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The Transition Radiation Detector for the PAMELA experiment

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Abstract. A Transition Radiation Detector (TRD) has been developed and tested for the PAMELA instrument. PAMELA is a satellite borne magnetic spectrometer aimed to the detection of antiparticles (positrons and antiprotons), protons and nuclear components of cosmic rays and to the search of cosmic antinuclei. The TRD detector will be used together with an electromagnetic calorimeter for particle identification. The TRD is composed of 9 active layers made of proportional straw tubes, interleaved with carbon fibers radiators. We describe here its performances as determined at particle beam tests, with different particles and at different energies performed at the CERN-PS and CERN-SPS.

1 Introduction

The PAMELA instrument is a satellite borne magnetic spectrometer designed to study the composition and energy spectra of cosmic rays, with special focus on antiparticle detection ($\bar{p}$ and e^+), at energies above 10 GeV (Bonvicini et al., 2001). The investigation of $\bar{p}$ and e^+ spectra is important to understand the origin and propagation of cosmic rays. Recent results (Bergström et al., 2000) are consistent with a hypothesis of secondary production but the measurements, specially at energies larger than 10 GeV, need to be extended.

PAMELA will be equipped with the following detectors, arranged as in Figure 1: a tracker spectrometer (Adriani et al., 1999), a transition radiation detector (TRD), a silicon-tungsten imaging calorimeter (Bonvicini et al., 2000), a time of flight system (TOF) and anticoincidence counters (ANTI). A detailed description of the PAMELA instrument will be given elsewhere in this conference (Adriani et al., 2001).

The selection of positrons, in particular, requires a rejection factor for singly charged particles greater than 10^{-5}. PAMELA will be able to reach this sensitivity by using the combined identification of the calorimeter and the TRD. In particular the TRD has been designed to reach, for the three years of the scheduled mission lifetime, a hadron rejection factor of 5% at an electron efficiency of about 90%.

In the following the PAMELA TRD will be described briefly. Next, results of beam tests carried out at the CERN Proton Synchrotron (PS) and Super Proton Synchrotron (SPS) facilities will be presented.

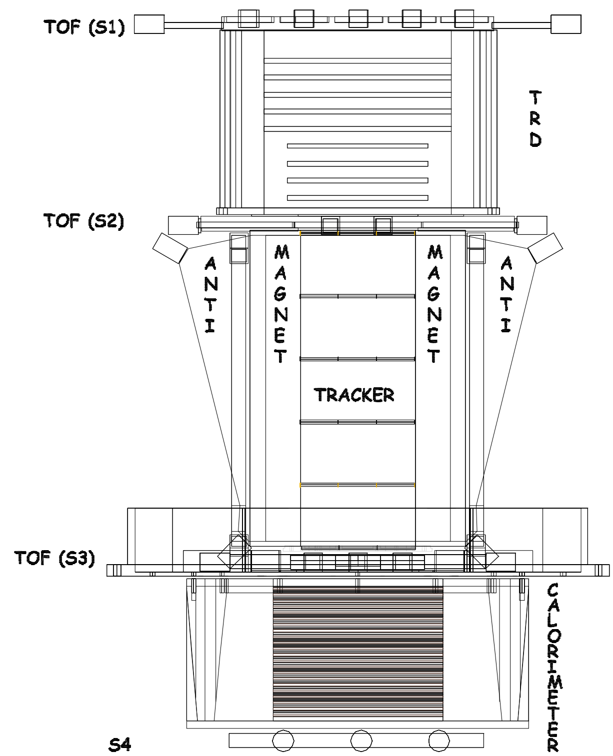

Fig. 1. Schematic view of PAMELA instrument.

