

Leptoquark models for anomalies in B decays

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In collaboration with

D. Bećirević, S. Fajfer, N. Košnik and R. Zukanovich Funchal

[hep-ph/1608.08501](https://arxiv.org/abs/hep-ph/1608.08501) and [1608.07583](https://arxiv.org/abs/hep-ph/1608.07583)



Moriond, March 21, 2017.



Motivation

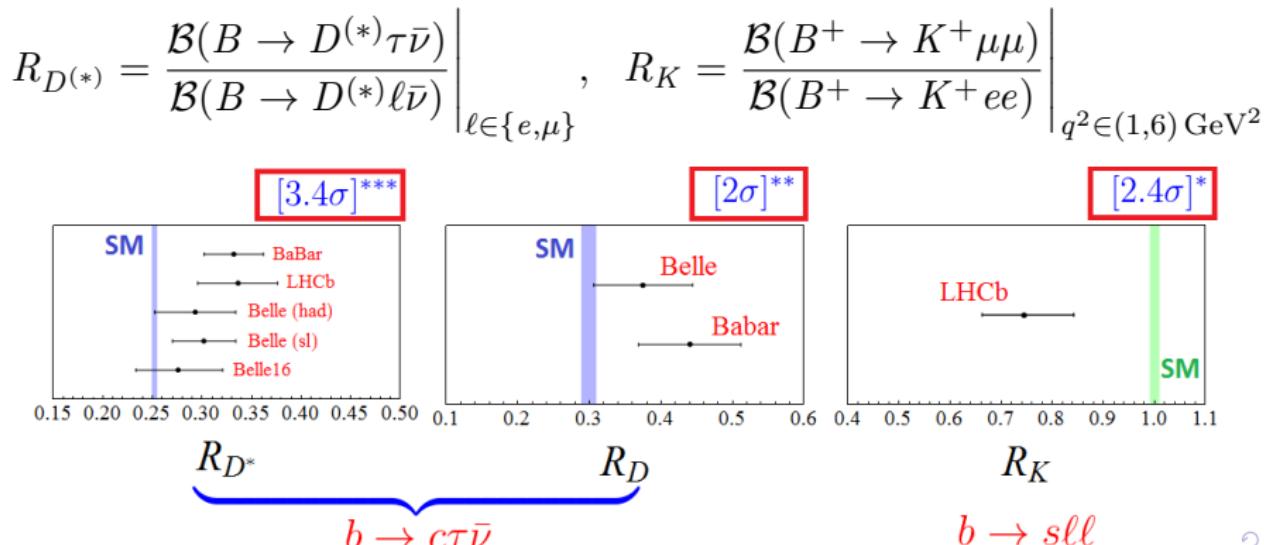
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⇒ unique opportunity for indirect searches (e.g. flavor physics).

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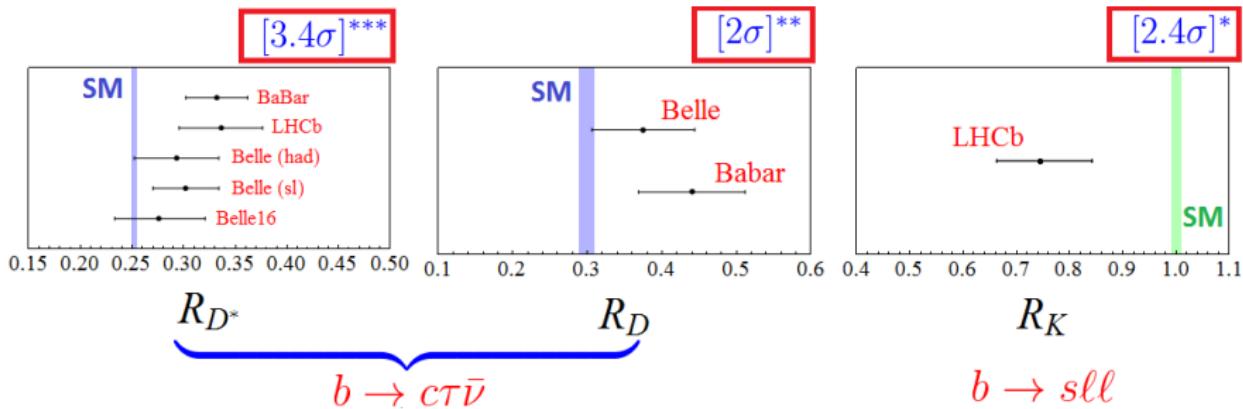
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- A few cracks [$\approx 2 - 3\sigma$] appeared recently in B meson decays
⇒ Violation of Lepton Flavor Universality (LFU)?

