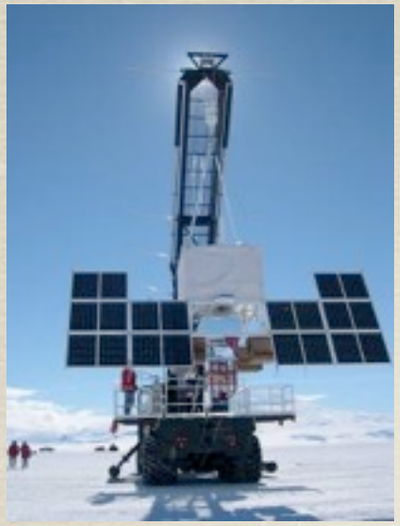
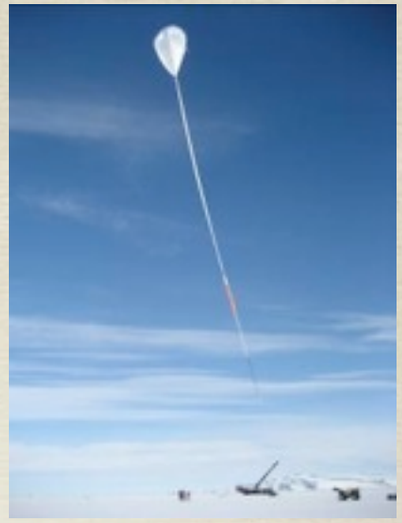


Cosmic Ray Energetics And Mass



The Energy Spectra of H and He from the CREAM-I Flight

Young Soo Yoon
University of Maryland

For the CREAM Collaboration

CREAM Collaboration for Flight 2004-2005

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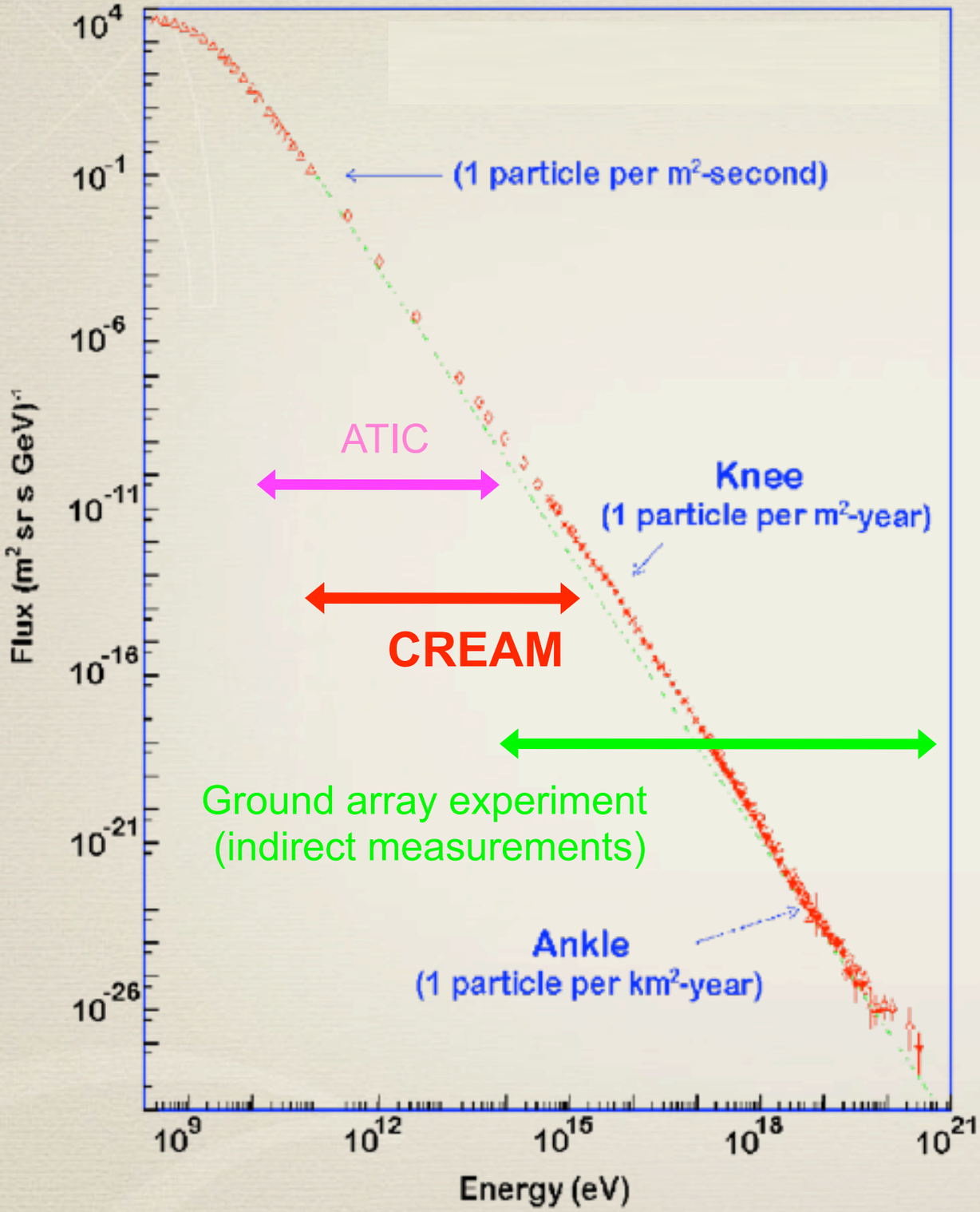
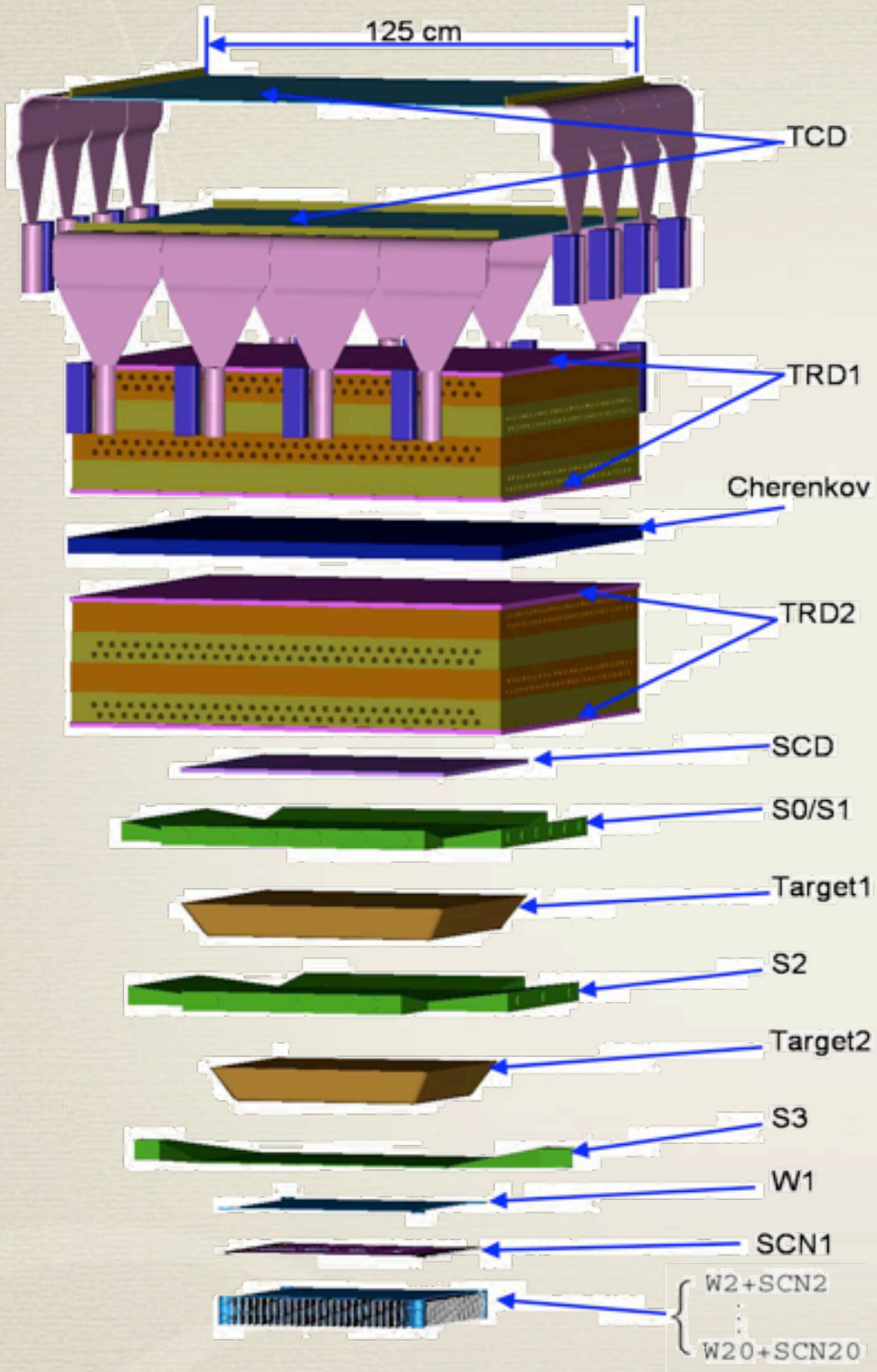
Cosmic-Ray All-Particle Spectrum



Known Questions

- ★ What is the origin of the "knee" in the all-particle cosmic-ray energy spectrum?
- ★ Are there energy spectral differences between protons, helium nuclei and heavier nuclei (above 10~100TeV)?
- ★ What is the propagation history on cosmic ray particles?

CREAM-I Detector Configuration



- **Timing based Charge Detector (TCD)**
  - Two layers of 4 scintillator paddles each
  - Identifies incoming particle ID
  - Provides high-Z & low-Z triggers
- **Transition Radiation Detector (TRD) and Cherenkov Detector**
  - Two modules with 512 gas-filled tubes each
  - Measures Lorentz factor (γ) for $Z \geq 3$
  - A plastic Cherenkov counter
  - Rejects low energy cosmic rays
- **Silicon Charge Detector (SCD)**
  - 380μm silicon sensors with 2912 pixels, each 2.12 cm^2 in area
  - Identifies particle charge for $1 \leq Z < 28$
- **Hodoscopes (S0/S1 and S2)**
  - Three pairs of layers of scintillating fibers
  - Provides supplemental particle ID
  - Provides tracking information
- **Single layer of scintillating fibers (S3)**
  - Provides a reference time for TCD triggers
- **Tungsten/Scintillator Calorimeter (CAL)**
  - 20 layer pairs of tungsten & scintillating fibers
  - Measures energies of interacting particles

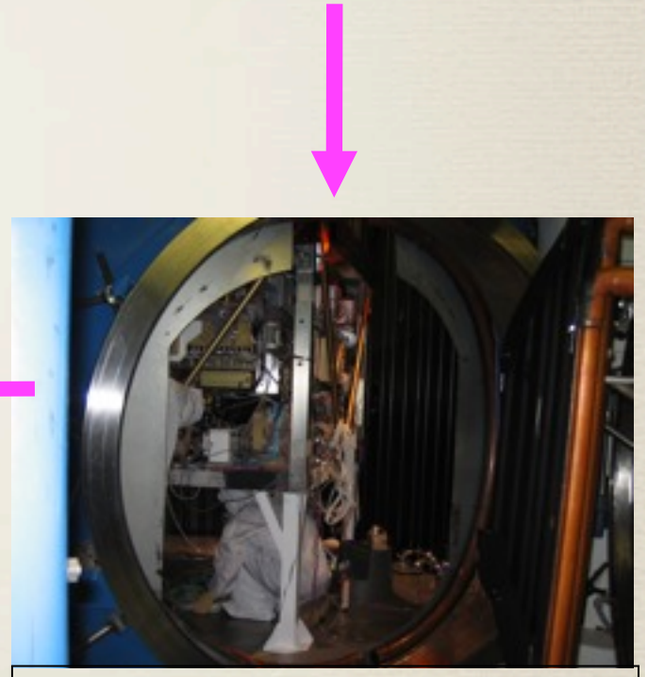
Test and Preparations of Flight 2004-2005

