DØnote 5160-CONF

Limits on Anomalous Trilinear Gauge Couplings from $WW \to e^+e^-$, $WW \to e^\pm\mu^\mp$, and $WW \to \mu^+\mu^-$ Decays from $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

The DØ Collaboration
URL http://www-d0.fnal.gov

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Examining data from the final states $W^+W^- \to e^+\nu_e e^-\bar{\nu}_e$, $W^+W^- \to e^\pm\nu_e\mu^\mp\nu_\mu$, and $W^+W^- \to \mu^+\nu_\mu\mu^-\bar{\nu}_\mu$, limits on anomalous $WW\gamma$ and WWZ trilinear gauge couplings are set using approximately 250 pb^{-1} of integrated luminosity at $\sqrt{s} = 1.96$ TeV from the Run II DØ detector at the Fermilab collider. Under the assumption that the $WW\gamma$ couplings are equal to the WWZ couplings and using a form factor scale of $\Lambda = 2.0$ TeV, the combined 95% confidence level one-dimensional coupling limits from all three channels are $-0.32 < \Delta\kappa < 0.45$ and $-0.29 < \lambda < 0.30$.

Preliminary Results for Summer 2006 Conferences

Channel	Signal	Background	Candidates
e^+e^-	3.26 ± 0.05	2.3 ± 0.21	6
$e^\pm\mu^\mp$	10.8 ± 0.1	3.81 ± 0.17	15
$\mu^+\mu^-$	2.01 ± 0.05	1.94 ± 0.41	4

TABLE I: Predicted signal and background, with statistical error, and number of candidate events for each decay channel.

Within the standard model the interactions between the bosons of the electroweak interaction are entirely determined by the gauge symmetry. Any deviations from the standard model couplings are therefore evidence of new physics.

The most general Lorentz invariant effective Lagrangian which describes the triple gauge couplings has fourteen independent coupling parameters, seven for each of the $WW\gamma$ and WWZ vertices [1]. With the assumption of electromagnetic gauge invariance and C and P conservation the number of independent couplings is reduced to five, and the Lagrangian takes this form:

$$\begin{aligned} \frac{\mathcal{L}_{WWV}}{g_{WWV}} &= ig_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) \\ &\quad + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{i\lambda_V}{M_W^2} W^\dagger_{\lambda\mu} W^\mu{}_\nu V^{\nu\lambda} \end{aligned} \tag{1}$$

where $V = \gamma$ or Z, W^μ is the W^- field, $W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$ and $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$. The overall couplings are $g_{WW\gamma} = -e$ and $g_{WWZ} = -e\cot\theta_W$.

The five surviving parameters are: g_1^Z, κ_Z, κ_γ, λ_Z and λ_γ. In the standard model $g_1^Z = \kappa_Z = \kappa_\gamma = 1$ and $\lambda_Z = \lambda_\gamma = 0$. The couplings g_1^Z, κ_Z and κ_γ are often written in terms of their deviation from the standard model values as $\Delta g_1^Z = g_1^Z - 1$, and similarly for $\Delta\kappa_Z$ and $\Delta\kappa_\gamma$.

One effect of introducing anomalous coupling parameters into the standard model Lagrangian is the increase of the cross section for the $q\bar{q} \to Z/\gamma \to W^+W^-$ process, particularly as parton center of mass energies rise to infinity. Thus, constant finite values of the anomalous couplings produce unphysically large cross sections, violating unitarity. To keep the cross section from diverging, the anomalous coupling must vanish as $s \to \infty$. This is done by introducing a dipole form factor for an arbitrary coupling α (g_1^Z, κ_V or λ_V from Equation 1):

$$\alpha(\hat{s}) = \frac{\alpha_0}{(1 + \hat{s}/\Lambda^2)^2} \tag{2}$$

where the form factor scale Λ is set by new physics. For a given value of Λ there is an upper limit on the size of the couplings, beyond which unitarity is exceeded.

