Global constraints on heavy neutrino mixing

Josu Hernandez-Garcia

Based on:

- JHEP 1510 (2015) 130: E. Fernandez-Martinez, JHG, J. Lopez-Pavon, and M. Lucente
- Work in progress: E. Fernandez-Martinez, JHG, J. Lopez-Pavon

MOTIVATION

Neutrino masses are one of the most promising open windows to physics beyond the Standard Model (SM).

By adding heavy ν_R to SM particle content, neutrino masses arise in a simple and natural way.

A set of EW and flavor observables are going to be used to constrain the additional neutrino mixing.

INTRODUCTION

Once the new heavy states are integrated out, the SM-Seesaw can be considered as a low energy effective theory:

- dim-5 Weinberg op. gives masses to the light ν:

$$\frac{c_{\alpha\beta}^{\text{dim-5}}}{\Lambda}\left(\overline{L^c}_\alpha\tilde{\phi}^*\right)\left(\tilde{\phi}^\dagger L_\beta\right) \quad \longrightarrow \quad \hat{m} = m_D^t M_N^{-1} m_D$$

S. Weinberg, Phys.Rev.Lett. **43**, 1566 (1979)

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- dim-6 op. induces non-unitarity in the mixing matrix N of lepton charged current interactions:

$$\frac{c^{\text{dim-6}}_{\alpha\beta}}{\Lambda^2}\left(\overline{L}_\alpha\tilde{\phi}\right) i\gamma^\mu\partial_\mu\left(\tilde{\phi}^\dagger L_\beta\right) \longrightarrow \eta = \frac{1}{2} m_D^\dagger M_N^{-2} m_D$$

A. Broncano, M.B. Gavela, and E.E. Jenkins, Phys. Lett. **B552**, 177 (2003)

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$$N = (I - \eta)\, U_{\text{PMNS}}$$

since η is Hermitian $\Rightarrow$ the most general parametrization for N.

INTRODUCTION

dim-5: $\hat{m} = m_D^t M_N^{-1} m_D$

dim-6: $\eta = \frac{1}{2} m_D^\dagger M_N^{-2} m_D$

Meaningful bounds imply $\left\{ \begin{array}{l} M_i \sim \mathcal{O}\left(\Lambda_{\mathrm{EW}}\right) \\ Y_N \sim \mathcal{O}\left(1\right) \end{array} \right.$ $\Rightarrow$ $\hat{m}$ too large

unless the lightness of $\hat{m}$ explained by an approximate L.

R. Mohapatra and J. Valle, Phys.Rev. **D34**, 1642 (1986)
J. Bernabeu, A. Santamaria, J. Vidal, A. Mendez, and J. Valle, Phys. Lett. **B187**, 303 (1987)
G.C. Branco, W. Grimus, and L. Lavoura, Nucl. Phys. **B312**, 492 (1989)

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In particular:

$$\begin{array}{ccc} & \begin{array}{ccc} \nu_e & \nu_\mu & \nu_\tau \\ 1 & 1 & 1 \end{array} & \\ m_D = \frac{v_{\rm EW}}{\sqrt{2}} & \left(\begin{array}{ccc} Y_e & Y_\mu & Y_\tau \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{array}\right) & \begin{array}{cc} 1 & N_1 \\ -1 & N_2 \\ 0 & N_3 \end{array} \end{array} \qquad \begin{array}{ccc} & \begin{array}{ccc} N_1 & N_2 & N_3 \\ 1 & -1 & 0 \end{array} & \\ M_N = & \left(\begin{array}{ccc} 0 & \Lambda & 0 \\ \Lambda & 0 & 0 \\ 0 & 0 & \Lambda' \end{array}\right) & \begin{array}{cc} 1 & N_1 \\ -1 & N_2 \\ 0 & N_3 \end{array} \end{array}$$

(with $L =$ labelling the row of lepton numbers above each matrix)

where N_i is an arbitrary number of extra heavy fields.

