LFV Higgs decays in low-scale seesaw models within the mass insertion approximation

Ernesto Arganda

Instituto de Física de La Plata - CONICET/UNLP

ernesto.arganda@fisica.unlp.edu.ar

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References

- E. A., M. J. Herrero, X. Marcano, R. Morales and A. Szynkman, Phys. Rev. D **95** (2017) no.9, 095029 [arXiv:1612.09290 [hep-ph]].

Outline

1.- Motivation/Introduction
2.- The inverse seesaw model (ISS)
3.- LFV Higgs decay (LFVHD) rates in the ISS: one-loop computation within mass insertion approximation (MIA)
4.- Effective vertex for $H\ell_i\ell_j$ in the large M_R expansion
5.- Maximum LFVHD rates allowed by data
6.- Conclusions

Motivation

Neutral LFV observed in Neutrino Oscillations!!!

Neutrino Oscillations $\Longrightarrow$ BSM for neutrino masses

$$\boxed{nLFV \xrightarrow{\text{New Neutrino Physics}} cLFV}$$

Low-scale seesaw models

- Accommodate light neutrino data.
- Large Yukawa couplings, $Y_\nu^2/4\pi \sim \mathcal{O}(1)$, with $M_N \sim \mathcal{O}(1\text{ TeV})$.
- New rich phenomenology: LFV (radiative and Higgs decays), heavy neutrinos reachable at LHC...

Mass insertion approximation (MIA)

Useful and intuitive formula valid for any low-scale seesaw model

Intense search program for cLFV

LFV transitions	LFV Present Bounds (90%CL)	Future Sensitivities
BR($\mu \to e\gamma$)	4.2×10^{-13} (MEG 2016)	6×10^{-14} (MEG-II)
BR($\tau \to e\gamma$)	3.3×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)
BR($\tau \to \mu\gamma$)	4.4×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)
BR($\mu \to eee$)	1.0×10^{-12} (SINDRUM 1988)	10^{-16} Mu3E (PSI)
BR($\tau \to eee$)	2.7×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
BR($\tau \to \mu\mu\mu$)	2.1×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
BR($\tau \to \mu\eta$)	2.3×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
CR($\mu - e$, Au)	7.0×10^{-13} (SINDRUM II 2006)	
CR($\mu - e$, Ti)	4.3×10^{-12} (SINDRUM II 2004)	10^{-18} PRISM (J-PARC)
CR($\mu - e$, Al)		3.1×10^{-15} COMET-I (J-PARC)
		2.6×10^{-17} COMET-II (J-PARC)
		2.5×10^{-17} Mu2E (Fermilab)

Bounds on	LEP(95%CL)	ATLAS(95%CL)	CMS(95%CL)
BR($Z \to \mu e$)	1.7×10^{-6}	7.5×10^{-7} PRD90(2014)072010	
BR($Z \to \tau e$)	9.8×10^{-6}		
BR($Z \to \tau\mu$)	1.2×10^{-5}	1.69×10^{-5} EPJC77(2017)70	
BR($H \to \mu e$)	-		3.5×10^{-4} PLB763(2016)472
BR($H \to \tau e$)	-	1.04×10^{-2} EPJC77(2017)70	6.1×10^{-3} CMS-PAS-HIG-17-001
BR($H \to \tau\mu$)	-	1.43×10^{-2} EPJC77(2017)70	2.5×10^{-3} CMS-PAS-HIG-17-001

CMS found 2.4σ excess: $\mathrm{BR}(H \to \tau\mu) = 0.84^{+0.39}_{-0.37}\%$ (95% C.L.) [PLB749(2015)337]

ATLAS found 1.3σ excess: $\mathrm{BR}(H \to \tau\mu) = 0.77 \pm 0.62\%$ (95% C.L.) [arXiv:1508.03372]

Focus on LFV Higgs(-mediated) processes induced by massive neutrinos

Effective vertex for $\boldsymbol{H\ell_i\ell_j}$

Type-I seesaw model

- Neutrino oscillations $\Longrightarrow$ Non-zero Neutrino masses m_ν
- Add ν_R to the SM $\Longrightarrow$ Dirac mass: $m_D = vY_\nu$
- ν_R is a SM singlet $\Longrightarrow$ Majorana mass: M

$$M_{\text{type}-\text{I}} = \begin{pmatrix} 0 & m_D \\ m_D^T & M \end{pmatrix}$$

