Effective Lagrangians for Lepton Flavor Violation interactions involving a boson (χ)

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Outline

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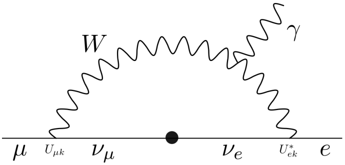

$$\mathcal{B}r(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{k=1,3} U_{\mu k} U^*_{ek} \frac{m^2_{\nu k}}{M^2_w}\right|^2 \sim 10^{-54}$$

T. P. Cheng and L. F. Li, '77

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Strongly suppressed by a GIM-like mechanism and their proportionality on m^2_ν.

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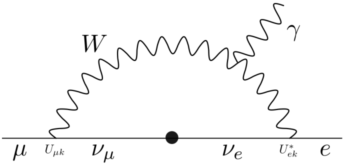

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⇒SM Predictions:

$\mathcal{B}r(Z \to \ell\ell') \sim 10^{-54}$ J. I. Illana & T. Riemann, '01
$\mathcal{B}r(H \to \ell\ell') \sim 10^{-55}$ E. Arganda, A. M. Curiel, M. J. Herrero & D. Temes, '05

$\mathcal{B}r(\mu \to 3e) \sim 10^{-54}$, $\mathcal{B}r(\tau \to 3\ell) \sim 10^{-55}$ Hernández-Tomé, López-Castro & Roig '19

Limits of cLFV channels for τ

$\tau \to \ell\alpha$ **UL at 95% CL**
ARGUS Collaboration 1995

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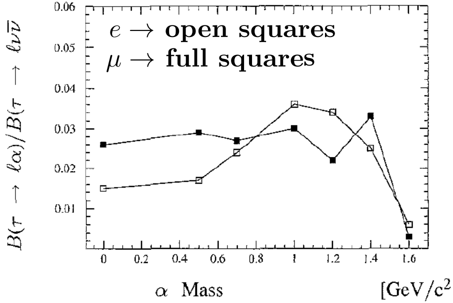

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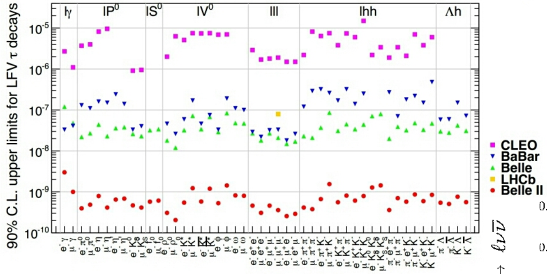

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Extrapolation of existing results in Belle II to $50ab^{-1}$ (best scenario)

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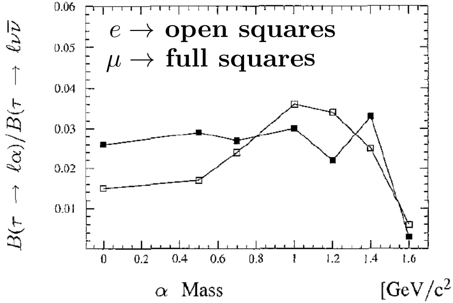

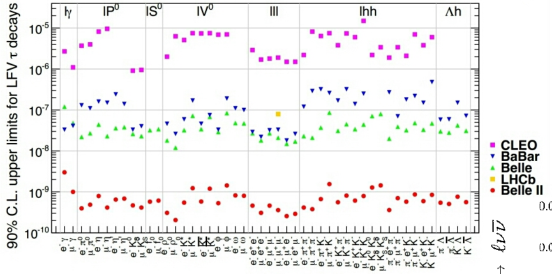

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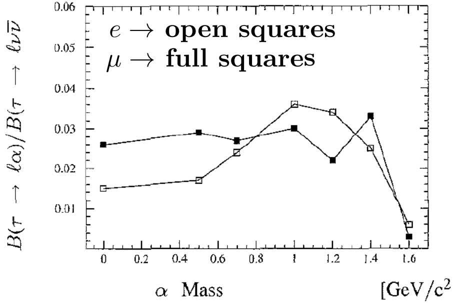

$\Rightarrow$ From ARGUS we have $\mathcal{B}r(\tau \to \alpha\ell) \lesssim 10^{-3}$, these limits contrast a lot with most of the upper bounds on LFV decays.

