Cosmic-Ray Nuclei in the Fermi-LAT

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The Anti-Coincidence Detector (ACD) on the Fermi Large Area Telescope (LAT) serves to identify charged particles which cross the LAT at a rate orders of magnitude higher than that of the γ-ray signal. We have improved the charge resolution of the light deposition measurement, signal uniformity, and gain linearity in the ACD at high light levels by implementing a method that uses cosmic-ray nuclei as a calibration source. In addition we present a preliminary study to measure cosmic ray energy via the calorimeter (CAL). We present the results of our method and demonstrate improved signal uniformity and charge resolution for cosmic-ray nuclei in the ACD.

Goals and Motivation

- **Goal**: Study energy dependence of the boron to carbon ratio using the LAT
- *Fermi* could measure the boron to carbon at energies $\geq$ 1 TeV/n
  - Less atmospheric contamination when compared to balloon-borne experiments
  - Region not well explored and models not well constrained
- **B:C ratio probes cosmic-ray propagation, galactic magnetic fields, and average composition of the Galaxy**

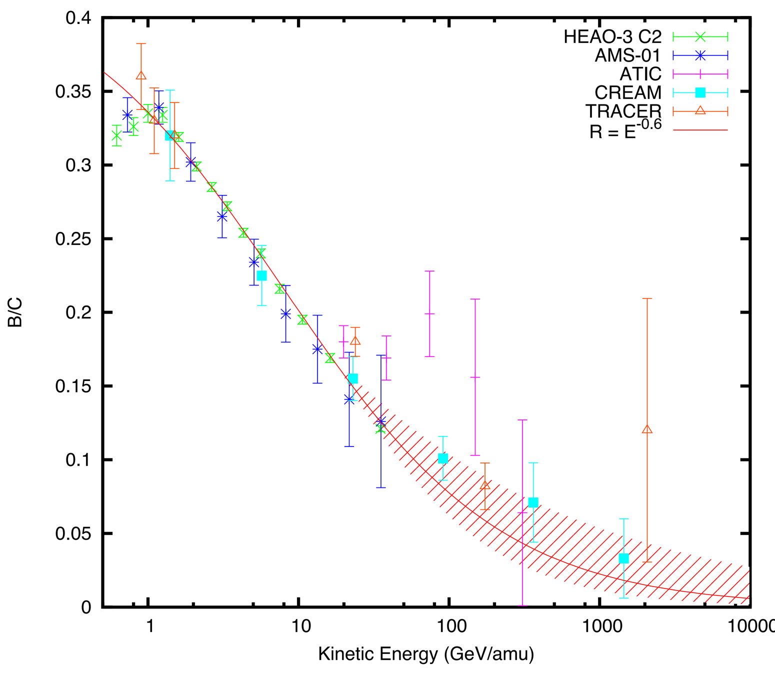

Figure 1: *The boron to carbon ratio vs Kinetic Energy per amu.*

AMS-02 B:C results http://www.ams02.org/2013/07/new-ams-data6-bc-ratio-5-gv-to-500-gv/

The Large Area Telescope

- The Large Area Telescope (LAT) on *Fermi* is a pair conversion γ-ray telescope
  - Field of view: 2.4 sr
  - Energy: 20 MeV - 300 GeV
- The LAT has three subsystems
  - Anti-Coincidence Detector (ACD): detects charged particles
  - Tracker (TKR): measures the direction of incoming charged particles
  - Calorimeter (CAL): measures the energy of the particle showers

