

Combining direct and indirect constraints on anomalous Wtb couplings

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Abstract. We look at anomalous interactions of the Wtb vertex. In case of the scenarios, when two of the four anomalous couplings can have non-SM values, we obtain constraints from three processes involving B-decays: $B_{d,s} - \bar{B}_{d,s}$ oscillations, the decay $B \rightarrow X_s \gamma$ and the decay $B \rightarrow X_s \ell^+ \ell^-$. We only consider scenarios when two of the four anomalous couplings are allowed to have values different from those in the Standard Model. We then compare our results with constraints from the t-channel single top quark production cross section from [1], which were obtained for the same scenarios.

1 Introduction

Of all elementary particles the top quark is known for its largest mass and shortest decay time and is expected to have large couplings with unknown physics beyond the Standard Model (SM). An interesting task is to study the possible anomalous interactions of the Wtb vertex. The diagram of the process is presented in Fig. 1.

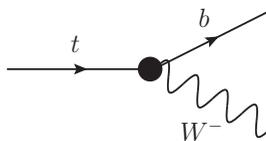


Figure 1: Feynman diagram of the Wtb transition. The black circle denotes the vertex which can contain anomalous couplings.

In the vertex of the diagram Fig. 1 four different anomalous couplings are possible (for the details see Sec. 2). The most stringent constraints on these couplings were obtained for the scenarios when only one coupling of the four was allowed to have non-SM values [3, 4]. These estimations come from the processes with a B-meson in the initial state, when the Wtb interaction is presented in the loops.

It is also possible to constrain the values of the couplings using data from direct experimental studies of the Wtb vertex. This was done by CMS collaboration in [1] for the t-channel

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single top quark production. In [1] they considered different scenarios, when not only one, but also two and three of the four couplings could have non-SM values.

In this work we analyzed scenarios with two non-SM couplings and obtained constraints from three channels in B-physics ($B_{d,s} - \bar{B}_{d,s}$ oscillations, the inclusive decay $B \rightarrow X_s \gamma$ and the inclusive decay $B \rightarrow X_s \ell^+ \ell^-$) and compared them to similar results from the t-channel single top quark production [1].

2 Effective Lagrangian

The effective Lagrangian, which represents both the SM and the New Physics (NP) contribution, has the following form:

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \sum_i C_i Q_i + \mathcal{O}\left(\frac{1}{\Lambda^3}\right), \quad (1)$$

where \mathcal{L}_{SM} is the SM contribution, Λ is the scale of NP and Q_i are the dimension-six operators, which are gauge invariant under SM gauge symmetries and consist of SM fields. We assume that the scale of NP Λ is large enough and the contribution of new heavy degrees of freedom can be decoupled. The Lagrangian (1) is a special case of a more general effective Lagrangian with operators starting from those of dimension five, see [2]. However, in case of Wtb interactions dimension-five operators do not contribute since they do not contain quark fields.

In this work we consider the following set of operators:

$$\begin{aligned} Q_{LL} &= \bar{Q}_L \tau^a \gamma^\mu Q_L (\phi^\dagger \tau^a i D_\mu \phi) - \bar{Q}_L \gamma^\mu Q_L (\phi^\dagger i D_\mu \phi) + \text{h.c.}, \\ Q_{RR} &= \bar{t}_R \gamma^\mu b_R (\tilde{\phi}^\dagger i D_\mu \phi) + \text{h.c.}, \\ Q_{LRb} &= \bar{Q}'_L \sigma^{\mu\nu} \tau^a b_R \phi W_{\mu\nu}^a + \text{h.c.}, \\ Q_{LRt} &= \bar{Q}_L \sigma^{\mu\nu} \tau^a t_R \tilde{\phi} W_{\mu\nu}^a + \text{h.c.}, \end{aligned} \quad (2)$$

where ϕ is the Higgs field, $\tilde{\phi} = i\tau^2 \phi^*$, $Q_L = (t_L, V_{tb} b_L + V_{ts} s_L + V_{td} d_L)^T$, $Q'_L = (V_{tb}^* t_L + V_{cb}^* c_L + V_{ub}^* u_L, b_L)^T$. After setting the Higgs field in (1) to its vacuum expectation value one comes to the Lagrangian of the Wtb vertex

$$\mathcal{L}^{Wtb} = \frac{g_w}{\sqrt{2}} \bar{b} \gamma^\mu (f_V^L P_L + f_V^R P_R) t W_\mu^- - \frac{g_w}{\sqrt{2}} \bar{b} \frac{\sigma^{\mu\nu} \partial_\nu W_\mu^-}{M_W} (f_T^L P_L + f_T^R P_R) t + \text{h.c.}, \quad (3)$$

where $P_{L,R} = (1 \mp \gamma_5)/2$, $\sigma_{\mu\nu} = i(\gamma_\mu \gamma_\nu - \gamma_\nu \gamma_\mu)/2$, g_w is the coupling constant of the weak interaction, the form factors $f_V^{L,R}$ are the left- and right-handed vector couplings; $f_T^{L,R}$ are the left- and right-handed tensor couplings. In the SM the couplings have the following values: $f_V^L = V_{tb}$, $f_V^R = f_T^L = f_T^R = 0$.

