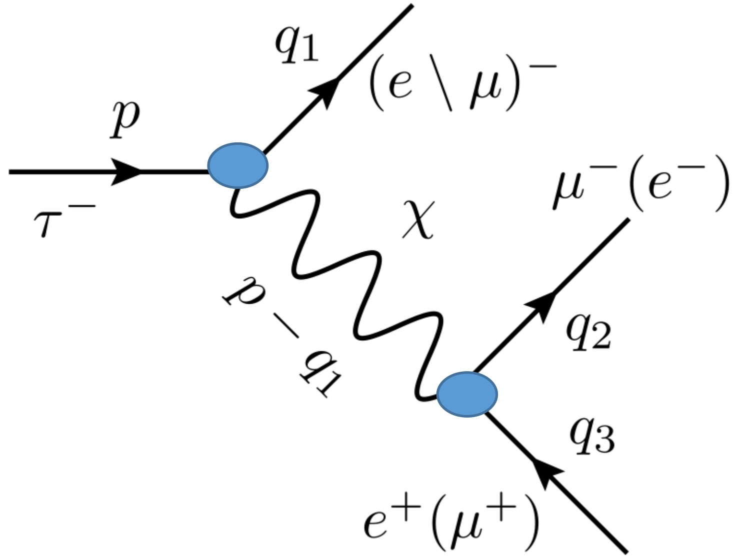
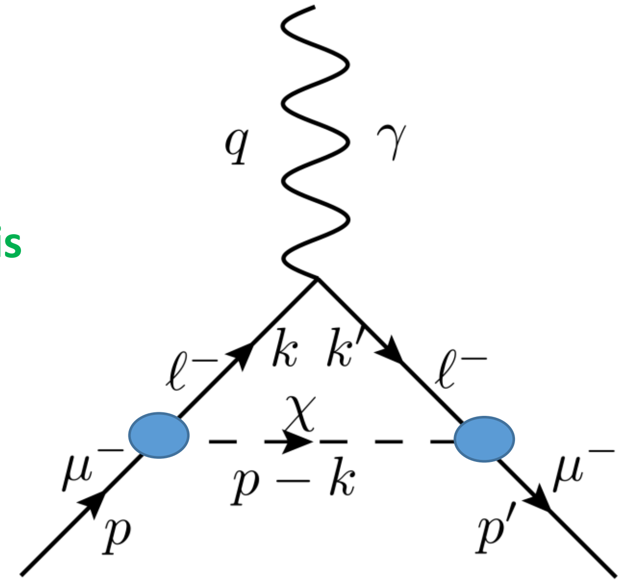
Effective Lagrangians for LFV interactions involving a boson (χ)



Work done as part of the Ph. D. Thesis
of Marcela Marín
Cinvestav (Mexico City)

Pablo Roig



Matter To The Deepest
Recent Developments In Physics Of Fundamental Interactions
XLIII International Conference of Theoretical Physics

Katowice, Poland, 1-6 Sept. 2019

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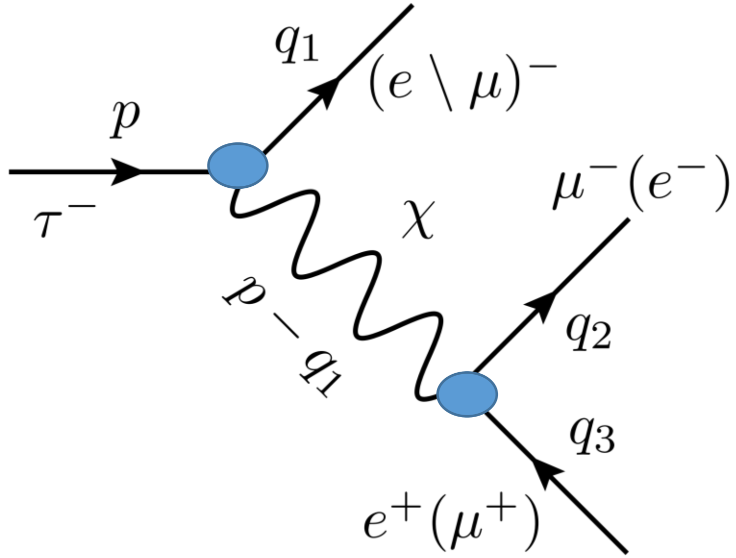

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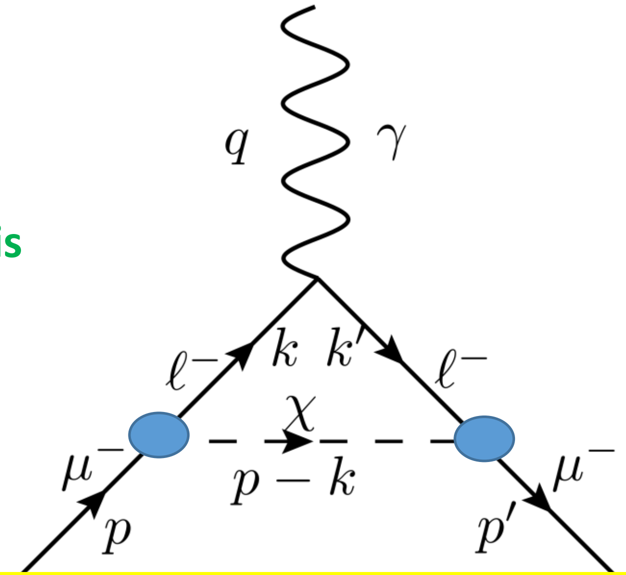

We should upload the pre-print to arXiv soon, so suggestions for improvements are very welcome!!

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CONTENTS

MOTIVATION

DESY 95-071
April 1995

ISSN 0418-9833

A Search for the lepton-flavour violating Decays $\tau \to e\alpha$, $\tau \to \mu\alpha$

The ARGUS Collaboration

Request by Denis Epifanov (Belle) to develop theory for this analysis.

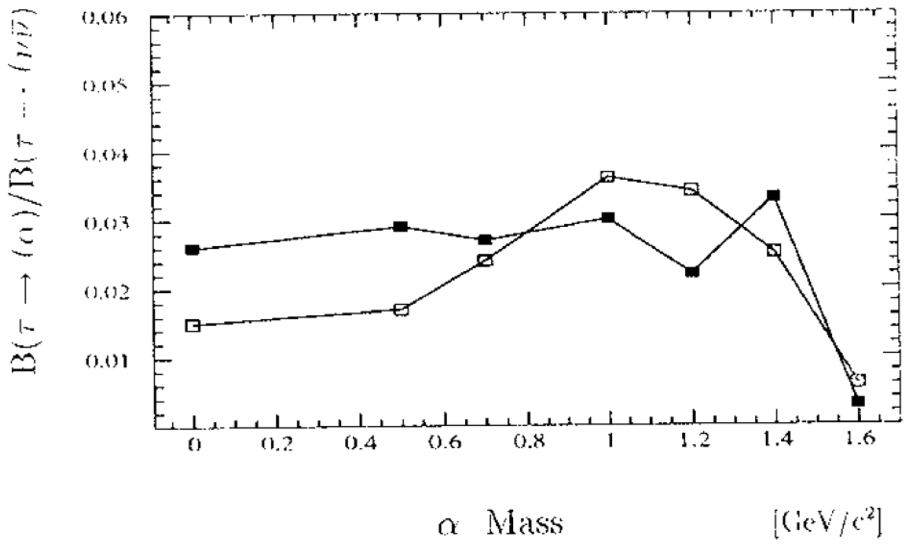

Figure 1: The upper limits at 95% confidence level on the ratio $B(\tau \to \ell\alpha)/B(\tau \to \ell\nu\bar{\nu})$ for electrons (open squares) and muons (full squares)

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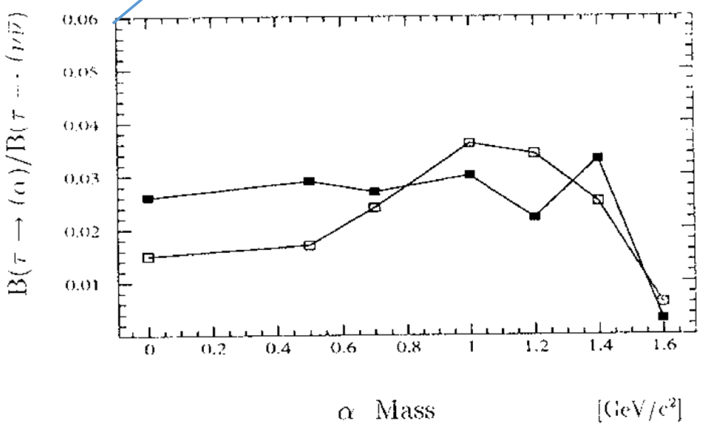
These limits (permille level) contrast a lot with most of the upper bounds on LFV decays



