Scalar Leptoquarks to Solve Flavour Anomalies

Pere Arnan

Universitat de Barcelona

ICCUB

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Lepton Flavour Universality

- **Neutral currents** (b $\longrightarrow$ s transitions)

$$R_{K^{(*)}}^{[q_1^2,q_2^2]} = \frac{\mathcal{B}'(B \to K^{(*)}\mu\mu)}{\mathcal{B}'(B \to K^{(*)}ee)}$$

$$R_{K^{(*)}}^{\rm exp} < R_{K^{(*)}}^{\rm SM}$$

- **Charged currents** (b $\longrightarrow$ c transitions)

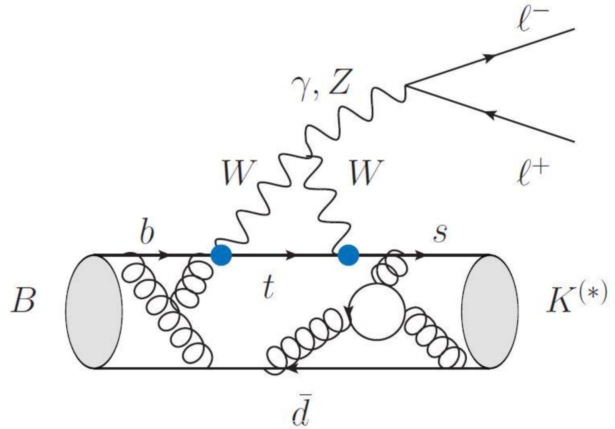
$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}l\bar{\nu})}\bigg|_{l\in\{e,\mu\}}$$

$$R_{D^{(*)}}^{\rm exp} > R_{D^{(*)}}^{\rm SM}$$

Lepton Flavour Universality SM

- **Neutral currents** (b $\longrightarrow$ s transitions)

$$R_{K^{(*)}}^{[q_1^2,q_2^2]} = \frac{\mathcal{B}'(B \to K^{(*)}\mu\mu)}{\mathcal{B}'(B \to K^{(*)}ee)}$$



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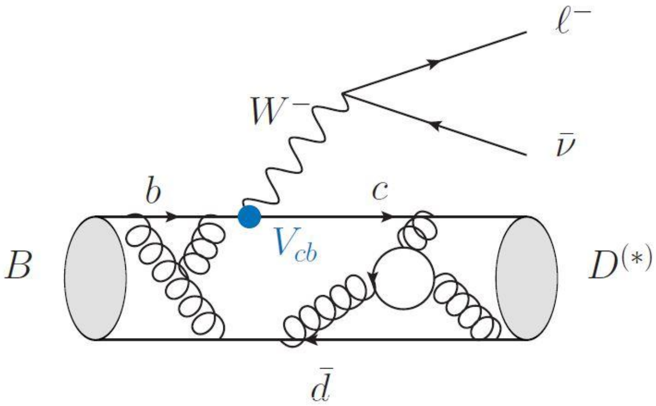

Lepton Flavour Universality NP

- **Neutral currents** (b $\longrightarrow$ s transitions)

$$R_{K^{(*)}}^{[q_1^2,q_2^2]} = \frac{\mathcal{B}'(B \to K^{(*)}\mu\mu)}{\mathcal{B}'(B \to K^{(*)}ee)}$$

Di Luzio and Nardecchia
1706.01868

$$\frac{\Lambda_{NP}}{g_{NP}} \sim 31 \text{ TeV}$$

- **Charged currents** (b $\longrightarrow$ c transitions)

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}l\bar{\nu})}\Bigg|_{l\in\{e,\mu\}}$$

$$\frac{\Lambda_{NP}}{g_{NP}} \sim 3.4 \text{ TeV}$$

b → s Effective Theory

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left(C_i(\mu) \mathcal{O}_i(\mu) + C_i'(\mu) \mathcal{O}_i'(\mu) \right) + \text{h.c.}$$

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell), \qquad \mathcal{O}_S = \frac{e^2}{(4\pi)^2} (\bar{s} P_R b)(\bar{\ell}\ell),$$

$$\mathcal{O}_{10} = \frac{e^2}{(4\pi)^2} (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell), \qquad \mathcal{O}_P = \frac{e^2}{(4\pi)^2} (\bar{s} P_R b)(\bar{\ell}\gamma_5 \ell),$$

b → s Effective Theory

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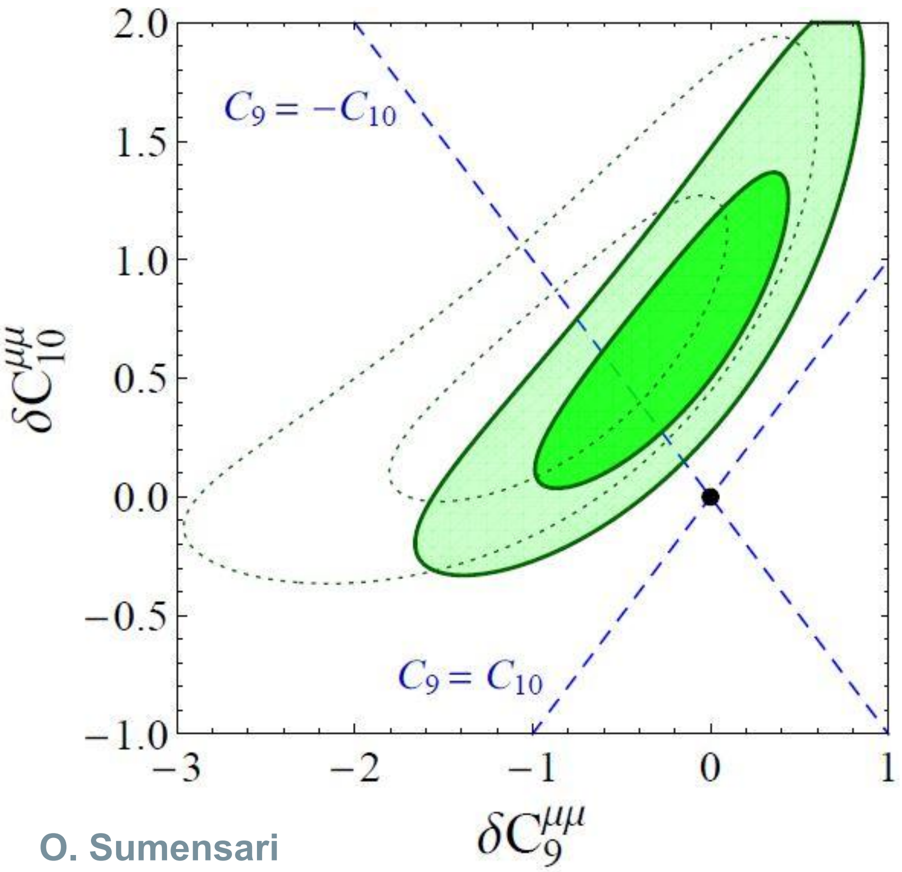
$$\mathcal{O}_S = \cdots(\bar{s}P_R \cdots \bar{\ell}\ell),$$

$$\mathcal{O}_P = \cdots \frac{e^2}{\cdots\pi)^2}(\cdots b)\cdots\gamma_5 \ell),$$

Due to $\mathcal{B}(B_s \to \mu\mu)$

$b \rightarrow s$ fit with clean observables



Fit with clean observables

$R_{K^{(*)}}$ $\mathcal{B}(B_s \to \mu\mu)$

$C_9 = -C_{10}$ is a good scenario.

