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Implication of the LHCb results for the anomalous tsW couplings

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We have studied the effects of anomalous tsW couplings on the CP violation in B physics. We show that there is a tension between the CP phase satisfying the like-sign dimuon charge asymmetry measured by the D0 collaboration at Tevatron and that in B_s mixing through $B \to J/\psi X$ by the LHCb collaboration.

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1. Introduction

We study effects of anomalous right-handed $\bar{t}sW$ couplings on the recently measured CP violating variables. We will consider the time-dependent CP asymmetry in $B \to \phi K$ decay at Belle and BaBar, the like-sign dimuon charge asymmetry at D0, and the CP violating phase in B_s mixing at the LHCb. Present experimental constraints from $B \to X_s \gamma$ decay and the mass difference of the neutral B_s mesons are applied.

We introduce additional top quark couplings to redefine the effective CKM matrix elements [1] :

$$\begin{aligned}\mathscr{L} &= -\frac{g}{\sqrt{2}} \sum_{q=b,s,d} V_{tq}^{\rm SM} \left(\bar{t}\gamma^\mu P_L q W_\mu^+ + \bar{t}\gamma^\mu (g_L^q P_L + g_R^q P_R) q W_\mu^+ \right) + H.c. \\ &= -\frac{g}{\sqrt{2}} \sum_{q=b,s,d} V_{tq}^{\rm eff}\, \bar{t}\gamma^\mu (P_L + \xi_q P_R) q W_\mu^+ + H.c., \end{aligned} \tag{1.1}$$

where $V_{tq}^{\rm eff} = V_{tq}^{\rm SM}(1+g_L^q)$ is the effective Cabibbo-Kobayashi-Maskawa (CKM) matrix elements and $V_{tq}^{\rm eff}\xi_q = V_{tq}^{\rm SM} g_R^q$ measures the anomalous right-handed couplings. In this work, we focus on the $\bar{t}sW$ coupling only. We do not specify underlying models and assume no effects of new particles and additional neutral currents interactions.

2. Bounds from $B \to X_s\gamma$ and $B_s - \bar{B}_s$ mixing

Since contributions of the right-handed top quark couplings to the penguin diagram for $b \to s$ transition are enhanced by a factor of m_t/m_b, the radiative $B \to X_s\gamma$ decays are sensitive to the anomalous right-handed top couplings and provide strong constraints on them. The branching ratio of the $B \to X_s\gamma$ decays including ξ_s effects is given by

$$\begin{aligned}{\rm Br}(B \to X_s\gamma) &= {\rm Br}^{\rm SM}(B \to X_s\gamma) \left(\frac{|V_{ts}^{\rm eff *} V_{tb}^{\rm eff}|}{0.0404} \right)^2 \\ &\times \left[1 + |\xi_s|^2 \frac{m_t^2}{m_b^2} \left(0.112 \frac{F_R^2(x_t)}{F^2(x_t)} + 0.002 \frac{G_R^2(x_t)}{G^2(x_t)} + 0.025 \frac{F_R(x_t)G_R(x_t)}{F(x_t)G(x_t)} \right) \right], \end{aligned} \tag{2.1}$$

where the numerical coefficients are obtained by using the RG evolution in Ref. [2] and the Inami-Lim loop functions $F(x), G(x), F_R(x)$ and $G_R(x)$ are found elsewhere [3, 4]. The Standard Model (SM) prediction for the branching ratio is given by ${\rm Br}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ [5] and the current world average value of the measured branching ratio given by ${\rm Br}(B \to X_s\gamma) = (3.55 \pm 0.24^{+0.09}_{-0.10} \pm 0.03) \times 10^{-4}$ [6] for the photon energy cut $E_\gamma > 1.6$ GeV.

The transition amplitude M_{12}^s for $B_s - \bar{B}_s$ mixing is obtained from the box diagrams in our model. Since the loop integral including an odd number of right-handed couplings vanishes, the leading contribution of ξ_s to M_{12}^s is of quadratic order. We write M_{12}^s as

$$M_{12}^s = M_{12}^{s,SM} \left(\frac{V_{ts}^{\rm eff *} V_{tb}^{\rm eff}}{V_{ts}^{\rm SM *} V_{tb}^{\rm SM}} \right)^2 \left(1 + \frac{S_3(x_t)}{S_0(x_t)} \frac{\xi_s^2}{4} \frac{\langle \bar{B}_s^0 | (\bar{b} P_R s)(\bar{b} P_R s) | B_s^0 \rangle}{\langle \bar{B}_s^0 | (\bar{b}\gamma^\mu P_L s)(\bar{b}\gamma_\mu P_L s) | B_s^0 \rangle} \right), \tag{2.2}$$

where the loop functions for new box diagrams are given in Ref. [1] and the SM loop function $S_0(x)$ found in Ref. [3]. The mass difference between the neutral B_s mesons are obtained by $\Delta M_s =$

