

Diquark explanation of $b \rightarrow s\ell^+\ell^-$

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The discrepancies between $b \rightarrow s\ell^+\ell^-$ data and the corresponding Standard Model predictions point to the existence of new physics with a significance at the 5σ level. While previously a lepton flavor universality violating effect was preferred, the new $R(K^{(*)})$ and $B_s \rightarrow \mu^+\mu^-$ measurements are now compatible with the Standard Model, favoring a lepton flavor universal beyond the Standard Model contribution to C_9 . Since heavy new physics is generally chiral, and because of the stringent constraints from charged lepton flavor violation, this poses a challenge for model building. In this article, we point out a novel possibility: a diquark, i.e., a colored scalar, induces the Wilson coefficient of the $(\bar{s}\gamma^\mu P_L b)(\bar{c}\gamma_\mu P_L c)$ operator at tree-level, which then mixes into O_9 via an off-shell photon penguin. This setup allows for a lepton flavor universal effect of $C_9 \approx -0.5$, without violating bounds from ΔM_s , $\Delta\Gamma$, $B \rightarrow X_s\gamma$ and $D^0 - \bar{D}^0$ mixing. This scenario predicts a small and negative C'_9 and a light diquark, preferably with a mass around 500 GeV, as compatible with the CMS di-dijet analysis, and a deficit in the inclusive $b \rightarrow c\bar{c}s$ rate.

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Introduction. While the Standard Model (SM) Cabibbo-Kobayashi-Maskawa (CKM) mechanism [1] of quark flavor violation was established by the B factories Belle [2] and BABAR [3], there is still room for new physics (NP) at the order of 10% in flavor changing neutral current (FCNC) processes. Such FCNC observables are loop suppressed and thus particularly sensitive to beyond-the-SM contributions. In fact, there are long-lasting hints for NP in $b \rightarrow s\ell^+\ell^-$ observables. However, the picture changed radically with the release of the latest LHCb results for the ratios $R(K^{(*)}) = \text{Br}[B \rightarrow K^{(*)}\mu^+\mu^-]/\text{Br}[B \rightarrow K^{(*)}e^+e^-]$ [4,5], superseding their previous measurements [6–8]. While previously all global fits [9–15] preferred lepton flavor universality (LFU) violating NP [16,17], now data is not only consistent with LFU but even stringently limits deviations from it.

Nonetheless, the case for physics beyond the SM in $b \rightarrow s\ell^+\ell^-$ transitions remains very strong (see Ref. [18] for a recent review). The main tensions with the SM predictions

are within the angular $B \rightarrow K^*\mu^+\mu^-$ observable P'_5 [19–22], the total branching ratio and angular observables in $B_s \rightarrow \phi\mu^+\mu^-$ [23–25] as well as in $\text{Br}[B \rightarrow K\mu^+\mu^-]$ [26,27],¹ with tensions at the 2–4 σ level in each of these modes. In fact, while SM predictions are challenging, due to the hadronic form factors involved [33–38] (including nonlocal charm-loop contributions [39–41]), the first lattice calculation over the full q^2 range of $\text{Br}[B \rightarrow K\mu^+\mu^-]$ leads to a stronger tension of 4.7 σ [42]. Furthermore, P'_5 , being an optimized angular observable [43–45] possess a reduced sensitivity to the form factors and semi-inclusive decays at high q^2 , that are independent of hadronic form factors, are fully compatible with the other observables [46]. Finally, dispersive methods based on analyticity confirm previous error estimates for the form factors [47,48] (including their nonlocal parts).

Combining the processes discussed above in a global fit together with all other available data on $b \rightarrow s\ell^+\ell^-$ transitions leads to a coherent picture. In fact, while before the $R(K^{(*)})$ update, the most strongly favored scenarios were at least two-dimensional [49], now a single one-dimensional scenario is clearly favored: the C_9^U scenario

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¹Measurements of these decays were also performed by the ATLAS, CMS and Belle collaborations [28–32] but with less precise results.

with a significance around 5σ [50–53]. This means that a left-handed $b-s$ current and a vectorial flavor-universal lepton current ($B_s \rightarrow \mu^+\mu^-$ [54–57] constrains an axial current) is needed.