Proto-type Research, Development and Test

Construction
(Univ. of Maryland, MD)

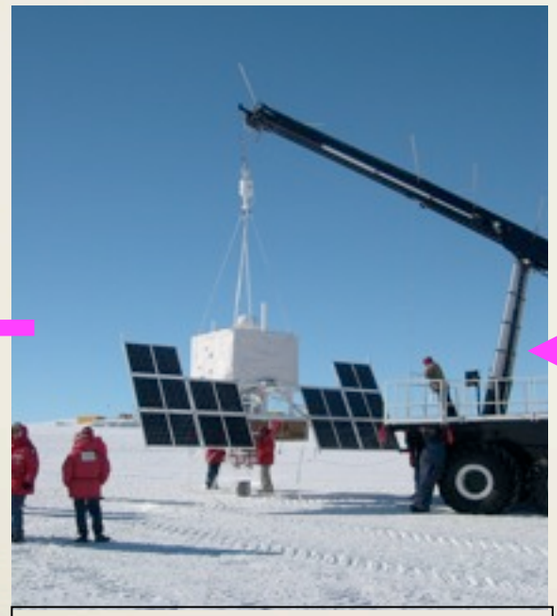
Calibration
Beam Test
(CERN, Geneva)

Integration and Test
(Univ. of Maryland, MD)

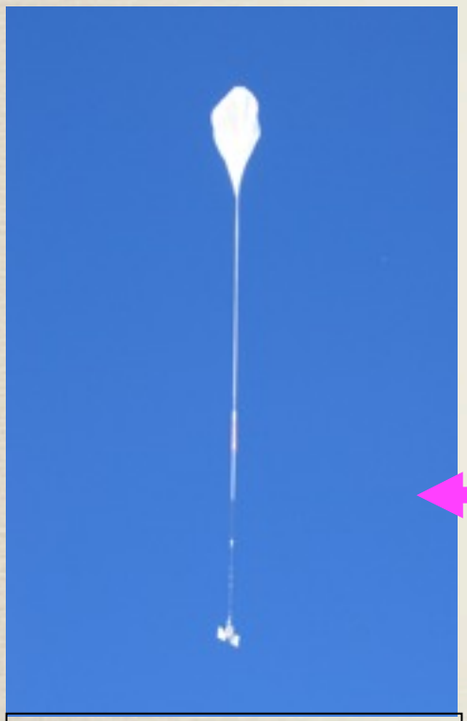


Thermal-Vacuum Test
(NASA Goddard Space Flight Center, MD)

External Hang Test
(NASA Wallops Flight Facility, VA)



Hang Test on the Ice in Dec, 2004
(McMurdo Station, Antarctica)



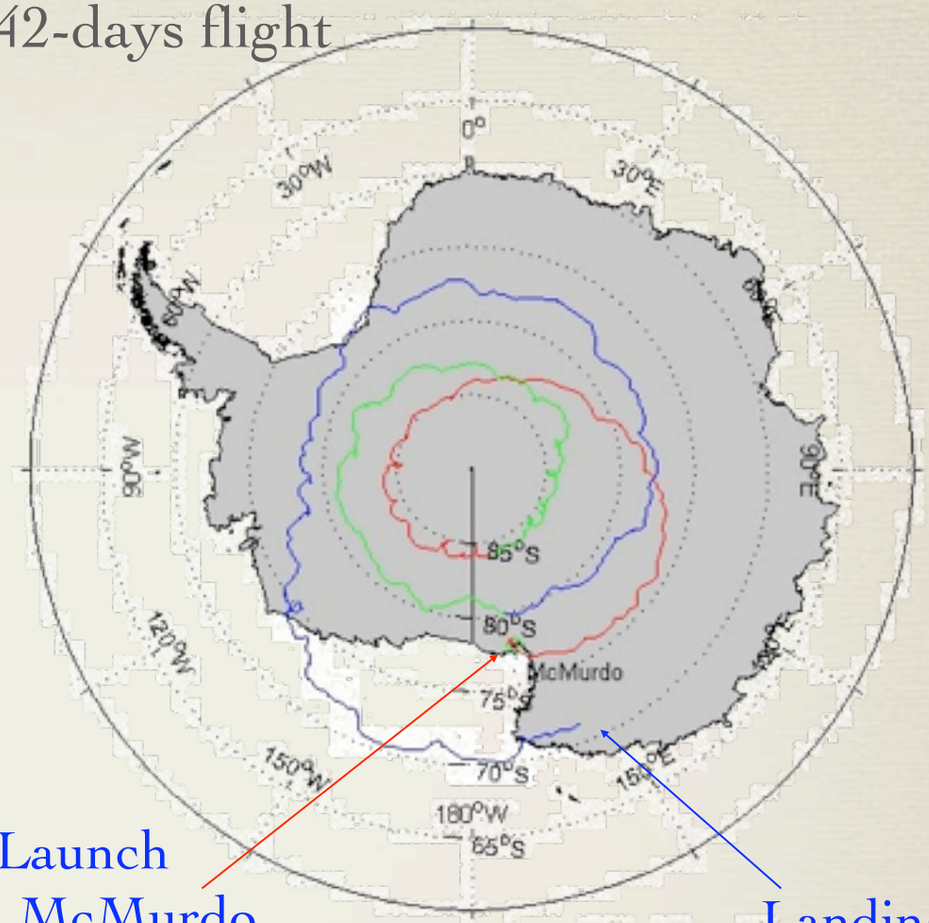
Launch
Dec 15, 2004
(McMurdo Station, Antarctica)

CREAM-I Flight 2004-2005

Before Launching

CREAM-I 2004/05 Landing

A record breaking
42-days flight

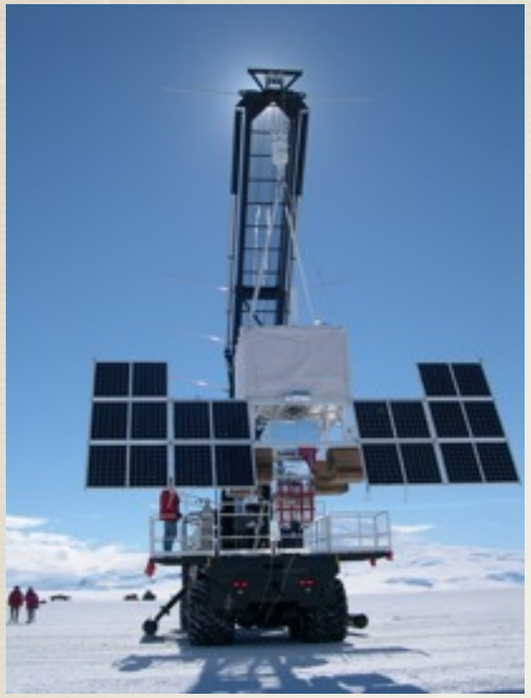


Launch
from McMurdo.
Dec. 16th 2004

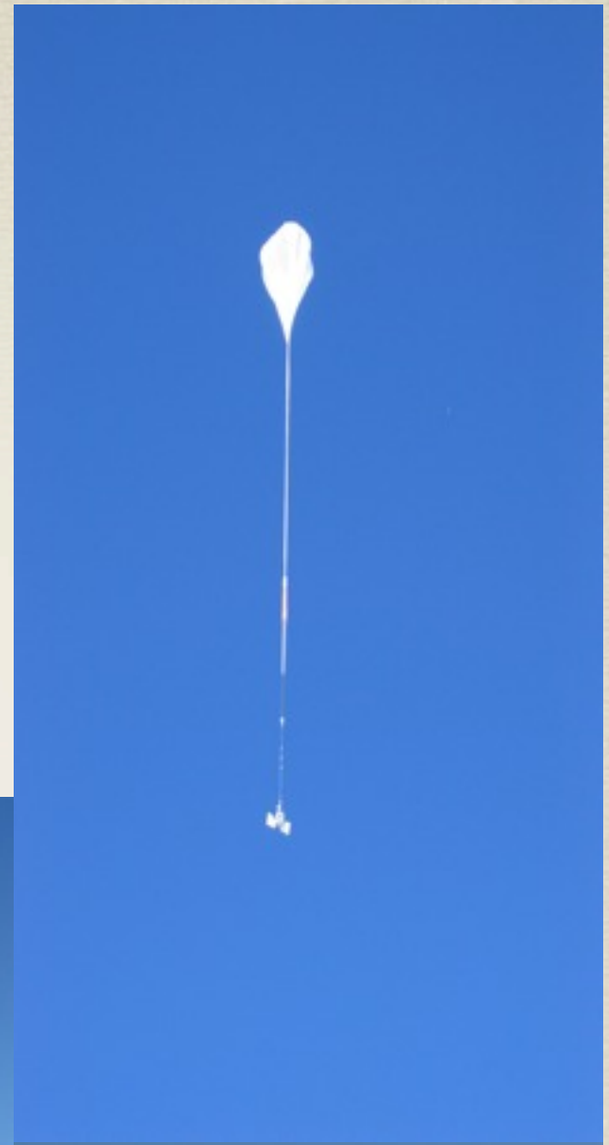
Landing.
Jan. 27th 2005

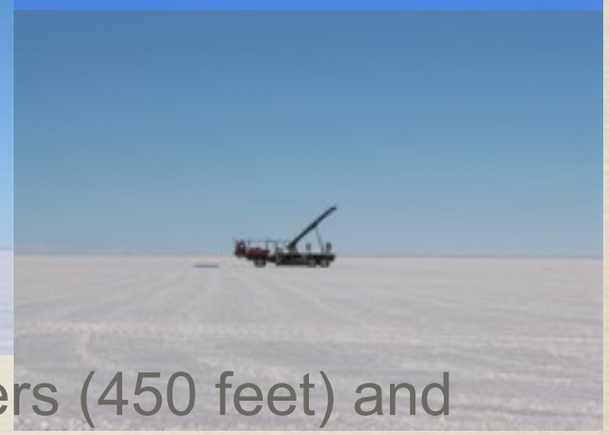
CREAM-I, -II, -III, -IV and -V have flown 42 days (2004/05), 28 days (2005/06), 29 days (2007/08), 19 days (2008/09), and 37 days (2009/10), respectively.

Launch of CREAM-I



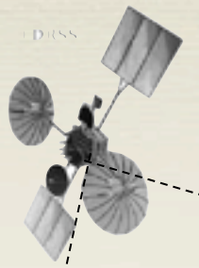
Launch Site: McMurdo Station, Antarctica
Date Launched: 16 DEC, 2004





NASA's balloon expanded to a diameter of more than 137 meters (450 feet) and total suspended weigh was about 2700 kilograms (6000 pounds). Balloons are made of thin polyethylene material, about the same thickness as ordinary sandwich wrap.

