Search for heavy resonances in the $\ell\ell qq$ final state in pp collisions at $\sqrt{s} = 13$ TeV with ATLAS

K. Bachas[a] , G. Chiodini[a] and S. Spagnolo[a,b] on behalf of the ATLAS Collaboration.

[a]Instituto Nazionale di Fisica Nucleare sez. di Lecce, Italy.

[b]Dipartimento di Matematica e Fisica "Ennio De Giorgi", Università del Salento, Italy.

The naturalness argument and the small mass of the recently discovered Higgs boson [1] suggest that the Standard Model (SM) is a low-energy approximation of a theory that includes other symmetries and new particles at the TeV scale. In several SM extension scenarios, di-boson resonant production is expected to appear. Examples of such models, that are under scrutiny with the LHC data, are the extended gauge models (EGM) [2], where a new charged boson W' decays to a WZ system, extended Randall-Sundrum models [3] of warped extra dimensions, where a Kaluza-Klein excitation of the spin-2 graviton G^* decays to pairs of W or Z bosons, technicolour models and generic composite Higgs models. In addition, di-boson production is a very important probe of the consistency of the SM and allows to measure with high precision crucial parameters of the theory like the trilinear and quartic gauge couplings implied by the gauge symmetries. Therefore, di-boson production was extensively studied in pp collisions at LHC at the center of mass energy of 7 TeV and 8 TeV and it is still under the focus of searches for new phenomena with the new data at $\sqrt{s} = 13$ TeV. A summary of the searches conducted at $\sqrt{s} = 8$ TeV is given in [4].

During 2016 a search for heavy resonances decaying to a pair of Z bosons has been performed using proton–proton collision data produced at $\sqrt{s} = 13$ TeV and recorded by the ATLAS detector at the LHC. The data corresponded to an integrated luminosity of L =3.2 fb^{-1} and preliminary results were published [5]. In addition, later in 2016, ATLAS produced updated results on searches for heavy ZZ but also ZW resonances in the $\ell\ell qq$ final states in pp collisions at $\sqrt{s} = 13$ TeV with L =13.2 fb^{-1} [6].

The analysis in both results above follows the same strategy, which is briefly described here. The online selection of $ZV \rightarrow \ell\ell qq$ events (where $V = W$ or Z) is based on a selection of various single-electron or single-muon triggers with quality and isolation requirements dependent on the E_T (electron) and p_T (muon) thresholds. The two leptons from the Z decay are required to be of same flavour, isolated and pass 'loose' identification criteria while at least one of the two is additionally required to fullfill 'medium' selection criteria. The dilepton invariant mass is required to be in the range of 83–99 GeV for electrons and wider for muons, 76–106 GeV, in order to accomodate effects of degraded muon momentum resolution at high-p_T. Events with more than two 'loose' leptons are vetoed.

The reconstruction of the $V \rightarrow qq$ was performed via two exclusive and complementary approaches. The corresponding event selections are called Resolved and Merged. In the Resolved Selection two separate jets(jj) are reconstructed with a leading(sub-leading) jet p_T requirement of 60(25) GeV. Candidate events are further categorized based on the number of b-tagged jets; events with two b-tagged jets (tagged category) and events with fewer than two b-tagged jets (untagged category). The dijet invariant mass is required to be in the range $70 \leq m_{jj} \leq 105$ GeV.

The Merged Selection is designed to be efficient for events where the heavy resonance decaying to di-bosons produces a highly boosted system where the two fermions are emitted within a small opening angle in the laboratory frame. In such conditions, the efficiency for reconstructing the two jets decreases due to the increasing overlap between them. The two partially overlapping jets are reconstructed as a single large-R jet with the anti-k_T algorithm and radius parameter $R = 1.0$, in the rapidity range $|\eta| < 2.0$ and its p_T should be greater than 200 GeV. The large-R jet mass m_J is required to be in a window of ± 15 GeV around 93.4 GeV. In this case jet-substructure techniques are used to identify the qq pair. Events are then subject to the boson tagging based on dedicated substructure variables and the jet mass. Events are further categorized as Low and High purity depending on the working point of the boson tagging procedure. The Merged channel has priority over the Resolved channel in the event selection flow.

With respect to the preliminary result of [5] the updated result included, apart from the additional interpretation of the result as a W'-like heavy resonance decaying to ZW within the EGM framework, the search for a heavy neutral Higgs boson to be produced through the vector-boson fusion (VBF) process (qq' $\rightarrow$ qq'H) in addition to the gluon-gluon fusion (ggF) process. Events from VBF production are characterised by two additional jets (referred to as the tag jets) in addition to those from the V$\rightarrow$qq decay. They typically have a large dijet invariant mass and a large separation in pseudorapidity. The VBF candidates are selected by requiring $m^{jj}_{\rm tag} > 600$ GeV and $|\Delta\eta|^{jj}_{\rm tag} > 3.1$. Events passing the $H \rightarrow ZZ \rightarrow \ell\ell qq$ requirements but failing the VBF selection are kept as the ggF candidates.

