Hi Eduardo and Steve -

First I want to apologize for joining the Friday meeting late. Apparently I missed some important discussion. For that reason, I have put together the following notes that address both the LAT Science Requirements Verification and the Beam Test Calibration Plan. In my opinion, those should be combined into one document. As described below, I am concerned that we have lost sight of the real goal of the gamma-beam calibrations.

Because of both funding and schedule constraints, the flight LAT will not be able to undergo a gamma-ray beam calibration. The LAT calibration will of necessity be accomplished primarily via Monte Carlo simulations. Thus the gamma-ray beam calibrations done with the Calibration Unit must be **primarily for the purpose of verifying the simulations**.

By the time of the gamma-beam calibration, the configuration and design of the LAT will have been frozen for a long time. Although it is important to check *eventually* that the proposal science requirements are met, that is not the most important goal of the combined simulations and gamma-ray beam calibration. The *essential task* is to generate a set of response tables, for the LAT being built at that time, that allow the flight data to be analyzed correctly. There are really only three such tables, one for effective area, $A_e(E,\theta,\phi)$, one for point spread function, $P_\delta(E,\theta,\phi,\delta)$, and one for energy resolution, $P_\varepsilon(E,\theta,\phi,\varepsilon)$. E, θ, and ϕ are the energy, polar angle, and azimuth angle; δ is the angle between the true and measured photon directions, and ε is the difference between the true and measured photon energies. P_δ and P_ε are the probabilities that the direction and energy errors fall within a particular bin in the direction and energy error distributions. The much-discussed θ_{68}, θ_{95} , and σ_E , as well as many of the other parameters in the list of science requirements, are useful for rough characterization of angular and energy resolution and other general instrument characteristics, *but are useless for data analysis*. They should eventually be derived from the tables.

As I see it, the beam calibrations must verify that the LAT simulations can generate those three tables accurately. It seems unlikely that any of the gamma-ray beam data taken with the Calibration Unit will actually be used directly in analysis of flight data. This is not to minimize its importance: without it, we could have little confidence that the simulations give accurate results.

Several of the items in the LAT Science Requirements Verification list must be derived from the three tables mentioned above:

5.2.1 Energy Range
5.2.2 Energy Resolution
5.2.3 Peak Effective Area
5.2.4? Point Spread Function 68% (on axis)
5.2.5 Point Spread Function 95% (on axis)
5.2.7 Point Spread Function (off axis)
5.2.8 Field of View
5.2.14 GRB Location Accuracy On-Board

Two others require a diffuse background model and working point source analysis software in addition to the tables mentioned above:

5.2.9 Source Location Determination
5.2.10 Point Source Sensitivity

(Note: Item 5.2.16, AGN location accuracy on-board, does not make much sense. AGN locations are known far better than LAT will be able to determine. I believe this requirement should be on transient location accuracy. In that case, it is a complex issue, depending on the time scale and strength of the transient and its position on the sky. However, it must be derived ultimately from the three tables.)

What do we need (ideally) from the Calibration Unit in the gamma-ray beam?

At a specific energy, any particular A_ε, P_δ, or P_ε value is an integral over the LAT projected surface as viewed from the direction (θ,ϕ). (For a rectangular block, that's a hexagon, which collapses to a rectangle when ϕ is a multiple of 90°.) It seems likely that the least certain portion of the integral/average is in the contributions from around the edges, where the beam is traversing only a fraction of the detector. Thus the ideal way to calibrate a detector is to cover the projected hexagon uniformly.

It appears to me that the Calibration Unit exposure to gamma-ray beams must simulate (with detectors, not computers) such a uniform coverage of the LAT. A feasible way to do this would be to do such a uniform exposure of the Calibration Unit at a number of (carefully chosen) combinations of (E,θ,ϕ). Computer simulations with a precise Calibration Unit model should be carried out *and analyzed, prior to the actual beam exposures*. With that in hand, it would be known at any point in the beam exposure sequence what is to be expected. That experience should make possible rapid analysis of the data from the beam exposures, which would make it possible to tell when additional data are required, or possibly when some portion of the planned program could be skipped.

Since the 2x2 configuration of the four towers makes a reasonable gamma-ray telescope, it seems that most of the gamma-beam tests should be done in that configuration. The 1x4 configuration is needed only for the extreme polar angles, which should be calibrated with uniform exposure also.

