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Next Generation TRD for CREAM Using Gas Straw Tubes and Foam Radiators

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Abstract: The Cosmic Ray Energetics And Mass (CREAM) experiment is designed to investigate the source, propagation and acceleration mechanism of high energy cosmic-ray nuclei, by directly measuring their energy and charge. Incorporating a transition radiation detector (TRD) provides an energy measurement complementary to the calorimeter, as well as additional track reconstruction capability. The next generation CREAM TRD is designed with 4 mm straw tubes to greatly improve tracking over the previous 20 mm tube design, thereby enhancing charge identification in the silicon charge detector (SCD). Plastic foam provides a weight-efficient radiator that doubles as a mechanical support for the straw layers. This design provides a compact, robust, reliable, low density detector to measure incident nucleus energy for $3 < Z < 30$ nuclei in the Lorentz gamma factor range of 10^2 - 10^5. This paper discusses the new TRD design and the low power front end electronics used to achieve the large dynamic range required. Beam test results of a prototype TRD are also reported.

Introduction

The CREAM (Cosmic Ray Energetics and Mass) is the balloon born experiment designed for direct measurements of the energy spectra and elementary composition of the TeV scale cosmic rays and above. The scientific goal of the CREAM experiment is to study the source, propagation and the acceleration mechanism of high energy cosmic-ray nuclei in the “knee” region. A detailed description of the CREAM instrument can be found elsewhere [1]. The Transition Radiation Detector (TRD) presence onboard of the CREAM experiment payload allows making a redundant energy measurement and inter-calibrating the thin ionization calorimeter data with the TRD data [2]. Such possibility is very important since the CREAM measured energy region extends to much higher values, than are available from the accelerator beams This paper describes the current status of the new project to develop the next generation CREAM TRD, capable to insure an energy measurement, complementary to the calorimeter, of the cosmic-ray nuclei ($3 < Z < 26$) at high energy and separation of them in the Lorentz factor region from 10^3 to ~5×10^4.

TRD mechanical design

The next generation CREAM TRD is designed with 4 mm straw tubes to greatly improve tracking over the previous 20 mm tube design, thereby enhancing charge identification in the silicon charge detector (SCD). The improvement over the TRD tracking accuracy will also reduce uncertainties of particle path-length corrections for the signals in TRD and other CREAM sub-detectors. The TRD consists of two independent sections; each of them (see Figure 1) contains 4 identical modules with the radiator foam block on the top of the straw tubes plane. The 4 mm diameter straw tubes are arranged into two layers and glued together. Straws in these two layers are shifted from layer to layer by the straw radius to minimize the particle path-length variations in the straw gas at different impact points and to achieve a high mechanical strength of the plane. Each polyethylene Ethafoam-220 radiator block, is supported by the side frame and has no direct contact with the straw plane inside the module. The Ethafoam-220 radiator was chosen since it provides a high TR saturation level [3] and has been already successfully employed in the CREAM-1 TRD. The adjacent modules straws are oriented alternately in two orthogonal directions to determine the particle trajectory. On the top of the upper TRD section an additional set of two double layer straw planes with perpendicular straw directions is placed to allow accurate particle dE/dx measurements. The gas manifold boxes with good thermo-conductivity are made of aluminium. They serve as a housing for the Front-End electronics, ASIC, and HV distribution boards. The gas manifolds are supported by composite G10 frames with CFC walls, to minimize the straw plane thermal stress.

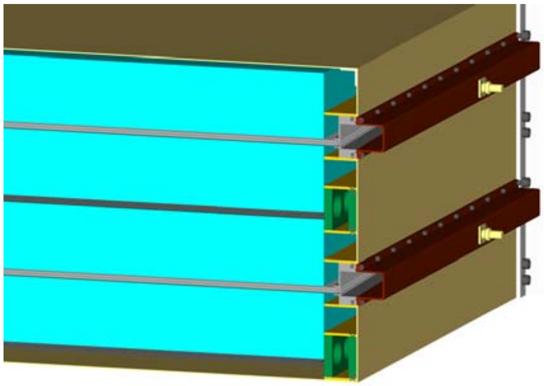

Figure 1: Cut view of the TRD bottom section.

Straw tubes

The basic detecting element in the TRD is the straw tube, working in proportional mode. The straw tube intended for use in the CREAM TRD construction is similar to the tube used in the TRT (Transition Radiation Tracker) detector of the ATLAS experiment. It has the same wall thickness, material and diameter, but it is longer (1200 mm) and will be arranged in the continuous double plane structure. The straws are made from a coated polyimide film. Two layers of polyimide film are used for the straw winding. The electrical conductivity is assured by a thin aluminium layer of about 0.2 μm thickness. This layer is protected from sparks discharges by a conductive composite layer of carbon and polyimide which is 6 μm thick.

