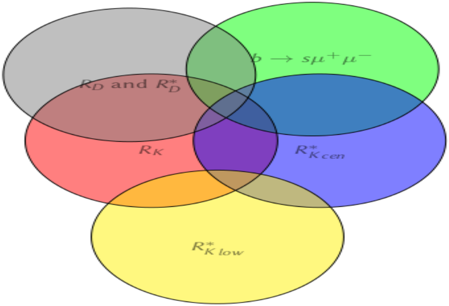
Combined explanation of the B-anomalies

@ FPCP 2019, University of Victoria

Presented by Jacky Kumar
Université de Montréal

Based on JK, David London, Ryoutaro Watanabe, Phys. Rev. D 99, 015007



B-Anomalies

- Discrepancies in $b \to s\mu^+\mu^-$ data and SM: Angular Observables in $B \to K^*\mu^+\mu^-$, Branching Ratio in $B_s \to \phi\mu^+\mu^-$: (Combined Significance **4**-5σ).

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• Discrepancies in Lepton Flavor Universality Ratios in $b \to s\ell\ell$:

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Both R_D and R_{D^*} are measured to be above the SM value, the combined significance is $\sim \mathbf{4.0}\sigma$. $R_{J/\psi}$ is measured to be $\sim \mathbf{2}\sigma$ above the SM.

Individual Explanations: EFT Approach

- The NP can be parameterized in terms of the Wilson Coefficients.

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(Global Fits):

- b $\to$ s$\mu\mu$:

$$C_9^{\mu\mu}(NP) = -C_{10}^{\mu\mu}(NP) \simeq -0.53.$$

- b $\to$ c$\tau\bar{\nu}$:

$$C_V^{\tau\tau}(NP) \simeq 0.10$$

See e.g. Phys. Rev. D 96, 095009, JHEP 1809 (2018) 152

Combined Explanation: EFT Approach

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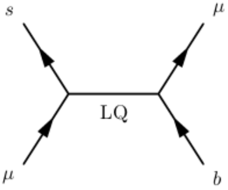
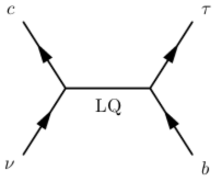
Operator $(\bar{Q}_{iL}\gamma_\mu \sigma^I Q_{jL})(\bar{L}_{kL}\gamma^\mu \sigma^I L_{lL})$ **relates** $b \to s\ell\ell$ **to** $b \to c\ell\bar{\nu}$ **transitions.**

[Phys.Lett. B742 (2015) 370-374]

EFT to Models: Leptoquarks

Scalar Triplet: S_3 $(\mathbf{3}, \mathbf{3}, -\mathbf{2}/\mathbf{3})$
Vector Triplet: U_3 $(\mathbf{3}, \mathbf{3}, \mathbf{4}/\mathbf{3})$
Vector Singlet: U_1 $(\mathbf{3}, \mathbf{1}, \mathbf{4}/\mathbf{3})$





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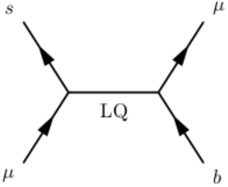

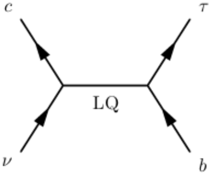

$$\Delta\mathcal{L}_{S_3} = h_{ij}^{S_3}\left(\overline{Q}_{iL}\sigma^I i\sigma^2 L_{jL}^c\right) S_3^I + \text{h.c.},$$

(We allow General Couplings)

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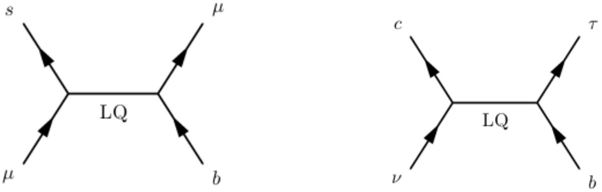

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Under the assumption that NP Couples to only II and III Generations we have 4 Free(Real) parameters for each Model:

$$h_{22},\ h_{33},\ h_{23},\ h_{32}.$$

Observables

Six Minimal + Five Lelpton Flavor Violating (LFV) constraints.

