Scalar leptoquarks: from GUT to B anomalies

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QCD@work 2018, 25-28 June, 2018, Matera

Outline

Experimental status: of - B anomalies $R_{D(*)}$ and $R_{K(*)}$

Scalar leptoquarks solution of $R_{D(*)}$ and $R_{K(*)}$

GUT and two scalar leptoquarks

Flavour constraints on LQs

Predictions

Signature at LHC

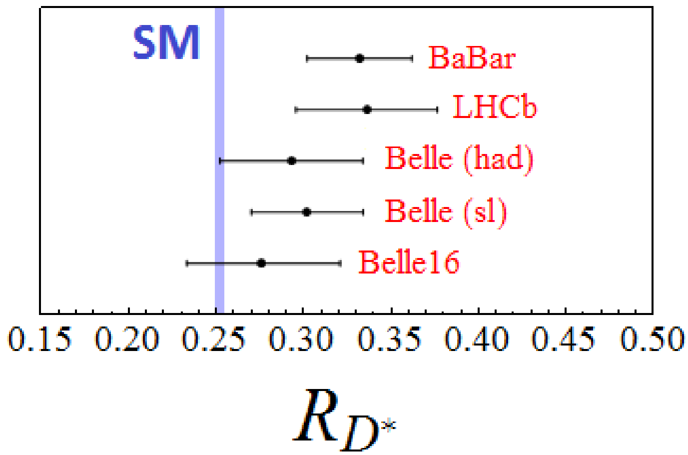
B physics anomalies: experimental results ≠ SM predictions!

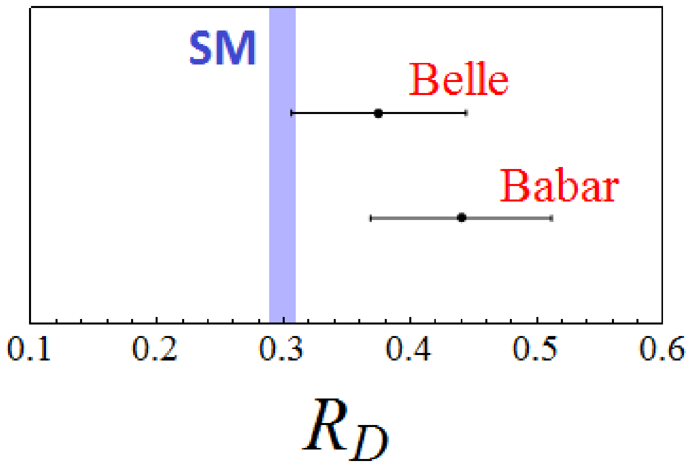
charged current (SM tree level)

$$R_{D^{(*)}} = \frac{BR(B \to D^{(*)}\tau\nu_\tau)}{BR(B \to D^{(*)}\mu\nu_\mu)}$$

3.9σ

3.4σ



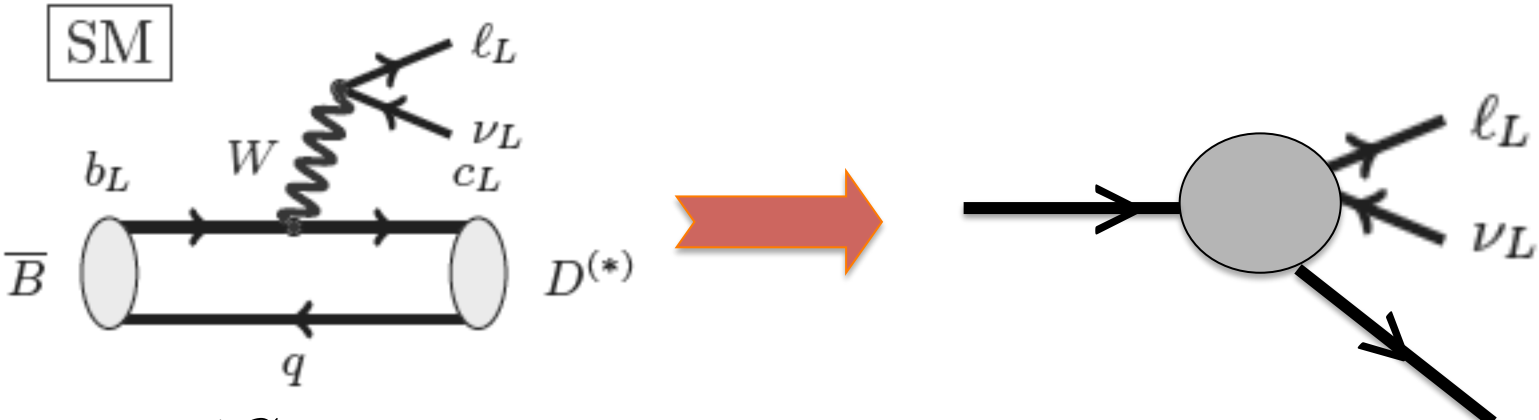


2σ

$$\frac{BR(B_c \to J/\Psi\tau\nu_\tau)}{BR(B_c \to J/\Psi\mu\nu_\mu)} = 0.71 \pm 0.17 \pm 0.18$$

2017
LHCb result

Effective Lagrangian approach for $b \to c\tau\nu_\tau$ decay



$$\mathcal{L}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{cb}[(1+g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{l}_L\gamma^\mu\nu_L) + g_{V_R}(\bar{c}_R\gamma_\mu b_R)(\bar{l}_L\gamma^\mu\nu_L)$$

$$+g_{S_R}(\bar{c}_L b_R)(\bar{l}_R\nu_L) + g_{T_R}(\bar{c}_L\sigma_{\mu\nu}b_R)(\bar{l}_R\sigma^{\mu\nu}\nu_L)]$$

If NP scale is above electroweak scale, NP effective operators have to respect SU(3) x $SU(2)_L$ x $U(1)_{Y,}$ (g_{VR} =0)

Freytsis, Ligeti, Ruderman 1506.08896
S.F. J.F. Kamenik, I. Nišandžić, J. Zupan, 1206.1872; Di Luzio Nardecchia, 1706.0!868

e.g: favorable solution by many authors

$$0.9 \leq g_{V_L} \leq 0.13$$

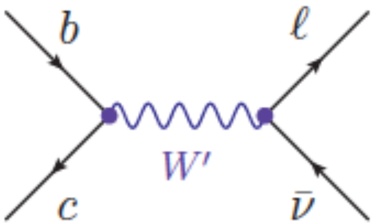
Assuming NP at scale Λ_{NP} (Di Luzio Nardecchia, 1706.0!868)

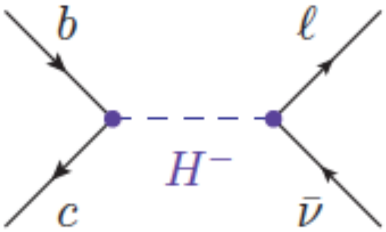
$$\frac{4G_F}{\sqrt{2}} V_{cb}\, g_V \to \frac{2}{\Lambda_{NP}^2}$$

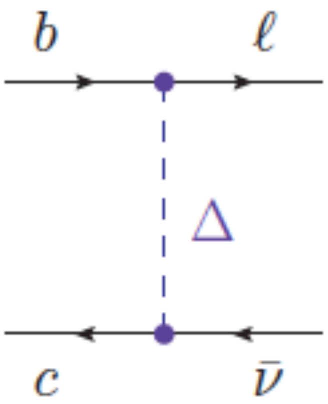
What is the scale of New Physics?

Proposals:

