A View From the Top: CDF Results of Top Counting Experiment

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A VIEW FROM THE TOP:
CDF RESULTS OF TOP COUNTING EXPERIMENT

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We present the CDF results relative to the observation of the top quark and its properties obtained with 100 pb\(^{-1}\) of data collected in the period 1992-1993 and 1994-1995. Updated results of the counting experiments are given, and consistency between this data and earlier published mass and cross section is shown.

1 Introduction

The top quark is required in the Standard Model as the weak-isospin partner of the \(b\) quark. Its existence was indirectly proven by studying flavour changing neutral currents and forward-backward asymmetry in \(\bar{b}b\) events\(^{1,2}\).

CDF announced direct evidence for \(t\bar{t}\) production in \(\bar{p}p\) collisions in 1994\(^3\), based on 19.7 pb\(^{-1}\) collected at the Tevatron collider at c.m.s. energy of \(\sqrt{s} = 1.8\) TeV.

In early 1995 both CDF\(^4\) (using 67 pb\(^{-1}\)) and D0\(^5\) announced the observation of the top quark, confirming CDF previous result. Here we present the CDF results based on a larger data set of 100 pb\(^{-1}\).

Top production at Tevatron mainly proceeds through \(q\bar{q}\) annihilation, this channel being responsible for \(\approx 90\%\) of the (predicted) S.M. cross section. A top quark decays into a real \(W\) and a \(b\) quark. It is customary to classify \(t\bar{t}\) events by looking at the \(W\) decay. If both \(W\)'s decay leptonically in \(\nu\nu\) or \(\mu\mu\) the event is classified as \textit{dilepton}. If one of the two \(W\)'s decays through one of its hadronic modes into quarks (which are identified as \textit{jets} in the detector) the event is defined as \textit{lepton+ jets}, if both \(W\)'s decay hadronically the event is classified as \textit{hadronic}. Here I will discuss only \(t\bar{t}\) events in which at least one
of the two $W$ decays leptonically. Kinematical studies of $t\bar{t}$ events are subjects of another contribution to this Conference.

2 CDF

The CDF detector has been described in detail elsewhere, here we recall only the main features used in this analysis.

The CDF tracking system is fully contained within a solenoidal magnetic field of 14 KG. It is composed of a Silicon Vertex Detector (SVX), used to reconstruct decays of long-lived particles ($b$ and $c$ hadrons), a vertex time projection chamber (mainly used to measure the $Z$ coordinate of the interaction) and a large Central Tracking Chamber (CTC). The latter is the heart of the tracking system and provides full reconstruction of tracks up to $\eta \approx 1^\circ$. The impact parameter ($d$) resolution of this system is $\sigma_d \approx 15 \mu m$ for high $P_T$ tracks, which is sufficient to reconstruct $b$-decays.

Outside the CTC electromagnetic and hadronic calorimeters surround the interaction region up to $|\eta| < 4.2$.

A muon detection system, made of drift chambers and scintillation counters, surrounds the calorimeters, with coverage up to $|\eta| < 1$. Muon stubs are detected and then linked to tracks measured in the inner tracking system. This provides the information needed to identify and trigger on $\mu$'s.

A three-level trigger selects the inclusive muon and electron events used in this analysis. To ensure maximum efficiency a missing transverse energy ($E_T$) trigger was also used.

3 The Counting Experiments

All the counting experiments start by identifying events containing at least a primary lepton with large transverse momentum. Selection criteria are the following: $E_T(P_T) \geq 20$ GeV (GeV/c) for $e$ ($\mu$), $|\eta| < 1$, lepton candidates must pass tight identification requirements which include conversion ($\gamma \rightarrow e^+e^-$) removal and fiducial cuts. Calorimeter isolation is required.

After applying these criteria we are left with approximately 100,000 events in the electron (60,000) and muon (40,000) channels combined. This data sample is then split into dilepton and lepton + jets for subsequent analysis.

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$^a$ $\eta$ is defined as $-\log(tan(\theta/2))$, $\theta$ being the angle with respect to the beamline.
3.1 Dilepton Analysis

In this analysis we search for events with a final state containing two leptons \((\ell\ell, \mu\mu, e\mu)\), \(E_T\) (signature of the \(\nu's\)) and two jets. We do not require these two jets to be \(b's\). In the search for the second lepton we use a looser set of lepton identification cuts. We ask for \(E_T(P_T) \geq 20\ \text{GeV} \ (\text{GeV}/c)\) for \(e\ (\mu)\), opposite sign charges and tracking isolation.

