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Abstract

We present preliminary results on the search for the top quark in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV by the DØ collaboration at the Fermilab Tevavtron. The results are based on an integrated luminosity of 13.5 pb^{-1} of data collected by the DØ detector during the 1992-3 Tevatron collider run. We have searched for Standard Model $t\bar{t}$ decays into the dilepton decay modes $ee + X$, $e\mu + X$ and $\mu\mu + X$. No significant signal is observed for top quark production in these channels. We find one candidate event in the $e\mu + X$ channel and no events in the other two channels with an estimated non-top background of 0.76 ± 0.16 events.

1. Introduction

The top quark (t) is one of the few remaining pieces of the Standard Model yet to be experimentally verified. Measurements of the isospin of the b quark [1] and the hadronic width of the Z [2] require the b quark to be the lower mass component of a weak isospin doublet. In the Standard Model its partner the t quark is known, through studies of the decay width of the W boson, to have a mass in excess of 62 GeV/c^2 at 95 % CL [3]. Additional evidence for the large mass of the top quark comes from the analysis of precision electroweak data from LEP and SLC which imply a mass of $m_t = 178 \pm 14^{+18}_{-19}$ GeV/c^2 [2].

Prior to this conference the most stringent results from direct top quark searches come the two $p\bar{p}$ experiments at the Fermilab Tevatron where strong $t\bar{t}$ pair production is believed to be the dominant production mechanism. Each t quark decays via the semiweak transition $t \rightarrow W + b$ and the experimental searches key on the decays of the W bosons. From such studies the DO collaboration has published an experimental lower bound on the top quark mass of $m_t > 131$ GeV/c^2 at 95 % CL [4] and the CDF collaboration has shown possible evidence for top quark production at a mass of $174 \pm 10^{+13}_{-12}$ GeV/c^2 [5, 6]. In this and the two following papers [7, 8], we present the results of a new analysis from the DØ collaboration which focuses on the search for the top quark in the mass region $m_t > 130$ GeV/c^2.

This paper concentrates on searches in the three 'dilepton' decay modes: $t\bar{t} \rightarrow ee + \not{E}_T$ +jets, $t\bar{t} \rightarrow e\mu + \not{E}_T$ + jets and $t\bar{t} \rightarrow \mu\mu + \not{E}_T$ + jets. The following paper [7] describes results of searches in the 'lepton+jet' decay modes: $t\bar{t} \rightarrow e\nu$ + jets and $t\bar{t} \rightarrow \mu\nu$ + jets and the third paper [8] describes the result of a search in the decay mode $t\bar{t} \rightarrow e\nu$ + jets in which a soft muon is used to tag possible b quark jets. The third paper also contains the overall analysis summary and a combined estimate of the top quark production cross-section.

2. The DØ Detector

DØ is a second generation multipurpose detector for the study of $p\bar{p}$ interactions at high luminosity. Its hermetic 4π coverage emphasizes good jet, charged lepton and missing energy measurement which are essential for the search for the decay of high mass top quarks. The detector consists of three subsystems:

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a central tracking system for charged track detection; three large uranium liquid argon calorimeters for electromagnetic and hadronic energy measurement; and a muon spectrometer for muon momentum analysis. A detailed description of the detector and data collection systems is given in reference [9]. Here we summarize the features relevent to the top search.

The calorimeter is a uranium liquid argon sampling detector, contained within three cryostats (one central, two forward) which provide coverage out to pseudorapidity $|\eta| = 4.2$. Its fine lateral and longitudinal granularity ($\Delta\phi \times \Delta\eta = 0.1 \times 0.1$ and 0.05×0.05 at shower maximum) are important for electron, muon and jet identification and isolation measurement. The energy resolution, $\sigma/E \approx 15\%/\sqrt{E}$ for electrons, $\approx 50\%/\sqrt{E}$ for single hadrons, and $\approx 80\%/\sqrt{E}$ for jets (where E is in GeV) [9]. For minimum bias events the resolution for either component of the missing transverse energy, $\not\!\!E_T$, is 1.1 GeV + 0.02$\times$(ΣE_T), where ΣE_T is the scalar sum of all the transverse energy in the calorimeter.

The muon system consists of three layers of chambers, with magnetized iron toroids located between the first and second layers. The innermost layer has 4 planes of proportional wire drift tubes and the second and third layers each have 3 planes. The magnetic field in the iron toroid is 1.9 T, providing momentum measurement with a resolution of $\delta(1/p)/(1/p) = 0.20 \oplus 0.01p$ (where p is in GeV/c). The thickness of the calorimeter plus the iron toroids varies from 14-19 λ and minimizes the background from hadronic punchthrough. In-flight π and K decay background is also negligible because of the compact calorimetry and central tracking volume.

DØ was proposed, reviewed, and approved in 1984. The detector was commissioned with $p\bar{p}$ collisions during the summer of 1992 and began its first physics run in August, 1992. This first run was completed in May, 1993 with a total data sample of 13.5 pb^{-1} written to tape. A second collider run began in January 1994 and the total data sample from this second run is expected to be in excess of 100 pb^{-1}.

3. Particle Identification

The experiment triggers on events with combinations of electron, muon and jet candidates and $\not\!\!E_T$. The trigger efficiencies are determined from full detector and trigger simulations and vary from 85% to 90% as m_t increases from 140 to 180 GeV/c^2.

Electron candidates are identified as energy clusters in the calorimeter for which more than 90% of the total energy is contained in the electromagnetic section and which have a matching track in the central tracking system. The clusters are also required to have longitudinal and transverse shower profiles consistent with Monte Carlo calculations and test beam electron measurements [10]. These are further required to be isolated by requiring that the energy deposited in the annular cone $0.2 < \Delta R < 0.4$ about the electron track be less than 10% of the electromagnetic energy contained in the inner cone of radius $\Delta R < 0.2$.

Muons are identified by tracks in the muon spectrometer and are required to be consistent with the reconstructed vertex position. Additional requirements include a matching minimum ionizing energy deposition in the calorimeter and an isolation cut on calorimeter activity near the muon track. Muons which pass through the transition region between the central and end toroids (and thus through an insufficient amount of magnetic field for good momentum measurement) are rejected by requiring a minimum path length in the magnetized iron toroid of $\int Bdl > 1.83$ Tm which corresponds to a p_T kick of 0.55 GeV/c.

Jets are reconstructed using a fixed cone algorithm with cone radius, $\Delta R = 0.5$, where $\Delta R^2 = \Delta\eta^2 + \Delta\phi^2$. The reconstructed jet energies are corrected for non-uniformity of the calorimeter response, out-of-cone leakage, noise, and for the underlying event. The missing transverse energy, as determined from the energy deposited in the calorimeter after all corrections, is denoted by $\not\!\!E_T^{cal}$ and same quantity, after correction for muon momentum is denoted $\not\!\!E_T$.

4. Dilepton Search

4.1. $t\bar{t} \to ee + \not\!\!E_T + jets$

For the ee channel the initial data sample is obtained by requiring two isolated electromagnetic clusters with $E_T > 20$ GeV in the region $|\eta| < 2.5$. After requiring that both clusters match to tracks in the central tracking chamber and that at least one track be consistent with a single minimum ionizing particle, an initial sample of 739 events is obtained. To reduce backgrounds from $Z \to ee$, a cut is made on the dielectron mass: $|M_{ee} - M_Z| > 12$ GeV/c^2 if $\not\!\!E_T < 40$ GeV; 111 events remain after this cut. To eliminate background from QCD and the Drell-Yan continuum, an additional cut of $\not\!\!E_T > 25$ GeV is imposed, leaving 4 events. Finally, to reduce backgrounds from diboson (WW, WZ) events and $Z \to \tau\tau$ decays, we require two hadronic jets with $E_T > 15$ GeV in the region $|\eta| < 2.5$. No events survive after this cut. To illustrate the basic features of the data, Fig. 1 shows the distribution of $\not\!\!E_T$ vs. M_{ee} for data and $t\bar{t}$ Monte Carlo ($m_t = 160$ GeV/c^2 after making the initial electron E_T and the final jet cuts.

The acceptance for $t\bar{t} \to ee$ decays is studied using samples of m_t = 140, 160 and 180 GeV/c^2 Monte Carlo events which were generated using ISAJET [11] and put through the full DØ detector simulation and