Observable	Measurement or Constraint
minimal	
$b \to s\mu^+\mu^-$ (all)	$C_9^{\mu\mu}(\mathrm{LQ}) = -C_{10}^{\mu\mu}(\mathrm{LQ}) = -0.68 \pm 0.12$ [17]
$R_{D^*}^{\tau/\ell}/(R_{D^*}^{\tau/\ell})_{\mathrm{SM}}$	1.18 ± 0.06 [18–21]
$R_{D}^{\tau/\ell}/(R_{D}^{\tau/\ell})_{\mathrm{SM}}$	1.36 ± 0.15 [18–21]
$R_{D^*}^{e/\mu}/(R_{D^*}^{e/\mu})_{\mathrm{SM}}$	1.04 ± 0.05 [68]
$R_{J/\psi}^{\tau/\mu}/(R_{J/\psi}^{\tau/\mu})_{\mathrm{SM}}$	2.51 ± 0.97 [22]
$\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})/\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})_{\mathrm{SM}}$	$-13\sum_{i=1}^{3} \mathrm{Re}[C_L^{ii}(\mathrm{LQ})] + \sum_{i,j=1}^{3} \lvert C_L^{ij}(\mathrm{LQ})\rvert^2 \le 248$ [69]
LFV	
$\mathcal{B}(B^+ \to K^+\tau^-\mu^+)$	$(0.8 \pm 1.7) \times 10^{-5}$; $< 4.5 \times 10^{-5}$ (90% C.L.) [70]
$\mathcal{B}(B^+ \to K^+\tau^+\mu^-)$	$(-0.4 \pm 1.2) \times 10^{-5}$; $< 2.8 \times 10^{-5}$ (90% C.L.) [70]
$\mathcal{B}(\Upsilon(2S) \to \mu^\pm\tau^\mp)$	$(0.2 \pm 1.5 \pm 1.3) \times 10^{-6}$; $< 3.3 \times 10^{-6}$ (90% C.L.) [71]
$\mathcal{B}(\tau \to \mu\phi)$	$< 8.4 \times 10^{-8}$ (90% C.L.) [72]
$\mathcal{B}(J/\psi \to \mu^\pm\tau^\mp)$	$< 2.0 \times 10^{-6}$ (90% C.L.) [73]

S_3 and U_3 Leptoquarks Models

The Fit of S_3 and U_3 to the Minimal set of Constraints yields:

$$\chi^2/\text{dof} = 7.5\ (S_3), \quad 10\ (U_3),$$

Implying that simultaneous explanation is not possible within S_3 or U_3.

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- For the S_3 LQ, we have

$$h_{33} h_{23} = -0.28 \pm 0.08\ (R_{D^{(*)}}),$$

$$h_{33} h_{23} \ge -0.094\ (B \to K^{(*)} \nu\bar{\nu}).$$

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The constraint from $B \to K^{(*)}\nu\bar{\nu}$ is not compatible with the $R_{D^{(*)}}$.

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$$\begin{aligned} \text{Minimal}: \quad & b \to s\mu\mu,\ R_D^{\tau//\ell},\ R_{D^*}^{\tau/\ell},\ R_{D^*}^{e/\mu},\ R_{J/\psi}^{\tau/\mu}. \\ \text{LFV}: \quad & \mathcal{B}(B \to K\tau^\pm\mu^\mp),\ \mathcal{B}(\tau \to \phi\mu),\ \mathcal{B}(\Upsilon \to \mu^\pm\tau^\mp). \end{aligned}$$

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Therefore U_1 LQ can explain both the charged and neutral current B-anomalies simultaneously.

LQ Couplings: Pattern & LFV Constraints

Using Minimal Observables only product of LQ couplings are constrained but the individual couplings remain unconstrained.

$$
\begin{aligned}
b \to s\mu^+\mu^- &: \quad h_{32}h_{22} \\
b \to c\tau\bar{\nu} &: \quad V_{cs}h_{33}h_{23} + V_{cb}h_{33}^2 \\
B^+ \to K^+\tau^-\mu^+ &: \quad h_{32}h_{23} \\
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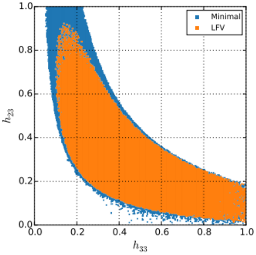

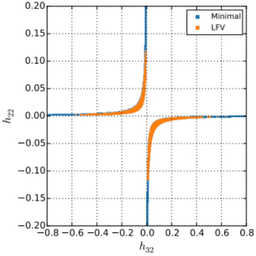

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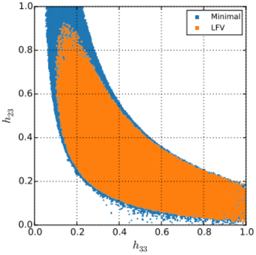
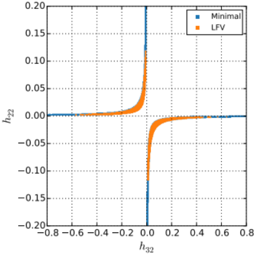
Lepton Flavor Violating Observables put additional constraints:

$$|h22| \leq 0.12, \ |h32| \leq 0.7$$
$$|h23| \leq 0.9, \ |h33| \geq 0.1.$$





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$R_{D^{(*)}}$ $\qquad$ $R_{K^{(*)}}$

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h_{33}	$\chi^2_{min,SM+U_1}$	h_{23}
1.0	5.0	0.10 ± 0.04
0.5	5.2	0.26 ± 0.07
0.2	6.8	0.60 ± 0.15
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LFV constraints prefer a large value of h_{33} coupling. A sizable $h_{23} \sim \mathcal{O}(0.1)$ is needed to fit the data.

