EPJ manuscript No.
(will be inserted by the editor)

FERMILAB-CONF-05-494-E

Single Top At The Tevatron

Anyes Taffard (on behalf of the CDF & DØ collaborations)

University of Ilinois
Urbana-Champaign, IL 61801

Received: date / Revised version: date

Abstract. We review the status of the search for the electroweak production of single top quarks by the CDF and DØ collaborations at the Fermilab Tevatron proton-antiproton collider using Run II data. With a dataset of approximatively 160 pb^{-1} for CDF and 230 pb^{-1} for DØ, neither experiment finds evidence for single top production and sets 95% C.L. upper limits on the production cross-sections. The CDF limits are 10.1 pb for the t channel, 13.6 pb for the s channel and 17.8 pb for the combined production cross-sections of s and t channel . The DØ limits are 5.0 pb for the t channel, 6.4 pb for the $s-$ channel production cross-sections. Both experiments investigate the prospect for a 3σ evidence and a 5σ discovery.

PACS. PACS-key discribing text of that key – PACS-key discribing text of that key

1 Introduction

In $p\bar{p}$ collisions at a center of mass of 1.96 GeV, top quarks are predominantly produced in pairs via strong interactions processes. Within the standard model (SM), top quarks can also be produced singly in electroweak interactions involving a Wtb vertex [1]. At the Tevatron, the two relevant production modes are the t and the s channel exchange of a virtual W boson. This production mechanism allows for a direct measurement of the CKM mixing angle $|V_{tb}|$. It is also sensitive to physics beyond the standard model which predicts anomalously altered single-top production rates [2]. The most recent next-to-leading order (NLO) calculations, assuming $|V_{tb}| = 1$, predict cross-sections of 1.98 ± 0.25 pb for the t channel and 0.88 ± 0.11 pb for the s channel at $\sqrt{s} = 1.96$ TeV with $m_t = 175$ GeV [3].

The final state for the s channel consists of the decay products from the W and a $b-$quark jet both originating from the top decay and a $b-$quark jet produced with the top quark. The final state for the t channel consists of the decay products from the W and a $b-$quark jet both originating from the top decay and a light quark jet produced with the top quark. High-order corrections can result in additional jets in both the s channel and t channel. In particular in the t channel, where an additional $b-$quark jet originates from the splitting of an initial state gluon in a $b\bar{b}$ pair. The experimental searches for single top production focus on the decay of the W to an electron or a muon since the all-hadronic channel has overwhelming background from QCD multi-jet events.

This document describes the searches for electroweak production of single top quark by the CDF [5] and the DØ [6] collaborations using a data sample from the Tevatron Run II . Results of searches performed at $\sqrt{s} = 1.8$ TeV (Run I) can be found in Refs. [4].

Send offprint requests to:

2 CDF Search For Single Top Quark Production

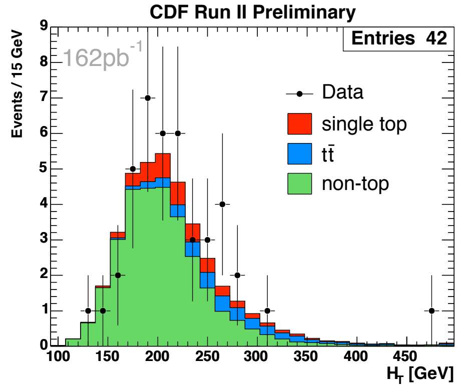
The CDF strategy consists of a combined search for the sum of the s and t channel single top signals aiming to optimize the discovery potential and a separate search where the rates for the two single top processes are measured in order to increase sensitivity to new physics. The data sample corresponds to an integrated luminosity of $162 \pm 10\ \mathrm{pb}^{-1}$. The common event selection for both analyses accepts events with the evidence of a leptonic W decay: one isolated electron(muon) with $E_T > 20$ GeV ($P_T > 20$ GeV/c) and $|\eta| < 1.0$, missing transverse energy from the neutrino, $\not{E}_T > 20$ GeV and requires exactly two jets with $E_T > 15$ GeV and $|\eta_{det}| < 2.8$. At least one of the jets must be identified as originating from a b quark with a secondary vertex algorithm (b-tagging) [7]. The effective coverage of the b-tagging ranges up to $|\eta_{det}| \leq 1.4$ with an efficiency per b jet averaging $\sim 40\%$ and a "mistags" rate, defined as the probability of erroneously identified a light-quark jet, ranging from 0.5% to 1%. The sensitivity is then increase by requiring that the invariant mass of the lepton, the neutrino and the $b-$tagged jet satisfies $140\ \mathrm{GeV}/c^2 \leq M_{l\nu b} \leq 210\ \mathrm{GeV}/c^2$. For the separate search, the sample is subdividing into events with exactly one $b-$tagged jet (t channel) and events with exactly two $b-$tagged jets (s channel). For the singly-tagged sample, the leading jet is required to have $E_T > 30$ GeV.

