ADDENDUM: Measurement of $t\bar{t}$ Cross Section in the Lepton Plus Jets Channel Using Neural Networks in 2.8 fb^{-1}. Ratio over Z Cross Section

J. Conway, R. Erbacher, **W. Johnson**, **A. Lister**, **T. Schwarz**
University of California at Davis
K. Lannon
University of Notre Dame
R. Hughes, B. Winer
The Ohio State University

CDF NOTE 9528

Version 2.0

January 27, 2009

Abstract

CDF note 9387 presents the $t\bar{t}$ cross section measurement using a NN fit in the Lepton+Jets Channel in $2.8 fb^{-1}$ of CDF data. This is the measurement on which this note is based. No change to the analysis methodology is applied here for obtaining the $t\bar{t}$ cross section, but the CMX trigger is excluded and the treatment of PDFs has changed, both in the reweighting of the central value to NLO PDFs as well as in the treatment of the uncertainties. The luminosity uncertainty is the dominant uncertainty in this measurement.
It is possible to significantly reduce the dependence on the CLC luminosity uncertainty by exploiting the correlation between the luminosity uncertainty of the $t\bar{t}$ and Z cross section measurements. The concept of this measurement is that by taking the ratio of the $t\bar{t}$ to Z cross section, one can reduce the total uncertainty as some of the systematics (mainly luminosity) are correlated between the two measurements.
The ratio $R = \frac{\sigma_{t\bar{t}}}{\sigma_Z}$ is found to be $0.0274 \pm 0.0016(stat)^{+0.0016}_{-0.0013}(syst)$. It might be easier to consider the ratio as $\frac{1}{R} = \frac{\sigma_Z}{\sigma_{t\bar{t}}} = 36.47^{+2.06}_{-2.29}(stat)^{+1.88}_{-1.96}(syst)$.
By multiplying this ratio by the NLO calculation of the Z cross section of 251.3 $\pm$ 5.0 pb, a value for the $t\bar{t}$ cross section can be obtained. The $t\bar{t}$ cross section is found to be $\sigma_{t\bar{t}} = 6.89 \pm 0.41(stat)^{+0.41}_{-0.37}(sys) \pm 0.14(theory)$ pb.
The total uncertainty on this measurement is 8.2% which is a significant improvement over the

direct $t\bar{t}$ cross section measurement shown in CDF note 9387 which has a statistical uncertainty of 5.4% and a systematic one of 7.7%, giving a total uncertainty of 9.4%.

1 Introduction

The reader is referred to CDF note 9387 [1] for details on the measurement method of the $t\bar{t}$ cross section and CDF note 9529 [2] for more details on the Z cross section measurement.
The only difference in the Z cross section measurement between this note and CDF note 9529 is the use of the good run list without silicon requirements (instead of the one with silicon requirements).
In the calculation of the ratio of the $t\bar{t}$ over the Z cross section we only consider the CEM and CMUP leptons. The CMX leptons were removed as they have a different luminosity, very little statistics in the dilepton channel and overall contribute very little to the total sensitivity of the measurement. W only consider the channel with the most sensitivity, the W+$\geq$3 jets case.
The PDF uncertainty has been revisited relative to the original note as the old Joint Physics method was found to contain bugs and we found we could further reduce the systematic uncertainties by using more recent PDF sets. In this measurement the new LHAPDF libraries are used, instead of PDFLIB which is no longer supported. The new method uses only NLO PDF sets. The most up to date CTEQ6.6 (2008) PDF sets with its 22 eigenvectors is used to compute the uncertainty due to the PDF fits themselves. CTEQ6AB (2004) is used to get a direct estimate of the effect of varying α_s, instead of it being one of the parameters of the global fit. Subsets 3, 4 and 5 were used to obtain the -1σ, nominal and $+1\sigma$ variations on α_s, respectively. The MRST2001 sample is used to cross check the CTEQ fit uncertainty. Moreover, in order to obtain a measurement using the more precise NLO PDFs, the central value for both the $t\bar{t}$ and the Z cross sections is obtained by reweighting the generated signal MC (that uses CTEQ5L) to the nominal CTEQ6.6 PDFs.

