Connecting lepton flavor violation and the muon anomalous magnetic moment

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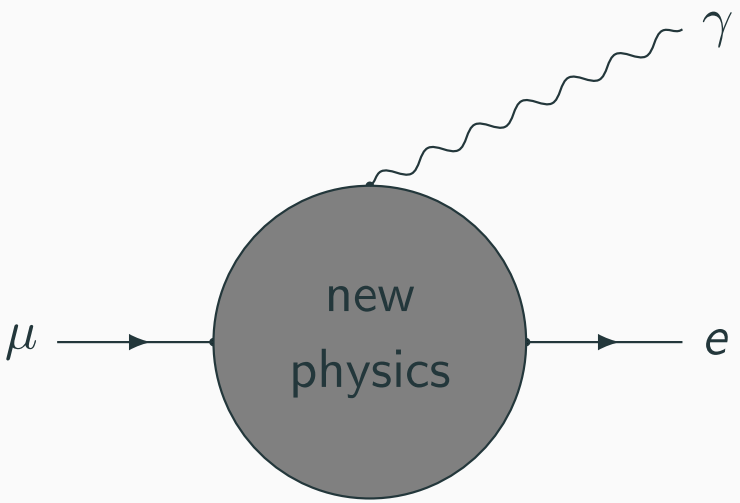
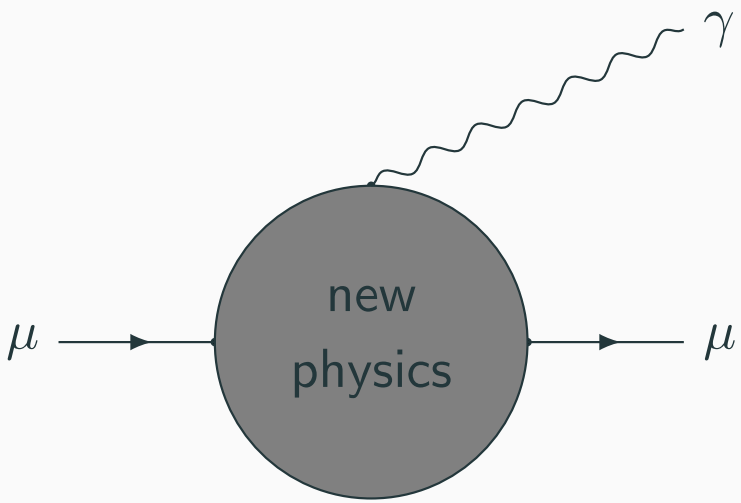
based on arXiv:1610.06587 [hep-ph]

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Introduction

- We see no definite sign of new physics at colliders (UV experiments)
- But new physics is needed: ν masses, DM, DE, B asymmetry, ...
- Maybe $\Lambda \gg m_{\text{Higgs}}$
  - $\Rightarrow$ Need a "telescope" to look at the distant physics!
  - $\Rightarrow$ Lepton flavor violation (LFV) and
  - $\Rightarrow$ Leptonic anomalous magnetic moments $(g-2)$ are very sensitive
- Both are related:

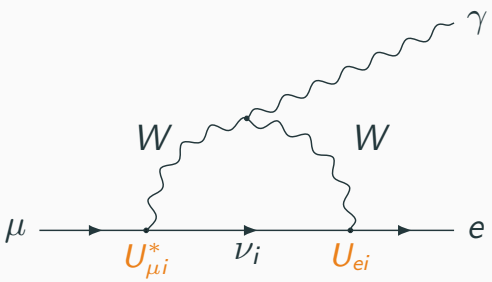




Introduction – Standard Model

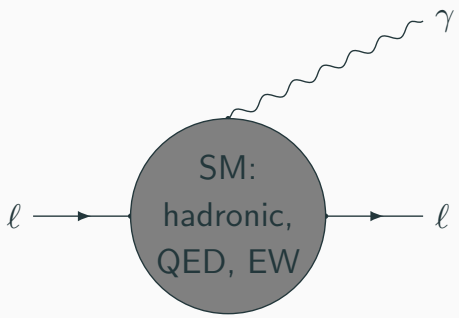
$\mu \to e\gamma$:

- forbidden in SM with $m_\nu = 0$,
- $m_\nu \neq 0$ implies LFV by neutrino flavor conversion
- charged LFV: $BR(\mu \to e\gamma) \sim 10^{-55}$ due to tiny neutrino mass

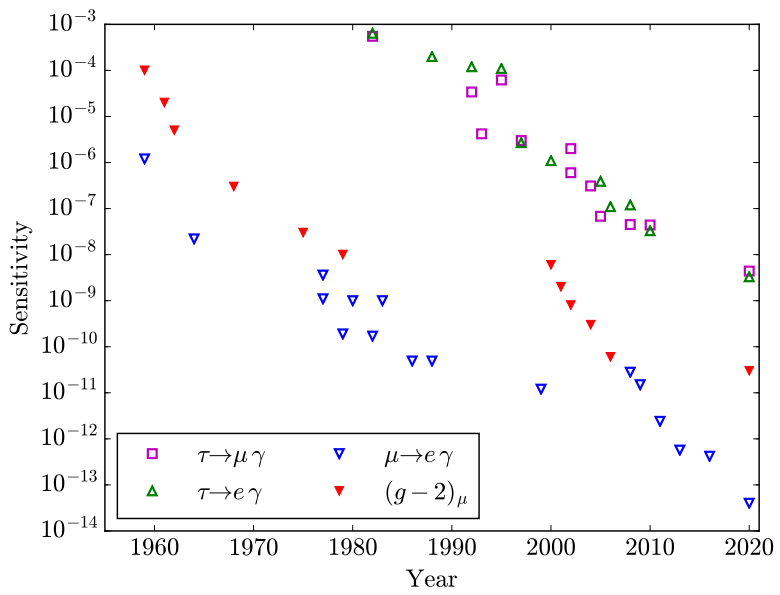


$g-2$:

- tau: very short life-time, but most sensitive to NP
- muon: $3.3\,\sigma$ discrepancy between SM prediction and measurement
- electron: very precise measurement of fine structure constant α_{em}



