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Probe a family non-universal Z' boson effects in $\bar{B}_s \to \phi\mu^+\mu^-$ decay

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Abstract

Motivated by the recent measurement on $\mathcal{B}(\bar{B}_s \to \phi\mu^+\mu^-)$ by CDF Collaboration, we study the effects of a family non-universal Z' boson on rare semileptonic $\bar{B}_s \to \phi\mu^+\mu^-$ decay. In our evaluations, we analyze the dependences of the dimuon invariant mass spectrum and normalized forward–backward asymmetry on Z' couplings and show that these observables are highly sensitive to new Z' contributions. Three limiting scenarios are presented in the detailed analyses. Numerically, within the allowed ranges of Z' couplings under the constraints from $\bar{B}_s - B_s$ mixing, $B \to \pi K$, $\bar{B}_d \to (X_s, K, K^*)\mu^+\mu^-$ decays and so on, $\mathcal{B}(\bar{B}_s \to \phi\mu^+\mu^-)$ and $A_{\rm FB}^{(L)}(\bar{B}_s \to \phi\mu^+\mu^-)$ could be enhanced by about 96% and 17% (133%) respectively at most by Z' contributions. However, $\mathcal{B}(\bar{B}_s \to \phi\mu^+\mu^-)$ is hardly to be reduced. Furthermore, the zero crossing in $A_{\rm FB}(\bar{B}_s \to \phi\mu^+\mu^-)$ spectrum at low dimuon mass always exists.

Keywords: B-physics; Rare decays; Beyond Standard Model

1. Introduction

Rare B decays induced by the flavor-changing neutral current (FCNC) occur at loop level in the Standard Model (SM) and thus proceed at a low rate. They can provide useful information on the parameters of the SM and test its predictions. Meanwhile, they offer a valuable possibility of an indirect search of new physics (NP) for their sensitivity to the gauge structure and new con-

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tributions. Experimentally, the fruitful running of BaBar, Belle and Tevatron in the past decade provides a very fertile ground for testing SM and probing possible NP effects. As particle physics is entering the era of LHC, B_s physics has attracted much more attention.

Recently, CDF Collaboration has reported the first observation of the rare semileptonic $\bar{B}_s \to \phi\mu^+\mu^-$ decay and measured its branching fraction to be [1]

$$\mathcal{B}(\bar{B}_s \to \phi\mu^+\mu^-) = \left[1.44 \pm 0.33(\text{stat.}) \pm 0.46(\text{syst.})\right] \times 10^{-6} \quad \text{CDF}. \tag{1}$$

Theoretically, many evaluations for $\bar{B}_s \to \phi\mu^+\mu^-$ decay have been done within both SM and various NP scenarios (for example, Refs. [2,3]). The SM prediction for $\mathcal{B}^{\text{SM}}(\bar{B}_s \to \phi\mu^+\mu^-)$ ($\sim 1.65 \times 10^{-6}$ (QCDSR) [2], for example) agrees well with CDF measurement $(1.44 \pm 0.57) \times 10^{-6}$ for large experimental error. If more exact measurement on $\bar{B}_s \to \phi\mu^+\mu^-$ is gotten by the running LHC-b and future super-B, the possible NP space will be strongly constrained or excluded. So, it is worth evaluating the effects of the possible NP, such as a family non-universal Z' boson, on $\bar{B}_s \to \phi\mu^+\mu^-$ decay.

A new family non-universal Z' boson could be naturally derived in certain string constructions [4], E_6 models [5] and so on. Searching for such an extra Z' boson is an important mission in the experimental programs of Tevatron [6] and LHC [7]. The general framework for non-universal Z' model has been developed in Ref. [8]. Within such model, FCNC in $b \to s$ and d transitions could be induced by family non-universal $U(1)'$ gauge symmetries at tree level. Its effects on $b \to s$ transition have attracted much more attention and been widely studied. Interestingly, the behavior of a family non-universal Z' boson is helpful to resolve many puzzles in $B_{(u,d,s)}$ decays, such as "πK puzzle" [9,10], anomalous $\bar{B}_s - B_s$ mixing phase [11,12] and mismatch in $A_{\text{FB}}(B \to K^*\mu^+\mu^-)$ spectrum at low q^2 region [13,14].

Within a family non-universal Z' model, $\bar{B}_s \to \phi\mu^+\mu^-$ decay involves b–s–Z' and μ–μ–Z' couplings, which have been strictly bounded by the constraints from $\bar{B}_s - B_s$ mixing, $B \to \pi K^{(*)}$, ρK, $\bar{B}_d \to X_s\mu\mu$, $K^{(*)}\mu\mu$ decays and so on [10,12,13]. So, it is worth evaluating the effects of a non-universal Z' boson on $\bar{B}_s \to \phi\mu^+\mu^-$ decay and checking whether such settled values of Z' couplings are permitted by CDF measurement on $\mathcal{B}(\bar{B}_s \to \phi\mu^+\mu^-)$.

Our paper is organized as follows. In Section 2, we briefly review the theoretical framework for $b \to s\ell^+\ell^-$ decay within both SM and a family non-universal Z' model. In Section 3, the effects of a non-universal Z' boson on $\bar{B}_s \to \phi\mu^+\mu^-$ decay are investigated in detail. Our conclusions are summarized in Section 4. Appendices A and B include all of the theoretical input parameters.

2. The theoretical framework for $b \to s\ell^+\ell^-$ decays

In the SM, neglecting the doubly Cabibbo-suppressed contributions, the effective Hamiltonian governing semileptonic $b \to s\ell^+\ell^-$ transition is given by [15,16]

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu). \tag{2}$$

Here we choose the operator basis given by Ref. [15], in which

$$O_9 = \frac{e^2}{g_s^2} (\bar{d}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l), \qquad O_{10} = \frac{e^2}{g_s^2} (\bar{d}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l). \tag{3}$$

Wilson coefficients C_i can be calculated perturbatively [17–20], with the numerical results listed in Table 1. The effective coefficients $C_{7,9}^{\text{eff}}$, which are particular combinations of $C_{7,9}$ with the