PROCEEDINGS OF SCIENCE

Recent results in the $\mathrm{H} \rightarrow \mathrm{WW}$ channel with CMS

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Recent results on the cross section measurement of the Higgs boson production in association with a leptonically decaying vector boson are presented. Events where the Higgs boson decays to a pair of W bosons are considered for this analysis, with at least one vector boson decaying leptonically. This report is focused on measurements exploiting the full Run 2 proton-proton collision dataset collected by the CMS detector.

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1. Introduction

This paper presents a measurement of the Higgs boson [1, 2] production cross section in association with a W or a Z boson that decays leptonically and with the Higgs boson decaying to a pair of W bosons [3]. This Higgs production mode is referred to as VH leptonic and provides a direct probe of the Higgs boson coupling to vector bosons. Due to the small branching ratios for the VH leptonic production and the Higgs WW decay channel, this measurement is particularly challenging.
The analysis is based on proton-proton collision data produced at the LHC with $\sqrt{s}$ = 13 TeV and collected by the CMS detector [4] during the LHC Run 2, for a total integrated luminosity of about 137 fb^{-1}. The events used in this analysis are selected by trigger algorithms requiring the presence of either a single high-p_T lepton or a lepton pair with a lower p_T threshold, passing identification and isolation requirements.

2. Analysis Strategy

The analysis is subdivided in four channels based on the number of leptons and jets required: $WHSS$, $WH3\ell$, $ZH3\ell$ and $ZH4\ell$. The VH leptonic production cross section is measured using a dedicated approach in each channel:

- $WHSS$: this channel targets the $WH \to 2\ell 2\nu qq$ final state, where the two leptons are required to have the Same-Sign (SS) to reduce the Drell-Yan background. The final state therefore contains two same-sign leptons, missing transverse energy E_T^{miss}, and at least one jet. Events in the signal region are categorized based on the number of jets in the event: $N_{jet} = 1$ and $N_{jet} > 1$.
  The N_{jet} categories are further divided into $e\mu$ and $\mu\mu$ categories. Events with two electrons are not considered, as this flavour category is less sensitive to signal. To improve discrimination between signal and background, a proxy for the Higgs boson mass is defined: $\tilde{m}_H$. It is computed as the invariant mass of the jet pair and twice the lepton four-momentum closest to the jet pair. The lepton four-momentum serves as a proxy for the neutrino. Events in all sub-categories are required to have $\tilde{m}_H > 60$ GeV. The signal extraction fit is performed with a simultaneous fit on binned templates of the $\tilde{m}_H$ variable.
  The main backgrounds in the $WHSS$ channel are WZ, $V\gamma^{(*)}$ productions and those related to non-prompt leptons. Two control regions for the WZ background are defined, one for each N_{jet} category.

- $WH3\ell$: this channel targets the $WH \to 3\ell 3\nu$ decay. The final state therefore contains three leptons and E_T^{miss}. The analysis selects events containing exctly three leptons with total charge $Q = \pm 1$. Events in the signal region are categorised as follows: events with a Same-Sign Same-Flavour lepton pair are placed in the SSSF category, while all other events are placed in the OSSF category. The signal extraction is performed with a simultaneous fit on binned templates of a discriminant built with a Boundary Decision Tree (BDT).
  The main backgrounds are WZ, ZZ and $V\gamma^{(*)}$ productions, as well as backgrounds containing non-prompt leptons. Two control regions are defined, one for the WZ background (with $N_{jet} = 0$) and one for $V\gamma^{(*)}$.

- $ZH3\ell$: this channel targets the $ZH \to 3\ell 3\nu qq$ decay. The final state therefore contains three leptons with total charge $Q = \pm 1$. Selected events must contain an opposite-sign same-flavour lepton pair. Events are categorized based on the number of jets in the event: $N_{jet} = 1$ and $N_{jet} > 1$. The signal extraction is performed with a simultaneous fit on binned templates of the Higgs boson transverse mass m_T^H.
  The main backgrounds of the $ZH3\ell$ channel are WZ, ZZ and $V\gamma^{(*)}$, as well as backgrounds containing non-prompt leptons. This channel shares the same WZ control regions of the $WHSS$ channel, one for each N_{jet} category.

- $ZH4\ell$: this channel targets the $ZH \to 4\ell 4\nu$ decay. The final state therefore contains four leptons and E_T^{miss}. The analysis selects events containing exactly four leptons and total charge $Q = 0$. The opposite-sign same flavour lepton pair with invariant mass closest to the Z boson mass is designated as the Z boson candidate, while the remaining lepton pair, coming from the Higgs boson, is referred to as the X candidate.
  Events in the signal region are categorized based on the flavour of the lepton pair forming the X candidate. Events in the XSF category have a same flavour X lepton pair, while events in the XDF category have a different flavour X lepton pair. The signal extraction is performed with a simultaneous fit on binned templates of a discriminant built with a BDT.
  Production of ZZ pairs is the main background in this channel. Two ZZ control regions are defined, one for each X lepton flavour category.

The VH leptonic cross section is also measured in the STXS framework, using the Stage 1.2 binning definitions [5]. Since the statistical precision is limited, the measurement is not sensitive to the Higgs boson production in every STXS bin. The cross section is therefore measured in two merged bins, defined by the vector boson transverse momentum: $p_T^V > 150$ GeV and $p_T^V < 150$ GeV. To extract the cross section as a function of the vector boson transverse momentum, events are categorized into corresponding regions of reconstructed p_T^V. The reconstructed p_T^V is defined differently depending on the vector boson type and decay channel. In the WH channels, the W boson p_T can not be fully reconstructed due to the presence of neutrinos: proxies for p_T^V are defined for these channels.

