Oscillation-enhanced search for new interaction with neutrinos

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Abstract. We study how well we can observe the effect of new physics in neutrino oscillation experiments.

1. Introduction

Precision measurement on neutrino mass difference and mixing angles for lepton will be done in neutrino oscillation experiments of next generation (see, for example, [1]). According to those study we will know the mass square difference and the mixing angle relevant to the atomospheric neutrino anomaly with 3% and 1% accuracy, we can measure U_{e3} down to $O(10^{-2})$, and also we can observe the CP violation effect in near future.

Till today the main concern about the next generation experiments has been on these parameters, mixing angles and the mass square difference. Therefore there arise a question whether we can mesure only these parameters in those experiments. There are several suggestions that we may see the effect of flavor-violating new physics[2].

In this talk we consider the potential power of the next generation experiments to observe the effect of new interactions. For the detail, see ref[3].

2. Measurement of Neutrino Oscillation

All we know in a neutrino factory is that the muons, say, with negative charge decay at an accumulate ring and wrong sign muons are observed in a detector located at a length L away just after the time L/c, where c is the light speed. Therefore if we have sevaral contributions which give the same signal, We have to calculate the graph fig.1 to get the transition rate.

Thus there is an interference phenomenon between several amplitudes in this process. Through this interference new physics effect gives a contribution to the transition rate of order of not $O(\epsilon^2)$ but $O(\epsilon)$. We get an enhancement of the effect

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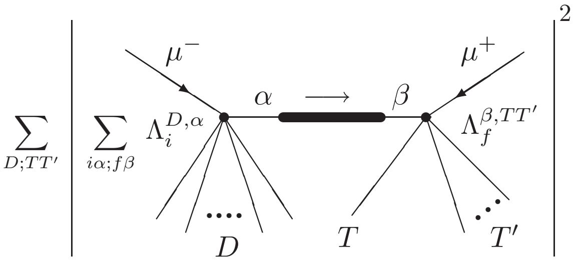

Figure 1. Transition rate for "$\bar{\nu}_e \to \bar{\nu}_\mu$".

of new physics, that is, we can make oscillation-enhanced search for new interactions with neutrinos.

The amplitude for "neutrino oscillation" can be divided into three pieces: (1) Amplitude relevant with decay of a parent particle denoted as A_α^C, here C describes the type of interactions. For μ decay, there are two types of interactions, $C = L, R$ while for π decay we do not need this label. α distinguishes the particle species which easily propagates in the matter and make an interaction at a detector. (2) Amplitude representing a transition of these propagating particles, which are usually neutrinos, from one species α to another/same β , denoted as $T_{\alpha\beta}$. (3) Amplitude responsible for producing a charged lepton l from a propagated particle β at a detector, stood for by $D_{\beta l}^I$. Here I denotes an interaction type. Using these notations we get the probability to observe a charged lepton $l^\pm$ at a detector as

$$P_{\mu^- \to l^+(l^-)} = \left| \sum_{\alpha\beta CI} A_\alpha^C T_{\alpha\beta} D_{\beta l^\pm}^I \right|^2 . \tag{1}$$

Therefore we can consider the effect of new physics separately for decay, propagation and detection processes.

In each process, we can paramterize new physics effects as a ratio to the weak interaction, $\epsilon_{\alpha\beta}^{s,m,d}$, where s, m, d denote "source"(decay), "matter"(propagation), and "detection" processes respectively.

3. Analysis

As an example of the sensitivity of nuetrino factory, Fig. 2 is shown.

4. Summary

For a neutrino factory:

- In $\nu_\alpha \to \nu_\beta$, $(\alpha = e, \mu,\ \beta = e, \mu, \tau)$ appearance channel, the observable effects of new $(V - A)(V - A)$ interactions come only from $\epsilon_{\alpha\beta}^{s,m}$. The others are too small or too vulnerable against the adjustment of the theoretical parameters. Note that δ and ϵ's phase are correlated. Namely the measured values are a certain combination of δ and ϵ.

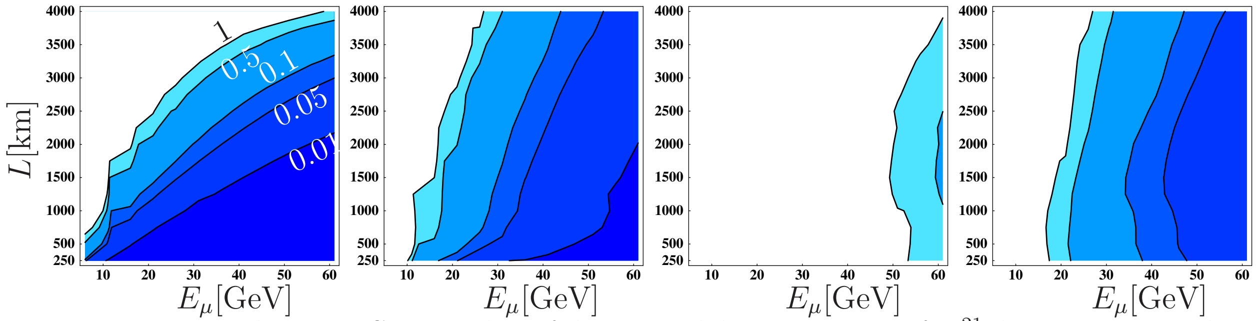

Figure 2. Contour plots of the required date size in unit of 10^{21} decay muon $\times$ 100kt detector to observe the new physics effects concerning $\epsilon^{s,m}_{e\mu}$ at 90% C.L. in $\nu_e \to \nu_\mu$ channel when there is no uncertainty for theoretical parameters. From left to right: $(\epsilon^s_{e\mu}, \epsilon^m_{e\mu}) = (3.0 \times 10^{-3}, 0)$, $(3.0 \times 10^{-3} i, 0)$, $(0, 3.0 \times 10^{-3})$, $(0, 3.0 \times 10^{-3} i)$. Here each oscillation parameter is assumed to have 10% uncertainty.

- In $\nu_\mu \to \nu_\mu$ disappearance channel, we can measure $\epsilon^{s,m}_{\mu\tau}$ depending on their phase. In other words, the signal includes information of the phase. Furthermore, there is no correlation between δ and ϵ, so the measurement tells us directly the phase concerning the lepton-flavor violating process. In $\nu_e \to \nu_e$ disappearance channel, we can not get anything for new interactions in the oscillation enhanced way.
- The χ^2 is proportional to $|\epsilon|^2$. The expected sensitivity is to $|\epsilon| \geq \mathcal{O}(10^{-4})$ by using this methodology.
- When the situations that new interactions exist not only in the source but also in the matter effect are considered, we can easily understand the sensitivity by simply adding each effect.
- Oscillation-enhanced effects for the $(V - A)(V + A)$ type interactions are strongly suppressed by m_e/m_μ, so we can not get an advantage over a direct measurement.

For an upgraded conventional beam:

- We do not have to care the types of new interactions in the source. The analyses for the feasibility are similar to that of $(V - A)(V - A)$ type for a neutrino factory. In the assumed energy and baseline region, there is no sensitivity to the new effect in matter.
- The ϵ's for a conventional beam have different dependence from those for a neutrino factory on new interactions. Therefore, the comparison between two methods makes clear the species of new physics.

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