$$\Lambda_{NP} \simeq 3\,\mathrm{TeV}$$

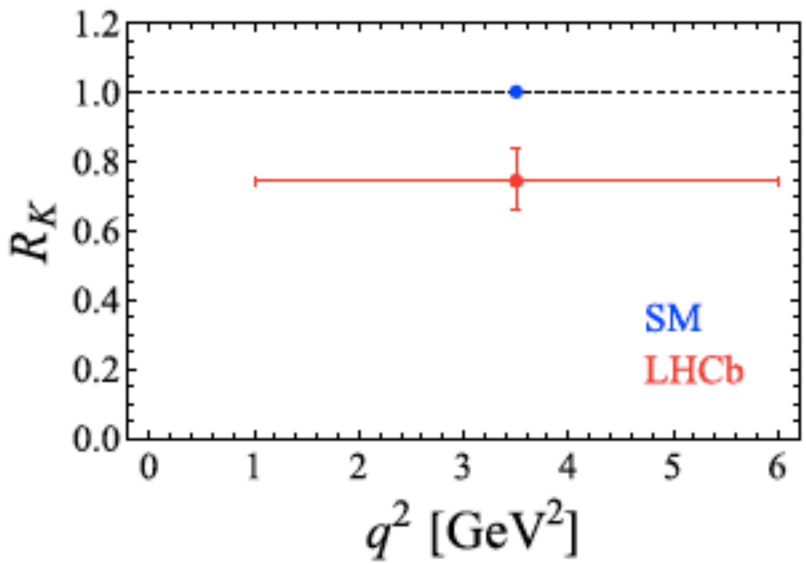


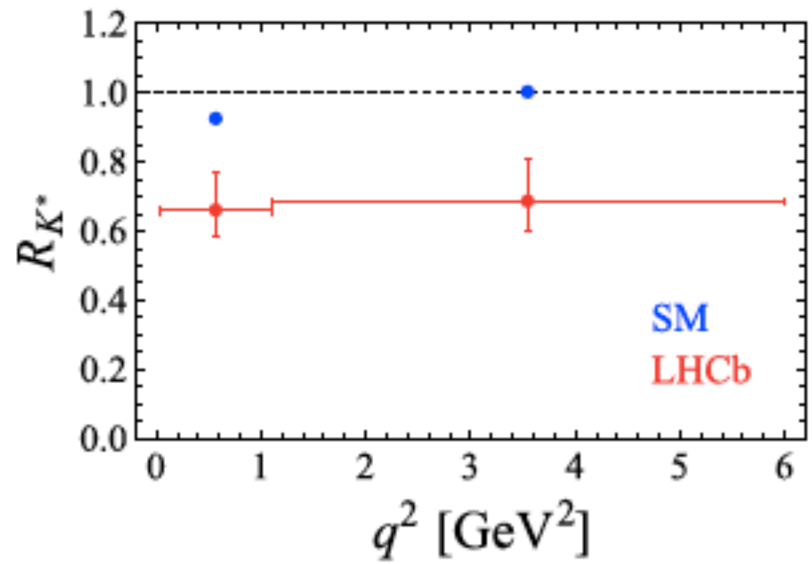




FCNC - SM loop process: $R_{K(*)}$ anomaly

$$R_{K^{(*)}} = \left. \frac{\mathcal{B}(B \to K^{(*)} \mu\mu)}{\mathcal{B}(B \to K^{(*)} ee)} \right|_{q^2 \in [q^2_{\min}, q^2_{\max}]}$$





2.4σ

2.2 σ - 2.4σ

P_5' in $B \to K^* \mu^+ \mu^-$ (angular distribution functions) 3σ

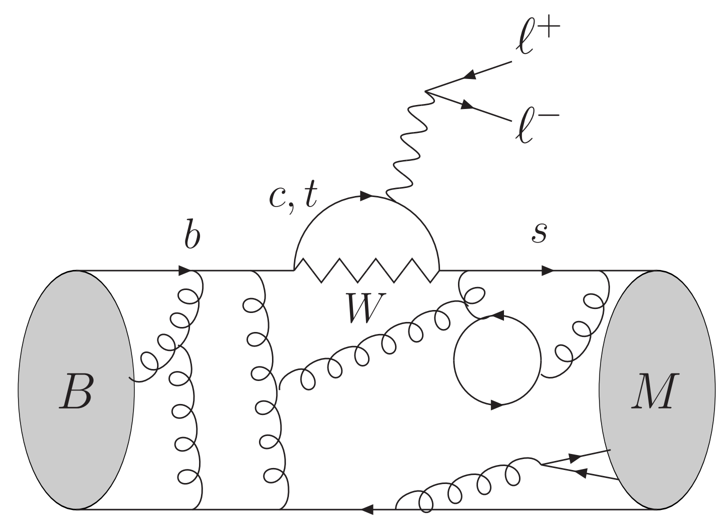
R_K and R_{K^*} and New Physics

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,\ldots,10} \left(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu) \right) \right]$$

$$\mathcal{O}_9 = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad \mathcal{O}_{10} = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

$$C_7^{SM} = 0.29;\ C_9^{SM} = 4.1;\ C_{10}^{SM} = -4.3;$$

$$\mu_b = 4.8\,\text{GeV}$$



Buras et al, hep_ph/9311345;
Altmannshofer et al, 0811.1214;
Bobeth et al, hep-ph/9910220

Global analysis suggests NP in $C_{9,10}$

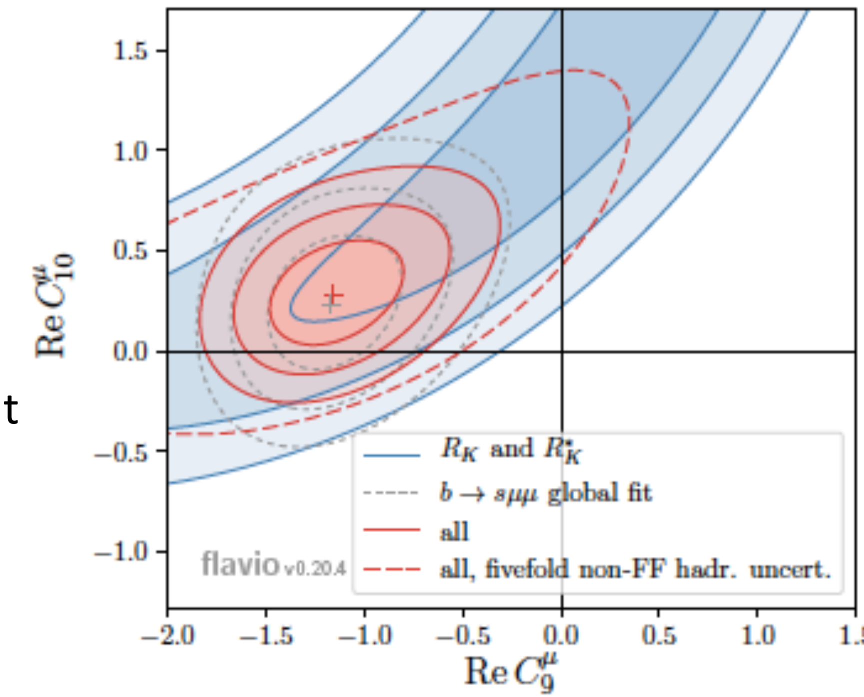
$$C_i = C_i^{SM} + C_i^{NP}$$

Instead of SM values for C_9 and C_{10}

$$C_9^\mu = -C_{10}^\mu = -0.64$$ best fit point

$$C_9^\mu = -C_{10}^\mu \in (-0.85, -0.50)$$

Altmannshofer et al,
1704.05435, Capdevila et al., 1704.05340
D'Amico et al., 1704.05438



What is the scale of New Physics?

$$\mathcal{L}_{NP} = \frac{1}{\Lambda_{NP}^2} \bar{s}_L \gamma^\alpha b_L \bar{\mu}_L \gamma_\alpha \mu_L$$

$$\Lambda_{NP} \simeq 30\,\text{TeV}$$

What is common to both B anomalies?

They show up in the ratios! Ratios are considered in order to avoid hadronic uncertainties (form factors CKM dependence).

NP explanation

- To construct effective Lagrangian which might explain experimental data;
- Find new particle which can mimic effective Lagrangian;
- Check all other low energy flavour constraints, check electroweak observables;
- Include LHC direct searches for NP

Construction of UV complete NP model!

$$R^{exp}_{D^{(*)}} > R^{SM}_{D^{(*)}}$$

$$\mathcal{L}_{NP} = \frac{1}{(\Lambda^D_{NP})^2} 2\, \bar{c}_L \gamma_\mu b_L \bar{\tau} \gamma^\mu \nu_L$$

$$\Lambda^D_{NP} \simeq 3\,\mathrm{TeV}$$

$$R^{exp}_{K^{(*)}} < R^{SM}_{K^{(*)}}$$

$$\mathcal{L}_{NP} = \frac{1}{(\Lambda^K_{NP})^2} \bar{s}_L \gamma_\mu b_L \bar{\mu}_L \gamma^\mu \mu_L$$

$$\Lambda^K_{NP} \simeq 30\,\mathrm{TeV}$$

If we want the same NP explaining both B anomalies, then

$$\Lambda^D_{NP} = \Lambda_{NP}$$

$$\frac{1}{(\Lambda^K_{NP})^2} = \frac{C_K}{\Lambda^2_{NP}}$$

The NP in FCNC $B \to K^{(*)} \mu^+ \mu^-$
should be suppressed in comparison with the NP
in $B \to D^{(*)} \tau \nu$

$$C_K \simeq 0.01$$

How to achieve this suppression?

1) NP couples preferentially to third generation and has the V- A form.

$$\mathcal{L}_{NP} = \frac{C_S}{\Lambda_{NP}^2}\bar{q}_{3L}\gamma_\mu q_{3L}\bar{l}_{3L}\gamma^\mu l_{3L} + \frac{C_T}{\Lambda_{NP}^2}\bar{q}_{3L}\gamma_\mu \tau_i q_{3L}\bar{l}_{3L}\gamma^\mu \tau_i l_{3L}$$

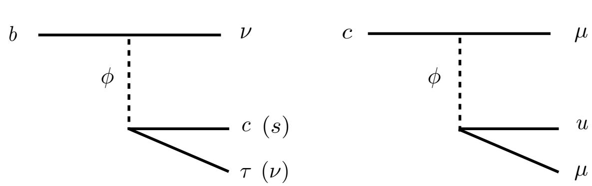
Feruglio, Paradisi, Pattori, 1606.00524; Battacharaya et al., 1412.7164; Glashow, Guadagnoli and Lane, 1411.0565...