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⇒ Violation of Lepton Flavor Universality (LFU)?



$$R_{D^{(*)}} = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \rightarrow D^{(*)}\ell\bar{\nu})} \Big|_{\ell \in \{e, \mu\}}, \quad R_K = \frac{\mathcal{B}(B^+ \rightarrow K^+\mu\mu)}{\mathcal{B}(B^+ \rightarrow K^+ee)} \Big|_{q^2 \in (1,6) \text{ GeV}^2}$$



- Is there a **model of NP** to explain these anomalies?
- What additional **experimental signatures** should we expect?

R_K in Leptoquark Models

D. Becirevic, N. Kosnik, R. Funchal and OS. 1608.07583

We scrutinize the **scalar leptoquark** (LQ) models that can **explain** R_K through contributions to $b \rightarrow s\mu\mu$.

All couplings allowed to which we impose:

- Proton stability bounds (\equiv absence of diquark couplings).
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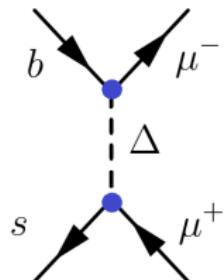
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Only one scenario is **phenomenologically viable**:

\Rightarrow Scalar doublet $\Delta^{1/6} \equiv (3, 2)_{1/6}$.

$$\mathcal{L}_Y = \mathbf{Y}_{ij}^L \bar{L}_i \tilde{\Delta}^{(1/6)} d_{Rj} + \text{h.c.}$$



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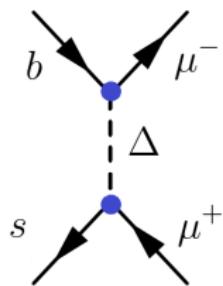
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Interesting: $SU(5)$ unification can be achieved via two LQs $(3, 2)_{1/6}$ in 10 multiplets with $m_{\Delta_1} \lesssim 16$ TeV.

[P. Cox, A. Kusenko, OS, T. T. Yanagida, 1612.03923]

A new model for R_K and R_D

D. Becirevic, S. Fajfer, N. Kosnik, OS. 1608.08051

We can also explain R_D if a **new ingredient** is added to the model
 $\Delta^{1/6} = (\mathbf{3}, \mathbf{2})_{1/6}$: three light RH neutrinos ν_R .

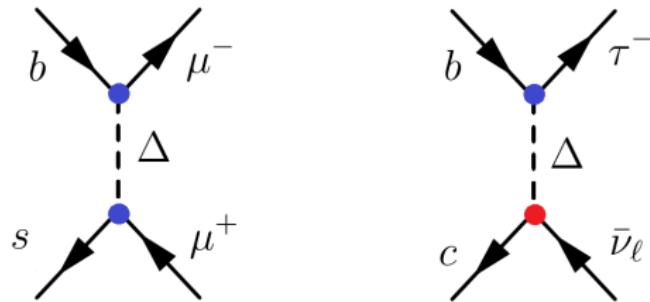
$$\mathcal{L}_Y = \mathbf{Y}_{ij}^L \bar{L}_i \tilde{\Delta}^{(1/6)} d_{Rj} + \mathbf{Y}_{ij}^R \bar{Q}_i \Delta^{(1/6)} \nu_{Rj} + \text{h.c.}$$

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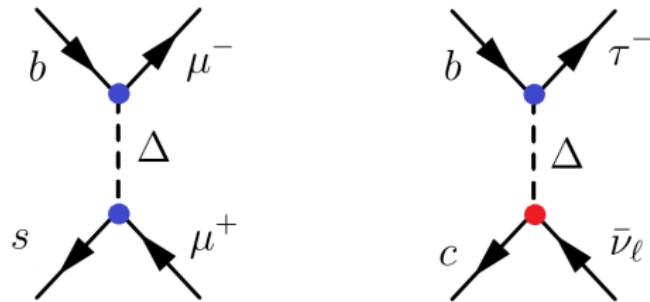


