GLAST Event Analysis

An examination of events recorded by the LAT prototype detector

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Abstract

GLAST Event Analysis: An examination of events recorded by the LAT prototype detector. JASON HEIMANN (University of California, Santa Cruz, 95064) E. DO COUTO E SILVA (Stanford Linear Accelerator Center, Menlo Park, California, 94025)

The GLAST mission requires an orbiting satellite that will detect and analyze gamma rays from distant cosmic sources. A prototype particle detector (called the minitower) has been built: a scaled-down model similar to that which will be used in the satellite. Previous experiments using the prototype detector have provided cosmic ray data taken at different signal thresholds. These data were processed with a track reconstruction algorithm that performed interpolations to approximate the path that each particle traveled. Using ROOT, we produced many graphs of the data to characterize the detector's response to cosmic rays and find correlations within the data. The coordinate system used in the data was verified against specifications and sensitive areas of the detector were measured. We have validated the geometry implementation of the detector using cosmic ray data, studied hit multiplicity and its angular dependence, and examined detector response under different threshold settings. A basic understanding of the detector's characteristics has been developed for future investigation of charge sharing between strips.

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1 Introduction

1.1 GLAST and Gamma Rays

Screaming toward Earth at the speed of light, gamma rays are bringing us information from deep within mysterious cosmic sources. Gamma rays are high energy, electrically neutral particles; they do not experience deflection in the presence of magnetic fields. This gives us a chance to intercept information that may have traveled across vast portions of the universe, in its original form. We have a chance, that is, if we develop tools and methods to accurately “see” gamma rays. With these tools we may probe the early Universe, resolve unidentified gamma ray sources and develop an understanding of how some cosmic particles are accelerated.

GLAST is a space-based observatory under development, a gamma ray telescope that should give us the most accurate and revealing views of gamma ray sources to date. Short for “Gamma ray Large Area Space Telescope,” GLAST utilizes technology developed by particle physicists to examine and gather data from astronomical events. The challenge of detecting a particle and tracking its trajectory had first been tackled by physicists in the early 1900’s. Since then, particle detector technology has become a powerful tool in the field of experimental particle physics. Using this technology in an astrophysical experiment will introduce new challenges, but the improvements in detection and measurement made possible by such technology should prove invaluable.

1.2 Particle Detection in GLAST

At the head of the GLAST satellite sits the Large Area Telescope (LAT), an instrument that includes scintillator tiles, a calorimeter and a particle tracker. The tracker module (TKR;

see figure 1) is a three dimensional array of detector trays. Each of these trays contain up to two layers of silicon, each layer containing a four-by-four arrangement of Silicon Strip Detectors (SSDs) that measure position along one axis. Placing one tray on top of another with a 90 degree change in orientation allows one to measure the x- and y- coordinates of a particle which traverses both trays. With a “tower” of many trays, successive measurements can be made, allowing for the interpolation of the particle’s path through the tower.

Before gamma rays are detected in the LAT, they must first undergo pair conversion. A layer of high-density metal (tungsten) is placed above the silicon layers in most of the detector trays to facilitate the conversion process. An electron and a positron are produced from the conversion. These charged particles ionize atoms in the silicon and produce a measurable current. A “hit” from a charged particle is reported when the current rises above a set threshold. Data from the TKR is recorded when an event is triggered; a “trigger” occurs when a hit is reported from six consecutive silicon layers.

After ionization occurs in the silicon, the free charges that result can be distributed across a significant portion of the layer, especially in events when a particle traversed through the layer at a large angle from the surface normal. These charges will propagate along different (and not necessarily adjacent) strips, creating a “cluster” of hits that may or may not accurately represent the position of the incident particle at the time(s) of ionization. The threshold level will determine the amount of charge that appears in each cluster.

1.3 Cosmic Rays and The Minitower

Before building the entire LAT, the LAT Collaboration produced a scaled down engineering prototype named “The Minitower.” It is composed of four full-size, fully instrumented detector trays and one tray with no detectors. In total, six silicon layers are present in the

minitower, the minimum number required to trigger a measurement event. For comparison, the launch-ready GLAST will contain a total of sixteen towers with nineteen detector trays in each tower. To determine the hardware, software, mechanical and thermal characteristics of the detector trays, the minitower is subject to a number of tests. One series of testing investigates the minitower's response to a variety of incoming particles.

