The Gamma-Ray Large Area Space Telescope:

The GLAST Silicon Strip Tracking System

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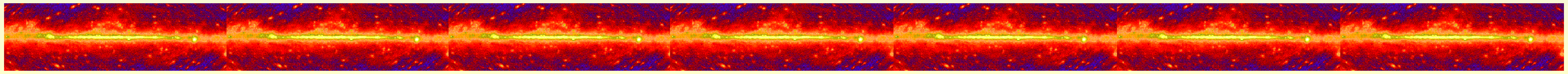
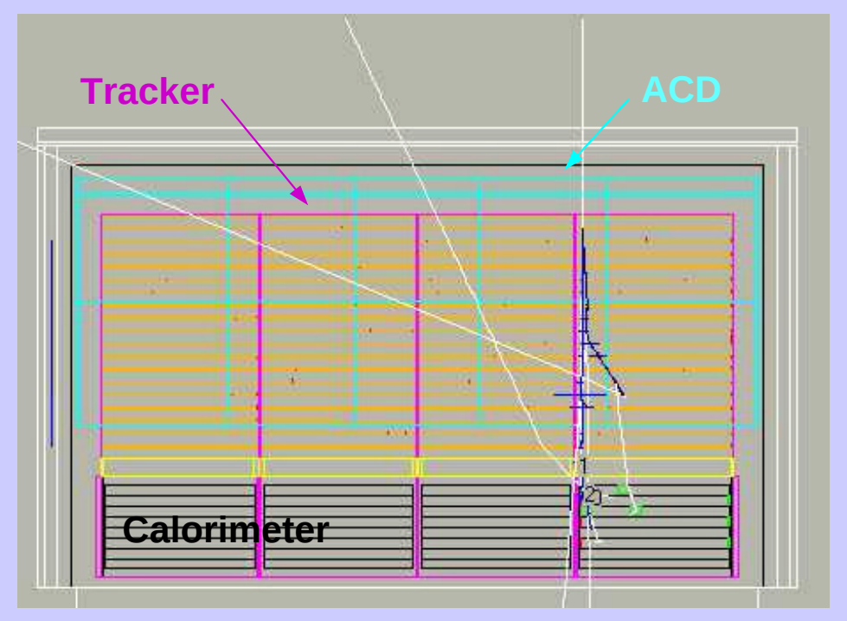
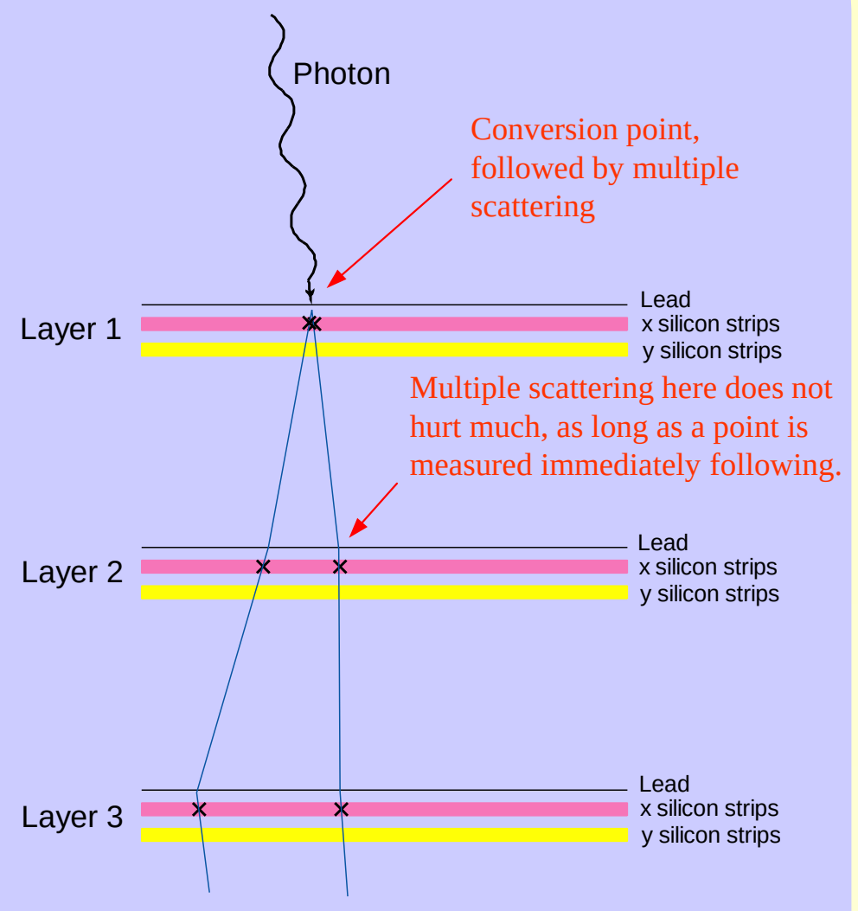
GLAST Collaboration



Pair Conversion Telescopes



Simulation of a GLAST event in a 4×4 array of tower modules. A 100 MeV gamma ray (white line) enters the right-most tower at 90 degrees and converts in the first lead foil. The blue lines show the reconstructed trajectories of the electron and positron. White lines show the trajectories of low-energy x-rays produced in the electromagnetic shower.

