# New Physics Models Facing Lepton Flavor Violating Higgs Decays

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Based on arXiv:1502.07784

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# Introduction

- Hint of huge Lepton Flavor Violation in Higgs decay

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

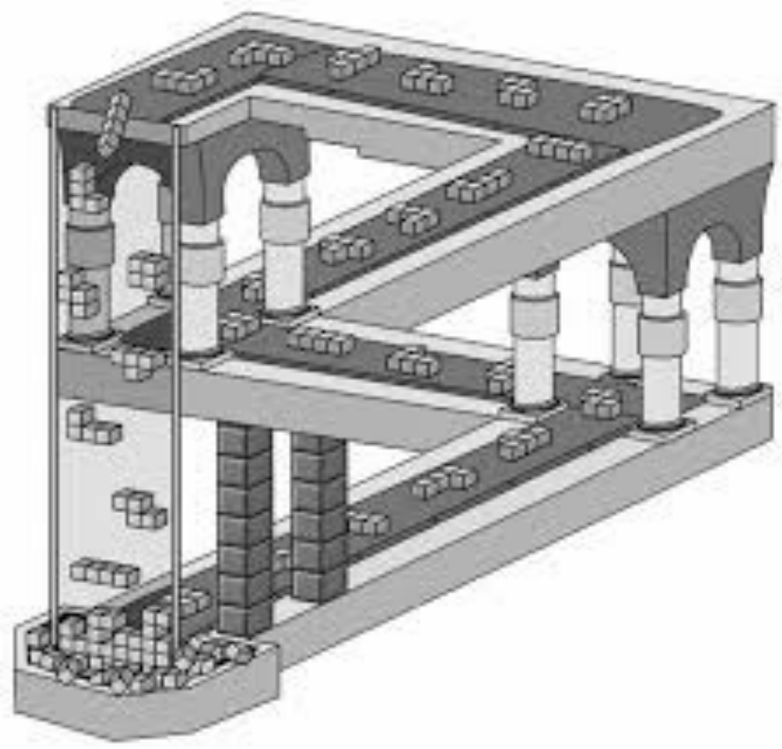
(null hypothesis 2.4σ excluded)

[CMS,1502.07400]

- Clearly beyond the SM (or SM with Dirac neutrinos)

- What kind of NP model could accommodate this result and be consistent with numerous (negative) tests of LFV?

| LFV process | branching fraction |
|---|---|
| $\tau \to \mu\gamma \qquad \tau \to 3\mu$ | $< 10^{-7}$ |
| $\mu \to e\gamma \qquad \mu N \to eN$ | $< 10^{-13}$ |
| $Z \to \ell_i \ell_j$ | $< 10^{-5}$ |
| $h \to \tau\mu$ | $\approx 10^{-2}$ |



# Outline

Motivation:

- Find complementary LFV observables
- Identify viable scenarios

1. Constraints on effective Higgs couplings
2. Effective theory approach
3. Extended scalar sector
4. Extended fermionic sector or loop-induced LFV
5. Summary and outlook

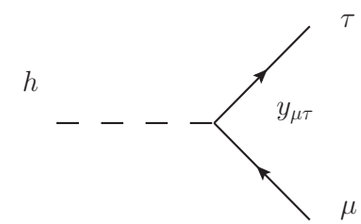
# 1. Constraints on effective Higgs couplings from $h \to \tau\mu$

# Effective Higgs couplings

- General parameterisation of the off-diagonal Yukawa couplings

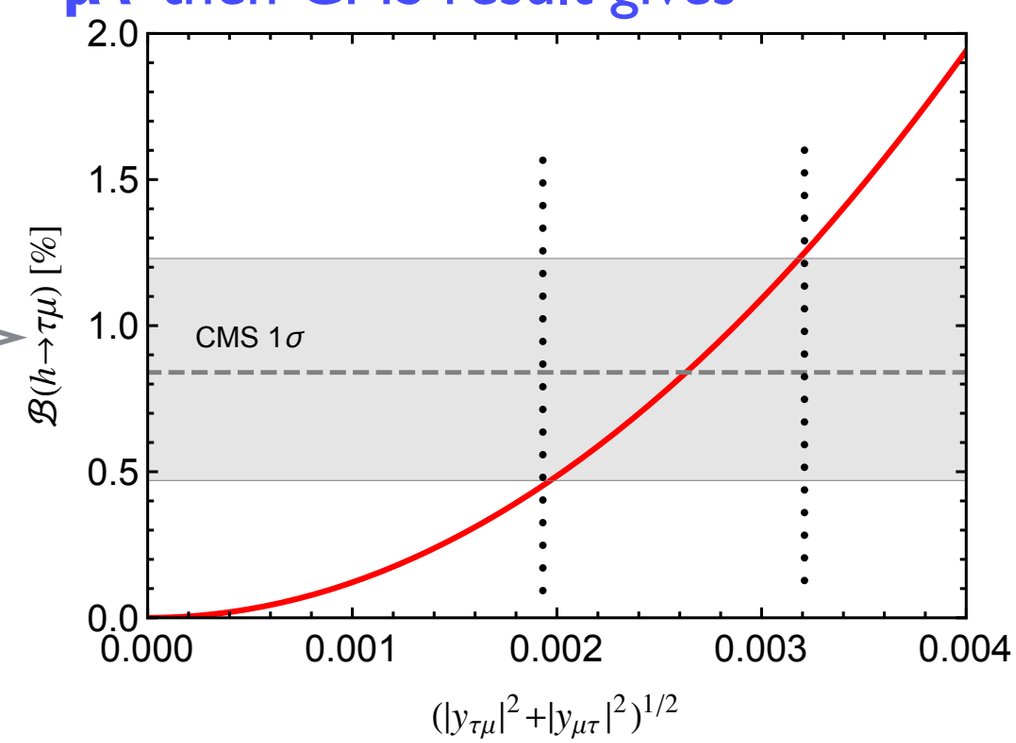
$$\mathcal{L}_{Y_\ell}^{\text{eff.}} = -m_i \delta_{ij} \bar{\ell}_L^i \ell_R^j - y_{ij} \left( \bar{\ell}_L^i \ell_R^j \right) h + \ldots + \text{h.c.} \qquad y_{ij}^{\text{SM}} = \delta_{ij} \frac{m_i}{v}$$

$$\mathcal{B}(h \to \tau\mu) = \frac{m_h}{8\pi\Gamma_h} \left( |y_{\tau\mu}|^2 + |y_{\mu\tau}|^2 \right)$$




- Assuming New Physics **only in h→μτ** then CMS result gives

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




$$0.0019(0.0008) < \sqrt{|y_{\tau\mu}|^2 + |y_{\mu\tau}|^2} < 0.0032(0.0036) \text{ at } 68\% \ (95\%) \text{ C.L.}$$

# Effective Higgs couplings

- Testing robustness of the lower bound of LFV Yukawas: allowing for non-SM Higgs production rate and total decay width

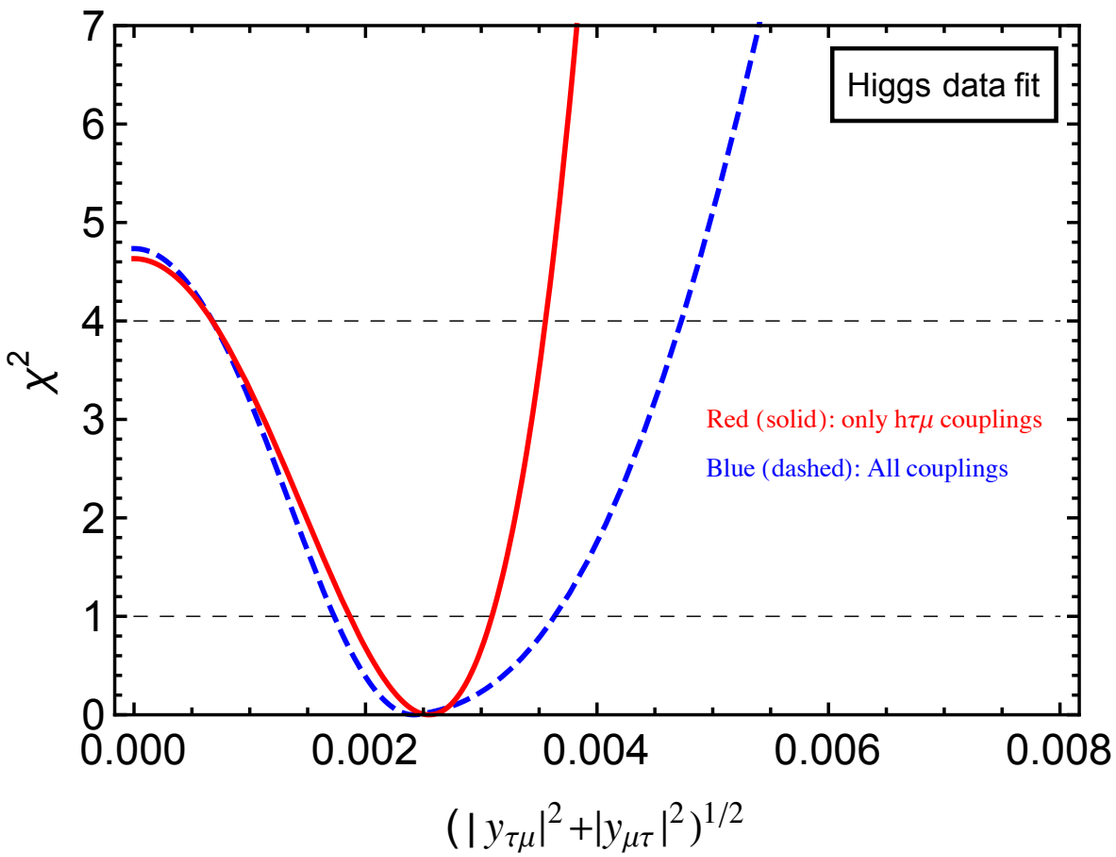
| Decay channel | Production mode | Signal strength |
|---|---|---|
| | | CMS |
| $h \to b\bar{b}$ | VH | $1.0 \pm 0.5$ |
| | VBF | $0.7 \pm 1.4$ |
| | ttH | $1.0 \pm 2.0$ |
| $h \to WW^*$ | ggF+ttH | $0.76 \pm 0.23$ |
| | VBF+VH | $0.74 \pm 0.62$ |
| $h \to ZZ^*$ | ggF+ttH | $0.90 \pm 0.45$ |
| | VBF+VH | $1.7 \pm 2.3$ |
| $h \to \gamma\gamma$ | ggF+ttH | $0.50 \pm 0.41$ |
| | VBF+VH | $1.64 \pm 0.88$ |
| $h \to \tau\tau$ | 0-jet | $0.34 \pm 1.09$ |
| | 1-jet | $1.07 \pm 0.46$ |
| | 2-jet (VBF-tag) | $0.94 \pm 0.41$ |
| | VH-tag | $-0.33 \pm 1.02$ |
| $\mathcal{B}(h \to \tau\mu)$ [%] | 0-jet | $0.77 \pm 0.55$ |
| | 1-jet | $0.59 \pm 0.62$ |
| | 2-jet | $1.1 \pm 0.80$ |
| $h \to$ invisible | VBF+VH | $0.14 \pm 0.22$ |
| $h \to Z\gamma$ | inclusive | $0.0 \pm 4.8$ |
| $h \to \mu\mu$ | inclusive | $2.9 \pm 2.8$ |

| Decay channel | Production mode | Signal strength |
|---|---|---|
| | | ATLAS |
| $h \to b\bar{b}$ | VH | $0.2 \pm 0.65$ |
| $h \to ZZ^*$ | ggF+ttH | $1.8 \pm 0.65$ |
| | VBF+VH | $-0.2 \pm 3.7$ |
| $h \to WW^*$ | ggF+ttH | $0.82 \pm 0.37$ |
| | VBF+VH | $1.74 \pm 0.80$ |
| $h \to \gamma\gamma$ | ggF+ttH | $1.61 \pm 0.41$ |
| | VBF+VH | $1.87 \pm 0.80$ |
| $h \to \tau\tau$ | ggF+ttH | $1.5 \pm 1.6$ |
| | VBF+VH | $1.7 \pm 0.84$ |
| $h \to$ invisible | VH | $0.13 \pm 0.31$ |
| $h \to Z\gamma$ | inclusive | $2.0 \pm 4.6$ |
| $h \to \mu\mu$ | inclusive | $1.6 \pm 4.2$ |

$$N_{h\to\tau\mu} \sim \sigma_h \frac{\Gamma_{h\to\tau\mu}}{\Gamma_h}$$

# Effective Higgs couplings

- Testing robustness of the lower bound of LFV Yukawas: allowing for non-SM Higgs production rate and total decay width




$$N_{h\to\tau\mu} \sim \sigma_h \frac{\Gamma_{h\to\tau\mu}}{\Gamma_h}$$

- Well known Higgs production
- Strong lower bound on $\Gamma_h$

$$0.0017(0.0007) < \sqrt{|y_{\tau\mu}|^2 + |y_{\mu\tau}|^2} < 0.0036(0.0047) \text{ at } 68\% \ (95\%) \text{ C.L.}$$