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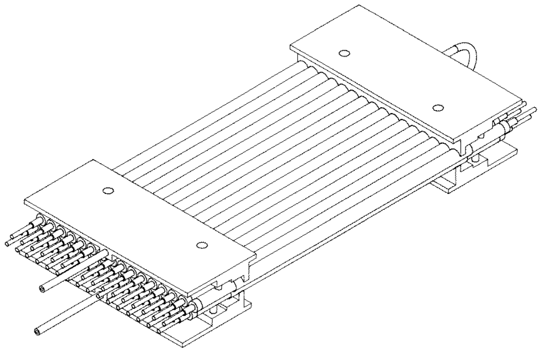

Fig. 2. Artistic view of a 32 straws module.

2 The Transition Radiation Detector

The PAMELA TRD will be placed on top of the magnetic spectrometer, between two scintillator layers of the TOF system. The detector has a modular design; the basic component is a straw tube of 4 mm diameter and of 28 cm length, made with a 30 μm thin copperized Kapton foil. A tungsten anode wire, 25 μm diameter, is placed inside the tube and stretched to a tension of $\approx$ 55 g. Sixteen tubes are arranged sideways in a layer. Two of these layers are glued in a close-pack configuration, to get a uniform X-ray yield. An artistic view of this 32 straws module is shown in Fig. 2.

Each straw module is filled with a mixture of Xe and CO_2 (80%, 20%) working at an operating voltage of 1400 V. This combination of gas mixture and operating voltage has been chosen to maximize the photon conversion and to operate the straw tubes in a region of moderate gain.

A detection plane is formed housing these modules on a special frame. The frames are stacked interleaved with radiators composed of carbon fibers packed with 60 g/l density. The full TRD is made of 9 of these planes and 10 radiators for a total of 32 modules, *i.e.* 1024 straw tubes.

The straw signal is read out using a charge integration technique. The charge signal, from each tube, is collected and sampled by a multiplexed preamplifier, custom made for PAMELA and the ATIC experiment: the CR1.4P VLSI chip (Adams et al., 1999). The chip output is digitized by a 12 bit ADC and written into the memory bank of a digital signal processor (DSP) that controls and generates the read-out sequence.

3 Beam tests

Prototypes of PAMELA detectors have been tested at CERN PS and SPS facilities (CERN PS and SL Divisions, 2000). The tracker prototype consisted of 5 silicon detectors inserted in the cavity of two modules of magnetic material. The field intensity in the centre of the cavity was $\approx$ 0.6 T. The calorimeter prototype consisted of 6 layers of silicon detectors and 17 tungsten layers, inserted into the full scale flight container. Nine modules of straw tubes and 10 radiator planes, *i.e.* a full length prototype, were used for the TRD. Prototypes of the anticoincidence counters and bottom scintillator counter were also present. All prototypes were aligned with a trigger system composed of scintillator paddles and exposed to pions, electrons and muons beams. In order to avoid multiple tracks, a veto scintillator paddle was used to restrict the beam geometry.

During the tests at the PS facility, pion and electron beams in the momentum range from 2 to 5 GeV/c were selected. A specialized trigger to tag both particle families was implemented using two threshold Cherenkov counters.

The tests at the SPS facility were carried out using pion, electron and muon beams in the momentum range from 40 to 100 GeV/c. No Cherenkov counter was used in this set-up.

In both cases the beam contamination was not negligible: at the PS the Cherenkov rejection factor was higher than 5%, while at SPS muons were present in the electron and pion beams.

4 Data analysis

Each data sample has been first reduced by applying a pedestal subtraction procedure along with a common noise correction. A pattern recognition procedure has been applied to the reduced data in order to select events with a single track traversing the TRD. A track has been reconstructed for each event having a minimum of 4 layers hit. Subsequently a fiducial area of 5 tubes, centered on the track, has been defined and only hits in this area were considered for the analysis.

The signal of each tube present in the fiducial area was summed up for each plane and then for the full TRD. In Fig. 3 the total energy distributions are shown for both radiating (electrons) and non-radiating (pions) particles with a momentum of 40 GeV/c.

In order to study the TRD rejection factor, clean samples of non-radiating and radiating particles are needed. In particular, the overall contamination of the samples has to be less than the detector rejection factor. The information from the calorimeter prototype was used in the analysis of both test data samples for this purpose.