3. Experimental Results

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

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

The probability of observing a signal at least as large under the background-only hypothesis corresponds to an observed (expected) significance of 4.7σ (2.8σ). The expected and observed likelihood profiles as a function of the signal strength are shown in Figure 1.
The four channels under study ($WHSS$, $WH3\ell$, $ZH3\ell$ and $ZH4\ell$) are also measured separately with an additional simultaneous fit. The signal processes in each category is scaled with a different

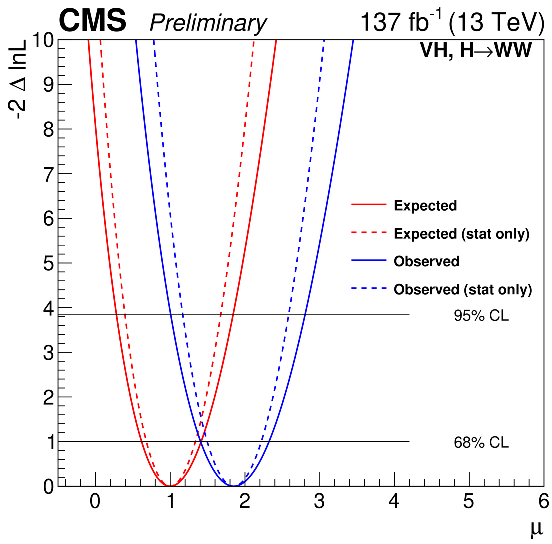

Figure 1: Expected and observed likelihood profiles as a function of the signal strength in the inclusive measurement [3]. Dashed curves include only statistical uncertainties. Horizontal lines marking the 68% and 95% likelihood intervals are also indicated.

signal strength modifier. The four signal strengths are reported in Figure 2. The $ZH4\ell$ category is the most sensitive final state, benefiting from the cleaner signature of a fully leptonic final state.
In the STXS measurement, the measured signal strength modifiers for the $p_T^V < 150$ GeV and $p_T^V > 150$ GeV STXS bins are:

$$\hat{\mu}_{p_T^V < 150\,\mathrm{GeV}} = 2.65^{+0.57}_{-0.55}(stat)^{+0.38}_{-0.32}(theo)^{+0.08}_{-0.07}(exp) \tag{2}$$

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

with corresponding measured (observed) significances of 4.7σ (2.0σ) and 1.8σ (1.5σ) respectively.
The STXS measurement is also performed by assuming separate signal strengths for the WH and ZH production modes. The signal strengths for each production mode and p_T^V bin, together with combined signal strengths for each p_T^V bin, are reported in Figure 3.
Finally, a combined signal strength $\hat{\mu}_{STXS} = 2.11^{+0.46}_{-0.43}$ is measured by applying a single common signal strength modifier in all STXS bins. This result is consistent within uncertainties with the result of the inclusive measurement.

References

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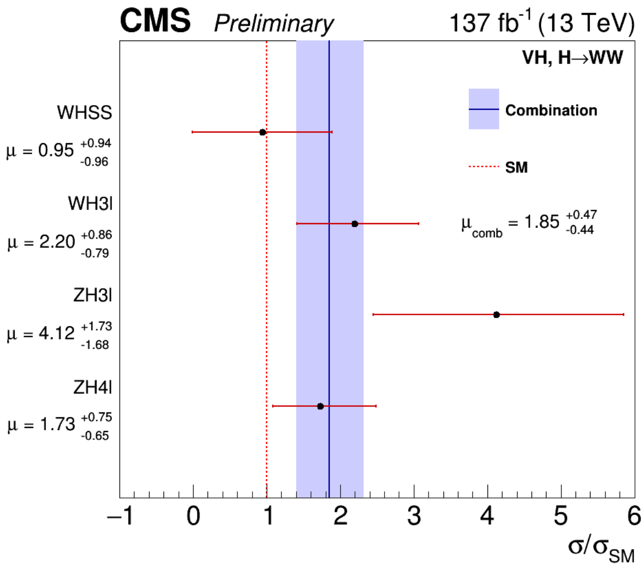

Figure 2: Comparison between the signal strengths for each channel ($WHSS$, $WH3\ell$, $ZH3\ell$ and $ZH4\ell$) in the inclusive measurement [3].

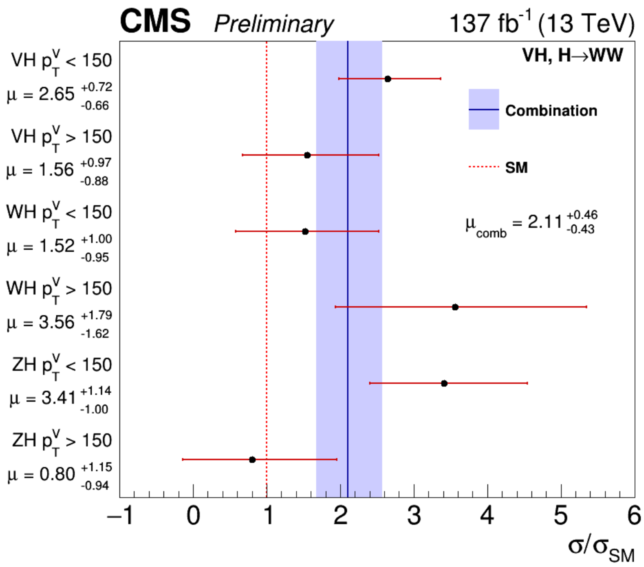

Figure 3: Comparison between the combined signal strengths for each p_T^V bin in the STXS measurement, and the signal strengths for each production mode and p_T^V bin [3].

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