Beam Test Calibration of the ISS-CREAM Calorimeter

Young Soo Yoon

On behalf of the ISS-CREAM Collaboration

Cosmic Ray Physics Group, IPST, UMD

CALOR 15-20 May, 2016 Daegu

ISS-CREAM Collaboration

E.S. Seo[1,2,*], Y. Amare[1], T. Anderson[3], D. Angelaszek[1,2], N.Anthony[1], H. Arnold[1], G.H. Choi[4], M. Copley[1], S. Coutu[3], L. Derome[5], C. Ebongue[1], L. Eraud[5], I. Faddis[1], J.H. Han[1], I.J. Howley[1], H.G. Huh[1], Y.S. Hwang[6], H.J. Hyun[6], S. Im[3], H.B. Jeon[6], J.A. Jeon[4], S. Jeong[4], D.Y. Kim[1,], H.J. Kim[6], K.C. Kim[1], M.H. Kim[1], P. King[1], H.Y. Lee[4], J. Lee[4], M.H. Lee[1,], J. Liang[1], J.T. Link[7,], L. Lutz[1], A. Menchaca-Rocha[8], J.W. Mitchell[7], S. Morton[1], M. Nester[1], S. Nutter[9], O. Ofoha[1], H. Park[6], I.H. Park[4], J.M. Park[6], N. Picot-Clemente[1], J.R. Smith[1], P. Walpole[1], R.P. Weinmann[1], J. Wu[1], B. Yon[1], Y.S. Yoon[1,2]

[1] Inst. for Phys. Sci. and Tech., University of Maryland, College Park, MD 20742, USA
[2] Dept. of Physics, University of Maryland, College Park, MD 20742, USA
* Principle Investigator

[3] Dept. of Physics, Penn State University, University Park, PA 16802, USA

[4] Sungkyunkwan University, Natural Sciences Campus, Physics Department, 2066 Seobu-ro, Jangan-gu, Suwon-si, Gyeonggi-do, 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, Deagu 702-701, Republic of Korea

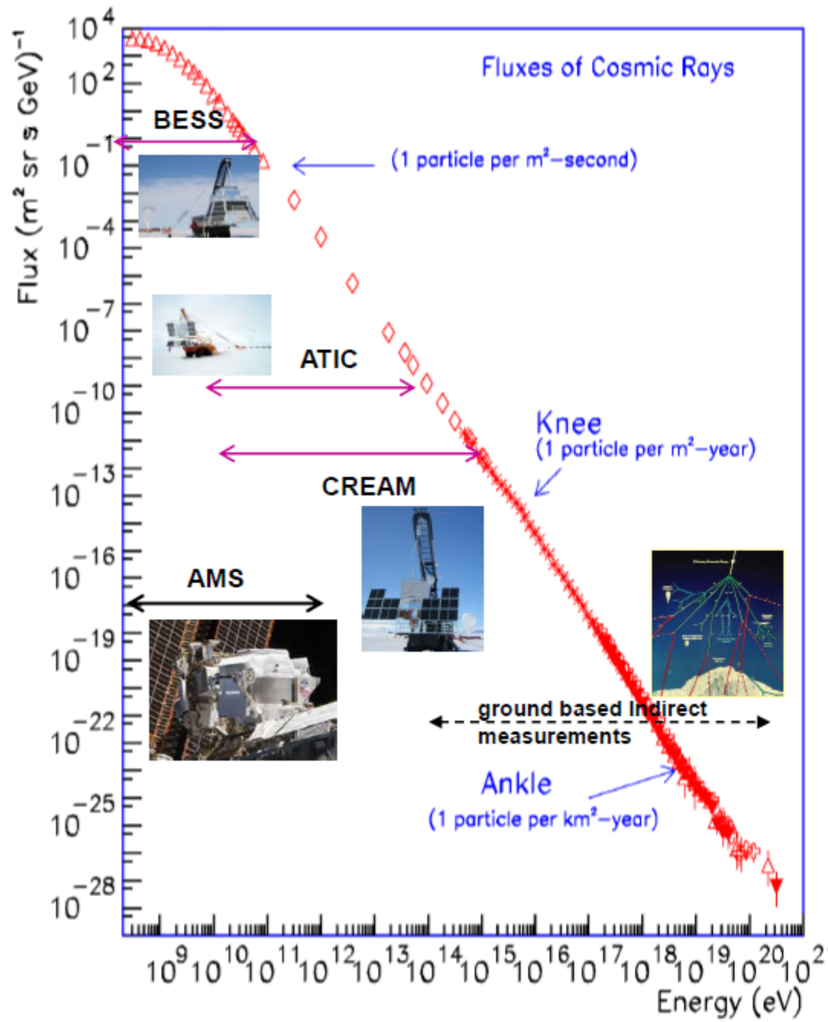
[7] Astrophysics Space Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

[8] Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Circuito de la Investigacion s/n, Ciudad Universitaria, CP 04510 Mexico Distrito Federal, Mexico

[9] Dept. of Physics & Geology, Northern Kentucky University, Highland Heights, KY 41076 USA

