Search for exotic di-boson production in the $\ell^+\ell^-$ + large-R jet final state with the ATLAS data from the LHC pp run at $\sqrt{s} = 13$ TeV

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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 [2] (EGM), 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 $G^\star$ 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 outcome of searches in ATLAS for resonant production of di-boson through the study of various final states is given in [4]. In this paper, no evidence for new phenomena is reported but an intriguing excess of data is apparent around $M_{VV} = 2$ TeV in the fully hadronic channel. The leptonic and semi-leptonic channels which have been studied in this paper do not show any interesting behaviour. Compared to the leptonic and semi-leptonic channels the fully hadronic channel has the advantage on one hand of not been statistically limited, due to the high branching ratio of W and Z to hadrons. On the other hand, hadronically decaying vector bosons with high p_T (typically above 400 GeV) can be reconstructed as a single jet-the so-called fat jet- with a large radius parameter, or large-R jet denoted by J, due to the collimated nature of their decay products. This enhances the efficiency of high-pt gauge boson tagging and further improves the sensitivity of the fully hadronic channel. The resulting p_0-value for the individual and combined channels $\ell\ell\ell'\nu$, $\ell\ell qq$, $\ell\nu qq$ and JJ obtained for the EGM W' search in these final states and the bulk $G^\star$ search are shown in fig. 1.

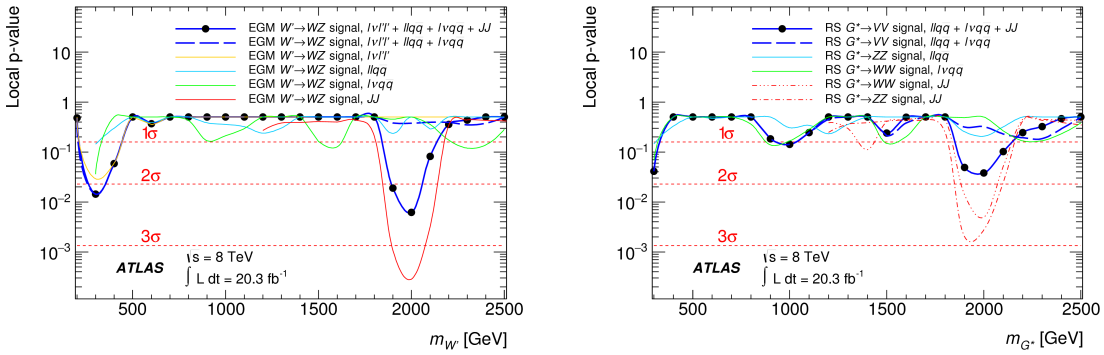

Figure 1. p_0-value for the individual and combined channels obtained for the EGM W' search (left, $\ell\ell\ell'\nu$, $\ell\ell qq$, $\ell\nu qq$ and JJ channels, from WZ production and decay) in these final states and the bulk $G^\star$ search (right, $\ell\ell qq$, $\ell\nu qq$ and JJ possibly arising from WW or ZZ pairs). The probability values are derived with the entire data set collected by ATLAS at $\sqrt{s} = 8$ TeV. The plots are from arXiv:1512.05099 [hep-ex].

With the new LHC data at $\sqrt{s} = 13$ TeV, the analysis of all the final states accessible from decays of WZ, WW or ZZ pairs (fully hadronic and semi-leptonic) is proceeding using both the approach of fat-jet for boson tagging and the traditional approach of selecting two standard jets with invariant mass close to the mass of the gauge boson.

Based on the experience with di-boson studies in the fully leptonic channel [5] and Z+b(b) production through SM QCD processes [6], we joined the working group carrying out the analysis of the ZV final state in the semi-leptonic decay channel $\ell\ell + J$. The ATLAS Collaboration produced preliminary results [7] at $\sqrt{s} = 13$ TeV already at the end of 2015.

Recently a new approach has been explored, aiming at optimising the sensitivity of the analysis to narrow resonances decaying to VV (with V=Z or W) at all values, from low to high, of the mass of the resonance. The optimisation implies that the same analysis is using either the reconstruction of the hadronically decaying boson V via a fat-jet or the identification of a system of two resolved jets compatible with a V decay. This strategy is driven by the focused effort of looking for confirmations, or disproval, in other final states of the possible existence of a new Higgs-like particle with a mass of about 750 GeV suggested by the excess of di-photon events reported by ATLAS, and consistently by CMS, in preliminary results [8] based on 2015 data, presented at the end of the year public seminar [9] at CERN.

