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Measurement of $t\bar{t}$ Production Cross Section in Dilepton Channel using 4.5 fb^{-1} of Run II Data

The CDF Collaboration[1]

Abstract

We report on a measurement of the top cross section using candidates events selected in dilepton channel with each lepton identified as electron or muon. We evaluate backgrounds using normalized simulation samples for both pre-tag and tagged events. In a sample of 4.47 fb^{-1} of data we obtain

$$\sigma_{t\bar{t}}^{pre} = 6.56 \pm 0.65_{stat} \pm 0.41_{syst} \pm 0.38_{lumi} \text{ pb}$$

for 215 candidate events before applying loose SecVtx tagging, and

$$\sigma_{t\bar{t}}^{tag} = 7.27 \pm 0.71_{stat} \pm 0.46_{syst} \pm 0.42_{lumi} \text{ pb}$$

for 119 candidate events containing at least one identified b-jet.

[1]http://www-cdf.fnal.gov

1 Introduction

After the great success of the Fermilab Tevatron in Run I (1992-1995), the CDF collaboration is eagerly pursuing an exhaustive program of top quark physics during Run II (2002 - present). In addition to improvements in the detector acceptance and performance resulting from the upgraded CDF detector, the center-of-mass energy of $p\bar{p}$ collisions produced at the Tevatron have gone from $\sqrt{s} = 1.8$ TeV in Run I to $\sqrt{s} = 1.96$ TeV in Run II.

Measurements of the $t\bar{t}$ production cross sections $\sigma(p\bar{p} \to t\bar{t})$ provide important tests of the consistency of the Standard Model top quark parameters as well as tests of theoretical QCD calculations. The analysis is based on the identification of both leptons in the decay chain $t\bar{t} \to (W^+b)(W^-\bar{b}) \to (\ell^+\bar{\nu}b)(\ell^-\nu\bar{b})$. The excess of events selected in the data over the background expectation from the production of $t\bar{t}$ events.

This measurement provides an independent test of the $t\bar{t}$ cross section result obtained in higher statistics channel where at least one W boson from the top quark is reconstructed via its hadronic decay, $W \to q\bar{q}$. It is also the only final state with a favorable signal to background ratio.

2 Data Sample and Event Selection

The top pair production signature in dilepton channel consists of two charged leptons, two b quarks which hadronize and are detected as jets, and two energetic neutrinos which escape the detector without interacting. In order to isolate this signature, we select events from the data with two reconstructed leptons, two or more jets, and significant missing transverse energy $\not{E}_T$ resulting from the neutrinos. In addition to this we use a higher purity configuration of the secondary vertex tagger to identify at least one jet in the event as a b-jet, the algorithm known as "b-tagging".

This analysis is based on a new data collected with the CDFII detector between March 2002 and May 2009 with total integrated luminosity of 4.47 fb^{-1}. The data are collected with an inclusive high-E_T central electron or muon trigger path. From this inclusive lepton dataset, events containing a pair of oppositely charged isolated leptons with $E_T \geq 20$ GeV are selected. Each central lepton is identified as a reconstructed stiff track matched to either calorimeter electromagnetic shower in case of electrons or calorimeter towers with small energy response consistent with minimum ionizing particle in case of muons. This dilepton dataset is cleaned of other known neutrinoless events with two leptons in the final states by requiring $\not{E}_T \geq 25$ GeV. For the purpose of our selection we define jets as the clusters of calorimeter energy separated from leptons and passing $E_T \geq 15$ GeV requiremnt from $|\eta| < 2.5$ region of the detector. In order to purify the signal events we require at least two jets one of which has 30 GeV or more in transverse energy.

3 Background Model

The sources of background processes considered for this selection are grouped into those where both leptons originating from vector boson decay and those where at least one reconstructed lepton is coming from a different source. The former background group includes Drell-Yan and diboson processes and the latter backgrounds is generated by semileptonic decays or fake leptons in hadronic production processes.

Backgrounds from diboson WW, WZ, ZZ and Z/γ^* events are predicted based on the normalized yields of the simulation samples which takes into account acceptance and efficiencies, the theoretical prediction for the cross-section, and matching the collected data luminosity. This normalization is also known as absolute normalization of simulation samples. Differences in various parameters between simulation and actual data are corrected by introducing scale factors. For example, we apply jet multiplicity scale factors for processes where hadronic production comes from QCD radiation such as Z/γ^* and WW.

For estimating the fake or QCD backcground we rely on dilepton data sample where both leptons have the same charge. By doing so we assume that same charge lepton pairs happen at the same rate as oppositely charged lepton pairs in data sample where at least one lepton is not originating from W or Z leptonic decay. This assumption is validated further is seen n Figures 1 and 2 by examining electron-muon control sample where most of the backgrounds contribute comparably.

