Combined Limits on Anomalous Couplings at DØ

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We present the first combination of limits across different diboson production processes using 1 fb^{-1} of data collected by the DØ detector at the Fermilab Tevatron collider. We set the most stringent limits on anomalous values of the γ/ZWW couplings at a hadron collider and present the most stringent measurements to date for the W boson magnetic dipole and quadrupole moments.

1 Phenomenology

Study of the vector bosons interactions and the trilinear gauge boson couplings (TGCs) [1] provides a test of the electroweak sector of the Standard Model (SM). Any deviation from predicted SM values could indicate New Physics (NP). The TGCs contribute to diboson production via s-channel diagram. Thus, production of WW contains two trilinear vertices, γWW and ZWW, while the WZ production contains the ZWW vertex only. The effective lagrangian which describes γ/ZWW vertices contains 14 charged TGCs which are grouped according to the symmetry properties into C (charge conjugation) and P (parity) conserving couplings. In the SM all couplings vanish except $g_1^V = \kappa_V = 1$ ($V = \gamma/Z$). The value of g_1^γ is fixed by electromagnetic (EM) gauge invariance ($g_1^\gamma = 1$) while the value of g_1^Z may differ from its SM value. Considering the C and P conserving couplings only, five couplings remain, and their deviations from the SM values are denoted as the anomalous TGCs: Δg_1^Z, $\Delta\kappa_\gamma$, $\Delta\kappa_Z$, λ_γ and λ_Z. Couplings g_1^Z, κ_γ and λ_γ also relate to the W boson magnetic dipole moment μ_W and electromagnetic quadrupole moment q_W as $\mu_W = \frac{e}{2M_W}(g_1^\gamma + \kappa_\gamma + \lambda_\gamma)$ and $q_W = -\frac{e}{M_W^2}(\kappa_\gamma - \lambda_\gamma)$.
Anomalous TGCs could cause an unphysical increase in diboson production cross sections as the center-of-mass energy, $\sqrt{\hat{s}}$, approaches NP scale, Λ_{NP}. These divergences are controlled by a form factor $\Delta a(\hat{s}) = \Delta a_0/(1+\hat{s}/\Lambda_{NP}^2)^n$ for which the anomalous coupling vanishes as $\hat{s} \to \infty$. The coupling a_0 is a low-energy approximation of the coupling $a(\hat{s})$ and $n = 2$ for γWW and ZWW couplings.
Because experimental evidence is consistent with the existence of an $SU(2)_L \times U(1)_Y$ gauge symmetry, it is reasonable to require the effective lagrangian to be invariant with respect to this symmetry. This gauge-invariant parametrization [2] gives the following relations between the $\Delta\kappa_\gamma$, Δg_1^Z and λ couplings: $\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \cdot \tan^2\theta_W$ and $\lambda = \lambda_Z = \lambda_\gamma$. We refer to this relationship as the $SU(2)_L \times U(1)_Y$ respecting scenario with three different parameters, $\Delta\kappa_\gamma$, λ and Δg_1^Z.
A second interpretive scenario, referred to as the equal couplings ($ZWW = \gamma WW$) scenario [3], specifies the γWW and ZWW couplings to be equal. In this case, $\Delta g_1^Z = \Delta g_1^\gamma = 0$ and the relations between the couplings become: $\Delta\kappa = \Delta\kappa_Z = \Delta\kappa_\gamma$ and $\lambda = \lambda_Z = \lambda_\gamma$.

