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**CDF**

## **Top Quark Physics at CDF**

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# Top Quark Physics at CDF

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## Abstract

We present preliminary results on top quark physics recently obtained by the CDF collaboration. The data sample consists of  $110 \text{ pb}^{-1}$  of  $\bar{p}p$  collisions at  $\sqrt{s} = 1.8$  TeV, collected with the Collider Detector at Fermilab during the period 1992–1995. We report on the  $t\bar{t}$  production cross section and on the top quark mass. The measurements are made in three topologies, corresponding to the decay modes of the  $Wb$  pairs in the final state: lepton + multi-jets, dilepton and all hadronic final state. The analysis performed on the single lepton sample yields the most accurate measurements, due to the good acceptance and the favourable signal to noise ratio obtained after applying some  $b$ -tagging techniques. In this channel we measure:

$$\sigma_{t\bar{t}} = 6.8_{-1.8}^{+2.3} \text{ pb}$$
$$M_t = 175.6 \pm 5.7 \text{ (stat)} \pm 7.1 \text{ (syst.) GeV}/c^2$$

Combining the cross sections measured with the lepton + multi-jet and dilepton data we obtain:

$$\sigma_{t\bar{t}} = 7.5_{-1.6}^{+1.9} \text{ pb}$$

A preliminary investigation of the production mechanism of the  $t\bar{t}$  system is shown and compared to Standard Model expectations.

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In 1994 CDF presented the first direct evidence for the top quark [1, 2], the weak isodoublet partner of the  $b$  quark required in the Standard Model. At the same time, an upper limit on the  $t\bar{t}$  cross section was published by the D0 collaboration [3]. The preliminary observation was confirmed in 1995, when the CDF [4] and D0 [5] collaborations had recorded larger data samples and announced the detection of signal from  $t\bar{t}$  pairs. Since then, the statistics collected has nearly doubled and both experiments have focused on improving the measurements of the top properties. The results reported here are based on a sample of  $110\text{ pb}^{-1}$  collected by CDF during the period 1992 – 1995.

According to the Standard Model, the production of top at the Tevatron is dominated by the reaction  $q\bar{q} \rightarrow t\bar{t}$  with only a small contribution from gluon fusion due to the heavy top mass; single top production is expected via electroweak processes characterized by lesser cross sections. We search for the presence of  $t\bar{t}$  pairs decaying as  $t\bar{t} \rightarrow WbW\bar{b}$ . The observed topology in such events is determined by the decay mode of the two  $W$  bosons. *Dilepton* events ( $e\mu$ ,  $ee$ ,  $\mu\mu$ ) are produced primarily when both  $W$  bosons decay into  $e\nu$  or  $\mu\nu$ . These events are characterized by high transverse momentum, isolated leptons and large transverse missing energy and occur about 5% of the times. The requirement of additional jet activity is effective to suppress the main background sources. Events in the *lepton+jets* (*single lepton*) channel ( $e, \mu$ +jets) occur when one  $W$  boson decays into leptons and the other decays into quarks, with a branching fraction of about 30%. To suppress background in the lepton+jets mode, we identify  $b$  quarks by reconstructing secondary vertices from  $b$  decay (SVX tag) and by finding additional leptons from  $b$  semileptonic decay (SLT tag). Multi-jet events occur when both bosons decay hadronically. The *all-hadron* channel has a branching fraction of 44.4%. For this topology the requirement of  $b$  quarks in the events is essential to separate the signal from the very large background generated by QCD jet production.

The CDF detector consists of a magnetic spectrometer surrounded by calorimeters and muon chambers [6]. A radiation-hard, four-layer silicon vertex detector, located immediately outside the beam pipe, provides precise track reconstruction in the plane transverse to the beam and is used to identify secondary vertices from  $b$  and  $c$  quark decays [7]. The momenta of charged particles are measured in the central tracking chamber (CTC), which is immersed in a 1.4-T superconducting solenoidal magnet. Outside the CTC, electromagnetic and hadronic calorimeters cover the pseudorapidity region  $|\eta| < 4.2$  and are used to identify jets and electron candidates. The calorimeters are also used to measure the missing transverse energy,  $\cancel{E}_T$ , which can indicate the presence of undetected

energetic neutrinos. Outside the calorimeters, drift chambers in the region  $|\eta| < 1.0$  provide muon identification. A three-level trigger selects the inclusive electron and muon events used in this analysis. To improve the  $t\bar{t}$  detection efficiency, triggers based on  $\cancel{E}_T$  are added to the lepton triggers used in Ref. [1]. To select the  $t\bar{t}$  pairs in the all-hadron topology a dedicated trigger requires the presence of at least 4 jets with transverse energy  $E_T \geq 15 \text{ GeV}$  and a total transverse energy in the event that be in excess of  $125 \text{ GeV}$ . The signal to noise ratio for this channel at the trigger level is of the order of  $10^{-3}$ .

The data samples for both the dilepton and lepton+jets analyses are subsets of a sample of high- $P_T$  inclusive lepton events that contain an isolated electron with  $E_T > 20 \text{ GeV}$  or an isolated muon with  $P_T > 20 \text{ GeV}/c$  in the central region ( $|\eta| < 1.0$ ). Events which contain a second lepton candidate are removed as possible  $Z$  bosons if an  $ee$  or  $\mu\mu$  invariant mass is between 75 and 105  $\text{GeV}/c^2$ . For the lepton+jets analysis, an inclusive  $W$  boson sample is made by requiring  $\cancel{E}_T > 20 \text{ GeV}$ . Table 1 classifies the  $W$  events by the number of jets with observed  $E_T > 15 \text{ GeV}$  and  $|\eta| < 2.0$ . The dilepton sample consists of inclusive lepton events that also have a second lepton with  $P_T > 20 \text{ GeV}/c$ , satisfying looser lepton identification requirements. The two leptons must have opposite electric charge.

