Cosmic ray electron and positron spectra measured with PAMELA

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Abstract. The PAMELA experiment is carried out on board of the satellite Resurs DK1 launched on June 15th 2006 on polar orbit (the inclination is 70, the altitude is 350-600 km). The instrument which consists of magnetic spectrometer, silicon-tungsten imaging electromagnetic calorimeter gives a possibility to measure electron and positron fluxes over wide energy range from hundreds MeVs to hundreds GeVs. Measurements made in June 2006- January 2010 are presented and compared with other results and models. Positron spectrum appears to be harder than standard diffusive propagation models predict.
1. Introduction
Since June 2006 the experiment PAMELA on board the Resurs DK satellite is measuring the antiparticle component of cosmic rays. PAMELA has been mainly designed to perform high precision spectral measurement of antiprotons and positrons and to search for antinuclei, over a wide energy range from 100 MeV to several hundreds GeV. Besides the study of cosmic antimatter, the instrument performance and the flight characteristics allow precise measurements of electrons, protons, helium and nuclei spectra [1]. First results concerning the $\frac{p}{p}$ fluxes ratio, $e^-$ and $p$ spectra and the positron fraction of cosmic rays have been presented. The experimental $\frac{p}{p}$ ratio measured between 1.5 and 100 GeV follows the expectations from secondary production calculations within diffusion models of cosmic ray propagations. However, the positron fraction measured in the same energy range shows a clear deviation from diffusion model. It increases sharply above 10 GeV while the positron fraction from secondary sources appears to be decreasing with energy. To explain these results an astrophysical sources and dark matter sources of positrons were proposed and widely discussed. Precise measurements of positron energy spectra in wide energy range, therefore, is an important tasks which might help to fix parameters of standard diffusion model and to restrict numbers of discussed models.

2. Instrument
The instrument is installed inside a pressurized container attached to the Resurs DK1 satellite that was launched into Earth orbit on June 15th 2006. The PAMELA apparatus comprises the following detectors: a time of flight system (TOF); a magnetic spectrometer; an anticoincidence system (AC); an electromagnetic imaging calorimeter; a shower tail catcher scintillator and a neutron detector. Planes of plastic scintillator mounted above and below the spectrometer form trigger and the TOF systems. The central components of PAMELA are a permanent magnet and a tracking system composed of six planes of double sided silicon sensors, which form the magnetic spectrometer. This device is used to determine the rigidity and the charge of particles crossing the magnetic cavity. The rigidity measurement is done through the reconstruction of the trajectory and determination of its the curvature in magnetic field. The magnetic field 0.4 T of the spectrometer of PAMELA is generated by a permanent magnet. The acceptance of the spectrometer, which also defines the overall acceptance of the PAMELA experiment, is 21.5 cm$^2$sr. The spatial resolution of the tracking system is better than 4 $\mu$m, corresponding to a maximum detectable rigidity exceeding 1 TV. The spectrometer is surrounded by a plastic scintillator of AC shield, aiming to identify false triggers generated by secondary particles produced in the apparatus. The sampling imaging calorimeter is mounted below the spectrometer and it comprises 44 silicon strip detector planes interleaved with 22 equidistant plates of tungsten absorber. The orientation of the strips of two consecutive detector planes is orthogonal and therefore provides two-dimensional spatial information with pitch 2.4mm. Each tungsten layer has a thickness of 0.26 cm corresponding to 0.74 radiation lengths, giving a total depth of 16.3$X_0$ (0.6 nuclear interaction lengths). The main task of the calorimeter is to select positrons and antiprotons from the large background of protons and electrons, respectively.

Positrons have to be identified from a background of protons that is about $10^3$ times more at 1 GeV/c. This means that PAMELA must have rejection power at a level $10^5$. Much of this rejection power in PAMELA is provided by the calorimeter [2]. Besides the electron-hadron separation, the calorimeter directly measure the energy of electrons and positrons. A plastic scintillator counter mounted beneath the calorimeter and neutron detector aid in the identification of high energy electrons. More technical details about the entire PAMELA instrument and launch preparations can be found in [1].
3. Data analysis and results

Here we report on the positron flux extending the previous PAMELA data to kinetic energies down to 100 MeV and up to 100 GeV. The results refer to data acquired in the period July 2006 to January 2010 (about 1400 days of continuous measurements). The satellite orbit was elliptical with an inclination 70° and an altitude varying between 350 km and 610 km. More then 3 billions triggers have been collected during this period. The events with rigidity 1.2 times more vertical cut-off were selected for analysis, using the satellite orbital information, to avoid an influence of geomagnetic field. Downward-going particles were selected using ToF information. Background protons were selected using the electromagnetic calorimeter information. For more details on the positron selection procedure see [2]. The thresholds of selections cuts were chosen to make residual proton contamination to be negligible. The energy dependence of the selection efficiencies were studied using simulated data and checked up with experimental electron data. Figure 1 shows acceptance power of the instrument calculated for adopted selection cuts. The time dependence of the detector efficiencies were analyzed using high energy proton data sample. Total live time was provided by an on-board clock that times the periods during which the instrument was ready for a trigger. This live time depends from rigidity due to geomagnetic cut-off selection (Figure 2). Finally, positron flux was obtained by an unfolding procedures [3, 4] taking into account the total live time, the gathering power and the energy resolution of the instrument. The procedure was tested with electron spectrum which was found in coincidence with published results in [5] within 3-5% over all energy range.

Figure 3 shows reconstructed positron energy spectrum along with other experimental data. On this figure PAMELA results are shown by gray band which represent 2 $\sigma$ confidential interval calculated with bootstrap method from experimental sample.

Figure 4 compares PAMELA experimental data with theoretical calculations assuming a pure secondary production of the positrons during interactions of cosmic rays with nuclei in the interstellar space. The curves were obtained using GALPROP code [6] for three different sets of parameters for plain diffusion (PD) , diffusion with reacceleration (DR) and diffusion reacceleration with dumping (DRD) models, according [7] . Appropriate solar modulation parameter for the force field approximation for data taking period was estimated from the best fit of PAMELA proton data. It is important to note that all three models provide reasonable fit of measured proton spectrum. However, the PAMELA positron spectrum is not in a good agreement with calculations as it can be seen from figure 4. Above 10 GeV the positron spectrum
is clearly more hard than modeled spectra. It might be an indication of existing of primary positron source. Models predicts rather different fluxes at low energies. Because experimental uncertainties , especially at low energies, are relatively small this provide important constrains on parameters for secondary calculation models. With parameters , proposed in [7], the DRD model provides better fit of spectrum at low energies. PD and DR models need in a modification to fit together positron and nuclei spectra.

4. Summary
Cosmic ray electron and positron energy spectra were measured in the PAMELA experiment on-board the Resurs-DK satellite. Positron spectrum appears to be more hard that standard models prediction based on the secondary production of positrons in cosmic ray interactions with interstellar matter. Comparison of experimental data with models at low energies shows that DRD model [7] provides better fit of the positron flux at low energies, whereas PD and DR models fail to describe data without modification of their parameters.

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