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MEASUREMENT OF THE $WW\gamma$, $ZZ\gamma$ AND $Z\gamma\gamma$ COUPLINGS AT THE FERMILAB TEVATRON

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ABSTRACT

The processes $p\overline{p} \rightarrow \ell\overline{\nu}\gamma + X$ and $p\overline{p} \rightarrow \ell^+\ell^-\gamma + X$ ($\ell = e, \mu$) have been observed using the DØ detector at the Fermilab Tevatron Collider at $\sqrt{s} = 1.8$ TeV. The observed signals in the electron and muon decay channels are used as a probe of the $WW\gamma$, $ZZ\gamma$ and $Z\gamma\gamma$ vertex couplings. By comparing the event rates and shapes of the photon E_T distributions with theoretical predictions, 95% confidence limits are obtained on the $WW\gamma$, $ZZ\gamma$ and $Z\gamma\gamma$ vertex coupling parameters.

1. Introduction

In $p\bar{p}$ collisions at the Fermilab Tevatron, the trilinear boson couplings can be probed by diboson production. Measurement of the $WW\gamma$ trilinear coupling, is possible by detecting $W\gamma$ production and measurement of the $ZZ\gamma$ and $Z\gamma\gamma$ trilinear couplings is possible via $Z\gamma$ production.

Requiring Lorentz covariance and gauge invariance of the on-shell photon, the most general $WW\gamma$ vertex can be parametrized by a vertex function which is described by four coupling parameters κ, λ, $\tilde{\kappa}$ and $\tilde{\lambda}$.[1] These parameters are related to the electromagnetic moments of the W. For example, combinations of κ and λ yield the W magnetic dipole moment $\mu_W = \frac{e}{2M_W}(1 + \kappa + \lambda)$ and electric quadrupole moment $Q_W = -\frac{e}{M_W^2}(\kappa - \lambda)$. In the standard model at tree level the $WW\gamma$ coupling is uniquely determined by the $\mathrm{SU(2)_L} \otimes \mathrm{U(1)_Y}$ gauge symmetry requiring $\kappa = 1$, $\lambda = 0$, $\tilde{\kappa} = 0$, $\tilde{\lambda} = 0$. Therefore, a measurement of the $WW\gamma$ coupling is a powerful test of the Standard Model gauge symmetry.

Anomalous couplings may arise due to radiative loop corrections to the $WW\gamma$ vertex or due to models in which the W is viewed as a composite particle. The experimental signature for anomalous couplings is an increase of the $W\gamma$ production cross section and changes in the kinematic distributions of the final state particles, such as an enhancement of the photon spectrum at high transverse energy.[2]

Table 1. $W\gamma$ and $Z\gamma$ selection trigger requirements and offline cuts.

	$e\nu\gamma$	$\mu\nu\gamma$	$ee\gamma$	$\mu\mu\gamma$
Trigger	$E_T^{em} \geq 20$ GeV	$p_t^{\mu} \geq 5$ GeV	$2 \times E_T^{em} \geq 10$ GeV	$p_t^{\mu} \geq 5$ GeV
	$\not{E}_T \geq 20$ GeV	$E_T^{em} \geq 7$ GeV		$E_T^{em} \geq 7$ GeV
Kinematic cuts:	$E_T^{e} \geq 25$ GeV	$p_T^{\mu} \geq 15$ GeV	$E_T^{e_1} \geq 25$ GeV	$p_T^{\mu_1} \geq 15$ GeV
	$\not{E}_T \geq 25$ GeV	$\not{E}_T \geq 15$ GeV	$E_T^{e_2} \geq 25$ GeV	$p_T^{\mu_2} \geq 10$ GeV
	$E_T^{\gamma} \geq 10$ GeV		$E_T^{\gamma} \geq 10$ GeV	
	$\Delta R \equiv \sqrt{\Delta\phi_{\ell\gamma}^2 + \Delta\eta_{\ell\gamma}^2} \geq 0.7$		$\Delta R \equiv \sqrt{\Delta\phi_{\ell\gamma}^2 + \Delta\eta_{\ell\gamma}^2} \geq 0.7$	

In contrast to the $WW\gamma$ coupling, the coupling of the photon to the Z boson is forbidden in the SM at tree level. However, to allow for the possibility of anomalous couplings, the vertex functions may be parametrized in terms of four parameters $(h_1^Z, h_2^Z, h_3^Z, h_4^Z)$ for the $ZZ\gamma$ vertex function and four parameters $(h_1^\gamma, h_2^\gamma, h_3^\gamma, h_4^\gamma)$ for the $Z\gamma\gamma$ vertex function.[3]

Tree level unitarity requires that the couplings must be described by form factors which vanish when any of the boson momenta become very large. The form factors used for this study are described in references 2 and 3.

