# THE TRANSITION RADIATION DETECTOR FOR THE PAMELA EXPERIMENT


O. Adriani[1], M. Ambriola[2], G. Barbiellini[3], L.M. Barbier[4], S. Bartalucci[5], G. Bazilevskaja[6], R. Bellotti[2], D. Bergström[7], V. Bidoli[8], M. Boezio[3], E. Bogomolov[9], V. Bonvicini[3], U. Bravar[10], F.S. Cafagna[2], P. Carlson[7], M. Casolino[8], G. Castellini[11], E.R. Christian[4], F. Ciacio[2], M. Circella[2], R. D'Alessandro[1], C.N. De Marzo[2], M.P. De Pascale[8], N. Finetti[1], T. Francke[7], A.M. Galper[12], N. Giglietto[2], A. Grigorjeva[6], M. Hof[13], S.V. Koldashov[10], M.G. Korotkov[10], J.F. Krizmanic[4], S. Krutkov[9], B. Marangelli[2], W. Menn[13], V.V. Mikhailov[10], N. Mirizzi[2], J.W. Mitchell[4], A.A. Moiseev[10], A. Morselli[8], J.F. Ormes[4], J.V. Ozerov[10], P. Papini[1], A. Perego[1], S. Piccardi[1], P. Picozza[8], M. Ricci[5], P. Schiavon[3], M. Simon[13], R. Sparvoli[8], P. Spillantini[1], P. Spinelli[2], S.A. Stephens[14], S.J. Stochaj[10], Y. Stozhkov[6], R.E. Streitmatter[4], F. Taccetti[14], A. Vacchi[3], Vasiljev[9], V. Vignoli[1], S.A. Voronov[10], N. Weber[7], Y. Yurkin[10], N. Zampa[3]

[1] *University and INFN, Firenze (Italy)*

[2] *University and INFN, Bari (Italy)*

[3] *University and INFN, Trieste (Italy)*

[4] *NASA Goddard Space Flight Center, Greenbelt (USA)*

[5] *Laboratori Nazionali INFN, Frascati (Italy)*

[6] *Lebedev Physical Institute (Russia)*

[7] *Royal Institute of Technology, Stockholm (Sweden)*

[8] *II University and INFN, Roma-Tor Vergata (Italy)*

[9] *Ioffe Physical Technical Institute (Russia)*

[10] *Particle Astrophysics Laboratory, NMSU, Las Cruces (USA)*

[11] *Istituto di Ricerca Onde Elettromagnetiche CNR, Firenze (Italy)*

[12] *Moscow Engineering and Physics Institute, Moscow (Russia)*

[13] *Siegen University, Physics Department, Siegen (Germany)*

[14] *Tata Institute of Fundamental Research, Bombay (India)*

## ABSTRACT

A Transition Radiation Detector (TRD) has been developed for the PAMELA instrument. PAMELA is a satellite born magnetic spectrometer aimed at the detection of cosmic-ray antiparticles (positrons and antiprotons), the measurement of proton and nuclear components of cosmic rays and the search of cosmic antinuclei. It will consist of a magnetic spectrometer with a permanent magnet and a microstrip silicon tracker shielded by an anticoincidence system, a scintillator time of flight detector, a 16.3 radiation length silicon-tungsten calorimeter and a TRD. The TRD detector will provide particle identification, in addition to the calorimeter measurements. It is composed of 9 active layers made of proportional straw tubes, interleaved with carbon fibers radiators. We will illustrate the design of this detector, and describe its performances as determined at particle beam tests.

## INTRODUCTION

The investigation of antiparticle, namely positrons and antiprotons, spectra has an important role in understanding the origin and propagation of cosmic rays. Earlier measurements, carried out with balloon borne detectors, showed, on both positron and antiproton spectra, a flux larger than expected by secondary production in the simple leaky box propagation model. More recent results showed a better agreement with an hypothesis of secondary production but still at energies greater than 10 GeV the measurements by CAPRICE98 (Bergström 2000) need to be extended.

