Recent results in the $H \to WW$ channel with full LHC Run-II data collected by the CMS experiment

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Abstract

There are several production channels of the Higgs boson and we are searching for the production of the Higgs boson in association with a vector boson in the $H \to WW$ decay channel with the CMS experiment at the LHC. This measurement provides a direct probe of the Higgs boson coupling to vector bosons. The latest CMS results on the Higgs boson decay to a W boson pair are presented. The focus of the report is on the inclusive and STXS measurements performed for the VH leptonic channel with full Run 2 data which corresponds to an integrated luminosity of 137 fb^{-1}, collected by the CMS detector at LHC.

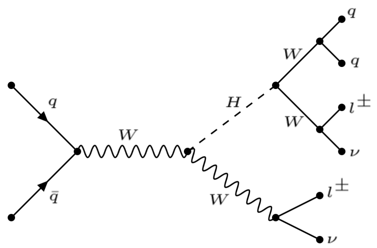
1 Introduction

This report presents a measurement of the Higgs boson [1, 2] production cross section decaying to WW boson in association with W or Z (collectively V) boson, and thus referred to as VH leptonic production. As the Higgs boson mass is smaller than twice the nominal mass of W boson, at least one of the W bosons is produced off-shell. This characteristic, along with the small branching ratios for the VH leptonic production and $H \to WW$ decay, make this measurement challenging. However, this analysis benefits from the data sample collected during Run-II with the compact muon solenoid (CMS) detector [3] at the large hadron collider (LHC) at a center-of-mass energy of $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 137 fb^{-1}.

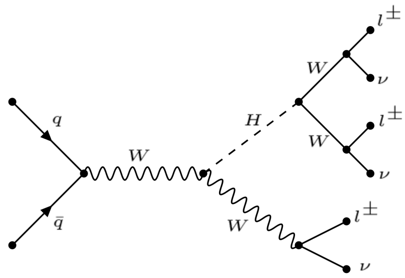
2 Analysis Strategy

In this analysis the events where associated vector bosos (Wor Z) is decaying leptonically are considered. Broadly, the analysis is subdivided into four channels based on the number of leptons and jets: $WHSS$, $WH3\ell$, $ZH3\ell$ and $ZH4\ell$. The production cross section, which is extracted as a signal strength modifier, are also measured using a simplified template cross sections framework [4] (STXS) in addition to inclusive measurement. Since final states with at least 2 leptons (electrons or muons) are studied, a combination of both single and double lepton triggers are used, feynman diagrams of these processes are shown in Figure.1. There are different challenges in each channel depending upon the dominating backgrounds, hence different approaches, and the following sections will focus on the strategies for each channel:

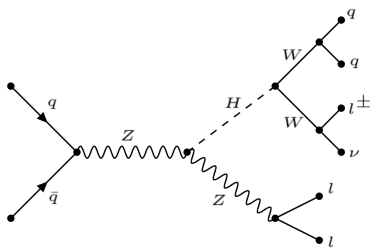
- WHSS: The final state contains two leptons, p$_T^{miss}$, and jets, as this channel targets the $WH \to 2\ell 2\nu qq$ as shown in Figure.1(a), and in order to reduce the Drell-Yann background two leptons are required to have the same sign. Based on the number of jets in the event and the lepton flavour, the Signal region (SR) events are divided into four categories 1j eμ, 1j $\mu\mu$, 2j eμ, 2j $\mu\mu$. The electron-electron flavor



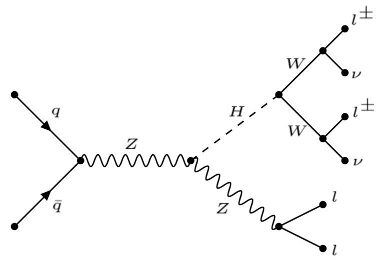
(a) $WHSS$



(b) $WH3\ell$



(c) $ZH3\ell$



(d) $ZH4\ell$

Figure 1: Feynman diagrams depicting the topology of $WHSS$, $WH3\ell$, $ZH3\ell$, $ZH4\ell$ signal processes

category is not considered as this is less sensitive to the signal. To improve discrimination between the signal and background, the $\tilde{m}_H$ variable is defined which serves as a proxy for the Higgs boson mass and is computed as the invariant mass of the dijet pair and twice the lepton four-momentum, where the second lepton four-momentum serves as a proxy for the neutrino. To extract the production cross section, a fit is performed to the $\tilde{m}_H$ variable. WZ, W+jets, and $V\gamma^{(*)}$ are the major background sources in this channel. The control regions for each N$_{jet}$ category (i.e. for 1j and 2j category) is defined for the WZ background.