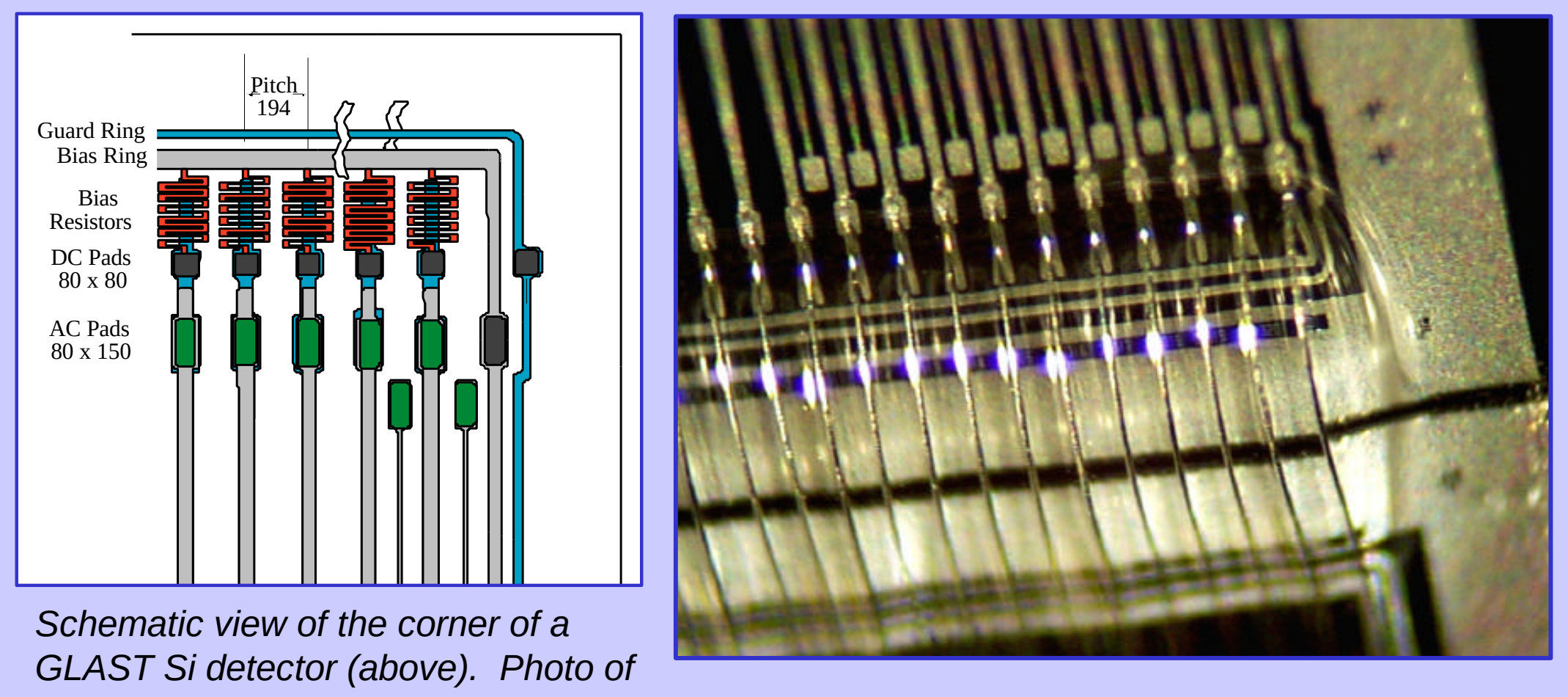


For all but the highest energy photons, the angular resolution is limited by multiple scattering in the lead converter foils. In that case, almost all of the direction measurement power comes from the first two tracker planes following the conversion. As long as a point is measured by detectors immediately following the second converter foil, then the measurement is only degraded by the lead foil in which the conversion occurred. If one of the first two points is missed, then the resolution is typically degraded by a factor of two. Therefore, high detector efficiency is crucial.

Summary

The GLAST instrument concept is a gamma-ray pair conversion telescope that uses silicon microstrip detector technology to track the electron-positron pairs resulting from gamma-ray conversions in thin lead foils. A cesium iodide calorimeter following the tracker is used to measure the energy. Silicon strip technology is mature and robust, with an excellent heritage in space science and particle physics. It has many characteristics important for optimal performance of a pair conversion telescope, including high efficiency in thin detector planes, low noise, and excellent resolution and two-track separation. The large size of GLAST and high channel count in the tracker puts demands on the technology to operate at very low power, yet with sufficiently low noise occupancy to allow self triggering. A prototype system employing custom-designed ASIC's has been built and tested that meets the design goal of approximately 200 microwatts per channel power consumption with a noise occupancy of less than one hit per trigger per 10,000 channels. Detailed design of the full-scale tracker is well advanced, with all components prototyped, and a complete 50,000 channel engineering prototype tower module is currently under construction and will be tested in particle beams in late 1999. The flight-instrument conceptual design is for a 5×5 array of tower modules with an aperture of 2.9 m^2 and an effective area of greater than 8000 cm^2.

