PROCEEDINGS OF SCIENCE

$(W/Z)Z$ with $Z \rightarrow b\bar{b}$ using the D0 Higgs Framework

Björn Penning* **for the D0 collaboration**
Fermi National Accelerator Laboratory
E-mail: penning@fnal.gov

....

36th International Conference on High Energy Physics,
July 4-11, 2012
Melbourne, Australia

*Speaker.

PoS(ICHEP2012)143

1. Introduction

Diboson production in $p\bar{p}$ (pp) collisions is one of the rarest Standard Model (SM) processes. Not only is the precise measurement of the cross sections, kinematics and couplings in these processes an important test of the SM but as well serves as indirect probe for new physics. Because new physics may itself manifest differently in different final states, it is important that corresponding analyses are performed. At the Tevatron diboson production has been observed first in fully leptonic and later in semileptonic final states [1]. With the large integrated luminosity available and improved analysis techniques it has become possible to study diboson production in final states containing heavy-flavor jets, in particular b-quark jets. An additional interest arises from the fact that these final states are almost identical in events with a low-mass Higgs boson produced in association with a vector boson. Diboson production with a decay in heavy flavor jets is the ultimate test of experimental and statistical techniques used in Higgs boson searches and the focus of this proceedings.

A brief summary for the low mass Higgs boson searches shows the similarity of the final states. The relevant production modes are $W(\to \ell\nu)H$, $Z(\to \ell\ell)H$ and $Z(\to \nu\nu)H$, whereas $\ell = e,\ \mu$ and the Higgs boson decays to b-quarks. Events are triggered using lepton, lepton plus jets and $\not{E}_T$ trigger and kinematic selections are applied to reduce Standard Model (SM) backgrounds while maintaining a very high efficiency for signal events. All these searches apply multivariate methods (MVA) like neural networks (NN), boosted decision trees (BDT) and random forests (RF) to separate background and signal like events before applying b-jet identification techniques (b-tagging). The sample after b-tagging is typically divided into sub-samples corresponding to the number of b-tagged jets and their purity. Then a second, final discriminant based again on multivariate methods is constructed. These typically take advantage of kinematic differences between signal and remaining backgrounds, dominated by the irreducible background $Vb\bar{b}$, with $V = W,\ Z$. Using this final discriminant a statistical analysis is performed based on the Log-Likelihood-Ratio (LLR) between the background-only and signal+background hypotheses. These types of modern analysis are quite involved and probe a very small signal within a large and mostly irreducible background. It is desirable to perform a validation of these methods using a similar but known signal. The search for diboson production with $Z \to b\bar{b}$ in the same final state is such a signal. Table 1 shows the comparison between the cross sections of $VH(\to b\bar{b})$ for $m_H = 115$ GeV and the $VZ(\to b\bar{b})$ signal in $p\bar{p}$ collisions at 1.96 TeV. While still small the cross section for the diboson process is about 4.5 times higher than the corresponding Higgs boson process and we should be able to observe it given the current sensitivities of the Higgs boson searches at D0.

Final State	$VH(\to b\bar{b})$	$VZ(\to b\bar{b})$
$\ell\nu b\bar{b}$	27 fb	105 fb
$\ell\ell b\bar{b}$	5 fb	24 fb
$\nu\nu b\bar{b}$	15 fb	73 fb

Table 1: Comparison of cross sections for the three most important low mass Higgs boson search channels $WH \to \ell\nu b\bar{b}$, $ZH \to \nu\nu b\bar{b}$ and $ZH \to \nu\nu b\bar{b}$ for $m_H = 115$ GeV and the corresponding VZ ($V = W,\ Z$) processes with $Z \to b\bar{b}$ for $\sqrt{s} = 1.96$ TeV in $p\bar{p}$

.

It should be noted that the dijet mass resolution of the D0 detector is not sufficient to separate the W and Z dijet mass peaks, therefore $WW \to \ell\nu cs$ is a significant resonant background. Furthermore, the Vbb and Vcc backgrounds along with their related large systematic uncertainties are substantially larger than for a Higgs boson with a mass 25 GeV higher than the Z boson. On the other side there is a relatively larger signal contribution from $Z \to cc$ compared to $H \to cc$.

