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Search for spatial and temporary variations of galactic cosmic ray positrons in PAMELA experiment

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Abstract

The PAMELA experiment is gathering data since 2006 on board the Resurs DK1 satellite (orbit with inclination 70.4°, the altitude 350-600 km). The instrument consists magnetic spectrometer, silicon-tungsten imaging electromagnetic calorimeter, neutron detector and shower scintillator that gives possibility to measure electron and positron fluxes over wide energy range from hundreds MeVs to hundreds GeVs. Results of the experiment indicate the presence of a large flux of positron with respect to electrons in the CR spectrum above 10 GeV. This excess might be originated through dark matter annihilation or in local astrophysical objects such as pulsars producing possible spatial and season variations. Electron and positron events have been analyzed searching for spatial and temporal variations from June 2006 till January 2014.

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Keywords: cosmic ray, positons, electrons,anisotropy

1. Introduction

New measurements of the electron–positron ratio in the PAMELA, FERMI-LAT, and AMS-02 experiments [1–3] showed that it increases along with energy starting at 5 GeV. The conventional cosmic ray propagation model assumes that all positrons are produced in the interaction between high energy cosmic rays with interstellar gas and ratio is decreasing with energy above several GeV. The observed increase suggests there is an additional source of positrons in cosmic rays. It is believed that pulsars or annihilation or decay of hypothetical dark matter particles could produce the positron excess. Important data on the spatial distribution of sources and thus their nature can be obtained by studying the anisotropy of positrons and electrons. Although positrons and electrons travelling through the interstellar medium are deflected in magnetic fields, the diffusion theory predicts anisotropy that can be observed experimentally. For example, the anisotropy of high energy (E~ 1TeV) electrons could be up to ~10% for the nearest young pulsars like Vela [4]. It might be possible also that positrons are originate from a local source. In particular, in some dark matter models [5] a significant fraction of positrons near the Earth could be produced in the neighborhood of the Sun direction. In this case, searches for anisotropies and season time variations of fluxes can provide unique information on the source. Observing the anisotropy of positron and electron fluxes could thus allow us to distinguish the sources associated with nearby astrophysical objects (the Sun, pulsars, supernovae, molecular clouds, etc.) from the radiation of dark matter clumps. In the latter case, the expected anisotropy of fluxes would not exceed 1%. In the papers [6] a directional analysis of sum of cosmic ray electrons and positrons measured by Fermi-LAT was preformed and an upper limit on the flux from the Sun was derived. No significant anisotropy been found in the ratio of the positron intensity to the total electron and positron intensity at energies above 16 GeV [3] in the galactic coordinate system. Direct study of positron flux anisotropy might be more efficient, since the contribution from the isotropic secondary component is small relative to any additional source at energies higher than ~10 GeV.

2. Experiment

The Magnetic spectrometer is composed by a permanent magnet of 0.4 T and a silicon tracker. The tracker has 6 planes of high-precision silicon microstrip detectors equally spaced inside the magnetic cavity. Both sides of each detector are divided in strips, providing X and Y coordinates of particle track. It allows to reconstruct the particle trajectory through the magnetic cavity and determinate its rigidity. The measured spatial resolution of the tracker is 4 μ on the bending side and 15μ on the magnetic unbending side. This device is used to determine the rigidity and the charge of particles. The rigidity measurement is done through the reconstruction of the trajectory based on the impact points on the tracker planes and the determination of the curvature into magnetic field. Direction of bending is used to determine particles sign-of-charge, e.g. to separate electrons and positrons. The extrapolation of the particle trajectory on the top of the instrument allows to determine the particle incident angles with accuracy ~2 degree. The satellite is 3-axis stabilized. Its orientation is calculated with accuracy better than 1 degree in geocentric equatorial inertial reference frame. Knowing the satellite position and the satellite inclination at the time of event registration, it is therefore possible to reconstruct the incoming direction of measured particles in space. The imaging calorimeter (16.3 X0) is mounted below the spectrometer. It comprises 44 single-sided silicon strip detector planes interleaved with 22 plates of tungsten absorber. The main task of the calorimeter is selection of positrons and antiprotons from the background of protons and electrons, respectively. This background is about 10^3 times the positrons component at 1 GeV/c and increasing to $\sim 10^4$at 100 GeV/c. The strip detectors provide detailed information on topology of showers of interacting particles that provide rejection factor of protons up to $\sim 10^5$. Used selection criteria of events are similar to described in paper Adriani et al. [1] and were combined with neutron detector data to reduce background contamination. The measuring the electromagnetic shower energy gives possibility also to obtain kinetic energy of positrons and electrons up to ~100GeV.

