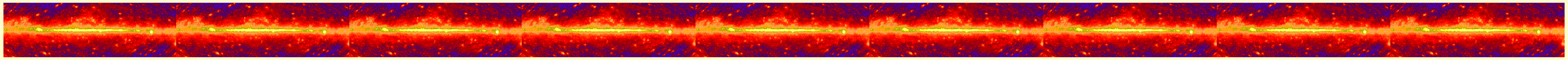
The Gamma-Ray Large Area Space Telescope:

CsI Hodoscopic Calorimeter for the GLAST Mission

B. F. Phlips (GMU), W. N. Johnson, J. E. Grove (NRL), J. Norris, S. Ritz, S. Singh (NASA/GSFC), I. Grenier (Saclay), P. Fleury (Ecole Polytechnique), A. Djannati-Atai (College de France), for the GLAST Collaboration

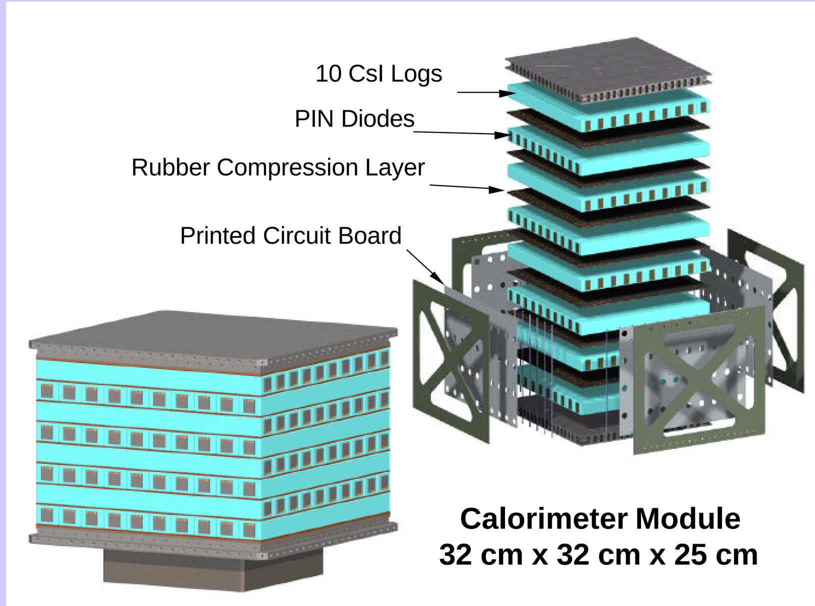


ABSTRACT

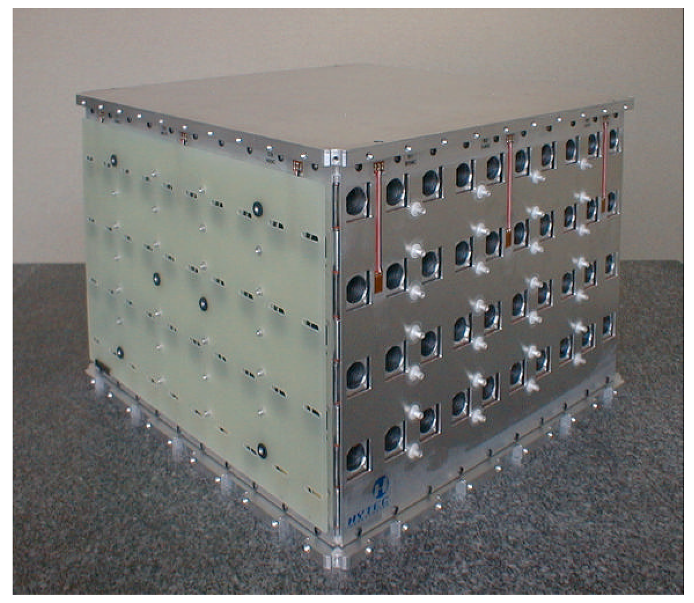
We report on the development of a CsI(Tl) hodoscopic calorimeter for the Gamma-ray Large Area Space Telescope (GLAST). The GLAST mission is part of NASA's strategic plan with a new start in the year 2002. The GLAST instrument observes gamma rays in the 10 MeV to 300 GeV energy range and is composed of an e^+-e^- pair conversion telescope and supporting calorimeter. Our team, led by Stanford University, is developing a tracker of silicon strip detectors, a CsI crystal calorimeter, a charged particle anticoincidence system, and data system as part of a GLAST technology development program supported by NASA and DoE. The calorimeter is segmented in a hodoscopic arrangement and instrumented to provide both good spectroscopy and moderate positioning (for shower tracking). We present here the prototype calorimeter and results of the technology development program, including simulations and performance testing of a previous prototype calorimeter in accelerator beams at SLAC, MSU, and CERN. The results of this technology program will be demonstrated in a beam test at SLAC in the fall of 1999.

