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CDF

CDF Top Quark Production and Mass

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Abstract

The top search in the dilepton and lepton plus jets channels with the Collider Detector at Fermilab is presented. The analysis uses a 67 pb^{-1}sample of $p\bar{p}$ collisions at 1.8 TeV. A 4.8σ excess of candidate events establishes the existence of the top quark. The $t\bar{t}$ production cross section is measured to be $\sigma_{t\bar{t}} = 7.6^{+2.4}_{-2.0}$ pb with branching Br(t $\rightarrow$ Wb) $= 0.87^{+0.13}_{-0.30}(stat)$ $^{+0.13}_{-0.11}(syst)$. The measured mass is $M_{top} = 176 \pm 8 \pm 10$ GeV.

Introduction

The CDF and D-Zero experiments have recently published conclusive evidence for the existence of the top quark [1, 2], confirming evidence presented by CDF a year earlier [3]. Top at the Tevatron is produced via $q\bar{q}$ annihilation with the final state topology dictated by the decays of the W's. The channel in which only one W decays leptonically to an e or μ represents $\sim$ 35% of top events as compared to 5% for e or μ decays of both W's. The remainder are in the hadronic and τ channels which have large multijet backgrounds.

The data were taken in two separate runs of the Fermilab collider. Run 1a took place in 1992-93 and resulted in a total integrated luminosity of 19 pb^{-1}on tape. CDF observed a 2.8 σ excess of top-like events over expected backgrounds in this sample and measured a top mass of $174 \pm 10^{+13}_{-12}$ GeV and cross section of $\sigma_{t\bar{t}} = 13.9^{+6.1}_{-4.8}$ pb. Changes for run 1b include a new silicon detector (SVX) with higher signal and lower noise, resulting in

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Table 1: $t\bar{t}$ Dilepton Channel

M_{top}	ϵ	$\sigma_{t\bar{t}}$ pb	Events Expected
160	0.0078	8.2	4.4
170	0.0083	5.8	3.0
180	0.0086	4.2	2.4

$\sim$ 20% higher b tagging efficiency, and a new SVX b tagging algorithm with 25% higher efficiency. Most importantly, the Fermilab accelerator has achieved luminosities of order 10^{31} $cm^{-2}sec^{-1}$. For the results presented here, 48 pb^{-1}of data from run 1b are used.

The event selection begins with the identification of an isolated e or μ with $\mathrm{E_T}$ or $\mathrm{P_T} > 20$ GeV. Both $\gamma \rightarrow \mathrm{e^+e^-}$ conversions and oppositely charged lepton pairs with $75 < M_{l^+l^-} < 105$ GeV are vetoed. These requirements yield an initial sample of 48k e and 32k μ events.

Dilepton Channel

The signature in this channel includes 2 energetic leptons, missing transverse energy ($\not\!\!E_T$), and 2 b jets. Backgrounds include WW pairs, $\gamma/Z \rightarrow \mathrm{e^+e^-}, \mu^+\mu^-$ (Drell-Yan), $Z \rightarrow \tau\tau$, $b\bar{b}$, and "fakes". The latter are jets misidentified as leptons (e.g. muons from π and K decay or residual conversion electrons). Requiring a second oppositely charged lepton with $\mathrm{E_T}$ or $\mathrm{P_T} > 20$ GeV leaves 25 $e\mu$, 215 ee and 233 $\mu\mu$ events. We next require $\not\!\!E_T > 25$ GeV and 2 jets with $\mathrm{E_T} > 10$ GeV. To reduce the Drell-Yan, $Z \rightarrow \tau\tau$, and fake backgrounds we require the direction of $\not\!\!E_T$ to be separated from the leptons and jets by 20^o in azimuth when $\not\!\!E_T < 50$ GeV. Table 1 shows the efficiency and expected number of events assuming the theoretical cross section [4]. The relative acceptances of the $e\mu$, $\mu\mu$ and ee channels are 59%, 26% and 15%.