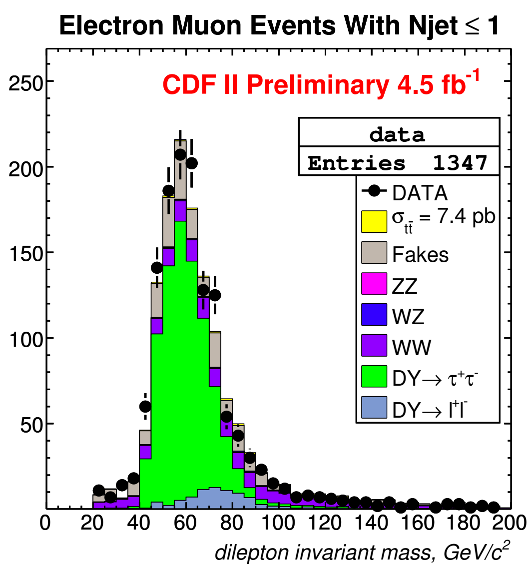

Figure 1: Dilepton invariant mass spectrum for electron muon events.

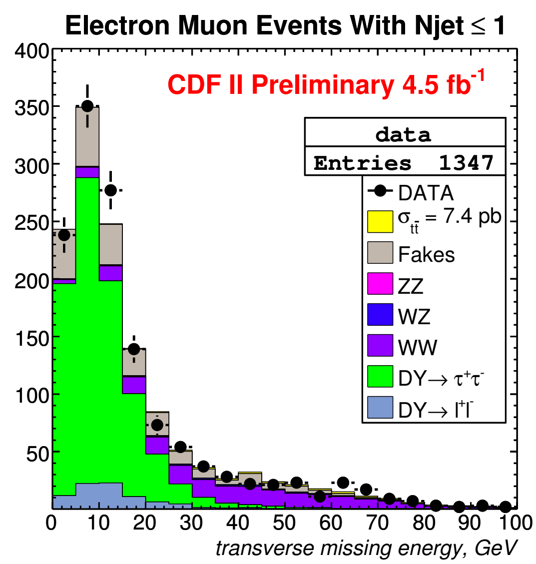

Figure 2: Missing transverse energy spectrum for electron muon events.

4 Measuring Production Cross Sections

The measured cross section can be expressed as

$$\sigma(p\bar{p} \to t\bar{t}) = \frac{N - B}{A\epsilon \int \mathcal{L}dt}, \tag{1}$$

where N is the number of observed events, B is the estimated amount of background events, A is the kinematic and geometric acceptance, ϵ is the event selection efficiency and $\int \mathcal{L}dt$ is the integrated luminosity of the data sample.

Tables 1 and 2 summarize the sample composition for our pre-tag and b-tag signal respectively according to lepton flavor contribution.

Process	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$	$\ell^+\ell^-$
$t\bar{t},\ \sigma = 7.4$ pb	47.9	33.4	90.8	172.2
$Z/\gamma^* \to \ell^+\ell^-$	13.4	6.2	0.4	20.0
$Z/\gamma^* \to \tau^+\tau^-$	3.6	2.9	7.5	14.0
$WW \to \ell^+\ell^-$	3.5	2.4	5.7	11.6
$WZ \to \ell^+\ell^-$	1.9	0.9	0.8	3.6
$ZZ \to \ell^+\ell^-$	0.9	0.5	0.3	1.7
Monte Carlo	71.2	46.3	105.6	223.1
Data SS	8	0.00	8	16
Sum	79.2 ± 3.4	46.3 ± 1.4	113.6 ± 3.1	239.1 ± 5.7
Data OS	63	48	104	215

Table 1: Top candidate pretag sample composition for dilepton events with $N_{jet} \geq 2$.

Process	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$	$\ell^+\ell^-$
$t\bar{t},\ \sigma = 7.4$ pb	31.9	22.1	60.7	114.7
$Z/\gamma^* \to \ell^+\ell^-$	1.2	0.6	0.0	1.8
$Z/\gamma^* \to \tau^+\tau^-$	0.3	0.2	0.6	1.2
$WW \to \ell^+\ell^-$	0.3	0.2	0.4	0.9
$WZ \to \ell^+\ell^-$	0.1	0.1	0.0	0.2
$ZZ \to \ell^+\ell^-$	0.1	0.1	0.0	0.2
Monte Carlo	33.9	23.3	61.8	119.0
Data SS	1	0	2	3
Sum	34.9±1.1	23.3±1.0	63.8±1.4	122.0 ±1.9
Data OS	33	28	58	119

Table 2: Sample composition for b-tag top candidate events.

