DIBOSON PRODUCTION CROSS SECTION AT THE TEVATRON

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Recent results in diboson production in diverse final states from the CDF and D0 experiments in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the Tevatron are reviewed. Special emphasis is given to the recent combined CDF and D0 measurement of WZ and ZZ production in final states with b-tagged jets. Assuming the ratio of the production cross sections $\sigma(WZ)$ and $\sigma(ZZ)$ as predicted by the standard model, the sum of the WZ and ZZ cross sections is measured to be $\sigma(WZ+WZ) = 4.47 \pm 0.64(\text{stat.})^{+0.73}_{-0.72}$ (syst.) pb. This is consistent with the standard model prediction and corresponds to a significance of 4.6 standard deviations above the background-only hypothesis.

1 Introduction

Studies on the production of VV ($V = W, Z$) boson pairs provide an important test of the electroweak sector of the standard model (SM). In $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, the next-to-leading order (NLO) SM cross sections for these processes are $\sigma(WW) = 11.3 \pm 0.8$ pb, $\sigma(WZ) = 3.2 \pm 0.2$ pb and $\sigma(ZZ) = 1.2 \pm 0.1$ pb [1]. These cross sections assume both $\gamma^\star$ and Z^0 components in the neutral current exchange and corresponding production of dilepton final states in the region $75 \leq m_{l^+l^-} \leq 105$ GeV/c^2. Measuring a significant departure in cross section or deviations in the predicted kinematic distributions would indicate the presence of anomalous gauge boson couplings [2] or new particles in extensions of the SM [3]. Diboson production is an important background in studies of the top quark, and searches for the Higgs boson and SUSY particles. Thus, precise knowledge of diboson processes and their proper modeling is important for current and future studies.

In the following sections, some of the most important measurements of the diboson production cross sections and of the trilinear gauge boson couplings (TGCs) [4] in different final states in $p\bar{p}$ collisions at the Fermilab Tevatron Collider will be presented.

2 $W\gamma$ and $Z\gamma$ Production

The cross section and the difference in rapidities between photons and charged leptons for inclusive $W(\to l\nu) + \gamma$ production in $e\gamma$ and $\mu\gamma$ final states is measured using D0 data corresponding to an integrated luminosity of 4.2 fb^{-1}. The measured cross section times branching fraction for the process $pp \to W\gamma + X \to l\nu\gamma + X$ and the distribution of the charge-signed photon-lepton rapidity difference are found to be in agreement with the standard model. These results provide limits on anomalous $WW\gamma$ couplings: $-0.4 < \Delta\kappa_\gamma < 0.4$ and $-0.08 < \lambda_\gamma < 0.07$ at the 95% confidence level [5].

The total and the differential production cross section, $d\sigma/dp_T^\gamma$, for $p\bar{p} \to Z\gamma \to l^+l^-\gamma$ ($l = e, \mu$) is measured with a D0 data sample corresponding to an integrated luminosity of 6.2 fb^{-1}. The results obtained are consistent with the standard model predictions from next-to-leading order calculations. The transverse momentum spectrum of the photon is used to place limits at 95% confidence level on anomalous $ZZ\gamma$ and $Z\gamma\gamma$ couplings for $\Lambda = 1.2$ TeV, $|h_{03}^Z| < 0.050$, $|h_{04}^Z| < 0.0033$, $|h_{03}^\gamma| < 0.052$, $|h_{04}^\gamma| < 0.0034$; and for $\Lambda = 1.5$ TeV, $|h_{03}^Z| < 0.041$, $|h_{04}^Z| < 0.0023$, $|h_{03}^\gamma| < 0.044$, $|h_{04}^\gamma| < 0.0023$ [6]. Another search for potential anomalous $Z\gamma$ couplings [7] is performed using 4.9 (5.1) fb^{-1} of CDF data using $Z\gamma$ candidates in the $Z \to \nu\bar{\nu}$ ($Z \to l^+l^-$, $l = e, \mu$) decay channel. Using an energy scale of $\Lambda = 1.5$ TeV the limits on the CP-conserving parameters that describe $Z\gamma$ couplings are set to $|h_{03}^{Z,\gamma}| < 0.022$ and $|h_{03}^{Z,\gamma}| < 0.0009$.

