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Search for top in lepton + jets in DØ using a topological tag

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Abstract

We have searched for production of $t\bar{t}$ pairs in $p\bar{p}$ interactions at 1.8 TeV center-of-mass energy at the FNAL Tevatron collider. The search assumes standard model decay for top quark into W + b quark. We observe in $e+$jets and $\mu+$jets final states a small, not statistically significant, excess above the background estimated by two different methods. The results presented are preliminary.

1. Introduction

Assuming the Standard Model decay for top quarks into a W and a b quark, events with $t\bar{t}$ pairs will have one isolated high p_T e or μ accompanied by multiple jets 30% of the time. These channels yield considerably more events than those with 2 isolated leptons in the final state, presented in the preceding contribution to these proceedings by S. Wimpenny [1] , but suffer from larger backgrounds from the channel W+ multi-jets. In this paper we discuss two different methods used to estimate whether a significant $t\bar{t}$ production can be observed in the DØ data over the $W+$jets background. A previous analysis of these data, searching for top in the mass region 90 to 140 GeV in single and di-lepton final states, has been published [2] and gave a top mass limit of 131 GeV (95% CL). The present analysis is optimized for masses above 130 GeV and should be considered preliminary. The two methods used yield a small, but not statistically significant, excess.

2. Event selection

The DØ detector is described in detail in [3] and in these proceedings by [1], so it will not be discussed here. The events for lepton + jets analysis are obtained with 3 triggers:

- One electromagnetic shower with transverse energy $(E_T) > 15$ GeV, one hadronic jet with $E_T > 10$ GeV and calorimeter missing E_T $(\not{E}_T^{cal})$ > 10 GeV
- One electromagnetic shower with $E_T > 20$ GeV and $\not{E}_T^{cal} > 20$ GeV
- One μ with $p_T > 8$ GeV and one hadronic jet with $E_T > 15$ GeV

Hadronic jets are defined as energy in a cone of $R = \sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.5$ where ϕ is the azimuthal angle in radians and η is the pseudo-rapidity.

After reconstruction the events are selected further by making stricter requirements. For the $e+$jets sample selection requirements on the electron are based on shower shape, cluster isolation, shower match with a reconstructed track and track ionization cuts to remove conversions. Electrons are required to have $E_T^e > 20$ GeV and $|\eta^e| < 2.0$. Additional requirements on the $e+$jets sample are $\not{E}_T^{cal} > 25$ GeV, $E_T^{jet} > 15$ GeV and $|\eta_{jet}| < 2.0$. Figure 1a (1b) shows the $\not{E}_T$ distribution for the selected events which pass (fail) the electron cuts. We will refer to the events that satisfied the triggers but failed the offline electron cuts and have $\not{E}_T^{cal} < 25$ GeV as the QCD sample. This sample is used to estimate the non-W background in the $e+$jets sample and to test the validity of jet multiplicity scaling in section 3.

Selection requirements on the μ are made to remove cosmic rays (by drift chamber timing and no other

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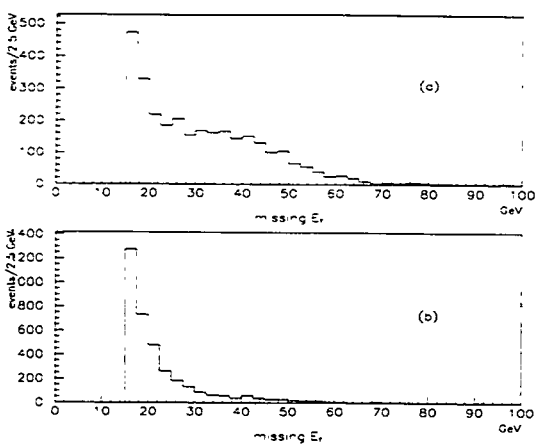

Figure 1. (a) $\not{E}_T^{cal}$ distribution for events satisfying all electron selection criteria, (b) $\not{E}_T^{cal}$ distribution for events satisfying the electron triggers but failing offline selection criteria.

