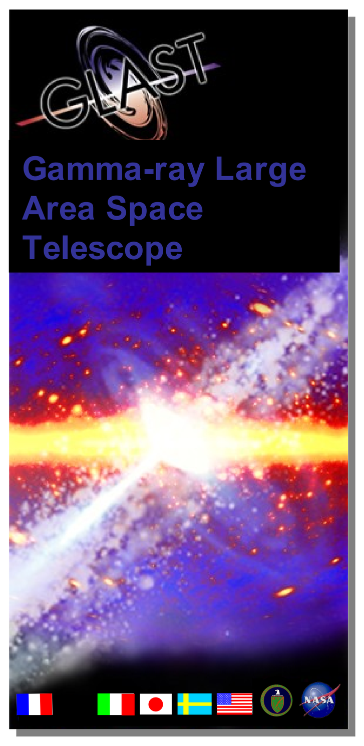
The Trigger and Onboard Filter of the GLAST Large Area Telescope (LAT)



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Abstract

The GLAST Large Area Telescope (LAT) will measure the cosmic gamma-ray flux in the energy range 20 MeV to >300 GeV. The LAT will open a new and important window on a wide variety of high-energy phenomena. Achieving this capability requires a hardware trigger and onboard software event filters that are robust and highly efficient for gamma rays while keeping the event rates due to the much larger fluxes of charged particle backgrounds at an acceptable level. Because of the important discovery windows for science and the uncertainties in the background fluxes, configuration flexibility is a particularly important system feature. This poster describes the purposes and architecture of the system, the components and capabilities of the hardware trigger and onboard software filters, testing and operation experience on the ground, and the on-orbit operations plan and expected performance.

Introduction

The hardware trigger and onboard software filters work together to provide high efficiency for celestial gamma-ray events over the full acceptance range of the LAT, while providing flexibility and background samples for systematic performance studies and keeping the instrument dead time in check.

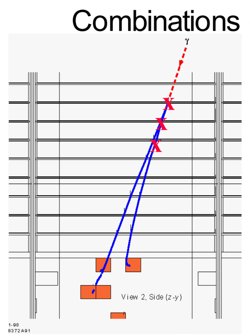
Hardware Trigger → **On-board Processing**

Based on special signals from each tower; initiates readout

Function:

- "did anything happen?"
- keep as simple as possible

Combinations of trigger primitives:



- **TKR 3 *x•y* pair planes in a row** **workhorse γ trigger**
- **CAL:**
  LO – independent check, energy info.
  HI – indicates high energy event

Upon a trigger, whole instrument is read out in 26.5 microseconds

Instrument Total Rate: <3 kHz>**

**using ACD ROI veto in hardware trigger

Onboard filters: reduce data to fit within downlink, provide samples for systematic studies.

- **flexible, loose cuts**
- **FSW filter code is wrapped and embedded in full detector simulation**
- **leak a fraction of otherwise-rejected events to the ground for diagnostics, along with events ID'd for calibration and monitoring**
- **signal/bkgd tunable, depending on analysis cuts:**
  γ rate: few Hz

Total Rate: <~400 Hz>**

On-board science analysis:
transient detection (bursts)

Spacecraft

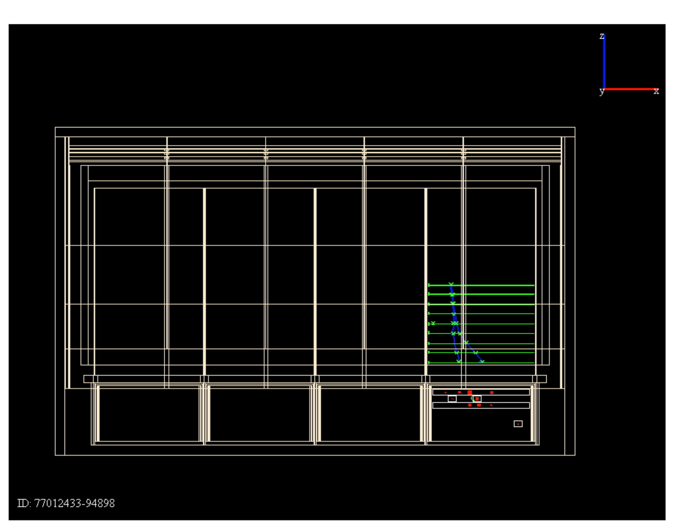
**CBE, assumes compression, 1.2 Mbps allocation.

