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In-flight calibration of the GLAST Large Area Telescope calorimeter

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Abstract: The Large Area Telescope (LAT) is one of the two instruments onboard the Gamma-ray Large Area Space Telescope (GLAST), the next generation high-energy gamma-ray telescope, to be launched in Winter 2007-2008. It is comprised of sixteen identical towers in a four by four grid, each tower containing a silicon tracker and a CsI calorimeter that together will give the incident direction of the pair-converting photon and the photon energy. The instrument is covered by an anti-coincidence detector to reject charged particle background. We will present the methods for calibrating the calorimeter on orbit using galactic cosmic rays from H to Fe, that will be necessary to ensure a satisfactory performance of the LAT in its energy range from 20 MeV to more than 300 GeV.

Introduction

GLAST, the next generation space based gamma-ray telescope, was designed to observe radiation with energies between 10 keV and more than 300 GeV, and consists of two instruments: the GLAST Burst Monitor (10 keV – 30 MeV) and the Large Area Telescope (20 MeV – 300 MeV and above). The LAT comprises three main detector subsystems [1]: a tracker (TKR) with active silicon strip detector layers and thin passive tungsten radiators, a hodoscopic CsI crystal calorimeter (CAL) and a plastic anticoincidence detector system (ACD). The TKR is responsible for determining incident photon direction and plays also a role in energy measurement below 1 GeV. The CAL is aimed to provide incident photon energy. Its calibration will be performed in flight using the energy deposited through ionization process by galactic cosmic protons and ions.

Calorimeter design

The CAL is built as a 4x4 array of identical modules. Each module contains 96 CsI crystals arranged in 8 horizontal layers of 12 crystals. Even layers are orthogonal to odd layers (hodoscopic configuration). Scintillation light is detected at each end of a crystal by two silicon PIN photodiodes with two amplification range each. The large diode (1.5 cm^2) is used to measure energy deposits from $\sim$2 MeV to $\sim$1 GeV, while the small diode (0.25 cm^2) covers energy deposits up to $\sim$70 GeV.

Each crystal end produces 4 output signals (2 for each diode) with maximum energies of $\sim$100 MeV, $\sim$1 GeV, $\sim$8 GeV and $\sim$70 GeV, which are digitized by a single 12 bit ADC. A programmable logic selects the lowest unsaturated energy range for readout, but 4-range readout is also available for calibration purposes.

The electronic chain of each photodiode also includes a trigger circuit, consisting of a fast shaper and a discriminator (FLE for low-energy diode and FHE for high-energy diode). The FLE and FHE discriminator thresholds can be set individually for each crystal end. The logical OR of all FLE and of all FHE outputs form the CAL_LO and CAL_HI triggers respectively. In flight, the discriminator threshold values for each crystal will be set to 100 MeV for FLE and 1 GeV for FHE.

Methods for energy scale calibration

Ground calibration

During CAL assembly and testing on ground, a first energy scale calibration has been performed

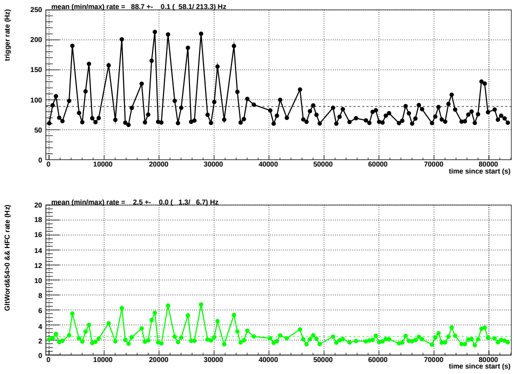

Figure 1: Onboard total GCR rate (top) and telemetered rate (after trigger "engine 4" and HFC filtering) (bottom), as a function of time, over 1 day. Peaks correspond to orbital modulation. Passages through SAA have been removed.

using surface muon ionization losses [2]. Vertical events were selected using either the hodoscopic segmentation of the CAL or the TKR.

For each crystal, a pulse height histogram was formed from the geometric means of the signals from each end of the crystal for each muon event. Electronic nonlinearities, previously calibrated by charge injection, were removed, resulting in an arbitrary linear "DAC" pulse height scale. The muon peaks in the resulting histogram were fitted using a Landau function convolved with a Gaussian, the latter representing slight instrumental broadening.