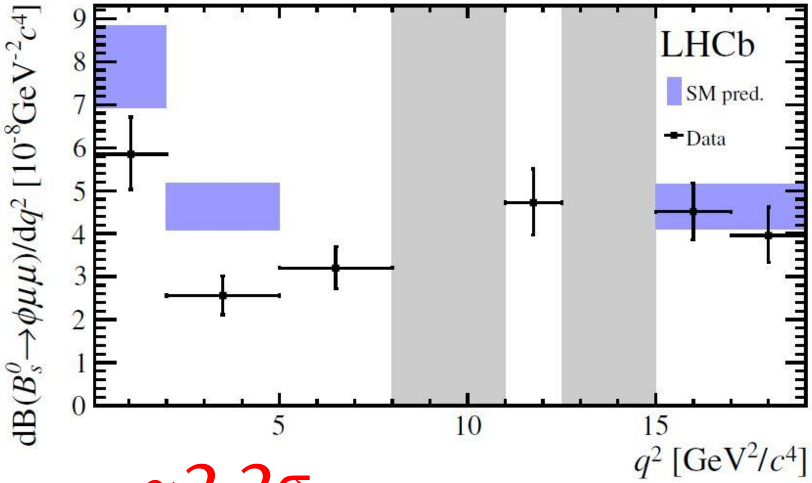
Left handed NP.

Also global fits.

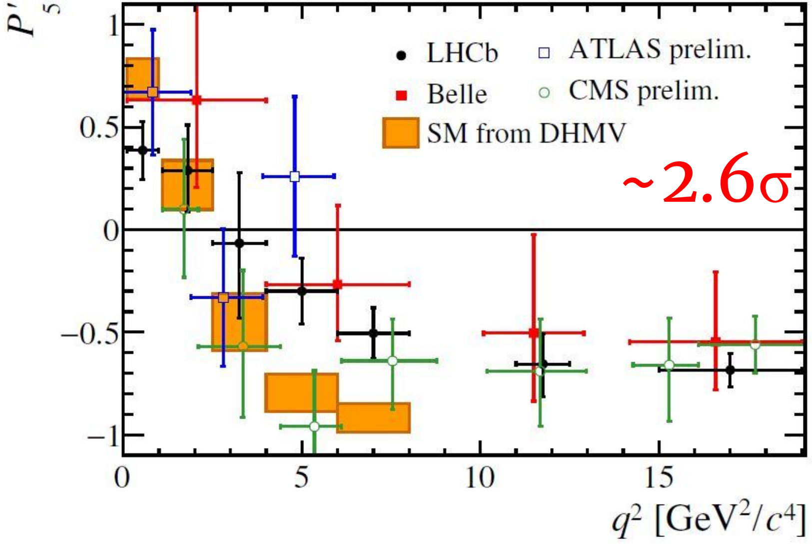
Fedele et al ,Capdevila et al, Arbey et al, Aebischer et al.

O. Sumensari

b ⟶ s fits with more observables



~2.2σ



~2.6σ

$$R_K^{[1.1,6]} = \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)} = 0.846^{+0.060}_{-0.054}{}^{+0.016}_{-0.014}$$

$$R_{K^*}^{[0.045,1.1]} = 0.52^{+0.36}_{-0.26} \pm 0.05$$

$$R_{K^*}^{[1.1,6]} = 0.96^{+0.45}_{-0.29} \pm 0.11$$

$$R_{K^*}^{[15,19]} = 1.18^{+0.52}_{-0.32} \pm 0.10$$

$b \rightarrow c$ Effective Theory

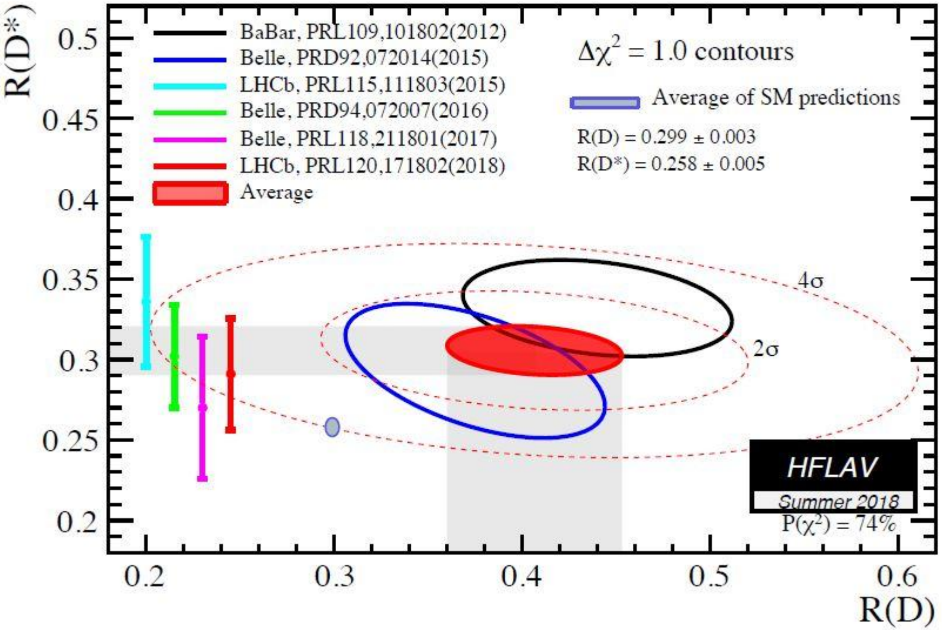
Angelescu et al.

$$\mathcal{L}_{\text{eff}} = -2\sqrt{2} G_F V_{cb} \Big[(1 + g_{V_L}) (\bar{c}_L \gamma_\mu b_L)(\bar{\ell}_L \gamma^\mu \nu_L) + g_{V_R} (\bar{c}_R \gamma_\mu b_R)(\bar{\ell}_L \gamma^\mu \nu_L) + g_{S_R} (\bar{c}_L b_R)(\bar{\ell}_R \nu_L) + g_{S_L} (\bar{c}_R b_L)(\bar{\ell}_R \nu_L) + g_T (\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\ell}_R \sigma^{\mu\nu} \nu_L) \Big] + \text{h.c.}$$

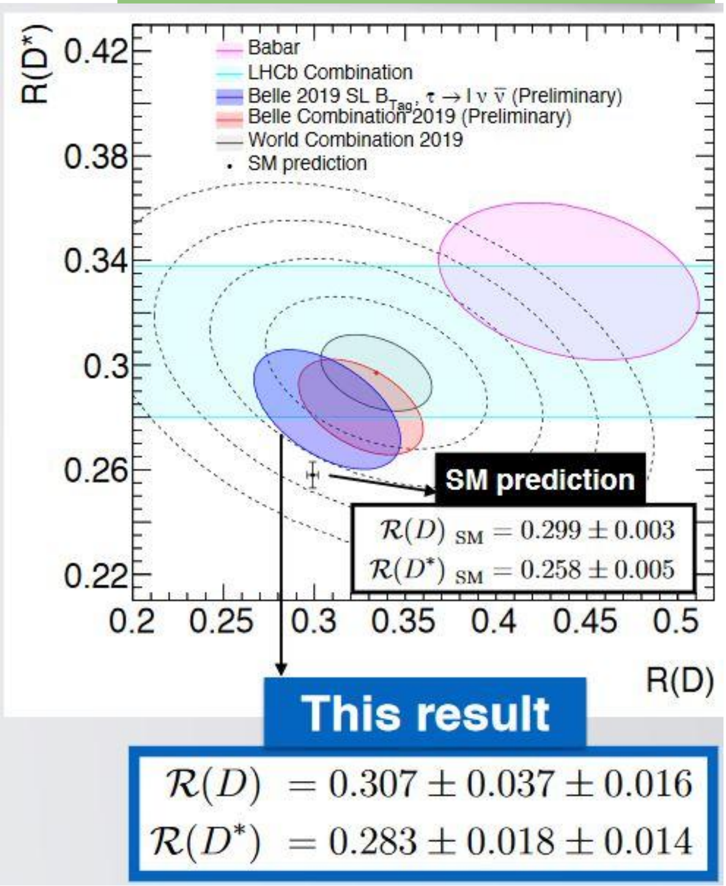
LFU at dimension 6

4 free parameters

Pre-Moriond



Post-Moriond



Discrepancy from SM is reduced from

3.8σ to 3.1σ

$b \longrightarrow c$ fit

$$\mathcal{L}_{\rm eff} = -2\sqrt{2}G_F V_{cb}\Big[(1+g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma^\mu\nu_L)$$

$$+ g_{S_R}(\bar{c}_L b_R)(\bar{\ell}_R\nu_L) + g_{S_L}(\bar{c}_R b_L)(\bar{\ell}_R\nu_L) + g_T(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\Big] + \text{h.c.}$$

Angelescu et al.

