Comparison of a Transition Radiation Detector Response with Numerical Simulations

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Abstract

In summer 2001 a simple one-layer transition radiation detector was exposed at a calibration beam of the CERN particle accelerator. The detector consisted of plastic foam radiator blocks penetrated by 2cm diameter xenon-filled proportional tube detectors. The particle test beam covered a range of Lorentz factors from ∼100 to >100,000. A careful comparison of the response observed in these tests has been made with a numerical simulation using the new transition radiation generation functionality of GEANT4.

1. Introduction

A key requirement of any cosmic ray instrument is an accurate energy scale and well-measured resolution characteristics. Transition radiation detectors (TRDs) have an advantage for these type of measurements because they can be directly calibrated with accelerator beams and they can be made with very large areas and relatively light weights in comparison with other methods. However, until recently the simulations of TRDs with aperiodic radiators have been unreliable and often require a combination with accelerator tests to produce accurate response characteristics. These aperiodic materials, such as foams or fibers, provide far greater flexibility in the construction of radiators than periodic multiple foil stacks. Consequently, an accurate tool for the prediction of their response is extremely valuable.

In this paper we discuss a TRD which has been designed to detect heavy cosmic ray nuclei in the region of $10^{12} - 10^{14}$eV. A version of this detector forms part of the NASA-supported CREAM[1] (Cosmic Ray Energetics And Mass) project, which is scheduled for an ultra-long duration balloon flight of 100 days around Antarctica in 2004/2005. Here we report on the performance of this TRD, in a test beam exposure in CERN in summer 2001, and a direct comparison with a new TRD simulation package for foam radiators which is part of GEANT4[2].

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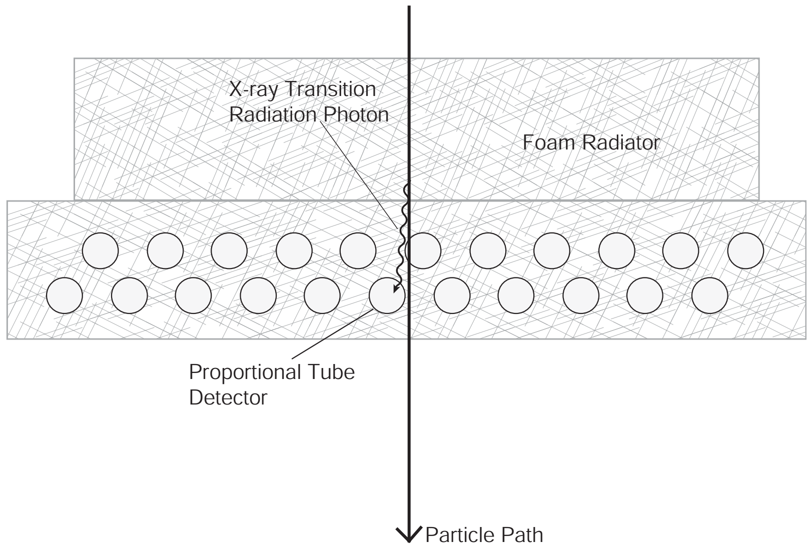

Fig. 1. A schematic diagram of the test TRD.

2. TRD design

A simplified cross section of the TRD is shown in Figure 1. The basic unit consists of plastic foam blocks with 2cm diameter holes punched in a two-layer pattern. The holes are filled with individual xenon-methane filled proportional tubes which detect the TR x-rays produced by the radiator material. The TR photons produced in the radiators have a distribution of energies from $\sim 1-100$keV. Their emission direction is closely aligned with the particle path and the x-rays, when absorbed, produce ionization in the tube in a region close to the ionization produced by the charged particle itself in the gas. The proportional tubes are 1.2m in length and constructed from wound layers of aluminized Mylar. The overall wall thickness is $\sim 100\mu$m which allows most x-rays above $\sim$ 3keV to enter the tube. The tubes are filled with a mixture of 95% Xe/ 5%CH_4 at 1 atmosphere, which has a high efficiency for capturing x-rays below $\sim$ 35keV. The sense wires are 1.2m long 75μm gold-plated tungsten stretched to $\sim$ 70g of tension. During operation, they are held at positive high voltage in the range 1-2kV.

To extract meaningful signals from the TRD, the impact parameter of the particle path from the center of the tube must be known. For this test a two-layer hodoscope which measures the location of each particle with an rms accuracy of $\sim 150\mu$m was used to determine the event geometry.

The properties of the foam materials used as radiators are shown in Table 1. A range of thicknesses of these materials was placed upstream of the proportional tubes as shown in Figure 1. By measuring the response as a function of radiator

Table 1. Properties of Foam Radiators tested

Property / Radiator	Ethafoam	Quash	(Units)
Density	0.035	0.032	g/cm^3
Width of Cell Wall (l_1)	35	290	μm
Cell Spacing (l_2)	870	5000	μm
Interfaces	11	1.9	cm^{-1}

thickness, systematic background effects can be excluded. Also measurements were taken of the 'bremsstrahlung background' using a thickness of solid plastic equivalent to a radiator. A range of momenta at the CERN test beam was used. By identifying protons, pions and electrons, a range of Lorentz factors from ~ 150 to above 3×10^5 could be sampled by the TRD.

