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Pamela tracking system: status report

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Abstract

The Pamela apparatus will be launched at the end of 2002 on board of the Resurs DK Russian satellite. The tracking system, composed of six planes of silicon sensors inserted inside a permanent magnetic field was intensively tested during these last years. Results of tests have shown a good signal-to-noise ratio and an excellent spatial resolution, which should allow to measure the antiproton flux in an energy range from 80 MeV up to 190 GeV. The production of the final detector modules is about to start and mechanical and thermal tests on the tracking tower are being performed according to the specifications of the Russian launcher and satellite. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

The Pamela experiment is part of the Russian–Italian Mission (RIM), conceived to study cosmic rays on satellite-borne missions. Pamela is planned to study mainly antiproton and positron fluxes in cosmic rays up to high energies (190 GeV for \bar{p} and 270 GeV for e^+), and to search for antinuclei, up to 30 GeV/n, with a sensitivity of 10^{-7} in the $\overline{\text{He}}/\text{He}$ ratio [1,2]. Pamela will be launched on board of the Russian satellite Resurs DK, and it will enter a sun-synchronous orbit, at 350–600 km of altitude and 70.4° of inclination. These orbital parameters allow a two-year long mission and the investigation of the Galactic component of cosmic rays close to the poles, where the geomagnetic cut-

off is lower. The tracking system is the core of the Pamela apparatus and consists of six planes of double-sided silicon detectors inserted inside a structure consisting of five permanent magnet rings (Fig. 1). Like all satellite experiments, Pamela needs at least to build two apparata: one is the flight model and the other the engineering model.¹ In the tracking system the differences between the two models lie in the performances of magnets and the detectors, but the design and assembly procedures are exactly the same. The design of the silicon tracker aims at two main goals: mechanical robustness of the structure,

¹ Pamela tracking system, according to Russian requests, has also a mass model and a thermal model. The differences of these models lie in the magnetic material, which is replaced by iron blocks, and the planes, which are built using dummy detectors and dummy hybrids. Mechanical properties, thermal properties and the assembly procedures are the same for the four models.

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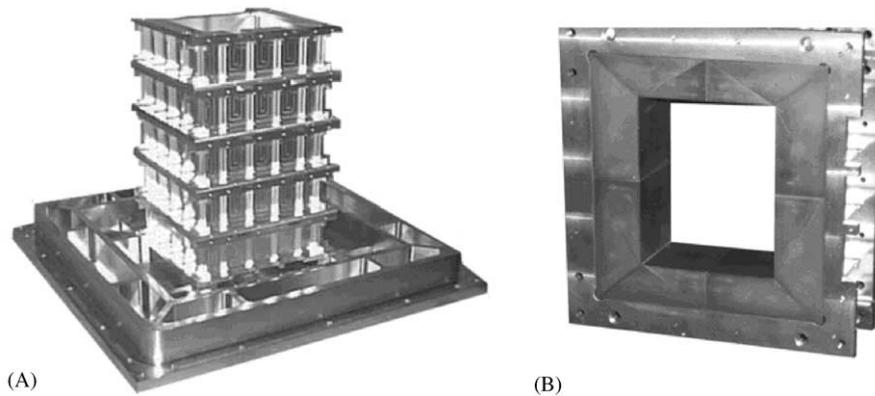


Fig. 1. (A) Modules of the flight tower posed on the baseplate, that is the interface between Pamela and Resurs DK. (B) A flight module filled with magnetic material.

which must survive the stresses during launch, and the measurement of the charge and momentum of the incoming particles with the highest possible precision, which means a resolution of at least $4\ \mu\text{m}$ to achieve the tasked maximum detectable rigidity of 740 GV.

2. Magnet

The magnetic system consists of five aluminum modules filled with an alloy of Nd–Fe–B with a high value of residual magnetic induction (1.3 T). These modules have an internal rectangular cavity, $131 \times 161\ \text{mm}^2$ wide and 445 mm high, that defines the tracking volume (Fig. 1). The field intensity inside the cavities reaches 0.48 T for the flight model and 0.39 T for the engineering model. The magnetic field of the engineering model was mapped by means of a triaxial Hall probe. The probe was fixed on the head of three-axis machine that sampled points with a step of 18 mm (Fig. 2). The magnetic field of the flight model is currently being sampled with a step of 5 mm in all directions. Uncertainty on position is 0.1 mm, while uncertainty on the field intensity is 0.1%, depending mainly on calibration. The result is an overall uncertainty in the field intensity, at a given coordinate, of 1%. This error has to be compared to the expected overall uncertainty on the measurement of the particle momentum, which, neglecting the error on the magnetic field, is of

the order of 4% (due to the multiple scattering) in the best case.

