A gauged horizontal SU(2) symmetry and $R_K$

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Based on work with M. Reboud and O. Sumensari
Several references on horizontal symmetries for B anomalies

E.g.

[Crivellin, D’Ambrosio, Heeck, PRD2015]
[Alonso, Cox, Han, Yanagida, PRD2017]
[Cline, Martin Camalich, PRD2017]

However, theory arguments quite distant from the one pursued here
$b \to s$ anomalies’ basic challenge

- $R_K \approx 0.75$

$O(15-25\%)$ effects in $j_{q\ell}$

$\ell$ $\ell$

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$b \rightarrow s$ anomalies’ basic challenge

- $R_K \approx 0.75$

At the same time:

- $\Delta M_s \approx (\Delta M_s)_{SM}$

O(15-25%) effects in

$$\begin{array}{c}
\text{j}_q & & \text{j}_e \\
b & & s \\
\ell & & \ell \\
\text{NP} & & \\
\end{array}$$

Small corrections to

$$\begin{array}{c}
\text{j}_q & & \text{j}_q \\
b & & b \\
s & & s \\
\text{NP} & & \\
\end{array}$$

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$b \to s$ anomalies’ basic challenge

- $R_K \approx 0.75$

At the same time:

- $\Delta M_s \approx (\Delta M_s)_{\text{SM}}$

- $\ell \to \ell' + X < \text{current limits}$

$O(15-25\%)$ effects in

\[ j_q \rightarrow j_e \]

small corrections to

\[ j_q \rightarrow j_q \]

and small corrections to

\[ j_e \rightarrow j_e \]

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The challenge in short

large enough \( j_q \) \( j_e \) yet \( j_q \) \( j_q \) \&\& \( j_e \) \( j_e \) small enough

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• The challenge in short

large enough yet small enough

\[ j_q \quad j_e \quad \text{yet} \quad j_q \quad j_q \quad \&\& \quad j_e \quad j_e \]

• This is potentially a problem when

\[ j_q \quad j_e \quad i.e. \text{when the semi-lep. 4-f structure arises from } Z'\text{-like NP} \]

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Leptoquark-like NP

Take

$q \rightarrow LQ$

$\ell \rightarrow LQ$

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Take $q_\ell$ then $q_\ell$ is tree

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Take

$q \ell \rightarrow \ell q$

then $j_q$ is tree

but $j_q$ is loop-suppressed

(at least for “genuine” LQs [Dorsner et al., LQ review])

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Can one accomplish a mechanism for suppressing flavour-changing

\[ J_q \otimes J_q \quad \&\& \quad J_\ell \otimes J_\ell \]

within gauge extensions?
A gauged horizontal SU(2)

- Place the two heavier generations of each fermion

\[ \mathcal{F} \equiv \begin{pmatrix} f_2 \\ f_3 \end{pmatrix} \quad \text{w/} \quad f = u_L, d_L, \ell_L, \nu_L, \]

or RH counterparts

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A gauged horizontal SU(2)

- Place the two heavier generations of each fermion in a doublet
\[ \mathcal{F} \equiv \begin{pmatrix} f_2 \\ f_3 \end{pmatrix} \]
with \( f = u_L, d_L, \ell_L, \nu_L, \) or RH counterparts

- Consider a new SU(2) interaction for each such doublet
\[ \delta \mathcal{L} = g \sum_{\mathcal{F}} \mathcal{F}_L \vec{r} \cdot \vec{G} \mathcal{F}_L + \text{RH counterpart} \]
A gauged horizontal SU(2)

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- Consider a new SU(2) interaction for each such doublet

\[
\delta \mathcal{L} = g \sum_{\mathcal{F}} \bar{\mathcal{F}}_L \cdot \mathcal{G} \mathcal{F}_L + \text{RH counterpart}
\]

- Integrate out horizontal bosons

\[
\delta \mathcal{L}_{\text{eff}} = -\sum_{\mathcal{F}, \mathcal{F}', a} \frac{g_L^2}{2M_G^2} \left( \bar{\mathcal{F}}_L \gamma^\mu \tau^a \mathcal{F}_L \right) \left( \bar{\mathcal{F}}'_L \gamma^\mu \tau^a \mathcal{F}'_L \right)
\]

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Basic argument

- Doublets \( \mathcal{F} \equiv \begin{pmatrix} f_2 \\ f_3 \end{pmatrix} \) aren't yet in the mass basis.

