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Search for Anomalous Couplings in WW and WZ Measurements at the Tevatron (D0 and CDF Results)

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Abstract

The search for WW and WZ production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV using the CDF and DØ detectors is presented. Three analyses, one concentrating on the leptons + jets decay channels and two concentrating on the dilepton decay channels are described in detail. Limits on anomalous $WW\gamma$ and WWZ trilinear gauge boson couplings are presented. Prospects for further study of diboson production and anomalous couplings with the Upgraded Tevatron are also presented.

Introduction

The Standard Model (SM) of electroweak interactions makes precise predictions for the gauge boson self-interactions due to the non-abelian gauge symmetry of $SU(2)_L \otimes U(1)_Y$. These self-interactions are described by the trilinear couplings $WW\gamma$ and WWZ and quartic couplings. Vector boson pair production provides a fundamental signature for the non-abelian nature of the trilinear couplings. The $WW\gamma$ coupling has been directly tested in studies of the process $p\bar{p} \rightarrow W\gamma$[1]. However, the WWZ trilinear coupling has not been previously tested. This paper reports information on the $WW\gamma$ and WWZ couplings from direct measurements of the the processes $p\bar{p} \rightarrow WW$ and $p\bar{p} \rightarrow WZ$ at $\sqrt{s} = 1.8$ TeV.

The dominant leading-order SM diagrams for vector boson pair production (WW or WZ) in $p\bar{p}$ collisions include the t- and u-channel diagrams which proceed via quark exchange and the s-channel diagrams, where either a photon, a W or a Z serves as the mediating particle. The s-channel diagrams for WW production include the $WW\gamma$ and WWZ trilinear couplings. For s-channel WZ production only the WWZ coupling contributes. The SM predicts the cancellation of unitarity violating t- and u-channel amplitudes by similar contributions, with opposite sign, in the s-channel process. As the u- and t-channel processes depend only on the well-measured couplings between W bosons and quarks, the cancellation sets the SM prediction for the gauge boson self-coupling. The SM predicts that these couplings are $g_{WW\gamma} = -e$ and $g_{WWZ} = -e \cot\theta_W$.

A formalism has been developed to describe the $WW\gamma$ and WWZ interactions for models beyond the SM [2]. The effective Lorentz invariant Lagrangian, after imposing C, P, and CP symmetry, is:

$$\frac{i\mathcal{L}_{WWV}}{g_{WWV}} = g_1^V \left(W^\dagger_{\mu\nu} W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu} \right) + \kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu V^{\nu\lambda},$$

where the overall couplings g_{WWV} are as in the SM. The couplings g_1^V, κ_V, and λ_V are to be determined by experiment. In the SM, $g_1^\gamma = g_1^Z = \kappa_\gamma = \kappa_Z = 1$ and $\lambda_\gamma = \lambda_Z = 0$. Electromagnetic gauge invariance restricts g_1^γ to 1; however, g_1^Z could be different from the SM prediction. The coupling parameters are related to the magnetic dipole moments (μ_W) and electric quadrupole moments (Q^e_W) of the W boson: $\mu_W = \frac{e}{2M_W}(1 + \kappa + \lambda)$ and $Q^e_W = -\frac{e}{M_W^2}(\kappa - \lambda)$, where e and M_W are the charge and the mass of the W boson [3].

The effective Lagrangian leads to vector boson pair production cross sections which grow with $\hat{s}$, the square of the invariant mass of the diboson system, for non-SM values of the couplings. In order to avoid unitarity violation, the anomalous couplings are parameterized as form factors with a scale, Λ (*e.g.* $\Delta\kappa/(1 + \hat{s}/\Lambda^2)^2$). For example, by requiring that tree-level unitarity is satisfied, a constraint $\Lambda \leq \left(\frac{6.88}{(\kappa-1)^2+2\lambda^2}\right)^{1/4}$ TeV is obtained in the case that the $WW\gamma$ couplings are equal to the WWZ couplings[4]. The cross section is enhanced, particularly at high $\hat{s}$, because the delicate cancellation of the SM is reduced. The cross section depends quadratically on the anomalous couplings. For example, under the assumption that $\lambda_\gamma = \lambda_Z$ and $\kappa_\gamma = \kappa_Z$, for $\Delta\kappa$, equal to $\kappa - 1$, and λ both equal to 1.0, the cross section is 52 pb, approximately 5 times the SM prediction of 9.5 pb[5]. Furthermore, the kinematic characteristics of the diboson events are increased due to the enhancement at high $P_t(V)$. Figure 1 shows the diboson invariant mass, $P_t(W)$, P_t(leptons), and the missing transverse energy for approximately 7 fb^{-1} of Monte Carlo $WW \to$ dileptons with SM and anomalous couplings ($\Delta\kappa = \lambda = 1$).

This paper describes results of three searches by CDF and DØ for WW and WZ production in $p\bar{p}$ collisions at the Tevatron. The first section describes the results of a search by CDF for WW and WZ with subsequent decay to leptons plus jets. The second and third sections describe the search for $WW \to$ dileptons plus missing E_T, first at DØ and second, at CDF. Limits on anomalous couplings are presented from the CDF leptons plus jets search and the DØ dileptons search. The fourth section presents a summary and prospects for diboson physics in one fb^{-1} of $p\bar{p}$ collisions at 1.8 TeV.

WW and $WZ \to$ Leptons + Jets (CDF)

This analysis[6] is a search for $WW \to l\nu jj$ and $WZ \to l\nu jj$ or $l\bar{l}jj$, where l is either an electron or muon and j is a hadronic jet. The SM WW and WZ signals are about 1/30th of the main background: single W boson or Z boson production accompanied by initial state radiation. Therefore the strategy adopted is to use the enhancement in the cross section for high P_t vector bosons to advantage by requiring a high P_t dijet which could have come from a W or Z boson decay. The dijet P_t threshold is set so that only one background event is expected in the final sample. With this choice it is unnecessary to perform a background subtraction and any uncertainty in the background calculation is avoided. However, the bulk of the SM diboson events are removed by this requirement. This makes the analysis sensitive to anomalous couplings but not to SM WW or WZ production.