Outline

Effective Lagrangian

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

$\chi = S, P, V_\mu, A_\mu, B_{\mu\nu}$ $\quad$ $ij \rightarrow i \neq j$, $i,j = e,\mu,\tau$ $\quad$ $B_{\mu\nu} \rightarrow J^{PC} = 1^{+-}$

and g^X_{ij} effective couplings. We will consider $m_\chi < M_\tau$, but this is not necessary.

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$\Rightarrow$ This Lagrangian is not invariant under $SU(2)_L \otimes U(1)_Y$ (but it does not have to be!). We can consider the Lagrangian

$$\mathcal{L'}_{int} = \left(\frac{g'^S_{L_iR_j}}{\Lambda}\bar{L}_{L_i}\Phi\ell_{R_j} + \frac{g'^S_{R_iL_j}}{\Lambda}\bar{L}_{R_i}\Phi^\dagger\ell_{L_j}\right)S + i\left(\frac{g'^P_{L_iR_j}}{\Lambda}\bar{L}_{L_i}\Phi\gamma_5\ell_{R_j} + \frac{g'^P_{R_iL_j}}{\Lambda}\bar{L}_{R_i}\gamma_5\Phi^\dagger\ell_{L_j}\right)P$$

$$+\left(g'^V_{L_iL_j}\bar{L}_{L_i}\gamma^\mu\ell_{L_j} + g'^V_{R_iR_j}\bar{L}_{R_i}\gamma^\mu\ell_{R_j}\right)V_\mu + \left(g'^A_{L_iL_j}\bar{L}_{L_i}\gamma^\mu\gamma_5\ell_{L_j} + g'^A_{R_iR_j}\bar{L}_{R_i}\gamma^\mu\gamma_5\ell_{R_j}\right)A_\mu$$

$$+\left(\frac{g'^T_{L_iR_j}}{\Lambda}\bar{L}_{L_i}\Phi\sigma^{\mu\nu}\ell_{R_j} + \frac{g'^T_{R_iL_j}}{\Lambda}\bar{L}_{R_i}\sigma^{\mu\nu}\Phi^\dagger\ell_{L_j}\right)B_{\mu\nu}$$

Effective Lagrangian

$L = left - handed$
$R = right - handed$

$$\mathcal{L}'_{int} = \left(\frac{g'^{S}_{L_i R_j}}{\Lambda} \bar{L}_{L_i} \Phi \ell_{R_j} + \frac{g'^{S}_{R_i L_j}}{\Lambda} \bar{L}_{R_i} \Phi^\dagger \ell_{L_j} \right) S + i \left(\frac{g'^{P}_{L_i R_j}}{\Lambda} \bar{L}_{L_i} \Phi \gamma_5 \ell_{R_j} + \frac{g'^{P}_{R_i L_j}}{\Lambda} \bar{L}_{R_i} \gamma_5 \Phi^\dagger \ell_{L_j} \right) P$$

$$+ \left(g'^{V}_{L_i L_j} \bar{L}_{L_i} \gamma^\mu \ell_{L_j} + g'^{V}_{R_i R_j} \bar{L}_{R_i} \gamma^\mu \ell_{R_j} \right) V_\mu + \left(g'^{A}_{L_i L_j} \bar{L}_{L_i} \gamma^\mu \gamma_5 \ell_{L_j} + g'^{A}_{R_i R_j} \bar{L}_{R_i} \gamma^\mu \gamma_5 \ell_{R_j} \right) A_\mu$$

$$+ \left(\frac{g'^{T}_{L_i R_j}}{\Lambda} \bar{L}_{L_i} \Phi \sigma^{\mu\nu} \ell_{R_j} + \frac{g'^{T}_{R_i L_j}}{\Lambda} \bar{L}_{R_i} \sigma^{\mu\nu} \Phi^\dagger \ell_{L_j} \right) B_{\mu\nu}$$

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + H \end{pmatrix}$$

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$$+ \left(g'^{V}_{L_iL_j} \bar{L}_{L_i} \gamma^\mu \ell_{L_j} + g'^{V}_{R_iR_j} \bar{L}_{R_i} \gamma^\mu \ell_{R_j} \right) V_\mu + \left(g'^{A}_{L_iL_j} \bar{L}_{L_i} \gamma^\mu \gamma_5 \ell_{L_j} + g'^{A}_{R_iR_j} \bar{L}_{R_i} \gamma^\mu \gamma_5 \ell_{R_j} \right) A_\mu$$
$$+ \left(\frac{g'^{T}_{L_iR_j}}{\Lambda} \bar{L}_{L_i} \Phi \sigma^{\mu\nu} \ell_{R_j} + \frac{g'^{T}_{R_iL_j}}{\Lambda} \bar{L}_{R_i} \sigma^{\mu\nu} \Phi^\dagger \ell_{L_j} \right) B_{\mu\nu}$$