Rotate as: \( \mathcal{F} = U_\mathcal{F} \hat{\mathcal{F}} \) mass eigenbasis

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Basic argument

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mass eigenbasis

- How does $\mathcal{L}_{\text{eff}}$ change?

$$\delta \mathcal{L}_{\text{eff}} \propto \frac{1}{2 M_G^2} \left( \hat{\mathcal{F}}_L U_{\mathcal{F}}^\dagger \gamma^\mu \tau^a U_{\mathcal{F}} \hat{\mathcal{F}}_L \right) \left( \hat{\mathcal{F}}'_L U_{\mathcal{F'}}^\dagger \gamma^\mu \tau^a U_{\mathcal{F'}} \hat{\mathcal{F}}'_L \right)$$

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Consider terms with $\mathcal{F} = \mathcal{F}'$

$$
\delta \mathcal{L}_{\text{eff}} \propto \frac{1}{2 M_G^2} \text{Tr} \left( \tilde{\mathcal{F}}_L U_{\mathcal{F}}^\dagger \gamma^\mu \tau^a U_{\mathcal{F}} \tilde{\mathcal{F}}_L \right) \text{Tr} \left( \tilde{\mathcal{F}}'_L U_{\mathcal{F}}^\dagger, \gamma^\mu \tau^a U_{\mathcal{F}}, \tilde{\mathcal{F}}'_L \right)
$$
Consider terms with $\mathcal{F} = \mathcal{F}'$

If $G_a$ degenerate

Rotations can be traded for $G_a$ basis redefinition

$\mathcal{F} = \mathcal{F}'$ terms
flavour-diag. in all generality

\[
\delta \mathcal{L}_\text{eff} \propto \frac{1}{2 M_{G_a}^2} \left( \mathcal{F}_L U_{\mathcal{F}}^\dagger \gamma^\mu \tau^a U_{\mathcal{F}} \mathcal{F}_L \right) \left( \mathcal{F}'_L U_{\mathcal{F}'}^\dagger \gamma^\mu \tau^a U_{\mathcal{F}'} \mathcal{F}'_L \right)
\]
\[ \delta \mathcal{L}_{\text{eff}} \propto \frac{1}{2 M_{G_a}^2} (\tilde{\mathcal{F}}_L \gamma^\mu \tau^a U \mathcal{F} \gamma^\mu \tau^a U \mathcal{F} \hat{\mathcal{F}}_L) \]

- Consider terms with \( \mathcal{F} = \mathcal{F}' \)

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- Our currents of interest: \( \hat{j}_q \otimes \hat{j}_q \), \( \hat{j}_\ell \otimes \hat{j}_\ell \)
would be flavour-diagonal in all generality

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For the original argument
(in unrelated context) see:
Cahn, Harari, NPB1980

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But

- Mixing beneath the EWSB scale has to involve all generations

  Contributions to meson mixings & leptonic decays not exactly zero

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• Contributions suppressed by powers of $1^{st} - (2^{nd} \text{ or } 3^{rd})$ mixing
  So they are “small”

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- Mixing beneath the EWSB scale has to involve all generations
  
  Contributions to meson mixings & leptonic decays not exactly zero

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  So they are “small”

- But processes like $K^0 - \bar{K}^0$ mixing and $\mu \rightarrow 3e$ very constraining
  
  Is “small” small enough?
Scenario 0: degenerate $G_a$ masses

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**Scenario 0: degenerate $G_a$ masses**

- Need to generalize our 2-generation relation $\mathcal{F} = U_\mathcal{F} \hat{\mathcal{F}}$ to 3 generations

- *It is these* $U_{3x3}$ *that are unitary*

Then $\text{CKM} = (U_{UL})^\dagger U_{DL}$
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  *but* $U_{UL} = \text{CKM}^\dagger$  \[\rightarrow\] *$D^0 - \bar{D}^0$ mixing $100 \times$ exp limit*
Scenario 0: degenerate $G_a$ masses

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- But $U_{UL} = \text{CKM}^\dagger$ \(\Rightarrow\) $D^0 - \bar{D}^0$ mixing $100 \times$ exp limit

- Still exploring whether, with different $U_{UL,DL}$ assumptions, scenario 0 fulfils all main constraints:

\[ \begin{align*}
&\text{CKM} \\
&\text{small } K^0 - \bar{K}^0 \\
&\text{small } D^0 - \bar{D}^0 \\
&R_K \text{ as measured}
\end{align*} \]

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Besides, several ways to generalize the idea that will fulfil all constraints.