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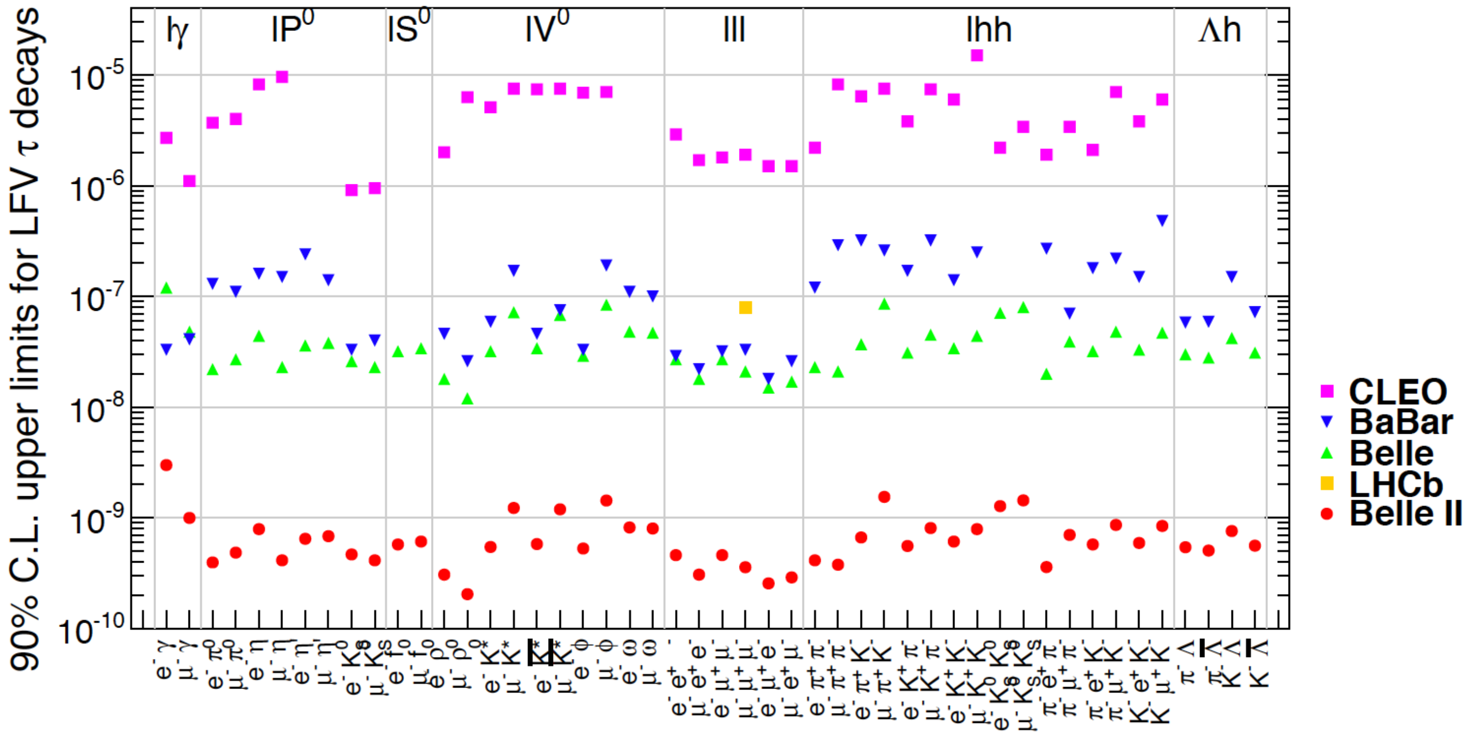

MOTIVATION: Why LFV?

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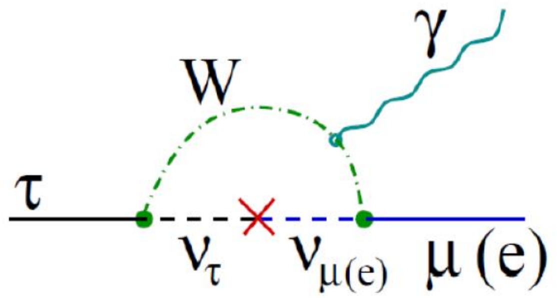

$$BR(\mu \to e\gamma) \simeq \frac{\Gamma(\mu\to e\gamma)}{\Gamma(\mu\to e\nu\bar{\nu})} = \frac{3\alpha}{32\pi}\left|\sum_{k=1,3}\frac{U_{\mu k}U^*_{ek}m^2_{\nu k}}{m^2_W}\right|^2 \sim 10^{-54}$$

UL @ 10^{-13} level

GIM-like

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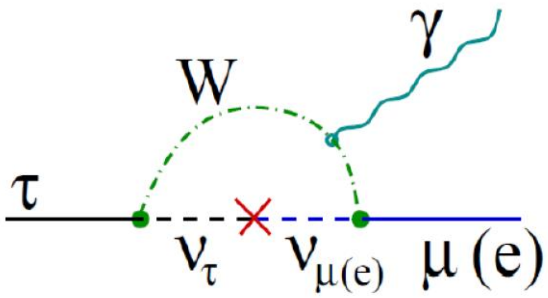

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Present limits	**SM predictions**
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LFV Process	Future Sensitivity
$\mu \to e\gamma$	6×10^{-14}
$\tau \to e\gamma$	$\sim 3 \times 10^{-9}$
$\tau \to \mu\gamma$	$\sim 3 \times 10^{-9}$
$\mu \to eee$	$\sim 10^{-16}$
$\tau \to \mu\mu\mu$	$\sim 10^{-9}$

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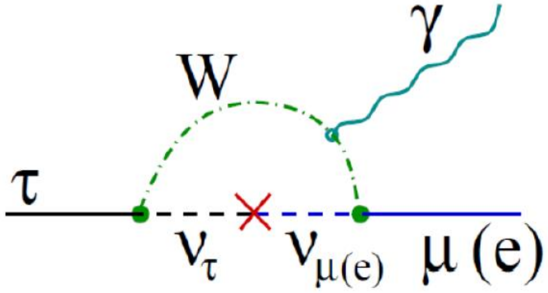

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It is easy for reasonable BSM extensions to reach it

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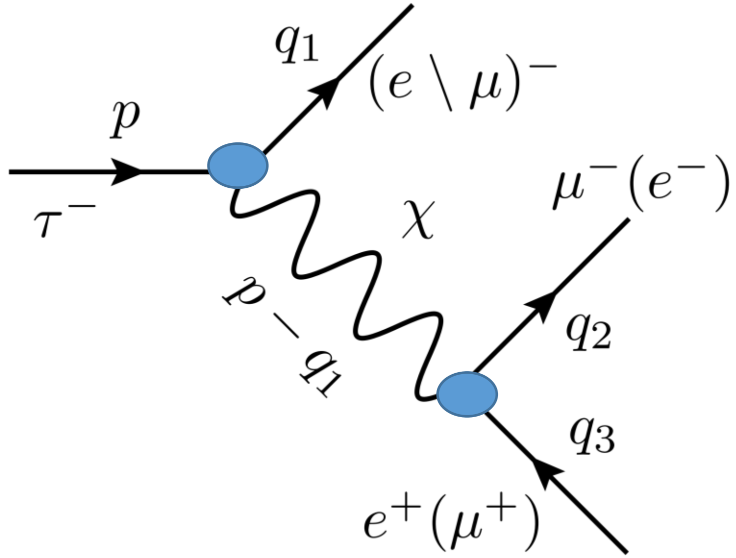
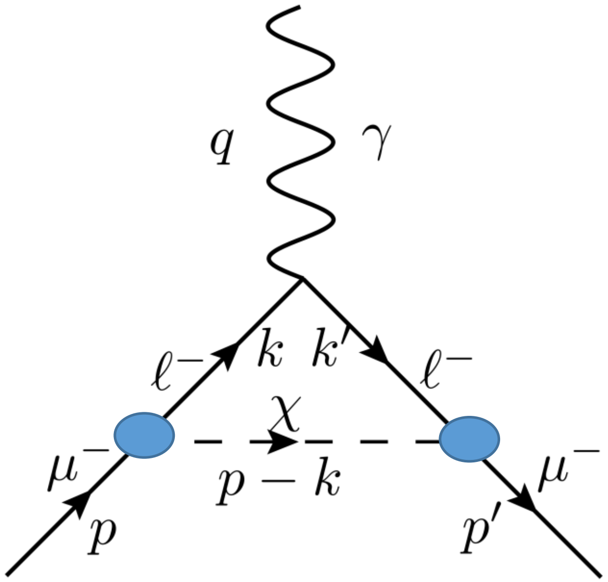
Effective Lagrangians offer the most general description of Physics that has not been resolved yet.





