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	Subsystem/Office Integration and Test	
Document Title Particle Beam Test Plan		

Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

Integration & Test Subsystem

Beam Test Plan

Change History Log

Revision	Effective Date	Description of Changes
-01	12/21/01	Initial release. Preliminary draft.
-02	4/15/02	Replaced coherent and channeling beams with a Photon Tagger in ESA. Corrected config of EM tracker. Changed LAT (mistake) to CU tested in beam. New ESA Fig 3. Removed airplane details and pointed at LAT-TD-00550.
-03	6/3/02	Added multiple positrons/pulse to calibrate CsI at up to 300 GeV.
-04	3/5/03	Changed 30 GeV positrons to 28 GeV positrons, 20-400 MeV tagged γ to 20-1500 MeV, updated Table 1 to LAT-00010-02. Changed Pb Glass to BGO. Elaborated on bremsstrahlung beam strategy.
-05	3/12/03	Changed lowest tagged photon energy from 20 MeV to 100 MeV. Added a scintillator hodoscope backup if no Si tagger.

Contents

1. Purpose	4
2. Scope	5
2.1. Items to be tested	5
2.2. Beams to be used	5
3. Definitions	5
3.1. Acronyms	5
3.2. Definitions	6
4. Applicable Documents	6
5. Description of Beams and Test Stations	6
5.1. Cosmic Rays on the ground	6
5.2. Van de Graaff Accelerator	6
5.3. End Station A Beams and Test Station	8
5.4. Cosmic rays in an Airplane	11
6. Calibration and Validation Methods	11
6.1. Types of calibration and validation to be done	11
6.1.1. Low level calibrations.....	11
6.1.2. Calibration of the GLAST Monte Carlo Simulation.....	11
6.1.3. Verification of the higher level Science Requirements using the Simulation.....	11
6.2. The Strategy for the particle beam measurements on the CU in ESA at SLAC	12
6.2.1. Calibrate the energy response of the Calibration Unit.....	12
6.2.2. Record data using the ESA Bremsstrahlung γ beam.....	12
6.2.3. Record data using the ESA Proton beam	16
7. Description of Tests	16
7.1. Cosmic Rays on the ground	16
7.2. Photons (17.6 MeV) from the Van de Graaff accelerator	16
7.3. Positrons in ESA	16
7.4. Photons in ESA	17
7.4.1. Bremsstrahlung Beam.....	17
7.4.2. Tagged Photon Beam.....	19
7.5. Protons in ESA	20
7.6. Cosmic Rays in the Airplane	20
8. References	21

1. Purpose

The requirements for the Beam Test program flow down from the LAT Performance Specification – Level II(b) Specification Document (LAT-SP-00010-02). The Beam Test program is designed to ensure that the performance of the LAT meets the requirements of LAT-SP-00010-02. The performance requirements, for which the Beam Test program is relevant, have been summarized in Table 1.

Table 1. Summary of Science Instrument Performance Verification (a subset of Table 1 of LAT-SS-00010-02). A column has been added to the table indicating which beam tests are relevant to verifying the requirement. The verification methods are T=Test., A=Analysis.

Req't #	Req't Title	Parameter	Verification Method	Beam Tests relevant to the Verification
5.2.1	EnergyRange/ Effective Area	At Normal Incidence: > 300 cm ² @ 20 MeV >3000 cm ² @ 100 MeV >6400 cm ² @ 300 GeV	T=Test A=Analysis T and A	1) Van de Graaff 17.6 MeV γ 2) Tagged photons 100 to 1500 MeV, norm incidence 3) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions. 4) Cosmic rays in airplane
5.2.2	Energy Resolution	On axis: $\leq 50\%$ 20–100 MeV $\leq 10\%$.1-10 GeV $\leq 20\%$ 10-300 GeV $\leq 6\%$ >10 GeV, Incidence>60°	T and A	1) Van de Graaff 17.6 MeV γ 2) Tagged photons 100 to 1500 MeV, norm incidence 3) Positrons 1,2,5,10,28, 45 GeV, variety of angles and transverse positions
5.2.3	Peak Effective Area	>8000 cm ²	T and A	1) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions. 2) Cosmic rays in airplane.
5.2.4	Effective Area Knowledge $\Delta A/A$, 1σ	<50% 20-50 MeV <25% .05-300 GeV	T and A	1) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.
5.2.5	Single Photon Ang Resolution 68% (on-axis)	< 3.5° front @ 100 MeV < 6° back < 0.15° front @ 10-300 GeV < 0.3° back	T and A	1) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions. 2) Tagged photons 100 to 1500 MeV, norm incidence
5.2.6	Single Photon Ang Resolution 95% (on-axis)	< 3 x $\theta_{68\%}$ On-Axis	T and A	1) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions. 2) Tagged photons 100 to 1500 MeV, norm incidence
5.2.7	Single Photon Ang Resolution (off axis at 55°)	< 1.7 times on-axis	T and A	1) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.
5.2.8	Field of View	> 2 sr	T and A	1) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.
5.2.11	Time Accuracy	Better than 10 usec rel to S/C time	T and A	1) All Beam Test events record time from Linac RF
5.2.12	Background Rejection	>10 ⁵ :1 (TBR)	T and A	1) 200 K protons (Pattern rejection) 2) Cosmic rays on the ground (ACD rejection)
5.2.13	Dead Time	<100 usec per event	T and A	1) Ground cosmic 2) All Beam Test runs 3) Airplane cosmic

2. Scope

2.1. Items to be tested

The Beam Test Plan describes the planned tests of the following hardware units with cosmic rays and/or particle beams:

- Engineering Model (EM): This is a single tower that is not fully instrumented. While the calorimeter will be fully instrumented, the tracker will consist of only four trays with 3x and 3y fully instrumented layers (x,yy, xx, y).
- Qualification Units (QUA, QUB): These are two fully instrumented towers. These are spares for the flight.
- Flight Units (FM1, FM2): These are two fully instrumented towers. They will be part of the flight LAT.
- Calibration Unit (CU): This is an assembly into a 1 x 4 array of the four towers (QUA, QUB, FM1, FM2). It includes a few ACD tiles, but not a full coverage ACD.
- LAT: This is the sixteen-tower fully instrumented flight hardware. It includes the fully instrumented ACD.

2.2. Beams to be used

The units (EM, QUA, QUB, FM1, FM2, CU, LAT) will be tested with cosmic rays in the SLAC Building 033 Clean Room.

The units (EM, CU, LAT) will be tested with photons from the Van de Graaff in the SLAC Building 033 Clean Room.

The CU will be tested using the positron, photon, and proton beams in a clean room in End Station A (ESA).

The LAT will be tested using cosmic rays in a airplane.

