LFV Higgs decays

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Qui Nhon, Vietnam

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- Introduction: Hints of LFV decays of the Higgs
- SUSY explanation
- Vector-like fermions explanation
- Conclusions

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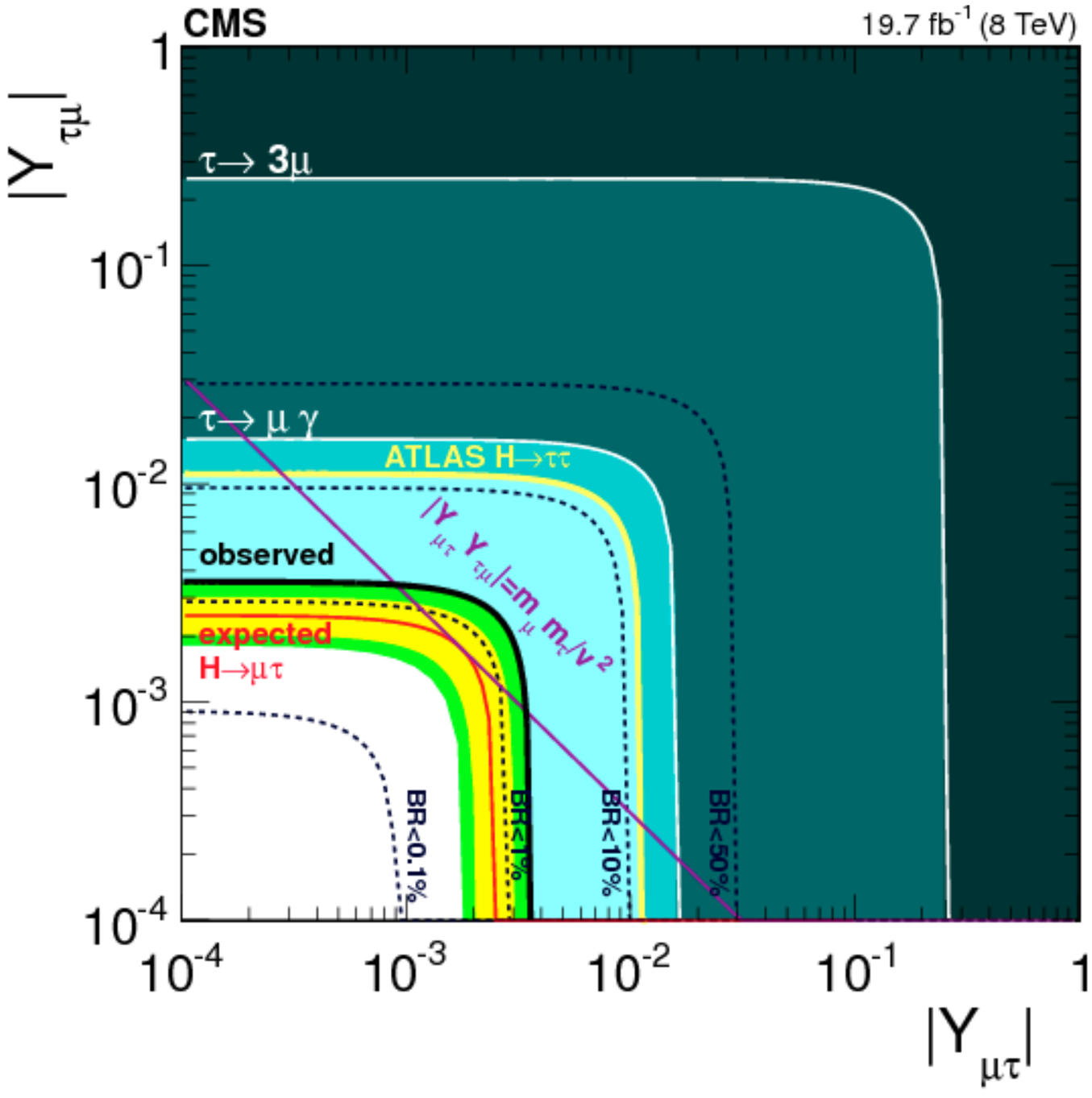
Introduction

- The LHC has searched for LFV Higgs decays and has reported a mild excess of the form:

$$\mathcal{B}r(h \to \tau\mu) = 0.82^{+0.33}_{-0.32}\%$$

at best 2.4 σ

- If interpreted as a LFV Yukawa this can be translated as:

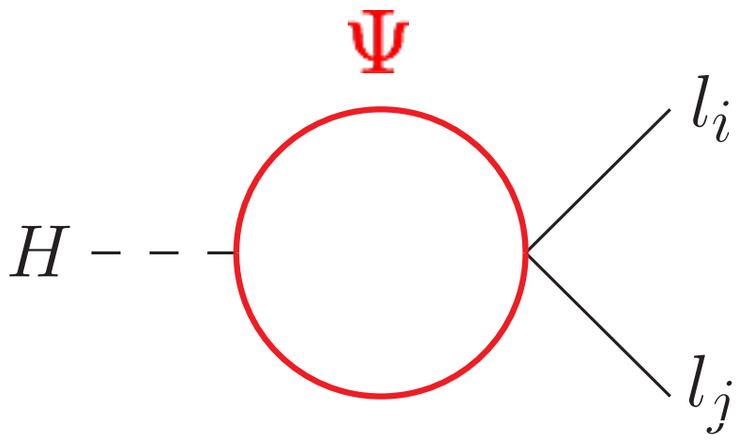


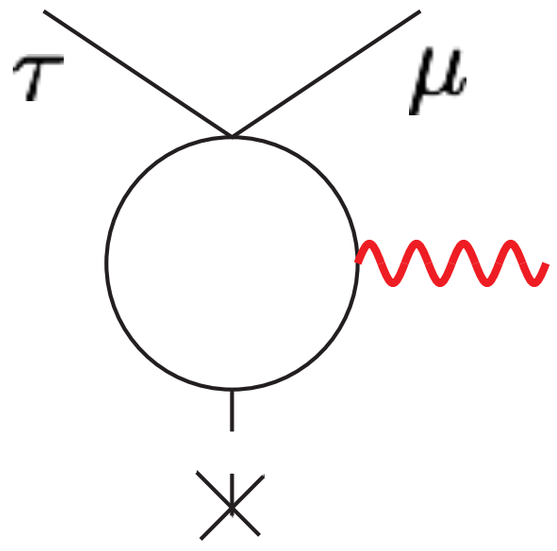
- In the SM any LFV is necessarily proportional to neutrino masses which means that:

$$\mathcal{B}r(\mu^- \to W^- \nu \to e^- \gamma) < 10^{-55}$$

- This observation implies that any LFV implies physics beyond the SM.

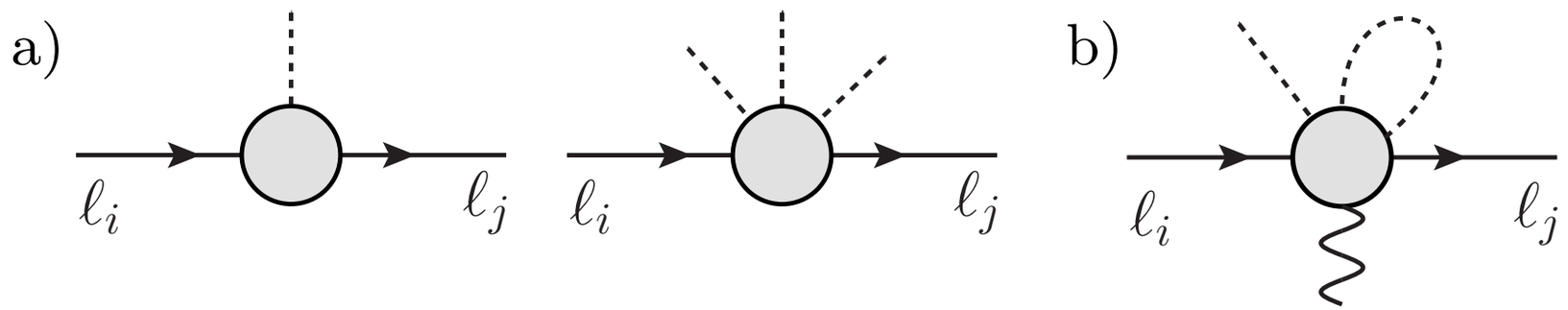
- On the other hand one has to be very careful while model building since a LFV Higgs decay could imply charge a LFV decay:





- From an SM effective field theory point of view there is a tension:

$$-\mathcal{L}_{\rm Y} = \lambda_{ij}(\bar{\ell}^i_L e^j_R)H + \frac{\lambda'_{ij}}{\Lambda^2}(\bar{\ell}^i_L e^j_R)H(H^\dagger H) + \text{h.c.}$$



$h \to \tau\mu$ Y=10^{-3}

$\tau \to \mu\gamma$ Y=10^{-5}

- That means one has to go a theory with at least two sources of EWSB:
  - MSSM with LFV soft terms
  - Vector like fermions

MSSM with LFV soft terms

- Since the MSSM is a type-II 2HDM there is no LFV at the superpotential level.
- We are going to add the following LFV soft lagrangian:

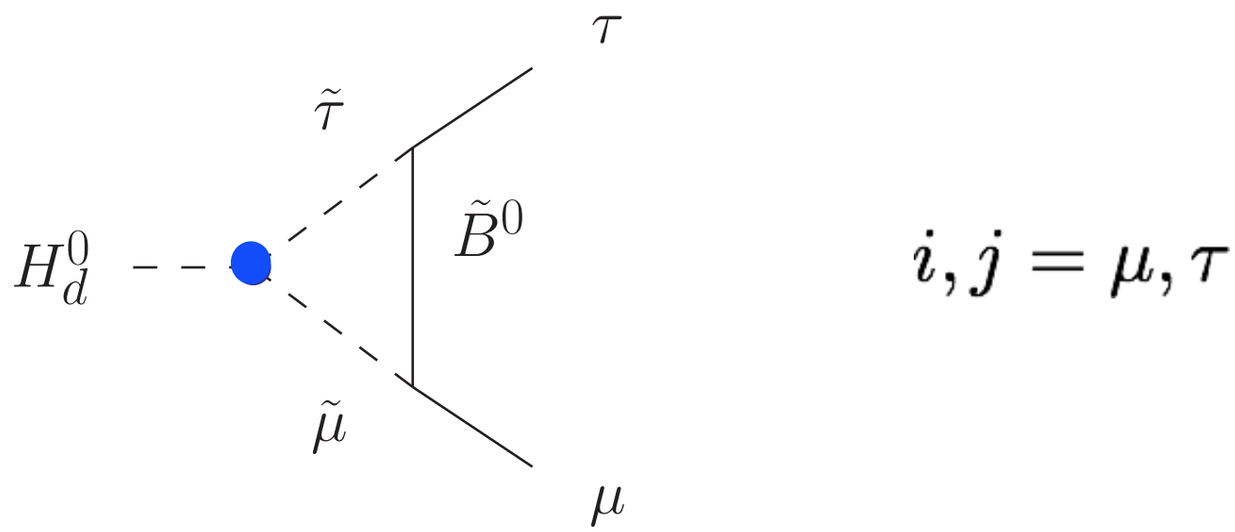
$$\mathcal{L}_{\not SUSY} \supset -(m^2_{\widetilde{L}})_{ij}\ \widetilde{L}^\dagger_i \widetilde{L}_j - (m^2_{\widetilde{E}})_{ij}\ \widetilde{E}^{c\dagger}_i \widetilde{E}^c_j \quad \Big\} \text{ scalar masses}$$

$$-A^e_{ij}\ \widetilde{L}_i H_d \widetilde{E}^c_j + \text{h.c.}$$

A-terms

- We can calculate the contribution to LFV higgs decays in a simplified setup:

$h \to \tau\mu$ via tri-scalar interaction $H_d \widetilde{L}_i \widetilde{E}^c_j$ with coefficient $A^{(e)}_{ij}$



$i, j = \mu, \tau$

SM Higgs

$$H^0_d = \cos\beta h^0 + \sin\beta H^0$$

Decay rate

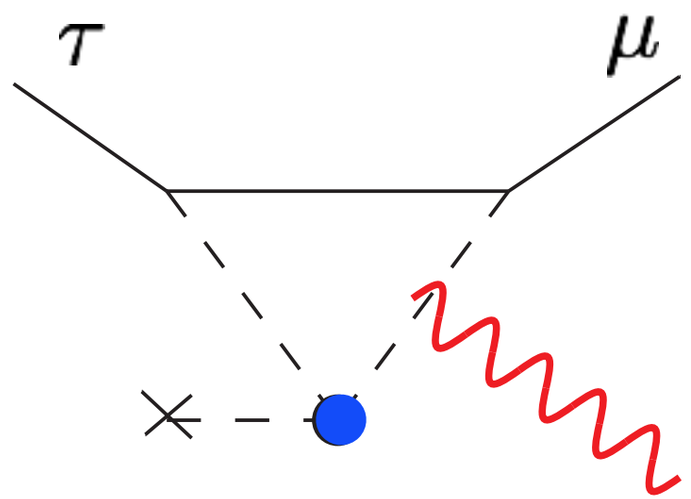
*$\mathcal{I}$ loop function

$$\Gamma(h \to \tau\mu) \propto m_h \left(\frac{A_{\tau\mu}}{m_{\tilde{l}}}\right)^2 \mathcal{I}^2(m_{\tilde{l}}/m_{\tilde{B}})$$