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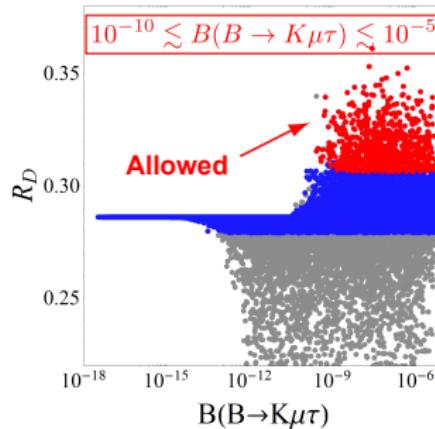
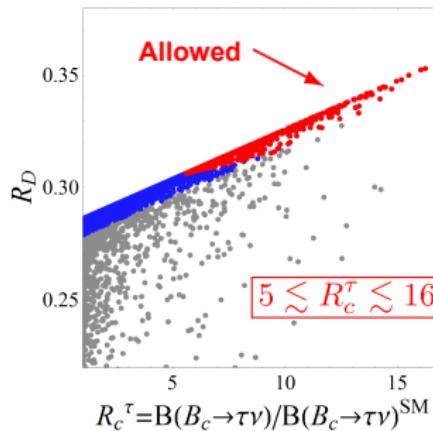
For $b \rightarrow c\tau\bar{\nu}$ $\Rightarrow |\mathcal{M}(B \rightarrow D^{(*)}\ell\nu)|^2 = |\mathcal{M}_{\text{SM}}|^2 + |\mathcal{M}_{\text{NP}}|^2$.

Naturally generates $R_{D^{(*)}}^{\text{NP}} > R_{D^{(*)}}^{\text{SM}}$ if $|Y_{b\tau}^L| \gtrsim |Y_{b\mu}^L|$.

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Several **distinctive predictions** wrt the SM:



- **Enhancement** of $\mathcal{B}(B_c \rightarrow \tau\bar{\nu})$ wrt $\mathcal{B}(B_c \rightarrow \tau\bar{\nu})^{\text{SM}} = 2.21(12)\%$.
- $R_{\eta_c} \equiv \mathcal{B}(B_c \rightarrow \eta_c \tau\nu)/\mathcal{B}(B_c \rightarrow \eta_c \ell\nu)$ can be **20% larger** than $R_{\eta_c}^{\text{SM}}$.
- Upper and **lower bounds** on the LFV rates.

Perspectives

- Interesting hints of LFU violation in R_K and $R_{D^{(*)}}$ – Use the experimental data to do physics!
- $R_K^{\text{NP}} < R_K^{\text{SM}}$ and $R_{D^{(*)}}^{\text{NP}} > R_{D^{(*)}}^{\text{SM}}$ can be simultaneously explained in minimal SLQ model with light RH neutrinos
⇒ Model can be tested at LHC(b) and Belle-II.
- Decays of B_c mesons can be used to confirm/refute our model.
⇒ Good control of hadronic uncertainties! Only accessible at LHCb.
- LFV is expected in most models aiming to explain R_K and/or $R_{D^{(*)}}$. We show that LQs can generate $\mathcal{B}(B \rightarrow K^{(*)}\mu\tau) \lesssim \mathcal{O}(10^{-5})$.

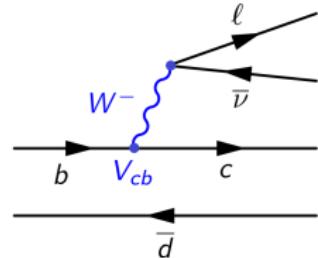
Thank you!

Back-up

LFU violation – $b \rightarrow c\tau\bar{\nu}$ [R_{D^(*)}]

- Tree-level process in the SM:

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \rightarrow D^{(*)}\ell\bar{\nu})}, \quad \ell = e, \mu.$$



- Non-perturbative QCD \iff form-factors (Lattice QCD)

e.g. for $B \rightarrow D$, $\langle D | \bar{c} \gamma_\mu b | B \rangle \propto f_{0,+}(q^2)$

- Situation less clear for $B \rightarrow D^* \Rightarrow$ (more FFs, less LQCD results)
[One form factor is unknown from LQCD (error that entails?)]

