

# Gamma Large Area Silicon Telescope (GLAST)\*

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## ABSTRACT

The recent discoveries and excitement generated by EGRET have prompted an investigation into modern technologies ultimately leading to the next generation space-based gamma ray telescope. The goal is to design a detector that will increase the data acquisition rate by almost two orders of magnitude beyond EGRET, while at the same time improving on the angular resolution, the energy measurement of reconstructed gamma rays, and the triggering capability of the instrument. The GLAST proposal is based on the assertion that silicon particle detectors are the technology of choice for space application: no consumables, no gas volume, robust (versus fragile), long lived, and self triggering. The GLAST detector is roughly modeled after EGRET in that a tracking module precedes a calorimeter. The GLAST Tracker has planes of thin radiator interspersed with planes of crossed-strip (x,y) 300- $\mu\text{m}$ -pitch silicon detectors to measure the coordinates of converted electron-positron pairs. The gap between the layers (~5 cm) provides a lever arm in track fitting resulting in an angular resolution of  $0.1^\circ$  at high energy (the low energy angular resolution at 100 MeV would be about  $2^\circ$ , limited by multiple scattering). A possible GLAST calorimeter is made of a mosaic of CsI crystals of order 10 r.l. in depth, with silicon photodiodes readout. The increased depth of the GLAST calorimeter over EGRET's extends the energy range to about 300 GeV.

## I. INTRODUCTION

GLAST is a new high-energy  $\gamma$ -ray telescope (approximately 20 MeV to 300 GeV) that will lead to major advances in high-energy astrophysics by achieving higher sensitivity and improved angular and energy resolution, over a broader energy range, than is possible with the *Energetic Gamma Ray Experiment Telescope* (EGRET) currently operating on the *Compton Gamma Ray Observatory* (CGRO).

The EGRET experiment has already extended our knowledge of the  $\gamma$ -ray sky and dramatically advanced our view of the universe at high energies (to ~30 GeV). EGRET has revealed that there are many bright and variable extragalactic sources of gamma radiation associated with Active Galactic Nuclei (AGNs), has detected new  $\gamma$ -ray pulsars in our own galaxy, and is mapping with unprecedented detail the diffuse galactic and extragalactic

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gamma emission. EGRET is also proving to be an important tool for increasing understanding of known sources as well as discovering new ones. The goal of GLAST is to make at least as large an improvement in capability compared to EGRET as EGRET did compared to COS-B or the Small Astronomy Satellite (SAS-2).

The exciting developments in using semiconductors for particle detection over the past decade are the main stimulus for this proposal. In particular, the development of large-area semiconductor detectors for use in tracking and calorimetry has resulted in working devices now in use in major high-energy physics particle detectors both in the USA and Europe (Almehed, et al., 1991; Berridge, et al., 1988, 1990). Much of the innovation has been stimulated by the detector challenges presented by the Superconducting Super Collider (SSC), and much time, money, and prototyping effort have already been invested. Our proposed usage "piggy backs" on these developments. Notable among the advances in the Silicon detector technology is the cost, now around \$18/cm<sup>2</sup> versus almost \$200/cm<sup>2</sup> a decade ago (Huyen et al., 1990).

## 2. DESCRIPTION OF GLAST

In common with EGRET, the proposed design relies on the unambiguous identification of incident  $\gamma$ -rays by detection of the electron and positron that result from pair creation in a thin converter material. Measurements of the energy and direction of the electron and positron provide information about the energy and direction of the incident  $\gamma$ -ray. In contrast to EGRET, which uses spark chambers to image the track pair, the proposed telescope design uses position-sensitive silicon strip detectors (nominal resolution of  $\pm 100 \mu\text{m}$ ) interleaved with thin converters. This converter/tracking stack is followed by a calorimeter ( $\sim 10$  radiation lengths thick) to measure the energy of the pair.