2. Analysis

The D0 collaboration performs all three low mass Higgs boson searches mentioned in the introduction [2, 3, 4]. Their key characteristics are outlined in Tab. 2.

Channel	Selection	Final Discriminant	Luminosity(fb^{-1})	Reference
$\ell\nu b\bar{b}$	ST/DT, 2/3 jets	BDT, 14 input variables	7.5	[2]
$\ell\ell b\bar{b}$	ST/DT, 2 jets	RF, 19 input variables	8.4	[3]
$\nu\nu b\bar{b}$	ST/DT, $\geq$2 jets	BDT, 32 input variables	7.5	[4]

Table 2: Overview of the three low mass Higgs boson searches performed at D0, $WH \to \ell\nu b\bar{b}$, $ZH \to \nu\nu b\bar{b}$ and $ZH \to \nu\nu b\bar{b}$, $\ell = e, \mu$. Analyses are divided into samples with a single (ST) and two (DT) b-tagged jets. The final discriminant are boosted decision trees (BDT) or random forest (RF).

.

The sub-channels are organized such that they are mutually exclusive. In the $\ell\nu b\bar{b}$ analysis [2] event containing an isolated electron or muon, and two or three jets are selected. The presence of a neutrino from the W decay is inferred from a large imbalance of transverse momentum ($\not\!\!E_T$). The $\ell\ell b\bar{b}$ analysis selects events with two electrons or two muons and at least two jets. The $\nu\nu b\bar{b}$ analysis requires the presence of large missing transverse momentum and exactly two jets. The leptonic analyses treat each lepton flavor as an independent sub-channel. To ensure that the samples are orthogonal the $\ell\nu b\bar{b}$ analysis rejects events with more than one isolated electron or muon and the $\nu\nu b\bar{b}$ analysis rejects any event with a electron or muon. An algorithm to identify b-jets is then applied to each event. This b-tagging algorithm is based on a combination of variables sensitive to the presence secondary vertices or tracks displaced from the primary interaction vertex. This analysis uses an updated b-tagger utilizing a multivariate analysis (MVA) [5] that provides improved performance over the previous neural network based algorithm [6]. By adjusting the minimum requirement on the b-tagging output, a spectrum of increasingly stringent b-ID operation points is achieved. Each of the analyses is separated into two groups: a double-tag (DT) sample in which two of the jets are b-tagged with a loose tag requirement ($\ell\nu b\bar{b}$ and $\nu\nu b\bar{b}$) or one loose and one tight tag requirement ($\nu\nu b\bar{b}$); and an orthogonal single-tag (ST) sample in which only one jet has a loose ($\ell\nu b\bar{b}$ and $\nu\nu b\bar{b}$) or tight ($\ell\ell b\bar{b}$) b-tag. A typical per-jet efficiency and fake rate for the loose (tight) b-tag selection is about 80% (50%) and 10% (0.5%), respectively. The $\ell\nu b\bar{b}$ and $\nu\nu b\bar{b}$ analyses use the output from the b-tagging algorithm as input to final discriminants. The signal in the DT sample is mainly composed of events with $Z \to b\bar{b}$ decays with smaller contributions from $Z \to c\bar{c}$ and WW $\to c\bar{s}$ decays. In the ST sample, which applies a much less stringent requirement on the b-jet content of the event, the contributions from the three decay modes are comparable. All three analyses use MVAs to separate the VZ signal and background processes.

Figure 1 shows the output discriminants of all three subchannels after background subtraction.