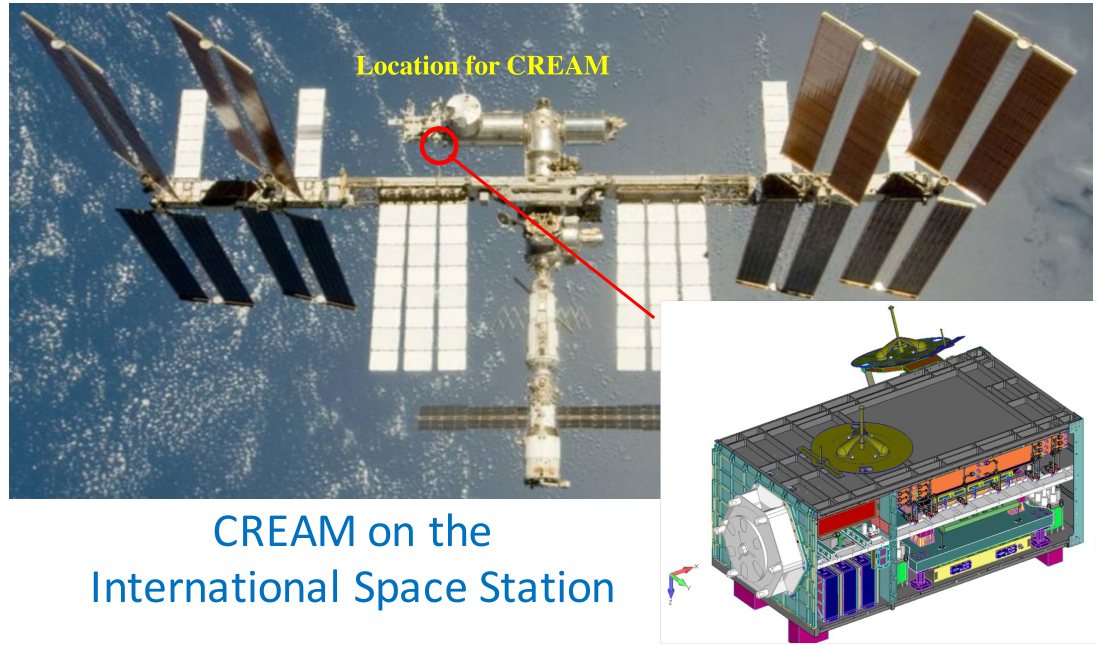
Cosmic Ray Energetics And Mass

- The CREAM Experiment is designed to measure the energy and identify the elemental composition of incident cosmic-ray nuclei (Z=1-26) and electrons in energy range 10^{11}-10^{15} eV.
- It's goal is to extend direct measurements to the highest energies with the best statistics possible.
- In doing so, CREAM can address several open questions in cosmic-ray physics such as,
  - What is the nature of the mechanism behind cosmic ray acceleration? Single Source?
  - What effect do propagation effects have on cosmic-ray energy spectra → Cosmic Ray History?
  - Origin of the so-called 'knee'?



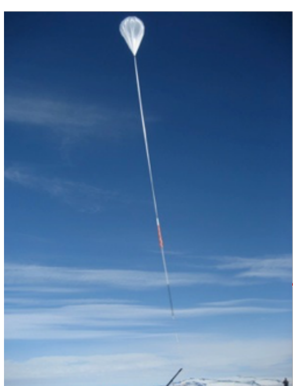
CREAM to ISS-CREAM

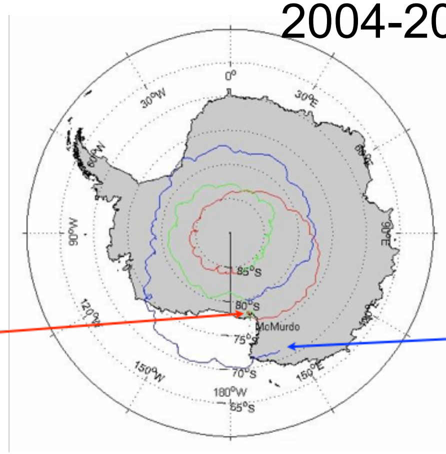
CREAM with
Long Duration Balloon

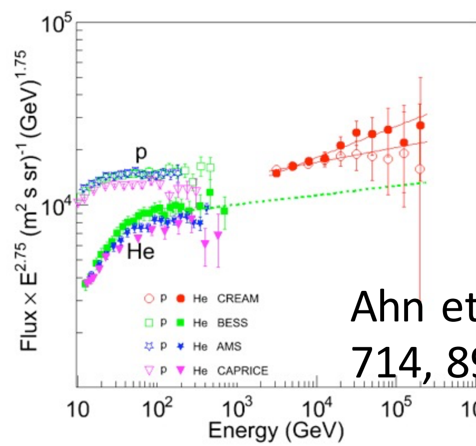


CREAM on the
International Space Station

6 CREAM balloon flights around Antarctica
2004-2010 with 161+ days of accumulated data.





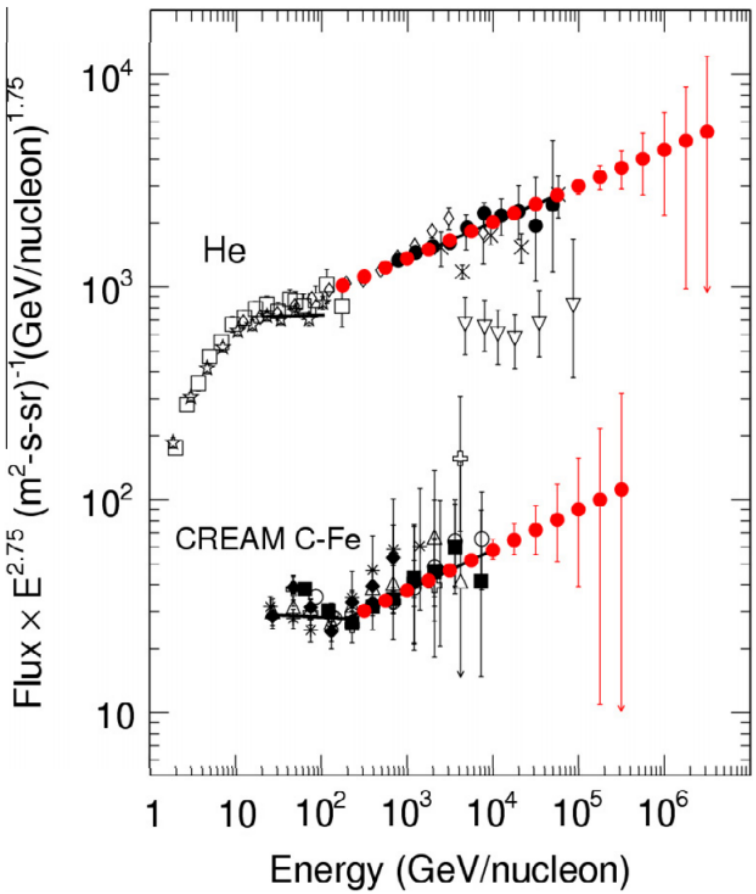


Ahn et al., ApJL 714, 89 (2010)

ISS-CREAM: Objectives

- ISS-CREAM
  Follow-up project that will integrate the CREAM payload onto the International Space Station (ISS).
- Spectral hardening discovered with CREAM-I flight.

