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MEASUREMENT OF THE $t\bar{t}$ PRODUCTION CROSS SECTION AT DØ[1]

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Abstract

We report on the results from the analyses of $t\bar{t}$ decays in *dilepton* and *lepton+jets* modes with $\sim$100 pb^{-1} of $p\bar{p}$ Collider data at $\sqrt{s}$ = 1.8 TeV collected by the DØ experiment at the Fermilab Tevatron. We have observed 37 $t\bar{t}$ candidate events while the estimated background is 13.4 $\pm$ 3.0 events. The $t\bar{t}$ production cross section has been measured to be 5.2 $\pm$ 1.8 pb at a top quark mass of 170 GeV/c^2.

[1]To be published in the Proceedings of the *XXXIst Rencontres de Moriond on QCD and High Energy Hadronic Interactions*

Introduction

The first observation of the top quark was made by the CDF and DØ collaborations[1,2], a year ago. Both collaborations are pursuing more precise measurements of the $t\bar{t}$ production cross section, the mass of the top quark[3] and other properties. DØ has accumulated about 120 pb^{-1} of $p\bar{p}$ collider data at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron, more than doubling the amount of data since the publication of the discovery of the top quark. In this paper, we report on the latest results on the measurement of the $t\bar{t}$ production cross section at the DØ experiment using a data sample corresponding to an integrated luminosity of about 100 pb^{-1}.

The DØ detector and various particle identification techniques are described in detail elsewhere[4,5]. Our electron and muon identification procedures have subsequently been refined. We use a four-variable likelihood for electron identification that provides better rejection of backgrounds. Muon identification has been improved by making use of the calorimeter information. Our understanding of the jet energy scale has improved, leading to better jet energy corrections with uncertainties reduced by a factor of two. We have optimized the event selection cuts using a grid search method[6] developed at DØ to minimize the fractional error in the cross section.

We have searched for events where top quarks are pair-produced in $p\bar{p}$ collisions. Each top quark decays into a W boson and a b quark (assuming Standard Model couplings). The $t\bar{t}$ events are categorized into *dilepton*, *lepton+jets* or *all jets* channels depending on whether one or both of the W bosons decay leptonically or hadronically. The *dilepton* channels studied are the ee, $e\mu$ and $\mu\mu$ channels (total BR $\sim$5%) with at least two jets coming from the two b quarks in each event. In the *lepton+jets* channel (the lepton being e or μ; BR$\sim$30%), we have two orthogonal analyses: (a) a topological analysis that uses event shape and kinematic variables and vetoes on events that have a non-isolated soft muon (b-tag) and (b) a b-tagged analysis. The b-tagged channels are denoted in this paper as $e + jets/\mu$ and $\mu + jets/\mu$. The cross section measurement uses the results from both the *dilepton* and *lepton+jets* analyses. Searches are also underway in other channels such as $e\nu + jets$ and the *all jets*. The current status of these searches is included in this paper.

The Dilepton Channels: (ee, $e\mu$, $\mu\mu$)

The signature for $t\bar{t}$ decay in these channels is the presence of two high p_T, central, isolated leptons, two jets initiated by the b quarks and a large missing transverse energy ($\not{E}_T$) in the event arising from the two neutrinos. The dominant backgrounds are from leptonic decays of the Z, WW and QCD ($b\bar{b}$ and $c\bar{c}$). The ee and $e\mu$ channels have a small amount of background from events with fake electrons due to mis-identification of jets as electrons. The kinematic selection criteria for candidate events used in each of the three channels are shown in Table 1.

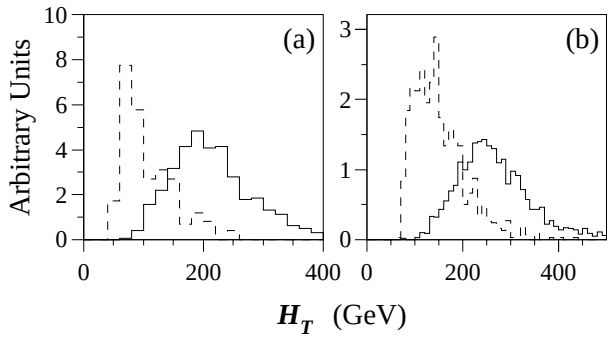

Figure 1: H_T distributions for signal events (180 GeV/c^2 top mass; solid histograms) and the dominant backgrounds (dashed histograms) in (a) $e\mu + jets$ channel and (b) untagged *lepton+jets* channel.

Channel	High-p_T Leptons		Jets		Missing E_T		Muon Tag	Topological		
	$E_T(e)$	$p_T\mu)$	$N_{\rm jet}$	E_T(jet)	$\not{E}_T^{\rm cal}$	$\not{E}_T$	$p_T(\mu)$	H_T	$\mathcal{A}$	specific
$e\mu$ + jets	15	15	2	20	20	10	-	120	-	-
ee + jets	20		2	20	25	-	-	120	-	$\lvert M_{ee} - M_{Z^0}\rvert$ >12 GeV/c^2
$\mu\mu$ + jets		15	2	20	-	-	-	100	-	P(χ^2_{Zfit})< 1%
$e\nu$ + jets*	20		2	30	50	50	-	-	-	$M_T(e, \not{E}_T)$ >115 GeV/c^2
e + jets	20		4	15	25	-	-	180	0.065	E_T^L >60 GeV
μ + jets		20	4	15	20	20	-	180	0.065	E_T^L >60 GeV
e + jets/μ	20		3	20	20	-	4	110	0.04	-
μ + jets/μ		20	3	20	20	20	4	110	0.04	P(χ^2_{Zfit})< 1%

* Not included in the cross section measurement.

Table 1: Minimum kinematic requirements for the standard event selection (energy in GeV).

Additional cuts have been applied to ee and $\mu\mu$ channels to suppress the large background from leptonic Z decays. In the ee channel, we also require the missing transverse energy measured in the calorimeter, $\not{E}_T^{cal}$, to be greater than 40 GeV when $|M_{ee} - M_Z| < 12\ GeV/c^2$. In the $\mu\mu$ channel, a kinematic fit to the Z has been performed and the event is required to be inconsistent with the Z +jets hypothesis. The probability of χ^2 for the Z fit, $P(\chi^2_{Zfit})$, is required to be less than 1%. The other notable kinematic quantity is H_T which is the scalar sum of E_T of all the selected objects in the event. In case of ee and $e\mu$ channels, the H_T includes the E_T of the leading electron, while for the $\mu\mu$ channel only E_T of jets are used. The distributions of H_T for 180 GeV/c^2 top quark events and for dominant background events in the case of $e\mu$ channel are compared in Fig. 1(a). It can be seen that H_T is indeed a powerful discriminator between signal and background.

After all the selection cuts, we observe 5 dilepton events in the data while the estimated background is (1.7 ± 0.4)events. The results for each channel along with expected signal are shown in Table 2.

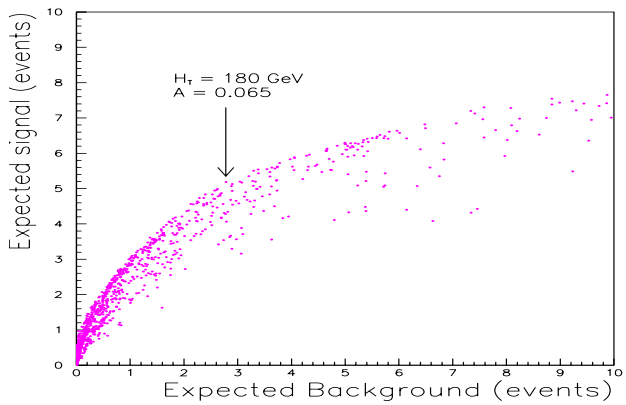

Figure 2: Expected signal (180 GeV/c^2 top) versus background yields in 77 pb^{-1} for various cuts on $\mathcal{A}$ and H_T, in the *e+jets* channel, as found by the *Random Grid Search* Method.

The lepton +jets Topological Analysis

The characteristics of the signal in the *lepton+jets* channel are the presence of a high p_T, central, isolated lepton, with $\not\!\!E_T$ due to the neutrino and several jets (two jets from the W decay and two from the b quarks). In the absence of a b-tag in the event, we use tight cuts on some event shape and kinematic variables to enhance the signal. The dominant backgrounds are W+multijet production with the W decaying to $e\nu$ or $\mu\nu$ and, QCD multijet events where a jet fakes an electron. The special variables used in the analysis are H_T (sum E_T of all selected jets), Aplanarity ($\frac{3}{2}\times$ smallest eigenvalue of the normalized total momentum tensor) and E_T^L (total leptonic E_T, $E_T^L = E_T^{e/\mu} + \not\!\!E_T$). Requiring large E_T^L suppresses the background from fakes. Large H_T signifies the decay of massive objects. The aplanarity should have a value of one half for spherical events and zero for planar events; $t\bar{t}$ events are expected to be more spherical than the radiative QCD processes and hence have higher values of aplanarity.

We have required E_T^L to be larger than 60 GeV. The optimum cuts for $\mathcal{A}$ and H_T have been deduced by performing a *random grid search*[6], a variant of the regular grid search, in the ($\mathcal{A}$, H_T) plane. The regular grid search is inefficient because the same amount of time (granularity) is used to scan the regions of the feature space that have few signal and background events as in the regions that are densely populated. In the random grid search technique, the actual distribution of some event sample can be used as the set of all possible cuts in the multi-dimensional feature space. In the present work, we have used each event in the signal Monte Carlo (180 GeV/c^2 $t\bar{t}$ events) to provide the possible sets of cuts for the grid search. The results of the grid search have been plotted in Fig. 2, as the expected number of signal events versus the expected number of background events (W +jets and QCD fakes together). Each point on this plot corresponds to a possible set of conventional cuts. As can

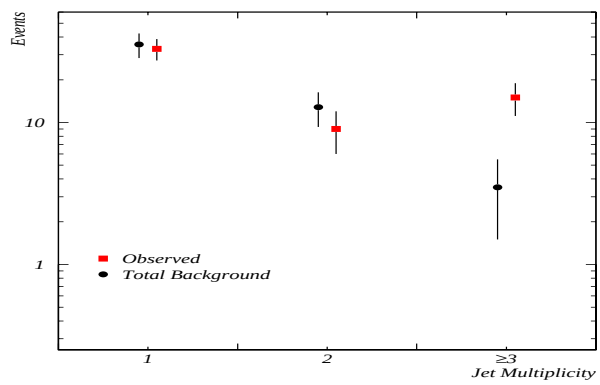

Figure 3: Jet multiplicity of b-tagged *lepton+jets* events before Aplanarity and H_T cuts. Square points represent data and the circles the expected background.

be easily inferred from Fig. 2, the outer envelope of the points pertain to optimal cuts since they maximize the signal efficiency corresponding to given background estimates. We pick the set of cuts that yields the smallest expected fractional error in cross section. The point as shown in Fig. 2, corresponds to the cuts $\mathcal{A} = 0.065$ and $H_T = 180$ GeV. The selection cuts yield 21 events in the data ($\int \mathcal{L}dt \sim$100 pb^{-1}), and an expected background of 9.2 ± 2.8 events.

The lepton+jets b-tag Analysis

Since every $t\bar{t}$ event has two b quarks, we expect $\sim$20% of the events would have a *detectable* soft muon coming from the semi-leptonic decays of the b quarks. In the background, however, only $\sim$2% of the events are expected to have a soft muon tag. In the presence of b-tags, the signal to background ratio is much higher than in the case of the untagged events. We therefore relax the event shape cuts and require only 3 or more jets in the event, in the b-tag analysis. The event selection cuts for the b-tag analysis are also shown in Table 1. Figure 3 shows the number of observed events and estimated background as a function of jet multiplicity for b-tagged events before $\mathcal{A}$ and H_T cuts are applied. The jet multiplicity spectrum for background events is obtained by convoluting the jet multiplicity spectrum for untagged events with the measured tagging rate. The tagging rate itself is determined from data and is observed to be a function of the jet E_T and the number of jets in the event. An excess of events with three or more jets can be clearly seen in Fig. 3. The optimal cuts for $\mathcal{A}$ and H_T are again determined using the random grid search method. After the event shape cuts, we observe 11 events in the data with a total estimated background of 2.6 ± 0.6 events.

The Cross Section

The results of analyses in all the *dilepton* and *lepton+jets* channels (seven channels total)

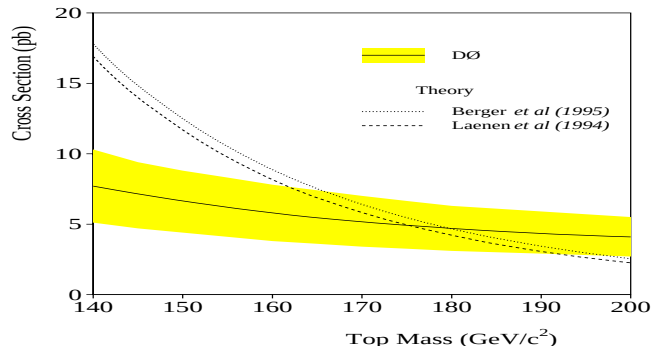

Figure 4: Preliminary $t\bar{t}$ production cross section measured by DØ. The solid line corresponds to central values and the band shows 1σ errors of the measured cross-section, as a function of assumed top quark mass. Also shown are two theoretical calculations (dashed line[7] and dotted line[8]).

Channel	$e\mu+$jets	$ee+$jets	$\mu\mu+$jets	$e+$jets	$\mu+$jets	$e+$jets/μ	$\mu+$jets/μ	ALL
$\langle N\rangle(M_{top}$ =180 GeV/c^2)	1.7 ± 0.3	0.9 ± 0.1	0.5 ± 0.1	6.5 ± 1.4	6.4 ± 1.5	2.4 ± 0.4	2.8 ± 0.9	21.2 ± 3.8
Background	0.4 ± 0.1	0.7 ± 0.2	0.6 ± 0.3	3.8 ± 1.4	5.4 ± 2.0	1.4 ± 0.4	1.1 ± 0.2	13.4 ± 3.0
$\int\mathcal{L}dt$ (pb^{-1})	90 ± 5	106 ± 6	87 ± 5	106 ± 6	96 ± 5	91 ± 5	96 ± 5	
Data	3	1	1	10	11	5	6	37

Table 2: Expected number of top quark events, $\langle N\rangle$, in the seven channels, based on the central theoretical $t\bar{t}$ production cross section of Ref.7, for a top mass of 180 GeV/c^2. Also given are expected background, integrated luminosity, and the number of observed events in each channel.

are summarized in Table 2. We observe a total of 37 events with an expected background of 13.4 $\pm$ 3.0 events. The integrated luminosity corresponding to each channel and the number of $t\bar{t}$ events expected for a top quark mass of 180 GeV/c^2 (using the $t\bar{t}$ production cross section from Laenen *et al.*[7]) are displayed in Table 2. We have calculated the acceptance for $t\bar{t}$ events using the ISAJET event generator and the DØ GEANT detector simulation. Differences in the acceptance found using HERWIG generator are included in the systematic errors. Our measured cross section is shown as a function of top quark mass in Fig. 4. The cross section is 5.2 $\pm$ 1.8 pb for our measured[3] top quark mass of 170 GeV/c^2.

Search in Other Channels

We have searched for $t\bar{t}$ decays in the $e\nu + jets$ channel using the kinematic selection cuts shown in Table 1. This channel provides acceptance to dilepton events where one of the leptons in the event (e or μ) is lost (either due to detector inefficiencies or E_T threshold cut); *e+jets* events can also contribute to this channel. The search in this channel is made orthogonal to other *dilepton* and *lepton+jets* analyses. The dominant backgrounds are from the W+jets process and from the QCD multijet fakes. After the analysis cuts, we expect the

background to be 1.4±0.1 events and the signal to be 1.1±0.1 events (assuming 180 GeV/c^2 top quark mass). We observe two events in the data.

The *all jets* channel has the largest branching fraction (~45%) for $t\bar{t}$ decays but suffers from a QCD multijet background that is many orders of magnitude larger than the signal. We use event shape variables such as Aplanarity, H_T^3 (sum E_T of all jets except the two leading ones), N_j^{ave} (average E_T-threshold-weighted jet multiplicity) and Centrality (ratio of sum E_T to Sum E of the selected jets). We employ the random grid search method to choose the cuts. We also require one or two soft, non-isolated b-tag muons. The cross sections we obtain from single b-tag and double b-tag analyses are 4.4±4.9 pb and 3.9±9.8 pb, respectively.

Summary and Future Prospects

We have presented preliminary results on the $t\bar{t}$ production cross section as a function of top quark mass, from the analyses in the *dilepton* and *lepton+jets* channels. The cross section is measured to be 5.2±1.8 pb for our measured top quark mass of 170 GeV/c^2. Preliminary results from searches in $e\nu$*+jets* and *all jets* channels are in agreement with results from other channels. Multivariate analysis methods[9] for determining the cross section show promise of reducing errors beyond those shown here. Improved results are also expected from the analysis of *all jets* channel.

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