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Cosmic ray energetics and mass: Expected performance

H. S. Ahn[1], S. Beach[2], J. J. Beatty[2], S. Coutu[2], M. A. DuVernois[3], O. Ganel[1], Y. J. Han[4], H. J. Kim[4], K. C. Kim[1], S. K. Kim[4], M. H. Lee[1], S. Minnick[2], S. Nutter[2], I. H. Park[4], E. S. Seo[1], S. Swordy[5], J. Z. Wang[1], and J. Wu[1]

[1]Inst. for Phys. Sci. and Tech., University of Maryland, College Park, MD 20742, USA
[2]Dept. of Physics, Penn State, University Park, PA 16802, USA
[3]School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA
[4]Dept. of Physics, Seoul National University, Seoul 151-742, South Korea
[5]Enrico Fermi Institute and Dept. of Physics, University of Chicago, Chicago, IL 60637, USA

Abstract.

The Cosmic Ray Energetics And Mass (CREAM) experiment is being constructed to study high energy cosmic rays over the approximate energy range from 1 TeV to $> 5 \times 10^{14}$ eV. CREAM is enabled by the Ultra Long Duration Balloon (ULDB) capability being developed by NASA, which will provide 60 to 100 days of flight duration. The instrument includes a sampling tungsten calorimeter, a transition radiation detector, and a timing-based charge detector. We will present details of the instrument configuration and simulated results of its performance, including trigger and data rates, energy resolution, energy response, etc.

1 Introduction

The CREAM instrument, illustrated in Fig. 1, consists of a timing-based charge detector, a transition radiation detector and a thin calorimeter with a carbon target. It is designed to determine the charge and energy of very high energy cosmic rays. The charge detector must identify the charge of the incident particle while minimizing the effect of back-scattered particles from the calorimeter. The transition radiation detector determines the Lorentz factor (γ) for $Z \geq 3$ nuclei by measuring transition x-rays using thin-walled gas tubes. The target induces hadronic interactions, while the calorimeter is used both to estimate the total shower energy and to provide tracking to determine which segment(s) of the charge detector must be used for charge measurement. The tracking is accomplished by extrapolating the shower axis to the charge detector. The unique TRD-calorimeter combination provides a powerful method of cosmic-ray energy measurements since the TRD response to a subset of nuclei can be used to calibrate the calorimeter energy scale. Furthermore, the calorimeter can also measure the energy of protons and He for which the TRD measurement is not reliable. More details about this powerful instrument can be found in the references (Beatty et al., 1999; Ganel et al., 2001; Seo et al., 1999; Seo et al., 2000).

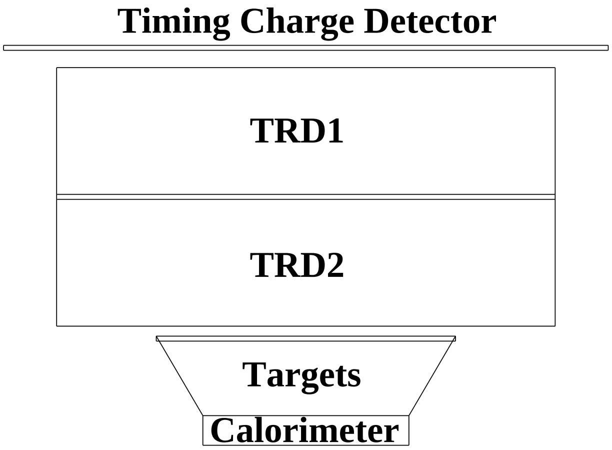

Fig. 1. A schematic diagram of the CREAM detector configuration.

2 Detector Configuration

2.1 Timing Charge Detector (TCD)

The CREAM charge determination utilizes the fact that the incident particle enters the charge detector before developing a shower in the calorimeter, while the albedo from the calorimeter scatters back to the charge detector several nanoseconds later. A TCD paddle consists of a long, thin slab of fast plastic scintillator with adiabatic lightpipes at each end that couple the scintillator to two fast photomultipliers. It can be shown that the scintillation light from the incident particle will arrive at one of the PMTs prior to that from any albedo particle, by simply considering the geometry and effective speed of light within the scintillator.

Correspondence to: H. S. Ahn (hsahn@cosmicray.umd.edu)

2.2 Transition Radiation Detector (TRD)

The CREAM TRD consists of 6 layers of polystyrene foam radiator combined with thin-walled proportional tubes filled with a xenon gas mixture. An advantage of this design lies in not requiring an external pressure vessel, which significantly reduces the weight of the overall TRD and allows a large unit to provide 1.4 m^2 sr geometry factor. The transition radiation x-rays produced by nuclei passing through the radiators are measured to estimate both the Lorentz factor and the trajectory of the particle through the instrument. The TRD will be used to measure $Z \geq 3$ nuclei with an energy resolution of 15 % for carbon and 7 % for iron at γ =3000. Importantly, the energy response can be calibrated using high Lorentz factor charged particles in a test beam. The calibration can be easily scaled according to Z^2 to determine the response for heavy nuclei.

