Probing LFV in Meson Decays with LHC Data

Ioannis Plakias
Pôle Théorie
IJCLab
Université Paris-Saclay, CNRS

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Introduction

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However, there are some questions that it cannot answer (e.g. Neutrino Masses & Oscillations, Flavor & Hierarchy problems).

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LFV processes are great probes for NP, since they are absent in the SM $\Rightarrow$ exp. observation is a clear signal of NP.

In this presentation I will talk about LFV in semileptonic transitions (e.g. $B_s \to \mu\tau$, $B \to \rho\mu\tau$).

The most general way to parameterize the effects of heavy NP in LFV processes, is in terms of non-renormalizable operators:

$$\mathcal{L}_{\rm EFT} = \sum_i \sum_{d>4} \frac{C_i^{(d)} \mathcal{O}_i^{(d)}}{\Lambda^{d-4}} , \quad \Lambda = \mathcal{O}(M) .$$

- M : Masses of the heavy degrees of freedom (dof).
- $\mathcal{O}_i^{(d)}$: d-dimension operators made of the light dof.
- $C_i^{(d)}$: Wilson coefficients (dimensionless constants).

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At low-energies ($E \ll \Lambda$) the EFT can be truncated at a given order in $1/\Lambda$, depending on the accuracy at which we want to compute an observable.

The SM Effective Field Theory (SMEFT) is made up by all the non-renormalizable operators which are made of SM fields, and are invariant under the gauge group of the SM,

$$G_{\rm SM} = SU(3)_C \times SU(2)_L \times U(1)_Y \,.$$

The scale of NP should be much larger than the EW scale $\Lambda_{\rm EW} \sim 100$ GeV in order for the EFT description to be valid.

LFV in the SMEFT

Already at dimension six in the SMEFT we have operators that contribute at <u>tree level</u> to semileptonic LFV processes.

$[Q^{(3)}_{lequ}]_{prst}$	$(\bar{L}^j_p \sigma_{\mu\nu} e_r)\epsilon_{jk}(\bar{Q}^k_s \sigma^{\mu\nu} u_t)$	$[Q_{eu}]_{prst}$	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$
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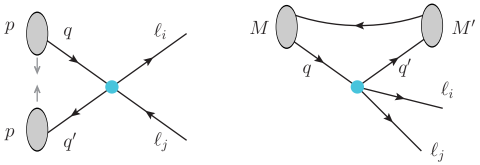

LFV processes in the SMEFT at $d = 6$.

LFV in the SMEFT

These semileptonic operators contribute at tree level, to semileptonic LFV processes (e.g. $B_s \to \mu\tau$, $B \to \rho e \tau$) related to the quark-level transitions $b \to d\ell_i\ell_j$ and $b \to s\ell_i\ell_j$.

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Our goal is to find upper bounds to the branching fractions of these Meson LFV decays, by using the LHC constraints on Drell-Yan (DY) processes from the Mathematica package **HighPT** (2207.10714 & 2207.10756), and to compare with the current exp. limits.

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But first, we have to study what happens when we go beyond tree level for these transitions...

1-loop effects in $b \to q$ transitions

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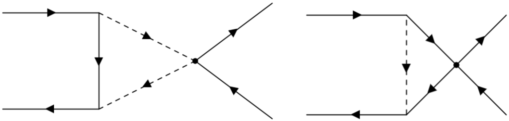

Examples of contributions from:

$[Q_{Hl}^{(1)}]_{pr} = [\bar{\ell}_p \gamma^\mu \ell_r][H^\dagger \overleftrightarrow{D}_\mu H]$ (Left) , $\quad [Q_{lu}]_{pr33} = [\bar{\ell}_p \gamma^\mu \ell_r][\bar{t} \gamma_\mu t]$ (Right)

which are both proportional to:

$$\sim \frac{y_t^2}{16\pi^2} V_{tb} V_{tq}^* \,,$$

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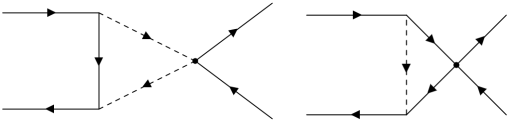

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which are both proportional to:

$$\sim \frac{y_t^2}{16\pi^2} V_{tb} V_{tq}^* ,$$

for $q = d, s$. These effects are negligible when we impose the perturbativity condition ($|C| < 4\pi$).

Maximization of Branching Fractions

Let us consider a branching fraction $\mathcal{O}$ related to a $b \to q$ transition, which will be given in terms of the SMEFT Wilson coefficients as,

$$\mathcal{O} = \vec{C}^{\dagger} M \vec{C} \ ,$$

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where B is a block diagonal Hermitian matrix, with a non-zero positive-definite block.