The detector is highly modular, consisting of an assembly of 18 cm x 18 cm towers. Currently, a 10 x 10 array of these towers is envisioned which results in a 3.2 m<sup>2</sup> area detector. Figure 1 shows a conceptual design of the telescope including a more detailed view of one of the tower modules (a tower we hope to construct and test next year). Each tower module has: three layers of Si xy that provide a charged particle veto, ten thin converter plates plus interleaved Si xy layers that total 1.0 radiation lengths in thickness, two more Si xy layers, and a CsI calorimeter (6 crystals x 6 crystals x 22 cm; read out by photodiodes).

The mass of the 3.2 m<sup>2</sup> GLAST is  $\sim 3100$  kg. This divides up into CsI (2700 kg), tungsten converter (259 kg), and silicon (49 kg). Thus GLAST could be optimized, perhaps with a little thinner CsI or fewer tower modules, for a launch on a Delta II rocket which can launch 4800 kg into a 450-km-high orbit with a 28.5° inclination (Larson and Wertz, 1992). EGRET's mass is 1830 kg.

We believe silicon detectors to be the "technology of choice" for future orbital high-energy  $\gamma$ -ray telescopes. They are robust and require *no consumables*. They operate at relatively low voltages ( $< 100$  volts). They have a fast time response and hence do not require auxiliary technologies to provide external triggers. They are relatively radiation hard. Finally, they allow for a granularity of individual detector elements unsurpassed by any other technology. The fine segmentation possible with this technology allows precision coordinate measurement as well as the ability to distinguish closely spaced tracks. In addition, the overall stack of silicon and radiators can be made quite thin (an aspect ratio that allows almost  $2\pi$  sky coverage) while still maintaining excellent angular resolution because of the fine position resolution of the silicon strip detectors.

Our proposal is based on industry-standard silicon. This currently means 6 cm x 6 cm tiles cut from 4-inch-diameter wafers with a thickness of 300  $\mu\text{m}$ . The tiles have back biased p<sup>+</sup> strips implanted on them. Tiles may be "ganged" together to reduce the overall channel count. The

strip separation (or pitch) commonly in use in high-energy physics is  $\sim 50 \mu\text{m}$ , but for our application wider strips will suffice, for example  $300 \mu\text{m}$  in the tracking portion of GLAST. This segmentation in strips results in a large number of channels per square meter of detector.

GLAST will require approximately  $78\text{m}^2$  of single-sided detectors ( $\sim \$14\text{M}$ ) in the converter/tracker and  $10\text{m}^2$  of double-sided detectors ( $\sim 5\text{M}\$$ ) in the three front veto/x-ray layers. These cost estimates are based on the SSC quote from Hamamatsu of  $\$18/\text{cm}^2$  for  $17\text{m}^2$  of single-sided silicon strip detectors. Double-sided detectors have been assumed to cost 3 times as much per  $\text{cm}^2$  as single-sided ones.

## 2.1 High-Energy Gamma Ray Detection (20 MeV to 300 GeV)

Behind each of the ten thin radiators are two single-sided detectors with their strips perpendicular to each other. The  $300\text{-}\mu\text{m}$  strip pitch will result in an rms position resolution of  $\sim 100 \mu\text{m}$  in  $x$  and  $y$ . The electron and positron from a just-converted photon will make one hit in the silicon immediately following the radiator. Some multiple scattering will have occurred in the radiator. This and the intrinsic opening angle are likely to cause two hits in the next layer of silicon  $5 \text{ cm}$  away (which is after the next radiator). Multiple scattering in the second radiator is of no concern because it is located directly on top of the second layer of silicon. The intrinsic two-hit resolution of  $\sim 600 \mu\text{m}$  allows for a more accurate tracking of the initial pair. This is to be compared with a gaseous tracking device, such as EGRET, in which the two hit resolution is  $3 \text{ mm}$ . For very high photon energies the rms projected angular resolution will be limited to  $\sim 100 \mu\text{m} / 5 \text{ cm} = 2 \text{ mrad} = 0.1^\circ$ . For the total  $1.0$  radiation length thickness of the converter, the probability of a photon converting is  $0.6$ . The design of the converter will clearly be a tradeoff among having more layers (greater conversion probability), thinner layers (less multiple scattering), closer spaced silicon strips (more electronics and power), and greater spacing between the layers (better angular resolution but a worse aspect ratio-solid angle for the whole detector).