NP in $R_{K(*)}$ "fine tuned" smaller parameters for the second generetion

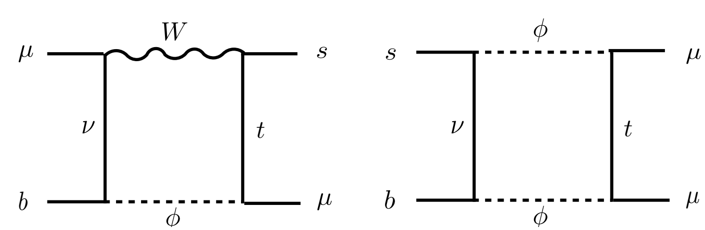
2) NP in $R_{K(*)}$ arises at loop level $C_K \approx 1 / 16\pi^2$

Bauer&Neubert, 1511.01900

$R_{D(*)}$ at tree level



$R_{K(*)}$ at loop level



Models at TeV scale

Scalar LQ as pseudo-Nambu-Goldstone bosons

Gripaios et al, 1010.3962
Gripaios, Nardecchia, Renner 1412.1791
Marzocca 1803.10972,
…

Vector resonances (from techni-fermions)

Barbieri et al.1506.09201, Buttazzo et al. 1604.03940
Barbieri, Murphy, Senia, 1611.04930
Blanke, Crivellin, 1801.07256,…

Non-renormalizeble , non-perturbaticve dynamics

Models with scalar LQs

Hiller & Schmaltz, 1408.1627
Becirevic et al. 1608.08501, SF and Kosnik, 1511.06024, Becirevic, SF and Kosnik, 1503.09
Dorsner, SF, Faroughy, Kosnik 1706.07779
Crivellin, Muller, Ota1703.09226
…

Gauge bosons

Cline, Camalich, 1706.08510
Calibbi, Crivellin, Li,1709.00692
Assad, Fornal, Grinstein, 1708.06350
Di Luzio, Greljo, Nardecchia, 1708.08450
Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368, 1805.09328

Renormalizable models, perturbative dynamics

Leptoquarks in $R_{D(*)}$ and $R_{K(*)}$

Suggested by many authors: naturally accommodate LUV and LFV

color SU(3), weak isospin SU(2) , weak hypercharge U(1) $Q=I_3+Y$

$SU(3)\times SU(2)\times U(1)$	Spin	Symbol	Type	$3B+L$
$(\overline{\mathbf{3}},\mathbf{3},1/3)$	0	S_3	$LL\,(S_1^L)$	-2
$(\mathbf{3},\mathbf{2},7/6)$	0	R_2	$RL\,(S_{1/2}^L),\ LR\,(S_{1/2}^R)$	0
$(\mathbf{3},\mathbf{2},1/6)$	0	$\tilde{R}_2$	$RL\,(\tilde{S}_{1/2}^L),\ \overline{LR}$	0
$(\overline{\mathbf{3}},\mathbf{1},4/3)$	0	$\tilde{S}_1$	$RR\,(\tilde{S}_0^R)$	-2
$(\overline{\mathbf{3}},\mathbf{1},1/3)$	0	S_1	$LL\,(S_0^L),\ RR\,(S_0^R),\ \overline{RR}$	-2
$(\overline{\mathbf{3}},\mathbf{1},-2/3)$	0	$\bar{S}_1$	$\overline{RR}$	-2
$(\mathbf{3},\mathbf{3},2/3)$	1	U_3	$LL\,(V_1^L)$	0
$(\overline{\mathbf{3}},\mathbf{2},5/6)$	1	V_2	$RL\,(V_{1/2}^L),\ LR\,(V_{1/2}^R)$	-2
$(\overline{\mathbf{3}},\mathbf{2},-1/6)$	1	$\tilde{V}_2$	$RL\,(\tilde{V}_{1/2}^L),\ \overline{LR}$	-2
$(\mathbf{3},\mathbf{1},5/3)$	1	U_1	$RR\,(V_0^R)$	0
$(\mathbf{3},\mathbf{1},2/3)$	1	U_1	$LL\,(V_0^L),\ RR\,(V_0^R),\ \overline{RR}$	0
$(\mathbf{3},\mathbf{1},-1/3)$	1	$\bar{U}_1$	$\overline{RR}$	0

F=3B +L fermion number; F=0 no proton decay at tree level (see Assad et al, 1708.06350)

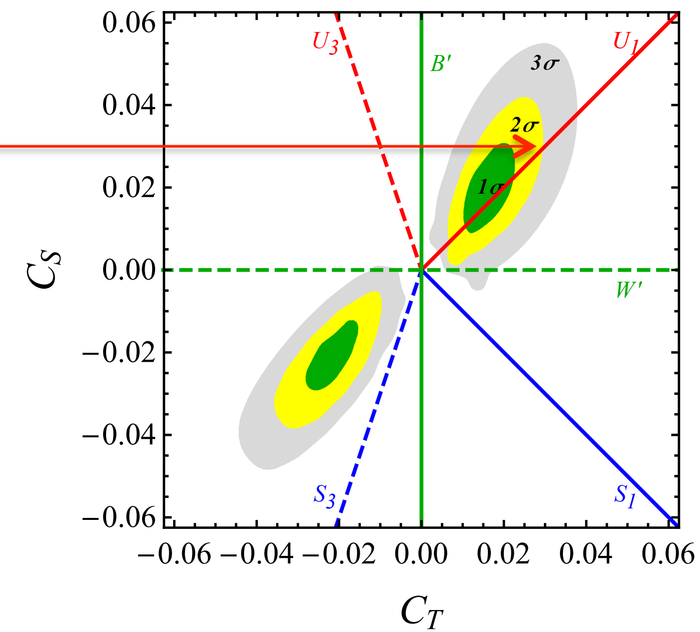
Doršner, SF, Greljo, Kamenik Košnik, (1603.04993)

$$\mathcal{L}_{NP} = \frac{C_S}{\Lambda_{NP}^2}\bar{q}_{3L}\gamma_\mu q_{3L}\bar{l}_{3L}\gamma^\mu l_{3L} + \frac{C_T}{\Lambda_{NP}^2}\bar{q}_{3L}\gamma_\mu \tau_i q_{3L}\bar{l}_{3L}\gamma^\mu \tau_i l_{3L}$$

Only one mediator!

Buttazzo, Greljo, Isidoria, Marzocca
1706.07808

leptoquark (3,1,2/3) passes all tests



if vector LQ is not a gauge boson − difficult to handle!

proton decay at tree cannot be mediated by U(3,1,2/3).

Asad, Fornal Grinstein 1708.06350;

Pati-Salam-like unified model vector LQ- gauge boson!:
Di Luzio, Greljo, Nardecchia, 1708.08450;
Bordone et al, 1712.01368;
Callibi, Crivellin, Li, 1709.00692, Marzocca, 1803.10972.

in these models $R_{D(*)}$ gets non V-A contributions

One scalar Leptoqaurk resolving both B anomalies:

e.g. (3,2,1/6)

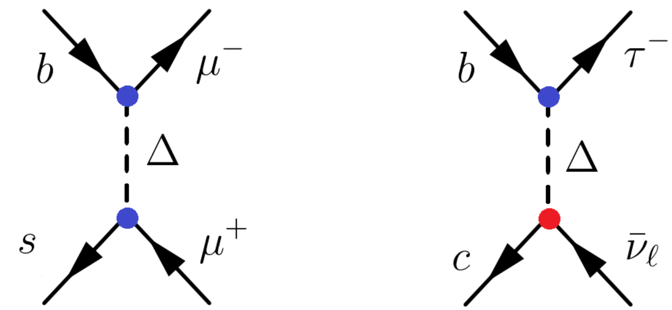
Tree level solutions for $R_{D(*)}$ and $R_{K(*)}$

Right-handed neutrino introduced LQ (3,2,1/6)

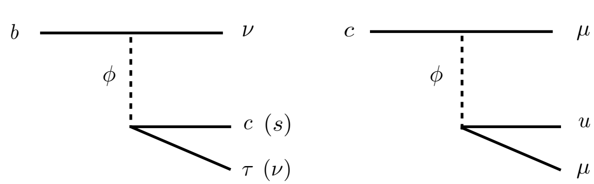
$$|M_{SM}|^2 + |M_{LQ}|^2$$

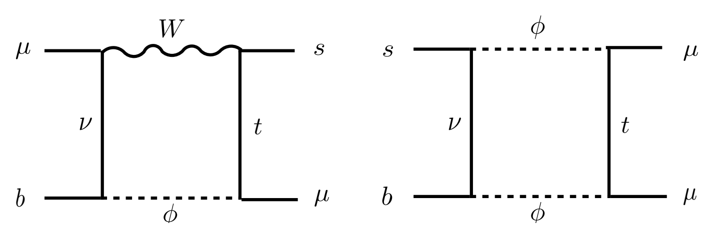
Becirevic et al, 1608.08501

passes all flavor constraints, but leads to R_{K*}>1!



