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 ≥ 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**
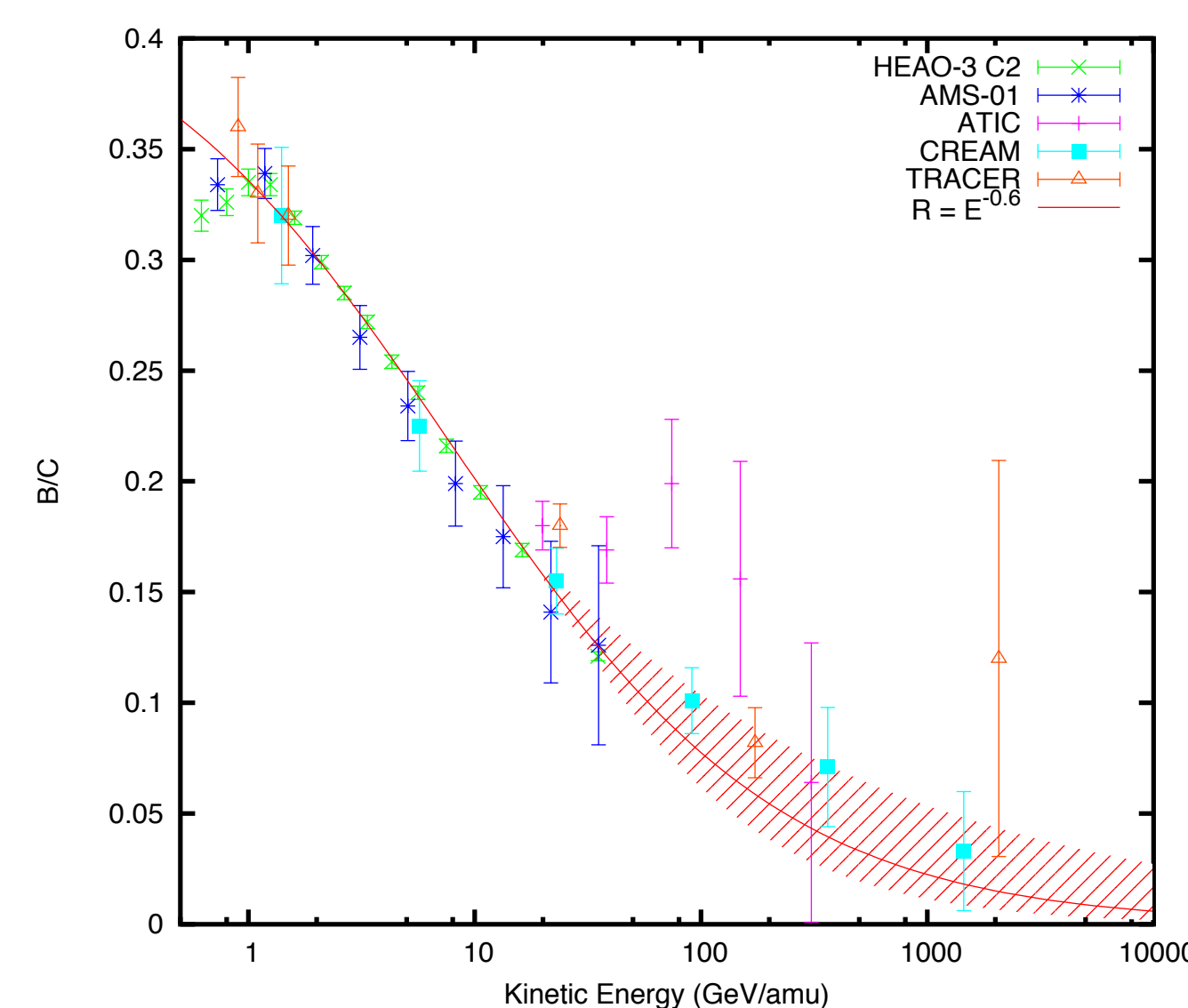

Figure 1: *The boron to carbon ratio vs Kinetic Energy per amu.*

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: *Cut a way 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≥3)
- LAT is designed and calibrated for γ-ray signal
- We can improve LAT's ability to measure cosmic-ray nuclei

