Simulated Performance of CALET on ISS Orbit

Yosui Akaike*, **Katsuaki Kasahara***, **Shoji Torii***, **Shunsuke Ozawa***, **Koichi Taira***
and Kenji Yoshida† **for the CALET Collaboration**

Research Institute for Science and Engineering, Waseda University, Tokyo, Japan
†*Department of Electronic Information Systems, Shibaura Institute of Technology, Saitama, Japan*

***Abstract*. Calorimetric Electron Telescope, CALET, is being developed to be on board the Japanese Experiment Module Exposed Facility, JEM/EF, of the International Space Station, ISS. Major goals of the mission are to search for nearby cosmic ray sources and dark matter by carrying out a precise measurement of the electrons in 1 GeV − 20 TeV and the gamma-rays in 20 MeV − a few TeV. CALET will measure the protons and the nuclei up to 1000 TeV as well. The main detector is composed of Imaging Calorimeter, IMC, Total Absorption Calorimeter, TASC, Silicon Array, SIA, and Anti-Coincidence Detector, ACD, to detect various kinds of particles in very wide energy range. The total absorber thickness is 31 X_0 for electromagnetic particles and 1.4 λ for protons. To get optimized CALET performance in observing each kind of particles, we have been carrying out Monte Carlo simulation. In this paper, we estimate the trigger rate at the ISS orbit by calculating the cosmic ray flux at an altitude of 400 km. The rate is 37 Hz for the shower trigger over 10 GeV, which is mainly adopted in the CALET mission. An expected performance of detector such as the geometrical factor, the energy resolution, the angular resolution and the electron/proton separation is also presented.**

***Keywords*: electrons, trigger rate, ISS**

I. Introduction

Scientific goals of the CALET mission are to investigate unsolved high energy phenomena in the Universe by carrying out a precise measurement of the electrons in 1 GeV − 20 TeV, the gamma-rays in 20 MeV − a few TeV and the protons and the nuclei in a few 10 GeV − 1000 TeV [1][2][3]. CALET plans to be on board the Japanese Experiment Module Exposed Facility, JEM-EF of the International Space Station, ISS.

In order to estimate the CALET performance, we have adopted Monte Carlo simulation. The simulation for the basic performance such as the geometrical factor, the energy resolution, the angular resolution and the electron/proton separation have been already performed. In this paper, we calculate the flux of cosmic rays at an altitude of the ISS orbit, 400 km, and estimate the trigger rate in consideration of the detection efficiency. We will present the trigger rate together with a summary of the basic performance.

II. Instruments

A. Detector

Figure 1 presents a schematic side view of the CALET detector which consists of Imaging Calorimeter (IMC), Total Absorption Calorimeter (TASC), Si Pixel Array (SIA) and Anti-Coincidence Detector (ACD). Examples of shower profiles by an electron, a gamma-ray and protons are presented.

IMC is composed of 18 layers of scintillating fiber (SciFi) belts for imaging pre-shower. Each layer consists of a tungsten plate and two SciFi belts arranged in the x and y direction. Each belt is composed of 896 SciFi's of 1mm square cross section. The total number of SciFi is 32,256. Total thickness of the tungsten plate is 4 X_0 or 0.14 λ. IMC is used for the particle identification, the incident direction and the energy measurement.

TASC has 12 layers of BGO logs each of which has a dimension of 25 mm × 25 mm × 300 mm. Each layer consists of 48 BGO logs and arranged alternatively in the x and y direction to use a hodoscope. The total thickness of TASC is 27.3 X_0 or 1.4 λ. Besides energy measurement, TASC offers shower development profile which is essential for e/p separation.

SIA put above IMC consists of two layers of the Si pixel array which is composed of square pixels (11.25 mm × 11.25 mm in each). It is used for an observation of heavy particles by achieving high charge resolution.

ACD is a plastic scintillator array which covers more than two third of the main body in order to reject charged particles for the gamma-rays observation at energies lower than 10 GeV. ACD is divided into segments for better particle identification. Each plastic scintillator at the top has a dimension of 240 mm × 240 mm and that at the side has 240 mm × 200 mm.

