Performance of the Calorimeter of the GLAST Large Area Telescope

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on behalf of the GLAST Calorimeter collaboration

The Calorimeter (CAL) of the GLAST Large Area Telescope (LAT) is designed to measure the energy of cosmic gamma rays. The CAL is comprised of a segmented, hodoscopic array of CsI(Tl) scintillating crystals totaling 8.3 radiation lengths in depth. This design allows the CAL to image the development of gamma ray showers and reconstruct their incident energy with greater accuracy, and it makes the CAL a powerful tool in background rejection. The performance of the sixteen CAL Modules has remained stable from subsystem environmental testing through LAT integration and environmental testing. In combination with simulations, this test program has demonstrated that the CAL meets its design requirements.

Calorimeter Design and Assembly

- *Modular design*
  - *4 x 4 array of Modules*
- *Each Module contains*
  - *8 layers of 12 CsI(Tl) crystals*
    - *Crystal dimensions*
      - *27 x 20 x 326 mm*
    - *Hodoscopic stacking*
      - *Alternating orthogonal layers*
    - *Dual PIN photodiode on each end of crystals*
  - *Mechanical packaging*
    - *Carbon Composite cell structure*
    - *Al base plate and side cell closeouts*
    - *Electronics boards attached to each side*
    - *Outer wall is EMI shield*

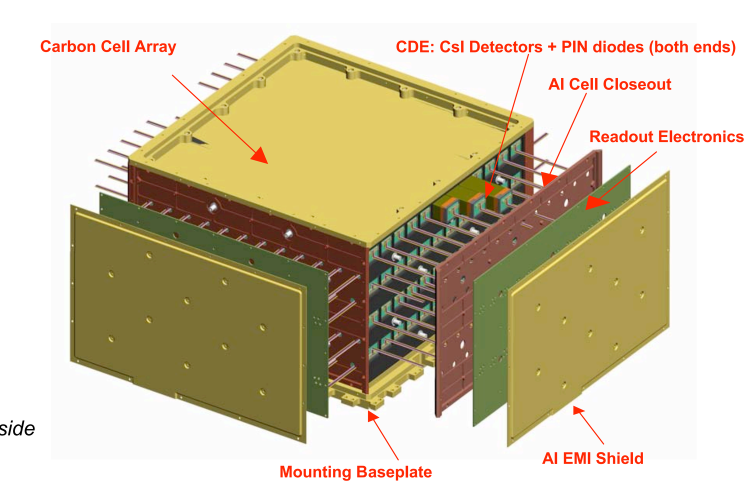

Figure 1: Exploded view of CAL Module

The GLAST Large Area Telescope (LAT) Calorimeter (CAL) is comprised of 16 identical modules, each of which is an array of 96 scintillating Crystal Detector Elements (CDEs) supported by a carbon composite mechanical structure. Scintillation light from each CsI(Tl) CDE is measured at both ends by a dual PIN photodiode. Each photodiode is processed by an electronics chain with preamp, shaper, and dual track-and-hold. The four-channel readout of each crystal end can then support the large 2 MeV – 60 GeV dynamic range imposed by the science performance requirements.

The sum of the signal at each end of the CDE gives a measure of the energy deposited in the crystal, while the ratio of the signal at each end is a measure of the location of the energy deposition along the crystal.

The segmentation of the CAL allows it to image photon and charged particle interactions, which significantly improves the ability of the CAL to measure photon energies and reject background.

