CALET Calibration on ISS Orbit Using Cosmic Rays

TAE NIITA[1], AND THE CALET COLLABORATION
[1] *Waseda University*
many-pictures@fuji.waseda.jp

Abstract: CALET (CALorimetric Electron Telescope) is a high energy cosmic ray detector to be installed on the International Space Station in 2014 for direct measurement of TeV electron sources with high energy resolution. The detector is composed of 3 main detector sub-systems and each component of the calorimeters is required to be calibrated on-orbit. In particular, the calibration of PWO logs that compose TASC (Total AbSorption Calorimeter) is important to obtain a precise energy spectrum of cosmic rays. For the on-board calibration we plan to use MIP (Minimum Ionizing Particle) derived from cosmic ray protons, plus comic ray Helium nuclei. We have been carrying out Monte Carlo simulations to develop an algorithm to select, by reconstructing the event track, penetrating events which pass through the detector without creating showers. In this paper, we present the calibration methods and the time estimation for a full detector calibration, considering the cosmic ray flux, including albedo particles, as a function of geomagnetic latitude.

Keywords: high energy cosmic ray, detector calibration.

1 Introduction

CALET has been developed as a high energy cosmic ray detector for direct measurement of TeV electron sources [1]. It will be installed on the ISS (International Space Station) in 2014 and will carry on the measurement for a planned 5 years. Each detector component will be calibrated on the ground with cosmic ray muons before the flight, but updated calibration, considering detector condition under the thermal variation or high radiation environment, is required to obtain a precise energy spectrum of cosmic rays. We plan therefore to carry out on-orbit calibration using cosmic ray protons and cosmic ray helium nuclei. Monte Carlo simulations showed us that effective event selections lead to a clear distribution of energy deposition of penetrating protons without the effect of hadron interaction. In this paper, we present the calibration methods we have developed and the time estimation for a full detector calibration.

2 CALET Detector

The CALET detector is composed of 3 main detector subsystems. The top part (CHD; CHarge Detector) is composed of plastic scintillator bars. This part is for charge identification of hadron nuclei. The middle part (IMC; IMaging Calorimeter) is composed of 7 tungsten plates and 8 detection layers made of scintillating fibers. We use this part mainly for shower axis reconstruction. The bottom part of the detector (TASC; Total AbSorption Calorimeter) is composed of 6 detection elements, each composed of an X-Y pair with 16 PWO logs in each layer. This part is for measurement of energy and shower development of incident particles. Total thickness of the detector is about 30 X_0 for electromagnetic particles, and 1.3 λ for protons. In this paper, we mainly focus on the calibration of the PWO logs because it directly affects the energy spectrum we will obtain from CALET observation.

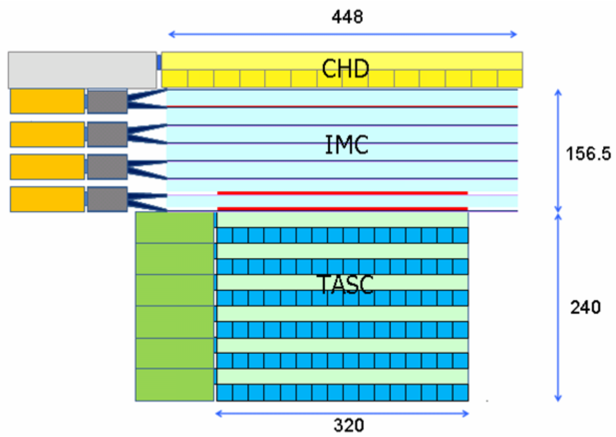

Fig. 1: CALET side view

3 Basic Method for Calibration

We have carried out several beam tests in 2010 - 2012 [2] [3] using CALET prototype and confirmed that each detector component can be calibrated with muons, which have a long interaction length and are convenient for the derivation of energy deposition corresponding to MIP (Minimum Ionizing Particle). Figure 2 shows a distribution of deposited energy in one PWO log. We determined the most probable value of the fitting function as 1 MIP. The plastic scintillators and scintillating fibers composing CHD and IMC could be also calculated in this way. There are no muons available in space, therefore we are planning to use cosmic ray protons instead. Protons are more likely to interact with the detector than muons, so careful event selection is needed to get a precise value of 1 MIP without the effect of shower particles generated in the detector. The methods for event selection are explained in section 5.

