Sub-cutoff electrons and positrons in the near Earth space

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***Abstract*. Precise spectra of electron and positron fluxes in energy range from 80 MeV to several GeV below the geomagnetic cutoff rigidity were obtained using data of the PAMELA spectrometer. It was launched on June 15^{th} 2006 onboard the Resurs-DK satellite on an elliptical orbit (the inclination is 70°, the altitude is 350-610 km). The work presents measurements of secondary lepton fluxes produced in interactions of cosmic ray protons with the atmosphere in the near Earth space (out of the South Atlantic Anomaly). Latitudinal dependences are discussed. These results are particularly interesting for more accurate definition of electron/positron flux model in the Earth magnetosphere.**

***Keywords*: magnetosphere, secondary flux**

I. Introduction

First papers concerning electrons and positrons in the near Earth space appeared in scientific journals more than 50 years ago. Since then numerous experimental results onboard different satellites have been obtained and flux forming mechanism was discussed. In particular in [1] it was suggested that electrons and positrons under the radiation belt have a secondary origin. Namely cosmic ray protons interact with the Earth atmosphere and produce pions that decay throw $\pi^\pm \rightarrow \mu^\pm \rightarrow e^\pm$ chain. Part of them can be quasitrapped by a geomagnetic field forming so-called "lepton halo". Several experimental works ([2], [3], [4] and references therein) confirmed the main conclusions of the model.

New opportunities in study of electron-positron generation in the near Earth's space are opened by the PAMELA experiment [5] due to its acceptance, long life in orbit and excellent particle identification power. The magnetic spectrometer PAMELA, set onboard the Resurs-DK1 satellite, was launched on the 15^{th} of June 2006 and inserted in a quasi-polar (70° inclination) elliptical orbit at an altitudes between 350 and 600 km. A large accumulated statistics allows to pioneer the study of albedo forming quantitatively and to solve applied problems (for example to elaborate an empiric model of secondary particles in the near Earth space) in addition to fundamental ones.

This work presents some results of the PAMELA experiment obtained within the first five months of its working.

II. The PAMELA spectrometer

The instrument consists of a Time-of-Flight system (TOF), an anticoincidence system, a magnetic spectrometer, an electromagnetic calorimeter, a shower tail catching scintillator and a neutron detector [5]. The TOF system gives the main trigger for particle acquisition, measures the absolute value of the particle charge and its flight time while crossing the apparatus (the accuracy is better than 350 psec). A rigidity is determined by the magnetic spectrometer, composed by a permanent magnet with a magnetic field intensity 0.4 T and a set of micro-strip silicon planes. During flight the spatial resolution is observed to be $\sim 4\mu$m, corresponding to a maximum detectable rigidity (MDR) exceeding 1 TV. The final particle identification is provided by the calorimeter, a series of mini-strip silicon layers interleaved by tungsten planes (16.3 radiation and 0.6 nuclear interaction lengths deep). Particles not cleanly entering the PAMELA acceptance are rejected by the anticoincidence system.

Using of the TOF system, the magnetic spectrometer and additional analysis of the calorimeter information allows extracting leptons and measuring their energy (from 50 MeV to several hundred GeV) effectively. An acceptance is about 21.6 cm^{2}sr (in case of S1 S2 S3 trigger configuration).

The main axis of PAMELA points to a local zenith. Such orbit characteristics allow measuring particles with pitch angles (the angle between the particle velocity and the magnetic field vector) of about 80-90° in the equatorial region. An angle between the main axis of PAMELA and magnetic field decreases with latitude, so for middle and high latitudes we can observe less values of pitch angles.

III. Data analysis

For each registered event the following parameters were measured or calculated: a number of tracks and energy losses in the magnetic spectrometer; a rigidity and a track length (by fitting the track in the magnetic field [6]); a time of flight. A particle velocity was calculated using the time of flight and the track length. Electrons and positrons were identified using information about energy losses in the spectrometer and the electromagnetic calorimeter, particle velocity and a rigidity.

