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CDF

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TOP PRODUCTION AND DECAY AT CDF

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(For the CDF Collaboration)

We report on the measurement of top production and decay properties obtained by the CDF experiment with $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The analyses presented here refer to $\int \mathcal{L}dt \approx 110\ pb^{-1}$) collected at the Fermilab Tevatron collider. About 85% of the possible $t\bar{t}$ decays have been studied in different channels according to the number of high-p_T leptons found in the final state. Combining the results from the channels with at least one W decaying leptonically into an e or μ we measure $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}$ pb. We report also on the observation of $t\bar{t}$ production in the all hadronic decay channel using kinematic selection and b identification, and in the channel containing one hadronically decaying τ lepton. Finally we discuss the kinematics of top events and measure the matrix element $|V_{tb}| = 1.12 \pm 0.12$.

1 Introduction

Following a first evidence presented by CDF in 1994[1], the top quark has been discovered by the CDF and D0 collaborations in 1995[2,3] using a larger data sample of $\int \mathcal{L}dt = 67\ pb^{-1}$. Here we report the results obtained with $\int \mathcal{L}dt = 109 \pm 7.2\ pb^{-1}$, out of 115 pb^{-1} collected between 1992 and early 1996.

In $p\bar{p}$ collision at $\sqrt{s} = 1.8\ TeV$, the dominant process for a high-mass top production is $q\bar{q} \rightarrow t\bar{t}$. In the Standard Model, top decays almost exclusively ($|V_{tb}| \approx 1$) into Wb, so the final state is classified according to the decay mode of the W boson by counting the number of high-p_T leptons.

CDF has studied the following channels:

- dilepton: both W's decay leptonically (to e or μ) ;
- single lepton plus jets: one W decays leptonically (to e or μ) the other goes into $q\bar{q}'$;
- all hadronic: both W's decay into quark pairs;
- τ dilepton: both W's decay leptonically, one to e or μ while the other goes $W \rightarrow \tau\nu_\tau$, the τ decaying into hadrons.

Using these samples, CDF derives a measurement for the top production cross section (which is presented here) and a measurement of its mass (subject of a different talk).

Besides these major topics, CDF studies the kinematic properties of top decays in order to check their consistency with the Standard Model. An additional measurement presented here is that of the Cabibbo–Kobayashi–Maskawa matrix element V_{tb}.

2 Dilepton analysis

The event selection requires two central and isolated leptons (e or μ only) oppositely charged, with $E_T^e \geq 20\ GeV$ or $p_T^\mu \geq 20\ GeV/c$, large missing transverse energy to account for the undetected neutrinos ($\not{E}_T \geq 25\ GeV$), and two central and energetic jets ($E_T \geq 10\ GeV$). $Z \rightarrow \ell\ell$ events are rejected with a cut on the lepton pair invariant mass. Further background rejection is provided by a topological cut on the angular separation between the $\not{E}_T$ direction and the direction of the closest object, either a lepton or a jet when $\not{E}_T \leq 50\ GeV$. Following this selection, we remain with 10 candidates: respectively 7 $e\mu$, 2 $\mu\mu$ and 1 ee, in agreement with the relative acceptances. The total background, amounting to 2.1 ± 0.4 events, is dominated by Drell–Yan, $Z \rightarrow \tau\tau$ decays, fake leptons and WW events.

With a total acceptance for $m_{top} = 175\ GeV/c^2$ of (0.77 ± 0.08)%, the measured $t\bar{t}$ production cross section amounts to $\sigma_{t\bar{t}}(DIL) = 9.3^{+4.4}_{-3.4}$ pb.

3 Lepton plus jets analysis

For this analysis we require a single, high-p_T lepton (e or μ), large $\not{E}_T$ ($\not{E}_T \geq 20\ GeV$) and at least three energetic jets ($E_T \geq 15\ GeV$) in the

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central region. We remove events consistent with $Z \to \ell\ell$ decays and events satisfying the dilepton requirements. The acceptance for such selection is $(9.94 \pm 0.95)\%$ plus $(92 \pm 9)\%$ for the trigger (evaluated for $m_{top} = 175\ GeV/c^2$).

