Top Quark Production Cross Section at $E_{cm} = 1.96\text{TeV}$

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Preliminary results on the top pair production cross section measurements by the DØ and CDF experiments in Run II at the Tevatron are presented. The measurements are obtained using various final state signatures.

1 Introduction

The top quark was discovered by the DØ and CDF collaborations in 1995 at the Tevatron $p\bar{p}$ collider. Top quarks are produced mainly in pairs through the strong interaction at the Tevatron. The Standard Model cross section including NNLO soft-gluon corrections is $\sigma_{t\bar{t}} = 6.77 \pm 0.47\text{pb}$. The decay of the two top quarks, $t \rightarrow Wb$, leads to three distinct final state signatures, depending on the decay products of the $W$. The lepton+jets channel where one of the $W$’s decays to an electron or a muon and the other one decays hadronically contains about 30% of the $t\bar{t}$ events. The di-lepton channel where both $W$’s decay to an electron or a muon contains only about 5% of the $t\bar{t}$ events, but it also has small backgrounds. The all-hadronic channel where both $W$’s decay hadronically contains 44% of the $t\bar{t}$ events but it also suffers from very large backgrounds due to QCD multi-jet production. Tau decays of the $W$ are not considered here.

In this paper we present preliminary results for the cross section measurement from the DØ and CDF experiments in the lepton+jets, di-lepton, and all-hadronic channels in Run II at the Tevatron with a center-of-mass energy of 1.96TeV.

2 Di-lepton Channel

Top pair decays to di-leptons provide a clean signature with small backgrounds from di-boson production and $Z \rightarrow \tau\tau$ events as well as $Z/\gamma+\text{jets}$ events with mis-measured $\not{E}_T$. The main

*On behalf of the DØ and CDF collaborations.
The measured scalar sum of the transverse energies of the jets, the leading lepton, and the expected Standard Model $t\bar{t}$ signal in the plot on the left-hand side of Fig. 1 shows a comparison between the sum of the background contributions and the $\mu\mu$ for the $ee$ and $ee$ channel as well as at least two jets with $E_T > 20$ GeV and $|\eta| < 2$. The resulting yield is compared to the sum of the background contributions plus the expected Standard Model $t\bar{t}$ signal in the plot on the left-hand side of Fig. 1. The measured cross section, including systematic uncertainties, is $\sigma_{t\bar{t}} = 7.0^{+2.7}_{-2.3}(stat)_{-1.3}^{+1.5}(syst) \pm 0.4(lumi)$pb. A cut-based analysis has also been performed, requiring two oppositely charged, well-identified leptons with $p_T > 20$ GeV, $E_T > 20$ GeV, at least two jets, and total transverse energy of the event $H_T > 200$ GeV, where $H_T$ is the scalar sum of the transverse energies of the lepton, $E_T$, and the jets. The measured cross section for this analysis is $\sigma_{t\bar{t}} = 8.4^{+3.2}_{-2.3}(stat)_{-1.5}^{+1.7}(syst) \pm 0.5(lumi)$pb. In a third analysis, a likelihood fit has been performed in the $E_T - n_{jets}$ plane to determine simultaneously the contributions from $t\bar{t}$, $WW$, and $Z \rightarrow \tau\tau$. The measured cross section for $t\bar{t}$ is $\sigma_{t\bar{t}} = 8.6^{+2.5}_{-2.4}(stat) \pm 1.1(syst)$pb.