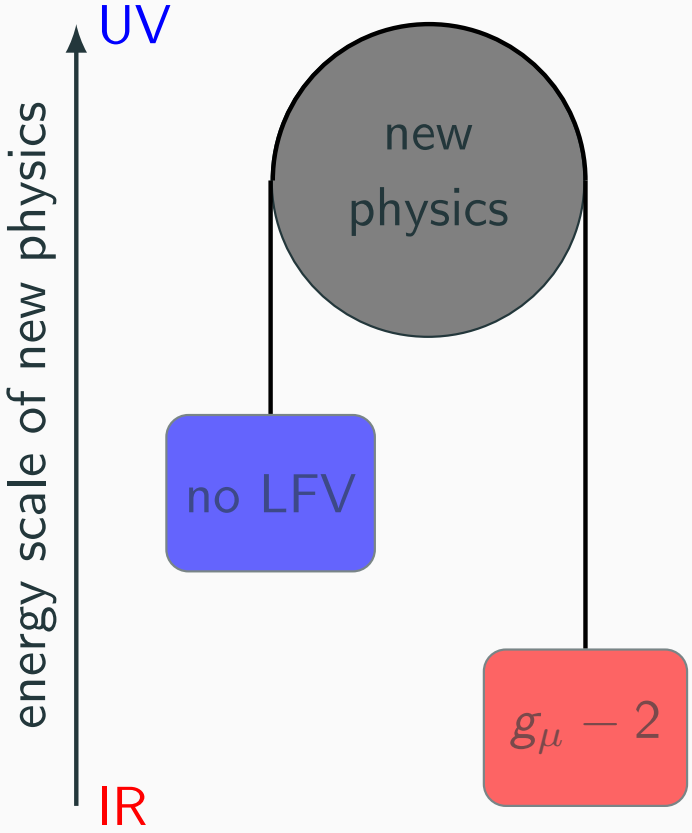
Introduction – current status



- $\mu \to e\gamma$: reached unprecedented precision: [MEG] $BR(\mu \to e\gamma) \leq 4 \cdot 10^{-13}$
- $(g_\mu - 2)$: 3.3 σ excess over SM prediction: $\Delta a_\mu = 288 \cdot 10^{-11}$ [BNL E821]

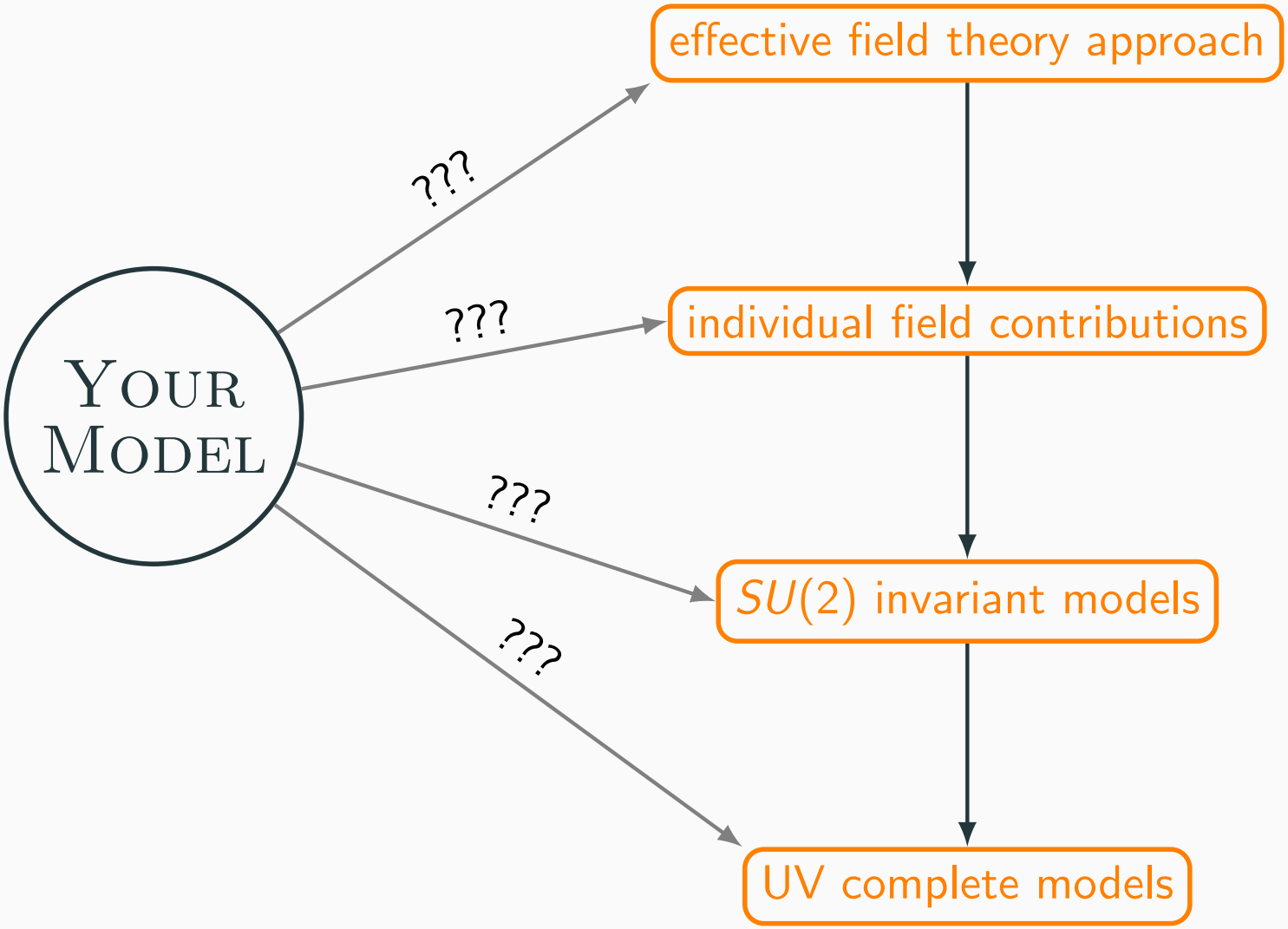
Maybe we are at the verge of seeing new physics in $\mathcal{O}(1 \ldots 10)$ years!

Observation & Conclusion



- Non-observation of LFV favors high scales for new physics
- Potential $g_\mu - 2$ excess indicates a rather low mass scale
- Use this tension to ask two questions:
  - $\rightarrow$ $g_\mu - 2$ excess confirmed
    $\Rightarrow$ should we see LFV?
  - $\rightarrow$ <u>no</u> $g_\mu - 2$ excess
    $\Rightarrow$ constraints on LFV!

