Global analysis of Neutral Current NSI's

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HIDDeν
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

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Summary

Outline

PAY ATENTION:

- We are going to combine Global Oscillation Data with Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) data!

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- Using mainly the improvements from Borexino phase II and CEvNS data, we will impose bounds on the Neutral Current NSIs.

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- Through this global analysis, we aim to place the most stringent bounds possible on the Large Mixing Angle Dark solution!

Global Analysis: Experiments

We have included all data used for the standard 3 ν's oscillation analysis in NuFIT-5.2 with **the only exception of T2K and NOνA appearance data favoring CP violation cannot be accommodated within the CP-conserving approximation assumed in this work.**
The analysis involved combining data from:

- **SOLAR** - Chlorine, Gallex/GNO, SAGE, SNO, SuperK[1-4], the first two phases of Borexino;
- **ATMOSPHERIC** - SuperK[1-4], Deepcore, IceCUBE;
- **REACTOR** - KamLAND, Double-Chooz, Daya-Bay, RENO;
- **ACCELERATOR** - Minos, T2K, NOvA;
- **CEvNS** - Dresden II, both the Ar target and the CSI target configurations of COHERENT) neutrino experiments.

Non-Standard interactions

The lagrangian for neutral current nonstandard interactions (NC-NSI) considered is:

$$\mathcal{L}_{\text{NSI,NC}} = -2\sqrt{2}\, G_F \sum_{f,P,\alpha,\beta} \varepsilon_{\alpha\beta}^{f,P} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{f}\gamma_\mu P f)\,.$$

Assuming the neutrino flavour dependence to be charge fermion independent we can factorize the NSI coefficients as

$$\varepsilon_{\alpha\beta}^{f,P} \equiv \varepsilon_{\alpha\beta}\, \xi^f \chi^P$$

To parameterize the NSI for each fermion, we are using two angles, η and ζ:

$$\xi^e = \sqrt{5}\cos\eta\sin\zeta\,, \qquad \xi^p = \sqrt{5}\cos\eta\cos\zeta\,, \qquad \xi^n = \sqrt{5}\sin\eta$$

In what follows we will show some of the results in terms of effective NSI coefficients in the Earth defined as:

$$\varepsilon_{\alpha\beta}^{\oplus} = \varepsilon_{\alpha\beta}^{e,V} + (2 + Y_n^{\oplus})\varepsilon_{\alpha\beta}^{u,V} + (1 + 2Y_n^{\oplus})\varepsilon_{\alpha\beta}^{d,V} = (\varepsilon_{\alpha\beta}^{e,V} + \varepsilon_{\alpha\beta}^{p,V}) + Y_n^{\oplus}\varepsilon_{\alpha\beta}^{n,V}\,,$$

where $Y_n^{\oplus} = \frac{N_n^{\oplus}}{N_e^{\oplus}} \simeq 1.051$ for the average Earth composition.

LMA-D solution

The evolution of the neutrino and antineutrino flavour state during propagation is governed by the Hamiltonian

$$H^{\nu} = H_{\text{vac}} + H_{\text{mat}} \quad \text{and} \quad H^{\bar{\nu}} = (H_{\text{vac}} - H_{\text{mat}})^* ,$$

such that the matter part H_{mat} of the

Hamiltonian which governs neutrino oscillations:

$$H_{\text{mat}} = \sqrt{2} G_F N_e(x) \begin{pmatrix} 1 + \mathcal{E}_{ee}(x) & \mathcal{E}_{e\mu}(x) & \mathcal{E}_{e\tau}(x) \\ \mathcal{E}^*_{e\mu}(x) & \mathcal{E}_{\mu\mu}(x) & \mathcal{E}_{\mu\tau}(x) \\ \mathcal{E}^*_{e\tau}(x) & \mathcal{E}^*_{\mu\tau}(x) & \mathcal{E}_{\tau\tau}(x) \end{pmatrix} ,$$

where $\mathcal{E}_{\alpha\beta}(x) = \sum_{f=p,n,e} \frac{N_f(x)}{N_e(x)} \epsilon^{f,V}_{\alpha\beta}$.

The neutrino transition probabilities remain invariant if the Hamiltonian $H^{\nu} = H_{\text{vac}} + H_{\text{mat}}$ is transformed as $H^{\nu} \to -(H^{\nu})^*$. This requires a simultaneous transformation of both the vacuum and the matter terms. The transformation of H_{vac} involves a change in the octant of θ_{12}, originating the so-called **LMA-D solution**, as described below: Miranda, O. G. et al, hep-ph/0406280 Coloma P. and Schwetz, T. et al, hep-ph/1604.05772

$$\theta_{12} \to \pi/2 - \theta_{12} ,$$
$$\Delta m^2_{31} \to -\Delta m^2_{31} + \Delta m^2_{21} = -\Delta m^2_{32} ,$$
$$\delta_{\text{CP}} \to \pi - \delta_{\text{CP}}$$

