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The PAMELA Electromagnetic Calorimeter: Flight Status

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Abstract: The current status of the PAMELA electromagnetic calorimeter on board the satellite Resurs–DK1 will be presented. The PAMELA apparatus was placed in orbit on 15 June 2006. The main task of the calorimeter is to select cosmic–ray antiprotons and positrons in a vast background of electrons and protons respectively with an high rejection power. Furthermore, the calorimeter is equipped with a self–trigger capability that allows PAMELA to measure very high–energy electrons. The calorimeter behaviour has been stable since the launch and no main differences can be noted respect to ground test prior the launch. In flight particle discrimination capabilities will be shown.

Introduction

The PAMELA apparatus [5] (a Payload for Antimatter Matter Exploration and Light–nuclei Astrophysics) is a satellite–borne experiment which is primarily designed to study antiparticles (antiprotons and positrons) in the cosmic radiation [6].

PAMELA is housed on-board the Resurs–DK1 earth–observation satellite which has been launched into space by a Soyuz rocket on June 15^{th} 2006 from the Russian cosmodrome of Baikonur. The satellite orbit is elliptical and semi–polar, with an altitude varying between 350 km and 600 km, at an inclination of 70°. PAMELA is collecting data continuously since 11^{th} July 2006 [2]. Detectors are performing in a nominal way and the analysis of data has started. The mission is foreseen to last for at least three years. The main scientific goal of the experiment is the precise measurement of the cosmic–ray antiproton and positron energy spectra.

The PAMELA experiment

PAMELA is built around a 0.43 T permanent magnet spectrometer (“tracker”) equipped with 6 planes of 300 μm thick double–sided silicon detectors. The tracker is surrounded by a plastic scintillator veto shield (AC). An electromagnetic calorimeter mounted below the tracker measures the energy of incident electrons and allows topological discrimination between electromagnetic and hadronic showers (or non–interacting particles). Planes of plastic scintillator mounted above and below the tracker form a time–of–flight (ToF) system which also provides the primary experimental trigger. The volume between the upper two time–of–flight planes is bounded by an additional plastic scintillator anticoincidence system. A plastic scintillator system (S4) mounted beneath the calorimeter provides an additional stand–alone trigger for high energy electrons and is followed by a neutron detection system (ND) comprising ^{3}He–filled tubes within a polyethylene moderator for the selection of very high energy electrons and positrons (up to 3 TeV) which shower in the calorimeter but do not necessarily pass through the spectrometer.

The electromagnetic calorimeter flight status

The sampling electromagnetic calorimeter comprises 44 single–sided silicon sensor planes (380 μm thick) interleaved with 22 plates of tungsten absorber [1]. Each tungsten layer has a thickness of 0.26 cm, which corresponds to 0.74 X_0 (radiation lengths), giving a total depth of 16.3 X_0

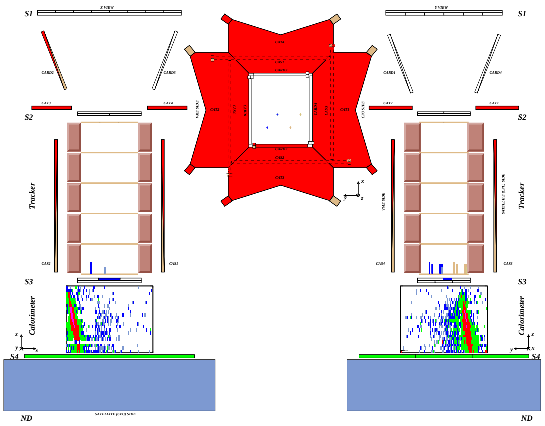

Figure 1: Display of a calorimeter self–trigger event from flight data. PAMELA is shown in the x–view on the left, in the y–view on the right and from above in the center. In this event anti–coincidence were hit and one neutron was detected. Notice that the trajectory of the event is out of the PAMELA acceptance.