How to use our paper



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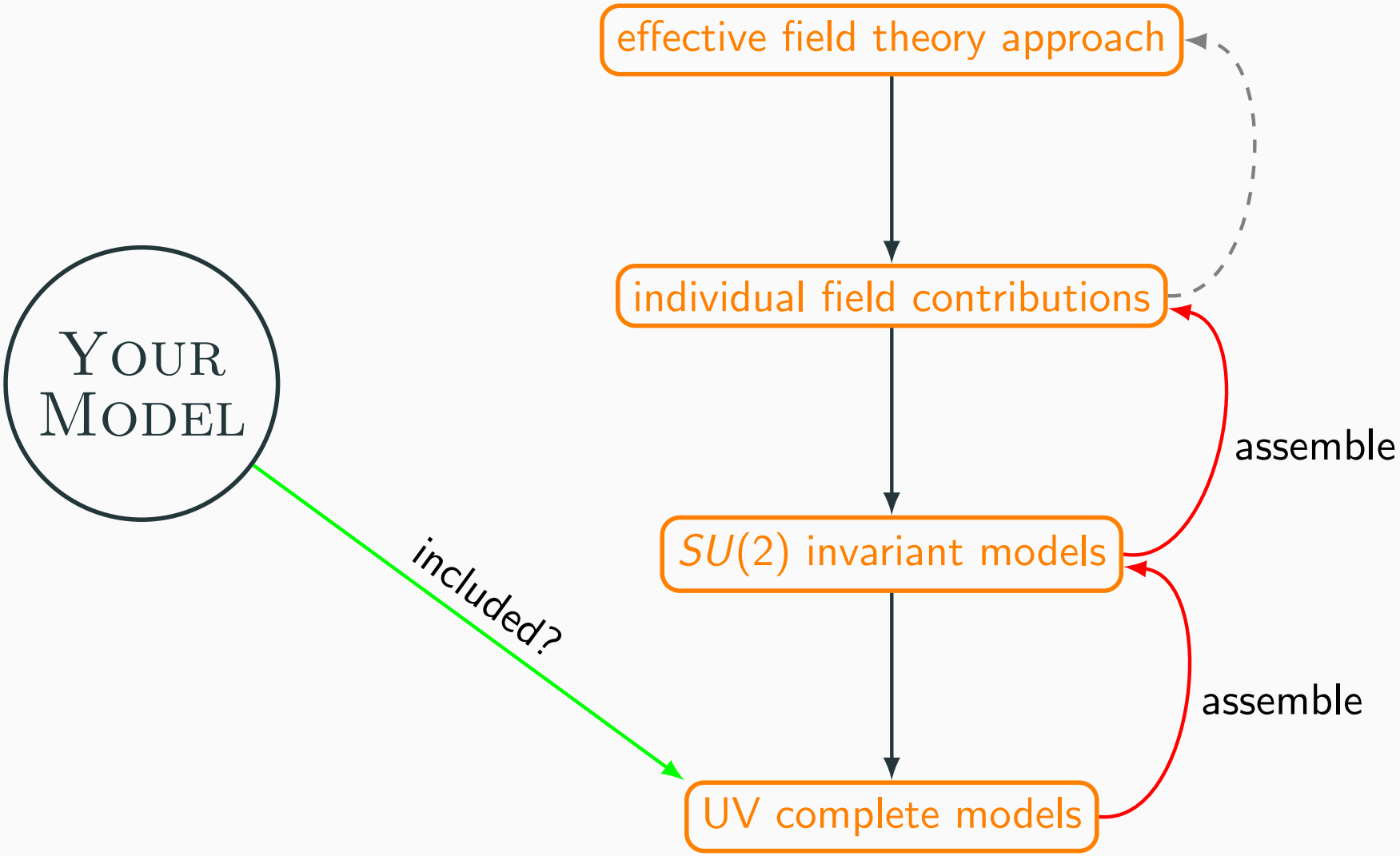


Model independent analysis

The general approach – EFTs

Start from an EFT point of view (NP $\Rightarrow d = 6$ operators):

$$\mathcal{L}_{\text{eff}} = \frac{\mu_{ij}^{M}}{2}\overline{\ell_i}\sigma^{\mu\nu}\ell_j F_{\mu\nu} + \frac{\mu_{ij}^{E}}{2}\overline{\ell_i}i\gamma^5\sigma^{\mu\nu}\ell_j F_{\mu\nu} + \textit{off-shell}\ \text{contributions}$$

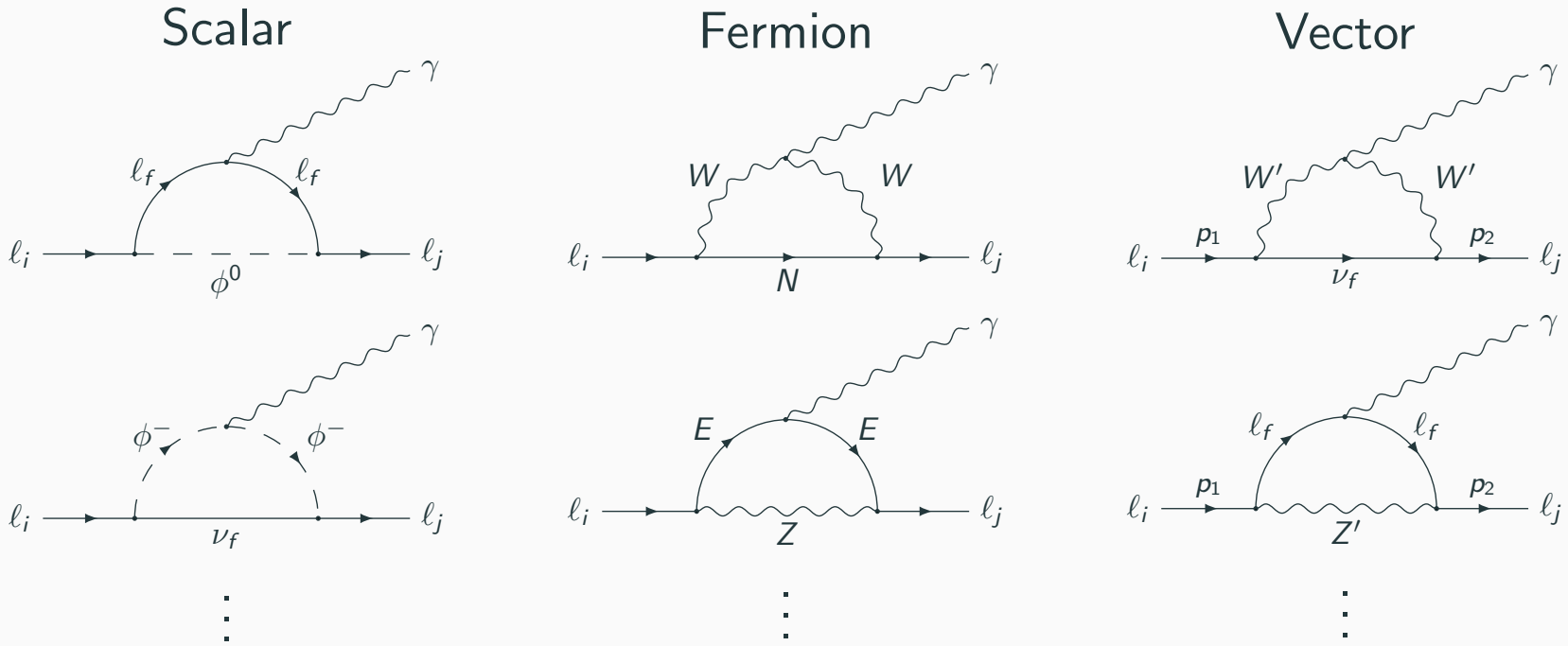
Consider form factors $\mu_{ij}^{M/E} \equiv e\, m_i A_{ij}^{M/E}/2$:

$$\Rightarrow \Delta a_{\ell_i} \equiv (g-2)/2 - (g-2)_{\text{SM}}/2 = A_{ii}^{M} m_i^2 \ \text{(no sum)}$$

$$\Rightarrow BR\left(\ell_i \to \ell_j \gamma\right) = \frac{3(4\pi)^3 \alpha_{\text{em}}}{4G_F^2}\left(\left|A_{ji}^{M}\right|^2 + \left|A_{ji}^{E}\right|^2\right) BR\left(\ell_i \to \ell_j \nu_i \overline{\nu_j}\right)$$

