Production, Calibration, and Environmental Testing of the GLAST/LAT CsI calorimeter Flight Modules

M. S. Strickman, J. E. Grove, W. N. Johnson (NRL), A. Chekhtman(GMU), D. A. Smith (CENBG, France), F. Piron, S. Guiriec (Univ. Montpellier II, France), P. Carlson, S. Carius (KTH, Sweden), on behalf of the GLAST LAT Collaboration

The GLAST Large Area Telescope (LAT) CsI calorimeter, which consists of 16 flight modules and 2 spare modules, was assembled in 2004-2005 by an international team from the USA, France and Sweden. Each module contains 96 CsI crystals supported by a carbon fiber composite structure and read out from both ends with silicon PIN photodiodes. Signals from the array of photodiodes are processed by custom analog ASICs and commercial ADCs. After assembly, each module underwent a full environmental test program including electromagnetic interference and compatibility, vibration, and thermal-vacuum test to flight-acceptance levels. The functional performance of each module was verified before and after each test, and calibration with cosmic muons and charge injection was performed throughout the test sequence. All 18 modules showed stable functioning over the few months of the assembly and test program. None of the 1728 crystals experienced mechanical or optical degradation. Integration of the calorimeter modules with the other detector and electronics subsystems into the complete Large Area Telescope began at SLAC in April 2005 and was completed in December 2005. This work is supported by NASA DPR S-15633-Y.

INTRODUCTION

GLAST [1] is the next generation space based gamma ray telescope in the photon energy range 30 MeV 300GeV. It consists of a spacecraft and two instruments: The Gamma Ray Burst Monitor (GBM) and the Large Area Telescope (LAT).

The LAT (Fig 1) contains three main detector subsystems: a tracker (TKR) with active silicon strip detector layers and thin passive tungsten radiators, a hodoscopic CsI crystal calorimeter (CAL), and a plastic anticoincidence detector system (ACD). The TKR is responsible for determining incident photon direction, and also plays a role in energy determination for incident photons with energies less than 1 GeV. The CAL supplies incident photon energy. In addition, its hodoscopic configuration allows it to determine photon direction, albeit with poorer resolution than the TKR.

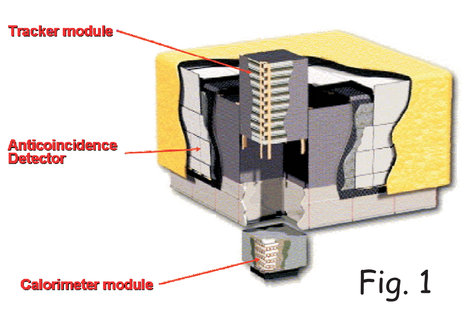


Fig. 1

CALORIMETER DESIGN

The Calorimeter [2] is built as a 4x4 array of identical modules. Each module contains 96 CsI crystals with dimensions 19.9x26.7x326 mm³ arranged in 8 horizontal layers of 12 crystals, as shown on Fig. 2. Crystals in even layers (0,2,4,6; also known as X layers) are orthogonal to crystals in odd layers (also known as Y layers), forming a hodoscopic arrangement supported by a carbon fiber composite structure.