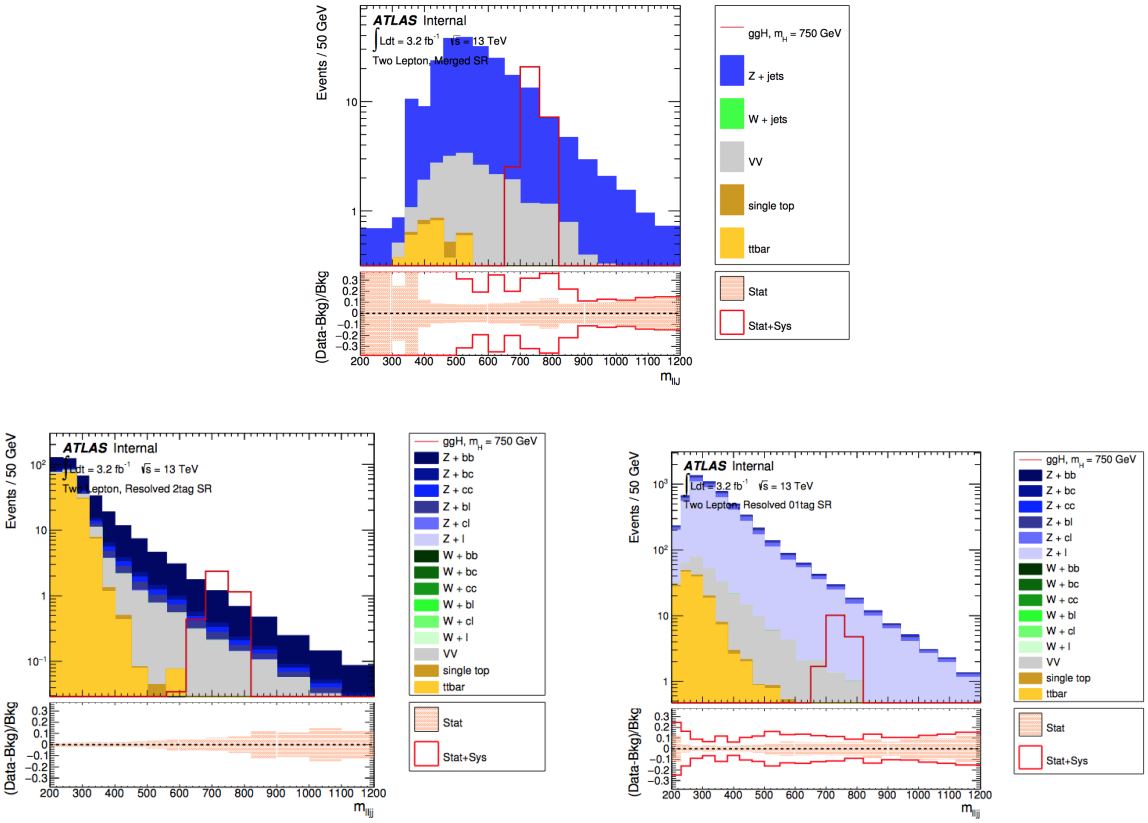

Figure 2. The m_{llJ} distribution for the merged jet selection (top), for the 2-resolved-jets selection with both jets b-tagged (bottom-left) for the other events passing the 2-resolved-jets selection (bottom-right). Predictions for the SM background processes and for the signal expected in case of an Heavy Higgs boson with mass of 750 GeV are shown. All these plots show simulation only and they are "work in progress" collected in ATL-COM-PHYS-2015-1559 for the seek of the internal review and validation of the analysis within the ATLAS Collaboration.

The current baseline analysis applies first a selection of a $\ell\ell J$ topology; if the event does not pass the selection, it is processed by the selection for a $\ell\ell qq$ final state, with two standard light jets compatible with the decay of a gauge boson. Events passing the 2-resolved-jets analysis are classified into two sets, one containing events where both jets are b-tagged, and the other set containing all the remaining events. The isolation of the double b-tagged events allows increasing the sensitivity to the H→ZZ process where the hadronic system comes from a Z boson decay. In fig. 2 the distribution of the invariant mass of the di-boson system is shown for the three categories of events ($\ell\ell J$, $\ell\ell qq$ with 2 b-tagged jets and $\ell\ell qq$ with less than 2 b-tagged jets) as predicted by the simulation of all the relevant Standard Model processes. The hypothetical signal of a heavy Higgs boson is superimposed to the background expectation as an illustrative example.

Preliminary results are in preparation for the winter conferences based on these steps. An ATLAS internal document [10] describes the work in progress.

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 $p\bar{p}$ 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 Collaboration, "Measurement of WZ Production in Proton-Proton Collisions at sqrt(s) = 7 TeV with the ATLAS Detector", Eur. Phys. J. C (2012) 72:2173; arXiv:1208.1390 [hep-ex].
6. ATLAS Collaboration, "Measurement of the production cross section of jets in association with a Z boson in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector", JHEP07(2013)032; arXiv:1304.7098 [hep-ex].
7. ATLAS Collaboration, "Search for di-boson resonances in the llqq final state in pp collisions at $\sqrt{\text{s}}$ = 13 TeV with the ATLAS detector", ATLAS-CONF-2015-071, https://cds.cern.ch/record/2114843
8. ATLAS Collaboration, "Search for di-boson resonances in the llqq final state in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector", ATLAS-CONF-2015-071; https://cds.cern.ch/record/2114843.
9. Jim Olsen (CMS, Princeton University, US) and Marumi Kado (ATLAS, Laboratoire de l'Accelerateur Lineaire, FR) "ATLAS and CMS Physics Results from Run 2", https://indico.cern.ch/event/442432/
10. Lailin Xu et at, "Search for a high mass resonance in the ZZ → $\ell\ell$qq decay channel", ATL-COM-PHYS-2015-1559, https://cds.cern.ch/record/2116469/