- Advantages of ISS:
  - Increased exposure time
    (3+ year mission = order of magnitude increase in exposure time)
  - No atmospheric overburden
- Direct measurement of cosmic rays will be extended to highest energies with best statistics to date.



ISS-CREAM Instrument

ISS-CREAM has 4 particle detectors:

Calorimeter (CAL)

- Energy measurements
- Sampling calorimeter with tungsten and scintillating fibers
- Providing a trigger

Silicon Charge Detector (SCD)

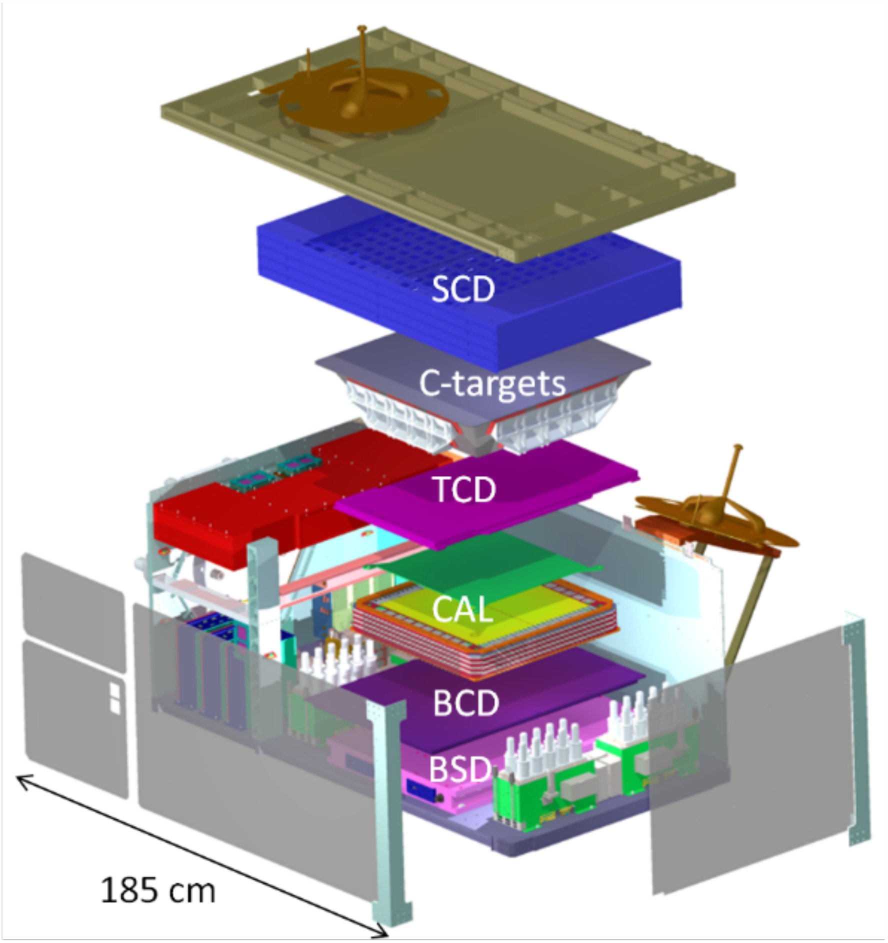
- Charge identifications
- 4 layers of silicon pixel sensors
- 380μm-thick 2.12 cm^2 pixels
- 79x79 cm^2 active detector area

Boronated Scintillating Detector

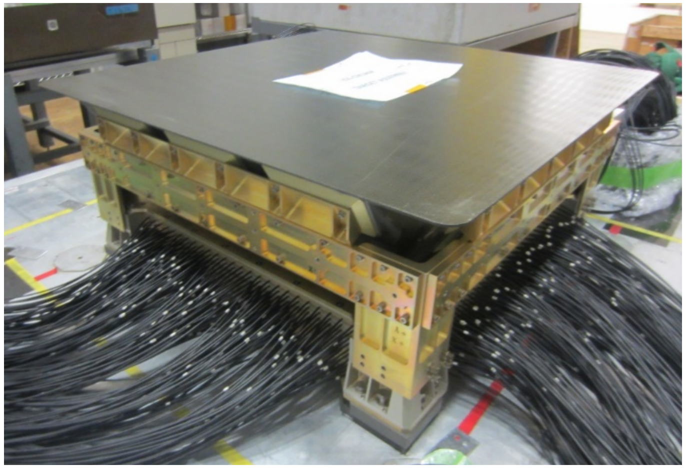
- e/p separation **(new for ISS-CREAM)**

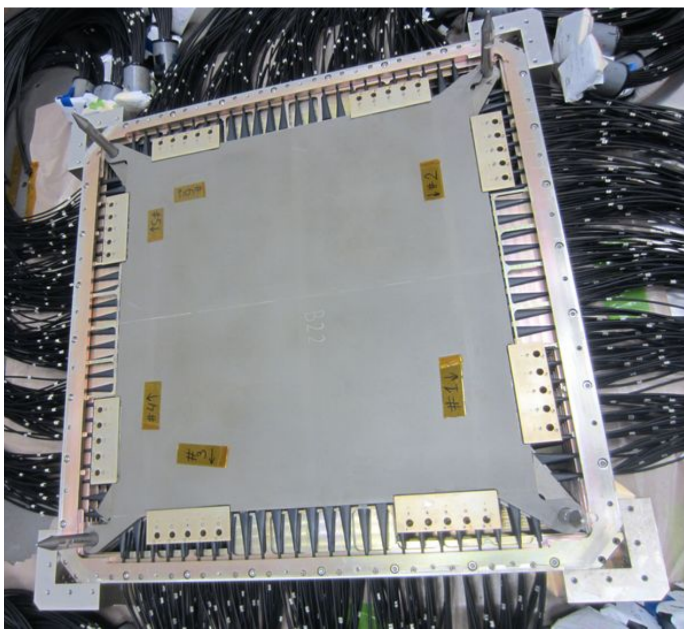
Top/Bottom Counting Detectors

- e/p separation **(new for ISS-CREAM)**
- Redundant trigger
- Segmented plastic scintillators



