PAMELA Space Mission: The Transition Radiation Detector

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Abstract

PAMELA telescope is a satellite-borne magnetic spectrometer built to fulfill the primary scientific objectives of detecting antiparticles (antiprotons and positrons) in the cosmic rays, and to measure spectra of particles in cosmic rays. The PAMELA telescope is currently under integration and is composed of: a silicon tracker housed in a permanent magnet, a time of flight and an anticoincidence system both made of plastic scintillators, a silicon imaging calorimeter, a neutron detector and a Transition Radiation Detector (TRD). The TRD detector is composed of 9 sensitive layers of straw tubes working in proportional mode for a total of 1024 channels. Each layer is interleaved with a radiator plane made of carbon fibers. The TRD detector characteristics will be described along with its performance studied exposing the detector to particle beams of electrons, pions, muons and protons of different momenta at both CERN-PS and CERN-SPS facilities.

1. Introduction

PAMELA is a satellite-borne magnetic spectrometer designed and built with the objectives of measuring the spectra of antiprotons, positrons, particles and nuclei in a wide range of energies. PAMELA will be able to measure magnetic rigidities up to a Maximum Detectable Rigidity (MDR) greater than 700 GV/c. This MDR will make it possible to extend the energy range of antimatter measurement up to 190 GeV for antiprotons and 270 GeV for positrons.

To measure the charge sign and momenta of a particle and to insure their identification PAMELA instrument is equipped with a permanent magnet silicon spectrometer [5], a time of flight system (TOF), an imaging silicon calorimeter [3] and a TRD. To help vetoing background events, an anticoincidence system is installed around the magnetic spectrometer. The secondary objective of measuring TeV electron will be made possible by a neutron detector and a scintillator counter placed at the bottom of the PAMELA instrument. A 3D view of the PAMELA instrument is shown in Fig.1. For full details on PAMELA space mission, please refer to the specific contribution in this conference [4].

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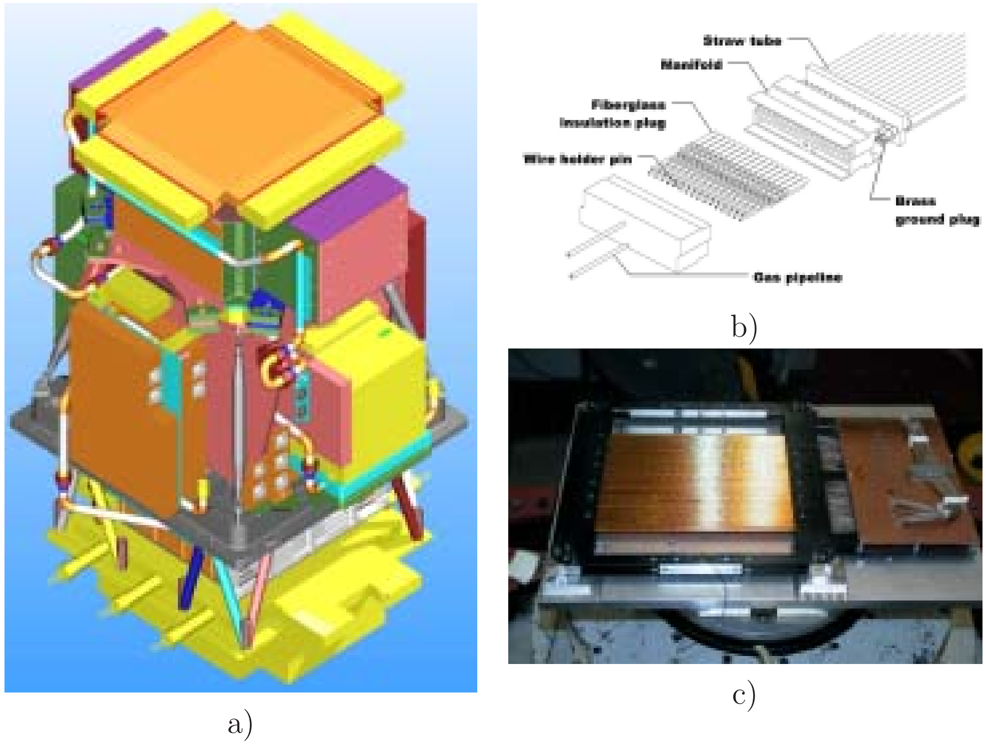


Fig. 1. a) A 3D view of the PAMELA instrument. b) Detail of a module assembly. c) A sensitive plane, without radiator.

2. The Transition Radiation Detector

The TRD will be used to is the discriminate positrons (electrons) from protons (antiprotons). This is achieved measuring the transition radiation (TR) emitted by a relativistic particle crossing boundaries of material with different electromagnetic characteristics.

The PAMELA TRD will use carbon fibers as radiator material and gas proportional straw tubes to detect the emitted radiation.

A proportional straw tube is 28 cm in length and 4 mm in diameter; it is made of a copperized kapton foil, 25 μm thick. Inside each tube a tungsten anode wire, 25 μm in diameter, is stretched up to a $\simeq$60 g tension. The straw tubes are grouped, in a closed pack layout, in modules of 32; they are attached to two aluminum parts acting as gas manifolds as well as holders for the signal pins, the insulator and ground plugs. The kapton foil is attached to the ground plug; the tungsten wire is soldered to the signal pin which is inserted on a fiberglass insulator plug. An explosed view of a manifold assembly on a module side is shown in Fig. 1.