Operation Overview



TDRSS
or IRIDIUM

Operation Control Center
Palestine, TX

White Sands,
NM

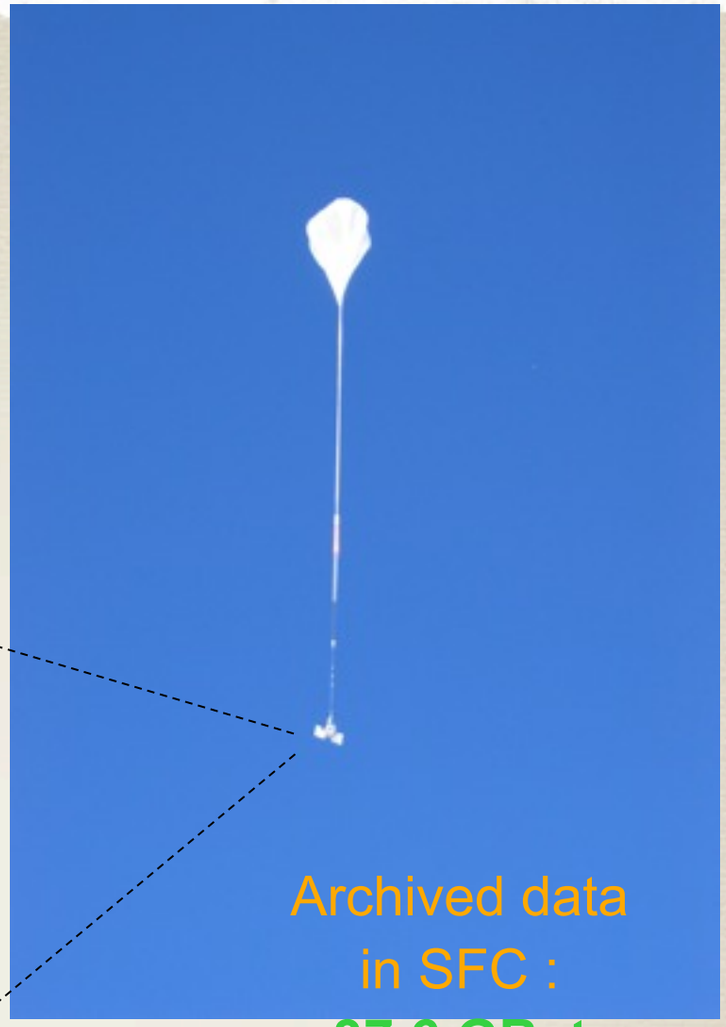
Engineering Support Center
NASA / WFF, VA

Remote commanding

Data streaming

Science Operation Center, UMD

(2004/12/16 ~ 2005/01/26)



Archived data in SFC :
~ 37.6 GBytes

Line of Sight

Remote commanding

Data streaming

Ice Operation
McMurdo, Antarctic

(Pre-launch 2004/12/15
to over the horizon 2004/12/16)

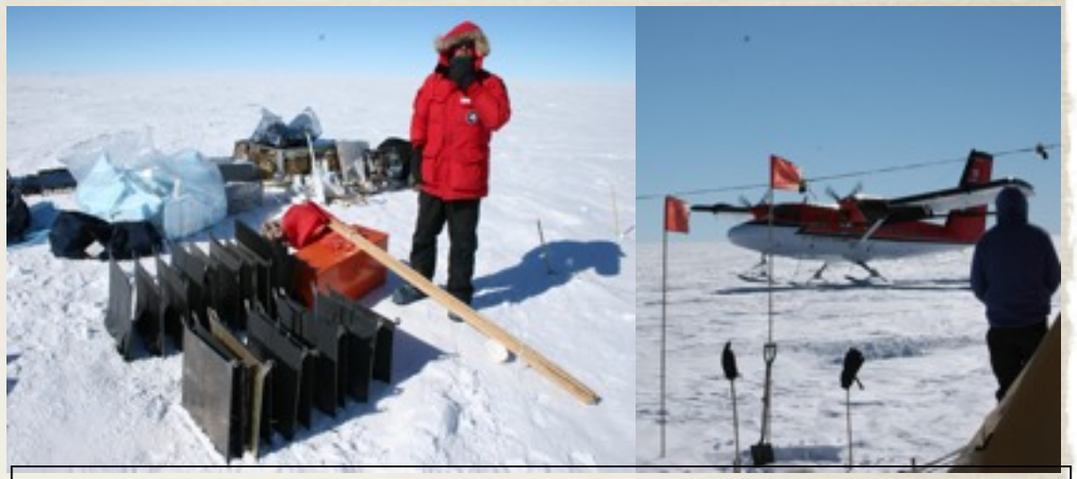
Transmitted data : ~ 19 GBytes

(All Calorimeter data and about 10 % of High-Z (Z>=3) data)

Termination and Recovery of CREAM-I

CREAM parachuting down after termination

CREAM after landing on the ICE

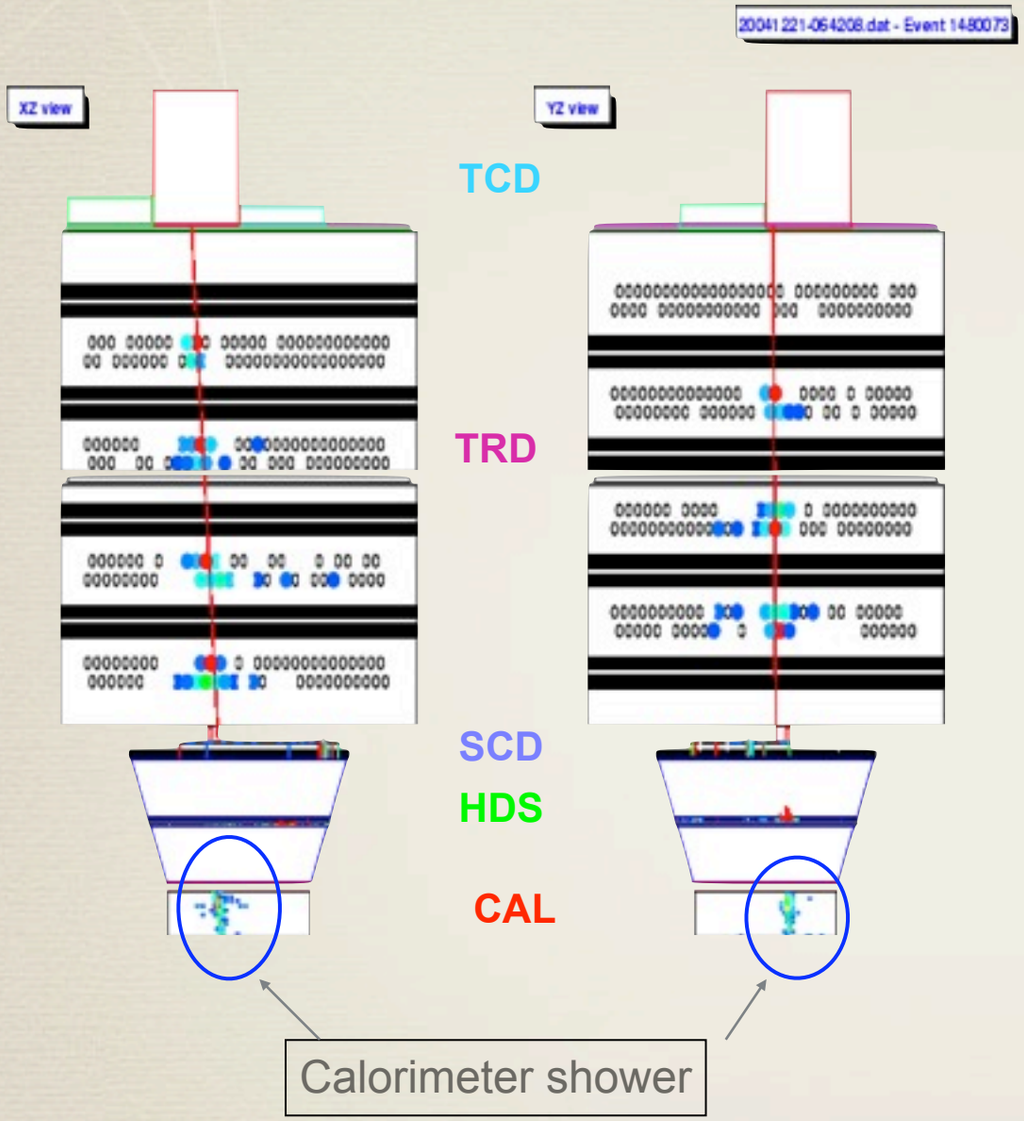


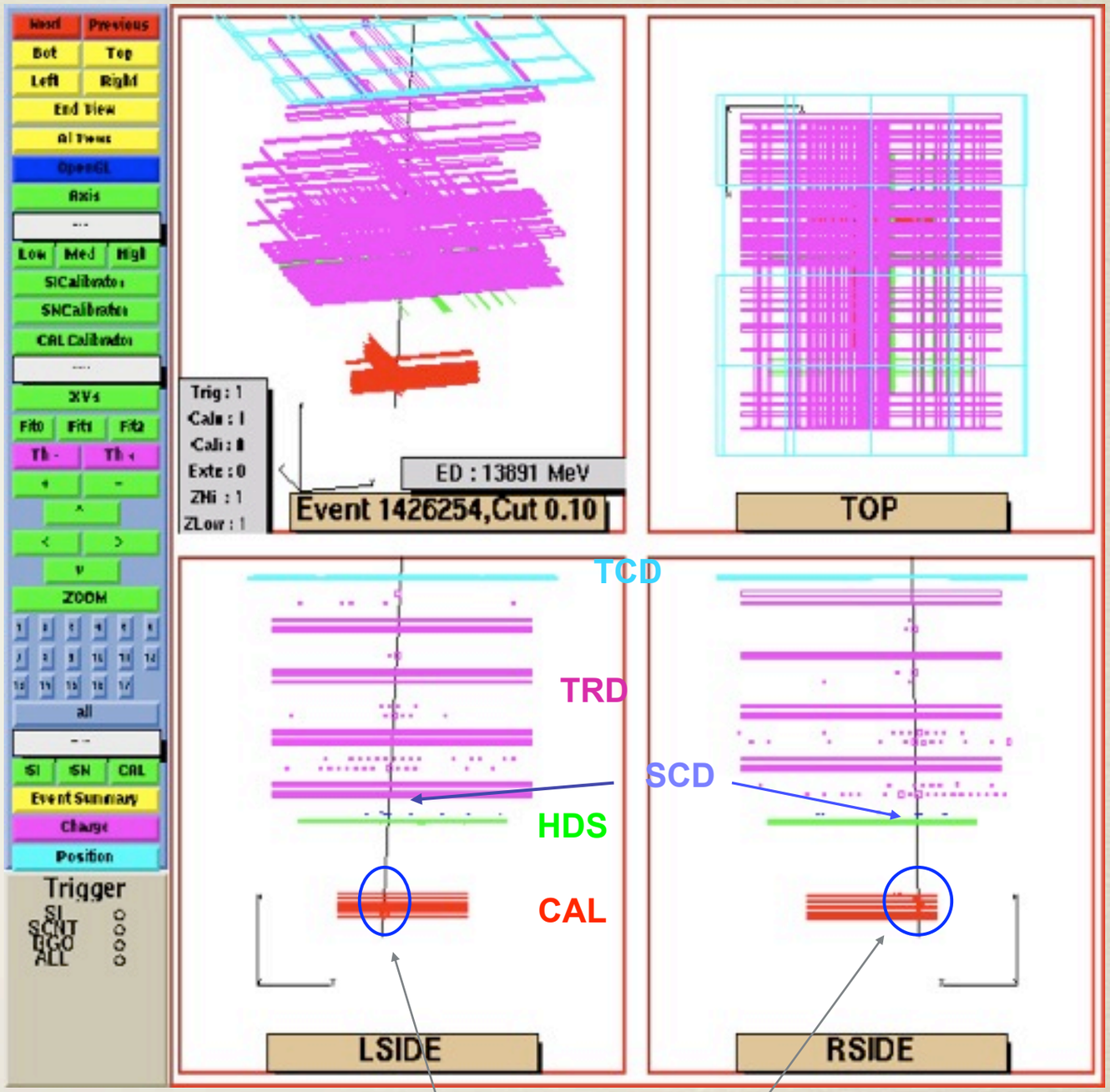
Recovery mission using a Twin Otter plane

Landing Date: 27 January 2005

Instruments came back to UMD in good shape. (2005/04/01)

