

CALET observational performance expected by CERN beam test

YOSUI AKAIKE¹ FOR THE CALET COLLABORATION.

¹ *Institute for Cosmic Ray Research, University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa City, Chiba, 277-8582, Japan*

yosui@icrr.u-tokyo.ac.jp

Abstract: CALorimetric Electron Telescope (CALET) is planned to be placed on the International Space Station in 2014 to carry out the accurate measurements of electrons in 1 GeV - 20 TeV, gamma-rays in 10 GeV - 10 TeV, and protons and nuclei in several 10 GeV - 1000 TeV. The main calorimeter consists of a Charge Detector (CHD), an Imaging Calorimeter (IMC), and a Total Absorption Calorimeter (TASC). The total thickness is $30 X_0$ for electromagnetic particles or 1.3λ for protons. CALET, with its imaging and deep calorimeter, provides excellent energy resolution and high background rejection. We carried out beam tests to assess the detector performances and the validity of our Monte Carlo simulations, using 10 - 290 GeV electron and 30 - 400 GeV proton beams at CERN-SPS. In this paper, we present the expected performance based on the agreement between measurements and predictions from the Monte Carlo simulations, including angular and energy resolutions and particle identification.

Keywords: beam test, Monte Carlo simulation, calorimeter, CERN-SPS

1 Introduction

CALorimetric Electron Telescope, CALET, is a new observatory being developed for the Japanese Experiment Module Exposed Facility of the International Space Station, ISS[1]. The instrument will be flown in 2014 and is scheduled to be operated for five years. The main purpose of the CALET mission is to search for nearby cosmic ray sources and dark matter signatures by carrying out the direct measurements of cosmic ray electrons from 1 GeV to 20 TeV and gamma-rays 10 GeV to 10 TeV[2]. CALET will measure protons and nuclei up to 1000 TeV as well. CALET, with its imaging and deep calorimeter, provides excellent energy resolution and high background rejection, which are confirmed by Monte Carlo simulation. In order to assess the detector performance and the validity of our Monte Carlo simulation, we carried out beam tests[3]. In this paper, the results of the beam tests are reported.

2 Beam Test at CERN-SPS

2.1 Experimental Outline

The beam test was carried out at CERN-SPS, using electron and proton beams in the energy region from 10 GeV to 290 GeV and from 30 GeV to 400 GeV, respectively, and 150, 180 GeV muon beams for calibration. We use the Beam-Test Model, BTM, as a detector, which has the same geometry with a flight model. In front of the CALET calorimeter, we put Si-tracker to detect incident position.

2.2 Detector

The main calorimeter of the CALET flight model consists of the CHarge Detector (CHD), the IMaging Calorimeter (IMC) and the Total AbSorption Calorimeter (TASC). CHD is located on the top of the calorimeter to provide dE/dx measurements for charge identification[4]. It is composed of two layers made of 14 plastic scintillator paddles. The size of each paddle is $45 \text{ cm} \times 3.2 \text{ cm} \times 1 \text{ cm}$ thick. IMC is composed of eight layers of paired $x-y$ scintillating fiber (SciFi) planes with interleaved tungsten plates.

The SciFi belt of 448 mm square is assembled with 448 SciFis of 1 mm square in cross-section. The total thickness of tungsten plates is three radiation length ($3 X_0$) or 0.1 nuclear interaction length (0.1λ). The five top tungsten plates each have a thickness of $0.2 X_0$ and the two lower tungsten each have a thickness of $1.0 X_0$. IMC provides the precise measurements to identify the charge of the incident particle and to determine the arrival direction. TASC is composed of 192 PWO scintillators, each of which has a dimension of $20 \text{ mm} \times 19 \text{ mm}$ in cross-section and 326 mm length. They are stacked in 12 layers arranged alternatively in the x and y direction as a hodoscope. TASC has a thickness of $27 X_0$ for electromagnetic particles or 1.2λ for protons and plays a key role for the energy measurement and the electron/proton separation.

