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The PAMELA silicon tracker

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The PAMELA tracker collaboration

Abstract

The silicon tracker of the PAMELA apparatus has been assembled and it is ready to fly on-board the Russian satellite Resurs DK for a 3-year mission. The experiment will study, mainly, spectra of particles and antiparticles in cosmic rays. The magnetic spectrometer's primary goal is to precisely measure momenta of charged particles, whose trajectories have been bent by a permanent magnet. The detector is composed of 6 planes of double-sided silicon microstrip detectors, inserted between adjacent modules of a permanent magnet which produces an almost uniform magnetic field inside a rectangular cavity that particles cross. The spatial resolution of the detectors is about 3 μm for the bending coordinate.

The development of such detectors required a complex manufacturing procedure in order to preserve the physical performance in a device suitable for a space mission. In the construction phase data originating from both beam tests and simulation helped to check the detector's characteristics and to optimize the achievable spatial resolution. The development and the final assembling of these detectors are described in this paper.

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Keywords: Silicon microstrip detectors; Spatial resolution; Position finding algorithms

1. The mission

The PAMELA experiment [1,2] has been conceived in the context of the Wizard collaboration, which has been developing studies on cosmic rays since the late 1980s. The first measurements were performed on board of balloons flying as high as about 40 km above the ground level. At such altitudes measurements of cosmic rays' primary fluxes were complicated by the presence of a residual atmospheric depth above the detector. In addition, the short duration of the flights (usually of the order of 24 h) resulted in low-statistics data samples.

In order to get over these limits, in 1994 the PAMELA experiment on satellite was proposed:

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now (2003) the apparatus is completed and it will fly in the next year from the Baikonur cosmodrome in Kazakhstan onboard of the Resurs DK satellite. The flying altitude of this kind of spacecraft ranges from 350 to 600 km and the inclination above the Equatorial plane is 70.4°, therefore it can explore the Earth's regions near the magnetic poles where the geomagnetic cut-off is lower.

The main challenge of the proposed experiment was the installation of detectors already used in high-energy physics onboard of a satellite. Compared to the traditional detectors used in balloon-borne experiments, the main novelty was the use of a solid state tracking system. This was possible since the technological progress reached in those years allowed to obtain spatial resolutions of only a few micrometers for such devices; these values could easily counterbalance the bigger density (and consequently the greater multiple scattering) with respect to gas detectors.

The spectrometer [3] is based on silicon microstrip detectors, whose characteristics and performances have been studied since 1994 by the Firenze group. The final detectors have been assembled in 2001 and they have been tested on particle beams at the CERN SPS in 2002 and 2003.

2. Description of the spectrometer

It is composed of a hollow tower, 44.5 cm tall, made of a magnetic material which produces a rather uniform magnetic field (about 0.45 T) in the cavity, whose inner dimensions are $13.2 \times 16.2\ \mathrm{cm}^2$. Six equidistant detector planes measure the transversal coordinates at equidistant levels inside the magnetic field to determine the track's curvature. The peculiar direction of the magnetization in each magnetic block (Fig. 1) results in a field oriented along a preferential direction. The geometrical factor of the spectrometer is $20.5\ \mathrm{cm}^2\mathrm{sr}$.

Double sided silicon microstrip detectors are used to obtain two independent impact coordinates per plane. Three *ladders* form each plane (a photograph is shown in Fig. 2). A ladder is composed of two sensors, each one $5.33 \times 7.00\ \mathrm{cm}^2$ wide, and a hybrid circuit which houses the front-end electronics. The ladders are inserted in an aluminum frame without any supporting structure above or beneath them, to limit multiple scattering in dead layers. Carbon fiber rails, visible in the photo, are glued at both sides of a ladder and connected to the frame in order to increase the stiffness of the structure in view of the mechanical stresses expected during the launch of the satellite.

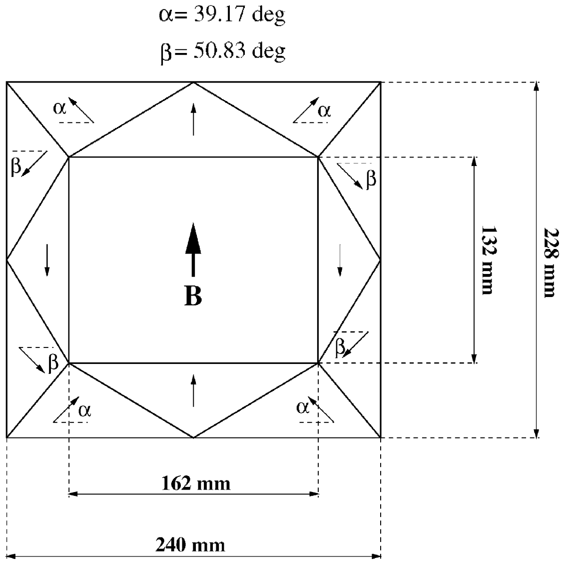

Fig. 1. Cross-sectional view of the magnetic cavity: each magnetic module, 80 mm high, is interleaved with a silicon detector plane, composed of 6 sensors.

