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Search for Anomalous WW and WZ Production at D0

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(July 25, 1995)

We present a preliminary result from a search for anomalous WW and WZ production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV using $p\bar{p} \to e\nu jj$ events observed during the 1992–1993 run of the Fermilab Tevatron collider. A fit to the p_T spectrum of $W(e\nu)$ yields direct limits on the CP–conserving anomalous $WW\gamma$ and WWZ coupling parameters of $-0.89 < \Delta\kappa < 1.07$ $(\lambda = 0)$ and $-0.66 < \lambda < 0.67$ $(\Delta\kappa = 0)$ at the 95 % confidence level, assuming that the WWZ coupling parameters are equal to the $WW\gamma$ coupling parameters, and a form factor scale $\Lambda = 1.5$ TeV.

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The self-interaction of electroweak gauge bosons is a direct consequence of the non-Abelian gauge theory of the Standard Model (SM) and can be tested through study of gauge boson pair ($W\gamma$, $Z\gamma$, WW and WZ) production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV [1]. The self-interaction coupling parameters are given precisely in the SM. Any deviation of the parameters from the SM values signals physics beyond the SM. Figure 1 shows leading order Feynman diagrams of $q\bar{q} \to WW$ and $q\bar{q}' \to WZ$ processes. The WW production process depends strongly on the $WW\gamma$ and WWZ coupling parameters due to destructive interference between contributing amplitudes. This interference prevents the SM WW cross section from violating unitarity at high energies. The SM predicts the production cross sections for $p\bar{p} \to W^+W^-$ and $p\bar{p} \to W^\pm Z$ at $\sqrt{s} = 1.8$ TeV to be 8.4 pb and 2.5 pb, respectively [2]. Based on a formalism developed by Hagiwara *et. al* [3] the $WW\gamma$ and WWZ interactions beyond the SM can be parametrized by four independent dimensionless coupling parameters[2], $\Delta\kappa_\gamma$ and λ_γ for the $WW\gamma$ vertex and $\Delta\kappa_Z$ and λ_Z for the WWZ vertex. For the SM, $\Delta\kappa_\gamma = \lambda_\gamma = \Delta\kappa_Z = \lambda_Z = 0$. Non-zero coupling parameters result in a dramatic increase of the production cross section and an enhancement in the transverse momentum (p_T^W) spectrum of the W boson in the high p_T region as shown in Fig. 2. Thus, a study of the p_T^W spectrum of WW production leads to a sensitive test of the $WW\gamma$ and WWZ couplings. Similarly, the p_T^W spectrum of WZ production provides a direct test of the WWZ coupling.

The DØ collaboration has previously reported limits on anomalous trilinear gauge boson couplings from three processes using the data from the 1992–93 Tevatron collider run: the $WW\gamma$ coupling based on a measurement of $W\gamma$ production [4], WWZ and $WW\gamma$ couplings from a search for W boson pair production in dilepton decay modes [5], and $ZZ\gamma$ and $Z\gamma\gamma$ couplings from a measurement of $Z\gamma$ production [6]. In this report we present a new, independent determination of limits on the anomalous $WW\gamma$ and WWZ couplings obtained from a search for $p\bar{p} \to WW + X$ followed by $W \to e\nu$ and $W \to jj$, where j represents a jet, and $p\bar{p} \to WZ + X$

[2]In this paper we only consider CP–conserving couplings.

followed by $W \to e\nu$ and $Z \to jj$, using the data from the 1992–1993 run, corresponding to an integrated luminosity of 13.7 ± 0.7 pb^{-1}. In this decay mode, WZ events are indistinguishable from WW events.[3] The CDF collaboration has reported a similar measurement [7].

