Electroweak Penguin and Leptophobic Z' model

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Abstract

We consider the leptophobic Z' model which can appear naturally in the flipped SU(5) or string-inspired E_6 models. This model can be constrained by measurements of the $B \to M\nu\bar{\nu}$ decays and Δm_s. We find that although the latter give much stronger constraints on the coupling than the former, they are complementary to each other.

1 Introduction

Since in the standard model (SM) the flavor changing neutral current (FCNC) processes appear at the quantum level with suppression factors by small electroweak gauge coupling, CKM matrix elements, and loop momenta, they are very sensitive to probe new physics (NP) beyond the SM which have an enhancement factor in the coupling or have tree-level FCNCs.

The decay of B mesons accumulated largely at asymmetric B-factories and Tevatron give an opportunity to probe NP models via the rare B decays induced by FCNCs. Recently, among several sources for FCNCs in the B decays, the electroweak (EW) penguin operators have drawn much interest. For example, the QCD penguin dominant $B \to K\pi$ decays appear to be very interesting since branching ratios (BRs) and mixing-induced CP asymmetry allow much room for large NP contribution, especially in the EW penguin sector [1, 2].

Most of models contributing to the EW penguin sector have a severe constraint from the $b \to s\gamma$ decay. While, models such as the Z' model are free from such constraints although they predict the EW penguin contributions. In order to probe such NP models, one must resort to nonleptonic decays or very rare process $B \to M\nu\bar{\nu}(M = \pi, K, \rho, K^*)$. However, nonleptonic decays might be inefficient since they suffer from large hadronic uncertainties and EW penguins contributions are subdominant in nonleptonic decays.

Recently, DØ [3] and CDF [4] Collaborations at Fermilab Tevatron have reported the first observation of the mass difference Δm_s in the $B_s^0 - \overline{B}_s^0$ system which induced by the $b \to s$ FCNC:

$$\begin{array}{lll} \text{DØ} & : & 17\ \text{ps}^{-1} < \Delta m_s < 21\ \text{ps}^{-1} \quad (90\%\ \text{C.L.})\,, \\ \text{CDF} & : & \Delta m_s = 17.33^{+0.42}_{-0.21}(\text{stat.}) \pm 0.07(\text{syst.})\ \text{ps}^{-1}. \end{array} \tag{1}$$

These measurements may give strong constraints on the NP models, which predict $b \to s$ FCNC transitions [5, 6].

In the present work, we focus on the leptophobic Z' model motivated from the flipped SU(5) or string-inspired E_6 models as a viable NP model. In Sec. 2, we briefly introduce the leptophobic Z' model. Section 3 deals with $B \to M\nu\bar{\nu}$ $(M = \pi, K, \rho, K^*)$ decays within the leptophobic Z' model. We investigate implications of Δm_s measurements on this model in Sec. 4 and conclude in Sec. 5.

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2 Leptophobic Z' model and FCNC

In many new physics scenarios containing an additional $U(1)'$ gauge group at the low energy, the new neutral gauge boson Z' would have a property of leptophobia, which means that the Z' boson does not couple to the ordinary SM charged leptons. In flipped SU(5)×U(1) scenario [7], leptophobia of the Z' boson can be given naturally because the neutrino is subject to the different representation with the charged leptons. Another scenario for leptophobia can be found in the E_6 model with kinetic mixing, where in this model leptophobia is somewhat accidental. After breaking of the E_6 group, the low energy effective theory contains an extra U(1)′ which is a linear combination of $\mathrm{U}(1)_\psi$ and $\mathrm{U}(1)_\chi$ with a E_6 mixing angle θ [8]. Then, the general interaction Lagrangian of fermion fields and Z' gauge boson can be written as

$$\mathcal{L}_{\rm int} = -\lambda \frac{g_2}{\cos\theta_W}\sqrt{\frac{5\sin^2\theta_W}{3}}\bar{\psi}\gamma^\mu\left(Q' + \sqrt{\frac{3}{5}}\delta Y_{SM}\right)\psi Z'_\mu , \tag{2}$$

where the ratio of gauge couplings $\lambda = g_{Q'}/g_Y$, and $\delta = -\tan\chi/\lambda$ [8]. Since the general fermion-Z' couplings depend on two free parameters, $\tan\theta$ and δ, effectively, the Z' boson can be leptophobic within an appropriate embedding of the SM particles [8, 9].