In this beam test, we use BTM, which has the same configuration as the flight model, but the number of active scintillators are limited. The number of active scintillators in CHD is three paddles in each layer, and the number of active PWO is also three logs in each layer. The others are replaced by acrylic paddles and brass logs as dummy materials, respectively. We confirmed from MC simulations that the replacement does not affect the detector performance. The active parts of the instruments are narrower than a flight model; however, the detector is able to detect almost the full shower energy, because the Molière radius of PWO is 2 cm, which is the same as one PWO's width. Figure 1 shows a schematic view of the CALET calorimeter and an example of a shower image of 290 GeV electron.

3 Data Analysis

For detector calibration, we use minimum ionizing particles (MIP) of muons. At first, exact coordinates of SciFi in IMC are corrected by muon track, which pass through the detector along a straight line. Next, using muon track reconstructed in IMC, pulse-height distributions of muon signals are made. Figure 2 shows the distributions of ADC counts for SciFi and PWO. These distributions are well described by a Landau convoluted with Gaussians. The

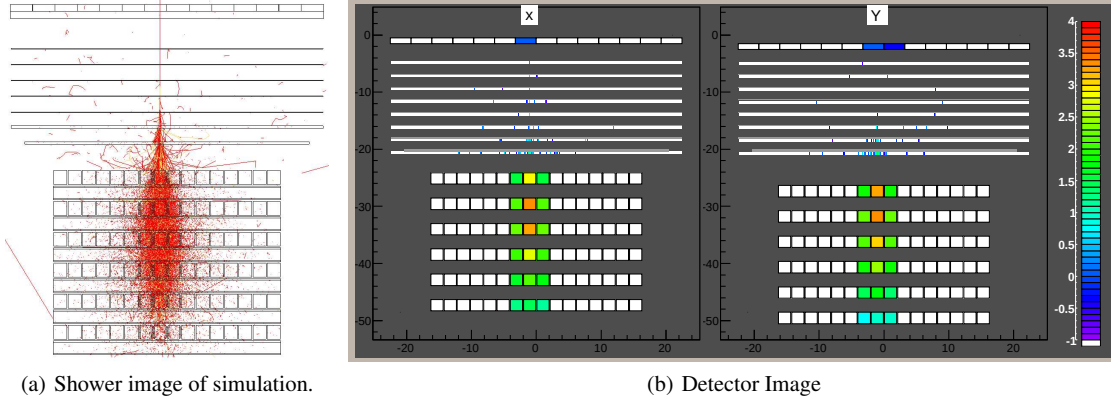


Figure 1: Shower image for 290 GeV electron. (a) is a shower image of simulation. (b) is a event viewer. For beam test in 2012 at CERN-SPS, three scintillators at each layer in CHD and TASC are active. The color shows the number of particles in logarithmic scale.