The primary method for finding top quarks in the lepton+jets channel is to search for secondary vertices from  $b$  quark decay (SVX tagging). The vertex-finding algorithm first searches for vertices with 3 or more tracks with looser track requirements, and if that fails, searches for 2-track vertices using more stringent track and vertex quality criteria. Other aspects of the algorithm are reported in [1]. The efficiency to tag  $b$  quarks varies with the physics process. The efficiency to  $b$ -tag a jet in single lepton top events is estimated in two steps: first, the algorithm is applied to a  $t\bar{t}$  Monte Carlo sample, second, the obtained efficiency is degraded by a scale factor that accounts mainly for some tracking inefficiency not well reproduced by the detector simulation. The scale factor is measured embedding known tracks in data and Montecarlo events and comparing the relative track finding efficiencies. The efficiency to tag at least one jet in a  $t\bar{t}$  events is measured to be  $0.41 \pm 0.04$ . Note that the first  $19 \text{ pb}^{-1}$  of data were collected using a different silicon detector: for this part of the sample the tagging efficiency is measured to be  $0.32 \pm 0.096$  [4]. The background sources to top signal in the  $W + \geq 3\text{-jets}$  sample are mainly contributed by fake tags and  $Wb\bar{b}(c\bar{c})$  events. The fake tags contribution is measured using inclusive jet samples, while the fraction of  $W + jet$  events that are  $Wb\bar{b}$  and  $Wc\bar{c}$  is estimated from a Monte Carlo sample, normalizing the cross section to the

$W + jet$  data and using the measured tagging efficiencies. The calculated background, including the small contributions from *non-W* events,  $Wc$  production, and vector boson pair production, is given in Table 1. The numbers of SVX tags in the 1-jet and 2-jet

$N_{jet}$	observed events	observed SVX tags	background tags expected
1	10716	70(70)	$69.0 \pm 10.9$
2	1663	51(45)	$29.0 \pm 3.9$
3	254	24(18)	$6.8 \pm 0.9$
$\geq 4$	69	18(16)	$2.6 \pm 0.5$

Table 1: Number of lepton+jet events in the  $110 \text{ pb}^{-1}$  data sample along with the numbers of SVX tags (events) observed and the estimated background. The total number of background events expected in the  $W + \geq 3 \text{ jets}$  is  $7.96 \pm 1.37$ .

samples are consistent with the expected background plus a small contribution (Table 1 and Figure 1). In the 2-jet sample we tag 45 events, estimate an expected background of 29 and a contribution of 6  $t\bar{t}$  events. A good understanding of this deviation will be achieved in the next CDF run. In the  $W + \geq 3\text{-jet}$  signal region, 42 tags are observed compared to a predicted background of  $9.47 \pm 1.4$  tags. Figure 2 shows the decay lifetime distribution for the SVX tags in  $W + \geq 3\text{-jet}$  events. It is consistent with the distribution predicted for  $b$  decay by the  $t\bar{t}$  Monte Carlo simulation.

The second technique for tagging  $b$  quarks (SLT tagging) is to search for an additional lepton from semileptonic  $b$  decay. Electrons and muons are found by matching CTC tracks with electromagnetic energy clusters or tracks in the muon chambers. To maintain acceptance for leptons coming directly from  $b$  decay and from the daughter  $c$  quark, the  $P_T$  threshold is kept low ( $2 \text{ GeV}/c$ ). The most significant change to the selection algorithm compared to Ref. [1] is that the fiducial region for SLT muons has been increased from  $|\eta| < 0.6$  to  $|\eta| < 1.0$ , resulting in an increase of the SLT total acceptance and background by a factor of 1.2.

The major backgrounds in the SLT analysis are hadrons that are misidentified as leptons, and electrons from unidentified photon conversions. These rates and the smaller  $Wb\bar{b}$  and  $Wc\bar{c}$  backgrounds are determined directly from inclusive jet data. The remaining

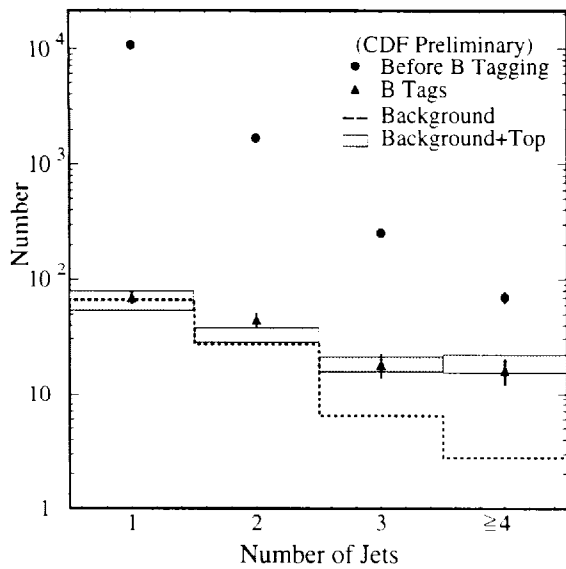


Figure 1: Number of events before SVX tagging (circles), number of observed tags (triangles), and expected number of background tags (hatched) versus jet multiplicity.

