In-flight measurement of the absolute energy scale of the Fermi Large Area Telescope

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To perform an in-flight verification of the absolute energy scale of the LAT it is necessary to find an astrophysical source with a spectral feature whose absolute energy and shape are well known. A potential candidate is the geomagnetic cutoff in the observed cosmic ray electron plus positron (CRE) spectrum in low Earth orbit. The energy and spectral shape of this cutoff can be calculated with the aid of a numerical code tracing charged particles in the Earth's magnetic field. This provides a reference value for the cutoff rigidity to compare with the value measured in flight. In order to obtain several calibration points we have measured the cutoff rigidity in different geomagnetic positions ranging between ∼6 and ∼13 GeV. In this poster, I present the result of this comparison and estimate the uncertainty on the absolute energy scale of the Fermi LAT.

LAT Energy Calibration

Method we use to calibrate the energy response in flight:

- Compare signals in CAL with MC predicted signals from on-orbit relativistic protons (MIPs).
  - Calibrates lowest-energy range of the CAL readout
- Enforce adjacent gain ranges to give same measured energy in the overlapping regions.

Scintillation efficiency of heavy ions in CsI(Tl) is different to that for EM showers, so we can't use GCR peaks for high energy calibration [1].
For the energy range of this analysis (6-13 GeV):

- The correction factors for energy losses from leakage out the back and sides of the CAL on average ∼30%
- Max energy per crystal is ∼1 GeV (100×MIP!) → Read-out in higher energy range of CAL
- Good alternative source to calibrate the high energy range of the CAL readout.

Measuring the Cutoff Energy

To reconstruct the CRE primary spectrum from flight data it is necessary to remove the secondary population (see *Estimating Fraction of Primary CRE* panel) from the count spectrum, correct for the hadronic contamination and divide by the geometry factor. Both the tracer and data spectra are divided by the width of the energy interval.
The CRE spectrum can be parameterized by [3]:

$$cE^{-\Gamma}/(1+(E/E_c)^{-6}) \quad (1)$$

We fit the primary CRE spectrum (both data and tracer) with equation 1 to get the value of the cutoff energy, E_c.