The energy of the electron-positron pair will be measured in the calorimeter. At lower energies ( $< 1 \text{ GeV}$ ) where leakage is not a problem, an rms energy resolution of  $2\% E^{-1/2}$  ( $E$  in  $\text{GeV}$ ) has been measured for CsI (Blucher et al., 1986) These relations hold as the energy increases until fluctuations in the energy leakage out the back of the calorimeter cause the resolution to plateau. We have chosen 10 radiation lengths (compared to EGRET with 8 radiation lengths) to improve the resolution at high energies. Figure 2 shows an EGS4 Monte Carlo calculation of the fractional energy resolution for a 12-radiation-length-thick CsI calorimeter. This calorimeter has a resolution of  $\pm 20\%$  at  $300 \text{ GeV}$  which is better than needed. Thus the thickness has been scaled back to 10 radiation lengths to save weight, and the Monte Carlo is being redone. As can be seen from the energy containment curve in Fig. 2, the response of the calorimeter will not be perfectly linear with photon energy due to leakage of the shower out the back of the calorimeter.

For a source with a differential photon spectrum of  $dN/dE \sim E^{-2}$ , the sensitivity increase of  $\sim 70$  over EGRET (Table 1) will permit GLAST to see a source to an energy  $\sim 8.4$  times higher than the maximum energy detectable with EGRET. Thus GLAST should be designed to have a better resolution than EGRET at high energies. We will clearly have to optimize weight and the desire for a thicker calorimeter.

Table 1 summarizes the  $\gamma$ -ray detection capabilities of the GLAST conceptual design compared with those obtained by EGRET. The parameters of GLAST are preliminary and are being refined. Our goal is to develop a space-quality  $\gamma$ -ray telescope with effective area, acceptance, and energy range at least an order-of-magnitude greater than those of EGRET. The lower end of the GLAST  $\gamma$ -ray energy range will be determined primarily by the properties of the converter/tracking stack and the calorimeter. The upper end is determined by the energy

at which the number of  $\gamma$ -rays expected to be detected in a reasonable observing time is small. This energy overlaps the lower end of what is observable with ground-based atmospheric detectors. Combining a factor of 10 increase in effective area with a major improvement in single photon direction determination at high energies implies that GLAST should determine the position of bright point sources to much better than 1 arcmin, compared to 10 arcmin for EGRET (assuming the source has a photon differential spectrum proportional to  $E^{-2}$ ). GLAST has a sensitivity (area x gamma detection efficiency x solid angle) that is 50–100 times greater than EGRET's.

## 2.2 Hard X-Ray Detection (3 to 30 KeV)

The front silicon veto layers of the detector are also sensitive to hard x-rays. A relatively simple coded mask placed in front of this layer would give GLAST its own self-contained system for monitoring sources in hard x-rays. Additional sensors are not required. Preliminary studies indicate that the parameters of this X-ray Monitoring Subsystem (XMS) would be: energy range, 3–30 keV; angular resolution, 3 arcminutes; field of view,  $5^\circ \times 5^\circ$ ; limiting sensitivity,  $10^{-5}$  photons-cm $^{-2}$ sec $^{-1}$  in the 3–30 keV band. The XMS could monitor the prime  $\gamma$ -ray target, looking for correlated variability. It could also play an important "handover" role in identification of  $\gamma$ -ray sources by providing cross-identification to a Roentgen Satellite (ROSAT) survey or an optical counterpart. An important constraint on the XMS design is that it not adversely impact the  $\gamma$ -ray performance.

