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CDF

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We present the CDF results relative to the observation of the top quark and its properties obtained with 100 pb^{-1} of data collected in the period 1992-1993 and 1994-1995. Updated results of the counting experiments are given, and consistency between this data and earlier published mass and cross section is shown.

1 Introduction

The top quark is required in the Standard Model as the weak-isospin partner of the b quark. Its existence was indirectly proven by studying flavour changing neutral currents and forward-backward asymmetry in $b\bar{b}$ events [1,2].

CDF announced direct evidence for $t\bar{t}$ production in $\bar{p}p$ collisions in 1994 [3], based on 19.7 pb^{-1} collected at the Tevatron collider at c.m.s. energy of $\sqrt{s}$ =1.8 TeV.

In early 1995 both CDF [4] (using 67 pb^{-1}) and D0 [5] announced the observation of the top quark, confirming CDF previous result. Here we present the CDF results based on a larger data set of 100 pb^{-1}.

Top production at Tevatron mainly proceeds through $q\bar{q}$ annihilation, this channel being responsible for $\simeq$ 90 % of the (predicted) S.M. cross section. A top quark decays into a real W and a b quark. It is customary to classify $t\bar{t}$ events by looking at the W decay. If both W's decay leptonically in $e\nu$ or $\mu\nu$ the event is classified as *dilepton*. If one of the two W's decays through one of its hadronic modes into quarks (which are identified as *jets* in the detector) the event is defined as *lepton+ jets*, if both W's decay hadronically the event is classified as *hadronic*. Here I will discuss only $t\bar{t}$ events in which at least one of the two W decays leptonically. Kinematical studies of $t\bar{t}$ events are subjects of another contribution to this Conference [6].

2 CDF

The CDF detector has been described in detail elsewhere [7], here we recall only the main features used in this analysis.

The CDF tracking system is fully contained within a solenoidal magnetic field of 14 KG. It is composed of a Silicon Vertex Detector (SVX) [8], used to reconstruct decays of long-lived particles (b and c hadrons), a vertex time projection chamber (mainly used to measure the Z coordinate of the interaction) and a large Central Tracking Chamber (CTC). The latter is -together with the SVX- the heart of the tracking system and provides full reconstruction of tracks up to $\eta \simeq 1$ [a]. The impact parameter (d) resolution of this system is $\sigma_d \simeq 15\,\mu m$ for high P_T tracks, which is sufficient to reconstruct b-decays.

Outside the CTC electromagnetic and hadronic calorimeters surround the interaction region up to $|\eta| < 4.2$.

A muon detection system, made of drift chambers and scintillation counters, surrounds the calorimeters, with coverage up to $|\eta| < 1$. Muon stubs are detected and then linked to tracks measured in the inner tracking system. This provides the information needed to identify and trigger on μ's.

A three-level trigger selects the inclusive muon and electron events used in this analysis. To ensure maximum efficiency a missing transverse energy ($\not\!\!E_T$) trigger was also used.

3 The Counting Experiments

All the counting experiments start by identifying events containing at least a primary lepton with large transverse momentum. Selection criteria are the following: $E_T(P_T) \geq 20$ GeV (GeV/c) for e (μ),$|\eta| < 1$, lepton candidates must pass tight identification requirements which include conversion ($\gamma \rightarrow e^+e^-$) removal and fiducial cuts. Calorimeter isolation is required.

After applying these criteria we are left with approximately 100,000 events in the electron (60,000) and muon (40,000) channels combined. This data sample is then split into *dilepton* and *lepton + jets* for subsequent analysis.

[a] η is defined as $-log(tan(\theta/2))$, θ being the angle with respect to the beamline.

3.1 Dilepton Analysis

In this analysis we search for events with a final state containing two leptons (ee, $\mu\mu$, $e\mu$), $\not\!\!E_T$ (signature of the ν's) and two jets. We do not require these two jets to be b's. In the search for the second lepton we use a looser set of lepton identification cuts. We ask for $E_T(P_T) \geq 20$ GeV (GeV/c) for e (μ), opposite sign charges and tracking isolation.

To further reduce the background we apply a set of kinematical requirements: $\not\!\!E_T \geq 25$ GeV (after correction for detector effects), $75 < M_{ll} < 105\,\mathrm{GeV/c^2}$ to remove $Z^o \to ee(\mu\mu)$ decays:, $\Delta\phi(l, \not\!\!E_T) > 20^o$ when $\not\!\!E_T < 50$ GeV to reject $Z^o \to \tau\tau$ events, $\Delta\phi(jet, \not\!\!E_T) > 20^o$ when $\not\!\!E_T < 50$ GeV to reject events in which the jet energy has been mismeasured and finally we require two jets with $E_t > 10$ GeV and $|\eta| < 2$.