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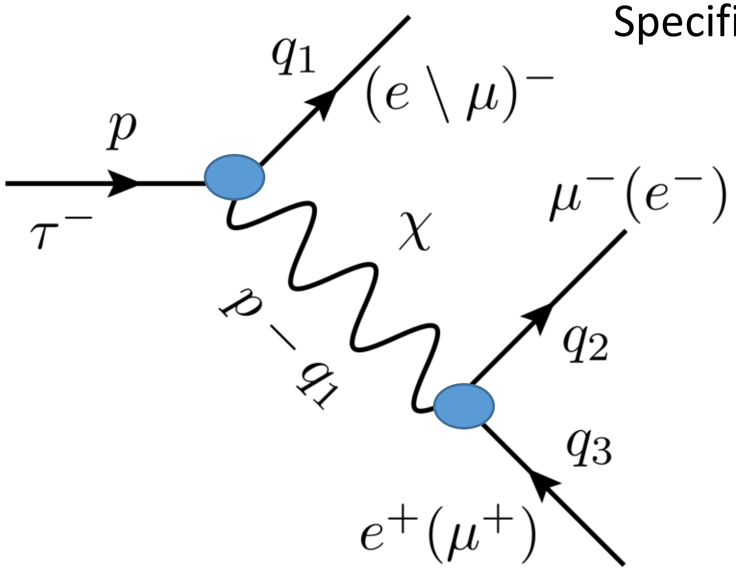
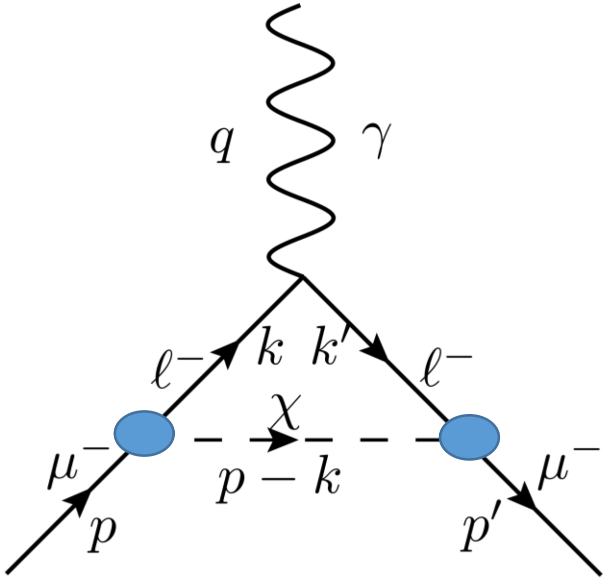
Specific BSM models are given realizations of them





EFFECTIVE LAGRANGIANS

$$\mathcal{L}_{int} = g^S_{L\ell}\bar{L}\ell S + i g^P_{L\ell}\bar{L}\gamma_5\ell P + g^V_{L\ell}\bar{L}\gamma^\mu\ell V_\mu + g^A_{L\ell}\bar{L}\gamma^\mu\gamma_5\ell A_\mu + g^T_{L\ell}\bar{L}\sigma^{\mu\nu}\ell B_{\mu\nu} + \text{h.c.}\,,$$

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χ = S, P, V, A, $B_{\mu\nu}$

We will consider $m_\chi < M_\tau$, but *this is not necessary*

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$$\mathcal{L'}_{int} = \left(\frac{g'^S_{\rm LR}}{\Lambda}\bar{\mathbb{L}}_{\rm L}\Phi\ell_{\rm R} + \frac{g'^S_{\rm RL}}{\Lambda}\bar{L}_{\rm R}\Phi^\dagger\ell_{\mathbb{L}}\right)S + i\left(\frac{g'^P_{\rm LR}}{\Lambda}\bar{\mathbb{L}}_{\rm L}\Phi\gamma_5\ell_{\rm R} + \frac{g'^P_{\rm RL}}{\Lambda}\bar{L}_{\rm R}\gamma_5\Phi^\dagger\ell_{\mathbb{L}}\right)P$$
$$+\left(g'^V_{\rm LL}\bar{\mathbb{L}}_{\rm L}\gamma^\mu\ell_{\mathbb{L}} + g'^V_{\rm RR}\bar{L}_{\rm R}\gamma^\mu\ell_{\rm R}\right)V_\mu + \left(g'^A_{\rm LL}\bar{\mathbb{L}}_{\rm L}\gamma^\mu\gamma_5\ell_{\mathbb{L}} + g'^A_{\rm RR}\bar{L}_{\rm R}\gamma^\mu\gamma_5\ell_{\rm R}\right)A_\mu$$
$$+\left(\frac{g'^T_{\rm LR}}{\Lambda}\bar{\mathbb{L}}_{\rm L}\Phi\sigma^{\mu\nu}\ell_{\rm R} + \frac{g'^T_{\rm RL}}{\Lambda}\bar{L}_{\rm R}\sigma^{\mu\nu}\Phi^\dagger\ell_{\mathbb{L}}\right)B_{\mu\nu} + \text{h.c.},$$

$L\ell$ is omitted

EFFECTIVE LAGRANGIANS

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$v \sim 246$ GeV

$$\mathbb{L}_{\mathrm{L}}(\ell_{\mathbb{L}}) = \begin{pmatrix}\mathcal{V}_{\mathrm{L}}(\nu_{\mathrm{L}})\\ L_{\mathrm{L}}(\ell_{\mathrm{L}})\end{pmatrix}$$

EFFECTIVE LAGRANGIANS

$$\mathcal{L}'_{int} = \left(\frac{g'^S_{\rm LR}}{\Lambda}\bar{\mathbb{L}}_{\rm L}\Phi\ell_{\rm R} + \frac{g'^S_{\rm RL}}{\Lambda}\bar{L}_{\rm R}\Phi^\dagger\ell_{\mathbb{L}}\right)S + i\left(\frac{g'^P_{\rm LR}}{\Lambda}\bar{\mathbb{L}}_{\rm L}\Phi\gamma_5\ell_{\rm R} + \frac{g'^P_{\rm RL}}{\Lambda}\bar{L}_{\rm R}\gamma_5\Phi^\dagger\ell_{\mathbb{L}}\right)P$$
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$$\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v+H\end{pmatrix},$$

$v \sim 246$ GeV

$$\mathbb{L}_{\rm L}(\ell_{\mathbb{L}}) = \begin{pmatrix}\mathcal{V}_{\rm L}(\nu_{\rm L})\\ L_{\rm L}(\ell_{\rm L})\end{pmatrix}$$

SEWSB

$$\mathcal{L}'_{int} = \left(g'^S_{\rm LR}\bar{L}_{\rm L}\ell_{\rm R} + g'^S_{\rm RL}\bar{L}_{\rm R}\ell_{\rm L}\right)S\frac{v+H}{\sqrt{2}\Lambda}$$
$$+ i\left(g'^P_{\rm LR}\bar{L}_{\rm L}\gamma_5\ell_{\rm R} + g'^P_{\rm RL}\bar{L}_{\rm R}\gamma_5\ell_{\rm L}\right)P\frac{v+H}{\sqrt{2}\Lambda} + \left(g'^V_{\rm LL}\bar{\mathcal{V}}_{\rm L}\gamma^\mu\nu_{\rm L}\right)V_\mu + \left(g'^A_{\rm LL}\bar{\mathcal{V}}_{\rm L}\gamma^\mu\gamma_5\nu_{\rm L}\right)A_\mu$$
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EFFECTIVE LAGRANGIANS

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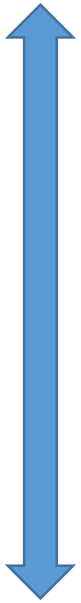

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$\mathcal{L}'_{\rm int}$ includes the interactions of $\mathcal{L}_{\rm int}$ provided

$$g^{(V,A)}_{L\ell} \equiv g'^{(V,A)}_{L\ell}$$

$$g^{(S,P,T)}_{L\ell} \equiv \frac{g'^{(S,P,T)}_{L\ell}\,v}{\sqrt{2}\Lambda}$$

Pablo Roig (Cinvestav)

