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The PAMELA experiment

The PAMELA Collaboration

Abstract

The PAMELA telescope will be installed on board of the Resurs-Arktika satellite (VNIIEM) and the launch is foreseen in 2002. The satellite will fly for at least 3 years in a polar orbit at about 700 km of altitude.The main goals of the PAMELA experiment are the measurement of the antiproton and positron fluxes in cosmic rays, with large statistics in an energy range between 100 MeV and 150 GeV, and the search for antinuclei, up to 30 GeV/n, with a sensitivity better than 10^{-7} in the $\overline{\mathrm{He}}/\mathrm{He}$ ratio. PAMELA will also study phenomena connected with Solar and Earth physics. The PAMELA telescope consists of a magnetic spectrometer, a TRD detector, an imaging electromagnetic calorimeter and a TOF system including anticoincidence detectors.

1 Introduction:

The PAMELA experiment is the main part of the Russian Italian Mission (RIM) program that was conceived in the '90s to study cosmic rays in space. The RIM program follows an approach consisting in several steps. The first experiment (RIM–0.1, called Si–eye–1, Bidoli, et al., 1997) has taken data on board of the Russian MIR Station starting from October '95, and a second one (RIM–0.2 experiment, called Si-eye–2) was brought to MIR in '97. These two experiments, based on small silicon telescope detectors, measure the path track and the energy loss of high ionizing particles in coincidence with the light flashes seen by astronauts during the flight. The second RIM experiment (called NINA, Bidoli, et al., 1999) has been launched in space on board of the Russian satellite Resurs–Arktika n.4 in July 1998. Its main goal is to study the anomalous, galactic and solar components of cosmic rays at low energy (10÷200 MeV/n).

The PAMELA experiment of the RIM program will be launched in the 2002 on board of the Russian Resurs–Arktika n.5 satellite. The satellite will fly on a polar orbit, 690 km high, and the duration of the flight will be at least three years. In figure 1 a schematic view of the telescope is shown. This is composed of:

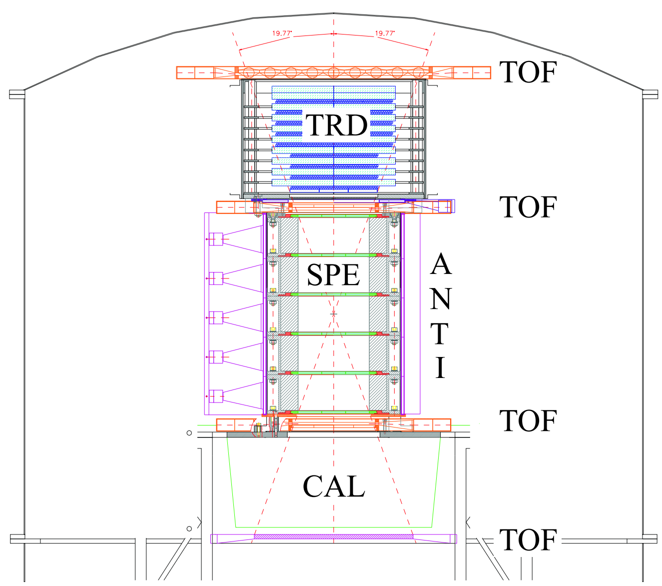

Figure 1: *the PAMELA telescope. The main detectors are: a transition radiation detector (TRD), a permanent magnet spectrometer equipped with silicon microstrip detector (SPE) and a silicon/tungsten calorimeter (CAL). There are also a time of flight detector (TOF) and an anti-coincidence system (ANTI) made by plastic scintillator.*

1. a magnetic spectrometer (SPE) based on permanent magnet system and silicon microstrip detectors capable of determining the sign and the absolute value of the electric charge with a very high confidence level, and of measuring the momentum of the particle up to the highest energies, allowing collect a useful flux of rare particles (as antiprotons and positrons) according to the PAMELA acceptance and the duration of the flight;

2. an electromagnetic imaging calorimeter which gives both the measurement of the energy released by the interacting electrons and positrons and the particle interaction pattern inside the calorimeter. The latter allows to distinguish electromagnetic from hadronic showers (and from non interacting particles) with a high level of confidence and efficiency;

3. a threshold velocity measurement system based on a Transition Radiation Detector (TRD). It is made by carbon fiber radiators and straw tube detectors and its main task is to complement the calorimeter in the particle identification;

4. a plastic scintillator hodoscope system as time of flight counter (TOF) plus an anti-coincidence system to identify particles interacting in the mechanical structure of the telescope (ANTI).