While this selection considerably reduces the background it also affects the signal as the expected (theoretical) [9] yield for a SM top with mass of 170 GeV/c^2 is $\simeq 6$ events. The relative acceptances of the three channels (ee, $\mu\mu$, $e\mu$ are approximately 15, 27, 58 %, respectively.

In our data set we find a total of 9 events (1,2,6 in the ee,$\mu\mu$, $e\mu$ channels). One of the $\mu\mu$ events also contain a large E_T γ, and is consistent with a $Z \to \mu\mu\gamma$ decay (the invariant mass $M_{\mu\mu\gamma}$ is $\sim$ 86GeV/c^2). This event is removed in the estimate of the significance. Background is estimated using Monte Carlo and data to be 1.9 $\pm$ 0.4 events. In Table 1 we show our results separately for the different channels.

Background source	ee+$\mu\mu$	$e\mu$	all channels
WW	0.11$\pm$0.04	0.18$\pm$0.08	0.29$\pm$0.09
$Z \to \tau\tau$	0.25$\pm$0.04	0.30$\pm$0.07	0.56$\pm$0.10
$b\overline{b}$	0.02$\pm$0.01	0.01$\pm$0.01	0.03$\pm$0.02
fake	0.19$\pm$0.01	0.16$\pm$0.01	0.35$\pm$0.21
Drell-Yan	0.70$\pm$0.37		0.70$\pm$0.37
total	1.27 $\pm$0.39	0.65$\pm$0.11	1.92$\pm$0.4
data	2	6	8

Table 1: Dilepton events and background in the different channels. $\mu\mu\gamma$ event removed.

The probability of the background to fluctuate to the observed number of events is 10^{-3}.

3.2 lepton+jets

The CDF lepton+jets sample is obtained by selecting $W \to e\nu$ and $W \to \mu\nu$ events. We start with the inclusive lepton sample with the additional requirements of $\not\!\!E_T \geq 20$ GeV (after Z^o removal). Then we ask for at least 3 jets with $E_T > 15$GeV, this cut considerably reduces background while retaining ~ 75 % of $t\bar{t}$ events.

The background in this search is mainly due to $W+$ jets events. The main difference is that $t\bar{t}$ events *always* contain a $b\bar{b}$ pair, while a W is produced in association with a heavy flavour (HF) pair only if a gluon splits into $b\bar{b}$ or $c\bar{c}$.

In 100 pb^{-1} we find 296 $W+\geq 3$ jets. From the theoretical estimate of the cross section we expect ~ 50 $t\bar{t}$ events, thus additional background rejection is needed. CDF improves the signal to background ratio in this channel by using b-tagging. Two different techniques are used. The first one is the Soft Lepton Tagging (SLT) in which a *tag* is defined as a soft ($P_T > 2$ GeV/c) e or μ coming from the semileptonic decay of a b (or from the chain decays: $b \to c$ with the c decaying semileptonically). The other (and more sensitive) search is performed by searching for a Secondary VerteX (SVX). First we select tracks with a large impact parameter ($|d/\sigma_d| \geq 3$). Then, using these tracks, we search for a secondary vertex in the plane transverse to the beamline. If one is found, we define L_{xy}, the distance between the primary and the secondary vertex. When $L_{xy}/\sigma_{L_{xy}} \geq 3$ we define the event as *tagged.*

Background sources are estimated using data and Monte Carlo samples. Using data CDF estimates the background coming from *fake* tags. Physical background, coming from associate production of W and HF is estimated in two different ways. One way is to look at inclusive jets data, under the assumption that heavy flavour content in generic jets is the same as in jets associated to W's. This is a conservative estimate as there are diagrams -present in HF production in jets- which do not contribute to W+HF production. The other way is to calculate the fraction of $W+$ jets events containing b and c quarks by using HERWIG MC and to normalize this number using the data. We checked our background estimate using our $Z+$ jets events sample. There is a good agreement between expected and measured tags, as shown in Table 2, although the statistics are limited. Recently, with increased statistics, CDF has been able to directly measure the HF content of $W+$ jets events, again the agreement with our previous estimate is good.

After applying b-tagging algorithms to the 296 $W+\geq 3$ jets events, we find 40 tags with a background of 9.87±2.8 in the SVX search and 40 tags (with a background of 23.8±3.6) in the SLT tags. Eight events are double-tagged in the SVX (i.e. there are two secondary vertices in the event) and 4 events are

	N.events	Background	Observed tags
$Z + 1$ jet	896	8.40±0.84	6
$Z + 2$ jets	119	2.30±0.23	3
$Z + 3$ jets	19	0.94±0.09	1

Table 2: Expected and observed number of tags in the $Z+$ jets sample.

double-tagged in the SLT search. The result of the SVX search is shown in fig. 1. The excess due to top production is clearly visible in bins $W + 3$ jets and $W+ \geq 4$ jets.