In-flight calibration

The calibration of the CAL on orbit will start with the ground calibration. It will be regularly refined using cosmic protons and ions (C, N, O, ... to Fe, called GCRs in the following) as primary particles, and the TKR to reconstruct their incident direction.

Protons: The procedure will be very similar to the one used for ground calibration with muons. To select useful events, an existing filter will be used to leak protons at some low rate. A specially dedicated filter could be eventually introduced, with the 4-range readout set on for ~1 day.

Ions: As we show in the following, ionization losses from cosmic ions (from C to Fe) provide well identified peaks over most of the dynamic range of the CAL and can therefore be used to determine the absolute energy scale.

Data acquisition will allow ion event collection, in parallel to the standard data collection, using a dedicated hardware trigger (see next section).

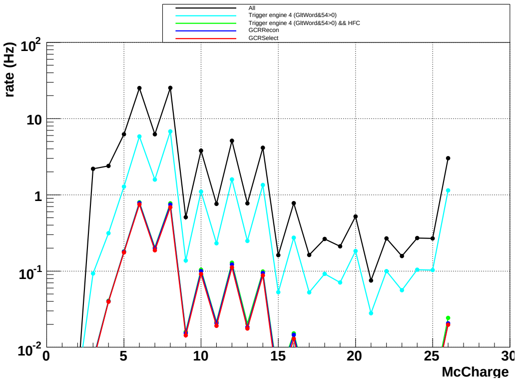

Figure 2: Trigger rates as functions of the atomic number, at various levels of onboard triggers, filters, and offline analysis (see text).

GCR calibration

Trigger rates

A preliminary estimate of the rates of cosmic ion events has been performed from a simulation, uniformly sampling 1 day of GLAST orbit. The cosmic ion source uses abondances as measured by [3] and a random distribution for incident direction. The whole geometry and responses of the LAT were simulated using the GLAST official software, which makes use of the GEANT4 toolkit [4].

Ion trigger rates were evaluated at two stages:

- after a hardware trigger named "engine 4" which selects events resembling heavy charged particles depositing some energy in the CAL, namely with: (a) 3 hits in a row of a TKR tower and an energy deposit of more than ~20 MIPs in a single ACD tile above this tower, (b) an energy deposit of at least ~100 MeV in one of the CAL crystals.
- after a flight software filter, named "HFC", which introduces two additional conditions:

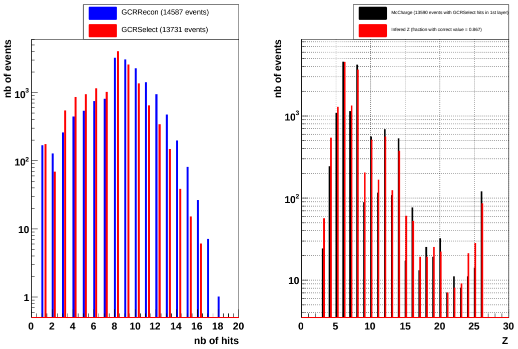

Figure 3: *GCRRecon/Select* algorithms result: number of selected crystals (left) and infered atomic number (right).

(a) 1 or 2 crystals in the first three CAL layers with energy deposit above 50 MeV, (b) the energies in these layers must match within a few tens of percent. This condition allows to reject those events with nuclear interaction occuring above or at the top of the CAL, which are not suitable for calibration.

Fig. 1 shows the global GCR trigger rate (∼90 Hz in average) and the telemetered rate after "engine 4" triggering and HFC filtering (∼2.5 Hz). Fig. 2 also shows the rates as functions of the atomic number. The current design of the HFC filter provides an efficiency between 10-15% for light ions and $< 5\%$ for heavy ions. It yields a telemetered rate of $\sim$ 1.8 Hz for C, N and O events. Most of these events are selected for calibration purposes (see next section).

Crystal selection procedure

For a given event, the selection of CAL hits useful for calibration is done using two algorithms that have been included in the official GLAST software package. This software has been developed using the CERN Gaudi framework specifications [5].

The *GCRRecon* algorithm allows to identify the crystals that should be crossed by the primary particle, and assumes an energy deposit proportional to the path-length, as expected from a simple ionization process. It consists of two steps:

- Propagation of the primary particle direction (as measured by the TKR) to the CAL and identification of crossed crystals.
- Calculation of the path-length corrected energy: using the current calibration, the raw energy of each hit is obtained, and then corrected for the path-length, which corresponds to the segment of the expected trajectory intercepted by the crystal.

