IL NUOVO CIMENTO **42 C** (2019) 167
DOI 10.1393/ncc/i2019-19167-9

COLLOQUIA: IFAE 2018

Strategies for new measurements in the VH, $H \to bb$ channel in ATLAS

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received 31 January 2019

Summary. — The analysis of the data collected by the ATLAS detector for the search of the associate production of a Higgs boson decaying in $b\bar{b}$ and a W or Z boson decaying leptonically is briefly described. This analysis led in 2017 to the first evidence of the Higgs boson decaying in $b\bar{b}$. The same analysis channel can be used in the so-called Simplified Template Cross-Section Framework to extract information on the Higgs couplings and eventually on their variations due to Beyond the Standard Model physics effects.

1. – Introduction

The search for the decay of the Higgs boson into two b-quarks is a particularly important test of the Standard Model (SM), this being the main Higgs decay channel with a branching ratio of about 58% [1]. The most promising channel to measure such decay is the associated production of the Higgs boson and a V-boson (W or Z) decaying to leptons. The leptonically decayed boson offers a clear trigger signature and helps in the multi-jet background suppression.

A recently published ATLAS paper reported a first evidence for the $H \to b\bar{b}$ decay (observed significance 3.5σ) [2]. In this analysis events are selected and classified according to the lepton content:

- 0-leptons channel, mainly selecting $Z \to \nu\nu$ events (trigger: missing transverse momentum p_T^{miss});
- 1-lepton channel, mainly selecting $W \to l\nu$ events (trigger: single electron or p_T^{miss});
- 2-leptons channel, mainly selecting $Z \to ll$ events (trigger: two leptons).

A multivariate analysis (MVA) is performed on the selected events and a fitting procedure is applied to extract the signal strength (μ) defined as

$$\mu = \frac{\sigma_{\text{measured}}}{\sigma_{\text{expected(SM)}}},$$

where σ is the $VH \to b\bar{b}$ cross-section. The μ measurement, assuming that the observed signal is due to the SM Higgs boson, can be interpreted as a measurement of the VH production cross-section times the $H \to b\bar{b}$ branching ratio. The measured cross-section is $\sigma(VH) \times B(H \to b\bar{b}) = 1.58^{+0.55}_{-0.47}$ pb, to be compared to an expectation of 1.31 pb.

2. – Simplified template cross-sections

The Simplified Template Cross-Sections (STXS) is a new framework that has been developed to maximize the sensitivity of the cross-section measurements while minimizing the theory dependence of the measurements [3].

In this framework cross-section measurements are performed in mutually exclusive phase-space regions, specific to the different production modes, that can be easily combined in all the decay channels. The criteria to define the STXS phase-space regions are [3]:

1) to minimize the dependence on theoretical uncertainties;

2) to maximize the experimental sensitivity;

3) to isolate possible Beyond the Standard Model effects;

4) to minimize the number of bins without loosing experimental sensitivity.

A preliminary study of the STXS measurements in the VH, $H \to b\bar{b}$ channel was carried out using the three phase-space regions ("bins") shown in fig. 1 (left), where p_{TV} indicates the transverse moments of the Vector boson produced in association with the Higgs boson. Studies were performed to check the sensitivity of the MVA variable to the chosen splitting, looking at the shape differences in the different phase-space regions. In fig. 1 (right) the MVA distribution for the 1-lepton channel ($W \to l\nu$) is shown as an example. A clear difference between the shape of the MVA distribution for events with $p_{TV} < 250$ GeV and $p_{TV} > 250$ GeV is present. Other channels are more sensitive to the split at $p_{TV} > 150$ GeV.

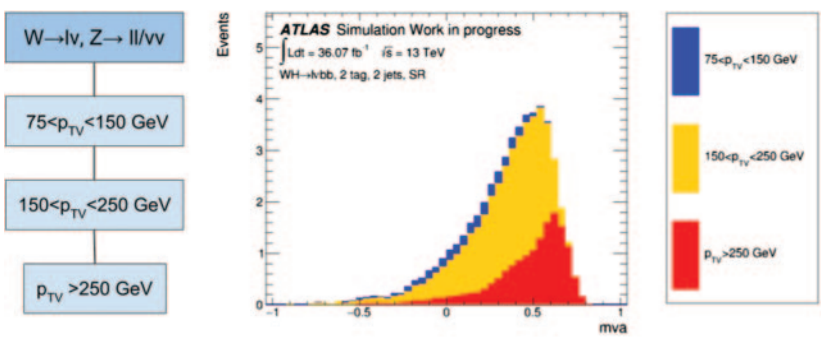

Fig. 1. – Left: scheme of the STXS definition, p_{TV} indicates the transverse moments of the Vector boson produced in association with the Higgs boson. Right: MVA distribution in the 1-lepton channel, the contributions of the STXS phase-space regions are shown in different colors.

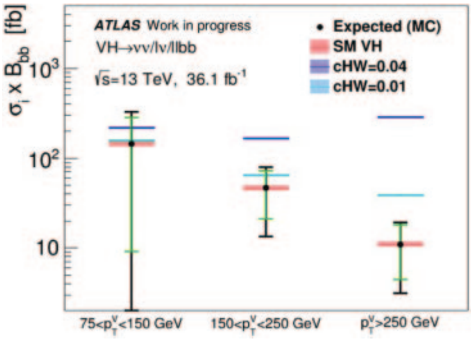

Fig. 2. – Expected cross-sections for $cHW = 0$ (SM value), $cHW = 0.01$ and $cHW = 0.04$ (expected limit from the $H \to ZZ^*$ and $H \to \gamma\gamma$ combination [4]).

3. – Beyond the Standard Model —Effective Field Theories

Beyond the Standard Model (BSM) physics could lead to large deviations from the SM expectations. One possibility to extract information on BSM physics from the cross-section measurements is to use the Effective Field Theories (EFT) formalism. In EFT the SM Lagrangian is extended to include terms that could deviate from the Standard Model predictions. The general form of the Lagrangian including dimension-6 operators is $\mathcal{L} = \mathcal{L}_{SM} + \sum_i c_i^{(6)} O_i^{(6)} / \Lambda^2$, where Λ is the energy scale of the new process [3]. Using the STXS measurements it is possible to measure the parameters c_i values or to extract limits.

The VH channel, that involves the HWW and HZZ couplings, is particularly sensitive to deviations of the cHW parameter ($cHW = 0$ in SM). A limit on the cHW parameter has been set by ATLAS using the combined $H \to ZZ^* \to 4l$ and $H \to \gamma\gamma$ channels and the expected limit is $cHW < 0.04$ [4].

In fig. 2 a preliminary study on the sensitivity of the VH, $H \to b\bar{b}$ channel to deviations in cHW is shown. In the plot the uncertainties on the cross-section measurements are shown in the three chosen STXS bins, together with the expected cross-section values assuming all couplings to be 0 except for cHW ($cHW = 0.01$ and $cHW = 0.04$).

The plot highlights the trend of the BSM deviations, increasing at high energies. Additional high-energy STXS bins could augment the sensitivity to BSM physics. From fig. 2 is also clear that the VH, $H \to b\bar{b}$ channel could be used to improve the current cHW limit. A final assessment of the sensitivity of this analysis to BSM physics will be obtained completing the study and taking into account simultaneously all others EFT couplings (assumed to be 0 in this preliminary study).

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