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Measurement of $t\bar{t}$ Production Cross Section using Dilepton Channel with Tight SecVtx Tagging in 2.0 fb^{-1}

The CDF Collaboration[1]

Abstract

We report on a measurement of the top cross section using candidates events selected in dilepton channel with at least one SecVtx tagged jet. We evaluate the tagged background by applying the SecVtx positive tag rate matrix to the pre-tagged dilepton sample. We validate our tagging model by comparing observed and predicted number of tags in Z data events. In a sample of 1981 pb^{-1} of data we obtain

$$\sigma_{t\bar{t}} = 8.96 \pm 1.12_{stat} \pm 0.72_{syst} \pm 0.52_{lumi} \text{ pb.}$$

[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. We use a higher purity configuration of teh SecVtx 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 2007 with total integrated luminosity of 2.0 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 $\not{E}_T \geq 20$ 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.

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 bear 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 conttribute comparably.

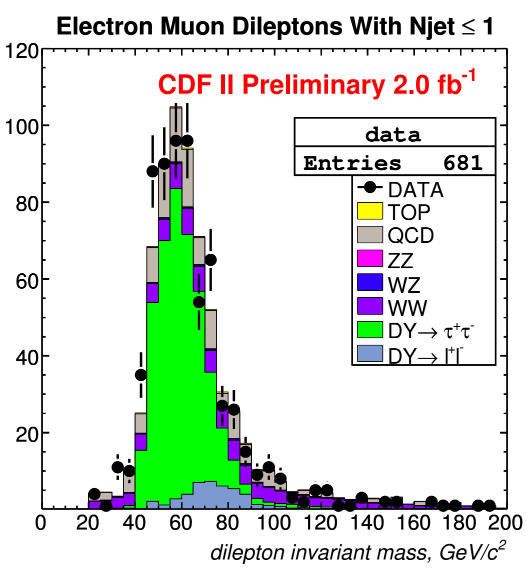

Figure 1: Dilepton invariant mass spectrum for electron muon events.

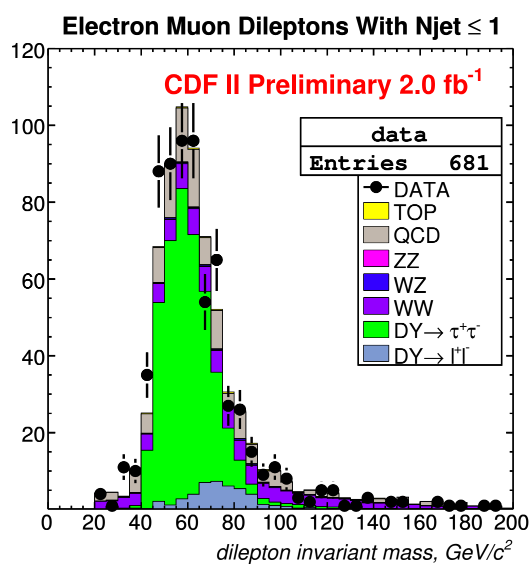

Figure 2: Missing transverse energy spectrum for electron muon events.

4 B-Tagging Model

For the purpose of establishing b-tagging model we divide our sample into two parts:

- processes such as $ZZ \to \ell^+\ell^- b\bar{b}$ and $t\bar{t} \to \ell^+\bar{\nu}b\ell^-\nu\bar{b}$ for which associated heavy flavor production rates considerably exceed those found in generic QCD samples
- processes such as Drell-Yan and WW for which associated heavy flavor production rates consistent with those found in generic QCD samples

For the former samples we just count the number of tags found in simulation. On the other hand for the latter processes we predict the tagging rate by using the b-tag matrix on pretag simulation samples. The matrix takes into consideration five quantities such as jet E_T , the number of tracks in the jet, jet η, the number of primary vertices in the event, and the total scalar sum of the E_T of all the jets. Generic QCD jet samples are used for calculating the matrix parameters.

We study how well the tag rate matrix method performs for an obvious control sample: Drell-Yan candidate events with invariant mass near the Z pole. We collect the Drell-Yan sample applying the same lepton and jet selection as used throughout this analysis. We constrained the dilepton invariant mass to be in the 80–100 GeV/c^2 value range.

Figure 3 shows the jet multiplicity distribution for events with positive and negative tags compared to the predicted rates. The agreement between the observed and predicted number of tags in each multiplicity bin is quite remarkable and well inside the statistical uncertainty of the sample. Table 1 summarizes the observed and predicted rates across various jet multiplicity bins.