2.3 Calorimeter Module

The CREAM calorimeter module has three major components: 1) an electromagnetic calorimeter comprised of twenty 50 cm × 50 cm tungsten plates, 3.5 mm (1 X_0) thick, alternating with twenty layers of fifty 50 cm × 1 cm plastic scintillating fiber ribbons, 0.5 mm thick, 2) a 19 cm (0.45 $\lambda_{\rm int}$) thick densified graphite trapezoidal target with an opening angle of 30° optimized for the largest effective geometry factor (Ganel, Seo and Wang, 1999): the target is interleaved with a set of plastic scintillating fiber hodoscopes above the calorimeter for triggering and tracking enhancement, and 3) plastic scintillator hodoscopes upstream of the target to serve as a supplementary charge detector for incident particles outside the Timing Charge Detector's acceptance.

3 Simulation

The performance of the CREAM calorimeter has been studied by simulating the detector response using the GEANT + FLUKA 3.21 package (Brun et al., 1984; Arino et al., 1987). Protons have been generated isotropically over an incident energy range from 100 GeV to 1 PeV (10^{15} eV).

The simulation results presented here were obtained by selecting events in which the particles enter the top of the target, exit through the bottom of the calorimeter, have their first interaction anywhere in the carbon target, and deposit significant amounts of energy in many layers of the calorimeter for tracking.

A tracking algorithm is used to reconstruct the particle trajectory by calculating the energy deposit centroid in each calorimeter layer, thereby providing up to 10 x and y cascade coordinate pairs. The cascade axis is determined by fitting a straight line through these coordinates separately in x and in y. The trajectory resolution is improved by including hodoscope information. In this case, hodoscopes with significant energy deposit are assumed to be below the first interaction position, and they are treated similar to calorimeter layers.

To keep the event record size at a manageable level, a sparsification scheme (discarding channels that do not have a signal significantly above the pedestal) is implemented with threshold levels that do not degrade calorimeter perfomance over the incident energy range from 1 TeV to 1 PeV. The effects of sparsification level on energy resolution and tracking efficiency, respectively, are shown as a function of incident particle energy in Figs. 2 and 3. The tracking efficiency is defined as the fraction of events that satisfy all the selection criteria, including tracking cuts, out of the events that satisfy all the other criteria. A sparsification level set around 5 MeV is expected to keep the energy resolution within 50 % and the tracking efficiency above 95 % for the energy range of CREAM.

The average 1 TeV event can be a conservative estimator of event record size, because 80 % of the triggered events are expected to have lower energy. The average 1 TeV event has 80 hits in the calorimeter with an energy above the 5 MeV sparsification level.

According to the simulated 1 PeV data, the maximum energy deposit in a single calorimeter scintillator readout is expected to be less than 1 TeV, so the CREAM calorimeter electronics is designed to cover the dynamic range from 5 MeV to 1 TeV.

The mean energy deposit and the energy resolution are shown as a function of incident energy in Figs. 4 and 5, respectively. The mean energy deposit, about 0.3 %, is quite linear with the incident energy, and the energy resolution, about 42 %, is quite independent of the incident energy. These characteristics are important for obtaining the true input spectra by deconvolution, because they avoid bias in the spectral-index measurements.

By extrapolating the reconstructed trajectory to the supplementary charge detector, the entrance position of the primary particle is calculated. The deviation between the actual incident position and this measured position is a Gaussian distribution with a sigma (position resolution) of about 1 cm as shown in Fig. 6.

4 Summary

Several simulation results for the present CREAM calorimeter configuration have been shown. The results indicate that the configuration will meet the CREAM requirements of energy resolution ($<$ 50 %) by implementing 5 MeV sparsification level.

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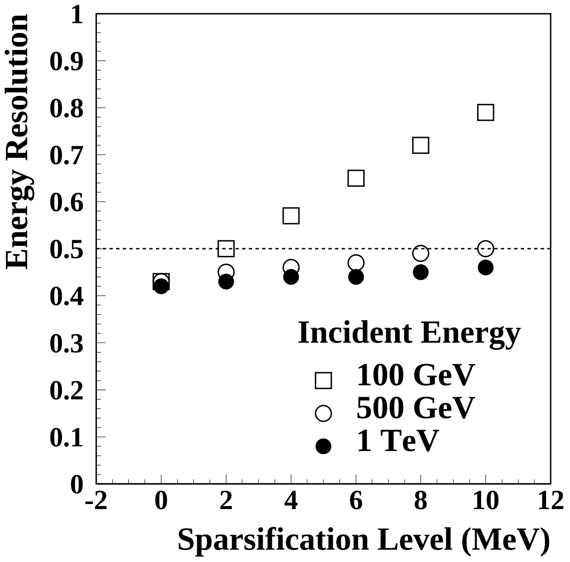

Fig. 2. Effect of the sparsification level on energy resolution for protons.