3. Results and comparison with simulations

The signal detected in the proportional tubes is normalized to a path-length corresponding to a tube diameter by using the hodoscope information. Events which impact in the outer 50% of a tube are excluded from analysis because of the larger inherent error in this correction. The results of the various test runs are shown as symbols in Figure 2. The data for various radiator thicknesses is represented as follows : background measurement - no radiator or plastic (filled circles), bremsstrahlung measurement - solid plastic (open diamonds), Quash 11cm (downward triangles), Quash 22cm (open circles), Quash 44cm (open squares) and Ethafoam 11cm (upward triangles).

Monte Carlo simulations of the experimental apparatus were performed using GEANT 4, version 3.2. The simulation included a complete description of the detector geometry and materials. Transition radiation from the different foam radiator configurations was simulated using the model G4FoamXrayTRmodel. This is a parameterized TR model which recreates the emission properties of foam radiators, assuming an exponential distribution of effective foil and gap thicknesses. Ionization energy losses for the simulated particles (protons) were modelled using the G4PAIonisation code for xenon detector volumes. This model is based on measured photo-absorption cross-section tables and provides satisfactory agreement with the data, even for thin gaseous detectors. The solid lines in Fig. 2 represent GEANT simulations as described above. Since there is no absolute energy scale, the monte carlo data is normalized to the low energy data using a single factor for all curves. The data and the Monte Carlo show remarkable agreement. This due to extensive work by the GEANT collaboration in improving the emitted x-ray spectrum. This simulation can be used to make reliable *a priori* predictions of the response of future detectors.

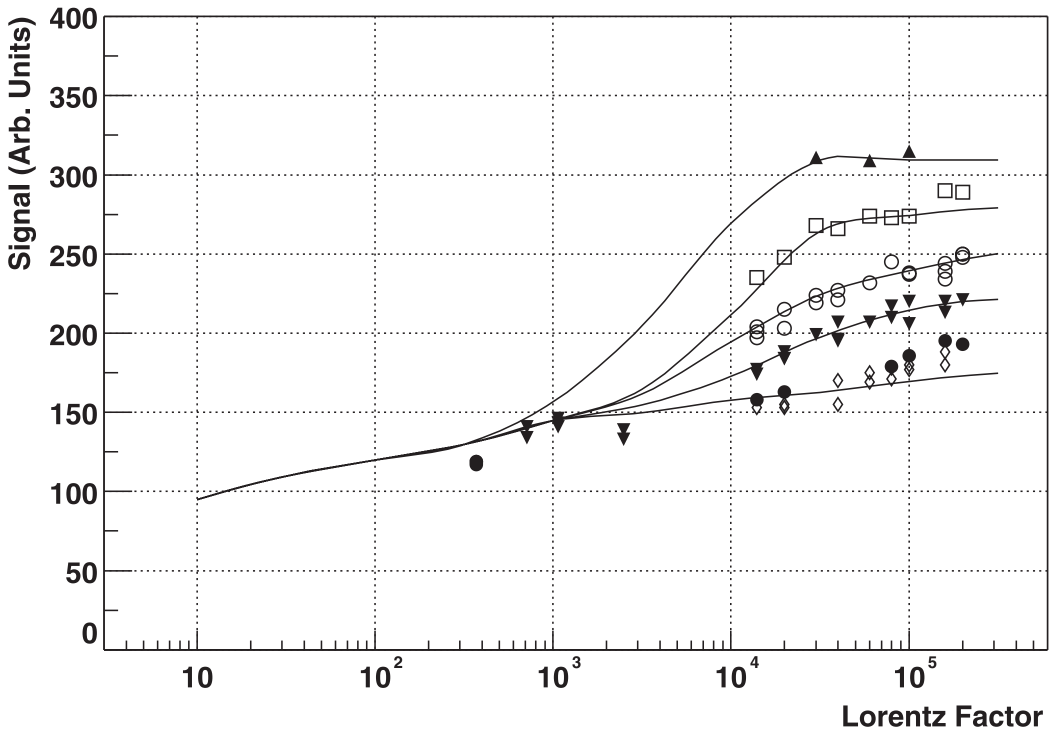

Fig. 2. The TRD response - see text for discussion

4. Conclusions

This calibration has demonstrated the usefulness of a TRD for measuring the energies of heavy nuclei up to $\gamma \sim 100,000$. The exciting improvements in the accuracy of the GEANT4 monte carlo for the production of TR will be extremely useful for the design process of new TRDs. With a sufficiently long flight, a future detector which can directly measure into the 'knee' region of the cosmic ray spectrum seems completely plausible.

5. Acknowledgements

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1. Seo, E-S., et al., Adv. Sp. Res., 2002, 30, 1263.
2. see GEANT4 at http://wwwasd.web.cern.ch/wwwasd/geant4/geant4.html