The $WW, WZ \to e\nu jj$ candidates were selected by searching for events containing a $W \to e\nu$ decay and two jets consistent with $W \to jj$ or $Z \to jj$. The data sample was obtained with a single electron trigger: an isolated electromagnetic (EM) cluster with transverse energy $E_T^e > 20$ GeV. This EM cluster was required to be within the fiducial region of the calorimeter $|\eta| \leq 1.1$ in the central calorimeter, or $1.5 \leq |\eta| \leq 2.5$ in the end calorimeters. Here η is the pseudorapidity defined as $\eta = -\ln(\tan(\theta/2))$, θ being the polar angle with respect to the beam axis. The electron cluster had to have (i) a ratio of EM energy to the total shower energy greater than 0.9; (ii) lateral and longitudinal shower shape consistent with an electron shower; (iii) the isolation variable of the cluster less than 0.1, where isolation is defined as $I = (E(0.4) - EM(0.2))/EM(0.2)$, and $E(0.4)$ is the total calorimeter energy inside a cone of radius $\mathcal{R} \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$, and $EM(0.2)$ is the EM energy inside a cone of 0.2; and (iv) a matching track in the drift chambers. The $W \to e\nu$ decay was identified by an isolated electron with $E_T^e > 25$ GeV and missing transverse energy $\not\!\!E_T > 25$ GeV forming a transverse mass $M_T^{e\nu} > 40$ GeV/c^2.

Jets were reconstructed by applying a cone algorithm with a radius $\mathcal{R} = 0.3$ to the calorimeter hits. This small cone size minimized the probability for two jets from the $W(Z)$ boson to merge into one cluster in the calorimeter, in particular, in the high p_T region. The jets were required to be within $|\eta| < 2.5$ and energy corrections including that for out-of-cone gluon radiation were applied [8]. We required that a candidate event contain at least two jets with $E_T^j > 20$ GeV and that dijet invariant mass (the largest invariant mass if more than two jets with $E_T^j > 20$ GeV in the event) satisfy $50 < m_{jj} < 110$ GeV/c^2, consistent with W and Z masses. The above selection criteria yielded 84 candidate events.

The background estimate, summarized in Table 1, includes contributions from: QCD production of $W+ \geq 2j$; QCD multijet events, where a jet was misidentified as an electron; $t\bar{t} \to W^+W^-b\bar{b} \to e\nu jjX$; WW with $W \to \tau\nu$ followed by $\tau \to e\nu\bar{\nu}$; and $ZX \to eeX$, where one electron was lost. The multijet background was estimated from the data by measuring the $\not\!\!E_T$ distribution of a background-dominated sample, obtained by selecting events containing an EM cluster which failed at least one of the electron quality requirements (isolation, shower shape and track-match). We extrapolated this $\not\!\!E_T$ distribution into the signal region ($\not\!\!E_T > 25$ GeV) by normalizing the number of events in the background sample to that in the candidate sample (without the $\not\!\!E_T$ requirement imposed) in the region of small $\not\!\!E_T$ ($0 < \not\!\!E_T < 15$ GeV). We measured the total number of multijet background events to be 12.2 ± 2.6. The $W+ \geq 2j$ background was estimated using the VECBOS [9] Monte Carlo followed by parton fragmentation using the ISAJET [10] program and a full detector simulation based on the GEANT program [11]. Using the dijet invariant mass distributions of the VECBOS sample and the observed Wjj sample after subtracting the contribution from the multijet events, we normalized the number of VECBOS $W+ \geq 2j$ events to the number of observed Wjj events outside of the signal region $50 < m_{jj} < 110$ GeV/c^2. This yielded the total number of $W+ \geq 2j$ background events (in the signal region) as 62.2 ± 13.0, where the uncertainty was due to the normalization (16%) and the limited statistics of the Monte Carlo events (13%). As a cross check of the normalization, we also calculated this background using the VECBOS prediction for the $W+ \geq 2j$ inclusive cross section and obtained a consistent result.

The backgrounds due to $t\bar{t} \to W^+W^-b\bar{b}$, $WW \to \tau\nu jj$ and $ZX \to eeX$ were estimated using the ISAJET program followed by the GEANT detector simulation and found to be small.

[3]The SM predicts $\sigma \cdot B(p\bar{p} \to W^+W^- \to e^\pm\nu jj) = 1.23$ pb and $\sigma \cdot B(p\bar{p} \to W^\pm Z \to e^\pm\nu jj) = 0.19$ pb.

TABLE 1. Summary of $e\nu jj$ data and backgrounds.

