OG 4.2.21

The FiberGLAST Detector: A fiber instrument concept for NASA's Gamma-ray Large Area Space Telescope

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Abstract

FiberGLAST is one of two primary instrument concepts currently under development for NASA's Gamma-ray Large Area Space Telescope (GLAST) mission. The detector consists of a photon pair tracker and calorimeter which uses scintillating fibers to image the shower and an anti-coincidence system to reject charged particles. The detector is composed of modular layers of thin sheets of tantalum and orthogonal layers of scintillating fibers read out with multianode photomultiplier tubes. The design offers a large effective area and good angular resolution for high-energy (10MeV<E<300GeV) gamma rays. The sensitivity of the instrument is ~30 times that of EGRET and has a wide field of view extending to ~80 degrees from the detector axis. We present an overview of the *FiberGLAST* design and report on the current status of engineering tests.

1 Introduction:

The Compton Gamma-ray Observatory (CGRO) and the SIGMA/GRANAT experiment have brought a wealth of new information on many phenomena in gamma-ray astronomy. The highly successful Energetic Gamma Ray Experiment Telescope (EGRET) on CGRO detected high-energy gamma rays from active galaxies whose emission at most wavebands is dominated by nonthermal processes. Over fifty "blazars" have now been detected including BL Lacertae objects, highly polarized quasars (HPQs), and optically violent variable (OVV) quasars (Mukherjee, et al. 1997). In addition, the discovery of variability of active galactic nuclei (AGN) by EGRET has caused a rapid growth in the field (Hartman, et al. 1992). Gamma-ray bursts, active galactic nuclei, and EGRET unidentified sources have led to a need to increase the sensitivity, energy resolution, effective area, and angular resolution for future gamma-ray astronomy missions.

NASA has made the construction of a new gamma-ray observatory a top priority for the next several years. The Gamma-ray Large Area Space Telescope (GLAST) is in the conceptual development stage and is scheduled for a New Start in FY 2001 with a planned launch in 2005. The telescope will cover an energy range from 10 MeV to 300 GeV. There are currently two instrument design concepts for GLAST: SiliconGLAST and *FiberGLAST*. Both designs are pair production telescopes, which use a detector to track the converted pair and its associated electromagnetic shower to determine the incident direction and energy of the incoming photon. SiliconGLAST utilizes silicon strip detectors and a CsI(Tl) calorimeter.

FiberGLAST utilizes scintillating fibers for both a tracker and a calorimeter. Scintillating fibers were first used in space on the CRIS instrument aboard the Advanced Composition Explorer (ACE) launched in 1997 (Stone, et al. 1998).

2 *FiberGLAST* Instrument Concept:

The *FiberGLAST* instrument is composed of three main parts: the tracker, the calorimeter, and the anti-coincidence shield (see figure 1). The tracker is composed of ninety detector modules spaced 2cm vertically. Figure 2 shows a close-up view of a detector plane. Each module includes a thin sheet of tantalum foil that stimulates pair production of high-energy photons. Directly beneath this plate are two orthogonal layers of scintillating fibers with an active area of 1.7m^2 used to detect the passage of ionizing particles. Plastic honeycomb or foam material is used as a substrate and for the mechanical support of the module. Each fiber is read out by an anode of a multianode photomultiplier tube (MAPMT).

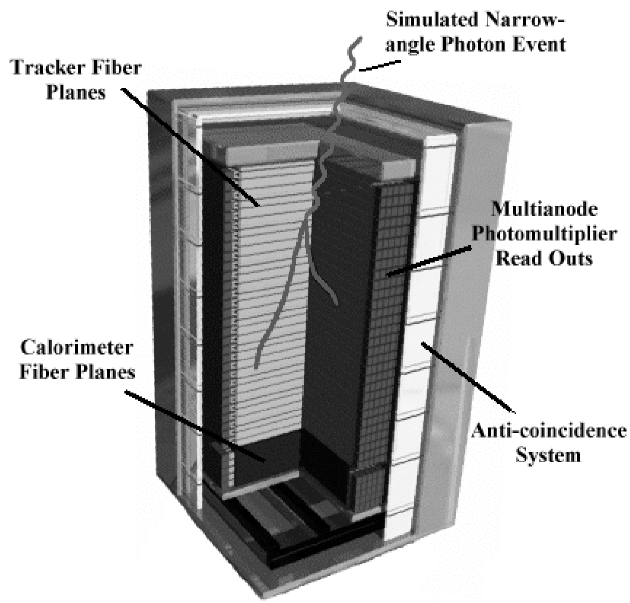

Figure 1 – FiberGLAST Instrument

An incident gamma ray will interact with the tantalum foil by pair production. The resulting electron-positron pair will be detected by the scintillating fibers which will provide the x-y position in the detector. As the pair proceeds through the ninety layers, the electromagnetic shower will be detected and can be reconstructed in three dimensions. The tracker will have almost two radiation lengths of interaction material. A low energy tracker is also being considered. It would be composed of several tracker detector modules at the top of the instrument that would have extremely thin tantalum sheets and would be separated by a larger vertical spacing. This would allow for better angular resolution and less coulomb scattering for photons in the low-energy regime (<~100MeV).