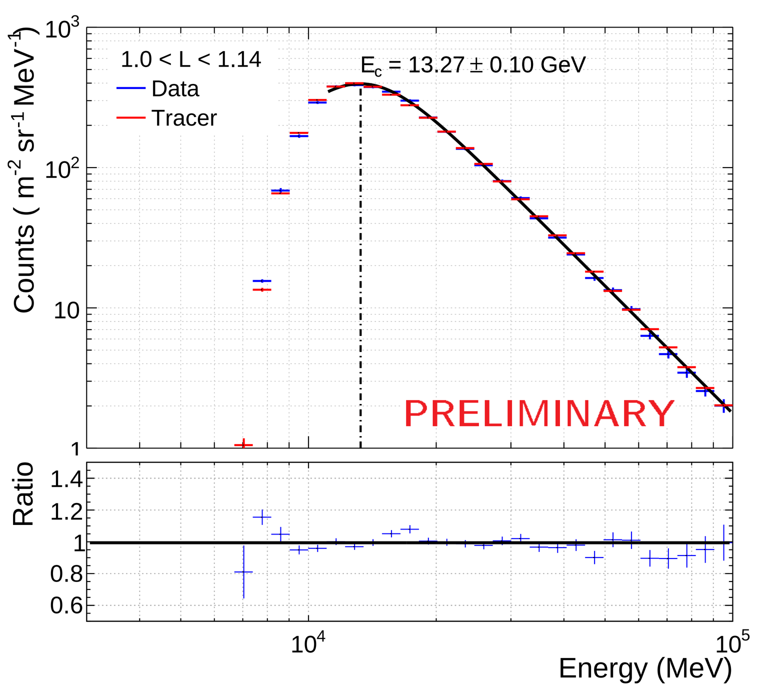


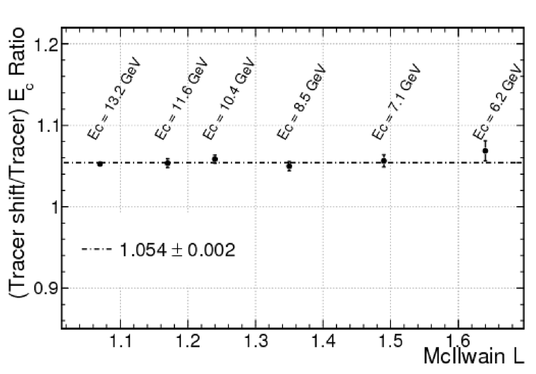
Fig. 5 Energy spectrum of data (blue) and tracer (red) for the McIlwain L interval 1.0<L<1.14. The black line is a fit to the data. Lower panel: Ratio of the two spectra.

Cross Check

- Traced particles with an added +5% shift in energy compared to standard→ Measure shift of 5.4±0.2% (as shown in left panel of figure 6.)
- Good! Method is sensitive % level deviations!

GCR element peaks used to measure radiation damage of CsI crystals (predicted to drift ∼1%/yr)

- B,C,N, and O peaks in data confirm this prediction.
- Measured cutoff position from first 60 days to last 60
- Drift of 1.9±0.9% →Consistent GCR peaks!



	Drift (%/yr)
B	1.49±0.05
C	1.60±0.04
N	1.50±0.06
O	1.46±0.03
CRE	1.90±0.90

Fig. 6 Left panel: Ratio shifted tracer to standard tracer. Right panel: Drift per year for B,C,N,and O peaks and CRE cutoff energy.

Particle Tracing

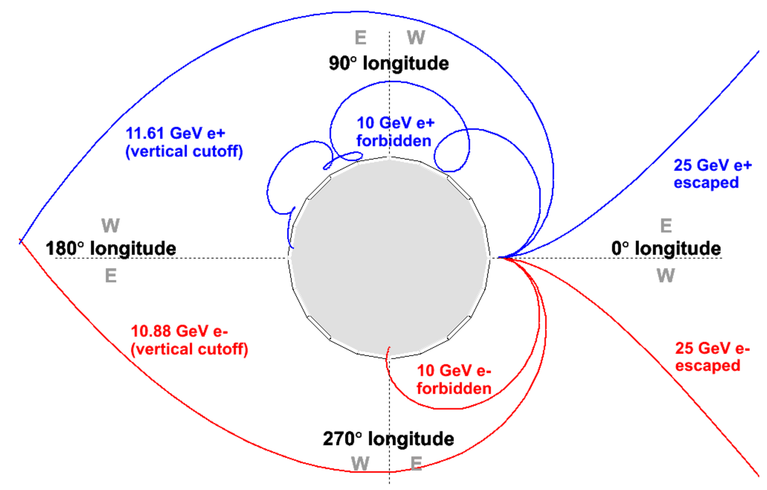


Fig. 1 Illustration of e^- (red) and e^+ (blue) of varying energies traced in the Earth's magnetic field viewed from the North Pole. The cutoff values are different for positively and negatively charged particles because the Earth's magnetic field is not a perfect dipole.

- Using particle tracing code developed by Smart and Shea [5] with geomagnetic coefficients from (IGRF-11)[4]
- Select test particles according to power-law spectrum with Γ = -3.11 [3].
- Positron fraction from the PAMELA [2].
- Angular distribution (LAT centered θ and ϕ)
- Use spacecraft orbit info to rotate into Earth centered zenith and azimuth.

Use output from tracer code to determine whether test particle at any given energy and direction is allowed (i.e., is of galactic origin) or forbidden. Use allowed particles to predict the cutoff energy.

- Overall good agreement between data and tracer, so angular distributions have been well described!

