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# Search for anomalous $Wtb$ couplings in single top quark production at D0

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**Abstract.** The large mass of the top quark, close to the electroweak symmetry-breaking scale, makes it a good candidate for probing physics beyond the Standard Model, including possible anomalous couplings. D0 has made measurements of single top quark production using 5.4 fb$^{-1}$ of integrated luminosity. The data are examined to study the Lorentz structure of the $Wtb$ coupling. It is found that the data prefer the left-handed vector coupling and set upper limits on the anomalous couplings.

**Keywords.** Single top quark; electroweak; anomalous couplings; D0; direct constraints.

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## 1. Introduction

In 2009, the electroweak single top quark production was observed by the D0 and CDF Collaborations [1]. Electroweak production of top quarks at the Tevatron proceeds mainly via the decay of a time-like virtual $W$ boson accompanied by a bottom quark in the $s$-channel ($tb = t\bar{b} + \bar{t}b$) [2], or via the exchange of a space-like virtual $W$ boson between a light quark and a bottom quark in the $t$-channel ($tqb = tq\bar{b} + \bar{t}qb$, where $q$ refers to the light quark) [3]. For a top quark mass of 172.5 GeV, the Standard Model (SM) prediction of single top production rate at next-to-leading order with soft-gluon contributions at next-to-next-to-leading order are $1.04 \pm 0.04$ pb ($s$-channel) and $2.26 \pm 0.12$ pb ($t$-channel) [4]. The large mass of the top quark implies that it has large couplings to the electroweak symmetry-breaking sector of the SM and may have non-standard interactions with the weak gauge bosons. Single top quark production provides a unique probe to study the interactions of the top quark with the $W$ boson.

## 2. Single top quark production cross-section measurement

The events are selected from 5.4 fb$^{-1}$ of data collected with the D0 detector from 2002 to 2009 with the following requirements: one high-$p_{\mathrm{T}}$ isolated electron with $p_{\mathrm{T}}^{e} > 15$ GeV

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and $|\eta^e| < 1.1$, or muon with $p_T^\mu > 15$ GeV and $|\eta^\mu| < 2.0$, missing transverse energy in the range of 20 to 200 GeV, and having two to four jets with leading jet $p_T > 25$ GeV and a second jet with $p_T > 15$ GeV, both within pseudorapidity $|\eta| < 3.4$. At least one jet should be identified as having originated from the hadronization of a long-lived $b$ hadron using a neural-network based algorithm [5]. Single top quark signal events with the SM and anomalous $Wtb$ couplings are modelled using the COMPHEP-based Monte Carlo (MC) event generator SINGLETOP [6]. The main backgrounds $t\bar{t}$, $W+$jets and $Z+$jets are simulated with ALPGEN [7] and multijet background is modelled directly from data. PYTHIA [8] is used to simulate parton showering and to model hadronization of all generated partons for all the signal and background samples. The sensitivity of our search is improved by dividing our data into six independent analysis channels based on the number of identified $b$ jets (1 or 2) and jet multiplicity (2, 3 or 4 jets). Systematic uncertainties are considered which arise from the theoretical and detector modelling of the background processes and from the subsequent corrections applied to that model. After the event selection, the expected single top quark contribution is smaller than the uncertainty on the background count prediction and hence to improve the discrimination between signal and background events, multivariate analysis (MVA) methods are used. Three different MVA techniques are used for the cross-section extraction: (i) Boosted decision trees (BDT) [9], (ii) Bayesian neural networks (BNN) [10] and (iii) neuroevolution of augmented topologies (NEAT) [11]. All three methods use the same data and model for background considering the same sources of systematic uncertainty separately for the six mutually exclusive channels. Each MVA method was trained separately for the two single top production channels: (i) for the $tb$ discriminants, with $tb$ considered as the signal and $tqb$ treated as a part of the background; (ii) for $tqb$ discriminants, with $tqb$ considered as the signal and $tb$ treated as a part of the background. To achieve the maximum sensitivity, a combined $tb + tqb$ discriminant is constructed by taking input from the six discriminant outputs of BDT, BNN and NEAT that are trained separately for the $tb$ and $tqb$ signals. The single top quark production cross-section is measured using a Bayesian inference approach [12,13]. To measure the individual $tb$ ($tqb$) production cross-section, a one-dimensional (1D) posterior probability density function is constructed with the $tqb$ ($tb$) contribution normalized with Gaussian priors centred in the predicted SM cross-section. This is implemented for each individual MVA method and also for their combination. To measure the total single top production cross-section of $tb + tqb$, a 1D posterior probability density function is constructed assuming the production ratio of $tb$ and $tqb$ predicted by the SM. Figure 1 shows the resulting expected and observed cross-sections for $tb$, $tqb$ and $tb + tqb$, respectively.