Apart from the technical difficulties of these measurements, in a balloon experiment the fraction of antiparticles produced in the atmosphere above the detector must be correctly determined and subtracted. In addition the small rates involved, especially for the higher energy antiprotons, require a longer exposure time than a tipical flight duration. The PAMELA detector has been designed to overcome these limitations:

it is a satellite borne detector studied to carry out a three year measurement cycle in orbit.

The PAMELA detector is a magnetic spectrometer designed and being built by the WiZard Collaboration (Adriani 1999, Vacchi 2000). This collaboration has been actively present, in the field of antiparticle measurements in cosmic rays, operating balloon borne detectors for more than a decade: several balloon campaigns have been undertaken using a superconducting magnet spectrometer. The spectrometer was complemented, in the different experiments, with a gas Cerenkov and a brass electromagnetic imaging spectrometer (Golden 1991, Bellotti 1999), a transition radiation detector (TRD) and a silicon electromagnetic imaging calorimeter (Golden 1996), a solid state or a gas ring imaging Cerenkov along with the same silicon calorimeter (Barbiellini 1996, Bocciolini 1996, Francke 1999, Ambriola 1999). The WiZard collaboration also built and flew NINA, a silicon detector telescope designed to study the galactic, solar and anomalous components of the cosmic rays in the energy interval 10-200 MeV/n (Sparvoli 2000). The PAMELA detector concept and design are the result of all these experiences in the field.

**THE PAMELA DETECTOR**

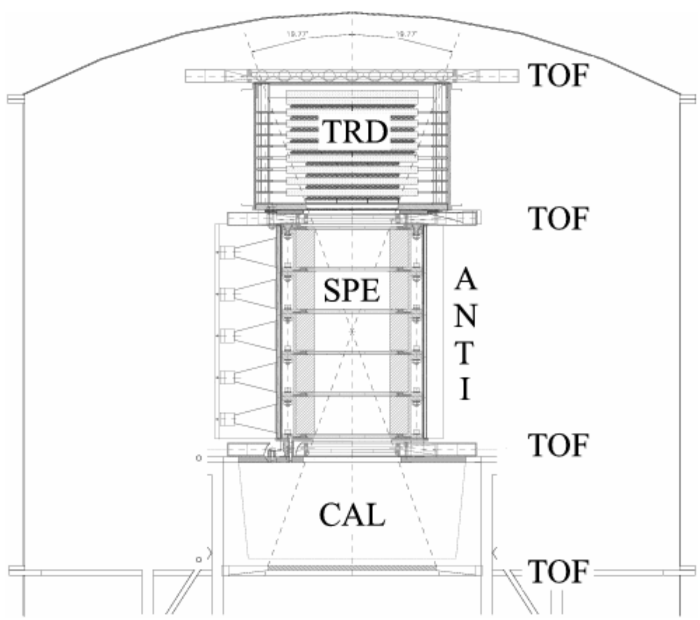


Fig. 1. A section of the PAMELA instrument.

In order to reliably measure positrons (antiprotons) spectra it is necessary to identify them in a large background of protons (electrons). Especially in the former case rejection factors in singly charged particle identification greater than $10^5$ are required.

The small statistics involved, especially at high energies, require redundancy and long time exposures. Also a spectrometer is needed with a high maximum detectable rigidity (MDR) in order to be able to separate oppositely charged particles and to reduce the errors in momentum determination, especially in the higher region of the spectra.

For these reasons the PAMELA detector is equipped with a silicon tracker spectrometer, having a spatial resolution of 4 $\mu$m which results in a MDR of 740 GV for a mean magnetic field of $\approx$0.4T (Adriani 1999b). The required hadron rejection is reached by means of an imaging silicon-tungsten calorimeter (Adriani 1999c), and a TRD. The detector stack is shown in fig.1. It is composed from the top to the bottom of: a time of flight system (TOF), the TRD, the silicon tracking system and permanent magnet (SPE), the silicon calorimeter (CAL). The tracker system volume will be covered with anticoincidence counters to reject multiple tracks and particles produced in the satellite shell.

