The flavor of Higgs

WEIZMANN INSTITUTE OF SCIENCE

Higgs and LFV

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Main goals of this talk

Ambitious: Prove Yuval wrong

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Realistic: answer few basic questions about LFV Higgs interactions

- What are the interesting/bottom line TH benchmarks?
- How do we probe it directly & indirectly?

For detailed discussion of dedicated search strategies see talk by S. Bressler

Outline

Recapitulation of Higgs (L)FV in EFT

- expectations within flavor models
- indirect constraints in EFT

Explicit model predictions (SM, MHDM, SUSY, compositeness)

- impact of constraints beyond EFT

Higgs (L)FV in EFT

Treat SM as EFT valid below NP scale Λ

$$\mathcal{L}_Y = -\lambda_{ij}\bar{\psi}^i_L \psi^j_R \phi - \frac{\lambda'_{ij}}{\Lambda^2}\bar{\psi}^i_L \psi^j_R \phi(\phi^\dagger \phi) + \text{h.c.} + \ldots$$

(modified kinetic terms, mixing into λ')

In EW vacuum $\phi = \begin{pmatrix} 0 \\ \frac{(v+h)}{\sqrt{2}} \end{pmatrix}$

$$\mathcal{L}_Y = -m_i \psi^i_L \psi^i_R - Y_{ij}(\psi^i_L \psi^j_R)h + \text{h.c.} + \ldots$$

$$m_i \delta_{ij} = \frac{v}{\sqrt{2}}[U_L(\lambda + \frac{v^2}{2\Lambda^2}\lambda')U_R^\dagger]_{ij} \qquad Y_{ij} = \frac{m_i}{v}\delta_{ij} + \underbrace{\frac{v^2}{\sqrt{2}\Lambda^2}[U_L \lambda' U_R^\dagger]_{ij}}_{\bar{Y}_{ij}}$$

What is natural size of Y?

Higgs (L)FV in models of flavor

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MFV: $\lambda' = a\lambda + b\lambda\lambda^\dagger\lambda + \mathcal{O}(\lambda^5)$ $\Rightarrow$ $Y_{ij} = \frac{m_i}{v}\delta_{ij}\left[1 + \frac{v^2}{\sqrt{2}\Lambda^2}\left(a + 2b\frac{m_i^2}{v^2}\right)\right]$

(neglecting neutrino masses)

- almost universal relative shift in Y_{ii}

Froggatt-Nielsen models: $\lambda_{ij}^{(\prime)} \sim \varepsilon_H^{H(E_i)-H(L_j)}$ $[H(\phi) = 0]$

$|U_L^{ij}| \sim \varepsilon^{H(L_i)-H(L_j)}$ $|U_R^{ij}| \sim \varepsilon^{H(E_i)-H(E_j)}$ $|U_R^{ij}||U_L^{ji}| \sim \frac{m_j}{m_i}$

- hierarchical $Y_{i\neq j}$ $\bar{Y}_{i<j} \sim |U_L^{ij}|\frac{m_j}{v}$ $\bar{Y}_{i>j} \sim \frac{1}{|U_L^{ij}|}\frac{m_j}{v}$

Stability of Yukawa sector

2-gen example: most general Yukawa matrices

$$\lambda \sim \begin{pmatrix} a & b \\ c & d \end{pmatrix} \qquad \lambda' = \mathcal{O}(1) \times \lambda$$

Obtaining hierarchical fermion masses $m_2 \gg m_1$

$$\Rightarrow \quad |ad - bc| \ll a^2 + b^2 + c^2 + d^2$$

requiring no intricate cancelations in m_1

$$\Rightarrow \quad |Y_{ij}||Y_{ji}| \lesssim \frac{m_i m_j}{v^2}$$

(Cheng-Sher bound)

PhysRevD.35.3484

Constraints on Y_{ii} (in EFT)

leptonic (g-2)

$$|\Re(Y_\mu)^2| \lesssim 0.05$$

electron EDM

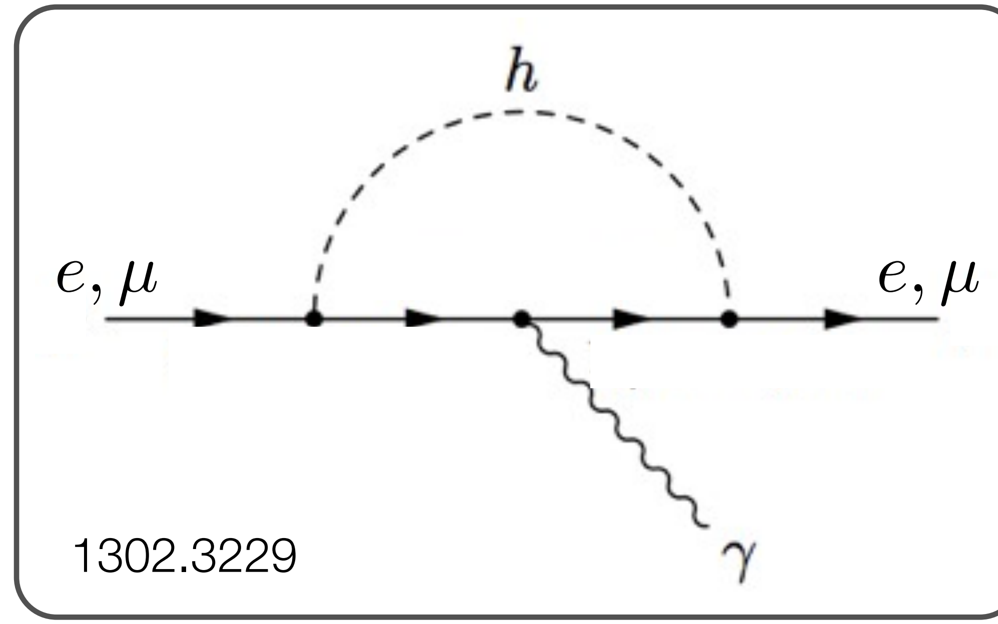
$$|\Im(Y_e)^2| \lesssim 2 \times 10^{-5}$$