collinear μ-track), isolation cuts to remove μ's from decays other than W's (minimum separation between μ and jets with $E_T > 8$ GeV of $\Delta R > 0.5$ and core cone isolation energy < 5 GeV in annular cone $0.2 < \Delta R < 0.4$ around μ track) plus calorimeter dE/dx confirmation to reduce accidentals. The μ is required to have $p_T^\mu > 15$ GeV and $|\eta_\mu| < 1.7$. In addition to the μ the $\mu+$jets sample is required to have at least 1 jet with $E_T > 15$ GeV and $|\eta_{jet}| < 2.0$, $\not{E}_T > 20$ GeV, and $\not{E}_T^{cal} > 20$ GeV. The trigger and selection requirements on the $\mu+$jets sample produces a bias for ≤ 2 jets which needs to be corrected when added to $e+$jets for the jet multiplicity analysis in section 3.

To avoid overlap with the analysis of events in which jets are tagged as containing heavy quarks by the observation of a non-isolated μ, discussed in the contribution to these proceedings by R. Raja [4], μ-tagged events have been excluded from the sample and their loss accounted for in the acceptance calculation.

3. Jet Multiplicity Analysis

The number of events as function of jet multiplicity and the estimated non-W background to $e+$jets and $\mu+$jets channels are given in table 1. The non-W background for $e+$jets is mostly from misidentified electrons. In $\mu+$jets events the background comes from two sources: Z + jets where one of the μ is not detected and QCD processes where the μ from a decay other than W satisfies the isolation criteria, the two backgrounds are roughly comparable.

As shown on fig. 3(a) the $e+$jets data after background subtraction are fit well by a scaling law (as

jets	$e+$jets	non-W bckg.	$\mu+$jets	non-W bckg.
≥ 1	1383	$94. \pm 6.$	303	$48. \pm 8.$
≥ 2	243	$26 \pm 3.$	92	$16. \pm 3.$
≥ 3	35	5.7 ± 0.9	22	4.8 ± 0.8
≥ 4	6	1.1 ± 0.3	6	1.3 ± 0.3
≥ 5	2	0.3 ± 0.1	1	0.3 ± 0.1

Table 1. Selected e and μ + jets events

jets	Data	non W backg.	calculated $W+$jets	calculated $t\bar{t}$
≥ 1	1686	$142. \pm 20.0$	1656 ± 96	5.7 ± 10.0
≥ 2	335	50.6 ± 7.0	278.8 ± 17	5.6 ± 9.9
≥ 3	57	10.3 ± 1.5	42.2 ± 7.1	4.5 ± 8.2
≥ 4	12	2.4 ± 0.4	6.6 ± 3.8	3.0 ± 4.6

Table 2. Estimated numbers of $W+$jets and $t\bar{t}$ events

expected by [5]):

$$W + n\ jets = \frac{[W + (n-1)\ jets] : [W + (n-1)\ jets)]}{[W + (n-2)\ jets)]}$$

This law seems to be satisfied for any E_T^{jet} threshold used for counting jets. The predictions from the VECBOS [6] Montecarlo agree well with the data after ISAJET [7] is used for hadronization and GEANT [8] for simulating the DØ detector. As $t\bar{t}$ events in channels with one isolated lepton are expected to have high multiplicities (2 jets from b's, 2 jets from hadronic W decay plus additional jets from initial and final state radiation) any noticeable $t\bar{t}$ production should appear as an excess of events at high multiplicity, in particular for 4 or more jets and for high E_T threshold. As shown in fig. 2 the 4th jet (ordered in E_T) from high mass top is expected to be considerably more energetic than for $W+$jets but no significant violation of the scaling law is observed in fig. 3(a). To find how much $t\bar{t}$ production can be accomodated and still satisfy the scaling law we can solve using the number of events with 2,3 and 4 jets for the number of W and top events:

$$N_4 - a_4 \cdot N_t = (N_3 - a_3 \cdot N_t)^2/(N_2 - a_2 \cdot N_t)$$

where N_i is observed number of lepton + jets events with $\geq$i jets, N_t the total number of top events and a_i the corresponding fraction at each multiplicity. The results are given in table 2, of particular interest is the total number of top events $N_t = 5.7 \pm 10.0$. The numbers for ≥ 1 jets are predicted from the numbers obtained using the events with 2,3 and 4 jets.

