Geomagnetic Cutoff Effect on Atmospheric Muon Spectra at Ground Level

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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[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[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 π and other mesons are always accompanied by neutrinos. Therefore a more detailed understanding of

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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 experimental site is 1270 m above sea level and the average atmospheric depth during a 4-hour data taking was 892 g/cm^2. 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 scintillation 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 scintilaltion counters. All the triggered events were recorded for offline 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, β is velocity of particle, m_μ is muon mass and rigidity(R) is momentum per charge. While the protons below 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 μ^+ and μ^- 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

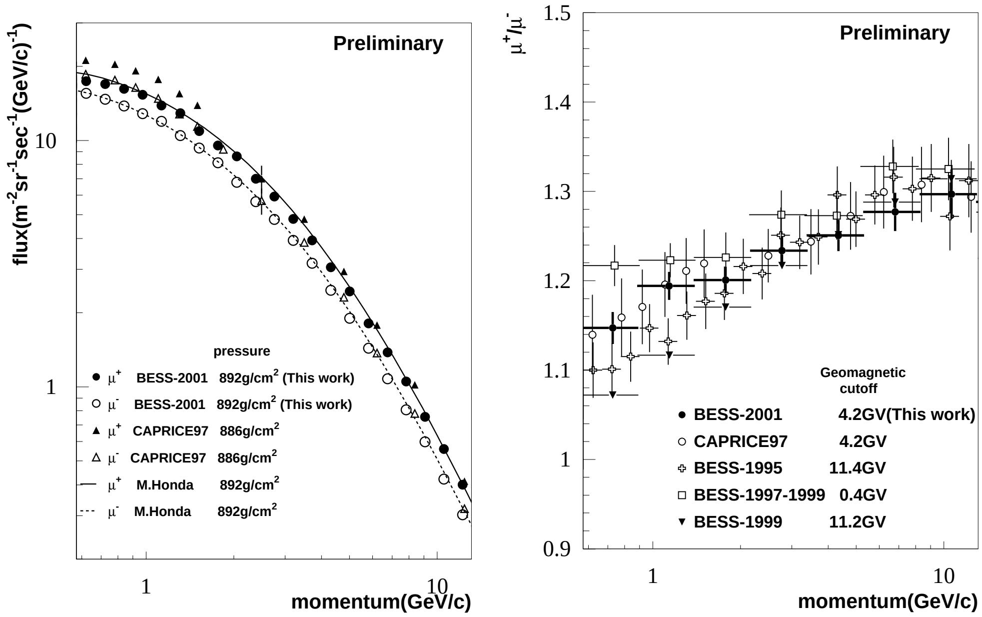

Fig. 1. (left):Result for momentum spectra of the positive and negative muons at Ft. Sumner. (right):μ^+/μ^- ratios at different geomagnetic locations, BESS-1999[11]

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 μ^+ and μ^- 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/cm^2 at both Lynn Lake and Tsukuba, 892 g/cm^2 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/cm^2 and 1000 g/cm^2 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/cm^2 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 μ^+/μ^- 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.

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1. Abe K., 2003, astro-ph/0304102, Phys. Lett. B, impress
2. Ajima Y., et al., 2000, Nucl. Instr. and Meth. A443, 71.
3. Asaoka Y., et al., 2001, Nucl. Instr. and Meth. A489, 170.
4. Boezio M., et al., 2000, Phys. Rev. D, 62, 032007
5. Gaisser K.T. and Honda M. 2002, Annu. Rev. Nucl. Part. Sci. 52:153-99
6. Golden L.R. et al., 1995, J. Geophys. Res. 100, 23515.
7. Honda M., et al,, 2001, Proc. 27th ICRC, hamburg, 162.
8. Honda M, 2003, Private communication and M.Honda et al. this conf.
9. Kremer J., et al., 1999, Phys. Rev. Lett. 83, 21, 4241-4244
10. Motoki M., et al., 2003, Astropart. Phys. 19, 113-126
11. Orito S., 1987, Poc. ASTROMAG Workshop, KEK Report KEK87-19, 111
12. Sanuki T., et al., 2002, Phys. Lett. B 541, 234-242
13. Shikaze Y., et al., 2000, Nucl. Instr. and Meth. A455, 596.
14. Yamamoto A., et al., 1994, Adv. Space Res. 14, 75.