A leptonic W boson decay is identified by an isolated electron or muon with $P_t \geq 20$ GeV/c and $\not{E}_T \geq 20$ GeV forming a transverse mass $M_T \geq 40$ GeV/c^2. A leptonic Z boson decay is identified by an electron or muon pair of opposite charge forming an invariant mass $70 \leq M_{l\bar{l}} \leq 110$ GeV/c^2. A candidate for a hadronic W or Z boson decay, defined by the two highest transverse energy jets with $E_T \geq 30$ GeV, is required. The invariant mass of the jet pair must be in the range $60 \leq M_{jj} \leq 110$ GeV/c^2. The P_t of the dijet interpreted as the W or Z boson decay is required to satisfy $P_t \geq 130$ GeV/c for leptonic W boson events and $P_t \geq 100$ GeV/c for leptonic Z boson events.

The data sample consists of 19.6 pb^{-1} collected during the 1992-93 Tevatron collider run. The dijet mass for events with a leptonic W boson decay and at least two jets with $E_T \geq 30$ GeV is shown in Figure 2a. The predicted SM WW and WZ signal, and the sum of the predicted SM WW and WZ signals along with the background expected is also shown. The background is normalized to the observed number of W boson events with two jets (minus the predicted signal). Figure 2b shows the dijet P_t distribution in the subset of events which satisfy the dijet mass criterion. The dijet P_t requirement is indicated by an arrow. One event passes the final selection for $l\nu jj$. There are no candidate events for the $WZ \rightarrow l\bar{l}jj$ decay mode. This yield is consistent with the expected background.

The expected number of WW and WZ events is estimated as a function of the anomalous couplings using a Monte Carlo event generator[4] combined with a fast detector simulation. Initial and final state QCD radiation effects and jet fragmentation are modeled with an adaptation of HERWIG[7, 8]. The jet response and resolution are tuned to match the collider and test beam data. The dijet mass resolution is expected to be 9 GeV/c^2 for diboson events that would pass the selection requirements. The efficiency of the dijet mass criterion is 88% for events passing all other selection requirements. Systematic uncertainties on the yield amount to 23%. With the SM prediction for the WW and WZ cross sections of 9.5 pb and 2.5 pb, respectively, 0.13 WW or WZ events with $l\nu jj$ signature and 0.02 WZ events with $l\bar{l}jj$ signature are expected.

Limits on anomalous couplings follow from a comparison of the signal with a Monte Carlo calculation of the expected event yield at various values of the couplings. Figure 3 presents the bounds at 95% confidence on four pairs of couplings for $\Lambda = 1000$ (outer solid line) and 1500 GeV/c^2 (inner solid line) in the form of ellipses. The limits from unitarity are shown as dotted lines. Except as noted in the figure caption, for each case all the other couplings are held at their SM values. Figure 3a shows the limits in the plane λ_γ vs. λ_Z. The limits are stronger for λ_Z due to the $\cot\theta_W$ advantage held by the

WWZ couplings. The unitarity limit at the two form factor scales is determined from the intersection of the unitarity limit from WW production (dotted ellipse) with the limit from $W\gamma$ production on λ_γ (vertical lines) and from WZ production on λ_Z (horizontal lines). Figure 3b shows the limits in the plane g_1^Z vs. κ_Z. That $g_1^Z = \kappa_Z = 0$ lies outside the allowed region is direct evidence for a non-zero WWZ coupling and for the destructive interference among the s-, t-, and u-channel diagrams. The unitarity contours are the intersection of the separate unitarity limits from WW and WZ production. Figures 3c and 3d show limits on λ vs. κ under various assumptions about the relation between the $WW\gamma$ and WWZ couplings for which previous indirect limits are not well constrained[9, 10]. In Figure 3c, it is assumed that $WW\gamma = WWZ$. The limits on the axes are $-1.11 \leq \Delta\kappa \leq 1.27 (\lambda = 0)$ and $-0.81 \leq \lambda \leq 0.84 (\Delta\kappa = 0)$ for $\Lambda = 1000$ GeV/c^2. In Figure 3d, the relations between the $WW\gamma$ and WWZ couplings are given by the HISZ[9] equations, which specify λ_Z, κ_Z, and g_1^Z in terms of λ_γ and κ_γ. The limits on the axes are $-1.35 \leq \Delta\kappa_\gamma \leq 1.57 (\lambda_\gamma = 0)$ and $-0.85 \leq \lambda_\gamma \leq 0.81 (\Delta\kappa_\gamma = 0)$ for $\Lambda = 1000$ GeV/c^2. In the latter two figures, the unitarity contours come from the single ellipse determined at the scale Λ.

$WW \to$ Dileptons + Missing E_T (DØ)

This analysis[11] is a search for $WW \to l\bar{l}'\bar{\nu}\nu'$ with the DØ detector where the leptons, l or l', are electrons or muons. The dilepton signature provides for a smaller background than the semileptonic decay modes of the previous section; however, the branching fraction is also smaller. The strategy adopted is to optimize the event selection for SM W boson pair production while avoiding criteria which select against anomalous WW production. Thus, this analysis has potential to be sensitive to SM WW production as well as anomalous couplings.

The event samples come from approximately 14 pb^{-1} of data collected in the 1992-93 Tevatron collider run.

In the the $e\mu$ channel, an isolated muon with $P_t \geq 15$ GeV/c and an electron with $E_T \geq 20$ GeV are required. Both $\not\!\!E_T^{\rm cal}$ and $\not\!\!E_T$, the missing E_T and muon-corrected missing E_T, are required to be ≥ 20 GeV. In order to suppress $Z \to \tau\bar{\tau}$ and $b\bar{b}$ backgrounds, it is required that $20^\circ \leq \Delta\phi(P_t^\mu, \not\!\!E_T) \leq 160^\circ$ if $\not\!\!E_T \leq 50$ GeV, where $\Delta\phi(P_t^\mu, \not\!\!E_T)$ is the angle in the transverse plane between the muon and $\not\!\!E_T$. One event survives these selection cuts in a data sample corresponding to an integrated luminosity of 13.9 ± 0.8 pb^{-1}.