For the calorimeter selection two discriminating quantities have been used: the number of strips hit, strictly connected to the event topology, and the total energy detected, connected to the interaction type. Cuts on these variables were studied in order to select three event classes: electrons, interacting pions and muons plus non-interacting pions. The different classes of events are shown in Fig. 4.

The electron samples, having a γ well over the radiation threshold, were used as a reference for particles emitting saturated transition radiation for the analysis of both PS and SPS data; non-interacting pions, instead, as non-radiating particles for the PS data. For the SPS data only interacting pions were used to select clean samples of pions. For momenta greater than $\approx$ 55 GeV$/c$, as expected, it has been observed that pions and muons begin to emit transition radiation. In

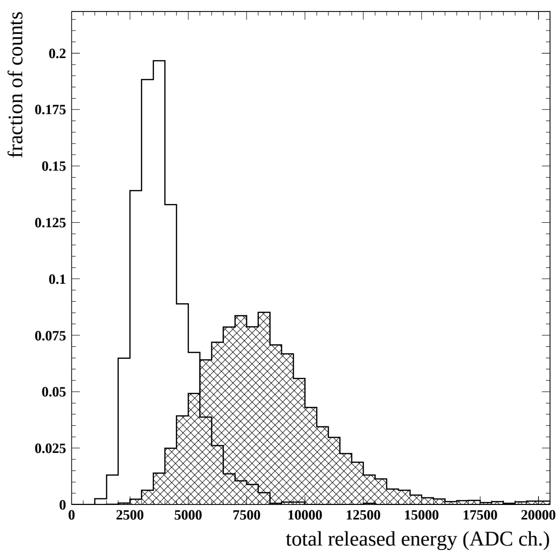

Fig. 3. Total energy detected in the TRD for radiating (electrons) and non-radiating (pions) particles of 40 GeV/c momentum.

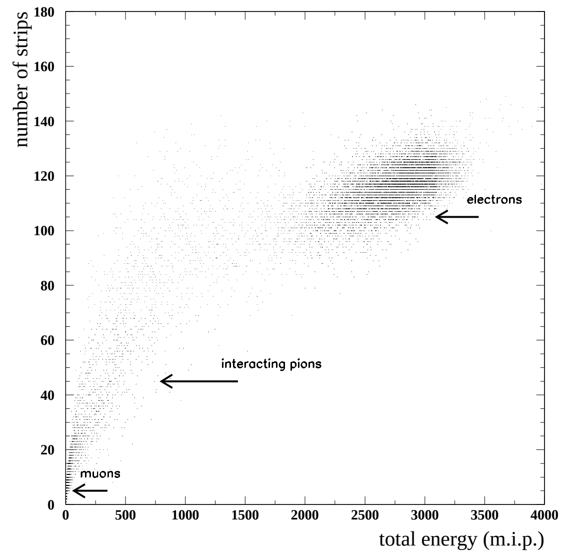

Fig. 4. Particle selection with the calorimeter: the discriminating variables are shown for particles at 80 GeV/c. The three event sets used for this data analysis are marked.

particular, due to the slight mass difference, muons start the emission at lower momentum than pions. For this reason only interacting pion events, at 40 GeV$/c$, were used as non-radiating particle sample, along with a 100 GeV$/c$ pion sample acquired without radiators.

5 TRD performances

The TRD performances can be described in terms of a rejection factor defined as:

$$R_{nonrad/rad} = \frac{\epsilon_{nonrad}}{\epsilon_{rad}}, \tag{1}$$

ϵ_{nonrad} and ϵ_{rad} being the identification efficiencies for non-radiating and radiating particles, respectively.