Can we consistently predict R_{D^*} in any NP scenario?

Conditions to fulfill:

- **Absence** of couplings to **electrons and muons**,

OR

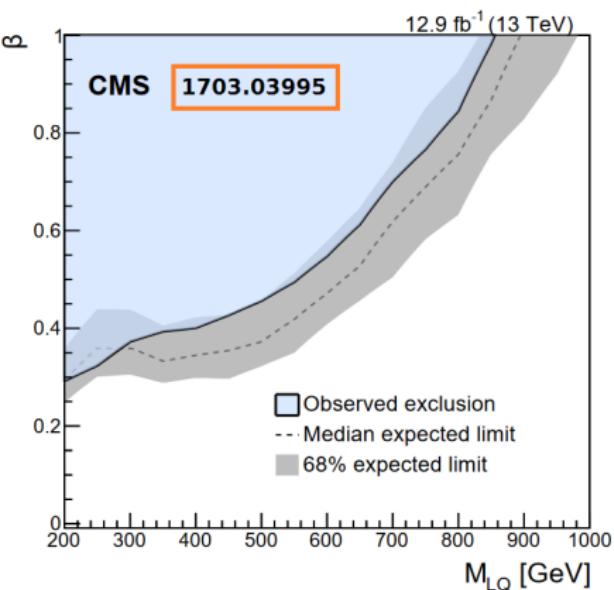
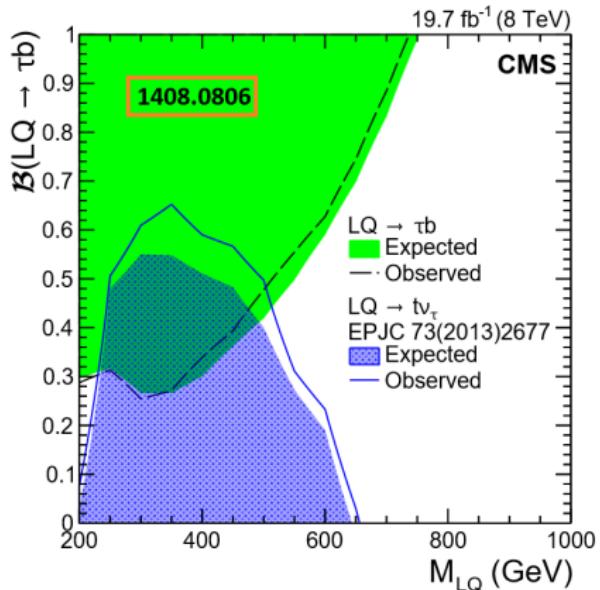
- $(V - A) \times (V - A)$ effective operator \Rightarrow overall modification of $R_{D^{(*)}}$.

$\Rightarrow V(q^2)$ and $A_{1,2}(q^2)$ can be extracted from $B \rightarrow D^* \ell \nu$ ($\ell = e, \mu$) data.

Caveat: $A_0(q^2)$ cannot be extracted from data (HQET)

\Rightarrow induces unknown systematic uncertainties – LQCD might help!

