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Status of the DØ Top Search

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Abstract

Preliminary new results on the top quark search with the D0 experiment in $\overline{p}p$ collisions at $\sqrt{s} = 1.8$ TeV for an integrated luminosity of 15.2 ± 1.8 pb^{-1} are reported. In this new analysis, which is optimized for high mass top search, a total of seven candidate events in the electron and muon dilepton decay channels ($t\bar{t} \rightarrow e\mu$, ee and $\mu\mu$), single lepton decay channels ($t\bar{t} \rightarrow e +$ jets and $t\bar{t} \rightarrow \mu +$ jets) without b tagging and single electron decay channel ($t\bar{t} \rightarrow e +$ jets) with b tagging have been observed. The estimated background is 4.7 ± 1.0 events. If we assume the top quark has a mass of 180 GeV/c^2, a $t\bar{t}$ production cross section of 3.2 ± 3.9 pb with upper limit of 13 pb at 95% C.L. is obtained.

1 Introduction

At a center of mass energy of 1.8 TeV top quarks heavier than W-bosons are predominantly produced in pairs. In the standard model a top quark heavier than the W boson decays almost 100% into a real W and a b quark. Each W boson decays either into a charged lepton and a neutrino or decays hadronically into a pair of quarks. Figure 1 shows the branching ratio of $t\bar{t}$ events. Although events of the type $t\bar{t} \to$ all jets, where both W bosons decay into $q\bar{q}$, have the highest branching ratio ($\sim \frac{36}{81}$), the background for this channel is overwhelming. The cleanest channel is events where $t\bar{t} \to$ 2 leptons + 2 neutrinos + 2 jets where both W bosons decay into leptons, which has a branching ratio of about $\frac{2}{81}$ for $e\mu$, $\frac{1}{81}$ for ee, and $\frac{1}{81}$ for $\mu\mu$.

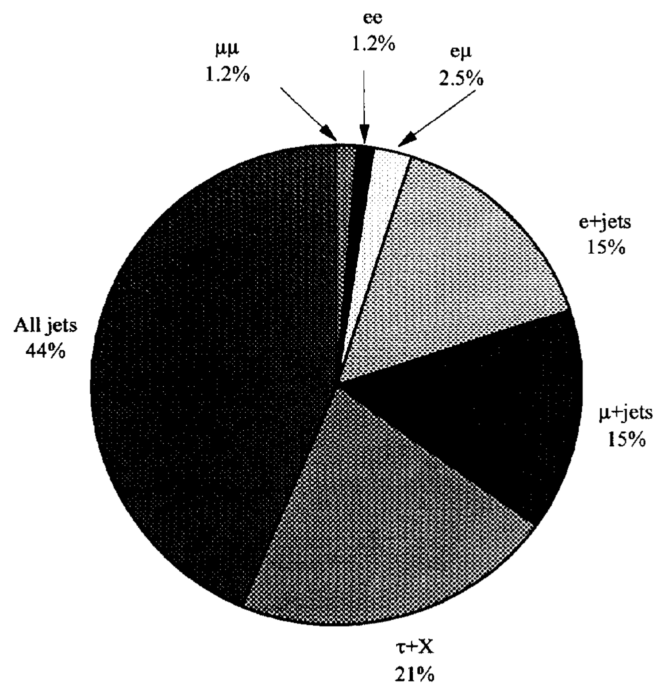

Figure 1: Branching Ratios for $t\bar{t}$ events

The DØ detector is one of the two large detectors at the Tevatron $\bar{p}p$ Collider located at Fermi National Accelerator Laboratory. It is designed for excellent identification and measurement of electrons and muons, good measurement of jets at large p_T with good energy resolution, and a well-controlled measure of missing transverse energy [1]. The DØ detector consists of three major subsystems: a central detector without magnet field, which includes a vertex chamber, central and forward drift chambers and a transition radiation detector; uranium/liquid argon calorimetry with fine segmentation, which provides a uniform coverage over the pseudorapidity range $|\eta| \leq 4.2$; and an outer muon system with one chamber inside a toroidal magnetic field and two chambers outside of the magnet. The energy resolution is $\sigma/E = 15\%/\sqrt{E}$ for electrons and $\sigma/E = 80\%/\sqrt{E}$ for hadrons.

The DØ collaboration recently published a lower limit on the mass of the top quark of 131 GeV/c^2 at a confidence level (C.L.) of 95% based on data recorded at the Fermilab Tevatron during the 1992-1993 collider run with an integrated luminosity of 15.2 pb^{-1} [2] for $t\bar{t}$ decay to $e\mu$, ee, $e + jets$ and $\mu + jets$. After setting a top mass limit, DØ has optimized the analysis to search for a higher mass top quark, $M_{top} > 130$ GeV/c^2, and has included the $\mu\mu$ and $e + jets + \mu$ tag channels. In this new analysis we reduced the backgrounds with improved particle identification and we have a better understanding of the backgrounds, especially for W+jets events. In this new analysis we subtract the background in the calculation of the top quark production cross section.

2 Dilepton Analysis

The signature of $t\bar{t}$ events in the dilepton channels is that it has two high-p_T isolated leptons, two jets and large missing E_T, ($\not{E}_T$). Compared with the analysis used in setting a top mass limit [2], the new analysis is able to retain the efficiencies in the high top mass region and is able to reduce the backgrounds by a factor of 2.