3. Silicon planes

The detector plane is the basic structure of the tracking system. A plane consists of three ladders composed by two detectors and a hybrid, on which the readout chips (front-end electronics) are placed, glued together by means of a thin deposition of $75\ \mu\text{m}$ of epoxy glue. Each ladder has a lateral stiffener consisting of a carbon fibre rail. The silicon plane with its carbon stiffeners is placed inside an aluminum frame and glued to it by means of a structural sealant (Fig. 3b).

3.1. Detectors and hybrid

Sensors and hybrids for the flight and engineering model of Pamela were available from the end of 1999 and during last two years they have been intensively tested [3]. The wafers are double-sided silicon sensors with geometric dimensions of $53.33 \times 70.00\ \text{mm}^2$ and 0.3 mm thick. The bulk of the detectors is made of high resistivity n-type silicon with implanted strips of p^+ -type on the junction side and orthogonal n^+ -type on the ohmic side. The implanted pitch is of $25\ \mu\text{m}$ on the junction side and of $67\ \mu\text{m}$ on the ohmic side. The ohmic side is also provided with p^+ blocking strips between adjacent n^+ strips (Fig. 3A).

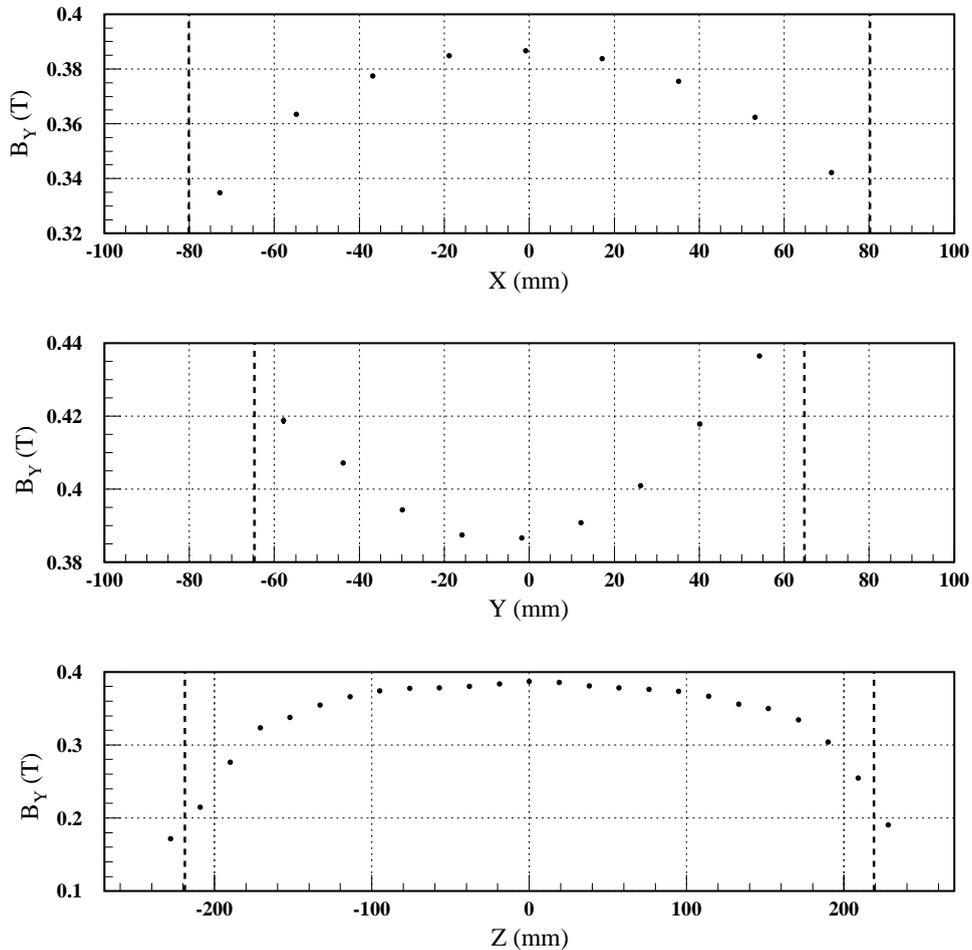


Fig. 2. Magnetic field vs. the axis for the engineering model. Dashed lines are the limits of the magnetic cavity. The measurements reported were made for each axes at the origin of the other two axes.