2 Analysis Methodology

The dominant source of systematic uncertainty from the $t\bar{t}$ cross section measurement presented in CDF note 9387 is the uncertainty due to the luminosity measurement. The uncertainty due to the CLC measurement of the elastic $p\bar{p}$ scattering leads to a 5.8% systematic on the measured cross section.
In order to reduce this uncertainty, we can take the ratio of the $t\bar{t}$ cross section to a well-known cross section with both small experimental and theoretical uncertainties, in which case the uncertainty due to the luminosity measurement should almost entirely cancel out. This is valid as long as the datasets considered are the same (or at least are known to have the same luminosity dependence and profile).
In this note we calculate the ratio of the $t\bar{t}$ to the Z cross section measured in the dilepton channel.
The luminosity uncertainty does not cancel entirely due to the fact that some of the backgrounds in the Z cross section are fixed from MC and not floated in the fit for the final cross section.
Once the ratio $R = \frac{\sigma_{t\bar{t}}}{\sigma_Z}$ is measured, the best theoretical calculation for the Z cross section

can be used to get back to the $t\bar{t}$ cross section. In effect one is replacing the luminosity uncertainty with the theoretical and experimental uncertainties on the Z cross section which are both rather small.
In detail the analysis steps are as follows

- Section 4: Measure the $t\bar{t}$ cross section as in CDF note 9387 with the following changes
  - Use only the CEM and CMUP triggers (to make the triggers identical to the Z cross section measurement);
  - Re-weight the $t\bar{t}$ templates to the NLO CTEQ6.6 nominal PDFs.
- Section 5: Measure the Z cross section
  - Measure the cross section in data using the mass window 66 - 116 GeV/c^2;
  - Re-weight acceptance to NLO CTEQ6.6 nominal PDFs;
  - Correct for virtual photon contribution as well as finite mass window of measurement.
- Section 6: Compute ratio of $t\bar{t}$ to Z cross section taking into account correlations in systematics
- Section 7: Multiply this ratio by the theoretical prediction for the Z cross section to obtain the best measurement of the $t\bar{t}$ cross section

Before going into the details of the measurement, the systematic uncertainty calculations are discussed. The PDF uncertainty is new to this measurement so we thought the reader should first get a clear idea of what we are doing for the PDF uncertainty and why.

3 Systematics

For a discussion on the general systematic strategy and calculation for the $t\bar{t}$ cross section, please refer to CDF note 9387.

This analysis involves the computation of ratios of measured cross sections so particular care should be taken when treating the systematics. The individual sources of systematic uncertainties are computed for each of the measurements and are assumed to be 100% correlated (or anti-correlated) between similar sources of uncertainty; unrelated errors are treated as uncorrelated. Some of the sources of systematic uncertainties are considered as asymmetric while others are symmetrised. This is based on whether or not one can trust the measurement of the systematic as being truly asymmetric or not in the $\pm$ 1 σ sense. Table 1 provides a definition of each of the sources of systematic uncertainties in this measurement as well as the method used to compute it and if it is symmetrised or not. For the symmetrisation process, we consider half of the maximum deviation obtained (where the maximum deviation is with respect to the nominal sample if both samples cause a shift in the same direction). For systematics correlated between the measurements, both cross section measurements are shifted up(down) by their upwards(downwards) uncertainties and the ratio is taken. The difference with the nominal ratio is taken as the systematic due to that effect.

The only systematics with a somewhat special treatment are the uncertainty quoted in the table as Lepton ID/trigger and as PDF. The Lepton ID/trigger systematic is actually computed separately for each component (CEM trigger efficiency, CMUP trigger efficiency, CEM lepton ID and reconstruction scale factor, CMUP lepton ID and reconstruction scale factor).

The variation on the final measurements due to each of these effects is computed and the final systematic is obtained by adding all of these effects up in quadrature.

The PDF uncertainty differs with respect to the default measurement and the standard Joint Physics prescription. Due to the fact that the nominal values for the cross sections are re-weighted to NLO, we can consider only PDF variations at NLO. A couple of bugs were found in the Joint Physics package (problems with the PDFLIB as well as the associations of which partons participate in the interaction). A new framework was developed that fixes these bugs and uses the new LHAPDF library, with its up-do-date PDF sets. The procedure remains similar in concept to the Joint Physics one in that we consider a variation in both the CTEQ eigenvectors, to account for the uncertainties of the PDF fits, as well as a variation on α_s. The new procedure is as follows

- CTEQ 6.6 (NLO) eigenvector variation;
- CTEQ6AB $\pm 1\sigma$ variation on α_s: subset 4 uses nominal α_s, subsets 3 and 5 use -1 and +1 σ variations respectively.

