Neutrino/Anti-neutrino oscillation analysis using non-identical atmospheric oscillation parameters

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Introduction

Neutrino oscillations are well described by mass square splittings and mixing angles of Pontecorvo-Maki-Nakagawa-Sakata (PMNS) mixing matrix. Under the CPT symmetry, these oscillation parameters for neutrino and antineutrino are expected to be identical. Any difference in the measurement of neutrino and anti-neutrino oscillation parameters may indicate a hint for CPT violation or new physics. The Iron Calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO) [1] is a prime experiment aimed to resolve various issues in neutrino physics using atmospheric neutrino source with the earth matter effects. We present a search for difference in neutrino and anti-neutrino oscillation parameters assuming that the oscillation parameters of neutrinos governing survival probabilities ($\nu_\mu \rightarrow \nu_\mu$) are different from that describing for anti-neutrinos P($\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$). We show the ICAL sensitivity to confirm a non-zero value of the differences $[|\Delta m^2_{32}| - |\Delta \bar{m}^2_{32}|]_{True}$ as a result of four oscillation parameter fit technique.

Methodology

A binned χ^2 analysis is performed, assuming all the four atmospheric oscillation parameters for neutrinos and anti-neutrinos, i.e. Δm^2, $\sin^2\theta$, $\Delta \bar{m}^2$, $\sin^2\bar{\theta}$, are non-identical. We use the same neutrino events data set, flavor oscillations, detector smearing and resolutions and the binning of events in several observed bins as explained in earlier ICAL analysis [2]. The "pulled" χ^2 analysis has been performed for two studies:

(1) **Fixed true values**:

Osc. parameters	True values	Marginalization
$\lvert\Delta m^2_{32}\rvert$ (eV^2)	2.5×10^{-3}	$(2.0\text{-}3.0) \times 10^{-3}$
$\lvert\Delta \overline{m^2}_{32}\rvert$ (eV^2)	2.4×10^{-3}	$(2.0\text{-}3.0) \times 10^{-3}$
$\sin^2\theta_{23}$	0.5	0.4-0.6
$\sin^2\bar{\theta}_{23}$	0.55	0.4-0.6

TABLE I: True values of the neutrino/antineutrino oscillation parameters.

Here, χ^2 have been calculated as a function of four atmospheric oscillation parameters ($|\Delta m^2_{32}|$, $\sin^2\theta_{23}$, $|\Delta \overline{m}^2_{32}|$, $\sin^2\bar{\theta}_{23}$). True values of all four oscillation parameters are fixed as shown in Table I while observed four parameters ($|\Delta m^2_{32}|$, $\sin^2\theta_{23}$, $|\Delta \overline{m}^2_{32}|$, $\sin^2\bar{\theta}_{23}$) are varied simultaneously in neutrino and anti-neutrino plane within their given marginalization range. The χ^2 for neutrino and anti-neutrino has been calculated separately, and a combined χ^2 sensitivity is considered for parameter estimation. Fig. 1 shows the sensitive region as a function of ($|\Delta m^2_{32}| - |\Delta \overline{m^2}_{32}|$) and ($\sin^2\theta_{23} - \sin^2\bar{\theta}_{23}$) parameter space at different Confidence Levels (C.L.)

(2) **With variation in true values:** Here, the True values of oscillation parameters have been allowed to vary independently as given in Table II. These parameters are varied simultaneously in a grid of 6×5 for neutrino plane and 6×5 for anti-neutrino plane. To test the null hypothesis mentioned in Table II, we estimate the $\chi^2(\nu + \bar{\nu})$ only for observed ($|\Delta m^2_{32}|$=$|\Delta \bar{m}^2_{32}|$) and ($\sin^2\theta_{23} = \sin^2\bar{\theta}_{23}$) values. The χ^2 is calculated for each set of

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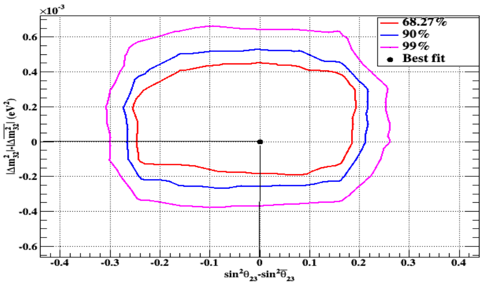

FIG. 1: The sensitivity region of the ICAL detector as a function of ($|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}|$) and ($\sin^2\theta_{23} - \sin^2\overline{\theta}_{23}$) parameter space at different Confidence Levels.

True values of $|\Delta m^2_{32}|$, $\sin^2\theta_{23}$, $|\Delta\bar{m}^2_{32}|$, and $\sin^2\overline{\theta}_{23}$.

True oscillation parameters	Marginalization range
$\lvert\Delta m^2_{32}\rvert$ (eV^2)	(2.0-3.0) $\times\ 10^{-3}$
$\lvert\Delta\overline{m^2}_{32}\rvert$ (eV^2)	(2.0-3.0) $\times\ 10^{-3}$
$\sin^2\theta_{23}$	0.3-0.7
$\sin^2\overline{\theta}_{23}$	0.3-0.7
Null hypothesis	
$\lvert\Delta m^2_{32}\rvert = \lvert\Delta\overline{m^2}_{32}\rvert$ (eV^2)	(2.0-3.0) $\times\ 10^{-3}$
$\sin^2\theta_{23} = \sin^2\overline{\theta}_{23}$	0.3-0.7

TABLE II: The true values of neutrino and anti-neutrino oscillation parameters and their marginalization range.

A minimum χ^2 has been binned as a function of differences in the true values of $[|\Delta m^2_{32}| - |\Delta\bar{m}^2_{32}|]_{True}$ keeping marginalization over [$\sin^2\theta_{23}$ and $\sin^2\overline{\theta}_{23}]_{True}$. For each set of difference $[|\Delta m^2_{32}| - |\Delta\bar{m}^2_{32}|]_{True}$, minimum $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ has been plotted as the functions of set of differences. Fig.2 represents the INO-ICAL potential for rulling out the null hypothesis at different confidence levels.

Results & Conclusions

Non-identical four oscillation parameters fitting technique for any difference in neutrino and anti-neutrino oscillation parameters has

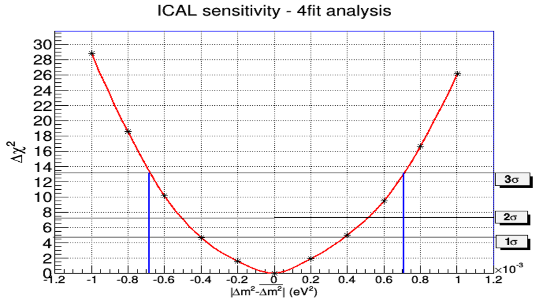

FIG. 2: The INO-ICAL sensitivity for ($|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}|)_{True}(eV^2) \neq 0$ at 1σ, 2σ and 3σ confidence levels.

been performed. Allowed parameter space for any difference in the oscillation parameters as a results of given fixed true values has been shown in Fig. 1. The INO-ICAL potential for ruling out the null hypothesis $|\Delta m^2_{32}| = |\Delta\overline{m^2}_{32}|$ as a results of variation in true values has been presented (Fig.2). It has been found that if the difference of true values of $|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}| \geq +0.7\times10^{-3}eV^2$ or $|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}| \leq -0.7\times10^{-3}eV^2$, then the ICAL detector can differentiate between ν_μ or $\bar{\nu}_\mu$ parameters at more than 3σ level.

Acknowledgments

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References

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