Calorimeter assembly process

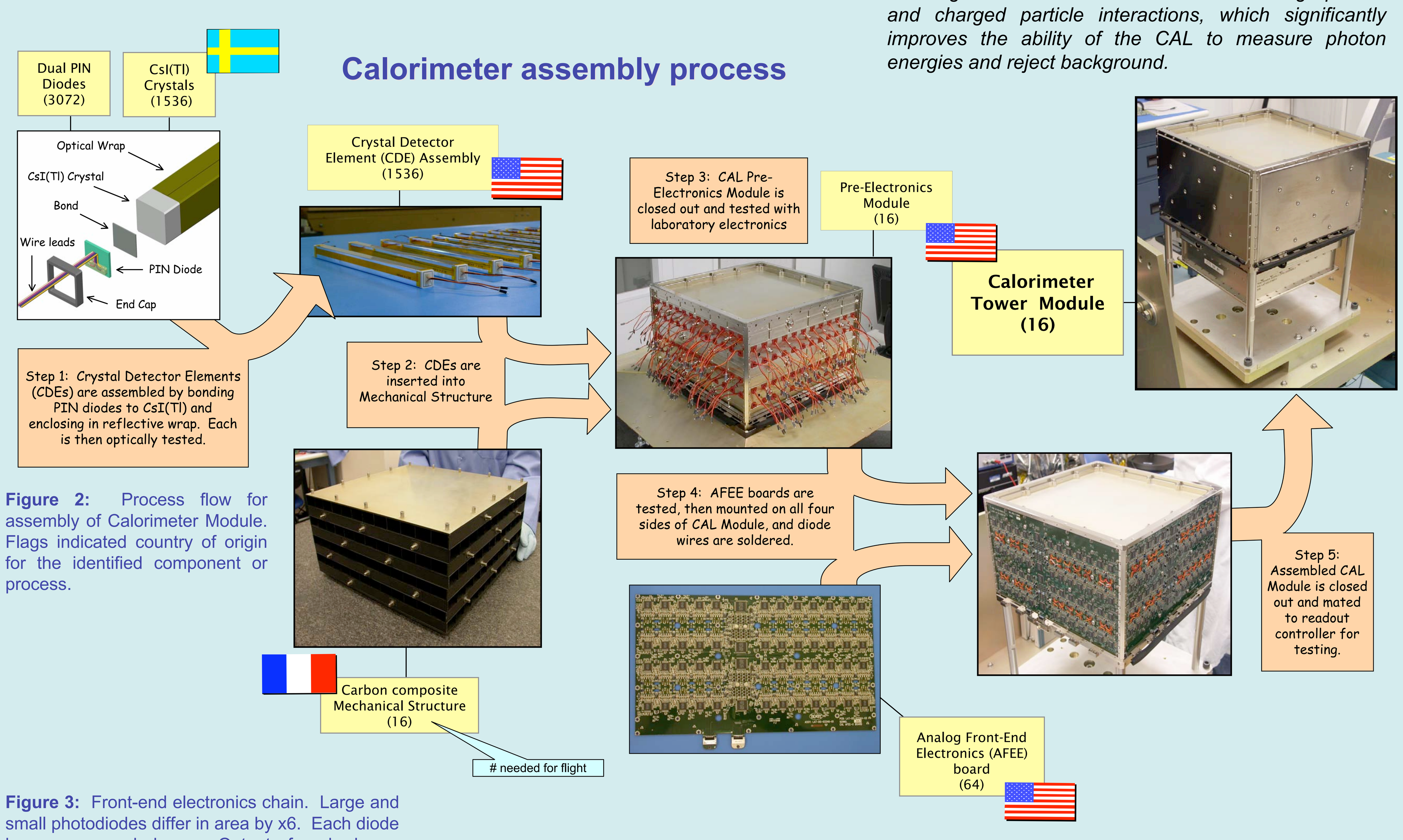

Figure 2: Process flow for assembly of Calorimeter Module. Flags indicated country of origin for the identified component or process.

Figure 3: Front-end electronics chain. Large and small photodiodes differ in area by x6. Each diode has preamp and shaper. Output of each shaper feeds two track-and-hold stages to produce nominal x1 and x8 output signals, for a total of four channels per crystal end with gain ratios spanning 512:1. An analog mux supplies these four signals to a single 12-bit ADC, and programmable range selection logic selects the lowest unsaturated energy range for readout.

Not shown is a trigger circuit for each diode, consisting of a fast shaper (0.3 us shaping time) and adjustable discriminator. The logical OR of the low and high energy discriminators from the CDEs in each layer form the CAL-LO and CAL-HI trigger primitives, respectively, with nominal flight thresholds of 100 MeV and 1 GeV per crystal.

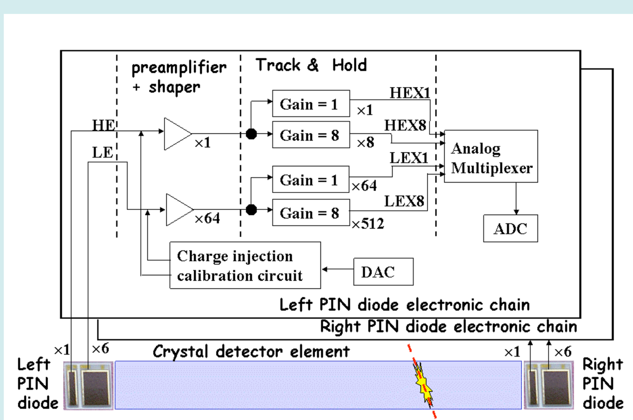

Figure 3: Front-end electronics chain

Twenty CAL modules were assembled in 2004-2005, including 16 flight units, 2 flight spares, an Engineering Model, and a beamtest unit. After production, each module underwent a full environmental test program – vibration, electromagnetic interference and compatibility, and thermal-vacuum – prior to delivery to SLAC for integration in the LAT. The integrated LAT was then subjected to a similar environmental test program.

