Neutrinos, DUNE and the world best bound on CPT invariance

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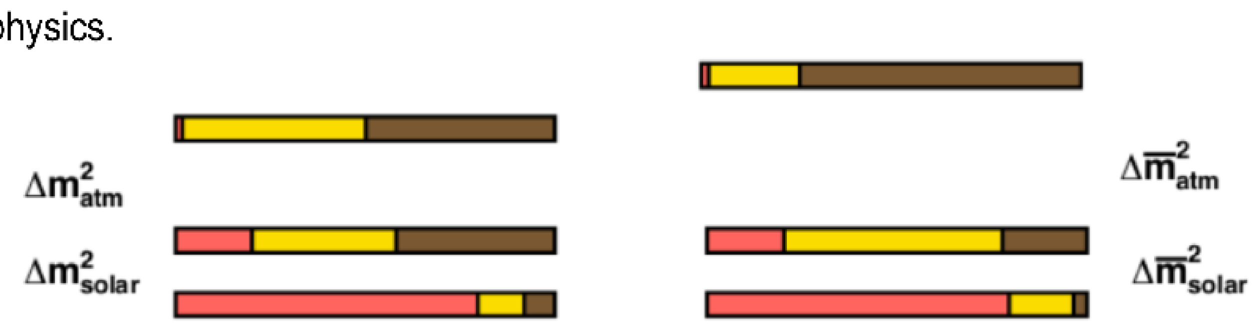
Motivation and current bounds

An observation of CPT invariance would imply that either Hermiticity, Locality or Lorentz invariance is not conserved, resulting in an gigantic impact on particle physics.



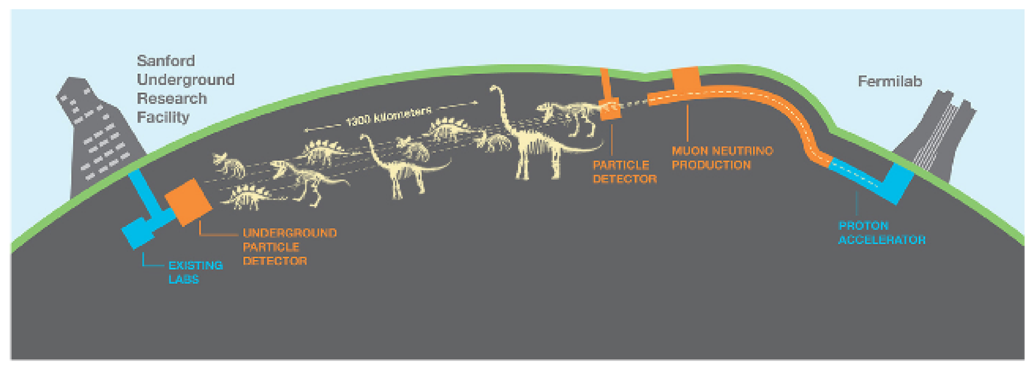
We assume that neutrinos oscillate with parameters $\theta_{12}, \theta_{13}, \theta_{23}, \Delta m^2_{21}, \Delta m^2_{31}, \delta$ and antineutrino with $\overline{\theta}_{12}, \overline{\theta}_{13}, \overline{\theta}_{23}, \Delta \overline{m}^2_{21}, \Delta \overline{m}^2_{31}, \overline{\delta}$, resulting in different mass spectra and mixings and compute current bounds[1] using data from Ref.[2].

3σ bounds:

$$\begin{aligned}
|\Delta m^2_{21} - \Delta \overline{m}^2_{21}| &< 4.7 \times 10^{-5} \mathrm{eV}^2, \\
|\Delta m^2_{31} - \Delta \overline{m}^2_{31}| &< 3.7 \times 10^{-4} \mathrm{eV}^2, \\
|\sin^2\theta_{12} - \sin^2\overline{\theta}_{12}| &< 0.14, \\
|\sin^2\theta_{13} - \sin^2\overline{\theta}_{13}| &< 0.03, \\
|\sin^2\theta_{23} - \sin^2\overline{\theta}_{23}| &< 0.32
\end{aligned}$$

Simulating the DUNE experiment

The simulation of DUNE is performed with the GLoBES package [3,4]. We simulate events and backgrounds for neutrinos and antineutrinos separately. We assume DUNE to be running 3.5 years in both neutrino and antineutrino mode scanning over all parameters except the solar ones and putting a prior on the reactor angle in antineutrino mode, due to the good measurement by the reactor experiments.

