

Gauging Lepton Flavour

Comparison with Minimal Flavour Violation

Pablo Quílez Lasanta

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In collaboration with: *R. Alonso, E. Fernandez-Martinez, M.B. Gavela, B. Grinstein, L. Merlo*

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 - Leptons \rightarrow **This work**

Gauged Lepton Flavour symmetry

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\implies Need to add exotic fermions $\mathcal{E}_L, \mathcal{E}_R, \mathcal{N}_R$

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Charged lepton masses \implies See-saw mechanism

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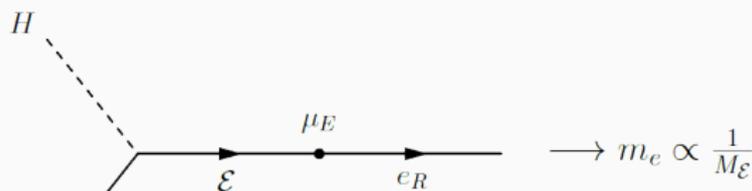
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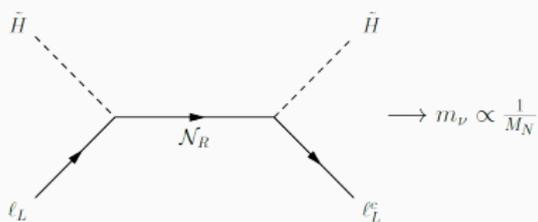
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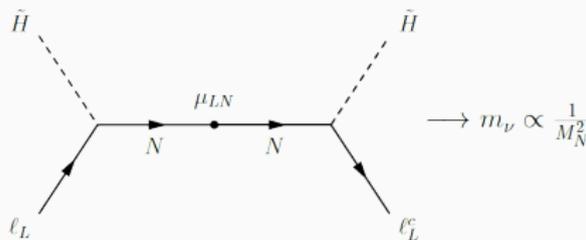
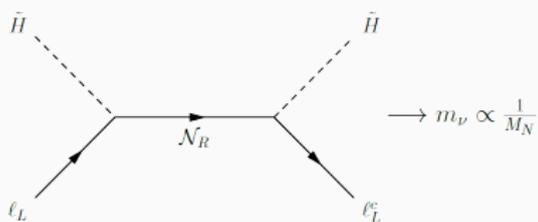
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- Integrating out the heavy fields $\left\{ \begin{array}{l} \text{Exotic fermions} \\ \text{Flavor Gauge bosons} \end{array} \right.$

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$$\begin{aligned}
 \mathcal{L}^{\text{eff}} = & \left(-\bar{\ell}_L H \frac{\lambda_{E\mu E}}{\lambda_E \mathcal{Y}_E} e_R - \ell_L^T \tilde{H} \frac{C_\nu}{\Lambda_{LN}} \tilde{H}^T \ell_L + \text{h.c.} \right) + \tag{4.1} \\
 & + i \bar{e}_R \frac{1}{\lambda_E^2} \frac{\mu_E^2}{\mathcal{Y}_E^\dagger \mathcal{Y}_E} \not{D} e_R + i \bar{\ell}_L H \frac{\lambda_E^2}{\lambda_E^2} \frac{1}{\mathcal{Y}_E \mathcal{Y}_E^\dagger} \not{D} (H^\dagger \ell_L) + i \bar{\ell}_L \tilde{H} \frac{\lambda_\nu^2}{\lambda_N^2} \frac{1}{\mathcal{Y}_N \mathcal{Y}_N^\dagger} \not{D} (\tilde{H}^\dagger \ell_L) + \\
 & - \frac{c_E}{2} \text{Tr} \left[\frac{1}{\mathcal{Y}_E^\dagger \mathcal{Y}_E} \right] (\bar{e}_R \gamma_\mu e_R)^2 - \frac{1}{2} \text{Tr} \left[\frac{1}{\mathcal{Y}_N^\dagger \mathcal{Y}_N} \right] (\bar{\ell}_L \gamma_\mu \ell_L) [c_\ell (\bar{\ell}_L \gamma_\mu \ell_L) + 2 c_{\ell E} (\bar{e}_R \gamma_\mu e_R)] + \dots
 \end{aligned}$$