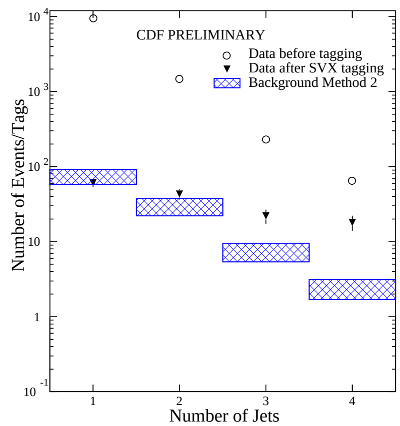

Figure 1: SVX results for the $W+$ jets sample. Open circles indicate number of events before tagging, full triangles data after tagging, boxes show the (estimated) background.

The overall combined probability, in the different counting experiments, of the signal being due to a background fluctuation is 4×10^{-9}. This probability is 2×10^{-6} for the SVX channel only.

4 Cross Section and Couplings

CDF measured the production cross section for $t\bar{t}$ events with 67 pb^{-1} using the combined information of the dilepton and the SVX and SLT searches [10] (fig. 2) After background subtraction, and correcting for efficiency, the production cross section is $\sigma_{t\bar{t}} = 7.6^{+2.4}_{-2.0}$ pb.

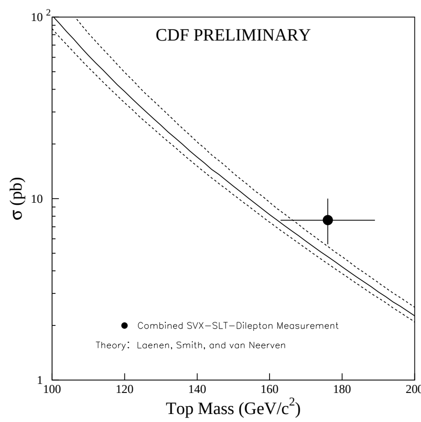

Figure 2: Combined SVX-SLT-Dilepton cross section.Theoretical NNLO calculation is also shown.

Channel	Predicted	Observed
SVX	34±10	32
SLT	37±6	36
DIL	9.5±2.4	9

Table 3: Expected (including background) and observed number of events in 100 pb^{-1}. Expectations are based on measured cross section.

With our data set of 100 pb^{-1} we checked that the observed yield is consistent with our measured cross section, this result is summarized in Table 3

By using the number of tags in dilepton and lepton+ jets events, CDF measured the branching fraction $BF(t \rightarrow Wb)/(t \rightarrow Wq) = 0.94 \pm 0.27(stat.) \pm 0.13(sys.)$ and -from this- the CKM matrix element $|V_{tb}| > 0.022$ (95 % C.L.).

5 Measurement of the Top Mass

We fit the *tagged* lepton+ jets events to the $t\bar{t}$ hypothesis. In order to kinematically reconstruct the event we first require a 4^{th} jet with $E_T > 8$GeV and $|\eta| < 2.4$. We then solve a system of constrained equations. The constraints are: the two t's must have the same mass, and constraining two jets and the $l\nu$ system to the W mass. In this process jet energies and momenta are allowed to fluctuate within the detector resolution. All combinations are attempted, and the b-tag information is used. The solution with the smallest χ^2 is kept. In fig. 3 we show the distribution of the reconstructed mass together with

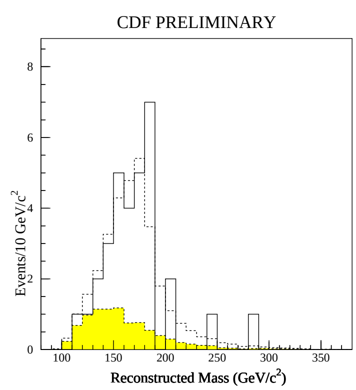

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Figure 3: Reconstructed mass for b-tagged events in the 100pb^{-1} data set (solid). Background contribution is shown as dotted area. Top MC ($M_{top} \simeq$175 GeV/c^2 with background contribution is shown as dashed line.

the expected background ($8.8^{+2.4}_{-2.2}$ events). CDF preliminary result in the 100 pb^{-1} data sample is $M_t = 175$ GeV/c^2, consistent with the published result [4] of $M_t = 176 \pm 8(stat) \pm 10(sys)$ GeV/c^2. Work is in progress to improve this measurement.

6 Conclusions

After observation of the top quark with 67 pb^{-1} of data, CDF -with increased statistics- proceeds towards the study of its *observables*. The results obtained so far in the ongoing run 1b confirm our previous measurements for the mass and cross section. The mass measurement is already limited by systematics and we expect improvements in the future. It is expecially relevant as this parameter can shed light on the problem of mass generation in the SM. CDF has also measured top couplings, although still limited by statistics.

In conclusion we are moving from the search for top to the study of top.

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