We determine the kinematic and geometric acceptance, A, using a Monte Carlo simulation. For selection with the tagged jets we define the event b-tagging efficiency,

ϵ, as the probability to tag at least one jet which passes the jet selection requirements in $t\bar{t}$ events. This parameter depends on the SecVtx scale factor and the fractions of $t\bar{t}$ events with 1 and 2 taggable jets.

For the pretag selection we have

- total number of candidate events is $N = 215$
- total background $B = 66.9 \pm 5.7$ dominated by uncertainty of fake dilepton events as well as jet multiplicity scale factor
- denominator $A(\epsilon \cdot SF)\mathcal{L} = 22.577 \pm 1.131$ pb^{-1} includes uncertainties for acceptance and efficiency scale factors

and for the events with the b-tag

- total number of candidate events is $N = 119$
- total background is $B = 7.3 \pm 1.9$ dominated by uncertainty of fake dilepton events as well as Method I tagging model
- pretag denominator is multiplied by the event tagging efficiency $\epsilon_{tag} = 0.681 \pm 0.024$ which invcludes 4.7% uncertainty on b-tag scale factor

We obtain the following production cross section values

$$\sigma_{t\bar{t}}^{pre} = 6.56 \pm 0.65_{stat} \pm 0.41_{syst} \pm 0.38_{lumi} \text{ pb}$$

for candidate events before applying loose SecVtx tagging, and

$$\sigma_{t\bar{t}}^{tag} = 7.27 \pm 0.71_{stat} \pm 0.46_{syst} \pm 0.42_{lumi} \text{ pb}$$

for events containing at least one loose b-tag. The first uncertainty number is statistical, the second is the convolution of the acceptance and background systematics and the third comes from the 6 % uncertainty in the luminosity measurement.

Figure 3 shows the jet multiplicity distribution for selected events both for candidate N$_{jet} \geq 2$ and control N$_{jet} = 1$ region. Figure 4 demonstrates the number of tags distribution for candidate events Figures 5–8 compare the various kinematic quantities such as lepton transverse momentum, dilepton invariant dilepton mass, and event energy quantities of the candidate events in the data to the expectation based on the Standard Model $t\bar{t}$ signal and background. Note that the measured cross-section is used to normalize the $t\bar{t}$ distribution, so that the integral number of observed events is equal to the number predicted, and the comparison is between shapes only. We find good agreement between the distribution in the data and the Standard Model expectation.

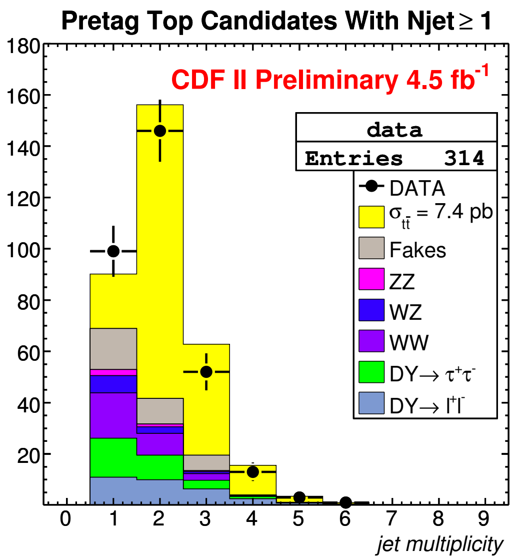

Figure 3: Jet multiplicity distribution for selected candidate and control events.

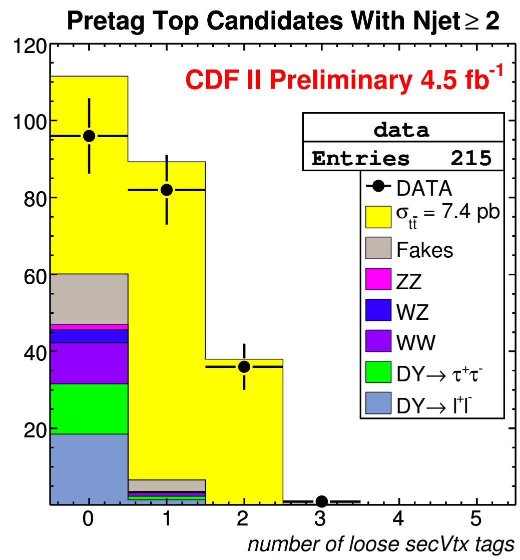

Figure 4: Number of SecVtx tags in $N_{jet} \geq 2$ candidate sample.

Source of systematics	Relative uncertainty, %
Pretag background	3.85
Lepton selection	1.69
Lepton P_T scale	0.82
Jet energy scale	2.70
ISR/FSR	1.58
PDF	0.80
Z vertex	0.21
Generator	0.94
Color reconnection	2.61
W leptonic branching	1.85
Total systematics	6.32

Table 3: Summary of systematic uncertainties when using pretag selection.