(3,1,-1/3) destabilizes proton!





Bauer&Neubert, 1511.01900

$R_{D(*)}$ at tree level

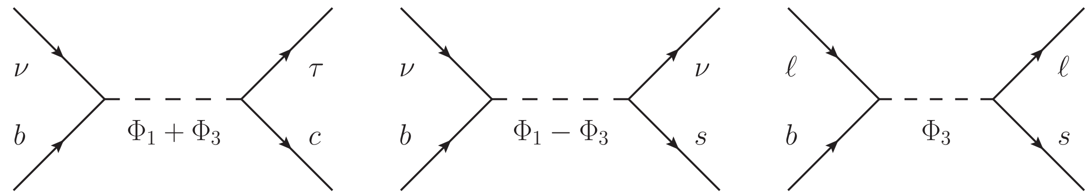
$R_{K(*)}$ at loop level

+ muon anomalous magnetic moment

Bečirević et al, 1608.07583 – troubles with charm, K, leptonic decays and $B \to D^{(*)} e(\mu)\nu$

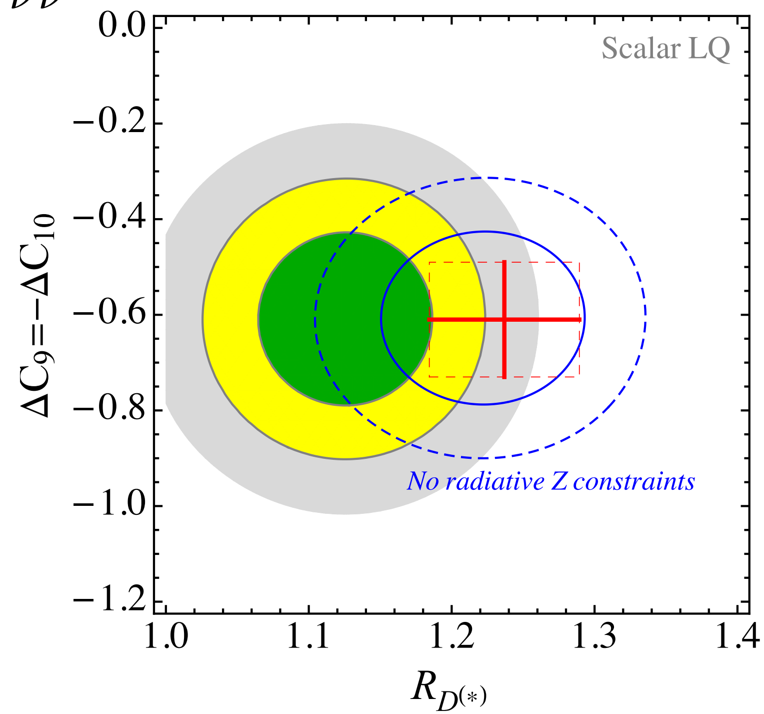
Two LQs solution of $R_{D(*)}$ and $R_{K(*)}$

(3,3,1/3) + (3,1,-1/3)
Crivellin et al, 1703.09226,
Marzocca, 1803.10972.



- (3,3,1/3) couples to only left-handed quarks and leptons.
- it leads to too large contribution in $B \to K^{(*)} \nu \bar{\nu}$

Buttazzo, Greljo, Isidori, Marzocca
1706.07808 :



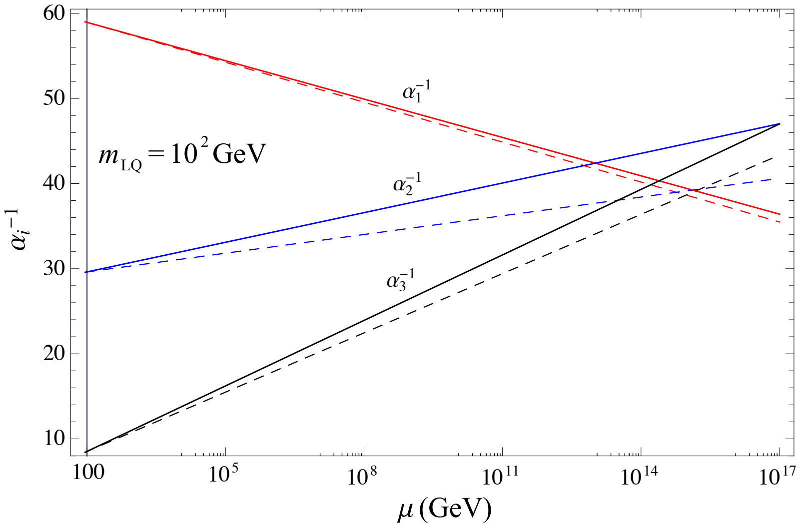
- radiative corrections to $Z \to \tau\bar{\tau}, \nu\bar{\nu}$

observables are enhanced by the factor of 3, implying a ~ 1.5σ tension in $R_{D(*)}$;

Potentially large sμ coupling disfavored by Ds/K $\longrightarrow$ μν

No constraints from τ $\longrightarrow$ μ ϕ!

SU(5) GUT with two light leptoquarks



- GUT possible with light scalar LQs within SU(5) if there are 2 LQs (Doršner, SF, Greljo, Kamenik, Košnik 1603.04993) ;
- LQ S_3 , if accommodated within SU(5) does not cause proton decay, Doršner, SF, Faroughy, Košnik 1706.07779;
- Neutrino masses might be explained with 2 light LQs within a loop (Doršner, SF, Košnik, 1701.08322);

New Proposal: two leptoquarks

D. Becirevic,I. Dorsner, , S. F, D. Faroughy, N. Kosnik and O. Sumensari 1806.05689

Not only V-A picture of NP!

Scalar LQ → simpler UV completion;

R_2 =(3,2,7/6) contains two states with electric charges 5/3 and 2/3.

$$\mathcal{L}_{R_2} = (V y_R)^{ij}\, \bar{u}_{Li} \ell_{Rj} R_2^{(5/3)} + y_R^{ij}\, \bar{d}_{Ri} \ell_{Rj} R_2^{(2/3)}$$

Flavour basis!

$$+ (y_L U)^{ij}\, \bar{u}_{Ri} \nu_{Lj} R_2^{(2/3)} - y_L^{ij}\, \bar{u}_{Ri} \ell_{Lj} R_2^{(5/3)} + \text{h.c.}$$

S_3 =($\bar{3}$,3,1/3) contains three states with electric charges $S_3^{2/3}, S_3^{-1/3}, S_3^{-4/3}$

$$\mathcal{L}_{S_3} = y^{ij}\, \bar{Q}_i^C i\tau_2 (\vec{\tau} \cdot \vec{S}_3) L_j + \text{h.c.}$$

Mass eigenstate basis:

$$\mathcal{L}_{R_2\&S_3} = + (V_{\rm CKM}\, y_R\, E_R^\dagger)^{ij}\, \bar{u}'_{Li}\ell'_{Rj} R_2^{(5/3)} + (y_R\, E_R^\dagger)^{ij}\, \bar{d}'_{Li}\ell'_{Rj} R_2^{(2/3)}$$
$$+ (U_R\, y_L\, U_{\rm PMNS})^{ij}\, \bar{u}'_{Ri}\nu'_{Lj} R_2^{(2/3)} - (U_R\, y_L)^{ij}\, \bar{u}'_{Ri}\ell'_{Lj} R_2^{(5/3)}$$
$$- (y\, U_{\rm PMNS})^{ij}\, \bar{d}'^{C}_{Li}\nu'_{Lj} S_3^{(1/3)} - \sqrt{2}\, y^{ij}\, \bar{d}'^{C}_{Li}\ell'_{Lj} S_3^{(4/3)}$$
$$+ \sqrt{2}(V^*_{\rm CKM}\, y\, U_{\rm PMNS})_{ij}\, \bar{u}'^{C}_{Li}\nu'_{Lj} S_3^{(-2/3)} - (V^*_{\rm CKM}\, y)_{ij}\, \bar{u}'^{C}_{Li}\ell'_{Lj} S_3^{(1/3)} + \text{h.c.}$$

$$u'_{L,R} = U_{L,R}\, u_{L,R},\; d'_{L,R} = D_{L,R}\, d_{L,R},\; \ell'_{L,R} = E_{L,R}\, \ell_{L,R},\; \nu'_L = N_L\, \nu_L$$

$$V_{\rm CKM} = U_L\, D_L^\dagger \qquad U_{\rm PMNS} \equiv E_L\, N_L^\dagger$$

couplings of S_3 and R_2 are related

$$y_R = y_R^T \qquad y = -y_L$$

both LQs can be accommodated within the same SU(5) representation (dimension 45)

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

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

phenomenology suggests: θ≈π/2 and $y_R^{b\tau}$ complex!

