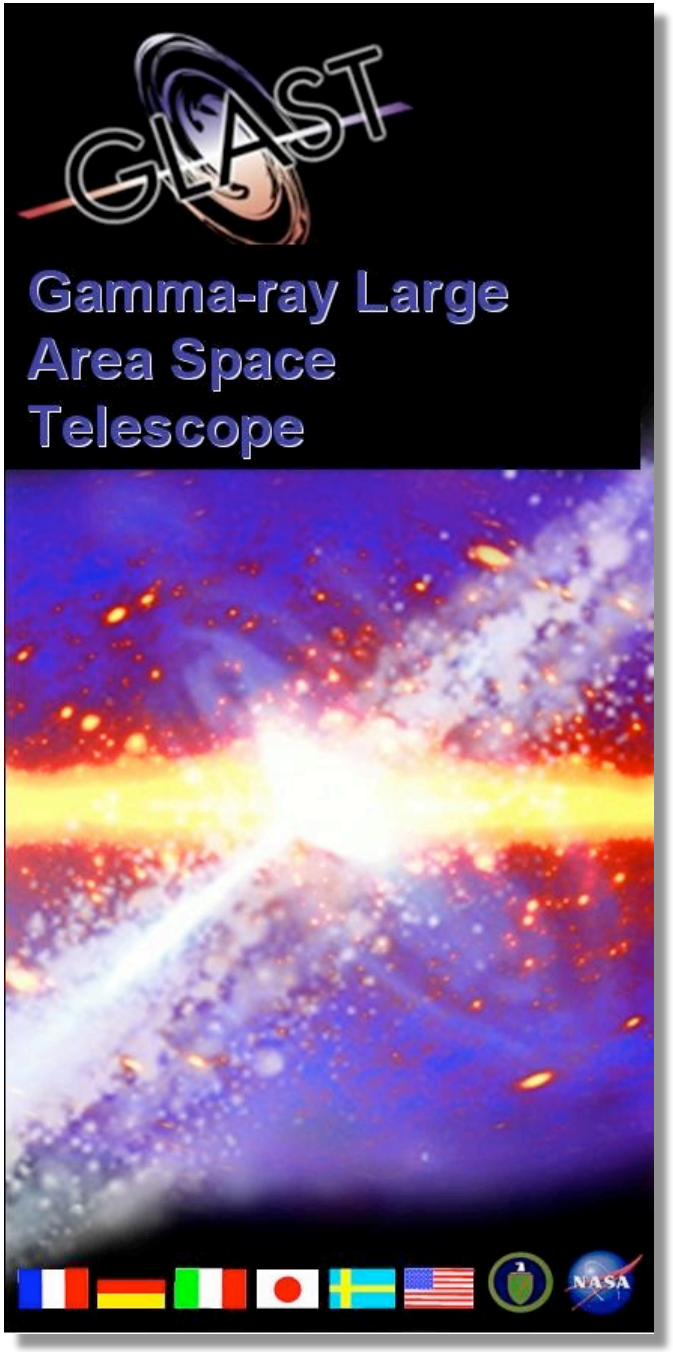
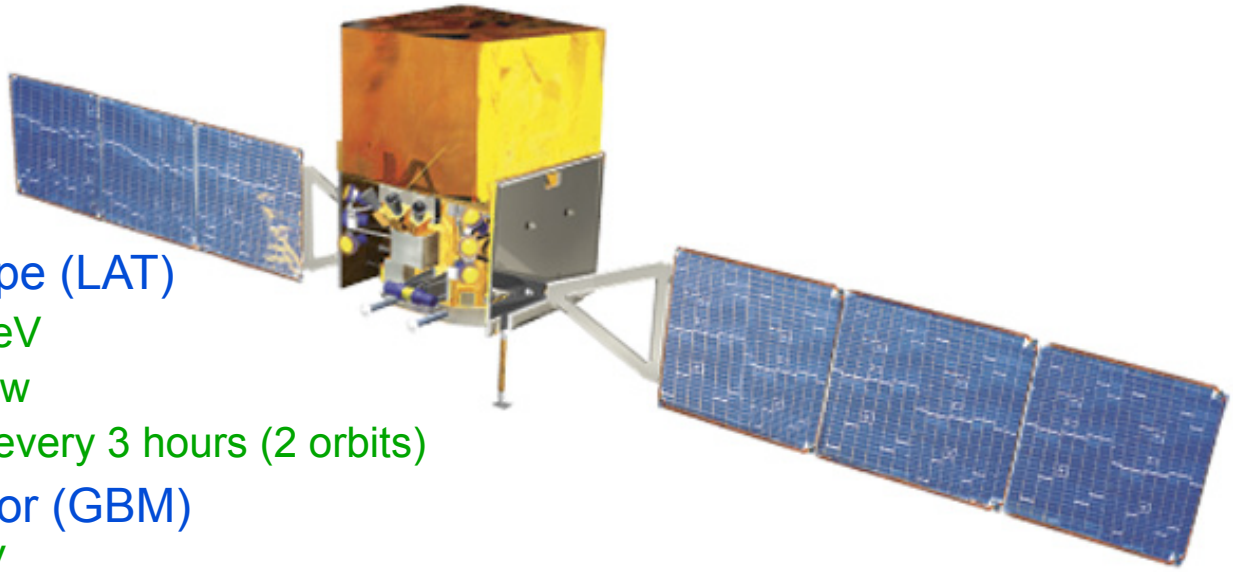


GLAST Large Area Telescope
Data Acquisition in Low Earth Orbit

Advanced Instrumentation Seminar
20 August 2008 (L+70)

Gregg Thayer
Stanford Linear Accelerator Center

Introduction to GLAST



- GLAST Observatory
  - Large Area Telescope (LAT)
    - 20 MeV to 300 GeV
    - > 2 sr Field of View
    - Scans entire sky every 3 hours (2 orbits)
  - GLAST Burst Monitor (GBM)
    - 10 keV to 30 MeV
    - 9 sr Field of View
  - Spacecraft Platform (SC)
    - Responsible for thermal survival of instruments
    - Provides Power
    - Controls pointing
    - Reports position, attitude, and time to LAT
    - Stores science data and housekeeping data in between downlinks
    - Command interface to ground (stored and real-time)
- 5 Year Mission (10 Year Goal)
  - Launched 11 June 2008 (yay!)

Pair Conversion Telescope Design

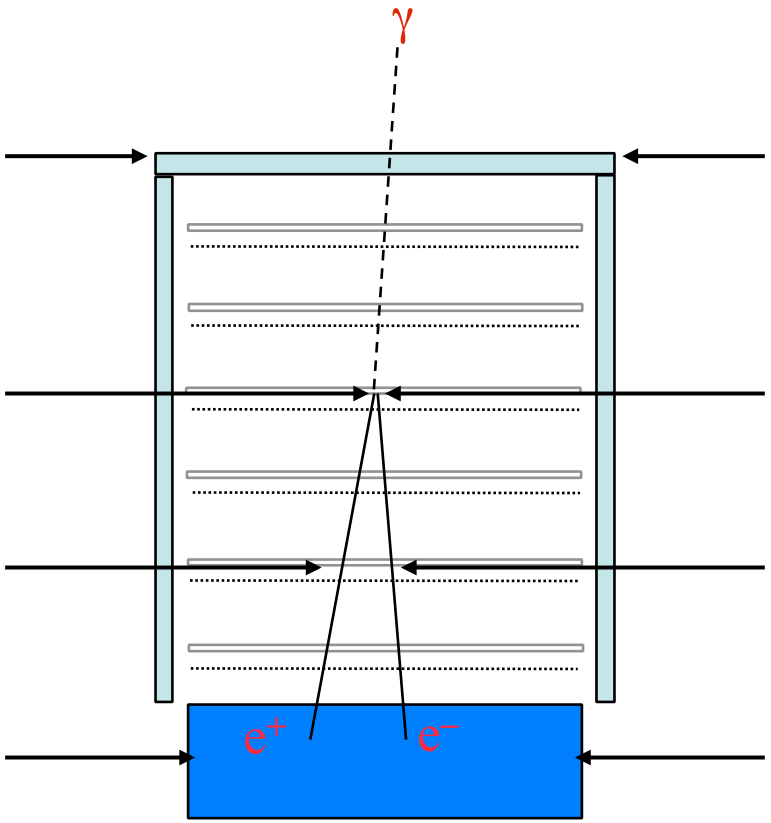
Component

Anti-coincidence detector vetoes incoming charged particles.

