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Searches for heavy resonances decaying to Higgs bosons at ATLAS & CMS

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This document highlights a selection of recent searches for new heavy resonances using the decay to Higgs bosons from ATLAS and CMS Collaborations. The results are obtained based on the proton-proton collision data collected during Run 2 of the LHC at a center-of-mass energy of 13 TeV. No significant deviations from the Standard Model expectations are observed.

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1. Introduction

After the Higgs (H) boson was discovered by the ATLAS [1] and CMS [2] Collaborations, one of the major focuses is the search for new physics beyond the Standard Model (SM). In many theoretical models, new resonances are predicted and could couple to Higgs bosons.

This proceeding presents five recent searches for new heavy resonances decaying to Higgs bosons. The di-Higgs (HH) and vector-boson association (VH) processes have been used to investigate different benchmark scenarios, including the spin-0 scalar in the two-higgs-doublet (2HDM) model [3], spin-1 W'/Z' in the heavy vector triplet (HVT) model [4], and spin-2 graviton in the bulk Randall-Sundrum (RSG) model [5]. The data samples used in the searches were collected with the ATLAS and CMS detectors during 2015 to 2018 pp collision runs at $\sqrt{s}$ = 13 TeV and correspond to total integrated luminosity up to 139 fb^{-1}.

2. General search strategy

For pp collisions, the new heavy resonance can be produced via gluon-gluon fusion (ggF), vector-boson fusion (VBF) and vector-boson association processes. Thus a series of searches is conducted to cover different signal signatures. The ggF and VBF processes are used to search for spin-0 and spin-2 resonances, while VH is used to search for spin-1 resonances.

Since all the studies are performed with at least one Higgs boson, the ideal decay channel for this search is $H \to bb$, which has the largest branch fraction. As for the backgrounds for all of these searches, the MC simulation and data-driven methods are used to estimate the contributions.

To search for resonances with extremely high mass, the Higgs or vector bosons could be highly boosted. Therefore the main experimental challenge is the reconstruction and identification of the boosted object. There are many advanced techniques that have been used to study the boosted object, more details are described in Ref. [6].

3. Boosted HH results

The recent result from CMS for HH resonant search is conducted with 35.9 fb^{-1} pp collision data. This search is designed for the resonance with mass greater than 0.8 TeV, therefore the Higgs bosons tends to have high transverse momentum and should be reconstructed from boosted objects in detector. The $HH \to bbWW^*$, $WW^* \to qql$ channel is used and boosted WW^* candidate is reconstructed by a large-radius jet and a nearby lepton. The boosted $H \to bb$ is reconstructed by another large radius jet and both the subjets are tagged as $b-$jet. No derivation from SM prediction is observed, and the upperlimits at 95% confidence level (CL) on the product of cross section and branching fraction range from 123 fb at 0.8 TeV to 8.3 fb at 3.5 TeV for spin-0 resonance, and from 103 fb at 0.8 TeV to 7.8 fb at 3.5 TeV for spin-2 resonance, as shown in Figure 1.

At ATLAS, the pp collison data at $\sqrt{s}$ = 13 TeV with a corresponding luminosity of 139 fb^{-1} has been first fully investigated for HH resonant search. The search is performed with $bb\tau\tau$ channel and designed for the resonance with mass greater than 1 TeV. A Boosted-Decision-Tree (BDT) with tracking, vertexing and calorimeter information is used to identify the boosted hadronic $\tau\tau$ [7], and the performance improvement compared to the previous approach is shown in Figure 2 (left). The