Light Leptoquarks in SU(5) GUT

- SM fermions are in 5 and 10;
- Scalars: $R_2 \in 45, 50, S_3 \in 45$. SM matter fields in 5_i and 10_i ;
- R_2 does not have diquark couplings − no proton decay. Operators $10_i\, 10_j\, 45$ might lead to proton decay (Dorsner, SF, Kosnik, 1701.08322).

$$\mathbf{10}_i \mathbf{5}_j \underline{\mathbf{45}} : \quad y_{2\,ij}^{RL} \overline{u}_R^i R_2^a \varepsilon^{ab} L_L^{j,b}, \quad y_{3ij}^{LL} \overline{Q^c}_L^{i,a} \varepsilon^{ab} (\tau^k S_3^k)^{bc} L_L^{j,c}$$

$$\mathbf{10}_i \mathbf{10}_j \underline{\mathbf{50}} : \quad y_{2\,ij}^{LR} \overline{e}_R^i R_2^{a\,*} Q_L^{j,a}$$

- by breaking SU(5) to SM, the two R_2's mix – one can be light and the other (very) heavy.
- the Yukawa couplings determined from flavor physics remain perturbative ($< \sqrt{4\pi}$) up to the GUT scale;

Perturbativity

- the low-energy Yukawa couplings are of order one - the GUT origin.
- SARAH_4.12.3 program implemented for running
- perturbativity holds up to the GUT scale 5 x 10^{15} GeV for $y_R^{b\tau}$, $y_L^{c\mu}$, $y_L^{c\tau}$ (they are smaller then $\sqrt{4\pi}$ from low-energy up to GUT scale)

$$16\pi^2 \frac{dy_R^{b\tau}}{d\ln\mu} = \left(-\frac{37}{20}g_1^2 - \frac{9}{4}g_2^2 - 4g_3^2 + y_L^{c\mu\,2} + y_L^{c\tau\,2} + \frac{9}{2}y_R^{b\tau\,2} + \frac{1}{2}y_t^2\right) y_R^{b\tau} + \dots$$

Proton decay

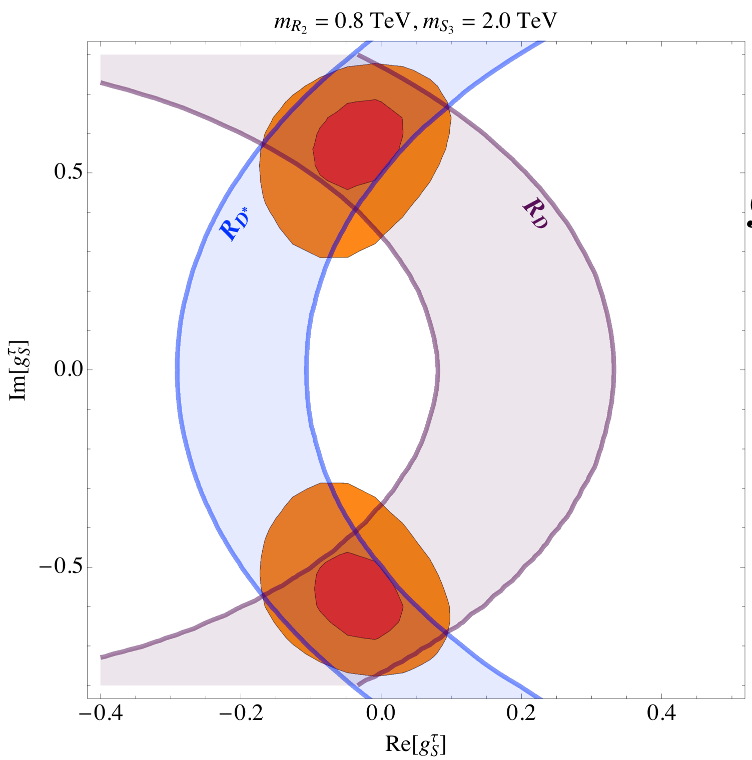
- R_2 cannot mediate proton decay at tree level (no diquark couplings)
- S_3 does not contribute towards proton decay if the contraction $c_{ij} 10_i 10_j 45$ is absent or suppressed and that S_3 does not mix with any other LQ with diquark couplings

Flavour constraints

Explaining $R_{D(*)}$

Not V-A explanation! T and S from R_2
very small contribution from S_3

$$\mathcal{L}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}} V_{cb}\big[(1+g_V)(\bar{u}_L\gamma_\mu d_L)(\bar{\ell}_L\gamma^\mu\nu_L) + g_S(\mu)\,(\bar{u}_R d_L)(\bar{\ell}_R\nu_L) + g_T(\mu)\,(\bar{u}_R\sigma_{\mu\nu}d_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\big] + \text{h.c.}$$



$$g_{S_L}(\Lambda) = 4\,g_T(\Lambda) = \frac{y_L^{u\ell'}\;y_R^{d\ell\,*}}{4\sqrt{2}\,m_{R_2}^2\,G_F V_{ud}}$$

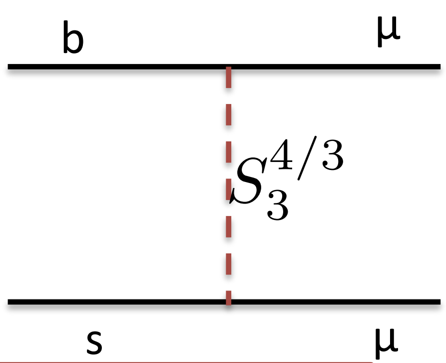
$$g_{V_L} = -\frac{y^{d\ell'}\,(V y^*)^{u\ell}}{4\sqrt{2}\,m_{S_3}^2 G_F V_{ud}}$$

Explaining $R_{K(*)}$

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

$$\delta C_9^{\mu\mu} = -\delta C_{10}^{\mu\mu} = \frac{\pi v^2}{\lambda_t \alpha_{\rm em}} \frac{y^{b\mu}\left(y^{s\mu}\right)^*}{m_{S_3}^2} \;\; C_9^{\mu\mu} = -C_{10}^{\mu\mu} \in (-0.85, -0.50)$$

S_3 explains it! V-A explanation:



$$y^{b\mu} y^{s\mu *} \in [0.7, 1.3] \times 10^{-3} \; (m_{S_3}/\mathrm{TeV})^2$$

$$y^{b\mu} = sin\theta \, y_L^{c\mu} \qquad y^{s\mu} = -cos\theta \, y_L^{c\mu}$$

the factor C_K ~ sin 2θ

Constraints from flavor observables

$(g-2)_\mu$

$B_c \to \tau\nu$

$B \to K^{(*)}\nu\bar{\nu}$

$B_s^0 - \bar{B}_s^0$

$B \to D\mu\nu_\mu$

$K \to \mu\nu_\mu$

$D_{d,s} \to \tau, \mu\nu$

$K \to \pi\mu\nu_\mu$

$W \to \tau\bar{\nu},\ \tau \to \ell\bar{\nu}\nu$

$Z \to b\bar{b} \qquad Z \to l^+l^-$

Constraints from LFV

$\tau \to \mu\gamma$

$\mu \to e\gamma$

$\tau \to K(\pi)\mu(e)$

$K \to \mu e$

$B \to K\mu e$

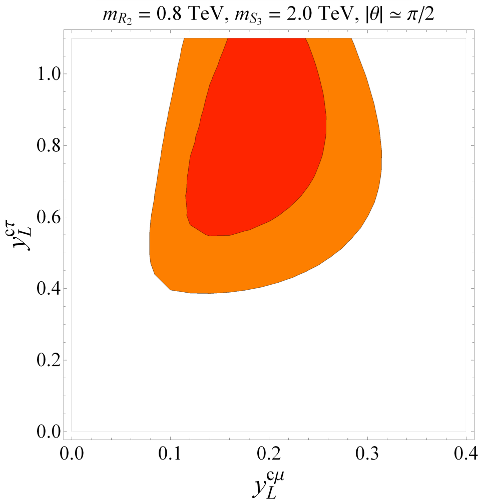
$\tau \to \mu\mu\mu$

$\tau \to \phi\mu$

$t \to c\ell^+\ell'^-$

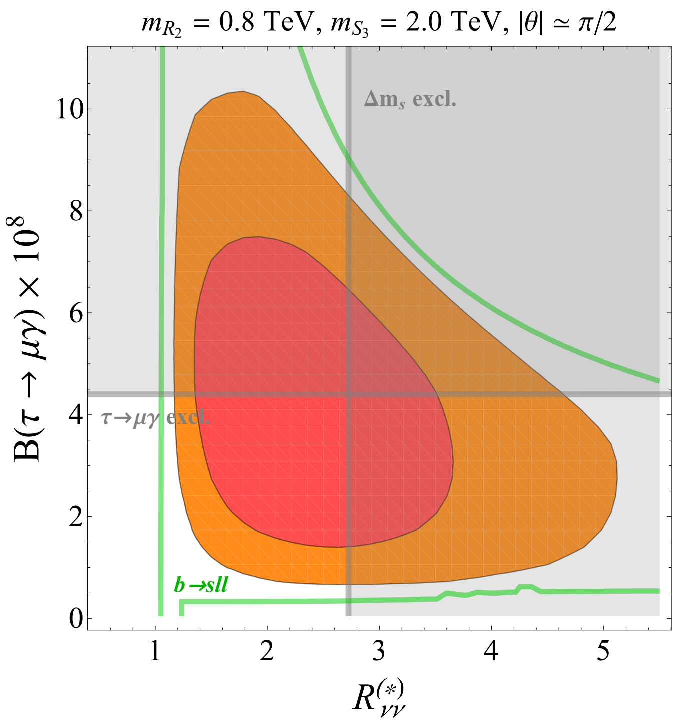
Becirevic et al, 1806.05689, 1608.07583, 1608.08501
Alonso et al, 1611.06676,…

