TOP QUARK PRODUCTION CROSS-SECTION AT THE TEVATRON RUN 2

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The top quark pair production cross-section $\sigma_{tt}$ has been measured in $p\bar{p}$ collisions at center of mass energies of 1.96 TeV using Tevatron Run 2 data. In the beginning of Run 2 both CDF and DØ $\sigma_{tt}$ measurements in the dilepton channel $tt\rightarrow Wb\bar{W}b\ell\bar{\ell}$ and in the lepton plus jets channel $tt\rightarrow WbW\bar{b}\rightarrow q\bar{q}b\bar{q}\ell\bar{\nu}\ell\nu$ agree with the NLO (Next-to-Leading-Order) theoretical predictions. The presence of a top signal in Tevatron data has been reestablished.

1 Introduction

To date, all direct measurements of top quark production have been performed by the CDF and DØ experiments at the Fermilab Tevatron collider in $p\bar{p}$ collisions. At the Tevatron top quarks are produced predominantly in pairs through the QCD processes $q\bar{q}\rightarrow tt$ and $gg\rightarrow tt$. Top quarks can also be produced singly via the electroweak vertex $Wtb$ with about half the cross section, but with final states difficult to extract from background.

In Run 1, at center of mass energies $\sqrt{s} = 1.8$ TeV, the top pair production cross-section was expected to be $5.19^{+0.52}_{-0.68}$ pb at $m_{top} = 175$ GeV/c$^2$ with a 90% (20%) contribution from $q\bar{q}\rightarrow tt$ ($gg\rightarrow tt$). The precision of the measured cross-sections by the Tevatron from about 100 pb$^{-1}$ of data in Run 1 was approximately 25%. The ratio of cross-sections at 1.96 TeV (Run 1) and 1.8 TeV (Run 2) is 1.295$^{+0.015}_{-0.01}$, with an expected Run 2 cross-section of $6.70^{+0.71}_{-0.88}$ pb with 85% (15%) contribution from $q\bar{q}\rightarrow tt$ ($gg\rightarrow tt$). In Run 2a, with the increased center of mass energy and the expected integrated luminosity of 2 fb$^{-1}$, we should measure $\sigma_{tt}$ to better than 7% precision and observe single top production for the first time with a 20% precision on the cross-section measurement.

a Results BCMN[1] updated in[2] taking into account the most recent determinations of systematic uncertainties in the extraction of the PDFs.

b The $\sigma_{tt}$ from all channels combined measurement by CDF[3] and DØ[4] was $6.5^{+1.7}_{-1.4}$ pb for $m_{top} = 176.1\pm6.6$ GeV/c$^2$ and $5.9\pm1.7$ pb for $m_{top} = 172.1\pm6.8$ GeV/c$^2$ respectively.
Within the SM the top quark decays almost exclusively into Wb. The $t\bar{t}$ dilepton channel, where both W’s decay leptonically to e or $\mu$, has the smallest BR: 5%. In the so called “lepton plus jets” one W decays leptonically and the other hadronically giving a higher BR: \sim 30%.

The Tevatron has delivered about 170 pb$^{-1}$ in Run 2a up until January 2003. The detector upgrades have been extensive. CDF has expanded the silicon coverage and installed a new drift chamber. DØ has a new inner tracking (silicon and fiber trackers) with a new 2T superconducting solenoid. CDF has extended the electron identification to rapidity regions $|\eta| > 1$ with a new plug calorimeter and the coverage of the muon systems.

2 $\sigma_{tt}$ measurements in the dilepton channel

The background processes that mimic the top dilepton signature are Drell-Yan ($Z^*/\gamma \rightarrow e^+e^-, \mu\mu$), $Z \rightarrow \tau\tau$, WW/WZ and processes with a real lepton and a jet or a track faking a second lepton.

Dilepton selection starts with 2 high-$P_T$ ($P_T > 20$ GeV/c) $e$ or $\mu$ oppositely charged. CDF requires both leptons to be well isolated from nearby calorimeter activity greatly reducing the fake lepton, Wbb and $bb$ backgrounds. The dilepton invariant mass, $M_{\ell\ell}$ or $M_{\mu\mu}$, is required to be outside the interval $76 - 106$ GeV/c$^2$ to reject $Z \rightarrow \ell^+\ell^-X$ events. DØ discriminates $t\bar{t}$ from $Z$'s in this interval by demanding larger $E_T$ than in the region outside this interval.

