Exploring minimally flavor violating Higgs decays

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Based on

S Baek & JT, arXiv:1604.08935

XG He, JT, YJ ZHeng, JHEP 09 (2015) 093 [arXiv:1507.02673]

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Outline

- Introduction
  - Data on Higgs decays into a pair of leptons
  - Minimal flavor violation hypothesis
- Minimally flavor violating Higgs dilepton decays
- Higgs dilepton decays in GUT framework with MFV
- Conclusions

- Data on the flavor-conserving channels
  - $\mathcal{B}(h \to e^+e^-) < 1.9 \times 10^{-3}$ at 95% CL from CMS 1410.6679
  - $\mathcal{B}(h \to \mu^+\mu^-) < \begin{cases} 1.5 \times 10^{-3} & \text{at 95\% CL from ATLAS} \\ 1.6 \times 10^{-3} & \text{at 95\% CL from CMS} \end{cases}$ 1406.7663, 1410.6679
  - $\dfrac{\mathcal{B}(h \to \tau^+\tau^-)}{\mathcal{B}(h \to \tau^+\tau^-)_{\rm SM}} = 1.12^{+0.25}_{-0.23}$ from ATLAS+CMS ATLAS-CONF-2015-044 CMS-PAS-HIG-15-002

- For comparison, the SM predicts
  - $\mathcal{B}(h \to e^+e^-) \approx 5.3 \times 10^{-9}$
  - $\mathcal{B}(h \to \mu^+\mu^-) \approx 2.19 \times 10^{-4}$
  - $\mathcal{B}(h \to \tau^+\tau^-) \approx 6.3\,\%$

- The SM predictions are consistent with the data.

Higgs flavor-changing dilepton decays

- CMS results
  - $\mathcal{B}(h\to\mu\tau) = \mathcal{B}(h\to\mu^+\tau^-)+\mathcal{B}(h\to\mu^-\tau^+) = \left(0.84^{+0.39}_{-0.37}\right)\%$

    $\mathcal{B}(h\to\mu\tau) < 1.51\,\%$ at 95% CL 1502.07400

  - $\mathcal{B}(h\to e\tau) < 0.7\,\%$ at 95% CL

    CMS PAS HIG-14-040

  - $\mathcal{B}(h\to e\mu) < 0.036\,\%$ at 95% CL
- ATLAS results

  1604.07730

  - $\mathcal{B}(h\to\mu\tau) = (0.53\pm0.51)\%$

    $\mathcal{B}(h\to\mu\tau) < 1.43\,\%$ at 95% CL

  - $\mathcal{B}(h\to e\tau) < 1.04\,\%$ at 95% CL
- A naive combination of ATLAS & CMS numbers yields $\mathcal{B}(h\to\mu\tau) = (0.73\pm0.31)\%$
- The minimal SM predicts no lepton flavor violation
  - The tentative $h\to\mu\tau$ hint would be new physics evidence if confirmed by upcoming data.

- The standard model has been successful in describing the current data on flavor-changing neutral currents & *CP* violation in the quark sector.
- This motivates the hypothesis of minimal flavor violation for quarks: Yukawa couplings are the only sources for the breaking of flavor & *CP* symmetries.

  Chivukula & Georgi
  Hall & Randall

  - Effective field theory approach with MFV.

  Buras *et al.*
  D'Ambrosio *et al.*

- It's interesting to extend the MFV idea to the lepton sector

  Cirigliano *et al.*

  - This may offer extra insights into the origin of neutrino mass
  - But there are ambiguities in implementing leptonic MFV.

  Davidson & Palorini
  Gavela *et al.*, 2009
  He, Lee, JT, Zheng
  . . . .

- We consider an effective MFV scenario involving the type-I seesaw mechanism with degenerate heavy right-handed neutrinos.
  - MFV is imposed in both the lepton and/or quark sectors.
  - This could also work with the type-III seesaw case.

- The kinetic Lagrangian for SM fermions plus 3 right-handed neutrinos

$$\mathcal{L} \supset i\bar{Q}_{kL}\not{\partial}Q_{kL} + i\bar{U}_{kR}\not{\partial}U_{kR} + i\bar{D}_{kR}\not{\partial}D_{kR} + i\bar{L}_{kL}\not{\partial}L_{kL} + i\bar{\nu}_{kR}\not{\partial}\nu_{kR} + i\bar{E}_{kR}\not{\partial}E_{kR}$$

$k = 1,2,3$ is summed over, $\quad Q_{jL} = \begin{pmatrix} U_{jL} \\ D_{jL} \end{pmatrix}, \quad L_{jL} = \begin{pmatrix} \nu_{jL} \\ \ell_{jL} \end{pmatrix}, \quad j = 1,2,3$