Limits on the $WW\gamma$ and WWZ anomalous couplings are set using the data, event selection and background calculations from the most recent WW cross section analysis published by the DØ Collaboration [2, 3]. The cross section analysis measures a $p\bar{p} \to WW$ cross section of $13.8^{+4.3}_{-3.8}$(stat)$^{+1.2}_{-0.9}$(syst) $\pm$ 0.9(lum) pb, compared with a standard model next-to-leading order prediction of $13.0 - 13.5$ pb [4].

The leptonic channels $WW \to \ell^+\nu\ell^-\bar{\nu}$ ($\ell = e,\ \mu$) are used to measure the cross section, with integrated luminosities 252 pb^{-1} for the e^+e^- channel, 235 pb^{-1} for the $e^\pm\mu^\mp$ channel, and 224 pb^{-1} for the $\mu^+\mu^-$ channel. Table I summarizes the signal and background events predicted by Monte Carlo (MC) and the number of observed candidate events in each channel. The details of selection cuts and efficiencies can be found in [3].

Four anomalous coupling relationships are considered. The first relationship assumes that the $WW\gamma$ parameters are equal to the WWZ parameters: $\Delta\kappa_\gamma = \Delta\kappa_Z$ and $\lambda_\gamma = \lambda_Z$. The second relationship, the HISZ parameterization, imposes SU(2)$\times$U(1) symmetry upon the coupling parameters [5]. The final pair assumes either the standard model $WW\gamma$ or WWZ interaction, while allowing the other parameters to vary.

In order to set anomalous couplings limits for a given coupling relationship and form factor combination, a grid of MC events is generated for a set of possible coupling values. The likelihood for getting the actual measured events is calculated at each of the grid points and the limits for the couplings can be extracted from a fit to the likelihood distribution across the grid.

A leading order MC generator by Hagiwara, Woodside and Zeppenfeld (HWZ) [1] is used to generate events for a grid in $(\Delta\kappa, \lambda)$ space. Each scenario of varying Λ values and γ and Z coupling relationships requires a separate grid. The central area of each grid has a finer spacing of generated coupling parameters to ensure that the likelihood surface is well defined inside the area where limits are set.

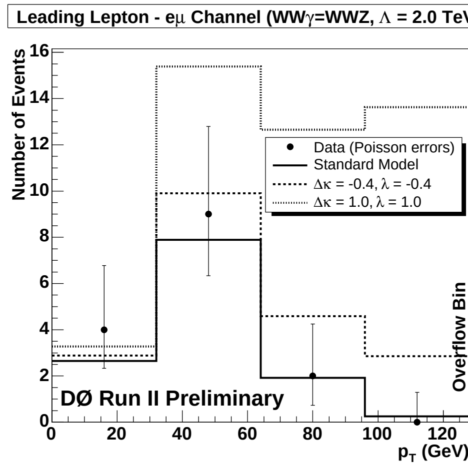

FIG. 1: Leading lepton p_T distributions for data (points), standard model MC (solid line) and two anomalous coupling MC scenarios (dashed lines), from the $WW \to e^{\pm}\mu^{\mp}$ channel, binned as used to calculate likelihood.

The generated events for each grid point are passed through a parameterized simulation of the DØ detector that is tuned to Z events. The output for each grid point is the simulated p_T spectra for the two leptons in the event scaled to match the luminosity of the data. Eight p_T bins were used to calculate the likelihood at each grid point: three bins plus an overflow bin for each of the two leptons. Figure 1 shows the data for the leading lepton in the $e^{\pm}\mu^{\mp}$ channel with MC estimations for the standard model and two sample anomalous coupling grid points.