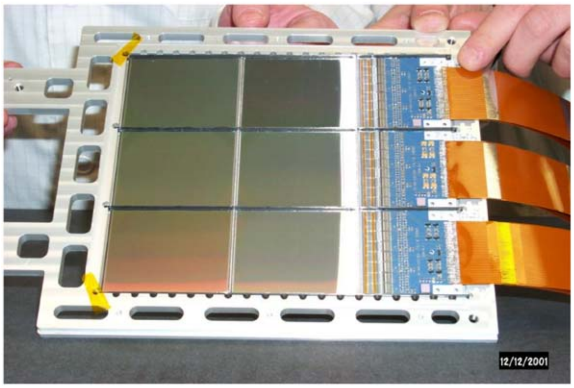

Fig. 2. A photograph of a detector plane in its aluminum frame.

The adequacy of the structure has been repeatedly checked: during dedicated vibrational test sessions, the "flight model" structure survived intensities about twice as large as those requested by the Russian space company.

2.1. Main characteristics of the sensors

On the junction side, used to measure the coordinate (X) along which particles are bent by the magnetic field (and for this reason called "bending view"), the read-out pitch is 51 μm and one intermediate floating strip is present. On the ohmic side, which measures the Y coordinate, the strip pitch is 66.5 μm; a p-stop strip is added to increase the interstrip resistance to prevent charge from spreading on the backplane. On both sides decoupling capacitors are integrated directly on the sensor.

The read-out electronics in based on VA1 chips [4,5] housed on the same substrate for both sides, thanks to a double metal layer on the ohmic view. The main requirements to be achieved by the electronics are a low noise (strictly related to the obtainable spatial resolution) and a small power consumption (because of the constraints imposed by the space mission). In the PAMELA configuration mean values of the signal-to-noise ratio greater than 50 and 25 have been obtained for minimum ionizing particles on junction and ohmic sides, respectively, with 1 mW per channel power consumption: S/N ratios are reported in Fig. 3 for data gathered at CERN-SPS in September 2003. In our configuration the corresponding values of the spatial resolution are 3 μm for the junction side and 12 μm for the ohmic view. The dynamic range of the VA1 chip is about 10 MIP.

3. Measurements of momenta

In order to reconstruct the momentum of a particle that crosses the spectrometer an algorithm, based on a numerical integration of its equation of motion, has been used. Starting from initial values of the particle's position and velocity the corresponding trajectory can be estimated, i.e. six incidence points on the spectrometer planes can be found. The magnetic field in each point inside the cavity has been previously determined by interpolation from a map obtained with 5 mm pitch in every direction by means of a three-axes Hall probe, moved by an automatic positioning machine. A χ^2 function is then exploited to find the best estimation of the trajectory, and therefore of the particle momentum.

The momentum resolution is directly connected to the spatial resolution of the detectors. In a well-known relationship [6]

$$p_t[\mathrm{GeV}/c] = 0.3zB[\mathrm{T}]\rho[\mathrm{m}]$$

the radius of curvature ρ of the track, the (constant) magnetic field B and the particle charge z determine the component p_t of the momentum that is orthogonal to B.

At a given value of the magnetic field integral, the error in curvature k, defined by $k \equiv 1/\rho$, is the sum of two contributions, the first one due to multiple scattering, dominant for low momenta, and the second one due to the finite resolution of the detectors, which becomes important for high-momentum tracks. Let us now introduce the so-called *magnetic rigidity*, defined as momentum-to-charge ratio and measured in GV/c: the finite spatial resolution sets a Maximum Detectable Rigidity (MDR) that is reached when the relative error in rigidity (or in momentum, for charge = 1 particles) is 100%. An estimation of the momentum resolution for 4 μm spatial resolution is reported in Fig. 4 for electrons, protons and alpha particles: for protons the minimum relative error $\Delta p/p$ is about 4% for $p \simeq 10$ GeV/c; MDR is 740 GV/c.