$(U_1, U_2, U_3) = (u, c, t), \quad (D_1, D_2, D_3) = (d, s, b), \quad (E_1, E_2, E_3) = (\ell_1, \ell_2, \ell_3) = (e, \mu, \tau)$

- It's invariant under the global flavor rotations

$$Q_{jL} \to (V_Q)_{jk} Q_{kL}, \quad U_{jR} \to (V_U)_{jk} U_{kR}, \quad D_{jR} \to (V_D)_{jk} D_{kR}$$
$$L_{jL} \to (V_L)_{jk} L_{kL}, \quad \nu_{jR} \to (V_\nu)_{jk} \nu_{kR}, \quad E_{jR} \to (V_E)_{jk} E_{kR}, \qquad V_X \in \mathrm{SU}(3)_X$$

- The flavor symmetry of the theory is explicitly broken by fermion mass terms

$$\mathcal{L} \supset -(Y_u)_{jk}\, \bar{Q}_{jL} U_{kR} \tilde{H} - (Y_d)_{jk}\, \bar{Q}_{jL} D_{kR} H - (Y_e)_{jk}\, \bar{L}_{jL} E_{kR} H$$
$$- (Y_\nu)_{jk}\, \bar{L}_{jL} \nu_{kR} \tilde{H} - \tfrac{1}{2} (M_\nu)_{jk}\, \overline{\nu^{\rm c}_{jR}}\, \nu_{kR} + \text{H.c.}$$

$Y_{u,d,\nu,e}$ are Yukawa matrices, H is the Higgs doublet, $\tilde{H} = i\tau_2 H^*$

$M_\nu = \mathcal{M}\, \mathrm{diag}(1,1,1)$ is the Majorana mass matrix of degenerate ν_{kR}

- $\mathcal{L}$ is formally flavor-symmetric if the Yukawas are spurions transforming as

$$Y_u \to V_Q Y_u V_U^\dagger, \quad Y_d \to V_Q Y_d V_D^\dagger, \quad Y_e \to V_L Y_e V_E^\dagger, \quad Y_\nu \to V_L Y_\nu \mathcal{O}_\nu^{\rm T}$$

Flavor spurion combinations for MFV operators

⋆ We work in the basis where Y_d and Y_e are diagonal

$$Y_d = \mathrm{diag}(y_d, y_s, y_b)\,, \qquad Y_e = \mathrm{diag}(y_e, y_\mu, y_\tau)\,, \qquad y_f \equiv \sqrt{2}\, m_f/v\,, \quad v = 246\ \mathrm{GeV}$$

and U_k, D_k, and E_k refer to the mass eigenstates. Thus

$$Q_{j,L} = \begin{pmatrix} (V^\dagger_{\rm CKM})_{jk} U_{k,L} \\ D_{j,L} \end{pmatrix}, \qquad Y_u = V^\dagger_{\rm CKM}\,\mathrm{diag}(y_u, y_c, y_t), \qquad L_{j,L} = \begin{pmatrix} (U_{\rm PMNS})_{jk} \nu_{k,L} \\ E_{j,L} \end{pmatrix}$$

$$Y_\nu = \frac{i\sqrt{2}}{v} U_{\rm PMNS}\, \hat{m}_\nu^{1/2} O M_\nu^{1/2}$$ with $OO^{\rm T} = \mathbb{1}$ and $M_\nu = \mathcal{M}\,\mathrm{diag}(1,1,1)$

Casas & Ibarra

$m_\nu = \mathrm{diag}(m_1, m_2, m_3)$ is the mass matrix of light νs

⋆ The Yukawa combinations of interest

$$\mathsf{A}_q = Y_u Y_u^\dagger = V^\dagger_{\rm CKM}\,\mathrm{diag}(y_u^2, y_c^2, y_t^2)\, V_{\rm CKM}\,, \qquad \mathsf{B}_q = Y_d Y_d^\dagger = \mathrm{diag}(y_d^2, y_s^2, y_b^2)$$

$$\mathsf{A}_\ell = Y_\nu Y_\nu^\dagger = \frac{2\mathcal{M}}{v^2} U_{\rm PMNS}\, \hat{m}_\nu^{1/2} O O^\dagger \hat{m}_\nu^{1/2} U^\dagger_{\rm PMNS}\,, \qquad \mathsf{B}_\ell = Y_e Y_e^\dagger = \mathrm{diag}(y_e^2, y_\mu^2, y_\tau^2)$$

⋆ Since $y_t^2 \gg y_b^2$, and sufficiently large $\mathcal{M}$ is chosen so that $|(\mathsf{B}_\ell)_{jk}| \ll |(\mathsf{A}_\ell)_{jk}| \lesssim 1$, in our model-independent approach the pertinent spurion building blocks are

$$\Delta_q = \zeta_1 \mathbb{1} + \zeta_2 \mathsf{A}_q + \zeta_4 \mathsf{A}_q^2\,, \qquad \Delta_\ell = \xi_1 \mathbb{1} + \xi_2 \mathsf{A}_\ell + \xi_4 \mathsf{A}_\ell^2$$

Colangelo, Mercolli, Smith

$\zeta_{1,2,4}$ and $\xi_{1,2,4}$ are free parameters at most of $\mathcal{O}(1)$ with negligible imaginary parts.

