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A Transition Radiation Detector for space borne apparatus

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A Transition Radiation Detector (TRD), has been built to be used as charged particle identifier in satellite born apparatus. Originally conceived to be used in the PAMELA telescope, this TRD has been qualified for space as well. The compact design and the low power consumption, make this detector, suitable to be used in space researches in which identification is required for particle of relativistic energies (i.e. with Lorentz factor $\gamma > 1000$). In this TRD, carbon fibers are used as radiator material, and 1024 straw tubes, as sensitive detectors. All components are piled up in 9 sensitive layers of radiators and straws working in proportional mode using a Xe-CO_2 gas mixture. The detector characteristics will be described along with its performances studied having exposed the detector to both cosmic rays and particle beams at CERN.

1. Introduction

In this work we report on a Transition Radiation Detector (TRD) designed and built to be used as a satellite-borne apparatus. For this reason special attention has been put in the compact mechanical design and the electronics low power consumption. Besides space qualifications required several vibrational and thermal tests. The instrument has been originally conceived to be used in the PAMELA satellite-borne magnetic spectrometer[4]. In beam tests campaigns, performed at both PS and SPS facilities at CERN, prototypes of this TRD have been tested along with those of other PAMELA detectors. Beam tests results were used to fine tune and check the TRD simulation. The detector has been also extensively checked using cosmic rays.

2. The Transition Radiation Detector

This TRD uses carbon fibers as radiator material and gas proportional straw tubes to detect the emitted radiation. The proportional straw tube used is 28 cm in length and 4 mm in diameter; it is made of a copperized kapton foil, 30 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 configuration, in modules of 32; they are attached to two aluminum blocks acting as gas manifolds as well as holders for the signal pins, the insulator and ground plugs. The kapton straw is attached to the ground plug; the tungsten wire is soldered to the signal pin which is inserted on a fiberglass insulator plug. An exploded view of a manifold assembly of a module side is shown in figure 2. These modules are closed between two carbon fiber frames to form a sensitive plane. The upper frame does include the radiator which is made of carbon fibers packed at 60 g/l density. A picture of a sensitive plane during the assembly is shown in figure 2. The full TRD is made of 9 of these sensitive planes, and 9 radiators, the topmost radiator has larger thickness respect to the others. They are arranged in an upside-down truncated pyramid shape, for a total of 1024 straw tubes. Once planes are piled up, each detector side is closed by aluminum plates to increase the overall structure mechanical rigidity and to support the read-out electronics cards, part of the gas system pressure sensors, and a set of by-pass valve to open the gas circuits.

The TRD front-end electronics (FE) does use the charge integration technique; each straw signal is collected into a custom made chip, the 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 serial 12-bit ADC. On each card 4 chips and 4 ADCs are present, controlled by a (Field Programmable Gate Array) FPGA that decode the read-out commands and operates chips and ADCs in parallel. Each electronic card has been coated after the burn-in test and each tube wire soldered to the corresponding card channel. FE cards are grouped in two blocks each controlled by a read-out card (RO). Each RO card is equipped with a FPGA and a

DSP (Digital Signal Processor). The FPGA forms and transmits the clock to each front-end card, reads the FE words and transfers them to the DSP. The DSP builds up the event performing, if requested, a zero suppression. When the event is ready the card transmits, upon request, the event to the DAQ master. All communications use a data/strobe encoding an an LVDS channel.

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. The straw tubes work in a semi-sealed mode. A gas system (GS), external to the main mechanical structure, insures the mixture purging flushing it through the straws and, eventually, out of the payload. A 15 l bottle, qualified to stand up to 100 atm, stores the gas mixture. The gas is circulate in three separated section and its flow is controlled and regulated using 12 solenoid valves and three pressure regulators. A total of 8 pressure sensors monitor the pressure in each section, inside the bottle, in an output buffer and in the external payload. Two temperature sensors measure the bottle temperature. To avoid underpressure in the straw tubes during parking, a bi-stable valve opens each pneumatic section. Valves, regulators and pressure sensors are housed in the bottle support plate and on a side panel of the TRD mechanical structure. The GS, along with the overall mechanical structure and straw modules, have been qualified according to the mechanical and thermal loads according to russian satellite standards. The GS valves are controlled by a card that regulates also the voltages needed by the sensors. Besides the possibility of operate each single valve, purge sequences and monitor procedures have been burned into a FPGA that manages the communication between a central slow control unit. Besides, shut-down emergency operations have been foreseen via external telecomands. Two different kind of external telecomands can operate the parking valves as well; this valves must be in a close state to enable the card to operate the GS.