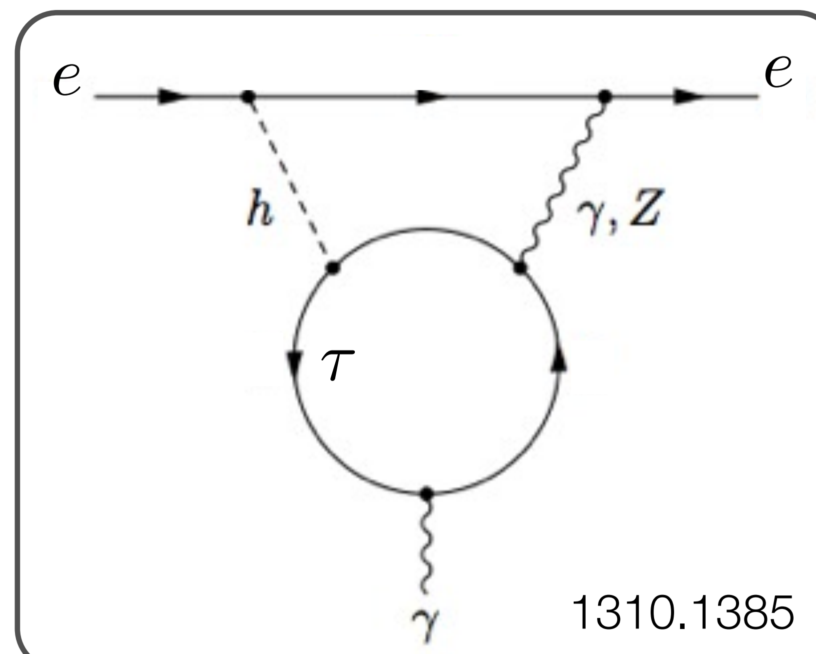
$$|\Im(Y_\tau)| \lesssim 0.02$$

Higgs data

$$|Y_e|, |Y_\mu| \lesssim 3 \times 10^{-3}$$

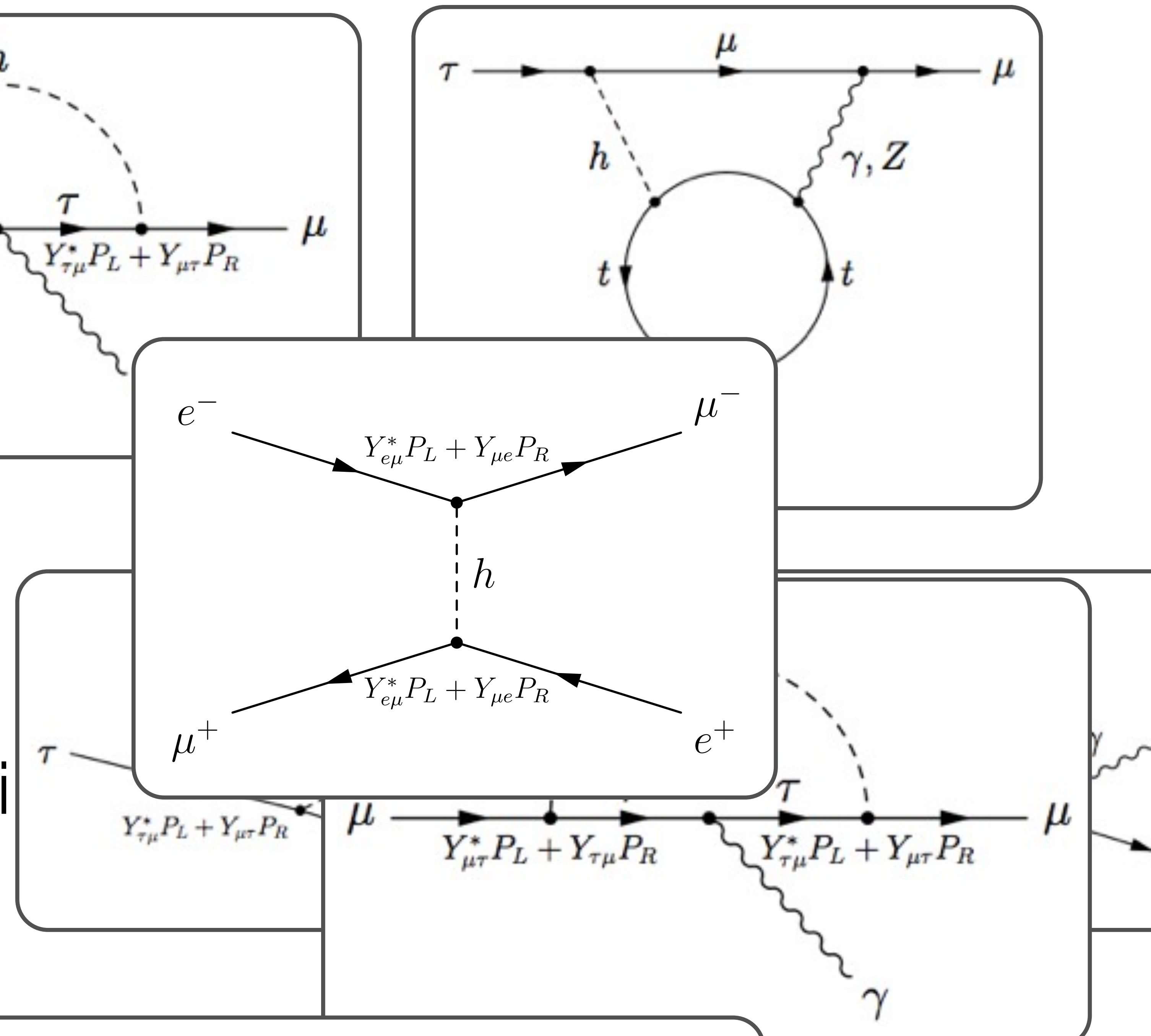
$$|Y_\tau| \sim (1 \pm 0.3) \times 10^{-2}$$

