

EFFECTIVE FIELD THEORY ANALYSIS FOR LEPTON-FLAVOR VIOLATING INTERACTIONS IN PRESENCE OF A BOSON*

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We consider an effective Lagrangian for lepton-flavor violating (LFV) interactions with an additional invisible boson (χ). Our most important result is that current and future searches for the $\ell_i^\pm \rightarrow \ell_j^\pm \chi$ decays (with $i \neq j$ lepton flavors) should not only aim to improve over the old ARGUS bounds (with upper limits $\sim 5 \times 10^{-3}$ on the corresponding $\tau \rightarrow \ell \chi$, $\ell = e, \mu$ branching fractions) but to reach the $\lesssim 10^{-7}$ exclusion region. Otherwise, they would not bring in additional restrictions on these LFV interactions beyond what the LFV $L \rightarrow 3\ell$ decays current limits are excluding indirectly.

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1. Introduction

This contribution is based on our work, see Ref. [1]. Our aim is to provide a suitable framework for analyzing the results of LFV searches including an invisible boson (*i.e.* $\ell_i^\pm \rightarrow \ell_j^\pm \chi$ processes, with i and j different lepton flavors) at present and future facilities. In this first analysis, we have focused on the construction of the effective Lagrangians and analyzed the most relevant associated phenomenology in the rest frame of the decaying lepton (this can correspond, for instance, to (super)-charm-tau factory data obtained running close to the $\tau^+ \tau^-$ production threshold). In a forthcoming contribution, we will collaborate with our experimental colleagues who have improved the reconstruction of the pseudorest frame of the decaying lepton in a B -factory environment [2]. In this case, the neutrinos produced in the tau decays necessarily escape undetected and make impossible a clean reconstruction of the tau rest frame.

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Current best upper limits on the $\tau \rightarrow \ell\chi$ ($\ell = e, \mu$) decays were obtained by the ARGUS Collaboration [3]. These depend mildly on m_χ and are at the level of $\sim 5 \times 10^{-3}$ for the corresponding branching ratios. These limits contrast sharply with those collected in *e.g.* [4], where the upper bounds on some 50 LFV tau decays (a few of them also lepton and baryon number violating) are in the range of $[10^{-8}, 10^{-6}]$. In fact, the limits on LFV $\tau \rightarrow 3\ell$ decays are around 10^{-8} and, as we will show, are more powerful in restricting indirectly the $\tau \rightarrow \ell\chi$ decays parameter space than the ARGUS result.

Several appealing theoretical scenarios where invisible χ bosons lighter than the tau lepton arise are briefly discussed in Ref. [1].

2. Theoretical setting

We consider the most general CP and P conserving¹ dimension-four Lagrangian inducing $\ell_i \bar{\ell}_j \chi$ vertices

$$\mathcal{L}_{\text{int}} = g_{ij}^S \bar{\ell}_i \ell_j S + i g_{ij}^P \bar{\ell}_i \gamma_5 \ell_j P + g_{ij}^V \bar{\ell}_i \gamma^\mu \ell_j V_\mu + g_{ij}^A \bar{\ell}_i \gamma^\mu \gamma_5 \ell_j A_\mu + g_{ij}^T \bar{\ell}_i \sigma^{\mu\nu} \ell_j B_{\mu\nu}, \quad (1)$$

where the χ boson can have scalar (S), pseudoscalar (P), vector (V), axial-vector (A) or ‘tensor’ ($B \equiv T$, with $J^{PC} = 1^{+-}$, see *e.g.* [5]) quantum numbers.

The previous Lagrangian is obviously not gauge-invariant. However, under the considered assumptions, it is possible (although not necessary) to derive it [1] from an $\text{SU}(2)_L \times \text{U}(1)_Y$ gauge-invariant Lagrangian, that involves the Higgs doublet for the $\chi = S, P, B$ cases. This results in:

- A v/Λ suppression (where Λ is the underlying new physics scale of the considered LFV interactions and $v \sim 246$ GeV is the Higgs field vacuum expectation value) for the $\chi = S, P, B$ couplings, as a consequence of electroweak symmetry breaking.
- New interactions giving rise to $H \rightarrow \ell_i^\pm \ell_j^\mp \chi$, ($\chi = S, P, B$) and $\chi \rightarrow \nu_i \bar{\nu}_j$, ($\chi = V, A$) decays. Both types of interactions, however, occur at unobservable levels once the g_{ij}^X , ($X = S, P, V, A, B$) couplings are restricted using the current upper limits on LFV decays.