(∼0.6 nuclear interaction lengths). Each tungsten plate is sandwiched between two printed circuit boards upon which the silicon detectors and associated read–out electronics are mounted. The 8×8 cm^2 silicon detectors are segmented into 32 read–out strips with a pitch of 2.4 mm. The silicon detectors are arranged in a 3×3 matrix and each of the 32 strips is bonded to the corresponding strip on the other two detectors in the same row (or column), thereby forming 24 cm long read–out strips. The orientation of the strips of two consecutive layers is orthogonal to provide two–dimensional spatial information. A self–trigger system was implemented in the calorimeter read–out electronics to measure high–energy electrons in the cosmic radiation. Requiring only that the particles enter from one of the first four planes and cross at least 10 radiation lengths in the calorimeter, the overall acceptance (∼600 cm^2 sr) becomes about a 30 factor larger than the normal acceptance of PAMELA. Figure 1 shows the display of a calorimeter self–trigger event taken in flight.

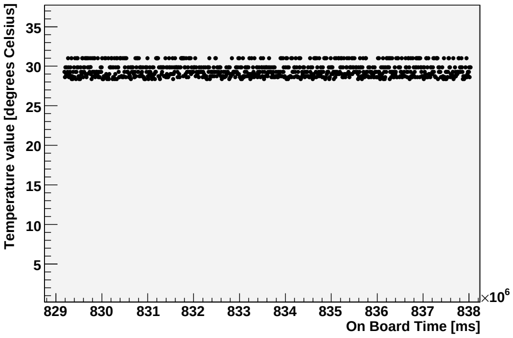

Figure 2: Temperature on the calorimeter external box as function of time during about two orbits. The temperature is stable at about 30° C.

The calorimeter performances have been monitored continuously since the integration in the PAMELA apparatus at the beginning of 2005. The calorimeter behaviour did not change from ground, where muons data were collected, to flight where now PAMELA is in continuous data taking mode. The stability of the instrument is monitored by the means of a set of external temperature, voltage and gain sensors and by looking at data taken every orbit during the calibration procedure.

Figure 2 shows the temperature measurement of the calorimeter box as function of the time. The time interval in the figure is of about three hours, two orbits around the Earth. Calorimeter temperature appears constant and no significant variations from the average value can be noticed. No variations in the calorimeter temperature have been notice since the first switch–on, except from the small warm up soon after the boot. No differences have been notice also respect to the position of the satellite respect to the Sun.

In figure 3 upper panel is shown the value of the pedestal for a given strip as function of the calibration number. The first points represent calibration taken at ground during the integration in Rome while the following points represent the flight calibrations from the middle of June 2006 to the end of May 2007. In the same figure lower panel the RMS value as determined during the calibration is reported for the same strip. The whole calorimeter has been stable since the integration of the detector at ground and no changes in the the detector performances could be noticed between ground and flight conditions.

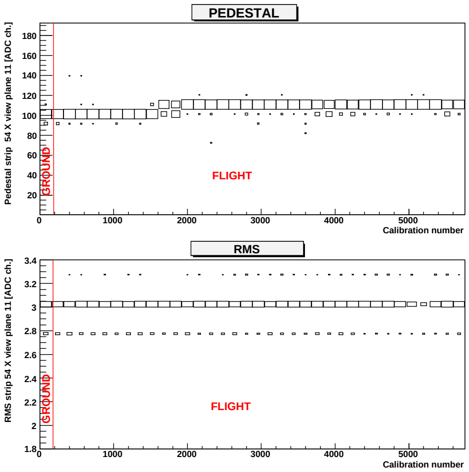

Figure 3: Upper panel: the value of the pedestal (ADC channels) for strip 54, X–view, plane 11 as function of the calibration number from ground to flight conditions till end of May 2007. Lower panel: the value of the RMS (ADC channels) for the same strip in the same time interval.

Particle selection and electron–hadron separation

Protons and electrons dominate the positively and negatively charged components of the cosmic radiation, respectively. Hence, positrons must be identified from a background of protons and antiprotons from a background of electrons. To achieve its scientific goals, the PAMELA system must separate electrons from hadrons at a level of $10^5 - 10^6$. Much of this separation must be provided by the calorimeter, i.e.: electrons must be selected with an acceptable efficiency and with as small a hadron contamination as possible.

The calorimeter capabilities has been evaluated using data from tests with particle beams at CERN and Monte Carlo simulations. Good agreement between simulations and beam test data can be seen [3]. Results obtained from test beam data indicate that even with a partially equipped calorimeter it is possible to achieve a proton rejection factor of at least 10^5 above 10 GeV/c while maintaining an electron selection efficiency of $\sim$90%. A first comparison shows a good agreement between flight data and simulations.

