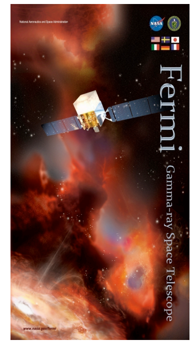
Methods for Measuring the Cosmic-Ray Proton Spectrum With the Fermi LAT



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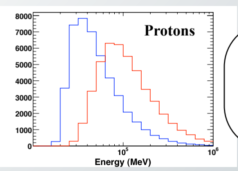
Abstract

The Fermi Gamma-Ray Space Telescope was launched in June 2008 and the onboard Large Area Telescope (LAT) has been collecting data since August of that same year. The LAT is currently being used to study a wide range of science topics in high-energy astrophysics, one of which is the study of high-energy cosmic rays. The LAT has recently demonstrated its ability to measure cosmic-ray electrons, and the Fermi LAT Collaboration has published a measurement of the high-energy cosmic-ray electron spectrum in the 20 GeV to 1 TeV energy range. Some methods for performing a similar analysis to measure the cosmic-ray proton spectrum using the LAT will be presented with emphasis on unfolding the reconstructed proton energy.

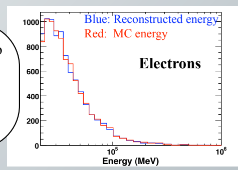
Challenges

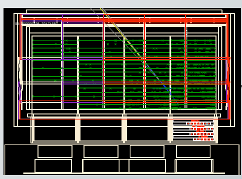
Main challenge is an accurate energy measurement for protons.

- Main contributor ⟶ The thickness of the LAT calorimeter is not optimized for hadronic showers
  - Calorimeter is optimized to measure the energy of the EM shower resulting from e^+/e^- pairs
  - Calorimeter is 8.6 radiation lengths (on-axis), whereas it is only approximately 0.43 interaction lengths.
- In addition, the event reconstruction is more complicated for protons than for gammas/electrons.



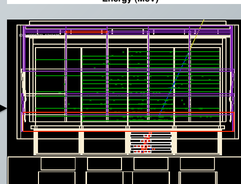
Comparison of recon. to MC energy for a selection of interacting particles, protons (left) and electrons (right)





Hadron Candidate Event Display

Electron Candidate Event Display



Hadron Candidate Event Characteristics:

- Large energy deposit per ACD tile
- Small number of extra clusters around main track; large number of extra clusters away from the track
- Large and asymmetric shower profile in the calorimeter

Electron Candidate Event Characteristics:

- Few ACD tiles hit in conjunction with the track
- Clean main track with extra clusters very close to the track – note backsplash from the calorimeter
- Well-defined symmetric shower in the calorimeter – not fully contained

Procedure

- Apply preliminary proton selections, and will collect events from two pathways: the Diagnostic filter and the High Energy Pass feature of the GAMMA filter. We will use these two sets independently.

Diagnostic filter (DGN): gives a prescaled sample of all trigger types
- Pro: Can use to extend spectrum to lower energies
- Con: Lower statistics than High Pass due to prescaling

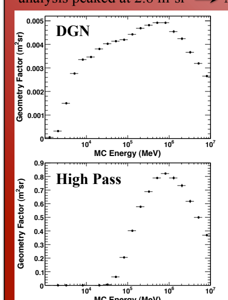
High Energy Pass feature of the GAMMA filter (High Pass): sends to ground any event that deposits >20 GeV in the calorimeter
- Pro: Higher statistics than DGN
- Con: Can only reconstruct spectrum above energy threshold

We will apply this procedure to Fermi LAT MC simulations of the cosmic-ray proton spectrum, and reconstruct an unfolded MC CR proton spectrum.

- Apply an energy unfolding algorithm to the reconstructed energy distributions.
- Use the unfolded distributions to reconstruct the proton energy spectra for the DGN and High Pass.

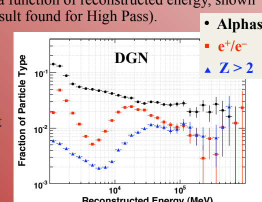
Geometry Factor:

- Peak geometry factor for DGN is approx. 0.005 m^2sr (effect of prescaling), occurs near 700 GeV.
- High Pass geometry factor drops to zero close to the 20 GeV energy threshold.
- Peak geometry factor for High Pass is approx. 0.8 m^2sr, occurs near 800 GeV.
- For comparison with the High Pass geometry factor, the geometry factor found for the CR electron analysis peaked at 2.8 m^2sr ⟶ Most protons are MIPs in the LAT.



