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Top quark production at the Tevatron

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Abstract. Preliminary results on the $t\bar{t}$ production cross section measurement at a center-of-mass energy of 1.96 TeV carried out by the CDF and DØ collaborations are presented. The data samples used for the analyses are collected in the current Tevatron run.

PACS. 14.65.Ha Top quarks – 13.85.Qk Hadron-induced inclusive production with identified leptons, photons, or other nonhadronic particles (energy > 10 GeV) – 13.85.Lg Hadron-induced total cross sections (energy > 10 GeV)

1 Introduction

The dominant production mechanism of top quarks in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV is in pairs, $p\bar{p} \to t\bar{t} + X$, via the strong interaction ($q\bar{q}$ annihilation (85%) and gluon fusion (15%)).

Existing theoretical predictions for the $t\bar{t}$ production cross section at NLO in QCD range from 6.7 to 7.5 pb [1, 2,3] (for $m_t = 175$ GeV and $\sqrt{s} = 2$ TeV), with an expected uncertainty of $\sim 5\%$. This represents a $\sim 30\%$ increase with respect to the cross section at $\sqrt{s} = 1.8$ TeV. The latest NNLO calculation using CTEQ6M NLO parton densities [4] predicts a cross section of 6.77±0.42 pb [5] for $m_t = 175$ GeV and $\sqrt{s} = 1.96$ TeV. The precise measurement of the $t\bar{t}$ production cross section is not only of interest as a test of QCD, but also to probe for new physics effects which can lead to deviations from the Standard Model (SM) expectation.

In the SM, the top quark decays almost 100% of the time to a W boson and b-quark. Therefore, in $t\bar{t}$ events the final state is completely determined by the W boson decay modes. This paper covers the recent top quark cross section measurements performed by the CDF and DØ in the dilepton channels, where both W bosons decay leptonically into an electron or a muon (ee, $e\mu$, $\mu\mu$), and in the lepton + jets channels, where one of the W bosons decays leptonically and the other hadronically (e+jets, μ+jets).

2 Dilepton channels

In the detector a dileptonic final state is characterized by the presence of two isolated high p_T leptons, two high p_T $b-$jets and a large missing transverse energy ($\not\!\!E_T$) from the two neutrinos. The background contributions are pure instrumental effects, entirely estimated from data, and irreducible physics backgrounds, derived from a Monte Carlo simulation. Sources of the former are QCD, W+jets and $Z \to l^+l^-$ events with mismeasured $\not\!\!E_T$, misidentified jets or misidentified isolated electrons or muons, whereas the latter mainly includes $Z \to \tau\tau$ and $WW \to l^+l^-$ processes. A summary of the expected top quark signals, backgrounds and observed number of events in dilepton channels obtained by CDF is presented in Table 1. The corresponding DØ results are shown in Table 2. The preliminary quoted $t\bar{t}$ cross section are:

Table 1. Summary result in the dilepton channels obtained by CDF (in number of events)

Source	ee	$\mu\mu$	$e\mu$
Luminosity (pb^{-1})	79	79	79
Background	0.10±0.06	0.09±0.05	0.10±0.04
$t\bar{t} \to l^+\nu l^-\bar{\nu}b\bar{b}$	0.47±0.05	0.59±0.07	1.44±0.16
SM expectation	0.57±0.08	0.68±0.09	1.5±0.2
Data	1	1	3

$$\text{CDF}: \sigma_{t\bar{t}} = 13.2 \pm 5.9\,(\text{stat}) \pm 1.5\,(\text{syst}) \pm 0.8\,(\text{lumi})\ \text{pb};$$
$$\text{D0}: \sigma_{t\bar{t}} = 29.9^{+21.9}_{-15.7}\,(\text{stat})\ ^{+14.1}_{-6.1}\,(\text{syst}) \pm 3.0\,(\text{lumi})\ \text{pb}.$$

3 Lepton + jets channels

The signature of the lepton + jets channel consists of one isolated high p_T lepton, $\not\!\!E_T$ due to the neutrino and at least four jets. The dominant background processes are W+jets and multijet production. To discriminate signal from background, which is significantly higher in lepton + jets channels compared to the dilepton ones two approaches are used. The first approach makes use of the distinct topology of $t\bar{t}$ events and relies on kinematic selection

Table 2. Summary result in the dilepton channels obtained by DØ (in number of events)