The general approach – simplified models

Calculate contributions to $A^{E/M}$ from one field of spin $s = 0,\ 1/2,\ 1$ and electric charge $Q = 0,\ 1,\ 2$ coupling to SM leptons:



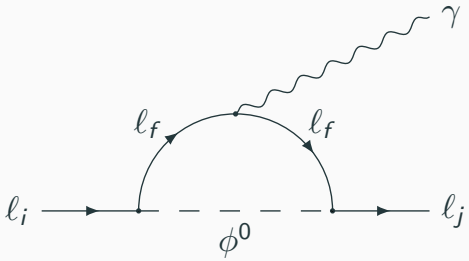
The general approach – $SU(2)_L$ invariant models

An example: scalar doublet $\phi = (\phi^+, \phi^0)^T$,

$$\mathcal{L}_{\rm int} = g_{ij}\,\overline{e_R^i}\,\phi^\dagger \cdot L^j + \text{h.c.}$$

$$g_{ij} = g \begin{pmatrix} 1 & 10^{-3} & 10^{-6} \\ 10^{-3} & 1 & 10^{-3} \\ 10^{-6} & 10^{-3} & 1 \end{pmatrix}$$

$\mathcal{A}(\ell_i \to \ell_j\,\gamma) =$



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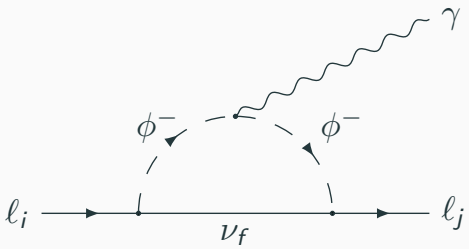

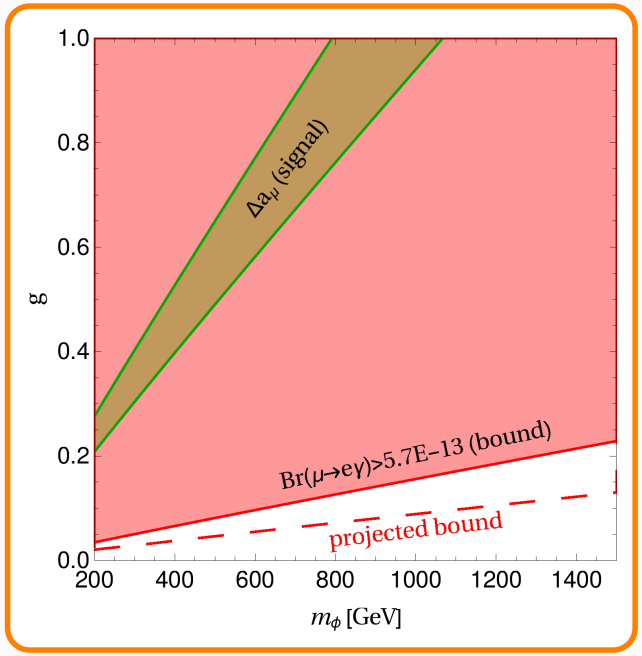

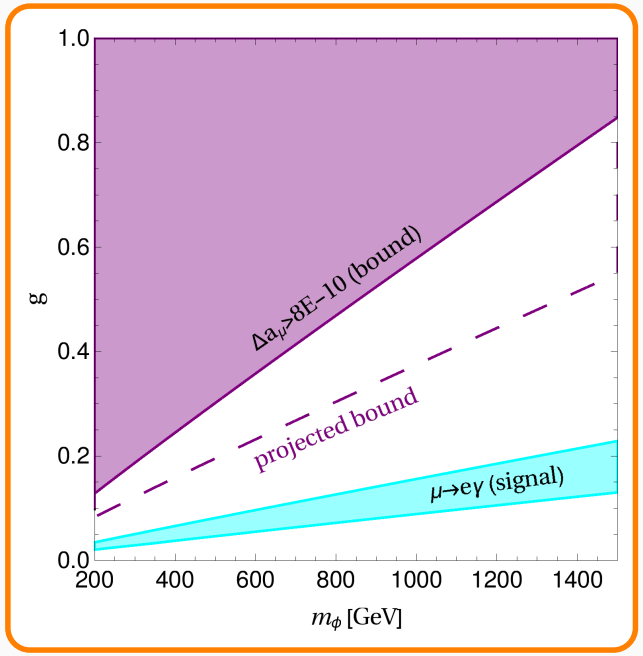

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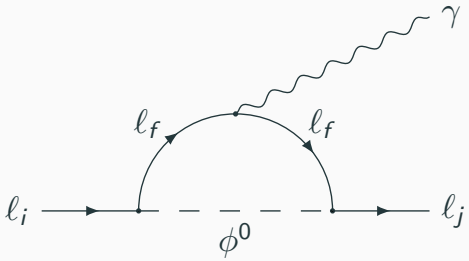

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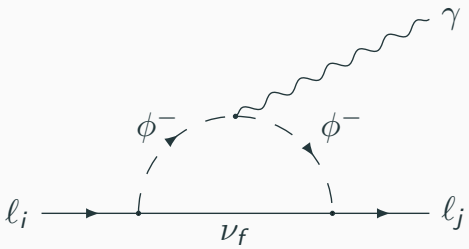