2.1 *ee* Channel

The data in this analysis corresponds to an integrated luminosity of $15.2 \pm 1.8\text{pb}^{-1}$ from the 1992-93 run. The offline event selection requires two identified electrons with transverse energy $E_T > 20$ GeV. Electrons are identified by their longitudinal and transverse shower shape of isolated energy clusters in the calorimeter, and through the requirement of a matching track in the central drift chamber [2] within a pseudorapidity region of $|\eta| < 2.5$. In addition, we impose an ionization (dE/dx) requirement on the drift chamber track to reduce the background. The missing E_T is required to be above 25 GeV. At least two jets are required to be reconstructed in the event with a transverse energy above 15 GeV. Events from $Z \rightarrow ee$ are rejected by requiring that the di-electron invarient mass, M_{ee}, is 12 GeV/c^2 away from the Z mass peak, if the $\not{E}_T$ is below 40 GeV. Figure 2 shows a scatter plots of $\not{E}_T$ versus the di-electron invariant mass for the events that passed the E_T requirements for the two electrons and the two jets for (a) D0 data (b) $t\bar{t} \rightarrow ee$ Monte Carlo events for a top quark of mass 160 GeV/c^2 ($\int Ldt = 19fb^{-1}$) . The dash lines indicate the cuts. No event survives all the cuts in this data sample.

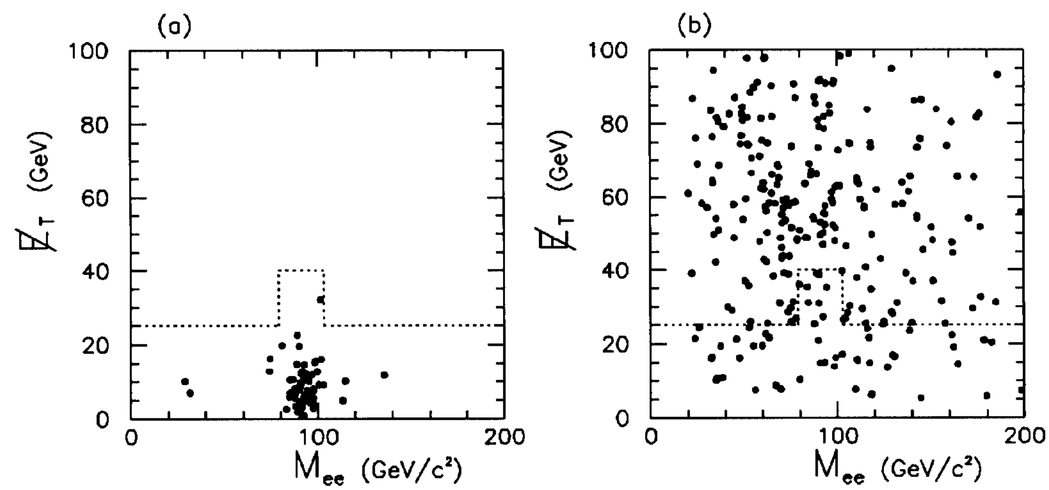

Figure 2: $\not{E}_T$ versus M_{ee} : (a) DØ data (b) $t\bar{t} \rightarrow ee$ MC ($M_{top} = 160$ GeV/c^2)

Considering the efficiency of detecting the top quark in this channel, the geometrical acceptance, the intergrated luminosity of the data sample, the $t\bar{t}$ production coss section [3] and the branching ratio for the $t\bar{t} \rightarrow ee$ decay channel, we expect 0.56 ± 0.10, 0.29 ± 0.02 and 0.15 ± 0.03 events for a 140 GeV/c^2, 160 GeV/c^2 and 180 GeV/c^2 top mass, respectively. The physics backgrounds for the ee channel mainly come from Z^0 decays and W pair events. However, the instrumental backgrounds for the ee channel are much larger than the physics backgrounds due to misidentification, where a jet is misidentified as an electron. The total backgrounds, including both the physics backgrounds and the instrumental background is estimated to be 0.25 ± 0.08 events.

2.2 $e\mu$ Channel

The data in the $e\mu$ analysis corresponds to an integrated luminosity of $15.2 \pm 1.8 \mathrm{pb}^{-1}$, the same data sample used for the ee channel analysis. However, the branching ratio for $t\bar{t} \to e\mu$ is a factor two larger than the $t\bar{t} \to ee$ channel. The offline event selection requires one identified electron with $E_T > 15$ GeV within $|\eta| < 2.5$ and one identified muon with $p_T > 12$ GeV within $|\eta| < 1.7$. We require the muon to be isolated from the jets. The isolation cut is the minimum separation in ΔR space, where $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ (η = pseudorapidity, ϕ = azimuth angle). We require $\Delta R > 0.5$ between the muon direction and the jet axis for jets of $E_T > 8$ GeV. An additional spatial separation, $\Delta R^{e\mu} > 0.25$, is required to remove background events with large P_t^W $W \to \mu\nu$ decays with a hard muon bremsstrahlung. The missing E_T is required to be above 20 GeV to reject Z^0 decays and Drell-Yan events. The jets requirements are the same as for the ee channel: at least two jets with a transverse energy above 15 GeV. One event survives all selection cuts, which was discussed in Ref. [2].