- WH3ℓ: The final state contains 3 leptons and moderate E_T^{miss}, as it targets $WH \to 3\ell 3\nu$ decay as shown in Figure.1(b). The analysis starts with selecting 3 well identified and isolated leptons with total charge ± 1 and an extra lepton veto. Events in the SR is divided into two categories, events with opposite-sign same-flavor(OSSF) lepton pair falls under OSSF category and all the other are placed in the smae-sign same-flavor (SSSF) category. There are a number of Standard Model (SM) processes contributing as backgrounds, the overall background contribution in this channel can be separated into Z-boson (WZ, ZZ, $Z\gamma$ and Z+ Jets) or non-Z ($t\bar{t}$, single top, WW) type. There are also sub-dominant backgrounds in the form of triple boson SM production. Two control regions are defined, one for the WZ background and one for $Z\gamma$. To separate signal and background, multivariate Boosted Decision Tree (BDT) is used and the fit is performed to the BDT discriminant for the cross-section extraction.

- ZH3ℓ: The final state targets $ZH \to 3\ell\nu qq$ decay which contains three leptons with total charge ± 1, missing energy, and two jets from the hadronic W decay as shown in Figure.1(c). The event conatining an opposite-sign same-flavor lepton pair are considered. Further based on the number of jets in the event, there are two SR for 1j and 2j event categories. The major background contribution comes from WZ, ZZ, and non-prmopt (Z+jets) while ZZ, VVV, ttZ are other minor backgrounds which contributes. The WZ CR is used to constrain the WZ background whose definition is also shared by the $WHSS$ channel. Finally, a fit is performed to the $m_T^H = m_T(\ell + p_T^{miss}, j(j))$ variable in order to extarct the producton cross-section of Higgs boson.

- ZH4ℓ: This channel targets the $ZH \to 4\ell\nu\nu$ decay, thus contains 4 leptons and missing energy in the final state, as shown in Figure.1(d), and can be termed as purely leptonic channel. The lepton pair coming form the Higgs boson candidates are termed as the X lepton pair, and based on that the event categories are categorised into same flavor X lepton pair (XSF) and different flavor X lepton pair (XDF). The ZZ production is the main background for this channel with additional contributions from VVV, ttZ, and $V\gamma$ processes. The ZZ CR is used to constrain the ZZ contribution. Finally, BDT approach is pursued to discriminate between signal and background and a fit is performed to the BDT

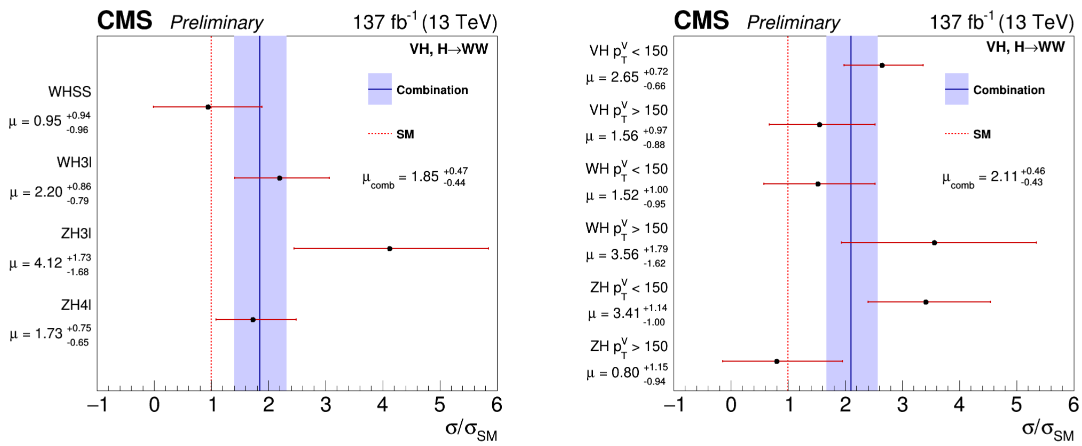


Figure 2: Left: Comparison between the signal strengths for each channel in the inclusive measurement , Right: Comparison between the combined signal strengths for each p_T^V bin in the STXS measurement, and the signal strengths for each production mode and p_T^V bin [5]

discriminant for the prodcution cross-section.