Now the problem is reduced to finding,

$$\mathcal{O}_{\text{max}} \equiv \text{Max}[\vec{C}^\dagger M \vec{C}; \ \text{with } \vec{C}^\dagger B \vec{C} \leq 1] \ .$$

Maximization of Branching Fractions

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where for reasons we argued earlier, $\mathcal{O}_{\mathrm{loop}}$ will be negligible, which we checked numerically.

To obtain $\mathcal{O}_{\mathrm{DY}}$ we simply need to solve an eigenvalue problem, after performing the diagonalization of the LHC matrix B, and the matrix M.

Numerical Results & EFT validity

Some important numerical results we found are:

$$\mathcal{B}(B_s \to K_S \mu\tau) \leq 4 \times 10^{-5} \, , \quad \mathcal{B}(B \to \rho\mu\tau) \leq 7 \times 10^{-5} \, ,$$

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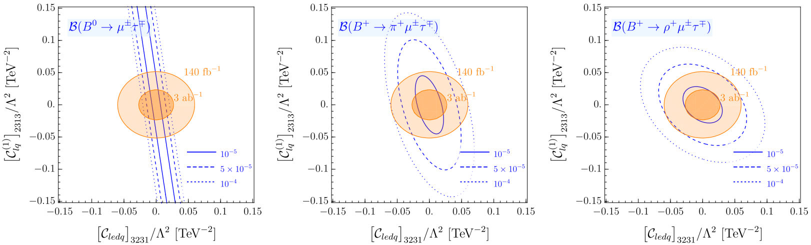

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In order for the EFT description to be valid for the LHC data, we need

$$E \ll \Lambda < \Lambda_{\rm max} \,,$$

where (from 1609.08157),

$$\Lambda_{\rm max} = \frac{\sqrt{4\pi}}{\sqrt{C_{\rm max}}}[\text{TeV}] \,.$$

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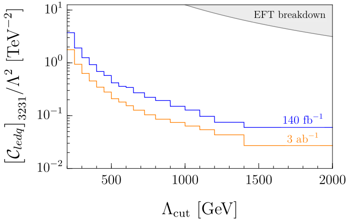
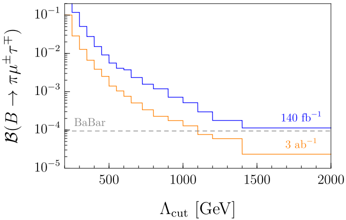
Numerically: $\Lambda_{\text{max}} = \mathcal{O}(10 \text{ TeV})$ for $B_{(s)}$ decays.





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- We showed that the effect of 1-loop contributions to $b \to q$ ($q = d, s$) LFV transitions is negligible for the maximization process.
- There is a complementarity between the direct exp. bounds and the indirect (DY) ones.
- Our results rely on the assumption that $E \ll \Lambda$, and therefore cannot be applied for light mediators.

Thank you!

Backup

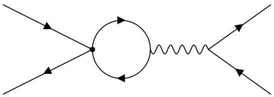
Observable	LHC (140 fb^{-1})	HL-LHC (3 ab^{-1})	Exp. limit
$\mathcal{B}(B^0 \to \mu^\pm\tau^\mp)$	8×10^{-4}	1.7×10^{-4}	1.4×10^{-5}
$\mathcal{B}(B^+ \to \pi^+\mu^\pm\tau^\mp)$	1.1×10^{-4}	2×10^{-5}	9.4×10^{-5}
$\mathcal{B}(B_s \to K_S^0\mu^\pm\tau^\mp)$	4×10^{-5}	8×10^{-6}	–
$\mathcal{B}(B^0 \to \rho\mu^\pm\tau^\mp)$	7×10^{-5}	1.5×10^{-5}	–
$\mathcal{B}(B_s \to \mu^\pm\tau^\mp)$	8×10^{-3}	1.7×10^{-3}	4.2×10^{-5}
$\mathcal{B}(B^+ \to K^+\mu^\pm\tau^\mp)$	9×10^{-4}	1.9×10^{-4}	3.9×10^{-5}
$\mathcal{B}(B^0 \to K^{*0}\mu^\pm\tau^\mp)$	4×10^{-4}	1.0×10^{-4}	2.2×10^{-5}
$\mathcal{B}(B_s \to \phi\mu^\pm\tau^\mp)$	5×10^{-4}	1.0×10^{-4}	–

In principle the same procedure can be applied to Upsilon LFV decays. For the part corresponding to $\mathcal{O}_{\mathrm{DY}}$, we obtain:

$$\mathcal{B}(\Upsilon \to \mu\tau) \leq 3 \times 10^{-9} \text{ at } 95\% \text{ CL },$$

which is much better than the exp. limit 6.0×10^{-6} at 95% CL.

However, since Υ is unflavored, loop effects cannot be neglected because they are not CKM suppressed. For example, QED corrections of the form:



are not negligible when we use the perturbativity constraint.
$\Rightarrow$ A more careful analysis is needed: take into account constraints from $\tau \to \mu\ell\ell$ to bound the 1-loop contributions from purely leptonic operators.