

## Measurements of $WW$ and $WZ$ production in $W + \text{jets}$ final states in $p\bar{p}$ collisions

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We study  $WW$  and  $WZ$  production with  $\ell\nu qq$  ( $\ell = e, \mu$ ) final states using data collected by the D0 detector at the Fermilab Tevatron Collider corresponding to  $4.3 \text{ fb}^{-1}$  of integrated luminosity from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ . Assuming the ratio between the production cross sections  $\sigma(WW)$  and  $\sigma(WZ)$  as predicted by the standard model, we measure the total  $WV$  ( $V = W, Z$ ) cross section to be  $\sigma(WV) = 19.6^{+3.2}_{-3.0} \text{ pb}$ , and reject the background-only hypothesis at a level of 7.9 standard deviations. We also use  $b$ -jet discrimination to separate the  $WZ$  component from the dominant  $WW$  component. Simultaneously fitting  $WW$  and  $WZ$  contributions, we measure  $\sigma(WW) = 15.9^{+3.7}_{-3.2} \text{ pb}$  and  $\sigma(WZ) = 3.3^{+4.1}_{-3.3} \text{ pb}$ , which is consistent with the standard model predictions.

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The study of the production of  $VV$  ( $V = W, Z$ ) boson pairs provides an important test of the electroweak sector of the standard model (SM). In  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96 \text{ TeV}$ , the next-to-leading order (NLO) SM cross sections for these processes are  $\sigma(WW) = 11.7 \pm 0.8 \text{ pb}$ ,  $\sigma(WZ) = 3.5 \pm 0.3 \text{ pb}$  and  $\sigma(ZZ) = 1.4 \pm 0.1 \text{ pb}$  [1]. Measuring a significant departure in cross section or deviations

in the predicted kinematic distributions would indicate the presence of anomalous gauge boson couplings [2] or new particles in extensions of the SM [3]. This analysis also provides a proving ground for the advanced analysis techniques used in low mass Higgs searches [4]. The production of  $VV$  in  $p\bar{p}$  collisions at the Fermilab Tevatron Collider has been observed in fully leptonic decay modes [5] and more recently, in leptons+jets decay modes [6], where the combined  $WW + WZ$  cross section was measured.

In this Letter, we report observation of the production of a  $W$  boson that decays leptonically in associated production with a second vector boson that decays hadronically ( $WV \rightarrow \ell\nu qq$ ;  $\ell = e^\pm$  or  $\mu^\pm$ , and  $\nu$  and  $q$  denote matter or anti-matter as appropriate). The data used for this analysis correspond to  $4.3 \text{ fb}^{-1}$  of integrated lumi-

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osity collected between 2006 and 2009 by the D0 detector [7] at the Fermilab Tevatron Collider. The D0 detector dijet mass resolution for  $W/Z$  decays of  $\approx 18\%$  results in significant overlap of  $W \rightarrow qq$  and  $Z \rightarrow qq$  dijet mass peaks. Therefore, we first consider  $WW$  and  $WZ$  simultaneously and measure the total  $WV$  cross section assuming the ratio of  $WW$  to  $WZ$  cross sections as predicted by the SM. We then apply  $b$ -jet identification to separate the  $WZ$  contribution, where the  $Z$  boson decays into  $b\bar{b}$  pairs, from the dominant  $WW$  production.

Candidate events in the electron channel are required to satisfy a single electron trigger or a trigger requiring electrons and jets, which results in a combined trigger efficiency of  $(98_{-3}^{+2})\%$  for the  $e\nu qq$  event selection described below. A comprehensive suite of triggers in the muon channel, based on leptons, jets and their combination, achieves a trigger efficiency of  $(95 \pm 5)\%$  for the  $\mu\nu qq$  event selection.

To select  $WV \rightarrow \ell\nu qq$  candidates, we require a single reconstructed electron (muon) with transverse momentum  $p_T > 15$  GeV (20 GeV) and pseudorapidity  $|\eta| < 1.1$  (2.0) [8], missing transverse energy  $\cancel{E}_T > 20$  GeV, and two or three jets reconstructed using a cone algorithm [9]. The jets must have  $p_T > 20$  GeV,  $|\eta| < 2.5$ , and at least two tracks within the jet cone [9] originating from the  $p\bar{p}$  interaction vertex. Lepton candidates must be spatially matched to a track that originates from the primary  $p\bar{p}$  interaction vertex and they must be isolated from energy depositions in the calorimeter and other tracks in the central tracking detector. To reduce background from processes that do not contain  $W \rightarrow \ell\nu$ , we require that the transverse mass [10] is  $M_T^{\ell\nu}$  (GeV)  $> 40 - 0.5\cancel{E}_T$ . In addition, we restrict  $M_T^{\mu\nu} < 200$  GeV to suppress muon candidates with poorly measured momenta.

Signal and most of the background processes are modeled with Monte Carlo (MC) simulation. The signal events are generated with PYTHIA [11] using CTEQ6L1 parton distribution functions (PDFs) [12] and include all SM decays. The fixed-order matrix element (FOME) generator ALPGEN [13] with CTEQ6L1 PDF is used to generate  $W$ +jets,  $Z$ +jets, and  $t\bar{t}$  events. The FOME generator COMPHEP [14] is used to produce single top-quark MC samples with CTEQ6M PDF [12]. Both ALPGEN and COMPHEP are interfaced to PYTHIA for parton showering and hadronization. The MC events undergo a GEANT-based [15] detector simulation and are reconstructed using the same algorithms as used for D0 data. The effect of multiple  $p\bar{p}$  interactions is included by overlaying data events from random beam crossings on simulated events. The next-to-NLO (NNLO) cross section is used to normalize the  $Z$ +jets (light and heavy-flavor jets) [16]. The approximate NNLO cross section [17] is used to normalize the  $t\bar{t}$  samples, while the single top-quark MC samples are normalized to the approximate next-to-NNLO cross section [18]. The normalization of the  $W$ +jets MC sample (for all flavor con-

tributions) is determined from data. Additional NLO heavy-flavor corrections are calculated with MCFM [19] and applied to  $Z/W$ +heavy-flavor jets MC samples.