3. Performances: beam tests and simulation results

This TRD has been designed to reach a rejection factor of 5%, for 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 prototype has been exposed to e, π and μ beams of momentum values in the range $2\div5$ GeV/c (PS) and $40\div80$ GeV/c (SPS). During these tests, particles have been tagged using the beam facilities. Due to the fact that tests have been performed in the framework of the PAMELA experiment, also a prototype of the PAMELA calorimeter[3] was present during the SPS tests. This detector have been used to further reduce the samples of clean tracks crossing the full TRD. In this way we eliminated the beam background due to tagging inefficiencies and beam secondaries. For these selected 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]. Results of the analysis are synthesized in figures 1. 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.At even higher energies, particles begin to radiate transition radiation.

In parallel with the detector construction an original TR simulation code has been developed using the GEANT 3.21[5] package. Using the field propagation method the TR energy converted in a straw is estimated and added to the contribution from ionization simulated using the HEED and GARFIELD packages[5]. 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 montecarlo has been used to produce simulated data sets with the same beam test energies; the obtained performances have been compared to the one estimated from the beam data sets[2]. Results of the simulation for two Lorentz factors (γ) values have been superimposed to the beam data in Fig.1. Besides the beam tests ones, we collected cosmic rays data with the full TRD in the configuration shown in figure 2. Using a scintillator telescope to trigger cosmic rays, we collect them to test the detector full functionality. An event collected in this configuration is shown in figure 1.

4. Conclusions

We built and space qualify a TRD ready to be used in satellite-borne apparatus. This TRD is able to discriminate protons from positrons with a rejection factor of 5% at 90% electron efficiency. Beam tests and simulation confirm this design performance.

