Measurements of the Electron Flux from 10 to 100 GeV with the BETS Calorimeter

S.Torii[1], K.Kasahara[2], T.Kobayashi[3], Y.Komori[4], H.Murakami[5], J.Nishimura[6], T.Ouchi[1], Y.Saito[7], T.Tamura[1], N.Tateyama[1], T.Yamagami[7], K.Yoshida[8] and T. Yuda[9]

[1] *Institute of Physics, Kanagawa University, Yokohama, Kanagawa, Japan*

[2] *Department of Electronic Information Systems, Shibaura Institue of Technology, Omiya, Saitama, Japan*

[3] *Department of Physics, Aoyama-gakuin University, Tokyo, Japan*

[4] *Kanagawa Prefectural College, Yokohama, Kanagawa, Japan*

[5] *Department of Physics, Rikkyo University, Tokyo, Japan*

[6] *Yamagata Institute of Technology, Yamagata, Japan*

[7] *Institute of Space and Astronautical Science, Sagamihara, Kanagawa, Japan*

[8] *Department of Industrial Engineering and Management, Kanagawa University, Yokohama, Kanagawa, Japan*

[9] *Institute for Cosmic Ray Research, University of Tokyo, Tanashi, Tokyo, Japan*

Abstract

We report on a new measurement of the electron flux from 10 to 100 GeV observed with the BETS (balloon-borne electron telescope with scintillating fibers) instrument. The detector is an imaging calorimeter consisting of the scintillating-fiber belts of 36 layers and the 8 plates of lead (5mm thick for each). The rejection of the background protons was performed with a power of $\sim$2500 using the shower imaging capability. The balloon observations were carried out in 1997 and 1998 at Sanriku Balloon Center (ISAS) in Japan. The observed flux is compared with previous results and discussed about the diffusion constant in the Galaxy and the local interstellar spectrum by a model of solar modulation.

1 Introduction:

It is commonly understood that high-energy electrons are accelerated in supernova remnants (SNRs), and they lose their energies by synchrotron radiation and by inverse Compton scattering during the propagation through the Galaxy. The energy spectrum of electrons from 10 to 100 GeV is, therefore, a key to investigate the diffusion characteristics in the Galaxy and the source characteristics. Since the energy-loss rate by these interactions is proportional to the square of the energy, the mean life of electrons becomes shorter with increasing of the energy. It is, therefore, suggested that each of the nearby sources can be identified by measurements of the energy spectrum and anisotropy in the TeV region (See for example, Nishimura, 1994).

Observation of high-energy electrons is, however, still quite difficult, although every effort has been done for the past 30 years by several types of detectors. The reason results from the copious hadronic-backgrounds which increases relatively with the increase of energy. This means that an electron detector must meet both requirements of a large geometric factor and a high hadron-rejection power. As such a detector, emulsion chamber (EC) has uniquely achieved in observing the electrons over 100 GeV (Nishimura *et al.*,1980). Despite of its several merits, EC can not be used for long duration exposure because of accumulation of background tracks and flooding by lower energy electrons. It can, moreover, not be used to observe the anisotropy of electrons, since it has no timing information.

The Balloon Borne Electron Telescope with Scintillating Fiber (BETS) has been developed as a detector which preserve the superior qualities of both electronic detectors and EC. Namely, we can observe details of shower starting points and shower profiles with a timing capability. Although the present observations are limited to a few 100 GeV due to the lack of observation time, the BETS instrument is expected to have potential capability in the higher energies. In the following, we shall present results from the balloon flights in 1997 and 1998, of 12.8 hours in total.

2 Balloon Observation:

2.1 Instrument: The BETS instrument consists of an imaging calorimeter, a trigger system and a data acquisition system. The calorimeter consists of 36 layers (18 in each of two orthogonal views, x and y) of scintillating fiber belts with the lead plates of total depth of ~7.1 r.l. Each belt is composed of 280 round fibers (1 mm ϕ each) in one millimeter pitch. The total number of fibers is 10,080 (5,040 for each direction). Each fiber is connected one by one to a clear-fiber for light guide, which has no efficiency to charged particles. This improvement of fibers could considerably enhance the accuracy of image data, and the image-analysis of data became very reliable.

