PROCEEDINGS OF SCIENCE

Search for non-resonant di-Higgs production in the $b\bar{b}b\bar{b}$ final state at $\sqrt{s} = 13$ TeV with the ATLAS experiment

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Results are presented of the search for non-resonant di-Higgs production in the $b\bar{b}b\bar{b}$ final state using the Run-2 dataset of proton-proton collisions at $\sqrt{s} = 13$ TeV accumulated with the ATLAS detector. The $b\bar{b}b\bar{b}$ final state is one of the most sensitive channels for measuring the Higgs self-coupling and the di-Higgs production cross-section, thanks to its high branching ratio. The analysis utilizes a novel neural network to estimate the large QCD multijet backgrounds, and employs analysis categorizations to improve the sensitivity to di-Higgs production. The analysis strategy and the latest result of the observed (expected) upper limits on the SM di-Higgs production cross-section and the constraint on the Higgs self-coupling in this analysis are presented.

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1. Introduction

After the Higgs boson (H) discovery [1, 2] in 2012, the measurements of the Higgs boson properties to test the Higgs mechanism in the Standard Model (SM) of particle physics are strongly motivated. This analysis targets non-resonant Higgs boson pair production (di-Higgs production, HH). The two leading production processes are gluon-fusion (ggF) and vector-boson fusion (VBF) (Figure 1). Their cross-sections depend on the trilinear Higgs self-coupling (κ_λ) and the quartic di-vector-boson and di-Higgs-boson ($HHVV$) coupling (κ_{2V}), which are defined as the ratios with respect to the SM predictions. The $b\bar{b}b\bar{b}$ final state, where both Higgs bosons decay to a pair of b quarks, is one of the most sensitive channels thanks to it having the highest branching ratio of approximately 34%. We searched for non-resonant di-Higgs production in the $b\bar{b}b\bar{b}$ final state using the Run-2 datasets corresponding to 126 fb^{-1} at $\sqrt{s} = 13$ TeV taken with the ATLAS detector [3] in 2016-2018, and obtained constraints on the signal strength, the trilinear Higgs self-coupling and the $HHVV$ coupling.

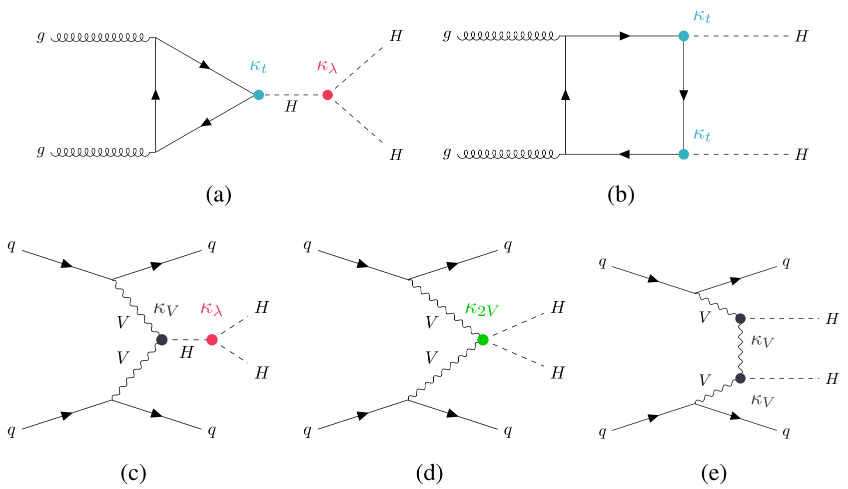

Figure 1: Feynman diagrams of di-Higgs production with (a,b) gluon-gluon fusion (ggF) and (c,d,e) vector boson fusion (VBF) at leading order [4].

2. Event Selection and Categorization

Events are selected by a set of multi b-jet triggers requiring one or two b-tagged jets and some additional jets. The events must contain at least four b-tagged jets with $p_{\mathrm{T}} > 40$ GeV and $|\eta| < 2.5$ (4b events). Higgs bosons are reconstructed from the leading four b-tagged jets in p_{T}. From the four b-tagged jets, in total three possible pairings can be defined. In this analysis, the pairing with the smallest opening angle, ΔR [1], between the jets in the leading Higgs boson candidate, is selected. This is based on the principle that the decay products of the Higgs bosons are usually collimated due to the initial momentum of the Higgs boson. The events are then

[1] The opening angle is defined as $\Delta R = \sqrt{(\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2}$, where i and j indicate different jets. η is pseudorapidity and ϕ is azimuthal angle.

categorized into two orthogonal channels, ggF channel and VBF channel, targeting ggF events and VBF events, respectively. The VBF channel is prioritized over the ggF channel. In the ggF channel, $|\Delta\eta_{HH}| < 1.5$ is applied to reduce QCD multijet background, where $|\Delta\eta_{HH}|$ is the opening angle in pseudorapidity between the two Higgs boson candidates. After that, in both channels, background events from $t\bar{t}$ process are suppressed by the $t\bar{t}$ veto cut [2]. Finally, events in both channels are selected by

$$X_{HH} = \sqrt{\left(\frac{m_{H1} - 124\ \mathrm{GeV}}{0.1\ m_{H1}}\right)^2 + \left(\frac{m_{H2} - 117\ \mathrm{GeV}}{0.1\ m_{H2}}\right)^2} < 1.6, \quad (1)$$

where m_{H1} and m_{H2} are the invariant mass of the leading and subleading Higgs boson candidates.