3. Definitions

3.1. Acronyms

ACD	Anti-Coincidence Detector
BFEM	Balloon Flight Engineering Module tower
BGO	Bismuth Germinate (scintillating crystal calorimeter)
CU	Calibration Unit (4 towers)
DAQ	Data Acquisition system
EM	Engineering Model tower.
ESA	End Station A area at SLAC where beam is delivered to
FM1	Flight Module 1 tower.
FM2	Flight Module 2 tower.

GLAST	Gamma-ray Large Area Space Telescope
EGSE	Ground Support Electronics
I&T	Integrate and Test
LAT	Large Area Telescope.
LPM	Landau, Pomeranchuk ^[2] , and Migdal ^[3] suppression of bremsstrahlung
NRL	Naval Research Lab in Washington, DC
QUA	Qualification Unit A tower.
QUB	Qualification Unit B tower.
SLAC	Stanford Linear Accelerator Center in Menlo Park, California
SPAR	Single Photon Angular Resolution
SSD	Silicon Strip Detector
TBD	To Be Determined
TBR	To Be Reviewed

3.2. Definitions

Tracker Silicon strip tracker within each tower of the LAT

4. Applicable Documents

- [1] LAT-SS-00010 LAT Performance Specification – Level II(b)
- [2] LAT-TD-01396 Calibration of the Van de Graff Photon Flux
- [3] LAT-TD-00550 LAT Test Plan for Airplane

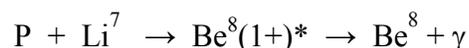
5. Description of Beams and Test Stations

5.1. Cosmic Rays on the ground

Cosmic rays at SLAC (sea level) are predominately charged muons with a mean energy of 2 GeV and a vertical flux of $\sim 110 \text{ m}^{-2}\text{sec}^{-1}\text{sterad}^{-1}$. These will pass completely through any of the units to be tested with minimum multiple scattering. The resulting straight tracks will be used for measuring efficiencies, testing the data acquisition system (DAQ), and aligning the silicon strip detectors (SSDs).

5.2. Van de Graaff Accelerator

The Van de Graaff is a small electrostatic accelerator that produces a 550 Kev proton beam. The proton beam strikes a Li^7 target that terminates the end of the vacuum pipe and produces monoenergetic 17.6 MeV gammas via the reaction:



The Van de Graaff (Figure 1) is operational and installed in the GLAST Assembly Bldg. 033.

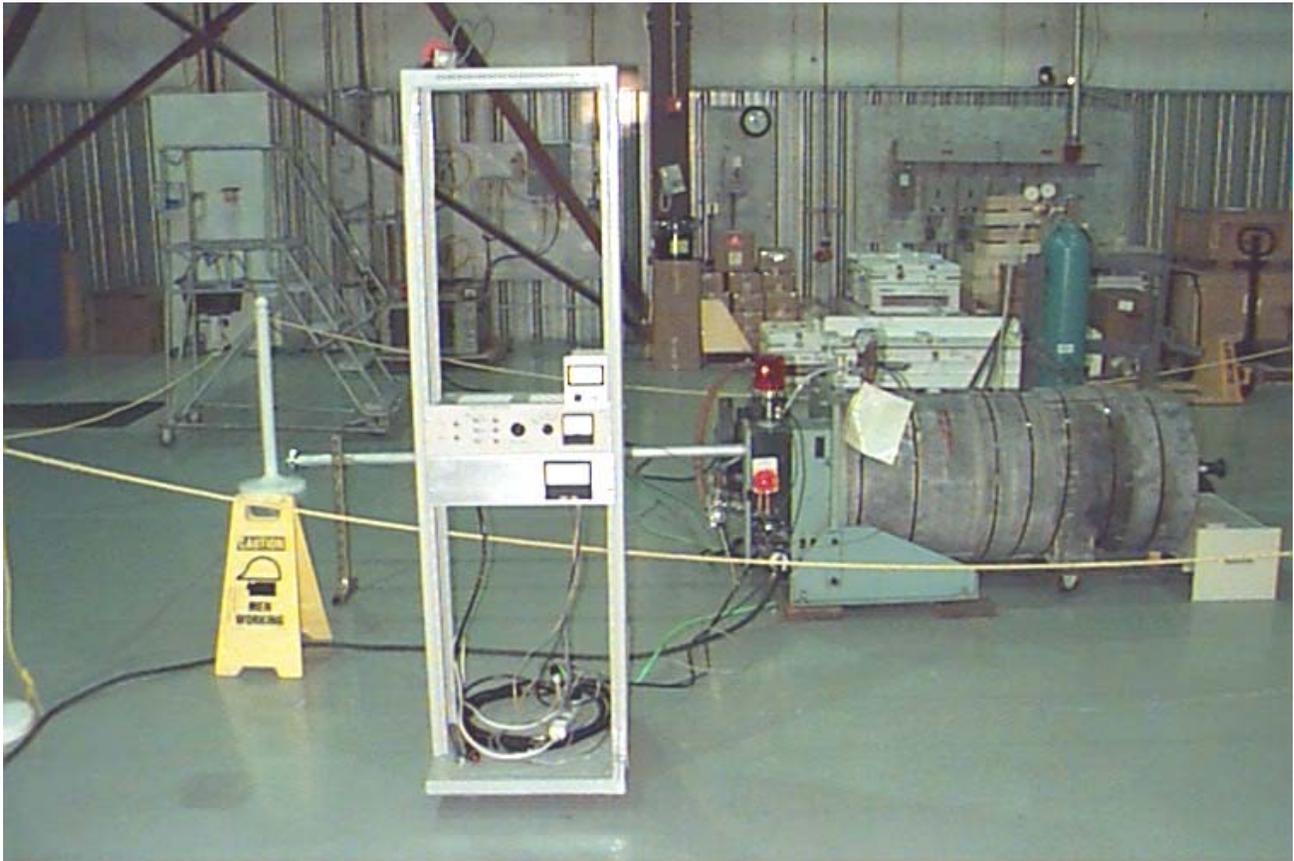


Figure 1. This small Van de Graaff accelerator has been refurbished and is operational in Bldg 33 adjacent to the clean room at SLAC. The Li target is mounted on the left end of the extension tube.

Figure 2 shows a spectrum taken with the Van de Graaff and the prototype Crystal Ball NaI calorimeter. The Van de Graaff photon flux will be calibrated using a BGO calorimeter as described in LAT-TD-01396. The BGO will also be placed toward the back of the target to measure the number of photons that are actually produced during data taking with the EM, CU, and LAT.