Note: The α_s value used by CTEQ6AB and CTEQ6.6 is not the same, thus care needs to be taken in computing the α_s variations wrt the nominal value in CTEQ6AB and not the nominal one of CTEQ6.6.
For the CTEQ6.6 uncertainty calculation we proceed as follows

- CTEQ6.6 has 22 sets of eigenvectors that represent the complete set of orthogonal (2 σ) variations of the various fit parameters;
- each set has 2 elements representing an upwards and downwards shift of that eigenvector;
- the total uncertainty is computing by summing in quadrature (asymmetrically) the shift due to the 22 eigenvectors;
- compute the total negative (positive) shift as the sum in quadrature of the negative (positive) shifts;
- if both variations of the eigenvector result a shift on the result of the same sign, consider as that shift the mean of these 2 values, the shift of the opposite sign is set to zero. (e.g. if both the positive and negative shift for eigenvector x result in a shift on the measurement of +0.004 and +0.002, the shift for eigenvector x will be set to +0.003 -0.00).

The individual shifts on the cross section due to the various eigenvectors are shown in Tabs. 2 and 3 for the CTEQ6.6 and CTEQ6AB PDFsets, respectively. Note that these are NOT shifts in the acceptance but in 1/acceptace, i.e. on the cross section. If we had assumed the $t\bar{t}$ and Z PDFs were completely uncorrelated (thus simply adding the 2 PDF uncertainties in quadrature) we would have obtained a total PDF uncertainty on R of 1.44% instead of the 1.47% obtained considering all correlations. The PDF uncertainties could thus have been treated as uncorrelated between $t\bar{t}$ and Z without affecting in any significant way the final result.

Table 4 shows a summary of all the systematic uncertainties considered for this analysis. It shows the values of each of the sources of uncertainty for each of the cross section measurements as well as the uncertainty on the ratio.

Effect	Calculation	Symmetrised?
Jet E_T Scale	For $t\bar{t}$: $\pm 1\sigma$ change of the JES	NO
W+jets Q^2 Scale	For $t\bar{t}$: $Q_{fact} \cdot 2$ and $Q_{fact}/2$ signal MC samples	YES
Z Q^2 Scale	For Z: $Q_{fact} \cdot 2$ and $Q_{fact}/2$ signal MC samples	YES
$t\bar{t}$ IFSR	IFSR more and IFSR less $t\bar{t}$ MC samples	YES
QCD shape	For $t\bar{t}$: Difference between using jet-electrons and anti-electrons for QCD model	YES
QCD fraction	For $t\bar{t}$: Input QCD normalisation $\cdot 2$ and $/2$	YES
$t\bar{t}$ generator	For $t\bar{t}$: Difference in between templates using PYTHIA and HERWIG	YES
PDF	CTEQ6.6 eigenvectors and α_s variation (1)	NO
Other EWK	For $t\bar{t}$: From previous iteration of $t\bar{t}$ measurement	YES
Background	For Z: Independently vary each background by its uncertainty; Sum in quadrature	NO
MC Statistics	For Z: Statistics of the Z MC	YES
N_{jet} Scale Factor	For Z: Reweight the Z N_{jet} spectrum from MC to that of data (2)	YES
Lepton ID/trigger	Use JP uncertainties for each trigger	NO
Lepton Scale	For Z: Increase lepton scale by 1%	YES
Track ID	For Z: increase and decrease the SF for track finding (3)	NO
Zvtx SF	Use JP uncertainties	NO

Table 1: Definition of the methods used to compute each of the systematic uncertainties in this measurement and if the uncertainty gets symmetrised or not before computing the ratio. For all cases where the individual measurement is not explicitly specified, the proper correlation between the $t\bar{t}$ and Z cross section measurements is taken into account. *Notes*: (1) The full propagation of each eigenvector and α_s variation is done, with the final uncertainty computed only on the ratio. (2) The N_{jet} spectrum is used as it was found to be the kinematic variable with the largest variation between data and MC. ALPGEN is known to not model the N_{jet} spectrum of Zs (or Ws), due to the fact that it is only a LO MC. (3) The difference in efficiency between data and MC in identifying track objects is not taken into account with the Lepton ID SF, similarly the uncertainty due to this effect is not accounted for, thus requiring its own uncertainty.

