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CP violating dimuon charge asymmetry in general left-right models

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The recently measured charge asymmetry of like-sign dimuon events by the D0 collaboration at Tevatron shows the 3.9σ deviation from the standard model prediction. In order to solve this mismatch, we investigate the right-handed current contributions to $B_s - \bar{B}_s$ and $B_d - \bar{B}_d$ mixings that are the major source of the like-sign dimuon events in $b\bar{b}$ production in general left-right models without imposing manifest or pseudomanifest left-right symmetry. We find the allowed region of new physics parameters satisfying the current experimental data.

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I. INTRODUCTION

Recently, the D0 collaboration has measured the *CP* violating like-sign dimuon charge asymmetry in semileptonic b hadron decays with the 9 fb^{-1} integrated luminosity of $p\bar{p}$ data at Tevatron [1]:

$$A_{sl}^b = -0.007\,87 \pm 0.001\,72(\text{stat.}) \pm 0.000\,93(\text{syst.}). \quad (1)$$

The like-sign dimuon events come from direct semileptonic decays of b hadrons following the $B^0 - \bar{B}^0$ oscillation in $b\bar{b}$ pair production at Tevatron, and the corresponding charge asymmetry is defined by

$$A_{sl}^b \equiv \frac{\Gamma(b\bar{b} \to \mu^+\mu^+X) - \Gamma(b\bar{b} \to \mu^-\mu^-X)}{\Gamma(b\bar{b} \to \mu^+\mu^+X) + \Gamma(b\bar{b} \to \mu^-\mu^-X)}. \quad (2)$$

At Tevatron experiment, both decays of B_d and B_s mesons contribute to the dimuon charge asymmetry. If we define the charge asymmetry of semileptonic decays of neutral B_q^0 mesons as

$$a_{sl}^q \equiv \frac{\Gamma(\bar{B}_q^0(t) \to \mu^+X) - \Gamma(B_q^0(t) \to \mu^-X)}{\Gamma(\bar{B}_q^0(t) \to \mu^+X) + \Gamma(B_q^0(t) \to \mu^-X)}, \quad (3)$$

the like-sign dimuon charge asymmetry can be expressed in terms of a_{sl}^q as [2]

$$A_{sl}^b = \frac{1}{f_dZ_d + f_sZ_s}(f_dZ_da_{sl}^d + f_sZ_sa_{sl}^s), \quad (4)$$

assuming that $\Gamma(B_d^0 \to \mu^+X) = \Gamma(B_s^0 \to \mu^+X)$ to a very good approximation, where f_q are the production fractions of B_q mesons and $Z_q = 1/(1-y_q^2) - 1/(1+x_q^2)$ with $y_q = \Delta\Gamma_q/(2\Gamma_q)$, $x_q = \Delta M_q/\Gamma_q$. These parameters are measured to be $f_d = 0.402 \pm 0.013$, $f_s = 0.112 \pm 0.013$, $x_d = 0.771 \pm 0.007$, $x_s = 26.3 \pm 0.4$, $y_d = 0$, and $y_s = 0.052 \pm 0.016$ [3]. With these values, Eq. (4) is rewritten by

$$A_{sl}^b = (0.572 \pm 0.030)a_{sl}^d + (0.428 \pm 0.030)a_{sl}^s. \quad (5)$$

The nonzero dimuon asymmetry is sensitive to *CP* violation in B meson mixing. In the standard model (SM), the source of *CP* violation in the neutral B_q^0 system is the single phase in the Cabibbo-Kobayashi-Maskawa matrix elements involved in the box diagram. Using the SM values for the semileptonic charge asymmetries a_{sl}^d and a_{sl}^s of B_d^0 and B_s^0 mesons, respectively [4], the prediction of the dimuon asymmetry in the SM is given by

$$A_{sl}^b = (-2.7^{+0.5}_{-0.6}) \times 10^{-4}, \quad (6)$$

which shows that the D0 measurement of Eq. (1) deviates about 3.9σ from the SM prediction. If the deviation is confirmed with other experiments, it indicates the existence of the new physics beyond the SM. Recently, there are several efforts devoted to the explanation of the current D0 dimuon asymmetry measurement in the SM and beyond [5].