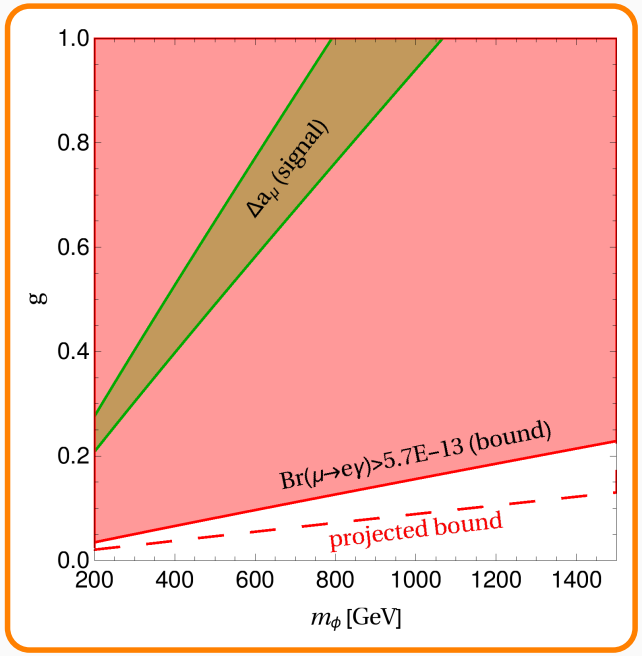

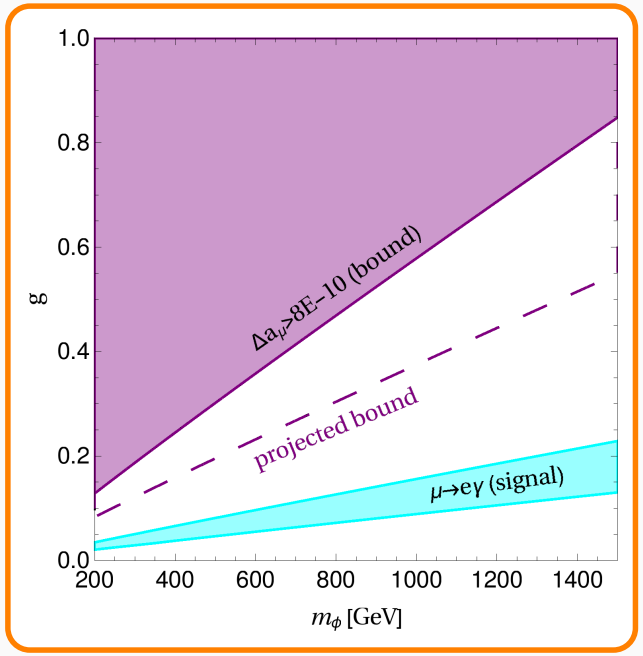

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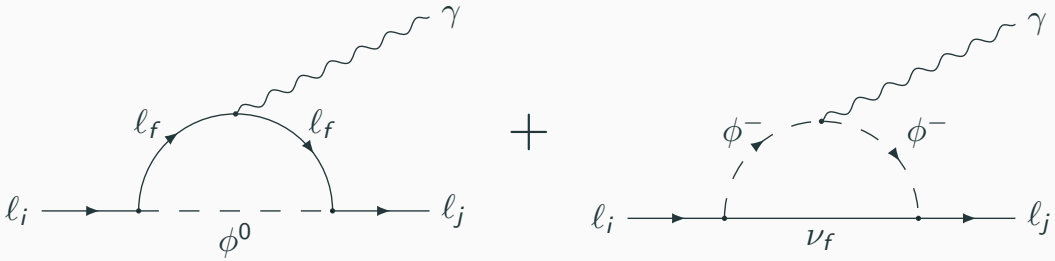

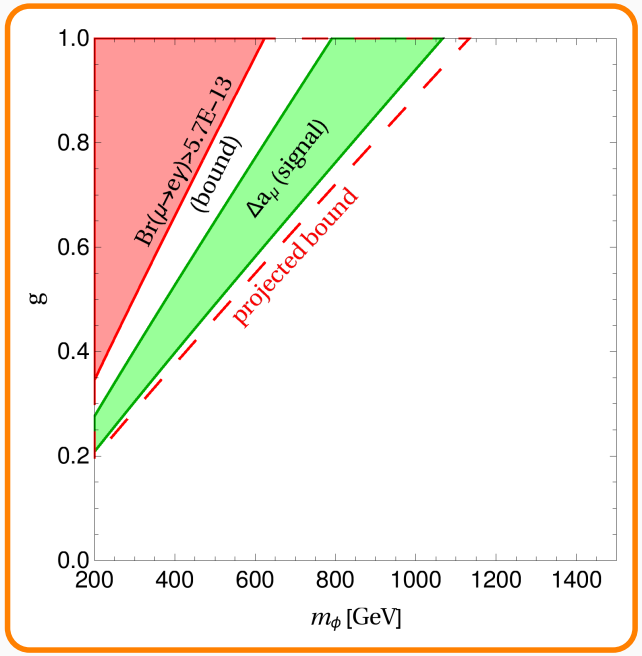

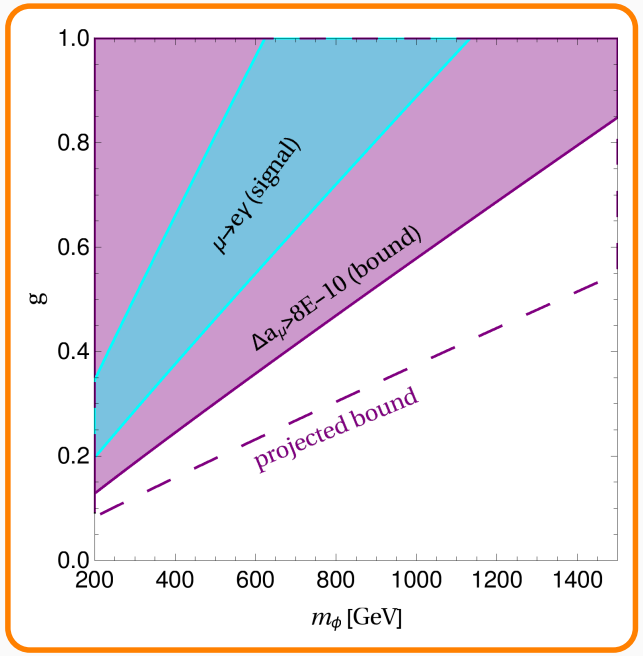

Results for specific models

UV complete models arXiv:1610.06587 [hep-ph]

- Minimal Supersymmetric Standard Model (MSSM)
- Left-Right symmetric model
- Two-Higgs-doublet models
- Scotogenic model (radiative seesaw)
- Zee-Babu model
- $B - L$ gauge symmetry (also with inverse seesaw)
- $SU(3) \times SU(3) \times U(1)$ model
- $L_\mu - L_\tau$ gauge symmetry
- Dark Photon