This poses a challenge for model building since both tree-level leptoquark effects [58,59] as well as loop contributions of new scalars and fermions [60–63], in general, give a chiral lepton current and have difficulties respecting the stringent bounds from $\mu \rightarrow e$ flavor violating [64] unless multiple generations are involved [65]. This leaves Z' models [66–68] as well as leptoquarks which generate a LFU effect in C_9^U via a tau-loop with an off-shell photon [68–73] as the remaining (simple) options. However, also in these cases $B_s - \bar{B}_s$ mixing [74], LEP and LHC constraints [75,76] make a full explanation challenging.

An alternative scenario that can naturally generate C_9^U is a NP contribution to the Wilson coefficient of the $(\bar{s}\gamma^\mu P_L b)(\bar{c}\gamma_\mu P_{L,R} c)$ operator [77] that mix into C_9 via an off-shell photon penguin [78]. As a tree-level effect in $\bar{s}b\bar{c}c$ operators is necessary, only Z' bosons, heavy gluons, Higgses [79–82] or diquarks (DQs) come into mind [83]. For the first two options the possible effect is stringently limited by $B_s - \bar{B}_s$ mixing (to which these particles also contribute at tree-level [84]) and there is only a small region in parameter space left that works for 2HDMs [82]. Therefore, we will consider the DQs in this article which have not been studied so far. Out of the 8 different scalar DQs [85,86], there is only a single representation that couples to left-handed down-type quarks, can have flavor-diagonal couplings to up-type quarks and does not lead to tree-level effects in $\Delta F = 2$: the scalar $SU(3)_c$ triplet, $SU(2)_L$ singlet with hypercharge $-1/3$ which we call ϕ .²

DQs are not only theoretically well motivated, e.g., by E_6 models [87] or the R-parity violating MSSM [88], but also lead to interesting LHC signatures [89–99]: They are candidates from an explanation [100] of the ATLAS dijet [101] and the CMS di-dijet [102] excesses. In fact, the nonresonant CMS analysis shows a weaker-than-expected limit for a diquark $SU(3)_c$ triplet with a mass around 500 GeV.

In the next section, we will define our model and perform the matching on the effective theory before we continue with the phenomenological analysis in Sec. III can conclude in Sec. IV.

Setup and observables. There are 8 representations of scalar DQs with couplings to quarks $SU(2)_L$ singlets or doublets which can have either symmetric or

antisymmetric couplings in flavor space. In order to get a sizable effect in $b \rightarrow s\ell^+\ell^-$ via the operator $(\bar{s}\gamma^\mu P_L b)(\bar{c}\gamma_\mu P_{L,R} c)$, we need (1) simultaneous couplings to up-type and down-type quarks, (2) flavor diagonal couplings to up-quarks (i.e., not antisymmetric ones), (3) left-handed down-quarks must be involved, (4) no tree-level effect in $B_s - \bar{B}_s$ mixing. These requirements only leave a single representation, i.e., IV in the conventions of Ref. [85] whose mass we label M_ϕ .

The couplings to quarks are given by

$$\mathcal{L} = \left(\frac{1}{2} \tilde{\lambda}_{ij}^L (\bar{Q}_i^{L,\alpha})^c Q_j^{L,\beta} \epsilon_{IJ} + \tilde{\lambda}_{ij}^R \bar{u}_i^{ac} d_j^\beta \right) \phi^\gamma \epsilon_{\alpha\beta\gamma} + \text{H.c.} \quad (1)$$

Here, α, β, γ are color indices, I, J (i, j) $SU(2)_L$ (flavor) indices and c stands for charge conjugation. Note that $\tilde{\lambda}^L$ can be chosen to be symmetric in flavor space, i.e., $\tilde{\lambda}_{ij}^L = \tilde{\lambda}_{ji}^L$, without loss of generality. After electroweak symmetry breaking, the quark doublets decompose into their $SU(2)_L$ components and in the mass eigenbasis we have

$$\mathcal{L} = \epsilon_{\alpha\beta\gamma} (\lambda_{ij}^L \bar{u}_i^{ac} P_L d_j^\beta + \lambda_{ij}^R \bar{u}_i^{ac} P_R d_j^\beta) \phi^\gamma + \text{H.c.}, \quad (2)$$

where we absorbed the rotation matrices into the definition of λ^R and, working in the down basis, defined $V_{ii'}^* \tilde{\lambda}_{ij'}^L = \lambda_{ij}^L$.

