Charged Lepton Flavor Violation from Low Scale Seesaw Neutrinos

Francesca Scarcella

Instituto de Física Teórica, Universidad Autónoma de Madrid/CSIC

francesca.scarcella@studio.unibo.it

Instituto de Física Teórica UAM-CSIC

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Based on: V. De Romeri, M.J. Herrero, X. Marcano, F. Scarcella

arXiv: 1607.05257

Flavor Violation in the Standard Model

- Quark sector: misalignment of mass and interaction eigenstates
  $\Rightarrow$ CKM matrix: tree level flavor violating transitions
- Lepton sector: massless neutrinos (no right handed component)
  $\Rightarrow$ no lepton flavor violation

Lepton Flavor Violation = New Physics

Observation of nLFV: neutrino oscillations

Neutral LFV observed in neutrino oscillations

Explained by **misalignment of mass basis and interaction basis**:
P-M-N-S unitary mixing matrix:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U^{\rm PMNS}(\theta_{12}, \theta_{13}, \theta_{23}, \not{C}\not{P} phases) \begin{pmatrix} n_1 \\ n_2 \\ n_3 \end{pmatrix} .$$

$$\begin{aligned} \sin^2\theta_{12} &= 0.306^{+0.012}_{-0.012}\,, & \Delta m^2_{12} &= 7.45^{+0.19}_{-0.16} \times 10^{-5}\ {\rm eV}^2\,, \\ \sin^2\theta_{23} &= 0.437^{+0.061}_{-0.031}\,, & \Delta m^2_{32} &= -2.410^{+0.062}_{-0.063} \times 10^{-3}\ {\rm eV}^2\ (IH)\,, \\ \sin^2\theta_{13} &= 0.0231^{+0.0023}_{-0.0022}\,, & \Delta m^2_{31} &= +2.421^{+0.022}_{-0.023} \times 10^{-3}\ {\rm eV}^2\ (NH)\,, \end{aligned} \qquad (1)$$

$\Longrightarrow$ Standard Model extension required to generate neutrino masses
Should possibly explain the very small values observed

Charged Lepton Flavour Violation

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

This new physics will induce beyond tree level flavour violating interactions between charged leptons

$\Rightarrow$ searches for cLFV could allow to discriminate between different models generating neutrino masses

cLFV not seen yet. Intense program (I).

LFV transitions	LFV Present Bounds (90%CL)	Future Sensitivities
BR($\mu \to e\gamma$)	4.2×10^{-13} (MEG 2016)	4×10^{-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)

Strongest present constraints on LFV - μe sector

(95%CL)	LEP	ATLAS	CMS
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} arXiv:1604.07730	
BR($H \to \mu e$)	-		3.6×10^{-3} CMS-PAS-HIG-14-040
BR($H \to \tau e$)	-	1.04×10^{-2} arXiv:1604.07730	0.7×10^{-2} CMS-PAS-HIG-14-040
BR($H \to \tau\mu$)	-	1.43×10^{-2} arXiv:1604.07730	1.51×10^{-2} PLB749(2015)337-362

Future sensitivities for LFV Z decays: $\sim 10^{-9}$ (linear colliders)

Generating neutrino masses with ν_R

- **Explicit Majorana mass term for ν_L not allowed** by SM gauge invariance (violates all gauge charges by two units)

$\Rightarrow$ **need new physics** to explain neutrino masses

. . Simplest extension: **add ν_R to the SM**

- **Dirac mass** $m_D(\overline{\nu_L}\nu_R + \overline{\nu_R}\nu_L)$

  $\rightarrow$ Generated through EWSB: $m_D = vY_\nu$, $v = <H> = 174$ GeV

- **Majorana mass** $M_R(\overline{\nu_R^C}\nu_R + \overline{\nu_R}\nu_R^C)$

  $\rightarrow$ Allowed since ν_R is a SM singlet

  $\rightarrow$ Not related to EWSB: new energy scale M_R

  $\rightarrow$ Violates lepton number $U(1)_L$

  $\rightarrow \nu = \bar{\nu}$?

