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Searches for high-mass resonances decaying to pairs of bosons using the ATLAS detector

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Several beyond the Standard Model theories predict the existence of new heavy particles decaying into pairs of gauge bosons. This review summarizes the latest ATLAS results on searches for resonances decaying into W, Z, Higgs bosons or photons, based on datasets of 36 and 80 fb^{-1} of pp collision data collected at 13 TeV. No excess of events is found over the Standard Model background-only expectation, exclusion limits are set for various hypotheses in a broad mass range.

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1. Introduction

The discovery of a Higgs-like particle announced by the ATLAS and CMS collaborations in 2012 [1, 2] has been an important milestone in the understanding of the mechanism of electroweak (EW) symmetry breaking. The next step is to figure out whether this particle is the only one or if it is part of an extended Higgs sector as predicted by several extensions of the Standard Model (SM): composite Higgs models, heavy vector triplets and models with warped extra dimensions.

In these proceedings a collection of different results is presented. A search for additional heavy resonances in diboson final states is presented for several channels. A search for leptonic decays of W and Z boson pairs is described in Section 2 and 3 using 36 fb^{-1} of data. A search for fully hadronic decays of VV is described in Section 4 using 80 fb^{-1} of data, results of a search for photon and hadronicaly decaying Z,W or H bosons are presented in Section 5 based on dataset with 36 fb^{-1}. The brief overview of searches are summarised in Section 6.

2. $WW \to e\nu\mu\nu$ decays

The search for a neutral heavy resonance H decaying to WW with a final state of $e\nu\mu\nu$ is described in detail in [3]. The search is performed for the production via quark-antiquark annihilation ($q\bar{q}A$), vector-boson fusion (VBF) or gluon-gluon fusion (ggF) process covering a mass range from 200 GeV up to 5 TeV for various benchmark models: a Higgs-like scalar in different width scenarios (NWA-LWA, Γ_X=0-15%m_X), a two-Higgs-doublet model (2HDM), the Georgi-Machacek (GM) model, a heavy vector triplet model (HVT), a warped extra dimensions model (G_{KK}) and an effective Lagrangian model (ELM).

The analysis studies opposite sign, different flavour leptons and categorises events into three signal regions (SR), two VBF enriched and one targeting $ggF/q\bar{q}A$. The main backgrounds ($t\bar{t}$ and non-resonant WW) are taken from simulation and normalised using dedicated CRs, while the W+jets background taken from data-drive estimates.

As no excess over the background prediction is observed, upper limits at 95% CL$_s$ on $\sigma_H \times B(H \to WW)$ are set for ggF(VBF) in the range of 0.2-4(3) TeV. Values above 6.4(1.3) pb at m_H=200 GeV and above 0.008(0.006) pb at 4(3) TeV are excluded at 95% CL by the quasi-inclusive ggF(VBF) NWA analysis. Limits are set for signal widths of 5, 10 and 15% that are compatible with the NWA one. NWA limits are translated to exclusion contours for Type I and Type II 2HDM in the plane of $tan\beta$ versus $cos(\beta - \alpha)$. The current sensitivity is not sufficient to exclude the GM signal with masses between 200 GeV and 1 TeV. Heavy vector triplet signals below about 1.3 TeV are excluded at 95% CL. The observed limits exclude a KK graviton signal lighter than 1.1 TeV (750 GeV) with the $k/\overline{M}_{Pl}$=1(0.5), while the current sensitivity is not sufficient to exclude the ELM spin-2 VBF signal.

3. $ZZ \to \ell^+\ell^-\ell^+\ell^-$ and $\ell^+\ell^-\nu\bar{\nu}$ decays

Searches for a heavy resonance decays into two SM Z bosons are performed in four lepton and two lepton, two neutrino channels (where lepton stands for either an electron or a muon) [4], with similar strategies as discussed in Section 2. The search is performed in a mass range from 200 GeV up to 1.4 TeV for narrow width signals and up to 1 TeV for large width hypothesis in a search for spin-0 resonances. A search for gravitons was done in the range up to 2 TeV.

The analysis is done selecting two same-flavour, opposite-sign lepton pairs in the 4ℓ channel and selecting one pair with 120 GeV cut on missing energy of escaping neutrinos in $2\ell2\nu$. Events are classified into categories: VBF or three ggF, for each of the lepton pair flavour. In the LWA case this search accounts for two interference effects between the heavy scalar and the SM Higgs boson and between the heavy scalar and non-resonant ZZ continuum. Non resonant ZZ contribution to the background os estimated from simulation, Z+jets from data; $t\bar{t}$, WZ and WW are estimated from dedicated CRs.