Straw modules are fixed sideways in between two frames to build a sensitive plane. The top frame does include the radiator which is made of carbon fibers packed with a 60 g/l density. Picture of a sensitive plane without radiator is shown in Fig.1. The full TRD is made of 9 of these sensitive planes, arranged to form an upside-down truncated pyramid shape, for a total of 1024 straw tubes.

The TRD front-end electronics does use the charge integration technique; each straw signal is collected into a custom made chip, CR1.4P [1], in which 16 charge preamplifiers and shapers, a multiplexed output buffer along with 16 multiplexed calibration inputs are packed. The amplified signals are digitized by a 12-bit ADC and sent to a DSP based read-out card that supervises the data packing and communications with the PAMELA data acquisition.

In order to have a high efficiency in converting TR photons and to work in proportional mode, each straw tube is filled with a gas mixture of Xenon and CO_2 (80% Xe, 20% CO_2) at a working voltage of 1400 V.

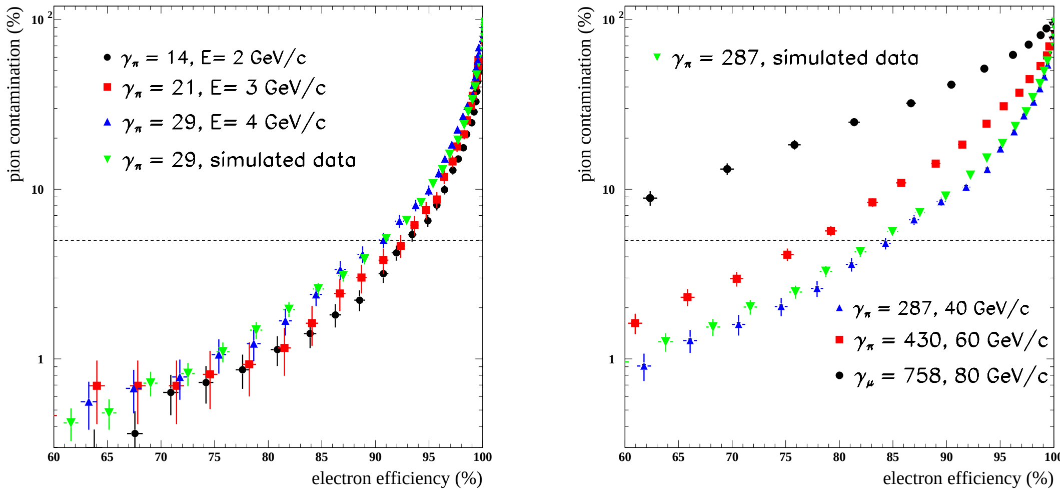
3. Beam test performance

The PAMELA TRD has been designed to reach a rejection factor of 5% from minimum ionizing particles at 90% of electron efficiency.

This performance has been verified during several beam tests at CERN PS and SPS facilities, where a TRD prototype has been exposed to electron, pion, muon beams of several values of momentum in the range $2\div5$ GeV/c (PS) and $40\div80$ GeV/c (SPS).

Particles in the beam have been tagged using the beam facilities, collected data have been further reduced selecting tracks crossing the full TRD and using a prototype of the PAMELA calorimeter to eliminate the beam background due to tagging inefficiencies and beam secondaries. For the reduced data samples the energy release in each TRD straw has been calculated and likelihoods indicator distributions have been estimated for each particle family. Using this indicator the performance, in terms of rejector factor as a function of the electron efficiency, have been evaluated for each energy [2]. The results of the analysis are reported in Fig. 2. At the SPS energies particles are no more in the minimum ionizing region, this produces an increase in ionization loss that reduces the signal (TR) to noise (ionization) ratio and deteriorates the detector performance. At even higher energies, particles begin to radiate transition radiation. However, it is worth noting that Lorentz factor (γ) values at these energies are greater than the ones in the range of the PAMELA primary objective.

Along with the data analysis an original TR simulation code has been developed in the GEANT 3.21 framework. Besides, an interface with the HEED and GARFIELD packages [6] has been developed to better simulate the ionization losses in the straws. Using this code it has been possible to calibrate in energy the collected data, and also to fine tune the TR simulation. Once tuned, the simulation has been used to produce simulated data set at the beam test energies;



a) b)

Fig. 2. Results from the PS, a), and SPS, b), data analysis. Simulated performance are superimposed.

the obtained performances have been compared to the one calculated for the real data sets [2]. Results of the simulation for two γ values have been superimposed to the beam data in Fig.2.

4. Conclusions

The PAMELA TRD will be able to discriminate protons from positrons with a rejection factor of 5% at 90% electron efficiency. The construction of the TRD flight model is almost completed. Beam tests confirm the design performance and have been used also to fine tune a custom made simulation included in the overall GEANT-based PAMELA simulation.

5. References

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6. See http://wwwasd.web.cern.ch/wwwasd/cernlib/ for details.