PROCEEDINGS OF SCIENCE

CPT violation sensitivity of NoVA, T2K and INO experiments using ν and $\bar{\nu}$ oscillation parameters

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Charge-Parity-Time (CPT) symmetry allows only identical oscillation parameters for ν and $\bar{\nu}$. But,different mass and mixing parameters for ν and $\bar{\nu}$ can give us possible hint for CPT violation or new physics. Using, different oscillation parameters for ν and $\bar{\nu}$, we find sensitivity for $(\Delta m^2_{32} - \Delta \bar{m}^2_{32})$ and $(\sin^2\theta_{23} - \sin^2\bar{\theta}_{23})$ for long-baseline (T2K and NOvA) and atmospheric neutrino (INO) experiments in different possible combinations of octant for neutrinos and anti-neutrinos. We present the joint sensitivity of the T2K, NOvA and INO experiments to such CPT violating observables.

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1. Introduction: CPT violation Analysis

The NOvA, T2K and INO experiments are quite sensitive to measure the atmospheric neutrino oscillation parameters ($\Delta m^2_{32} and \sin^2\theta_{23}$). The CPT violation sensitivity could be measured by determining how well these experiments can rule out the conserved CPT assumption for ν and $\bar{\nu}$ parameters. All the experimental and simulation details are given in Ref[1].

In the present analysis, the identical atmospheric oscillation parameters or we can say that the null difference between mass-squarred splitting and mixing angles of ν and $\bar{\nu}$ i.e. [$\Delta(\Delta m^2_{32}) = (\Delta m^2_{32} - \Delta \bar{m}^2{}_{32}) \neq 0$], and [$\Delta \sin^2\theta_{23} = (\sin^2\theta_{23} - \sin^2\bar{\theta}_{23}) \neq 0$] is considered as null hypothesis. To test the CPT violation, a fake dataset is generated at a given set of true values of neutrino and anti-neutrino oscillation parameters (Δm^2_{32}, $\sin^2\theta_{23}$, $\Delta\bar{m}^2_{32}$, $\sin^2\bar{\theta}_{23}$). All the oscillation parameters and their marginalisation range as given in Ref[1]. A four dimensional grid search is performed for the predicted dataset. χ^2 is calculated between the fake dataset and predicted dataset for each set of true values of oscillation parameters. Now, the true values of the oscillation parameters are not fixed at single value rather it also varied in the range as mentioned in Ref.[1] and same procedure is repeated again for each set of true values. We calculated $\Delta(\Delta m^2_{32})$ and $\Delta\sin^2\theta_{23}$. To find out the sensitivity for the difference $\Delta(\Delta m^2_{32})$, a minimum χ^2 has been binned as a function of difference in the true values of $\Delta(\Delta m^2_{32})$ keeping marginalization over $\Delta\sin^2\theta_{23}$ and for the sensitivity for difference of mixing angles $\Delta\sin^2\theta_{23}$, same has been done with the marginalization over $\Delta(\Delta m^2_{32})$. Further, for each set of difference $\Delta(\Delta m^2_{32})$ or $\Delta\sin^2\theta_{23}$, we calculate $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ and plot it as the functions of set of differences.

It is quite possible that in nature neutrino and anti-neutrino may lie in same or different octant. We also try to simulate the data considering this possibility to obtained the detector sensitivity for $\Delta(\Delta m^2_{32})$ and $\Delta\sin^2\theta_{23}$ in combination of different octants. There are four possible combinations of octants for neutrino and anti-neutrinos:
Case 1: νs and $\bar{\nu}$s both in Higher Octant (HO) [$\sin^2\theta_{23}(\sin^2\bar{\theta}_{23})$ in range 0.5-0.7]
Case 2: νs and $\bar{\nu}$s both in Lower Octant (LO) [$\sin^2\theta_{23}(\sin^2\bar{\theta}_{23})$ in range 0.3-0.5]
Case 3: νs in HO and $\bar{\nu}$s in LO
Case 4: νs in LO and $\bar{\nu}$s in HO

2. Results and Conclusion

With the considered exposure and run time, the NOvA and T2K experiment's sensitivity is quite better compared to the INO-ICAL experimental sensitivity. Hence, we also show a combined long base-line (T2K and NOvA) sensitivity for a better estimation of $\Delta(\Delta m^2_{32})$ and $\Delta\sin^2\theta_{23}$. We observed that $\Delta(\Delta m^2_{32})$ is not affected from different octant considerations for neutrinos and anti-neutrinos. So, we show an overall estimation for the measurement of $\Delta(\Delta m^2_{32})$ [Figure 1] from the NOvA, T2K and INO-ICAL experiments.

