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Construction, test and calibration of the GLAST silicon tracker

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Abstract

The Gamma-ray Large Area Space Telescope represents a great advance in space application of silicon detectors. With a surface of 80 m^2 and about 1 M readout channels it is the largest silicon tracker ever built for a space experiment.

GLAST is an astro-particle mission that will study the mostly unexplored, high energy (20 MeV–300 GeV) spectrum coming from active sources or diffused in the Universe. The detector integration and test phase is complete. The full instrument underwent environmental testing and the spacecraft integration phase has just started: the launch is foreseen in late 2007. In the meanwhile the spare modules are being used for instrument calibration and performance verification employing the CERN accelerator complex. A Calibration Unit has been exposed to photon, electron and hadron beams from a few GeV up to 300 GeV. We report on the status of the instrument and on the calibration campaign.

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1. Introduction

The Large Area Telescope (*LAT*) of the Gamma-ray Large Area Space Telescope (*GLAST*) mission [1] is the next generation pair conversion gamma-ray telescope dedicated to the exploration of the high energy sky. It is designed to cover the energy band from 20 MeV up to more than 300 GeV with sensitivity at least 30 times better than its predecessor, EGRET. The great improvement in performance will allow the solution of the several mysteries left by past experiments. The scientific case of the mission is indeed vast and goes from traditional astrophysical topics (like understanding the emission models of celestial sources) to fundamental physics (like searches for dark matter).

The LAT comprises three detector subsystems. A tracker/converter made of *XY* layers of Silicon Strip Detectors (*SSDs*) and tungsten conversion foils wherein the incident gamma-ray converts into an electron–positron pair. An electromagnetic calorimeter composed of CsI logs in hodoscopic configuration allows the reconstruction of the photon energy. The whole system is surrounded by a segmented anticoincidence shield (composed of plastic scintillator tiles) to veto the charged particles. The LAT is composed of a 4×4 array of identical modules called towers. Each tower has a tracker, a calorimeter and an electronic module for triggering and data handling. A very aggressive mechanical design was required to minimize the dead areas between detector planes: the gaps between towers, only a few millimeters wide, are used to accommodate the front-end electronics. The GLAST mission is planned to operate in orbit for about 10 years. The space environment poses major constraints on total weight and power budgets, moreover the hardware survival to launch and operations has to be proved with specific tests: all the instrument building blocks, from the single detector element to the complete satellite, have to pass such environmental tests.

2. Tracker construction and test

The active sensor of the tracker is a SSD: 400 μm thick with strips at 228 μm pitch. About 11500 detectors have been produced by Hamamatsu and tested by INFN and only 0.5% were rejected. The SSDs were glued and bonded in groups of four to form a ladder: a single detector with 36 cm long strips. Each of the 2700 flight ladders produced was fully tested by repeating the IV and CV scan performed on single SSDs and verifying insulation and continuity at the strip level.

The tracker tower building block is the tray [2,3]. It is a lightweight carbon-composite panel with sensors bonded on both sides (four ladder per side). The conversion foil is placed in the bottom part of the tray just above the silicon layer while the front-end electronics [4] is placed on two sides of the tray at 90° with respect to the detector planes. Both the mechanical panel and the fully equipped tray are qualified for space operation with a series of vacuum and thermal cycles. Full functional tests are performed before and after the cycles to investigate any damage. Trays are then stacked to form a tracker tower whose supporting structure is composed of four carbon fiber sidewalls (Fig. 1).

During the assembly each tower undergoes comprehensive performance tests before and after final closure of the structure with the sidewalls. The environmental test for a tracker tower comprises vibration tests (to measure proper resonance frequencies and to ensure that the structure will survive the launch) and a thermal–vacuum (*TV*) test: tower performance is continuously monitored while the temperature cycles from −15 to +45 °C. About 360 trays have been produced and tested and a total of 18 towers were assembled in 10 months during 2005. All tracker modules satisfy the requirements in terms of detector performance [5]: the average layer efficiency (within the active area) is more than 99.4% (Fig. 2) with a strip noise occupancy lower than 10^{-6}.