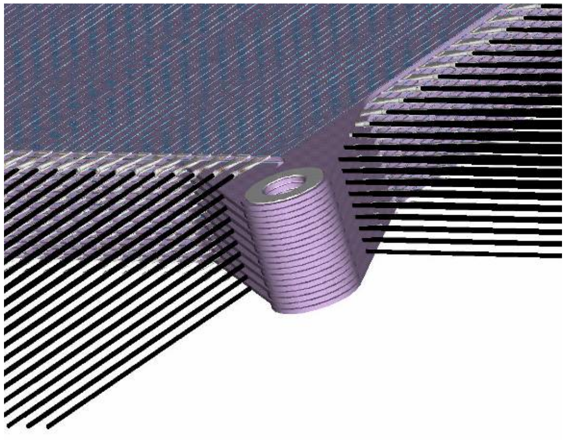
ISS-CREAM Calorimeter





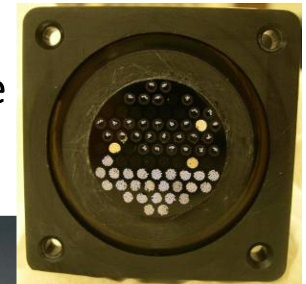
- Designed to measure cosmic-rays in the energy range of 10^{11}-10^{15} eV
- Flared densified C-target, ~0.5 λ, 1 χ_0 to increase hadronic interactions
- Thin calorimeter to increase acceptance, ~20χ_0
- Twenty alternating W and scintillating fiber ribbon layers
  - W: 50 cm x 50 cm x 0.35 cm, 1 χ_0 each
  - Fibers: fifty-1 cm wide of nineteen 0.05 cm BCF-12MC scintillating fibers per layer
  - **Epoxy fiberglass mesh to glue calorimeter for mechanical stability in rocket launch**
- Optical division, HPD, and electronics
  - Three range optical divisions to support wide dynamic range (43:5:1)
  - Hybrid Photo-Diodes (HPD): Linear 1 – 100,000 p.e.
  - **16-bit ASIC IDE single package VA32HDR14.2/TA32cg3**
  - **Increased trigger gain and range from balloon**

