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The space mission PAMELA

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On behalf of the PAMELA Collaboration

Abstract

Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) is a satellite-borne experiment which will investigate the matter–antimatter (a)symmetry of the universe and other cosmological problems through precise cosmic-ray measurements. The primary objectives of the PAMELA mission include measurements of the energy spectra of cosmic-ray antiprotons and positrons over a large energy range (up to 190 GeV for antiprotons, 270 GeV for positrons) and with unprecedented accuracy, the search for an antimatter component with a sensitivity of 10^{-7} in the $\overline{\mathrm{He}}/\mathrm{He}$ ratio, the measurement of the light nuclear components of cosmic rays up to 200 GeV/n and of the electron component up to at least 400 GeV. The apparatus is built around a permanent magnetic spectrometer equipped with a double-sided silicon microstrip tracking system and surrounded by a scintillator anticoincidence system. State-of-the-art detectors are used for particle identification: a silicon–tungsten imaging calorimeter, augmented by a scintillator shower tail catcher, and a transition radiation detector made up of carbon fibre radiators and proportional straw tubes. Fast scintillators are used for time-of-flight measurements and to provide the primary trigger. A neutron detector is finally provided to extend the range of particle measurements to energies as high as 10^{11}–10^{13} eV. PAMELA will be operated on-board of the Resurs-DK1 satellite, which will be put into its semi-polar orbit in 2004. Here we illustrate the main features of the apparatus and its current status.

Keywords: Satellite experiment; Cosmic rays; Antimatter

1. Introduction – the PAMELA experiment

Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) is an experiment for cosmic-ray measurements to be performed on-board of the Russian Resurs-DK1 satellite. This satellite, which will be launched into space by a Soyuz rocket in 2004, will execute a semi-polar, elliptical orbit with an inclination of 70.4° and an altitude varying between 350 and 600 km.

PAMELA will be housed in a dedicated pressurized vessel attached to the satellite, as shown in Fig. 1. During launch and orbital manoeuvers the vessel is secured to the satellite's body (dashed contour in the figure). During data taking the pressure vessel is swung up (shaded position in the figure) to give PAMELA a clear view into space. Three years of data taking are expected in orbit.

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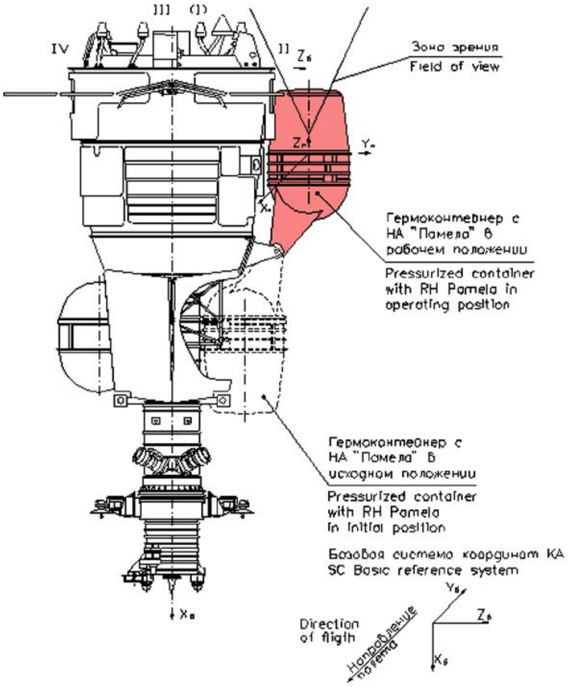

Fig. 1. Schematic view of the Resurs DK1 satellite and the pressurized vessel in which PAMELA will be located. The vessel is shown in both the 'launch' (dashed) and 'data-taking' positions (shaded).

The primary objective of PAMELA is to measure the antiparticle components of cosmic rays over an extended energy range and with unprecedented accuracy. The unique capabilities of the apparatus and the long exposure time on the satellite will allow such measurements to be performed from 80 MeV up to about 190 GeV for antiprotons and from 50 MeV up to 270 GeV for positrons. Additional objectives are the search for cosmic antimatter with a sensitivity of the order of 10^{-7} in the $\overline{\mathrm{He}}/\mathrm{He}$ ratio and measurements of the energy spectra of protons, electrons and of the light nuclear components of cosmic rays, up to $Z = 6$. Finally, as a consequence of the long experiment lifetime and of the orbit features, it will be possible to monitor the long- and short-term modulation of cosmic rays in the heliosphere, to detect solar emission particles and to study the fluxes of high-energy particles up to 10 TeV.