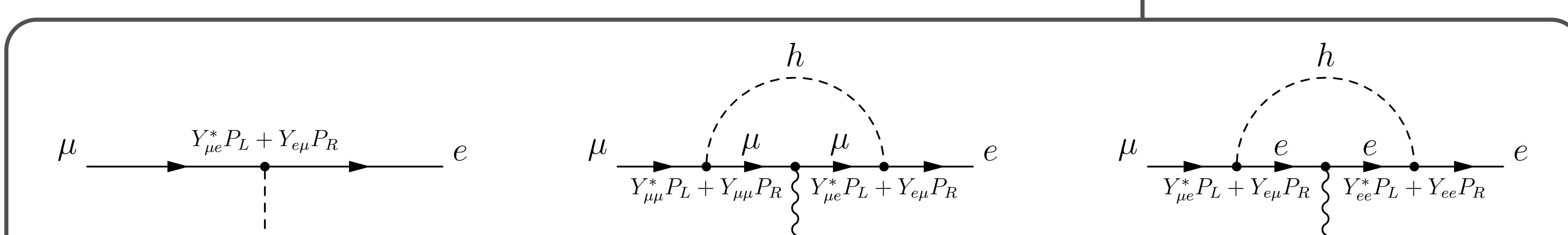




Indirect constraints on Y_{ij} (in EFT)

- l→l'γ
- l→3l'
- leptonic (g-2)
- leptonic & nuclear EDMs
- muonium oscillations
- mu-e conversion in nuclei
- ...





Indirect constraints on Y_{ij} (in EFT)