For each single-track event passing the calorimeter cuts, these efficiencies have been estimated from a likelihood distribution calculated from the energy released on each TRD plane. First the probability distributions for releasing the measured values of energy have been estimated from the electron (radiating) and pion (non-radiating) reference samples. Then using these reference distributions the following likelihood indicator has been calculated for each event:

$$\log L_e = \log \frac{\prod_{i=1}^{n} P_e^i}{\prod_{i=1}^{n} P_\pi^i}, \tag{2}$$

where $P^i_{e(\pi)}$ is the probability of an electron (pion) to produce the detected signal in plane i. The amount of pion contamination in the electron sample has been therefore estimated in correspondence to a cut on this indicator which selects a given fraction (90$\%$) of the electron sample.

The values of pion and muon contamination obtained at 90% of electron selection efficiency are shown in Fig. 5 versus γ for the different data samples acquired in the two test set-ups.

As expected, pions and electrons of few GeV$/c$ of momenta can be rejected to the level of about 5 $\%$ at an electron efficiency of about 90$\%$. At higher energies, the relativistic increase of ionization losses of pions and muons slightly degrades the detector performance. As Fig. 5 also shows, the contamination estimated for pions and muons rapidly increases for $\gamma > 400$ thus giving an indication of the threshold for transition radiation emission. Since the pion contamination at 90 $\%$ electron efficiency increases with increasing momentum, we can conclude that the transition radiation emission is not saturated in this range of velocities. The presence of transition radiation emitted by high-momentum pions and muons has been checked with data acquired without radiators from 100 GeV$/c$ pions ($\gamma = 716$). As shown in Figure 5 the estimated contamination for this sample is comparable to that of 40 GeV$/c$ ($\gamma = 286$) pion one, as it is expected since pions with this momentum do not emit transition radiation.

6 Conclusion

A full length prototype of the PAMELA TRD has been tested at the CERN PS and SPS facilities along with prototypes of all the other detectors of PAMELA.

Here we have shown results from a combined analysis of the signals from different detector prototypes. The TRD performances estimated from this analysis comply with the design specifications. A rejection factor of the order of 5$\%$ for

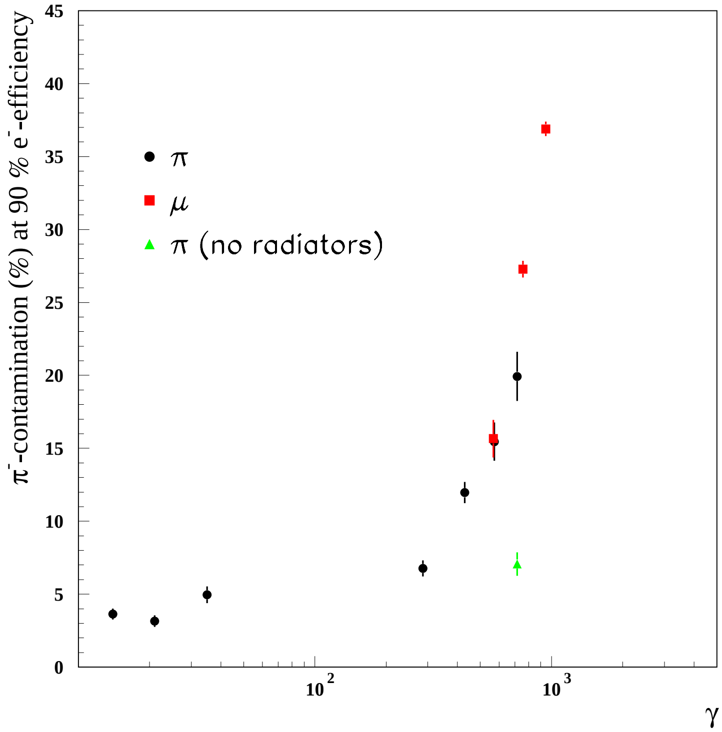

Fig. 5. Contamination from pions and muons at 90% electron efficiency versus the Lorentz factor γ.

non-radiating particles is obtained at an electron efficiency of about 90%. The γ threshold for transition radiation has also been estimated. Further analysis including also the other prototypes of the PAMELA detectors present at beam-test and a software simulation of the TRD are in progress.

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CERN PS and SL Divisions, see CERN Accelerators description at: http://user.web.cern.ch/user/Index/Accelerators.html