The balloon-bone CALET prototype detector (bCALET)

SHUNSUKE OZAWA[1], SHOJI TORII[1], KATSUAKI KASAHARA[1], HIROYUKI MURAKAMI[1], YOSUI AKAIKE[1], YOSHITAKA UEYAMA[1], DAIJIRO ITO[1], MOTOHIKO KARUBE[1], KEINOSUKE KONDO[1], TAE NIITA[1], TADAHISA TAMURA[2], YUSAKU KATAYOSE[3], KENJI YOSHIDA[4], YOSHITAKA SAITO[5], HIDEYUKI FUKE[5], JIRO KAWADA[6]
[1]*Research Institute for Science and Engineering, Waseda University*
[2]*Faculty of Engineering, Kanagawa University*
[3]*Department of Physics, Yokohama National University*
[4]*Department of Electronic and Information Systems, Shibaura Institute of Technology*
[5]*ISAS/JAXA*
[6]*Laboratory for High Energy Physics, Bern University*
shunsuke@aoni.waseda.jp
DOI: 10.7529/ICRC2011/V06/0821

Abstract: The CALET payload will be installed in the Japanese Experiment Module Exposed Facility (JEM-EF) of the International Space Station (ISS). We developed a balloon-borne payload to evaluate the performance of CALET by carrying out precursor flights for the electron and gamma-ray observations. The first flight of bCALET-1 (balloon-borne CALET prototype) was carried out in 2006, and the enhanced version, bCALET-2, was successfully flown in August 2009. The bCALET-2 is composed of IMaging Calorimeter (IMC) and Total AbSorption Calorimeter (TASC). The IMC has an area of 256 mm $\times$ 256 mm, and is consisted of 8 layers of scintillating fiber belts with a total 3.6 radiation lengths of tungsten plates interleaved within the fiber planes for imaging the pre-shower development. TASC is consisted of crossed BGO logs (25 mm $\times$ 25 mm $\times$ 300 mm in each) with a total of 13.4 radiation lengths depth, for measuring the total energy deposit of incoming shower particles. The geometry factor is nearly 320 cm^{2}sr over 10 GeV. We succeeded the observation of the electron energy spectrum in 1 GeV $\sim$ several 10 GeV electron and the atmospheric gamma-rays in 1 GeV $\sim$ a few 10 GeV, which are consistent with previous observations by BETS. The results are compared with simulations for confirming the detector performance.

Keywords: CALET, Balloon-bone experiment, Electron, Gamma-ray

1 Introduction

The CALorimetric Electron Telescope (CALET) mission aims to reveal high energy phenomena in the universe by space-based observation of the high energy cosmic rays [1], [2]. The detector is planned to be placed on the Japanese Experiment Module (JEM) of the International Space Station (ISS). We have developed the subcomponents of CALET such as the imaging calorimeter, the total absorption calorimeter, and the readout electronics. For verification of the observation capability, a balloon-borne experiment with CALET prototype was carried out two times. The first campaign of bCALET-1 was successfully done in May, 2006 [3]. We collected about 3×10^3 electron-like events during the level flight at about 35 km for 3.5 hours.

The bCALET-2 detector, used for the second campaign, was much more enlarged comparing to the bCALET-1; the geometric factor was increased by 16 times. In addition to this improvement, an anti-coincidence detector (ACD) was installed for observing the low energy gamma-rays ($>$ 200 MeV). In the flight of bCALET-2 done in August, 2009, the observation time was 2.5 hours at a level altitude around 35 km.

We have confirmed the basic performance of the subcomponents used for CALET, and verified the capability of the front-end circuit for readout of many channels of PMTs/PDs and the DAQ system. In this paper, we mainly report the bCALET-2 experiment.

2 bCALET-2 detector

The major part of the CALET instrument consists of a large-mass calorimeter [2], which is divided into three subcomponents arranged in the vertical direction: Charge Detector (CHD), Imaging Calorimeter (IMC), and Total Absorption Calorimeter (TASC).

A structure of the bCALET-1 and -2 as similar with the CALET is shown in Fig. 1, and the characteristics of these detectors are compared in Table 1.

