Observations of primary, trapped and quasi trapped particles with PAMELA experiment.

M. CASOLINO[1], ON BEHALF OF THE PAMELA COLLABORATION.
[1] *INFN and University of Rome Tor Vergata, Department of Physics, Via della Ricerca Scientifica 1, 00133 Rome, Italy*
casolino@roma2.infn.it

Abstract: PAMELA was launched on June 15^{th} 2006 on board the Russian Resurs-DK1 satellite. The satellite is flying in high inclination (70^o), low Earth Orbit (350-600 km), performing measurements in different points and conditions of the geomagnetosphere. It is a multi-purpose apparatus composed of a permanent magnet spectrometer to provide particle charge, rigidity and incoming angle. A series of six scintillator counters arranged at its extremities provide redundant Time-of-Flight and charge data. Lepton/hadron identification is performed by a Silicon-Tungsten calorimeter and a Neutron detector placed at the bottom of the device. An Anticounter system is used offline to reject false triggers coming from the satellite. PAMELA is capable of detecting protons (80 MeV- 700 GeV), antiprotons (80 MeV-190 GeV), electrons (50 MeV - 400 GeV), positrons (50 MeV - 270 Gev) and nuclei ($\simeq$ 100 MeV/n - 200GeV/nuc). In addition, a technique employing scintillator counting rate and range energy methods allows to lower the minimum detectable energy range to 36 MeV and 3.5 MeV for protons and electrons respectively. The orbit of the satellite and the characteristics of the magnet spectrometer allow PAMELA to perform a very detailed measurement of the nature and spectra of primary (above cutoff) and secondary particles (sub-cutoff: trapped, reentrant albedo, etc.). The precise measurements of particle distribution in different regions of the orbit provides information on the processes of production, propagation and interaction of particles in Earth's magnetosphere. In this work we present some measurements of galactic and secondary particles performed in the first months of operation.

Introduction

The PAMELA experiment is a satellite-borne apparatus devoted to the study of cosmic rays, with an emphasis on its antiparticle component. The device is constituted by a number of detectors capable of identifying particles providing charge, mass, rigidity and beta information over a very wide energy range [1, 2, 3]. The instrument is built around a permanent magnet [4] with a microstrip tracker (6 double sided planes) providing rigidity and sign of charge information. A scintillator system (six layers arranged in three planes for a total of 48 phototubes) is used to provide trigger, charge and time of flight information [5]. Hadron/lepton separation is performed with a 44 plane silicon-tungsten calorimeter [6] (16.3 radiation lengths, 0.6 interaction lengths). A shower tail catcher and a neutron detector [7] at the bottom of the apparatus increase this separation. An Anticounter system [8] is used to reject spurious events in the off-line phase. Around the detectors are housed the readout electronics, the interfaces with the CPU and all primary and secondary power supplies. The detector is capable of identifying protons (in the energy range 80 MeV - 700 GeV), electrons (50 MeV - 400 GeV), antiprotons (80 MeV - 190 GeV), positrons (50 MeV - 270 GeV) and nuclei up to Z=8 up to $\simeq$ 100 GeV. The launch occurred on June the 15^{th} 2006 from the cosmodrome of Baikonur with a Soyuz rocket. A description of the main scientific objectives can be found in [9]. The satellite flies on a quasi-polar (70° inclination), elliptical (altitude 350–600 km) orbit with an expected mission duration of 3 years. The orbit, the long observational lifetime, and the structure of the detector allow PAMELA to address several items in cosmic-ray physics, increasing knowledge of cosmic ray origin and propagation[10]. In this work we focus on the scientific objectives and observational