Calorimeter Mechanical Concept

The calorimeter design matches the modularity of the GLAST tracker system. Each calorimeter module contains 80 crystals of size 2.3 × 3.0 × 31 cm readout by PIN photodiodes. The crystals are individually wrapped for optical isolation, and are arranged horizontally in 8 layers of 10 crystals each. The size of the CsI crystals has been chosen as a compromise between electronic channel count and desired segmentation within the calorimeter. The indicated size is comparable to the CsI radiation length (1.86 cm) and Moliere radius (3.8 cm) for electromagnetic showers. The crystals are held in place against Delta II launch loads by a compression frame designed by Hytec, Inc, of Los Alamos, NM. The design is additionally complicated by the requirements to accommodate the large coefficient of thermal expansion of the CsI. Signals from the PIN diodes pass through the frame on flex circuits to the analog front-end electronics, which are mounted on narrow printed circuit boards fastened on the four sides.



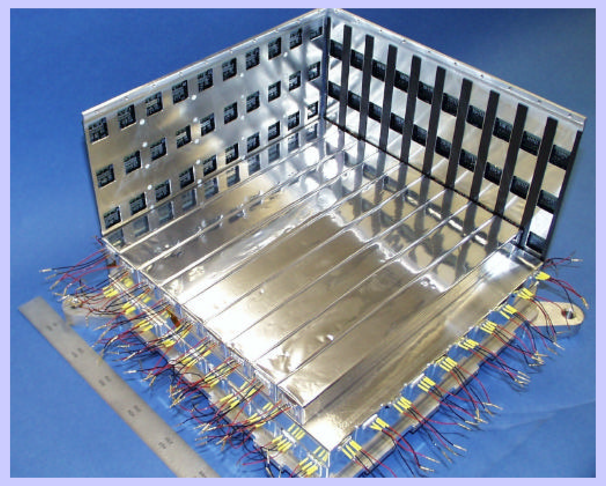
Calorimeter Module
32 cm x 32 cm x 25 cm

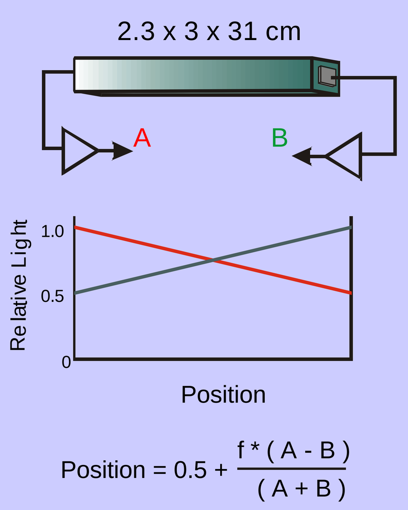


Calorimeter Requirements

Modular Design:	25 Modules in a 5 x 5 array matching Si Tracker design
Energy Range:	10 MeV – 300 GeV
Energy Resolution:	10% for E > 100 MeV 2% for E > 10 GeV (goal)
Field of View:	> 2 steradians
Mass:	~ 2100 kg (total); 85 kg/ module
Power:	~ 125 Watts (total); 5 Watts/module
Trigger Rate:	1200 Hz (Tracker, orbit ave) +250 Hz (Cal, orbit ave) 4000 Hz (peak)
Self trigger delay:	< 1 µsec
Trigger Dead time:	10 µsec (goal)

