Abstract

This is the abstract

The Fermi LAT Calibration Unit Beam Test

Mario Rossi

December 4, 2008

Contents

1 Introduction

The calibration strategy of the GLAST Large Area Telescope (LAT) combines analysis of cosmic ray data with accelerator particle beams measurements. An advanced Monte Carlo simulation of the LAT, based on the Geant4 package, was set up to reproduce the LAT response to such radiation and to benchmark the event reconstruction and the background rejection strategy before launch and during operation.

To validate the LAT simulation, a massive campaign of beam tests was performed between July and November 2006, in parallel with the LAT integration and test, on the LAT Calibration Unit. This is a detector built with spare flight modules and flight-like readout electronics, which was exposed to a large variety of beams, representing the whole spectrum of the signal that will be detected by the LAT, using the CERN and the GSI accelerator facilities. Beams of photons ($0 - 2.5\ GeV$), electrons ($1 - 300\ GeV$), hadrons (π and p, a few $GeV - 100\ GeV$) and ions (C, Xe, 1.5 GeV/n) were shot through the CU to measure the physical processes taking place in the detector and eventually fine-tune their description in the LAT Monte Carlo simulation.

The main goal of the BT was to validate the MC simulation of the LAT, therefore comparing data and MC of basic quantities over the largest possible phase space. Derived, more complex quantities used in the event selection analysis, which are based on LAT global analysis and classification tecniques trained on the whole phase space (**I mean CTB* variables here**), are harder to compare due to differences in the LAT and CU geometries.

Great attention was paid to generate systematics comparison plots over the phase space for most variables. Discrepancies of O(0.1) were found since the very beginning of the analysis, mostly for the number of TKR hits and the CAL energy scale; such differences varies over the energy/angle/impact-point phase space, and therefore could not be absorbed into single calibration constants.

Many cross-checks and updates on the geometry, simulation package, digitization algorithms, hardware calibrations were performed, and the status of discrepancies was monitored after each change. Such verifications allow us to put constraints the impact of these effects on the overall agreement. In particular it was realized that rate effects and imperfect calibration of the CU CAL units leave a residual systematic uncertainty on the agreement factors of a few percent (**need a good mumber**).

Eventually a wrong implementation in the Landau-Pomeranchuck-Migdal effect was found in the Geant4 routines for simulating EM showers. This was fixed in collaboration with the G4 developers, and turned the data-MC disagreement into common calibration factors over the whole phase space, with few percent spread.

It is important to realize the uniqueness of the CU detector and its substantial differences with respect to traditional high energy physics instrumentation, which allowed us to sample the EM shower with fine granularity and therefore spot the importance of the LPM effect in not-fully contained EM showers already at low energy ($> 5GeV$):

- in order to favour cosmic gamma-rays conversion into e-e+ pairs, the tracker is composed of 36 position sensitive silicon micro-strip detectors interspersed with 16 tungsten foils; the tracker total thickness is 1.5 X0, so that most high energy events (¿1GeV) start developing an EM shower in the tracker, which can be effectively considered as a calorimeter preshower

- the CU Calorimeter, being limited to a depth of 8 X0 from mass constraints for satellite operations, was designed with a hodoscopic configuration (8 layers of 12 columns per module) to be able to infer the event energy for showers that are not fully contained through a fit of the longitudinal profile, and to measure the lateral development of the shower to greatly contribute to the rejection of the overwhelming proton background on-orbit

1.1 The LAT Calibration Plan

LAT calibration and performance parameterization as a combination of ground and on-orbit cosmic ray measurements, beam test measurements and simulations.

1.2 Goals of the Calibration Unit Beam Test

It is important to realize the big difference between the LAT and CU geometries. This has a big impact on setting the goals of a direct measurement on the CU that can be extrapolated to the LAT only under certain circumstances. The primary goal of the BT campaing was therefore to validate LAT MC simulation used for tuning both the reconstruction and the event selection analysis algorithm in the LAT. Such validation is more direct for some very basic quantities, like energy deposit in some CAL layers or TKR hits, and can be extremely complicated or even meaningless when applied to derived, high level quantities like classifiers used for event selection of on-orbit data.

2 The BT campaign

Details of the CU, the experimental setup, the dataset, were given in our previous paper. We should decide what to repeat here, but essentially everything is ready.