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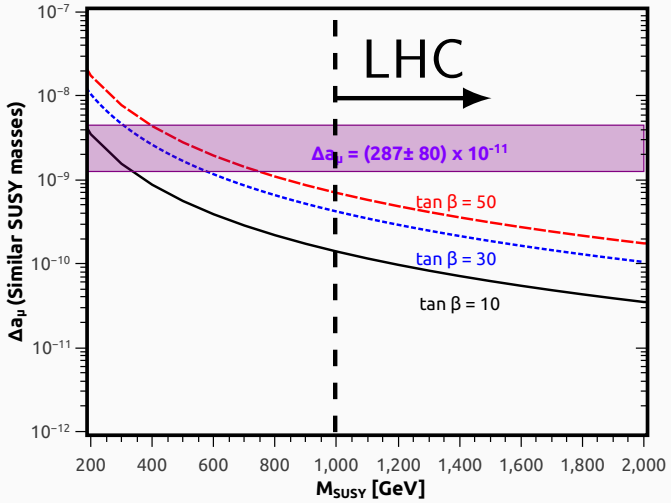
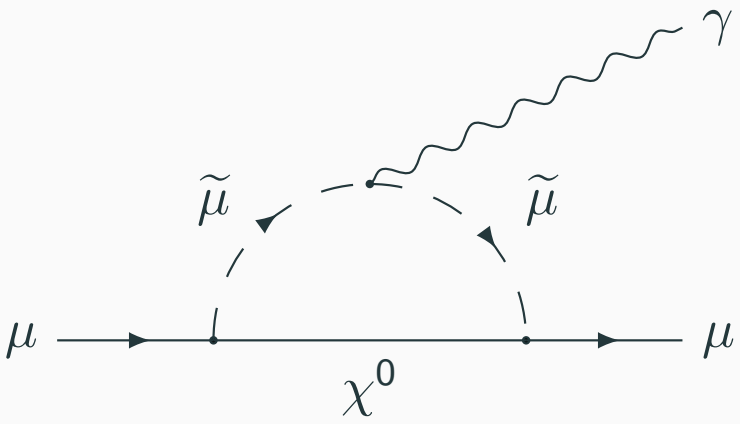
MSSM – $(g_\mu - 2)$

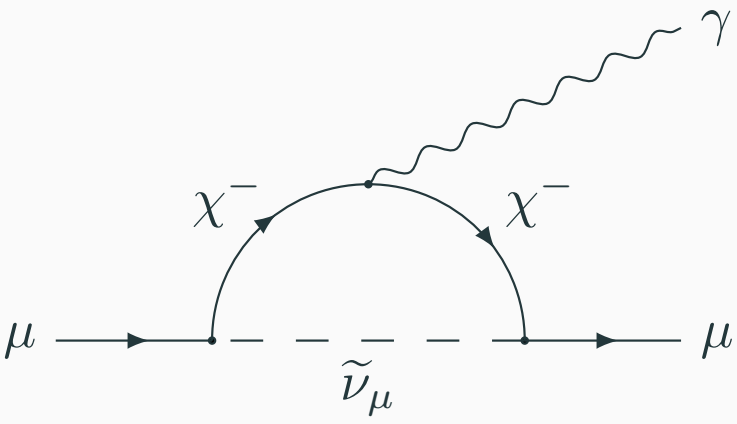
SUSY: connects bosons & fermions $\Rightarrow$ 'doubling' of SM field content + 2nd Higgs

- Many contributions (χ^0, $\chi^\pm$, $\widetilde{\mu}$, $\widetilde{\nu}_\mu$)
- Large viable parameter space, e.g. $\tan\beta = \frac{\langle H_2 \rangle}{\langle H_1 \rangle}$
  $\Rightarrow$ Make simplifying assumptions

$\xrightarrow{\text{similar SUSY masses}}$







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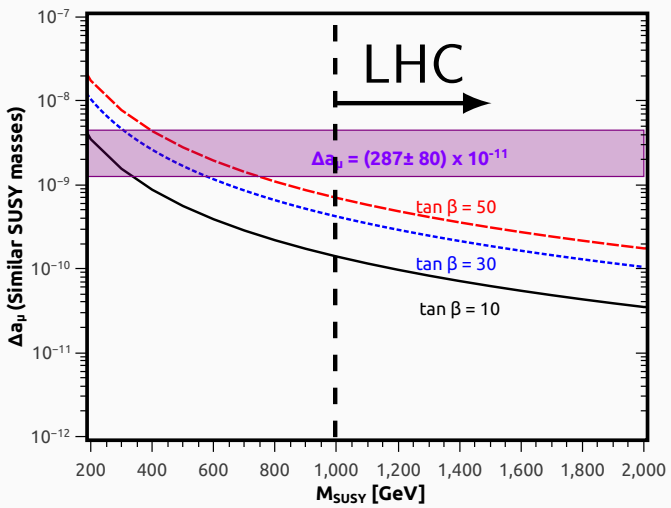
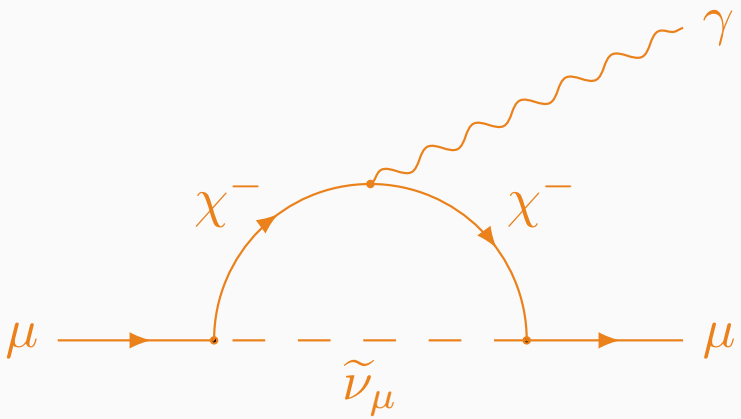
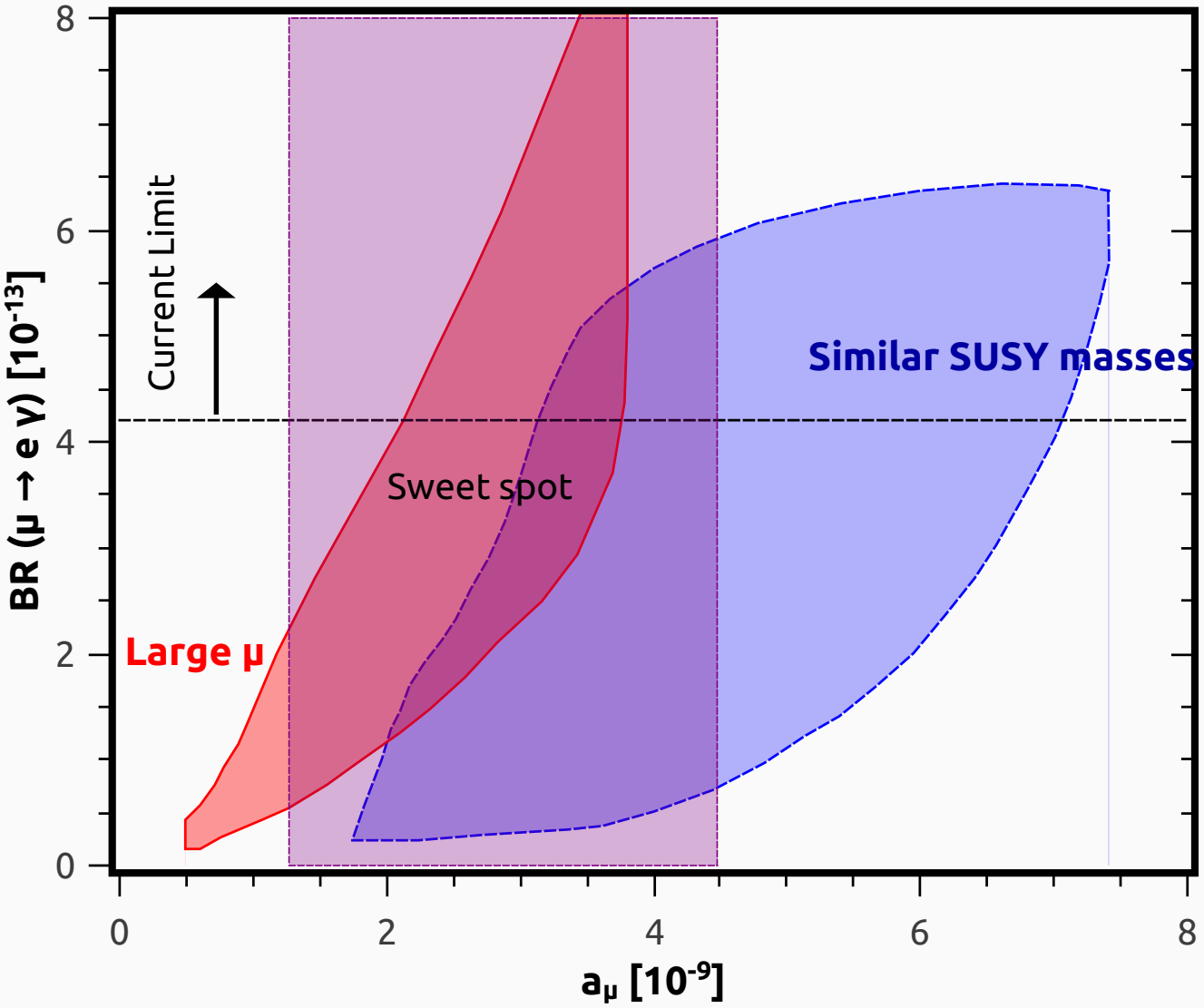