For the ee channel, two electrons are required, each with $E_T \geq 20$ GeV. The $\not\!\!E_T$ is required to be ≥ 20 GeV. The Z boson background is reduced by removing events where the dielectron invariant mass is between 77 and 105 GeV/c^2. It is required that $20^\circ \leq \Delta\phi(P_t^e, \not\!\!E_T) \leq 160^\circ$ for the lower energy electron if $\not\!\!E_T \leq 50$ GeV. This selection suppresses $Z \to ee$ as well as $\tau\bar{\tau}$. The integrated luminosity in this channel is 14.3 ± 0.8 pb^{-1}. One event survives these selection requirements.

For the $\mu\mu$ channel, two isolated muons are required, one with $P_t \geq 20$ GeV/c and another with $P_t \geq 15$ GeV/c. In order to remove Z boson events, it is required that the $\not\!\!E_T$ projected on the line bisecting the muon tracks in the transverse plane be greater than 30

Background	$e\mu$	ee	$\mu\mu$
$Z \to ee$ or $\mu\mu$	—	0.02 ± 0.01	0.068 ± 0.026
$Z \to \tau\tau$	0.11 ± 0.05	$< 10^{-3}$	$< 10^{-3}$
Drell-Yan dileptons	—	$< 10^{-3}$	$< 10^{-3}$
$W\gamma$	0.04 ± 0.03	0.02 ± 0.01	—
$t\bar{t}$	0.04 ± 0.02	0.03 ± 0.01	0.009 ± 0.003
Total	0.26 ± 0.10	0.22 ± 0.08	0.077 ± 0.026

Table 1: DØ. Summary of backgrounds to $WW \to ee$, $WW \to e\mu$ and $WW \to \mu\mu$. The units are expected number of background events in the data sample. The uncertainties include both statistical and systematic contributions.

GeV. This selection requirement is less sensitive to the momentum resolution of the muons than is a dimuon invariant mass cut. It is required that $\Delta\phi(P_t^\mu, \not\!\!E_T) \leq 170°$ for the higher P_t muon. No events survive these selection requirements in a data sample corresponding to an integrated luminosity of 12.2 ± 0.7 pb^{-1}.

Finally, in order to suppress background from $t\bar{t}$ production, the vector sum of the E_T from hadrons, $\vec{E}_T^{\rm had}$, defined as $-(\vec{E}_T^{l1} + \vec{E}_T^{l2} + \vec{\not\!\!E}_T)$ is required to be less than 40 GeV in magnitude for all channels. Figure 4 shows a Monte Carlo simulation of $E_T^{\rm had}$ for ~ 20 fb^{-1} of SM WW and $t\bar{t}$ events. For WW events, non-zero values of $E_T^{\rm had}$ are due to gluon radiation and detector resolution. For $t\bar{t}$ events, the most significant contribution is the b-quark jets from the t-quark decays. This selection reduces the background from $t\bar{t}$ production by a factor of four for a t-quark mass of 160 GeV/c^2 and is slightly more effective for a more massive t-quark. The efficiency of this selection criterion for SM W boson pair production events is $0.95^{+0.01}_{-0.04}$ and decreases slightly with increasing W boson pair invariant mass. The surviving ee candidate passes this selection requirement but the $e\mu$ candidate [12] is rejected.

The detection efficiency for SM W boson pair production events is determined using the PYTHIA [13] event generator followed by a detailed GEANT[14] simulation of the DØ detector. Muon trigger and electron identification efficiencies are derived from the data. The overall detection efficiency for SM $WW \to e\mu$ is 0.092 ± 0.010. For the ee channel the efficiency is 0.094 ± 0.008. For the $\mu\mu$ channel it is 0.033 ± 0.003. For the three channels combined, the expected number of events for SM W boson pair production, based on a cross section of 9.5 pb [5], is 0.47 ± 0.07. The efficiency is larger for anomalous couplings because of the increase in the W boson P_t.

The backgrounds due to Z boson, Drell-Yan dilepton, $W\gamma$, and $t\bar{t}$ events are estimated using the PYTHIA and ISAJET [15] Monte Carlo event generators followed by the GEANT detector simulation. The backgrounds from $b\bar{b}$, $c\bar{c}$, multi-jet, and W + jet events, where a jet is mis-identified as an electron, are estimated using the data. The $t\bar{t}$ cross section estimates are from calculations of Laenen *et al.* [16]. The $t\bar{t}$ background is averaged for $M_{\rm top} = 160$, 170, and 180 GeV/c^2. The background estimates are summarized in Table 1.

The 95% confidence level upper limit on the W boson pair production cross section is estimated based on one signal event including a subtraction of the expected background of 0.56 ± 0.13 events. For SM W boson pair production, the upper limit for the cross section is 87 pb at the 95% confidence level. From the observed limit, as a function of λ and κ, and the theoretical prediction of the W boson pair production cross section, the 95% confidence level limits on the coupling parameters shown in Fig. 5 (solid line) are obtained. Also shown in Fig. 5 (dotted line) is the contour of the unitarity constraint on the coupling limits for the form factor scale $\Lambda = 900$ GeV. This value of Λ is chosen so that the observed coupling limits lie within this ellipse. The limits on the CP-conserving anomalous coupling parameters are $-2.6 < \Delta\kappa < 2.8$ ($\lambda = 0$) and $-2.1 < \lambda < 2.1$ ($\Delta\kappa = 0$).

The coupling limits are insensitive to the decrease in the expected $t\bar{t}$ background which would occur if the top quark is much more massive than $160 - 180$ GeV/c^2. If the top background is negligible, the 95% confidence level upper limit for SM W boson pair production is 89 pb.