Figure 3(a) shows the probability that an x-ray is captured photoelectrically and deposits all its energy in the 300  $\mu$ m of one of the first three silicon strip detectors. There is useful quantum efficiency from the electronic readout noise at a few keV up to  $\sim$ 100 keV. In order to determine the X-ray direction, a coded aperture with  $\sim$ 50% transmission will be placed in front of GLAST. The unique pattern made on the silicon by a flux of photons from any particular direction in the sky is a transform of the brightness distribution in that region. The coded aperture is placed at some distance from GLAST so as to limit the field of view (and increase the signal to noise in the unfolding process). The coded aperture must be made thin enough to avoid being a significant background source of high-energy  $\gamma$ -rays. The thin coded aperture baselined for GLAST becomes transparent to x-rays  $>$ 30 keV as shown in Fig. 3(b). This sets the upper end of GLAST's x-ray energy window. Some of the problems that must be investigated to make this idea feasible are backgrounds, the effectiveness of the coded aperture unfolding, signal to noise, trigger, and data rates.

## 3. SCIENCE OBJECTIVES

High-energy  $\gamma$ -rays are excellent probes of dynamical nonthermal processes occurring in nature. These include interactions of high-energy electrons with matter, photons, and magnetic fields; high energy nuclear interactions; matter-antimatter annihilation; and possibly other fundamental particle interactions. The sites of these energetic processes include stellar objects, in particular compact objects such as neutron stars and black holes; the nuclei of active galaxies that likely contain massive black holes; interstellar gas in the galaxy that interacts with high-energy cosmic rays; supernovae that may be sites of cosmic ray acceleration;  $\gamma$ -ray bursts; and the Sun, which during active periods can produce high-energy charged particles. Results currently being obtained with EGRET are impacting all of these areas. For example, before EGRET only one extragalactic high-energy  $\gamma$ -ray source was known (3C273). EGRET has so far detected more than a dozen extragalactic sources during the first year of observations.

The potential scientific impact of GLAST falls into three energy bands:

- (i) In the EGRET energy range (approximately 20 MeV to 10 GeV) GLAST can provide an important follow-on to EGRET, with larger area and acceptance and better angular resolution.
- (ii) The 10 GeV to 300 GeV energy range is a spectral range in which there is currently little information. This is an exploratory domain in which new discoveries could be made. Filling in this spectral region bridges a gap between EGRET and ground-based high-energy observations.
- (iii) Hard x-ray observations (approximately 3 keV to 30 keV), utilizing the x-ray sensitivity of the front silicon layers and a coded aperture, will cover a factor of nearly 10 in energy above the ROSAT cutoff. Each of these spectral ranges is important in its own right; in GLAST they are integrated together scientifically as well as instrumentally because in each range a major new sky survey can be done, and simultaneous multiwavelength observations of variable compact objects and other transients will be possible.

#### 4. NARROW STRIP SILICON DETECTORS

Recently, narrow strip silicon detectors have been developed that have ~1/3 the capacitance per cm of previous detectors. If we assume a typical field-effect-transistor (FET) preamplifier with feedback, one source of noise is directly proportional to this capacitance:

$$\sigma_{FETGateVoltage} = \sqrt{\frac{4kT(R_{strip} + R_{FETchannel})}{\tau_{integration}}}$$

$$\sigma_{Energy(Capacitance)} = \frac{3[eV]}{1.6 \times 10^{-19}} C_{Detector} \sigma_{FETGateVoltage}$$

As the integration time gets longer this noise decreases, and noise due to fluctuations in the detector leakage current begins to dominate:

$$\sigma_{Energy(Leakage)} = 3[eV] \sqrt{\frac{I_{Leak} \tau_{integration}}{1.6 \times 10^{-19}}}$$

For  $C_{Detector} = 18[cm] \times 1.3[\frac{pF}{cm}]$ ,  $kT=293^{\circ}K$ ,  $R_{strip}=42\Omega$ ,  $R_{FETchannel}=100\Omega$ , and  $I_{Leakage} = 1$  na, the optimum  $\tau_{integration} = 2\mu sec$ . This yields  $\sigma_{Energy} = 1.0[keV]$  when the two noise sources are added in quadrature. The lowest energy for viewing x-rays will therefore be  $\geq 3$  keV.