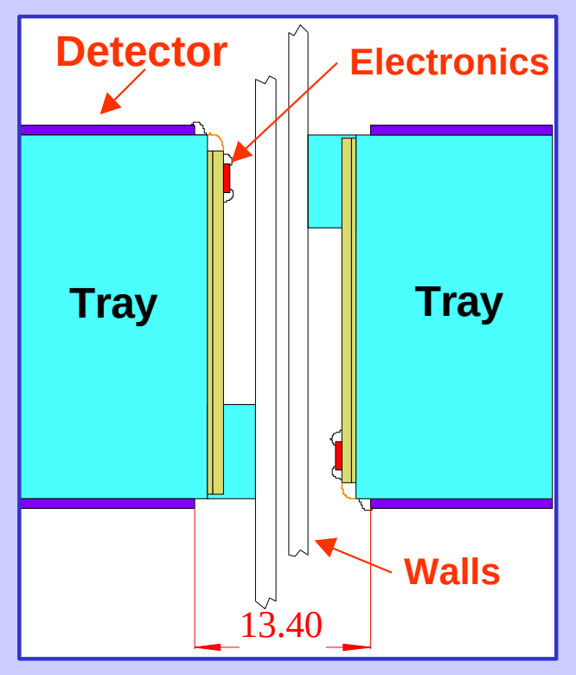
Silicon-Strip Detectors



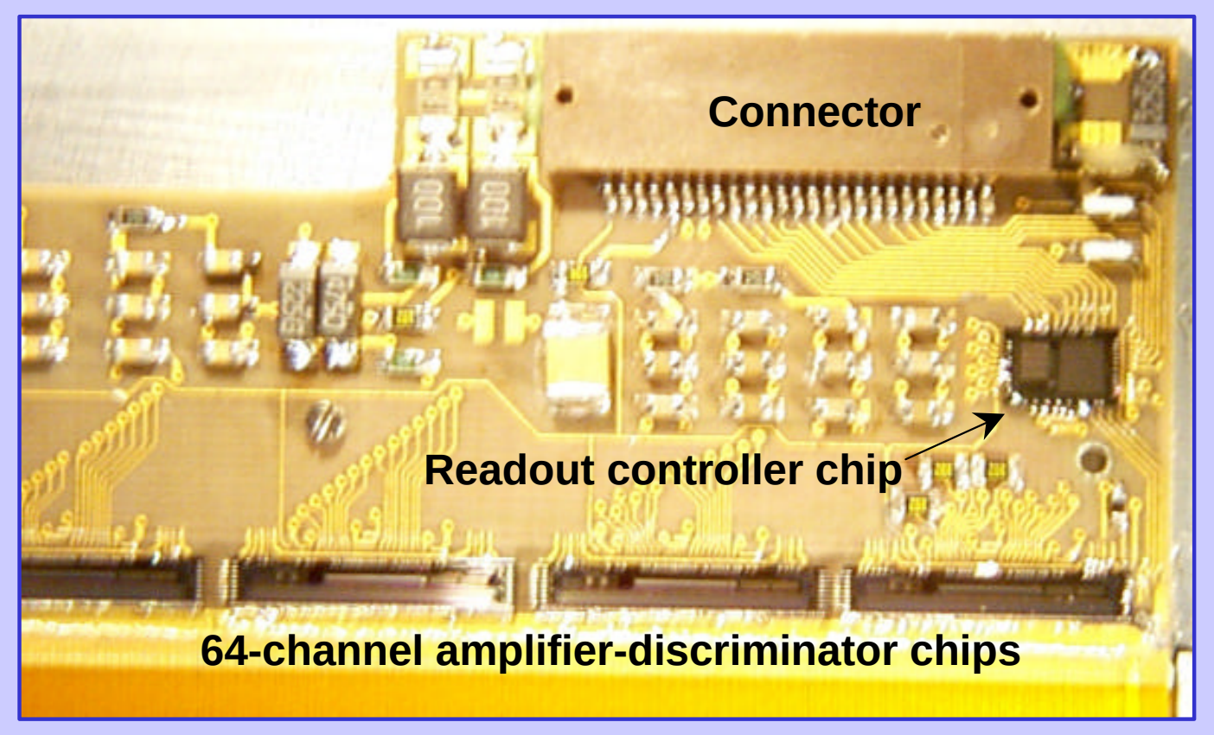
Schematic view of the corner of a GLAST Si detector (above). Photo of epoxy encapsulated wire bonds joining two detectors (right).

The silicon-strip detectors are manufactured by several industrial companies using well-developed technology. They are 400 um thick PIN diode structures made on high-resistivity *n*-intrinsic silicon which is fully depleted at a bias potential of about 100 volts. Strips of about 200 µm pitch are patterned on the junction side with AC coupling capacitors built in. Polysilicon resistors are used to bias the *p*-type diode strip implants. A minimum-ionizing particle passing through a detector typically produces 32,000 electrons-hole pairs, a signal which is readily amplified by integrated circuit FET amplifiers.

Readout Electronics



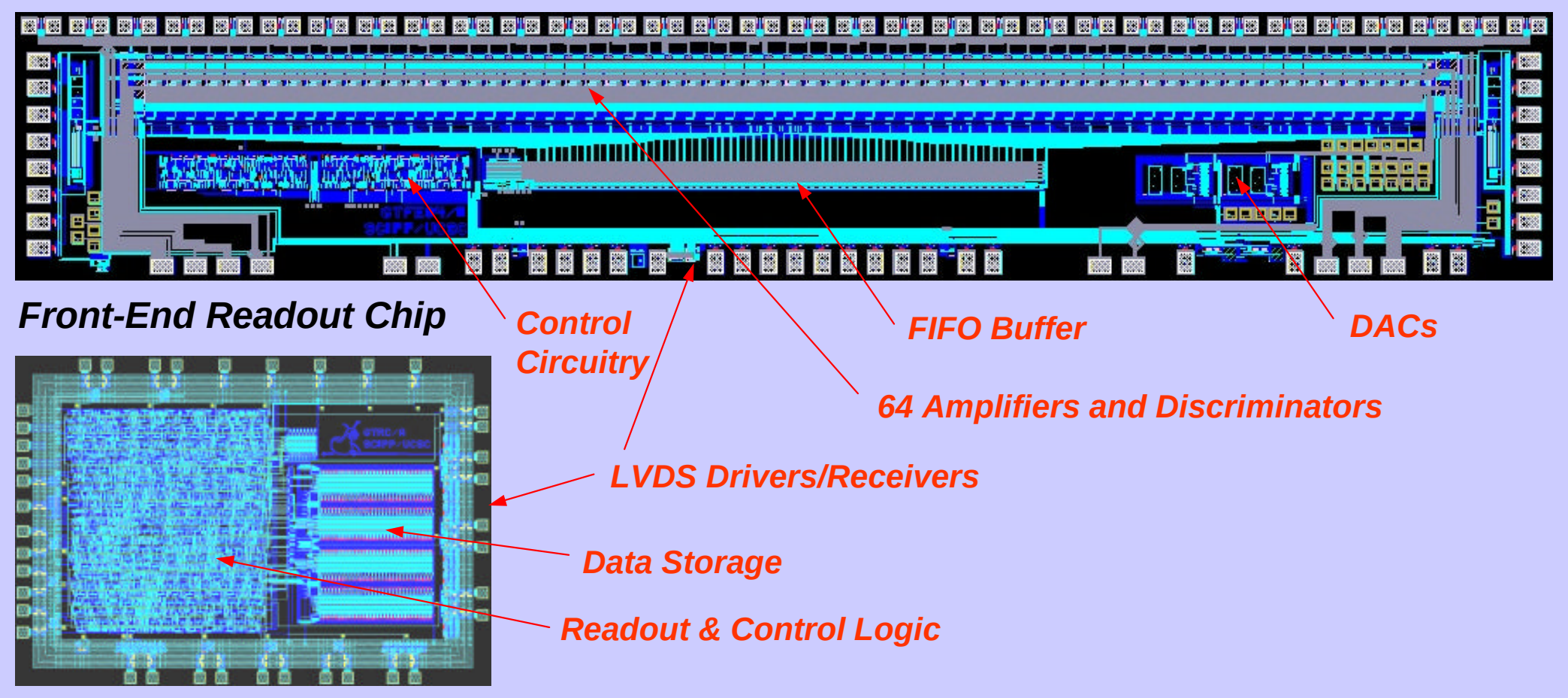
The readout electronics are located on the edges of the trays to give only 13.4 mm dead space between towers.