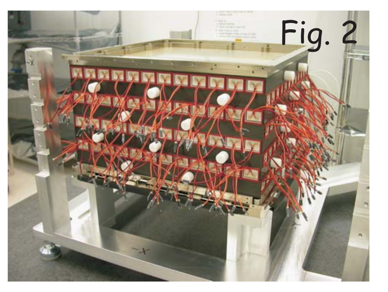


Fig. 2

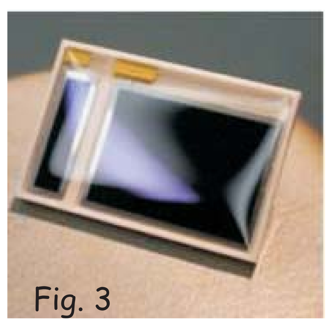


Fig. 3

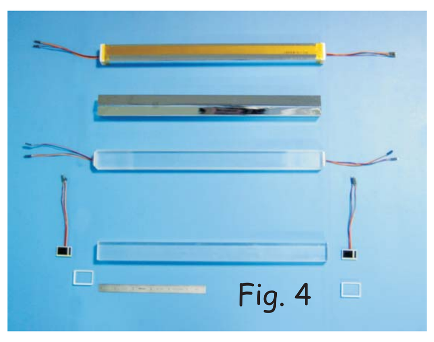


Fig. 4

Scintillation light is detected at each end of a crystal by two silicon PIN photodiodes (Figs. 3 & 4). The large diode (1.5 cm²) is used to measure energy deposits from ~2 MeV to ~1.1 GeV, while the small diode (0.25 cm²) covers energy deposits up to 70 GeV. The PIN diodes are mounted in a ceramic carrier (Fig. 3) and bonded with an optical bond to either end of a CsI crystal, which is then given a light-tight, reflective wrap (process shown in Fig. 4). The resulting unit is referred to as a Crystal Detector Element (CDE).

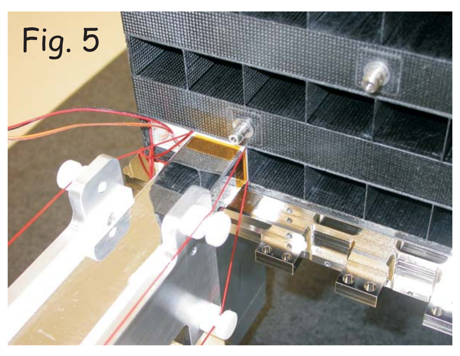


Fig. 5

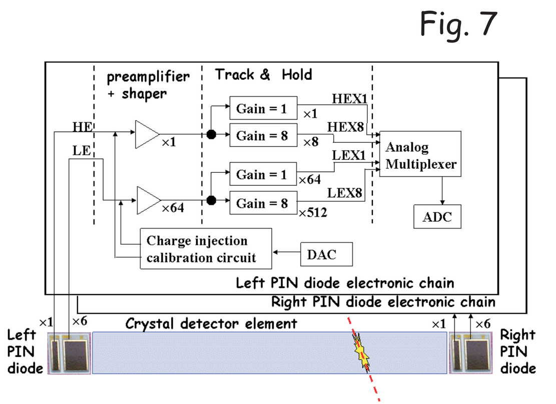
Two of four side surfaces of each crystal are roughened to provide known attenuation of light collection along the crystal. This allows measurement of the longitudinal coordinate using the relative signal ("light asymmetry") from the two ends of a crystal.

CDEs are inserted into the carbon fiber structure using a precision insertion tool (Fig. 5). Longitudinal elastic bands keep the CDEs in place the their cells. Fig 2 shows a module with all CDEs inserted.


Fig. 6

The front-end electronics boards are mounted over each of the four vertical faces of the CAL module. The PIN diode leads are passed through feedthroughs in the boards and soldered in place (Fig. 6), after which closeout plates are attached to complete the module.

The signal from each photodiode is processed by an individual electronics chain (Fig. 7) including preamplifier, shaper with ~3.5 μs shaping time, and two track-and-hold stages to produce nominal "x1" and "x8" output signals to cover the large dynamic range (the measured signal ratio between these two outputs, ~1:9, is somewhat different from the nominal value). In total, each crystal end produces 4 output signals ("energy ranges"; 2 for each diode) with ratio 1:9:60:540, digitized by a single 12-bit ADC. Programmable "range selection logic" selects the lowest unsaturated energy range for readout. Four range readout is available for calibration purposes.

Fig. 7


To decrease the data volume it is possible to suppress the transfer of the digitized data for crystal ends with signals below the Log Accept (LAC) threshold which can be set individually for each crystal end. In flight the LAC thresholds will be ~1.5 MeV.

