Are Lepton-Flavour Violating Decays Within Experimental Reach?

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LAPTh Annecy

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Disclaimer

I'll provide arguments for LFV in B decays.

By well-known pre-LHC arguments, LFV is expected in leptonic decays as well.

Will comment on this in last slide.

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    ⇒ *That's what one expects of new interactions above the EW scale*

b → s anomalies: EFT understanding

- *Consider the following Hamiltonian*

$$H_{\mathrm{SM+NP}}(\bar{b} \to \bar{s}\,\mu\,\mu) \;=\; -\frac{4\,G_F}{\sqrt{2}}\,V_{tb}^{*}V_{ts}\,\frac{\alpha_{\mathrm{em}}}{4\,\pi}\left[\bar{b}_L\,\gamma^{\lambda}\,s_L\cdot\left(C_9^{(\mu)}\,\bar{\mu}\,\gamma_{\lambda}\,\mu \;+\; C_{10}^{(\mu)}\,\bar{\mu}\,\gamma_{\lambda}\,\gamma_5\,\mu\right)\right]$$

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  - *R_K <u>and</u> R_{K^*} lower than 1*
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- *A fully quantitative test by a global fit leads to the same conclusions.*
  See [Ghosh, Nardecchia, Renner, 2014] [global fits]

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$$H_{\mathrm{NP}} = G\,(\bar{b}'_L \gamma^\lambda b'_L)\,(\bar{\tau}'_L \gamma_\lambda \tau'_L)$$

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- ***Note:*** *primed fields*
  - *Fields are in the "gauge" basis (= primed)*
  - *They need to be rotated to the mass eigenbasis* ☞
  - *So, in general, this rotation induces <u>LUV and LFV</u> effects*

mass basis

$$b'_L \equiv (d'_L)_3 = (U_L^d)_{3i}\,(d_L)_i$$

$$\tau'_L \equiv (\ell'_L)_3 = (U_L^\ell)_{3i}\,(\ell_L)_i$$

LFV signatures: B decays

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$$\frac{BR(B^+ \to K^+ \mu e)}{BR(B^+ \to K^+ \mu \mu)} = \frac{|\delta C_{10}|^2}{|C_{10}^{\mathrm{SM}} + \delta C_{10}|^2} \cdot \frac{|(U_L^{\ell})_{31}|^2}{|(U_L^{\ell})_{32}|^2} \cdot 2$$

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= 0.159 ²
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The current BR(B⁺ → K⁺ μe) limit yields the weak bound

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We expect this U-matrix factor to be O(1) – or larger – in at least one of these channels, just because U_L^ℓ *is unitary*

In particular, note that $BR(B^+ \to K^+ \mu \tau)$ *scales as* $|(U_L^\ell)_{33} / (U_L^\ell)_{32}|^2$

More quantitative LFV predictions? Need flavour models

- ***Ex. 1*** **[DG, Lane, 2015]**
  - *SM Yukawa couplings are brought to diagonal form through rotations like* $\left(U_L^\ell\right)^\dagger Y_\ell \, U_R^\ell = \hat{Y}_\ell$

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In any of these models one gets effects of $O(10^{-8})$

This confirms the general argument given previously

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is long-distance dominated [D'Ambrosio et al., 1998]
hence in general less promising

See recent reappraisal in [Crivellin et al., 1601.00970]

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  - Obviously, LFV modes don't suffer from this shortcoming

    Competitive playground for NA62, and even for LHCb...
    [work in progress]

LFV in K decays

- *The interaction advocated in [Glashow et al.]*

$$H_{\rm NP} = G \left(\bar{b}'_L \gamma^\lambda b'_L\right) \left(\bar{\tau}'_L \gamma_\lambda \tau'_L\right)$$

can also manifest itself in $K \to (\pi)\, \ell\, \ell'$ decays such as

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[*BNL E871 Collab., 1998*]

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$BR(K^+ \to \pi^+ \mu^+ e^-) < 1.3 \times 10^{-11}$ [*BNL E865 Collab., 2005*]

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LFV in K decays

- *To get rid of phase-space factors, we can define the useful ratios*

$$\frac{\Gamma(K_L^0 \to e^\pm \mu^\mp)}{\Gamma(K^+ \to \mu^+ \nu_\mu)} = |\beta^{(K)}|^2 \qquad \frac{\Gamma(K^+ \to \pi^+ \mu^\pm e^\mp)}{\Gamma(K^+ \to \pi^0 \mu^+ \nu_\mu)} = 4\,|\beta^{(K)}|^2$$

where $$\beta^{(K)} = \frac{\text{normalization of the new-physics operator } (\bar{s}_L \gamma^\lambda d_L)(\bar{e}_L \gamma_\lambda \mu_L)}{\text{normalization of the SM operator } (\bar{s}_L \gamma^\lambda u_L)(\bar{\nu}_L \gamma_\lambda \mu_L)}$$

LFV in K decays

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- Actually, under well-motivated TH assumptions, one gets even larger signals [work-in-prog.]

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So, BSM LUV $\Rightarrow$ BSM LFV (i.e. not suppressed by m_ν)

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  - *Theory arguments in classical papers such as* [Hall-Kostelecky, Raby, NPB 1986]
    [Barbieri-Hall, PLB 1994]

Models with LUV and no LFV

Ex. 1: *[Alonso, Grinstein, Martin-Camalich, 2015]*

- *Take Minimal Flavour Violation (MFV) in the lepton sector*
  - *By def, in MFV the only sources of flavour violation are the SM ones, i.e. the SM Yukawas*
  - *Tricky to define MFV in the lepton sector:*
    we don't know whether LH ν are Dirac or Majorana and whether RH ν exist at all.
    Must-read ref: Cirigliano-Grinstein-Isidori-Wise, NPB 2005

- *Bottom line: In such scenarios, LFV couplings are related to LH ν masses.*
  (Neglecting CPV in the LH ν mass matrix, the above statement is generic within MLFV.)

$\Rightarrow$ *Low-energy LFV processes are generally small, being suppressed by LH ν masses*

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Ex. 2: [Celis *et al.*, *2015*]

- *Take a Branco-Grimus-Lavoura (BGL) global symmetry.*
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Plausible mechanism? Fine-tuning in model space?