Global constraints on heavy neutrino mixing

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Introduction

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

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

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

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

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]:

$$m_D = \frac{v_{\rm EW}}{\sqrt{2}}\begin{pmatrix} Y_e & Y_\mu & Y_\tau \\ \epsilon_1 Y'_e & \epsilon_1 Y'_\mu & \epsilon_1 Y'_\tau \\ \epsilon_2 Y''_e & \epsilon_2 Y''_\mu & \epsilon_2 Y''_\tau\end{pmatrix} \quad \text{and} \quad M_N = \begin{pmatrix} \mu_1 & \Lambda & \mu_3 \\ \Lambda & \mu_2 & \mu_4 \\ \mu_3 & \mu_4 & \Lambda'\end{pmatrix}$$

ϵ_i and μ_j $\cancel{L}$ terms

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

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

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

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

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:

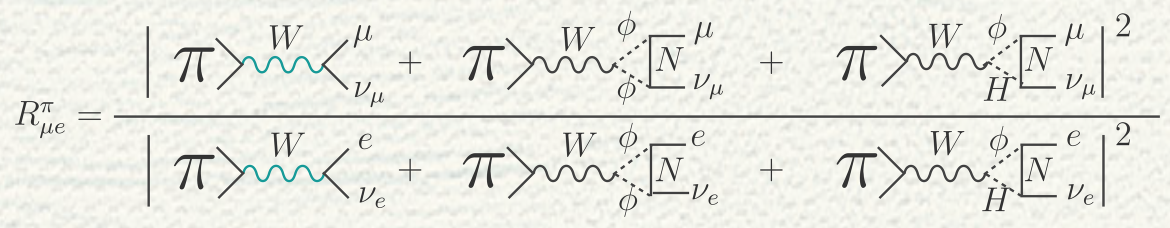
Parameter	$\lvert Y_e\rvert$ & $\lvert Y_\mu\rvert$	m_1 [eV]	Λ [GeV]	Phases: α_e, α_μ, δ, α_1 & α_2	Osc. data
Range	$(0, 4)$	$(10^{-5}, 1)$	$(10^3, 10^4)$	$(0, 2\pi)$	fixed [2]

Observables

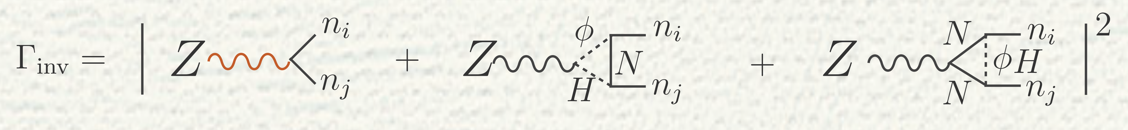
We compute the EW observables at 1 loop in the Equivalence Theorem [3] regime, i.e. $M_N \gg M_{Z,W}$, in terms of M_Z, α and G_μ.

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

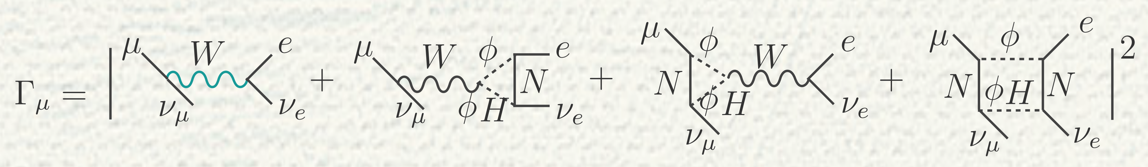
- Universality ratios: $R^\pi_{\mu e}$, $R^\pi_{\tau\mu}$, $R^W_{e\mu}$, $R^W_{\tau\mu}$, $R^K_{\mu e}$, $R^K_{\tau\mu}$, $R^l_{\mu e}$ and $R^l_{\tau\mu}$



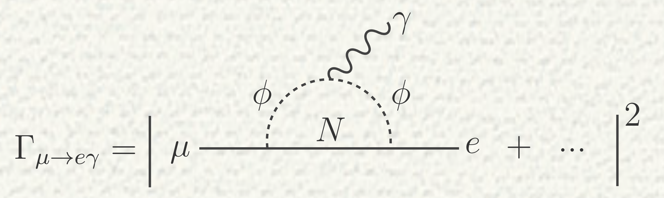
- Invisible Z decay:



- M_W through G_F in μ decay:



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



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

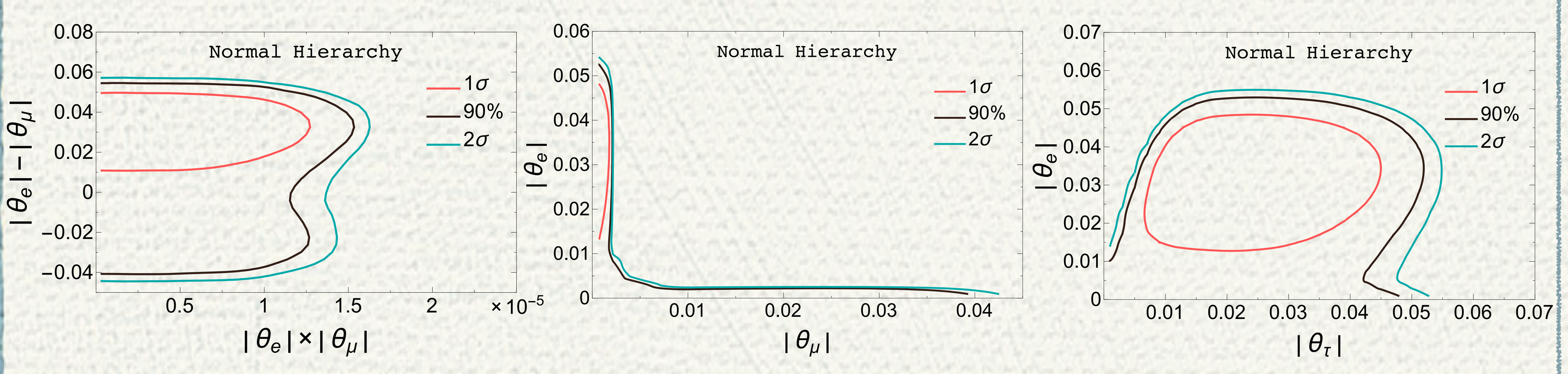
$$\text{obs.} \sim \frac{|\theta_e|^2}{2} + \frac{|\theta_\mu|^2}{2} + 2\alpha T \qquad \text{where} \qquad T = \frac{\Sigma_{WW}(0)}{M_W^2} - \frac{\Sigma_{ZZ}(0)}{M_Z^2}$$

Results: global fit & constraints

MCMC with the 13 observables scanning over the 9 parameters.

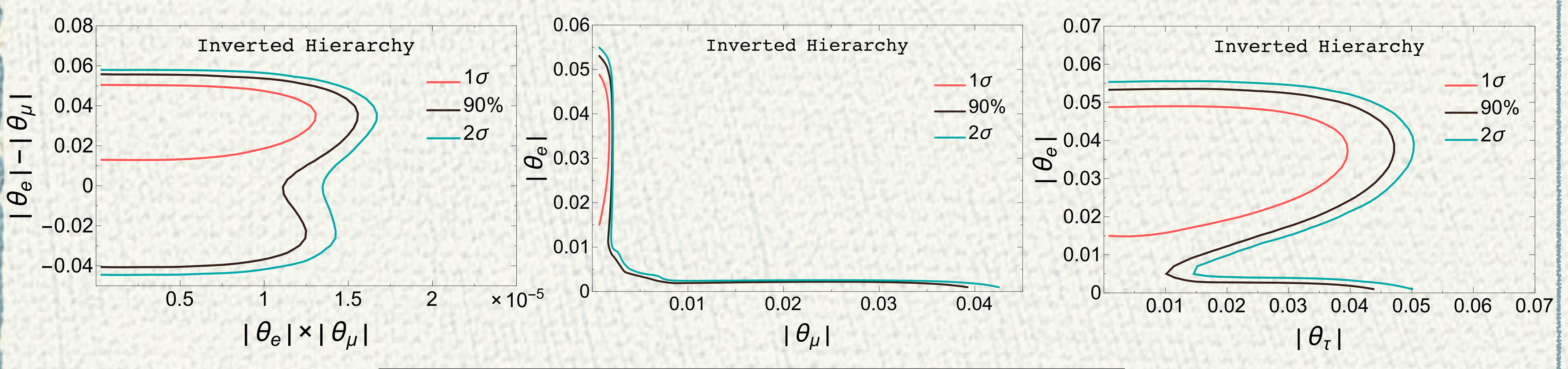
Frequentist constraints and values of the mixing in the BF:

- Normal hierarchy



	θ_e	θ_μ	θ_τ
NH	$0.034^{+0.009}_{-0.014}$	$< 3.2\cdot 10^{-4}$	$0.018^{+0.019}_{-0.013}$

- Inverted hierarchy



	θ_e	θ_μ	θ_τ
IH	$0.035^{+0.009}_{-0.014}$	$< 3.3\cdot 10^{-4}$	< 0.031

Results: loop effect

If L is mildly broken $\Rightarrow T \geq 0 \Rightarrow$ no cancellation allowed.

$T < 0$ only possible for large $\cancel{L}$.

