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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 small 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 electrons and 150 GeV protons. 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 , while approximately 96.8% of electrons are correctly identified. The performance of the 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[2]. A small model of CALET was made and its performance was tested by accelerator beams at CERN-SPS in 2003. In this paper, we describe the design of the detector, the pulse height calibration and the results of the accelerator tests.

2. Beam test model of CALET

The CALET model was made with a size of 2/3 in thickness. The IMC consists of 512 scintillating fibers(SciFi) with a size of 1mm $\times$ 1mm in cross section and lead plates with a 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, a lead plate with a thickness of 0.5 r.l. is 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 a total thickness of 22r.l. in longitudinal direction . The 8 layers from the top consist of 2 bars, and the following 3 layers 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 presents side view of structure of the model.

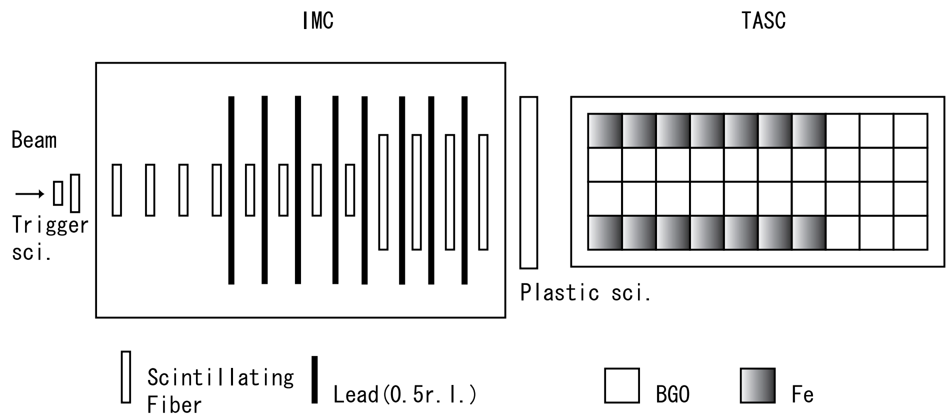

Figure 1. The model of CALET used for beam test

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 a beam, two small plastic scintillators(5mm × 5mm × 5mm, 30mm × 5mm × 5mm) were placed in front of the detector. The incident positions of beams were 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 small model on the energy resolution and the proton rejection power. We collected twenty thousands of events of electrons with the energy of 50GeV and 100GeV for each, and one hundred thousands of events of protons with 150GeV. The beams were incident to the top of detector in perpendicular.

4. Results

4.1 Pulse height calibration

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

4.2 Energy resolution

The total energy deposits in the TASC by 50GeV electrons and 100GeV electrons were measured. The electron beam was injected perpendicularly to the top surface and the incident positions were adjusted to be around the center of the detector as shown in Figure 1. Beam position was estimated precisely with the forward 8 layers

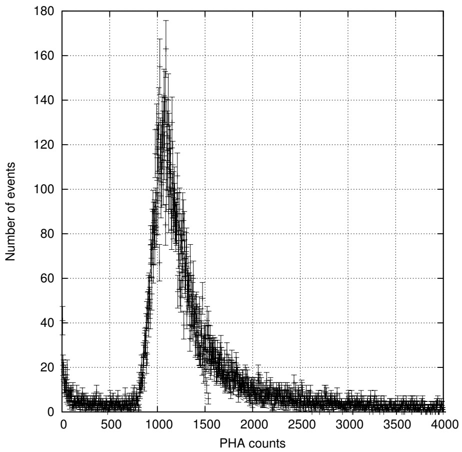

Figure 2. The pulse height distribution with 120 GeV muons. Peak is 1069 counts and σ is 117 counts.

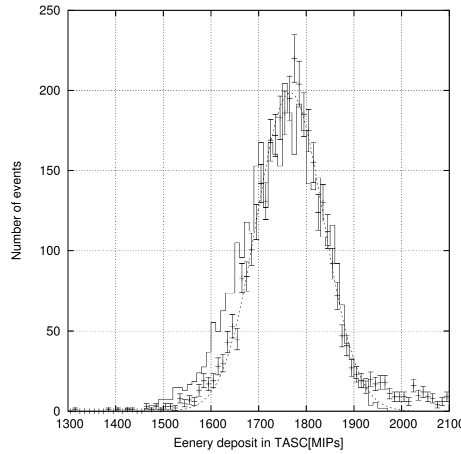

Figure 3. Energy deposit distribution of 50GeV in the TASC. Cross signs show experimental data and histogram shows simulation. Dotted line is a gaussian fit to experiment.

of the scintillating fiber belts. Only those events injected within a area of ± 1 mm from the center were used in the analysis. Figure 3 shows the energy deposit in the 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 small model was also investigated by Monte Carlo simulation using Epics8.06 code [5]. 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 the 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 a thickness of 32r.l. can realize such a high rejection power [6]. Primary electrons deposit about 95% of their energy in the 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 the TASC, $v.s.$ the r.m.s. of lateral spreads of the shower. Plus signs show 150GeV protons and dots show 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 was investigated by simulation as shown in Figure 5. In Epics8.06, hadronic interaction was calculated by "dpmjet3" model. Approximately 97.1% of electrons are 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.

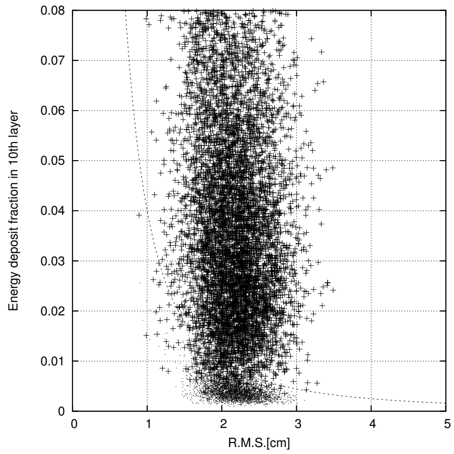

Figure 4. The fractional energy deposit at the 10th BGO-layer as a function of the spread of the shower. Plus signs show 150GeV protons and dot signs show 50GeV electrons. Dotted line shows the function, $f(x) = 0.04/x^2$.

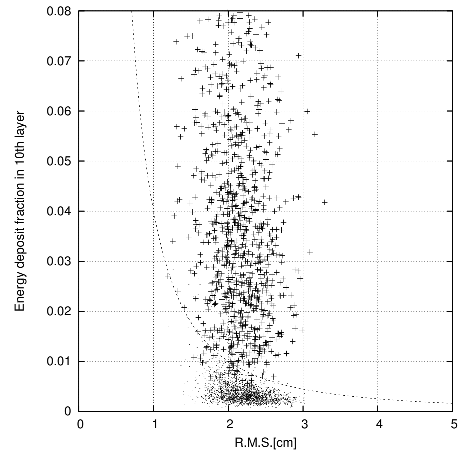

Figure 5. Simulated results which could be compared with the experimental results in Fig. 4

5. Conclusions

We made the small 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 detector 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.

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