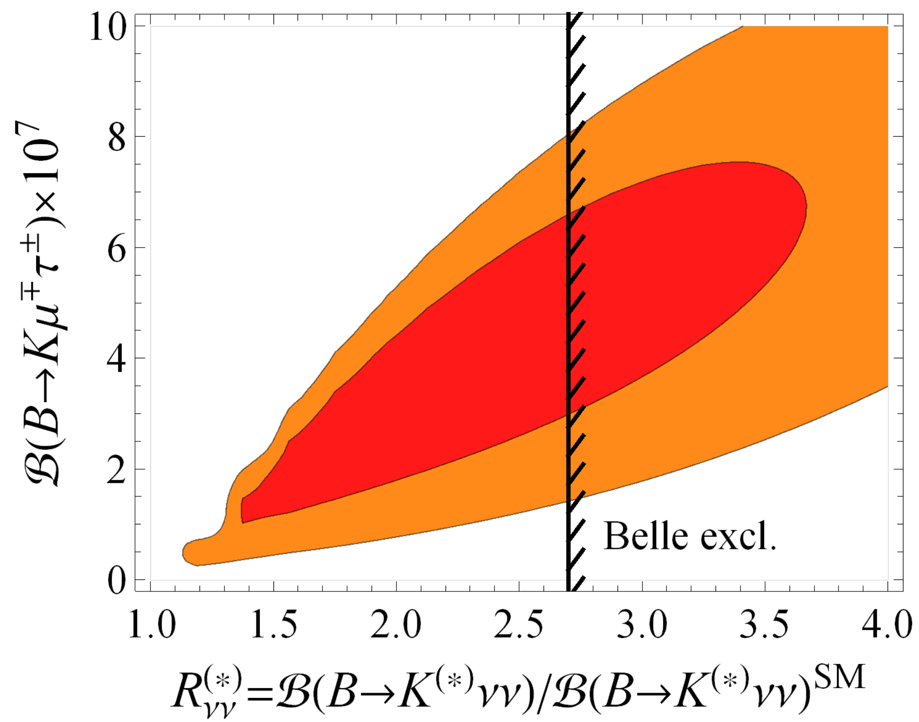
Predictions

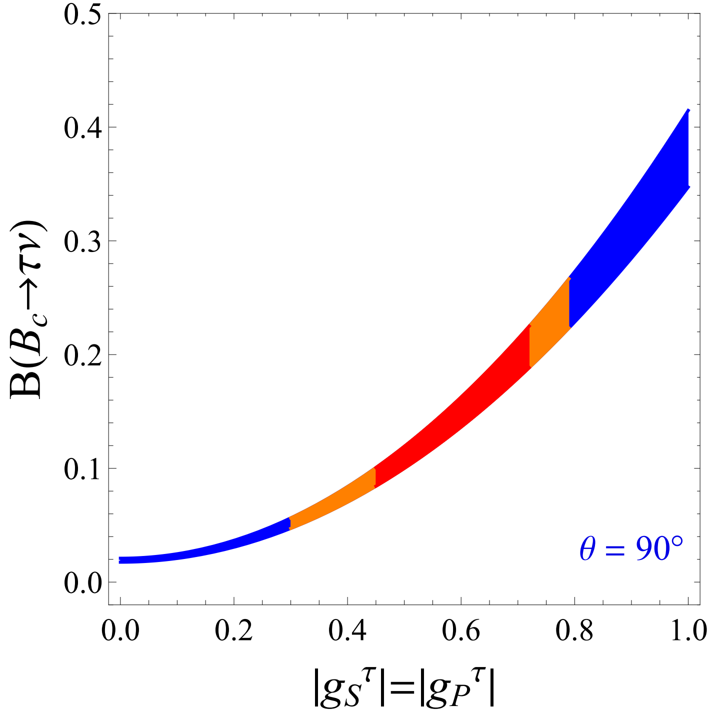


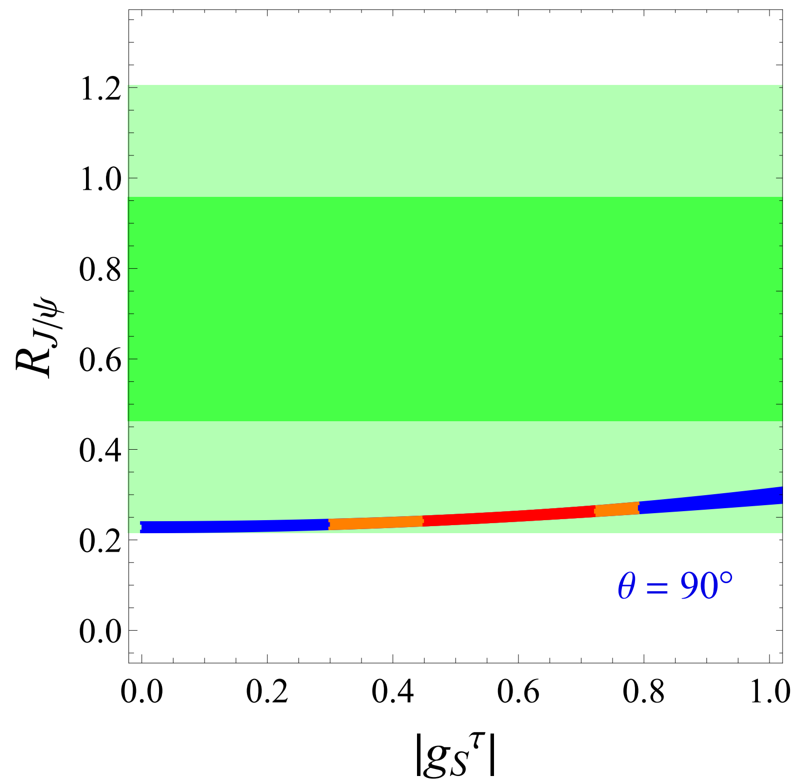
Increase of $\mathcal{B}(B \to K\nu\bar{\nu})$ by $\gtrsim 50\%$ in comparison with SM value

Upper and lower bounds on the LFV rates: B(B → Kμτ) ≥2 × 10^{-7}









$$\mathcal{B}(B_c \to \tau\nu) < 30\%$$

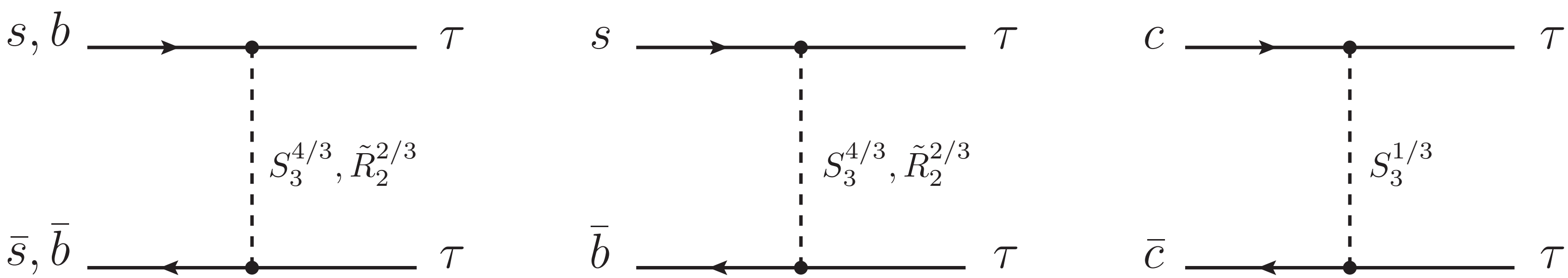
Alonso, Grinstein, Camalich, 1611.06676

$$R_{J/\psi} > R_{J/\psi}^{SM}$$

new FF estimate QCDSR + latt
(Becirevic et al., 2018)