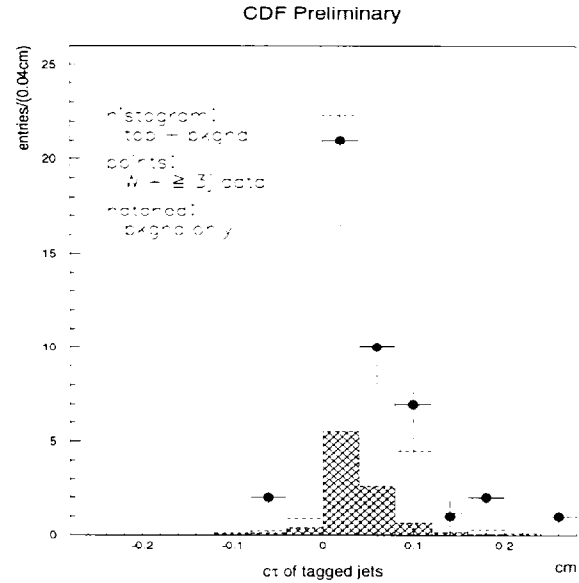


Figure 2: The secondary vertex proper time distribution for the 42 SVX-tagged jets in the  $W + \geq 3$ -jet data (dots) compared to the expectation for  $b$  quark jets from  $t\bar{t}$  decay and background.

backgrounds are much smaller and are calculated using the techniques discussed in Ref. [1]. The efficiency of the algorithm is measured with photon conversion and  $J/\psi \rightarrow \mu\mu$  data. The probability of finding an additional  $e$  or  $\mu$ , from a  $b$ -decay, in a  $t\bar{t}$  event with  $\geq 3$  jets is  $(20 \pm 2)\%$ . Figure 3 shows the background and the number of observed tags in the  $W + jet$  sample. The comparison of these numbers for the low jet multiplicity events shows the accuracy of the background predictions. There are 44 tags in 40 events, with  $25.2 \pm 3.8$  tags expected from background.

The dilepton analysis is very similar to that previously reported [1], with slight modifications to the lepton identification requirements to make them the same as those used in the single lepton analysis. The dilepton data sample, described above, is reduced by additional requirements on  $\cancel{E}_T$  and the number of jets. In order to suppress background from Drell-Yan lepton pairs, which have little or no true  $\cancel{E}_T$ , the  $\cancel{E}_T$  is corrected to account for jet energy mismeasurement [1]. The magnitude of the corrected  $\cancel{E}_T$  is required to be at least 25 GeV and, if  $\cancel{E}_T$  is less than 50 GeV, the azimuthal angle between the  $\cancel{E}_T$  vector and the nearest lepton or jet must be greater than  $20^\circ$ . Finally, all events are required to have at least two jets with observed  $E_T > 10$  GeV and  $|\eta| < 2.0$ .

$N_{\text{jet}}$	observed SVX tags	background tags expected
1	245(245)	$273.0 \pm 35.0$
2	82(80)	$79.0 \pm 10.0$
3	27(25)	$17.4 \pm 2.8$
$\geq 4$	17(15)	$7.8 \pm 1.0$

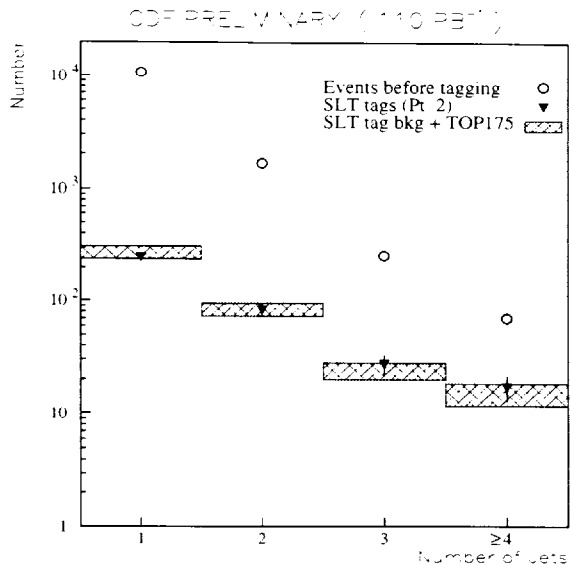


Figure 3: *Left: observed SLT tags (events) and the estimated background as a function of jet multiplicity. The total number of background events expected in the  $W + \geq 3$  jets is  $24.3 \pm 3.5$ . Right: lepton+jet data as a function of the jet multiplicity (open dots) along with the results reported in the table and top+background expectations.*

The major backgrounds are Drell-Yan lepton pairs,  $Z \rightarrow \tau\tau$ , hadrons misidentified as leptons,  $WW$ , and  $b\bar{b}$  production. We calculate the first three from data and the last two with Monte Carlo simulation [1]. As shown in Table 2 the total background expected is  $2.1 \pm 0.4$  events. We observe a total of 10 events, 7  $e\mu$ , 1  $ee$ , 2  $\mu\mu$ . The relative frequencies are consistent with our dilepton acceptance, 60% of which is in the  $e\mu$  channel. Notice that one of the candidate is consistent with being a radiative  $Z$  decay. Four of these events contain a total of 6  $b$ -tags, compared with an expected 1 (in 10) if the events were background, thus providing additional evidence for  $WWb$  production. The dilepton candidate are shown in Figure 4 displaying the azimuthal angle between the  $\cancel{E}_T$  and the nearest lepton or jet as function of the  $\cancel{E}_T$  for the dilepton candidates. The Monte Carlo predictions for a top of mass  $175 \text{ GeV}/c^2$  are overlaid.