2.1. LAT status

The LAT construction phase has been successfully completed. All the tracker and calorimeter modules have

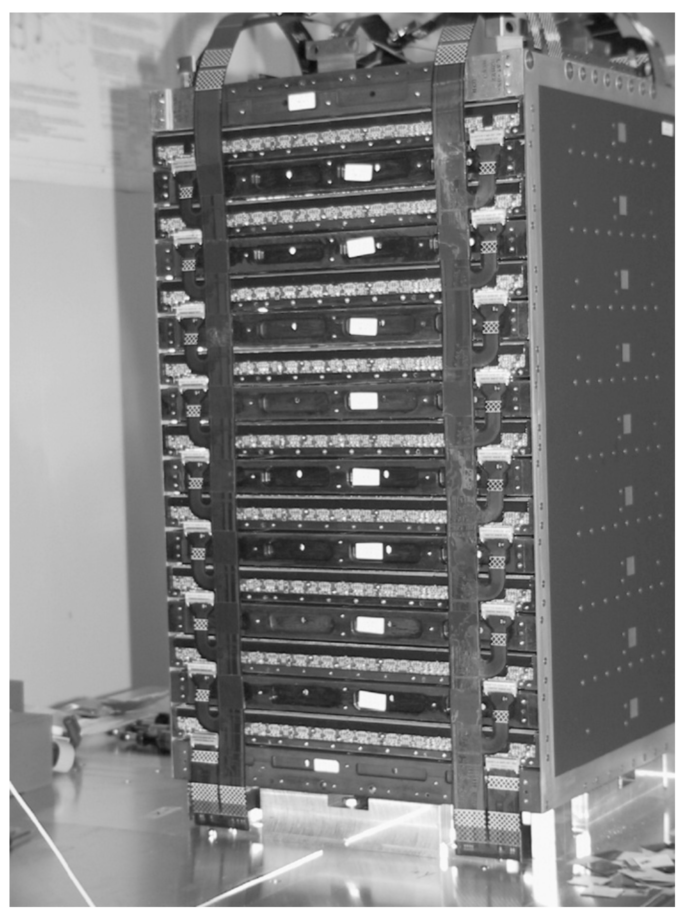

Fig. 1. A tracker tower during the assembly. The trays structure and the front–end electronic boards are visible.

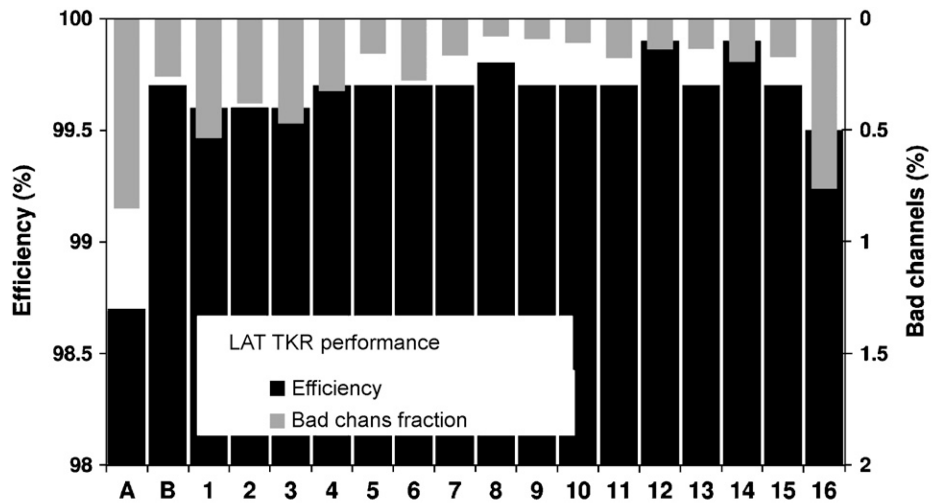

Fig. 2. Average MIP detection efficiency and fraction of defective channels for the 18 towers produced. Strips with broken connection between SSDs are not included: this problem was discovered in the first flight trays and promptly solved, it affects only the modules "A" and "B" increasing the fraction of defective channels, respectively, to about 2.6% and 0.4%. The last module was produced with residual nonflight hardware, but is still well within specification (98% efficiency). The module used for the CU are towers 8 and 16.

been integrated in the 4×4 aluminum grid together with the anticoincidence detector and all the electronic modules. The LAT environmental tests lasted for more than four months (from May to September 2006). The test sequence included vibration and acoustic test, EMI and a one month long TV test.