The anomalous couplings $f_V^{L,R}$ and $f_T^{L,R}$ in (3) are expressed in terms of Wilson coefficients from (1) as follows:

$$f_V^L = V_{tb}^* + \frac{C_{LL} V_{tb}^*}{\sqrt{2} G_F \Lambda^2}, \quad f_V^R = \frac{C_{RR}}{2 \sqrt{2} G_F \Lambda^2}, \quad f_T^L = \frac{C_{LRb} V_{tb}^*}{G_F \Lambda^2}, \quad f_T^R = \frac{C_{LRt} V_{tb}^*}{G_F \Lambda^2}. \quad (4)$$

We assume that in (1) the operators (2) are Hermitian and the Wilson coefficients in (1) as well as the anomalous couplings in (3) are real.

The effective Lagrangian appropriate for B-decays has the following form

$$\mathcal{L} = \mathcal{L}_{QCD \times QED} + \frac{4G_F}{\sqrt{2}} \left[\sum_{i=1}^2 C_i (V_{ub} V_{us}^* \mathcal{O}_i^{(u)} + V_{cb} V_{cs}^* \mathcal{O}_i^{(c)}) \right] + \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=3}^{10} C_i \mathcal{O}_i, \quad (5)$$

where the first term consists of kinetic terms of the light SM particles and their QCD and QED interactions. To obtain the Lagrangian (5) from (1) one needs to separate the contributions of heavy degrees of freedom of the SM, integrating out the top quark as well as the heavy W and Z bosons, the contribution of which is encoded in the Wilson coefficients C_i of (5). (Please, note that the Wilson coefficients in (5) are different from those in (1).) In this work we do not perform this calculation, it was done previously in several works, see [3, 4]. Detailed structure of the operators O_i can be found in [4]. The Wilson coefficients have the form $C_i = C_i^{SM} + \delta C_i$, where the additional term δC_i corresponds to NP contributions. The constraints on anomalous Wtb couplings are related to the constraints on the non-SM additions δC_i of the Wilson coefficients.

3 Constraints on anomalous tWb couplings

We used three channels, all of them with a B-meson in the initial state (data on $B_{d,s} - \bar{B}_{d,s}$ oscillations, the branching ratio of the $\bar{B} \rightarrow X_s \gamma$ decay, the branching ratio of the $\bar{B} \rightarrow X_s \mu^+ \mu^-$ decay) to obtain constraints on anomalous Wtb couplings. The data for the processes as well as the approximated theoretical formulae were taken from [5–8]. We considered the following scenarios, when two of the four couplings could have values different from those in the SM: (f_V^L, f_V^R) ; (f_V^L, f_T^L) and (f_V^L, f_T^R) . We compared our results to those of [1] for the t-channel single top quark production. The results are presented in Fig. 2.

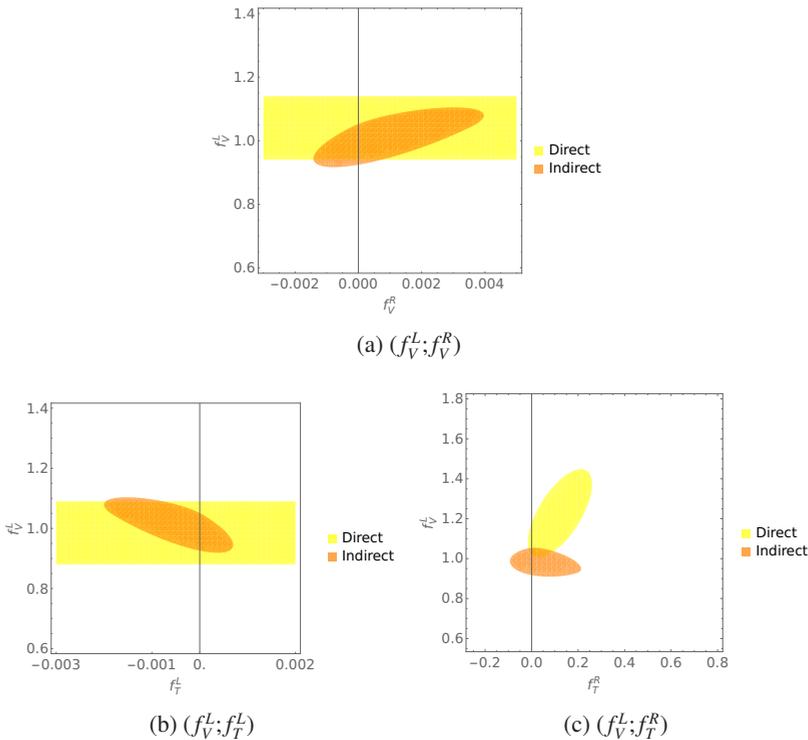


Figure 2: The images correspond to 95% C.L. allowed $(f_i; f_j)$ regions for three channels: $B - \bar{B}$ oscillations, $B \rightarrow X_s \gamma$, $B \rightarrow X_s \ell^+ \ell^-$ («indirect»); and from the t-channel single top quark production cross section («direct») from [1].

4 Conclusion and outlook

We obtained constraints on the anomalous couplings of the Wtb vertex for the scenarios, when two of the four couplings were allowed to have non-SM values. In particular, we considered the following scenarios: (f_V^L, f_V^R) ; (f_V^L, f_T^L) ; (f_V^L, f_T^R) . We used data from the following processes, which involved B-decays: data on $B_{d,s} - \bar{B}_{d,s}$ oscillations; the branching ratio of the $\bar{B} \rightarrow X_s \gamma$ decay and the branching ratio of the $\bar{B} \rightarrow X_s \mu^+ \mu^-$ decay. We compared our results to those of [1] received from t-channel single top quark production cross section. We found that our results are more rigid than those of [1]. So far, no deviations from the Standard Model have been observed.

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