Description of the Event Reconstruction for the Fermi Large Area Telescope

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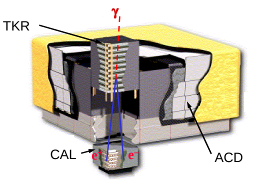
on behalf of the Fermi Large Area Telescope Collaboration

Abstract

We present a description of the event reconstruction of the data from the Fermi Large Area Telescope (LAT) . The data consist of the responses of the tracker (TKR), calorimeter (CAL) and anticoincidence-detector (ACD) subsystems of the LAT. For each event, the raw energy measured in the CAL is used to constrain tracks in the TKR, which are then used to refine the energy measurement. In addition, quantities relating the struck ACD tiles to the tracks are computed. In a subsequent step, many of the quantities calculated during the reconstruction are used to separate incident gammas from background and to arrive at the final energy and direction on the sky of the incident particles. The algorithms and implementations were developed pre-launch using simulated data from a detailed Monte Carlo model of the detector and particle sources, both gammas and background.

LAT Overview



This cutaway diagram of the LAT shows the ACD, Tracker, and Calorimeter. The dimensions of the LAT are approx. 1.8×1.8×0.75 m.

- Tracker (TKR): Silicon strip detector stacks with superb position resolution and efficiency, with low-power readout. Multiple tungsten foils allow good angular resolution while providing high conversion efficiency. 1.5 radiation lengths total.
- Calorimeter (CAL) Hodoscopic array of cesium iodide (CsI) crystals with PIN diode readout. Segmentation provides shower imaging for improved energy reconstruction and background rejection. 8.6 *Xo* total at normal incidence.
- Anti Coincidence Detector (ACD): Plastic scintillator array for high charged-particle efficiency and minimal self-veto of γ-ray showers (which limited EGRET at high energy).

Reconstruction Overview

A C++ framework (Gaudi) integrates all processing steps for event reconstruction and analysis into one configurable application :

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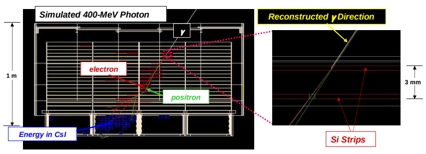
Step 1: Processing of the digitized raw data including application of calibration constants to produce energy and positions in the CAL, TKR and ACD

Step 2: Application of reconstruction algorithms (energy determination, track finding and fitting) to determine the incident direction and energy, including pattern recognition to identify tracks, a Kalman-filter fitting algorithm and shower shape algorithms to determine event energy. The fitting is iterative because it requires estimates of the event energy, which are derived from corrected CAL data plus the scattering in the TKR.



Step 3: Event analysis consisting of the application of classification algorithms to determine the particle type and event 'quality'. The classification must be robust; only ~10^{-3} of the triggers on orbit will be celestial γ-rays.

Calorimeter Reconstruction Pass I

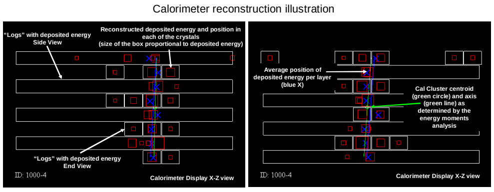
Step 1 takes the digitized raw data for each CsI crystal and converts to deposited energy and longitudinal position

- Calibrations applied to convert ADC counts to energy and to convert ADC asymmetry into longitudinal position

Step 2 then forms a Calorimeter "Cluster"

- Associates all logs with deposited energy into one cluster
- Determines the Cluster centroid and Cluster axis using an energy weighted moments analysis
- Determines a "raw" event energy as the total energy deposited in the calorimeter

Calorimeter reconstruction illustration



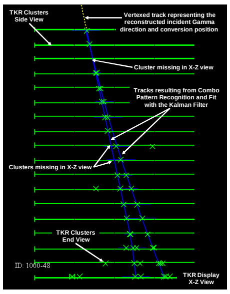
Tracker Reconstruction Pass I

Raw digitized data from the TKR is "clustered":

- TKR Clusters are formed by associating adjacent hit strips, taking into account known "hot" or "dead" strips, and determining the position of the centroid of the cluster
- The "Time over Threshold" (ToT) is formed.
  For each half-plane of the detector, the maximum duration of the OR'ed signal is converted into a charge deposition using a calibration done with charge injection and minimum-ionizing particles. For half-planes with only one hit, this unambiguously assigns an energy loss to the particle traversing that plane.

Track Finding

- In the next step, tracks are found with a track-following algorithm based on a Kalman Filter. When available, the information from the CAL cluster is used to set the initial search region and direction and the event energy is used to set the energy scale for the Kalman Filter. Loops over TKR clusters in adjacent and near-adjacent X-Y layers are combined to form trial vectors. The search algorithm uses the initial vectors to extrapolate to subsequent layers and add hits based on running track errors, which include the effects of multiple scattering. Found tracks are ordered by a quality factor that favors "longer, straighter" tracks.
  If the CAL cluster information is not available then the combinatoric loops run over all possible X-Y cluster combinations and the Kalman Filter energy is set to a minimal value.
  The track extrapolation algorithm skips over layers with missing hits near known gaps, dead strips, etc.



