Constraining CPT violation with Hyper-Kamiokande and ESSνSB

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Contents

Introduction

- CPT Symmetry is considered to be an exact symmetry of nature.
- Breafly, CPT theorem states that particles and anti-particles will have same mass and same life time.
- There is no evidence of CPT violation in any experiments so far.
- In case CPT symmetry is violated then for neutrino oscillation case we have to specify neutrinos and anti-neutrinos with different set of oscillation parameters.

$$|\nu_\alpha\rangle = \sum_{i=1}^{3} U_{\alpha i}(\theta_{12}, \theta_{13}, \theta_{23}, \delta_{CP})|\nu_i\rangle \; . \quad (1)$$

$$|\overline{\nu}_\alpha\rangle = \sum_{i=1}^{3} U^*_{\alpha i}(\overline{\theta}_{12}, \overline{\theta}_{13}, \overline{\theta}_{23}, \overline{\delta}_{CP})|\overline{\nu}_i\rangle \; . \quad (2)$$

CPT Asymmetry

- For Neutrino Oscillation case CPT Asymmetry can be defined as

$$A_{\alpha\beta}^{\mathrm{CPT}} \equiv P_{\alpha\beta} - \overline{P}_{\beta\alpha} \,. \quad (3)$$

  where $P_{\alpha\beta}$ and $\overline{P}_{\beta\alpha}$ are the oscillation probabilities for neutrinos and anti-neutrinos respectively.
  And $\alpha, \beta = e, \mu$.
- As we are considering CPT is conserved in nature, $A_{\alpha\beta}^{\mathrm{CPT}}$ will be zero in vacuum.
- But for long base line experiments this $A_{\alpha\beta}^{\mathrm{CPT}}$ will be non-zero due to matter effect giving an illusion of CPT violation.

Simulations

- For simulation purpose we have used GLoBES software.
- *ESSνSB($2\nu + 8\overline{\nu}$):* POT of 27×10^{22} corresponding to 5 MW proton beam, Baseline of 540 km, a water Cherenkov detector of fiducial volume 500 kt, neutrino beam energy of 0.25 GeV.
- *T2HK($1\nu + 3\overline{\nu}$):* POT of 27×10^{21} corresponding to 1.3 MW proton beam, Baseline of 295 km, two water Cherenkov detector (F.D) of fiducial volume 187 kt ($2 \times 187kt = 374kt$), neutrino beam energy of 0.56 GeV.
- *T2HKK($1\nu + 3\overline{\nu}$):* POT of 27×10^{21} corresponding to 1.3 MW proton beam, Baseline of 1100 km, a water Cherenkov detector (F.D) of fiducial volume 187 kt, neutrino beam energy of 0.56 GeV.
- *DUNE($5\nu + 5\overline{\nu}$):* POT of 10×10^{21} corresponding to 1.2 MW proton beam, Baseline of 1300 km, Liquid argon time projection chamber (LArTPC) of fiducial volume 40 kt, neutrino beam energy 0.5-8 GeV.

Simulation

- we simulate each experiment with $\Delta x = \left| x - \overline{x} \right| = 0$, where $x(\overline{x})$ is the oscillation parameter for neutrinos (antineutrinos).
- Later, we evaluate the sensitivity of each of the experiments to non-zero Δx.
- In each case, we choose three values for θ_{23} : lower octant ($\sin^2\theta_{23} = 0.43$), maximal ($\sin^2\theta_{23} = 0.5$) and higher octant ($\sin^2\theta_{23} = 0.57$) to study the correlation between the CPT violation sensitivity and the octant of θ_{23}.
- In the test values, we marginalize over all the oscillation parameters for both neutrinos and antineutrinos except $x, \overline{x}$ and the solar parameters.
- $\chi^2(\Delta X) = \chi^2(\left| x - \overline{x} \right|) = \chi^2(x) + \chi^2(\overline{x})$
- minimum $\chi^2(\Delta X)$ has been calculated over all possible combinations of $\left| x - \overline{x} \right|$.

Simulation

- For our study we have taken ΔX to be $\Delta(\Delta m^2_{31})$, $\Delta(\delta_{CP})$ and $\Delta(sin^2\theta_{23})$.
- Further more we have analysed neutrino and anti-neutrino data independently assuming nature is invariant under CPT.
- We have done this study for combination of DUNE + T2HKK and DUNE + ESSνSB experiments and scrutinized whether they provide the same oscillation parameters as predicted by CPT symmetry.
- Again we have assumed that CPT is violated in nature and estimated the sensitivity of T2HK, T2HKK, ESSnuSB, and DUNE to establish CPT invariance violation individually.