Assuming $V_L^d = 1$ in the E_6 model and flipped SU(5) model, only Z'-mediating FCNCs in the right-handed down-type quarks survive. Then, one can get the FCNC Lagrangian for the $b \to q (q = s, d)$ transition [10]

$$\mathcal{L}^{Z'}_{\rm FCNC} = -\frac{g_2}{2\cos\theta_W}U^{Z'}_{qb}\bar{q}_R\gamma^\mu b_R Z'_\mu, \tag{3}$$

where all the theoretical uncertainties including the mixing parameters are absorbed into the coupling $U^{Z'}_{qb}$. The coupling $U^{Z'}_{sb}$ has in general CP violating complex phase, which we denote as $\phi^{Z'}_{sb}$. We note that the leptophobic Z' boson is not well constrained by experiments including the charged leptons such as $b \to s\ell^+\ell^-$ or $B_{(s)} \to \ell^+\ell^-$, while the typical new physics models are strongly constrained by such experiments.

3 Exclusive $B \to M\nu\bar{\nu}$ Decays

In this section, we consider the $B \to M\nu\bar{\nu}$ decays in the leptophobic Z' model. The $B \to M\nu\bar{\nu}$ decays are measured via the scalar or vector meson with the missing energy signal.

Theoretical estimates for BRs of the $B \to M\nu\bar{\nu}$ decays in the SM are $0.22^{+0.27}_{-0.17}$, $5.31^{+1.11}_{-1.03}$, $0.49^{+0.61}_{-0.38}$, and $11.15^{+3.05}_{-2.70}$ in units of 10^{-6}, respectively. While experiments by the Belle and BaBar Collaborations have reported only upper limits on BRs of $B \to K\nu\bar{\nu}$ and $B \to \pi\nu\bar{\nu}$ decays [12, 13], where the experimental bounds are about 7 times larger than the SM expectation for the K production and much larger by an order of 10^3 for the π production.

The leptophobic Z' model can yield same signals as $B \to K\nu_{\rm SM}\bar{\nu}_{\rm SM}$ at detectors via the production of a pair of right-handed neutrinos instead of the ordinary SM neutrinos. In Fig. 1, we present our predictions for the BRs in the leptophobic Z' model as a function of the effective coupling $|U^{Z'}_{qb}|$, where the mass of the Z' boson is assumed to be 700 GeV. The solid and dotted lines represent the estimates in the SM and the current experimental bounds, respectively. The dashed line denotes the expected BRs in the leptophobic Z' model. In spite that we choose a specific mass for the Z' boson, the present analysis can be easily translated through the corresponding changes in the effective coupling $|U^{Z'}_{qb}|$ for different Z' boson mass. We extract the following constraints for the FCNC couplings from Fig. 1

