Search for Terrestrial Gamma-ray Flashes with Fermi LAT

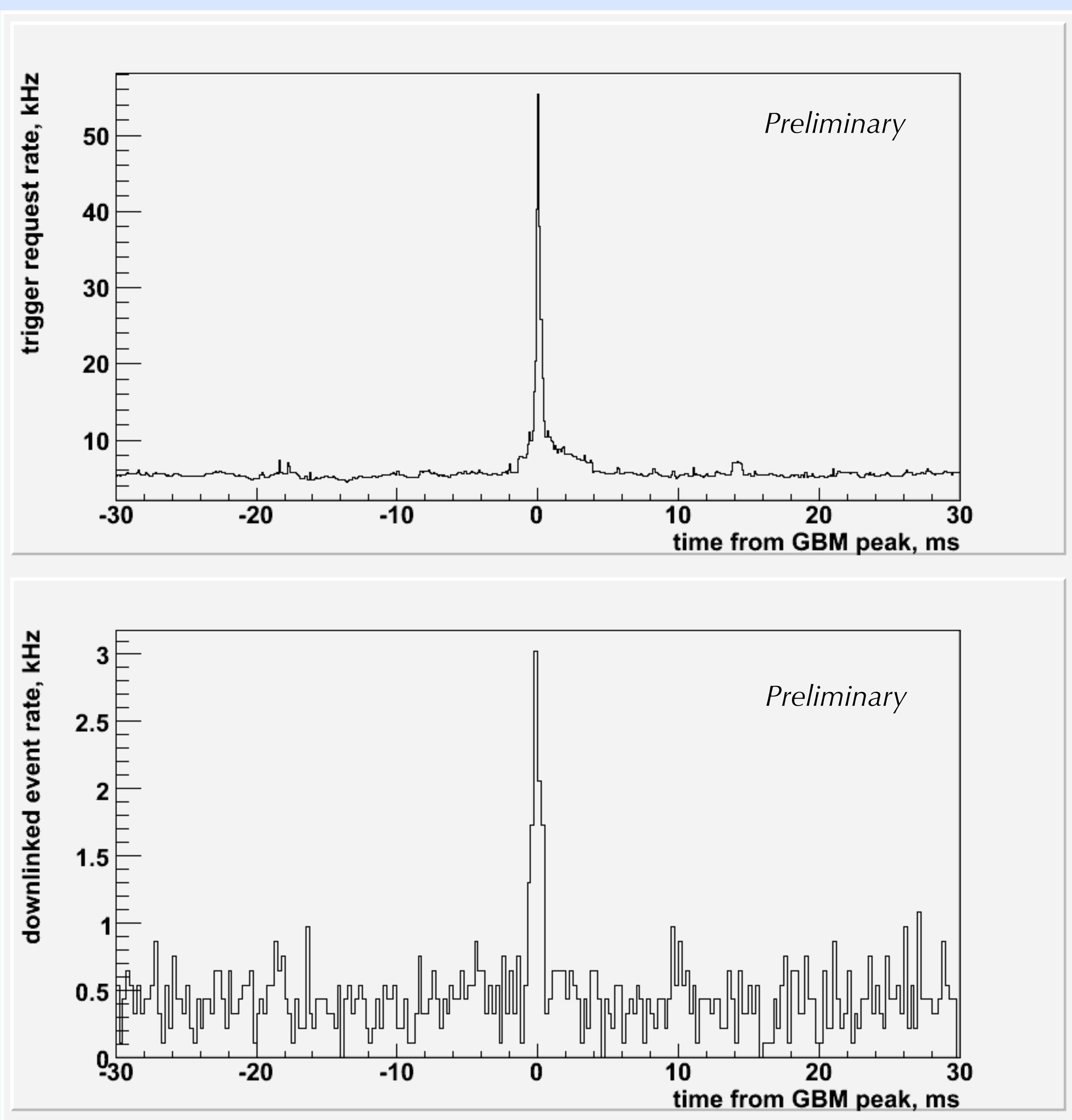
J.E. Grove, A. Chekhtman, J. McEnery, N. Omodei, and F. Longo on behalf of the Fermi LAT collaboration
M. Briggs, V. Connaughton, and G. Fishman on behalf of the Fermi GBM collaboration

Terrestrial Gamma-Ray Flashes (TGFs) are millisecond bursts of high energy photons, electrons, and positrons originating in Earth's atmosphere and associated with powerful thunderstorms. The Fermi GBM has detected over 100 TGFs, some with energies up to 40 MeV. Recent AGILE observations of photons up to ~100 MeV in TGFs pose a significant challenge to the relativistic runaway electron avalanche mechanism that is generally believed to be responsible for these bremsstrahlung gamma rays. Here we present the search for high energy events in the LAT coincident with the large sample of TGFs detected by the GBM.

