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The GLAST LAT tracker construction and test

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Abstract

GLAST is a next generation high-energy gamma-ray observatory designed for making observations of celestial gamma-ray sources in the energy band extending from 10 KeV to more than 300 GeV. Respect to the previous instrument EGRET, GLAST will have a higher effective area (six times more), higher field of view, energy range and resolution, providing an unprecedented advance in sensitivity (a factor 30 or more). The main scientific goals are the study of all gamma-ray sources such as blazars, gamma-ray bursts, supernova remnants, pulsars, diffuse radiation, and unidentified high-energy sources. The construction and test of the Large Area Telescope (LAT) tracker, has been a great effort during the past years, involving tens of people from many Italian INFN sections and industrial partners. Environmental and performance tests of the hardware, detectors and reading electronics, have been carried on during all the steps of the LAT construction. The resulting LAT performance are better than the ones required by the original science proposal, demonstrating the quality of the italian group effort. In this article we summarize the LAT construction and test workflow, presenting its main results.
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1. The GLAST scientific program

GLAST (Gamma-Ray Large Area Telescope) [1] is a next generation experiment for the observation of cosmic-gamma rays in the energy range from 10 KeV to more than

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300 GeV. This will permit the study of gamma-ray sources such as blazars, gamma-ray bursts, supernova remnants, pulsars, diffuse radiation and unidentified sources in an uncovered energy range with respect to previous experiments, such as EGRET [2] and with an overlap at higher energies with ground experiments (Fig. 1). Furthermore, in comparison with EGRET, GLAST will have better performance in terms of effective area, angular resolution, field of view and dead time (Fig. 2), providing an improvement factor of 30 or more in sensitivity, and better capability to study transient phenomena [3].

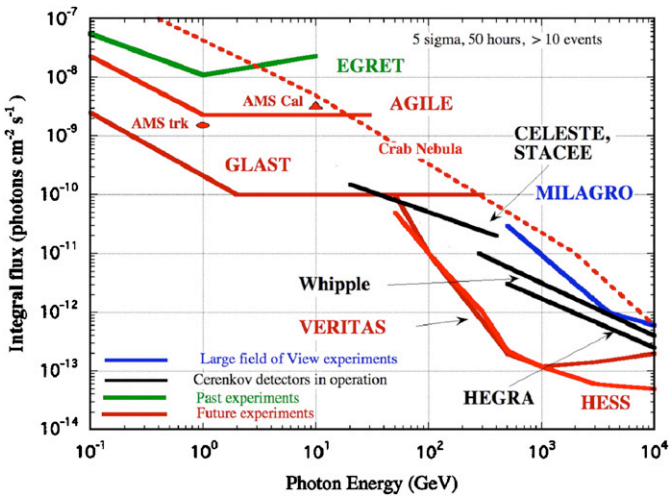

Fig. 1. GLAST energy range.

The GLAST construction has involved many worldwide partners from United States, Italy, Japan, France and Sweden, both from research institutions and from industries. The construction of the Large Area Telescope (LAT) Tracker modules [4] performed in Italy and finished last September, after years of efforts with excellent results, demonstrating a great coordination work between researchers and industrial partners.

2. The LAT tracker construction and test workflow

Modularity is the main concept in the tracker design. This allows the necessary redundancy to guarantee a safe operability in space environment and reproducibility in the construction workflow. Furthermore, severe acceptance, functional, mechanical and environmental tests are indispensable during all the instrument construction steps.

The LAT (Fig. 3) is a 4×4 array of 16 towers, each one composed by a tracker, in which the photon conversion takes place, followed by a calorimeter; the whole is surrounded by a segmented anticoincidence shield to allow the charged particle signal rejection.

The tracker (composed by 16 towers, for a total detecting surface of $83\,m^2$), has been built with almost 10,000 single sided, 8.95×8.95 cm microstrip silicon sensors, 228 μm pitch, bonded in groups of four to form a ladder; four ladders constitute a tracker tower plane. These planes are stacked with their strips alternatively oriented at 90° to form an *xy* coordinates grid: a tower is composed by 19 panels for a total of 18 of such *xy* planes.