Unfortunately, with only four towers it is not possible to configure so as to fully examine wide-angle events that cross two or more *rows* of towers. Some possible tower configurations that might help in this area are:

x000		x000
xx00	AND	0x00
0x00		00x0
0000		000x

(This brings up the question of what the Cal Unit grid consists of. I believe it should be a good representation of the flight LAT grid, possibly with some mods to facilitate changes in configuration. An accurate grid representation is essential to understanding the CAL response, especially at low energies.)

Comparison of the beam exposure results with the corresponding output from the computer simulations should provide a good indication of how well the simulations represent the real world. If the simulations represent the results of the beam tests on the Calibration Unit well, simulations of cosmic gamma-ray exposures of the LAT, with a model of the same or better level of fidelity, should provide a good basis for generating the required LAT calibration tables.

Can We Do Such a Test Program?

Obtaining an exposure over the full area of the hexagon/rectangle mentioned above would be most easily done with a calibration fixture such as that built for EGRET. Although that hardware could not have handled the full LAT, it probably could handle the Calibration Unit with some modifications. Unfortunately, the hardware was junked some years ago. On the other hand, it should be possible to get copies of fabrication drawings from MPE. Those would need to be modernized and modified for the LAT Calibration Unit. The cost of the original unit was several million $ in ~1984, but some of the engineering would not have to be redone. I don't know whether there is a budget for that kind of hardware. We might consider investigating whether MPE would be interested in providing that item, as they did for EGRET.

In the absence of such a fixture, the beam calibration suggested above would take much longer because of the time necessary to change positions and angles.

The Matrix of (E,θ,ϕ) To Be Tested

<u>Energies</u> - The energies included in the 19 May 2001 Test Plan were 20, 50, 100, 500, 1000, 10,000 MeV. I suggest the following:

adding 200 MeV, or changing 50 and 100 MeV to 70 and 200 MeV, because the cross-section and effective area are still changing rapidly at 100 MeV
substituting for 10 GeV the maximum energy obtainable at SLAC

Finally, I think it's necessary to be prepared for two eventualities at 20 MeV:

If the efficiency and/or PSF there appear to make LAT of little use scientifically at 20 MeV, be prepared to change to 25 or 30 MeV.
If the efficiency and PSF at 20 MeV appear to be better than expected, be prepared to try 15 MeV, or even 10 MeV

(I realize that this is a difficult energy range to deal with, but it is important scientifically, and is virtually unexplored because of the very small effective area of COMPTEL. The low-energy point is important because it is probably the least likely to be simulated well.)

Polar Angle θ - The 19 May 2001 Test Plan shows 0°, 30°, 60°, 80°. The proposal curve shows a fairly weak dependence on angle through and beyond 30°, and then a "shoulder" at about 40°, with a steeper fall-off beyond that. For that reason, *I suggest changing the 30° point to 40°.*

Azimuth Angle ϕ - Two azimuth angles, 0° and 45°, are essential. 22.5° is highly desirable.

Required Knowledge of Effective Area and Point Spread Function

The EGRET effective area was known (at launch) to 10-15%. (We thought we knew it better, but in-flight calibration demonstrated that it was in that range.) It seems that for LAT, we should have as our goal knowledge better than that, say 5-7%; the requirement should be that it be no worse than the 10-15% of EGRET, at least over the central 2 steradians. Unlike the PSF (see next paragraph), knowledge of the effective area is difficult or impossible to improve with flight data.

The ratio θ_{95}/θ_{68} should not drive the calibration. What's important about the PSF is to know the function $P_\delta(E,\theta,\phi,\delta)$ well enough to be able to do reasonably accurate analysis immediately after launch. The gamma-beam calibration of the Calibration Unit must be able to verify the computer simulations to accuracy sufficient to do that. Knowledge of the PSF will be improved after launch via observation of bright pulsars. θ_{95}/θ_{68} falls out easily from $P_\delta(E,\theta,\phi,\delta)$.

How do we get A_ε, P_δ, and P_ε tables for the flight LAT?

Presumably the final tables for use in data analysis will be generated on a (E,θ,ϕ) grid fine enough that linear interpolation (probably on a log scale in some places) is sufficient everywhere. This does not mean that the LAT simulations must be done on such a fine grid. Curve fitting on points from a coarser simulation grid can be used to generate the functions that produce the fine grid.