GLOBAL FIT TO RIGHT-HANDED NEUTRINO MIXING AT 1 LOOP

Josu Hernandez-Garcia

in collaboration with E. Fernandez-Martinez, J. Lopez-Pavon and M. Lucente

ift

invisibles
neutrinos, dark matter & dark energy physics

MOTIVATION

EW obs. used to constrain additional ν mixing in Seesaw model.

MOTIVATION

EW obs. used to constrain additional ν mixing in Seesaw model.

Sizeable phenomenology requires $\begin{cases} M_i \sim \mathcal{O}(\Lambda_{EW}) \\ Y_N \sim \mathcal{O}(1) \end{cases} \Rightarrow m_i$ too large

MOTIVATION

EW obs. used to constrain additional ν mixing in Seesaw model.

Sizeable phenomenology requires $\begin{cases} M_i \sim \mathcal{O}(\Lambda_{EW}) \\ Y_N \sim \mathcal{O}(1) \end{cases} \Rightarrow$ approximate L needed

MOTIVATION

EW obs. used to constrain additional ν mixing in Seesaw model.

Sizeable phenomenology requires $\left\{ \begin{array}{l} M_i \sim \mathcal{O}(\Lambda_{EW}) \\ Y_N \sim \mathcal{O}(1) \end{array} \right. \Rightarrow$ approximate L needed

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

If L exact $\Rightarrow m_i = 0$

MOTIVATION

EW obs. used to constrain additional ν mixing in Seesaw model.

Sizeable phenomenology requires $\begin{cases} M_i \sim \mathcal{O}(\Lambda_{EW}) \\ Y_N \sim \mathcal{O}(1) \end{cases} \Rightarrow$ approximate L needed

$$m_D = \frac{v_{\text{EW}}}{\sqrt{2}} \begin{array}{c} \begin{array}{ccc} \nu_e & \nu_\mu & \nu_\tau \end{array} \\ \left(\begin{array}{ccc} Y_e & Y_\mu & Y_\tau \\ \epsilon_1 Y'_e & \epsilon_1 Y'_\mu & \epsilon_1 Y'_\tau \\ \epsilon_2 Y''_e & \epsilon_2 Y''_\mu & \epsilon_2 Y''_\tau \end{array} \right) \begin{array}{c} N_1 \\ N_2 \\ N_3 \end{array} \end{array} \qquad M_N = \begin{array}{c} \begin{array}{ccc} N_1 & N_2 & N_3 \end{array} \\ \left(\begin{array}{ccc} \mu' & \Lambda & \mu'' \\ \Lambda & \mu & \mu''' \\ \mu'' & \mu''' & \Lambda' \end{array} \right) \begin{array}{c} N_1 \\ N_2 \\ N_3 \end{array} \end{array}$$

If L softly broken $\Rightarrow m_i \neq 0$ but small.

Motivation

EW obs. used to constrain additional ν mixing in Seesaw model.

Sizeable phenomenology requires $\left\{ \begin{array}{l} M_i \sim \mathcal{O}(\Lambda_{EW}) \\ Y_N \sim \mathcal{O}(1) \end{array} \right. \Rightarrow$ approximate L needed

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

If L softly broken $\Rightarrow m_i \neq 0$ but small.

Motivation

EW obs. used to constrain additional ν mixing in Seesaw model.

Sizeable phenomenology requires $\begin{cases} M_i \sim \mathcal{O}(\Lambda_{EW}) \\ Y_N \sim \mathcal{O}(1) \end{cases} \Rightarrow$ approximate L needed

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

ϵ_i and μ^α
$\not{L}$ terms

If L softly broken $\Rightarrow m_i \neq 0$ but small.

MOTIVATION

EW obs. used to constrain additional ν mixing in Seesaw model.

Sizeable phenomenology requires $\begin{cases} M_i \sim \mathcal{O}(\Lambda_{EW}) \\ Y_N \sim \mathcal{O}(1) \end{cases} \Rightarrow$ approximate L needed

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

ϵ_i and μ^α
$\not{L}$ terms

If L softly broken $\Rightarrow m_i \neq 0$ but small.

$M_1 = M_2 = \Lambda$ (Dirac pair), $M_3 = \Lambda'$ (decoupled) but large mixing.