The electronic chain of each photodiode also includes a trigger circuit, consisting of a fast shaper with ~0.3 μs shaping time and a discriminator (FLE for low energy diode and FHE for high energy diode). The FLE and FHE discriminator thresholds can be set individually for each crystal end. The logical OR of all FLE and of all FHE outputs form the CAL_LO and CAL_HI triggers respectively. In flight the FLE discriminator threshold will be set to ~100 MeV and FHE discriminator threshold to ~1 GeV per crystal. To trigger from cosmic muons during ground calibration, the FLE discriminator thresholds were set to ~10-15 MeV.

The front-end electronics boards are controlled and read out by the Tower Electronic Module (TEM), installed below the calorimeter module. The TEM provides collection of trigger signals and formation of the trigger decision; commands to the front-end boards to digitize the signals; buffering of the digitized data; optional collection of the diagnostic information on the status of LAC, FLE, and FHE discriminators on the front-end board; and data transfer to the online Ground Support Equipment (GSE) processor or LAT central processor.

CALORIMETER PRODUCTION RESPONSIBILITIES

Eighteen calorimeter modules were assembled in 2004-2005. This number includes 16 modules which have been integrated into the LAT instrument, and two additional modules that function as flight-qualified spares and/or post-launch reference units plus a third identical spare module not flight-tested. AMCRYS (Kharkov, Ukraine) manufactured 1850 CsI crystals for the GLAST calorimeter (1728 required for 18 modules plus some spares) and sent them to Kalmar University, Sweden, for acceptance testing. The custom PIN diode assemblies (Fig. 3), containing two PIN diodes on one ceramic carrier, were produced by Hamamatsu (Japan). The crystals were assembled into detector elements (CDEs, see Fig. 4) at Swales Aerospace (USA).

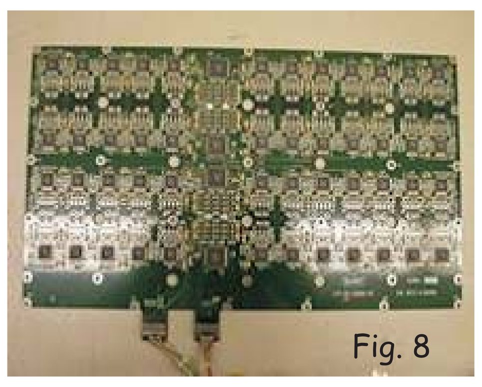


Fig. 8

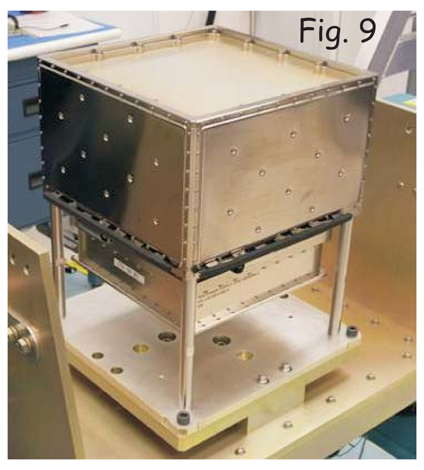


Fig. 9

The carbon fiber supporting structures (Fig. 5) were produced by LLR (Paris, France).

The production of the front-end electronics boards (Fig. 8) and the final assembly of the calorimeter modules (Fig. 9) were done at Naval Research Laboratory.

ENVIRONMENTAL TESTING

After production each module underwent a full environmental test program: vibration, electromagnetic interference (EMI) and compatibility (EMC), and thermal-vacuum. The functional performance of each Module was verified before and after each test, and calibration with cosmic muons and charge injection was performed throughout the test sequence. Then modules were delivered to SLAC for integration together with other detector and electronics subsystems into the complete LAT device. The assembled LAT will be tested at SLAC using cosmic muons, charge injection and low energy photons and early in 2006 will be delivered to NRL for thermal-vacuum test. After LAT-level environmental tests, the LAT will be delivered to General Dynamics for the integration with the GLAST spacecraft.

