Anomalous tWb couplings: Interplay of $t \to Wb$ decays and $B - \overline{B}$ mixing in MFV models

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1 Introduction

Precision studies of top quark properties are currently underway at the LHC and Tevatron colliders with the prospect of probing anomalous tWb interactions. In particular helicity fractions of the W boson produced in the main decay channel of the top quark are sensitive to the structure of the tWb vertex. In the recent years the CDF and D0 collaborations have been measuring the helicity fractions with increasing precision [1, 2]. Motivated by these results and the well know SM predictions [3] we consider contributions of effective operators of dimension six or less [5] contributing at tree level to the decay of an unpolarized top quark to a bottom quark and a W gauge boson at next-to-leading order (NLO) in QCD [6].

On the other hand, anomalous tWb couplings can also influence processes in B physics, since at one loop level virtual top quark contributions are dominant. The precisely measured and theoretically clean observables, such as $\overline{B} \to X_s\gamma$ and $\overline{B} \to X_s\mu^+\mu^-$ serve to constrain such new physics [7, 8]. Recent experimental and theoretical results for the $B_{d,s} - \overline{B}_{d,s}$ oscillation have stimulated many studies of physics beyond the standard model (c.f. [9] and references within). In particular recent global analyses allowing NP in mixing amplitudes shows SM solution as disfavored [9], with the CP phase in $B_s - \overline{B}_s$ mixing considerably larger than predicted in SM . In Ref. [10], we investigate weather anomalous tWb couplings could accommodate these findings and if so, to what extent would that modify the predictions for helicity fractions[1].

2 Framework

We work in the framework of an effective theory, described by the Lagrangian

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2}\sum_i C_i \mathcal{Q}_i + \text{h.c.} + \mathcal{O}(1/\Lambda^3)\,, \qquad (1)$$

[1]We note that after the completion of our work, LHCb presented results on ϕ_s measurements [4] where contrary to Tevatron, they find its value to be compatible with SM. This calls for an update of the global fit.

where $\mathcal{L}_{\rm SM}$ is the SM part, Λ is the scale of NP and $\mathcal{Q}_i$ are dimension-six operators, invariant under SM gauge transformations and consisting of SM fields.

The determination of the operator basis through consideration of gauge and flavor structure is described in [10]. In short, gauge structure is chosen such that all operators include tWb vertices, while for the flavor structure we employ the Minimal Flavor Violation hypotheses yielding the following operators

$$
\begin{aligned}
\mathcal{Q}_{LL} &= [\overline{Q}'_3\tau^a\gamma^\mu Q'_3](\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d) - [\overline{Q}'_3\gamma^\mu Q'_3](\phi_d^\dagger \mathrm{i}D_\mu\phi_d),\\
\mathcal{Q}'_{LL} &= [\overline{Q}_3\tau^a\gamma^\mu Q_3](\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d) - [\overline{Q}_3\gamma^\mu Q_3](\phi_d^\dagger \mathrm{i}D_\mu\phi_d),\\
\mathcal{Q}''_{LL} &= V_{tb}^*\Big\{[\overline{Q}'_3\tau^a\gamma^\mu Q_3](\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d) - [\overline{Q}'_3\gamma^\mu Q_3](\phi_d^\dagger \mathrm{i}D_\mu\phi_d)\Big\}\,,\\
\mathcal{Q}_{RR} &= V_{tb}[\bar{t}_R\gamma^\mu b_R](\phi_u^\dagger \mathrm{i}D_\mu\phi_d)\,, \quad \mathcal{Q}_{LRb} = [\overline{Q}_3\sigma^{\mu\nu}\tau^a b_R]\phi_d W^a_{\mu\nu}\,,\\
\mathcal{Q}_{LRt} &= [\overline{Q}'_3\sigma^{\mu\nu}\tau^a t_R]\phi_u W^a_{\mu\nu}\,, \quad \mathcal{Q}'_{LRt} = V_{tb}^*[\overline{Q}_3\sigma^{\mu\nu}\tau^a t_R]\phi_u W^a_{\mu\nu}\,,
\end{aligned}
$$

where we have introduced the left-handed $SU(2)$ doublets

$$
Q_3 = (V_{ib}^* u_{Li}, b_L)\,, \quad Q'_3 = (t_L, V_{tj} d_{jL})\,, \tag{2}
$$

with i,j flavor indices. We note that our operators contribute to processes of interest in B physics with grater intricacy than just a mere modification of the tWb vertex.

3 Results

The suppressed transverse-plus helicity fraction F_+ obtains nonzero value from m_b/m_t terms, higher order QCD and electroweak corrections and possible new physics. We find that for anomalous couplings within the 95% C.L. allowed intervals obtained from B physics only dipole operators $\mathcal{Q}^{(\prime)}_{LRt}$ significantly alter the helicity fractions.