Majorana neutrinos from ν_R: Seesaw I

The simplest model able to generate Majorana neutrinos is the **Type-I Seesaw Model**: add three fermionic singlets with both m_D and M_R, with $m_D \ll M_R$

$$\mathcal{L}_{\text{type-I}} = -Y_\nu^{ij}\overline{L_i}\tilde{\phi}\nu_{R_j} - M_R^{ij}\overline{\nu^c_{R_i}}\nu_{R_j} + h.c. \quad i,j = 1..3$$

$$\text{EWSB} \downarrow m_D = vY_\nu$$

$$\mathcal{L}^{mass}_{\text{type-I}} = -\frac{1}{2}\begin{pmatrix}\overline{\nu_L} & \overline{\nu^c_R}\end{pmatrix}\begin{pmatrix}0 & m_D \\ m_D^T & M_R\end{pmatrix}\begin{pmatrix}\nu^c_L \\ \nu_R\end{pmatrix} + h.c.$$

Symmetrical mass matrix $\Rightarrow$ diagonalized by unitary transformation :

$${U_\nu}^T\begin{pmatrix}0 & m_D \\ m_D^T & M_R\end{pmatrix}U_\nu = \begin{pmatrix}m^{light} & 0 \\ 0 & M^{heavy}\end{pmatrix}$$

$\rightarrow$ basis of **Majorana neutrino** mass eigenstates n, N.

Small neutrino masses in the Type-I Seesaw Model

$\rightarrow$ interaction neutrinos = superposition of light and heavy mass eigenstates

$$\begin{pmatrix} \nu_L \\ \nu_R^c \end{pmatrix} = U_\nu^* P_L \begin{pmatrix} n \\ N \end{pmatrix}$$

$\rightarrow m^{light}$ **suppressed** by ratio m_D / M_R :

$$m^{light}, M^{heavy} = \mp \frac{M_R}{2} + \sqrt{\left(\frac{M_R}{2}\right)^2 + m_D^2} \simeq \frac{m_D^2}{M_R}, M_R$$

$$\left.\begin{array}{ll} m^{light} & \sim 1 \text{ eV} \\ Y_\nu & \sim \mathcal{O}(1) \end{array}\right\} \quad M_R \sim 10^{15} \text{ GeV}$$

Low Scale Seesaw Models - Motivation

Small ratio $\frac{m_D}{M_R}$ controls model's BSM phenomenology:
$\rightarrow$ not accessible experimentally.

Way out: use symmetry arguments to obtain small m^{light} yet keeping the ratio $\frac{m_D}{M_R}$ larger

Example: The Inverse Seesaw Model

Approximate Lepton Number conservation: $U(1)_L$

Smallness of neutrino masses $\longleftrightarrow$ small violation of $U(1)_L$

The Inverse Seesaw Model

[Mohapatra and Valle, 1986]

SM extended with 3 pairs of fermion singlets: $\nu_R(L=1)$ & $X(L=-1)$

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

Small violation of lepton number: μ_X

$$\begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M_R \\ 0 & M_R^T & \mu_X \end{pmatrix} \longrightarrow \begin{array}{l} m_\nu^{light} \sim m_D M_R^{T-1} \mu_X M_R^{-1} m_D^T \\ M_\nu^{heavy} \sim M_R \end{array}$$

Physical Majorana neutrinos: three light and six heavy

$$\begin{pmatrix} \nu_L \\ \nu_R^C \\ X^C \end{pmatrix} = U_\nu^* P_L \begin{pmatrix} n_1 \\ \vdots \\ n_9 \end{pmatrix}.$$

