Constraints to Triplet Higgs model from oscillation experiments

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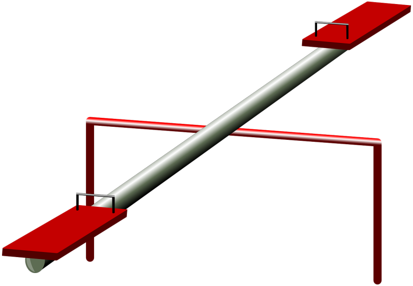
Work in progress.

Neutrino mass $\Rightarrow$ Standard model is incomplete!

- Triplet Higgs model as a neutrino mass generation mechanism.
- Lepton number violation and subleading effects to neutrino oscillation.
- Constraints on $\frac{M_\Delta}{|\lambda_\phi|}$ and small λ_ϕ ($\Delta\phi\phi$ coupling).



Triplet seesaw model contributes to neutrino oscillation

Magg, Wetterich, Schechter, Valle, Cheng, Li, Lazarides, Mohapatra, Senjanović, Gelmini, Roncadelli... (1980)

- $\mathrm{SU}(2)_{\mathrm{L}} \times \mathrm{U}(1)_Y$ electroweak model + scalar triplet field $\Delta = (\Delta_1, \Delta_2, \Delta_3) \sim (\mathbf{3}, 2)$ with $L = -2$.

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- Can be understood as an effective theory of the left-right symmetric $\mathrm{SU}(3)_\mathrm{C} \times \mathrm{SU}(2)_\mathrm{L} \times \mathrm{SU}(2)_\mathrm{R} \times \mathrm{U}(1)_{B-L} < \mathrm{SO}(10)$

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The Lagrangian relevant to nonstandard neutrino oscillation is

$$\mathcal{L}_\Delta = \mathcal{L}_Y + \mathcal{L}_{\not{L}} = Y_{\alpha\beta}\, L^T_{\alpha L}\, C\, i\sigma_2\, \Delta\, L_{\beta L} + \lambda_\phi\, \phi^T\, i\sigma_2\, \Delta^\dagger \phi + \mathrm{h.c.},$$

where the triplet is represented by 2×2 matrix form

$$\Delta = \frac{1}{\sqrt{2}} \sigma_i \Delta_i = \begin{pmatrix} \frac{\Delta^+}{\sqrt{2}} & \Delta^{++} \\ \Delta^0 & -\frac{\Delta^+}{\sqrt{2}} \end{pmatrix},$$

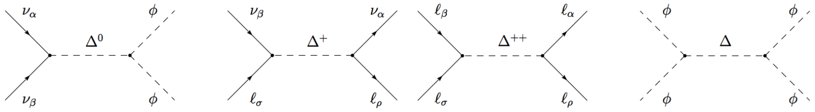
Interactions between ν, ℓ and SM Higgs mediated by Δ

The model features an L-breaking term in the Lagrangian:

$$\mathcal{L}_{\not{L}} = \lambda_\phi \phi^T i\sigma_2 \Delta^\dagger \phi + \text{h.c.}$$

where the trilinear dimension-1 coupling λ_ϕ can be naturally small, since at the limit $\lambda_\phi \to 0$ the symmetry of the theory is enhanced. Written in terms of component fields, the Yukawa term is

$$\mathcal{L}_Y = Y_{\alpha\beta} \left[\Delta^0 \, \overline{\nu^C_{\alpha R}} \, \nu_{\beta L} - \frac{1}{\sqrt{2}} \Delta^+ \left(\overline{\ell^C_{\alpha R}} \, \nu_{\beta L} + \overline{\nu^C_{\alpha R}} \, \ell_{\beta L} \right) - \Delta^{++} \, \overline{\ell^C_{\alpha R}} \, \ell_{\beta L} \right] + \text{h.c.}$$



