = 70\pm 10$ degree. For the value of amplitude the factor $k=2/\pi$ (the difference between amplitude of the real dipole and the one obtained by the approximation) was taking into account. Uncertainties are the results

of this approximation. It should be noticed that the obtained results are in good agreement with Ice-Cube experimental data [6].

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