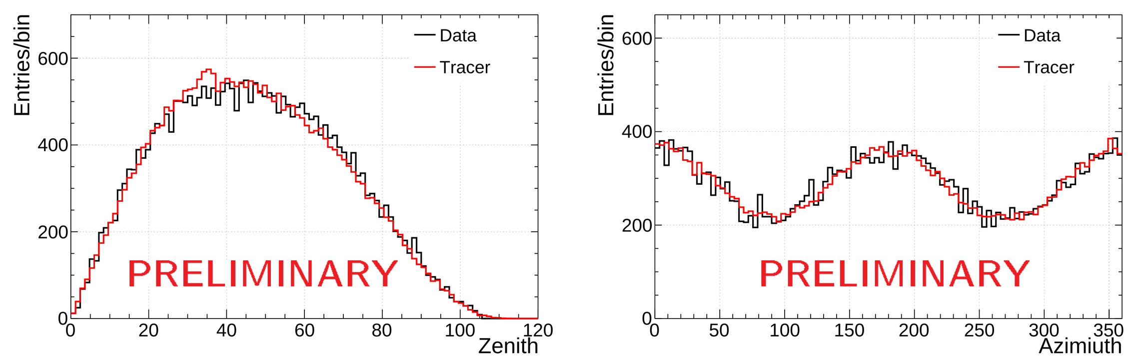


Fig. 2 The reconstructed angle with respect to local zenith (upper panel) and azimuth (lower panel) for data (black) and tracer (red). The LAT acceptance for electrons and positrons as well as the rocking profile have been convolved in these distributions and influence their shape. Both are averaged over the orbit and for energies greater than 20 GeV in order to compare the distribution of primary CREs.

Estimating Fraction of Primary CRE

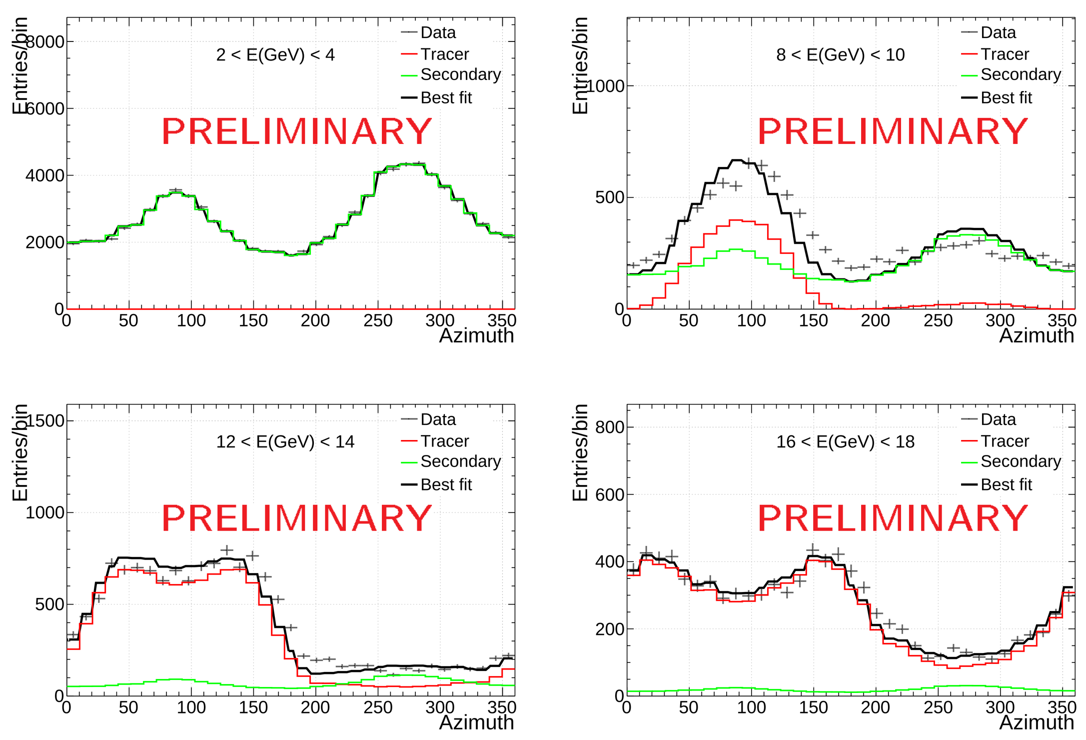


Fig. 3 Azimuthal distribution in the McIlwain L interval 1.0 < L < 1.14. Each panel depicts the distributions in a given energy interval (labeled in the panel). The LAT acceptance and rocking profile have been convolved, which in turn effects the overall shape of the azimuth distribution.