$$|U^{Z'}_{sb}| \le 0.29, \quad |U^{Z'}_{db}| \le 0.61, \tag{4}$$

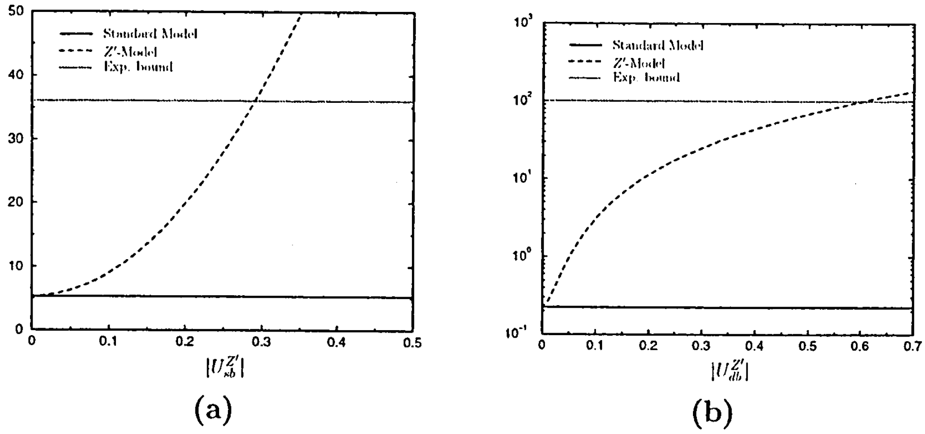

Figure 1: Branching ratios for (a) $B^{\pm} \to K^{\pm}\nu\bar{\nu}$ and (b) $B^{\pm} \to \pi^{\pm}\nu\bar{\nu}$, where ν can be the ordinary SM neutrinos or right-handed neutrinos.

for $B \to K\nu\bar{\nu}$ and $B \to \pi\nu\bar{\nu}$ decays, respectively [10]. The present exclusive mode gives more stringent bounds on the leptophobic FCNC coupling compared with the inclusive $b \to s\nu\bar{\nu}$ decay [9].

Recently, the Belle Collaboration has reported upper limits on the production of the K^* meson with the missing energy signal at the B decay where its BR is expected to be about 3 times larger than that of the scalar meson production in the SM [11]. It provides the constraint on the FCNC coupling

$$|U_{sb}^{Z'}| \leq 0.66, \tag{5}$$

which is larger than that in Eq. (4). At the super-B factory, all four decay modes $B \to M\nu\bar{\nu}$ would be well measured and give more stringent bounds on the FCNC couplings.

The exclusive modes are much easier at the experimental detection than the inclusive ones. However, the exclusive modes have inevitable large theoretical uncertainties from hadronic transition form factors. In order to reduce hadronic uncertainties, one can take ratios for $\mathcal{B}(B \to M\nu\bar{\nu})$ to $\mathcal{B}(B \to Me\nu)$ for $M = \pi, \rho$ mesons [10].

4 $B_s^0 - \bar{B}_s^0$ Mixing

The Z'-exchanging $\Delta B = \Delta S = 2$ tree diagram contributes to the $B_s^0 - \overline{B}_s^0$ mixing [14]. The mass difference Δm_s of the mixing parameters then read

$$\Delta m_s = \Delta m_s^{\rm SM} \left| 1 + R\, e^{2i\phi_{sb}^{Z'}} \right|, \tag{6}$$

$$R \equiv \frac{2\sqrt{2}\pi^2}{G_F M_W^2 \left(V_{tb}V_{ts}^*\right)^2 S_0(x_t)} \frac{M_Z^2}{M_{Z'}^2} \left|U_{sb}^{Z'}\right|^2 = 1.62 \times 10^3 \left(\frac{700\ \text{GeV}}{M_{Z'}}\right)^2 \left|U_{sb}^{Z'}\right|^2. \tag{7}$$

In Figs. 2, the allowed region in ($|U_{sb}^{Z'}|$,$\phi_{sb}^{Z'}$) plane is shown. We obtain

$$|U_{sb}^{Z'}| \leq 0.0055 \qquad \text{for } \mathrm{M}_{Z'} = 700\ \text{GeV}, \tag{8}$$

for $\phi_{sb}^{Z'} = 0$. This bound is about two orders of magnitude stronger than (4) obtained from exclusive semileptonic $B \to M\nu\bar{\nu}$ decays.