3. Results

In figure 1, we show the constraints on the $|g_{ij}^X|$ effective couplings given by current non-observation of the $\ell_i \rightarrow \ell_j \chi$ decays as a function of m_χ . The corresponding constraints on the $|g_{\tau\ell}^X|$ couplings are, however, superseded by those coming from $\tau \rightarrow \ell_i \ell_j \ell_i$ decays (which are predicted with $[10^{-56}, 10^{-54}]$

¹ Possible P violating interactions are mentioned in Ref. [1].

branching ratios in the SM with massive neutrinos [7]) that are shown in figure 2 for the $\tau^- \rightarrow e^- \mu^- e^+$ and $\tau^- \rightarrow \mu^- e^- \mu^+$ decay channels (very similar results are obtained for the $\tau^- \rightarrow \mu^- \mu^- e^+$ and $\tau^- \rightarrow e^- e^- \mu^+$ cases). These were calculated using the narrow width approximation for the (long-lived) χ boson. The restrictions from LFV $\tau \rightarrow 3\ell$ decays imply $\text{BR}(\tau \rightarrow \ell\chi) \lesssim 10^{-7}$, much stronger than the ARGUS bound.

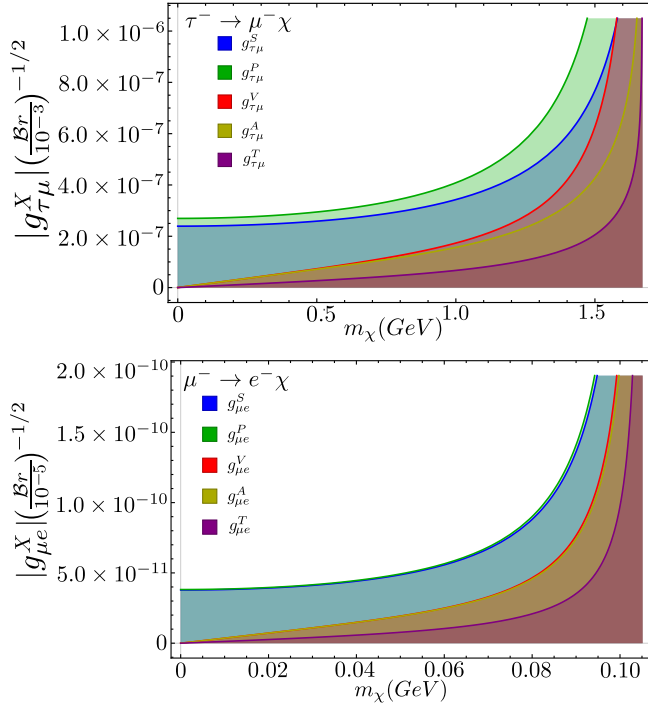


Fig. 1. Top: $|g_{\tau\mu}^X|$ constraints for $\text{BR} \sim 10^{-3}$ as a function of m_χ ; bottom: $|g_{\mu e}^X|$ constraints for $\text{BR} \sim 10^{-5}$ as a function of m_χ . Reach on $|g_{ij}^X|$ vs. m_χ for $\text{BR}(\tau \rightarrow \ell\chi) \sim 10^{-3}$ and $\text{BR}(\mu \rightarrow e\chi) \sim 10^{-5}$ (the corresponding reach for $\text{BR}(\tau \rightarrow \ell\chi) \sim 10^{-9}$ [8] are three orders of magnitude smaller, and for $\text{BR}(\mu \rightarrow e\chi) \sim 10^{-13}$ [9] are four orders of magnitude smaller). The shaded areas correspond to the allowed regions for the effective couplings $|g_{ij}^X|$.

Noteworthy, the interpretation of the bounds on the $|g_{ij}^{S,P,B}|$ couplings yields an underlying new physics scale as high as $[10^8, 10^9]$ TeV.

Finally, we consider angular observables reflecting the orientation of the two leptons in the rest frame of the $\ell\text{-}\chi$ system in $\tau \rightarrow \ell\chi\gamma$ decays. These are most sensitive to the nature of the χ particle for $\ell = \mu$ and small m_χ . As shown in figure 3, from this information one might infer if χ is a scalar or vector particle (assuming the background from $\tau^- \rightarrow \mu^- \nu_\tau \bar{\nu}_\mu \gamma$ be con-