Photon converts to e+e- pair in conversion foil.

Direction of the resulting charged particles is measured in tracking detector, tracks then point back to source.

Energy of resulting shower is measured in calorimeter.



Design Drivers

Must have high efficiency for rejecting charged particles w/o vetoing photons.

Foil thickness balances multiple scattering at low energies with conversion probability at high energies.

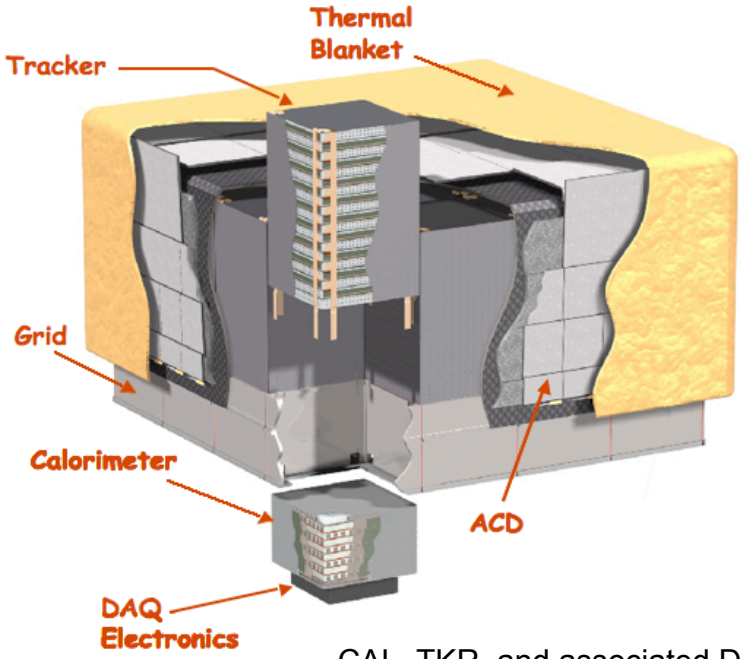
High energy position resolution requires fine pitch tracking detectors

Energy range and energy resolution requirements bound the thickness of calorimeter

Aspect ratio (height/width) determines the Field of View

Introduction to the LAT

- Precision Si-strip Trackers (TKR)
  - 18 X/Y tracking planes
    - Single-sided silicon strip detectors
    - 228 μm pitch, ~900k strips
  - Tungsten foil converters
- Hodoscopic CsI Calorimeters (CAL)
  - Array of 1536 CsI(Tl) crystals in 8 layers
- Segmented Anticoincidence Detector (ACD)
  - 89 plastic scintillator tiles
    - Segmented to mitigate self-veto effects at high energy
- Trigger and Dataflow System (DAQ)
  - Hierarchical trigger with level 0 and level 3
  - Distributed event processing
  - Integrated with slow control
- Flight Software (FSW)
  - Configures the instrument
  - Controls data taking
  - Performs charge injection calibration
  - Performs onboard science
  - Can be updated during mission



CAL, TKR, and associated DAQ are segmented into 16 identical Towers mounted on the GRID.

Event Environment (designed for)
- Trigger rate 3-4 kHz (peak: 10-13 kHz)
- Average event size: 1-2 kB (un-compressed)
- Average event size: 400 Bytes (compressed)
- Downlink event rate: ~300 Hz
- Minimum deadtime: 27 μs/event