In the first graph of Fig. 1 we show the LO and NLO prediction for F_+ as a function of anomalous couplings $\kappa^{(\prime)}_{LRt} = C^{(\prime)}_{LRt}/(\Lambda^2 G_F)$. It can be seen that the effects of NLO contributions are significant, however, these anomalous couplings can not increase the F_+ to the measurable percent level. All considered NP contributions to F_L get lowered by about 1% when going from LO to NLO in QCD. The second graph shows the prediction for F_L helicity fraction as a function of $\kappa^{(\prime)}_{LRt}$ along with the combined Tevatron central value and 95% C.L. band. The direct bounds from F_L are competitive with the indirect bounds indicated by the shaded regions obtained in [6].

On the $B_{d,s} - \overline{B}_{d,s}$ mixing side we find that at one operator insertion operators $\mathcal{Q}_{RR}$ and $\mathcal{Q}_{LRb}$ do not contribute. What is more, operators $\mathcal{Q}_{LL}$ and $\mathcal{Q}_{LRt}$ do not contribute any new phase, since only real parts of their Wilson coefficients enter the mixing amplitude expressions. The three primed operators on the other hand can contribute new mixing phases and we can fix the real and imaginary parts of their

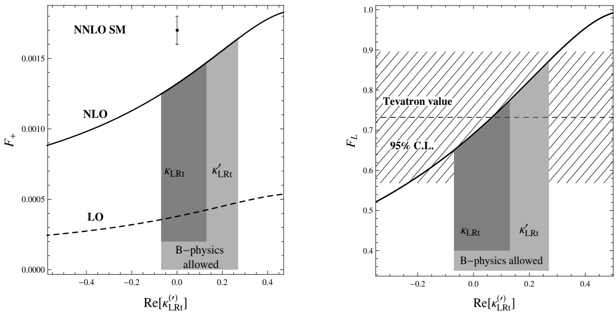

Figure 1: Left: F_+ as a function of $\kappa^{(\prime)}_{LRt}$, LO (dashed) and NLO (solid). Also shown the NNLO SM point with theoretical errors. Right: F_L as a function of κ'_{LRt} along with combined Tevatron central value and 95% C.L. band. Shaded regions present the 95% C.L. allowed intervals for $\kappa^{(\prime)}_{LRt}$ as obtained from B physics.

Wilson coefficients such, that they improve the global fits compared to the SM . The central fitted values and 1σ C.L. intervals are given in the Tab. 1. The accompanying graph shows a contour plot of relative change in helicity fractions $\delta_{+,L} = F_{+,L}/F^{\rm SM}_{+,L}$ when the real and imaginary parts of κ'_{LRt} are varied within the 1σ intervals ($\kappa'^{(\prime\prime)}_{LL}$ do not affect the helicity fractions). We can see that F_L can be altered by as much as 15%.

	Re	Im
κ'_{LL}	$-0.062^{+0.063}_{-0.030}$	$-0.110^{+0.029}_{-0.024}$
κ''_{LL}	$0.097^{+0.048}_{-0.098}$	$0.180^{+0.037}_{-0.044}$
κ'_{LRt}	$0.160^{+0.079}_{-0.160}$	$0.290^{+0.062}_{-0.074}$

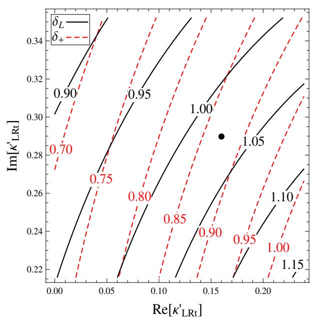

Table 1: Best-fit values for real and imaginary parts of κ_i parameters and 1σ C.L. intervals. Accompanying picture shows the contour plot of $\delta_{+,L} = F_{+,L}/F^{\rm SM}_{+,L}$ when κ'_{LRt} is varied within the 95% C.L. intervals.

4 Conclusions

Further improvement of experimental errors on F_L is expected to provide most stringent bounds on $\kappa_{LRt}^{(\prime)}$ anomalous couplings in the future. QCD corrections alter the On the other hand, a potential measured value of F_+ of the 1% level could not be explained by the anomalous couplings.

Primed operators can contribute new phases to B meson mixing. The Wilson coefficients can fixed to accommodate the fits of [9]. For $\mathcal{Q}'_{LRt}$ such a determination of Wilson coefficient predicts a change in the $F_{+,L}$. The deviation can be as high as 30% for F_+, and 15% for F_L with respect to their SM values. The latter modification is within the expected precision of the LHC experiments.

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