Observations of Primary Electrons with an Emulsion Chamber by Automatic Scanning Method

Y.Sato,[1] R.Ohmori,[1] Y.Komori,[2] K.Yoshida,[3] N.Tateyama,[3] T.Shirai,[3] T.Yuda,[4] T.Kobayashi,[5] T.Yamagami,[6] Y.Saito[6] and J.Nishimura[6]
(1) Utsunomiya University, Utsunomiya, Japan.
(2) Kanagawa Prefectural College, Yokohama, Japan.
(3) Faculty of Engineering, Kanagawa University, Yokohama, Japan.
(4) Institute for Cosmic Ray Research, University of Tokyo, Chiba, Japan.
(5) Department of Physics, Aoyama Gakuin University, Sagamihara, Japan.
(6) The Institute of Space and Astronautical Science, Sagamihara, Japan.

Abstract

This experiment is designed to observe the accurate electron spectrum beyond 20GeV with an emulsion chamber, which was exposed to cosmic rays at a balloon altitude. The balloon was launched from Sanriku Balloon Center (ISAS, Japan), in 2001. A new automatic scanning system is introduced for scanning and analysis of the electron showers in the chamber. The performance of this system was carefully studied by using calibration plates exposed to electron beams from the accelerator. Scanning and analysis for primary electrons beyond 20 GeV and the future prospect of obsevations using this method is reported.

1. Introduction

It is commonly understood that most of high-energy electrons in the cosmic rays are accelerated in supernova remnants (SNRs), and they lose their energies by the processes of synchrotron and inverse Compton scattering during the propagation through the Galaxy. Thus, the energy spectrum of electrons brings us a unique information of the propagation in the Galaxy and the acceleration process of the cosmic-ray electrons[2,3,7,9].

The emulsion chamber (EC) is the only detector succeeded to observe the cosmic-ray electrons in TeV region up to now. Although the emulsion chamber is almost an ideal detector for the electron spectrum measurements, one of the difficulties is the detection of electrons below a few hundred GeV, where we need a skill and laborious microscope scanning of the emulsion plates. This microscope scanning of a large area prevents to obtain the accurate electron spectrum below a few hundred GeV with this detector, while a naked eye scanning on the sensitive X-ray films is effectively used beyond this energy region[7,9]. Thus, it has been long desired to introduce a new scanning method to detect the low energy electron

pp. 1821–1824

showers. Nagoya Group has developed an efficient automatic scanning system for the Neutrino Oscillation experiment(CHORUS) with a hybrid detector consisting of nuclear emulsion for the precise visual analysis[5]. We apply this system for scanning and analysis of the low energy electron showers in the emulsion chamber exposed to cosmic rays at balloon altitude.

2. Balloon experiment

This emulsion chamber consists of 24 nuclear emulsion plates and lead plates. Each emulsion plate is an 800μm thick acrylic plate coated on both sides with 90μm thickness emulsion (Fuji ET7D). The dimension is 40cm x 50cm and the depth is 9 radiation length. The reference marks were put on each plate for trace back of the minimum ionization track through the chamber.

The balloon flight was carried at the Sanriku Balloon Center in May, 2001. The effective exposure time was 18h 28m at a level altitude of 36.1km (5.5g/cm^2). The chamber was flipped when it attainded to the observation altitude. This is to discriminate the background showers due to the atmospheric electrons and gamma rays during balloon ascending and after the flight termination.

3. Automatic Scanning System and Calibration

A full automatic emulsion scanning system developed by CHORUS group consists of a motor-driven microscope XYZ stage with a controller, a fast read-out CCD and a special hardware for 3D image processing. It is called "Track Selector"(TS). It takes the image of 16 sliced layer of an emulsion plate, each of 512 x 512 pixels with a field of view of 147 x 106μm^2, and then outputs the data of the position and angle of each track in the emulsion plate[8].

To see the performance of the track selector, we first check the detection efficiency of the electron tracks as a function of its incident angle to the emulsion plate. We exposed emulsion plates to the electron beam from the linac at Tohoku University. The energy of electrons is 200MeV, and the electron beam density was adjusted to about 10 tracks/mm^2. Incident angles, θ, of electron beam to the vertical of emulsion plate were set as $tan\theta = 0.02$, 0.08, 0.15, 0.2, 0.25, 0.30, 0.35, 0.40. Track detection efficiency was measured as a function of incident angle, and the results are as shown in Figure 1. The detection efficiency of our system is higher than 98% in the incident angle region of $tan\theta \leq 0.3$. No significant dependence on the azimuthal angle of ϕ was observed in this angular region.

4. Analysis

We analyze showes in the follwing 4 steps. (1) Scanning and selection of shower candidates, (2) Trace back, (3) Electron identification and (4) Energy

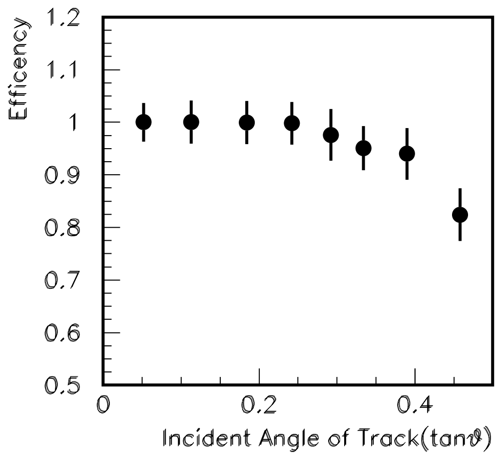

Fig. 1. Detection efficiency as a function of incident angles of the track.