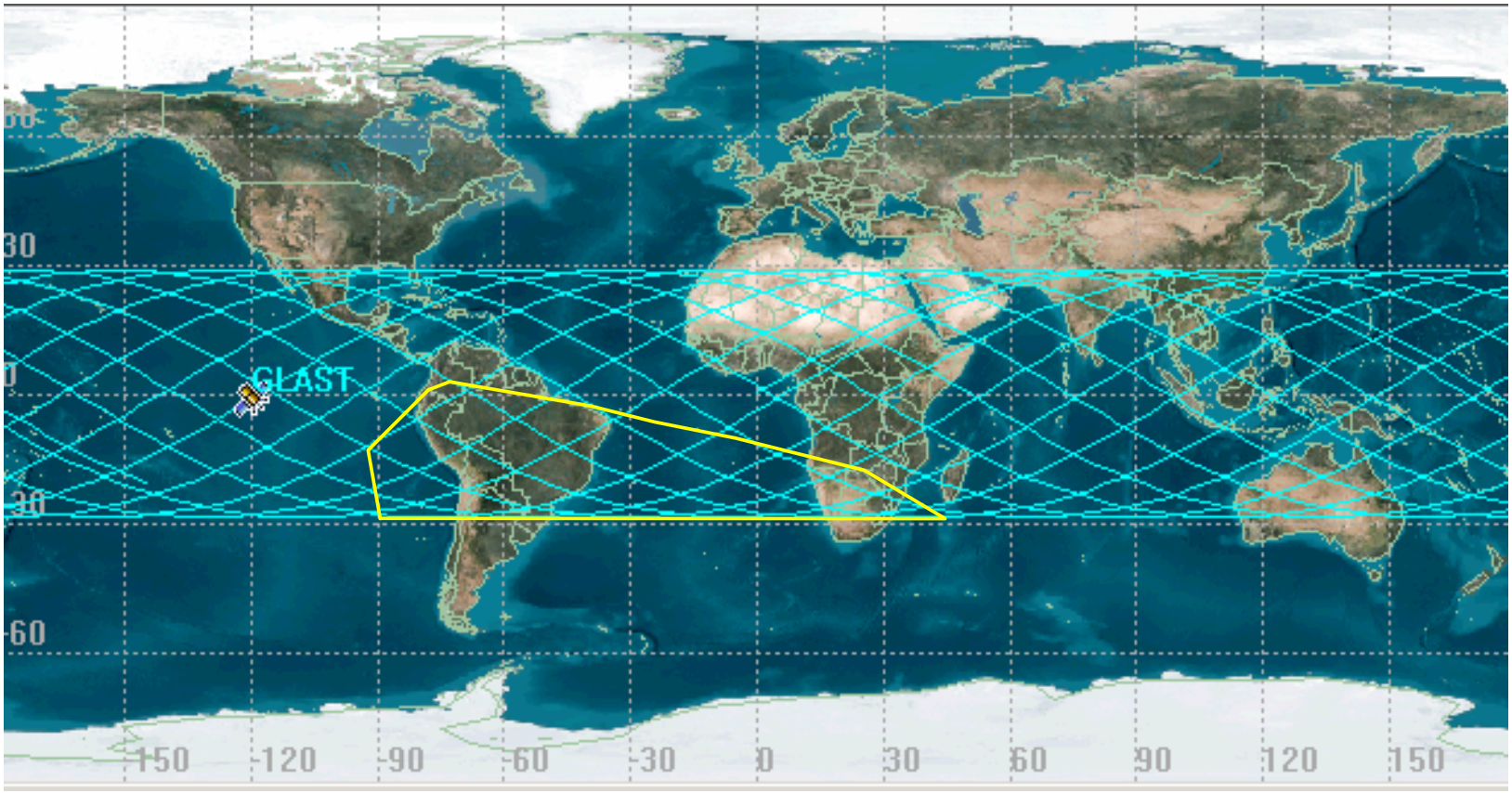
Orbit Constraints on DAQ System

- Power Budget 650 W
  - – Set by size of thermal radiators
  - → Restricts processor power
- Electromagnetic Interference on Orbit
  - – Must not generate EMI
  - – Must not be susceptible to EMI
  - → Instrument must be EMI tested at all levels of integration
- Ionizing Radiation
  - – Must survive total Ionizing dose over 5 years of 4.5 kRad
  - → Use radiation tolerant components and design
- Data Bandwidth < 1.2 Mbits/sec on average
  - – Expect 10-12 minute ground contacts 6-8 times per day
  - → Sets required level of background rejection
- Access to LAT impossible on orbit
  - → Design must be tolerant of component failures
  - → No single point of failure allowed to impair fulfillment of requirements

DAQ in Low Earth Orbit 5

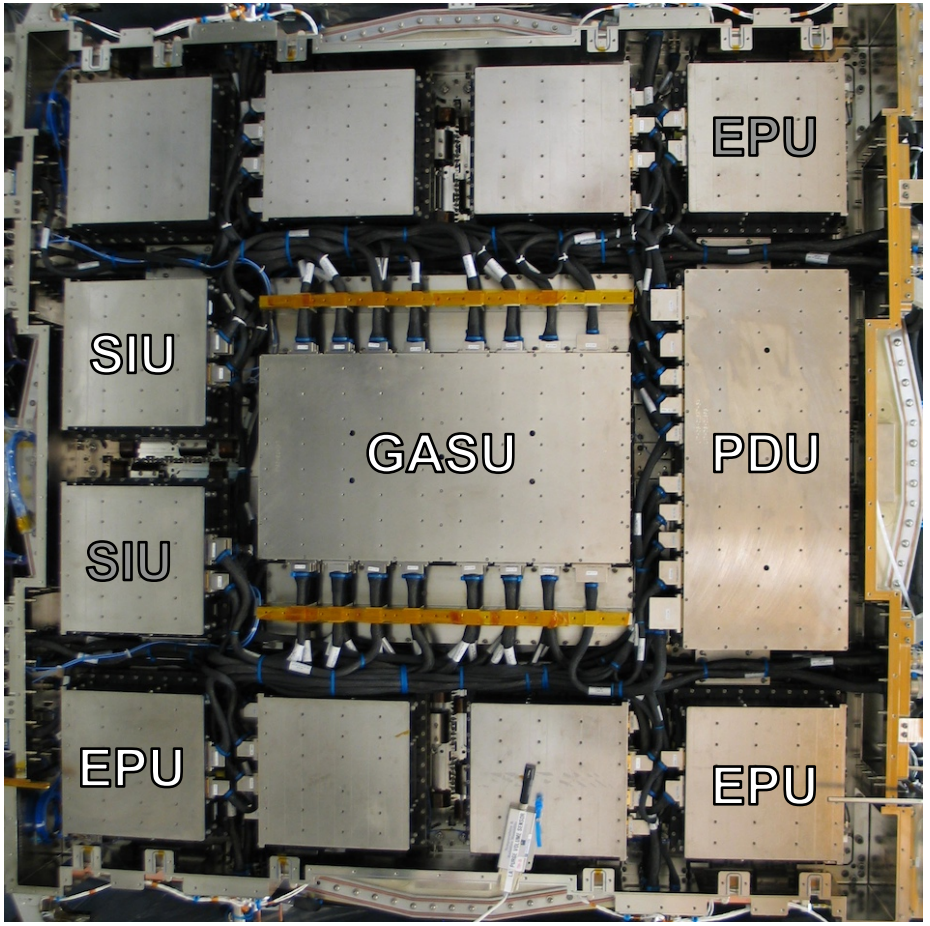
GLAST Orbit

- Inclination 25.6°, Altitude 560 km
- Period 90 minutes, orbits alternate ±35° from zenith attitude
- Data is not taken in South Atlantic Anomaly (SAA)



Trigger and Dataflow System

- Tower Electronics Modules (TEM)
  - Control, monitoring, data collection for CAL and TKR
- GASU
  - Communications hub of the LAT
  - Global trigger (level 0)
  - Event builder
- Spacecraft Interface Unit (SIU)
  - FSW instrument control
- Event Processing Units (EPU)
  - Event filtering (level 3)
  - Data compression
- Power Distribution Unit (PDU)
  - Power control and monitoring
- Box Level Redundancy
- Signals that communicate between boxes can be masked at the input and output
  - Prevents stuck signals from hanging up system