The all-hadron analysis rejects a large background fraction with the aid of some requirements on the global kinematics of the event. The selection asks for at least 5 jets with  $E_T \geq 15 \text{ GeV}$  and  $\eta \leq 2$  and with a minimal separation of 0.5 in  $(\eta, \phi)$  space. The events are required to deposit a large transverse energy in the central region of the detector by imposing that  $\sum E_T \geq 300 \text{ GeV}$  and  $\sum E_T/\sqrt{\hat{s}} \geq 0.75$ . Additional rejection against background is obtained when the aplanarity satisfies the condition  $A + 0.0025 \times \sum_3^N E_T \geq 0.54$ . The signal to noise ratio is at this point  $\sim 1/30$ ; further rejection power is obtained by requiring at least one jet to be tagged by the standard secondary-vertex algorithm al-



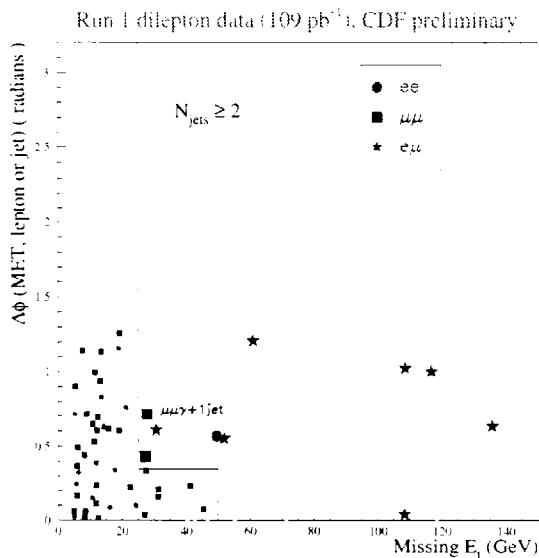


Figure 4: *Dilepton sample. Azimuthal angle between the  $\vec{E}_T$  and the nearest lepton or jet as function of the  $\vec{E}_T$  for the dilepton candidates. The Monte Carlo predictions for a top of mass  $175 \text{ GeV}/c^2$  are shown in small dots. The line represents the  $\vec{E}_T$  selection cut.*

ready described ( $S/N \sim 1/2$ ). The background in the final sample is contributed by QCD multi-jet events and mistags. The method to estimate the background is described in [1] (Method 1, for the single lepton data); an exclusive 4-jets data sample is used to parametrize the tagging probability as a function of jet variables. The probability spectrum is then used to evaluate the expected background in the signal sample. We select 192 events (230 tags) on an expected background of  $137.1 \pm 11.3$ . The data and background expectations as a function of the event jet multiplicity are shown in Figure 5.

Channel	N tagged evts.	Background	$\epsilon(\%)$	$\sigma(tt)$ (pb)
SVX	34	$8.0 \pm 1.4$	$3.5 \pm 0.6$	$6.8^{+2.3}_{-1.8}$
SLT	40	$24.3 \pm 3.5$	$1.7 \pm 0.3$	$8.0^{+4.4}_{-3.6}$
Dilepton	10	$2.1 \pm 0.4$	$0.78 \pm 0.08$	$9.3^{+4.4}_{-3.4}$
All-hadron	192	$137.1 \pm 11.3$	$9.9 \pm 3.5$	$10.7^{+7.6}_{-4.0}$

Table 2: *Summary of the counting experiment: for each channel the table reports the number of events containing at least one b-tag, the estimated number of background events, the overall efficiency of the data selection and the measured cross section. Errors include statistic and systematic contributions. The acceptance has been estimated for  $M_t = 175 \text{ GeV}/c^2$ . The integrated luminosity for all samples is  $L = 109.4 \pm 7 \text{ pb}^{-1}$ .*

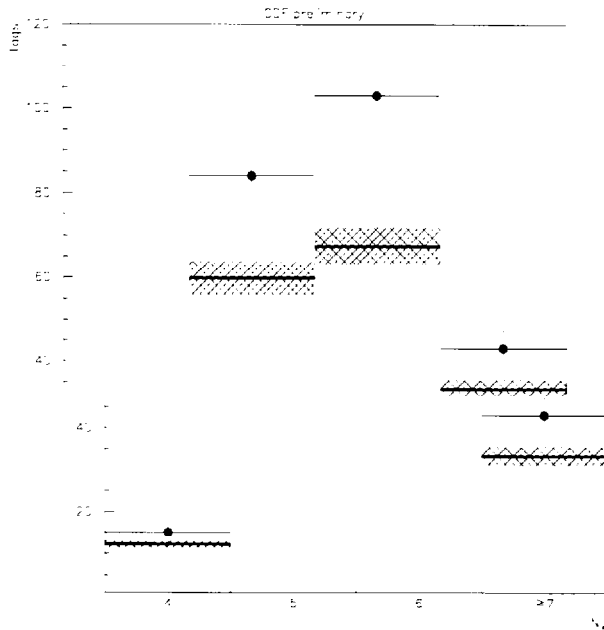


Figure 5: Number of tags in the all-hadron channel as a function of the event jet multiplicity. The background predictions and their uncertainty are shown by the shadowed boxes.