One end of a front-end electronics readout module.

One principal goal that has been realized in the GLAST tracker technology development program is the design and prototype testing of miniaturized, low-power, low-noise readout electronics. The circuitry fits into a 3-mm gap along the sides of a tower module and includes sufficient redundancy that any single chip can fail without affecting the readout of the remaining channels. The readout is fast enough, with sufficient buffering, that events can be accumulated at rates exceeding 1 kHz with negligible dead time.

ASIC Development

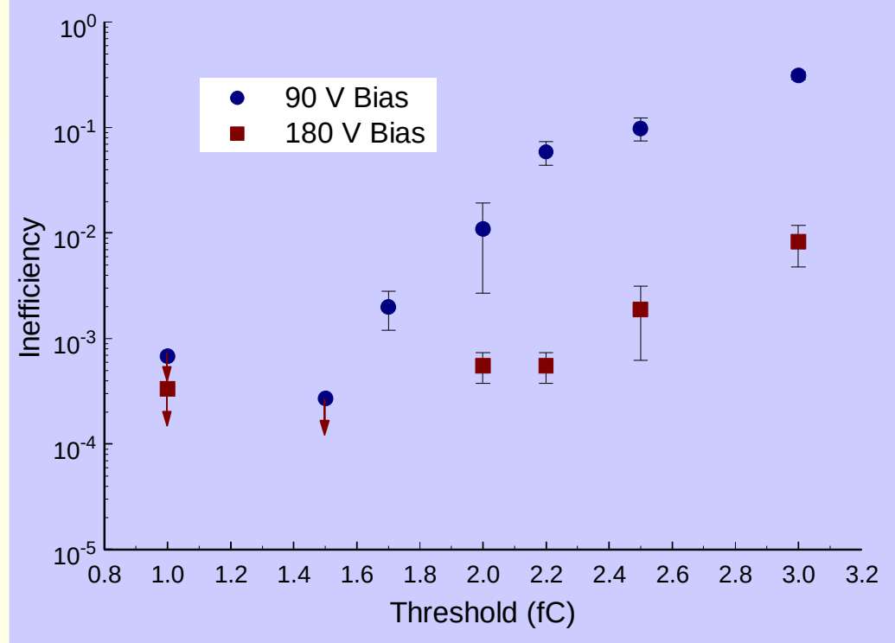


Front-End Readout Chip

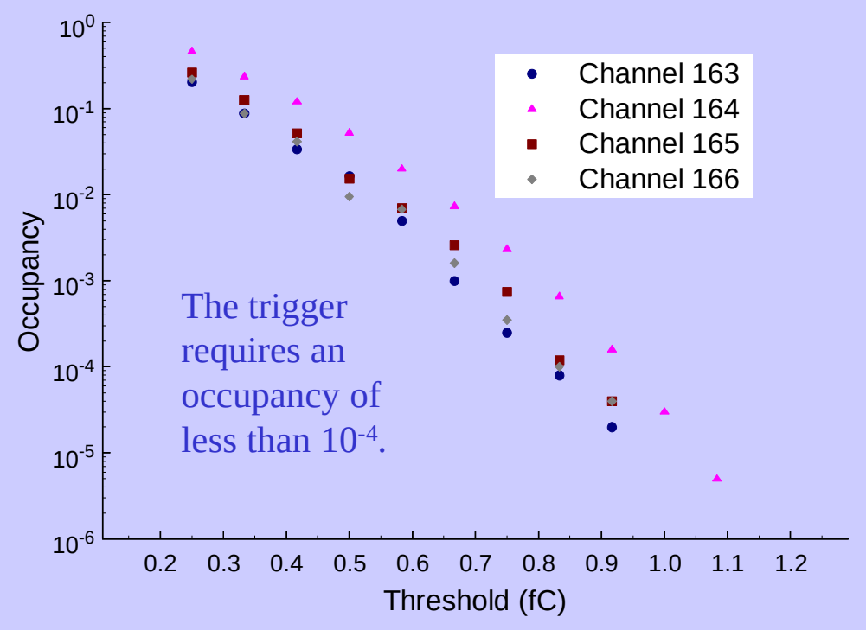
Readout Controller Chip

The signals from silicon-strip detectors must be amplified by electronics located nearby the strips. That is readily accomplished by the use of VLSI technology. Two different CMOS IC chips have been custom designed and prototyped for the GLAST tracker. The first is a mixed analog-digital chip that includes 64 amplifiers and discriminators, digital circuitry for control, calibration, data buffering and readout, DACs for calibration and threshold settings, and differential drivers and receivers for communication. The second is a digital chip that acts as an interface between 25 amplifier chips and the data acquisition system.