## 3. Anomalous *Wtb* couplings

The SM predicts a purely left-handed vector coupling ($f_{L_V}$) at the $Wtb$ vertex, while the most general, lowest dimension Lagrangian [14] allows right-handed vector ($f_{R_V}$) and left-handed tensor ($f_{L_T}$) or right-handed tensor ($f_{R_T}$) couplings as well. An analysis has been performed using the same dataset, event selection and background modelling as the cross-section measurement, between SM background (including SM single top quark) and

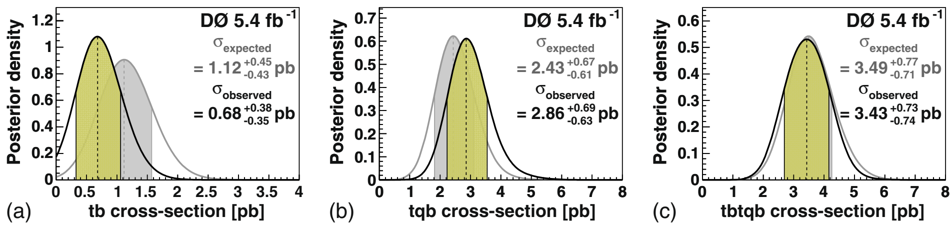


**Figure 1.** The expected (grey) and observed (yellow) posterior probability densities for (**a**) $tb$, (**b**) $tqb$ and (**c**) $tb + tqb$ production. The shaded bands indicate ranges for 68% CL for the peak values.

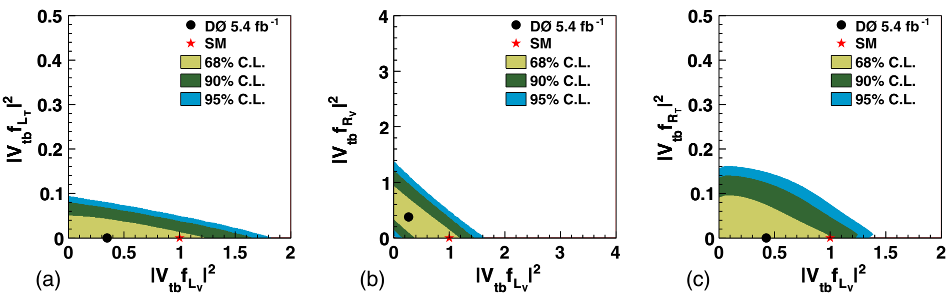


**Figure 2.** Two-dimensional posterior probability density distributions for the anomalous couplings for (**a**) ($L_{\rm V}$, $L_{\rm T}$) scenario, (**b**) ($L_{\rm V}$, $R_{\rm V}$) scenario and (**c**) ($L_{\rm V}$, $R_{\rm T}$) scenario.

anomalous single top quark production as a signal, to set limits to $Wtb$ coupling other than a pure left-handed vector form [15]. A BNN is used to discriminate between signal and background. A Bayesian statistical approach is followed to compare data to the signal predictions given by different anomalous couplings. A two-dimensional (2D) posterior probability density is computed as a function of $|V_{tb} \cdot f_{\rm L_V}|^2$ and $|V_{tb} \cdot f_X|^2$, where $f_X$ is any of the three non-standard couplings and $V_{tb}$ is the Cabibbo–Kobayashi–Maskawa matrix element [16]. The 2D limit contours are shown in figure 2. We measure upper limits for $|V_{tb} \cdot f_{\rm L_T}|^2 < 0.06$, $|V_{tb} \cdot f_{\rm R_V}|^2 < 0.93$ and $|V_{tb} \cdot f_{\rm R_T}|^2 < 0.13$ at 95% CL after integrating the 2D posterior over $|V_{tb} \cdot f_{\rm L_V}|^2$.

## 4. Summary

In summary, we have presented the measurement of single top quark production cross-section and search for anomalous $Wtb$ couplings using 5.4 fb$^{-1}$ of D0 data. We find no evidence for anomalous couplings and set 95% CL limits on these couplings. This result represents the most stringent direct constraints on anomalous $Wtb$ interactions.

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