CTEQ6.6 (NLO) fractional shifts relative to nominal				
	$\sigma_{t\bar{t}}$	σ_Z	$R = \frac{\sigma_{t\bar{t}}}{\sigma_Z}$	1/R
Nominal	0.00000	0.00000	0.00000	0.00000
1	-0.00037	0.00441	-0.00476	0.00479
-1	0.00038	-0.00445	0.00485	-0.00483
2	0.00019	-0.00395	0.00416	-0.00414
-2	-0.00019	0.00400	-0.00418	0.00419
3	0.00007	0.00043	-0.00036	0.00036
-3	-0.00007	-0.00043	0.00036	-0.00036
4	0.00014	0.00262	-0.00248	0.00248
-4	-0.00015	-0.00268	0.00254	-0.00253
5	-0.00012	-0.00074	0.00062	-0.00062
-5	0.00016	0.00095	-0.00079	0.00079
6	0.00101	-0.00478	0.00582	-0.00578
-6	-0.00095	0.00528	-0.00620	0.00624
7	0.00112	0.00347	-0.00234	0.00235
-7	-0.00108	-0.00325	0.00217	-0.00217
8	0.00043	0.00114	-0.00072	0.00072
-8	-0.00045	-0.00109	0.00064	-0.00064
9	-0.00072	0.00065	-0.00137	0.00137
-9	0.00084	-0.00086	0.00171	-0.00170
10	-0.00012	0.00373	-0.00384	0.00385
-10	0.00016	-0.00356	0.00373	-0.00372
11	0.00182	-0.00012	0.00193	-0.00193
-11	-0.00130	0.00043	-0.00174	0.00174
12	-0.00039	0.00052	-0.00091	0.00091
-12	0.00098	-0.00059	0.00157	-0.00157
13	-0.00079	0.00141	-0.00220	0.00221
-13	0.00100	-0.00162	0.00263	-0.00262
14	-0.00049	-0.00545	0.00499	-0.00496
-14	0.00054	0.00492	-0.00436	0.00438
15	0.00013	-0.00211	0.00224	-0.00224
-15	0.00004	0.00244	-0.00239	0.00240
16	0.00159	-0.00230	0.00390	-0.00388
-16	-0.00087	0.00281	-0.00367	0.00368
17	0.00208	0.00175	0.00033	-0.00033
-17	-0.00115	-0.00245	0.00131	-0.00131
18	0.00017	0.00037	-0.00021	0.00021
-18	0.00017	-0.00176	0.00193	-0.00193
19	0.00166	0.00046	0.00120	-0.00120
-19	-0.00091	-0.00020	-0.00071	0.00071
20	-0.00016	-0.00085	0.00070	-0.00070
-20	0.00046	0.00100	-0.00054	0.00054
21	-0.00022	-0.00237	0.00216	-0.00215
-21	0.00051	0.00171	-0.00120	0.00120
22	0.00010	-0.00635	0.00649	-0.00645
-22	-0.00018	-0.00594	0.00580	-0.00577

Table 2: PDF uncertainty on the $t\bar{t}$ and Z cross section as well as on the ratios R and 1/R. The table shows the fractional shifts on the cross section (i.e. not acceptance) due to the individual CTEQ6.6 eigenvectors. The shifts are shown relative to the CTEQ6.6 nominal PDFs, which are used to compute the central value of this measurement.

CTEQ6AB				
subset	$\sigma_{t\bar{t}}$	σ_Z	$R = \frac{\sigma_{t\bar{t}}}{\sigma_Z}$	1/R
3 (-1 σ)	-0.00097	0.00341	-0.00436	0.00438
4	0.00000	0.00000	0.00000	0.00000
5 (+1 σ)	0.00089	-0.00352	0.00442	-0.00440

Total PDF uncertainty				
	$\sigma_{t\bar{t}}$	σ_Z	$R = \frac{\sigma_{t\bar{t}}}{\sigma_Z}$	1/R
CTEQ6.6 +	0.0043694	0.0121224	0.01452496	0.01259574
CTEQ6.6 -	-0.0029558	-0.0136792	-0.01254183	-0.01446016
α_s +	0.00089	0.003408	0.00442074	0.00438225
α_s -	-0.00097	-0.003519	-0.004363	-0.00440128
Total +	0.00446	0.01259	0.01518	0.01334
Total -	-0.00311	-0.01412	-0.01328	-0.01512
Total $\pm$	0.00378	0.013358	0.01423	0.01423