The lower capacitance of the new detectors will also allow lower power preamplifiers to be made for the charge particle tracking layers of GLAST. A minimum ionizing track passing through 300  $\mu m$  of silicon deposits ~70 keV. The resulting Signal/Noise (S/N) of 70 is unnecessarily large and could comfortably be dropped by a factor of 3. Thus the channel resistance of the FET could be increased by 9, which corresponds to decreasing the FET bias by 81 times ! Thus the 1/3 capacitance new silicon strip detectors will achieve a typical S/N = 20 for minimum ionizing tracks with preamplifiers using 81 times less power than previously.

## 5. ELECTRONICS

Each silicon strip and CsI photodiode will have its own preamplifier and discriminator. Whenever a discriminator threshold is exceeded, the channel number, time, and pulse height are digitized and sent to the local tower CPU. The local tower CPU must make a "trigger" decision as to whether the information is from a high-energy  $\gamma$ -ray or from charge particle backgrounds. The information from good  $\gamma$ -rays is then packaged and set to ground telemetry.

Power will be a critical consideration for GLAST because of the large number of electronic channels. Table 2 gives estimates of power usage for the various pieces of GLAST. Each silicon strip electronics channel has been assumed to use only 100  $\mu$ W so that the total power budget stays comfortably below the typical 1000 watts available on a satellite of this size. The factor of  $\sim$ 100 decrease in low-noise preamp power from a more typical 10 mW per channel has been made possible by the decreased capacitance of the narrow implants on the new generation of silicon strip detectors as discussed in the previous section.

The close spacing (.3 mm) of the silicon strips and the limited volume dictate that large scale integrated circuits must be developed (or borrowed from other high-energy physics applications) which will contain the preamplifier, discriminator, time recording, ADC, and bus interface functions. A possible interconnection scheme is shown in Fig. 4. Each front end LSI chip (one LSI chip for each 6 cm x 18 cm silicon) is connected by its own serial link (serial to minimize a morass of wires) to a tower CPU located beneath the CsI. The 100 tower CPUs communicate with each other over a standard high-speed network such as Ethernet.

Each tower CPU must group hits that occur close in time and become the investigator of a trigger if its CsI has exceeded an energy threshold. Track segments from the investigator will point at other towers. Messages will be sent to these towers over the network, requesting any in time hits. The investigator then can decide whether to pass the accumulated information along as a valid  $\gamma$ -ray trigger to the telemetry. Notice that the data flow is completely asynchronous. Only the local piece of silicon that the track passed through experiences any deadtime. All 100 tower CPUs are processing different information in parallel.

An expected background rate (exceeding the CsI energy threshold of  $\sim$ 10 MeV) of 1 charged particle / sec-cm<sup>2</sup> would mean the tower CPU would have to investigate 324 tracks / sec. If the investigation of 1 track requires 1000 floating point operations, then a 1 megaflop CPU chip should easily handle the load. For comparison, a 486-33 MHz CPU does  $\sim$ 4 megaflops.

Aside from an energy threshold in the CsI, the determination of which events are valid high-energy  $\gamma$ -rays is done entirely in software. This has not been the case in previous satellite experiments. For instance, EGRET required a hardware coincidence between NaI energy and time-of-flight scintillators that was not hardware vetoed by a large plastic scintillator dome. However, software triggers have become the norm in high-energy particle physics experiments in which tracks may enter a detector at 10<sup>6</sup> /sec from a colliding beam storage ring or from a fixed-target machine. The software sorts through the detector information to pick out only the interesting events (of the correct topology, momenta, etc.) which are recorded to tape at typically  $\sim$ 1 /sec. The software can make much more complex (and easily modifiable) trigger decisions than those based only on hardware thresholds and coincidences. Usually, this results in a much more background-free trigger than that available from hardware alone.

## 6. BACKGROUND RATES

Because of the very small source strengths, it is essential in the design of any high-energy  $\gamma$ -ray telescope to minimize detector generated backgrounds and maximize the signal-to-noise ratio. For example, the diffuse extragalactic flux of  $\gamma$ -rays is about  $1.3 \times 10^{-5}$  cm<sup>-2</sup>sr<sup>-1</sup>s<sup>-1</sup>

(Thompson & Fichtel 1982). A very bright point source like the Vela pulsar has a flux of about  $10^{-5} \text{ cm}^{-2} \text{ s}^{-1}$ .