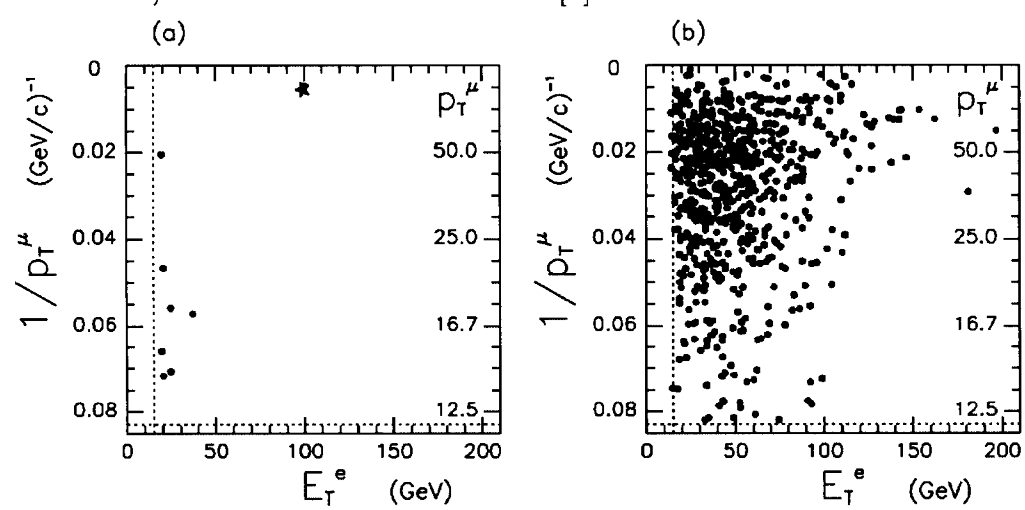

Figure 3: $1/p_T^\mu$ vs E_T^e (a) DØ data (b) $t\bar{t} \to e\mu$ MC ($M_{top} = 170$ GeV/c^2)

Figure 3 shows a scatter plots of $1/p_T$ of the muon vs E_T of the electron before the jets requirements for (a) D0 data (b) $t\bar{t} \to e\mu$ Monte Carlo events for a top quark of mass 170 GeV/c^2 ($\int Ldt = 21.3 fb^{-1}$) . The dash lines indicate the cuts on the lepton p_T. The event which passed all the cuts is indicated by an $\star$ in figure 3.

The expected number of $t\bar{t} \to e\mu + X$ events are calculated in the same way as for the ee channel. We expect 1.2 ± 0.3, 0.6 ± 0.1 and 0.3 ± 0.1 events for a top mass of 140 GeV/c^2, 160 GeV/c^2 and 180 GeV/c^2, respectively. The dominant backgrounds in this channel are from the $Z^0 \to \tau^+\tau^- \to e\mu$ process and W pair production. The estimated total background in the $e\mu$ channel is 0.37 ± 0.09 events, which is factor two smaller than the backgrounds in the earlier analysis described in [2].

2.3 $\mu\mu$ Channel

This channel is new compared with the analysis used in setting a top mass limit [2]. The data in this analysis corresponds to an integrated luminosity of $11.0 \pm 1.3\text{pb}^{-1}$ from the 1992-93 run. The offline event selection requires two identified isolated muons with $E_T > 15$ GeV and $|\eta| < 1.1$. The jets requirements are as same as for the other dilepton channels. To exclude events with a decay of a high transverse momentum J/ψ or ψ' into a muon pair, a requirement of $M_{\mu\mu} > 10$ GeV is imposed. The events from Z^0 decays are rejected by applying cuts on the azimuthal opening angle $(\Delta\phi)$ between the dimuon p_T and the $\not{E}_T{}^{cal}$ vectors, where $\not{E}_T{}^{cal}$ is the missing transverse energy as computed from energy deposited in the calorimeter. We require $\Delta\phi_{\mu\mu} < 140°$ if $\not{E}_T < 40$ GeV and $\Delta\phi(\not{E}_T{}^{cal}, p_T^{\mu\mu}) > 30.°$ No event survives all the cuts in this data sample.

We expect 0.24 ± 0.04, 0.12 ± 0.02 and 0.06 ± 0.01 events from $t\bar{t} \to \mu\mu+X$ for a 140 GeV/c^2, 160 GeV/c^2 and 180 GeV/c^2 top mass, respectively. The major backgrounds contributing to the $\mu\mu$ channel are Z^0 decays, Drell-Yan and W pair events. The estimated total background in this channel is 0.36 ± 0.06 events.

3 Lepton + Jets Analysis

The signature of $t\bar{t}$ events in the lepton + jets channels is that of a high-p_T isolated lepton, large $\not{E}_T$ and high jet multiplicity.

We divide the lepton + jets analysis into two complementary and orthogonal analyses: Event Shape analysis and b Tagging analysis. The main source of the backgrounds in the lepton + jets channel are W + jet events with high jet multiplicity and QCD events with fake electrons and missing E_T due to mismeasurement or misidentification.

3.1 Event Shape analysis

In this analysis the search for $t\bar{t} \to$ e + jets and $t\bar{t} \to \mu$ + jets events is achieved by use of topological and kinematic cuts and event shape.

The data for the search for $t\bar{t} \to$ e + jets events corresponds to an integrated luminosity of $15.2 \pm 1.8\text{pb}^{-1}$; for $t\bar{t} \to \mu$ + jets events the integrated luminosity is $11.0 \pm 1.3\text{pb}^{-1}$. The offline event selection requires one identified electron within $|\eta| < 2.0$ with $E_T > 20$ GeV and missing E_T above 25 GeV for e + jets channel; one identified muon within $|\eta| < 1.7$ with $E_T > 20$ GeV and missing E_T above 20 GeV for μ + jets channel. The jet counting starts for jets with $E_T > 15$ GeV and within a pseudorapidity region of $|\eta| < 2.0$. Figure 4 shows the jet multiplicity in e + jets events with different E_T cuts ($E_T > 15$, 25 GeV) on the jets compared to VECBOS Monte Carlo [4] predictions.

The event shape analysis uses the global event variable aplanarity, $\mathcal{A}$, which is defined as $\frac{3}{2}$ of the smallest normalized eigenvalue of the 3-momentum tensor in the laboratory frame. The background events can be expected to have smaller $\mathcal{A}$ than the signal events. Another variable used in the event shape analysis is H_T, which is defined as the sum of the E_T's of the W and the jets for the e + jets channel. For the μ + jets channel, H_T is the sum of the E_T's of the jets, not including the W because the momentum resolution is poorer for muons than for electrons. The H_T variable measures the transverse hadronic jet activity. We expect a higher E_T for jets from $t\bar{t}$ than from background events.