Robust lower bound on the LFV Yukawas

# 2. Effective theory approach

# Effective Theory Framework

- Integrate out heavy Higgses, fermions, scalars. Keep terms up to dim-6:

$$\mathcal{L}_{Y_\ell} = -\lambda^{\alpha}_{ij}\bar{L}_i H_\alpha E_j - \lambda'^{\alpha\beta\gamma}_{ij}\frac{1}{\Lambda^2}\bar{L}_i H_\alpha E_j (H^\dagger_\beta H_\gamma) + \text{h.c.}$$

Multiple higgses $\quad H_\alpha = (h^+_\alpha, v_\alpha + x_\alpha h + \ldots)^T$

$$\sum_\alpha v_\alpha^2 \sim v^2/2 \qquad \sum_\alpha |x_\alpha|^2 \sim 1/2$$

Dim-6 operator creates mismatch between mass and Yukawa matrices

$$y_{ij} = \frac{m_i}{v}\delta_{ij} + \epsilon_{ij} \qquad \frac{m}{v} = V_L\left(\lambda^\alpha \bar{v}_\alpha + \lambda'^{\alpha\beta\gamma}\frac{v^2}{\Lambda^2}\bar{v}_\alpha\bar{v}_\beta\bar{v}_\gamma\right)V_R^\dagger$$

$$\epsilon = V_L\left[\lambda^\alpha\bar{v}_\alpha\left(\frac{x_\alpha}{\bar{v}_\alpha} - 1\right) + \lambda'^{\alpha\beta\gamma}\frac{v^2}{\Lambda^2}\bar{v}_\alpha\bar{v}_\beta\bar{v}_\gamma\left(\frac{x_\alpha}{\bar{v}_\alpha} + \frac{x_\beta}{\bar{v}_\beta} + \frac{x_\gamma}{\bar{v}_\gamma} - 1\right)\right]V_R^\dagger$$

vanishing in single Higgs scenarios

$$\Lambda \simeq 4\ \text{TeV}\left[\left(\frac{0.84\%}{\mathcal{B}(h\to\tau\mu)}\right)\left(|V_L\lambda'^{111}V_R^\dagger|^2_{\tau\mu} + |V_L\lambda'^{111}V_R^\dagger|^2_{\mu\tau}\right)\right]^{1/4}$$

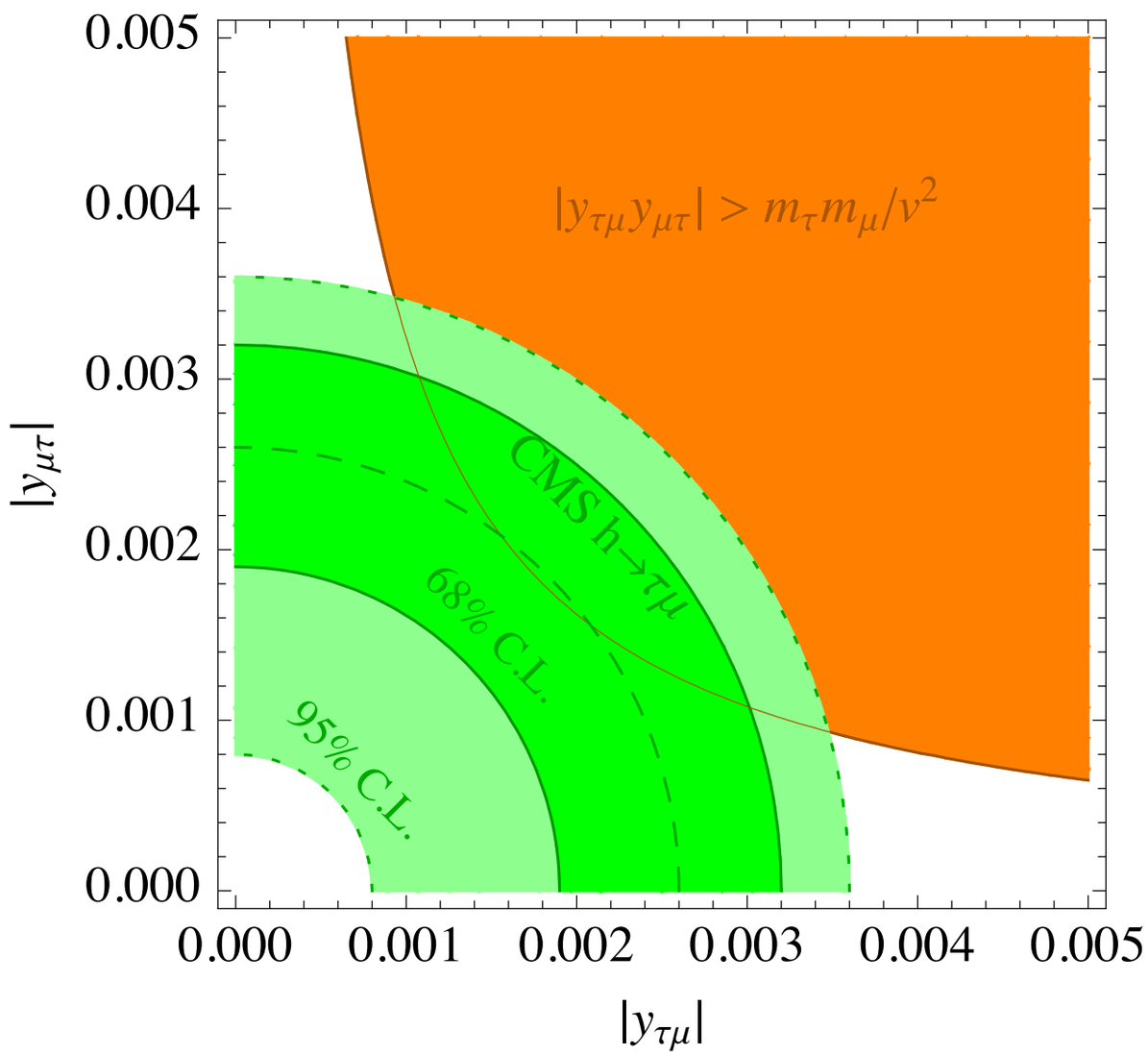
# Naturalness

- Naturalness criterium for effective Higgs couplings (to avoid cancellations in the mass matrix)

$$\sqrt{|y_{\tau\mu} y_{\mu\tau}|} \lesssim \frac{\sqrt{m_\mu m_\tau}}{v} = 0.0018$$

[Cheng,Sher, Phys.Rev. D35, 3484]

[Branco et al,, Phys.Rept. 516, 1]



# Tau LFV radiative decay

- Constraint from $\tau \to \mu\gamma$

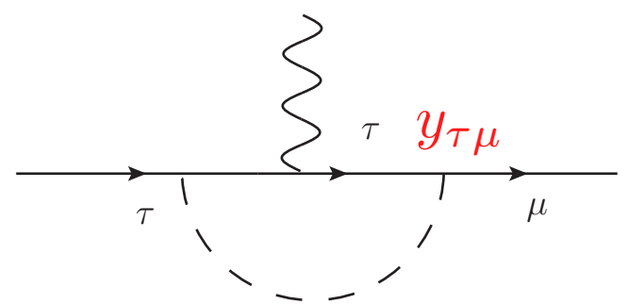
[Harnik, Kopp, Zupan, JHEP 1303, 026]
[Goudelis, Lebedev, Park, Phys.Lett. B707, 369 ]
[Blankenburg, Ellis, Isidori, Phys.Lett. B712, 386]

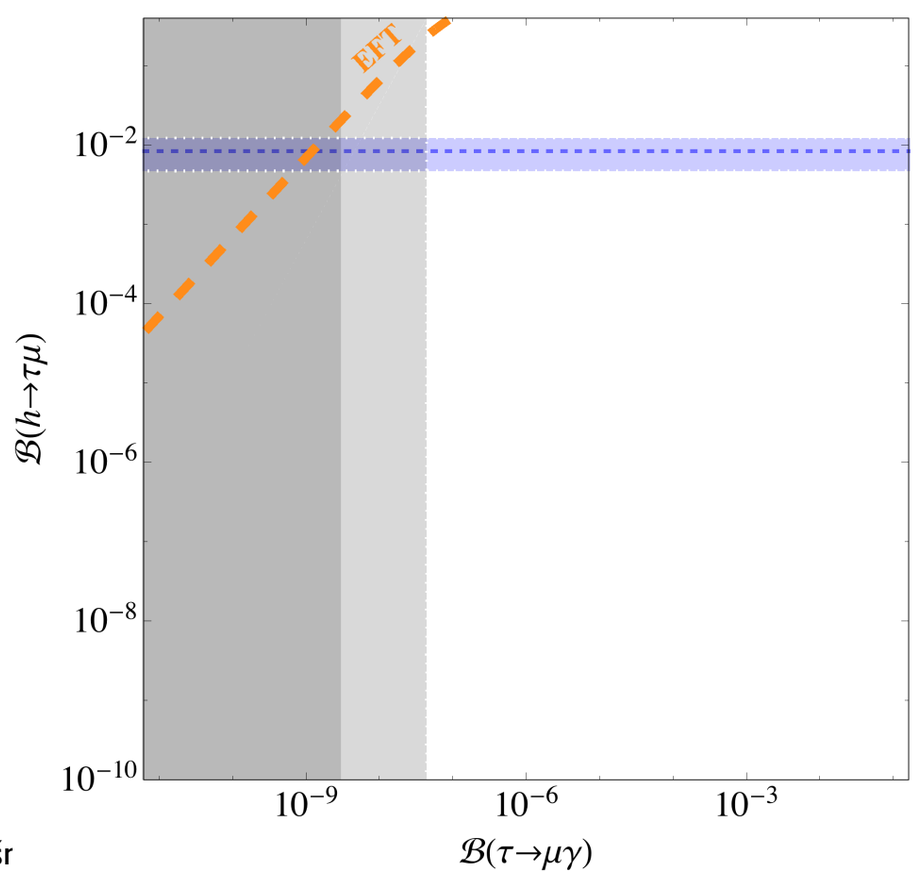
$$\mathcal{L}_{\text{eff.}} = c_L \mathcal{Q}_{L\gamma} + c_R \mathcal{Q}_{R\gamma} + \text{h.c.}$$

$$\mathcal{Q}_{L,R\gamma} = (e/8\pi^2) m_\tau (\bar{\mu}\sigma^{\alpha\beta} P_{L,R}\tau) F_{\alpha\beta},$$