The simulated signal from the HWZ generator and the simulated background, taken from a full detector simulation, are compared to the p_T of the real data events by calculating a bin-by-bin likelihood. Each bin is assumed to have a Poisson distribution with a mean equal to the sum of the signal and background bins. The errors on the signal and background distributions are accounted for by weighting with Gaussian distributions. Correlations between the signal and background errors for each channel are small, so they are handled separately. The error on the luminosity is 100% correlated, and so varies the same way for all channels. The likelihood, L, is calculated as

$$L = \int \mathcal{G}_{f_l} P_{ee}(f_l) P_{e\mu}(f_l) P_{\mu\mu}(f_l) df_l \tag{3}$$

$$P_{\ell\ell}(f_l) = \int \mathcal{G}_{f_n} \int \mathcal{G}_{f_b} \prod_{i=1}^{N_{\rm bins}} \mathcal{P}\left(N^i_{\ell\ell}; \left(f_l f_n n^i_{\ell\ell} + f_l f_b b^i_{\ell\ell}\right)\right) df_n df_b \tag{4}$$

where $\mathcal{P}(a;\alpha)$ is the Poisson probability of obtaining a events if the mean expected number is α; $n^i_{\ell\ell'}$ and $b^i_{\ell\ell'}$ are the simulated number of signal and background events for the $\ell\ell'$ channel in bin i; $N^i_{\ell\ell'}$ is the measured number of events for this channel in this bin; and f_l, f_n and f_b are the luminosity, signal, and background weights drawn from the Gaussian distributions $\mathcal{G}_{f_l}$, $\mathcal{G}_{f_n}$ and $\mathcal{G}_{f_b}$ respectively.

To extract the limits, a 6th order polynomial is fitted to the grid of negative log likelihood values. The one- and two-dimensional 95% confidence level limits are determined by integrating the likelihood curve or surface, respectively. In the one-dimensional case, the 95% C.L. limits represent the pair of points of equal likelihood that bound 95% of the total integrated area between the ends of the MC grid. The two-dimensional 95% C.L. countour line is the set of points of equal likelihood that bound a region containing 95% of the total integrated volume between the MC grid boundaries.

Using $224 - 252$ pb^{-1} of data in the $WW \to e^+e^-$, $WW \to e^{\pm}\mu^{\mp}$ and $WW \to \mu^+\mu^-$ channels, limits are set on anomalous trilinear gauge couplings for various coupling parameterizations and values of Λ. One-dimensional 95% C.L. limits are summarized in Table II, and two-dimensional 95% C.L. contours are shown in Figures 2 and 3.

Under the assumption that the $WW\gamma$ and WWZ couplings are equal and using a form factor scale of $\Lambda = 2.0$ TeV, the 95% C.L. limits obtained are $-0.32 < \Delta\kappa < 0.45$ and $-0.29 < \lambda < 0.30$. This significantly improves upon the previous limits from the DØ Collaboration, $-0.62 < \Delta\kappa < 0.77$ and $-0.53 < \lambda < 0.56$, set in Run I at Fermilab for the same channels under the same assumption using an integrated luminosity of 100 pb^{-1} [6]. Although the

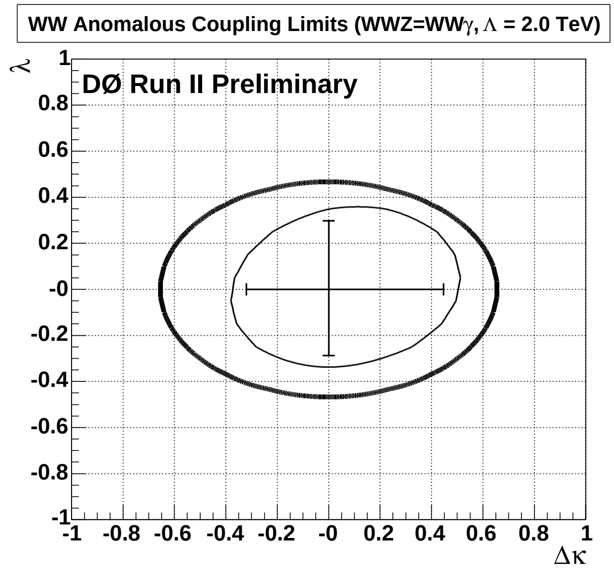

FIG. 2: One- and two-dimensional 95% C.L. limits when WWZ couplings are equal to $WW\gamma$ couplings, at $\Lambda = 2.0$ TeV. The bold outer curve is the unitarity limit, and the inner curve is the two-dimensional 95% C.L.

