Lepton Flavor Violation in $b \to s\ell_i\ell_j$

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Based on D. Becirevic, S. Fajfer, F. Jaffredo and O.Sumensari *(in preparation)*

Motivations

- Hints of **Lepton Flavor Universality Violation** (LFUV) observed in B meson decays:

$$R_{K^{(*)}} = \left.\frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}\right|_{q^2\in[1,6]\ \mathrm{GeV}^2} \qquad R_{K^*}^{[0.042,1]} = \left.\frac{\mathcal{B}(B \to K^{*}\mu^+\mu^-)}{\mathcal{B}(B \to K^{*}e^+e^-)}\right|_{q^2\in[0.042,1]\ \mathrm{GeV}^2}$$

- R_K, R_{K^*} and $B_s \to \ell_i \ell_j$ are all smaller than their SM prediction (3.1σ for R_K alone).

- What model of NP can explain these B anomalies?

In most of the models **LFUV ⇒ LFV** ?

EFT for $b \to s\ell_i\ell_j$

- **OPE** at dimension 6:

$$\mathcal{H}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_{a=9,10,\dots} \left(C_a^{ij}(\mu)\mathcal{O}_a^{ij}(\mu) + C_a^{ij\prime}(\mu)\mathcal{O}_a^{ij\prime}(\mu) \right) + \text{h.c.}$$

$$\mathcal{O}_9^{ij(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}_i\gamma^\mu \ell_j), \qquad \mathcal{O}_{10}^{ij(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}_i\gamma^\mu\gamma^5 \ell_j),$$

$$\mathcal{O}_S^{ij(\prime)} = (\bar{s} P_{R(L)} b)(\bar{\ell}_i \ell_j), \qquad \mathcal{O}_P^{ij(\prime)} = (\bar{s} P_{R(L)} b)(\bar{\ell}_i\gamma^5 \ell_j),$$

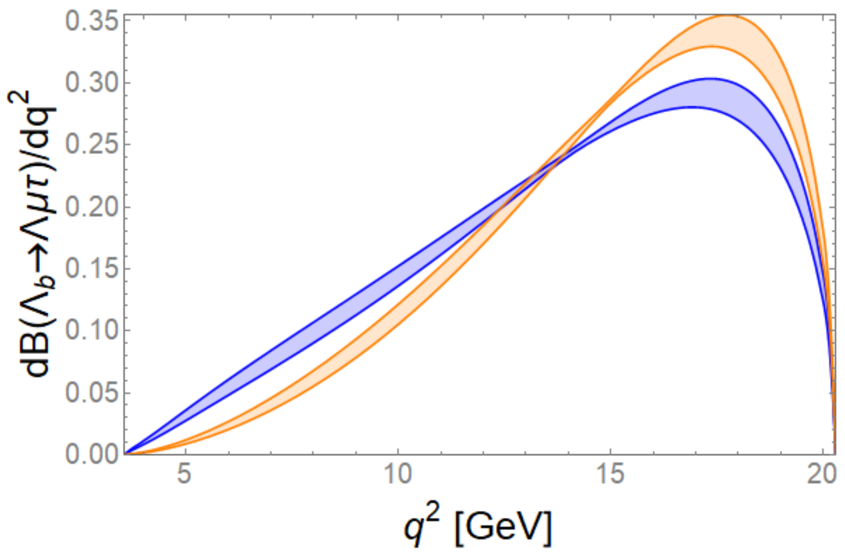
- from quark to hadrons: **LQCD** $\quad \langle H_i \,|\Gamma|\, H_f \rangle \propto f_0, f_+, f_\perp, g_0, g_+, g_\perp$

- $B_s \to l_i l_j$
- $B_s \to \phi l_i l_j$
- $B \to K^{(*)} l_i l_j$
- ***$\Lambda_b \to \Lambda l_i l_j$ (NEW)***

The case $\Lambda_b \to \Lambda \ell_i \ell_j$

$$\frac{d^2\Gamma(\Lambda_b \to \Lambda \bar{\ell}_i \ell_j)}{dq^2 d\cos\theta} = \frac{|K|^2}{256\pi^3 m_{\Lambda_b}^3} \frac{1}{q^2} \frac{\sqrt{s_+ s_-}}{2} \frac{\sqrt{r_+ r_-}}{2} \sum_{16\ \text{spins}} |\mathcal{M}|^2,$$

$$= \sum_s \left(a_s + b_s \cos\theta + c_s \cos^2\theta \right),$$



- Prediction concerning LFV decay modes:

- If NP comes from the **scalar** sector ($C_S^{ij} \neq 0$, $C_P^{ij} \neq 0$)

$$\mathcal{B}(B \to K^* \ell_i \ell_j) < \mathcal{B}(\Lambda_b \to \Lambda \ell_i \ell_j) < \mathcal{B}(B \to K \ell_i \ell_j) < \mathcal{B}(B_s \to \ell_i \ell_j)$$

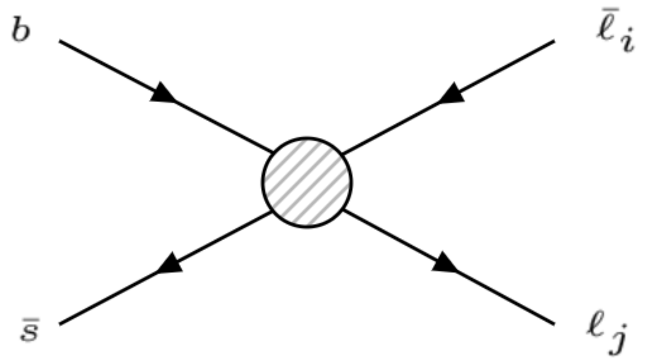
- If NP comes from the **vector** sector ($C_9^{ij} \neq 0$, $C_{10}^{ij} \neq 0$)

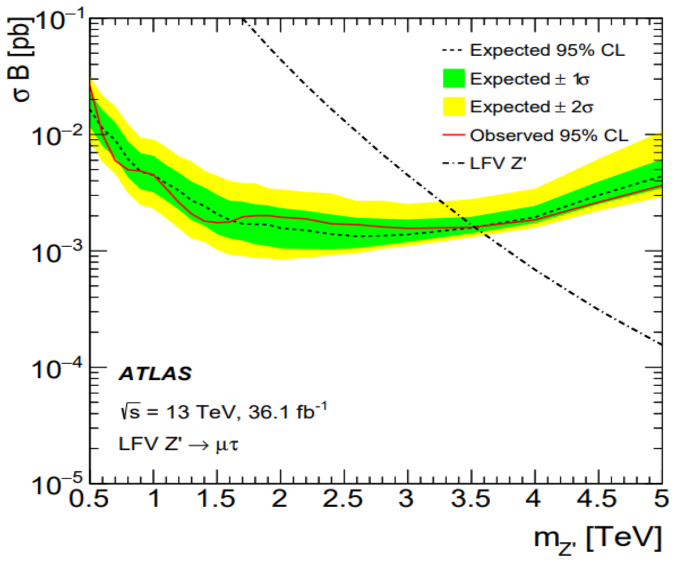
$$\mathcal{B}(B_s \to \ell_i \ell_j) < \mathcal{B}(B \to K \ell_i \ell_j) < \mathcal{B}(\Lambda_b \to \Lambda \ell_i \ell_j) \approx \mathcal{B}(B \to K^* \ell_i \ell_j)$$

LFV in dilepton tails at LHC

- Directly probing $bs \to \ell_1 \ell_2$ in p-p collisions.
- Partonic cross-section:

$$[\hat{\sigma}(\hat{s})]_{ij} = \frac{\hat{s}}{144\pi v^4} \sum_{\alpha\beta} C_\alpha^{ij} C_\beta^{ij} M_{\alpha\beta}$$





- Model independent limits are obtained by recasting searches for $Z' \to \ell_1 \ell_2$.

Process	Projected LHC limit (3 ab^{-1})	L.E. exp limit
$\mathcal{B}(B_s \to \tau^\pm \mu^\mp)$	2.5×10^{-4}	4.2×10^{-5}
$\mathcal{B}(B \to K \tau^\pm \mu^\mp)$	5.3×10^{-4}	3.9×10^{-5}
$\mathcal{B}(B \to K^* \tau^\pm \mu^\mp)$	8.9×10^{-4}	$N.A.$
$\mathcal{B}(\Lambda_b \to \Lambda \tau^\pm \mu^\mp)$	8.9×10^{-4}	$N.A.$

Example of explicit model: Z’

- Z-like boson, with non-diagonal flavor structure.

$$\mathcal{L}_{Z'} \supset g^L_{\ell_i \ell_j} \bar{\ell}_i \gamma^\mu P_L \ell_j Z'_\mu + g^L_{sb} \bar{s} \gamma^\mu P_L b Z'_\mu + (L \longleftrightarrow R),$$

- Matching to the EFT:

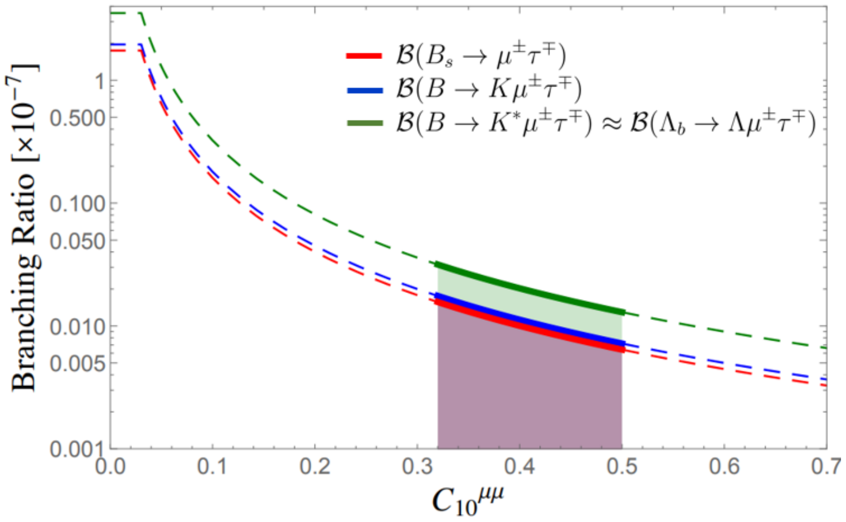
$$C_9^{(\prime)\mu\tau} = -\frac{\pi}{\sqrt{2} m_{Z'}^2} \frac{1}{\alpha G_F V_{tb} V_{ts}^*} g_{sb}^{L(R)} \left(g^R_{\mu\tau} + g^L_{\mu\tau} \right),$$

$$C_{10}^{(\prime)\mu\tau} = -\frac{\pi}{\sqrt{2} m_{Z'}^2} \frac{1}{\alpha G_F V_{tb} V_{ts}^*} g_{sb}^{L(R)} \left(g^R_{\mu\tau} - g^L_{\mu\tau} \right),$$

Can be bounded from $B_s - \overline{B_s}$ mixing

Can be bounded from $\tau \to \mu\mu\mu$ and $\tau \to \mu \nu_\mu \nu_\tau$ (and fit to $b \to s\mu\mu$)

- Results:



$$\mathcal{B}(B_s \to \mu^\pm \tau^\mp) < 1.6 \times 10^{-9}$$

$$\mathcal{B}(B \to K \mu^\pm \tau^\mp) < 1.8 \times 10^{-9}$$

$$\mathcal{B}(B \to K^* \mu^\pm \tau^\mp) < 3.3 \times 10^{-9} \approx \mathcal{B}(\Lambda_b \to \Lambda \mu^\pm \tau^\mp)$$

Conclusion

- **LFV** present in most model of NP accommodating **LFUV** (as observed in LHCb with R_K, R_{K^*})
- The required NP effects are encoded in the WCs of the EFT for $b \to s\ell_i\ell_j$.
- Exclusive $b \to s\ell_i\ell_j$ modes are studied at LHCb and at Belle II.
- In addition to $\mathcal{B}(B_s \to \ell_i\ell_j)$, $\mathcal{B}(B \to K^{(*)}\ell_i\ell_j)$ we derive expression for $\mathcal{B}(\Lambda_b \to \Lambda\ell_i\ell_j)$ for which the hadronic matrix elements are already determined in LQCD.
- Bounds on WCs obtained from high-p_T tails of $pp \to \ell_i\ell_j$ at LHC are not useful for $B_S \to \ell_i\ell_j$ and $B \to K\ell_i\ell_j$, but they are for $B \to K^*\ell_i\ell_j$ and $\Lambda_b \to \Lambda\ell_i\ell_j$.
- Bounds from low energy observables: efficient if we adopt an explicit scenario of NP (Z', Leptoquark, sterile neutrino, extended Higgs sector, …)
- We show that a combination of LE constraints in a scenario with Z' boson results in upper bounds:

$$\mathcal{B}(B_s \to \mu\tau) < 1.6 \times 10^{-9}, \qquad \mathcal{B}(B \to K\mu\tau) < 1.8 \times 10^{-9}$$
$$\mathcal{B}(B \to K^*\mu\tau) < 3.3 \times 10^{-9} \qquad \mathcal{B}(\Lambda_b \to \Lambda\tau\mu) < 3.3 \times 10^{-9}$$