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Balloon observation of electrons and gamma rays with CALET prototype

Y. SHIMIZU[1], S. TORII[1], K. KASAHARA[1], Y. AKAIKE[1], Y. FUKUTA[1], K. HIDAKA[1], K. TAIRA[1], T. TAMURA[2], K. YOSHIDA[3], Y. KATAYOSE[4], H. MURAKAMI[5]
FOR THE CALET COLLABORATION
[1]*Research Institute for Science and Engineering, Waseda University, Japan*
[2]*Faculty of Engineering, Kanagawa University, Japan*
[3]*Department of Electronic Information Systems, Shibaura Institute of Technology, Japan*
[4]*Department of Physics, Yokohama National University, Japan*
[5]*Department of Physics, Rikkyo University, Japan*
y.shimizu@waseda.jp

Abstract: We carried out a balloon observation of cosmic rays using a prototype of the CALET at the Sanriku Balloon Center of the Japan Aerospace Exploration Agency. The prototype detector consists of 1024 scintillating fibers for track imaging and 24 BGO scintillator "logs" for total absorption of showers. The observation was carried at an altiude between 35 and 37 km for about 3.5 hours. We measured electrons and γ-rays in the energy region between 1 to 100 GeV, and 20 MeV to 1 GeV, respectively. In addition to verification of the prototype system, we have obtained the electron flux which is useful to investigate solar modulation. Now we are planning a series of balloon experiments with larger-scale detectors and longer-duration flights, which includes one-month observation by a super-pressure balloon.

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 scintillator, scintillating fiber and readout electronics for them. For the verification of observation capability, a balloon-borne experiment with a prototype of the CALET was carried out. We report the results of this balloon experiment.

Prototype detector

As described in the reference [2], the major part of the CALET detector consists of a large-mass calorimeter, which is divided into two parts. The upper part is an imaging calorimeter (IMC), and the lower part is a total absorption calorimeter (TASC). A structure of the prototype is shown in Fig 1. While the prototype is not covered with anti-coincidence detector, two layers of plastic scintillator is installed for the trigger.

The IMC of the prototype is composed of four layers for track 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 128 of 1 mm square cross section fibers, so that the total number is 1024. The dimension of the IMC is about 128 mm by 128 mm. The total thickness of the tungsten plates is 1.3 radiation length (r.l.). The image measured by the IMC is used for estimation of the incident direction and the shower development of cosmic rays. Signals of each fiber are detected by 64ch multi-anode PMTs.

The TASC is composed of 6 layers of BGO scintillator. Each layer consists of 4 of 25mm square cross section BGO logs. Alternate layers are orientated 90 degrees to each other to provide an x and y coordinate. The total thickness of the TASC is 13 r.l. The TASC is used for the measurement of the shower development to determine the total energy of the incident particle 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 in measurement of cosmic-ray muons.

Two layers of 20mm-thick plastic scintillators and the top layer of the TASC are used to generate a trigger signal. To obtained both of electron and γ-ray events, we provide two trigger modes. The trigger condition shown in Table 1 is set to eliminate effectively the background proton events.

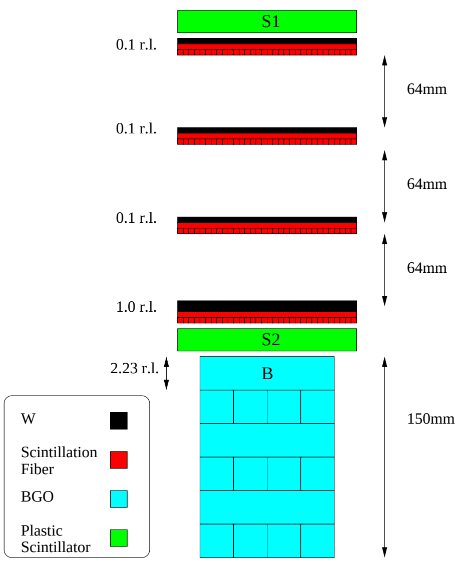

Figure 1: Schematic side view of the CALET prototype detector.