## 6.1 Cosmic Ray Protons

An important source of background  $\gamma$ -rays that can mimic celestial  $\gamma$ -rays is generated by the interaction of cosmic rays with any inert material outside the outer charged-particle veto layer of the telescope. A proton with sufficient energy that interacts with such material (e.g., in the spacecraft, heat shields, coded-aperture mask, etc.) can produce a shower of secondary particles, including  $\gamma$ -rays and charged particles. A background event is produced if one of these  $\gamma$ -rays traverses the detector and the veto layer does not detect any associated charged particles. This problem was studied with detailed Monte Carlo simulations for the EGRET telescope and for the proposed Gamma Ray Imaging Telescope System (GRITS) by Edwards et al. (1990). The simulations were done for an incident intensity of cosmic-ray protons appropriate to a low-inclination, low-altitude earth orbit ( $10^{-2} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$ ) and included important details about the detector geometry. For  $0.16 \text{ gm/cm}^2$  of inert material outside the veto scintillator, the predicted background diffuse  $\gamma$ -ray flux above 100 MeV was  $5.3(\pm 3.2) \times 10^{-7} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$  for EGRET. This flux is about 4% of the diffuse extragalactic emission detected by SAS-2. The EGRET telescope was also placed in a proton beam at Brookhaven to test these predictions. The beam was collimated to produce a grazing incidence beam with width equal to the thickness of the outer thermal blanket (Edwards et al. 1990) Of the protons incident, about  $2 \times 10^{-6}$  produced an unvetted  $\gamma$ -ray. This was about an order of magnitude less than the predicted rate. Edwards et al. attributed the discrepancy to the neglect in the Monte Carlo code of evaporation nuclei that could leave the thermal blanket, enter the anticoincidence shield, and veto some events. There are now improved Monte Carlo codes that include these effects. It has been found that the in-flight background rates in EGRET meet these expectations in that the backgrounds are at least an order of magnitude below the expected diffuse extragalactic radiation.

The goal in the design of the proposed telescope is to achieve a background rate due to cosmic-ray protons that is at least an order of magnitude below the rate due to diffuse extragalactic radiation. In view of the EGRET experience this appears to be achievable. We will evaluate the expected rates for the proposed telescope and, in particular, calculate the rate expected from placement of a coded-aperture x-ray mask in front of the outer Si veto layer. We do not anticipate that this mask (of order  $100 \text{ }\mu\text{m}$  thick x 50% open area) will add substantially to the background rates; it will add of order  $0.15 \text{ gm/cm}^2$  to the inert material outside the anticoincidence layer.

## 6.2 Charged Particle Rejection

All high-energy  $\gamma$ -ray telescopes incorporate an anticoincidence shield to reject charged particles. In a spark chamber telescope like EGRET it is especially important that this shield be very efficient (of order  $10^{-6}$ ) in order to prevent fast charged particles incident from outside the telescope that have triggered the directional time-of-flight coincidence system from triggering the spark chamber readout. In EGRET a low false trigger rate is important for conserving the finite supply of spark chamber gas and reducing the data handling/telemetry requirements. The rate from the plastic scintillator anticoincidence shield in EGRET is typically 1 to  $3 \times 10^4 \text{ s}^{-1}$ . The expected rate from the outermost silicon layer of one detector module of GLAST is about  $500 \text{ s}^{-1}$ . This rate will necessarily be higher for modules at the edges of the telescope which must be instrumented to detect charged particles entering from the sides. These rates are sufficiently low that the performance of each individual module will not be impacted. The rates in the South Atlantic Anomaly (SAA) will be substantially higher, but this only represents about 10% of a typical orbit.

