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CREAM Flight Data Processing

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The Cosmic Ray Energetics And Mass (CREAM) instrument is a balloon-borne experiment designed to measure the composition and energy spectra of cosmic rays up to $\sim 10^{15}$ eV. The instrument consists of, from top to bottom, an 8-paddle Timing Charge Detector (TCD), a 512-tube Transition Radiation Detector (TRD), a 2912-pixel Silicon Charge Detector (SCD), 2035 scintillating fibers in 3 hodoscopes interleaved with a pair of graphite targets, and a 20-layer tungsten/scintillating-fiber sampling calorimeter with 1000 fiber ribbons. We have developed the CREAM Data Processing System (CDPS), an object-oriented data processing program based on ROOT. In this paper we describe the data processing scheme used to handle flight data.

1. Introduction

The CREAM balloon-borne experiment is a new instrument designed to investigate the charge and energy spectra of cosmic rays over the energy range from $\sim 10^{12}$ eV to $\sim 10^{15}$ eV. The first flight of CREAM by Long Duration Balloon launched from McMurdo, Antarctica lasted for 42 days, starting December 16, 2004, collecting a total of 60 GB of data including more than 43 million science events. The details of the experiment are described in [1] and references therein.

The TCD and SCD provide charge measurements, the TRD and sampling tungsten/scintillator ionization calorimeter (CAL) measure energy, and 3 hodoscopes (HDS) interleaved with interaction graphite targets enhance trajectory reconstruction. The measurement redundancy is expected to provide a unique feature of in-flight cross calibration.

The flight data have been studied using the CREAM Data Processing System based on ROOT [2], along with a development of a calibration/reconstruction algorithm. In this paper, we provide a brief description of the data processing scheme.

2. CREAM Data Processing System

For CREAM flight data processing, the CDPS incorporates various processors: (1) 'Data-Reader' which generates Level 0 output by reading, unpacking and sorting raw data, (2) a 'Calibrator' for each sub-detector system, which generates Level 1 output by converting ADC counts to energy units, (3) and 'Shower-Handler' which generates Level 2 output by reconstructing event parameters such as particle trajectory, incident charge, total energy deposit, Lorentz factor, etc. The generated objects can be viewed in graphical form by 'Event-Display,' including various functions such as zooming, 3-D rotations, etc. A simplified structure of CDPS is shown in Figure 1.

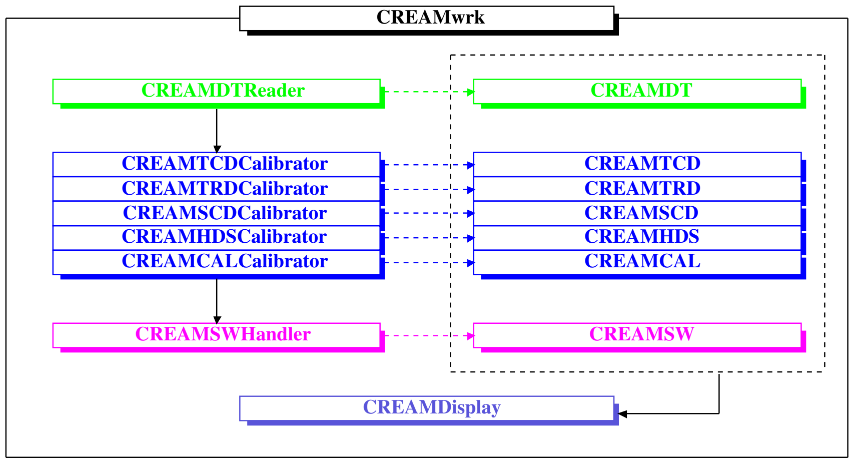

Figure 1. CDPS schematic flow diagram. 'CREAMwrk' manages the processors on the left-hand side, which generate the objects (in a dashed box) that can be viewed by the event display.

CDPS is written in C++ by incorporating user-defined classes and methods optimized for the CREAM experiment, which are compiled into shared libraries and dynamically integrated into the ROOT environment. By loading shared libraries produced in C/C++ scripts, and interpreted by ROOT, CDPS utilizes various ROOT tools for creating multi-dimensional histograms and ntuples, fitting, minimization, on-screen editing, etc.

2.1 Data-Reader

The CREAM data acquisition software system recorded various types of events (science, calibration, pedestal and housekeeping) in binary format [3]. CDPS reads in all the channels' sparsified pulse height amplitudes and the associated pedestal values which were measured and recorded every 5 minutes, and maps the electronic addresses to physical paddles, tubes, pixels, fibers and ribbons along with their 3 dimensional locations.

2.2 Calibrator

The responses of each sub-detector were calibrated in several beam tests at the European Organization for Nuclear Research, CERN, and compared to simulation results. Detailed understanding of flight conditions further improves event reconstruction accuracy. Preliminary calibration algorithm and parameters were implemented into CDPS for further study and feedback. More details of data calibration of the sub-detectors can be found in [4, 5, 6].

