Development of Total Absorption Calorimeter of CALET

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Abstract

We have been developing a total absorption calorimeter (TASC) for CALET instrument. The performance of two types' crystal scintillators, i.e. bismuth germanate (BGO) and lead tungstate ($PbWO_4$), has been studied as the material of TASC. We have compared several products, BGO by Crismatec and SICAAS and $PbWO_4$ by SICAAS and Belarus. The light yield for low energy deposit was measured by a photomultiplier tube (PMT). It was almost the same both for Crismatec's BGO (372.0 p.e./MeV) and for SICAAS's (363.6 p.e./MeV). The light yield of $PbWO_4$ is smaller than that of BGO, as expected, by a factor of 45 on average. The read-out using a photodiode (PD) was tested for BGO in realistic set-up. The results of PD is consistent with that of PMT, and it is confirmed that PD is capable of detecting 0.5 MIPs in BGO with thickness of 2.5 cm.

1. Introduction

The CALET instrument, planned to be installed in the Japanese Experiment Module (JEM) Exposed Facility (EF) of the International Space Station(ISS)[1,2] consists of an imaging calorimeter (IMC) and a total absorption calorimeter (TASC). The role of IMC is to identify the incident particle by imaging the shower tracks with scintillating fibers. TASC is used for observing the total development of shower particles with a stack of crystal scintillators. IMC is under development based on BETS (Balloon borne Electron Telescope). In this paper, the current status of the development of TASC is reported.

2. Total Absorption Calorimeter

It is required to achieve a proton-rejection power of 10^6 for observing electrons up to 10 TeV as reported in our previous paper[1]. From simulation study, we found that TASC which consists of BGO with thickness of 32r.l. and IMC can realize such a high rejection power. Therefore, the current structure of TASC is

pp. 2197–2200

composed of several hundred of BGO logs with a volume of $25 \times 25 \times 350$ mm^3 for each. Each layer consists of 56 logs to have 700×700 mm^2 area. For simulation study, we assumed a TASC composed of 14 layers as shown in the paper by S.Torii *et al.*[2]. We have carried out Monte Carlo simulation [3] to obtain the proton rejection power and its dependence on the threshold of light yield by BGO. Figure 1 shows the scatter plot of the energy deposit fraction in the 14th layer, the bottom layer, of BGO and the r.m.s lateral spread of the shower. In this simulation, the lower threshold was set to 2.0 minimum ionizing particles (MIP). Five events in 10^6 protons are found among the electron region (separated by dotted line in the figure). This means that the proton rejection power is 2 $\times 10^5$ at 4 TeV. The rejection power increases with decreasing threshold of light yield as shown in Fig. 2, and the rejection power can be 5 $\times 10^5$ for the threshold of 0.5 MIPs.
On the other hand, we have found that the highest number of MIPs is 10^5 and 10^6 MIPs for the highest energy of electron (10 TeV) and of proton (1000 TeV), respectively. Therefore, we need to confirm the read-out for TASC should have the dynamic range of a few 10^6 to measure from 0.5 to 10^6 MIPs.

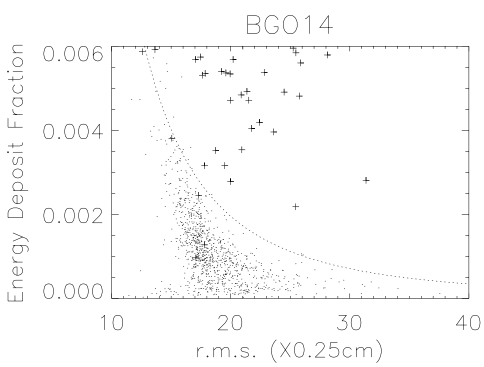

Fig. 1. The energy deposit fraction in the 14th BGO-layer as a function of the spread of the shower. Plus sign shows 10 TeV protons and dot sign shows 4 TeV electrons.

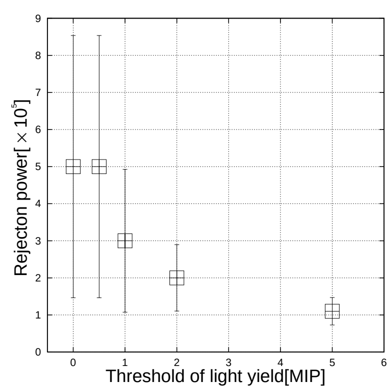

Fig. 2. The dependence of the proton rejection power on the lower energy threshold.

