UP-DOWN ASYMMETRY OF NEUTRAL CURRENT EVENTS AS A DIAGNOSTIC FOR $\nu_\mu - \nu_{st}$ VERSUS $\nu_\mu - \nu_\tau$ OSCILLATIONS

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Abstract

We show that the asymmetry in the neutral current events (e.g. $\nu N \rightarrow \nu N \pi^0$) can be used to discriminate between $\nu_\mu - \nu_\tau$ and $\nu_\mu - \nu_{st}$ mixing as being responsible for the atmospheric neutrino anomaly. Specifically, A_N vanishes for $\nu_\mu - \nu_\tau$ mixing and is about $2/3 A_\mu$ for $\nu_\mu - \nu_{st}$ mixing.

The neutrino oscillation interpretation [1] of the atmospheric neutrino seems more and more probable with the new data from Superkamiokande [2]. If this holds up, it is very important to determine the specific oscillation scenario at work here. Recently, it was shown how the up-down asymmetry of the charged current events with muons and electrons is a strong discriminant for many different scenarios [3,4]. Preliminary results [5] for the asymmetry from Superkamiokande favor ν_μ oscillating into ν_τ (or $\nu_{sterile}$). However, this asymmetry does not distinguish between the possibility of $\nu_\mu - \nu_\tau$ oscillations and $\nu_\mu - \nu_{st}$ oscillations. The reason for this is that at the energies in question ($E_\nu < 10\ GeV$) there are not enough ν_τ charged current events to be recognised, due to the small cross-section below about 20 GeV. Here we extend the asymmetry to neutral current events (e.g. $\nu N \to \nu N \pi^0$) [6] and show how this asymmetry can be used to distinguish easily between the two possibilities. We assume here that the correlation between the direction of π^0 in $\nu N \to \nu N \pi^0$ and the initial neutrino direction is strong enough to distinguish up from down, not a very stringent requirement.

We define the asymmetry as before

$$A = \frac{D - U}{D + U} \tag{1}$$

where D is the number of downward-going events and U is the number of upward-going events. A can be defined for both muon charged current events A_μ as well for single π^0 neutral current events A_N. We assume the detector to be up/down symmetric, and the data set to be free of significant background.

We now calculate this asymmetry for the cases of interest: (i) $\nu_\mu - \nu_\tau$ oscillations and (ii) $\nu_\mu - \nu_{st}$ oscillations.

I. $\nu_\mu - \nu_\tau$ MIXING

The ν_μ flux is modified as

$$N_\mu = N_\mu^0 \ P_{\mu\mu} \tag{2}$$

where $P_{\mu\mu} = 1 - \sin^2 2\theta \sin^2\left(\frac{\delta m^2 L}{4E}\right)$ and N_μ^0 is the flux of ν_μ's in absence of oscillations. At very low energies, $P_{\mu\mu} \approx 1 - \frac{1}{2}\sin^2 2\theta$ and $A_\mu \to 0$. At higher energies, L/E is negligible for down $\nu_\mu' s$ and hence $N_\mu^d = N_\mu^0$. For upward going $\nu_\mu' s$, $N_\mu^u = P_{\mu\mu} N_\mu^0$ and

$$A_\mu = \frac{1 - P_{\mu\mu}}{1 + P_{\mu\mu}} \approx \frac{sin^2 2\theta}{4 - sin^2 2\theta} \tag{3}$$

which has a maximum of 1/3 for $\sin^2 2\theta \approx 1$.

In the $\nu_\mu - \nu_\tau$ case, since total flux of flavor neutrinos: $N_{\nu_e} + N_{\nu_\mu} + N_{\nu_\tau}$ does not change, the neutral current asymmetry A_N is zero.

II. $\nu_\mu - \nu_{ST}$ MIXING

In this case A_μ is the same as in the $\nu_\mu - \nu_\tau$ case. The asymmetry A_N in neutral current events is given by

$$A_N = \frac{(N_{\nu_e}^d + N_{\nu_\mu}^d) - (N_{\nu_e}^u + N_{\nu_\mu}^u)}{(N_{\nu_e}^d + N_{\nu_\mu}^d) + (N_{\nu_e}^u + N_{\nu_\mu}^u)} \tag{4}$$

$$\simeq \frac{N_{\nu_\mu}^d - N_{\nu_\mu}^u}{(N_{\nu_e}^d + N_{\nu_e}^u) + (N_{\nu_\mu}^d + N_{\nu_\mu}^u)}$$

$$A_N \simeq \frac{A_\mu}{1 + \left\{\frac{2r}{(1+P_{\mu\mu})}\right\}} \simeq \frac{A_\mu}{1 + \{r(1 + A_\mu)\}} \tag{5}$$

Here r $= N_{\nu_e}^0 / N_{\nu_\mu}^0$ and for $r \sim 0.45$ to $0.37 (E_\nu$ upto 5 GeV), and A_μ near 1/3, A_N is in the range 0.2 to 0.22.

