Observation of east-west effect in atmospheric neutrinos by Super-Kamiokande

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Abstract

The east-west effect is observed for the first time in the atmospheric neutrino data. A total of 552 e-like and 633 μ-like horizontally-going events are selected from a 45kton·yr exposure of the Super-Kamiokande detector. The azimuthal distribution and the east-west asymmetry of the data agrees with the Monte Carlo expectation based on the atmospheric neutrino flux calculations which take into account the earth's magnetic field.

1 Introduction

The east-west effect, the azimuthal anisotropy, was discovered in the 1930's as a deficit of muons coming from the east (Johnson 1933). The positive charge of the primary cosmic rays was determined by this effect. The location of the Super-Kamiokande detector is close to the geomagnetic equator, the cut-off momentum for the proton horizontally coming from the east is about 50GeV/c, which is much higher than other directions (Honda et al, 1995, Lipari et al, 1998). Atmospheric neutrinos are produce by the decay chain of mesons, which are generated by the collisions of the primary protons and nucleus. Therefore, neutrinos coming from the east are expected to be depleted by the geomagnetic effect to the primary cosmic rays.

2 East-west effect in the atmospheric neutrino data

The Super-Kamiokande is a 50 kton Water Cherenkov detector at the Kamioka observatory, ($36^o25'33''$N, $137^o18'37''$E and 372m above the sea level). The detector consists of a cylindrical tank to store 50 kton water, viewed by 11,146 of 50cm diameter PMTs distributed at wall of the inner detector and 1885 of 20cm diameter PMTs in the outer detector. Fiducial volume of this analysis is defined as 22.5 kton, 2m inside from the inner detector wall. Using a 45kton·yr exposure of the Super-Kamiokande detector, a total of 6085 fully contained events were selected in the fiducial volume as atmospheric neutrino candidates. Single ring events were used for this analysis, because these events reflect the parent neutrino species and directions well. Each single ring event was identified as e-like and μ-like event by using the Cherenkov ring pattern and the opening angle of the Cherenkov ring. The following additional cut were applied to emphasize the east-west effect; momentum was required to be between 400MeV/c and 3000MeV/c, cosine of the zenith angle of reconstructed ring was required to be between -0.5 and 0.5.

Figure 1 shows the momentum dependence of the east-west asymmetry defined as $(\mathrm{N_E} - \mathrm{N_W})$ / $(\mathrm{N_E} + \mathrm{N_W})$ compare to the M.C. expectation without the momentum cut, where $\mathrm{N_E}(\mathrm{N_W})$ is the number of the eastward(westward)-going events. The distributions of data are consistent with the M.C. expectations which include the geomagnetic field. The χ^2 between the data and the M.C. is 5.9/6dof for e-like and 5.8/5dof for μ-like events, while the χ^2 between the data and the flat distribution (no asymmetry) is 26.5/6dof for e-like and 10.5/5dof for μ-like events. The east-west asymmetry become small at the momentum below $400MeV/c$ and more than $3000MeV/c$. From this figure, the east-west effect become small at the higher momentum because the effect of the geomagnetic field become negligible, and become larger at the lower momentum. However, the

