Establishing neutrino mass hierarchy and CP violation by two identical detectors with different baselines using the J-PARC ν beam*

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We discuss how and to what extent one can determine the neutrino mass hierarchy, normal or inverted, and at the same time uncover CP violation in the lepton sector by using two identical detectors with different baselines in neutrino oscillation experiments using low energy superbeam from the J-PARC facility.

1. Introduction

In the neutrino sector, we still do not know the value of θ_{13}, the sign of Δm^2_{31}, which is positive (negative) if the mass hierarchy is normal (inverted), and the value of the CP violating phase δ. It is well known that the determination of these parameters by accelerator-based neutrino oscillation experiments suffer from the ambiguities coming from so called the parameter degeneracy [2]. In this work, we discuss possible way of determining the type of the neutrino mass hierarchy as well as the CP violating phase simultaneously by resolving the degeneracy using two identical detectors with different baselines.

2. Principle of two-detector measurement

We start from the original proposal of phase II of the J-PARC neutrino project [3] in which an off axis neutrino beam with 4 MW beam power and a megaton (Mton) water Cherenkov detector, Hyper-Kamiokande (HK), whose fiducial volume is 0.54 Mton will be used to measure appearance events in $\nu_\mu \to \nu_\mathrm{e}$ and $\bar{\nu}_\mu \to \bar{\nu}_\mathrm{e}$ channels. We then propose a "minor" modification; Instead of placing a 1 Mton HK at Kamioka with the baseline $L = 295$ km, we propose to divide the detector into two identical half Mton detectors with fiducial volume 0.27 Mton, and place one of them in Kamioka and the other somewhere in Korea with the baseline $L = 1050$ km.

Assuming the same performance for the two identical detectors, most of the systematic errors cancel between the detectors. Furthermore, we expect that the neutrino energy spectra are the same at the two sites without oscillation because of the same off axis angle of 2.5° both at Kamioka and Korean detectors with peak energy of 650 MeV. It is possible under the current design of the J-PARAC neutrino beam line. The overall normalization simply scales as $1/L^2 \sim 1/10$.

Such an experimental set up implies that one can perform clean detection of the distortion of neutrino energy spectrum caused purely by the oscillation effect, if the difference in background due to different conditions at the two sites is tolerable. Namely, any differences of the ν energy spectra among the front and the two half Mton detectors are due to vacuum oscillation which is sensitive to δ at such low energy, and to the matter effect which is crucial to determine the hierarchy, the sign of Δm^2_{31}.

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3. Analysis Results

In order to quantify the determination power of the mass hierarchy as well as the CP violating phase, we performed a detailed χ^2 analysis. We present in Fig.1 the parameter region in the $\delta - \sin^2 2\theta_{13}$ plane in which the mass hierarchy can be determined at 2σ and 3σ CL. One can establish the type of the mass hierarchy in any region above these curves. In fact, we have also examined the cases of various volume ratios of the two detectors keeping the total volume equals to 0.54 Mton, as reported in Fig.1.

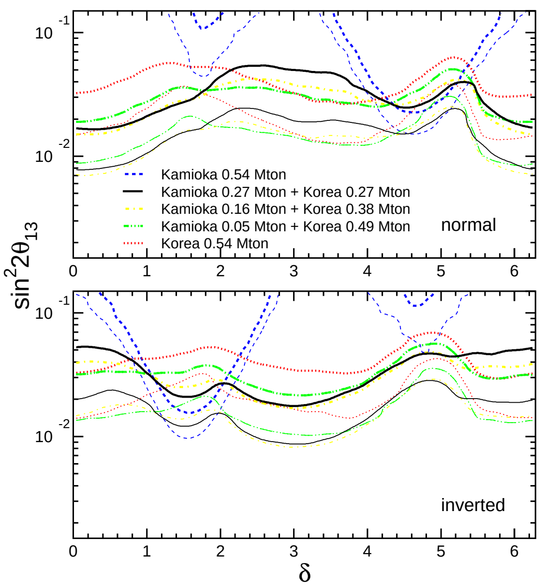

Figure 1. 2(thin lines) and 3(thick lines) standard deviation sensitivities to the mass hierarchy for the various fiducial volume ratio of [Kamioka: Korea] = [1:0] (dashed lines, blue), [1:1] (solid lines, black), [3:7] (dash-dot lines, yellow), [1:9] (dash-dot-dot lines, green), and [0:1] (dotted lines, red), keeping the total volume equals to 0.54 Mton. 4 years running with neutrino beam and another 4 years with anti-neutrino beam are assumed. The other mixing parameters are fixed to the current best fit values as described in [1].

In Fig.2 we show the similar curves but for the CP violation. We can establish the CP violation (if δ is different from 0 or π) in any region above these curves. From Figs.1 and 2 we conclude that the option of the two detectors with fiducial volume of 0.27 Mton each at Kamioka and Korea seem to be close to the optimal.

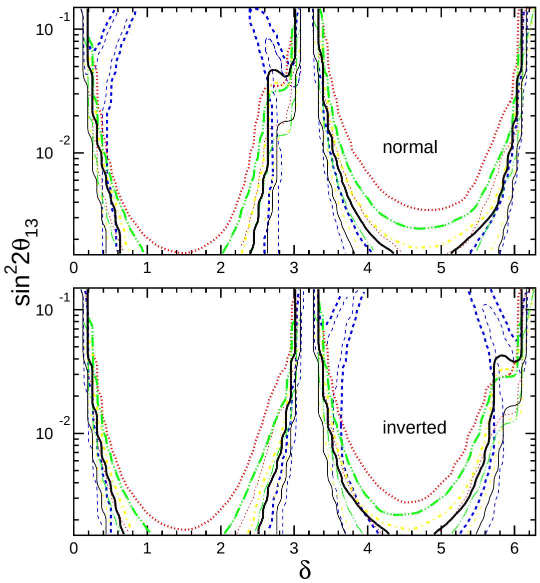

Figure 2. Same as Fig.1 but for the CP violation (see the text).

4. Conclusions

We have demonstrated that the two-detector complex can determine neutrino mass hierarchy down to $\sin^2 2\theta_{13} \gtrsim 0.03$ (0.055) for any value of δ at 2σ (3σ) CL, as indicated in Fig.1. It should be noted that the sensitivity to the CP violation of the current design of J-PARC phase II project is essentially kept or even enhanced at $\sin^2 2\theta_{13} \gtrsim 0.01$. See Ref. [1] for more details of this work.

REFERENCES

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2. See T. Schwetz, N. Okamura, S. Palomares-Ruiz, T. Ota, A. Donini, and D. Meloni, in these proceedings.
3. Y. Itow *et al.*, arXiv:hep-ex/0106019. For an updated version, see: http://neutrino.kek.jp/jhfnu/loi/loi.v2.030528.pdf