Hence $\quad \Delta_q \to V_Q \Delta_q V_Q^\dagger\,, \quad \Delta_\ell \to V_L \Delta_\ell V_\ell^\dagger$

- The effective operators need to be invariant under the flavor rotations and SM gauge symmetry.

- Effective dimension-6 MFV operators involving leptons & H

$$\mathcal{L}_{\rm MFV} \supset \frac{1}{\Lambda^2}\Big(O_{RL}^{(e1)} + O_{RL}^{(e2)} + O_{RL}^{(e3)} + O_{RL}^{(e4)} + O_{LL}^{(1)} + O_{LL}^{(2)} + {\rm H.c.}\Big) + \cdots$$

Λ is the scale of MFV,

$$O_{RL}^{(e1)} = g'\bar{E}_R Y_e^\dagger \Delta_{RL}^{(1)} \sigma_{\rho\omega} H^\dagger L_L B^{\rho\omega}$$

$$O_{RL}^{(e2)} = g\,\bar{E}_R Y_e^\dagger \Delta_{RL}^{(2)} \sigma_{\rho\omega} H^\dagger \tau_a L_L W_a^{\rho\omega}$$

$$O_{RL}^{(e3)} = (\mathcal{D}^\rho H)^\dagger\, \overline{E}_R Y_e^\dagger \Delta_{RL}^{(3)} \mathcal{D}_\rho L_L$$

$$O_{LL}^{(1)} = \tfrac{i}{4}\big[H^\dagger(\mathcal{D}_\rho H) - (\mathcal{D}_\rho H)^\dagger H\big]\,\bar{L}_L\gamma^\rho\Delta_{LL}^{(1)} L_L\,,$$

$$O_{LL}^{(2)} = \tfrac{i}{4}\big[H^\dagger\tau_a(\mathcal{D}_\rho H) - (\mathcal{D}_\rho H)^\dagger\tau_a H\big]\,\bar{L}_L\gamma^\rho\tau_a\Delta_{LL}^{(2)} L_L$$

generalized from
D'Ambrosio *et al.*
Cirigliano *et al.*

- $\Delta_{RL}^{(1,2,3)}$ and $\Delta_{LL}^{(1,2)}$ are the same in form as Δ_ℓ, but have their own coefficients ξ_r

- If MFV is also imposed in the quark sector, it has an analogous Lagrangian.

He, JT, Zheng, 1507.02673

★ $\mathcal{L}_{\rm MFV} \supset \dfrac{O_{RL}^{(e3)}}{\Lambda^2} + {\rm H.c.}\,,\qquad O_{RL}^{(e3)} = (\mathcal{D}^\rho H)^\dagger \overline{E}_R Y_e^\dagger \Delta\, \mathcal{D}_\rho L_L$

★ Alternative $h \to \ell\bar{\ell}'$ operator: $H^\dagger H\, \overline{E}_{jR} H^\dagger L_{kL}$

★ They are related

$$
\begin{aligned}
O_{RL}^{(e3)} + {\rm H.c.} = {} & \tfrac{i}{8}\Big[H^\dagger \mathcal{D}_\rho H - (\mathcal{D}_\rho H)^\dagger H\Big]\Big(\overline{L}_L \gamma^\rho \big\{\Delta, Y_e Y_e^\dagger\big\} L_L + 4\overline{E}_R \gamma^\rho Y_e^\dagger \Delta Y_e E_R\Big) \\
& + \tfrac{i}{8}\Big[H^\dagger \tau_a \mathcal{D}_\rho H - (\mathcal{D}_\rho H)^\dagger \tau_a H\Big]\, \overline{L}_L \gamma^\rho \big\{\Delta, Y_e Y_e^\dagger\big\} \tau_a L_L \\
& + \tfrac{i}{8}\Big[H^\dagger \mathcal{D}_\rho H + (\mathcal{D}_\rho H)^\dagger H\Big]\, \overline{L}_L \gamma^\rho \big[\Delta, Y_e Y_e^\dagger\big] L_L \\
& + \tfrac{i}{8}\Big[H^\dagger \tau_a \mathcal{D}_\rho H + (\mathcal{D}_\rho H)^\dagger \tau_a H\Big]\, \overline{L}_L \gamma^\rho \big[\Delta, Y_e Y_e^\dagger\big] \tau_a L_L \\
& + \tfrac{1}{8}\Bigg[\bigg(\frac{4H^\dagger H}{v^2} - 2\bigg) m_h^2\, \overline{E}_R Y_e^\dagger \Delta H^\dagger L_L + 4\overline{L}_L Y_e E_R \overline{E}_R Y_e^\dagger \Delta L_L \\
& \qquad + \overline{E}_R Y_e^\dagger \Delta\, \sigma_{\rho\omega} H^\dagger (g' B^{\rho\omega} + g\,\tau_a W_a^{\rho\omega}) L_L + {\rm H.c.}\Bigg] \\
& + (\text{quark terms})
\end{aligned}
$$

