Trapped charged particle flux in the Earth radiation belt measured by the PAMELA experiment

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Abstract— **Since its launch on-board the satellite Resurs DK1 in June 2006 the PAMELA instrument is collecting data on geomagnetically trapped protons, electrons and positrons with energy E>100MeV. The satellite was launched on a 70 degrees inclination elliptical orbit with altitude 350-610 km and its orbit covers the region of the lower boundary of the radiation belt at L-shell ~1.2 and 0.18<B<0.22Gs. A method of reconstruction for pitch-angle distributions is discussed. The paper presents the observations performed from July 2006 until August 2007. A precise knowledge of charged particle composition and fluxes at high energy is important to reach an accurate theoretical description of particle propagation in the Earth's magnetic field**

1. INTRODUCTION

The exploration of Earth's radiation belts started fairly rapidly about fifty years ago. Numerous experiments and theoretical models provided understanding of the main sources and sinks of radiation belts , their configuration and dynamics. The empirical trapped radiation models such as the NASA AP-8 were developed to practical purposes, for example for dose estimation during human flight [1]. More recent missions such as SAMPEX and CRESS showed that these models are inaccurate at high energies (E>100MeV) and at low altitudes (e.g., <1000 km). Over the last decades it was shown that the composition of radiation belts is rather complex and includes not only protons and electrons but also positrons and light nuclei. In the SAMPEX and NINA-2 experiments it was found that the spectra of light isotopes extend up to some tens of MeV [2,3].

Some attempts were made recently to improve the proton model using modern knowledge about the atmospheric composition, galactic and solar cosmic rays, time variations of geomagnetic field etc. Predicted fluxes and spectral shapes of models differ from NASA models noticeably [4].

In this paper we demonstrate the performance of the PAMELA instrument in the observation of trapped particles near the lower edge of the inner radiation belt, in the wide energy range from 100 MeV to several tens of GeV.

2. INSTRUMENT

PAMELA has been acquiring data since July 11th 2006. The Resurs DK1 satellite orbit is elliptical and semi-polar, with an inclination of 70.0^o and an altitude varying between 350 km and 610 km. The PAMELA data-set therefore covers the lower edge of the inner radiation belt in the South Atlantic Anomaly (SAA) region. Orbital information such as the attitude, orientation and inclination of the satellite and the PAMELA are determined on-board and recorded approximately once a second.

The PAMELA apparatus comprises the following sub-detectors: a time of flight system (ToF); a magnetic

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spectrometer; an anticoincidence system (AC); an electromagnetic imaging calorimeter; a shower tail catcher scintillator and a neutron detector. The ToF system provides a fast signal for triggering the data acquisition and measures the time-of-flight and ionization energy losses of traversing particles. The central part of the PAMELA apparatus is a magnetic spectrometer consisting of a permanent magnet and a silicon tracking system. The spectrometer measures rigidities of charged particles through their deflection in the magnetic field.

Particle identification is based on ionization energy losses in ToF and spectrometer to select single tracks, the determination of rigidity by the spectrometer and the properties of the energy deposit and interaction topology in the calorimeter. The instrument provides the observation of particles in wide rigidity range from ~100 MV up to some hundreds of GV. Geometric factor is ~21 sm^2ster. Aperture is about 20 degrees. Detailed description of the instrument and data processing can be found in ref. [5].

