	Document Number: **LAT-TD-04631-02**	Release Date: March 8, 2005
	Authors: Eduardo do Couto e Silva, Lee Steele	Supersedes: Rev 1
GLAST LAT Technical Document	Subsystem/Office: Integration and Test	
Document Title: **GLAST LAT Instrument Data Analysis Primer**		

Gamma Ray Large Area Space Telescope (GLAST)
Large Area Telescope (LAT)
Integration & Test (I&T)
Instrument Data Analysis Primer

Change History Log

Revision	Effective Date	Description of Changes
1	27 September 2004	Initial release
2	8 March 2005	Revised Fig. 6, Fig. 12, Table 2 and text to reflect change in Recon file plane numbering scheme.

Contents

List of Illustrations

List of Tables

1. Introduction

This document is intended to provide the LAT collaborators with sufficient information to perform data analysis during LAT integration. It is intended for users who are familiar with the LAT instrument, however a brief overview is provided.

Most of the information in this document is either copied from the website of Instrument Analysis Workshop presentations, or existing LATDocs documents. A list of references is provided in Resources, section 12.

1.1. Hardware Overview

The Large Array Telescope (LAT) is an integrated instrument consisting of 16 towers set into a 4x4 grid. Each tower consists of a Tracker (TKR), Calorimeter (CAL), and Tower Electronics Module (TEM). The LAT is shown in Figure 1. The 16 towers are surrounded by an Anti-Coincidence Detector (ACD) which is surrounded by a micro-meteorite shield.

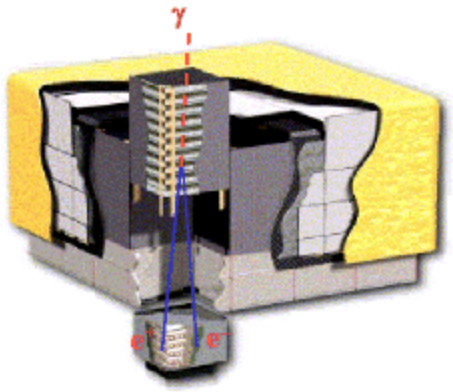


Figure 1: The LAT

The following paragraphs provide a brief description of how the major components are used during pre-launch tests and are shown in Figure 2.

The ACD is mostly used to either identify charged particles for cosmic ray calibration runs, or to reject charged particles during Van de Graaff photon calibration runs.

The TKR's function is to reconstruct the original direction of travel of either incoming photons (from 18 MeV photons from a Van de Graaff generator) or of charged particles (cosmic rays).

The CAL's function is to measure the energy deposited by incoming charged particles, either from photon pair creation or cosmic rays.

The TEM assembles trigger primitives from the TKR and CAL (or simulated input) to determine whether or not there has been an event in the LAT. If so, it alerts the GLAST Electronics Module (GEM). It also communicates with the Event Builder Module. Trigger parameters are stored in the TEM.

The GEM (also referred to as the GLAST LAT Trigger - GLT) responds to a TEM's message that an event has been detected and decides whether or not to generate a trigger. The GEM is an important component when performing Dead Time and Trigger analyses.

The Anti-Coincidence Detector Electronics Module (AEM) performs the same function for the ACD as the TEM does for the TKR and CAL detectors.

The Event Builder Module (EBM) communicates with the GEM, TEM and AEM.

The Global-trigger/ACD-module/Signal-distribution Unit (GASU) performs the highest logic level of event decision making, and comprises the AEM, GEM and EBM.

The Power Distribution Unit (PDU) supplies DC current to operate the electronics.

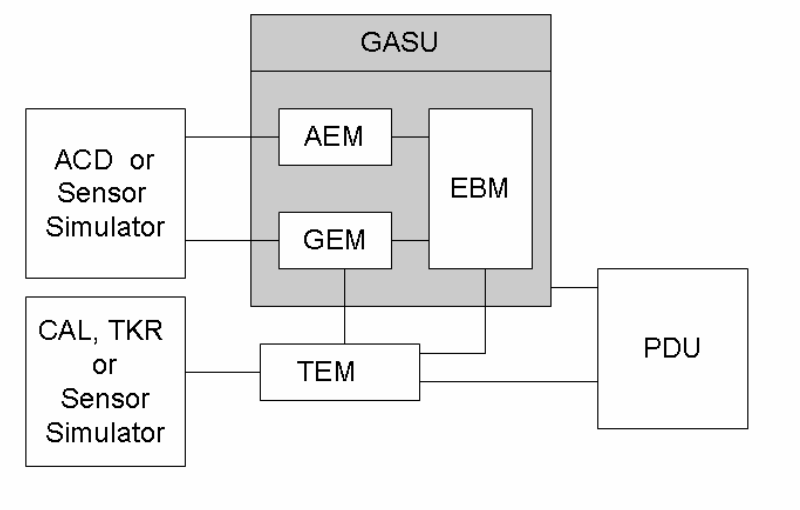


Figure 2: Principal LAT Components (Block Diagram)

NOTE: Real detectors (ACD, TKR, CAL) can be replaced by simulated input that mimics the behavior of the physical detectors beginning at the cables that readout the detectors. Although the Front End Electronics (FEE) are not simulated, a pattern can be created to generate events.

1.2. Overview of Data Taking During LAT Integration

Data taking with cosmic ray muons will occur with 1, 2, 4, 6, 8, 10, 12, 14 and 16 Flight Modules (FMs) installed in the LAT grid. The first position filled is position #0. The second position filled is #4. 15 hours of cosmic ray data taking (plus one hour with zero suppression OFF) occurs every time towers are added to the LAT. 16 hours of data taking with Van de Graaff photons occurs for tower A. Please refer to LAT-MD-00575 for detailed information on data taking during integration. Figure 3 shows the tower positions filled in each data taking configuration. **Note that shaded squares indicate a tower installed in the grid**.

For each hardware configuration there will be a baseline cosmic ray data-taking run for which the hardware is configured with nominal settings (please refer to the Nominal Register Settings in section 5) for ground analysis for the integrated hardware (towers).

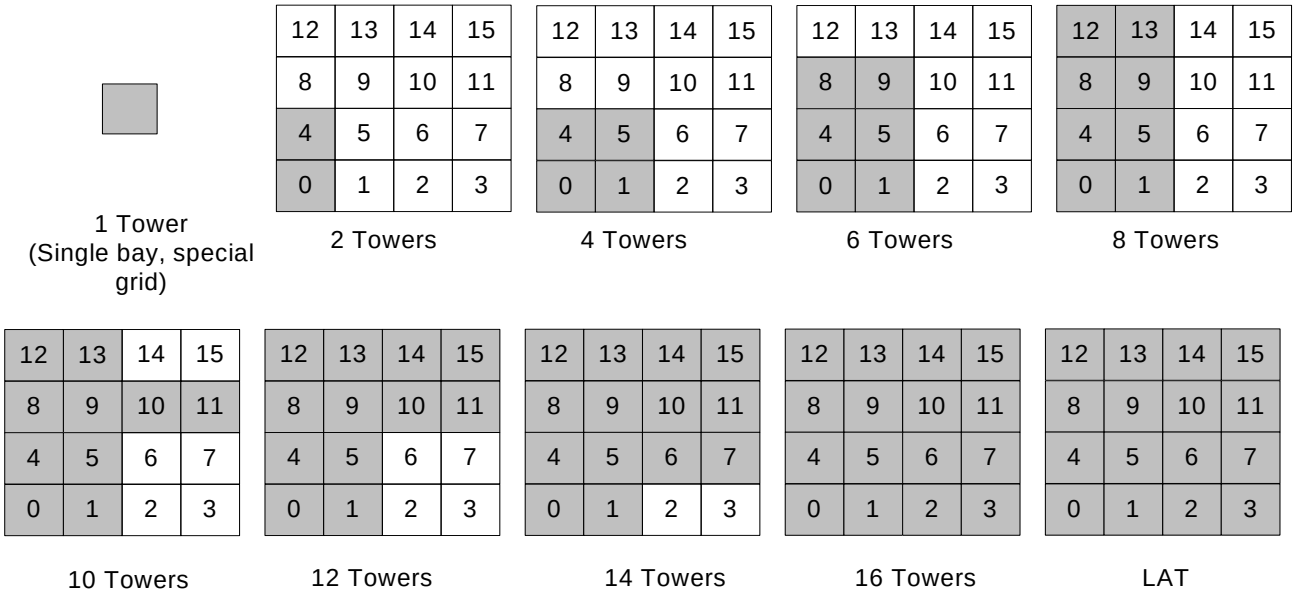


Figure 3: Tower Placement for Cosmic Ray Data Taking

Monte Carlo simulations for Flight Modules will be performed for 1, 2, and 8 towers, and the fully integrated LAT grid, as shown in Figure 4.

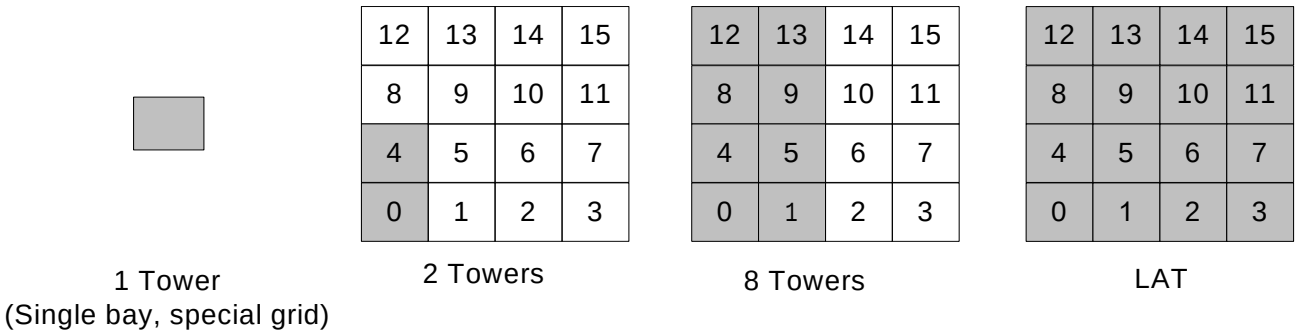


Figure 4: Grid Tower Positions for Monte Carlo Simulations

2. Geometry and Numbering Scheme

The global instrument coordinate system for the LAT is consistent with the coordinate system for the observatory. It is a right-handed coordinate system with the Y-axis parallel to the solar panel axis, the Z axis normal to the planes of the TKR, CAL, and Grid (i.e., parallel to the "bore sight"), and the X axis is mutually perpendicular to Y and Z. The positive Z-axis points from the CAL to the TKR. Particles entering the instrument at normal incidence are thus oriented along the -Z direction (please see Figure 5).

The point X=Y=0 is at the center of the Grid. The Z=0 plane is at the top face of the Grid, between the TKR and CAL units on the TKR side of the Grid. The TKR silicon plane closest to Z = 0 is at Z = +33 mm; the crystal plane closest to Z = 0 is at Z = -46 mm.

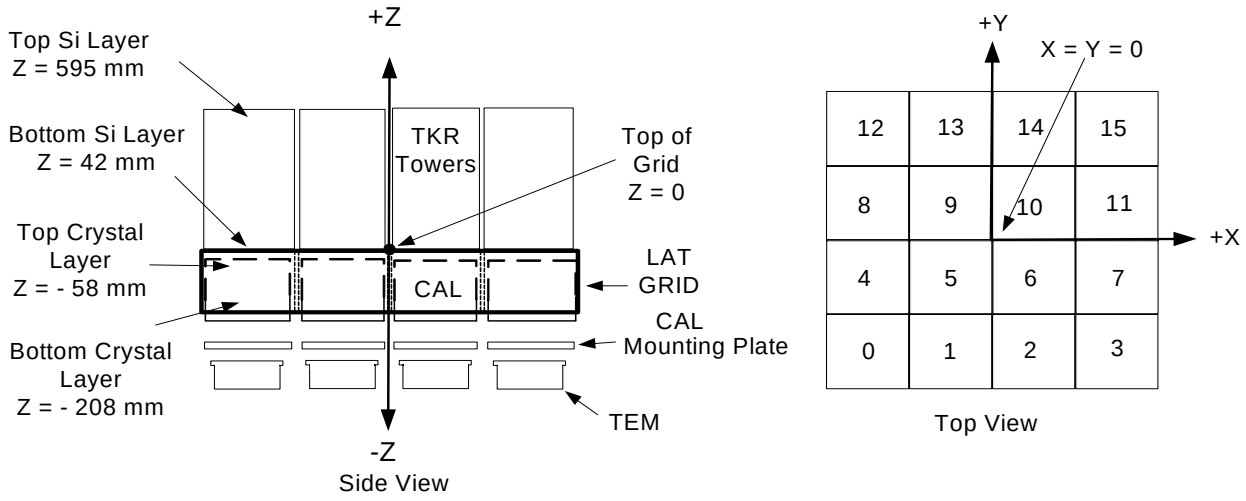


Figure 5: LAT Tower Numbering and Grid Coordinate System

2.1. ACD Geometry and Numbering Scheme

The active elements of the ACD consist of 89 tiles and 9 ribbons. (A figure will be added later.)

2.2. TKR Geometry and Numbering Scheme

The tracker is made up of 19 trays comprising 36 planes as shown in Figure 6. The 36 planes are mated into 18 layers.

The TKR trays are numbered in increasing order with increasing Z. Each tray has two active planes, except the top half of the top tray (+Z) and bottom half of the bottom tray.

A tray measures in either the X or Y direction, i.e., has an X or Y view. To get X and Y information, planes from two adjacent trays are electronically combined. Mated X and Y planes are about 2 mm apart. This arrangement leaves the top-most and bottom-most planes without a partner and without silicon detectors.

A tray with detector strips physically parallel to the Y axis is an X tray: it measures the X coordinate (has an X view) and is called an X tray. Most planes have an embedded tungsten foil for γ conversion: The top 12 X and

Y pairs have a thin foil (3% of X_0), the next four have a thick foil (18% of X_0), and the bottom two X and Y pairs have no tungsten.

The active region of each TKR plane is comprised of 16 square Silicon Strip Detectors (SSDs - please see Figure 7). Each SSD has 384 conducting strips. Four SSDs are end-joined to make a ladder with the four SSDs in a given ladder joined mechanically and electrically to make 384 long strips. Four ladders per plane laid side-by-side make up a total of 1536 strips per plane. Each plane is about 360 mm by 360 mm in area.

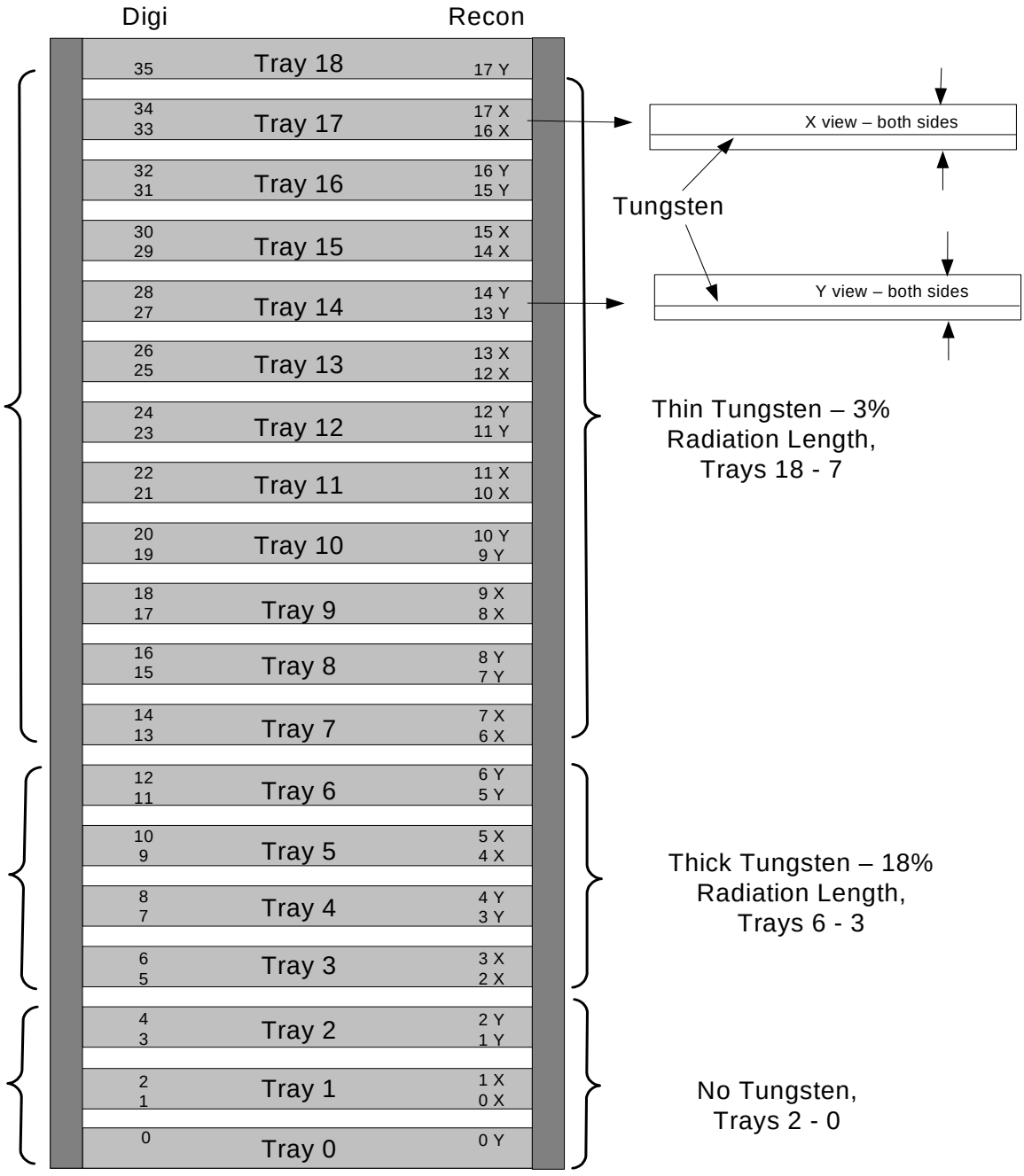


Figure 6: TKR Tower Numbering Scheme.