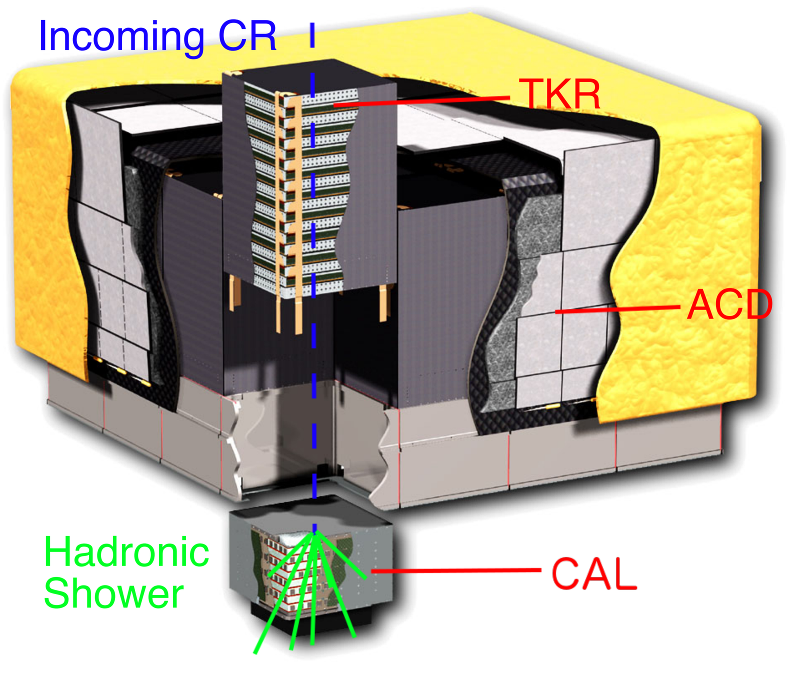

Figure 2: *Cutaway diagram of the LAT with subsystems labeled and an example of a cosmic ray interaction.*

- Majority of events measured by *Fermi* are cosmic rays
  - Galactic origin electrons, protons, helium, and heavy elements (Z$\geq$3)
- LAT is designed and calibrated for γ-ray signal
- We can improve LAT's ability to measure cosmic-ray nuclei

Cosmic-Ray Nuclei Calibration Sample

- Three main requirements:
  - Well reconstructed track in Tracker (TKR)
  - Large energy deposit in Anti-Coincidence Detector (ACD)
  - Energy deposit in first three layers of the Calorimeter (CAL)
- Apply quality cuts to remove protons, helium, and poorly reconstructed events
  - General agreement between TKR and CAL direction
  - Clean track in TKR with limited backsplash
  - Simple phenomenological model of top down hadronic shower in CAL
- Use initial charge measurement from CAL to separate CR elements

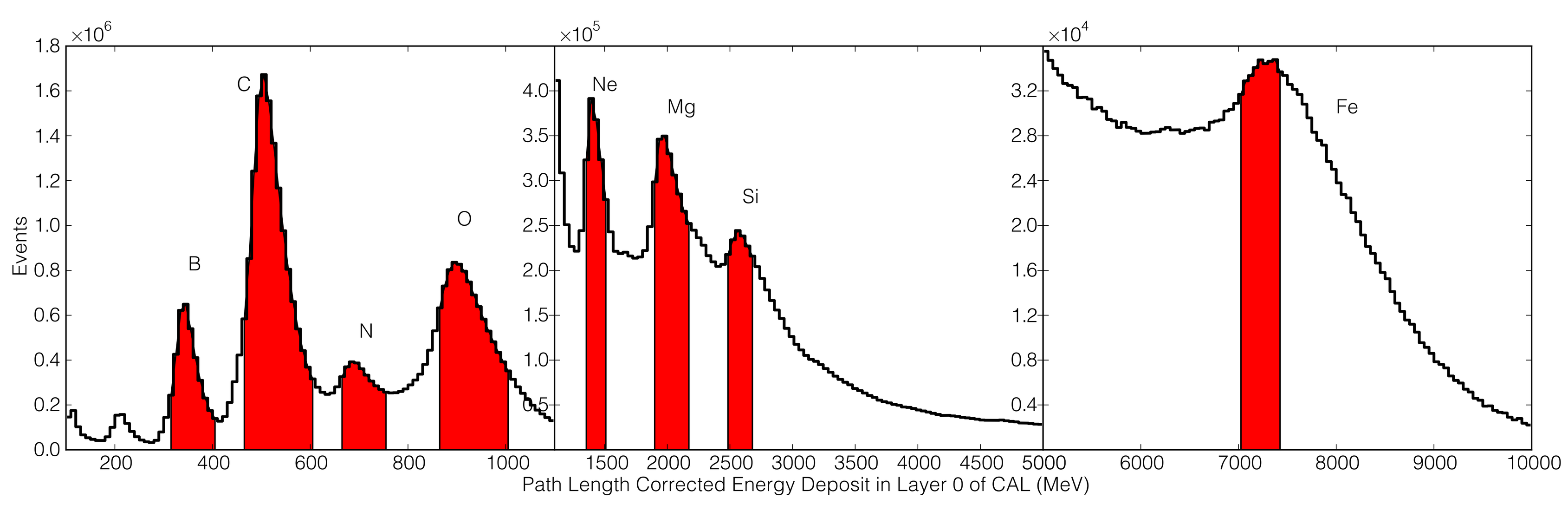

Figure 3: *Path length corrected energy deposition in the top of CAL. Red areas indicate selection used for calibration sample.*