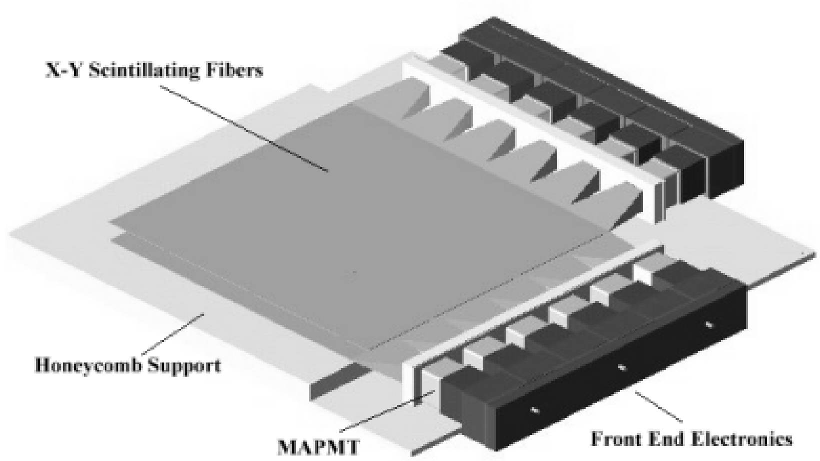

Figure 2 – Closeup of Detector Module Corner

The calorimeter is composed of thirty-six detector modules with thicker tantalum sheets, spaced 0.5cm apart in the vertical direction. Two fibers will be readout by each anode of a MAPMT and the signal will be pulse height analyzed to provide additional energy deposition information. The calorimeter will contain ~5 radiation lengths of interaction material.

The anti-coincidence system features plastic scintillator panels that completely cover all four sides, top and bottom of the detector stack. Each panel has two layers of orthogonal plastic scintillator elements read out by photomultiplier tubes. The system of segmented panels will provide the onboard computer with topological trigger information to distinguish and veto incident charged particle events, including the high rate of cosmic rays, from good events.

The instrument will use ~500,000 square blue-emitting scintillating fibers measuring 0.75mm in size and 1.35m in length. One end is read out and the opposite end is polished and mirrored to increase the light output. The light output, measured by a Hamamatsu R1924, produced by an electron from Sr^{90} triggered by a scintillator below the fiber is shown in figure 3 for distances of 20cm and 120cm from the read out device. A single photoelectron curve is also shown for reference. Several other fiber sizes and types are also being studied. The fibers will be read out using the Hamamatsu R5900-M64 multianode photomultiplier tube (MAPMT) with a bialkali photocathode. This device has 64 anodes in an 8x8 array with each anode having a 2mm x 2mm active area. The MAPMT is capable of resolving a single photoelectron signal and front end electronics are being developed in an application specific integrated circuit (ASIC) to allow the tube to be self-triggered. The triggering threshold can be set at <0.2 PEs allowing for a >90% detection efficiency of single photoelectron events. The dark count for the MAPMT is ~5 counts/anode/second at room temperature and causes a negligible accidental trigger rate in the instrument. Figure 4 shows a self-triggered MAPMT anode signal for single photoelectron events. The fiber/MAPMT system has a detection efficiency of >92% for the full 1.35m active length of the fiber.