Final Track Fits

- After track finding is complete the total raw event energy is assigned to the found tracks and a final Pass I fit performed using the Kalman Filter

Gamma Vertex determination

- The final step in Pass I is to determine the conversion point and direction of the incident γ-ray. If more than one track is found in the event then an attempt is made to form a vertex between two tracks, otherwise a vertex is formed from the parameters at the head of the best track.

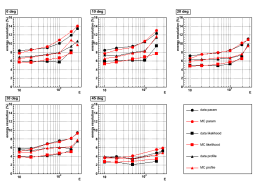
Calorimeter Reconstruction Pass II

The phase space for detecting γ-ray's in the LAT is large, ranging from ~30 MeV to ~300 GeV. For Gamma-Rays below ~1 GeV the energy deposited in the Tracker cannot be ignored while above 1 GeV leakage out the back of the Calorimeter becomes dominant. Three energy reconstruction algorithms are run after completion of the Pass I tracking:

- Parametric Method – Parameterized shower model with corrections for energy deposited in Tracker, missing energy due to gaps and leakage out the back.
  - Provides energy estimate over the full field of view
- Shower Profile Fit – 3D fit to the shower profile in the Calorimeter to determine the event energy.
  - "Best" over 1 GeV where energy deposited in tracker becomes small compared to that deposited in the Calorimeter (or leaked out the back)
- Maximum Likelihood Method – Fit to parameterized shower profiles to determine energy leaked out the back of the Calorimeter.
  - "Best" range over 1 GeV and Gamma-Ray angle of incidence < ~60°

During the Summer of 2007 a calibration unit, consisting of two TKR towers and three CAL modules, was tested at the CERN SPS.

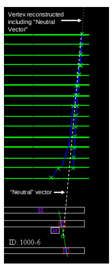
These plots compare the Calorimeter energy reconstruction for data taken at the CERN SPS with the expected results from simulation. All three energy correction methods show good agreement with the simulation.



Tracker Recon Pass II

Once the event energy has been determined a final pass is made through the track and vertex recon:

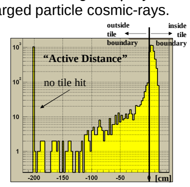
- Re-fit the best two tracks: the best two tracks have their energies constrained to sum to the total event energy as determined by the parametric method. The energy sharing is determined by the track fit parameters from the Pass I fit.
- Re-run the vertex finding: with new track parameters, the Pass I vertices are discarded and the vertex algorithm re-run. In addition, a technique unique to FGST, a "Neutral Vertex" is determined which combines the best vertex with a neutral energy vector whose direction goes from the head of the best track to the Cal Cluster centroid.



ACD Reconstruction

The segmented ACD serves as the primary tool to distinguish γ-ray's from the much larger background flux of charged particle cosmic-rays.

- Two phototubes readout each of the 89 ACD scintillation tiles. These are combined into a measure of the energy deposited in hit tiles.
- Hit tiles are associated with tracks in an order determined by closest approach.



Event Analysis

Once the iterative reconstruction and track extrapolation to the ACD has completed, the event is subjected to a detailed analysis, based on Classification Trees, to determine the best event parameters. There are three main stages to this analysis:

1) Determination of the best energy correction method, between the shower parameterization, maximum likelihood and shower profile fit methods

2) Determination of the best pointing between single, two track, one track + neutral and two track + neutral vertex possibilities

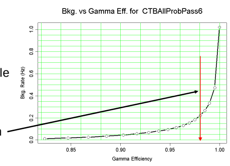
3) Determination of particle type and background rejection.

The output is a set of probabilities which allow users to fine tune their end analysis to maximize their sensitivity to the signal of interest.

Example: Background Rejection

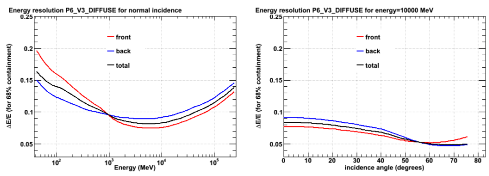
This plot illustrates the interplay between efficiency for keeping gamma rays in the data sample versus the purity of the sample as a function of the Classification Tree purity probability.

"Standard" cut on the purity level results in an efficiency of .98 for gamma rays and leaves a background rate of 0.2 Hz.

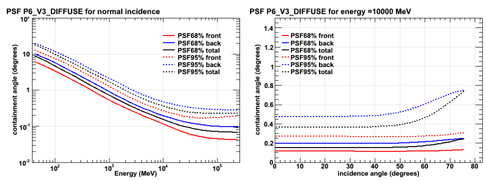


Performance

Energy Resolution: 68% containment of the reconstructed incoming photon energy. The plot on the left is for normal incident photons (defined as "cos(theta)>0.9"); the one on the right is for 10 GeV photons as a function of incidence angle.



Point Spread Function: Angles for 68% and 95% containment of the reconstructed incoming photon direction. The plot on the left is for normal incident photons (defined as "cos(theta)>0.9"); the one on the right is for 10 GeV photons as a function of incidence angle.



Effective Area: The plot on the left is for normal incidence photons (defined here as "cos(theta)>0.975"); the one on the right is for 10 GeV photons as a function of incidence angle.