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Performance of the CALET Calorimeter by Accelerator Beam Test

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We are developing the CALET (CALorimetric Electron Telescope) instrument for observing high energy electrons and gamma rays on ISS. For confirming the CALET capability expected by simulations, we made a scale model of CALET with a size of 2/3 in thickness and had the experimental tests by using beams available in CERN. The beams used are 50GeV, 100GeV electron and 150 GeV proton. The energy resolution is $\sigma/E = 4.0 \pm 0.1\%$ and $2.25 \pm 0.04\%$ for 50GeV and 100GeV electrons, respectively. About 97.3% of protons can be rejected by shower image with Total Absorption Calorimeter, TASC, while approximately 96.8% of electrons were correctly identified. The performance of the scale model was also investigated by Monte Carlo simulation to compare with the results by beam tests. We confirmed good consistency between simulation and the beam test.

1. Introduction

The CALET mission is proposed to be launched on the Japanese Experiment Module (JEM), Exposed Facility (EF) of the ISS [1]. CALET consists of an imaging calorimeter (IMC) and a total absorption calorimeter (TASC). Role of the IMC is the identification of the incident particle by imaging the shower tracks with scintillating fibers. The TASC is used for observing the total development of shower particles with a stack of crystal scintillators[5]. A scale model of CALET was made and its performance has been tested by accelerator beams at CERN-SPS in 2003. In this paper, we describe the design of the scale model detector, the pulse height calibration and the results of the accelerator tests.

2. Scale model of CALET

The CALET scale model with a size of about 2/3 in thickness has been made. The IMC consists of 512 scintillating fibers(SciFi) with size of 1mm $\times$ 1mm and lead plates with total thickness of 4r.l. Eight belts of

SciFi with a width of 32mm for each are placed from the top, and four belts of 64mm are followed. After the first four belts, lead plates with a thickness of 0.5 r.l. are inserted between the belts. Each signal was read out by 64ch multi-anode PMT(HAMAMATSU R5900) by using a front-end circuit including analog ASIC, 16 bit ADC, FPGA [3],[4]. The TASC , placed after the IMC, consists of 26 Bismuth Germanate(BGO) bars with total thickness of 22r.l. in longitudinal direction . The 8 stacks from the top consist of 2 bars, and the following 3 stacks consist of 4 bars. Size of each BGO is $25 \times 25 \times 300\text{mm}^3$. The light yield of BGO were measured by PD(HAMAMATSU S3204-8 with an active area of $18 \times 18\text{mm}^2$) with a preamplifier and a shaping amplifier. Figure 1 shows side view of structure of scale the model.

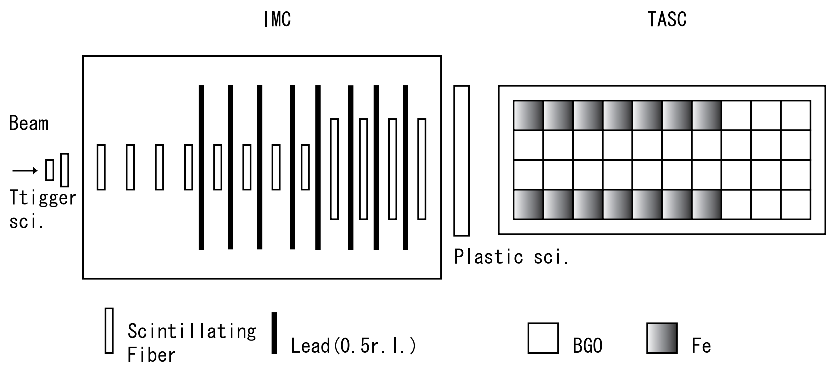

Figure 1. The scale model of CALET used for beam test

3. Beam test

The beam test was carried out at the beam line T4-H6 in Sep. 2003. In order to get a trigger signal from beams, two small plastic scintillators($5\text{mm} \times 5\text{mm} \times 5\text{mm}$, $30\text{mm} \times 5\text{mm} \times 5\text{mm}$) were places in front of the detector. The incident position of beams are measured by the IMC. Between the TASC and the IMC, a plastic scintillator was inserted to reject double hit events within the timing gate of 6μsec. We tested performance of the scale model on the energy resolution and the proton rejection power. We collected twenty thousands of events of electrons with energy of 50 GeV and 100 GeV for each, and one hundred thousands of events of protons with 150 GeV. The beams are incident to the top of detector in perpendicular.

4. Results

4.1 Pulse height calibration

The output signal of 1 MIP(Minimum Ionization Particle) has been calibrated by muon beam with the energy of 120GeV for both scintillating fibers and BGOs. Figure 2 shows the pulse height distribution of a BGO for muon beams. Muon peaks have been estimated by fitting the Landau function to the pulse height distributions. A pulse height has been converted into a particle number in MIP unit using thus obtained peak value which was calculated to be 23.2MeV by a Monte Carlo simulation .

4.2 Energy resolution

The total energy deposits in TASC by 50GeV electrons and 100GeV electrons have been measured. The electron beam was injected perpendicularly to the top surface and the incident positions were adjusted to

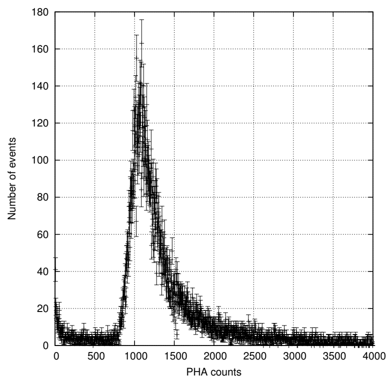

Figure 2. The pulse height distribution with 120 GeV muons. Peak is 1068.5 counts and σ is 116.5 counts.