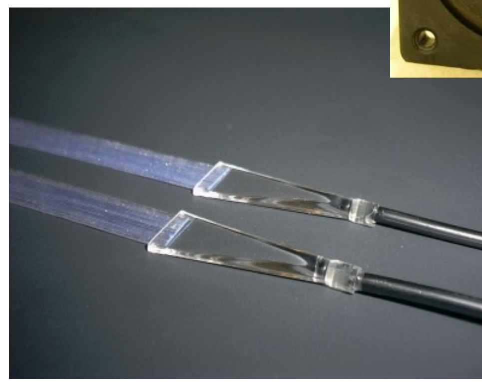
Calorimeter Components and Scheme



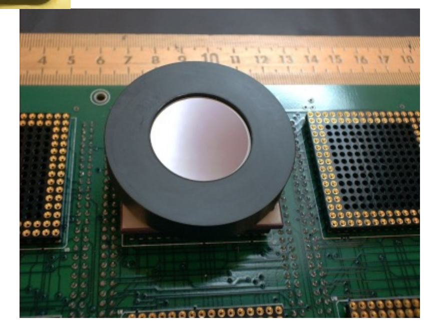
W/Scint stack

Cookie



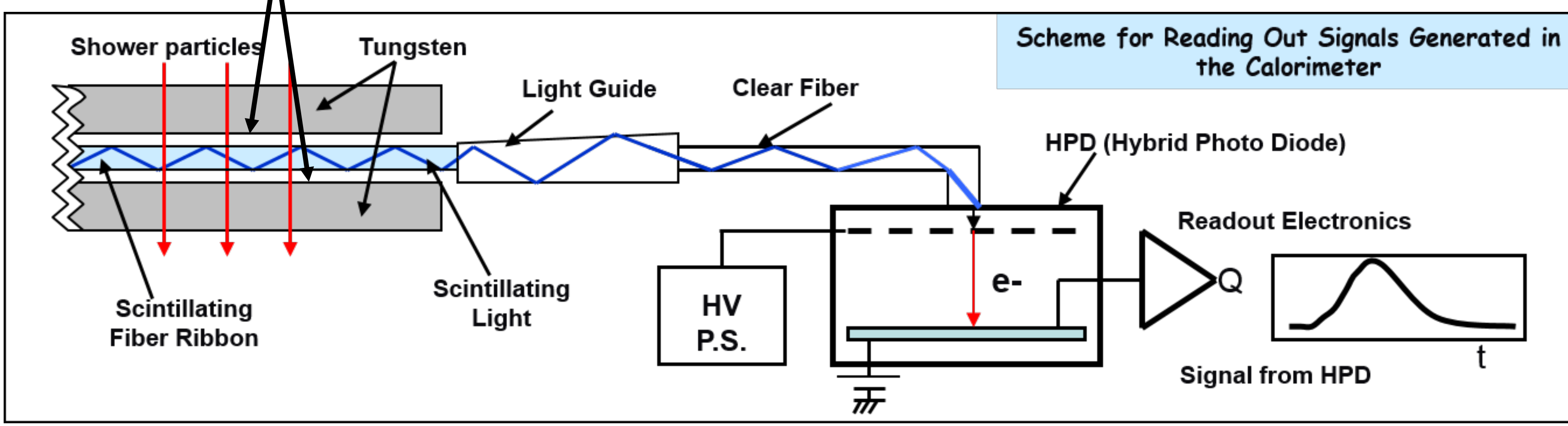


Fiber light guides

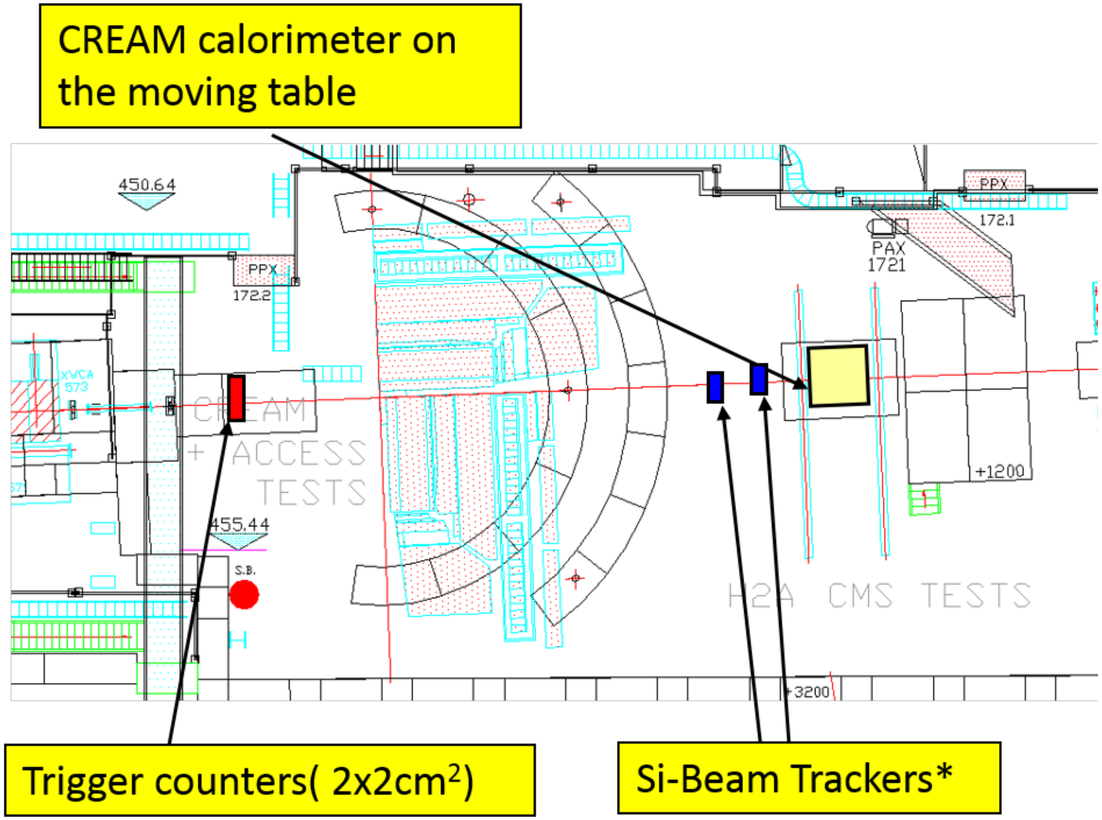


Mounted HPD

Epoxy Fiberglass Mesh



Calibration in CERN H2 beam line



- Electron beam: 50-250 GeV
- Pion beam: 150-350 GeV

Position scans

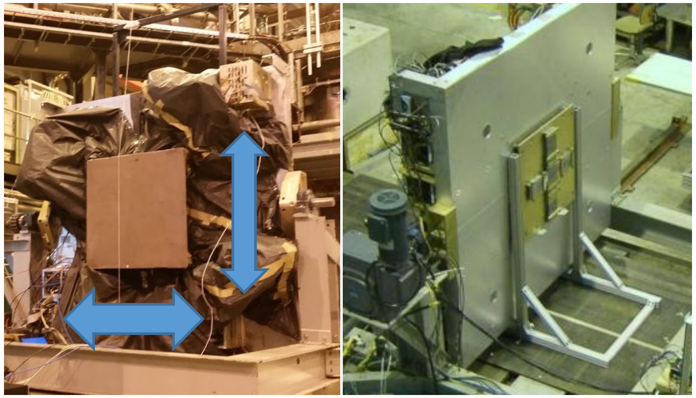
- to measure calibration constants for each fiber ribbon

