Measurements of the $t\bar{t}$ Cross Section at D0 and Interpretations

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**Abstract.** We present measurements of the $t\bar{t}$ production cross section in $p\bar{p}$ collisions at a center of mass energy of $\sqrt{s} = 1.96$ TeV using dilepton, hadronic tau, lepton+jets and all hadronic events with data collected by the D0 detector. We use the ratios of $t\bar{t}$ cross sections in different final states to set upper limits on the branching fractions $B(t \rightarrow H^+ b \rightarrow \tau \nu b) < 15\%$ and $B(t \rightarrow H^+ b \rightarrow c \bar{s} b) < 57\%$ for low charged-Higgs masses. Finally, based on predictions from higher order quantum chromodynamics, we extract a mass for the top quark from the combined $t\bar{t}$ cross section.

**Keywords:** top quark, cross section, charged Higgs, Tevatron, D0

**PACS:** 12.15.Ff, 13.85.Lg, 13.85.Qk, 13.85.Rm, 14.65.Ha, 14.80.Cp

**INTRODUCTION**

Precise measurements of the production and decay properties of the top quark provide important tests of the standard model and offer a window for searches for new physics. At the Tevatron $p\bar{p}$ collider, top quarks are produced in pairs through the strong interaction or singly, without an antiparticle partner, via the electroweak interaction. We report here the most precise measurements of the top-antitop quark pair ($t\bar{t}$) production cross section to date, using the Run II data of the Tevatron collider operated at $\sqrt{s} = 1.96$ TeV and collected with the D0 detector.

In the standard model, top quarks are predicted to decay into a W boson and a b quark with a branching fraction of nearly 100%. The decay modes of the W boson define the possible final states. We will focus here on the lepton+jets and dilepton channels. Compatibility with the SM results will be tested via the ratios of the cross sections in different final states and limits on the branching fractions of the top to a charged Higgs and a b quark will be derived. Finally, the top mass extraction from the cross sections results will be presented.

**MEASUREMENT IN LEPTON+JETS CHANNELS**

The lepton+jets channels correspond to approximately 38% of all top-antitop quark events: one W boson will decay leptonically to $e\nu$, $\mu\nu$, or $\tau\nu$ followed by $\tau \rightarrow e\nu\nu$ or $\mu\nu\nu$ and the other W will decay to jets or to $\tau\nu$ followed by a hadronic $\tau$ decay.

The D0 detector acquires these events by triggering on an electron or muon and at least one jet with large momentum component transverse to the beam direction ($p_T$). The event selection requires exactly one electron or muon that is isolated from other objects in the detector, with $p_T > 20$ GeV/c and a pseudorapidity $|\eta| < 1.1$ (for e) or
|\eta| < 2 \text{ (for } \mu \text{), missing transverse momentum } p_T > 20 \text{ GeV/c (for } e+\text{jets) or 25 \text{ GeV/c (for } \mu+\text{jets), and at least three jets with } p_T > 20 \text{ GeV/c and } |\eta| < 2.5. The jet with the highest } p_T \text{ (leading jet) must have } p_T > 40 \text{ GeV/c and the lepton } p_T \text{ and } p_T \text{ vectors must be separated in azimuth to reject background events with mismeasured particles. Then, two complementary techniques are used to distinguish the } t\bar{t} \text{ signal from the remaining backgrounds: b-tagging and a kinematic likelihood discriminant.

For the b-tagging analysis, the cross section is extracted by a maximum likelihood fit to the number of events in the 8 channels (e or } \mu \text{, 3 or 4 jets, 1 or 2 b-tagged jets). The obtained cross section on a sample of 0.9 fb}^{-1} \text{ of data, assuming } m_{t\bar{t}} = 175 \text{ GeV/c}^2, \text{ is:}

$$\sigma_{t\bar{t}} = 8.05 \pm 0.54 \text{(stat)} \pm 0.70 \text{(syst)} \pm 0.49 \text{(lumi)} \text{pb} \quad (1)$$

For the kinematic likelihood discriminant analysis, a maximum likelihood fit to the likelihood discriminant distributions based on topological variables is performed in the 4 channels simultaneously (e or } \mu \text{, 3 or 4 jets). The obtained cross section for the same sample is:

$$\sigma_{t\bar{t}} = 6.62 \pm 0.78 \text{(stat)} \pm 0.36 \text{(syst)} \pm 0.40 \text{(lumi)} \text{pb} \quad (2)$$

The combined result is [1]:

$$\sigma_{t\bar{t}} = 7.42 \pm 0.53 \text{(stat)} \pm 0.46 \text{(syst)} \pm 0.45 \text{(lumi)} \text{pb} \quad (3)$$

**MEASUREMENT IN DILEPTON CHANNELS**

We consider dilepton final states with two identified electrons or muons from the W boson leptonic decays, i.e., ee, e\mu and } \mu\mu \text{, and final states with a } \tau \text{ lepton that decays into hadrons+}\nu \text{ from the decay of one W boson and an accompanying electron or muon from the other W boson, i.e., e}\tau \text{ and } \mu\tau. \text{ The events are selected by asking for one isolated electron with } p_T > 15 \text{ GeV/c or one muon with } p_T > 20 \text{ GeV/c for the } \ell\tau \text{ channel or two isolated oppositely charged leptons with } p_T > 15 \text{ GeV/c for the } \ell\ell \text{ channels.}