Tree-level matching: The Lagrangian

$$\mathcal{L} = -N_{ij} \sum_{X=1}^{10} (C_X^{ij} Q_X^{ij} + C_X'^{ij} Q_X'^{ij}) \quad (3)$$

with $N_{ij} = 4G_F V_{ib} V_{js}^* / \sqrt{2}$ and the operators

$$\begin{aligned} Q_1^{ij} &= (\bar{u}_i^\alpha \gamma_\mu P_L b^\beta) (\bar{s}^\beta \gamma^\mu P_L u_j^\alpha), \\ Q_2^{ij} &= (\bar{u}_i^\alpha \gamma_\mu P_L b^\alpha) (\bar{s}^\beta \gamma^\mu P_L u_j^\beta), \\ Q_7^{ij} &= (\bar{u}_i^\alpha P_R b^\beta) (\bar{s}^\beta P_R u_j^\alpha), \\ Q_8^{ij} &= (\bar{u}_i^\alpha P_R b^\alpha) (\bar{s}^\beta P_R u_j^\beta), \\ Q_9^{ij} &= (\bar{u}_i^\alpha \sigma_{\mu\nu} P_R b^\beta) (\bar{s}^\beta \sigma^{\mu\nu} P_R u_j^\alpha), \\ Q_{10}^{ij} &= (\bar{u}_i^\alpha \sigma_{\mu\nu} P_R b^\alpha) (\bar{s}^\beta \sigma^{\mu\nu} P_R u_j^\beta), \end{aligned} \quad (4)$$

defines the charged current interactions. Our diquark, integrated out at tree level at the electroweak scale, leads to the coefficients

$$C_1^{ij} = -C_2^{ij} = -\frac{\lambda_{i2}^{L*} \lambda_{j3}^L}{2N_{ij} M_\phi^2}, \quad (5)$$

$$C_7^{ij} = -C_8^{ij} = -4C_9^{ij} = 4C_{10}^{ij} = \frac{\lambda_{i2}^{L*} \lambda_{j3}^R}{2N_{ij} M_\phi^2}, \quad (6)$$

²This field is also known as the S_1 leptoquark when it couples to quarks and leptons instead of two quarks. However, to avoid proton decay, we will assume that it couples only to quarks which can be achieved by, e.g., assuming that lepton number is conserved.

with the primed coefficients obtained by $\lambda^L \leftrightarrow \lambda^R$.³

$b \rightarrow s\ell^+\ell^-$: The effective Lagrangian governing $b \rightarrow s\ell\ell$ transitions is given by

$$\mathcal{L} \supset N_{33} \frac{\alpha}{4\pi} [C_9(\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell) + C_{10}(\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma^5 \ell)], \quad (7)$$

where the primed operators and coefficients are again obtained by exchanging L and R . The tree-level induced operators $Q_{1,2}^{cc}$ generate via mixing

$$C_9(m_b) = 8.5C_1^{cc}(M_W) + 2.1C_2^{cc}(M_W) + [3.1C_1^{cc}(M_W) + 0.32C_2^{cc}(M_W)] \times h(q^2), \quad (8)$$

at the B meson scale (and similarly for C_9') with

$$h(q^2, m_c) = -\frac{4}{9} \left[\ln \frac{m_c^2}{m_b^2} - \frac{2}{3} + (2+z)a(z) - z \right], \quad (9)$$

$a(z) = \sqrt{|z-1|} \arctan \frac{1}{\sqrt{z-1}}$, and $z = 4m_c^2/q^2$. Note that h also includes finite subleading q^2 -dependent effects (which we evaluate at $q^2 = 5 \text{ GeV}^2$) [77].

The threshold effects from top quark loops induce at the EW scale

$$\frac{-C_9}{1-4s_W^2} = C_{10} = -\frac{\lambda_{32}^{L*}\lambda_{33}^L}{2e^2 V_{tb} V_{ts}^*} f\left(\frac{m_t^2}{M_\phi^2}\right), \quad (10)$$

with $f(x) = x(x - \log x - 1)/(x - 1)^2$ and $C_{9,10}'$ obtained from $C_{9,10}$ by exchanging L and R .

