Diboson Physics at CDF

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Abstract. This article presents the most recent results of the diboson production properties, using up to $\int \mathcal{L}dt = 1.9$ fb^{-1} of data taken with the CDF Run II detector, at Tevatron. We summarize measurements of the $W\gamma$, $Z\gamma$, WW, WZ and ZZ production cross sections in leptonic channels. A search for the combined WW and WZ production in lepton-neutrino plus dijet final states is also presented.

1. Introduction

In the Standard Model (SM), the weak bosons and the photon are the gauge bosons of the local $SU(2) \times U(1)$ symmetry. The spontaneous breaking of this symmetry gives masses to the W and Z bosons, while the gauge symmetry defines the interactions between these heavy bosons and with the photon. Given that the fundamental laws of nature, as we currently know them, rely on the validity of this picture, it is of prime importance to test the boson self-couplings experimentally.

At the Tevatron energy scale ($\sqrt{s} = 1.96$ TeV), the diboson production cross sections are expected to be small, according to the SM. The diboson production processes are sensitive to the Triple Gauge Couplings (TGC) $WW(Z/\gamma)$, and would be enhanced by the presence of nonstandard couplings $Z(Z/\gamma)(Z/\gamma)$ (anomalous TGC, or aTGC) [1]. Therefore, measurements that deviate from the SM predicted cross sections would give an indication of new physics.

We summarize in this article the recent diboson measurements performed by the CDF collaboration at the Fermilab Tevatron. These results are complementary to LEP since $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV probe higher invariant masses because of the higher accessible energies, and also different combinations of TGC, where new physics effects might become more evident.

2. Vector boson plus photon production

The $(W/Z)\gamma$ channels have clean signatures and high event yields, allowing precise measurements. CDF has made measurements using leptonic decays of heavy bosons and $\int \mathcal{L}dt = 1$ fb^{-1} of data.

The $W\gamma$ final state observed at hadron colliders provides a direct test of the $WW\gamma$ TGC. The signature of a $W\gamma$ signal is an isolated high-E_T lepton, large missing transverse energy, an isolated photon with $E_T^\gamma > 7$ GeV and $|\eta^\gamma| < 1.0$. In order to suppress events with final state radiation of the photon from the outgoing lepton, a lepton-photon separation requirement in $\eta - \phi$ space is made. The dominant background is from W+jets events, where a jet mimics a photon.

The $Z\gamma$ final state is sensitive to new physics, since the photon does not couple with a Z in the SM. The signature of a $Z\gamma$ signal is two isolated, same flavor and opposite charge, high-E_T leptons, with invariant mass consistent with the decay of a Z boson and an isolated photon with $E_T^\gamma > 7$ GeV and $|\eta^\gamma| < 1.0$. As in the $W\gamma$ case, in order to suppress events with final state radiation of the photon from the outgoing lepton, a lepton-photon separation requirement in $\eta - \phi$ space is made. The dominant background is from Z+jets events, where a jet mimics a photon.

The CDF measurements for $W\gamma$ and $Z\gamma$ final states are summarized in Table 1. The results are compatible with the SM predictions [2].

Process	Measurement (pb)	NLO (pb)	Comment
$\sigma(p\bar{p} \to W\gamma) \times BR(W \to \ell\nu)$	$18.03 \pm 0.5_{\text{(stat)}} \pm 2.55_{\text{(sys)}} \pm 1.05_{\text{(lumi)}}$	19.3 ± 1.4	$\ell = e, \mu$
$\sigma(p\bar{p} \to Z\gamma) \times BR(Z \to e^+e^-)$	$4.9 \pm 0.3_{\text{(stat)}} \pm 0.3_{\text{(sys)}} \pm 0.3_{\text{(lumi)}}$	4.7 ± 0.4	$M_{e^+e^-\gamma} > 40$ GeV
	$1.4 \pm 0.1_{\text{(stat)}} \pm 0.2_{\text{(sys)}} \pm 0.1_{\text{(lumi)}}$	1.4 ± 0.1	$M_{e^+e^-\gamma} > 100$ GeV Sensitive to aTGC

Table 1. Summary of heavy boson plus photon cross section measurements.

3. Double vector boson production in leptonic final states

The diboson final states with two heavy bosons decaying leptonically have small branching fractions. However the backgrounds for these states are very low, resulting in very clean signals, but with low event-yields.

Production of W boson pairs involves both $WW\gamma$ and WWZ couplings. The signature of the WW signal in leptonic decay is two isolated high-E_T leptons with opposite charge and large missing transverse energy from the W neutrinos. After the selection cuts, the dominant backgrounds are from Drell-Yan, other diboson decays and the W+jets where a jet fakes an isolated lepton [4].