Process	$N_{jet} = 1$				$N_{jet} \geq 2$			
	Pretag		Tag		Pretag		Tag	
	e^+e^-	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$
$Z/\gamma^* \to \ell^+\ell^-$	12369	5642	123.8	58.5	3062	1523	85.7	41.8
$ZZ \to \ell^+\ell^-$	7.14	3.80	0.36	0.19	18.6	10.3	2.38	1.33
$t\bar{t},\ \sigma = 6.7$ pb	0.65	0.35	0.25	0.12	5.49	3.44	3.31	2.04
Monte Carlo	12376	5647	127.4	58.8	3164	1537	94.4	45.1
Data SS (QCD)	261	1	3	0	77	0	3	0
Sum	12376	5647	127.4	58.8	3164	1537	94.4	45.1
Data OS	12369	5529	105	58	3222	1464	84	47
Data Prediction			119.5	55.9			81.8	36.7

Table 1: Observed and predicted tag rates of Drell-Yan events across various jet multiplicity bins. The last raw reports matrix prediction by using pretag data sample.

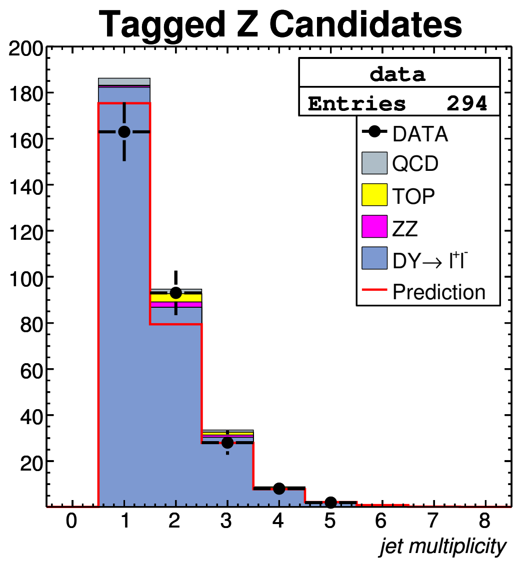

Figure 3: Jet multiplicity distribution for Drell-Yan candidate events containing at least one jet reconstructed with b-tag.

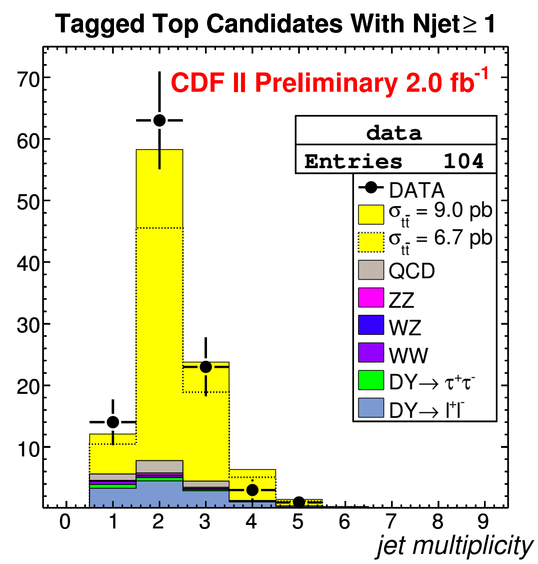

Figure 4: Jet multiplicity distribution for top candidate events containing at least one jet with b-tag.

5 Measuring Production Cross Sections

The measured cross section can be expressed as

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

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 b-tagging efficiency for top quark events and $\int \mathcal{L}dt$ is the integrated luminosity of the data sample.

Table 2 summarizes the sample composition for our b-tag signal divided by lepton flavor contribution.

We determine the kinematic and geometric acceptance, A, using a Monte Carlo simulation. The event b-tagging efficiency, ϵ, is 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 integrated luminosity of 1980.8 pb^{-1} the total denominator is 8.5±0.6 pb^{-1}

For $t\bar{t}$ events in the dilepton channel with b-tag, we find a cross section of:

$$\sigma_{t\bar{t}} = 8.96 \pm 1.12_{stat} \pm 0.72_{syst} \pm 0.52_{lumi} \text{ pb},$$

where the first uncertainty 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.

Process	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$	$\ell^+\ell^-$
$t\bar{t},\ \sigma = 6.7$ pb	16.41±1.78	10.64±1.61	29.92±3.8	56.96±7.19
$Z/\gamma^* \to \ell^+\ell^-$	6.18± 1.00	2.65±0.63	0.07±0.04	8.91±1.67
$ZZ \to \ell^+\ell^-$	0.28±0.02	0.18±0.02	0.01±0.00	0.48±0.05
$Z/\gamma^* \to \tau^+\tau^-$	0.21±0.04	0.14±0.03	0.44±0.10	0.79±0.17
$WW \to \ell^+\ell^-$	0.14±0.02	0.08±0.02	0.20±0.04	0.42±0.08
$WZ \to \ell^+\ell^-$	0.24±0.02	0.07±0.01	0.02±0.00	0.23±0.04
Monte Carlo	23.36 ± 2.18	13.77 ± 1.73	30.65 ± 2.49	67.79 ± 6.10
Data SS	1	0	2	3
Sum	24.36±2.27	13.77±1.73	32.65± 4.29	70.79 ±7.7
Data OS	26	21	43	90

Table 2: Sample composition for signal events.