EFFECTIVE LAGRANGIANS

χ = S, P, V, A, $B_{\mu\nu}$

$$\mathcal{L}'_{int} = \left(g'^{S}_{\rm LR}\bar{L}_{\rm L}\ell_{\rm R} + g'^{S}_{\rm RL}\bar{L}_{\rm R}\ell_{\rm L}\right) S\frac{v+H}{\sqrt{2}\Lambda}$$
$$+ i\left(g'^{P}_{\rm LR}\bar{L}_{\rm L}\gamma_5\ell_{\rm R} + g'^{P}_{\rm RL}\bar{L}_{\rm R}\gamma_5\ell_{\rm L}\right) P\frac{v+H}{\sqrt{2}\Lambda} + \left(g'^{V}_{\rm LL}\bar{\mathcal{V}}_{\rm L}\gamma^\mu\nu_{\rm L}\right)V_\mu + \left(g'^{A}_{\rm LL}\bar{\mathcal{V}}_{\rm L}\gamma^\mu\gamma_5\nu_{\rm L}\right)A_\mu$$
$$+ \left(g'^{V}_{\rm LL}\bar{L}_{\rm L}\gamma^\mu\ell_{\rm L} + g'^{V}_{\rm RR}\bar{L}_{\rm R}\gamma^\mu\ell_{\rm R}\right)V_\mu + \left(g'^{A}_{\rm LL}\bar{L}_{\rm L}\gamma^\mu\gamma_5\ell_{\rm L} + g'^{A}_{\rm RR}\bar{L}_{\rm R}\gamma^\mu\gamma_5\ell_{\rm R}\right)A_\mu$$
$$+ \left(g'^{T}_{\rm LR}\bar{L}_{\rm L}\sigma^{\mu\nu}\ell_{\rm R} + g'^{T}_{\rm RL}\bar{L}_{\rm R}\sigma^{\mu\nu}\ell_{\rm L}\right)B_{\mu\nu}\frac{v+H}{\sqrt{2}\Lambda} + \text{h.c.}$$

New interactions of the Higgs field with Llχ (and with νs)

$$\mathcal{L}_{int} = g^S_{L\ell}\bar{L}\ell S + ig^P_{L\ell}\bar{L}\gamma_5\ell P + g^V_{L\ell}\bar{L}\gamma^\mu\ell V_\mu + g^A_{L\ell}\bar{L}\gamma^\mu\gamma_5\ell A_\mu + g^T_{L\ell}\bar{L}\sigma^{\mu\nu}\ell B_{\mu\nu} + \text{h.c.},$$

If we **IMPOSE**

- $g'^{(S,P,T)}_{\rm LR} = g'^{(S,P,T)}_{\rm RL} \equiv g'^{(S,P,T)}_{L\ell}$,
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Small!

Effective LFV interactions involving a boson (χ)

MOTIVATION: Why effective LFV for L→lχ?

Effective Lagrangians offer the most general description of Physics that has not been resolved yet.

Specific BSM models are given realizations of them. **For instance**:

Invisible **axions** are pGbs accounting for the smallness of $\overline{\theta}$ & are viable with a large PQ SB scale.
They can be DM candidates & linked to the smallness of ν masses.

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(also of S-type)

(on-shell fermions)

$$J^{\mu a} = \bar{\psi}_i \gamma^\mu (g_V + g_A \gamma_5) T^a_{ij} \psi_j$$

↓

$$\mathcal{L}_f = -\frac{i}{F} f^a \bar{\psi}_i \left[g_V (m_i - m_j) + g_A (m_i + m_j)\gamma_5 \right] T^a_{ij} \psi_j$$

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Any χ can also be the **mediator of SM-DM interactions**

…

(Refs. will be given in the proceedings)

PHENOMENOLOGY

I restrict here to the decaying particle rest frame (not B-Factory environment)

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Work in progress

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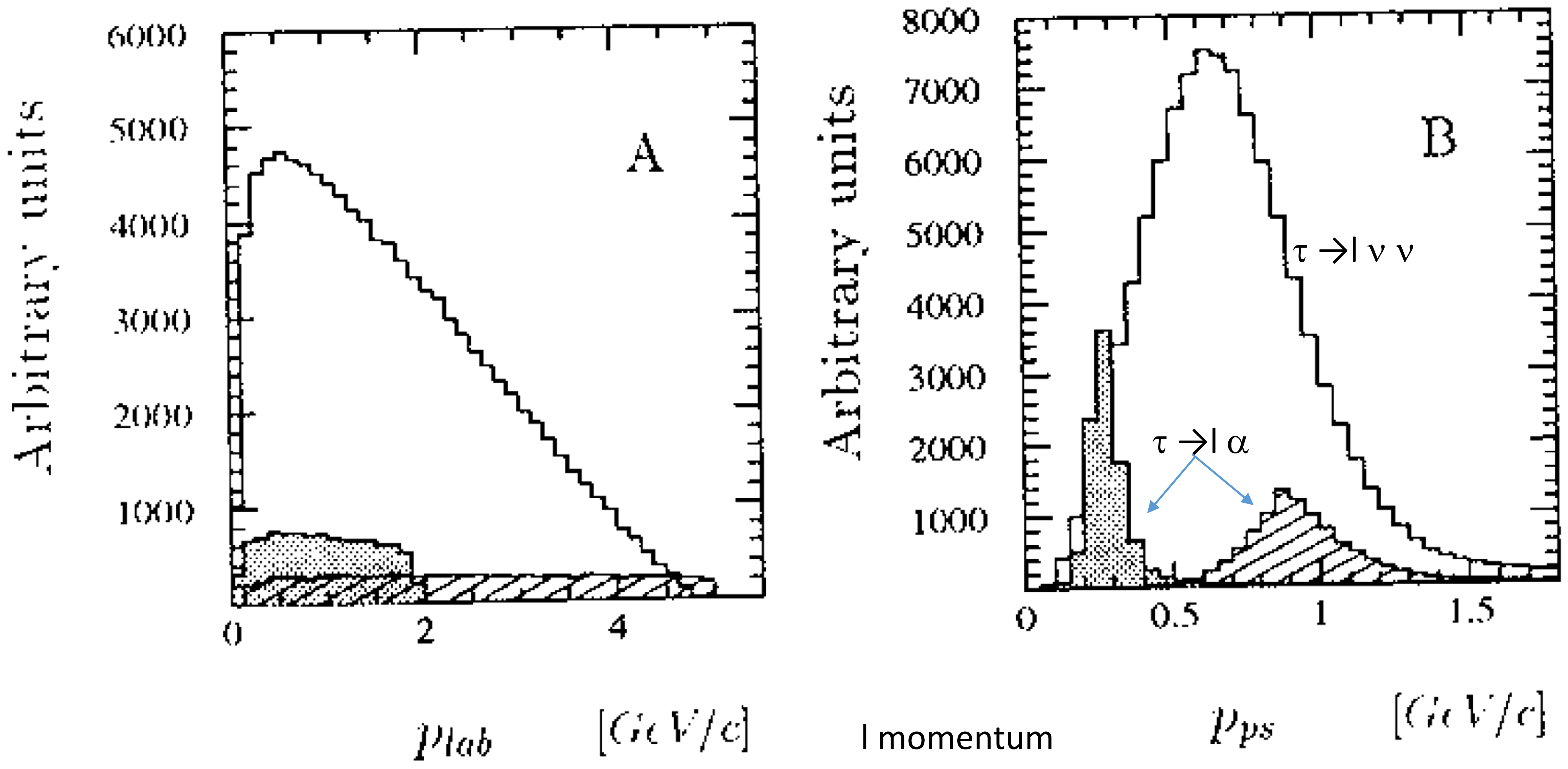
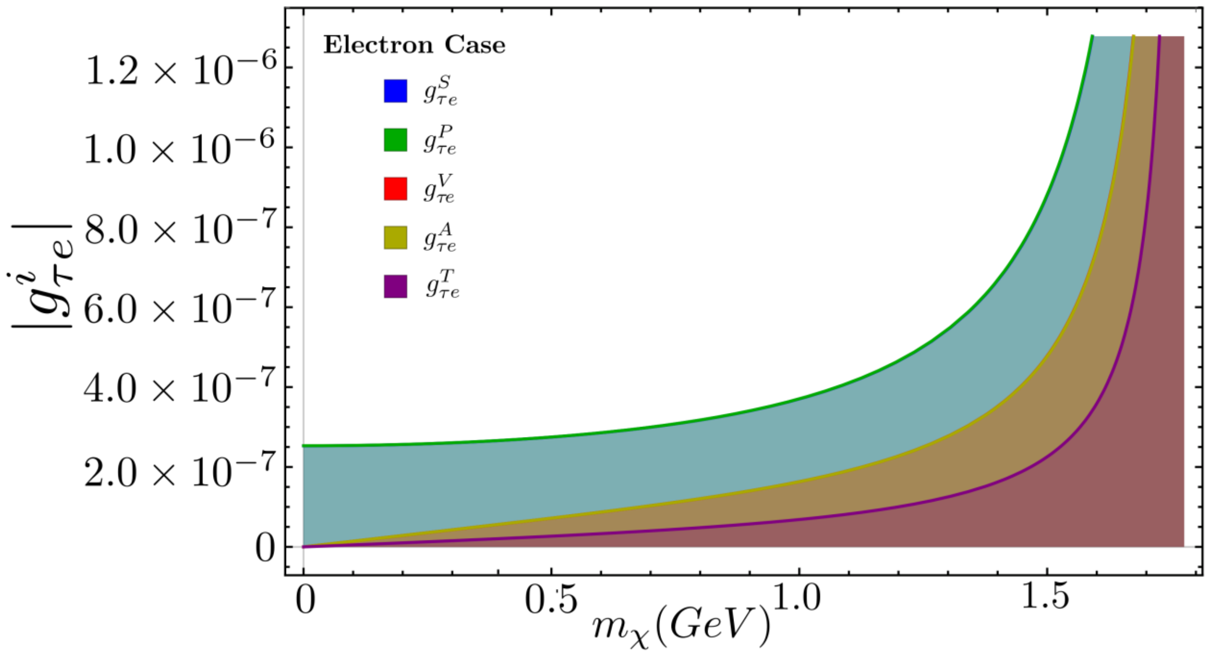
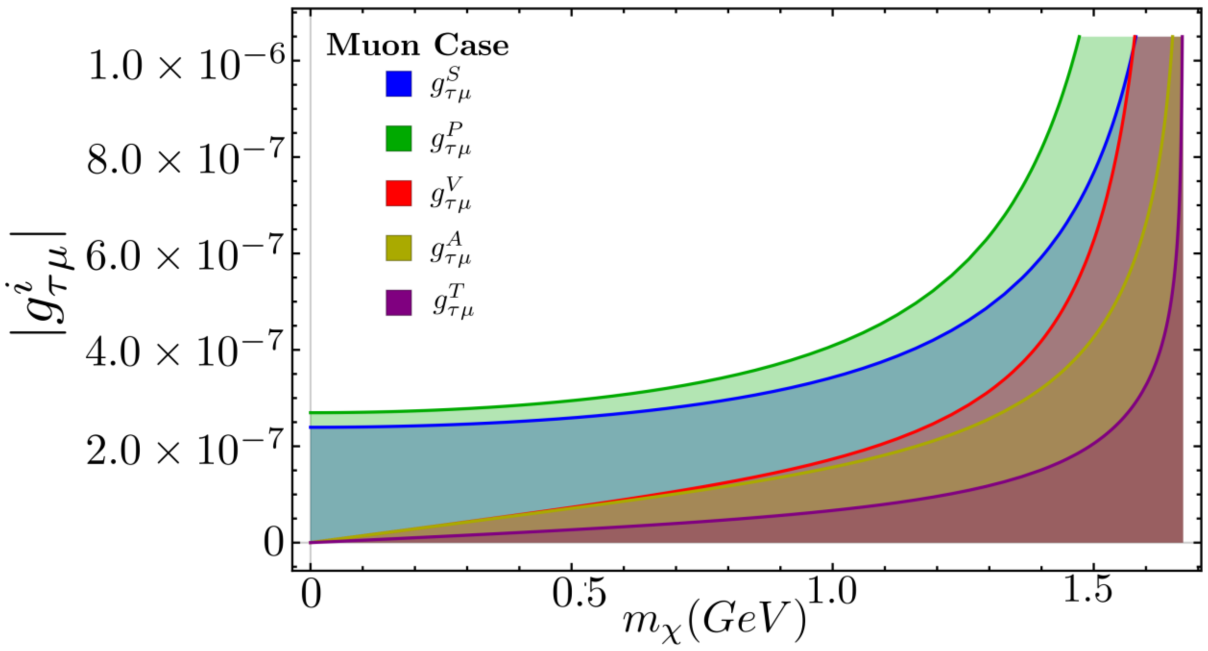


