Recent WW, WZ and ZZ Results from the Tevatron

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Recent results on WW,WZ and ZZ production from the CDF and D0 experiments are presented. Measurements of $WZ \to \ell\nu\ell\ell$ production are consistent with predictions of the standard model. For the first time in the $\ell\nu jj$ final state, the WZ and WW signals are disentangled. Measurements of ZZ/WZ production with final states including b-tagged jets provide an excellent validation of searches for the low mass Higgs boson.

1 Introduction

The pair production of electroweak vector bosons (only combinations of W and Z [1] bosons are discussed here) is a powerful testing ground for the predictions of the standard model, and the measured cross sections can be enhanced in many new physics scenarios. The non-Abelian structure of the electroweak sector implies a specific set of triple gauge couplings, that maintain unitarity in WW and WZ production. However, the standard model does not contains any such tree level couplings that contribute to ZZ production. Whilst these diboson processes are of interest in their own right, they also contribute significant background in searches for a standard model Higgs boson, and thus need to be understood to a high degree of accuracy. In $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, the standard model predicts production cross sections of; $\sigma(WW) = 11.3 \pm 0.8$ pb, $\sigma(WZ) = 3.2 \pm 0.2$ pb, $\sigma(ZZ) = 1.2 \pm 0.1$ pb, computed at next-to-leading order in the strong coupling [1, 2]. These cross sections correspond to the decay $Z \to \ell\ell$ with the dilepton invariant mass satisfying, $75 < M_{\ell\ell} < 105$ GeV. These processes are already well established at hadron colliders, with ZZ production being the most recent observation in 2008 [3], using 2.7 fb^{-1}. With roughly 10 fb^{-1} of data per experiment, the emphasis now moves towards precision measurements of the cleanest (leptonic) modes, and to the exploration of more challenging final states, in particular those that are common to searches for a Higgs boson.

2 Production of WZ in fully leptonic final states

For WZ production, the golden decay mode is into the $\ell\nu\ell\ell$ ($\ell = e$ or μ) final state, that is easily triggered on and isolated from QCD backgrounds. The D0 Collaboration recently updated the study of this mode with 8.6 fb^{-1} [4], measuring a cross section of $\sigma(WZ) = 4.5^{+0.6}_{-0.7}$ pb, which

[1] For decays into charged fermions, Z implies Z/γ^*.

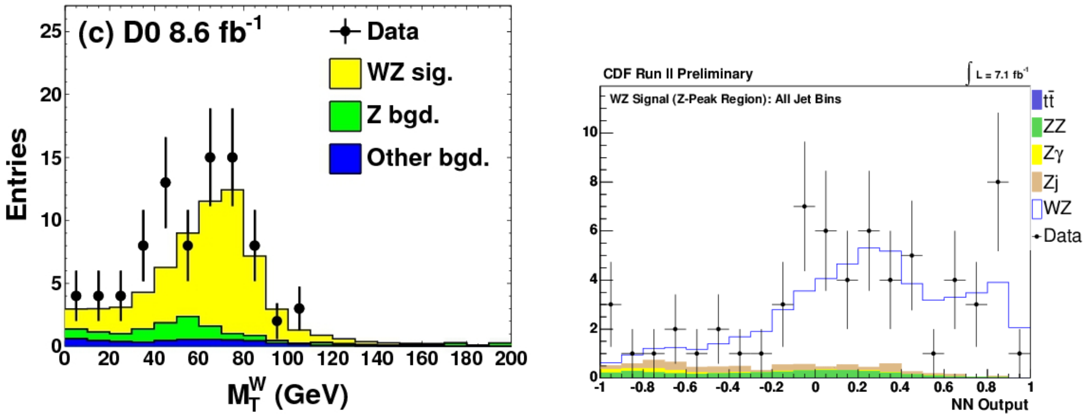

Figure 1: Left: The W transverse mass distribution of the candidate $WZ \to \ell\nu\ell\ell$ events in the D0 analysis of this channel. Right: the neural network output distribution of the candidate $WZ \to \ell\nu\ell\ell$ events in the CDF analysis
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is higher than, but still compatible with the standard model prediction. The left-hand panel of Figure 1 shows the W transverse mass [2] distribution of the selected $WZ \to \ell\nu\ell\ell$ candidate events. This analysis actually measures the ratio of cross sections for WZ production relative to Z production. A next-to-next-to-leading-order calculation [5, 6] of the Z cross section is used to translate this ratio into a WZ cross section. This approach has the advantage of largely canceling systematic uncertainties in, for example, the luminosity and the lepton reconstruction efficiencies.

The CDF Collaboration also recently released an updated study of this channel using 7.1 fb^{-1} [7], measuring a cross section of $\sigma(WZ) = 3.9^{+0.8}_{-0.7}$ pb, in agreement with the D0 measurement and with the standard model prediction. The right-hand panel of Figure 1 shows the distribution of a neural network output, that helps to separate the signal from the backgrounds. Stringent limits are set on anomalous WWZ couplings.

3 WW/WZ production in semi-leptonic final states

The production of WW/WZ with decays into the $\ell\nu jj$ final state was first observed by the CDF Collaboration in 3.5 fb^{-1} [8]. The D0 Collaboration recently published an updated study of this channel using 4.3 fb^{-1} [9], that measures a cross section of $\sigma(WW + WZ) = 19.6 \pm 3.2$ pb. Neither experiment has sufficient dijet invariant mass resolution to directly resolve the decay $W \to jj$ from the decay $Z \to jj$. By dividing the sample into categories with 0, and and 2 b-tagged jets, the D0 analysis [9] manages to de-correlate the WW and WZ cross sections. Figure 2 shows the dijet invariant mass distributions in the 0 and 2 b-tag samples, after background subtraction. The b-tagging tends to enrich the sample with the decays

[2] The transverse mass is defined as $M_T = \sqrt{p_T^\ell p_T^\nu (1 - \cos\phi)}$, where p_T^ℓ and p_T^ν are the transverse momenta of the charged lepton and the neutrino, respectively. The opening angle between the charged lepton and the neutrino, in the plane transverse to the beam direction is denoted ϕ.

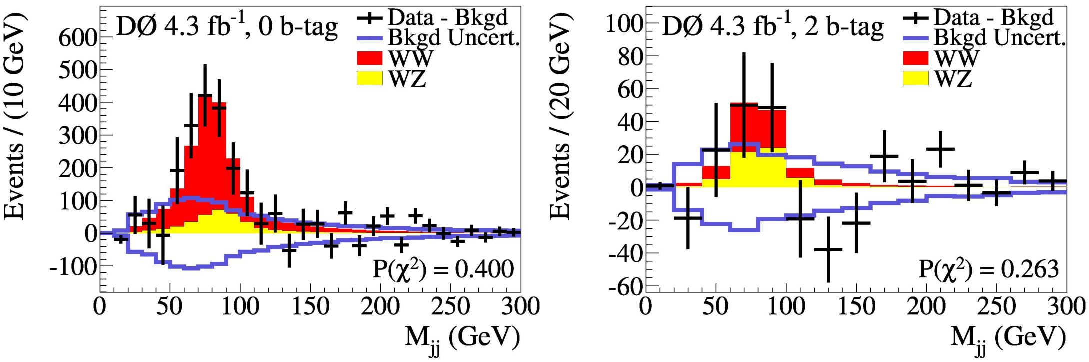

Figure 2: The background subtracted dijet invariant mass distribution in a sample of $WW/WZ \to \ell\nu jj$ events. Left: events in which neither jet is b-tagged. Right: events in which both jets are b-tagged.

$Z \to bb$ and $Z \to cc$. A simultaneous fit to the WW and WZ cross sections reveals a WW cross section of $\sigma(WW) = 15.9^{+3.7}_{-3.2}$ pb, but no significant WZ signal is measured. However, by constraining the WW cross section to the standard model value, a WZ cross section of $\sigma(WZ) = 6.5 \pm 0.9(\text{stat}) \pm 3.0(\text{syst})$ pb is measured, corresponding to an observed(expected) significance of 2.2(1.2) standard deviations.

4 ZZ/WZ production with heavy flavour jets

Three of the most sensitive search channels for a low mass standard model Higgs boson at the Tevatron are; $ZH \to \nu\nu bb$, $ZH \to \ell\ell bb$ and $WH \to \ell\nu bb$. All three search channels are contaminated by VZ ($V = W$ or Z) with the decay $Z \to bb$, and to a lesser extend $Z \to cc$. A powerful validation of these analyses is to actually attempt to observe a significant VZ signal. Diboson interpretations for each of these channels have been reported by the CDF Collaboration [10, 11, 12], and by the D0 Collaboration [13, 14, 15]. In all of these analyses, the event selection and background modeling is identical to the corresponding standard model Higgs search. Recently, a combination of results from the two experiments was performed [16]. The left hand panel of Figure 3 shows the background subtracted dijet invariant mass distribution of this combination. A significant VZ signal can be seen in this event sample that requires at least one b-tagged jet. Each of the input analyses uses a multivariate classifier to improve sensitivity to the signal. The D0 analyses use boosted decision trees, whilst the CDF analyses use neural networks. An optimal combination of inputs groups together bins of similar S/B, as shown in the right hand panel of Figure 3. This yields a cross section of $\sigma(WZ + ZZ) = 4.47 \pm 0.64(\text{stat}) \pm 0.73(\text{syst})$, corresponding to a significance of 4.6 standard deviations, and in agreement with the standard model predictions.

