Fermi-LAT Measurement of Cosmic-ray Proton Spectrum
Paper Outline - Version 0

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Abstract

The Pass 8 gamma-ray simulation and reconstruction package for the Large Area Telescope (LAT) on the Fermi Gamma-ray Space Telescope has allowed for the development of a new cosmic-ray proton analysis. Using the Pass 8 direction and energy reconstruction, we create a new proton event selection. This event selection has an acceptance of 1 m^2 sr over the incident proton energy range from 50 GeV to over 8 TeV and when applied to over 7 years of LAT observations provides over 700 million events for a spectral measurement. The systematic errors in the acceptance and energy reconstruction require careful study and will contribute significantly to the spectral measurement. The event selection and spectral measurement of the Pass 8 proton analysis opens the door to additional proton analyses with the LAT, such as the evaluation of proton anisotropy. We present a detailed study on the measurement of the cosmic-ray proton spectrum with Pass 8 data for the Fermi LAT.

1 Introduction

(I) Describe overview of LAT

(II) Event selection for high quality proton sample

(III) Energy reconstruction, biases, energy resolution, and limitations

(IV) Describe out instrument response: acceptance and contamination

(V) Describe the methods used for spectral reconstruction: unfolding and forward folding using response matrix derived from MCs

(VI) Describe evaluation of systematic uncertainties

- (A) Due to event selection: acceptance and contamination
- (B) Energy measurement: absolute energy scale and energy resolution
- (C) From hadronic model of Geant4 simulations
- (D) Spectral reconstruction: comparing unfolding and forward folding methods

(VII) Finally discuss observations and features of measured spectral, including possible spectral break and agreement with recent results (definitely need to but this in context with other measurements since while energy resolution is poor and systematics less precises than AMS-02 we can extend the energy further into the region of balloon-borne detectors which have never been done before and makes a quantitative connection between two different observation environments)

2 Event Analysis

(I) Overview

   (A) Description of the LAT
   (B) 4×4 array of towers which measure direction and energy of incoming cosmic-ray
   (C) Each tower is composed of TKR and CAL
   (D) TKR information
      (i) Each TKR module is 18 x-y planes of silicon-strip detectors with tungsten converter foil
      (ii) Total of 1.5 X_0 at normal incidence (should convert this to nuclear interaction length)
      (iii) X-Y nature and depth of TKR allows for determination of initial direction of cosmic-ray
      (iv) Additionally able to measure the time over threshold of CR
      (v) ToT allows for measurement of signal $\propto$ Z^2
   (E) CAL information
      (i) CAL is homogeneous electromagnetic calorimeter
      (ii) Each CAL module is 96 CsI(Tl) crystals in an hodoscopic array in 8 layers.
      (iii) The hodoscopic nature of the CAL allows for measuring the shape and evolution of each particle shower which can be used with a profile fitter to determine the incident energy of the cosmic-ray
      (iv) At normal incidence the CAL is 0.5 λ_i lengths deep but at horizontal incidence is it 1.5 λ_i deep
   (F) Anti-coincidence detector (ACD) surrounds the 4×4 tower array
   (G) ACD information
      (i) 89 segmented covering 5 sides of the tower array
      (ii) Each tile independently measures deposited energy from CR
      (iii) Deposited energy $\propto$ Z^2
   (H) LAT was not designed for accurate measurement of hadronic showers
      (i) Very shallow homogeneous calorimeter not idea for fully capturing energy hadronic shower profile
      (ii) Compare to CREAM and/or AMS-02
      (iii) Unable to measure energy on an event by event basis, need to focus on a statistical ensemble approach with high event rate
      (iv) Therefore need to be aware of limitation of energy measurement and associated systematic uncertainties

(II) Monte Carlo simulations

(III) Event Selection

(IV) Energy reconstruction

3 Spectral Analysis

(I) Instrument Acceptance

(II) Residual Contamination

(III) Spectral Reconstruction

(IV) Systematic Uncertainties

4 Results and Discussion