As for H_{mat} we need:

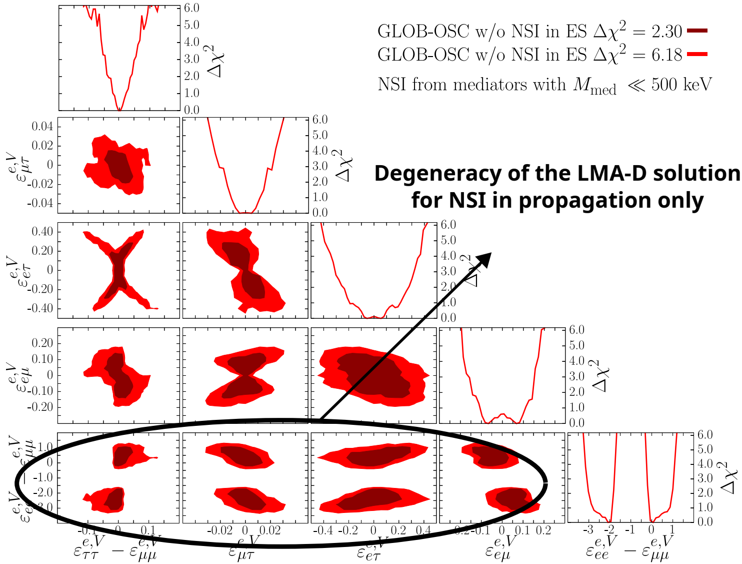
$$[\mathcal{E}_{ee}(x) - \mathcal{E}_{\mu\mu}(x)] \to -[\mathcal{E}_{ee}(x) - \mathcal{E}_{\mu\mu}(x)] - 2 ,$$
$$[\mathcal{E}_{\tau\tau}(x) - \mathcal{E}_{\mu\mu}(x)] \to -[\mathcal{E}_{\tau\tau}(x) - \mathcal{E}_{\mu\mu}(x)] ,$$
$$\mathcal{E}_{\alpha\beta}(x) \to -\mathcal{E}^*_{\alpha\beta}(x) \qquad (\alpha \neq \beta) .$$

Analysis

We have considered **two scenarios**:

- Including the NSI **only** in the matter effects (mediators much lighter than $\mathcal{O}$(500 keV));
- Including the NSI both in propagation, CEνNS, and electron scattering (ES) scattering (mediators heavier than $\mathcal{O}$(50 MeV)).

GLOB-OSC w/o NSI in ES - electrons/protons only

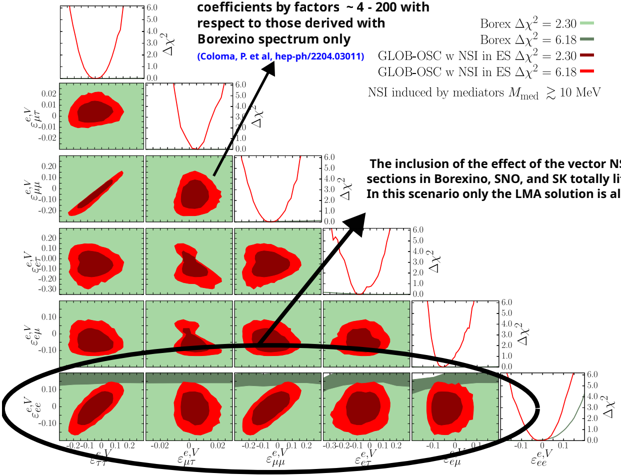


Degeneracy of the LMA-D solution for NSI in propagation only

GLOB-OSC w NSI in ES - electrons only - Vector

The comparison shows that for vector NSI with electrons the global analysis of the oscillation data reduces the allowed ranges of the NSI coefficients by factors ~ 4 - 200 with respect to those derived with Borexino spectrum only

(Coloma, P. et al, hep-ph/2204.03011)

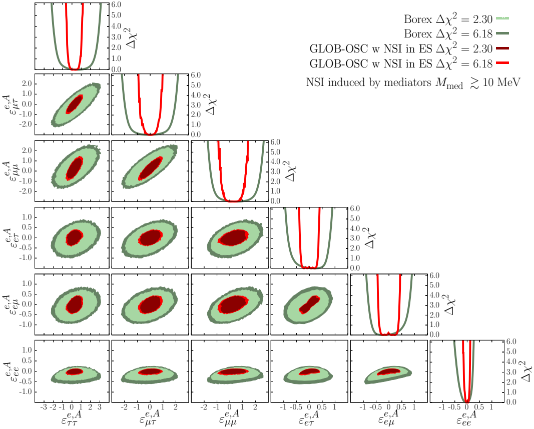


The inclusion of the effect of the vector NSI in the ES cross sections in Borexino, SNO, and SK totally lifts the degeneracy. In this scenario only the LMA solution is allowed.