	$e\nu jj$ events
Background source:	
$W+\geq 2j$	62.2 ± 13.0
multijets	12.2 ± 2.6
$t\bar{t}(m_t = 180$ GeV/c$^2)$	0.87 ± 0.01
$WW \rightarrow \tau\nu jj$	0.19 ± 0.01
$ZX \rightarrow eeX$	$0.00^{+0.34}_{-0.00}$
Total Background	75.5 ± 13.3
Data	84
SM $WW + WZ$ prediction	2.9 ± 0.5

The total number of background events was estimated to be 75.5 ± 13.3. Thus we observed no statistically significant signal above the background.

The trigger and electron selection efficiencies [12] were estimated using $Z \rightarrow ee$ events. The jet finding efficiency is a function of p_T^W, due to the E_T^j requirement in the low p_T^W region and due to the probability for two jets to merge into one in the high p_T^W region. Using the ISAJET and PYTHIA [13] event generators followed by a full detector simulation, we estimated the efficiency for $W \rightarrow jj$ selection, including the jet finding efficiency and the efficiency for the dijet mass requirement, as a function of p_T^W, shown in Fig. 3. In estimating the sensitivity to the anomalous $WW\gamma$ and WWZ coupling parameters, we used the $W \rightarrow jj$ efficiency obtained from ISAJET, which is smaller than that from PYTHIA and therefore gives a conservative estimate. We included the difference between the ISAJET and PYTHIA numbers in the systematic uncertainty. We calculated the overall event selection efficiency as a function of the coupling parameters using the efficiencies described above and the WW, WZ Monte Carlo program of Zeppenfeld [2,14], in which the processes were generated to leading order, and higher order QCD effects were approximated by a K-factor of $1 + \frac{8}{9}\pi\alpha_s = 1.34$. A dipole form factor with a scale $\Lambda = 1.5$ TeV was used in the Monte Carlo event generation (e.g. $\Delta\kappa_\gamma(\hat{s}) = \Delta\kappa/(1 + \hat{s}/\Lambda^2)^2$, where $\hat{s}$ is the square of the invariant mass of the WW or WZ system). We simulated the p_T distribution of the WW and WZ systems using the observed p_T^Z spectrum in our inclusive $Z \rightarrow ee$ data sample. We calculated the total efficiency with the SM couplings to be 0.15 ± 0.02 for WW and 0.16 ± 0.02 for WZ. Thus the total number of expected SM events was 2.9 ± 0.5: 2.5 ± 0.5 for WW and 0.4 ± 0.1 WZ. Using these efficiencies and the background-subtracted signal, we set the upper limit on the cross section times branching fraction of $\sigma B(W^+W^- \rightarrow e^\pm\nu jj) + \sigma B(W^\pm Z \rightarrow e^\pm\nu jj)$ for the SM couplings to be 17 pb at the 95% confidence level (CL). Figure 4 shows the p_T distribution of the $e\nu$ system.

The absence of an excess of events with high p_T^W excludes large deviations from the SM couplings. To set limits on the anomalous coupling parameters, a binned likelihood fit was performed on the p_T spectrum of the $e\nu$ system, by calculating the probability for the sum of the background and the Monte Carlo signal prediction as a function of anomalous coupling parameters, to fluctuate to the observed number of events. The uncertainties in the background estimate, efficiencies, acceptance and integrated luminosity were convoluted in the likelihood function with Gaussian distributions. Figure 5 shows the limit contour at the 95% CL for the CP–conserving anomalous coupling parameters, assuming that CP–violating anomalous coupling parameters are zero and that the WWZ coupling parameters are equal to the $WW\gamma$ coupling parameters:

$\Delta\kappa \equiv \Delta\kappa_\gamma = \Delta\kappa_Z$ and $\lambda \equiv \lambda_\gamma = \lambda_Z$. We obtained limits at the 95% CL of

$$-0.89 < \Delta\kappa < 1.07 \;\; (\lambda = 0), \qquad -0.66 < \lambda < 0.67 \;\; (\Delta\kappa = 0),$$

for $\hat{s} = 0$ (i.e. the static limit). The limits obtained are within the constraints imposed by the S–matrix unitarity for $\Lambda = 1.5$ TeV. Figure 6 compares the limits obtained in this paper with limits obtained by DØ from a measurement of $W\gamma$ production [4] and a search for $WW \to \ell\ell'\nu\bar{\nu}'$ [5]. The preliminary result obtained from this analysis gives the most stringent limit on $\Delta\kappa$.