2 Combined Final States

The TGC limits presented here are derived combining previously published measurements in four diboson final states: $W\gamma \to \ell\nu\gamma$, $WW/WZ \to \ell\nu jj$, $WW \to \ell\nu\ell'\nu$, and $WZ \to \ell\nu\ell'\bar{\ell}'$ [4].
The process $W\gamma \to \ell\nu\gamma$ is sensitive to the $WW\gamma$ coupling. The 0.7 fb^{-1} of data were analyzed to select events with an electron (muon) with $E_T > 25$ GeV (20 GeV), $\not\!\!E_T > 25$ (20) GeV and a photon with $E_T^\gamma > 9$ GeV. It is required that the photon and lepton are separated in space of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} > 0.7$. The final state radiation is suppressed requiring the transverse mass of the lepton, photon, and $\not\!\!E_T$ to be > 120 (110) GeV. In total 263 candidate events are observed. After subtracting backgrounds, the signal is measured to be $187 \pm 17_{\text{stat}} \pm 4_{\text{sys}}$ events and is consistent with the SM prediction of 197 ± 15 events. The photon spectra are input for the combination. For $W\gamma$ production in presence of anomalous TGCs, spectra were simulated using the Baur Monte Carlo (MC) event generator [5].
The $WW/WZ \to \ell\nu jj$ analysis probes both the ZWW and γWW vertex. We analyze 1.07 fb^{-1} of data selecting events with a lepton of $p_T > 20$ GeV, $\not\!\!E_T > 20$ GeV, and at least two jets with $p_T > 20$ GeV with the leading jet of $p_T > 30$ GeV. In total 26865 candidate events are observed which is consistent with the SM prediction of 26830 ± 828 events. The dijet p_T spectrum is used as input for the combination. Spectra with anomalous TGCs are generated by re-weighting the Pythia MC SM spectra to match spectra generated by a LO MC from Hagiwara, Zeppenfeld, and Woodside (HZW) [3].
The $WW \to \ell\nu\ell'\nu$ analysis uses 1 fb^{-1} of data. For all channels (ee, $e\mu$, and $\mu\mu$), the leading lepton must satisfy $p_T > 25$ GeV and the trailing lepton with $p_T > 15$ GeV. Both leptons must be of opposite charge. In the data 100 candidate events are observed, which is consistent with the prediction of 102.9 ± 4.4 events. Two-dimensional histograms of leading and trailing lepton p_T are used as input in the combination. Histograms are generated using the HZW MC.
Analysis of $WZ \to \ell\nu\ell'\bar{\ell}'$ final states uses 1 fb^{-1} of data. Four final states (eee, $ee\mu$, $\mu\mu e$, and $\mu\mu\mu$), require three leptons with $p_T > 15$ GeV and $\not\!\!E_T > 20$ GeV. To select Z candidates, like-flavor leptons must satisfy $71 < m_{ee} < 111$ GeV or $50 < m_{\mu\mu} < 130$ GeV. To reduce $t\bar{t}$ background events the magnitude of the vector sum of the charged lepton p_T and the $\not\!\!E_T$ must be less than 50 GeV. The sum over all channels yields 13 candidate events which is in agreement with the SM prediction of 13.7 ± 1.2 events. The p_T^Z of the Z boson is used in the combination and simulated using the HZW MC.

3 Results

The one-dimensional 68% and 95% C.L. limits for each coupling are shown in Table 1 for two scenarios. The measured values and the one-dimensional 68% C.L. intervals of the W boson magnetic dipole and electric quadrupole moments for $SU(2)_L \times U(1)_Y$ scenario (with $g_1^Z = 1$) are $\mu_W = 2.02^{+0.08}_{-0.09}$ $(e/2M_W)$ and $q_W = -1.00 \pm 0.09$ (e/M_W^2), respectively. Two-dimensional surfaces in $q_W - \mu_W$ space for both scenarios are shown in Figure 1.

4 Summary

Presented results are the most stringent limits on anomalous values of γWW and WWZ TGCs measured from hadronic collisions to date. The 95% C.L limits in both scenarios improve relative to the previous combined DØ [6] and CDF [7] results by a factor of ~ 3. Our measurements

Par.I	Min.	68% C.L.	95% C.L.	Par.II	Min.	68% C.L.	95% C.L.
$\Delta\kappa_\gamma$	0.07	-0.13, 0.23	-0.29, 0.38	$\Delta\kappa$	0.03	-0.04, 0.11	-0.11, 0.18
Δg_1^Z	0.05	-0.01, 0.11	-0.07, 0.16				
λ	0.00	-0.04, 0.05	-0.08, 0.08	λ	0.00	-0.05, 0.05	-0.08, 0.08

Table 1: One-dimensional minimum and combined 68% and 95% C.L. limits on anomalous γ/ZWW couplings for two scenarios: $SU(2)_L \times U(1)_Y$ (Par.I) and equal couplins (Par.II), both with $\Lambda_{NP} = 2$ TeV.

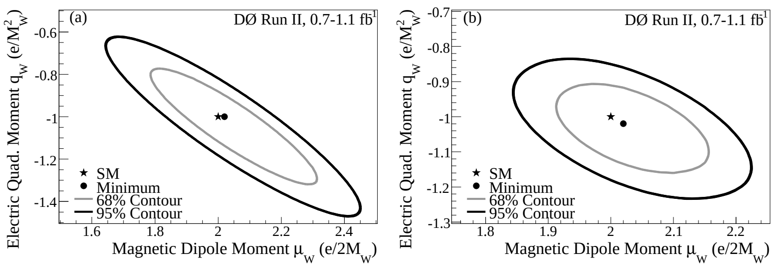

Figure 1: Two-dimensional 68% and 95% C.L. limits for the W boson electric quadrupole moment versus the magnetic dipole moment for (a) $SU(2)_L \times U(1)_Y$ scenario and (b) equal couplings scenario ($\Lambda_{NP} = 2$ TeV in both scenarios).

are comparable to that of an individual LEP2 experiments [8] even though all four analyses considered in this combination are limited by statistics. The DØ experiment also sets the most stringent measurements of μ_W and q_W moments to date.

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