PROCEEDINGS OF SCIENCE

Performance of the ISS-CREAM Calorimeter

N. Picot-Clémente*†1, **Y. Amare**1, **T. Anderson**2, **D. Angelaszek**1,3, **N. Anthony**3, **K. Cheryian**3, **G.H. Choi**4, **M. Copley**1, **S. Coutu**2, **L. Derome**5, **L. Eraud**5, **L. Hagenau**3, **J.H. Han**1, **H.G. Huh**1, **Y.S. Hwang**6, **H.J. Hyun**6, **S. Im**2, **H.B. Jeon**6, **J.A. Jeon**4, **S. Jeong**4, **S.C. Kang**6, **H.J. Kim**6, **K.C. Kim**1, **M.H. Kim**1, **H.Y. Lee**4, **J. Lee**4, **M.H. Lee**1, **J. Liang**3, **J.T. Link**7, **L. Lu**3, **L. Lutz**1, **A. Menchaca-Rocha**8, **T. Mernik**1, **J.W. Mitchell**7, **S.I. Mognet**2, **S. Morton**3, **M. Nester**3, **S. Nutter**9, **O. Ofoha**1, **H. Park**6, **I.H. Park**4, **J.M. Park**6, **R. Quinn**3, **E.S. Seo**1,3, **J.R. Smith**1, **P. Walpole**1, **R.P. Weinmann**1, **J.Wu**1, **Y.S. Yoon**1

1 *Inst. for Phys. Sci. and Tech., University of Maryland, College Park, MD 20742, USA*
2 *Dept. of Physics, Penn State University, University Park, PA 16802, USA*
3 *Dept. of Physics, University of Maryland, College Park, MD 20742, USA*
4 *Dept. of Physics, Sungkyunkwan University, Suwon 440-746, Republic of Korea*
5 *Laboratoire de Physique Subatomique et de Cosmologie, UJF - CNRS/IN2P3 - INP, 53 rue des Martyrs, 38026 Grenoble Cedex, France*
6 *Dept. of Physics, Kyungpook National University, Daegu 702-701, Republic of Korea*
7 *Astroparticle Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*
8 *Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Circuito de la Investigación s/n, Ciudad Universitaria, CP 04510 México Distrito Federal, Mexico*
9 *Dept. of Physics and Geology, Northern Kentucky University, Highland Heights, KY 41099, USA*

The Cosmic Ray Energetics And Mass experiment for the International Space Station (ISS-CREAM) is scheduled for launch in 2017. It is designed to directly measure and identify the elemental composition of incident Galactic cosmic rays from a few hundred GeV to PeV energies. Such large energy range sensitivity is reached by using an electromagnetic sampling calorimeter (CAL) which measures the energy deposit of particle-induced showers. The CAL is composed of twenty layers of tungsten plates interleaved with scintillating fibers, and glued together using epoxy-coated fiberglass to comply with space launch requirements. In August 2015, beam test measurements were performed at CERN to verify the performance of the CAL using layers of epoxy-coated fiberglass placed between tungsten plates. The CAL response to electron and pion beams and its performance are reported and compared with previous beam test configurations.

35th International Cosmic Ray Conference - ICRC2017-
10-20 July, 2017
Bexco, Busan, Korea

---

[*] Speaker.

[†] Email: picot@umd.edu

PoS(ICRC2017)247

1. Introduction

Since recently, with the launch of AMS [1] in 2011 and CALET [2] in 2015, the International Space Station (ISS) has become a cosmic-ray observatory with the goal to bring a better understanding of cosmic-ray sources, acceleration and propagation in the Galaxy, and to discover the nature of dark matter. The ISS-CREAM experiment [3] is the successor of the Antarctic balloon-borne CREAM mission [4], which flew successfully 7 times for a total accumulated time of 191 days. It is planned to be launched and installed on the ISS on the Japanese Experiment Module External Facility 2 (JEM-EF 2) in 2017. ISS-CREAM is aimed to measure cosmic rays to the highest energy possible up to the "so-called" knee at a few PeV. For this purpose, the ISS offers an ideal platform to increase the exposure to these particles by at least an order of magnitude compared to previous experiments. Taking data on the ISS also provides the advantage to not necessitate any atmospheric corrections.

The ISS-CREAM instrument is made of multiple independent particle detectors that, combined together, can characterize incident particles. The charge of cosmic rays is measured using 4 independent layers of silicon charge detectors (SCD) [5, 6], sensitive in the range from Z=1 to Z=26. Their energy is obtained from the 20-radiation length electromagnetic sampling calorimeter (CAL), with a preceding densified graphite target that initiates hadronic interactions of cosmic-ray nuclei. The ISS-CREAM CAL is designed to measure energies from a few hundred GeV to 1 PeV. Electron/proton separation can be performed with the CAL, the top and bottom counting detectors (T/BCD) [7, 8], and the boronated scintillator detector (BSD) [9]. Triggering of incident particles is performed by using the CAL and T/BCD.