- Effective Lagrangian satisfying MFV criterion

$$\mathcal{L}_{\rm MFV} \supset \frac{1}{\Lambda^2}(\mathcal{D}^\alpha H)^\dagger \overline{E}_R Y_e^\dagger \Delta_\ell \mathcal{D}_\alpha L_L$$

Λ is the MFV scale, $\Delta_\ell = \xi_1 \mathbb{1} + \xi_2 \mathsf{A}_\ell + \xi_4 \mathsf{A}_\ell^2$

$\xi_{1,2,4}$ are free parameters at most of $\mathcal{O}(1)$

- Effective Lagrangian describing $h \to f\bar{f}'$

$$\mathcal{L}_{hf\bar{f}'} = -\overline{f}\left(\mathcal{Y}^*_{f'f} P_L + \mathcal{Y}_{ff'} P_R\right) f' h$$

Decay rate $\Gamma_{h\to f\bar{f}'} = \dfrac{m_h}{16\pi}\left(|\mathcal{Y}_{ff'}|^2 + |\mathcal{Y}_{f'f}|^2\right)$

- Combined SM and $\mathcal{L}_{\rm MFV}$ contribution to $h \to E_k^- E_l^+$

$$\mathcal{Y}_{E_k E_l} = \delta_{kl}\, \mathcal{Y}^{\rm SM}_{E_k E_k} - \frac{m_{E_l} m_h^2}{2\Lambda^2 v}(\Delta_\ell)_{kl}\,, \qquad \mathcal{Y}^{\rm SM}_{E_k E_k} = \frac{m_{E_k}}{v}$$

- Indirect limit from new MEG data $\mathcal{B}(\mu \to e\gamma) < 4.2 \times 10^{-13}$

1605.05081

$$\sqrt{\left|(\mathcal{Y}_{\mu\mu} + r_\mu)\mathcal{Y}_{\mu e} + 9.19\,\mathcal{Y}_{\mu\tau}\mathcal{Y}_{\tau e}\right|^2 + \left|(\mathcal{Y}_{\mu\mu} + r_\mu)\mathcal{Y}_{e\mu} + 9.19\,\mathcal{Y}_{e\tau}\mathcal{Y}_{\tau\mu}\right|^2} < 4.4 \times 10^{-7}$$

$$r_\mu = 0.29$$

Goudelis, Lebedev, Park
Blankenburg, Ellis, Isidori
Harnik, Kopp, Zupan
Dery *et al.*

- From LHC data on $h \to \mu^+\mu^-, \tau^+\tau^-$

$$\left|\mathcal{Y}_{\mu\mu}/\mathcal{Y}_{\mu\mu}^{\rm SM}\right|^2 < 6.5\,, \qquad 0.9 < \left|\mathcal{Y}_{\tau\tau}/\mathcal{Y}_{\tau\tau}^{\rm SM}\right|^2 < 1.4$$

- CMS data on $h \to \mu\tau$

1502.07400

$$2.0 \times 10^{-3} < \sqrt{|\mathcal{Y}_{\tau\mu}|^2 + |\mathcal{Y}_{\mu\tau}|^2} < 3.3 \times 10^{-3}$$

- CMS data on $h \to e\mu, e\tau$

$$\sqrt{|\mathcal{Y}_{e\mu}|^2 + |\mathcal{Y}_{\mu e}|^2} < 5.43 \times 10^{-4}\,, \qquad \sqrt{|\mathcal{Y}_{e\tau}|^2 + |\mathcal{Y}_{\tau e}|^2} < 2.41 \times 10^{-3}$$

