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The GLAST Large Area Telescope

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Abstract

The *Large Area Telescope* (*LAT*) is the main instrument of the GLAST satellite, designed for the study of the gamma-ray sky between 20 MeV and 1 TeV, scheduled for launch by NASA in 2006. The LAT will revolutionize the field addressing many of the unresolved questions in high-energy astrophysics with unprecedented resolution and sensitivity. Key to efficient and precise photon detection and measurement is the $\gamma \rightarrow e^+e^-$ vertex reconstruction from the LAT tracker. Technologies that make the LAT such an expectional detector, mainly due to the use of particle physics instrumentation, are discussed in this paper.

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1. Introduction and motivation—the GLAST mission

In the past decades, observation of the sky at progressively higher photon energies revealed unexpectedly rich phenomenologies. It was only after the beginning of satellite experiments that it became possible to detect high-energy γ-rays before they converted to secondary particles after interacting with the earth atmosphere. Few pioneering satellite missions, like COS-B, had detected a diffused γ-ray emission from the galaxy, but it was EGRET [1], the first dedicated detector, that was able to partially resolve this emission into few hundreds point sources, ranging from steady-state black holes and blazars to supernovae, pulsars or even very short, finely structured transient emissions like gamma-ray bursts or Active Galactic Nuclei flares. Most of the EGRET sources remain unidentified, as a direct association to known sources was not possible.

The GLAST mission [2] is a γ-ray telescope that will have optimized performance for detection and measurement of photons in the 20 MeV–1 TeV energy range, due to a specific design which makes extensive use of high-resolution detectors from particle physics instrumentation. The overall improvement in sensitivity with respect to EGRET will be of more than an order of magnitude, so that GLAST is expected to discover thousands of new sources and probe the nature of their core engines.

2. The Large Area Telescope (LAT)

The Large Area Telescope (LAT), the main instrument on board GLAST, has to efficiently

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measure direction and energy of gammas from the sky in a wide energy range, so the pair conversion telescope design was adopted. It is based on a sequence of thin, heavy conversion layers interleaved with X–Y detection planes, followed by an electromagnetic calorimeter (CAL): high energy photons (>10 MeV) crossing the telescope interact with one of the converters producing e^+e^- pairs, and their direction is reconstructed by measuring the leptons tracks and energies. The GLAST LAT is composed of an array of 4×4 identical towers, each equipped with a high resolution tracker, an imaging CsI calorimeter and a custom read-out electronics module. The telescope is surrounded by a segmented anticoincidence detector (ACD) for charged particles background rejection, at a level of 10^5 the expected γ-ray flux.

2.1. The LAT Tracker

The LAT tracker is the largest ever built for space applications, with an overall area close to 80 m^2 and a total number of channels approaching 10^6. In order to maximize reliability and simplify the assembly with reasonable costs, modularity was extended to all levels in the LAT towers. Each tracker tower is composed of a sequence of 18 X–Y detection planes, obtained by stacking 19 composite panels (*trays*), each equipped with a tungsten (W) converter and Si-strip detectors. The W thickness varies across the tower, while the tracking layers are obtained with 4 baseline Si-strip detectors (*ladders*), mounted side by side and connected to the front-end electronics located on the tray side; each ladder is obtained by wire-bonding four Si-strip sensors (SSD) in a line (Fig. 1).

The design of the LAT tracker rely on large area, single-sided, AC-coupled, state-of-the-art SSDs, which today can be purchased at acceptable costs. Other Si-strip sensors features which much improve the LAT performance include intrinsic high resolution, absence of consumables and no signal deterioration for a typical space irradiation. Furthermore, very thin detecting elements such as silicon layers give a favourable aspect ratio to the telescope, yet allowing a stack of many high-resolution sensitive planes, so that photons from a wide field of view cross enough layers for efficient reconstruction. This much increases the statistics of detected photons, with benefits on the sensitivity and the resolution of the LAT.