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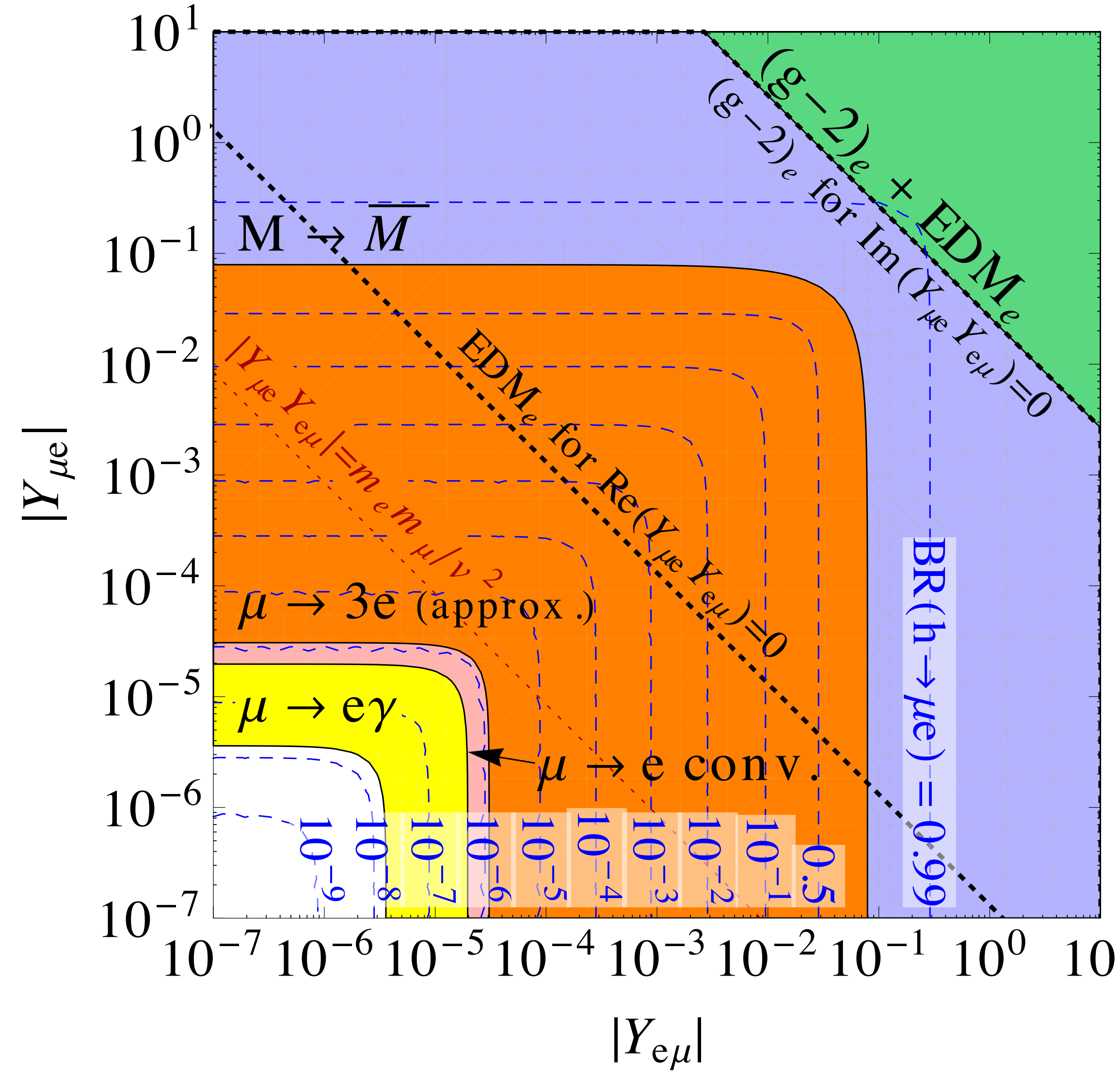

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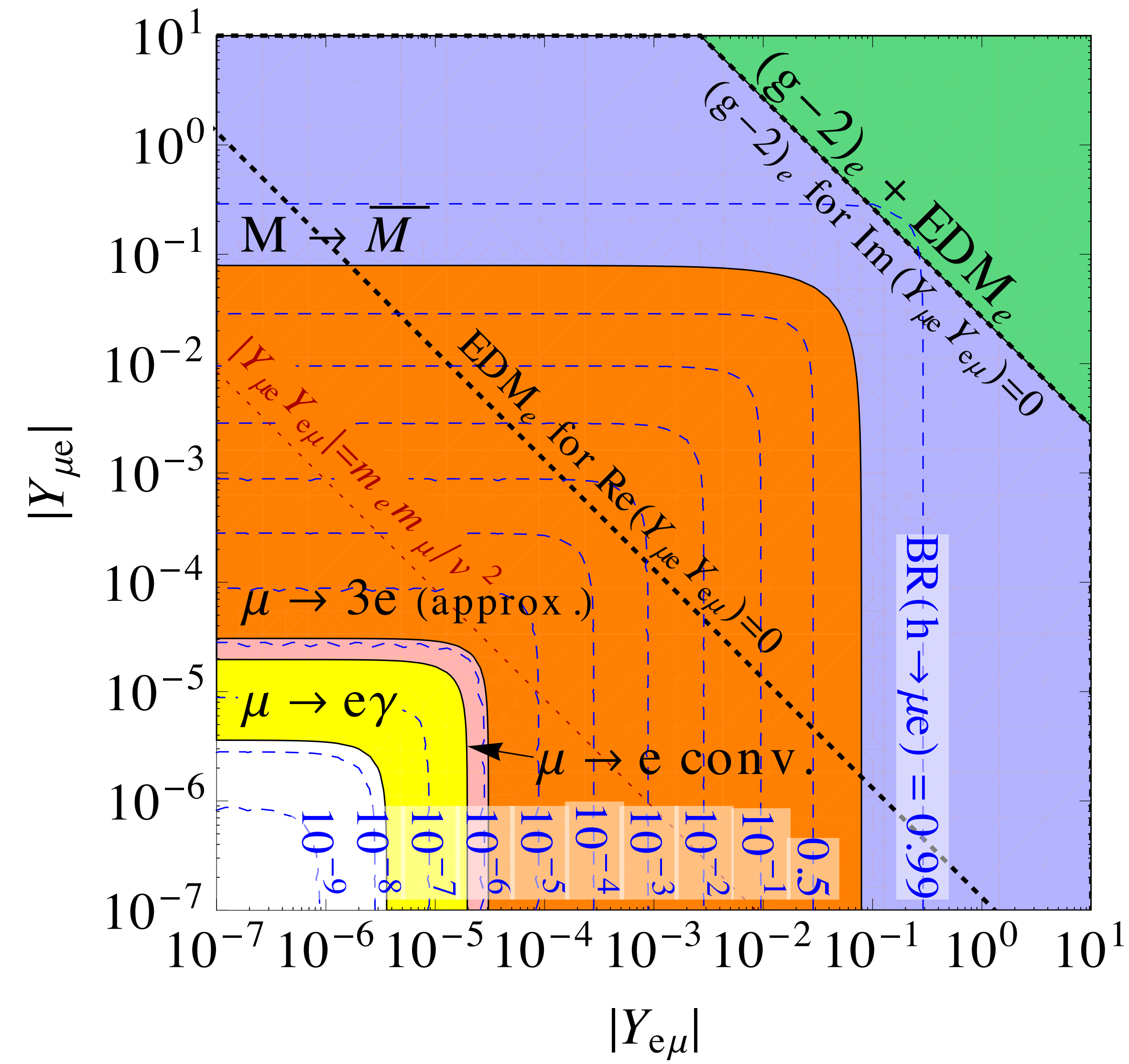