The multijet background in which a jet is misidentified as a prompt lepton is determined from data. For the muon channel, the multijet background is modeled with data that fail the muon isolation requirements, but pass all other selections. For the electron channel, the multijet background is estimated using a data sample containing events that pass less restrictive electron quality requirements. Both multijet samples are corrected for contributions from processes modeled by MC. The multijet normalizations are determined from fits to the  $M_T^{\ell\nu}$  distributions and assigned uncertainties of 20%.

To identify  $b$ -quark jets, in particular those originating from  $Z \rightarrow b\bar{b}$  decays, we use the D0 neural network (NN)  $b$ -tagging algorithm [20]. The NN is trained to separate light-flavor jets from heavy-flavor jets based on a combination of variables sensitive to the presence of tracks and vertices displaced from the primary  $p\bar{p}$  interaction vertex. The NN outputs for the two highest  $p_T$  jets are then used as inputs to the final multivariate discriminant. We define non-overlapping 0, 1, and 2-tag sub-channels based on whether neither, only one, or both of the two highest  $p_T$  jets pass the least restrictive NN operating point, for which the  $b$ -jet identification efficiency and the light-flavor jet misidentification rate are approximately 80% and 10%. Scale factors are applied to the MC events to account for any difference in efficiency or misidentification rate between data and simulation.

The dominant background is  $W$ +jets and therefore the modeling of this process in ALPGEN and the corresponding sources of uncertainties were studied in detail. Comparison of ALPGEN with other generators [21] and with data shows discrepancies in jet  $\eta$ , dijet angular separation and the transverse momentum of the  $W$  boson candidate. Thus, data are used to correct these quantities in the ALPGEN  $W$ +jets and  $Z$ +jets samples before  $b$ -tagging is performed [22]. The possible bias in this procedure from the presence of the diboson signal in data is small, but is taken into account as a systematic uncertainty.

As the diboson events are generated with a LO generator, changes to the event kinematics and the acceptance due to a NLO and resummation effects are studied using events from the MC@NLO [23] interfaced to HERWIG [24] for parton showering and hadronization and using the CTEQ6M PDF set. Comparing kinematics at the generator level after final state radiation, we parameterize a two-dimensional correction matrix in the  $p_T$  of the diboson system and of the highest  $p_T$  boson. After applying this correction to our PYTHIA sample, we find good agreement with MC@NLO for all distributions studied. Half of the difference between the PYTHIA and MC@NLO predictions is used as systematic uncertainty on the diboson production model, accounting for the possible effects of higher order corrections beyond NLO and of different

TABLE I: Number of events for signal and each background after the combined fit of  $WV$  using the RF output distribution (with total uncertainties determined from the fit) and the number of events observed in data.

	Electron channel	Muon channel
Diboson signal	$1725 \pm 84$	$1465 \pm 67$
$W/Z$ +light-flavor jets	$37232 \pm 1033$	$33516 \pm 709$
$W/Z$ +heavy-flavor jets	$5371 \pm 608$	$4854 \pm 490$
$t\bar{t}$ and single top	$1746 \pm 127$	$1214 \pm 86$
Multijet	$10630 \pm 1007$	$1982 \pm 384$
Total predicted	$56704 \pm 635$	$43031 \pm 531$
Data	56698	43044

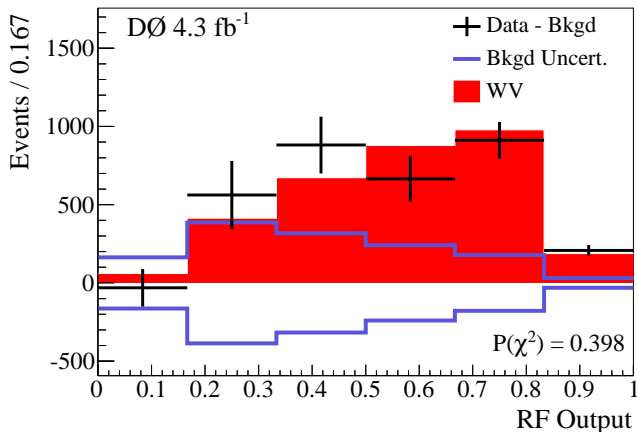


FIG. 1: (color online) A comparison of the measured  $WV$  signal (filled histogram) to background-subtracted data (points) in the RF output distribution (summed over electron and muon channels, and 0, 1, and 2-tag sub-channels), after the combined fit to data using the RF output distributions. Also shown is the  $\pm 1$  standard deviation uncertainty on the background prediction. The  $\chi^2$  fit probability,  $P(\chi^2)$ , is based on the residuals using data and MC statistical uncertainties.

showering scenarios.

The signal and the backgrounds are further separated using a multivariate classifier to combine information from several variables. This analysis uses a random forest (RF) classifier [25, 26], from which the output distribution is used as a final variable to measure the production cross sections by performing a template fit. Fifteen well-modeled variables [27] that demonstrate a difference in probability density between signal and at least one of the backgrounds are used as inputs to the RF. The RF is trained using a fraction of each MC sample. The remainder of each MC sample, along with the multijet background samples, is then evaluated by the RF and used in the measurement.