As GLAST flies through space it will experience a continuous flux of cosmic particles, similar to that experienced by the Earth on its flight through space. To study the detectors' response to this flux, the minitower is monitored while it is subject to cosmic rays under various conditions. The minitower is set in different orientations for some tests, while other tests involve the adjustment of selected electrical characteristics of the detectors. These tests take place in a clean room at the surface of the Earth, where the muon is the dominant component of cosmic ray flux [1]. Other notable components are electrons, positrons and photons.

2 Reconstruction Software

When a particle travels through the detector, one can imagine it leaves a set of "tracks" in its path. With careful analysis, the number and type of particles that traversed the tower may be determined, as well as their locations and momenta. The raw data that is collected from the cosmic ray experiments are processed by a track reconstruction algorithm in an attempt to characterize each triggered event. This algorithm tries to fit one or more straight lines (called "tracks") to the hits reported by each SSD during one event. The algorithm allows for small deviations along individual tracks, and recognizes interaction events such as pair production and scattering within the detector. The reconstruction process is crucial in

obtaining meaningful data from the tower, but it also introduces some uncertainties. Since line fitting requires the approximation of slopes and intercepts, we lose some of the accuracy provided by the SSDs.

For the cosmic ray tests we expect to see a predominance of events with a single track of hits through the detector: the signature of a muon in passing. Unfortunately, many factors make this signature harder to resolve. The data that is obtained from the detectors contains events whose topology is different than what one would naively expect. Understanding the evolution of a measurement event gives one insight into the challenges of particle detection and tracking. One must first come to terms with the fact that particles passing through the detector will not always be detected. It must also be understood that the detector does not determine the type of particle that creates the interaction. This must be inferred from the data. In short, the SSD can only report events of ionization that occur within the sensitive areas of the silicon layer.

3 Data Analysis Software

The primary tool used to aggregate and analyze data is a C++ based system called “ROOT”. The ROOT system is a powerful framework of object-oriented code that provides methods with which to manipulate and visualize large data sets. The ROOT environment includes a command-line interface, a script interpreter and C++ libraries for production of compiled programs. ROOT was mainly used to produce histograms and scatter plots of data with various quantitative constraints (or “cuts”) placed on the data going into the graph.

Measurements recorded in the process of building the minitower were obtained from the project web site. Raw data was gathered onto a disk as the minitower executed several trials

of cosmic ray measurements. The runs were completed with the detector trays oriented parallel to the earth’s surface. Some trials included adjustments to the detector’s hit threshold. The raw data from each trial was then converted into a ROOT data format and processed by the track reconstruction algorithm, which outputs a separate ROOT data file.

The resulting data files include raw and reconstructed data. Raw data includes parameters such as $nStripsPLayerX$, the number of SSD strips hit in each layer that measures X position (“X layers”), and $nStripsPLayerY$. The actual strip where hits were detected is represented by the parameters $xStrip$ and $yStrip$. Reconstructed data includes parameters that describe the number of reconstructed tracks in each event $nTkrTracks$, the approximate center of the first measured cluster in each track $xPos$, $yPos$ and $zPos$, as well as the angle that track makes with the detector’s surface normal $zDir$.

4 Results

4.1 Geometry

Scatter plots of raw and reconstructed data were used to verify dimensions specified in the engineering drawings. Examining the coordinate system used in the data sets, we found the origin ($xPos$, $yPos$) (0, 0) at the centroid of a detector tray.

Figure 2 is a scatter plot of $xStrip$ versus $yStrip$, showing an aggregate of over 65,000 hits in all layers. With this amount of statistics the gaps between SSDs become clearly visible. While the data provides 0.001mm of resolution, this precision is an artifact of the algorithms used to record data; actual resolution is determined by the accuracy achieved in engineering the prototype. Collapsing figure 2 into a one-dimensional histogram we are able to measure the gaps perpendicular to the X axis (X gaps); we determined these gaps are

2.376 ± 0.010 mm wide, the specified distance between adjacent columns of SSDs. We measure the gaps perpendicular to the Y axis (Y gaps) and obtain 3.060 ± 0.010 mm. Zooming in even further we can see the positions of individual SSD strips; in figure 3 we observe a separation of 0.228 ± 0.010 mm. This agrees exactly with specifications.

