The PAMELA space experiment: first year of operation

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Abstract. On the 15^{th} of June 2006 the PAMELA experiment, mounted on the Resurs DK1 satellite, was launched from the Baikonur cosmodrome and it has been collecting data since July 2006. PAMELA is a satellite-borne apparatus designed to study charged particles in the cosmic radiation, to investigate the nature of dark matter, measuring the cosmic-ray antiproton and positron spectra over the largest energy range ever achieved, and to search for antinuclei with unprecedented sensitivity. The apparatus comprises a time-of-flight system, a silicon-microstrip magnetic spectrometer, a silicon-tungsten electromagnetic calorimeter, an anticoincidence system, a shower tail catcher scintillator and a neutron detector. The combination of these devices allows charged particle identification over a wide energy range.

1. Introduction

The PAMELA (a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) experiment [1] was launched into space in a semi-polar (70°) elliptical (350×600 km) orbit by a Soyuz-U rocket from the Baikonur cosmodrome in Kazakhstan on the 15^{th} June 2006 . The apparatus is installed inside a pressurized container attached to the Russian Resurs DK1 earth-observation satellite. The mission is foreseen to last for at least three years.

2. The Science of PAMELA

Antiparticle measurements are the main scientific goals of this experiment. Antiparticles can provide hints of new physics since they can be produced from exotic sources such as: primordial black holes (e.g. see [2]), annihilation of supersymmetric particles (e.g. see [3]) or Kaluza-Klein particles (e.g. see [4]). Moreover, PAMELA will extend the observational limit in the search of antihelium to the $\sim 10^{-8}$ level. The detection of antinuclei with $Z>2$ in cosmic rays would provide direct evidence of the existence of antistellar nucleosyntesis and it would be a discovery of fundamental significance

In detail, the PAMELA experiment focuses on:

1. searching for evidence of annihilations of dark matter particles and other exotic antiparticle production processes by precisely measuring the antiproton and positron energy spectra;
2. searching for antinuclei, in particular antihelium;
3. testing cosmic-ray propagation models through detailed measurements of primary and secondary components of the cosmic radiation.

Concomitant goals include:

4. a study of solar physics [5] and solar modulation during the 24^{th} solar minimum;
5. a study of trapped particles in the radiation belts.

The semi-polar orbit allows PAMELA to investigate the various particles and nuclei in a wide energy range. The extended period of data taking provides unprecedented statistics with no atmospheric overburden reducing the systematic uncertainties of previous measurements obtained by balloon-borne experiments. Furthermore, for the first time the $\bar{p}$ and e^+ high energy spectra is explored well beyond the present limit of experimental data (∼50 GeV).

3. The PAMELA apparatus

The apparatus is composed of the following sub-detectors, arranged as in Figure 1, from top to bottom:

- a time of flight system (ToF (S1,S2,S3));
- a magnetic spectrometer;
- an anticoincidence system (CARD, CAT, CAS);
- an electromagnetic imaging calorimeter;
- a shower tail catcher scintillator (S4);
- a neutron detector.

4. In-flight operations

On June 21^{st} 2006 PAMELA was switched on for the first time. The commissioning phase, during which several trigger and hardware configurations were tested, ended in mid September 2006. However, PAMELA has been in a nearly continuous science data taking mode since July 11^{th} 2006. Until September 2007, the total acquisition time has been ∼380 days, for a total of ∼800 million triggers and 6.4 TByte of down-linked raw data.

All in-flight operations are handled by the PSCU (PAMELA Storage and Control Unit). The PSCU manages the data acquisition and other physics tasks and continuously checks for proper operation of the apparatus. The average trigger rate of the experiment is $\sim$ 25 Hz, varying from

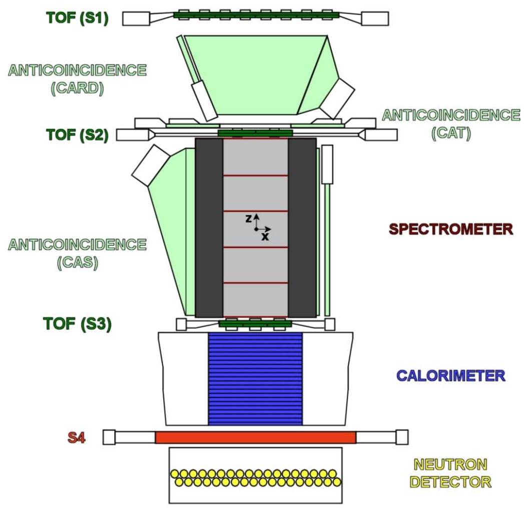

Figure 1. Schematic overview of the PAMELA apparatus. The detector is approximately 1.3 m high, has a mass of 470 kg and an average power consumption of 355 W. The magnetic field lines inside the spectrometer cavity are oriented along the y direction. The average value of the magnetic field is 0.43 T.

