Top Quark Physics at CDF

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Abstract

We present a study of the kinematics of $W+\geq 3$ jets events produced in $p\bar{p}$ collisions at $\sqrt{s}$=1.8 TeV. We find that a number of kinematic variables are sensitive to the $t\bar{t}$ contribution, and are distributed in good agreement with the expectations. Evidence for a top signal in the $t\bar{t} \rightarrow 6$ jets channel is also presented. For the first time we present a search for top dilepton events with hadronic τ decays.

1 Introduction

At the Tevatron Collider top quarks are expected to be produced primarily in pair, $p\bar{p} \rightarrow t\bar{t}$. In the framework of the Standard Model each top quark decays into a W and a b quark. The final state of a $t\bar{t}$ decay therefore has two W bosons and two b quarks.

Direct evidence of the existence of the top quark was presented by CDF [1] in early 1994. Later, in 1995, both the CDF [2] Collaboration and the D0 [3] Collaboration announced conclusive discovery of the top quark. CDF has also identified top quark production events from other kinematic studies [4]. The CDF data presented here was collected during 4 years of data taking, from 1992 to 1995, and corresponds to a larger data sample (100 pb^{-1}). A characteristic signature of the top quark is the presence of jets initiated by b quarks. CDF uses b tagging information, especially secondary decay vertices in jets, as a powerful tool to identify the presence of b quarks in the candidate events.
In this paper we study events where one of the W's decays leptonically and the other decays hadronically ("single lepton channel"), or events in which both W's decay hadronically ("all–hadronic channel"). We study new kinematic features of the events and compare them with the expected distributions from Monte Carlo. b–tagging information is used either as an event selection parameter, or to certify the top nature of kinematically top–like events.

2 Lepton+jets studies

2.1 H Analysis

Due to the large measured top mass, $t\bar{t}$ decay partons are emitted with large total transverse energy compared to other background processes. As described in [5], the scalar sum of the lepton momentum, of the transverse energy of all jets with E_T >8 GeV and $|\eta| < 2.0$, and of the transverse missing energy $\not{E}_T$, has a strong discriminating power for isolating $t\bar{t}$ events from background processes. In Figure 1(L) we show the H distribution for $W+ \geq 4$ jets events. We find 144 events in the data sample under study (100 pb^{-1}). The distribution is much harder than expected for QCD, and is well fit by a sum of simulated events with a QCD component and a large $t\bar{t}$ component (M_{top}=175 GeV/c^2). As an additional confirmation of the presence of top quarks in our data sample we identify b quarks in our events. The shaded histogram represents those events which have at least one jet identified as a b jet. As expected for top, the b tagged events have large values for H.
We performed a maximum likelihood fit to this data sample with a combination of background and $t\bar{t}$, as a function of the top mass. The best–fit likelihood values are shown in Figure 1(R). The minimum of this curve indicates a mass around 180 GeV/c^2, fully consistent with our measured value $M_{top} = 176 \pm 8(\mathrm{stat}) \pm 10(\mathrm{syst})$ GeV/c^2.

2.2 W decays in top candidates

An even stronger proof that b tagged events are due to top quark pairs requires the identification of both W bosons in the events. We can reconstruct the hadronically decaying W using $W+ \geq 4$ jets events when two jets are b tagged. The two non–tagged jets should be the W decay products.

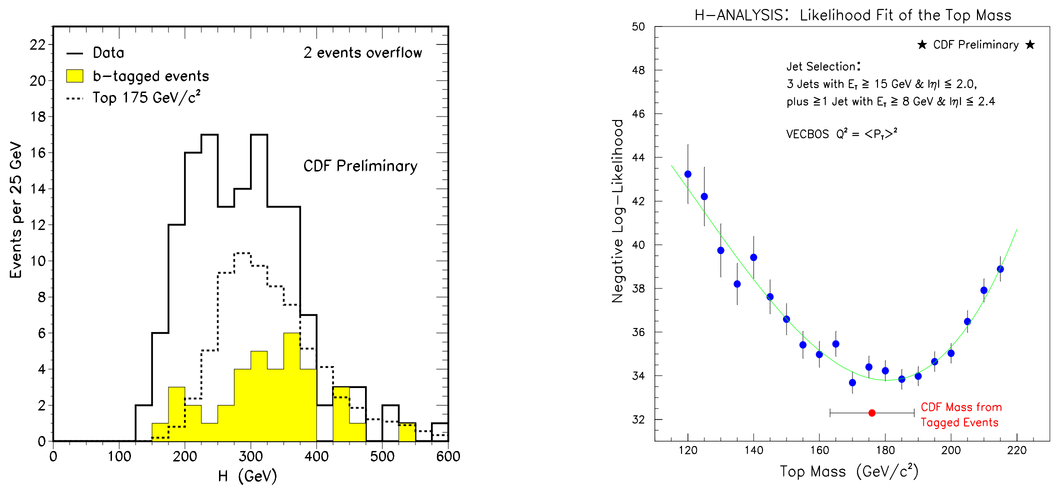

Figure 1: Left (L): H distribution of the W+$\geq$4 jets data. Solid line is data, dashed line expectation from $t\bar{t}$ Monte Carlo, shaded area are b tagged events. Right (R): Likelihood fit of data to Monte Carlo (QCD+$t\bar{t}$) as a function of the top mass.