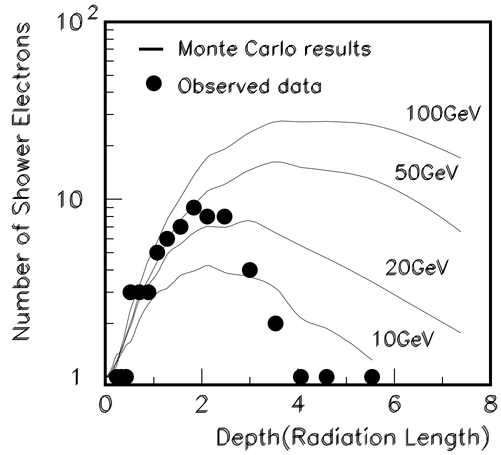

Fig. 2. Transition of shower particles within a circle of radius 200μm and angular spread within 0.07rad.

determination. We scan the emulsion plate at 3 r.l. depth with the track selector, and readout all tracks of $tan\theta \leq 0.3$. A shower candidate in the track data is identified with a following offline program. A relative position,R_{ij}, and the angle,θ_{ij},ϕ_{ij} of two arbitrary track combination are calculated from the recorded data. Next we search for a group of tracks with $R_{ij} \leq 150\mu m$, $\theta_{ij} \leq 0.07rad$ and $\phi_{ij} \leq \pi$. If the conditions are satisfied, we take it as a shower candidate. The efficiency of electron shower recognition by this procedure is estimated by using the Monte Carlo showers calculated with EPICS[6] at 3 r.l. depth in our emulsion chamber. The efficiency was found to be higher than 80% at 20GeV, 95% at 50GeV, 100% at 100GeV, respectively, within a domain of $tan\theta \leq 0.3$.

Selected shower candidates are traced back to the top plate of the chamber by searching for a track having the predicted angle and position. We inspect carefully the starting behaviour of a shower to see whether the shower is initiated by an electron[9]. Electron energies are estimated by comparing the observed data with theoretical transition curve for the number of shower particles within a circle radius of $200\mu m$. An example is shown in Figure 2. The accuracy by using the track length[9] is $\Delta E/E \approx 30(10GeV/E)^{1/2}\%$ for $E \leq 100GeV$. This is estimated by the track length distribution of Monte Carlo shower with EPICS[6].

Our effective total exposure is $S\Omega T = 3.4 \times 10^3 m^2.s.sr$, where $\Omega = 0.259sr$ for accepted angles of $tan\theta \leq 0.3$, $S = 40 \times 50cm^2$, and exposure time is 18h 28m. The number of electrons are expected as almost $1/cm^2(E \geq 10GeV)$, $0.2/cm^2(E \geq 20GeV)$, $0.02/cm^2(E \geq 50GeV)$, and $0.005/cm^2(E \geq 100GeV)$ which are calculated from the published data of primary electron spectrum[1,4,7,10]. At the time of this writing, about 6000 shower candidates are found after scanning 60 cm^2 at

3r.l. depth. By tracing back and analyzing these candidates, 15 electrons beyond about 20GeV are detected.

5. Summary and Discussions

The performance of track selector system is studied using emulsion plates exposed to electron beams from the accelerator. The track detection efficiency is higher than 98% and no azimuth angle dependence is observed within the angular range of $tan\theta \leq 0.3$. Fifteen electrons beyond about 20GeV are detected in the area of 60 cm^2, which is almost consistent with the existing data[1,4,7,10] considering the statistical errors and exposure condition of this chamber. Accumulation of the data are now in progress, and some details of the electron spectrum observed by this automatic scanning system will be presented at the meeting.

It is clear that we can make a significant improvement of the precision of data by increasing the processing speed. We are now going to introduce a upgraded system developed for CHORUS experiment by Nagoya group with higher processing speed, having better detection efficiency for the tracks of large zenith angles. The processing speed for general scanning is dramatically increased at least one hundred times, and we can also make a precise electron spectrum measurements below 100GeV region where it was not quite effective in the past emulsion chamber experiments.

6. Acknowledgements

We express our gratitude to the staff of the Sanriku Balloon Center, ISAS for the successful balloon flight of this experiment. We also wish to acknowledge the fruitfull discussions of Dr.T.Nakano of CHORUS group in Nagoya University.

7. References

1. Aguilar M. et al. 2002, Phys. Rep., 366, 331
2. Aharonian F.A. et al. 1995, A A, 294, L41
3. Berezinskii V.S. et al. 1990, Astrophysics of Cosmic Rays, ed. Ginzburg,V.L. (North-Holland)
4. DuVernois M.A. et al. 2001, ApJ, 559, 973
5. Eskut E. et al.(CHORUS Coll.) 1997, Nucl. Instr. and Meth. A401, 7
6. Kasahara K. 2001, http://eweb.b6.Kanagawa-u.ac.jp/Kasahara
7. Kobayashi T. et al. 2001, Adv.Space.Res. 26, 1827
8. Nakano T. 1997, Ph.D. Thesis, University of Nagoya
9. Nishimura J. et al. 1980, ApJ 238, 394
10. Torii S. et al. 2001, ApJ, 559, 973