Mass ratios only

$\Rightarrow$ No mass scale picked

$\Rightarrow$ Leaves $m_{\tilde{B}}$ still free for $\tau \to \mu\gamma$

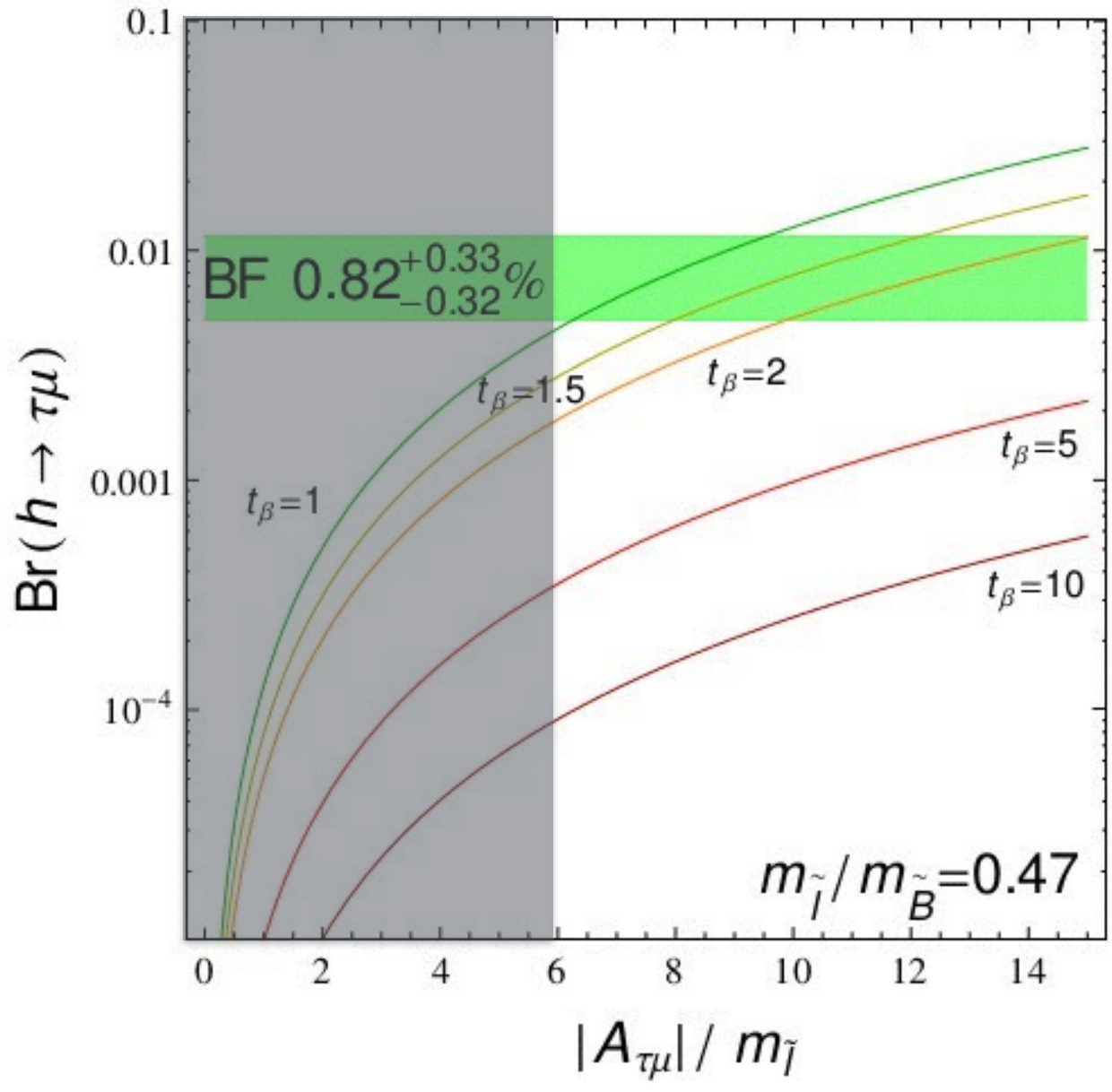


- Including just the triangle diagram which is a overestimation we get:

- Cannot lower $\tan\beta$ beyond ~1.0

- **Requires**

$$A_{\tau\mu}/m_{\tilde{l}} > 6$$



- But there is a problem with CCB minima:

$$|A_{\tau\mu}| \leq y_\tau \sqrt{m_{Hd}^2 + m_{\widetilde{\tau}}^2 + m_{\widetilde{\mu}}^2}$$

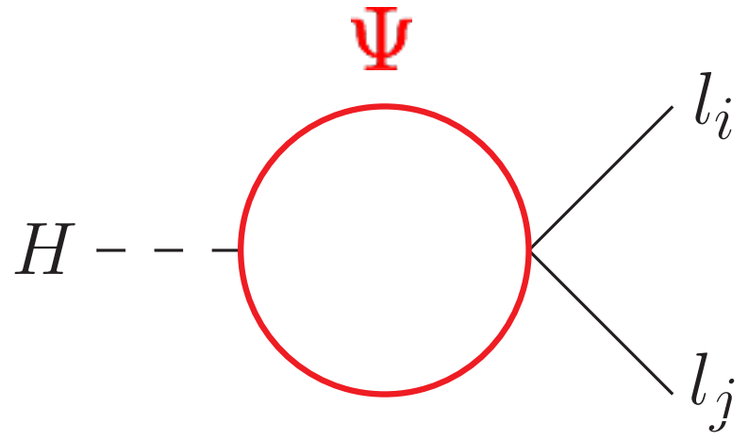
- So even with our overestimation of the effect it seems that SUSY has issues to accommodate this LFV decay.

Vector-like explanation

- We are going to add new vector-like fermions to the SM to induce LFV decays:

$$\mathcal{O}_{\text{4fermion}} = \frac{\lambda_{ij}}{\Lambda^2}\Psi\Psi L_i e_j^c \qquad i,j = 1,2,3$$

$$\mathcal{L}_{\text{UV}} \supset \frac{y_\phi^{(1)}}{\sqrt{2}}\phi\psi^c\chi + \frac{(y_\phi^{(2)})_{ij}}{\sqrt{2}}\phi L_i e_j^c + \text{h.c.}$$ For large mass



Yukawa vertex

Two new fermions (vector-like)

