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NSIs

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Non-Standard Interactions (NSIs)

Motivation:

It has been firmly established that neutrino oscillations is the best and leading description of neutrino flavor transitions. However, there might still be room for new physics effects on the sub-leading level that could be described by so-called **non-standard neutrino interactions**.

Wolfenstein; Valle; Guzzo et al.; Roulet; Grossman

Other scenarios are e.g.:

- Neutrino decay (e.g. Pakvasa, Weiler, Winter)
- Neutrino decoherence (e.g. Pakvasa, Weiler, Winter)
- Non-unitary mixing (e.g. Winter)

We have some specialists on NSIs in the audience

- Friedland: atmospheric neutrinos, K2K, MINOS, NOvA, LHC monojets
- Hernandez: large gauge invariant NSIs
- Minakata: neutrino factories, T2KK, CP violation, parameter degeneracy, perturbation theory
- Pakvasa: before and after KamLAND
- Salvado: long-baseline exps., atmospheric neutrinos
- Winter: large gauge invariant NSIs, neutrino factories

You can find out more about NSIs in the review that I wrote:

T. Ohlsson, Rep. Prog. Phys. **76**, 044201 (2013), 1209.2710

From a Lagrangian to effective NSI parameters

Lagrangian for NSIs (in terms of operators):

$$\mathcal{L}_{\mathrm{NSI}} = -2\sqrt{2} G_F \varepsilon_{\alpha\beta}^{ff'C} \left(\overline{\nu_\alpha} \gamma^\mu P_L \nu_\beta\right) \left(\overline{f} \gamma_\mu P_C f'\right)$$

Wolfenstein; Grossman; Berezhiani & Rossi; Davidson et al.

Note that the operators are non-renormalizable and not gauge inv.!

Integration of heavy degrees of freedom:

$$\varepsilon \propto \frac{m_W^2}{m_X^2}$$

If the NSI scale is 1 (10) TeV, then the NSI parameters are 10^{-2} (10^{-4}).

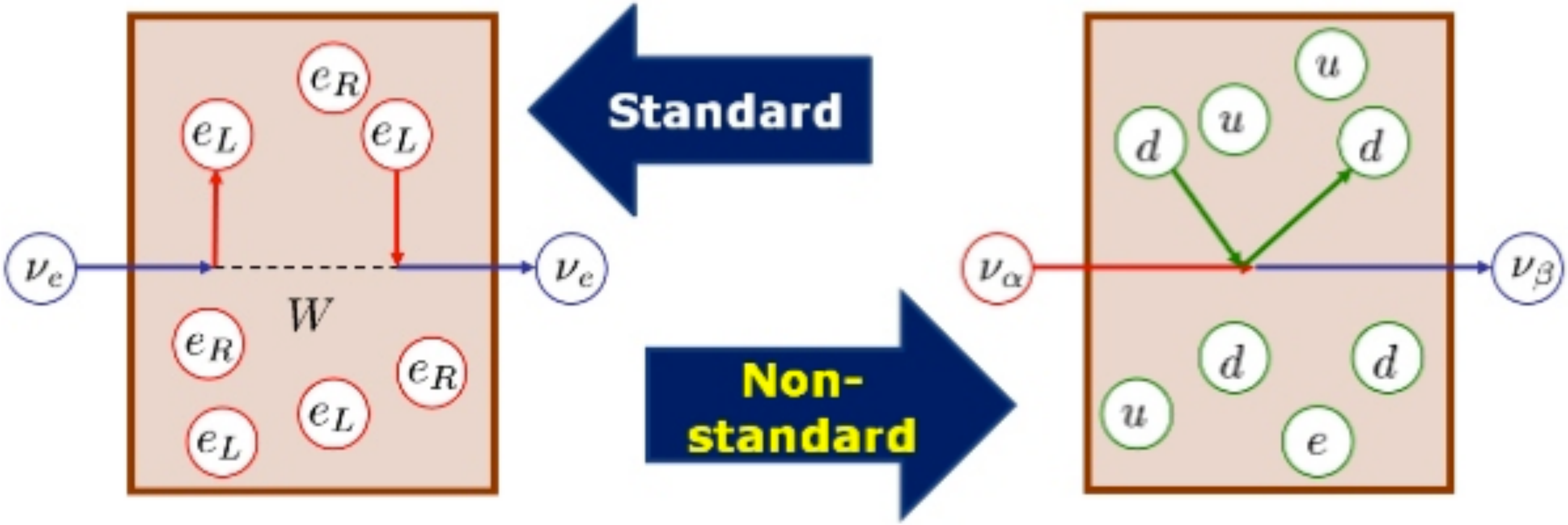
Different types of NSIs

- Production and detection NSIs
- Propagation (or matter) NSIs
- Combination of both

Here we will discuss matter NSIs only!