In our data we find 5 $e\mu$, 2 $\mu\mu$ and 0 ee candidates. One of the $\mu\mu$ events contains an energetic γ and satisfys $M_{\mu\mu\gamma} = 86$ GeV. (We expect 0.04 events from $Z \rightarrow \mu\mu\gamma$.) This event is not counted when calculating the significance of our signal. The expected numbers of WW, $\tau\tau$, $b\bar{b}$ and fake events in the $e\mu$ channel are 0.13 ± 0.06, 0.21 ± 0.05, 0.01 ± 0.01 and 0.10 ± 0.10, respectively, for a total of 0.45 ± 0.14. For the combined ee

and $\mu\mu$ channels the corresponding numbers are 0.108 ± 0.03, 0.17 ± 0.05, 0.02 ± 0.01 and 0.13 ± 0.10 to which we add 0.44 ± 0.28 for Drell-Yan to obtain a total of 0.84 ± 0.28. The probability that the background could fluctuate to the observed 6 events is 0.33% (2.7 σ). We find that 3 events contain 5 jets tagged as b's. In the absence of top, the mean number of expected b tags is less than 1.

Lepton + Jets Channel

In this channel we expect an energetic lepton, $\not{E}_T$, and jets from the 2 b's and from the hadronic W decay. We require $\not{E}_T > 25$ GeV and 3 or more jets with $|\eta^{det}| \leq 2$ and $E_T > 15$ GeV. After these requirements the signal-to-background ratio is ~1/6 for $M_{top} = 180$ GeV. Further background reduction is attained by tagging b jets via secondary vertices (SVX) or low P_T leptons (SLT).

Soft Lepton Tagging

On average, one expects approximately 0.8 additional e or μ leptons per top event from b, c or τ decay. These leptons will usually have low P_T and occur in jets. The SLT analysis requries E_T or $P_T > 2$ GeV. A good source of non-isolated e's is γ conversion while J/ψ decay provides an analogous source for μ's. We use these to define and study our identification criteria and their efficiencies[3]. To determine false tag rates, we parametrize the tag rate per track as a function of P_T using dijet samples. We estimate $\sim 25\%$ of dijet tags are real heavy flavor. Tag rates in b-enriched samples significantly exceed fake rate predictions. We determine our top efficiency from MC by applying measured efficiencies to tracks for leptons from b, c or τ decays and find $\epsilon_{slt} = 20 \pm 2$ %. There is an additional $\sim 10\%$ probability that top is tagged via a track not associated to a lepton. The "mistag" rate is $\sim 8\%$ for W plus 3 or more jets background.

Results are presented in table 2. Expected backgrounds in the 1 and 2 jet bins are consistent with the numbers observed, while a $\sim 1.9\sigma$ excess is seen in the signal region.

Table 2: b tagging results in the lepton plus jets sample

Subsample N jets	SLT est. bkg.	SLT Tags (Evts)	SVX est. bkg.	SVX Tags (Evts)
$W\ +\ 1\ Jet$	159 ± 24	163 (161)	50.4 ± 12.4	40 (40)
$W\ +\ 2\ Jets$	47 ± 7	55 (54)	21.1 ± 6.5	34 (30)
$W + \geq\ 3\ Jets$	15.4 ± 2.0	23 (22)	6.7 ± 2.1	27 (21)

SVX Tagging

An impact parameter resolution of $\sim\ 16\ (1\ +\ (0.8/\mathrm{P_T})^2)\ \mu m$ afforded by the SVX detector is used to find, and vertex, tracks from long-lived particles in a two-pass algorithm [5]. The first pass attempts to construct vertices with 3 or more tracks which have lower fake background than those with 2 tracks, allowing less stringent track criteria. A tag occurs if the transverse displacement of the vertex satisfies $L_{xy}\ >\ 3 \cdot \sigma_{L_{xy}}$. If no vertex is found, a second pass searches for a 2 track vertex using strict track requirements. From MC we find that the algorithm has a top efficiency of $\epsilon_{svx}\ =\ 42 \pm 5\%$ which is 25% higher than our previous algorithm.