Depending on the source, we consider the effect of systematic uncertainty on the normalization and/or on the shape of differential distributions for signal and backgrounds [27]. Systematic effects on the differential distributions of the ALPGEN  $W$ +jets and  $Z$ +jets MC events

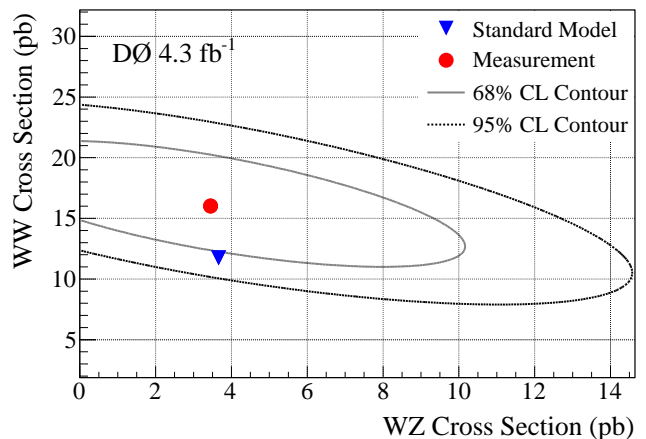


FIG. 2: (color online) Results from the simultaneous fit of  $\sigma(WW)$  and  $\sigma(WZ)$  using the RF output distributions. The plot shows the best fit value with 68% and 95% confidence level (CL) regions and the NLO SM prediction.

from changes of the renormalization and factorization scales and of the parameters used in the MLM parton-jet matching algorithm [28] are also considered. Uncertainties on PDFs [29], as well as uncertainties from object reconstruction and identification, are evaluated for all MC samples.

The total  $WV$  cross section is determined from a fit to the data of the signal and background RF output distributions. This fit is performed simultaneously on the distributions in the electron and muon channels, and in the 0, 1, and 2-tag sub-channels, by minimizing a Poisson  $\chi^2$  function with respect to variations in the systematic uncertainties [30]. The magnitude of the systematic uncertainties is effectively constrained by the regions of the RF output distribution with low signal over background ratio. A Gaussian prior is used for each systematic uncertainty. The effects on separate samples or sub-channels due to the same uncertainty are assumed to be 100% correlated. However, different uncertainties are assumed to be mutually independent.

The fit simultaneously varies the signal and  $W$ +jets contributions, thereby also determining the normalization factor for the  $W$ +jets MC sample. This obviates the need for using the predicted ALPGEN cross section, and provides a more rigorous approach that incorporates an unbiased uncertainty from  $W$ +jets when extracting the signal cross section. The  $W$ +jets normalization factor from the fit is consistent with the theoretical NNLO prediction [31]. The yields for signal and each background are given in Table I. Though the total diboson yield includes a small contribution from  $ZZ \rightarrow \ell\ell q\bar{q}$  events (1.5%), in which one of the charged leptons escapes detection, the cross sections presented here are corrected for this contribution assuming that the ratios between  $WW$ ,  $WZ$  and  $ZZ$  cross sections are given by the SM.

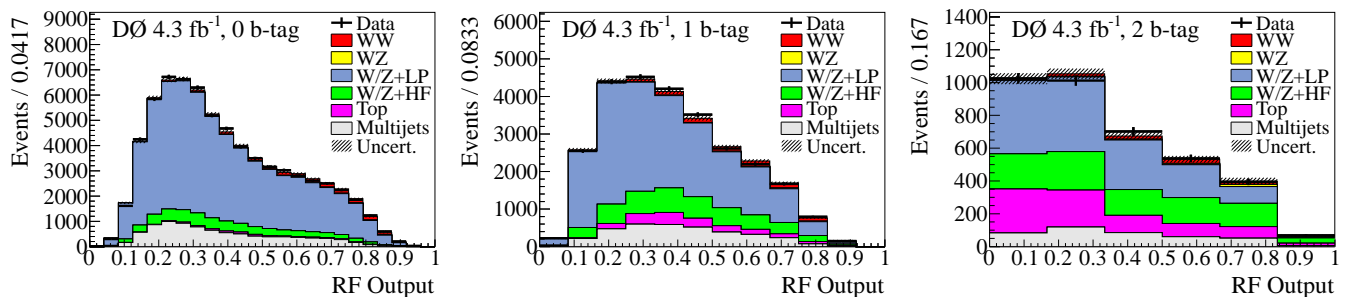


FIG. 3: (color online) A comparison of the signal+background prediction to data in the RF output distribution (summed over electron and muon channels) for 0, 1, and 2-tag sub-channels after the combined fit to data using the RF output distribution (LP denotes light partons such as  $u$ ,  $d$ ,  $s$  or gluon, and HF denotes heavy-flavor such as  $c\bar{c}$  or  $b\bar{b}$ ). The systematic uncertainty band is evaluated after the fit of the total  $WV$  cross section in the RF output distribution.