mu-e LFV already probed beyond Cheng-Sher bound

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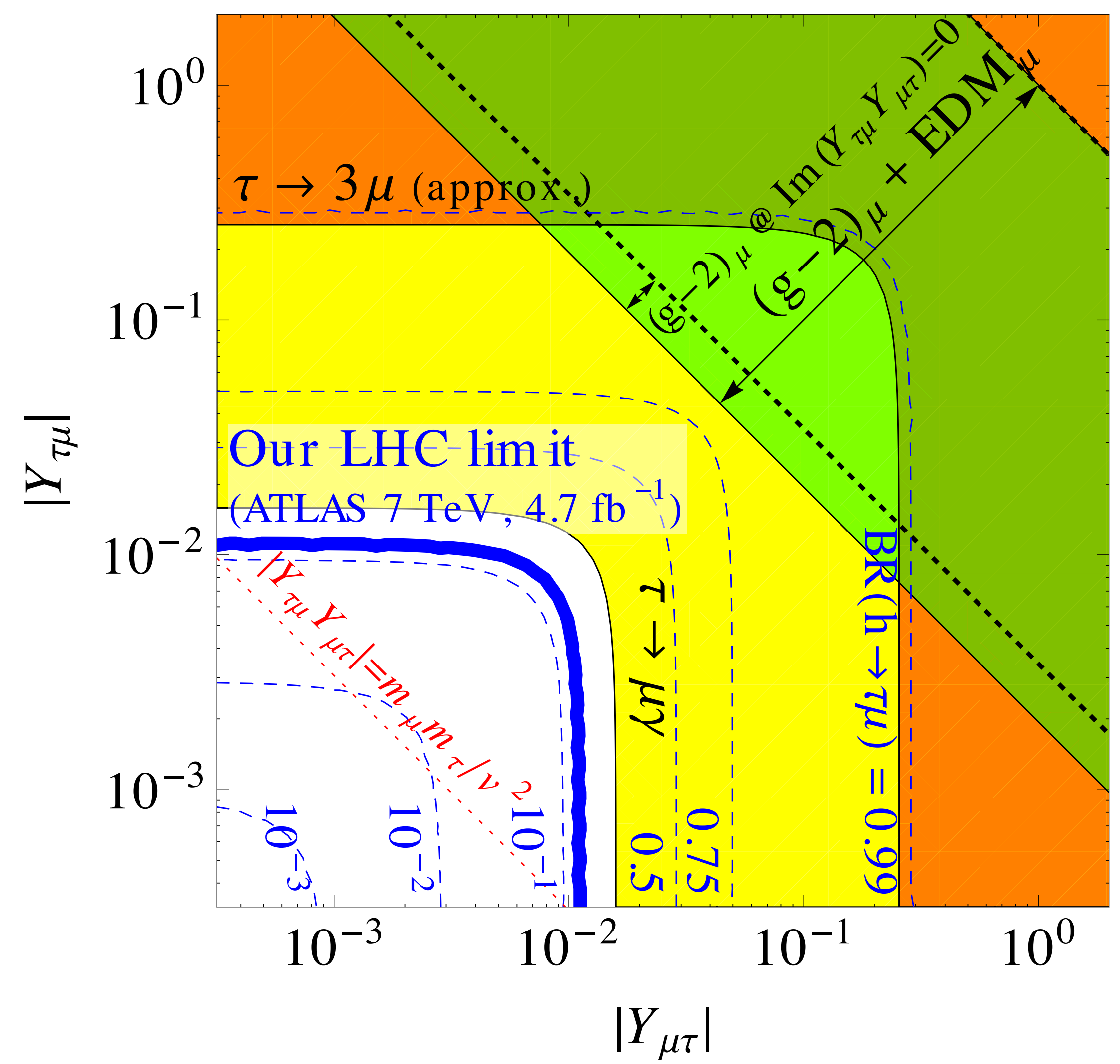