2. The PAMELA apparatus

A schematic view of PAMELA is shown in Fig. 2.

The apparatus is built around a permanent magnetic spectrometer, equipped with a silicon microstrip tracking system, which will determine the charge of the particles, both in sign and value, and measure their momentum. The spectrometer is surrounded by a scintillator anticoincidence system, which will reject particles that do not pass through the acceptance window of the spectrometer. The trigger is provided by a scintillator time-of-flight (ToF) system. Particle identification

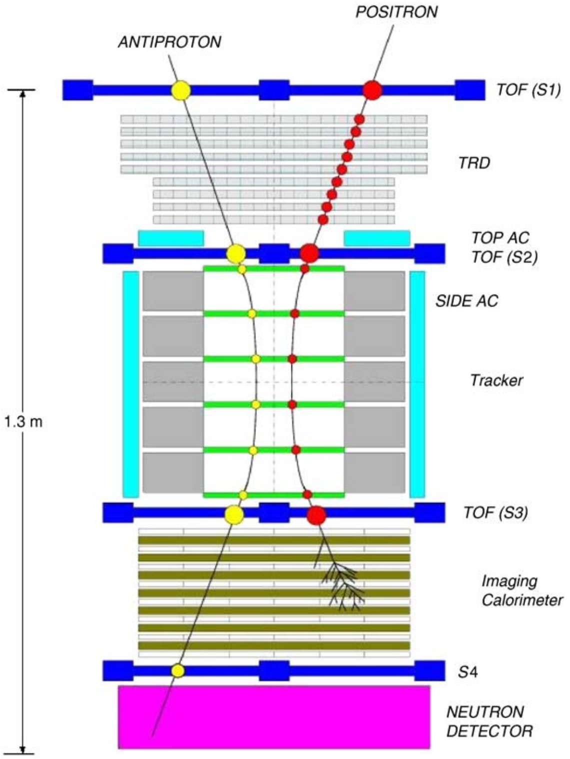

Fig. 2. Schematic view of the PAMELA apparatus: the magnetic spectrometer, equipped with a silicon microstrip tracking system, is complemented by a three-planes scintillator ToF system, a TRD and a silicon–tungsten calorimeter. A scintillator shower tail catcher and a neutron detector are located below the calorimeter. The magnetic spectrometer is surrounded by a scintillator anticoincidence system. An antiproton and a positron event are also shown in order to illustrate the signatures of different particles in the apparatus.

will rely mainly on a silicon–tungsten calorimeter, complemented at low energy by the ToF system and, for momenta larger than 1 GeV/c, by a transition radiation detector (TRD). A scintillator shower tail catcher and a neutron detector are located below the calorimeter.

The entire telescope stands approximately 130 cm high, has an overall mass of 450 kg and a power consumption of about 350 W.

2.1. The magnetic spectrometer

The magnetic spectrometer consists of a permanent magnet and a silicon microstrip tracking system. The magnet is made up from five modules of a sintered Nd–B–Fe alloy with a high residual magnetic induction (~ 1.3 T). The modules are assembled in such a way to give rise to an approximately uniform magnetic field of intensity of about 0.48 T in an internal rectangular cavity of section $132 \times 162\,\mathrm{mm}^2$ and 445 mm height. The geometric factor of the spectrometer is thus of $20.5\,\mathrm{cm}^2\,\mathrm{sr}$.

The tracking system consists of six sensitive planes interleaved to the magnet blocks. Each plane is made up from six double-sided silicon detectors, 300 μm thick. These detectors are built by implanting p^+-type strips in a high resistivity n-type silicon wafer, on the other side of which n^+-type strips are implanted. The strips on opposite sides are arranged along two perpendicular directions. A metal layer on the ohmic side provides convenient read-out lines, so that it is possible to acquire data from both sides from the same edge. The implantation pitch is of 25 μm for the junction side, 67 μm on the ohmic side. The read-out pitch is 50 μm for both views. This layout gives a total of 6144 electronic channels for each tracker plane. A significant effort has thus been made to develop a powerful compression algorithm to reduce the tracker data to a manageable size. Extensive tests have shown that this algorithm performs at a 95% compression factor, with no degradation of the detector response.

The capabilities of the tracking system have been studied extensively through simulations and beam tests, as reported separately at this Conference [1]. A spatial resolution is achieved of about 3 μm on the junction side, which will be used for measurements along the bending direction in the spectrometer, and of about 10 μm along the perpendicular view. The resulting maximum detectable rigidity (MDR) of the spectrometer exceeds 740 GV.