In this paper we present preliminary measurements of the $WW\gamma$, $ZZ\gamma$ and $Z\gamma\gamma$ couplings using $W\gamma$ and $Z\gamma$ events in the electron ($e\overline{\nu}\gamma$ and $e^+e^-\gamma$) and muon ($\mu\overline{\nu}\gamma$ and $\mu^+\mu^-\gamma$) channels observed at DØ during the 1992-93 run, corresponding to an integrated luminosity of approximately 14 pb^{-1}.

2. Event selection

$W\gamma$ candidates were obtained by searching for events containing an isolated high-p_T lepton (electron or muon) and an isolated photon. The events must have large missing transverse energy to signify the presence of a neutrino. Table 1 summarizes the trigger requirements and offline kinematic cuts used.

Since anomalous couplings result in an enhancement of events at large E_T^γ, lowering the E_T^γ cut below 10 GeV does not increase the sensitivity to anomalous couplings. A further requirement was that the photon be well separated from the lepton ($\Delta R_{\ell\gamma} \geq 0.7$). This cut suppresses the contribution of the radiative W decay where the photon originates from bremsstrahlung from the final state lepton.

The $W\gamma$ selection criteria yielded 9 candidate events in the electron channel and 10 candidates in the muon channel.

The $Z\gamma$ candidates were obtained by searching for events containing two isolated electrons or muons and an isolated photon (see table 1). This resulted in 4 candidate events in the electron channel and 2 $Z\gamma$ candidates in the muon channel.

3. Background calculations

The background estimate for the $W\gamma$ events, includes contributions from: $W+$ jets, where a jet is misidentified as a photon; $Z\gamma$, where Z decays to $\ell^+\ell^-$ and one of the leptons is missed or mismeasued by the detector and so contributes to the measured missing E_T; $W\gamma$ with $W \to \tau\nu$ followed by $\tau \to \ell\nu\overline{\nu}$; and $ee+$jets, where an electron is misidentified as a photon due to tracking inefficiency.

We have estimated the $W+$jets background using the observed E_T distributions of jets in the inclusive W data sample and the measured probability for a jet to fake a photon. This probability was determined, as a function of E_T of the jet, using samples of QCD multijet events. The probability was found to be less than 10^{-3} and varied slowly with E_T. The $Z\gamma$ background was estimated using monte carlo with a full GEANT simulation of the DØ detector. The remaining backgrounds were much smaller and were estimated from monte carlo and data.

Subtracting the estimated backgrounds from the observed number of events, we obtain the number of signal events to be $6.5^{+4.0+1.1}_{-2.1-1.2}$ for the electron channel and $7.0^{+4.2+0.5}_{-3.1-1.1}$ for the muon channel, where the first uncertainty is statistical and the second is systematic.

The background estimate for the $Z\gamma$ events includes contributions from $Z+$jets, where a jet is misidentified as a photon, and $Z\gamma$ with $Z\rightarrow\tau\tau$ followed by $\tau\rightarrow\ell\nu\overline{\nu}$. These backgrounds were estimated from data and monte carlo respectively, as for the $W\gamma$ background study described above.

Subtracting the estimated backgrounds from the observed number of events, we obtain the number of signal events to be $3.8^{+3.2}_{-1.9}\pm 0.09$ for the electron channel and $1.96^{+2.62}_{-1.29}\pm 0.03$ for the muon channel.

4. Limits on anomalous couplings

To compare with the SM predictions for $W\gamma$ and $Z\gamma$ production we used the event generator of Baur and Zeppenfeld.[2,3] This program generates 4-vectors for the $W\gamma$ and $Z\gamma$ processes which were then put through a fast DØ detector simulation. This monte carlo simulates the energy and momentum resolutions for electrons, muons and missing E_T and includes fiducial cuts and detector efficiencies.

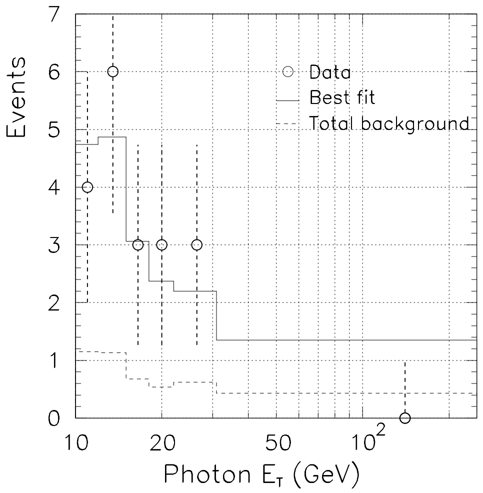

Fig. 1. E_T^γ distribution for $W\gamma$ candidates.

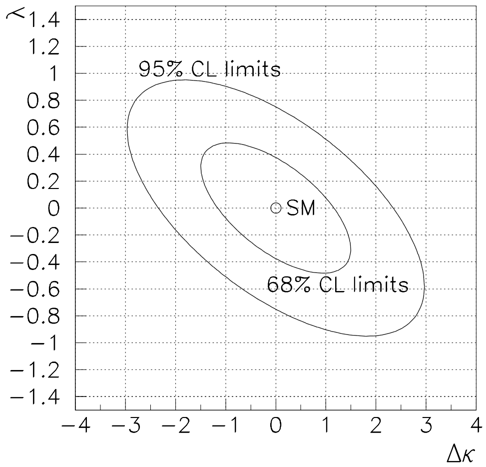

Fig. 2. $\Delta\kappa-\lambda$ contour plot from E_T^γ fit.