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$\Rightarrow$ After Spontaneous Electroweak Symmetry Breaking

$$\mathcal{L}'_{int} = \left(g'^{S}_{L_iR_j} \bar{\ell}_{L_i} \ell_{R_j} + g'^{S}_{R_iL_j} \bar{\ell}_{R_i} \ell_{L_j} \right) S \frac{v+H}{\sqrt{2}\Lambda} + i \left(g'^{P}_{L_iR_j} \bar{\ell}_{L_i} \gamma_5 \ell_{R_j} + g'^{P}_{R_iL_j} \bar{\ell}_{R_i} \gamma_5 \ell_{L_j} \right) P \frac{v+H}{\sqrt{2}\Lambda}$$
$$+ \left(g'^{V}_{L_iL_j} \bar{\ell}_{L_i} \gamma^\mu \ell_{L_j} + g'^{V}_{R_iR_i} \bar{\ell}_{R_i} \gamma^\mu \ell_{R_j} \right) V_\mu + \left(g'^{A}_{L_iL_j} \bar{\ell}_{L_i} \gamma^\mu \gamma_5 \ell_{L_j} + g'^{A}_{R_iR_j} \bar{\ell}_{R_i} \gamma^\mu \gamma_5 \ell_{R_j} \right) A_\mu$$
$$+ \left(g'^{V}_{L_iL_j} \bar{\nu}_{L_i} \gamma^\mu \nu_{L_j} \right) V_\mu + \left(g'^{A}_{L_iL_j} \bar{\nu}_{L_i} \gamma^\mu \gamma_5 \nu_{L_j} \right) A_\mu$$
$$+ \left(g'^{T}_{L_iR_j} \bar{\ell}_{L_i} \sigma^{\mu\nu} \ell_{R_j} + g'^{T}_{R_iL_j} \bar{\ell}_{R_i} \sigma^{\mu\nu} \ell_{L_j} \right) B_{\mu\nu} \frac{v+H}{\sqrt{2}\Lambda}$$

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⇒ If P is a conserved symmetry

- $g'^{(S,P,T)}_{L_iR_j} = g'^{(S,P,T)}_{R_iL_j} \equiv g'^{(S,P,T)}_{ij}$, and
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New Interactions

$\bar{\nu}_{L_i}\nu_{L_j}\chi,\ \chi = V_\mu, A_\mu$

$\bar{\ell}_i\ell_j\chi H,\ \chi = S, P, B_{\mu\nu}$

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$\Rightarrow$ We restrict here to the decaying particle rest frame (work in progress for B-Factory environment).

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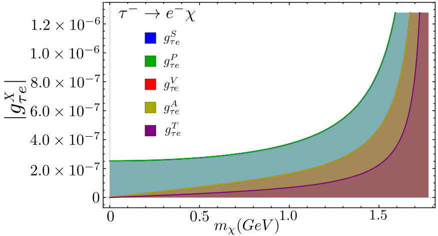
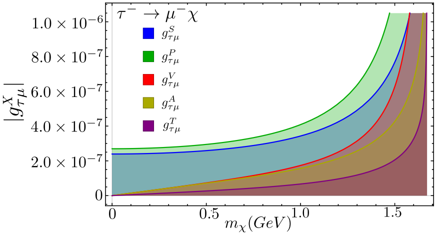
$\Rightarrow$ From ARGUS Collaboration $\mathcal{B}r(\tau \to \mu\alpha) < 5 \times 10^{-3}$ and $\mathcal{B}r(\tau \to e\alpha) < 2.7 \times 10^{-3}$ with $CL = 95\%$.
$\Rightarrow$ $|g^X_{\tau\ell}|$ constraints for $\mathcal{B}r \sim 10^{-3}$ (ARGUS) as a funtion of m_χ, with $X = S, P, V, A, T$.

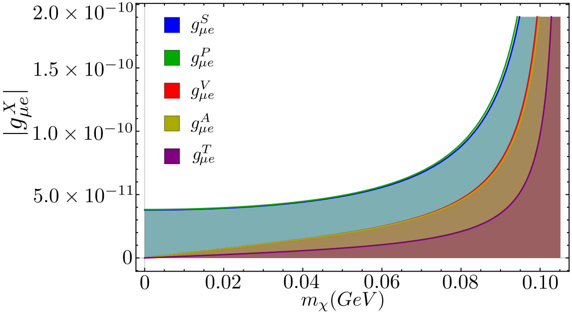




$\Rightarrow$ For $\mathcal{B}r < 10^{-9}$ (Belle-II reach) UL on coupling is three orders of magnitude smaller.

