A Study of the In-Orbit Particle Rate with the PAMELA Anticoincidence System

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Abstract: PAMELA is a satellite-borne experiment designed to study the charged component of the cosmic radiation of galactic, solar and trapped nature. The main scientific objective is the study of the antimatter component of cosmic rays over a wide range of energies. PAMELA is mounted on the Resurs DK1 satellite that was launched on June 15^{th} 2006 from the Baikonur cosmodrome and is now on a semipolar (70°) elliptical (350×600 km) orbit. The PAMELA apparatus consists of a permanent magnet silicon spectrometer, an electromagnetic imaging calorimeter, a time of flight system, a scintillator-based anticoincidence (AC) system, a tail catcher scintillator and a neutron detector. The AC system can be used to reject particles not cleanly entering the PAMELA acceptance. A standalone study of the functionality of the AC system during in-flight operations is presented. The in-orbit particle rates measured by the AC system during the first 6 months of operation are shown. The orbital dependence of the particle rates, the energy and the directionality of the trapped particles are also discussed.

Introduction

PAMELA [1] (a 'Payload for Antimatter–Matter Exploration and Light-nuclei Astrophysics') was launched into space in a semipolar (70°) elliptical (350×600 km) orbit on the 15^{th} June 2006 by a Soyuz-U rocket from the Baikonur cosmodrome in Kazakhstan. The PAMELA instrument is installed inside a pressurised container attached to the Russian Resurs-DK1 Earth-observation satellite. After a short commissioning phase, PAMELA has been acquiring data since July 11^{th} 2006 [2]. PAMELA is a powerful particle identifier consisting of a permanent magnet spectrometer, an electromagnetic imaging calorimeter, a time-of-flight system, a shower tail catcher scintillator, a neutron detector and an anticoincidence system. The apparatus is able to measure with unprecedented precision and sensitivity abundances and energy spectra of cosmic rays over a very large range of energy (50 MeV$-$400 GeV for electrons, 50 Mev–270 GeV for positrons, 80 MeV–700 GeV for protons, 80 MeV–190 GeV for antiprotons, up 200 GeV/n for light nuclei and up to 2 TeV for $e^{-}+e^{+}$). The PAMELA mission is devoted to the investigation of dark matter, the baryon asymmetry in the Universe, cosmic ray generation and propagation in our galaxy and the solar system, and to the study of solar modulation and interaction of cosmic rays with the Earth's magnetosphere [3].

The Anticoincidence System

The PAMELA experiment is equipped with an anticoincidence (AC) shield [4] to help reject events characterised by an incoming particle not cleanly entering the acceptance of the experiment, but generating secondary particles through an interaction with the mechanical structure of the experiment or the satellite ('false trigger'). These secondary particles may deposit coincidental energy in the ToF scintillators and be erroneously interpreted as 'good triggers'. Information from the AC detectors will help identify 'false-trigger' events and reject them during off-line data analysis and has been implemented in the logical condition for a second level trigger [6, 7] that may be activated by an uplink command from ground. The AC system consists of nine 8 mm thick plastic scintillators that cover the sides of the magnet (CAS1-4), the sides of the volume between the first two time-of-flight

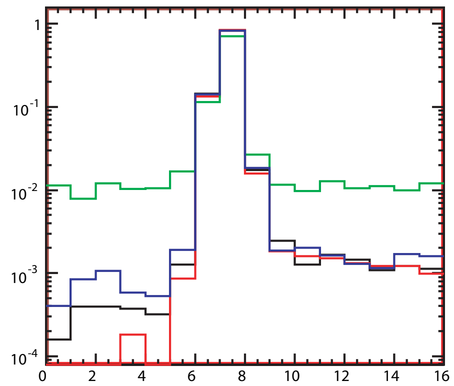

Figure 1: Shift register contents as function of the orbital position. Data are shown only for the channels connected to the main board for polar regions (black lines), equatorial regions (red), SAA (green) and electron belts (blue). All histograms are normalised to unit area.

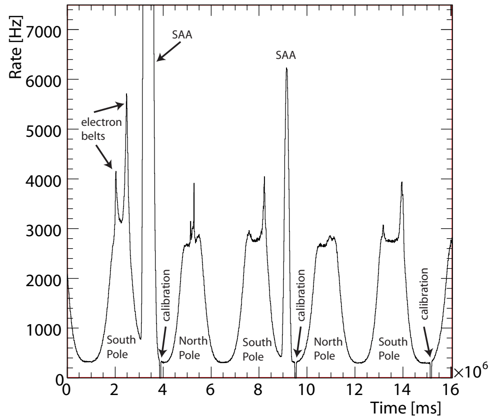

Figure 2: Singles rates (Hz) in the CAS1 detector as function of time. The peak out of scale reaches a rate of 71.4 kHz and is due to a passage of PAMELA through the SAA. The smaller peaks correspond to the passage in the electron belts.

