CDF note 7135

Measurement of the WW Cross Section in the Dilepton Channel

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We present a measurement of the W-pair production cross-section in the leptonic decay channel $W^+W^- \to l^+l^-\nu\bar{\nu}$ $(l = e, \mu)$ in 184 pb^{-1} of proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV collected with the Collider Detector at Fermilab. We find 17 candidate events against an expectation of 11.3 ± 1.3 signal and 4.8 ± 0.8 background events. The resulting measured cross section, $\sigma(p\bar{p} \to W^+W^-) = 14.3^{+5.6}_{-4.9}\,(\text{stat}) \pm 1.6\,(\text{syst}) \pm 0.9\,(\text{lum})$ pb agrees well with the Standard Model value.

Preliminary Results for Winter 2004 Conferences

I. INTRODUCTION

W pair production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV has an expected cross section of 13.3 ± 0.8 pb [1] [10], approximately 2000 times smaller than the inclusive single W cross section. Although rare, W pair production provides an important test of the Standard Model. Anomalous triple gauge boson couplings ($WW\gamma$ and WWZ) [2], as well as the decays of new heavy particles such as the Higgs boson [3], can result in an enhanced rate of W pair production.

In this note we describe a measurement of the WW production cross section through the dilepton channel $W^+W^- \rightarrow l^+l^-\nu\bar{\nu}$ ($l = e, \mu$) and a comparison of the events with Standard Model predictions. The analysis is based on 184 pb^{-1} of data collected by the Collider Detector at Fermilab (CDF) from 2002 and 2003. The CDF detector itself is described in detail elsewhere [4].

II. EVENT SELECTION

Our event selection begins with the requirement of two well identified electrons (muons) with $E_T > 20$ GeV ($P_T > 20$ GeV/c). Electrons are identified as electromagnetic clusters in either the central ($|\eta^e| < 1.1$) or plug ($1.2 < |\eta^e| < 2.0$) calorimeters. The shower shape measured in shower-maximum detectors in both calorimeters must be consistent with that expected for incident electrons. Central electrons must have a well measured track reconstructed in the fiducial region of the drift chamber pointing to the calorimeter energy cluster. For electrons with $|\eta| > 1.2$, the track-energy cluster association utilizes a calorimeter seeded silicon tracking algorithm [5]. Muons are identified by the presence of calorimeter energy deposits consistent with the passage of a minimum ionizing particle, in addition to track segments reconstructed in the muon detectors for tracks that fall within the muon chamber coverage. Further details of the electron and muon identification can be found in [6].

All leptons are required to be calorimeter isolated by demanding that the non-lepton E_T in an $\eta - \phi$ cone of radius 0.4 around the lepton direction be less than 10% of the lepton E_T. Moreover, central electrons and muons are required to be isolated of any track activity by demanding the ratio of the P_T for all tracks except the lepton track found in a cone of radius 0.4 around the lepton direction to the lepton P_T to be less than 10%. These isolation requirements reduce significantly the background from events containing fake leptons.

Candidate events must have been selected by one of three triggers, requiring either a central electron with $E_T >$ 18 GeV, a muon with $P_T > 18$ GeV or a plug electron with $E_T > 20$ GeV combined with $\not\!\!E_T > 15$ GeV.

After full event reconstruction, candidate events are required to have two well identified isolated leptons (electrons or muons) and are classified in three dilepton final states: ee, $\mu\mu$ and $e\mu$.

WW candidate events are required to have $\not\!\!E_T$, corrected for muons and the primary vertex position, greater than 25 GeV. If the $\not\!\!E_T$ is within 20° in azimuthal angle to either lepton, this cut is raised to 50 GeV to reduce the likelihood of falsely reconstructed $\not\!\!E_T$ due to mismeasured leptons (this cut is shown graphically in figure 1).

In order to further reduce the background from Drell-Yan events, the missing-E_T significance, defined through the relation $\not\!\!E_T^{sig} = \not\!\!E_T/\Sigma E_T$ [11], is required to be greater than 3 for like-flavor dilepton pair (ee and $\mu\mu$) candidates with a mass between 76 and 106 GeV.

For dilepton $e\mu$ candidates without track segments in the muon chambers, the muon track must be fiducial in the calorimeter to ensure a well measured minimum ionizing energy. This helps to reduce a potentially large background from electrons faking muons in Drell-Yan events.

Candidates with three or more isolated leptons are rejected.

