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Atmospheric muon measurements III: Azimuthal angular dependence

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Abstract. We have measured the atmospheric muons at sea level using the OKAYAMA telescope. We report more reliable results of the absolute differential muon fluxes and the muon charge ratio in 8 azimuthal directions at zenith angle 40° in the momentum range 1 to 10 GeV/c. These results show the geomagnetic effect clear than previous ones. We suggest the significance of the azimuthal angular dependence of muons at sea level.

1 Introduction

Recently, Atmospheric neutrino(AN) fluxes that mainly produced at the atmosphere are actively measured by using the underground neutrino detector (Kajita et al., 1999; Peterson et al., 1999; Ronga et al., 1999). Many AN fluxes are calculated (Honda et al., 1995; Gaisser et al., 1988; Bugaev and Naumov., 1989). However, the validity of the AN flux calculation is still controversial, that include the many uncertainties. One of them is the propagation of the atmospheric muons that related to the AN production. Then, track of muon is bended by the geomagnetic field because muon is charged particle. This effect is called the Geomagnetic effect or the East-West effect. For particles coming from the east a positive muon has a longer path length than a negative one, whereas for those coming from the west a positive muon has a shorter path length than a negative one (Hayakawa, 1969). Thus, positive muon fluxes coming from the east decrease and vice versa. Decreasing muon fluxes by the geomagnetic effect means electron neutrino productions. Different results are also predicted between the AN flux calculation that includes the geomagnetic effect and do not include it (Lipari, 2000). The geomagnetic effect should not be negligible. Thus, to obtain the information on the propagation of the atmospheric muons, precise measurement of the muon fluxes from some incident directions over a wide energy range are crucial. In particular, Geomagnetic effect is large for low momentum muon. We had measured the atmospheric muons from 22 February 2001 to 8 April 2001 for lower momentum than previous our experiment (Tsuji et al, 1999).

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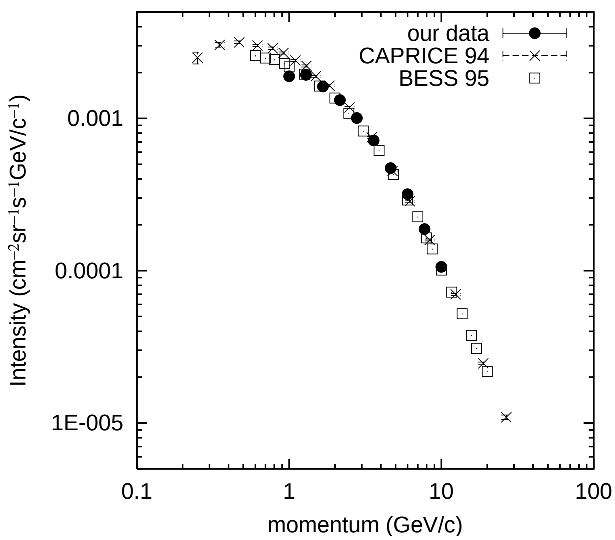

Fig. 1. Muon momentum spectrum in vertical at sea level.

2 Experiment

Shifting the OKAYAMA telescope (Yamashita et al., 1996; Tsuji et al., 1998) to new building in 2000 in detail (Tsuji et al, 2001), the wall thickness became thin and uniform compared with previous our experiment. Moreover, we improved to measure for low energy range (above 1 GeV/c).

2.1 Instrument

The OKAYAMA telescope (34° 40' N latitude, 133° 56' E longitude, 28 m above sea level) is installed in the building

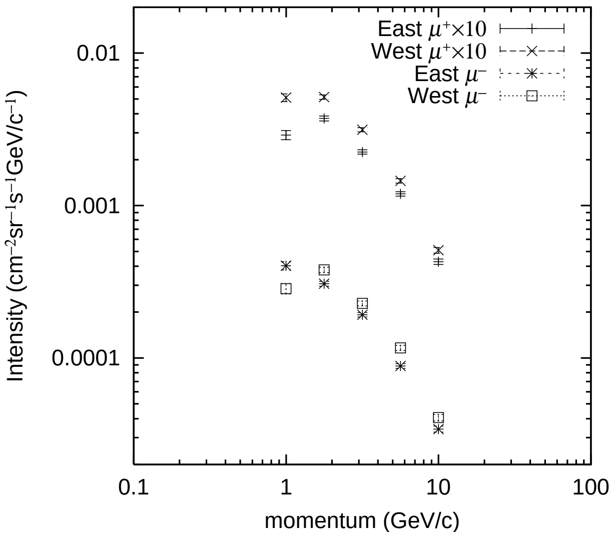

Fig. 2. Muon momentum spectrum in the east and west at zenith angle 40°.

