

Measurement of Cosmic-Ray Nuclei with the Third Flight of the CREAM Balloon- Borne Experiment

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CREAM Project Summary

CREAM (Cosmic Ray Energetics And Mass) Project

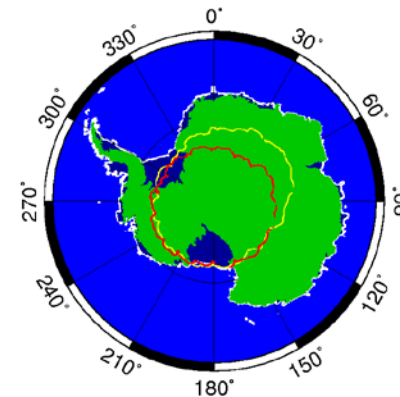
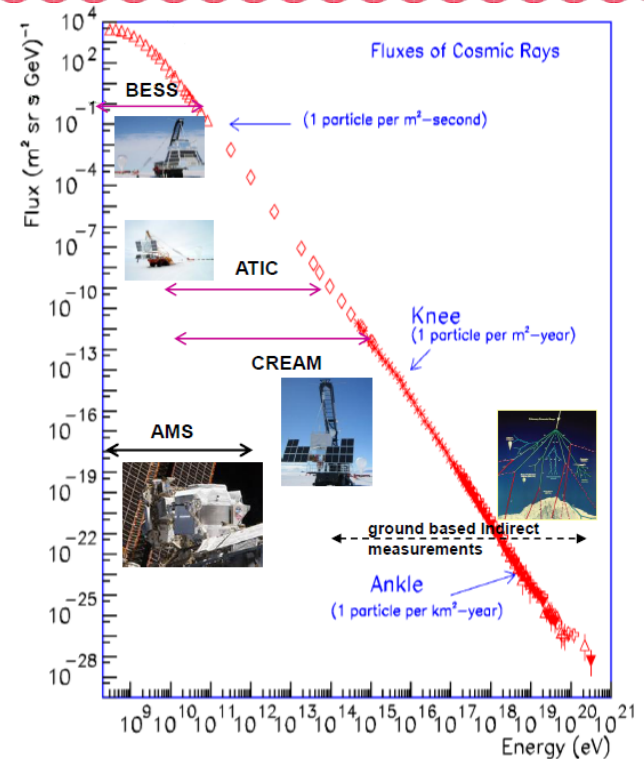
- The CREAM instrument directly measures elemental spectra of cosmic rays
 - Energy range: $10^{12} - 10^{15}$ eV
 - Composition: proton to iron

Mission Goal

- Extend the energy reach of direct measurements of cosmic rays to the highest energy possible to investigate cosmic ray origins, acceleration and propagation.

Balloon Flight Heritage

- Seven successful Long-Duration Balloon flights from McMurdo station, Antarctica 2004-2016
- **~191 days** of cumulative exposures, the longest of any balloon project
- Highlight of balloon project results is discovery of spectral hardening