Motivation

The full neutrino mass matrix diagonalized by:

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

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

MOTIVATION

The full neutrino mass matrix diagonalized by:

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

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

Fixing ν osc. data: θ_{ij}, Δm^2_{21} and Δm^2_{31} $\Rightarrow$ $Y_\tau = Y_\tau\left(m_1, \delta, \alpha_1, \alpha_2\right)$ $\Rightarrow$

9 free parameters

MOTIVATION

The full neutrino mass matrix diagonalized by:

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

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

Fixing ν osc. data: θ_{ij}, Δm^2_{21} and Δm^2_{31} $\Rightarrow$ $Y_\tau = Y_\tau\left(m_1, \delta, \alpha_1, \alpha_2\right)$ $\Rightarrow$

9 free parameters

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

OBSERVABLES

The 13 observables computed[*] at 1 loop in terms of M_Z, α and G_μ.

Z and W boson propagators corrected by the new dof:

which directly enter in the list of obs.:

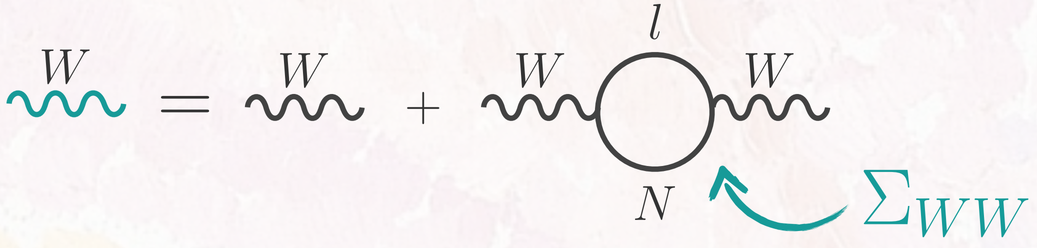
---

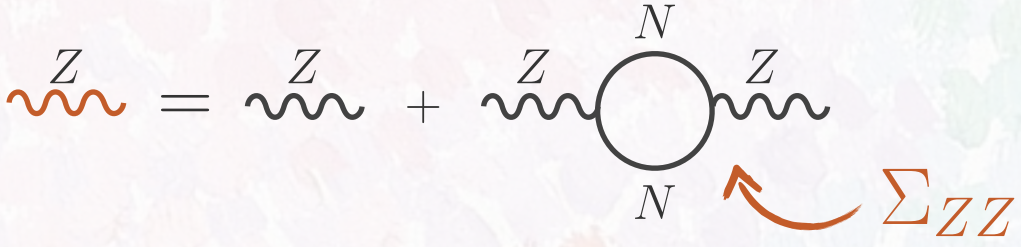
[*] in the Equivalence Theorem regime

OBSERVABLES

The 13 observables computed* at 1 loop in terms of M_Z, α and G_μ.

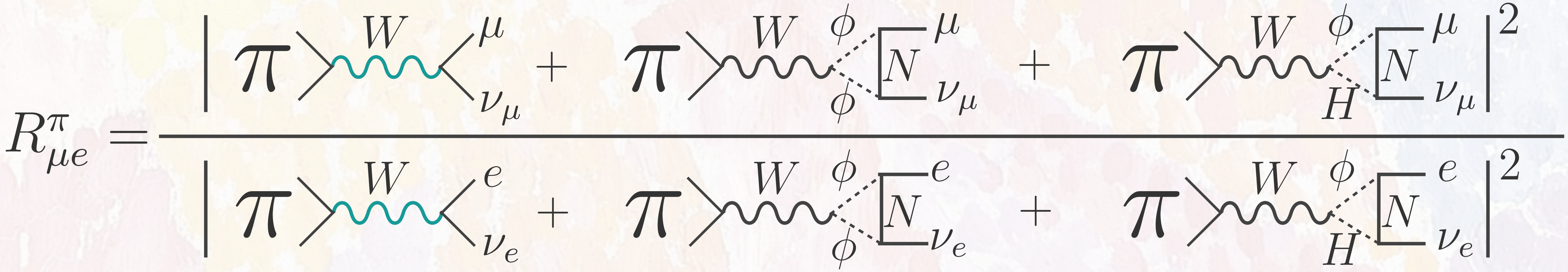
Z and W boson propagators corrected by the new dof:





which directly enter in the list of obs.:

- 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 $R^l_{\tau\mu}$



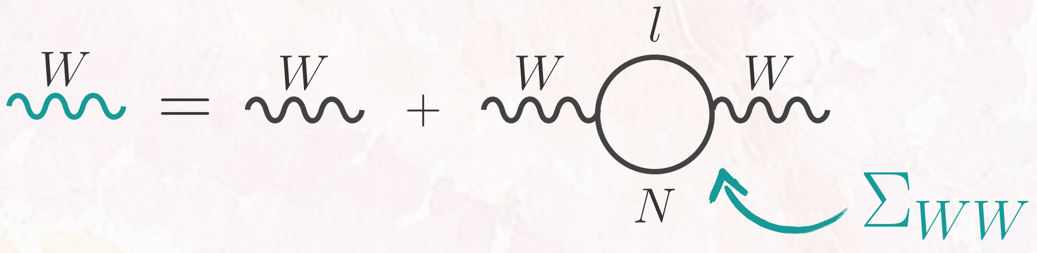
---

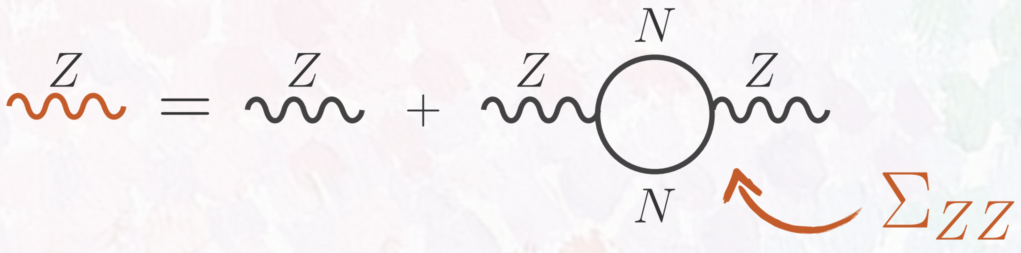
*in the Equivalence Theorem regime

OBSERVABLES

The 13 observables computed* at 1 loop in terms of M_Z, α and G_μ.

Z and W boson propagators corrected by the new dof:

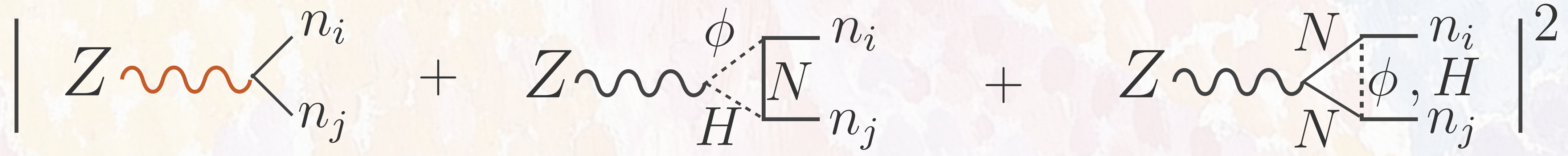




which directly enter in the list of obs.:

- 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

$\Gamma_{\rm inv} =$



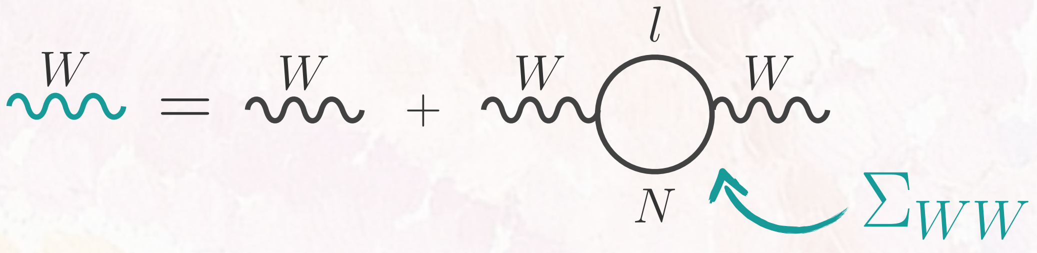
---

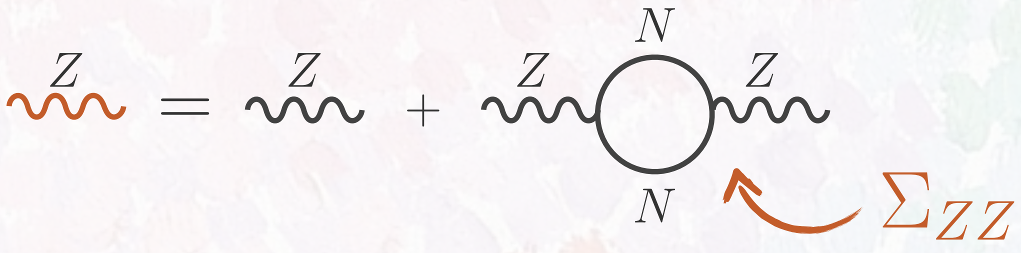
*in the Equivalence Theorem regime

OBSERVABLES

The 13 observables computed* at 1 loop in terms of M_Z, α and G_μ.

