Geomagnetic Cutoff Effect on Atmospheric Muon Spectra at Ground Level

K. Tanizaki\textsuperscript{1}, K. Abe\textsuperscript{1}, T. Sanuki\textsuperscript{2}, K. Anraku\textsuperscript{2,a}, H. Fuke\textsuperscript{2}, S. Haino\textsuperscript{2}, N. Ikeda\textsuperscript{1}, A. Itasaki\textsuperscript{1}, K. Izumi\textsuperscript{2}, T. Maeno\textsuperscript{1,b}, Y. Makida\textsuperscript{3}, S. Matsuda\textsuperscript{2}, N. Matsui\textsuperscript{2}, M. Motoki\textsuperscript{1,c}, J. Nishimura\textsuperscript{2}, M. Nozaki\textsuperscript{1}, H. Omiya\textsuperscript{3}, S. Orito\textsuperscript{2,s}, M. Sasaki\textsuperscript{3,d}, Y. Shikaze\textsuperscript{1}, J. Suzuki\textsuperscript{3}, K. Tanaka\textsuperscript{3}, T. Yamagami\textsuperscript{4}, A. Yamamoto\textsuperscript{3}, Y. Yamamoto\textsuperscript{2}, K. Yamato\textsuperscript{1}, T. Yoshida\textsuperscript{3}, and K. Yoshimura\textsuperscript{3}

(1) Kobe University, Kobe, Hyogo 657-8501, Japan
(2) The University of Tokyo, Tokyo 113-0033, Japan
(3) High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan
(4) The Institute of Space and Astronautical Science (ISAS), Sagamihara, Kanagawa 229-8510, Japan

Abstract

We observed ground level atmospheric muon fluxes at Ft. Sumner, New Mexico in September 2001. We have obtained an absolute flux and a charge ratio of muon in a momentum range from 0.6 to 10 GeV/c. In this report, we compare the observed results of the flux and charge dependence with those previous measured at different locations, and discuss the geomagnetic cutoff effect on the atmospheric muon fluxes.

1. Introduction

Atmospheric muons convey information of primary cosmic rays and interaction processes inside the atmosphere. The temporal and locational variations of the muon spectrum measured at sea level, for example, reflects the changes of the spectrum of primary protons and helium nuclei\cite{1}. Aside from the local change in the density profile of the atmosphere, the annual variation can be explained by the solar modulation and the locational variation by the geomagnetic cut off, which is 11.4 GV at Tsukuba in Japan and 0.4 GV at Lynn Lake in northern Canada. The difference is clearly seen in the charge ratio of muons for two different geomagnetic latitudes, Tsukuba and Lynn Lake\cite{10}. This observation means that the primary cosmic rays below median energy of the parent particles have an observable effect on low energy muons measured at sea level. The flux of the atmospheric muons has close connection with the flux of atmospheric neutrino. Muons produced through decay processes of $\pi$ and other mesons are

\textsuperscript{pp. 1-4} \textsuperscript{©2003 by Universal Academy Press, Inc.}
always accompanied by neutrinos. Therefore a more detailed understanding of
the effect of geomagnetic cut off will help to improve the accuracy to estimate the
neutrino flux. We report here a new measurement of muon flux using the BESS
spectrometer at Ft. Sumner, New Mexico, where the cut-off rigidity is 4.2 GV.

2. Experiment

A ground observation using the BESS spectrometer was carried out in
September 2001 during a standby for a balloon flight. The altitude of the experi-
mental site is 1270 m above sea level and the average atmospheric depth during
a 4-hour data taking was 892 g/cm². The detector configuration was the same as
the one used in the flight; a superconducting solenoid, which generates an axial 1
tesla magnetic field, a tracking chamber system for rigidity measurement, a sci-
tillation counter hodoscope for time-of-flight measurement. A 11.2 mm thick lead
plate, which covers 30 % of acceptance, is installed above the lower TOF counters
for e/μ separation. A trigger is generated by a coincidence between upper and
lower TOF scintillation counters. All the triggered events were recorded for off-
line analysis. The details of the spectrometer is described elsewhere[2,3,11,13,14].

3. Analysis

We first selected “single track events” that are defined as the event with an
isolated track with one or two hit counters in each layer of the TOF hodoscope.
Then we selected events as muon candidates, which are inside the beta-band
defined by \(1/\beta = \sqrt{(m_\mu/R)^2 + 1} \pm 3.89\sigma\). Here, \(\beta\) is velocity of particle, \(m_\mu\)
is muon mass and rigidit\(y(R)\) is momentum per charge. While the protons be-
low 1.6 GeV/c can be clearly separated from muons by the TOF measurement,
protons with higher momentum contaminate the muon samples. The maximum
fraction of proton contaminations was estimated to be 4 % at 3.4 GeV/c, and the
fraction decreases in higher momentum because of steeper spectrum of protons[6].
Since electrons and positrons can not be rejected by the TOF measurement, the
contamination was estimated by using the events passing through the lead plate.
Electrons deposit larger signals in the scintillation counter below the lead plate
compared with muons because of the generation of electron showers. The fraction
of electron contaminations in the muon samples was estimated to be below 1 % at
the lowest momentum (0.6 GeV/c) and decreases for higher momentum. These
backgrounds were subtracted from observed muon candidate samples.

