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Status of the PAMELA silicon tracker

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Abstract

PAMELA is a composite particle detector which will be launched during the first half of 2006 on board the Russian satellite Resurs DK-1 from Baikonur cosmodrome in Kazakhstan. This experiment is mainly conceived for the study of cosmic-ray antiparticles and for the search for light antinuclei, but other issues related to the cosmic-ray physics will be investigated. In this work the structure of the whole apparatus is shortly discussed with particular attention to the magnetic spectrometer, which has been designed and built in Firenze.

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Keywords: Magnetic spectrometer; Silicon microstrip detectors; Cosmic rays

1. Introduction

PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics [1]) is a satellite experiment developed by the WiZard international collaboration for the study of antiparticles in cosmic rays hitting the Earth atmosphere. The main goals of the experiment are the measurement of the fluxes of antiprotons and positrons, which are known, thanks to several previous balloon-borne experiments, only for momenta below some tens of GeV/c, and the search for antinuclei, which have never been observed until now. The mission will last for a period of at least 3 years, during which PAMELA can achieve high statistic measurements without suffering the problem of interaction of cosmic rays with the atmosphere, an important limit to the capabilities of the balloon–borne experiments. On the other hand strict limits on mass, volume and power consumption of the apparatus are imposed by the satellite mission requirements. For this reason the whole detector is only 470 kg weight, with a height of about 120 cm and cross–sectional diameter around 102 cm. The resulting geometrical factor is quite small, around 20.5 cm^2 sr, but high statistics is anyway guaranteed by the long duration of the mission. A careful selection of the electronic components has been done to have a low power consumption and to survive a radiation dose up to 3 krad. The total power consumption is finally less than 360 W. Thanks to its performance PAMELA will improve the present knowledge of cosmic–ray antiparticles by measuring the antiproton flux between 80 MeV/c and 190 GeV/c, the positron flux between 50 MeV/c and 270 GeV/c and searching for anti–Helium with a sensitivity of 10^{-7} in the $\overline{\mathrm{He}}/\mathrm{He}$ ratio.

The PAMELA detector has been delivered to Russia at the beginning of 2005 and it is presently in Baikonur (Kazahstan) for the definitive installation into the satellite. The apparatus is presented in Section 2. More details about the magnetic spectrometer, which has been developed by the Firenze group, can be found in Section 3. This subdetector is located in the central part of PAMELA and will be used to measure the momentum of the particles.

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2. The PAMELA detector

The PAMELA set up is shown and schematically described in Fig. 1. A magnetic spectrometer [2] is used to reconstruct the trajectory of incoming charged particles in a spatial region where a magnetic field ($\simeq 0.43\,$T) is present. By analyzing a single particle track, the arrival direction, the momentum and the sign of the charge of the particle can be determined. Nevertheless, the spectrometer is not enough to completely distinguish between the different types of particles which can be detected during the mission. For this reason further information from different subdetectors is necessary. The velocity of the particles is measured by means of a time of flight system (TOF [3]) composed of three scintillator planes (S1, S2 and S3). Combining the information given by the TOF and the spectrometer the identification of the mass of the particle is possible for momenta lower than $1\,\mathrm{GeV}/c$. A sampling electromagnetic calorimeter [4], made of 22 0.26 cm thick tungsten layers, each enclosed between two layers of silicon strip detectors, is used to distinguish between hadrons and leptons at higher energies. The silicon sensors are used for the longitudinal sampling of the energy releases and for the study of the lateral development of the showers, by means of 2.4 mm pitch strips. The whole calorimeter has a depth of 16.3 radiation lengths (or 0.6 interaction length) and allows the rejection of protons from positrons and electrons from antiprotons with a rejection power (defined as the ratio between the efficiencies of selection of background events and good events) better then 10^{-4} for a selection efficiency of good events greater than 95%. A further scintillator [5] (S4) is located at the end of the calorimeter to detect partially contained showers initiated by very high energy particles. Beyond this scintillator a neutron detector [5] allows the discrimination between hadrons and leptons for energies around a few TeV, thus extending the calorimeter capabilities. An anti–coincidence system [6], made of plastic scintillators, completely surrounds the spectrometer walls and the incoming region to identify particles entering from the sides or interacting somewhere in the apparatus.