One important information we should repeat here is that we operated the CU with external trigger and w/o flight software, and the CU had very incomplete ACD coverage, so BT data are not useful to verify the LAT effective area, which can only be modelled in MC and validated with on-orbit data.

3 Simulation

Overall description of the CU simulation in the GLAST simulation software. Roles of Geant4 and Geometry for description of physical interactions.

3.1 Geant4 package and simulations checks

Short list of checks performed to validate Geant4 itself.

- G3-G4 comparisons: test cases indicating good agreement
- G4-EGSE comparisons: test cases indicating good agreement
- CU geometry handling: standalone G4 CUTower simulation
- Low energy EM physics and discovery of LPM effect - improvement in TKR hits
- Hadronic physics lists
- Realistics TKR signal digitization algorithm

3.2 Detector geometry cross-checks

- TKR material audit (w thickness corrected in BT and GR; missing mass in the tray boundaries and in the bottom tray, not corrected)
- CAL material audit - implemented
- Realistic TKR tray geometry (honeycomb core, glue dots, strips)
- Effect of TKR alignment on TKR variables

3.3 Beamline checks and scan on extra material

- beam spot tuning and effect on data-MC agreement
- extra material scan (cerenkov, extra layers)

4 Instrumental effects

4.1 Rate and temperature effects

- CAL pedestal drift vs rate
- verification of no rate effect on TKR
- CAL pedestal variation and correction with T
- light yeld correction with temperature ?

4.2 CAL calibration

- LAC thresholds measurement and update in the simulation
- CAL Cross-talks: FLE-FHE, inter-layer and effects on small-big diode intercalibration

5 Results

5.1 Data-MC agreement matrix for raw quantities

This is a high level summary of data-MC comparison in form of tables of (data/MC-1) vs energy and angle. Such tables should be produced for most relevant raw quantities:

5.1.1 TKR variables

Executive summary: the TKR behaviour is well reproduced by the Monte-Carlo simuation, with a number of differences listed below.

NB: We need to support this with summary plots

- hits: the total number of measured hit strips in the TKR exceeds those predicted by MC by a few %, with no dependence on energy and angle
- cluster: the number of clusters predicted by MC agrees with our measurements over the whole phase space; the distribution of clusters around the main track is also well reproduced (Tkr1CoREHC and similar)
- cluster size: the average cluster size is about 20% larger in data wrt MC, which reconciles the two observations above **TBC**. Heavy ions clusters are measured to be larger wrt MC predictions by a factor of 2; a model based on our observations at GSI was input into the simulation
- time over threshold: the analog response of the TKR is availble as a layer average time over threshold;

These differences are not significant as event analysis is based on cluster variables. A confirmation of this statement is provided by the direct measurement of the PSF in the beam test, which agrees well between data and MC.

5.1.2 CAL variables

Executive summary: the CAL behaviour is well reproduced by the MonteCarlo after i) correct LPM implementation, ii) fine-tuning of the extra-material along the beam line, iii) proper recalibration of the energy scale

- number of hit logs: this number is strongly dependent on the zero suppression (Log ACcept, LAC) threshold for the single CAL log. The actual LAC is temperature dependent, and varied across the test. After careful measurement of the real LAC, simulations with the correct LAC threshold were generated and the number of log hit matched in data and MC. **NB: we rerun all simulation with the best-fit LAC, but we observe differences in several runs that reflect into data-MC disagreement for CalNumHit**

- raw energy deposition: a systematically higher deposited energy is observed in the data wrt MC; after correction of environmental conditions (rate, temperature), correction of the LPM bug and careful tuning of the extra material along the beam line, it was possible to reduce such shift to a 10% on average over the whole phase space (energy, angle, impact point), which was absorbed into a single calibration constant. After this a-posteriori recalibration both the raw deposited energy and the energy deposited in each layer of the CAL is within ±5% wrt MC predictions **NB: final numbers TBD**

- shower transverse size: the transverse size of the shower is well reproduced within a few % **- final numbers TBD - NB: this is using the new variable CalTrSizeTkrT95 instead of CalTransRms; the new variable computes the transverse size using only transverse position measurement and summing up to 95% of the total signal in the CAL; we will have to check that using this new variable in the rejection the performances do not change**

5.1.3 ACD variables

5.2 ElectroMagnetic Shower development

5.2.1 Longitudinal shower development

At low energy (¡1GeV) most of the energy is released in the tracker, and the event energy is estimated from the number of clusters and the information from the Kalman filter applied to track reconstruction. At high energy, the CAL response becomes dominant in the event energy reconstruction.