CMS PAS HIG-14-040

He, JT, Zheng, 1507.02673

⋆ In the SM plus 3 degenerate heavy right-handed neutrinos

$$\Delta_\ell = \xi_1 \mathbb{1} + \xi_2 \mathsf{A}_\ell + \xi_4 \mathsf{A}_\ell^2, \qquad \mathsf{A}_\ell = Y_\nu Y_\nu^\dagger = \frac{2\mathcal{M}}{v^2} U_{\rm PMNS}\, \hat{m}_\nu^{1/2} O O^\dagger \hat{m}_\nu^{1/2} U_{\rm PMNS}^\dagger$$

$$M_\nu = \mathcal{M}\, {\rm diag}(1,1,1)$$

⋆ If O in Y_ν is real, $|\mathcal{Y}_{\mu\tau}|$ can only reach $\sim 2\times 10^{-4} \ll |\mathcal{Y}_{\mu\tau}^{\rm CMS}| \sim 3\times 10^{-3}$

⋆ To attain $|\mathcal{Y}_{\mu\tau}^{\rm CMS}|$, less simple structure of Y_ν is needed, particularly with complex O so that $O O^\dagger = e^{2i\mathsf{R}}$ with $\mathsf{R} = \begin{pmatrix} 0 & r_1 & r_2 \\ -r_1 & 0 & r_3 \\ -r_2 & -r_3 & 0 \end{pmatrix}$ and real $r_{1,2,3}$

Numerical results

	$\frac{\alpha_1}{\pi}$	$\frac{\alpha_2}{\pi}$	r_1	r_2	r_3	$10^5\xi_1/\Lambda^2$ (GeV^{-2})	$10^5\xi_2/\Lambda^2$ (GeV^{-2})	$10^5\xi_4/\Lambda^2$ (GeV^{-2})	$\frac{\mathcal{Y}_{ee}}{\mathcal{Y}_{ee}^{\rm SM}}$	$\frac{\mathcal{Y}_{\mu\mu}}{\mathcal{Y}_{\mu\mu}^{\rm SM}}$	$\frac{\mathcal{Y}_{\tau\tau}}{\mathcal{Y}_{\tau\tau}^{\rm SM}}$	$\frac{\lvert\mathcal{Y}_{e\mu}\rvert}{10^{-6}}$	$\frac{\lvert\mathcal{Y}_{e\tau}\rvert}{10^{-4}}$	$\frac{\lvert\mathcal{Y}_{\mu\tau}\rvert}{10^{-3}}$
NH	0	0	0.81	-1.6	-0.89	-7.5	6.4	5.8	1.6	1.3	0.95	1.0	0.1	3.2
	0	0	-0.90	1.8	-0.92	-8.4	6.0	7.1	1.7	1.3	0.97	1.4	0.4	3.5
	0	0.23	0.74	-0.80	-0.23	7.0	-5.3	-7.5	0.46	0.77	1.15	1.5	1.7	3.3
IH	0	0	0.04	0.63	-0.93	-7.9	8.8	3.0	1.5	1.2	1.08	2.3	2.9	3.3
	0	0	0.02	-0.75	1.1	-6.2	3.7	7.7	1.4	1.1	0.97	2.2	1.2	3.2
	0.79	1.3	-0.61	-0.79	1.4	-6.8	5.0	7.6	1.5	1.0	0.96	1.2	0.4	3.5

Leptonic Yukawa couplings for sample values of the Majorana phases $\alpha_{1,2}$, parameters $r_{1,2,3}$ of the complex O matrix, and coefficients $\xi_{1,2,4}$ in the MFV matrix Δ which can yield $|\mathcal{Y}_{\mu\tau}| \gtrsim 3\times10^{-3}$, corresponding to measured neutrino mixing parameters for the normal (NH) or inverted (IH) hierarchy of neutrino masses.

★ In these instances $\mathcal{B}(\mu\to e\gamma) = (1.8-4.3)\times10^{-13}$, $\mathcal{B}(\mu\mathrm{Al}\to e\mathrm{Al}) = (2.3-8.2)\times10^{-15}$

- $|\mathcal{Y}_{\mu\tau}|/|\mathcal{Y}_{e\tau}| \sim 10$ or more, consistent with CMS $h\to e\tau,\mu\tau$ results
- The $\mathcal{Y}_{\mu\mu}$ and $\mathcal{Y}_{\tau\tau}$ predictions are testable with future collider data
- MEG II may probe the $\mu\to e\gamma$ predictions more stringently

