SEARCH FOR SINGLE-TOP PRODUCTION AT THE TEVATRON

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This article reports on recent searches for single-top-quark production by the CDF and DØ collaborations at the Tevatron. Neither two CDF analyses, using data corresponding to $695 \, \text{pb}^{-1}$ of integrated luminosity, nor a DØ search based on $370 \, \text{pb}^{-1}$ of data can establish a signal for this standard model process. These null results translate in upper limits on the cross section of $2.9 \, \text{pb}$ for the t-channel production mode and $3.2 \, \text{pb}$ for the s-channel mode at the 95% C.L. In addition, the DØ collaboration has searched for non-standard model production of single-top-quarks via a heavy W' boson. No signal of this process is found resulting in lower mass limits of $610 \, \text{GeV}/c^2$ for a left-handed W' and $630 \, \text{GeV}/c^2$ for a right-handed W' boson.

Keywords: single-top; electroweak top quark production; W' boson.

1. Introduction

According to the standard model, in $p\bar{p}$ collisions at the Tevatron top quarks can be created in pairs via the strong force, of singly via the electroweak interaction. The latter production mode is referred to as "single-top-quark" production and takes place mainly through the s- or t- channel exchange of a W boson. The CDF and DØ collaborations have published single-top results at $\sqrt{s} = 1.8$ TeV and $\sqrt{s} = 1.96$ TeV [1,2]. None of these analyses established single-top evidence, and 95% confidence level (C.L.) upper limits on the single-top production cross section were set.

The theoretical single-top production cross section is $\sigma_{s+t} = 2.9 \pm 0.4$ pb for a top mass of 175 GeV/c^2 [3]. Despite this small rate, the main obstacle in finding single-top is in fact the large associated background. After all section requirements are imposed, the signal to background ratio is approximately 1/20. This challenging, background-dominated dataset is the main motivation for using multivariate techniques.

2. Standard Model Searches

In this article we present three new searches, two by CDF [4], in subsections 2.1 and 2.2, and one by DØ [5], in subsection 2.3. The two CDF analyses use a dataset corresponding to $695 \, \text{pb}^{-1}$. One analyses is performed with neural networks, the second utilizes likelihood functions. Both use a common event selection.

2.1. *CDF Neural Network Search*

The CDF event selection exploits the kinematic features of the signal final state, which contains a top quark, a bottom quark, and possibly additional light quark jets. To reduce multijet backgrounds, the W originating from the top quark is required to have decayed leptonically. One therefore demands a single high-energy electron or muon ($E_T(e) > 20$ GeV, or $P_T(\mu) > 20$ GeV/c) and large missing transverse energy from the undetected neutrino $\not{E}_T > 20$ GeV. The analysis uses electrons measured in the central and in the forward calorimeter. The usage of forward electrons is new for top physics analyses at CDF. The remaining backgrounds be-

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long to the following categories: $Wb\bar{b}$, $Wc\bar{c}$, Wc, mistags (light quarks misidentified as heavy flavor jets), non-W (events where a jet is erroneously identified as a lepton), and diboson WW, WZ, and ZZ. We remove a large fraction of the backgrounds by demanding exactly two jets with $E_T > 15$ GeV and $|\eta| < 2.8$ be present in the event. At least one of these two jets should be tagged as a b quark jet by using displaced vertex information from the silicon vertex detector (SVX). The non-W content of the selected dataset is further reduced by requiring the angle between the $\not{E}_T$ vector and the transverse momentum vector of the leading jet to satisfy: $0.5 < \Delta\Phi < 2.5$. The numbers of expected and observed events are listed in table 1.

Fig. 1.   Output distribution of the neural net b tagger for 689 candidate events in the $W + 2$ jets bin. Overlayed are the fitted components of beauty-like, charm-like and mistag templates.

Table 1.   Expected number of signal and background events and total number of events observed in 695 pb^{-1} in the CDF single-top dataset.

Process	N events
t-channel	16.7 ± 1.7
s-channel	11.5 ± 0.9
$t\bar{t}$	40.3 ± 3.5
diboson, Z	17.2 ± 0.8
$W + b\bar{b}$	170.7 ± 49.2
$W + c\bar{c}$	64.5 ± 17.3
Wc	69.4 ± 15.3
$W + q\bar{q}$, mistags	164.3 ± 29.6
non-W	119.5 ± 40.4
Total	674.1 ± 96.1
Observed	689