Modified interaction Lagrangian

Weak interaction Lagrangian modified:

$$\mathcal{L}_{\rm int}^{W^\pm} = \frac{-g}{\sqrt{2}} W^{\mu -} \bar{l}_i B_{l_i n_j} \gamma_\mu P_L n_j + h.c\,,$$

$$\mathcal{L}_{\rm int}^{Z} = -\frac{g}{4c_W} \sum_{i,j=1}^{9} Z_\mu\, \bar{n}_i \gamma^\mu \Big[C_{n_i n_j} P_L - C^*_{n_i n_j} P_R \Big] n_j, \tag{2}$$

$$\mathcal{L}_{\rm int}^{H} = \frac{-g}{2m_W} H \bar{n}_i C_{n_i n_j} \left[m_{n_i} P_L + m_{n_j} P_R \right] n_j\;,$$

$$\mathcal{L}_{\rm int}^{G^\pm} = \frac{-g}{\sqrt{2} m_W} G^- \left[\bar{l}_i B_{l_i n_j} (m_{l_i} P_L - m_{n_j} P_R) n_j \right] + h.c\,, \tag{3}$$

where:

$$B_{l_i n_j} = U^{\nu *}_{ij}\;, \tag{4}$$

$$C_{n_i n_j} = \sum_{k=1}^{3} U^{\nu}_{ki} U^{\nu *}_{kj}\;. \tag{5}$$

Our work: Lepton Flavour violating Z decays

We expect an **increase in sensitivity to rates of LFV Z decays** in future experiments:

Future linear collider: $\simeq 10^{-9}$

Future circular collider: $\simeq 10^{-13}$

$\rightarrow$ Focus of our work: **explore the predictions of the ISS for this channel.**

Previous studies within ISS suggested: max BR $\simeq 10^{-9}$

Our goal: verify if larger BR can be predicted

Idea: find configurations that suppress LFV in the $\mu - e$ sector (strongest bounds)

Our Choice Of Parametrization

The ISS gives prediction for the light neutrino masses and their mixing angles → must agree with **oscillation experiments**

We **impose agreegement a priori on input parameters** μ_X by inverting approximate formula for m^{light} : Arganda et al., PRD91(2015)1,015001

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

Free Input Parameters

$M_R \longrightarrow$ Masses of the 6 heavy Majorana neutrinos (3 pseudo-Dirac pairs). Set $M_{R_{ij}} = M_R \delta_{ij}$

$Y_\nu \longrightarrow$ Yukawa interaction between ν_L-ν_R-H. Controls LFV phenomenology

Finding ISS scenarios with suppressed $\text{LFV}_{\mu e}$

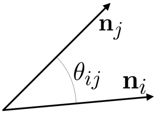
E. Arganda, M.J. Herrero, XM, C. Weiland, PRD91(2015)1,015001

Assuming $M_{R_{ij}} = M_R \delta_{ij}$ and real Y_ν matrix:

$$\text{LFV}_{ij} \longleftrightarrow \left(Y_\nu Y_\nu^T\right)_{ij}$$

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

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



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

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: $\text{LFV}_{\mu e}$ very suppressed $\Longrightarrow$ $\text{LFV}_{\mu e} = 0 \rightarrow \boldsymbol{n}_e \cdot \boldsymbol{n}_\mu = 0 \leftrightarrow c_{\mu e} = 0$

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

Finding ISS scenarios with highly suppressed $\mathrm{LFV}_{\mu e}$

E. Arganda, M.J. Herrero, XM, C. Weiland, PRD91(2015)1,015001
V. De Romeri, M.J. Herrero, XM, F. Scarcella, arXiv: 1607.05257

Dominant contributions:

$$\mathrm{BR}(\tau \to e\gamma) \sim \frac{f^4}{M_R^4}\ c_{\tau e}^2$$

$$\mathrm{BR}(\tau \to \mu\gamma) \sim \frac{f^4}{M_R^4}\ c_{\tau\mu}^2$$

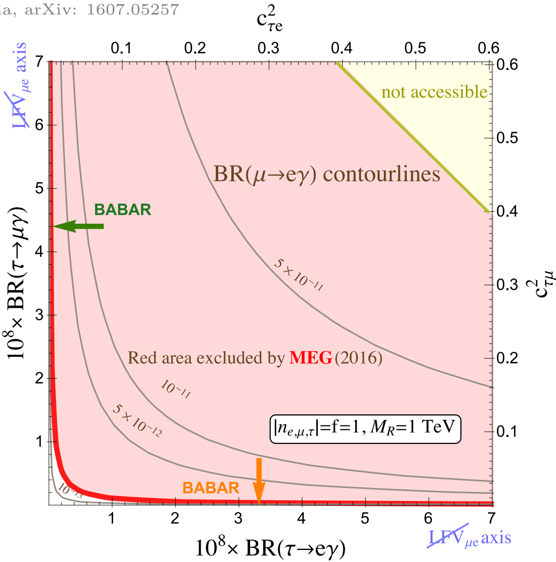
$\mathrm{LFV}_{\mu e}$ highly suppressed :
(occurs at next order)

$$\mathrm{BR}(\mu \to e\gamma) \sim \frac{f^8}{M_R^8}\ c_{\tau e}^2 c_{\tau\mu}^2$$

Focus on either of the two axes:

– $\mathrm{LFV}_{\tau\mu}$ with ~~LFV~~$_{\tau e,\mu e}$

– $\mathrm{LFV}_{\tau e}$ with ~~LFV~~$_{\tau\mu,\mu e}$



Our choice for Y_ν: Specific scenarios

We focus on the **classes of scenarios** with ~~LFV~~$_{\mu e}$ in the LFV$_{\tau\mu}$ direction ($\equiv$ TM), defined by Yukawas of the form:

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

$\mu - e$ and $\tau - e$ transitions suppressed by construction
$\rightarrow$ all experimental bounds from LFV in these sectors satisfied

Numerical examples used (equivalent ones for the LFV$_{\tau e}$ direction):

Scenario	$c_{\tau\mu}$	$\lvert\boldsymbol{n}_e\rvert$	$\lvert\boldsymbol{n}_\mu\rvert$	$\lvert\boldsymbol{n}_\tau\rvert$
TM-1	$1/\sqrt{2}$	1	1	1
TM-2	1	1	1	1
TM-3	$1/\sqrt{2}$	0.1	1	1
TM-4	1	0.1	1	1
TM-5	1	$\sqrt{2}$	1.7	$\sqrt{3}$
TM-6	$1/3$	$\sqrt{2}$	$\sqrt{3}$	$\sqrt{3}$
TM-7	0.1	$\sqrt{2}$	$\sqrt{3}$	1.1

Full study of the ISS-~~LFV~~$_{\mu e}$: Constraints

We consider the following subset of most constraining observables:

- **LFV transitions:** formulas from Ilakovac,Pilaftsis NPB437(1995)491

$$\text{BR}(\tau \to \mu\gamma) < 4.4 \times 10^{-8} \text{ (BABAR'10)}$$
$$\text{BR}(\tau \to \mu\mu\mu) < 2.1 \times 10^{-8} \text{ (BELLE'10)}$$

- **Lepton flavor Universality:** formulas from Abada et al. JHEP1402(2014)091

$$\Delta {r_k}^{3\sigma} \equiv \frac{R_K}{R_K^{SM}} - 1 = (4 \pm 12) \times 10^{-3} \text{ (NA62)} \quad \text{with} \quad R_K \equiv \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)}$$

- **Lepton flavor Conserving observables**

  Z invisible width: formulas from Abada et al. JHEP1402(2014)091

$$\Gamma(Z \to \text{inv.})^{3\sigma} = 499.0 \pm 4.5 \text{ MeV (LEP)}$$

  EWPO: S, T, U parameters formulas from Akhmedov et al. JHEP1305(2013)081

$$S^{3\sigma} = -0.03 \pm 0.30, \quad T^{3\sigma} = 0.01 \pm 0.12, \quad U^{3\sigma} = 0.05 \pm 0.10 \text{ (PDG'14)}$$