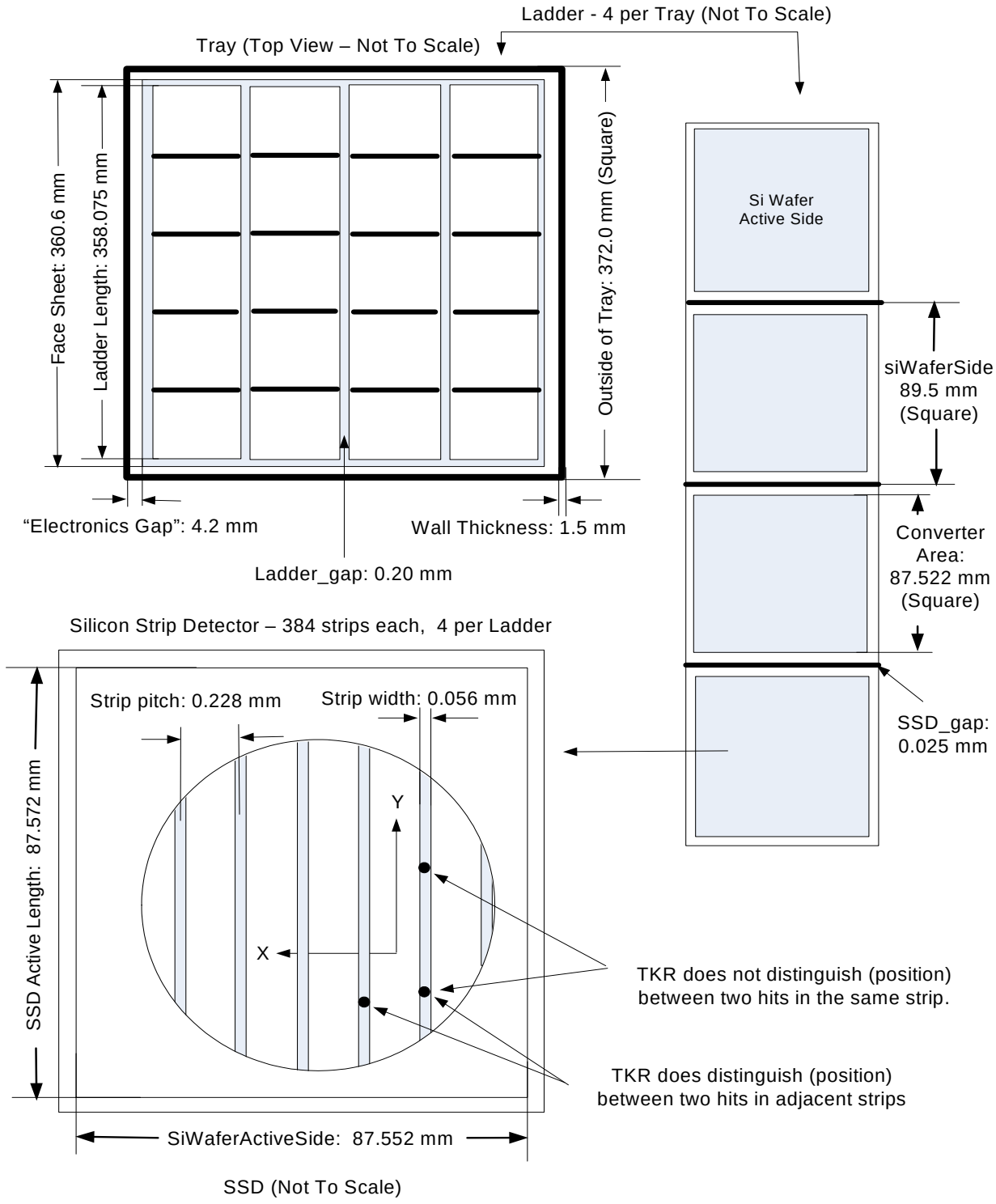


Figure 7: TKR Plane Physical Details (X-View)

2.2.1. CAL Geometry and Numbering Scheme

Each CAL module is made up of 96 crystals oriented in a hodoscopic configuration of 8 layers of 12 crystals each. In contrast to a TKR plane, a CAL crystal makes its coordinate measurement along its principal axis: an X crystal has its principal axis along the X direction, as shown in Figure 8.

Each crystal has two PIN diodes at each end for reading out the signal. Each PIN diode (at either end) reads out for either the low or high energy measurement. The low energy PIN has an area four times greater than the high energy PIN.

The CAL layers are numbered from 0 – 7 in increasing order with decreasing Z. The CAL layers closest to the TKR is plane 0. CAL layers 0 has X crystals; CAL layers 7 has Y crystals. Each CAL crystal is read from each end, and each crystal end is either plus or minus: the end with the larger value of the coordinate is the “plus” end and the end with the smaller value of the coordinate is the “minus.”

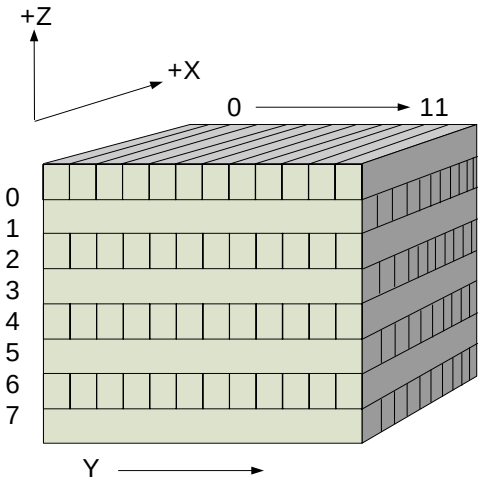


Figure 8: CAL Crystal Layer Numbering and Orientation

Figure 10 shows an accurate representation of a CAL module.

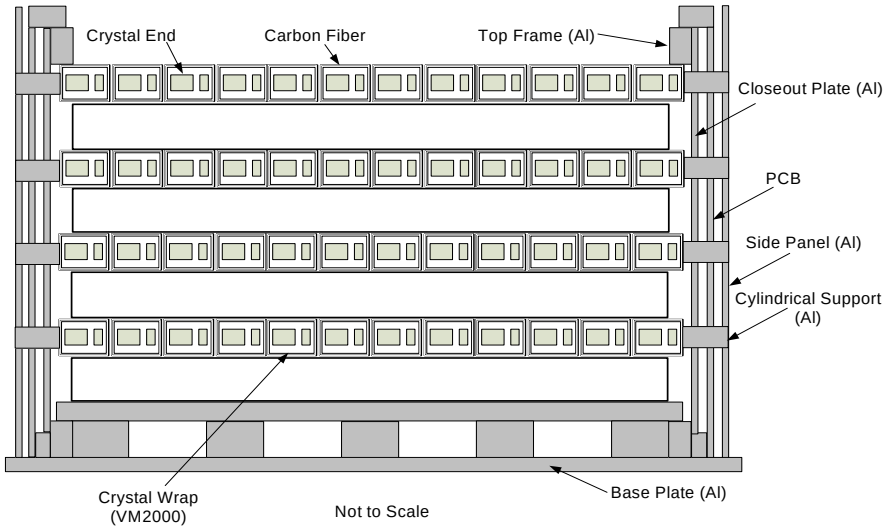


Figure 9: CAL Module Cross Section

Figure 10 shows a close-up view of the displacement of CAL crystal ends of two adjacent CAL modules. It is important to note that crystal ends that face each other are at a different spacing than the closest crystals in adjacent modules that are parallel to each other.

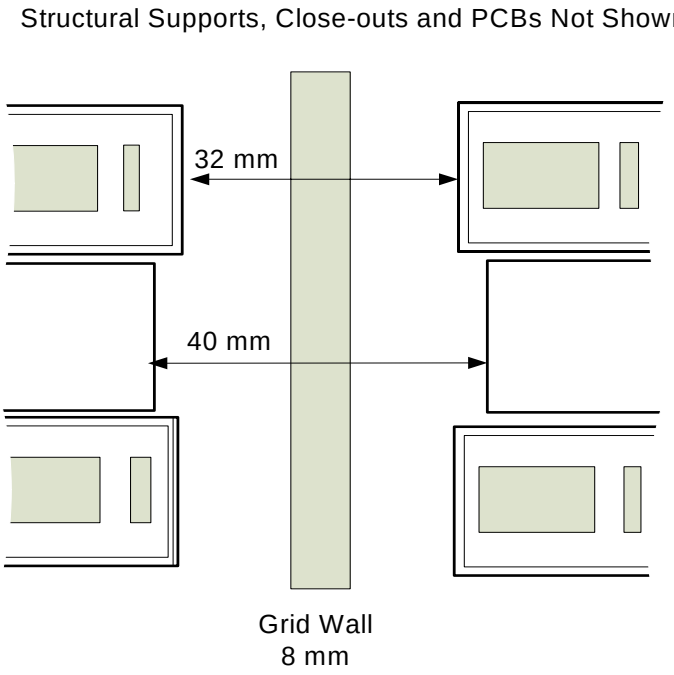


Figure 10: Zoom of Region between Two Adjacent CAL Modules (3 layers shown)

The CAL crystal profile is shown in Figure 11 along with the dimensions of a CAL crystal, including its carbon fiber enclosure.

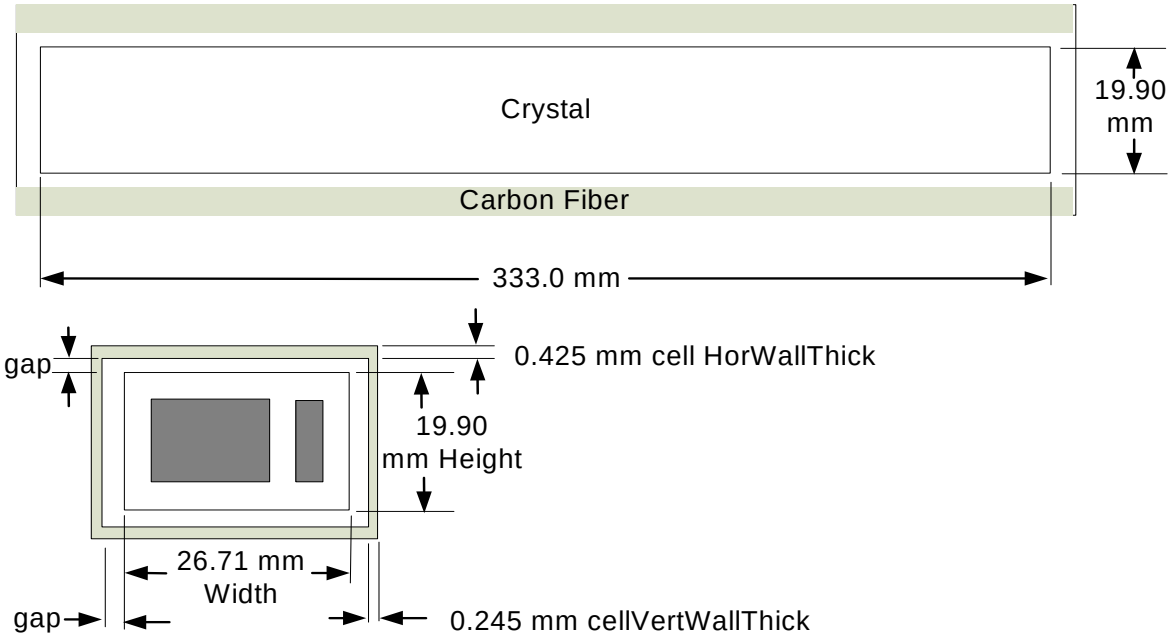


Figure 11: CAL Crystal Dimensions

3. Readout Sequence

Table 1 lists the number of readout channels (active elements) for the ACD, TKR and CAL in a 1, 2, 4, 8, and the full LAT configuration. Note that the ACD front-end PCBs actually have 216 channels, but because each tile is read by 2 PMTs that are assembled with a logical OR, the number of tiles that can be read out is actually 108. With a total number of 97 tiles and ribbons, some channels are not used.

Table 1: Detector Readout Channels

	ACD		TKR	CAL
	Tiles/Channels	**Ribbons/Channels**	**Planes/ Channels**	**Crystals/ Channels**
1 Tower			36 / 55,296	96 / 384
2 Tower			72 / 110,592	192 / 768
4 Tower			144 / 221,184	384 / 1536
8 Tower			288 / 442,368	768 / 3072
LAT	89/178	8/16	576 / 884,736	1536 / 6144

3.1. ACD Readout Sequence

To be written.

3.2. TKR Readout Sequence

Data from each silicon plane is read out by 24 GTFE ASICs located in a Multi-Chip-Module (MCM), controlled by 2 GLAST Tracker Readout Controllers (GTRC). There are 2 (GTRC 0 and GTRC 1) per plane or 4 per tray, except trays 0 and 18 (please see Figure 19). The two GTRCs are situated at the edge of the plane. GTRC 0 (RC0) is defined as being closest to where strip 0 is located. RC1 is defined as where strip 1535 is located. The default mode is to read from both ends. The readouts of a TKR are carried through eight cables (please see Figure 12).

If any shaper-out signal of a channel in a GTFE chip is over threshold, a trigger request (TREQ) signal is issued and transferred to the TEM, which then checks the trigger status. If a trigger condition (3-in-a-row) is satisfied, the TEM sends the trigger request acknowledge (TACK) signal to all planes to latch hit strip data into GTFE event buffers. Each GTFE has 4 event buffers. **Note that it is not the TREQ but the TACK signal that starts the Time over Threshold (ToT) counter in the GTRC**.

The TEM sends the READ-OUT command and transfers event data from GTFE event buffers to GTRC event buffers. A GTRC event buffer is limited to 64 hit-strips. The GTRC has 2 buffers. The TEM sends the TOKEN signal and transfers event data from the GTRC event buffers to the TEM one plane at a time. The GTRC waits to send data until the process of the READ-OUT command finishes, and the ToT counter terminates. The ToT counter saturates at 1000 clock cycles (= 50 μs). In a case where the ToT counter overflows, the GTRC will start to send data at the overflow point (1000 clock cycles).