The trigger system is composed of three plastic scintillators incorporated at the top of calorimeter (S_1), the depth of $\sim$ 2 r.l. (S_2) and the bottom (S_3). Each scintillator with a thickness of 1cm is viewed by a photomultiplier through a light guide. Event triggers were generated by three-fold coincidence of these signals, and the trigger condition was optimized by Monte Carlo simulations using the EPICS software packages (K.Kasahara, 1998). By the simulations, it is found that the highest proton-rejection power of $\sim$ 150 at 85% electron efficiency is expected for electrons over 10 GeV with a zenith angle smaller than 30 degrees. In the real observations, capability of the on-board rejection is not so complete as expected since some events which entered from the side could make spurious trigger. The reduction of such events was done by an imaging analysis.

Outputs from the fibers were observed with an image-intensified CCD camera in each direction. The CCD camera has an input window with a diameter of 10 cm and has a gate function which is generated by trigger signal. The signals which exceed a noise level are digitized with an 8-bit flash ADC. One picture has 256 $\times$ 256 pixels.

A detailed description of the instrument is given by Torii *et al.* 1996, 1999a. The performance of detector studied by the accelerator tests at CERN-SPS and by simulations is presented in an accompanying paper (Tamura *et al.*, 1999 paper OG 4.1.6). In Table 1, basic parameters of the instrument are listed.

Table 1: Instrument Parameter

Energy Range	10 GeV $\sim$ a few 100 GeV
Geometric Factor ($\theta < 30°$)	300 cm^2 sr
Proton/Electron Discrimination	$\sim$ 2,500
Energy Resolution	$\sim$ 17 %
Angular resolution	1 degree typical
Total Weight	$\sim$ 320 kg
Power Consumption	130 W (at maximum)

2.2 Balloon Flight: The balloon flights were carried two timesat the Sanriku Balloon Center (39.2°North Latitude 141.8°East Longitude); one on June 2, 1997 and the other on May 24, 1998. The vertical rigidity cut-off is about 10 GV. The data were collected for 4.5 hours at a level altitude of 35 $\sim$ 36 km in 1997 and for 8.3 hours at a level of 34 $\sim$ 35 km in 1998. Rate of event trigger was $\sim$ 1.7 Hz.

2.3 Data Analysis: Shower images in the fiber space of detector were reconstructed from the CCD pixel images, and the shower axes were obtained by an energy-weighted least-square fitting for the images in detector. Electrons were selected by the following conditions.

1) The shower axis passes through all scintillating-fiber layers.
2) The zenith angle is less than 30 degrees.
3) Charge of the incident particle is single.
4) Ratio of energy-deposition within 5mm from the shower axis in total (RE) is larger than 0.7.

The condition of 4) was obtained from an analysis of simulated events. The events generated from realistic energy spectra of electrons and protons are selected by the conditions of 1) , 2) and 3) by the same analysis of the real events. Figure 1 presents RE distribution of such simulation events. We assumed in the simulation that the integral flux of protons is larger by 150 times than that of electrons at 10 GeV. The number of protons in the figure is reduced by 1/120 by the selections. Furthermore, if we select the events of which RE is higher than 0.7, the protons are rejected by 95 % remaining the 85 % electrons.

The observed RE distribution presented in Fig.2 is very consistent with the simulation. Therefore, the events selected by the condition of 4) are most likely electrons with a contamination of protons of $\sim$ 6 %. Gamma-rays were also mostly rejected by the shower trigger and the condition of 3).