Event Display

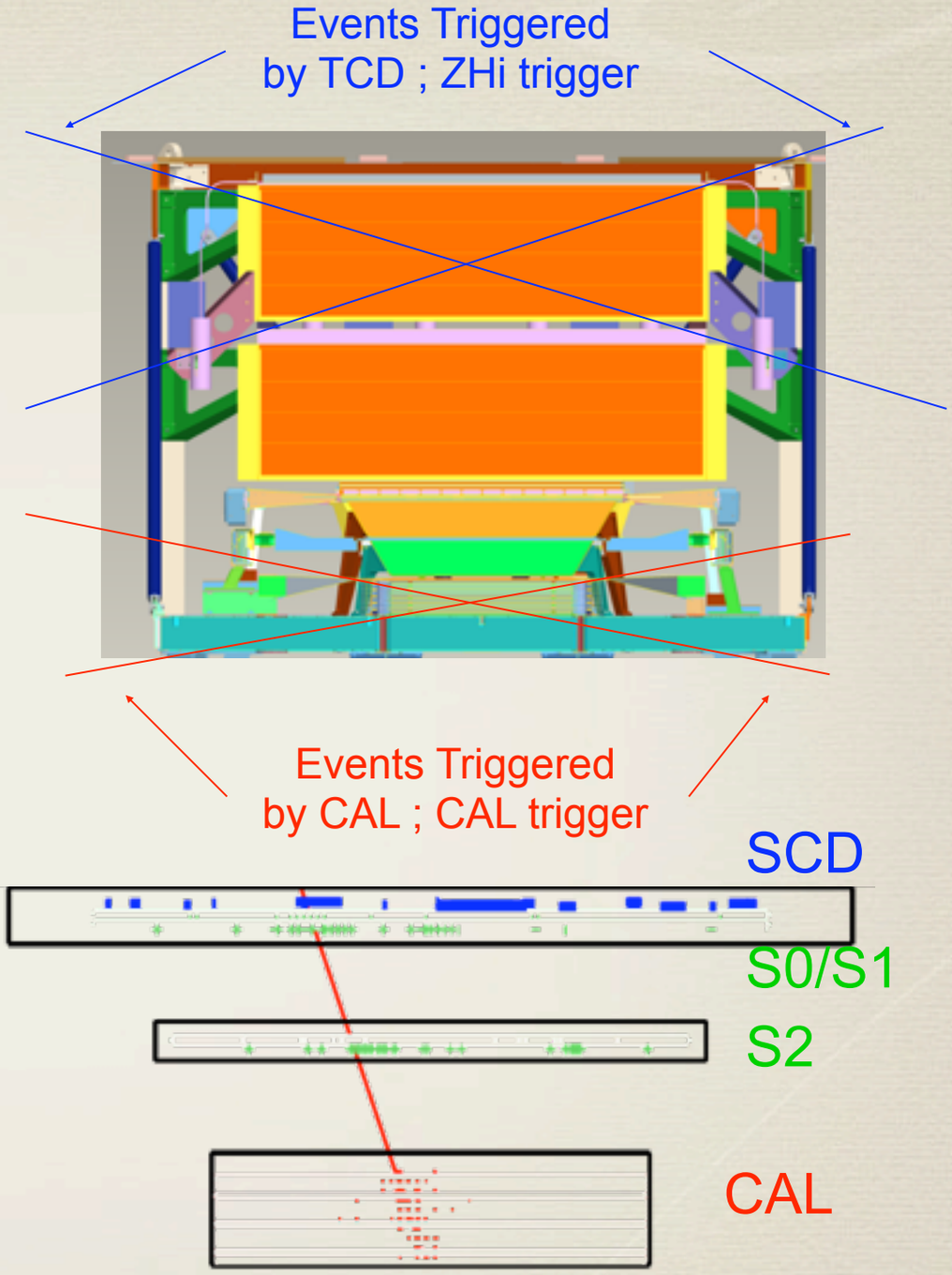




For TCD, SCD, and HDS,
bigger signal boxes mean larger signals.

Event Selection and Reconstruction

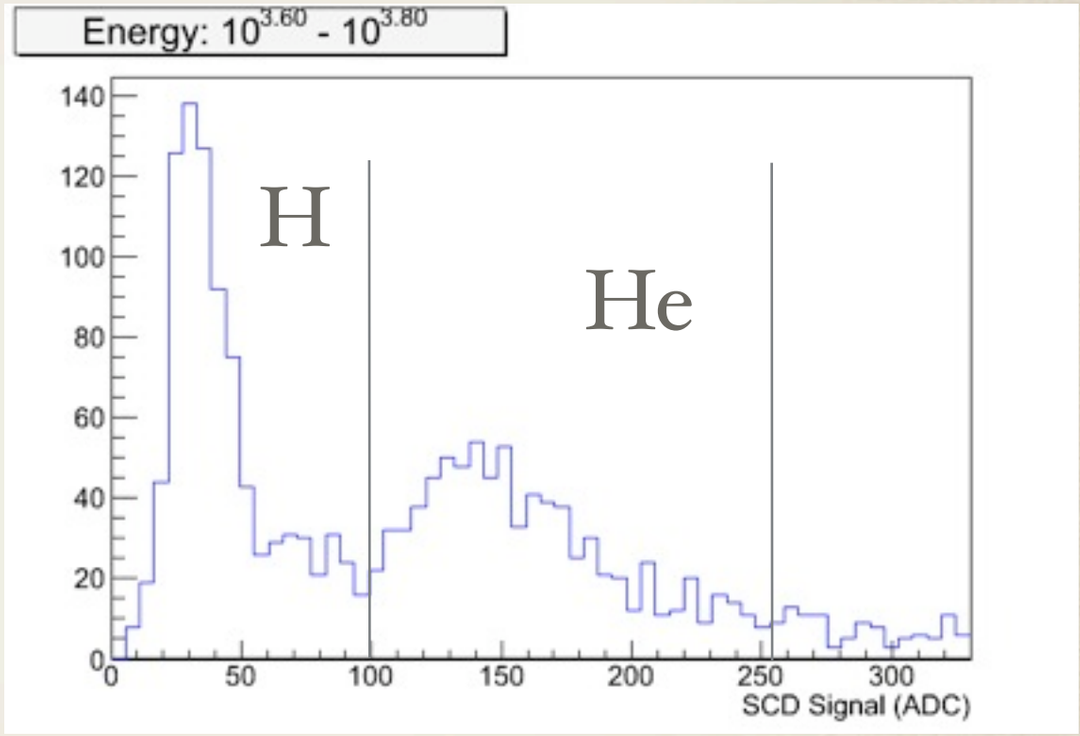
- CREAM-I trigger
  - Hi-Z/Low-Z trigger
  - High energy trigger with Calorimeter
- Calorimeter trigger
  - The calorimeter trigger selects high energy shower events in an unbiased manner by requiring 6 consecutive layers, each with at least one ribbon recording more than 60 MeV.
- Reconstruction
  - The calorimeter reconstruction uses the highest energy deposit in each layer and its neighbors.
  - Reconstructed trajectory was used for event selection and charge determination.



An example of reconstruction from the calorimeter to the SCD

Charge Determination

- The reconstructed shower axis from the calorimeter was extrapolated to the SCD, and a 7x7 pixel area, centered on the extrapolated position was scanned to seek for the highest pixel signal.
- Events with $Z < 1.7$ were selected as protons, while events with $1.7 < Z < 2.7$ were considered as helium nuclei.
- The charge resolutions are estimated as 0.15 e and 0.2 e for protons and helium nuclei, respectively.



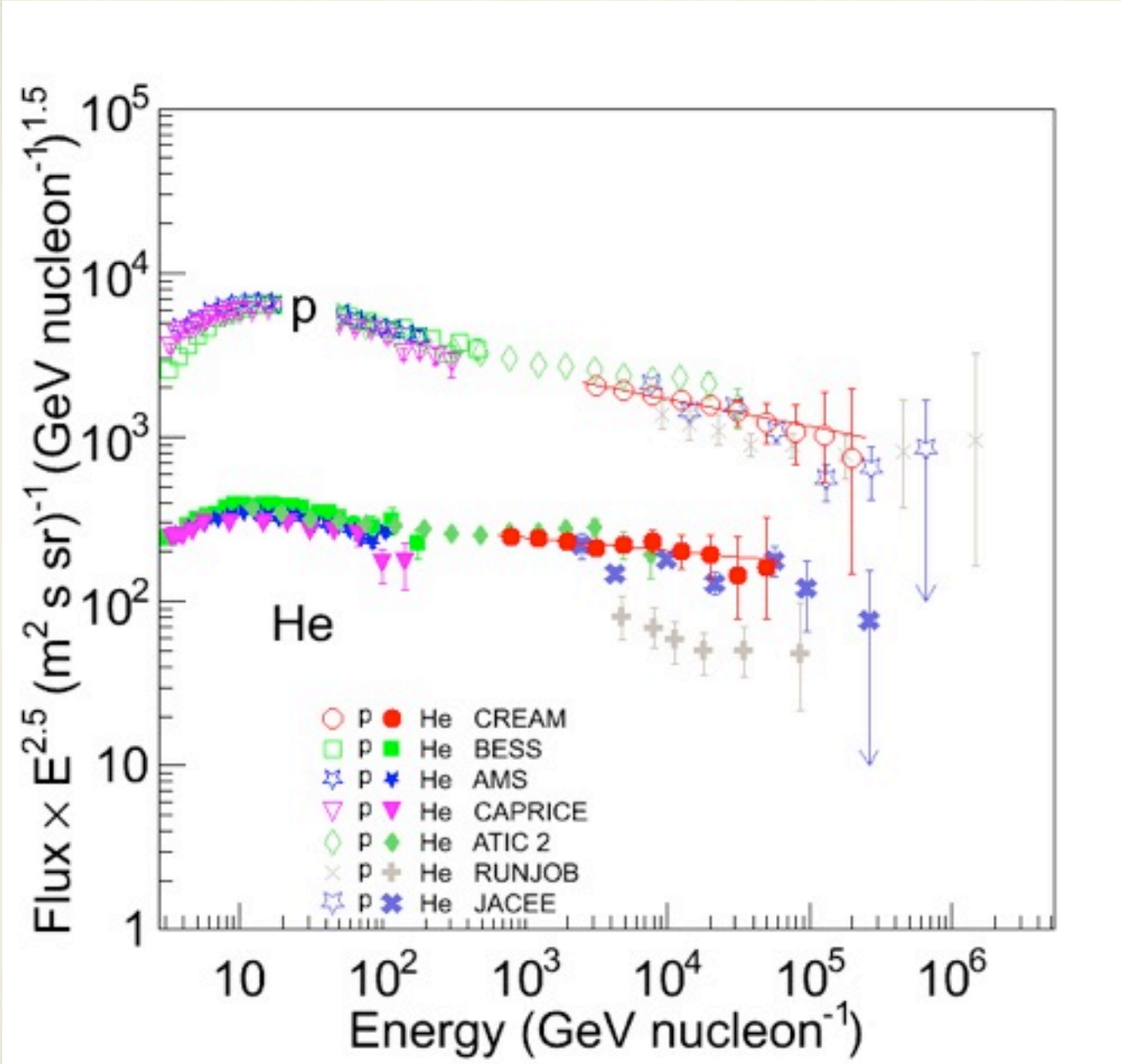
SCD ADC distribution in an energy bin

Absolute Flux

$$Flux = \frac{N \cdot (1-\delta)}{\Delta E \cdot GF \cdot \varepsilon \cdot \eta \cdot T}$$