Z and W boson propagators corrected by the new dof:

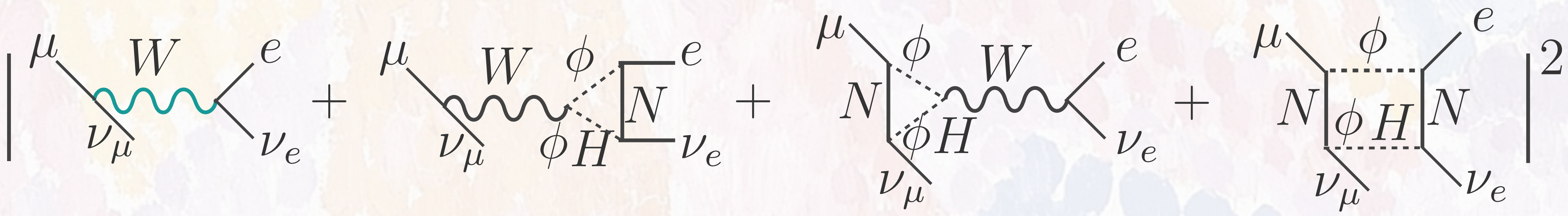




which directly enter in the list of obs.:

- 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 μ decay

$\Gamma_\mu =$



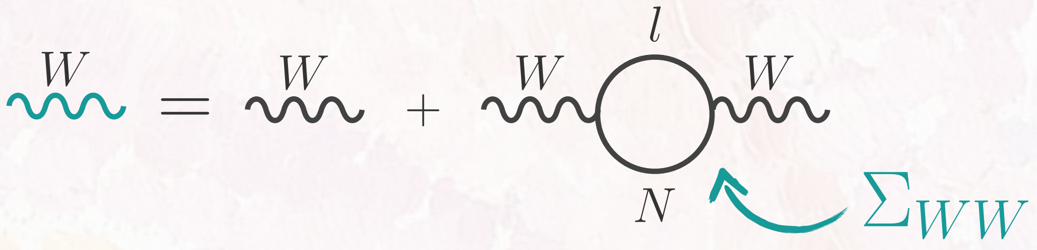
---

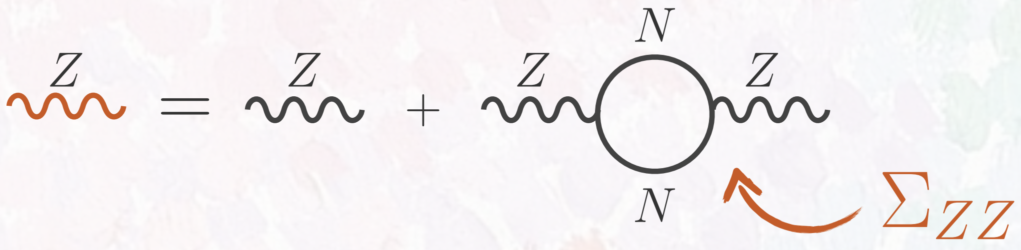
*in the Equivalence Theorem regime

OBSERVABLES

The 13 observables computed* at 1 loop in terms of M_Z, α and G_μ.

Z and W boson propagators corrected by the new dof:





which directly enter in the list of obs.:

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

---

*in the Equivalence Theorem regime

OBSERVABLES

The 13 observables computed* at 1 loop in terms of M_Z, α and G_μ.

Z and W boson propagators corrected by the new dof:

Several observables go with:

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

A cancellation between tree and loop level could be possible.

This relaxes some bounds allowing to fit some anomalies.