Energy scans of electrons and pions

- to measure linearity and resolution

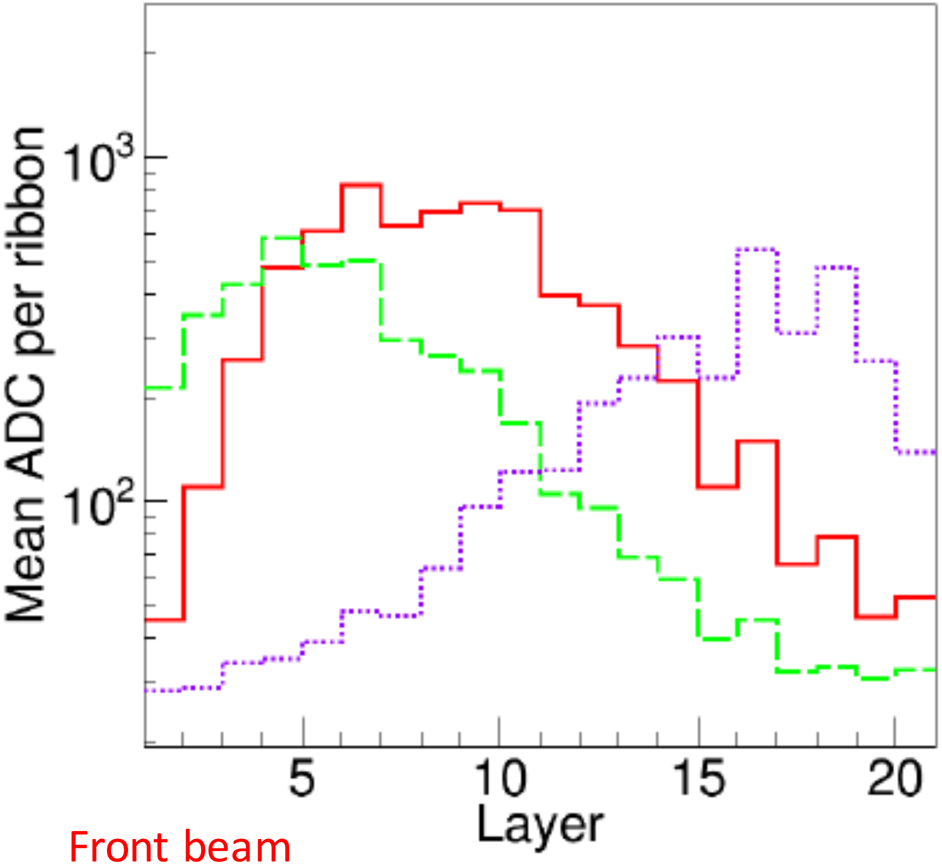
Position Scans with Electrons

- Electron sampling fraction ~0.5%
- Calibration front and rear layers' ribbons additional Pb bricks and W plates are used.
- Shower max is located at 9 χ_0, i.e. layer 8.



All 50 positions along x and y

Average longitudinal profile with 150 GeV e^-



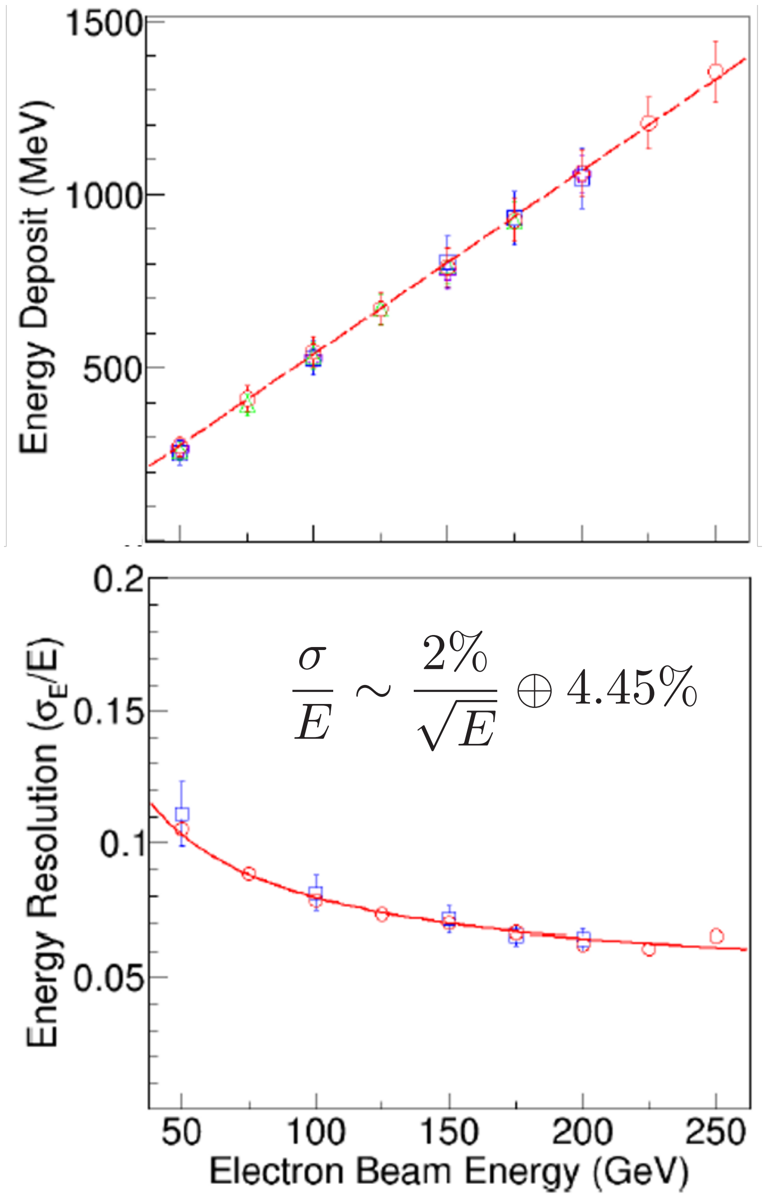
Front beam

Front beam with lead bricks (5 χ_0)