B. Event Trigger

For electron/gamma identification, a part of the background protons is rejected without a serious loss of the objective particles. The trigger mode is classified into three categories according to particles of different energies and types.

- **Low energy gamma-rays trigger** (20 MeV ∼ 10 GeV)
  This mode requires no signal in ACD and signals from more than 3 consecutive SciFi layers in IMC.
- **Low energy shower trigger** (1 GeV ∼)
  This mode uses the energy threshold at the top BGO

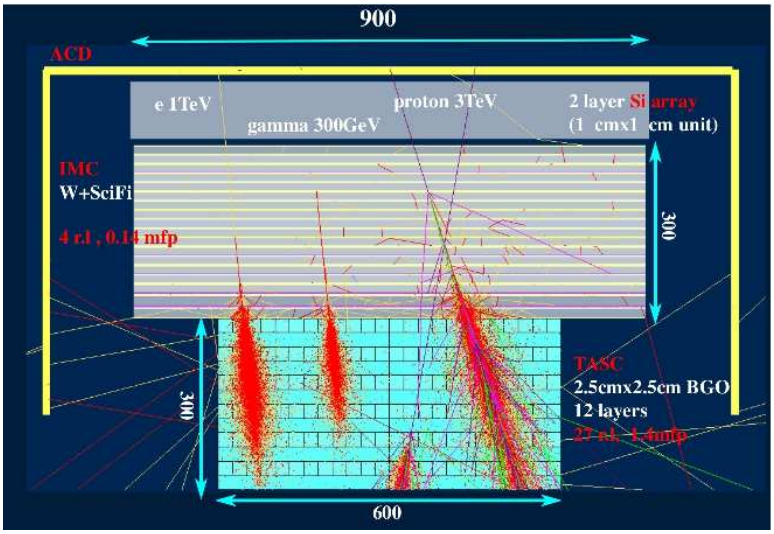


Fig. 1. Schematic view of CALET and examples of simulated high energy showers. The leftmost one is a shower by a 1 TeV electron. The next one is by a 300 GeV gamma-ray which can be discriminated from electron by absence of tracks at the upper part. Next two are by 3 TeV protons which could be the main background source for electron identification.

TABLE I
BASIC PERFORMANCE

	Electrons	Gamma-rays	Protons
Energy range	1 GeV∼20 TeV	20 MeV∼a few TeV	∼1000 TeV
Geometrical factor [cm^{2}sr]	7000	5400	1300
Energy resolution [%]	2∼12	2∼35	∼30
Angular resolution [deg]	0.04∼1.3	0.07∼22	<0.1

layer which is determined to detect 95 % of the 1 GeV electrons as well as signals from more than 3 consecutive SciFi layers in IMC.

- **High energy shower trigger** (10 GeV ∼)
  This mode is same for low energy shower trigger except shower trigger threshold. The threshold is determined to detect 95 % of the 10 GeV electrons.

C. Basic Performance

We have evaluated performance of CALET by Monte Carlo simulation. We used EPICS[1] code [4] for simulation and adopted dpmjet3 [5] for a hadronic interaction model. As presented in Table I, CALET has capability to observe electrons and gamma-rays with high energy resolution, ∼ 2%, over 100 GeV due to the thick absorber in TASC. The angular resolution for gamma-rays is 0.07 degree over 100 GeV with IMC. Since the geometrical factor for electrons is 7000 cm^{2}sr, CALET will be able to observe more than 2000 electrons in TeV region with the 3-year exposure.

For high energy electrons/gamma-rays observation, protons are the largest sources of the background. As the ratio of proton to electron increase at higher energies, excellent proton rejection power is required over 1 TeV. We distinguish electrons from protons mainly by the difference of shower development in TASC [6]. The rejection power of CALET in TeV region is 1.0×10^5 with a condition of retaining 95 % of the electrons (90 % C.L.).

III. TRIGGER RATE AND DATA SIZE

A. Estimated Flux on ISS Orbit

In order to estimate a trigger rate for the CALET observation, we evaluate the flux of various cosmic rays on ISS orbit. We used ATMNC3[2] which was originally made for calculation of atmospheric muons and neutrinos [7]. This simulation code is recently applied to calculate the cosmic ray flux observed by Fermi and PAMELA over a few hundreds MeV, and proved to be consistent with these results.