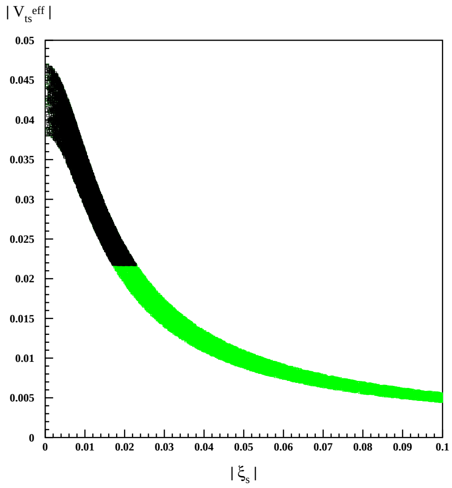

Figure 1: Allowed parameters $(|\xi_s|, |V_{ts}^{\rm eff}|)$ under the B physics constraints. The whole band of the green (grey) + black regions is allowed by $\mathrm{Br}(B \to X_s \gamma)$ only. The black regions are allowed by $\mathrm{Br}(B \to X_s \gamma)$ and ΔM_s. The confidence level is at 95 % C.L..

$2|M_{12}^s|$. The SM prediction for ΔM_s is $\Delta M_s = 19.30 \pm 6.74 \pm 0.07$ ps^{-1} [7] and the measurement is $\Delta M_s = 17.77 \pm 0.10 \pm 0.07$ ps^{-1} [6].

We get constraints on the tsW couplings from $B \to X_s \gamma$ decays and ΔM_s. Figure 1 shows the allowed values of $|\xi_s|$ and $|V_{ts}^{\rm eff}|$ at the 95 % C.L. A substantial change of the amplitude by a large contribution of ξ_s is possible due to the compensation by a shift of $V_{ts}^{\rm eff}$.

3. CP violation

3.1 $B \to \phi K$ decays

The decay amplitude of $B \to \phi K$ decays with anomalous top couplings are given in Ref. [1]. The time-dependent CP asymmetry in $B \to \phi K$ decays is given by

$$a_{\phi K}(t) \equiv \frac{\Gamma(\bar{B}^0(t) \to \phi \bar{K}^0) - \Gamma(B^0(t) \to \phi K^0)}{\Gamma(\bar{B}^0(t) \to \phi \bar{K}^0) + \Gamma(B^0(t) \to \phi K^0)} = S_{\phi K} \sin \Delta m_B t - C_{\phi K} \cos \Delta m_B t, \qquad (3.1)$$

where the coefficients are written as

$$S_{\phi K} = \frac{2 \mathrm{Im} \lambda}{1 + |\lambda|^2}, \quad C_{\phi K} = \frac{1 - |\lambda|^2}{1 + |\lambda|^2} = -A_{\phi K}, \qquad (3.2)$$

in terms of $\lambda \equiv \sqrt{M_{12}^{d\,*}/M_{12}^d}(\bar{A}/A)$, with $A = \mathscr{A}(B^0 \to \phi K^0)$, $\bar{A} = \mathscr{A}(\bar{B}^0 \to \phi \bar{K}^0)$. Note that the direct CP violation arises in $b \to s$ decays due to new phases of ξ_s and $V_{ts}^{\rm eff}$ in our model. The average measured values are $-\eta S_{\phi K} = 0.44^{+0.17}_{-0.18}$, and $C_{\phi K} = -0.23 \pm 0.15$ [6], which yield the allowed values of the phase of $V_{ts}^{\rm eff}$ is given by $-87.8^o < \theta_{ts}^{\rm eff} < 20.1^o$ at 95% C.L..

3.2 D0 dimuon charge asymmetry

Recently, the CP violating like-sign dimuon charge asymmetry for b hadrons measured by the D0 collaboration at Tevatron shows a deviation of 3.9 σ from the SM prediction [8]. The like-sign dimuon charge asymmetry is defined by

$$A^b_{sl} \equiv \frac{\Gamma(b\bar{b} \to \mu^+\mu^+X) - \Gamma(b\bar{b} \to \mu^-\mu^-X)}{\Gamma(bb \to \mu^+\mu^+X) + \Gamma(bb \to \mu^-\mu^-X)} = (0.506 \pm 0.043)a^d_{sl} + (0.494 \pm 0.043)a^s_{sl}, \quad (3.3)$$

where a^q_{sl} are the charge asymmetry of semileptonic decays of neutral B^0_q mesons. In the SM, the asymmetry is close to zero, $A^b_{sl} \sim 10^{-4}$.