$WW \rightarrow$ Dileptons + Missing E_T (CDF)

This analysis reports the preliminary results from a search for $WW \rightarrow l\bar{l}'\bar{\nu}\nu'$ with the CDF detector where the leptons, l or l', are electrons or muons. The data sample is approximately 67 pb^{-1} of collisions collected during the 1992-93 and part of the 1994-95 Tevatron collider runs. The strategy is to optimize the event selection for SM WW production without regard to anomalous couplings.

The event selection requires the signature expected from two W boson decays. Two isolated leptons are required, either electrons or muons, with $E_T \geq 20$ GeV as well as $\not\!\!E_T \geq 25$ GeV/c. In order to remove events where the $\not\!\!E_T$ originates from mismeasured lepton E_T and backgrounds from $\tau\bar{\tau}$, $\Delta\phi(P_t^{lepton}, \not\!\!E_T) \geq 20°$, where $\Delta\phi$ is, again, the angle in the transverse plane. For the $e\mu$ and ee channels this selection is not applied if the missing transverse energy is greater than 50 GeV. For the ee and $\mu\mu$ channels, events with leptonic Z boson decays are rejected by removing candidates with $75 \leq m_{l\bar{l}} \leq 105$ GeV/c^2.

Finally, in order to remove background from $t\bar{t}$ production, events with at least one jet with uncorrected $E_T \geq 10$ GeV are rejected. The jets are formed with cone size $\delta R = 0.7$. Uncorrected jets of $E_T = 10$ GeV correspond to corrected jets of ~ 15 GeV[17]. Monte Carlo studies indicate this "jet veto" removes 96% of the top background when the t-quark has mass $= 170$ GeV/c^2. The efficiency for SM W boson pair production is calculated from various Monte Carlo simulations and modified by a comparison between Monte Carlo and data of the efficiency of this selection criteria for a sample of leptonic Z boson decays. That is: $\epsilon(WW \text{ Data}) = \epsilon(WW \text{ MC}) \times \epsilon(Z \text{ Data})/\epsilon(Z \text{ MC}) = 0.61 \times \frac{0.79}{0.71}$. The efficiency of this selection criterion is then 0.68 ± 0.12. The efficiency is not as high as for the $\vec{E}_T^{\rm had}$ criterion but the $t\bar{t}$ rejection is better. The uncertainty shown represents differences in the efficiency of this selection criterion when calculated with various Monte Carlos.

The detection efficiency is determined using WW events generated with the ISAJET Monte Carlo[18] and a fast detector simulation. Trigger and particle identification efficiencies are determined from the data. The overall efficiency for the three channels is 0.082 ± 0.012.

Source	Without Jet Veto	With Jet Veto
$t\bar{t}$	3.75	0.15 ± 0.04
$Z \rightarrow \tau\tau$	1.24	0.09 ± 0.02
$b\bar{b}$	0.07	0.03 ± 0.01
Drell-Yan	1.50	0.23 ± 0.16
Fake	1.46	0.73 ± 0.40
Total	8.02	1.23 ± 0.43

Table 2: CDF summary of backgrounds to $WW \rightarrow$ dileptons in the search with 67 pb^{-1} before and after the "jet veto". The units are expected number of background events in the data sample. The uncertainties include both statistical and systematic contributions.

With the SM prediction for the W pair production cross section, a signal of 2.59 ± 0.91 events is expected in 67 ± 7 pb^{-1} of collisions.

The backgrounds are estimated from data and Monte Carlo methods. The background from $t\bar{t}$ production, and $b\bar{b}$ production are estimated using Monte Carlo techniques. The backgrounds from Z boson decay to e^+e^- or $\mu^+\mu^-$ and from Drell-Yan production outside of the Z boson mass window are estimated using the data. The background from Z boson decay to $\tau\bar{\tau}$ with subsequent decay to electrons and/or muons is estimated using a hybrid Monte Carlo technique whereby the leptons in $Z \rightarrow e^+e^-$ data are replaced by taus. The taus are then allowed to decay to leptons. Finally the background from events where one or more jets is misidentified as an electron is estimated using the data. The background estimates are summarized in Table 2. The total expected background is 1.23 ± 0.43 events.

There were five candidates which passed all of the selection requirements. Figure 6 shows the missing transverse energy distribution of the five events as well as that expected from SM W boson pair production and from background. The 95% confidence level upper limit, calculated as in the previous section, based on 5 signal events and including a subtraction of the expected 1.23 ± 0.43 background events, is 34 pb. With the statistics available the cross section for SM W boson pair production is $13.8^{+9.2}_{-7.4}(stat) \pm 2.9(sys)$ pb, where the statistical fluctuation is based on the Poisson uncertainty for five events.

Summary and Prospects

The Tevatron will provide approximately 100 pb^{-1} of collisions to both CDF and DØ during the 1994-95 run. This provides a turning point for physics involving dibosons.

Between CDF and DØ the sensitivity to measure the WW cross section will be available for the first time as a result of the 1994-95 run. Hints of that are seen in the CDF and DØ $WW \rightarrow$ dileptons analysis presented here. Sufficient W boson pair signal will exist to allow measurements of the kinematic properties of the events, as opposed to counting experiments dominated by the limited statistics of background fluctuations. Simply projecting the DØ analysis to one fb^{-1} gives limits $|\lambda| \leq 0.3$ and $|\Delta\kappa| \leq 0.4$ for $\Lambda = 1000$

GeV. However, anomalous coupling analyses will be made using, perhaps, the spectrum of the scaler sum of the leptons E_T. $\not{E}_T$ is not the best variable for setting anomalous coupling limits because the W boson decay products, including the neutrinos, to be rather back-to-back.