The cross section in each channel is calculated using the relation [1]:

$$\sigma = \frac{n - b}{\epsilon^{tot} \cdot L}$$

$n$  and  $b$  being the number of tagged and background events and  $L$  the integrated luminosity. The global selection efficiency  $\epsilon^{tot}$  has been estimated for a top mass  $M_t = 175 \text{ GeV}/c^2$ . The branching ratio of  $t \rightarrow Wb$  is consistently set to 1. The results for each topology are reported in Table 2. The measurements in the dilepton and single lepton channel have been combined yielding a higher precision measurement  $\sigma(t\bar{t}) = 7.5_{-1.6}^{+1.9}$ . Work to include the cross section measured in the all-hadron channel is in progress. A comparison of our results to the most recent calculations is shown in Figure 6 [9].

Single lepton events with 4 or more jets can be kinematically constrained to the  $t\bar{t} \rightarrow WbW\bar{b}$  hypothesis, yielding for each event an estimate of the top quark mass [1]. The lepton, neutrino ( $\cancel{E}_T$ ), and the four highest- $E_T$  jets are assumed to be the  $t\bar{t}$  daughters and are constrained to the following processes by a  $2C$ -fit:

- 1)  $p\bar{p} \rightarrow t\bar{t}$
- 2)  $t \rightarrow W^+b$
- 3)  $\bar{t} \rightarrow W^-\bar{b}$

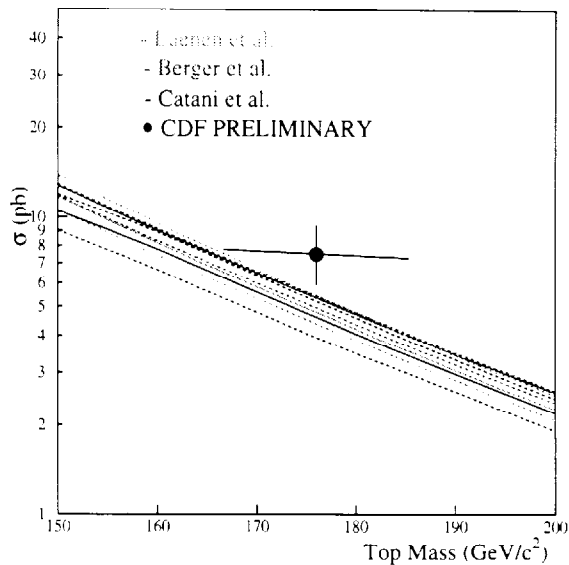


Figure 6: *CDF* combined  $t\bar{t}$  cross section compared with the recent calculation by *Catani et al.* (solid), *Laenen et al.* (grey dash) and *Berger et al.* (black dash).

4)  $W^+ \rightarrow l^+\nu$

5)  $W^- \rightarrow l^-\bar{\nu}$

Additional requirements are  $M_t = M_{\bar{t}}$ ,  $M_W = 80.2 \text{ GeV}/c^2$  and  $\Gamma_W = 2.1 \text{ GeV}$ . There are multiple solutions, due to both the quadratic ambiguity in determining the longitudinal momentum of the neutrino and the assignment of jets to the parent  $W$ 's and  $b$ 's. For each event, the solution with the lowest fit  $\chi^2$  is chosen. Starting with the 323 events with  $\geq 3$  jets, we require each event to contain a fourth jet with  $E_T > 8 \text{ GeV}$  and  $|\eta| < 2.4$ . Jets are clustered in a cone of radius 0.4. The measured jet energy is corrected back to the original parton energy with the procedure detailed in [1]. The selection yields a sample of 153 events, passing a loose  $\chi^2$  requirement on the fit. The background in this sample is estimated to be  $99 \pm 10$  events and it is mainly contributed by  $W + jet$  events. The mass distribution for these data is shown in Figure 7 together with the predicted background. A well clustered number of events is visible in excess of the background, even in this relatively low purity sample. After requiring an SVX or SLT  $b$ -tag, 34 events remain, of which  $6.4_{-1.4}^{+2.1}$  are expected to be background. The background in this sample is contributed by *non-W* events, mistags and  $Wb\bar{b}(c\bar{c})$  events. The first two sources are estimated from the data, the others with Monte Carlo sample and using the measured  $b$ -tagging efficiency. For this sample, only solutions in which the tagged jet is assigned to one of the  $b$  quarks are considered. Figure 7 shows the mass distribution for the tagged events. To find the most likely top mass, we fit the mass distribution to a sum of the expected distributions from the  $W + jets$  background and a top quark of mass  $M_t$  [1].