CALIBRATION PROCEDURES

Calorimeter calibration procedures consist of the following measurements:

- Charge injection calibration to determine electronic nonlinearity of the pulse height system
- Position of energy deposition in a crystal as a function of "asymmetry," defined as log(Plus End Signal/Minus End Signal)
- Energy deposited in a single crystal as a function of the geometric mean of the signals at each end of the crystal
- Trigger thresholds

A. Nonlinearity Calibration

The charge-injection calibration subsystem sends a known signal controlled by a 12-bit DAC (digital-to-analog converter) to the input of each preamplifier. For each output channel it permits a measurement of the deviation from linearity as a function of input signal. The resulting electronic non-linearity correction can then be applied to signals produced by scintillation.

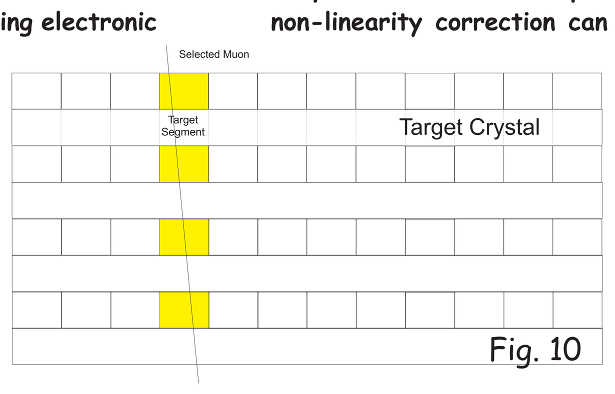


Fig. 10

B. Position Measurement Calibration

In order to calibrate position as a function of light asymmetry (as defined above), the hodoscopic nature of the calorimeter allows the selection of samples of cosmic muons that penetrate one of 12 equal width segments of the crystal to be calibrated. Each segment represents 1/12th of the length of the crystal, or approximately one crystal width (as defined by the orthogonal crystals). In order to be included in a segment sample, muons must meet the following criteria (Fig. 10):

- Have hits in four vertically aligned crystals orthogonal to the target crystal
- Have no hits in any other orthogonal crystals
- Have no hits in any other crystals in the target crystal layer

The first two criteria assure that the muon penetrates the target crystal in one and only one of the 12 segments. The third criterion assures that the muon does not exit the side of the target crystal.

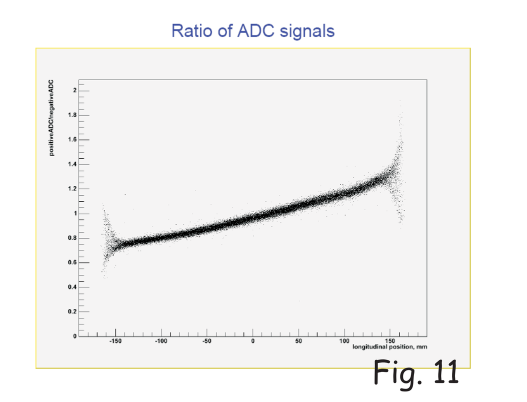


Fig. 11

The mean asymmetry of the muons selected for each segement is stored as a function of the mean position of that segment along the crystal, resulting in a set of points that can be interpolated to measure the position of energy deposits in that crystal.

Note that the position measurement scheme using asymmetry fails near the ends of the crystal, due to the asymmetric positioning of the PIN diodes, so only the central 10 segment points are actually stored, the points at each end being discarded. Fig. 11 shows how the relationship between asymmetry and position ceases to be unique in the last 3 cm or so near each end of the crystal. To handle this effect, events near the crystal end are detected using a variety of techniques (e.g. apparent position off the end of the crystal). For these events, position is assumed to be in the last "segment" of the crystal and energy is computed using the signal from the opposite end only, along with the assumed position.

It is possible that the signal at one crystal end will be read out from the big PIN diode, while at another end from the small PIN diode. To handle this situation correctly we calibrate position measurements with light asymmetry for all 4 combinations of different PIN diode sizes (big-big, small-big, big-small and small-small).