Hodoscopic Calorimeter

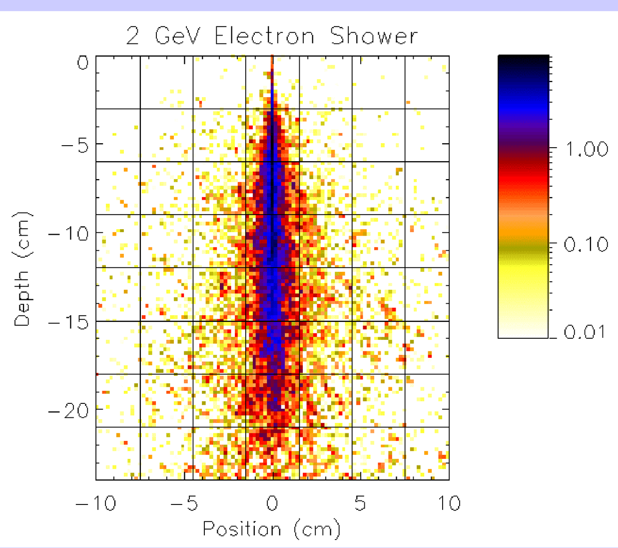




SLAC '99 Beam Test Prototype
Calorimeter (partial Stack)
2.3 x 3 x 31 cm blocks

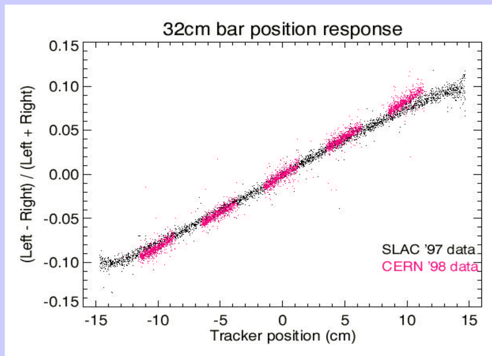
The modular GLAST calorimeter is constructed from CsI(Tl) scintillation blocks read out by PIN photodiodes. Each tower contains 80 blocks of approximate size 2.3 cm × 3 cm × 31 cm. The blocks are arranged horizontally in 8 layers of 10 blocks with alternate layers oriented with the long axis of the block perpendicular to that of the adjacent layers to form an x-y hodoscope. PIN photodiodes mounted on each end of the block measure the scintillation light seen at each end. The difference in the light levels at each end provides a determination of the position of the energy deposition along the CsI block. Thus, the layering and orthogonal positioning of events in the calorimeter provide the ability to reconstruct the electromagnetic shower in the calorimeter and, consequently, to determine the incident direction. In this mode, the calorimeter measurements alone can image the gamma-ray sky.

Development of Electromagnetic Shower

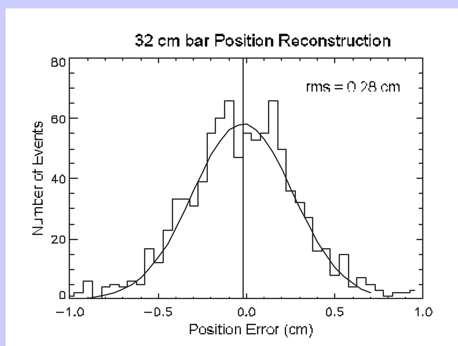


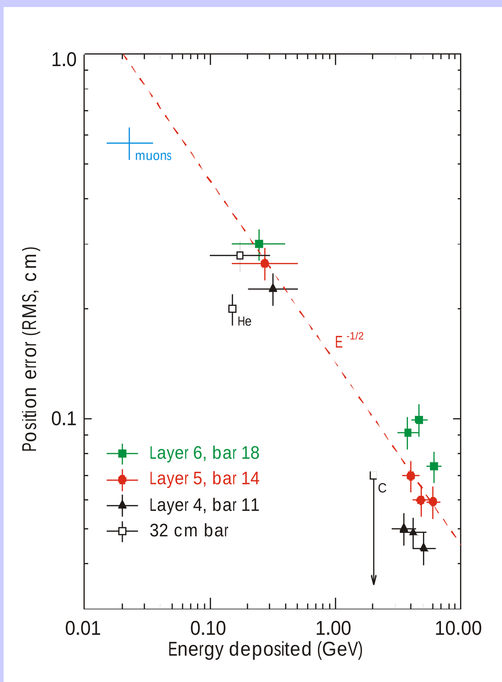
This simulation of a 2 GeV electron entering a CsI calorimeter from the top shows the spatial distribution of the energy deposition. The color coding shows the energy (in MeV) deposited in 2 mm pixels. Maximum energy loss rate (shower max) occurs at a depth of ~10 cm for 2 GeV. The grid represents the approximate segmentation of the GLAST calorimeter (3 cm).