$$m_\nu \sim \frac{m_D^2}{M}$$

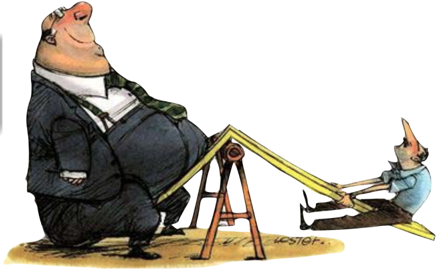
$$\left.\begin{array}{l} \text{Low } M \sim 1 \text{ TeV} \Longrightarrow \text{small } Y_\nu \ll 1 \\ \text{Large coupling } Y_\nu \sim 1 \Longrightarrow \text{heavy } M \sim 10^{14} \text{ GeV} \end{array}\right\} \begin{array}{c} \text{Suppressed} \\ \text{Pheno} \end{array}$$

Low-scale seesaw models

- Use symmetries to lower M yet keeping the coupling Y_ν large.
- Approximate Lepton Number conservation: $U(1)_L$
- Smallness of neutrino masses $\Longleftrightarrow$ small violation of $U(1)_L$

μ_X small scale $\not{L}$

$$m_\nu \propto \mu_X$$



Decouple M and Y_ν from m_ν:

$$\left.\begin{array}{l}\text{Low heavy masses } M \sim 1 \text{ TeV} \\ \text{Large coupling } Y_\nu \sim 1\end{array}\right\} \begin{array}{c}\text{Enhanced} \\ \text{Pheno}\end{array}$$

The inverse seesaw model [Mohapatra and Valle, 1986]

SM extended with 3 pairs of fermionic singlets: $\nu_{Ri}(L=+1)$ & $X_j(L=-1)$

$$\mathcal{L}_{\rm ISS} = -Y_\nu^{ij}\overline{L_i}\tilde{H}\nu_{R_j} - M_R^{ij}\overline{\nu_{R_i}^C}X_j - \frac{1}{2}\mu_X^{ij}\overline{X_i^C}X_j + h.c. \quad i,j=1..3$$

Neutrino mass matrix

$$M^\nu = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M_R \\ 0 & M_R^T & \mu_X \end{pmatrix}$$

$m_D = vY_\nu$: Dirac mass, ν_L-ν_R-H Yukawa interaction

M_R: Controls heavy N masses

μ_X: Controls light ν masses ($\not{L}$)

Use μ_X to accommodate low energy neutrino data. Arganda et al., PRD91(2015)1,015001

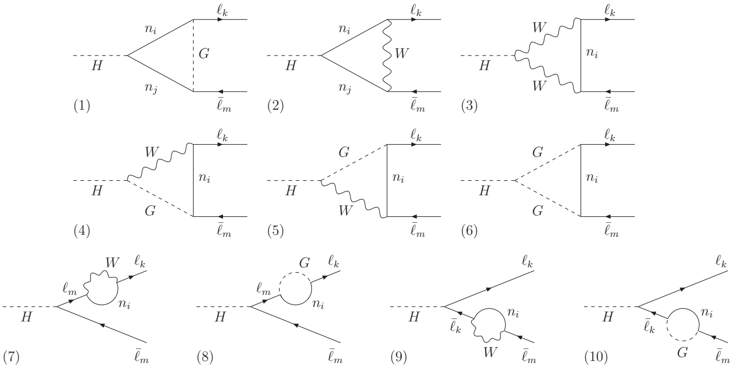
$$\mu_X = M_R^T m_D^{-1} U^*_{\rm PMNS} m_\nu U^\dagger_{\rm PMNS} m_D^{T^{-1}} M_R$$

it allows to choose **Intuitive Input Parameters**

- $M_R \longrightarrow$ Masses of the 6 heavy Majorana neutrinos (3 pseudo-Dirac pairs)
- $Y_\nu \longrightarrow$ Yukawa interaction between ν_L-ν_R-H

LFVHD within the ISS: full 1-loop calculation

E. A., M.J. Herrero, X. Marcano, C. Weiland, PRD91(2015)1,015001



- Calculated in the Feynman-'t Hooft gauge.
- Formulas from [Arganda *et al.*, PRD71(2005)035011] and adapted for ISS.
- Diagrams 1, 8 and 10 divergent and dominant at large Y_ν and M_R.

LFVHD in the ISS within the MIA

Diagramatic calculation of $\Gamma(H \to l_k \bar{l}_m)$ by means of the mass insertion approximation (MIA):

1.- EW chiral neutrino basis for the internal loop particles.

2.- External particles H, l_k and $\bar{l}_m$ in physical mass basis.