3. The magnetic spectrometer and its performance

The structure of the magnetic spectrometer of PAMELA can be described as a regular array of tracking detectors located in a high–intensity magnetic field region. The field is produced by a permanent magnet made of five identical Ni–Fe–B modules, 80 mm thick, which are assembled (based on the "yokeless" configuration described in Ref. [7]) in such a way to form a $(16.2 \times 13.2 \times 44.5)\,\mathrm{cm}^3$ magnetic cavity, where the field intensity is around 0.43 T, and to minimize the residual field outside it. An aluminum structure fixes these modules 9 mm apart from each other, thus allowing to dispose a tracking plane between each couple of modules. Other two planes are fixed at the two ends of the magnetic cavity. Each plane of the tracking system (left Fig. 2) is made of three identical basic detecting units, the *ladders*. Each *ladder* contains two microstrip silicon sensors ($53.33\,\mathrm{mm} \times 70.00\,\mathrm{mm} \times 300\,\mu\mathrm{m}$) and a

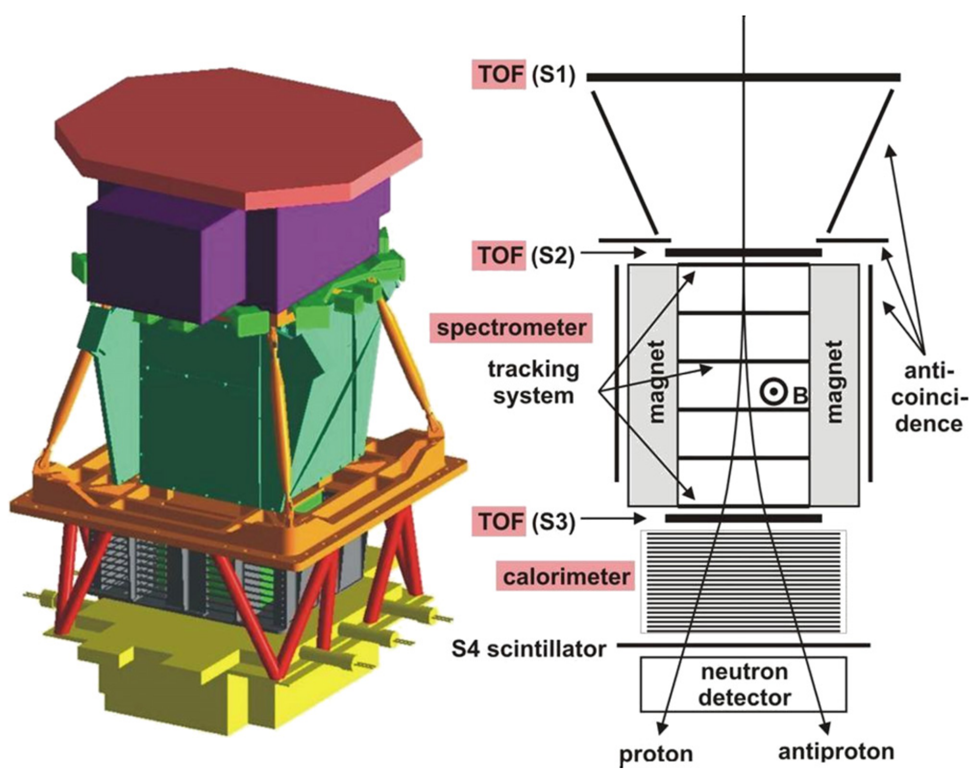


Fig. 1. The PAMELA detector set up.

