Construction and test of a Tungsten/Sci-Fi imaging calorimeter for the CREAM experiment

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Abstract

CREAM (Cosmic Ray Energetics And Mass) is a balloon-borne experiment 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 first flight of CREAM will take place at the end of 2004 from Antarctica. 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 thin ionization calorimeter has been designed to operate in the range of energies from a few hundred GeV to 1 PeV providing imaging capability in the recostruction of the showers originating from the interaction of primary nuclei in the carbon target. A twin calorimeter for the second CREAM payload has been built and tested at CERN. Its construction technique and preliminary test results are presented.

1 Introduction

Direct measurements of the energy spectra and elemental composition of charged cosmic rays are provided by experiments in flight above the atmosphere, where the primary particle can be unambiguously identified. The current generation of balloon-borne experiments dedicated to these measurements [1,2,5,6] track the incoming particle and measure its charge and energy by means of a number of different detection techniques. They are designed to

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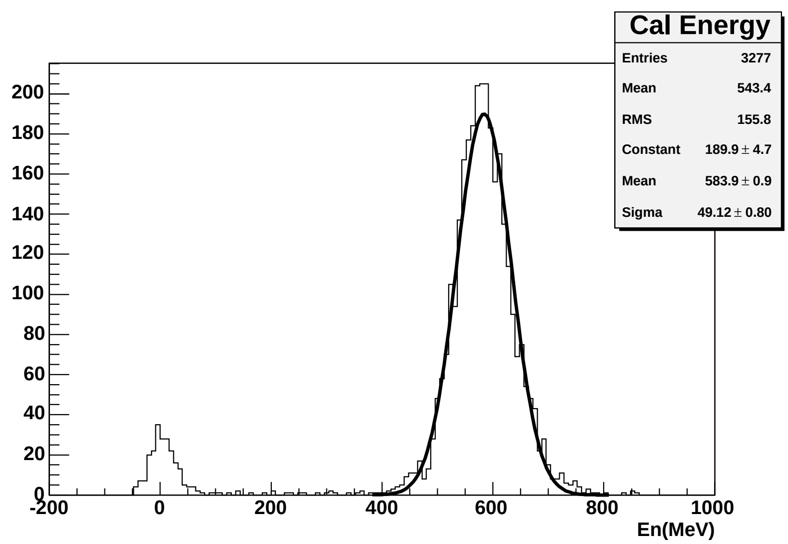
record data electronically in flight and may implement data trasmission capability to the ground. This represents a large improvement with respect to previous balloon payloads [3,4] which made use of nuclear emulsions and had to be recovered to extract, in a non trivial way, the information on energy and charge. However, despite the recent advances in instrumentation, collection power remains the major limitation to all direct measurements due to the low fluxes at high energy. This limit is constantly being pushed as with the development of a new generation of balloons (ULDB) by NASA aiming to 60 to 90 days flights. Designed as a ULDB mission, the CREAM experiment [5,6], will search for the possible onset of cutoffs in the individual spectra of light elements at energies of order Z x 10^{14} eV, where Z is the charge of the primary nucleus. It will also measure the abundances of light nuclei to improve the current understanding of the propagation of cosmic rays in the interstellar medium. The CREAM payload is currently under preparation for its first flight scheduled for December 2004 from Antarctica.
The instrument layout and expected performance are described in [6] and references therein. The calorimeter, designed and built in the US, was tested with high-energy electrons and hadron beams at CERN in July 2002 and fully calibrated in 2003. Its response to ion fragments from a 158 GeV/n primary Indium beam was tested at CERN in November 2003. A twin calorimeter for the second CREAM payload (CREAM-2) was built in Italy. In this paper we report on its construction and on the preliminary results of a beam test performed at CERN during the Summer 2003.

2 Construction of the CREAM-2 calorimeter

Limitations on the calorimeter mass for balloon-borne or space-based payloads led to the development of the concept of Thin Ionization Calorimetry with the use of a low-Z target preceding the calorimeter [7]. An inelastic interaction of the primary nucleus in the target initiates an hadronic shower containing a narrow e.m. core, generated by the decay of neutral pions, which is imaged by a fine grained calorimeter. The baseline CREAM configuration includes a tungsten scintillating-fiber calorimeter [8] with an active area of 50×50 cm^2 preceded by a densified graphite target ($\sim 0.46\ \lambda_{int}$) of about 1 X_0 thickness. The calorimeter longitudinal segmentation is in layers of 1 X_0 while the lateral segmentation of 1 cm is close to one Moliere radius ($\rho_M \sim 9$ mm). It is constructed as a stack of 20 tungsten plates, each 3.5 mm thick, a bottom carbon fiber plate and 20 interleaved scintillator layers made up of 1 cm wide ribbons of 0.5 mm diameter scintillating fibers. Each ribbon is read out, via an acrylic light-mixer connected to a bundle of 265 μm diameter round clear fibers, by a multi-pixel Hybrid PhotoDiode (HPD). For mechanical reasons, alternate ribbons are read out on opposite ends. Non-readout ends are aluminized by vacuum sputtering to increase the light-yield and effective attenuation length. Each bundle of 48 fibers is split into three sub-bundles to create low-, mid- and high-energy readouts. Alignment of the fiber bundles with the HPD pixels

(a)

(b)



(c)

Fig. 1. (a) The CREAM-2 calorimeter at the CERN beam test; (b) Assembly of one X-Y module; (c) Energy measurement with 150 GeV electrons.

is guided by 3 LEDs. The calorimeter is equipped with a total of 40 HPDs for a total of 2560 readout channels.

The CREAM-2 calorimeter in Fig.1(a) was built by the INFN group of Siena/Pisa and completed in July 2003. The baseline mechanical design was modified to allow for a modularization of the stack into completely independent light-tight elements. Each Tungsten plate is glued onto a carbon fiber composite frame which accommodates 25 light-guides on each side. The building block is the assembly of two consecutive X-Y layers in Fig.1(b). Particular care was taken in the design of the routing of the fiber bundles from the light-guides, contained inside the assembly, to the photodetectors to ensure light-tightness. Superlayers consist of 4 calorimeter layers each. The disassembly of the calorimeter can be done either into superlayers or X-Y layer pairs. Modularization was introduced in view of the difficult conditions during payload recovery on the ice in Antarctica after the flight.

The capability of the calorimeter (without target) to image e.m. showers was tested with electrons of energies up to 200 GeV in the H2 beamline at CERN. Individual channels were equalized by steering the beam into each ribbon and the energy response of each layer was determined by fitting the longitudinal distribution of the shower at a given beam energy. A single set of constants turned out to fit all longitudinal distributions taken at different energies and to provide the correct absolute energy scale. Preliminary data from the beam test are plotted in Fig.1(c). The CREAM calorimeter is optimized to maximize the rate of measured high energy cosmic-ray nuclei, requiring a thin, large area calorimeter with a low-Z target to induce nuclear interactions above the calorimeter. Since energy resolution for protons (and heavier nuclei) with such a thin calorimeter is dominated by fluctuations in the e.m. fraction of the shower energy, photon statistics are relatively unimportant and the sampling fraction can be kept below 1%, allowing a thinner detector. With such a small sampling fraction, the electron energy resolution (dominated by photon statistics) was found to be 8% at 150 GeV, in agreement with expectations.

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