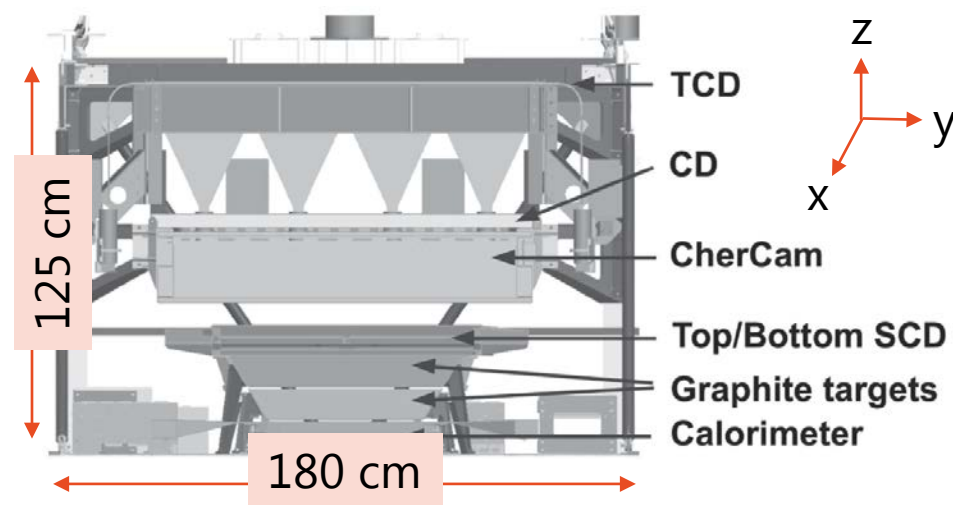
CREAM-III Instrument and Flight

CREAM-III Flight

- launched Dec 19 2007 and landed Jan 17 2008
- 29 days duration
- float altitude ~ 38 km
- Average atmospheric overburden 3.9 ± 0.4 gcm $^{-2}$

CREAM-III Instrument

- **Silicon Charge Detector**
 - Two layers provide independent charge measurement with average resolution of $\sim 0.2e$
 - Each layer is an array of 2.12cm^2 silicon pixels over $\sim 78 \times 79$ cm
- **Calorimeter**
 - Trigger and energy measurement
 - Twenty layers of W (each $1 X_0$) and scintillating fiber ribbons below a densified carbon target ($0.5 \lambda_L$)
 - 50 ribbons (~ 1 cm wide) per layer
 - Ribbons alternate orientation: 10 layers XZ, 10 in YZ
- Timing Charge Detector
- Cherenkov Detector
- Cherenkov Camera



CREAM is the only multi-TeV cosmic-ray experiment to have all 3 charge measurement techniques to minimize backscattering effects

Outline of Analysis



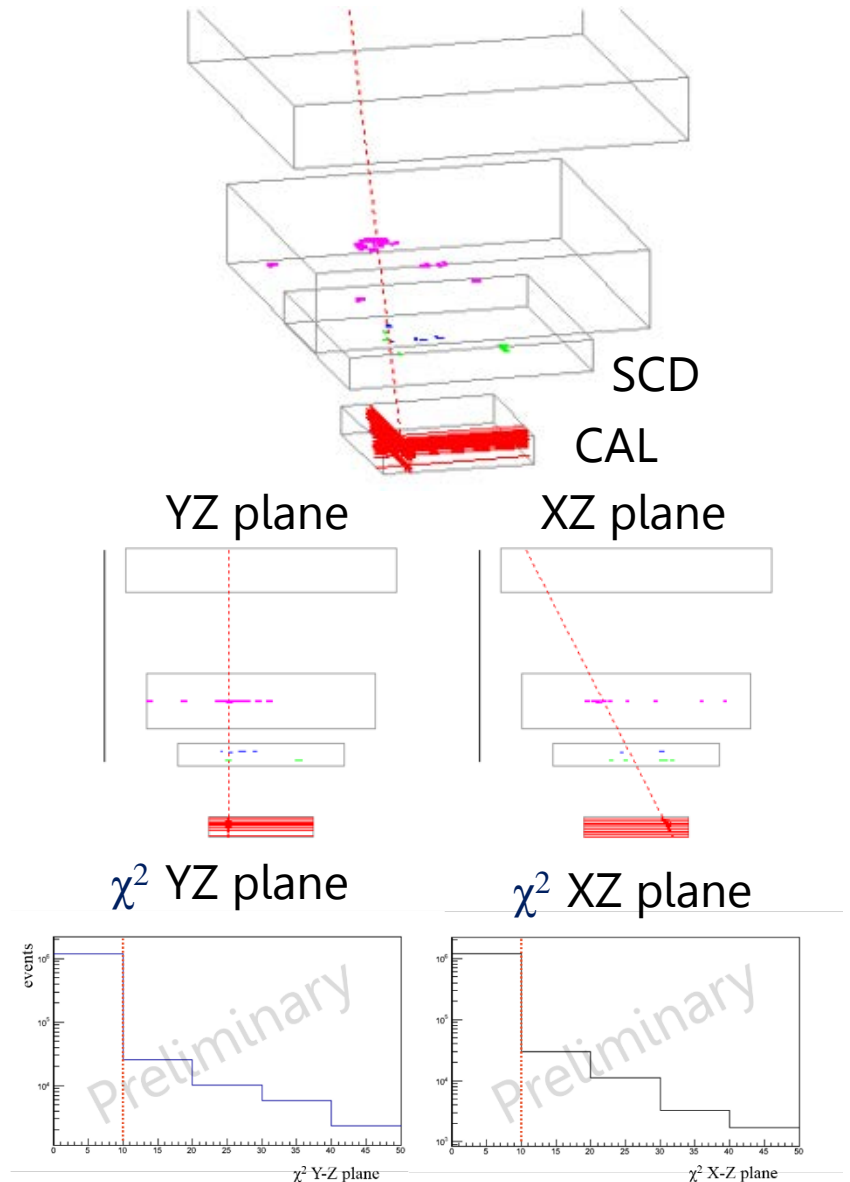
Analysis of relative abundance ratio for $2 < Z \leq 26$.*