R. Alonso, M. Dhen, M. Gavela, and T. Hambye, JHEP **1301**, 118 (2013)
A. Abada, D. Das, A. Teixeira, A. Vicente, and C. Weiland, JHEP **1302**, 048 (2013)

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where N_i is an arbitrary number of extra heavy fields.

If L is exact: $\hat{m} = 0$ while $\eta \neq 0$ and arbitrarily large.

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In particular:

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

$$\left. \begin{array}{r} \hat{m} \neq 0 \\ m_i \sim \mathcal{O}\left(\text{eV}\right) \end{array} \right\} \Rightarrow L \text{ mildly broken} \Rightarrow \begin{array}{c} \epsilon_i \text{ and } \mu_j \text{ small } \not{L} \\ \text{terms introduced} \end{array}$$

while $\eta \neq 0$ and arbitrarily large.

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while $\eta \neq 0$ and arbitrarily large.

PARAMETRIZATIONS

We have studied in 2 different scenarios:

- Completely general scenario:

  $$N = (I - \eta)\, U_{\text{PMNS}}$$

  the more general one since η is Hermitian.

- 3-heavy-neutrino scenario:

  A more restrictive one with only 3 heavy states that implies correlations among the η elements so as to recover $\hat{m}$.

OBSERVABLES

The 29 observables are computed in terms of α, G_μ and M_Z.

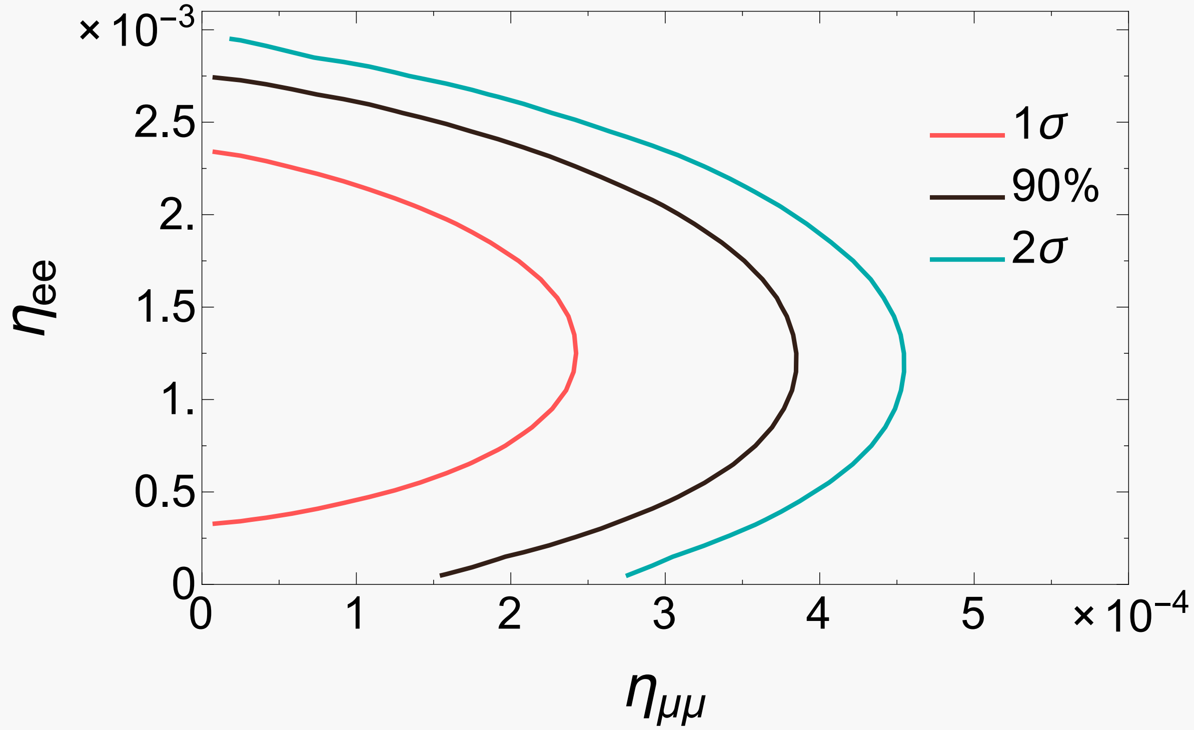
- The W boson mass M_W
- The effective weak mixing angle θ_{W}: $s^{2\ \mathrm{lep}}_{\mathrm{W\ eff}}$ & $s^{2\ \mathrm{had}}_{\mathrm{W\ eff}}$
- LFC Z fermionic decays: R_l, R_c, R_b & σ^0_{had}
- The invisible Z width Γ_{inv}
- Universality ratios: $R^\pi_{\mu e}$, $R^\pi_{\tau\mu}$, $R^W_{\mu e}$, $R^W_{\tau\mu}$, $R^K_{\mu e}$, $R^K_{\tau\mu}$, $R^l_{\mu e}$ & $R^l_{\tau\mu}$
- The weak charge: Q^p_{W} & Q^{Cs}_{W}
- 8 decays constraining the CKM unitarity
- 3 rare LFV decays: $\mu \to e\gamma$, $\tau \to \mu\gamma$ & $\tau \to e\gamma$