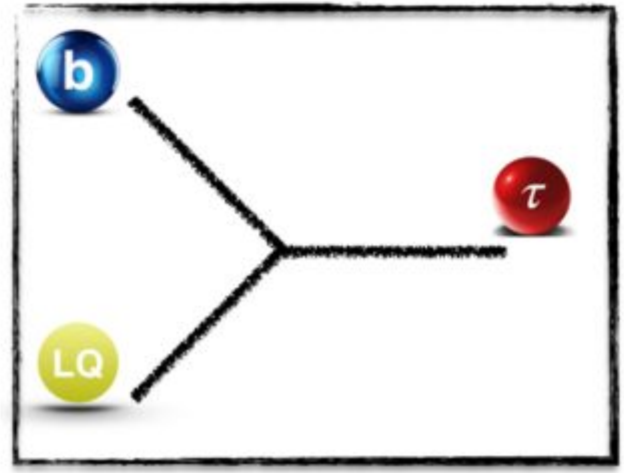
BEST FIT achieved via $g_{V_L} = (0.04, 0.11)$

Other possible scenarios $g_{S_L} = \pm 4 g_T$ either real or imaginary

$B \longrightarrow D^*$ observables can help

Fedele et al. Murgui et al.
Bordone et al.

Leptoquarks

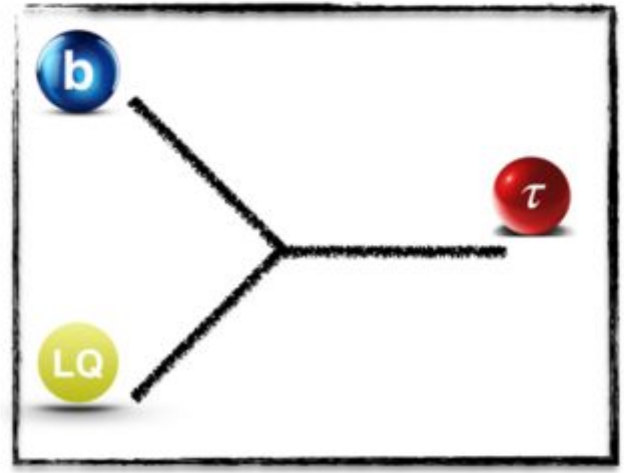


LQ can be scalar or vector particle

Carry color and fractional charge

Are predicted in many models
GUT,PS,Compositeness...

Leptoquarks



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GUT,PS,Compositeness...

Scalar LQs: $S_3, R_2, \tilde{R}_2, S_1$

Scalar Leptoquarks

Angelescu et al. 1808.08179

$S_3\ (\bar{\mathbf{3}}, \mathbf{3})_{1/3}$

$$\mathcal{L}_{S_3} = -y_L^{ij}\, \overline{d^C_{L\,i}} \nu_{L\,j}\, S_3^{(1/3)} - \sqrt{2}\, y_L^{ij}\, \overline{d^C_{L\,i}} \ell_{L\,j}\, S_3^{(4/3)} + \sqrt{2}\, (V^* y_L)_{ij}\, \overline{u^C_{L\,i}} \nu_{L\,j}\, S_3^{(-2/3)} - (V^* y_L)_{ij}\, \overline{u^C_{L\,i}} \ell_{L\,j}\, S_3^{(1/3)} + \text{h.c.}$$

$$C_9^{kl} = -C_{10}^{kl} = \frac{\pi v^2}{V_{tb} V_{ts}^* \alpha_{\rm em}} \frac{y_L^{bk} \left(y_L^{sl}\right)^*}{m_{S_3}^2}$$

$R_{K^{(*)}}^{\rm exp} < R_{K^{(*)}}^{\rm SM}$

$$g_{V_L} = -\frac{v^2\, y_L^{b\ell'}\, (V y_L^*)_{c\ell}}{4 V_{cb}\, m_{S_3}^2} = -\frac{v^2}{4 m_{S_3}^2} y_L^{b\ell'} \left[(y_L^{b\ell})^* + \frac{V_{cs}}{V_{cb}} (y_L^{s\ell})^* + \frac{V_{cd}}{V_{cb}} (y_L^{d\ell})^* \right]$$

g_{V_L} Wrong sign.

Scalar Leptoquarks

Angelescu et al. 1808.08179

R_2 $(\mathbf{3}, \mathbf{2})_{7/6}$

$$\mathcal{L}_{R_2} = (V y_R)_{ij}\, \overline{u}_{L\,i} \ell_{R\,j}\, R_2^{(5/3)} + (y_R)_{ij}\, \overline{d}_{L\,i} \ell_{R\,j}\, R_2^{(2/3)}$$
$$+ (y_L)_{ij} \overline{u}_{R\,i} \nu_{L\,j}\, R_2^{(2/3)} - (y_L)_{ij} \overline{u}_{R\,i} \ell_{L\,j}\, R_2^{(5/3)} + \text{h.c.}$$

$$C_9^{kl} = C_{10}^{kl} \overset{\text{tree}}{=} -\frac{\pi v^2}{2 V_{tb} V_{ts}^* \alpha_{\text{em}}} \frac{y_R^{sl} \left(y_R^{bk}\right)^*}{m_{R_2}^2}$$

but setting yR=0

$$C_9^{kl} = -C_{10}^{kl} \overset{\text{loop}}{=} \sum_{u,u' \in \{u,c,t\}} \frac{V_{ub} V_{u's}^*}{V_{tb} V_{ts}^*} y_L^{u'k} \left(y_L^{ul}\right)^* \mathcal{F}(x_u, x_{u'})$$

$$R_{K^{(*)}}^{\text{exp}} < R_{K^{(*)}}^{\text{SM}}$$

large muon couplings

Direct searches.

Scalar Leptoquarks

Angelescu et al. 1808.08179

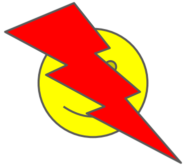
R_2 $(\mathbf{3}, \mathbf{2})_{7/6}$

$$\mathcal{L}_{R_2} = (V y_R)_{ij}\, \overline{u}_{L\,i} \ell_{R\,j}\, R_2^{(5/3)} + (y_R)_{ij}\, \overline{d}_{L\,i} \ell_{R\,j}\, R_2^{(2/3)}$$

$$+ (y_L)_{ij} \overline{u}_{R\,i} \nu_{L\,j}\, R_2^{(2/3)} - (y_L)_{ij} \overline{u}_{R\,i} \ell_{L\,j}\, R_2^{(5/3)} + \text{h.c.}$$

$$g_{S_L} = 4\, g_T = \frac{v^2}{4V_{cb}} \frac{y_L^{c\ell'} \left(y_R^{b\ell}\right)^*}{m_{R_2}^2}$$

Good solution but in conflict with τ→μγ



Scalar Leptoquarks

Angelescu et al. 1808.08179

$\tilde{R}_2$ $(\mathbf{3}, \mathbf{2})_{1/6}$

$$\mathcal{L}_{\tilde{R}_2} = -y_L^{ij}\, \overline{d_{Ri}} \widetilde{R}_2 i\tau_2 L_j + \text{h.c.}\,,$$

$$= -y_L^{ij}\, \overline{d_{Ri}} \ell_{Lj}\, \widetilde{R}_2^{(2/3)} + y_L^{ij}\, \overline{d_{Ri}} \nu_{Lj}\, \widetilde{R}_2^{(-1/3)}$$

$$C_9^{\prime\, kl} = -C_{10}^{\prime\, kl} = -\frac{\pi v^2}{2 V_{tb} V_{ts}^* \alpha_{\text{em}}} \frac{y_L^{sk} \left(y_L^{bl}\right)^*}{m_{\tilde{R}_2}^2}$$

$R_K^{\text{exp}} < R_K^{\text{SM}}$

$R_{K^*}^{\text{exp}} < R_{K^*}^{\text{SM}}$

NOT generating CHARGED CURRENTS unless RH neutrino is included. But still small.