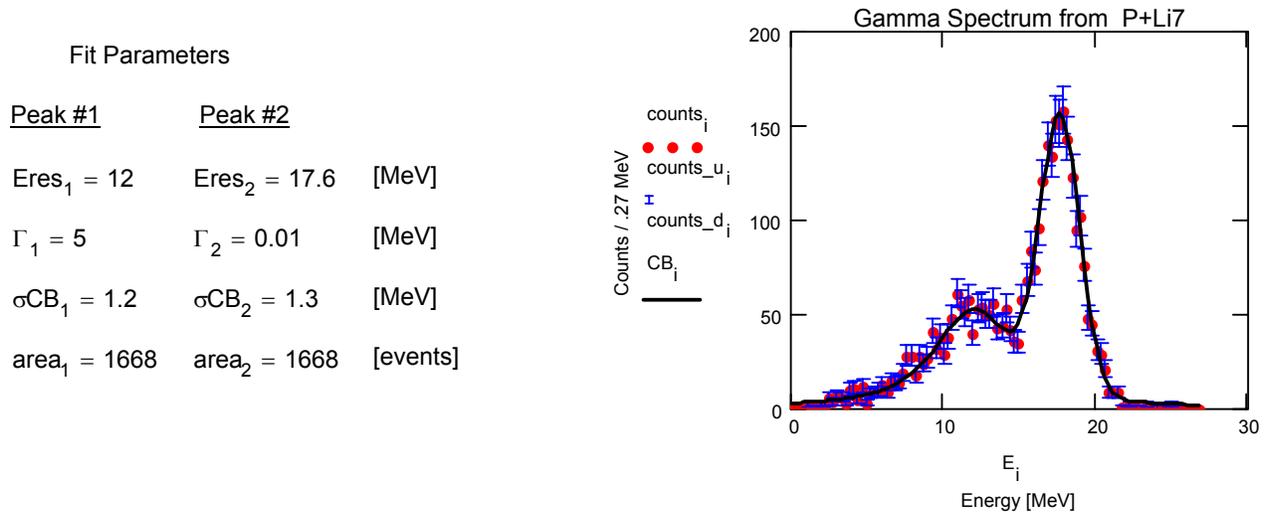


Figure 2. The photon spectrum, from the Van de Graaff with a LiF target, clearly shows the 17.6 MeV peak. For each peak, the fit is a convolution of a Breit-Wigner for the intrinsic line width and a Gaussian for the detector resolution. The fit parameters are shown to the left of the figure. The bump at ~ 12 MeV is due to a broad excited state in Li.

5.3. End Station A Beams and Test Station

The SLAC Linac accelerates ~ 1 mm long bunches of electrons or positrons. The energy of the bunches can be tuned from a few GeV to 50 GeV, and the number of particles in a bunch can be adjusted between 10^9 and a few 10^{10} . It is expected that 30 pulses/sec will be available for our experiment. As shown in Figure 3, a secondary beam of positrons or hadrons can be generated before entering the A line. The A line has bend magnets and momentum slits, and acts as an $\sim \pm 0.5\%$ momentum width spectrometer ($\pm 2.0\%$ when slits are wide open) as it transports the beam to End Station A. In End Station A, a radiator may be inserted in the beam to generate photons. The energy of the radiated photons are determined by measuring the energy of the degraded electrons with a Si Tagger. Because of funding, the Si telescopes may not be available. A scintillator hodoscope backup option is being planned as shown in Figure 3.

The End Station A test station hardware is mostly the same as that used in the single tower GLAST Beamtest '99 except that new compact Si telescopes and magnet will replace the old scintillator hodoscope and magnet. A gas Cherenkov detector and time of flight are used to cleanly separate protons from kaons, pions, and positrons. A scintillating fiber hodoscope is used for recording the charged beam position and width. There is a back stop BGO (Bismuth Germinate) calorimeter (Figure 4) for measuring leakage from the CU and for verifying the photon tagger energies. A new instrument x, y, Θ translation table will support the CU in a clean, controlled, monitored, and approved environment. Only certified people will work with the flight hardware. The coordinate system for the x, y, Θ translation table is shown in Figure 5.

ESA Test Beams and GLAST Calibration Unit (Beamtest 2004)

