(Pseudo-) Scalar Operators in the MSSM and $B \to \phi K^*, K\eta^{(\prime)}$ Decays

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We study the effect of $b \to s\bar{s}s$ scalar/pseudoscalar operators, originating from penguin diagrams of neutral Higgs bosons in the MSSM, in $B \to K\eta^{(\prime)}$ and $B \to \phi K^*$ decays. These operators can be Fierz-transformed into tensor operators, and the resultant tensor operators could affect the transverse polarization amplitudes in $B \to \phi K^*$ decays. We find that only when the weak annihilations in $B \to \phi K^*$ into account, the polarization puzzle can be resolved, so that new physics effects are strongly suppressed and no more relevant to the enhancement of the transverse modes in $B \to \phi K^*$ decays. (This presentation is based on the work [1])

I. INTRODUCTION

In the $B \to VV$ (V denotes a vector meson) decays, polarizations of the two vector mesons have been extensively studied by experiments. The decay amplitude for the B meson to two vector mesons can be decomposed into three parts. In the transversity basis they are longitudinal A_0 and two transverse modes, where the latter consist of the parallel $A_\parallel$ and the perpendicular $A_\perp$. In terms of them we can define the polarization fractions as $f_L = |A_0|^2$, $f_\parallel = |A_\parallel|^2$ and $f_\perp = |A_\perp|^2$. Here we take the normalization: $|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$. The naive factorization estimation yields $f_L : f_\parallel : f_\perp = 1 - \mathcal{O}(\Lambda^2/m_b^2) : \mathcal{O}(\Lambda^2/m_b^2) : \mathcal{O}(\Lambda^2/m_b^2)$. However, in the penguin dominated $B \to VV$ decays it is not the case. For example, the polarization fractions in $B \to \phi K^*(892)$ decays are [2, 3, 4, 5]

$$\begin{aligned} f_L(B^+ \to \phi K^{*+}) &= 0.50 \pm 0.05, \\ f_L(B^0 \to \phi K^{*0}) &= 0.484 \pm 0.034, \\ f_\perp(B^+ \to \phi K^{*+}) &= 0.20 \pm 0.05, \\ f_\perp(B^0 \to \phi K^{*0}) &= 0.256 \pm 0.032. \end{aligned} \tag{1}$$

These results are very different from the naive expectations. Such discrepancy between the theory and experiments in the $B \to VV$ decays is referred as "the polarization puzzle (anomaly)". One possibility of resolving the puzzle is to resort to the new physics (NP). In [6] it is pointed out that tensor operators may play an essential role of helicity flipping of the quarks. One of the resolutions within the standard model (SM) framework is to take into account the large weak-annihilation effect [7, 8, 9]. In [7, 8], the author pointed out that the magnitude of annihilation correction is order of $\mathcal{O}(1/m_b^2 \log^2 m_b/\Lambda_h)$, and the effect can interfere with the longitudinal and transverse modes destructively and constructively, respectively. It is noted, however, that the perturbative QCD (pQCD) yields $f_L \gtrsim 0.75$ even with annihilation effects [10]. In this presentation, we take into account $B \to \phi K^*$ and $B \to K\eta^{(\prime)}$ data to further constrain the possible NP contributions.

II. FORMULATION AND ANALYSIS

In [6], $b \to s\bar{s}s$ NP operators O_i ($i = 11, \cdots, 26$) are introduced to resolve the polarization puzzle. These operators are not independent and can be related with each other through the following Fierz transformations:

$$\begin{aligned} &O_{19} = -\frac{1}{2}O_{14}, \quad O_{20} = -\frac{1}{2}O_{13}, \\ &O_{21} = -\frac{1}{2}O_6, \quad O_{22} = -\frac{1}{2}O_5, \\ &O_{23} = -4O_{15} - 8O_{16}, \quad O_{24} = -8O_{15} - 4O_{16}, \\ &O_{25} = -4O_{17} - 8O_{18}, \quad O_{26} = -8O_{17} - 4O_{18}. \end{aligned} \tag{2}$$

In the naive factorization, the $B \to VV$ decay amplitudes are sensitive to tensor operators but insensitive to scalar ones. On the other hand, for $B \to PP$ (where P is a pseudo-scalar meson) decay amplitudes it is the other way around.