The 1994-95 run will provide better statistics for the leptons + jets decay mode, but one is frustrated by the large background and challenged to extract a signal. With the strategy presented here, the dijet P_t cut is raised with higher luminosity. With one fb^{-1}, the cut is set to 200 GeV. The sensitivity to anomalous couplings is $|\lambda| \leq 0.2$ and $|\Delta\kappa| \leq 0.3$ for $\Lambda = 1000$ GeV. For higher luminosity, with a higher dijet P_t cut, the W bosons have so much P_t that the decay products cause jet merging to be a serious issue. This analysis becomes weakened unless the background can be understood well enough to allow a background subtraction. In that case limits in the neighborhood of 0.2 to 0.1 are possible [19] and perhaps a signal can be extracted.

One fb^{-1} creates opportunities for WZ and ZZ as well. Approximately 40 trilepton WZ events will occur at each experiment. This is modified by an expected 25% detection and identification efficiency. Perhaps the approximate amplitude zero [20] can be observed. And a few ZZ to four lepton events will occur.

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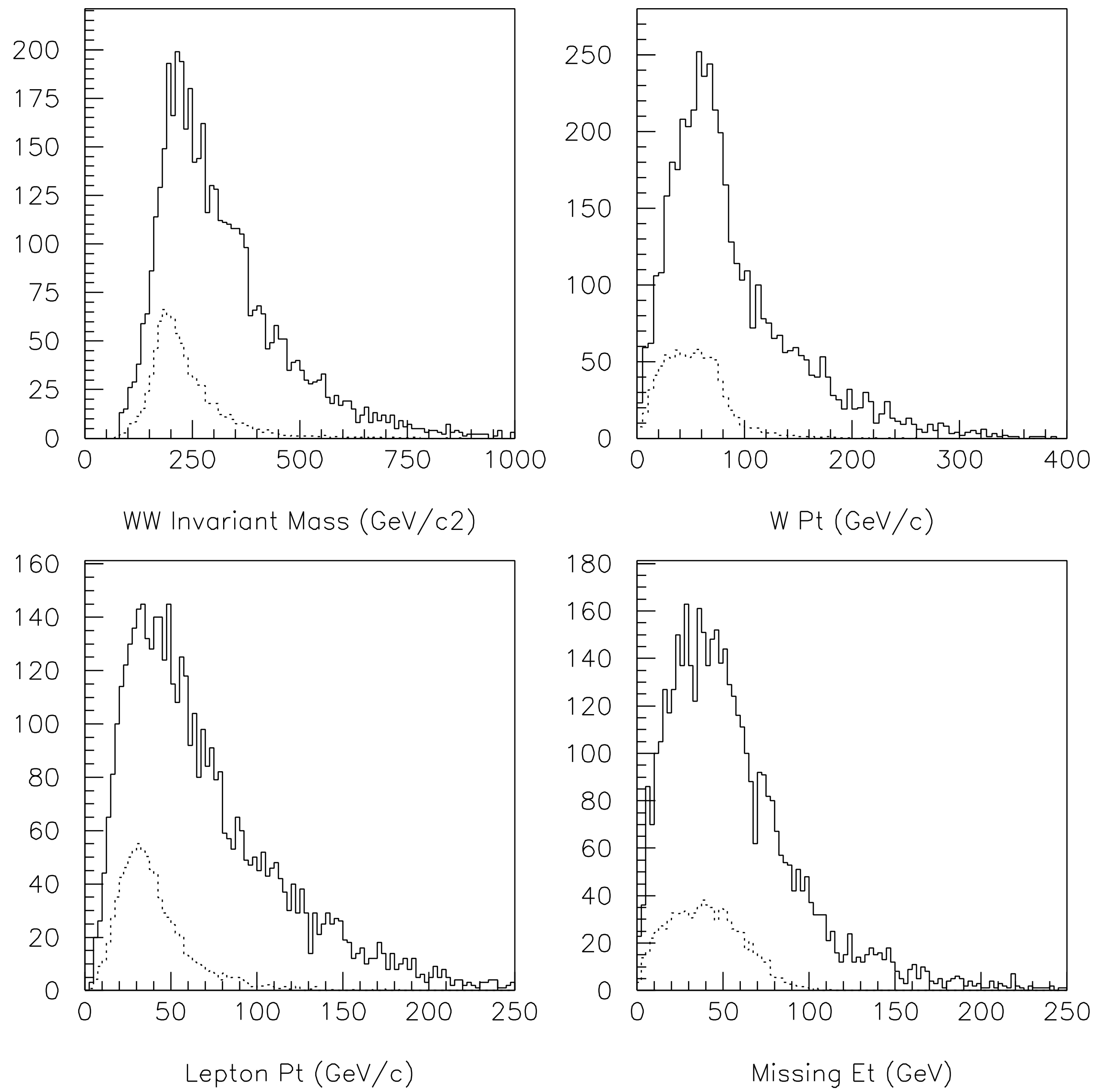

Figure 1: Comparison of kinematic properties of SM W boson pair production with that of anomalous couplings ($\Delta\kappa = \lambda = 1$). The MC samples comprise approximately 7 fb^{-1} of $p\bar{p}$ collisions at center-of-mass energy 1.8 TeV. They are normalized by their relative cross sections.