Table 3: PDF uncertainty on the $t\bar{t}$ and Z cross section as well as on the ratios R and 1/R. The table shows the shift on the cross section (i.e. not acceptance) due to the α_s variation. These CTEQ6AB values are shown relative to the nominal α_s value (subset 4). Also shown in this table are the total uncertainties used to compute the final PDF uncertainty: the CTEQ and α_s uncertainties are added in quadrature.

Effect	$\Delta\sigma_{t\bar{t}}$ (%)	$\Delta\sigma_Z$(%)	ΔR%
Statistical	5.9	0.4	6.0
Jet E_T Scale	3.2	-	3.2
W+jets Q^2 Scale	1.7	-	1.7
Z Q^2 Scale	-	0.3	0.3
$t\bar{t}$ IFSR	0.5	0.00	0.5
QCD shape	1.1	-	1.1
QCD fraction	1.4	-	1.4
$t\bar{t}$ generator	2.7	-	2.7
PDF	0.4	1.3	1.4
Other EWK	1.0	-	1.0
Background	-	0.06	0.06
MC Statistics	-	0.2	0.2
N_{jet} Scale Factor	-	0.02	0.02
Lepton Scale	-	0.1	0.1
Track ID	-	0.6	0.6
Lepton ID/trigger	0.6	0.9	0.6
Zvtx SF	0.3	0.3	0.3
Systematic before Lumi	5.1	1.8	5.4
Luminosity	5.8	5.9	0.4
Total Systematic	7.8	6.2	5.4
Total (stat and sys)	9.8	6.2	8.0

Table 4: Table for systematic errors for the $t\bar{t}$ and Z cross section measurements as well as the ratio of the two. The overall uncertainty is obtained by adding in quadrature the individual effects. A dash indicates that this source of uncertainty does not apply to that particular measurement. A value of zero means that the source was investigated but found to have lower uncertainty that rounding quoted in this table.

4 $t\bar{t}$ Cross Section Using Only CEM and CMUP Triggers

The cross section for $t\bar{t}$ production is defined based on the following formula.

$$\sigma_{t\bar{t}} = \frac{N_{t\bar{t}}}{\sum_{\rm trig} A_{\rm trig}(t\bar{t}) \cdot \mathcal{L}_{\rm trig}}, \tag{1}$$

where $N_{t\bar{t}}$ is the number of observed $t\bar{t}$ events in the data, $\sigma_{t\bar{t}}$ is the $t\bar{t}$ cross section that we fit for, $\mathcal{L}_{trig}$ is the integrated luminosity, and A_{trig} is the acceptance.

The following sections detail the calculation of each of these components.

4.1 Data Events

Table 5 contains the number of observed events in data separated by trigger. These are the same numbers as presented in CDF note 9387. We can see that removing the CMX trigger decreases the total number of events by 814 (15%). The number of expected $t\bar{t}$ events is also shown based with an assumed $t\bar{t}$ cross section of 6.7 pb. The expected statistical uncertainty, shown in Tab. 6, is increased from 0.38 to 0.41; the observed statistical uncertainties are similar.

CEM	CMUP	CMX	Total	CEM + CMUP	Expected (CEM+CMUP) $t\bar{t}$ (6.7 pb)
3101	1473	814	5388	4574	1036 ‘

Table 5: The number of events selected as a function of jet multiplicity for 2.819 fb^{-1} of CEM and CMUP data. The expected number of $t\bar{t}$ events, assuming a cross section of 6.7 pb, is also shown.

	Expected Statistical Sensitivity [pb] (%)	Observed Statistical Sensitivity [pb] (%)
W+≥3 jets	0.409 (6.1%)	0.408 (6.1%)

Table 6: Expected and observed statistical sensitivity (and fractional sensitivity in %).