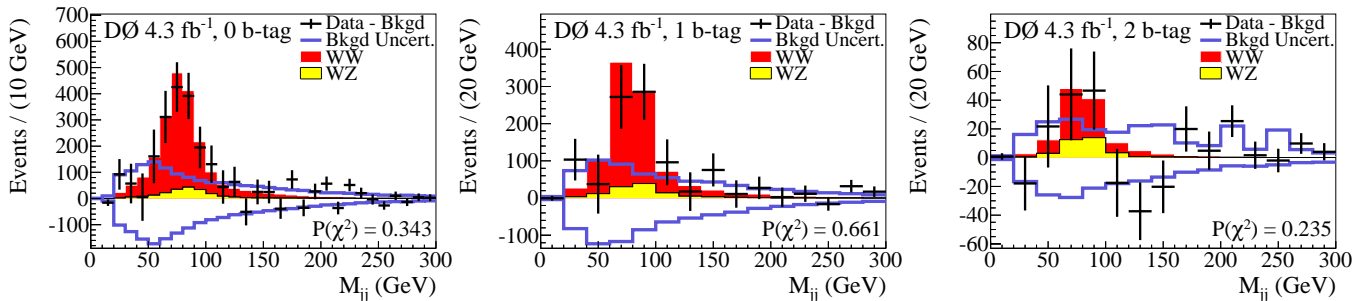


FIG. 4: (color online) A comparison of the measured  $WW$  and  $WZ$  signals (filled histograms) to background-subtracted data (points) in the dijet mass distribution (summed over electron and muon channels) for 0, 1, and 2-tag sub-channels after the combined fit to data using the dijet mass distribution. Also shown is the  $\pm 1$  standard deviation uncertainty on the background prediction. The  $\chi^2$  fit probability,  $P(\chi^2)$ , is based on the residuals using data and MC statistical uncertainties.

The fit of the total  $WV$  cross section using the RF output distributions yields  $\sigma(WV) = 19.6^{+3.2}_{-3.0}$  pb, corresponding to an observed (expected) significance of 7.9 (5.9) standard deviations (s.d.). Figure 1 shows the background-subtracted RF output distribution summed over all sub-channels after the fit. As a cross check, we perform the measurement using the dijet mass distribution in place of the full RF output distribution [27]. This measurement yields a  $WV$  cross section of  $\sigma(WV) = 18.3^{+3.8}_{-3.6}$  pb, consistent with that obtained using the RF output distribution.

The fit is then performed with the signal divided into the separate  $WW$  and  $WZ$  components, which are allowed to float independently. The result of this simultaneous fit of  $\sigma(WW)$  and  $\sigma(WZ)$  using the RF output distributions is shown in Fig. 2. It yields  $\sigma(WW) = 15.9^{+1.9}_{-1.5}$  (stat)  $^{+3.2}_{-2.9}$  (syst) pb and  $\sigma(WZ) = 3.3^{+3.4}_{-2.7}$  (stat)  $^{+2.2}_{-1.8}$  (syst) pb. The RF output distributions for the 0, 1, and 2-tag sub-channels from this fit are shown in Fig. 3. This measurement is also verified fitting the dijet mass distribution, which yields  $\sigma(WW) = 13.3^{+2.8}_{-2.2}$  (stat)  $^{+3.6}_{-2.9}$  (syst) pb and  $\sigma(WZ) = 5.4^{+2.7}_{-2.6}$  (stat)  $^{+4.5}_{-4.3}$  (syst) pb. Figure 4 shows plots for the background-subtracted dijet mass after the dijet mass fit.

We also perform a fit in which we constrain the  $WW$

cross section to its SM prediction with a Gaussian prior equal to the theoretical uncertainty of 7% [1]. The fit of the RF output distribution yields a  $WZ$  cross section of  $\sigma(WZ) = 6.5 \pm 0.9$  (stat)  $\pm 3.0$  (syst) pb with observed (expected) significance of 2.2 (1.2) s.d., and the dijet mass fit yields  $\sigma(WZ) = 6.7 \pm 1.0$  (stat)  $\pm 3.9$  (syst) pb with observed (expected) significance of 1.7 (0.9) s.d. As expected, now that  $\sigma(WW)$  is constrained to the SM prediction, the fit requires a higher rate for  $WZ$  in order to account for the excess of signal-like events.

In summary, we have measured the cross section for total  $WV$  production to be  $\sigma(WV) = 19.6^{+3.2}_{-3.0}$  pb ( $V = W$  or  $Z$ ) with a significance of 7.9 s.d. above the background-only hypothesis. This result demonstrates the ability of the D0 experiment to measure a dijet signal in a background-dominated final state directly relevant to low mass Higgs searches. Furthermore, we have used  $b$ -jet tagging to measure the contributions from  $WW$  and  $WZ$  and measured the cross sections for the separate processes to be  $\sigma(WW) = 15.9^{+3.7}_{-3.2}$  pb and  $\sigma(WZ) = 3.3^{+4.1}_{-3.3}$  pb. Although we cannot yet claim 3 s.d. evidence of a  $WZ$  signal in the  $lvjj$  final states, the extracted  $WV$  and  $WZ$  cross sections are in agreement with the SM prediction and their precise measurement represents an independent test to new physics which

could manifest itself differently in different final states.

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## APPENDIX

## INPUT VARIABLES TO THE RANDOM FOREST CLASSIFIER

Here we define the fifteen variables used as inputs to the RF classifier. The observed distribution for each variable is shown in Figs. 5, 6 and 7 along with the predicted distribution after the fit of the total  $WV$  ( $V = W, Z$ ) cross section using the RF output distribution.

The RF input variables can be classified into three categories: (i)  $b$ -jet identification variables, (ii) kinematics of individual final state particles, and (iii) kinematics of multiple final state particles. Several variables are calculated using the four-momentum of the dijet system, which we define as the sum of the four-momenta of the two highest  $p_T$  jets. We also reconstruct a  $W \rightarrow \ell\nu$  candidate  $W^{\ell\nu}$ , from the charged lepton and the  $\cancel{E}_T$ . The neutrino from the  $W \rightarrow \ell\nu$  decay is assigned the transverse momentum defined by  $\cancel{E}_T$  and a longitudinal momentum that is calculated assuming the mass of the  $\ell\nu$  system is 80.4 GeV. Of the two possible solutions, we choose the real component that provides the smaller total invariant mass of all objects in the event.

- **$b$ -jet Identification Variables:**

The NN  $b$ -tagger has 12 operating points characterized by different purities. Each jet is assigned an integer  $b$ -tag value based on the highest purity operating point that it passes.