The final requirement on the jet multiplicity is at least four jets with $E_T > 15$ GeV for both the e + jets and μ + jets channels. Figure 5 shows a scatter plots of $\mathcal{A}$ vs H_T for W + jets VECBOS Monte Carlo events, $t\bar{t}$ ($M_{top} = 160$ GeV/c^2) Monte Carlo events, QCD data

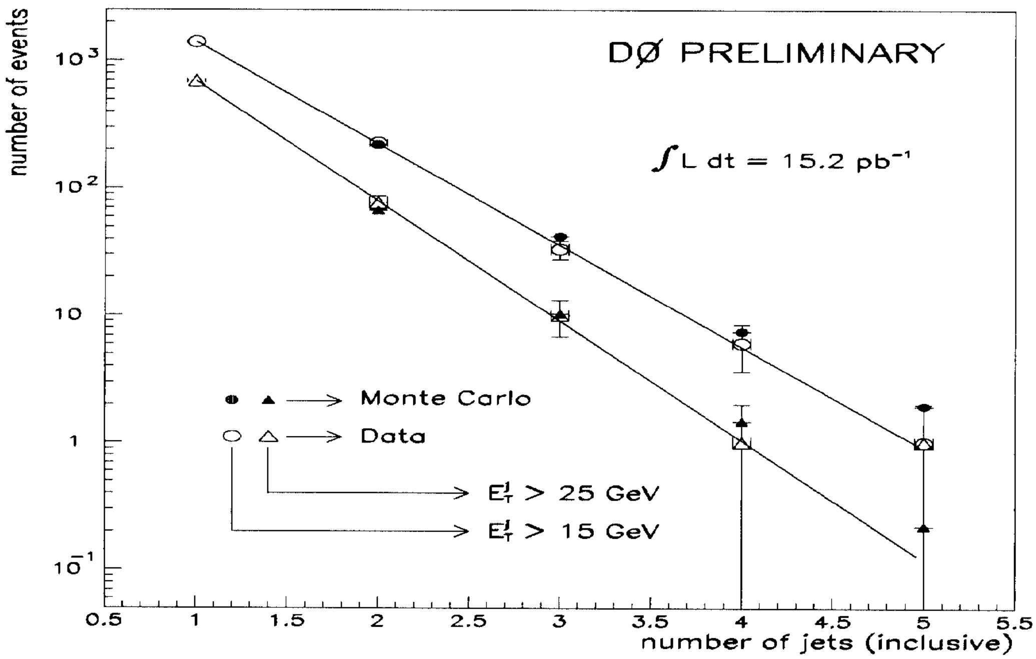

Figure 4: Jet Multiplicity

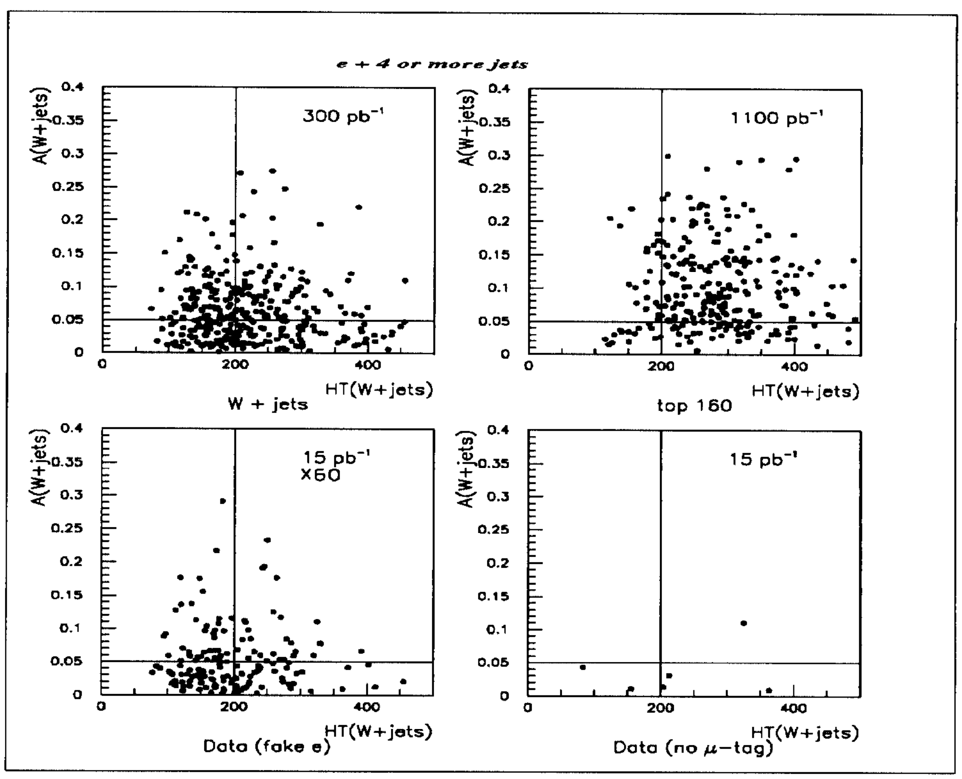

Figure 5: Aplanarity vs H_T for e + jets analysis

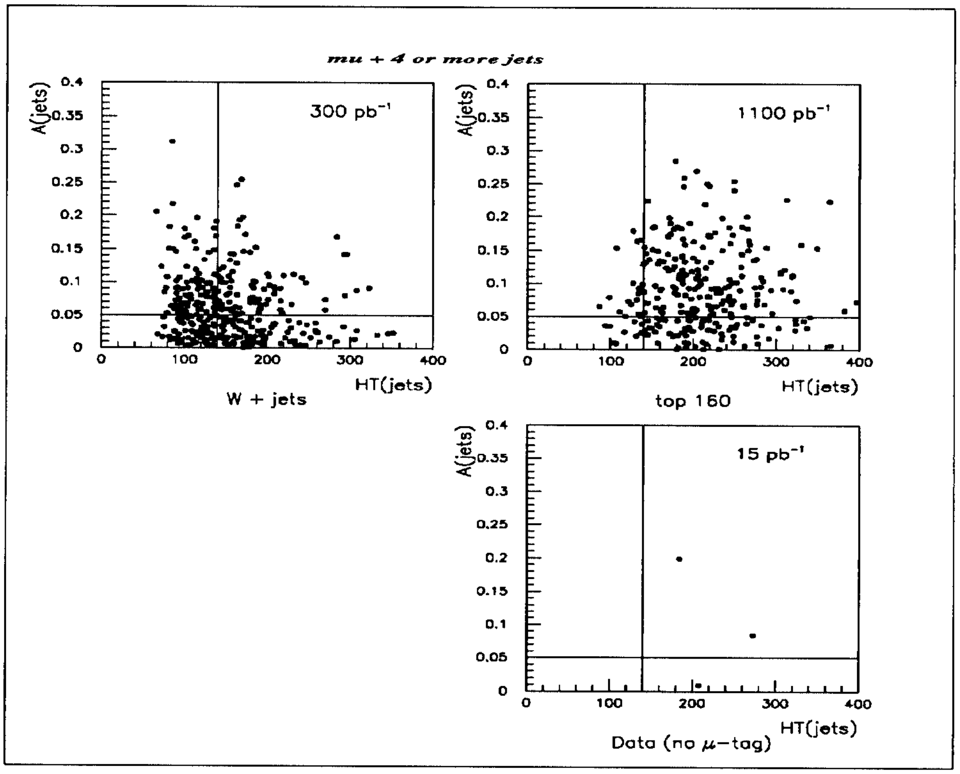

Figure 6: Aplanarity vs H_T for μ + jets analysis

with fake electrons and the D0 data in the e + jets channel. The solid lines show the cuts on aplanarity and H_T. The QCD data plot shown in Figure 5 has a normalization factor of 60. Requiring $\mathcal{A} > 0.05$ and $H_T > 200$ GeV gives good rejection for W + jets background events and QCD fake electron events. It still retains a very high efficiency for $t\bar{t}$ events. One event survived all the cuts in the event shape analysis for the e + jets channel.

Figure 6 shows scatter plots of $\mathcal{A}$ vs H_T for W + jets VECBOS Monte Carlo events, $t\bar{t}$ (M_{top} = 160 GeV/c^2) Monte Carlo events, and D0 data in the μ + jets channel. The cuts for the μ + jets channel are $\mathcal{A} > 0.05$ and $H_T > 140$ GeV. Two events survived all the cuts in the event shape analysis for the μ + jets channel.

Figure 7 is the LEGO display in the $\phi - \eta$ plane for the e + jets event that passed all the cuts. The object in Figure 7 which has the highest E_T is the electron; the object indicated by dash lines is the vector $\not{E}_T$; in total there are five jets in the event.

The expected number of $t\bar{t}$ events is 3.3 ± 0.9, 2.1 ± 0.5 and 1.2 ± 0.2 for a 140 GeV/c^2, 160 GeV/c^2 and 180 GeV/c^2 top mass, respectively, in the e + jets channel and 0.9 ± 0.4, 0.7 ± 0.3 and 0.4 ± 0.2 events for a 140 GeV/c^2, 160 GeV/c^2 and 180 GeV/c^2 top mass, respectively, in the μ + jets channel.

W + jets background events and the QCD events are the main source of backgrounds in the lepton + jets channel. Since the number of W + jets events is expected to decrease exponentially as function of the jet multiplicity [5], by fitting the number of W + jets events at the lower jet multiplicity and extrapolating it to high jet multiplicities, we can estimate the number of W + jets background events in the data sample. The QCD background events are multijet QCD events with one jet misidentified as an electron. We estimated the QCD