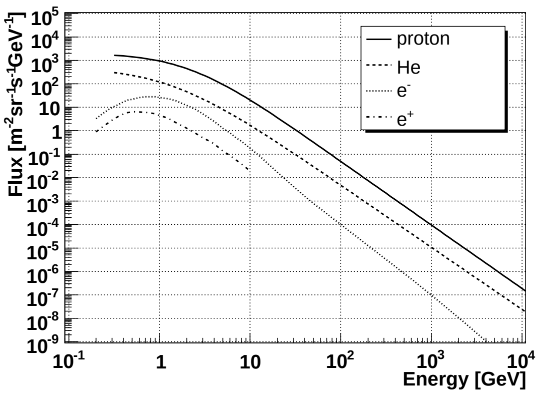


Fig. 2. The flux assumed as primary comic rays, which are based on the results of AMS and BESS observation

[1]EPICS stands for Electron-Photon Induced Cascade Simulator in a detector

[2]ATMNC3 stands for Atmospheric Muon Neutrino Calculation code 3-dimensional version.

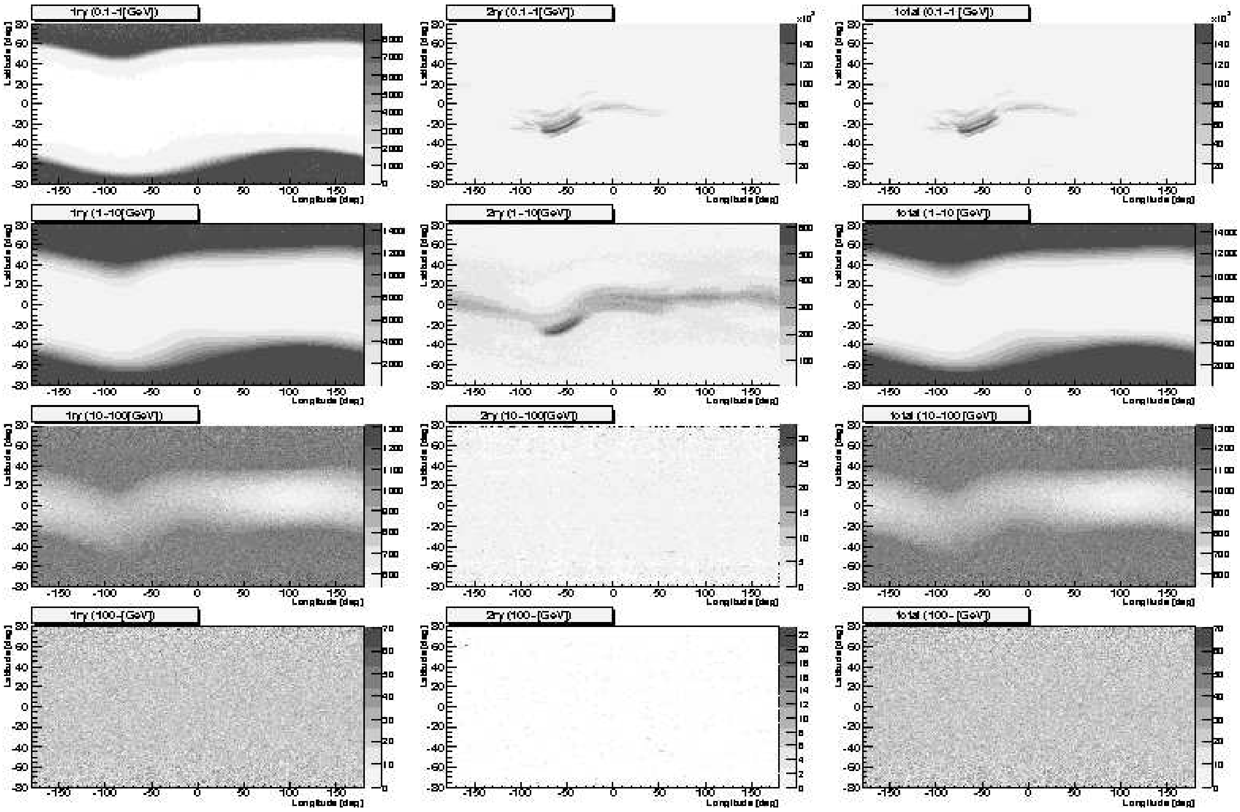


Fig. 3. The cosmic ray flux [$m^{-2}sr^{-1}s^{-1}$] on ISS orbit of which altitude is 400 km. The flux is shown in grey scale of which magnitude is indicated on the right hand side. The four figures in the left column are for primary particles, the middle for the albedo, and the right for the total (primary + albedo). The three figure at the first raw is for 100 MeV∼ 1 GeV, 2nd raw for 1 ∼10 GeV, 3rd raw for 10∼100 GeV and the last raw for over 100 GeV.

We assumed the primary cosmic ray flux of proton, He, e^- and e^+, which is based on the results of AMS [8][9] and BESS [10][11]. In Fig. 2, these energy spectra are shown. We used US-standard 1976 [12] for a model of atmosphere, and adopted IGRF2005 [13] for a model of the geomagnetic field.

The flux estimation on ISS orbit was done by two steps. First, we estimate the flux of primary cosmic rays at an altitude of 400 km after passing the geomagnetic field. We trace back the objective particle from the spherical surface at the altitude. For this purpose, the inverse