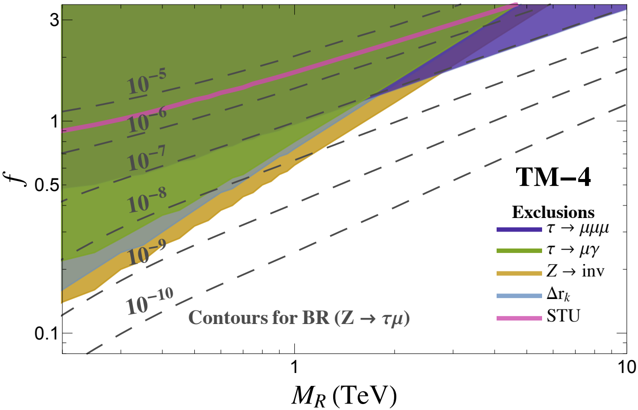
- **Theoretical constraints:**

  Perturbativity imposed by constraining heavy neutrino widths: $\Gamma_N/M_N < 1/2$

  Agreement with **light neutrino data**: validity of the μ_X parametrization

Full study of the ISS-~~LFV~~$_{\mu e}$: Results

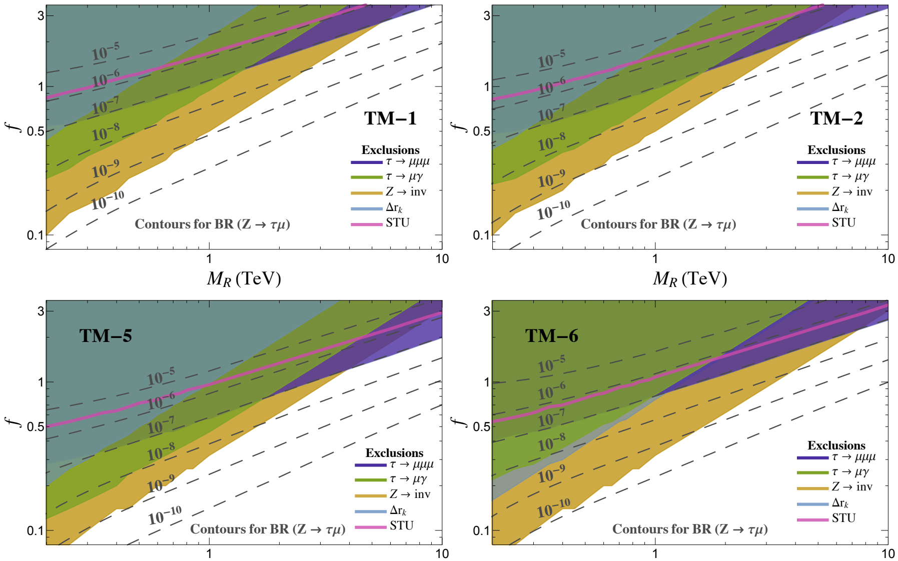
For a given scenario, two free parameters: f = Strength of the Yukawa coupling
M_R= Heavy mass scale



BR$(Z \to \tau\mu)_{\max} \sim 10^{-7}$ allowed by all the constrains for masses $M_R \sim 2-3$ TeV

Full study of the ISS-~~LFV~~$_{\mu e}$: Other scenarios

Similar results for other scenarios



Conclusions

- The Inverse Seesaw is an appealing Model for explaining light neutrino data.
- Heavy neutrinos from the ISS model can have important implications for charged lepton flavor violation.
- Strong experimental bounds motivate scenarios with suppressed LFV$_{\mu e}$
- Studying the LFV$_{\tau\mu}$ sector within the ISS-~~LFV~~$_{\mu e}$ (similar for LFV$_{\tau e}$).:
  - **LFV Z decays:** We found ratios, as large as $\mathrm{BR}(Z \to \tau\mu) \sim 10^{-7}$, potentially measurable at Future Linear Colliders and FCCee.

LFV is a promising window to Low scale Seesaw neutrinos

Thank you!