Using a neural network 14 kinematic or event shape variables are combined to a powerful discriminant. One of the variables is the output of a neural net b tagger. In figure 1 the distribution of this b tag variable is shown for the 689 data events. In case of double-tagged events the leading b jet (highest in E_T) is included in this distribution. The neural net b tagger gives an additional handle to reduce the large background components where no real b quarks are contained, mistags and charm-backgrounds. Both of them amount to about 50% in the $W + 2$
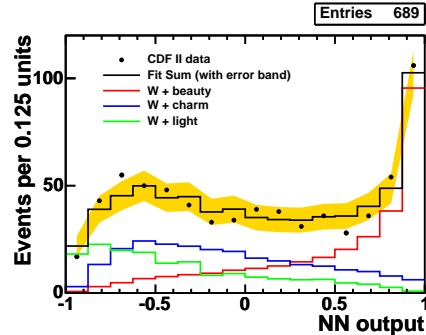
jets data sample even after imposing the requirement that one jet is identified by the secondary vertex tagger of CDF [6].

Figure 2 shows the observed data compared to the fit result (a) and the expectation in the signal region (b) for the single-top neural network. For comparison, the Monte Carlo template distributions normalized to unit area are shown in figure 3. The data are fitted with a binned likelihood function. The t- and the s-channel are treated as one single-top signal assuming the ratio of the two processes to be the one predicted by the standard model. The most probable value of the likelihood function is $0.8^{+1.3}_{-0.8}$ (stat) $^{+0.2}_{-0.3}$ (syst) pb. providing no significant evidence for single-top production. The corresponding upper limit on the cross section is 3.4 pb at the 95% confidence level, quite close to the expected standard model value of 2.9 ± 0.4 pb.

To separate t- and s-channel production two additional networks are trained and a simultaneous fit to both discriminants is performed. The fit results are summarized in table 2. The expected limits are calculated from pseudo-experiments which include single-top quark events at the standard model rate. Again, there is no evidence for single-top production yet.
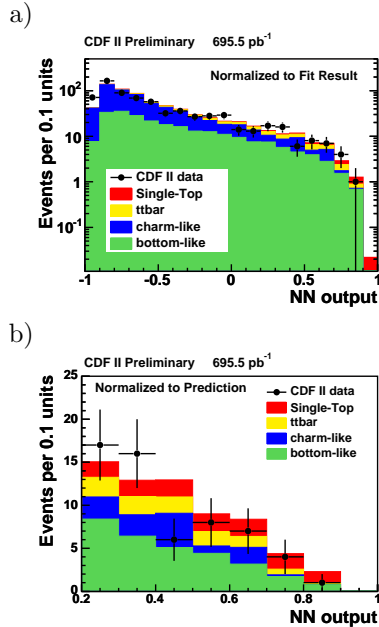
a)

b)

Fig. 2. Single-top search with neural networks at CDF: a) data compared to the fit result, b) data compared to the standard model expectation in the signal region.
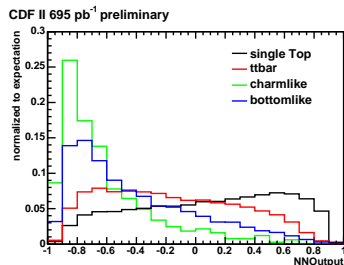

Fig. 3. Monte Carlo template distributions for the single-top neural network search. The distributions are normalized to unit area.

2.2. CDF Likelihood Function Analysis

In a second analysis CDF uses likelihood functions to combine several variables to a discriminant to separate single-top events from background events. The same data events as for the neural network search are analyzed. One likelihood function is defined for the t-channel, one for the s-channel

Table 2. Fit results on the separate search for t- and s-channel single-top production. The quoted limits are set at the 95% C.L.

	t-channel	s-channel
Observed most probable value	$0.6^{+1.9}_{-0.6}$ (stat) $^{+0.1}_{-0.1}$ (sys) pb	$0.3^{+2.2}_{-0.3}$ (stat) $^{+0.5}_{-0.3}$ (sys) pb
Observed upper limit	3.1 pb	3.2 pb
Expected upper limit	4.2 pb	3.7 pb

search. Seven or six variables are used, respectively. The likelihood functions are constructed by first forming histograms of each variable. The histograms are produced separately for signal and several background processes. The histograms are normalized such that the sum of their bin contents equals 1. For one variable the different processes are combined by computing the ratio of signal and the sum of the background histograms. These ratios are multiplicatively combined to form the likelihood functions. The t-channel likelihood function is shown in figure 4. The observed data show no indica-
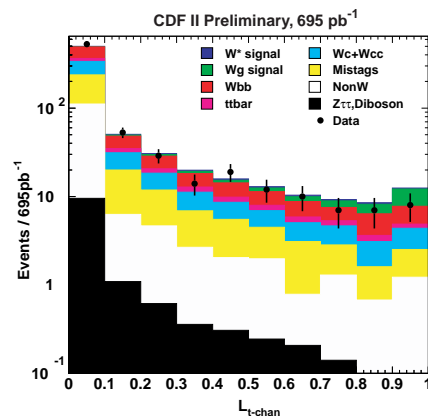