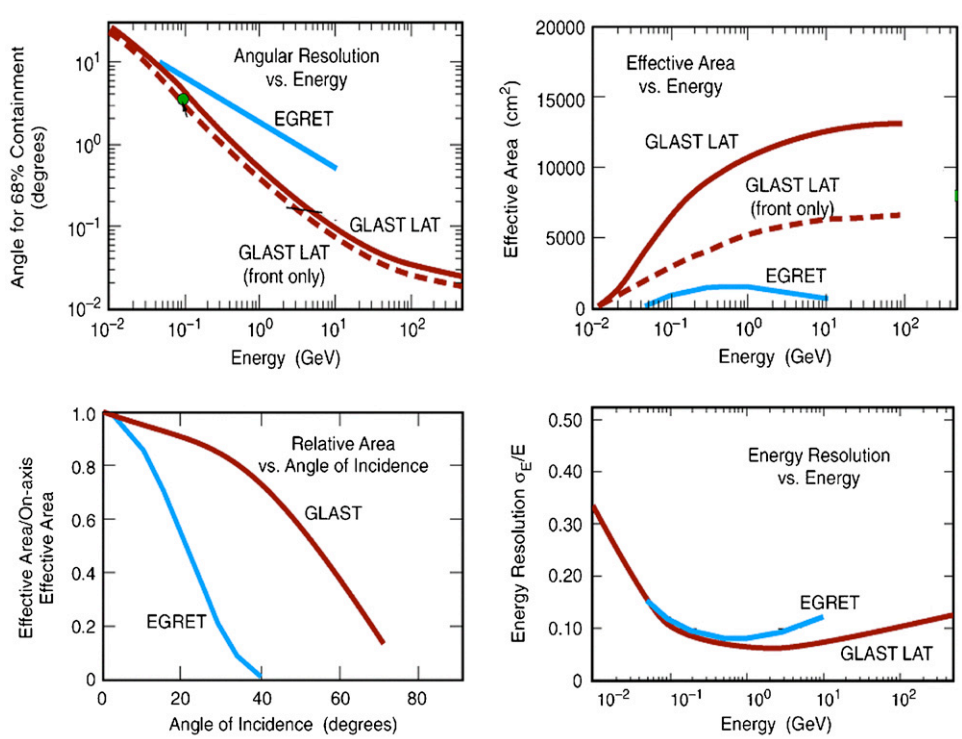

Fig. 2. GLAST LAT performance compared to Egret.

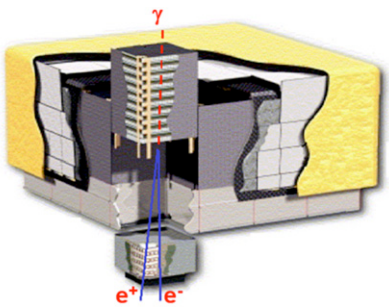

Fig. 3. The GLAST-LAT instrument.

The planes are interleaved with tungsten converter foils, for a total radiation length of 1.5 X_0. The tracker will have a total of 880,000 reading channels and will measure photon direction, using any three consecutive xy plane trigger signal, with a hit efficiency $>99\%$ and a noise occupancy $<\sim 10^{-5}$ for each channel. The whole LAT payload will be about 3000 kg, for a total consumption of about 650 W.

The low consumption of silicon sensors (vendor: Hamamatsu Photonics) is provided by their low leakage current (<500 nA@150 V; <200 nA averaged on any 100 SSDs), low depletion voltage (<120 V) and high breakdown voltage (>175 V). Hamamatsu produced and tested 11,500 of such sensors. After delivery they have been tested by INFN both for geometrical and electrical characterization: only a fraction of 0.5% from the total of SSDs have been rejected, the remaining ones showing an excellent agreement with the features declared by the vendor, in average already better than the aggressive required specifications. Good mechanical alignment is the first important feature to assure tracker precision, and the excellent silicon wafer slicing has been the first step to assure a good final result.