PHENOMENOLOGY: τ → l χ



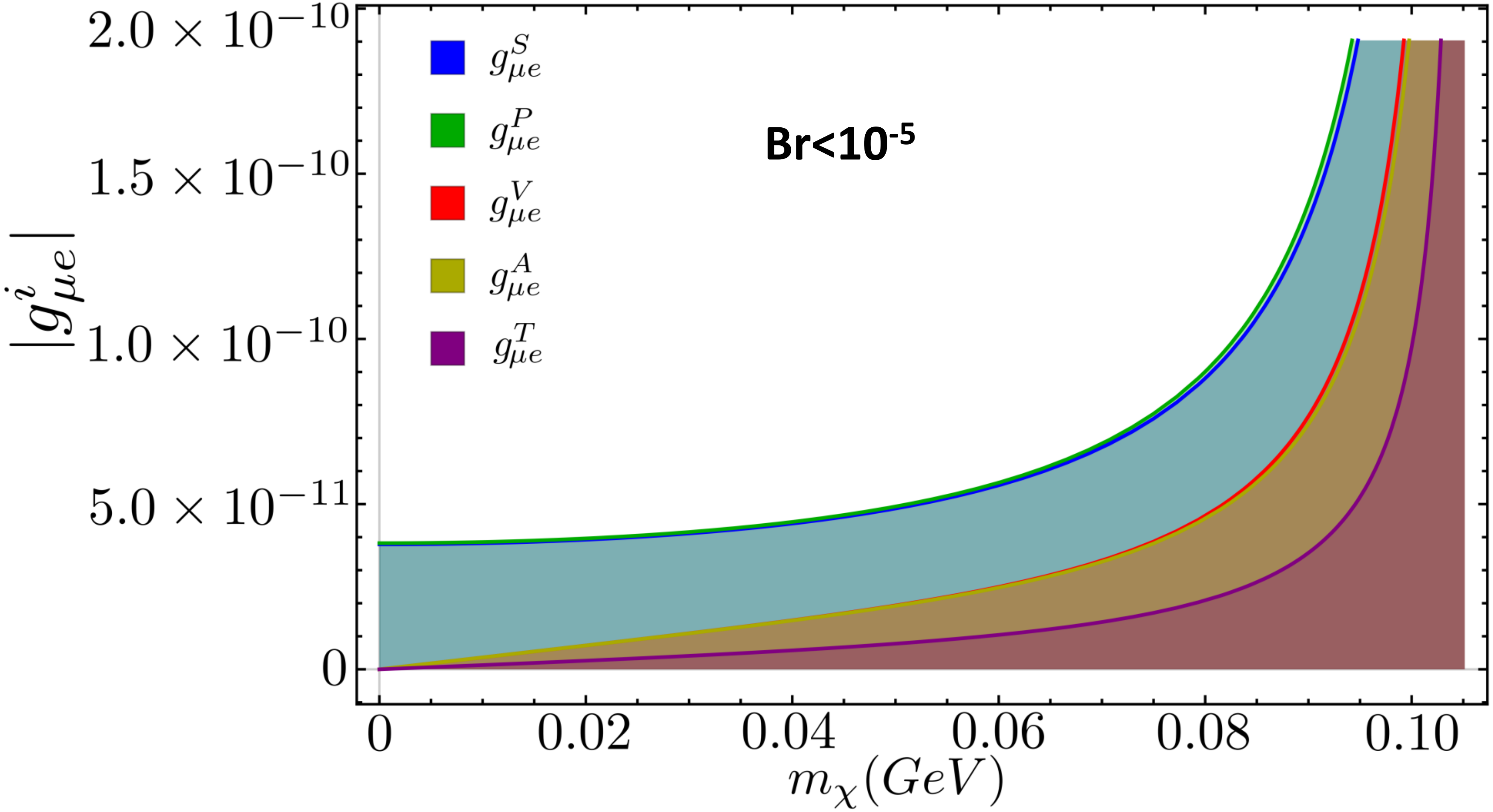
(a) $|g^i_{\tau e}|$ constraints for $\mathcal{B}r \sim 10^{-3}$ as a function of m_χ.



(b) $|g^i_{\tau \mu}|$ constraints for $\mathcal{B}r \sim 10^{-3}$ as a function of m_χ.