E. Akhmedov *et al.* arXiv:1302.1872 [hep-ph]

---

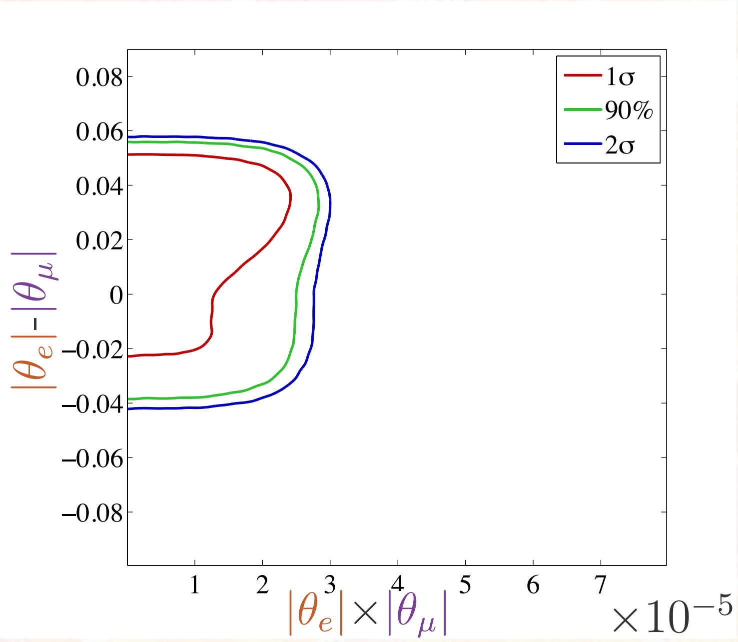
*in the Equivalence Theorem regime

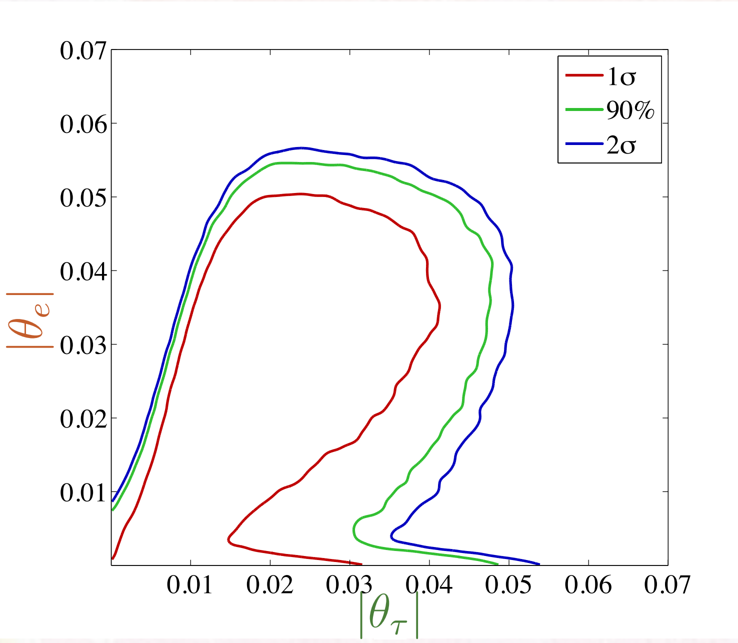
RESULTS

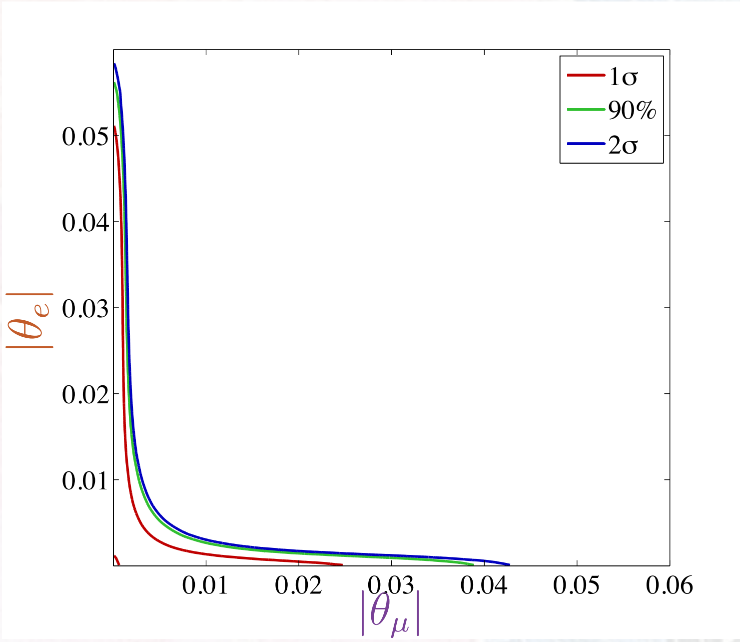
- Global fit and constraints

MCMC with the 13 observables scanning over the 9 parameters.