LHC constraints on LQ couplings

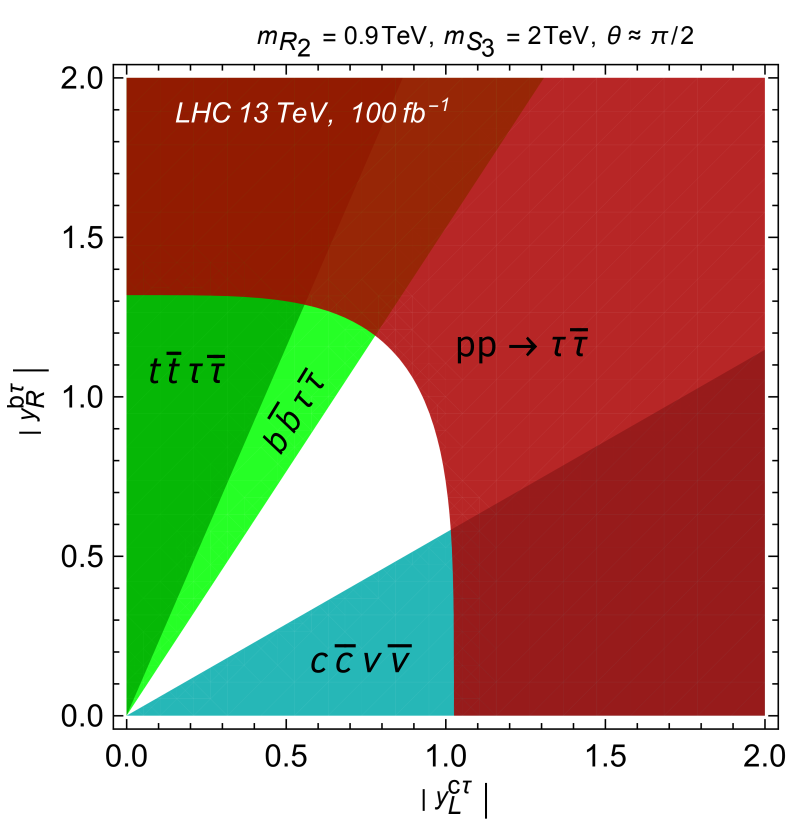
Processes in t-channel $pp \to \tau^+\tau^-$

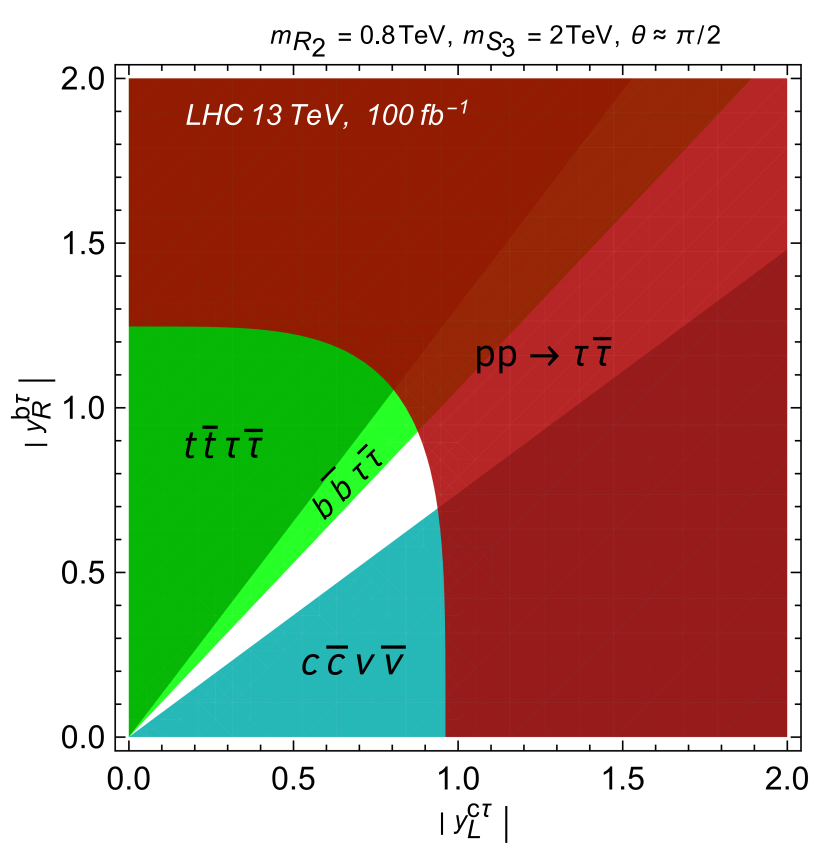


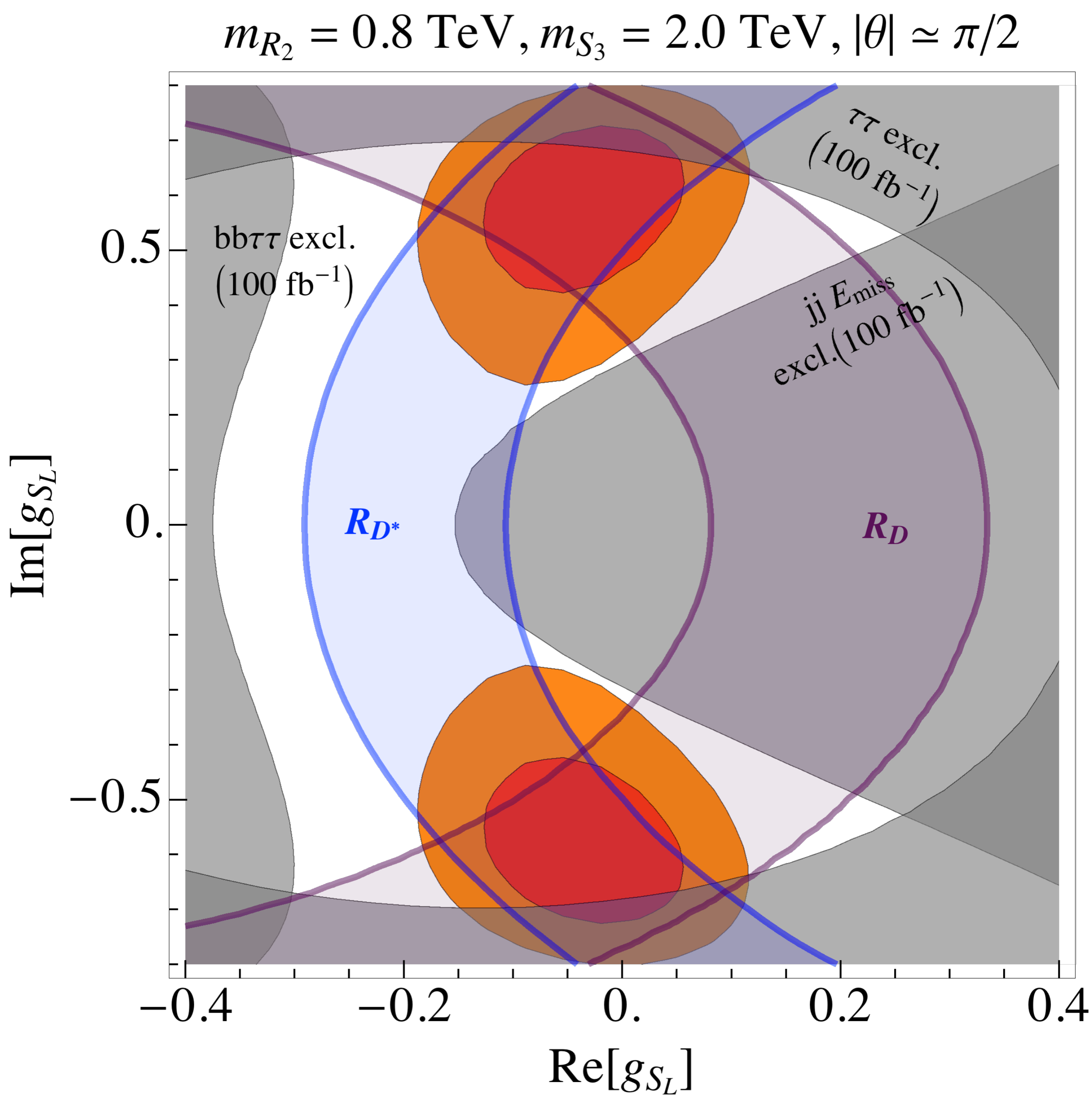
Flavour anomalies generate s τ , bτ and cτ relatively large couplings.
s quark pdf function for protons are ~ 3 times lagrer contribution then for b quark.