The statistical interpretation of the analysis results is based on a profile-likelihood-ratio test statistic which is used to measure the compatibility of the background-only hypothesis with the observed data and to test the hypothesis of a heavy resonance, with its production cross section times branching ratio to ZV, as the parameter of interest. A maximum likelihood fit is made to the observed binned distributions of the final discriminants, $m_{\ell\ell J}$ or $m_{\ell\ell jj}$ of the $ZV \rightarrow \ell\ell qq$ search in signal and properly defined control regions simultaneously. Systematic uncertainties and their correlations are incorporated into the fit with nuisance parameters. The observed distributions of the final discriminants,$m_{\ell\ell J}$ or $m_{\ell\ell jj}$ of the $gg \rightarrow H \rightarrow ZZ \rightarrow \ell\ell qq$ search are compared with the background expectation in Fig. 1. Upper bounds on the production cross sections times their decay branching ratios to ZZ or ZW pairs are derived for heavy resonances in the mass range of 300–5000 GeV, within the context of Standard Model extensions with an extended Higgs sector, a heavy vector triplet or warped extra dimensions. These are illustrated in Fig. 2. The data are found to be in good agreements with the background expectations and no evidence for the production of heavy resonances is observed.

Preliminary results are in preparation for the winter conferences of 2017 based on the above baseline strategies. These results will incoorparate the full 2015+2016 data available at the LHC and recorded by ATLAS which amounts to $L = 36.5$ fb^{-1}.