3.- Use of *fat* propagators for heavy neutrinos and corresponding Feynman rules

4.- LFVHD amplitude evaluated at 1-loop order in Feynman-'tHooft gauge.

5.- Loops must contain 1 RH neutrino at least: only particles transmitting LFV through the flavor off-diagonal neutrino Yukawa matrix entries.

6.- Y_ν^{mk}, with $m \neq k$, appear just in 2 places: mass insertions given by m_D and interactions of the scalar sector with the RH neutrinos proportional to Y_ν.

7.- All 1-loop diagrams will get an even number of powers of Y_ν.

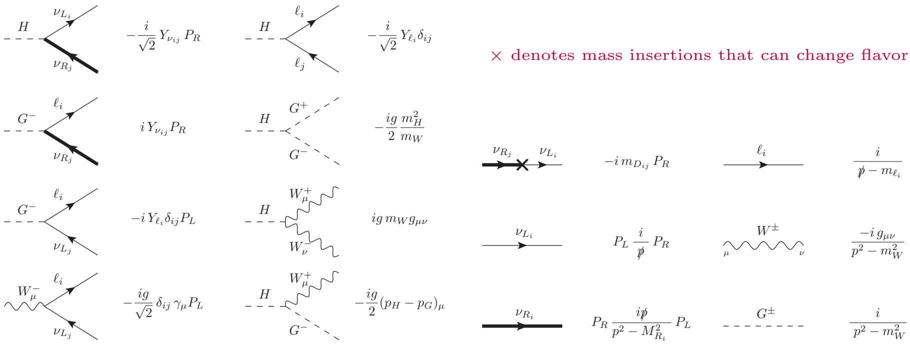
1-loop contributions to LFVHD amplitude, computed with the MIA, given by an expansion in even powers of Y_ν:

- LO terms: $\mathcal{O}(Y_\nu Y_\nu^\dagger) \propto (v/M_R)^2$.
- NLO terms (diags. 1+8+10): $\mathcal{O}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger) \propto (v/M_R)^2$, genuine of LFVHD!!!
- $\mathcal{O}(Y_\nu^6) \propto (v/M_R)^4$: negligible!

Feynman rules and *fat* propagators

Relevant Feynman rules for the present MIA computation of $\Gamma(H \to \ell_k \bar{\ell}_m)$:

$\times$ denotes mass insertions that can change flavor



Fat propagators resume an infinite number of large M_R insertions, in a way such that M_R appears effectively in the denominator:

$$P_R \, \frac{i\not{p}}{p^2 - |M_{R_i}|^2} \, P_L$$

Easier tracking of ν_R decoupling behavior at large $M_R \gg v$

$\Gamma(H \to \ell_k \bar{\ell}_m)$ to one-loop within the MIA

The decay amplitude of the process $H(p_1) \to \ell_k(-p_2)\bar{\ell}_m(p_3)$ can be generically decomposed in terms of two form factors $F_{L,R}$ by

$$i\mathcal{M} = -ig\bar{u}_{\ell_k}(-p_2)(F_L P_L + F_R P_R)v_{\ell_m}(p_3)\,,$$

and the partial decay width can then be written as follows:

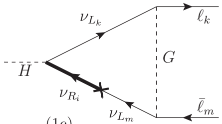
$$\begin{aligned}\Gamma(H \to \ell_k\bar{\ell}_m) \quad &= \quad \frac{g^2}{16\pi m_H}\sqrt{\left(1-\left(\frac{m_{\ell_k}+m_{\ell_m}}{m_H}\right)^2\right)\left(1-\left(\frac{m_{\ell_k}-m_{\ell_m}}{m_H}\right)^2\right)} \\ &\times\Big((m_H^2 - m_{\ell_k}^2 - m_{\ell_m}^2)\big(|F_L|^2+|F_R|^2\big) - 4m_{\ell_k}m_{\ell_m}Re(F_L F_R^*)\Big)\,.\end{aligned}$$

We consider the 2 most relevant contributions in the expansion in even powers of Y_ν, which in terms of the form factors can be written in the following way:

$$F_{L,R}^{\mathrm{MIA}\ \ (Y^2+Y^4)} = \left(Y_\nu Y_\nu^\dagger\right)^{km} f_{L,R}^{(Y^2)} + \left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right)^{km} f_{L,R}^{(Y^4)}\,.$$

MIA computation: $\mathcal{O}(Y_\nu^2)$

Example! (25 contributing diagrams)