The DØ experiment has done separate analyses in the $ee$, $e\mu$, and $\mu\mu$ final states in about 140 pb$^{-1}$ of Run II data. The analyses are requiring two isolated leptons (electron or muon) with $p_T > 15$ GeV ($p_T > 20$ GeV for the $ee$ channel) and $|\eta_{det}| < 1.1$ for electrons and $|\eta_{det}| < 2.0$ for muons. Additional requirements are $E_T > 25$ GeV for the $e\mu$ channel and $E_T > 35$ GeV for the $ee$ and $\mu\mu$ channel as well as at least two jets with $E_T > 20$ GeV. Events in which the invariant mass of the $ee$ or $e\mu$ pair is consistent with a $Z$ boson are removed. To separate signal events from the backgrounds, a cut is made on the transverse event energy $H_T^{leading \, lepton} > 120$ GeV for the $\mu\mu$ channel and $H_T^{leading \, lepton} > 140$ GeV for the $e\mu$ channel, where $H_T^{leading \, lepton}$ is the scalar sum of the transverse energies of the jets, the leading lepton, and $E_T$. The right-hand side of Fig. 1 shows a comparison between the sum of the background contributions and the expected Standard Model $t\bar{t}$ signal to the data for $H_T^{leading \, lepton}$. The measured cross section is $\sigma_{t\bar{t}} = 14.3^{+5.1}_{-4.3}(stat)_{-2.6}^{+2.9}(syst) \pm 0.9(lumi)$pb. The DØ experiment has also performed a measurement in the $e\mu$ channel requiring that one of the jets is b-tagged with a secondary-vertex tagger. As a result this channel is virtually background-free but has low statistics. The measured contributions to the systematic uncertainty are from jet energy scale, object ID, as well as background normalization. Modeling of b-tagging in the Monte Carlo also contributes to the systematic uncertainty.

The CDF experiment uses several different approaches to measure the $t\bar{t}$ cross section in the di-lepton channel in 200 pb$^{-1}$ of Run II data. The lepton+track analysis asks for one electron or muon to be well identified in the detector with $p_T > 20$ GeV and $|\eta| < 1$ (muons) or $|\eta| < 2$ (electrons). The requirement on the additional lepton is only to ask for one isolated track with $p_T > 20$ GeV, thus maximizing the acceptance for di-lepton events and even including some $W \rightarrow \tau$ events. Further requirements are $E_T > 25$ GeV and at least two jets with $E_T > 20$ GeV and $|\eta| < 2$. The resulting yield is compared to the sum of the background contributions plus the expected Standard Model $t\bar{t}$ signal in the plot on the left-hand side of Fig. 1. The measured cross section, including systematic uncertainties, is $\sigma_{t\bar{t}} = 7.0^{+2.7}_{-2.3}(stat)_{-1.3}^{+1.5}(syst) \pm 0.4(lumi)$pb.

| Event count per jet bin |
|-------------------------|
| WW + WZ + ZZ | + Drell-Yan | + fakes | + $t\bar{t}$ ($\sigma_{\mu\mu} = 6.7$ pb) |

| $H_T^{leading \, lepton}$ (GeV) |
|----------------------------------|
| 0 | 100 | 200 | 300 | 400 | 500 |
| Number of Events |
| 0 | 1 | 2 | 3 | 4 | 5 |

Figure 1: The jet multiplicity distribution for the CDF lepton+track analysis (left) and the $H_T^{leading \, lepton}$ distribution for the DØ di-lepton analysis (right).
This additional requirement reduces the backgrounds significantly. One of the b-tagging analyses requires that at least one of the jets is tagged with a secondary vertex b-tagging algorithm.

The measured cross section using 140pb$^{-1}$ of Run II data is $\sigma_{t\bar{t}} = 11.1^{+5.8}_{-4.3}(stat) \pm 1.1(syst) \pm 0.6(lumi)pb$.

### 3 Lepton+Jets Channel

The $t\bar{t}$ decay mode where one of the $W$’s decays to an electron or muon and the other $W$ to quarks results in a final state of one lepton and at least three high-$E_T$ jets. The dominant background to this event signature is from $W/Z+\text{jets}$ production, and an additional background comes from QCD multi-jet events where one of the jets is mis-identified as an isolated lepton.

The CDF experiment has done several separate analyses using 200pb$^{-1}$ of Run II data, all using the same basic selection cuts: exactly one isolated lepton (electron or muon) with $p_T > 20GeV$, $E_T > 20GeV$, and at least three jets with $E_T > 15GeV$. One analysis requires at least four jets and performs a template fit of the background and signal $H_T$ distributions to the observed data. The result is shown on the left-hand side of Fig. 2. The measured cross section in this analysis is $\sigma_{t\bar{t}} = 4.7 \pm 1.6(stat) \pm 1.8(syst)pb$. Another analysis uses a 7-input Neural Network to separate signal from background and performs a template fit to the Neural Network output, giving a measured cross section of $\sigma_{t\bar{t}} = 6.7 \pm 1.1(stat) \pm 1.5(syst)pb$.