Low-energy Lagrangians of triplet model

Malinský, Ohlsson, Zhang (2008) arXiv:0811.3346

Assuming triplet masses M_Δ are degenerate, and large compared with momenta of the processes, the amplitudes are described by effective Lagrangians

$$\mathcal{L}_\nu^m = \frac{Y_{\alpha\beta}\,\lambda_\phi\,v^2}{M_\Delta^2}\,\left(\overline{\nu_{\alpha R}^C}\,\nu_{\beta L}\right) = -\frac{1}{2}\,(m_\nu)_{\alpha\beta}\,\overline{\nu_{\alpha R}^C}\,\nu_{\beta L},$$

$$\mathcal{L}_{\mathrm{NSI}} = \frac{Y_{\sigma\beta}\,Y_{\alpha\rho}^\dagger}{M_\Delta^2}\,\left(\overline{\nu_{\alpha L}}\,\gamma_\mu\,\nu_{\beta L}\right)\,\left(\overline{\ell_{\rho L}}\,\gamma^\mu\,\ell_{\sigma L}\right).$$

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$$\mathcal{L}_{\rm NSI} = \frac{Y_{\sigma\beta}\, Y^\dagger_{\alpha\rho}}{M_\Delta^2} \left(\overline{\nu_{\alpha L}}\,\gamma_\mu\,\nu_{\beta L}\right) \left(\overline{\ell_{\rho L}}\,\gamma^\mu\,\ell_{\sigma L}\right).$$

Now solving the Yukawa coupling from neutrino Majorana mass term, we obtain the following result:

$$\mathcal{L}_{\rm NSI} = 2\sqrt{2}G_F \frac{M_\Delta^2}{8\sqrt{2}\,G_F\,v^4\,\lambda_\phi^2}\,(m_\nu)_{\sigma\beta}\,(m_\nu^\dagger)_{\alpha\rho}(\overline{\nu}_{\alpha L}\gamma_\mu\nu_{\beta L})\left(\overline{\ell_{\rho L}}\,\gamma^\mu\,\ell_{\sigma L}\right)$$

$$= 2\sqrt{2}G_F\varepsilon_{\alpha\beta}^{\rho\sigma}(\overline{\nu}_{\alpha L}\gamma_\mu\nu_{\beta L})\left(\overline{\ell_{\rho L}}\,\gamma\mu\,\ell_{\sigma L}\right)$$

Determining upper limit of $\frac{M_\Delta}{|\lambda_\phi|}$

$\mathcal{L}_{\text{NSI}}$ affects neutrino propagation in matter. Neutrino oscillation experiments are sensitive to $\varepsilon^{m}_{\alpha\beta}$ and $\varepsilon^{m}_{\alpha\alpha} - \varepsilon^{m}_{\beta\beta}$, where $\varepsilon^{m}_{\alpha\beta} \equiv \varepsilon^{ee}_{\alpha\beta}$.

We calculate the upper bound for $M_\Delta/|\lambda_\phi|$ by maximizing the matrix element products $(m_\nu)_{\sigma\beta}(m_\nu^\dagger)_{\alpha\rho}$ and their differences by varying all relevant oscillation parameters within their current experimental bounds.