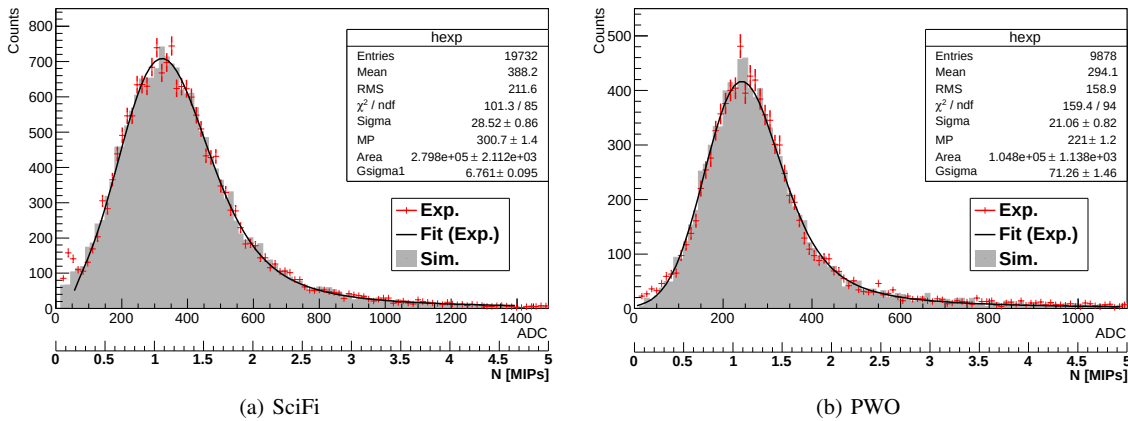


Figure 2: Distributions of ADC counts for SciFi and PWO with 150 GeV muons.

Landau Most Probable Value (MP) is used to equalize as one MIP. Since SciFis are read out by 64ch multi-anode PMT, we corrected optical cross talk in front of the window covering the photo-cathode. In case of PWO, since wide dynamic range is required to detect 1000 TeV protons, four dynamic ranges are implemented[5]. Higher range read-out is calibrated by a correlation with the low range read-out. In analysis of this beam test, we use two ranges because the maximum signals are up to a few thousand MIPs due to the beam energy which is not so high.

4 Comparison of Experimental Data with Monte Carlo Simulation

4.1 Monte Carlo Simulation

We use EPICS¹ v9.15 (Cosmos v7.633) as a detector simulation code, which is well consistent with Geant4[6] and Fluka[7].

The beam profiles of particle incident point are derived from Si-tracker and IMC.

In order to compare the beam test data, the deposited energy in MC simulation should be converted to the number of particles using muon peak, then we add some fluctuation derived from instruments such as the pedestal noise, number of photo-electrons, crosstalk and so on. In Fig. 2,

the distributions of the simulation data are well consistent with those of the experiment data.

4.2 Energy Resolution

Figure 3 shows distributions of deposited energy in each IMC layer compared with simulation for 10 GeV electrons. In middle layer, the peak of single events and shower events (around 3 MIPs peak) are clearly divided. The first interaction point of shower development can be confirmed by identification of single event and shower event. This is important for particle identification such as electron/proton and electron/gamma-ray.

Total deposited energy in TASC are shown in Fig. 4 compared with simulation for 100 GeV electrons. A consistency of our simulation and experiment is found. Figure 5 shows energy resolution as a function of energy. We note that due to a very thick absorber the energy resolution over 100 GeV is excellent, better than 3 %.

4.3 Angular Resolution

We estimate the incident direction by fitting the shower axis in IMC and TASC. Electrons and gamma-rays are

1. EPICS stands for Electron-Photon Induced Cascade Simulator in a detector. EPICS HP: <http://cosmos.n.kanagawa-u.ac.jp/EPICSHome/>

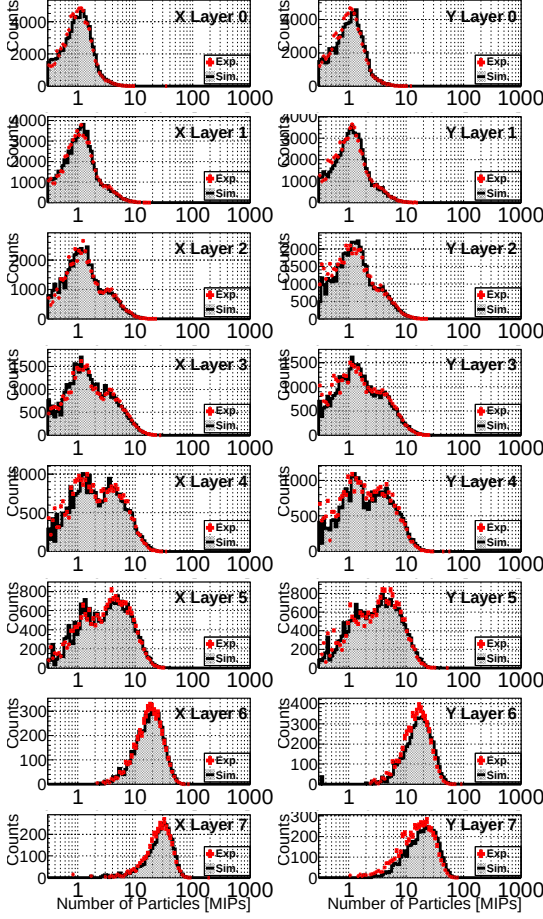


Figure 3: Distributions of the number of particles in each IMC layer for 10 GeV electrons. The shower starting point is clearly seen.

distinguished by presence or absence of the signals of the incident position SciFi in IMC or scintillator paddles in CHD. Because of the background in the fibers due to the back scattered products, accurate track reconstruction is essential for particle identification.

The shower core is clear at the bottom layer in IMC because the shower is developed. So we reconstruct shower axis from the bottom layer and then trace back the shower axis to the upper layers. Figure 6 is the distribution of angular error at 100 GeV electrons. Figure 7 shows the angular resolution for normal incidence as a function of energy. The red line and plots are simulation data with SciFi alignment corrected by muon track, consistent with experiment data. Assuming a perfect alignment, we expect the angular resolution to improve as shown by the blue line and plots.

4.4 Lateral Shower Spread

Since protons are the largest source of background for the high energy electron observation, excellent electron/proton separation is mandatory. We distinguish electrons from protons by imaging the shower development. Therefore, lateral shower spread is a critical parameter for particle identification. Here, the shower spread R_E is defined as follows;

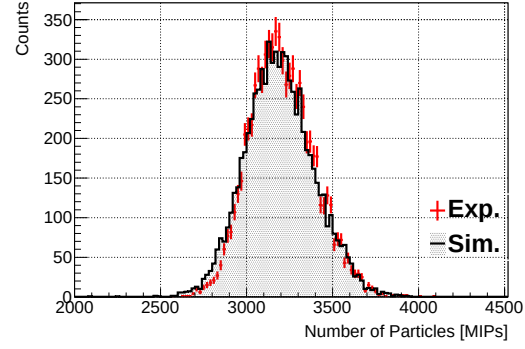


Figure 4: A distribution of energy deposit in PWO by 100 GeV electron, in comparison with MC simulation.

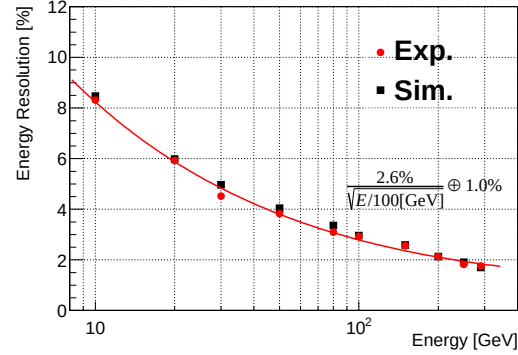


Figure 5: Energy resolution, in comparison with MC simulation.

$$R_E = \sqrt{\frac{\sum_i (\sum_j \Delta E_{i,j} \times R_i^2)}{\sum_i \sum_j \Delta E_{i,j}}} \quad (1)$$

$\Delta E_{i,j}$ is the deposited energy of the j th log scintillator in i th layer. R_i is lateral spread at i th layer which is calculated by the following formula;

$$R_i = \sqrt{\frac{\sum_j \Delta E_{i,j} \times (x_{i,j} - x_{i,c})^2}{\sum_j \Delta E_{i,j}}} \quad (2)$$

where $x_{i,c}$ is the i th layer's coordinate of shower axis reconstructed in IMC, $x_{i,j}$ is the coordinate of the center of j th scintillator in i th layer. Figure 8 shows the measured lateral spread in IMC and TASC compared with simulation. The difference of averages evaluated on the basis of experimental results are within a few %.

