Gauging Lepton Flavor

Comparison with Minimal Flavor Violation

Pablo Quílez

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

September 13th 2016

The idea

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    - Quarks⟶ [Grinstein, Redi, Villadoro]

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- Gauging flavor symmetries
  - Quarks ⟶ [Grinstein, Redi, Villadoro]
  - Leptons ⟶ **This work**

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$\mu_{LN} \overline{N_R^c} N_R$

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

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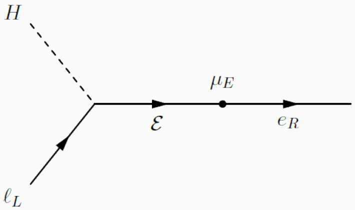

$\longrightarrow m_e \propto \frac{1}{M_{\mathcal{E}}}$

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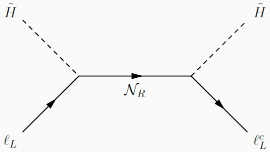
Neutrinos $\Longrightarrow$ Type I See-saw



$\longrightarrow m_\nu \propto \frac{1}{M_N}$

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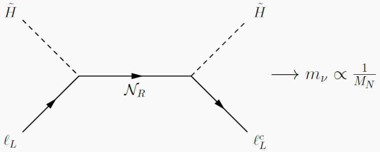
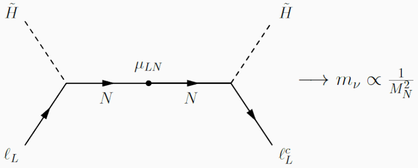


Neutrinos $\Longrightarrow$ Inverse See-saw



Low-energy Lagrangian

- Integrating out the heavy fields $\begin{cases} \text{Exotic fermions} \\ \text{Flavor Gauge bosons} \end{cases}$

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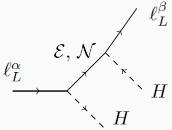
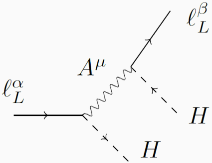
$$\mathscr{L}^{\rm eff} = \left(-\bar{\ell}_L H \frac{\lambda_E \mu_E}{\lambda_{\mathcal{E}} \mathcal{Y}_E} e_R - \ell_L^T \tilde{H} \frac{C_\nu}{\Lambda_{LN}} \tilde{H}^T \ell_L + \text{h.c.} \right) + \tag{4.1}$$
$$+ \, i \, \bar{e}_R \frac{1}{\lambda_{\mathcal{E}}^2} \frac{\mu_E^2}{\mathcal{Y}_E^\dagger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

Low-energy Lagrangian

<table>
<tr><th>Gauged Lepton Flavor</th><th>Diagram</th></tr>
<tr><td>$i\,\bar\ell_L H \frac{\lambda_E^2}{\lambda_{\mathcal{E}}^2}\frac{1}{\mathcal{Y}_E\mathcal{Y}_E^\dagger}\not{D}\,(H^\dagger \ell_L)$</td><td rowspan="2">

Exotic Fermion Exchange</td></tr>
<tr><td>$i\,\bar\ell_L \widetilde H \frac{\lambda_\nu^2}{\lambda_N^2}\frac{1}{\mathcal{Y}_N\mathcal{Y}_N^\dagger}\not{D}\left(\widetilde H^\dagger\ell_L\right)$</td></tr>
<tr><td>$\frac{c_E}{2}\mathrm{Tr}\left[\frac{1}{\mathcal{Y}_E^\dagger\mathcal{Y}_E}\right](\bar e_R\gamma_\mu e_R)^2$</td><td rowspan="3">

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<tr><td>$\frac{c_\ell}{2}\mathrm{Tr}\left[\frac{1}{\mathcal{Y}_N^\dagger\mathcal{Y}_N}\right](\bar\ell_L\gamma_\mu\ell_L)\,(\bar\ell_L\gamma_\mu\ell_L)$</td></tr>
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  - Yukawas are spurions and the operators are flavor invariant

Low-energy Lagrangian

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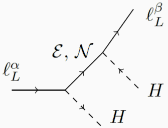
<tr><td>$i\,\bar{\ell}_L H \frac{\lambda_E^2}{\lambda_{\mathcal{E}}^2}\frac{1}{\mathcal{Y}_E\mathcal{Y}_E^\dagger}\not{D}\left(H^\dagger \ell_L\right)$</td><td rowspan="2">