Scalar Leptoquarks

Angelescu et al. 1808.08179

S_1 $(\bar{\mathbf{3}}, \mathbf{1})_{1/3}$

$$\mathcal{L}_{S_1} = y_L^{ij}\, \overline{Q^C} i\tau_2 L_j\, S_1 + y_R^{ij}\, \overline{u_{R\,i}^C} e_{R\,j}\, S_1 + \text{h.c.}$$

$$= S_1 \left[\left(V^* y_L\right)_{ij} \overline{u_{L\,i}^C} \ell_{L\,j} - y_L^{ij}\, \overline{d_{L\,i}^C} \nu_{L\,j} + y_R^{ij}\, \overline{u_{R\,i}^C} \ell_{R\,j} \right] + \text{h.c.}$$

$$g_{V_L} = \frac{v^2}{4V_{cb}} \frac{y_L^{b\ell'} \left(V y_L^*\right)_{c\ell}}{m_{S_1}^2},$$

$$g_{S_L} = -4\, g_T = -\frac{v^2}{4V_{cb}} \frac{y_L^{b\ell'} \left(y_R^{c\ell}\right)^*}{m_{S_1}^2}$$

RD can be accommodated with the two solutions

Scalar Leptoquarks

Angelescu et al. 1808.08179

$S_1\ (\bar{\mathbf{3}}, \mathbf{1})_{1/3}$

$$\mathcal{L}_{S_1} = y_L^{ij}\, \overline{Q^C} i\tau_2 L_j\, S_1 + y_R^{ij}\, \overline{u_{R\,i}^C} e_{R\,j}\, S_1 + \text{h.c.}$$

$$= S_1 \left[\left(V^* y_L\right)_{ij} \overline{u_{L\,i}^C} \ell_{L\,j} - y_L^{ij}\, \overline{d_{L\,i}^C} \nu_{L\,j} + y_R^{ij}\, \overline{u_{R\,i}^C} \ell_{R\,j} \right] + \text{h.c.}$$

$C_9 = -C_{10}$ can be generated via box diagrams 

-This would involve large masses and very large couplings in the muon sector.
-Problems with RDμ/e due to muon enhancement .

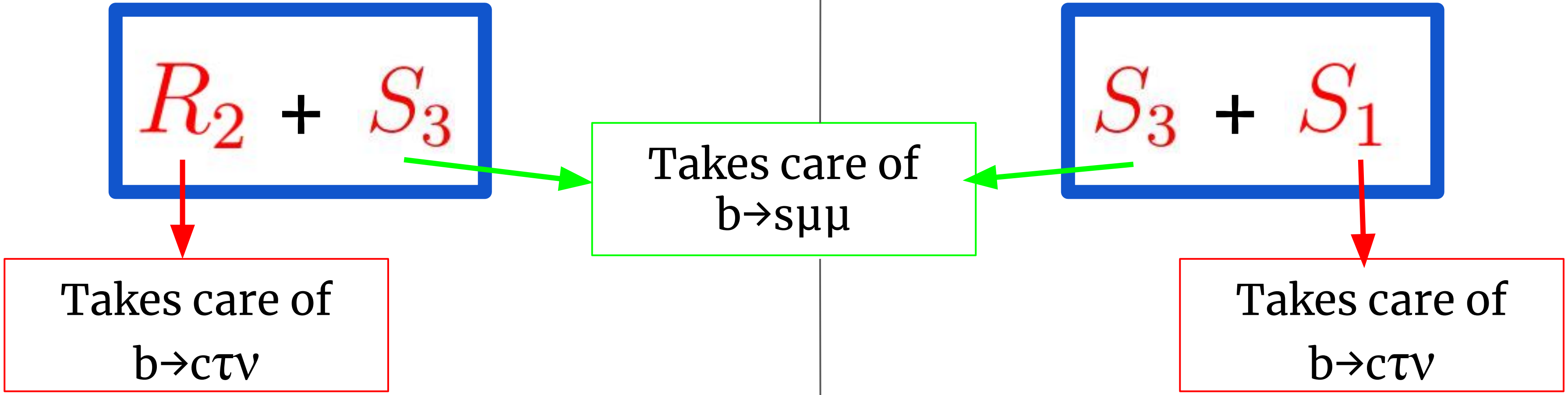
Scalar Leptoquarks

Angelescu et al. 1808.08179

Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
S_1	✗*	✓	✗*
R_2	✗*	✓	✗
$\widetilde{R}_2$	✗	✗	✗
S_3	✓	✗	✗

No need UV theory to cancel divergences

Two Scalar Leptoquarks



Dorsner, Fajfer, Kosnik, Sumensari, Becirevic, Faroughy...

Sumensari, Becirevic, Kosnik, Fajfer, Arnan, Mescia, Isidori, Greljo, Crivellin, Marzocca, Müller, Ota...

Two Scalar Leptoquarks

Buttazzo et al. 1706.07808

$S_3 + S_1$

$$y^L_{S_1} = g_{S_1} \begin{pmatrix} 0 & 0 & 0 \\ 0 & \beta_{s\mu} & \beta^{S_1}_{s\tau} \\ 0 & \beta_{b\mu} & 1 \end{pmatrix} \qquad y^L_{S_3} = g_{S_3} \begin{pmatrix} 0 & 0 & 0 \\ 0 & \beta_{s\mu} & \beta^{S_3}_{s\tau} \\ 0 & \beta_{b\mu} & 1 \end{pmatrix}$$

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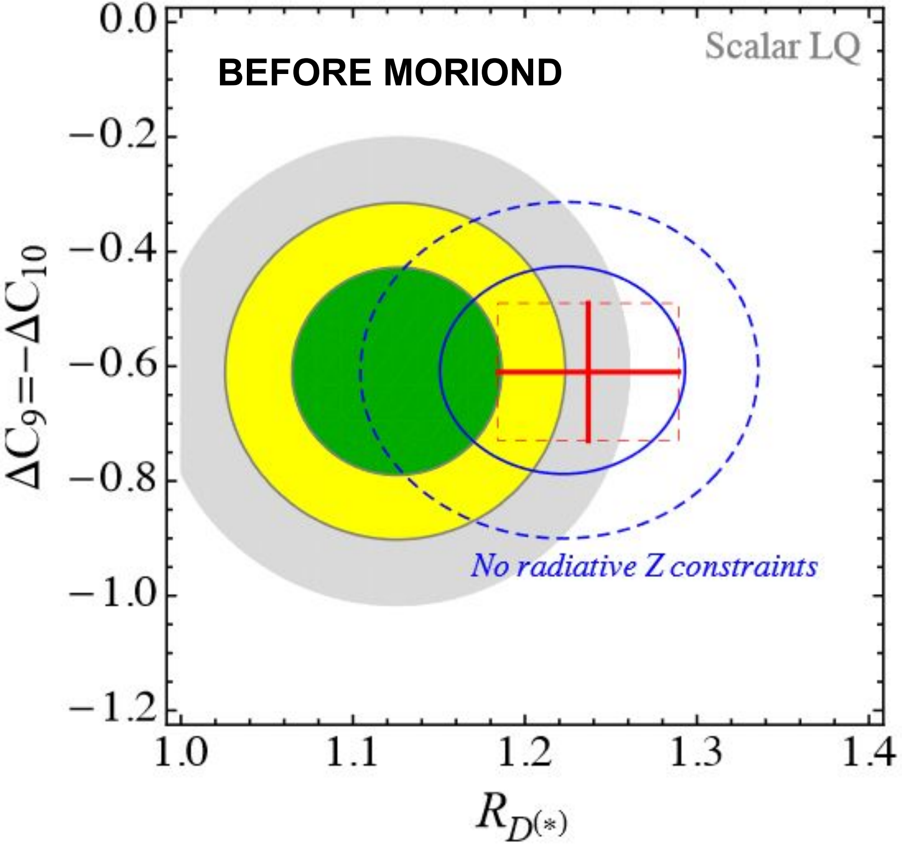
equal for simplicity.