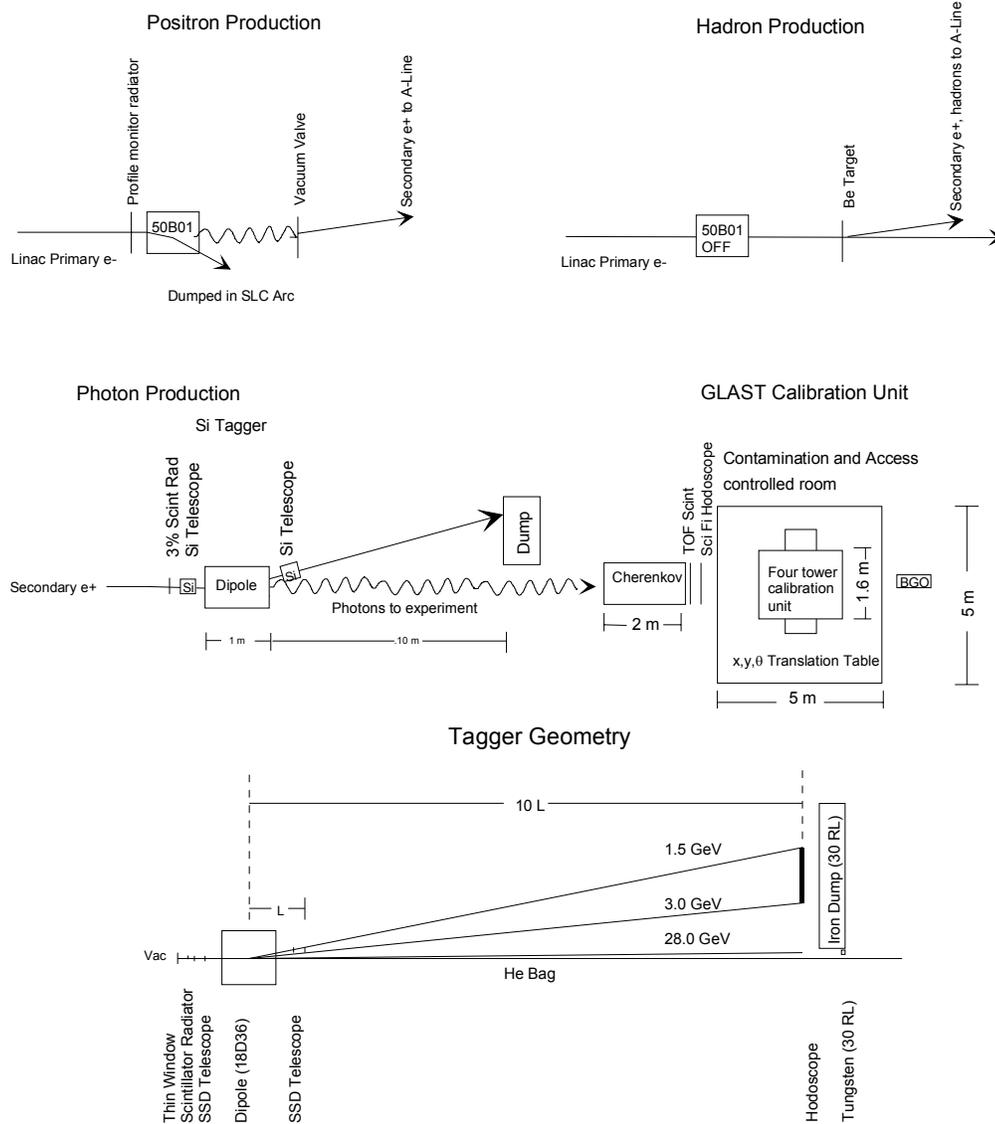


Figure 3. The End Station A test beams and experimental layout is shown for the GLAST CU Beamtest in 2004. The tagger geometry shows where the scintillator hodoscope will go if the SSD telescopes are not available. The magnet and dump remain in the same positions ($L=1.0$ meters). The 28 GeV beam hits the tungsten tip of the dump 7.3 cm from its inside edge (8 Moliere radii). The inner edge of the tungsten is 4.0 cm from the beamline.

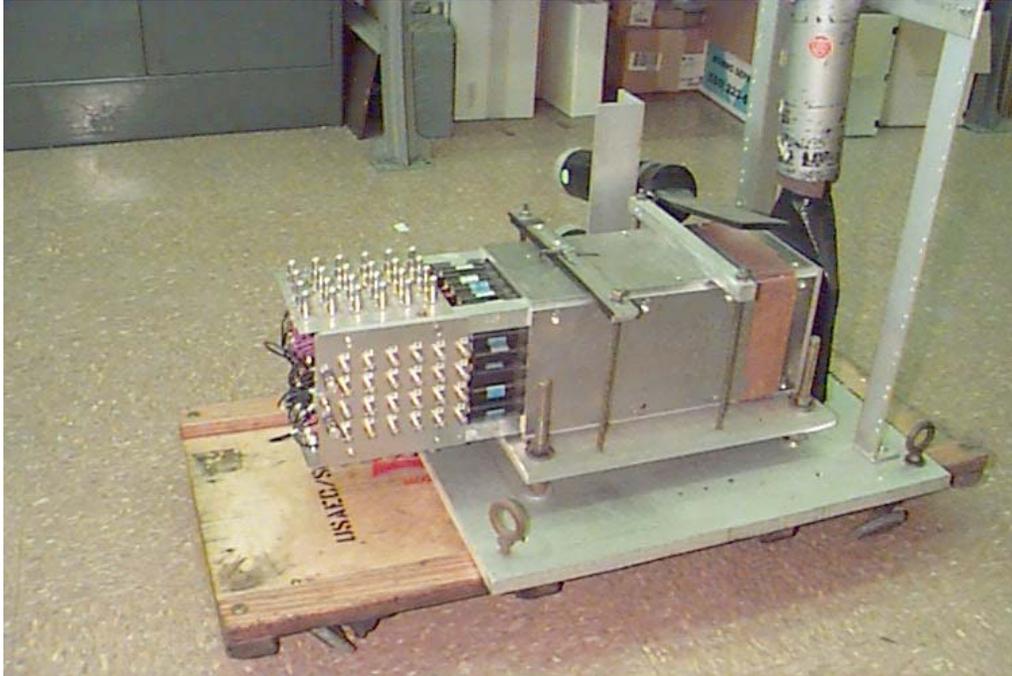


Figure 4. The BGO calorimeter from SLAC E146 that will be used in the GLAST CU 2004 Beamtest. It consists of 45 BGO crystals (a 7 x 7 array with the four corners missing), each crystal measuring 2 cm x 2 cm x 20 cm (18 X_0). Each crystal is read out by a 3/4" photomultiplier tube. The PMTs detect ~ 1 photoelectron per 30 keV of energy deposition in the BGO.

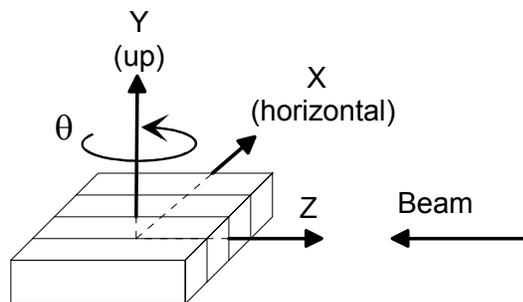


Figure 5. This is the Coordinate system and orientation of the 1 x 4 Calibration Unit. The origin of the coordinate system will be translated in Z to be beneath the center of mass of the unit. It is a right handed coordinate system with $\hat{x} \otimes \hat{y} = \hat{z}$.

The Linac and beamline instrument readouts will be put into a reflective memory by the existing End Station A data acquisition system. A companion reflective memory module will sit in the GLAST CU PCI crate. The CU will be triggered by an external "beam is here" signal on each Linac pulse (30 Hz). After a trigger, the external trigger input will be blocked, the data from the reflective memory captured, and the CU read out. When the CU readout is complete, the CU data and reflective memory data will be combined into an event record and written to disk. Synchronization between CU data and reflective memory data will be maintained by blocking the external trigger input until the assembly of the last event is complete. This will usually happen in $< 1/30$ sec so no beam pulses should be lost.

5.4. Cosmic rays in an Airplane

At 25,000 feet altitude the L1T rate will be the same as in orbit. The in-orbit L1T rate is ~22 higher than the ground L1T rate. The few hour airplane ride, between SLAC and environmental testing at NRL, will be the only exposure of the flight configuration LAT to the full in-orbit cosmic rate. It will functionally test the performance of all LAT instruments and that they work together as a system at orbital rates. It will test the DAQ performance, verify that the software filter handles the rate and produces the expected downlink rate, verify that the data stream is not corrupt, and verify that the livetime is accurately measured. It will be the I&T end-to-end test of the LAT. The airplane cosmic test is more fully explained in LAT-TD-00550 LAT Test Plan for Airplane.

6. Calibration and Validation Methods

6.1. Types of calibration and validation to be done

6.1.1. Low level calibrations

Low level calibration consists of taking data from which parameters are directly calculated. Examples include the ADC chan / MeV response of each CsI crystals and which strips are dead in the tracker. Some of the simpler science requirements, such as time accuracy and dead time, will also be demonstrated directly from the experimental data.

6.1.2. Calibration of the GLAST Monte Carlo Simulation

Most of the particle beam data will be used to verify and, if necessary, adjust parameters in the GLAST Monte Carlo Simulation code. The simulation is absolutely essential for demonstrating compliance with many of the LAT Science Requirements as well as eventually interpreting in orbit data. The LAT response must be known for many particle types (e,p, γ), energies (20 MeV to 300 GeV), angles of incidence (θ,ϕ), and positions (x,y,z) of entry. We need a library of data taken at very many points in this 7 dimensional "phase space". Unfortunately, making this library experimentally would take prohibitively long. Instead, experimental data will be taken at only a small number of points. This data will be compared with the simulation output at the same phase space points, and, if necessary, the simulation code calibrated (adjusted) to give agreement. The full library of data will then be generated with the calibrated GLAST simulation.