As an alternative solution to the mismatch between the measurement and the SM prediction of the dimuon charge asymmetry, we consider the left-right model (LRM) based on the $SU(2)_L \times SU(2)_R \times U(1)$ gauge symmetry, which is one of the attractive extensions of the SM [6]. The current measurement of the dimuon charge asymmetry can be explained in the LRM due to the sizable right-handed current contributions to $B^0 - \bar{B}^0$ mixing [7]. This model arises as an intermediate theory in the SO(10) grand unified theory. The manifest left-right symmetry provides a natural answer to the origin of the parity violation. In the LRM, the right-handed fermions transform as doublets under $SU(2)_R$ and singlets under $SU(2)_L$, and the left-handed fermions behave reversely. Thus, a bidoublet Higgs field is required for the Yukawa couplings and also responsible for the electoweak symmetry breaking. Involving the triplet Higgs field $\Delta_{L,R}$ to break the additional $SU(2)_R$ symmetry, the lepton-number-violating Yukawa terms are introduced and the seesaw mechanism for light neutrino masses can be

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exploited in the LRM. The scale of the masses of the new gauge bosons in the LRM is constrained by direct searches and indirect analysis [8–11], and we will discuss the constraints on the model in further detail.

This paper is organized as follows. In Sec. II, we briefly review the charged sector in the general LRM. We explicitly show the right-handed current contributions in the neutral B meson system in Sec. III, and present the numerical analysis of $B^0-\bar{B}^0$ mixing and the dimuon charge asymmetry of B mesons in the general LRM in Sec. IV. Finally, we conclude in Sec. V.

II. THE LEFT-RIGHT MODEL

We briefly review the main features of the LRM, which are necessary for our analysis. The gauge group of the LRM is $SU(2)_L \times SU(2)_R \times U(1)$. There exist a bidoublet Higgs field $\phi(2, \bar{2}, 0)$ and two triplet Higgs fields, $\Delta_L(3, 1, 2)$ and $\Delta_R(1, 3, 2)$ in the minimal LRM represented by

$$\phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}, \quad \Delta_{L,R} = \frac{1}{\sqrt{2}}\begin{pmatrix} \delta_{L,R}^+ & \sqrt{2}\delta_{L,R}^{++} \\ \sqrt{2}\delta_{L,R}^0 & -\delta_{L,R}^+ \end{pmatrix}, \tag{7}$$

of which kinetic terms are given by

$$\mathcal{L} = \mathbf{Tr}[(D_\mu \Delta_{L,R})^\dagger (D^\mu \Delta_{L,R})] + \mathbf{Tr}[(D_\mu \phi)^\dagger (D^\mu \phi)], \tag{8}$$

where the covariant derivatives are defined by

$$D_\mu \phi = \partial_\mu \phi - i\frac{g_L}{2} W_{L\mu}^a \tau^a \phi + i\frac{g_R}{2} \phi W_{R\mu}^a \tau^a,$$
$$D_\mu \Delta_{L,R} = \partial_\mu \Delta_{L,R} - i\frac{g_{L,R}}{2}[W_{L,R\mu}^a \tau^a, \Delta_{L,R}] - ig' B_\mu \Delta_{L,R}. \tag{9}$$

The gauge symmetries are spontaneously broken by the vacuum expectation values

$$\langle \phi \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} k_1 & 0 \\ 0 & k_2 \end{pmatrix}, \quad \langle \Delta_{L,R} \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 0 \\ v_{L,R} & 0 \end{pmatrix}, \tag{10}$$

where $k_{1,2}$ are complex in general and $v_{L,R}$ are real, which lead to the charged gauge boson masses

$$\mathcal{M}_{W^\pm}^2 = \frac{1}{4}\begin{pmatrix} g_L^2(k_+^2 + 2v_L^2) & -2g_L g_R k_1^* k_2 \\ -2g_L g_R k_1 k_2^* & g_R^2(k_+^2 + 2v_R^2) \end{pmatrix} = \begin{pmatrix} M_{W_L}^2 & M_{W_{LR}}^2 e^{i\alpha} \\ M_{W_{LR}}^2 e^{-i\alpha} & M_{W_R}^2 \end{pmatrix}, \tag{11}$$

