SINGLE TOP PRODUCTION AT THE TEVATRON

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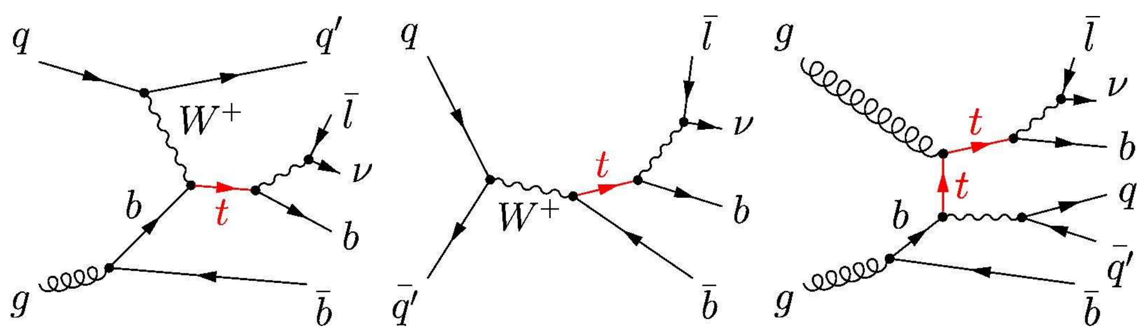
We present recent results of single top quark production in the lepton plus jet final state, performed by the CDF and D0 collaborations based on 7.5 and 5.4 fb^{-1} of $p\bar{p}$ collision data collected at $\sqrt{s} = 1.96$ TeV from the Fermilab Tevatron collider. Multivariate techniques are used to separate the single top signal from the backgrounds. Both collaborations present measurements of the single top quark cross section and the CKM matrix element $|V_{tb}|$. A search for anomalous Wtb coupling from D0 is also presented.

1 Introduction

In the Standard Model (SM), the top quark can be produced via the strong interaction as a $t\bar{t}$ pair. The SM also allows for the top quark to be produced through the electroweak interaction as a single top quark plus jets. This is referred to as single top. As illustrated in Figure 1, there are three production modes: the t-channel (tbq), the s-channel (tb) and the Wt-channel processes. Single top quark production was first observed simultaneously by the CDF and D0 experiments in 2009.[1 2] The study of single top quark events will provide access to the properties of the Wtb coupling. Within the SM, the single top signal allows for a direct measurement of the Cabibbo-Kobayashi-Maskawa (CKM) matrix element V_{tb}.[3] Furthermore, since the top quark decays before hadronization, its polarization can be directly observed in the angular correlations of its decay products.[4 5] Single top processes are expected to be sensitive to several kinds of new physics such as flavor-changing neutral currents (FCNC).



(a) t-channel (b) s-channel (c) Wt-channel

Figure 1: Representative Feynman diagrams of single top quark production channels: (a) t-channel $2 \rightarrow 3$ process at NLO with initial-state gluon splitting, (b) s-channel at leading order, and (c) Wt associated production at next-to-leading order (NLO) with initial-state gluon splitting.

2 Event Selection

The CDF collaboration performed the analysis on a lepton + jets dataset corresponding to an integrated luminosity of 7.5 fb^{-1}. Events are required to have an isolated electron or muon with $p_{\mathrm{T}} > 20$ GeV, $\not{E}_T > 25$ GeV, and 2–3 jets with $p_{\mathrm{T}} > 20$ GeV where at least one jet is b-tagged. By selecting a high quality, high-p_{T} isolated track, the signal acceptance increases by 15% compared to the previous CDF analysis. In this analysis, the CDF collaboration uses the POWHEG generator[9] for single top signal modeling with NLO accuracy.