Fig. 4. The distributions of the t-channel likelihood function for CDF data compared to the Monte Carlo distribution normalized to the expected contributions. A logarithmic scale is used.

tion of a single-top signal and are compatible

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with a background-only hypothesis. The t-channel analysis yields an upper limit on the cross section of 2.9 pb at the 95% C.L. A fit to the s-channel likelihood function lead to an upper limit of 5.1 pb. Both likelihood functions are also combined in a two-dimensional fit resulting in an upper limit of 4.3 pb on the combined single-top cross section. The expected upper limit for the combined search is 3.4 pb, assuming no single-top events to be present.

2.3. DØ Likelihood Ratio Analysis

In search for single-top the DØ collaboration has analyzed a data set corresponding to $370 \, \text{pb}^{-1}$ of integrated luminosity. The event selection asks for one isolated electron or muon with $p_T > 15 \, \text{GeV}$. Electrons are accepted in the pseudorapidity region of $|\eta| < 1.1$, muons in the interval $|\eta| < 2.0$. The missing transverse energy is required to be above 15 GeV. The DØ analysis uses events with 2, 3 or 4 jets with $E_T > 15 \, \text{GeV}$ and $|\eta| < 3.4$. The leading jet is required to have a minimum transverse energy of 25 GeV. At least one jet is required to be identified as originating from a b quark. A jet lifetime probability algorithm [7] is used for that purpose. After all selection cuts DØ observes 443 events, 367 of those have a single b tagged jet, 76 events have at least two b tagged jets. According to the standard model prediction 15.0 t-channel and 9.5 s-channel events are expected to be present in this data set. The expected background is 452 events.

The data set is subdivided into the electron and muon channels, and one-tag and more-than-two-tag samples. Likelihood discriminants are formed to separate t- and s-channel single-top on one hand and $t\bar{t}$ and W + jets on the other hand. In total, this approach leads to 16 likelihood discriminants. An example for a likelihood discriminant is shown in figure 5. A combined fit to all dis-
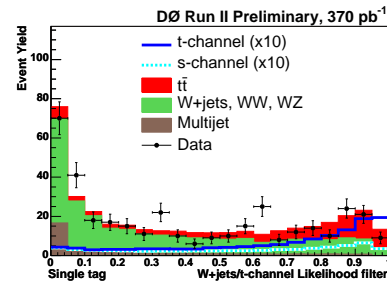

Fig. 5.   The distribution of the t-channel versus W + jets likelihood discriminant of the DØ analysis.

criminants yields no evidence for single-top production and is translated into upper limits on the single-top cross sections at the 95% C.L.: σ (t-channel) < 4.4 pb, σ (s-channel) < 5.0 pb. The corresponding expected limits are 4.3 pb and 3.3 pb, respectively, assuming no single-top events to be present.

3. Search for a W' boson at DØ

Based on a similar event selection as discussed in section 2.3 the DØ collaboration has also searched for a W' boson in the decay channel, $W' \to t\bar{b}$ [8]. Data corresponding to an integrated luminosity of $230 \, \text{pb}^{-1}$ are used. The signal is modeled using the event generator COMPHEP [9] which takes the interference between a left-handed W' boson and the standard model W boson into account. The analysis is designed to search for a left-handed and a right-handed W' boson. The invariant mass of charged lepton, the reconstructed neutrino and the two leading jets is used as a discriminant. No evidence for a W' boson is found. Lower limits on the mass of the W' are set: $M(W'_L) > 610 \, \text{GeV}$ for a left-handed W' and $M(W'_R) > 630 \, \text{GeV}$ for a right-handed W'. These limits assume that the W' is allowed to decay to both leptons and quarks.

4. Conclusions

The CDF and DØ collaborations have performed searches for single-top production via

the electroweak interaction. No evidence for this process has been found so far. The two CDF analyses are based on a data set corresponding to an integrated luminosity of $695\,\mathrm{pb}^{-1}$. Both analyses observe a deficit of events in the signal region of their discriminant, where single-top events are expected. Upper limits on the single-top cross sections, quite close to the predicted values, are set: $\sigma(t\text{-channel}) < 2.9\,\mathrm{pb}$ and $\sigma(s\text{-channel}) < 3.2\,\mathrm{pb}$, both at the 95% C.L. Currently data sets corresponding to $1\,\mathrm{fb}^{-1}$ are being analyzed. Even larger data samples will be available in the future. It will be very interesting to see whether the trend to a deficit in single-top events continues or whether first hints of a signal emerge.

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