1. Max  $b$ -tag Value: The greater  $b$ -tag value of the two highest  $p_T$  jets. The neural network  $b$ -tagger has 12 operating points of increasing purity and the  $b$ -tag value corresponds to the highest operating point satisfied by the jet (or zero if the jet did not satisfy any of the operating points).
2. Min  $b$ -tag Value: The lesser  $b$ -tag value of the two highest  $p_T$  jets.

These variables are shown in Fig. 5, both in logarithmic and linear scales.

- **Kinematics of Individual Final State Particles:**

1.  $p_T(\ell)$ : The  $p_T$  of the charged lepton.
2.  $p_T(\text{jet}_1)$ : The highest jet  $p_T$ .
3.  $p_T(\text{jet}_2)$ : The second highest jet  $p_T$ .
4.  $\cancel{E}_T$ : The imbalance in transverse energy determined from the energy measured in each calorimeter cell and then corrected for reconstructed muons, jets, and electrons/photons.

- **Kinematics of Multiple Final State Particles:**

1.  $M_{jj}$ : The invariant mass of the dijet system reconstructed from the two highest  $p_T$  jets.
2.  $M_T^{\ell\nu} = \sqrt{2 p_T^\ell \cancel{E}_T (1 - \cos(\Delta\phi(\ell, \cancel{E}_T)))}$ : The transverse  $W$  mass reconstructed from the charged lepton and the  $\cancel{E}_T$ .
3.  $H_T = p_T(\text{jet}_1) + p_T(\text{jet}_2)$ : The scalar sum of the two highest jet  $p_T$ s.
4.  $p_T^{\text{rel}}(\text{dijet}, \text{jet}_1)^W = |\vec{p}_T(\text{jet}_1) \times \hat{p}_T(\text{jet}_1 + \text{jet}_2)|$ : The magnitude of the leading jet transverse momentum perpendicular to the dijet system in the rest frame of the  $W^{\ell\nu}$  candidate;
5.  $p_T^{\text{rel}}(\text{dijet}, \text{jet}_2) = |\vec{p}_T(\text{jet}_2) \times \hat{p}_T(\text{jet}_1 + \text{jet}_2)|$ : The magnitude of the second-leading jet transverse momentum perpendicular to the dijet system in the laboratory frame.
6.  $k_T^{\text{min}} = \Delta R(\text{jet}_1, \text{jet}_2) \frac{p_T(\text{jet}_2)}{p_T(\ell) + \cancel{E}_T}$ : The angular separation between the two jets of highest  $p_T$ , weighted by the ratio of the transverse momentum of the second-leading jet and a scalar sum of the transverse momenta of the  $W^{\ell\nu}$  constituents.
7.  $\cos(\angle(\text{dijet}, \text{jet}_1))$ : The cosine of the angle between the momentum vectors of the dijet system and the highest  $p_T$  jet in the laboratory frame.
8.  $\cos(\angle(W^{\ell\nu}, \text{jet}_1))^{jj}$ : Cosine of the angle between the momentum vectors of the leading jet and the  $W^{\ell\nu}$  candidate, evaluated in the rest frame of the dijet system.
9. Centrality: The scalar sum of transverse momenta of the charged lepton and all jets in the event divided by the sum of their energies.

## SYSTEMATIC UNCERTAINTIES

Table II gives the size of the systematic uncertainties for Monte Carlo simulations and multijet estimates. We consider the effect of systematic uncertainties both on the normalization and on the shape of differential distributions for signal and backgrounds. Although Table II lists uncertainties for the diboson and  $W$ +jets simulation, these uncertainties are not used when measuring the diboson signal cross section, for which the diboson and  $W$ +jets normalizations are free parameters. However, the size of the uncertainty must be specified when estimating the significance and when we constrain the cross section for  $WW$  production to its SM prediction in the fit.