RESULTS

MCMC with the 29 observables scanning over the free parameters.

Frequentist contours and values of the mixing in the BF:

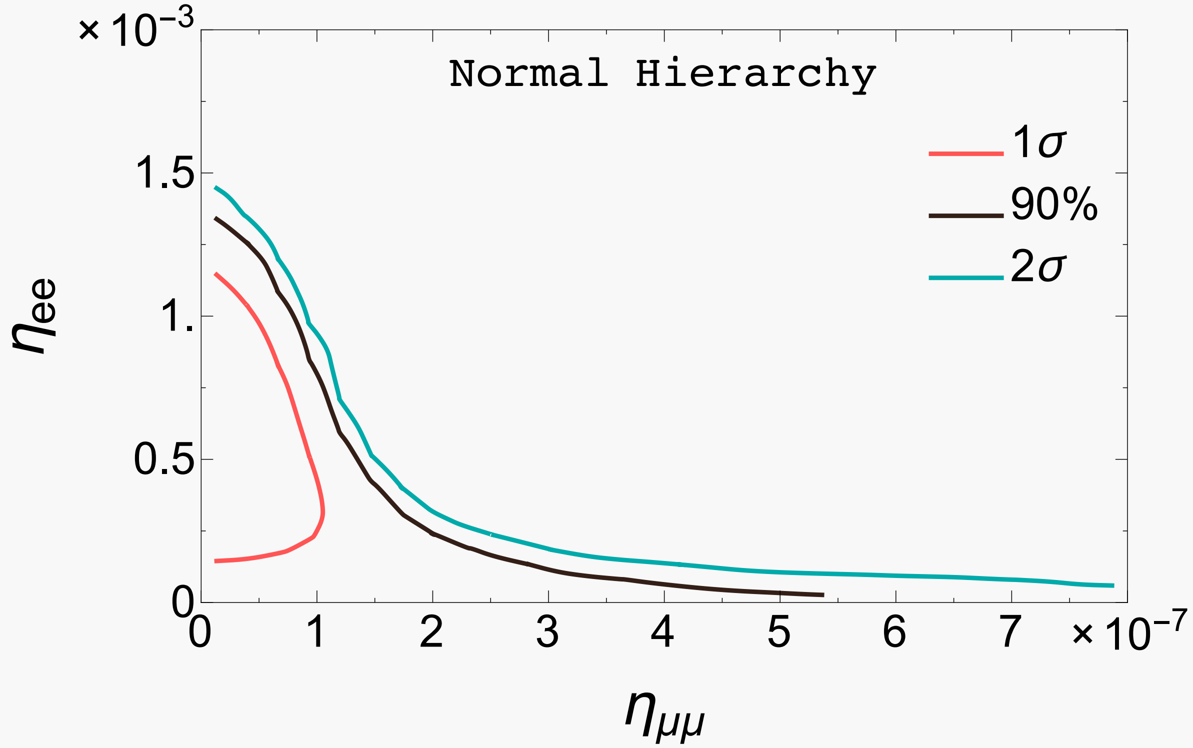
General scenario:



