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Atmospheric gamma-ray observation over 100GeV with PPB-BETS by long duration balloon flight in Antarctica

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Since atmospheric gamma rays at high altitude are mainly produced by a single interaction of primary cosmic rays with atmospheric nuclei, they are very useful to study nuclear interaction models and atmospheric neutrinos. We have observed atmospheric gamma rays from 100 GeV to 1 TeV with PPB-BETS by a long duration balloon flight of Polar Patrol Balloon (PPB) in Antarctica. The observation was carried out for 13 days at an altitudeof ∼35 km in January 2004. The detector of PPB-BETS is an imaging calorimeter composed of scintillating-fiber belts and plastic scintillators inserted between lead plates. We have collected 5.7×10^3 events over 100 GeV. The number of observed atmospheric gamma rays is 1.0×10^2 events in the energy range of 100 GeV to 1 TeV.

1. Introduction

For the precise determination of neutrino oscillation parameters observed by the Super Kamiokande group, it is important to calculate the flux of atmospheric neutrinos in higher energy of ∼100GeV, which are measured as upward through-going muons. The uncertainty of the absolute flux calculation of atmospheric neutrinos comes mainly from the uncertainties in the primary cosmic-ray flux and nuclear interaction models. Recently, the primary proton and helium spectra have been measured with high precision by the BESS-TeV[1] and AMS groups[2]. On the contrary, the accuracy of the measurement of secondary cosmic rays, which are originated from nuclear interactions of primary cosmic rays in the atmosphere, is still insufficient in the high energy region over ∼100GeV.

In 1998-2000 we have observed atmospheric gamma rays in the energy range of 5GeV to a few 10GeV with the BETS detector at balloon altitudes of 15-32km and at a mountain of 2.77km. We found that nuclear interaction models such as Lund Fritiof7.02 and DPMJET3.03 gave much better agreement with our observations than Lund Fritiof1.6 [3]. For observing primary electrons and atmospheric gamma rays over 100GeV, we developed an advanced detector of the Balloon-borne Electron Telescope with Scintillating fibers (BETS) by a long duration flight of Polar Patrol Balloon (PPB) in Antarctica [4, 5]. In this paper, we present the observation of atmospheric gamma rays in the energy range of 100 GeV to 1 TeV with PPB-BETS at an altitude of ∼35km in Antarctica.

2. Instrumentation and Observations

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 1 mm square cross section for each. The basic structure is similar to the BETS [6], but several improvements were introduced to achieve the observation of electrons and gamma rays up to 1 TeV by using a long duration flight. The area of the detector is 28cm×28cm and the total thickness is 23cm, including spacers placed between sensitive layers. The scintillating fibers perform the 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 adopted for the instrument trigger and the energy measurement. Thus PPB-BETS is an instrument to observe the details of three dimensional shower development with a timing capability. Detailed parameters of the PPB-BETS instrument are described in the references [4].

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 level flight was started at 18:00 on January 4, and continued till 1:46 on January 17, 2004 (UTC) at altitudes of 33-37 km (35km on average). The total duration of the exposure time is 2.96×10^2 hr. The balloon drifted round the Antarctica at ∼65° latitude south from east to west with a speed of $\sim 30 - 35$ km h^{-1}, as presented in Fig. 1. The altitude was controlled to be a flight level of ∼35km with automatic level control system, as shown in Fig. 2.

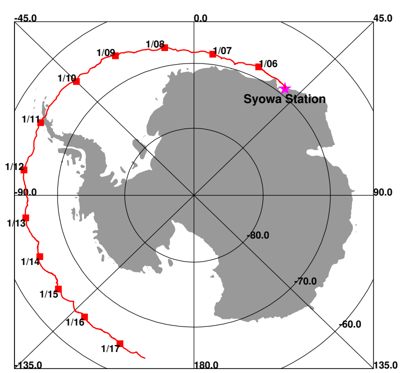


Figure 1. The trajectory of the PPB-BETS in Antarctica.

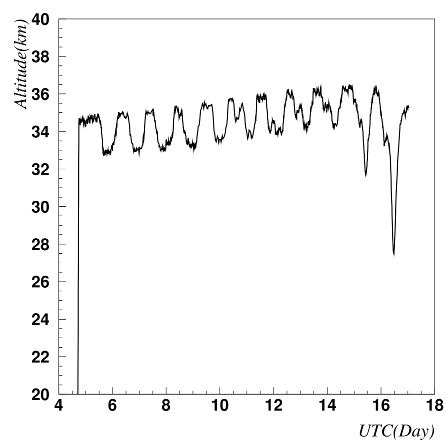
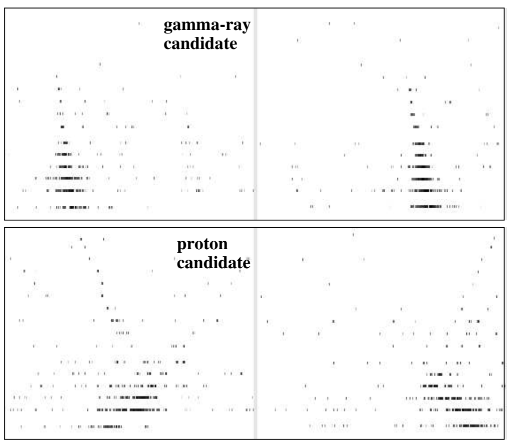


Figure 2. The altitude profile of the PPB-BETS.