$B \rightarrow X_s \gamma$: The relevant effective operators are defined by

$$\mathcal{L} \supset N_{33} C_{7\gamma(8g)} \frac{e(g_s)m_b}{16\pi^2} \bar{s}\sigma^{\mu\nu}(t^a) P_R b F_{\mu\nu}(G_{\mu\nu}^a), \quad (11)$$

with primed operators obtained through $P_R \rightarrow P_L$. We have two NP contributions to $C_{7\gamma}$. The mixing of the $\bar{s}b\bar{c}c$ operators into $C_{7\gamma}$ leads to [77,112]

³It can be seen that C_X^{uc} (which give $b \rightarrow u\bar{c}s$ transitions) are enhanced relative to the SM by the large ratio V_{us}/V_{ub} . However, the effects of these operators in meson mixing-related observables is too small [103]. Furthermore, C_X^{cu} (which give $b \rightarrow c\bar{u}s$ transitions) have been considered as part of a potential explanation of the discrepancy between the SM prediction with QCD factorization and experiment for $\bar{B}_{(s)}^0 \rightarrow D_{(s)}^{*+}\{\pi^-, K^-\}$ [104–111]. However as no analysis has been done with just NP in $\bar{s}b\bar{c}u$, this interesting future direction is beyond the scope of this article.

$$C_{7\gamma}(m_b) = 0.02C_1^{cc}(M_W) - 0.19C_2^{cc}(M_W) - 1.0C_7^{cc}(M_W) - 0.47C_8^{cc}(M_W) + 4.0C_9^{cc}(M_W) + 0.47C_{10}^{cc}(M_W) - \frac{m_c}{m_b} (2.5C_7^{cc} + 1.3C_8^{cc} - 10C_9^{cc} + 0.89C_{10}^{cc}) \times y, \quad (12)$$

where, similarly to the case of C_9 , we have included subleading q^2 dependent terms via $y = -(1 + 2\log(m_c^2/m_b^2))/6$. The equivalent result for the primed operators is again obtained by an exchange of chiralities.⁴

Second, the direct matching at the new physics scale (to be taken the weak scale) gives direct contributions to $C_{7\gamma,8g}^{(\prime)}(M_W)$. The most important result is the existence of m_t/m_b enhanced terms for both coefficients which are proportional to $\lambda_{22}^L \lambda_{33}^R$, while the full expressions can be found in the Supplemental Material [113]. These coefficients are then evolved to the B meson scale resulting in

$$C_{7\gamma}^{(\prime)}(m_b) = 0.65C_{7\gamma}^{(\prime)}(M_W) + 0.10C_{8g}^{(\prime)}(M_W). \quad (13)$$

The latest SM prediction for the inclusive radiative decay $B \rightarrow X_s \gamma$ [114]

$$\text{Br}[B \rightarrow X_s \gamma]^{\text{SM}} = (3.40 \pm 0.17)10^{-4}, \quad (14)$$

is in good agreement with the experimental average [115]

$$\text{Br}[B \rightarrow X_s \gamma]^{\text{EXP}} = (3.49 \pm 0.19)10^{-4}. \quad (15)$$

This measurement stringently constrains a BSM contribution to $C_{7\gamma}$. In addition, asymmetries in $B \rightarrow K^* e^+ e^-$ [116] are very sensitive to $C_{7\gamma}'$. We performed a fit to $C_{7\gamma}$ and $C_{7\gamma}'$ using `smelli` [117–119].

$B_s - \bar{B}_s$ mixing: In the SM, EW box diagrams give rise to $B_s - \bar{B}_s$ mixing, which can be measured through observables including ΔM_s , $\Delta\Gamma_s$, and a_{sl}^s that can in principle constrain our NP model.

The mass difference $\Delta M_s = 2|M_{12}^s|$ in the SM is

$$\Delta M_s^{\text{SM}} = (18.2_{-0.8}^{+0.6}) \text{ ps}^{-1}, \quad (16)$$

using the nonperturbative bag parameter combination from Ref. [75] (based on results in Refs. [120–122]), the FLAG 2023 average for f_{B_s} from FLAG 2023 [123] (based on results in Refs. [124–126]), m_t from PDG 2022 [127], and the Spring 2021 CKMfitter collaboration results [128,129],

⁴In principle, there are potential RGE contributions from $\bar{s}b\bar{c}c$ operators in C_{8g} which are however expected to be very small (see appendix of Ref. [77]).

which should be compared to the latest HFLAV average of [115]

$$\Delta M_s^{\text{EXP}} = (17.765 \pm 0.006) \text{ ps}^{-1}. \quad (17)$$

Our new physics contributes through various 1-loop box diagrams, which generate electroweak scale $\Delta B = 2$ coefficients whose full expressions are given in the Supplemental Material [113].

The width difference for B_s mesons can be calculated as $\Delta\Gamma_s = 2|\Gamma_{12}^s| \cos(\arg(-M_{12}^s/\Gamma_{12}^s))$, where the current SM prediction is [130]

$$\Delta\Gamma_s = (0.0895 \pm 0.0131) \text{ ps}^{-1}, \quad (18)$$

and the latest HFLAV average⁵ is [115]

$$\Delta\Gamma_s = (0.083 \pm 0.005) \text{ ps}^{-1}. \quad (19)$$

Our model alters this quantity through the $\bar{s}b\bar{c}c$ operators, where the full NP contributions were calculated in Refs. [77,112].

In addition the semileptonic asymmetry a_{sl}^s receives a large NP contribution since our NP does not suffer the severe GIM cancellation seen in the SM. However, at least orders of magnitude improvement in the experimental precision would be required for this effect to be observable, and so we make no further mention of it here (some more detailed discussion can be found in the Supplemental Material [113]).

$D^0 - \bar{D}^0$ mixing: The $\Delta C = 2$ coefficients which give a short-distance contribution to ΔM_D are

$$C_1 = \frac{1}{64\pi^2 M_\phi^2} [(\lambda^L \lambda^{L\dagger})_{12}]^2, \quad (20)$$

$$C_2 = C_3 = 0, \quad (21)$$

$$C_4 = C_5 = -\frac{1}{32\pi^2 M_\phi^2} (\lambda^L \lambda^{L\dagger})_{12} (\lambda^R \lambda^{R\dagger})_{12}. \quad (22)$$

$C'_{1,2,3}$ are found from $C_{1,2,3}$ by exchanging $\lambda^L \leftrightarrow \lambda^R$.

The SM prediction is currently unclear, as a naive calculation gives a result four or five orders of magnitude too small, while other estimates (albeit not from first principles) suggest the SM alone could give a result $x^{\text{SM}} \sim 0.1\%$ [131–137], where

$$x \equiv \frac{2\Delta M_D}{\Gamma_D}, \quad (23)$$

is the commonly reported observable in $D^0 - \bar{D}^0$ -mixing. Comparing this to the current HFLAV average [115]

⁵There is some tension between the ATLAS, CMS, and LHCb measurements, such that this HFLAV average applied a scale factor of 1.8 (according to the PDG prescription) to the total uncertainty.

$$x^{\text{EXP}} = (0.407 \pm 0.044)\%, \quad (24)$$

we take a conservative approach and allow the short-distance NP contribution to be up to twice the size of the experimental value (i.e. we impose $\Delta M_D^{\text{NP}} \leq 2\Delta M_D^{\text{EXP}}$, allowing in principle for a 100% cancellation between BSM and SM).

B_s/B_d lifetime ratio: The ratio of the B_s to B_d lifetimes was long thought to be a theoretically clean observable, benefiting from many cancellations of uncertainties. However, recent calculations of the SM contribution to the Darwin operator [138–140] has lead to a situation where the theory prediction is unclear, and in addition there is some tension between the different experimental measurements [115] (see the Supplemental Material [113] for further discussion). As such we do not consider this observable further.

Phenomenology. We now turn to the phenomenology of our model. First of all, we set $M_\phi = 500 \text{ GeV}$ which is compatible with the nonresonant paired dijet search of CMS due to the weaker-than-expected limit in this mass region [102]. Note that using a light DQ helps to reduce the relative effect in $\Delta F = 2$ processes since here the DQ contribution is proportional to λ^4/M_ϕ^2 while for all other flavor processes the leading DQ effect has a λ^2/M_ϕ^2 scaling.

