Abstract

This is the abstract

The Fermi LAT Calibration Unit Beam Test

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November 26, 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 simluation 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:

TKR variables

- hits, cluster
- cluster size
- cluster merit variables, e.g. TKR1COREHC and similar

CAL variables

- numhits
- CalLongRms, CalTransRms

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

CalTransRms and other measurements of the lateral shower development.

Discuss discrepancy for CalTransRms.

5.2.3 Energy scale

We must finalize the global scaling factor and compare it with the updated on-orbit calibration that uses an improved p peak value.

How do we transfer this into the LAT simulation? Should we scale the MIP peak or add an independent factor?

5.2.4 Shower development for hadronic events

Hadronic events behave very differntly in the CAL wrt to photons and electrons. Such information can be efficiently used for reducing the background of protons. 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 used 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.

5.3 Direct performance measurement

5.3.1 Direction measurement

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

5.3.2 Energy Recontruction

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

5.3.3 ACD Backsplash

5.4 Results from heavy ions beams

GSI results. This was essentially already discussed in our previous paper.

- TKR cluster size for ion events

- discussion on optimized split-point for large occupancy events
- 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
- CAL cross-talks corrections

7 Conclusion

References

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