Ground Operation Experience and Testing

The LAT has been fully integrated and operating under the control of flight software since April 2006. Tests undertaken since then demonstrate that

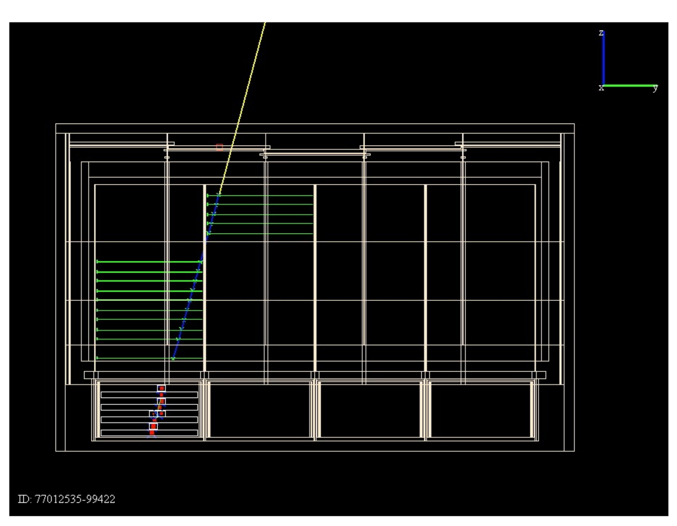
- Trigger hardware is fully functioning
- On-board filters are installed and operating on the LAT

- Test bed
  - Duplicates flight Trigger & Data Flow (T&DF) hardware
  - Allows software development and testing
- Flight T&DF hardware tests
  - Thorough flight qualification and verification test program demonstrates that flight units perform within spec.
  - Test program with T&DF integrated into the LAT has accumulated >1200 hours of run time in flight configuration, including multiple trigger engines spanning full set of 256 combinations of trigger conditions and reading out LAT detectors in science and calibration data modes.
  - Integrated LAT has registered $>10^9$ cosmic-ray triggers. Data are used for detector calibration and T&DF data integrity tests.
- Ground tests of filter performance
  - Gamma filter, MIP filter, and heavy ion filter FSW code modules are loaded on LAT
  - Tests on LAT include >300 hours with gamma filter and >150 hours with MIP filter.
  - Detailed analysis of filter performance is in progress, but data clearly show enriched output of gamma rays and simple muon tracks, as expected. Sample events are shown below.



Examples of gamma-ray (left) and muon events (right) passed by their respective filters during ground tests of LAT.

- *Blue tracks indicate path of e+e- or muon in TKR.*
- *Red squares indicate energy deposition in CAL or ACD tile hit.*
- *Yellow track is projected muon incident direction.*



Hardware Trigger

- Combines special signals (primitives) from tracker (TKR), calorimeter (CAL), and anticoincidence detector (ACD) to decide if an event is to be recorded.
- Very fast trigger decision to minimize deadtime due to the processing of backgrounds.
- Flexible to allow optimization of trigger efficiency, and versatile to accommodate for various different signatures of events.

Integrated LAT is a 4 x 4 array of towers that consist of a tracker and a calorimeter each. The tracker is covered with scintillating ACD tiles on the top and on the sides. All of these elements contribute to the trigger by generating trigger primitives and sending them to the central trigger unit.