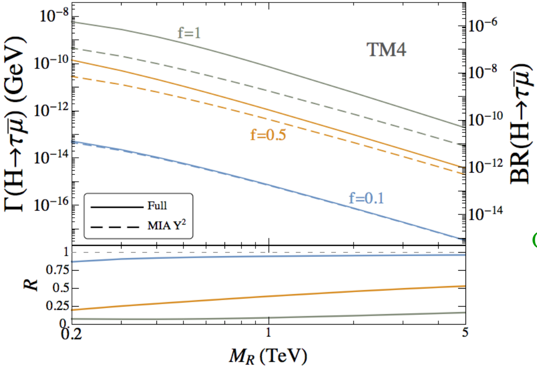


(1c)

$$F_L^{\mathrm{MIA(1c)\ (Y^2)}} = -\frac{1}{32\pi^2}\frac{m_{\ell_k}}{m_W}\left(Y_\nu Y_\nu^\dagger\right)^{km} m_{\ell_m}^2 C_{12}(p_2, p_1, m_W, 0, M_R)$$

$$F_R^{\mathrm{MIA(1c)\ (Y^2)}} = -\frac{1}{32\pi^2}\frac{m_{\ell_m}}{m_W}\left(Y_\nu Y_\nu^\dagger\right)^{km} m_{\ell_k}^2 (C_0 + C_{11} - C_{12})$$

$\propto v^2/M_R^2$ (up to logarithms)



Scenario with suppressed μe and τe mixing

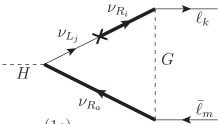
$$Y_\nu^{\mathrm{TM4}} = f\begin{pmatrix} 0.1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0.014 \end{pmatrix}$$

Good agreement for low values of f

$\mathcal{O}(Y_\nu^2)$ MIA insufficient for large f

MIA computation: $\mathcal{O}(Y_\nu^2 + Y_\nu^4)$

Example! (Besides previous 25 $\mathcal{O}(Y_\nu^2)$-diagrams, there are 14 $\mathcal{O}(Y_\nu^4)$-diagrams)



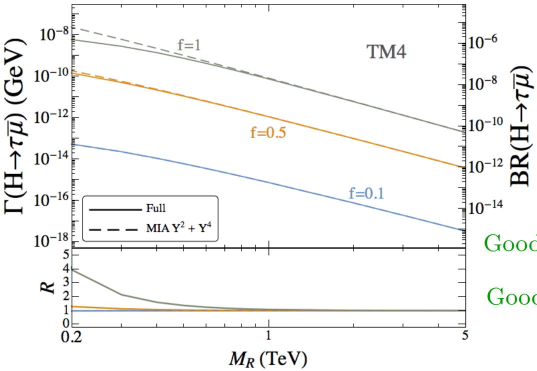
(1e)

$$F_L^{\mathrm{MIA(1e)}\ (\mathrm{Y}^4)} = -\frac{1}{32\pi^2}\frac{m_{\ell_k}}{m_W}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right)^{km} v^2 (C_{11} - C_{12})$$

$$F_R^{\mathrm{MIA(1e)}\ (\mathrm{Y}^4)} = -\frac{1}{32\pi^2}\frac{m_{\ell_m}}{m_W}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right)^{km} v^2 (C_0 + C_{12})$$

$\propto v^2/M_R^2$ at large M_R

$$C_i = C_i(p_2, p_1, m_W, M_R, M_R)$$



Scenario with suppressed μe and τe mixing

$$Y_\nu^{\mathrm{TM4}} = f \begin{pmatrix} 0.1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0.014 \end{pmatrix}$$

Good for $f \lesssim 0.5$ with $M_R > 400$ GeV

Good for $f > 0.5$ with $M_R \gtrsim 1$ TeV

1-loop effective vertex for LFVHD in the MIA

In the large $M_R \gg v$ regime, with $m_{\ell_m} \ll m_{\ell_k} \ll m_W, m_H \ll M_R$, we perform a systematic expansion in powers of (v/M_R) of the 1-loop MIA amplitude for LFVHD, and after the large M_R expansion of the loop integrals, we get the effective vertex $V^{\rm eff}_{Hl_k l_m}$,

$$i\mathcal{M} = -ig\bar{u}_{l_k} V^{\rm eff}_{Hl_k l_m} P_L v_{l_m}$$

$$\boxed{V^{eff}_{Hl_k l_m} = \frac{1}{64\pi^2}\frac{m_{\ell_k}}{m_W}\left[\frac{m_H^2}{M_R^2}\left(r(\frac{m_W^2}{m_H^2}) + \log\left(\frac{m_W^2}{M_R^2}\right)\right)\left(Y_\nu Y_\nu^\dagger\right)^{km} - \frac{3v^2}{M_R^2}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right)^{km}\right]}$$

with $r(\frac{m_W^2}{m_H^2}) \simeq 0.315$, valid for any low-scale model if $m_{\ell_{k,m}} \ll vY_\nu, m_W, m_H \ll M_R$.
Note that $\mathcal{O}(Y_\nu Y_\nu^\dagger)$ term depends on m_H but not $\mathcal{O}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger)$ term.