C. Energy scale calibration

The energy scale calibration requires a selection of cosmic muons with directions approximately parallel to the side surfaces of the crystal being calibrated. This was achieved by applying the following criteria (see Fig. 12; this procedure is similar to that used for the position calibration but differs in that the target crystal is one of the four in a vertical column):

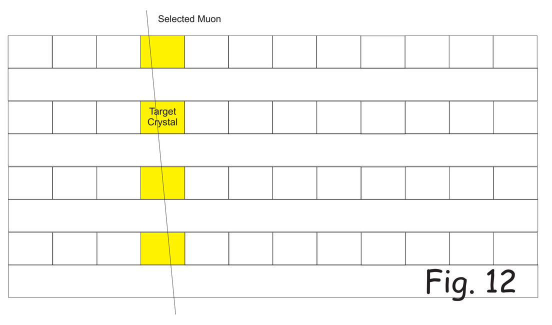


Fig. 12

- Four crystals in a vertical column (including the crystal being calibrated) have signals above the "hit" threshold (~0.2 MIP)
- All other crystals have signals below the threshold

This selection significantly decreases the low energy tail (Fig. 13) produced by muons that exit the side crystal surface yielding path lengths smaller than crystal height.

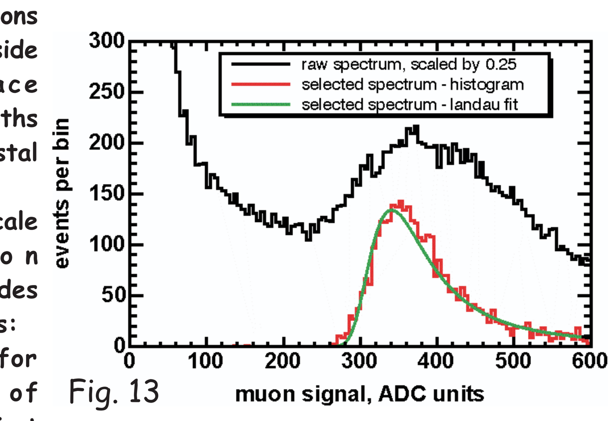


Fig. 13

The energy scale calibration procedure includes the following steps:

- To correct for nonlinearity of electronics we first convert the ADC values to an arbitrary linear scale (the "DAC scale") using the nonlinearity correction from the charge injection calibration
- For muons that meet the above criteria, compute a path length using crystal positions
- Reject muons greater than 52 degrees from the vertical
- For the remaining muons, compute an improved path using asymmetry-generated positions along crystals
- Correct energy deposition for path length for each target crystal
- Histogram the geometric means of the DAC-scale values from the two crystal ends for each crystal. The geometric mean is almost independent of position along the crystal because the crystal light attenuation law is close to exponential, resulting in a position-independent calibration
- Fit a Landau distribution model to each histogram. Most probable value is equated to expected muon energy deposition, yielding the calibration quantity known as MevPerDac. When a crystal signal is computed by converting each end into DAC units (i.e. correcting for electronic nonlinearity) then taking the geometric mean, MevPerDac converts the result to deposited energy in MeV.

D. Trigger thresholds calibration

In order to measure the FLE and FHE discriminator thresholds, we use available diagnostic information that indicates whether or not a trigger occured from each layer of a module. This, together with muon or charge injection collections, allows us to calibrate the trigger thresholds for each crystal end (see Fig. 14). The calibration with cosmic muons gives the true threshold value, but requires a few hours of data taking. A charge injection calibration is much faster, but the result is biased for the following reasons:

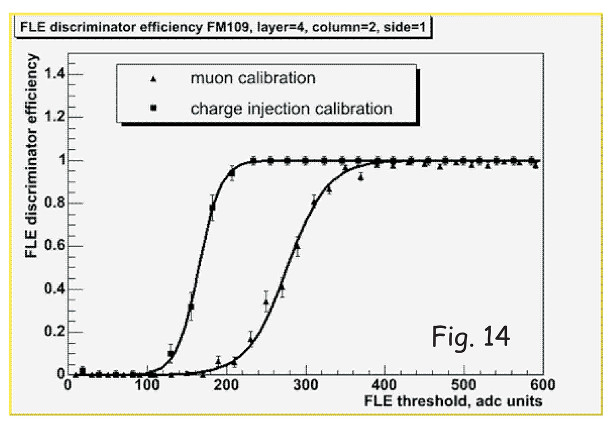


Fig. 14

- Charge injection produces some direct crosstalk into trigger circuits, which could be significant at low threshold values
- The shape of the charge injection signal could be different from the scintillation signal