The simplified template cross section framework (STXS Stage-1.2) is also explored for the VH leptonic channel, however as a consequences of the limited statistical precision, this measurement is not currently sensitive to the Higgs boson production cross section in every STXS bin. Therefore the cross section is measured in two merged bins, defined by requiring the vector boson p$_T$ to be less than or greater than 150 GeV. The background CRs, SR categories, and signal-discriminating kinematic observables are kept same as that of the inclusive measurement for the fit to extract the STXS binned cross section.

3 Results

The signal strength modifier $\hat{\mu}$ is extracted by performing a simultaneous fit to all categories. In the inclusive measurement, the signal strength is applied to WH and ZH production in the $H \to WW$ and $H \to \tau\tau$ final states, assuming that the relative rates of the different production mechanisms and decays are as the SM ones. The measured signal strength modifier is

$$\hat{\mu} = 1.85^{+0.33}_{-0.32}(stat)^{+0.27}_{-0.25}(exp)^{+0.10}_{-0.07}(theo) \tag{1}$$

The observed significance of the inclusive VH production cross section is 4.7σ, significance for the separate channel is tabulated in Table1 and can bee seen in the left Figure.2, with $ZH4\ell$ being the most sensitive final state of all.

Category	μ	Significance
$WHSS$	$0.95^{+0.94}_{-0.96}$	1.0 σ (1.1 σ expected)
$WH3\ell$	$2.20^{+0.96}_{-0.79}$	3.01 σ (1.6 σ expected)
$ZH3\ell$	$4.12^{+1.73}_{-1.68}$	2.5 σ (0.6 σ expected)
$ZH4\ell$	$1.73^{+0.75}_{-0.65}$	3.1 σ (2.1 σ expected)
Combination	$1.85^{+0.47}_{-0.44}$	4.7 σ (2.8 σ expected)

Table 1: The posterior signal strengths and significances for the signal strengths decorrelated among the $WHSS$, $WH3\ell$, $ZH3\ell$, and $ZH4\ell$ categories.

The signal strength modifiers for the STXS, $p_T < 150\ GeV$ and $p_T > 150\ GeV$ are:

$$\hat{\mu}_{p_T^V < 150\ GeV} = 2.65^{+0.57}_{-0.55}(stat)^{+0.38}_{-0.32}(exp)^{+0.11}_{-0.00}(theo) \tag{2}$$

$$\hat{\mu}_{p_T^V > 150\ GeV} = 1.56^{+0.85}_{-0.77}(stat)^{+0.43}_{-0.40}(exp)^{+0.11}_{-0.09}(theo) \quad (3)$$

and the observed significance of the VH production cross section for $p_T^V < 150(> 150\ )$ is $4.7\sigma(1.8\sigma)$, the signal strength and significance for the WH and ZH production mode is tabulated in Table.2 and the overall comparison is shown in the right Figure.2. Finally, the measured combined signal strength for STXS is $2.11^{+0.46}_{-0.43}$, which differ from the inclusive result as a consequence of the event categorization in STXS, however the two results agree within uncertainties.

	μ	Significance
$WH\ p_T^V < 150$ GeV	$1.5^{+1.0}_{-0.9}$	1.64 σ (1.24 σ expected)
$WH\ p_T^V > 150$ GeV	$3.6^{+1.8}_{-1.6}$	2.23 σ (0.83 σ expected)
$ZH\ p_T^V < 150$ GeV	$3.4^{+1.1}_{-1.0}$	4.37 σ (1.59 σ expected)
$ZH\ p_T^V > 150$ GeV	$0.8^{+1.2}_{-0.9}$	0.83 σ (1.18 σ expected)

Table 2: The posterior signal strengths and significances for the signal strengths in each p_T^V bin, for the WH and ZH ($qqZH$+$ggZH$) production modes.

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