Method to Improve Charge Resolution

1. Average ACD signal for each element for all tiles and path length (proportional to incoming angle w.r.t. to LAT) through ACD
2. Align each tile's signal for a given element and path length to its global average by fitting the channel's data with a power law
3. Use coefficients from fit to determine new uniform PHA for each event
4. Apply correction coefficients and path length correction to data

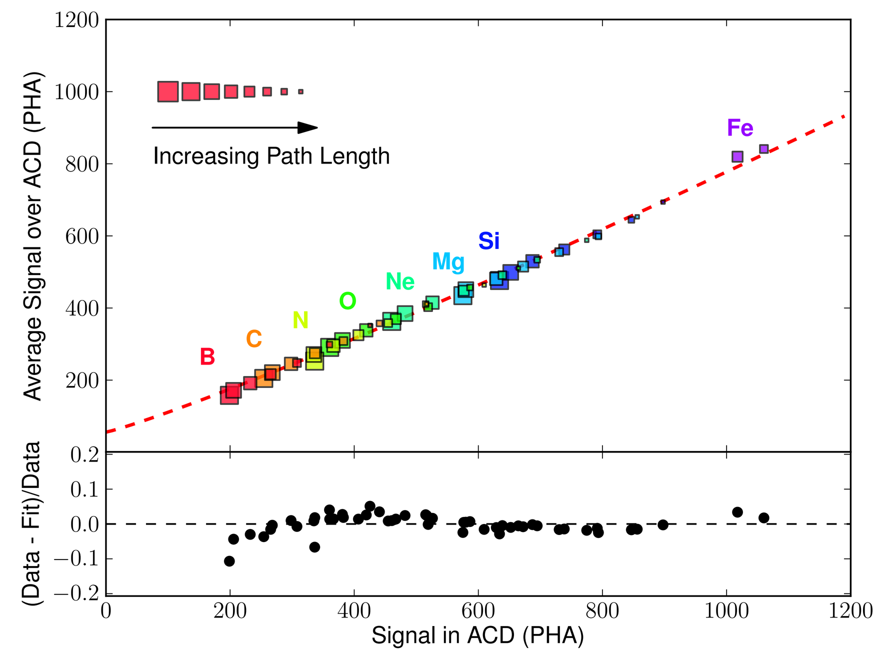

Figure 4: *Response for tile 212 PMT 0 for all charges and path lengths.*

Charge Measurement

- B, C, O, Ne, Mg, Si and Fe peaks all become visible in ACD data
- Uniform response improves ACD charge resolution, reduces charge overlap
- New path length correction eliminates angular dependence in ACD data
- Now possible to use ACD (and CAL) to select cosmic ray elements