3.2.1. Mapping across TKR Physical and Electronic Space

The TKR mapping scheme is shown in Table 2. This table maps the TKR physical information in LDF, digi and recon files. Note that GTRC value is an address. These numbers are unique taken in combination with the cable controller. Figure 12 shows the four faces of the TKR. **A typical user does not need to know the information in electronics space.** This table is intended to serve as a reference for hardware-oriented people. **Before using the Electronics Space information, always verify that it is the latest information in the TEM manual.**

Table 2: TKR Mapping between Physical and Electronics Space. Note that "X" or "Y" Means Measured Coordinate, T= Top Side of Tray, B=Bottom Side of Tray

Physical Space (data analysis)				Electronics Space (command the instrument)	
Tray #	Digi file	Recon file		LDF file	
	Plane	bi-Layer	View	GTCC (Cable)	GTRC
18/B	35	17	Y	4,5	8
17/T	34	17	X	6,7	8
17/B	33	16	X	2,3	8
16/T	32	16	Y	0,1	8
16/B	31	15	Y	4,5	7
15/T	30	15	X	6,7	7
15/B	29	14	X	2,3	7
14/T	28	14	Y	0,1	7
14/B	27	13	Y	4,5	6
13/T	26	13	X	6,7	6
13/B	25	12	X	2,3	6
12/T	24	12	Y	0,1	6
12/B	23	11	Y	4,5	5
11/T	22	11	X	6,7	5
11/B	21	10	X	2,3	5
10/T	20	10	Y	0,1	5
10/B	19	9	Y	4,5	4
9/T	18	9	X	6,7	4
9/B	17	8	X	2,3	4
8/T	16	8	Y	0,1	4
8/B	15	7	Y	4,5	3
7/T	14	7	X	6,7	3
7/B	13	6	X	2,3	3
6/T	12	6	Y	0,1	3
6/B	11	5	Y	4,5	2
5/T	10	5	X	6,7	2
5/B	9	4	X	2,3	2
4/T	8	4	Y	0,1	2
4/B	7	3	Y	4,5	1
3/T	6	3	X	6,7	1
3/B	5	2	X	2,3	1
2/T	4	2	Y	0,1	1
2/B	3	1	Y	4,5	0
1/T	2	1	X	6,7	0
1/B	1	0	X	2,3	0
0/T	0	0	Y	0,1	0

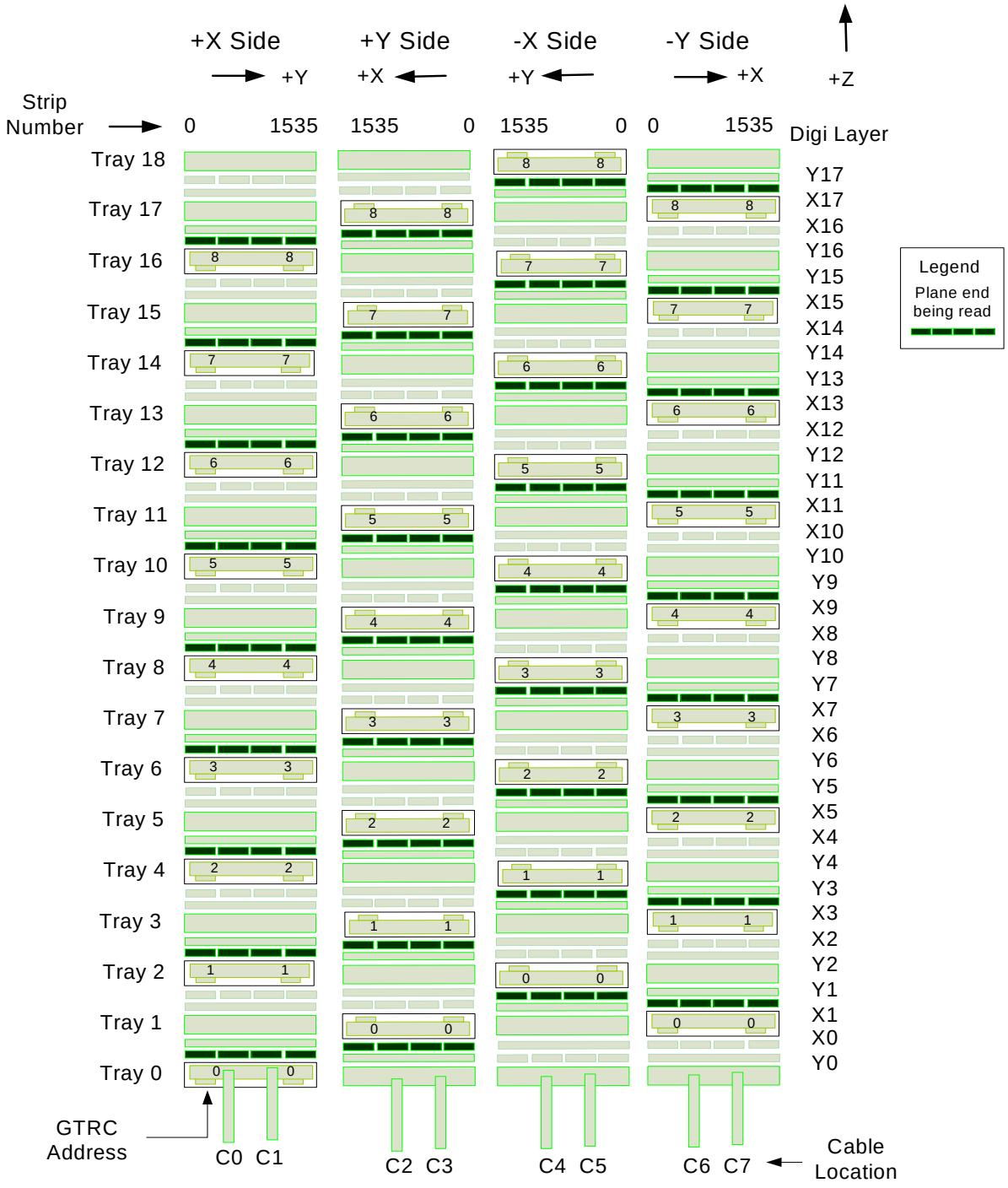


Figure 12: The Four Sides of the TKR Tower with Cables. "X" or "Y" Means Measured Coordinate.

3.3. CAL Readout Sequence

The CAL crystals are normally read from both ends through a total of four cables – each crystal is read out by two cables, one + and one -. Each crystal end has two PIN diodes, one large and one small, for low and high energy, respectively. Each crystal end (left and right, or + and -) has its own FEE pre-amplifier electronics assembly for a total of 192. Both low and high energy signals go through a pre amp and shaper then a Track and Hold gain multiplier and into an analog multiplexer and finally to the Analog to Digital Converter (ADC).

Each row of crystals has a GCRC for each end for a total of 16. (There are 8 rows and each row is read out at both ends.) The 16 GCRCs feed four cables (and four GCCCs). The cables carry +X, -X, +Y and -Y signals to the GCCCs. The two X GCCCs combine +X and -X information to produce X0, X1, X2, X3 signals; the Y GCCCs do the same to produce Y0, Y1, Y2, and Y3. A simplified FEE schematic diagram is shown in Figure 13. The calibration charge injection signal is fed to the front end of these pre amps.

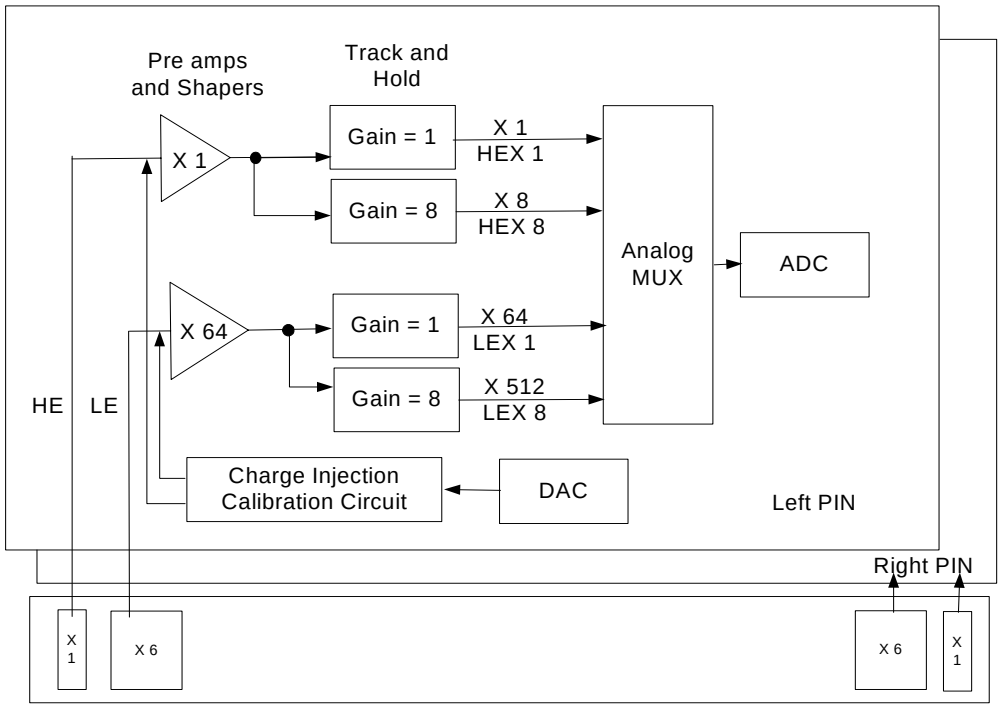


Figure 13: CAL FEE Simplified Schematic Diagram

Table 3 shows the gain stages.

Table 3: CAL FEE Signal Gain Characteristics

Channel	Diode Discrimination	Pre Amp Gain	Track and Hold Gain	Signal Out of Track and Hold	Relative Gain
Low Energy	X 6	X 64	X 1	LEX1	64
			X 8	LEX8	512
High Energy	X 1	X 1	X 1	HEX1	1
			X 8	HEX8	8

Figure 14 shows how the energy ranges overlap. During cosmic ray data taking on the ground most of the events fall within the low range diodes.

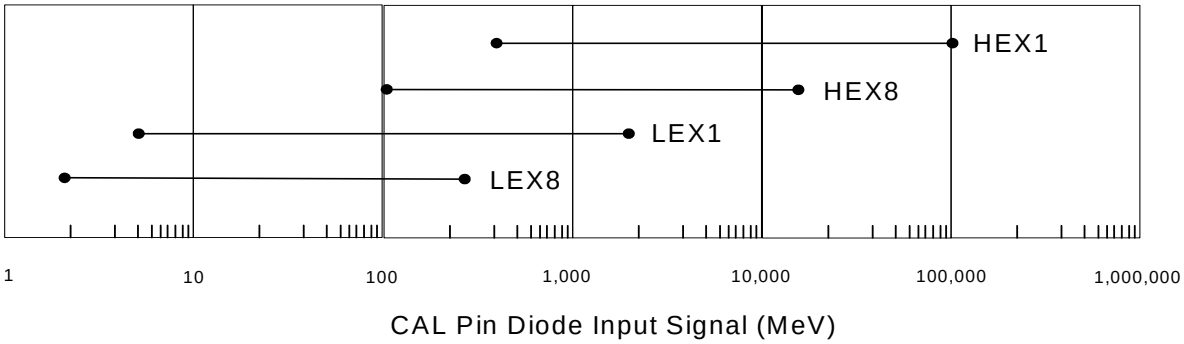


Figure 14: CAL Channel Signal Range Energy Overlap

3.3.1. Mapping across CAL Physical and Electronic Space

Table 4 maps the locations of layers and crystal ends between the electronics space and the physical space. **A typical user does not need to know the information in electronics space.** This table is intended to serve as a reference for hardware-oriented people. **Before using the Electronics Space information, always verify that it is the latest information in the TEM manual.**

Table 4: CAL Mapping between Physical and Electronics Space

Physical Space (Used for data analysis)			**Electronics Space (Used to command the instrument)**	
Layer # / Layer Type	**Digi File Layer**	**Recon File Layer**	**LDF File**	
			GCCC (Cable)	**GCRC**
0 / X	0	0	0,2	0
1 / Y	1	1	1,3	0
2 / X	2	2	0,2	1
3 / Y	3	3	1,3	1
4 / X	4	4	0,2	2
5 / Y	5	5	1,3	2
6 / X	6	6	0,2	3
7 / Y	7	7	1,3	3

The CAL readout cables and the associated GCCC are shown in Figure 15.

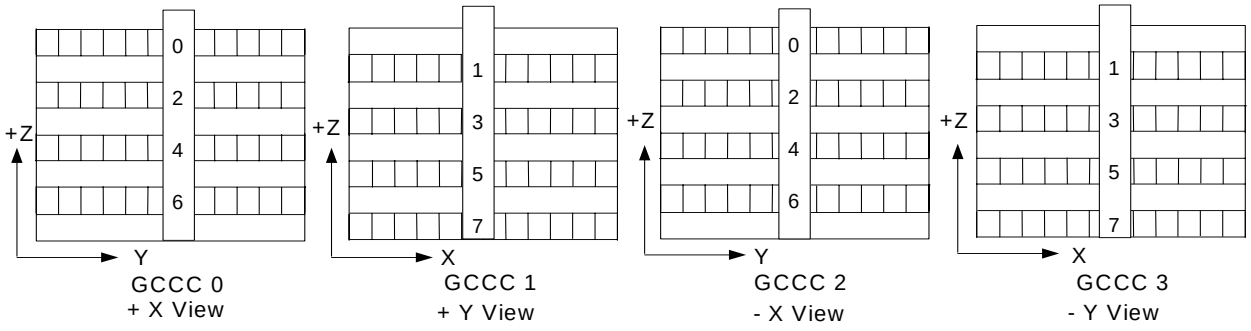


Figure 15: The Four Sides of the CAL Module with Cables

4. Global Trigger and Dead Time

The Trigger inputs from the ACD, CAL and TKR are processed by the GEM. The GEM decides whether to read out an event, or not, based on all inputs received. Therefore trigger primitives can be issued but may lead to no data latched if the GEM decides that all necessary conditions have not been met.

Any of the three detectors (ACD, CAL and TKR) can issue a trigger request (TREQ) but data is only latched from the detector buffers if the GEM logic is satisfied that a trigger acknowledge (TACK) is warranted.

The ACD signals are usually used as a veto for charged particles. However, the CNO signal can be used to trigger on heavy nuclei (mostly used for calibrations). During ground testing we can only test the CNO signal through charge injection. Another useful concept one has to keep in mind is that Regions Of Interest (ROI) can be defined using the ACD tiles. So a number of tiles can be logically grouped for trigger/veto purposes.

The TKR trigger logic requires at least one hit above a predetermined threshold in three consecutive XY planes (six planes).

The CAL trigger logic requires at least one hit above a predetermined threshold in any of the crystals. One can have a low energy trigger and a high energy trigger. For ground testing with cosmic rays the nominal CAL low-energy trigger is already too high and one must lower the discriminator thresholds or use the TKR trigger, instead.

During ground testing there will be a pattern generator (software) that will produce several trigger rates from a few Hz to tens of kHz. These solicited triggers will be overlaid with the nominal trigger conditions (e.g. TKR trigger) to study the behavior of the trigger and data flow system.

To trigger on a set of trigger inputs coming from different detectors, they must all fall within the same time coincidence window, but the system must not be busy (already reading an event). Note that during ground testing, in order to cope with rates greater than 1.5 kHz, one may have to prescale (discard) events. **Note that an otherwise "triggerable" event may not be latched because it was prescaled away, or because the instrument was busy.** Trigger information the GEM reports:

- Number of triggered events not passing the prescalers (Prescale count – 24 bits)
- Number of triggered events passing the prescalers, but lost due to the LAT being busy (Discarded counts – 24 bits)
- Number of triggered events read out (Sent count – 16 bits)

For the TKR, the hit threshold is also the trigger threshold. The threshold is that six consecutive planes must be fired. Nominal trigger rate on the ground (no ACD) is roughly 25 Hz (TBR) for each TKR tower for cosmic ray analysis.

Trigger studies are performed as illustrated in Figure 16. Actual tracker trigger primitives are received by the TEM, which makes a trigger request, and then by the GEM, which evaluates the request and either does, or doesn't, issue a trigger acknowledge. Trigger request information does not include which strip was fired (and initiated the trigger request). Therefore, it is useful to compare real trigger requests with simulated trigger requests.

When a tracker requests a trigger, the possibility exists that the charge will not be held when the data is latched. This should be investigated during timing studies.

Without Flight Software (FSW) there are possible timing problems, such as difficulty in relating GEM time counters to the Online 60Hz and 20 MHz event time stamps. The 20 MHz time stamp is applied when the event is moved from the Event Builder, and this time may increase as events queue up. Above 300 Hz the GEM Delta event time is usable. It is the time between event (n-1) and event n. It is a 16-bit counter that saturates at 3.2 ms.

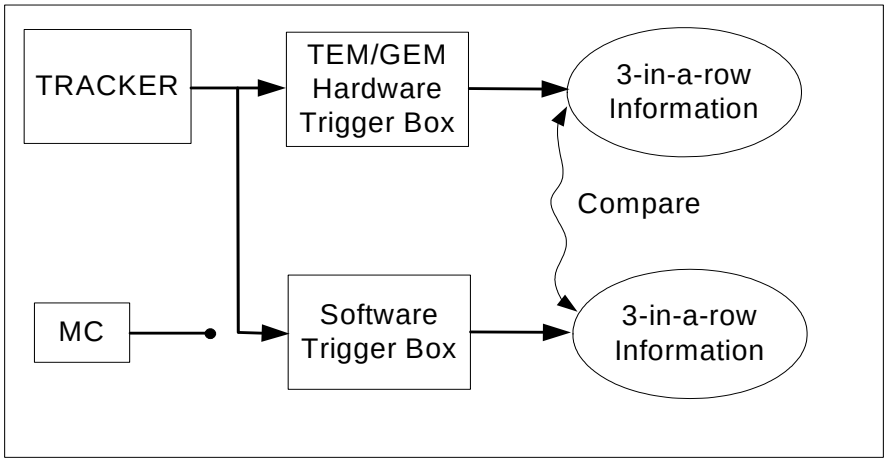


Figure 16: Trigger Studies of Real Triggers vs. MC Simulations

4.1. Time Delays

All three subsystems have preamps that put out shaped pulses that peak at different times after the entrance time (t_0) for the particle into the LAT.

Any one of the three detectors can cause the GEM to issue a TACK which latches the buffered data of all three detectors regardless of whether or not they issued a trigger request. The purpose of the time delays is to ensure that the trigger window is open at the correct time to receive data from all the detectors at the peak of the input pulses for a given detector. Table 5 shows the different delays for the ACD, CAL and TKR. The table is for the entire ACD but just one of the 16 tower modules.

