CDF Note 9616

Measurement of the Ratio of the Top Pair Cross Section with the Z boson Cross Section

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The ratio of the top pair cross section with the Z boson cross section has been measured in 2.7 fb^{-1} of collected CDF data. The ratio is insensitive to the uncertainty on luminosity, which previously had been the leading systematic of the top pair cross section measurement. The $t\bar{t}$ cross section is measured in the lepton plus jets channel using SecVtx tagged lepton plus jets events. The Z boson cross section is measured in opposite signed dilepton events in the mass window 66 to 116 GeV. The result is $1/R = 35.7 \pm 2.0_{stat} \pm 3.2_{syst}$ where $R = \sigma_{t\bar{t}}/\sigma_{Z\rightarrow ll}$. The top cross section can be extracted by applying the theoretical Z boson cross section. The result is $\sigma_{t\bar{t}} = 7.0 \pm 0.4_{stat} \pm 0.6_{syst} \pm 0.1_{theory}$.

I. INTRODUCTION

The top cross-section has recently been measured at CDF near the precision of the theoretical uncertainty ($\sim 10\%$) [1][2]. The dominant systematic on the measurement is the uncertainty of the luminosity at 6 %. At first glance, this systematic would appear irreducible outside of rolling up our sleeves and building a better way to measure luminosity. Fortunately, we can apply a common technique from electroweak physics which is to measure the ratio of cross sections. Generally, this has been applied to the measurement of the W and Z boson cross sections, but the same method can be applied to the top measurement [3]. The ratio of the top pair cross section to the cross section of the Z boson will be nearly invariant to the luminosity: only Monte Carlo based backgrounds having any remnant effect. Furthermore, by multiplying the ratio by the theoretical Z cross section, we produce a measurement of the top pair cross section free of the luminosity systematic.

Another way to look at this measurement is to start from the standard cross section formula:

$$\sigma_Z = \frac{N_{data} - N_{bkg}}{A \cdot \mathcal{L}} \tag{1}$$

where, N_{data} is the amount of collected data in the signal region, N_{bkg} is the predicted background content, A is the acceptance of Z boson events and $\mathcal{L}$ is the luminosity. Instead of solving for the cross-section, we can input the theoretical cross-section and calculate the luminosity:

$$\mathcal{L} = \frac{N_{data} - N_{bkg}}{A \cdot \sigma_Z^{theory}} \tag{2}$$

This is essentially what is being done when we measure the ratio and apply the theoretical Z cross section to extract the top cross section.

Our procedure is to measure the top pair cross section using SecVtx tagged lepton plus jets events as described in reference [1]. The Z cross section is measured in events with exactly two opposite signed leptons. Both cross-section measurements use exactly the same triggers and therefore, have the exact same luminosity. Common systematics are fluctuated simultaneously in both measurements to calculate the systematic uncertainties on the ratio. We calculate the luminosity-free top cross section by applying the most recent theoretical Z cross section, $\sigma_Z = 251.3 \pm 5.0\, pb$ [4].

II. MEASURING THE TOP PAIR CROSS SECTION

For the top pair cross-section, data is selected using an inclusive high Pt lepton trigger requiring an electron or muon with at least 20 GeV. In addition, we require missing transverse energy $\not\!\!E_T > 25$ GeV, at least three jets present in the event with Et> 20 GeV, and the scalar sum of the transverse energy (Ht) of the jets, lepton, and $\not\!\!E_T$ to be greater then 230 GeV. A "tagging" algorithm, SecVtx, is used to find a displaced secondary vertex as evidence of a bottom quark decay [7].

In general, the cross section is calculated with the formula:

$$\sigma_{t\bar{t}} = \frac{N_{data} - N_{bkg}}{A \cdot \epsilon \cdot L} \tag{3}$$

where, N_{data} is the amount of collected data in the signal region, N_{bkg} is the predicted background content, A is the acceptance of $t\bar{t}$ events before requiring a tag, ϵ is the tagging efficiency, and L is the luminosity. Monte Carlo is relied upon to estimate acceptance and tagging efficiency, with corrections applied to account for differences in trigger efficiencies, tagging, and mis-tagging.