6.1.3. Verification of the higher level Science Requirements using the Simulation

Compliance with the science requirements will be demonstrated using the output of the calibrated simulation. For example, the effective area for energy E photons at a particular angle of incidence will come from simulating a large number of energy E photons, thrown uniformly over a large plane. The fraction of these photons that trigger and survive the software cuts multiplied times the area of

the large plane is the effective area for energy E photons that will be reported. The number of simulated photons should be sufficiently large so that the error on the effective area is overwhelmingly dominated by systematics rather than statistics.

6.2. The Strategy for the particle beam measurements on the CU in ESA at SLAC.

6.2.1. Calibrate the energy response of the Calibration Unit

Mono-energetic positrons (1 to 45 GeV) and tagged photons (100 MeV to 1500 MeV) will be put into the CU at a variety of x , y , θ . Linac pulses that contain more than one positron will be used to calibrate the CsI electronics response up to 300 GeV (eg: $7 \times 45 \text{ GeV} = 300 \text{ GeV}$). Individual energy peaks corresponding to each multiplicity of positrons will be seen in the CsI. Mono-energetic photons from the Van de Graaff (17.6 MeV γ) will also be put into the front of the CU at \sim normal incidence.

6.2.2. Record data using the ESA Bremsstrahlung γ beam

A bremsstrahlung γ beam (from 28 GeV positrons) will be used to simultaneously take data at all γ energies from below 20 MeV to 28 GeV. To first approximation, the bremsstrahlung spectrum has equal numbers of γ s per percent width energy bin. The already energy calibrated LAT (see 6.2.1) will be used to bin these photons into $\pm 25\%$ energy bins. Possible bin edges are .017, .026, .038, .057, .086, .19, .29, .44, .65, .98, 1.5, 2.2, 3.3, 5.0, 7.4, 11, 17, 25 GeV. The bremsstrahlung beam will be put into the CU at a variety of x , y , θ . The analysis of both the experimental data and the simulation output will be compared to verify the simulation. The simulation code will be modified, if necessary, to obtain agreement with the data.

The CU Monte Carlo will include the radiator. Monte Carlo results for positrons incident on the radiator + CU will be compared to the measured data. Notice that we will not Monte Carlo generate monochromatic photons for comparison with the data. Including the radiator in the Monte Carlo will not only provide the correct shape and intensity bremsstrahlung spectrum, but it will also correctly provide multiple photons to the CU when the positron radiates more than once.

The actual bremsstrahlung γ spectrum has been measured in the SLAC E146 experiment by Anthony, et al⁽¹⁾. Their results for a carbon radiator are shown in Figure 6. Their 2% carbon radiator with a 25 GeV beam is close to the GLAST beam test configuration. The classic bremsstrahlung spectrum should be flat on this plot. The gradual down slope between 500 MeV and 20 MeV is due to the experimental depletion of lower energy photon bins when the electron radiates more than once in the radiator and the summed photon energies populate a higher energy bin. There is a dipping suppression of the bremsstrahlung spectrum below 20 MeV that is theoretically understood as due to the LPM and dielectric effect. This suppression is due to the electron multiple scattering while traversing the bremsstrahlung formation zone. The bremsstrahlung amplitude from before and after the scattering can interfere thus reducing the amplitude for bremsstrahlung photon emission. It should be confirmed that the CU Monte Carlo uses the same electron passing through matter code as in SLAC E146.

In a repeat of SLAC E146, the CU can also be used to measure the bremsstrahlung spectrum during data taking, and verify that the CU Monte Carlo is correctly reproducing it. The CU will be

triggered externally on every beam pulse. Whereas the 3-in-a-row tracker trigger bit and subsequent offline track finding will yield the photon detection efficiency, the CsI (corrected in energy for tracker energy loss when there is a conversion) is a well energy calibrated calorimeter of high efficiency for measuring the spectrum and absolute number of incident photons.

A low Z (to minimize the LPM effect) plastic scintillator (CH) will be used as the radiator. The scintillator (with an ADC to determine multiple positrons) will count the incident positrons, thus providing a second normalization of the bremsstrahlung spectrum.

The demonstration of how well the Monte Carlo is calibrated would include the following plots.

- 1) A plot of the number of internally triggered on and reconstructed photons versus CU determined energy in logarithmic energy bins. This plot would be made at each CU rotation and transverse position, resulting in 18 plots with 10,000 incident photons contributing to each energy bin on each plot.
- 2) A plot of the number of photons versus the cosine of the angle between the beam direction and the reconstructed photon direction in $d(\cos)$ bins. This plot would be made for each CU $\pm 25\%$ energy bin at each CU position, resulting in $(18 \text{ energy bins}) \times (18 \text{ positions}) = 324$ plots with 10,000 incident photons contributing to each plot.

Each of these plots would be made for both the real and Monte Carlo data. Statistically significant differences will either lead to correction of the Monte Carlo or left as a systematic error to be stated on LAT measurements.

As an additional diagnostic for background effects three differential bremsstrahlung beam analysis can be done. For example, an angular distribution plot can be made with all energy bremsstrahlung photons that come from a 1 GeV e^+ beam. Likewise, an angular distribution plot can be made with all photons that come from the same number of 3 GeV e^+ . Subtracting the 1 GeV angular distribution plot from the 3 GeV angular distribution plot, yields the angular distribution (point spread function) of the CU response for a pseudo 2 ± 1 GeV photon beam. Notice that this does not depend on the tagger or CU determining the energy of the photons being used in the point spread function. Some normal incidence bremsstrahlung data from a 9 GeV e^+ beam will taken to subtract from the normal incidence 11 GeV e^+ data to yield the CU response to a pseudo 10 ± 1 GeV photon beam, and some normal incidence bremsstrahlung data from a 26 GeV e^+ beam will taken to subtract from the normal incidence 28 GeV e^+ data to yield the CU response to a pseudo 27 ± 1 GeV photon beam.

As a further diagnostic, the tagger will be left on for all the above bremsstrahlung running. If the tagger is left at its setting to measure 1.5 to 3.0 GeV positrons, it will have tagged photons with 1.5 to 3.0 GeV less energy than whatever positron beam we are running with. A summary of these energies for bremsstrahlung running is shown in Table 2.

Table 2. Summary of the positron energies for the bremsstrahlung running.