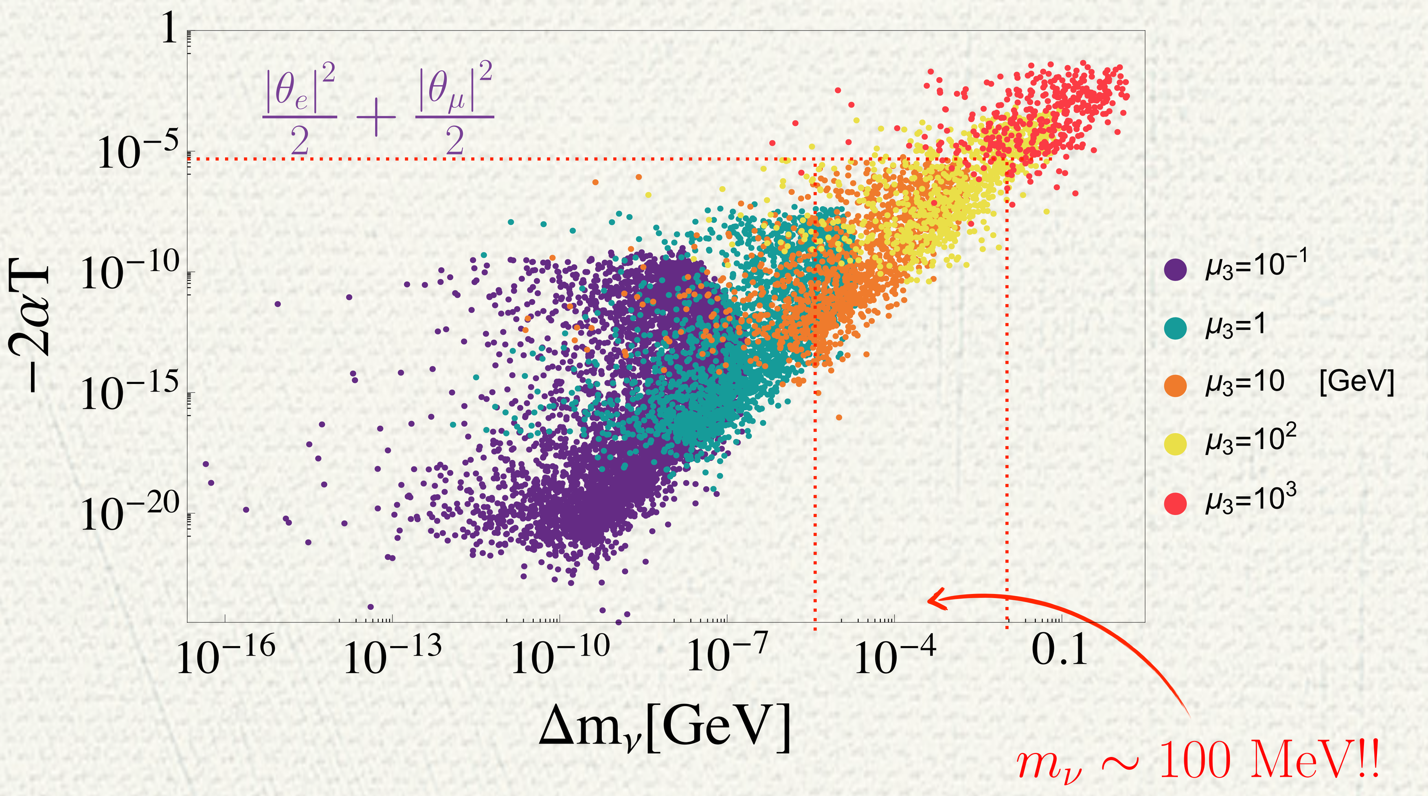
$$m_i^{\rm tree} \sim v_{EW}^2 Y^2\left(\frac{1}{\Lambda}\mathcal{O}\left(\epsilon_1, \frac{\mu_2}{2\Lambda}\right) + \frac{1}{\Lambda'}\mathcal{O}\left(\epsilon_2^2, \frac{\mu_4}{4\Lambda^2}\right)\right) \Rightarrow \cancel{L} \text{ driven by } \mu_1 \text{ and } \mu_3$$

$$\Downarrow$$

$$T \simeq \frac{v_{\rm EW}^4}{64\pi s_w^2 M_W^2}\left(\sum_\alpha |Y_\alpha|^2\right)^2 f(\mu_1, \mu_3)$$

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

$$\Delta m_{\nu_{\alpha\beta}} = \frac{Y_\alpha Y_\beta}{32\pi^2}\left(3M_Z^2 f(\mu_1, \mu_3, M_Z) + M_h^2 f(\mu_1, \mu_3, M_h)\right)$$



References

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[4] E. Akhmedov, A. Kartavtsev, M. Lindner, L. Michaels and J. Smirnov, JHEP **1305**, 081 (2013) [arXiv:1302.1872 [hep-ph]]
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