Possible K-physics tests of LHCb anomalies

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

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vs.

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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 ?*

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Basic observation:

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

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  $\Rightarrow$ $C_9^{\mathrm{SM}}(m_b) \approx -C_{10}^{\mathrm{SM}}(m_b)$

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

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

Such an hypothesis provides a successful fit to the discussed data.
See Altmannshofer-Straub, EPJC 2015.

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

Model example

- *In short, our model requirements are:*
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  In the gauge basis, one may then start from a *<u>purely 3</u>*

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

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  - *This rotation induces* *LFNU and LFV* *effects*

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Explaining b → s data

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

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Approximations

- *phase-space factor is about the same in the μμ- and in the ee-channel*
- *dominance of the $|C_{9,10}|^2$ contributions in the concerned q^2 region*

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

factors of 2:
equal contributions from $|C_9|^2$ and $|C_{10}|^2$

Approximations

- *phase-space factor is about the same in the μμ- and in the ee-channel*
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$$0.77 \pm 0.20 = \frac{BR(B_s \to \mu\mu)_{\rm exp}}{BR(B_s \to \mu\mu)_{\rm SM}} = \frac{BR(B_s \to \mu\mu)_{\rm SM+NP}}{BR(B_s \to \mu\mu)_{\rm SM}} = \frac{(\beta_{\rm SM}+\beta_{\rm NP})^2}{\beta_{\rm SM}^2}$$

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implying (within our model) the correlations

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

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

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)*

LFV model signatures

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

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☑ $BR(B^+ \to K^+ \mu \tau)$ *would be even more promising, as it scales with* $|(U_L^\ell)_{33} / (U_L^\ell)_{32}|^2$
(a potential enhancement factor, actually)

Phase-space corrections are more important than in the μμ and ee cases, but easy to account for

LFV model signatures

Analogous considerations hold for purely leptonic LFV decays

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

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Reminder:

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

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  - *Appelquist-Bai-Piai ansatz:*
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- An interesting signature outside B physics would be $K \to (\pi)\ \ell\ \ell'$
  - Note that, while at LHCb lots of K mesons are produced, they decay too late for the detector size (except the K_S)

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See however Crivellin et al., 1601.00970 for a recent reappraisal

⇨ Tunstall's talk

LFV in K decays

- *The interaction advocated in GGL*

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

can also manifest itself in $K \to (\pi)\, \ell\, \ell'$, for example

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- *Exp limits*

$$\mathrm{BR}\left(K_L^0 \to e^\pm \mu^\mp\right) < 4.7 \times 10^{-12}$$

BNL E871 Collab., PRL 1998

$$\mathrm{BR}\left(K^+ \to \pi^+ \mu^+ e^-\right) < 1.3 \times 10^{-11}$$

$$\mathrm{BR}\left(K^+ \to \pi^+ \mu^- e^+\right) < 5.2 \times 10^{-10}$$

BNL E865 Collab., PRD 2005

BNL E865 Collab., PRL 2000

LFV in K decays

- *Defining the basic quantity*

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with

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Spares

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

Take the SM with zero ν masses.

- *Charged-lepton Yukawa couplings are LFNU, but they are diagonal in the mass eigenbasis (hence no LFV)*

Or more generally, take the SM plus a minimal mechanism for ν masses.

- *Physical LFV will appear in W couplings, but it's suppressed by powers of* $(m_\nu / m_W)^2$

Bottom line: in the SM+ν there is LFNU, but LFV is nowhere to be seen (in decays)

- *But nobody ordered that the reason (=tiny m_ν) behind the above conclusion be at work also beyond the SM*

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

Some Exceptions

Alonso, Grinstein, Martin-Camalich, 1505.05164

- *Take Minimal Flavor Violation (MFV) in the lepton sector*
  - *By def, in MFV the only sources of flavor 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.)

  ⇨ *Low-energy LFV processes are generally small, being suppressed by LH ν masses.*
  (This brings back to the previous slide)

- *"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.)

Some Exceptions

Celis et al., PRD 2015

- *Take a Branco-Grimus-Lavoura (BGL) global symmetry.*
  - *BGL models are a proposal to solve the monstrous flavor problem of general 2HDM (tree-level FCNCs)*
  - *They engineer an Abelian global symmetry that relates all Higgs-quark flavor-changing couplings to CKM entries*
- *Gauge this symmetry, and require anomaly cancellation.*
- *This requirement yields diagonal charged-lepton Yukawa couplings.*

⇒ *BSM LFNU but no BSM LFV*

Plausible mechanism? Fine-tuning in model space?

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.