The largest deviation from the background expectation was found at 700 GeV in the 4ℓ analysis for ggF corresponding to 3.6(2.2)σ local(global), while no significant deviation is observed in $2\ell2\nu$. Combined results are compatible with SM expectations. Upper limits on $\sigma_H \times B(H \to ZZ)$ are set for ggF(VBF) in m_H range 200-1200 GeV, correspond to 0.68(0.41) pb at m_H=240 GeV to 11(13) fb at m_H=1200 GeV. NWA limits are translated to exclusion limits in the $tan\beta$ versus $cos(\beta-\alpha)$ plane for Type-I and Type-II 2HDM. The limits on the production rate of a large-width scalar are obtained for widths of 1, 5 and 10% of the mass of the resonance. The results are interpreted as a search for a Kaluza-Klein graviton excitation, excluding this signal up to a mass of 1.3 TeV.

4. $VV \to qqqq$

A search for narrow resonances decaying into WW, WZ or ZZ boson pairs, with hadronic decays of V, is performed with 80 fb^{-1} as described in [5]. The search covers diboson resonances with masses in the range of 1.2-5.0 TeV for two specific benchmark models: a spin-1 HVT model with signals such as W’ and Z’ and a spin-2 Kaluza-Klein graviton.

Bosons produced in the decay of TeV-scale resonances are highly boosted and therefore are reconstructed in ATLAS as a single large radius parameter jet. This analysis uses a new unified object built from both tracking and calorimeter information, referred to as Track-CaloCluster [6]. Jet substructure and mass are exploited to enhance the separation between signal boson jets and jets from multijet background. The efficiency of the boson tagger is determined in a V+jet CR, by fitting the jet mass distribution after applying jet substructure cut. After boson-tagging, the data is categorised in five non-exclusive signal regions with different signal efficiencies. The signal model is taken from simulation and background parametrised with functional form. The modelling of the parametric shape tested in a dedicated fit control region in data.

A signal-plus-background fit performed on the discriminant distribution m_{JJ}. No significant deviation found, therefore upper limits on the production cross section times branching ratio to diboson final states for new resonances with masses between 1.2 and 5.0 TeV are set at the 95% CL, excluding the production of $WW+WZ$ from the HVT model A(B), with g_V=1(3) and masses in the range of 1.20-3.40(1.20-4.15) TeV. Production of a G_{KK} in the bulk RS model with $k/\overline{M}_{Pl}$=1 is excluded in the range of 1.20-1.90 TeV and 2.1-2.3 TeV, at the 95% CL.

5. $Z/W/H+\gamma$ hadronic decays

A search for resonance decays to a photon and a Z, W or Higgs boson with subsequent hadronic decay of these bosons is presented and discussed in details in [7]. Searches for $Z\gamma$ ($W\gamma$) are carried out in the mass range of 1.0-6.8 TeV for spin-0 and 2 (spin-1) signals and for $H\gamma$ in the range of 1.0-3.0 TeV for spin-1 signal in the $q\bar{q}A$ channel.

This analysis looks for energetic photons and boosted bosons reconstructed as one large jet. Events are classified into four categories to improve the expected signal sensitivity, presented by different signal efficiency: exploiting b-tagging for Z and Higgs to $b\bar{b}$ (BTAG), apply cuts on jet substructure (D2) and jet mass window (VMASS) selections to separate hadronically decaying bosons from quark-gluon initiated jets. The signal is modelled by CrystalBall+gaussian, and the background is modelled as a functional form using spurious signal as uncertainty. γ+jet and SM γV are taken from simulation and multijet is estimated from data-driven tecnhiques. Jet-photon mass distribution ($m_{J\gamma}$) are used as a discriminant variable.

The largest deviation from the expectation, corresponding to a significance of 2.7σ, is found in the $W\gamma$ search at $m_{J\gamma}$=2.5 TeV. In the absence of any significant excess, limits are set - this is the first evaluation of a limit utilising hadronic W boson decays. The limit varies from about 10 fb at m_X=1.0 TeV to 0.1 fb for 6.6 TeV, as shown on the left at Figure 1. This is the first search for a heavy resonance in $H\gamma$ with this decay mode. The limit is evaluated for resonance masses between 1 and 3 TeV and varies between 10 fb and 4 fb depending on m_X. The limits on $Z\gamma$ production, vary from about 10 fb to 0.1 fb, for m_X between 1.0 and 6.8 TeV, for spin-0 and spin-2 hypothesis.