$$\eta_{ee} = 0.00128^{+0.00064}_{-0.00066}$$

$$\eta_{\mu\mu} = < 0.00012$$

3-heavy-neutrino scenario:



$$\eta_{ee} = 0.00064^{+0.00033}_{-0.00034}$$

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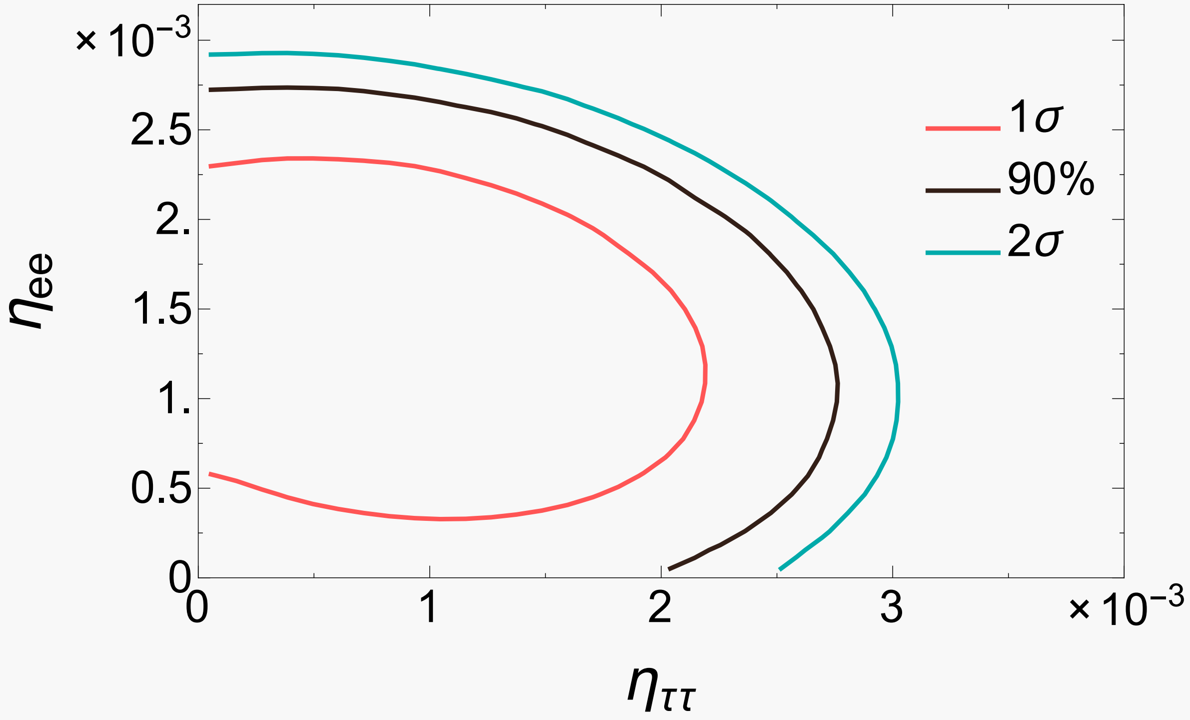

$$
\begin{aligned}
\eta_{ee} &= 0.00128^{+0.00064}_{-0.00066} \\
\eta_{\mu\mu} &= < 0.00012 \\
\eta_{\tau\tau} &= < 0.0007
\end{aligned}
$$

