Cosmic-Ray Proton and Helium Spectra Measured with BESS-TeV

S. Haino,[1] K. Abe,[3] K. Anraku,[1,a] Y. Asaoka,[1,b] H. Fuke,[1] N. Ikeda,[3] M. Imori,[1] A. Itasaki,[3] K. Izumi,[1] T. Maeno,[3,c] Y. Makida,[2] S. Matsuda,[1] N. Matsui,[1] T. Matsukawa,[3] H. Matsumoto,[1] J. Mitchell,[4] A.A. Moiseev,[4] J. Nishimura,[1] M. Nozaki,[3] H. Omiya,[2] S. Orito,[1,*] J.F. Ormes,[4] T. Sanuki,[1] M. Sasaki,[4] E.S. Seo,[5] Y. Shikaze,[3] R.E. Streitmatter,[4] J. Suzuki,[2] Y. Takasugi,[3] K. Tanaka,[2] T. Taniguchi,[2] K. Tanizaki,[3] T. Yamagami,[6] A. Yamamoto,[2] Y. Yamamoto,[1] K. Yamato,[3] T. Yoshida,[2] and K. Yoshimura[2]

(1) The University of Tokyo, Tokyo, 113-0033, Japan
(2) High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, 305-0801 Japan
(3) Kobe University, Kobe, Hyogo, 657-8501, Japan
(4) NASA/GSFC, Greenbelt, Maryland, 20771, USA
(5) University of Maryland, College Park, Maryland, 20742, USA
(6) Institute of Space and Astronautical Science (ISAS), Sagamihara, Kanagawa, 229-8510, Japan

Abstract

In order to measure primary cosmic-ray spectra of protons and helium nuclei up to several hundred GeV/n, the BESS superconducting spectrometer was upgraded. We developed new drift chambers to obtain about one order higher momentum resolution. A balloon flight was performed at northern Canada, with a live data-taking time of 11 hours in August 2002. The whole detector system functioned as designed during the entire flight. The maximum detectable rigidity of 1.3 TV was achieved.

1. Introduction

Protons and helium nuclei are two dominant components among primary cosmic-ray particles. Their absolute fluxes and spectrum shapes are fundamental information in cosmic-ray physics. They are also indispensable for calculation of the accurate fluxes of atmospheric neutrinos. Although BESS-98 and other experiments provided precise proton and helium spectra up to around 200 GeV/nucleon [2,5,6], there is no precise measurement using a magnetic spectrometer in the higher energy. For the extension of the spectra up to several hundred GeV, we upgraded the BESS detector [1,3,7] as the "BESS-TeV Spectrometer" to improve the rigidity resolution.

pp. 1–4

2. The BESS-TeV Spectrometer

As shown in Fig. 1, the BESS-TeV spectrometer has the same design concept as that at BESS-98. The magnetic rigidity of an incident particle is obtained from its curvature in a solenoidal magnetic field of 1 Tesla measured by a central JET-type drift chamber (JET) and two inner drift chambers (IDCs). The BESS-TeV upgrade consists of three developments; (1) new JET and IDCs which can measure the incoming particle track at 48 points in maximum, twice as those of BESS-98, with better spacial resolution, (2) Outer Drift Chambers(ODCs) installed outside the solenoid to obtain twice long track length, and (3) new FADC modules to read increased number of signals from drift chambers within a limited power capacity of primary batteries. According to a simple simulation, the maximum detectable rigidity of 1.4 TV was expected.

3. Calibration of Drift Chambers

To obtain reliable absolute flux of primary cosmic-rays nearly up to 1 TeV, much higher reliability of the absolute rigidity measurement is required for BESS-TeV. Therefore, a new off-line calibration procedure was developed for the new drift chambers. In this procedure, calibration parameters are reduced as small as possible. Only a few common parameters such as drift velocity, Lorentz angle correction and FADC time offset are calibrated. The procedure uses a standard template of drift properties calculated by Garfield/Magboltz [4,8] from

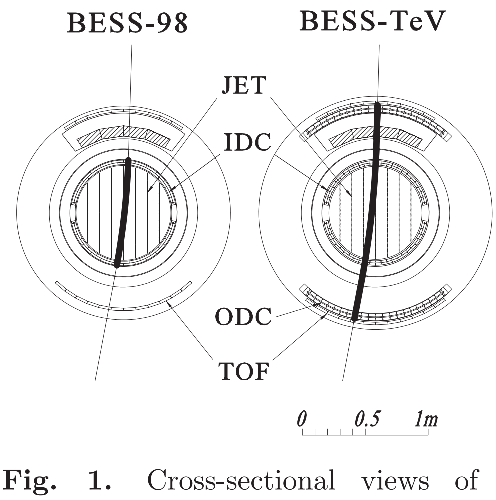

Fig. 1. Cross-sectional views of BESS-98 and BESS-TeV spectrometer. Thick lines represent the track length used in rigidity measurements.

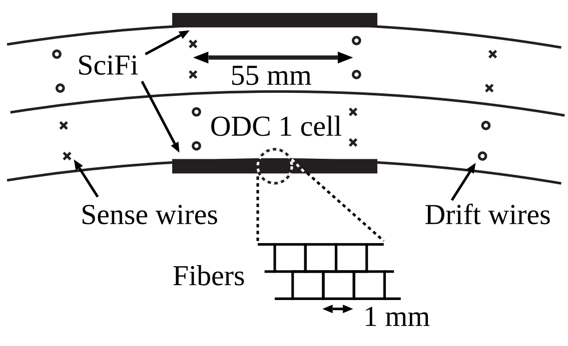

Fig. 2. Schematic view of SciFi mounted on ODC

the detailed geometries of wires and etched patterns. The nonlinear effects due to the distortion of the electric field are corrected using the data. Considering the variations of the pressure and temperature of the chamber gas, the calibration is carried out for each one-hour run.