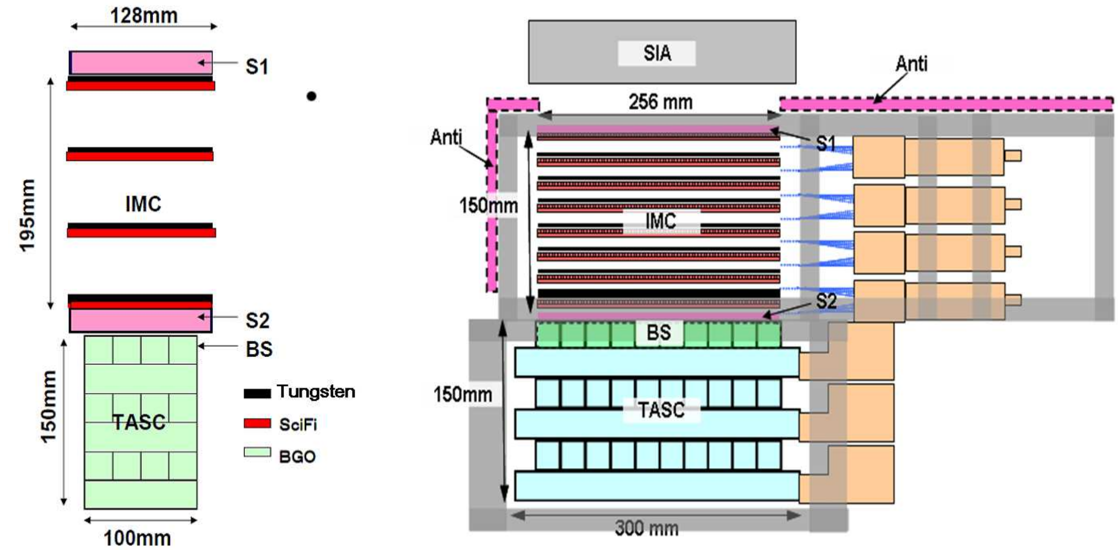

Figure 1: The side view of bCALET-1 and bCALET-2. In bCALET-2, the Silicon Pixel Array (SIA) for charge measurement of incident particles was used only for calibration on ground.

Table 1: bCALET-1 and bCALET-2 characteristics.

	bCALET-1 (2006)	bCALET-2 (2009)
IMC (SciFi)	1024ch (128 mm × 128 mm × 4 x-y)	4096ch (256 mm × 256 mm × 8 x-y)
IMC (Tungsten)	1.3 r.l.	1.69 r.l.
TASC (BGO)	13.4 r.l. (4 logs/layer)	13.4 r.l (10 logs/layer)
$S\Omega$	21 cm^{2}sr	320 cm^{2}sr

2.1 Imaging calorimeter

IMC is composed of eight layers of scintillating fiber belts for making visible the shower image of incoming cosmic rays. Each layer consists of scintillating fiber belts arranged in the x and y direction, and each belt is composed 256 fibers with a 1mm square cross section in each. The total number of scintillating fibers used in IMC is 4096, and its dimension at surface is 256 mm×256 mm. A tungsten plate, as an absorber, is placed over each layer except the first layer at the top of IMC. The total thickness of the tungsten plates is 3.6 radiation length (r.l.). Photons emitted in each fiber are detected by 64-anodes PMTs, and the output signals are digitize by a front end circuit using ASICs and sampling-hold ADCs as same as bCALET-1 [3]. The shower images observed by IMC are adopted to determine the incident direction of incoming particle and to detect the pre-shower development.

2.2 Total absorption calorimeter

TASC is composed of 6 layers of BGO logs where each log has a dimension of 25 mm (H) × 25 mm (W) × 300 mm (L). There is 10 such log in one layer, and each layer is alternatively orientated in 90 degrees with each other for providing the x and y coordinate. The total thickness of BGOs in TASC is 13.4 r.l., and TASC is utilized for measuring the shower development to determine the energy and to discriminate electrons and gamma-rays from the background protons. To detect the photons emitted in BGO, a PIN photo-diode (PIN-PD) is attached to side end of each log.

The signal peak corresponding to a minimum ionizing particle (MIP) is clearly seen by measuring a cosmic-ray muon. The front end circuit has dual, low and high, gain to accomplish a wide dynamic range for each PIN-PD as presented in Fig. 2. As a result, this circuit has achieved a dynamic range of 0.5 MIPs $\sim$ over a few thousands MIPs. We also developed a new module which includes preAMP/AMP and ADC, and used a digital signal read-out in same way with the front-end module of IMC.

2.3 Trigger detector and anti-coincidence counter

Two layers of plastic scintillator were installed as a trigger detector at the top and the bottom of IMC, respectively. Each scintillator (BC-404) plate has a thickness of 1 cm (upper) and of 0.5 cm (lower), embedded with the wave length shifting fibers (WLSF, BCF-92). Trigger signal was

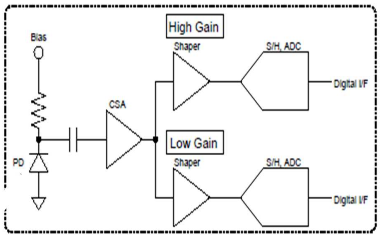

Figure 2: A schematic diagram of dual range read out circuit for PIN-PDs.

generated by coincidence of the following three signals; two signals from the top and bottom plastic scintillator and the total signal summation for 10 BGO logs located at the top of TASC.