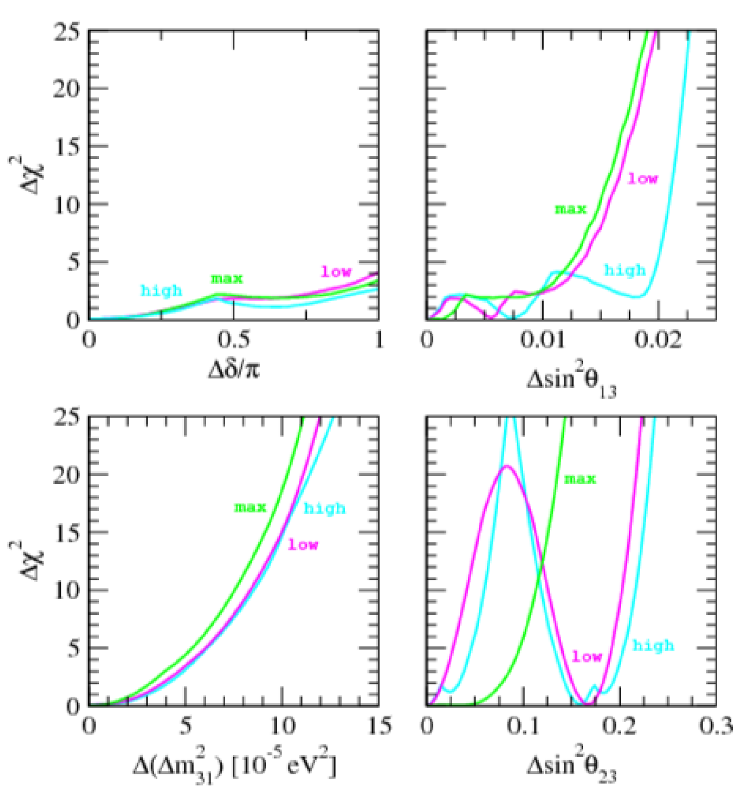


Having the results of the simulations we can marginalize over all parameters except the ones of interest and calculate the sensitivity to CPT invariance using the function

$$\chi^2(\Delta x) = \chi^2(|x - \overline{x}|) = \chi^2(x) + \chi^2(\overline{x})$$

where x is any of the oscillation parameters.