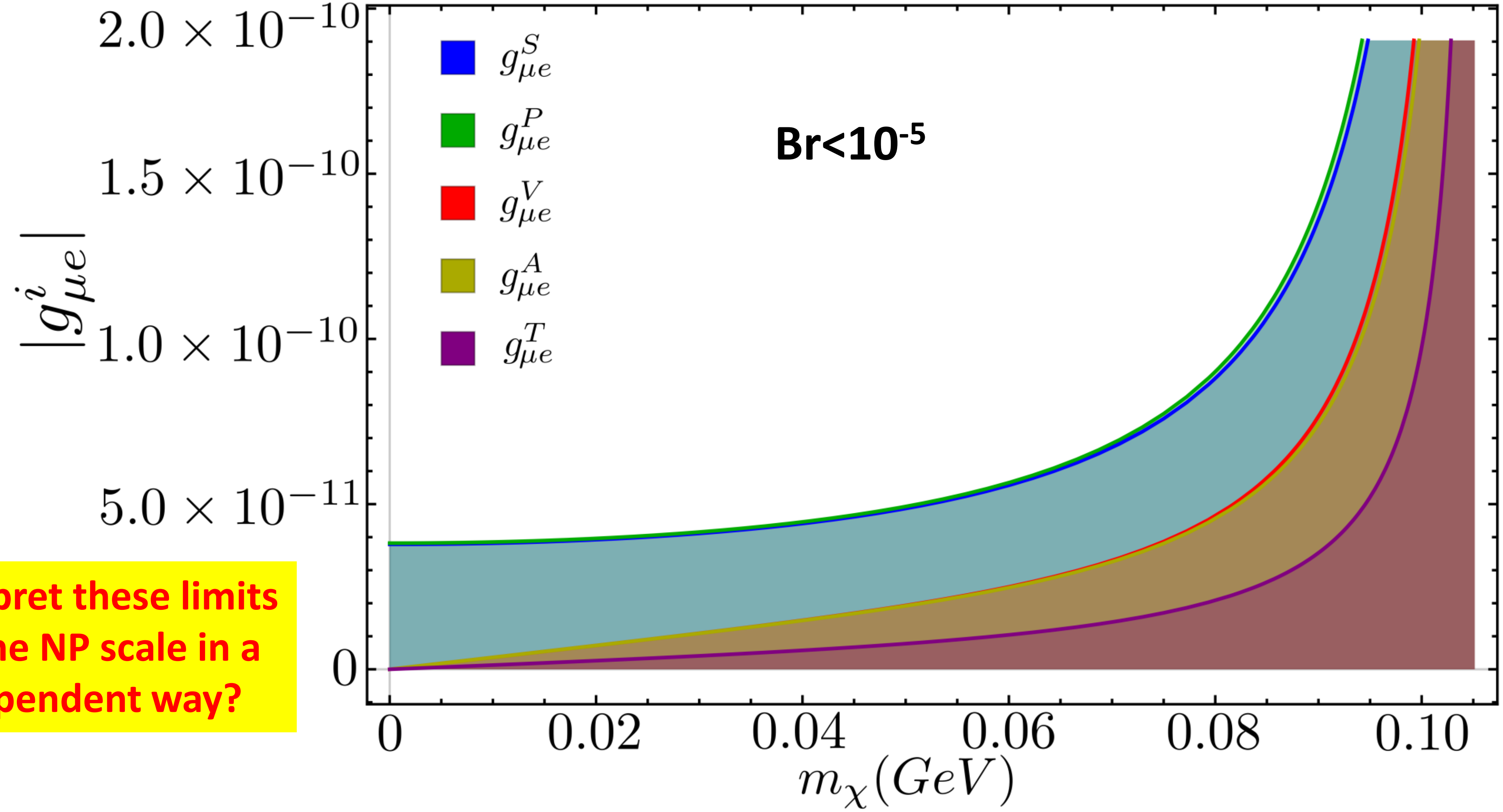
For Br<10^{-9} (Belle-II reach) UL on coupling is three orders of magnitude smaller than shown

PHENOMENOLOGY: $\mu \rightarrow e\,\chi$



For Br<10^{-13} (MEG reach) UL on coupling is four orders of magnitude smaller than shown

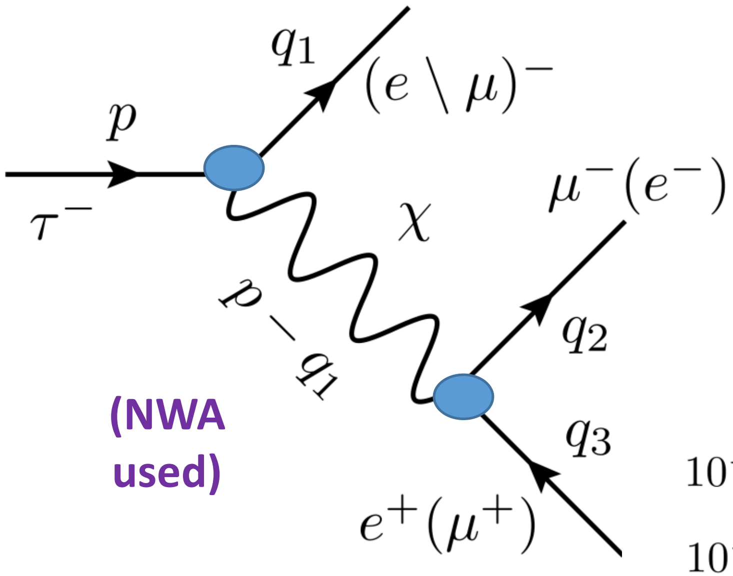
PHENOMENOLOGY: μ→ e χ



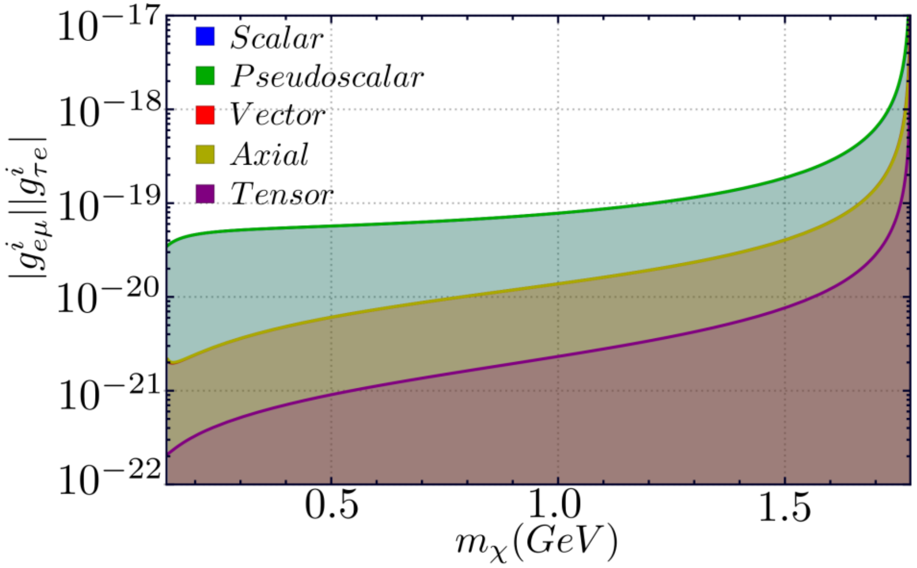
Can one interpret these limits in terms of the NP scale in a model-independent way?

For Br<10^{-13} (MEG reach) UL on coupling is four orders of magnitude smaller than shown

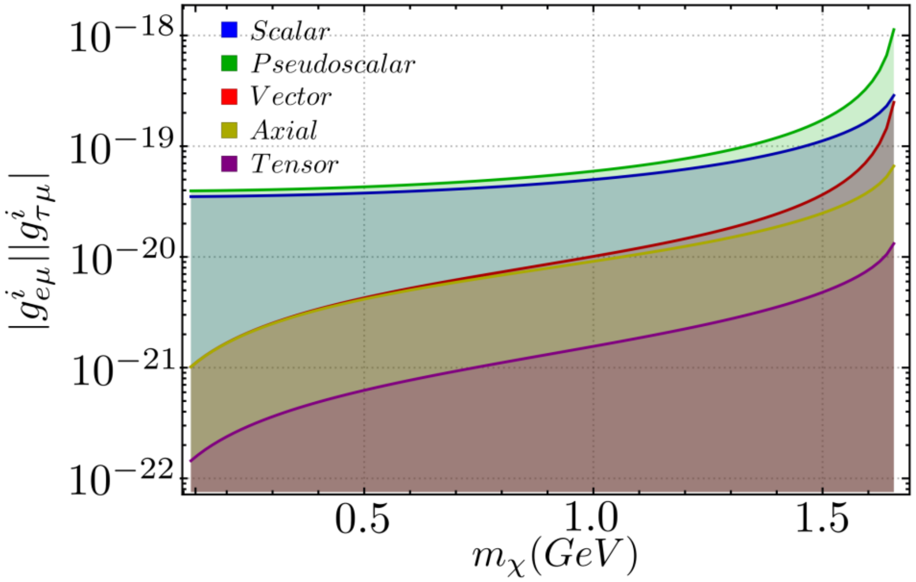
PHENOMENOLOGY: τ→ 3l



(NWA used)