4.2 Top Acceptance

The denominator of equation 1 can be written out explicitly in the following form (modified from CDF note 9387 based on the exclusion of the CMX trigger):

$$\sum_{trig} A_{trig}(t\bar{t}) \cdot \mathcal{L}_{trig} = [\ \varepsilon^{trigger}_{cmup}(t\bar{t}) \cdot SF^{IDreco}_{cmup}(t\bar{t}) \cdot A^{MC}_{cmup}(t\bar{t}) \cdot \mathcal{L}_{cmup} \tag{2}$$

$$+\ \varepsilon^{trigger}_{cem}(t\bar{t}) \cdot SF^{IDreco}_{cem}(t\bar{t}) \cdot A^{MC}_{cem}(t\bar{t}) \cdot \mathcal{L}_{cem}] \cdot SF_{Z_{vtx}}, \tag{3}$$

where $\varepsilon^{trig}(t\bar{t})$ is the trigger efficiency for that particular trigger, $SF^{IDreco}(t\bar{t})$ is the data / MC scale factor for the lepton identification and reconstruction and $A^{MC}(t\bar{t})$ in the $t\bar{t}$ acceptance in MC. These numbers are computed separately for each trigger. $SF_{Z_{vtx}}$ is the Z_{vtx} scale factor to account for the small difference in efficiency between data and MC when applying the $|Z_{vtx}| < 60$ cm cut.

The only difference in this method relative to CDF note 8387 is the exclusion of the CMX trigger (equivalent to setting the CMX trigger acceptance to zero) as well as using the MC acceptance from ttkt75 but re-weighted to the CTEQ6.6 PDF.

The raw acceptance numbers are shown in Tab. 7 for both the nominal CTEQ5L PDFs as well as the re-weighted CTEQ6.6 PDFs. Also shown in this table are the corrected acceptance numbers for data, i.e. after correction for the trigger efficiencies and ID+reconstruction scale factors.

Trigger	MC		Data	
	Nominal CTEQ5L	Re-weighted CTEQ6.6	Nominal CTEQ5L	Re-weighted CTEQ6.6
CEM	0.0367137	0.0366080	0.0354945	0.0353923
CMUP	0.0231969	0.0231404	0.0193777	0.0193305
CMX	0.0099541	0.0099222	0.0089634	0.0089347

Table 7: Top acceptance computed from ttkt75 PYTHIA MC as a function of trigger. Both the nominal generated numbers as well as those re-weighted to CTEQ6.6 PDFs are shown. The last 2 columns show the acceptance values corrected for trigger efficiencies and ID+reconstruction scale factors.

4.3 Top Cross Sectin Results

The input QCD normalisation is obtained in the same way as in CDF note 9387 but with the new templates for $t\bar{t}$ (re-weighted to CTEQ6.6) and with only the CEM and CMUP triggers. The input QCD normalisation is found to be 252.1 events. As a reminder, in the final fit the QCD normalisation is allowed to float within ±50% of the nominal value.

Figure 1 shows the final fit to the NN output distribution.

The total number of data events is 4574. The fit to the NN output returns 427 QCD events, 3064 W+jets events and 1078 $t\bar{t}$ events. Converting this to a cross section, the fit returns a value for the $t\bar{t}$ cross section of

$$\sigma_{t\bar{t}} = 6.97 \pm 0.41(stat)pb. \quad (4)$$

Taking into account the systematic uncertainties shown in Tab. 4, the final measured $t\bar{t}$ cross section for a top mass of 175 GeV/c^2 is

$$\sigma_{t\bar{t}} = 6.97 \pm 0.41(stat)^{+0.40}_{-0.32}(syst) \pm 0.40(lumi)pb. \quad (5)$$