charged primary particle is isotropically injected to the opposite direction from an altitude of 400 km. If the particle reaches the distance enough to be free from the geomagnetic field ($11R_e$), we regard the particle to be a primary. On the other hand, if the particle returns to the earth, the particle is discarded.

Second, for the selected primary particles, we inject them to the earth and track the trajectory. All the particles generated in the atmosphere are traced until the energy becomes lower than 100 MeV or the flight time exceeds 100 seconds. When the particles pass through the altitude of 400 km, we record information of the particles such as the type, the energy and the incident angle.

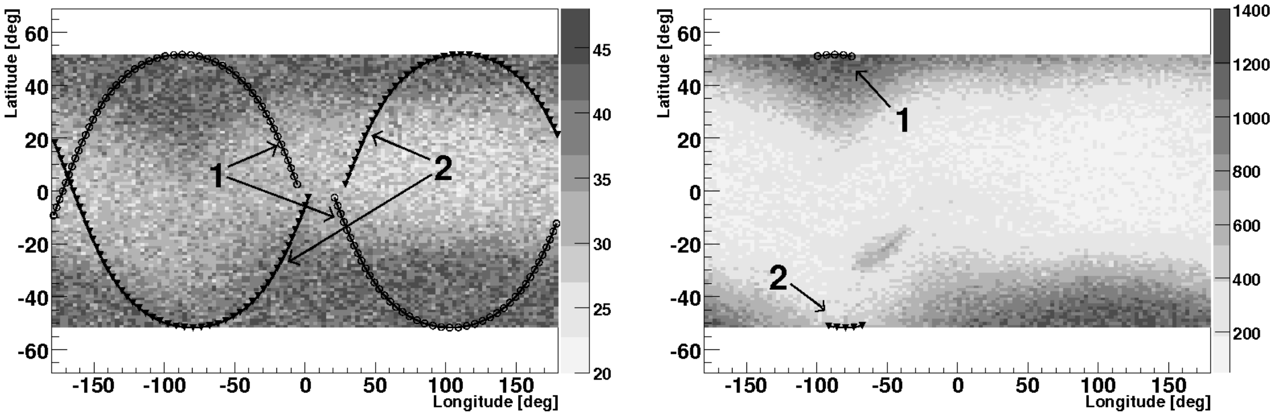
Figure 3 shows the density map of cosmic ray flux including charged particles and gamma-rays. The left group shows the primary particles, and we note the primary flux at lower latitude is smaller due to the rigidity cut. The center group shows the albedo particles. In the low energy region, South Atlantic Anomaly is clearly seen. The right group is total (primary + albedo) flux.

B. Trigger Rate

ATMNC3 gives particles with various energies and incident angles, which are supposed to enter the CALET detector. For such particles, we made a detector-response simulation by EPICS to obtain the trigger rate and detection efficiency of CALET.

