LAT On-Orbit Performance at 10 Years

Robert A. Cameron (SLAC), J. Eric Grove (NRL), Hiro Tajima (Nagoya U), Donggeun Tak (UMd)
on behalf of the *Fermi* Large Area Telescope Collaboration

Abstract

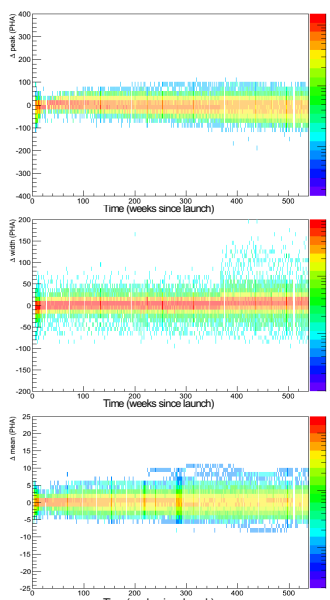
The *Fermi* observatory, and the Large Area Telescope (LAT) on *Fermi,* were designed and built with an operating lifetime goal of 10 years. The *Fermi* LAT now has been successfully operating in low Earth orbit almost continuously since its initial turn-on on 24 June 2008, for over 10 years. Details are presented of the current performance of the LAT detector and data acquisition sub-systems together with long-term trends of key performance measures and we assess their expected future performance. Future staffing support for routine ground-based LAT operations is being moved from SLAC to NASA and the Collaboration.

Anti-Coincidence Detector

- All 89 ACD scintillator tiles and both readout channels from all ACD tiles are operating well
  - Some noise is seen infrequently on one PMT readout channel of one ACD tile
- One ACD ribbon end (of 8 scintillator ribbons between ACD tiles) has been non-responsive since 2008
- No light leaks have been detected
- Electronic pedestals drift is about 0.01% per year
- Electronic gain drift is about 0.4% per year

- No change of any PMT bias voltage has been performed since launch, and no bias voltage update is planned for the foreseeable future.

Future performance: trends are small and stable. Overall ACD performance is stable, and expected to remain stable.



Trend of ACD channel gain from MIP peak fit with time

Trend of ACD channel MIP peak fit width with time

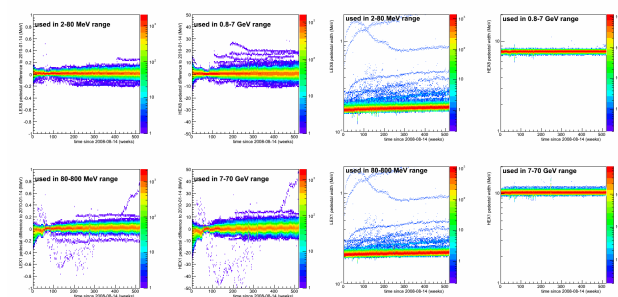
Trend of ACD channel electronic pedestal with time

Calorimeter

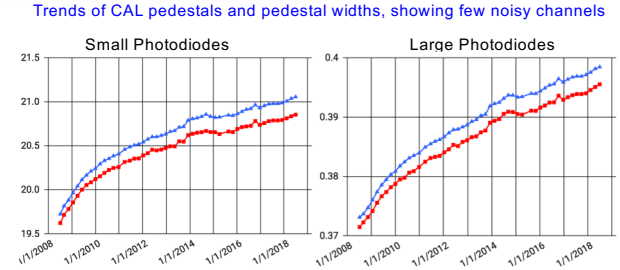
- All 1536 CsI crystal logs in the CAL are alive and calibrated
- One CAL pre-amplifier of 6144 is dead, since July 2010, in Tower 4, Layer 2
- Disabled low (FLE) and high (FHE) energy triggers from the associated Tower 4 CAL front end (GCFE) in August 2017
- All data suppression discriminators are alive and set with correct thresholds
- Only 12 of 6144 readout channels show excessive out-of-family front-end noise

Decrease of light yield in CsI crystals in the CAL due to cumulative radiation dose since launch has produced ~6% gain change. Also associated increasing light attenuation along each CsI crystal. Gain changes, in "MeV per DAC unit", and asymmetric end-to-end position bias changes are each calibrated over time and compensated for in ground processing of CAL data.

Future performance: trends are stable or slowing. Overall, the CAL performance is stable and within specification, and is expected to remain stable.



Trends of CAL pedestals and pedestal widths, showing few noisy channels



Trends of average (blue) and median (red) "MeV per DAC unit" gain calibrations for large and small photodiodes on 1536 CsI logs in the CAL

Data Acquisition

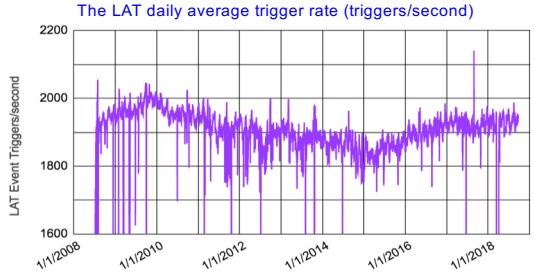
- 613 billion event triggers on the LAT since launch. Average trigger rate is ~1900 triggers/second.
  - On-board software filtering of triggered event readouts in the LAT reduces the average rate of events delivered to *Fermi* and then to the ground to about 400 Hz
  - 123 billion LAT event readouts have been sent to the ground for processing and analysis, resulting in 1.16 billion source-class photons

- Average LAT output data rate is ~1.5 Mbps
  - Rate decreases during calibrations or LAT resets
  - Rate increase spikes shown are typically due to *Fermi* repoints for GRBs or Targets of Opportunity
- Almost no data generated by the LAT is lost, thanks to support by NASA's *Fermi* Flight Operations Team
  - More than 99.99% of LAT output data are successfully delivered to the ground

