NEW OBSERVATIONS OF TOP AT CDF

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We report preliminary results from the analyses looking for top candidates in the channel with 6 jets in the final state (all hadronic) and in the dilepton channel with one tau lepton (τ dilepton), using a data sample of about 110 pb$^{-1}$ collected by the CDF experiment.

1 Introduction

After the first direct evidence for the top quark presented by CDF in 1994, the top quark discovery was announced by the CDF and D0 Collaborations in the early 1995. The channels with at least one lepton (electron $e$ or muon $\mu$) in the final state have been used for those studies.

After the top discovery, CDF focused to obtain a better understanding of the top quark properties and searched for a top signal in the other decay channels. This paper describes some preliminary studies that isolated a top signal in the all hadronic mode and in the dilepton channel with a τ lepton in the final state. A data sample of $\approx 110$ pb$^{-1}$ has been used, corresponding to the full statistics collected between 1992 and 1995.

In the all hadronic channel both $W$’s from top decay to hadrons:

$$t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow (q\bar{q}')(b(q\bar{q}'))\bar{b}.$$  

The branching ratio is the largest of all top decays ($\approx 44\%$). The final state has a 6 jets topology, with two jets coming from $b$ quarks. In principle the two top quarks could be fully reconstructed because there are no neutrinos in the event. However, there is a huge QCD multijet background, orders of magnitude bigger than the signal, which includes real heavy flavor production through various processes.

Concerning the dilepton channel where one $W$ decays to a τ lepton and the other one to an $e$ or $\mu$, it represents 5% of the total $t\bar{t}$ decay, exactly like the standard dilepton channels originally used for top search. We look for τ’s in their hadronic decay:

$$t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow \epsilon(\mu)\nu_{\epsilon(\mu)}\tau_{\nu_{\epsilon(\mu)}b\bar{b}}, \ \tau \rightarrow hadrons + \nu_{\tau}.$$  

Compared to the other dilepton modes, this channel has a considerable background from jets misidentified as τ’s.

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The goal of the analysis in the all hadronic channel is to drastically reduce the background while keeping an efficiency as high as possible for \( t\bar{t} \) detection. The strategy consists in first making a kinematic selection and then requiring the presence of \( b \) quarks in the events. The starting sample is made of approximately 230,000 events, collected by a trigger requiring at least 4 jets reconstructed in a cone of radius \( R = 0.4 \) in the \( \eta - \phi \) space, with transverse energy \( E_T \geq 15 \) \( \text{GeV} \) and pseudorapidity \( |\eta| \leq 2 \). The signal over background ratio \((S/B)\) at the trigger level is about 1/1000.

![Figure 1](image-url)  
Figure 1: Left (L): Number of SVX tags as a function of jet multiplicity, compared with the expectations from background. Right (R): \( b \)-tagged jet \( E_T \) distributions.

### 2.1 Kinematic selection and \( b \) tag

Top signal events are expected to have a higher jet multiplicity, to be more central and to have a larger aplanarity than QCD background events. The selection starts by requiring a high jet multiplicity \((N(\text{jets}) \geq 5)\). We then cut on some global calorimetric variables like the total transverse energy of jets \((\sum E_T \geq 300 \text{ GeV})\), the fraction of transverse energy \((\sum E_T / \sqrt{s} \geq 0.75)\) and the aplanarity \((\text{Apl} \geq -0.0025 \times \sum_3^N E_T + 0.54\), where the sum does not include the contribution from the 2 leading jets\). The cuts have been chosen at the values which maximize the \( S/B \) significance. After this kinematic selection, \( S/B \approx 1/30 \). The resulting data sample is still dominated by multijet production from QCD processes.
The requirement of at least one secondary vertex (SVX) $b$-tag helps to further increase $S/B$ and extract a signal. Besides from $t\bar{t}$ events, $b$-tags can come from real heavy flavor production and from tracking mismeasurements. The tagging rate, defined as the number of tagged jets divided by the number of taggable jets, has been parametrized as a function of $E_T(jet)$, $\eta(jet)$, number of SVX tracks associated with a jet and $Ap(jet)$. It has been calculated using a sample of events collected with a multijet trigger. This parametrization is found to describe well the jet multiplicity distribution of observed tags in multijet events.