References

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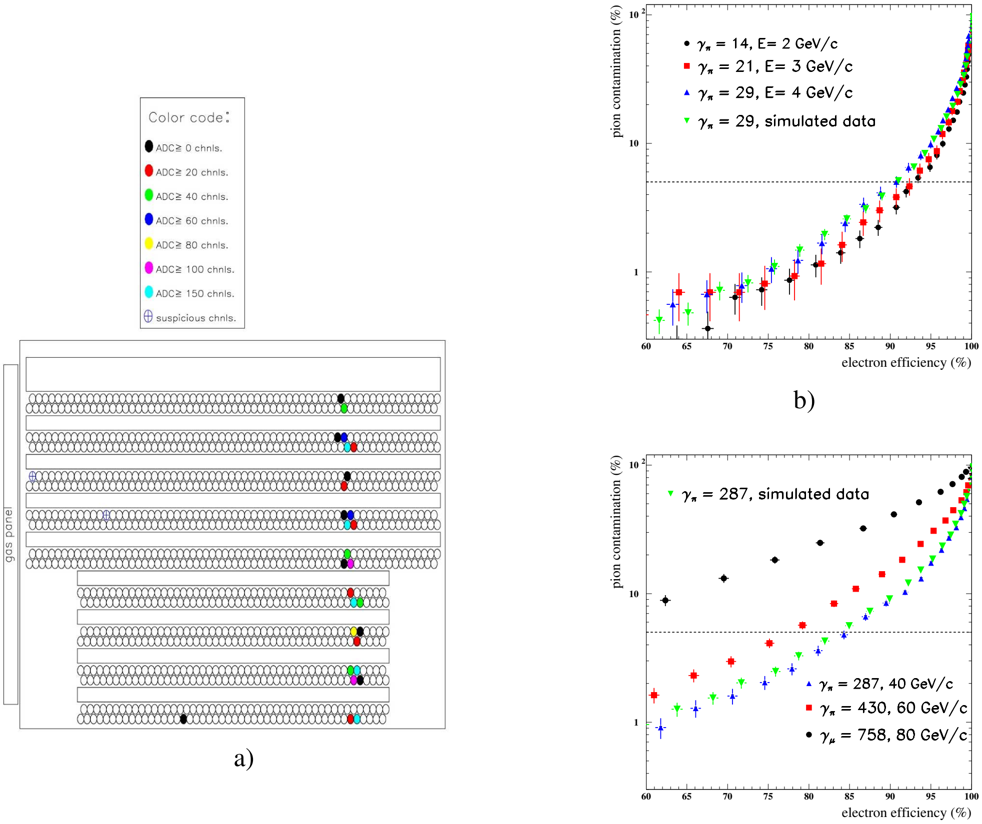
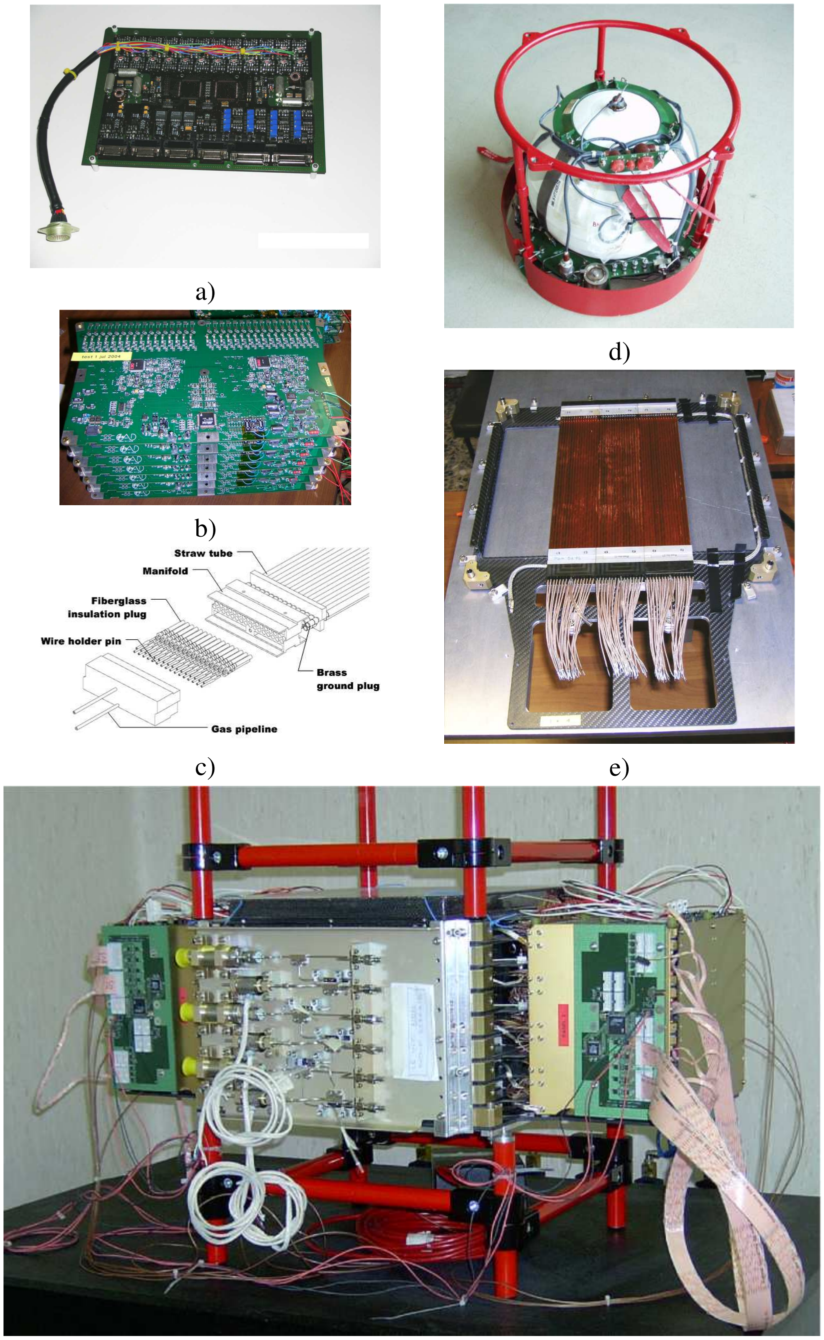


a)

b)

c)

Figure 1. a) A particle track in the TRD. Energy release is color coded according to the table shown. Hadron contamination vs. electron efficiencies evaluated in the CERN PS, b), and SPS, c), beam tests. Simulated performance are superimposed on both graphs.



a)

d)

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e)

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Figure 2. Parts of the TRD detectors. a) Gas System control board. b) Front end electronic cards. c) Exploded view of a TRD module assembly. d) The TRD gas system, the withe spherical bottle with valves and regulators housed around the battle stand. e) a sensitive plane during the assembly on the carbon fiber frames. e) The full TRD. The read out electronic cards are placed on the left and right side while the panel housing the gas tubing, valves and pressure sensors.