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Threshold transition radiation detectors in astroparticle physics

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Abstract

Transition Radiation Detectors (TRDs) have been used to study highly relativistic cosmic rays in the last three decades. In recent and in future balloon or space experiments TRDs will be used as energy measuring or threshold devices with large acceptances and long flight durations. Energy measuring TRDs will be required to study the origin of high-energy particles in the cosmic rays at energies near 10^{15} eV. Threshold TRDs will be used for particle identification which is a key issue for dark matter and SUSY searches relying on positron spectroscopy up to 300 GeV. This requires a proton rejection above 10^2 from the TRDs. A review will be given of the different requirements and experimental solutions for threshold TRDs and the astrophysical significance of their measurements. Special emphasis will be dedicated to the space qualification and long flight duration aspects of the AMS-02 TRD.

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1. Introduction

During the last decades, Transition Radiation Detectors (TRDs) became practical and powerful devices for particle detection and identification. The typical TRD configuration consists of a radiator of foils, foam or fibers, followed by a gaseous X-ray detector. The intensity of transition radiation depends on the Lorentz-factor $\gamma = E/mc^2$ of the primary particle. The TR X-rays are emitted in the forward direction. In the detector the X-ray signal is superimposed upon the ionization signal of the primary particle.

With threshold and energy measuring TRDs the TR X-rays can be observed above a Lorentz factor threshold γ_0 (typically $\approx 10^3$). The saturation point γ_{sat} occurs rapidly over a small range in γ (one order of magnitude) for threshold TRDs whereas for energy measuring devices the location of γ_{sat} depends on the physical properties of the radiator [1] and can be optimized to meet specific design requirements.

2. Energy measuring TRDs

Energy measuring TRDs will be required to study the nature and origin of high-energy particles in the cosmic rays at energies near 10^{15} eV, known as the "knee". The knee is the energy range in which measurements of the spectra of individual elements are expected to provide crucial clues to the details of the acceleration mechanism. The measurements done by the Cosmic Ray Nuclei (CRN) Detector [2], using an energy measuring TRD in space, indicate that all cosmic ray species are generated at the acceleration sites with the same source energy spectrum which has a power law shape of $\approx E^{-2.2}$, close to supernova-shock acceleration theories prediction. Long duration balloon or space experiments with large area TRDs like the TRACER, CREAM or ACCESS experiment are described in Refs. [3–6].

3. Threshold TRDs

Threshold TRDs are used to identify particles and to distinguish between particles of the same energy but with different masses, for instance, between electrons and

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antiprotons or positrons and protons. The indirect searches for dark matter candidates with high statistic measurements of positrons from neutralino annihilations [7] require experiments with large acceptance factors and long flight duration operation. The dominating proton background has to be reduced by a factor 10^6 to reach the required precision in e^+-spectroscopy in the momentum range between 10 and 300 GeV.

The WIZARD collaboration has performed the TS93-experiment to measure the e^+-spectrum in the energy range of 4–50 GeV [8,9]. The TS93-apparatus was flown by balloon from Ft. Sumner on September 8th, 1993 at a constant altitude of 36 km for 25 h. The experiment (Fig. 1) combined a superconducting magnet spectrometer, a time-of-flight system on top and bottom of the spectrometer, a silicon–tungsten imaging calorimeter at the bottom and a TRD above the spectrometer. The TRD had an active area of $76 \times 80\,\mathrm{cm}^2$, a weight of 237 kg and a power consumption of 100 W for 2560 electronic channels. The detector consisted of 10 layers of carbon fiber radiators, each followed by a multiwire proportional chamber (MWPC) with 256 gold-plated tungsten wires of 25 μm diameter (tensioned to $70g$). The MWPCs were filled with a xenon/methane (80%/20%) mixture. The TRD signals during flight were processed by different analysis techniques, leading to a rejection power of <100 against hadrons at an electron efficiency of 70%. The combination of the electromagnetic calorimeter and threshold TRD reached an overall rejection factor for protons of 3×0^4 in the momentum range $4-50\,\mathrm{GeV}/c$.

The High Energy Antimatter Telescope (HEAT, Fig. 2) experiment was optimized for the detection of cosmic ray $e^{\pm}$ below 100 GeV by using a combination of a superconducting magnet spectrometer (~1 T magnetic field), time-of-flight scintillators, a threshold TRD and an electromagnetic calorimeter [10,11]. The balloon instrument was first flown on May 3rd, 1994 from Ft. Sumner, New Mexico, and collected data for 29.5 h at float altitudes of $3.8-7.4\,\mathrm{g/cm}^2$ of residual atmosphere and again on August 23rd, 1995 from Lynn Lake, Manitoba, for a data taking period of 26 h at $3.3-6.8\,\mathrm{g/cm}^2$.