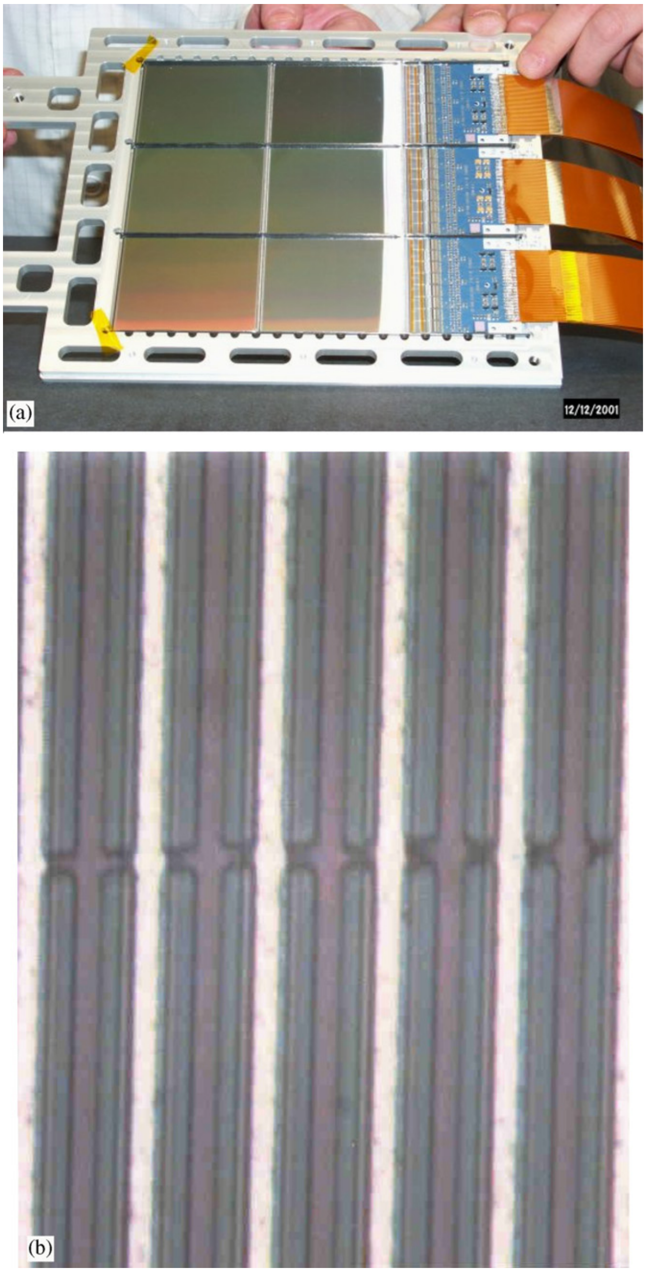
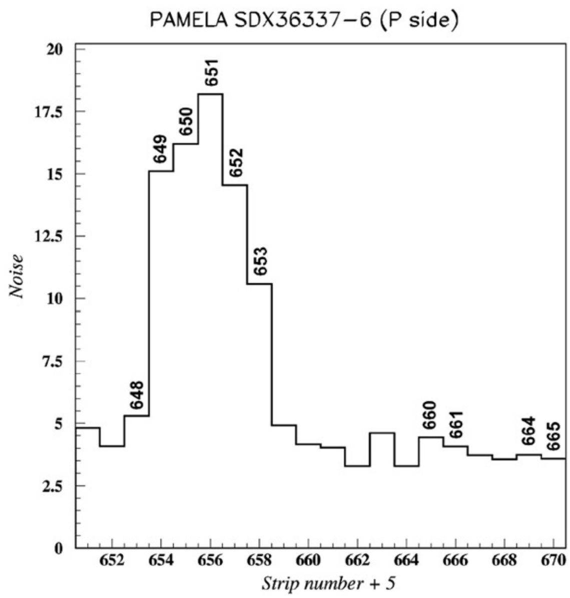


Fig. 2. (a) Complete tracking plane. (b) Example of implantation defects found on the P-side of the first set of microstrip silicon sensors of the tracking system.

hybrid circuit with the front–end electronics. These three parts are glued together on their edges and wire bonded. Pultruded carbon fiber bars allow to fix three *ladders* together to form a plane, and the whole plane to an aluminum frame, giving this structure enough rigidity to be safely used in a satellite experiment. The pultruded bars guarantee a first resonance frequency for the silicon planes around 340 Hz, well above the main resonances of the satellite and the rest of the detector (around 100–150 Hz). This structure has been studied in such a way to avoid adding material layers along the trajectory of incoming particles passing through the spectrometer, thus minimizing the contribution of multiple scattering to the uncertainty in the measurement of the momentum. The silicon sensor, produced by Hamamatsu, is double sided, with integrated decoupling capacitors and with a double metalization on the ohmic side which allows to bring all the signals of both the two sides on the same edge of the sensor. The implantation pitch is 25.5 μm on the junction side (P-side) and 66.5 μm on the ohmic side (N-side). On the P-side the microstrips are read out one every two. On the N-side all the microstrips are read out and *p*-type blocking strips are realized. Other relevant parameters of this sensor have been measured by Hamamatsu. On the P-side the decoupling capacitance is 160 pF and the interstrip capacitance is 8 pF considering first neighbours and 10 pF with either second neighbours. For the N-side the same parameters are 120, 7 and 9 pF.