1. Apply data corrections (e.g. temperature dependence, electronics gains corrections, dead channels)
2. Calibration of detector signals to physics units
3. Trajectory Reconstruction
4. Charge Measurement
5. Consistency requirements between SCD layers
6. Selection of nuclei for analysis
7. Measurement of abundance ratio

* for $Z=1,2$ see Y.S.Yoon, et al, Proton and Helium Spectra from the CREAM-III Flight, ApJ, 839 (2017)

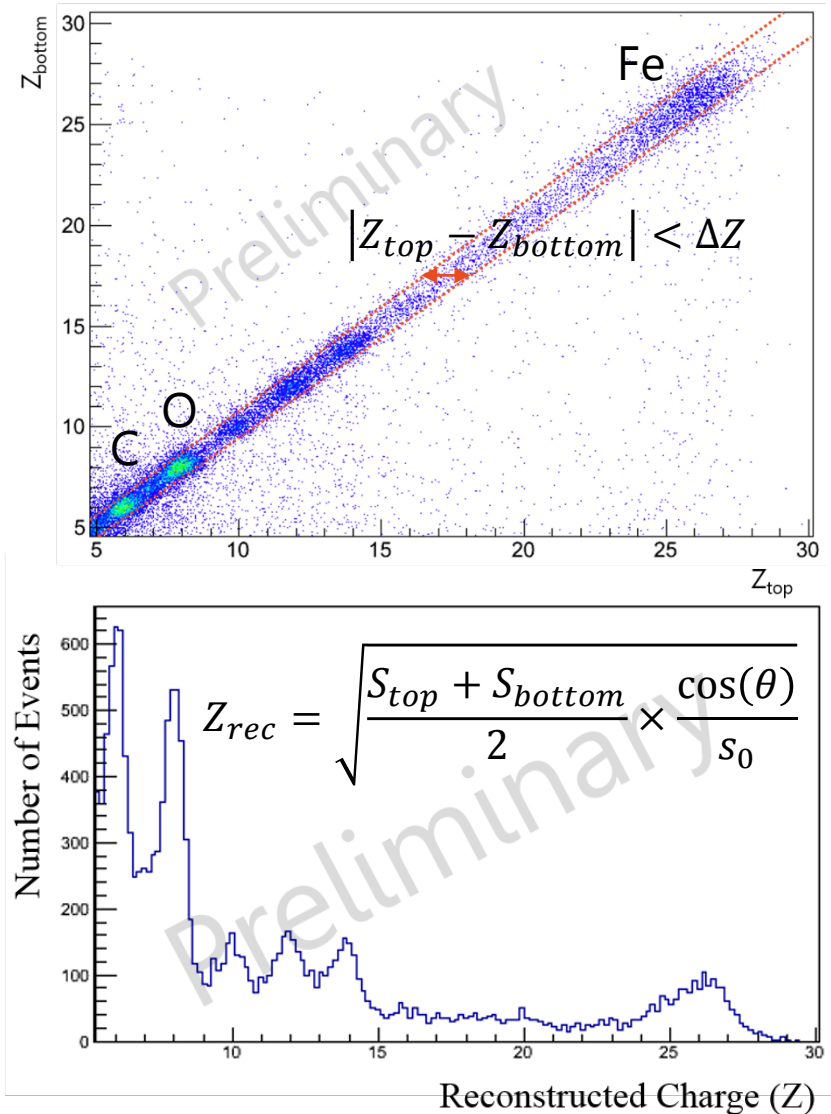
Trajectory Reconstruction

- In flight, events are triggered by the CAL when 6 consecutive layers (3 XZ, 3 YZ) have energy deposit above 15 MeV
 - CREAM-III CAL has lower electronics noise compared to CREAM-I (60 MeV), resulting in a lower trigger threshold
 - 1,238,689 events (~ 2 Hz)
 - 99% live time; CREAM-I (56%), CREAM-II (75%)
 - Signal response for each ribbon in the CAL was calibrated to MeV using results from CREAM-III CAL beam test at CERN
- The shower axis in the CAL is reconstructed to determine the trajectory of the incident nuclei