The event detection efficiency, ϵ_{evt}, estimated with signal events generated by the matrix element event generator MadEvent [8], followed by parton showering with PYTHIA [9] and the full CDF II detector simulation [10]. MadEvent features the correct spin polarization of the top quark and its decay products. For the t channel, two samples are generated, one $b + q \to t + q'$ and the other $g + q \to t + \bar{b} + q'$, which are then merged to reproduce the P_T spectrum of the $\bar{b}$ expected from NLO differential cross-section calculations [3]. The event detection efficiency is $1.06 \pm 0.08\%$ for the s channel and $0.89 \pm 0.07\%$ for the t channel and includes the kinematic and fiducial acceptance, branching ratios, lepton and $b-$jet identification as well as trigger efficiencies.

Two backgrounds components are considered: $t\bar{t}$ and non-top background. The $t\bar{t}$ background is estimated from events generated with PYTHIA, normalized to the theoretical cross-section $\sigma_{t\bar{t}} = 6.7^{+0.7}_{-0.9}$ pb for $m_t = 175$ GeV [11]. The primary source of non-top background is $W+$heavy flavor processes, where the rates are extracted from ALPGEN [12] Monte Carlo (MC) events and normalized to the data before $b-$tagging correcting for the presence of QCD multi-jets and $t\bar{t}$ [7]. Additional background from $W+$light-flavor jets and QCD multi-jet events, such as $b\bar{b}$ production, are determined from Run II data. Diboson production are estimated from PYTHIA MC events normalized to theory predictions [13].

Good agreement is found between observation and expectation, with a total of 42, 33 and 6 events observed versus 38.1 ± 5.9, 30.3 ± 4.7 and 3.53 ± 0.72 expected for the combined, t channel and s channel respectively.

In order to test for the signal content in the data, a maximum likelihood fit to a discriminant variable in data is performed, using a sum of templates determined from Monte Carlo events. In the case of the combined search, the variable H_T, defined as the sum of the lepton P_T, $\not\!\!E_T$ and jets E_T, is chosen since it shows a similar distribution for both the s and t channel processes but is different for the background processes (see Figure 1). For the t channel, the $Q \times \eta$ distribution (see Figure 1) , where Q is the charge of the lepton and η is the pseudorapidity of the untagged jet, is very asymmetric and peaked in the forward direction for $t-$channel signal events while it is symmetric and centrally distributed for the backgrounds. This distribution is used in the case of the separate search in a join likelihood with the number of events with two b-tagged jets, to obtain separately the contribution from s and t channel events. In the fits, the backgrounds are allowed to float but are constrained to their SM expectation with a Gaussian prior. The systematic uncertainties on the shapes of the distributions are included in the likelihood. The actual fit parameters are the deviations with respect to the SM cross-sections, *i.e.* $\beta_i = \sigma_i/\sigma_i^{SM}$, with the index i denoting single top s or t channel, $t\bar{t}$ and non-top. The fitted signal content in data are found to be compatible with zero in both searches: $\beta = 0.0^{+2.4}_{-0.0}$ for the t channel, $\beta = 5.2^{+4.3}_{-4.3}$ for the s channel and $\beta = 2.7^{+1.8}_{-1.7}$ for the combined $s + t$ channel. An upper limit on the single top cross-section is determined from a Bayesian approach using the likelihood and a flat prior on β. The single top cross-section limits at 95% C.L. observed in the data are $\sigma_s < 13.6$ pb for the s channel, $\sigma_t < 10.1$ pb for the t channel and $\sigma_{s+t} < 17.8$ pb for the combined $s + t$ channel.



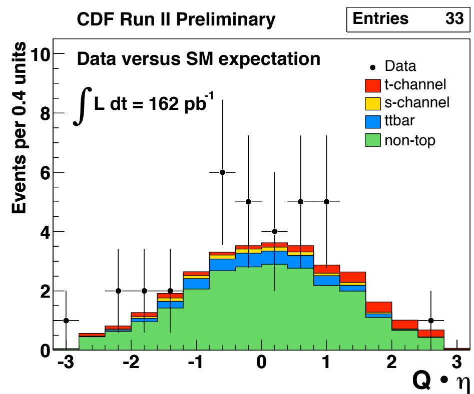


Fig. 1. H_T (top) and $Q \times \eta$ (bottom) distributions for data in the combined and $t-$channel searches respectively compared to the MC predictions for signal and background.