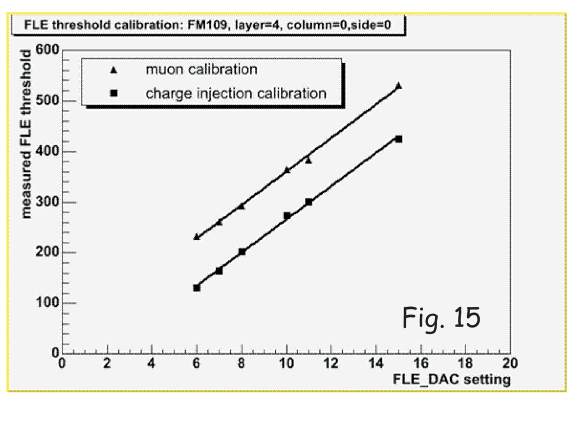


Fig. 15

The variation of measured FLE threshold between muon and charge injection measurements for one crystal end at room temperature and for different threshold settings is shown in Fig. 15.

This plot demonstrates that there is a constant bias of ~100 ADC units (~3 MeV) between charge injection and muon calibrations of the trigger threshold. Measurements at different temperatures show that these two methods of trigger threshold calibration have different temperature dependences as well.

For calibrations on the ground, when a low trigger threshold was needed, charge injection measurements, corrected for the bias, were used. The bias was calibrated with cosmic muons for one threshold setting. In flight, we plan to calibrate trigger thresholds directly with scintillation signals from cosmic rays. This is practical due to a much higher rate than observed from cosmic muons on the ground.

CALORIMETER PERFORMANCE MONITORING

A variety of calorimeter performance figures have been monitored over the course of environmental testing. For the most part, performance has remained stable, although small changes have been observed. For example, the energy calibration has changed by a small amount in some cases.

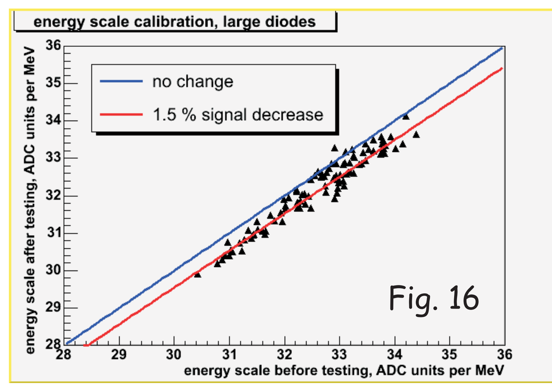


Fig. 16

Fig. 16 shows the comparison of the energy scale (in ADC units per MeV) for all 96 crystals of one module, measured right after the module was assembled (horizontal axis) and 2 months later after the end of environmental testing (vertical axis). Each point corresponds to one crystal. In the ideal case of no change in energy scale, all points should be along the blue line. The spread along the line corresponds to ~10% crystal to crystal non-uniformity within a module. However, the distribution demonstrates ~1.5% signal decrease after environmental testing. The change is small relative to calorimeter energy resolution (~6%) and will be taken care of by future calibrations. This change in energy scale is more than likely caused by small drifts in the electronics chain due to differences in measurement setup and/or environment.

TRENDING

In addition to studies such as the one above, a regular program of trending a variety of measured parameters has been undertaken as part of the study of instrument stability during environmental test.

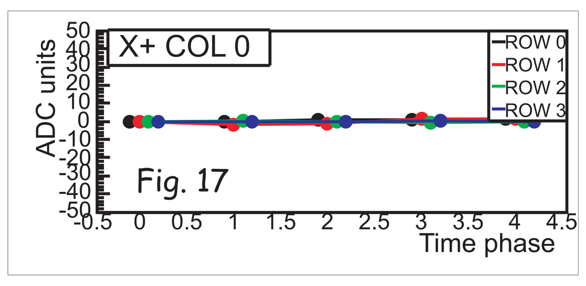


Fig. 17

The Comprehensive Performance Test (CPT) is a standard suite of tests run before and after each environmental test and multiply during each thermal-vac test cycle.