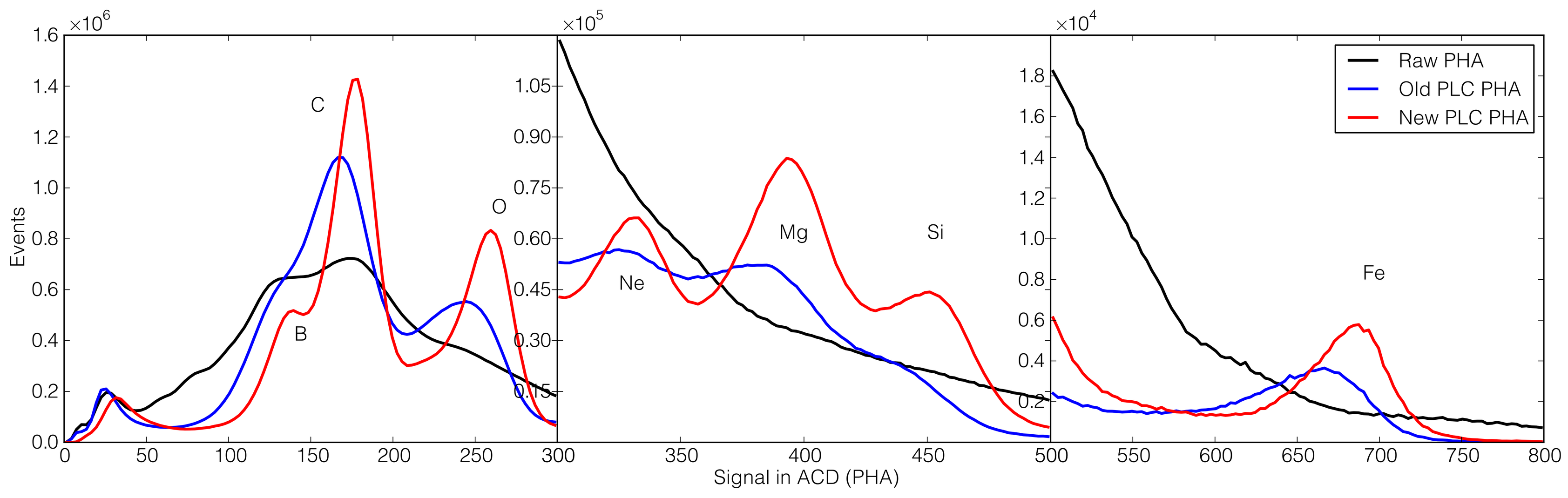

Figure 5: *Improved charge resolution of ACD signal.*

Energy Measurement and the Future

- Simulations show that incident energy scales with deposited energy in CAL
- Use long path length events to calibrate Monte Carlo simulation
- "Unfold" incident energy from deposited energy
- Use charge and energy to measure the energy dependence of the B:C ratio
- Explore properties of cosmic-ray propagation and the Galaxy using the B:C ratio

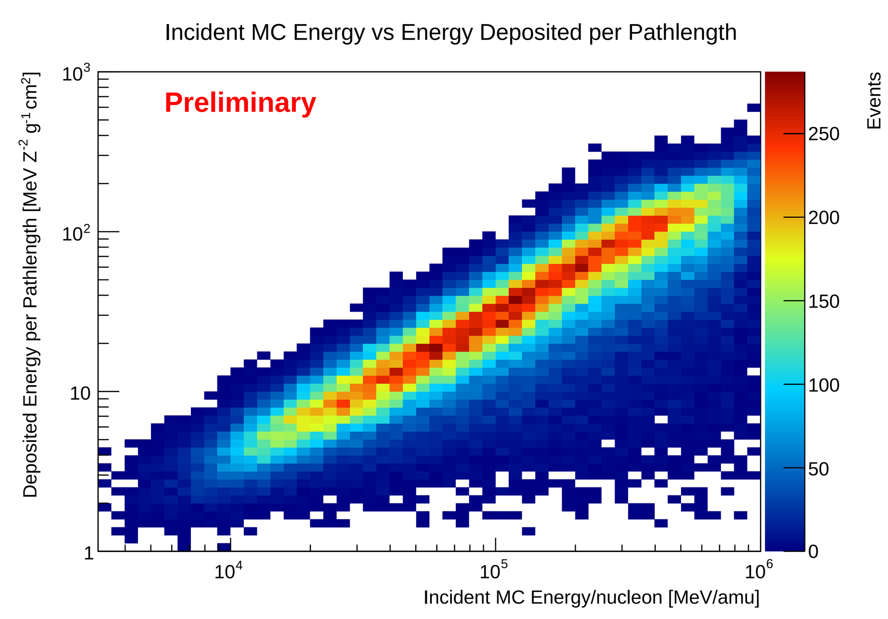

Figure 6: *Monte Carlo Energy per amu vs Deposited Energy per unit path length in units of g/cm^2.*

Conclusion

- We are able to measure cosmic rays' charge and energy with the LAT.
- ACD charge resolution is drastically improved via uniform signal and path length correction using cosmic-ray nuclei as a calibration source
- Simulations suggest incident energy and deposited energy are correlated
- Study boron to carbon ratio using combined Z and E measurements

References

1. HEAO-3-C2. A&A, 233(1):96-111, July 1990.
2. AMS-01. ApJ, 724(1):329, 2010.
3. ATIC-2. ICRC 30th. Vol 2:3-6, 2008.
4. CREAM. A Phys, 30(3):133 - 141, 2008.
5. TRACER. ApJ, 742:14, 2011.
6. ACD. A Phys, 27:339-358, February 2007.