In the MSSM, scalar operators are induced by the neutral-Higgs penguin diagrams [1, 11]:

$$\begin{aligned} c_{15} = D(A-B)\xi, \quad c_{17} = D(A-B)\xi', \\ c_{19} = D(A+B)\xi, \quad c_{21} = D(A+B)\xi', \end{aligned} \tag{3}$$

where

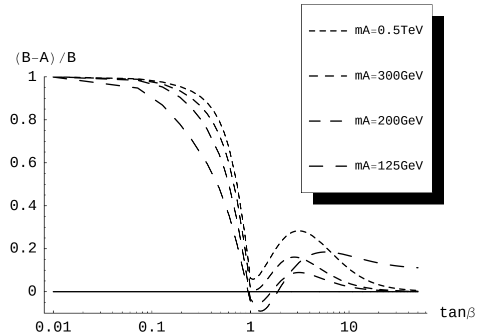
$$\begin{aligned} D &\equiv \frac{1}{12\pi^2}\frac{1}{\lambda_t}\frac{e^2 g_s^2}{g^2 \sin^2\theta_W} f_b'(m_{\tilde{q}}^2/m_{\tilde{g}}^2) m_s m_{\tilde{g}}, \\ A &\equiv \frac{1}{m_{H^0}^2}\left(\frac{\cos^2\alpha + (m_{H^0}^2/m_{h^0}^2)\sin^2\alpha}{\cos^2\beta}\right), \\ B &\equiv \frac{1}{m_{A^0}^2}\left(\frac{m_{A^0}^2}{m_{Z^0}^2} + \tan^2\beta\right), \\ \xi &\equiv \delta_{23}^{dLL}\delta_{33}^{dLR}, \quad \xi' \equiv \delta_{23}^{dRR}\delta_{33}^{dLR*}. \end{aligned} \tag{4}$$

We find that A and B are not independent and constrained by $-0.1 \lesssim (B-A)/B \leq 1$ (see FIG. 1).

Tensor operators are not directly induced in the MSSM and can be obtained from scalar operators through the Fierz-transformations. In the $B \to K\eta^{(\prime)}$ decays, the NP effects modify the Wilson coefficients $c_{5,6} \to c_{5,6} + \Delta c_{5,6}$:

$$\Delta c_6 = \begin{cases} DB(\xi - \xi'), & \text{for } \alpha_4, \beta_3 \\ \frac{1}{2}[2 - (B-A)/2], & \text{for } \alpha_3, \beta_2, \beta_{S3}, \end{cases}$$

FIG. 1: The ratio $(B-A)/B$ for various $\tan\beta$ and m_A



$$\Delta c_5 \;=\; 0. \qquad (5)$$

Here the α_i, β_j are defined in [1, 12, 13]. In $B \to \phi K^*$ decays the NP effects modify the Wilson coefficients $c_i \to \bar{c}_i$, where

$$\bar{c}_6 - c_6 = \frac{1}{2}\left(\frac{B-A}{B} - 2\right) DB\xi',$$
$$\bar{c}_{14} = \frac{1}{2}\left(\frac{B-A}{B} - 2\right) DB\xi,$$
$$c_{23} = \frac{1}{12}D(A-B)\xi, \quad c_{24} = -\frac{1}{6}D(A-B)\xi,$$
$$c_{25} = \frac{1}{12}D(A-B)\xi', \quad c_{24} = -\frac{1}{6}D(A-B)\xi'. \quad (6)$$

The contributions of the NP tensor operators to the decay amplitudes in the transversity basis are given by

$$\begin{aligned}
\overline{A}_0^{NP} &= -4if_\phi^T m_B^2[\tilde{a}_{23} - \tilde{a}_{25}][h_2T_2(m_\phi^2) - h_3T_3(m_\phi^2)], \\
\overline{A}_\parallel^{NP} &= 4i\sqrt{2}f_\phi^T m_B^2[\tilde{a}_{23} - \tilde{a}_{25}]f_2T_2(m_\phi^2), \\
\overline{A}_\perp^{NP} &= 4i\sqrt{2}f_\phi^T m_B^2[\tilde{a}_{23} + \tilde{a}_{25}]f_1T_1(m_\phi^2), \qquad (7)
\end{aligned}$$

where

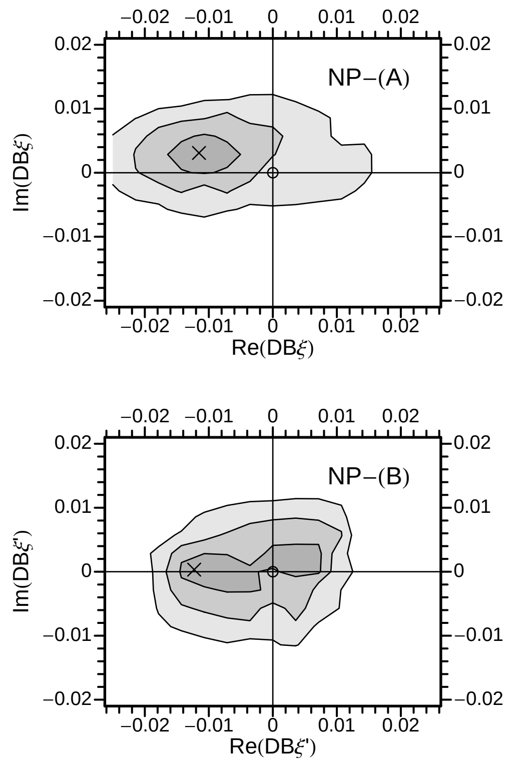
$$\tilde{a}_{23} \equiv \bar{c}_{23} + \frac{1}{2}\bar{c}_{24} + \mathcal{O}(\alpha_s) \simeq \frac{1}{8N_c}\frac{B-A}{B}DB\xi,$$
$$\tilde{a}_{25} \equiv \bar{c}_{25} + \frac{1}{2}\bar{c}_{25} + \mathcal{O}(\alpha_s) \simeq \frac{1}{8N_c}\frac{B-A}{B}DB\xi'. \quad (8)$$