Readout Electronics Performance



Inefficiency for detection of ***single*** *minimum ionizing electrons at normal incidence in a single detector plane. The nominal threshold used is 1.5 fC.*

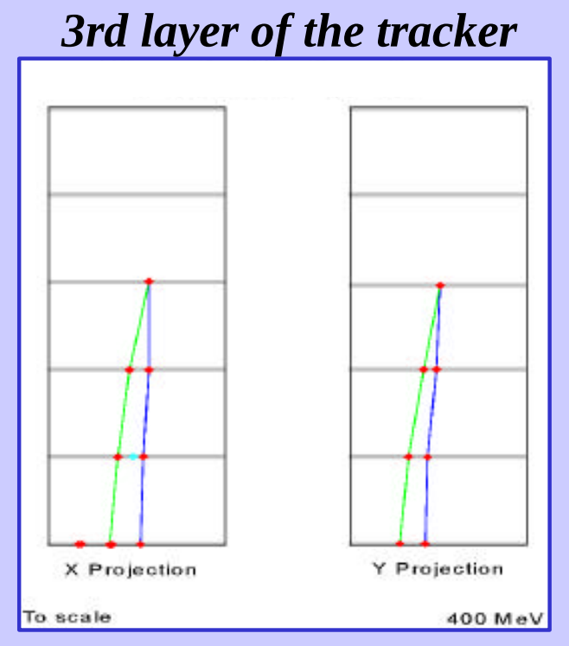


Noise occupancy, in a 1ms trigger window, versus threshold for four different channels connected to 30 cm long detector strips. The nominal threshold of 1.5 fC is off scale.

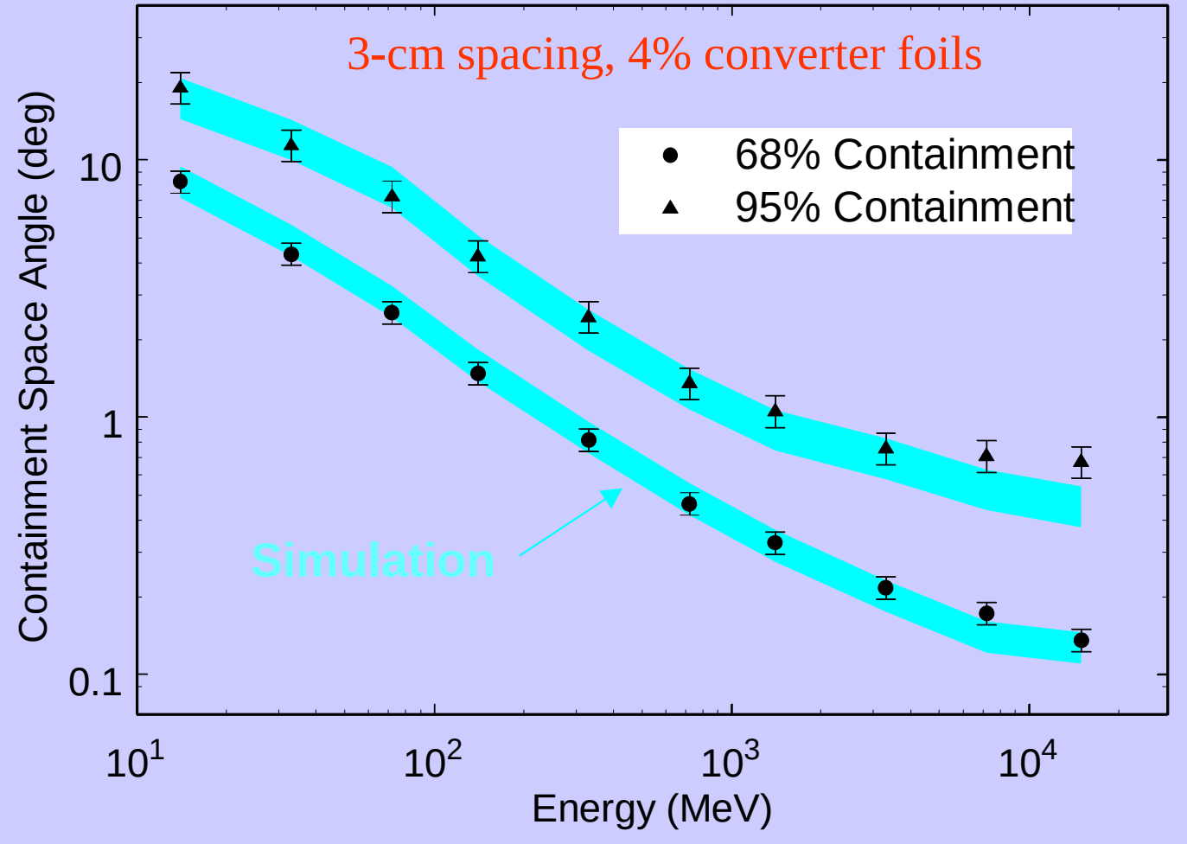
Prototype amplifier-discriminator chips have been tested with 30-cm detector strips in particle beams. The detection of single minimum ionizing electrons was demonstrated to be >99.9% efficient with a threshold sufficiently high to ensure a noise level of much less than one noise hit per trigger in 10,000 channels. This performance allows implementation of simple self-trigger algorithms for the tracker. The power consumption of the amplifier-discriminator chain was 140 uW per channel.