A large $E_T$ is required as a signature of the two W decay neutrinos. All backgrounds with real $E_T$ contribution due to the presence of neutrinos are reduced. In addition CDF requires $|E_T| > 50$ GeV if $\Delta\phi(E_T, \ell)$ or $j < 20^{\circ}$ to eliminate instrumental contributions to the $E_T$ due to mismeasured energies of lepton or jets$^d$ (see Figure 2).

![Figure 1: On the left side, the 5 CDF $t\bar{t}$ dilepton candidates found in 72 pb$^{-1}$ in the plane $\Delta\phi(E_T, \text{nearest } \ell \text{ or } j)$ versus $E_T$ in comparison with MC Herwig $t\bar{t}$. On the right side, number of events in the $W + \text{jets}$ sample with at least one b-tag: the 3 and $\geq 4$ jet bins are used to extract $\sigma_{tt}$.](image)

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Two high energy jets are demanded as expected by the fragmentation of the top decay b quarks. The backgrounds with softer jets originating from QCD radiation are reduced. Finally, to enhance the signal-to-background ratio, large $H_T$ is required$^e$. The results from CDF and DØ are summarized in Tables 1 and 2.

3 $\sigma_{tt}$ measurements in the lepton+jets channel

The CDF event selection required one $e$ or $\mu$ with $P_T > 20$ GeV/c, $E_T > 20$ GeV and at least 3 high E$_T$ jets. Cosmic rays, electron conversions, Drell-Yan and $t\bar{t}$ dilepton events are removed.

$^d\Delta\phi(E_T, \ell)$ or $j$) is the azimuthal separation between the vector $E_T$ and the nearest lepton or jet.

$^eH_T$ is the scalar sum of the transverse energy of the leptons, jets and neutrinos in the event.
Table 1: Run 2 CDF results in the $t\bar{t}$ dilepton channel for a data sample of 72 $pb^{-1}$

| Source            | ee     | $\mu\mu$ | $e\mu$ | $\ell\ell$ |
|-------------------|--------|----------|--------|------------|
| All Backgrounds   | 0.103±0.056 | 0.093±0.054 | 0.100±0.037 | 0.30±0.12  |
| Expected $t\bar{t}\rightarrow\ell\nu b\bar{b}\ell\nu\bar{b}$ | 0.47±0.05 | 0.59±0.07 | 1.44±0.16 | 2.5±0.3   |
| Data              | 1      | 1        | 3      | 5          |

To increase the signal-to-background ratio, CDF uses the Silicon Vertex Detector to identify the b-quark displaced vertices. A jet is b-tagged if it contains a secondary vertex with at least two charged tracks and $L_{xy}/\sigma_{xy}>3$. The efficiency for identifying at least one of the b quarks from $t\bar{t}$ decays is about 45%, which is measured using $t\bar{t}$ MC and corrected with a data to MC scale factor. The mistags from light quarks and gluon jets are evaluated using the negative rate of $L_{xy}$ extracted from inclusive jet data and applied to $W+$jets data. The W/Z+heavy flavour: $g\rightarrow b\bar{b}, c\bar{c}$ background is evaluated from $W+$jets data, the b tag rate and the Run 1 flavour composition in $W+$jets events. The non-W background is evaluated from $W+$jets data assuming it is flat in the plane of lepton calorimeter isolation versus $\not{E}_T$, and extrapolated from the low isolation and small $\not{E}_T$ (non-W) region to the high isolation and large $\not{E}_T$ (W dominated) region. Small contributions from diboson WW/WZ, Drell-Yan and single top production are evaluated from MC (see results in Table 3).

Table 2: Run 2 DØ results in the $t\bar{t}$ dilepton channel

| Source | ee | $\mu\mu$ | $e\mu$ |
|--------|----|----------|--------|
| $L$ pb$^{-1}$ | 48.2 | 42 | 33 |
| All Backgrounds | 1.00±0.48 | 0.6±0.30 | 0.07±0.01 |
| Expected $t\bar{t}\rightarrow\ell\nu b\bar{b}\ell\nu\bar{b}$ | 0.25±0.02 | 0.3±0.04 | 0.50±0.01 |
| Data | 4 | 2 | 1 |

The DØ topological analysis does not use b-tagging. First, a data sample enriched with W events is preselected by demanding a loose e or $\mu$ with $P_T>20$ GeV/c, $\not{E}_T>20$ GeV and a Soft Muon Tag veto. Then, the QCD background is evaluated from data for each jet multiplicity. In the e-channel this background is due to $\pi^0$ and $\gamma$ QCD compton in jets faking e’s and in the $\mu$-channel is due to real $\mu$’s from heavy flavour decays. The $W+\geq 4$ jets background is estimated using the Berends scaling law. Finally, the topological cuts are applied to further reduce background: at least 4 jets, and large values of $H_T$ and $A^\theta$ (see results in Table 4).