PoS(ICHEP2012)143

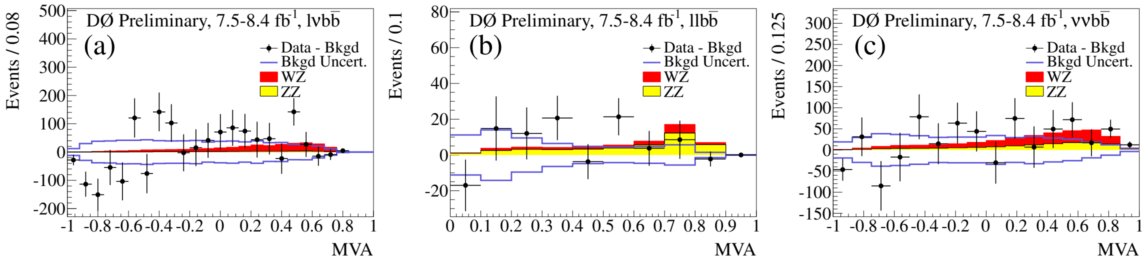

Figure 1: comparison of fitted signal+background to the data in the final MVA distributions for the (a) $\ell\nu b\bar{b}$, (b) $\ell\ell b\bar{b}$ and (c) $\nu\nu b\bar{b}$ analyses (each summed over all sub-channels). The background has been fitted to the data in the hypothesis that both signal and background are present. Also shown is the ± 1 standard deviation uncertainty on the fitted background.

3. Combination

The D0 searches for VZ reported in the previous subsection were combined using the exact same techniques as the combination of the searches for the Higgs boson at D0. Since the binning of the final discriminant outputs are not identical in the various sub-channels, these outputs were converted into bins of signal-to-background ratio as shown in Fig. 2.

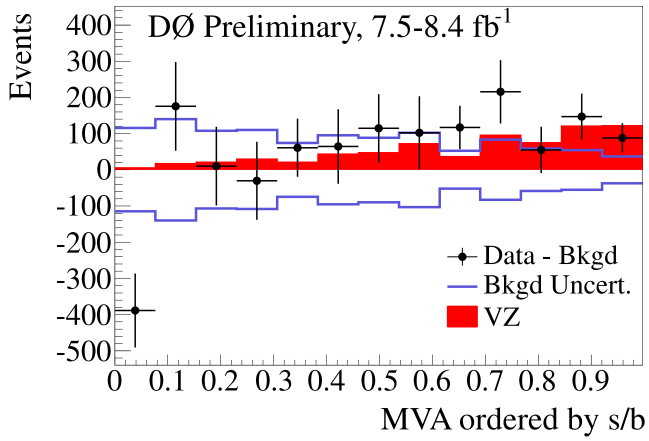

Figure 2: Combination of D0 searches for WZ/ZZ, final discriminant converted into common bins of signal-to-background ratio. The fitted background has been subtracted, with the blue lines indicating the fitted background uncertainty. The fitted signal is shown as the red histogram.

The total VZ cross section is determined from a fit of the MVA distributions of the background and signal samples to the data. The ratio of the WZ and ZZ cross sections is fixed to its SM prediction. The production of WW events is considered as a background. This fit is performed simultaneously on the distributions in all sub-channels by minimizing a negative log likelihood ratio function with respect to the signal cross section and variations in the systematic uncertainties. Different uncertainties are assumed to be mutually independent, but those common to multiple sub-channels are assumed to be 100% correlated. The combined fit yields as results $\sigma(VZ) = 5.0 \pm 1.0$ (stat.) $^{+1.3}_{-1.2}$ (syst) pb, or 1.13 ± 0.36 times the SM cross section. This result can be compared with the expectation from pseudo-experiments drawn in the background-only and signal+background hypotheses in Fig. 3. From the former, a signal significance of 3.3 s.d. is deduced (2.9 expected), while the latter shows consistency with the signal+background hypothesis within 0.3 s.d. The observed LLR is compared to expected distributions in the two hypotheses in Fig. 4. A fit was also performed in which the WZ and ZZ cross sections were left uncorrelated. The results are, relative to the SM cross sections, 1.8 ± 0.5 for WZ and 0.4 ± 1.1 for ZZ. These results are correlated as shown in Fig. 5 , where it can be seen that the SM expectation lies within the 68% C.L. contour of the data. The deviation from the SM is as expected, given the results of the individual channels reported in the previous subsections.