The misidentification of protons and pions is the largest source of background. This can occur if electron- and proton-like interaction patterns are confused in the calorimeter data. Particle identification based on the total measured energy and the starting point of the reconstructed shower in the calorimeter can be tuned to rejection power 10^{-4} - 10^{-5} for protons and pions, while selecting $> 95\%$ of the electrons or positrons.

An efficiency of the magnetic spectrometer changes with time and must be taken into account carefully in a data proceeding. An analysis shows that at the beginning of our experiment (from August till November 2006) it was constant, so in this work we present results only for the first five months of the PAMELA's flight.

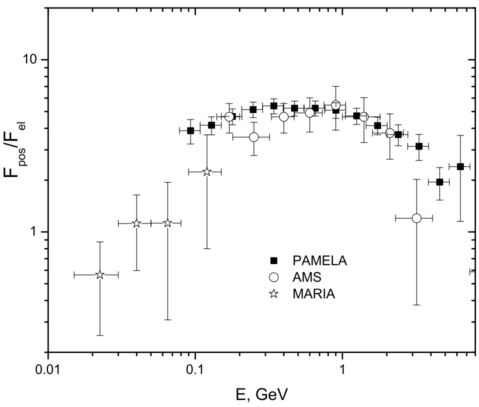

Fig. 1: Positron to electron ratio in the equatorial region (L-shell<1.2 and B>0.23).

Using a geographical coordinates and an orientation of PAMELA as a function of time, the McIlvain geomagnetic coordinates L-shell and B were calculated for every event. For the calculation, the model IGRF'05 (http://nssdcftp.gsfc.nasa.gov/models/geomagnetic/igrf) of the Earth magnetic field was used. We analyzed electron and positron fluxes mainly in the equatorial region (L-shell<1.2). The South Atlantic Anomaly was rejected selecting B>0.23 G.

IV. Results

For the extracted events dependence of e^+/e^- ratio on particle energy for the equatorial region below the Earth Inner Radiation Belt (L-shell<1.2, B>0.23 and zenith angle of the PAMELA main axis $=$ 80-90°) is presented at the figure 1 (square points). We can see that e^+/e^- ratio depends on particle energy and reaches the maximal value of $\sim$ 5 for energy region from 300 to 800 MeV. So in this region positrons predominate over electrons. This result is in agreement with the AMS [4] (open circles) in energy range >250 MeV and coincides with the MARIA [3] data (asterisks, energy range $<$ 100 MeV), but the statistics and wide energy range of the PAMELA's data permit to reach a very detailed energy dependence.

Such a large e^+/e^- ratio can be explained by a East-West asymmetry (see e.g. [7] and [8]). Electrons with big Larmor radius (with high energy) loss their energy in the atmosphere and scatter, while positrons with the same energy turn to the opposite direction and can be registered. For lower energies larmor radius of particles decreases and this effect becomes lower. So the ratio for energies $<$ 100 MeV is about 1. A e^+/e^- ratio diminution in the high energy region (more than 2 GeV) concerns with a contribution of primary cosmic rays.

Considering real efficiencies of the PAMELA's detectors differential energy fluxes of positrons and electrons under the Radiation Belt were obtained (figures 2 and

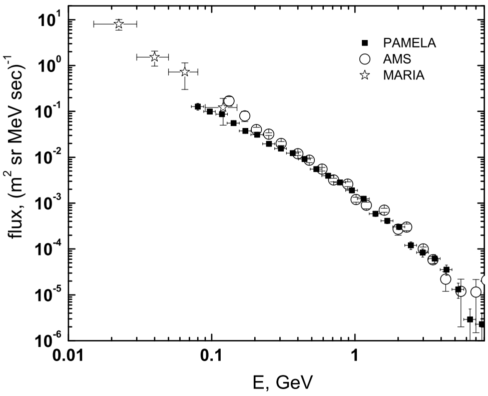

Fig. 2: Differential energy fluxes of electrons under the Radiation Belt.

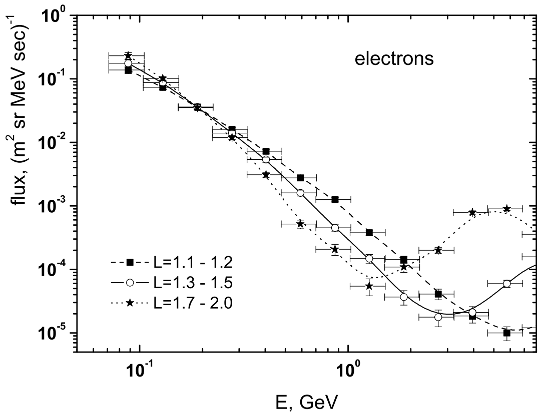

Fig. 4: Differential energy fluxes of electrons under the Radiation Belt for different geomagnetical latitudes.

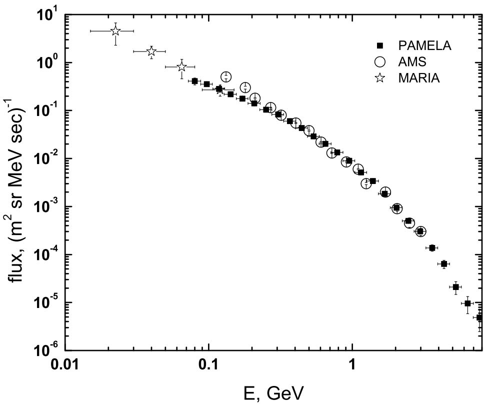

Fig. 3: Differential energy fluxes of positrons under the Radiation Belt.

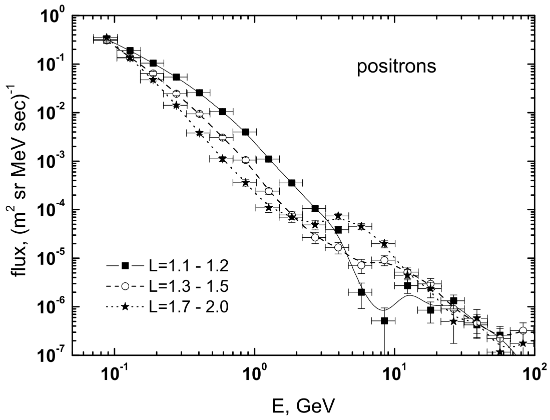

Fig. 5: Differential energy fluxes of positrons under the Radiation Belt for different geomagnetical latitudes.

3).

Superimposed to PAMELA data results of the MARIA and AMS experiments are shown. We can see an agreement between all these data. At low energies ($<$0.2 GeV) electron and positron fluxes measured in the PAMELA experiment are less then in AMS one. A possible explanation of this fact is an anisotropy of secondary lepton fluxes in considered energy range and differences between AMS and PAMELA aperture (aperture of AMS is larger, so it registers particles coming from lateral directions). Note that experimental data show very detail dependence of electron and positron fluxes on particle energy. Such an accuracy was not reproduced in calculations to date. Moreover PAMELA gives lepton fluxes in wider energy range than previous experiments (we can study secondary particle fluxes up to a geomagnetic cutoff rigidity). So the results obtained by PAMELA spectrometer can be used to specify existing models.

For electrons and positrons differential spectra, a latitudinal analysis was performed too. The results are presented in figures 4 and 5. We can see that both the electron and positron spectra became softer for high geomagnetic latitudes. This fact can be explained by the decreasing of the particle quasitrapping limit [1] for high latitudes. Note a different behavior of the electron and positron spectra for low energies (about 100 MeV). The electron flux for L-shell about 1.1 is less than for L=2.0, while the positron flux is practically the same for all geomagnetic latitudes. Probably this is due to a combination of: East-West asymmetry of the geomagnetic cutoff, forward peaking of the production cross-section and atmospheric absorption of the produced leptons [7].

V. SUMMARY

Secondary electron and positron fluxes have complex spatial structure caused by geomagnetic field, cross-sections of production and atmospheric absorption of produced leptons. Measured in the PAMELA experiment fluxes and ratios due to large accumulated statistics allow to pioneer the study of albedo forming quantitatively and to elaborate an empiric model of secondary particles in the near Earth space.

VI. Acknowlegments

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