The sample selected with these characteristics consists of 192 events, containing 230 $b$-tagged jets. The number of tagged jets expected from background is $160.5 \pm 10.4$ tags. Fig. (L) shows the number of tags as a function of jet multiplicity. The rectangles represent the background estimate from tag rate parametrization with systematic and statistical uncertainties. There is an excess of tagged jets in the jet multiplicity bins $N = 5, 6$ and $\geq 7$. The significance of the excess is estimated from the probability that the background fluctuates up to the number of found tags or greater. We found a $P = 1.5 \times 10^{-4}$, corresponding to a 3.6$\sigma$ for a gaussian distribution (the effect of multiple tags is included in the calculation). Fig. (R) shows the comparison between the $E_T$ spectra of the tagged jets in the data (black dots) and of the estimated background (shaded histogram). The white histogram is the sum of the background and $t\bar{t}$ contribution.

2.2 Cross section evaluation

The cross section is evaluated, under the assumption of $t\bar{t}$ production in the data, using the observed number of candidate $b$-tagged events, the expected background corrected for the presence of top events in the sample and the kinematic and $b$-tagging acceptances. Fig. (L) shows the $t\bar{t}$ production cross section as a function of the top mass. The solid line represents the all hadronic data measurement, the dashed lines the $\pm$ global uncertainty. The main contributions to the systematic uncertainty come from the jet energy scale and from the choice of the fragmentation and gluon radiation modeling. The result is consistent with the CDF measurements from leptonic channels. Using the acceptance of the kinematic requirements for $M_{top} = 175$ GeV/$c^2$ we measure the production cross section to be $\sigma_{HAD}^{t\bar{t}} = 10.7^{+7.6}_{-4.0}$ pb.

2.3 Mass determination

A kinematic reconstruction of the mass is applied to a sub-sample of events with 6 or more jets, selected with a looser kinematic set of cuts. A maximum
likelihood method is used to extract the top mass value. The minimum is found at $M_{\text{top}} = 187 \pm 8 \text{ (stat.)} \pm 13 \text{ (syst.) GeV}/c^2$. Fig. 2(R) shows the reconstructed top quark mass for the $b$-tagged events. The black dots are the data, the shaded histogram indicates the background shape and the white histogram is the sum of background and $t\bar{t}$ contribution, assuming $M_{\text{top}} = 175 \text{ GeV}/c^2$. The background is normalized to the estimate from the tag rate. For more details on the mass determination we refer to another contribution to this Conference.

3 Double tags study

In the same channel a second analysis has been performed, with a different approach to the isolation of a $t\bar{t}$ signal. Starting from the same sample, we require the presence of a second $b$ tag in the events satisfying $\sum E_T \geq 300 \text{ GeV}$. All the physics processes that can result in $\geq 2$ heavy flavor quarks in the final state have been studied. The dominant sources of background are mistags and QCD heavy flavor pair production. In four jet events, where the
top contribution is expected to be negligible, these two processes describe well the data. In the events with a higher jet multiplicity, an excess is observed which requires the presence of a $t\bar{t}$ component in order to be explained. To enhance the significance of the excess we use three kinematic variables that have different distributions for signal and background: the azimuth difference between the two $b$ tags ($\Delta \phi(b\bar{b})$), the separation in $\eta-\phi$ space ($\Delta R(b\bar{b})$) and the invariant mass of the two $b$ jets. From a combined fit of these distributions we obtain a $t\bar{t}$ production cross section $\sigma_{H\text{AD}}^{t\bar{t}} = 7.1^{+4.8}_{-3.5}$ pb (preliminary uncertainty estimate), consistent with the value found in the previous analysis.