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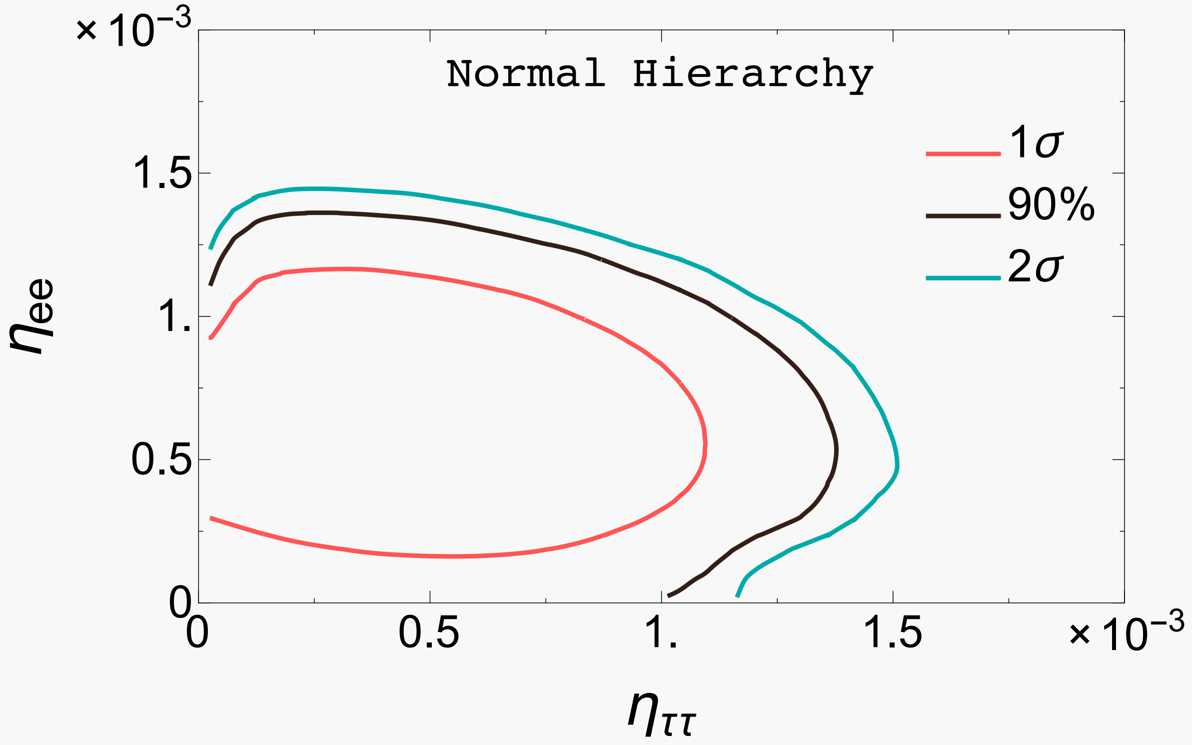

$$
\begin{aligned}
\eta_{ee} &= 0.00064^{+0.00033}_{-0.00034} \\
\eta_{\mu\mu} &= < 4 \times 10^{-8} \\
\eta_{\tau\tau} &= < 0.0004
\end{aligned}
$$

SUMMARY

A set of EW and flavor observables have been used to constrain the additional mixing in two different scenarios.

