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Performance of the transition radiation detector and the timing charge detector in the first flight of the CREAM instrument

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During the 2004-2005 season in Antarctica the CREAM (Cosmic Ray Energetics And Mass) experiment had a record breaking flight of nearly 42 days. A major science goal of this instrument is the measurement of secondary nuclei at high energy with a transition radiation detector (TRD) using xenon-filled proportional tubes and charge identification devices comprising plastic scintillator and plastic Cherenkov counters. Accurate and stable performance of the TRD and the charge counters is crucial for the reliable identification of secondary nuclei. The performance of these detectors during the flight is discussed and preliminary data are presented.

1. The CREAM Instrument

The CREAM payload flew on a high altitude balloon in Antarctica in 2004/2005 for nearly 42 days. This instrument is designed to measure the energy spectra and elemental abundances of cosmic rays up to 1000TeV. In particular, the measurement of secondary nuclei in the cosmic ray flux can be made with elemental resolution and with high statistical accuracy up to energies of ~500GeV/n. These data will make it possible to determine the primary (source) and secondary (spallogenic) energy spectra of heavy cosmic rays in this energy range for the first time. The full CREAM instrument has been described previously [1]. It combines a timing charge detector (TCD), a TRD, a plastic Cherenkov counter, a silicon pixel charge detector, and a calorimeter module. Here we focus on the TCD, TRD and Cherenkov devices, which are used for the determination of secondary nuclei abundances.

Figure 1 is a schematic cross section through the mid-part of the TRD showing the location of these detectors in the upper part of the CREAM payload. The TCD [2] is made of two layers of 5mm-thick plastic scintillators, each covering 1.44m^2 (four Bicron BC-408 slabs, each 1.2m × 0.3m), read out with fast timing photomultiplier tubes (Photonis XP2020UR) via twisted-strip adiabatic light guides and pipes. It is used to measure the scintillation signal generated by incident cosmic rays to determine their charge with sufficient accuracy (~0.2e for O to ~0.35e for Fe) to resolve individual elements. The amplitude of the signal is measured at four different dynodes (for increased dynamic range), as is the time structure (with 50ps resolution) of the leading edge of the light pulse at the anode. This aids in discrimination against possible backsplash of albedo particles from the calorimeter, which arrive at the TCD 3 to 8ns after the initial passage of the parent cosmic ray.

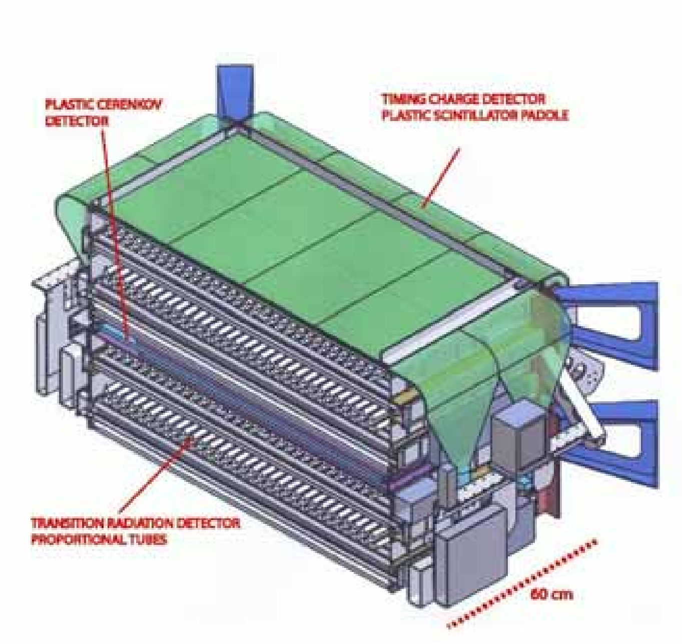

Figure 1. A mid cross-section of the CREAM TRD/TCD/ Cherenkov detectors. The overall detector is 1.2m × 1.2m square.

The TRD consists of eight layers of polystyrene foam radiator combined with a total of 512 1.2m long thin-walled proportional tubes, each 2cm in diameter. They are filled with a mixture of xenon (95%) and methane (5%) gas at a pressure of 1 atmosphere. The tubes are constructed from wound mylar with a wall thickness of 100μm to allow easy penetration of transition radiation x-rays. The tubes are arranged in 16 layers, and the pattern of hits in the tubes due to nuclei traveling through them is analyzed to reconstruct the particle's trajectory in three dimensions. A simple weighted line fit to these hits provides a tracking (RMS) resolution better than σ~5mm. A further fit to the relative pulse heights in the tubes can improve this accuracy to better than 2mm. The Lorentz factor γ of a heavy nucleus can be determined from the energy loss per unit path-length in the TRD gas. In the region from minimum ionizing to ~500GeV/n, this is provided by the logarithmic relativistic increase in ionization loss, which is large (~1.6) for xenon gas. At higher energies, above 1TeV/n, significant transition radiation is produced in the radiator material and accompanies the direct particle energy losses, providing an additional logarithmic rise in response until saturation sets in near γ ~20,000. The response of this TRD has been calibrated in a CERN test beam in 2001 [3].

The Cherenkov detector is a 1 cm-thick 1.2m × 1.2m plastic radiator sheet doped with blue wavelength shifter. This is viewed along the edges by eight small photomultiplier tubes via plastic wavelength shifting bars, which capture the blue light produced in the radiator and shift it into the green region. This technique provides a compact detector with uniform response. The measured variations of light collection with position in this device during the flight are <15%. The Cherenkov detector is inserted between the two sections of the TRD as shown in Figure 1. This is used to identify relativistic nuclei, which is important because of the high flux of unwanted low-energy particles at Antarctic latitudes. The Cherenkov detector also provides a complementary determination of the incident cosmic ray charge with the TCD measurement.

The heavy nucleus trigger of CREAM is set by thresholds in the TCD and Cherenkov detectors. During the flight these were adjusted so that a vertical relativistic Boron nucleus is well above these thresholds. The effective trigger aperture of the heavy nucleus trigger is fairly large with an acceptance of 2.2m^2sr, providing a large sample of secondary nuclei. All these heavy nuclei events were recorded to an onboard flash memory disk providing a total data set of heavy nuclei containing ~40 million events.

A tungsten/scintillating-fiber calorimeter and silicon charge detector are also present at the bottom of the instrument. These provide redundant energy and charge measurements to the TRD and TCD/Cherenkov detector, for a fraction of events (in addition to providing energy measurements for elements lighter than Li), and therefore allowing for cross-calibration of the detectors. These detectors are discussed elsewhere at this conference [4,5,6]. All detector components are designed to operate in the near vacuum conditions of float altitudes, without the benefit of a pressure vessel.

2. Instrument Performance in Flight

The TCD, TRD and Cherenkov detectors operated well throughout the entire length of the flight. One of 18 photomultiplier tubes in the TCD systems failed near the end of the flight. The loss rate of the xenon mixture from the TRD gas system was very low and amounted to only ~10% of the system volume over the 42 days of the flight even though this gas was contained in a total of ~0.6km of 100μm wall thickness tubing at an over pressure of 1 atmosphere. This leak rate was slow enough that periodic redistribution of the gas already in the system every few days was sufficient to maintain good response from all layers. No top-off from the onboard gas reservoir was needed. Perhaps more remarkable was the stability of the signal response using the same gas for over 40 days. The proportional counter resolution did not noticeably degrade during the duration of the flight, even though no fresh gas flowed through the tubes. Similar assemblies with an over pressure operated at ground level typically lose resolution even after 12 hours or so, suggesting that diffusion of electronegative oxygen into the tubes is the most likely culprit for this gradual degradation of resolution with time observed in the lab. The oxygen concentration at balloon altitudes is low enough that the rate of this effect is at least 100 times slower.

The TCD has four gain ranges corresponding to signals derived from the various photomultiplier dynode feeds. Each of these is targeted at a range of elements. Figure 2 shows a distribution of energy deposited per unit pathlength in the TCD scintillators derived from the mid-level gain range as a function of the light yield per unit pathlength from the Cherenkov detector. This TCD gain range is targeted at 'L/M' nuclei. These events are selected from the first day of the flight by restricting the geometry to the central parts of these counters. The clear populations of the signals due to B, C, N and O nuclei show the intrinsic charge resolution for heavy nuclei expected from CREAM. After mapping corrections have been applied a similar resolution is possible across the entire aperture. For the accurate measurement of secondary nuclei a good separation between B and C is very important. These preliminary data show the instrument has sufficient