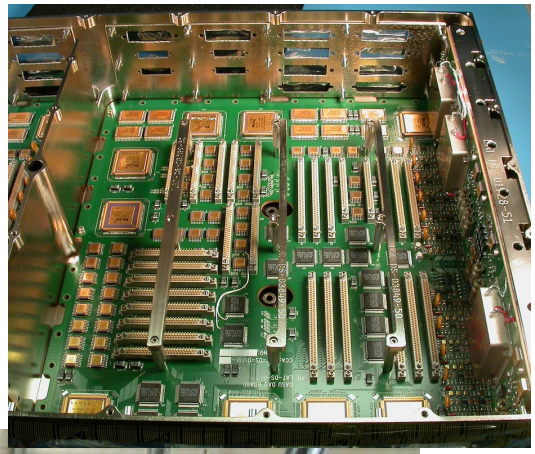


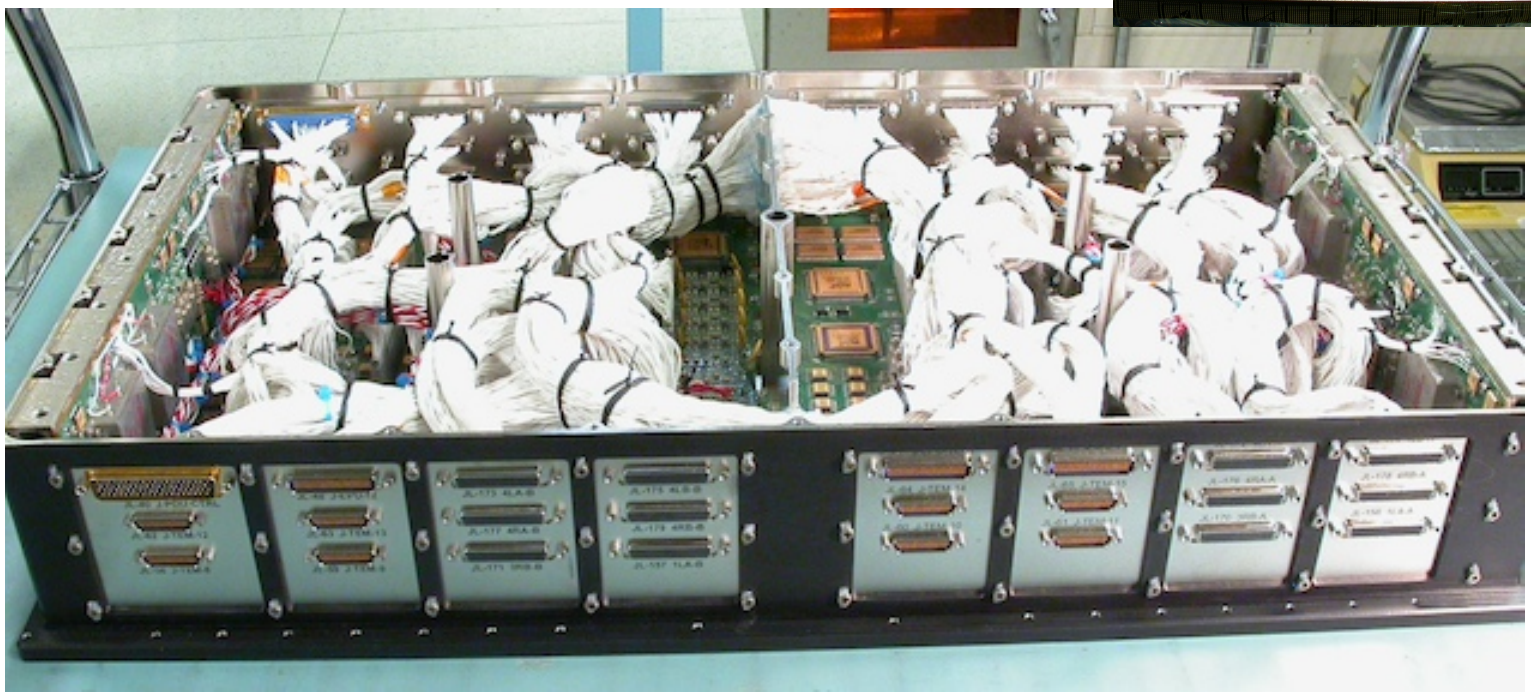
A note about components

- Components without “Space Heritage” are subject to Flight Qualification
  - Flight Qualification = Paperwork + Meetings + $$$$
    - Process must be qualified
    - Design must be qualified
- Actel Radiation Hard RT54SX-SU FPGA
  - Device has Space Heritage
    - 32k and 72k gate models
    - Triple module redundancy (for some structures)
    - One-time programmable anti-fuse interconnects
  - LAT specific designs required Flight Qualification process
    - 15 different designs (67 instances)
- Commercial ADC
  - Flight Qualified for this mission
    - Only ADC part used throughout LAT (over 4000 instances)
- Custom ASICs used
  - 9 varieties, over 15k instances
    - All used same process (only had to qualify the process once)

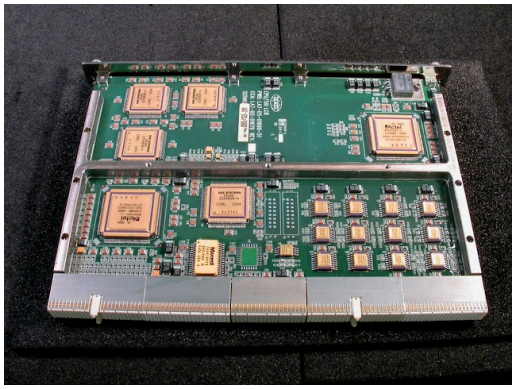
GASU

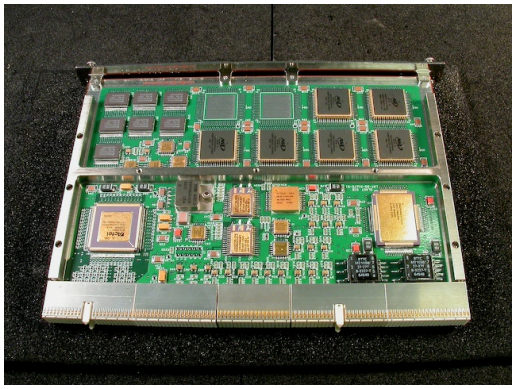
- GASU contains 4 separate components
  - ACD Electronics Module (AEM)
  - Global Trigger Electronics Module (GEM)
  - Event Builder Module (EBM)
  - Command Response Unit (CRU)
  - Also home to the LAT 20MHz system clock