Sensitivity to CPT invariance at DUNE



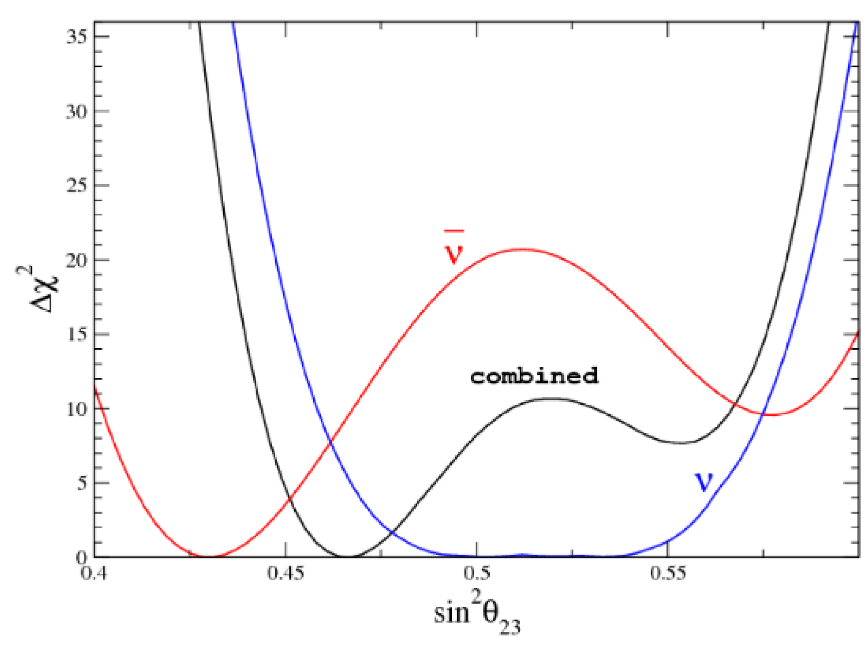
We show the sensitivity of DUNE to measure CPT invariance for three different values of the atmospheric angle. DUNE will not have sensitivity to the difference of CP-phases, neither improve the bound on the difference of reactor angles. But it is possible to improve the bounds on the difference of the atmospheric parameters. We observe that for the (true) atmospheric angles in the lower or upper octant there is a second minimum in the sensitivity to the difference. This arises because of degenerate solutions of the atmospheric angle. In the case of the atmospheric mass splitting DUNE could improve the current bound by at least one order of magnitude, obtaining

$$|\Delta m^2_{31} - \Delta \overline{m}^2_{31}| < 8.1 \times 10^{-5} \ \mathrm{eV}^2$$

at 3σ confidence level.

Obtaining imposter solutions

If CPT turns our to be not conserved in nature we are comitting errors in analyzing neutrino and antineutrino data in a joint way. This is illustrated in this figure. We create fake data assuming two different values for the atmospheric angles, namely $\sin^2\theta_{23} = 0.5$ and $\sin^2\overline{\theta}_{23} = 0.43$. Performing the analysis in the traditional way assuming CPT to be conserved results in a new best fit value $\sin^2\theta_{23}^{\mathrm{comb}} = 0.467$ excluding the real values at approximately 3σ and 5σ, respectively.

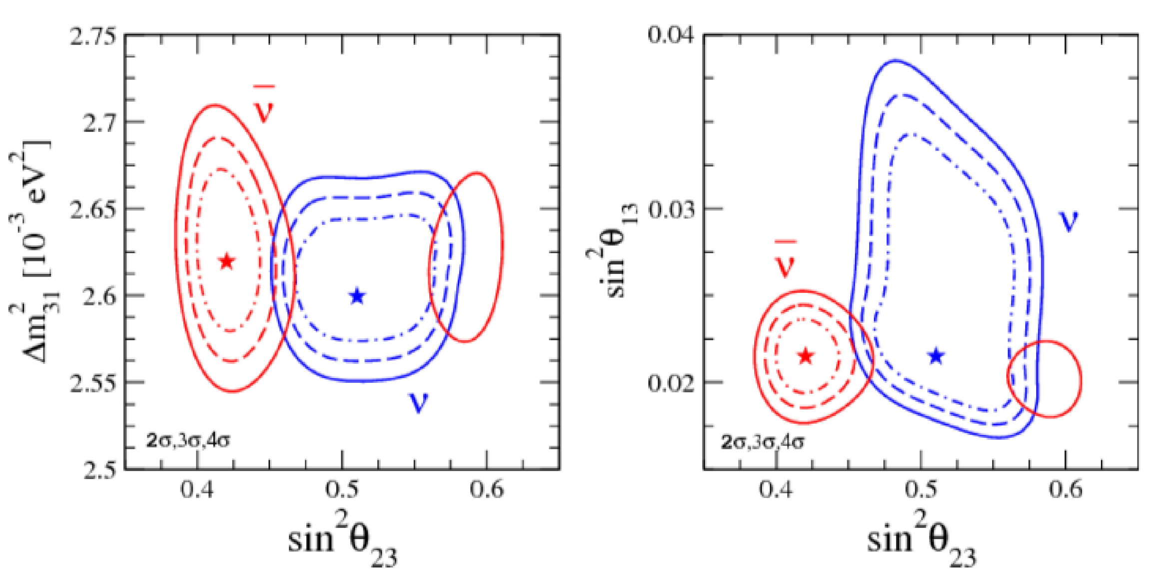


Probing the T2K results

The T2K collaboration reported different best fit values for neutrinos and antineutrinos in Ref.[5]:

$$\sin^2\theta_{23} = 0.51, \quad \Delta m^2_{32} = 2.53 \times 10^{-3} \mathrm{eV}^2$$
$$\sin^2\overline{\theta}_{23} = 0.42, \quad \Delta \overline{m}^2_{32} = 2.55 \times 10^{-3} \mathrm{eV}^2$$

Although not producing a big tension there, DUNE could measure CPT violation with very high statistical significance, if these values turned out to be true. As can be seen in the figure especially in the case of the atmospheric angles the signal would be seen at more than 3σ.

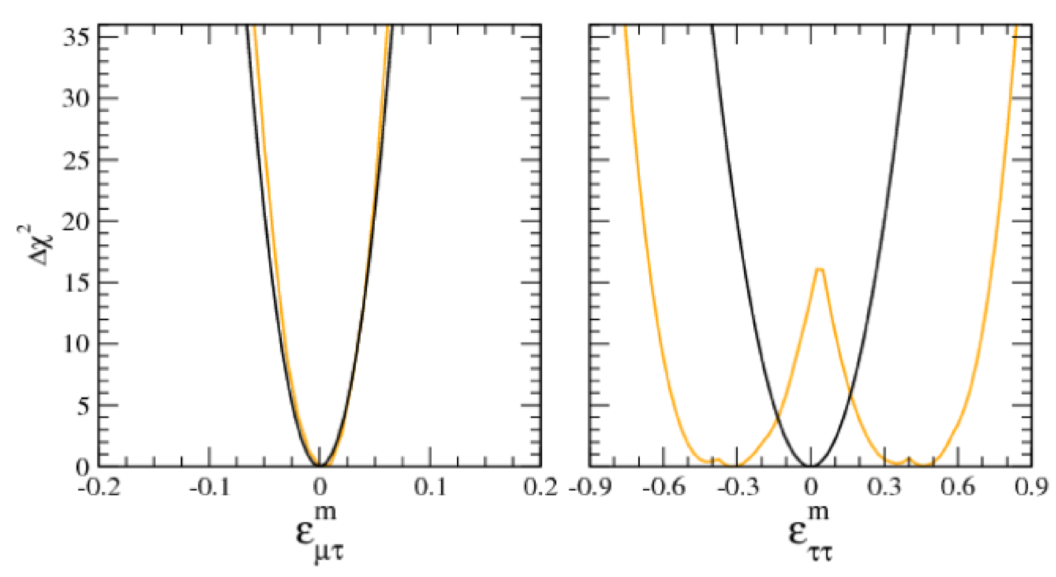


CPT invariance versus NSI

One might argue that this signal could be induced through nonstandard neutrino interactions. Indeed, NSIs affect the neutrino and antineutrino parameters differently. In the 2-neutrino approximation one finds:

$$\begin{aligned}
2A\epsilon^m_{\tau\tau} &= \Delta m^2_\nu \cos 2\theta_\nu - \Delta m^2_{\overline{\nu}} \cos 2\theta_{\overline{\nu}} \\
4A\epsilon^m_{\mu\tau} &= \Delta m^2_\nu \sin 2\theta_\nu - \Delta m^2_{\overline{\nu}} \sin 2\theta_{\overline{\nu}}
\end{aligned}$$

We find that the signal observed by T2K, in the context of DUNE could be explained by an NSI of $\epsilon^m_{\tau\tau} = -0.33$. Anyway, this value is highly disfavored[7] and therefore the result would rather indicate a violation of CPT invariance than an observation of NSI.



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