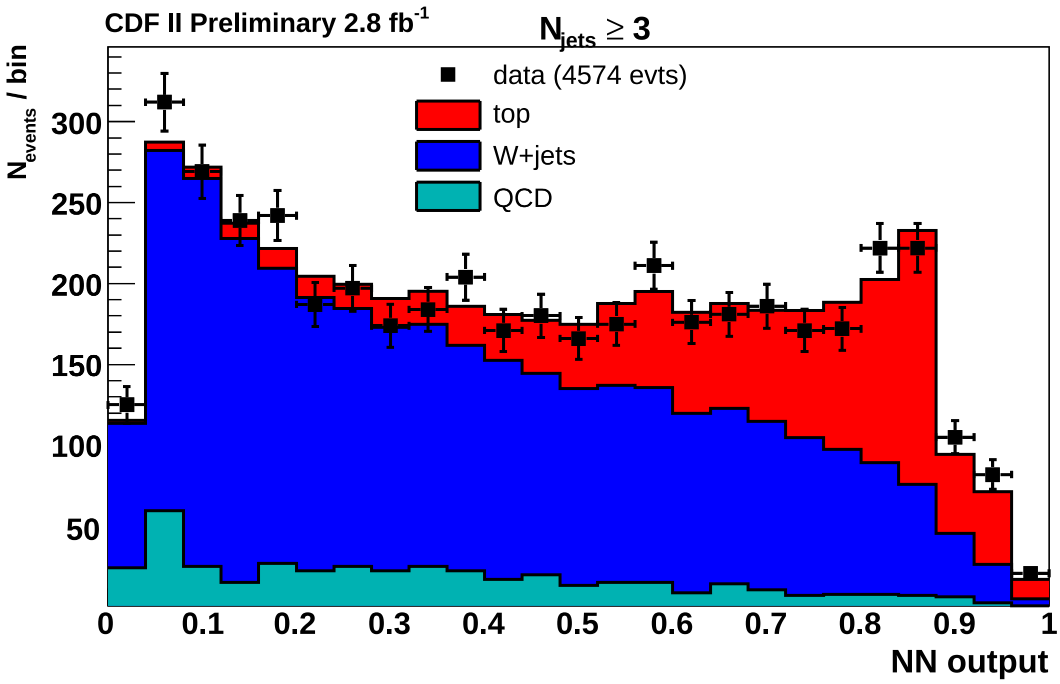

Figure 1: Fit to the NN output variable in the ≥ 3 jet sample using only the CEM and CMUP triggers and reweighting the $t\bar{t}$ templates to the CTEQ6.6 PDFs.

Combining the luminosity into the systematic we get

$$\sigma_{t\bar{t}} = 6.97 \pm 0.41(stat)^{+0.57}_{-0.52}(syst)pb. \tag{6}$$

This corresponds to a statistical uncertainty of +6.0%-5.9%, a systematic uncertainty of +5.7%-4.6% and a luminosity uncertainty of ± 5.8%. The total uncertainty on the $t\bar{t}$ cross section measurement at this point is is 9.8%; this number is to be compared with the 9.4% when including the CMX trigger.

5 Measurement of the Z Cross Section

The measurement of the Z cross section is described in detail in CDF note 9529 [2]. In essence the cross section is measured in the CEM+CEM and CMUP+CMUP channels. This counting experiment has very little background and the systematics are dominated by the uncertainty due to the PDFs. The only difference with respect to the other note is the use of the good run list without the silicon requirements, thus slightly increasing the luminosity.

The measurement follows the following procedure

- Measure the cross section in data using the mass window 66-116 GeV/c^2;
- Re-weight acceptance to NLO CTEQ6.6 nominal PDFs;
- Correct for virtual photon contribution as well as finite mass window of measurement.

The raw Z cross section is measured to be

$$\sigma_Z^{raw} = 263.55 \pm 1.05(stat)pb. \tag{7}$$

The increase in acceptance from CTEQ5L to CTEQ6.6 is

$$C_{acc}^{NLOPDF} = 1.04055. \tag{8}$$

To correct for the virtual photon contribution as well as for the finite mass window, the cross section is increased by a factor

$$F_{mass,\gamma^*} = 1.004. \tag{9}$$

The corrected Z cross section measurement is thus given by

$$\sigma_Z = \sigma_Z^{raw} \cdot \frac{F_{mass,\gamma^*}}{C_{acc}^{NLOPDF}}. \tag{10}$$

The systematic uncertainties on this measurement are shown in the third column of Tab. 4.

The resulting corrected Z cross section is

$$\sigma_Z = 253.27 \pm 1.01(stat)^{+4.4}_{-4.6}(syst)^{+16.63}_{-13.71}(lumi.)pb \tag{11}$$

This corresponds to a statistical uncertainty of 0.4%, a systematic uncertainty of +1.7%-1.8% and a luminosity uncertainty of +6.6%-5.2%. The total uncertainty on the Z cross section measurement is thus 6.1%, most of which comes from the luminosity uncertainty.