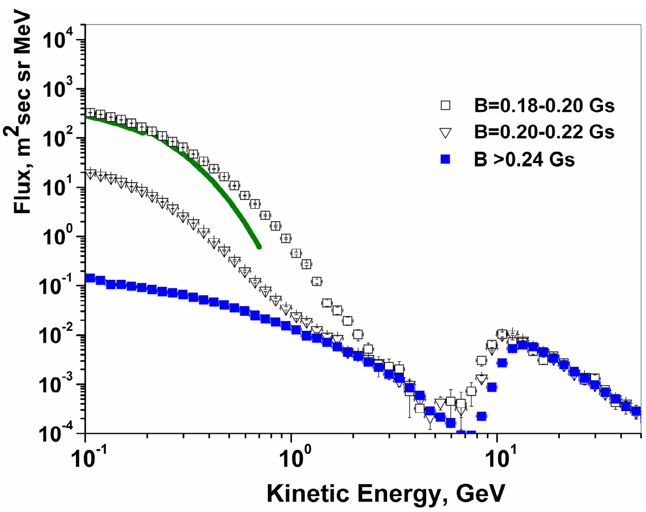

Figure 1. Estimation of differential fluxes of protons in the region L<1.2 for regions with different local geomagnetic field B. Data for August 2006. The line presents AP8min flux at L=1.2 , B=0.19 Gs and B/B_0=1.1 (data are taken from the site http://www.spenvis.oma.be). The model is normalized to data points at 0.1 GeV

3. OBSERVATIONS

Figure 1 shows an estimation of observed spectra of protons in SAA regions for different regions separated by local geomagnetic field B. For comparison equatorial flux outside SAA (B>0.24 Gs) is also shown. It is possible to see in this picture that the proton flux is increasing significantly with decreasing B. The trigger rate reaches ~100Hz in the core of region (B<0.19 Gs) and it is close to the instrument limit. Meanwhile it is seen from the figure that high energy part of the spectra E>10 GeV is not affected by high load of the instrument data acquisitions system. Comparison of the spectra shows that inside SAA there is a fraction of high energy trapped particles with energy up to ~2 GeV. The line in the figure presents AP8min model for L=1.2, B=0.19 Gs, B/Bo=1.1 (http://www.spenvis.oma.be). It easy to see that empirical model spectra are softer than those experimental spectra at energy more than ~0.5GeV.

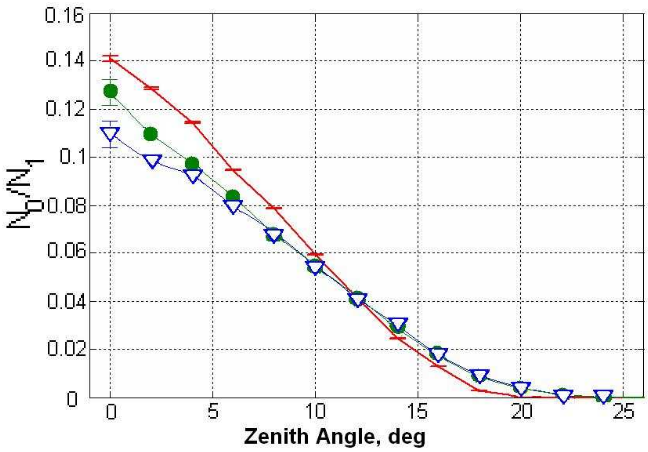

Figure 2. The angular efficiency of the instrument. The thick line is the Monte-Carlo simulation. Points present an estimation of efficiency in polar region, Rcutoff<0.4 GeV (circles are 1.2 GV protons, triangles are 0.8 GV protons)

The PAMELA instrument is pointed mainly to the zenith. This orientation provides observation of particles with pitch-angles 70-130 degree in the SAA region. To determine a particle pitch-angle, position and inclination of the satellite, and ascending angles of particles in the instrument were taken into account. Geomagnetic field was calculated using the IGRF95 model.

An angular efficiency of the instrument was estimated using Monte-Carlo simulation of particle trajectories in the magnetic field of the spectrometer. It is known also that the flux of interplanetary cosmic rays is almost isotropic. With this assumption it is possible to estimate a number of incident particles to the instrument in given direction. Then the angular efficiency can be calculated using measured angular distributions. Figure 2 compares simulated angular efficiency with estimated efficiency from data in the polar region.