- 6 parameters
- Left-handed: C9=-C10 and gV
- B→Kνν , RDμe and Z poles at LLA
- mΔ=2 TeV

Two Scalar Leptoquarks

Buttazzo et al. 1706.07808

$S_3 + S_1$

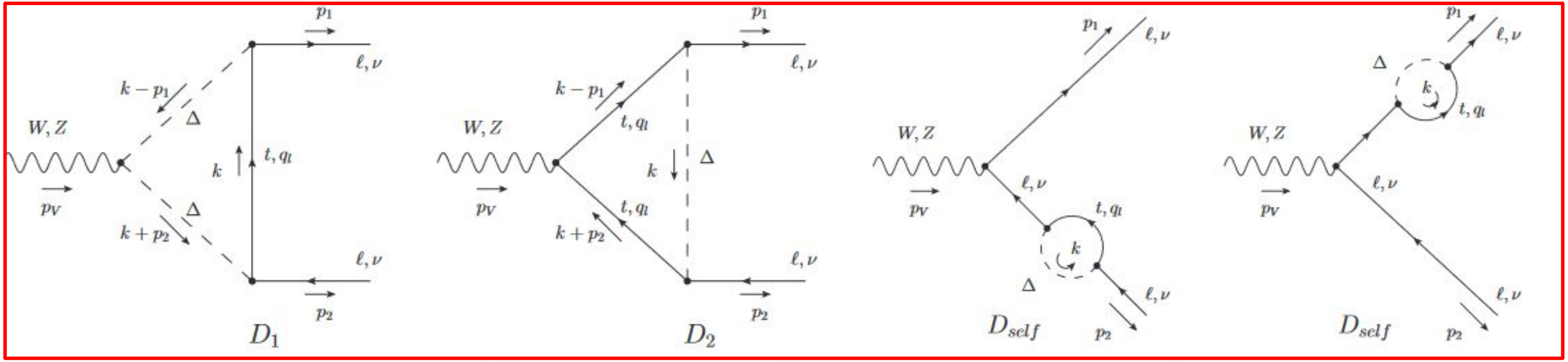


mΔ=2 TeV

Z-pole obs are in LLA, is it worth it to compute NLL?

Z-pole parenthesis

Arnan et al. 1901.06315

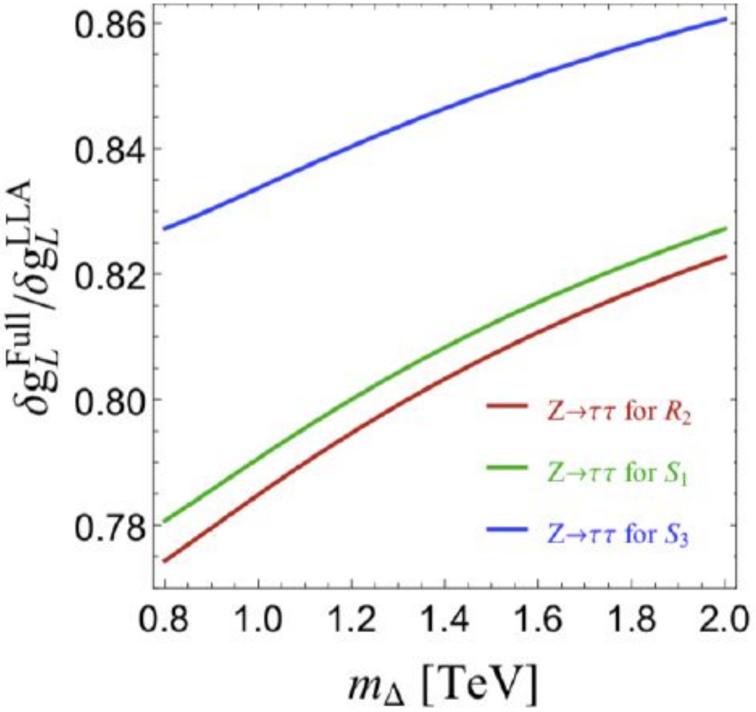


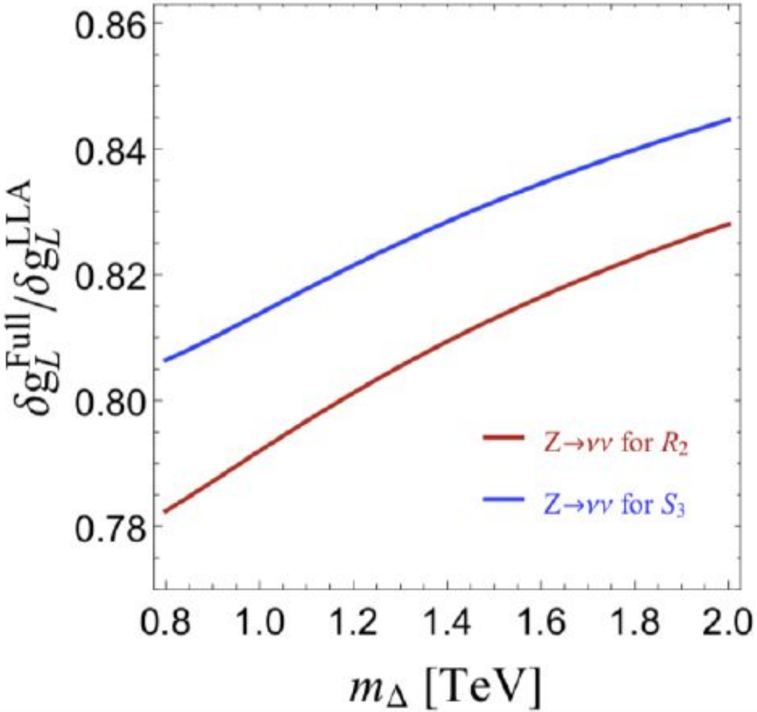
$$\delta\mathcal{L}_{\rm eff}^{Z} = \frac{g}{\cos\theta_W}\sum_{f,i,j}\bar{f}_i\gamma^\mu\left[g^{ij}_{f_L}\,P_L + g^{ij}_{f_R}\,P_R\right]f_j\,Z_\mu$$

$$g^{ij}_{f_{L(R)}} = \delta_{ij}\,g^{\rm SM}_{f_{L(R)}} + \delta g^{ij}_{f_{L(R)}}$$