Table 5: Number of Timing Delay Registers

Detector	**Delays on GEM Input**		**Delays on GEM Output**	
ACD	12 TREQ Delays		12 TACK Delays	
CAL High	4 TREQ Cable Delays	1 TREQ Delay (OR of 4 inputs)	1 TACK Delay (applied to all 4 cables)	4 TACK Cable Delays
CAL Low		1 TREQ Delay (OR of 4 inputs)		
TKR	8 TREQ Cable Delays	1 TREQ Delay (OR of 8 inputs)	1 TACK Delay (applied to all 8 cables)	8 TACK Cable Delays

Figure 17 shows the various time delay registers that are available at the input to the GEM. CAL low and CAL high come in on the same four cables, each with a cable delay. The two CAL high signals are OR'd as are the two CAL low signals with each line having a TREQ delay as input to the GEM. The TKR signals come in on eight cables, each with a delay register. The eight signals are OR'd into one line which has a delay register before input into the GEM. The ACD signals come in through 12 lines, each with a delay in the GEM input.

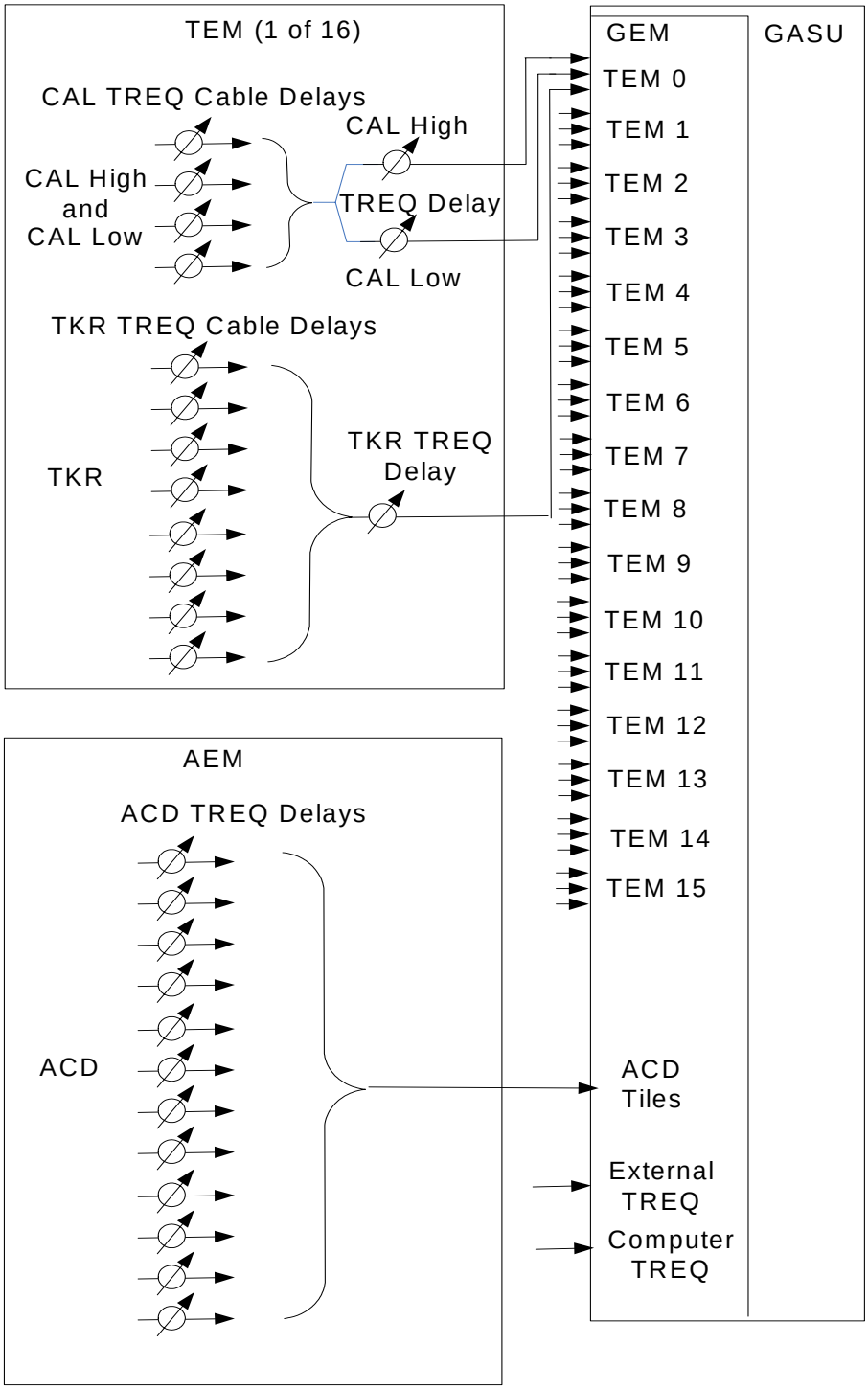


Figure 17: Conceptual Trigger Delay Adjustments Diagram (GEM Inputs)

The GASU output (please see Figure 18) has an adjustable Trigger Window Width register that feeds all three detectors with a single signal line. For the CAL it passes through a TACK delay register before being split into four lines, each with a CAL TACK cable delay. Likewise, the GASU output signal passes through a TKR TACK delay before being split into eight lines, each with a TKR TACK cable delay. For the ACD the GASU output signal splits into 12 lines, each with an ACD TACK delay register.

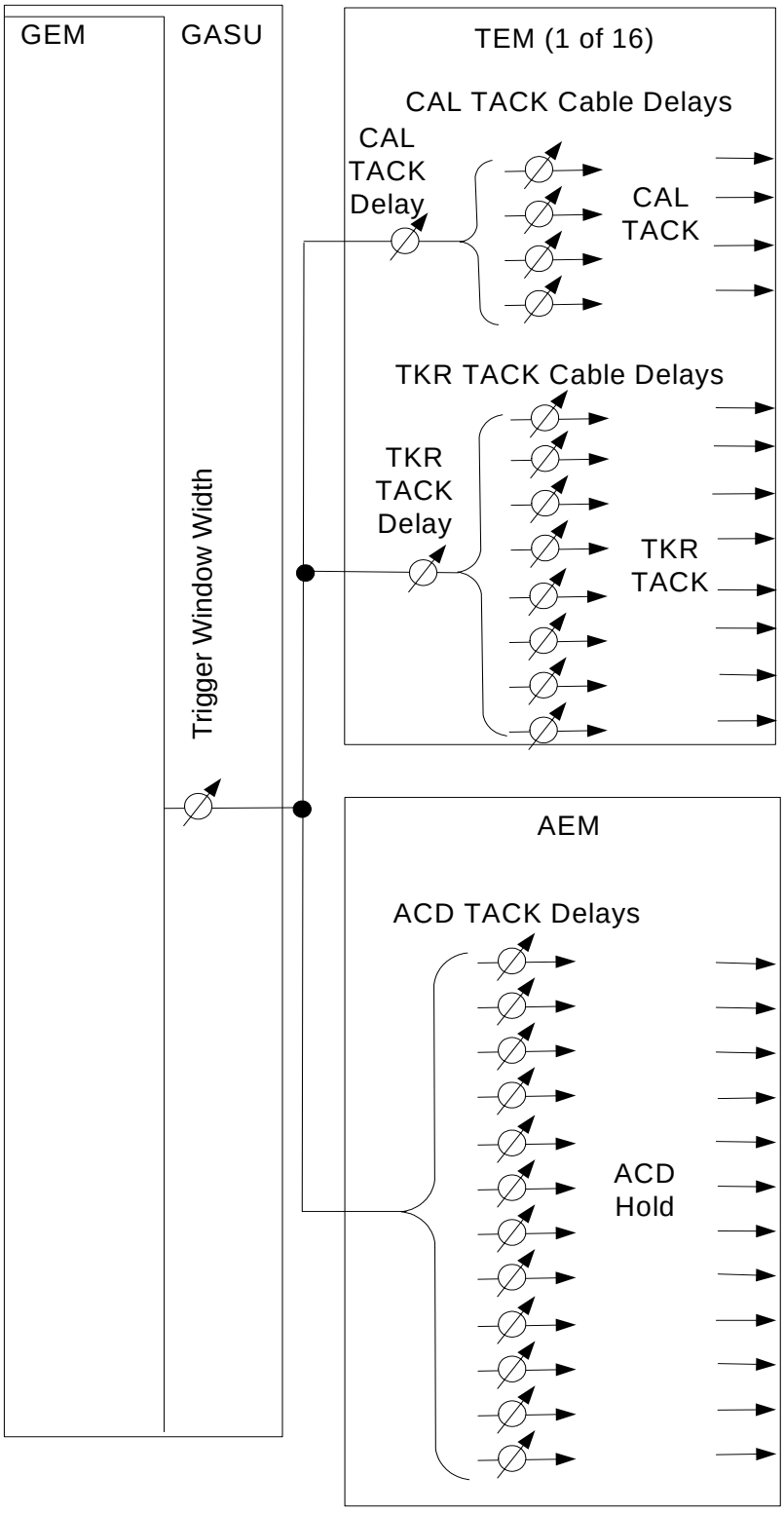


Figure 18: Conceptual Trigger Delay Adjustments Diagram (GEM Outputs)

4.2. Dead Time

Dead time will be monitored with the Online System and calculated with Offline tests. The dead time is always measured on an event-by-event basis for the entire detector. **If information is needed for dead time for individual systems, e.g., CAL/TKR/ACD, we will need to produce a special data taking run with only one detector enabled.**

When zero suppression is turned OFF, dead time increases considerably. For example, the CAL, which dominates the dead time, is expected to be at around 26 μs for flight configuration and about 600 μs with zero suppression OFF.

4.3. Live Time

Live Time is 1/ Dead Time.

Every time a cosmic ray or gamma ray interacts in the LAT, i.e., causes the LAT to trigger, further data taking is disabled until the data from the event are read out. During the readout, the LAT is effectively 'dead' as a detector. The dead time per event is small, probably about 20 microseconds, but the LAT will trigger several thousand times per second on cosmic rays, so the fraction of the time that the LAT is dead will be on the order of 10%. The rate of triggers on cosmic rays will vary with orbital position. Also, during solar flares or even possibly during extremely bright gamma-ray bursts, the dead time fraction could become close to 1. The reason we care about dead time is so that we can convert the rates of detections of gamma rays from a given celestial sources into actual fluxes (numbers of photons per unit area per unit time). In terms of optical astronomy, this is roughly equivalent to the difference between seeing stars and measuring their magnitudes. Keeping track of live time is essential for getting the brightness correct.

5. Nominal Register Settings

There are hundreds of registers in the LAT. Here we discuss only a few registers that one need be aware of for data analysis.

5.1. ACD Nominal Register Settings

To be written.

5.1.1. ACD Veto (hit) Threshold Discriminator

To be written.

5.1.2. ACD Zero-Suppression Threshold

To be written.

5.1.3. ACD Time Delays

The ACD has 12 ACD TREQ delay registers feeding into the GEM. There are also 12 ACD TACK delay registers applied to the output of the GEM for ACD hold. Table 6 lists the nominal settings for the ACD delays. Until test are performed assume that all 12 delays for the input or output are equal.

Table 6: ACD Delay Register Nominal Settings

Register	Setting
12 TREQ Delays	To be written
12 TACK Delays	To be written

5.1.4. ACD Known Features

To be written.

5.2. TKR Nominal Register Settings

Nominal settings for the registers of interest are described here**.** The registers of interest are the GTFE registers MODE, DAC and MASK, and the GTRC registers for GTFE_CNT, SIZE, and TOT_EN and time delays.

5.2.1. TKR Hit Threshold Discriminator (DAC)

The GTFE threshold setting defines an energy value above which the preamplifier in each channel integrates the charge collected until the charge signal re-crosses the threshold as it drops. The time the signal remains over the threshold is the ToT. Please see Figure 20.

Each strip hit in a silicon plane contributes with a ToT value. A logical OR of all strips in the plane is used to determine the value of the ToT per plane. ToT can be used to crudely determine the amount of energy deposited on a TKR plane because its value is dominated by the strip with the highest energy deposited. Channel-to-channel variations exist and this is discussed further in the Calibrations Section, 6.2.

Each plane generates two ToT values because it can be read out by 2 GTRC chips (please see Figure 19). The default configuration is to read 12 GTFEs with each GTRC: 12 GTFE chips read out by GTRC0 and 12 GTFE chips read out by GTRC1. If a GTFE fails it can be by-passed and the split is modified from the usual

12/12. Every data analysis run includes a report that states what the GTRC split is, which is important for Timing and Trigger studies.

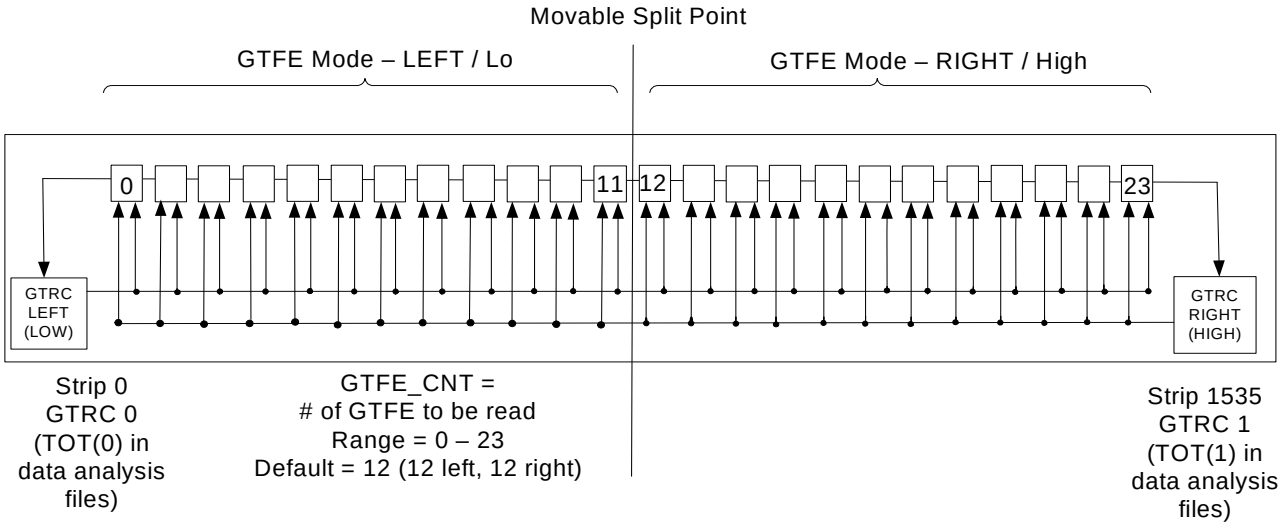


Figure 19: TKR FEE Readout Channel Splitting

The hit threshold can be set individually for each GTFE with a default value of 0.25 of that of a Minimum Ionizing Particle (MIP). The goal for the data taking with cosmic rays and VDG accelerator is to have a uniform set of thresholds across all readout chips. These are determined by measuring both the trigger capture efficiency and the noise rate as a function of the discriminator DAC settings.

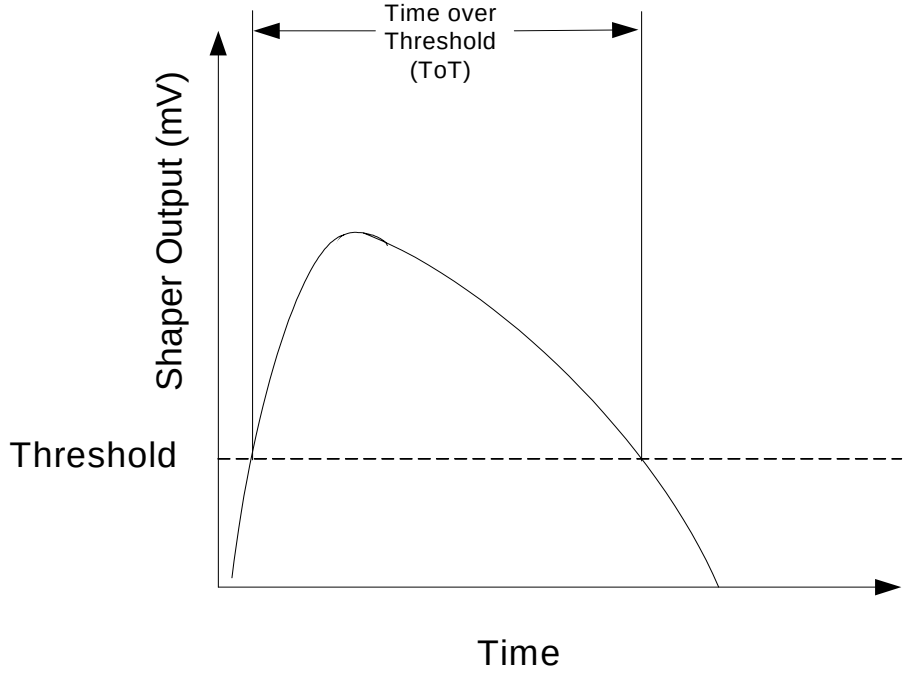


Figure 20: Shaper Output Time over Threshold

5.2.2. Some Relevant TKR GTFE and GTRC Registers

The GTFE and GTRC registers of interest are shown in Table 7.