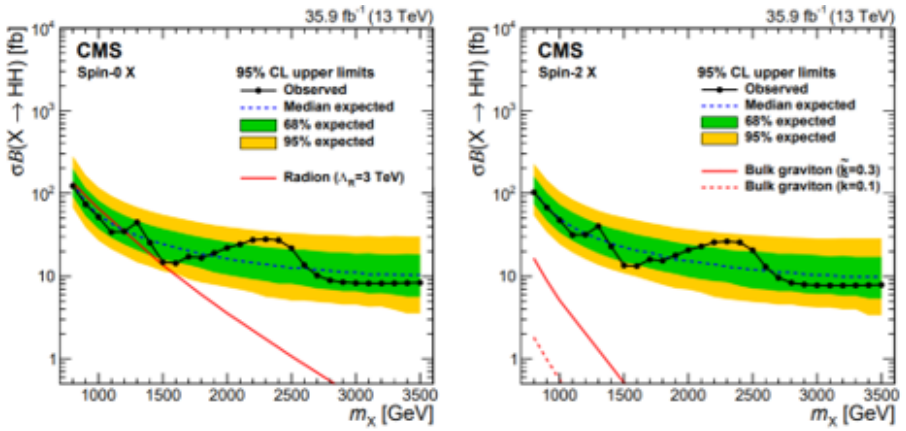

Figure 1: Upperlimit on the product of cross section times branch fraction for spin-0 (left) and spin-2 (right) resonance.

boosted $H \to bb$ is reconstructed with a large-radius jet and the two variable-radius (VR) subjets are tagged as b jets No significant deviations from the SM predictions are observed, and upperlimits are set on the cross section of a heavy, narrow, spin-0 resonance as shown in Figure 2 (right). The observed upperlimits range from 88 to 46 fb for resonant mass at 1.2 and 3.0 TeV.

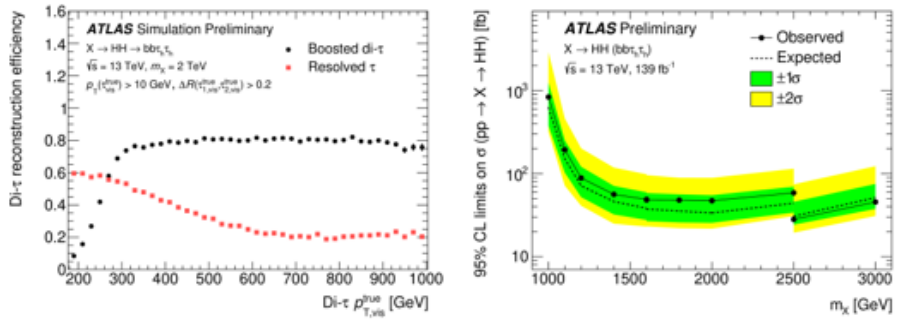

Figure 2: Right: Reconstruction efficiency for hadronic $\tau\tau$ from the BDT tagger. Left: Expected and observed 95% CL upper limits on the production cross-section of a spin-0 resonance decaying into a pair of Higgs bosons. The discontinuities in the limits around 2.5 TeV caused by the different requirements applied on visible mass.

4. Resolved HH results

Besides the resonant search with boosted objects, ATLAS and CMS have conducted the searchs for resonance below 1 TeV with resolved objects. The ggF $HH \to bbZZ^*$ and VBF $HH \to bbbb$ channels are investigated with the data from CMS and ATLAS, respectively. The $ZZ^* \to jjll$ or $llvv(l = e, \mu)$ channel is used and the upperlimits on the product of cross sections of spin-0 resonance [8] is shown in Figure 3 (left). The VBF process has unique sensitivity to di-vector-boson–di-Higgs-boson quartic coupling compared with ggF and also can be used to search for HH resonant. At ATLAS, due to the inefficiency b-jet trigger during 2016 data taking, this channel is

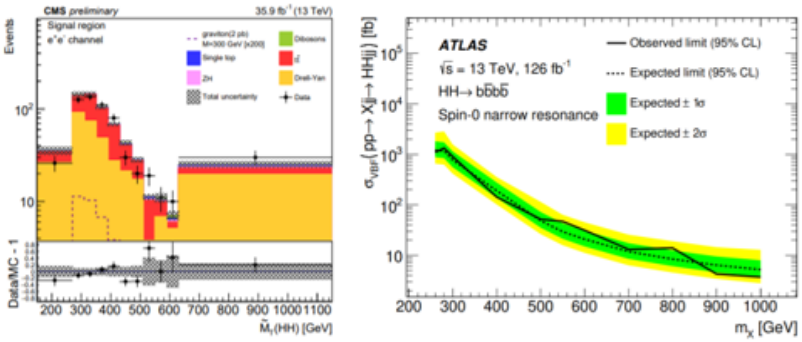

Figure 3: Expected (black dashed line) and observed (black solid line) limits on the cross section of resonant HH production as a function of the mass of the resonance from the ggF $bbZZ^*$ (left) and VBF $bbbb$ channel (right).

