

Balloon borne CALET Prototype Payload (bCALET) for Electron and Gamma-ray Observation

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Abstract. We are planning a balloon observation of cosmic-ray electrons, γ -rays and heavy nuclei, using the CALET prototype detector, named bCALET-2. bCALET-2 is 1/12 scale model of the CALET detector. It is composed Imaging Calorimeter(IMC), Total Absorption Calorimeter(TASC) and Silicon pixel Array(SIA). IMC has an area of 256mm \times 256mm, and is consisted 8 x-y layers of scintillating fiber belts inserted below tungsten plates (3.57 r.l. in total) for a fine imaging of shower particles. TASC is made 6 layers of BGO scintillator logs (25mm \times 25mm \times 300mm in each) with an area of 250mm \times 250mm, for measuring the total energy deposit of incoming shower particles. The geometrical factor, $S\Omega$, is nearly 300cm²sr. A part of detector is covered at the top by SIA for distinction of the charge of primary heavy particles. We will observe 1 - 100GeV electron and a few 10MeV - 10GeV γ -ray to study the feasibility of CALET. The balloon flight is scheduled in Sep. 2009 at Taiki Aerospace Research Field, Hokkaido, Japan. In this paper, we will report the R&D study of the bCALET-2 detector and a future plan for bCALET-3 and CALET.

Keywords: ISS, Balloon, electron telescope

I. 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]. The detector is intended to be placed on the Japanese Experiment Module (JEM) of the International Space Station (ISS). We have researched and developed elemental components of the CALET such as BGO scintillators, scintillating fibers and readout electronics for them. For the verification of observation capability, a balloon-borne experiment with a prototype of the CALET, bCALET-1 was carried out. We succeeded the first campaign of the bCALET observational flight at May 2006[2]. In this flight, the observation

was terminated after the duration of about 6 hours. The duration of the level flight above 35km was 3.5 hours. We collected about 3×10^3 electron trigger events and 4×10^4 γ -ray trigger events in the level flight. We could confirm the basic performance of the CALET conceptual design.

The bCALET-2 is increased by four times in detection area and in the layers of IMC(4 to 8) and TASC (6 to 10). In addition to this improvement we installed a silicon detector array and an anti-coincidence detector. We are planning to launch bCALET-2 in 2009 and to do a test of flight performance. We aim to confirm the design concept and the actual architecture work correct in this flight.

II. EQUIPMENTS

The major part of the CALET detector consists of a large-mass calorimeter, which is divided into 4 equipments. The top part is Silicon detector array (SIA), the middle part is an imaging calorimeter (IMC), and the lower part is a total absorption calorimeter (TASC). At around IMC, the anti-coincidence detector(ACD) is installed. A structure of the bCALET-2 as similar with the CALET structure is shown in Fig.1 and Fig.2.

A. IMC

IMC is composed of eight layers for shown imaging. Each layer consists of a tungsten plate and two scintillating fiber belts arranged in the x and y direction. Each belt is composed of 256 fibers with a 1mm square cross section in each. The total number is 4096. The area of IMC is about 256mm by 256mm. The total thickness of the tungsten plates is 3.57 radiation length (r.l.). The shown image observed by IMC is adopted an estimation of the incident direction and the shower development. Signals of each fiber are detected by 64ch multi-anode PMTs. The front end circuit developed by using Viking chip and peak-hold ADC as same as bCALET-1[2].