Front-end and readout electronics

The Front-End electronics design is driven by the TR signal range. It provides a good signal over noise ratio per channel, as well as a low cross talk (coherent noise) levels required yet must have a large dynamic range, sufficient to cover high Z~26 ions signals. Compact new electronics will replace the old bulky VME based electronics box of the CREAM-1 TRD. The ASIC chip we chose is 32-channel VA32-HDR14, produced by the IDEAS SA, Norway. It has an input noise level (single straw) of: 5200e + 22 pF x 5e/pF = 5310e (0.849 fC) and 15pC maximum input charge which satisfies the dynamic range and noise requirements. If the sparsification threshold is set at 5 sigma noise, then the dynamic range is equal to: 15 000 fC / (0.849 fC x 5) = 3530. The power dissipation of this chip is 3.4 mW /channel. The readout electronics contains a simple sequencer (one per detection plane), activated by the CREAM trigger box signals, to control the ASIC hold, analog multiplexer, ADC, and clear logic. After processing by the sparsification DSP board the data in CREAM format are written into a double port FIFO memory together with event number and time stamp. It is subsequently read out by the SFC (Science Flight Computer) through the USB-2 interface. The slow control (house keeping) box will collect the temperature and TRD gas pressure data in flight, as well as the HV and low voltage settings data. It controls the power supplies and the TRD gas system solenoid valves.

Gas system

The gas system provides the gas mixture circulation and density control in the TRD straws. The straw ends are hermetically glued into the gas manifolds and the gas mixture from the bottle flows through two parallel straw planes from inlet manifold to outlet one. The flows and densities in different manifold pairs are controlled by the electromagnetic solenoid valves. The pressure sensors and the slow control temperature sensors will allow the gas density measurement and insure its monitoring during the instrument operation. The general lay-out of the gas system is similar to that of the first TRD flown with the CREAM-1 payload in 2004/2005 season.

Weight and power

The weight of the TRD-2 was estimated using the CAD model (no electronics weight included) as follows:

- Aluminum parts: 36170 cm^3/ 97.5 kg
- G10 and CFC parts: 23700 cm^3 /40 kg
- Straws (Kapton): 6040 cm^3/8.6 kg
- Screws etc: 320 cm3/2.5 kg
- Foam radiators: 861716 cm3 /30.2 kg

which gives the total TRD weight of: 178.7 kg. The Front-End electronics power dissipation was estimated using the preliminary circuitry design, the components specifications and power DC-DC converters efficiencies to be 23.5 W. Including the readout and house-keeping part the total power required was estimated to not exceed 40 W.

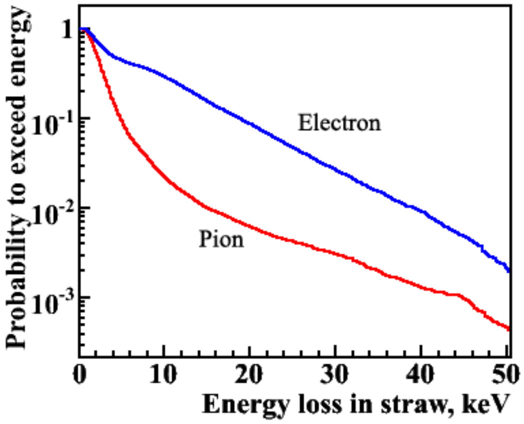

Figure 2: The probability of a particle (red line for pions and blue line for electrons) to exceed a certain value of ionization signal in the simulated TRD module with 4 mm straws.

Monte-Carlo simulation and tests

A stand-alone Monte-Carlo simulation program has been used to estimate a signal detected in the proportional tubes and the rejection power of the proposed TRD. The model was initially developed for the ATLAS TRT [5, 6] and has been extensively used to describe the ATLAS TRT test beam data (CERN RD-6 collaboration), showing a good agreement [7]. The simulated TRD module consists of 4 identical layers of the radiator volumes and adjacent straw tubes. Three sets of straw diameters (20 mm, 10 mm, and 2 x 4 mm) were considered. From the simulation results it was concluded that the probability to exceed the threshold energy of 6 keV is approximately one order of magnitude higher for electrons than for pions in case of 4 mm tubes (Figure 2), yet for the tubes of 20 mm diameter this probability is practically the same for pions and electrons. This effect is caused by a smaller ionisation loss contribution respect to the TR photon energy deposit for 4 mm tube.