In addition, to maximize the sensitivity, analysis categorizations are adopted in both channels. Events in the ggF channel are categorized by two variables, $|\Delta\eta_{HH}|$ and X_{HH}. Three $|\Delta\eta_{HH}|$ bins with an equal space of 0.5 between 0 and 1.5 and two X_{HH} bins with a boundary of 0.95 are used, and in total six categories are defined. The VBF channel is split in $|\Delta\eta_{HH}|$ with a boundary of 1.5. Approximately 40% improvement on the signal strength limit is achieved, compared to that with no analysis categorization.

3. Background Estimation

After the event selection and categorization described above, approximately 90% of the background events arise from QCD multijet processes and the remainder is almost entirely $t\bar{t}$ events. To estimate these 4b backgrounds inclusively, a fully data-driven approach using neural networks is utilized. Events with exactly two b-tagged jets (2b events) are used in this approach. The kinematics of the 2b events are assumed to be similar to the kinematics of the events with more b-tagged jets such as the 4b events. However, their kinematics are not exactly the same, due to different physics processes contributing to the 2b and 4b events. Therefore, the 2b sample is reweighted to have the same kinematic distributions as in the 4b sample. The reweighting function, corresponding to the density ratio of 2b to 4b sample, is derived by an artificial neural network based on Ref. [5, 6] using the 2b and 4b samples in the Control Regions. The 2b sample is reweighted by a reweighting function in the Signal regions and is used for the 4b background estimation. Several validation studies, such as using the events with three b-tagged jets and all other jets that are not b-tagged (3b1f events), were performed, and the background estimation procedure was validated.

4. Results

The analysis strategy described above was applied to the Run-2 data corresponding to 126 fb^{-1} taken with the ATLAS detector. A simultaneous fit was performed on the invariant mass of the two Higgs boson candidates m_{HH} across the ggF categories and the VBF categories to test signal hypotheses with various κ_λ and κ_{2V} values. No significant excess for the di-Higgs production has been observed, and the results are consistent with the SM. The upper limit of the ggF + VBF

[2] $X_{Wt} = \min\left[\sqrt{\left(\frac{m_W - 80.4\ \mathrm{GeV}}{0.1\ m_W}\right)^2 + \left(\frac{m_t - 172.5\ \mathrm{GeV}}{0.1\ m_t}\right)^2}\right] < 1.6$, where m_W and m_t indicate the invariant mass of W boson and top-quark candidate formed from jet combinations in each event.

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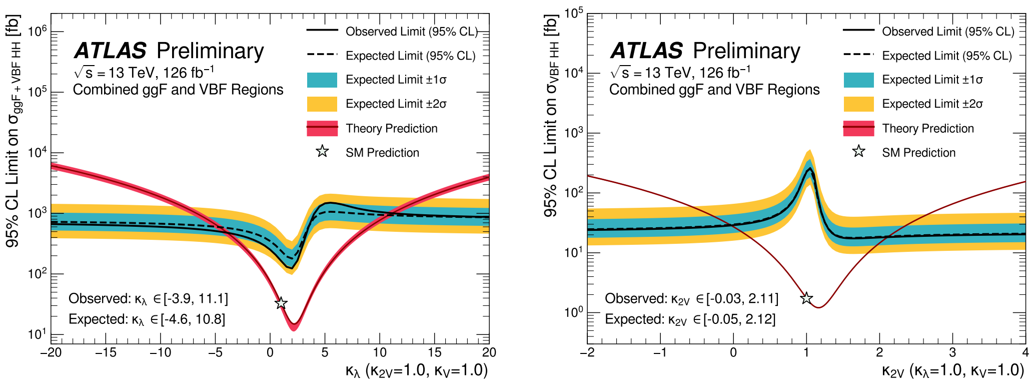
signal strength is set to 5.4 at 95% confidence level (CL). The observed constraint on the trilinear Higgs self-coupling is $\kappa_\lambda \in [-3.9, 11.1]$, and the observed constraint on the $HHVV$ coupling is $\kappa_{2V} \in [-0.05, 2.11]$. Large improvements on these constraints are achieved with respect to the previous analyses [7, 8].



(a) (b)

Figure 2: The observed and expected 95% CL exclusion limits as a function of (a) κ_λ and (b) κ_{2V} [4].

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