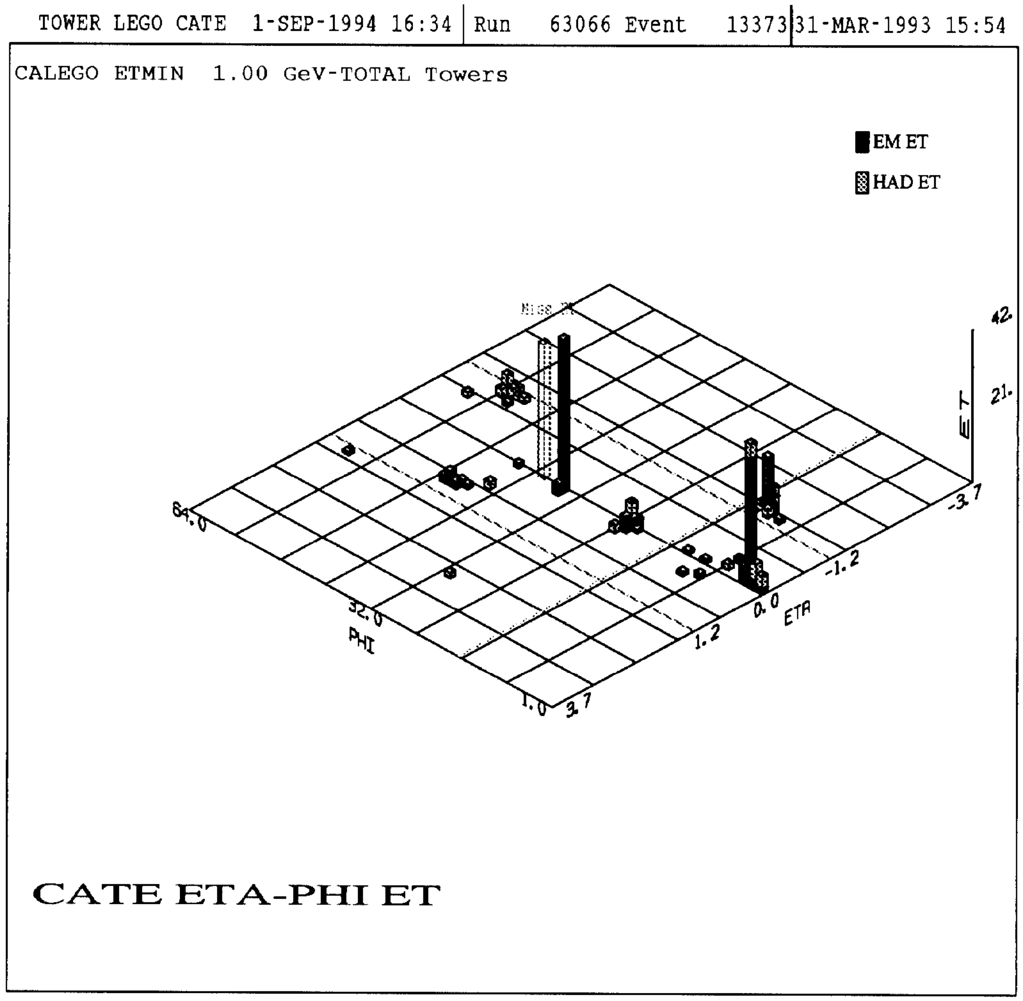

Figure 7: LEGO display for the e+jets event that passed all the cuts.

background from the data itself. The total background is estimated to be 1.1 ± 0.5 events for the e + jets channel and 0.5 ± 0.3 events for the μ + jets channel.

3.2 b Tagging Analysis

The background for the lepton + jets channel can be significantly reduced by requiring that one of the jets is tagged as a b-jet. In DØ b tagging is done by detecting a soft muon in a jet. The probability that at least one of the b quarks will decay to a muon, either directly or through a cascade ($b \to c \to \mu$), is approximately 40%. The muons from b-decays in $t\bar{t}$ events have low p_T and are non-isolated. A soft muon in the DØ top quark search is defined to have $p_T^\mu > 4$GeV and be within $\Delta R = 0.5$ of a jet if the p_T of the muon is greater than 12 GeV. Figure 8 (a) shows the muon p_T distribution, figure 8 (b) shows the distribution of ΔR between the muon and the jet and figure 8 (c) shows the distribution of the muon p_T relative to the jet axis. The dots are for D0 data and the open symbols are for Monte Carlo events. There is good agreement between data and the Monte Carlo prediction. The offline event selection in the b tagging analysis for e + jets channel requires one identified electron with $E_T > 20$ GeV, $\not{E}_T > 20$ GeV, at least three jets with $E_T > 15$ GeV and a soft muon. Three events passed all the cuts.