To select the electron-like events and the gamma-ray-like events, we applied two types of the trigger mode. These trigger modes can be selected by a preset timer or an online command.

In the gamma-ray mode, the charged particles coming from the side of IMC, which do not pass through the top scintillator, S_1, were mostly rejected by using ACD. It enables to distinguish gamma-ray-like events from charged particles, mainly protons, incident from out of the effective area. ACD is composed of plastic scintillator tiles (1cm thick) embedded with 1mmϕ WLSFs as same as the trigger detector. The photon signal from scintillator is transmitted to PMT through WLSFs attached to the input window.

2.4 Data acquisition system

The data acquisition system of bCALET-2 was designed on the base of the system of bCALET-1. The read out interfaces were enhanced for increasing IMC/TASC channels. New CPU boards were adopted to improve the data processing speed. Since the data size rate was expected about 200 kbytes/s, we introduced a compact flash memory for recording all of the acquired onboard data. A radio telecommunication system was employed for down-link of the HK data and the sampled event data, and for sending commands. Block diagram of the DAQ system is shown in Fig. 3

3 bCALET-2 performance by Monte Calro simulation

The performance of bCALET-2 detector was evaluated by using Monte Carlo simulations. Due to ACD adopted in bCALET-2, a total rate of the electron-like events (> 10 GeV) and the gamma-ray-like events at level altitude was predicted to be reduced to about 20 Hz by simulations as shown in Fig. 4. The rate was consistent with the observation, and we succeed to considerably decrease the dead time in data taking. The $S\Omega$ estimated by simulations is about 320 cm^{2}sr for the electrons over 10 GeV.

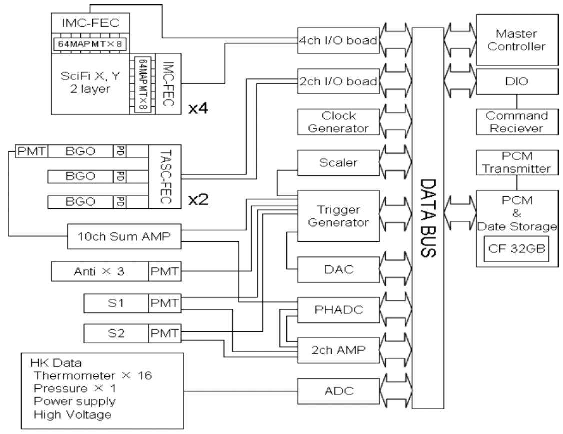

Figure 3: Block diagram of the data acquisition system used in bCALET-2

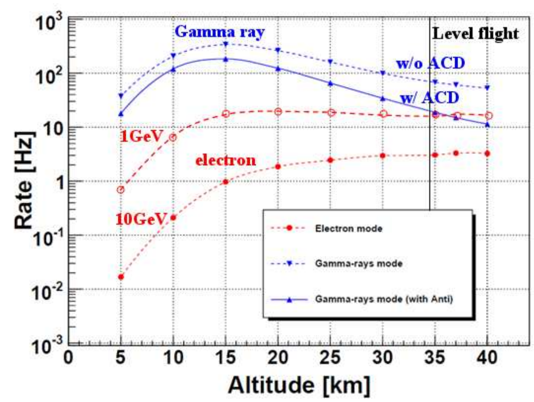

Figure 4: Simulated trigger rates of electrons and atmospheric gamma-rays at different altitudes. At the flight level (∼34km), the rate decreases very effectively (nearly 1/3) by adopting ACD.

The energy resolution of incident electrons is expected 15% around 1 GeV and $\sim$ 7% in 5-50 GeV. The resolution is much more improved than our previous detectors using a sampling calorimeter, BETS (14∼17%) [4] and PPB-BETS (12∼20%) [5], since bCALET employed a thick active calorimeter. It is very effective not only in the energy determination, but also in the rejection of the background protons by the off-line analysis.

4 bCALET-2 observation

The bCALET-2 payload was launched at JAXA Taiki Aerospace Research Field in Hokkaido, and was flown for 2 hours at level altitude. Figure 5 shows the flight curve of the balloon.