Positioning with Light Asymmetry



SLAC e^- beam, 2 GeV
DE ~ 130 MeV





Each CsI crystal provides three spatial coordinates for the energy deposited in it, two from the physical location of the crystal in the array and one along the length of the bar. To determine the position of a shower along the CsI crystal (the longitudinal position), we calculate a measure of the light asymmetry,

$$A = (Left - Right)/(Left + Right),$$

that is independent of the total energy deposited in the crystal. Note that if the light attenuation in the crystal is strictly exponential, the longitudinal position is proportional to the inverse hyperbolic tangent of the light asymmetry,

$$x = K\, tanh^{-1} A.$$

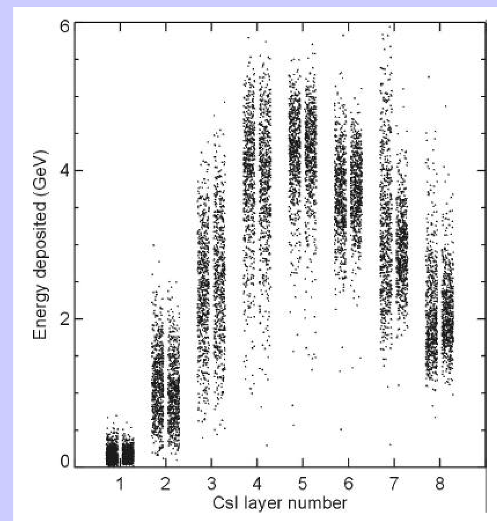
The figure to the upper left demonstrates this relationship as measured in beam tests at SLAC and CERN. Each dot in the figure plots the light asymmetry for a single event vs position determined by the Si Tracker. The CERN measurements were made in collaboration with team members from IN2P3 in France and included a modification in the crystal preparation which improved linearity at the ends of the crystal.

The distribution of the position errors determined by the light asymmetry measure indicates a gaussian distribution with 0.28-cm rms error for this energy deposition of ~ 130 MeV in the crystal. Measurements at energies of 2, 25, 30, and 40 GeV at SLAC indicate that the position error scales roughly as $1/\sqrt{E}$, indicating that the measurement error is dominated by photon statistics.

Measurements with muons and with He and C beams at Michigan State Superconducting Cyclotron Center show improved position measurement over the shower positions because fluctuations in the transverse shower development contribute to the position uncertainty.

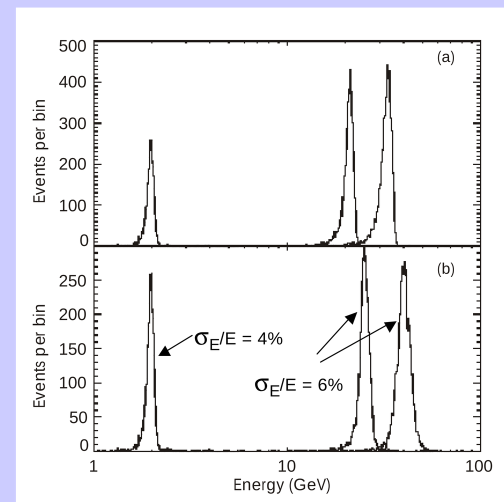
Calorimeter Energy Measurements

The principal function of the calorimeter is to measure the energy of incident γ-rays. At the lower end of the sensitive range of GLAST, where electromagnetic showers are fully contained within the calorimeter, the best measurement of the incident gamma-ray energy is obtained from the simple sum of all the signals from the CsI crystals. At energies above ~1 GeV, an appreciable fraction of the shower escapes out the back of the calorimeter, and this fraction increases with γ-ray energy. At moderate energies (~few GeV), fluctuations in the shower development thus create a substantial tail to lower energy depositions.



Energy distributions in each calorimeter layer for a large number of events. Monte Carlo comparison is to the right of each layer distribution.

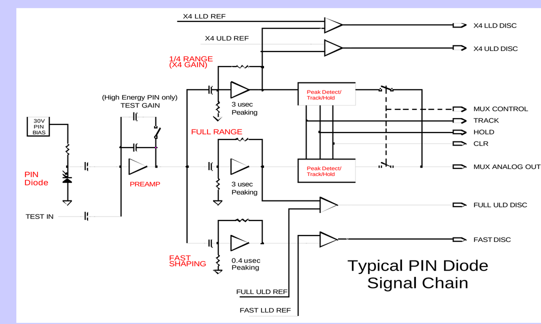
The top figure at right shows the distributions of energy deposition for 25 GeV electron showers in each of the 8 layers of the '97 beam test calorimeter. A pair of distributions is shown for each layer; the left member of the pair is from the beam test data, with one event producing one point in each layer. The right member of the pair is the same distribution from the Monte Carlo simulation. The centroid and width of the beam test and Monte Carlo distributions in each layer are in good agreement. The broad energy distributions seen in the figure are dominated by shower fluctuations, and the energy depositions are strongly correlated from layer to layer. Using a monoenergetic 160 MeV/nucleon ^{12}C beam at the National Superconducting Cyclotron Laboratory at MSU, the intrinsic energy resolution of these CsI crystals with PIN readout was measured to be 0.3% (rms) at ~ 2 GeV.