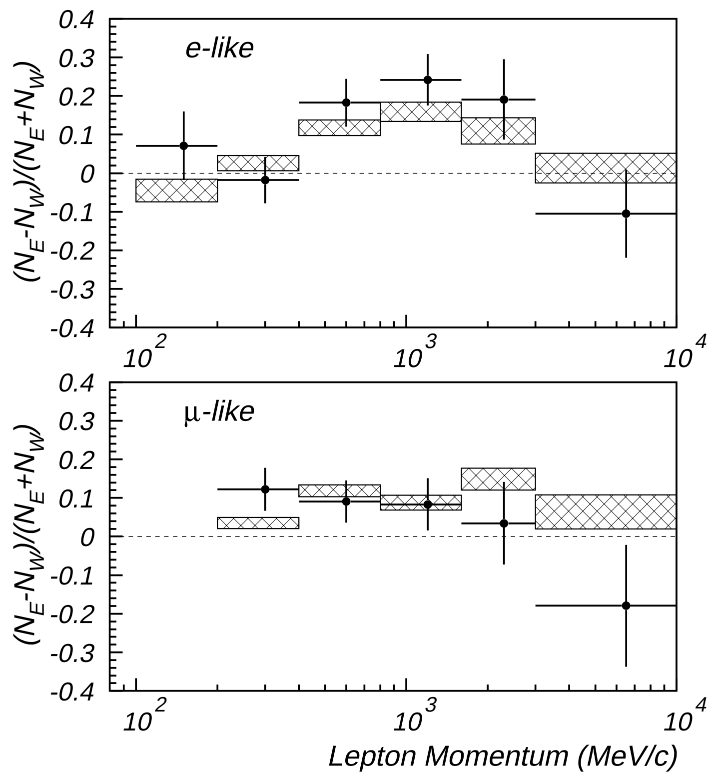

Figure 1: The momentum correlation of the east-west asymmetry $(\mathrm{N_E} - \mathrm{N_W})/(\mathrm{N_E} + \mathrm{N_W})$ for e-like and μ-like events. The Closed circles show the data and hatched regions show the M.C. expectation based on (Honda et al, 1995).

directional correlation of the neutrino and the charged lepton become worse at the low momentum. Therefore, we required the momentum should be between 400MeV/c and 3000GeV/c. After this momentum cut, a total of 552 e-like and 633 μ-like events are selected for the analysis of the east-west effect.

Figure 2 shows the azimuthal distribution of e-like and μ-like data compare to the M.C. expectations based on the two neutrino flux calculations. The number of M.C. expectation is normalized to the number of data, because there is large uncertainty on the normalization. The neutrino oscillation may alos change the normalization of the expectation. However, the effect of neutrino oscillations is not included to this M.C., because the oscillation affects the azimuthal shape little. The deficits of westward-going event are clearly seen, and both expectations reproduce data well. The χ^2 were 5.1/7dof and 2.6/7dof for e-like and μ-like events, respectively.

We also tested the correlation of data and the expectation using the Kuiper test (Stephens, 1970). This test is similar to a Kolmogorov-Smirnov test, it can be used for the stating point free distributions. The Kuiper statistic V is defined as:

$$V = \max_{0<\phi<2\pi}[S_N(\phi) - P(\phi)] + \max_{0<\phi<2\pi}[P(\phi) - S_N(\phi)],$$

where ϕ is the azimuthal angle in this case, $S_N(\phi)$ is a cumulative probability function from data and $P(\phi)$ is the one from Monte Carlo. The significance is obtained from the statistic $V^* = V(\sqrt{n}+$