In addition, we will concentrate on atmospheric and accelerator neutrinos.

Schematic picture of matter NSIs



$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \frac{1}{2E}\left[U\begin{pmatrix}0 & 0 & 0\\ 0 & \Delta m^2_{21} & 0\\ 0 & 0 & \Delta m^2_{31}\end{pmatrix}U^\dagger + A\begin{pmatrix}1+\varepsilon_{ee} & \varepsilon_{e\mu} & \varepsilon_{e\tau}\\ \varepsilon^*_{e\mu} & \varepsilon_{\mu\mu} & \varepsilon_{\mu\tau}\\ \varepsilon^*_{e\tau} & \varepsilon^*_{\mu\tau} & \varepsilon_{\tau\tau}\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}$$

Mappings and approximative formulas with NSIs

First-order non-degenerate perturbation theory leads to model-independent mappings for the effective NSI parameters:

$$\tilde{U}_{e3} \simeq \frac{s_{13}e^{-i\delta}}{1-\hat{A}} + \frac{\hat{A}(s_{23}\varepsilon_{e\mu} + c_{23}\varepsilon_{e\tau})}{1-\hat{A}}$$

Meloni et al., 0901.1784

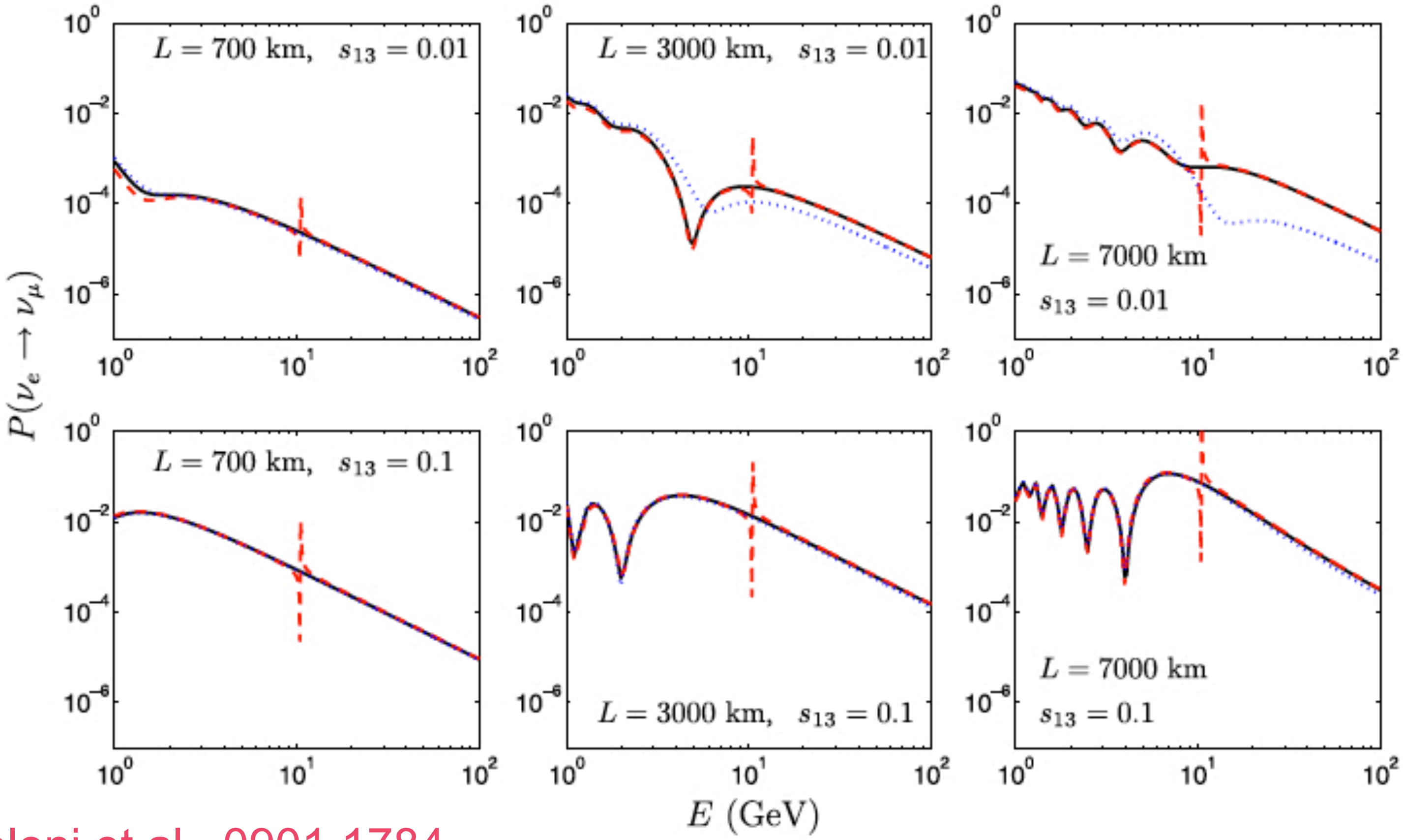
Using two-flavor neutrino oscillations, we have MSW-like mappings:

$$(\Delta\tilde{m}^2)^2 = \left[\Delta m^2 \cos(2\theta) - A\,(1 + \varepsilon_{ee} - \varepsilon_{\tau\tau})\right]^2 + \left[\Delta m^2 \sin(2\theta) + 2A\varepsilon_{e\tau}\right]^2,$$

$$\sin\left(2\tilde{\theta}\right) = \frac{\Delta m^2 \sin(2\theta) + 2A\varepsilon_{e\tau}}{\Delta\tilde{m}^2}.$$

Kitazawa et al., hep-ph/0606013

Neutrino oscillations probabilities with NSIs
Electron neutrino-muon neutrino channel



Meloni et al., 0901.1784

solid = exact numeric; dashed = approximate; dotted = result without NSIs

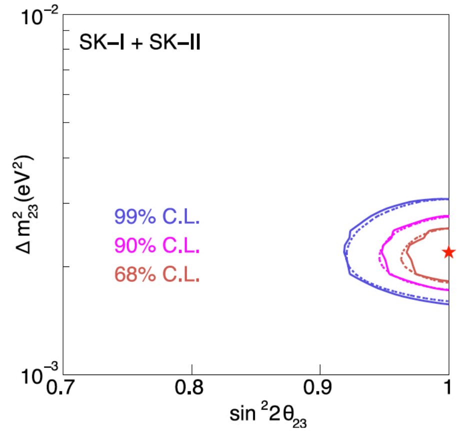
Atmospheric neutrinos with NSIs

Super-Kamiokande I and II:

Bounds @ 90 % C.L.:

$$|\varepsilon_{\mu\tau}| < 0.033 \qquad \text{and} \qquad |\varepsilon_{\tau\tau} - \varepsilon_{\mu\mu}| < 0.147$$

Super-Kamiokande, Mitsuka et al., 1109.1889



PINGU:

Bounds @ 90 % C.L.: $-0.0043\ (-0.0048) < \varepsilon_{\mu\tau} < 0.0047\ (0.0046)$

$$-0.03\ (-0.016) < \varepsilon_{\tau\tau} < 0.017\ (0.032)$$

PINGU could improve the Super-K bounds by one order of magnitude!

Choubey & Ohlsson, 1410.0410

Accelerator neutrinos with NSIs

MINOS:

Bounds @ 90 % C.L.:

$$-0.200 < \varepsilon_{\mu\tau} < 0.070$$

MINOS, Adamson et al., 1303.5314

MINOS + T2K:

Bounds @ 90 % C.L.:

maximum value allowed to $|\epsilon_{e\tau}|$ varies from 0.7 to 2.3

Coelho et al., 1209.3757

Phenomenological NSIs

Model-independent bounds on matter NSI parameters:

$$\begin{pmatrix} |\varepsilon_{ee}| < 4.2 & |\varepsilon_{e\mu}| < 0.33 & |\varepsilon_{e\tau}| < 3.0 \\ & |\varepsilon_{\mu\mu}| < 0.068 & |\varepsilon_{\mu\tau}| < 0.33 \\ & & |\varepsilon_{\tau\tau}| < 21 \end{pmatrix} \quad \text{(Earth)},$$

$$\begin{pmatrix} |\varepsilon_{ee}| < 2.5 & |\varepsilon_{e\mu}| < 0.21 & |\varepsilon_{e\tau}| < 1.7 \\ & |\varepsilon_{\mu\mu}| < 0.046 & |\varepsilon_{\mu\tau}| < 0.21 \\ & & |\varepsilon_{\tau\tau}| < 9.0 \end{pmatrix} \quad \text{(solar)},$$

Bounds on matter NSIs ~ 10^{-2} – 10

Biggio et al., 0907.0097

Phenomenological NSIs

Ruled out by experiments!

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Bounds on matter NSIs ~ 10^{-2} – 10

Biggio et al., 0907.0097

Future

- Investigate sensitivity and discovery reaches of NSIs.
- Determine better bounds on the NSI parameters.
- Find values of NSI parameters.