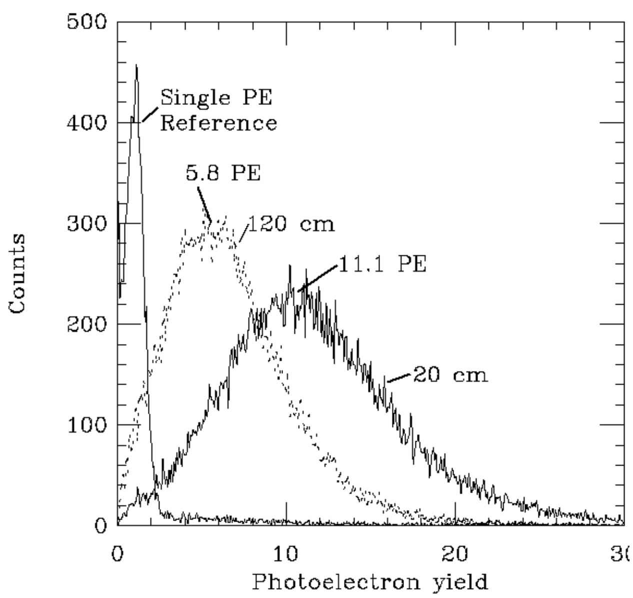

Figure 3 – Light output of 0.75mm mirrored fiber

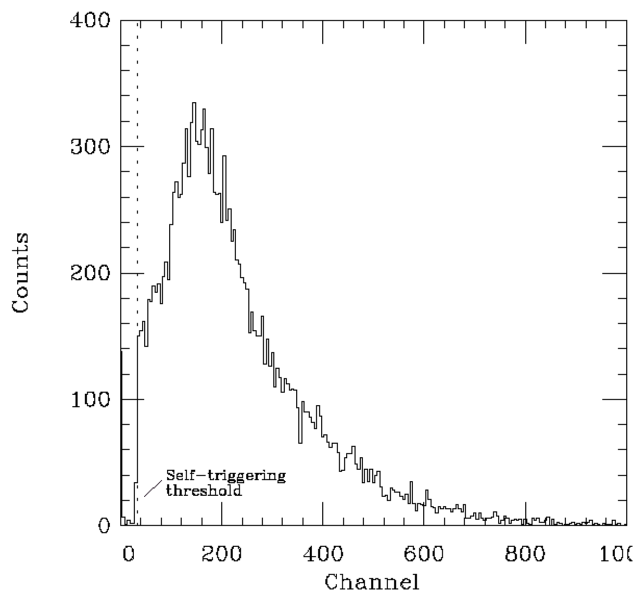

Figure 4 – Typical self-triggered MAPMT anode signal for single photoelectron events

3 Current status of *FiberGLAST* engineering tests:

An engineering test apparatus of the tracker composed of twenty small detector planes is planned for testing in summer 1999 using the tagged photon beam at Thomas Jefferson National Laboratory (TJNAL). The apparatus used 0.75mm square scintillating fibers with tantalum conversion material and was read out using 20 MAPMTs. The triggering electronics were also tested to realistically simulate the full design. This apparatus will also be tested in fall 1999 in combination with a scintillating fiber calorimeter. Preliminary results will be presented at the conference. In July 1998, a single MAPMT was tested at TJNAL and resolved pair tracks in one dimension (Kippen, et al. 1998).

The basic fiber/MAPMT assembly has undergone a number of engineering tests to verify its ability to operate in the extremes of space. Thermal, vacuum, and vibration tests have been successfully completed. The fiber /MAPMT system has been fully characterized to determine its efficiency at detecting minimum ionizing particles using electrons, Sr^{90} betas, and atmospheric muons (Rielage, et al. 1999). Radiation damage tests of the fibers were conducted earlier this year and simulations have been performed to calculate the expected dose the instrument will receive in orbit. We currently believe there are no technical obstacles remaining in the fundamental design of *FiberGLAST*.

A low-power application specific integrated circuit (ASIC) is being developed by the collaboration to read out the MAPMT signals (Visser, et al. 1999). The trigger logic has been developed and will continue to be improved with results from the two beam tests. Mechanical and thermal studies are continuing for the full instrument.

4 *FiberGLAST* Instrument Characteristics and Performance:

There are several classes of events that are detected by the *FiberGLAST* instrument. Incident photons entering the instrument from directions close to normal incidence will be contained in the tracker and calorimeter and allow for excellent angular and energy measurements. A significant fraction of photons will enter through the sides of the instrument and be only partially contained in the tracker. Photons incident at less than $<80^o$ will have enough fiber hits to permit an energy measurement. These wide-field photons have poorer angular and energy resolution than contained events but provide valuable scientific data.

The *FiberGLAST* instrument provides a significant improvement in sensitivity, effective area, and angular resolution over EGRET. The greatest advantages of the *FiberGLAST* instrument concept are its large effective area which is the product of geometric detector area and photon detection efficiency and its wide field of view. The current instrument design and triggering algorithm allows the detector to have an effective area of over 12,000 cm^2 depending upon the incident angle and the energy of the photon. This large effective area is valuable in making variability measurements of AGN where multiple instruments are needed to examine the spectra from radio to VHE gamma rays. Such measurements do not require excellent energy resolution. *FiberGLAST's* wide field of view allows the instrument to be observing multiple objects in a non-pointed mode by using wide-field photons. This is crucial in AGN variability measurements where one wishes to maximize the amount of observing time to effectively study variability on the inter-day and intra-day time scales. Known sources can be monitored for outbursts at higher energy and used to trigger observations at other wavelengths. Wide-field photons will also be useful for the study of prompt emission from GRBs.

A detailed description of the *FiberGLAST* detector performance, triggering system, and characteristics given by current simulations can be found in these proceedings (Kippen, et al. 1999).

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