Characterization of the GLAST-LAT instrument with PS and SPS beams

1 Introduction

The Gamma-Ray Large-Area Space Telescope (GLAST) is the next generation high-energy gamma-ray satellite, to be launched by NASA in August 2007. GLAST's main instrument, the large area telescope (LAT) will cover the energy range between 30 MeV and 300 GeV and will have a sensitivity 25 times better than its predecessor, EGRET. The LAT field of view will be about 2.4 sr, its peak effective area will be about 10000 cm^2. Used in survey mode in space, the LAT will be rocked 35° up or down for alternating orbits, providing a very uniform exposure over the entire sky, which will be covered in about 3 hours. The final EGRET catalog includes 271 sources, while about 9000 new sources are expected to be detected in the first year of operation in addition to the diffuse galactic emission and a large number of gamma-ray bursts. These sources will include active galaxy nuclei, pulsars, pulsar-wind nebulae, the flaring sun... and possibly one or several totally new source classes. Dark matter annihilation signals and signals for other physics will be searched for as well.

The LAT comprises three detector sub-systems. The tracker is made of 18 XY layers of Silicon strips (1M channels, 80 m^2) interlaced with W converter foils, wherein the incident gamma ray converts into a e^+e^- pair. The point spread function (PSF)[1] improves dramatically as the energy increases: the 68% containment angle, $\theta_{68\%}$, is equal to 3.5° and 0.1° at 100 MeV and 10 GeV respectively. A CsI calorimeter (8.5 radiation lengths, X_0, in thickness, made of 1536 logs) allows the electromagnetic shower energy to be estimated ($\sigma_E \simeq 10\%$ at 10 GeV). Finally, an anticoincidence shield vetoes the charged cosmic rays. This veto is essential as the cosmic-ray flux will exceed that of gamma-rays by a factor of about 10^4. For instance, the brightest point source, the Vela pulsar, leads to a detection rate of less than 0.1 photon per second (E_γ>100 MeV) when it is within the field of view, i.e. 20% of the time.

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[1] The point spread function corresponds to the reconstructed image of a point source and characterizes the angular resolution of the instrument.

The LAT is composed of 16 elements called towers, each made of a tracker and a calorimeter module. Gaps in between the towers accommodate the front-end electronics and are 4 cm wide, the width being driven by mechanical issues and stay-clear volumes during launch loads. At the time of this writing, the LAT is about to be completed at SLAC, before undergoing environmental testing in early 2006 and being delivered for integration to the satellite in early summer 2006. The existing towers have undergone extensive tests with cosmic-ray muons and perform well within the requirements.

2 Motivation of the experiments

A sophisticated Monte-Carlo model of the instrument has been developed based on GEANT4. The instrument response functions (IRFs), including effective area,PSF, reconstructed energy distributions, required for analyzing the data must be established with this model. It is indeed not feasible to scan the whole phase space continuously in terms of angle, position and energy with a gamma-ray beam provided by an accelerator facility. However, a thorough characterization experiment must be performed to verify that the response of the actual instrument matches the predictions of the current simulations and to serve as a basis for improving the simulations in case of significant discrepancies. The good reproduction of both directly-measured parameters (energy deposits, hit multiplicities) and quantities resulting from a high-level analysis (reconstructed energy and direction) must be investigated in different regions and at both ends of the LAT energy band, each being important in its own right. Most photons detected by the LAT will have low energy, since typical γ-ray sources are associated with power-law photon distributions with indices close to -2. On the other hand, the coverage of the energy band 1-300 GeV is of prime scientific importance and constitutes one of the major breakthroughs with respect to EGRET. The extinction of most EGRET sources takes place within this energy band, the precise high-energy cutoffs remaining unknown so far.
Thereafter are listed specific points requiring verification.

Reconstructed direction of photons
A precise measurement of the PSF, the LAT key parameter, with low-energy γ-rays is thus of paramount importance, in particular to enable the resolution of faint sources in the vicinity of bright ones. In the low-energy regime,

multiple-scattering suffered by the primary e^+e^- pair essentially in the W conversion foils governs the PSF. Unfortunately, the modeling of the multiple-scattering process for electrons has proved erratic and even unphysical in recent GEANT4 versions and must be carefully checked against real data. At higher energy, the large density of delta electrons complicates the direction reconstruction. Moreover, backsplash electrons produced in the calorimeter and detected by the tracker may spoil the results at the highest energies.

Energy reconstruction

Different energy-reconstruction algorithms are necessary as the LAT energy band covers 4 decades. In the low end of the band, the algorithm makes use of the information from both the tracker (strip hit multiplicity) and the calorimeter, as a large fraction of the energy is lost in the 1.5 X_0-thick tracker in that case. At higher energy, as the calorimeter is only 8.5 X_0-deep, the energy deposited in the calorimeter represents a small fraction of the initial particle energy (40% for a 300 GeV on-axis γ-ray). Three algorithms each giving optimal results in different regions of the (angle, position, energy) phase space have been developed to estimate the energy leakage. The accuracy of the different methods will be tested at SPS.

Backsplash determination

For high energy gamma-ray showers, some low-energy electrons or positrons are scattered backward and can fire the ACD, producing a false veto signal. This problem greatly hampered EGRET's acceptance at high energy, severely limiting its energy range. To mitigate this problem, the LAT's ACD is segmented into 89 tiles and it is imposed in the analysis that the incident particle's trajectory does not intersect any firing tile. It is in principle possible to alleviate possible ACD deficiencies by identifying isolated tracks exiting from the tracker. The backsplash characteristics must be carefully verified at SPS.