3. Data analysis and results

For this study we have used electrons and positrons collected from July 2006 up to January 2014. First of all, positrons have to be identified from a background of protons. In this work we choose the cut thresholds to provide residual proton contamination less then 10% in positron sample. Primary cosmic ray particles were selected with condition that their measured rigidity R is more then 1.2Rc, where Rc is vertical geomagnetic cut-off. Secondly, for each detected particle a arrival direction was reconstructed using trajectory inside the instrument and the satellite position and orientation on the orbit. To take into account deflection of particles in the Earth magnetic field above the satellite orbit special tracking program was applied. The trajectories of all selected particles were propagated back from the measurement location until they reached an altitude 20×10^3 km (about 3 radius of the Earth) using IGRF model and known particle rigidity. Geographic reference frame was used for computations. To perform the transformations between the coordinate systems formulae from paper [7] were used.

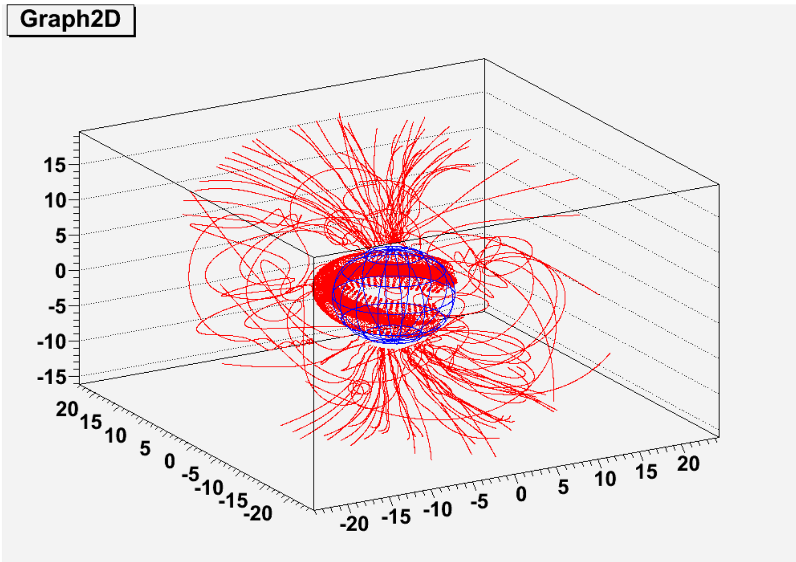

Fig. 1. Examples of trajectories of electrons and positrons measured by PAMELA .

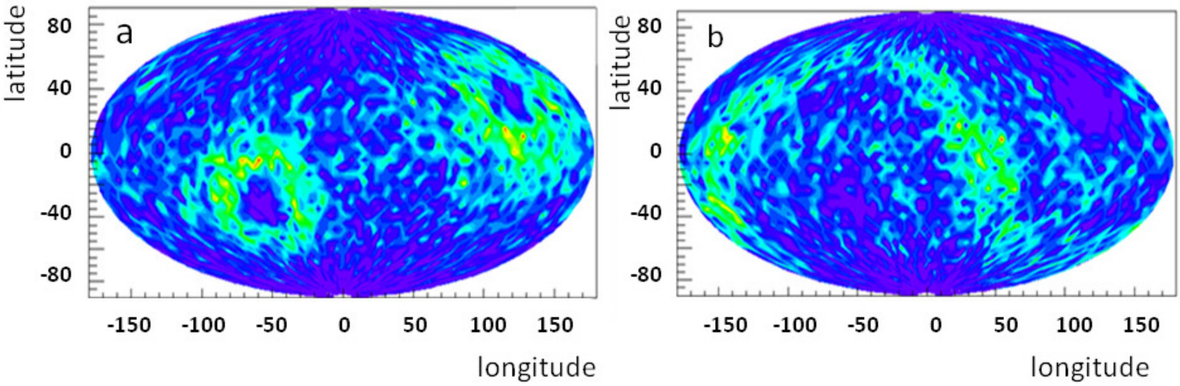

Fig. 2. Electron map in galactic reference frame (longitude and latitude in degrees) before (a) and after (b) correction for geomagnetic effects.

Figure 1 shows an example of trajectory calculations for electrons and positrons. Effects of geomagnetic field are visible especially in near equatorial region. For example, from calculations it follows that for vertical incoming direction in near equatorial plane positrons and electrons with energy E=15 GeV have opposite directions outside the magnetosphere. Interplanetary magnetic field is much more weak but travelling distance is much more. To reduce the effect of the heliospheric fields there were considered only events with energy E more then 10 GeV. Giroradius of such particles is compatible with heliosphere size. Finally, there were selected about $8x10^3$ electrons and $1x10^3$positrons above 20 GeV. No spatial and time variations of positron fraction along the satellite orbit in geographical frame was found for that sample of events.