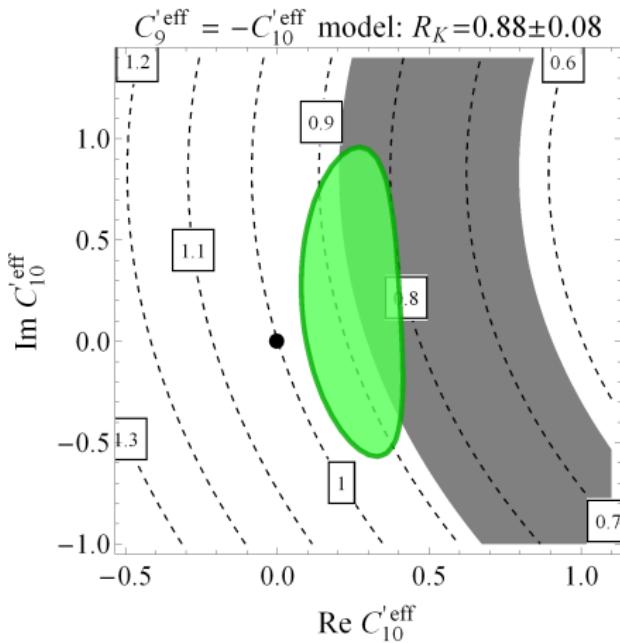
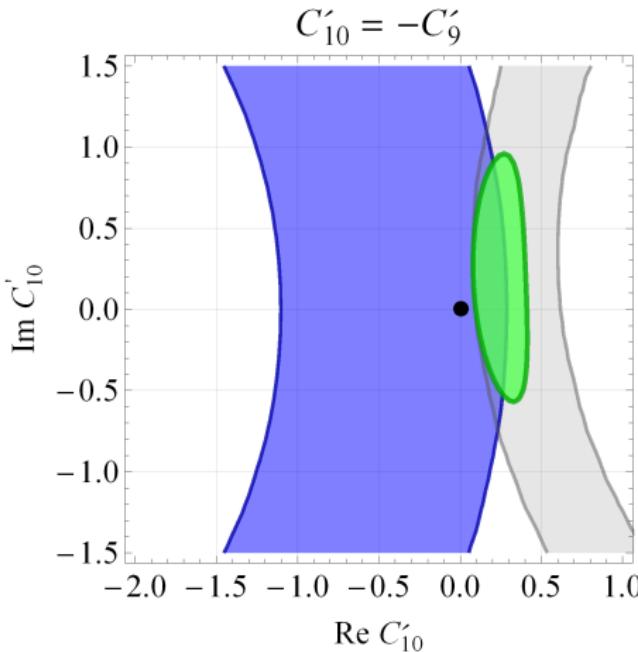
LQ Direct Searches: $\Delta \rightarrow \tau b$



NP fit of $b \rightarrow s\mu^+\mu^-$

[Becirevic et al. 1503.09024]

$\mathcal{B}(B_s \rightarrow \mu\mu)$ and $\mathcal{B}(B^+ \rightarrow K^+\mu\mu)_{\text{high } q^2}$ vs R_K



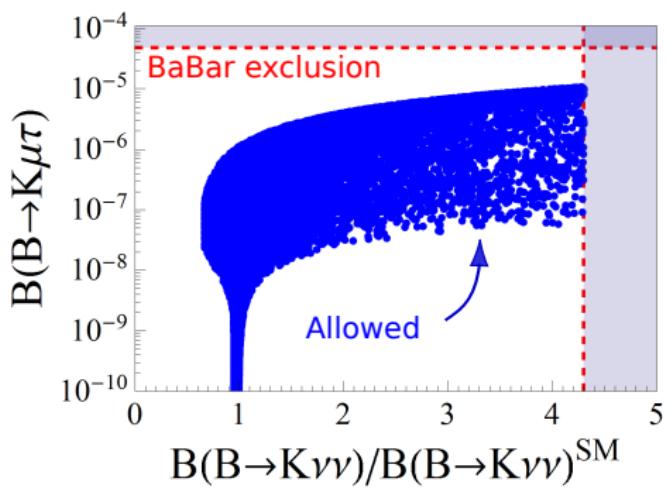
Scalar Leptoquark $\Delta^{1/6} = (3, 2)_{1/6}$

[D. Becirevic, N. Kosnik, OS, R. Funchal. 1608.07583]

$$\mathcal{L}_Y = Y_{ij} \bar{L}_i \tilde{\Delta}^{(1/6)} d_{Rj} + \text{h.c.}$$

$$C'_9 = -C'_{10} \propto \frac{Y_{\mu s} Y_{\mu b}^*}{m_\Delta^2}$$

$$\mathbb{Y} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \mathbf{Y}_{\mu s} & \mathbf{Y}_{\mu b} \\ 0 & \mathbf{Y}_{\tau s} & \mathbf{Y}_{\tau b} \end{pmatrix}$$



- Maximally allowed values lie just below the (old) BaBar limit:
 $\mathcal{B}(B^+ \rightarrow K^+ \mu\tau) \leq 4.8 \times 10^{-5}$.
- Even weak limits on $\mathcal{B}(B_s \rightarrow \mu\tau)$ or $\mathcal{B}(B \rightarrow K^{(*)}\mu\tau)$ can be useful.