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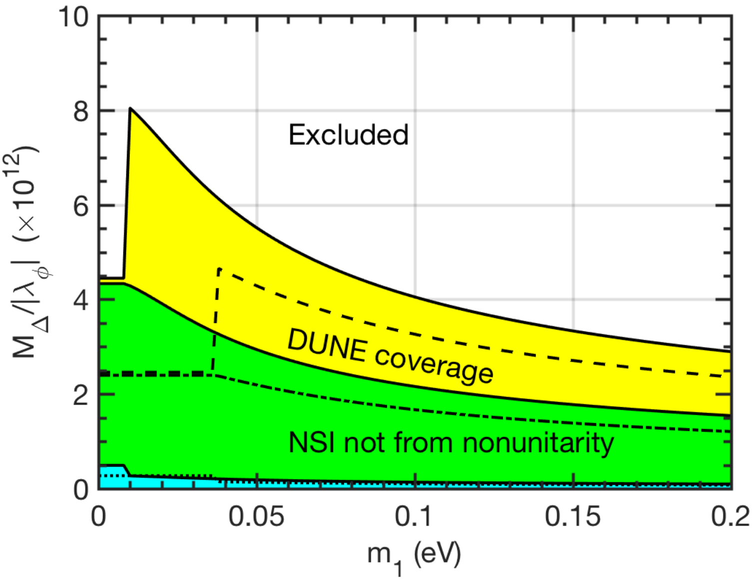
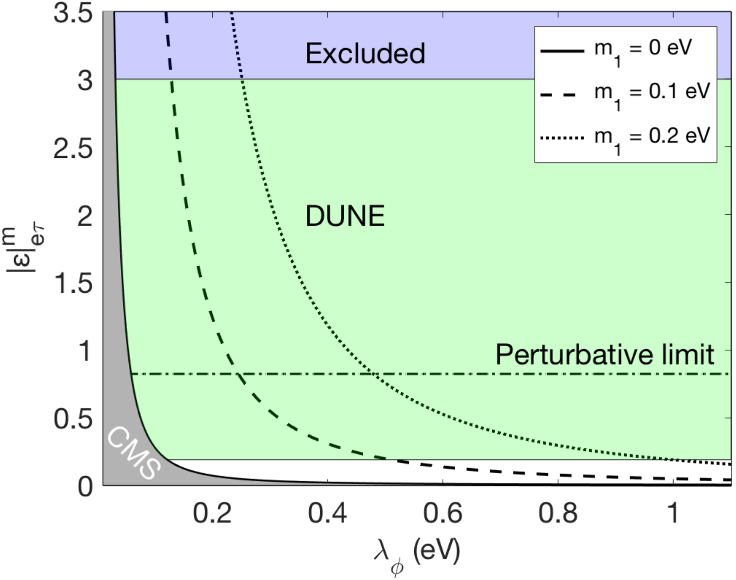
$$\left|\frac{M_\Delta^2}{\lambda_\phi^2}\right| = \left|-\frac{8\sqrt{2}\, G_F\, v^4\, \varepsilon^m_{\alpha\beta}}{(m_\nu)_{e\beta}(m_\nu^\dagger)_{\alpha e}}\right|,$$

$$m_\nu^2 = U \begin{pmatrix} m_1^2 & 0 & 0 \\ 0 & m_2^2 & 0 \\ 0 & 0 & m_3^2 \end{pmatrix} U^\dagger + A \begin{pmatrix} 1+\varepsilon^m_{ee} & \varepsilon^m_{e\mu} & \varepsilon^m_{e\tau} \\ \varepsilon^{m*}_{e\mu} & \varepsilon^m_{\mu\mu} & \varepsilon^m_{\mu\tau} \\ \varepsilon^{m*}_{e\tau} & \varepsilon^{m*}_{\mu\tau} & \varepsilon^m_{\tau\tau} \end{pmatrix},$$

Constraining $M_\Delta/|\lambda_\phi|$ from oscillations and DUNE



M_Δ and $\varepsilon^m_{\alpha\beta}$ bounds $\Rightarrow$ constraints for λ_ϕ



Conclusions

- We have presented a novel method to constrain the triplet seesaw model by looking for effective limits for $\varepsilon^{m}_{\alpha\beta}$ and maximizing the neutrino mass matrix elements.
- DUNE will constrain upper limits of $\frac{M_\Delta}{|\lambda_\phi|}$ by ~ 50 %.
- For a triplet mass $M_\Delta \sim 750$ GeV we get limits for trilinear $\Delta\phi\phi$ coupling.
  - Currently $\lambda_\phi \gtrsim 0.03$ eV.
  - DUNE is sensitive to $\lambda_\phi \lesssim 0.12$ eV.

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