The product of $\tilde{\lambda}_{23}^L$ and $\tilde{\lambda}_{22}^L$ is necessary to give the effect in $b \rightarrow s\ell^+\ell^-$ via C_9 while the product of $\tilde{\lambda}_{22}^R$ and $\tilde{\lambda}_{23}^R$ (λ_{12}^R) helps to weaken the bound from $B_s - \bar{B}_s$ mixing ($D^0 - \bar{D}^0$). To avoid a chirally enhanced effect in $b \rightarrow s\gamma$ $\lambda_{33}^R \approx 0$ is helpful. Furthermore, to avoid bounds from dijet resonance searches [141,142] and Kaon mixing, we assume the left-handed coupling involving the first generation to be approximately zero. Thus we consider the following structure for the DQ quark couplings

$$\tilde{\lambda}^L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \tilde{\lambda}_{22}^L & \tilde{\lambda}_{23}^L \\ 0 & \tilde{\lambda}_{23}^L & 0 \end{pmatrix}, \quad \lambda^R = \begin{pmatrix} 0 & \lambda_{12}^R & 0 \\ 0 & \lambda_{22}^R & \lambda_{23}^R \\ 0 & 0 & 0 \end{pmatrix}. \quad (25)$$

Note that we input $\tilde{\lambda}^L$ in the down quark basis (not including CKM rotations).

Since $\tilde{\lambda}_{22}^{L*}\tilde{\lambda}_{23}^L$ must be positive to give the preferred sign in C_9 we set for simplicity $\tilde{\lambda}_{22}^L = \tilde{\lambda}_{23}^L$ and $\lambda_{22}^R = \lambda_{23}^R$, assume real couplings and show the preferred regions of the various observables in Fig. 1. We see that a reasonably sizable LFU C_9 , of the order of -0.5 , can be generated in our model while still respecting the other experimental constraints. For $D^0 - \bar{D}^0$ -mixing, we show the regions compatible with our fine-tuning argument for $\lambda_{12}^R = 0$ and floating it within two different (small) ranges which are compatible with LHC dijet searches. Interestingly, our model predicts $|C'_9| \ll |C_9|$ but with the same sign as (slightly) preferred