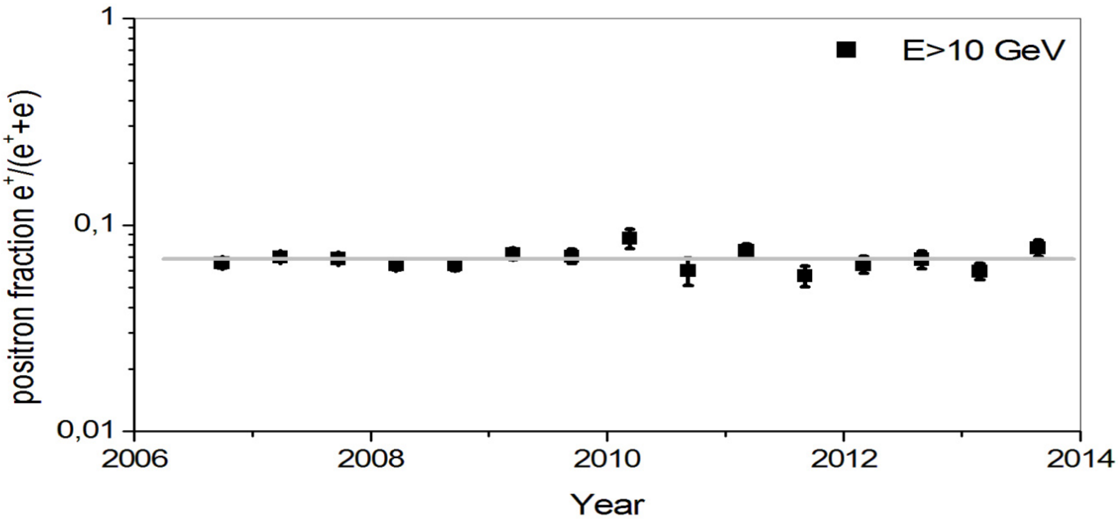

Fig. 3. Positron fraction vs time.

Figure 2 shows, for example, measured positron fraction as a function of time. At high energy measured positron fraction demonstrates no significant time variations during all period of the observations.

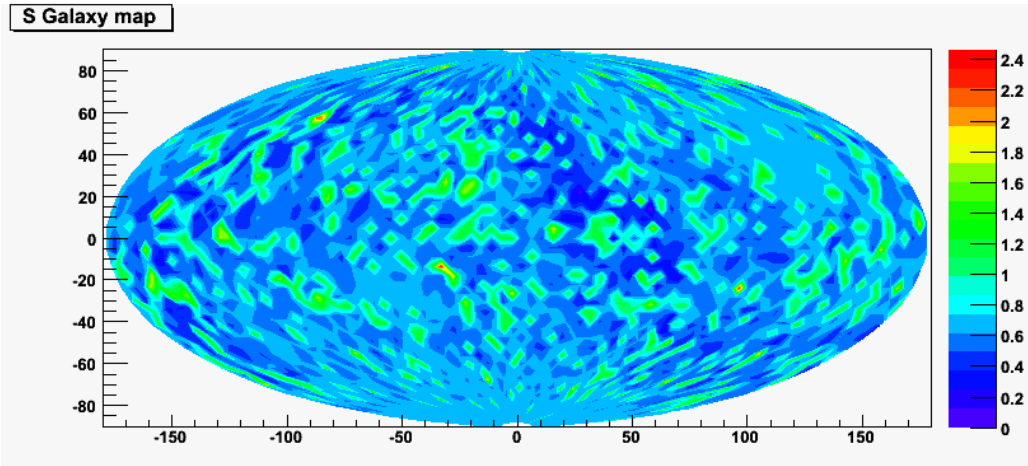

Fig. 4. Significance map of the positrons measured by PAMELA in galactic coordinates.

To search for anisotropies of positrons due to local sources , e.g. solar DM annihilation, an isotropic map is required. In this analysis electron fluxes were compared with the measured positron maps. Before this comparison all events were backtracking to take in to account deflection in geomagnetic field. Figure 3 shows observed map (left) and obtained after correction map for electrons. To compare maps an significance S was calculated using formulae from paper [8]. Comparing two maps we do not find evidence positron anisotropy in energy range between 16 GeV to 100 GeV in a equatorial frame and also in solar rest frame. An example of significance distribution for energy E>20 GeV is shown in figure 4. Above 70 GeV statistical accuracy is not enough to make definite conclusion

4. Conclusion

Arrival directions of all electrons and positrons were used to build a sky map of observed positrons and electrons. Spatial distributions of positrons in a equatorial frame were reconstructed based on PAMELA instrument data taken from July 2006 to November 2014 on board the satellite Resurs-DK. To take into account the Earth magnetic field the backtracking procedure was applied to reconstruct particles directions in interplanetary space outside magnetosphere. To search for anisotropous due to local sources , e.g. solar DM annihilation, isotropic maps of fluxes were simulated to be compared to the measured maps. No evidence was found for positron anisotropy in in a equatorial and also in galactic frames .

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