3 DØ Search for Single Top Quark Production

The DØ strategy for the single top search consists of a very loose event selection designed to select events containing a W and at least two jets while keeping a high acceptance for single top events. The analysis is performed separately for the electron and muon channels, using a data sample corresponding to an integrated luminosity of $\sim 230 \pm 15$ pb^{-1}. The event selection consists of identifying exactly one isolated electron (muon) with $P_T > 15$ GeV and $|\eta_{det}| < 1.1$ ($|\eta_{det}| < 2.0$), $\not\!\!E_T > 15$ GeV and between two to four jets where the leading jet must have $P_T > 25$ GeV and $|\eta_{det}| < 2.5$ and all the other jets must satisfy $P_T > 15$ GeV and $|\eta_{det}| < 3.4$. At least one of the jets must be identified as originating from a b quark with a secondary vertex algorithm [14]. The DØ $b-$tagger performance is similar to that of the CDF one. For both the s channel and $t-$channel searches, the data sample is separated into independent analysis sets based on the lepton flavor and the number of $b-$tagged jets: exactly 1-tag and ≥ 2 tags. For the $t-$channel search, it is required that one of the jets is not $b-$tagged.

The kinematic and geometrical acceptances for the s channel and t channel are estimated with signal events generated by the matrix element event generator COMPHEP [15]. The overall acceptances, including trigger and selection efficiencies, for events with at least one $b-$tagged jet are $2.7 \pm 0.2\%$ for the s channel and $1.9 \pm 0.2\%$ for the t channel. For the $s-$channel search, the t channel is considered as background and vice versa.

The W+jets and diboson backgrounds are estimated using events generated with ALPGEN [12]. The W+jets yield is normalized to the yield in the data before $b-$tagging, corrected for the presence of QCD multi-jets, $t\bar{t}$ and dibosons. The fraction of heavy flavor events ($Wb\bar{b}$) is obtained from the ratio of the NLO cross-sections for $Wb\bar{b}$ and W+jets [16]. The $t\bar{t}$ background is estimated using events generated with ALPGEN and normalized to the cross-section of $\sigma_{t\bar{t}} = 6.7^{+0.7}_{-0.9}$pb for $m_t = 175$ GeV [11]. The parton-level samples are then processed with PYTHIA [9] and the full GEANT-based simulation of the DØ detector [17]. Additional background from QCD multi-jet events is determined from data.

Good agreement is found between observation and expectation, with a total of 283 and 271 events observed versus 287.4 ± 31.4 and 275.8 ± 31.5 expected for the s channel and t channel, respectively.

In order to discriminate between signal and background events, 25 variables are combined in neural networks using eleven variables each . The set of variables can be categories as object kinematics (*e.g,* P_T^1 of the leading $b-$tagged jet, jet_{1b}), global event kinematics ($e.g\ M_{W,jet_{1b}}$) and angular correlations ($e.g$ cos($lepton, jet_{1b}$)). Eight different neural networks are trained separately for electron and muon (to account for the differen η coverage) and the four pair combinations of signals (s or t channel) and backgrounds($t\bar{t}$ or $Wb\bar{b}$). Figure 2 shows an example of the neural net output for the s channel trained for $t\bar{t}$ (top) and $Wb\bar{b}$ (bottom), combining the electron and muon channels, and requiring at least one $b-$tagged jet. The $Wb\bar{b}$ neural networks separate less efficiently the signal from the background than the $t\bar{t}$ one because the event kinematics are similar between the signal and background.

The observed data are consistent with the background predictions for all eight neural networks analyses. Upper limits on the single top quark production cross-section separately for the $s-$ channel and $t-$ channel searches are set using a Bayesian approach [18]. In each search, two-dimensional histograms are constructed from the $t\bar{t}$ and $Wb\bar{b}$ neural-network outputs. A likelihood is built from these histograms for signal, background and data as a product of all channels (electron, muon, single and double b tagged events) and bins. For the observed number of events in each bin, a Poisson distribution is assumed and a flat prior probability is use for the signal cross-section. The prior for the background yield and the combined signal acceptance is a mutivariate Gaussian with uncertainties and

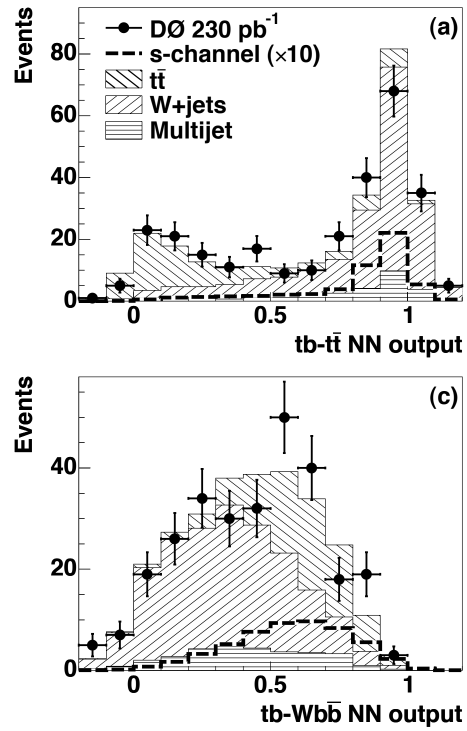


Fig. 2. Comparison of $s-$channel signal, background and data for the neural networks outputs, trained with $t\bar{t}$ (a) and $Wb\bar{b}$ (c) for the electron and muon channels combined, requiring at least one $b-$tagged jet.

