PROCEEDINGS OF SCIENCE

ATLAS Searches for $VV/V\gamma$ Resonances

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Many extensions to the Standard Model predict new particles decaying into two bosons (WW, WZ, ZZ, $Z\gamma$) making these important signatures in the search for new physics. Searches for such diboson resonances have been performed in final states with different numbers of leptons, photons and jets, where new jet substructure techniques to disentangle the hadronic decay products in highly boosted configuration are being used. ATLAS searches for diboson resonances with LHC Run 2 data collected in 2015 and 2016 at $\sqrt{s} = 13$ TeV are summarized.

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1. Introduction

The Standard Model (SM) appears to describe particle interactions for energy scales up to a few hundred GeV. Despite the fact that a plethora of precision measurements and searches with data from the Large Hadron Collider (LHC) show no significant deviations from the SM, a number of unaddressed issues require either extreme fine-tuning or the presence of new physics. Examples include the hierarchy problem, the nature of dark matter, dark energy and gravity.

Many theories beyond the SM predict diboson resonances with different properties. In general, the final states include W or Z bosons (collectively denoted as V), photons (γ) and the Higgs boson (H). The diboson resonances can be neutral or charged, and with different spins, masses and widths. In the ATLAS studies reported here, three different categories of models are used to interpret the data, composite Higgs models [2], Heavy Vector Triplets (HVT) [3] and Randall-Sundrum (RS) models of warped extra dimensions [4]. The composite Higgs model assumes that the recently discovered Higgs boson contains a hidden structure. As a result, there is a bound state of a new force that manifests itself at the $\mathcal{O}(1)$ TeV scale and resonances related to this new dynamics decay to dibosons. A HVT could be produced in either weakly coupled vector resonances from extension of the gauge group (Model-A) or in a strong scenario (Model-B), such as a composite Higgs model. Lastly, the most distinctive feature of the RS scenario is the existence of spin-2 Kaluza–Klein gravitons (G_{KK}) whose properties depend on $\kappa/\bar{M}_{Pl}$, where $\bar{M}_{Pl} = M_{Pl}/8\pi$ is the reduced Planck scale and κ is the curvature of the extra dimension.

The latest results from the ATLAS experiment [1] are presented for VV and $V\gamma$ resonant production. The studies were performed using data collected in 2015 and 2016 at a center-of-mass energy $\sqrt{s} = 13$ TeV. To accommodate a wide variety of interpretations the selection criteria of the signal events are independent of the theoretical models. However, to increase the sensitivity to rare processes, categories are defined according to the production mechanism. The Vector Boson Fusion (VBF) process, which occurs when two vector bosons are radiated from quarks and fuse, is prioritized due to its smaller cross-section. Absence of this topology is interpreted as Drell-Yan (DY) production from either quark–quark (qq) fusion or gluon–gluon (ggF) fusion.

The searches are performed by looking for localized excesses above the smoothly falling SM background. For this purpose, the mass (m) of the diboson system is used as the final discriminant. This is the invariant mass unless Z boson decays to neutrinos (ν) are included, where only the transverse mass reconstruction is feasible.

2. V Boson Tagging

To probe high mass resonances, the study of hadronic decays is a necessity because the branching ratios (BR) to quarks are 66.6% and 69.2% for W and Z boson decays, respectively. The tagging of hadronically decaying V bosons depends on their Lorentz boost [5]. The angular separation between the daughter quarks follows the equation: $\Delta R(q,q) \approx 2m/p_{\mathrm{T}}$, where p_{T} is the transverse momentum of the boson. For low resonance masses, the identification is more efficiently performed by two jets with radius parameter $R = 0.4$, as opposed to high mass resonances where one large-R jet is used ($R = 1.0$). In both cases, the anti-k_t algorithm [6] is utilized and the topologies are referred to as the “resolved” and “merged” regimes, respectively.

Highly boosted V bosons are tagged using jet mass and substructure techniques, while in the low mass region, the compatibility of two small-R jets with a boson candidate relies on the dijet invariant mass. For large-R jets, the “trimming” method [5] is applied to subtract pile-up and soft QCD contributions and then variable mass windows around the expected V boson mass are imposed according to the jet p_{T}. The mass is calculated from combining calorimeter and tracking information, to improve over the limited angular resolution of the calorimeter [7]. The D_2 variable [8] is used to identify two-prong structure, optimized as detailed in Ref. [9], at the working points that provide 50% and 80% signal efficiency. The corresponding analysis regions are called high (HP) and low (LP) purity, respectively.