Table 7: TKR GTFE and GTRC Registers

	Register	Type	Selects
GTFE (Please refer to LAT-SS-00169 for further details.)	Mode	2-bit	Left or Right mode (Is the GTFE read out by the left or right GTRC)
			Deaf mode ON / OFF (Is the GTFE deaf to the GTFE beside it?)
	DAC	7-bit + 7-bit	THR_DAC: (0-2 MIPS) Sets the threshold level of the comparator. Range: about 0.05 -10 fC
			CAL_DAC: (0-8 MIPS) Sets pulse height of calibration strobe signal. Range: about 0.072-43 fC
	Mask	64-bit	Channel mask Trigger mask Calibration mask
GTRC (Please refer to LAT-SS-00170 for further details.)	GTRC_CNT		Sets the number of GTFEs to read by defining the LEFT/RIGHT split point. Range: 0-24. The default is 12 LEFT and 12 RIGHT. Please see Figure 19.
	Size		Sets the maximum number of hits to get from the GTFEs. Range: 0-64. The default is 64. **NOTE: Max hits/plane: 128 can be read using both LEFT and RIGHT sides.**
	TOT_EN	1-bit	ENABLE TOT (1) or DISABLE TOT (0). The default is 1.

5.2.3. TKR Time Delays

Each TKR has a total of nine TREQ delays. Each TKR has a total of nine TACK delays. Table 8 lists the TKR delay register nominal settings. Until test are performed assume that the cable delays for an input or output are equal.

Table 8: TKR Delay Registers Nominal Settings

Register	# of Ticks (1 tick – 50 µs)	Time (µs)
TREQ (8 – 1 per cable)	0	
OR'd TREQ (1)	0	
TACK (1 – applied to all 8 cables)	0	
TACK (8 – 1 per cable)	0	

5.2.4. TKR Known Features

Some known features for the TKR electronics are shown in Table 9.

Table 9: TKR Electronics Known Features

Feature	Description
Limit of TOT Counter	The TOT counter saturates at 1000 count, corresponding to 50 µs. (c.f. 1 MIP ~ 10 µs.)
Limitation of Calibration-Strobe Signal in GTFE	The calibration strobe signal of GTFE used in charge-injection tests is a signal with a duration of 512 clock cycles = 25.6 µs. Thus, we cannot simulate TRIG signal longer than 25.6 µs with the internal calibration system.
TACK Too Late in a Small Signal	Small signal events with the pulse height very close to threshold will be missed at the TACK time, which causes the event with a trigger but no hit. The probability of such events was 10^{-5} in EM1 tower.
2 TACKs in One TREQ Signal	If multiple TACK signals are sent within one long trigger signal, TOT in the second readout event shows an illegal number (2044).

5.3. CAL Register Nominal Settings

CAL Nominal register settings are divided into the three categories of Gain, Triggering and Data Volume. These are shown in Table 10.

Table 10: CAL Registers for Gain, Triggering and Data Volume

	Register	Range	Comments
Gain	LE	8 programmable settings for a x3 gain-range.	One setting per CAL face (= 16 towers x 4 faces)
	HE	9 programmable settings, x3 in gain plus test gain for muons.	One setting per CAL face (= 16 towers x 4 faces)
	Time to Peak	Adjustable so that track-and-hold occurs at the peak of the shaped signal.	One setting per tower with different settings for muons and charge injection.
Triggering	FLE	Threshold adjustable for every CAL crystal end (1536/crystal x 2 faces) with 64 fine and 64 coarse programmable DAC settings that cover about 200 MeV	Fast Low Energy (FLE) and Fast High Energy (FHE) have a timing constant of .5 µs, important for timing and analysis.
	FHE	Threshold is adjustable for every CAL crystal end (1536/LAT x 2 faces) with 64 fine and 64 coarse programmable DAC settings that cover about 25 GeV.	(For reference, the Slow Low Energy shaper has a timing constant of about 3.5 µs.)
Data Volume	Range Read	Range Readout can be either commanded or run in Auto-range. The range modes are one range or four ranges.	In Auto-range, the appropriate energy channel is selected and read out.

Table 11 shows the nominal register settings for the different modes of data taking, of which there are two: flight and ground.

Flight mode tests flight operations with a best guess at on-orbit configuration. Ground mode tests high gain in the HE channels to see muons and VDG photons, and with thresholds low enough for CAL to trigger on muons and VDG photons.

Table 11: CAL Thresholds Nominal Settings

Mode	Test	Settings
Flight	Ground test of flight operations	TKR: trigger enabled FLE: ~ 100 MeV but disabled FHE: ~ 1 GeV enabled LE saturation: ~ 1.6 GeV HE saturation: ~ 100 GeV Auto Range: one range readout Zero-suppression: enabled LAC threshold ~ 2 MeV or below
Ground Calibrations	Muons visible in HE ranges. Muon runs to test stability.	Flight Trigger TKR: trigger enabled FLE: ~ 100 MeV but disabled FHE: ~ 1 GeV, enabled Muon Gain: LE saturation: ~1.6 GeV HE saturation: ~4 GeV Intermediate Data Volume: Auto-range, four-range readout Zero-suppression: enabled LAC threshold ~ 2 MeV or below
Ground	Muons visible in HE ranges. Ground test of CAL self-trigger.	CAL Trigger TKR trigger: disabled FLE: ~2 MeV and FHE ~ 1 GeV (trigger on FLE) FLE: ~ 100 MeV and FLE < 10 MeV (trigger on FHE) Auto-range, four-range readout Zero-suppression: enabled LAC threshold ~ 2 MeV or below

5.3.1. CAL Time Delays

Each CAL has a total of six TREQ delays. Each CAL has a total of five TACK delays. Table 12 lists the delay register nominal settings. Until tests are performed assume that the cable delays (on split signals) for an input or output are equal.

Table 12: CAL Delay Registers Nominal Settings

Register	# of Ticks (1 tick – 50 µs)	Time (µs)
TREQ (4 – 1 per cable)		
CAL Low TREQ (1)		
CAL High TREQ (1)		

TACK (1 – applied to all 4 cables)		
TACK (4 – 1 per cable)		

5.3.2. CAL Known Features

Table 13 below lists some of the known features of the CAL electronics.

Table 13: CAL Known Features

Feature	Description
Readout time can be long	In a case with 4-range, unsuppressed CAL readout of ~ 600 µs: Because of the TEM readout buffer logic, one of these events does indeed paralyze the entire system for ~ 600 us. FIFO has space for less than 2 of these events, and readout is paralyzed if space for less than 1 remains.
Solicited triggers with zero suppression enabled	Readout time is a function of the CAL data volume. Either set the LAC threshold low so that some pedestals sneak through, or inject charge in some specific channels, or CAL data will be null. Tests with high-rate, Poisson solicited triggers must be carefully posed.
CAL can retrigger	If CAL self-trigger is enabled with a low threshold and zero suppression is enabled, CAL may double-trigger because the trigger gets re-enabled before it settles. Retrigger does not occur with zero supp disabled (i.e. large CAL data volume) because TEM readout is slow enough that FLE has had time to settle.
CAL trigger biases energy	If the FLE fires (whether or not it's enabled) about 2 MeV gets added to LEX8 and LEX1 signals. Don't calibrate gain scale with FLE set low for CAL self-trigger on muons or VDG photons. There is a similar effect for FHE firing which adds ~ 20 MeV.
Pedestals for trigger delay	There is a large variation in the thresholds between channels.
Trigger jitter	CI trigger jitter needs to be cross-checked with muons.

6. Calibrations

Instrument calibrations consist of:

- Creation of response maps for all detectors;
- Determination of nominal instrumental settings for astrophysical science observations, and;
- Determination of energy scales.

The program is divided into electronic calibrations (using charge injection) and calibrations using cosmic rays (selected muons). These will have calibration trends characterized during the LAT integration. For details, please refer to LAT-MD-00575.

The user should be aware that data taking will occur with zero suppression ON and OFF at several stages of integration.

ACD, TKR and CAL electronic calibrations are performed using charge injection and with EGSE scripts and/or Flight Software. Whenever appropriate EGSE output calibration files will be used as input to the reconstruction code. Be aware that the trigger behavior may be different when triggering with cosmic rays and with charge injection. Data from charge injection will be available in digi format but this primer is not intended to guide general users to analyze those data.

Calibrations will be performed after particle data is taken using offline analysis of the L1 data converted into digitized data analysis files. Calibration data is then used as input to generate reconstructed data analysis files.

6.1. ACD Calibration

The ACD electronic calibration suite establishes the calibration tables for the following features of each GAFE. These calibration tables give the correspondence between relevant DAC settings and output ADC bin or energy, as appropriate.

Units of calibration tables can be converted to MeV in all gain settings. The ACD calibration will determine:

- Pedestals for all energy ranges in all gain settings. An estimate of the electronic noise can be derived from the pedestal width;
- FEE transfer function for all energy ranges, i.e., the integral non-linearity of the analog and digital chain for each energy range. The electronic gain of each energy range is given by the linear term of the correspondence between injected charge and output ADC bin;
- Calibration of the veto (hit) threshold discriminator DAC; and
- Calibration of the zero-suppression threshold DAC.

The ACD calibrations with cosmic rays determine pedestals and measure the muon peaks in the ACD tiles. Data for pedestal calibration shall be taken with ACD zero suppression OFF.

6.2. TKR Calibration

The TKR calibration will determine:

- The list of bad channels (open, dead, noisy);
- Calibration of the hit discriminator DAC;
- The GTFE will scan the hit thresholds for a fixed charge injection DAC (noise can be extracted from these measurements); and,

- The response of the time-over-threshold to injected charge up to saturation. The appropriate function will be used to fit the charge injection curve and extract the necessary constants that will be used for the SAS reconstruction.

The TKR muon calibrations of the ToT scale for a MIP are made at two levels: read out chip-level and strip-level. (This in turn provides the calibration of the charge injection scale, which is essential to adjust the threshold using the charge injection.) It is also part of verification of bad channels with cosmic rays, measurement of trigger and detection efficiencies and collection of necessary data for the hit resolution measurement.

NOTE: Although alignment procedures produce calibration "constants," these will be treated as a performance measure.

6.3. CAL Calibration

The CAL electronic calibration suite establishes the calibration tables for the following features of each GCFE. These calibration tables give the correspondence between relevant DAC setting and output ADC bin or energy, as appropriate. Also calibrated is light asymmetry (the ratio of signals from the two ends of one crystal). There are two basic types of calibration: Charge Injection and Cosmic Muons.

Units of calibration tables can be converted to MeV in all gain settings. The CAL calibration determine:

- Pedestals for all energy ranges in all gain settings. An estimate of the electronic noise can be derived from the pedestal width;
- FEE transfer function for all energy ranges, i.e., the integral non-linearity of the analog and digital chain for each energy range;
- Calibration of the low-energy discriminator (FLE) DAC;
- Calibration of the high-energy discriminator (FHE) DAC;
- Calibration of the zero-suppression threshold (LAC) DAC; and
- Calibration of the auto-ranging discriminator (ULD) DAC.

NOTE: The electronic gain of each energy range is given by the linear term of the correspondence between injected charge and output ADC bin.

The CAL muon calibration suite is primarily the calibration of the "optical gain" of each photodiode to establish the correspondence between ADC bin and energy deposited. From this calibration the following are achieved:

- Optimization of the time delay between trigger and peak hold to give maximal light yield for the ensemble of CDEs in a module;
- Verification of the calibration in energy units of the FLE and FHE tables generated in the electronic calibration;
- Fitting of the muon peak in each LE and HE photodiode in muon analysis gain setting. From the muon peak, a calibration table (correspondence between ADC values and energy) is created; and,
- Mapping of the light taper and light asymmetry in each CDE as a function of position.

There are two trigger types used: 1) CAL internally triggering ("self-triggering") on muons, and 2) with an ancillary detector generating external triggers for the CAL Tower Module. The CAL self-triggering is simpler and requires no additional hardware, but it results in a modestly biased energy calibration. By contrast, the externally triggered muons do not create a biased calibration, and therefore are used to generate the final energy calibration of each channel. During LAT integration the tracker trigger can be used by CAL to provide unbiased calibrations. An externally triggered system shall be available as a reference system.

7. Event Data

Monte Carlo "truth," raw and reconstructed data are held in Transient Data Storage (TDS). Data analysis files (Merit and SVAC) are produced from TDS. Please see Figure 21.

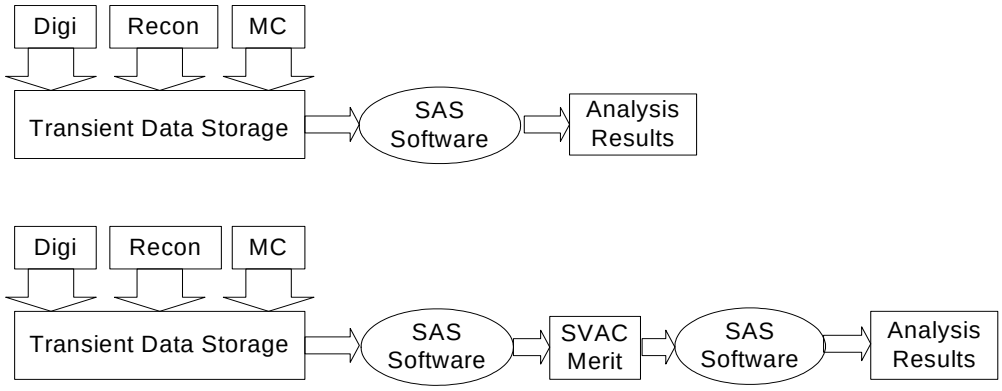


Figure 21: TDS Input and Output

7.1. Event Contributions

An event has several contributions: the TEM (AEM) carries the contributions from TKR and CAL (ACD) and corresponding trigger primitives while the GEM contains trigger and deadtime related information. All contributions are assembled in the Event Builder that lives inside the GASU.

7.1.1. AEM

To be written.

7.1.2. TEM

Each TEM receives detailed trigger primitive information through the cable controllers: eight GTCCs from the TKR (please refer to TKR Readout, section 3.2) and four from the CAL (please refer to CAL Readout, section 3.3). CAL and TKR trigger primitives come from each layer/plane end. Please refer to Table 14.

Table 14: CAL and TKR Trigger Primitive Data

CAL	TKR
CAL LE and HE trigger request for: • Each layer • Each end • A bit to tell whether a signal was above zero suppression	3-in-a-row trigger request information for: • Each plane • Each view (X and Y) • Each end (GTRC0 and GTRC1)

TEM trigger primitive data is present in: TDS, digi root files and SVAC ntuples. Each cable controller can transmit trigger primitives to the GEM – the presence or absence of data is indicated by a bit in the event summary. Each TEM can contribute up to12, 32-bit words – one word of 32-bits per plane.

7.1.3. GEM

The GEM receives the aggregate trigger information from all the TEMs as well as from the ACD. All event entries are sampled at window closing. The system clock is 20 MHz, i.e., one tick is 50 ns.

The GEM event contributions are shown in Table 15.

Table 15: GEM Event Contribution

Data	Description
TKR Vector	16 bits containing TKR trigger signals - One per tower
ACD ROI Vector	16 bits to define Regions of Interest. Format depends on whether used
CAL Low Energy Vector	16 bits containing CAL low energy trigger signals
CAL High Energy Vector	16 bits containing CAL high energy trigger signals
ACD CNO Vector	12 bits containing CNO trigger signals
Tile List	State of all the ACD tiles
Livetime	• 1/Deadtime • 25-bit counter (rolls over at 1.67 sec)
Prescale Count	• Number of triggered events not passing the prescaler • 24-bit counter (1 GHz)
Discarded Count	• Number of triggered events passing prescaler but lost to **LAT busy**. • 24-bit counter (1 GHz)
Sent Count	• Number of triggered events read out (TAMs sent by the GEM) • 16-bit counter (65 K)
Trigger time	• Free running counter incrementing at the system clock • Count from when it was reset to when the event was declared. • 25-bits (rolls over at 1.67 sec)

1-PPS time:	• Seconds:
	  • Number of seconds since the GEM was reset
	  • 7-bits (128 sec)
	• 1-PPS time:
	  • Time in 50ns ticks of the last arrived 1-PPS signal
	  • 25-bits (1.67 sec)

Delta event time	• Time from event (n-1) to event n • 16-bits (3 ms)

7.2. Data Analysis Files

The data files are:

LDF.FITS – binary format readable by online tools but not used for data analysis

digi.root, recon.root and mc.root – ROOT trees

Merit.root and SVAC.root. – ntuple files

A ROOT tree file stores a snapshot of the compiler internal data structures at the end of a successful compilation. It contains all the syntactic and semantic information for the compiled unit and all the units upon which it depends semantically. Trees are very efficient for storing the complex structure of the LAT event but retrieval of data from trees requires some basic knowledge of C++.

An ntuple is like a table where *X* variables from data collection are the columns, and each event is a row. The storage requirement is proportional to the number of columns in one event and can become significant for large event samples. Ntuples are flat files which are easy to access with minimal knowledge of ROOT.