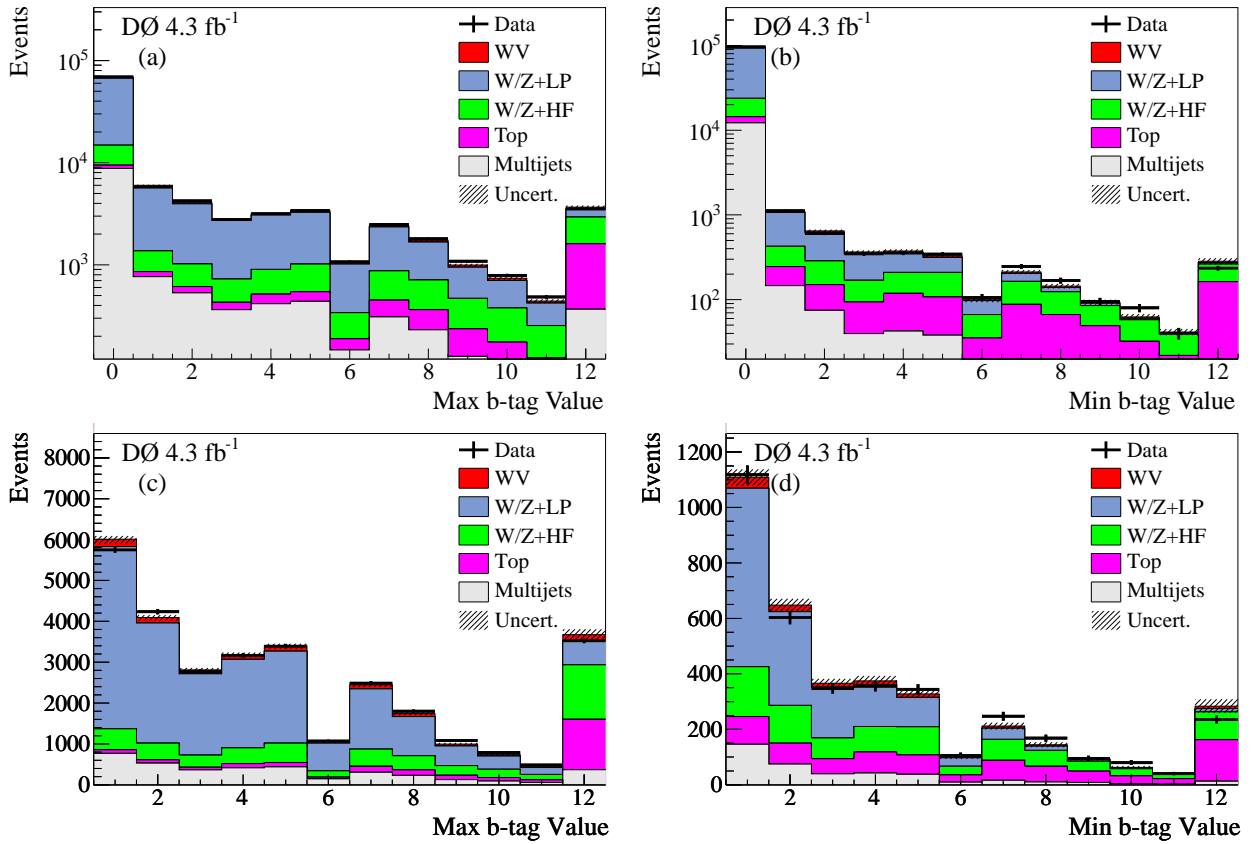


FIG. 5: (color online) Distributions of the  $b$ -jet identification variables used as inputs to the RF classifier (first two of fifteen) for electron and muon channels combined, with logarithmic ((a) and (b)) and linear ((c) and (d)) scales. To better show the  $WV$  and  $WZ$  signals the lowest bin is cut off in the distributions with a linear scale. The signal and background predictions and the systematic uncertainty band are evaluated after the fit of the total  $WV$  cross section in the RF output distribution. Definitions for each variable are provided in the text (LP denotes light partons such as  $u$ ,  $d$ ,  $s$  or gluon, and HF denotes heavy-flavor such as  $c\bar{c}$  or  $b\bar{b}$ ).

### $\Delta\chi^2$ FOR $WV$ MEASUREMENT

The statistical significance of the diboson signal yield from the fit to the data is estimated via analysis of the  $\Delta\chi^2$  curve obtained by fitting the data to the sum of background and signal templates as a function of the signal rate. The results of this analysis are given in Table III. Figure 8 shows how the  $\chi^2$  of the fit changes as a function of the signal cross section when using either the dijet mass or the RF output distribution to measure the total  $WV$  cross section.