$\sim$ 20 Hz at the equatorial region to $\sim$ 30 Hz at the poles. The average fractional live time of the experiment is $\sim$ 73%.

During this time some error conditions (approximately three per week) have occurred, mainly attributable to anomalous conditions in the detector electronics. Every time the PSCU has been able to recover the system functionality and continue the acquisition.

5. Data handling and analysis

About 14 GB of PAMELA data are transferred to ground via a few down-link sessions every day. The receiving station is located at the Research Center for Earth Operative Monitoring (NTs OMZ) in Moscow, Russia. After receiving the data, a dedicated computer facility unpacks and transfers them to various institutions for further data processing and analysis.

The aim of the data analysis is the identification of the particle types and the determination of their energy enabling the measurement of the energy spectrum for various cosmic-ray components. Each PAMELA sub-detector plays a specific role in the analysis. The trigger to the instrument is provided by the particles crossing the ToF scintillator paddles. This system also measures the absolute value of the particle charge Z and flight time crossing its planes. In this way down-going particles can be separated from up-going ones. Particles not cleanly entering the PAMELA acceptance are rejected by the anticounter system. Then, the rigidities of the particles are determined by the magnetic spectrometer. Thus, positively and negatively charged particles are identified and separated. The final identification (i.e. positrons, electrons, antiprotons, etc.) is provide by the combination of the calorimeter and neutron detector information plus the velocity measurements from the ToF system and ionization losses in the tracker system at low momenta.

In this way, several tens of thousand events have been identified as positrons and about a thousand of events as antiprotons. As an example, figure 2 shows a $\sim$84 GV negatively-charged particle with an hadronic interaction in the calorimeter identified as an antiproton and figure 3 shows a $\sim$92 GV positively-charged particle with a typical electromagnetic shower in the calorimeter identified as a positron. In these figures a different signature in the neutron detector can be clearly noticed. Additional hadron-rejection power is provided by the neutron detector and this increases as the energy increases.

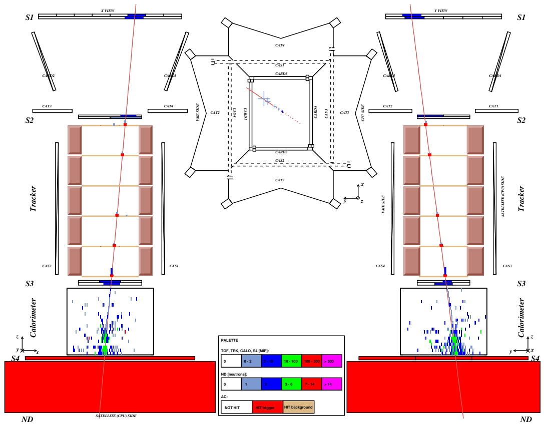

Figure 2. The event display an ∼84 GV antiproton interacting in the calorimeter. The bending (x) and non-bending (y) views are shown on the left and on the right, respectively. A plan view of PAMELA is shown in the center. The signal as detected by PAMELA detectors are shown (plane 19 of the calorimeter x-view was malfunctioning) along with the particle trajectory (solid line) reconstructed by the fitting procedure of the tracking system.

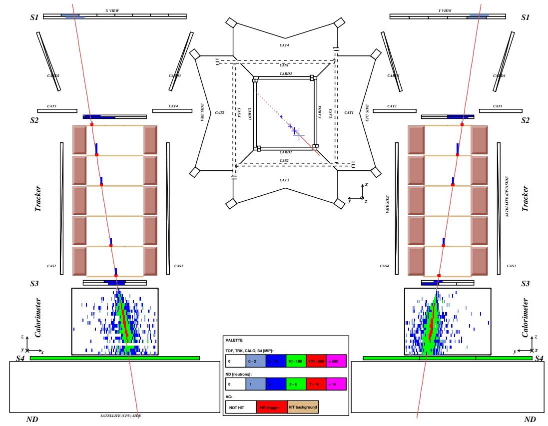

Figure 3. The event display a ∼92 GV positron. The bending (x) and non-bending (y) views are shown on the left and on the right, respectively. A plan view of PAMELA is shown in the center. The signal as detected by PAMELA detectors are shown (plane 19 of the calorimeter x-view was malfunctioning) along with the particle trajectory (solid line) reconstructed by the fitting procedure of the tracking system.

Besides selection of charge one particles, PAMELA is able to identify light nuclei particles, up at least to Oxygen, using the ionization losses in the calorimeter, ToF and tracker systems.

6. Conclusions

The PAMELA satellite experiment was successfully launched on the 15^{th} of June 2006 and it has been continuously taking data since then. Individual detectors are performing nominally allowing for precise measurement of cosmic-ray spectra over a wide energy range. Up to now, PAMELA has recorded the largest antiparticle statistic ever and results will be published soon.

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