I warmly thank my advisor M.J. Herrero and my colleague X. Marcano for their valuable help in preparing this presentation

Backup slides

Other results

Studying the $\text{LFV}_{\tau\mu}$ sector within the ISS-~~LFV~~$_{\mu e}$ (similar for $\text{LFV}_{\tau e}$).:

- **LFV Z decays:** We found ratios, as large as $\text{BR}(Z \to \tau\mu) \sim 10^{-7}$, potentially measurable at Future Linear Colliders and FCCee.
- **LFV H decays:** large ratios for $\text{BR}(h \to \tau\mu)$, specially in the SUSY-ISS with contributions of the order of the CMS excess.
- **Production at colliders:** We predicted detectable number of singular LFV events $\mu^{\pm}\tau^{\mp}jj$ for heavy neutrino masses reachable at the LHC.

Neutrino mass model : Dirac vs Majorana

$$\mathcal{L}^D = \overline{\psi} \imath \partial\!\!\!/ \psi - m\overline{\psi}\psi$$

$$= \overline{\psi} \imath \partial\!\!\!/ \psi \quad - \quad m(\overline{\psi_L}\psi_R + \overline{\psi_R}\psi_L)$$

where $\psi_{R,L} \equiv \frac{\mathbf{1} \pm \gamma^5}{2}\psi$

- Dirac mass: ψ_R, ψ_L independent
- Majorana mass: $\psi_L = \psi_R^C \Longleftrightarrow \psi = \psi^C$

where $\psi^C \equiv \mathcal{C}\bar{\psi}^T$

$$\text{so: } m(\overline{\psi_L^C}\psi_L + \overline{\psi_L}\psi_L^C) = m\overline{\psi^C}\psi$$

$$\mathcal{C}^{-1}\gamma^\mu\mathcal{C} = -\gamma^{\mu T}$$

$\rightarrow$ violates all gauge charges by two units

$$\psi \rightarrow e^{i\alpha}\psi$$

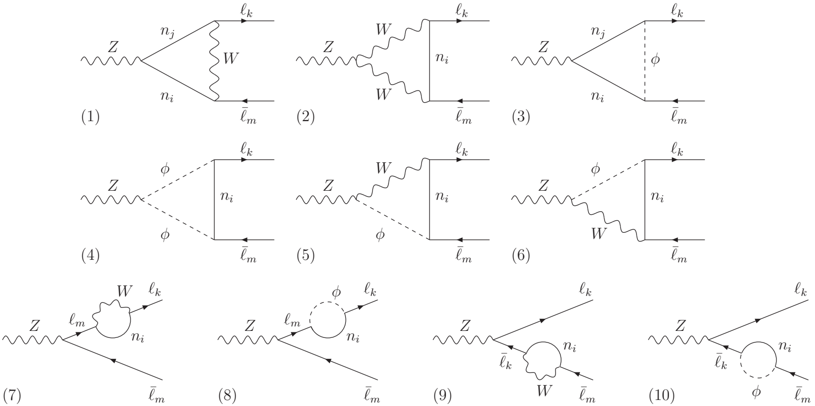
$$\bar{\psi}^C \rightarrow \bar{\psi}^C e^{i\alpha}$$

Examples of ISS neutrino mass spectrum

ISS examples	A	B	C
M_{R_1}(GeV)	1.5×10^4	1.5×10^2	1.5×10^2
M_{R_2}(GeV)	1.5×10^4	1.5×10^3	1.5×10^3
M_{R_3}(GeV)	1.5×10^4	1.5×10^4	1.5×10^4
$\mu_{X_{1,2,3}}$(GeV)	5×10^{-8}	5×10^{-8}	5×10^{-8}
m_{ν_1}(eV)	0.1	0.1	0.1
$\theta_{1,2,3}$(rad)	$0, 0, 0$	$0, 0, 0$	$\pi/4, 0, 0$
m_{n_1}(eV)	0.0998	0.0998	0.0998
m_{n_2}(eV)	0.1002	0.1002	0.1002
m_{n_3}(eV)	0.1112	0.1112	0.1112
m_{n_4}(GeV)	15014.99250747	150.1499250500	150.1499250500
m_{n_5}(GeV)	15014.99250752	150.1499250999	150.1499250999
m_{n_6}(GeV)	15015.04822299	1501.504822277	1501.587676006
m_{n_7}(GeV)	15015.04822304	1501.504822327	1501.587676056
m_{n_8}(GeV)	15016.70543659	15016.70543659	15015.87685358
m_{n_9}(GeV)	15016.70543664	15016.70543664	15015.87685363
$\lvert(Y_\nu Y_\nu^\dagger)_{23}\rvert$	0.8	8.0	1.4
$\lvert(Y_\nu Y_\nu^\dagger)_{12}\rvert$	0.2	1.7	0.3
$\lvert(Y_\nu Y_\nu^\dagger)_{13}\rvert$	0.2	1.8	4.0

