Explaining $B \to K^{(*)}\ell^+\ell^-$ anomaly by radiatively induced coupling in $U(1)_{\mu-\tau}$ gauge symmetry

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(Dated: May 30, 2017)

We propose a scenario to generate flavor violating $Z'$ interactions at one loop level, by introducing $U(1)_{\mu-\tau}$ gauge symmetry, extra vectorlike quark doublets $Q_a'$ and singlet scalar $\chi$. Both $Q_a'$ and $\chi$ are charged under $U(1)_{\mu-\tau}$ and carry odd dark $Z_2$ parity. Assuming that $\chi$ is the dark matter (DM) of the universe and imposing various constraints from dark matter search, flavor physics and collider search for $Q_a'$, one can show that radiative corrections to $b \to sZ' \to sl^+\ell^-$ involving $Q_a'$ and $\chi$ can induce $\Delta C_9 \sim -1$ which can resolve the LHCb anomalies related with $B \to K^{(*)}\ell^+\ell^-$. Therefore both DM and $B$ physics anomalies could be accommodated in the model.

I. INTRODUCTION

Flavor violating interactions via new gauge boson $Z'$ is one of the interesting possible physics scenarios beyond the standard model (BSM). For the last few years there have been some indication of such interactions in $B$ physics; the angular observable $P_\ell$ in decay of $B$ meson, $B \to K^{*}\mu^+\mu^-$ [1], where 3.4$\sigma$ deviations are measured from the integrated luminosity of 3.0 fb$^{-1}$ at the LHCb [2], confirming an earlier result with 3.7$\sigma$ deviations [3]. Moreover, 2.1$\sigma$ deviations were reported in the same observable by Belle [4, 5]. In addition, an anomaly in the measurement of the ratio $R_K = BR(B^+ \to K^{*}\mu^+\mu^-)/BR(B^+ \to K^+\mu^+\mu^-)$ [6, 7] at the LHCb indicates a 2.6$\sigma$ deviations from the lepton universality predicted in the SM [8]. Moreover the LHCb collaboration also presented the ratio $R_K' = BR(B \to K^{*}\mu^+\mu^-)/BR(B \to K^+\mu^+\mu^-)$ which is deviated from the SM prediction by $\sim 2.4\sigma$ as $R_K' = 0.660^{+0.110}_{-0.070} \pm 0.024(0.685^{+0.078}_{-0.069} \pm 0.047)$ for $(2m^2_\ell) < q^2 < 1.1$ GeV$^2$ (1.1 GeV$^2 < q^2 < 6$ GeV$^2$) [9]. One of the explanations for these anomalies in the $B$ decay could come from $Z'$ which has flavor dependent interactions in the quark sector [10-17] and can induce shift of the Wilson coefficient $C_9$ where the shift $\Delta C_9 \sim -1$ is indicated to resolve the anomalies [18, 21]. In previous attempts, flavor violating $Z'$ interactions in the quark sector were obtained at tree level, assuming non-trivial charge assignments of extra $U(1)$ gauge symmetry or nonzero mixings between quarks and new vector-like quarks charged under extra $U(1)$. On the other hand, flavor dependent couplings can also arise at loop levels if we add few exotic fermions and/or scalar fields. Furthermore, if these extra particles have $Z_2$ odd dark parity, motivated by dark matter of the universe, such a scenario provides interesting connection between $B$ physics anomaly and DM physics.

In this letter, we propose a new resolution of these $B$ physics anomalies by introducing exotic vector-like quarks ($Q'$) and an inert singlet boson ($\chi$) which are charged under the gauged $U(1)_{\mu-\tau}$ symmetry and have $Z_2$ odd parity which guarantees dark matter stability. These two new fields play a crucial role in connecting leptons and quarks at one-loop level. Furthermore, $\chi$ is assumed to be the lightest $Z_2$-odd particle, making the DM candidate within our model. We then explore explanation of $B \to K^{(*)}\ell^+\ell^-$ anomaly and relic density of DM, simultaneously taking into account various constraints from the $B_s - \bar{B}_s$ meson mixing, $b \to s\gamma$, and direct detection of DM via $Z'$ portal at one-loop level originating from these new fields.

This letter is organized as follows. In Sec. II, we present our model and study $B$ physics and DM phenomenology: the Wilson coefficients for $B \to K^{(*)}\ell^+\ell^-$ anomaly and $B_s - \bar{B}_s$ meson mixing, the branching ratio of $b \to s\gamma$, thermal relic density of DM, and the spin independent DM-nucleon scattering cross section via $Z'$ portal. In Sec.III we carry out the numerical analysis and find out the parameter space region in which we can satisfy all the relevant experimental constraints. In Sec.IV we discuss two miscellaneous issues for completeness: (i) breaking of extra $U(1)_{\mu-\tau}$ and (ii) the spin-flipped case...
TABLE I: Charge assignments of the new fields $Q'$ and $\chi$ under $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{\mu - \tau}$ with $q_\chi \neq 0$ where we assume these fields have $Z_2$ odd parity. Here $Q'$ is vector-like fermions, and its lower index $a$ is the number of family that runs over $1 - 3$. $\chi$ is a complex scalar boson that is considered as a DM candidate.

| Field           | $Q_a$ | $\chi$ |
|-----------------|-------|--------|
| $SU(3)_C$       | 3     |        |
| $SU(2)_L$       | 2     | 1      |
| $U(1)_Y$        | $\pm$ | 0      |
| $U(1)_{\mu - \tau}$ | $q_\chi$ | $q_\mu$ |

where $SU(2)_L$ doublet vectorlike fermions are replaced by colored scalar fields and DM is $SU(2)$ singlet colorless Dirac fermion. Finally Sec. V is devoted to the summary of our results and the conclusion.

II. MODEL SETUP AND CONSTRAINTS

In this section we set up our model and derive some formula in $B$ physics and DM phenomenology, which will be used in Sec. III for the numerical analysis. We introduce three vector-like exotic quarks $Q'$ and a complex scalar boson $\chi$, both of which carry nonzero $\mu - \tau$ charges and odd parity under discrete $Z_2$ symmetry that stabilizes DM. Here $\chi$ is the lightest $Z_2$-odd particle, and considered as a DM candidate. Charge assignments of these new field are summarized in Table I. The relevant Lagrangian under these symmetries is given by

$$\mathcal{L}_{VLQ + \chi} = M_\delta Q'_a Q' + m_\chi^2 \chi^\dagger \chi + (f_{a \delta} Q_{L_a} Q_{L} \chi + h.c.),$$

(1)

where $(a, j) = 1 - 3$ are generation indices, $Q_{L_j}$’s are the SM quark doublets. We have omitted kinetic term and scalar potential associated with $\chi$ for simplicity.

The anomaly in $B \to K^{(*)}\ell^+\ell^-$ decay can be explained by the shift of the Wilson coefficient $C_9$ associated with the corresponding operator $(\bar{s} \gamma_\mu P_L b)(\mu \gamma^\mu \mu)$. The effective coupling for $Z'_\mu \gamma^\mu P_L b + h.c.$ is induced at one loop level as shown in Fig. 1 with the Yukawa coupling in Eq. (1). Then the effective Hamiltonian $(\bar{s} \gamma_\mu P_L b)(\mu \gamma^\mu \mu)$ arises from $Z'$ mediation and the contribution to Wilson coefficient $\Delta C_9^{\mu\mu}$ is obtained as:

$$\Delta C_9^{\mu\mu} \simeq \frac{g_2^2 G^2_{SM}}{m_\chi^2} \sum_{a = 1}^{3} f_{3a} f_{2a} \int [dX] \ln \left( \frac{\Delta[m_a, m_\chi]}{\Delta[m_\chi, M_a]} \right),$$

(2)

where $V_{tb} \approx 0.999, V_{ts} \approx -0.040$ are the 3-3 and 3-2 elements of CKM matrix respectively, $G_F \approx 1.17 \times 10^{-5}$ GeV is the Fermi constant, $\alpha_{em} \approx 1/137$ is the electromagnetic fine-structure constant, $\int_0^1 \int [dX] \equiv \int_0^1 dX dY dZ 2\delta(1 - X - Y - Z)$, $m_b \approx 4.18$ GeV and $m_{t} \approx 0.095$ GeV are respectively the bottom and strange quark masses given in the $M_S$ scheme at a renormalization scale $\mu = 2$ GeV $[20]$, $m_\chi$ is the mass of $\chi$, and $M_a$ is the mass of $Q'_a$. Notice here that we have assumed $m_b, m_s \ll m_{Z'}$ to derive the formula of $C_9$ in Eq. (2).

In the following numerical analysis, we explore possible value of the $\Delta C_9$ in the model defined in Table I.

$M - M$ mixing: The exotic vector-like quarks and the complex scalar DM $\chi$ induce contributions to the neutral meson $(M)$-antimeson $(\bar{M})$ mixings such as $K^0 - \bar{K}^0$, $B_d - \bar{B}_d$, $B_s - \bar{B}_s$, and $D^0 - \bar{D}^0$ from the box type one-loop diagrams. The formulae for the mass splitting are respectively given by $[21]$

$$\Delta m_K \approx \sum_{a, b = 1}^{3} f_{1a} f_{1b} f_{2a} f_{2b} G_{box}^K [m_\chi, M_a, M_b] \lesssim 3.48 \times 10^{-15} [\text{GeV}],$$

(4)

$$\Delta m_{B_d} \approx \sum_{a, b = 1}^{3} f_{1a} f_{1b} f_{3a} f_{3b} G_{box}^{B_d} [m_\chi, M_a, M_b] \lesssim 3.36 \times 10^{-13} [\text{GeV}],$$

(5)

$$\Delta m_{B_s} \approx \sum_{a, b = 1}^{3} f_{2a} f_{2b} f_{3a} f_{3b} G_{box}^{B_s} [m_\chi, M_a, M_b] \lesssim 1.17 \times 10^{-11} [\text{GeV}],$$

(6)

$$\Delta m_D \approx \sum_{a, b = 1}^{3} f_{2a} f_{2b} f_{1a} f_{1b} G_{box}^{D} [m_\chi, M_a, M_b] \lesssim 6.25 \times 10^{-15} [\text{GeV}],$$

(7)

where $G_{box}^{M} (m_1, m_2, m_3)$

$$= \frac{G_F m_\chi^2}{3(4\pi)^2} \int_0^1 \frac{X [dX]}{X m_1^2 + Y m_2^2 + Z m_3^2},$$

(8)
where relevant quarks \((q, q')\) are respectively \((d, s)\) for \(K, (b, d)\) for \(B_d\), \((b, s)\) for \(B_s\), and \((u, c)\) for \(D\), each of the last inequalities of the above equations represent the upper bound from the experimental values \([26]\), and \(f_K \approx 0.156 \text{ GeV}, f_{B_d(B_s)} \approx 0.191(0.200) \text{ GeV}, f_D \approx 0.212 \text{ GeV}, m_K \approx 0.498 \text{ GeV}, m_{B_d(B_s)} \approx 5.280(5.367) \text{ GeV}, \) and \(m_D \approx 1.865 \text{ GeV}.

\[
b \rightarrow s\gamma; \quad \Gamma_{b \rightarrow s\gamma} \text{ in our model is given by}
\]
\[
\Gamma_{b \rightarrow s\gamma} \approx \frac{\alpha em_m^2}{12(4\pi)} \left| \left( m^2 + m_\chi^2 \right) \sum_{a=1}^{3} \frac{f_{2a}f_{3a}F(M_a, m_\chi)}{36(M_a^2 - m_\chi^2)^2} \right|^2,
\]
\[
F(m_1, m_2) = 5m_1^6 - 27m_1^4m_2^2 + 27m_1^2m_2^4 - 5m_2^6
\]
\[
\quad - 12m_1^4(-3m_1^2 + m_2^2) \ln(m_1/m_2),
\]
(9)

then the branching ratio \(\text{BR}(b \rightarrow s\gamma)\) and its constraint is found as

\[
\text{BR}(b \rightarrow s\gamma) = \frac{\Gamma(b \rightarrow s\gamma)}{\Gamma_{\text{tot}}} \leq 3.29 \times 10^{-4},
\]
(10)

\[
\Gamma_{\text{tot}} \approx 4.02 \times 10^{-13} \text{ GeV}.
\]
(11)

**Constraints from direct production of \(Q's\):** The exotic quarks \(Q's\) can be pair produced via QCD processes at the LHC and then each \(Q'\) will decay through \(Q' \rightarrow q_i \chi\) where \(q_i\) represents a quark with flavor \(i\). Therefore search for \(\{tt, bb, tj, bj, jj\} + \) missing \(E_T\) signals will constrain our model, the branching ratios into a particular quark flavor \(i\) depending on the relative sizes of Yukawa couplings, \(f_{ij}\) and \(f_{aj}\) with \(a = 1, 2\). We roughly estimate the lower limit on the mass of \(Q'\) from the current LHC data for squark searches \([22, 23]\), which indicates the mass should be larger than \(\sim 0.5-1 \text{ TeV}\) depending on the mass difference between \(Q'\) and \(\chi\). In our following analysis, we simply take \(M_a > 1 \text{ TeV}\) to satisfy this constraint.

**Dark matter:** In our scenario, complex scalar \(\chi\) is considered as a DM candidate that dominantly annihilate into SM leptons via \(\chi \chi \rightarrow Z' \rightarrow \mu^+ \mu^- (\tau^+ \tau^-), \)
\(\sim\) so that the DM in our model is naturally leptonophilic. The relic density of DM is given by

\[
\Omega h^2 = \frac{1.07 \times 10^9}{\sqrt{g^*(x_f)}M_{pl}J(x_f)} \text{GeV},
\]
(12)

where \(g^*(x_f) \approx 25\) \(\approx 100, M_{pl} \approx 1.22 \times 10^{19}, \) and

\[
J(x_f) = \int_0^\infty dx \frac{(\sigma v_{\text{rel}})}{m_\chi},
\]
(13)

\[
J(x_f) = \int_0^\infty dx \left[ \frac{1}{\pi} \frac{1}{x} \sqrt{m_\chi^2 x - 4m_e^2} \right]
\]
\[
\times \frac{(2\pi)^2 \sigma_{\text{rel}}}{m_\chi x[K_2(x)]^2},
\]
(14)

\[
\sigma_{\text{rel}} \approx \frac{C_{\text{eff}}}{16\pi} \left[ \frac{m_\chi m_N}{m_N + m_\chi} \right] \frac{q_{\text{h}}^2 g_{\text{h}}^2}{(4\pi)^2 m_Z^2}.
\]
\[
\times \sum_{a=1}^{3} f_{1a}f_{a1} \int [dX] \ln \left( \frac{\Delta[M_a, m_\chi]}{\Delta[m_\chi, M_a]} \right),
\]
(15)

where \(C_{\text{eff}} \approx 6.58 \times 10^{-24}, \) and \(m_N \approx 0.939 \text{ GeV}.\) The current experimental upper bound is \(\sigma_{\text{exp}} \lesssim 2.2 \times 10^{-46} \text{ cm}^2\) at \(m_\chi \approx 50 \text{ GeV}\) according to the LUX data \([31]\). In our numerical analysis, we conservatively restrict the LUX bound for the whole DM mass range.

\(U(1)\) **kinetic mixing:** The kinetic mixing between \(U(1)_Y\) and \(U(1)_{\mu - \tau}\) is induced by fermion loops including \(\mu, \tau\) and \(Q'_a\). The kinetic mixing term is given by

\[
L_{\text{mix}} = \epsilon/2B_{\mu \nu}X_{\mu \nu},
\]
(16)

where \(B_{\mu \nu}\) and \(X_{\mu \nu}\) are respectively the field strength of \(U(1)_Y\) and \(U(1)_{\mu - \tau}\) gauge fields. The mixing parameter \(\epsilon\) is roughly obtained as

\[
\epsilon \sim \frac{eg'}{6\pi^2} \ln(m_\tau/m_\mu) + \frac{g_\tau g'}{6\pi^2} \sum_a \ln(\Lambda/M_a)
\]
(17)

where \(\Lambda\) is some heavy scale \([32, 33]\), for example it can be heavy vector like quark with opposite \(U(1)_{\mu - \tau}\) charge. For \(g' = 0.1\) the size of mixing parameter is \(|\epsilon| \lesssim 10^{-3}\) if \(\Lambda\) is not too large compared to \(M_a\). In such a case, \(Z'-Z'\) mixing angle is roughly given by \(\theta_{ZZZ} \sim \epsilon(m_Z^2/m_{Z'}^2)\). Thus the effect of \(Z'-Z'\) mixing is small in decays of \(Z\) boson and SM fermions due to small mixing angle; the mixing is also consistent with other constraints \([30]\).

**III. NUMERICAL ANALYSIS**

In this section, we perform the numerical analysis. First of all, we fix two parameters \(g' = 0.1\) and \(|q_f| = 1\) for simplicity. In this case, the lower bound on the mass of \(Z'\) is at about 60 GeV, which arises from the neutrino...
trident production \[37\]. On the other hand, the effective operator to obtain \(\Delta C_9 \sim -1\) requires rather large \(Z'\) mass \(^3\). Thus this bound is always safe in our case. The ranges of the other input parameters are set to be as follows:

\[
f \in [10^{-3}, 1], \quad m_{Z'} \in [200, 3000] \text{ [GeV]},
\]
\[
m_\chi \in [1, 2000] \text{ [GeV]}, \quad M_\phi \in [1000, 3000] \text{ [GeV]}.
\]

(17)

We also assume \(M_1 < M_2 < M_3\), \(m_{Z'} > m_\chi\), and take \(m_\chi < 1.2 M_1\) for simplicity so that we can ignore contributions from coannihilation processes. Then we randomly scan over \(3 \times 10^7\) parameter points in the above ranges and select the points that satisfy all the constraints such as \(M - M\) mixing, \(b \rightarrow s \gamma\) branching ratio, measured relic density of DM, the spin independent DM-nucleon scattering cross section via \(Z'\) portal as discussed in the previous section. In the left panel of Figs. 2 we show the allowed parameter region for \(m_\chi\) and \(m_{Z'}\). The correlation between \(m_\chi\) and \(m_{Z'}\) in this plot arises from the relation of relic density of DM, which indicate the relation \(m_{Z'} \sim 2 m_\chi\) is required to obtain the relevant DM annihilation cross section via the \(s\)-channel resonant enhancement. On the other hand, the right panel of Fig. 2 represents the allowed range for \(m_{Z'}\) and \(\Delta C_9\). In this plot, one can easily obtain \(\Delta C_9 \sim -1\) for \(m_{Z'} \lesssim 2000\) GeV so that one can resolve \(B \rightarrow K^{(*)}\ell^+\ell^-\) anomalies. Notice here that the most stringent bound on \(C_9\) arises from the constraint of \(B_s - \bar{B}_s\) mixing.