CDF has also performed two analyses in the lepton+jets channel with 200pb$^{-1}$ of Run II data, requiring that at least one of the jets is tagged with a secondary vertex b-tagging algorithm. This additional requirement reduces the backgrounds significantly. One of the b-tagging analyses makes the additional requirement that $H_T > 200GeV$. The resulting jet multiplicity distribution is shown on the right-hand side of Fig. 2. The measured cross section for events with at least one b-tag is $\sigma_{t\bar{t}} = 5.6^{+1.2}_{-1.1}(stat)^{+0.9}_{-0.6}(syst)pb$. The measured cross section for events with at least two b-tag and no cut on $H_T$ is $\sigma_{t\bar{t}} = 5.0^{+2.4}_{-1.9}(stat)^{+1.1}_{-0.8}(syst)pb$. The other b-tagging analysis performs a template fit to the $E_T$ distribution of the leading jet in the event to separate signal from backgrounds, resulting in a measured cross section of $\sigma_{t\bar{t}} = 6.0^{+2.1}_{-1.2}(stat) \pm 0.8(syst)pb$.

The DØ experiment has performed several analyses in the lepton+jets channel using 160pb$^{-1}$ of Run II data. The same basic selection cuts are used for all lepton+jets analyses: one isolated lepton (electron or muon) with $E_T > 20GeV$, $E_T > 20GeV$ ($E_T > 17GeV$) for the electron (muon) channel, and at least three jets with $E_T > 15GeV$ and $|\eta| < 2.5$. A topological analysis requires at least four jets and then builds a likelihood discriminant from four topological variables that each give good signal-background separation. A template fit to the likelihood discriminant is then performed to obtain a cross section measurement. The likelihood discriminant for the electron channel data is shown in the left-hand plot of Fig. 3 together with the fit result. The measured cross section is $\sigma_{t\bar{t}} = 7.2^{+2.7}_{-2.4}(stat)^{+1.6}_{-1.7}(syst) \pm 0.5(lumi)pb$. 

![CDF Preliminary](image_url)
The DØ experiment has also performed an analysis in the muon channel using two different tagging algorithms, a) based on the reconstruction of a secondary vertex (SVT), and b) based on measuring the impact parameter of tracks with respect to the primary interaction vertex (CSIP). The jet multiplicity distribution for CSIP tagged events in data is shown on the right-hand side of Fig. 3, together with the individual background and signal contributions. The measured cross section for the CSIP tagger is $\sigma_{tt} = 5.2^{+1.7}_{-1.5} (stat) +^{1.7}_{-1.2} (syst) \pm 0.3(lumi) pb$. The measured cross section using the SVT tagger is $\sigma_{tt} = 6.9^{+2.0}_{-1.8} (stat) +^{1.8}_{-1.7} (syst) \pm 0.4(lumi) pb$.

4 All-Hadronic Channel

The all-hadronic decay mode is a more difficult measurement because it has a large background from QCD multi-jet production. This background is suppressed by requiring at least one of the jets to be b-tagged. The CDF experiment selects events with at least six jets, requires at least one b-tag, and makes several cuts on kinematical variables to reduce the multi-jet background further. The measured cross section is $\sigma_{tt} = 7.8 \pm 2.5(stat) +^{1.7}_{-2.3} (syst) pb$. The DØ experiment selects events with at least six jets and requires at least one secondary vertex b-tag. A neural network is then constructed using several kinematical variables. The cross section is measured in a fit to the neural network output. The measured cross section is $\sigma_{tt} = 7.7^{+3.4}_{-3.3} (stat) +^{4.7}_{-3.7} (syst) \pm 0.5(lumi) pb$.

5 Summary

The top pair production cross section has been measured in Run II at the Tevatron by both the DØ and CDF collaborations in various final states using several different approaches, in datasets of 140pb$^{-1}$ to 200pb$^{-1}$. The statistical uncertainty is comparable to the systematic uncertainty in many analysis channels. The measured cross sections are consistent with the Standard Model expectation.

References

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