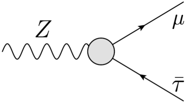
LFV Z decays

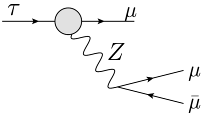
Feynman diagrams for $Z \to \ell_k \bar{\ell}_m$



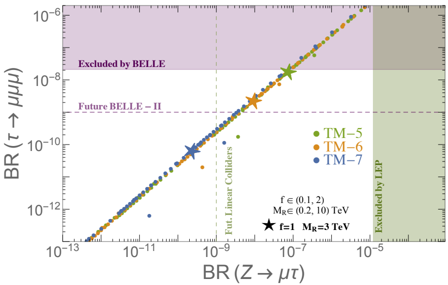
We find **Strong correlation** between $Z \to \tau\mu$ and $\tau \to \mu\mu\mu$
in agreement with Abada et al.JHEP1504(2015)051

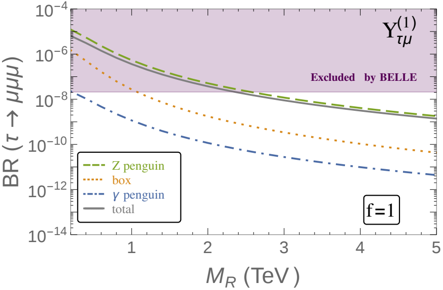
We have checked it is due to the dominance of the Z penguin in $\tau \to \mu\mu\mu$





ISS-~~LFV~~$_{\mu e}$: Bounds on $\mathrm{BR}(\tau \to \mu\mu\mu)$ suggest $\mathrm{BR}(Z \to \tau\mu)_{\max} \sim 10^{-7}$





Results: LFV $Z \to \tau\mu, \tau e$ in the ISS with ~~LFV~~$_{\mu e}$

V. De Romeri, M.J. Herrero, XM, F. Scarcella, About to appear

LFV Z decays: a promising window to Low scale Seesaw neutrinos!!

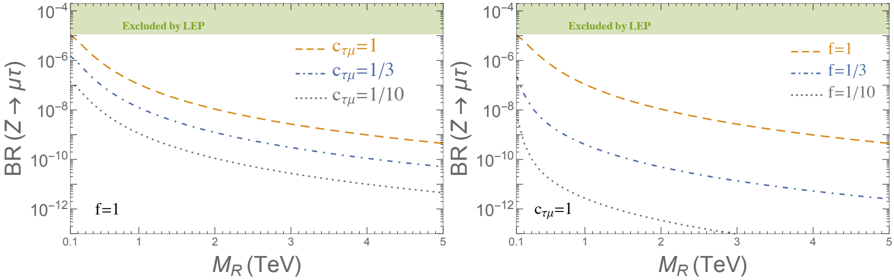
Bounds from LEP: $\text{BR}(Z \to \tau\mu) < 1.2 \times 10^{-5}, \text{BR}(Z \to \tau e) < 9.8 \times 10^{-6}$

Present searches by LHC: $\text{BR}(Z \to \tau\mu) < 1.69 \times 10^{-5}$ (ATLAS, April'16)

LFV Z decays in the ISS-~~LFV~~$_{\mu e}$

Formulas from Illana et al. arXiv:hep-ph/0001273

Large rates within present experimental sensitivities†



†Similar results for $\text{BR}(Z \to \tau e)$