Global fit to right-handed neutrino mixing at 1 loop

E. Fernandez-Martinez, J. Hernandez-Garcia, J. Lopez-Pavon, M.Lucente

Introduction

We use EW observables to constrain the mixing of the extra neutrino mass eigenstates in a Seesaw model:

$$\mathscr{L} = \mathscr{L}_{\rm SM} - \frac{1}{2}\overline{N^i_{\rm R}}(M_N)_{ij}N^{cj}_{\rm R} - (Y_N)_{i\alpha}\overline{N^i_{\rm R}}\phi^\dagger\ell^\alpha_{\rm L} + \text{H.c.}$$

The full neutrino mass matrix is diagonalized by the unitary 6×6 mixing matrix $U_{\rm tot}$:

$$U^T_{\rm tot}\begin{pmatrix} 0 & m_D^T \\ m_D & M_N\end{pmatrix}U_{\rm tot} = \begin{pmatrix} m & 0 \\ 0 & M\end{pmatrix}$$

For phenomenological impact, $M_i\sim\mathcal{O}(\text{EW scale})$ and $Y_N\sim\mathcal{O}(1)$ while $m_i\sim\mathcal{O}(\text{eV})$ are required $\Rightarrow$ a mass matrix with an approximate L symmetry is needed [1]:

$$m_D = \frac{v_{\rm EW}}{\sqrt{2}}\begin{pmatrix} Y_e & Y_\mu & Y_\tau \\ \epsilon_1 Y'_e & \epsilon_1 Y'_\mu & \epsilon_1 Y'_\tau \\ \epsilon_2 Y''_e & \epsilon_2 Y''_\mu & \epsilon_2 Y''_\tau\end{pmatrix} \quad\text{and}\quad M_N = \begin{pmatrix} \mu' & \Lambda & \mu'' \\ \Lambda & \mu & \mu''' \\ \mu'' & \mu''' & \Lambda'\end{pmatrix}$$

ϵ_i and μ^α small $\not{L}$ terms

If $\epsilon_i = \mu^\alpha = 0 \Rightarrow L$ is recovered $\Rightarrow$
- $m_{\nu_i} = 0$ (3 massless ν)
- $M_{N_1} = M_{N_2} = \Lambda$ (a Dirac pair)
- $M_{N_3} = \Lambda'$ (a decoupled singlet)
- Arbitrarily large Θ (mixing between ν and N)

In this configuration $U_{\rm tot}$ is:

$$U_{\rm tot}\simeq\begin{pmatrix}\left(\mathbb{1}-\frac{\Theta\Theta^\dagger}{2}\right)U_{\rm PMNS} & \Theta \\ -\Theta^\dagger U_{\rm PMNS} & \mathbb{1}-\frac{\Theta\Theta^\dagger}{2}\end{pmatrix} \quad\text{where}\quad \Theta\equiv\frac{1}{\sqrt{2}}\begin{pmatrix}-i\theta_e & \theta_e & 0 \\ -i\theta_\mu & \theta_\mu & 0 \\ -i\theta_\tau & \theta_\tau & 0\end{pmatrix}$$

$\theta_i \simeq \frac{v_{\rm EW}Y_i^*}{\sqrt{2}\Lambda}$

Fixing neutrino oscillation data [2]: θ_{ij}, Δm^2_{21} and $\Delta m^2_{31} \Rightarrow Y_\tau = Y_\tau(m_1,\delta,\alpha_1,\alpha_2)$.