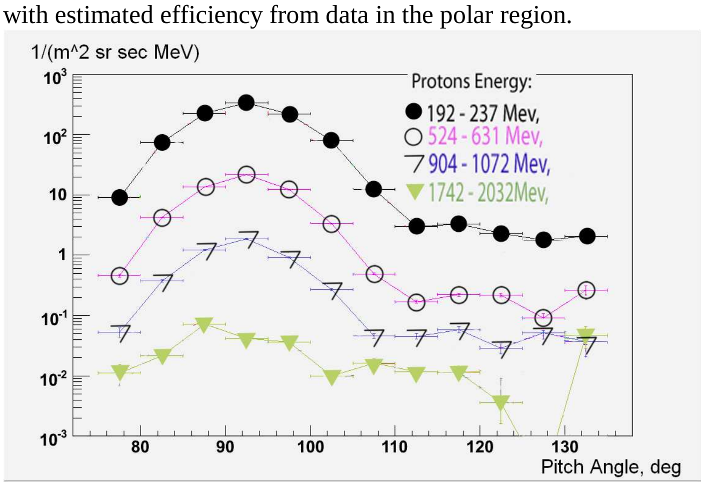

Figure 3 Pitch angle distributions of protons in the region L<1.2, B<0.21 Gs for different kinetic energies.

As we know this efficiency and time of observation in given direction, it is possible to reconstruct the pitch-angle distribution of particles. Figure 3 shows pitch angle distributions of protons with different kinetic energies in region L<1.2 , B<0.21 Gs. All curves on this figure peaked at about 90 degrees that confirms trapping of particles up to ~2 GeV.
Energy spectra at different pitch-angles are shown in figure 4.

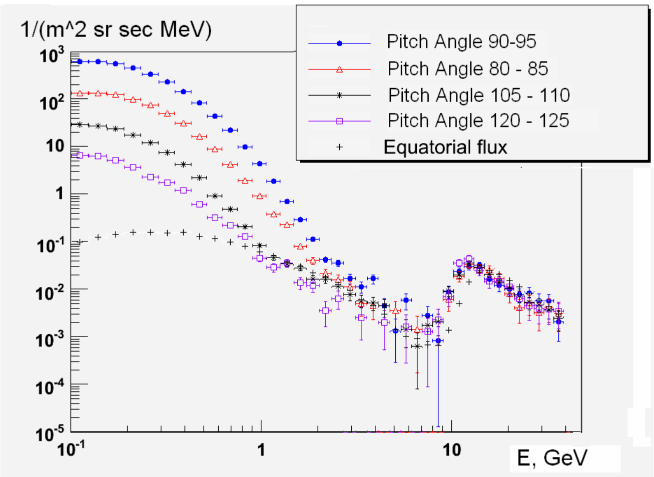

Figure 4 Estimation of proton energy spectra in region L<1.2, B<0.21 Gs for different pitch-angles.

The PAMELA instruments have good capabilities for particle identification [5]. This is valid also for the region of the SAA. Figure 5 shows estimation of the electron energy spectrum in the inner radiation belt. Electron selection was made by magnetic spectrometer and calorimeter data. Proton contamination is practically negligible. The spectrum is comparable with measurements in the equatorial region outside of the SAA.

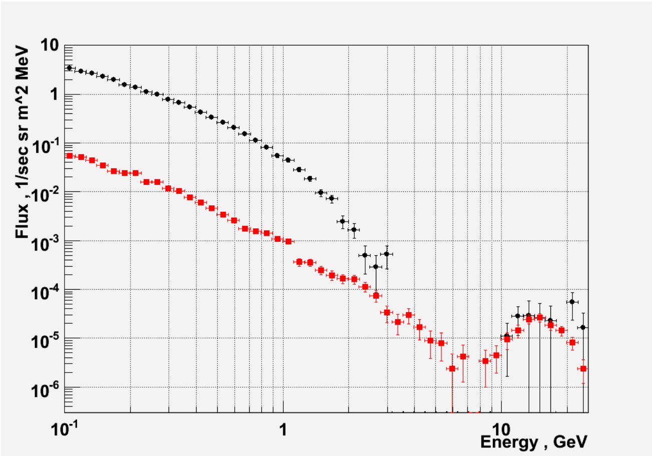

Figure 5 Preliminary estimation of electron energy spectra in regions L<1.2, B<0.21 Gs (top) and L<1.2, B>0.24 Gs (bottom).

Detailed analysis of electron and positron spectra as well as deuterium and helium data needs simulation of angular efficiency and pitch-angular distributions for those species. This work is now in progress.

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