5 Conclusions

We carried out the accelerator beam test with CALET-BTM at CERN-SPS and investigated the accuracy of the Monte Carlo simulation. Comparing the experimental data with the simulation results, consistencies of the energy deposition in each component, the energy resolution and the lateral shower spread are confirmed. We are still continuing analysis of the beam test data to evaluate the performance for protons. We also carried out beam test using nu-

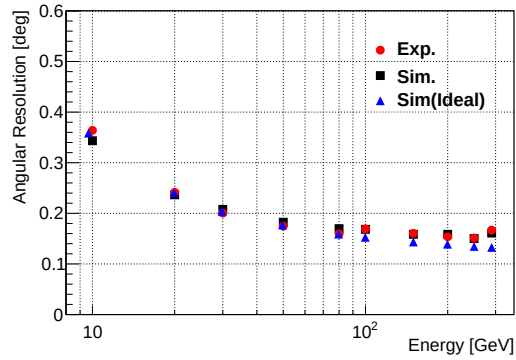
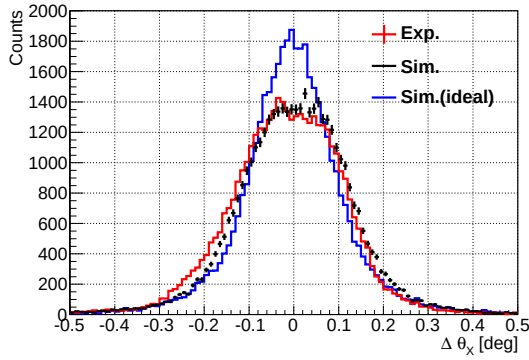
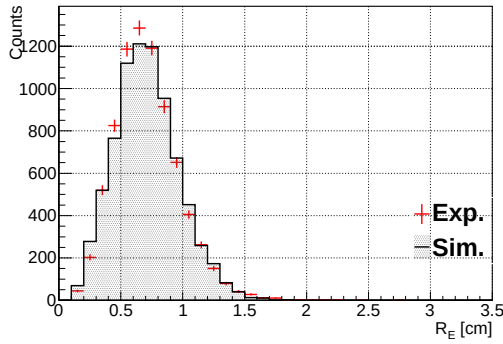
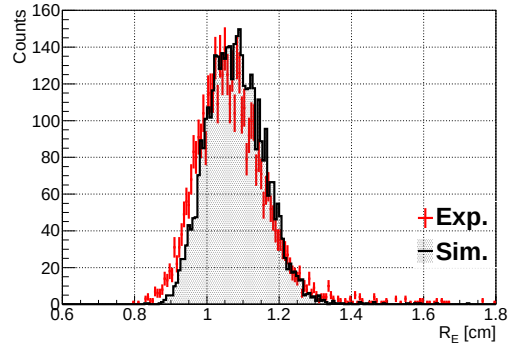


Figure 6: Distributions of x side angular error for normal incidence for 150 GeV electrons.

Figure 7: Angular resolution as a function of energy for normal incidence for electrons.



(a) IMC



(b) TASC

Figure 8: Lateral Spread in IMC and TASC for 10 GeV electrons.

clei beam, the performance of CHD is described in an accompanying paper[4]. We have carried out the MC simulation optimized by beam tests, in order to evaluate the CALET performance.

Acknowledgment: We owe a part of the present calculations to ICRR, University of Tokyo. Author is supported by the Japan Society for Promotion of Science.

References

- [1] S. Torii *et al.*, This conference, 33rd ICRC.
- [2] K. Yoshida *et al.*, This conference, 33rd ICRC.
- [3] T. Tamura *et al.*, This conference, 33rd ICRC.
- [4] P. S. Marrocchesi *et al.*, This conference, 33rd ICRC.
- [5] D. Ito *et al.*, Proc. of 32nd ICRC, Vol.6, pp.371-374
- [6] S. Agostinelli *et al.*, NIM A **506**, (2003), 250-303
- [7] FLUKA HP <http://www.fluka.org/fluka.php>