Indirect constraints on Y_{ij} (in EFT)

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- $l \to l'\gamma$
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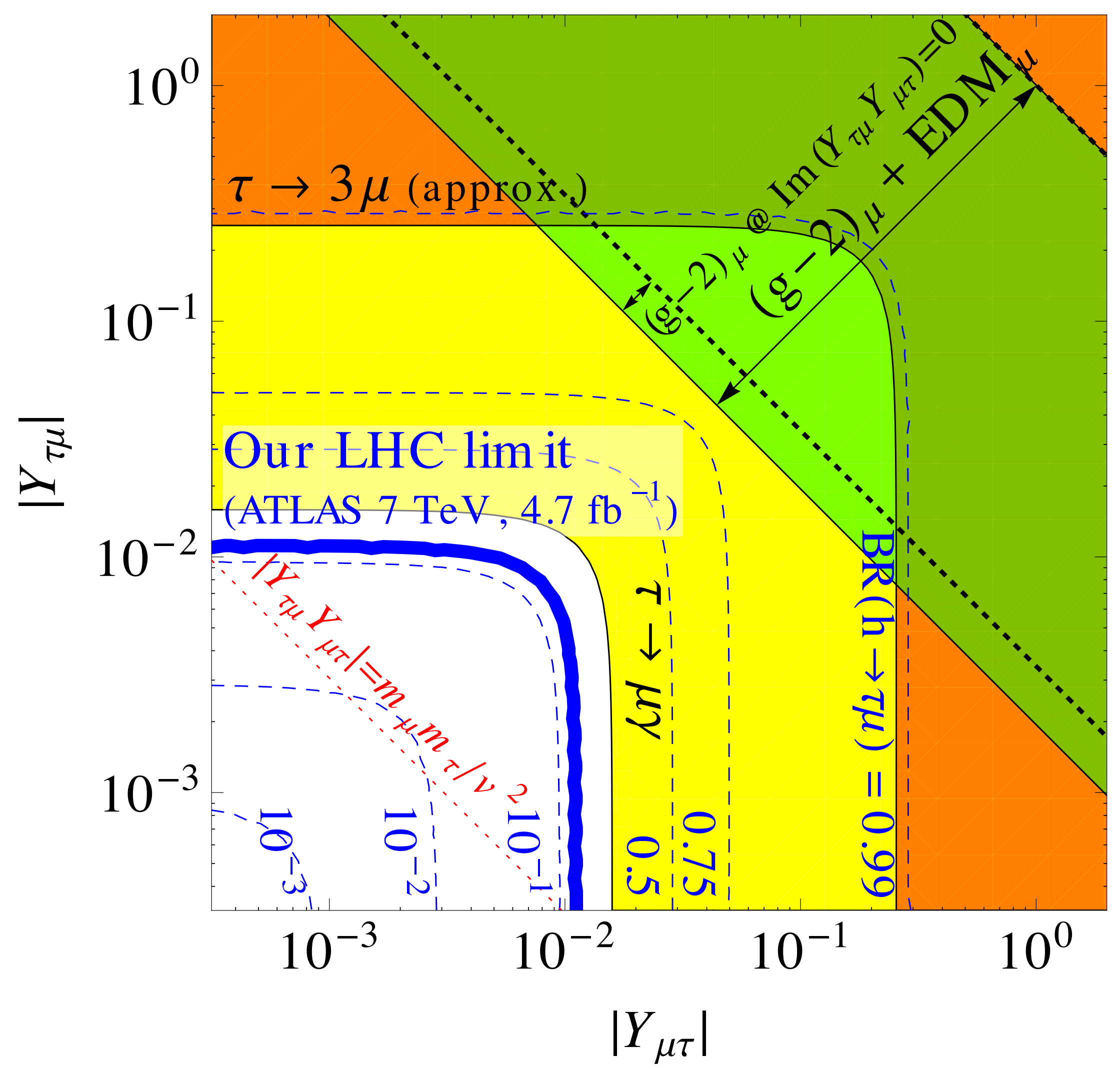

Br(h→**τμ**/e) ~ O(10%) allowed!

Higgs LFV expectations within models

SM: $Y_{ij}^{\rm SM} = \frac{m_i}{v}\delta_{ij}$ (tree level)

$$Y_\tau^{\rm SM} \sim 1\% \qquad Y_\mu^{\rm SM} \sim 6\times 10^{-4} \qquad Y_e^{\rm SM} \sim 3\times 10^{-6}$$

weak radiative corrections:

$$\bar{Y}_{ii} \sim \frac{m_i}{v16\pi^2}\mathcal{O}(\frac{m_W^2}{v^2}, \frac{m_Z^2}{v^2}, \frac{m_t^2}{v^2}, \ldots)$$ (v, Z_h renormalization)

$$\bar{Y}_{i\neq j} \sim \alpha_w^2 \frac{m_j}{v} V_{ik}\frac{m_k^2}{m_W^2}V_{jk}^*$$ (zero in absence of m_ν)