Rear beam with lead bricks and two W-plates

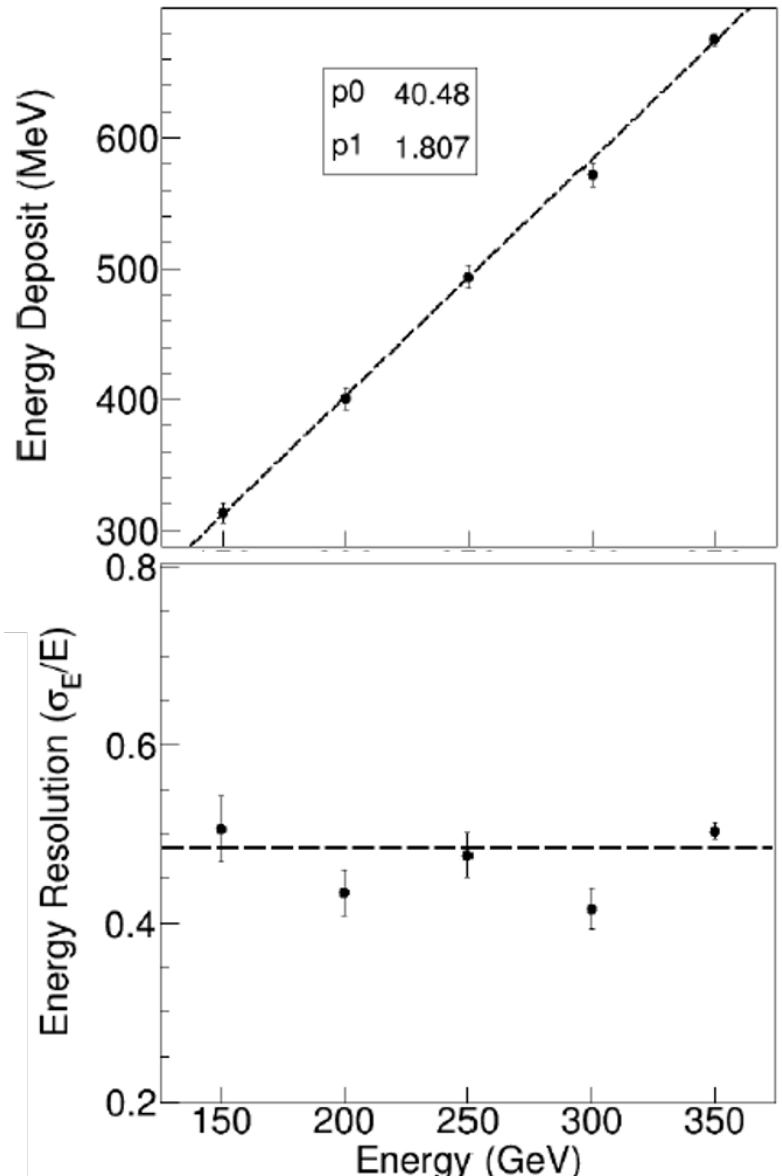
Response to Electrons

- Energy scans with 50-250 GeV elections
  - ADC to energy is ~ 0.085 MeV/ADC
- Linearity was compared with former calibration results of calorimeter for balloon flights: ISS-CREAM (open circle), CREAM-V (open square), CREAM-VII (open triangle)
- 5.3 MeV/GeV response and 0.53% sampling fraction measured
- Resolution: ~2%/√E(TeV), const term 4.45%



Response to Hadrons

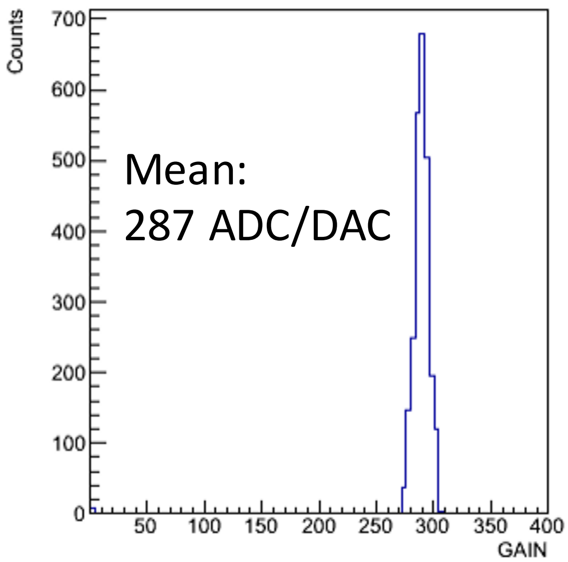
- Pion energy scans with150-350 GeV
- Energy cuts in first three layers select events that interacted hadronically in the carbon target
- Hadrons show 1.8 MeV/GeV linearity
- Resolution is ~50% constant term
- Sufficient to cover dynamic range of cosmic-rays energies



In-Flight Calibration and Energy Reach

- ISS-CREAM Calorimeter has capability to perform in-flight calibrations
- Charge injections calibrate entire dynamic range of electronics
  - 8-bit DAC over 20 pC charge injection range
  - 287 ADC/DAC electronics gain
- LED injections calibrate response of HPDs to light.

Electronics gain at certain input charge



Possible energy reach:

~32000 ADC (16-bit ADC – pedestal) × 42 (High range optical gain)

× 0.085 MeV/ADC (Calibration)

/ (0.53% / 3) (electron sampling fraction to proton)

× 100 channels (assumed shower contained in 20 layer x 5 ribbons)

~ 6.4 × 10^9 MeV → ~ several-tens PeV energy

SpaceX Integration and Launch

FRAMs In Dragon trunk

Flight Releasable Attachment Mechanism

BEAM above Dragon trunk

Bigelow Expandable Activity Module

Dragon is the name of the module that's on top of the SpaceX falcon rocket that carries various payloads to the space station.

SpaceX Integration and Launch

Photos from the web…
Hanger with Falcon rocket (left)
Dragon integration with Falcon in adjacent high-bay (right)

Summary

- ISS-CREAM is designed to directly measure the energy and identify the elemental composition of cosmic-rays in the energy range 10^{11}-10^{15} eV.
- The Calorimeter has been upgraded from the balloon to withstand a rocket launch and its trigger energy range has been increased.
- Beam tests have successfully been completed at CERN's H2 beam line to characterize the Calorimeter performance and measure its response to electrons and hadrons.
- In-flight calibration will monitor the calorimeter performance in real time.
- ISS-CREAM is planned to launch on SpaceX 12 in April 2017.

Thank you

Dynamic Range of CREAM-I

Target energy range : ~ 100 GeV - 1000 TeV

Optical division by dividing clear fibers in 37:5:1 (Low:Middle:High) +
Neutral density filter 1: 0.5 : 0.16 (Low:Middle:High)
→ Final division : 231 : 15 : 1

VA HDR 32 chip (Low range) linear range : up to 1 pC (1000 ADC counts)
Gain : 1 MeV / ADC count (from beam test)
Noise : 1 ADC count (~ 1 fC)

HPD: Linear between 1 p.e. – 100,000 p.e.