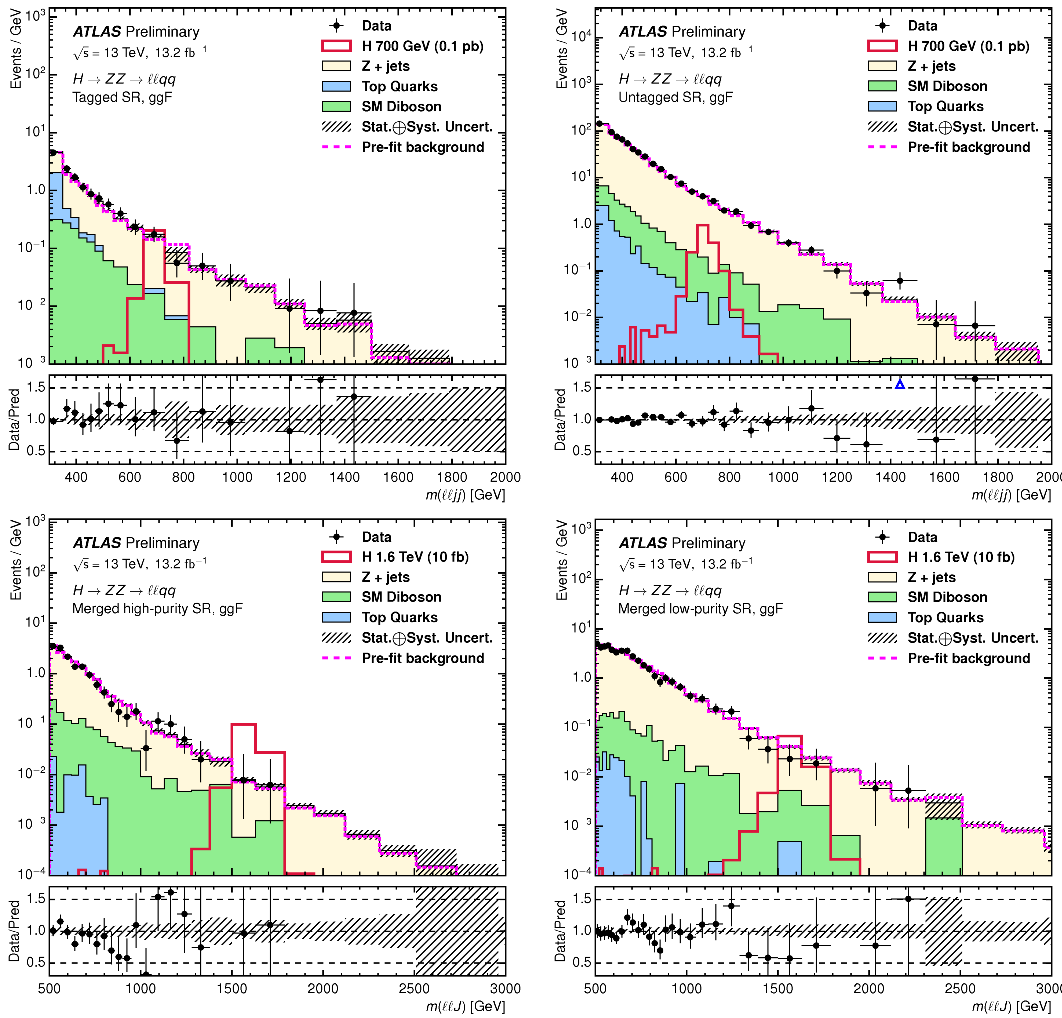

Figure 1. Comparisons of the observed and fitted distributions of the final discriminants of the $gg \to H \to ZZ \to \ell\ell qq$ search for events passing all selections: the $m_{\ell\ell jj}$ distributions of the resolved analysis for (top left) tagged and (top right) untagged categories; the $m_{\ell\ell J}$ distributions of the merged analysis for (bottom left) high-purity and (bottom right) low-purity regions. The dashed magenta lines show the total background contributions expected purely from MC simulations. For illustration, expected distributions from a Higgs boson at 700 GeV (top) and 1600 GeV (bottom) are also shown. The bottom panes show the ratios of the observed data to the predicted background. The uncertainty on the total background prediction, shown as bands, combines statistical and systematic contributions. The blue triangles in the bottom panes indicate bins where the ratio is outside the vertical range of the plot.

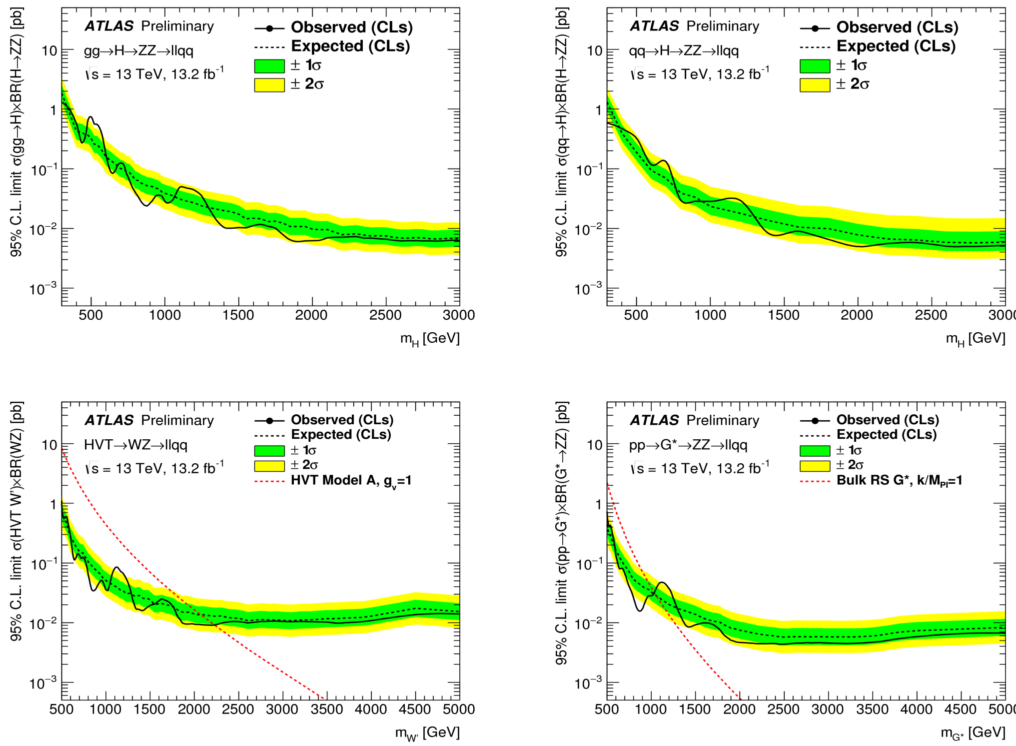

Figure 2. Observed and expected 95% CL upper limits on the production cross section of a heavy resonance at $\sqrt{s} = 13$ TeV times its decay branching ratio to ZV for $gg \to H \to ZZ$(top left), VBF $H \to ZZ$ (top right), HVT $W' \to WZ$ (bottom left) and RS graviton $G^* \to ZZ$ (bottom right) as functions of the resonance mass. The theoretical predictions as functions of resonance mass for the W' and the RS graviton with $\kappa/M_{\rm Pl} = 1.0$ are also shown in the bottom plots. The green (inner) and yellow (outer) bands represent $\pm 1\sigma$ and $\pm 2\sigma$ uncertainty on the expected limits.

REFERENCES

1. ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, Phys. Lett. B 716.1 (2012) 1, issn: 0370-2693, url: http://www.sciencedirect.com/science/article/pii/S037026931200857;
2. G. Altarelli, B. Mele, M. Ruiz-Altaba, Searching for new heavy vector bosons in pp colliders, Z. Phys. C, 45 (1989), p. 109.
3. K. Agashe, et al. Warped gravitons at the LHC and beyond, Phys. Rev. D, 76 (2007) 036006.
4. ATLAS Collaboration, Combination of searches for WW, WZ, and ZZ resonances in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, doi:10.1016/j.physletb.2016.02.015; arXiv:1512.05099 [hep-ex]
5. ATLAS Collabolation, **ATLAS-CONF-2016-016**
6. ATLAS Collabolation, **ATLAS-CONF-2016-082**