Figure 4a shows the trigger rate under the high energy shower trigger. The inclination angle of ISS is 51.6° and the one lap is about 90 minutes. When ISS takes an orbit closest to the geomagnetic poles (the orbit-1 in Fig.4a), an average trigger rate over one orbital cycle is 37.8 Hz. When the orbit is most far from the pole (the orbit-2 in the Fig.4a), an average over one cycle is 36.5 Hz. An average over one day is 37.1 Hz with the high energy shower trigger. There is little difference between the orbits. The main source of the triggered events is the primary particles obtained by the high energy shower trigger, and the influence of the albedo particles is less than 0.3 %.

Figure 4b shows the trigger rate by the low energy



(a) High energy shower trigger

(b) Low energy shower trigger

Fig. 4. The density map of trigger rate [Hz]. The rate is shown in grey scale. The inclination angle of the ISS orbit is 51.6 degree. The orbit-1 takes a path closest to the geomagnetic poles. The orbit-2 is for the case most far from the poles.

TABLE II
TRIGGER RATE

	one day	geo_max	geo_min
High energy shower trigger	37.1 [Hz]	37.8 [Hz]	36.5 [Hz]
Low energy shower trigger	-	1,197 [Hz]	446.8 [Hz]

shower trigger. In this trigger mode, we will observe low energy particles in the highest latitude for studying solar activity [3]. We plan to carry out the observation during 5 minutes every two orbits. It is equivalent to about 2.8 % of all observation time. An average trigger rate over 5 minutes is 1,197 Hz in the orbit-1, and an average in the orbit-2 is 446.8 Hz.

In Table II, The average trigger rates are listed. For the high energy shower trigger, the averages are presented over one day and over one cycle, respectively. For the low energy shower trigger, the average is obtained over 5 minutes. In table II, ‘geo_max‘ means the closest orbit to magnetic pole and ‘geo_min‘ means the most far orbit.

IV. SUMMARY

We have being carrying out the Monte Carlo simulation to evaluate the CALET performance. We have confirmed that CALET has the excellent proton rejection power, 1.0×10^5, in TeV region and the high energy resolution, ~ 2 %, over 100 GeV. Since geometrical factor is about 7000 $cm^2 sr$ for electrons, CALET is capable of collecting significant number of electrons up to 20 TeV.

We have also evaluated the trigger rate on ISS orbit by an estimation of comic ray flux including albedo particles. This evaluation is indispensable for the detector development. For the high energy shower trigger which is mainly used for the CALET mission, the trigger rate is about 37 Hz. For the low energy shower trigger mode, the maximum trigger rate is about 1.2 kHz.

ACKNOWLEDGMENTS

We owe a part of the present calculations to the Institute of Cosmic Ray Research, University of Tokyo. This work is partially supported by Grant-in-Aid for JSPS Fellows.

REFERENCES

[1] S.Torii *et al.* , OG.1.5 in this proceedings.
[2] K.Yoshida *et al.* , OG.1.5 in this proceedings.
[3] Y.Komori *et al.* , SH.3.6 in this proceedings.
[4] http://cosmos.n.kanagawa-u.ac.jp/
[5] S.Roesler, R.Engel, J.Ranft, Report SLAC-PUB-8730, hep-ph/0012252; Proc. Monte Carlo 2000 (Lisbon), 71, p.23
[6] J.Chang *et al.* , Proc. of 28th ICRC, 2185-2188; J.Chang *et al.* , Proc. of 29th ICRC, **3** 273-276, (2005)
[7] M.Honda, T.Kajita, K.Kasahara and S.Midorikawa, Phys. Rev. D **70**, 043008 (2004)
[8] J.Alcaraz *et al.* . (AMS), Phys. Lett. B **490**, 27 (2000)
[9] J.Alcaraz *et al.* . (AMS), Phys. Lett. B **494**, 193 (2000)
[10] S.Haino *et al.* . (BESS), Phys, Lett. B **594**, 35 (2004)
[11] T.Sanuki *et al.* . (BESS), Astrophys.J. **545**, 1135 (2000)
[12] http://ccmc.gsfc.nasa.gov/modelweb/atmos/us_standard.html
[13] http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html