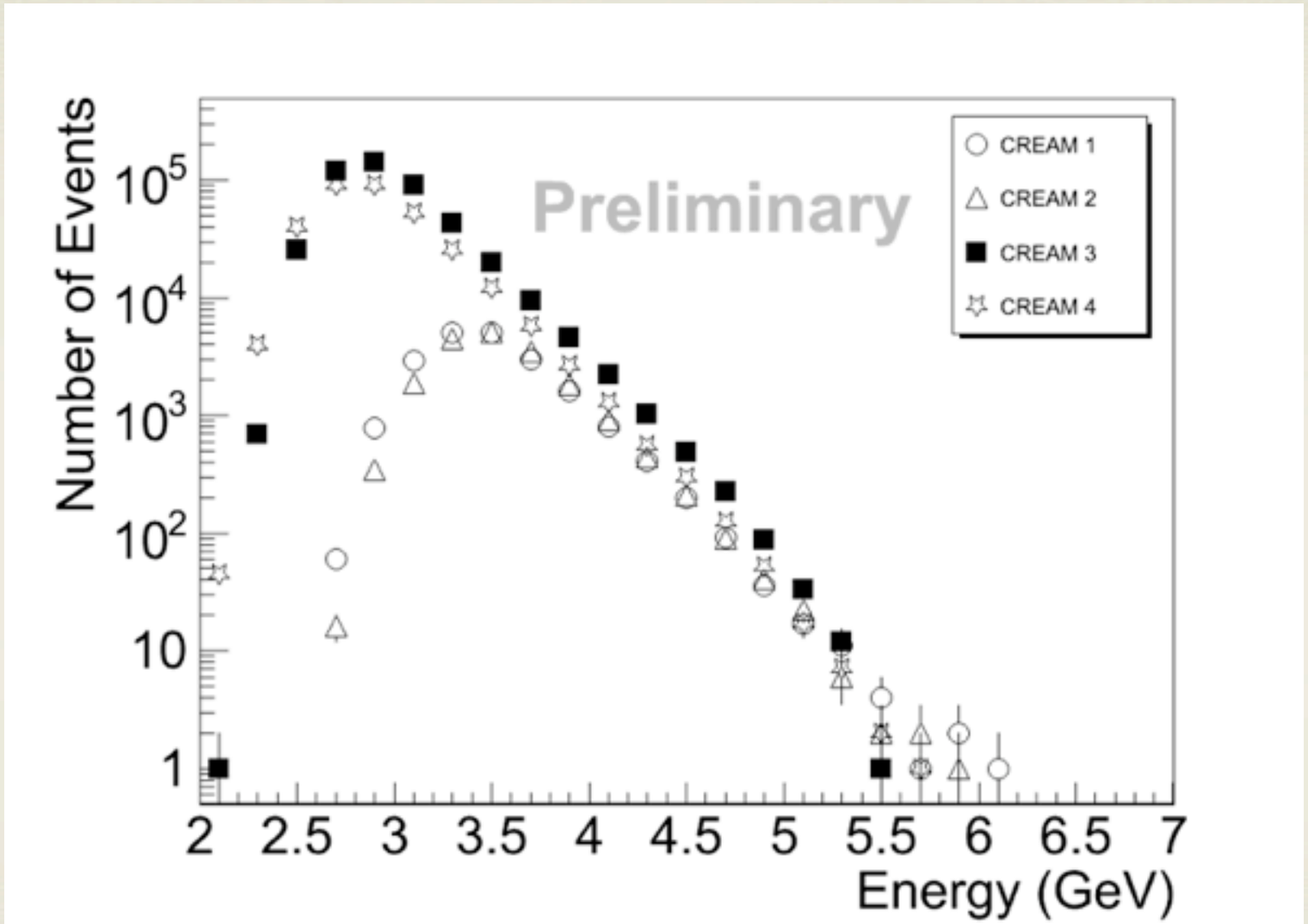
- N: Number of entry in a bin
- Geometry Factor: ~ 0.41 m^2 sr
  - SCD Active Area
  - Bottom of Calorimeter (50x50cm)
- Live time, T
  - Estimated Live-time: 1,099,760 s
  - ~54% live time fraction
- η , Survival Fraction in the air
  - H: 95%, He: 90%
- ε, Efficiencies
  - Trigger efficiency: 76%, 91%
  - Reconstruction efficiency: 98%, 99%
  - Event selection efficiency: 90%, 96%
  - Charge efficiency: 77%, 67%
- δ, Backgrounds
  - BG from reconstruction: 3.6%, 4.0%
  - BG from secondaries: 5.1%, 6.5%

Preliminary Proton and Helium Spectra



- Preliminary proton and helium spectra follow power laws up to ~100 TeV and show reasonable agreement with previous measurements.
- Only statistical uncertainties are shown. Systematic uncertainties will be estimated.

CREAM-I,-II,-III and -IV Calorimeter Events



- Due to electronics noise improvements in CREAM-III and -IV calorimeter, energy measurements in CREAM-III and -IV were extended to lower energy region.

Acknowledgement

This work was funded by NASA research grant to the University of Maryland, the University of Chicago, Penn State University, and the Ohio State University, by the Korean Ministry of Science and Technology in Korea, and by INFN in Italy. We wish to acknowledge NASA/WFF for provision and operation of flight support system; CERN for provision of excellent accelerator beams; and Columbia Scientific Ballooning Facility, National Science Foundations Office of Polar Programs, and Raytheon Polar Services Company for outstanding support of launch, flight and recovery operations in Antarctica.

Thank you!

Preliminary
Proton and Helium Spectra from CREAM-III Flight

Young Soo Yoon
University of Maryland

for
CREAM Collaboration Flight 2007/2008

CREAM Collaboration for Flight 2007/2008

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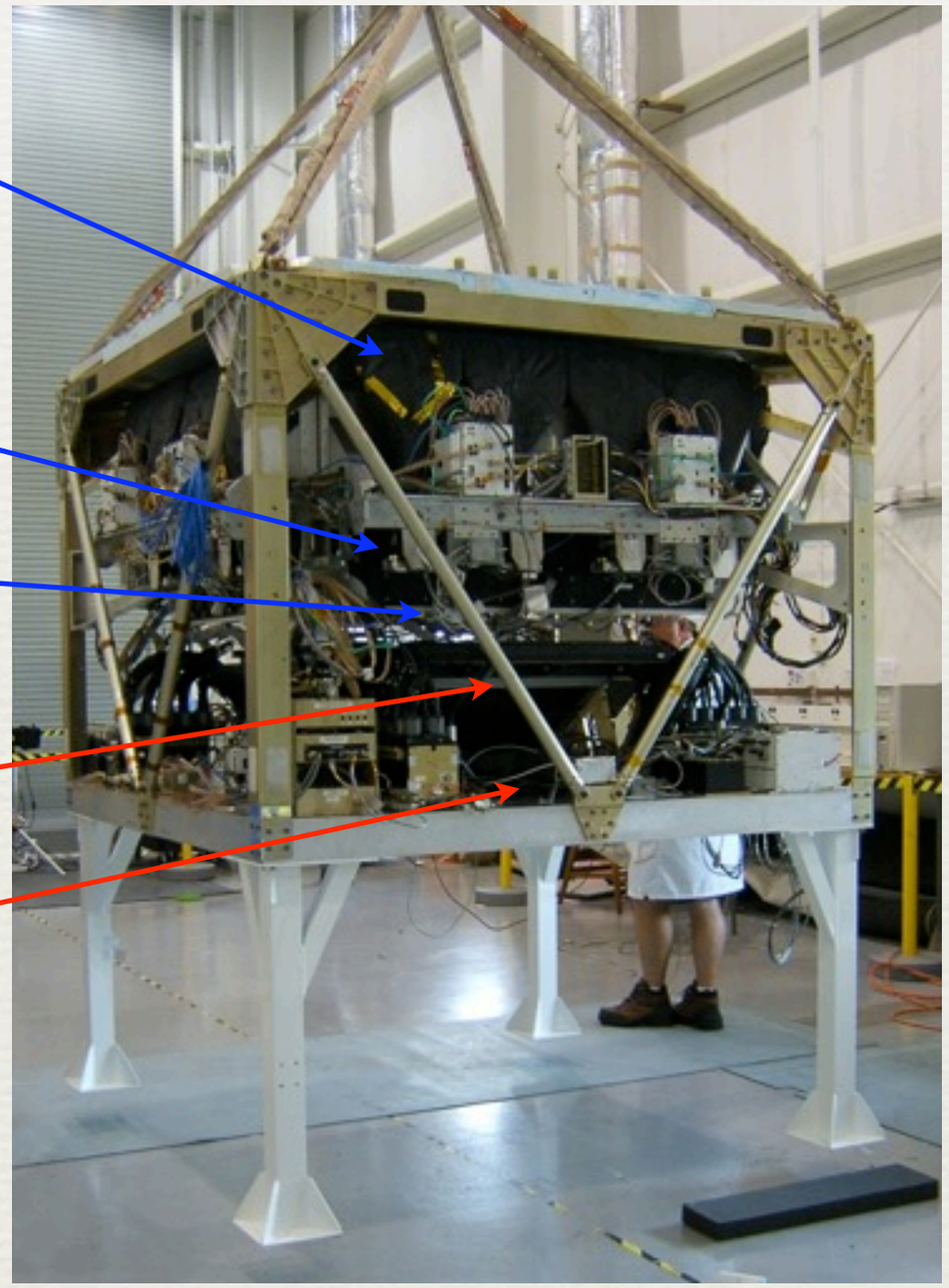
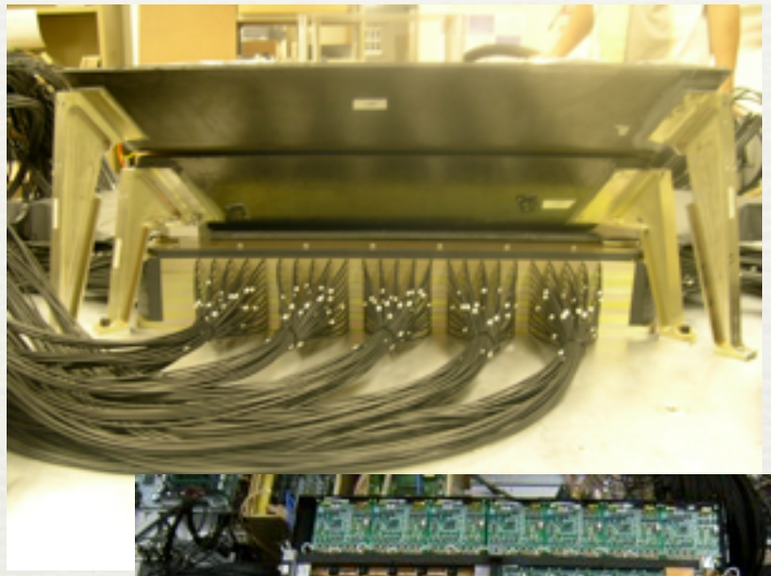
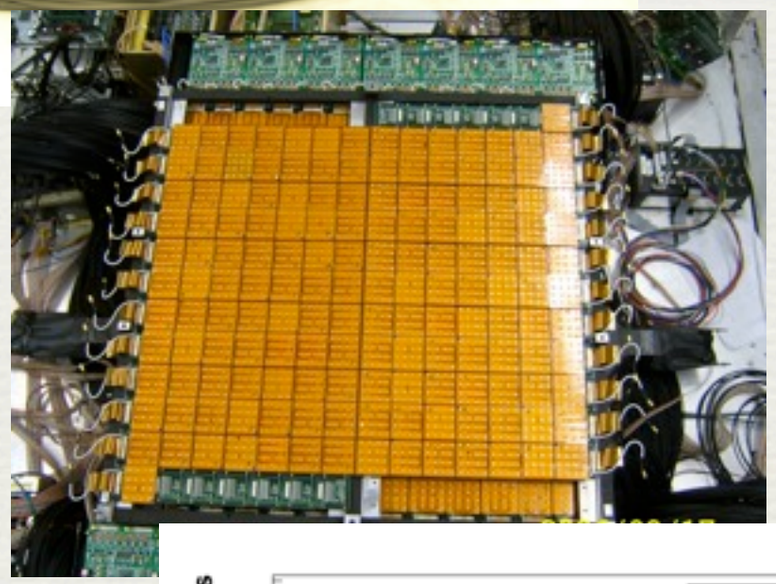
CREAM-III Detector Configuration