The LFVHD width $\Gamma(H \to l_k \bar{l}_m) = \frac{g^2}{16\pi} m_H |V^{eff}_{Hl_k l_m}|^2$ reads as:

$$\Gamma = \frac{g^2 m_{\ell_k}^2 m_H}{2^{16}\pi^5 m_W^2}\left|\frac{m_H^2}{M_R^2}\left(r(\frac{m_W^2}{m_H^2}) + \log\left(\frac{m_W^2}{M_R^2}\right)\right)\left(Y_\nu Y_\nu^\dagger\right)^{km} - \frac{3v^2}{M_R^2}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right)^{km}\right|^2$$

We also obtained the effective vertex for Higgs-mediated processes with off-shell Higgs boson (zero external momenta):

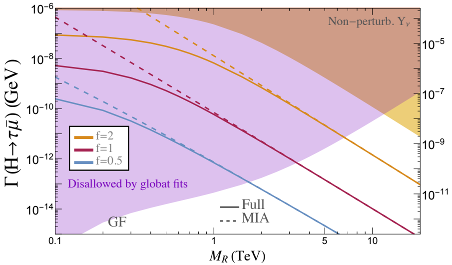
$$V^{eff,\,\text{off-shell}}_{Hl_k l_m} = -\frac{1}{32\pi^2}\frac{m_{\ell_k}}{m_W}\left(\frac{3m_W^2}{2M_R^2}\right)\left[\left(Y_\nu Y_\nu^\dagger\right)^{km} + v^2\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right)^{km}\right].$$

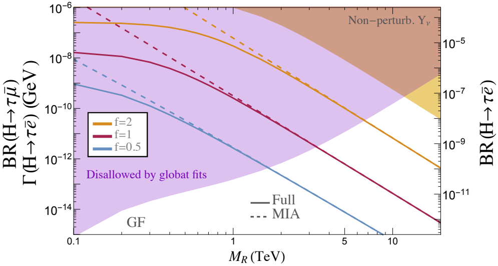
Results on LFVHD in the ISS imposing Global Fits (I)

"Global Fits" constraints [E. Fernández-Martínez *et al.*, JHEP 1608 (2016) 033] imposed into the product $Y_\nu Y_\nu^\dagger$ by means of matrix $\eta = (v^2/(2M_R^2))(Y_\nu Y_\nu^\dagger)$, saturated at 3σ level defining a "maximum allowed by data" matrix:

$$\eta_{3\sigma}^{\max} = \begin{pmatrix} 1.62 \times 10^{-3} & 1.51 \times 10^{-5} & 1.57 \times 10^{-3} \\ 1.51 \times 10^{-5} & 3.92 \times 10^{-4} & 9.24 \times 10^{-4} \\ 1.57 \times 10^{-4} & 9.24 \times 10^{-4} & 3.67 \times 10^{-3} \end{pmatrix} \Rightarrow Y_\nu^{\rm GF} = f \begin{pmatrix} 0.33 & 0.83 & 0.6 \\ -0.5 & 0.13 & 0.1 \\ -0.87 & 1 & 1 \end{pmatrix}$$

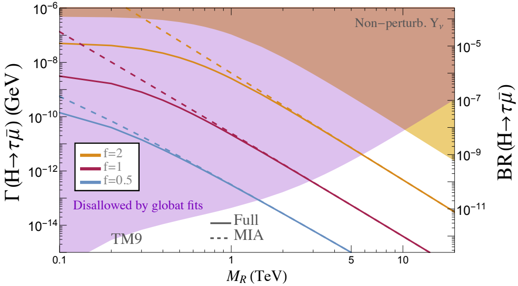
in a parameter space line given by the ratio $f/M_R = (3/10)\,\mathrm{TeV}^{-1}$.