To further reduce the background we apply a set of kinematical requirements: \(E_T \geq 25\ \text{GeV}\) (after correction for detector effects), \(75 < M_H < 105\ \text{GeV}/c^2\) to remove \(Z^0 \to \ell\ell(\mu\mu)\) decays; \(\Delta \phi(l, E_T) > 20^\circ\) when \(E_T < 50\ \text{GeV}\) to reject \(Z^0 \to \tau\tau\) events, \(\Delta \phi(jet, E_T) > 20^\circ\) when \(E_T < 50\ \text{GeV}\) to reject events in which the jet energy has been mismeasured and finally we require two jets with \(E_T > 10\ \text{GeV}\) and \(|\eta| < 2\).

While this selection considerably reduces the background it also affects the signal as the expected (theoretical) \(^9\) yield for a SM top with mass of 170 GeV/c\(^2\) is \(\approx 6\) events. The relative acceptances of the three channels \((e\ell, \mu\mu, e\mu)\) are approximately 15, 27, 58 \%, respectively.

In our data set we find a total of 9 events \((1, 2, 6\) in the \(e\ell\mu\mu, e\mu\) channels). One of the \(\mu\mu\) events also contain a large \(E_T\ \gamma\), and is consistent with a \(Z \to \mu\mu\gamma\) decay (the invariant mass \(M_{\mu\mu\gamma}\) is \(\sim 86\ \text{GeV}/c^2\)). This event is removed in the estimate of the significance. Background is estimated using Monte Carlo and data to be \(1.9 \pm 0.4\) events. In Table 1 we show our results separately for the different channels.

<table>
<thead>
<tr>
<th>Background source</th>
<th>(e\ell+\mu\mu)</th>
<th>(e\mu)</th>
<th>all channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>(WW)</td>
<td>0.11\pm0.04</td>
<td>0.18\pm0.08</td>
<td>0.29\pm0.09</td>
</tr>
<tr>
<td>(Z \to \tau\tau)</td>
<td>0.25\pm0.04</td>
<td>0.30\pm0.07</td>
<td>0.56\pm0.10</td>
</tr>
<tr>
<td>(b\bar{b}) bx</td>
<td>0.02\pm0.01</td>
<td>0.01\pm0.01</td>
<td>0.03\pm0.02</td>
</tr>
<tr>
<td>fake</td>
<td>0.19\pm0.01</td>
<td>0.16\pm0.01</td>
<td>0.35\pm0.21</td>
</tr>
<tr>
<td>Drell-Yan</td>
<td>0.70\pm0.37</td>
<td>0.70\pm0.37</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>1.27 \pm 0.39</td>
<td>0.65 \pm 0.11</td>
<td>1.92 \pm 0.4</td>
</tr>
<tr>
<td>data</td>
<td>2</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 1: Dilepton events and background in the different channels. \(\mu\mu\gamma\) event removed.

The probability of the background to fluctuate to the observed number of events is \(10^{-3}\).
3.2 lepton+jets

The CDF lepton+jets sample is obtained by selecting $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ events. We start with the inclusive lepton sample with the additional requirements of $E_T \geq 20$ GeV (after $Z^0$ removal). Then we ask for at least 3 jets with $E_T > 15$ GeV, this cut considerably reduces background while retaining $\sim 75\%$ of $t\bar{t}$ events.

The background in this search is mainly due to $W+$ jets events. The main difference is that $t\bar{t}$ events always contain a $b\bar{b}$ pair, while a $W$ is produced in association with a heavy flavour (HF) pair only if a gluon splits into $b\bar{b}$ or $c\bar{c}$.

In $100\,pb^{-1}$ we find 296 $W+ \geq 3$ jets. From the theoretical estimate of the cross section we expect $\sim 50$ $t\bar{t}$ events, thus additional background rejection is needed. CDF improves the signal to background ratio in this channel by using $b$-tagging. Two different techniques are used. The first one is the Soft Lepton Tagging (SLT) in which a tag is defined as a soft ($P_T > 2$ GeV/$c$) $e$ or $\mu$ coming from the semileptonic decay of a $b$ (or from the chain decays: $b \rightarrow c$ with the $c$ decaying semileptonically). The other (and more sensitive) search is performed by searching for a Secondary Vertex (SVX). First we select tracks with a large impact parameter ($|d_\text{j}| > 3$). Then, using these tracks, we search for a secondary vertex in the plane transverse to the beamline. If one is found, we define $L_{xy}$, the distance between the primary and the secondary vertex. When $L_{xy}/\sigma_{L_{xy}} \geq 3$ we define the event as tagged.

Background sources are estimated using data and Monte Carlo samples. Using data CDF estimates the background coming from fake tags. Physical background, coming from associate production of $W$ and HF is estimated in two different ways. One way is to look at inclusive jets data, under the assumption that heavy flavour content in generic jets is the same as in jets associated to $W$'s. This is a conservative estimate as there are diagrams present in HF production in jets which do not contribute to $W+$HF production. The other way is to calculate the fraction of $W+$ jets events containing $b$ and $c$ quarks by using HERWIG MC and to normalize this number using the data. We checked our background estimate using our $Z+$ jets events sample. There is a good agreement between expected and measured tags, as shown in Table 2, although the statistics are limited. Recently, with increased statistics, CDF has been able to directly measure the HF content of $W+$ jets events, again the agreement with our previous estimate is good.