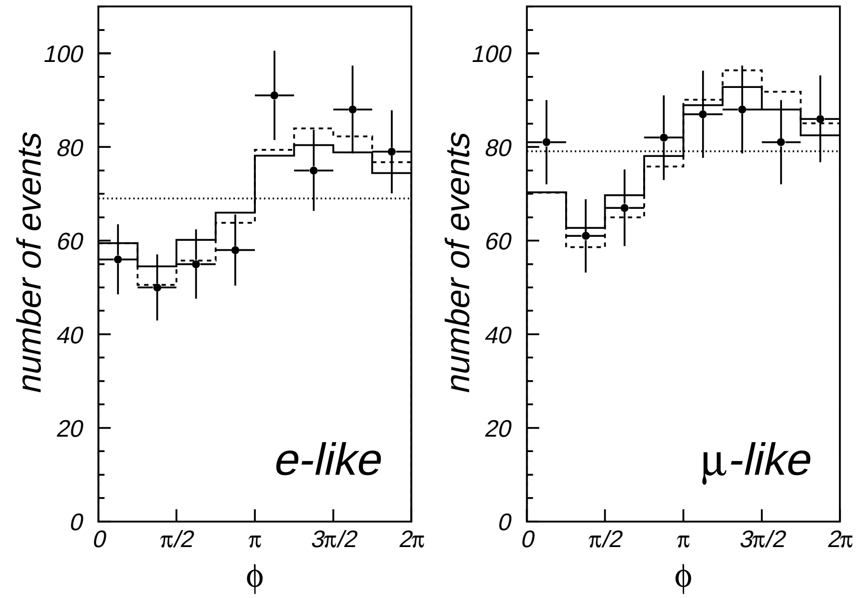

Figure 2: Azimuthal distribution of e-like and μ-like events. Closed circles show the data, solid histgrams show the expectation based on (Honda et al. 1995) and dashed histgrams show the expectation based on (Lipari et al. 1998). ϕ=0,$\pi/2$,π and $3\pi/2$ are coresponding to the events going to north, west, south and east.

$0.155 + 0.24/\sqrt{n}$), and defined as

$$Prob = 2\sum_{j=1}^{\infty}(4j^2V^{*2} - 1)\exp(-2j^2V^{*2}),$$

where n is number of events.

Table 1 shows the summary of the χ^2 test and Kuiper test results. The east-west asymmetry of each distribution is also listed. The azimuthal distributions of data and M.C. expectation agree well from the χ^2 and Kuiper tests. If $\nu_\mu - \nu_\tau$ oscillation with $(\sin^2 2\theta, \Delta m^2) = (1.0, 2.2\times10^{-3})$ is assumed, the difference of the probability from the no oscillation case is less than 1%. The probabilities for the correlation between the data and the flat distribution are 0.0008% and 20% for e-like and μ-like events, respectably, With the current statistics, the east-west anisotropy is more significant in the e-like data than μ-like data. The east-west asymmetry for the momentum between 400MeV/c and 3000MeV/c for e-like and μ-like data were 0.21 ± 0.04 and 0.08 ± 0.04, respectably. These values are also consistent with the expected value based on the two flux calculations.

3 Conclusion

The east-west effect on the atmospheric neutrino is observed for the first time. The deficits of westward-going event are clearly seen on the atizuthal zenith angle distribution. The azimuthal zenith angle distribution of e-like data was not consistent with the flat distribution for more than 99% confidence level. The significance of μ-like data were not enough at the current statistics. However,

	e-like	μ-like
χ^2(data,M.C.)	64.8%(5.1/7dof)	91.9%(2.6/7dof)
Kuiper(data,M.C.)	42.0%	92.4%
χ^2(data,flat)	0.04%(26.5/7dof)	28.3%(8.6/7dof)
Kuiper(data,flat)	0.0008%	19.8%
east-west asymmetry		
data	0.21 ± 0.04	0.08 ± 0.04
Honda et al. 1995	0.13	0.11
Lipari et al. 1998	0.17	0.15

Table 1: Summary of the χ^2 test and Kuiper test results for the correlation between the data and the M.C. expectation, and between the data and the flat distribution. The east-west asymmetry for the data and the M.C. expectations are also listed.

two M.C. expectations based on the independent flux calculation, which take into accout the earth's magnetic filed, reproduce data well. The momentum dependence of the east-west asymmetry of data also agrees with the expectaion.

References

Fukuda, Y. et al., 1998, Phys. Lett. B433, 9.
Fukuda, Y. et al., 1998, Phys. Lett. B436, 33.
Fukuda, Y. et al., 1998, Phys. Rev. Lett. 81, 1562.
Honda, M. et al., 1995, Phys. Rev. D 58, 4985.
Johnson, T. H. 1933, Phys. Rev. D43, 307.
Lipari, P. et al., 1998, Phys. Rev. D58, 73003.
Stephens, M.A. 1970, J. Royal Statist. Soc. B32, 115