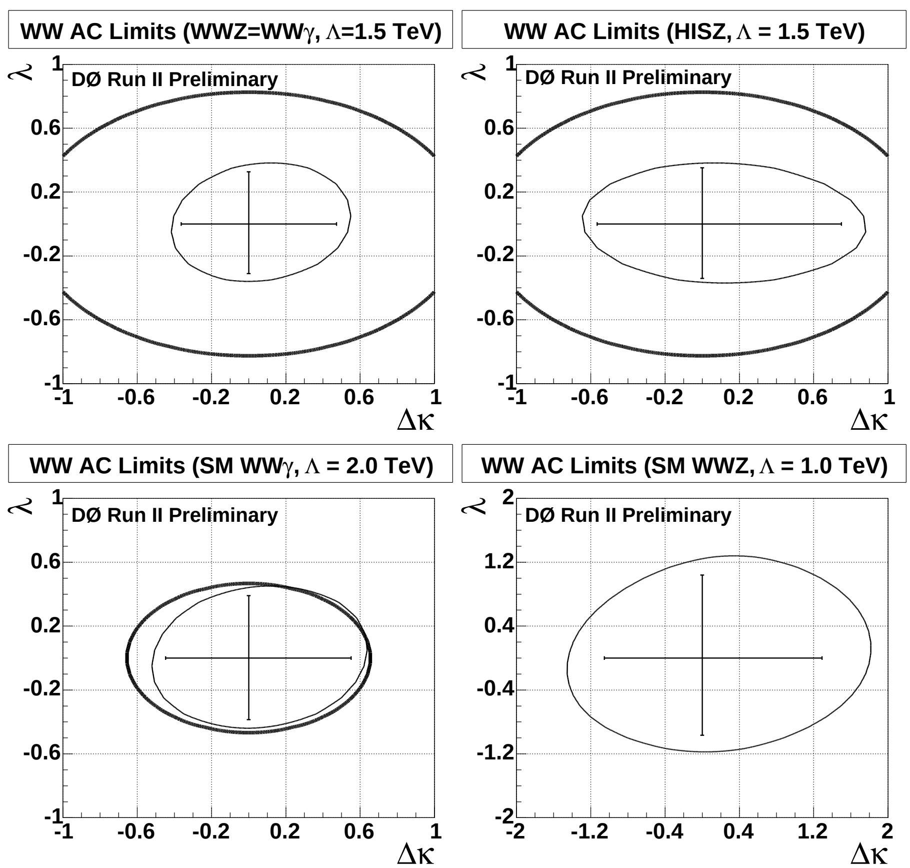

FIG. 3: One- and two-dimensional 95% C.L. limits with various coupling relationships and Λ values. The bold curve is the unitarity limit (where it fits within the plot boundaries) and the inner curve is the two-dimensional 95% C.L.

Coupling		95% C.L. Limits	Λ (TeV)
$WW\gamma = WWZ$	λ	$-0.31, 0.33$	1.5
	$\Delta\kappa$	$-0.36, 0.47$	1.5
$WW\gamma = WWZ$	λ	$-0.29, 0.30$	2.0
	$\Delta\kappa$	$-0.32, 0.45$	2.0
HISZ	λ	$-0.34, 0.35$	1.5
	$\Delta\kappa_\gamma$	$-0.57, 0.75$	1.5
SM $WW\gamma$	λ_Z	$-0.39, 0.39$	2.0
	$\Delta\kappa_Z$	$-0.45, 0.55$	2.0
SM WWZ	λ_γ	$-0.97, 1.04$	1.0
	$\Delta\kappa_\gamma$	$-1.05, 1.29$	1.0

TABLE II: One-dimensional axis limits at the 95% C.L. with various assumptions relating the $WW\gamma$ and WWZ couplings at various values of Λ. Parameters which are not constrained by the coupling relationships are set to their standard model values.

combined limits from the LEP collaborations have set tighter anomalous coupling limits [7], the hadronic collisions at the Tevatron explore a range of parton center-of-mass energies, including energy scales not explored at LEP.

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