For our MC we use PYTHIA with the CLEO b-decay tables and the full detector simulation. MC systematics (generators, radiation, fragmentation, decay tables etc.) were studied in detail [6] and have little effect on tagging. A 30% discrepancy between data and MC b tag efficiencies in run 1a motivated a careful study and simulation of the SVX detector. The discrepancy is now understood to be caused by reduced efficiency and resolution in the previous silicon detector due to radiation damage. The ratio of data to MC b tag efficiencies in the run 1b data is 0.96 ± 0.07. The ratio is obtained by comparing tags in $b\bar{b}$ MC events in which one b decays semi-leptonically, to tags in inclusive lepton data. We find an efficiency in excess of 40% for b jets above $\sim$ 30 GeV.

For top in the range 160 to 180 GeV the cross section [4] varies between 8.2 and 4.2 pb and we expect between 20 and 10 tagged events in 67 pb^{-1}. We observe 27 tagged jets in 21 events. Backgrounds are predominantly W plus jets events where the tagged jet is either real heavy flavor (e.g. $Wb\bar{b}$, $Wc\bar{c}$, Wc) or a mistagged jet. Smaller backgrounds include $b\bar{b}$, WW, WZ and $Z \rightarrow \tau\tau$. To estimate the background we first parametrize the negative decay length tag rate in inclusive dijet data as a function of jet $\mathrm{E_T}$, track multiplicity, and total transverse energy (ΣE_T) and apply this to the jets in our lepton plus jets sample to estimate the number of mistagged events. For all other backgrounds we use MC samples to calculate the expected tags. The results are shown in table 2. The probability that the excess events in the signal region are the result of a background fluctuation is 2×10^{-5} ($\sim$ 4 σ). Combining the SVX, SLT, and Dilepton analyses the probability for the excess to be due to a background fluctuation is 1×10^{-6} ($\sim$ 4.8 σ).

A number of crosschecks can be performed to validate this result. For example, we observe 6 events with two SVX tagged jets, which is consistent with an expectation of ~ 4 for 170 GeV top plus background but significantly higher than the expectation of < 1 for background alone. Also, for 1,2 and 3 or more jets, the predicted numbers of tagged Z events are 17.5, 4.2 and 1.5 while we observe 15, 3 and 2, respectively. This lends credence to our estimates for W plus jet backgrounds.

Cross Section and Branching Fraction

We calculate the top production cross section using

$$\sigma = \frac{n - b}{\epsilon \times \int L dt} \tag{1}$$

The total efficiency ϵ, number of events n, and estimated background b, are decomposed into factors which are or are not common to the two runs and the various channels. Combining all channels we obtain $\sigma_{t\bar{t}} = 7.6^{+2.4}_{-2.0}\ pb$. Figure 1 plots the CDF measured mass and cross section point and the theoretical expectation [4].

One can also measure the branching fraction $Br(t \rightarrow Wb)$ using the numbers of events with 0,1 or 2 b tags since $Br(t \rightarrow Wb)$ values significantly smaller than 1.0 would have a noticable effect on the relative fraction of multiply tagged top events. We find $Br(t \rightarrow Wb) = 0.87^{+0.13}_{-0.30}(stat)^{+0.13}_{-0.11}(syst)$.