(ToF) layers (CARD1-4) and the top of the magnet (CAT, with a rectangular hole corresponding to the tracker acceptance). The AC detectors are read-out by redundant photomultiplier tubes connected to two independent and identical read-out boards for a total of 24 read-out channels. The AC system does not store information on the deposited energy, but only binary information whether the deposited energy is larger than a pre-set value, chosen to register all minimum ionising particles (mip). The read-out electronics stores the data in memory, in the form of a 1.28 μs long shift register (SR), with a time resolution of 80 ns. The time of 1.28 μs has been chosen to allow the calorimeter to read out self-trigger events, which takes $\sim$500-700 ns [5]. Activity in a channel in time with the trigger appears in the centre of the SR, where the first bin on the left (right) corresponds to the a time 600 ns before (after) the trigger.

Hits registered before the trigger are visible as the flat population on the left of the peak. These hits are due to random coincidences of particles not related to the particle that induced the trigger. On the right of the peak there is a population of hits coming up to $\sim$600 ns after the trigger. These include random coincidences (same as on the left of the peak) and a second contribution, consistent with particles interacting in the satellite mechanical structure. This hypothesis cannot be verified with simulations due to the absence of a satellite model, but is consistent with previous results with beam particles, where the population of delayed hits in the shift register was assumed to be due to interactions in the infrastructure in the test area around PAMELA (10 - 20 m away) with consequent generation of particles, some of them directed toward the AC detectors. This interpretation is supported by an analysis performed separately in different regions of the orbit. Figure 1 shows the shift register population for a typical channel in polar regions, equatorial regions, in the electron belts and in the SAA. In equatorial regions the random coincidences are almost negligible, since the particle flux is relatively very low. This is seen as a much lower plateau on the left of the main peak, while delayed hits are still present. In polar regions and in the electron belts both delayed hits and random coincidences are present. In the SAA the trapped proton flux is so high that random coincidences are a large contribution of hits in most bits in the shift register, accounting for $\sim$20% of the total population of hits in the shift register. Only the central 2 bins show activity higher (less than a factor 100) than the random coincidences back-

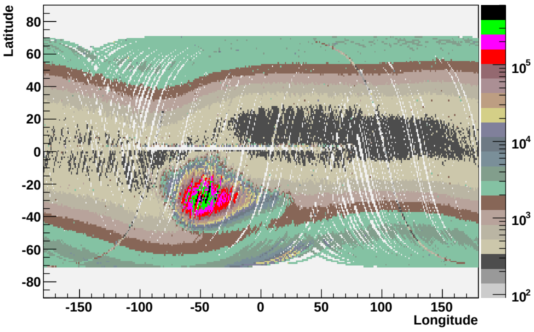

Figure 3: Singles rate (Hz) in the CAS1 detector as function of the geographical latitude and longitude for several runs. See text for details.

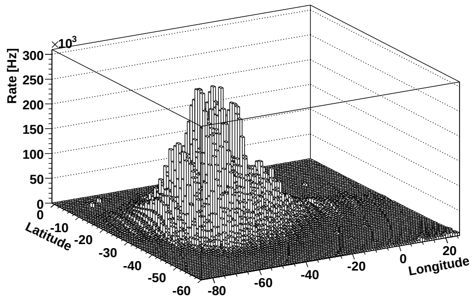

Figure 4: Singles rates (Hz) in the CAS1 detector as function of the orbital position averaged on several orbits traversing the SAA from South to North. The figure shows a detail of the rates in the vicinity of the SAA. Each bin in the histogram corresponds to the average rate in a 1 square degree.

ground, accounting for the other ~80% of hits in the shift registers. An analysis of trigger-related activity is presented in [9].

In-Orbit Particle Rates

The AC detectors are equipped with free running counters (independent of the triggers) used for monitoring the stability of the system. These counters are also used to monitor the particle rates in orbit.