Several performance tests were done during LAT integration and test, including cosmic ray collection, to verify the functionality of the single subsystems and trace the instrument behavior. No significant change in the number of bad channels or degradation of performance has been found.

Integration with the spacecraft is now going on. After that the complete satellite will undergo environmental test: in the current schedule GLAST will be launched at the end of 2007.

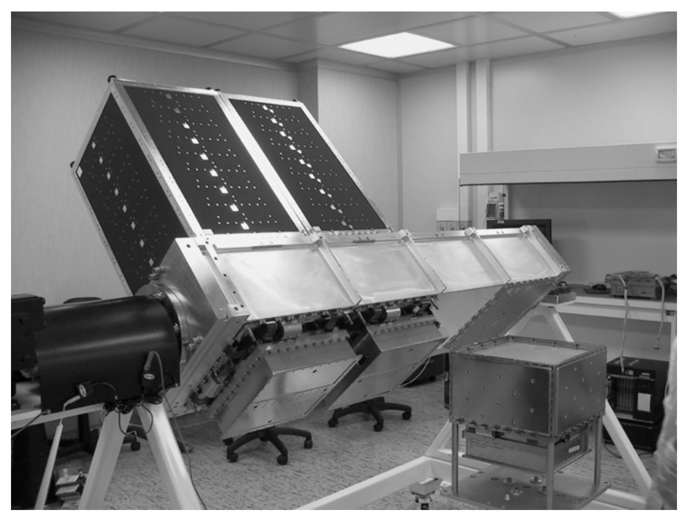

Fig. 3. The Calibration unit during its assembly: the third calorimeter is ready for installation in the grid. The Tower Electronic Module (*TEM* [5]), located below the calorimeter is also visible.

3. LAT calibration: the beam test program

A sophisticated Monte Carlo model of the LAT has been developed based on the GEANT4 toolkit. This model is used to study reconstruction algorithms (including event filtering for background rejection both on-board and off line) and instrument response functions (*IRF*) like angular and energy resolution and effective area. It is indeed not feasible to scan the whole space phase of the LAT in terms of angle, position and energy with a gamma-ray beam provided by an accelerator facility. However an experimental characterization of the instrument must be performed to verify that the response of the actual instrument matches the simulation prediction. It is important to reach a good reproducibility of both directly measured quantities (energy deposit, hit multiplicity) and high-level analysis (reconstructed energy and direction). Moreover, a direct measurement of the IRF is required for some critical configurations, in particular with low energy photons. For all these reasons a small fraction of the LAT hardware was assembled in the so called Calibration Unit (*CU*) and a beam test campaign was carried out using the CERN beam lines at PS and SPS in summer 2006. A further advantage of using LAT spare modules for the beam test is the minimum impact on the mission schedule.

3.1. The calibration unit

The CU (Fig. 3) is made with spare and flight-like hardware of the LAT, assembled in a 1×4 grid and placed horizontally on a remotely controlled motion stage, used to vary the beam angle and impact point. The CU is composed of two tracker modules and three calorimeter modules. Since the flight hardware must be kept in a clean and dry atmosphere, the CU was protected by an aluminum container that can be flushed with nitrogen and liquid cooled. All the electronic equipment, with the obvious exception of the front-end boards and the tower control modules (the *TEM* [5]), was placed outside the container. Five anticoincidence tiles were placed around the container to study shower backsplash.

The CU used the same control system of the LAT. All the front-end boards successfully completed the space qualification tests while the remaining electronics was flight-like. Several computers shared a local network with a central server. This machine had the role of locally storing the raw data, save beam and moving table information in a database, send events to other machines for event display and online monitoring, send data to a remote site for storage and complete automatic processing: events are reconstructed at SLAC and ready for analysis a few hours after the end of the run.

3.2. The CERN campaign

The T9 line at CERN PS was used in August 2006 for about 15 days of data collection. The line provides a mixed beam of energy from 0.5 up to 15 GeV. Particle identification was done with a Cherenkov detector (part of the T9 line) and a coincidence of scintillator tiles was used as trigger.