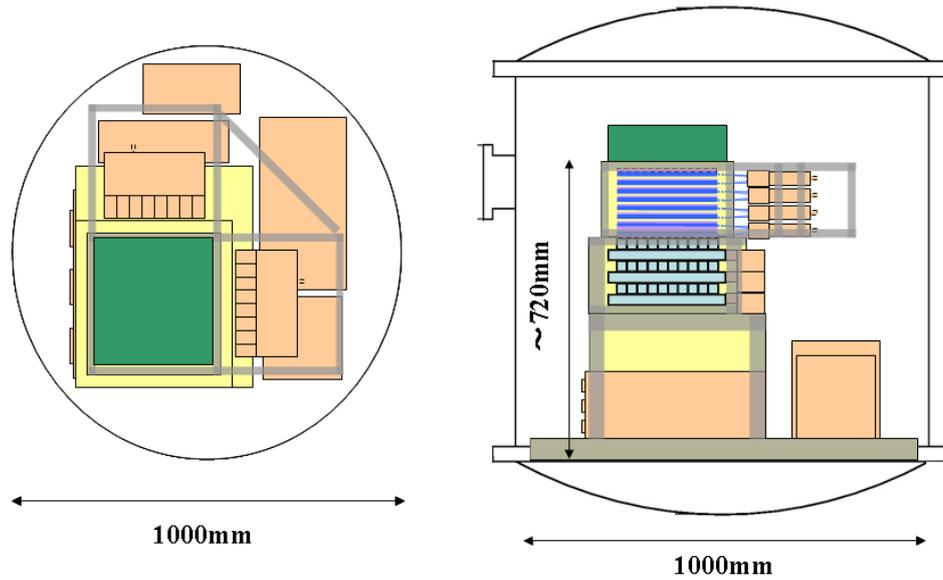


Fig. 1. The over view of bCALET-2 payload. The left is the top view of bCALET-2 and right is side view. The detector will be contained in a vacume vessel.

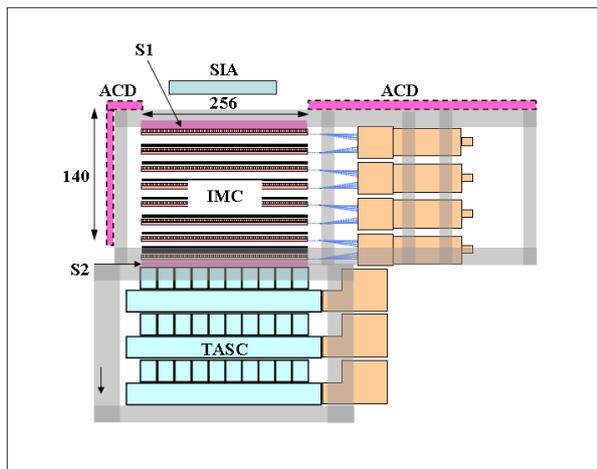


Fig. 2. The side view of bCALET-2.

B. TASC

TASC is composed of 6 layers of BGO scintillator. Each layer consists of 10. Each log has 25mm square cross section. Alternate layers are orientated 90 degrees to each other to provide an x and y coordinate. The total thickness of TASC is 13.4 r.l. TASC is used for measurement of the shower development to determine the total energy and to discriminate electrons and γ -rays from protons. To measure BGO signals, a single photodiode is attached to each log. The peak corresponding to the minimum ionizing particle (MIP) is clearly seen by measuring a cosmic-ray muon.

C. SIA

SIA owns to measure the charge number of incoming particle. As shown in Fig.3, the metal box contain one

layer of four pixelated silicon charge sensor and the sensitive area is $9\text{cm} \times 9\text{cm}$. In this time, SIA has two x-y layers of position sensitive silicon strip detector also.

The pixelated silicon sensor has same performance as the one used by the CREAM experiment, and its charge resolution is 0.1 electron charge unit (e) for (H, He) and $0.35e$ For (Fe)[5]. These are packed into a metal box, and covered detection area with acryle plate(Fig.3).

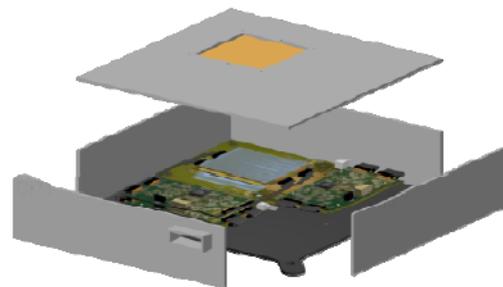


Fig. 3. SIA box view

D. Trigger detectors and ACD

Two layers of plastic scintillator are installed as trigger detector at the top and the bottom of IMC. Each detector is 1cm(upper) and 0.5cm(lower) thick plastic scintillators(BC-404) with the wave length shifting fiber(WLSF,BCF-92). The signals of two layers of plastic scintillators and the top layer of TASC is used to generate a trigger signal.

To obtaine both of electron and γ -ray events, we provide two trigger modes. This trigger mode can be changed by preset timer or online command.

ACD rejects charged particle events coming from out of the effective area of the trigger detector. It enables to distinguish electron events incident from out of effective area and γ -ray events. ACD is composed of 1cm thick plastic scintillator and 1mm ϕ WLSFs same as the trigger detector. The light signal from scintillator is transmitted to PMT through WLSFs.