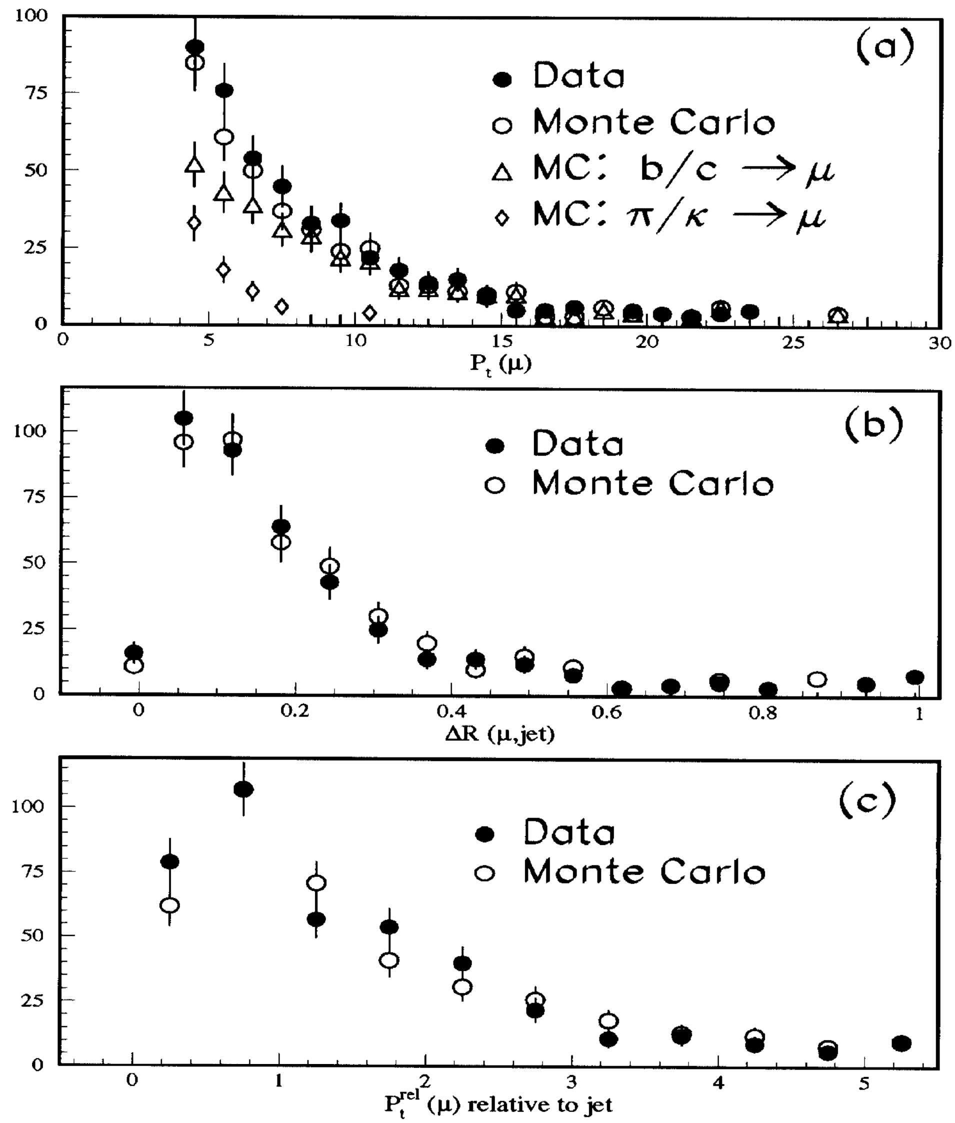

Figure 8: Distribution of (a) muon p_T of (b) ΔR between muon and jet (c) muon p_T relative to jet axis for DØ data and Monte Carlo

The expected number of $t\bar{t}$ events in the e + jets + μ tag channel is 2.3 ± 0.6, 1.6 ± 0.3 and 1.0 ± 0.2 for a top mass of 140 GeV/c^2, 160 GeV/c^2 and 180 GeV/c^2, respectively.

We use a tagged QCD data sample to normalize the $\not{E}_T$ distribution at low $\not{E}_T$ to predict the background for $\not{E}_T > 20$ GeV for QCD events which have a fake electron and mismeasured missing E_T. The W + jets background is estimated by using the observed number of e + ≥ 3 jets events to subtract the estimated QCD background events, then apply the muon tag rate, which is measured to be 0.5%/jet. Figure 9 (a) shows the number of muons per event versus the number of inclusive jets for e + jets data as well as for Monte Carlo events. Figure 9 (b) shows the number of events for different inclusive jet multiplicities for data, estimated background and the Monte Carlo prediction for $t\bar{t}$ events in e + jets + μ tag channel. The estimated total background is 2.1 ± 0.8 events.

As a cross check, we compare the observed e + 1, or 2, jets + μ tag events with the estimated background as shown in table 1. The data agrees with the estimated number of

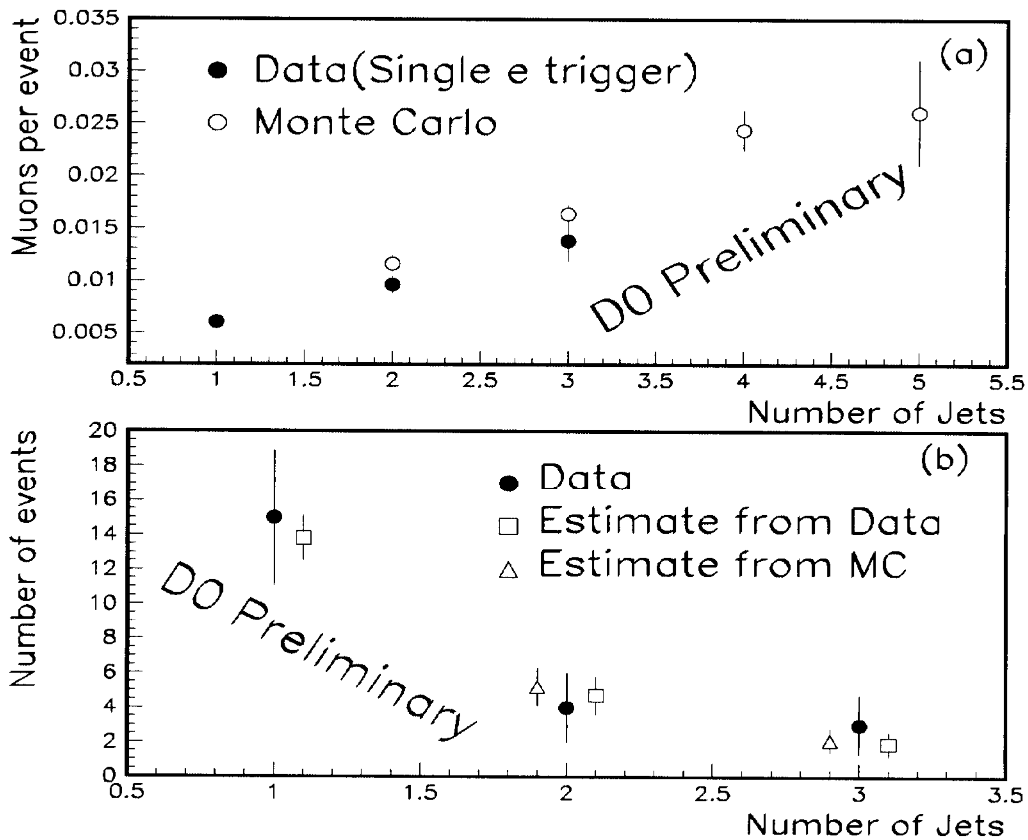

Figure 9: (a) Muons per events vs number of jets for data and MC events (b) inclusive jet multiplicity for data, estimated backgrounds from data and $t\bar{t}$ MC events.