Trigger Primitives:

- **Tracker** If silicon strips produce hits above threshold in 3 consecutive x-y layer pairs (i.e. 6 consecutive layers) of one tower, the tracker will send a trigger request.
- **Calorimeter** Two thresholds for every crystal face. In flight, one (CAL-LO) will be set to 100 MeV, the other (CAL-HI) to 1 GeV. If any crystal signal goes above threshold, the appropriate trigger request (CAL-HI or CAL-LO) will be sent.
- **Anti Coincidence detector** Two thresholds for every scintillator tile. One (VETO) is set to 1/2 MIP and is meant to veto charged particles. The other (CNO) is set to several MIPs to trigger on cosmic ray ions for CAL calibration.
- **Other trigger sources** External trigger for ground testing, periodic trigger, and software trigger.

Since the timing is different for the individual subsystems each trigger line has an input delay which has to be set such that all trigger primitives arrive at the central trigger unit at the same time. This requires a timing calibration.

Central Trigger Unit (GEM):

- Receives trigger primitives from the subsystems.
- Incoming trigger primitives can be masked at the input of the GEM.
- Rising edge in a trigger primitive causes a trigger window of fixed length (typically 600 ns).
- At window closing time, each trigger primitive type that was asserted during this window sets a bit in the Conditions Summary Word which will then be used to evaluate the event.

Shadowing ROI:

- The main purpose of the anti coincidence detector (ACD) is to reject charged particles. Each TKR tower has a list of associated ACD tiles (region of interest, ROI) that "shadow" it. The lower two rows of ACD tiles are not used in the ROIs to avoid removing gamma events whose conversion products scatter out the sides. If the GEM is configured for shadowing, the bit in the conditions summary that usually contains the ACD trigger condition will instead indicate if there was a shadow coincidence between a tracker and an ACD tile. If any TKR has a positive primitive and an associated tile hit, the event is likely to be a charged particle.

Trigger engines:

- For every combination of trigger primitives in the conditions summary word there is an entry in a lookup-table pointing to one of 16 trigger engines.
- The trigger engine corresponding to the Conditions Summary Word is executed.
- The trigger engine contains the following main options to select from:
  - Action: Trigger acknowledge or Inhibit or Strobe for charge injection calibration.
  - Readout mode: Zero-suppression on/off, CAL readout all ranges / best range.
  - Prescale: Only issue a trigger on every i-th request (I = 1…256)
- If the action was a trigger acknowledge, the trigger message is sent back to the detector front ends with an appropriate delay to capture the signal at the peak for each subsystem.

Deadtime:

- If a trigger is inhibited in the trigger engine, the trigger system becomes ready within 100 ns after the trigger window closes. The deadtime for most events where the data is read out is 26.5 microseconds. Single front ends can be dead for several microseconds while the pulse is above threshold. To minimize the deadtime, the inputs to the GEM are segmented into towers for TKR and CAL and into controller boards for the ACD. Each segment can assert a trigger request independently.

Onboard Software Filter Design and Implementation

- Implementation
  - Processor: EPU (115.5 MHz RAD750)
  - Operating System: VxWorks
  - Language: mostly C, some assembler
- Data sent to the filters
  - 18 blocks: 1 Global Trigger, 16 CAL+TKR, 1 ACD
- During normal operation, filtering software
  - Monitors event data for integrity, tracking changes in event and detector statistics.
  - Filters the input stream of events using a set of tests into an output stream whose volume meets the spacecraft storage rate and capacity, while keeping events that meet the science objectives.
  - Tests are evaluated sequentially: generally, as soon as an event fails it is rejected. A pass-through mode allows the events to proceed for diagnostic purposes.
- Categories of tests in Gamma Filter
  - Number and spatial distribution of ACD tiles hit; disengaged by significant CAL energy depositions to avoid backsplash self-veto (uses CAL-LO, CAL-HI, or summed CAL energy)
  - TKR trigger with associated hit tile (like hardware trigger ROI veto)
  - Rudimentary 2D track-finding: test if a track projection points to a hit ACD tile; disengaged by sufficiently large summed CAL energy.
- Flexible
  - Tests can be individually enabled or disabled; summed energy selection thresholds and other values are parameters that can be tuned.

On-orbit Configuration and Expected Rates

Trigger. LAT is configured to read out from TKR, CAL-LO, CAL-HI, CNO, and Periodic trigger requests. The ROIs are configured for tower-shadow coincidence. No prescaling is applied to gamma-ray related trigger engines. The expected rates are shown below.