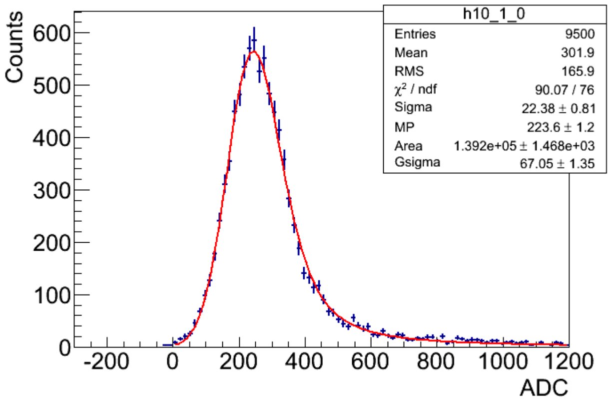

Fig. 2: Distribution of deposited energy in PWO based on 150 GeV muon beam test at CERN-SPS in 2010. Experimental data (blue dots) are in good agreement with fit function (red line).

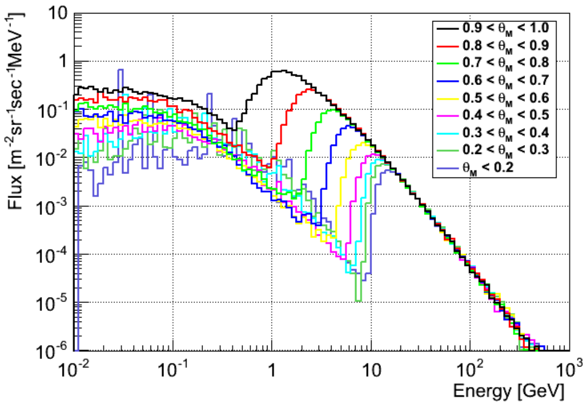

Fig. 4: Estimated proton flux at various geomagnetic latitudes. Primary flux was assumed on the basis of the results of AMS-01 [5].

4 Data Acquisition for On-orbit Calibration

4.1 Estimated Proton Flux

In order to estimate the time we need for on-orbit calibration, we calculated the proton flux on the ISS orbit using ATMNC3 [4]; a simulation code which was originally made for calculation of atmospheric muons and neutrinos. This code was recently applied to calculate the cosmic ray flux observed by Fermi and PAMELA over a few hundreds MeV, and proved to be consistent with these results. Fig. 3 and Fig. 4 show the results of our calculation. Primary proton flux was assumed from the results of AMS-01 [5]. Atmospheric structure and geomagnetic field were set on the basis of US-standard 1976 [6] and IGRF2010 [7].

4.2 Trigger Mode for Calibration

We use a specific trigger mode for calibration with low thresholds (∼0.7 MIP) to detect penetrating particles. Figure 5 shows the estimated flux of triggered particles in a certain range of geomagnetic latitude. Particles which create showers in the detector may also be detected, but Monte Carlo simulation shows that ∼20 % of triggered protons pass through the detector from the top to the bottom without interaction and are useful for calibration.