(a) $\tau^- \to e^-\mu^-e^+$



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Effective LFV interactions involving a boson (χ)

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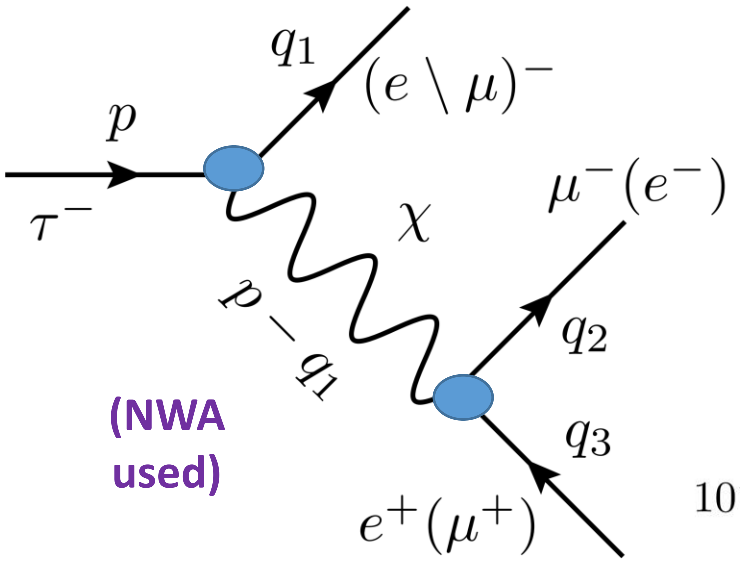
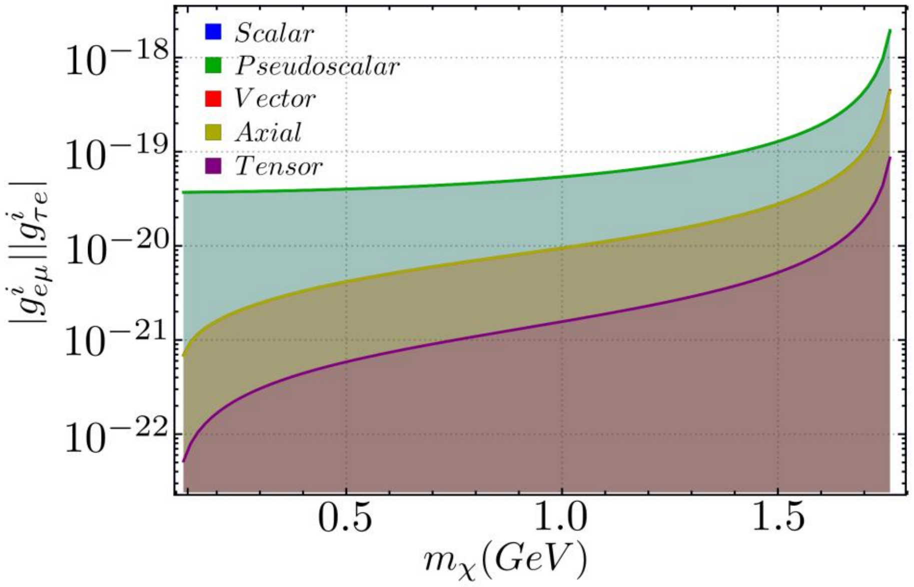
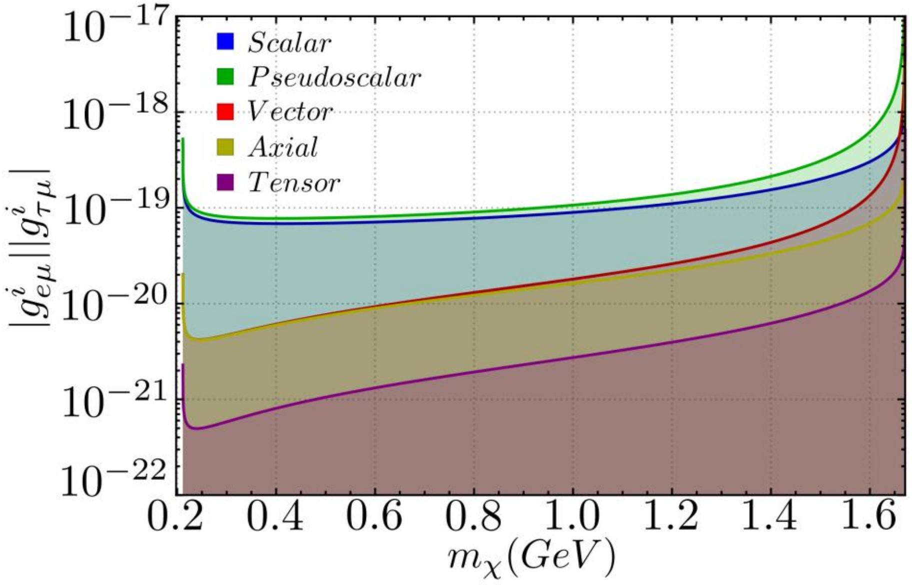


(NWA used)

These limits imply BR($\tau \rightarrow l\, \chi$)<$10^{-7}$, which supersedes the ARGUS bound: BaBar & Belle(-II) should not only improve that bound but reach similar ULs to other LFV decays



(c) $\tau^- \rightarrow e^- e^- \mu^+$



(d) $\tau^- \rightarrow \mu^- e^- \mu^+$

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PHENOMENOLOGY: What if $SU(2)_L xU(1)_Y$?

Then we have LFV processes involving H (with χ=S,P,$B_{\mu\nu}$) & νs (with χ=V,A)

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S or P

$$\mathcal{B}r(H \to \tau^+\mu^-\chi) \lesssim 1 \times 10^{-18},\ \mathcal{B}r(H \to \tau^+e^-\chi) \lesssim 2 \times 10^{-18}\ ,\ \mathcal{B}r(H \to \mu^+e^-\chi) \lesssim 3 \times 10^{-22}$$

$B_{\mu\nu}$

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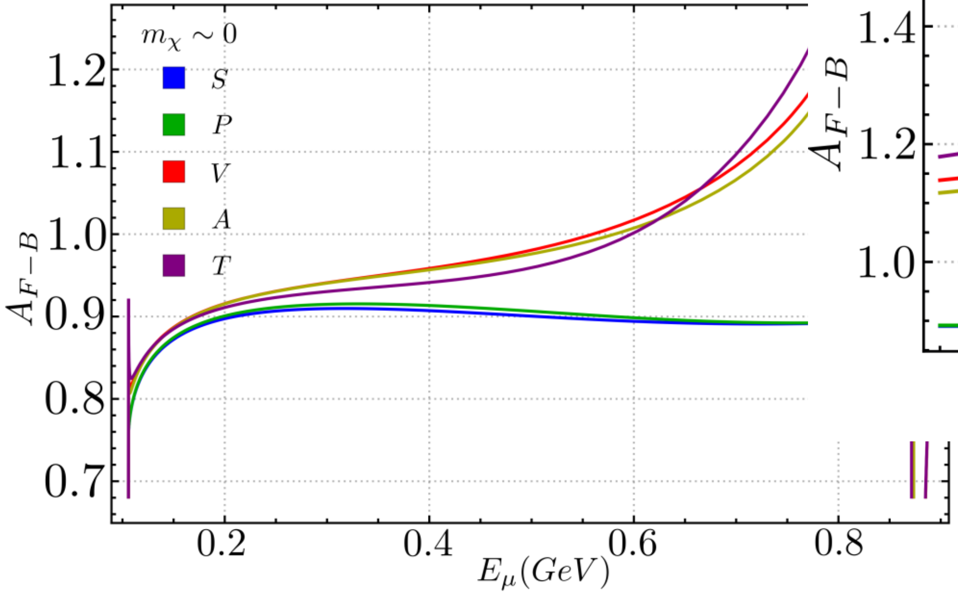
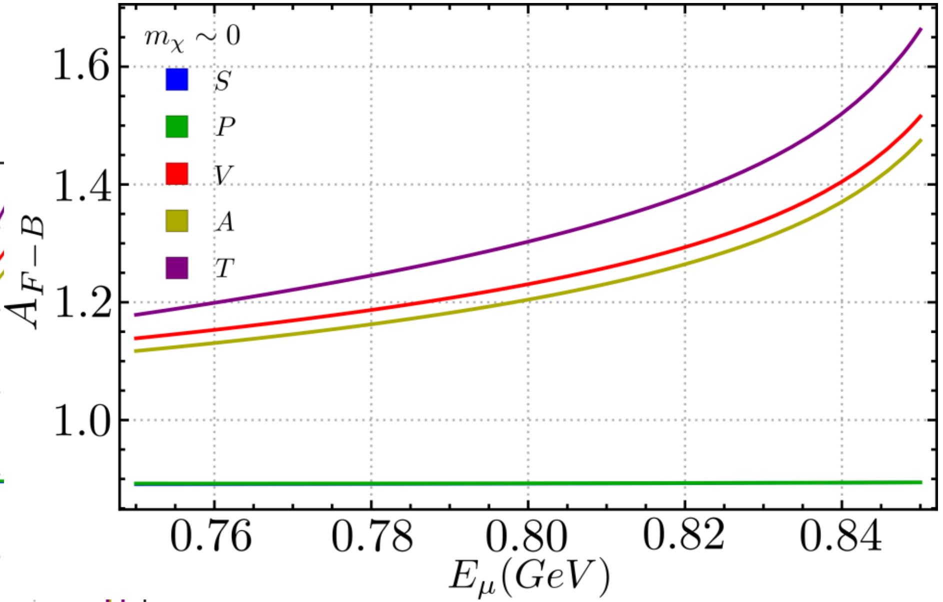
But, what if we have a heavy χ instead?

