

Performance of BETS SciFi-Pb Imaging Calorimeter for Electron Observation

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Abstract

Performance of the BETS detector as an electron imaging calorimeter was studied by electron and proton beams at CERN-SPS in 1996 and 1997. It is confirmed that the rejection power against proton backgrounds is better than 4×10^{-4} in the energy range between 10 GeV and 100 GeV, the energy resolution ranges 15~18 %, and the angular resolution is $0^\circ.8 \sim 1^\circ.3$. The performance is adequate for observing the electrons with a reliable accuracy.

1 Introduction:

The BETS (Balloon-borne Electron Telescope with Scintillating fibers) instrument has been developed for high-altitude balloon flights in order to observe the cosmic ray electrons with energies over 10 GeV (Torii *et al.*, 1998). The detector is a lead/SciFi (Scintillating Fiber) sampling calorimeter consisting of 36 layers of the SciFi belts and 8 lead plates (5 mm thick each). The design of detector was optimized by simulations especially for the rejection power against the proton backgrounds. The ratio of the integral flux of protons to that of electrons is about 150 in the energy range over 10 GeV. Protons are reduced to about 1/120 by the trigger system composed of three plastic scintillators placed at depth of 0, 1.8, 7.1 radiation length (r.l.). Thus the ratio of protons to electrons acquired with BETS detector during an observation is estimated to be about 1.3. Proton backgrounds are to be rejected in the off-line analysis by the profile of the shower images. As described in Murakami *et al.*(1998), a technique to discriminate protons from electrons with a parameter, RE (the ratio of energy deposition within 5 mm from the shower axis), was turned out to reduce the triggered protons to about 1/20 with simulated data. The total rejection power against the protons is consequently expected to be 5×10^{-4} with the technique. Another method with a neural network analysis achieved the total rejection power of 1×10^{-4} with simulated data. However it is clear that real data acquired with the accelerator are essential to study the performance of detector.

2 Calibration Test at CERN-SPS:

For calibrating the detector by accelerator beam, we used protons accelerated up to 450 GeV as the primary beam in the main ring of CERN-SPS. In 1996, electrons of the tertiary beam in the energy range between 5 GeV and 100 GeV were available. The calibration experiment was made with the electron beams set to the energies of 5, 10, 20, 30, 50, 70, and 100 GeV. In 1997, proton of the secondary beam with an energy of 250 GeV was the beam of the highest available energy. Protons with lower energies were available as the tertiary beam. The proton beam energies of 60 GeV, 120 GeV, and 250 GeV were used for the calibration. Both electron and proton beams were operated at the X-5 test beam line.

2.1 Energy Calibration: Incident energy of electron is determined with the bottom plastic scintillator placed at 7.1 r.l. near the shower maximum of the electron with the energy over 10 GeV. Energy resolution as which the root mean square of the pulse height of the bottom scintillator is defined for each incident energy is shown in Figure 1. It ranges between 15~18%. If energy resolution depends on the incident energy, a shape of electron spectrum is deformed through measurement. The original electron flux is, however, obtained by simply multiplying a flux observed with BETS detector by a certain factor, because the energy resolution may be regarded as a constant in the energy range.

2.2 Angular Response: Shower axis was determined by fitting a line to the shower image. Distributions of fitted angles of shower axes were obtained from data taken with electron beams of several energies mentioned above. Angular resolution was obtained by fitting a Gaussian function to the distribution of angles of shower axes. Angular resolution as which the standard deviation of Gaussian distribution is defined for each incident energy of electron is shown in Figure 2. It ranges between $0^{\circ}.8$ and $1^{\circ}.3$.

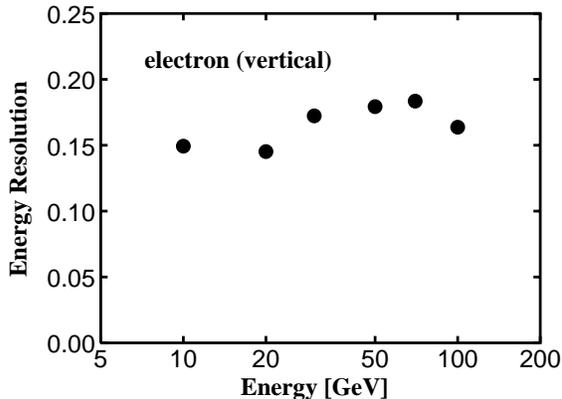


Figure 1: Energy resolution as which the root mean square of pulse height of the bottom scintillator is defined.

