Independent measurement of neutrino and antineutrino mass-square splittings at the INO-ICAL experiment.

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Introduction

Neutrino oscillation, a phenomenon explaning the change in flavor of one neutrino to another, is well established by many experiments. Neutrino oscillation experiments have emerged at a very rapid rate and different experiments are using different neutrino sources to study this phenomenon. The oscillation parameters governing the neutrino oscillations are getting measured with a very good precision. The hint of having non-zero masses of neutrinos establish the fact that the three flavors of neutrinos are mixed which is described by a 3×3 unitary mixing matrix known as Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix. The three flavor eigenstates of neutrinos are mixtures of three mass eigenstates according to the PMNS matrix. Under the parameterization of PMNS matrix, the parameters governing the neutrino oscillations are: three mixing angles θ_{12}, θ_{23}, θ_{13}; two mass-squared differences Δm^2_{21}, Δm^2_{32} and a Dirac CP-violation phase δ_{CP}.

India-based Neutrino Observatory (INO) is a science project with a huge 50kTon ICAL detector [1] with the magnetized iron as target material. INO-ICAL detector is going to use RPC's as active detector element because of the long lifetime of RPC's. The distinguished feature of ICAL experiment is its 1.5T magnetic field which will help to distinguish charge of the interacting particles.

We explore the ICAL ability to find out any non-zero difference in the atmospheric mass squared differences of neutrinos and antineutrinos i.e. $|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}|$. The three flavor oscillation probabilities are calculated taking earth matter effects into account. The complete details of this analysis can be found in [2].

GEANT4 simulations package is used to introduce the detector effects. Neutrino (or anti-neutrino) events are reconstructed by the measurement of the secondary particles like muons (or anti-muon) and hadrons. The muons form a track inside the magnetized detector while hadrons form a shower while depositing their energy in the detector.

Different true values of $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$

In the present work, we study the INO's good ability to differentiate between $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$ which will enable us to either establish or rule out the hypothesis that neutrinos and antineutrinos have same the true value of $|\Delta m^2_{32}|$.

We took few different representative cases of the true values of $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$ and estimate χ^2 as a function of $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$. The χ^2 contours at different confidence levels (C.L.) have been plotted on the ($|\Delta m^2_{32}|$, $|\Delta\overline{m^2}_{32}|$) parameter space and a null hypothesis ($|\Delta\overline{m^2}_{32}|$=$|\Delta m^2_{32}|$) is also shown in 1. If this line is nσ (n=1,2,..) away from the χ^2 minimum, it can be concluded that the null hypothesis ($|\Delta\overline{m^2}_{32}|$=$|\Delta m^2_{32}|$) is ruled out at n$\sigma$ C.L. The two plots in Fig. 1 correspond to the true values of $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$ as shown in Table I.

ICAL sensitivity for $|\Delta m^2_{32}|$−$|\Delta\overline{m^2}_{32}| \neq 0$

In order to check the ICAL sensitivity for a non-zero value of the difference between

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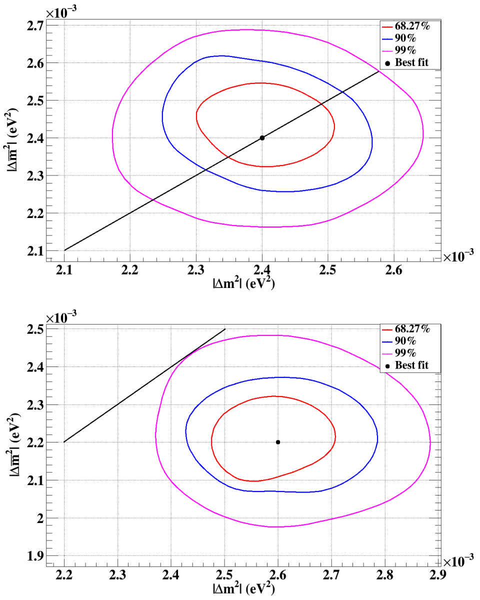

FIG. 1: Contour plots at 68%, 90% and 99% C.L. for different true values of $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$ as mentioned in Table I.

TABLE I: Different combinations of $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$ values used in Fig 1.

S.No.	$|\Delta m^2_{32}|$ (eV^2)	$|\Delta\overline{m^2}_{32}|$ (eV^2)
(a)	2.4×10^{-3}	2.4×10^{-3}
(b)	2.6×10^{-3}	2.2×10^{-3}

$|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$, the true values of $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$ have been varied independently in a range $(0.0021-0.0028eV^2)$. The $\chi^2(\nu+\overline{\nu})$ is being estimated on the null hypothesis line where the $|\Delta m^2_{32}|$ and $|\Delta\overline{m^2}_{32}|$ values are equal. The minimum value of χ^2 is chosen on this line that corresponds to the tangential point where the null hypothesis line coincides with the corresponding contour. Finally, this minimum χ^2 is binned as a function of difference in the true values of ($|\Delta m^2_{32}|$-$|\Delta\overline{m^2}_{32}|$). The points having the smallest χ^2 values are plotted and shown in Fig. 2.

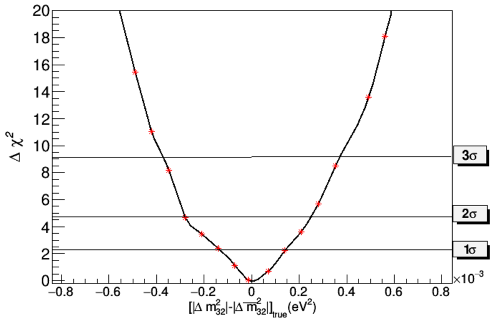

FIG. 2: The INO-ICAL sensitivity for $(|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}|)_{True}(eV^2)$ at 1σ, 2σ and 3σ confidence levels.

Results and Conclusions

The scenario where the neutrino and antineutrino oscillation parameters have different values have been investigated. The ICAL sensitivity for ruling out the null hypothesis ($|\Delta m^2_{32}| = |\Delta\overline{m^2}_{32}|$) by estimating the difference between the true values of mass squared differences of neutrinos and antineutrinos i.e. ($|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}|$) has been measured. Also, ICAL can rule out the null hypothesis of $|\Delta m^2_{32}| = |\Delta\overline{m^2}_{32}|$ at more than 3σ level if the difference of true values of $|\Delta m^2_{32}| - |\Delta\overline{m^2}_{32}| \geq +0.4\times10^{-3}eV^2$.

Acknowledgments

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References

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[2] Daljeet Kaur, Zubair Ahmad Dar, Sanjeev Kumar and Md. Naimuddin, Search for the differences in atmospheric neutrino and antineutrino oscillation parameters at the INO-ICAL experiment, Phys. Rev. D 95, 093005 (2017).