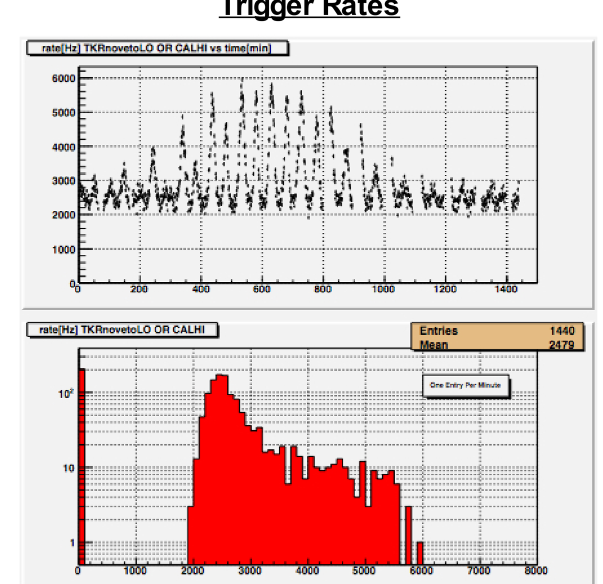
- Background diagnostic engines are prescaled (e.g., TKR & ROI triggers that have no other requests asserted) to provide an unbiased background sample with small incremental deadtime.
- A special CNO coincidence engine (CNO & CAL-LO & TKR & ROI) for calibration also does not require a prescale.

Filters. The expected rates out of the gamma filter are shown below. Additional filters are configured for special purposes:

- To provide ACD and CAL calibration with heavy ions, the heavy ion filter will be configured to pass an average rate of ~20 Hz. With that throughput, ACD and CAL energy calibrations can be updated every few weeks.
- To monitor noise occupancy and ACD and CAL pedestals, periodic triggers will be generated at 2 Hz and passed to the ground with the diagnostic filter.
- To monitor on-orbit backgrounds and study filter performance, the diagnostic filter will also be configured to pass an unbiased sample of all trigger types at an average rate of ~30 Hz.

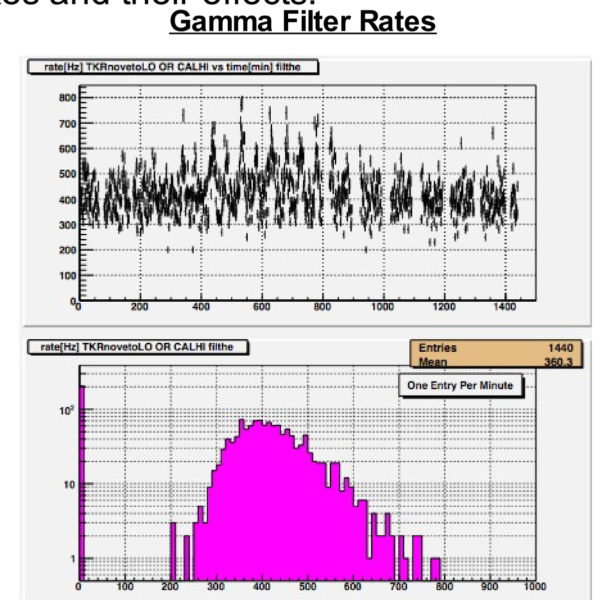
Configurations will be evaluated and tuned during the first year, as more is learned about the background fluxes and their effects.

Trigger Rates



- *Operating daily-average rate is 2.9 kHz*
- *Peak rate is 6 kHz (watch deadtime)*
- *Prescaled diagnostic triggers add ~100 Hz*
- *For this simulated day, 201 minutes spent in SAA (14%).*

Gamma Filter Rates



- *Gamma filter rate is 360 Hz*
- *Pass any event w/ E>20 GeV: +40 Hz*
- *Plus other filters for MIPs and heavy ions, diagnostic pass-thrus: +50 Hz*
- *Handles to reduce this rate significantly if needed*