2.2. The calorimeter

The calorimeter is a sampling detector made of silicon sensors interleaved with plates of tungsten absorber. The detector is composed of 22 planes, each made of a tungsten layer of 2.6 mm thickness on each side of which a layer of silicon sensors is glued. The silicon sensors are 380 μm thick and segmented into 2.4 mm strips. The strips of the two sensor layers of the same plane are oriented along perpendicular directions. The detector is therefore capable of a 3-D reconstruction of the showers and is characterized by a high granularity both in the longitudinal and transversal views. The total depth of the calorimeter is of 16.3 radiation lengths (approximately 0.6 interaction lengths).

The front-end electronics is based on the VLSI ASIC CR1.4P designed specifically to meet the PAMELA needs [2]: it features a wide dynamic range (~ 1400 minimum ionizing particles), the ability to cope with a large detector capacitance (up to ~ 180 pF), good noise performance ($\sim 2700e^- + 5e^-/\mathrm{pF}$), low power consumption (< 100 mW/chip) and the possibility of being configured to accept signals of either polarities: the same chip is in fact used also for the acquisition of the TRD data. Compression algorithms have been developed and successfully tested to decrease the size of the calorimeter data which will be transmitted to Earth.

Beam test and simulation studies show that this calorimeter is capable of a 10^4 rejection factor for protons and electrons in high-efficiency ($\sim 95\%$) measurements of, respectively, electrons and antiprotons [3].

2.3. Transition radiation detector

The TRD is built with a modular structure in which carbon fibre radiators are interleaved with sensitive layers of straw tubes. The tubes are made from a kapton foil of 30 μm thickness. The internal part of the tube is copper-coated, so as to act as a cathode surface. A tungsten tube of 25 μm diameter is stretched to a tension of about 60 g and will act as the anode. The tubes are filled with an 80–20% mixture of Xe–CO_2 and will be operated in proportional mode at a high voltage of 1400 V. A gas system including a 1500 l atm gas supply will ensure proper operating conditions of the TRD for the full mission lifetime.

The detector has the shape of a truncated pyramid, in order to match the acceptance of the underlying spectrometer. A total of 1024 channels will be individually sampled and digitized. A fast pedestal suppression algorithm will be used to decrease the size of information to be recorded and transmitted to Earth. Test beam and simulation studies confirm that this detector is capable of discriminating radiating particles with high efficiency (larger than 90%) at a level of 5% of contamination from non-radiating particles [4].

2.4. The scintillators and the neutron detector

Scintillator detectors are used for different purposes in the PAMELA apparatus. A scintillator system is used for providing the first-level trigger for data acquisition as well as for charge and ToF measurements. This system is illustrated separately at this Conference [5] and will not be discussed further here.

The PAMELA anticoincidence system consists of four lateral detectors covering the sides of the magnet spectrometer and one top detector placed above it. The read-out is performed by a total of 16 Hamamatsu R5900U photomultiplier tubes. The signals from the PMTs are discriminated and fed to a 32-bit shift register which is time-shifted in such a way that pulses in time with the trigger appear in the centre of the shift register. This allows one to check whether a triggered event is accompanied by any activity in the anticoincidence system.

The purpose of the anticoincidence system is to help select particles that cleanly enter the acceptance window of the magnet spectrometer. Studies conducted by simulations and beam tests show that proper combinations of the information from this system and from the calorimeter allow one to perform a suppression of ‘false triggers’ of at least 60% without a sizeable loss of single-particle events, even at high energy [6]. A fast response which may be used for building up such trigger conditions may also be obtained by the additional layer of scintillator located immediately below the calorimeter which detects particles escaping from it.

Below such scintillator, PAMELA houses also a neutron detector. The purpose of this detector is to extend the electron/proton discrimination capabilities of PAMELA to the energy region of 10^{11}–10^{13} eV by means of a measurement of the neutron component which would accompany such high-energy hadronic interactions in the calorimeter. More details on this detector may be found in Ref. [7].

3. Status of the experiment

All tests performed so far show that all detectors of the PAMELA experiment comply with their design performance.

In preparation to the space mission, extensive space qualification tests have also been conducted in the past years and are still in progress: so far, all detectors have proved their capability to survive the severe conditions of the launch. Final qualification tests of the apparatus design are ongoing at TsSKB-Progress in Samara, Russia on an integrated Mass and Thermal Model of PAMELA.

The integration of the PAMELA flight model is already in progress in Rome. Integration in the satellite and launch are foreseen for early 2004.

Please visit the PAMELA web-page[1] for a vast documentation on this program and future updates on its status.

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