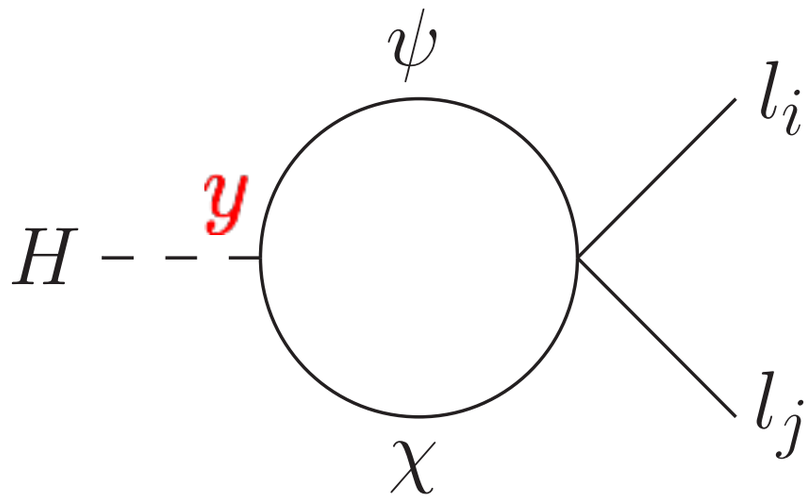
$$\psi = (\mathbf{2}, 1/2 + x)$$

$$\chi = (\mathbf{1}, x)$$

under $SU(2)_L \times U(1)_Y$

$x = +2$ good enough

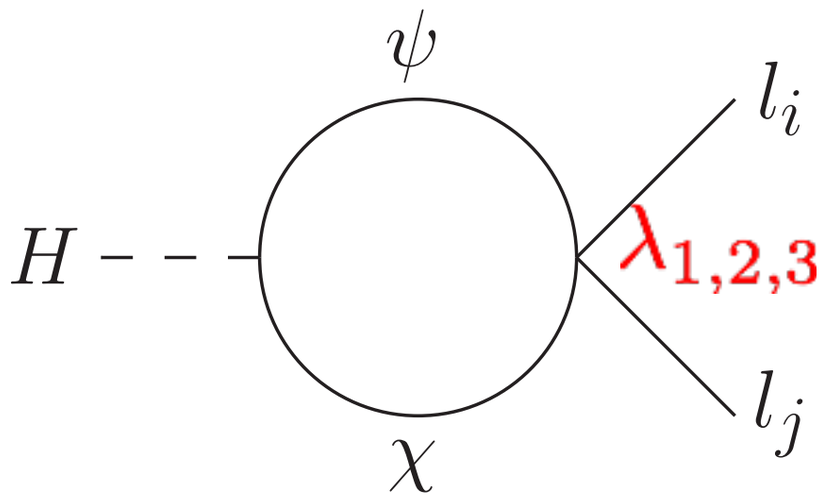
$$\mathcal{O}_{\text{Yukawa}} = y H \psi^c \chi$$



4-fermion vertex

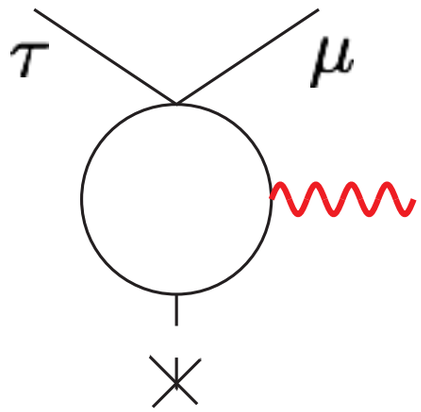
Effective theory: 3 contractions for $\mathcal{O}_{\rm 4fermion}$

$$\frac{(\lambda_1)_{ij}}{\Lambda^2}\psi^c L_i \chi e_j^c \quad , \qquad \frac{(\lambda_2)_{ij}}{\Lambda^2}\psi^c \chi L_i e_j^c \quad , \qquad \frac{(\lambda_3)_{ij}}{\Lambda^2}\psi \chi^c L_i^\dagger e_j^{c\dagger}$$