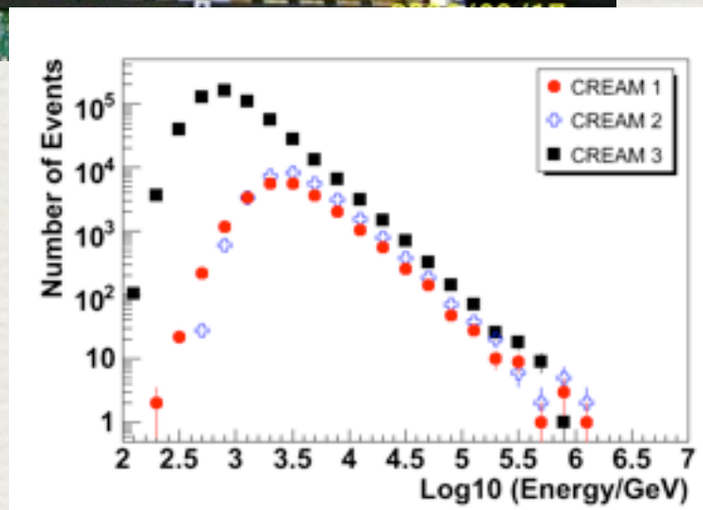
- Timing Charge Detector (TCD)
  - High Charge Event Trigger
  - Charge measurement
- Cherenkov Detector
  - A plastic cherenkov layer
  - TCD trigger support
- Cherenkov Camera
  - Charge measurement
  - Aerogel and 1600 PMTs
- Dual Layers of Silicon Charge Detector
  - Charge measurement
  - 380 μm silicon sensors with 4992 pixels
- Calorimeter
  - High Energy Event Trigger
  - Energy measurement
  - Tungsten/Scintillating fiber



Calorimeter and SCDs

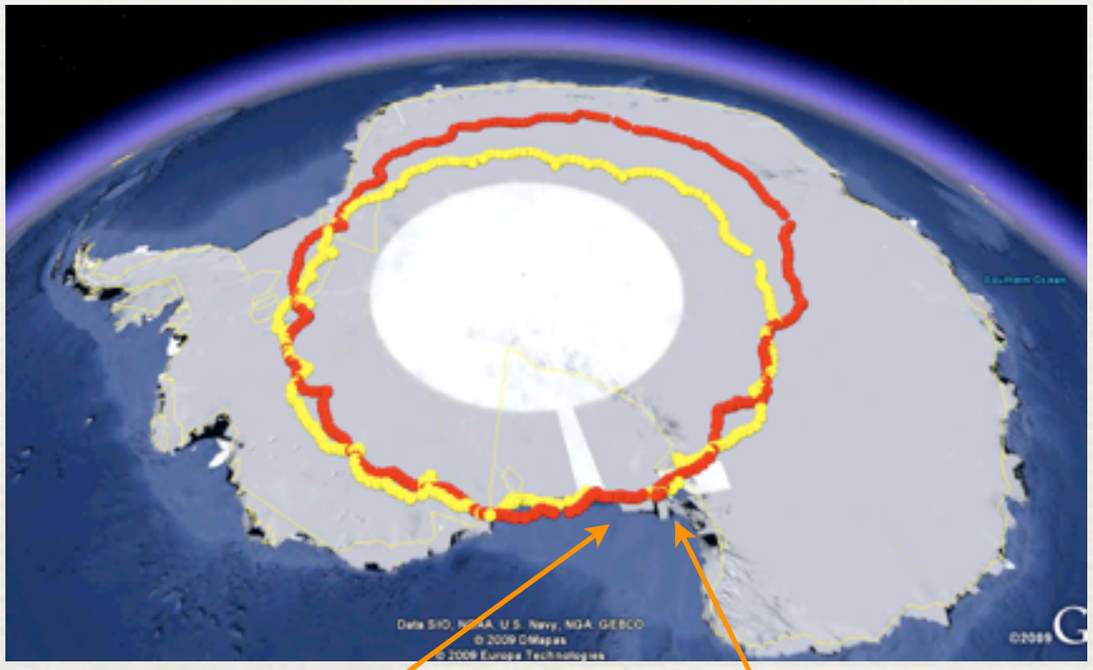




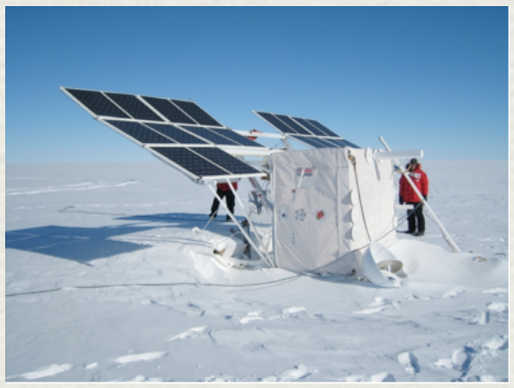


- Calorimeter
  - Two carbon targets with 1/2 X_0
  - 20 layer pairs of tungsten and scintillating fibers -> 20 X_0
  - Hybrid photo-diode(HPD)
- Dual Layer SCD
  - 380 μm silicon sensors with 2496 pixels each 2.12cm^2 in each layer
  - dE/dx ~ Z^2
- Features in CREAM-III
  - Upgraded Calorimeter electronics
    -> Lower CAL trigger threshold
    -> Lower CAL Sparsification Level

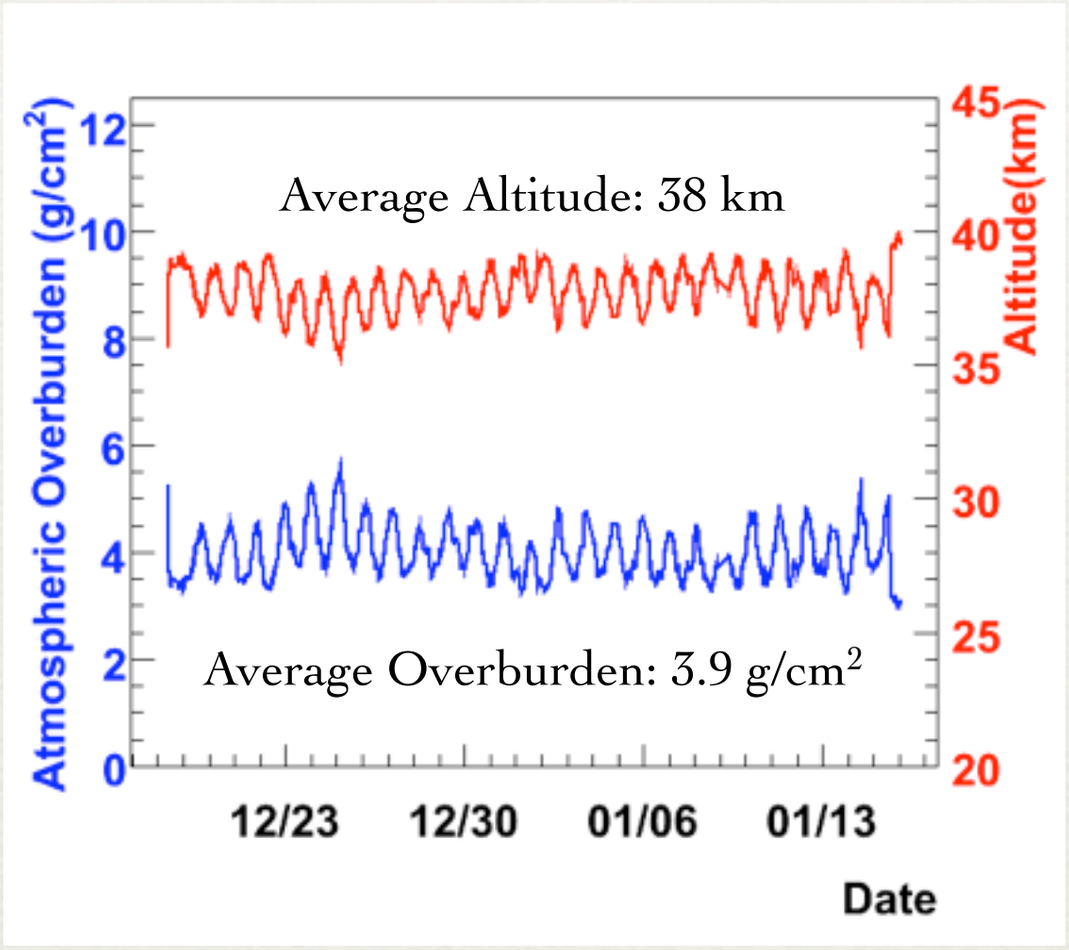
CREAM-III Flight



Landed on
17 Jan, 2008



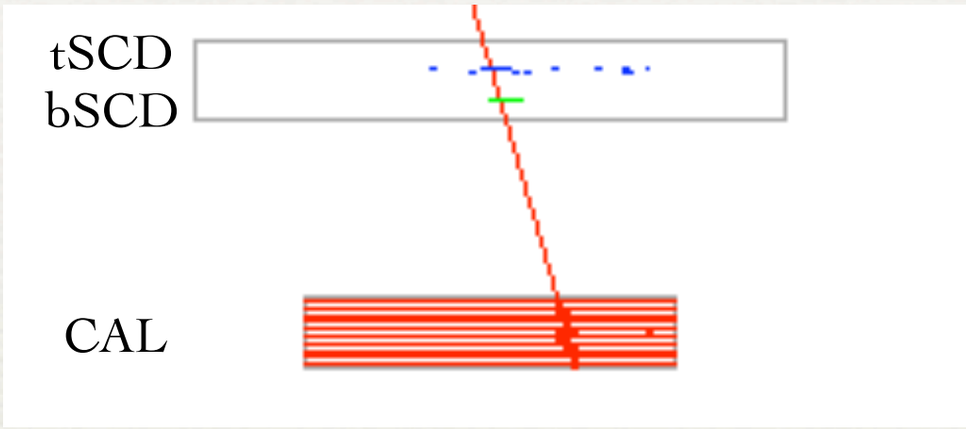
Launched on
19 Dec, 2007



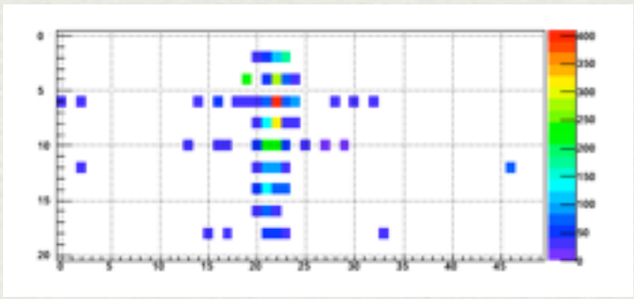
- The flight lasted 29 days.
- 1.2 million science events were collected.
- Live time fraction is 99% during the flight.

Event Selection

- Calorimeter Trigger
  - The Calorimeter trigger condition requires 6 consecutive layers, each with at least one ribbon recording more than trigger threshold, 15MeV.
- Reconstructions
  - Trajectories were reconstructed from the ribbon with the highest energy deposit and neighboring ribbons on both sides at least three layers.
- Interaction Position
  - Events with an interaction in the carbon target or in the top six layers of the Calorimeter are selected.