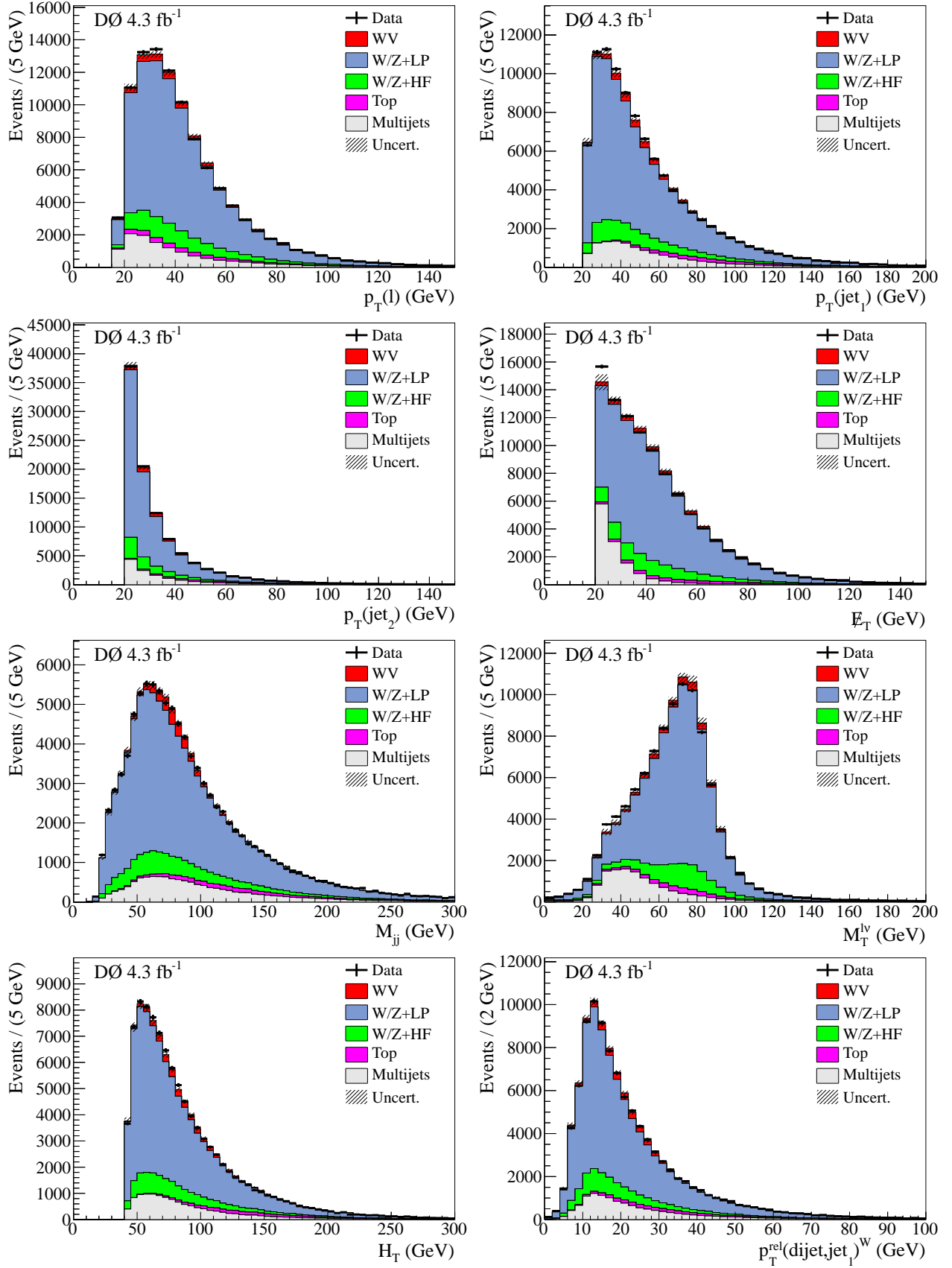


FIG. 6: (color online) Distributions of the variables (next eight of fifteen) used as inputs to the RF classifier for electron and muon channels combined, and before  $b$ -tagging. The signal and background predictions and the systematic uncertainty band are evaluated after the fit of the total  $WV$  cross section in the RF output distribution. Definitions for each variable are provided in the text (LP denotes light partons such as  $u$ ,  $d$ ,  $s$  or gluon, and HF denotes heavy-flavor such as  $c\bar{c}$  or  $b\bar{b}$ ).

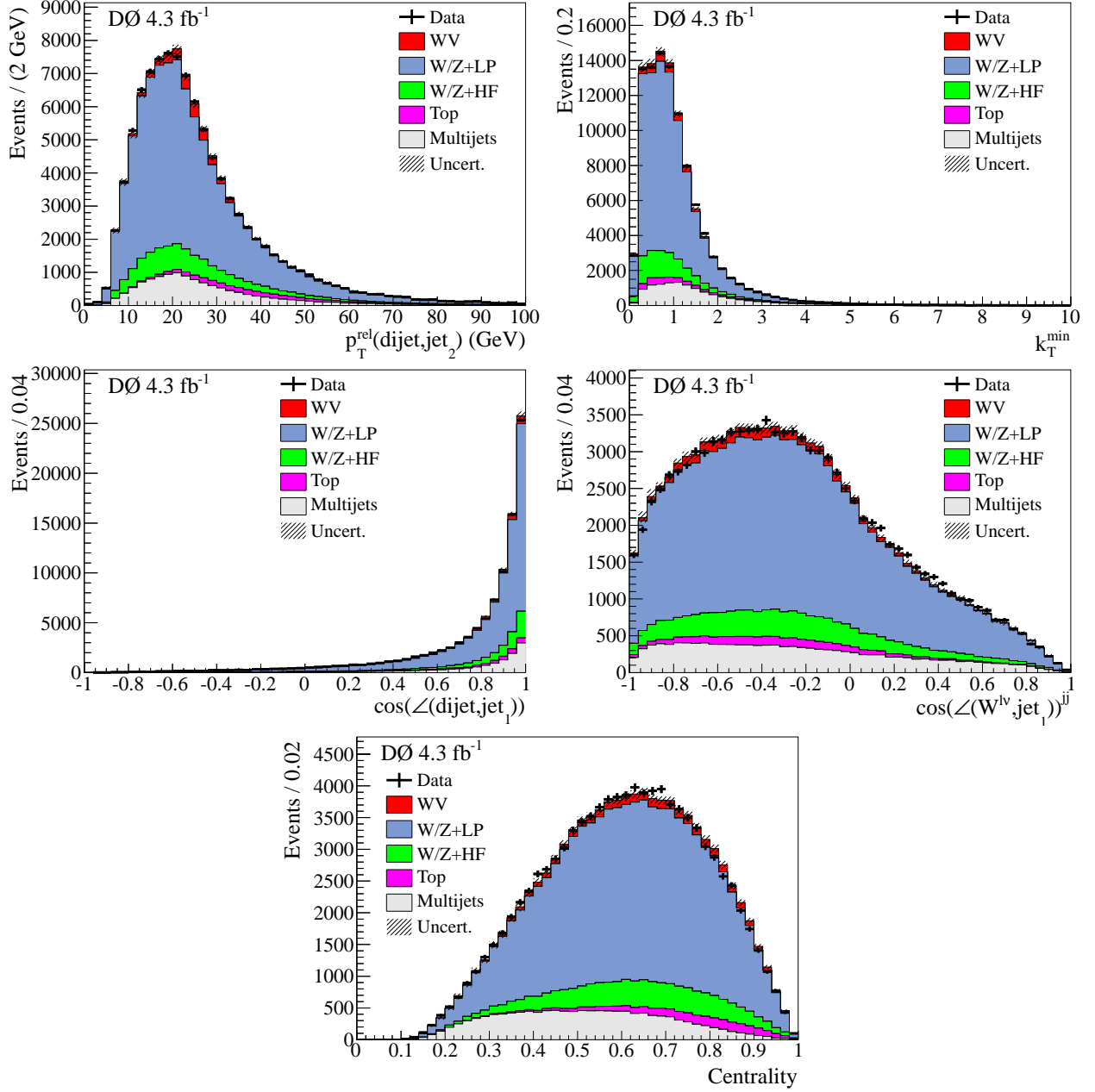


FIG. 7: (color online) Distributions of the variables (remaining five of fifteen) used as inputs to the RF classifier for electron and muon channels combined, and before  $b$ -tagging. The signal and background predictions and the systematic uncertainty band are evaluated after the fit of the total  $WV$  cross section in the RF output distribution. Definitions for each variable are provided in the text (LP denotes light partons such as  $u$ ,  $d$ ,  $s$  or gluon, and HF denotes heavy-flavor such as  $c\bar{c}$  or  $b\bar{b}$ ).

