29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

Observation of Electrons above 100 GeV with the BETS Detector Using Long-Duration Balloon in Antarctica

S.Torii[a], T.Tamura[b], T.Yamagami[c], M.Ejiri[d], H.Kitamura[e], I.Iijima[f], A.Kadokura[d], K.Kasahara[f], Y.Katayose[g], T.Kobayashi[h], Y.Komori[i], Y.Matsuzaka[c], K.Mizutani[j], H.Murakami[k], M.Namiki[c], J.Nishimura[f], S.Ohta[c], Y.Saito[c], M.Shibata[g], N.Tateyama[b], H.Yamagishi[d], K.Yoshida[b], T.Yuda[b], J.Chang[l]

(a) Advanced Research Institute for Science and Engineering, Waseda University, Japan
(b) Faculty of Engineering, Kanagawa University, Japan
(c) Institute of Space and Astronautical Science, JAXA, Japan
(d) National Institute of Polar Research, Japan
(e) National Institute of Radiological Sciences, Japan
(f) Department of Electronic & Information Systems, Shibaura Institute of Technology, Japan
(g) Department of Physics, Yokohama National University, Japan
(h) Department of Physics, Aoyama Gakuin University, Japan
(i) Kanagawa University of Human Services, Japan
(j) Department of Physics, Saitama University, Japan
(k) Department of Physics, Rikkyo University, Japan
(l) Purple Mountain Observatory, Chinese Academy of Science, China
Presenter: S.Torii (torii.shoji@waseda.jp), jap-torii-S-abs2-og11-poster

We had a long duration balloon flight for observing cosmic-ray electrons from 10 GeV to 1000 GeV by the Polar Patrol Balloon (PPB) in Antarctica. The observation was carried out for 13 days at an average altitude of 35 km in January 2004. The detector is an imaging calorimeter composed of scintillating-fiber belts and plastic scintillators inserted between lead plates. The performance of the detector has been confirmed by the beam test at CERN-SPS and also investigated by Monte-Carlo simulations. We have collected 5.7×10^3 events above 100GeV including nearly 100 candidates of primary electrons. Preliminary result of the electron energy spectrum in 100~1000 GeV has been obtained.

1. Introduction

Since high-energy electrons can bring us a unique information of the sources and the propagation in the Galaxy[1], the observations with many kinds of detectors borne on balloons have been carried out. However, most observations are still limited below ~100 GeV. As an exceptional instance, the observation with the emulsion chambers has achieved to detect electrons above 1TeV by the large amount of exposures of ~10 m^2.day.sr in total for 30 years [2]. The difficulty of observation originates from that the electron flux itself is very small and decreases with energy much more rapidly than that of protons because of the electromagnetic energy loss by radiation. The electron flux is estimated to be ~1% of protons around 10GeV and less than 0.2% of protons over 100GeV from the observed energy spectra with a power-law index of -3.0 ~ -3.3 for electrons [3] and -2.7 for protons [4]. Therefore, for the electron observations above 100GeV, we need a long duration observation by a detector with an excellent capability of large geometrical factor and powerful background rejection.

In order to accomplish a cosmic-ray electron observation above 10 GeV, we developed a highly granulated imaging calorimeter, the Balloon-borne Electron Telescope with Scintillating fibers (BETS) [5], that preserves the superior qualities to meet the above mentioned conditions of electron observation. We have successfully observed electrons in the energy range from 10 to 100GeV at Sanriku in Japan [3]. The BETS was improved to observe atmospheric gamma rays at mountain and balloon altitudes for calibrating the atmospheric neutrino flux calculations [6]. Furthermore, for observing the electrons above 100GeV by a long duration balloon experiment, we have achieved the development of an advanced detector of BETS flown by PPB in Antarctica. The PPB has a capability to realize a flight for 2 ~ 4 weeks in one round of the Antarctica at an altitude of ~35 km [7]. The PPB project is carried out by the inter-university collaboration with Institute of Space and Astronautical Science, JAXA and National Institute of Polar Research (NIPR).

2. Instrumentation and Performance

The PPB-BETS detector consists of 36 scintillating fiber belts, 9 plastic scintillators, and 14 lead plates with 9 radiation lengths (r.l.) in total. Each fiber belt is composed of 280 fibers with a 1mm square cross section for each. A schematic cross section of the detector is shown in Fig. 1. The basic structure is similar to the BETS, but several improvements were adopted to achieve observation of the electrons up to 1TeV by a long duration flight. The area of the detector is 28cm × 28cm and the total height is 23cm, including spacers inserted between sensitive layers.