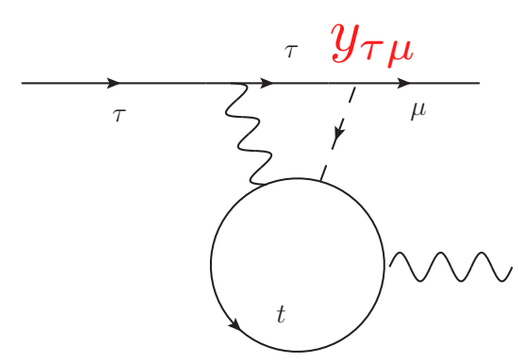
$$c_L^{(1-\text{loop})} \simeq \frac{1}{m_h^2} y_{\tau\mu}^* y_{\tau\tau} \left( -\frac{1}{3} + \frac{1}{4} \log \frac{m_h^2}{m_\tau^2} \right) ,$$

$$c_L^{(2-\text{loop})} \simeq \frac{1}{(125\,\text{GeV})^2} y_{\tau\mu}^* (0.11 - 0.082 y_{tt}) ,$$



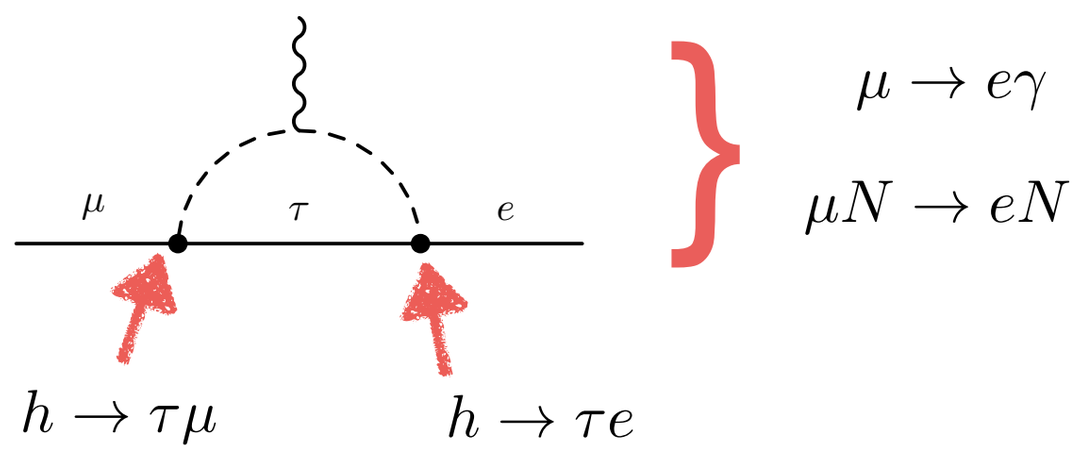




Comparable 1-loop and Barr-Zee contributions



# Additional LFV correlations

Suppose that hτe is nonzero.




$$\mathcal{B}(\mu \to e\gamma) \simeq 185 \left(|y_{\mu\tau} y_{\tau e}|^2 + |y_{\tau\mu} y_{e\tau}|^2\right)$$

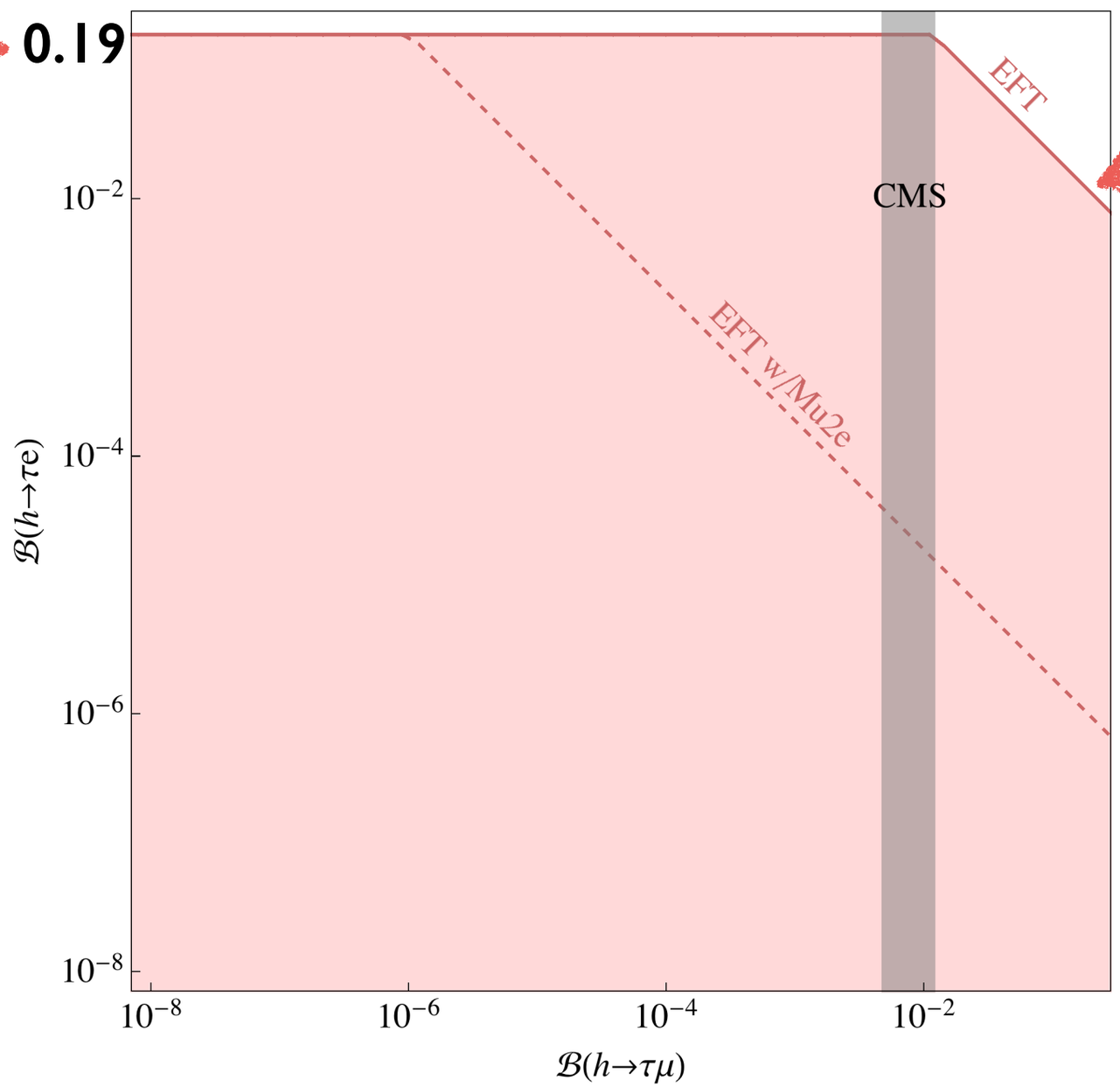
$$\mathcal{B}(\mu \to e)_{\mathrm{Au}} \simeq 4.67 \times 10^{-4} \left(|y_{e\tau} y_{\mu\tau}|^2 + |y_{\tau e} y_{\tau\mu}|^2\right)$$

$$\mathcal{B}(h \to \tau\mu) \times \mathcal{B}(h \to \tau e) = 7.95 \times 10^{-10} \left[\frac{\mathcal{B}(\mu \to e\gamma)}{10^{-13}}\right] + 3.15 \times 10^{-4} \left[\frac{\mathcal{B}(\mu \to e)_{\mathrm{Au}}}{10^{-13}}\right]$$

# h→μτ Vs. h→eτ

τ→eγ
< 3.3×10$^{-8}$

[BaBar. PRL104, 021802 (2010)]




SINDRUM II, μe conv. on Au
< 7×10$^{-13}$

[Eur.Phys.J. C47, 337 (2006)]

projected Mu2e limit on μe
< 6×10$^{-17}$

# 3. Two Higgs doublet mode (type III)

# Framework

$$H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}, \quad H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$$

[Crivellin et al, PRD,87,094031 (2013)]

$$H_u^0 = \frac{1}{\sqrt{2}}\left(H^0 \sin\alpha + h^0 \cos\alpha + iA^0 \cos\beta\right)$$
$$H_d^0 = \frac{1}{\sqrt{2}}\left(H^0 \cos\alpha - h^0 \sin\alpha + iA^0 \sin\beta\right)$$
$$H_u^1 = H^+ \cos\beta$$
$$H_u^2 = H^- \sin\beta$$

5 physical scalars:
h, $H^0$, $H^\pm$, A

2 parameters: tan β, $m_A$

$$\tan\beta = \frac{v_u}{v_d}, \quad \tan 2\alpha = \tan 2\beta \frac{m_A^2 + m_Z^2}{m_A^2 - m_Z^2},$$
$$m_{H^\pm}^2 = m_A^2 + m_W^2 \quad m_H^2 = m_A^2 + m_Z^2 - m_h^2$$

# Flavor couplings

- **Type-III THDM**: no restrictions on the Higgs couplings to fermions
- Tree-level Higgs couplings exhibit
  - ➡ Charged and FCN currents in the quark sector (K, D, B meson mixing, rare decays)
  - ➡ Lepton Flavor Violation
- Decoupling limit of MSSM

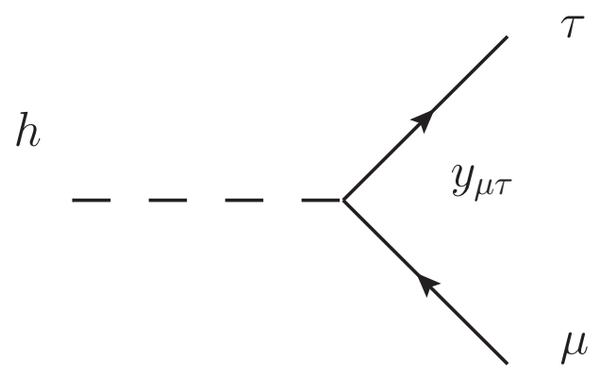
$$\mathcal{L} = \frac{y_{fi}^{H_k}}{\sqrt{2}} H_k \bar{\ell}_{L,f} \ell_{R,i} + \frac{y_{fi}^{H^+}}{\sqrt{2}} H^+ \bar{\nu}_{L,f} \ell_{R,i} + \text{h.c.}$$

$$y_{fi}^{H_k} = x_d^k \frac{m_{\ell_i}}{v_d} \delta_{fi} - \epsilon_{fi}^{\ell} \left( x_d^k \tan\beta - x_u^{k*} \right)$$ Neutral Higges couplings

$$y_{fi}^{H^\pm} = \sqrt{2} \sum_{j=1}^{3} \sin\beta \, V_{fj}^{\text{PMNS}} \left( \frac{m_{\ell_i}}{v_d} \delta_{ji} - \epsilon_{ji}^{\ell} \tan\beta \right)$$ Charged Higgs couplings