Beam Test Results

400 MeV g Conversion in the 3rd layer of the tracker



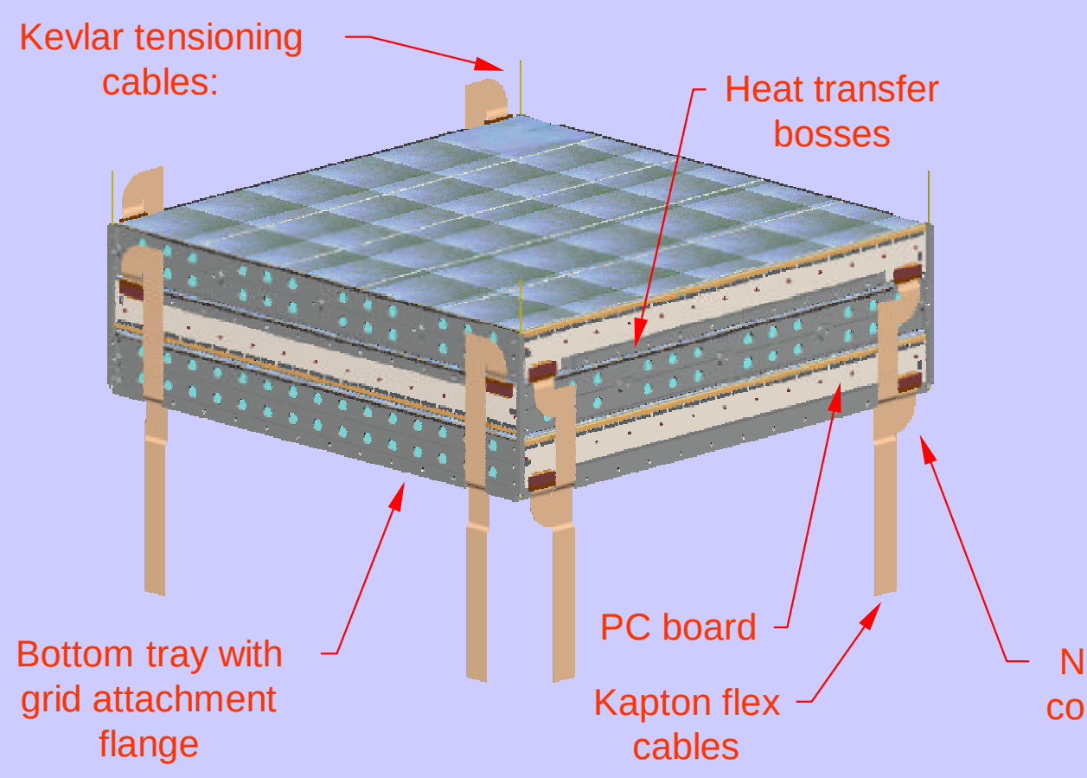
Measured Angular Resolution for Gamma Rays



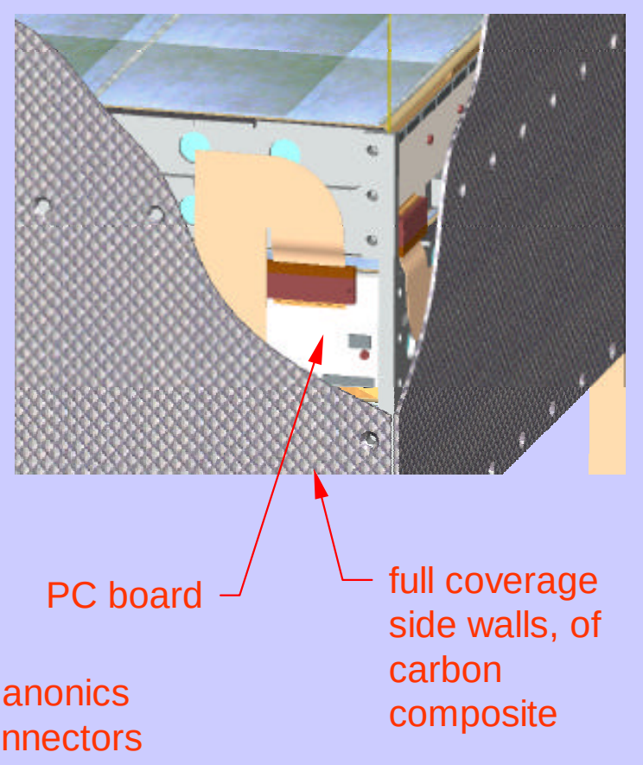
A small prototype tracker with 12 planes of silicon-strip detectors was tested in electron and photon beams in 1997. The angular resolution of reconstructed photon conversions was measured for several configurations of detector spacing and lead converter thickness. In all cases the results were in excellent agreement with predictions made by the Monte Carlo simulation program used in the design of the GLAST instrument.