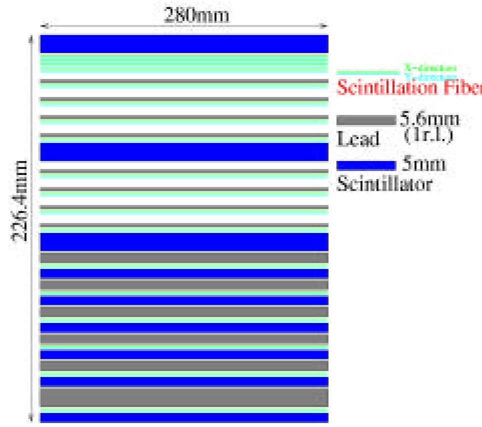

Fig. 1: Schematic side view of detector.

The scintillating fibers perform a function to detect the shower particles developing in lead plates and to fulfill a detailed imaging of the shower. Scintillating fiber belts are set in right angle alternately to observe the projected shower profile in x and y directions. For the read-out of scintillation light in the fibers, we used an image-intensified CCD camera in each direction of x and y. The plastic scintillators were used for event trigger and energy measurement. Thus the PPB-BETS is an instrument to observe details of the three dimensional shower development with a timing capability.

The total performance of detector was approved by beam tests using CERN-SPS and by Monte-Carlo simulations. The simulations were carried out with several codes such as FLUKA2002, GEANT3, and EPICS, in which we could not find serious differences. The trigger rate in actual observation is critically important to know the data amount transmitted by telemetry since we have no guarantee of the recovery of instrument. Therefore, we had a test flight of the trigger system at Sanriku in advance of the flight in Antarctica. Basic parameters of the PPB-BETS instrument are summarize in Table 1.

Table.1: Basic Parameters of PPB-BETS

Instrument weight (Total weight)	200 kg (480 kg)	including un-pressurized vessel and gondola (including ballast)
Power consumption	70 W	supplied by solar battery
Level altitude	~35 km	by automatic level control
Data transfer rate	2.4 kbps 64 kbps	by the Iridium satellite telephone line by down link to the station
Energy range	10 ~ 1000 GeV	by two trigger mode
Geometrical factor	550~600 cm^2 sr	> 100 GeV by simulation
Energy resolution	10 ~ 25 %	in 10~1000 GeV by plastic scintillators
Angular resolution	0.35 ~ 0.60 deg.	by imaging with scintillating fibers

The PPB-BETS has been much more improved in comparison with the BETS at several points. The thickness of lead is increased from 7 to 9 r.l. to observe the higher energy electrons, and the number of plastic scintillators is increased from 3 to 9 to detect accurately the shower development. The image-intensified CCD camera (I.I.-CCD) system for the read-out of scintillating fibers was newly developed by using a better quality of CCD to detect 1TeV electron showers without saturation. As a ballooning technology of the long duration flight, we developed the telemetry system with the Iridium satellite phone system, the power supply system by solar batteries, the automatic level control system, and so on. Since the detector weight should be saved for loading heavy ballast, we used an un-pressurized vessel with a light shield, designing the instrument to meet vacuum and heat conditions during the observation. We examined validity of the instrument by environmental tests as long as more than one week.

3. Balloon Observation

The balloon was launched at the Syowa station (69•± 00' latitude south, 35•± 35' longitude east) in Antarctica at 15:57 on January 4, 2004 (UTC). The flight was continued till 1:46 on January 17, 2004 (UTC) at a level altitude of 33~37 km (35km on average). The balloon went round the Antarctica at ~65• latitude south from east to west with a speed of 30 ~ 35 km/ h for 13 days. Power consumption of 70W in the instrument was normally supplied by the solar batteries. Automatic level control system successfully operated. The trajectory and the altitude curve of the balloon are presented in accompanying paper [8].

Event triggers were executed by two modes, the high-energy (HE) mode and the low-energy (LE) mode. The LE mode corresponds to electron observation over 10GeV, and was assigned for the observation during 10 hours just after the launching. The data acquired by the LE mode were directly transferred to the Syowa station with telemetry at a speed of 64kbps. The HE mode, which corresponds to the electron observation over 100GeV, was used through all the flight. The acquired data were further selected by the software trigger (2nd trigger) on-board, and transmitted to our operation room at NIPR in Japan, via a receiving station in US, with an Iridium satellite phone line at a rate of 2.4kbps. The commands from the operation room to the PPB-BETS were also sent by the Iridium line. The monitoring data were delivered to each institute via Internet. The data transfer rates were ~ 1×10^4 events per hour (3Hz) for the LE mode and ~70 events per hour (0.02Hz) for the HE mode, respectively.

Examples of the observed raw CCD images and shower development during the flight are presented in Fig. 2. The upper panel of the figure shows a typical event of an electron-induced shower, and the lower panel shows that of a proton-induced shower. A proton-induced shower should have a wider spread than an electron-induced shower due to the spread of secondary pions in the nuclear interactions. This difference is clearly observed in the raw CCD images. The proton rejection can be done by off-line analysis of shower imaging data, using the energy concentration ratio, *RE*, along the shower axis as presented in Fig. 3.

