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ELECTROWEAK BOSON PAIR PRODUCTION IN $p\bar{p}$ COLLISIONS AT $\sqrt{s} = 1.8$ TeV

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ABSTRACT

Results from CDF on W^+W^-, WZ, and $W\gamma$ production in $\sqrt{s} = 1.8$ TeV $\bar{\text{p}}$-p collisions from the 1992-93 collider run are presented. Direct limits on $WW\gamma$ and WWZ anomalous couplings are obtained.

1. Introduction

Since the discovery of the W and Z electroweak force carriers, many predictions of the SU(2)$\times$U(1) gauge theory have been confirmed and its parameters determined with ever increasing precision. Among the most characteristic and fundamental signatures of non-Abelian symmetry in the theory are the interactions of W, Z, and γ bosons with each other. The interaction between W and γ was previously studied in the process $p\bar{p} \rightarrow W\gamma$.[1] Here we report on improved bounds on the $WW\gamma$ and WWZ couplings obtained from production of WW, WZ, and $W\gamma$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV.

The most general $WW\gamma$ and WWZ couplings consistent with Lorentz invariance have been formulated and may be parameterized in terms of fourteen independent constants (or form factors), seven for the $WW\gamma$ vertex and seven for the WWZ vertex.[2] They are g_1^V, g_4^V, g_5^V, λ^V, κ^V, $\tilde{\lambda}^V$, and $\tilde{\kappa}^V$ where V is either γ (for $WW\gamma$) or Z (for WWZ). The standard SU(2) $\times$ U(1) electroweak theory corresponds to the choice $g_1^\gamma = g_1^Z = 1$ and $\kappa^\gamma = \kappa^Z = 1$ with all other couplings set to zero.

In the standard model, the dominant contribution to diboson production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV comes from two types of Feynman diagrams (figure 1). There are substantial cancellations between the t- or u-channel diagrams, which involve only the couplings of the bosons to fermions, and the s-channel diagrams which contain the three-boson coupling. To the extent that the fermionic couplings of the W, Z, and γ have been well tested, we may regard diboson production as primarily a test of the three-boson couplings. If any of these couplings differ substantially from the standard model values then the cross section increases. The enhancement is greatest at high boson P_T where the strongest cancellations occur in the standard model. Therefore, this analysis looks for anomalously large cross sections at high boson P_T in order to obtain information on the couplings.

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Any couplings, differing from the standard model couplings, that are independent of $\sqrt{\hat{s}}$ cause the diboson production cross section to violate unitarity at some large $\sqrt{\hat{s}}$. To avoid this the couplings are made functions of $\sqrt{\hat{s}}$ and a form factor scale Λ_{FF} in such a way that they approach their standard model values when $\sqrt{\hat{s}}$ is bigger than Λ_{FF}. The sensitivity of the measurement of the couplings can depend on the value of Λ_{FF} used. However, if Λ_{FF} is big enough, there is little effect at lower energies where the measurement is made.

2. $p\bar{p} \to WW$, WZ, and $W\gamma$ Event Selection

Measurement of WW and WZ production provides information on both $WW\gamma$ and WWZ couplings. $W\gamma$ production provides information on the $WW\gamma$ vertex only.

The standard model cross sections for WW and WZ production are 9.5 and 2.5 pb, respectively.[3] The decay modes $WW \to l\nu jj$, $WZ \to l\nu jj$, and $ZW \to l\bar{l}jj$ are more sensitive to anomalous couplings than purely leptonic decay modes. The leptonic decay modes suffer from top quark background, low branching ratios, and lepton acceptance. The leptons plus jets decay modes have large QCD backgrounds but these background events typically have lower $P_T(V)$ than the events expected from anomalous three-boson couplings. A cut at high $P_T(V)$ eliminates this background so that excess events can be attributed to anomalous three-boson couplings.

Candidate WW and WZ events are selected by looking for events with leptons and missing energy consistent with a W or a Z and with two leading jets with $60 < M(JJ) < 110$ GeV/c^2 and $P_T(JJ) > 130$ or 100 GeV/c for $l\nu jj$ or $l\bar{l}jj$ events. The standard model prediction of the number of diboson events detected, after all cuts, acceptances, efficiencies, and without adding the expected background, is 0.08 in the $l\nu jj$ channel and 0.01 in the $l\bar{l}jj$ channel. One event in the $l\nu jj$ channel passes the cuts. In the $l\bar{l}jj$ channel there are no events that pass.

Candidate $W\gamma$ events are selected from events with a lepton and missing energy consistent with a W and with an isolated, well measured photon with $E_T > 7$ GeV/c. Background in this channel is from QCD $W + j$ production and is calculated from the observed $W + j$ data sample together with a fake photon probability determined from an independent jet data sample. There are 25 $W\gamma$ events selected before background subtraction. Figure 2 shows the cross section times branching ratio for $W\gamma$ production as a function of the minimum photon E_T together with the standard model prediction.

3. Bounds on Three-Boson Couplings

Lack of excess events at high boson P_T leads to bounds on the three-boson couplings. Figures 3a and 3b show the bounds obtained on two of the three-boson couplings. In figure 3a it is assumed that the couplings for the WWZ vertex are the same as that for the $WW\gamma$ vertex. In figure 3b one of the couplings is allowed to be different for the two vertices. Assuming that the couplings for the WWZ vertex are the same as those for the $WW\gamma$ vertex, and using $\Lambda_{FF} = 1.5$ TeV, and holding all other couplings to their standard model values, 95% confidence level limits can be set on $|\Delta\kappa| \equiv |\kappa - 1| < 1.0$ and $|\lambda| < 0.5$. The precision of this measurement is expected to improve by a factor of two with data from the present 1994 CDF data taking run.