Results

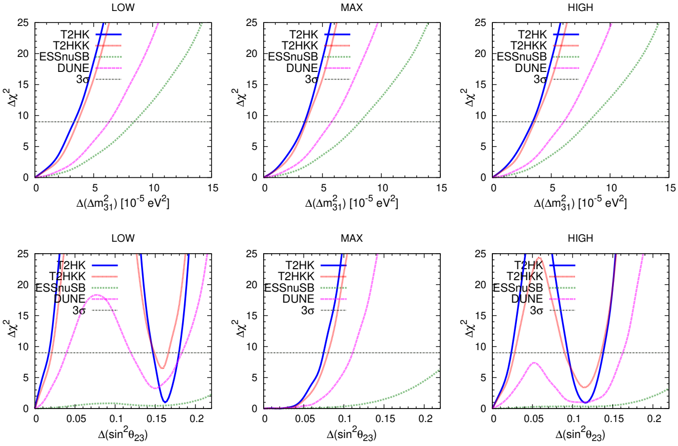


Figure: CPT violation sensitivity for Δm^2_{31} and $sin^2\theta_{23}$ for long baseline experiments T2HK, T2HKK, ESSnuSB and DUNE

Results

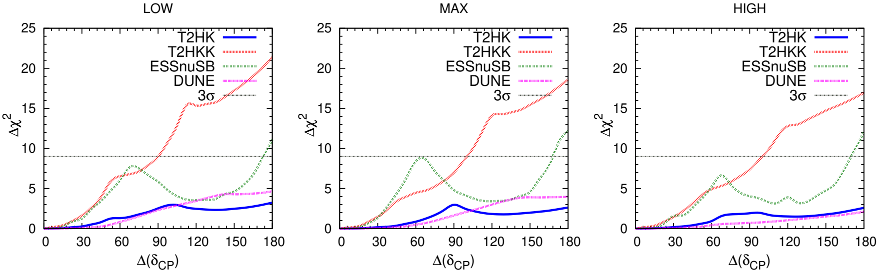


Figure: CPT violation sensitivity for $\Delta(\delta_{CP})$ for long baseline experiments T2HK, T2HKK, ESSnuSB and DUNE

Results

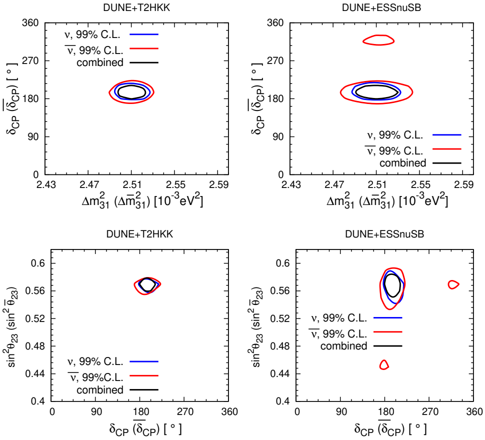
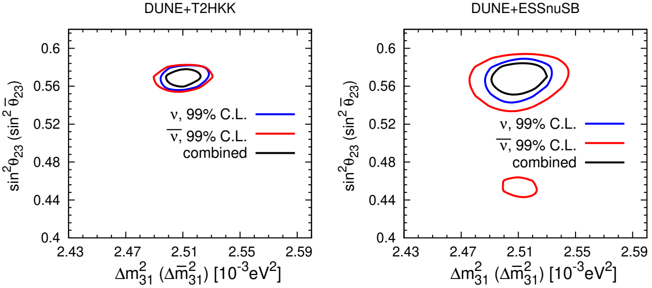


Figure: Allowed parameter space between different neutrino and antineutrino oscillation parameters at 99% C.L. for combination of experiments.

Results



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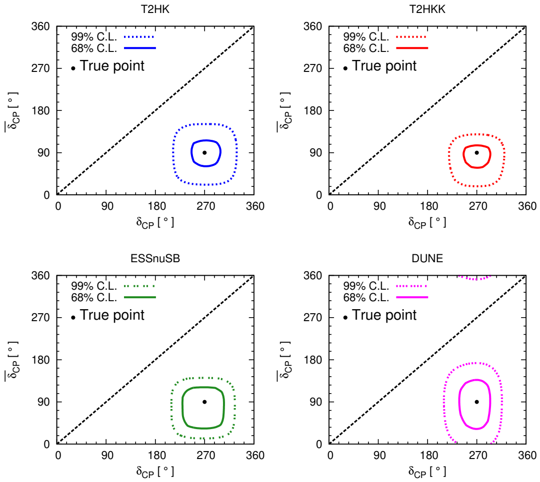

Figure: Allowed regions between δ_{CP} and $\overline{\delta}_{CP}$ in the CPT violating scenario

Conclusion

- T2HKK and ESSνSB experiments are more sensitive towards δ_{CP} to obtain the bounds on $\Delta(\delta_{CP})$.
- T2HK, T2HKK and DUNE are sensitive to the atmospheric mixing parameters [$\Delta(\Delta m^2_{31})$ and $\Delta(sin^2\theta_{23})$].
- T2HK gives most stringent limits on $\Delta(\Delta m^2_{31})$ and $\Delta(sin^2\theta_{23})$.
- T2HKK gives best bound on $\Delta(\delta_{CP})$.
- Both DUNE + T2HKK and DUNE + ESSnuSB experiments are sensitive to CPT violation.
- DUNE + T2HKK can even resolve the octant degeneracy in θ_{23} and $\overline{\theta}_{23}$ at 99% C.L.
- All the upcoming long-baseline experiments will be able to establish CPT violation individually at 99% C.L. in their proposed run time by demonstrating $\delta_{CP} \neq \overline{\delta}_{CP}$.

References

R. Majhi, D. K. Singha, K. N. Deepthi and R. Mohanta, Phys. Rev. D **104** (2021) no.5, 055002 doi:10.1103/PhysRevD.104.055002 [arXiv:2101.08202 [hep-ph]].

Thank You.