	S1	S2	B
e	>0.7 MIPs	>0.7 MIPs	>5 MIPs
γ	<0.7 MIPs	> 0.7 MIPs	>0.5 MIPs

Table 1: Trigger mode. The pulse height is normalized to the peak of the minimum ionizing particle (MIP).

Balloon observation

The balloon observation was carried out at the Sanriku Balloon Center (SBC) of the Japan Aerospace Exploration Agency on 31 May 2006. The CALET prototype was successfully launched from the SBC at 6:00 and drifted toward the Pacific Ocean. The flight was terminated after the duration of about 6 hours. The payload was recovered on the ocean. The variation of the altitude is shown in Fig. 2. The duration of the level flight above 35 km was 3.5 hours. At the level flight, the rate for the electron and γ-ray modes are 0.35 and 2.1 Hz, respectively. We collected about 3×10^3 electron trigger events and 4×10^4 γ-ray trigger events in the level flight.

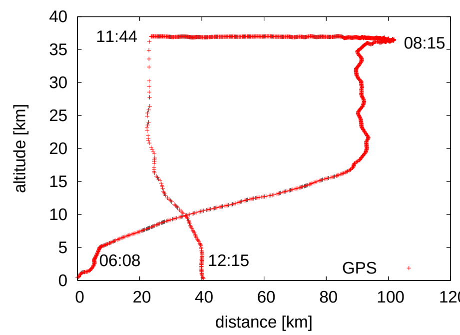

Figure 2: Balloon altitude in the flight.

Data analysis

Our current data analysis is focused on electron events during the level flight observation. Using the shower image measured by the IMC and the TASC, we obtained the incident energy and the particle track and eliminated the proton background. Detection capability was estimated by the Monte-Carlo simulation code, EPICS[3]. Figure 3 shows an example of an observed event with the energy of 3 GeV.

Incident energy

The incident energy was estimated by the sum of the deposited energy in the IMC and the TASC. Energy loss in tungsten plates was estimated from the observed energy in scintillating fibers. Estimated energy resolution is shown in Fig 4.

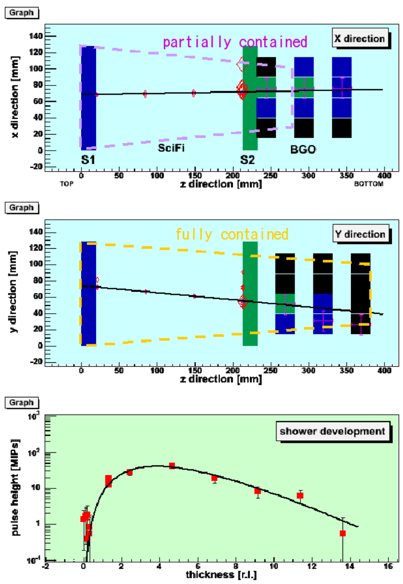

Figure 3: Example of an observed electron-like event with the energy of 3GeV. Pulse height of a scintillation fiber is described by size of the red diamond. BGO logs are represented by colored boxes. Light color indicates larger pulse height.

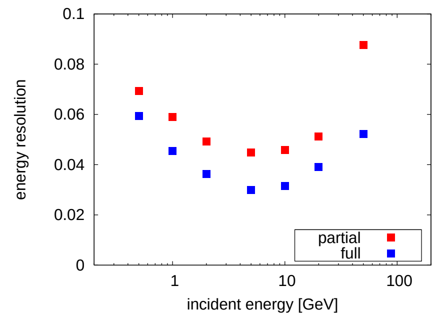

Figure 4: Energy resolution estimated by the Monte-Carlo simulation.

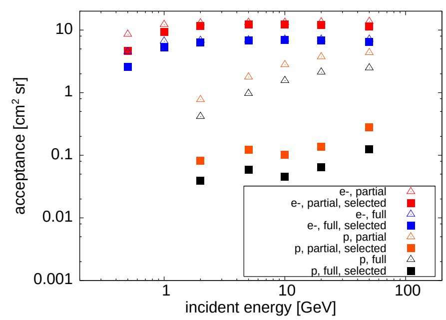

Figure 5: Detector acceptance estimated by the Monte-Carlo simulation.