In Fig. 1 we show a plot of A_μ and A_N as functions of E_ν for $\sin^2 2\theta \approx 1$ and $\delta m^2 \approx 5.10^{-3} eV^2$. At low energies the small negative asymmetry in the ν_e flux due to the earth magnetic field effects makes A_N non-zero in the case of $\nu_\mu - \nu_\tau$ mixing and dilutes A_N in the $\nu_\mu - \nu_{st}$ mixing. We calculated energy spectra between 0.2 and 5.0 GeV for a detector with an exposure of 22 kiloton-years (approximately one year of Super-Kamiokande data). We use the Bartol flux model [7], and a simple quark model for the cross-sections, and assume a perfect detector. Detailed calculations for a particular instrument will of course vary, but the asymmetry will change little, the general behavior being insensitive to details. Matter effects (which are present for $\nu_\mu - \nu_{st}$ mixing but absent for $\nu_\mu - \nu_\tau$ mixing) and the angular spread will be discussed elsewhere, but should have no major effect on the different behavior in the two cases discussed here. A different method to distinguish $\nu_\mu - \nu_\tau$ mixing from $\nu_\mu - \nu_{st}$ mixing has been proposed recently [8]. This technique depends on the fact that the ratio of the neutral current event rate to the charged current event rate is quite different in the two cases. The method we propose here has the advantage that it is independent of the efficiency for detecting π^0's and of the knowledge of neutral current cross-sections.

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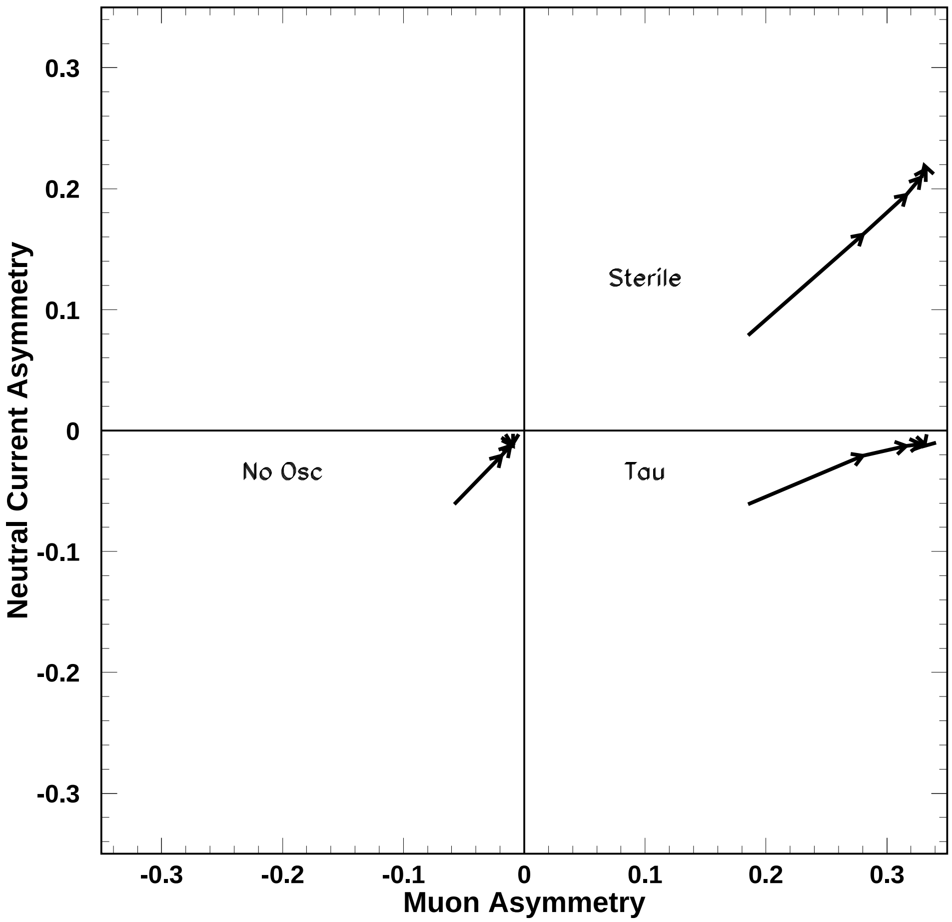

FIG. 1. The trajectories of muon asymmetry and neutral current asymmetry for $\nu_\mu - \nu_\tau$ mixing, for $\nu_\mu - \nu_{st}$, mixing, and for no oscillations.