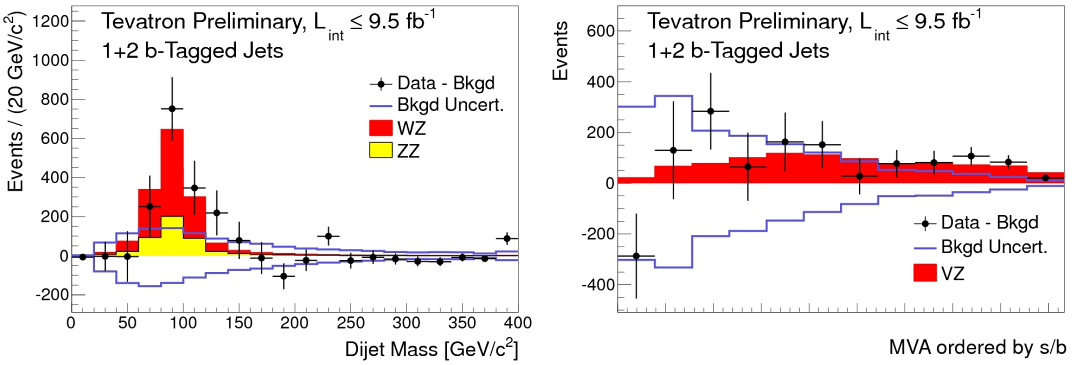

Figure 3: Left: The background subtracted dijet invariant mass distribution of the combination of CDF and D0 inputs for VZ production with heavy flavour jets. Right: The background subtracted distribution, binned by expected S/B.

5 Conclusions

Updated measurements are reported for $WZ \to \ell\nu\ell\ell$ production and $WW/WZ \to \ell\nu jj$ production. The measured cross sections are in agreement with predictions of the standard model. For the first time, separate measurements are made for WW and WZ cross sections using the $\ell\nu jj$ final state. A combined Tevatron search for VZ production in final states with b-tagged jets obtains a signal significance of 4.6 standard deviations, that is consistent with predictions of the standard model. This demonstrates the sensitivity of the Tevatron searches for a low mass Higgs boson.

References

[1] J. M. Campbell and R. K. Ellis. Phys. Rev. D **60** (1999) 113006.

[2] A. Martin, W. Stirling, R. Thorne, and G. Watt. Eur. Phys. J. C **63** (2009) 189–285.

[3] V. Abazov *et al.* Phys. Rev. Lett. **101** (2008) 171803.

[4] D0 Collaboration, V.M Abazov *et al.*, arXiv:1201.5652[hep-ex], *accepted by Phys. Rev. D* (2012).

[5] R. Hamberg, W. van Neerven, and T. Matsuura. Nucl. Phys. B **359** (1991) 343.

[6] A. D. Martin, R. G. Roberts, W. J. Stirling, and R. S. Thorne. Phys. Lett. B **604** (2004) 61.

[7] CDF Collaboration, T. Aaltonen *et al.*, arXiv:1202.6629v1[hep-ex], *submitted to Phys. Rev. Lett.* (2012).

[8] T. Aaltonen *et al.* Phys. Rev. Lett. **103** (2009) 091803.

[9] V. Abazov *et al.* Phys. Rev. Lett. **108** (2012) 181803.

[10] CDF Collaboration, T. Aaltonen *et al.*, CDF Conference Note 10796 (2012).

[11] CDF Collaboration, T. Aaltonen *et al.*, CDF Conference Note 10798 (2012).

[12] CDF Collaboration, T. Aaltonen *et al.*, CDF Conference Note 10799 (2012).

[13] D0 Collaboration, V.M. Abazov *et al.*, D0 Note 6220-CONF (2011).

[14] D0 Collaboration, V.M. Abazov *et al.*, D0 Note 6223-CONF (2011).

[15] D0 Collaboration, V.M. Abazov *et al.*, D0 Note 6256-CONF (2011).

[16] Tevatron New Phenomina and Higgs Working Group, CDF Collaboration, D0 Collaboration, FERMILAB-CONF-12-068-E, CDF-NOTE-10802, D0-NOTE-6311, arXiv:1203.3782[hep-ex] (2012).