Most of the work in the measurement is in estimating the number of expected background events. For small electroweak backgrounds, such as di-boson and single top, we rely entirely upon Monte Carlo and measured or theoretical cross sections to calculate normalizations. Because of the difficultly in modeling non-W and W+jets, we rely on data-driven techniques. To determine the non-W fraction we fit the $\not\!\!E_T$ distribution of a non-W template and a MC signal template to data. Both data and model templates are fitted to the $\not\!\!E_T$ distribution of data events using a binned likelihood fit. In W+jets, we have to estimate two separate types of background, W in association with light flavor jets (W+LF) and that with heavy flavor (W+HF). Because W+HF events are poorly modeled in Monte Carlo, a data-driven correction factor is calculated in a non-signal region which effectively scales the amount

Systematic	$\Delta\sigma$	$\Delta\sigma/\sigma$
JES	0.29	4.1
B-Tagging	0.38	5.4
C-Tagging	0.09	1.3
Mistags	0.17	2.3
W+HF Correction	0.27	3.7
Luminosity	0.43	6.1
QCD Fraction	0.06	0.8
MC Generator	0.2	3.0
ISR/FSR	0.06	0.8
Trigger Eff/SF	0.04	0.6
PDF	0.04	0.6
Total	0.76	10.7%

TABLE I: Systematic uncertainties on the top pair measurement

of W+HF events predicted in the signal region. Events from W+LF only pass our selection requirements by faking a secondary vertex tag. This happens usually because of poorly reconstructed tracks. A data based parameterization of mis-tagged events is applied to data events that pass selection but before requiring a secondary vertex tag. The result is a prediction of the number of those events that could fake a tag.

With backgrounds in hand, we measure the cross section with a likelihood based upon the data, the top cross-section, and the predicted background for that cross-section. The measured value and statistical uncertainty is extracted from this likelihood. Systematic uncertainties are calculated by re-performing the measurement under $\pm 1\sigma$ deviations for a particular uncertainty. The result is:

$$\sigma_{t\bar{t}} = 7.1 \pm 0.4_{stat} \pm 0.6_{syst} \pm 0.4_{lumi} \tag{4}$$

A table of systematic uncertainties is shown in Figure I. Notice the largest systematic comes from the uncertainty on luminosity. A more complete description of this measurement can be found in reference [1].

III. MEASURING THE Z BOSON CROSS SECTION

We measure the inclusive Z/γ^* cross section in the invariant mass range of 66-116 GeV, using consistent lepton ID definition and trigger requirements with the top cross section measurement. Events are selected using two oppositely charged leptons. The leptons must form an invariant mass in the range 66-116 GeV. Additionally, we veto events where any of the leptons are flagged as originating from photon conversions or cosmic rays.

The Z/γ^* signal acceptance is modeled by inclusive PYTHIA monte carlo, generated with $M_{\ell\ell} > 20\,GeV$, and includes Z/γ^* decays to $e\bar{e}$ and $\mu\bar{\mu}$ final states. We take into account trigger efficiencies and differences in lepton reconstruction efficiencies between data and monte carlo using corresponding scale factors.

Although the $Z/\gamma^* \to \ell\bar{\ell}$ is an incredibly clean signal, there are some small backgrounds, most notably dibosons, top quarks, W+ fake lepton, and Drell-Yan from outside the mass range. Diboson contributions (including WW$^{(*)}$, WZ$^{(*)}$, ZZ$^{(*)}$) are modeled from inclusive PYTHIA monte carlo and fixed to their respective theoretical cross sections. The top contribution is also modeled using PYTHIA monte carlo, but is normalized to the measured cross section.

One of the dominant backgrounds to this measurement is the Z/γ^* process itself. Since we wish to compare this measurement to theory predictions, we must correct our experimental numbers to correspond more closely to theoretical quantities. We wish to determine the cross section of events were the Z/γ^* has a mass in the range 66-116 GeV, not events with a measured $M_{\ell\ell}$ in this mass range. For example, due to mis-measurements, or bremsstrahlung of an electron, an event with the Z/γ^* outside of the desired mass range might get reconstructed inside of the mass range; we do not wish to consider these events signal. We also consider $Z/\gamma^* \to \tau\bar{\tau}$ events, where both τ's are reconstructed as either electrons or muons, and thus fake our signal. These backgrounds are modeled by similar

Process	Events
Z+jets (signal)	59259.1
Z+jets (bkg)	199.4
Top	14.6
Di-boson	94.9
Fakes	28.0
Total Bkg	336.9
Data	59839

TABLE II: Estimated backgrounds for Z cross section calculation

Systematic Uncertainties Taken	
Source	Value (%)
Luminosity	5.9
Lepton ID	1.1
Z_0 Vertex Eff.	0.3
PDF Acceptance	1.3
Background Uncert.	0.1
Q^2	0.3
Total	15.6

TABLE III: Systematic uncertainties for the Z/γ^* cross section

monte carlo as the signal region, with the normalization determined via a data-derived k-factor (k_{Z/γ^*}) multiple to the LO cross section.