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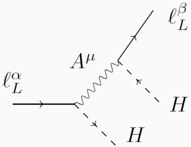
<tr><td>$\frac{c_E}{2}\mathrm{Tr}\left[\frac{1}{\mathcal{Y}_E^\dagger\mathcal{Y}_E}\right]\left(\bar{e}_R\gamma_\mu e_R\right)^2$</td><td rowspan="3">

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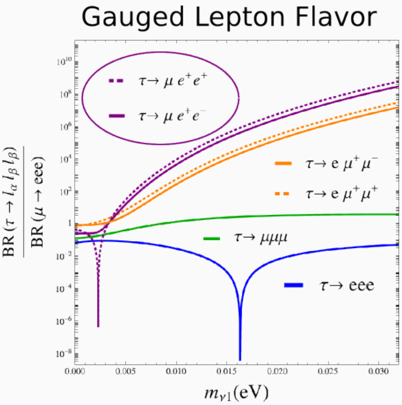
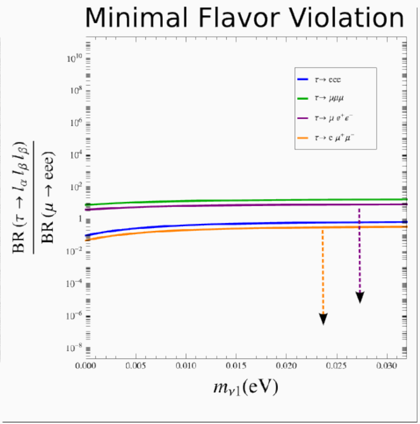
Different Phenomenology





- The decays $\tau \to \mu e^+ e^+$,$\tau \to e\mu^+\mu^+$:
  - MFV: Suppressed, they need higher order insertions
  - GLF: Leading order.

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- Gauged flavor symmetries $\implies$ See-saw for all leptons
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- Exotic fermion effects $\subset$ Minimal Lepton Flavor Violation
- Flavor gauge boson effects $\neq$ Minimal Lepton Flavor 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

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

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

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$\ell_L \equiv (\nu_L\,, e_L)$	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

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

Backup slides, Gauge boson Exchange

$$c_\ell^{ijrs} = \frac{1}{\sum_k m_{\nu_k}} \left(\frac{\delta_{is}\delta_{jr} m_{\nu_i} m_{\nu_r} (m_{\nu_i}^2 + m_{\nu_r}^2)}{\left(m_{\nu_i}^2 - m_{\nu_r}^2\right)(m_{\nu_i} - m_{\nu_r}) + \delta_{ir}(2m_{\nu_i})^3} + \right.$$

$$\left. - \frac{2\delta_{ir}\delta_{js} m_{\nu_i}^2 m_{\nu_j}^2}{(m_{\nu_i}^2 - m_{\nu_j}^2)(m_{\nu_i} - m_{\nu_j}) - \delta_{ij}(2m_{\nu_i})^3} - \frac{\delta_{ij}\delta_{rs} m_{\nu_i} m_{\nu_r}}{2\sum_k m_{\nu_k}} \right),$$

$$c_{\ell E}^{ij\kappa\rho} = \frac{m_\kappa m_\rho}{m_\kappa^2 + m_\rho^2} \frac{1}{\sum_k m_{\nu_k}} \left(\frac{2U_{\kappa j} U_{i\rho}^\dagger m_{\nu_i} m_{\nu_j} (m_{\nu_i}^2 + m_{\nu_j}^2)}{(m_{\nu_i}^2 - m_{\nu_j}^2)(m_{\nu_i} - m_{\nu_j}) + \delta_{ij}(2m_{\nu_i})^3} + \right.$$

$$\left. - \frac{4U_{\kappa i} U_{j\rho}^\dagger m_{\nu_i}^2 m_{\nu_j}^2}{(m_{\nu_i}^2 - m_{\nu_j}^2)(m_{\nu_i} - m_{\nu_j}) - \delta_{ij}(2m_{\nu_i})^3} - \frac{\sum_k U_{\kappa\gamma} m_{\nu_k} U_{\gamma\rho}^\dagger \, \delta_{ij} m_{\nu_i}}{\sum_k m_{\nu_k}} \right),$$