Searching for LAT events coincident with TGFs

The Fermi Gamma ray Burst Monitor (GBM) detects TGFs at a rate of one every ~3.7 days (Briggs et al. 2009, Briggs et al. 2010, Connaughton et al. 2010) with its on-board burst detection algorithms. TGFs typically last 0.1-1 μs and contain photons up to ~20 MeV. A subset of these TGFs has been found to be simultaneous with lightning events to within ~40 μs. The lightning locations are typically within 300 km of the sub-satellite point. Recent observations with AGILE (Tavani et al. 2011) show a power-law spectrum of gamma rays above 10 MeV, extending to ~100 MeV, which is in significant disagreement with the prediction of the generally accepted model for the production of TGFs, the Relativistic Runaway Electron Avalanche process. If confirmed, such high energy photons would require a new acceleration mechanism.

Although the Fermi LAT is generally pointed away from the Earth, surveying the sky, upward-going gamma rays can trigger the instrument. We searched the LAT science data stream near the times of the first 40 TGFs detected by GBM, looking for evidence of high energy photons. We aligned the time series of LAT events with the time of the peak of TGFs as measured by GBM, and we calculated the trigger rate and the downlinked event rate. The figure at left shows that, away from the times of TGFs, the mean "trigger request" rate is ~4000 Hz, and the mean downlinked event rate is ~400 Hz, as is typical for LAT. Readily apparent in the figure, however, is an unambiguous excess of events within a millisecond of the TGF peak time.