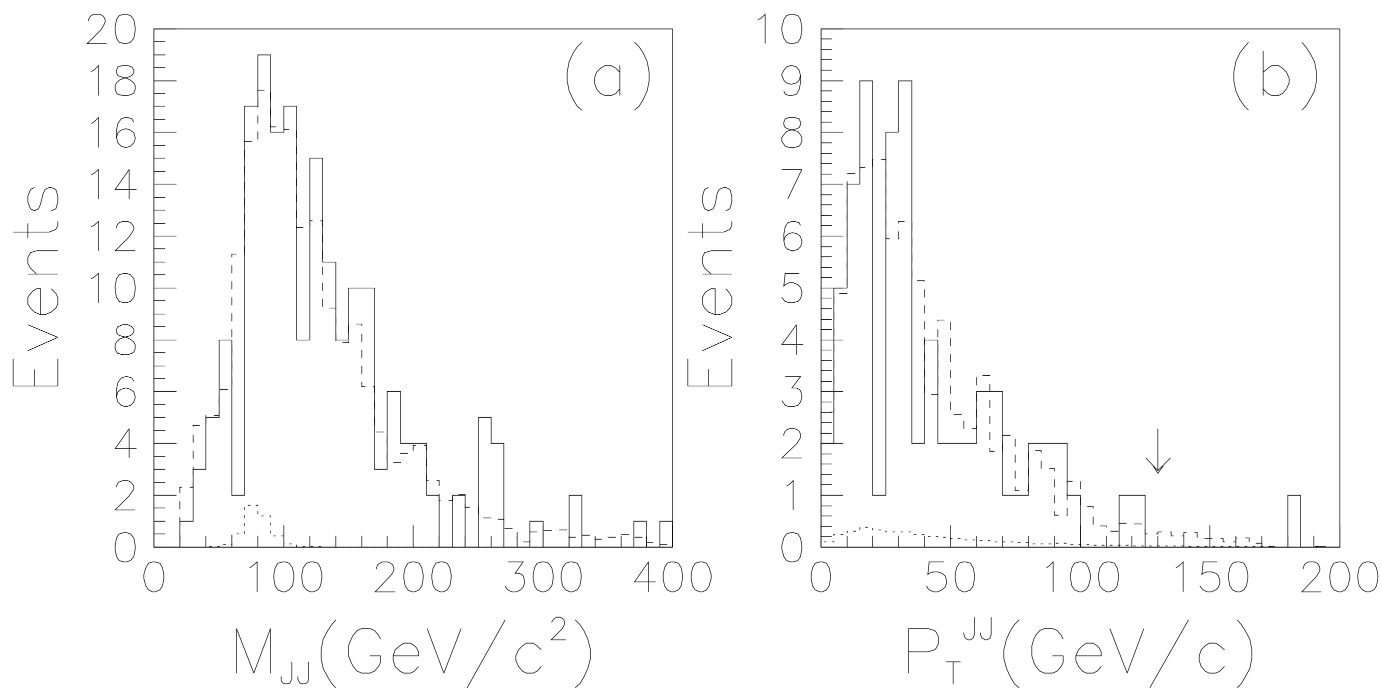

Figure 2: CDF selection of WW and $WZ \rightarrow l\nu jj$ candidates. All event selection criteria except dijet mass and dijet P_t cut were used for (a). The subset of events in (a) which pass the dijet mass cut are shown in (b). The solid line shows the data; the dots show the expected diboson signal; and the dashes show the predicted signal plus background shape.

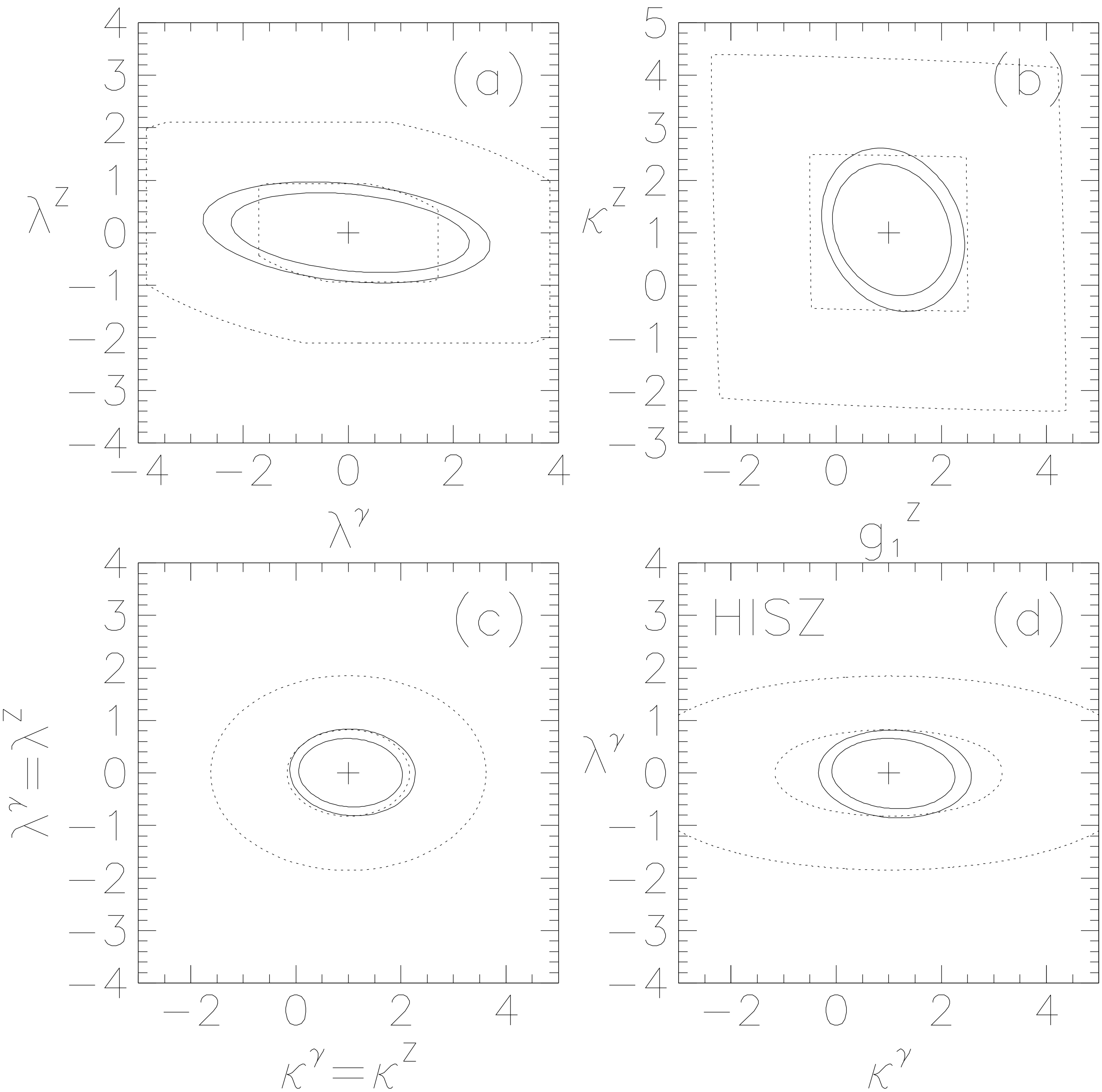

Figure 3: CDF allowed regions for pairs of anomalous couplings from the analysis of leptons + jets final states. All couplings, other than those listed for each contour, are held at their SM values. The solid lines are the 95% CL limits and the dotted lines are the unitarity limits; each is shown for $\Lambda = 1000$ (outer) and 1500 GeV (inner). The + signs indicate the SM values of the couplings.