To check the validity of the scaling law in a case with no $t\bar{t}$ events, we fitted the QCD sample to a simple exponential. In Fig. 3(b) we show the jet multiplicities for that sample (after correcting for

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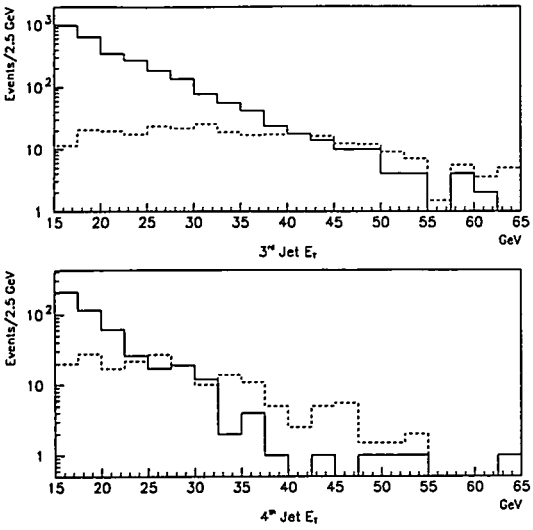

Figure 2. E_T distributions of 3rd and 4th jet from $W+\geq 3$ jets Montecarlo (solid) and $t\bar{t}$ (dotted) with top mass 160 GeV, normalized to 500 pb^{-1}.

the higher probability as a function of increasing multiplicity for having a jet fake an electron). The QCD data is clearly well fitted. We also fitted the predictions of the VECBOS Montecarlo. All the fits give similar values for the ratio of $[W+3 \text{ jets}]/[W+2 \text{ jets}]$: $.151 \pm .020$ for the data, $.160 \pm .013$ for VECBOS Montecarlo, $.187 \pm .004$ for the QCD sample. The fit to the VECBOS Montecarlo tends to underestimate the predicted number of 4 or more jet events by 15% while the QCD fit overestimates by the number of 4 jet events by 12%. To account for these deviations we estimate a 20% systematic error in the validity of the scaling law. The fraction (a_i) of top events expected at each multiplicity is obtained from Montecarlo; to estimate the uncertainty in this procedure we compared 2 different Montecarlos (ISAJET and HERWIG [9]). The differences between them were at the level of 10%. There is an additional 15% uncertainty in the top acceptance from the uncertainty in the jet energy scale. From the number of top events and the calculated acceptance times branching ratio we can estimate a cross section for $t\bar{t}$ production:

$$\sigma_{t\bar{t}} = 6.4 \pm 9.8 \text{ (stat.)} \pm 4.0 \text{ (sys.)} \; pb$$

the sytematic error includes a 12% uncertainty in the luminosity.

This cross section is for masses between 160 and 180 GeV. As the acceptance falls moderately below 160 GeV it should be increased by 25% around 140 GeV.