3 VV Production in Fully Leptonic Final States

VV production has been observed both by CDF and D0 collaborations in all of the 3 production modes (WW, WZ, ZZ) in fully leptonic final states. The W boson pair-production is observed using an integrated luminosity as low as 252 pb^{-1} of D0 data in the $l^+\nu l^-\bar{\nu}$ final state [8]. A more recent result using 3.6 fb^{-1} of CDF data [9] measures a W boson pair-production cross section of $\sigma(p\bar{p} \to W^+W^- + X) = 12.1 \pm 0.9(\text{stat.})^{+1.6}_{-1.4}(\text{syst.})$ pb using the same final state. The WZ production cross section is measured in the three charged lepton (e, μ) and one neutrino final state using 7.1 fb^{-1} of CDF data [10]. The measured cross section is $3.96^{+0.6}_{-0.5}(\text{stat.})^{+0.6}_{-0.4}(\text{syst.})$ pb. The ZZ production cross section is measured using the $l^+l^-l^+l^-$ and the $l^+l^-\nu\bar{\nu}$ final states using 8.6 fb^{-1} of D0 data [11]. The measured cross section is $1.44^{+0.35}_{-0.34}$ pb. All the previously described results are in good agreement with the standard model predictions.

4 VV Production in Semileptonic Final States

VV production has been observed as well at the Tevatron in semileptonic final states. The WW and WZ production with $l\nu q\bar{q}$ final states has been studied both by the CDF and D0 collaborations. Using matrix-element calculations a signal significance for $WW + WZ$ of 5.4 standard deviations is measured using 2.7 fb^{-1} of CDF data [12]. A complementary analysis uses the dijet invariant mass distribution and 3.9 fb^{-1} of data. Combining the results for both methods gives $\sigma(WW + WZ) = 16.0 \pm 3.3$ pb. Another analysis using 4.3 fb^{-1} of D0 data [13] rejects the background-only hypothesis at a level of 7.9 σ and measures a cross section of $\sigma(WW + WZ) = 19.6^{+3.2}_{-3.0}$ pb. Another analysis is performed using 3.5 fb^{-1} of CDF data [14] on a sample of events with large transverse momentum imbalance and two jets. This signature is sensitive not only to $l\nu q\bar{q}$, but also to $\nu\bar{\nu}q\bar{q}$ decays because no explicit requirement on the presence of identified charged leptons is applied. A cross section of $\sigma(p\bar{p} \to VV + X) = 18.0 \pm 2.8(\text{stat.}) \pm 2.4(\text{syst.}) \pm 1.1(\text{lumi.})$ pb, in agreement with the standard model prediction, is measured.

5 WZ and ZZ Production in Final States with b-tagged Jets

During the last years, the CDF and D0 experiments have studied the WZ and ZZ production in semileptonic decays with heavy flavor jets in the final state. The use of b-tagging requirements allows to separate the WW from the WZ and ZZ components. Assuming the ratio between the production cross sections $\sigma(WW)$ and $\sigma(WZ)$ as predicted by the standard model, the $WZ + ZZ$ signal is seen with a significance of 2.2 σ above the background-only hypothesis in the $l\nu q\bar{q}$ final state using 4.3 fb^{-1} of D0 data [13]. A similar CDF analysis [15] measures a significance of 1.08 σ using 7.5 fb^{-1} of data, while 1.9 σ are measured in a CDF search in the $\nu\nu q\bar{q}$ final state using 5.2 fb^{-1} of data [16]. More recently, the CDF and D0 collaborations have presented