A strip pitch of 228 μm was chosen, to compromise between the requirement of a high resolution, the unavoidable multiple scattering introduced by the W-converters and the need to limit to overall number of channels. From a 6 inch, high-resistivity (<5 kΩ/cm) Si-wafer, 384 p^+ strips are implanted on a n-type substrate, biased through polysilicon resistors and AC-coupled to the front-end electronics.

The tracker read-out electronics is built with low-power (<240 μW/ch), custom design ASICs, and has on-board digital zero-suppression to cope with the limited bandwidth available on the satellite for downloading data to ground. The LAT towers are self-triggered when a signal is detected in any three consecutive X–Y planes; further trigger selection is applied using events from all 16 towers and the ACD data, in order to reduce the raw trigger rate from few kHz to few Hz.

2.2. Status of the tracker construction

Construction of the tracker has begun with fabrication and test of the silicon sensors. So far 4000 SSDs have been produced by Hamamatsu Photonics (HPK), and all tests performed to asses their quality gave excellent results (see Table 1) with an overall number of rejected wafers after all qualification test of $\simeq 1\%$.

Standard tests for flight SSDs mass production include voltage scans (0–200V, 5V steps) for the measurement of the sensors leakage current, bulk capacitance, depletion voltage, and measurement of the strips pattern alignment with the wafer cut ([3]). These measurements are performed both at HPK and in three test lines distributed in several Italian INFN laboratories, showing very good agreement. HPK also provides a sample measurement of the polysilicon bias resistors and of the Al strips resistance from a sensor randomly chosen in each production batch; a complete scan of the AC coupling for all strips is done on all sensors, in order to identify bad channels and check the

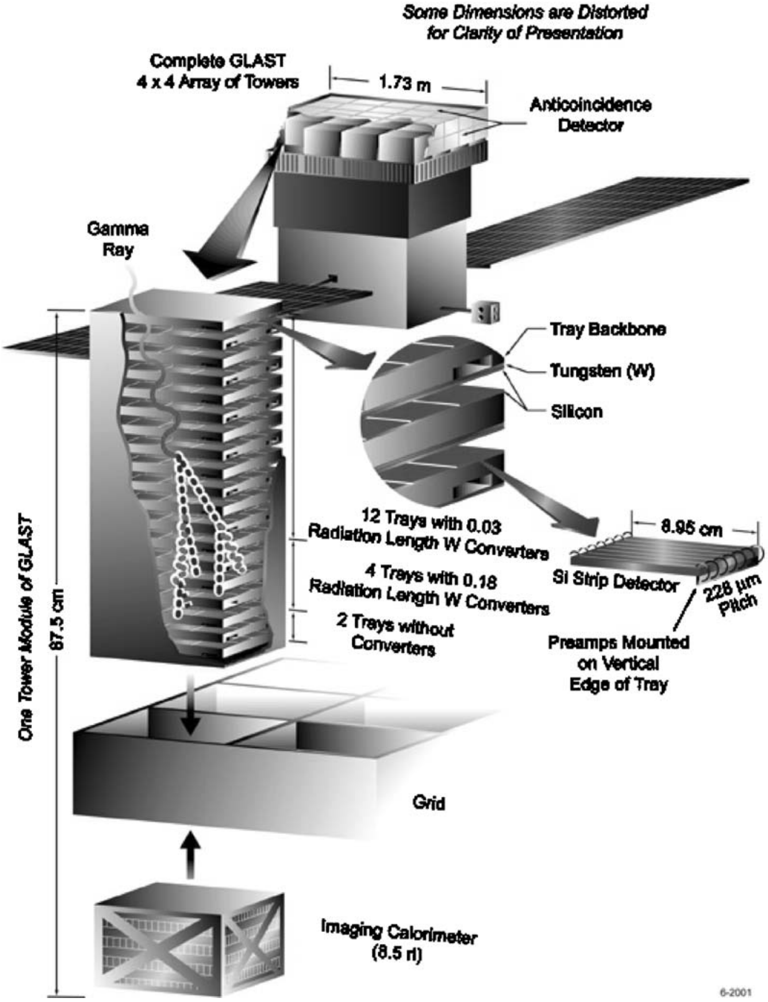

Fig. 1. The GLAST-LAT detector.

requirement of a maximum of three bad strips per sensor.