Low-energy Lagrangian

Gauged Lepton Flavour	Diagram
$i \bar{\ell}_L H \frac{\lambda_E^2}{\lambda_E^2} \frac{1}{\mathcal{Y}_E \mathcal{Y}_E^\dagger} \not{D} (H^\dagger \ell_L)$	<p>Exotic Fermion Exchange</p>
$i \bar{\ell}_L \tilde{H} \frac{\lambda_N^2}{\lambda_N^2} \frac{1}{\mathcal{Y}_N \mathcal{Y}_N^\dagger} \not{D} (\tilde{H}^\dagger \ell_L)$	
$\frac{c_E}{2} \text{Tr} \left[\frac{1}{\mathcal{Y}_E^\dagger \mathcal{Y}_E} \right] (\bar{e}_R \gamma_\mu e_R)^2$	
$\frac{c_\ell}{2} \text{Tr} \left[\frac{1}{\mathcal{Y}_N^\dagger \mathcal{Y}_N} \right] (\bar{\ell}_L \gamma_\mu \ell_L) (\bar{\ell}_L \gamma_\mu \ell_L)$	<p>Flavor Gauge Boson Exchange</p>
$c_{\ell E} \text{Tr} \left[\frac{1}{\mathcal{Y}_N^\dagger \mathcal{Y}_N} \right] (\bar{\ell}_L \gamma_\mu \ell_L) (\bar{e}_R \gamma_\mu e_R)$	

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 - General flavour operator:

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 - Minimal Flavour Violation operator:

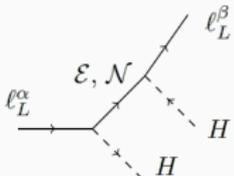
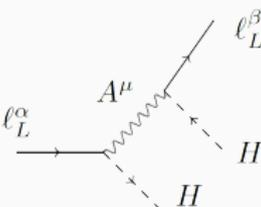
$$\frac{Y_{\alpha\beta}^\dagger Y_{\gamma\delta}}{\Lambda} \bar{\Psi}_\alpha \Psi_\beta \bar{\Psi}_\gamma \Psi_\delta$$

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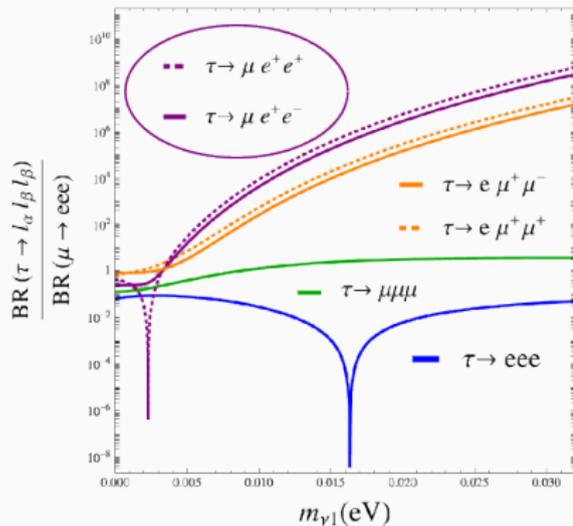
- Yukawas are spurions and the operators are flavour invariant