### 6.3 Earth Albedo $\gamma$ -Rays

There will be a large number of  $\gamma$ -rays coming up from the earth limb. In EGRET these are rejected by only accepting events which trigger appropriate modes of the time-of-flight (TOF) telescope coincidence system. The TOF modes change as the earth's limb comes into the field-of-view of the telescope. Without such a system to define the acceptance of EGRET the  $\gamma$ -ray event rate would be unacceptably high, resulting in higher gas usage and higher telemetry requirements. The TOF system also serves to reject backward-moving charged particles.

The present conceptual design of GLAST does not have a TOF system. We intend to develop efficient on-board event recognition algorithms that can restrict the field-of-view and determine the direction of showers in software. The feasibility of doing this, subject to realistic expectations about available telemetry, must be demonstrated. The development of these algorithms and the sizing of instrumental telemetry requirements is part of our research program. Our experience indicates that this should be feasible. Nonetheless, we will also consider implementing a hardware TOF system if necessary.

### 6.4 The Self-Veto Problem

This problem is not really a background problem but it needs to be studied with detailed simulations. The problem arises from shower interactions in the telescope, primarily in the calorimeter, that generate back-scattered charged particles (which can be appreciable in the GeV region) and many 0.5 MeV photons traveling in all directions. The latter are very penetrating. If any of these charged particles or a sufficient number of the photons reach the charged-particle veto layer and interact there they can mimic an interaction with an external charged particle and lead to rejection of the  $\gamma$ -ray. In EGRET this is a significant effect above about 1 GeV; near the upper end of the EGRET energy range the effective area of the telescope is reduced to about 700 cm<sup>2</sup> (at 10 GeV) compared to 1600 cm<sup>2</sup> at 500 MeV (Hartman et al. 1991). Above 10 GeV the effects are even more significant.

We will study this problem in the design of GLAST as part of the simulations we will perform. The geometry and placement of the charged-particle anticoincidence layers will be optimized, in particular with respect to the sides of the instrument.

### 6.5 Other Backgrounds

There are several other background considerations that could effect the  $\gamma$ -ray detection performance of the instrument and almost certainly will impact the x-ray performance. Some of these require careful consideration of the materials from which the detector is constructed. For example, each time the spacecraft passes through the SAA, the materials in it will undergo nuclear reactions. If radioactive isotopes are produced, they can decay later, producing electrons/positrons and/or  $\gamma$ -rays typically in the 0.1 to 1 MeV range. Silicon is a good material in this respect because all the plausible products have half-lives of a few seconds or less. The converters and detector support structures must also be considered.

There are other interactions that may significantly contribute to the background of the x-ray detecting function of the instrument. These include low-energy electrons that stop in the first silicon veto layer and Compton scattering of intermediate energy photons in the x-ray detecting layers. As part of the proposed study we will evaluate the contribution that each of these makes to the detector background.

## 7. SIMULATION OF GLAST

The object-oriented simulation package GISMO, recently developed for modelling high-energy physics particle detectors, has been used to simulate the interaction of electrons,



photons, and protons with GLAST. GISMO (Atwood 1992) uses EGS4 for electromagnetic interactions and GHEISHA for hadronic interactions.

In Fig. 4(a), using the Gismo package, a 1-GeV photon entering the front of GLAST is displayed. In Fig. 4(b), a 15 GeV proton entering the back of GLAST is similarly shown. With a little imagination, it is easy to conceive of software cuts that will distinguish the two events. The rejection efficiency for backgrounds and acceptance efficiency for good gammas will be studied for a variety of software algorithms using the GISMO simulation. Clearly, the intrinsic facility built into Gismo to vary detector parameters will also be of prime importance in optimizing the design of GLAST.

## 8. CONCLUSION

Optimization of the GLAST design is continuing. Next year we hope to design the LSI front end chip and build a prototype tower module. The tower module would then be tested in an accelerator beam. Further simulation studies will also be done to improve the software trigger algorithm with respect to background rejection. Plans are also being discussed for a possible space mission of a light GLAST prototype that would have layers of silicon, but no heavy CsI. This mission would test critical pieces of the new GLAST ideas as well as providing good physics in the x-ray and possibly Compton energy range.