Selecting Cosmic-Ray Nuclei

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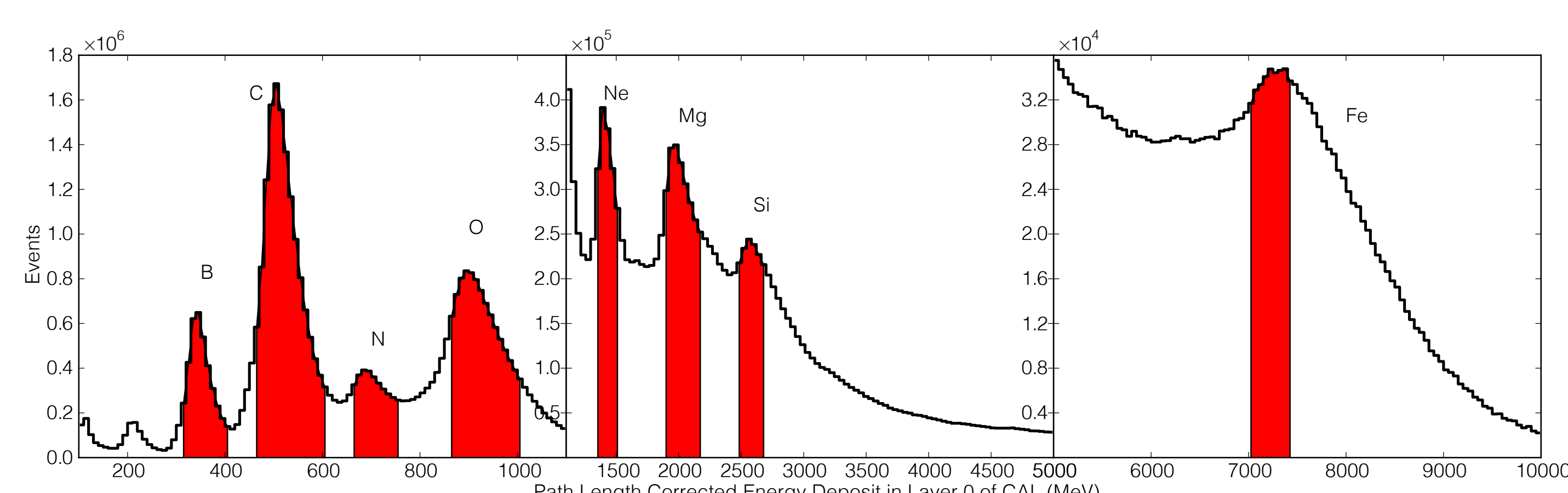
Figure 3: *Pathlength corrected energy deposition in the top of CAL. Red areas indicate selection used for calibration sample.*