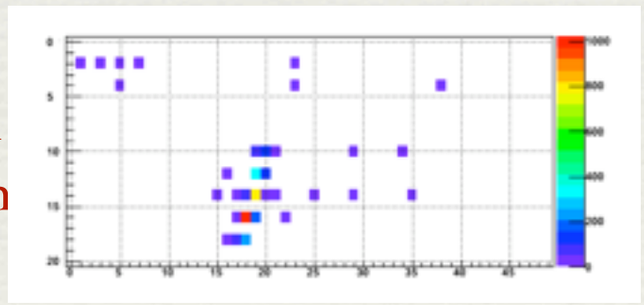


An example of reconstructed trajectory



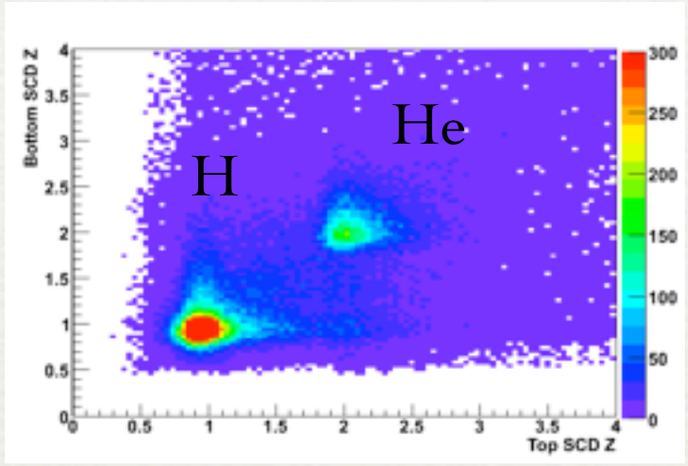
A good Event

An event with late interaction

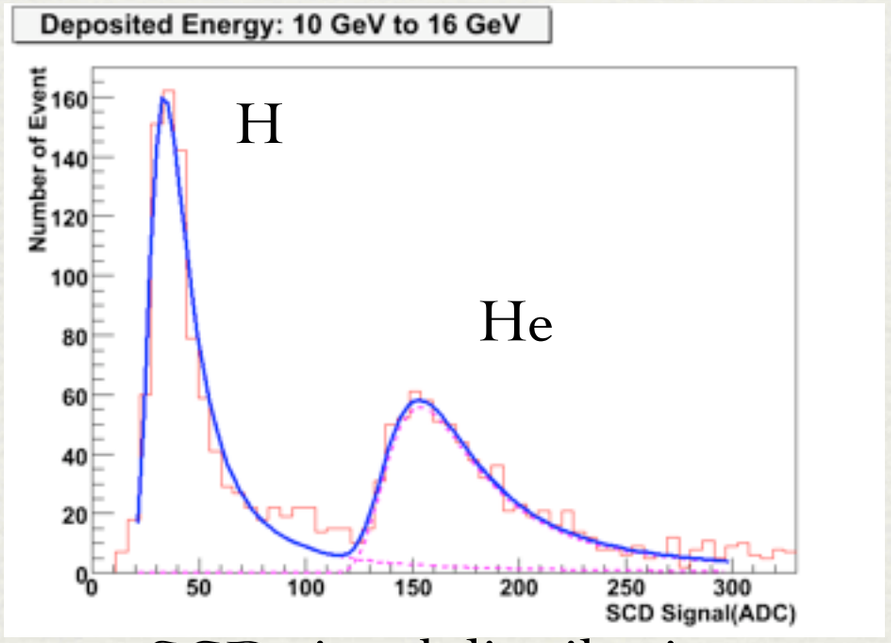


Charge Determination

- The dual SCD setup provides us with two independent charge measurement.
- In this analysis, the charge identification uses the top SCD.
- The SCD signal is corrected for the path length due to the incident angle.
- A 7x7 pixel area (10x10cm) centered on the extrapolated position in the top SCD from the reconstructed trajectory is scanned for the highest pixel signal.



Top and bottom SCD Z distribution



SCD signal distribution in a energy bin

Energy Measurement

- The calorimeter were calibrated with an 150 GeV electron beam at CERN before the flight.
  (Han, J.H., et al, ICRC 2009)

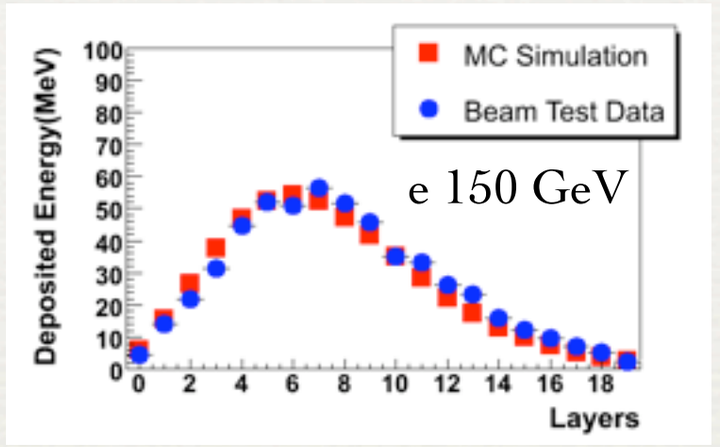
- Entries in the deposited energy are deconvolved to the incident energy using matrix relations.

$$N_{inc,i} = \sum_j P_{i,j} N_{dep,j}$$

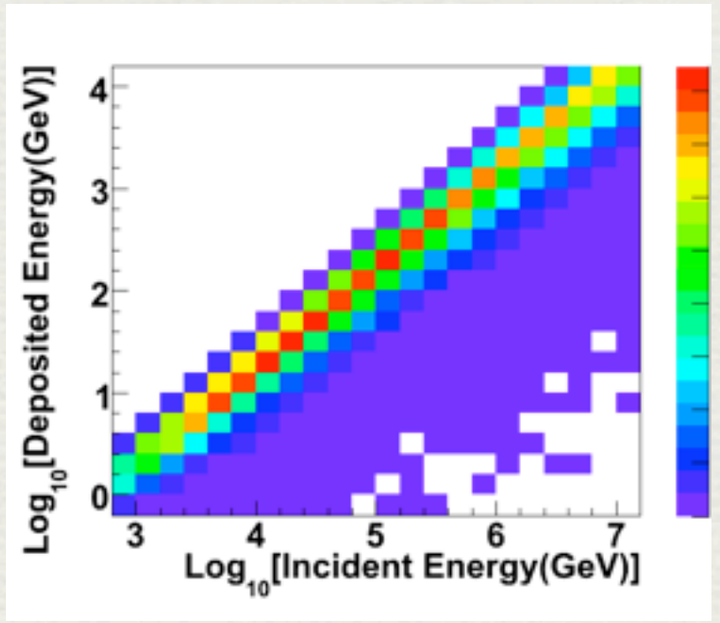
where $P_{i,j}$ is the probability that the events in the deposited energy bin j are from the incident energy bin i.

- A GEANT/FLUKA 3.21-based Monte Carlo simulation results were used.

- A MC simulation with CREAM 3 full detector configuration is in progress.



Longitudinal Shower Profile between MC and Beam Test



Proton Response Matrix with MC Simulation

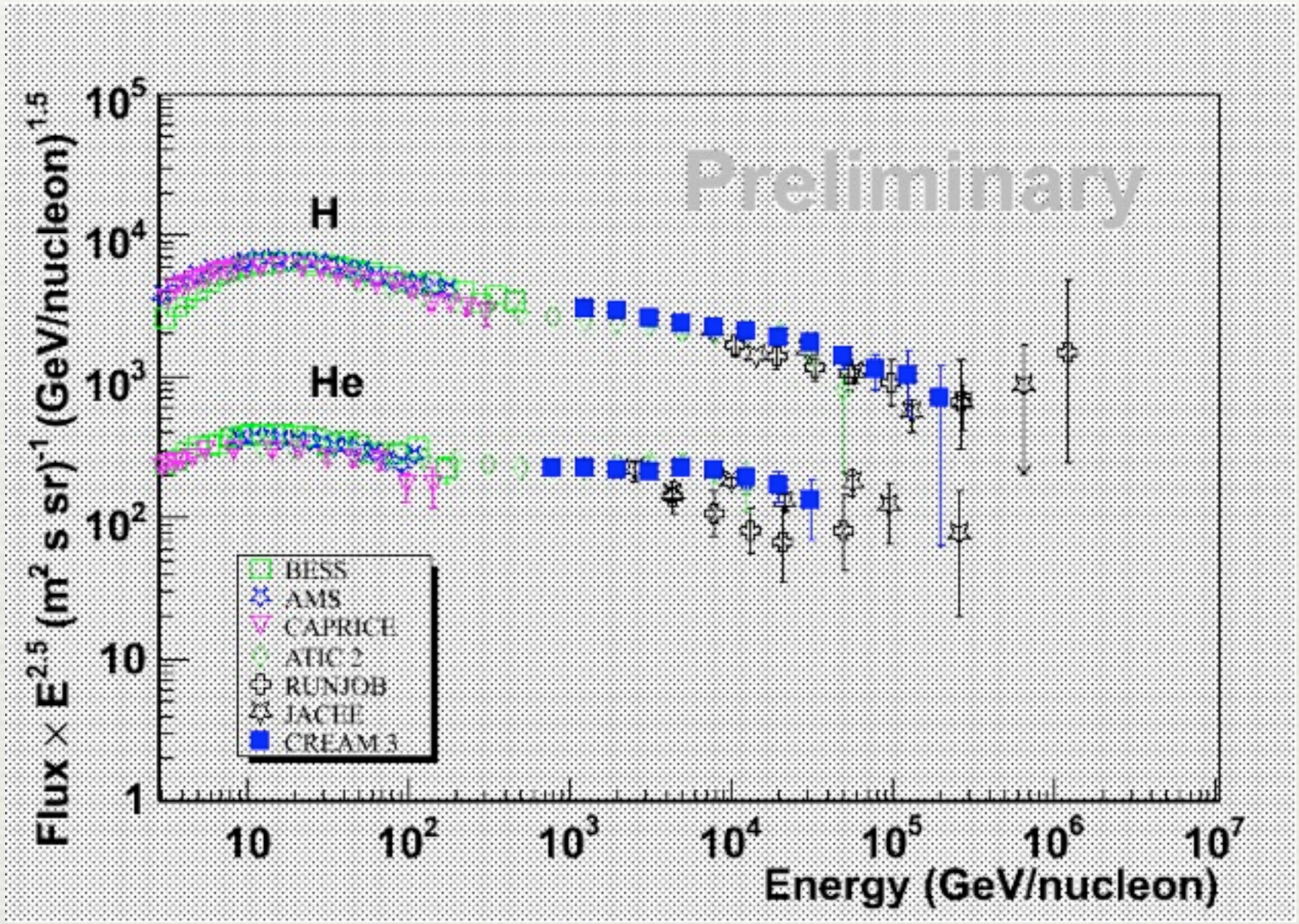
Absolute Flux

$$Flux = \frac{N}{\Delta \mathrm{E} \cdot GF \cdot \varepsilon \cdot \eta \cdot T}$$

- N: Number of entry in a bin
- Geometry Factor: ~ 0.41 m^2 sr
  - Top SCD Active Area
  - Bottom of Calorimeter (50x50cm)
- Live time, T
  - Selected data: ~ 23 days
  - 99% live time fraction
- η , Survival Fraction in the air
  - H: 95%, He: 90%
- ε, Efficiencies
  - Trigger efficiency: 78%, 99%
  - Reconstruction efficiency: 98%, 92%
  - Event selection efficiency: 95%, 95%
  - SCD area efficiency: 89%, 90%
- δ, Background
  - BG from reconstruction: 2%, 4%
  - BG from secondaries: 5%, 9%