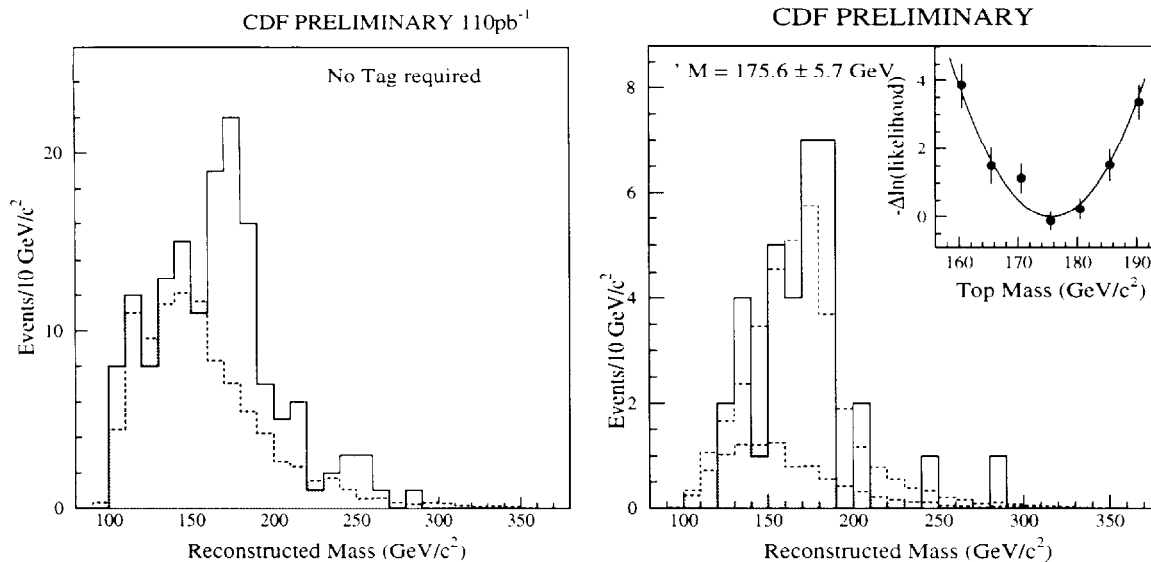


Figure 7: *Top mass distribution for events with a high- $P_T$  lepton and at least four jets. Left: no  $b$ -tag requirement is imposed. Right: only events with at least one tagged jet are shown.*

The background returned by the fit is  $6.3 \pm 1.7$  events. The  $-\ln(\text{likelihood})$  distribution from the fit is shown in the Figure 7 inset. The best fit mass is  $175.6 \text{ GeV}/c^2$  with a  $\pm 5.7 \text{ GeV}/c^2$  statistical uncertainty corresponding to 0.5 units of variation in  $-\ln(\text{likelihood})$ . The systematic uncertainty is described in detail in [1] and we shall mention here only the recent improvements. A break-up of the sources of error and their relative contribution is reported in Table 3. The most recent work has focused on the estimate of the uncertainty

Systematics	Value	
	$\text{GeV}/c^2$	%
Jet $E_T$ scale	3.1	1.8
Soft gluon effects	1.9	1.1
Different Generators	0.9	0.6
Hard gluon effect	3.6	2.1
Fit configuration	2.5	1.4
$b$ -tagging bias	2.3	1.3
Background spectrum	1.6	0.9
Likelihood method	2.0	1.1
Monte Carlo statistics	2.3	1.3
Total	7.1	4.0

Table 3: *Systematic uncertainties on the top mass measured in the lepton+  $\geq 4$ -jets sample.*

on the jet and parton energy. New studies have been carried out on the energy scale uncertainty [10], that contributes an uncertainty of  $3.1 \text{ GeV}/c^2$  to the systematic error.

The modelling of the soft gluon radiation is largely responsible for the percentage of the jet energy that escapes the clustering cone. An incorrect modelling of the jet shape leads to a mismeasurement of the jet energy. This effect has been investigated comparing the energy flow in annuli of maximum radius 1 around the jet cones, in data and Monte Carlo samples. The jet shape has been studied on  $W + 1 \text{ jet}$ ,  $Z + 1 \text{ jet}$  and  $b\bar{b}$  data. A discrepancy has been measured, resulting in an uncertainty on the top mass of  $1.9 \text{ GeV}/c^2$

Hard gluon emitted by the final state partons can generate jets in the detector that are considerably displaced from the direction of the parton itself. In a percentage of cases the fit procedure will then choose a wrong parton-jet assignment. Hard gluon effects have been estimated by varying in the HERWIG Monte Carlo the percentage of events for which the jets at the generator level are considerably displaced from the reconstructed jet used in the mass fit. This effect contributes an uncertainty of  $3.6 \text{ GeV}/c^2$  on the top mass. We estimate the total systematic uncertainty on the top mass to be  $7.1 \text{ GeV}/c^2$ .

A procedure similar to the one described in the previous section has been used to measure the top mass using the all-hadron data. The vertices used in this analysis are

- 1)  $t \rightarrow W^+ b$
- 2)  $\bar{t} \rightarrow W^- \bar{b}$
- 3)  $W^+ \rightarrow j_1 j_2$
- 4)  $W^- \rightarrow j_3 j_4$

In this case no  $E_T$  is involved in the measurement and the system recoiling against the  $t\bar{t}$  pair can be neglected. The fit is then simply to the hard reaction, for a total of 16 equations and 13 unknowns (*3C-fit*). The data sample differs from the one used to measure the cross section in the fact that the requirement on the total transverse energy is relaxed to  $\sum E_T \geq 200 \text{ GeV}/c^2$  to avoid biases. The six leading jets are corrected as in the single lepton analysis. The sample selected includes 142  $b$ -tagged events, 28 of which contain an additional tag. The background rate is estimated by using the tag rate parametrization on the 6-jet sample, the background shape is inferred by applying the mass fit to the pretagged all-hadron sample ( $S/B \sim 30$ ). The measurements yields  $M_t = 187 \pm 8 \text{ (stat)} \pm 12 \text{ (syst)}$  and a background estimate of  $108.8 \pm 6.6$  events. The systematic

error is estimated along the lines discussed in the previous section. The reconstructed invariant mass is shown in Figure 8 together with the Monte Carlo predictions and the fit likelihood.