Hadronic reaction patterns

As already pointed out, the rejection of the hadronic background is a crucial issue for the LAT. The corresponding algorithms have been developed thanks to simulations. Benchmarking the hadronic simulations with real data is necessary, all the more as hadronic showers are much more difficult to model accurately than electromagnetic showers. High statistics is required here since only the rare hadronic showers having patterns mimicking those of electromagnetic showers are of interest.

It is well established that π- and proton-induced reactions are essentially indistinguishable at energies beyond 5 GeV, so pion beams will be used for this purpose as their intensity is greater than for protons.

Absolute energy calibration
The current absolute energy calibration of the LAT is based on the energy deposited by cosmic muons, as calculated by Monte-Carlo simulations. A mono-energetic muon beam easily available at CERN will be used to verify the accuracy of the calibration procedure.

Flight electronics
The high counting-rate behavior of the flight electronics (dead time, readout timing adjustment) will be checked with particle intensities beyond 10000 p/s. In orbit, different trigger types are foreseen, the main ones being based either on the information from the tracker ("3 Si planes hit in a row") or the calorimeter("CAL-low" and "CAL-high", with thresholds $\simeq$100 MeV and 1 GeV, respectively). The efficiency of these triggers will be determined as a function of the counting rate. These verifications are crucial and can be done only at a beam facility since both the energy deposited and the count rate are too low with cosmic-ray muons. The conditions will not be the same as in orbit where the flux will be distributed over the whole instrument area, but will nevertheless provide very valuable information.
The accuracy of the event time delivered by the electronics will also be verified.

3 Description of the "Calibration Unit"

The GLAST experiments at PS and SPS will serve these different purposes. The whole LAT won't be available for these tests, as it will be in the integration phase in 2006. The "Calibration Unit" (CU) will be used instead: it will comprise two spare towers meeting the flight standards, with two additional calorimeters forming a line of 4 adjacent elements. All detector elements will be fitted with flight electronics.
Using 4 towers in line will allow the effects of inter-tower gaps on the direction and energy reconstructions to be investigated. This configuration will also enable the study of "CAL-only" events where particles enter the calorimeter sideways at a very shallow angle, without traversing the tracker.

The energy resolution is improved in that case as the particles encounter a larger calorimeter depth than particles close to the instrument axis, at the expense of a poor direction reconstruction. This event class can be of interest for dark matter searches for instance.

4 Beam time request

The LAT's phase space (angle, position, energy, particle) being very large, a great number of different data points have to be measured. The detector will be tilted with respect to the beam axis at angles ranging from 0 to 60 deg. At finite angles, different positions will be scanned corresponding to particles crossing gaps at different depths in the tracker or the calorimeter.
Given the long program outlined in the Appendix, we request 3 weeks at the SPS and 3 weeks at the PS, with enough time in between (at least 2 weeks) to enable the transfer of the CU between the two areas. We would prefer to have the PS experiment scheduled before the SPS one.
Because of the strong involvement of the technical personnel in the environmental tests (thermal, vibration) of the instrument in the Spring, we request that the experiments be scheduled after the end of July.

Appendix: Detail of the beam test plan

For the SPS:
Because of the long scintillation decay constants (up to 7 μs) of CsI, one has to run at a fairly low rate (300 Hz or so) to limit the pile-up probability. Measuring at 4 angles (0, 20, 40, 60 deg), 6 positions at 6 energies (10, 20, 50, 100, 200, 300 GeV) corresponds to a total of 144 different settings. For an estimated overall time of 2 hours on the average per setting (data taking + setting changing + beam tuning), a total of 12 days is required at the SPS for the scanning with electrons alone. Two additional days with electrons at 200 GeV will be used to test the flight electronics under various conditions. It is best to do this study at high energy with rates up to 10^4 Hz. For hadrons, high statistics is required, a total of 3 days will be necessary (same energies as for the electrons, beam on-axis).
Total of data taking: 17 days.

For the PS:
Tagged γ-ray photons with energy between 50 MeV and about 3 GeV will be produced via Bremsstrahlung in silicon detectors measuring the positions of the incident electrons. The same setup developed for AGILE will be reused. Because of the limited energy resolutions of the tagger and beam dispersion, different beam energies ranging from 300 MeV to 6 GeV will be used. The rate of photons will be about 100 per 400 ms spill. Accumulating 10000 events per energy bin (assuming 4 bins per energy decade) and per geometrical setting will necessitate 2 hours of beam time with 2 spills per master cycle. Using the same (position, angle) combinations as for the SPS will require 2 days of beam time per beam energy. Six electron energies between 300 MeV and 6 GeV will be used. It must be stressed that in the past beam tuning proved very problematic in the AGILE experiments using the same tagging setup. We estimate that a total of 2 days will be needed for tuning so as to obtain the proper conditions regarding the beam quality, as well for calibrating the spectrometer. As for the SPS, 3 days with hadrons will be necessary. One day with mono-energetic muons will be used to check the absolute calibration with atmospheric muons (20 positions). The flight electronics was not designed to run in conjunction with external devices, making the synchronization of the different data acquisition systems (for the LAT and the ancillary beam diagnostic detectors) a non trivial task.

This synchronization will be tested in advance with cosmic muons, but a very low rate only, so some on-line checks will be necessary before the real data taking is possible. One day is foreseen in this respect. **Total of data taking+tuning: 19 days.**