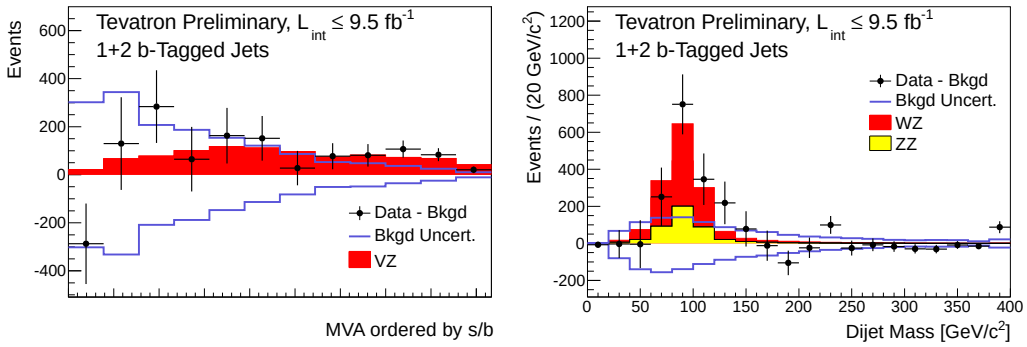

Figure 1: Comparison of the measured VZ signal (filled histograms) to background-subtracted data (points) after the maximum likelihood fit. Distributions of a variable that combines all final discriminants, where the bins are ordered by their expected signal to background ratio (s/b), and bins of comparable s/b are combined for display purposes (left), and of the dijet mass (right). Also shown is the ± 1 standard deviation uncertainty on the fitted background.

a combined measurement showing evidence for WZ and ZZ production in semileptonic decays with a b-tagged final state [17]. This analysis is relevant as a proving ground for the combined Tevatron search for a low-mass Higgs boson produced in association with a weak boson and decaying into a $b\bar{b}$ pair [18] since it shares the same selection criteria as well as analysis and combination techniques.

This result is a combination of the CDF and D0 searches in the $l\nu b\bar{b}$, $l^+l^-b\bar{b}$, and $\nu\bar{\nu}b\bar{b}$ final states. The total VZ cross section is determined from a maximum likelihood fit of the distributions of the multivariate discriminants (MVA) for the background and signal samples from the contributing analyses to the data. The cross section for the signal ($WZ + ZZ$) is a free parameter in the fit, but the ratio of the WZ and ZZ cross sections is fixed to the SM prediction. The combined fit for the total VZ cross section distributions yields $\sigma(WW+WZ) = 4.47 \pm 0.64(\text{stat.})^{+0.73}_{-0.72}(\text{syst.})$ pb. This measurement is consistent with the NLO SM prediction of $\sigma(WW+WZ) = 4.4 \pm 0.3$ pb [1]. Based on the measured central value for the VZ cross section and its uncertainties, the observed significance is estimated to be 4.6 σ, while the expected significance is 4.8 σ.

To visualize the sensitivity of the combined analysis, the expected signal over background (s/b) is calculated in each bin of the MVA distributions from the contributing analyses. Bins with similar s/b are then combined to produce a single distribution, shown in Figure 1. The background subtracted dijet mass distribution is also shown in Figure 1 demonstrating the presence of a hadronic resonance in the data consistent with the SM expectation, both in shape and normalization.

Summary

A wealth of results about diboson production in diverse final states from the CDF and D0 experiments in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the Tevatron has been presented. In the most recent one, the combined CDF and D0 measurement of WZ and ZZ production in final states with b-tagged jets, a diboson production cross section of $\sigma(WW+WZ) = 4.47 \pm 0.64(\text{stat.})^{+0.73}_{-0.72}(\text{syst.})$ pb, in good agreement with the standard model prediction, is measured. This result validates the analysis techniques applied to the Tevatron search for a low-mass Higgs boson produced in association with a weak boson and decaying into a $b\bar{b}$ pair.

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