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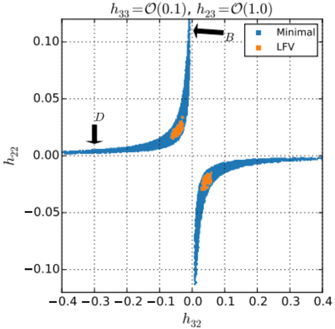
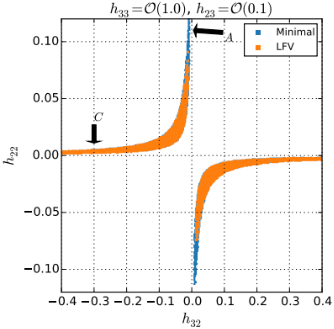
LFV constraints prefer a large value of h_{33} coupling. A sizable $h_{23} \sim \mathcal{O}(0.1)$ is needed to fit the data.





Predictions for U_1 model

- **Enhancement of same size in $b \to u\ell\bar{\nu}$ modes is predicted:**

$$R_{\pi\ell\bar{\nu}}^{\tau/\mu} = \frac{\mathcal{B}(B\to\pi\tau\bar{\nu})}{\mathcal{B}(B\to\pi\ell\bar{\nu})} \simeq R_{D^*}^{\tau/\ell} \simeq 1.20.$$

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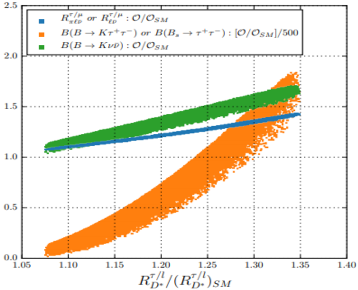
- **More than two orders of enhancement is expected in the $b \to s\tau\tau$ modes !**

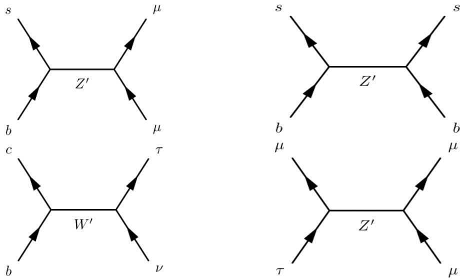
$$\mathcal{B}(B \to K\tau\bar{\tau}) \simeq 250 \times \mathcal{B}(B \to K\tau\bar{\tau})_{SM}.$$



Vector Boson (VB) Triplet Model

• An SM-like VB (W', Z') which transforms as $(\mathbf{1}, \mathbf{3}, \mathbf{0})$ under the SM Gauge group is another possibility.

Six Couplings : $(g_{\mu\mu}, g_{\tau\tau}, g_{\mu\tau})$, (g_{ss}, g_{bb}, g_{sb})



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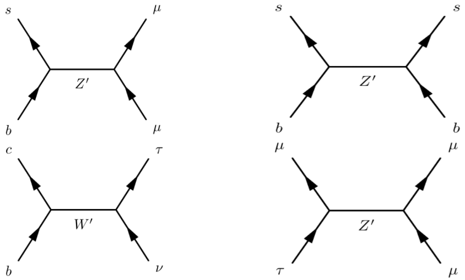

• In addition to the Semi-Leptonic operators required to explain the B-Anomalies the four Fermion are also generated at the Tree Level.

• Additional constraints like $B_s - \overline{B}_s$ Mixing, $\tau \to 3\mu$, $\tau \to \ell\nu\bar{\nu}$ come into play.

VB Triplet Model: Results

• Due to the constraints from $\tau \to \ell\nu\bar{\nu}$ and B_s-Mixing the $g_{\tau\tau} \sim \mathcal{O}(0.01 - 0.1)$ is small, so the NP effect in $b \to c\tau\bar{\nu}$ are limited.

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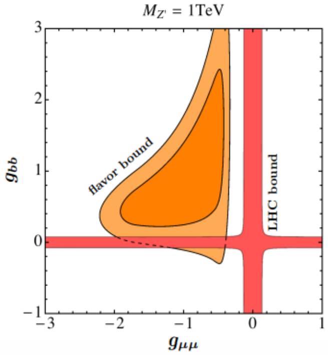

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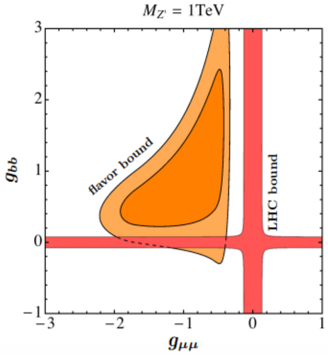

• So, we conclude that the VB model is excluded.

Summary

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Thanks for your attention !