The DØ Soft Muon Tag analysis has same preselection as the topological analysis. The topological requirements on $H_T$ and $A$ are milder and at least 3 high-$E_T$ jets are required.

$LA_{xy}$ is the distance in the transverse plane to the beam direction between the secondary vertex and the primary vertex. $\sigma_{xy}$ is the resolution in the determination of $L_{xy}$.

$A$The Aplanarity $A$ measures the relative activity perpendicular to the plane of maximum activity.
Background is reduced by demanding one low momentum $\mu$ in a jet coming from the semileptonic $b$ decay (see results in Table 5).

Table 4: Run 2 DØ results in the $t\bar{t}$ lepton plus jets topologic analysis

|            | $N_W$        | $N_{QCD}$   | All BG   | Exp Signal | $N_{\text{obs}}$ | $\mathcal{L}(pb^{-1})$ |
|------------|--------------|-------------|----------|------------|------------------|------------------------|
| $e+$jets   | $1.3\pm0.5$  | $1.4\pm0.4$ | $2.7\pm0.6$ | $1.8$      | $4$              | $49.5$                 |
| $\mu+$jets | $2.1\pm0.9$  | $0.6\pm0.4$ | $2.7\pm1.1$ | $2.4$      | $4$              | $40$                   |

Table 5: Run 2 DØ results in the $t\bar{t}$ lepton plus jets Soft Muon Tag analysis

|            | All BG     | Exp Signal | $N_{\text{obs}}$ | $\mathcal{L}(pb^{-1})$ |
|------------|------------|------------|------------------|------------------------|
| $e+$jets   | $0.2\pm0.1$ | $0.5$      | $2$              | $49.5$                 |
| $\mu+$jets | $0.7\pm0.4$ | $0.8$      | $0$              | $40$                   |

4 Summary and conclusions

The $t\bar{t}$ production cross-section in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV has been determined from the number of observed top candidates in a given channel, the estimated background, the integrated luminosity and the $t\bar{t}$ acceptance for a top mass $175$ GeV/c$^2$: $\sigma_{t\bar{t}} = \frac{N_{\text{obs}} - N_{\text{bkq}}}{A \cdot \mathcal{L}}$. All results are in agreement with the NLO prediction: $6.70^{+0.71}_{-0.88} \text{ pb}$. Attributing the excess of events over the expected backgrounds to $t\bar{t}$ production in the decay channels considered, we obtain the following first Run 2 results:

- **CDF dilepton channels**: $\sigma_{t\bar{t}} = 13.2 \pm 5.9(\text{stat}) \pm 1.5(\text{sys}) \pm 0.8(\text{lum})$ pb.
- **CDF lepton plus jets channels**: $\sigma_{t\bar{t}} = 5.3 \pm 1.9(\text{stat}) \pm 0.8(\text{sys}) \pm 0.3(\text{lum})$ pb.
- **DØ dilepton channels**: $\sigma_{t\bar{t}} = 29.9^{+21.0}_{-15.7}(\text{stat})^{+14.1}_{-6.1}(\text{sys}) \pm 3.0(\text{lum})$ pb.
- **DØ lepton plus jets channels**: $\sigma_{t\bar{t}} = 5.8^{+4.3}_{-3.4}(\text{stat})^{+4.1}_{-2.6}(\text{sys}) \pm 0.6(\text{lum})$ pb.
- **DØ all combined channels**: $\sigma_{t\bar{t}} = 8.5^{+4.5}_{-3.6}(\text{stat})^{+6.3}_{-3.5}(\text{sys}) \pm 0.8(\text{lum})$ pb.

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References

1. R. Bonciani et al, Nucl. Phys. B 529, 424 (1998), arXiv:hep-ph/9801375.
2. M. Cacciari et al, CERN-TH-2003-054, arXiv:hep-ph/0303085.
3. T. Affolder et al, Phys. Rev. D 64, 0320022 (2001).
4. V.M. Abazov et al, Phys. Rev. D 67, 012004 (2003).
5. M. Kruse for the CDF collaboration. FERMILAB-CONF-03/050-E.
6. R. Zitoun, these proceedings.

\[^{\text{h}}\text{For the latest results on top mass see}^{3}\]