Overlap between the W and Z final states in both the resolved (qq) and merged (J) regimes is inevitable as the mass windows overlap.

3. VV Searches

The searches for VV resonances include $\ell\nu qq$, $\ell\ell qq$, $\nu\nu qq$ and JJ final states, where $\ell = \mu, e$. Orthogonality among the channels is achieved through the lepton selection, to easily accommodate a future combination.

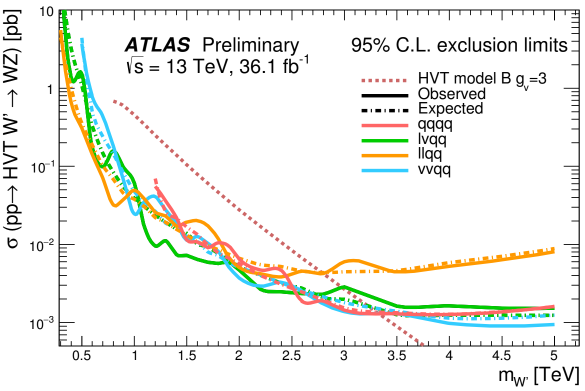

Figure 1: Summary limits on the production cross section for HVT $W' \to WZ$ as extracted from VV [14] studies. No significant excess above the SM backgrounds is observed in any of the decay modes.

In the semi-leptonic final states [10, 11], one boson candidate is required to be formed by a $\ell\nu$, $\ell\ell$ or $\nu\nu$ pair and the other boson by a qq pair or single-J, where both bosons should satisfy V mass window cuts. As a result, resolved and merged HP and LP regions are defined which are further categorized to distinguish the production mechanism. Events with two additional small-R jets with large pseudorapidity separation and invariant mass are classified as VBF candidates, while absence of this topology is interpreted as DY production. The final states are dominated $V+$jets, $t\bar{t}$ and smaller contributions arising from diboson, single top and QCD processes.

The fully hadronic final state is studied by requiring events with two large-R jets, each tagged as a HP V boson. The main background originates from multijet processes and it is parametrized separately in the WW, WZ and ZZ channels [12].

No excess is seen and limits on the production cross-section (Figure 1) are set for scalar signals, HVT and G_{KK} at the 95% confidence level (CL) from the individual channels using 36.1 fb^{-1} of data.

4. $V\gamma$ Searches

Searches for $V\gamma$ resonances using $\sqrt{s} = 13$ data are available for the $Z\gamma$ channel using 3.2 fb^{-1}. Two separate analyses are performed for $Z \to \ell^+\ell^-$ and $Z \to qq/J$ decays. In the leptonic case, non-resonant $Z+\gamma$ and $Z+$jet processes dominate the final state, while the background in the hadronic case is composed of events from $\gamma+$jet, multijet and $V+$jet productions. The misidentification of jets as photons leads to the contamination with these backgrounds.

The $Z\gamma$ invariant masses are formed and the distributions are parametrized [13] separately in each analysis. An unbinned fit is performed to extract the final results and upper limits on the production cross section times BR are set at 95% CL for resonant scalar production (Figure 2). No excess is observed above the expected background.

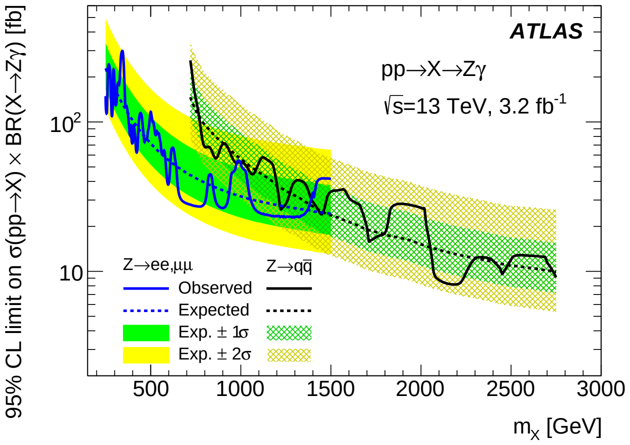

Figure 2: Upper limits on the production cross section for scalar $pp \to X \to Z\gamma$ from leptonic and hadronic channels [13]. No significant excess above the SM backgrounds is observed in any of the decay modes.

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