$$\Delta a_\mu^{\text{SUSY}} \simeq \Delta a_\mu^{\chi^\pm}$$
$$\simeq 10^{-9} \tan\beta \left(\frac{100\,\text{GeV}}{M_{\text{SUSY}}}\right)^2$$



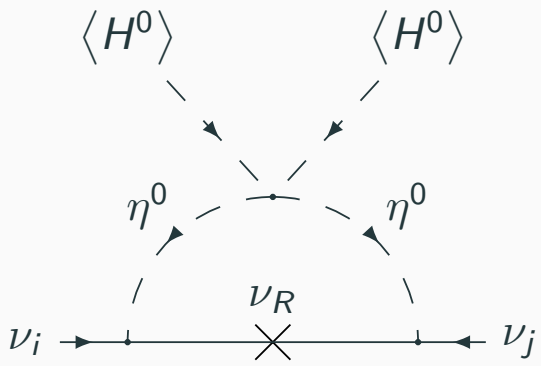
MSSM – general discussion

parameter study:



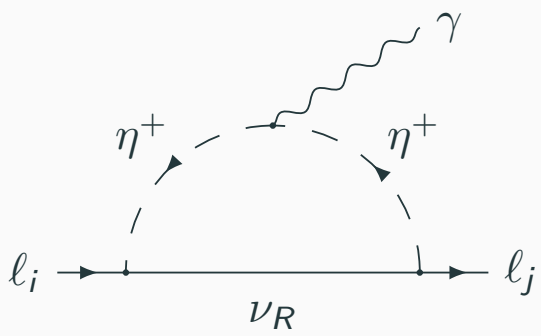
Radiative seesaw model [Ma, 2006]

- 1-Loop-level ν-mass generation
- 2nd *inert* Higgs doublet & RH ν_R
- ν-masses via DM interactions
  $\rightarrow$ *scotogenic*
- $\mathcal{L}_{\text{Yuk}} = -y_\nu^{ij}\, \overline{\nu_R}_i\, \widetilde{\eta}^\dagger \cdot L_j + \text{h.c.}$



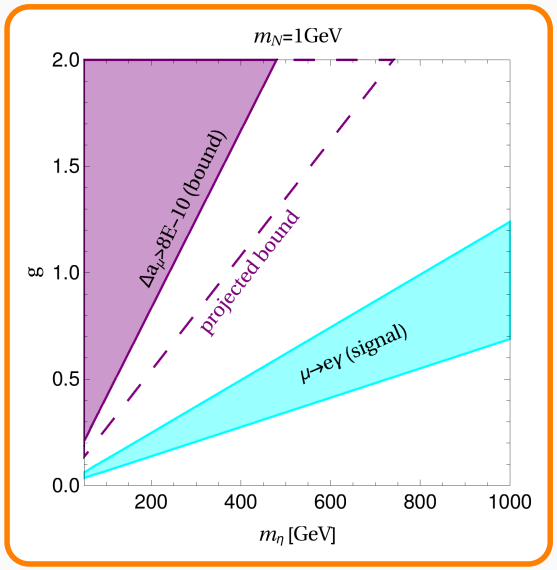
$\Delta a_\mu < 0!$

$$A_{\mu e}^{M/E} = \sum_i \frac{\left(y_\nu^\dagger y_\nu\right)_{\mu e}}{2(4\pi)^2} \frac{F\left(\frac{m_{\nu_R}}{m_{\eta^+}}\right)}{m_{\eta^+}^2}$$

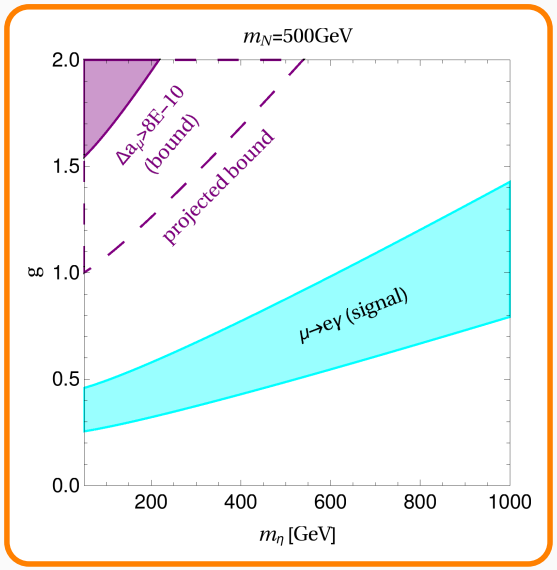


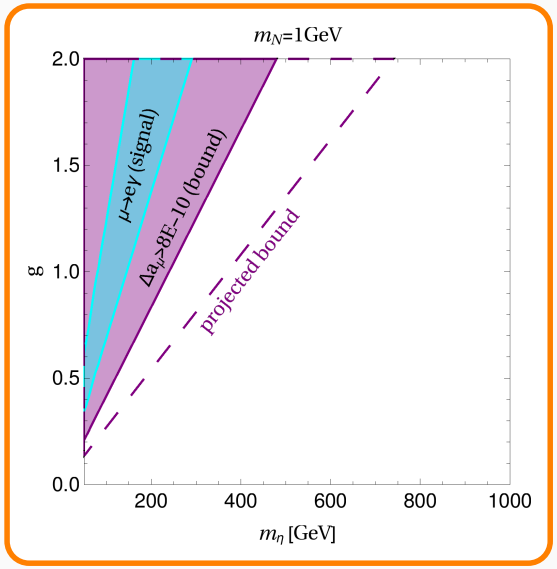
This model gives no viable explanation for the $(g_\mu - 2)$ excess!