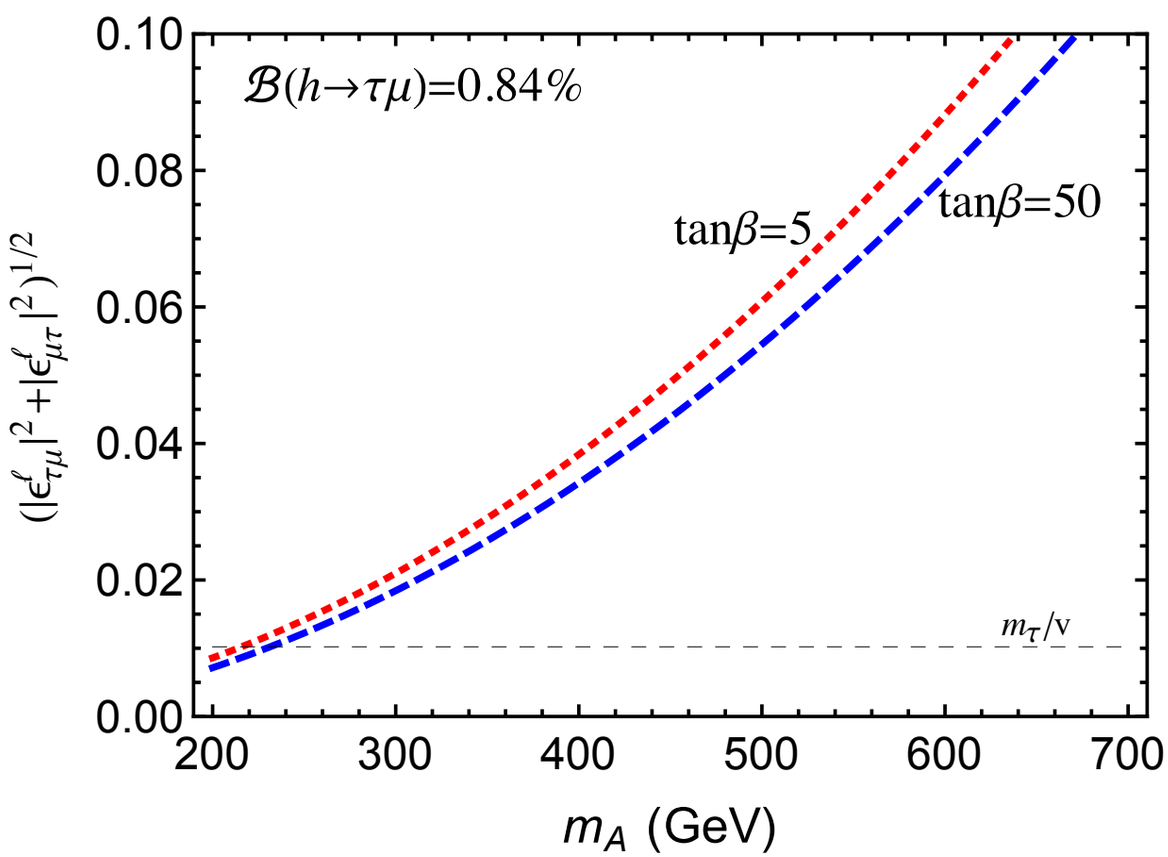
- LFV parameters are $\varepsilon^{l}_{ij}$

# h→τμ




$$y_{\mu\tau\,(\tau\mu)} = \frac{\epsilon^{\ell}_{\mu\tau\,(\tau\mu)}}{\sqrt{2}}\,(\sin\alpha\tan\beta + \cos\alpha)$$

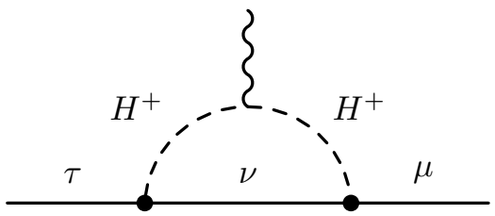
$$\mathcal{B}(h\to\tau\mu) = \frac{m_h}{16\pi\Gamma_h}\,(\sin\alpha\tan\beta+\cos\alpha)^2\,\left(|\epsilon^{\ell}_{\mu\tau}|^2 + |\epsilon^{\ell}_{\tau\mu}|^2\right)$$

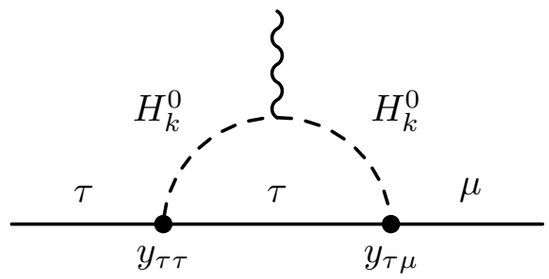



$$\sin\alpha\tan\beta + \cos\alpha \simeq -\frac{2m_Z^2}{m_A^2}$$

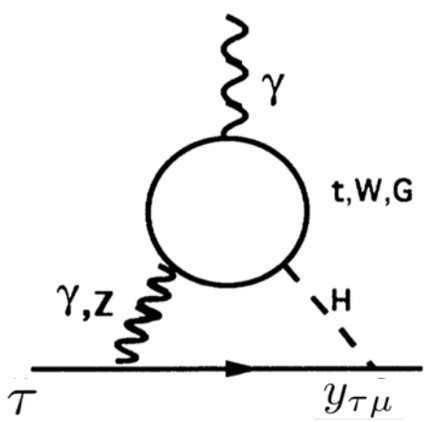
Effect decouples for large $m_A$

# Tau LFV decays




$A_{1\text{-loop}}$ ~ (LFV Yukawa) * (tiny LFC Yukawa)



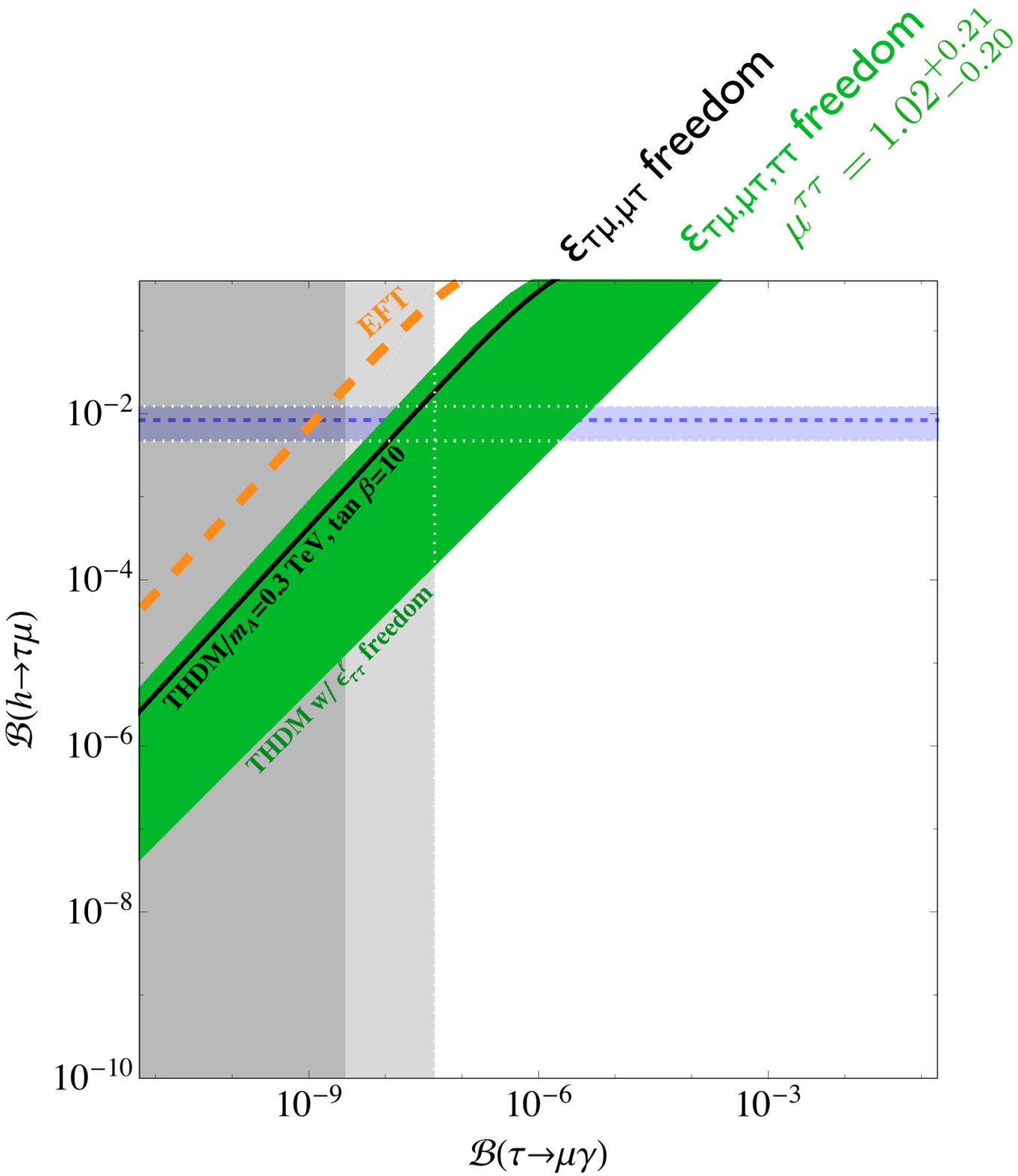

Dominant Barr-Zee contributions

$A_{\text{Barr-Zee}}$ ~ (LFV Yukawa) * (loop suppression) [Chang et al, PRD48, 217(1993)]

*Missing contributions at 2-loops with $H^+$ mediator

# LFV correlations

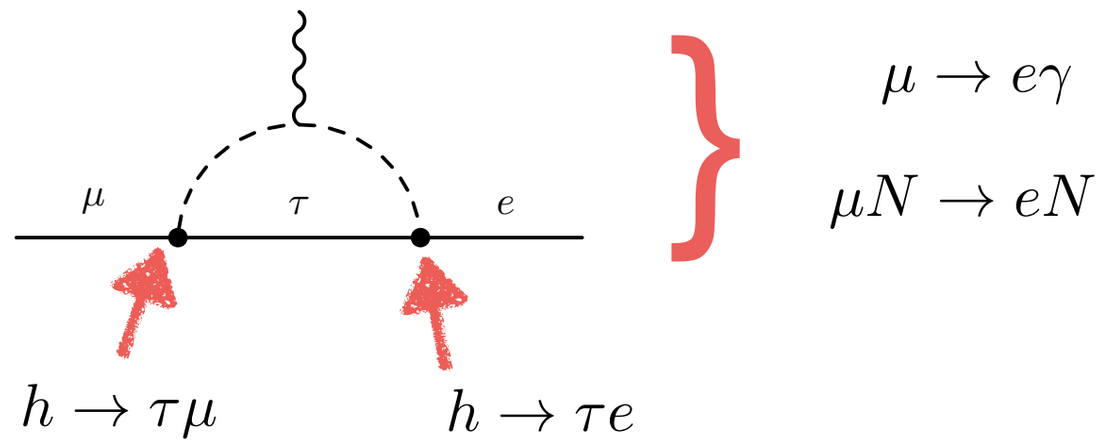
[CMS '14, ATLAS '15]




Works up to $m_A \sim 0.5$ TeV

# Two Higgs Doublet Model

Correlation with h→τe decay!