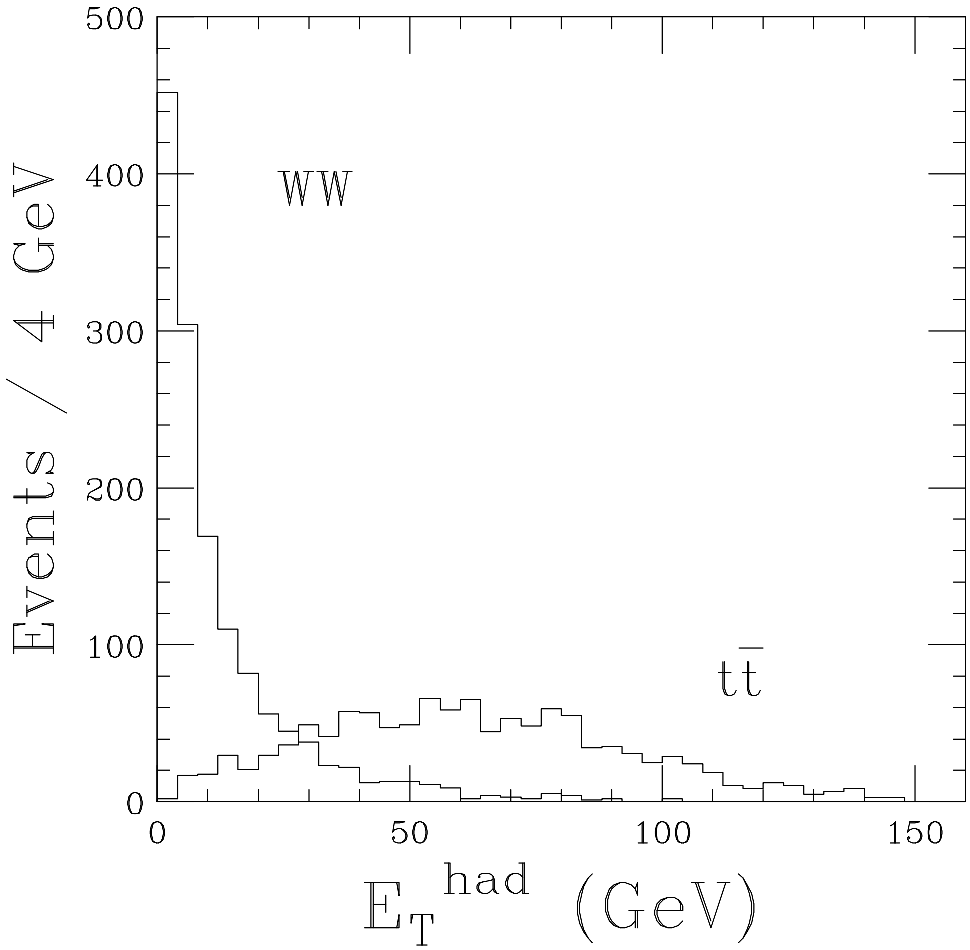

Figure 4: DØ $E_T^{\rm had}$ for Monte Carlo WW and $t\bar{t}$ events with $M_{\rm top} = 160$ GeV/c^2 ($\int Ldt \sim 20$ fb^{-1}). Events with $E_T^{\rm had} \geq 40$ GeV were rejected.