Low-energy Lagrangian

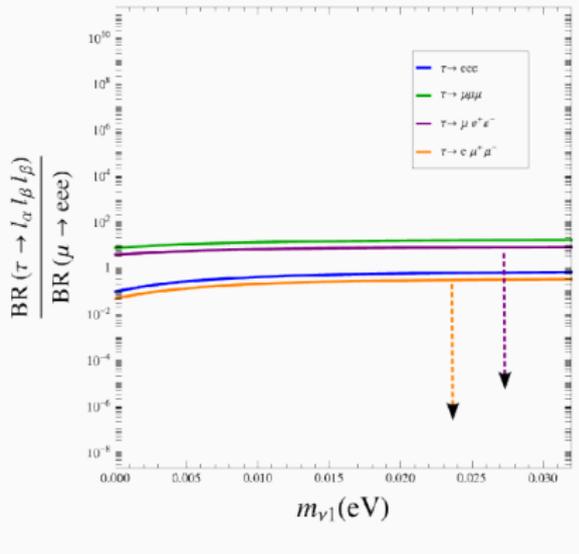
Gauged Lepton Flavour	Diagram	Minimal Flavour Violation
$i \bar{\ell}_L H \frac{\lambda_E^2}{\lambda_E^2} \frac{1}{\mathcal{Y}_E \mathcal{Y}_E^\dagger} \not{D} (H^\dagger \ell_L)$	 <p>Exotic Fermion Exchange</p>	$\frac{1}{\Lambda^2} \bar{\ell}_L H Y_E Y_E^\dagger \not{D} (H^\dagger \ell_L)$
$i \bar{\ell}_L \tilde{H} \frac{\lambda_N^2}{\lambda_N^2} \frac{1}{\mathcal{Y}_N \mathcal{Y}_N^\dagger} \not{D} (\tilde{H}^\dagger \ell_L)$		$\frac{1}{\Lambda^2} \bar{\ell}_L \tilde{H} Y_\nu Y_\nu^\dagger \not{D} (\tilde{H}^\dagger \ell_L)$
$\frac{c_E^E}{2} \text{Tr} \left[\frac{1}{\mathcal{Y}_E^\dagger \mathcal{Y}_E} \right] (\bar{e}_R \gamma_\mu e_R)^2$	 <p>Flavor Gauge Boson Exchange</p>	<p>NO MFV COUNTERPART</p>
$\frac{c_L^E}{2} \text{Tr} \left[\frac{1}{\mathcal{Y}_N^\dagger \mathcal{Y}_N} \right] (\bar{\ell}_L \gamma_\mu \ell_L) (\bar{\ell}_L \gamma_\mu \ell_L)$		
$c_{LE} \text{Tr} \left[\frac{1}{\mathcal{Y}_N^\dagger \mathcal{Y}_N} \right] (\bar{\ell}_L \gamma_\mu \ell_L) (\bar{e}_R \gamma_\mu e_R)$		

Different Phenomenology

Gauged Lepton Flavor



Minimal Flavor Violation



- The decays $\tau \rightarrow \mu e^+ e^+$, $\tau \rightarrow e \mu^+ \mu^+$:

- MFV: Suppressed, they need higher order insertions
- GLF: Leading order.

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- Exotic fermion effects \subset Minimal Lepton Flavour Violation
- Flavour gauge boson effects \neq Minimal Lepton Flavour Violation
- CP violation is more protected in our model than MFV.

Thank you!

Backup slides, $SU(3)_\ell \times SU(3)_E$

	$SU(2)_L$	$U(1)_Y$	$SU(3)_\ell$	$SU(3)_E$
$\ell_L \equiv (\nu_L, e_L)$	2	-1/2	3	1
e_R	1	-1	1	3
\mathcal{E}_R	1	-1	3	1
\mathcal{E}_L	1	-1	1	3
\mathcal{N}_R	1	0	3	1
\mathcal{Y}_E	1	0	$\bar{3}$	3
\mathcal{Y}_N	1	0	$\bar{6}$	1

$$\begin{aligned}
 \mathcal{L}_Y = & \lambda_E \bar{\ell}_L H \mathcal{E}_R + \mu_E \bar{\mathcal{E}}_L e_R + \lambda_E \bar{\mathcal{E}}_L \mathcal{Y}_E \mathcal{E}_R + \text{h.c.} \\
 & + \lambda_\nu \bar{\ell}_L \tilde{H} \mathcal{N}_R + \frac{\lambda_N}{2} \overline{\mathcal{N}_R^c} \mathcal{Y}_N \mathcal{N}_R + \text{h.c.},
 \end{aligned}$$