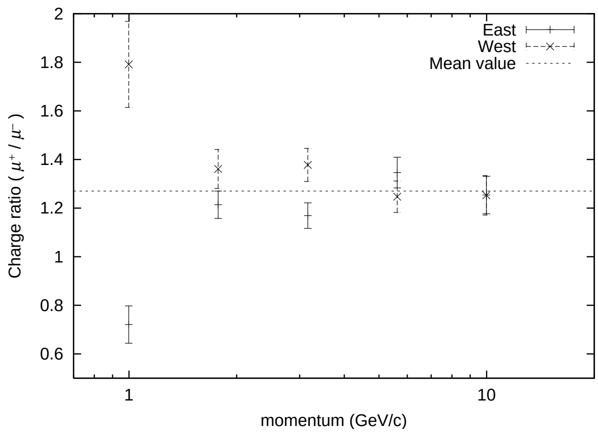

Fig. 3. Muon charge ratio in the east and west at zenith angle 40°.

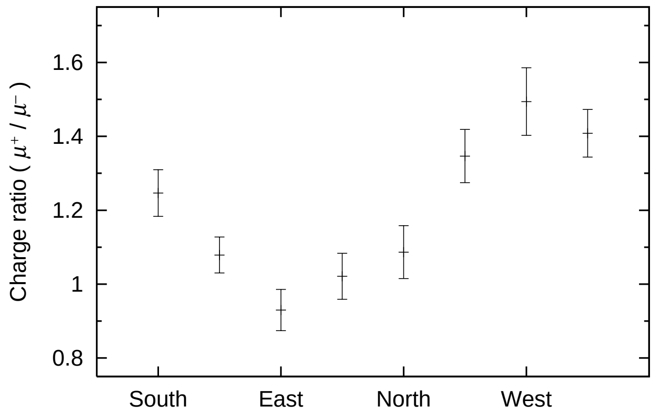

Fig. 4. The azimuthal angular dependence of the muon charge ratio at zenith angle $40°$ in momentum region, 1.0 $\sim$ 2.0 GeV/c.

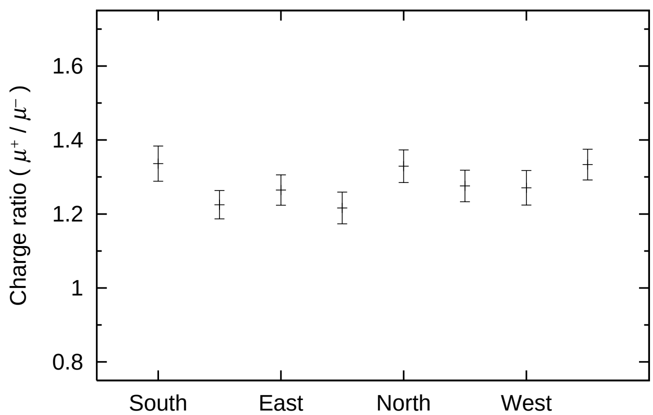

Fig. 5. The azimuthal angular dependence of the muon charge ratio at zenith angle $40°$ in momentum region, 3.0 $\sim$ 10.0 GeV/c.

of Okayama University in Japan. Rigidity cutoff is about 12 GV. The telescope consists of trigger counters (scintillators), position chambers (multi-wire proportional chambers used as drift chambers), and measures the momentum and charged sign by passing through an iron core magnet (thickness 32 cm, magnetic induction 18000 Gauss). Geometrical solid angle area is 12.8 cm^2sr, that opening angle is $\pm5°$. The telescope efficiency is 0.605, when the scintillation counter efficiency is 1.0.

2.2 Analyses and Results

Since the OKAYAMA telescope is in the building, we need to take into account energy losses by wall of the building and the iron materials in an instrument. We analyzed the muon events in the momentum range 1 $\sim$ 10 GeV/c. Muon differential momentum spectrum in vertical is shown in fig. 1. The muon momentum spectrum in east and west at zenith angle $40°$, and charge ratio are shown in fig. 2, 3. The muon charge ratio and fluxes in 8 azimuthal directions at zenith angle $40°$ in the momentum ranges 1 $\sim$ 2 GeV/c and 3 $\sim$ 10 GeV/c are shown in fig. 4, 5, 6, 7, respectively.

3 Discussion

We had measured the Muon momentum spectrum in vertical. They are shown in good agreement with other experiments (Motoki et al., 2000; Kremer et al., 1999). We had also measured the muon fluxes in 8 azimuthal directions at zenith angle $40°$. Fig. 2 shows the east-west effect nearby 1GeV/c that for a positive muon the intensities coming from the west is 167 % larger than ones coming from the east, and for a negative muon the intensities coming from the east is 133 % larger than ones coming from the west. In fig. 3, 4, charge ratio in the east-west effect is that east and west is 43 % dif-

