LFV in B decays

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☞ *Main line of argument based on Glashow, DG, Lane, PRL 2015*

Motivation:
LHCb's b $\to$ s data

Renewed interest in B-decay LFV is motivated by the following pieces of exp info (LHCb):

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$$R_K = \frac{BR\left(B^+ \to K^+ \mu\mu\right)_{[1,6]}}{BR\left(B^+ \to K^+ e\,e\right)_{[1,6]}} = 0.745 \cdot \left(1 \pm 13\%\right)$$

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❶ + ❷ + ❸ $\Rightarrow$ *There seems to be BSM LFNU and the effect is in μμ, not ee*

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Actually, after some effective-theory insights, two further pieces of info support the above picture

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- *Yet:*
  - ***Q1:*** *Can we (easily) make sense of* ❶ to ❺ ?
  - ***Q2:*** *What are the most immediate signatures to expect ?*

Concerning Q2: most immediate signatures to expect

Basic observation:

- *In the presence of LFNU at a non-SM level, one expects also LFV at a non-SM level.*

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- *Rotating q and* ℓ *to the mass eigenbasis generates LFV interactions.*

Frequently made objection:
what about the SM? It has LFNU, but no LFV

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

Some Exceptions

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- *"Generally small" means:*

  Barring MFV models where sizable LFV and small LH ν masses can be engineered to be so by tuning a dimensionful parameter to be small. (Back to fine tuning.)

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Plausible mechanism?

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purely axial lepton current

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We assume the above V – A structure to hold also beyond the SM, namely

$$C_9^{(\ell)} \approx -C_{10}^{(\ell)} \qquad \textit{with} \qquad C_{9,10}^{(\ell)} = C_{9,10}^{\mathrm{SM}} + C_{9,10}^{(\ell),\mathrm{NP}}$$

Why? Makes theoretical sense.
And fits successfully the discussed data (Altmannshofer-Straub, EPJC 2015).

cf. also Hiller, Schmaltz; Ghosh, Nardecchia, Renner; Hurth, Mahmoudi, Neshatpour

Model example

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- *To account for effects hierarchical between generations, one may then start from a purely 3rd-generation interaction (in the gauge basis):*

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

with $G = 1/\Lambda_{\mathrm{NP}}^2 \ll G_F$

expected e.g. in topcolor models
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  - *This rotation induces* *LFNU and LFV* *effects*

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Explaining b → s data

- *Recalling our full Hamiltonian*

k_{SM} (SM norm. factor)

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the shift to the C_9 Wilson coeff. in the μμ-channel becomes

$$k_{\mathrm{SM}} C_9^{(\mu)} = k_{\mathrm{SM}} C_{9,\mathrm{SM}} + \frac{G}{2} (U_L^d)_{33}^* (U_L^d)_{32} |(U_L^\ell)_{32}|^2$$

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$$= \quad \beta_{\mathrm{SM}} \quad + \quad \beta_{\mathrm{NP}}$$

The NP contribution has opposite sign than the SM one if

$$G\, (U_L^d)_{32} < 0$$

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$$k_{\mathrm{SM}}\, C_9^{(\mu)} = \boxed{k_{\mathrm{SM}}\, C_{9,\mathrm{SM}}} + \boxed{\frac{G}{2} (U_L^d)_{33}^* (U_L^d)_{32} |(U_L^\ell)_{32}|^2}$$

$$= \beta_{\mathrm{SM}} + \beta_{\mathrm{NP}}$$

The NP contribution has opposite sign than the SM one if

$$G\,(U_L^d)_{32} < 0$$

- *On the other hand, in the ee-channel*

$$k_{\mathrm{SM}}\, C_9^{(e)} = k_{\mathrm{SM}}\, C_{9,\mathrm{SM}} + \frac{G}{2} (U_L^d)_{33}^* (U_L^d)_{32} |(U_L^\ell)_{31}|^2$$

Explaining b → s data

- *Recalling our full Hamiltonian*

k_{SM} (SM norm. factor)

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$$\cong \beta_{\mathrm{SM}}$$

The NP contrib. in the ee-channel is negligible, provided

$$|(U_L^\ell)_{31}|^2 \ll |(U_L^\ell)_{32}|^2$$

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$$R_K \approx \frac{|C_9^{(\mu)}|^2 + |C_{10}^{(\mu)}|^2}{|C_9^{(e)}|^2 + |C_{10}^{(e)}|^2} = \frac{2\cdot(\beta_{\mathrm{SM}} + \beta_{\mathrm{NP}})^2}{2\cdot\beta_{\mathrm{SM}}^2}$$

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$$0.77 \pm 0.20 = \frac{BR(B_s \to \mu\mu)_{\exp}}{BR(B_s \to \mu\mu)_{SM}} = \frac{BR(B_s \to \mu\mu)_{SM+NP}}{BR(B_s \to \mu\mu)_{SM}} = \frac{(\beta_{SM} + \beta_{NP})^2}{\beta_{SM}^2}$$

