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The CREAM balloon experiment

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Abstract. CREAM (Cosmic Ray Energetic and Mass) is an experiment aiming at the measurement of the composition of the cosmic ray nuclei from proton to iron, in an energy range between $\simeq 10^{11}$ and $\simeq 10^{15}$ eV, by exploiting the Ultra Long Duration Balloon (ULDB) flights technology. Goal of the experiment is to give new insights in the origin, propagation and acceleration of the Galactic cosmic rays. A first balloon flight took place in December 2004- January 2005 in Antarctica, for a total of more than 42 days.

Key words. Cosmic Rays – Direct measurements – Scientific Balloons payloads – Galaxy: abundances – Galaxy: diffusion

1. Introduction

The cosmic ray energy spectrum above $\simeq 3 \times 10^{11}$ eV can be well described by a power law, $\Phi_A(E) \propto E^{-\gamma}$, which steepens at $\simeq 3 \times 10^{15}$ eV, a feature called the "knee". Most of the cosmic rays up to the knee region are believed to be of Galactic origin, their acceleration being due to diffusive shock acceleration in Supernovae remnants.

Arguments involving energetics, composition and secondary γ ray production support this model, according to which the knee is an astrophysical feature of the spectrum, being related either to the maximum attainable energy via the diffusive shock acceleration ($\simeq$ Z $\times 10^{14}$ eV, where Z is the charge of the primary nucleus) or to a rigidity dependent escape probability from the Galaxy.
The diffusion of the cosmic ray particles in the Galaxy is driven by the turbulent galactic magnetic field. While the low energy tail of the cosmic ray particles undergo solar modulation, and mechanisms like electromagnetic energy losses, convection and reacceleration play a major role in shaping their spectra, at higher energy they are mostly depending on acceleration and diffusion, the other effects becoming negligible. Diffusion depends on the rigidity R=p/Z of the particle, the diffusion coefficient being $K(E) \propto R^{-\delta}$.
From the experimental point of view, it is most important to test the model through a measurement of the cosmic ray composition near the energy limit of the shock models. Support to the theory could come from the observation of the existence of the expected cut-off in the proton spectrum around 10^{14} eV, while differencies in the spectral slopes of individual elements could be interpreted as evidence for different source or acceleration mechanisms.

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The measure of the ratio between secondary (produced by spallation in the interstellar medium) and primary nuclei gives information on the diffusion properties; the determination of primary fluxes trace back to the acceleration sites, thus giving insights on the diffusion and acceleration properties.
At energies approaching the knee, the primary cosmic ray flux is too low and only indirect detection is possible: there, the primary particle nature can only be inferred from the measured observables, thus heavily relying on simulations. On the other hand, at lower energies the primary particles identity and energy can be measured directly event-by-event by flying detectors on board balloons of spacecrafts, the only limitations being the collecting power.
To overcome these problems, CREAM (Seo et al. 2004) has been designed as a ULDB experiment. It will search for the expected primary nuclei cutoffs at increasing Z up to energies just below the knee; it will measure the abundances of primary and secondary nuclei, thus giving new information about the propagation of Galactic cosmic rays in the interstellar medium. Its potentialities to study the diffusion and acceleration properties have been recently studied (Castellina & Donato 2005); Fig.1 shows an example of the expected B/C ratio as measured by CREAM in comparison with various predictions from models. The data obtained in the past by the HEAO-3 (Engelmann et al. 1990) and CRN (Swordy et al. 1990) experiments are also plotted for comparison.

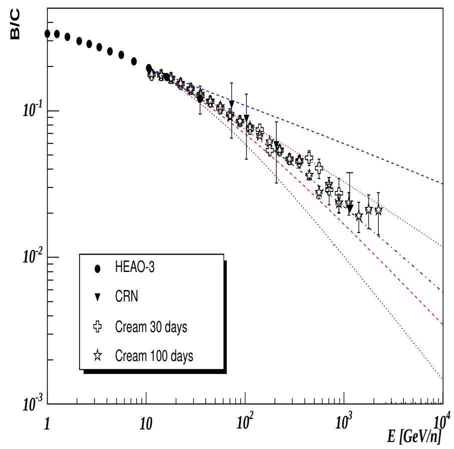

Fig. 1. B/C ratio vs kinetic energy/nucleon. The 5 curves derive from different theoretical predictions.