- In grand unified theories, quarks & leptons appear in the same representations.
- In the Georgi-Glashow GUT based on the SU(5) gauge group

$$\bar{5}:\ \psi_k = \begin{pmatrix} (D^1_{k,R})^c \\ (D^2_{k,R})^c \\ (D^3_{k,R})^c \\ E_{k,L} \\ -\nu_{k,L} \end{pmatrix}, \quad 10:\ \chi_k = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & (U^3_{k,R})^c & -(U^2_{k,R})^c & -U^1_{k,L} & -D^1_{k,L} \\ -(U^3_{k,R})^c & 0 & (U^1_{k,R})^c & -U^2_{k,L} & -D^2_{k,L} \\ (U^2_{k,R})^c & -(U^1_{k,R})^c & 0 & -U^3_{k,L} & -D^3_{k,L} \\ U^1_{k,L} & U^2_{k,L} & U^3_{k,L} & 0 & -(E_{k,R})^c \\ D^1_{k,L} & D^2_{k,L} & D^3_{k,L} & (E_{k,R})^c & 0 \end{pmatrix}, \quad k = 1,2,3$$

♦ Fermion mass Lagrangian

Ellis & Gaillard

$$\mathcal{L}_{\rm m}^{\rm GUT} = (\lambda_5)_{kl}\, \psi_k^{\rm T} \chi_l\, {\rm H}_5^* + (\lambda_{10})_{kl}\, \chi_k^{\rm T} \chi_l\, {\rm H}_5 + \frac{(\lambda_5')_{kl}}{M_{\rm P}}\, \psi_k^{\rm T} \Sigma_{24} \chi_l\, {\rm H}_5^* + (\lambda_1)_{kl}\, \nu_{k,R}^{\rm T} \psi_l\, {\rm H}_5 - \tfrac{1}{2}(M_\nu)_{kl}\, \nu_{k,R}^{\rm T} \nu_{l,R} + {\rm H.c.}$$

the λs are Yukawa matrices

$$Y_u^\dagger \propto \lambda_{10}\,, \quad Y_d^\dagger \propto \lambda_5 + \epsilon\lambda_5'\,, \quad Y_e^* \propto \lambda_5 - \tfrac{3}{2}\,\epsilon\lambda_5'\,, \quad Y_\nu^\dagger = \lambda_1\,, \quad \epsilon = \frac{M_{\rm GUT}}{M_{\rm P}} \ll 1$$

${\rm H}_5$ and Σ_{24} are Higgses in the 5 and 24 of SU(5), the Planck scale $M_{\rm P} \gg M_{\rm GUT}$

Grinstein *et al.*

♦ $\mathcal{L}_{\rm m}^{\rm GUT}$ is formally flavor-symmetric if the fields & Yukawas transform as

$$\psi \to V_{\bar{5}}\,\psi\,, \qquad \chi \to V_{10}\,\chi\,, \qquad \nu_R \to \mathcal{O}_1 \nu_R\,, \qquad V_{\bar{5},10} \in {\rm SU}(3)_{\bar{5},10}$$

$$\lambda_5^{(\prime)} \to V_{\bar{5}}^* \lambda_5^{(\prime)} V_{10}^\dagger\,, \quad \lambda_{10} \to V_{10}^* \lambda_{10} V_{10}^\dagger\,, \quad \lambda_1 \to \mathcal{O}_1 \lambda_1 V_{\bar{5}}^\dagger\,, \quad \mathcal{O}_1 \in {\rm O}(3)_1$$

- The effective new-physics Lagrangian contributing to $h \to f'f$ need to be symmetric under the flavor group $\mathrm{SU}(3)_5 \otimes \mathrm{SU}(3)_{10} \otimes \mathrm{O}(3)_1$ and also SM gauge invariant.

- Flavor rotation properties of fermion fields and Yukawa spurions in $\mathcal{L}_{\mathrm{m}}^{\mathrm{GUT}}$

$$Q_L \to V_{10} Q_L\,, \quad U_R \to V_{10}^* U_R\,, \quad D_R \to V_{\bar 5}^* D_R\,, \quad L_L \to V_{\bar 5} L_L\,, \quad E_R \to V_{10}^* E_R$$

$$Y_u \to V_{10} Y_u V_{10}^{\mathrm{T}}\,, \quad Y_d \to V_{10} Y_d V_{\bar 5}^{\mathrm{T}}\,, \quad Y_e \to V_{\bar 5} Y_e V_{10}^{\mathrm{T}}\,, \quad Y_\nu \to V_{\bar 5} Y_\nu \mathcal{O}_1^{\mathrm{T}}$$