The D0 collaboration uses 5.4 fb^{-1} of data collected with a logical OR of many trigger conditions, which together are fully efficient for the single top quark signal. The main event selection criteria applied is similar to the previous analysis:[2] an isolated electron or muon with $p_{\mathrm{T}} > 15$ GeV, $\not{E}_T > 20$ GeV, 2–4 jets with $p_{\mathrm{T}} > 15$ GeV out of which one jet has $p_{\mathrm{T}} > 25$ GeV and at least one jet tagged with a neural-network-based b-tagging algorithm. Additional selection criteria remove multijet background events with misidentified leptons.

Both collaborations use similar methods for signal and background modeling. They normalized the $t\bar{t}$, diboson and Z + jets processes to the SM prediction. The QCD models are derived from the data with a non-isolated lepton (D0) or anti-lepton (CDF). Before b–tagging, the W + jets and QCD backgrounds are normalized to the data using the $\not{E}_T$ variable (CDF) or several kinematic variables (D0).

3 Signal-Background Separation

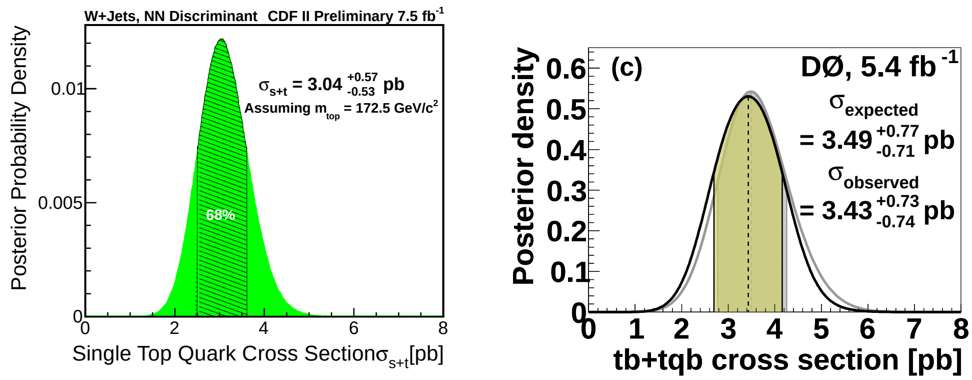
After the event selection, additional multivariate techniques are used by both collaborations to further separate signal from backgrounds. Each multivariate technique constructs a powerful discriminant variable from different input variables that is proportional to the probability of an event being signal. The discriminant distribution is used as input to the cross section measurement. Several validation tests are conducted by studying the discriminant output distributions in background-enriched control samples.

The CDF collaboration uses a neural network (NN) multivariate technique to obtain a single top discriminant. By using 11–14 input variables, four separate NNs are constructed for different analysis channels based on the number of jets and b-tags. For each of the four different channels, the NN is optimized separately. In the channel with 2 jets and 2 b-tags, the NN is trained for the s-channel process as signal without knowledge of the t-channel. The remaining analysis channels are trained for the t-channel process as signal without knowledge of the s-channel. To further constrain the cross section measurement uncertainty, the CDF collaboration trained the NNs with samples that include a small fraction of events with variations in the jet energy scale and Q^2 scales. This method is expected to yield a 3% improvement in the uncertainty of the single top cross section measurement.

The D0 collaboration uses three individual techniques to separate single top quark events from the background, namely boosted decision trees (BDT), bayesian neural networks (BNN), and a neuroevolution of augmented topologies (NEAT).[6] All three methods use the same data and background models, and are trained separately for two channels: for the tb discriminant, which treats the tb process as the signal and the tqb process as a part of the background, and vice versa for the tbq discriminant. With 70% correlations among the outputs of the individual methods, a second BNN is used to construct a combined discriminant from the three discriminant outputs to increase sensitivity.

4 Measurement of Cross Section and $|V_{tb}|$

Both experiments measure the single top quark production cross section from the discriminant output distributions using a Bayesian-binned likelihood technique. The statistical uncertainty and all systematic uncertainties and their correlations are considered in these calculations. The single top cross section measured by the CDF collaboration is $3.04^{+0.57}_{-0.53}$ pb. The D0 collaboration measured the single top cross section for $tb + tqb$ to be $3.43^{+0.73}_{-0.74}$ pb.[6] Both of the measurements are shown in Figure 2.