In order to improve the $W + jets$ background rejection we ask for at least one b jet in the event using two different identification tagging techiques. One (SVX tagging) searches for displaced vertices using the high spatial resolution of the CDF silicon vertex detector SVX: its tagging efficiency on $t\bar{t}$ events is $41 \pm 4\%$. The other one (called SLT for *soft lepton tagging*) is based on the identification of low p_T leptons (e or μ) coming from the semileptonic b decays: the efficiency for having at least one tag in a $t\bar{t}$ event amounts to $20 \pm 2\%$.

We count 34 observed events with an SVX tag. The corresponding background amounts to 7.96 ± 1.37 events, coming mainly from $Wb\bar{b}$, $Wc\bar{c}$, $b\bar{b}$ events and fake tags. The total acceptance amounts to $(3.52 \pm 0.65)\%$ (evaluated for $m_t = 175\ GeV/c^2$) and we measure a top production cross section $\sigma_{t\bar{t}}(SVX) = 6.8^{+2.3}_{-1.8}\ pb$.

SLT tags 40 events with a total background of 24.3 ± 3.5 events. This background is dominated by events with fake leptons, $Wb\bar{b}$, $Wc\bar{c}$ and Drell–Yan events. Using a total acceptance of $(1.73 \pm 0.28)\%$ we measure a production cross section $\sigma_{t\bar{t}}(SLT) = 8.0^{+4.4}_{-3.6}\ pb$.

4 All hadronic analysis

The all hadronic final state represents a large fraction of the branching ratio ($\approx 44\%$), but the search for top in such channel is a very challenging task due to the huge QCD background, orders of magnitude bigger than the signal.

A multijet dedicated trigger selects 230,000 events with at least four jets with $E_T \geq 15\ GeV$: at this level the S/B is about 1/1000. Applying a tight kinematical selection we manage to strongly reduce the background while maintaining a reasonable efficiency on the signal. We begin requiring high jet multiplicity (≥ 5 jets with $E_T \geq 15\ GeV$ and $|\eta| \leq 2$) and large total transverse energy $\sum E_T \geq 300\ GeV$, "centrally" deposited in the detector ($\sum E_T/\sqrt{\hat{s}} \geq 0.75$). Additional separation between top and background events is obtained by a cut on the aplanarity–$\sum E_T$ space ($\mathcal{A} + 0.0025 \times \sum E_T \geq 0.54$, where the energy sum does not include the 2 leading jets).

This kinematical selection is not enough and we need the requirement of at least one SVX b–tag. We observe 230 tagged jets with a background of 160.5 ± 10.4 from QCD heavy flavor production and mistags. The probability that such number of tags observed is purely due to a background fluctuation is $\mathcal{P} = 1.5 \times 10^{-4}$ (3.6σ).

The number of events with at least one SVX tag is 192 with a corresponding background of 137.1 ± 11.3 events. The acceptance for the kinematical requirements for $m_{top} = 175\ GeV/c^2$ amounts to $(9.9^{+3.0}_{-3.5})\%$, while the b–tagging efficiency in this channel is $(47.2 \pm 4.7)\%$. We measure the production cross section to be $\sigma_{t\bar{t}}(HAD) = 10.7^{+7.6}_{-4.0}\ pb$.

This channel has not been combined yet with the others because the correlations between the hadronic final state and the single/double lepton ones are still under study.

5 τ dilepton analysis

In this case one lepton (e or μ) is selected as in the dilepton case described above, while the other one is required to be identified as a τ with hadronic decay. The τ identification requires a narrow calorimeter cluster with a low multiplicity of associated charged tracks. Such a cluster must have $p_T^\tau \geq 15\ GeV/c$, and we ask for at least 2 additional jets with $E_T \geq 10\ GeV$. There is an explicit removal of $Z \to \ell\ell$ events based on tracking and calorimeter information, and additional background rejection is obtained with a cut on the $\mathcal{H}_T$ variable[a] of the event, $\mathcal{H}_T \geq 180\ GeV$, and on the $\not{E}_T$ significance[b] $\sigma(\not{E}_T) \geq 3\ GeV^{\frac{1}{2}}$.