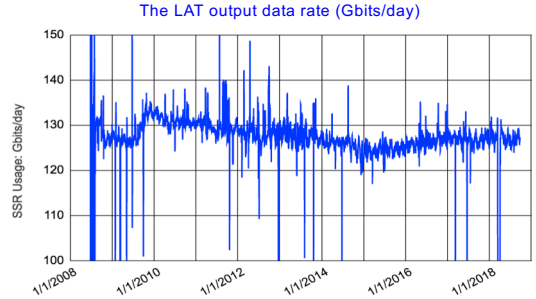
- There have been no hard failures of LAT data acquisition and detector electronics since launch.
- The LAT on-board computers have had 20 software updates since launch, for bug fixes and performance improvements
- Occasional electronics upsets have occurred and have been mitigated through operations changes
  - Single bit and double bit memory errors, all recoverable, routinely occur in the LAT onboard computers. These generally occur as *Fermi* passes through the high-background South Atlantic Anomaly region shown in green

Future performance: All electronics temperatures, voltages and currents are stable. No major failures or performance changes are expected to occur in the near future.

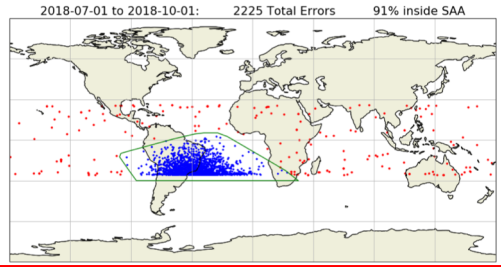
The LAT daily average trigger rate (triggers/second)



The LAT output data rate (Gbits/day)



LAT CPU memory errors in a recent 3-month period



Acknowledgements This work is supported by Stanford University and the SLAC National Accelerator Laboratory under DOE contract DE-AC03-76SFO0515 and NASA grant NAS5-00147. Non-USA sources of funding also support the efforts of *Fermi* LAT science collaborators in France, Germany, Italy, Japan and Sweden.

Tracker

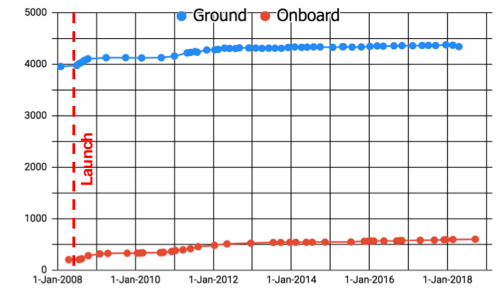
- Each Tracker (TKR) tower has 36 Si strip layers, with each layer having 1536 strips, for a total of 884,736 TKR strips in the LAT
- TKR readout uses 15k ASICs, with only 1 failed ASIC in tower 12, which failed before launch and has been reconfigured around to avoid any loss of TKR readout
- Average strip noise occupancy is 8x less than the design requirement
- Noisy strips can be electronically masked off in the LAT
  - 203 strips were masked on the LAT at launch, and another 399 strips have been masked since launch, mostly in Tower 0 (early mission) and in one Si ladder of Layer 35 in Tower 3 (since 2010).

- The LAT also has dead strips, often due to disconnected or unresponsive pre-amps
- The set of dead + noisy strips is trended and recorded in the LAT calibration database for use in LAT ground data processing
- The latest TKR bad strip calibration shows 4343 dead or noisy strips in total (0.49% of the TKR)
- Tower 0 (Flight Model A), the first tower made, has the highest number of bad strips, but still meets performance specification

- A slow increase in TKR leakage current (mA) is seen over the mission duration. It is expected, due to cumulative radiation dose in the Si layers. Leakage current has increased most in TKR tower 3, since 2010. The bias voltage power supplies have plenty of power margin for the expected remaining mission.

- Trending Noise Occupancy for layer 35 of TKR tower 3 shows early mission noise due to a few very noisy Si strips, then increasing noise since 2010, reduced by mask updates

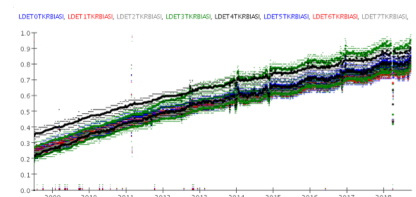
Future performance: TKR trends are stable or slowing. No increase in degradation rates is foreseen in the near future. Overall, the TKR performance is stable, and expected to stay so.



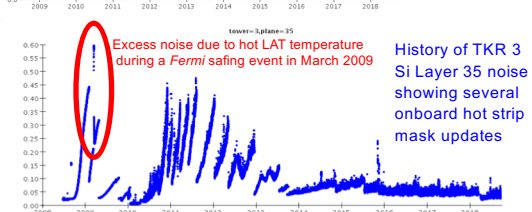
History of TKR Onboard and Ground masked strip counts

12 FM6 34 162	13 FM4 8 235	14 FM10 21 63	15 FM11 12 67
8 FM5 23 149	9 FM3 10 344	10 FM7 27 83	11 FM9 17 55
4 FMB 7 355	5 FM1 15 420	6 FM12 19 58	7 FM13 17 55
0 FMA 111 1660	1 FM2 5 247	2 FM14 18 66	3 FM15 258 324

Map of number of dead or noisy strips for ground data processing (green) and onboard masked noisy strips (black), per TKR tower.



Trend of bias current per TKR tower



History of TKR 3 Si Layer 35 noise showing several onboard hot strip mask updates