Ten events are in our final sample. In the upper plot of Figure 2 we show the invariant mass spectrum of the two untagged jets. In the middle and lower plots we show the dijet invariant mass when using only one b tagged jet and the two tagged jets, respectively.
A peak in the dijet mass spectrum around 80 GeV can be observed in the untagged jet sample. Assuming a flat distribution, as for b tagged dijet events, the probability to obtain such a peak by statistical fluctuation is approximately 3.5 σ.

3 All hadronic channel

Hadronic decays of both W's in $t\bar{t}$ events have the highest branching ratio (44%). The final state has 6 jets: 4 jets are due to the 2 W's and the 2 jets come from the b quarks. The signal/background (S/B) ratio is very small at the trigger level since the QCD multijet background is overwhelming. To achieve a significant improvement in S/B ratio we combine kinematic and b tagging selection. The analysis described here is based upon a data sample of 85 pb^{-1}.
The final $t\bar{t}$ state is characterized by central jets with large transverse energy. To maximize the purity of the $t\bar{t}$ events in our data sample we use kinematic quantities and select events by requiring:

- $N_{jet} \geq 6$, where N_{jet} is the number of jets with $E_T > 15$ GeV and $|\eta| < 2.0$ with minimum separation between jets in (η, ϕ), $\Delta R_{jj} \geq 0.5$;
- $\Sigma E_T > 130 + 15 \times N_{jets}$, where ΣE_T is the sum of the transverse energy of all the jets;
- $\Sigma E_T/\sqrt{\hat{s}} \geq 0.75$;
- A$>$ $(-0.003 \times \Sigma_3^N E_T + 0.45)$, where A is the aplanarity.

The total acceptance of this selection is 7.4$\pm$0.2(stat)% for M$_{top}$=175 GeV/c^2. In addition to the kinematical selection, we also require at least one SVX b tagged jet (with $E_T > 25$ GeV) in

Selection	N_{obs}	N_{exp}	$N_{obs}-N_{exp}$
$N_{jets} \geq 6$	446 (473)	403 (431.5)	43 (41.5)
All cuts	62 (69)	42.9 (45.3)	19.1 (23.7)

Table 1: Preliminary results from the top search in the all hadronic channel. Left, number of b tagged data events (tags); center, expectation for background; right, excess over background.

our final selected sample. The sample has a ratio S/B$\approx$1/20, which becomes S/B$\approx$1/2 after b tagging. b–tags can also be produced by mistags and by heavy–flavours in generic jets. We can define the background tagging rate as the ratio between the tagged jets in a generic jet sample and all the taggable jets, i.e. those jets contained in the SVX acceptance. Prior to any selection, we can thus measure this rate in multijet events as a function of the jet E_T. We then compute the expected background in our top candidate sample by applying the parametrized rate to the jets in the sample. In a "counting experiment", the excess of b tagged events in the sample can be attributed to $t\bar{t}$ events. Results are shown in Table 1. The probability that the excess is due only to a background fluctuation is 3.3×10^{-3} (2.9 σ). We attribute the excess to top production and we calculate the cross section to be $\sigma_{t\bar{t}} = 9.7 \pm 3.3(\text{stat})$ pb. The systematic error is under study and is estimated to be of the order of 30%. Events with six jets can be reconstructed to fit the all–hadronic $t\bar{t}$ hypothesis. Momentum conservation is required and the mass of the t and $\bar{t}$ are constrained to be equal. Some of the tight kinematical cuts adopted in the previous counting experiment would bias the mass reconstruction and therefore we loosen them. The running ΣE_T jet cut is modified to a fixed, less stringent cut at $\Sigma E_T \geq 150$ GeV and the b tagged jet is required to have only E_T >15 GeV. The total acceptance of this relaxed data selection is computed to be 8.6$\pm$0.4(stat)% for M_{top}=175 GeV/c^2. In Figure 3 we show a comparison between the invariant mass spectrum for the b tagged events and the background spectrum obtained from the data sample before b–tagging. The mass spectrum is fit to a gaussian for the $t\bar{t}$ signal plus a function which describes the background. The best–fit top mass agrees qualitatively well with the expectations.

4 Top dileptons with hadronic tau decays

We also present a new search for $t\bar{t}$ dilepton events with one electron or muon and one additional hadronically decaying tau lepton [6]. Hadronic tau decays are identified using tracking and calorimeter quantities. We use kinematical variables to isolate $t\bar{t}$ events by requiring:

- $N_{jets} \geq 2$, where N_{jets} is the number of jets at $|\eta| < 2.0$ and $E_T > 10$ GeV;
- H >180 GeV;
- $\sigma_{\not{E}_T}$ >3 (GeV)$^{1/2}$, where $\sigma_{\not{E}_T}$ is the significance of the missing transverse energy $\not{E}_T$.