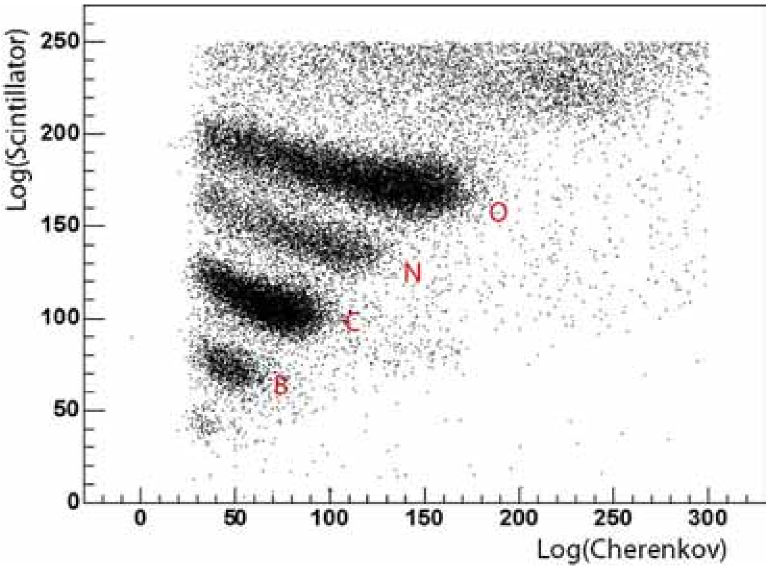

Figure 2. Measured energy losses in the TCD scintillator versus Cherenkov light signal for a short (~1 day) portion of the flight. B,C,N and O nuclei populations are clearly visible.

charge resolution to allow efficient use of B and C events for the determination of the abundance ratio of secondary to primary nuclei. The Cherenkov trigger threshold is clearly visible in Figure 2, and relativistic B nuclei are well above threshold. Also visible are the abundant lower energy events of heavier nuclei because of the low geomagnetic rigidity cutoff over Antarctica, which produce higher ionization loss and a lower Cherenkov signal. Signals from heavier cosmic rays up to Fe are also present in the flight data, but appear in different TCD gain ranges from that shown in Figure 2.

Figure 3 shows a preliminary distribution of energy deposited per unit pathlength in the TRD proportional tubes along the particle trajectory, as a function of light from the Cherenkov detector, for the same event subset used in Figure 2. Populations of events due to B, C, N, O, Ne, Mg, Si, and Fe nuclei are clearly visible. The TRD signal is derived from a dual-gain range system using Amplex 1.5 ASICs with an effective dynamic range of 12 bits. The resulting TRD and Cherenkov signal systems are quite linear over the entire dynamic range. The high energy events will ultimately be derived from those which are relativistic in the Cherenkov and have a large signal in the TRD for a given charge.

3. Conclusions

The detectors on CREAM designed to measure heavy nuclei performed well during the recent Antarctic flight. The TRD gas system would have been operable for longer than the design goal of 100 days. A large sample of nuclei have been collected which prelimi-nary analysis demonstra-tes have sufficient signal resolution to provide a measurement of the abun-dance ratio of secondary to primary nuclei up to ~500GeV/n.

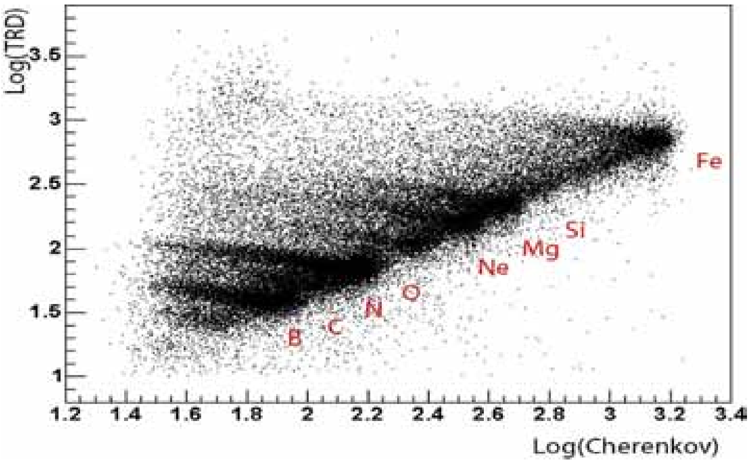

Figure 3: Measurements of the energy deposited in the TRD tubes versus the normalized Cherenkov light signal during the flight (~1 day).

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