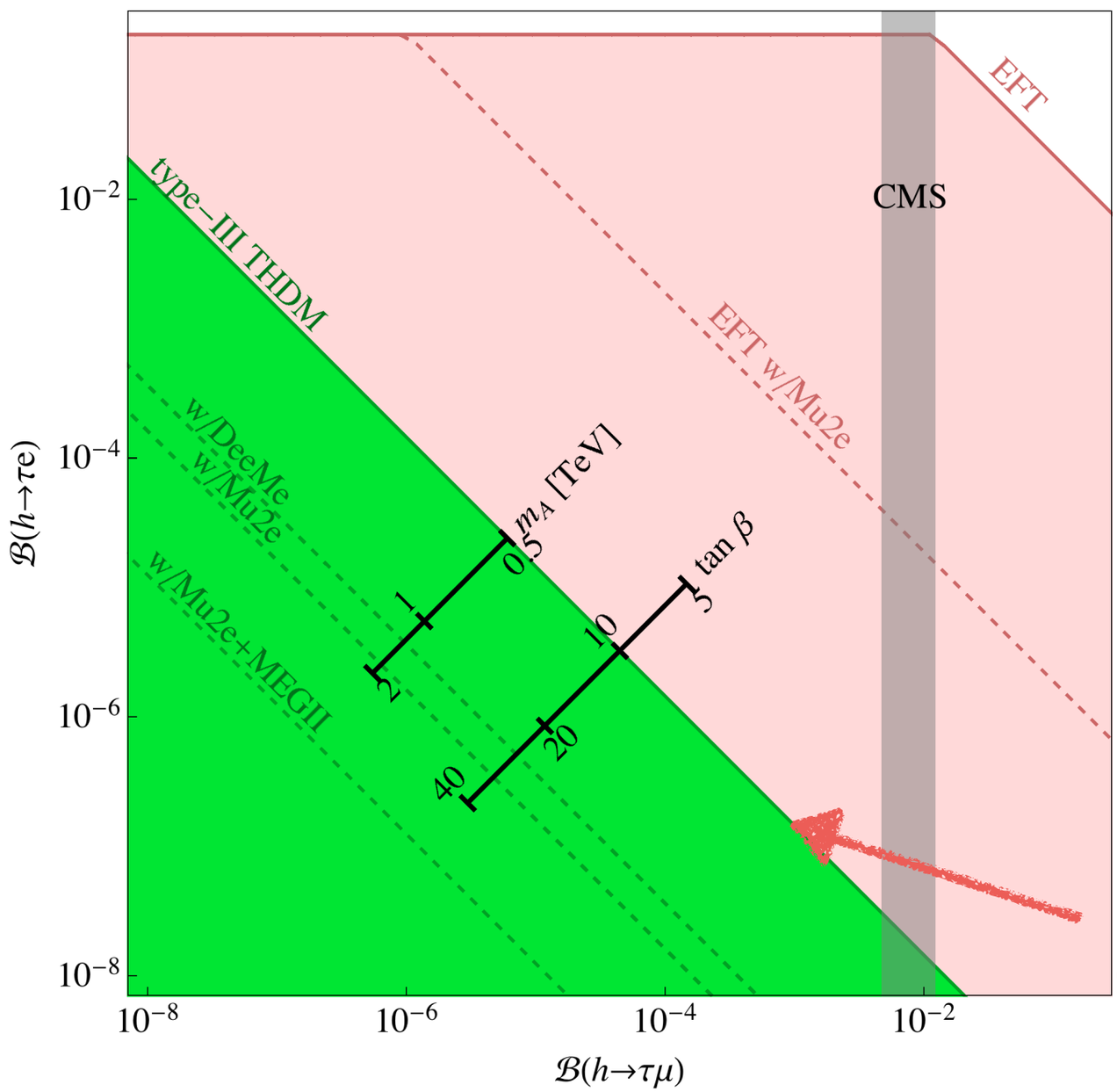



$$\mathcal{B}(\mu \to e\gamma) \simeq \mathcal{B}_0^{\mu\to e\gamma}(t_\beta, m_A)\left(|\epsilon_{\mu\tau}\epsilon_{\tau e}|^2 + |\epsilon_{e\tau}y_{\tau\mu}|^2\right) ,$$

$$\mathcal{B}(\mu \to e)_{\mathrm{A}u} \simeq \mathcal{B}_0^{\mu e}(t_\beta, m_A)\left(|\epsilon_{e\tau}\epsilon_{\mu\tau}|^2 + |\epsilon_{\tau e}\epsilon_{\tau\mu}|^2\right)$$

$$\mathcal{B}(h \to \tau\mu) \times \mathcal{B}(h \to \tau e) \sim \frac{\mathcal{B}(\mu \to e\gamma)}{\mathcal{B}_0^{\mu\to e\gamma}(t_\beta, m_A)} + \frac{\mathcal{B}(\mu \to e)_{\mathrm{Au}}}{\mathcal{B}_0^{\mu e}(t_\beta, m_A)}$$

# h→μτ Vs. h→eτ




$$\mathcal{B}(h \to \tau e) < 6 \times 10^{-6}$$

(taking central value for h→τμ)

SINDRUM II, μe conv. on Au
< 7×10$^{-13}$ [Eur.Phys.J. C47, 337 (2006)]
and
MEG μ→eγ <5.7×10$^{-13}$ [PRL110, 201801 (2013)]

# 4. Extended fermionic sector or loop-induced LFV

# Vector-like leptons

- Chiral leptons get additional Higgs couplings through mixing with VL leptons:

[Falkowski et al, JHEP1405, 092 (2014)]

$$\Psi^L \text{ transforms as } (1,2)_{1/2} \oplus (1,2)_{-1/2}$$
$$\Psi^E \text{ transforms as } (1,1)_1 \oplus (1,1)_{-1}$$

VL Yukawas

$$-\mathcal{L}_{VLL} = \lambda_\Psi \bar{\Psi}^E H(1-\gamma_5)\Psi^L + \tilde{\lambda}_\Psi \bar{\Psi}^E H(1+\gamma_5)\Psi^L$$
$$+ M_\Psi \left(\lambda_e \bar{E}\Psi^E + \lambda_l \bar{L}\Psi^L + C_L \bar{\Psi}^L \Psi^L + C_R \bar{\Psi}^E \Psi^E\right) + \text{h.c.}$$

mixings mass terms of VL leptons

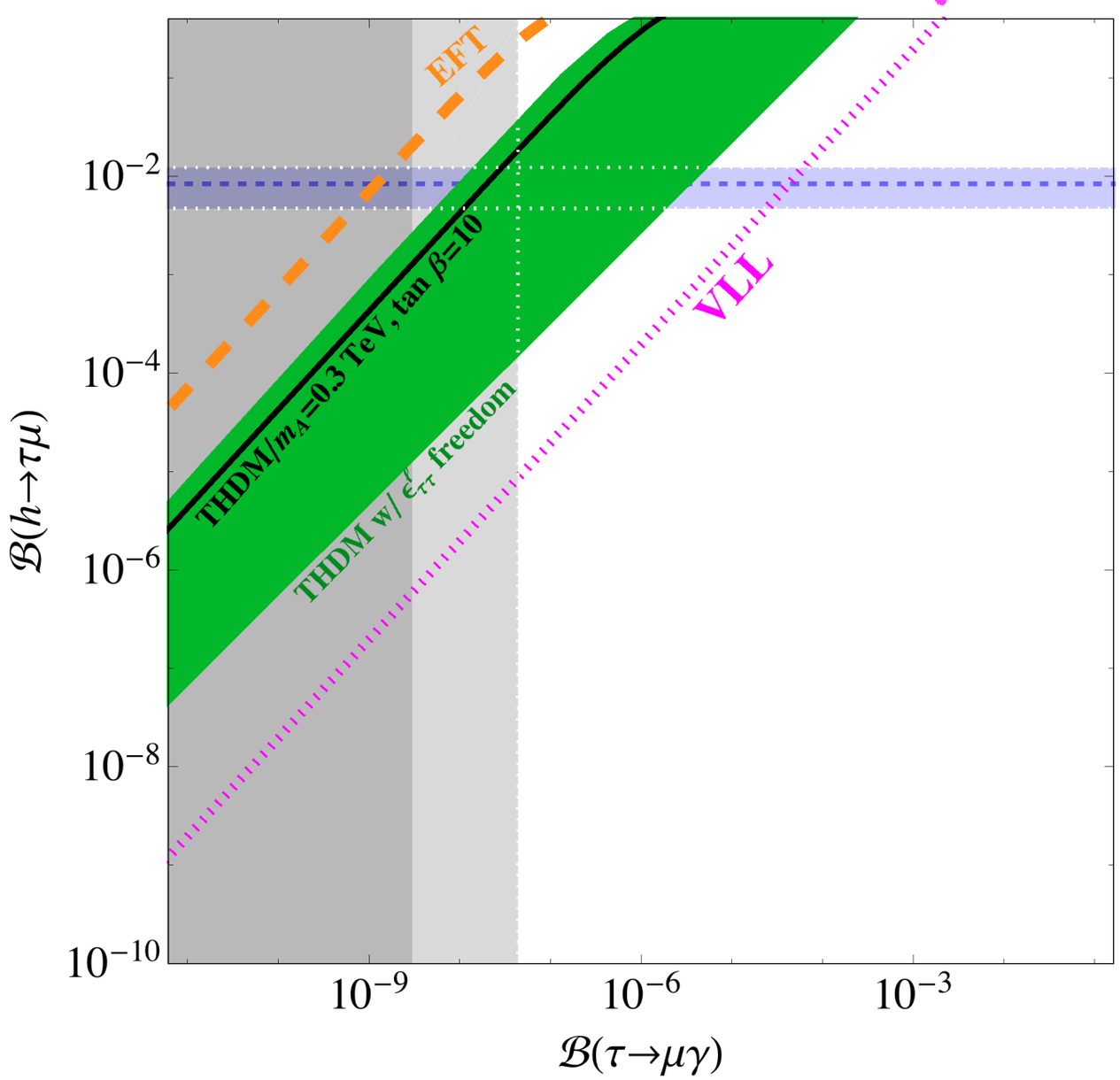
- Yukawas with chiral leptons are obtained when VL leptons are integrated out:

A single LFV Yukawa matrix: $\epsilon = \frac{8v^2}{M_\Psi^2} \lambda_l C_L^{-1} \lambda_\Psi C_R^{-1} \tilde{\lambda}_\Psi C_L^{-1} \lambda_\Psi C_R^{-1} \lambda_e$

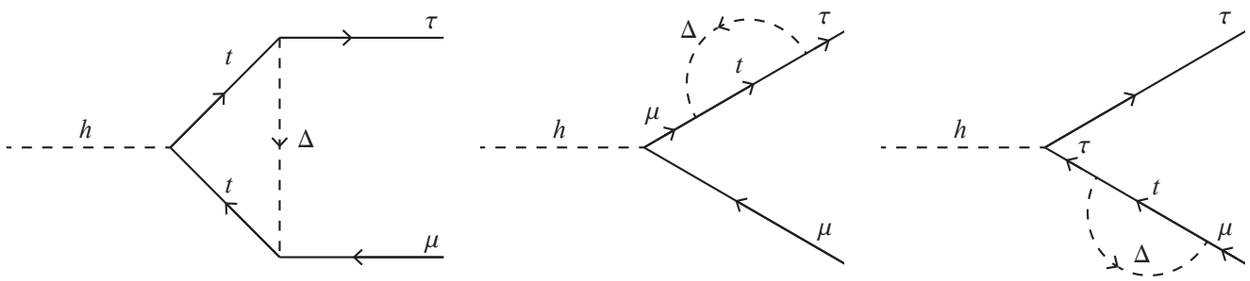
one-to-one correlation: $\frac{\mathcal{B}(h \to \tau\mu)}{\mathcal{B}(\tau \to \mu\gamma)} = \frac{4\pi}{3\alpha} \frac{\mathcal{B}(h \to \tau^+\tau^-)_{\rm SM}}{\mathcal{B}(\tau \to \mu\bar{\nu}\nu)_{\rm SM}} \approx 2 \times 10^2$

# Vector-like leptons

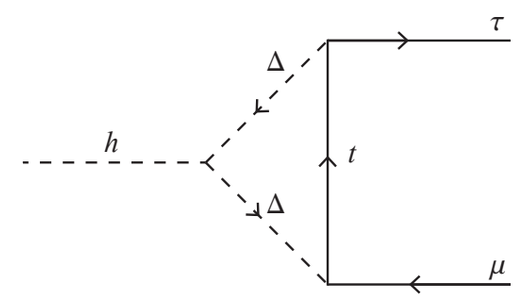
$$\frac{\mathcal{B}(h \to \tau\mu)}{\mathcal{B}(\tau \to \mu\gamma)} = \frac{4\pi}{3\alpha} \frac{\mathcal{B}(h \to \tau^+\tau^-)_{\rm SM}}{\mathcal{B}(\tau \to \mu\bar{\nu}\nu)_{\rm SM}} \approx 2 \times 10^2$$