The results of the global fit:

General scenario:

$$\eta_{ee} = 0.00128^{+0.00064}_{-0.00066}$$

$$\eta_{\mu\mu} = < 0.00012$$

$$\eta_{\tau\tau} = < 0.0007$$

3-heavy-neutrino scenario:

NH

$$\eta_{ee} = 0.00064^{+0.00033}_{-0.00034}$$

$$\eta_{\mu\mu} = < 4 \times 10^{-8}$$

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IH

$$\eta_{ee} = 0.00064^{+0.00034}_{-0.00031}$$

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THANKS

BACK-UP

Correlations among the η elements in 3HN case:

$M_1 \sim M_2 \sim \Lambda$ (pseudo Dirac pair), $M_3 \sim \Lambda'$ (decoupled) but large mixing:

$$\eta = \frac{1}{2}\begin{pmatrix} |\theta_e|^2 & \theta_e\theta_\mu^* & \theta_e\theta_\tau^* \\ \theta_\mu\theta_e^* & |\theta_\mu|^2 & \theta_\mu\theta_\tau^* \\ \theta_\tau\theta_e^* & \theta_\tau\theta_\mu^* & |\theta_\tau|^2 \end{pmatrix} \text{ with } \theta_\alpha \equiv \frac{vY_\alpha}{\sqrt{2}\Lambda}$$

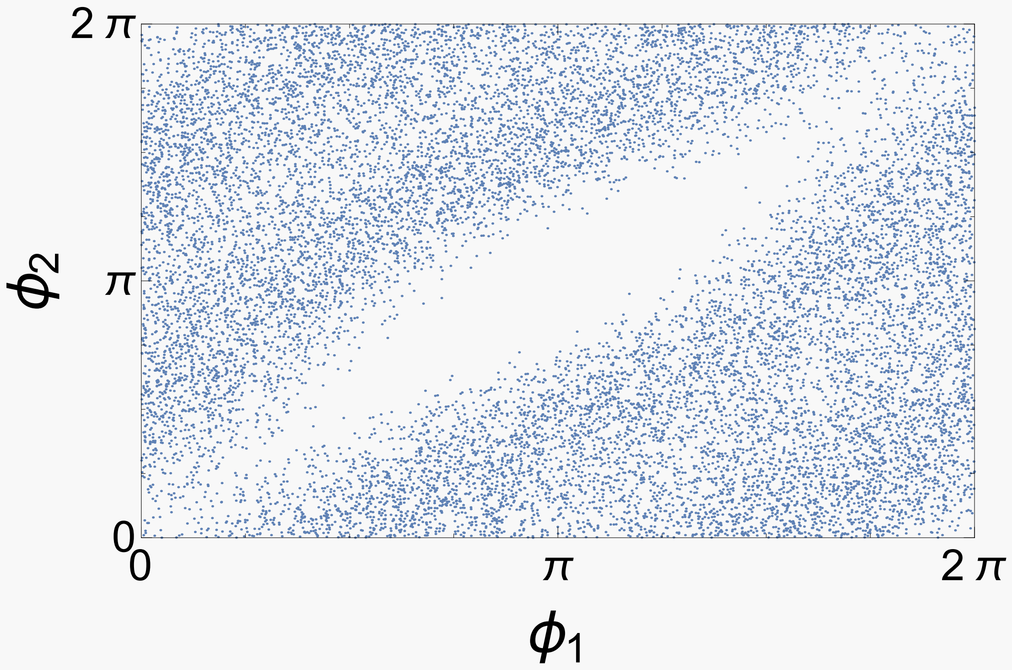
Fixing ν oscillation data: θ_{ij}, Δm_{21}^2 and $\Delta m_{31}^2 \Rightarrow$

$$Y_\tau = Y_\tau\left(m_1, \delta, \phi_1, \phi_2\right) \Rightarrow 9 \text{ free parameters}$$

Parameter	$\lvert Y_e\rvert \times \lvert Y_\mu\rvert$	$\lvert Y_e\rvert - \lvert Y_\mu\rvert$	m_1 [eV]	Λ [GeV]	Phases: α_e, α_μ, δ, ϕ_1 & ϕ_2
Range	$(0, 10^{-4})$	$(-0.1, 0.1)$	$(10^{-5}, 1)$	$(10^3, 10^4)$	$(0, 2\pi)$

