LFV B decays in generic Z' models

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Workshop “Rare B decays”

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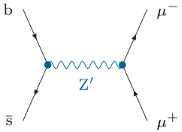
Motivation

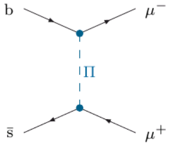
- Tensions in
  - $B \to K^* \mu^+ \mu^-$
  - $R(K) = \mathrm{Br}(B \to K \mu^+ \mu-)/\mathrm{Br}(B \to K e^+ e^-)$
  - $B_s \to \phi \mu^+ \mu^-$
- Can be explained by new physics in the effective operator

$$\mathcal{O}_9^{\mu\mu} = \frac{\alpha}{4\pi} [\bar{s}\gamma^\mu P_L b][\bar{\mu}\gamma_\mu \mu]$$

- Natural NP cadidates inducing this operator at tree level:



Z' models
Buras et al;
Altmannshofer,Gori,Pospelov,Yavin;
Crivellin,D'Ambrosio,Heeck; ...



lepto-quarks
Hiller,Schmaltz;
Gripaios,Nardecchia,Renner; ...

LFV Z' coupling?

- solve $B \to K^* \mu^+ \mu^-$ anomaly and R_K tension simultaneously

  $\Rightarrow$ Z' couples to muons but not electrons

- Z' model violates lepton universality

  $\Rightarrow$ natural to assume also presence of LFV $Z'\tau\mu$ coupling

- search for LFV decays $B_s \to \tau\mu$, $B \to K^{(*)}\tau\mu$

  [Glashow,Guadagnoli,Kane]

  $\Rightarrow$ measurable effects possible?

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- study most general framework: arbitrary couplings

$$Z' sb : \Gamma_{sb}, \qquad Z'\mu\mu : \Gamma_{\mu\mu}, \qquad Z'\tau\mu : \Gamma_{\tau\mu}$$

Constraints in lepton sector

- $\tau \to 3\mu$: $\Gamma_{\mu\tau}^2 \Gamma_{\mu\mu}^2$

  Belle + BarBar (90% conf. lev.): $\mathrm{Br}(\tau \to 3\mu) < 1.2 \times 10^{-8}$

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- $\tau \to \mu\nu\bar{\nu}$: $\Gamma^2_{\mu\tau}$ (at loop-level $\Gamma_{\mu\mu}\Gamma_{\tau\tau}$)

  $\mathrm{Br}_{\mathrm{exp}} = (17.41 \pm 0.04)\%$, $\mathrm{Br}_{\mathrm{SM}} = (17.29 \pm 0.03)\%$ [Pich]

  already more than $2\,\sigma$ difference $\rightarrow$ included at $3\,\sigma$

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- loop corrections to $Z \to \ell\ell'$: $\Gamma^2_{\mu\tau}$, $\Gamma^2_{\mu\mu}$, $\Gamma_{\mu\tau}\Gamma_{\mu\mu}$

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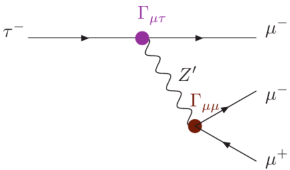
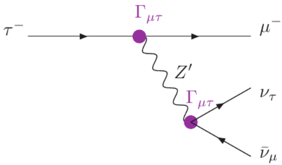
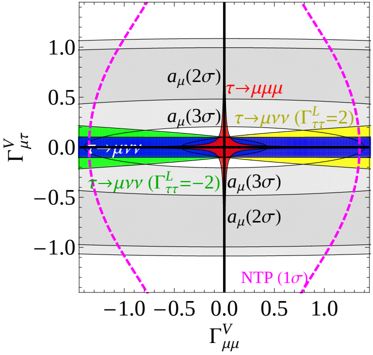
- neutrino tridents $\nu_\mu N \to \nu_\ell N \mu^+\mu^+$: $\Gamma^2_{\mu\mu}$, $\Gamma^2_{\mu\tau}\Gamma^2_{\mu\mu}$
  [Altmannshofer,Pospelov,Gori,Yavin]

  combined bound from CHARM-II/CCFR/NuTeV:
  $\sigma_{\mathrm{exp}}/\sigma_{\mathrm{SM}} = 0.83 \pm 0.18$