## THE TRANSITION RADIATION DETECTOR

The PAMELA TRD has a modular design. It is made of proportional straw tubes of 4 mm in diameter and 28 cm in length. The tubes are made of a 30 $\mu$m thin Kapton foil while a 25 $\mu$m in diameter tungsten wire is streched inside to a tension of 70 g.

The straw tubes are filled with a mixture of Xe and $CO_2$ (80%, 20%) and operate in semi-sealed mode. Between the anode wire and the cathode straw wall the operating voltage of $\approx$1400 V is mantained. Laboratory tests showed that this mixture and voltage are the best combination in order to maximize the photon detection efficiency, thanks to the larger percentage of Xe, and to operate the tubes in a moderate gain region.

These modules are housed in a special frame to form a sensitive plane. The full TRD is made of 9 of these planes, interleaved with radiator layers, for a total of 32 modules or 1024 straws. To maximize the acceptance a configuration of 5 planes with 4 modules each, placed on top of 4 planes with 3 modules each, has been chosen.

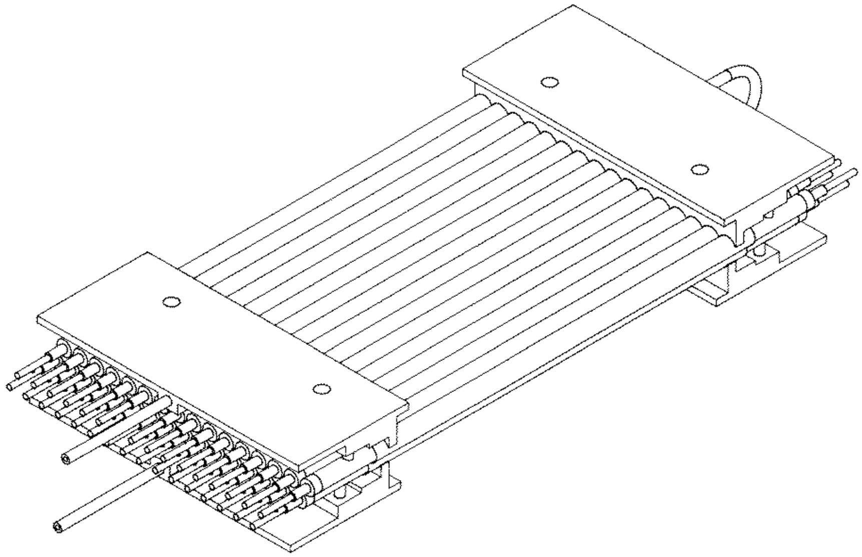

Fig. 2. Artistic view of a 32 straw tube module.

From Monte Carlo simulation and the previous experience in designing and operating TRD's, a carbon fiber radiator has been chosen for this detector (Barbarito 1992). Carbon fibers are packed in bags of 60 g/l density and placed in the space left in between consecutive tube planes.

Special care has been put on the mechanical design of the gas feeding system and the high voltage distribution. Due to small volume available, these functions have been integrated in a specially designed manifold plate that holds the high voltage pin and ensure gas circulation for each tube inside a module. An exploded view of a straw tube end and its insertion into the manifold plate is shown in fig.3.

To ensure mechanical stability and proper gas sealing the two 16 straw tube layers are glued face to face with liquid epoxy.

The tube front end electronics is equipped with a custom VLSI ASIC chip: the CR1.4P (Adams 1999). This is the same chip used for the calorimeter front end electronics; it is composed of 16 channels, each one including a charge sensitive amplifier, a shaping amplifier and a sample and hold circuit, which can be read out via an output multiplexer. The chip output is then sent to a 12 bit ADC for the digitization.

The frond end electronics is controlled by a digital signal processor (DSP) based read out card that also acquires and elaborates the 12 bit data from the ADC, packs the event from all the data of the front end card data, and sends it to the main CPU.