After applying $b$-tagging algorithms to the 296 $W+ \geq 3$ jets events, we find 40 tags with a background of $9.8\pm2.8$ in the SVX search and 40 tags (with a background of $23.8\pm3.6$) in the SLT tags. Eight events are double-tagged in the SVX (i.e. there are two secondary vertices in the event) and 4 events are
double-tagged in the SLT search. The result of the SVX search is shown in fig. 1. The excess due to top production is clearly visible in bins $W + 3$ jets and $W + \geq 4$ jets.

<table>
<thead>
<tr>
<th></th>
<th>N. events</th>
<th>Background</th>
<th>Observed tags</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z + 1$ jet</td>
<td>896</td>
<td>8.40±0.84</td>
<td>6</td>
</tr>
<tr>
<td>$Z + 2$ jets</td>
<td>119</td>
<td>2.30±0.23</td>
<td>3</td>
</tr>
<tr>
<td>$Z + 3$ jets</td>
<td>19</td>
<td>0.94±0.09</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: Expected and observed number of tags in the $Z+$ jets sample.

The overall combined probability, in the different counting experiments, of the signal being due to a background fluctuation is $4 \times 10^{-9}$. This probability is $2 \times 10^{-6}$ for the SVX channel only.

4 Cross Section and Couplings

CDF measured the production cross section for $t\bar{t}$ events with 67 pb$^{-1}$ using the combined information of the dilepton and the SVX and SLT searches\textsuperscript{13}(fig. 2) After background subtraction, and correcting for efficiency, the production cross section is $\sigma_{t\bar{t}} = 7.6^{+3.4}_{-2.8}$ pb.
Figure 2: Combined SVX-SLT-Dilepton cross section. Theoretical NNLO calculation is also shown.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Predicted</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVX</td>
<td>34±10</td>
<td>32</td>
</tr>
<tr>
<td>SLT</td>
<td>37±6</td>
<td>36</td>
</tr>
<tr>
<td>DIL</td>
<td>9.5±2.4</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 3: Expected (including background) and observed number of events in 100 pb$^{-1}$. Expectations are based on measured cross section.
With our data set of 100 pb\(^{-1}\) we checked that the observed yield is consistent with our measured cross section, this result is summarized in Table 3.

By using the number of tags in dilepton and lepton+ jets events, CDF measured the branching fraction \(BF(t \rightarrow Wh)/(t \rightarrow Wq) = 0.94 \pm 0.27(stat.) \pm 0.13(sys.)\) and -from this- the CKM matrix element \(|V_{tb}| > 0.022\) (95 % C.L.).

5 Measurement of the Top Mass

We fit the tagged lepton+ jets events to the \(t\overline{t}\) hypothesis. In order to kinematically reconstruct the event we first require a 4 \(^{1/2}\) jet with \(E_T > 8\) GeV and \(|\eta| < 2.4\). We then solve a system of constrained equations. The constraints are: the two \(t\)'s must have the same mass, and constraining two jets and the \(l\nu\) system to the \(W\) mass. In this process jet energies and momenta are allowed to fluctuate within the detector resolution. All combinations are attempted, and the \(b\)-tag information is used. The solution with the smallest \(\chi^2\) is kept. In fig. 3 we show the distribution of the reconstructed mass together with

![CDF Preliminary graph](image)

Figure 3: Reconstructed mass for \(b\)-tagged events in the 100 pb\(^{-1}\) data set [solid]. Background contribution is shown as dotted area. Top MC \(M_{t\overline{t}} \geq 175\) GeV/c\(^2\) with background contribution is shown as dashed line.

the expected background (8.8\(_{+2.4}^{-2.2}\)) events. CDF preliminary result in the 100 pb\(^{-1}\) data sample is \(M_t = 175\) GeV/c\(^2\), consistent with the published result\(^4\) of \(M_t = 176 \pm 8(stat.) \pm 10(sys.)\) GeV/c\(^2\). Work is in progress to improve this measurement.
6 Conclusions

After observation of the top quark with 67 pb$^{-1}$ of data, CDF -with increased statistics- proceeds towards the study of its observables. The results obtained so far in the ongoing run 1b confirm our previous measurements for the mass and cross section. The mass measurement is already limited by systematics and we expect improvements in the future. It is especially relevant as this parameter can shed light on the problem of mass generation in the SM. CDF has also measured top couplings, although still limited by statistics.

In conclusion we are moving from the search for top to the study of top.

References

6. S.Leone, this Conference.
10. J.Incandela, talk given at the X $\sqrt{s}$ workshop.