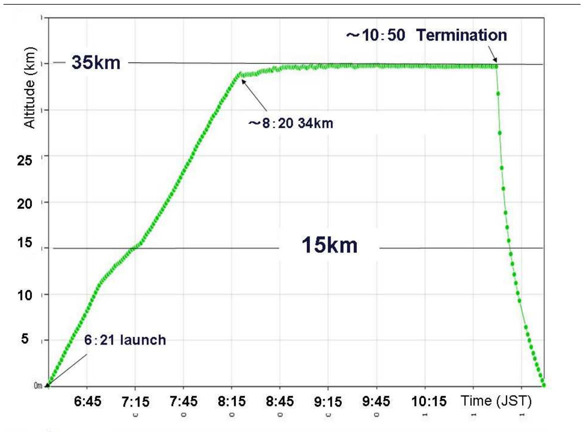

Figure 5: The transition at time of flight altitude. For two hours until shifting to the level flight (∼35km).

The event trigger for electrons was executed by two modes; low energy (LE) mode and high energy (HE) mode. An example of the observed event is shown in Fig. 6. In the LE mode for electrons over 1 GeV, 2720 events were triggered, and 5671 events in the HE mode for electrons over 10 GeV. In the gamma-ray mode, 3466 events were triggered over 200 MeV. We collected over 10,000 events in the total observation time.

By an analysis of the observed events, the electron energy spectrum in 1 GeV-30 GeV at level altitude was obtained as presented in Fig. 7. As shown in the figure, the observed spectrum is very consistent with the expected one by simulations calculated by using the present data of the primary particles, and the effects of the geomagnetic cut-off are clearly seen below 10 GeV. The results are also consistent with previous observation, BETS and bCALET-1, considering the difference of observation altitudes and the different rigidity cut-offs. The details of data analysis including the atmospheric gamma-rays, is reported in this conference [6].

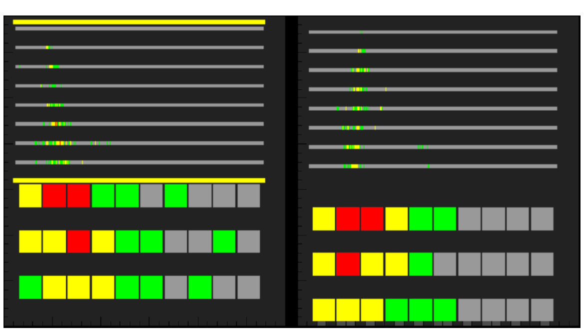

Figure 6: A example of event display of the observed electron-like shower.

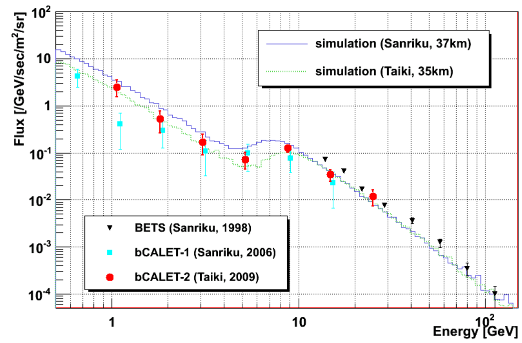

Figure 7: The energy spectrum of electrons observed with bCALET-2 compared with simulations and previous observations.

5 Summary

The bCALET-2 payload was developed to confirm the performance of detector as the CALET prototype for balloon experiment. The detector worked well in expected performance, and the obtained electron energy spectrum is compatible with simulations and previous observations. The final results will be published soon elsewhere.

The experience in research done for development of the bCALET detectors is made use of the CALET development, which is being carried on for the target schedule of launching in 2013 to the ISS. The observation period is planned to be for 5-year at the JEM/EF. Since the geometric factor of CALET is 1200 cm^{2}sr for electrons, we can extend the electron observation to the trans-TeV region.

Acknowledgments

We greatly thank the staff of Balloon Team in ISAS for their essential contributions to the successful flight of bCALET detectors. This work is partly supported by Grant-in-Aid for Scientific Research S (Grant no. 21224006) by Japan Society for the Promotion of Science.

References

[1] S. Trier *et al.* , Nucl. Phys. B, 2007, **166** (Proc. Suppl.): 43-49.
[2] S. Torii *et al.* , 35ti International Cosmic Ray Conference, 2011, this conference.
[3] Y. Shimizu *et al.* , Proc. of ICRC2007, 2007, **2**: 433-436.
[4] S. Torii *et al.* , Nucl. Insturum. Methods Phys. Res A, 2000, **452**: 81-93.
[5] K. Yoshida *et al.* , AdSpR, 2008, **42**: 1670-1675.
[6] T. Niita *et al.* , 35th International Cosmic Ray Conference, 2011, this conference.