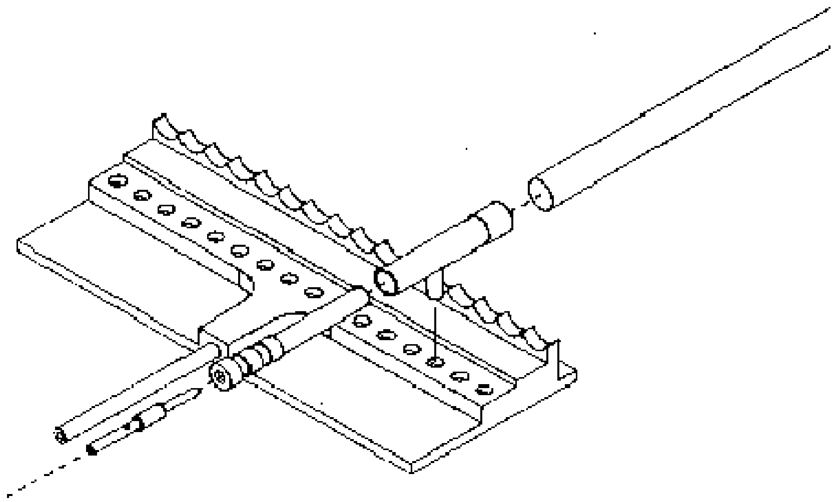

Fig. 3. Exploded view of a straw tube connection to the gas manifold plate and HV connector.

**Prototype Tests and Performances**

Prototypes of TRD straw modules, to be qualified for space usage, have been tested for gas leakage, mechanical strength, resistance to vibrations and overpressure showing no substantial modification in their electrical and mechanical characteristics.

Tests have been also done in order to choose the proper front-end electronic technique. From a dedicated beam test, done at the CERN Proton Synchroton (PS) facility using 3 GeV/$c$ pions and electrons, the charge integrating electronics (ADC technique) showed better performances, in terms of hadron rejection, than a fast discriminating approach (Cluster Counting technique).

The perfomances of a full TRD prototype, *i.e.* 9 sensitive layers and radiators, have been investigated, along with the other PAMELA detector prototypes, during beam tests performed at both the PS and Super Proton Synchroton (SPS) at CERN. Electron, pion and muon beams have been used in the momentum ranges 2$\div$5 GeV/$c$ at PS and 40$\div$100 GeV/$c$ at SPS. As shown in fig.4, discriminations based on a likelihood statistical indicator performed at a pion rejection factor of 5% for an electron detection efficiency better than 90% in these tests.

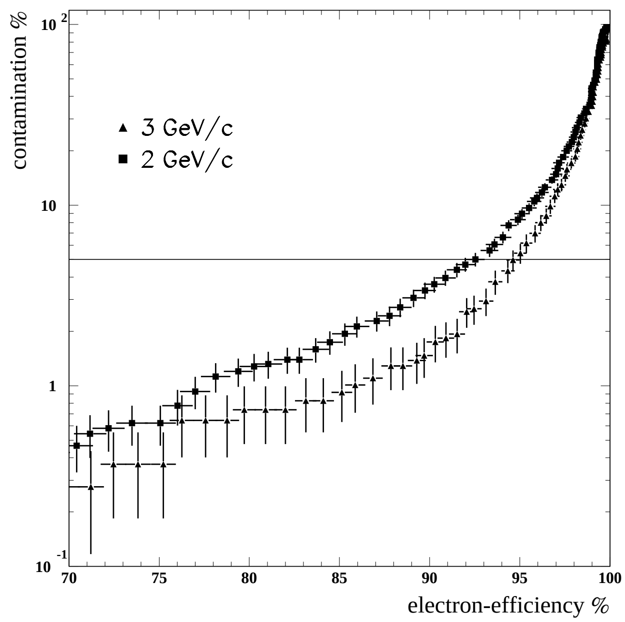


Fig. 4. PAMELA TRD hadron contamination versus electron detection efficiency from a beam test performed at CERN PS.

## CONCLUSIONS

The PAMELA TRD detector has been designed to work for three years in a satellite enviroment and to reach an hadron rejection factor of 5% for an electron efficiency of about 90%.

Prototypes of the TRD have been extensively tested and qualified for usage in the PAMELA satellite. Besides beam test campains at CERN showed that the design performances have been obtained for a full scale prototype.