The set of observables will be written in terms of these 9 parameters that will vary in the following ranges:

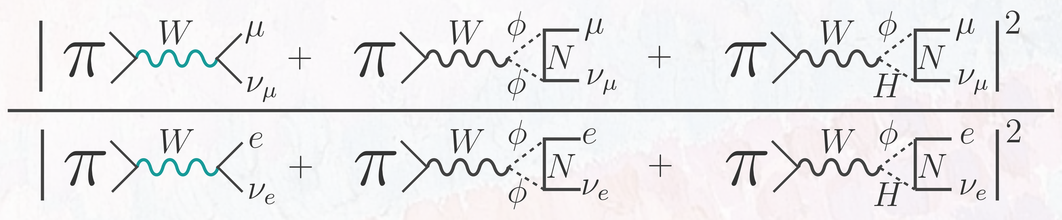
Parameter	$\lvert Y_e\rvert$ & $\lvert Y_\mu\rvert$	m_1 [eV]	Λ [GeV]	Phases: α_e, α_μ, δ, α_1 & α_2	Osc. data
Range	$(0,4)$	$(10^{-5},1)$	$(10^3,10^4)$	$(0,2\pi)$	fixed [2]

Observables

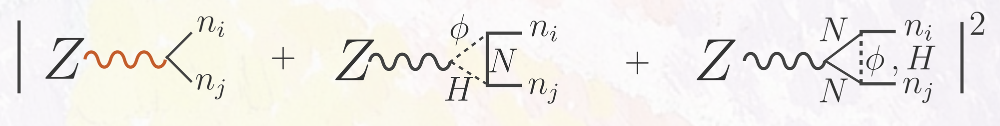
We compute the EW observables at 1 loop in the Equivalence Theorem [3] regime, i.e. $M_N \gg M_{Z,W}$, in terms of M_Z, α and G_μ.

The new degrees of freedom correct the W and Z boson propagators that will enter in the observable amplitudes at tree level.

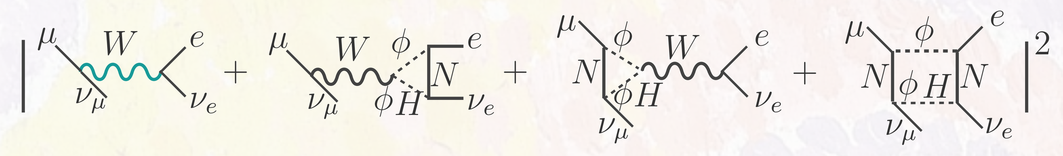
- Universality ratios: $R^\pi_{\mu e}$, $R^\pi_{\tau\mu}$, $R^W_{\mu e}$, $R^W_{\tau\mu}$, $R^W_{e\mu}$, $R^K_{\mu e}$, $R^K_{\tau\mu}$, $R^l_{\mu e}$ and $R^l_{\tau\mu}$

$R^\pi_{\mu e} =$ 

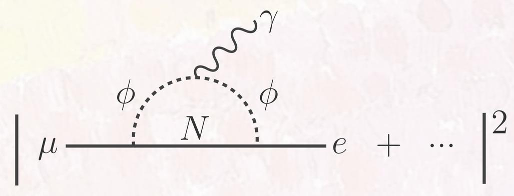
- Invisible Z decay:

$\Gamma_{\rm inv} =$ 

- M_W through G_F in μ decay:

$\Gamma_\mu =$ 

- Rare decays: $\mu\to e\gamma$, $\tau\to\mu\gamma$ and $\tau\to e\gamma$

$\Gamma_{\mu\to e\gamma} =$ 

A partial cancellation between the tree and the loop contributions could be possible in some observables [4]:

$$\text{obs.}\sim\frac{|\theta_e|^2}{2}+\frac{|\theta_\mu|^2}{2}+2\alpha T \qquad\text{where}\qquad T = \frac{\Sigma_{WW}(0)}{M_W^2}-\frac{\Sigma_{ZZ}(0)}{M_Z^2}$$