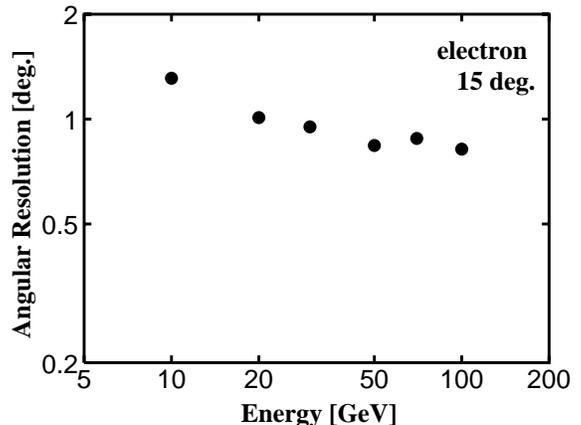


Figure 2: Angular resolution for electron beams of each energy with the incident angle of 15° .

2.3 Separation of Electron from Proton: Some examples of distributions of the RE parameter for electron and proton beams are shown in Figure 3. The distribution for electron has a narrower peak in large RE, while that for proton is widely spread. It is consistent with the result estimated with simulated data (Torii *et al.*, 1999a). The proton backgrounds can be reduced further by RE-cut, rejecting the events with the RE less than 0.7. Probability that the triggered events survive through the RE-cut with the criterion of $RE \geq 0.7$ for each incident energy of electron and proton is shown in Figure 4 as a result of the beam experiments. The probabilities for electrons with the incident angles of 0° , 15° , and 30° are indicated by open circle, open triangle, and open square, respectively. That for protons with the incident angles of 0° , 30° , 60° , and 90° are indicated by circle, square, plus, and times, respectively. An additional horizontal axis for the incident energy of proton is drawn by taking into account that the deposition energy is reduced to about 1/3 for the protons in comparison to the electrons with the same incident energy. Probabilities that the triggered protons with the incident energy of 60 GeV and 250 GeV survive through the RE-cut are estimated to be 5 % and 6 % respectively for an incident angle of 19° , which is an averaged angle of events observed in the balloon flight in 1997 and left after all event reductions. The total rejection power against the proton backgrounds consequently reaches to about 4×10^{-4} . However, in order to get a conclusive

rejection power more detailed study is necessary on the dependence of the rejection power on the incident angle.

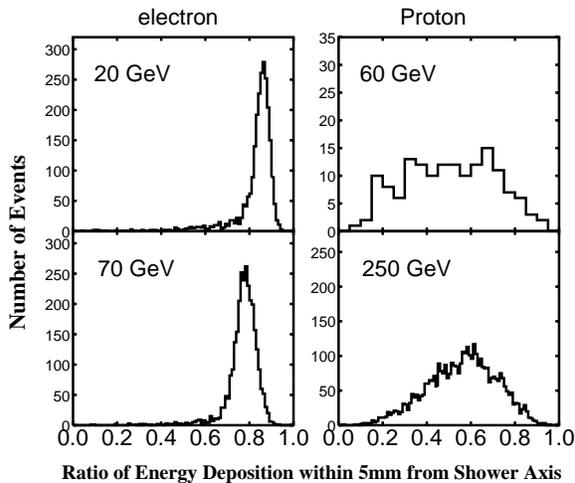


Figure 3: Distributions of the RE parameter for electron and proton beams with vertical incident angle.

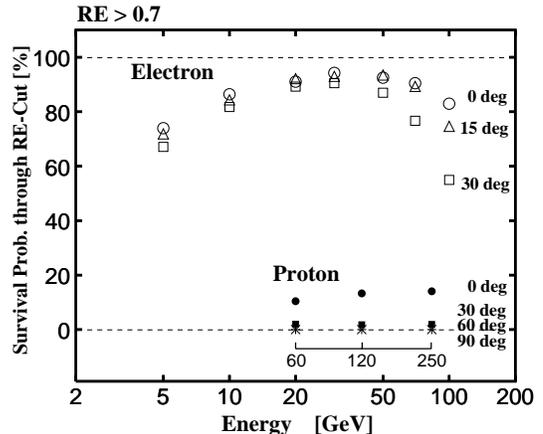


Figure 4: Energy dependence of survival probabilities through RE-cut with a criterion of $RE \geq 0.7$ for triggered events. See text for details.

