New physics in neutrino oscillations

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Origin of neutrino masses

$$\mathcal{L}_{\rm SM}^{\rm eff} = \mathcal{L}_{\rm SM}^{\rm ren} + \frac{h_{ij}}{\Lambda_L}(HL_i)(HL_j) + \ldots$$

$$m_\nu = hv \times \frac{v}{\Lambda}$$

$$\Lambda \sim 0.5 \times 10^{15}\,{\rm GeV} h \left(\frac{0.05\,{\rm eV}}{m_\nu}\right)$$

* $M_{GUT} \approx 2 \times 10^{16}$ GeV
* L_{eff} is sensitive to the GUT scale only through L- and B-violating operators
* $\Lambda_L \sim 10^{15}$ GeV, $\Lambda_B > 4 \times 10^{15}$ GeV (no or small L, B violation at TeV scale)

Alternative physics
(do neutrino masses originate at $\Lambda \gg \langle H \rangle$?)

* Dirac neutrinos $\lambda \nu_c L H \to m_\nu = \lambda_\nu v$ (like the other fermions)

  need $\lambda < 10^{-11}$ and $M_R \ll \langle H \rangle$: why?

  - L is conserved + $\lambda \nu_c L H$ forbidden by a symmetry, e.g. because it is charged under a U(1) symmetry:
    $$\lambda \nu_c L H \to \lambda \left(\frac{\phi}{M}\right)^n \nu_c L H, \qquad \lambda_{\rm eff} = \lambda \left(\frac{\langle\phi\rangle}{M}\right)^n$$
  - L is conserved + λ originates in extra-dimensions
    - ν_c's live in the flat bulk of large extra dimensions: $\lambda \propto \dfrac{1}{(2\pi R M_*)^{\delta/2}}$
    - ν_c and L are localized in distant points of an extra dimension (with delocalized Higgs): $\lambda \propto e^{-(\text{superposition of the wave functions})}$
  - ...

[Checko Hall Okui Oliver Davoudiasl Kitano Kribs Murayama Pascoli Petcov Schwetz Zralek et al]

* Additional sterile neutrinos (analogous issues)
* Probe Majorana nature of neutrinos, implications of specific frameworks

Additional physics

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$$\Lambda_{\rm NP} \ll \Lambda_L$$

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* Atmospheric

  Ma Roy, Brooijmans, Gonzalez-Garcia et al, Lipari Lusignoli, Fornengo et al, Bergmann Grossman Pierce

* LSND

  Bergmann Grossman, Pascoli Petcov Schwetz

* Supernovae

  Mansour Kuo, Bergmann Kagan, Fogli et al

* Accelerators
  * production, detection Mansour Kuo, Bergmann Kagan, Fogli et al
  * propagation in matter Ota Sato Yamashita, Gago, Huber Valle, Huber Schwetz Valle

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  → gives rise to an unmistakable signal at high energy Campanelli R

Enhancement of NP effects at high energy

$$M^2_{\rm eff} = \Delta m^2_{23} \begin{pmatrix} s^2_{13} & s_{13}/\sqrt{2} & s_{13}/\sqrt{2} \\ s_{13}/\sqrt{2} & 1/2 & 1/2 \\ s_{13}/\sqrt{2} & 1/2 & 1/2 \end{pmatrix}$$

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Enhancement of NP effects at high energy

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$$\theta_{1i} \to \text{const}, \quad P(\nu_e \to \nu_{e_i}) \to 4\epsilon^2_{ee_i} \sin^2 \frac{LV}{2} \quad \text{for } E\epsilon \gg E_{\rm res}\ (i \neq 1) \qquad \epsilon_{ij} \neq 0$$

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depends on the size of $SU(2)_W$ breaking effects
should be reconsidered

Sensitivity at a neutrino factory

- The high E enhancement of the ν_τ spectrum can be observed through $\tau \to \mu$ decays (BR ~ 17%) $\Rightarrow$ no confusion
- With E_μ = 40 GeV, L = 3000 km, 40 kt, the experiment would be sensitive to $\epsilon_{\tau e} \gtrsim 0.008$
  - e.g. for $\epsilon_{\tau e}$ = 0.07, $\sin^2 2\theta_{13} = 10^{-3}$: