Fermi National Accelerator Laboratory

FERMILAB-Conf-95/158-E
CDF

Top Decays in the Dilepton Channel at CDF

Robert M. Roser
For the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

University of Illinois
1110 W. Green Street, Urbana, Illinois

June 1995

To Appear in the Proceedings of the *10th Topical Workshop on Proton-Antiproton Collider Physics*, Fermilab, Batavia, Illinois, May 9-13, 1995

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Top Decays in the Dilepton Channel at CDF

Robert M. Roser [1]

University of Illinois
1110 W. Green St. Urbana, IL 61801

We present an observation of $t\bar{t}$ production in the dilepton decay channel using the CDF detector at the Fermilab Tevatron Collider. This measurement was made using $\approx 67\ pb^{-1}$ of data, 19.3 of which was taken during the 1992-93 data run while the remaining data has been acquired this past year (94-95). We observe 6 events in the $t\bar{t}$ signal region with an expected background of 1.3 $\pm$ 0.3 events. This signal is inconsistent with the background prediction by 2.7σ. Additionally, three of these events contain a total of 5 b-tags – strong evidence for WWb production. We measure the $t\bar{t}$ production cross section in the dilepton channel to be $\sigma_{t\bar{t}} = 10.9^{+5.9}_{-4.5}$ pb.

INTRODUCTION

The experimental observation of the top quark (t) is required to complete the three generations of quarks in the Standard Model. (1,2) We have previously reported evidence for the top quark with a mass of $174 \pm 10^{+13}_{-12}$ GeV/c^2 (3). This paper presents our results from one of the three counting experiments which was used to confirm our previous measurement (4).

The dominant production mechanism at the Fermilab Collider is expected to be pair production through the $q\bar{q}$ annihilation diagram as shown in Fig. 1. Based on the Standard Model, each top quark will decay into a W boson and a b quark. The decay mode of the W bosons determines the event topology. Events in which at least one of the W's decays to an e or μ provide a characteristic decay signature in which to search for top. Those events in which the second W decays to an $e\nu$ or $\mu\nu$, are referred to as a "dilepton" events. The branching ratio for top to dileptons is $\approx 5\%$. If instead, the second W boson decays into a $q\bar{q}$ pair, then the decay is referred to as a "leptons+jets" event. Here, the branching ratio is $\approx 30\%$. Top decays involving τ's, and purely hadronic modes are much more difficult to identify. This paper will focus on the production of $t\bar{t}$ in the dilepton channel.

The CDF detector is described in detail in Ref. (6). However, there have been a number of changes that have occurred since the 1992-93 collider run at Fermilab which have greatly enhanced our ability to search for top. First

[1] for the CDF Collaboration

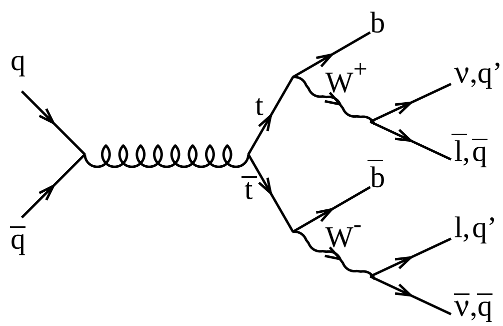

FIG. 1. Tree level top quark production by $q\bar{q}$ annihilation followed by the Standard Model decay chain.

and foremost is the upgrades made to the Tevatron Collider. The average and peak luminosities for the current run have reached 1.6×10^{31} and 2.5×10^{31} cm^{-2}s^{-1}, respectively. This is a substantial improvement over what was delivered during the 1992-93 collider run. As a result, the CDF detector, for this analysis, has recorded data with an integrated luminosity of 50 pb^{-1}. This represents a factor of 2.5 more data than what was presented in our previous analysis and more data is on the way. Furthermore, there have been a number of improvements made to the spectrometer, most notably being a new silicon vertex detector (SVX'). This new device, with its improved signal/noise ratio allows us to identify b quarks from top quark decays with higher efficiency than we previously could do.

BACKGROUNDS

The characteristic signature for the production and decay of a $t\bar{t}$ pair to dileptons is 2 oppositely charged, high p_T leptons (e or μ), together with large missing energy, and 2 b jets. There are however other physics processes which mimic this signature. These background events need to be accounted for. They include WW pairs, $\gamma/Z \rightarrow ee$, $\mu\mu$ (Drell-Yan), $Z \rightarrow \tau\tau$, $b\bar{b}$, and "fake" lepton misidentification. These "fake" events come from QCD multijet or W + jet processes where there is at least one misidentified lepton, conversion electron, or muon from hadron decay in flight which mimics the $t\bar{t}$ signature.

SAMPLE SELECTION

All of the top counting experiments start with the same lepton (e or μ) identification cuts. We begin by requiring that an event contain an electron or muon with E_t (p_T) $\geq$ 20 GeV (GeV/c). A series of track quality cuts and fiducial cuts are then imposed. The primary lepton must be isolated from other jet activity in the event. Photon conversions are removed. Finally, we remove $Z \rightarrow ee(\mu\mu)$ events by making an invariant mass cut on the two leptons such that $75 < M_{ll} < 105\ GeV/c^2$ in order to reduce the Z^0 and Drell-Yan backgrounds. From this event sample, the dilepton events are selected.

For the secondary lepton, the E_t (p_T) cut is still applied. This threshold was chosen to preserve a large portion of the top signal while suppressing the backgrounds from $b\overline{b}$, $Z \rightarrow \tau\tau$ decays, and from particle misidentification. A looser set of track quality cuts is imposed in order to increase the overall acceptance. Furthermore, the electric charge of the two leptons must be of opposite sign.

After the P_T and lepton identification cuts described above have been made, there are 25 eμ, 215 ee, and 233 $\mu\mu$ events remaining. Further kinematic and event topology cuts are applied to reduce the remaining backgrounds and exploit the characteristic signature of dilepton events.

Two neutrinos are produced in dilepton top events hence we require that there be significant missing transverse energy ($\not{E}_T$) in the event. For this analysis, $\not{E}_T > 25$ GeV. Since there are 2 b quarks as well, we require each event to contain two or more jets. Each jet must satisfy $|\eta| < 2.0$ and have uncorrected $E_T > 10$ GeV inside a cone of radius 0.4 around the jet axis. Finally, for those events with $\not{E}_T < 50$ GeV, we also require $\Delta\phi(\not{E}_T, \ell) > 20^o$, and $\Delta\phi(\not{E}_T, j) > 20^o$, where $\Delta\phi(\not{E}_T, \ell)$ is the azimuthal angle between the direction of $\not{E}_T$and the direction of either of the two leptons, and $\Delta\phi(\not{E}_T, j)$ is the azimuthal angle between the direction of $\not{E}_T$and the direction of either of the two leading jets. This requirement suppresses both the $Z \rightarrow \tau\tau$ background in which $\not{E}_T$along the lepton direction can arise from neutrinos originating from the decay of the τ lepton and the Drell-Yan background in which $\not{E}_T$can be due to jet energy mismeasurement.

ACCEPTANCE

For M_{top} in the range of 120 - 180 GeV/c^2 about 80% of the dilepton acceptance after the selection cuts have been applied comes from real W's decaying into $e\nu$ or $\mu\nu$. However it is also possible for one or both of the leptons to come from the decay of a b quark, or for one or both of the W bosons to decay to a τ which subsequently decays to an electron or muon. All of these cases are included in the acceptance calculation. The expected number of top dilepton events in the ee, $\mu\mu$ and $e\mu$ channels for a luminosity of 67 pb^{-1} is shown in Table 1. The theoretical cross sections were calculated

M_{top} GeV/c^2	ϵ_{DIL}	$\sigma_{t\bar{t}}$ pb	$N_{e\mu,ee,\mu\mu}$ events
160	0.0078	8.2	4.4
170	0.0083	5.8	3.0
180	0.0086	4.2	2.4

TABLE 1. Detection efficiencies, $\epsilon_{DIL} = Br \cdot \epsilon_{total}$, the predicted central value of $t\bar{t}$ production cross section from Laenen *et al* and the number of events expected in 67 pb^{-1}, as functions of top mass.

by Laenen *et al.* (5). Most of the acceptance for top is in the $e\mu$ channel – ≈ 60% to be exact. The remaining acceptance is split between the ee and $\mu\mu$ channels.

RESULTS

Once all of the selection criteria have been applied to the 67 pb^{-1} of data we are left with 7 events which satisfy all of our requirements. Five of these events are in the $e\mu$ channel, 2 are in the $\mu\mu$ channel, and none have been detected in the ee channel.

The breakdown of the 7 observed events by category is consistent with the relative dilepton acceptance. Recall that 60% of the total dilepton acceptance is in the $e\mu$ channel. Although we have estimated the expected background from radiative Z decay to be small (≈ 0.04 events), one of the $\mu\mu$ events contains an energetic photon with a $\mu\mu\gamma$ invariant mass of 86 GeV/c^2. To be conservative, we have removed that event from the final sample when calculating the significance, thus we are left with a total of 6 events.

One way in which the events in the $e\mu$ channel can be characterized is shown in Fig. 2. Here, we plot the azimuthal angle between $\not{E}_T$and the closest lepton or jet versus $\not{E}_T$for all jet multiplicities (a.) as well as for events with 0 (b.), 1 (c.), and 2 or more jets (d.) – which is the signal region. The two lines in each plot indicate where we cut on these variables. Points to the left and below these lines are considered background, while those above the lines and to the right lie in the signal region. Focusing on Fig. 2d., we see that once the 2 jet requirement is implemented, no events remain in the background region while there are 5 events which remain in the signal region.

The backgrounds in the dilepton channel are summarized in Table 2. Drell-Yan lepton pairs, $Z \rightarrow \tau\tau$ and hadrons misidentified as leptons are all calculated from the data. WW and $b\bar{b}$ production are calculated from Monte Carlo simulation. Other backgrounds, such as WZ, $Wb\bar{b}$, and $Z \rightarrow b\bar{b}$, have been studied and are negligible. From Table 2, the total background expected is 1.3 ± 0.3 events.

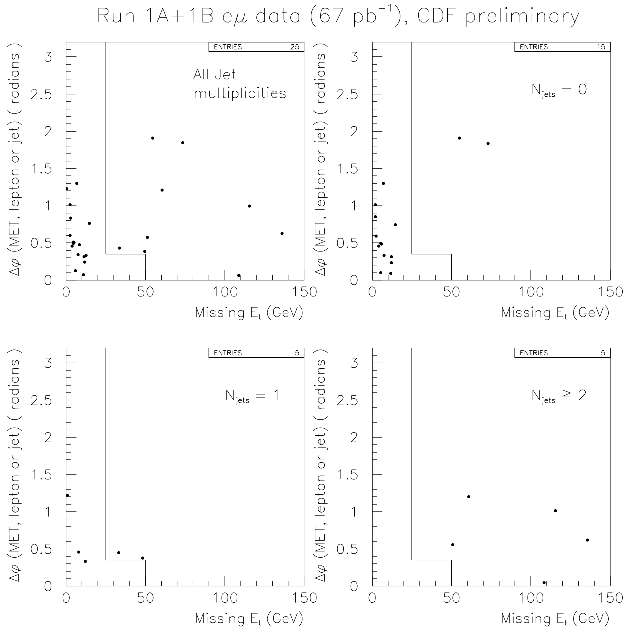

FIG. 2. The azimuthal angle between $\not\!\!E_{\rm T}$ and the closest lepton or jet versus $\not\!\!E_{\rm T}$ for the $e\mu$ data channel. a) all jet multiplicities. b) 0 jets required, c) 1 jet required d) 2 or more jets required (signal region).

Significance

The background numbers presented above are the expected mean values for each process. In a given experiment, the actual value may fluctuate high or low. Therefore, we calculate the probability that the background could have fluctuated up to the number of events observed or more. For the dilepton channel, this probability is 0.33% (2.7σ). The dilepton channel, with this increase in luminosity, now has the same significance as does the combined significance of all 3 counting experiments in Run 1A [(3)]..

b Tagging

We have two independent methods of identifying b quark jets in CDF. One method is to search for displaced secondary vertices using the Silicon Vertex Detector (SVX). The second method is to look for soft leptons which come from the semileptonic decay of the b quark (SLT). Three of the 6 candidate events (not including the $\mu\mu\gamma$) contain a total of 5 b-tags. One event is tagged with the SLT algorithm. Two other events are double tagged – the same jet is tagged by both the SVX and SLT algorithms. The expected number of tags

		Without $\not{E}_T$ and Jet Cut	Without Jet Cut	Two-Jets Reqd.
$e\mu$	WW	3.0	2.61	0.13±0.06
	$Z \rightarrow \tau\tau$	12.0	0.69	0.21±0.05
	$b\bar{b}$	0.5	0.03	0.01±0.01
	Fake	3.8	0.63	0.10±0.10
	Total background	19.3	3.96	0.45±0.14
	CDF data	25	9	5
$ee, \mu\mu$	WW	2.2	1.47	0.08± 0.03
	$Z \rightarrow \tau\tau$	9.8	0.55	0.17±0.05
	$b\bar{b}$	0.6	0.04	0.04±0.01
	Fake	5.6	0.83	0.13±0.1
	Drell-Yan	401	1.43	0.44±0.28
	Total background	419	4.32	0.84±0.28
	CDF data	448	9	1

TABLE 2. Number of background events expected in 67 pb^{-1} and the number of events observed in the data.

in 6 background events is 0.5 tags. We would expect to see 3.6 tags if the events are from $t\bar{t}$ decay.

Cross Section

The $t\bar{t}$ production cross section can be written as :

$$\sigma_{t\bar{t}} = \frac{N_{top}}{\int \mathcal{L}dt \; \epsilon_{top}} \qquad (1)$$

where N_{top} is the number of observed events (7) minus the expected background (1.3), $\int \mathcal{L}dt$ (= 67 pb^{-1}) is the integrated luminosity and ϵ_{top} (0.8%) is the detection efficiency of the analysis for observing top events. The dilepton cross section is measured to be:

$$\sigma_{t\bar{t}} = 10.9^{+5.9}_{-4.5} \text{ pb}$$

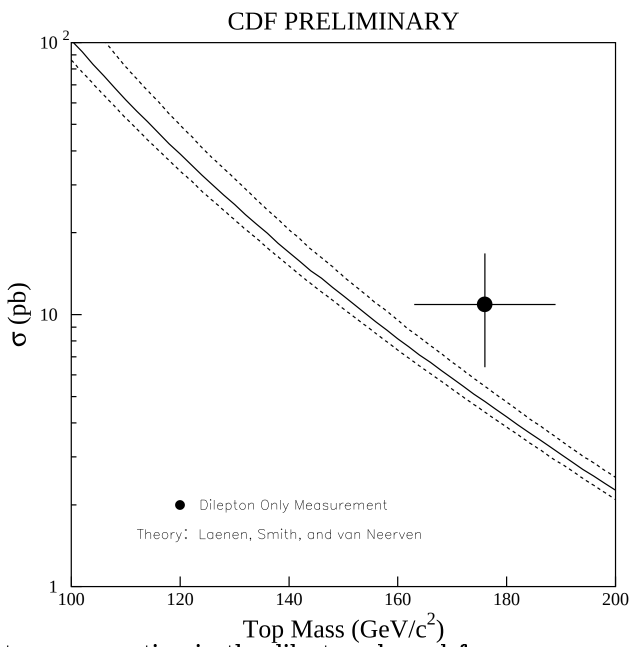

FIG. 3. The top cross section in the dilepton channel for our measured value of $M_{top} = 176 \pm 13$ GeV/c^2 is plotted together with the theoretical QCD calculation of Laenen *et al.* as a function of top mass. The dashed lines indicate the size of the uncertainty in the theoretical calculation.

Figure 3 shows a comparison between the dilepton cross section for our measured value of $M_{top} = 176 \pm 13$ GeV/c^2 and the theoretical QCD calculation to order α_s^3 of the heavy quark production cross section as a function of top mass. Ref. (5). The dashed lines represents the uncertainty in the theoretical calculation based on different choices of the renormalization scale and the QCD scale parameter Λ.

CONCLUSION

With this additional data, we confirm the top quark evidence presented in Ref. [3]. We now have a large excess in the signal that is inconsistent with the background prediction. Based on 67 pb^{-1} of data, we expect a total background of 1.3 events in the dilepton channel. We have found 7 events which satisfy all of our selection criteria. This excess in the signal is inconsistent with the background prediction by 2.7σ (once the $\mu\mu\gamma$ event is removed). Combined with the results from our other counting experiments, we have established the existence of the top quark. A preliminary cross section measurement for the dilepton channel yield $\sigma_{t\bar{t}} = 10.9^{+5.9}_{-4.5}$ pb.

We have collected an additional $30pb^{-1}$ of data since this analysis was published. We hope to collect a great deal more data before the completion of the Run 1b collider program at the TeVatron. Approximately 20 pb^{-1} of this new data have already been analyzed. We see two new candidate events which satisfy all of our criteria; one is our sixth $e\mu$ event and the other our first ee event.

REFERENCES

1. S. L. Glashow, Nucl. Phys. 22, 579 (1961). S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967). A. Salam, in *Elementary Particle Theory*, edited by N. Svartholm (Almqvist and Wiksell, Sweden, 1968), p. 367.
2. S. L. Glashow, J. Illiopoulos and L. Maiani, Phys. Rev. D2, 1285 (1970); M. Kobayashi and M. Maskawa, Prog. Theor. Phys. 49, 652 (1973).
3. F. Abe *et al.*, Phys. Rev. **D50**, 2966; F. Abe *et al.*, Phys. Rev. Lett. **73**, 225 (1994).
4. F. Abe *et al.*, Phys. Rev. Lett. **74**, 2626 (1995).
5. E. Laenen, J. Smith, and W.L. van Neerven, Phys. Lett. **321B**, 254 (1994).
6. F. Abe *et al.*, Nucl. Instrum. Meth. Phys. Res. A **271**, 387 (1988).