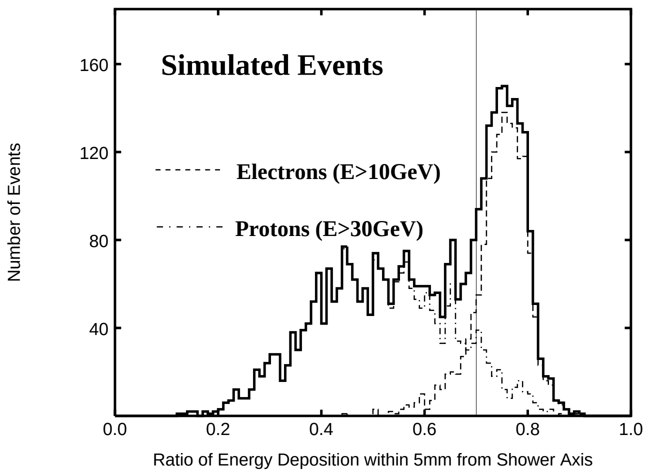

Figure 1: Distributions of REs for the simulated proton and electron events which are selected by the conditions which are same with the experiment (see text).

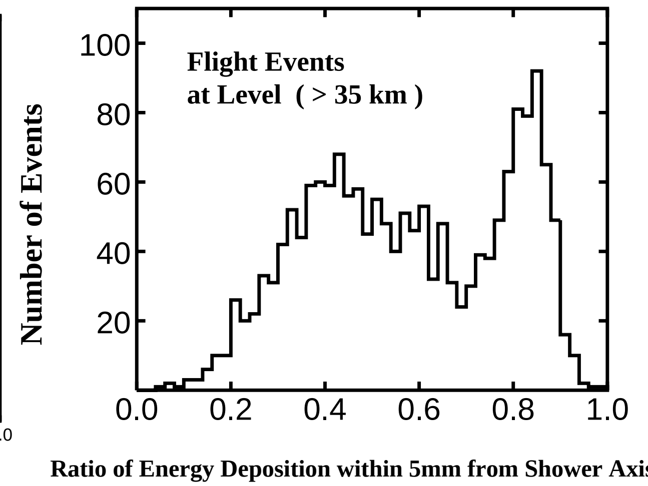

Figure 2: Observed RE distribution for the flight events at an altitude over 35 km in 1997. The events are selected by the conditions of 1) to 3) in text.

3 Electron Flux:

Table 2 shows raw number of the observed electron candidates in each energy interval. The electron fluxes were obtained from the numbers considering the energy dependence of geometric factor and energy resolution. (Tamura *et al.*, 1999 paper OG 4.1.6). Correction factors for the flux were calculated for the atmospheric effects (21.2 %), the proton/electron ratio in RE distribution (11.5 %), the dead time of data acquisition (19.5 %) and the effect of energy resolution (4 %). The weighted average-energy and the weighted energy-interval were calculated using a power index of -3.

Table 2: Raw number of electron-candidates.

Energy(GeV)	June 2, 1997	May 24, 1998	Sum of 2 flights
11.09 - 13.91	102	163	265
13.91 - 17.45	72	123	195
17.45 - 21.89	37	73	110
21.89 - 30.76	40	57	97
30.76 - 43.22	23	37	60
43.22 - 60.71	12	22	34
60.71 - 85.30	5	8	13
85.30 - 119.84	0	6	6
Total	291	480	780

Figure 3 presents the results of electron flux from 10 to 100 GeV. Our flux is considerably smaller than previous observations. It is, however, consistent with the recent measurement of all-electrons by the HEAT detector (Barwick *et al.*, 1998) around a few 10 GeV. The azimuthal-angle distribution was obtained for the electrons with an energy from 8 GeV to 14 GeV. The distribution has an expected excess from the east and gives a direct proof of the hadron rejection power around 10 GeV.

4 Summary and Discussion:

The BETS calorimeter has successfully observed electrons using a new technology of shower imaging with scintillating fibers. The observation was carried out under $\sim$ 6 g/cm^2 of average residual atmosphere in 1997 and 1998. Our final conclusion on the electron energy spectrum will be published after minor corrections on the proton-rejection power over several 10 GeV.

The best fit of flux value compared with diffusion-model calculations gives a diffusion coefficient of $1 \times 10^{28} (E/GeV)^{0.3}$ cm^2/sec for the SN rate of once per 30 years in the Galaxy (Nishimura *et al.*, 1997). The estimated average magnetic-field in the Galaxy is obtained to be $\sim 7\ \mu G$ comparing the electron flux around 10 GeV to the radio flux. Solar modulation effects are seen around 10 GeV by calculations using the Force Field Approximation (Komori *et al.*, 1999). Local interstellar spectrum obtained from the observed flux will be presented at the conference.