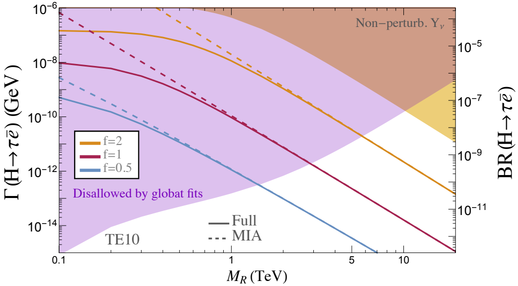
Maximum rates: $\mathrm{BR}(H \to \tau\mu) \sim 3 \times 10^{-8}$ and $\mathrm{BR}(H \to \tau e) \sim 2 \times 10^{-7}$

Results on LFVHD in the ISS imposing Global Fits (II)



Scenario with suppressed μe and τe mixing

$$Y_\nu^{\rm TM9} = f \begin{pmatrix} 0.1 & 0 & 0 \\ 0 & 0.46 & 0.04 \\ 0 & 1 & 1 \end{pmatrix}$$



Scenario with suppressed μe and $\tau\mu$ mixing

$$Y_\nu^{\rm TE10} = f \begin{pmatrix} 0.94 & 0 & 0.08 \\ 0 & 0.1 & 0 \\ 1 & 0 & -1 \end{pmatrix}$$

Conclusions

- MIA results very simple and useful:
  - Extremely good approximation valid for $M_R \gg v$.
  - Decoupling behavior with M_R is manifest.
  - Interesting implications for phenomenology.
  - Valid for any low-scale seesaw model with same Feynman rules.
- Maximum LFVHD rates allowed by data in the ISS of $\mathcal{O}(10^{-7} - 10^{-8})$. Not testable at the LHC.
- If ATLAS and CMS excesses on $h \to \tau\mu$ confirmed, no low-scale seesaw model can be responsible for this LFV.

Backup slides

Neutrino data

The lightest neutrino mass m_{ν_1} is assumed as a free input parameter in agreement with the upper limit on the effective electron neutrino mass in β decays from the Mainz [C. Kraus *et al.*, 2005] and Troitsk [V. N. Aseev *et al.*, 2011] experiments,

$$m_\beta < 2.05 \text{ eV} \quad \text{at } 95\% \text{ CL}\,. \tag{1}$$

The other two light masses are obtained from:

$$m_{\nu_2} = \sqrt{m_{\nu_1}^2 + \Delta m_{21}^2}\,, \quad m_{\nu_3} = \sqrt{m_{\nu_1}^2 + \Delta m_{31}^2}\,. \tag{2}$$

For simplicity, we set to zero the CP-violating phase of the U_{PMNS} matrix and we have used the results of the global fit [M. C. Gonzalez-Garcia *et al.*, 2012] leading to:

$$\begin{aligned} \sin^2\theta_{12} &= 0.306^{+0.012}_{-0.012}\,, & \Delta m_{21}^2 &= 7.45^{+0.19}_{-0.16} \times 10^{-5} \text{ eV}^2\,, \\ \sin^2\theta_{23} &= 0.446^{+0.008}_{-0.008}\,, & \Delta m_{31}^2 &= 2.417^{+0.014}_{-0.014} \times 10^{-3} \text{ eV}^2\,, \\ \sin^2\theta_{13} &= 0.0231^{+0.0019}_{-0.0019}\,, \end{aligned} \tag{3}$$

where we have assumed a normal hierarchy.

The ISS with 3 pairs

- We will consider neutrino mass spectrum for 3 generations: 3 light neutrinos and 6 heavy neutrinos with masses $m_N \sim M_R \sim \mathcal{O}(\text{TeV})$.
- Successfully accommodate low energy neutrino masses and oscillations.
- Smallness of light neutrino masses is associated with the smallness of lepton number violating parameter μ_X (in contrast to Type-I seesaw),

$$M_{\text{light}}^{\text{ISS}} \approx m_D M_R^{T-1} \mu_X M_R^{-1} m_D^T$$
$$M_{\text{light}}^{\text{Type-I}} \approx m_D M^{-1} m_D^T$$

- The new scale μ_X decouples LFV effects from low energy neutrino data.

$$\mu_X = M_R^T m_D^{-1} U_{\text{PMNS}}^* m_\nu U_{\text{PMNS}}^\dagger m_D^{T^{-1}} M_R$$

New particle content $\Longrightarrow$ New Phenomenlogy

6 heavy Majorana neutrinos, quasi degenerate in (pseudo-Dirac) pairs

$$N_{1/2}, N_{3/4}, N_{5/6}$$

whose masses, driven by M_R, can be in the TeV range for $Y_\nu^2/4\pi \sim \mathcal{O}(1)$