Positron Energy [GeV]	Primary Purpose	# of positions (=runs)	Tagged γ Energy [GeV]
1	CU Energy calibration	4	.1 - .5
3	CU Energy calibration	4	.15 - 1.5

9	Differential brems subtraction	2	6 – 7.5
11	Tagged photons at CU “sweet spot”	2	8 – 9.5
26	Differential brems subtraction	2	23 – 24.5
28	.02 – 28 GeV γ for verifying MC	12	25 – 26.5

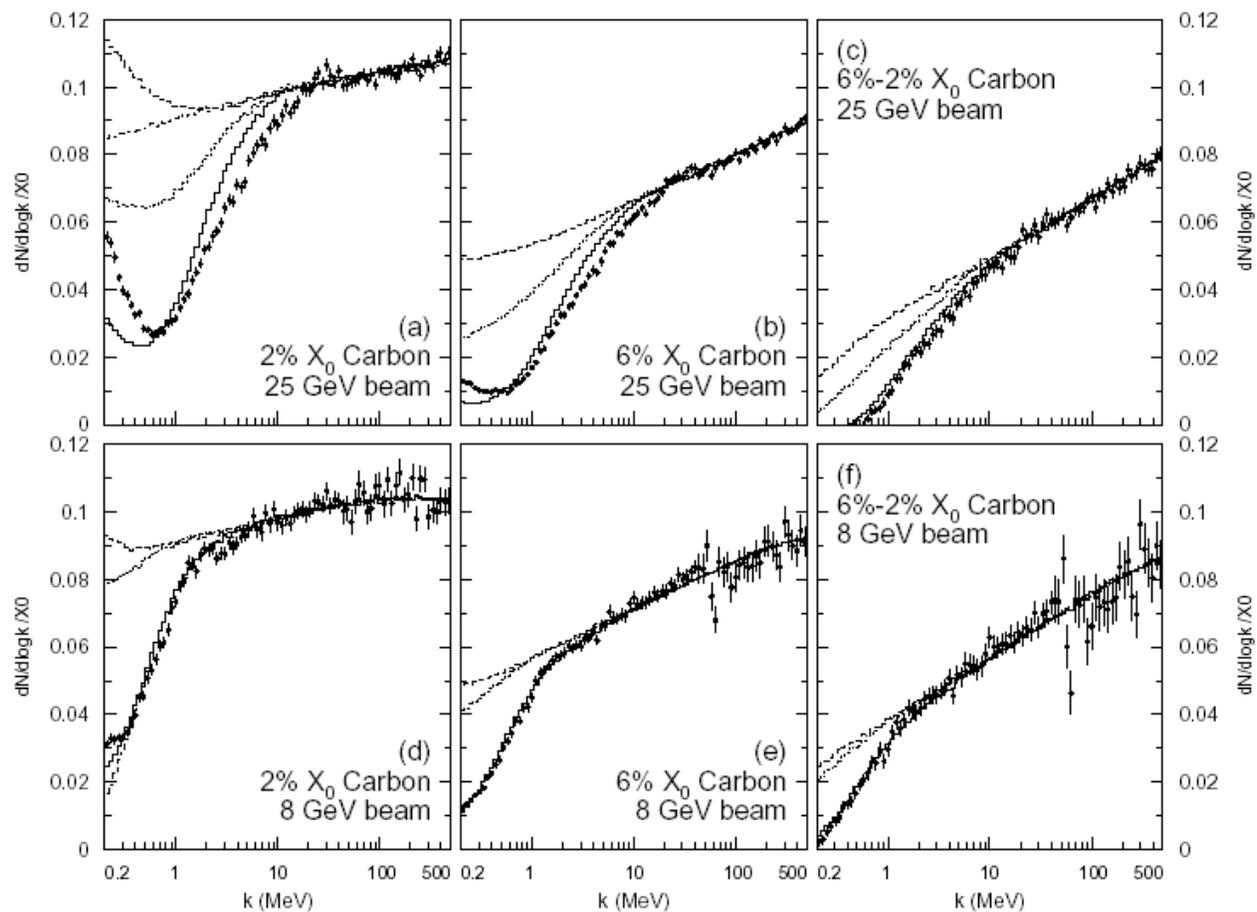


Figure 6. Bremsstrahlung measurements from SLAC E146 (Anthony, *etal*^[1]). Measurements with statistical errors only of $dN=d(\log k)$ are compared with the LPM (Landau, Pomeranchuk^[2], and Migdal^[3]) plus dielectric effect plus transition radiation Monte Carlo curves (solid line), for (a) 2% X_0 carbon and (b) 6% X_0 carbon targets in 25 GeV electron beams, while (d) shows the 2% X_0 carbon and (e) the 6% X_0 carbon target in the 8 GeV beam. The cross sections are given as $dN=d(\log k)/X_0$ where N is the number of events per photon energy bin per incident electron. Panel (c) shows the result of subtracting the data in (b) from that in (a), while (f) is the result of subtracting (e) from (d). Also shown are the Bethe-Heitler plus transition radiation MC (dashed line), LPM suppression only plus transition radiation (dotted line) and, for comparison, Bethe-Heitler without transition radiation (dot-dashed line).

Typically, the simulation normalization had to be decreased by a few percent to match the data (-3.0% for (a) Carbon), an amount consistent with the authors' estimate of a 3.5% systematic error (2% of which came from their knowledge of the target thickness).

6.2.3. Record data using the ESA Proton beam

Protons will be put into the CU at a few x, y, θ . As in 6.2.2, the analysis of the experimental data and simulation output will be compared to verify and correct the simulation.

7. Description of Tests

7.1. Cosmic Rays on the ground

Each tower (EM, QUA, QUB, FM1, FM2), soon after it arrives at SLAC, will be connected to the EGSE and $\sim 10^6$ cosmic rays recorded with the 3-in-a-row tracker trigger. This will take <1 day at the expected ~ 20 Hz trigger rate.

The 4 tower CU will be connected to the EGSE and $\sim 10^7$ cosmic rays recorded with the 3-in-a-row tracker trigger. This will take 2 days at the expected ~ 60 Hz trigger rate.

The full LAT will be connected to the EGSE and $\sim 10^8$ cosmic rays recorded with the 3-in-a-row tracker trigger. This will take 5 days at the expected 220 Hz trigger rate.

7.2. Photons (17.6 MeV) from the Van de Graaff accelerator

The Van de Graaff will be installed in Bldg 33 with its target pipe inserted through the wall of the Clean Room. The target end of the accelerator pipe will be placed in the center and as close as possible to the front face of the EM, CU, and LAT. Measurements show that the Van de Graaff will produce ~ 50 photons/sec (1/2 of which are the 17.6 MeV line) into the calorimeter solid angle for a CU tower. Each tower's calorimeter will therefore see ~ 90000 photons/hr = 25 Hz. One hour running for each of the units (EM, CU, and LAT) will determine the center of the 17.6 MeV peak in each tower's calorimeter to $\pm \frac{50\%}{\sqrt{90000}} = .2\%$ where the energy resolution of each calorimeter is assumed to be $\pm 50\%$ at 17.6 MeV.