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implying (within our model) the correlations

$$\frac{BR(B_s \to \mu\mu)_{\rm exp}}{BR(B_s \to \mu\mu)_{\rm SM}} \simeq R_K \simeq \frac{BR(B^+ \to K^+\mu\mu)_{\rm exp}}{BR(B^+ \to K^+\mu\mu)_{\rm SM}}$$

Another good reason to pursue accuracy in the $B_s \to \mu\mu$ measurement

LFV model signatures

☑ $$\frac{BR(B^+ \to K^+ \mu\, e)}{BR(B^+ \to K^+ \mu\, \mu)} = \frac{\beta_{\mathrm{NP}}^2}{(\beta_{\mathrm{SM}} + \beta_{\mathrm{NP}})^2} \cdot \frac{|(U_L^\ell)_{31}|^2}{|(U_L^\ell)_{32}|^2} \cdot 2$$

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= 0.159^2 according to R_K

μ^+e^- & $\mu^- e^+$ modes

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

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Main message

With the measured R_K value, and without tuning U-matrix values, we obtain LFV signals in the 10^{-8} ballpark.

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Analogous considerations hold for purely leptonic LFV decays

- ☑ $$\frac{BR(B_s \to \mu e)}{BR(B_s \to \mu \mu)} = \frac{\beta_{NP}^2}{(\beta_{SM}+\beta_{NP})^2} \cdot \frac{|(U_L^{\ell})_{31}|^2}{|(U_L^{\ell})_{32}|^2}$$

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☑ *Again,* $B_s \to \mu\tau$ *would be even more promising*

☑ *An interesting signature outside B physics would be* $K \to \pi\, \ell\, \ell'$

Note, instead, that the "K-physics analogue" of R_K:

$$\frac{BR(K \to \pi \mu \mu)}{BR(K \to \pi e e)}$$

less interesting as it is long-distance dominated [see D'Ambrosio et al., 1998]

More quantitative LFV predictions

- *More quantitative LFV predictions require knowledge of* U_L^ℓ

Reminder:

$$\left(U_L^\ell\right)^\dagger Y_\ell \, U_R^\ell = \hat{Y}_\ell$$

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  - *Appelquist-Bai-Piai ansatz:*
    The 5 flavor-SU(3) rotations are not all independent. Choosing 3 to be the independent ones allows to predict one SM Yukawa in terms of the other two.

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  - *One has* $(U_L^{\ell})^\dagger \, U_L^{\nu} =$ *PMNS matrix*
  - *Taking* $U_L^{\nu} = 1$, U_L^{ℓ} *can be univocally predicted*

More quantitative LFV predictions

LFV predictions in one of the two scenarios of [DG, Lane]

	$B^+ \to K^+ \mu^\pm \tau^\mp$	$B^+ \to K^+ e^\pm \tau^\mp$	$B^+ \to K^+ e^\pm \mu^\mp$
	1.14×10^{-8}	3.84×10^{-10}	0.52×10^{-9}
Exp:	$< 4.8 \times 10^{-5}$	$< 3.0 \times 10^{-5}$	$< 9.1 \times 10^{-8}$

	$B_s \to \mu^\pm \tau^\mp$	$B_s \to e^\pm \tau^\mp$	$B_s \to e^\pm \mu^\mp$
	1.37×10^{-8}	4.57×10^{-10}	1.73×10^{-12}
Exp:	—	—	$< 1.1 \times 10^{-8}$

All predictions are phase-space corrected.

More signatures

For a recent discussion:
Alonso, Grinstein, Martin-Camalich,
PRL 14

- *Being defined above the EWSB scale, our assumed operator* $G\, \bar{b}'_L \gamma^\lambda b'_L\, \bar{\tau}'_L \gamma_\lambda \tau'_L$ *must actually be made invariant under* $SU(3)_c \times SU(2)_L \times U(1)_Y$

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See:
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$$\bar{b}'_L \gamma^\lambda b'_L \, \bar{\tau}'_L \gamma_\lambda \tau'_L \quad \xrightarrow[\text{inv.}]{SU(2)_L} \quad \begin{cases} \bar{Q}'_L \gamma^\lambda Q'_L \, \bar{L}'_L \gamma_\lambda L'_L & \text{[neutral-current int's only]} \\ \bar{Q}'^i_L \gamma^\lambda Q'^j_L \, \bar{L}'^j_L \gamma_\lambda L'^i_L & \text{[also charged-current int's]} \end{cases}$$

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- *After rotation to the mass basis (unprimed), the last structure contributes to* $\Gamma(b \to c\, \tau\, \bar{\nu}_i)$

Can explain BaBar deviations on $R(D^{(*)}) = \dfrac{BR(\bar{B} \to D^{(*)+} \tau^- \bar{\nu}_\tau)}{BR(\bar{B} \to D^{(*)+} \ell^- \bar{\nu}_\ell)}$
(D channel confirmed by LHCb)*