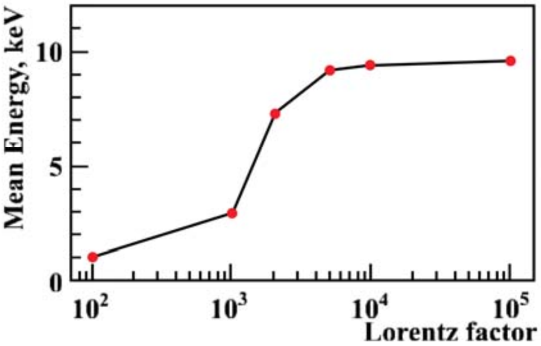

Figure 3: Monte-Carlo simulation results for the TRD signal vs particle Lorentz factor with four double layers of 4 mm straws.

In the Figure 3 the mean energy loss in a single straw as a function of the Lorentz factor of incident particles is shown for one of the considered detector configurations. The main goal of the simulation was to confirm that the double straw layer with the 4 mm diameter has enough TR detection efficiency compared to the larger diameter tubes used for the TRACER and CREAM-1 TRD. The results of the simulation show that 4 mm straw, chosen for the detector, would meet all the TRD physical requirements. The TRD MC study demonstrated a sufficient TR detection efficiency even for the particles with Z=1 with a good electron/hadron separation. To further validate the TRD-2 concept, two prototypes (one for mechanical and gas tightness tests and another for the beam tests) were built and tested. The results of the mechanical and gas tightness tests of the first prototype demonstrated a very good stiffness and a negligible leak level (<1.2 x10^{-3} mbar/min at 1 bar) of the proposed design. The tests with the second prototype were performed in the CERN SPS secondary beam. The pion and electron beams from 20 to 100 GeV were used. Four sets of 4 mm diameter, 1200 mm long straws were separated by 80 mm thick Ethafoam-220 blocks. The Xe/CO2 80/20 gas mixture at atmospheric pressure was chosen. The results of the beam tests as well as with Fe^{55} gamma source obtained with two different ASIC chips (VA32-HDR14 and Gassiplex-1.5 [4], used for comparison) show generally a good agreement with the expected prototype performance. The noise levels measured were substantially higher than the ASIC intrinsic values according to the specifications. The reason was identified with the noisy beam area environment and inadequate grounding.

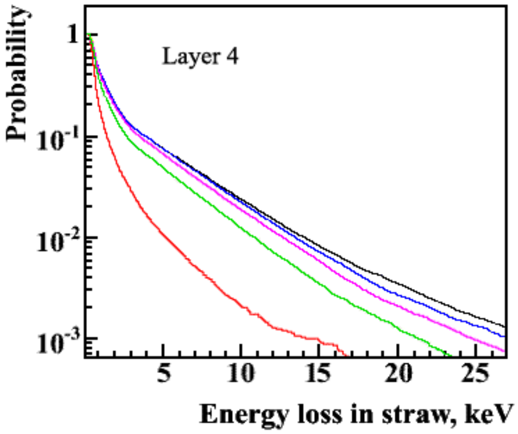

Figure 4 The TR photon detection probabilities measured by the TRD four layers prototype in the last consecutive layer of straws, each separated by 80 mm thick Ethafoam-220 radiator. The lines (from top to bottom) represent 100 GeV, 75 GeV, 50 GeV, 20 GeV electrons, and 100 GeV pions from the CERN SPS secondary beams.

Nevertheless the prototype demonstrated a sufficient TR photon detection efficiency ~10% per straw. This conclusion follows from comparison of the probability for pion to deposit the energy exceeding the 6 keV threshold (red line), to that probability for 100 GeV electron (black line), shown in the Figure 4. Unlike pions, the 100 GeV electrons produce TR photons in the Ethafoam radiator. Otherwise both particles would produce the same ionisation loss energy spectra and would give the equal detection probabilities as minimum ionizing particles. The number of TR photons, generated by electron, is increasing with the particle Lorentz factor as expected. The Fe^{55} gamma source was used to calibrate the TR response and measure the straw TR signal over noise ratio, since the energy of the source 5.9 keV photons approximately corresponds to the TR threshold energy. The measured signal over noise ratio was ~10 with VA32-HDR14 and ~50 with Gassiplex-1.5 at nominal straw gas gain.

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