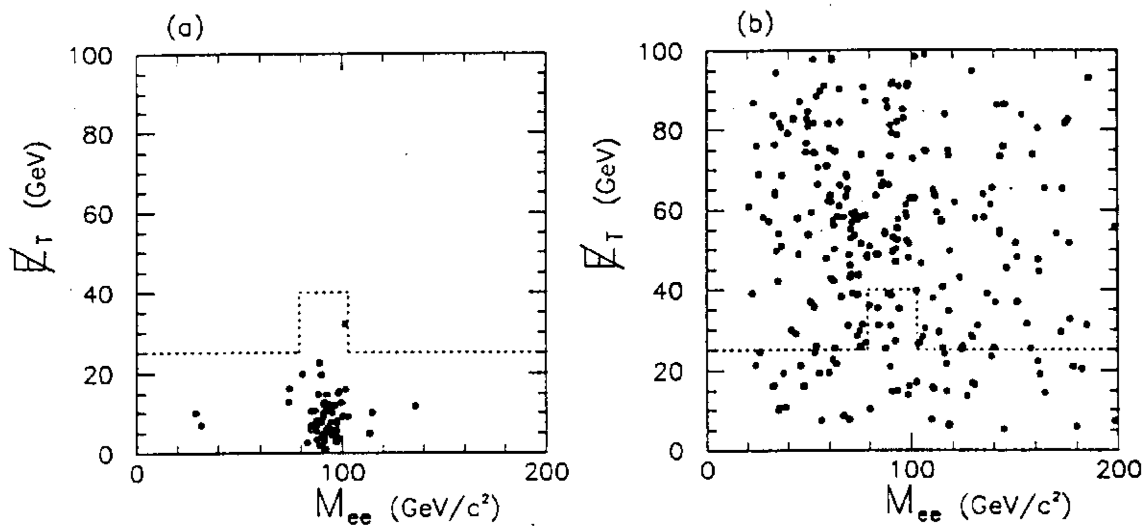

Figure 1. Scatter plots of $\not{E}_T$ vs M_{ee} after all but the $\not{E}_T$ cuts for ee events from (a) data, and (b) $t\bar{t} \to ee$ MC ($m_t = 160$ GeV/c^2 and $\int \mathcal{L}dt \approx 19$ fb^{-1}).

reconstruction. After making small corrections to the electron efficiencies to account for the differences between simulation and data, the expected top event yields vary from 0.41 ± 0.07 to 0.12 ± 0.02 events as m_t is changed from 140 GeV/c^2 to 180 GeV/c^2 for an integrated luminosity of 13.5 pb^{-1}. This is based on the central QCD cross sections of Laenen *et al* to NLO with soft gluon summation [12].

Estimation of non-top background is based on Monte Carlo and data studies. The sources considered include the Drell-Yan continuum, $Z \to ee, Z \to \tau\tau$, $Z \to b\bar{b}$ and $c\bar{c}$, strong production of $b\bar{b}$ and $c\bar{c}$, WW, WZ, W + jets, Z + jets, and fake leptons. The dominant contributions come from $Z \to \tau\tau$ (0.05 events), misidentified electrons (0.05 events) and $Z \to ee$ (0.03 events). Combining all sources gives a total expected background of 0.16 ± 0.07 events.

4.2. $t\bar{t} \to e\mu + \not{E}_T$ + jets

The initial $e\mu$ data set is selected by requiring an isolated electron with $E_T > 15$ GeV in the region $|\eta| < 2.5$ and an isolated muon with $p_T > 12$ GeV/c and $|\eta| < 1.7$. For the electron we impose all of the cuts used in the ee analysis except for the single minimum ionizing particle requirement. 12 events satisfy these criteria. Backgrounds from $Z \to \tau\tau$ and QCD/$Z \to b\bar{b}$ and $c\bar{c}$ are suppressed by making a cut on the missing transverse energy: $\not{E}_T > 10$ GeV; 8 events remain after this cut. To eliminate misidentification background from W + jets $\to \mu$ + jets events in which one of the jets fakes an electron, a cut is made on the vector energy imbalance in the calorimeters, $\not{E}_T^{cal} > 20$ GeV. This cut is particularly useful since for $W \to \mu\nu$ events, $\not{E}_T^{cal}$ is a direct measure of the W transverse momentum. To reject backgrounds due to muon bremsstrahlung (where the outgoing muon radiates a photon which is matched to the muon track in the central tracking chamber), a cut is made on the opening angle, ΔR, between the muon and "electron": $\Delta R^{e\mu} > 0.25$. This leaves 7 events. Lastly, to reduce backgrounds from WW, WZ, and $Z \to \tau\tau$ we imposed the same two jet requirements as were used for the ee channel. One event survives this final cut. Figures 2a and 2b show the distribution of $1/p_T^{\mu}$ vs E_T^{e} for the data and $t\bar{t}$ Monte Carlo ($m_t = 170$ GeV/c^2) prior to the final jet cuts. The surviving $e\mu$ candidate is marked by a $\star$ in Fig. 2a.

The high mass $t\bar{t} \to e\mu$ acceptance is studied using Monte Carlo event samples generated using ISAJET [11] and put through a full simulation of the DØ detector and trigger system. After folding the resulting acceptances with the Laenen *et al.* production cross section [12] we obtain predicted event yields which vary from 0.72 ± 0.16 to 0.23 ± 0.05 as m_t is varied from 140 GeV/c^2 to 180 GeV/c^2.

The corresponding non-top background has been estimated using a combination of Monte Carlo calculations and data measurements. Among the sources investigated are $Z \to \tau\tau$, $b\bar{b}$ and $c\bar{c}$ production in Z decays and QCD multijet events, WW, WZ, and W (or Z) + jet events in which one of the jets fakes a lepton. The dominant contributions come from $Z \to \tau\tau$ (0.18 events), and W + jets $\to \mu$ + jet (fake e) + jets (0.05 events).

remain after this cut. Lastly to reduce backgrounds   is consistent with the expectations for a top quark