BACK-UP

CP-phases correlations in the 3HN scenario with a NH:



$$\theta_\mu \quad \ll \quad \theta_e \text{ and } \theta_\tau \Rightarrow$$

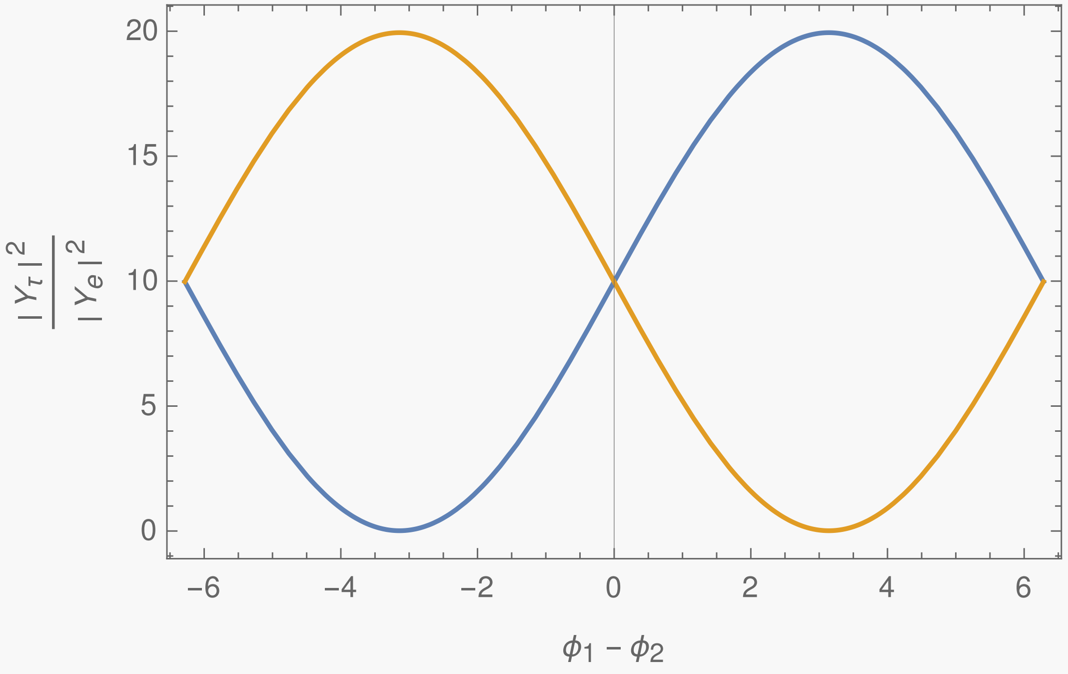
$$\frac{Y_\tau}{Y_e} \quad \simeq \quad -\frac{\sqrt{2}}{t_{12}} \pm i \frac{e^{\frac{i(\phi_1-\phi_2)}{2}}}{s_{12}^2} \sqrt{\frac{2m_1}{\sqrt{\Delta m_{12}^2}}}$$

Since $\theta_\tau \gg \theta_e$ disfavored by data

$$\Downarrow$$

$$\phi_1 - \phi_2 \simeq 2n\pi$$

disfavored



BACK-UP

CP-phases correlations in the 3HN scenario with a NH:

$$\begin{aligned} \theta_\mu &\ll \theta_e \text{ and } \theta_\tau \Rightarrow \\ \frac{Y_\tau}{Y_e} &\simeq -\frac{\sqrt{2}}{t_{12}} \pm i \frac{e^{\frac{i(\phi_1-\phi_2)}{2}}}{s_{12}^2} \sqrt{\frac{2m_1}{\sqrt{\Delta m_{12}^2}}} \end{aligned}$$

Moreover, $\theta_\tau < \theta_e$ preferred by data $\Rightarrow \alpha_\tau - \alpha_e \simeq (2n+1)\,\pi$