Can LHCb do better?

On (in)viability of SLQ $(3, 1)_{-1/3}$

November 9, 2015



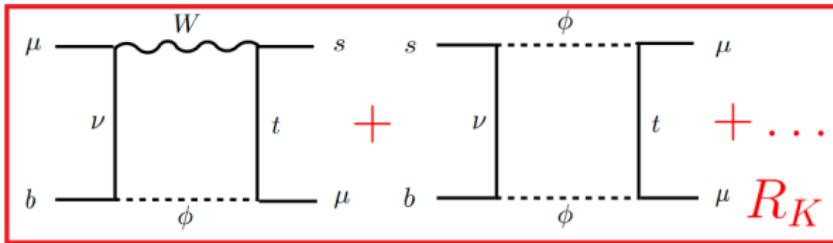
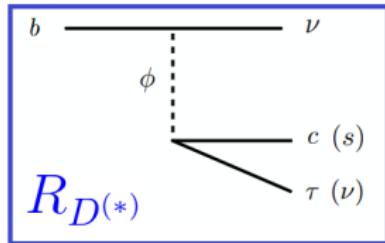
One Leptoquark to Rule Them All: A Minimal Explanation for $R_D^{(*)}$, R_K and $(g - 2)_\mu$

Martin Bauer^a and Matthias Neubert^{b,c}

1511.01900

An interesting idea: to explain R_D at tree-level and R_K at loop-level.

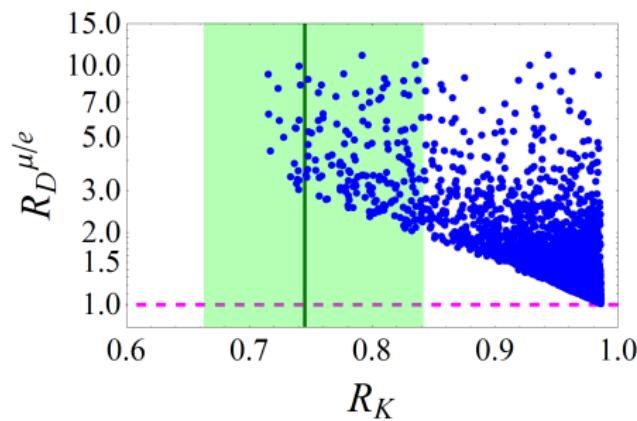
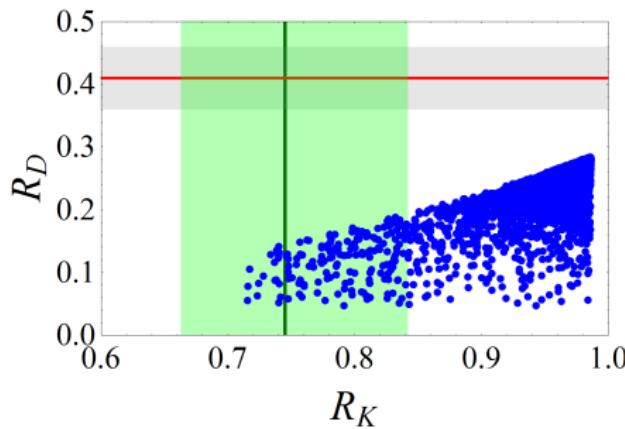
$$\mathcal{L}_{\Delta(1/3)} = \Delta^{(1/3)*} \left[(\textcolor{blue}{V^* g_L})_{ij} \overline{u_i^C} P_L \ell_j - (g_L)_{ij} \overline{d_i^C} P_L \nu_j + (\textcolor{magenta}{g_R})_{ij} \overline{u_i^C} P_R \ell_j \right]$$



On (in)viability of SLQ $(3, 1)_{-1/3}$

Scan Results

[D. Becirevic, N. Kosnik, OS, R. Zukanovich. 1608.07583]



- Large couplings to the muon (to get R_K) \Rightarrow push R_D to small values.
- Explanation of $R_K \Rightarrow$ unacceptably large $R_D^{\mu/e} = \frac{\mathcal{B}(B \rightarrow D\mu\nu)}{\mathcal{B}(B \rightarrow D e \nu)} \gtrsim 2$.