The selection isolates 4 candidate events, with an expected background of 1.96 ± 0.35 events. Given the acceptance of $(0.119 \pm 0.014)\%$ (for $m_{top} = 175\ GeV/c^2$) we have a preliminary evaluation of the cross section of $\sigma_{t\bar{t}} = 15.6^{+18.6}_{-13.2}\ pb$ where the uncertainties are statistical only.

6 Combined cross section

The three measurements in the dilepton and single lepton channels are combined together into a sin-

[a] Defined as the sum of the leptons p_T, the $\not{E}_T$ and the jet $E_T^{\prime}s$.

[b] Defined as $\sigma(\not{E}_T) = \not{E}_T/\sqrt{\sum E_T}$.

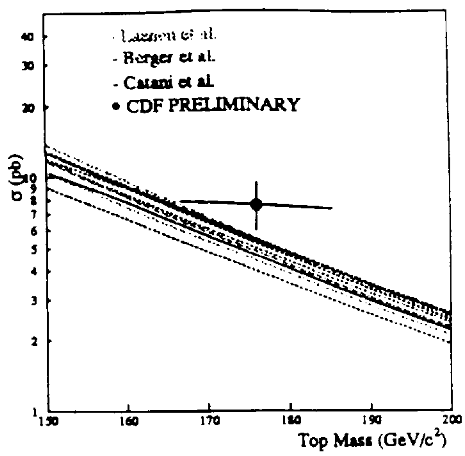

Figure 1: *CDF combined cross section compared with some of the most recent theoretical calculation*

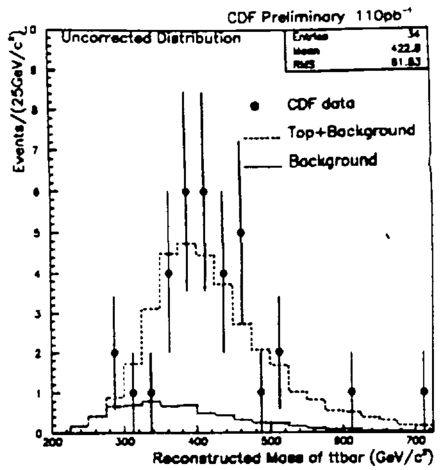

Figure 2: *Distribution of $M(t\bar{t})$ for the tagged mass sample.*

gle cross section measurement, taking into proper account all the correlations. Assuming a top mass of 175 GeV/c^2 (as measured by CDF) we obtain:

$$\sigma_{t\bar{t}}(DIL, SVX, SLT) = 7.5^{+1.9}_{-1.6}\ pb$$

In fig.1 is reported the CDF measurement compared with some of the most recent theoretical calculation [4,5,6]. The horizontal error bar indicates the uncertainty on the mass measured by CDF, while its tilt represents the change in the central value of cross section due to the dependence of the acceptance on the top mass.

Table 1 summarizes the cross section measurement obtained in all the individual channels.

7 Kinematic distribution of the $t\bar{t}$ system

The sample used for the measurement of the top mass is a portion of the lepton plus jets data set with the additional requirement of at least four jets, with the E_T threshold on the fourth jet lowered to 8 GeV. Kinematical properties of the $t\bar{t}$ system (other than the top mass) are compared with the expectation from the Standard Model. We define two samples: one before b–tag (153 events), one for event with at least one SVX or SLT tag (34 events). The background in the first sample amounts to 98 ± 11 events, while in the tagged sample amounts to $6.4^{+2.1}_{-1.4}$ events. Each event is kinematically constrained to the $t\bar{t}$ hypotesis assuming the tagged jet to be one of the b partons. From the fit we extract several kinematical quantities of the $t\bar{t}$ system, but, for the time being, we work with ***observed*** variables, biased by detector resolution, selection cuts and the fitting algorithm, instead of the ***true*** ones. These quantities are then compared with those expected from Monte Carlo events ($t\bar{t}$ plus background). This is not only an important check of the consistency of the $t\bar{t}$ production properties with the Standard Model but can also evidentiate effects of non-standard $t\bar{t}$ pair production. As an example of this consistency check we show in fig.2 the distribution in the tagged sample of the invariant mass of the $t\bar{t}$ system. No discrepancy with respect to the Standard Model predictions is observed in this and in all the other variables studied.