Light LQ → impact on the shape of pp → ll distributions (Faroughy, Greljo and Kamenik, 1609.07138, Greljo and Marzocca, 1704.09015)

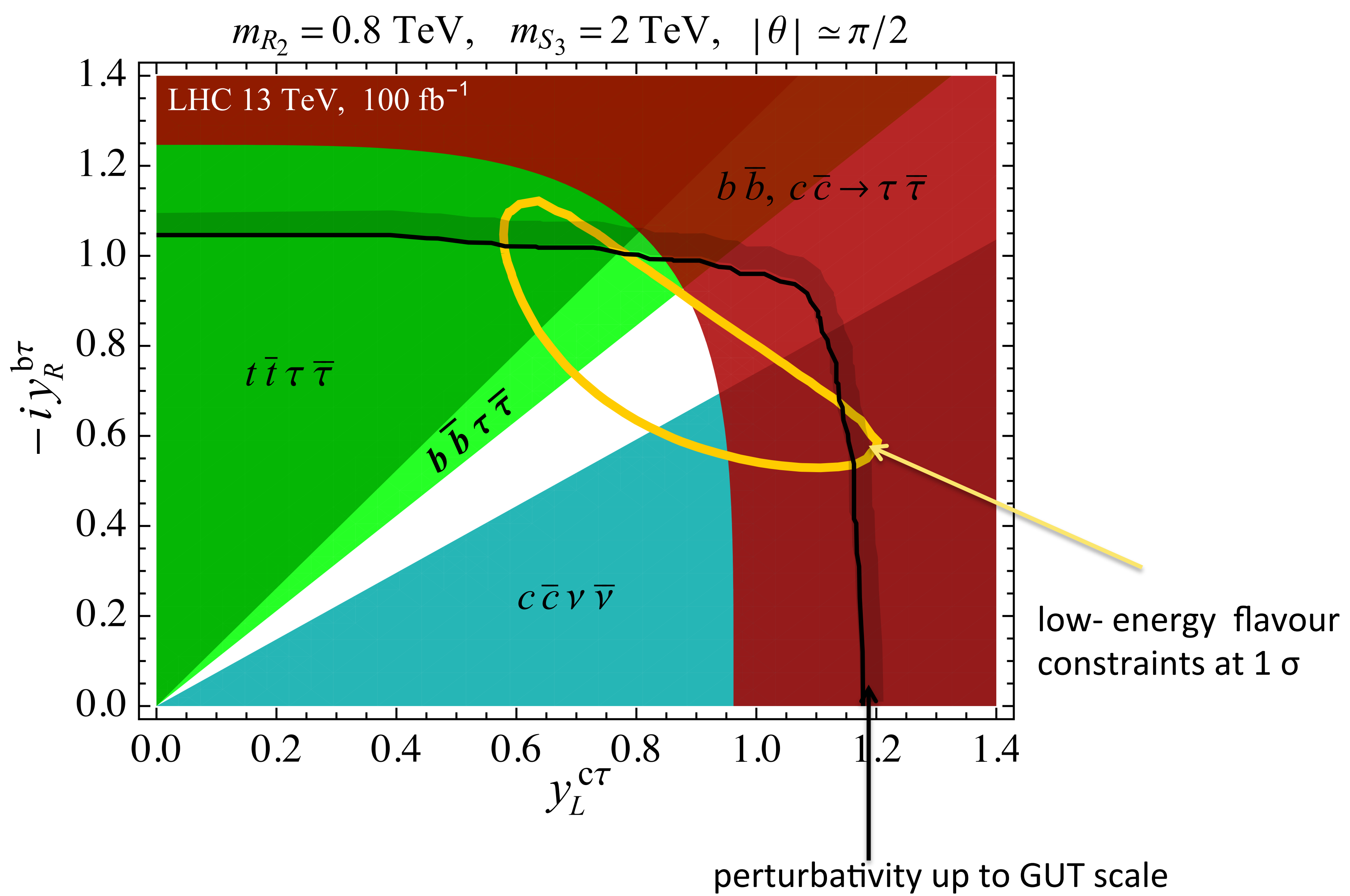
- Recast Atlas searches for pp → (Z′ →)ττ leads to bounds on R_2 and (weak) ones on S_3 for our θ≈π/2
- pp → μμ not very useful to us, but LQ pair-production data are
- Experimental bounds with 3.2 fb^{-1} result in constraints not competitive with those obtained from LE flavor data. Projecting to 100 fb^{-1}(careful with errors on bg):







$m_{R_2} = 0.8$ TeV, $m_{S_3} = 2.0$ TeV, $|\theta| \simeq \pi/2$
$\tau\tau$ excl. $(100\ \text{fb}^{-1})$
$bb\tau\tau$ excl. $(100\ \text{fb}^{-1})$
jj E_{miss} excl.$(100\ \text{fb}^{-1})$
R_{D^*}
R_D
0.5
0.
−0.5
−0.4
−0.2
0.
0.2
0.4
$\text{Im}[g_{S_L}]$
$\text{Re}[g_{S_L}]$



$m_{R_2} = 0.8$ TeV, $m_{S_3} = 2$ TeV, $|\theta| \simeq \pi/2$
LHC 13 TeV, 100 fb^{-1}
$b\bar{b},\ c\bar{c} \to \tau\bar{\tau}$
$t\bar{t}\tau\bar{\tau}$
$b\bar{b}\tau\bar{\tau}$
$c\bar{c}\nu\bar{\nu}$
$-i\,y_R^{b\tau}$
$y_L^{c\tau}$
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
low- energy flavour constraints at 1 σ
perturbativity up to GUT scale

Summary

- Building a viable model which accommodates B-physics anomalies and remains consistent with all other measured flavor observables is difficult.

- We propose a minimalistic model with two light (O(1 TeV)) scalar leptoquarks. Model passes all constraints and satisfactorily accommodates B-physics anomalies. (g_S complex, i.e. one Yukawa must be complex - e.g. $y^{b\tau}_{R}$)

- Model is of "V − A" structure in describing $b \to sll$, but it is NOT for $b \to cl\bar{\nu}$. At $\mu = m_{R2}$, effective $b \to c$ couplings satisfy $g_S = -g_P = 4g_T$

- Our model is GUT inspired and allows for unification with only two LQ's. Yukawa couplings remain perturbative after 1-loop running to Λ_{GUT}

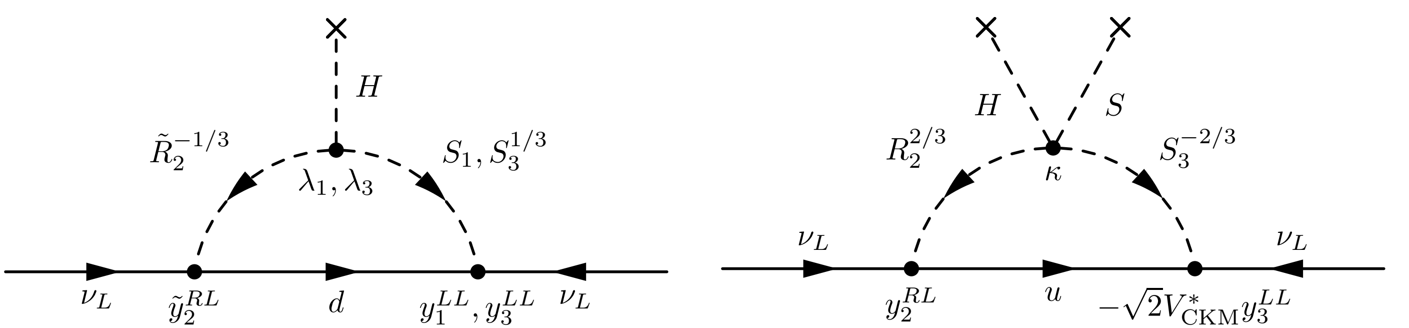
- Results of the direct LHC searches might soon become relevant constraints too. Opportunities for direct searches at LHC!

Thanks!

SU(5) GUT with (3,3,1/3) + (3,2,1/6)
Doršner, SF, Faroughy, Košnik

- GUT possible with light scalar LQs within SU(5) if there are 2 LQs (Doršner, SF, Greljo, Kamenik, Košnik 1603.04993) ;
- LQ S_3 , if accommodated within SU(5) does not cause proton decay;
- Neutrino masses might be explained with 2 light LQs within a loop (Doršner, SF, Košnik, 1701.08322);
-

Our proposal S_3 and $\tilde{R}_2$



one-loop neutrino mass mechanism within the framework of GUT

Recent update on SM value of $R_{D(*)}$

Bigi, Gambino, Schacht 1707.09509

"Luke's theorem does not protect the form factors from $1/m^2$ corrections, it is therefore natural to expect $1/m^2$ corrections of order 10-20%, and one cannot exclude that occasionally they can be even larger".

$$A_1(1) = 0.857(41)$$

$$A_1(1) = 0.906(13)$$

approach now includes HQET constraints with realistic uncertainties and improves on the CLN parametrization.