Decoupling capacitors are directly integrated on the sensors by means of silicon dioxide deposition, 100 nm thick, placed between the implanted strips and the metal readout strips. On the ohmic side a second metal layer is present to route the signals from the strips to the front-end hybrid. The readout pitch is of 50 μm on both sides. Measurements on the detectors show that the decoupling capacitances are 20 pF/cm. Bias is fed to the strips by means of the punch through effect (foxfet structure) on the junction side and by polysilicon resistors on the ohmic side. Measurements show values $>1\text{ G}\Omega$ for the bias structures on the junction side, while on the ohmic side values range

from 31 up to 49 M Ω . Full depletion is reached at 80 V and leakage currents, measured at 100 V, fall between 1820 and 66 nA with an average value of about 200 nA. Defects on detectors, AC shorts, shorts between adjacent lines and interrupted lines, range from 0.39% to 1.81%, with an average value of 1.05%.

The hybrid is a double-sided alumina supporting the frontend electronics and has geometric dimensions of $55.00 \times 53.33\text{ mm}^2$ with a thickness of 0.3 mm. Each side of the hybrid is subdivided into two independent sections. Each section is equipped with four VA1 chips and has independent power and logic lines. This solution avoids

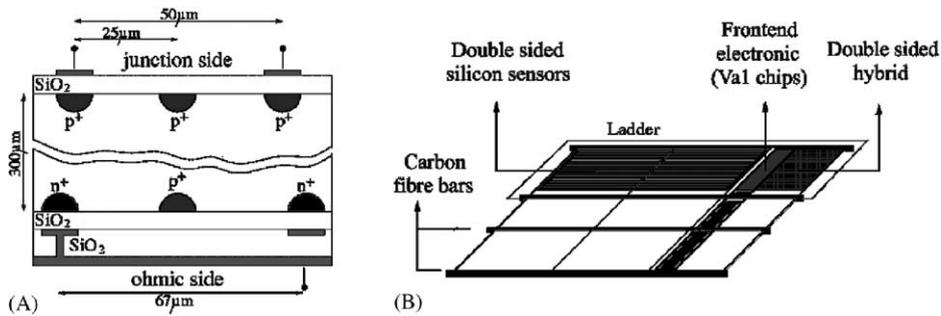


Fig. 3. (A) Section of a detector. (B) Scheme of a Pamela plane.

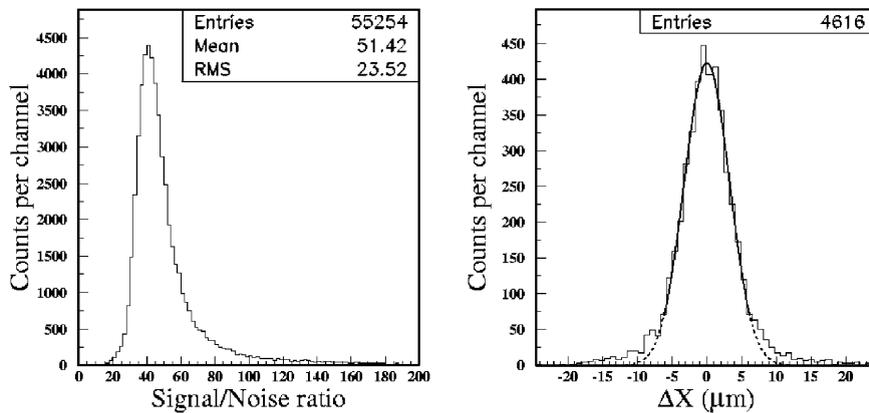


Fig. 4. Signal-to-noise ratio and spatial resolution for a ladder on the junction side.

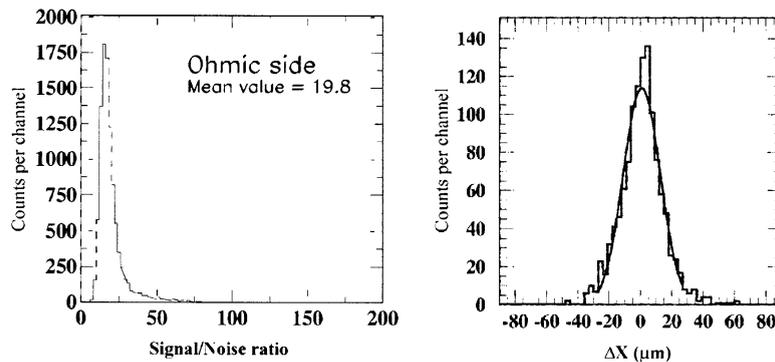


Fig. 5. Signal-to-noise ratio and spatial resolution for a ladder on the ohmic side.