III. EVALUATION OF bCALET-2 BY MONTE CARLO SIMULATION

We have evaluated the performance of bCALET-2 detector by using Monte Carlo simulation. We considered two condition for off-line analysis as following.

- 1) Standard
Top 3 layer of BGO detected the cosmic-ray showers
- 2) Contained
All layers of BGO detected the cosmic-ray showers

The examples of simulated event are shown in Fig.4.

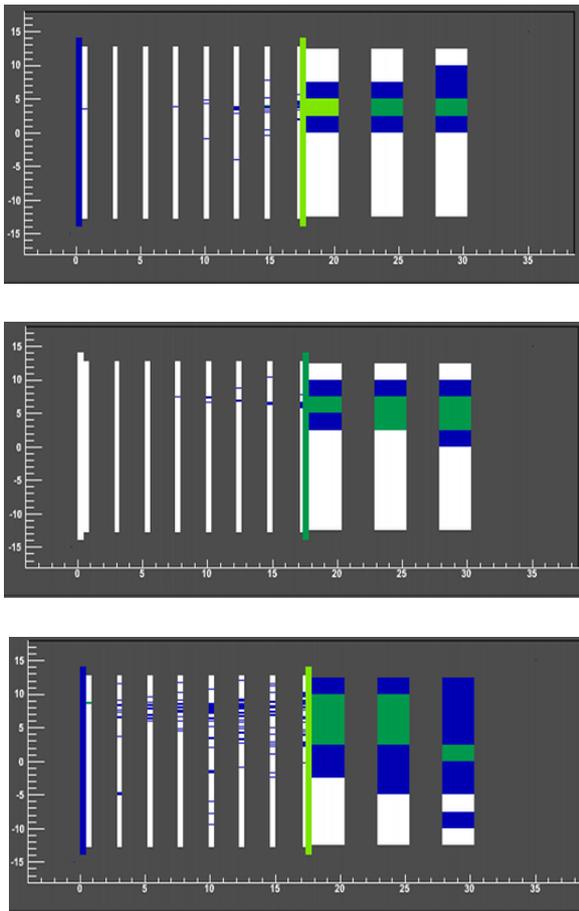


Fig. 4. The example of incident events. Each figures are Electron 10GeV(upper), γ -ray 10GeV(middle) and proton 27.3GeV(lower).

A. Geometrical factor and trigger efficiency

$S\Omega$ is about 320cm²sr in the standard condition(Fig.5) as same as BETS[4]. The electron trigger efficiency become 90% over 1GeV(Fig.6).

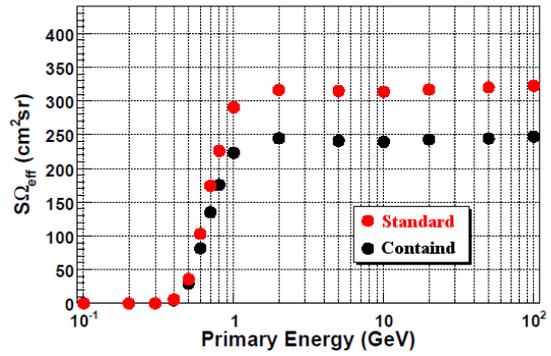


Fig. 5. Geometrical factor of two incident condition.

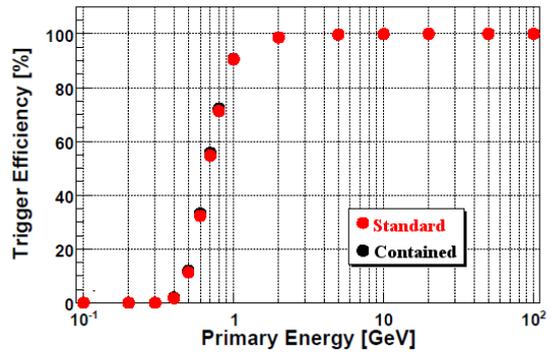


Fig. 6. Trigger efficiency of electron

B. Energy resolution

The resolution of incident electron energy is expected below 4% above 10GeV(Fig.7). It is expected that it improves more than PPB-BETS(12~20%)[3] and BETS(14~17%). Because bCALET has TASC that is thick active calorimeter, it is effective not only the energy determine, but also the rejection of proton event at the off-line analysis.