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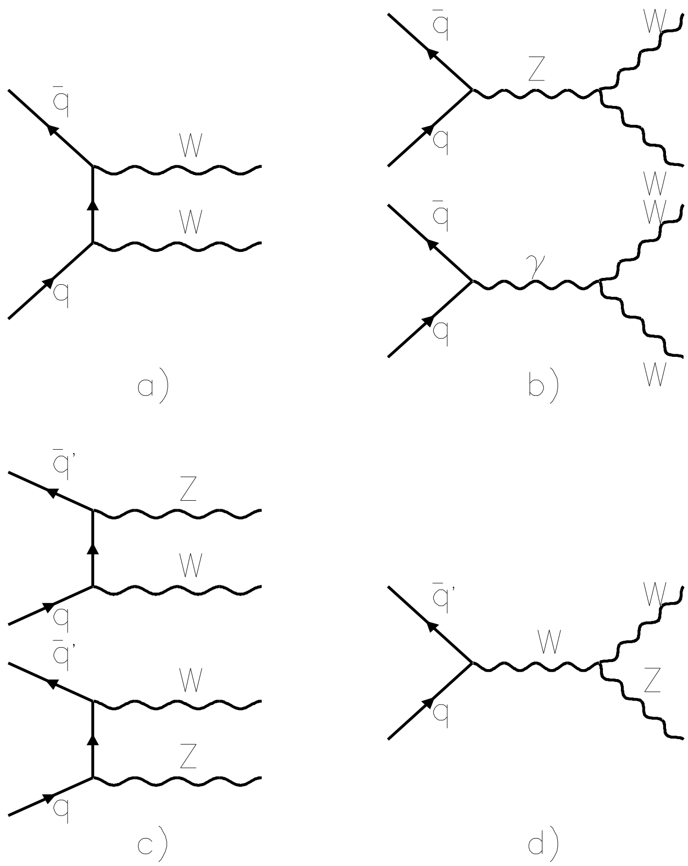

FIG. 1. Leading order Feynman diagrams for $q\bar{q} \to WW$ (a,b) and $q\bar{q}' \to WZ$ (c,d)