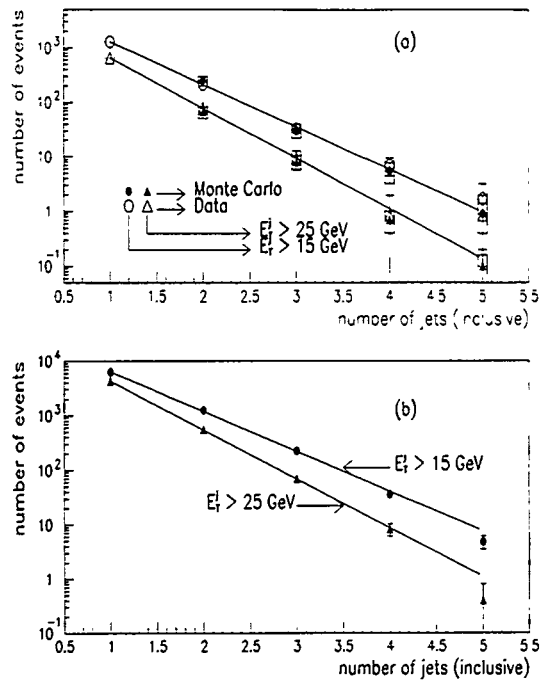

Figure 3. Number of events as function of jet multiplicity (a) $e+$jets data after non-W background subtraction and VECBOS predictions, boxes indicate uncertainty in prediction, (b) QCD sample after correcting for increased probability for triggering with increasing multiplicity.

4. $\mathcal{A}$, H_T Analysis

Another method to estimate the number of $t\bar{t}$ and $W+$jets events in the lepton + jets data is to use event shape information to discriminate between them. As the ratio of signal/background is small for jet multiplicities below 4, this analysis concentrates on events with 4 or more jets. Two parameters found to be useful discriminants are H_T, defined as the scalar E_T sum over jets with $|\eta| < 2.0$, and the aplanarity ($\mathcal{A}$), defined as 3/2 times the smallest eigenvalue of the laboratory 3-momentum tensor of reconstructed objects, normalized to unit trace. Fig. 4 shows the distribution of events in this two variables for the QCD sample, VECBOS Montecarlo, $t\bar{t}$ events with mass 180 GeV and the data. If we divide the $\mathcal{A}$, H_T into 4 quadrants using axes $\mathcal{A} = 0.05$ and $H_T = 140$ GeV we see that the QCD sample and the $W+$jets Montecarlo sample populate those quadrants more or less equally while the $t\bar{t}$ events are concentrated in the quadrant with $\mathcal{A} > .05$ and $H_T > 140$ GeV. In table 3 we give the expected fractions of $W+$jets , QCD and $t\bar{t}$ events in each quadrant. To estimate the uncertainties in the $W+$jets estimation we generated $W+$jets events in two different ways: one was to use VECBOS to generate $W+3$ jets events

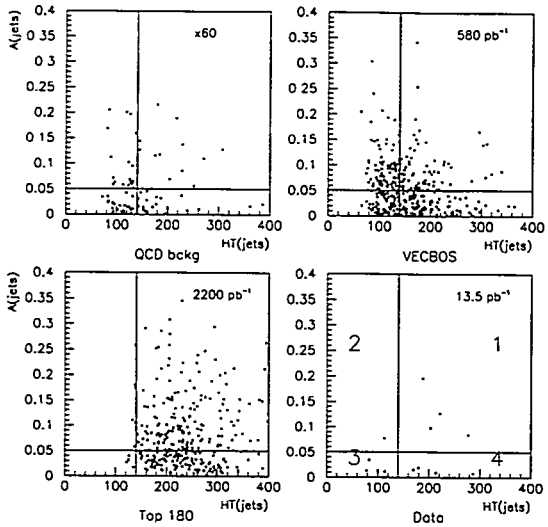

Figure 4. $\mathcal{A}$ vs H_T distributions for events with 4 or more jets: (a) QCD sample, (b) VECBOS Montecarlo, (c) $t\bar{t}$ events, top mass 180 GeV, (d) data, the quadrants used in the fit are numbered, see text.