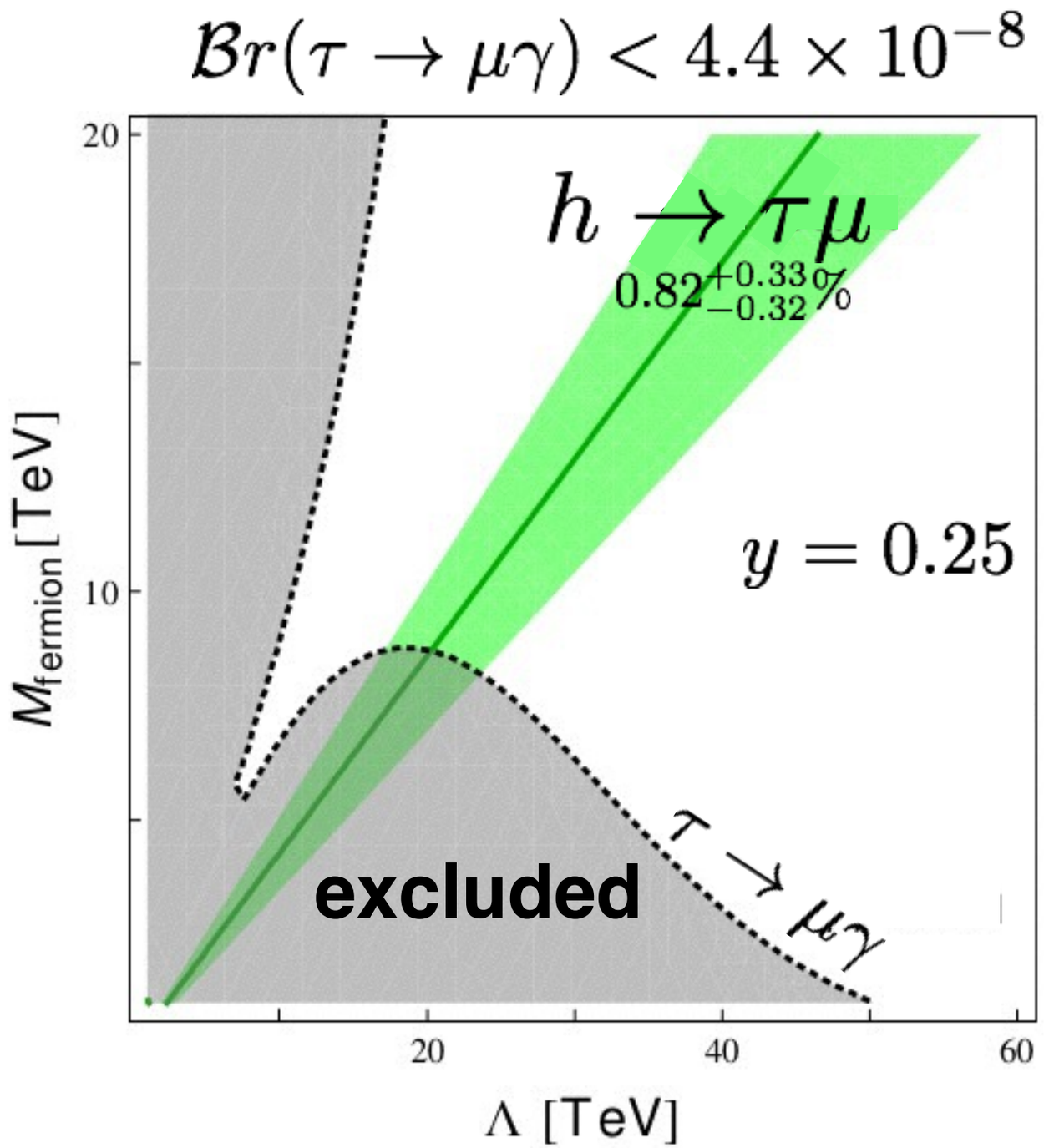


$\tau\mu$ LFV

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



- All $(\lambda_{1,2,3})_{\tau\mu} = 1$



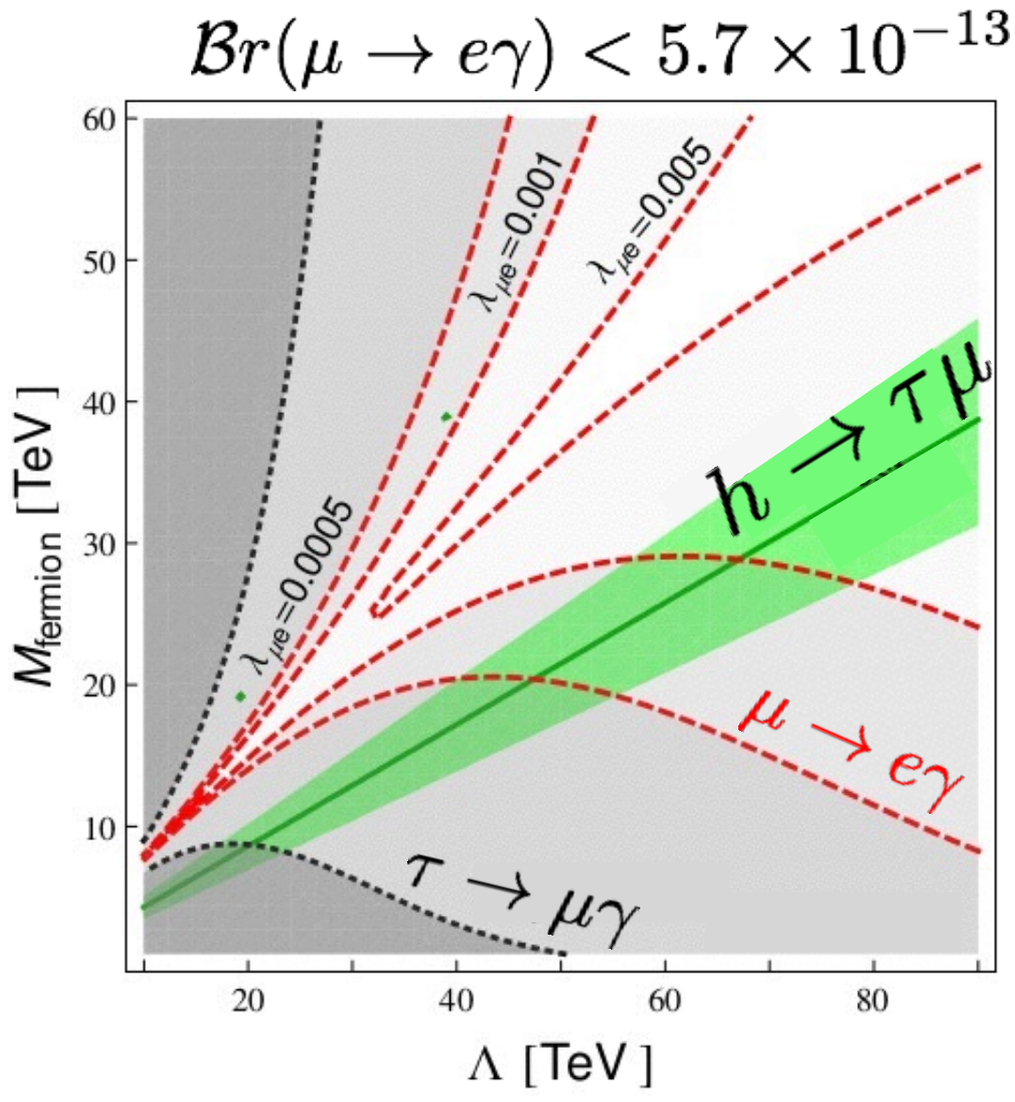
*Belle, BaBar collabs.