- Iteratively fit a line (least-squares method) to the 50 ribbons in the 10 layers in XZ, weighted by the energy deposit in each ribbon; the same is done for the 10 layers in YZ
- Events with $\chi^2 < 10$ in both XZ and YZ are selected



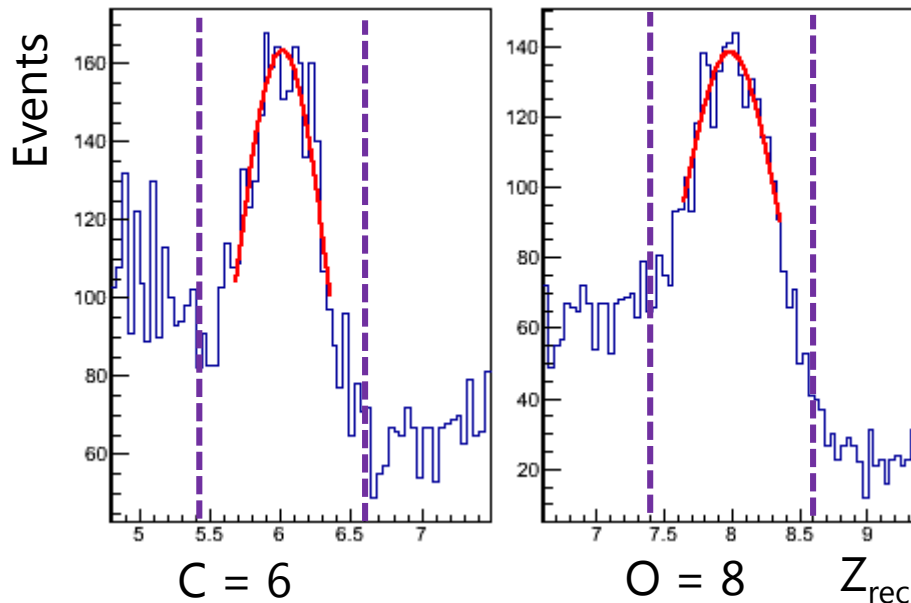
Charge Measurement

- The SCD pixel with the maximum signal within 3 cm (in XY) from the reconstruction track is used to determine the charge of the incident cosmic ray
- Charge is measured with both layers of the SCD and proportional to the square root of the signal
- Charge is corrected by the path length and calibrated from flight data to convert pulse height to charge scale
- Events selected for analysis if $|Z_{top} - Z_{bottom}| < \Delta Z$
 - ΔZ starts at 0.57 for Carbon and increases linearly to 0.88 for Iron
- Final reconstructed charge for event selection is calculated using equation on right
 - S_{top} , S_{bottom} signal from SCD layers, $\cos(\theta)$ is path length correction, s_0 is calibration constant