Source	ee	$\mu\mu$	$e\mu$
Luminosity (pb^{-1})	48.2	33	42
Background	1.00±0.48	0.60±0.30	0.07±0.01
$t\bar{t} \to l^+\nu l^-\bar{\nu}b\bar{b}$	0.25±0.02	0.30±0.04	0.50±0.01
SM expectation	1.25±0.48	0.90±0.30	0.57±0.01
Data	4	1	1

criteria only. The second approach requires that at least one of the jets per event is identified as a $b-$jet ($b-$tagging selection). To distinguish a heavy-flavor jet (arising from a b-, c-quark) from a light-flavor jet (u-, d-, s-quark or gluon) one can make use of the presence of a soft electron or muon within the jet cone, indicating a semileptonic B- or D-meson decay (soft lepton tagging), or of charged tracks significantly displaced from the primary vertex due to the finite lifetime of the B- or D-meson (lifetime tagging). In both approaches, at the first stage of the analysis a data sample enriched in W+jets and $t\bar{t}$ events is defined. The remaining QCD multijet background originates primarily from π^0's and γ's misidentified as jets (e+jets channel) or from heavy flavor decays (μ+jets channel), and is evaluated directly from data by studying the lepton isolation in the low $\not{E}_T$ (< 10 GeV) and in the high $\not{E}_T$ (> 20 GeV) regions.

3.1 Topological analysis

The W+jets background for events with ≥ 4 jets, where the $t\bar{t}$ contribution is expected, is estimated by DØ by extrapolating from a W+jets data sample at low multiplicities, assuming that the number of W+jets events falls exponentially with the number of jets in the event[6].Two kinematical variables that provide significant discrimination between $t\bar{t}$ events and background are the scalar sum of all jets transverse energy (H_T) and the aplanarity A[7], computed using the leptonic W boson and jets momenta. In the topological analysis performed by DØ $t\bar{t}$ events were selected requiring A>0.065 and H_T>180 GeV (H_T>220 GeV[1]) in the e+jets (μ+jets) channel. Expected backgrounds, $t\bar{t}$ signal and observed number of events with ≥ 4 jets after topological selection are summarized in Table 3.

3.2 Soft muon tag analysis

The soft muon tag analysis carried out by DØ makes use of a preselected sample similar to the one used in the topological analysis. Events with ≥ 3 jets are considered and looser topological cuts are applied (A>0.04, H_T>110 GeV) to improve the purity of the sample before applying the $b-$tagging algorithm. A jet is tagged if a muon with $p_T > 4$ GeV/c and $|\eta| < 2$ is found within $\Delta R = 0.5$ of the jet axis. Two (zero) events in the four-jet topology were tagged in the e+jets (μ + jets) channel. The total expected background contribution is 0.2 ± 0.1 (0.7 ± 0.4) events in the e+jets (μ + jets) channel. The combined $t\bar{t}$ cross section measured by DØ in dilepton channels and lepton + jets channels using topological and soft muon tagging techniques yields:

$$\sigma_{t\bar{t}} = 8.5^{+4.5}_{-3.6}\,(\text{stat})\,^{+6.3}_{-3.5}\,(\text{syst})\,\pm 0.8\,(\text{lumi})\text{ pb}.$$

[1] For the μ+jets channel, the H_T variable is chosen to include the transverse momentum of the leptonic W

Table 3. Summary of topological analysis results in lepton+jets channels obtained by DØ

Channel	$e + jets$	$\mu + jets$
Luminosity (pb^{-1})	49.5	40
Background	2.7±0.6	2.7±1.1
$t\bar{t} \to l\nu jjb\bar{b}$	1.8	2.4
Data	4	4

3.3 Lifetime tag analysis

Both the CDF and DØ have measured the $t\bar{t}$ production cross section using lifetime tagging. CDF analysis follows the same techniques and uses the secondary vertex identification algorithm (SVX) developed in Run I[8]. The new tracking system built for the current Tevatron run has allowed DØ to perform for the first time this analysis. The DØ analysis is carried out using two different taggers. The first algorithm (similar to CDF's SVX algorithm), called Secondary Vertex Tagger (SVT), performs an explicit reconstruction of a secondary vertex with a large decay length significance with respect to the primary vertex. The second algorithm, called Counting Signed Impact Parameter (CSIP), requires a minimum number of tracks with large impact parameter significance with respect to the primary vertex.

The method used by DØ starts from a preselected sample enriched in W+jets events. The W+jets and QCD multijets contributions are determined by the methods described above, for each final state jet multiplicity. Then, in each bin of jet multiplicity the number of W events associated with the different relevant flavor configurations is calculated from fractions determined using a Monte Carlo simulation. Next, the probabilities to tag events with different final state jet multiplicity and flavor content are obtained through a Monte Carlo simulation. However, since Monte Carlo does not reproduce the b-tagging efficiency and mistag rate observed in the data, the simulation is calibrated using a variety of independent data samples. Tagging probabilities are applied to each background component to determine its contribution to the tagged sample. Finally, the $t\bar{t}$ production cross section is calculated from the excess observed in the actual number of tagged events with 3 and ≥ 4 jets with respect to the background expectation. Contributions of various backgrounds compared to