The background from $t\bar{t}$ production is minimized by requiring the events to have no jets with $E_T > 15$ GeV within the pseudorapidity range $|\eta^{jet}| < 2.5$. Finally, the leptons are required to have opposite charge, further helping to reduce the background from events containing fake leptons.

III. SIGNAL MODELING

We use a large sample of WW events generated by the `PYTHIA` Monte Carlo program [7] and forced to decay leptonically, in order to determine our event acceptance and selection efficiencies. We adjust the Monte Carlo lepton identification efficiencies to reflect those measured in Z data. We apply additional factors to take into account small measured trigger inefficiencies. Finally, we scale down the central acceptance estimate by approximately 5% to take into account an underestimate of the $WW+ \geq 1$jet rate by a leading-order parton shower Monte Carlo program such as `PYTHIA`. This factor has been computed from an analysis of Drell-Yan data and confirmed by a comparison of `PYTHIA` with the next-to-leading order generator `MC@NLO` [8]. The final product of acceptance and efficiency for WW events in all decay channels is estimated to be 0.5%.

	CDF Run II Preliminary, $184\,\mathrm{pb}^{-1}$			
Source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
Drell-Yan e^+e^-	0.69 ± 0.31	0.00 ± 0.00	0.048 ± 0.039	0.74 ± 0.31
Drell-Yan $\mu^+\mu^-$	0.00 ± 0.00	0.61 ± 0.24	0.28 ± 0.12	0.89 ± 0.27
Drell-Yan $\tau^+\tau^-$	0.047 ± 0.018	0.046 ± 0.018	0.098 ± 0.037	0.19 ± 0.05
WZ	0.29 ± 0.03	0.32 ± 0.03	0.15 ± 0.02	0.76 ± 0.06
$W\gamma$	0.48 ± 0.13	0.00 ± 0.00	0.57 ± 0.13	1.05 ± 0.19
$t\bar{t}$	0.013 ± 0.008	0.008 ± 0.005	0.033 ± 0.014	0.053 ± 0.017
Fake	0.45 ± 0.20	0.15 ± 0.13	0.48 ± 0.23	1.08 ± 0.49
Total Background	1.97 ± 0.40	1.14 ± 0.28	1.66 ± 0.31	4.77 ± 0.70
$WW \to$ dileptons	2.90 ± 0.34	2.75 ± 0.32	5.69 ± 0.66	11.3 ± 1.3
Total Expectation	4.87 ± 0.55	3.89 ± 0.45	7.35 ± 0.76	16.1 ± 1.6
Run 2 Data	6	6	5	17

TABLE I: Summary of the expected and observed numbers of events. Systematic uncertainties are included. See text for details

The systematic uncertainty on the signal acceptance is estimated to be 10%, dominated by uncertainties in the modeling of the signal, in particular the jet multiplicity distribution and the effect of jet energy scale uncertainties on the zero jet requirement. Other, smaller, systematic error sources include uncertainties in the lepton identification and isolation efficiencies as well as the trigger acceptances.

IV. BACKGROUNDS

Backgrounds from $t\bar{t}$ and WZ production are estimated using fully detector simulated Monte Carlo samples generated using `PYTHIA` and normalized to Standard Model cross-sections of 7.0 pb and 4.0 pb respectively. The background from $W+\gamma$ production in which the photon converts and fakes an electron, can also be estimated reliably using fully detector simulated Monte Carlo events, in this case generated using a leading order $p\bar{p} \to W\gamma X \to l\nu\gamma X$ generator [9] with initial state QCD radiation implemented using `PYTHIA`.

A significant background is $W+$jet events in which the jet fakes a second lepton in the event. The rate at which some object D fakes a lepton (R_D) is measured in independently triggered jet samples with 20, 50, 70 and 100 GeV thresholds and multiplied by the number of events in the signal sample containing a single lepton ℓ, $\not\!\!E_T$, and an instance of object D but passing all other WW selection cuts ($N_{\ell+\not E_T+D}$).

Schematically, the fake lepton background (N_{FL}) is then given by $N_{FL} = R_D \times N_{\ell+\not E_T+D}$. For fake electrons D is a 0.4-cone radius jet and for fake muons D is a track loosely consistent with being a minimum ionizing particle. Fake rates are of order $10^{-3} \to 10^{-4}$ depending on the lepton type, detector region and transverse momentum. Systematic uncertainties are calculated by examining the variation of the measured fake rates in different jet samples, by varying over wide ranges the criteria used to define D objects and by examining possible charge correlations between real and fake leptons in $W+$jet events. Combining all statistical and systematic errors, the fake background estimate is uncertain by almost 50%. Since the overall fake estimate is small (approximately 1 event) this does not translate into a large error on the final measured cross-section.