- One can also study LFV with other leptons.

μe **LFV**

- Demands a tiny LFV coupling

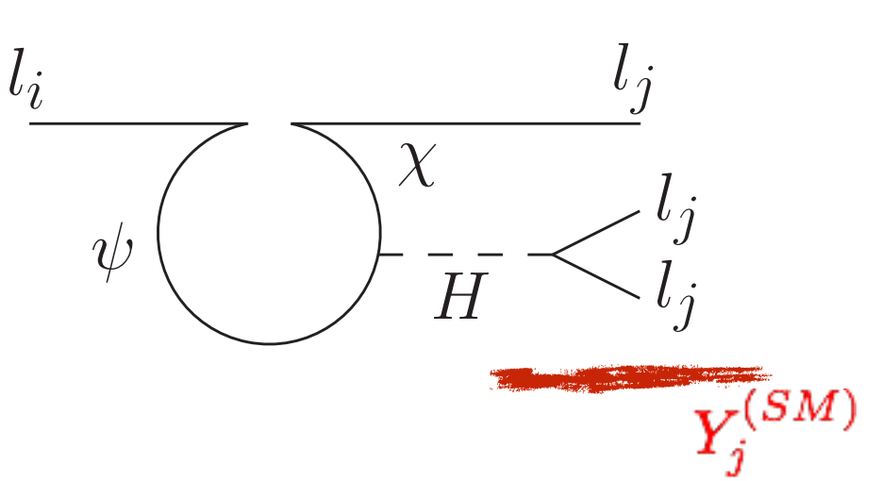
$$\lambda_{\mu e} \sim 10^{-3} - 10^{-4}$$

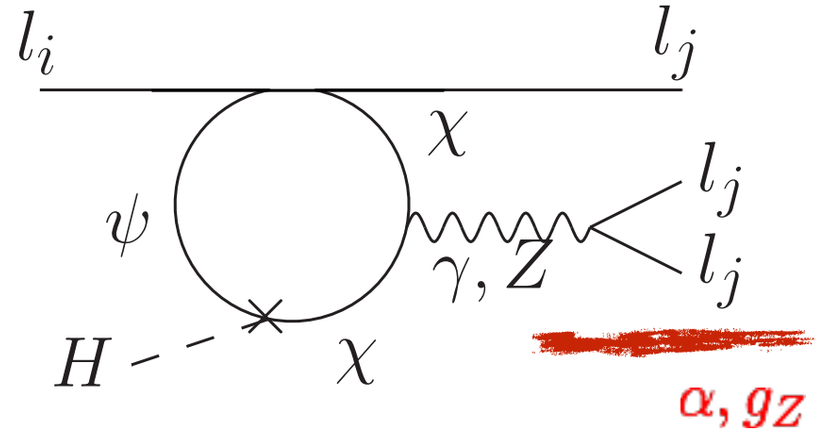


*MEG collab.

More μe observables

- $\tau \to \mu\mu\mu$ and $\mu \to eee$ (subdominant)





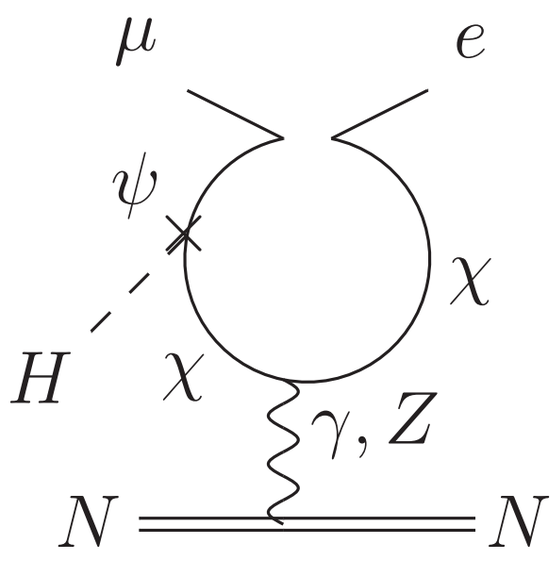
$$\mathcal{B}r(\mu \to eee) < 1.0 \times 10^{-12}$$ SINDRUM

$$\mathcal{B}r(\tau \to \mu\mu\mu) < 2.1 \times 10^{-8}$$ Belle collab.