In conclusion, R_K cannot be explained by this model.

Light Leptoquarks and $SU(5)$ GUT

Can we embed the leptoquark $(3, 2)_{1/6}$ in a UV completion?

An old idea:

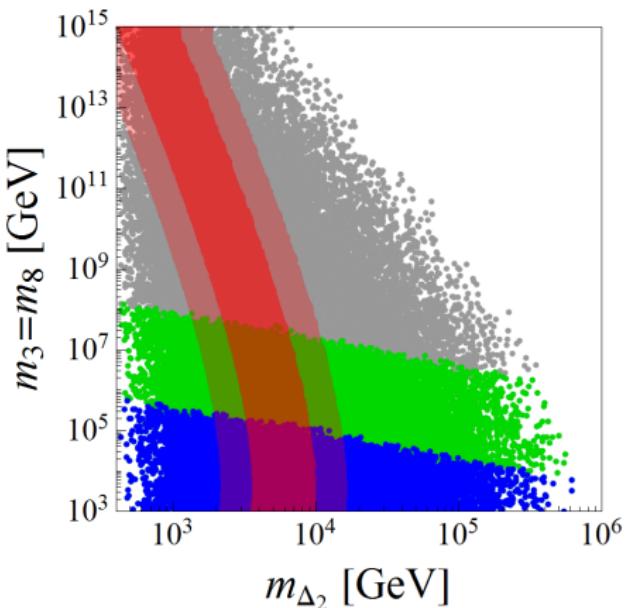
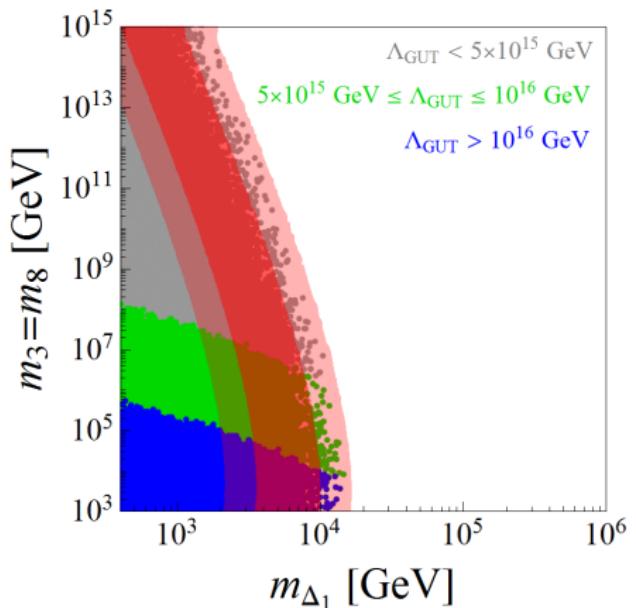
One pair of $(3, 2)_{1/6}$ and one additional Higgs doublet $(1, 2)_{1/2}$ at the EW scale can lead to unification.
[Murayama and Yanagida, 1992.]

Setup:

	\mathcal{G}_{SM}	$U(1)_{\text{PQ}}$
$\bar{5}_F$	$(\bar{3}, 1)_{1/3} \oplus (1, 2)_{-1/2}$	+1
10_F	$(3, 2)_{1/6} \oplus (\bar{3}, 1)_{-2/3} \oplus (1, 1)_1$	+1
5_Δ	$(1, 2)_{1/2} \oplus \dots$	-2
$\bar{5}_\Delta$	$(1, 2)_{-1/2} \oplus \dots$	-2
$(2 \times) \mathbf{10}_\Delta$	$(3, 2)_{1/6} \oplus \dots$	-2
24_Δ	...	

+ desert assumption (only the LQs and the new Higgs are light).

- Λ_{GUT} can be raised by a splitting of 24Δ : $m_{38} = m_3 = m_8 \ll \Lambda_{\text{GUT}}$



The **unification** of gauge couplings gives a **strong constraint** on the lightest LQ mass $m_{\Delta_1} \lesssim 16$ TeV.