The data in these files may be on different disks, or even move from disk to disk. The best way to find a run is to use the shift log:

http://www.slac.stanford.edu/cgi-wrap/eLog.pl/index

Click on a "SvacReport" and then navigate to the file you want to review.

Wherever the data are, the structure of a run directory will be the same: $(HEAD) represents the location of the run directory in following file descriptions shown in Table 16.

Table 16: Data Analysis Files Locations

UnCalibrated Data	Calibrated Data	Description
$(HEAD)/rawData/$(runID)/		LDF, configuration snapshots, schema, run report
$(HEAD)/rootData/$(runID)/grRoot		Digi, MC
$(HEAD)/rootData/$(runID)		Configuration report
$(HEAD)/rootData/$(runID)/digi_report		Report on contents of Digi file
	$(HEAD)/rootData/$(runID)/$(calib_ver)/	All that depends on calibration
	$(HEAD)/$(calib_ver)/grRoot	Recon & Merit
	$(HEAD)/$(calib_ver)/recon_report	Report on contents of recon (& digi) files
	$(HEAD)/$(calib_ver)/svacRoot	SVAC "tuple"

7.2.1. LDF.FITS

A binary file wrapped in an Online-provided FITS header. All event contributions are included and information is stored in electronics parameter space. For details please refer to the GEM (LAT-TD-01545) and TEM (LAT-TD-00605) manuals

It is important to realize that for data analysis, events **that have errors and cannot be written by Online are discarded**. If events are written but contents are corrupted a flag is set in the next step in the digi.root file. For details, please refer to the SAS workbook.

7.2.2. Digi.root

The digi.root file is a raw-data ROOT tree which contains the same data from LDF.FITS but in a representation that is better suited for SAS reconstruction code (physical space instead of electronics space).

For mapping between spaces see the mapping sections in the section on geometry. If the process of parsing information from LDF to digi generates “bad” events, these are not reconstructed and the flag BadEvt is set to 1 in digi.root.

7.2.3. Recon.root

The Recon.root file is a cooked ROOT tree file which contains reconstructed data using digi.root and calibration constants as input. During the initial phase of ground testing one may produce recon files without calibration, but in general, energy scales in recon files are usually calibrated.

7.2.4. MC.root

The MC.root file is a ROOT tree which contains the MC true information and is only available for simulated data. The MC.root file does not contain all events from MC.

7.2.5. Merit.root

The Merit.root file is a ROOT ntuple which contains high-level reconstruction data in about 240 variables in five classes: ACD, TKR, CAL, MC and Run. Scripting is available through ROOT in C++. Integration & Test provides Hippodraw as an additional visualization tool for data analysis, with scripting via Python.

7.2.6. SVAC.root

This is a ROOT file which contains most of the low level instrument variables (hits/plane, trigger primitives, GEM information) and some high level data which are stored in tuples plus fixed-sized arrays. Storage is less efficient than root Trees but access is as simple as from a flat file. Scripting is available through ROOT in C++. Integration & Test provides Hippodraw as an additional visualization tool for data analysis, with scripting via Python.

SVAC and Merit can be loaded into root at the same time and data display cuts can be applied in each one through the ROOT “friends” class.

7.2.7. Reports: Configuration and SVAC

A configuration report is available for every run. Currently, the file contains the CAL DAC thresholds and TKR split points, and is currently only available in HTML format.

The SVAC reports detail the contents of the recon and digi files, including text, tables, distributions and graphs. A sample can be seen at:

http://www.slac.stanford.edu/cgi-wrap/eLog.pl/index

7.3. Data Processing Steps

Raw data sets (LDF.FITS), derived from the hardware, are parsed to create another representation of the data in a format that is readable by the SAS reconstruction software (digi.root). Digi.root is processed with SAS calibration software to generate the calibration constants files. These are loaded into the primary (SAS) database which provides a format-independent interface to allow the reconstruction software to retrieve constants when needed. With these constants the SAS reconstruction software produces calibrated data files (recon.root). After processing with analysis software, recon.root is used to create the analysis files.

A separate process queries the SAS database to retrieve calibration constants and store them in a SVAC database whose design is optimized for trending.

In a parallel path using Monte Carlo simulations, the LDF.FITS file is replaced by simulated input from a model that contains a description of the detector geometry and physics processes relevant to the LAT. The entire analysis chain follows the recipe described in the previous paragraphs until final MC analysis files are produced.

Results from the hardware analysis files can then be compared to Monte Carlo simulation results to validate the MC simulations. Data files and reports described above will be generated using an automated data processing facility, hereafter referred to as the pipeline.

Figure 22 shows the data analysis flow.

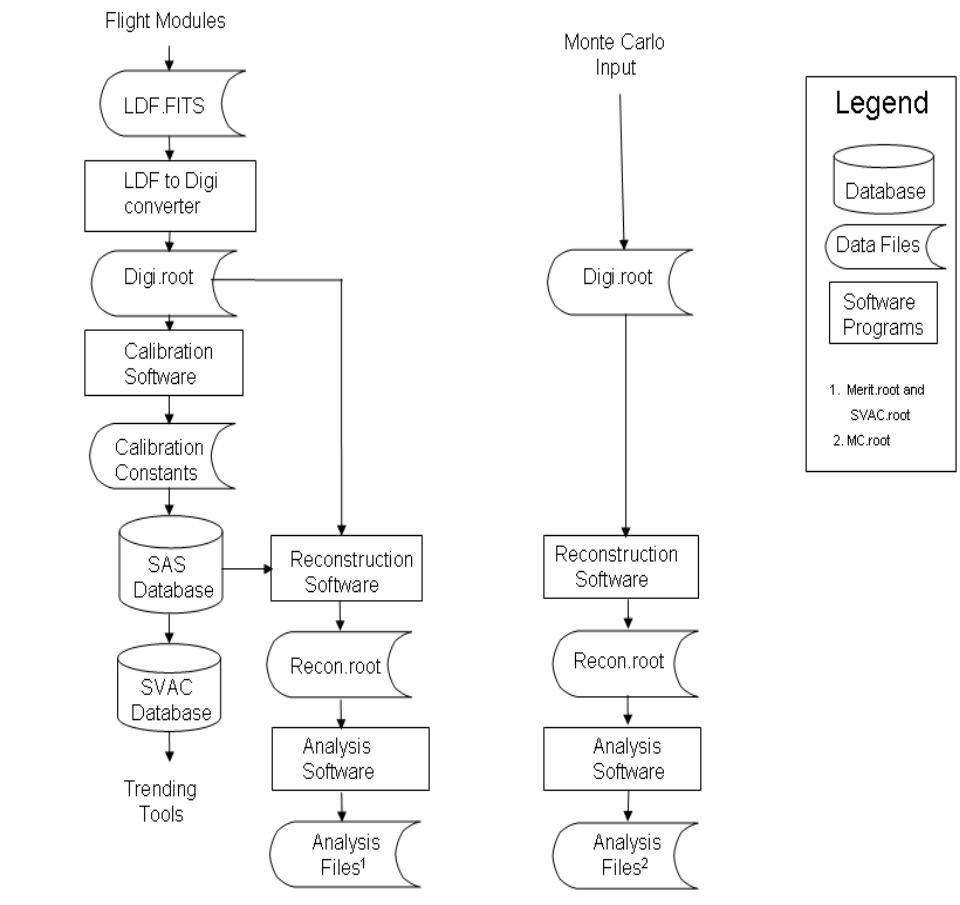


Figure 22: Data Analysis Process Flow

8. TKR Reconstruction (To Be Re-written for new TKR Recon)

TKR reconstruction is an iterative process using information from both the CAL and TKR. The TKR reconstruction method adopts the following four-step procedure (please see Figure 23 and Figure 24)

1. Form “Cluster Hits”

    Done by converting the hit strips to positions. Adjacent hit strips are merged to form a single hit.

2. Pattern Recognize individual tracks

    Done by associating cluster hits into candidate tracks. Individual track energies are assigned to aid in track recognition.

3. “Fit” Track to obtain track parameters

    Inherently two-dimensional cluster locations are processed to determine three-dimensional position and direction. The errors are estimated then the energy calculations are used to help with track fitting.

4. “Vertex” fit tracks

    The common intersection point of fit tracks is determined, and a position and direction is calculated.

For **cosmic rays**, the first hit plane determines the “vertex” location. The diagrams presented in Figure 24 illustrate how a cosmic ray event can have more than one track and even multiple vertices.

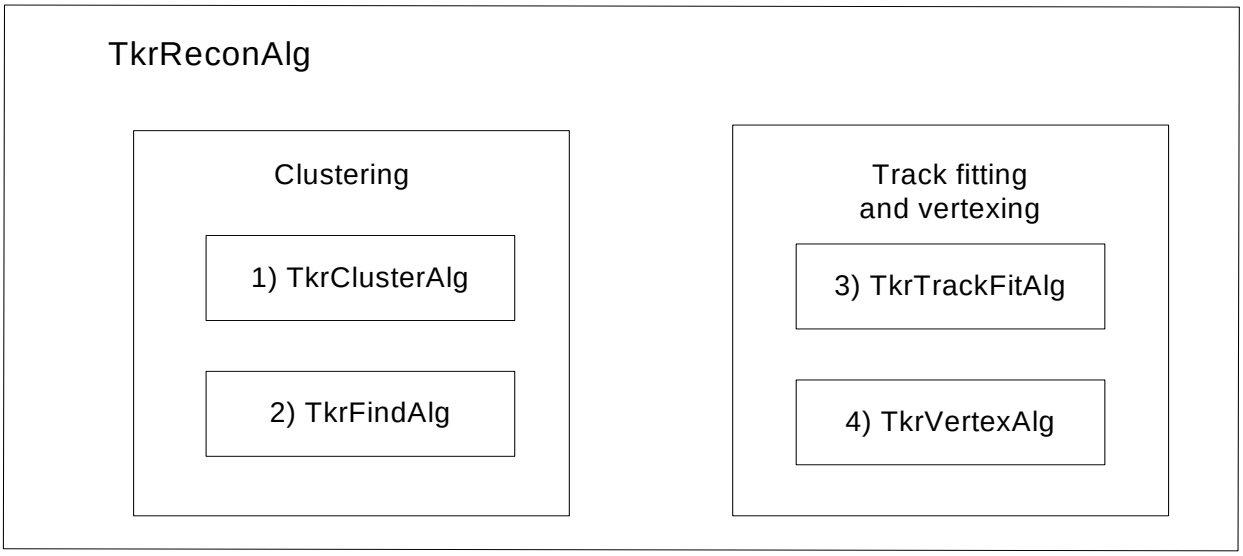


Figure 23: Four TKR Reconstruction Steps (Block Diagram)

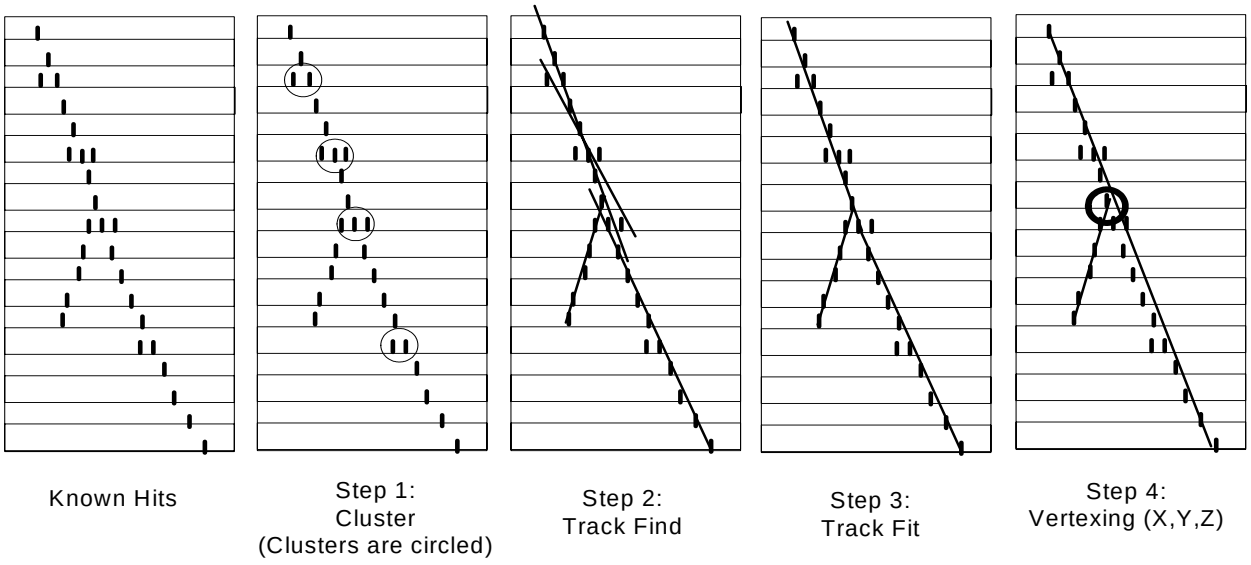


Figure 24: Four Steps of TKR Reconstruction (Illustrated)

Iterative Recon allows parts of the TKR Reconstruction software to be called more than once per event. The overview is shown in Figure 25. In particular, existing pattern recognition tracks can be refit and the vertex algorithm re-run.

The Iterative Recon provides the CAL Recon with sufficient tracking information to get an improved energy estimate, which can be fed back to the track fit and vertexing algorithms. The process can be repeated as many times as the user likes (in principle) but the default is **two passes**.

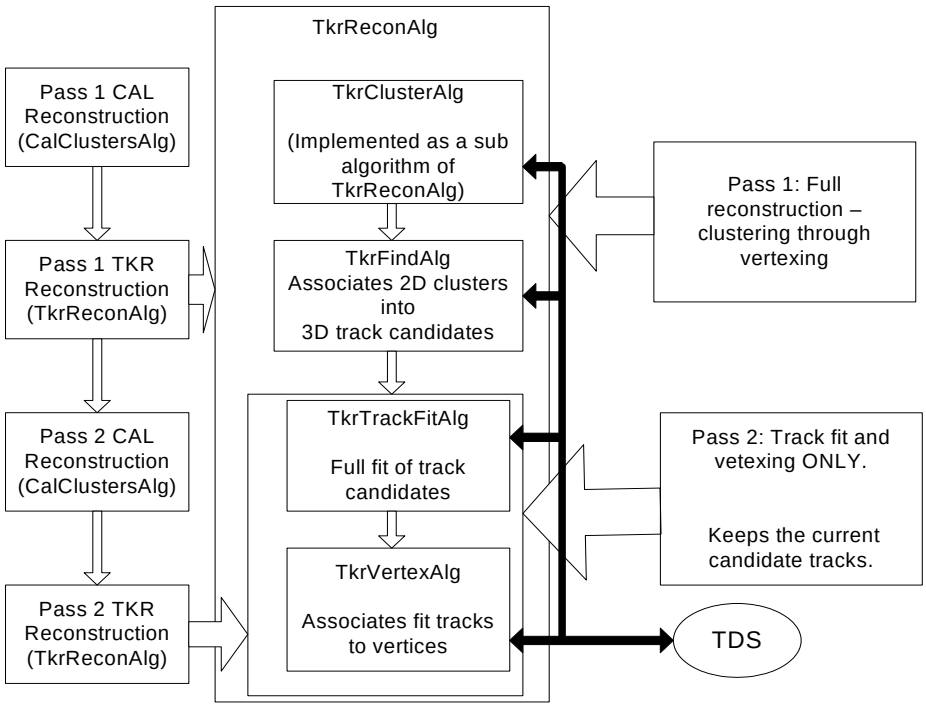


Figure 25: Iterative TKR Reconstruction Algorithms (Block Diagram)

8.1. Clustering (TrkClusterAlg)

The clustering algorithms group strips with adjacent hits to form a cluster. **TkrClusterAlg** takes the strip hits to calculate the center position to use in track fitting. The digi.root file (please refer to Digi.root in section 7.2.2) provides clustering of the hit strip numbers, and Time over Threshold (ToT).

The clustering algorithms apply the TKR calibration data to account for hot/dead/sick strips and merges clusters with known dead strips between them. It also decides whether to add known hot strips to clusters.

The result of **TkrClusterAlg** is a list of clusters in TDS with associated XYZ coordinates and the value of ToT associated with these strips. This information is used in the next step by **TkrFindAlg.**

8.2. Track Finding (TrkFindAlg)

The output of track finding is an ordered list of candidate tracks to be fit. **TkrPatCand,** contained in a **TkrPatCandCol** Gaudi object vector, outputs:

- Estimated track parameters for the candidate track (position, direction);
- The energy assigned to the track;
- Track candidate "quality" estimates, and;
- Starting tower / plane information.

TkrPatCand contains the Gaudi object vector of **TkrPatCandHits** for each hit (cluster) associated with the candidate track. Any cluster associated with this hit is needed for the fit stage.

All are stored in the TDS.

TkrFindAlg associates clusters into candidate tracks. Three approaches exist within the **TkrRecon** package, as described in Table 17.