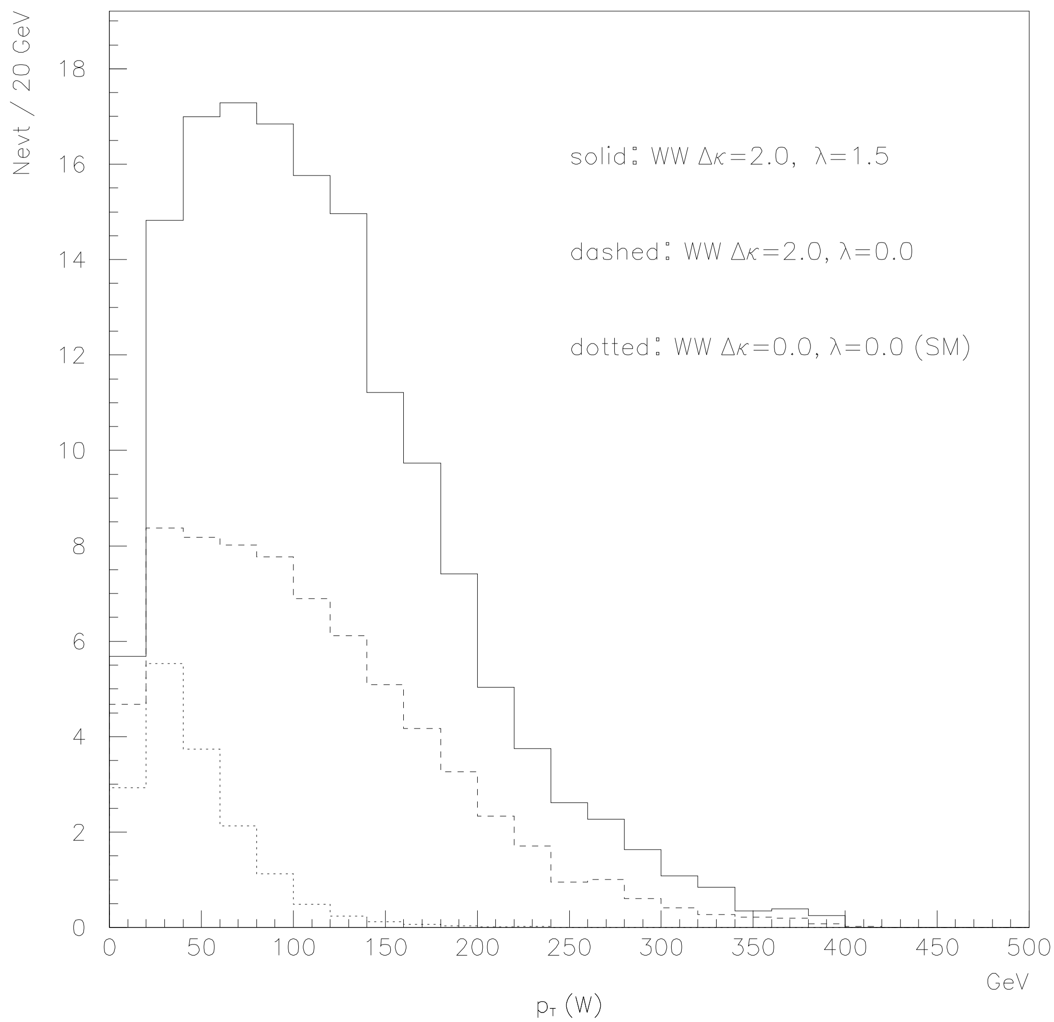

FIG. 2. p_T distributions of Monte Carlo $WW \to e\nu jj$ events with various coupling parameters. The dotted line represents the Standard Model (SM) couplings. The cross section increases and the p_T spectrum becomes harder with anomalous coupling parameters. The samples are normalized to 13.7 pb^{-1}.