PHENOMENOLOGY: Lessons from L → l χ γ

'FB' asymmetry with θ angle between photons in the rest frame of the lχ system





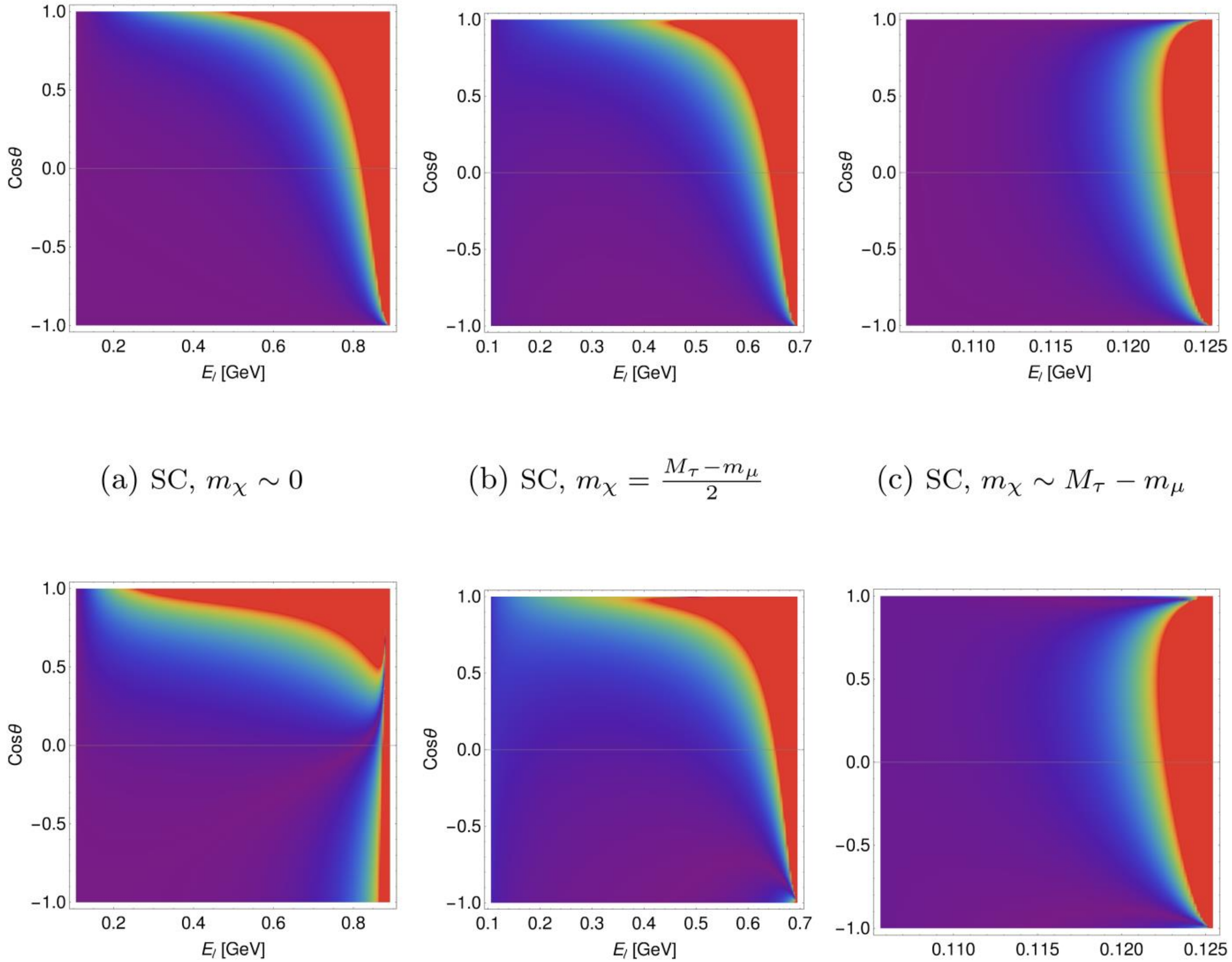
Spin 0 (S,P) & Spin 1 cases (V,A,B) could be disentangled easily.

PHENOMENOLOGY: Lessons from L → l χ γ

Dalitz plot distributions

Spin 0 cases (S,P) are pretty similar.

Spin 1 cases (V,A,B) look very alike.



(a) SC, $m_\chi \sim 0$ (b) SC, $m_\chi = \frac{M_\tau - m_\mu}{2}$ (c) SC, $m_\chi \sim M_\tau - m_\mu$

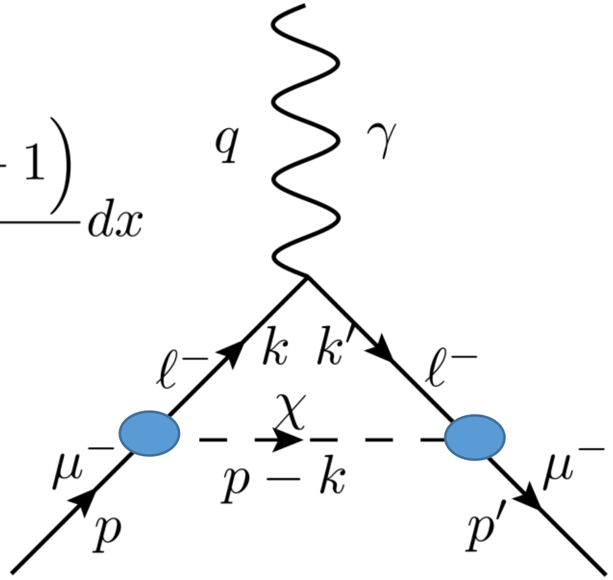
(d) VC, $m_\chi \sim 0$ (e) VC, $m_\chi = \frac{M_\tau - m_\mu}{2}$ (f) VC, $m_\chi \sim M_\tau - m_\mu$

PHENOMENOLOGY: Effects on a_l are too small

$$\Delta a_\mu = a_\mu^{Exp} - a_\mu^{SM} = 268(63)_{exp}(43)_{theo}\times 10^{-11}, \quad \Delta a_e = a_e^{Exp} - a_e^{SM} = -87(36)_{exp}\times 10^{-14}$$

$$\Delta a_\mu^B = \left(g_{\mu\ell}^T\right)^2 \frac{2m_\mu^2}{\pi^2 m_\chi^2}\int_0^1 \frac{2\frac{m_\ell}{m_\mu}(x-1)(3x+1) + \frac{m_\mu^2}{m_\chi^2}(x-1)^3\left(x-\frac{m_\ell}{m_\mu}\right)\left(x-2\frac{m_\ell}{m_\mu}+1\right)}{(1-x)\left(\frac{m_\ell^2}{m_\chi^2}-\frac{m_\mu^2}{m_\chi^2}x\right)+x}dx$$

(Apparently this type of contribution was not computed before)



The largest contribution to a_μ (a_e) that we get is $\lesssim 10^{-13}$ ($\lesssim 10^{-16}$) for small m_χ and the spin-zero cases, so it clear that it is impossible that the LFV interactions considered in this work provide any solutions for such large discrepancies as currently reported in a_ℓ.

CONCLUSIONS

It is interesting to consider LFV+boson with effective Lagrangians: experimentally & theoretically (B- & τ-c factories)

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Can we interpret our impressive bounds on the χ couplings in terms of a LARGE NP scale model-independently?