Table 17: TKR Reconstruction Clustering Methods

Name	Method	Pro's	Con's
Combo	Track by track. Combinatoric search through space points to find candidates.	Simple to understand (although details add complications)	Finding "wrong" tracks early in the process throws off the rest of the track finding by mis-associating hits. Can be quite time consuming depending upon the depth of the search.
Link and Tree	Global pattern recognition. Associate hits into a tree like structure.	Optimized to find tracks in entire event, less susceptible to miss associating hits.	Can be quite time consuming.
Neural Net	Global pattern recognition. Links nearby space points forming "neurons."	Optimized to find tracks in entire event, less susceptible to miss associating hits.	Can be quite time consuming. Operates in 2D and then requires mating to get 3D track.

Also: "Monte Carlo" pattern recognition exists for testing, fitting and vertexing.

There are two basic Combinatoric strategies for track finding: CAL based or Blind search. CAL based is used when there is enough CAL energy present to use the energy centroid. When there is too little CAL energy we use only Track Hits, and make a "Blind" search.

Table 18 differentiates between the types of combinatoric track finding methods available to **ComboFindTrackTool.** In either case its starting plane is always the one furthest from the CAL. It works to combine clusters in adjacent X-Y planes to form 3D space points.

Table 18: TKR Reconstruction Combinatoric Track Finding Methods

Name	When Used	Strategy
CAL Energy Present	Sufficient CAL energy, about 42 MeV.	Track fit uses the CAL centroid by first attempting to connect the hit with CAL centroid. It connects the first two hits, then projects and adds hits along the track within the search region. The search region is set by propagating the track errors through the GLAST geometry. Please see Figure 26.
Blind search	Insufficient CAL energy.	The first hit found is tried in combinatoric order. The 2nd hit is selected in combinatoric order. The first two hits are used to project into next plane, and a 3rd Hit is searched for. If a 3rd hit is found the track is built by "finding – following."

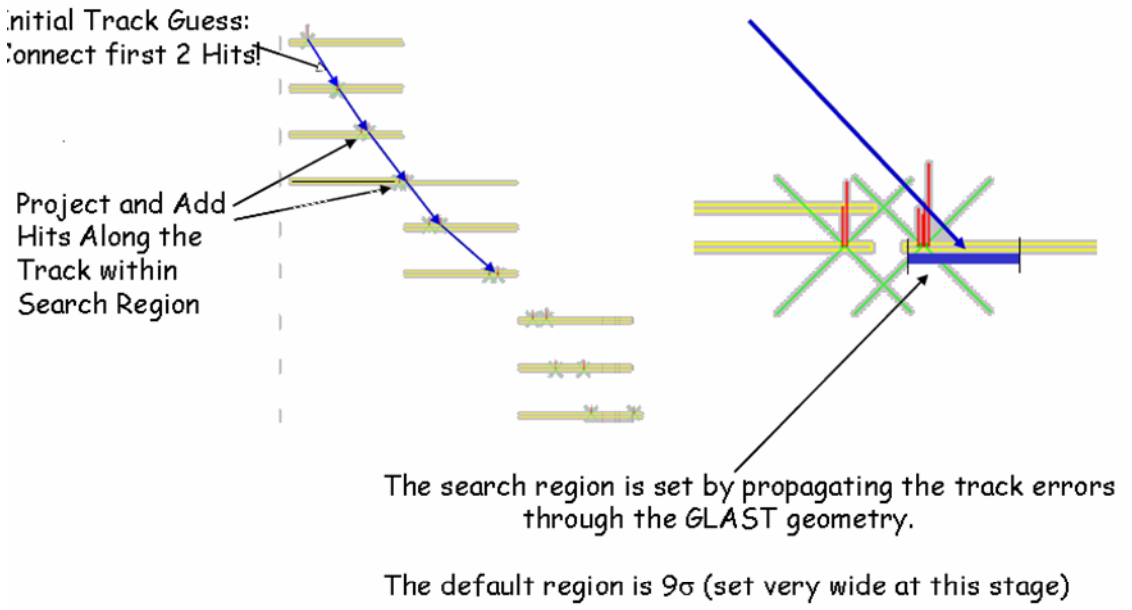


Figure 26: Combinatoric Pattern Recognition: ComboFindTrack Tool

8.3. Track Fitting (TkrFitTrackAlg)

The next step is for the **TkrReconAlg** to fit the candidate tracks using the parameters of X, Y and the slopes of X and Y. It tracks the parameter error matrix (parameter errors and correlations) and measures of the quality of the track fit using the Kalman filter method.

The filter process starts at the conversion point, but we want the best estimate of the track parameters at the conversion point. This requires propagating the influence of all the subsequent hits backwards to the beginning of the track, essentially running the filter in reverse. This is called the smoother, and the linear algebra is similar:

Residuals: r(k) = X(k) -Pm(k)

Covariance of r(k): Cr(k) = V(k) -C(k)

Then: $X^2 = r(k)^T Cr(k)^{-1} r(k)$ for the k^{th} step

8.4. Vertexing (TkrVertexAlg)

A pair conversion results in 2 primary tracks, but one track could be lost due to:

- Low energy (track must cross three planes);
- Tracks from pair conversion don't separate for several planes; and,
- Track separation due to multiple scattering.

In addition, wrong vertex associations could occur because secondary tracks may be associated with primary tracks but are not part of the γ conversion process.

The vertexing algorithm attempts to associate "best" track (from track finding) with one of the other found tracks by finding "the" vertex and returning unassociated ("isolated") tracks as single prong vertices. It determines the reconstructed position of the conversion and the reconstructed direction of the conversion. Currently two methods available, as listed in Table 19.

In the presence of charged particles only, the vertex is considered to be at the first plane hit.

Table 19: TKR Reconstruction Vertexing Tools

Tool	Method	Description
"Combo" (default)	Uses track Distance of Closest Approach (DOCA) to associate tracks.	1. The vertex is determined at two tracks' Distance of Closest Approach (DOCA). 2. The first track is the "best" track from track finding/fitting algorithms. 3. It is looped through "other" tracks looking for best match: • Smallest DOCA • Weighting factors: • Separation between the starting points of the two tracks • Track energy • Track quality 4. It calculates vertex quantities: • Vertex Position: Midpoint of DOCA vector • Vertex Direction: Weighted vector sum of individual track directions Not a true HEP Vertex Fit
Kalman Filter	Kalman Filter	

The output from the vertexing algorithms is an ordered list of vertices with the following **TkrVertex** objects contained in a Gaudi Object Vector:

- The vertex track parameters (x, m_X, y, m_Y);
- The vertex track parameter covariance matrix;
- The vertex energy;
- The vertex quality;

- The first tower/plane information; and,
- Gaudi reference vector to the tracks in the vertex.

The first vertex in the list is the “best” vertex, and the rest are mostly associated with an “isolated” track.

8.5. Track Hypothesis for Integration and Test

By default, the track finding and fitting assume that all tracks are electrons. This has two consequences: It will use the electron hypothesis to calculate the energy loss in the tracker, and it can use the total energy deposited in the calorimeter as a reliable estimate of the true track energy.

However, for most of the Integration and Test period we will have surface muons in the detector. Using the electron hypothesis to find and fit muon tracks has two consequences: The energy loss in the tracker will be vastly overestimated as a muon loses much less energy than an electron per radiation length, and the energy deposited in the calorimeter is no longer a good estimate of the true track energy. A MIP leaves about 90 MeV in the calorimeter.

This means that a 5 GeV muon, for example, will be treated as a 90 MeV electron in the track finding and fitting. Note that this will affect the track reconstruction strategy. For a 90 MeV electron only the first few points on the track are used to estimate the incident direction, the assumption being that multiple scattering will make the points further down on the track useless.

The track reconstruction has the ability to use a muon hypothesis. This means the energy loss will be calculated correctly. However, because the energy deposited in the calorimeter can no longer be used as an estimator for the true track energy, we need to set a fixed minimum track energy. The maximum of the minimum track energy and the energy deposited in the calorimeter will then be used. Studies are underway to find the precise minimum track energy to use. Preliminary studies indicate that it will be in the range of 500 MeV to a few GeV.

For all runs with surface muons during Integration and Test we will use the muon hypothesis for the track finding and fitting.

Another point to note is that for a specific event only one particle hypothesis can be used. This means that for runs with photons, like VDG runs, where we will specify the electron hypothesis and set the minimum track energy to 4 MeV, any surface muon passing through the detector at the same time will also be reconstructed as an electron with a track energy which is the greater of either 4 MeV or the energy deposited in the calorimeter. One should keep this in mind when comparing MIP distributions from VDG runs and normal surface muon runs.

9. CAL Reconstruction

To be written.

10. Monte Carlo Simulations

MC simulations are run for both simulated cosmic rays at sea level and photons generated by a Van De Graaff generator.

MC simulations on thresholds and noise are taken for data analysis purposes, and are also described here.

10.1. Low Energy Photon Source

Simulated γ photons are derived from real proton / Lithium ^{7} collisions according to Figure 27.

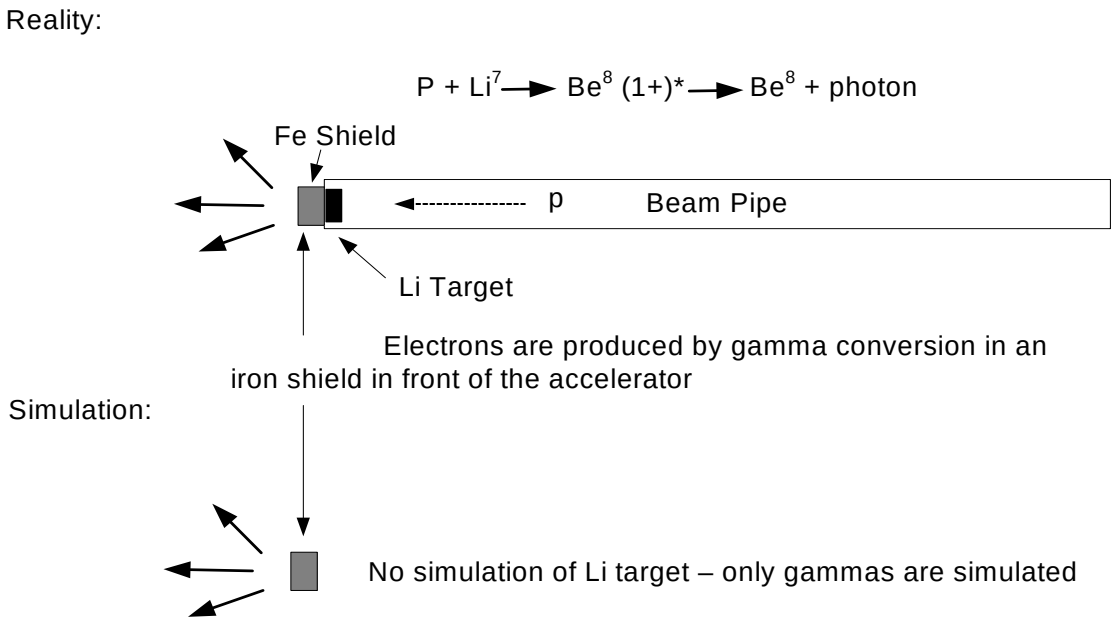


Figure 27: Simulation of VDG Gammas – Simulated Particle Source Generation

For MC simulation, there is no Li target – only the γ are simulated, with an energy spectrum having the main distribution at 14.6 MeV and a 17.6 MeV line spectrum. The ratio of numbers of events at 17.6 MeV / number of events at 14.6 MeV is 2:1.

The shielding is defined as a simulated iron cylinder with radius of 26 mm and thickness of 1.25 mm (7% X_0). The X position = -200 mm; the Y position = 200 mm; the Z position = 636 mm, ~ 3mm above the TKR. The energy spectrum is angular-dependent.

Note that γ photons which convert in the Fe shield generate an unwanted experimental background of charged particles.

10.2. Cosmic Ray Source

The default scenario program name is surface_muons (muons at the earth's surface). It models energy / angle correlations and has a spectrum to include events below 1 GeV. It can produce a small number of unphysical, **low energy events that are platform dependent.** There is no simulation of particle showers.

Figure 28 shows the distribution of kinetic energy vs. particle flux for surface_muons.

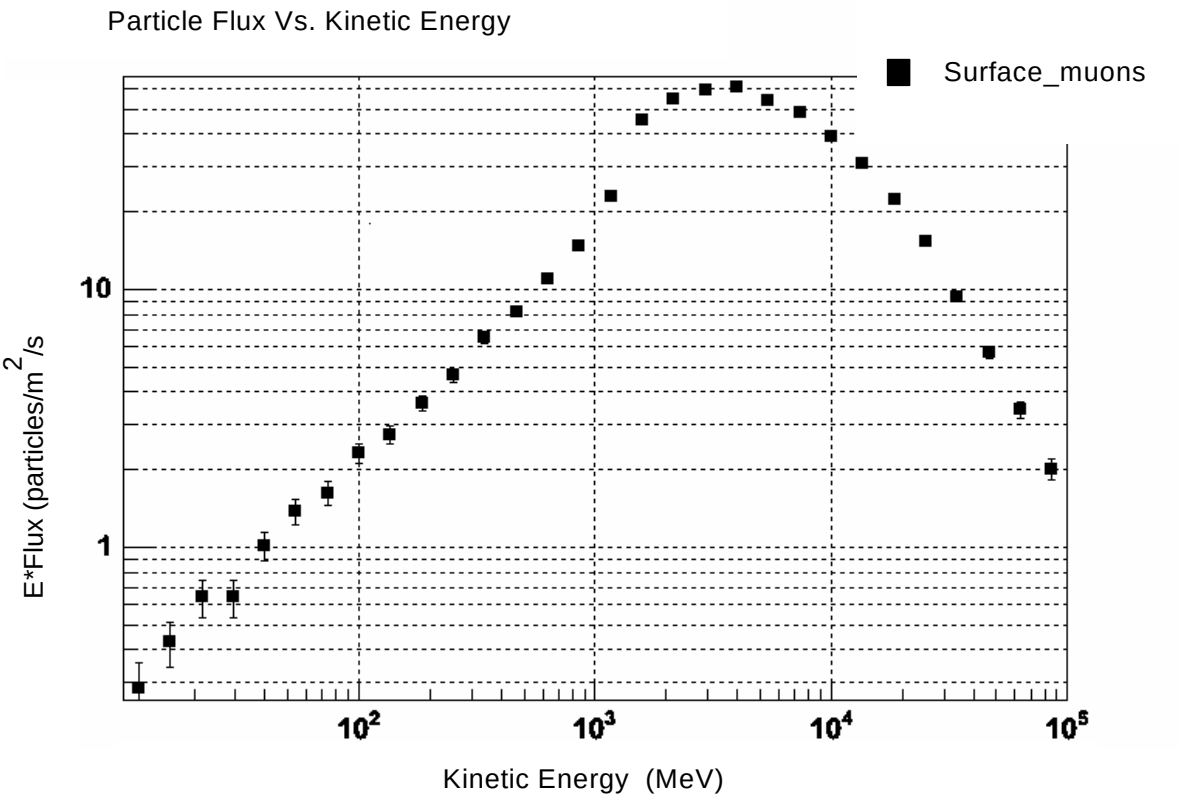


Figure 28: Particle Flux vs. Kinetic Energy for surface_muon Source

10.3. Thresholds and Noise

The TKR occupancy in MC is usually set at 5 x 10 $^{-5}$ / strip, meaning that one should expect about 3 noisy hits per tower, on average (5 x 10 $^{-5}$ /strip x 1536 strips x 36 planes per tower).

11. Data Analysis

This section is intended to guide users in the usage of the existing data analysis variables. It is impossible to provide a recipe for data analysis, but the idea is to illustrate how to use the information in the data analysis files.

11.1. Identification of Minimum Ionizing Particles

A MIP selection can involve information from TKR, CAL and ACD.

The most naïve search is for a single straight track, with one hit in each TKR plane, that when extrapolated to the CAL, deposits about 11 MeV in each crystal layer.

The SVAC file has hits per plane and clusters per plane for each tower while the Merit ntuple has clusters associated to tracks for all towers.

Care needs to be exercised when using variables such as **TkrTrackLength.** This variable measures an extrapolated length from the first hit plane to the grid by dividing **Tkr1Z0** (Z position at first hit of track1) by **Tkr1ZDir** (direction cosine for track1). Thus, for a situation illustrated in Figure 29, both track lengths are equal.