2.3 Shower-Handler

After calibrations are applied, reconstruction algorithms are used to determine the charge, trajectory and energy of each event. These quantities can then be used to reproduce the incident spectra of each element, allowing determination of spectral indices, relative abundances, etc.

To reconstruct particle trajectory, the signal core is estimated in each layer of the cross-stacked TRD and/or CAL, providing up to 4+10 points each in x and y. Fitting straight lines through these points, the trajectory is reconstructed and extrapolated to TCD and/or SCD to calculate the primary particle incident position. The RMS width of this deviation between the actual incident position and the reconstructed position in simulations defines a circle of confusion within which the pixel with the largest charge signal is assumed to be the incident particle's trajectory. GEANT [7] simulation shows that the deviation at the SCD, with CAL trajectory reconstruction, follows a Gaussian distribution with position resolution better than 1 cm for electrons at several hundred GeV as shown in Figure 2(a). By applying the same CAL trajectory reconstruction to the flight data, the SCD charge distribution shows clear peaks of hydrogen and helium in Figure 2(b).

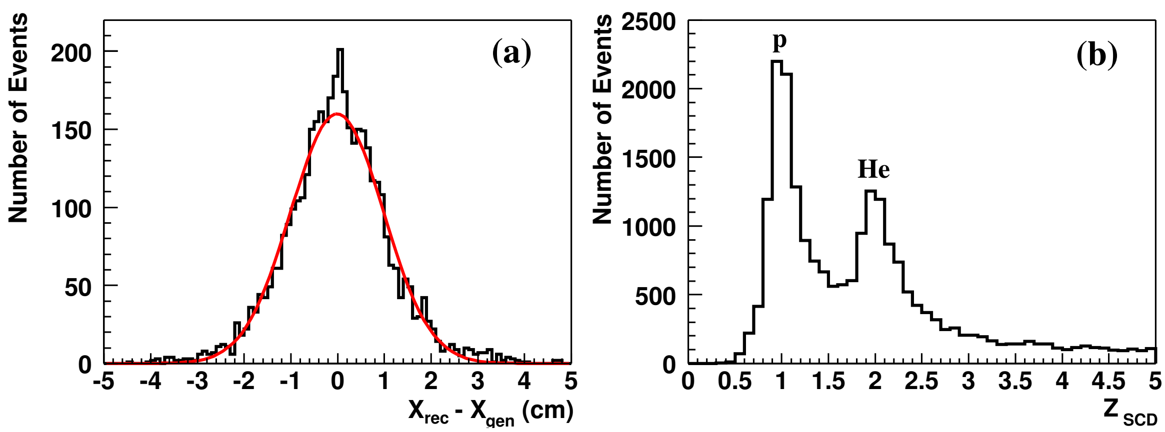

Figure 2. Results of CAL trajectory reconstruction, (a) difference between the measured position and the actual incident position at the SCD, from electron simulation, (b) preliminary SCD charge distribution for hydrogen and helium from the first CREAM flight.

2.4 Event Display

An example of a high energy event with a reconstructed trajectory in the CREAM detector system is shown in Figure 3. From top to bottom, it shows each sub-detector's components with signals, for TCD paddles, TRD tubes, SCD pixels, HDS fibers, and CAL ribbons. The box is scaled for the signal size. In this example the incident particle obviously passed through TCD, TRD and SCD, interacted in the graphite target between HDS layers, and initiated a shower in the CAL. Based on the total energy deposit and SCD charge measurement, this particular event is attributed to a 13 TeV cosmic-ray carbon.

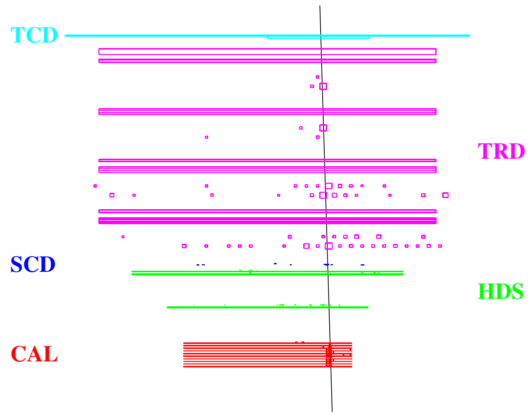

Figure 3. CREAM event display shows each sub-detector's responses to a high energy carbon candidate, along which a trajectory is reconstructed. Box size is proportional to the corresponding signal size.

3. Summary

The first flight data of the CREAM instrument have been studied with preliminary understanding of the experiment to produce various levels of datasets. More detailed studies are in progress to improve calibration, event reconstruction, etc. and to obtain the final spectra for various elements.

4. Acknowledgements

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