Consecutive layers of the CAL comprised of a tungsten plate plus scintillating fibers are interleaved with epoxy-coated fiberglass to comply with space launch requirements. In order to characterize and verify the performance of the detector in this configuration, a beam test was performed at the CERN-SPS in August 2015. This paper will present the ISS-CREAM carbon target and calorimeter module in Section § 2. The response of the CAL to electron and pion beams will then be shown and discussed in Section § 3.

PoS(ICRC2017)247

2. The Carbon Target and Calorimeter

Figure 1 shows a schematic view of the CAL, preceded by a densified-graphite target. The direction of the orthogonal beam used during testing is also indicated. The CAL stack of 9.6 cm is made of twenty 3.5 mm thick tungsten plates alternating with fifty 0.64 mm thick and 1 cm wide scintillating ribbon fibers between each plates. Consecutive layers of ribbon fibers are installed orthogonal to each other. For the ISS-CREAM CAL, a stainless steel wire of 1.02 mm thickness, instead of 0.9 mm for CREAM, is placed at the middle point to protect the scintillating fibers. To better maintain the stack and preserve the fibers, epoxy-coated fiberglass and tedlar sheets were added between the plates.

Preceding the ISS-CREAM CAL, two blocks of densified-graphite target of 19.8 cm total thickness with density of 1.92 g/cm^3 are used to initiate hadronic interactions of incident nuclei. The electromagnetic component of the hadronic shower, which contains on average $\sim 1/3$ of the nucleus' energy is then measured by the CAL. About 47% of cosmic-ray protons and 60% of

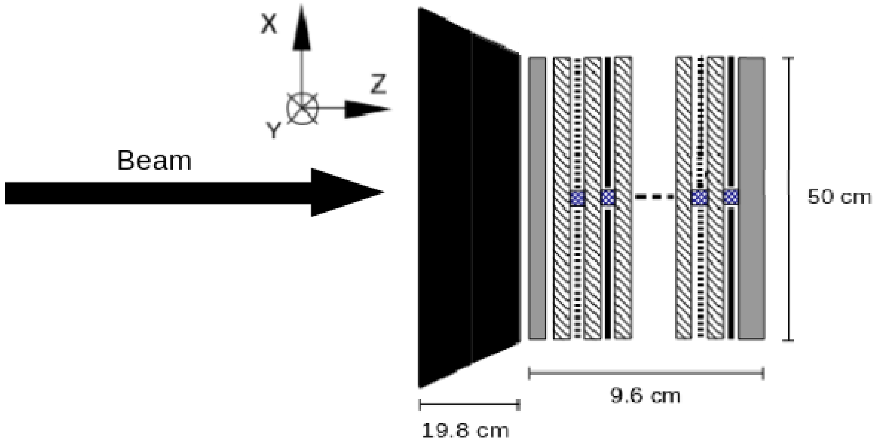

Figure 1: Schematic view of the densified-graphite target with the CAL (not to scale).

cosmic-ray iron nuclei are expected to interact hadronically in the carbon target. The ISS-CREAM CAL is designed to sufficiently contain the electromagnetic core of the initial interaction and its shower maximum within the energy range of interest between a few hundred GeV and 1 PeV.

The CAL was shipped to the CERN-SPS H2 beam line in August 2015. Tests were performed using electron beams in the energy range of 50 to 250 GeV, with RMS beam profile diameter of $\sim$ 0.6 cm, and using pion beams in the energy range of 150 to 350 GeV. For the purpose of these tests, the CAL was installed on a moving table and rotated at 90^o so that the beam was orthogonally incident to the carbon target (as displayed in Figure 1). To calibrate each of the ribbon fibers, we performed measurements at multiple positions in the X and Y coordinates. In this paper, only energy scans using electron and pion beams are presented.

3. CAL Energy Scans

3.1 Response Using Electron Beams

In order to calibrate the energy response of the calorimeter, and improve Monte Carlo simulations, we performed energy scans using electron beams. Figure 2 presents the energy deposit in the CAL ribbon fibers using electron beams with energy in the range of 50 GeV to 250 GeV. On the top right of the figure is also shown the CAL energy deposit as a function of the electron beam energy, compared with CREAM III, V and VII measurements [10]. The response of the ISS-CREAM CAL is comparable to previous CREAM CAL with a linear response of $\sim$ 5.3 MeV/GeV, and an offset of 12 MeV, and thus small for a multi-TeV shower detector.