Examples:

(i) non-degenerate $G_a$ masses

(ii) non-zero (but small) $1^{st}$ – $(2^{nd} & 3^{rd})$ gen. mixing terms
**Scenario 1:** split $G_a$ masses

- Take one mass split from the other two, e.g.:

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  - $R_K$ & Co.
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- **Plus:** All data explained at one stroke
  - $R_K$ & Co.
  - $\Delta M_s$ ok, if somewhat $< \text{SM}$
  - $B \to K \bar{\nu}\nu$ shift small, due to underlying SU(2) sym.
  - Small shifts to $\tau \to \ell \nu\nu$ & $D^0 \to \mu\mu$
  - Small effects in di-muon tails [Greljo, Marzocca, EPJC2017]

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Scenario 1: predictions

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Scenario 1: predictions

1. \( \delta C_{9,10}^{\tau\tau} = -\delta C_{9,10}^{\mu\mu} \) → \( \text{Shifts to } BR(B_{(s)} \rightarrow (K) \tau\tau) \) \( R_K \) shift

2. LFV-mode correlations
**Scenario 1: predictions**

1. \( \delta C_{9,10}^{\tau \tau} = -\delta C_{9,10}^{\mu \mu} \) → Shifts to \( BR(B_s \rightarrow K \tau \tau) \)

2. LFV-mode correlations

**Excluded at 90\% CL**

\[ \mathcal{B}(B \rightarrow K \mu^\tau \tau^-) \]

\[ \mathcal{B}(B \rightarrow K \mu \mu \mu) \]

\[ \mathcal{B}(B \rightarrow K \mu \tau) \]
Scenario 1: predictions

1. \( \delta C_{9,10}^{\tau \tau} = -\delta C_{9,10}^{\mu \mu} \)

Shifts to \( BR(B_{(s)} \rightarrow (K) \tau \tau) \) ↔ \( R_K \) shift

2. LFV-mode correlations

Note: \( 1.3 \times 10^{-8} \lesssim B(B \rightarrow K\mu^+\tau^-) + B(B \rightarrow K\mu^-\tau^+) \lesssim 5.2 \times 10^{-6} \)
Conclusions / Outlook

- I discussed a Z-like setup that accomplishes:

  \[ j_q \otimes j_\ell \]  
  
  (for \( R_K \))

  yet

  \[ j_q \otimes j_q \]  
  \[ j_\ell \otimes j_\ell \]  
  
  (\( \Delta M_s \) && leptonic LFV constraints)

D. Guadagnoli, A gauged horizontal SU(2) and \( R_K \)
I discussed a Z’-like setup that accomplishes:

- **large** \( j_q \otimes j_e \) (for \( R_K \))
- **yet** small
  - \( j_q \otimes j_q \) & \( j_e \otimes j_e \)
  - \( \Delta M_s \) & leptonic LFV constraints

through a symmetry

D. Guadagnoli, A gauged horizontal SU(2) and \( R_K \)
I discussed a Z’-like setup that accomplishes:

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- Small $j_q \otimes j_q$ & $j_e \otimes j_e$ ($\Delta M_s$ & leptonic LFV constraints)

through a symmetry

- The SU(2) case implies automatically no gauge anomalies
Conclusions / Outlook

I discussed a Z’-like setup that accomplishes:

- Large $j_q \otimes j_\ell$ (for $R_K$) yet small $j_q \otimes j_q$ & $j_\ell \otimes j_\ell$ ($\Delta M_s$ & leptonic LFV constraints)

through a symmetry

- The SU(2) case implies automatically no gauge anomalies

A larger group would require extra matter

But maybe it would help solve extra problems?

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