Sample	W+jets	QCD	Total	Data
$e \geq 1$ jet $+\mu$tag	11.4 ± 3.4	2.4 ± 1.0	13.8 ± 3.5	15
$e \geq 2$ jet $+\mu$tag	4.2 ± 1.1	1.2 ± 1.0	5.4 ± 1.5	4

Table 1: Comparision of observed e + 1, 2 jet events with background estimates.

m_t (GeV/c^2)		$e\mu$	ee	$\mu\mu$	$e+$jets	$\mu+$jets	$e+$jets$+\mu$tag	ALL
	$\varepsilon\times\mathcal{B}(\%)$	0.45 ± 0.10	0.22 ± 0.03	0.13 ± 0.02	1.3 ± 0.3	0.5 ± 0.2	0.9 ± 0.2	
140	$\langle N\rangle$	1.2 ± 0.3	0.56 ± 0.10	0.24 ± 0.04	3.3 ± 0.9	0.9 ± 0.4	2.3 ± 0.6	8.5 ± 1.4
	$\varepsilon\times\mathcal{B}(\%)$	0.47 ± 0.11	0.23 ± 0.03	0.13 ± 0.02	1.7 ± 0.4	0.7 ± 0.3	1.3 ± 0.2	
160	$\langle N\rangle$	0.6 ± 0.1	0.29 ± 0.05	0.12 ± 0.02	2.1 ± 0.5	0.7 ± 0.3	1.6 ± 0.3	5.4 ± 0.9
	$\varepsilon\times\mathcal{B}(\%)$	0.46 ± 0.11	0.24 ± 0.03	0.13 ± 0.02	1.9 ± 0.4	0.8 ± 0.3	1.5 ± 0.2	
180	$\langle N\rangle$	0.3 ± 0.1	0.15 ± 0.03	0.06 ± 0.01	1.2 ± 0.2	0.4 ± 0.2	1.0 ± 0.2	3.1 ± 0.5
Background		0.37 ± 0.09	0.25 ± 0.08	0.36 ± 0.06	1.1 ± 0.5	0.5 ± 0.3	2.1 ± 0.8	4.7 ± 1.0
$\int\mathcal{L}dt$ (pb^{-1})		15.2 ± 1.8	15.2 ± 1.8	11.0 ± 1.3	15.2 ± 1.8	11.0 ± 1.3	15.2 ± 1.8	
Data		1	0	0	1	2	3	7

Table 2: Efficiency $\times$ branching fraction ($\varepsilon\times\mathcal{B}$) and the expected number of events ($\langle N\rangle$) for $t\bar{t}$ production in the six decay channels, as a function of top mass. Also given is the expected background and the number of observed events in each channel.

events from W + jets and QCD processes in the low jet multiplicity region.

4 Top Production Cross Section

Table 2 combines the results from the six analyses defined above. It gives the acceptance, which is the efficiency $\times$ the branching ratio, the expected number of $t\bar{t}$ events for three top mass hypotheses, the estimated number of background events, the intergrated luminosity for the data used in the analysis and the number of observed events for all six decay channels.

The top production cross section is calculated by the formula

$$\sigma_{t\bar{t}} = \frac{\sum_{i=1}^{6}(N_i - B_i)}{\sum_{i=1}^{6}\varepsilon_i\mathcal{B}_i L_i} \tag{1}$$

where N_i is the number of observed events, B_i is the expected background, ε_i is the detection efficiency for top, $\mathcal{B}_i$ is the branching ratio and L_i is integrated luminosity for decay channel i.

The likelihood function for the top production cross section is obtained by fluctuating the errors on the efficiencies, backgrounds and luminosities. Figure 10 shows the resulting 95% C.L. upper limit on the $t\bar{t}$ cross section as function of top quark mass, together with DØ's previous upper limit [2], the recent CDF measurement [6], the central value and the lower bound of NNLO theoretical predictions [3]. If we assume the top quark has a mass of 180 GeV/c^2, we obtain a $t\bar{t}$ production cross section of 3.2 ± 3.9 pb with an upper limit of 13 pb at 95% C.L.

To conclude, we observe a total of seven candidate events in the electron and muon dilepton decay channels ($t\bar{t}\to e\mu$, ee and $\mu\mu$), single lepton decay channels ($t\bar{t}\to e+$jets and $t\bar{t}\to\mu+$jets) without b tagging and single electron decay channel ($t\bar{t}\to e+$jets) with b tagging. The estimated background is 4.7 ± 1.0 events. For a top quark mass hypotheses of 180 GeV/c^2,

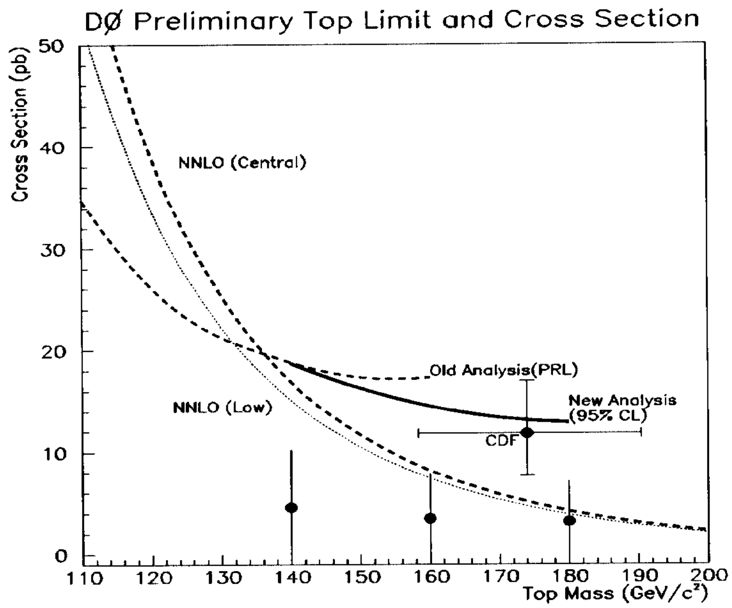

Figure 10: top cross section vs top mass

we obtain a $t\bar{t}$ production cross section of 3.2 ± 3.9 pb with an upper limit of 13 pb at 95% C.L. Work is in progress to include more decay channels, to reduce the background and the systematic errors. Much more data will be collected during the current 1994-1995 run.

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