Higgs LFV expectations within models

0908.3451

Type III see-saw

tree-level mixing of Majorana triplets T~(1,3,0) with leptons

⇒ deviations in weak gauge & Higgs couplings (universality & FCNCs)

$$\mathcal{L}_Z = -\frac{g}{2c_W}(L_{ij}\bar{e}^i\gamma^\mu P_L e^j + R_{ij}\bar{e}^i\gamma^\mu P_R e^j - 2s_W^2 J^\mu_{\rm EM})Z_\mu$$

$$L_{e\mu} \simeq \frac{v^2}{2}\sum_{\alpha=1}^{n_T} y^*_{\alpha e} y_{\alpha\mu}/m_\alpha^2 \quad = \sum_{\alpha=1}^{n_T}\sum_{i,j=1}^{3}\left(\sqrt{m_i^\nu m_j^\nu}/m_\alpha\right) O_{\alpha i}O_{\alpha j} U_{ei}U_{\mu j}$$

param. enhancement (fine-tune.)

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$$\Rightarrow \quad Y_{ij} \sim (L_{ij}-R_{ij})\frac{m_j}{v}$$

h→τμ constrained by τ→3μ

generic also in models with VL leptons! 1304.4219

Higgs LFV expectations within models

Partial compositeness:

$$-\mathcal{L}_Y^{\rm PC} = M_i \Psi_L^i \Psi_R^i + m_{ij}^{LR} \psi_L^i \Psi_R^j + m_{ij}^{RL} \psi_R^i \Psi_L^j + Y_{ij} \Psi_L^i \Psi_R^j \phi + Y'_{ij} \Psi_R^i \Psi_L^j \phi + \text{h.c.}$$

in presence of both Y, Y'

$$\lambda_{ij} \sim \frac{m_{ik}^{LR}}{M_k} Y_{kl} \frac{m_{jl}^{RL}}{M_l} \qquad \frac{\lambda'_{ij}}{\Lambda^2} \sim \frac{m_{ik}^{LR}}{M_k} Y_{km} \frac{Y'_{mn}}{M_m M_n} Y_{nl} \frac{m_{jl}^{RL}}{M_l}$$

Higgs LFV expectations within models

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Flavor anarchy: $Y, Y' \sim \mathcal{O}(1)$

⇒ flavor hierarchies from hierarchical mixing

⇒ Higgs (L)FV can saturate Cheng-Sher bound

Higgs LFV expectations within models

0906.1542

<u>Pseudo-Goldstone Higgs</u>:

$$\mathcal{L}_Y = -\bar{\psi}^i_L \phi(\lambda_{ij} + \lambda'_{ij}\frac{\phi^\dagger\phi}{\Lambda} + \ldots)\psi^j_R \to \bar{\psi}^i_L P(\Sigma)_{ij}\psi^j_R \qquad \Sigma = e^{\frac{i\phi}{f}}$$

non-linear realization of a global symmetry group

$$P(\Sigma)_{ij} = \lambda_{ij}\Sigma\Sigma^T = \lambda_{ij}\sin\frac{\phi}{f}\cos\frac{\phi}{f} \quad \Rightarrow \quad \boxed{\lambda' \propto \lambda}$$

flavor alignment of leading Yukawa contributions

Higgs LFV expectations within models

1302.3229

Multi Higgs doublet models:

$$-\mathcal{L}_Y^{\rm MHDM} = \sum_m \lambda_{ij}^{(m)} \bar{\psi}_L^i \psi_R^j \phi^{(m)}$$

$$v = \sum_m \langle \phi^{(m)} \rangle \qquad h = \sum_k V_{hk} \phi_k^0 \qquad \sum_k |V_{hk}|^2 = 1$$

Natural flavor conservation: only single Higgs couples to any combination of fermion gauge reps.

$$\Rightarrow \quad Y^{ij} = V_{hk}^* \frac{m_i}{v_k} \delta_{ij}$$

Higgs LFV expectations within models

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Example: NFC THDM $\quad Y_i = -\frac{\sin\alpha}{\cos\beta} Y_i^{\rm SM}$

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h_1 \\ h_2 \end{pmatrix}$$

$$\tan\beta \equiv v_2/v_1$$

Higgs data already constrain such effects $\quad \beta - \alpha \simeq \pi/2$

Higgs LFV expectations within models

THDM III & MSSM:

after EWSB $$Y_{fi}^{(k)} = x_d^k \left(\frac{m_{\ell_i}}{v_d/\sqrt{2}} \delta_{fi} - \epsilon_{fi}^{\ell} \tan\beta \right) + x_u^{k\star} \epsilon_{fi}^{\ell} . \qquad H_k^0 = (H^0, h^0, A^0)_k$$

$$x_u^k = \left(-\frac{1}{\sqrt{2}} \sin\alpha, \, -\frac{1}{\sqrt{2}} \cos\alpha, \, \frac{i}{\sqrt{2}} \cos\beta \right)_k ,$$