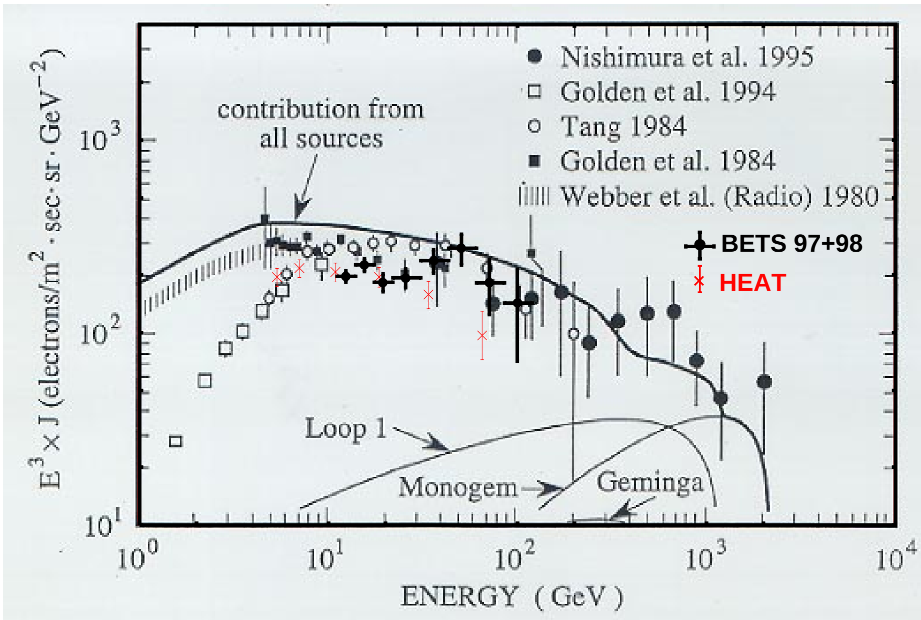

Fig.3: Comparison of our results (BETS 97+98) with the all-electron flux of HEAT and previous observations. Solid line presents the calculated spectrum by a diffusion model for all sources; dotted the nearby sources.

The rejection power of the background protons can be improved to be 10^4 by an image analysis of neural-network technique as expected by our simulations. We are trying to confirm the rejection power by the accelerator events.

Further balloon experiments will be carried out to observe the electrons up to several 100 GeV with sufficient statistics. It is considered to use a BETS-type detector for the TeV observation on ISS/JEM (Torii *et al.*, 1999b paper OG 4.2.5 Torii *et al.*, 1999c).

Acknowledgments

We are indebted to the crew of the Sanriku Balloon Center, ISAS for the successful balloon flight. We express sincere thanks to the technical staffs in Kanagawa University for their helps in manufacturing of the detector. This work is partially supported by Grants-in-Aid for Scientific Research (A), the Ministry of Education, Science, Sports and Culture.

References

Barwick, S.W. *et al.* 1998, ApJ 498, 779.
Kasahara K. 1998, the EPICS Home Page at the web site of http://www.b6.kanagawa-u.ac.jp/~kasahara.
Komori Y. 1999, in preparation.
Nishimura J. *et al.* 1980, ApJ 238, 394.
Nishimura J. Proc. of Towards a Major Atmospheric Cherenkov Detector III (Tokyo, 1994), 1.
Nishimura J. *et al.* Proc. 25th ICRC (Durban,1997) 4, 233.
Tamura T. *et al.*, Proc. 26th ICRC (Salt Lake City, 1999) OG 4.1.6.
Torii, S. *et al.*, Proc. SPIE (Denver 1996) 2806, 145.
Torii, S. *et al.* 1999a, submitted to Nucl. Instr. Meth.
Torii, S., *et al.*, Proc. 26th ICRC (Salt Lake City, 1999b) OG 4.2.5.
Torii, S., *et al.*, AIP Conf. Proc. STAIF99 (Albuquerque, 1999c) 458.