The ISS-CREAM CAL energy resolution is shown in Figure 3 as a function of the incident electron beam energy, and is compared to previous measurements with the CREAM V CAL. The resolution improves with increasing energy and shows comparable performance to that of CREAM V. As shown in the figure, data can be fitted with a sampling fluctuation term of $\sim 2\%/\sqrt{\mathrm{E}(TeV)}$ and a constant term of $\sim 4.5\%$.

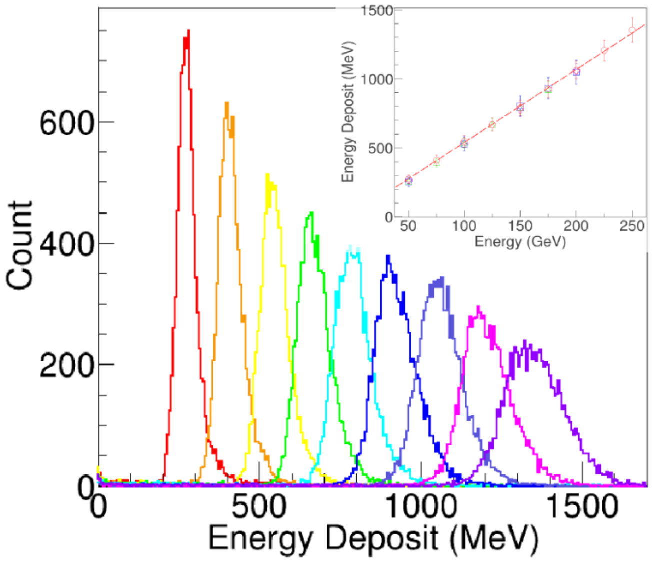

Figure 2: CAL energy deposit using electron beam energies, from left to right, of 50 GeV, 75 GeV, 100 GeV, 125 GeV, 150 GeV, 175 GeV, 200 GeV, 225 GeV and 250 GeV, respectively. The inset shows the mean CAL energy deposit as a function of the incident electron energy beam for ISS-CREAM, compared with previous measurements from CREAM III, V and VII [10].

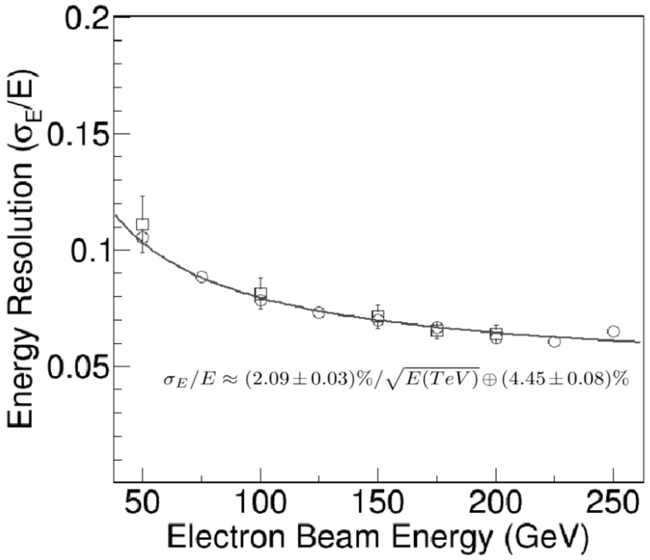

Figure 3: CAL energy resolution (circle) as a function of the electron beam energy, compared to CREAM V beam test measurements [10] (square).

3.2 Response Using Pion Beams

When interacting hadronically in the preceding densified-graphite target, incident nuclei induce a shower that can be separated into hadronic and electromagnetic components. The CAL measures mostly the electromagnetic component of the shower, which contains on average $\sim 1/3$

of the total initial energy of the nucleus. In order to characterize the CAL energy response to hadrons, energy scans were performed using pions for beam energy in the range of 150 GeV to 350 GeV. Figure 4 presents the CAL energy deposit as a function of the pion beam energy. For these measurements, we require enough signal detected in the first 3 layers of the CAL, in order to ensure that pions interacted hadronically in the carbon target. Due to the intrinsic stochasticity of hadronic interactions, the CAL energy resolution to orthogonally incident hadrons is significantly higher than for incident electrons, and is found to be at $\sim 48.5\%$. As expected, the linear energy dependence of $\sim$ 1.8 MeV/GeV observed for pions is consistent with $\sim 1/3$ of the energy dependence of the CAL response to electrons, as the detector is designed to measure mainly the electromagnetic component of the hadronic shower initiated after interaction of incident cosmic-ray nuclei with the densified-graphite target.