IV. MISCELLANEOUS ISSUES

A. Effects of \(U(1)_{\mu - \tau}\) symmetry breaking on \(B\) physics

It is worthwhile to mention that the \(U(1)_{\mu - \tau}\) breaking mechanism does not affect the \(B\) physics anomalies that is our main subject. Here let us for example consider the singlet scalar \(\phi\) with charge 2, and assume \(\chi\) has charge 1 for simplicity. Then there is a term \((\text{dim-}3)\chi^2\phi^1 + \text{H.c.}\) which breaks \(U(1)_{\mu - \tau}\) into \(Z_2\) subgroup, \(\chi \rightarrow -\chi\) in the scalar potential. In this framework neutrino masses and their mixings can be fitted to the current experimental data \[38\]. As for such kind of model, see Ref. \[39\] in the dark \(U(1)\) case. Also one finds the \(Z_3\) case in Ref. \[40\], if we choose the \(\phi\) charge is 3. In this case an additional contribution to the relic density of DM and the direct detection via Higgs portal are arisen, and we can relax the resonant allowed region in the left panel of Fig. 2.

B. Variation where the new fields spins are flipped

Here let us briefly mention on a variation of our model where new particle spins are flipped: namely we consider \(SU(2)_L\) doublet colored scalars and a gauge singlet Dirac fermion, like SUSY partners. Let us define \(\bar{Q}'\) as the \(SU(2)_L\) doublet scalar boson, and \(\tilde{\chi}\) as the gauge singlet (Dirac) fermion. Then one finds a Yukawa Lagrangian \(f_{ij}' \tilde{Q}_L \bar{\chi}_R Q' + \text{h.c.}\). \(^4\) Even in this case, the result for the \(\Delta C_9\) is almost the same as one in the original model setup. However a remarkable difference arises in the relic density of DM, where the Dirac fermion \(\tilde{\chi}\) is considered

\(^3\) Here we set the lowest bound on \(Z'\) mass as \(m_{Z'} \geq 200\) GeV.

\(^4\) Notice here the sign of \(U(1)_{\mu - \tau}\) charge assignments between \(\tilde{\chi}\) and \(\bar{Q}'\) are taken to be opposite, although the the absolute value is the same.
as the DM candidate. Then its annihilation cross section, which is s-wave dominant, is given by
\[
\sigma_{v\text{rel}} \simeq \frac{m_{\chi}^2}{32\pi(m_{\chi}^2 + m_Q^2)^2} + \frac{g^4 x_{\chi}^2 m_{\chi}^2}{16\pi(-4m_{\chi}^2 + m_{Z'}^2)^2}
\]
even in the limit of the massless final state. Then it suggests that the allowed region that satisfies thermal relic density would be wider. The $M - \overline{M}$ mixing, which arises from $Q_1$ operator, is the same as one in the original model. Therefore it does not give stringent constraints.

Furthermore, an interesting phenomenology will appear if $|q_{zr}| = 1$. In this case, one has an additional term
\[
g'_{r7}d_R L_L i\sigma_2 Q^T + \text{h.c.},
\]
that would induce the following operators:
\[
g_{\alpha\beta}g'_{\mu\nu}(\bar{\phi}\gamma^\mu P_R b)(\ell'\gamma_\mu \ell) - \bar{g}_{\alpha\beta}g'_{\mu\nu}(\bar{\phi}\gamma^\mu P_R b)(\ell'\gamma_\mu \ell),
\]
which respectively correspond to $C_{\nu}'$ and $C_{\nu}' i$ with $C_{\nu}' = -C_{\nu}'$. These Wilson coefficients can also resolve anomalies in $B \to K^{(*)} \ell^+ \ell^-$ decay. Notice here that for $|q_{zr}| = 1$ the colored scalar $\tilde{Q}'$ is identical to a scalar leptoquark. Therefore its mass is strongly constrained by the LHC data that its lower bound is about 1 TeV as in the vector like quark case discussed in the previous section.