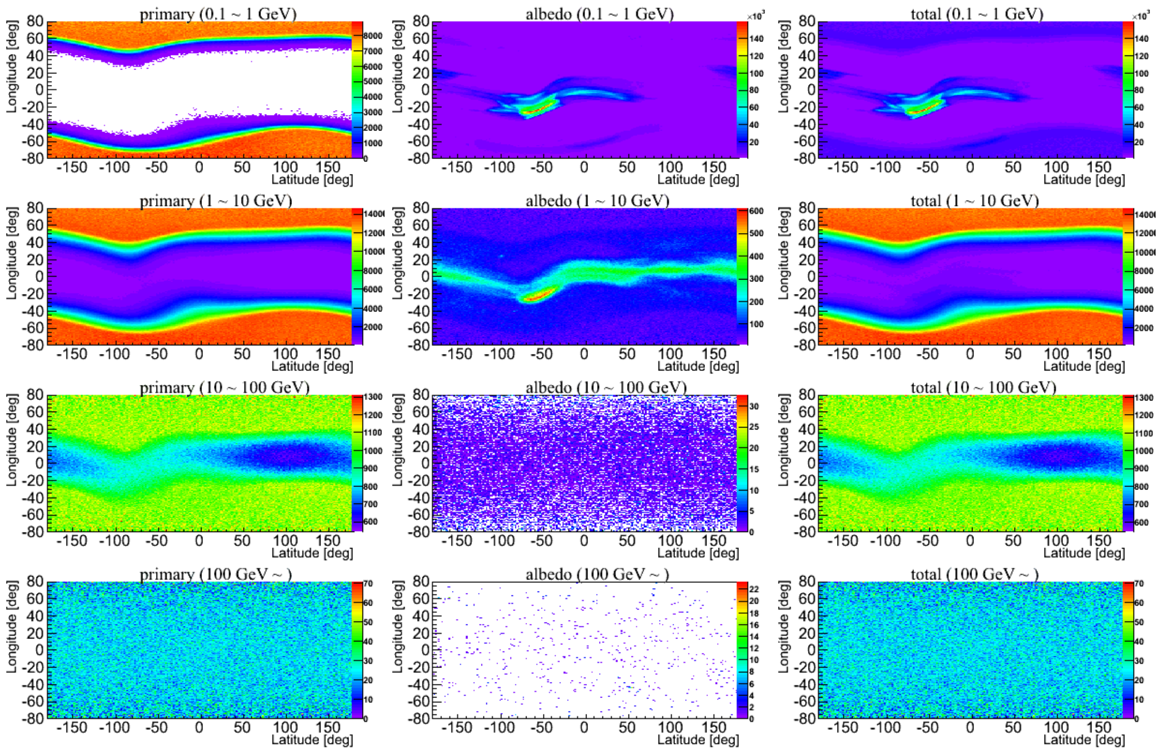

Fig. 3: The cosmic ray flux vs location on the ISS orbit at an altitude of 400 km. Four figures in the left column are for primary particles, the middle for the albedo, and the right for the total (primary + albedo). Three figures in the first row are for 100 MeV - 1 GeV, 2nd row for 1 - 10 GeV, 3rd row for 10 - 100 GeV and the last row for above 100 GeV.

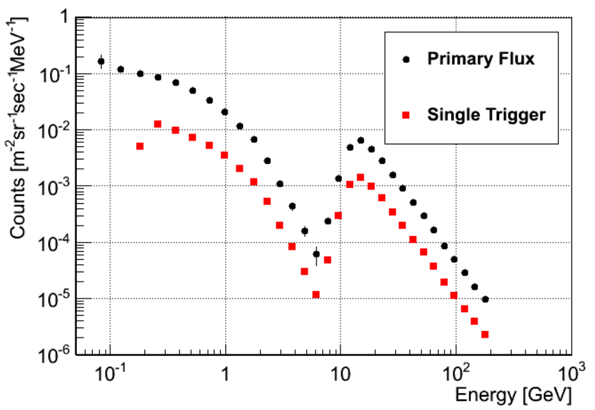

Fig. 5: Estimated flux of primary protons (black dots) and triggered particles (red dots) in latitude of 0 - 5.16 degree. Trigger efficiency decreases in low energy region ($<$ 200 MeV) because most of particles stop before reaching TASC.

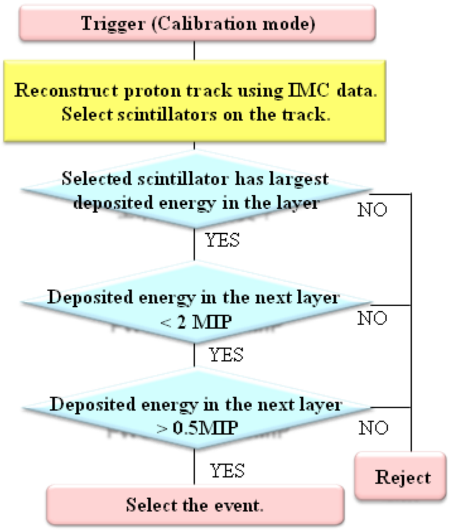

Fig. 7: An algorithm of event selection

5 Off-line Analysis

As mentioned in section 3, careful analysis is needed to separate penetrating particles from shower events when we seek to calibrate the detector by protons. ATMNC3 gave us event samples with various energies and incident angles, so we simulated detector-response for those events using EPICS [8] to develop an algorithm of event selection. Adopted hadron interaction model is dpmjet3 [9].

5.1 Track Reconstruction

The first step of the event selection is track reconstruction using IMC data. The events which enter the detector from the side or escape through the side are rejected in this step. Figure 6 shows an example of proton track reconstruction. As seen in Fig. 6, reconstruction helps us to identify the scintillators through which a particle passes, and then to valuate the energy deposition around the track as will be explained in the next paragraph.

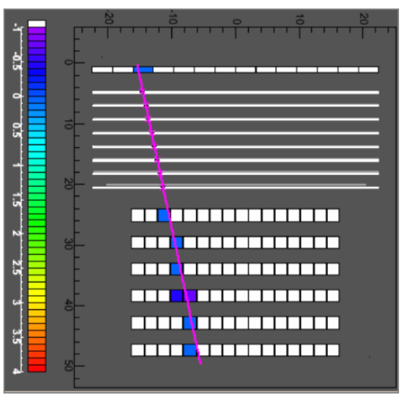

Fig. 6: An example of track reconstruction. Reconstructed track (purple line) is almost overlapped with true incident direction (green line).

5.2 Selection by Deposited Energy

As second step of the selection, we check deposited energy in scintillators around the reconstructed track and reject the events which seem to create a shower in the detector or lose all their energy before passing completely through the detector. We select useful events in the following order.