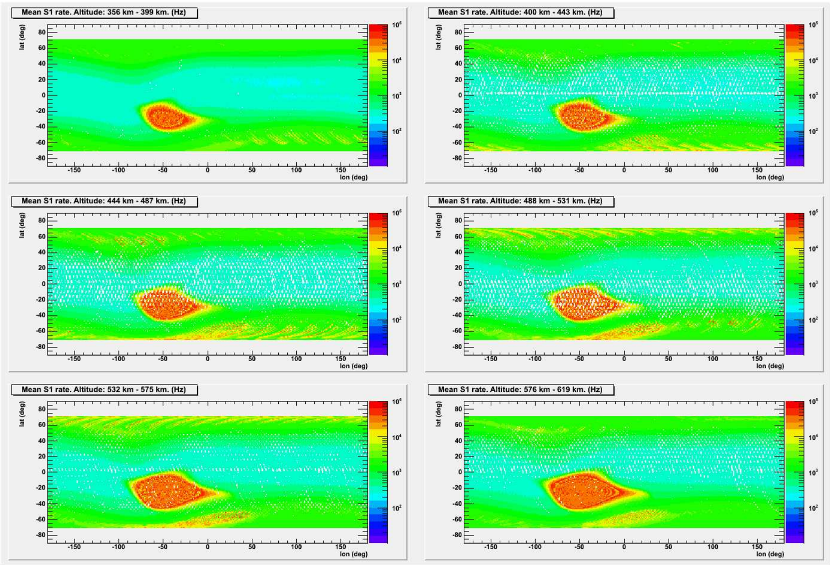

Figure 1: Maps of top scintillator counting rates observed with different altitudes. From left to right, top to bottom: 356-399 km; 400-443 km; 444-487 km; 488-531 km; 532-575 km; 576-619 km. The peak in the Brazilian region is due to protons with $E_{kin} > 36$ MeV. Electrons in the high latitude regions have $E_{kin} > 3.5$ MeV)

capabilities for PAMELA to detect secondary and trapped cosmic rays.

Particle measurements in Low Earth Orbit

PAMELA can perform a detailed measurement of the composition and energy spectra of cosmic rays of galactic, trapped and secondary nature in low earth orbit. The long duration of the mission and the orbit configuration should allow for studies of spatial and temporal dependence in solar quiet and active conditions [11, 12, 13, 14]. Protons with $E \geq 80$ MeV cross all three scintillator planes and the tracker of PAMELA allowing a precise determination of the energy spectrum of particle of various origin. Data can be used to validate existing models, for instance trapped protons in the South Atlantic Anomaly (SAA), and to extend their validity to higher energies. PAMELA can also perform measurements at lower energies using the counting rate of the scintillators. In this way it is possible to extend the range to integral proton measurements above 36 MeV and electron above 3.5 MeV[1]. In Figure 1 is shown the world particle rate for S11*S12 counters at different altitudes[2] The high latitude electron radiation belts and the proton belt in the South Atlantic Anomaly are clearly visible in the figure. It can also be noticed that the particle flux and dimensions of the belt regions increase as the altitude increases.

In Figure 2 is shown the $\beta = v/c$ of particles measured with the Time of Flight (TOF) system as function of the geographical latitude observed. It is possible to see the effect of geomagnetic cutoff on low energy particles, present only closer to

1. These thresholds are determined by the minimum energy required to cross the Aluminum of the pressurized container and release a signal in the two layers of the top scintillator: S11 and part of S12. Other trigger configurations (requiring crossing of the center and bottom scintillators) allow to measure integral spectra with higher minimum energy.

2. The ellipticity of the orbit allows to sample cosmic ray fluxes in different regions of Earth's environment: for instance passage toward the north and toward the south occur at different altitudes.

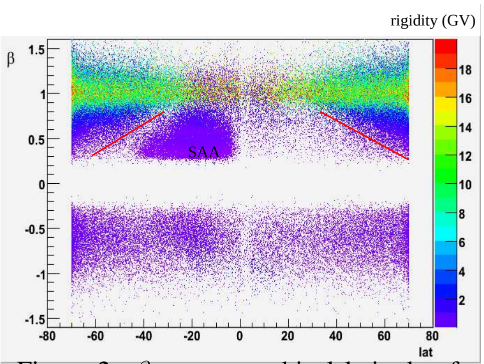

Figure 2: β vs geographical latitude of particles measured with PAMELA. Color code represents rigidity measured with the tracker. The red lines are to guide the eye and show the cutoff on galactic particles. High rigidity particles are present at all latitudes, whereas lower β events (mostly due to protons) are observed only at high latitudes and in the SAA.

the poles. Also the South Atlantic region, composed mostly of low energy ($E < 200 MeV$), low β trapped protons is clearly seen at the latitudes between 40^o and 20^o S.

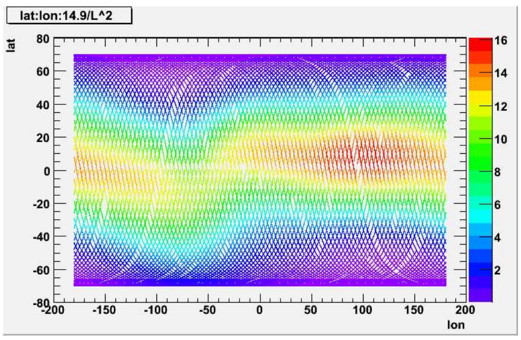

Figure 3: Vertical Stormer cutoff evaluated along the orbit of PAMELA.