The normal 3-in-a-row tracker trigger will be used. This will also record cosmic rays at ~ 20 Hz/tower which is similar to the trigger rate of the Van de Graaff photons. There will be a tail on the energy deposition for cosmics that extends down to 17.6 MeV. For the full LAT, the ACD will be used to reject the charged cosmics. For the EM and CU the cosmics will be rejected by requiring the tracks to point toward a scintillator placed in front of the Li target. The scintillator will veto cosmics but not most photons.

7.3. Positrons in ESA

A secondary beam of positrons travels down the A-line and arrives in End Station A. The A-line has momentum slits and is therefore a long spectrometer. The positrons have an energy known to $\sim \pm 0.5\%$ with a spread in energy of $\sim \pm 0.5\%$ (depending on how open the slits are). The CU energy

calibration is referenced to this spectrometer and to the minimum ionizing energy deposition of cosmics crossing the CsI crystals. We will run with an average of 1 positron / pulse to maximize the number of pulses that have exactly one positron. The calculation of runtime for the positron beam is shown in Figure 7. The CU will be triggered externally on each beam pulse.

poserpulse := .37	Poisson probability of exactly one positron per pulse for an average of 1.
pulserate := 30	[Hz]
npositrons := 5000	Number of positrons per point
nenergies := 6	Number of energies (1,2,5,10,30,45 GeV)
nangles θ := 4	0, 30, 55, 70 deg
nangles ϕ := 1	0 deg
nxy := 3	Transverse positions
acceleffic := .5	Accelerator running effic
grid := 64	Grid of xy positions at normal incidence
setup := .25	[days] Setup time for each energy
$\text{Runtime} := \frac{\text{npositrons} \cdot (\text{nangles } \theta \cdot \text{nangles } \phi \cdot \text{nxy} + \text{grid}) \cdot \text{nenergies}}{\text{acceleffic} \cdot \text{pulserate} \cdot 86400 \cdot \text{poserpulse}} + \text{nenergies} \cdot \text{setup}$	
Runtime =	[days]

Figure 7. The calculation of runtime is shown for the positron beam.

7.4. Photons in ESA

7.4.1. Bremsstrahlung Beam

The average number of positrons per pulse and the radiator thickness will be adjusted to yield n_{avg} photons per pulse. An $n_{\text{avg}}=1$ maximizes the Poisson probability ($=.37$) of exactly 1 photon in the pulse. However, sometimes 2 γ /pulse may come out of the bremsstrahlung target, for example 20 MeV and 980 MeV. The LAT will record the sum energy of 1 GeV, and a track will be seen in the tracker if one of the photons converts. However, it is not known which of the photons converted. When 20 MeV conversions are unknowingly added to the 1 GeV photon bin, wide tails will be put on the 1 GeV SPAR. What will be verified is that the simulation of the LAT + bremsstrahlung radiator agrees with the measured SPAR. The pollution from more than one photon will be kept as small as possible by keeping n_{avg} as small as possible, consistent with getting enough photons in our allotted run time. Figure 8 shows the fraction of pulses that have 2 gammas in them for different n_{avg} . An $n_{\text{avg}}=.22$ will be used which will give approximately the same pollution as in Beamtest '99. An average of one 28 GeV positron/pulse into a .5 inch thick ($=.030$ radiation lengths) polystyrene scintillator radiator will produce an average of .22 bremsstrahlung photons per

pulse between 20 MeV and 28 GeV. If a silicon tagger telescope is placed downstream of the scintillator, the scintillator thickness will be decreased to account for radiation in the silicon (.004 radiation lengths per silicon detector). The calculation of the required running time is shown in Figure 9. The CU will be triggered externally on each beam pulse.

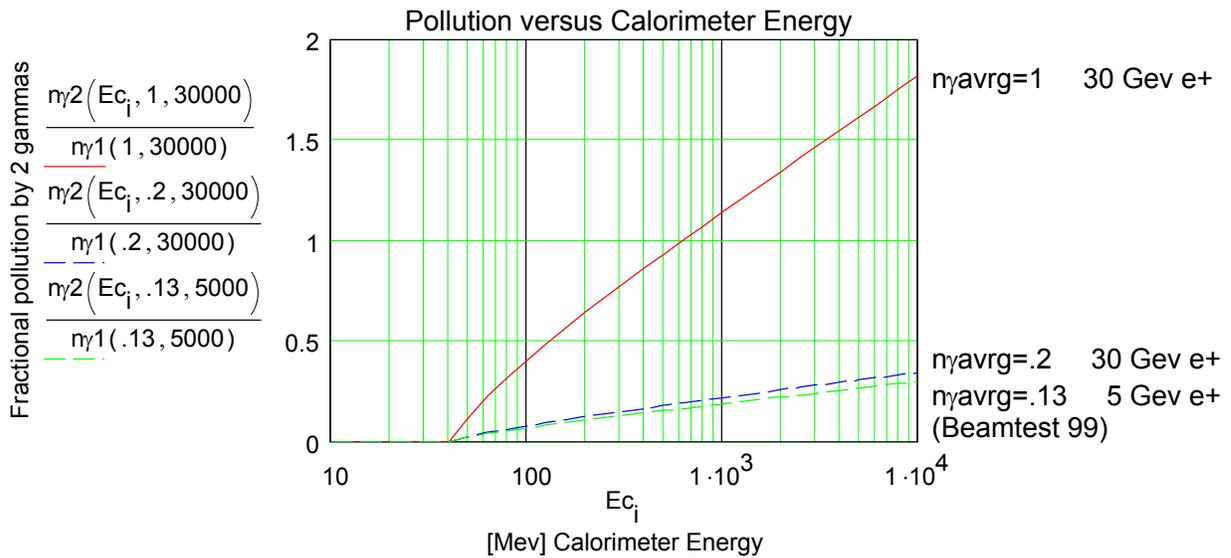


Figure 8. This is the fraction of bremsstrahlung pulses that have 2 gammas adding up to the total energy seen by the calorimeter. We will use $n_{\gamma avg} \sim .2$ which yields the dashed curve in the figure.

Gamma running to measure PSF and Effic with a brems beam.	
$n_{\gamma avg} =$	Avg number of full spectrum (20 mev - 28 GeV) gammas per pulse
$ngambrem =$	Poisson prob of exactly one γ per pulse that is in a 50% full width energy bin
$pulserate := 30$	[Hz]
$ngammas := 10000$	Calorimeter gammas per energy bin (psf measurement)
$nangles \theta := 4$	0, 30, 55, 70 deg
$nangles \phi := 1$	0 deg
$nxy := 3$	Transverse positions
$grid := 6$	Normal incidence positions (2 for 8 GeV e+, 2 for 10 GeV e+, 2 for 26 GeV e+)
$acceleffic := .5$	Accelerator running effic
Runtime := $\frac{ngammas \cdot (nangles \theta \cdot nangles \phi \cdot nxy + grid)}{acceleffic \cdot pulserate \cdot 86400 \cdot ngambrem}$ Runtime = [days]	

Figure 9. The calculation of runtime is shown for the Bremsstrahlung Beam.