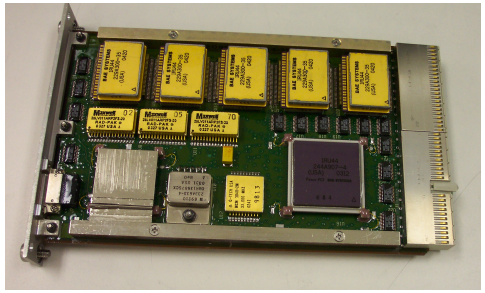


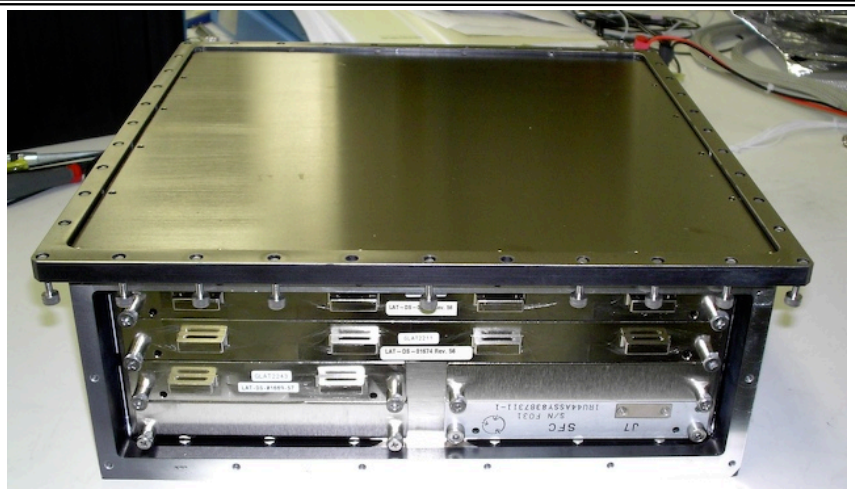


SIU and EPU







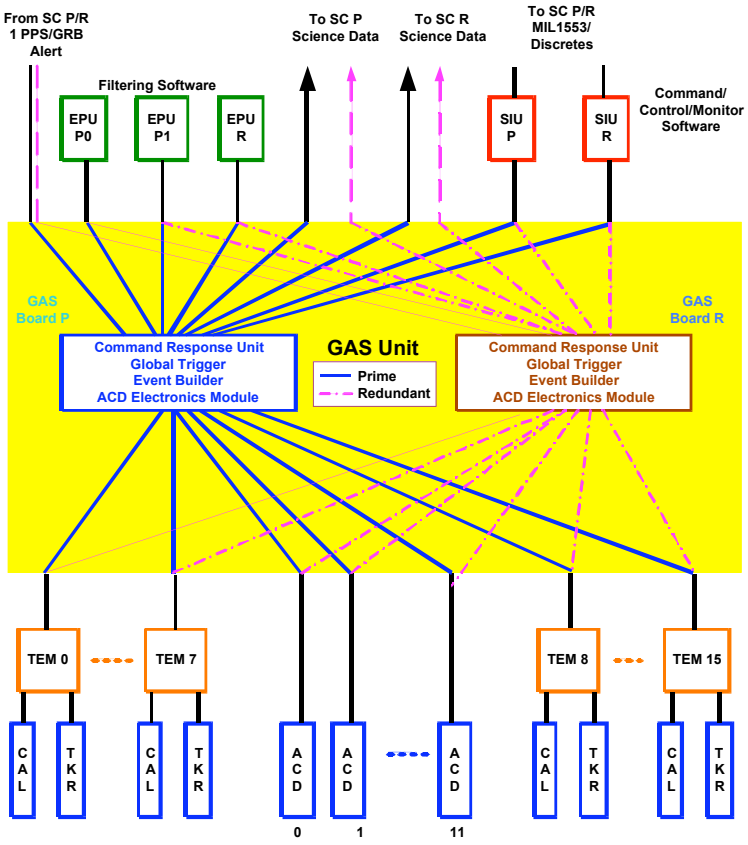


- SIU and EPU are identical
  - cPCI based
  - VxWorks operating system
  - Flight Software is distributed system over 3 active crates
- LAT Communication Board
  - Connects 20 MHz LAT clock domain to 33MHz cPCI
- Storage Interface Board
  - 6 Mb of EEPROM in 2 banks
  - 1553 interface used to communication w/ SC on SIU
- BAE RAD750 Processor
  - 750 class Power-PC
  - ~90 MIPS at 116 MHz (in typical applications)
  - < 12 W
  - 128 MB main memory
  - 256 KB SUROM
  - Radiation tolerant

Communication Fabrics

- Slow Control - Command Response Fabric
  - Bit wide bus distributed by the CRU
    - Transmissions are composed of 128 bit cells
    - Transmissions at 20 Mbits/s
  - Connects SIU to all LAT Electronics Modules
    - Includes sub-detectors and EPUs
  - Used to configure the LAT for data taking
    - Register access to all sub-detector components
  - Used to monitor housekeeping quantities
    - Temperatures, Voltages, Currents, Counters

- Event Processing - Event Fabric
  - Bit wide bus connecting sub-detector components and SIU/EPU to EBM
    - Transmissions are composed of 128 bit cells
    - Event transmissions to EBM at 20 Mbits/sec
  - Byte wide bus connecting EBM to SIU/EPUs and SSR
    - Transmissions are composed of 128 byte cells
    - EBM to SIU/EPUs transmissions at 20 MB/s
    - EBM to SSR transmissions at 40 Mbits/s
  - Connects SIU/EPUs to each other
    - CPU monitoring and synchronization
    - Onboard Science

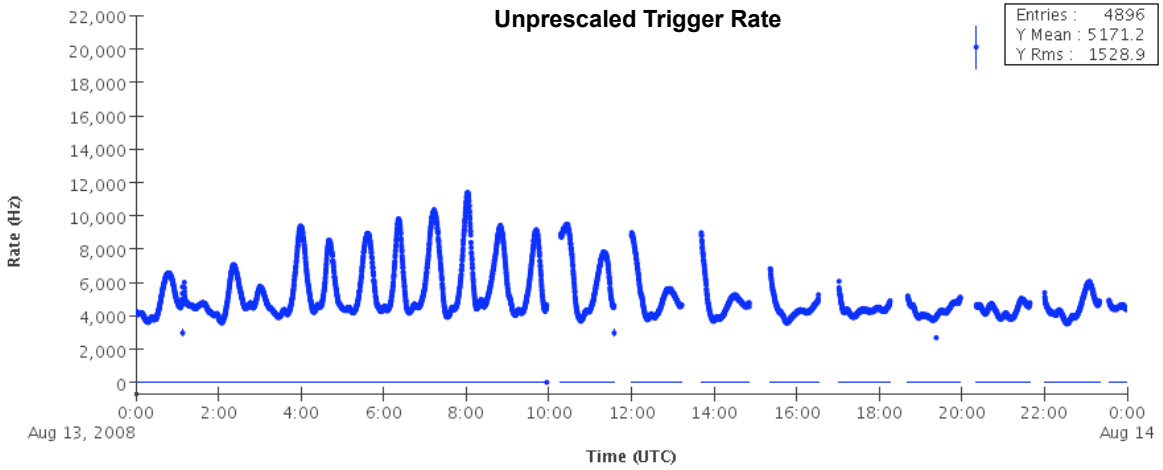


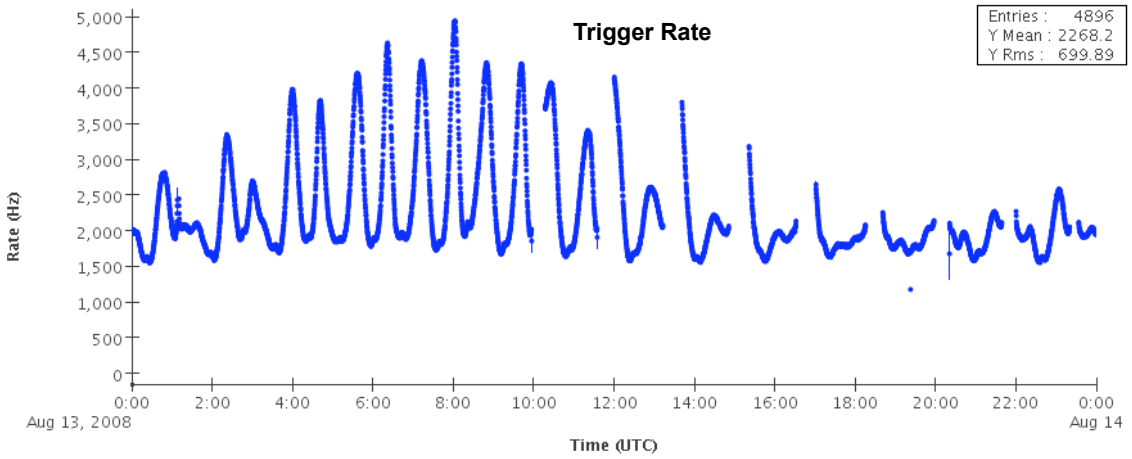
Global Trigger

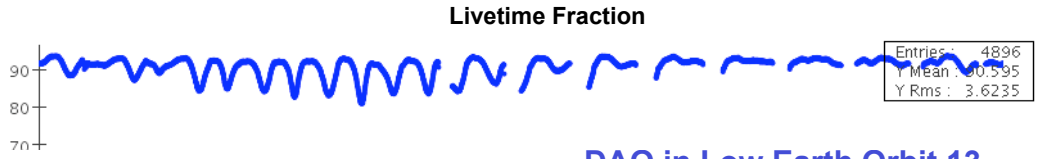
- Combines trigger primitives using a programmable length integration window
  - TEM
    - TKR 3-in-a-row, CAL high and low energy
  - ACD
    - CNO (ACD high level)
    - Veto (ACD low level)
      - An arbitrary combination of ACD tiles form each of 16 Regions of Interest
      - Each ROI can negate the presence of a TKR trigger in its associated tower
  - Periodic triggers can be generated by the global trigger
  - Triggers can be solicited by command
- Trigger primitives are sampled on each tick of the 20 MHz system clock.
  - Trigger is configured with which primitives are allowed to open the trigger window
- The combination of trigger primitives present during the trigger window are mapped to one of 16 trigger engines by a simple look up table
  - Each trigger engine can be configured to initiate a different type of readout
    - Non-zero suppressed
    - CAL 4-range readout
  - Each trigger engine can be prescaled in hardware
- Global trigger is responsible for timing measurements and statistics
  - Livetime
  - Event time

Trigger Performance

- Event rate is dominated by background
  - Background rate varies by more than a factor of 2 over a day
  - Due to variation in protection afforded by Earth's magnetic field
  - GEM is configured such that charged particle background is heavily prescaled
- Gaps in data are due to SAA
- Deadtime is dominated by detector readout
  - More on this later…