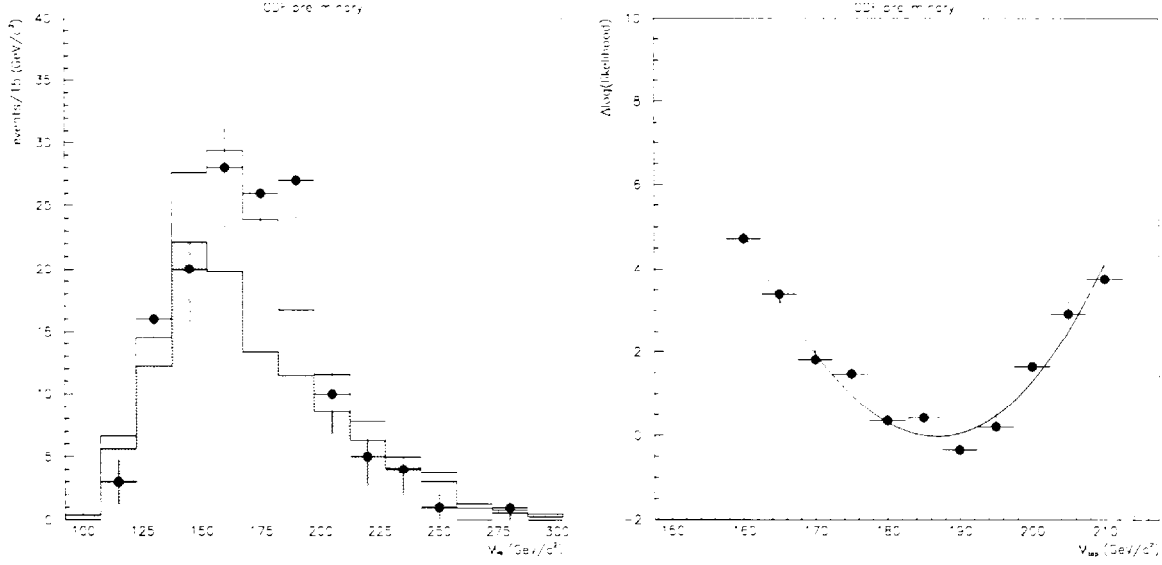


Figure 8: *Left: The top invariant mass reconstructed in the all-hadron sample. The data (dots) are superimposed to the background (shaded) and to the background plus signal (white) expectations. Right:  $-\ln(\text{likelihood})$  distribution and fit.*

In the dilepton topology the event kinematics is underconstrained due to the presence of two neutrinos. To measure the top mass in this channel we have exploited the tight correlation between the energy of the  $b$ -jets and the mass of the top quark. The data sample is a subset of the one used to measure the cross section, obtained adding the requirement  $H_T = \sum E_T^{\text{leptons, jets}} + \cancel{E}_T \geq 170 \text{ GeV}$ . There are 8 events satisfying the selection of which  $1.1 \pm 0.3$  is expected to be background. A likelihood procedure compares the two leading jets in the events to Monte Carlo jet energy templates. The best fit and the likelihood are shown in Figure 9. Even though the sources of systematics are partially different than in the other topologies, the dominant uncertainty is still contributed by the jet energy scale ( $\leq 10\%$ ); another relevant contribution comes from the uncertainty on the background shape (5%). In this channel we measure  $M_t = 159_{-22}^{+24} (\text{stat}) \pm 17 (\text{syst})$ .

Based on the mass fit informations in the single lepton sample we can study some properties of the  $t\bar{t}$  system. The available statistics allows for some preliminary study of

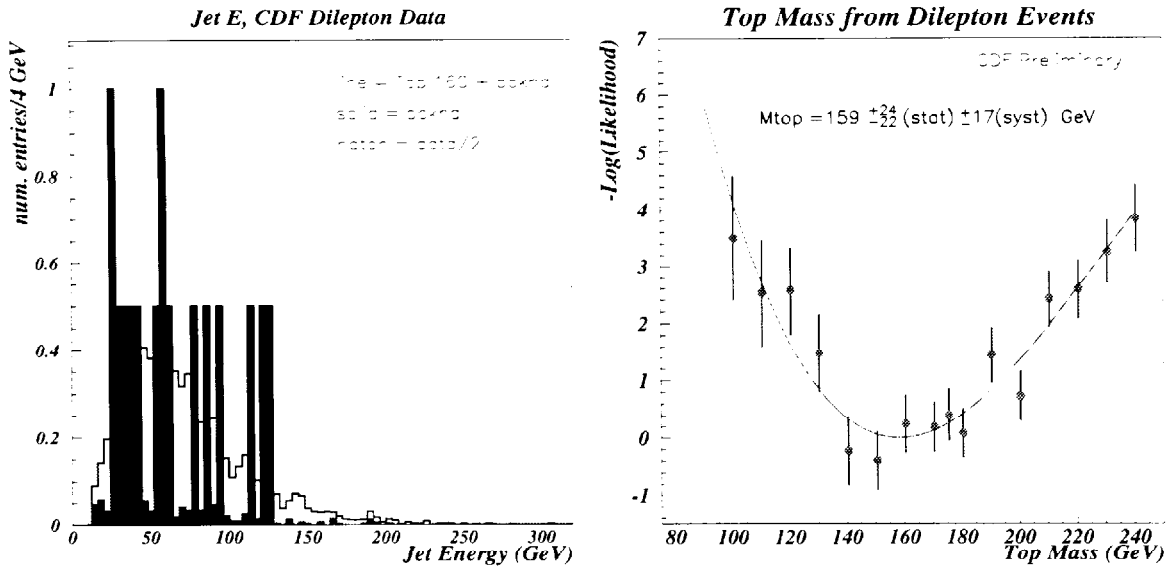


Figure 9: *Left: Energy distribution of the two leading jets in dilepton events. The background (shaded) and background plus best fit signal (white) are overlaid. Right:  $-\ln(\text{likelihood})$  distribution and fit.*

the mass and transverse momentum of the  $t\bar{t}$  pair and of the transverse momentum of the top quarks. These variables are sensitive to the production mechanisms and will become a fine probe to test the Standard Model as the collected statistics will increase. The comparison between data and predictions has been carried out on the pretagged, tagged and double-tagged data sample. The data shown in Figure 10 are the 1-tag inclusive sample: no corrections for detector and selection biases are applied. The distributions show the transverse momentum of the two top quarks, separately for the reconstructed hadronic and leptonic decays as well as the mass of the  $t\bar{t}$  system. At present, no indication of discrepancy can be observed.