Frequentist constraints and values in the BF 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.

$$\frac{|\theta_e|^2}{2} + \frac{|\theta_\mu|^2}{2} + 2\alpha T$$

RESULTS

- Loop effect

If L is softly broken $\Rightarrow T \geq 0 \Rightarrow$ NO cancellation allowed.

$$\frac{|\theta_e|^2}{2} + \frac{|\theta_\mu|^2}{2} + 2\alpha T$$

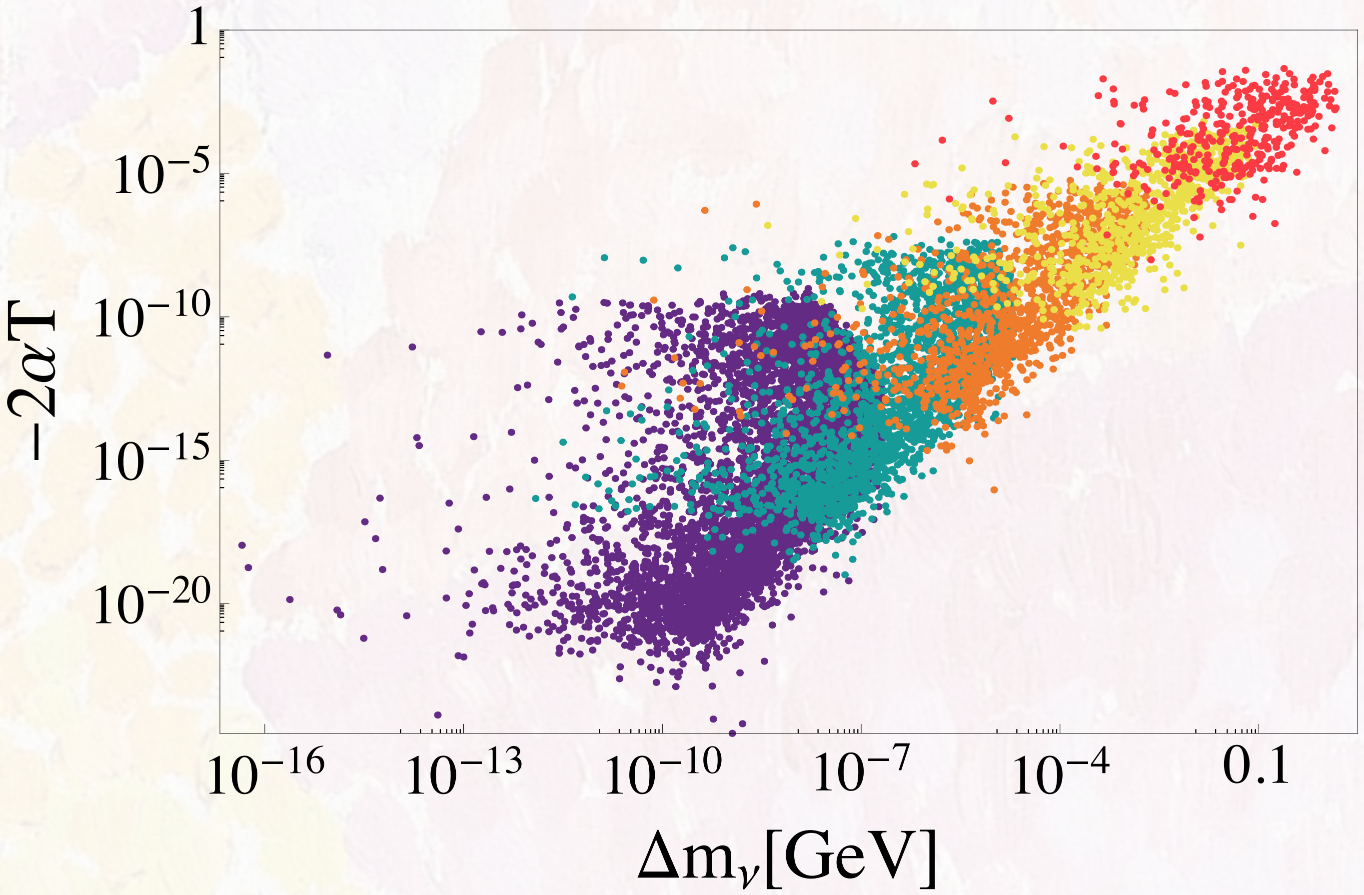
$T < 0$ only possible for large $\not{L}$.