Radiative seesaw – results

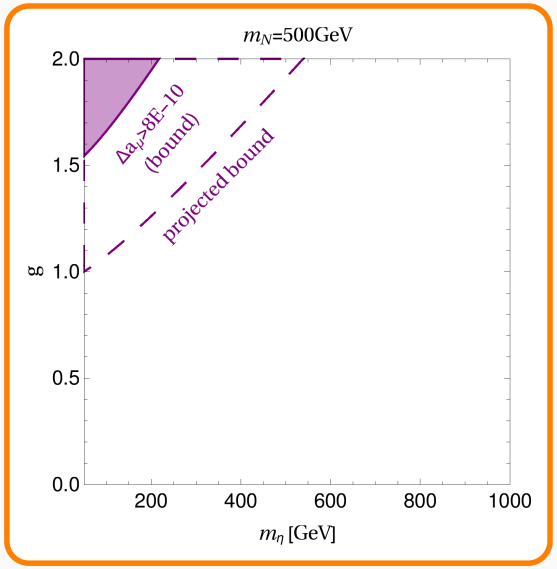


"mild hierarchy"





"strong hierarchy"



Conclusions

Conclusions

Summary

- LFV decays and $(g-2)$ are closely related
- Use one to constrain the other and reconcile potential signals with constraints
- Catalog of contributions to both processes ranging from simplified models, $SU(2)_L$ invariant models to UV complete models

Outlook

- Study other LFV processes (*off-shell* γ: $\mu \to 3e$, $\mu - e$ conversion)
- Relation to other BSM constraints (DM, collider, EWPO etc)

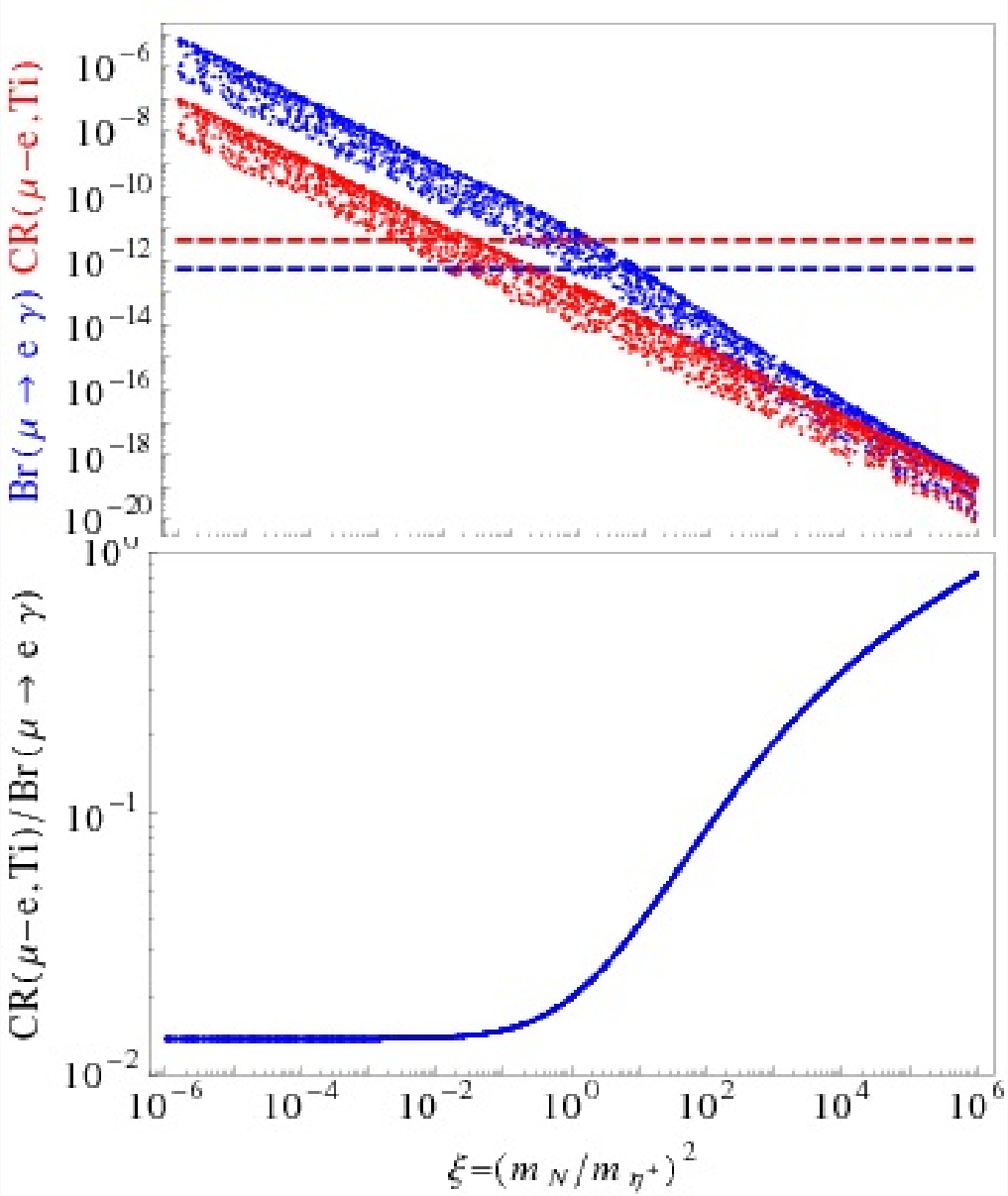
$\Rightarrow$ work in progress for the final version

Thank You!

Questions?

The full photonic amplitude

$$\mathcal{A}^{\text{photonic}} = -eA^*_\mu(q)\overline{u}_{\ell_j}(p_j)\left[\left(f^{ji}_{E0}(q^2) + \gamma_5 f^{ji}_{M0}(q^2)\right)\left(\gamma^\mu - \frac{\not{q}q^\mu}{q^2}\right) + \right.$$

$$\left. + \left(f^{ji}_{M1}(q^2) + \gamma_5 f^{ji}_{E1}(q^2)\right)\frac{i\sigma^{\mu\nu}q_\nu}{m_i}\right]u_{\ell_i}(p_i).$$

Radiative seesaw – results from [Toma, Vicente, 2013]