analyzed with a 126 fb$^-$1 dataset and the upperlimits on the product cross sections (Figure 3 (right)) for resonance below 1 TeV in VBF process is obtained for the first time [9].

5. Boosted VH results

In the context of HVT model, the spin-1 $W'Z'$ interacts with quarks and the Higgs field with coupling strength of g_q and g_H, respectively. Therefore it could be searched with WH and ZH channels. ATLAS has performed a corresponding search with the 139 fb^{-1} pp collision data. The search is designed for resonance with a narrow width and a mass above 1.5 TeV, thus both V and H bosons tend to be boosted objects in detector. The dominant decay channel, $VH \to qqbb$, is utilized with two large-radius jets. The jet substructure techniques and VR subjet-based b tagging are used to distinguish V and H jets from backgrounds. No significant derivation from SM prediction is observed and the upperlimits on cross sections for $pp \to W' \to WH$ and $pp \to Z' \to ZH$ range from 6.8 fb to 0.53 fb and from 8.7 fb to 0.53 fb, respectively [10]. The lower limit on the mass of $W'(Z')$ is calculated to be 2.90(2.20) TeV and 3.20 (2.65) TeV in the scenario of weekly coupled HVT model A ($g_q = -0.55$ and $g_H = -0.56$) and strongly coupled HVT model B ($g_q = 0.14$ and $g_H = -2.9$), respectively. The exclusions of the couplings can be derived from the above results and shown in Figure 4.

6. Summary

ATLAS and CMS has a suite of HH and VH resonant searches across a large mass range in $bbWW^*$, $bb\tau\tau$, $bbZZ^*$, $bbbb$ and $qqbb$ channels. In particular, the boosted $HH \to bb\tau\tau$ and $VH \to qqbb$ channels are investigated with the pp collision data at $\sqrt{s} = 13$ TeV during the LHC full Run2 period for the first time. No significant sign of heavy resonant has been observed so far, and the corresponding upperlimits on product cross sections are reported. The sensitivity is improved remarkably benefited from the increased integrated luminosity and better-performing techniques. Discovery potential for new resonance will be further enhanced with more data and new techniques at HL-LHC.

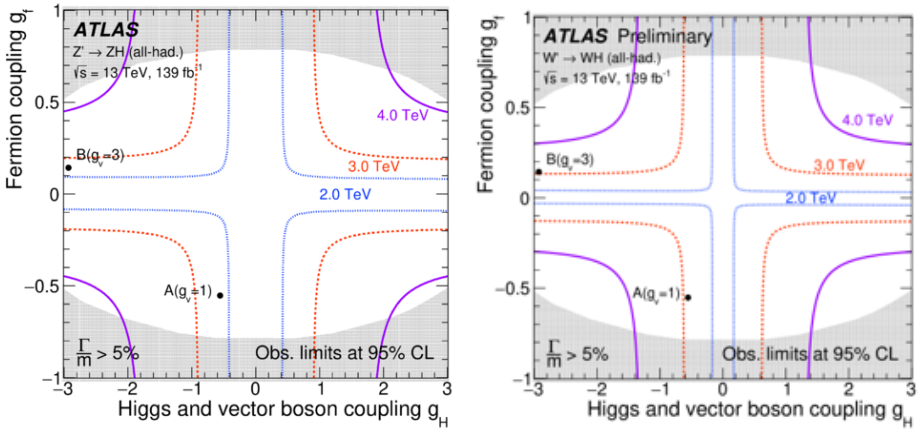

Figure 4: Upperlimits on the couplings for the WH (left) and ZH (right) channels with resonant masses of 2, 3 and 4 TeV.

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