Construction and test of a scintillator hodoscope for the CREAM experiment

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CREAM (Cosmic Ray Energetics And Mass) is a balloon-borne experiment being prepared for the first flight which is scheduled for the end of 2004 from Antarctica. It is designed to perform direct measurements of cosmic ray composition over the elemental range from proton to iron to the supernova energy scale of 10^{15} eV in a series of balloon flights using the new Ultra Long Duration Balloon (ULDB) capability under development by NASA. The instrument includes a sampling tungsten/scintillating fiber calorimeter preceded by a graphite target with scintillating fiber hodoscopes, a pixelated silicon charge detector, a transition radiation detector and a segmented timing-based particle-charge detector. The hodoscope system provides track reconstruction capability by means of 4 orthogonal layers of fibers (S0,S1) on top of the carbon target and 2 additional layers (S2) located in between the upper and lower target sections. Its construction technique and beam test results are presented.

1. Introduction

CREAM (Cosmic Ray Energetics And Mass) belongs to a new generation of balloon-borne instruments [1–3] designed to provide direct measurements of the energy spectra of primary cosmic rays and of their elemental composition at energies approaching 10^{15} eV. The main science goals of the experiment are to shed light on the so far unknown mechanism of acceleration of primary cosmic rays of very high energy and to improve the understanding of their interactions with the inter-galactic medium. CREAM will have adequate exposure to resolve the spectral shapes of the cosmic-ray H, He and heavier nuclei (up to Iron) at energies approaching the lower end of the "knee" transition region where the all-particle spectral index increases from from ~ 2.7 below 10^{14} eV to ~ 3.3 above 10^{16} eV. Taking advantage of the new Ultra Long Duration Balloon (ULDB) flight capability under development by NASA, CREAM will be able to reach 500 TeV after 3 flights designed to last from 60 to 100 days each. The possibility to explore spectral features beyond 100 TeV will allow CREAM to search for the onset of cutoffs in the individual spectra of light elements at an energy scale of order Z x 10^{14} eV, where Z is the charge of the primary nucleus, as predicted [4] by a class of models of CR acceleration by supernovae shocks.

CREAM is currently under preparation for its first balloon flight. According to the current schedule, the first launch will take place from Antarctica in December 2004. A key feature of the CREAM instrument is that the energy measurement relies on two complementary techniques based respectively on a 20 X_0 tungsten scintillating-fiber imaging calorimeter and on a Transition Radiation detector (TRD). Their energy scales will be inter-calibrated in flight by simultaneous measurements of the energy and

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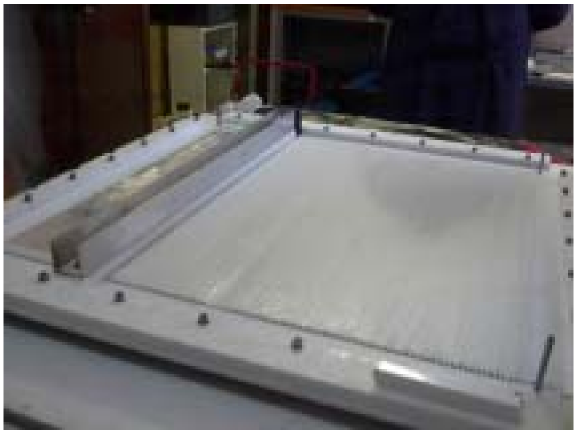

Figure 1. One plane of scintillating fibers under construction for the S2 hodoscope.

charge of a subset of nuclei. The ability to identify the primary particle relies on multiple accurate measurements of its charge. From top to bottom, charge is measured by a segmented timing-based charge detector (TCD), a pixelated silicon detector (SCD) and scintillating fiber hodoscopes. The CREAM instrument layout and expected performance are described in [3,5] and references therein. In this paper we report on the construction of the S2 hodoscope and on the preliminary results of a beam test performed at CERN with heavy ion fragments from a 158 GeV/n primary Indium beam.