The systematic uncertainty is dominated by dependence of the acceptance on the jet energy scale 3 %. Uncertainties on the background are also essential and make up about 2 % for Drell-Yan tagged contribution and 2 % for fake lepton background with tags.

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.

Acknowledgments

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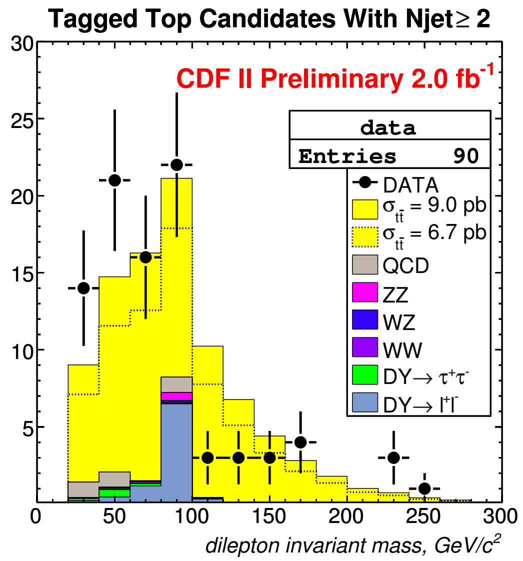

Figure 5: Dilepton invariant mass for tagged top candidate events.

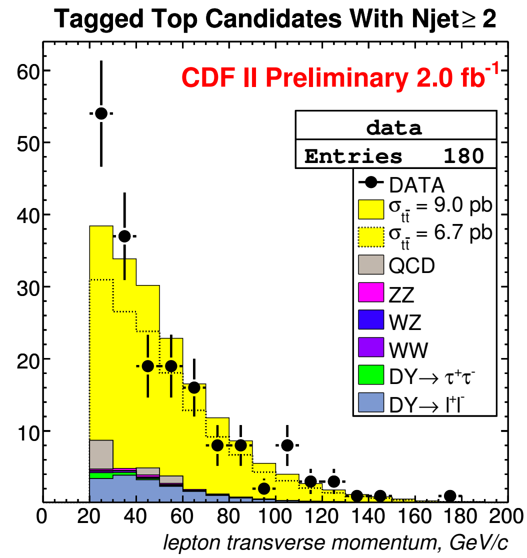

Figure 6: Lepton transverse momentum for tagged top candidate events.

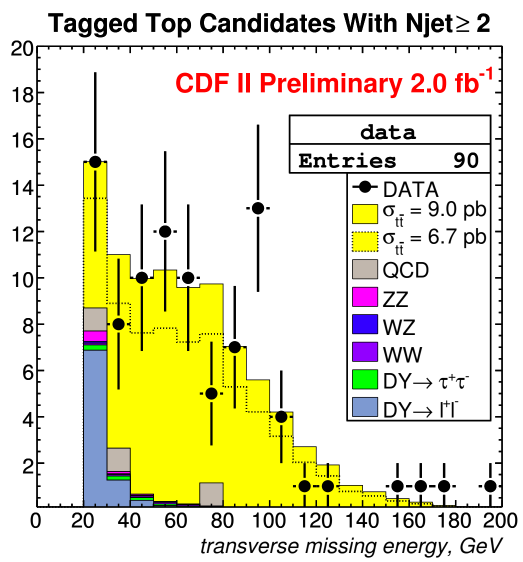

Figure 7: Transverse missing energy for tagged top candidate events.

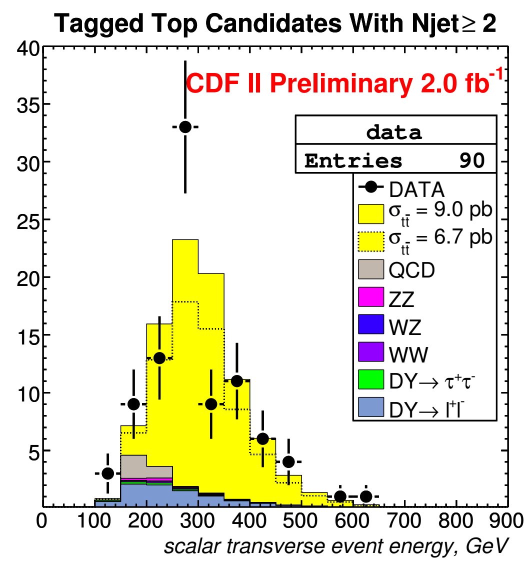

Figure 8: Event transverse momentum for tagged top candidate events.

References