In order to assembly a ladder, four SSDs are glued, their strips bonded and these junction zones encapsulated, obtaining a strips 40 cm long detector. This assembly was performed by two high-tech italian companies (G&A Engineering and Mipot), in close collaboration with INFN personnel. Mechanical measures of the ladders alignment showed no differences from the single SSD 2 μm tolerance. Electrical measures on bulk capacitance, depletion voltage and leakage current of the 2850 produced ladders are shown in Fig. 4, with a final rejection rate of ~1%, and a global result of the measured quantities in excellent agreement with what expected from the component SSDs. The slight difference in the expected and measured leakage current distribution is due to differences in temperature and humidity of the testing environments. Single strip current and capacitance tests have been performed on any ladder, with a final result of 0.016% bad channels, caused by bonding or probing.

The trays, the mechanical supports for the sensors, are composite panels (see Fig. 5): an Al honeycomb core is surrounded by carbon–carbon close-outs, on which the read-out electronics (tracker multi chip modules, TMCMs, from SLAC) are mounted, while the top and bottom sides, where the sensors are glued, are carbon fiber sheets with kapton bias circuits, interleaved in the bottom side by the converter foils.

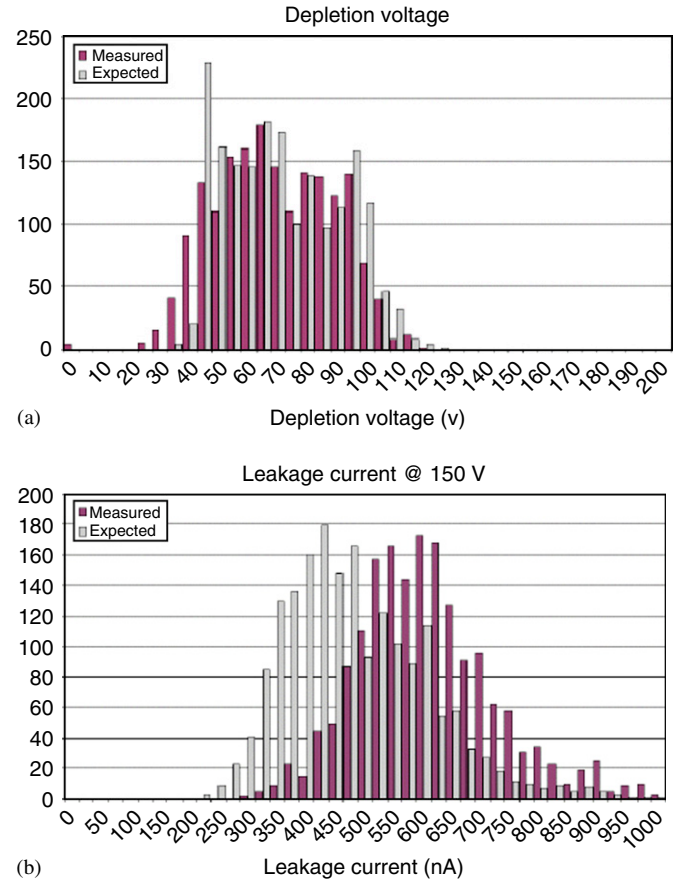

Fig. 4. Ladder measurement results.

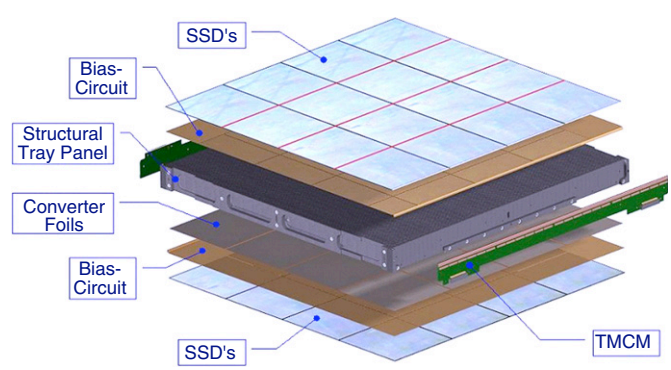

Fig. 5. Exploded view of a tray.

