PROCEEDINGS OF SCIENCE

Testing CPT invariance with the solar neutrino sector

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CPT invariance is a key pillar in our description of nature. Neutrinos, as elementary particles, provide a unique opportunity to test this fundamental symmetry. CPT violation could manifest as particles and antiparticles having different masses. From a separate analysis of neutrino and antineutrino data, one can set bounds on CPT violation in the neutrino sector. We show how next-generation solar neutrino and medium-baseline reactor experiments will allow constraining, or proving, CPT violation with unprecedented sensitivity.

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1. Introduction

CPT symmetry, which corresponds to the simultaneous action of parity (P), charge-conjugation (C) and time-reversal (T) transformations, is a fundamental pillar in high-energy physics. It stems from requiring that our quantum field theories are local, Lorentz-invariant, and respect unitarity. From the CPT theorem, it is known that particles and antiparticles have the same mass and, if unstable, the same lifetime. However, in high-energy theories with Lorentz invariance violation [1, 2] or Lorentz-invariant local interactions, such statement does not necessarily hold [3, 4].

2. Neutrino oscillations and CPT invariance

Our description of the phenomenon of neutrino oscillations is based on combined fits to neutrino and antineutrino data simultaneously (see, for instance, [5]), i.e. it assumes CPT invariance. However, it is also possible to analyse data from particles and antiparticles separately. The agreement (or disagreement) between the results of both fits can be interpreted as a test of CPT invariance [6]. Following this procedure, the current limits on the difference between the oscillation parameters from neutrino and antineutrino data at 3σ level read [7]

$$|\Delta(\Delta m^2_{21})| = |\Delta m^2_{21} - \Delta\bar{m}^2_{21}| < 3.7 \times 10^{-5}\text{eV}^2 \tag{1}$$

$$|\Delta(\Delta m^2_{31})| = |\Delta m^2_{31} - \Delta\bar{m}^2_{31}| < 2.5 \times 10^{-4}\text{eV}^2 \tag{2}$$

$$|\Delta(\sin^2\theta_{12})| = |\sin^2\theta_{12} - \sin^2\bar{\theta}_{12}| < 0.187 \tag{3}$$

$$|\Delta(\sin^2\theta_{13}| = |\sin^2\theta_{13} - \sin^2\bar{\theta}_{13}| < 0.029 \tag{4}$$

$$|\Delta(\sin^2\theta_{23})| = |\sin^2\theta_{23} - \sin^2\bar{\theta}_{23}| < 0.19\,. \tag{5}$$

Motivated by the apparent mismatch between the preferred values of $\sin^2\theta_{12}$ and Δm^2_{21} between solar data and KamLAND, we proceed to discuss the future sensitivity to potential CPT violation in the solar neutrino sector.

On the one hand, JUNO will reach a subpercent determination of the solar parameters from reactor antineutrino oscillations. Simultaneously, DUNE and Hyper-Kamiokande (HK) will separately measure solar neutrinos, using electron-neutrino interactions on argon and elastic scattering on electrons respectively. A combined analysis of both experiments would then also provide an accurate determination of $\sin^2\theta_{12}$ and Δm^2_{21}. Since some of the details related to the setup of these experiments are still unclear, we considered two different configurations for our analysis, a conservative and an optimal one, as detailed in [7].

In the left panel of Figure 1, we show the expected sensitivity for the individual experiments and the combined analysis if one assumed CPT violation with the preferred best-fit values obtained from current data. One can see that in the optimal case, the tension between JUNO and a joint fit of DUNE and Hyper-Kamiokande would go beyond the 3σ level. However, one should notice that such discrepancy can also be explained in terms of non-standard interactions.

On the contrary, if one assumed CPT is conserved, the existing limits from neutrino oscillation would improve significantly. This is shown in the right panel of Figure 1, where the same analysis has been performed but assumes the best-fit value from [5]. The new bounds expected in this case are summarised in Table 1. One can see that the limit from the solar mixing angle $\sin^2\theta_{12}$ will

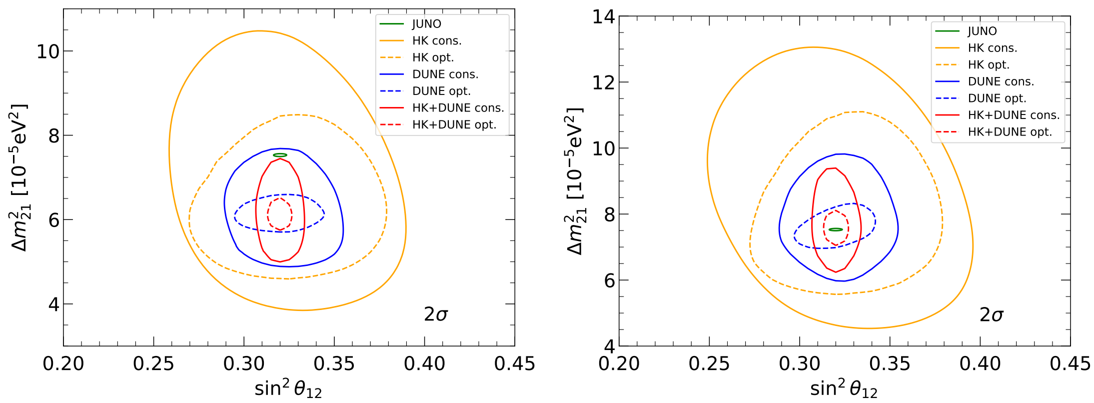

Figure 1: Allowed regions at 1σ, 2σ and 3σ in the $\sin^2\theta_{12}$-Δm^2_{21} plane for a CPT violating and a CPT conserving scenario, in the left and right panels respectively.

Table 1: Current and future limits at 3σ level from the parameters of the neutrino solar sector.

	$\Delta(\sin^2\theta_{12})$	$\Delta(\Delta m^2_{21})$ [$\times10^{-5}$eV^2]
Current limit	0.187	3.7
JUNO + DUNE + HK conservative	0.018	2.4
JUNO + DUNE + HK optimal	0.011	0.8

improve at least in order of magnitude where a constraint 4-5 times more stringent on Δm^2_{21} could be achieved in optimal conditions for DUNE and Hyper-Kamiokande.

3. Discussion

CPT symmetry is a cornerstone in our description of nature and therefore, it is of interest to test it. Moreover, neutrinos, as elementary and neutral particles, are an ideal system to perform such tests. In particular, CPT violation could manifest as neutrinos and antineutrinos having different masses and mixing. It is possible to derive constraints on this form of CPT violation by analysing neutrino and antineutrino oscillation data separately. In the future, such an approach would lead to an even more stringent limit from a joint fit of JUNO, DUNE and Hyper-Kamiokande data. Nonetheless, the exact improvement will depend on the experimental configuration achieved in solar neutrino experiments. On the contrary, if CPT was not conserved, the tension between JUNO and a joint fit of DUNE and Hyper-Kamiokande data could go beyond the 3σ level for optimal experimental setups. This illustrates that next-generation neutrino observatories have the potential to enrich their physics programs to test CPT symmetry.

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