The branching ratio for $e\tau$ and $\mu\tau$ events is 4/81, i.e. the number of dilepton events could be doubled including tau decays in the dilepton analysis. However, the B.R. for hadronic τ decays

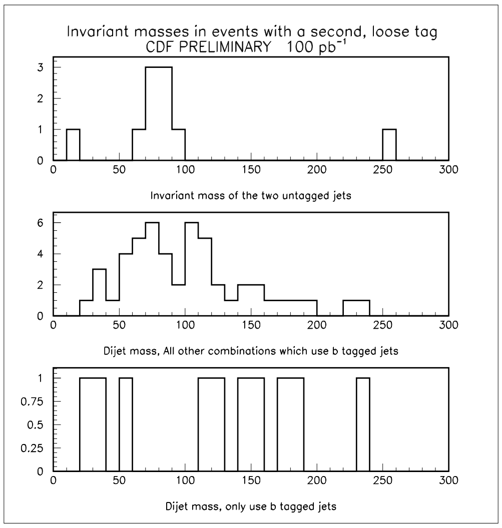

Figure 2: Dijet mass distributions for the $W+\geq 4$ jets events: for the two untagged jets (upper plot), using only one b tagged jet (middle plot), for the two b tagged jets (lower plot).

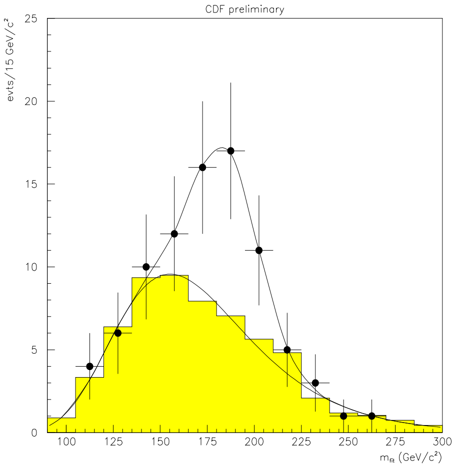

Figure 3: Fitted top mass distribution in the all–hadronic channel. Points with error bars are b tagged data events. Shaded area is the expected background.

is about 64% and each τ decay involves an undetectable neutrino. This means that the total acceptance is considerably smaller than for the standard dilepton decays. We look for high–P_T isolated tracks (P_T >15 GeV/c). To perform the τ identification we use primarily the tracking isolation (I_{trk} <1 GeV/c) in a cone ΔR=0.4 as a powerful way to discriminate beween signal and background. Furthermore, using calorimeter information, we discriminate taus from electrons and muons by rejecting highly electromagnetic calorimeter clusters and minimum ionizing particles, respectively. Within these selection criteria the τ–id efficiency is 59±4%. We call this method a "track–based" τ algorithm. The total acceptance is (0.088±0.010)% for M_{top}=175 GeV/c^2. In 110 pb^{-1} of data we expect approximately 1 signal event. We observe 4 candidate events with a total background of 0.89±0.22 events. We find that three of these events are b tagged.

Decays of τ leptons often produce neutral pions. We can thus use calorimeter informations to identify π°'s. We can add to the previous selection a search for the photons from the decay $\pi^\circ \rightarrow \gamma\gamma$ in the electromagnetic shower detector. Using this method we can also extend the search to three–prongs decays of τ leptons. The τ–id efficiency becomes 51±3%.

We call this method a "calorimeter–based" τ algorithm. The total acceptance of this selection is (0.119±0.014)% for M_{top}=175 GeV/c^2. The expected background is 1.96±0.35 events. Although this search includes one and three–prongs τ decays, we do not find any additional event. We observe the same 4 candidate events as in the track–based method.

A first measurement of the $t\bar{t}$ cross section based on these events yields $\sigma_{t\bar{t}} = 15.6^{+18.7}_{-13.2}(32.1^{+25.4}_{-17.7})$ pb using the calorimeter (track) based τ algorithm. Due to the large statistical error, this value is fully consistent with our best estimate for the top cross section, $\sigma_{t\bar{t}} = 7.6^{+2.4}_{-2.0}$ pb.

In order to reduce the background we can repeat this analysis and calculate the S/B, when requiring the presence of at least one b tagged event. We expect 0.23$\pm$0.01 events from background and find 3 b tagged events. The probability for the background to fluctuate to the 3 observed events is 0.13% (3 σ).

5 Conclusions

We observe an excess of W + jets events with large total transverse energy H as expected from a $t\bar{t}$ component in the sample. We also observe a large content of b quarks in these $t\bar{t}$ candidate events.

In events with two b tagged jets, we reconstruct a dijet invariant mass peak at about the W mass for the untagged jets.

Evidence for $t\bar{t}$ in the all–hadronic channel is also presented here. After tight kinematical cuts and b tagging, events are fit to the $t\bar{t}$ hypothesis, and a top mass distribution is obtained that evidentiates a signal consistent with $t\bar{t}$ production. The cross section and the estimated top mass are consistent with the values previously published by CDF.

We have also presented the first measurement of the top quark production cross section based on top dilepton events with hadronic τ decays.

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