High Energy Electron Observation by Polar Patrol Balloon Flight in Antarctica

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Abstract

We will carry out the observation of high-energy electrons by the Polar Patrol Balloon (PPB) in Antarctica in December, 2003 at the Showa Station of National Institute of Polar Research. The detector is an imaging calorimeter composed of scintillating-fiber belts and plastic scintillators sandwiched by lead plates. By the 30-days observation, we expect nearly 600 electrons at energies higher than 100 GeV . The performance of detector has been confirmed by the test flight and the accelerator beam test at CERN-SPS.

1. Introduction

Several theoretical studies have revealed the importance of measurement of the electrons in TeV region since these must be only produced in the nearby sources. Then, from these measurements, it is possible to identify the acceleration sites and to define the propagation properties in the Galaxy. The reason why the electron measurements can still not have a sufficient accuracy to meet the requirements by the calculations, is mainly due to the difficulty of observation caused by the copious background protons (more than 100 times in flux) as well

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as the low absolute flux. The detector should, therefore, satisfy the contradicting two requirements of the large scale and the high rejection power.

Although many detectors have been invented to overcome the difficulties during the past $\sim$ 30 years, only the emulsion chambers (ECC) has achieved the observation of electrons above 100 GeV [1]. The Balloon Borne Electron Telescope with Scintillating Fibers (BETS) has been developed as an electronic detector which preserve the superior qualities of ECC. Namely, it can observe the details of 3 dimensional shower development with a timing capability. Our primary aim to measure the energy spectrum in 10 $\sim$ 100 GeV has already been concluded [2]. For the observation over 100 GeV, we have developed an advanced detector of BETS, PPB-BETS, for the long-duration balloon flight in Antarctica.

2. Instrumentation

Basic parameters of the PPB-BETS instrument are given with the comments in Table 1, including the expected performance explained below.

Table 1. Basic Parameters of PPB-BETS.

Parameter	Number	Comment
Energy Range	10 $\sim$ 1000 GeV	by two modes of trigger
Geometrical Factor	550 $\sim$ 600 cm^{2}sr	in the energy region over 100 GeV
Energy Resolution	12 % $\sim$ 18 %	in r.m.s
Angular Resolution	0.35 $\sim$ 0.6 degrees	in r.m.s (better resolution expected)
Detector Weight	200 kg	including un-pressurized container
Power Consumption	70 W	supplied by solar panels
Observation Altitude	$\sim$ 35 km	controlled by auto-level system
Down-link Rate	2.4 kbps	via the Iridium telephone line
	(64 kbps	by the telemetry to the stations)

The PPB-BETS detector has been improved comparing to the BETS in following points. The thickness of lead is increased from 7 to 9 r.l, and the number of plastic scintillators used for the event-trigger and energy measurement is increased from 3 to 9 to observe accurately the shower development. The image intensifier and CCD system for the read-out of scintillating fibers has newly been developed by using a better quality of CCD to avoid the saturation effects of image intensities up to 1 TeV shower. The detector structure and the shower-imaging system are reported in accompanying paper by Kitamura et al. [3].

Since the weight of instrument is very limited as light as 200 kg, we can not use the pressurized gondola to contain the detector. Therefore, we should design the detector to meet the vacuum and heat conditions during the long duration flight. The validity of detector was examined in an environmental test chamber. Moreover, following new functions are added to the PPB-BETS: 1) Power supply system by solar panels, 2) Data telemetry system in up and down link by the commercial Iridium telephone line, 3) Auto-level control system, and so on.

3. Observation

Due to the limited geometrical factor, ~ 0.05 m^2 sr, we should try to float the detector as long as possible. The Showa Station is located in lower latitude (69^{o}00'S, 35^{o}35'E), and the duration of flight in one circle is longer than 20 days [4]. Since recovery of the payload is not scheduled in the experiment, all of the data must be sent to the ground by telemetry. Therefore, we shall adopt an elaborated method for the data acquisition as described in following.

We will use two modes of the event-trigger, the high-energy (HE) mode and the low-energy (LE), which might detect the showers with energies over 10 GeV and 100 GeV, respectively. The LE-mode observation will be done in region near from the station, where the telemetry of 64 kbits in rate can be available. Duration of this observation is expected to be 10 hours. During most of the observation period, the HE-mode observation might be carried out by using the Iridium telephone line at a rate of 2.4 kbits . The data is firstly transmitted to a receiving station in US and secondary to our laboratory in Japan by telephone line. Commands can also be sent by the line via the inverse direction.

In Table 2, the expected number of electrons is listed both in the HE-mode and in the LE-mode. The duration of the HE-mode observation is assumed to be 30 days. Although the statistics around 1 TeV is not enough, we might give the best energy spectrum in the region of 100 GeV $\sim$ 1 TeV, in which a change of spectral index is expected due to the effect of the nearby sources.

Table 2. Expected Number of Electrons by PPB-BETS in Two Modes of Trigger.

Energy(GeV)	10 -100	100-500	>500
HE-mode (1.5 m^2 sr day)	–	550	14
LE-mode (0.025 m^2 sr day)	1800	–	–
ECC (7.7 m^2 sr day $>$ 1 TeV)	51 (100−600 GeV)	55 (>600GeV)	
BETS (0.013 m^2 sr day)	600 (>12 GeV)		

4. Beam Test, Flight Test and Simulation

We have done the beam test of the flight model at the CERN SPS by using the electrons from 10 to 200 GeV and the 150 to 350 GeV. The detection efficiency of the shower trigger system is examined by adjusting the discrimination levels at each scintillator. The results were compared with simulation presented in Fig. 1 to estimate the trigger rate and the data size for the telemetry. The trigger rate in the HE-mode might be 50 per hour including the background protons. Since the electron flux is expected to be nearly one per hour, most of the events are backgrounds. In this rate, we should considerably compress the data size of shower images to meet the telemetry rate of 2.4 kbits. As reported in the paper [3], this difficult development is successfully achieved, and the expected rejection power against protons is also confirmed by the image analysis of the accelerator events. The test flight has also proven that the trigger system can demonstrate the performance expected by simulation. In Fig. 2, as an example of various simulations, the geometrical factor in the HE-mode trigger is presented.

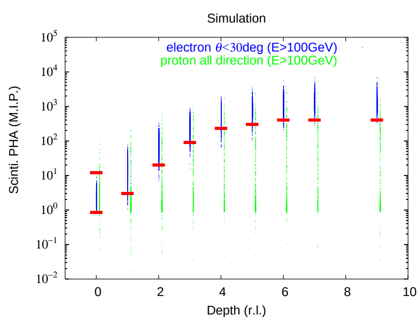

Fig. 1. Simulated shower development of electron and protons over 100 GeV. Lines denote discrimination levels.

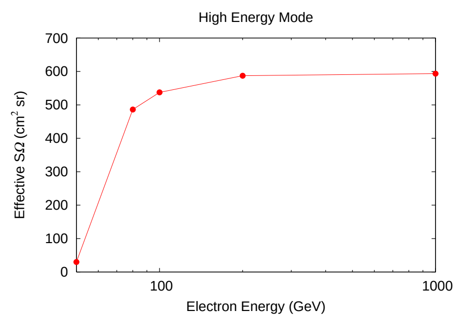

Fig. 2. Energy dependence of the geometrical factor for electrons in the HE-mode by simulation.

5. Summary and Discussion

The PPB-BETS detector has successfully been developed for the observation of electrons beyond 100 GeV. The performance was confirmed by the test flight and the beam tests. The flight is scheduled in December, 2003 for 30 days.

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