The event trigger was executed by two modes, the high-energy (HE) mode and low-energy (LE) mode. The LE mode corresponds to electron observation over 10GeV, and was assigned for the observation during 10 hours just after launching. The data acquired by the LE mode were directly transfered to the Syowa station with a telemetry 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 National Institute of Polar Research in Japan, via a receiving station in US, with an Iridium satellite phone line at a bit rate of 2.4kbps. Gamma rays over 100 GeV are triggered similar to electrons, because they have backscattered charged particles, and have very similar features of shower development as electrons. The number of observed events is 5.7×10^3 for the HE mode and 2.2×10^4 for the LE mode.

3. Data Analysis

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 in the flight was calibrated by the LED fiber on-board. Examples of the reconstructed shower image observed in the flight are presented in Fig. 3. A typical event of an electro-magnetic shower has a narrower lateral spread concentrated along the shower axis. On the contrary, that of a proton-induced shower usually has secondary tracks, and present a wider lateral spread. This difference in lateral shower development is adopted to the separation of gamma rays and electrons from background protons.



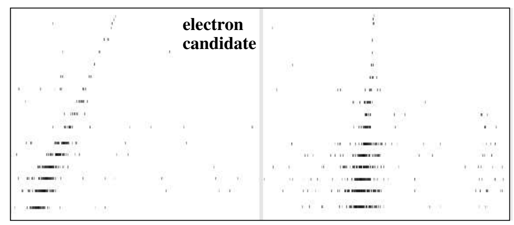


Figure 3. Examples of the shower images in detector space. Typical candidates of a gamma ray, electron, and proton are shown in x and y directions.

The selection of electro-magnetic shower events from backgrounds has been carried out by the method used in BETS as explained below. At first, proton backgrounds are reduced to 5% with the on-board trigger system. The discrimination levels are set with each scintillator. Second, protons are reduced to 10% for the triggered proton events by the selection of contained events in which the shower axis passes through the top and bottom detector, because most of the background events triggered during the flight are particles incident from the side of the detector. Third, we introduced the ratio of energy deposition within 5mm from the shower axis to the total (RE parameter) as described in [6]. By the selection with the RE parameter, protons are reduced to 5% for the events surviving through the above selections. As a result, the total rejection power of protons becomes $0.05\times0.1\times0.05 = 2.5\times10^{-4}$.

As for the selection between gamma rays and electrons, gamma rays could be identified by the no presence of hits in the scintillating fibers at 0 r.l. along the shower axis, as shown in Fig. 3. Figure 4 shows the simulated distributions of the distances of the nearest hit fiber position from the shower axis at the top layer. As incident electrons leave signals on the fibers along the shower axis, the distribution of electrons is concentrated around the distance of 0 mm. On the other hand, as incident gamma rays leave no signals except for the back-scattered particles, the gamma-ray distribution becomes much broader. We selected the events whose distances are larger than 5 mm. Electron events are estimated to be rejected by 98 % from the simulations. As a result, the number of the observed gamma-ray events is 1.0×10^2 in the energy range of 100 GeV to 1 TeV. Preliminary atmospheric gamma-ray spectrum at 7 g cm^{-2} is presented in Fig. 5. The power-law index is -2.7 ± 0.3, and the flux over 100 GeV is consistent with that of the emulsion chambers [7].

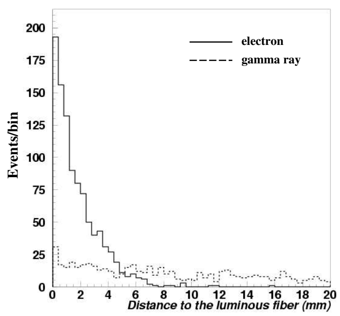


Figure 4. Simulated distributions of the nearest hit fiber positions from the shower axis.

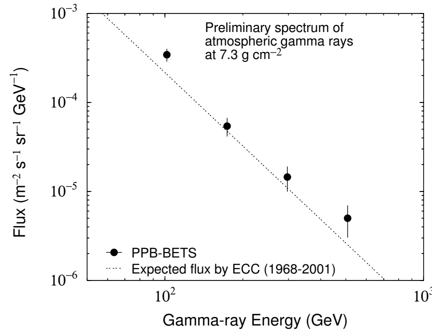


Figure 5. Preliminary atmospheric gamma-ray spectrum at 7 g cm^{-2} observed with PPB-BETS.

4. Summary

We have carried out the long duration balloon observation of gamma rays and electrons with the PPB-BETS in January 2004 at the Syowa station in Antarctica. The duration of the observation was 13 days at a level altitude of ~35 km. Atmospheric gamma rays were successfully observed with the expected performance of the detector, telemetry using Iridium satellite, power supply by solar batteries, and automatic level control using CPU. The total number of the observed events is 5.7×10^3 over 100GeV. The number of the gamma-ray events is 1.0×10^2 over 100 GeV. The analysis will be improved further, and the final energy spectrum will be presented in our future paper.

5. Acknowledgments

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