Top Quark Mass Measurement

We measure the mass using those lepton + jet events which contain a fourth jet satisfying $E_T > 8$ GeV in $|\eta^{det}| \leq 2.4$. We restrict our consideration

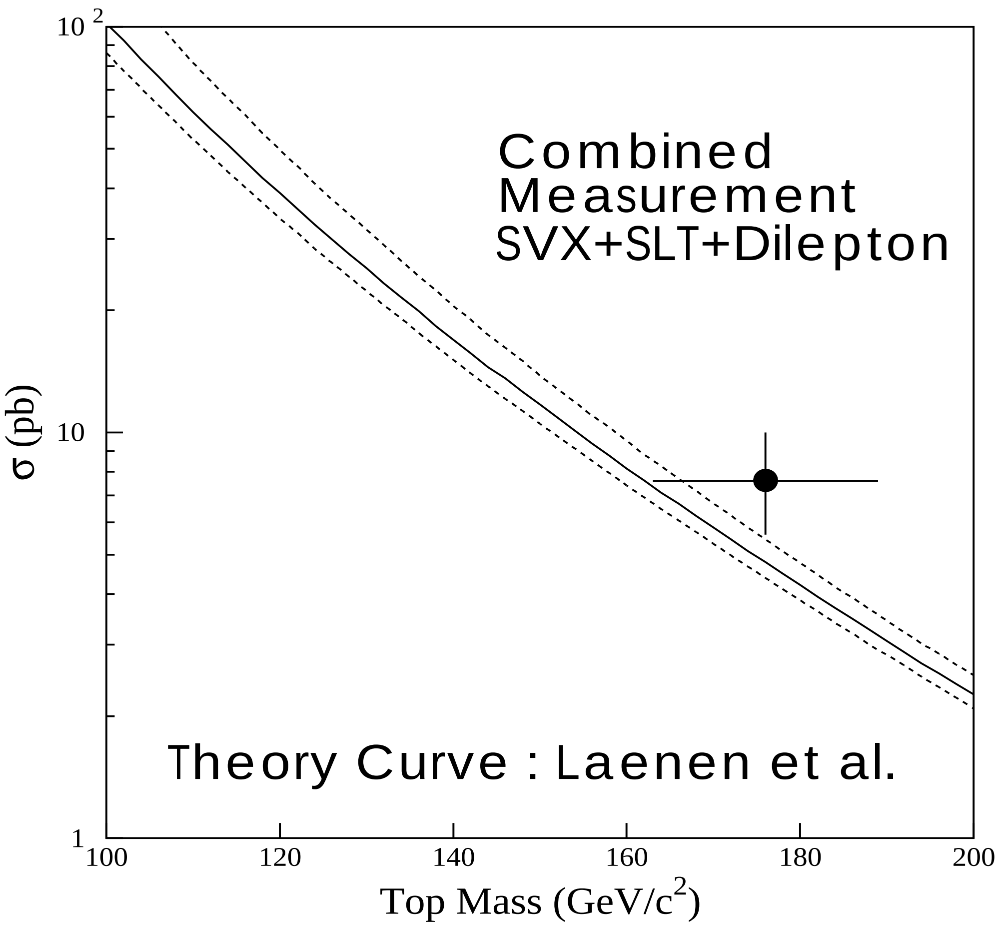

Figure 1: CDF $\sigma_{t\bar{t}}$ and M_{top} measurements compared with theory.