4 $\tau$ dilepton channel

The first motivation for investigating this channel is to test the Standard Model prediction. In addition, opening a new channel is a way to increase the acceptance for top quark decay, especially in the dilepton channel, which has a small branching ratio.

The hadronic branching ratio of $\tau$ decays is $\approx 64\%$. Each $\tau$ decay involves an undetectable neutrino, which decreases the kinematic acceptance for the $\tau$ decay products. The $\tau$ identification is not as efficient as for $e$ and $\mu$, if we want to keep under control the background from jets. The total acceptance for $\tau$’s is therefore smaller than for standard dileptons.

In the past, an algorithm to identify hadronically decaying $\tau$’s was used to study lepton universality in $W \rightarrow \tau \nu$ decays. Top dileptons with hadronic $\tau$’s were previously searched for in a smaller data sample. Now we present the first evidence of a top signal in the $\tau$ dilepton channel obtained using the full data sample.

4.1 Event Selection

The primary lepton is selected as in the standard dilepton analysis. $Z \rightarrow l^+l^-$ events are removed using tracking and calorimeter information. We require at least 2 jets with $E_T \geq 10$ GeV. Additional background rejection is obtained cutting on the total transverse energy $H_T$ of the events ($H_T \geq 180$ GeV) and on missing $E_T$ significance ($\sigma_{E_T} = E_T/\sqrt{\sum E_T} (\sum E_T/P_T^{\tau}) \geq 3$ GeV$^{1/2}$ for $e\tau$ ($\mu\tau$)). Due to the softer $P_T$ spectrum for $\tau$ decay products, we increase the acceptance requiring $P_T(\tau) \geq 15$ GeV, $|\eta_{\tau}| \leq 1.2$. We impose the $\tau$ candidate tracks to be isolated and reject tracks associated to a calorimeter energy deposition consistent with coming from an $e$ or $\mu$. For more details on the variables used for $\tau$ identification, we refer to.
Figure 3: $\sigma_{E_T}$ versus $E_T$ distribution for $\tau$ dilepton events. Top: after identifying a primary $e$ ($\mu$) and a $\tau$. Center: after requiring $\geq 2$ jets. Bottom: $\geq 2$ jets and $H_{\tau} \geq 180$ GeV. The line represents the $\sigma_{E_T}$ cut, applied in the plots on the right. Events containing $b$ tags are labeled $SECVTX$: secondary vertex tag or $SLT$: soft lepton tag. (CDF preliminary).

4.2 Backgrounds estimate

The main background comes from generic jets. There is a small probability for a jet to fragment with a low track multiplicity and to be identified as a $\tau$ candidate. Leptonically decaying $W + \geq 3$ jets, where one jet is misidentified as a $\tau$, would give a fake $\tau$ dilepton event. We obtain the probability for a jet to be wrongly identified as a $\tau$ from a sample of generic jets, making the assumption that jets in $W + \geq 3$ jets behave the same as generic jets. We parametrize this probability as a function of $E_T(jet)$. We then apply this parametrization to the $W + \geq 3$ jet sample and obtain the background expectation from fakes. The physics background is evaluated using Monte Carlo simulations and data.
4.3 Observation in the data

The selection yields 4 candidate events: 2 eτ and 2 µτ. Three of them are b-tagged. The expected background amounts to 1.96 ± 0.35 events. Fig. 3 shows the $\sigma_{E/T}$ as a function of the $E/T$ for events passing all the other cuts. A first measurement of the $t\bar{t}$ production cross section based on these events yields $\sigma_{t\bar{t}} = 15.6^{+18.6}_{-13.2} (\text{stat.})$ pb. Studies of systematic errors are in progress.

5 Conclusion

We reported evidence for $t\bar{t}$ production in the all hadronic channel and in the $\tau$ dilepton channel. The cross section and mass measured in the hadronic mode agree with the values previously measured from leptonic channels. The observation established in the $\tau$ dilepton channel confirms the Standard Model predictions and increases the sample of dilepton candidates by including four additional events.

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