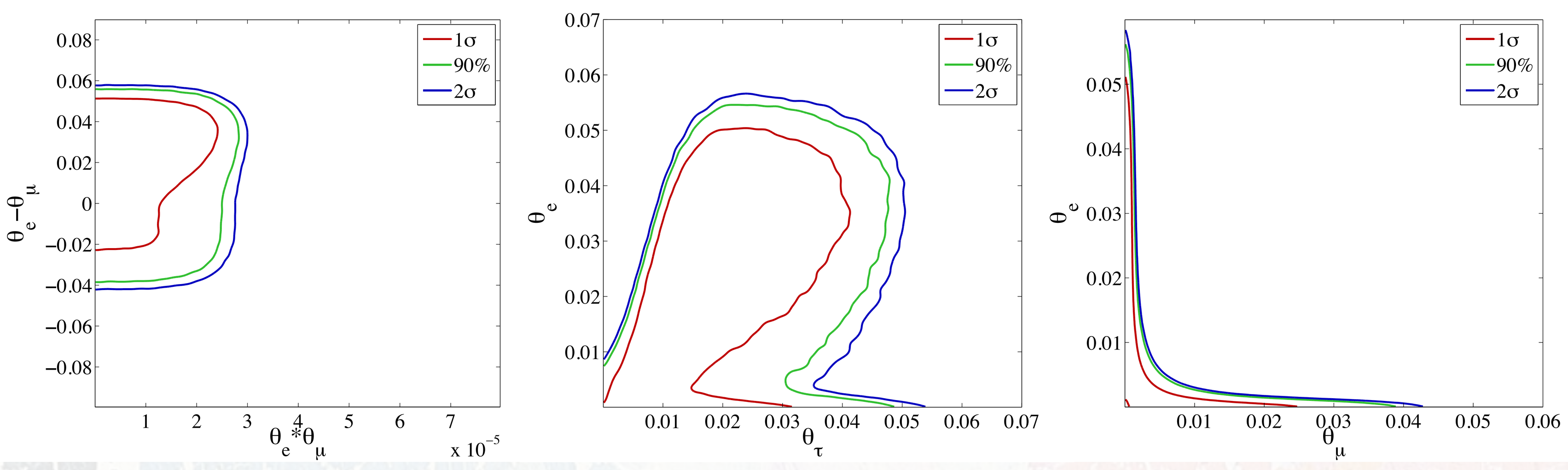
Results: global fit & constraints

Markov Chain Monte Carlo with the 13 observables scanning over the 9 parameters.

The individual contributions from the observables to the χ^2 in the SM (left), in the best fit (middle) and $\Delta\chi^2_i \equiv \chi^2_i(SM)-\chi^2_i(BF)$ (right) are shown:

$\Delta\chi^2 = 2.53$

Frequentist constraints and values in the best-fit point of $|\theta_e|$, $|\theta_\mu|$ and $|\theta_\tau|$:



$|\theta_e| = 0.037^{+0.012}_{-0.014}$
$|\theta_\mu| < 0.0006$
$|\theta_\tau| = 0.021^{+0.016}_{-0.010}$