Figure 5 is a scatter plot of $xPos$ versus $yPos$. Since this plot is made from reconstructed data, we only see points from measurement events (requiring hits in six successive layers). From this plot one can still make out the gaps, but a closer inspection (figure 6) reveals a small number of points appearing within the gaps. This observation is discussed in section 5 on page 11.

4.2 Hit Multiplicity

We continue our analysis with an investigation of the charge distributions that occur within the detectors. Figure 7 is a collection of histograms indicating the number of strip hits in each layer. From these histograms we quickly deduce that single hit events dominate the data. Examining plots similar to figure 9 we determined we could expect only single-hit events when track angles are no greater than 20° from the surface normal of the detector. We use this angle as a cut to achieve the plot in figure 8; this plot includes data taken at two different threshold levels. A numerical analysis of this plot is presented in Table 1, where the number of events with two or three strip hits per layer are compared to the events with one strip hit. Another comparison of threshold levels yields the findings in Table 2, where we calculated the fraction of events with ≥ 20 hits in a given layer for the same two threshold levels indicated in figure 8. Looking for an angular correlation we make a plot of the average $nStripsPLayer$ vs. $zDir$, seen in figure 9. This plot includes a fit to Equation 1, a line plus a tangent function.

$$nStripsPLayer = p_0 \cdot zDir + p_1 + p_2 \cdot \frac{\tan zDir}{0.228} \quad (1)$$

The linear terms (p_0 , p_1) represent the baseline response of the detector: the minimum number of strips hit by a single particle coming in at zero angle to the surface normal of the detector. The tangent function describes the geometric relationship between the angle of incidence (see figure 10) and the number of strips hit.

5 Discussion

Many obstacles were encountered when producing the minitower; problems encountered during fabrication made our data analysis even more difficult. In order to generate any pertinent physics from this prototype, it must first be put in working order and its characteristics must become well known. During assembly, portions of the electronics were known to be bad or had to be disconnected. A layer-by-layer view of the raw data in figure 2 reveals over three quarters of the middle X and Y layers and over one half of the top X and Y layers are comprised of “dead” strips (those that do not respond to stimuli). The functional area of the detector is represented in figure 4.

Despite the successes in identifying the dimensions of the SSDs many unexpected details appeared, as visible in figures 5 and 6. The 3.060mm Y gap measurement can only be produced by adding the width of three strips ($3 \times 0.228\text{mm} = 0.684\text{mm}$) to the expected gap of 2.376mm. The regular occurrence of this measurement suggests several strips may have been disabled within each SSD. Examining figure 5 carefully we notice six faint gaps at regular intervals along the Y axis; measurements of the intermediate gaps yield values near 0.6mm. This effect correlates to disabled channels in the front end electronics during data

taking. Further study of the minitower is required to investigate this correlation.

Difficulties involved in recreating a particle's track from raw data are manifest in figure 6. The detector contains a gap of about 2mm in which no hits are expected; the reconstruction shows hit positions located in this gap. As the track angle is calculated from reconstructed hit position, a correlated uncertainty is introduced. A simple geometric analysis (figure 10) would lead one to believe the correlation follows a tangent function, but the fit in figure 9 yielded several values we did not expect. From this we conclude Equation 1 is not an accurate representation of an interaction within a SSD; uncertainties in angular measurement contribute to our inability to accurately model the interaction.

Figure 8 and Table 1 show an increase in single hit events for a higher hit threshold. The higher threshold will prevent hits from occurring where less charge is collected. With a lower threshold, the probability of an event containing a “noise” hit is higher, therefore we expect more two hit events at the low threshold.

The presence of high hit counts (≥ 20 hits in a layer, an arbitrarily large value) in some events can make track reconstruction more difficult. False hits can be created from random thermal fluctuations, and multiple hits can occur in a single layer when a particle experiences multiple scattering within the detector. Multiple scattering cannot be prevented but it can be minimized by reducing the amount of material used in the structure of the detector. The volume of material used in the detector must be above a minimum amount, however, to achieve a desired photon conversion rate. Events with high hit counts can mimic situations when a proton interacts with the detector, creating an electromagnetic shower. The likelihood of an incident proton is nearly two orders of magnitude less than that of a muon [2]; further studies are needed to identify these events.