Phenomenology: $\mu \to e\chi$

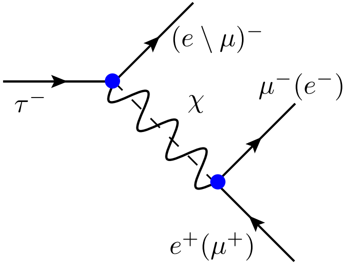
$\Rightarrow$ $|g^X_{\mu e}|$ constraints for $\mathcal{B}r \sim 10^{-5}$ as a funtion of m_χ, with $X = S, P, V, A, T$.



$\Rightarrow$ For $\mathcal{B}r<10^{-13}$ (MEG reach) UL on coupling is four orders of magnitude smaller.

$\Rightarrow$ $L \to \ell\gamma$ are induced at one-level, but the bounds obtained are superseded by the limits imposed by the current non-observation of the $L \to 3\ell$, as will be discussed in the following.

Phenomenology: $\tau^- \to \ell_i^- \ell_j^- \ell_i^+$ and $\tau^- \to \ell_i^- \ell_i^- \ell_j^+$



$\Downarrow$

Using Narrow-width approximation

We have Upper Limits on the branching fractions with 90% CL from BaBar & Belle, '10.

$\mathcal{B}r(\tau^- \to e^- \mu^- e^+) < 1.8 \times 10^{-8}$,

$\mathcal{B}r(\tau^- \to \mu^- \mu^- e^+) < 1.7 \times 10^{-8}$,

$\mathcal{B}r(\tau^- \to e^- e^- \mu^+) < 1.5 \times 10^{-8}$, &

$\mathcal{B}r(\tau^- \to \mu^- e^- \mu^+) < 2.7 \times 10^{-8}$.

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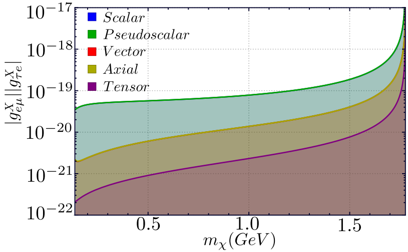
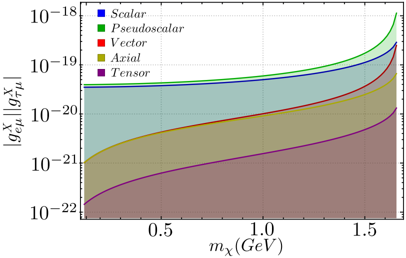
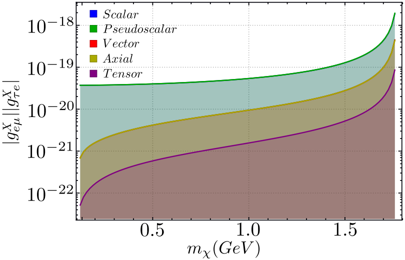


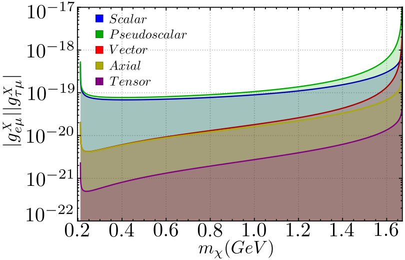
(a) $\tau^- \to e^- \mu^- e^+$



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



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



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

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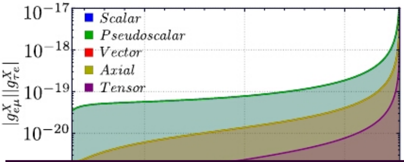
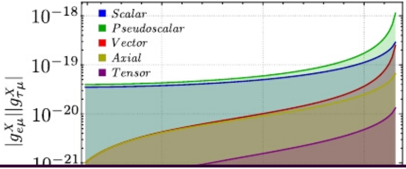
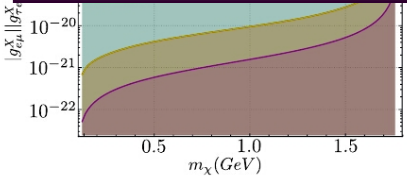