8 Decay properties: measurement of $|V_{tb}|$

The fraction $B = \frac{BR(t\to W+b)}{BR(t\to W+q)} = \frac{|V_{tb}|^2}{|V_{td}|^2+|V_{ts}|^2+|V_{tb}|^2}$ of top decaying to bottom has been determined from the ratio of b–tagged and untagged events. Two samples have been used[c]: a W+jet sample (68 events, 10 with one tag, 5 with two tags), in which the top content has been enhanced by cuts on kinematical variables (similar to those of ref. 7), and the standard dilepton sample (7 events, 2 with one tag), much cleaner. The two samples are orthogonal and the results are combined in a single measurement of B.

From the number of untagged, single and double tagged events, background estimates, acceptances and tagging efficiency, we derive a likelihood function in which B is a free parame-

[c]Referring to only 90 pb^{-1}.

Table 1: *Summary of the individual channels. All acceptances are evaluated for* $m_{top} = 175\ GeV/c^2$.

Channel	$Acceptance(\%)$	N_{bkg}	Data	$\sigma_{t\bar{t}}(pb)$
DIL	0.77 ± 0.08	2.1 ± 0.4	10	$9.3^{+4.4}_{-3.4}$
SVX	3.52 ± 0.65	7.96 ± 1.37	34	$6.8^{+2.3}_{-1.8}$
SLT	1.73 ± 0.28	24.3 ± 3.5	40	$8.0^{+4.4}_{-3.6}$
HAD	$4.7^{+1.5}_{-1.7}$	137.1 ± 11.3	192	$10.7^{+7.6}_{-4.0}$
τ-DIL	0.119 ± 0.014	1.96 ± 0.35	4	$15.6^{+18.6}_{-13.2}(stat)$

ter. The maximum of this function is obtained for $B = 1.23^{+0.37}_{-0.31}$, where the uncertainty quoted is mainly statistical. Under the assumption of three generation unitarity, we derive the value of the Cabibbo–Kobayashi–Maskawa matrix element $|V_{tb}| = \sqrt{B} = 1.12 \pm 0.12$ or $|V_{tb}| > 0.78$ (95% C.L.). If we remove the unitarity constraint and use the available estimates for V_{td} and V_{ts} we obtain the limit $|V_{tb}| > 0.05$ (95% C.L.)

9 Conclusions

We have reported the results obtained in 110 pb^{-1} of data collected with the CDF detector, considering several decay channels for a total $B.R.$ of 85%.

We have measured the top production cross section using the dilepton and single lepton channels to be $\sigma_{t\bar{t}}(DIL, SVX, SLT) = 7.5^{+1.9}_{-1.6}\ pb$.

Furthermore, evidence for $t\bar{t}$ production in the all hadronic channel has been presented, with a measured cross section in agreement with $\sigma_{t\bar{t}}(DIL, SVX, SLT)$.

We have also presented a preliminary evidence for $t\bar{t}$ production in the τ-dilepton channel.

For a deeper understanding of top properties we have compared some kinematic distributions of the $t\bar{t}$ system with the Monte Carlo predictions. The results are still preliminary, but a good consistency is seen between the data and the Monte Carlo.

Finally, we have made a preliminary measurement of the Cabibbo–Kobayashi–Maskawa matrix element $|V_{tb}| = \sqrt{B} = 1.12 \pm 0.12$

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