4. Simulation of the tracking system

In order to better investigate the spatial resolution capabilities of the sensors, for both orthogonal and inclined tracks, a simulation of the detectors has been developed. The code is based on GEANT and reproduces ionization in silicon with 10 μm intrinsic pitch to check the displacement of charge in silicon in case of emission of secondary energetic electrons (δ-rays). Charge packets created in the sensitive volume are drifted

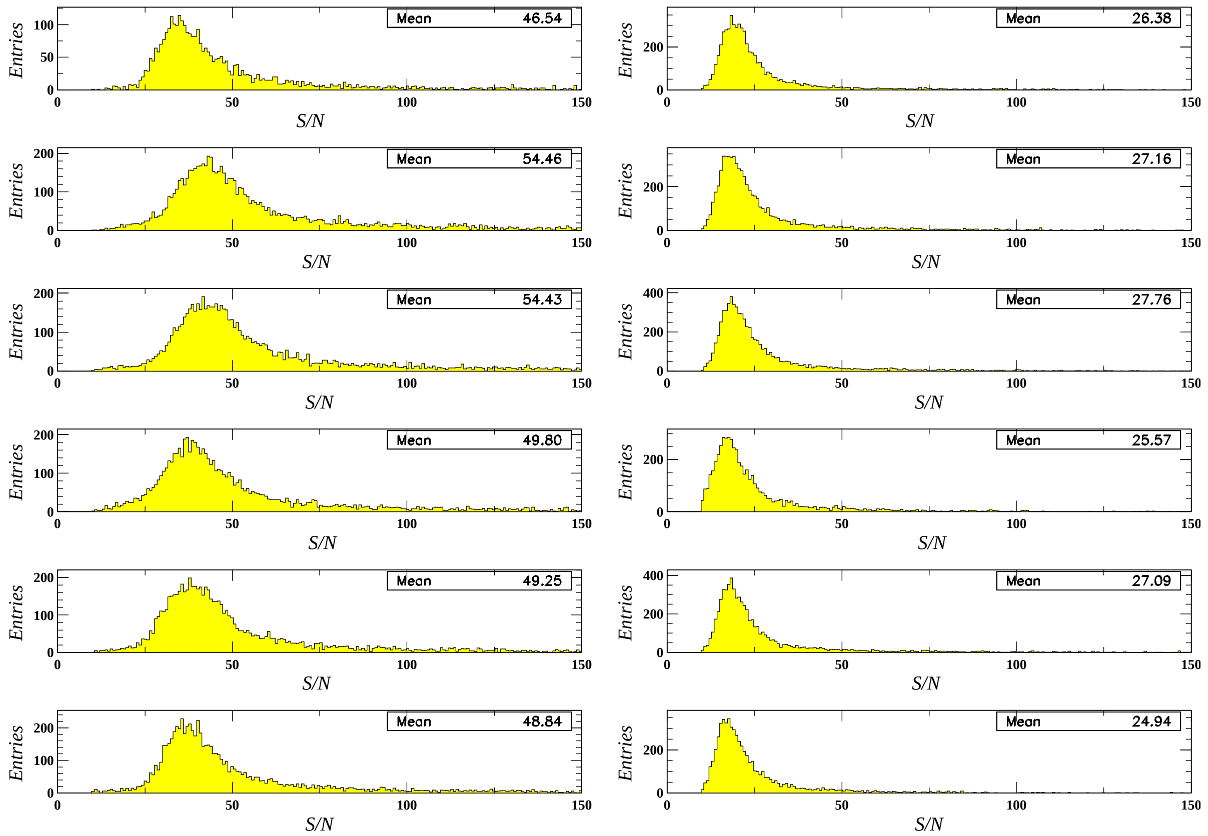

Fig. 3. Signal-to-noise ratios for the six detector planes of the spectrometer as measured from MIP data acquired at CERN-SPS in 2003 (junction side on the left column, ohmic side on the right one).