The total height of PAMELA is 105 cm, the mass is 380 kg, the power consumption is 345 W and the geometrical factor is 20.5 cm^2 sr.

2 Scientific objectives:

The observational objectives of the PAMELA experiment are to measure the spectra of antiprotons, positrons and nuclei in a wide range of energies, to search for antimatter and to study the cosmic ray fluxes over a portion of a solar cycle.

The main observational objectives can be schematically listed as the following:

a) measurement of the $\overline{p}$ spectrum in the energy range 100 MeV $\div$ 150 GeV;
b) measurement of the e^+ spectrum in the energy range 100 MeV $\div$ 200 GeV;
c) search for antinuclei with a sensitivity of about 10^{-7} in the $\overline{He}$/He ratio;
d) measurement of the nuclei spectra (from H to C) in the energy range 100 MeV/n $\div$ 200 GeV/n;
e) measurement of the electron spectrum in the energy range 100 MeV $\div$ 300 GeV.

Moreover, the PAMELA experiment has the following additional objectives:

a) continuous monitoring of the cosmic rays solar modulation during and after the 23rd maximum of the solar activity;
b) study of the time and energy distributions of the energetic particles emitted in solar flares;
c) measurement of the anomalous component of cosmic rays;
d) study of stationary and disturbed fluxes of high energy particles in the Earth's magneto-sphere.

Figure 2: *view of the PAMELA magnetic spectrometer prototype.*

These objectives are in the reach of PAMELA because the satellite travels in a polar orbit, indeed spending a large fraction of its time in the high latitude and polar regions, where the cut–off due to the terrestrial magnetic field is negligible. The scientific relevance of these four objectives is enhanced by the length of the mission.

PAMELA is a powerful instrument that will carry out astrophysical observations at a level of sensitivity never reached either by previous experiments or any conceivable high altitude balloon-borne experiment which are limited by the effects of the overlying atmosphere and by the low statistics. The PAMELA observations will extend the results over an unexplored range of energies with large statistics and will complement information gathered from Great Space Observatories and ground–based cosmic–ray experiments. In the case of particles such as positrons and antiprotons, the spectra will be determined over three decades of energy to test many theoretical predictions and models. Also the spectra of primary components of cosmic rays will be measured over more than three decades in energy with high accuracy; the availability of long duration exposure provides the first opportunity for a detailed study of temporal variations of cosmic rays at relativistic energies; the possibility of measuring the cosmic ray spectra with the same instrument over a significant portion of a solar cycle from its beginning to beyond its maximum is of major importance.

3 Detector performances:

Prototypes of each sub–detector of PAMELA have been built and tested to measure the detector performances. Moreover, the prototypes have been also tested to probe the resistance at vibrations and shocks during the launch phase. The results show a good mechanical behaviour for all the sub–detectors.

3.1 Magnetic spectrometer: The general scheme of the magnet system consists of five modules, each 81 mm high, interleaving six frames 8 mm high, in which the silicon sensors are accommodated. The total height of the spectrometer is 445 mm with a rectangular cavity 131×161 mm^2 corresponding to a geometrical factor of 20.5 cm^2 sr. The magnetic material used is a sintered Nd–Fe–B alloy with large residual magnetic induction ($\sim$ 1.3 T). The field inside the spectrometer is 0.4 T at the center. Outside the spectrometer the field is screened by a ferrimagnetic shield. A view of the magnetic spectrometer prototype is shown in figure 2. Inside the spectrometer are inserted six detector planes composed by 6 silicon sensors, 70×53.33 mm^2 wide and 300 μm thick (Adriani, et al., 1998 and The PAMELA Collaboration, 1999a). The tracker detectors have been tested using particle beams at PSI (Zurich) and at CERN (Geneva). The main result is the measurement of the spatial resolution of a single detector. As shown in figure 3 the resolution results 3.0±0.1 μm in the coordinate corresponding to the bending direction of the particles passing through the spectrometer. In the other coordinate the measured resolution is 11.5±0.6 μm. The Maximum Detectable Rigidity of the PAMELA spectrometer, resulting from the performed tests, is about 800 GV/c and the spectrometer simulation shows that the proton and electron spillover sets a maximum energy limit in the antiproton and positron measurements to about 200 GeV.