With the considered experiments, precise determination of $\Delta\sin^2\theta_{23}$ is possible if both ν and $\bar{\nu}$ are assumed to have similar octant combinations (either LO or HO) and these experiments are least sensitive for different octant combinations for neutrinos and anti-neutrinos. Our study shows that with the proposed fiducial volume and run time, the NOvA detector independently found the best among all the considered experiments for constraining these parameters as shown in Table 1.

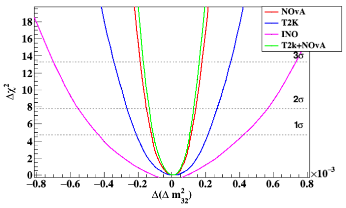
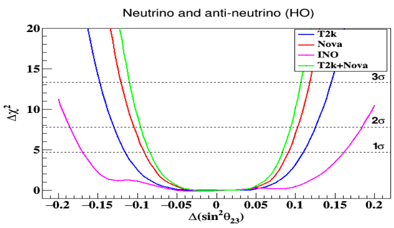
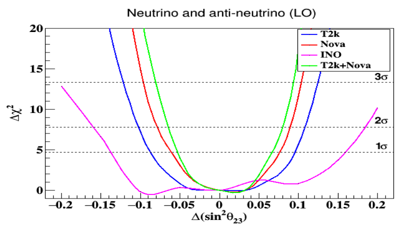


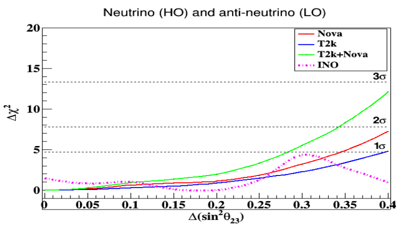
Figure 1: Experimental sensitivity of the NOvA, T2K and the INO experiments for $\Delta(\Delta m^2_{32})eV^2$.



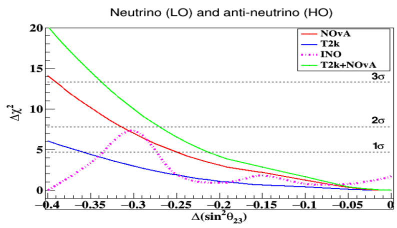
(a) case 1



(b) case 2



(c) case 3



(d) case 4

Figure 2: Combined sensitivity of the NOvA, T2K and INO experiments for $\Delta\sin^2\theta_{23} = sin^2\theta_{23} - sin^2\bar{\theta_{23}}$ when (a) ν and $\bar{\nu}$ in HO, (b) ν and $\bar{\nu}$ in LO, (c) ν in HO and $\bar{\nu}$ in LO and (d) when ν in LO and $\bar{\nu}$ in HO.

$\lvert\Delta(\Delta m^2_{32})\rvert \times 10^{-3} eV^2$				
Osc.parameter	NOvA	T2K	INO	T2K+NOvA
$\lvert\Delta(\Delta m^2_{32})\rvert$	0.10	0.22	0.40	0.10
$\lvert\Delta\sin^2\theta_{23}\rvert$				
Octant Case 1	0.1	0.13	0.16	0.07
Octant Case 2	0.08	0.12	0.17	0.09
Octant Case 3	0.34	0.4	$< 1\sigma$	0.28
Octant Case 4	0.24	0.36	$< 1\sigma$	0.21

Table 1: $\lvert\Delta(\Delta m^2_{32})\rvert$ and $\lvert\Delta\sin^2\theta_{23}\rvert$ sensitivity at the 1σ confidence level.

NOvA sensitivity is almost comparable to joint (NOvA+T2K) sensitivity for $\Delta(\Delta m^2_{32})$. However, NOvA+T2k joint results enhances the sensitivities for $\Delta\sin^2\theta_{23}$ if the neutrinos and anti-neutrinos are in different octants. The present CPT bounds at 1σ confidence interval are summarized in Table 1.

References

[1] Daljeet Kaur, Phys.Rev.D 101 (2020) 5, 5. DOI: 10.1103/PhysRevD.101.055017