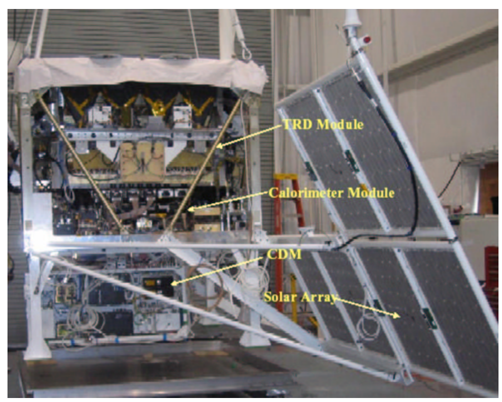

Fig. 2. Schematic view of the CREAM detector.

2. The apparatus

The CREAM instrument, shown in Fig.2, consists of many particle detectors aiming at the measure of the charge and energy of the cosmic ray particles.

A Timing Charge Detector (TCD), a Silicon Charge Detector (SCD) and four scintillating fiber hodoscopes provide independent measurements of the charge of the incident particles. The energy is measured by means of a Transition Radiation Detector (TRD) and a tungsten-scintillating fibers calorimeter.

The TCD is located on top, and measures the charge of all particles entering the TRD acceptance. With a specifically developped timing technique (Beatty et al. 2002), this detector allows to get rid of secondary particles backscattered from the calorimeter (relying on the time delay of these secondaries as compared to the incident particle); one of the hodoscopes provides a reference time.
The SCD covers the top area of the carbon target above the calorimeter, and measures the charge with a resolution of 0.2 charge units; since no timing-based discrimination against backscattered particles is possible, this

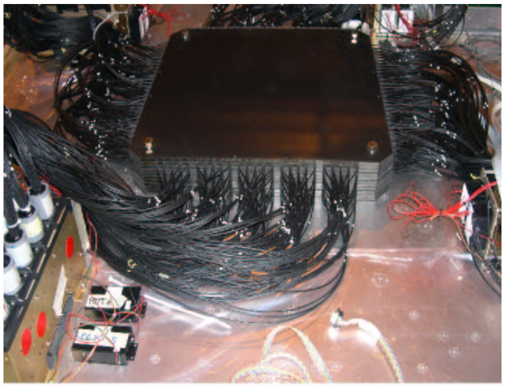

Fig. 3. The CREAM-II calorimeter (20 radiation lengths).

detector has been divided in pixels of about 2 cm^2 area, so that only few percent of low Z particles can be misidentified at 10^{15} eV incident energy.
The fiber hodoscopes provide tracking reconstruction and some additional charge information.
The TRD is formed by two modules ($120 \times 120 \times 35$ cm^3 active volume), each with 8 layers of tubes filled with 95% Xenon and 5% Methane embedded in a plastic foam acting both as radiator and mechanical support. It is optimized to measure the Lorentz factor of nuclei with Z>3, which for these highly relativistic particles is equal to the energy to mass ratio, and to track their trajectory with 1 mm resolution. The two sections of the TRD are separated by a Cerenkov threshold detector, by means of which CREAM can reject the abundant background of low energy particles measured near the South Pole, at low geomagnetic cutoff.

Fig.3 shows the calorimeter module (Marrocchesi et al. 2004), which consists of a densified graphite target ($\simeq 0.46\ \lambda_{int}$, $\simeq 1\ X_0$) inducing hadronic interactions in a stack of twenty 50 cm × 50 cm tungsten plates interleaved by 20 layers of 50 scintillating fibers each. It can measure the energy of all nuclei, including the Z≤2 ones, for which no other methods can be envisaged, with an energy resolution better than 40%. From the calorimeter, each shower is tracked back to the TCD to define which segment of the detector must be used for charge determination. CREAM is the first experiment employing both a TRD and a calorimeter; since they have different systematic biases in the determination of the particle energy, their use will allow an in-flight intercalibration of the energy measurements.

3. The first flight and future plans

The first flight of CREAM took place in Antarctica from December 16, 2004 to January 27, 2005. The payload circumnavigated the South Pole three times, at an altitude between 38 and 40 km ($\simeq$ 3-4 g cm^{-2}). More than 30 millions events were collected: the events corresponding to low energy were recorded on board, while for the first time the high energy ones were trasmitted directly at Earth via TDRSS (Tracking and Data Relay Satellite System).
Data analysis is now under way.
CREAM is planned to fly each year by alternating two science instruments on board; the next mission will take place with CREAM II in December 2005. CREAM is designed to exploit the Ultra Long Duration Balloon flight technology, now under test at NASA so to achieve up to 100 days exposure per flight.

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