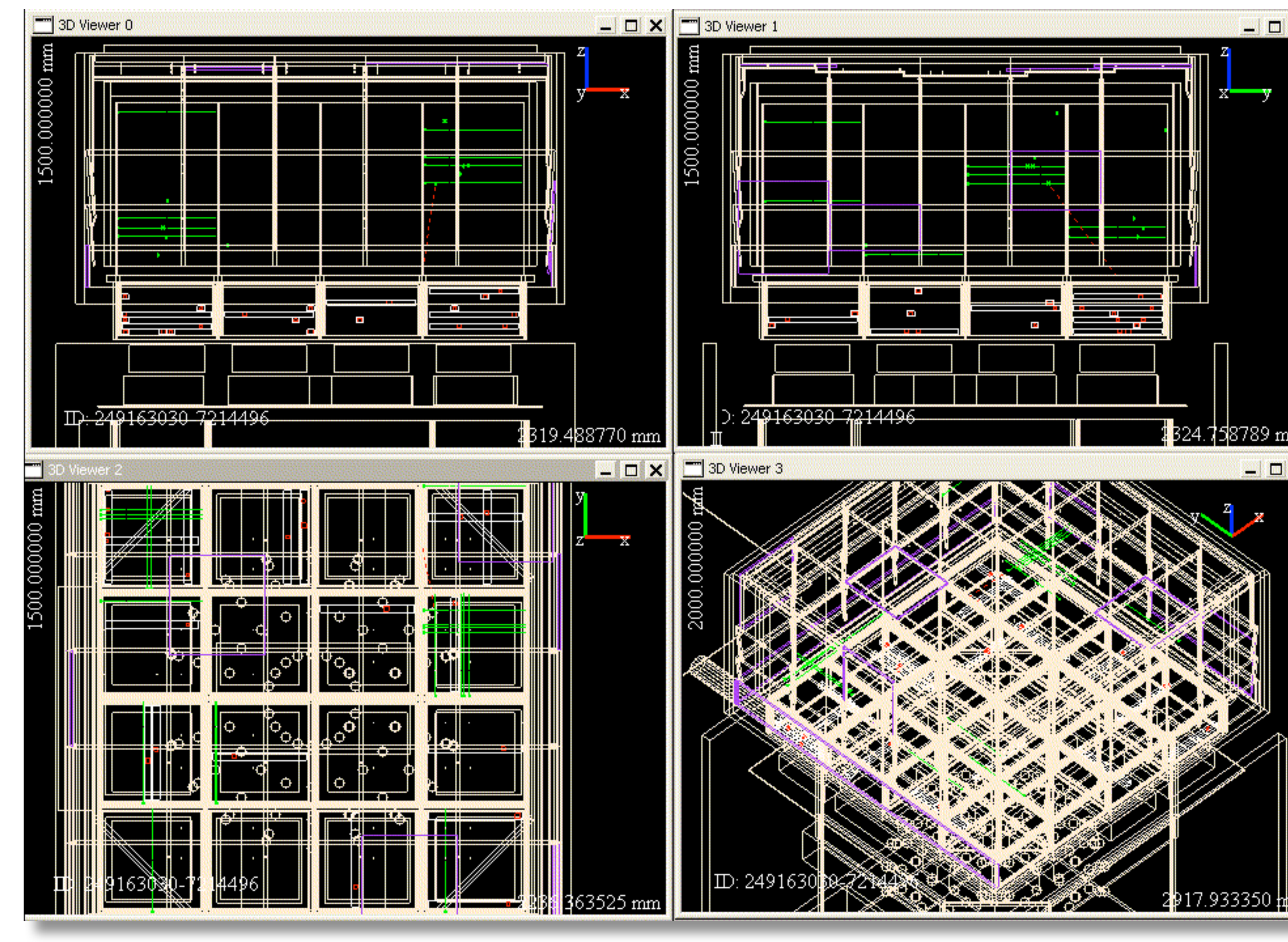


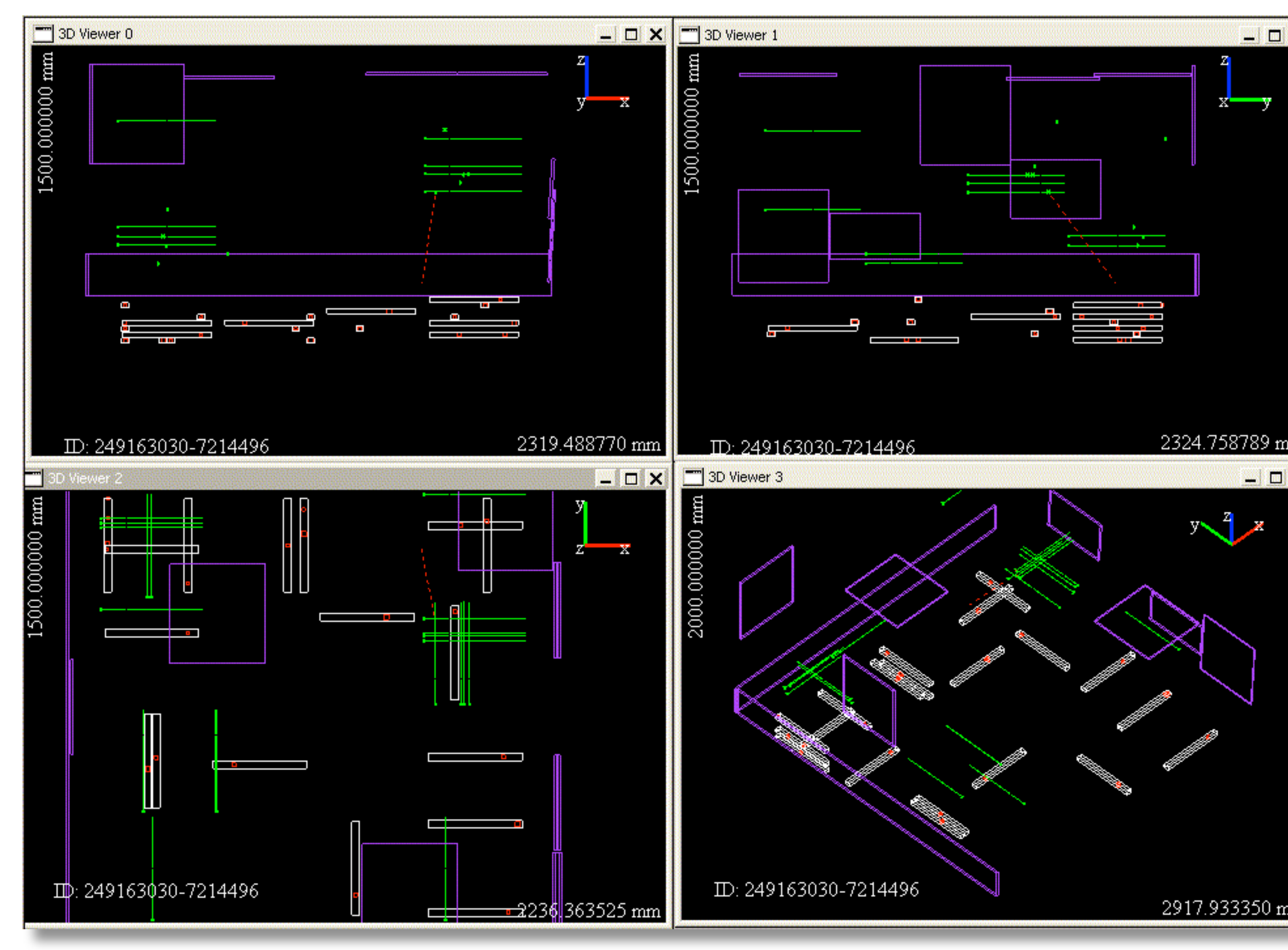
In order to generate a LAT trigger request, an event must hit 3 consecutive xy TKR layers. The LAT trigger system then evaluates whether to read out the event, and the read out event is passed through the on-board filter, which adjudicates whether the event will be downlinked. See trigger and on-board selection box below for additional details.