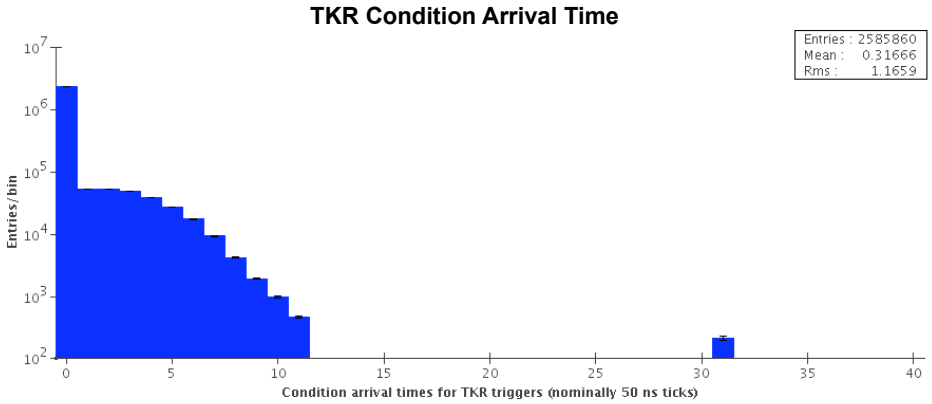


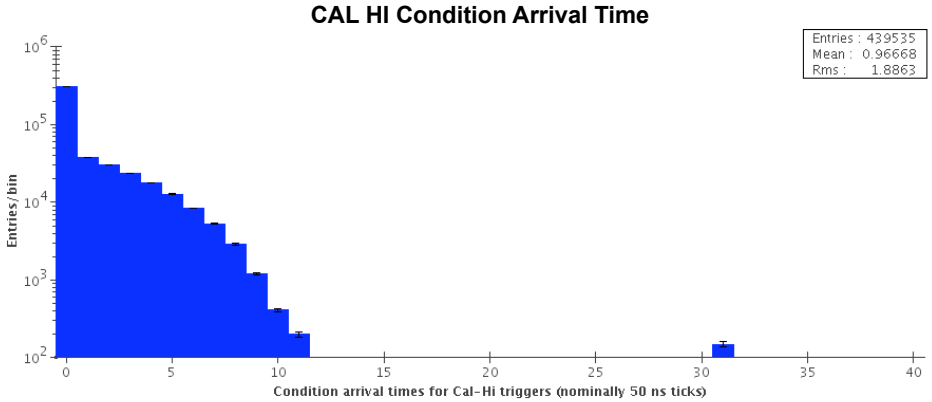


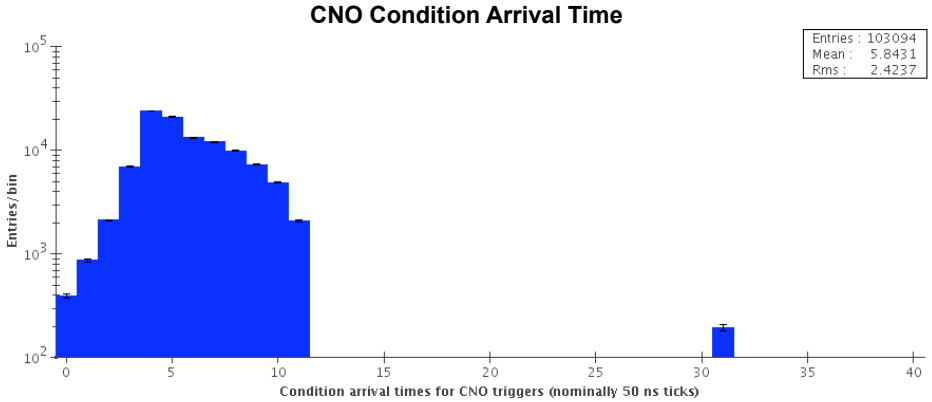


"Online" Trigger Monitoring

- With every event the arrival times of each of the trigger primitives is recorded
  - Histograms are created/reviewed for every run (orbit)
  - Allows us to monitor for timing drift
  - Timing of the primitives are set relative to the TKR
- The integration window of 12 ticks is apparent







Event Readout

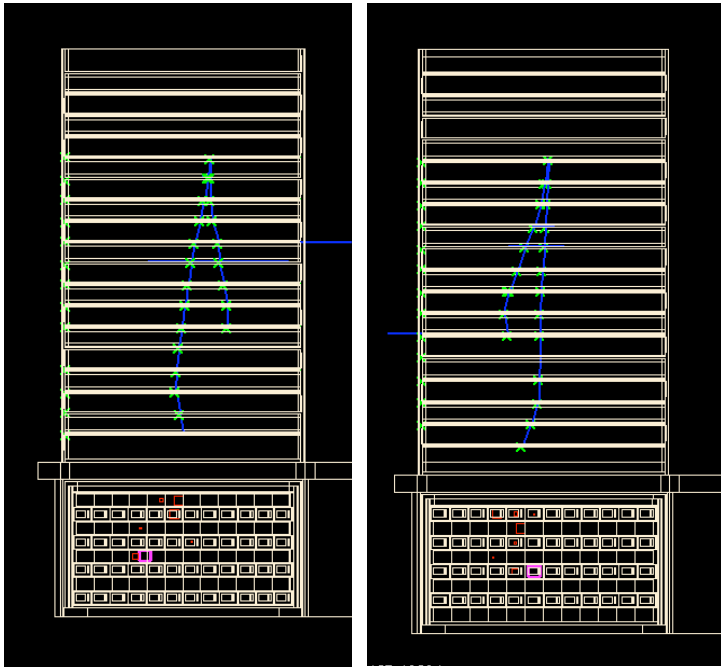
- Upon successful triggering (non-prescaled) the GEM
  - Transmits a trigger accept message to each of the TEMs and AEM
    - This message includes the type of readout being requested
  - Builds its own contribution to the event
- Minimum deadtime per event is ~27 μs
  - Time required for GEM to build and transmit its event contribution
  - Depending on readout mode, the CAL can contribute much more deadtime
    - Non-Zero Suppressed events
    - 4 Range Readout
  - TKR front end can buffer up to 4 events without contributing to deadtime
  - Because CAL zero suppression is done in the TEM, there is no data buffering in the CAL front end
- TKR and CAL data are buffered in the TEM
  - TEM then constructs its event contribution from these buffers
  - Buffer depths are configured such that they can accept a maximum size event
    - This is made possible by limiting the number of TKR hits which can be sent by each TKR layer end
- AEM reads out the ACD and forms its event contribution
- Event contributions from GEM, TEMs, and AEM are forwarded to the Event Builder

Event Processing

- The EBM receives and buffers the event contributions from the GEM, TEMs, and AEM
- It then constructs the event and passes it on to the EPUs
  - In normal operation, events are sent to two EPUs alternatively
- The event filter then decides whether the event should be sent to the ground or not
  - EPUs collect events in a circular buffer for processing
  - EPUs capable of compressing output data
- The EBM is also responsible for transmitting events from the EPUs to the solid state recorder on the spacecraft
- Flow control model is one of backpressure and trigger throttle
  - If both EPUs back up, then the data fills the circular buffers
  - Then the the EPUs assert backpressure to the EBM
  - The EBM asserts backpressure to the TEMs and AEM
  - When the TEM cannot accept any more data it throttles the trigger