The TRD is comprised of six modules: each module consists of a radiator and a MWPC. The 12.7 cm thick radiators are composed of polyethylene fiber blankets with an effective fiber diameter of 21 μm and a mean fiber spacing of 380 μm.

The MWPCs had a thickness of 2 cm and employed 13 μm diameter gold-plated tungsten wires, with a 5 mm spacing between wires. The chosen gas was a xenon/methane (70%/30%) mixture. The chambers were operated in proportional mode at a high voltage of 3700 V at 1 atm. The TRD signals were processed by a likelihood analysis, leading to a rejection power of 170 against protons at an electron efficiency of 90%.

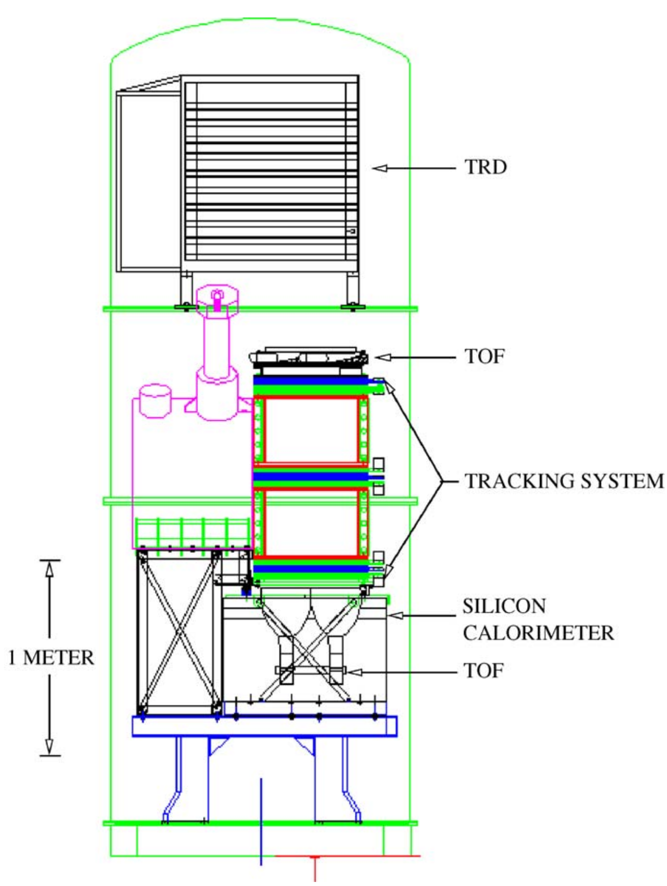

Fig. 1. Schematic diagram of TS93-experiment [8].

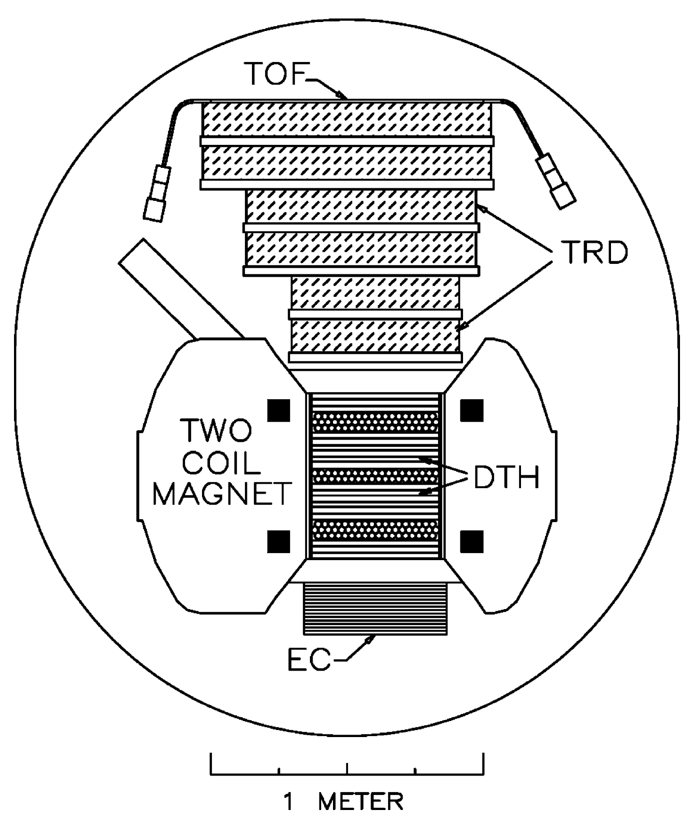

Fig. 2. Schematic diagram of HEAT-experiment [10].