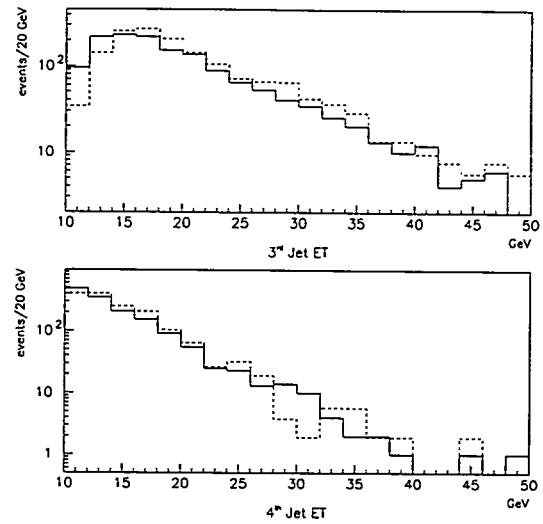

Figure 5. E_T distributions for 3rd and 4th jet in events with ≥ 4 jets starting from VECBOS with 3 jets (dotted lines) and from VECBOS with 4 jets (solid lines).

(at the parton level) and use ISAJET with those events as input to generate events with 4 or more jets. The other was to use VECBOS to generate W + 4 jets and then proceed as in the previous case. One can see from fig. 5 that both sets generate quite similar E_T distributions for the 3rd and 4th jet in events with $\geq$ 4 jets. As shown in table 3 the fractions estimated with the two different Montecarlo samples differ by less than 20%. The fractions for $t\bar{t}$ were estimated using ISAJET, comparison of ISAJET with HERWIG showed the differences to be less than 10%. Figure 6 illustrates this for $t\bar{t}$ events generated with ISAJET and HERWIG at a top mass of 140 GeV. The number of $t\bar{t}$ events in a given quadrant i ($N^i_{t\bar{t}}$) is given by

$$N^i_{t\bar{t}} = \epsilon^i_{t\bar{t}} \cdot f_{t\bar{t}} \cdot N$$

where N is the total number of observed events with 4 or more jets, $\epsilon^i_{t\bar{t}}$ is the fraction of $t\bar{t}$ expected in quadrant i and $f_{t\bar{t}}$ is the fraction of N that are $t\bar{t}$ events. The number of expected background events is then:

$$N^i_{bkg} = \epsilon^i_{bkg} \cdot (1 - f_{t\bar{t}}) \cdot N$$

where N^i_{bkg} is the number of background events in quadrant i and ϵ^i_{bkg} is the expected fraction. Given N and the ϵ's one can fit for $f_{t\bar{t}}$ using Poisson statistics. The results of the fit give $f_{t\bar{t}} = 0.32 \pm 0.30$ events in the sample of data with 4 or more jets. The numbers of observed events (in the 4 quadrants of fig. 4) are 4, 1, 3, 4 while the predicted numbers are 4.1, 2.4, 2.0, 3.5. There is a large systematic error (35%) from

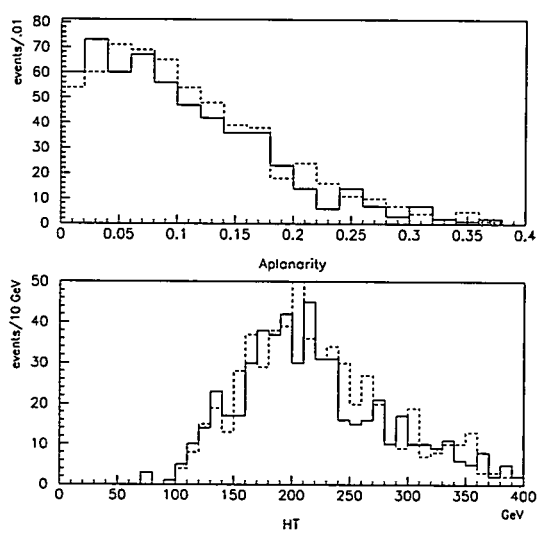

Figure 6. $\mathcal{A}$ and H_T distributions for $t\bar{t}$ events with 4 or more jets for top mass 140 GeV. Events generated by ISAJET are in solid lines, by HERWIG in dotted lines.