Z–pole parenthesis

Arnan et al. 1901.06315



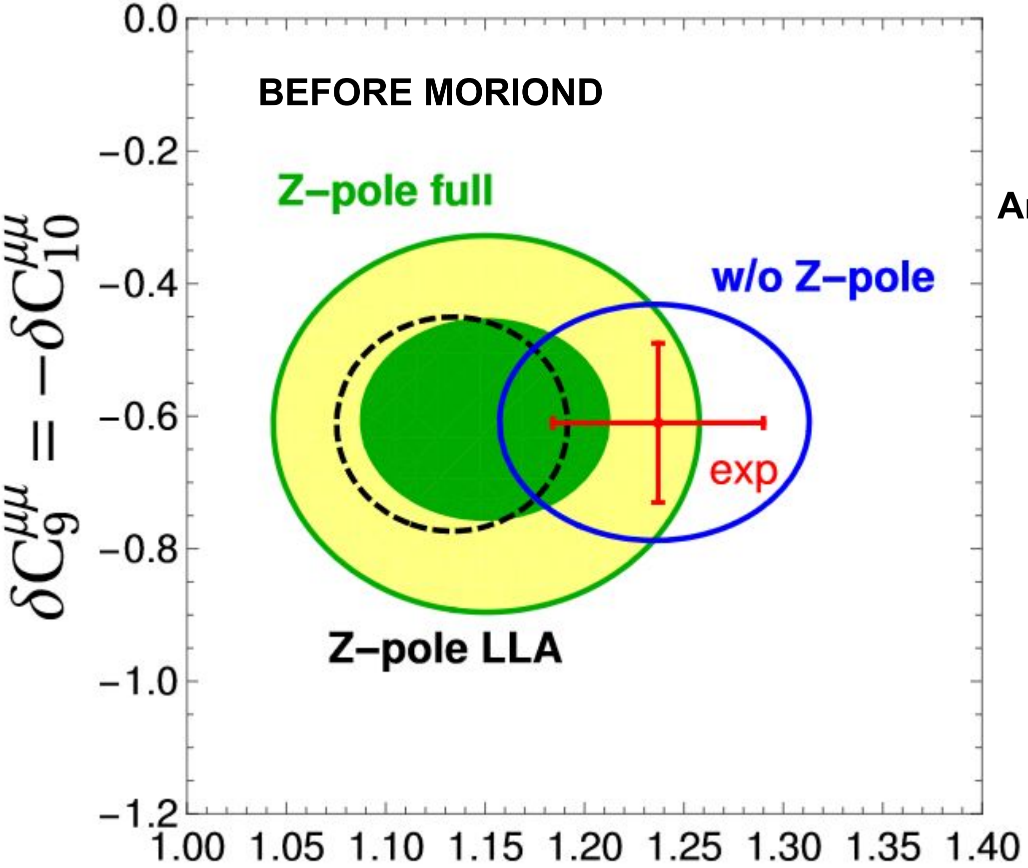


LLA: $\mathcal{O}(x_t \log x_t)$, $\mathcal{O}(x_Z \log x_Z)$ $\quad x_j = m_j^2/m_\Delta^2$

Full: most significant $\mathcal{O}(x_Z \log x_t)$

Two Scalar Leptoquarks with full Z-pole

$S_3 + S_1$



mΔ=2 TeV

Arnan et al. 1901.06315

Two Scalar Leptoquarks

Crivellin et al. 1703.09226

$S_3 + S_1$

$$y^L_{S_1} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \lambda_{s\mu} & \lambda_{s\tau} \\ 0 & \lambda_{b\mu} & \lambda_{b\tau} \end{pmatrix} \qquad y^L_{S_3} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \lambda_{s\mu} & \lambda_{s\tau} \\ 0 & -\lambda_{b\mu} & -\lambda_{b\tau} \end{pmatrix}$$

-5 parameters
-Left-handed: C9=-C10 and gV
- Specially thought to pass B→Kνν
-Aiming to explain (g-2) with RH coupling but not possible due to chiral enhancement in τ→μγ
-Predictions in b→sττ and LFV b→sτμ
-mΔ=1 TeV

Two Scalar Leptoquarks

In preparation

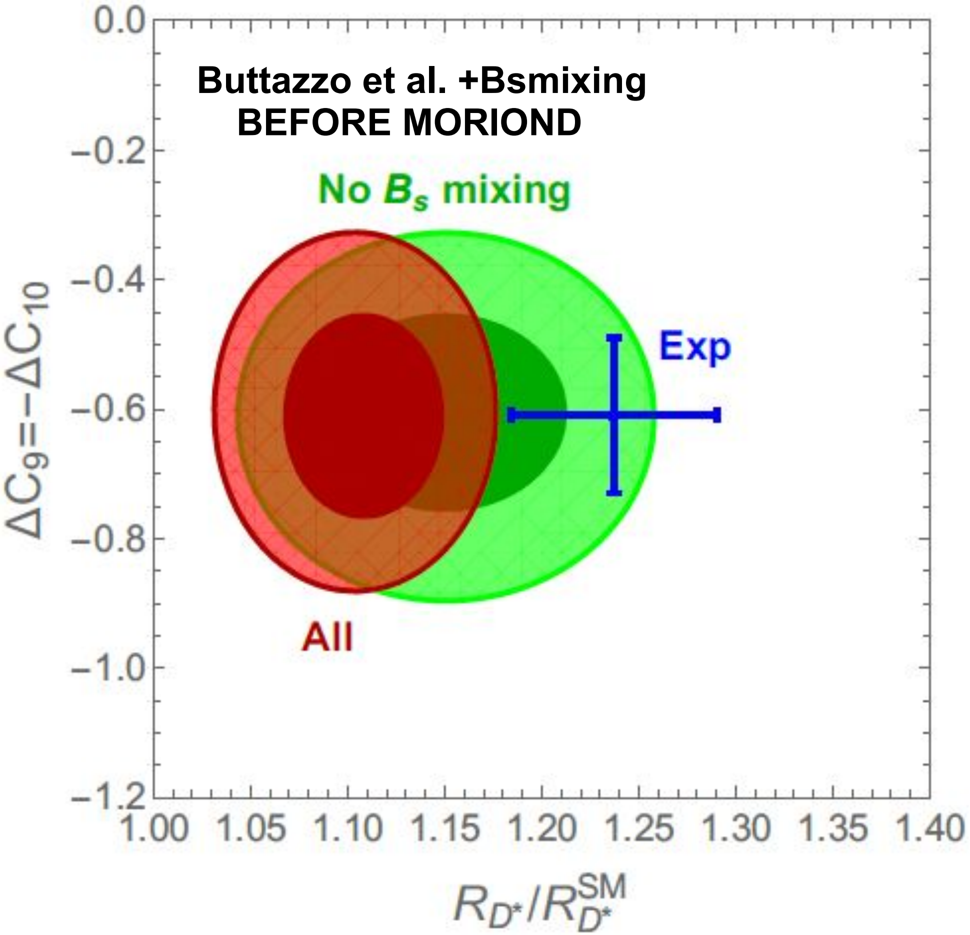
$S_3 + S_1$

$$y^L_{S_1} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & y^{S_1}_{s\tau} \\ 0 & 0 & y^{S_1}_{b\tau} \end{pmatrix} \qquad y^L_{S_3} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & y^{S_3}_{s\mu} & y^{S_3}_{s\tau} \\ 0 & y^{S_3}_{b\mu} & y^{S_3}_{b\tau} \end{pmatrix}$$

-6 parameters
-Left-handed: C9=-C10 and gV
-Assuming no muon couplings in S1 since it only contributes to RD.
-mΔ=1.5 TeV