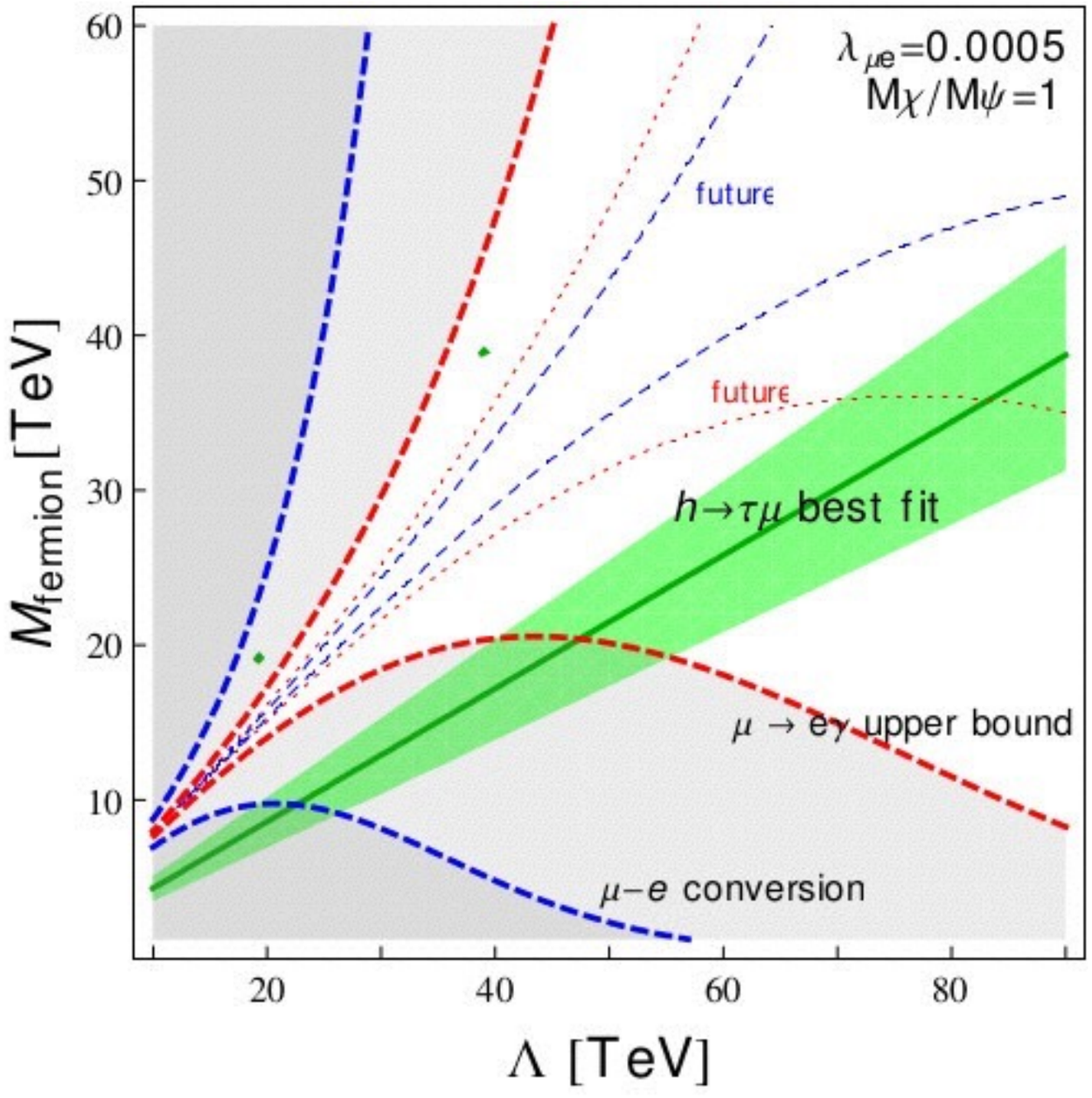
Muon-to-electron conversion in nuclei

- For $Z = 79$ *

$$\frac{\Gamma^{(Z)}_{\text{conversion}}}{\Gamma^{(Z)}_{\text{capture}}} < 7 \times 10^{-13}$$



*SINDRUM-II



- As can be seen in this model there is not a strict correlation in LFV decays of the Higgs and LFV decays of leptons. They are controlled by a different set of effective operators.

- A possible UV completion for our model is to supposed that there is a second scalar with mass Λ or a Z' with that mass.

- The relation between the different coefficients depend on the details of the UV.

Conclusions

- LFV processes are rare but any positive measurement in that sector will necessarily imply physics beyond the standard model.

- The LHC has put bounds on LFV decays of the Higgs and the best fit is on a non-zero value for the branching ratio to μ and τ.

- More data is needed to make sure that the signal is real.

- I have presented two possible models to try to accommodate the possible signal:

  - In SUSY it seems difficult to describe the signal without potentially generate CCB minima.

  - In the context of an EFT with vector like leptons the LFV decay can be explained via a LFV four fermion interaction.

- Apart from the LFV Higgs decays there are contributions to other observables but…..

- These contributions are not completely correlated since they depend on the particular UV theory that resolves the four fermion interaction.

- Charged LFV decays do not have to appear at the same order than LFV Higgs decays.

- There is a clear complementarity between LHC and low energy precision experiments.

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