6 Ratio of the $t\bar{t}$ to the Z Cross Section

Having obtained both the $t\bar{t}$ and the Z cross section measurements, one can now consider the ratio of this two quantities

$$R = \frac{\sigma_{t\bar{t}}}{\sigma_Z}, \tag{12}$$

Or in a somewhat easier number to grasp (nobody likes grasping small numbers...)

$$\frac{1}{R} = \frac{\sigma_Z}{\sigma_{t\bar{t}}}. \tag{13}$$

The systematics take into account the correct correlations between the $t\bar{t}$ and the Z cross sections measurements, as described in section 3. Table 4 shows the systematic uncertainties on R in the 4th column. The residual luminosity uncertainty is 0.36% which comes mostly from the fact that in the Z cross section, some of the backgrounds are not proportional to the luminosity but estimated directly from data, where as in the $t\bar{t}$ cross section measurement, because the backgrounds are also floated in the fit, no such effect is present.

The final ratio comes out to be (including the luminosity in the systematic uncertainty)

$$R = 0.0274 \pm 0.0016(stat)^{+0.0016}_{-0.0013}(sys). \tag{14}$$

The total uncertainty on R is thus +8.4%-7.7% which symmetrised gives ±8.0%. The inverse of this ratio is

$$\frac{1}{R} = 36.47^{+2.06}_{-2.29}(stat)^{+1.88}_{-1.96}(sys). \tag{15}$$

The total uncertainty on $\frac{1}{R}$ is thus +8.1%-7.9%, which symmetrised also gives ±8.0%.

7 Unfolding Back to the $t\bar{t}$ Cross Section

The final step in this process is to obtain the value for the $t\bar{t}$ cross section by multiplying the ratio R calculated in the previous section by the theoretical Z cross section.
The best theoretical cross section prediction [3] is

$$\sigma_Z^{theory} = 251.3 \pm 5.0 pb(sys). \quad (16)$$

The systematic uncertainty on this calculation are due to the PDF uncertainties (computed from CTEQ6M PDFs) and the uncertainty on the factorisation and renormalisation scales.

The final $t\bar{t}$ cross section is thus given by

$$\sigma_{t\bar{t}} = R \cdot \sigma_Z^{theory}. \quad (17)$$

In this case the systematics between R and the theoretical calculation are taken to be uncorrelated. The PDF uncertainties are found to be essentially uncorrelated; this was verified by computing the PDF uncertainty on R using the same PDF set as used in the calculation and correctly accounting for the correlations when computing the total PDF uncertainty. Thus using CTEQ6M PDF uncertainties for the theoretical prediction and CTEQ6.6 for the experimental values is not a problem.

Taking the results from Sec. 6 we obtain the final result of this measurement

$$\sigma_{t\bar{t}} = 6.89 \pm 0.41(stat)^{+0.41}_{-0.37}(sys) \pm 0.14(theory) pb. \quad (18)$$

The uncertainties in percent on this measurement are +6.0%-5.9% statistical, +5.9%-4.9% systematic, and ±2.0% due to the theoretical Z cross section calculation. The total uncertainty on this measurement is 8.2%.

8 Conclusions

CDF note 9387 shows for the $t\bar{t}$ cross section a central value of 7.08 pb with total uncertainty of 9.8%. The statistical uncertainty was 5.4% and the total systematic of 7.7%. The measurement presented in this note significantly reduces the total uncertainty which is now 8.2%. This uncertainty is now comparable, if not better than the best theoretical predictions of the $t\bar{t}$ cross section.
Without any changes to the analysis with respect to CDF note 8387 except for increased statistics, to obtain a total uncertainty of 8.2%, the statistical uncertainty would have to be reduced to 2.8%. Assuming that the statistical uncertainty goes as $\frac{1}{\sqrt{\mathcal{L}}}$, this precision would have required a total usable luminosity of 10 fb^{-1}, about 3.5 times the amount of data currently available, more than any realistic Tevatron integrated luminosity projection.

References

[1] A. Lister, K. Lannon, J. Conway, R. Erbacher , R. Hughes, B. Winer, *Measurement of ttbar Cross Section in Lepton Plus Jets Channel Using Neural Networks in 2.8 fb^{-1}*, CDF Note 9387 (2008).

[2] T. Schwarz, A. Ivanov, R. Erbacher, W. Johnson, *Meausurement of the Ratio of the Top Pair Cross Section to the Z boson Cross Section*, CDF note 9529 (2008).

[3] CDF Collaboration, hep-ex/0508029 (2005).