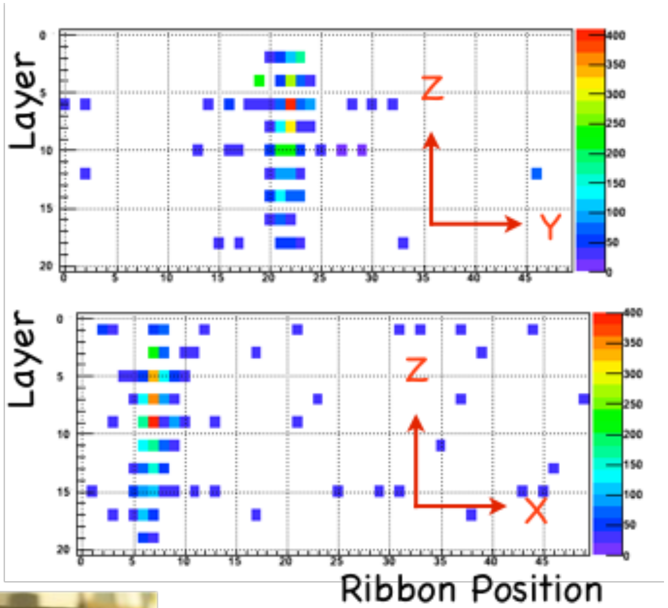
Low range : 1 MeV – 1 GeV per strip (HV@10.5 kV)
Middle range : up to 14.8 GeV per strip
High range : up to 231 GeV per strip (~ 1000 TeV incident E proton)

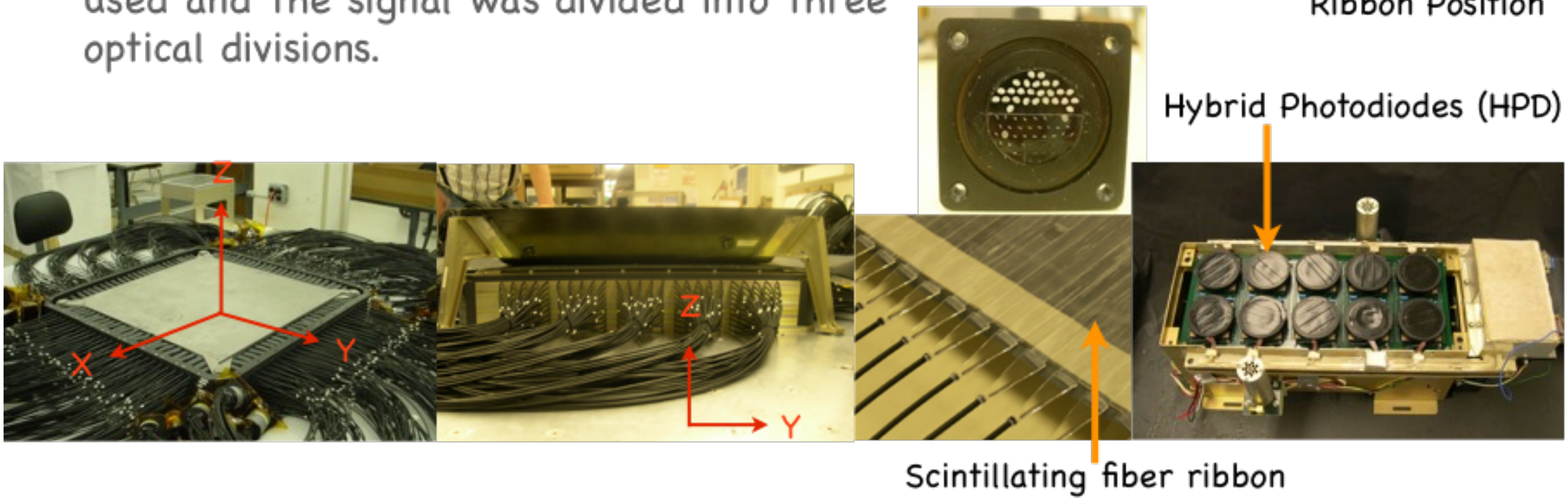
1 MeV – 231 GeV (*1:200,000) range covered*

Moo Hyun Lee

Tungsten/Scintillator Calorimeter

- CREAM Calorimeter composed of 20 layers of tungsten (20 radiation length) and scintillating fiber ribbons.
- The ribbons are laid down along X and Y direction alternatively.
  ➜ The trajectories are reconstructed.
- To increase the dynamic range of energy measurement, Hybrid Photodiodes (HPD) were used and the signal was divided into three optical divisions.

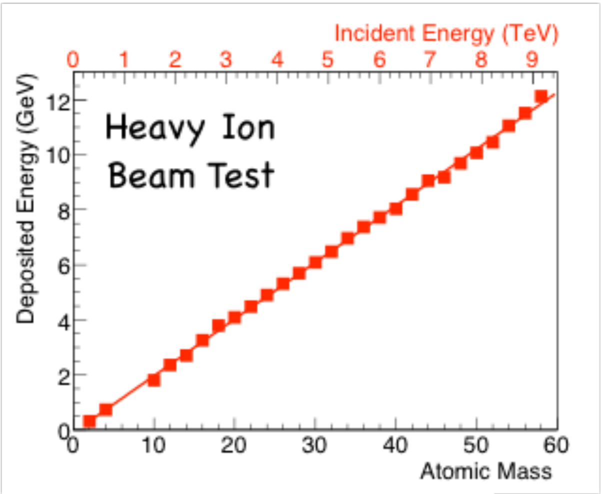


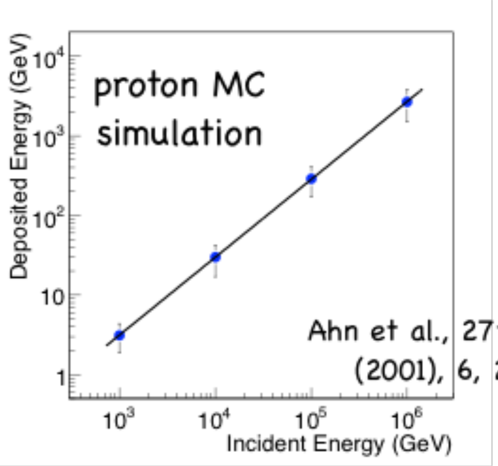


Linearity of Calorimeter Response

Heavy-Ion Beam test with CREAM-I Calorimeter

- The calorimeter response over the range was confirmed with nuclear fragments (A/Z=2) of a 158 GeV/nucleon Indium beam at CERN.
- The energy response was linear up to the maximum bin energy of ~9 TeV.
- Above the available accelerator beam energy, MC simulations indicate that the calorimeter response is quite linear in the CREAM measurement energy range.





Ahn et al., 27th ICRC (2001), 6, 2159