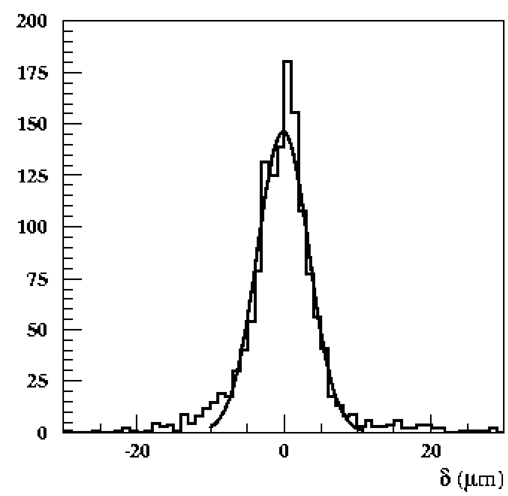

Figure 3: *measured spatial resolution of the microstrip silicon detector of the PAMELA spectrometer.*

3.2 Electromagnetic imaging calorimeter: It is a sampling calorimeter made of silicon sensor planes interleaved with tungsten absorbers (The PAMELA Collaboration, 1999b). The sensitive area of one detector plane is 240×240 mm^2 and it consists of a 3×3 matrix of single sided silicon detectors 80×80 mm^2 wide, which are divided in strips with an implant pitch of 2.4 mm. This high granularity permits a very good path reconstruction of the particle energy released in the calorimetric volume. The thickness of the silicon sensors is 380 μm and that of the absorber tungsten layers is 2.6 mm corresponding to 0.7 X_0. The whole calorimeter is made of 46 detector layers (23 for the X view and 23 for the Y view) and 22 absorber layers. Several calorimeters of this kind have been already built, tested and used in balloon flight experiments of the WiZard collaboration (TS93, CAPRICE94, CAPRICE98). The performances of these calorimeters are well studied and the simulation of the Si/W calorimeter in the PAMELA configuration gives a resolution in the electron and positron energy measurement better than 5% in the range 20–100 GeV (and $\sim$6.5% at 250 GeV) and a rejection power of protons and electrons in the positron and antiproton identification of 10^4 with a selection efficiency better than 90% as shown in table 1.

3.3 Transition Radiation Detector: The PAMELA Transition Radiation Detector (TRD) (The PAMELA Collaboration, 1999c) is used to select electromagnetic particles out of hadrons up to very high energy

p (GeV/c)	# electrons	# antiprotons	# contam. electrons	# selected antiprotons	contam. (%)	efficiency (%)
5	10000	10000	1	9163	0.01±0.01	92±1
10	8000	4000	1	3648	0.01±0.01	91±1

p (GeV/c)	# protons	# positrons	# contam. protons	# selected positrons	contam. (%)	efficiency (%)
5	43000	3000	2	2892	0.005±0.003	96±2
10	48000	3000	1	2945	0.003±0.003	98±2

Table 1: *efficiency of $\overline{p}$ selection and electron residual contamination in the $\overline{p}$ sample and efficiency of positron selection and proton residual contamination in the positron sample using the PAMELA calorimeter.*

(∼1000 GeV) and it is based on small diameter straw tubes (4 mm) arranged in 9 double layer planes interleaved by carbon fiber radiators.

The use of the pulse–height measurement technique allows to perform the particle selection based on energy loss criteria and to track all particles before their entrance in the magnetic spectrometer, cleaning the sample of the particles accepted at its entrance. The PAMELA TRD detector has been tested at CERN using a 3 GeV pion and electron beam. In figure 4 is shown the pion contamination as a function of the efficiency of the electron selection.

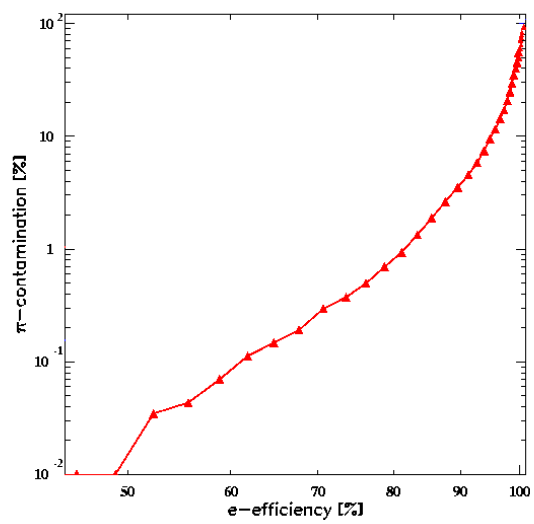

Figure 4: *plot of residual contamination of π^- versus e^- selection efficiency with the PAMELA TRD detector.*

4 Conclusions:

The PAMELA project is completely defined and each sub–system and detector prototype has been built and tested. These tests show that the performances meet the requirements and that the PAMELA experiment can fulfil its scientific objectives. The flight model is under construction and it will be ready for the integration on–board of the Resurs–Arktika satellite in 2001. The launch is foreseen in 2002 with a mission duration at least three years long.

References

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