Mechanical Structure

Tracker Tower Module: Lower 3 Trays

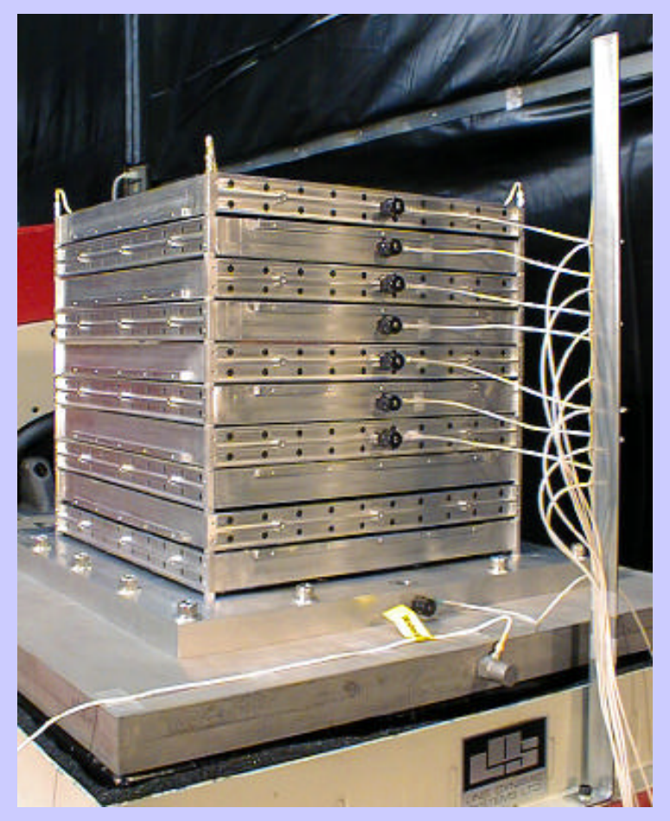


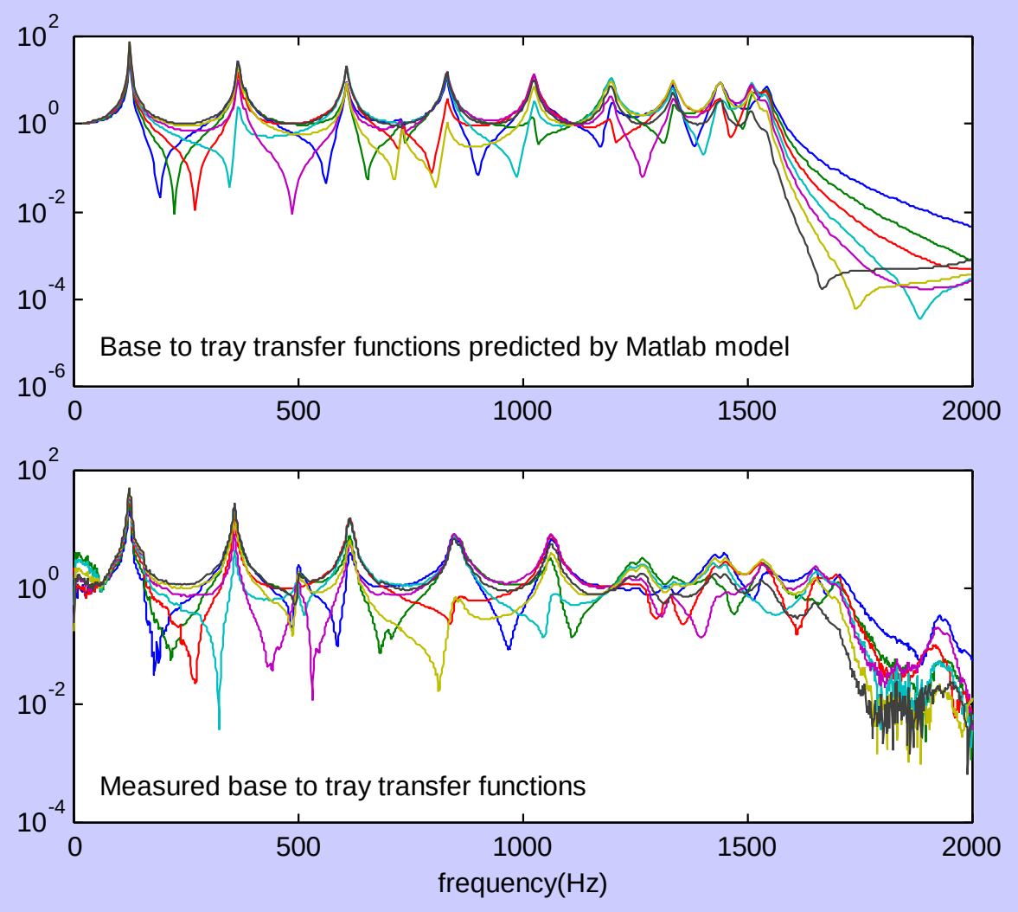
Corner Detail with Side Walls



The mechanical structure of the tracker towers must withstand a Delta-II launch while protecting the detectors and electronics and maintaining accurate alignment. The design, illustrated above, is based upon a stack of detector "trays." Each tray has detectors on the top and bottom and electronics along two opposing sides. Alternating trays are rotated by 90 degrees with respect to each other. Each gap between trays thus has an *x*-*y* pair of detectors facing each other and separated by about 2 mm. The trays are of a very rigid lightweight composite construction.