correlations described by a covariance matrix. The single top cross-section limits at 95% C.L. are $\sigma_s < 6.4$ pb for the s channel, $\sigma_t < 5.0$ pb for the t channel for expected upper limits of $\sigma_s < 4.5$ pb and $\sigma_s < 5.8$ pb respectively.

4 Conclusions And Projections

The Tevatron collider experiments, CDF and DØ, are in a unique position to search for new physics in the top quark sector. Both experiments have searched for single top production in the s channel and t channel using a data sample of 160 pb^{-1} for CDF and 230 pb^{-1} for DØ. They find good agreement between the expected backgrounds and the observed data and set 95% C.L. upper limits on the single top production cross-section.

Currently, each experiment is taking an aggressive approach in developing advance analysis technique, optimizing event selections and improving the systematics uncertainties. Both experiments have looked into the projection for a 3σ evidence and a 5σ discovery, and find that, although the task is challenging, advanced analysis techniques can significantly improve the sensitivity. CDF projects to reach a 3σ evidence[1] with 1.5 fb^{-1}. With the Tevatron performing on design and expected to deliver

[1] This projection does not take into account the systematic uncertainties

8 fb^{-1} by 2009 and the already 0.8 to 1 fb^{-1} that is being analysed for the Winter conferences of 2006, the next few years of the Tevatron could turn out to be quite exciting.

4.1 Acknowledgments

I would like to thanks the HCP organizers for providing and excellent conference that was very enjoyable despite the poor weather. I also would like to thanks my colleagues from CDF and DØ top groups whose works went in to the results presented here in those proceedings.

References

1. T. Stelzer, Z. Sullivan, S.S. Willenbrock, Phys. Rev D**56**, (1997) 5919; M.C. Smith and S.S Willenbrock, Phys. Rev D**54**, (1996) 6696; S. Mrenna and C.-P. Yuan, Phys. Lett. B**416**, (1998) 200.
2. T. Tait and C.-P. Yuan, Phys. Rev. D**63**, (2001) 014018.
3. B.W. Harris, E.Laenen, L. Phaf, Z. Sullivan and S. Weinzierl, Phys. Rev. D**66**, (2002) 054024.
4. CDF Collaboration, D. Acosta *et al.*, Phys. Rev. D**65**, (2002) 091102; DØ Collaboration, B. Abbott *et al.*, Phys. Rev. D**63**, (2001) 031101; DØ Collaboration, V. M. Abazov *et al.*, Phys. Lettr. B**517**, (2001) 282.
5. CDF Collaboration, D. Acosta *et al.*, Phys. Rev. D**71**, (2005) 012005.
6. DØ Collaboration, V. M. Abazov *et al.*, Phys. Lett. B**622** (2005) 265.
7. CDF Collaboration, D. Acosta *et al.*, Phys. Rev. D**71**, (2005) 052003.
8. T. Stelzer and W.F. Long, Comput. Phys. Commun, **81**, (1994) 337; F. Maltoni and T. Stelzer, J. High Energy Phys. **02**, (2003) 027.
9. T. Sjöstrand *et al.*, Comput. Phys. Commun. **135**, (2001) 238.
10. E. Gerchtein and M. Paulini, ECONF **C0303241**, TUMT005 (2003), arXiv:physics/0306031.
11. R. Bonciani *et al.*, Nucl. Phys. B**529**, (1998) 424; M. Cacciari *et al.*, J. High. Energy Phys. **04** (2004) 068.
12. F. Caravaglios *et al.*, Nucl. Phys. B**539**, (1999) 215; M. Mangano *et al.*, Nucl. Phys. B**632**, (2002) 343; M. Mangano *et al.*, J. High Energy Phys. **07**, (2003) 001.
13. S. R. Slabospitsky and L. Sonnenschein, Comput. Phys. Commu. **148**, (2002) 87.
14. DØ Collaboration, V. M. Abazov *et al.*, hep-ex**0504058**, submitted to Phys. Rev. Lett.
15. CompHEP Collaboration, E.Boos *et al.*, Nucl. Instrum. Meth A**534**, (2004) 250.
16. DØ Collaboration, V. M. Abazov *et al.*, Phys. Rev. Lett**93**, (2004) 141801 .
17. R. Brun *et al.* CERN Program Library Long Writeup W**5013**, (1994).
18. I. Bertram *et al.*, FERMILAB-TM2104 (2000).