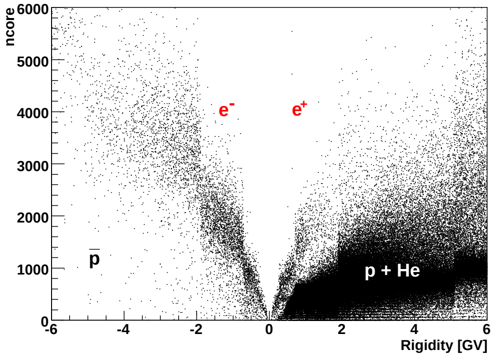

Figure 4: Distribution of the topological variable “ncore” as function of the rigidity for a sample of events. Electrons, positrons, anti–protons and protons/helium bands can be distinguished.

A complex set of variables is used to separate electromagnetic and hadronic showers in the calorimeter. These variables characterize the shower inside the calorimeter taking into account its starting point, its longitudinal and transverse profiles, its topological development and the energy release compared to the one given by the tracking system.

Figure 4 represents the particle discrimination capabilities using a topological variable as function of the rigidity as measured by the tracking system. This variable takes into account the number of hits along the track till the plane of maximum calculated using the momentum of the particle and assuming an electromagnetic shower. Hence this variable grows when the shower inside the calorimeter started in the first planes and is collimated along the track while it tends to be smaller for non interacting or hadronic particles. Electron and positrons bands can be clearly distinguished from anti–protons and protons plus helium bands.

Figures 5 and 6 shows an example of positron selection on a sample of events using a full set of variable to reject hadronic particles. Figure 5 shows the fraction of energy released along the track in the calorimeter as given by the tracker for negative and positive particles, upper and lower panel respectively. On the negative side the electron distribution is dominant and the electrons release about half of the energy along the track. A

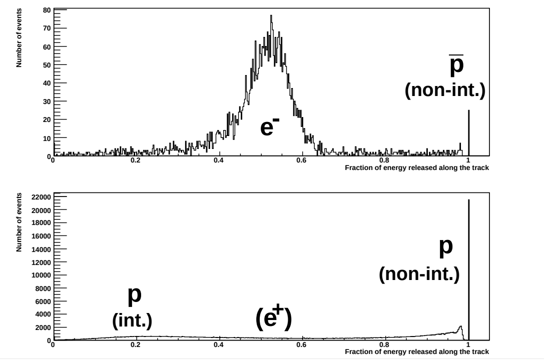

Figure 5: Fraction of energy released along the track for negative and positive particles, upper and lower panel respectively.

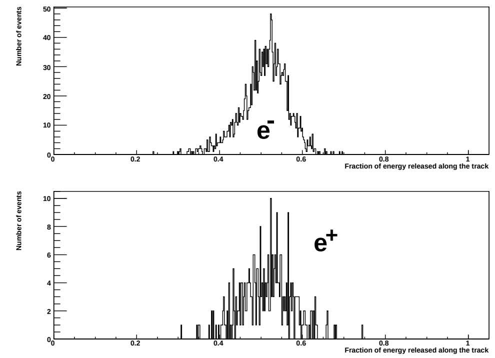

Figure 6: Same as figure 5 once the selection cuts have been applied, upper and lower panel respectively (preliminary results).

small peak of non-interacting negative particles, anti–protons, can also be noticed. On the contrary on the positive side protons are dominants and a wide distribution of protons interacting at different depths in the calorimeter can be noticed. Again a large peak of non–interacting protons can be seen at one. The positron component is not visible, overwhelmed by protons. After applying the positron selection cuts the distributions on figure 5 become the one shown in figure 6, upper panel negative side, lower panel positive side. On the negative side non–interacting particles disappeared and the tail of the electron distribution are cut. On the positive side the positron distribution appear since most of the protons were discarded.

Light nuclei selection with the calorimeter

The dE/dx measurement on the calorimeter silicon planes can be used to determine the charge of the incident nuclei. Nuclei data analysis has started and the charge separation with the calorimeter has been found at present to be possible at least till the Silicon nuclei [4].

Conclusions

The PAMELA calorimeter has been extensively tested at particle beam facilities and studied with simulations. Combining these data, it has been shown that the calorimeter is able to provide the rejection power needed by PAMELA to fulfill the scientific goals for which it was designed. The calorimeter performances in flight are nominal and the instrument is in a stable condition. Data analysis has started and flight data are in agreement with simulation and test beam data.

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