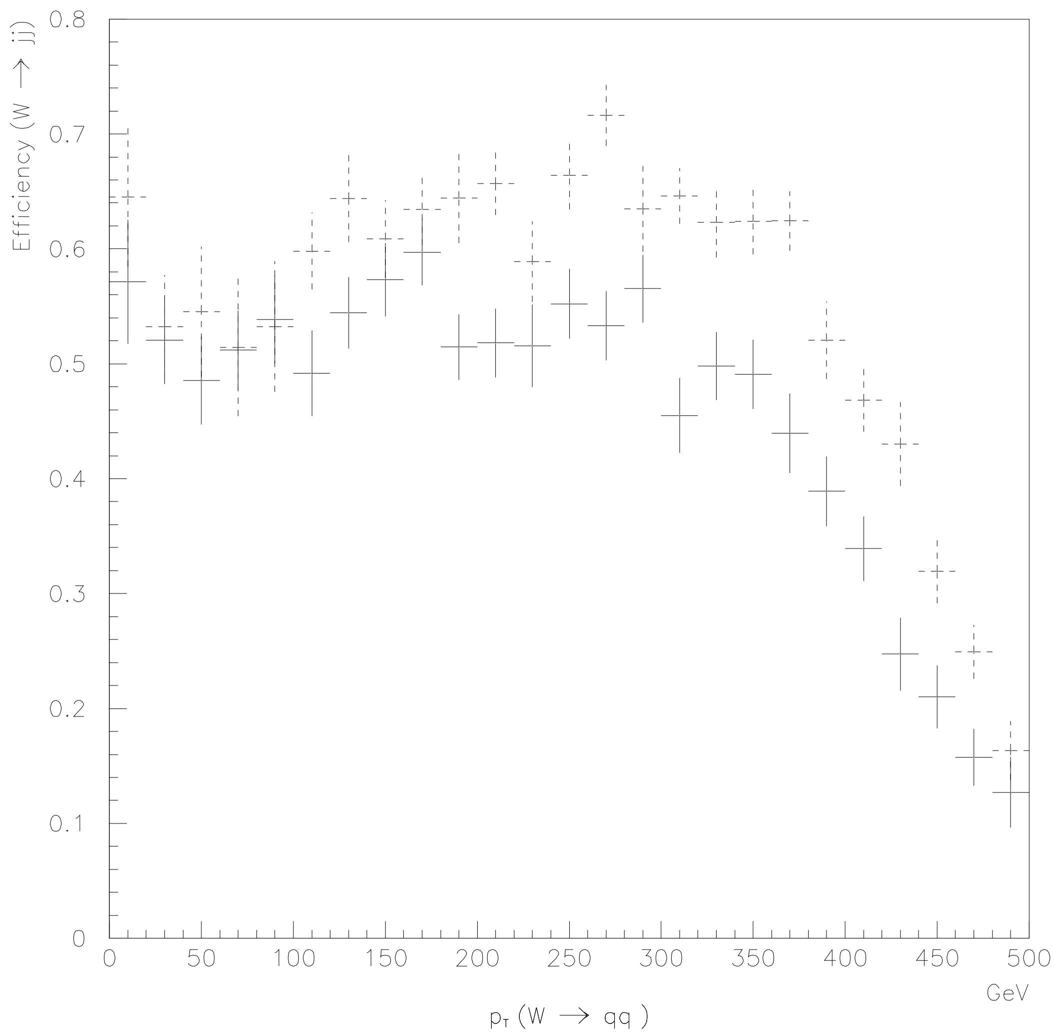

FIG. 3. Total efficiency for $W \to jj$ selection as a function of p_T^W, estimated using the ISAJET(solid) and the PYTHIA(dashed) generators followed by a full detector simulation.