Trays manufacturer was the Italian company Plyform, specialized in the assembly of composite materials. The gluing of their wide face-sheets needed great care and structural verification tests were performed along any assembly step. Opto-acoustic (Electronic Speckle Pattern Interferometry, ESPI) tests were performed at INFN site

after the carbon fiber sheets gluing, to detect honeycomb skin debonding; before mounting electronics and SSDs, a thermal–vacuum test (24-h vacuum at 60 °C, performed at INFN site) on tray panels detected trays with badly glued kapton circuits (this problem was resolved using etched/primed W tiles). The tower bottom trays have special flexures for mounting them on the integration grid together with the calorimeter modules, as well as to permit their thermal exchange inside the satellite. This flexures will suffer particular mechanical stress, especially during the satellite launch: for this reason bottom trays were subject to static tests to demonstrate the static strength and stability of the bonding of each flexure. All parts and assembly phases have been dimensionally checked with a Coordinate Measuring Machine (CMM). The ladders displacement ($X/Y/Z$) on trays has an RMS ~20 μm. After read-out electronics were mounted, tray functional tests were performed in order to verify leakage current, single channel gain and noise (to detect disconnected channels), along with cosmic rays data taking. The resulting average leakage current was ~100 nA/SSD, showing that the SSD performance were preserved all along the assembly phases. After completion of assembly and test at G&A, each tray went through four thermal cycles from −15 to 45 °C (at INFN site), then tray group were stacked in parallel to reproduce a tower configuration (Fig. 6 on the left). Functional tests with cosmic rays, monitored with an external trigger setup (three scintillator planes) verified the self-trigger capability of the detector planes.

To build a tower (Fig. 6 on the right) trays were slit in position with a crane and stacked into the assembly jig (top to bottom and alternatively rotated by 90°). Each tray position was referred to the assembly jig (absolute reference frame) and displacements in X, Y or Z were averaged out and did not sum. Tower sides are equipped with two redundant cables, each connecting to a custom Tower readout Electronics Module (TEM). The complete towers were measured under the INFN CMM, and each tower was well aligned and inside the stay-clear zone (1.5 mm/side) defined to interface the towers to the satellite grid. The alignment did not change after the vibration tests and shipment steps.

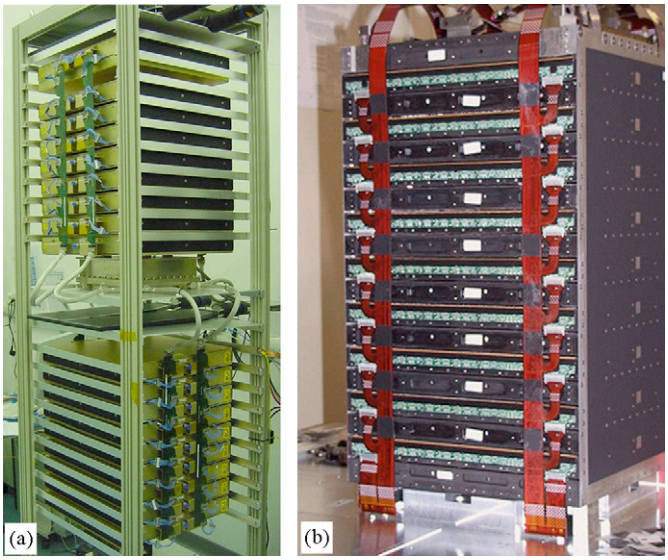

Fig. 6. On the left: stacked trays reproducing a tower configuration. On the right: an assembled tower.

Cosmic rays data taking permitted also towers analysis with offline reconstructed events, showing all towers layer efficiencies >99.5% (inefficiencies due to missing channels), and typical layer displacement and rotation, respectively, of 90 μm and 0.2 mrad (see Figs. 7 and 8).