Particle track

The particle track in the detector was obtained by the best-fit line of shower cores in each layer. We estimated the core position by the position of the scintillating fiber with the highest signal in each layer for IMC and by the energy weighted center of four BGO logs in one layer for TASC. We used only events in which the track was partially (up to the second BGO layer)or fully (up to the bottom BGO layer) contained in the detector for further analysis. The definition of the contained events is described in Fig 3. Estimated acceptance of the detector is shown in Fig 5.

Proton rejection

Proton background was rejected by imaging the shower development. The curve of the vertical development was estimated by an equation:

$$\frac{dE}{dt} = \frac{E_0 b}{\Gamma(a)}(bt)^{a-1}e^{-bt} \qquad (1)$$

where t is the thickness, E_0 is the incident energy, a and b are parameters. We used parameters (a, b) and χ^2 of the best fit to distinguish electrons and protons. The transverse development was distinguished by energy concentration around the estimated track and the standard deviation from the energy weighted centers. As shown in Fig 5, proton acceptance of the detector was 100 times lower than that of electron at the same incident energy. The rejection power of protons was estimated to be 10 times larger due to the energy shift of protons. Then, the rejection power at the same deposited energy should be better than 1000.

Results

To derive energy spectrum of electrons, we analyzed 3×10^3 electron trigger events obtained at an altitude between 35km and 37km. These events

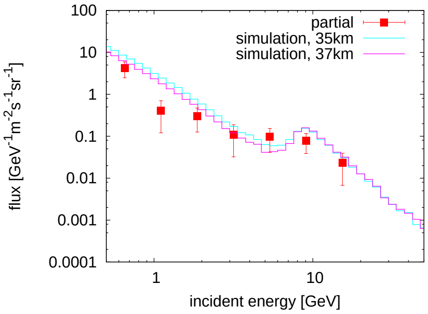

Figure 6: Obtained electron flux. It is superimposed on the curves calculated by the simulation.

include large amount of background proton events and accidental trigger events in which particles enter from the side of the detector. Selection of electron candidates was carried out by criteria imposed by the analysis of the simulation events. Considering the estimated acceptance, the electron flux has been derived. As shown in Fig. 6, the result is consistent with expected values by calculation using the COSMOS code[3].

Future plans

For further development of CALET and much more precise observation, a longer balloon experiment is prospected. At first, we are preparing for one-day flight with a detector which has four times larger area than the prototype in 2008. It will be carried out in Taiki-cho, Hokkaido. To extend flight duration and add BGO logs, a low power consumption readout for the TASC is developed [4]. For the next step, we are planning one-month flight with a super-pressure balloon that is developed by the SBC. The balloon will be launched from Brazil and landed in Australia. The detector for this flight is 16 times larger than the prototype. The statistics of the observation with the super-pressure balloon is expected to be 2000 times larger than that of the prototype (Fig 7). There is a possibility to observe mono-energetic electrons produced by the WIMP dark matter annihilation in the energy range of several hundred GeV by the super-pressure balloon observation.

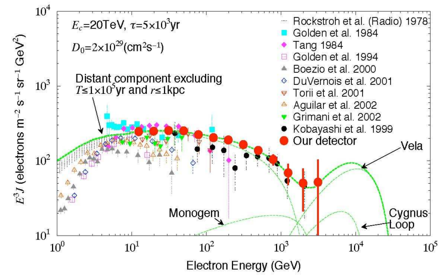

Figure 7: Expected electron flux by the super-pressure balloon observation.

Summary

The first balloon experiment with the CALET prototype is carried out. We obtained thousands of electron and γ-ray trigger events at the altitude between 35 and 37 km. The shower image of cosmic rays were clearly observed by the calorimeter. Event reconstruction technique was developed to select electron events. Consequently, we obtained the electron flux in the energy range between 0.5 and 20 GeV. This result was consistent with our estimation. Furthermore, we are planning longer balloon experiments by a super-pressure balloon as a precursor flight of the CALET mission.

References

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