Method to Improve Charge Resolution

1. Average ACD signal for each element (proportional to incoming angle wrt to LAT) through ACD
2. Align each tile's signal for a given element and pathlength to its global average by fitting the data with a power law
3. Use coefficients from fit to determine new uniform PHA for each event
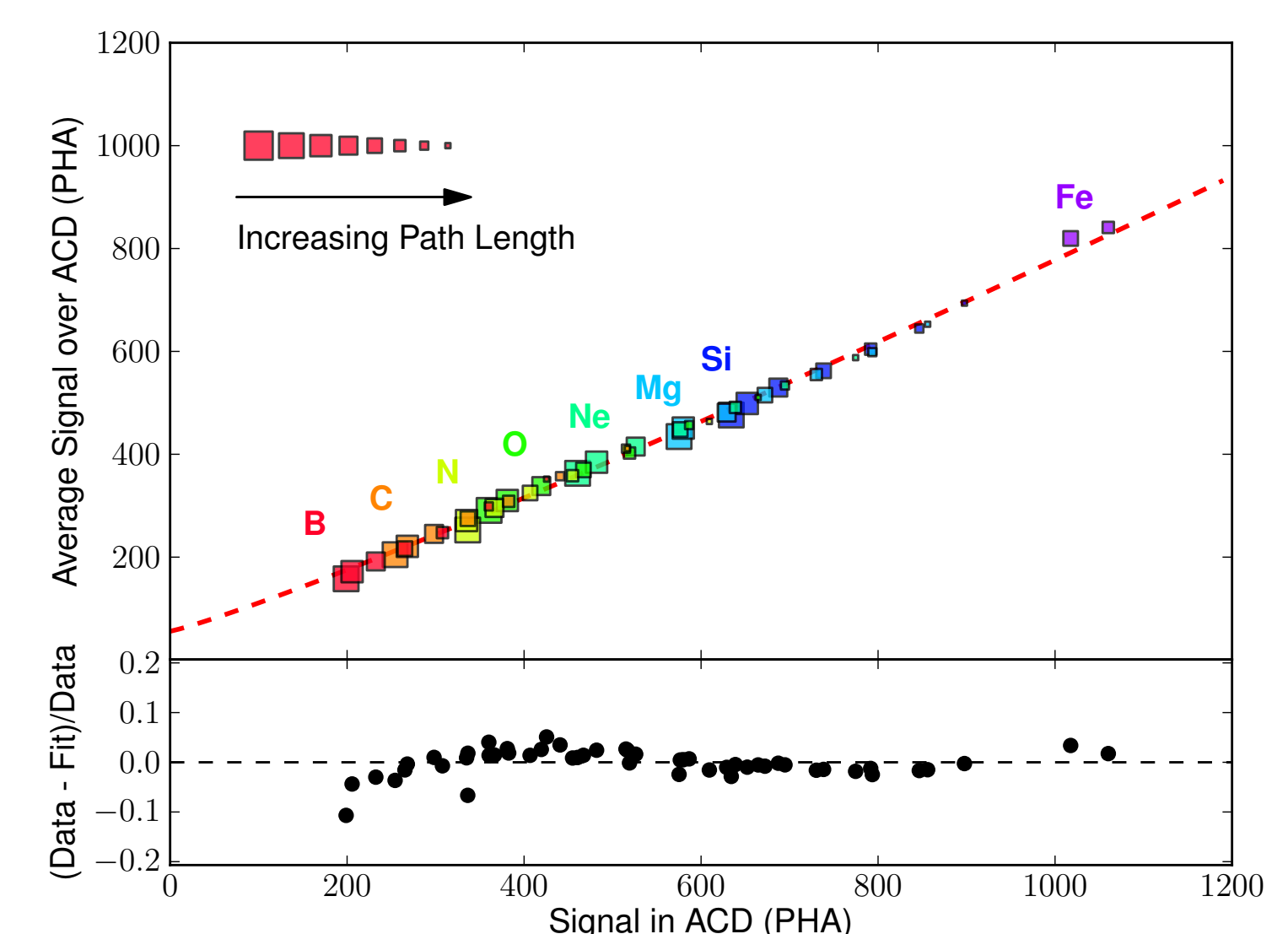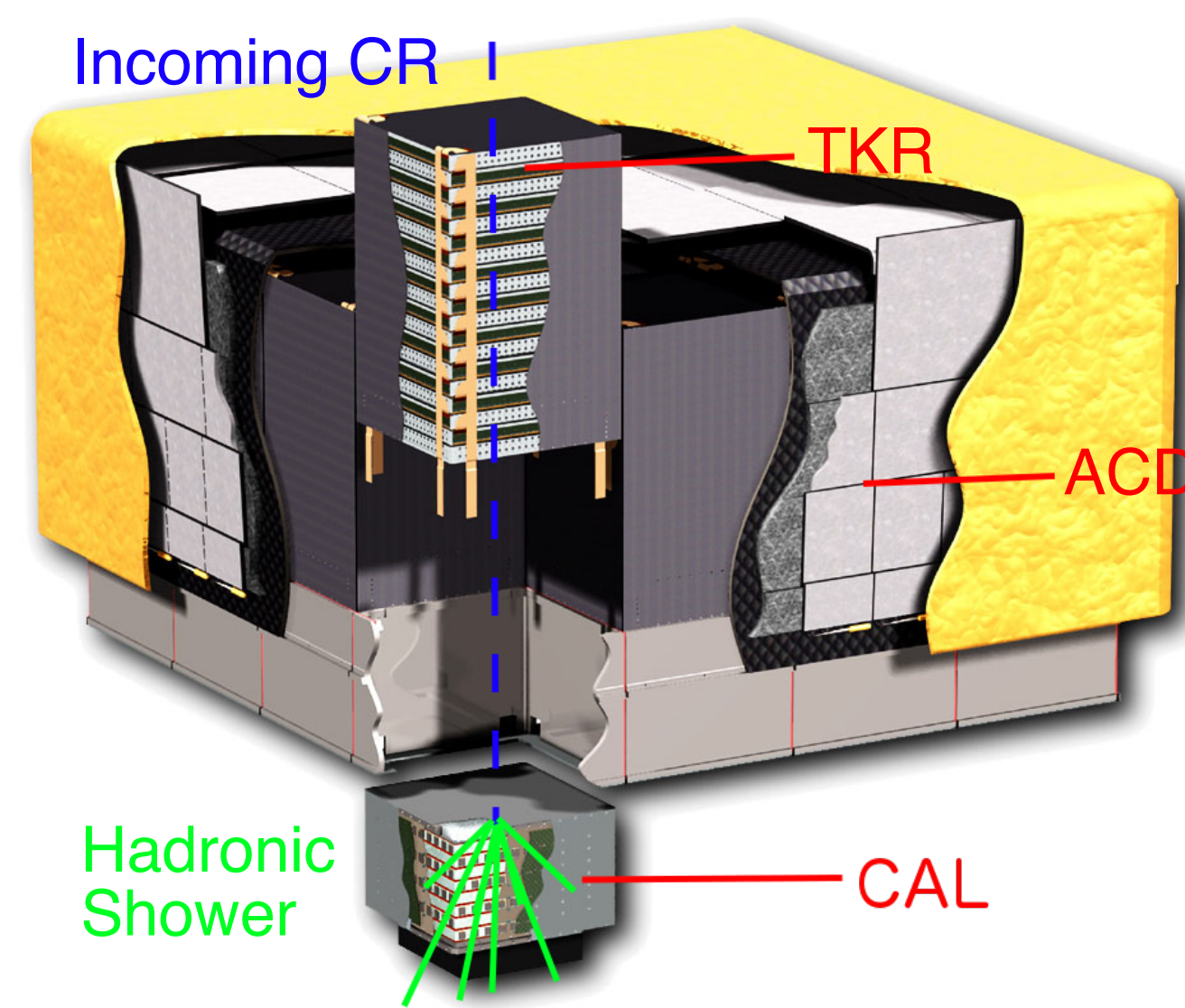4. Apply correction coefficients and pathlength correction to data