7.4.2. **Tagged Photon Beam**

Figure 10 shows a drawing of the Tagged Photon Beam. A ~3% radiator is followed downstream by a silicon telescope consisting of two silicon strip detectors to determine the positron’s velocity unit vector before the tagger magnet. Another two detector telescope downstream of the tagger magnet determines the deflected positron’s velocity unit vector. The tagger is configured so that the unradiated 1 or 3 GeV positron beam will hit the inner edge of the last detector and a .5 or 1.5 GeV positron will hit the outer edge (9.6 cm wide detector). Multiple scattering (silicon and air) and the 242 um pitch of the silicon detectors results in the photon energy resolution shown in Figure 11. The calculation of required running time is shown in Figure 12.

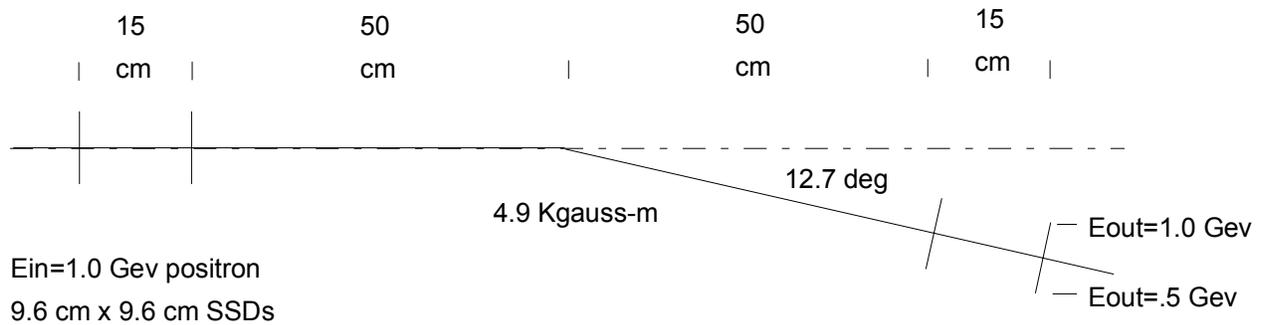


Figure 10. Layout of the Photon Tagger.

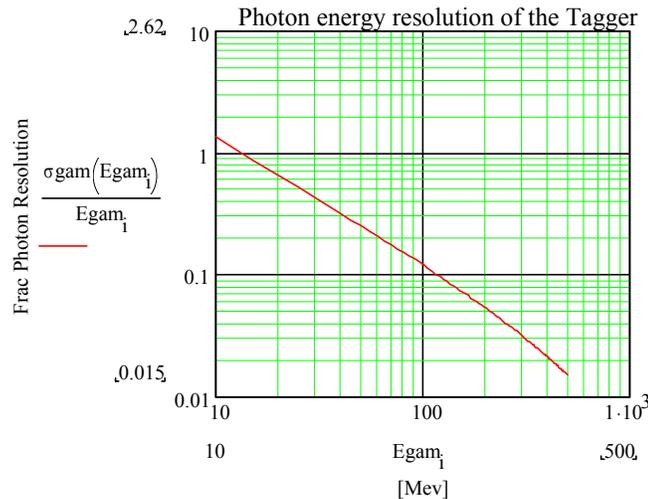


Figure 11. Energy resolution (RMS) of the Photon Tagger as a function of photon energy for a 1 GeV positron beam.

Tagged Photon beam (Epositron=1, 3 Gev) for GLAST energy calibration.	
n _γ avg =	Avrg number of full spectrum (20 mev - Epositron GeV) gammas per pulse
ngambrem := .025	Poisson prob of exactly one γ per pulse that is in a 50% full width energy bin
pulserate := 30	[Hz]
ngammas := 10000	Gammas per energy bin
nenergies := 2	Number of energies (Epositron=1 and 3 GeV)
nangles θ := 1	0 deg
nangles ϕ := 1	0 deg
nxy := 4	Transverse positions (one has the CU out of the beam so the beam hits the BGO backstop)
grid := 0	Normal incidence positions exploring the edge of the LAT
accefffic := .5	Accelerator running efffic
Runtime := $\frac{\text{ngammas} \cdot (\text{nenergies} \cdot \text{nangles } \theta \cdot \text{nangles } \phi \cdot \text{nxy} + \text{grid})}{\text{accefffic} \cdot \text{pulserate} \cdot 86400 \cdot \text{ngambrem}}$	Runtime = [days]

Figure 12. The calculation of runtime for the Tagged Photon beam.

7.5. Protons in ESA

The A line will be set to deliver 13 GeV/c with an average of 1 particle/pulse. This maximizes the number of pulses which have exactly 1 particle. The beam contains mostly positrons and pions, and we measured .0044 protons/pulse in Beamtest '99. These protons are very cleanly identified using time-of-flight and a cherenkov counter. In one month with a .58 accelerator efficiency we will get ~200K protons as we did in Beamtest '99. In the full LAT, proton rejection is a product of the ACD rejection ($\sim 10^3$) times the Pattern Cut rejection ($\sim 10^2$). These ~200K protons will be used to calibrate the simulation at a small number of x, y, θ (TBD). Then the simulation will be used to demonstrate the actual Pattern Cut rejection. The large cosmic ray sample on the full LAT will be used to demonstrate the ACD rejection factor. The CU will be triggered externally on each beam pulse.

A request has been put into SLAC for 2 months of beam in Mar-June 2004. Thirty days are for positron and photon data, and thirty days are for proton data.

7.6. Cosmic Rays in the Airplane

It will be assumed here that the airplane ride is the one necessary to transport the LAT from SLAC to environmental tests at NRL, and that this ride will take ~6 hours. At least one hour of the ride shall be at an altitude (nominally 25,000 feet) such that the LIT trigger rate is equal to that expected in orbit. The remainder of the ride shall be at as great an altitude as possible (but below the Pfozter

maximum at ~50,000 feet) so as to stress the DAQ with greater than in orbit rates. The airplane cosmic test is more fully explained in LAT-TD-00550 LAT Test Plan for Airplane.

8. References

- 1) Anthony, et al.; Phys Rev D56:1373-1390, 1997. (also hep-ex/9703016)
- 2) L. D. Landau and I. J. Pomeranchuk, Dokl. Akad. Nauk. SSSR **92**, 535 (1953); **92**, 735 (1953). These two papers are available in English in L. Landau, *The Collected Papers of L. D. Landau*, Pergamon Press, 1965.
- 3) A. B. Migdal, Phys. Rev. **103**, 1811 (1956).