Calorimeter performance trending

Throughout the CAL assembly, LAT integration, and environmental test programs, we verified the functional performance of each CAL Module with a standard suite of tests – the Comprehensive Performance Test (CPT) – and we calibrated the response with cosmic muons and electronic charge injection. To assess the stability of the CAL performance, we instituted a regular program of trending of the results of analysis of CPT and calibration data.

The figures below show sample results from this monitoring.

In the CPT, we measured a number of electronic performance parameters, e.g. the pedestal centroid and width (which is a measure of noise), the front-end electronic gain and linearity, and the trigger and zero suppression threshold gains. Each test in the CPT reported its results in tabular form, which we then post-processed with the trending application. By comparing the parameters as a function of time, we could assess the stability of each Module through the environmental test process, and by contrasting the parameters as a function of temperature, we could estimate the performance at on-orbit conditions. From those trends, it is apparent that all CAL Modules maintained good performance through all test environments. Figure 4 shows the electronic pedestal as a function of time and temperature for a sample of four of the 3072 channels.

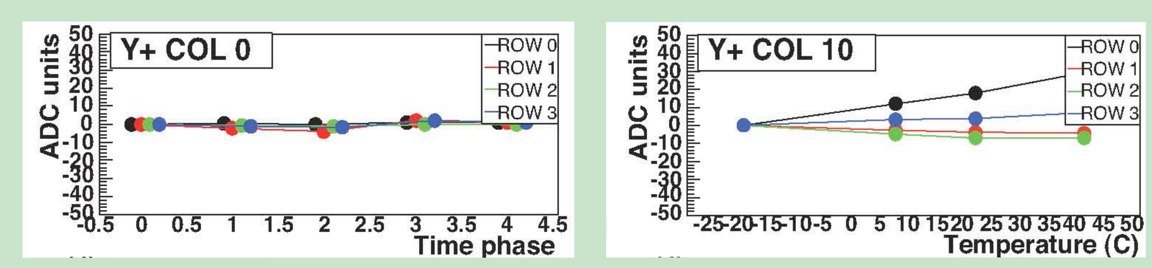

Figure 4: Examples of dependence of pedestal centroid on time and temperature. Pedestal is quite stable with time, and reproducibly dependent on temperature, although sign and amplitude vary from channel to channel. X axis is time expressed as test phase (left) or temperature (right). Y axis is ADC units, where 30 units corresponds to ~1 MeV.

From the muon and charge injection data sets, we calibrated the energy scale and position response of each CDE. While the full set of calibration coefficients includes optical and electronic gain, front-end linearity, and maps of a representation differential light yield in each crystal, for presentation purposes we can summarize the stability of the calibration with a single quantity, the overall gain of each channel, expressed as energy per ADC bin. Figure 5 shows the percentage change in the overall gain at the time the LAT completed its environmental test program relative to the overall gain prior to the start of that program. Collectively, the overall gain is quite stable – the average is unchanged to within 0.1% – while the drift of individual channels has rms ~ 0.6%, which is an order of magnitude smaller than the energy resolution of the CAL.

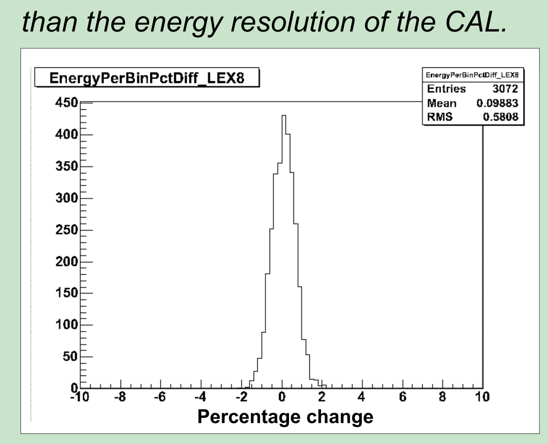

Figure 5: Gain stability through environmental testing. The overall gain, expressed as energy per ADC bin, is a simple quantity that monitors the combined optical and electronic response of the CAL. This histogram of the 3072 low energy CAL channels shows that average gain of the CDEs was unchanged to within 0.1% throughout the LAT environmental test program.