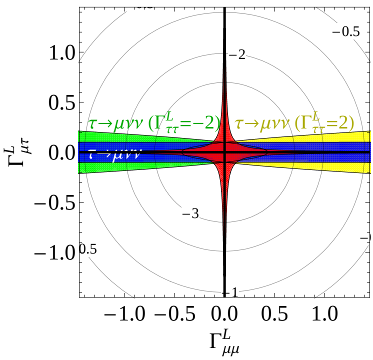
Lepton couplings





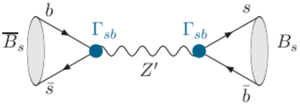


vectorial $Z'\ell\ell'$ coupling

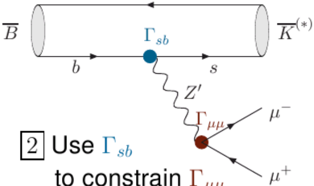


left-handed $Z'\ell\ell'$ coupling

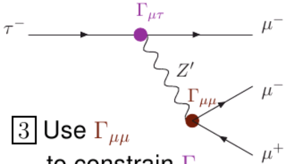
Strategy of our analysis



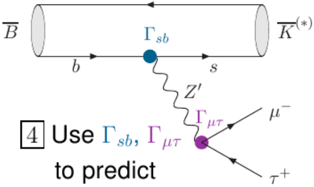
1 Constrain Γ_{sb}
from $B_s - \overline{B}_s$ mixing



2 Use Γ_{sb}
to constrain $\Gamma_{\mu\mu}$
from $B \to K^{(*)}\mu^+\mu^-$

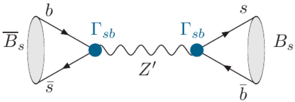


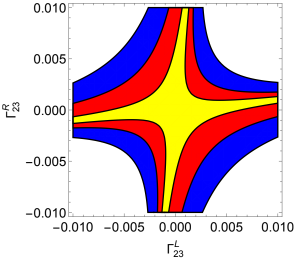
3 Use $\Gamma_{\mu\mu}$
to constrain $\Gamma_{\mu\tau}$
from $\tau^- \to \mu^-\mu^+\mu^-$
(and $\tau^- \to \mu^-\nu\bar{\nu}$)



4 Use Γ_{sb}, $\Gamma_{\mu\tau}$
to predict
$B \to K^{(*)}\tau^+\mu^-$
$\Rightarrow$ Large effects possible?

$B_s - \overline{B}_s$ mixing





- contributions from left- and righthanded Z' couplings:

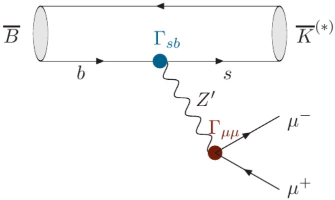
$$(\Gamma^L_{sb})^2 + (\Gamma^R_{sb})^2 - b_{B_s}\Gamma^L_{sb}\Gamma^R_{sb}$$

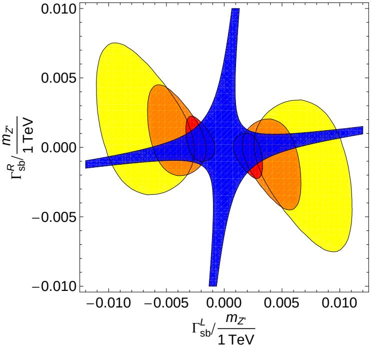
- solution of $B \to K^*\mu^+\mu^-$ anomaly requires non-zero Γ^L_{sb}

- constraint from $B_s - \overline{B}_s$ mixing can be softened by same-size coupling Γ^R_{sb} with $\Gamma^R_{sb} \ll \Gamma^L_{sb}$:

  fine-tuning measure: $X_{B_s} = \dfrac{(\Gamma^L_{sb})^2 + (\Gamma^R_{sb})^2 + b_{B_s}\Gamma^L_{sb}\Gamma^R_{sb}}{(\Gamma^L_{sb})^2 + (\Gamma^R_{sb})^2 - b_{B_s}\Gamma^L_{sb}\Gamma^R_{sb}}$

$B \to K^{(*)}\mu^+\mu^-$

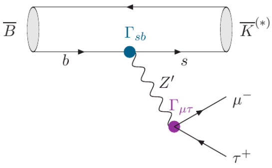




$\Gamma_{\mu\mu} = 1.0$, $\Gamma_{\mu\mu} = 0.5$, $\Gamma_{\mu\mu} = 0.3$

- $C_9^{\text{NP}} \sim \Gamma_{sb}^L \Gamma_{\mu\mu}$, $C_9'^{\text{NP}} \sim \Gamma_{sb}^R \Gamma_{\mu\mu}$
- small $\Gamma_{\mu\mu}$ requires large Γ_{sb}^L and because of the correlation with $B_s - \overline{B}_s$ mixing a small same-size Γ_{sb}^R

$B_s \to \tau\mu, \quad B \to K^{(*)}\tau\mu$



$$C_{9,10}^{(\prime)\tau\mu} \propto \Gamma_{bs}^{L(R)} \Gamma_{\mu\tau}^{V,A}$$

$$\begin{aligned} \mathrm{Br} \;=\;& a\,|C_9^{\tau\mu} + C_9^{\prime\tau\mu}|^2 + b\,|C_{10}^{\tau\mu} + C_{10}^{\prime\tau\mu}|^2 + \\ & c\,|C_9^{\tau\mu} - C_9^{\prime\tau\mu}|^2 + d\,|C_{10}^{\tau\mu} - C_{10}^{\prime\tau\mu}|^2 \end{aligned}$$