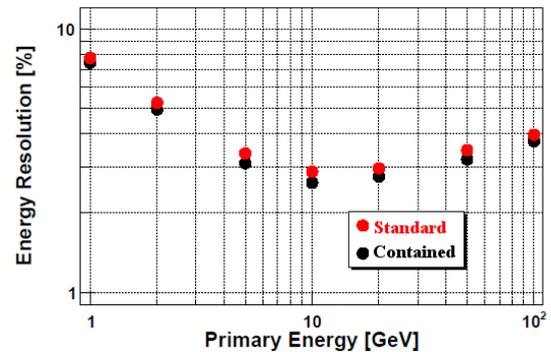


Fig. 7. Energy resolution of electron at each energy.

C. Power of Proton Rejection

For the precise observation of the electron flux, we need the rejection of proton events. Fig.8 shows a difference of the shower structure. The data of electron

is mono energy but protons have a power law spectrum $\propto E^{-2.7}$ in this case. Though we still have a room for optimization of the analysis method, we calculated that proton rejection power is around 10^{-4} with the electrons remained over 90%.

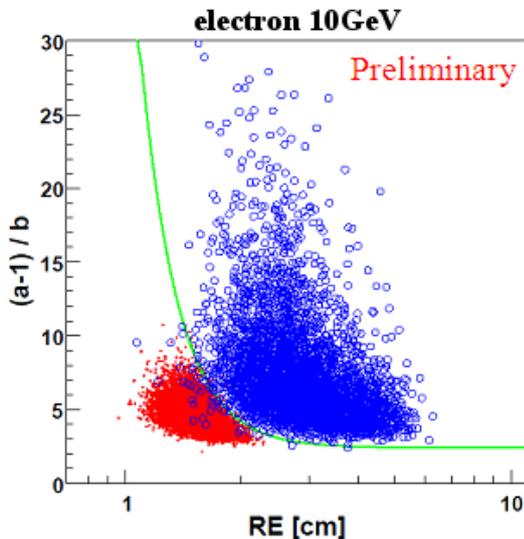


Fig. 8. The scatter plot is the radius of shower v.s. the maximum depth of shower development. Dots and circles denote electron and proton, respectively

D. Trigger rate

Since bCALET-2 is covered by ACD, the rate of event taking will be decreased to about 20Hz as shown in Fig.9. It does not exceed the ability of data acquisition (~30Hz), and we succeed to decrease the dead time of data taking considerably.

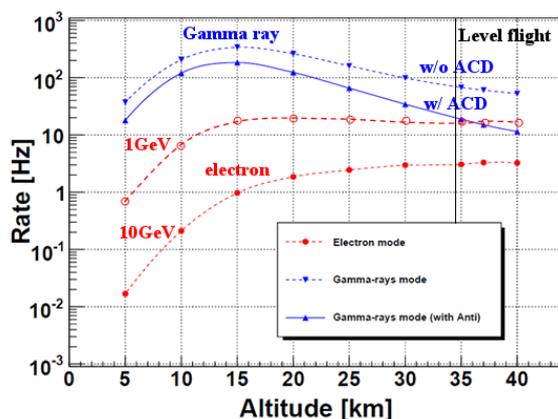


Fig. 9. Trigger rate calculation. At the flight level (~34km), the rate becomes 1/3.

IV. SUMMARY AND FUTURE PLAN OF BCALET

The bCALET-2 flight is scheduled in Sep. 2009. We are preparing the detector and the system to achieve the balloon flight. By using the Monte Carlo simulations,

we realize a good performance of the detector. After the flight, we will have an accelerator beam test at CERN-SPS.

We are planning a long duration observation with bCALET-3. The detector concept of bCALET-3 is same as bCALET-2, and is enlarged by a factor four in $S\Omega$. IMC will be extended to $512\text{mm} \times 512\text{mm} \times 18$ x-y layers. The number of MA-PMT increases to 288. Moreover, TASK will be composed of 10 layers, and each layer has 12 BGO logs.

We are proposing a flight of bCALET-3 from Brazil to Australia, by using a super pressur balloon. In addition, a series of long duration ballooning for 50 days in total in the southern hemisphere and/or in Arctic. In this observation will be accomplished, we will take nearly 10^6 electron events over 10GeV; 30 events over 1TeV. We will be able to confirm the excess reported in the sub-TeV region[6].

Finally, we aim to the CALET mission. The research and development of the bCALET detectors is a base of the CALET detector. CALET is planned on-board JEM-EF on ISS for the observation over 3 years. Since the geometrical factor will be $0.7 \text{ m}^2\text{sr}$, we can measure the energy spectrum of electrons at the trans-TeV region.

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