In summary, we have reported the measurements of the top mass and  $t\bar{t}$  cross section obtained in the three different decay topologies of the  $WbW\bar{b}$  final state. The top mass has been measured with a precision of  $\sim 5\%$  in the single lepton channel  $M_t = 175.6 \pm 5.7 (stat) \pm 7.1 (syst.) GeV/c^2$ , fully consistent with previous determinations. This result has been obtained through an improved study of the jet systematics and ranks top as the quark with the best known mass. Work is underway to combine the mass measurements in all the decay channels investigated. Figure 11 shows the relationship between the  $W$  and top mass direct measurements at CDF, for different masses of the Higgs boson. The next Tevatron run will allow this measurement to achieve a precision of about  $4 GeV/c^2$  [10]. The  $t\bar{t}$  cross section estimated combining the lepton topologies is  $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6} pb$ ; this result will be combined with the measurement in the all-hadron

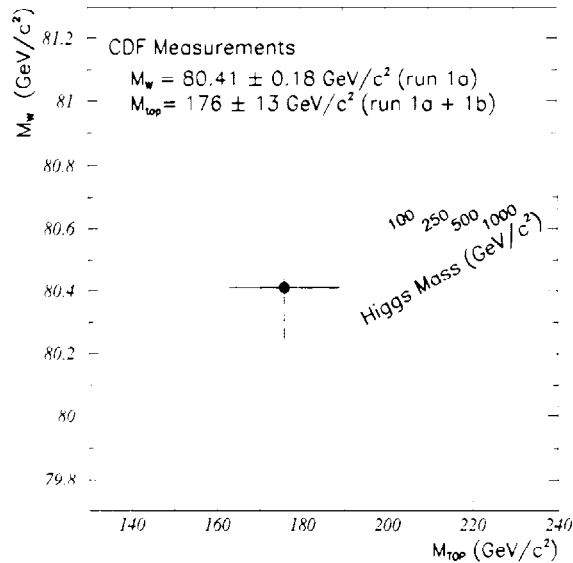


Figure 11: *CDF measurements of the  $W$  and top mass compared to Standard Model expectations for different values of the Higgs mass.*

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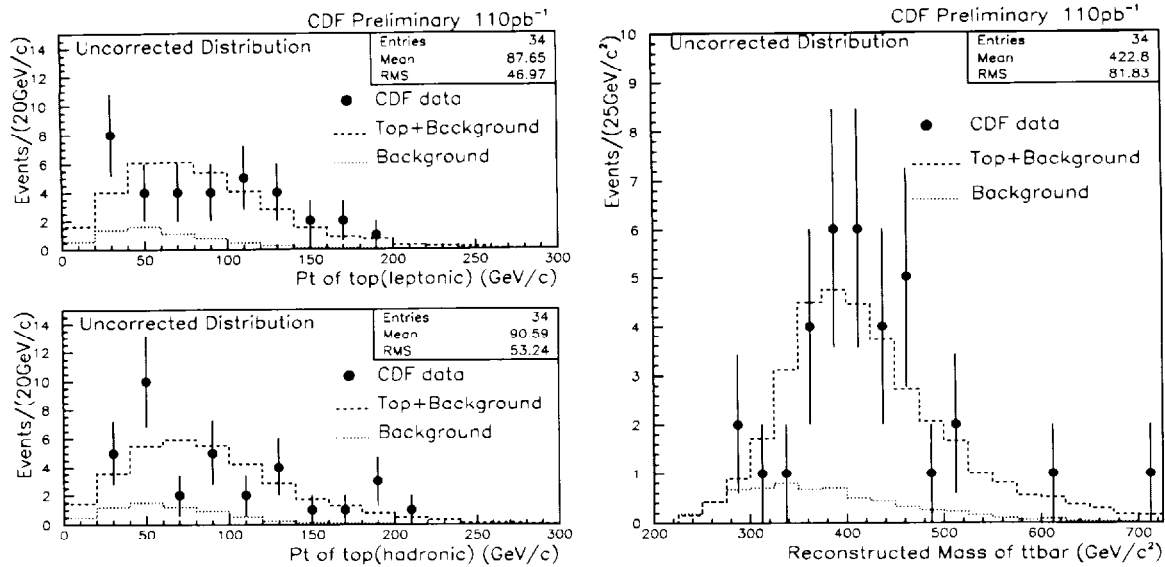


Figure 10: *Left: Top transverse momentum measured in the single lepton mass sample ( $\geq 1$  b-tag). Top quarks reconstructed from different decay topology are plotted separately. Right: Invariant mass distribution of the  $t\bar{t}$  pair, measured with the same data. Data (closed dots) are superimposed to the expectations of the Standard Model top production.*

channel. A preliminary investigation of the  $t\bar{t}$  kinematic properties shows no discrepancy with the expectations. The large statistics that will be collected in the next years ( $\sim 500$  tagged  $t\bar{t}$  events/ $fb^{-1}$  [10]), will establish top physics as a novel workshop to probe the Standard Model.

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