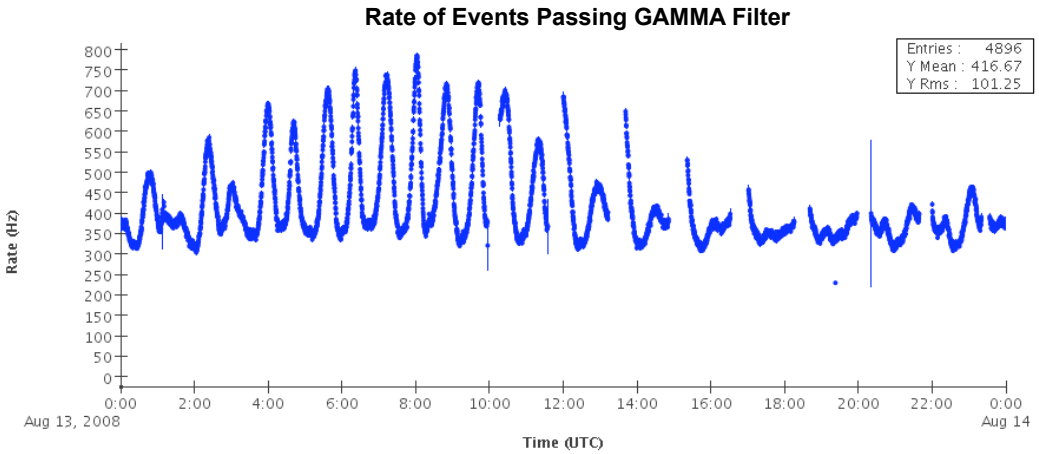
Event Filtering

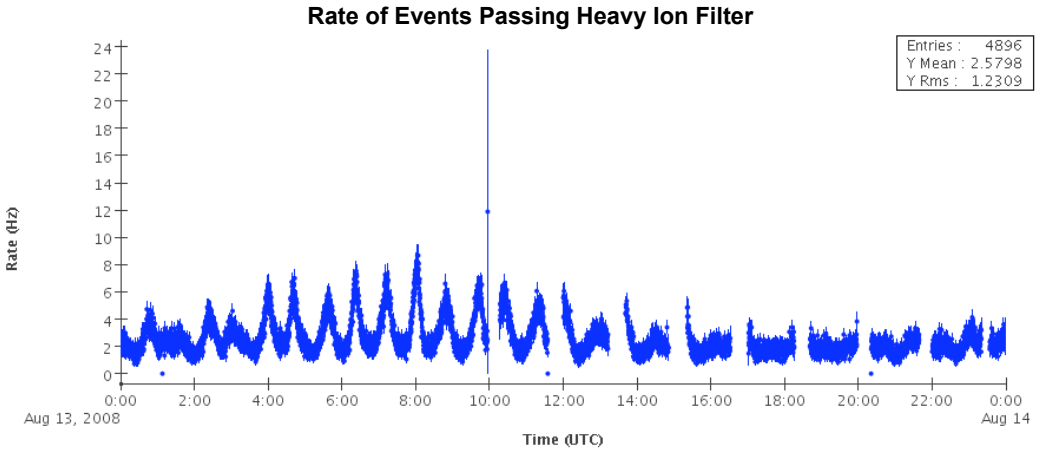
- Event filters work fast
  - Event filters only locate and bring in to cache as much of event as is needed to dispose it
    - Events can arrive in multiple packets
    - RAD750 CPU-memory latency is poor
    - Most events are rejected by the GAMMA filter using only the GEM contribution (first contribution in event)
  - All integer arithmetic on EPUs
  - Tracking is done in 2-D only
- Event filters don't duplicate effort
  - If two filters need tracking information or energy reconstruction this information is only calculated once, and stored until the event is disposed
- Same infrastructure can be used to for other purposes
  - Event monitoring and statistics gathering

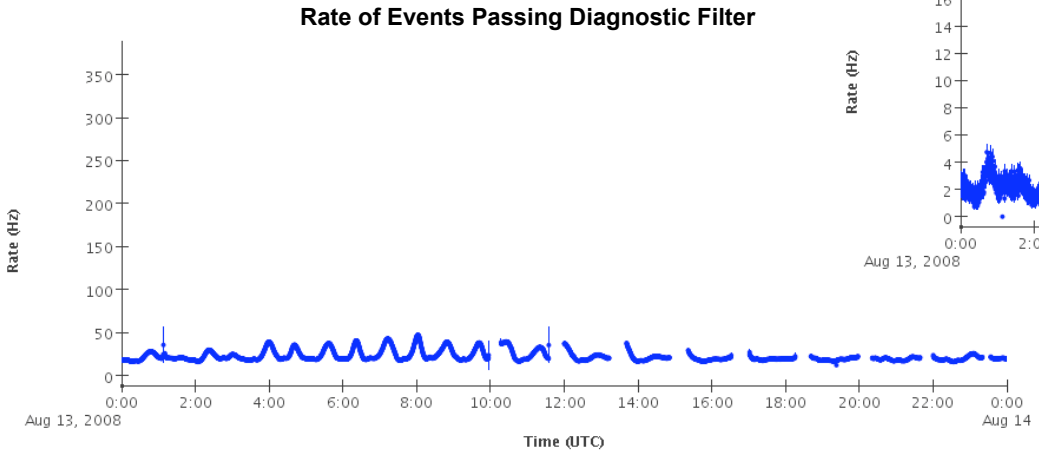


Event Filter Performance

- GAMMA filter is the main science filter
  - Designed to be loose
    - Designed to utilize full allowed bandwidth
      - And then some! (see next slide)
    - Dominated by background
  - Minimizes photon rejection at the expense of downlink bandwidth
    - Actual photon rate Is a few Hz
- Other filters used to collect diagnostic event samples
  - Charged particles for calibration
  - Unbiased sample for offline studies