Environmental tests of the complete towers were performed in Alenia Spazio facilities in Rome, under supervision of INFN personnel. Vibration tests (sinusoidal and random vibrations, plus low level sweeps for resonance frequency search) showed first resonance frequencies within specifications, with no significant changes throughout the test. During thermal–vacuum tests (four complete cycles, −15 °/ + 45 °C, 10^{-5} torr), tower functionalities and performance were continuously monitored for about one week test duration. Study of fine effects (gain and noise of front-end chip) together with statistics of bad channels, alignment and detection efficiency, as a function of the temperature, showed a stable behaviour. Only four failures on a total of 306 trays (580 detector planes) were detected (tower 1,7,8,14). These towers were partially disassembled and fixed.

All the workflow steps have been recorded into a custom electronic database developed by INFN, to permit the

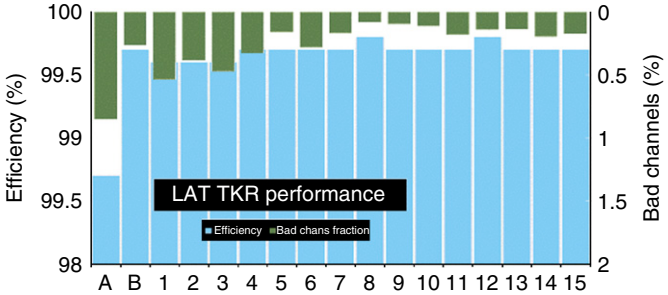

Fig. 7. Tower efficiencies.

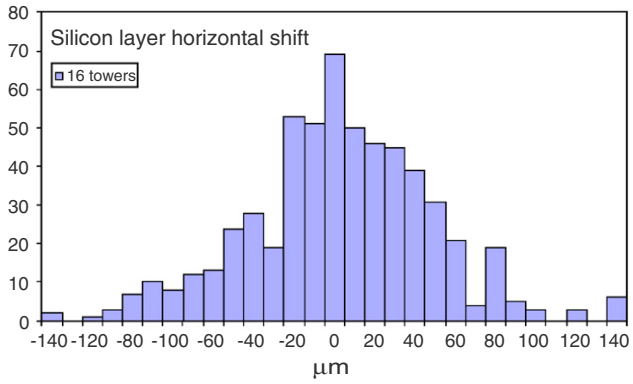

Fig. 8. Tower plane horizontal shift.

Parameter	SRD Value	Present Design Value
Peak Effective Area (in range 1-10 GeV)	>8000 cm^2	10,000 cm^2 at 10 GeV
Energy Resolution 100 MeV on-axis	<10%	9%
Energy Resolution 10 GeV on-axis	<10%	8%
Energy Resolution 10-300 GeV on-axis	<20%	<15%
Energy Resolution 10-300 GeV off-axis (>60°)	<6%	<4.5%
PSF 68% 100 MeV on-axis	<3.5°	3.37° (front), 4.64° (total)
PSF 68% 10 GeV on-axis	<0.15°	0.086° (front), 0.115° (total)
PSF 95/68 ratio	<3	2.1 front, 2.6 back (100 MeV)
PSF 55°/normal ratio	<1.7	1.6
Field of View	>2sr	2.4 sr
Background rejection (E>100 MeV)	<10% diffuse	6% diffuse (adjustable)
Point Source Sensitivity(>100MeV)	$<6\times10^{-9}$ $cm^{-2}s^{-1}$	3×10^{-9} $cm^{-2}s^{-1}$
Source Location Determination	<0.5 arcmin	<0.4 arcmin (Ignoring BACK info)
GRB localization	<10 arcmin	5 arcmin (Ignoring BACK Info)

Fig. 9. LAT final performance.

traceability and managing (analysis, quality control and non-conformance reports) of all the production and test data.

The final performance of the LAT are summarized in Fig. 9, compared to the ones required by the original Science Document [5].

3. Conclusions

The completion of the LAT tracker in Italy marked a milestone in the space detector construction, obtaining the largest (83 m^2 of silicon microstrip detector), high efficient, low noise detector of this kind ever built so far. The same performance homogeneity hold among all the tracker construction steps has been crucial for a smooth integration with the other subsystems and a good calibration of the LAT. Furthermore, the good coordination, skill and efforts of all the involved collaborating institutions and groups led to final performance better than the originally required ones, with undoubted positive impact on the GLAST (whose launch is scheduled for August 2007) final performance.

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