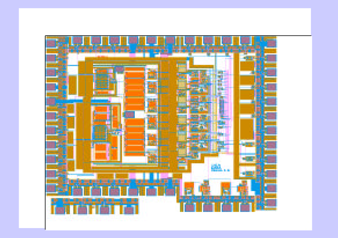
Total energy measurement in the calorimeter before and after shower profile fitting corrections.

Using the longitudinal shower profile provided by the segmentation of the calorimeter, one can improve the measurement of the incident electron energy by fitting the profile of the captured energy to an analytical description of the energy-dependent mean longitudinal profile. This shower profile is reasonably well-described by a gamma distribution which is a function only of the location of the shower starting point and the incident energy. In the figure above, panel (a) shows the histograms of the measured energy loss in the calorimeter for electron energies of 2, 25, and 40 GeV. Panel (b) shows the resultant histograms from the shower profile fitting.

Calorimeter ASIC Development



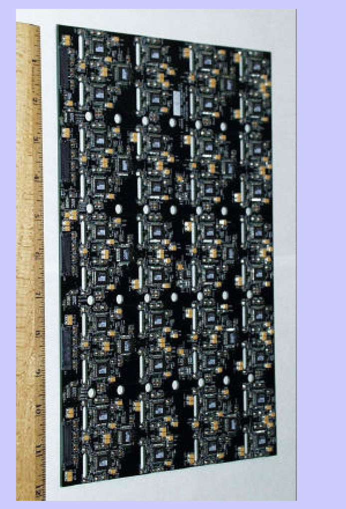
Front End Electronics Block Diagram



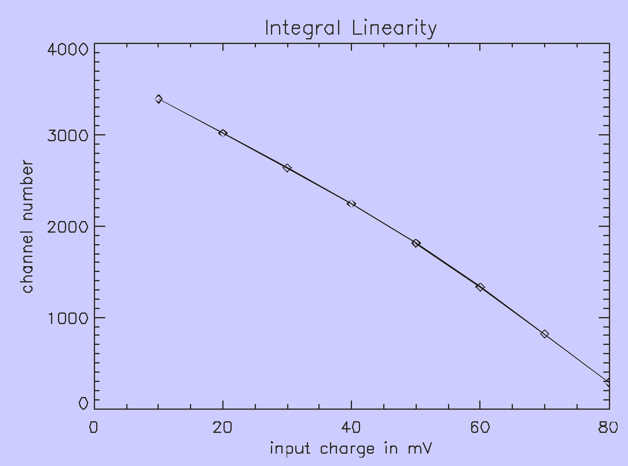
GSFC Custom Analog ASIC Design

The large number of electronics channels in the calorimeter and the large dynamic range (~10^6) requires the development of custom, low power front end analog application specific integrated circuits (ASICs). The front end electronics concept is shown above. Each end of a CsI block has two PIN diodes which support two differing gain ranges. Each signal chain consists of a preamp, shaping amp, track/hold and multiplexer to an analog to digital converter (ADC). When a GLAST event trigger is created (principally from signals in the silicon tracker), all calorimeter signal chains are digitized. Prototype ASICs have been designed and fabricated by GSFC and have achieved the required performance.

Front-End Electronics



Front end electronics board



Integral Linearity of Front-End Electronics

The Front-end electronics board (shown in photograph above) holds the electronics for the readout of all the PIN-diodes on one side of the calorimeter. It is located inside the side walls of the mechanical structure supporting the crystals. It contains custom ASICs (two different complementary custom ASICs), ADCs and FPGAs. Two commercial ADCs are being tested in the prototype: the Maxim MAX189 and the Burr Brown ADS7816. The integral linearity of the entire electronics chain was tested with test pulses and is shown in the figure. The dynamic range of the four channels of electronics on each crystal-end allows an energy coverage ranging from a few Mev to 100 GeV per crystal. The power consumption of the front end electronics will be less than 5 W per tower.

GLAST UNDERSTANDING THE MOST POWERFUL ENERGY SOURCES IN THE UNIVERSE