TABLE II: The RMS amplitude (in percent) of each systematic uncertainty in the RF output distributions for the signal and background predictions. The RMS amplitude is defined as:  $\sqrt{\sum_{i=0}^n p_i \Delta_i^2 / \sum_{i=0}^n p_i}$ ; where  $p_i$  is the predicted number of events in bin  $i$ ,  $\Delta_i$  is the percent change in bin  $i$  when the uncertainty is varied by 1 s.d., and  $n$  is the number of bins. In cases where the amplitude is different for different subchannels, the range of amplitudes is given. The rightmost column indicates whether the uncertainty only affects the normalization (N) or if it has also a differential dependence (D).

Source of systematic uncertainty	Diboson signal	$W$ +jets	$Z$ +jets	Top	Multijet	Nature
Electron trigger/ID efficiency	$\pm 5$	$\pm 5$	$\pm 5$	$\pm 5$		N
Muon trigger/ID efficiency	$\pm 5$	$\pm 5$	$\pm 5$	$\pm 5$		N
Jet identification	$\pm 1$	$\pm 1-2$	$\pm 1-2$	$\pm <1-2$		D
Jet energy scale	$\pm 2-4$	$\pm 6-8$	$\pm 4-12$	$\pm 2-3$		D
Jet energy resolution	$\pm 2-3$	$\pm 3-12$	$\pm 4-10$	$\pm 1-2$		D
Jet vertex confirmation	$\pm 2-3$	$\pm 3-4$	$\pm 3-5$	$\pm 1-3$		D
Taggability correction	$\pm <1$	$\pm <1$	$\pm <1$	$\pm <1$		D
$b$ -tagging	$\pm 1-5$	$\pm 1-4$	$\pm 1-5$	$\pm 8-10$		D
Luminosity	$\pm 6.1$	$\pm 6.1$	$\pm 6.1$	$\pm 6.1$		N
Cross section	$\pm 7$	$\pm 6.3$	$\pm 6.3$	$\pm 10$		N
$V$ +heavy-flavor cross section		$\pm 20$	$\pm 20$			N
$V+2$ jets/ $V+3$ jets cross section		$\pm 10$	$\pm 10$			N
Multijet normalization					$\pm 20$	N
Multijet shape, electron channel					$\pm <1$	D
Multijet shape, muon channel					$\pm <1$	D
Diboson modeling	$\pm 2-3$					D
Parton distribution function	$\pm 1$	$\pm 2$	$\pm 1-3$	$\pm 2-4$		D
Unclustered Energy correction	$\pm <1$	$\pm <1$	$\pm <1$	$\pm <1$		D
ALPGEN jet $\eta$ corrections		$\pm <1$	$\pm <1$			D
ALPGEN $\Delta R(jj)$ and $p_T(W)$ corrections		$\pm <1$	$\pm <1$			D
Re-weighting diboson bias		$\pm <1$	$\pm <1$	$\pm <1$		D
Renormalization and factorization scales		$\pm <1$	$\pm <1$			D
Underlying event model		$\pm <1$	$\pm 1$			D
ALPGEN parton-jet matching parameters		$\pm <1$	$\pm <1$			D

TABLE III: Results from fitting the total  $WV$  cross section and the uncertainties resulting from limited data statistics (stat), and possible systematic biases (syst). Also, the expected and observed  $\Delta\chi^2$  obtained by fitting the data with and without the specified signal process and the corresponding significance in number of standard deviations (s.d.) for a one-sided Gaussian integral.

	Measured $\sigma(WV)$ [pb]	$\Delta\chi^2$ (significance)	
		Expected	Observed
RF Output	$19.6 \pm 1.4$ (stat) $^{+2.9}_{-2.7}$ (syst)	35.8 (5.9 s.d.)	63.5 (7.9 s.d.)
Dijet Mass	$18.3 \pm 1.5$ (stat) $^{+3.5}_{-3.3}$ (syst)	22.1 (4.6 s.d.)	33.0 (5.6 s.d.)

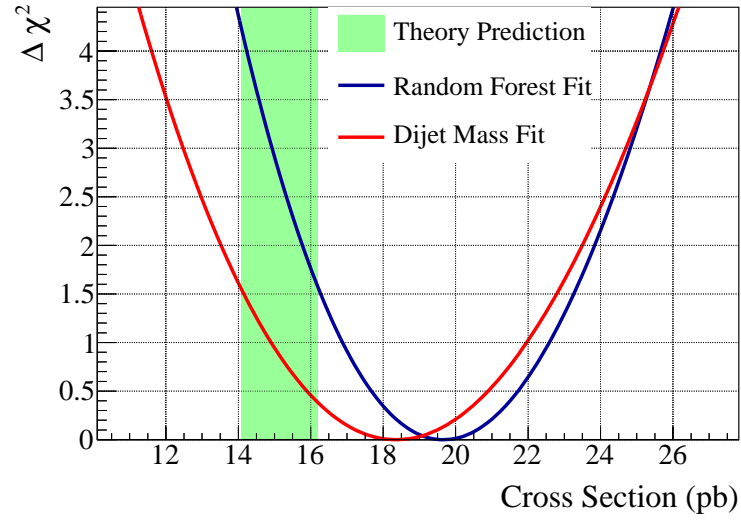


FIG. 8: (color online) The change in  $\chi^2$  relative to the best fit value when fitting the total  $WV$  cross section using either the dijet mass or the RF output distribution.