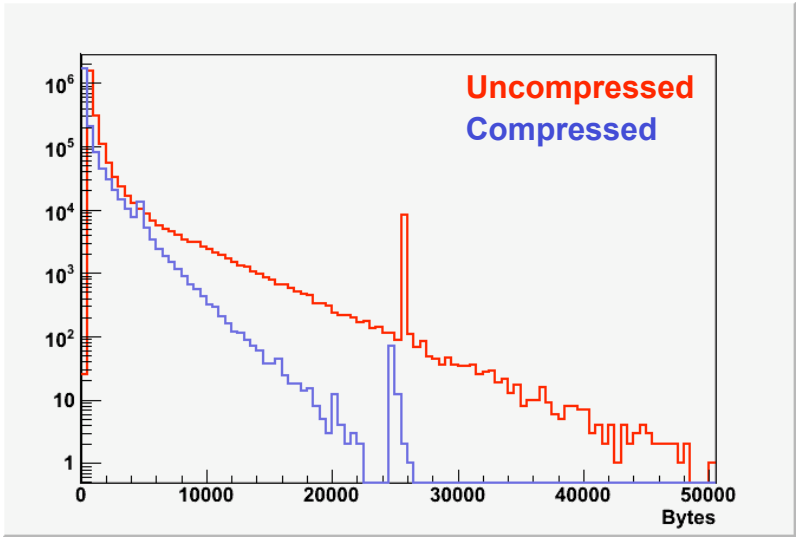


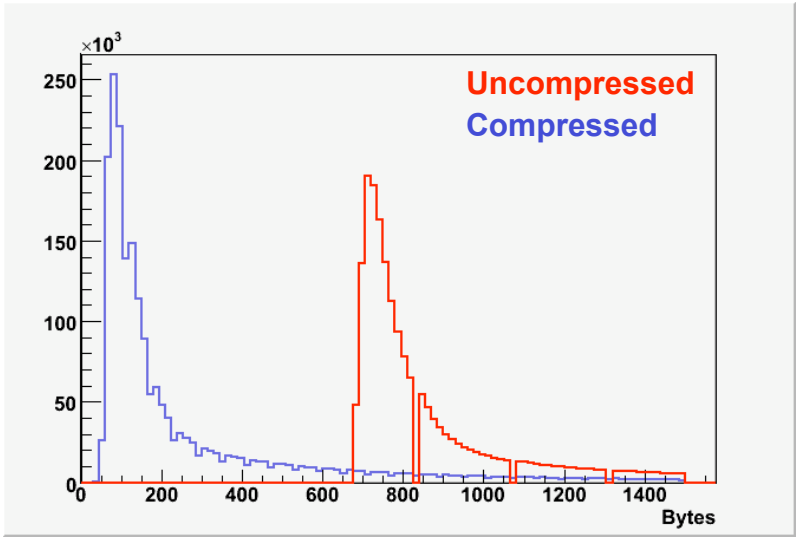




Event Compression Performance

- Event compression is critical to meeting bandwidth requirements
  - Compression reduces average event size from ~1400 to ~480
- Current LAT science bandwidth requirement
  - 104 Gbits/day or 1.2 Mbits/s
  - The LAT is currently overproducing in its nominal science configuration
    - Producing ~130 Gbits/day or 1.5 Mbits/s
  - The LAT collaboration is pursuing various means of dealing with this
    - Reducing the LAT data volume
    - Changing the requirement
- Breakdown of LAT data volume
  - Gamma Filter: 120 Gbits/day
  - Other Filters: 10 Gbits/day
  - Other information
    - Filter statistics
    - Hardware rate counters
    - Position and Attitude information





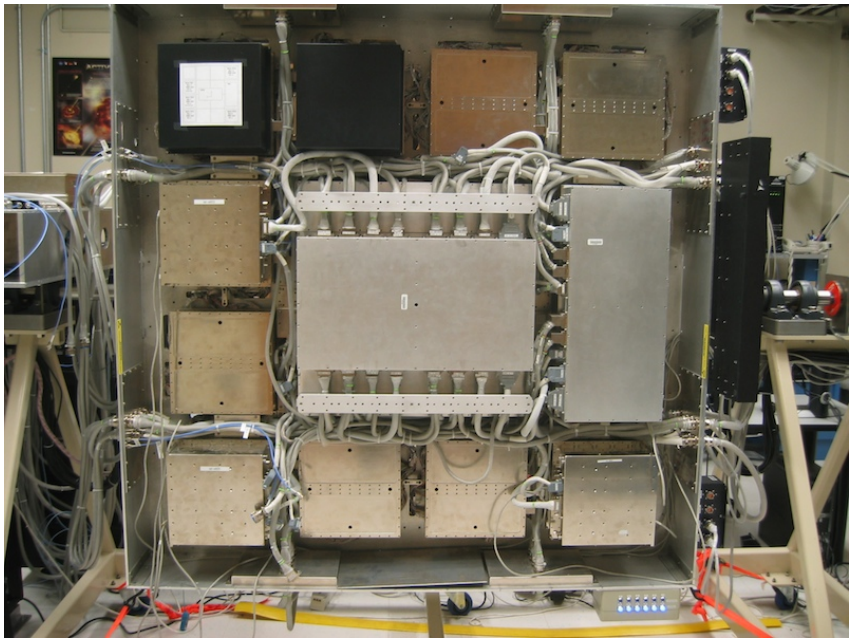
Onboard Science (GRB Detection)

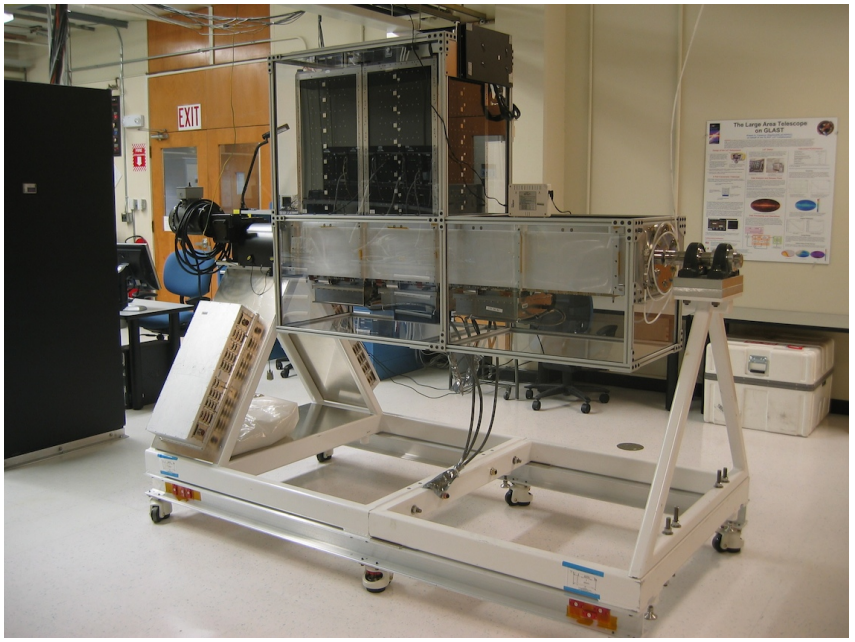
- EPU processing
  - Photon candidates are chosen from the event stream
    - Pass the GAMMA filter and contain at least one track
    - Direction, energy and event time are sent to the SIU
- SIU processing
  - Photon candidates
    - SIU merges photon candidate streams from the two EPUs
    - Uses SC attitude to transform direction from LAT coordinates to J2000
  - GRB detection algorithm
    - Cluster finding to seed probability calculations
      - Can use GBM localization as seed position
    - GRB detection algorithm calculates the probabilities
      - That photons came from the same point
      - That the photons arrived close in time
    - If GRB confirmation threshold is exceeded LAT can send a request to the spacecraft to dwell on GRB location for 5 hours

Ground Support

Dataflow Lab at SLAC contains equipment to support ongoing FSW development and testing

- LAT Testbed
  - Complete Data Acquisition System
  - Front End Simulator which can inject Monte Carlo events into TEMs
- LAT Calibration Unit
  - Two full flight spare towers in a rotating stand
  - Can be used for tests which require real detector elements and electronics





GLAST Mission Status

- 11 June, 1605 UT
  - Launch from Pad 17B Cape Canaveral Air Force Station
- 11 June, 1720 UT
  - GLAST separated from the second stage
  - Entered circular orbit at 560 km altitude
- 24 June, 1059 UT
  - LAT power on began
- 25 June, 1057 UT
  - First LAT Physics Acquisition
- 24 July, 1425 UT
  - LAT Collaboration reports “Detection of extraordinary gamma-ray activity in 3C 454.3”
- 8 August, 0002 UT
  - LAT Collaboration reports “Detection of a possible new gamma-ray flaring blazar: PKS 1502+106”
- 11 August
  - 60 day checkout period ended
  - Commissioning has gone remarkably smoothly
  - LAT in nominal science configuration
  - Admittedly, some tweaks remain
- 26 August, 1800 UT
  - NASA press conference
  - Release of “First Light” image and early results
  - Renaming GLAST
  - Streamed live at http://www.nasa.gov/newsaudio

DAQ in Low Earth Orbit 22