Drell-Yan events with large $\not\!\!E_T$ constitute another serious background to WW production. We use Monte Carlo normalized to the NLO Drell-Yan cross-section to estimate this background. However we introduce additional smearing into the Monte Carlo in order to match the shape of the $\not\!\!E_T$ spectrum observed in the data. The wide variation in the amount of additional smearing that can be tolerated by the data is responsible for the large 40% error on the estimated Drell-Yan background in this analysis.

V. CROSS SECTION DETERMINATION

The expected number of signal and background events expected in our data samples is summarized in table V. The signal to background ratio is of order 2 : 1. The largest and most uncertain backgrounds are those due to fake leptons and Drell-Yan events. Since we see good agreement between the expected and observed numbers of events, we proceed to measure a cross-section using the formula :

$$\sigma^{WW}_{meas} \;=\; \frac{(N_{obs} - N_{bk})}{N_{exp}} \times \sigma^{WW}_{theory} \;\; ,$$

where σ^{WW}_{theory} is the 13.3 pb used to compute the expected number of WW events in table V. The resulting cross-section is :

$$\sigma^{WW}_{meas} \;=\; 14.3^{+5.6}_{-4.9}\;(\mathrm{stat}) \;\pm\; 1.6\;(\mathrm{syst}) \;\pm\; 0.9\;(\mathrm{lum})\;\mathrm{pb} \;\; .$$

Figures 2 to 4 show kinematic comparisons between the data and the expectations from signal and background processes. Within the limited statistics available, the distributions are in good overall agreement.

VI. CONCLUSIONS

The cross-section for WW production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV has been measured in the dilepton channel at CDF. The measured value for the cross section and the distributions of candidate events are in good agreement with Standard Model expectations. We look forward to improving the precision of this measurement with higher luminosities, and placing limits on non-Standard Model sources of WW-like events.

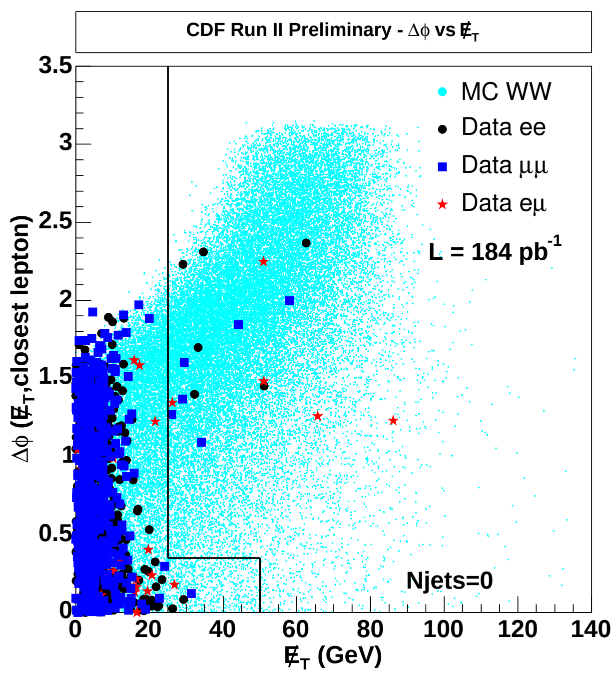

FIG. 1: The azimuthal separation between the $\not\!\!E_T$ and the closest lepton or jet versus the $\not\!\!E_T$. The data is overlayed on the $WW \rightarrow l^+l^-\nu\bar{\nu}$ Monte Carlo after all cuts except $\not\!\!E_T > 25$ and $\Delta\phi(\not\!\!E_T$, nearest lepton$) > 20^\circ$ (for $\not\!\!E_T < 50$ GeV).