## REFERENCES

Adams, J. H. Jr., J. Ampe, G. Bashindzhagyan, V. Bonvicini, R. Kroeger, et al., CR-1 Chip: Custom VLSI Circuitry for Cosmic Rays, *Proc.* 26$^{th}$ *Int. Cosmic Ray Conf.*, Salt Lake City (USA), **5**, 69, 1999.

Adriani, O., M. Ambriola, G. Barbiellini, M. L. Barbier, S. Bartalucci, et al., The PAMELA experiment, *Proc.* 26$^{\text{th}}$ *Int. Cosmic Ray Conf.*, Salt Lake City (USA), **5**, 96, 1999a.

Adriani, O., M. Ambriola, G. Barbiellini, M. L. Barbier, S. Bartalucci, et al., The microstrip Silicon magnetic spectrometer of the PAMELA experiment, *Proc.* 26$^{\text{th}}$ *Int. Cosmic Ray Conf.*, Salt Lake City (USA), **5**, 116, 1999b.

Adriani, O., M. Ambriola, G. Barbiellini, M. L. Barbier, S. Bartalucci, et al., A Silicon-Tungsten Imaging Calorimeter for PAMELA, *Proc.* 26$^{\text{th}}$ *Int. Cosmic Ray Conf.*, Salt Lake City (USA), **5**, 187, 1999c.

Ambriola, M., G. Barbiellini, S. Bartalucci, G. Basini, R. Bellotti, et al., CAPRICE98: A balloon borne magnetic spectrometer to study cosmic ray antimatter and composition at different atmospheric depths, *Nucl. Phys. B*, **78**, 32, 1999.

Barbarito, E., R. Bellotti, F. Cafagna, M. Calicchio. M. Castellano, et al., A High rejection transition radiation detector prototype to distinguish positrons from protons in a cosmic ray space laboratory, *Nucl. Instr. Meth. A*, **313**, 295, 1992.

Barbiellini, G., G. Basini, R. Bellotti, M. Bocciolini, M. Boezio, et al., Performance of the CAPRICE RICH detector during the 1994 balloon flight, *Nucl. Instr. Meth. A*, **371**, 169, 1996.

Bellotti, R., F. Cafagna, M. Circella, C. N. De Marzo, R. L. Golden, et al., Balloon measurements of cosmic ray muon spectra in the atmosphere along with those of primary protons and helium nuclei over mid-latitude, *Phys. Rev. D*, **60**, 052002, 1999.

Bidoli, V., M. Casolino, M. P. De Pascale, A. Morselli, G. Furano, et al., The space telescope NINA: results of a beam test calibration, *Nucl. Instr. Meth.*, **424**, 1999.

Bocciolini, M., F. Celletti, N. Finetti, M. Grandi, P. Papini, et al., The WiZard/CAPRICE silicon tungsten calorimeter, *Nucl. Instr. Meth. A*, **370**, 403, 1996.

Francke, T., D. Bergström, M. Boezio, P. Carlson, M. Suffert, A gas-RICH detector for space, *Nucl. Instr. Meth. A*, **433**, 87, 1999.

Golden, R. L., C. Grimani, R. Hull, B. L. Kimbell, R. Park, et al., Performance of a balloon borne magnet spectrometer for cosmic ray studies, *Nucl. Instr. Meth. A*, **306**, 366, 1991.

Golden, R. L., S. J. Stochaj, S. A. Stephens, F. Aversa, G. Barbiellini, et al., Measurement of the positron to electron ration in the cosmic rays above 5 GeV, *Astrophys. J.*, **457**, L103, 1996.

Sparvoli, R., V. Bidoli, A. Canestro, M. Casolino, M. P. De Pascale, et al., Launch in orbit of the telescope NINA for cosmic ray observations: preliminary results, *Nucl. Phys. B*, **85**, 28, 2000.

Vacchi, A., and the WiZard Collaboration, The PAMELA satellite-borne experiment, Talk given at the *33rd COSPAR Scientific Assembly*, 2000, H0.1-0005.