Anisotropy analysis of positron data with the PAMELA experiment

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Abstract: The PAMELA experiment is carried out on board of satellite the Resurs DK1 since 2006 for precision study of cosmic ray antiparticles. The instrument is equipped with magnetic spectrometer, silicon-tungsten imaging electromagnetic calorimeter, neutron detector which give possibility to separate electron and positron over wide energy range up to hundreds GeVs and to measure their incoming direction with accuracy about 2 degree. For each detected particle a space arriving direction was reconstructed using trajectory inside the instrument and the satellite position on the orbit. Backtracking in geomagnetic field was done to obtain initial spatial distribution of particles outside of the Earth magnetosphere. This paper discuss a result of search a possible local sources by anisotropy analysis of positron data.

Keywords: cosmic ray, anisotropy , positron, electron

1 Introduction

Recently new data on the ratio of the positron flux to the total flux of positrons and electrons in cosmic rays were presented [1, 2, 3] . The positron fraction unexpectedly increasing with energy increasing above ∼10 GeV. This can not be explained by diffusive model where only secondary production of positrons is considered [4]. A new additional source of cosmic rays is necessary to explain results of anomaly behavior of positrons at high energy. It might be possible also that positrons are originate from a nearby source. In particular, in some dark matter models [5, 6] a significant fraction of positrons near the Earth could be produced in the neighborhood of the Sun direction. In last case , searches for anisotropies and time behavior of fluxes can provide unique information on the source. In the papers [7] 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. Anisotropy of only electron data of PAMELA experiment was studied [8] and again the analysis around the Sun direction did not show any significant excess. Nevertheless additional not diffusive source of electrons is relatively small , it gives only about 10% of total flux. On the contrary, non standard positrons prevails over diffusive secondary positrons starting from energy ∼10GeV and their anisotropy , if exists, might appear more distinctly. This paper presents results of search a possible local sources by analysis of positron data in the PAMELA experiment.
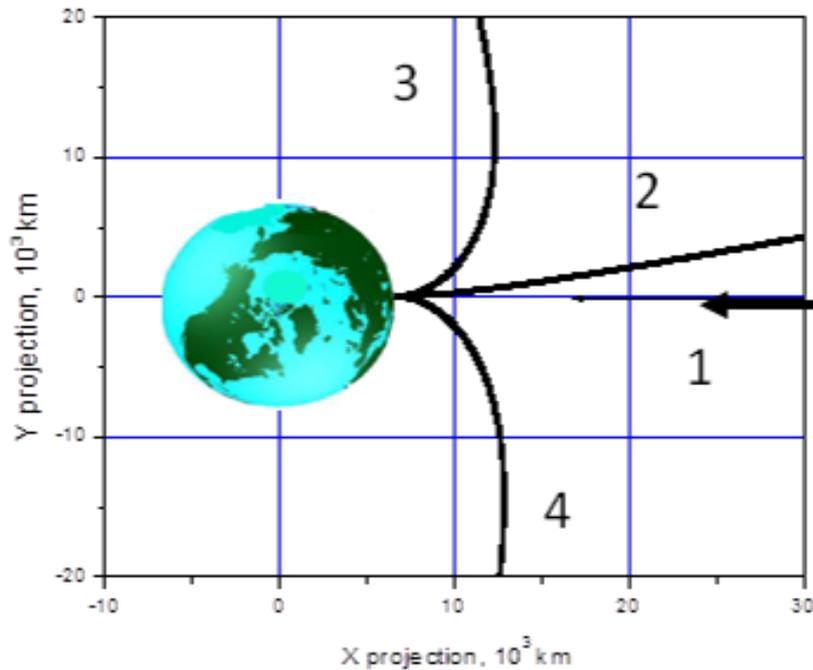
Fig. 1: A sample of calculated trajectories in the Earth magnetic field (see text).

2 Experiment

The PAMELA instrument comprises a time of flight system, a magnetic spectrometer, anticoincidence counters, an electromagnetic imaging calorimeter, a shower tail scintillator counter and a neutron detector [9]. The experiment is devoted to a precise measurement of the cosmic-ray particles and , in particular, of the antiparticle component of the cosmic radiation in wide energy range from hundreds MeV up to hundreds GeV.

The instrument was launched 15 June 2006 on-board of the Resurs-DK satellite (350-610 km altitude, 70^0 inclination orbit).

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 μm on the bending side and 15μm on the magnetic unbending side. 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 an accuracy better than 1 degree in Geocentric Equatorial Inertial reference frame (GEI [14]). Knowing the satellite position and the satellite orientation at the time of event registration, it is therefore possible to reconstruct the incoming direction of measured particles.

The electromagnetic 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 strip detectors provide detailed information on the longitudinal and lateral profiles of interacting particles and measure the total electromagnetic shower energy up to ~100GeV. The main task of the calorimeter is select positrons and antiprotons from the background of protons and electrons, respectively.

The acceptance of the PAMELA instrument is 21.6 cm^{2}sr

3 Search for anisotropy

For this study we have used electrons and positrons collected from July 2006 up to November 2009. First of all, positrons have to be identified from a background of protons. This background is about 10^3 times the positrons component at 1 GeV/c increasing to ~10^4 at 100 GeV/c. The combination of the imaging calorimeter information and magnetic spectrometer data provides the proton rejection factor necessary for a clean positron identification. Selection criteria of events described in papers [1]. In this work we choose the cut thresholds to provide residual proton contamination less then ~10% in positron sample.