The predictions for the number of expected $W\gamma$ events using SM couplings are $7.7\pm0.8\pm0.9$ (e channel) and $6.1\pm1.0\pm0.7$ (μ channel), where the first error is the systematic error and the second error is due to the uncertainly in the integrated luminosity. For $Z\gamma$ the corresponding predictions are $2.3\pm0.4\pm0.3$ and $1.84\pm0.29\pm0.22$. The

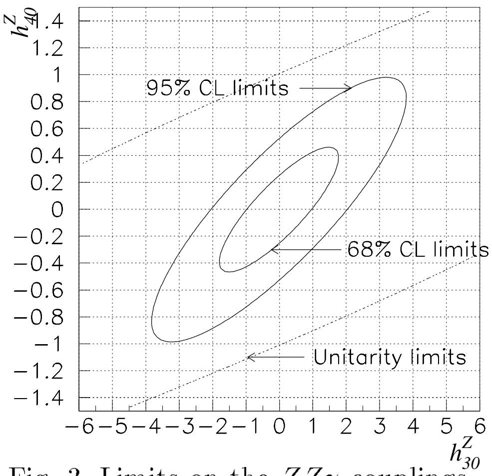

Fig. 3. Limits on the $ZZ\gamma$ couplings.

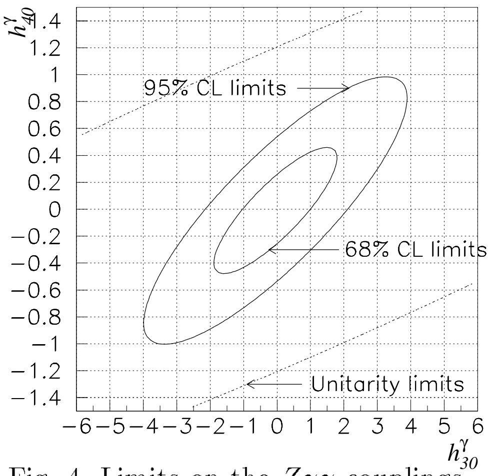

Fig. 4. Limits on the $Z\gamma\gamma$ couplings.

systematic error includes the uncertainty in electron efficiency, muon efficiency, photon efficiency including conversion modelling, $\not{E}_T$ smearing, choice of structure function, and choice of Q^2 scale. Comparing with the observed signal (section 3) we see that the data are in good agreement with the SM within errors. Therefore, we see no evidence for anomalous couplings. However, we are able to set limits on the anomalous couplings by comparing our data with the predictions of the event generator for different anomalous couplings.

To set limits on the anomalous couplings, we fit the E_T^γ spectrum using a binned likelihood method (Fig. 1). The $W\gamma$ 95% confidence level (CL) limits derived from this method are $-2.3 < \Delta\kappa < 2.3$ (for $\lambda = 0$) and $-0.75 < \lambda < 0.75$ (for $\Delta\kappa = 0$) as shown in the $\Delta\kappa - \lambda$ contour plot in Fig. 2. The 95% CL limits on couplings independent of each other, is represented by the furthermost points on the contour: $-3.0 < \Delta\kappa < 3.0$ and $-0.95 < \lambda < 0.95$.

The same method was used to obtain limits for the $ZZ\gamma$ and $Z\gamma\gamma$ couplings. Because of the form of the vertex functions for these couplings our measurement is sensitive to the form factor sacle Λ and the results given here are for $\Lambda = 500$ GeV. For $ZZ\gamma$ (Fig. 3) we obtained the 95% CL limits $-2.1 \leq h^Z_{30} \leq 2.1$ (for $h^Z_{40} = 0$) and $-0.5 \leq h^Z_{40} \leq 0.5$ (for $h^Z_{30} = 0$) and the independent limits $-3.8 \leq h^Z_{30} \leq 3.8$ and $-1.0 \leq h^Z_{40} \leq 1.0$. For $Z\gamma\gamma$ the limits are only slightly weaker as shown in Fig. 4.

5. Conclusions

The processes $p\overline{p} \rightarrow \ell\overline{\nu}\gamma+X$ and $p\overline{p} \rightarrow \ell^+\ell^-\gamma+X$ ($\ell = e, \mu$) have been observed in DØ and were used to set limits on the $WW\gamma$, $ZZ\gamma$ and $Z\gamma\gamma$ vertex couplings. The limits obtained are a considerable improvement on previous measurements (UA2[4] and the CDF 1988-89 data[5]) and are comparable in sensitivity with the CDF 1992-93 results. Using data from the current Tevatron run (1993-94) and combining results from DØ and CDF, we can expect a significant improvement in sensitivity in the near future.

References

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