During TGFs, we see that the

- trigger request rate peaks at ~50 kHz; and
- downlinked event rate peaks at ~3 kHz, which corresponds to an average of two downlinked events per TGF.

It is clear, then, that the LAT indeed is triggering on additional energetic charged particles or photons during TGFs above the general background rate. The question is what those additional triggers are.





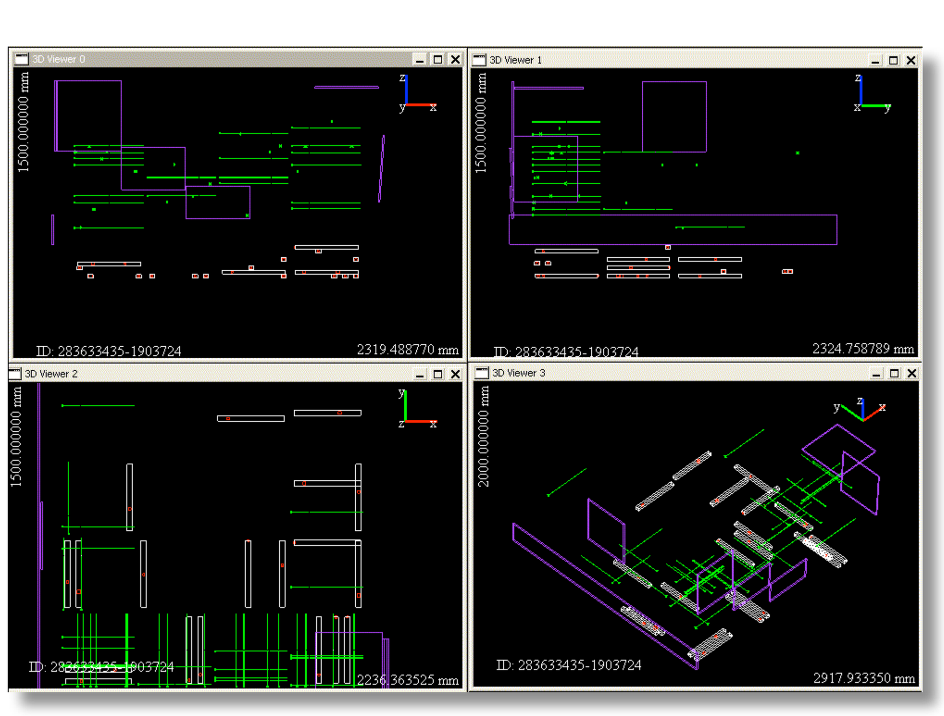
Visualizing individual LAT events

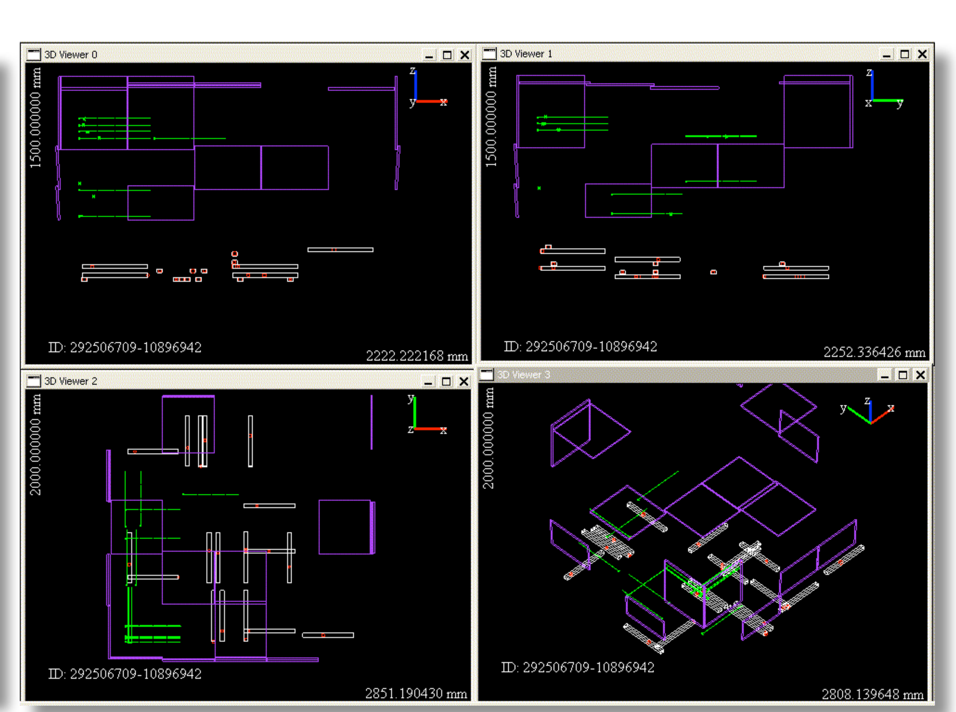
We then inspected each LAT "event" that was temporally coincident, within 1 ms, of a TGF identified in GBM and that deposited >50 MeV in the LAT Calorimeter. The goal was to try to understand whether the event was comprised of a single, upward-going photon with energy >50 MeV, or a coincidence of several upward-going several-MeV photons within the several-microsecond shaping time of the detector front-end electronics.

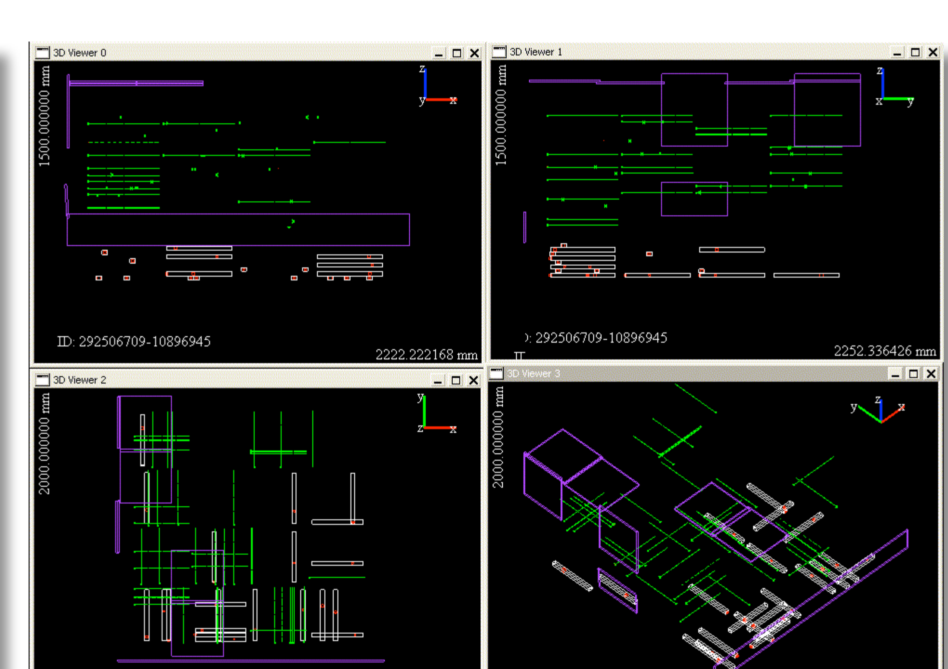
Here we show displays of several example events (see figures and caption).