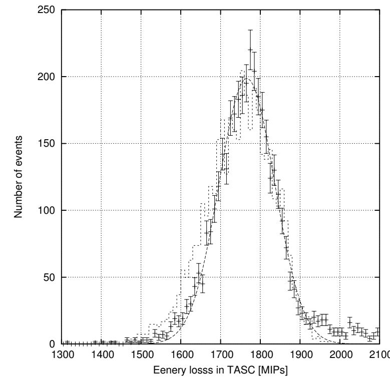

Figure 3. Energy deposit of 50GeV in TASC. Cross signs show experimental data and histgram shows simulation. Dotted line is a gaussian fit to experiment.

be around the center of the detector as shown in Figure 1. Beam position was estimated precisely with the forward 8 layers of the scintillating fiber belts. Only those events injected within a area of ± 0.125 mm from the center were used in the analysis. Figure 3 shows the energy deposit in TASC by 50GeV and 100GeV electrons. The energy resolution for electron is $\sigma/E = 4.0 \pm 0.1\%$ and $2.25 \pm 0.04\%$ at 50GeV and 100GeV, respectively. The performance of scale model has been also investigated by Monte Carlo simulation using Epics8.06 code [6]. The peak value of 50GeV and 100GeV electron is about 1760 MIPs and 3651 MIPs, respectively. The differences between simulation and experiment are a few tenth percents for both energies as shown Figure3. The energy resolution is $4.5 \pm 0.2\%$ and $3.2 \pm 0.1\%$ for 50 GeV and 100GeV electrons, respectively. The resolution is almost consistent with that by experiment within error at 50 GeV. However, at 100 GeV the discrepancy is larger by the reason that the estimations of beam axis and the fluctuation by IMC are not enough.

4.3 Proton rejection

It is required to achieve a proton-rejection power of 10^6 to observe electrons at energies up to 10 TeV[1]. From simulation study, we found that the shower image in IMC and TASC which consists of BGO with thickness of 32r.l. can realize such a high rejection power [2]. Primary electrons deposit about 95% of their energy in TASC, while protons can survive due to the small energy deposit with the average of about 40%. Proton induced shower have a wider spread than electron due to the spread of secondary particles in the nuclear interactions. In other words, electron can be selected by the image of shower which has the small energy deposit and the narrow spread at the bottom BGO layer. Figure 4 shows the scatter plot of the fraction of the energy deposit at the 10th layer, the most bottom layer in TASC, $v.s.$ the r.m.s. of lateral spread of the shower. Plus sign shows 150GeV protons and dot shows 50GeV electrons. Protons spread over vertical axis widely, while electrons are concentrated around the bottom area. Electrons can be separated from proton by cut expressed by a function $f(x) = 0.04/x^2$. Approximately 96.8% of electrons are in lower area(electron area) and only 2.7% of protons remain in the lower area. The capability for proton rejection has been ivestigated by simulation as shown in Figure 5. In Epics8.06, hadronic interaction was calculated by “dpmjet3” model. Approximately 97.1% of electrons have been be separated from protons by the function $f(x) = 0.04/x^2$. Only 2.5% of proton remain in the electron region which is very consistent with the results of beam test.

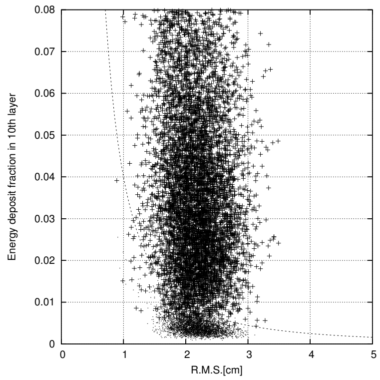

Figure 4. The fractional energy deposit at the 10th BGO-layers as a function of the spread of the shower. Plus sign shows 150GeV protons and dot sign shows 50TeV electrons. Dotted line shows the function, $f(x) = 0.04/x^2$.

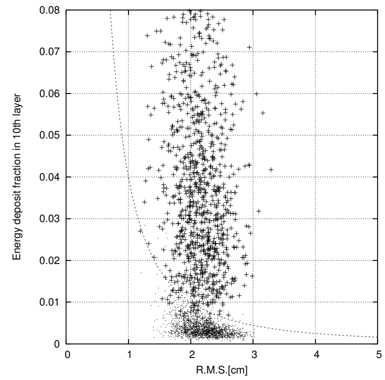

Figure 5. Simulated result which could be compared with the experimental results in Fig. 4

5. Conclusions

We made the scale model of CALET detector with a size of about 2/3 in thickness for the test of performance by accelerator beams. The energy resolution is 4.0% and 2.3% for 50GeV and 100GeV electrons, respectively. The prototype could reject 97.3% of 150GeV protons and could identify 96.8% of electrons. These results are almost consistent with Monte Carlo simulation. To confirm the detector performance for the experiment on space station, the flight test by a balloon is scheduled in this fall and we are developing a read out system of BGO with a wide dynamic range of 10^6 by using both multi PDs and Viking chips for measuring protons to irons up to 1000 TeV.

6. Acknowledgments

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