These limits imply $\mathcal{B}r(\tau \to \ell\chi) < 10^{-7}$, which supersedes the ARGUS bound: BaBar & Belle(-II) should not only improve that bound but reach similar ULs to other LFV decays



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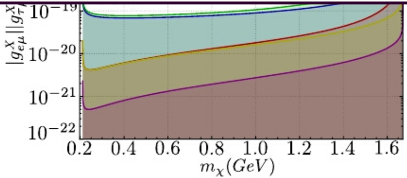
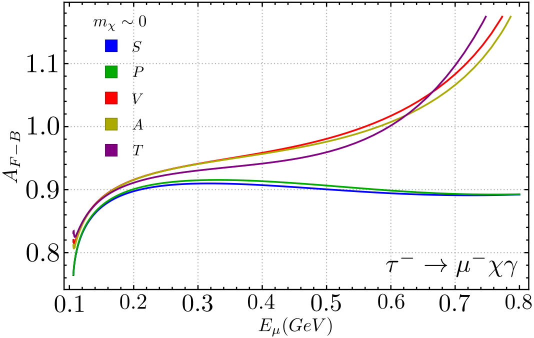


(d) $\tau^- \to \mu^- e^- \mu^+$

Phenomenology: Forward-Backward Asymmetry $L \to \ell\chi\gamma$

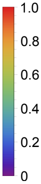
$\Rightarrow$ Forward-Backward Asymmetry with θ angle between leptons in the rest frame of the $\ell - \chi$ $(\vec{p}_\ell + \vec{p}_\chi = 0)$ system.

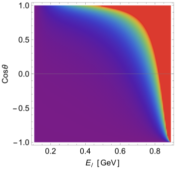


$\Rightarrow$ Spin 0 (S,P) & Spin 1 cases (V, A, B) could be disentangled easily.

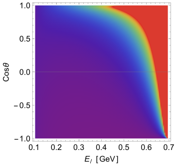
Phenomenology: Dalitz Plot distributions $L \to \ell\chi\gamma$

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

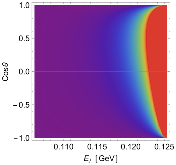




(e) $m_\chi \to 0$

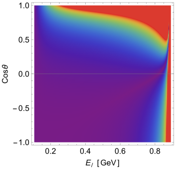


(f) $m_\chi = \frac{M_\tau - m_\mu}{2}$

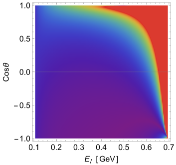


(g) $m_\chi \to M_\tau - m_\mu$

$\Rightarrow$ Spin 1 cases $(V_\mu, A_\mu, B_{\mu\nu})$ are pretty similar.



(h) $m_\chi \to 0$



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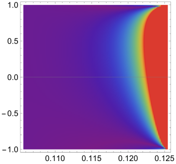

(j) $m_\chi \to M_\tau - m_\mu$

Phenomenology: Scale Model-Independently?

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

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$$\Downarrow$$

Assuming $g_{ij}'^{(S,P,T)} \sim e \sim 1/3$ (for $m_\chi \to 0$):

- If $\chi = B_{\mu\nu}$, for $L \leftrightarrow \ell$ transitions $\Rightarrow 10^9\ TeV$.
- If $\chi = S, P$, for $\mu \leftrightarrow e$ transitions $\Rightarrow 10^9\ TeV$.
- If $\chi = S, P$, for $\tau \leftrightarrow \ell$ transitions $\Rightarrow 10^8\ TeV$.

Phenomenology:Leptons Anomalous Magnetic Moment

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

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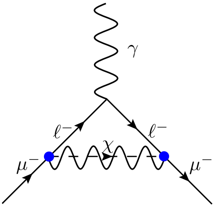

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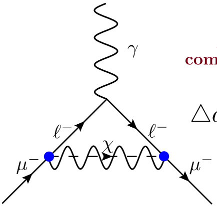

$\chi = B_{\mu\nu}$, this contribution was not computed before

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

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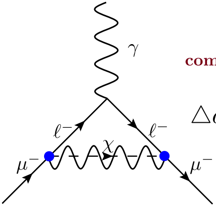

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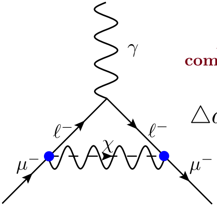

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$\triangle a_e^B$ **can be obtained with trivial changes**

The largest contribution to $|\triangle a_{\mu/e}|$ 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 $\triangle a_{\mu/e}$.