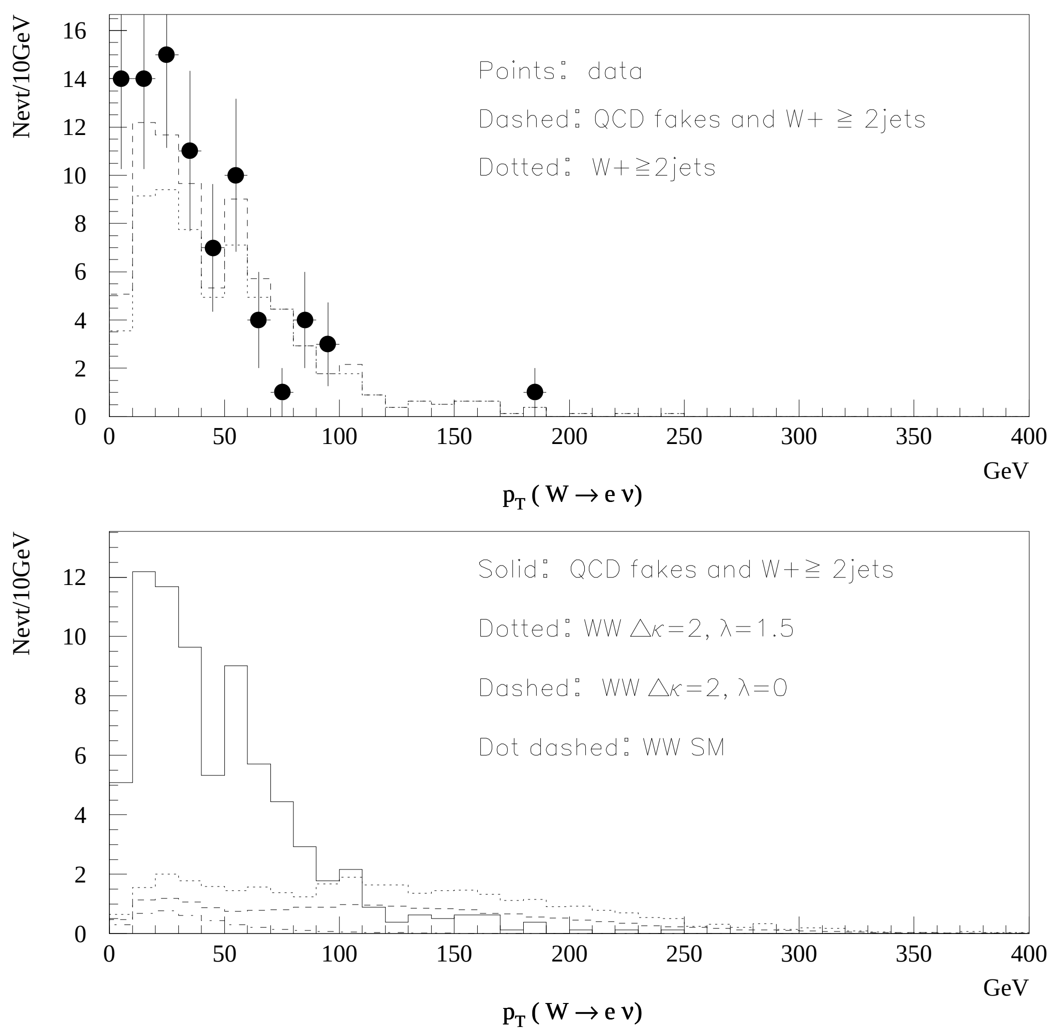

FIG. 4. p_T distributions of the $e\nu$ systems. The solid circle indicates the observed spectrum. The dashed and dotted lines are background estimates from the QCD multi-jet events and $W+\geq 2j$ events, and $W+\geq 2j$ events only respectively (top plot). The Monte Carlo predictions of p_T spectrum of the $e\nu$ system for the SM and non-SM productions are shown in the bottom plot.