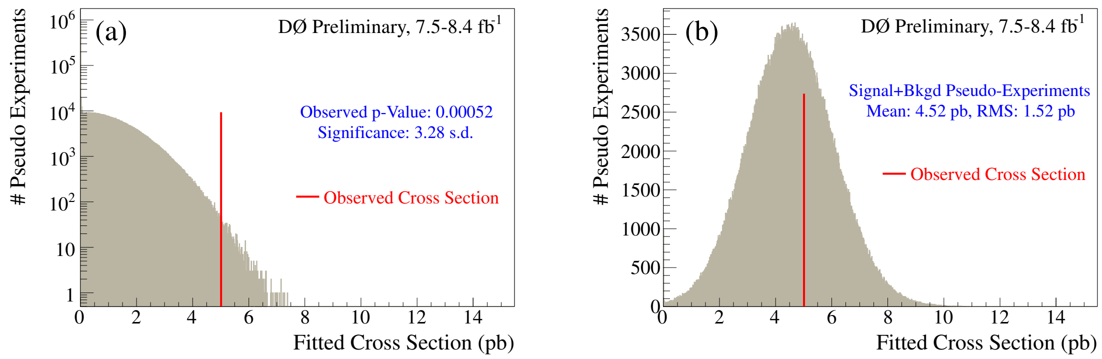

Figure 3: Combination of D0 searches for WZ/ZZ, comparison of the measured signal cross section with expectations from pseudo-experiments in the background-only (a) and signal+background (b) hypotheses.

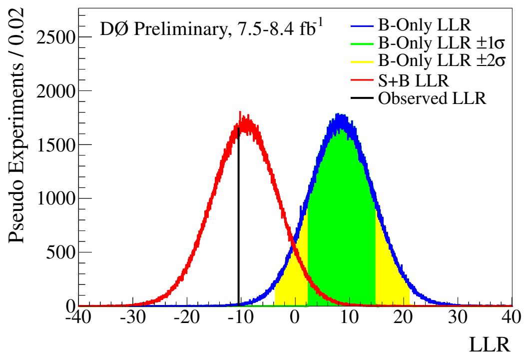

Figure 4: Combination of D0 searches for WZ/ZZ, observed LLR and expected LLR distributions in the signal+background and background-only hypotheses.

4. Summary

The D0 collaboration validated their searches for a low mass Higgs boson in data samples corresponding to integrated luminosity of 7.5 to 8.4 fb^{-1} by searching for WZ and ZZ production with $Z \to b\bar{b}$ corresponding to WH and ZH with $H \to b\bar{b}$. For the WZ signal in the $\ell\nu b\bar{b}$ final state, a significance of 2.2 s.d. was obtained [2]. For the ZZ signal in the $\ell\ell b\bar{b}$ the significance is only 0.1 s.d. [3]. Using the WW/ZZ signal in the $\nu\nu b\bar{b}$ final state with no identified leptons, a significance of 2.8 s.d. is obtained [4]. Those three searches were combined to reach a significance of 3.3 s.d. (2.9 expected), thereby establishing evidence for diboson production in final states containing heavy-flavor jets [7]. The production cross section was measured to be 1.13 ± 0.36 times

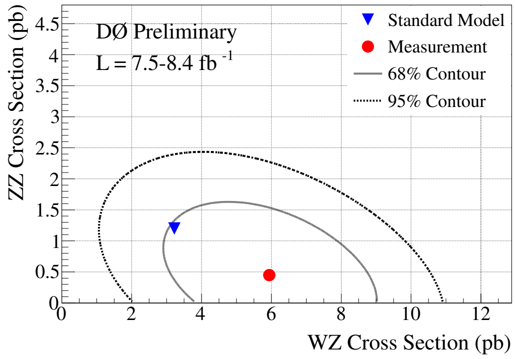

Figure 5: Combination of D0 searches for WZ/ZZ, fitted WZ and ZZ production cross sections compared to the SM expectation.

its standard model expectation. These analyses have provided a direct validation of the procedures and techniques used in the searches for a low mass Higgs boson at the Tevatron.

References

[1] J. Sekaric, ERMILAB-CONF-10-252-E.

[2] V. M. Abazov et al. (D0 Collaboration), D0 Note 6220-CONF (2011).

[3] V. M. Abazov et al. (D0 Collaboration), D0 Note 6220-CONF (2011).

[4] V. M. Abazov et al. (D0 Collaboration), D0 Note 6220-CONF (2011).

[5] A. Hoecker, PoS ACAT (2007) 040, CERN-OPEN-2007-007.

[6] V. M. Abazov et al. (D0 Collaboration), Nucl. Instrum. Meth. A 620 (2010) 490.

[7] V. M. Abazov et al. (D0 Collaboration), D0 Note 6260-CONF., arXiv:1204.4496.