where $k_+^2 = |k_1|^2 + |k_2|^2$ and α is the phase of $k_1^* k_2$. Since the $SU(2)_R$ breaking scale v_R should be higher than the electroweak scale, $k_{1,2} \ll v_R$, W_R is heavier than W_L. Note that v_L is unnecessary for the symmetry breaking and just introduced in order to manifest the left-right symmetry. If the neutrino mass is determined solely by the seesaw relation $m_\nu \sim v_L + k_+^2/v_R$, v_R should be very large $\sim 10^{11}$ GeV. It indicates that the heavy gauge bosons are too heavy to be produced at the accelerator experiments and the direct search of the $SU(2)_R$ structure is hardly achieved. Therefore, we assume that v_R is only moderately large, $v_R \sim \mathcal{O}(\text{TeV})$, for the heavy gauge bosons to be found at the LHC, and the Yukawa couplings are suppressed in order that the neutrino masses are at the eV scale. We let v_L be very small or close to 0 without loss of generality. This is achieved when the quartic couplings of $(\phi\phi\Delta_L\Delta_R)$-type terms in the Higgs potential are set to be zero [12,13], and warranted by the approximate horizontal U(1) symmetry [14] as well as the see-saw picture for light neutrino masses. We adopt this limit here and note that the Higgs boson masses are not affected by taking this limit [13].

The general Higgs potential in the LRM has been studied in Refs. [12,13,15]. After the mass matrix is diagonalized by a unitary transformation, the mass eigenstates are written as

$$\begin{pmatrix} W^\pm \\ W'^\pm \end{pmatrix} = \begin{pmatrix} \cos\xi & e^{-i\alpha}\sin\xi \\ -\sin\xi & e^{-i\alpha}\cos\xi \end{pmatrix}\begin{pmatrix} W_L^\pm \\ W_R^\pm \end{pmatrix}, \tag{12}$$

with the mixing angle

$$\tan 2\xi = -\frac{2M_{W_{LR}}^2}{M_{W_R}^2 - M_{W_L}^2}. \tag{13}$$

For $v_R \gg |k_{1,2}|$, the mass eigenvalues and the mixing angle reduce to

$$M_W^2 \approx \tfrac{1}{4}g_L^2(|k_1|^2 + |k_2|^2), \quad M_{W'}^2 \approx \tfrac{1}{2}g_R^2 v_R^2, \quad \xi \approx \frac{g_L|k_1^* k_2|}{g_R v_R^2}. \tag{14}$$

Here, the Schwarz inequality requires that $\zeta_g \equiv (g_R/g_L)^2\zeta \geq \xi_g \equiv (g_R/g_L)\xi$ where $\zeta \equiv M_W^2/M_{W'}^2$. From the global analysis of muon decay measurements [16], the lower bound on ζ_g can be obtained without imposing discrete symmetry as follows:

$$\zeta_g < 0.031 \quad \text{or} \quad M_{W'} > (g_R/g_L) \times 460 \text{ GeV}. \tag{15}$$

The new gauge boson mass $M_{W'}$ is severely constrained from $K_L - K_S$ mixing if the model has manifest ($V^R = V^L$) left-right symmetry ($g_R = g_L$): $M_{W'} > 2.5$ TeV [17], where $V^L(V^R)$ is the left(right)-handed quark mixing matrice. But, in general, the form of V^R is not necessarily restricted to manifest or pseudomanifest ($V^R = V^{L*}K$) symmetric type, where K is a diagonal phase matrix [6]. Instead, if we take the following form of V^R, the limit on $M_{W'}$ may be significantly relaxed to approximately 300 GeV, and the W' boson contributions to $B_{d(s)}\bar{B}_{d(s)}$ mixings can be large [18]:

$$V_I^R = \begin{pmatrix} e^{i\omega} & \sim 0 & \sim 0 \\ \sim 0 & c_R e^{i\alpha_1} & s_R e^{i\alpha_2} \\ \sim 0 & -s_R e^{i\alpha_3} & c_R e^{i\alpha_4} \end{pmatrix},$$
$$V_{II}^R = \begin{pmatrix} \sim 0 & e^{i\omega} & \sim 0 \\ c_R e^{i\alpha_1} & \sim 0 & s_R e^{i\alpha_2} \\ -s_R e^{i\alpha_3} & \sim 0 & c_R e^{i\alpha_4} \end{pmatrix}, \tag{16}$$

where $c_R(s_R) \equiv \cos\theta_R(\sin\theta_R)$ $(0° \leq \theta_R \leq 90°)$. Here, the matrix elements indicated ~ 0 may be $\lesssim 10^{-2}$ and the unitarity requires $\alpha_1 + \alpha_4 = \alpha_2 + \alpha_3$. From the $b \to c$ semileptonic decays of the B mesons, we can get an approximate bound $\xi_g \sin\theta_R \lesssim 0.013$ by assuming $|V^L_{cb}| \approx 0.04$ [19].

III. $B^0 - \bar{B}^0$ MIXING

The neutral B_q meson system $(q = d, s)$ is described by the Schrödinger equation

$$i\frac{d}{dt}\begin{pmatrix} B_q(t) \\ \bar{B}_q(t)\end{pmatrix} = \left(M - \frac{i}{2}\Gamma\right)\begin{pmatrix} B_q(t) \\ \bar{B}_q(t)\end{pmatrix}, \tag{17}$$

where M is the mass matrix and Γ the decay matrix. The $\Delta B = 2$ transition amplitudes

$$\langle B^0_q|\mathcal{H}^{\Delta B=2}_{\rm eff}|\bar{B}^0_q\rangle = M^q_{12} \tag{18}$$

yield the mass difference between the heavy and the light states of B meson,

$$\Delta M_q \equiv M^q_H - M^q_L = 2|M^q_{12}|, \tag{19}$$

where M^q_H and M^q_L are the mass eigenvalues for the heavy and the light eigenstates, respectively. The decay width difference is defined by

$$\Delta\Gamma_q \equiv \Gamma^q_L - \Gamma^q_H = 2|\Gamma^q_{12}|\cos\phi^q, \tag{20}$$

where the decay widths Γ_L and Γ_H are corresponding to the physical eigenstates B_L and B_H, respectively, and the *CP* phase is $\phi^q \equiv \arg(-M^q_{12}/\Gamma^q_{12})$. The charge asymmetry in Eq. (3) is expressed as

$$a^q_{sl} = \frac{|\Gamma^q_{12}|}{|M^q_{12}|}\sin\phi^q = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi^q, \tag{21}$$

of which the SM predictions are given by [4]

$$\begin{aligned} &a^d_{sl} = (-4.8^{+1.0}_{-1.2})\times 10^{-4}, \quad a^s_{sl} = (2.1 \pm 0.6)\times 10^{-5},\\ &\phi^d = (-9.1^{+2.6}_{-3.8})\times 10^{-2}, \quad \phi^s = (4.2 \pm 1.4)\times 10^{-3}. \end{aligned} \tag{22}$$

In the SM, $\Delta\Gamma_d/\Gamma_d$ is less than 1%, while $\Delta\Gamma_s/\Gamma_s \sim 10\%$ is rather large. The decay matrix elements Γ^q_{12} are obtained from the tree-level decays $b \to c\bar{c}q$ where the dominant right-handed current contribution is suppressed by the heavy right-handed gauge boson mass M_{W_R} [20]. Therefore, we ignore the contributions of our model to Γ^q_{12} in this work.

We first consider the right-handed current contributions in the $B^0_d - \bar{B}^0_d$ system. The $\Delta B = 2$ transition amplitudes in Eq. (18) are given by the following effective Hamiltonian in the LRM [7]:

$$H^{B\bar{B}}_{\rm eff} = H^{\rm SM}_{\rm eff} + H^{RR}_{\rm eff} + H^{LR}_{\rm eff}, \tag{23}$$

where

$$H^{\rm SM}_{\rm eff} = \frac{G_F^2 M_W^2}{4\pi^2}(\lambda^{LL}_t)^2 S(x_t^2)(\bar{d}_L\gamma_\mu b_L)^2, \tag{24}$$

$$\begin{aligned} H^{LR}_{\rm eff} = \frac{G_F^2 M_W^2}{2\pi^2}\{&[\lambda^{LR}_c\lambda^{RL}_t x_c x_t \zeta_g A_1(x_t^2, \zeta)\\ &+ \lambda^{LR}_t\lambda^{RL}_t x_t^2\zeta_g A_2(x_t^2,\zeta)](\bar{d}_L b_R)(\bar{d}_R b_L)\\ &+ \lambda^{LL}_t\lambda^{RL}_t x_b \xi^-_g[x_t^3 A_3(x_t^2)(\bar{d}_L\gamma_\mu b_L)(\bar{d}_R\gamma_\mu b_R)\\ &+ x_t A_4(x_t^2)(\bar{d}_L b_R)(\bar{d}_R b_L)]\}, \end{aligned} \tag{25}$$

and

$$\lambda^{AB}_i \equiv V^{A*}_{id}V^B_{ib}, \quad x_i \equiv \frac{m_i}{M_W}(i = u, c, t), \quad \xi^\pm_g \equiv e^{\pm\alpha}\xi_g, \tag{26}$$

with

$$\begin{aligned} S(x) &= \frac{x(4 - 11x + x^2)}{4(1-x)^2} - \frac{3x^3\ln x}{2(1-x)^3},\\ A_1(x,\zeta) &= \frac{(4-x)\ln x}{(1-x)(1-x\zeta)} + \frac{(1-4\zeta)\ln\zeta}{(1-\zeta)(1-x\zeta)},\\ A_2(x,\zeta) &= \frac{4-x}{(1-x)(1-x\zeta)} + \frac{(4-2x+x^2(1-3\zeta))\ln x}{(1-x)^2(1-x\zeta)^2}\\ &\quad + \frac{(1-4\zeta)\ln\zeta}{(1-\zeta)(1-x\zeta)^2},\\ A_3(x) &= \frac{7-x}{4(1-x)^2} + \frac{(2+x)\ln x}{2(1-x)^3}, \quad A_4(x) = \frac{2x}{1-x} + \frac{x(1+x)\ln x}{(1-x)^2}. \end{aligned} \tag{27}$$

Note that $S(x)$ is the usual Inami-Lim function, $A_1(x,\zeta)$ is obtained by taking the limit $x_c^2 = 0$, and $H^{RR}_{\rm eff}$ is suppressed because it is proportional to ζ^2. Also, in the case of V^R_I, one can see from Eq. (16) that there is no significant contribution of $H^{LR}_{\rm eff}$ to $B^0_d - \bar{B}^0_d$ mixing, so we only consider the V^R_{II}-type mixing matrix for $B^0_d - \bar{B}^0_d$ mixing. The dispersive part of the $B^0_d - \bar{B}^0_d$ mixing matrix element can then be written as

$$M^d_{12} = M^{\rm SM}_{12} + M^{LR}_{12} = M^{\rm SM}_{12}(1 + r^d_{LR}), \tag{28}$$

where

$$r^d_{LR} \equiv \frac{M^{LR}_{12}}{M^{\rm SM}_{12}} = \frac{\langle\bar{B}^0_d|H^{LR}_{\rm eff}|B^0_d\rangle}{\langle\bar{B}^0_d|H^{\rm SM}_{\rm eff}|B^0_d\rangle}. \tag{29}$$

One needs the hadronic matrix elements of the operators in Eqs. (24) and (25) in order to evaluate the mixing matrix element. We use the following parametrization:

$$\begin{aligned} \langle\bar{B}^0_d|(\bar{d}_L\gamma_\mu b_L)^2|B^0_d\rangle &= \tfrac{1}{3}B_1 f_B^2 m_B,\\ \langle\bar{B}^0_d|(\bar{d}_L\gamma_\mu b_L)(\bar{d}_R\gamma_\mu b_R)|B^0_d\rangle &= -\frac{5}{12}B_2 f_B^2 m_B,\\ \langle\bar{B}^0_d|(\bar{d}_L b_R)(\bar{d}_R b_L)|B^0_d\rangle &= \frac{7}{24}B_3 f_B^2 m_B, \end{aligned} \tag{30}$$

where

$$\langle 0|\bar{d}_\beta \gamma^\mu \gamma_5 b_\alpha |B_d^0\rangle = -\langle \bar{B}_d^0|\bar{d}_\beta \gamma^\mu \gamma_5 b_\alpha|0\rangle = -\frac{if_B p_B^\mu}{\sqrt{2m_B}}\frac{\delta_{\alpha\beta}}{3}, \tag{31}$$

and where f_B is the B meson decay constant and B_i ($i = 1, 2, 3$) bag parameters. In the vacuum-insertion approximation [21], $B_i = 1$ in the limit $m_b \simeq m_B$. We will use $f_B B_i^{1/2} = (216 \pm 15)$ MeV [22] for our numerical estimates. Using widely used values of the quark masses and $|V_{cd}^L| \approx 0.225$, one can express r_{LR}^d in terms of the mixing angle and phases in the case of V_{II}^R in Eq. (16) as

$$\begin{aligned} r_{LR}^d \approx\ & 17.5\left(\frac{1-\zeta_g-(4.08-16.3\zeta_g)\ln(1/\zeta_g))}{1-5.58\zeta_g}\right)\zeta_g s_R^2 e^{-i(2\beta-\alpha_2+\alpha_3)} \\ & - 756\left(\frac{1-5.03\zeta_g-(0.490-1.96\zeta_g)\ln(1/\zeta_g)}{1-10.2\zeta_g+30.1\zeta_g^2}\right)\zeta_g s_R c_R e^{-i(\beta+\alpha_3-\alpha_4)} - 7.94\xi_g s_R e^{-i(\beta+\alpha_3)}, \end{aligned} \tag{32}$$

where the mixing phase α was absorbed in α_i by redefining $\alpha_i + \alpha \to \alpha_i$, and we used the approximation $A_i(x, \zeta) \simeq A_i(x, \zeta_g)$ ($i = 1, 2$) because ζ dependence on A_i in Eq. (27) is rather weak for $M_{W'} > 100$ GeV unless g_R/g_L is drastically different from unity.

On the other hand, the right-handed current contributions to $B_s^0 - \bar{B}_s^0$ mixing is sizable only in the case of V_I^R as one can see from Eq. (16). Similarly to r_{LR}^d, we obtain r_{LR}^s in the case of V_I^R as

$$\begin{aligned} r_{LR}^s \approx\ & -3.47\left(\frac{1-\zeta_g-(4.08-16.3\zeta_g)\ln(1/\zeta_g))}{1-5.58\zeta_g}\right)\zeta_g s_R^2 e^{-i(-\alpha_2+\alpha_3)} \\ & + 162\left(\frac{1-5.03\zeta_g-(0.490-1.96\zeta_g)\ln(1/\zeta_g)}{1-10.2\zeta_g+30.1\zeta_g^2}\right)\zeta_g s_R c_R e^{-i(\alpha_3-\alpha_4)} + 1.70\xi_g s_R e^{-i\alpha_3}. \end{aligned} \tag{33}$$

The charge asymmetry a_{sl}^q in Eq. (21) can then be written in terms of r_{LR}^q in the LRM as

$$\begin{aligned} a_{LR}^q &= a_{\rm SM}^q \frac{\cos\phi_{LR}^q}{|1+r_{LR}^q|}\left(1+\frac{\tan\phi_{LR}^q}{\tan\phi_{\rm SM}^q}\right), \\ \phi_{LR}^q &\equiv \arg(1+r_{LR}^q), \end{aligned} \tag{34}$$

where we omitted the subscript sl and the SM values of a_{sl}^q and ϕ^q are given in Eq. (22). We use the above results for our numerical investigation of the right-handed current contributions to the like-sign dimuon charge asymmetry in semileptonic B decays in the next section.

IV. RESULTS

For our numerical analysis, we use the following 2σ bounds obtained from the deviation of the present experimental data from the SM predictions on B meson mixing [23]:

$$0.62 < |1 + r_{LR}^d| < 1.15, \quad 0.79 < |1 + r_{LR}^s| < 1.23. \tag{35}$$

Note from Eqs. (32) and (33) that we have six independent new parameters (ζ_g, ξ_g, θ_R, α_2, α_3, α_4). It is beyond the scope of this paper to perform a complete analysis by varying all six parameters. For simple illustration of the possible effect of the new interaction on B meson mixing, instead, we set $\xi_g = \zeta_g/2$ and $\alpha_{2,4} = 0$ because ξ_g contributions to B meson mixing is expected to be much smaller than ζ_g's and α_3 is important as the overall phase of r_{LR}^q.

In the case of V_I^R, as discussed earlier, the right-handed current contributions to $B_s - \bar{B}_s$ mixing could be sizable while those to $B_d - \bar{B}_d$ mixing is negligible. With the present experimental bounds of the dimuon charge asymmetry and $B_s - \bar{B}_s$ mixing given in Eqs. (1) and (35), we first plot the allowed region of α_3 and θ_R for $M_{W'} = 800$ GeV at 2σ level in Fig. 1. One can see that large values of θ_R are preferred from the overlapped region in the figure. This is the clear indication that manifest or pseudomanifest LRM is disfavored in this case. In Fig. 2, we plot the allowed region of θ_R and ζ_g for $\alpha_3 = 90°$ at 2σ level. One can obtain the lower bound of $\zeta_g \gtrsim 0.004$ from the figure that corresponds to the upper bound of W' mass $M_{W'} \lesssim (g_R/g_L) \times 1.3$ TeV. Varying α_3, the mass bound on $M_{W'}$ also varies, but not very much. In other words, if it happens that the mass of W' is much larger than the obtained upper bound, the right-handed contributions are not big enough to explain the present measurement of the dimuon charge asymmetry.

In the case of V_{II}^R, on the other hand, the right-handed current contributions to $B_d - \bar{B}_d$ mixing could be sizable while those to $B_s - \bar{B}_s$ mixing is negligible. Similarly to the V_I^R case, we plot the allowed region of α_3 and θ_R for $M_{W'} = 800$ GeV at 2σ level in Fig. 3. The figure shows that small or large values of θ_R are allowed unlike the V_I^R case. In order for direct comparison with the V_I^R

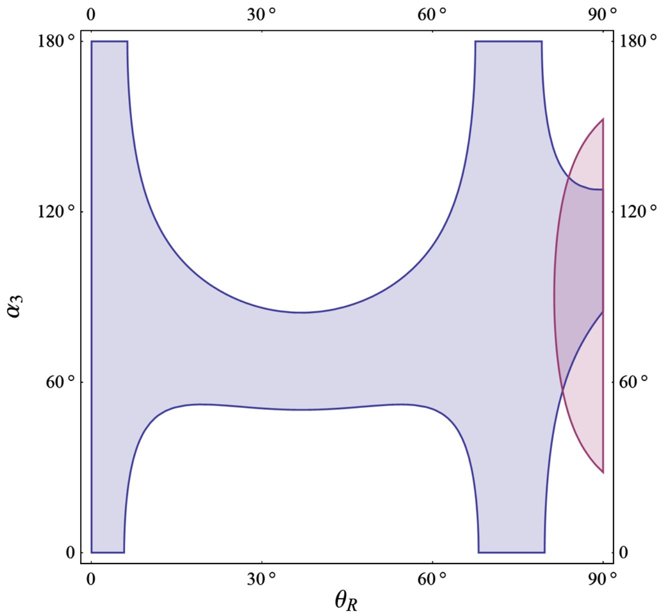

FIG. 1 (color online). Allowed regions for α_3 and θ_R at 2σ level for $M_{W'} = 800$ GeV in the case of V_I^R. The red (narrower) and blue (broader) regions are allowed by the current measurements of the like-sign dimuon charge asymmetry and $B_s - \bar{B}_s$ mixing, respectively.

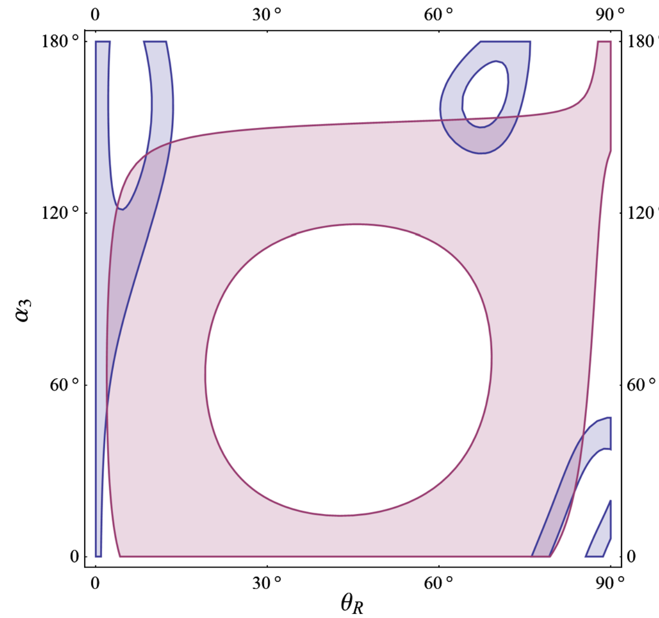

FIG. 3 (color online). Allowed regions for α_3 and θ_R at 2σ level for $M_{W'} = 800$ GeV in the case of V_{II}^R. The red (broader) and blue (narrower) regions are allowed by the current measurements of the like-sign dimuon charge asymmetry and $B_d - \bar{B}_d$ mixing, respectively.

case, we plot again the allowed region of θ_R and ζ_g for $\alpha_3 = 90°$ at 2σ level in Fig. 4. The figure shows that V_{II}^R scenario allows more wide range of allowed area of new parameter space and the lower bound of ζ_g is approximately $\zeta_g \gtrsim 0.0004$. We obtain the corresponding upper bound of W' mass $M_{W'} \lesssim (g_R/g_L) \times 4$ TeV. We found that this mass bound could be somewhat lower for different values of α_3. It should also be noted that we