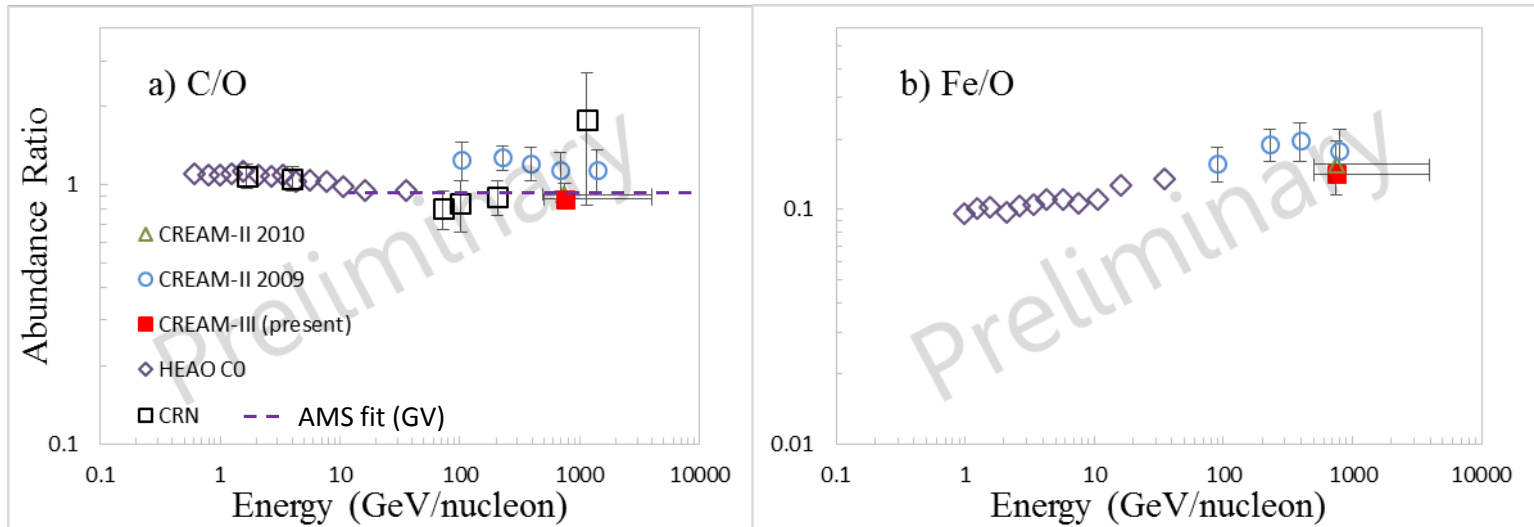
Nuclei Selection

- The charge distribution of each nuclei is fit by hand with a Gaussian (red line) in order to characterize the peak location and width
 - Future work: use multi-Landau ($Z \leq 8$) and multi-Gaussian fits ($Z > 8$)
 - Ratios of secondaries may be biased from Landau tails of adjacent nuclei so this must be done carefully
- The fit results are used to define the range in Z to select nuclei for the abundance ratio measurements
- Events within the dashed lines are selected



Measured Abundance Ratios

Preliminary relative abundance of C/O and Fe/O in the energy range 500-3980 GeV/nucleon after applying tracking, consistency, and selection cuts



- A single sampling fraction of 0.015% is used to convert energy deposit in CAL to incident energy
- The uncertainty for CREAM-III result is statistical only and is derived by error propagation of each element to a ratio (~4769 O events)
- Ratios are corrected for secondaries produced inside the atmosphere and the instruments using the same correction factors as CREAM-II (C/O 12% reduction and Fe/O 32% increase)
 - CREAM-II had less material above the SCD so a full calculation is needed for CREAM-III
- CREAM-III abundance ratios are consistent with CRN, HEAO, AMS, and CREAM-II

AMS C/O fit taken from S. Ting, The First Five Years of the Alpha Magnetic Spectrometer on the International Space Station, CERN Colloquium 2016

Summary and Future Plans

- CREAM (Cosmic Ray Energetics And Mass) is a balloon experiment designed to measure the composition and energy spectra of cosmic ray nuclei ($Z \leq 26$) from 10^{12} - 10^{15} eV to study their origin, acceleration and propagation of cosmic rays
- CREAM-III launched on December 19 2007 and circumnavigated Antarctica for 29 days at an altitude ~ 38 km with an atmospheric overburden of ~ 3.9 g/cm²
- Preliminary abundance ratios of C/O and Fe/O were measured with CREAM-III data and are consistent with previous CREAM results and other experiments
- **Future plans**
 - Optimize nuclei selection algorithm with multi-Landau ($Z \leq 8$) and multi-Gaussian fits ($Z > 8$)
 - Complete study of energy bins and energy deconvolution to measure the elemental spectra $5 \leq Z \leq 26$
 - Incorporate complete MC study of CREAM-III configuration to correct for secondaries produced in the instrument and atmosphere
 - Includes detailed study of reconstruction efficiencies (trigger, track, charge...)
 - Apply analysis to secondaries and additional nuclei: B, N, Ne, Mg, Si,...