In the χ^2 fit, we have used 20 observables from $B^0 \to \phi K^{*0}$ and $B^+ \to \phi K^{*+}$ data, and 7 observables from $B \to K\eta^{(\prime)}$. As for NP fitting parameters we use $(B-A)/B$, $DB\xi$, and $DB\xi'$. For simplicity we consider the two NP scenarios: (A) NP-scenario where $\xi \neq 0$, $\xi' = 0$ and (B) NP scenario where $\xi = 0$, $\xi' \neq 0$. We include the annihilation contributions in the decay amplitudes [9].

III. RESULTS AND COMMENTS

We take the annihilation effects into account and perform χ^2 fitting. The results are $\chi^2_{\rm min}/{\rm d.o.f} =$ 9.8/17 for the scenario (A) and 15.5/17 for (B). The contour-plots of the χ^2 fits are shown in FIG. 2. It should be noted that, if ignoring the $B \to \phi K^*$ annihilation contributions we could not find any solutions which explain both the $B \to K\eta^{(\prime)}$ and $B \to \phi K^*$ data cannot be satisfied simultaneously.

FIG. 2: Contour plots for $\Delta\chi^2 \equiv \chi^2 - \chi^2_{min}$ [1]. Allowed regions of $\Delta\chi^2 \leq 1$, $1 \leq \Delta\chi^2 \leq 4$ and $4 \leq \Delta\chi^2 \leq 9$ are shown by dark, medium-dark and light-gray regions. "×" indicates the location of the global minimum. The origin corresponds to the SM, and the circle at the origin indicates the allowed upper-limit from the $B_s \to \mu^+\mu^-$ data.



From the results for $DB\xi^{(\prime)}$ and the fact that $-0.1 \lesssim (B-A)/B \leq 1$ we obtain

$$|\tilde{a}_{23}| \leq 7.1 \times 10^{-4}, \quad |\tilde{a}_{25}| \leq 6.1 \times 10^{-4}, \qquad (9)$$

which are much smaller than the values given in [6],

$$\begin{aligned}
|\tilde{a}_{23,\rm DY}| &= 4.4^{+0.3}_{-0.2} \times 10^{-3}, \\
|\tilde{a}_{25,\rm DY}| &= 5.4^{+0.5}_{-0.3} \times 10^{-3}, \qquad (10)
\end{aligned}$$

where the annihilation contributions are ignored. We conclude that the polarization puzzle can be resolved by the SM weak-annihilation effect if the NP tensor operators are induced by the NP scalar ones. Moreover, scalar operators can be strongly constrained by the upper-bound of the $B_s \to \mu^+\mu^-$ decay [14]:

$$\mathcal{B}(B_s \to \mu^+\mu^-) \leq 7.5 \times 10^{-8}. \qquad (11)$$

In FIG. 2 the bound is indicated as the small circle at the origin. Since in both scenarios the $B_s \to \mu^+\mu^-$ data and the SM are located within contours where χ^2/d.o.f. is sufficiently small, we thus conclude that the new-physics effects due to the scalar operators may be negligible.

Finally we make a remark on the recently observed large polarization fraction f_L for $B \to \phi K_2^*(1430)$ [2]. If tensor operators play an significant role in $B \to VT$ (T denotes a tensor meson) decays, f_L may significantly deviate from unity. The current experiment is consistent with our result since in our analysis the tensor operator are found to be tiny. However, in the present study we cannot exclude the possibility that sizable NP effects contribute directly to tensor operators, instead of scalar/pseudoscalar operators, and, moreover, a cancellation may take place between weak annihilation and contributions due to NP tensor operators in the $B \to \phi K_2^*(1430)$ decay. For the point of view of the new physics, $B \to \phi K_2^*(1430)$ may be sensitive to the $B \to K_2^*(1430)$ tensor form factor which can be further explored from the $B \to K_2^*(1430)\gamma$ decay.

Acknowledgments

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