loosing a whole side of a ladder in case of chip failure, such as latch up, and it is a compromise between redundancy and hybrid feasibility. The VA1 chip [4,5] consists of 128 charge sensitive

preamplifiers, each one connected to a CR-RC shaper and followed by a sample and hold circuitry. The VA1 chip, using a shaping time of 1µs and with the input capacitance of Pamela

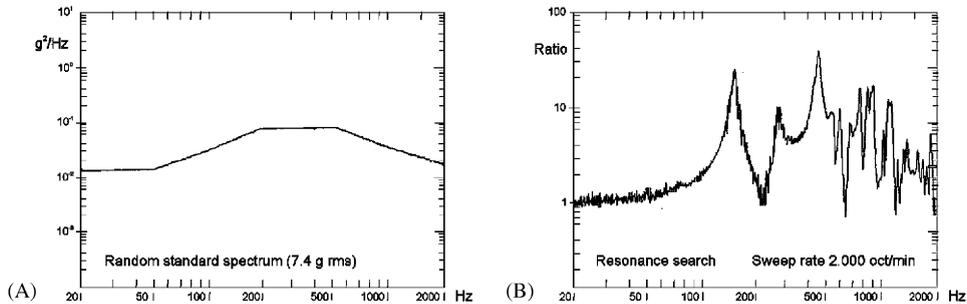


Fig. 6. (A) Power spectral density injected on Pamela during the launch phase. (B) Plane proper resonances.

sensors (10 pF), has an equivalent noise charge of about 500 electrons to be compared with 24000 electrons released by a MIP.

3.2. Readout and DAQ

The hybrid is connected to the ADC board by means of a 38 pin kapton cable 50 mm long. The analog-to-digital conversion of the signals coming from the VAs is performed on an electronic board lodged on the magnet tower wall. Each side of a plane is served by one board housing three ADC sections and a FPGA device which provides the digital sequences needed by the A/D converter and VAs. The digital data are then sent to the data acquisition board (DAQ) by means of a ADuM1100 chip which is an inductive decoupler. Thus the front-end digitizer is a fully electrically floating board which can be referred to the bias voltage of the silicon sensor. This avoids electrical stresses to the strip decoupling capacitors. On the DAQ board a master logic and a DSP are also present to generate the signals needed for the floating FPGA boards and to compress the data stored in the main CPU.

3.2.1. Beam tests

From 1996 beam tests have been performed at CERN to investigate the tracking performances and improve the front-end and readout electronics. Tests were made using telescopes of five ladders and MIP beams, typically muons and protons with an energy range from 3.5 up to 100 GeV. Results of signal-to-noise ratio and spatial resolution, for the best electronics config-

uration achieved, are shown in Fig. 4 for the bending view (junction side) and in Fig. 5 for the ohmic side.

4. Structural tests

From 1999 structural tests were performed on planes following the Russian specifications. In the launch phase a random load with a Power Spectral Density (PSD) reported in Fig. 6A is injected on Pamela by the vector for the first 120 s. The structural tests were made following these three steps. In the first step a preliminary search for resonances was made in the frequency range from 10 Hz up to 2 kHz using a 0.65 g accelerometer glued in the middle of the central ladder and applying a sinusoidal load of 0.5 g. A control sensor was put on the aluminium frame to check the applied load and to normalise the response values given by the accelerometer on the plane. In the second step the accelerometer on the plane was removed² and a random load of the same shape of the one of the launcher is applied at 0 dB. In the last step a search for resonances is performed in order to check structural damages on planes. The resonances of the planes of the flight model have been increased from 140 Hz (see Fig. 6B) up to 320 Hz using pulltruded carbon fibre bars.³ In this

²This is because the accelerometer has an approximate weight of 3 g/cm² against the 0.15 g/cm² of the plane, thus introducing dramatic local effect.

³Novel techniques allow the construction of bars with the fibres aligned in the same direction thus increasing the Young modulus.

way the planes are completely decoupled from the launcher and the payload main modes. All dummy planes tested survived at least a +6 dB load, that is 14.8 g rms. A first plane of the flight model was also tested at 0 dB and no electric damages were found in the successive functionality tests.

5. Conclusions

The Pamela tracking system must be delivered to Rome for the integration at the beginning of 2002. Currently the magnetic towers is being mapped, while the detectors and hybrids are fully tested. Final ADCs and DAQs boards are in production. The plane assembly has started and

their electrical and mechanical characterization will take up to the end of 2001.

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