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

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 pathlength correction eliminates angular dependence in ACD data
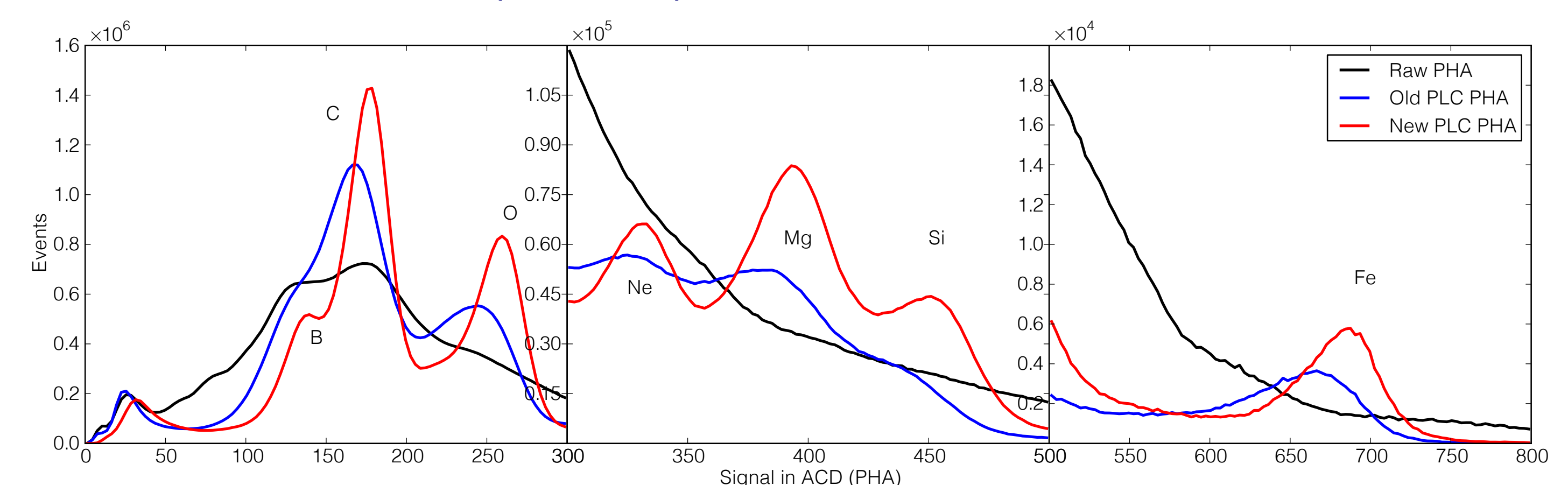- Possible to use ACD (and CAL) to select cosmic ray elements