Since the decay matrix element Γ^q_{12} is dominated by the tree level decays $b \to c\bar{c}q$, and the anomalous top couplings contributes only through loops, we ignore the new physics effects on Γ^s_{12} in this work. Then the like-sign dimuon charge asymmetry is determined by M^s_{12}. We find that a shift of $V^{\rm eff}_{ts}$ with a nonzero ξ_s. can lead to the sizable deviation of A^b_{sl} from the SM value. We also find that these values of $V^{\rm eff}_{ts}$ and ξ_s also satisfy the CP asymmetry in $B \to \phi K$ decays. We show the allowed region of the complex parameter $V^{\rm eff}_{ts}$ at the 95 % C.L. in Fig. 2. The sizable phase is predicted, $14^o < \theta^{\rm eff}_{ts} < 22^o$ and $194^o < \theta^{\rm eff}_{ts} < 202^o$, from the measured A^b_{sl} value in this plot while it is very small, $\sim 2^o$ in the SM. Note that this phase is essential to explain the dimuon charge asymmetry. Ignoring new physics effects on Γ^q_{12}, the CP phase comes only from the $B_s - \bar{B}_s$ mixing, $\phi_s = -2\theta^{\rm eff}_{ts}$. Our results are consistent with the 2010 results, $\phi_s(\mathrm{CDF}) = (-29^{+44}_{-49})^o$ [9] and $\phi_s(\mathrm{D0}) = (-44^{+59}_{-51})^o$ [10], from $B_s \to J/\psi\phi$ decays and with the recent best-fit value $\phi_s = (-52^{+32}_{-25})^o$ at 2-σ level [11].

We note that our results indicate a sizable deviation from the value of $|V_{ts}| = 0.0403$ for a global fit of the unitary triangle in the SM [12]. However, this result does not mean that the CKM unitarity is violated but just an "effective" parameter $V^{\rm eff}_{ts}$ extracted from $B_s - \bar{B}_s$ mixing looks different from the SM value.

3.3 CP violation in B_s mixing at the LHCb

Using the full 1 fb^{-1} of data collected in 2011, the LHCb collaboration has reported the new measurement of the CP violating phase ϕ_s in $B_s \to J/\psi\phi$ and $B_s \to J/\psi\pi\pi$ decays. The measured value is the relative phase difference between $B^0_s \to J/\psi X$ and $B^0_s \to \bar{B}^0_s \to J/\psi X$ decays. Since the dominant decays $b \to c\bar{c}s(d)$ are tree-level processes, the direct CP violation is ignored and the measured Cp phase is of the B_s mixing. In the SM, the phase of B_s mixing is also very small, ~ -0.04.

The combined results in $B_s \to J/\psi\phi$ and $B_s \to J/\psi\pi\pi$ decays are $\phi_s = -0.002 \pm 0.083(\mathrm{stat.}) \pm 0.027(\mathrm{syst.})$ and we translate it to the phse of $V^{\rm eff}_{ts}$,

$$-15.48^o < \theta^{\rm eff}_{ts} < 6.88^o, \quad (3.4)$$

at 95% C.L. [13, 14], which are consistent withe the SM predictions.

4. Concluding Remarks

We have studied the effects of the anomalous tsW couplings to explain the recently measured CP violation in B physics. The anomalous tsW couplings can explain the deviation of the like-sign dimuon charge asymmetry from the SM prediction under all the B physics constraints except

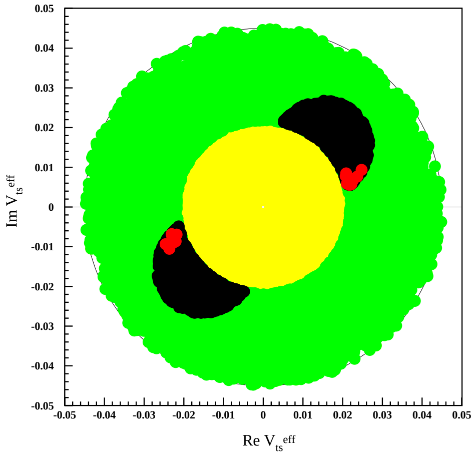

Figure 2: Allowed parameters $(\mathrm{Re}V_{ts}^{\mathrm{eff}}, \mathrm{Im}V_{ts}^{\mathrm{eff}})$ under the B physics constraints and D0 dimuon asymmetry. The whole circle of the yellow (light grey) + green (grey) + black regions is allowed by $\mathrm{Br}(B \to X_s\gamma)$ only, the ring shape of the green (grey) + black regions allowed by $\mathrm{Br}(B \to X_s\gamma)$ and ΔM_s. The black regions allowed by both constraints of $\mathrm{Br}(B \to X_s\gamma)$ and ΔM_s, and satisfies A_{sl}^b measured by D0. The red (dark grey) dots denote points additionally allowed by CP asymmetries in $B \to \phi K$ decays. The confidence level is at 95 % C.L..

for $B \to J/\psi\phi$ decays. We conclude that the CP phase measured in $B \to J/\psi\phi$ decays by the LHCb group, translated into the phase of V_{ts}^{eff} $-15.48^o < \theta_{ts}^{\mathrm{eff}} < 6.88^o$, shows a tension with that accommodating the like-sign dimuon charge asymmetry by D0 at Tevatron, $14^o < \theta_{ts}^{\mathrm{eff}} < 22^o$.

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