# Scalar leptoquarks




~ top Yukawa * (LFV Yukawas)




~ portal coupling

$\lambda v\, h\, \mathrm{LQLQ}$

- Loop induced LFV
- Need top-quark mass chiral enhancemet:
  - ⇒ non-chiral LQ
  - ⇒ $\tau \to \mu\gamma$ enhanced in the same way as $h \to \tau\mu$
- $\lambda$ decouples the two observables

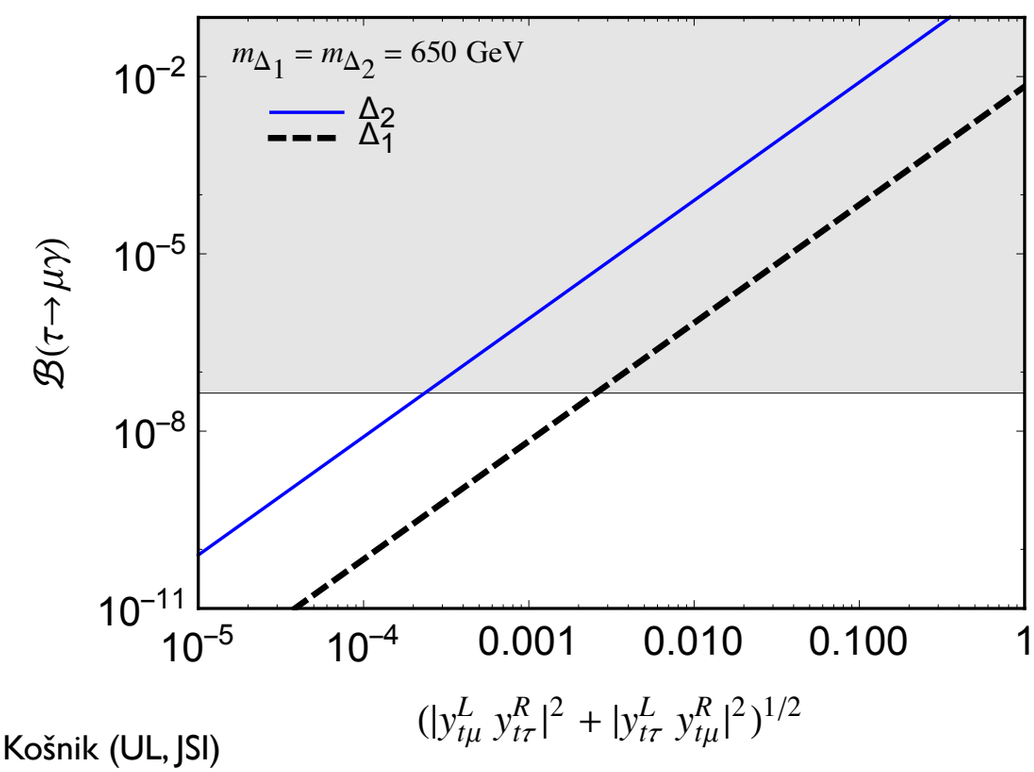
# Scalar leptoquarks

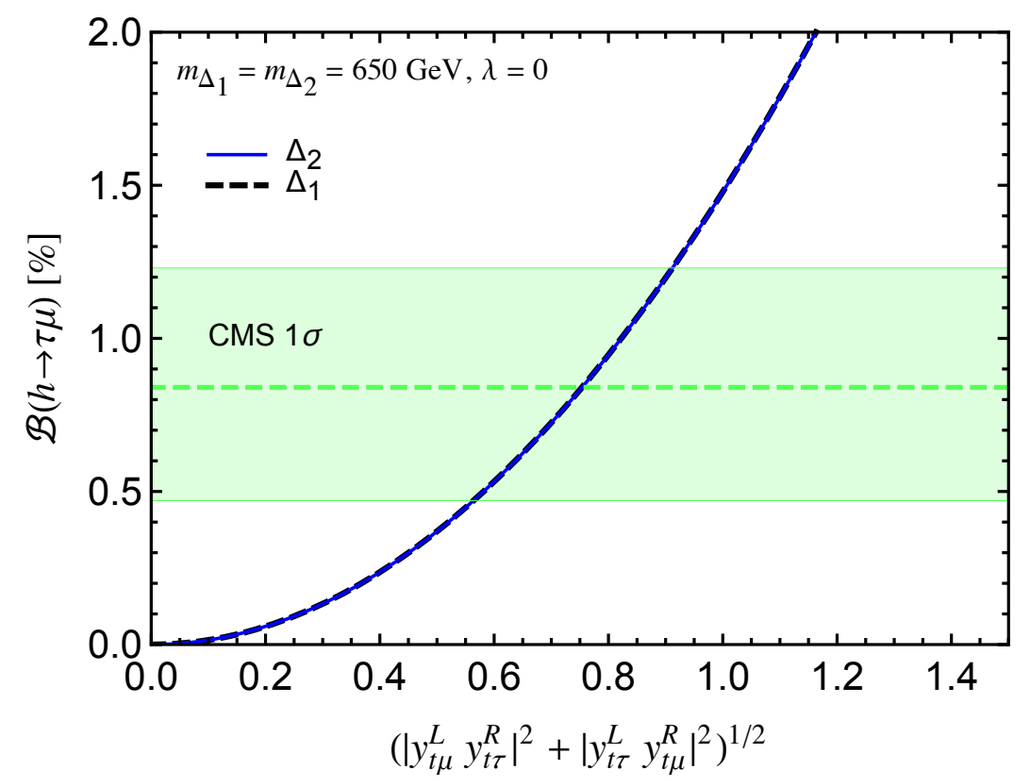
$$\mathcal{L}_{\Delta_1} = y^L_{ij}\bar{u}^i_L \ell^{C\,j}_L \Delta_1 - (V^\dagger_{\rm CKM} y^L_{ij} V_{\rm PMNS})\bar{d}^i_L \nu^{C\,j}_L \Delta_1 + y^R_{ij}\bar{u}^i_R \ell^{C\,j}_R \Delta_1 + \text{h.c.}$$

$\Delta_1(3,1,-1/3)$

$$\Gamma(h\to\tau\mu) = \frac{9 m_h m_t^2}{2^{13}\pi^5 v^2}\left(\left|y^L_{t\mu}y^R_{t\tau}\right|^2 + \left|y^L_{t\tau}y^R_{t\mu}\right|^2\right)|g_1(\lambda, m_{\Delta_1})|^2$$

$$\mathcal{B}(\tau\to\mu\gamma) = \frac{\alpha m_\tau^3}{2^{12}\pi^4\Gamma_\tau}\frac{m_t^2}{m^4_{\Delta_1}} h_1(x_t)^2\left(\left|y^L_{t\mu}y^R_{t\tau}\right|^2 + \left|y^L_{t\tau}y^R_{t\mu}\right|^2\right)$$



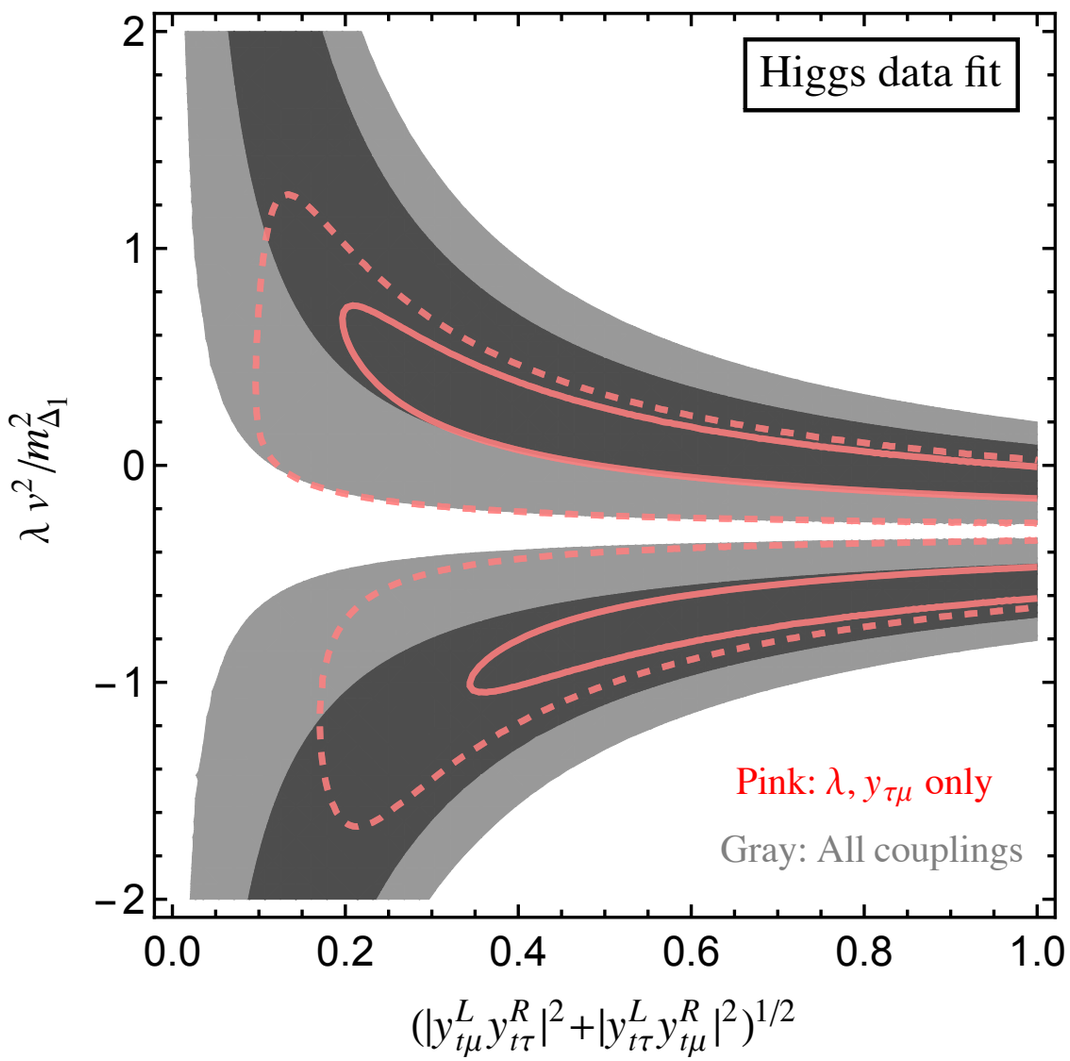



# Scalar leptoquarks

Portal coupling has an effect on h→γγ and gg→h !