Source of systematics	Relative uncertainty, %
Tagged background	1.73
Lepton selection	1.69
Lepton P_T scale	0.82
Jet energy scale	2.70
ISR/FSR	1.58
PDF	0.80
Z vertex	0.21
Generator	0.94
Color reconnection	2.61
W leptonic branching	1.85
b-tagging efficiency	3.52
Total systematics	6.36

Table 4: Summary of systematic uncertainties when using selection with b-tag
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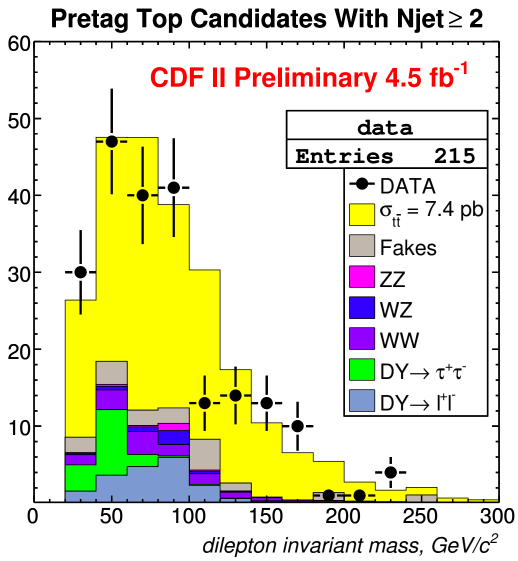

Figure 5: Dilepton invariant mass for pre-tag top candidate events.

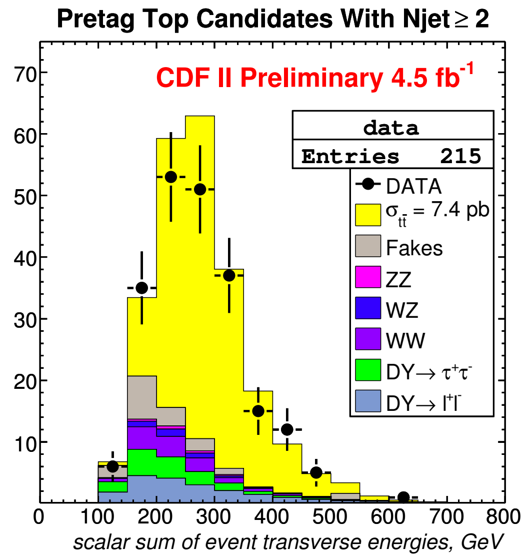

Figure 6: Event transverse momentum for pre-tag top candidate events.

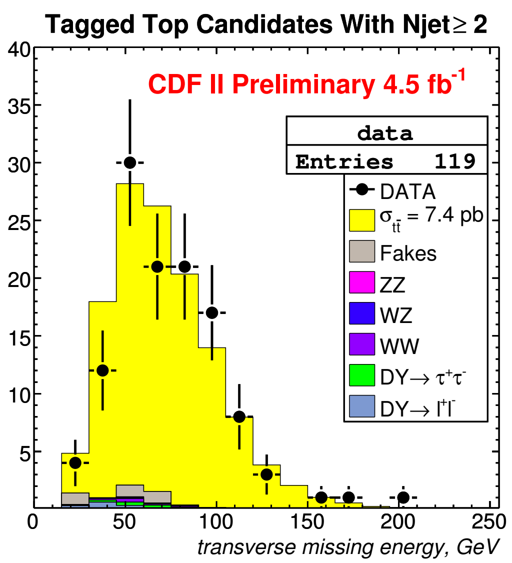

Figure 7: Transverse missing energy for tagged top candidate events.

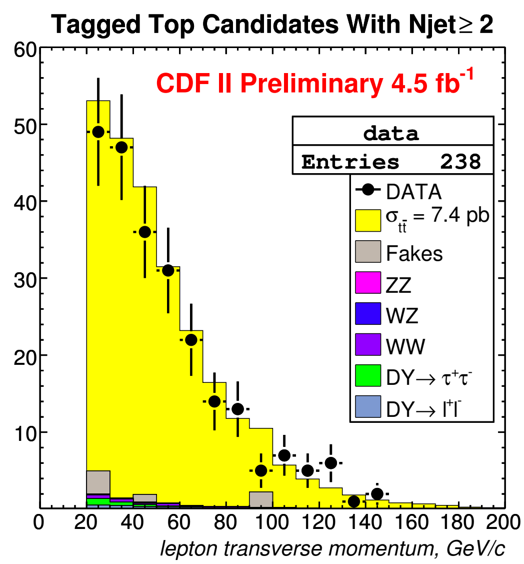

Figure 8: Lepton transverse momentum for tagged top candidate events.

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