$m_i^{\rm tree} \sim v_{EW}^2 Y_i^2 \left(\frac{1}{\Lambda}\mathcal{O}(\epsilon_1, \frac{\mu}{2\Lambda}) + \frac{1}{\Lambda'}\mathcal{O}(\epsilon_2^2, \frac{\mu''^2}{4\Lambda^2}, \frac{\mu'''^2}{4\Lambda^2}) \right) \Rightarrow \not{L}$ driven by μ'

RESULTS

- Loop effect

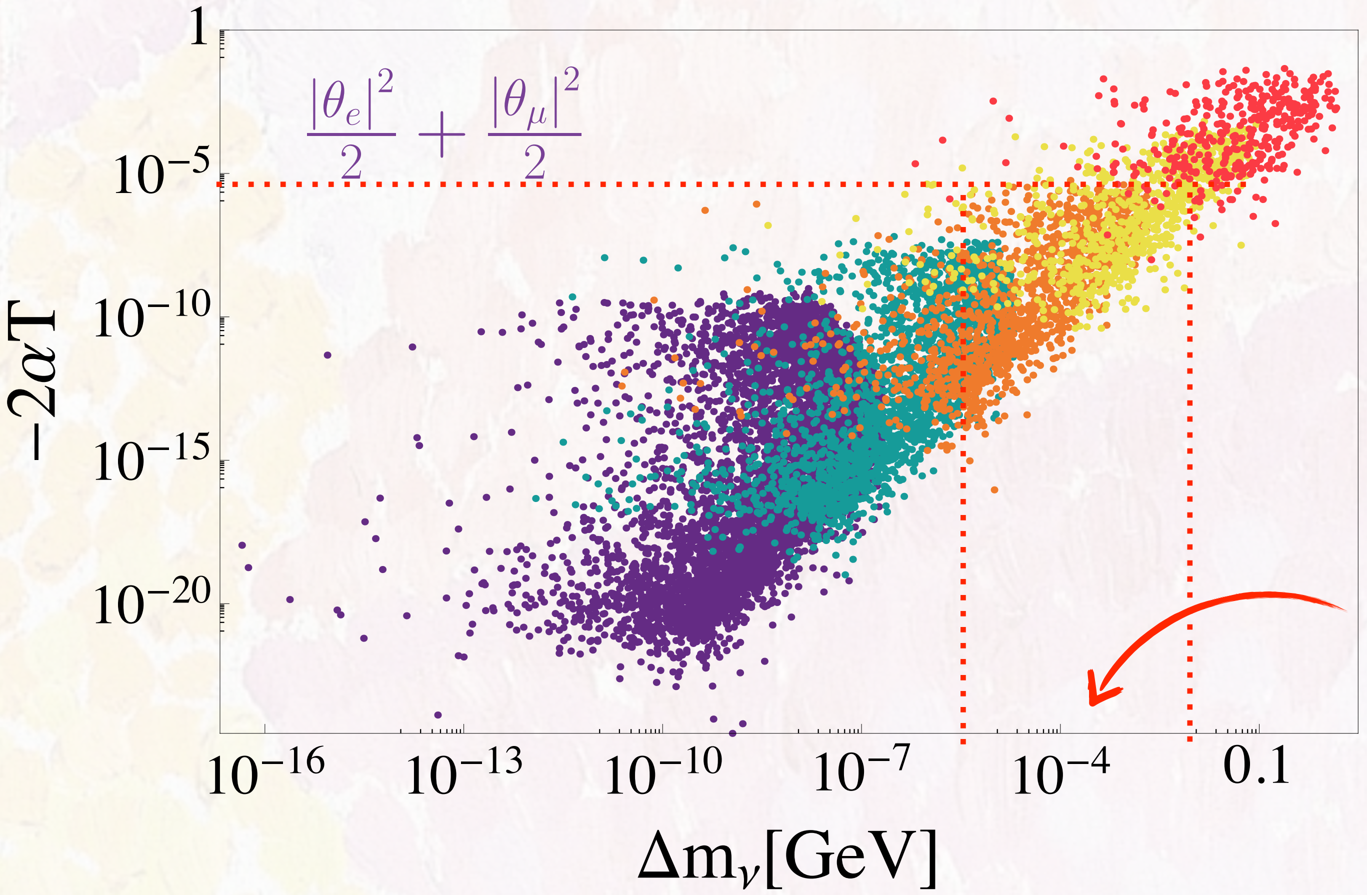
Loop corrections of μ' to m_i should be taken into account:



RESULTS

- Loop effect

Loop corrections of μ' to m_i should be taken into account:

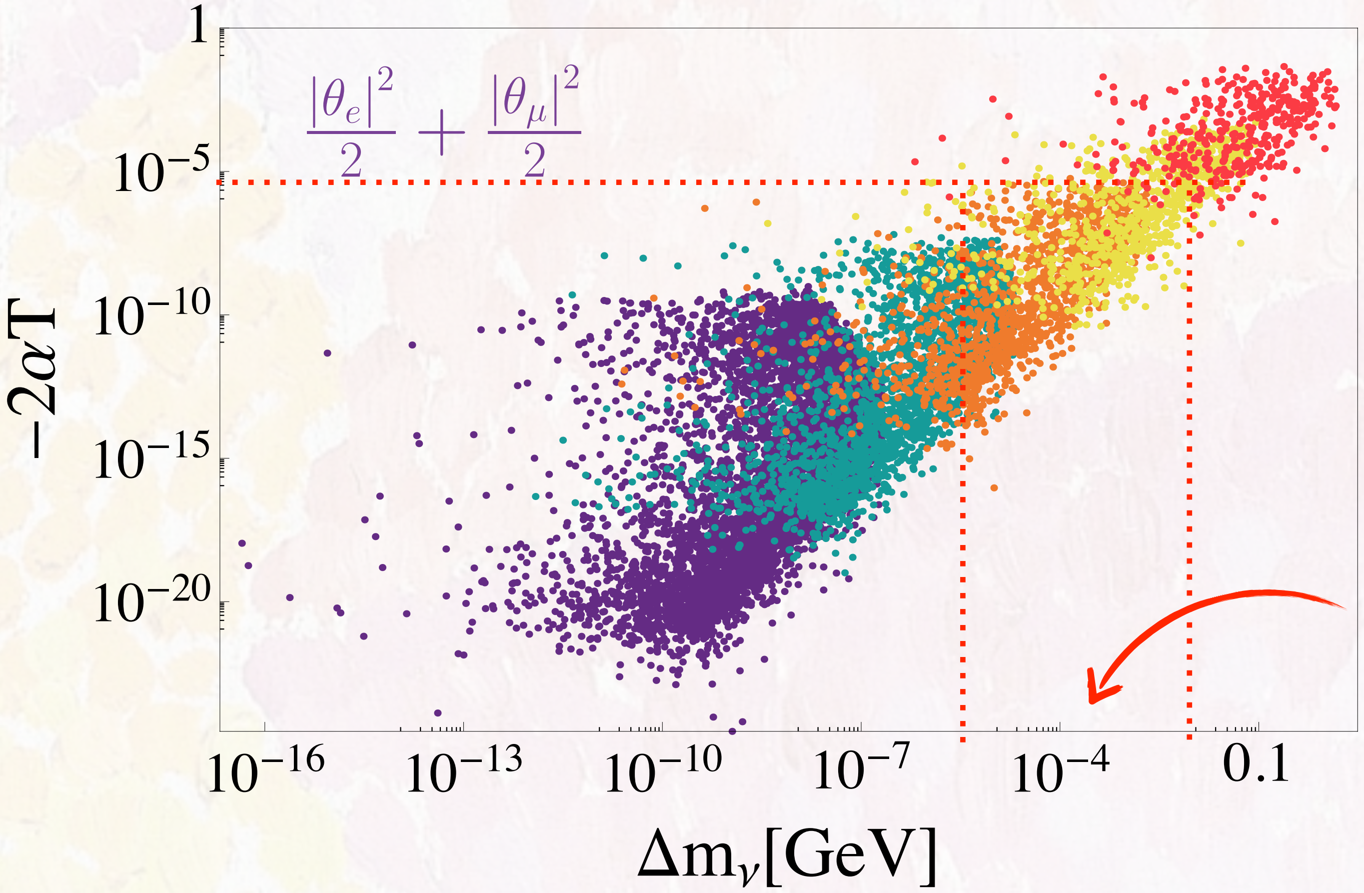


$m_\nu \sim 100$ MeV!!
since no symmetry
protects it

RESULTS

- Loop effect

Loop corrections of μ' to m_i should be taken into account:



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

Thanks

BACK-UP

For $|\mu'| \gg \Lambda,\ Y_\alpha v_{\mathrm{EW}}$:

$$T \simeq \frac{v_{\mathrm{EW}}^4}{32\pi s_W^2 M_W^2 \mu'^2}\left(\sum_\alpha |Y_\alpha|^2\right)^2\left(3 - 8\log\left(\frac{\mu'}{\Lambda}\right)\right)$$

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

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