Three types of hadronic } \tau \text{ are defined as (i) } \tau\text{-type 1 (} \pi^\pm \text{-like), consisting of a single track, with energy deposition in the hadronic calorimeter, (ii) } \tau\text{-type 2 (} \rho^\pm \text{-like), a single track, with an energy deposit in both the hadronic and the electromagnetic calorimeters and (iii) } \tau\text{-type 3, having two or three tracks. A set of neural networks, one for each type, based on isolation shower shape and cal-track correlations variables, is used to discriminate hadronic taus from jets. In addition, tau leptons are required to have } E_T > 10, 5, \text{ or } 10 \text{ GeV for } \tau\text{-type 1, 2 or 3 respectively and an opposite charge with respect to the lepton.}

At least one jet is required to have } p_T > 30 \text{ GeV/c. All channels, except for } e\mu, \text{ which has the best signal over background ratio, require another jet with } p_T > 20 \text{ GeV/c.}

The final selection in } \ell\ell \text{ channels requires dilepton invariant mass cuts and other topological cuts like requirements on the scalar sum of the leptons and the jets, on missing transverse energy or on the sphericity. The final selection in the } \ell\tau \text{ channels requires at least one b-tagged jet and MET cuts.}

The various selections have been constructed to have no overlap between channels. The combined cross section obtained with a sample of 1 fb}^{-1} \text{ and assuming a top mass
The $t\bar{t}$ production cross section measurements at D0 for an energy of 175 GeV/c$^2$ is [2]:

$$\sigma_{t\bar{t}} = 7.5^{+1.0}_{-1.0}(\text{stat})^{+0.7}_{-0.6}(\text{syst})^{+0.6}_{-0.5}(\text{lumi})\text{pb}$$ \hspace{1cm} (4)

The $\tau\ell$ analysis has been also performed on a bigger sample of data (2.2 fb$^{-1}$) and gives a similar result:

$$\sigma_{t\bar{t}} = 7.32^{+1.34}_{-1.24}(\text{stat})^{+1.20}_{-1.06}(\text{syst}) \pm 0.45(\text{lumi})\text{pb}$$ \hspace{1cm} (5)

### COMBINATION

The measurement in lepton+jets and dilepton channels with 1 fb$^{-1}$ previously presented have been combined with a simultaneous fit of all the channels via a joint likelihood where systematic uncertainties are included through “nuisance” parameters [3]. The obtained cross-section for a top mass of 170 GeV/c$^2$ is:

$$\sigma_{t\bar{t}} = 8.18^{+0.98}_{-0.87}\text{pb}$$ \hspace{1cm} (6)

The results in all the channels and the combination are presented on the figure 1. For the current Tevatron measured top mass ($m_{top} = 173.1 \pm 0.6(\text{stat}) \pm 1.1(\text{syst})$ GeV/c$^2$ [4]), the expected “NNLO”$^1$ $t\bar{t}$ production cross section is $7.32^{+0.47}_{-0.66}$ pb [5]. All the cross section measurements are in agreement with the standard model expectation.

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$^1$ The expected $t\bar{t}$ production cross section is computed in next-to-leading order perturbative quantum chromodynamics, including higher order soft gluon resummations.
RATIO AND LIMITS ON THE CHARGED HIGGS BOSON

We compute ratios $R_\sigma$ of measured cross sections, $R_\sigma^{\ell\ell/\ell+\text{jets}} = \sigma_\ell/\sigma_\ell^{\ell+\text{jets}}$ and $R_\sigma^{\tau\ell/\ell+\ell+\text{jets}} = \sigma_\tau/\sigma_\ell^{\ell+\text{jets}}$, by generating pseudo-datasets in the numerator and denominator [3]. The pseudo-datasets are created by varying the number of signal and background events around the expected number according to Poisson probabilities. We obtained $R_\sigma^{\ell\ell/\ell+\text{jets}} = 0.86^{+0.19}_{-0.17}$ and $R_\sigma^{\tau\ell/\ell+\ell+\text{jets}} = 0.97^{+0.32}_{-0.29}$, which is consistent with the SM expectation of $R_\sigma = 1$.

We use these ratios to extract upper limits on the branching ratio $B(\ell \rightarrow H^+ b)$. In particular, a charged Higgs boson decaying into a tau and a neutrino ($B(H^+ \rightarrow \tau \nu) = 1$) results in more events in the $\tau\ell$ channel, while fewer events appear in the $\ell\ell$ and $\ell+\text{jets}$ final states compared to the SM prediction. In case of the leptophobic ($B(H^+ \rightarrow c\bar{s}) = 1$) model, the number of dilepton events decreases faster than the number of $\ell+\text{jets}$ events for increasing $B(\ell \rightarrow H^+ b)$. To extract the limits, we generate pseudo-datasets assuming different branching fractions $B(\ell \rightarrow H^+ b)$. The results are presented on the figure 2.

TOP MASS EXTRACTION

Owing to the significant dependence of the $t\bar{t}$ cross section on the mass of the top quark, a precise cross section measurement allows the extraction of the mass of the top quark in a way complementary to direct reconstruction methods and hence provides a valuable consistency check. From the cross section measurements in lepton+jets and dileptons channels with 1 fb$^{-1}$ we extract the most probable top quark pole mass values and the 68% CL band. The results are given in Table 1. All values are in good agreement with the current Tevatron average of 173.1 ± 0.6(stat)±1.1(syst) GeV/c$^2$ [4].
<table>
<thead>
<tr>
<th>Theoretical predictions</th>
<th>$m_t$ (GeV)</th>
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<tbody>
<tr>
<td>NLO [6]</td>
<td>165.5$^{+6.1}_{-3.9}$</td>
</tr>
<tr>
<td>NLO+NLL [7]</td>
<td>167.5$^{+3.8}_{-3.6}$</td>
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<tr>
<td>approximate NNLO [5]</td>
<td>169.1$^{+3.9}_{-3.2}$</td>
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<td>approximate NNLO [8]</td>
<td>168.2$^{+3.9}_{-3.4}$</td>
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**REFERENCES**