4. Results and Discussion

We show momentum spectra for \(\mu^+\) and \(\mu^-\) in a range from 0.6 to 13 GeV/c
in Fig.1(left) together with spectra obtained by CAPRICE in 1997[4,9], which was
also measured at Ft. Sumner. The difference is as large as about 20% around 1 GeV/c. Since the atmospheric conditions are similar in both observations, it may be considered that the difference is attributed to the effect of solar modulation. The annual variation of muon flux at sea level has been studied in our previous work using the data collected at Lynn Lake in 1997 through 1999[10]. During this period, the flux of primary protons changed about 10% at 10 GeV and the flux of muons at 1 GeV/c changed by about 5%. The proton flux measured by BESS in 2000, just after the solar-field reversal, is much lower than the previous years. After the polarity reversal of solar magnetic field, we entered the negative-polarity cycle in which positive particles suffer large modulation effect. It is therefore expected that the proton flux in 2001 is lower than 1999 and the muon flux is also lower. Also shown in Fig.1(left) are the predicted spectra calculated by [8] under the same experimental conditions of atmospheric profile and geomagnetic cut off. The primary spectrum was tuned to reproduce a measured proton spectrum[1] at a balloon altitude by BESS in 2001. The prediction is in good agreement with our result. The flux of both $\mu^+$ and $\mu^-$ are higher than the flux observed at Lynn Lake in 1997 through 1999 and at Tsukuba in 1995. The major part of this difference arises from the difference in the altitude of the experimental site; $\sim$ 1000 g/cm² at both Lynn Lake and Tsukuba, 892 g/cm² at Ft. Sumner. For a comparison with these data, energy loss and decay during the last $\sim$1200 m between the altitudes of 892 g/cm² and 1000 g/cm² should be properly corrected for. In Fig.1(right), the charge ratio of muons observed each location is also presented.

We observed atmospheric muon fluxes on the ground level at Ft. Sumner, New Mexico, USA in a momentum range of 0.6 - 10 GeV/c. The corresponding atmospheric depth was 892 g/cm² during the measurement. The observed result has good agreement with the results obtained by a theoretical calculation, based on the hadronic interaction model developed for the evaluation of the atmospheric neutrino fluxes[7]. The atmospheric depth dependence on the muon flux was clearly observed in the lower energy region. The geomagnetic cutoff effect was observed in $\mu^+/\mu^-$ ratio. Some details of the analysis on the atmospheric depth dependence and the geomagnetic cut off effect to the muon flux and charge ratio will be presented at the conference.

Acknowledgements

We are indebted to M. Honda of ICRR, the University of Tokyo for his calculation with Monte Carlo simulations. We would like to thank NASA, NSBF, ISAS and KEK for their continuous support. This experiment was supported by Grants in Aid, KAKENHI(12047206 and 12047227) from Mext, Japan.
Fig. 1. (left): Result for momentum spectra of the positive and negative muons at Ft. Sumner. (right): $\mu^+/\mu^-$ ratios at different geomagnetic locations, BESS-1999[11]

\[\text{Flux (m}^{-2} \text{sr}^{-1} \text{sec}^{-1} (\text{GeV/c})^{-1})\]

- \(\mu^+\) BESS-2001 892 g/cm\(^2\) (This work)
- \(\mu^-\) BESS-2001 892 g/cm\(^2\) (This work)
- \(\mu^+\) CAPRICE97 886 g/cm\(^2\)
- \(\mu^-\) CAPRICE97 886 g/cm\(^2\)
- \(\mu^+\) M.Honda 892 g/cm\(^2\)
- \(\mu^-\) M.Honda 892 g/cm\(^2\)

\[\text{Geomagnetic cutoff}\]
- BESS-2001 4.2 GV (This work)
- CAPRICE97 4.2 GV
- BESS-1995 11.4 GV
- BESS-1997-1999 0.4 GV
- BESS-1999 11.2 GV

---

\(^a\) Present address: Kanagawa Univ., Yokohama, Kanagawa, 221-8686, Japan
\(^b\) Present address: CERN, Geneve, CH-1211, Switzerland
\(^c\) Present address: Tohoku University, Sendai, Miyagi, 980-8578, Japan
\(^d\) Present address: NASA/GSFC, Greenbelt, MD 20771, USA

* deceased