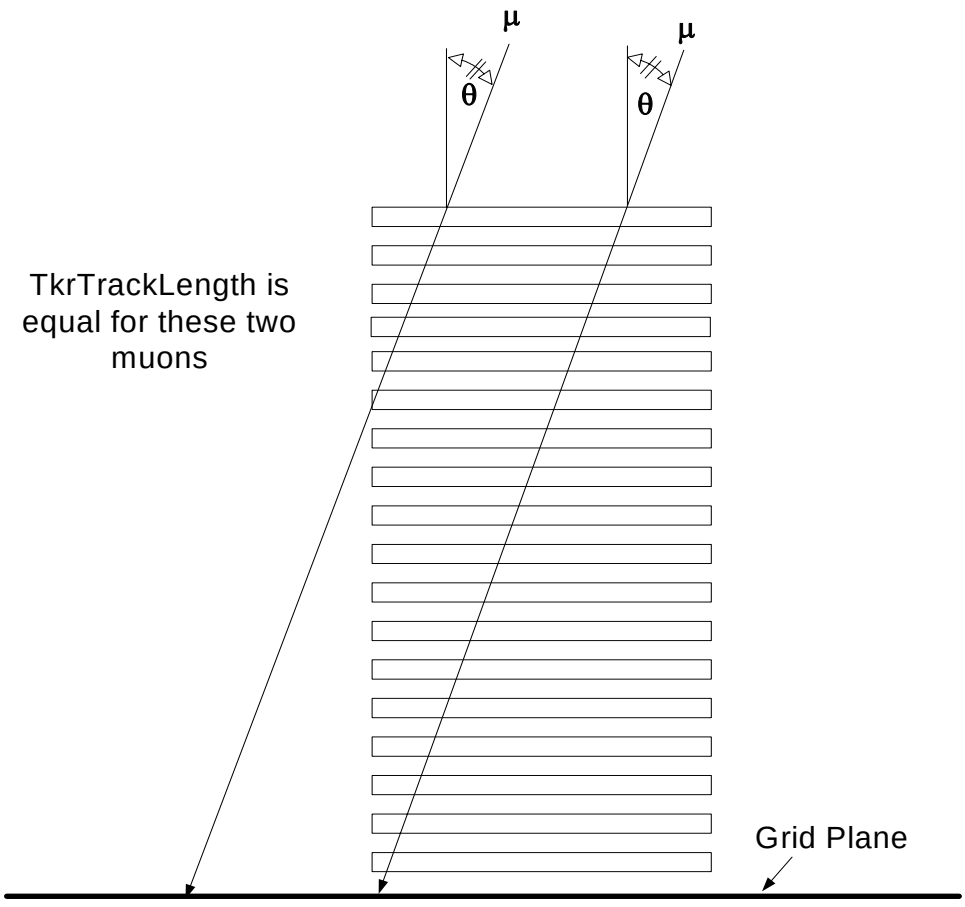


Figure 29: TrkTrackLength Example of Easily Misinterpreted Data

11.2. CALTowerGap

Note that when extrapolating a track into the CAL, sometimes the track will traverse different amounts of material even if it is a straight track. The reason is depicted in Figure 30. In this case there is an offset between successive CAL layers, so an on-axis muon, contrary to naive intuition, may hit every other plane.

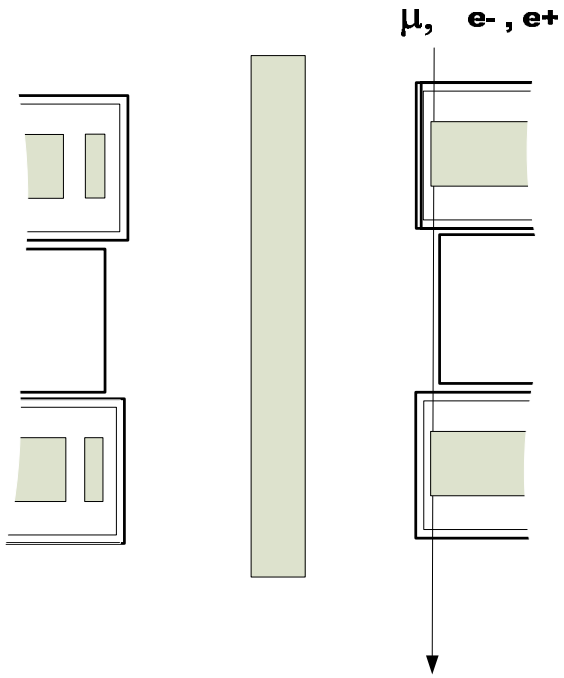


Figure 30: A Charged Particle's Path is Parallel to the Z Axis and only Strikes Every Other Crystal

11.3. Timing Analysis

Note that when we have even and odd bays populated with towers, it is important to verify timing settings because cable lengths will be different.

12. Resources

Please see the following references for additional information.

AEM: LAT-TD-00639: The Anti-Coincidence Detector Electronics Module (AEM) Programming ICD Specification
GEM: LAT-TD-01545: The GLT Electronics Module Programming ICD Specification
GENERAL: LAT-TD-00376: Naming Convention for GLAST Tracker Construction and Tray Orientation in Tracker Tower LAT-TD-00035: LAT Coordinate System
TEM: LAT-TD-00605: The Tower Electronics Module (TEM) Programming ICD Specification
Timing Registers: LAT-TD-04134-01: How to Set the LAT Timing Registers
Trigger: LAT-SS-00286: LAT Global Trigger Specification LAT-TD-00560: LAT Global Trigger and ACD Hit Map LAT-TD-01545: GEM Programming ICD http://www-glast.slac.stanford.edu/Trigger/
Integration and Test Peer Reviews: http://www-glast.slac.stanford.edu/IntegrationTest/ReadinessReviews/IRR_Peer_Reviews/IRR_Peer_Reviews.htm

Instrument Analysis Group Workshops, SLAC, June 7, 8 2004:

http://www-glast.slac.stanford.edu/IntegrationTest/SVAC/Instrument_Analysis/agenda.htm

Instrument Analysis Group Friday Morning Meetings:

http://www-glast.slac.stanford.edu/IntegrationTest/SVAC/Instrument_Analysis/agenda.htm

Integration and Test SVAC/SAS Telecoms:

http://www-glast.slac.stanford.edu/IntegrationTest/SVAC/meetings/Default.htm

Science Verification Analysis and Calibration (SVAC) Website:

http://www-glast.slac.stanford.edu/IntegrationTest/SVAC/default.htm

Appendix A - eLog

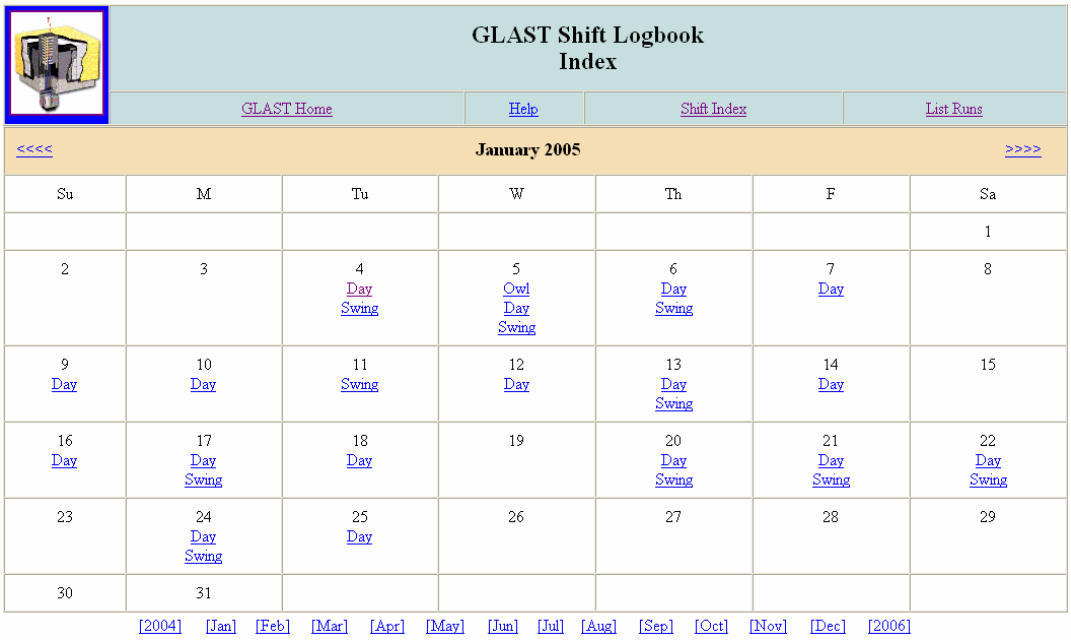
The eLog makes available all the run data information for any of the electronics tests run on the LAT components.

There are two eLog displays with similar names described here: The GLAST Shift Index and the Run Selection Index.

A.1. Shift Logbook Index

The Shift Log Index's calendar, shown below in Figure 31, accesses day-to-day activities at SLAC.

Its URL is: http://www.slac.stanford.edu/cgi-wrap/eLog.pl/index



GLAST Shift Logbook Index

GLAST Home | Help | Shift Index | List Runs

<<<< January 2005 >>>>

Su	M	Tu	W	Th	F	Sa
						1
2	3	4 Day Swing	5 Owl Day Swing	6 Day Swing	7 Day	8
9 Day	10 Day	11 Swing	12 Day	13 Day Swing	14 Day	15
16 Day	17 Day Swing	18 Day	19	20 Day Swing	21 Day Swing	22 Day Swing
23	24 Day Swing	25 Day	26	27	28	29
30	31					

[2004] [Jan] [Feb] [Mar] [Apr] [May] [Jun] [Jul] [Aug] [Sep] [Oct] [Nov] [Dec] [2006]

Figure 31: GLAST Shift Log Index

This access route to the data displays all the same information categories as the query form, but the only sort function is time of test, e.g., the day shift on Wednesday, 01/05/05. The categories are described below. Selecting **List Runs** from the Index page displays the GLAST Shift Logbook Shift Run Info menu, shown below in Figure 32.

A.2. Run Selection Index

The Run Selection Index is used to retrieve run data by specifying specifics you enter, such as the particle type and / or the site where the test was run and / or instrument type (the unit under test) serial number, and / or date of test, etc., and is shown in Figure 32.

Its URL is: http://www.slac.stanford.edu/cgi-wrap/eLog.pl/list

- **Asterisk (*) wildcards are allowed for queries.**
- **Fields are not case sensitive.**

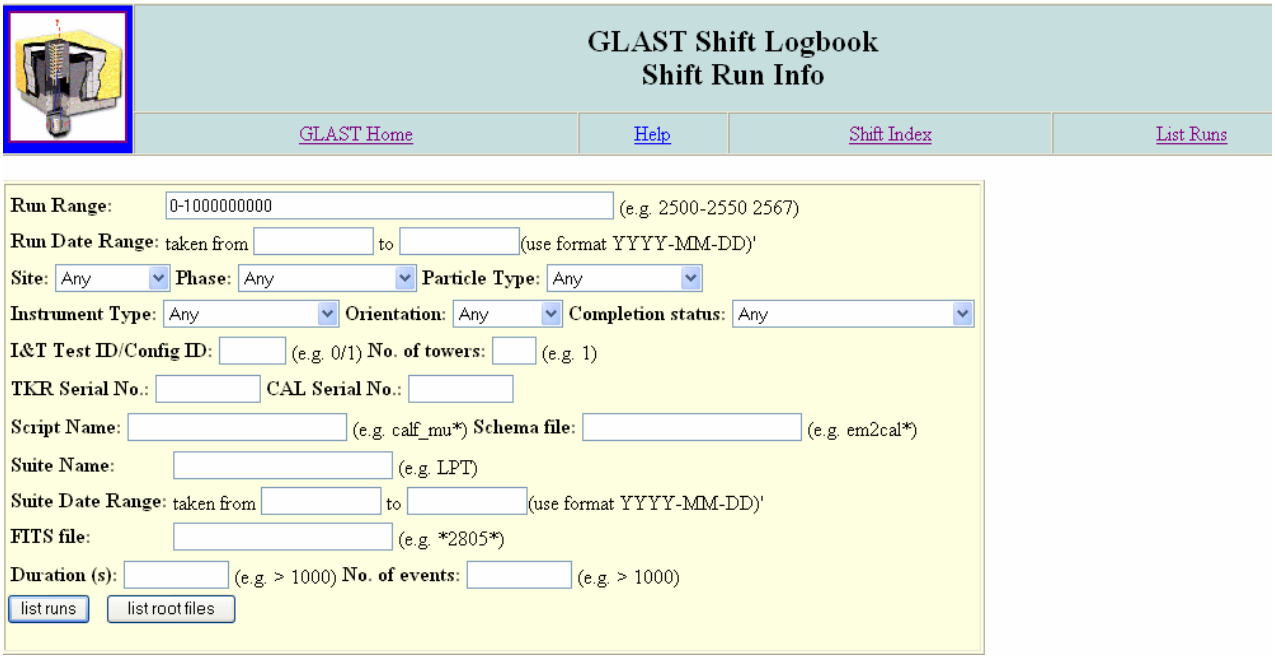
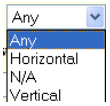
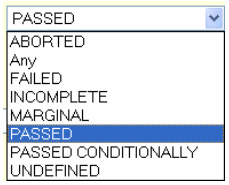
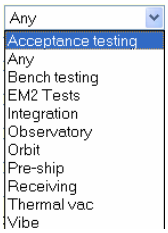
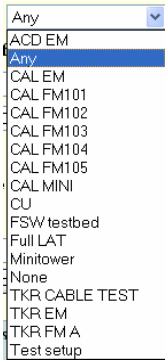


Figure 32: Logbook Shift Run Info

The fields from Figure 32: Logbook Shift Run Info are described below in Table 20. The table is divided into two parts: the top half lists fields most used for data analysis; the bottom half is for subsystem experts.

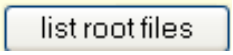
Table 20: Logbook Shift Run Menu Fields

Field	Entry Types	Comment
Most-used fields for data analysis.		
Run Range	Numeric * wildcard allowed	A range or set of run numbers
Run Date Range	YYYY-MM-DD * wildcard allowed	A range or set of runs by date
Particle type	Any Any Charge Injection Cosmics None Photons	Photon = Van de Graaff γ; peaks at 14.6 MeV and 17.6 MeV with a ratio of 2:1. Cosmics = cosmic rays Charge injection is for subsystem experts

Field	Entry Types	Comment
Orientation		Orientation of instrument (important for cosmic ray runs). Photon tests are always horizontal.
Completion status		Test status. Indicates that a test executed successfully or unsuccessfully – not an indicator of the equipment's status.
No. of Towers e.g.1	1 - 16	Number of towers in the grid.
TKR Serial No.	Normal TKR range is: TKR FMA to TKR FM16	TKR unit. Same as instrument type.
CAL Serial No.	Normal CAL range is: FM101 to FM118	CAL unit. Same as instrument type.
Duration(s)	Numeric value in seconds. < > allowed, e.g., < 1000 or >1000	Test duration in seconds.
No. of events	Numeric value. < > allowed, e.g., < 1000 or >1000	Number of events in the runs.
I&T Test ID/Config ID (e.g. 0/1)		End-to-end test IDs
Fields for subsystem experts.		
Site		Test site where data was collected.
Phase		Test phase during LAT integration.
Instrument type		Flight hardware CAL range is: FM 101, FM 102 …FM 118 Flight hardware TKR range is: TKR FMA to TKR FM16 **Superseded- please do not rely on this. Use Serial Numbers.**
Script name (e.g. calf_mu*):		Test script

Field	Entry Types	Comment
Schema File (e.g. em2cal*):		Description of register configurations
Suite name (e.g. LPT):		A group of tests bound together
Suite Date Range	YYYY-MM-DD	Specify a range of test suites.
FITS file	Numeric value that corresponds to run numbers. Wildcards allowed.	Raw data

Table 21: Logbook Shift Run Menu Active Buttons

Button	Action	Comment
	Get runs according to menu choices.	View shown in Figure 33
	ftp path for test-run created root files at SLAC for analysis.	Will be updated to show URLs for the test-run created root files.

A.3. List Runs

Selecting **List Runs** from either the Shift Log Index or from the Run Selection Index displays the table of information shown in Figure 33.

Run	Status	Script Name	Online Report	SVAC Report	Events / Errors	Duration (s)	Root Files	Start	Particle	Instrument	Orientation	FITS file
398000359	PASSED	TkrDataTaking	online	digi recon config	100006/4	2407	digi recon merit svac	2005-01-20 20:39:56	Cosmics	TKR FM A	Vertical	
398000362	PASSED	TkrDataTaking	online	digi recon config	100014/12	2405	digi recon merit svac	2005-01-20 22:01:42	Cosmics	TKR FM A	Vertical	

Figure 33: List Runs Table

The fields in Figure 33: List Runs Table are described in Table 22.

Table 22: List Runs Fields

Field	Contents
Run	Summary run information. All information fields from Run Info (Table 20) plus processing files package.
Status	Flag for test results
Script Name	Name of LATTE script used for the run
Online Products	Links to all files created by LATTE for the test run.
SVAC Report	Links to: http, .ps or .pdf versions of **digi**, **recon** and **config** file data quality reports. **Digi**: digi file details, run results, test settings. **Recon**: details of recon software and result displays. **Config**: Details of CAL, TKR and ACD configuration settings while under test. Digi and Recon reports are used in offline data analyses to identify apparent problems in cosmic ray muon and VDG data.
Events/Errors	Number of events in the test / number of errors in the test
Duration (s)	Number of seconds the test lasted.
Root files	Links to: digi, recon, merit, SVAC data analysis files. Requires Root to visualize data. Please see the Instrument Analysis main page at: http://www-glast.slac.stanford.edu/IntegrationTest/SVAC/Instrument_Analysis/Instrument_Analysis.html
Start	Date and time test started
Particle type	Particle type of test run (cosmics, photons)
Orientation	Unit orientation (vertical or horizontal)