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TESTING THE SENSITIVITY OF OSCILLATION EXPERIMENTS TO CSD(n) NEUTRINO MODELS*

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The CSD(3) constrained sequential dominance model of neutrino mass gives a very good fit to neutrino oscillation data. Using predictions of the neutrino masses, mixing angles and phases from just three free parameters, current and future neutrino oscillation experiments can probe this model. Reactor and long-baseline accelerator experiments are found to be sensitive to the TM1 sum rules obeyed by CSD(n), with further sensitivity possible through an additional CSD(3) constraint beyond those of TM1 mixing.

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Sequential dominance models of neutrinos arise from the proposal that, via the type I seesaw mechanism, a dominant heavy right-handed (RH) neutrino is mainly responsible for the atmospheric neutrino mass, a heavier subdominant RH neutrino for the solar neutrino mass, and a possible third largely decoupled RH neutrino for the lightest neutrino mass [1]. Constrained sequential dominance (CSD) constrains these models through the introduction of flavour symmetry, with the indirect approach used to fix the mass matrix from vacuum alignments of flavon fields [2]. A family of constrained sequential dominance (CSD) models parametrised by n, either integer or real using the flavour symmetry groups S_4 or A_4 respectively, predict the CSD(n) mass matrix for left-handed neutrinos [3, 4]. For the two right-handed neutrino case where the lightest left-handed neutrino is massless, the mass matrix is given by

$$m^{\nu} = m_a \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{pmatrix} + m_b e^{i\eta} \begin{pmatrix} 1 & n & (n-2) \\ n & n^2 & n(n-2) \\ (n-2) & n(n-2) & (n-2)^2 \end{pmatrix} , \qquad (1)$$

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where in addition to n, there are three free real parameters; m_a and m_b proportional to the reciprocal of the masses of the dominant and subdominant right-handed neutrinos and a relative phase η.

CSD(n) with two RH neutrinos can be tested through predictions of the mass ordering (normal), the absolute neutrino mass scale ($m_1 = 0$), and the neutrino-less double-beta decay rate (well below measurable limits). The prediction of all neutrino masses, mixing angles and phases through diagonalising the mass matrix, with relatively few free parameters, allows CSD(n) to also be tested through oscillation experiments. Existing data have shown that, although values of $n \leq 2$ and $n \geq 5$ are excluded and $n = 4$ gives a poor fit, CSD(3) gives an extremely good fit to all existing data, with a prediction of $\delta \approx \pm\pi/2$ [5].