(a) (b)

Figure 2: The posterior curve of the cross section measurement for the (a) CDF and (b) D0 collaborations.

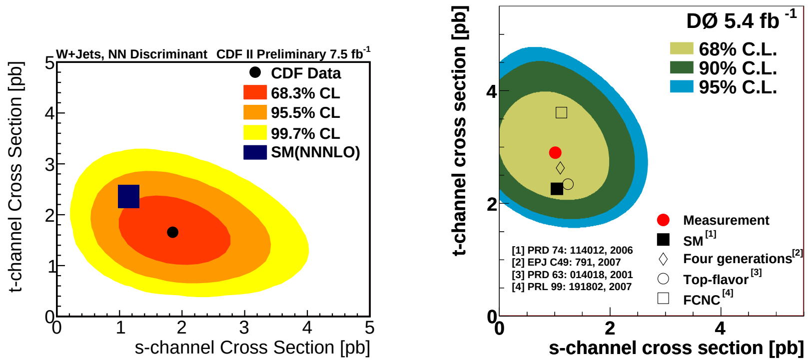
Since the single top cross section is directly proportional to $|V_{tb}|^2$, both collaborations use the cross section measurements to extract $|V_{tb}|$. By restricting the measurement to the SM interval [0, 1], CDF measures $|V_{tb}| = 0.96 \pm 0.09$ (stat+syst) $\pm$ 0.05 (theory), and sets a limit of $|V_{tb}| > 0.78$ at 95% C.L. Using the same interval [0, 1], D0 extracts the limit of $|V_{tb}| > 0.79$ at 95% C.L.; after removing the upper constraint of the interval, D0 measures $|V_{tb} f_1^L| = 1.02^{+0.10}_{-0.11}$, where f_1^L is the strength of the left-handed Wtb coupling.

5 t-Channel Observation

With the same multivariate discriminant for the t-channel process, D0 computes the significance of the t-channel cross section using a log-likelihood ratio approach, which tests the compatibility of the data with two hypotheses: a null hypothesis with only background and a test hypothesis with background plus signal. The computation of the distributions for these two hypotheses is given by an asymptotic Gaussian approximation. With this approximation, the significance of the measured t-channel cross section is independent of any assumption on the production rate of s-channel.[8] The estimated probability corresponds to an observed significance of 5.5 standard deviations with an expected significance of 4.6 standard deviations.

6 Two-Dimensional Fit Results

The combined signal cross section (σ_{s+t}) is extracted by constructing a one-dimensional Bayesian posterior. An extension is to form a two-dimensional posterior probability density as a function of the cross sections for the s- and t-channel as in Figure 3. The best-fit cross section is the one for which the posterior is maximized without assuming the SM-predicted ratio between the cross section for the s- and t-channels.



(a) (b)

Figure 3: The results of the two-dimensional fit for σ_s and σ_t. The circle point shows the best fit value and the 68%, 95%, and 99% credibility regions are shown as shaded areas. The SM prediction is also indicated with theoretical uncertainties included.

7 Anomalous Wtb Coupling

Within the SM theory, the top quark coupling to the bottom quark and the W boson (tWb) has the V–A form of a left-handed vector interaction. Deviations from the SM expectation in the coupling form factors can manifest themselves by altering the fraction of W boson from top quark decays or by changing the rate and kinematic distributions of electroweak single top quark production. Three separate scenarios are investigated and upper limits are set with the same dataset by D0 for f_V^R, f_T^L, and f_T^R.[7]

8 Summary

The CDF and D0 collaborations have performed precise measurements of the electroweak single top quark production cross section and the CKM matrix element $|V_{tb}|$ using 7.5 and 5.4 fb^{-1} of data, respectively. An anomalous Wtb coupling search by D0 investigates three separate scenarios and sets an upper limit on each of them.

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