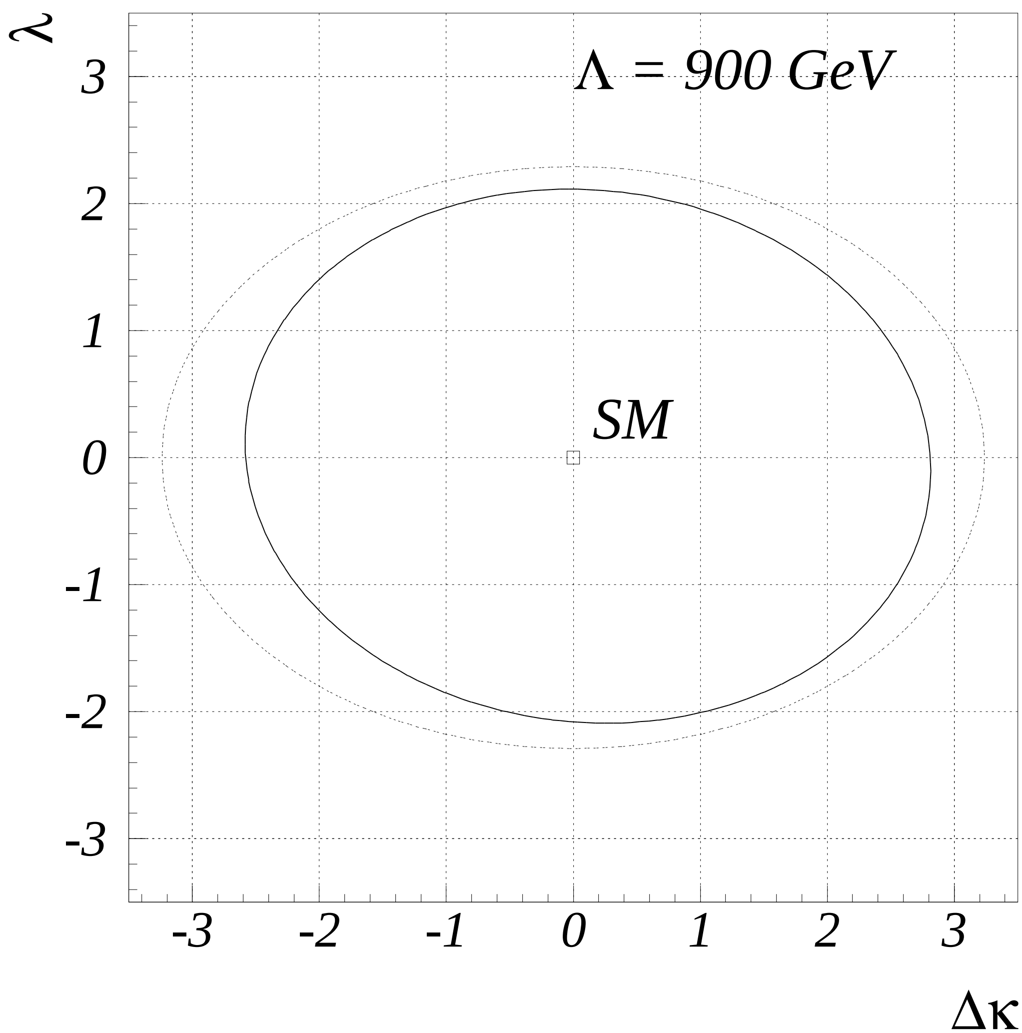

Figure 5: DØ. 95% CL limits on the CP-conserving anomalous couplings λ and $\Delta\kappa$, assuming $\lambda_\gamma = \lambda_Z$ and $\kappa_\gamma = \kappa_Z$. The dotted contour is the unitarity limit for the form factor scale $\Lambda = 900$ GeV which was used to set the coupling limits.

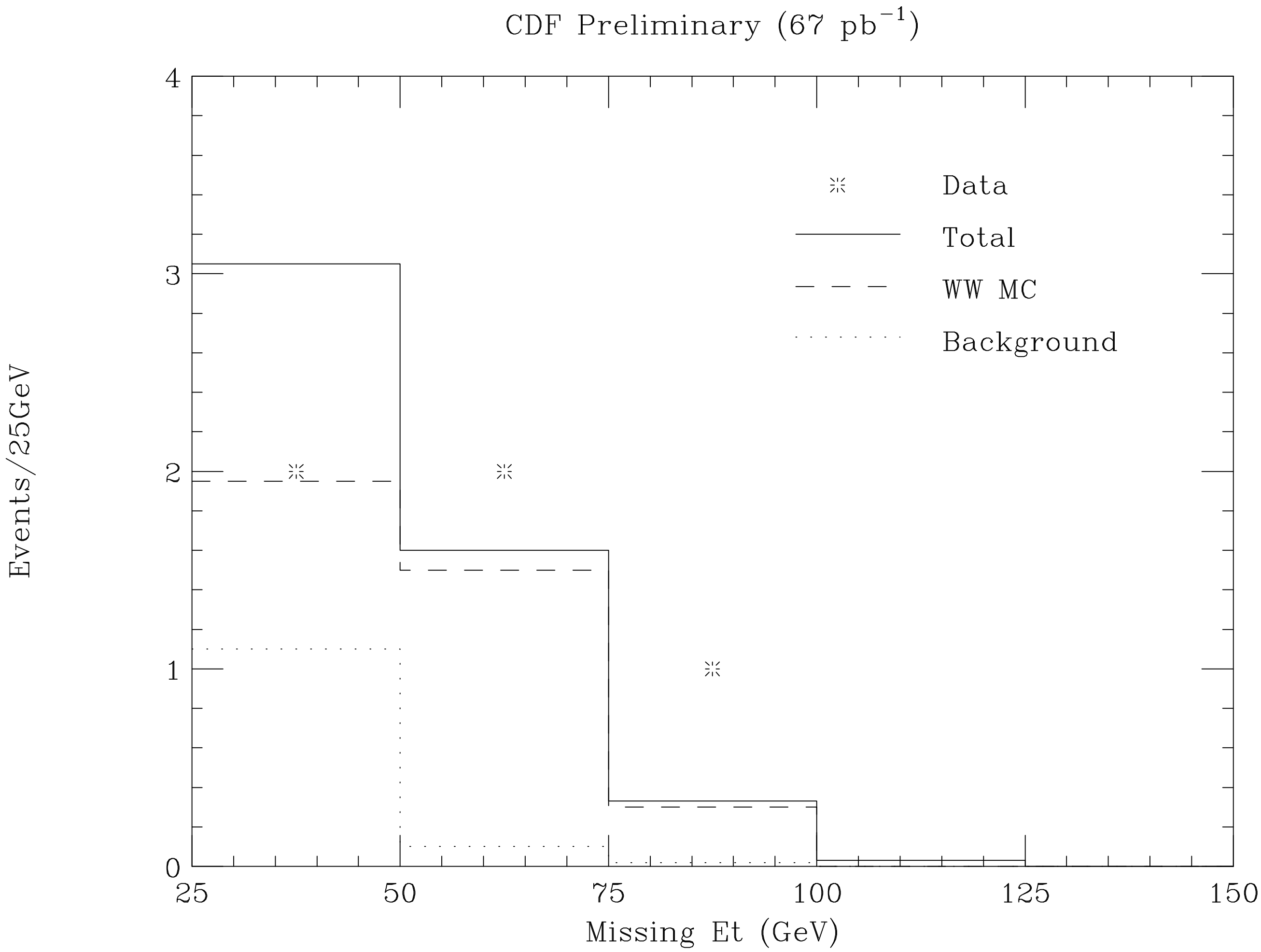

Figure 6: CDF $WW \rightarrow$ dilepton analysis. The $\not\!\!E_T$ distributions of the five candidate events and the background (dots) are shown. The $\not\!\!E_T$ distribution of the WW Monte Carlo is normalized (dashes) so as to make the total (solid) equal to five expected candidates.