The NSI contribution to ES break the LMA-D degeneracy and impose independent bounds on the three flavour-diagonal NSI coefficients. Within the LMA solution the effect of the vector NSI on the matter potential also leads to stronger constraints.

GLOB-OSC w NSI in ES - electrons only- Axial

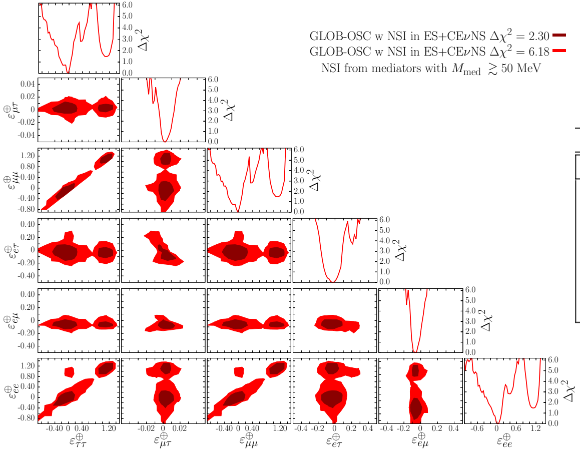
Axial-vector NSI do not contribute to the matter potential and therefore the difference between the results of the global oscillation and the Borexino-only analysis in this case arises solely from the effect of the axial-vector NSI on the ES cross section in SNO and SK.



The improvement over the bounds derived with Borexino-only analysis is just a factor $\sim 2-3$!!

GLOB-OSC w NSI in ES + CEνNS - quarks+electrons

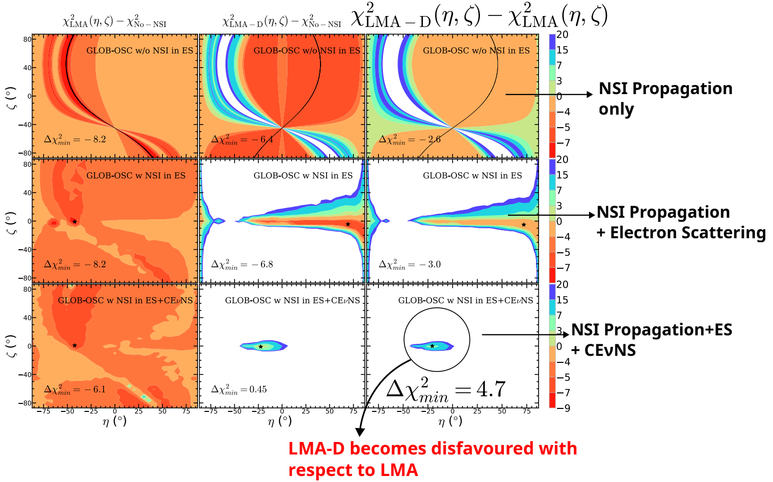
The bounds on the most general couplings projected over the effective Earth NSI coefficients relevant for LBL experiments are:



Ranges at 99% CL marginalized	
GLOB-OSC w NSI in ES + CEνNS	
$\varepsilon^{\oplus}_{ee}$	[-0.23, +0.25] $\oplus$ [+0.81, +1.3]
$\varepsilon^{\oplus}_{\mu\mu}$	[-0.29, +0.20] $\oplus$ [+0.83, +1.4]
$\varepsilon^{\oplus}_{\tau\tau}$	[-0.29, +0.20]$\oplus$ [+0.83, +1.4]
$\varepsilon^{\oplus}_{e\mu}$	[-0.18, +0.08]
$\varepsilon^{\oplus}_{e\tau}$	[-0.25, +0.33]
$\varepsilon^{\oplus}_{\mu\tau}$	[-0.020, +0.021]

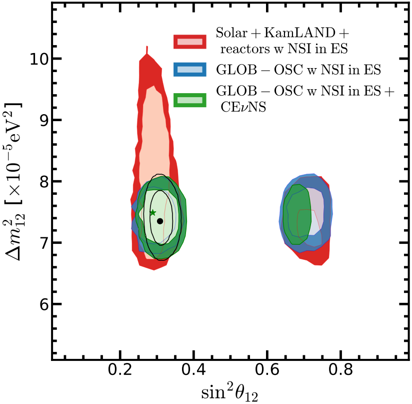
Present status of the LMA-D solution

We show projections in the plane of angles (ζ, η) (after marginalization of all other parameters) which parametrize the relative strength of the NSI couplings to up-quarks, down-quark, and electrons. Contours beyond 20 are white.



Effect of NSI's in the oscillation parameters

Two-dimensional projections of the allowed regions (at 90% and 3σ confidence levels) onto the parameters Δm^2_{12} and θ_{12} are shown, after marginalizing over all other oscillation parameters and NSI couplings to quarks and electrons.



LMA is favored by the fit ⇒ Even after the inclusion of NSI couplings to both quarks and electrons.

The LMA-D is only allowed at 97% CL or above (for 2 d.o.f.).

Thank you!

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