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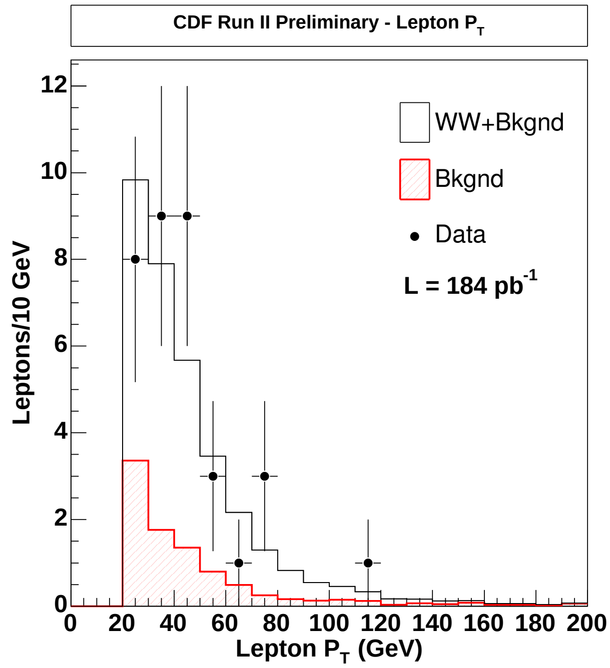

FIG. 2: The lepton-P_T distribution for candidate events, compared to the expectation from WW signal and combined backgrounds.

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[10] We note that an update of this calculation incorporating the latest data on electroweak Standard Model parameters and using the CTEQ6 set of PDF's, yields the somewhat smaller value of 12.4 ± 0.8 pb. $\sigma(WW) = 13.3$ pb and $\mathrm{BR}(W \to l\nu) = 0.11043$ have nevertheless been used to calculate expected event yields in the analysis described here.

[11] ΣE_T is the scalar sum tower by tower of the raw energy measured in the calorimeter.

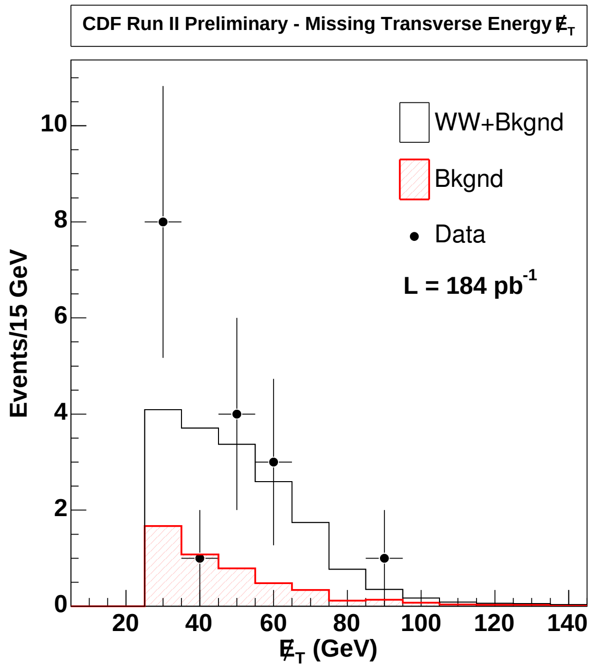

FIG. 3: The $\not\!\!E_T$ distribution for candidate events, compared to the expectation from WW signal and combined backgrounds.

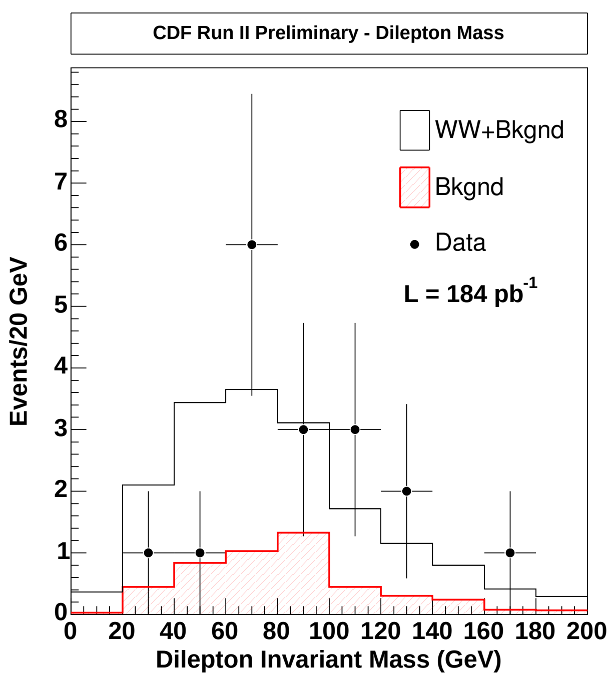

FIG. 4: The invariant mass distribution for candidate events, compared to the expectation from WW signal and combined backgrounds.