⇒we obtain fully correlated signs of $\triangle a_{\mu/e}$, with $\triangle a_\mu > 0$ for the $\chi = S, V$ cases and $\triangle a_e < 0$ for the $\chi = P, A, T$ cases.

Outline

Conclusions\Summary

- It is in interesting to consider $LFV + boson$ with effective Lagrangians: experimentally & theoretically (B & $\tau - c$ factories).
- If discovered, it would be easy to find out χ spin, but not parity (Dalitz Plot & A_{F-B}).
- In case there is an underlying EW symmetry χ interactions with H & $\nu's$ would be out of reach.
- For $\chi = S, P, B_{\mu\nu}$, if the Lagrangian is invariant under the electroweak symmetry, the bounds on our couplings translate into a new physics scale as high as $10^8, 10^9\ TeV$.
- χ has irrelevant contributions to $\triangle a_\mu$ and $\triangle a_e$.

Thank you!

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

Why effective LFV for $L \to \ell\chi$?

⇒ 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 associated with one symmetry breaking scale larger than the electroweak. They can be DM candidates & linked to the smallness of ν masses.
✠A Majoron or familon could be a light (pseudo)Goldstone boson corresponding to the spontaneous breaking of a flavor symmetry

⇓
Included in the spin-zero part of our Lagrangians.

✠Z' bosons violating lepton universality (and most often lepton flavor) have been suggested to explain several current anomalies.

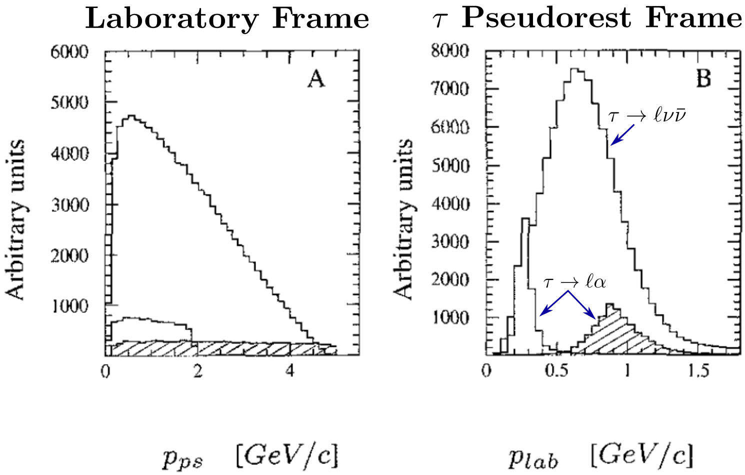
⇓
Included in the spin-one part of our Lagrangians.

✠Invisible bosons of all types allowed by symmetry can also be mediators of LFV Standard Model – Dark Matter interactions.

...

Phenomenology: $\tau \to \ell\chi$

$\Rightarrow$ We restrict here to the decaying particle rest frame (work in progress for B-Factory environment).
$\Rightarrow$ From ARGUS Collaboration $\mathcal{B}r(\tau \to \alpha\mu) < 5 \times 10^{-3}$ and $\mathcal{B}r(\tau \to \alpha e) < 2.7 \times 10^{-3}$ with $CL = 95\%$.



Phenomenology: If $\mathcal{L}$ is invariant under $SU(2)_L \otimes U(1)_y$

$\Rightarrow$Additional LFV processes show up in the original Lagrangian, involving H $(\chi = S, P, B_{\mu\nu})$ and left-handed ν_s $(\chi = V_\mu, A_\mu)$.

S or P

$$\mathcal{B}r(H \to \tau^+\mu^-\chi) \lesssim 1\times10^{-18}, \quad \mathcal{B}r(H \to \tau^+e^-\chi) \lesssim 2\times10^{-18}, \quad \mathcal{B}r(H \to \mu^+e^-\chi) \lesssim 3\times10^{-22}.$$

$B_{\mu\nu}$

$$\mathcal{B}r(H \to \tau^+\ell^-\chi) \lesssim 2.5 \times 10^{-14}, \quad \mathcal{B}r(H \to \mu^+e^-\chi) \lesssim 5 \times 10^{-18}.$$

$\Rightarrow$However, since a Higgs-portal type coupling would be allowed, this would generate $H \to \chi\chi$ (and consequently $H \to \chi\ell_i\ell_j$) processes at rates likely much higher than those given by our Lagrangian.

$\chi \to \bar{\nu}_{L_i}\nu_{L_j}$ are unmeasurably small