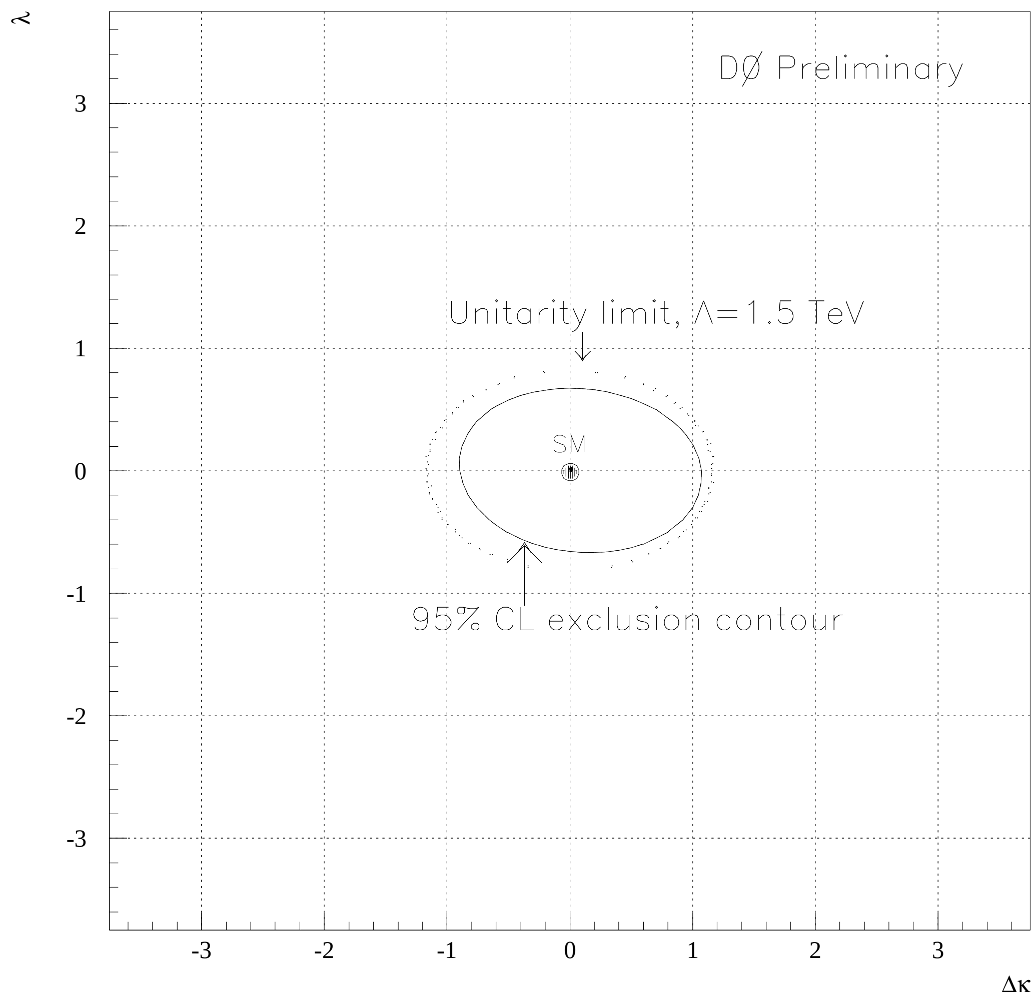

FIG. 5. Limit contour (solid line) on CP–conserving anomalous coupling parameters at the 95% CL, assuming $\Delta\kappa \equiv \Delta\kappa_\gamma = \Delta\kappa_Z$ and $\lambda \equiv \lambda_\gamma = \lambda_Z$. The constraint imposed by the S-matrix unitarity for $\Lambda = 1.5$ TeV is also shown (dotted line).

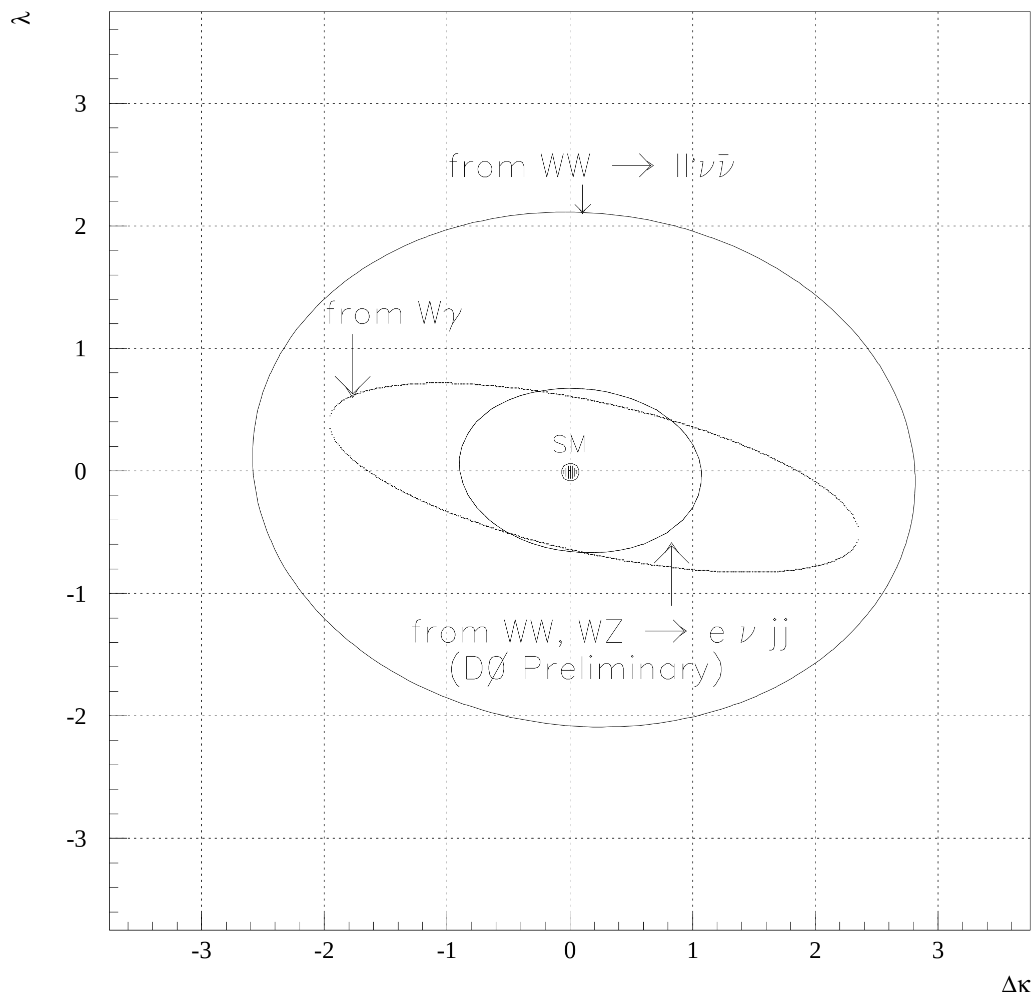

FIG. 6. Comparison of the limit obtained in this paper with limits obtained from a measurement of $W\gamma$ production [4] and a search for $WW \rightarrow \ell\ell'\nu\bar{\nu}'$ [5].