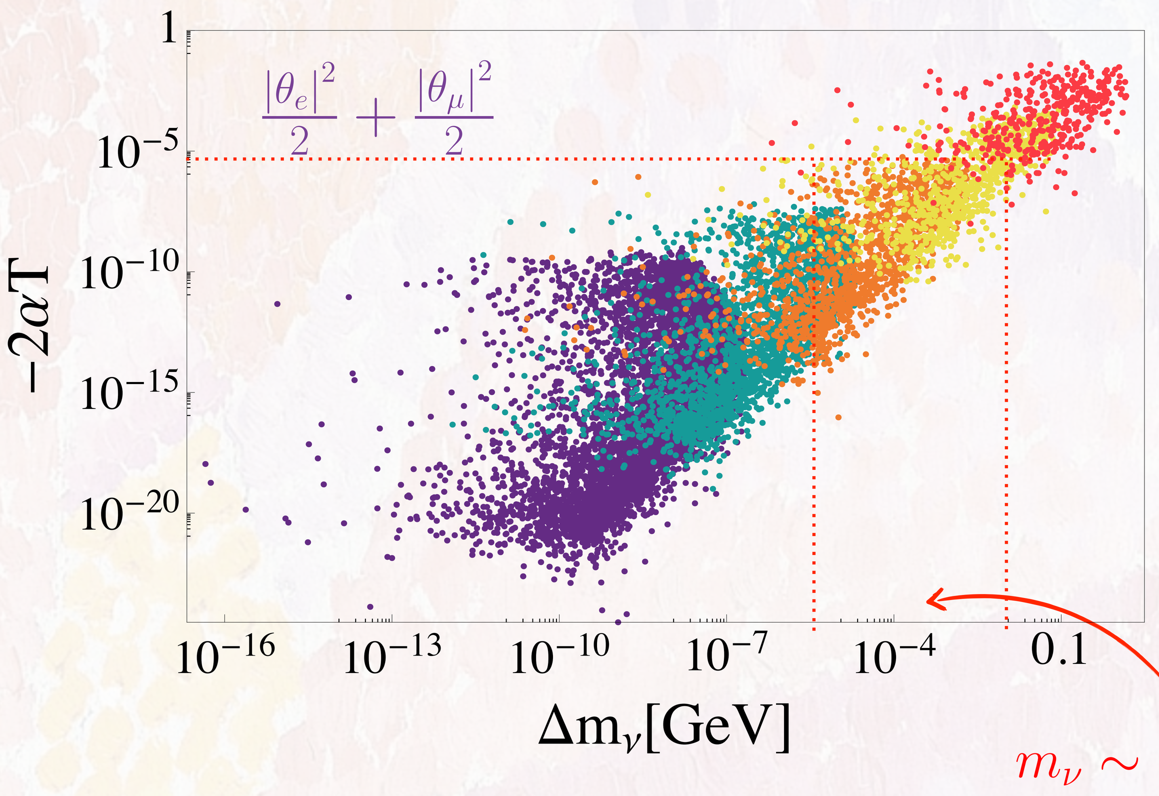
Results: loop effect

If L is softly broken $\Rightarrow T\geq 0 \Rightarrow$ no cancellation allowed.
$T<0$ only possible for large $\not{L}$. As μ' is the only $\not{L}$ parameter that doesn't contribute to m_ν at tree level $\Rightarrow$ for $|\mu'|\gg\Lambda$, $Y_\alpha v_{\rm EW}$:

$$T\simeq\frac{v^4_{\rm EW}}{32\pi s^2_{\rm W}M^2_W\mu'^2}\left(\sum_\alpha|Y_\alpha|^2\right)^2\left(3-8\log\left(\frac{\mu'}{\Lambda}\right)\right)$$

But loop level correction to m_ν should be taken into account [5]:

$$\Delta m_{\nu_{\alpha\beta}}\simeq\frac{\mu' Y_\alpha Y_\beta}{16\pi^2}\left(\frac{3M_Z^2}{\mu'^2-M_Z^2}\log\left(\frac{\mu'}{M_Z}\right)+\frac{M_H^2}{\mu'^2-M_H^2}\log\left(\frac{\mu'}{M_H}\right)\right)$$



$m_\nu\sim 100$ MeV!!
since no symmetry protects it

References

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[2] M. Gonzalez-Garcia, M. Maltoni, and T. Schwetz, JHEP **1411**, 052 (2014), 1409.5439
[3] J.M. Cornwall, D.N. Levin, and G. Tiktopoulos, Phys. Rev. **D10** (1974) 1145; (E) **11** (1975) 972
[4] E. Akhmedov, A. Kartavtsev, M. Lindner, L. Michaels and J. Smirnov, JHEP **1305**, 081 (2013) [arXiv:1302.1872 [hep-ph]]
[5] A. Pilaftsis, Z. Phys. C **55**, 275 (1992) [hep-ph/9901206]

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G.Severini