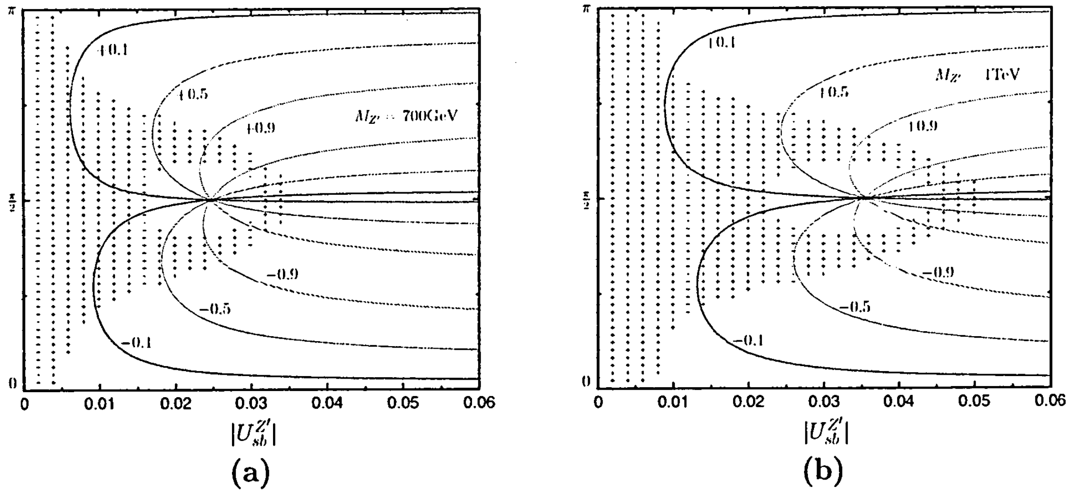

Figure 2: The allowed region in ($|U_{sb}^{Z'}|$,$\phi_{sb}^{Z'}$) plane for (a) $M_{Z'}$ = 700 GeV and (b) $M_{Z'}$ = 1 TeV . We used (HP+JL)QCD result in [15] for the hadronic parameter. Constant contour lines for the time dependent CP asymmetry $S_{\psi\phi}$ in $B_s \to J/\psi\ \phi$ are also shown.

The holes appear because they predict too small Δm_s. For a given $M_{Z'}$ we can see that large CP violating phase can enhance the allowed coupling $|U_{sb}^{Z'}|$ up to almost factor 10. This shows the importance of the role played by CP violating phase even in CP conserving observable such as Δm_s. As can be seen from Fig. 3(b), irrespective of its phase $\phi_{sb}^{Z'}$ value

$$|U_{sb}^{Z'}| \leq 0.051 \qquad \text{for } \mathrm{M}_{Z'} = 1 \text{ TeV}. \tag{9}$$

The CP violating phase in $B_s^0 - \overline{B}_s^0$ mixing amplitude can be measured at LHC in near future through the time-dependent CP asymmetry in $B_s \to J/\psi\ \phi$ decay

$$\frac{\Gamma\left(\overline{B}_s^0(t) \to J/\psi\ \phi\right) - \Gamma\left(B_s^0(t) \to J/\psi\ \phi\right)}{\Gamma\left(\overline{B}_s^0(t) \to J/\psi\ \phi\right) + \Gamma\left(B_s^0(t) \to J/\psi\ \phi\right)} \equiv S_{\psi\phi} \sin\left(\Delta m_s t\right). \tag{10}$$

We note that although the final states are not CP-eigenstates, the time-dependent analysis of the $B_s^0 \to J/\psi\ \phi$ angular distribution allows a clean extraction of $S_{\psi\phi}$ [16]. In the SM, $S_{\psi\phi}$ is predicted to be very small, $S_{\psi\phi}^{\rm SM} = -\sin 2\beta_s = 0.038 \pm 0.003$ ($\beta_s \equiv \arg\left[(V_{ts}^* V_{tb})/(V_{cs}^* V_{cb})\right]$). If NP has an additional CP violating phase $\phi_{sb}^{Z'}$, however, the experimental value of

$$S_{\psi\phi} = -\sin\left[2\beta_s + \arg\left(1 + R\ e^{2i\phi_{sb}^{Z'}}\right)\right] \tag{11}$$

would be significantly different from the SM prediction. Constant contour lines for $S_{\psi\phi}$ are also shown in Figs. 2. We can see that even with the strong constraint from the present Δm_s observation, large $S_{\psi\phi}$ are still allowed.

5 Concluding Remarks

In this talk, we have considered the leptophobic Z' model with FCNC couplings. Since the direct probe of the leptophobic Z' model is very difficult, the exclusive $B \to M\nu\bar{\nu}$ decay are very adequate to measure the FCNC coming form this model. We have also showed that the recently measured mass difference Δm_s of $B_s^0-\overline{B}_s^0$ system can constrain this kind of models very efficiently. Although the bounds on the coupling estimated from the latter are about two orders of magnitudes stronger than those from the former, both measurements are complementary.

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