All the tests performed on each single SSD are repeated after the sensors are assembled into Si-strip ladders, whose production require high quality standards for the construction of more than 2700 detectors, each of them involving many delicate operations like handling, alignment and gluing of the silicon sensors, microbonding of more than 1500 Si-strips, bonding encapsulation, micro-probing for electrical tests. It was decided to develop and engineer assembly procedures in collaboration with space-qualified companies, which would eventually build the ladders, leaving the quality control to the institutes collaborating in the project. Two Italian companies were selected, and the production of the first 160 ladders gave excellent results: all the relevant parameters like leakage current, bulk capacitance, depletion voltage and bad strips were measured on all ladders, matching very well with what expected from the composing SSDs (see Table 1). The last step in ladder assembly, micro-bonding encapsulation, is performed with the *dam and fill* technique, where a harder-glue (*Nusil* 1142), outer dam is deposited around the bondings, and is finally filled with a softer siliconic glue (*Nusil* 15-2500). This technique proved to be very stable and always

Table 1
Test results summary

Tested device	4000-SSDs			160-Ladders	
Measurement	Average	RMS	Specs	Average	RMS
Leakage current[a](nA)	115	50	<200	480	105
Depletion voltage (V)	70	20	<120	62	10
Bulk capacitance[a](pF)	1840	10	—	7410	30
Wafer alignment (μm)	0	2	<20	0	4
Poly-Si resistance[b] (MΩ)	39	3	>20, <80, rms± 10	—	—
Al strip resistance[b] (Ω)	26	2	<50	—	—
Al strip AC coupling (pF)	581	8	>500	—	—
Broken strips (overall rate)	10^{-4}	—	$<10^{-2}$	3×10^{-4}	—

[a] Measured at 150 V bias.
[b] Measured on a sample SSD per production batch.

gave results well within specifications, i.e. all bonds covered with encapsulation height $<500\,\mu$m and lateral overflow $<50\,\mu$m. As expected, bonds encapsulation did not change the detectors properties, and only produced a slight increase in the current for some ladders. Intermediate testing before encapsulation can therefore be skipped and mass production qualification will rely on tests performed when the ladder is already encapsulated.

The design of mechanical trays is now well established, and makes use of carbon fiber for the top and bottom face-sheets, carbon-carbon for the structure close-outs and aluminum for the honeycomb core; this solution offers high resistance to mechanical stresses, high thermal conductivity for heat dissipation and low material budget. Prototypes produced with this design had excellent planarity ($<20\,\mu$m) and successfully passed specific NASA space qualification tests. Thermal testing cycled each tray four times between a 4-hours plateau at -30°C and a 4-hours plateau at $+60^\circ$C, and no tray broke despite the CTE differences of the many subcomponents. During vibrational tests a sine-sweep vibration (20–2000Hz range) located the trays main resonance mode at 650, 800 and 1000 Hz for heavy trays (18% R.L. W), standard trays (3% R.L. W) and no-W trays respectively. After a random vibration at ± 3dB of launch level a new sine-sweep was run to check the trays resonance, showing a $\Delta v/v$ change $<2\%$, demonstrating high structural stability.

The first flight trays are now being assembled and will be used to build a tracker tower equipped with flight hardware, that will be exposed to cosmic rays and 17.6 MeVγ in the next months.

3. Conclusions

The Large Area Telescope of the GLAST mission is a very good example of a successful partnership between the HEP and Astrophysics communities. A careful design and use of state-of-the-art particle detectors will give the LAT superior angular and energy resolution, enabling a high-resolution exploration of the rich yet still poorly explored gamma-ray sky. Particularly important for this achievements will be the LAT silicon tracker, whose construction is on schedule for the 2006 launch, with results far better than the project specifications.

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