Finally, a small number of QCD and W+jets events can sneak through selection by faking an additional lepton. We estimate this contribution with a data driven approach based on studying same sign events that pass our event selection. The full background table is shown in Table II.

To calculate the cross section we use

$$\sigma_{Z/\gamma^*} = \frac{N_{data} - N_{background}}{\mathcal{A} \int \mathcal{L}dt} \tag{5}$$

where $\mathcal{A}$ is the acceptance (4.23 %), we report the cross section times branching ratio for Z/γ^* events in the invariant mass range of 66-116 GeV to be

$$BR(Z/\gamma^* \rightarrow \ell\ell) \times \sigma_{Z/\gamma^* \rightarrow \ell\ell} = 253.5 \pm 1.1_{stat} \pm 4.5_{syst} \pm 14.9_{lumi} \;\; pb. \tag{6}$$

The γ/Z cross-section is measured in the mass range 66-116 GeV. This measurement includes the correction factor to convert this to a Z-only measurement across the entire range (1.004) [4]. Systematic uncertainties are shown in Table III. Again the largest systematic is luminosity.

IV. MEASURING THE RATIO

From the two measured cross sections the ratio, $R = \sigma_{t\bar{t}}/\sigma_{Z\rightarrow ll}$ is:

$$1/R = 35.7 \pm 2.0_{stat} \pm 3.2_{syst} \tag{7}$$

The systematics are calculated by either error propagation or, for common systematics, by simultaneously varying the effect for both cross-section values and re-calculating the ratio. The individual evaluated systematic uncertainties are shown in Table IV.

My multiplying by the theoretical Z boson cross section we can convert out R measurement to a top pair cross section. Using $\sigma_Z = 251.3 \pm 5.0\ pb$ [4] we measure:

$$\sigma_{t\bar{t}} = 7.0 \pm 0.4_{stat} \pm 0.6_{syst} \pm 0.1_{theory} \tag{8}$$

The result has a 10% uncertainty. The precision on the top cross section has increased by 20% by using the Z cross section to marginalize the luminosity systematic. The combined systematic uncertainties on the ratio are shown in Table IV.

Systematic	$\Delta\sigma/\sigma$
JES	4.0
BTag SF	5.4
C Tag SF	1.3
Mistag Matrix	2.3
K Factor	3.8
Luminosity	0.2
QCD Fraction	0.8
MC Generator	3.1
ISR/FSR	0.8
CEM ID	0.5
CEM Trig	0.3
CMUP ID	0.0
CMUP Trig	0.1
Track ID	0.6
Z0	0.0
PDF	1.4
CEM Energy Scale	0.0
CMUP Energy Scale	0.0
Z Background	0.1
NJet SF	0.0
Q^2	0.3
Total	8.98

TABLE IV: Systematic uncertainties on 1/R

Acknowledgments

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[1] Ivanov, Schwarz, Erbacher, CDF Note 9462
[2] A. Lister, J. Conway, R. Erbacher, K. Lannon, R. Hughes, B. Winer, CDF Note 9474
[3] Schmitt, CDF Note 6895
[4] CDF Collaboration, hep-ex/0508029
[5] F. Abe et al., Nucl. Instrum. Methods Phys. Res A 271, 387 (1988)
D. Amidei, et al, Nucl. Imstrum. Methods Phys. Res. A 350, 73 (1994)
F. Abe et al., Phys Rev D 52, 4784 (1995)
P. Azzi et al., Nucl. Instrum. Methods Phys. Res A 360, 137(1995)
CDFII Technical Design Report, FERMILAB-PUB-96/390-E
[6] CDF Collaboration, "Measurement of the $t\bar{t}$ Production Cross Section in $p\bar{p}$ Collisions at $sqrts = 1.96$ TeV using Lepton + Jets Events with Secondary Vertex b-tagging" ,Conference Note 8795
[7] T.Affolder et al., Phys Rev D, 64, 032002 (2001)
[8] M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau, A. Polosa, "ALPGEN, a generator for hard multiparton processes in hadronic collisions", JHEP 0307:001,2003, hep-ph/0206293.
[9] T.Sjostrand et al., Comput. Phys. Commun. 135, 238, (2001)
[10] G.Corcella et al., JHEP 01,10 (2001)