Show plots of TKR clusters and TKR cluster distribution around the main track for data and MC.

Show longitudinal shower profile fits for data and MC in the CAL.

5.2.2 Lateral shower development

Definition of the transverse size is key in reconciling data and MC. The original CalTransRms definition makes use of longitudinal position measurement, which are too sensitive to electronics non-linearities and crystal saturations. A new variable was defined to overcome such limitations, which computes the transverse size using only transverse position measurement and summing up to 95% of the total signal in the CAL. Data-MC agreement for this variable is good.

NB: we will have to check that using this new variable in the rejection the performances do not change

5.2.3 Energy scale

We have obtained a global scaling factor which is independent of angle and impact point, and only mildly energy dependent. When this is used to recalibrate the CU data-MC agreement is achieved to within few % in the raw deposited energy

NB: there are two important details to discuss:

- **how do we transfer this into the LAT simulation? Should we scale the MIP peak or add an independent factor?**
- **how do we transfer this into the LAT calibration**

5.3 Hadronic interactions

Hadronic events behave very differently in the CAL wrt to photons and electrons. Such information can be efficiently used for reducing the background of protons for both gamma and electron identifications. While EM processes are well established in simulation packages and in particular in Geant4, hadronic interactions can be modelled in different ways, and Geant4 offers several different options (physics list) from which the user should choose those that best reproduce the interactions he is interested in. For this reason we systematically compared available hadronic physics lists with our data, and came to a recommended set of packages to use in the context of FERMI-LAT simulations.

Details follow.

5.4 Direct performance measurement

5.4.1 Direction measurement

Measurement of the PSF with full-brem+tagged photons and high energy electrons.

I would like to place a single plot combining the above over the whole energy range; similar plots could be produced for different incoming angles.

5.4.2 Energy Recontruction

Discussion of energy recon algorithms and comparison plots for bias and resolution.

It is important to stress that the BT data only sample a part of the LAT phase space, although rather big, and the LAT and the CU have different geometries. As a consequence, BT data cannot be used to validate the reconstruction method entirely, or even the selection of the best energy, since this is based on minimizing the bias wrt MC and it is averaged over the whole phase space. The important result we get is that bias and width of each single method match between data and MC for the configurations we scanned in the phase space.

NB: this analysis MUST be repeated after the recalibration

We should then specifically discuss the differences with the energy dispersion in the IRFs, in order to avoid possible confusion for the reader.

- the BT energy resolution is defined for specific configurations in angle, energy and impact point, while the energy dispersion is provided in much larger bins
- we have defined the resolution in BT analysis as the FWHM or the sigma of a gaussian or lognormal fit to the reconstructed energy, while the IRF energy dispersion uses the 68% containment as a measurement of the dispersion
- the existing event classes for the LAT analysis were defined to get predefined residual background rates thought to be adequate for specific analysis; there was no specific attempt to define a class with the best possible energy resolution, this yet has to be done

5.4.3 ACD Backsplash

5.5 Results from heavy ions beams

GSI results. This was essentially already discussed in our previous paper and we have no udpates. We should mention the following:

- TKR cluster size for ion events measured and input in the digi algorithm
- discussion on optimized split-point for large occupancy events (btw this was never used for the LAT - should we push on this?)
- verification of quenching effects and comparison with results from 2003

6 Elements for the LAT simulation and calibration

List of things that were transferred to the LAT simulation:

- TKR digitization algorithm
- TKR cluster width modelling for heavy ions
- optimized hadronic phyiscs list

List of things that were transferred to the LAT calibration

- CAL energy scale
- CAL temperature effects on LAC and pedestals (obviously not the corrections per-se, but the fact that temperature dependence is an issue and is therefore monitored in the LAT)
- CAL cross-talks corrections: these are implemented in the LAT through a single-module calibration that was performed on the ground (ref LAT Calibration paper)
- ACD high range calibration:

7 Conclusion

References

[1] S. Agostinelli et al., (2003) NIM A **506**, 250-303

[2] W. Atwood et al., **LAT paper**, 2009

[3] W. Atwood et al., **LAT Calibration**, 2009

[4] W. Atwood et al., **LAT Performance**, 2009

[5] B. Lott, et al., *Response of the GLAST LAT calorimeter to relativistic heavy ions*, Nuclear Instruments and Methods A, **560**, 395–404, 2006