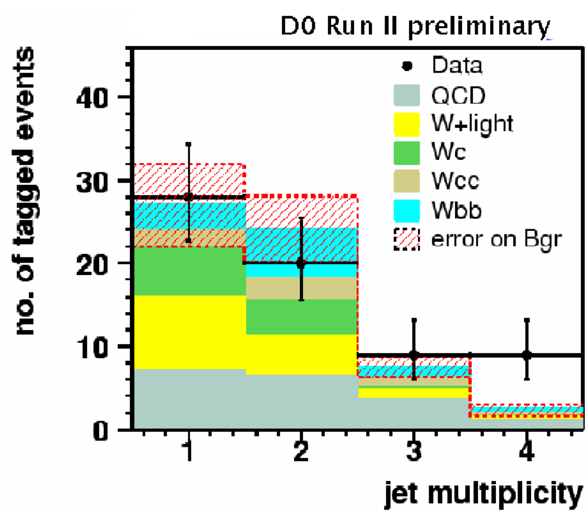

Fig. 1. Summary of background contributions in lepton+jets channels measured using the SVT tagging algorithm. The dots denote observed number of tagged events in data. The band shows the $\pm1\sigma$ variation of the background

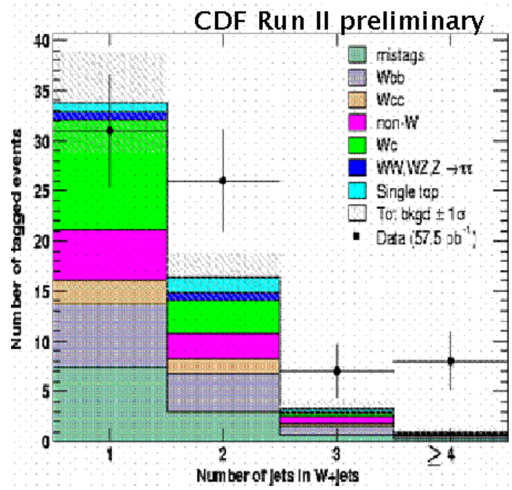

Fig. 2. Summary of background contributions in the lepton+jets channels measured by CDF. The dots denote the observed number of tagged events in data. The band shows the $\pm1\sigma$ variation of the background

Table 4. Summary of the b-tagging analysis results in lepton+jets channels obtained by DØ using the CSIP tagging algorithm on a data sample of 45 pb^{-1}

l+jets	1 jet	2 jets	3 jets	≥4 jets
Background	30.6±5.0	26.4±3.5	8.3±1.3	2.5±0.7
$t\bar{t} \rightarrow l\nu jjb\bar{b}$		0.7±0.1	2.8±0.2	4.0±0.6
SM expectation	30.6±5.0	27.1±3.6	11.1±1.4	6.5±1.0
Data	34	27	13	4

Table 5. Summary of the b-tagging analysis results in lepton+jets channels obtained by CDF on a data sample of 57.5 pb^{-1}

l+jets	1 jet	2 jets	3 jets	≥4 jets
Background	33.8±5.0	16.4±2.4	2.88±0.05	0.87±0.20
SM expextation	34.0±5.0	18.7±2.4	7.35±1.40	7.6±2.0
Data	31	26	7	8

the observed number of tagged events for different jet multiplicity bins as measured by DØ using the SVT method are summarized in Fig. 1. Table 4 obtained with the CSIP algorithm presents the number of tagged events, predicted background and the expected number of $t\bar{t}$ events (calculated assuming $t\bar{t}$ cross section of 7 pb). The resulting cross section obtained by DØ is:

$$\text{SVT}: \quad \sigma_{t\bar{t}} = 10.8^{+4.9}_{-4.0}\,(\text{stat})\ ^{+2.1}_{-2.0}\,(\text{syst})\ \pm 1.1\,(\text{lumi})\ \text{pb};$$

$$\text{CSIP}: \quad \sigma_{t\bar{t}} = 7.4^{+4.4}_{-3.6}\,(\text{stat})\ ^{+2.1}_{-1.8}\,(\text{syst})\ \pm 0.7\,(\text{lumi})\ \text{pb}.$$

A comparison of the observed number of tagged events with the predicted background split in the different contributions as measured by CDF is presented in Fig. 2. Table 5 summarises the background and expected $t\bar{t}$ signal. The resulting cross section obtained by CDF is:

$$\sigma_{t\bar{t}} = 5.3 \pm 1.9\,(\text{stat})\ \pm 0.8\,(\text{syst})\ \pm 0.3\,(\text{lumi})\ \text{pb}.$$

In both CDF and DØ analyses the number of tagged events observed in data agrees within errors with the predicted background for the one- and two-jet event topologies. For the events with 3 and $\geq$ 4 jets the actual number of tagged events shows an excess with respect to the background expectation which is attributed to $t\bar{t}$ production.

4 Summary

Both the CDF and DØ collaborations have re-established the $t\bar{t}$ signals and measured $t\bar{t}$ cross section in the majority of decay channels using data collected in the current Tevatron run. DØ has presented the first physics result based on the application of lifetime b-tagging techniques which makes use of the new tracking system.

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