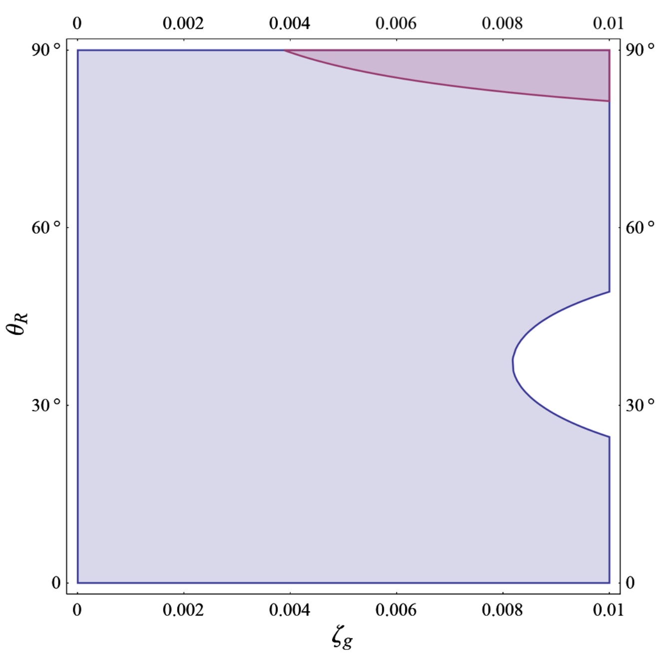

FIG. 2 (color online). Allowed regions for θ_R and ζ_g at 2σ level for $\alpha_3 = 90°$ in the case of V_I^R. The red (narrower) and blue (broader) regions are allowed by the current measurements of the like-sign dimuon charge asymmetry and $B_s - \bar{B}_s$ mixing, respectively.

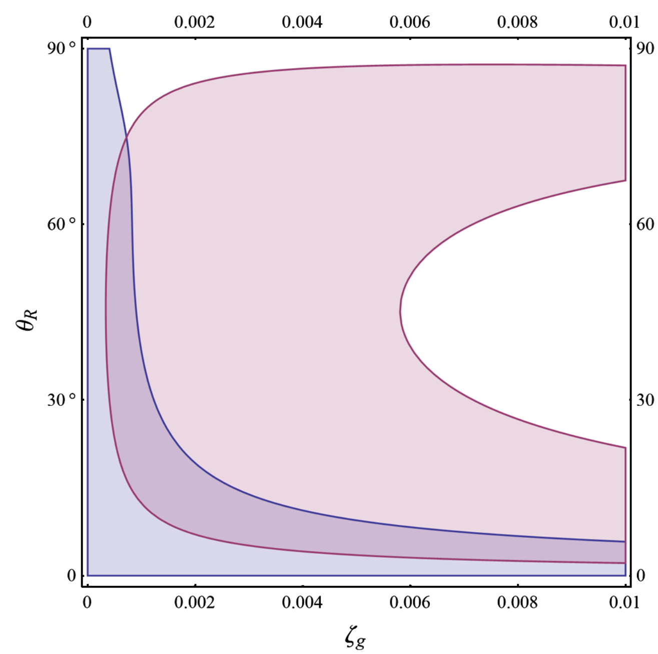

FIG. 4 (color online). Allowed regions for θ_R and ζ_g at 2σ level for $\alpha_3 = 90°$ in the case of V_{II}^R. The red (broader) and blue (narrower) regions are allowed by the current measurements of the like-sign dimuon charge asymmetry and $B_d - \bar{B}_d$ mixing, respectively.

have similar results for different values of $\alpha_{2,4}$ in both scenarios.

V. CONCLUDING REMARKS

In this paper, we studied the right-handed current contributions to the CP violating like-sign dimuon charge asymmetry in semiletonic B decays in general left-right models. Without imposing manifest or pseudo-manifest left-right symmetry, we consider two types of mass mixing matrix V^R with which W' contributions are big enough to explain the current mismatch of the present measurements of the dimuon charge asymmetry and the SM prediction. We evaluated the sizes of W' contributions to $B_d - \bar{B}_d$ and $B_s - \bar{B}_s$ mixings that govern the dimuon charge asymmetry, and obtained the allowed regions of NP parameter spaces. With the given parameter sets, we have the following mass bounds of W': $M_{W'} \lesssim (g_R/g_L) \times 1.3$ TeV for Type I (V_I^R) or $M_{W'} \lesssim (g_R/g_L) \times 4$ TeV for Type II (V_{II}^R), which represent the amount of NP effects enough to explain the present measurement of the dimuon charge asymmetry. If we consider the early LHC bound on W' [24], Type I model including manifest or pseudomanifest LRM is disfavored if $g_R = g_L$. This analysis can affect other B-meson-mixing related observables such as $\sin 2\beta$ and mixing induced CP violation in B decays. A detailed discussion on such mixing-induced CP asymmetries in general LRM can be found in Ref. [25], and a combined study including other decays with new experimental results will be discussed in the follow-up paper.

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