Also albedo ($\beta < 0$) particles hitting the detector from the bottom are shown in the plot. Note also the absence of high energy albedo particles. To clearly separate primary component from the reentrant albedo (particles produced in interactions of cosmic rays with the atmosphere below the cutoff and propagating on Earth's magnetic field line) component it is necessary to evaluate the local geomagnetic cutoff. This is estimated using IGRF

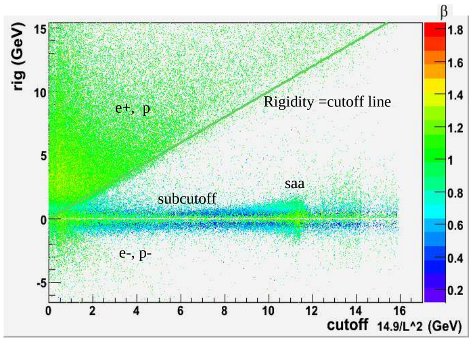

Figure 4: Rigidity vs Stormer Cutoff observed with PAMELA. Colour bar represents β of particles. The effect of the cutoff on galactic particles is clearly visible and well separated from reentrant albedo events, which have a rigidity below the expected cutoff.

magnetic field model along the orbit; from this the McIlwain L shell is calculated[15]. In this work we have used the vertical Stormer (defined as $G = 14.9/L^2$) approximation[16] , shown in Figure 3. More detailed calculations using the Corrected Geomagnetic Coordinates are in progress. Figure 4 shows the rigidity of particles as function of the evaluated cutoff G. The primary (galactic) component, with rigidities above the cutoff is clearly separated from the reentrant albedo (below cutoff) component, containing also trapped protons in the SAA. Note that color code shows the absolute value of β so that negative rigidity particles in the SAA region are albedo ($\beta < 0$ protons) with negative curvature in the tracker due to the opposite velocity vector. In Figure 5 is shown the particle flux measured at different cutoff regions. It is possible to see the primary (above cutoff) and the secondary (reentrant albedo - below cutoff) component. At the poles, where cutoff is below the detection threshold of PAMELA the secondary component is not present. Moving toward lower latitude regions the cutoff increases and it is possible to see the two components, with the position of the gap increasing with the increase of the cutoff.

Conclusions

In this work we have briefly described some of the observational capabilities of PAMELA in relation to trapped and secondary particles. It is possible to

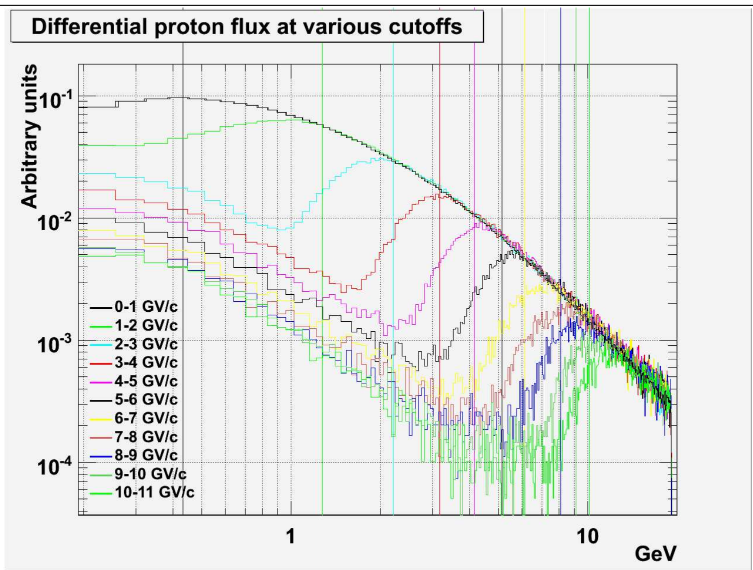

Figure 5: Plot of the differential energy spectrum of PAMELAat different cutoff regions. It is possible to see the primary spectrum at high rigidities and the reentrant albedo (secondary) flux at low rigidities. The transition between primary and secondary spectra is lower at lower cutoffs.

see from the preliminary results that the device is functioning correctly and will provide information on the composition, spatial and temporal dependence of cosmic rays of different nature: primary, secondary and trapped.

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