Science Performance

The performance of the CAL was evaluated using a combination of cosmic muon calibrations, charge injection calibrations, beam tests, and Monte Carlo simulations. The measured or expected performance was then evaluated against a set of requirements derived from the science needs. The following table lists a subset of the CAL and LAT requirements, how they were verified, and the expected on-orbit performance. In all cases, the CAL meets or exceeds specifications.

Parameter	Requirement	Verification	Expected Performance
Energy Range	20 MeV – 300 GeV 20 MeV – 1 TeV (goal)	Simulation, Beam Tests	Required performance
Energy Resolution (1 sigma)	< 20% (20 MeV < E < 100 MeV) < 10% (100 MeV < E < 10 GeV) < 6% (10 GeV < E < 300 GeV, incident angle > 60 deg)	Simulations, EM and Calib Unit beam tests	Simulations demonstrate required contribution from CAL
Energy Range Single Crystal	5 MeV – 60 GeV		~2 MeV to >60 GeV
Energy Resolution (1 sigma) Single Crystal	< 2% for Carbon Ions of energy >100 MeV/nuc at a point	EM and Calib Unit beam tests	< 0.5% (correlation of ends removes Landau)
Energy Measurement, Integral linearity	Max deviation from linearity < 2% of full scale, for charge injection	Test	~1% of full scale
Position Resolution	< 3 cm in 3 dims, min ionizing particles, incident angle < 45 deg.	Test with cosmic muons, all modules	< 1.5 cm in longitudinal measurement
Angular Resolution	15 × cosθ deg, for cosmic muons in 8 layers	Test with cosmic muons, all modules	8 × cosθ deg
Low Energy Trigger	> 90% efficiency for 1 GeV photons traversing 6 RL of CsI < 2 μs trigger latency	Simulations	> 93% < 1 μs
High Energy Trigger	> 90% efficiency for 20 GeV photons depositing at least 10 GeV < 2 μs trigger latency	Simulations, Calib Unit beam tests	> 91% < 1 μs
Mass	< 1440 kg (90.0 kg/Module)	Test	1376 kg
Active Area	> 1050 cm² per module < 16% of total mass is passive mtrl.	Inspection	1080 cm² per module < 14% is passive

Calorimeter Status

The Calorimeter is fully integrated into the LAT instrument and is in regular operation while the GLAST Observatory is being assembled and tested at General Dynamics C4 Systems in Gilbert, AZ.

The CAL is fully functional and operating within specs

- *–Spectroscopy*
  - *•All channels are alive and calibrated*
  - *•Noise performance is within spec and stable*
- *–Trigger*
  - *•All discriminators are alive and can be set to flight thresholds*
- *–Data suppression*
  - *•All discriminators are alive and can be set to flight thresholds*

References

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Ampe, J. et al., "The calibration and environmental testing of the Engineering Model GLAST CsI calorimeter," IEEE TNS **51**, 2008 (2004).

Chekhtman, A., "Status of the GLAST Calorimeter," in CALORIMETRY IN PARTICLE PHYSICS. Proceedings of the Twelfth International Conference, AIP Conference Proceedings Series, **867**, 151 (2006).

Collaborating Institutions

The LAT is managed at Stanford Linear Accelerator Center (SLAC),
The PI is Peter Michelson (Stanford)

NASA Goddard Space Flight Center
Naval Research Laboratory[1]
Ohio State University
Sonoma State University
University of California at Santa Cruz

Stanford University
Hansen Experimental Physics Lab.
Stanford Linear Accelerator Center
Texas A&M University – Kingsville
University of Washington

Istituto di Fisica Cosmica, CNR (Milan)
Italian Space Agency (ASI)
Istituto Nazionale di Fisica Nucleare (INFN)
Bari, Padova, Perugia, Pisa, Rome, Trieste, Udine

Hiroshima University
Institute for Space and Astronautical Science
RIKEN

Institut National de Physique Nucleaire et de Physique des Particules (IN2P3)
LLR, Bordeaux, Montpellier[2]
Commissariat a l'Energie Atomique (CEA), Saclay

Royal Institute of Technology (KTH)
Stockholm University

Calorimeter collaborating institutions are shown in **boldface type**

First GLAST Symposium
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