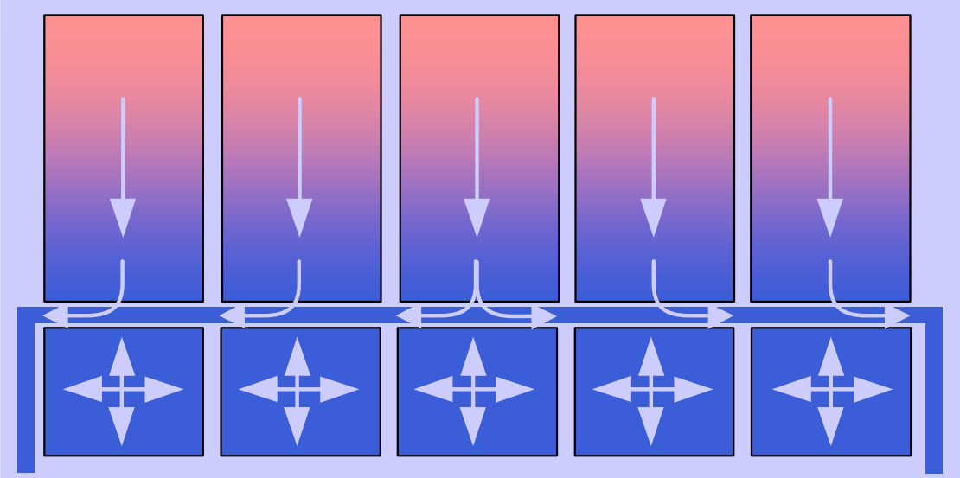
Mechanical Testing





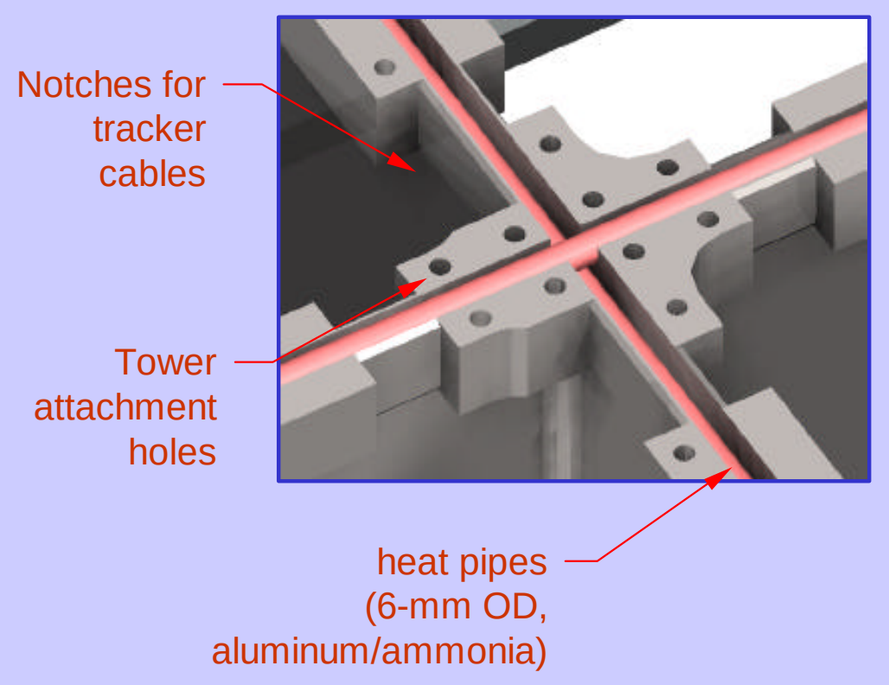
A mechanical prototype tower with 10 trays was constructed from aluminum and carbon composites to validate the design and construction techniques. It was vibration tested to the levels required for a Delta-II launch. Measurements made during the testing were shown to agree well with predictions of computer models, thus validating the techniques being used to design the GLAST tracker structure.

Thermal Design



Schematic of the flow of heat from the tracker and calorimeter electronics out the sides of the instrument.

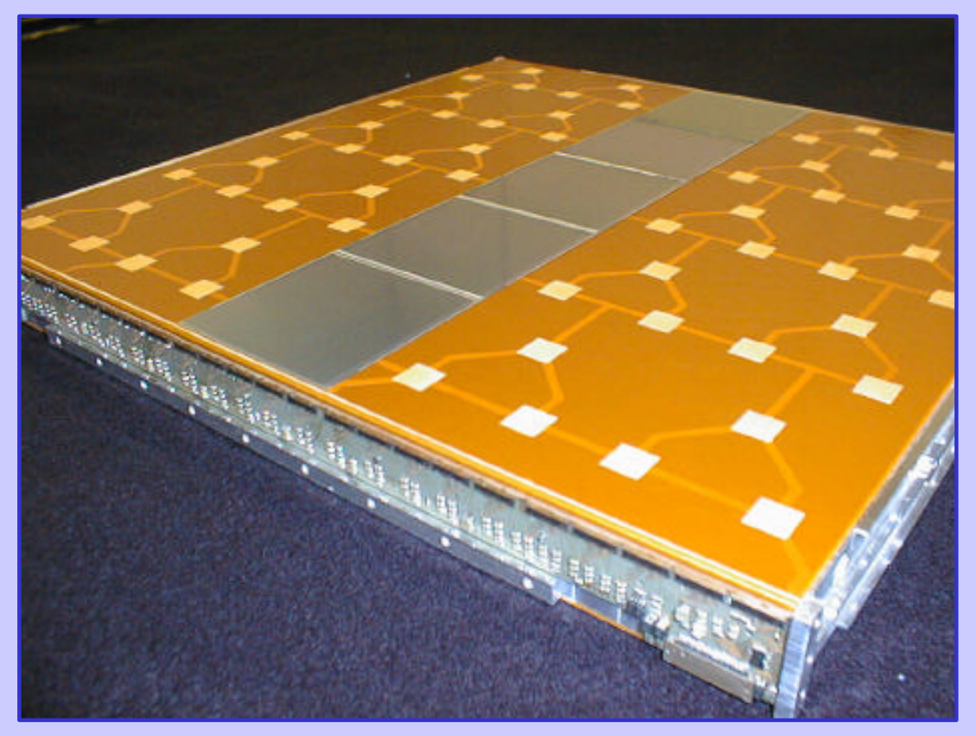
Detail of the grid structure that supports the tracker towers.



The GLAST tracker is cooled by passive conduction of heat from the electronics down the tower walls and into the grid support structure. Heat pipes in the grid then carry the heat to radiator panels on the spacecraft's periphery. Thermal simulations have shown that the required maximum temperature gradients in the tower can be readily met by the use of structural carbon fiber materials for the walls.

Assembly

Photograph of a tracker "tray", with a complete readout section mounted on the edge, with 1600 amplifier channels. One 32-cm "ladder" of Si-strip detectors is mounted on the top surface. Four more such detector ladders will mount on the top face, and five will mount on the bottom face, connected to electronics on the opposite edge.



Prototype trays of aluminum construction have been built for use in the engineering prototype tower, which will be tested in electron and photon beams in late 1999. The photograph above is of a tray outfitted with fully functional detectors and readout electronics. Work is beginning on development of trays constructed from carbon composites, to minimize scattering of the electrons, to minimize photon conversions in the structural material, and for improved strength and thermal stability.

GLAST

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