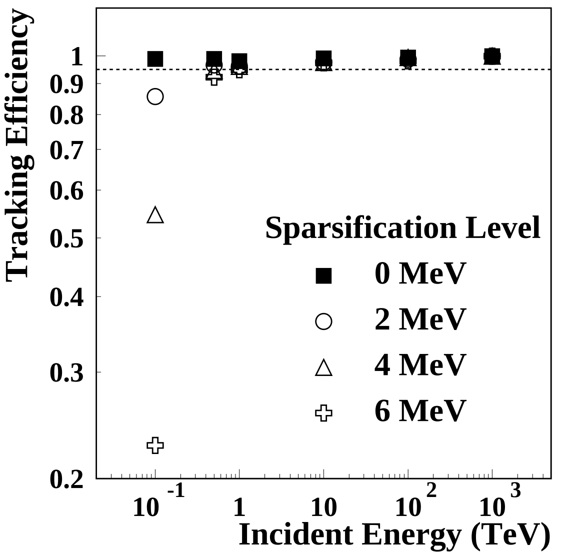

Fig. 3. Effect of the sparsification level on tracking efficiency for protons.

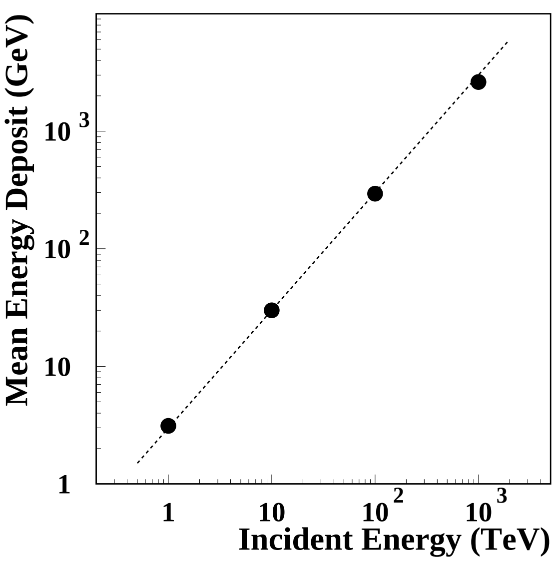

Fig. 4. Incident energy dependence of the mean energy deposit for protons.

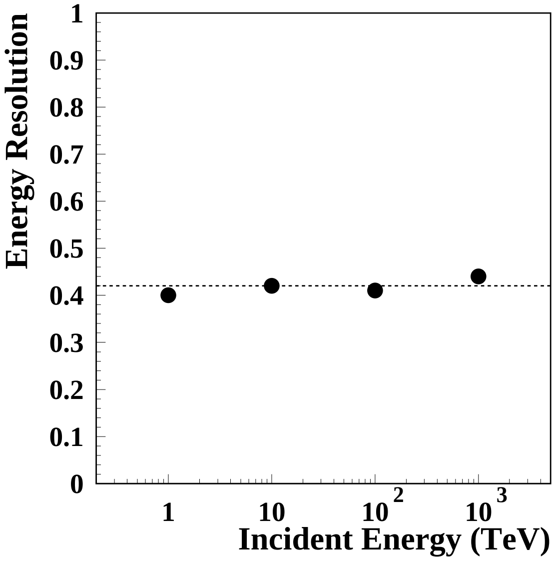

Fig. 5. Incident energy dependence of the energy resolution for protons.

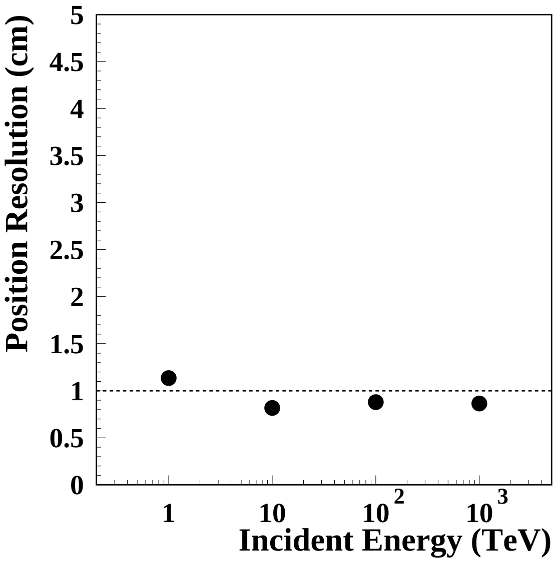

Fig. 6. Incident energy dependence of the position resolution for protons.

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