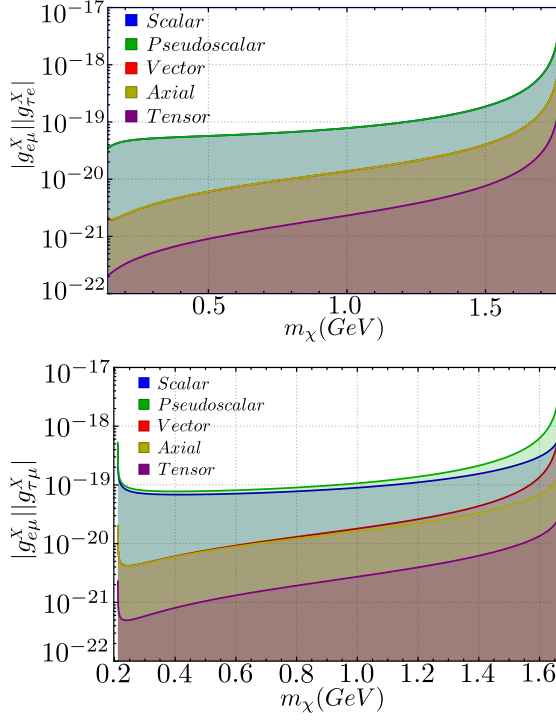


Fig. 2. Reach on $|g_{e\mu}^X||g_{\tau\ell}^X|$ vs. m_χ according to the BaBar and Belle upper bounds on $\ell_i \rightarrow 3\ell$ decays [6]. The shaded areas correspond to the allowed regions for the product of effective couplings $|g_{e\mu}^X||g_{\tau\ell}^X|$. Top: $\tau^- \rightarrow e^- \mu^- e^+$; bottom: $\tau^- \rightarrow \mu^- e^- \mu^+$.

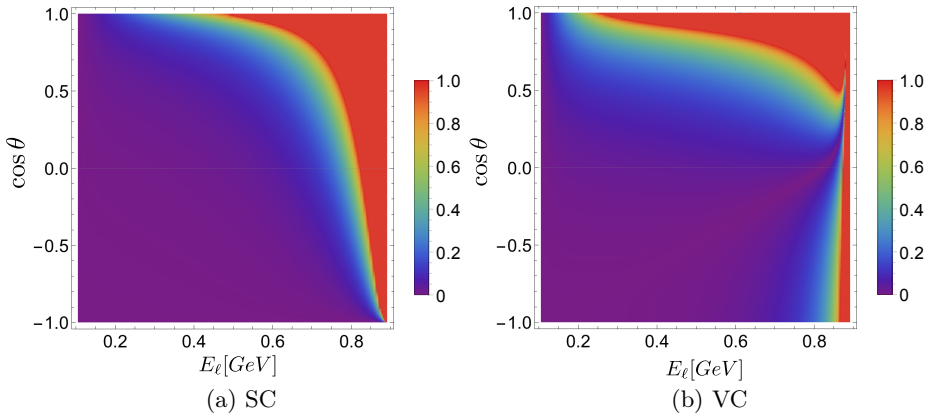


Fig. 3. Normalized Dalitz plot distributions for $\tau^- \rightarrow \mu^- \chi \gamma$ decays for the scalar (SC) and vector (VC) cases, for $m_\chi \sim 0$.

trolled). Results are very similar for $\chi = S, P$ or for $\chi = V, A, B$, so this could tell the χ spin, but not its parity or charge conjugation. Integrating over E_ℓ , we are left with the purely angular distribution, from which we can build an asymmetry in the usual way. The corresponding results are consistent with the Dalitz plots already shown and could be used either to derive χ 's spin if doubly-differential measurements are not available, or to strengthen the significance of the outcome through a joint analysis.

We quote in Ref. [1] the contribution to the ℓ anomalous magnetic moment (a_ℓ) given by $\chi = B$ exchange (this result is new to our knowledge) and checked that, by no means, it can alleviate the tension between the (both extremely precise) SM predictions and the corresponding measurements of a_ℓ for $\ell = e, \mu$ [6] (independently of the nature of the χ boson). Since Δa_ℓ^B was obtained without any approximation, it can straightforwardly be used for calculating the contribution of 1^{+-} exchanges to a_ℓ irrespective of the particular value of m_χ .

4. Conclusions

We have provided an effective field theory description of LFV $\ell_i \rightarrow \ell_j \chi$ decays, with χ an invisible boson, and discussed the consequences of it possibly having electroweak gauge symmetry. We focused here on the case where the rest frame of the decaying lepton can be reconstructed and leave to future work its generalization to the B -factory case. In this experimental setting, we have shown that the strongest bounds on the considered interactions (which can be translated into underlying new physics scales as high as 10^9 TeV) come from LFV $\tau \rightarrow 3\ell$ decays, so that searches of $\ell_i \rightarrow \ell_j \chi$ decays should not aim just to improve the ARGUS bound on them but to reach comparable accuracy to the standard LFV tau decay searches, so that they will further restrict the parameter space of the effective interactions that we considered.

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