3. Light yield of BGO and $PbWO_4$ measured with PMT

We measured the light yield of BGO and $PbWO_4$ with PMT. $PbWO_4$ is a candidate of the scintillators for TASC, which has the advantages such as larger density, shorter radiation length and smaller Moliere unit than BGO. These characteristics are important for space experiments like CALET because the calorimeter should be as light and small as possible. It has, however, the disadvantage

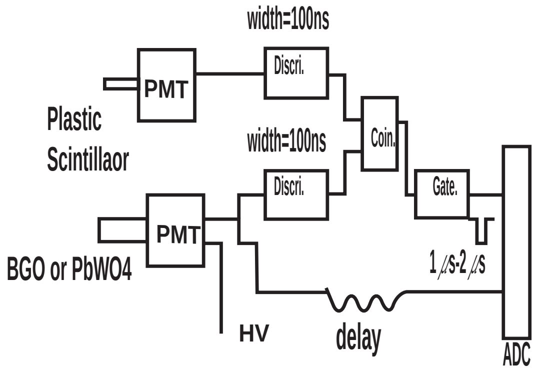

Fig. 3. An experimental setup for the muon measurement. All scintillators were wrapped by the Teflon sheet with reflectivity $\geq 90\%$

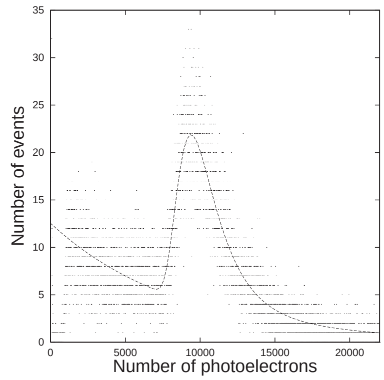

Fig. 4. The light yield of BGO by cosmic muon measured with PMT as shown in Fig. 3. Solid curve shows a fitting function by sum of a Landau and a exponential distribution.

of less light yield. The light yield for low energy deposit have been measured by PMT with radioactive sources and cosmic muons by the experimental setup as shown in Fig. 3. The size of each scintillator is $25 \times 25 \times 300$ mm^3 for BGO and $25 \times 25 \times 240$ mm^3 for $PbWO_4$. Figure 4 shows the light yield distribution for SICAAS's BGO by cosmic muons. The energy deposit by cosmic muons was calculated by the simulation with "GEANT4"[4]. Figure 5 shows the light yield as a function of energy deposit. In the figure, following four products are compared, i.e. BGO (Crismatec), BGO (SICAAS High Technology corporation), $PbWO_4$ (Belarus) and $PbWO_4$ (SICAAS). The light yield of BGO was almost the same both for Crismatec (372.0 p.e/MeV) and for SICAAS (363.6 p.e./MeV) as shown in Fig. 5. The light yield of $PbWO_4$ was 8.3 p.e./MeV and 7.9 p.e./MeV for Belarus and SICAAS, respectively. It was smaller than that of BGO by a factor of 45 on average.

4. Read-out with PD

We have tested the capability of PD read-out system to be used for the TASC in CALET. The light yield by cosmic muons has been measured by PD (HAMAMATSU S3204-5 with an active area of 18×18 mm^2) with a preamplifier and a shaping amplifier. The average number of photo electrons detected by the PD was 3.659×10^4 as shown in Fig. 6. On the other hand , the number obtained by PMT was 9.429×10^3 p.e. as shown in Fig. 4. The detection efficiencies of emitted photons by using PD and PMT with BGO were estimated by Monte Calro simulator "Litrani"[5]. The light yield measured by PD is in a good agreement with the PMT's within a few percents after the corrections of the efficiencies.

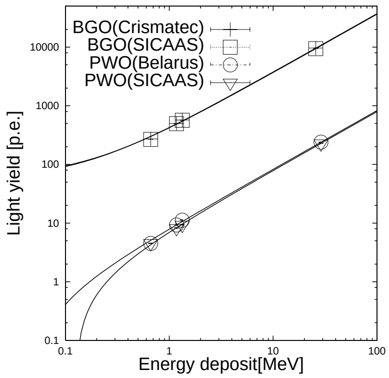

Fig. 5. The light yield of BGO and $PbWO_4$. The solid lines show the linear functions.

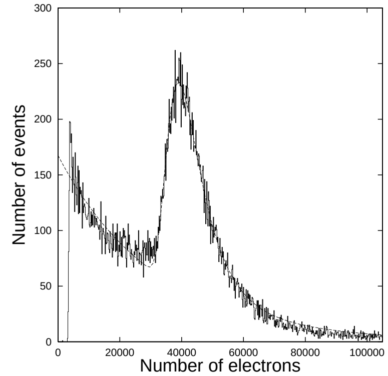

Fig. 6. The light yield of BGO by cosmic muon measured with PD. Solid curve shows a fitting function by sum of a landau and a exponential distribution.

Therefore, we have confirmed that PD with BGO is capable of detecting 0.5 MIPs.

5. Result and Discussion

The performance of two types' crystal scintillators, BGO and $PbWO_4$, has been studied as the material of TASC. The measured light yield was ~ 370 p.e./MeV and ~ 8 p.e./MeV for BGO and $PbWO_4$, respectively. The consistency of read-out by PD and PMT has been confirmed and the PD read-out of BGO for low energy deposit is to be promising. However, the PD read-out of $PbWO_4$ has a difficult point due to the low light yield unless we use PD of an avalanche type. The electronics system to realize the dynamic range of 10^6 is under development now. The beam test with the prototype detector is on plan in this fall at CERN. The performance of TASC will be evaluated experimentally.

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6. References

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