Backup slides, $SU(3)_\ell \times SU(3)_E \times SO(3)_N$

	$SU(2)_L$	$U(1)_Y$	$SU(3)_\ell$	$SU(3)_E$	$SO(3)_N$
$\ell_L \equiv (\nu_L, e_L)$	2	-1/2	3	1	1
e_R	1	-1	1	3	1
N_R	1	0	1	1	3
\mathcal{E}_R	1	-1	3	1	1
\mathcal{E}_L	1	-1	1	3	1
\mathcal{N}_R	1	0	3	1	1
\mathcal{Y}_E	1	0	$\bar{3}$	3	1
\mathcal{Y}_N	1	0	$\bar{3}$	1	3

$$\begin{aligned}
 \mathcal{L}_Y = & \lambda_E \bar{\ell}_L H \mathcal{E}_R + \mu_E \bar{\mathcal{E}}_L e_R + \lambda_\mathcal{E} \bar{\mathcal{E}}_L \mathcal{Y}_E \mathcal{E}_R \\
 & + \lambda_\nu \bar{\ell}_L \tilde{H} \mathcal{N}_R + \lambda_N \bar{\mathcal{N}}_R^c \mathcal{Y}_N \mathcal{N}_R + \frac{\mu_{LN}}{2} \bar{\mathcal{N}}_R^c \mathcal{N}_R + \text{h.c.},
 \end{aligned}$$

Backup slides, Gauge boson Exchange

$$\begin{aligned}
 c_{\ell}^{ijrs} &= \frac{1}{\sum_k m_{\nu_k}} \left(\frac{\delta_{is} \delta_{jr} m_{\nu_i} m_{\nu_r} (m_{\nu_i}^2 + m_{\nu_r}^2)}{(m_{\nu_i}^2 - m_{\nu_r}^2) (m_{\nu_i} - m_{\nu_r}) + \delta_{ir} (2m_{\nu_i})^3} + \right. \\
 &\quad \left. - \frac{2\delta_{ir} \delta_{js} m_{\nu_i}^2 m_{\nu_j}^2}{(m_{\nu_i}^2 - m_{\nu_j}^2) (m_{\nu_i} - m_{\nu_j}) - \delta_{ij} (2m_{\nu_i})^3} - \frac{\delta_{ij} \delta_{rs} m_{\nu_i} m_{\nu_r}}{2 \sum_k m_{\nu_k}} \right), \\
 c_{\ell E}^{ijk\rho} &= \frac{m_{\kappa} m_{\rho}}{m_{\kappa}^2 + m_{\rho}^2} \frac{1}{\sum_k m_{\nu_k}} \left(\frac{2U_{\kappa j} U_{i\rho}^{\dagger} m_{\nu_i} m_{\nu_j} (m_{\nu_i}^2 + m_{\nu_j}^2)}{(m_{\nu_i}^2 - m_{\nu_j}^2) (m_{\nu_i} - m_{\nu_j}) + \delta_{ij} (2m_{\nu_i})^3} + \right. \\
 &\quad \left. - \frac{4U_{\kappa i} U_{j\rho}^{\dagger} m_{\nu_i}^2 m_{\nu_j}^2}{(m_{\nu_i}^2 - m_{\nu_j}^2) (m_{\nu_i} - m_{\nu_j}) - \delta_{ij} (2m_{\nu_i})^3} - \frac{\sum_k U_{\kappa\gamma} m_{\nu_k} U_{\gamma\rho}^{\dagger} \delta_{ij} m_{\nu_i}}{\sum_k m_{\nu_k}} \right),
 \end{aligned}$$