Two Scalar Leptoquarks with Bs mixing

$S_3 + S_1$



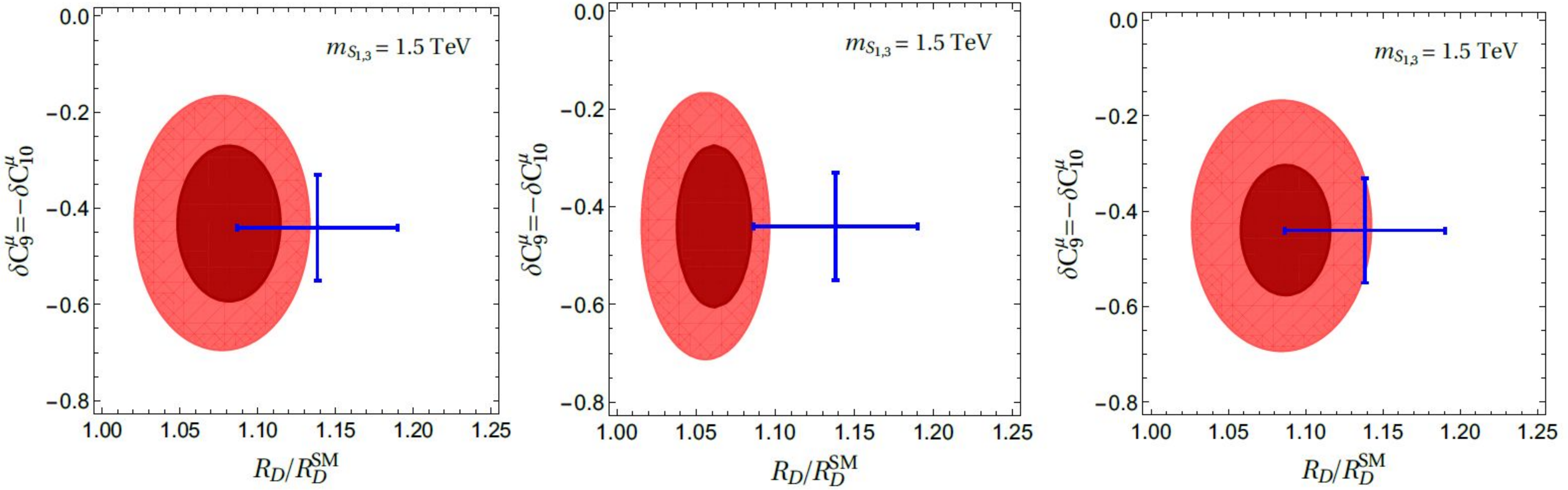
mΔ=2 TeV

Should we introduce RH coupling?

AFTER MORIOND 2019

In preparation

$S_3 + S_1$



Average RD reduced. Models work fine.

Two Scalar Leptoquarks

Becirevic et al. 1806.05689

$$\mathcal{L} \supset + (VY_RE_R^\dagger)^{ij}\bar{u}_{Li}\ell_{Rj}R_2^{\frac{5}{3}} + (Y_RE_R^\dagger)^{ij}\bar{d}_{Li}\ell_{Rj}R_2^{\frac{2}{3}}$$
$$+ (U_RY_LU)^{ij}\bar{u}_{Ri}\nu_{Lj}R_2^{\frac{2}{3}} - (U_RY_L)^{ij}\bar{u}_{Ri}\ell_{Lj}R_2^{\frac{5}{3}}$$
$$- (YU)^{ij}\bar{d}_{Li}^C\nu_{Lj}S_3^{\frac{1}{3}} + 2^{\frac{1}{2}}(V^*YU)^{ij}\bar{u}_{Li}^C\nu_{Lj}S_3^{-\frac{2}{3}}$$
$$- 2^{\frac{1}{2}}Y^{ij}\bar{d}_{Li}^C\ell_{Lj}S_3^{\frac{4}{3}} - (V^*Y)^{ij}\bar{u}_{Li}^C\ell_{Lj}S_3^{\frac{1}{3}},$$

R_2

S_3

Assume $Y_RE_R^\dagger = (Y_RE_R^\dagger)^T\,, \qquad Y = -Y_L$ viable embedding in SU(5)

$$Y_RE_R^\dagger = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & y_R^{b\tau} \end{pmatrix}, \; U_RY_L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & y_L^{c\mu} & y_L^{c\tau} \\ 0 & 0 & 0 \end{pmatrix} \; U_R = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix}$$

6 parameters $m_{R_2},\ m_{S_3},\ y_R^{b\tau},\ y_L^{c\mu},\ y_L^{c\tau}$ and θ

Two Scalar Leptoquarks

Becirevic et al. 1806.05689

R_2 S_3

$b \to c\tau\nu$

$$\propto \frac{y_L^{c\tau}\, y_R^{b\tau\,*}}{m_{R_2}^2}\left[(\bar{c}_R b_L)(\bar{\tau}_R \nu_L) + \frac{1}{4}(\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\tau}_R \sigma^{\mu\nu} \nu_L)\right]$$

$b \to s\mu\mu$

$$\propto s_{2\theta} \frac{|y_L^{c\mu}|^2}{m_{S_3}^2}(\bar{s}_L \gamma^\mu b_L)(\bar{\mu}_L \gamma_\mu \nu_L)$$

sin2θ suppression

Bs mixing also suppressed by $\sin^2 2\theta$.

Fit results $\theta \approx \pi/2,\ m_{R_2}^2 < m_{S_3}^2,\ y_R^{b\tau} \in \mathbb{C}$

Summary and Conclusions

One single scalar LQ cannot accommodate successfully B anomalies.

Two LQ such as S1+S3 or can explain data in light of New RD.

R2+S3 is also able to explain flavour data and can be based in a SU(5) gauge theory

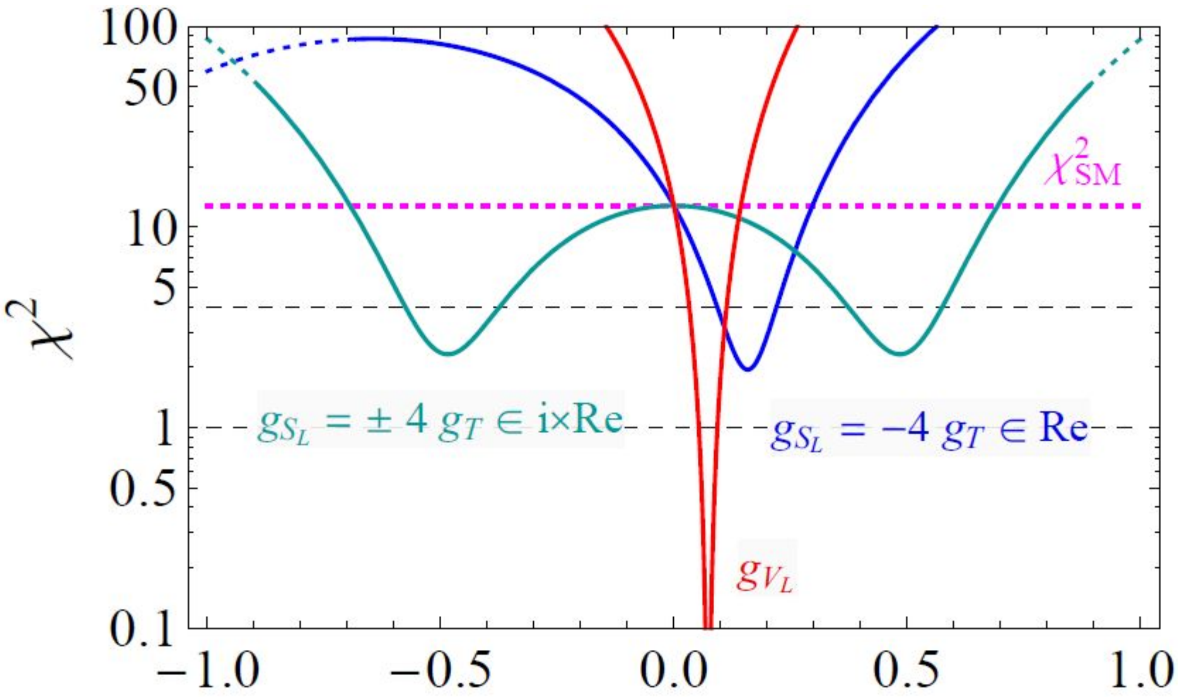
These models might be tested with observables involving tau or LFV.
Such as $B \to K\mu\tau$.