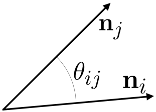
Geometrical parametrization for Y_ν

E. Arganda, M.J. Herrero, XM, C. Weiland, PRD91(2015)1,015001

Assuming $M_{R_{ij}} = M_R \delta_{ij}$ and real Y_ν matrix: $\boxed{\mathrm{LFV}_{ij} \longleftrightarrow \left(Y_\nu Y_\nu^T\right)_{ij}}$

Y_ν 9 d.o.f $\longrightarrow$ 3 vectors (+ global strength f):

$$Y_\nu \equiv f \begin{pmatrix} \boldsymbol{n}_e \\ \boldsymbol{n}_\mu \\ \boldsymbol{n}_\tau \end{pmatrix} \left\{ \begin{array}{l} \text{3 modulus} : |\boldsymbol{n}_e|, |\boldsymbol{n}_\mu|, |\boldsymbol{n}_\tau| \\ \text{3 relative flavor angles:}\, \theta_{\mu e}, \theta_{\tau e}, \theta_{\tau\mu} \\ \text{global rotation } O(\theta_1, \theta_2, \theta_3),\ OO^T = 1 \end{array} \right.$$



$$Y_\nu Y_\nu^T = f^2 \begin{pmatrix} |\boldsymbol{n}_e|^2 & \boldsymbol{n}_e \cdot \boldsymbol{n}_\mu & \boldsymbol{n}_e \cdot \boldsymbol{n}_\tau \\ \boldsymbol{n}_e \cdot \boldsymbol{n}_\mu & |\boldsymbol{n}_\mu|^2 & \boldsymbol{n}_\mu \cdot \boldsymbol{n}_\tau \\ \boldsymbol{n}_e \cdot \boldsymbol{n}_\tau & \boldsymbol{n}_\mu \cdot \boldsymbol{n}_\tau & |\boldsymbol{n}_\tau|^2 \end{pmatrix}$$

Fully determined by $(c_{ij} \equiv \cos\theta_{ij})$
$(f, |\boldsymbol{n}_e|, |\boldsymbol{n}_\mu|, |\boldsymbol{n}_\tau|, c_{\mu e}, c_{\tau e}, c_{\tau\mu})$

Independent of O

Exp. Searches: $\mathrm{LFV}_{\mu e}$ very suppressed $\Longrightarrow$ $\boxed{\mathrm{LFV}_{\mu e} = 0 \leftrightarrow \boldsymbol{n}_e \cdot \boldsymbol{n}_\mu = 0 \leftrightarrow c_{\mu e} = 0}$
(denote as $\cancel{\mathrm{LFV}}_{\mu e}$)

We can choose $Y_\nu = A \cdot O$ with $A = f \begin{pmatrix} |\boldsymbol{n}_e| & 0 & 0 \\ 0 & |\boldsymbol{n}_\mu| & 0 \\ |\boldsymbol{n}_\tau| c_{\tau e} & |\boldsymbol{n}_\tau| c_{\tau\mu} & |\boldsymbol{n}_\tau| \sqrt{1 - c_{\tau e}^2 - c_{\tau\mu}^2} \end{pmatrix}$

Examples of geometrical parametrization

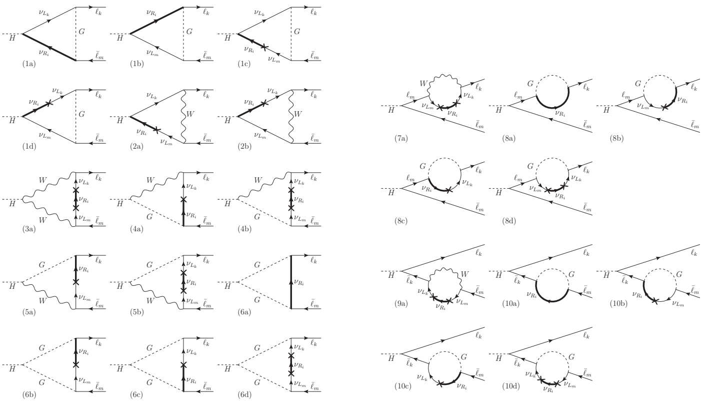
Particular textures with extremely suppressed μe transitions but large LFV in $\tau\mu$ (TM scenarios) or τe sectors (TE scenarios), although not simultaneously:

$$Y_\nu^{\text{TM4}} = f \begin{pmatrix} 0.1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0.014 \end{pmatrix}, \quad Y_\nu^{\text{TM5}} = f \begin{pmatrix} 0 & 1 & -1 \\ 0.9 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix},$$

$$Y_\nu^{\text{TM9}} = f \begin{pmatrix} 0.1 & 0 & 0 \\ 0 & 0.46 & 0.04 \\ 0 & 1 & 1 \end{pmatrix}, \quad Y_\nu^{\text{TE10}} = f \begin{pmatrix} 0.94 & 0 & 0.08 \\ 0 & 0.1 & 0 \\ 1 & 0 & -1 \end{pmatrix}.$$