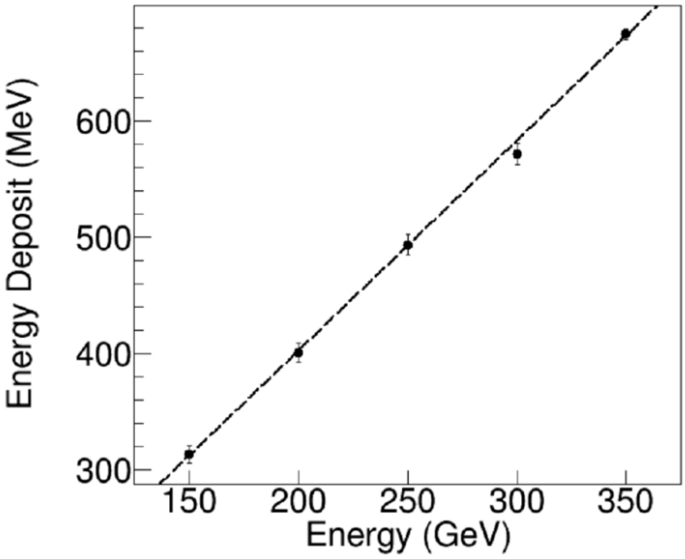

Figure 4: Mean CAL energy deposit as a function of pion beam energy.

4. Conclusion

ISS-CREAM aims to measure cosmic-ray nuclei from protons to iron, in the energy range of a few hundred GeV to 1 PeV. The twenty radiation-length sampling calorimeter, interleaved with epoxy-coated fiberglass sheets for space launch requirements, is designed to measure the energy of particle showers induced by the densified-graphite target. The performance of the calorimeter design was characterized and verified at CERN in 2015 using beams of electrons and pions. In this paper, we presented the calorimeter response to multiple beam energies, which shows a robust linear energy dependence for both electrons and pions. About 1/3 of the pion initial energy is deposited in the calorimeter, which agrees with expectations, as the detector measures mainly the electromagnetic components of hadronic showers created by incident cosmic-ray nuclei. Results are consistent with previous CREAM beam tests, which confirms that the addition of fiberglass sheets between layers does not have a significant impact on the calorimeter response. The ISS-CREAM instrument is now ready, and scheduled for launch on SpaceX-12 in 2017.

Acknowledgments

The authors thank NASA GSFC WFF for project management and engineering support, and NASA JSC ISS Program Office for launch support and the ISS accommodation. They also thank CERN for provision of excellent accelerator beams. This work was supported in the U.S. by NASA grants NNX11AC52G, NNX08AC15G, NNX08AC16G and their predecessor grants, as well as by directed RTOP funds to NASA GSFC WFF. It is supported in Korea by the Creative Research Initiatives of MEST/NRF and by National Research Foundation Grants NRF-2014R1A2A2A01002734, NRF-2014R1A1A2006456. It is supported in France by IN2P3/CNRS and CNES and in Mexico by DGAPA-UNAM and CONACYT.

References

[1] S. Ting., *The Alpha Magnetic Spectrometer on the International Space Station*, Nucl. Phys. B, Proc. Suppl. 243-244, 12-24 (2013).

[2] S. Torii for the CALET Collaboration, *CALET Mission for Exploring the High Energy Universe*, IEEE Trans. on Fundamentals and Materials 132, 8, 603 (2012).

[3] E.S. Seo et al., *Cosmic Ray Energetics And Mass for the International Space Station (ISS-CREAM)*, Adv. Sp. Res. 53, 10, 1451-1455 (2014).

[4] E.S. Seo et al., *Cosmic-ray energetics and mass (CREAM) balloon project*, Adv. in Sp. Res. 33, 10, 1777-1785 (2004).

[5] I.H. Park, N.H. Park, S.W. Nam et al., *Silicon charge detector for the CREAM experiment*, Nucl. Inst. Meth. A 570, 286-291 (2007).

[6] J. Lee et al., *Design, Fabrication and Performance of the Silicon Charge Detector for the ISS-CREAM*, Proc. 34th Int. Cosmic Ray Conf., The Hague, Netherlands, ID 693 (2015).

[7] Y.S. Hwang et al., *Construction and Testing of a Top Counting Detector and a Bottom Counting Detector for the Cosmic Ray Energetics And Mass Experiment on the International Space Station*, J. INST 10 (07), P07018 (2015).

[8] H.J. Hyun et al., *Performances of photodiode detectors for top and bottom counting detectors of ISS-CREAM experiment*, Nucl. Inst. Meth. A 787, 134-139 (2015)

[9] J.T. Link et al., *Design and Performance of the ISS-CREAM Boronated Scintillator Detector*, Proc. 34th Int. Cosmic Ray Conf., The Hague, Netherlands, ID 611 (2015).

[10] J.H. Han et al., *Performance of the CREAM-V and CREAM-VI calorimeters in flight*, Proc. 32nd Int. Cosmic Ray Conf., Beijing, China, ID 1107 (2011).