BR($\tau \to 3\,\mu$) phenomenolgy

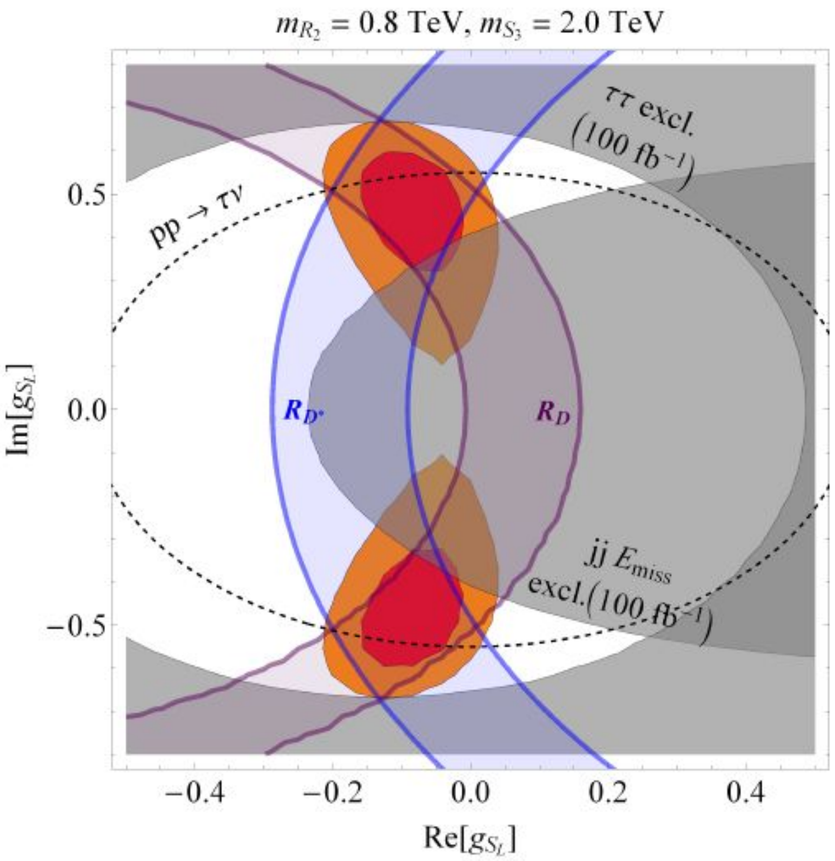
Backup Pair production

Decays	LQs	Scalar LQ limits	Vector LQ limits	$\mathcal{L}_{\rm int}$ / Ref.
$jj\,\tau\bar{\tau}$	S_1, R_2, S_3, U_1, U_3	–	–	–
$b\bar{b}\,\tau\bar{\tau}$	R_2, S_3, U_1, U_3	850 (550) GeV	1550 (1290) GeV	12.9 $\rm fb^{-1}$ [49]
$t\bar{t}\,\tau\bar{\tau}$	S_1, R_2, S_3, U_3	900 (560) GeV	1440 (1220) GeV	35.9 $\rm fb^{-1}$ [50]
$jj\,\mu\bar{\mu}$	S_1, R_2, S_3, U_1, U_3	1530 (1275) GeV	2110 (1860) GeV	35.9 $\rm fb^{-1}$ [51]
$b\bar{b}\,\mu\bar{\mu}$	R_2, U_1, U_3	1400 (1160) GeV	1900 (1700) GeV	36.1 $\rm fb^{-1}$ [52]
$t\bar{t}\,\mu\bar{\mu}$	S_1, R_2, S_3, U_3	1420 (950) GeV	1780 (1560) GeV	36.1 $\rm fb^{-1}$ [53, 54]
$jj\,\nu\bar{\nu}$	R_2, S_3, U_1, U_3	980 (640) GeV	1790 (1500) GeV	35.9 $\rm fb^{-1}$ [55]
$b\bar{b}\,\nu\bar{\nu}$	S_1, R_2, S_3, U_3	1100 (800) GeV	1810 (1540) GeV	35.9 $\rm fb^{-1}$ [55]
$t\bar{t}\,\nu\bar{\nu}$	R_2, S_3, U_1, U_3	1020 (820) GeV	1780 (1530) GeV	35.9 $\rm fb^{-1}$ [55]

Backup fit b→cτν



Backup S3+R2 model



Backup Bs mixing

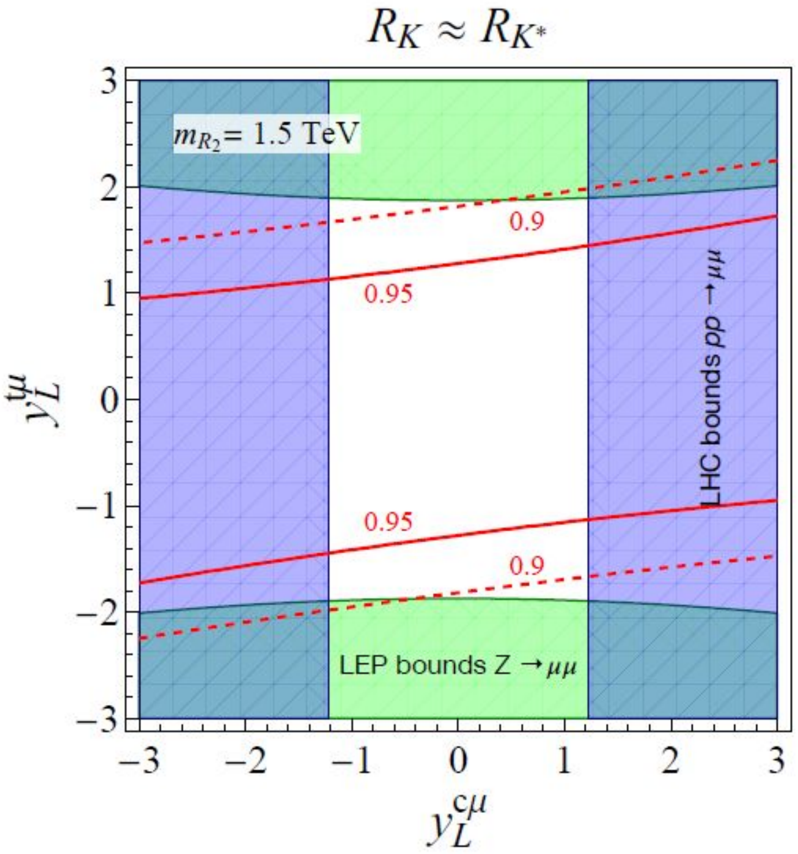
$$C_{BB}^{\rm NP} = \frac{1}{128\pi^2 m_{S_1}^2}(y_{s\mu}^{S_1\,*} y_{b\mu}^{S_1} + y_{s\tau}^{S_1\,*} y_{b\tau}^{S_1})^2 + \frac{5}{128\pi^2 m_{S_3}^2}(y_{s\mu}^{S_3\,*} y_{b\mu}^{S_3} + y_{s\tau}^{S_3\,*} y_{b\tau}^{S_3})^2$$
$$+\frac{1}{32\pi^2(m_{S_1}^2 - m_{S_3}^2)}(y_{s\mu}^{S_1\,*} y_{b\mu}^{S_3} + y_{s\tau}^{S_1\,*} y_{b\tau}^{S_3})(y_{s\mu}^{S_3\,*} y_{b\mu}^{S_1} + y_{s\tau}^{S_3\,*} y_{b\tau}^{S_1}) \log\left(\frac{m_{S_1}}{m_{S_3}}\right)$$

$$\frac{\Delta M_S^{\rm NP}}{\Delta M_S^{\rm SM}} = \left|1 + \frac{\langle \mathcal{H}_{B\bar{B}}^{\rm NP}\rangle}{\langle \mathcal{H}_{B\bar{B}}^{\rm SM}\rangle}\right| = \left|1 + \frac{C_{B\bar{B}}^{\rm NP}(\mu_b)}{C_{B\bar{B}}^{\rm SM}(\mu_b)}\right| = \left|1 + \frac{U(\mu_t, \mu_{\rm LQ}) C_{B\bar{B}}^{\rm NP}}{\frac{G_F^2 M_W^2}{4\pi^2}\lambda_t^2 S_0(x_t)}\right|$$

where

$$C_{B\bar{B}}^{\rm SM}(\mu_b) = \frac{G_F^2 M_W^2}{4\pi^2}\lambda_t^2 U(\mu_b, \mu_t) S_0(x_t) \quad \text{and} \quad \mathrm{C}_{\mathrm{B\bar{B}}}^{\rm SM}(\mu_{\rm b}) = \mathrm{U}(\mu_{\rm b}, \mu_{\rm LQ})\mathrm{C}_{\mathrm{B\bar{B}}}^{\rm NP}$$

Backup R2 2019



Backup tau->3mu