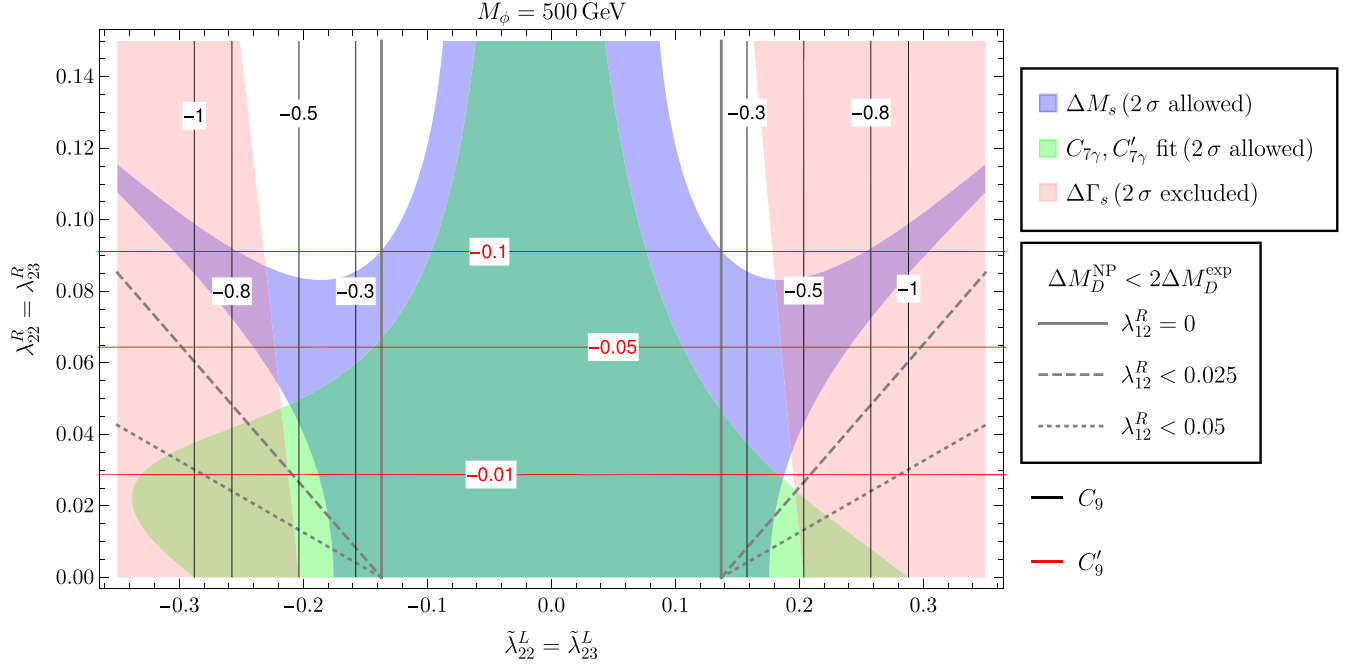


FIG. 1. Experimental constraints given our assumed UV couplings matrices. The black and red vertical and horizontal lines show the generated LFU contributions to C_9 and C'_9 , respectively.

by the current global fit [52]. Note that generating the sizeable negative C_9 leads to a positive shift in $\Delta\Gamma_s$. This is more in line with the latest experimental result from CMS, which is in slight tension with LHCb and ATLAS measurements [115].

Conclusions and outlook. There are persistent and significant tensions in $b \rightarrow s\ell^+\ell^-$ observables. They are most pronounced in $\text{Br}[B \rightarrow K\mu^+\mu^-]$, in the angular observable P'_5 (in $B \rightarrow K^*\mu^+\mu^-$) and the total branching ratio as well as angular observables in $B_s \rightarrow \phi\mu^+\mu^-$. In combination with the constraints from $R(K^{(*)})$ and $B_s \rightarrow \mu^+\mu^-$ they point toward lepton flavor universal NP in C_9 with a significance at the 5σ level. This poses a challenge for model building because heavy NP is generally chiral, while for generating a dominant effect in C_9 , a vectorial lepton current is needed. Furthermore, bounds from charged lepton flavor violation require a separation of the electron and muon sectors, which is difficult to achieve in many models.

In this article, we proposed a novel model explaining the $b \rightarrow s\ell^+\ell^-$ anomalies: an $SU(3)_c$ triplet scalar DQ with hypercharge $Y = -1/3$. This field can generate a LFU effect in C_9 via the mixing of the $(\bar{s}\gamma^\mu P_L b)(\bar{c}\gamma_\mu P_L c)$ operator into O_9 . Since only quarks are directly involved in this model, charged lepton flavor violation is automatically respected. Furthermore, due to the weaker-than-expected LHC limit, DQs can still be relatively light, around 500 GeV.

We show that in this setup one can obtain $C_9 \approx -0.5$ while respecting the bounds from $B_s - \bar{B}_s$ and $D^0 - \bar{D}^0$ mixing as well as LHC searches. We predict a small negative value of

C'_9 as well as a positive shift in $\Delta\Gamma_s$ of around 20% with respect to the SM prediction. For $b \rightarrow s\gamma$ our model predicts NP shifts in $|C_{7\gamma}^{(\ell)}| \approx 0.05$. Furthermore, DQs are candidates for sizable effects in hadronic decays of mesons, like ϵ'/ϵ [143,144] and could explain several anomalies in nonleptonic B decays like the longitudinal polarization in $B_q \rightarrow K^*\bar{K}^*$ [145], the $B \rightarrow K\pi$ puzzle [146–148], the $B_{(s)} \rightarrow D_{(s)}\{K, \pi\}$ [104–110] discrepancy within QCD factorization or the LHC di-dijet excess [100].

Finally, our NP contributions to the $C_{1,2}^{cc}$ coefficients have opposite sign than C_1^{cc} in the SM. This reduces the theory prediction for the inclusive branching ratio $b \rightarrow c\bar{c}s$ where in the SM we have $\text{Br}[b \rightarrow c\bar{c}s]_{\text{SM}} = 23 \pm 2\%$ [149]. However, while the situation for the experimental determination of this fully inclusive quantity is currently quite unclear, and $O(30\%)$ effects in $\text{Br}[b \rightarrow c\bar{c}s]$ are possible, our model prediction is in line with the so-called “missing charm puzzle” [150]. A clarification of the experimental situation would therefore be of great interest.

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