Grinstein *et al.*

- Effective Lagrangian satisfying MFV criterion $\quad \mathcal{L}_{\mathrm{MFV}}^{\mathrm{GUT}} \supset \dfrac{\tilde{\mathcal{O}}}{\Lambda^2} + \mathrm{H.c.}$

$$\tilde{\mathcal{O}} = (\mathcal{D}^\eta H)^\dagger \overline{E}_R \Big(Y_e^\dagger \Delta_{\ell 1} + Y_d^* \Delta_{\ell 2} + \Delta_{q1}^{\mathrm{T}} Y_d^* + \Delta_{q2}^{\mathrm{T}} Y_e^\dagger + \Delta_{q3}^{\mathrm{T}} Y_e^\dagger \Delta_{\ell 3} + \Delta_{q4}^{\mathrm{T}} Y_d^* \Delta_{\ell 4} \Big) \mathcal{D}_\eta L_L$$

$$\Delta_{qj} \sim \Delta_q = \zeta_1 \mathbb{1} + \zeta_2 \mathsf{A}_q + \zeta_4 \mathsf{A}_q^2 \to V_{10} \Delta_q V_{10}^\dagger\,, \qquad \mathsf{A}_q = Y_u Y_u^\dagger$$

$$\Delta_{\ell j} \sim \Delta_\ell = \xi_1 \mathbb{1} + \xi_2 \mathsf{A}_\ell + \xi_4 \mathsf{A}_\ell^2 \to V_{\bar 5} \Delta_\ell V_{\bar 5}^\dagger\,, \qquad \mathsf{A}_\ell = Y_\nu Y_\nu^\dagger$$

★ In the mass-eigenstate basis

$$\tilde{\mathcal{O}} \supset \frac{\partial^\eta h}{\sqrt{2}\,\Lambda^2}\,\overline{E}_R\Big(Y_e\Delta_{\ell 1} + \mathsf{C}^* Y_d \mathsf{G}^{\mathrm{T}}\Delta_{\ell 2} + \mathsf{C}^*\Delta_{q1}^{\mathrm{T}} Y_d \mathsf{G}^{\mathrm{T}} + \mathsf{C}^*\Delta_{q2}^{\mathrm{T}}\mathsf{C}^{\mathrm{T}} Y_e \\ + \mathsf{C}^*\Delta_{q3}^{\mathrm{T}}\mathsf{C}^{\mathrm{T}} Y_e\Delta_{\ell 3} + \mathsf{C}^*\Delta_{q4}^{\mathrm{T}} Y_d \mathsf{G}^{\mathrm{T}}\Delta_{\ell 4}\Big)\partial_\eta E_L$$

now $\quad Y_d = \mathrm{diag}(y_d, y_s, y_b)$, $\quad Y_e = \mathrm{diag}(y_e, y_\mu, y_\tau)$, $\qquad \mathsf{C} = \mathcal{V}_{e_R}^{\mathrm{T}}\mathcal{V}_{d_L}$, $\quad \mathsf{G} = \mathcal{V}_{e_L}^{\mathrm{T}}\mathcal{V}_{d_R}$

$\mathcal{V}_{d_L,d_R}$ $(\mathcal{V}_{e_L,e_R})$ diagonalize Y_d (Y_e)

★ C & G appear because the nondiagonal $\quad Y_d \propto (\lambda_5 + \epsilon\lambda_5')^\dagger \not\propto Y_e^{\mathrm{T}} \propto \big(\lambda_5 - \frac{3}{2}\,\epsilon\lambda_5'\big)^\dagger$

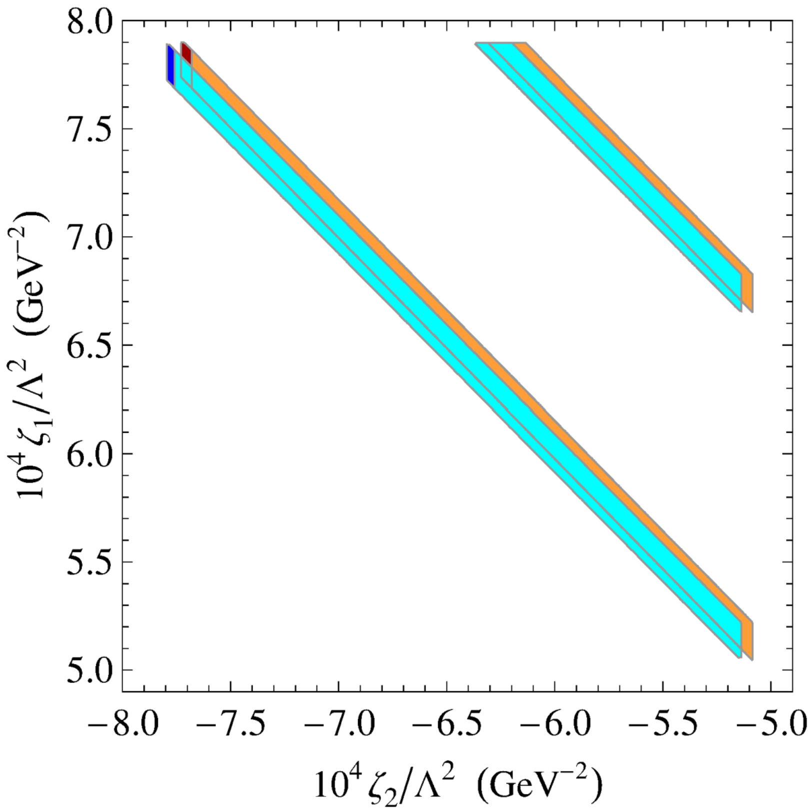
★ Since C & G are unknown, for simplicity one may roughly adopt $\mathsf{C} = \mathsf{G} = \mathbb{1}$ Grinstein *et al.*
in which case the $\mathcal{L}_{\rm MFV}^{\rm GUT}$ contributions to $h \to E_k^- E_l^+$ are