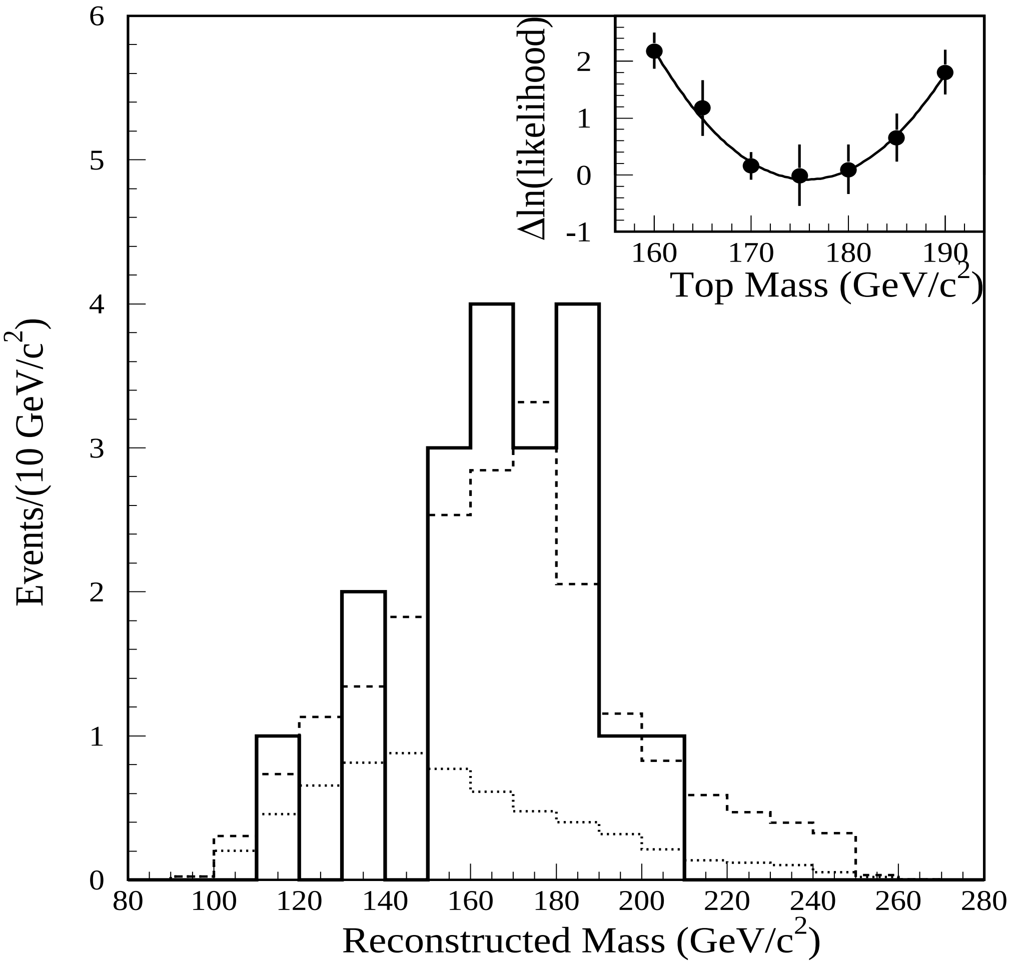

Figure 2: Mass of b-tagged events with expectation from top (dashed) and background (dotted) superimposed.

to events with at least one tagged jet. Assuming the tagged jet is a b, there are 6 combinations of jet-flavor assignments and a 2-fold ambiguity in the ν momentum along the beam axis. Of the 12 reconstruction combinations per event, the one with the lowest fit χ^2 below 10 is used. The distribution for all events is then compared to the expectation for top plus background at various top masses. Figure 2 shows the distribution and best fit expectation for signal plus background. The inset shows the likelihood for various mass hypotheses. The best fit has value $M_{top} \ = \ 176 \pm 8 \ (stat)$.

A large number of contributions to the systematic uncertainty are considered (see [3, 7]). The largest is due to the effect of soft gluon radiation on the jet $\mathrm{E_T}$ scale. Corrections are applied to the jet $\mathrm{E_T}$ to take into account energy added by the underlying event or lost outside the jet cone. The corrections are determined from data and MC, respectively, and studied in Z + jet and γ + jet events. The corrections are consistent between MC and data to within a few percent except at low $\mathrm{E_T}$ values, below what is expected for top, where a discrepancy of 10% is seen. We assume a 10% systematic uncertainty in jet energy scale which leads to a 4.4% uncertainty on the mass. This is an overestimate and will be reduced in future. A previous uncertainty in the non-W background shape has been eliminated [7]. All other uncertainties are taken from [3]. The total systematic uncertainty is then ± 10 GeV yielding $M_{top} \ = \ 176 \pm 8 \pm 10$ GeV.

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