- Trajectories of secondaries are difficult to simulate reliably.
- Estimate fraction of secondaries and remove from flight data.
- Azimuthal distribution is different for the two components.
- Use template fitting to identify fraction of each population.
- Population at low energy (E<<E_c)) is predominately composed of secondaries→Template for secondaries
- Template for the primaries taken from tracer output.

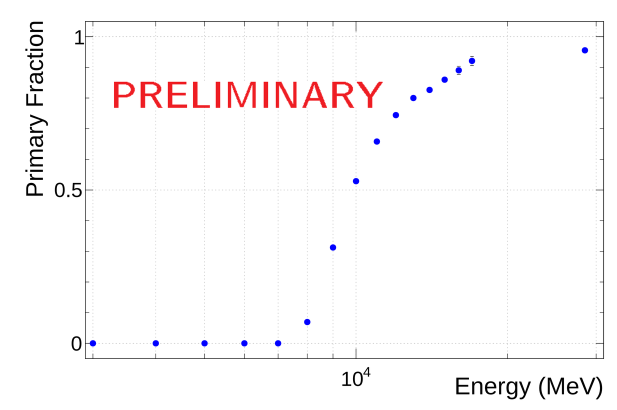


Fig. 4 Fraction of primary electrons and positrons as a function of energy for the McIlwain L interval 1.00 < L < 1.14

Systematic Uncertainties

- Interval for spectral fitting (∼0.8%)
- Interval for the secondary template (∼2%)
- Accuracy of geomagnetic field model (estimated no larger than +3-5%) [5]
- Monte Carlo to estimate hadronic contamination (∼0.5%) and geometry factor (∼1%).

References

[1] B. Lott, et al., *Response of the GLAST LAT calorimeter to relativistic heavy ions*, Nucl. Instrum. Meth.(2006)

[2] O. Adriani, et. al., *An anomalous positron abundance in cosmic rays with energies 1.5 - 100 GeV.*, Nature Letters (2009).

[3] M. Ackermann, et. al. *Fermi LAT observations of cosmic ray electrons from 7 GeV to 1 TeV*, PRD (2010).

[4] International Geomagnetic Reference Field, IAGA Division. http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

[5] Smart, D. F. and Shea, M. A., *A review of geomagnetic cutoff rigidities for earth-orbiting spacecraft*, Advances in Space Research (2005)

Result

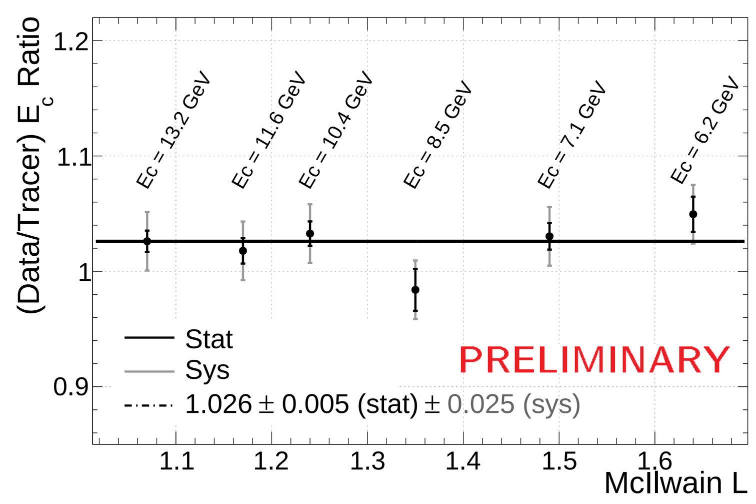


Fig 7 Distribution of cutoff energy ratios as a function of McIlwain L. The quoted value for the ratio is the weighted mean. The statistical errors are in black and systematic errors in gray. The systematic errors summed in quadrature (excluding those from the magnetic field model).

- The measured cutoff energy is found to be 1.026±0.005 (stat) ±0.025 (sys) larger than predicted by tracer code.
  - Sys from geomagnetic field model excluded because unknown in our McIlwain L range.
- Our result implies that the energy scale used in the Pass 6 and Pass 7 data sets has ∼2% systematic uncertainty in the 6-13 GeV range.