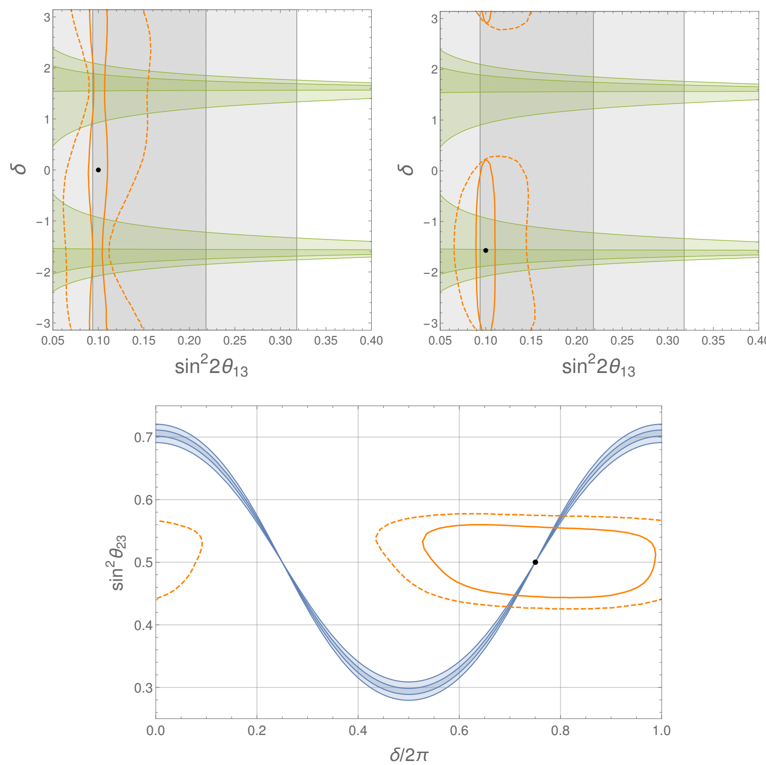

Fig. 1. (Colour on-line) Top: Predicted 90% C.L. sensitivity (black/orange) for T2K (black dashed) and T2K plus reactor experiments (black solid) for two different assumed true points. Regions allowed by the CSD(3) sum rules are shown with the NuFIT 1σ and 3σ ranges for θ_{12} (vertical grey) and for θ_{23} (horizontal green). Bottom: Predicted 1σ (black solid) and 2σ (black dashed) sensitivity at NOvA for $\delta = 3\pi/2, \sin^2\theta_{23} = 0.5$ with the allowed regions for (2) with the 1σ and 3σ NuFIT ranges for θ_{13}.

The first column of the CSD(3) mixing matrix is the same as tri-bimaximal mixing, leading to TM1 mixing, which has the sum rules [4]

$$\cos\theta_{12} = \sqrt{\frac{2}{3}}\frac{1}{\cos\theta_{13}}\,, \qquad \cos\delta = -\frac{\cot 2\theta_{23}\left(1-5\sin^2\theta_{13}\right)}{2\sqrt{2}\sin\theta_{13}\sqrt{1-3\sin^2\theta_{13}}}\,. \tag{2}$$

The first of these provides a simple constraint not yet excluded by measurements of θ_{13} and θ_{12}. Improved precision from current-generation reactor and accelerator experiments will test this constraint. Testing the second sum rule requires a measurement of δ, which could be measured with low precision at current long-baseline accelerator experiments. Figure 1 shows the predicted sensitivities of NOvA [6] and T2K [7] with the constraint enforced by the TM1 sum rules with NuFIT global fit data [8].

An additional constraint beyond those of TM1 mixing exists for CSD(3) relating θ_{13}, θ_{23}, Δm^2_{21}, Δm^2_{32}. If θ_{23} is not maximal, current long-baseline experiments may have sensitivity to CSD(3) by testing this, as shown for T2K and NOvA sensitivities in Fig. 2.

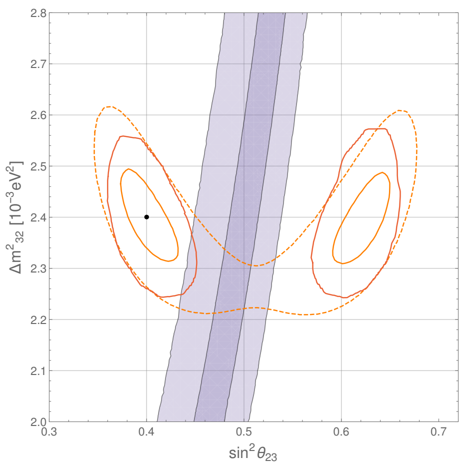

Fig. 2. (Colour on-line) Predicted 90% C.L. sensitivity for T2K after 7.8e21 POT (black/red) and NOvA (grey/orange) after 1.2e21 POT (grey/solid) and 6e21POT (grey/dashed), for the true values $\sin^2\theta_{23} = 0.4$, $\Delta m^2_{32} = 2.4\times10^{-3}\mathrm{eV}^2$. The regions allowed by CSD(3) are shown after the restricting θ_{13} and Δm^2_{21} to their NuFIT 1σ and 3σ ranges.

To further probe the sensitivity of future experiments to CSD(n), the combined sensitivity of measurements on all parameters is needed. Under development is a set of tools extending the GLoBES simulation package for testing any models that predict the neutrino mass matrix. With this input, these tools enable the sensitivity to be determined for combined simulations of long-baseline and reactor experiments, and constraints from past data. This framework will provide a general method of testing sensitivity of oscillation experiments to any predictive neutrino mass models, without the requiring explicit sum rules.

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