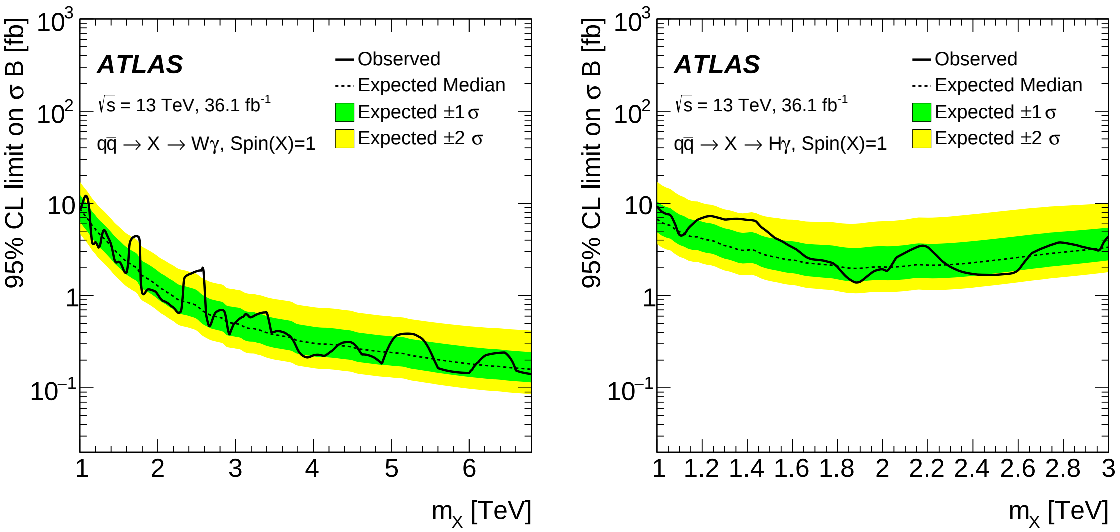

Figure 1: The 95% CL observed (solid line) and expected (dashed line) upper limits on σB for a spin-1 resonance decaying to $W\gamma$ (left) and $H\gamma$ (right), as a function of the resonance mass [7].

6. Summary

The ATLAS Collaboration has performed a rich search program for additional heavy resonances in various final states, testing several benchmark models. The searches presented in this review used datasets collected in pp collisions at $\sqrt{s}$=13 TeV corresponding to 36 and 80 fb^{-1}. No excess of events over the SM background-only expectation was found in any of the final states taken into account. Figure 2 presents a sketch, combining a variety of upper limits set on the collection of diboson channels, covering various spin hypotheses and a broad mass range from 200 GeV up to 6.8 TeV.

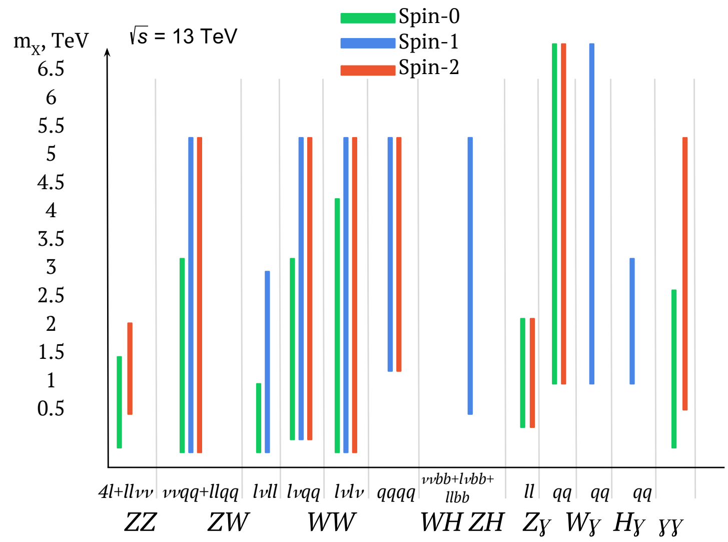

Figure 2: A sketch, combining upper limits set on various diboson channels, covering a broad mass range and spin hypotheses.

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