A big effort has been done in the development of such a kind of tracking detector, to face the difficulties related to the strong requirements of a satellite mission. IDEAS VA1 chips [8] have been adopted as the front–end electronics for the silicon detectors and are used in a reduced gain regime in such a way that the power consumption of the whole front–end is lower than 40 W for 36 864 readout channels. The dynamic range of the single channel is around 10 MIP. Tests have been performed to verify the radiation hardness of the electronics [9] and the thermal and vibrational behaviour of the apparatus [10,11]. Before the final production of the tracking planes, an accurate analysis of the surfaces of the silicon sensors has also been done to find out any possible unknown imperfection. An implantation defect has been found for some sensors, especially on the P-side (right Fig. 2). Groups of implanted microstrips were clearly interconnected by orthogonal ‘‘scratches’’. A measurement of the interstrip resistance (table at right in Fig. 3) has shown that its value is of the order of 80 GΩ for good microstrips (greater than 10 GΩ, according to the measurements done by Hamamatsu) while it decreases to a few hundreds kΩ in the regions of the ‘‘scratches’’. This problem had been previously identified as an anomalous electronic noise on the same groups of microstrips. Fig. 3, together with the measured values of the interstrip resistance, demonstrates the correlation between anomalous values of the electronic noise and the implantation defects. A careful analysis has been done over all the produced sensors to select those with the minimum percentage of defects. The final *ladders* have no more than 5% defective channels.

Several beam test have been performed at CERN (Geneva) to characterize this detector. As a result, a spatial resolution around 3 μm has been achieved, by means of vertical minimum ionizing particles, on the P-side, which is used to measure the deflection of the particles in the magnetic field. This particularly good value (compared with an implantation pitch of 25.5 μm) is achieved by means of an algorithm which is based on an accurate study of the repartition between different microstrips of the charges produced inside the silicon layer. Good agreement



Strip #	R
648–649	≃80 GΩ
649–650	≃500 kΩ
650–651	≃500 kΩ
651–652	≃500 kΩ
652–653	≃1.5 MΩ
660–661	≃50 GΩ
664–665	≃80 GΩ

Fig. 3. Left: electronic noise (in ADC channels) for a group of microstrips around the bad ones; strip numbers are indicated over the histogram bars. Right: table of interstrip resistance values for the same group of microstrips.

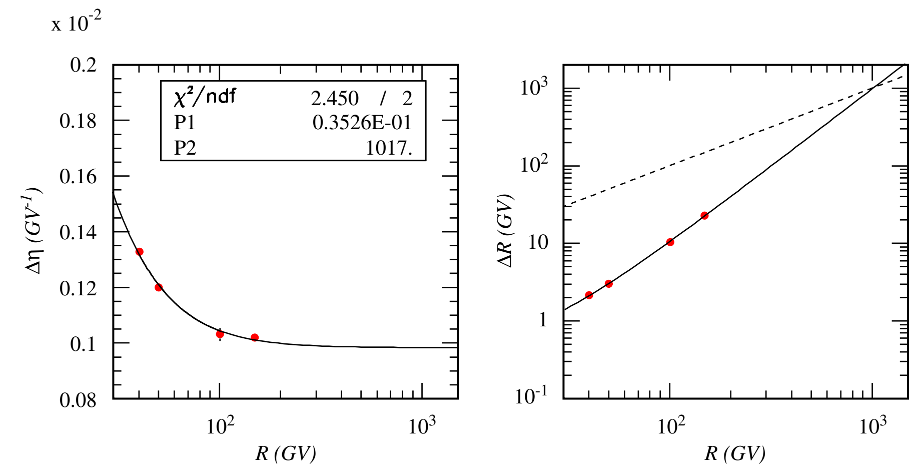


Fig. 4. Results of a test at SPS (CERN) using a proton beam. Uncertainties on the deflection η (left) and on the rigidity R (right) as functions of R.

is found with the value foreseen by a simulation of this detector, which also shows that the resolution is better than 4 μm up to an incidence angle of 10° and becomes 8 μm at 20°, the maximum angle allowed by the acceptance [12]. In Fig. 4 the results of the last beam test, held at CERN SPS in 2003, are shown. A proton beam was used to measure the uncertainty in the measurement of the deflection η (defined as the ratio between the charge of the particle and its momentum), that is reported in the left picture of fig. 4 as a function of the rigidity R ($R = 1/\eta$). In the picture on the right the uncertainty on R is reported as a function of R. From these results we can extrapolate a value of the maximum detectable rigidity of the spectrometer (defined as the value of R where $\Delta R/R = 1$) around 1000 GV/c, better than the minimum value (740 GV/c) required to reach the proposed scientific goals.

During the last weeks of the integration, PAMELA has been switched on to intensively test all the flight operative modes; during this time a first set of ground-level cosmic-ray data has been acquired. A preliminary analysis of these data has been performed and presented at the last International Cosmic Ray Conference, held in Pune (India) on August 2005 [1,2]. The results confirm the expected performance of the spectrometer.

In conclusion, the PAMELA magnetic spectrometer has been accurately tested, both from the point of view of the hardware robustness and from the point of view of its performance. All the achieved results confirm that this subdetector satisfy all the requirements of the satellite mission.

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