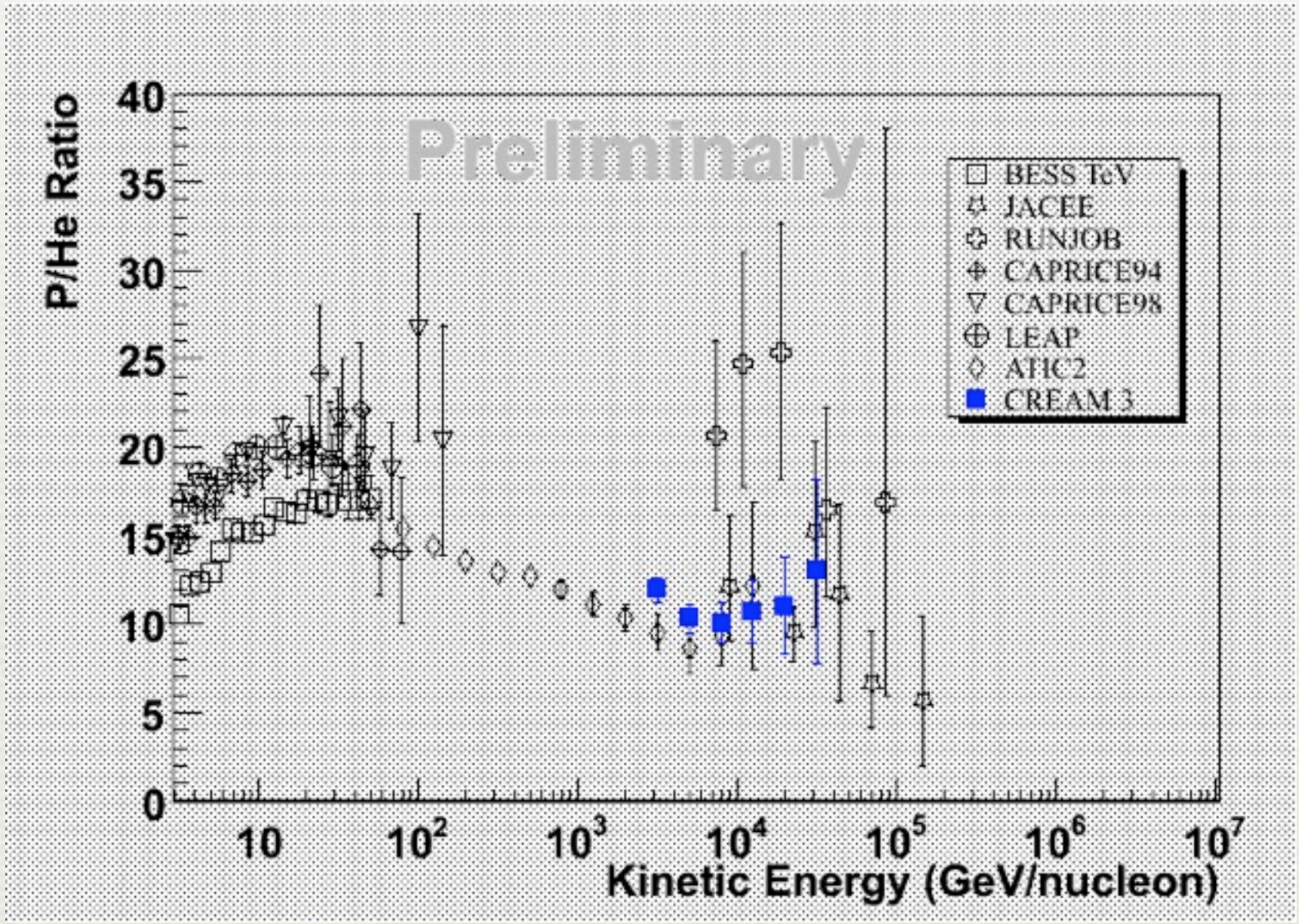
Efficiency and background are preliminary with CREAM-I MC results.

Preliminary Proton and Helium Spectra



Proton spectrum agrees with ATIC2, JACEE, and RUNJOB results.
Helium spectrum agrees with ATIC2, and JACEE, but it is higher than RUNJOB results.

Preliminary Proton and Helium Ratio



Due to efficiency uncertainties, ratio might be changed later.
Statistical uncertainties are shown.

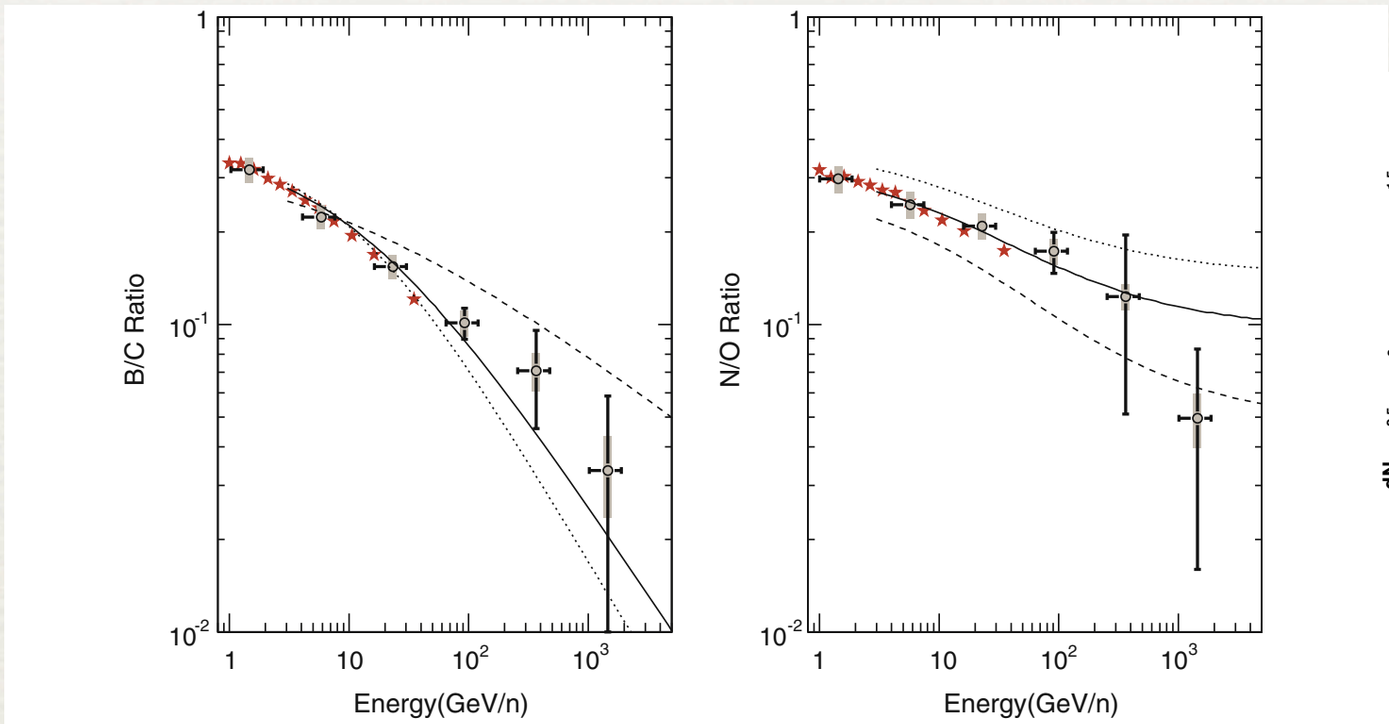
Summary

- Preliminary proton and helium spectra are presented as measured during the third CREAM flight.
- The proton spectrum shows good agreements with ATIC2, JACEE, and RUNJOB results.
- The Helium spectrum shows good agreements with ATIC2 and JACEE, but not with RUNJOB results.
- Future work remains to be done
  - Efficiency and background calculation with CREAM 3 MC simulation.
  - Systematic uncertainties estimation.

Acknowledgements

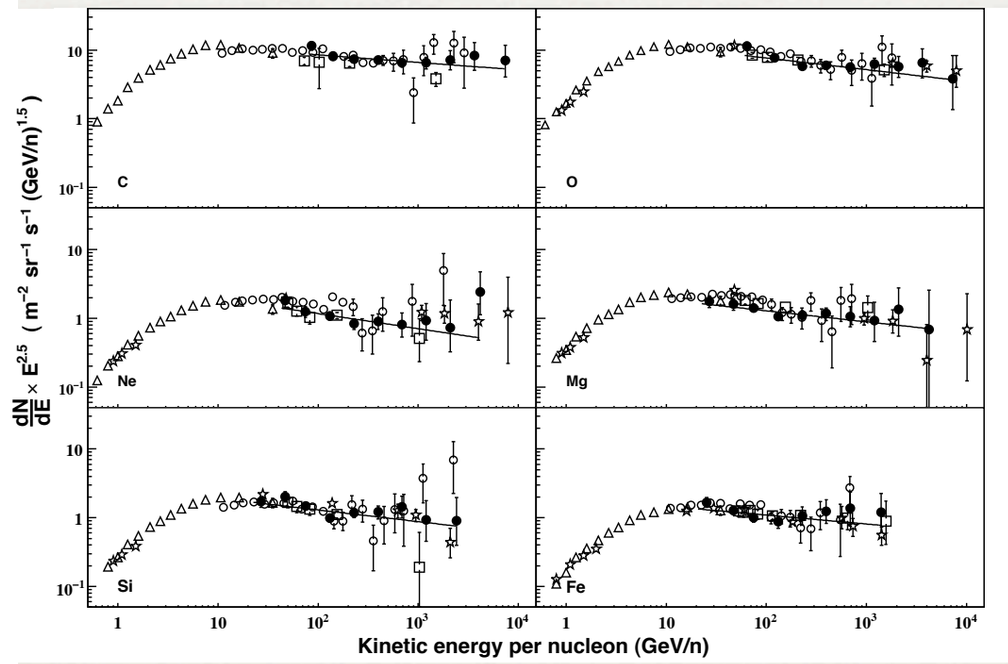
This work is supported by NASA, NSF, INFN, KICOS, MOST and CSBF.

Published CREAM Results



B/C and N/O Ratios
from CREAM-I TRD

Astroparticle Physics, 30, 133 (2008)



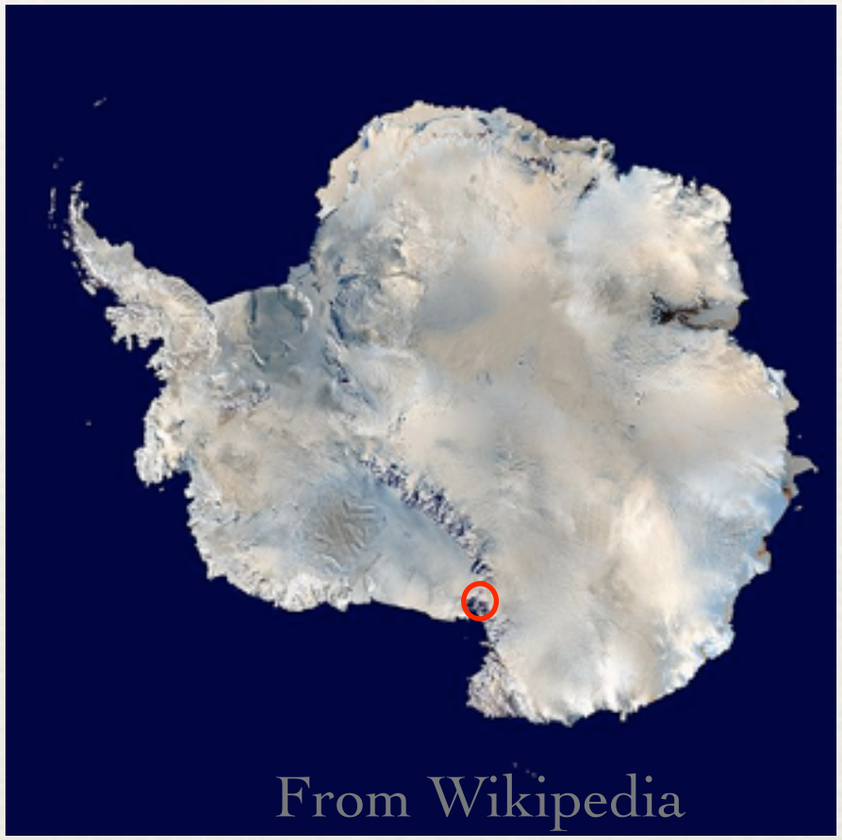
C, O, Ne, Mg, Si and Fe Fluxes
from CREAM-II Calorimeter

Astrophysical Journal, 707, 593 (2009)

During the CREAM-II Launch in Dec 2005

C-131

C-17



McMurdo Station

CREAM Launch Crews

CREAM-II 2005-2006

CREAM-III 2007-2008