$$\mathcal{Y}_{E_k E_l} - \delta_{kl}\,\mathcal{Y}_{E_k E_k}^{\rm SM} = \frac{-m_h^2}{2\Lambda^2 v}\Big[(\Delta_{\ell 1})_{kl}\, m_{E_l} + (\Delta_{\ell 2})_{kl}\, m_{D_l} + m_{D_k}(\Delta_{q1})_{lk} + m_{E_k}(\Delta_{q2})_{lk} \\ + (\Delta_{\ell 3}\hat{M}_e\Delta_{q3}^{\mathrm{T}})_{kl} + (\Delta_{\ell 4}\hat{M}_d\Delta_{q4}^{\mathrm{T}})_{kl}\Big]$$

An interesting case

- Δ_{q1} contributing, the other Δs absent

$$\Delta_q = \zeta_1 \mathbb{1} + \zeta_2 \mathsf{A}_q + \zeta_4 \mathsf{A}_q^2$$



Regions of $(\zeta_1, \zeta_2)/\Lambda^2$ (cyan and dark blue) which satisfy the empirical constraints if the Δ_{q1} term is the only new-physics contribution in $\mathcal{Y}_{ff'}$ and $\zeta_4 = 0$. For the orange and dark red regions, the roles of ζ_2 and ζ_4 are interchanged. The dark (blue and red) patches correspond to $|\mathcal{Y}_{\tau\mu}| \simeq 0.003$ and hence $\mathcal{B}(h \to \mu\tau) \simeq 1\%$.

These contributions are determined mainly by the CKM parameters & quark masses

$\frac{\mathcal{Y}_{ee}}{\mathcal{Y}_{ee}^{\rm SM}}$	$\frac{\mathcal{Y}_{\mu\mu}}{\mathcal{Y}_{\mu\mu}^{\rm SM}}$	$\frac{\mathcal{Y}_{\tau\tau}}{\mathcal{Y}_{\tau\tau}^{\rm SM}}$	$\frac{\mathcal{Y}_{\mu e}}{10^{-7}}$	$\frac{\mathcal{Y}_{\tau e}}{10^{-4}}$	$\frac{\mathcal{Y}_{\tau\mu}}{10^{-3}}$	$\mathcal{B}(\mu \to e\gamma)$	$\mathcal{B}(\mu{\rm Al} \to e{\rm Al})$
-34	-2.5	1.1	$-4.8-2.0i$	$5.9+2.4i$	$-3.0+0.06i$	5.4×10^{-13}	2.6×10^{-15}
-28	-1.9	1.2	$-4.0-1.7i$	$4.9+2.0i$	$-2.5+0.05i$	2.9×10^{-13}	1.5×10^{-15}
-24	-1.5	0.95	$-3.3-1.4i$	$4.1+1.7i$	$-2.1+0.04i$	1.6×10^{-13}	9.1×10^{-16}

Conclusions

- Experimental quests for charged-lepton flavor violation offer excellent probes for many models.
- We have explored the flavor-changing decays of the Higgs boson into charged leptons in the MFV framework based on the SM extended with the addition of right-handed neutrinos plus effective dimension-6 operators and in its SU(5) GUT counterpart.
- The non-GUT framework involving the type-I (or type-III) seesaw mechanism can accommodate the recent tentative hint of $h \to \mu\tau$ from the LHC with $\mathcal{B}(h \to \mu\tau) \sim 1\,\%$ if the right-handed neutrinos have nontrivial couplings to the Higgs boson.
- In the SU(5) GUT case, there can be instances in which $\mathcal{B}(h \to \mu\tau) \sim 1\,\%$ is achievable with contributions depending mainly on known quark parameters and the predictions on other lepton-flavor-violating processes, such as $\mu \to e\gamma$, are potentially testable by upcoming searches.