- $B_s \to \tau\mu$: $\quad a = b = 0, \quad c \approx d$
  $B \to K\tau\mu$: $\quad a \approx b, \quad c = d = 0$
  $B \to K^*\tau\mu$: $\quad a \approx b, \quad c \approx d$

- experimental bounds:

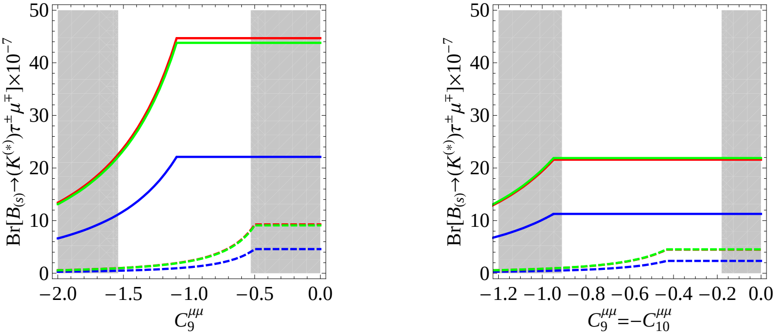
$$\mathrm{Br}\left(B^+ \to K^+\tau^\pm\mu^\mp\right) \leq 4.8\times 10^{-5}, \quad \mathrm{Br}\left(B^+ \to K^+\mu^\pm e^\mp\right) \leq 9.1\times 10^{-8},$$

$$\mathrm{Br}\left(B \to K^*\tau^\pm\mu^\mp\right) \leq --, \quad \mathrm{Br}\left(B \to K^*\mu^\pm e^\mp\right) \leq 1.4\times 10^{-6},$$

$$\mathrm{Br}\left(B_s \to \tau^\pm\mu^\mp\right) \leq --, \quad \mathrm{Br}\left(B_s \to \mu^\pm e^\mp\right) \leq 1.2\times 10^{-8}$$

$B_s \to \tau\mu$ and $B \to K^{(*)}\tau\mu$

Max. branching ratio of $B_s \to \tau\mu$, $B \to K^*\tau\mu$, $B \to K\tau\mu$ tuning B_s mixing to $X_{B_s} = 100$ (solid), $X_{B_s} = 20$ (dashed)

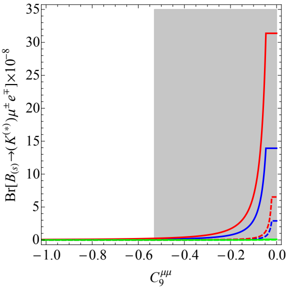


constraints from

- $\tau \to 3\mu$: $\propto \; (1 + X_{B_s})^2/|C_9^{\mu\mu}|^2$
- $\tau \to \mu\nu\bar{\nu}$: $\propto \; (1 + X_{B_s})$

$B_s \to \mu e$ and $B \to K^{(*)} \mu e$

Max. branching ratio of $B_s \to \mu e$, $B \to K^* \mu e$, $B \to K \mu e$
tuning B_s mixing to $X_{B_s} = 100$ (solid), $X_{B_s} = 20$ (dashed)



constraints from

- $\mu \to e\gamma$: $\propto \; (1 + X_{B_s})^2 / |C_9^{\mu\mu}|^2$
- $\mu \to e\nu\bar{\nu}$: $\propto \; (1 + X_{B_s})$

Conclusions

- we have studied the possible size of $B_s \to \ell\ell'$, $B \to K^{(*)}\ell\ell'$ with $\ell\ell' = \tau\mu, \mu e$ considering
  - two scenarios with vectorial and left-handed $Z'\ell\ell'$ couplings
  - existing constraints on $Z'\ell\ell'$ couplings
- sizable effects require cancellations in $B_s - \overline{B}_s$ mixing implying non-vanishing $C'^{\mu\mu}_{9,10}$ with $C'^{\mu\mu}_{9,10} \ll C^{\mu\mu}_{9,10}$ (if $Z'\mu\mu$ does not vanish)
- For $\tau\mu$ final states branching ratios can be up to 5×10^{-6} for a fine-tuning of $X_{B_s} \sim 100$ in $B_s - \overline{B}_s$ mixing
- For μe final states branching ratios can only be up to $\sim 10^{-7}$ for a fine-tuning of $X_{B_s} \sim 100$ in $B_s - \overline{B}_s$ mixing, and this only in a region of parameter space disfavoured by $b \to s$ anomalies