The run program for the PS campaign included:

- electrons from 1 to 5 GeV: to provide a direct energy calibration of the calorimeter and to validate the electromagnetic interaction model in the simulation,
- protons at 6 and 10 GeV: to validate the low energy hadronic interaction models,
- tagged photons from 0.5 to 2.5 GeV of primary electron beam: for a direct measurement of angular response and energy resolution of the instrument,
- non tagged photons (primary beam energy 2.5 GeV): to verify the simulation of photon interactions and collect events with a higher rate, taking advantage of the full bremsstrahlung spectrum.

The photons in the T9 line were produced by bremsstrahlung of the electron beam. The photon energy was evaluated by measuring the electron momentum with a magnetic spectrometer (the tagger). Such a device was set up with the magnet in the T9 area and four SSD based tracking devices (for the two spectrometer arms) in a configuration already used by another experiment. A detailed description of the tagger detectors and their configuration can be found in [6].

The data from the tagger were synchronized and merged online with the CU data resulting in a more reliable monitoring of the beam and the instrument. In fact it was possible to correlate quantities regarding the CU, the beam and the tagger online. Fig. 4 shows an example of online monitoring of the tracker and the beam: the integrated hits in the tracker give informations on both the beam position and the instrument functionality.

In September 2006 the CU was moved to the H4 beam line at the CERN SPS that provides particles with energy up to 400 GeV.

The run program at SPS was mainly composed of:

- electrons from 10 to 280 GeV: to validate the electromagnetic interaction model in the simulation and improve the high energy reconstruction algorithm,
- hadrons from 20 to 150 GeV: to validate the high energy hadronic interaction models.

The analysis of the huge amount of data collected with the beam test is in progress. The activity is now concentrated on the simulation of a more realistic beam and comparison of data with Monte Carlo predictions. A new beam test is

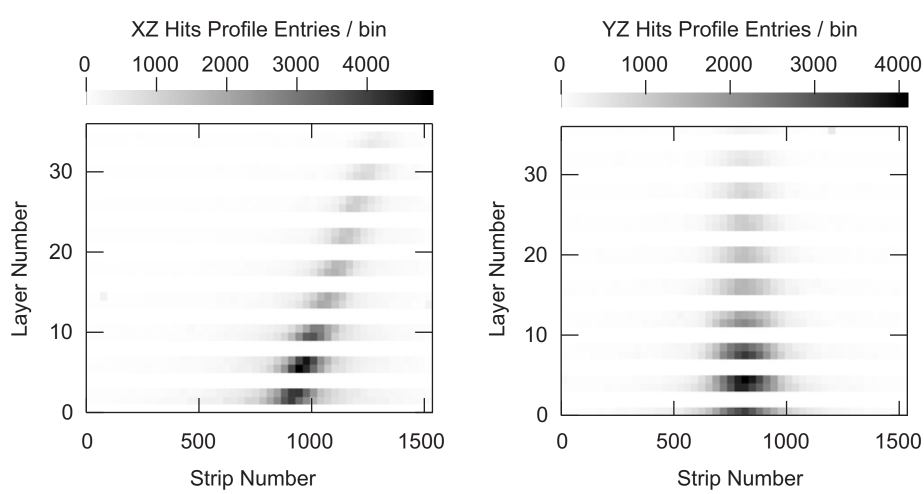

Fig. 4. The cumulative electromagnetic showers for a tagged photons beam, as seen with the online monitoring tool. These plots show the number of hits per 32 adjacent strips (a "bin"), in a tracker tower, integrated over a data taking run. The left plot refers to the horizontal plane (*XZ* view) and the right plot refers to the vertical plane (*YZ* view).

foreseen to verify flight hardware response to heavy ions that can be used for absolute energy calibration on orbit.

4. Conclusion

The LAT is now assembled and performing extremely well. The integration with the spacecraft is proceeding at full speed; the satellite will complete all its tests next year. An intense beam test calibration campaign was carried out at CERN during summer 2006 exposing the Calibration Unit to a variety of particle beams. Data analysis and Monte Carlo comparison is in progress. GLAST is on its path for launch at the end of 2007.

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