Comparing the data taken at two hit thresholds in Table 2 little difference is noted

(<5% in most cases). This suggests that threshold settings have little effect on large hit multiplicities. Seeing fewer strips hit in each layer will give a more definite location of a particle and could improve the accuracy of reconstruction.

6 Conclusion

We have validated the geometry implementation of the detector using cosmic ray data, studied hit multiplicity and its angular dependence, and examined detector response under different threshold settings. A basic understanding of the detector's characteristics has been developed for future investigation of charge sharing between strips. Our observations match expectations, but further studies are necessary for a complete understanding of the detector's behavior in different situations. Comparisons to Monte Carlo simulations are required to quantify the detector's response to a change in threshold, including effects on the detector's efficiency.

7 Tables and Figures

Layer	Threshold	1 Hit Events	Ratio of 2:1	Ratio of 3:1
X3	Low	468	0.47 ± 0.04	0.10 ± 0.02
X3	High	397	0.22 ± 0.03	0.08 ± 0.01
Y3	Low	489	0.40 ± 0.03	0.09 ± 0.01
Y3	High	385	0.27 ± 0.03	0.05 ± 0.01
X2	Low	538	0.31 ± 0.03	0.09 ± 0.01
X2	High	418	0.21 ± 0.02	0.06 ± 0.01
Y2	Low	582	0.26 ± 0.02	0.07 ± 0.01
Y2	High	431	0.20 ± 0.02	0.04 ± 0.01
X1	Low	516	0.36 ± 0.03	0.09 ± 0.01
X1	High	395	0.27 ± 0.03	0.07 ± 0.01
Y1	Low	537	0.33 ± 0.03	0.10 ± 0.01
Y1	High	388	0.26 ± 0.03	0.09 ± 0.02

Table 1: Ratios of single strip hit events versus multiple strip hit events. The data is separated by layer.

Layer	Threshold	Fraction
X3	Low	$7.28 \pm 0.55 \times 10^{-3}$
X3	High	$7.10 \pm 0.62 \times 10^{-3}$
Y3	Low	$5.07 \pm 0.46 \times 10^{-3}$
Y3	High	$4.80 \pm 0.51 \times 10^{-3}$
X2	Low	$6.51 \pm 0.52 \times 10^{-3}$
X2	High	$4.87 \pm 0.51 \times 10^{-3}$
Y2	Low	$9.74 \pm 0.20 \times 10^{-4}$
Y2	High	$1.08 \pm 0.24 \times 10^{-3}$
X1	Low	$4.20 \pm 0.42 \times 10^{-3}$
X1	High	$4.06 \pm 0.47 \times 10^{-3}$
Y1	Low	$2.87 \pm 0.34 \times 10^{-3}$
Y1	High	$2.64 \pm 0.38 \times 10^{-3}$

Table 2: Fractions of total events where ≥ 20 hits are detected in a single layer.

Figure 1: An exploded view of the LAT showing the location of the anti-coincidence scintillator detector (ACD), the segmented calorimeter (CAL) and the tracker module (TKR).

Figure 2: A plot made from raw data indicating the positions within the tracker module where a hit was detected

Figure 3: A detail of the previous plot; individual strips within two adjacent SSDs are clearly visible

Figure 4: A plot made from reconstructed data indicating the positions within the tracker module where a particle was first detected

Figure 5: A detail of the previous plot; gaps appear within individual SSDs

Figure 6: Another detail of figure 4; no definite edges are visible. Hits appear in the gap between two adjacent SSDs.

Figure 7: Histograms indicating the frequency of single and multiple strip hits in each layer for each triggered event

Figure 8: Histograms indicating the frequency of single and multiple strip hits in each layer. Two threshold levels are compared in the plots; the data is cut on reconstructed track angle to exclude tracks coming in at angles greater than 20 degrees

Figure 9: A plot of the average number of strips hit in a layer versus the reconstructed track angle. The plots include a fit to Equation 1.

Figure 10: A sketch of a portion of an SSD showing the geometric relationship between track angle and the number of strips hit. As the angle increases, the track traverses more strips; a tangent function is used to describe the relationship.

References

- [1] K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002)
- [2] *ibid.*

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