Individual upward-going gamma rays above 50 MeV would appear as clustered energy depositions in CAL developing into directed tracks in TKR. Instead, events coincident with TGFs instead show isolated crystal hits and small TKR hit clusters, which is the signature of the coincident arrival of multiple several-MeV gammas. The average energy deposited in a crystal is ~4 MeV, slightly above the 2 MeV zero-suppression threshold in the CAL readout. As these low-energy (i.e. several MeV) gamma rays Compton scatter in the CAL, much of their incident energy is not registered because of the 2 MeV threshold, and they appear as isolated hits.

LAT Event Display. Each contains four views: the upper panels are XZ and YZ projections ("elevation views"; the lower left panel is an XY projection ("plan view"); and the lower right panel is an isometric view. The Z direction is the LAT boresight, and the TKR and CAL towers are arrayed in the XY plane. Individual ACD tiles, TKR towers, CAL towers, electronics boxes, and major structural components are indicated by white outlines in the first event display. For clarity, we have suppressed those fiducial outlines and left only the indicators of measured energy deposition: purple outlines for ACD tiles, green lines and crosses for TKR strips, and white outlines with red squares for CAL crystals. The size of the red square is related to the amount of energy deposited in the crystal. Only energy depositions above the 2 MeV zero-suppression threshold are registered in CAL.







LAT triggering and on-board event selection

Upward-going TGF photons will be strongly suppressed in the standard LAT science data analysis event classes (i.e. Transient and higher quality) because of data filtering algorithms running on board and in ground data processing. This is largely because photons entering the LAT from behind will convert in the Calorimeter (CAL) or Tracker (TKR) and send daughter particles upward that deposit energy in the anticoincidence detector (ACD). Large energy depositions in the ACD are not characteristic of celestial gamma rays entering the aperture, so the on-board and on-ground processing is tuned to reject such events as not being gamma rays. The on-board selection is significantly less stringent than on-ground selection and should pass some TGF photons, so we have elected to analyze the full downlinked event stream.

The trigger system and on-board filter (Atwood et al. 2009) will reject an event if it deposits at least ~1 MeV in an ACD tile without depositing a large amount of energy (>350 MeV) in the CAL. Such an event will be registered as a "trigger request," but it will not be downlinked. The vetoing tile must be near the TKR tower that issued the trigger request. Some fraction of upward-going TGF photons that convert and trigger LAT will be rejected precisely because they have put energy into the ACD. We are currently running Monte Carlo simulations to calculate the acceptance.

Status and conclusions

We have searched LAT data for >50 MeV photons coincident with the first 50 TGFs detected by GBM.

- The LAT clearly detects TGFs: there are excess events above the average background rates at the times of TGFs. A typical TGF generates ~2 downlinked events in LAT in sky survey attitude.
- The detected events are clearly dominated by multiple low energy gamma rays in coincidence within the few-microsecond shaping time of the LAT detector electronics.
- To date, we have found no evidence for individual >50 MeV gamma rays among the events. There are, however, more TGFs to be searched.
- Simulations to calculate the acceptance of the LAT to upward-going >50 MeV gamma rays are in progress.

References
Atwood, W. B., et al. (2009), ApJ 697, 1071.
Briggs, M. S., et al. (2010), J. Geophys. Res., 115, A07323, doi:10.1029/2009JA015242.
Connaughton, V. et al. (2010), J. Geophys. Res. 115, A12307, doi:10.1029/2010JA015681.
Tavani et al. 2011, PRL 106, 018501

Authors and affiliations
J. E. Grove, Naval Research Laboratory
A. Chekhtman, ARTEP Inc.
J. McEnery, NASA Goddard Space Flight Center
N. Omodei, Stanford University
F. Longo, University of Trieste
M. Briggs, University of Alabama Huntsville
V. Connaughton, University of Alabama Huntsville
G. Fishman, NASA Marshall Space Flight Center

Acknowledgements
The Fermi LAT Collaboration acknowledges support from a number of agencies and institutes for both development and the operation of the LAT as well as scientific data analysis. These include NASA and DOE in the United States, CEA/Irfu and IN2P3/CNRS in France, ASI and INFN in Italy, MEXT, KEK, and JAXA in Japan, and the K. A. Wallenberg Foundation, the Swedish Research Council and the National Space Board in Sweden. Additional support from INAF in Italy and CNES in France for science analysis during the operations phase is also gratefully acknowledged. This work was performed at NRL, sponsored by NASA DPR S-15633-Y.