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

Energy Measurement and the Future

- Simulations show incident energy scales with deposited energy in CAL
- Use long pathlength 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
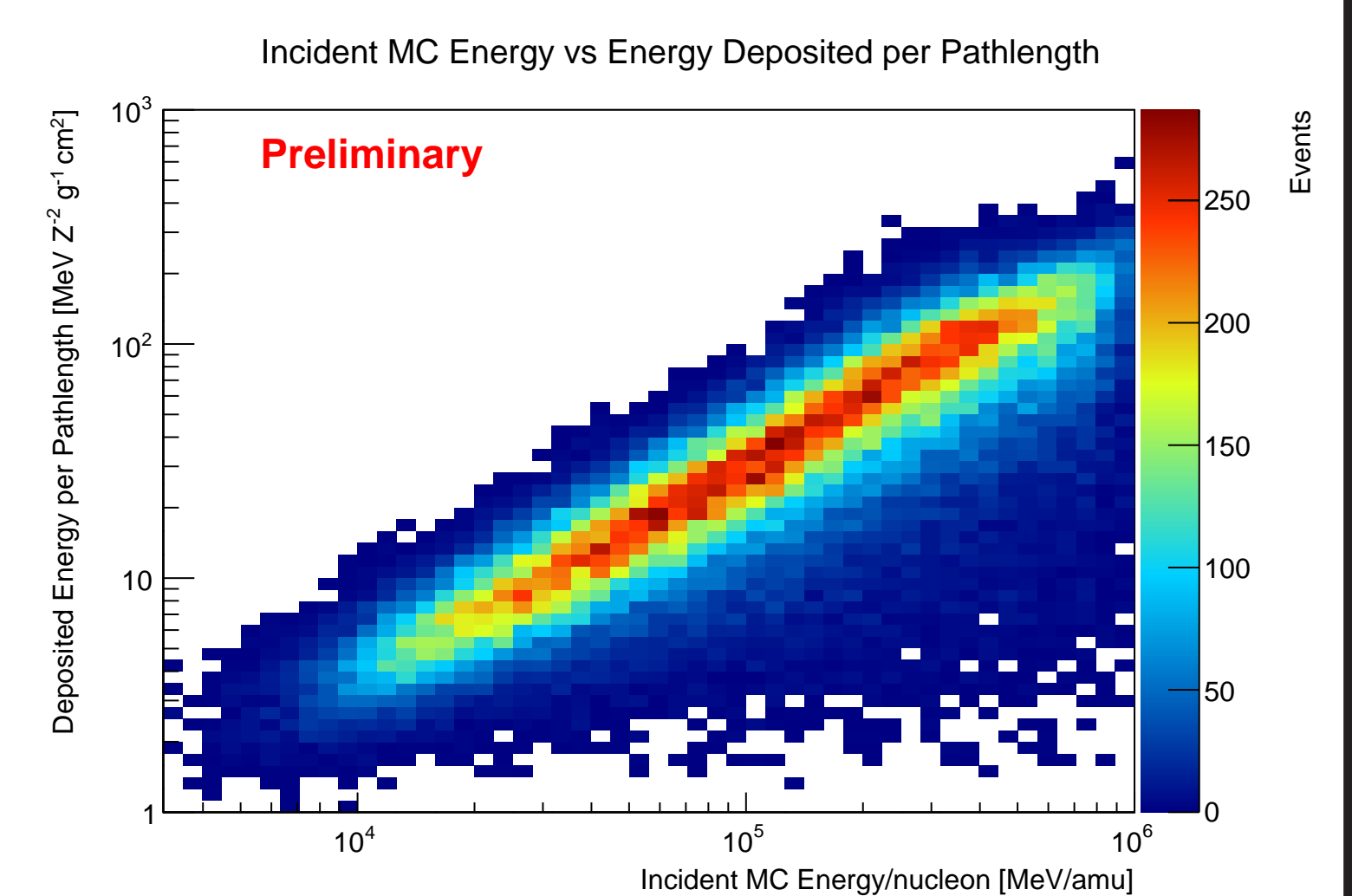- Explore properties of cosmic-ray propagation and the Galaxy using the B:C ratio

Figure 6: *Monte Carlo Energy vs Deposited Energy per unit pathlength.*

Conclusion

- We are able to measure cosmic-ray nuclei charge and energy with the LAT
- ACD charge resolution is drastically improved via uniform signal and pathlength correction using cosmic-ray nuclei as a calibration source
- Simulations suggest correlation between energy deposited and incident energy of cosmic ray
- Combine Z and E measurements to study the boron to carbon ratio

References

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