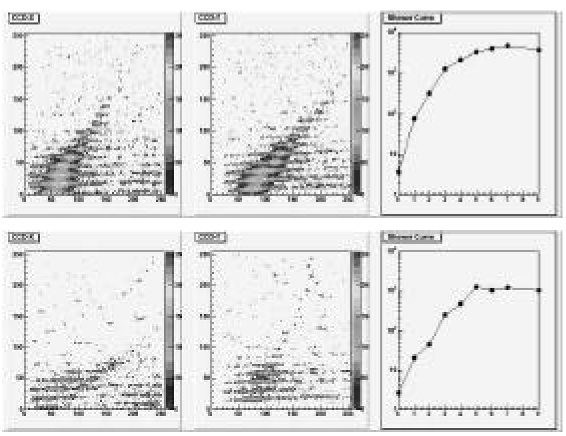

Fig. **2** Examples of observed shower images (x and y) and shower transition curves. The upper is electron candidate; the lower is proton.

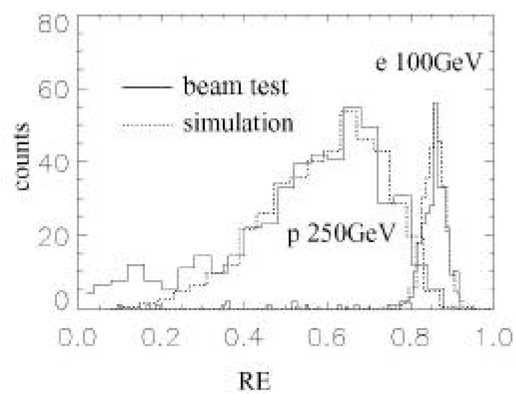

Fig.3: Proton rejection by the energy concentration parameter (RE) of showers. See the reference [3] for details

4. Data Analysis

In the HE mode, we observed the electrons almost with two parameter sets of discrimination levels of the plastic scintillators. The one set corresponds to the threshold for the observation of electrons over 100GeV, and the other corresponds to the threshold over 150GeV. The number of observed events is 3.1×10^3 for the 100GeV threshold and 1.6×10^3 for the 150GeV threshold. There are also $\sim1.0\times10^3$ events for the other thresholds on the HE mode. The number of events in the LE mode was 2.2×10^4. The number of electron candidates above 100GeV is estimated to be about 100 events among these observed events by calculations.

For the imaging analysis, we reconstructed the raw CCD images to the fiber positions in detector space by using the positions of each fiber on the CCD image. The positions of the fibers were allocated by observing cosmic-ray muon tracks on the ground. Relative displacement of the fiber position during the flight was calibrated on-board by LED signals in fibers . Electron-induced shower has generally a narrower lateral spread concentrated along the shower axis. This difference in lateral shower development between electrons and protons is applied for the observed events to separate electrons from the background protons by using the RE parameters shown in Fig.3. Preliminary result of the electron energy spectrum is presented in Fig. 4. The final result will be reported in the conference.

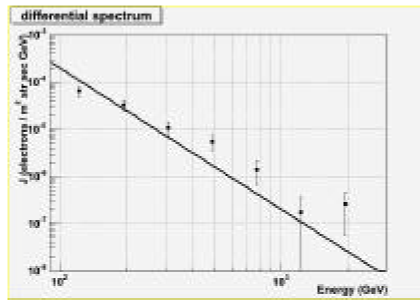

Fig.4: Preliminary result of electron energy spectrum observed by PPB-BETS. Solid line presents extrapolation of the BETS result.

5. Summary

We carried out the balloon observation of electrons using the PPB-BETS in January 2004 at the Syowa station in Antarctica. The observation period was 13 days at a level altitude of ~35 km. Cosmic-ray electrons were successfully observed with the expected performance of the detector, the telemetry using Iridium satellite, the power supply by solar batteries and the automatic level control using CPU. The total number of the observed events is 57×10^3 above 100GeV. By the data analysis of shower images, we have selected electron candidate and obtained a preliminary energy spectrum which is consistent with the BETS result. The detailed analysis is still on the way, and the energy spectrum will finally be presented in the conference.

6. Acknowledgments

We sincerely thank the crew of the Syowa station in Antarctica and the Sanriku Balloon Center in Japan for their excellent and successful balloon flights. We also thank the staffs of the H4 beam line of CERN-SPS for their kind supports. This work was partly supported by Grants in Aid for Scientific Research on Priority Area A (No.14039212) and Scientific Research C (No.16540268).

References

[1] J.Nishimura et al., ApJ 238, 394 (1980).
[2] T.Koboyashi et al., ApJ 601, 340 (2004).
[3] S.Torii et al., ApJ 559, 973 (2001).
[4] S.Haino et al., Phys.Lett.B 594, 35 (2004).
[5] S.Torii et al, NIM 452, 81 (2000).
[6] K.Kasahara et al., Phys.Rev. D 66, 052004 (2002).
[7] A.Kadokura et al., Advances in Polar Upper Asmosphere Phusics 16, 157 (2002).
[8] K.Yoshida et al., HE 2.1 in this conference volume.