2. The scintillating fiber hodoscopes

The CREAM calorimeter is preceded by a densified graphite target ($\sim 0.46\ \lambda_{int}$) where the primary nucleus interacts inelastically generating secondaries. Neutral pions initiate an e.m. shower whose axis is reconstructed by the finely segmented imaging calorimeter, projected backwards and matched with the SCD pixels. The aim is to provide an unambiguous measurement of the primary charge by discriminating against pixels affected by backscattering from the calorimeter. The target is divided into two elements. The top two hodoscopes (S0, S1) are positioned just above the upper section (T1) of the target and below the SCD. They provide supplemental charge measurement for particles already measured both by the TCD and SCD (or by SCD alone for calorimeter events that miss the TCD). A third hodoscope (S2) is located between the upper and lower target sections. The tracking information from S2 discriminates events where the primary interacts in T1 against events where the hadronic interaction takes place below S2. In the latter case, the dE/dx information from S2 is used as a supplemental charge measurement. Each hodoscope module consists of two orthogonal layers of scintillating fibers. The three hodoscope systems also provide tracking information, complementing the position information from the TRD straw tubes and the impact position in the SCD.

3. Construction of the S2 hodoscope

The S2 hodoscope has an active area of $\sim 64\times64\ cm^2$ covered by two orthogonal planes with a total of 640 scintillating fibers with square $2\times2\ mm^2$ cross section. Each scintillating fiber is glued head-on to a clear fiber of identical cross section, with alternate fibers read-out by the two opposite side of each plane. The clear fibers are routed, in groups of no more than 64, to 12 proximity-focus Hybrid Photo Diodes (HPD). The double-cladding scintillating fibers, covered by a white EMA coating, were cut and polished at one end and mirrored at the opposite end by Al vacuum sputtering. The latter technique minimizes the impact of light attenuation along the fiber. Measurements of the light output showed a maximum non-uniformity below 10% along the fiber. Each scintillator layer was sandwiched between an outer 0.5 mm thick Al plate and an inner 0.2 mm thick Al plate. The two orthogonal layers were mounted on top of each other with the two 0.2 mm plates glued together. Scintillating fibers were first aligned into a Teflon fixture, staggered by 5 mm on either end and closely packed during the glueing (Fig.1). Then clear-fibers were aligned and glued head-on to the scintillating fibers. Each group of clear fibers (Fig.2) was routed and then glued into an Al mask ("cookie") which reproduces accurately the HPD pixels arrangement. After milling and polishing, the optical surface of the cookie was optically coupled to the HPD and pixels were aligned by shining

Figure 2. The S2 flight module during the final assembly phase in Pisa.

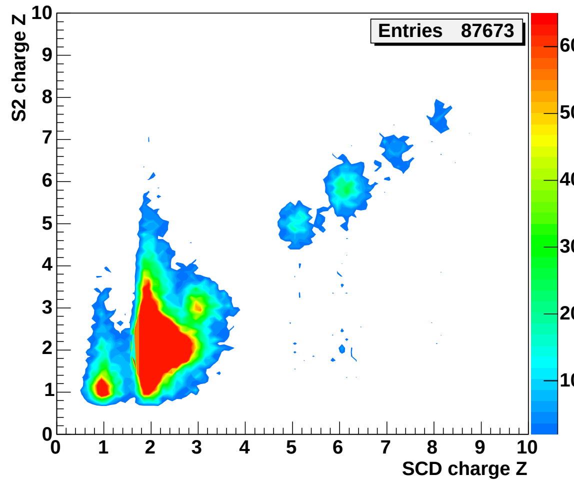

Figure 3. Correlation between S2 and SCD charge measurements for events non-interacting in T1.

light simultaneously onto 3 different pixels connected, via optical fibers, to blue LEDs. The path of the clear fibers takes place inside light-tight boxes with a light-weight mechanical structure based on a Carbon composite structure. The S2 hodoscope was built in Pisa/Siena and integrated in the CREAM target in July 2002.

4. The CERN heavy ions beam test

Heavy ion fragments with A/Z =2 were selected in the H2 beam line at CERN tuned as as described in [6]. Data were collected during a period of 10 days in November 2003. Test beam data were analyzed by reconstructing clusters of hits in each plane of the hodoscopes. Events where the primary did not interact above S2 were selected by requiring a low number of hits with small cluster size in S2. Preliminary results from the beam test are shown in (Fig.3) where the charge measurement from S2 is plotted against the charge assignment by the SCD for non-interacting events. The superior charge resolution of the SCD ($\sim$5% relative error on He) is evident from the picture where D, He, B, and C,N,O are clearly separated. The Li peak is barely visible due to its very low abundance in the beam. Preliminary indication from the data suggests that S2 can provide a supplementary charge assignment for non-interacting events in the upper target section.

5. Acknowledgements

This work is supported by INFN in Italy and NASA in the US. The authors greatly appreciated the support and technical skill of S.Bottari, E.Hahn, A.Orsini, A.Tazioli, S.Tolaini.

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