1. Select the most luminous scintillator of a layer. If this scintillator is not on the reconstructed track, it's likely that the reconstruction accuracy is not very high, so we reject the event.

2. Check deposited energy in scintillators under the layer. Too large deposition (more than 2 MIPs) suggests that the particle developed a shower in the layer. Too small deposition (less than 0.5 MIPs) suggests otherwise that the particle lost all its energy before reaching the next layer. So we select the event only if the deposition is in the range of 0.5 - 2 MIPs.

This sequence is shown in Fig. 7. We can see in Fig. 8 that this selection produces distributions of deposited energy in PWO logs suitable to get the correct value of 1 MIP.

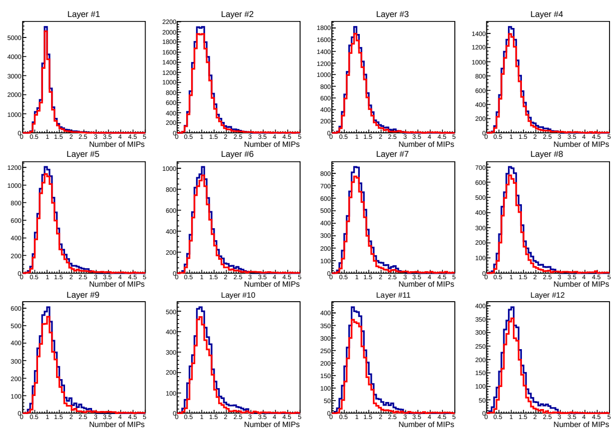

Fig. 8: Distributions of deposited energy in PWO of each layer (layer 1st to 12th; from the left top to the right bottom). The black line shows distribution of selected events and the red line shows that of real penetrating events.

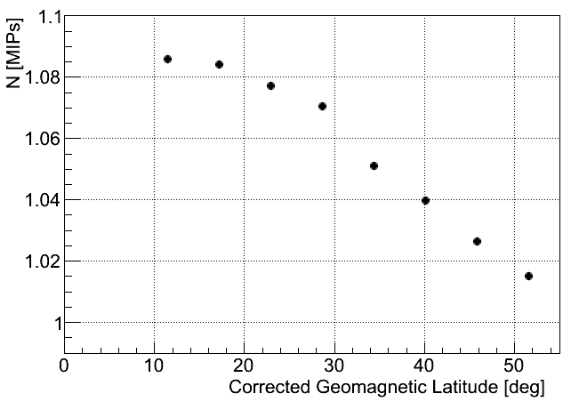

Fig. 9: Variation of MIP in the bottom layer PWO as a function of geomagnetic latitude. Each dot is obtained through the analysis of simulated events. The difference depending on the latitude is up to 6.8 %.

Table 1: Trigger rate and selected event rate for calibration

Latitude [deg]	Trigger Rate [s^{-1}]	Selected Rate [s^{-1}]
0.00 - 5.16	45.1	0.067
5.16 - 10.32	40.9	0.070
10.32 - 15.48	39.0	0.070
15.48 - 20.64	43.3	0.086
20.64 - 25.80	47.7	0.089
25.80 - 30.96	52.9	0.13
30.96 - 36.12	67.1	0.23
36.12 - 41.82	95.2	0.39
41.82 - 46.44	139	0.56
46.44 - 51.60	191	0.69

6 Correction of MIP variation

We calibrate the detector using MIP obtained from the distribution of deposited energy, but we should take notice of the fact that the MIP value varies with particle energy as described in Bethe-Bloch equation. The average energy of incident protons differs depending on geomagnetic latitude, so the derived MIP values have variations as in Fig. 9. We should correct this effect when we combine the data obtained at different geomagnetic latitudes.

7 Selection Efficiency and Time Estimation

Table 1 shows trigger rate and selected event rate we estimated from our simulation data analysis. These values in the table are for PWO logs in the TASC bottom layer, which have the lowest rate of penetration. We calculated from this table, considering the sojourn time in each latitude, that the number of events we can get for calibration during one ISS orbit is about 1300 per log. We can conclude therefore that an accurate calibration will be done in several orbital periods while short-term variation can be monitored orbit by orbit.

8 Conclusions

We carried out Monte Carlo simulations and confirmed that we can calibrate the CALET detector on the ISS orbit using cosmic ray protons by selecting penetrating events in off-line analysis. The number of useful events we can get during one ISS orbit is more than 1000 events per each PWO log, so we can calibrate the full detector within a reasonable time. We are now studying, as the next step, about the calibration using cosmic ray helium nuclei, expecting higher accuracy due to their larger energy deposition. The result of this analysis will let us make a specific operating plan for optimal detector calibration.

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