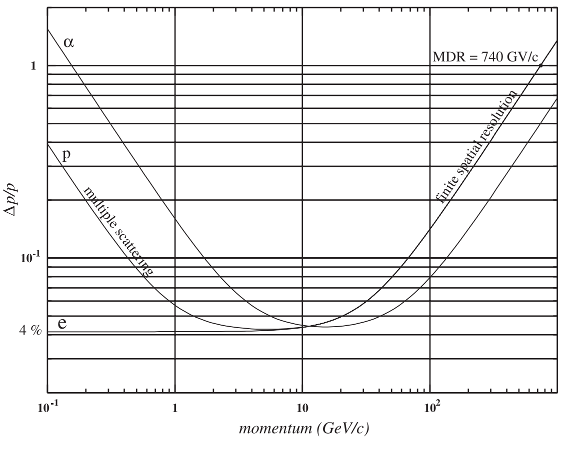

Fig. 4. Simulated relative error $\Delta p/p$ for electrons, protons and α particles in the PAMELA spectrometer: MDR is 740 GV/c.

along the electric field lines toward the electrodes, where reverse bias is applied. Interstrip capacitive couplings rearrange the collected charge among adjacent channels.

The code has been tuned on data: it can accurately reproduce the event multiplicity (defined as the number of fired strips) for tracks orthogonal to the sensor or inclined. Simulation has been exploited to study the spatial resolution obtainable at different incidence angles by means of different position finding algorithms. For orthogonal tracks the best resolution is obtained by the non linear eta algorithm [7]: the corresponding resolution function on the bending view has been found to be not Gaussian (Fig. 5), but well described by a generalized Lorentz

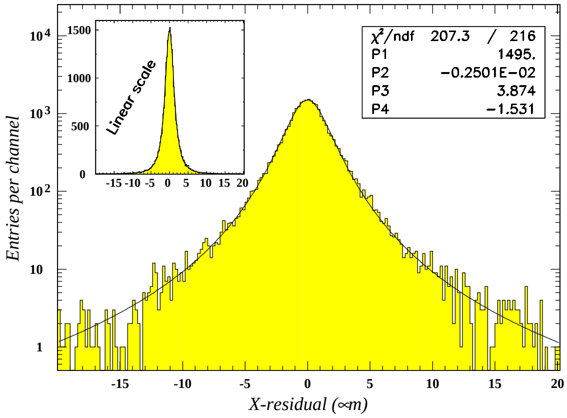

Fig. 5. Simulated distribution of residuals for the junction side of the detectors. The distribution around the mean is not Gaussian but it can be described by a Lorentz function as that reported in Eq. (1).

function L

$$L = p_1 \cdot \left[1 + \left(\frac{2 \cdot (x - p_2)}{p_3}\right)^2\right]^{p_4} \tag{1}$$

whose parameters $p_1, \ldots, p_4$ are evaluated in the box in the figure. The RMS of the distribution is 2.87 μm, which is in agreement with the measured resolution on the junction side. If in a simulation of the tracking system the positions of the impact points are distributed according to this function, the effect of the spatial resolution on the momentum uncertainty $\Delta p/p$ can be studied.

Concerning the momentum resolution, the problem of the *spillover background* is of particular interest in antimatter measurements in cosmic rays. Although the estimated MDR is 740 GV/c, we expect to measure the antiproton spectrum up to about 200 GV/c. In fact, for small curvature tracks the charge sign can result wrong due to both finite spatial resolution and multiple scattering. The error in sign is then amplified by the very different intensities of the fluxes Φ of p and $\bar{p}$ in cosmic rays: $\Phi(\bar{p})/\Phi(p) \sim 10^{-4}$. Looking at the preliminary estimation reported in Fig. 4 for the MDR, a better spatial resolution has been found in real detectors (3 μm instead of 4 μm), that increases the MDR and consequently decreases the spillover, but tails larger than those of a Gaussian function are present in the resolution function, resulting in a bigger than expected spillover. A simulation study is in progress to analyze in detail the net result of these conflicting effects in antimatter measurements.

5. Conclusions

The PAMELA spectrometer has been assembled with the other subdetectors and now it is ready to be delivered to the Russian counterpart for installation onboard the Resurs DK satellite. Launch is foreseen in the first half of 2004. The flight model complies with the proposal: the characteristics of the detector will allow to perform high energy antiparticle measurements in orbit during a three year data taking.

References

[1] S. Straulino, et al., Nucl. Instr. and Meth. A 478 (2002) 114.
[2] P. Spillantini, et al., Nucl. Phys. B (Proc. Suppl.) 122 (2003) 66.
[3] O. Adriani, et al., Nucl. Instr. and Meth. A 511 (2003) 72.
[4] O. Toker, et al., Nucl. Instr. and Meth. A 340 (1994) 572.
[5] IDEAS, The VA1, web page: `http://www.ideas.no`.
[6] Particle Data Group, Review of Particle Physics, Springer, Berlin, 2002.
[7] R. Turchetta, Nucl. Instr. and Meth. A 335 (1993) 44.