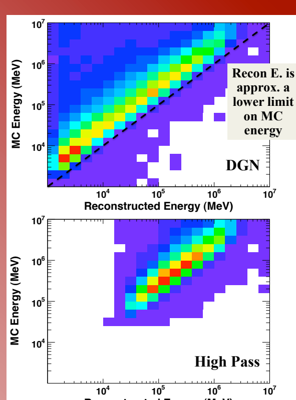
Background Contamination:

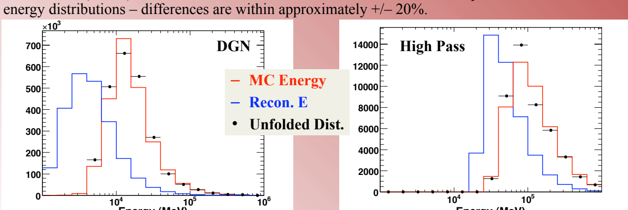
- Estimated the background contamination for the preliminary proton selections using Fermi LAT MC cosmic-ray simulations.
- Fraction that each particle species contributes to the selected event sample, plotted as a function of reconstructed energy, shown here for DGN (similar result found for High Pass).
- A low background contamination is found, and we will therefore not attempt a background subtraction here – in the MC simulations, will just select out the real proton events from the events passing the preliminary selections.



Energy Unfolding

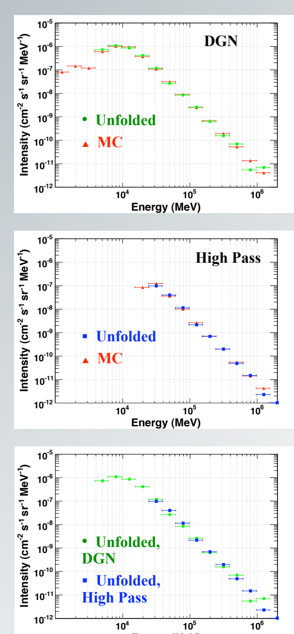
- The process of energy unfolding is to calculate the distribution of incoming energies for an event sample, using as input a detector response matrix and the distribution of reconstructed energies.
- It is important to note that this method is not a correction on an event-by-event basis, but rather a procedure by which to obtain an estimate for the distribution of incident particle energies.
- This is a similar method to what was used for the CR electron analysis, however the effect of the energy unfolding procedure on the reconstructed proton spectrum will be much greater.
- The energy response has been calculated for DGN and High Pass selected events (at right), using MC simulations of proton interaction in the LAT, starting from a hard spectrum of E^{-1}, which allows more events to be collected in the higher energy bins.
- The reconstructed energy distribution is calculated using Fermi LAT MC cosmic-ray simulations, with a more typical CR spectra.
- As a test of the procedure, the unfolded distributions are compared with the MC energy distributions (below). The unfolded distributions obtained are reasonable reproductions of the MC energy distributions – differences are within approximately +/– 20%.





Unfolded MC Spectra

- The unfolded distributions calculated for the DGN and High Pass selected events are used to reconstructed the unfolded MC cosmic-ray proton spectrum.
- The spectra are calculated by dividing the unfolded distributions by the simulated livetime of the MC and by the geometry factor.
- TOP: The DGN unfolded spectrum (green circles) agrees well with the reconstructed spectrum using the MC energy distribution (red triangles), over most of the energy range.
- MIDDLE: The High Pass unfolded spectrum (blue boxes) also agrees well with the reconstructed spectrum using the MC energy distribution (red triangles), over most of the energy range.
- BOTTOM: The two unfolded spectra show a reasonable agreement over most of the energy range in which they overlap.



Future Steps in Analysis

- Investigate improved proton selections (see poster on Identification of Cosmic Ray Protons with the Fermi LAT).
- Continue work to improve the resulting unfolded energy distributions.
- Estimate systematic uncertainties associated with unfolding procedure.
- Apply selections and unfolding algorithm to data.
- Calculate estimated background rates and subtract from candidate proton event rate, and estimate errors.
- Understand systematic errors from MC/Data discrepancies in the selection variables.