Especially for the calibration of ODCs, scintillating fiber counters (SciFi) were installed to provide absolute position references, since hit positions measured by ODCs are most important to determine the accurate deflection of high energy particles. As shown in Fig. 2, a set of SciFi consists of 2 layers of 1 mm^2 square-shaped scintillation fibers and is mounted on each inner and outer of ODC, covering one cell. As an overlap of two fiber layers is 0.5 mm, a residual between a ODC track and the center of a SciFi hit distributes in 0.5 mm width. Accumulating enough numbers of events, the location of the center of the distribution becomes an accurate reference of the order of 10 μm. The calibration parameters of ODC are derived so that the center of the distribution becomes zero.

4. Performance of Rigidity Measurement in the BESS-02 Flight

The balloon for the BESS-TeV was launched from Lynn Lake, Canada (cutoff rigidity 0.4 GV), in August 2002. The balloon kept the level altitude of an atmospheric depth of 4.7 g/cm^2. We accumulated 11.8 M events of cosmic-ray data during the floating period with the data-taking live time of 11.3 hours.

The overall spacial resolutions of the drift chambers were estimated from their residual distributions defined as the difference between the measured and fitted positions. Spacial resolutions better than 160 μm were achieved both for JET and IDCs as designed during the entire flight. The calibration using the SciFi was succesful and a spacial resolution of 150 μm was achieved for ODC as shown in Fig. 3. The performance of the rigidity measurement was also evaluated from the combined fit of the points measured by JET, IDCs, and ODCs for high energy particles. Fig. 4 shows the distribution of the deflection resolution evaluated in the track-fitting procedure. The peak position of 0.77 TV^{-1} corresponds to a MDR of 1.3 TV. Although the designed rigidity resolution was achieved during the flight, the absolute value of the measured rigidity still needs to be calibrated. Especially, the alignment between JET and ODCs is important to obtain accurate absolute rigidity. Though the installations of drift chambers were performed with keeping the precision of 100 μm, further precise alignment needs to be obtained at an order of 10 μm by using the measured data.

5. Summary and Conclusion

The absolute energy spectra of primary cosmic-rays will be obtained with small systematic errors owing to the precise and reliable rigidity measurement enabled by the newly developed drift chambers and a calibration procedure. Al-

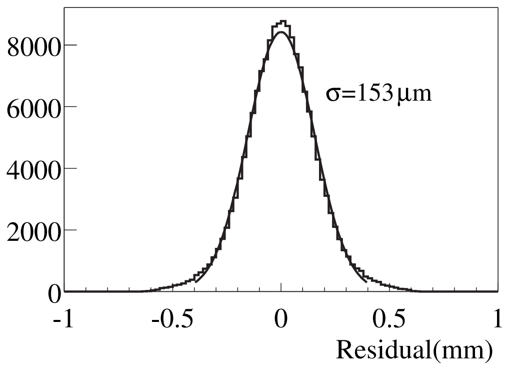

Fig. 3. Residual distribution of ODC

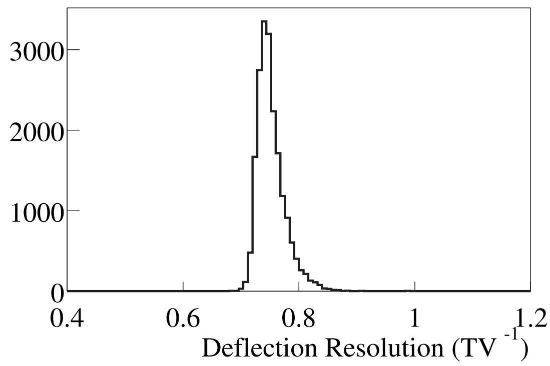

Fig. 4. Distribution of the deflection resolution.

though an estimated MDR of 1.3 TV was achieved, to keep the statistic errors around 10% by using the flight data obtained during a live time of 11 hours, the energy spectrum limits for proton and helium nuclei are expected to be 600 GeV and 300 GeV/nucleon respectively. The resultant primary cosmic-ray spectra measured with BESS-TeV will be discussed at the conference.

Acknowledgment

The BESS-TeV experiment has been supported by Grand-in-Aid for Scientific Research on Priority Areas (12047227 and 12047206) from the Ministry of Education, Culture, Sports Science and Technology (MEXT). We would like to thank NASA, ISAS, ICEPP, and KEK for their continuous support.

[a] Present address: Kanagawa University, Yokohama, Kanagawa 221-8686, Japan
[b] Present address: ICRR, University of Tokyo, Kashiwa, Chiba 227-8582, Japan
[c] Present address: CERN, CH-1211, Geneva 23, Switzerland
[*] deceased.

References

1. Ajima Y. et al. 2000, Nucl. Instr. and Meth. A, 443, 71
2. Alcaraz J. et al. 2000, Phys. Lett. B, 490, 27
3. Asaoka Y. et al. 1998, Nucl. Instr. and Meth. A, 416, 236
4. Biagi S. F. 1989, Nucl. Instr. and Meth. A, 283, 716
5. Boezio M. et al. 2002, astro-ph/0212253
6. Sanuki T. et al. 2000, ApJ, 545, 1135; and references therein
7. Shikaze Y. et al. 2000, Nucl. Instr. and Meth. A, 455, 596
8. Verrnhof R. 1988, CERN Program Library