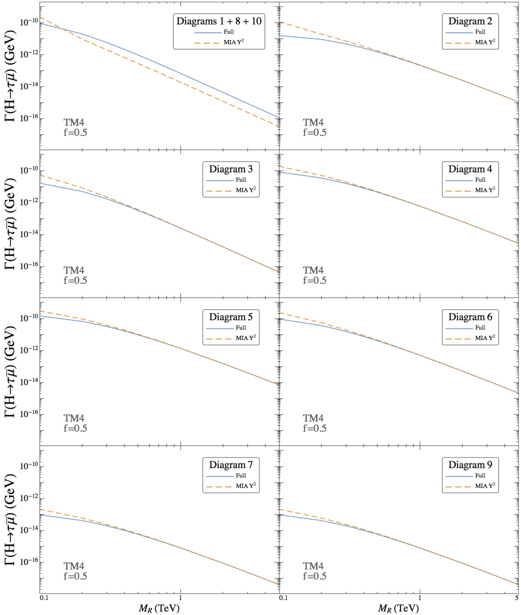
f is a scaling factor that characterizes global strength of Y_ν

MIA computation: diagrams contributing to $\mathcal{O}(Y_\nu^2)$



$$F_L^{\mathrm{MIA}} = \frac{1}{32\pi^2}\frac{m_{\ell_k}}{m_W}\left(Y_\nu Y_\nu^\dagger\right)^{km}\Big(\tilde{C}_0(p_2,p_1,m_W,0,M_R) - B_0(0,M_R,m_W)$$
$$- 2m_W^2\left((C_0 + C_{11} - C_{12})(p_2,p_1,m_W,0,M_R) + (C_{11} - C_{12})(p_2,p_1,m_W,M_R,0)\right)$$
$$+ 4m_W^4(D_{12} - D_{13})(0,p_2,p_1,0,M_R,m_W,m_W)$$
$$- 2m_W^2 m_H^2 D_{13}(0,p_2,p_1,0,M_R,m_W,m_W) + 2m_W^2(C_0 + C_{11} - C_{12})(p_2,p_1,M_R,m_W,m_W)$$
$$+ m_H^2(C_0 + C_{11} - C_{12})(p_2,p_1,M_R,m_W,m_W)\Big)$$

$\mathcal{O}(Y_\nu^2)$ MIA results: diagram by diagram



Scenario with suppressed μe and τe mixing

$$Y_\nu^{\mathrm{TM4}} = f \begin{pmatrix} 0.1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0.014 \end{pmatrix}$$

Sum 1+8+10 to have a finite contribution

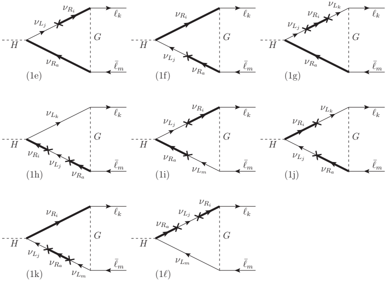
Diags. 2-7 and 9 good full/MIA agreement

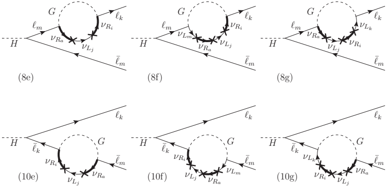
Sum 1+8+10 same behavior but mismatch

We need to include NLO terms
$\mathcal{O}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger) \propto (v/M_R)^2$
in MIA expansion

MIA computation: diagrams contributing to $\mathcal{O}(Y_\nu^4)$

We have to take into account only dominant diagrams 1, 8, and 10





$$F_L^{\rm MIA} = \frac{1}{32\pi^2}\frac{m_{\ell_k}}{m_W}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right)^{km} v^2\Big(-2(C_{11}-C_{12})(p_2,p_1,m_W,M_R,M_R)$$
$$+\tilde{D}_0(p_2,0,p_1,m_W,0,M_R,M_R)+\tilde{D}_0(p_2,p_1,0,m_W,0,M_R,M_R)-C_0(0,0,M_R,M_R,m_W)\Big)$$