Figure 2 shows the particle rate (Hz) as function of the on board time (OBT) for one channel of the CAS1 detector. The geomagnetic cutoff prevents low energy particles reaching PAMELA in equatorial regions (low rate, ~400 Hz), whereas in polar regions both low and high energy particles reach PAMELA (higher rate, ~3 kHz). The sharp and thin peaks in the polar regions correspond to the passage of PAMELA in the outer (electron) belts. These peaks usually appear in pairs since PAMELA traverses the belt first moving from the equator toward the pole and then traverses it again on the way back to the equator. Since the belts are located unevenly with respect to geographic coordinates, all passages in the polar regions look different from each other. The peak at ~6.3 kHz and the one out of scale (~71.4 kHz) correspond to the passages through the South Atlantic Anomaly (SAA), populated mainly by trapped protons. The three short gaps (~1 minute) in the data are due to the calibration of the PAMELA instrument, performed once per orbit on the equatorial ascending node. Figure 4 shows the particle rate for CAS for several passages (from South to North) through the SAA. The maximum rate is higher than the peak shown in figure 2, which reflects the fact that the particular single orbit chosen for that figure was not traversing the core of the SAA. Figure 3 shows the particle rate superimposed to the world map for the CAS1 detector for all the runs where the satellite crosses the SAA moving northwards. Each bin in the histogram corresponds to the average rate in a 1 square degree. The white areas correspond to missing data in some geographical locations. The dependence of the rate as function of the geographical position is here shown in logarithmic scale, which hides some of the features shown in figure 2 but allows to visualise on a single map the whole globe. The highest rate region at about $50°$W $25°$S is the SAA. There the rate is about 3 (2) orders of magnitudes higher compared to the rate in equatorial (polar) regions. The distribution of the particle rates for the other AC detectors shows the same behaviour. The variations of the particle rate of the AC detectors reproduce closely the values of the geomagnetic latitude, as expected.

The ratio of particle rates in the CAS detectors placed opposite to each other with respect to PAMELA are shown in figure 5, where CAS3 is

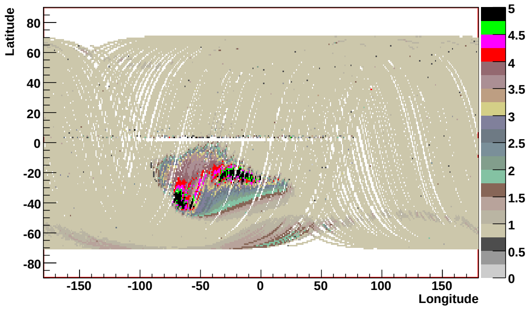

Figure 5: Ratio of the singles rates CAS4/CAS3 as function of the geographical latitude and longitude for all the runs where the satellite crosses the SAA moving northwards.

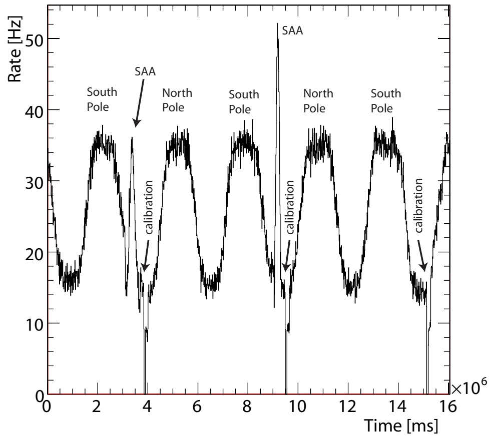

Figure 6: PAMELA trigger rate along 3 consecutive orbits.

placed between the magnet and the satellite and CAS4 is opposite to CAS3. In polar and equatorial regions the ratio assumes values around 0.8. The larger count rate in CAS3 may indicate that most particles that hit PAMELA outside the belts are secondary particles originated from hadronic showers developed in the mechanical structure of the satellite. Low energy secondaries coming from the satellite do not reach CAS4 because it is shielded by the magnet. The positive peaks in the figure correspond to passages through the electron belts and through the SAA. The trapped particles have a mean energy lower than that of galactic cosmic rays, and many of the particles interact and are absorbed before reaching the more shielded CAS3, while most of them reach CAS4.

Figure 6 shows the total PAMELA trigger rate as a function of time for a 4.5 hour long run. The large periodical variation is due to the latitude of PAMELA, where the minima correspond to passages through the equator and the maxima passages in the polar regions. The two sharp peaks are due to trapped particles in the SAA. It is interesting to notice that during the second passage through the SAA the trigger rate is much higher than during the previous passage, even if the particle rate in AC (figure 2) shows the opposite behaviour for the same orbits. During the first passage through the SAA the trapped proton flux is higher than during the second passage but their energy is lower (see e.g. [8]), making the singles rate higher but the trigger rate lower.

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