the choice of partitioning the $\mathcal{A}$, H_T plane, this error is estimated by moving the axes until one event falls into a different quadrant. An additional 20% systematic error is estimated for the uncertainty in calculating the fractions for each quadrant. The number of $t\bar{t}$ events estimated in the sample with 4 or more jets is thus $N_{t\bar{t}} = 3.8 \pm 3.6(stat.) \pm 1.5(sys.)$ which leads to a $t\bar{t}$ production cross section of

$$\sigma_{t\bar{t}} = 8.1 \pm 6.9(\text{stat.}) \pm 3.8(\text{sys.})\ pb$$

	ϵ^1 $\mathcal{A} > .05$ $H_T > 140$	ϵ^2 $\mathcal{A} > .05$ $H_T < 140$	ϵ^3 $\mathcal{A} < .05$ $H_T < 140$	ϵ^4 $\mathcal{A} < .05$ $H_T > 140$
VECBOS(4)	$0.21 \pm .025$	$0.27 \pm .03$	$0.21 \pm .025$	$0.31 \pm .03$
VECBOS(3)	$0.19 \pm .04$	$0.28 \pm .05$	$0.25 \pm .05$	$0.28 \pm .05$
QCD	$0.19 \pm .04$	$0.25 \pm .05$	$0.28 \pm .05$	$0.28 \pm .05$
$t\bar{t}$ 180	$0.60 \pm .05$	$0.02 \pm .01$	$0.02 \pm .01$	$0.36 \pm .04$

Table 3. Fractions in ≥ 4 jets

additional systematic errors in this estimate are the luminosity (12%), and the $t\bar{t}$ acceptance (20%). This value is in good agreement with that obtained with a totally different method in section 3.

The two methods used to estimate $\sigma_{t\bar{t}}$ can also be used as an estimate of the number of background events after applying cuts of $\mathcal{A} > .05$ and $H_T > 140$ GeV which improve the signal/background ratio by a factor of 3. For method 1 (section 3) we add the fraction of $W+ \geq 4$ jets (predicted from the fit) and the fraction non-W events, expected after cuts, to obtain $N_{bckg}(cut) = 1.8 \pm 0.75 \pm 0.40$. From the method used in this section, the background is given by $N_{bckg}(cut) = \epsilon^1_{bckg} \cdot (1 - f_{t\bar{t}}) \cdot N$ which gives $N_{bckg}(cut) = 1.7 \pm 0.8 \pm 0.5$. The two ways of estimating the background share in common only the fraction expected after $\mathcal{A}$, H_T cuts. The total amount of background to the 4 or more jets channel is estimated in one case by the fit to jet multiplicities, in the other by a fit to the $\mathcal{A}$, H_T plane. It is worth emphasizing that neither method uses the total number of $W + \geq 4$ jet events predicted from Montecarlo. We can compute the $t\bar{t}$ cross section after doing a background subtraction (averaging the background obtained with the 2 methods) to get $\sigma_{t\bar{t}} = 7.3 \pm 7.2 \pm 3.3$ pb for $m_{top} = 160 - 180$ GeV. The value should be increased by 25% for $m_{top} = 140$ GeV.

5. Conclusion

Two different ways of analyzing lepton+jets final states lead to a similar estimate of the top production cross section in $p\bar{p}$ interactions at 1.8 TeV center-of-mass energy:

$$\sigma_{t\bar{t}} = 6.4 \pm 9.8 \pm 4.0 \; pb$$

$$\sigma_{t\bar{t}} = 8.1 \pm 6.9 \pm 3.8 \; pb$$

and of the background after $\mathcal{A} > .05$, $H_T > 140$ GeV cuts:

$$1.8 \pm 0.9, \text{ and } 1.7 \pm 0.9$$

with 4 events observed.

The data shows a small excess of events above the expected background but the excess is not statistically significant. The excess above background corresponds to a top cross section of $\sigma_{t\bar{t}} = 7.3 \pm 7.2 \pm 3.3$ pb. These results should be considered preliminary.

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