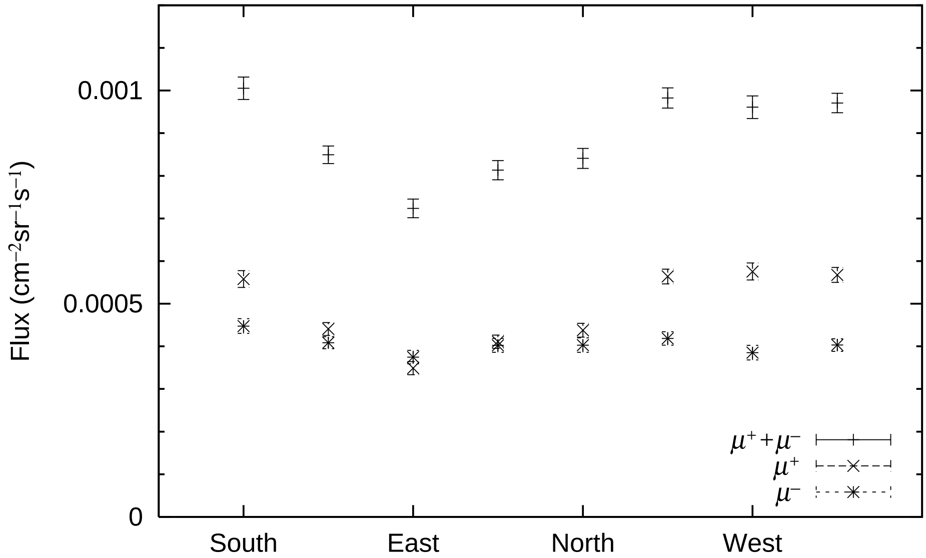

Fig. 6. The azimuthal angular dependence of the muon fluxes at zenith angle 40° in momentum region, 1.0 $\sim$ 2.0 GeV/c.

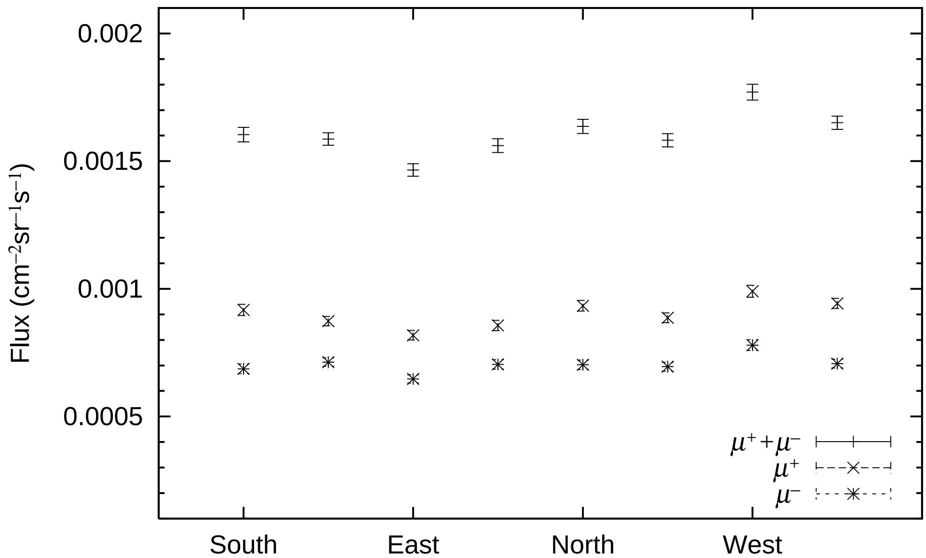

Fig. 7. The azimuthal angular dependence of the muon fluxes at zenith angle 40° in momentum region, 3.0 $\sim$ 10.0 GeV/c.

ferent with the average value 1.27 below 2 GeV/c. These results are consistency with the geomagnetic effect that for particles coming from the east a positive muon has a longer path length than a negative one, whereas for those coming from the west a positive muon has a shorter path length than a negative one. In fig. 6, the azimuthal dependence of fluxes has the successively distribution. In fig. 5, 7, the fluctuation of azimuthal dependence of muon intensities is within 13 %, that of charge ratio is within 10 %.

4 Conclusion

We had measured the muon fluxes in vertical and 8 azimuthal angles at zenith angle 40° directions in momentum 1 $\sim$ 10 GeV/c at sea level by using OKAYAMA telescope. This results is more reliable than previous experiments. Muon measurements in vertical are shown in good agreement with other experiments. Muon measurements in east and west at zenith angle 40° showed the tendency of geomagnetic effect in low momentum range.Coming from the east a positive muon fluxes decrease and a negative muon fluxes increase by the geomagnetic effect and vice versa. Variation of the muon fluxes by the geomagnetic effect affects the neutrino fluxes that are produced by the muon decay. Thus, AN flux calculations should take into account the geomagnetic effect for muon. More detail AN flux calculations will also be need for new generation high precision neutrino detectors. However, muon measurements are few to check it. We are going to improve the OKAYAMA telescope that can measure the muon in the more lower momentum range.

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