Production of WZ involves the WWZ TGC. The study of WZ production allows one to search for anomalous WWZ coupling independently of the $WW\gamma$ coupling, in contrast to WW production. The WZ production was unavailable at LEP and has been observed by CDF in October 2006 [5], using 1.1 fb^{-1}. Improving the lepton selection by using all tracks and electromagnetic objects found in the detector was essential for the WZ observation. The new selection improved the lepton acceptance by approximately 50%. CDF has an update to the first observation of WZ, using $\int \mathcal{L}dt = 1.9$ fb^{-1}. The WZ analysis uses a final state of 3 leptons (e or μ) and missing transverse energy. The dominant backgrounds are from Z+X, where X is a Z, γ or jet faking a lepton. Figure 1 shows the missing transverse energy distribution for candidates both inside and outside the WZ signal region.

Production of ZZ involves the aTGCs $ZZ\gamma$ and ZZZ. The ZZ final state has been observed at LEP, but at the Tevatron it is the only diboson final state that has not been observed so far. CDF has a 3σ evidence for ZZ production, using the combination of two final states: four charged leptons (e, μ) final state, with dominant background being the Z+X, where X is a Z, γ or jet faking leptons; and two charged leptons plus two neutrinos final state, with the WW final state being the dominant background. WW/WZ separation is achieved using an event by event calculation of the matrix element probability.

The measured cross sections for the processes described in this section are summarized in Table 2. All results are compatible with the SM predictions [3].

Process	Measurement (pb)	NLO (pb)	$\int \mathcal{L}dt$
$\sigma(p\bar{p} \to WW)$	$13.6 \pm 2.3_{\text{(stat)}} \pm 1.6_{\text{(sys)}} \pm 1.2_{\text{(lumi)}}$	12.4 ± 0.8	825 pb^{-1}
$\sigma(p\bar{p} \to WZ)$	$4.3^{+1.3}_{-1.0}{}_{\text{(stat)}} \pm 0.2_{\text{(sys)}} \pm 0.3_{\text{(lumi)}}$	3.7 ± 0.3	1.9 fb^{-1}
$\sigma(p\bar{p} \to ZZ)$	$0.75^{+0.71}_{-0.54}{}_{\text{(stat+sys)}}$	1.4 ± 0.1	$1.1 \text{ fb}^{-1}(\ell\ell\nu\nu)$ & $1.4 \text{ fb}^{-1}(4\ell)$ (3σ significance)

Table 2. Double vector boson production in leptonic final states cross section measurements.

4. Double vector boson production in semi-leptonic final states

The WW and WZ production in lepton-neutrino plus jets final states has not been observed in hadron colliders so far, because of the large single $W +$ jets background. This mode however has much larger branching fractions than the cleaner fully leptonic mode making it more sensitive to aTGC which would manifest themselves at higher transverse W momenta.

CDF has a preliminary analysis using $\int \mathcal{L}dt = 1.3 \text{ fb}^{-1}$. The event selection includes exactly one lepton, missing transverse energy and two or more jets. At this phase of the analysis, only electrons are considered in the lepton selection, optimized using an artificial neural network that improves the signal to background separation. Fitting the expected dijet invariant mass to the data, the result shows about 1.5σ statistical significance. A 95% C.L. limit on the cross section $\sigma(p\bar{p} \to WW/WZ) \times BR(W \to e\nu, W/Z \to jets) < 3.4$ pb is determined.

5. Summary

With the increasingly large integrated luminosity delivered by the Tevatron, CDF is probing electroweak diboson production with large sensitivity. Figure 2 summarizes the diboson measurements from CDF. Various diboson production signatures have been studied and no deviation from the SM is observed.
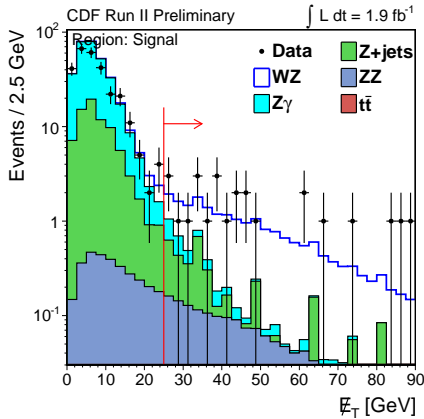

Figure 1. Missing E_T distribution, for the $WZ \to \ell\ell\ell\nu$ process.
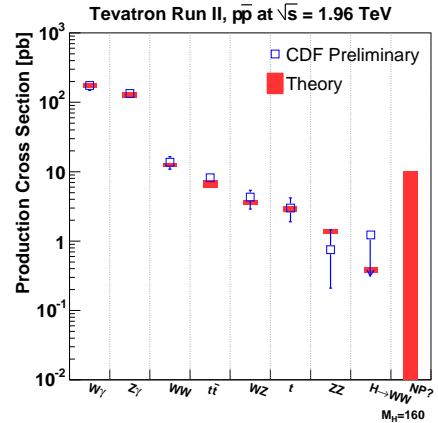

Figure 2. Summary of the CDF diboson results.

References

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