2.4 Reduction of Gamma-rays: At an altitude of the balloon flight some secondary gamma-rays are to be observed. Gamma-rays with back scattered particles can be triggered by BETS detector. Trigger efficiency for the gamma-rays ranges from 1.7~9.8 % in the energy range between 10 GeV and 100 GeV according to simulations. In order to reject the gamma-rays, it is examined whether a hit (fiber with a signal) exists near the shower axis in the top SciFi belts at 0 r.l. A result of accelerator experiments indicates that almost all events of electrons have more than one hit within 5 mm from the shower axis, while about a half of the triggered gamma-rays have no hit within 5 mm from the shower axis according to simulations. Figure 5 shows probabilities that the triggered electrons or gamma-rays have at least one hit within 5 mm from the shower axis in the SciFi belts at 0 r.l. and survive through γ -cut. In analyzing data obtained by the balloon observations, events with no hit within 5mm from shower axes at 0 r.l. are regarded as gamma-rays and they are to be rejected (γ -cut).

3 Effective Acceptance:

Figure 6 shows dependence of the effective acceptance of BETS detector on the incident electron energies. The effective acceptance was estimated with events simulated by the EPICS code (Kasahara, 1998). The detailed detector configuration and dimensions of BETS, which were used for the simulation, are described in Torii *et al.*, 1999b. The effective acceptance includes effects of the on-line trigger condition determined with three plastic scintillators mentioned above, the rejection of event with an angle of fitted shower axis larger than 30° (angle-cut), and the other rejection of event with fitted shower axis coming out of the bottom scintillator at a distance of less than 20mm from the edge of the scintillator (edge-cut). The edge-cut is applied so as to reject the partially contained showers, which can appear to have lower energies than actual energies and can cause fault parameters obtained from image analysis. The criterion of 20mm for the edge-cut is tentative, and it may be possible to use smaller one.

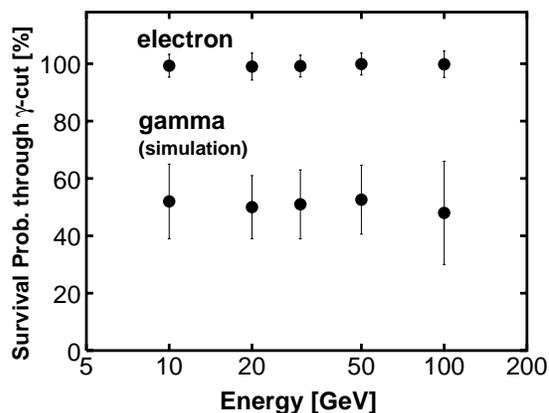


Figure 5: Survival probabilities of electrons and gamma-rays through γ -cut.

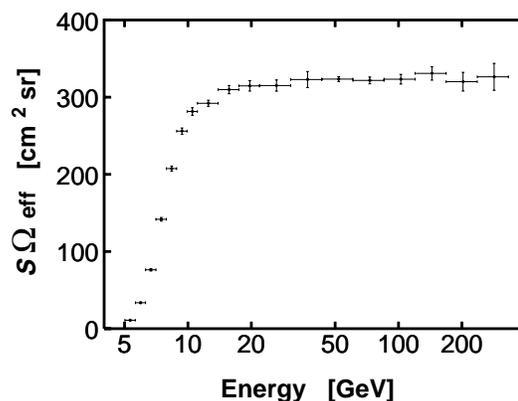


Figure 6: Effective Acceptance estimated with simulated events. The acceptance includes the effects of the trigger condition, shower angle-cut, and bottom edge-cut.

4 Summary:

BETS was proved to have the sufficient performance expected from simulations for observing the cosmic ray electrons. More detailed study on efficiencies of electrons and protons for the event reductions is necessary to derive an absolute flux of electrons around several 10 GeV with high accuracy. The rejection power against the proton backgrounds is requested to be better than 10^{-4} for the detection of electrons with higher energies than 1 TeV. New techniques to discriminate electrons from protons, for instance with a neural network method, are under investigation with the data taken at CERN-SPS and with those simulated by EPICS code.

5 Acknowledgments:

We extend sincere thanks to Dr. S.Suzuki, Prof. P.Picchi, Prof. L.Periale, Dr. L.Gatignou, and other staffs in CERN for their support in the accelerator experiments. We are indebted to the crew of the Sanriku Balloon Center, ISAS for the successful balloon flights. We express sincere thanks to the technical staffs in Kanagawa University for their helps in manufacturing of the detector. This work was partially supported by Grants-in-Aid for Scientific Research (A) and International Scientific Research.

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