The *GCRSelect* algorithm analyses the observed energy-deposit pattern to eliminate interacting events. It consists of four steps:

- Identification of clusters of hits, defined as groups of adjacent crystals with energy deposits greater than 100 MeV.
- Selection of crystals using hit multiplicity: all layers in the 16 CAL modules are analysed. A layer is kept for calibration if it contains one and only one cluster consisting of at most two hits. Only hits in successive layers (starting from the top of the CAL) which fulfill the above criterion are kept.
- A comparison of the path-length corrected energy in the first layer, with the energy deposit expected for ions at normal incidence, allows to infer the atomic number of the incoming particle.
- Hit identificators and energy deposits, as well as the infered atomic number are stored in a ROOT format file.

Using the latter ROOT file, and a code similar to that used with muons, an histogramming analysis will be performed to yield the new calibration constants. Quenching effects, as characterized by [6], will be taken into account in this analysis.

Results

- After HFC filtering, more than 90% of events are found to be useful for calibration. Left side of Fig. 3 shows the distribution of the number of crystals identified as being crossed by the primary particle and useful for calibration according to *GCRRecon*

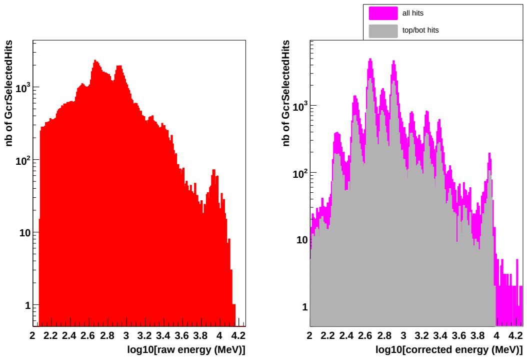

Figure 4: Raw (left) and path-length corrected (right) energy distribution: well identified peaks correspond to different atomic numbers.

(in blue) and *GCRSelect* (in red), for events passing the HFC filter.

- The atomic number estimation from first layer energy deposit is reliable for 87% of events, as shown on the right side of Fig. 3 which compares the distribution of simulated (black) and infered (red) atomic numbers, for events passing the HFC filter.
- Energy spectrum: Fig. 4 compares the energy distribution for selected hits, before and after path-length correction. Path-length corrected energy distribution provides well identified peaks up to ∼10 GeV and can be used to determine new calibration constants.
- Carbon statistics: Fig. 5 shows the energy distribution of carbon selected hits for the same simulation run, layer per layer. A good statistics is obtained even for bottom layers. Preliminary results show that sufficient statistics should be obtained after a collection time of ∼ 1 day, for this particular ion. Indeed, 100 to 500 hits are expected per individual crystal, depending on its position in the CAL (close to the center or to an edge, near the top or bottom of a module).

Conclusion

- The calibration of the GLAST LAT calorimeter will be performed on orbit using the energy deposited through ionization process by galactic cosmic protons and ions.

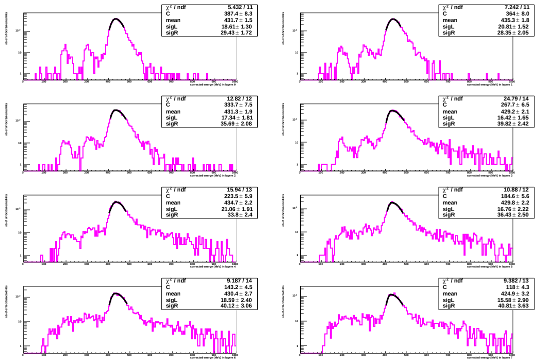

Figure 5: Distribution of energy deposited by carbon ions, for each of the 8 layers of the CAL.

- The selection of non-interacting ions and of the hits useful for calibration has been implemented. The corresponding Gaudi algorithms are now available as part of the GLAST official analysis software, and currently being validated.
- Preliminary results based on a realistic simulation of GLAST operation on orbit show that a collection time of ∼1 day should be enough to have sufficient statistics, at least for the lightest ions. The same estimation is planned for heavier ions in the near future.

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