Secondly, for each detected particle a arrival direction was reconstructed using trajectory inside the instrument and the satellite position 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 ~150×10^3 km (about 20 radius of the Earth) using IGRF model [10] and known particle rigidity. Geographic reference frame was used for computations. To perform the transformations between the coordinate systems formulae from paper [14] were used. Figure 1 shows an example of trajectory simulations. For given incoming direction in near
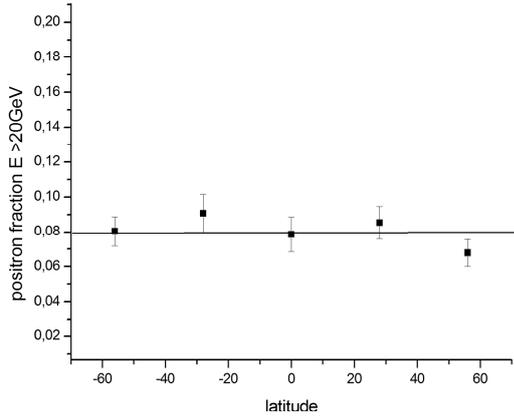
Fig. 2: Positron fraction as function of latitude.
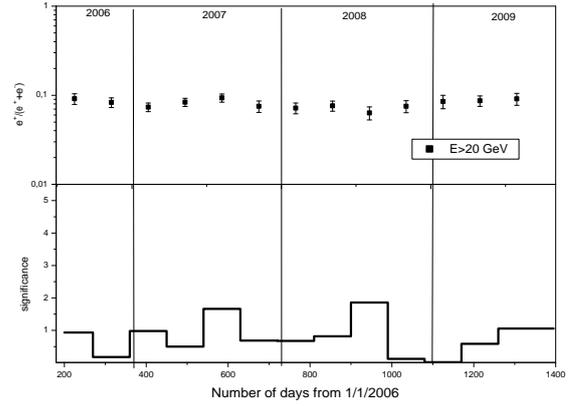
Fig. 3: Positron fraction as function of time.

equatorial plane (1) three trajectories are shown : positrons with energy E=90 GeV (2) and E=15 GeV (3), an electron with E=15 GeV.

To reduce the effect of the heliospheric fields there were considered only events with energy more than 20 GeV. Finally, there were selected $\sim 6.6 \times 10^3$ electrons and 611 positrons.

No space variations of positron fraction along the satellite orbit was found for that sample of events. Figure 2 shows , for example, measured positron fraction as a function of latitude. Measured positron fraction demonstrates also no significant time variations during all period of the observations (figure 3).

Arrival directions of all electrons and positrons were used to build a sky map of observed positrons and electrons.

Time shuffling technic [11, 12] was used to generate the background signal expected for an isotropic flux. This consist in random associating of the time and the direction of measured events. In this method the exposure and the efficiency of the isotropic background are the same as for the measured map. The other approach is to use proton data sample.It is known that the proton spatial distribution is practically isotropic. Since particles of same rigidity have the same curvature radius in magnetic field, the proton distribution might be a good approximation of an isotropic positron sky map. The both approaches give similar results.

Then estimation of the significance S=Ns/σ of deviations N_s-αN_b of the measured signal N_s from the background signal N_b was done using the Li and Ma [13] formula for every bin of sky map. The coefficient α is ratio n_{on}/n_{off} of total numbers of measured and background events.

$$S^2 = 2\{N_s\{\ln[\tfrac{1+\alpha}{\alpha}]\tfrac{N_s}{Ntot}] + N_b\{\ln[(1+\alpha)\tfrac{N_b}{Ntot}\}$$

We then apply our method to the measured positron spatial distribution. There was found no evidence of significant anisotropy for spatial distribution of positrons with energies E¿20GeV, E¿30GeV and E¿40GeV.

To perform analysis of excess in Sun direction we chose the same equatorial reference frame. Sun is moving object in this frame. Sun position , latitude and longitude, $(\varepsilon, \Lambda_\odot)$ was calculated using the formulae in paper [14]. Figure 4 shows positron fraction versus corrected longitude $\Lambda - \Lambda\odot$ respect to the Sun position.
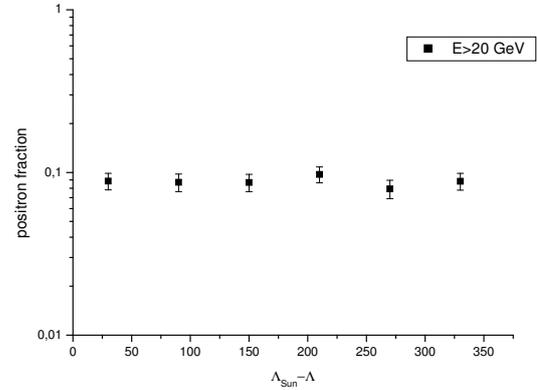
Fig. 4: Positron fraction vs corrected solar longitude

4   Conclusions

Spatial distributions of positrons in a equatorial frame were reconstructed based on PAMELA instrument data taken from July 2006 to November 2009 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. Comparing to maps, we do not find evidence positron anisotropy in energy range between 20 GeV to 100 GeV in a equatorial frame and also in solar rest frame. Above 70 GeV statistical accuracy is not enough to make definite conclusion.

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