$\Delta_1(3,1,-1/3)$

$$\frac{\Gamma_{h\to\gamma\gamma}}{\Gamma^{SM}_{h\to\gamma\gamma}} = |1 - 0.025\frac{\lambda v^2}{m_\Delta^2} d(r_\Delta)\sum_i Q^2_{\Delta^i}|^2 \qquad \frac{\sigma_{ggF}}{\sigma^{SM}_{ggF}} = |1 + 0.24\frac{\lambda v^2}{m_\Delta^2} N_{\Delta^i} C(r_\Delta)|^2$$




⇒ λ is bounded from above

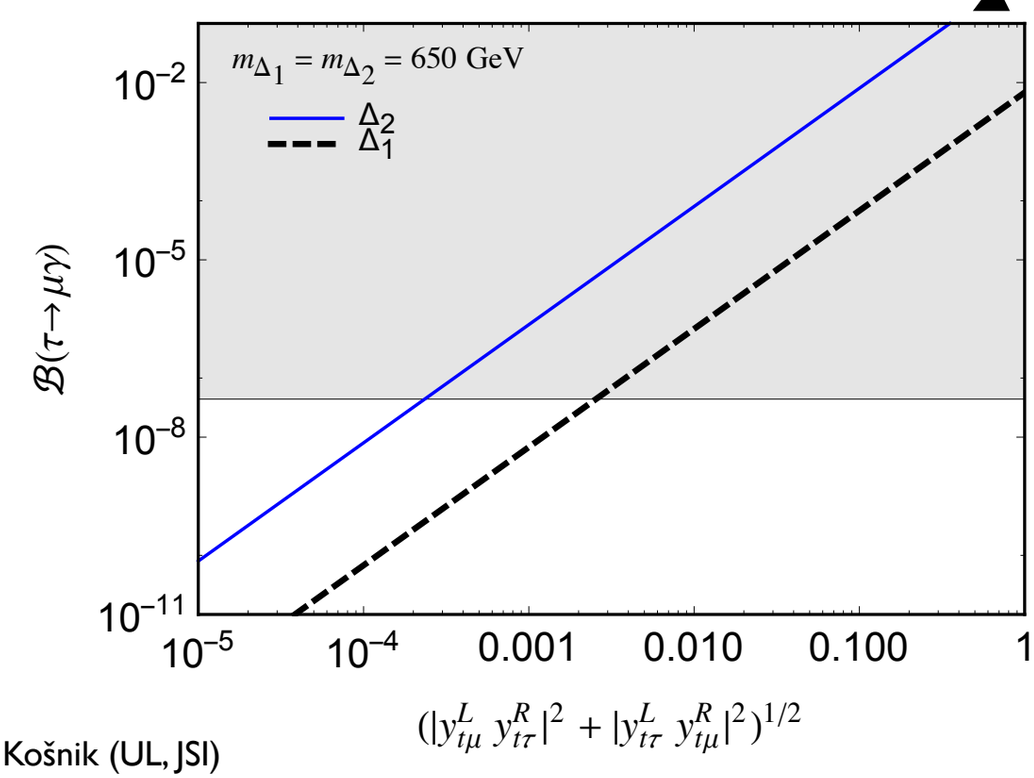
# Scalar leptoquarks

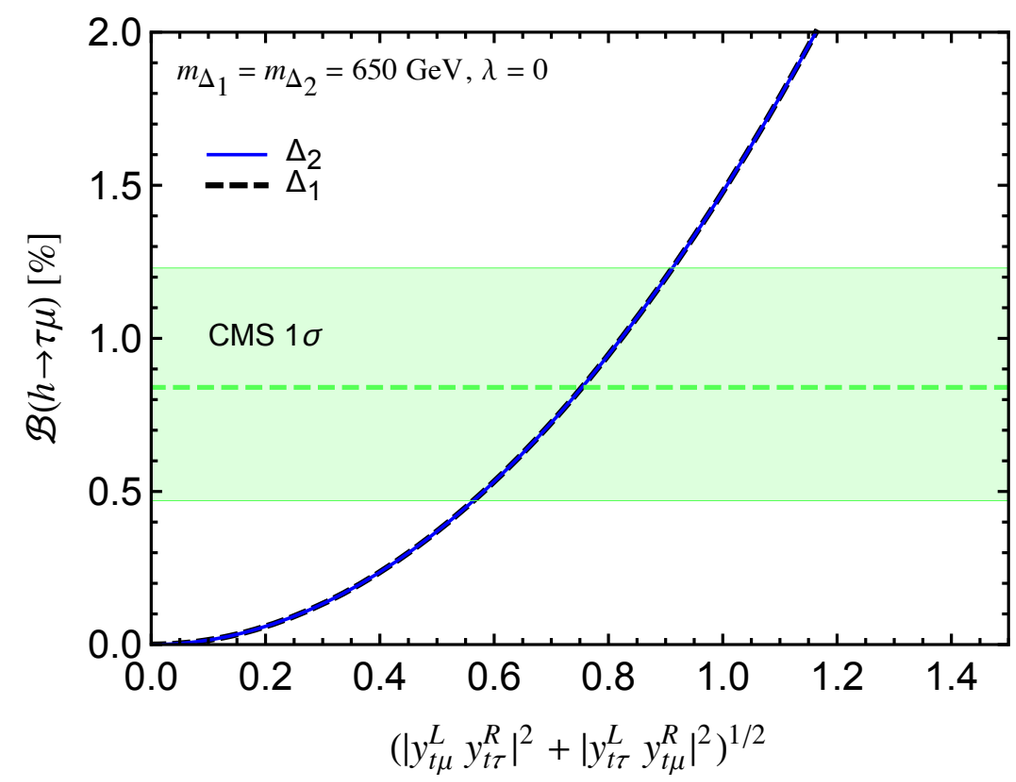
$\Delta_2(3,2,7/6)$

$$\mathcal{L}_{\Delta_2} = y^L_{ij}\bar{\ell}^i_R d^j_L \Delta_2^{2/3\,*} + (y^L V^\dagger_{\rm CKM})_{ij}\bar{\ell}^i_R u^j_L \Delta_2^{5/3\,*}$$
$$+ (y^R V_{\rm PMNS})_{ij}\bar{u}^i_R \nu^j_L \Delta_2^{2/3} - y^R_{ij}\bar{u}^i_R \ell^j_L \Delta_2^{5/3} + \text{h.c.}$$

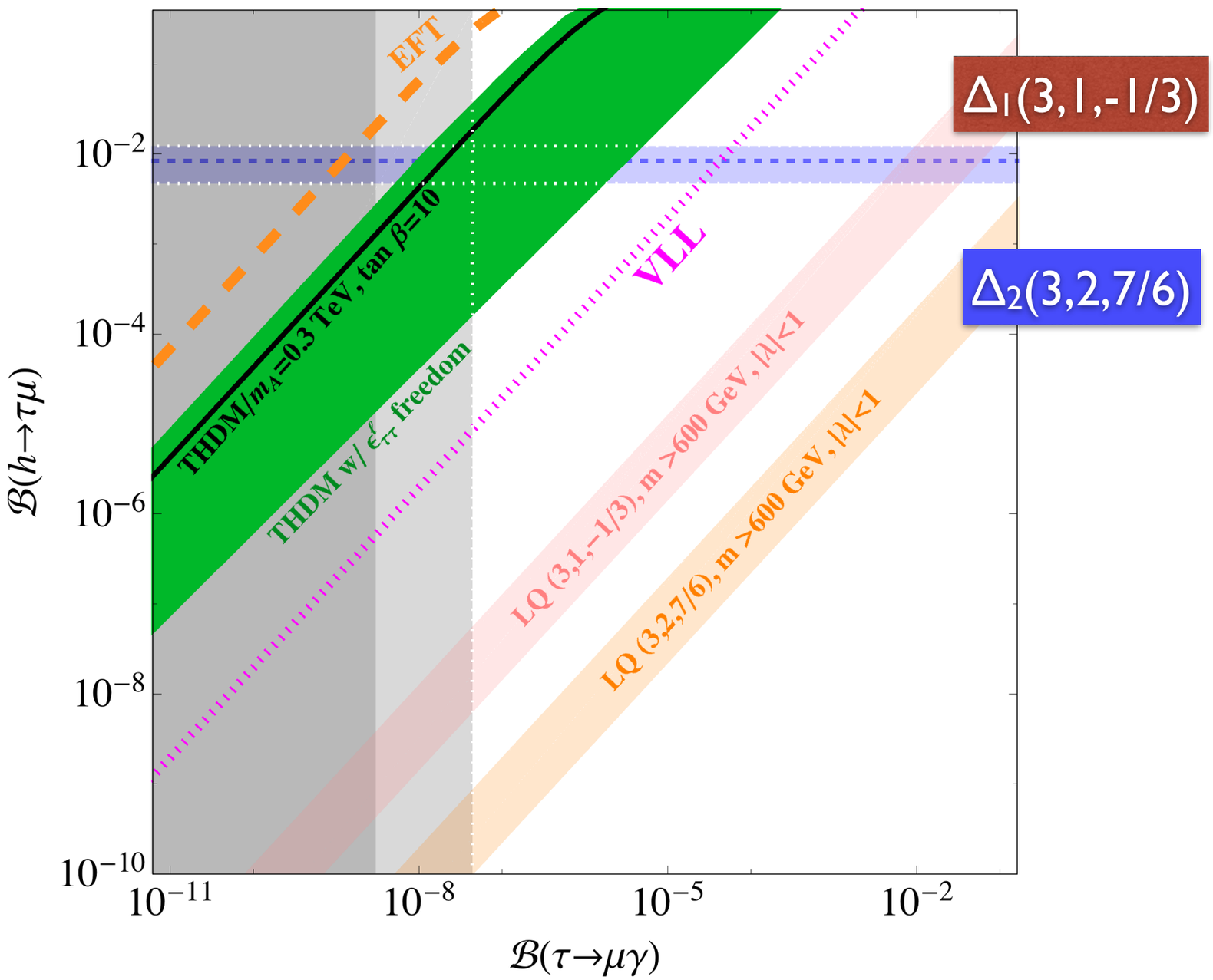
$$\Gamma(h\to\tau\mu) = \frac{9 m_h m_t^2}{2^{13}\pi^5 v^2}|g_1(\lambda, m_{\Delta_2})|^2 \left(|y^L_{\mu t} y^R_{t\tau}|^2 + |y^L_{\tau t} y^R_{t\mu}|^2\right)$$

$$\mathcal{B}(\tau\to\mu\gamma) = \frac{\alpha m_\tau^3}{2^{12}\pi^4\Gamma_\tau}\frac{m_t^2}{m_\Delta^4}\, h_2(x_t)^2 \left(|y^R_{t\tau} y^L_{\mu t}|^2 + |y^R_{t\mu} y^L_{\tau t}|^2\right)$$



# Scalar leptoquarks



# Leptoquark and vector-like quark T

Add a vector like top-partner to either of the LQ scenarios

$$\mathcal{L} \ni y_{33}^L \bar{t}_L \Delta \tau_R + y_{32}^R \bar{t}_R \Delta \mu_L + x_{33}^L \bar{T}_L \Delta \tau_R + x_{32}^R \bar{T}_R \Delta \mu_L + \text{h.c.}$$