4. Acknowledgements

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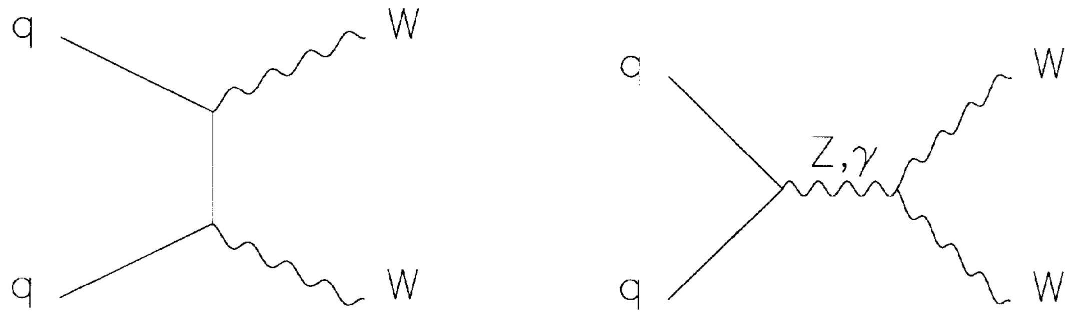

Fig. 1. Feynman diagrams for WW production.

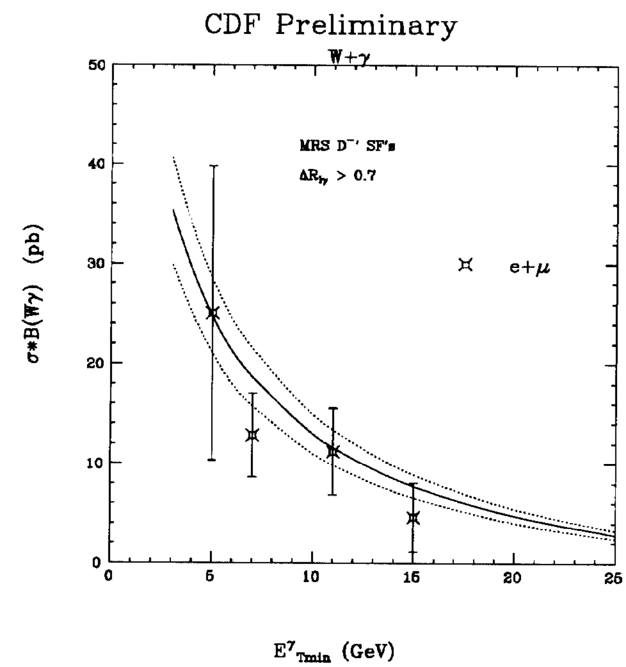

Fig. 2. Cross section times branching ratio for $W\gamma$ production as a function of the minimum photon E_T. The symbols represent the data. The solid line and dashed lines represent the standard model prediction and uncertainty.

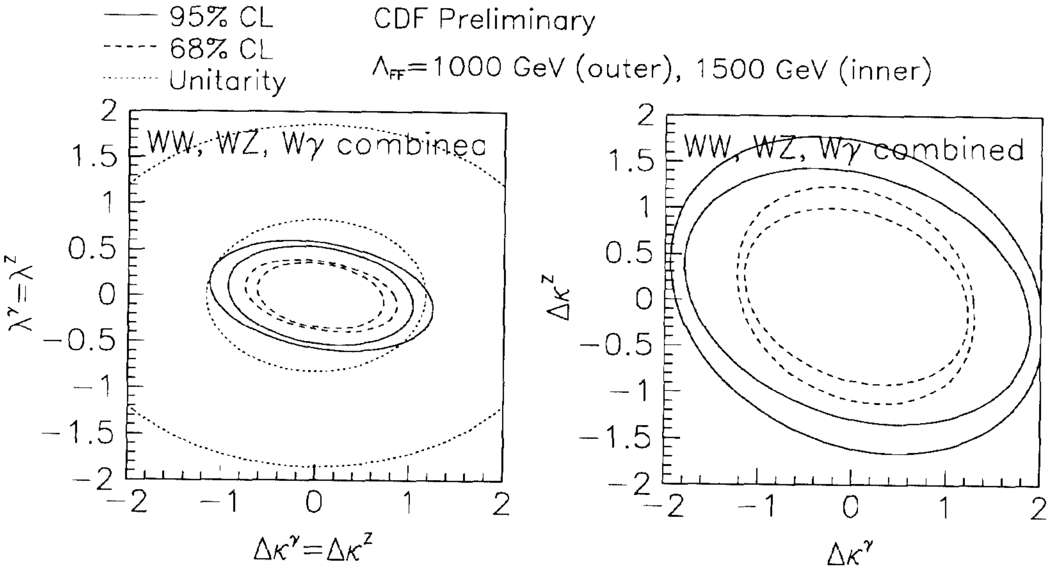

Fig. 3. Bounds on two of the three-boson couplings, λ and $\Delta\kappa \equiv \kappa - 1$. Standard model values are $\lambda = \Delta\kappa = 0$. a) Bounds on the couplings λ versus $\Delta\kappa$ assuming that the couplings are equal for WWZ and $WW\gamma$ vertices. b) Bounds on $\Delta\kappa^Z$ versus $\Delta\kappa^\gamma$ holding $\lambda^Z = \lambda^\gamma = 0$.