C. $Z'$ production at the LHC

The $Z'$ boson can be produced at the LHC via loop induced couplings to SM quarks, $g_{\text{eff}}(q') \gamma^\mu P_L q' Z'_\mu$. Here we consider the case where $\Delta C_{9} \sim -1$ is obtained by fixing extra $U(1)$ gauge coupling and charge for $(Q'_a, \chi')$ as $g' = 0.1$ and $|q_{zr}| = 1$. In this case, the $g_{\text{eff}} \sim 0.002$ is required for $q(q') = s(b)$ for $m_{Z'} = 500$ GeV. Then we consider two scenarios for illustration: (i) $g_{\text{eff}} = 0.002$ for all quark combinations; (ii) $g_{\text{eff}} = 0.002$ for operators including only second and third generation quarks but $g_{\text{eff}} = 0$ if first generation quarks are included, where $m_{Z'} = 500$ GeV is fixed for both scenarios. The $Z'$ production cross section is estimated with CalcHEP by implementing relevant interactions and using $\sqrt{s} = 13$ TeV. We obtain the cross section such as $\sigma_{pp \to Z'} \simeq 1.6 \times 10^{-2}[1.1 \times 10^{-3}]$ pb for scenario (i)[(ii)]. Assuming $m_{Z'} < 2m_\chi(2M_a)$, the dominant branching ratio for $Z'$ decay is given by $BR(Z' \to \mu^+ \mu^-) \simeq BR(Z' \to \tau^+ \tau^-) \simeq 0.5$. Then we find the cross section for scenario (i) is marginal of the current upper limit by the LHC data from $Z' \to \mu^+ \mu^-$ search while that of scenario (ii) is much lower than the current limit. These cross sections will be further tested by data with more integrated luminosity.

V. SUMMARY AND CONCLUSIONS

In this paper, we have proposed an extension of the SM with three families of exotic quarks and an inert singlet scalar boson $\chi$ imposing a gauged $\mu - \tau$ symmetry. Then we have explained the measured anomalies in $B \to K^{(*)} \ell^+ \ell^-$ through the one-loop radiative effect and relic density of dark matter $\chi$ without conflict with the constraints from spin independent dark matter direct detection searches via $Z'$ boson exchange, $M - \overline{M}$ mixing processes, and branching ratio of $b \to s\tau$.

We have shown the allowed parameter region that is consistent with all the relevant constraints. The left panel of Figs. 2 shows the allowed range for $m_\chi$ and $m_{Z'}$, in which we have shown the correlation between $m_\chi$ and $m_{Z'}$ that arises from the relation of relic density of DM, indicating $m_{Z'} \sim 2m_\chi$ to enhance the annihilation cross section through the s-channel resonance. On the other hand we have shown the allowed range for $m_{Z'}$ and $\Delta C_{9}$ in the right panel of Figs. 2. In this figure, we have found that one can easily obtain $\Delta C_{9} \sim -1$ for $m_{Z'} \lesssim 2000$ GeV, resolving the $B \to K^{(*)} \ell^+ \ell^-$ anomalies.

In addition, we have discussed the case where the extra particle spins are flipped. In this variational model, we could obtain the required $\Delta C_{9}$ in a similar manner, while dark matter annihilation cross section is s-wave dominant so that the allowed parameter region is extended. Note that other constraints are similar to the original model setup. The case $|q_{zr}| = 1$ is special since in this case $\tilde{Q}'$ becomes a scalar leptoquark. Then we have additional contributions to $b \to s\ell^+ \ell^-$ in such a way $C'_{9} = -C'_{10}$ that also help to resolve the $B \to K^{(*)} \ell^+ \ell^-$ anomalies.

Before closing, we emphasize that our mechanism of generating flavor violating $Z'$ couplings can be generalized readily by including both quark and lepton sectors by selecting the $Z_2$ odd exotic particle contents. Therefore this mechanism provides interesting connection between flavor physics and dark matter physics where our model represents one explicit example giving connection between $B$-physics and dark matter physics.

Acknowledgments

H. O. is sincerely grateful for all the KIAS members, Korean cordial persons, foods, culture, weather, and all the other things. This work is supported in part by National Research Foundation of Korea (NRF) Research Grant NRF-2015R1A2A1A05001869 (PK), and by the NRF grant funded by the Korea government (MSIP) (No. 2009-0083526) through Korea Neutrino Research Center at Seoul National University (PK).
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