T does not affect the h→τμ, if the portal is turned off

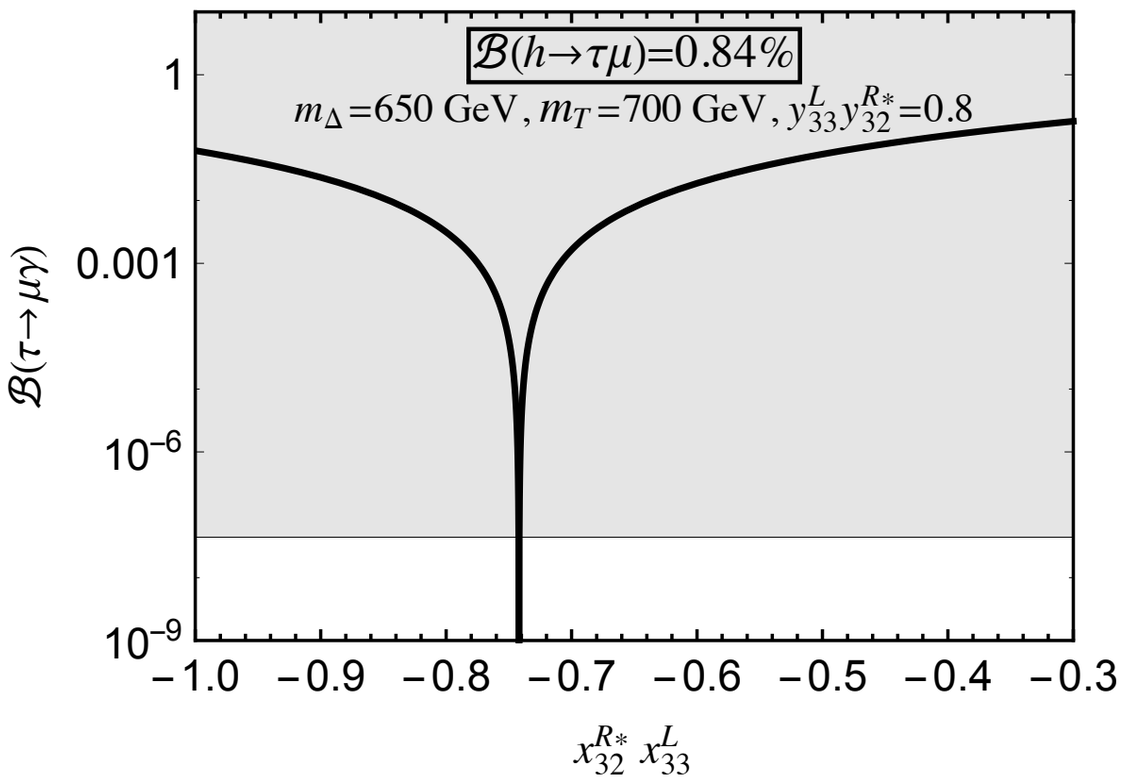
Finely tune T and t contributions to cancel τ→μγ amplitudes

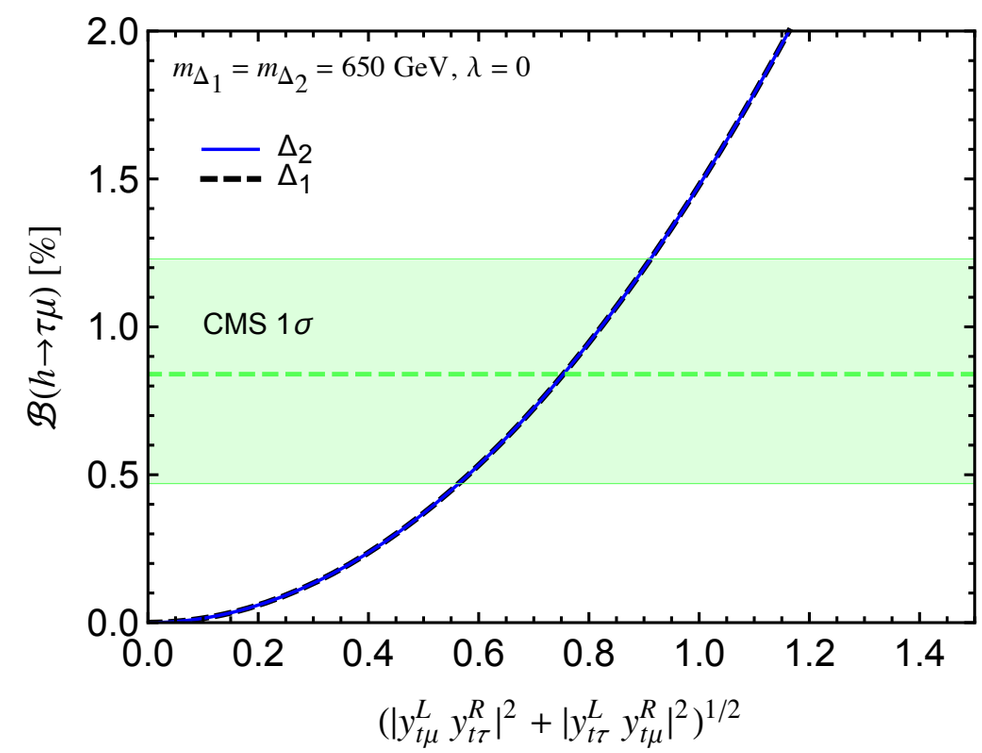
$$\mathcal{B}(\tau \to \mu\gamma) = \frac{\alpha_{\rm EM} m_\tau^3}{2^{12}\pi^4 \Gamma_\tau m_\Delta^4} \left| y_{33}^L y_{32}^{R*}\, m_t h_2(m_t^2/m_\Delta^2) + x_{33}^L x_{32}^{R*}\, m_T h_2(m_T^2/m_\Delta^2) \right|^2$$

# Leptoquark and vector-like quark T

Finely tune T and t contributions to achieve small τ→μγ

$$\mathcal{B}(\tau \to \mu\gamma) = \frac{\alpha_{\rm EM} m_\tau^3}{2^{12}\pi^4 \Gamma_\tau m_\Delta^4} \left| y_{33}^L y_{32}^{R*}\, m_t h_2(m_t^2/m_\Delta^2) + x_{33}^L x_{32}^{R*}\, m_T h_2(m_T^2/m_\Delta^2) \right|^2$$



# Summary and Outlook

- A positive signal of $Br(h \to \mu\tau)$ implies a robust **lower bound on the LFV Higgs couplings**.
- This bound is robust even after allowing for deviations in other Higgs couplings

- Higgs-EFT framework: Belle II should see $\tau \to \mu\gamma$
- With future $\mu e$ conversion measurements, $Br(h \to \mu\tau)\, Br(h \to e\tau) < 10^{-7}$

- In concrete models $Br(\tau \to \mu\gamma)$ is more restrictive

  ★Extensions with vector like leptons or models with loop-induced $h \to \mu\tau$ (leptoquark) imply a too large $Br(\tau \to \mu\gamma)$, unless ad-hoc fine tuning is introduced (LQ + VL top)

  ★Two Higgs doublet model is testable by $Br(\tau \to \mu\gamma)$ at Belle II

  ★Two Higgs doublet model is further constrained by $\mu e$ conversion.
  Correlation $Br(h \to \mu\tau)\, Br(h \to e\tau) < 10^{-10}$ ($10^{-12}$ with improved limits in $\mu e$ sector)

Thanks!

# Effective Higgs couplings

- General parameterisation of the off-diagonal Yukawa couplings

$$\mathcal{L}_{Y_\ell}^{\text{eff.}} = -m_i \delta_{ij} \bar{\ell}_L^i \ell_R^j - y_{ij} \left( \bar{\ell}_L^i \ell_R^j \right) h + \ldots + \text{h.c.} \qquad y_{ij}^{\text{SM}} = \delta_{ij} \frac{m_i}{v}$$

$$\mathcal{B}(h \to \tau\mu) = \frac{m_h}{8\pi\Gamma_h} \left( |y_{\tau\mu}|^2 + |y_{\mu\tau}|^2 \right) \qquad \Gamma_h = \Gamma_h^{\text{SM}} / [1 - \mathcal{B}(h \to \tau\mu)]$$

- Assuming New Physics only **in h→μτ** then CMS result gives

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

$$0.0019(0.0008) < \sqrt{|y_{\tau\mu}|^2 + |y_{\mu\tau}|^2} < 0.0032(0.0036) \text{ at } 68\% \ (95\%) \text{ C.L.}$$

# Effective Theory Framework

- Integrate out heavy Higgses, fermions, scalars. Keep terms to dim-6

$$\mathcal{L}_{Y_\ell} = -\lambda^{\alpha}_{ij}\bar{L}_i H_\alpha E_j - \lambda'^{\alpha\beta\gamma}_{ij}\frac{1}{\Lambda^2}\bar{L}_i H_\alpha E_j (H^\dagger_\beta H_\gamma) + \text{h.c.}$$

Multiple higgses $\quad H_\alpha = (h^+_\alpha, v_\alpha + x_\alpha h + \ldots)^T$

$$\sum_\alpha v_\alpha^2 \sim v^2/2 \qquad \sum_\alpha |x_\alpha|^2 \sim 1/2$$

Dim-6 operator creates mismatch between mass and Yukawa matrices

$$y_{ij} = \frac{m_i}{v}\delta_{ij} + \epsilon_{ij} \qquad \frac{m}{v} = V_L\left(\lambda^\alpha \bar{v}_\alpha + \lambda'^{\alpha\beta\gamma}\frac{v^2}{\Lambda^2}\bar{v}_\alpha\bar{v}_\beta\bar{v}_\gamma\right)V_R^\dagger$$

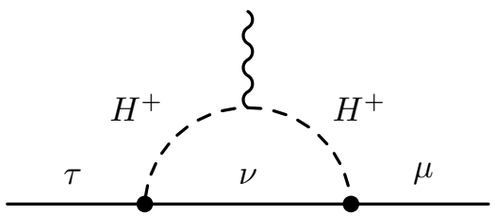
$$\epsilon = V_L\left[\lambda^\alpha \bar{v}_\alpha\left(\frac{x_\alpha}{\bar{v}_\alpha} - 1\right) + \lambda'^{\alpha\beta\gamma}\frac{v^2}{\Lambda^2}\bar{v}_\alpha\bar{v}_\beta\bar{v}_\gamma\left(\frac{x_\alpha}{\bar{v}_\alpha} + \frac{x_\beta}{\bar{v}_\beta} + \frac{x_\gamma}{\bar{v}_\gamma} - 1\right)\right]V_R^\dagger$$

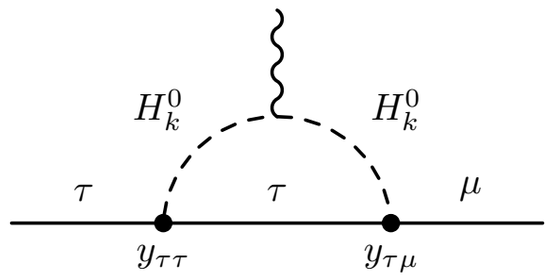
$$\bar{v}_\alpha = v_\alpha/v$$

vanishing in single Higgs scenarios

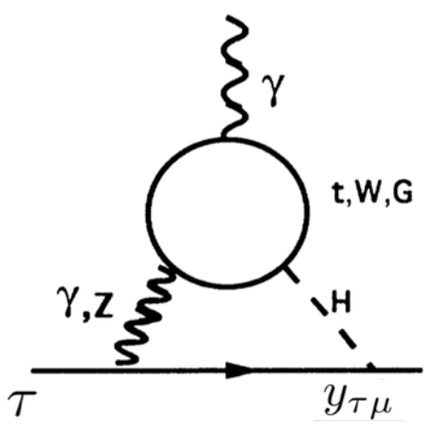
$$\Lambda \simeq 4\ \text{TeV}\left[\left(\frac{0.84\%}{\mathcal{B}(h\to\tau\mu)}\right)\left(|V_L\lambda'^{111}V_R^\dagger|^2_{\tau\mu} + |V_L\lambda'^{111}V_R^\dagger|^2_{\mu\tau}\right)\right]^{1/4}$$

# Tau LFV decays

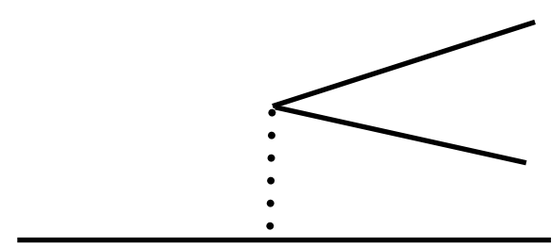



$A_{1\text{-loop}}$ ~ (LFV Yukawa) * (tiny LFC Yukawa)




$A_{\text{Barr-Zee}}$ ~ (LFV Yukawa) * (loop suppression) [Chang et al, PRD48, 217(1993)]

Missing contributions at 2-loops with $H^+$ mediator

$\tau \to \mu\mu\mu$ is tree-level but less sensitive due to small muon Yukawa