Fig. 17 shows a sample trending time history for the module Fm115 pedestal position value. The trending application generates these histories for each electronic chain or "channel" for each crystal in the module. These curves show the "X+" end of four crystals ("column 0" for the four layers or "rows" of crystals parallel to the module x-axis). Each curve is slightly offset from the others for visibility. The "phases" (abscissa) can be either various times or temperatures, while the ordinate is the difference between the pedestal value and that of a designated "reference phase", in this case the first phase. Fig. 18 shows a similar sample history of pedestal position vs temperature.

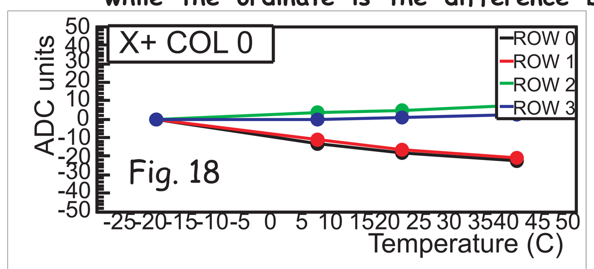


Fig. 18

Fig. 17 demonstrates that pedestal positions do not vary much with time (at room temperature), but Fig. 18 shows that they are dependent on temperature, and that different crystals have different characteristic temperature dependence.

In addition, the trending application shows the behavior of each trended quantity for each phase as a function of channel, allowing the determination of variation from crystal to crystal. Fig. 19 is an example of this plot. The left panel shows the pedestal position value for each X+ face channel (all four energy ranges). This information is histogrammed in the right panel. Note that the pedestal position varies substantially from crystal to crystal for the X8 energy ranges, but is rather tightly grouped for the X1 ranges.

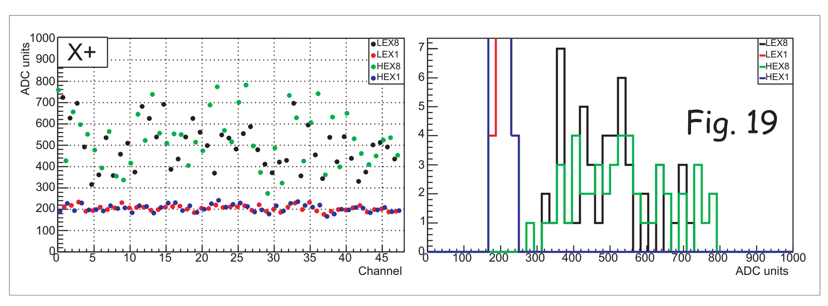


Fig. 19

CONCLUSION

The assembly and test phase for the GLAST/LAT calorimeter modules resulted in delivery of 16 flight modules, 3 spare modules (of which 2 underwent full testing) and one engineering model module to SLAC for integration with the LAT and further testing. These modules were extensively monitored during and after the assembly and test period. None of them showed evidence of significant degradation. Integration at SLAC was completed in December 2005. After further testing with flight software, the LAT will be shipped to NRL for instrument environmental tests, during which further monitoring and calibration of the calorimeter modules will be undertaken.

REFERENCES

[1] P. E. Michelson, " GLAST: A detector for high-energy gamma rays," Proc. SPIE Conf. Gamma-Rays and Cosmic-Ray Detectors, Techniques and Missions., vol. 2806, pp. 31-40, Aug. 1996.

[2] J.Ampe, A.Chekhtman, P.Dizon, J. E. Grove, W. N. Johnson, B. E. Leas, D. P. Sandora, M.S. Strickman, "The calibration and environmental testing of the Engineering Module of GLAST CsI calorimeter", IEEE Trans. Nucl. Sci., vol.51, No.5, pp. 2008-2011, Oct. 2004.