$$x_d^k = \left(-\frac{1}{\sqrt{2}} \cos\alpha, \, \frac{1}{\sqrt{2}} \sin\alpha, \, \frac{i}{\sqrt{2}} \sin\beta \right)_k .$$

low energy observables receive contributions from all H_k

in MSSM-like potential $\tan 2\alpha = \tan 2\beta \, \frac{m_{A^0}^2 + m_Z^2}{m_{A^0}^2 - m_Z^2}$

non-holomorphic **ε** corrections - non-decoupling

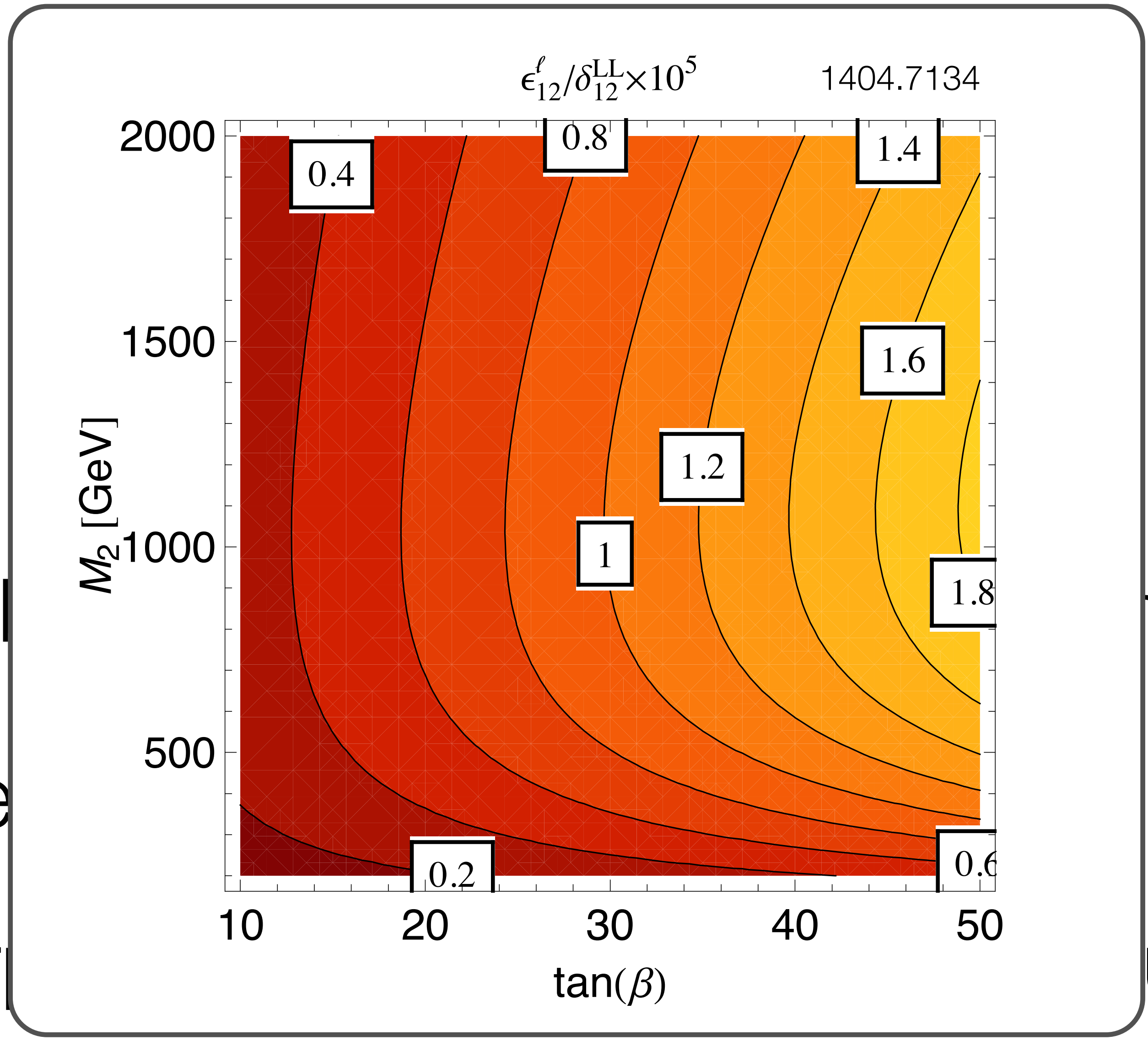
in practice, ε from weak SUSY loops - small

Higgs LFV expectations within models

<u>THDM III & MSSM</u>:

after EWSB

$H_k^0 = (H^0, h^0, A^0)_k$



low energy ol... ...ns from all H_k

in MSSM-like

non-holomor... ...upling

in practice, ε from weak SUSY loops - small

Conclusions (on the positive note)

Higgs LFV powerful null-test of SM (and many BSMs)

Intrinsically related to mechanism behind generation of lepton masses (both charged and neutrinos)

Complimentarily of indirect and direct probes
(e/mu vs tau sectors, CPC vs CPV)

Viable sizes of LFV Higgs couplings can be probed in all sectors (except Y_e?)