PROCEEDINGS OF SCIENCE

Search for resonant diboson production with the ATLAS detector

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The study of electroweak boson pair production can be used to search for phenomena beyond the Standard Model, as many scenarios of new physics predict heavy particles decaying to gauge boson pairs. We present the results of generic searches for a heavy particle decaying to a pair of bosons in the WW, WZ and ZZ decay channels, using the data sample recorded in 2011 at $\sqrt{s} = 7$ TeV center-of-mass energy by the ATLAS experiment at the LHC.

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1. Introduction

Several extensions to the Standard Model (SM) [1, 2, 3] predict new massive particles which can decay to WW, WZ or ZZ final states. In some of these models [4], the branching ratio of new particles to heavy bosons can be larger than the branching ratio to light fermions or photons, granting these channels a unique perspective in searches for new physics. We present searches for charged resonances decaying to WZ [5] and for neutral resonances decaying to WW [6] and ZZ [8]. The benchmark charged resonances considered are the spin-1 Sequential Standard Model (SSM) W' boson, with the $W'WZ$ coupling strength (c_{EGM}) set by the Extended Gauge Model [1], and the spin-1 Low Scale Technicolor (LSTC) ρ_{T} and a_{T} technimesons [3]. The neutral resonances considered are the spin-2 Randall-Sundrum (RS) graviton (G^*) [2], which decays preferentially to light fermions, and the bulk RS graviton (G^*_{Bulk}) [4], which decays preferentially to heavy particles (including WW and ZZ) but is produced with a smaller cross-section.

Searches are performed using 1 to 5 fb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV collected by the ATLAS detector [9] at the Large Hadron Collider (LHC). The leptonic final states of the W and Z boson are primarily used, while the hadronic final states only play a role in the very high mass region of the ZZ channel due to their large branching fraction. Diboson invariant mass distributions[1] observed in data are compared to the expectations from SM processes. No excesses above the SM expectations are observed, and limits are set as a function of mass on the production cross-section times branching ratio of new particles: $\sigma(pp \to X) \times \mathrm{BR}(X \to WW/WZ/ZZ)$. These limits can also be expressed as lower limits on the mass of new particles in a specific model, given a set of predicted σ and branching ratios.

2. Event Selection and Backgrounds

Events are selected with reconstructed leptons (e or μ) and missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) consistent with originating from $W \to \ell\nu$ and $Z \to \ell\ell$ decays in the WW (two leptons plus $E_{\mathrm{T}}^{\mathrm{miss}}$), WZ (three leptons plus $E_{\mathrm{T}}^{\mathrm{miss}}$) and ZZ (two or four leptons) searches. Jets are built by clustering energy depositions in the calorimeters using the anti-k_{T} algorithm [10], and pairs of jets consistent with originating from $Z \to q\bar{q}$ decays are used in the ZZ search with two leptons. Several Standard Model processes can enter the signal regions and give rise to background events. Three separate strategies are used in order to reduce and evaluate their contributions.

W+jets, Z+jets and $t\bar{t}$ events can enter the signal regions due to jets reconstructed as leptons, or non-prompt leptons produced in heavy-flavor decays. These backgrounds are first reduced by applying tight lepton selection criteria to variables such as track isolation, impact parameter, and energy deposition shape. Their remaining contribution is then estimated using data-driven methods based on loosening the leptonic selection to construct background-enriched control regions.

Some of the backgrounds containing the same number of prompt leptons as the signal can be reduced by taking advantage of their kinematic properties. For example, the Z+jets background to $WW \to \ell\nu\ell\nu$ searches is reduced by excluding events containing a lepton pair with an invariant

[1]The invariant mass is calculated using all the reconstructed objects associated to the diboson pair. In WW and WZ events, the transverse mass (m_{T}) is calculated from the transverse momenta of the leptons and neutrinos, using the $E_{\mathrm{T}}^{\mathrm{miss}}$ vector as an estimator of the neutrino transverse momentum.

mass, $m_{\ell\ell}$, consistent with that of a Z boson. Similarly, the $t\bar{t}$ background is reduced by rejecting events with b-quark jets expected from $t \to Wb$ decays. The rejected events constitute control regions that are used to validate the Monte Carlo models of these backgrounds.

Irreducible backgrounds, such as the Standard Model diboson processes, have small theoretical uncertainties [11], and their total cross-sections have been measured by ATLAS to be in good agreement with calculations [12, 13, 14]. Since resonance searches explore the high tails of mass distributions, Monte Carlo models have to be used to estimate the Standard Model diboson contributions in these regions.

3. Results and Limits

The search for WW resonances [6] uses an integrated luminosity of 4.7 fb^{-1} and it is conducted in three channels: $\mu\mu$, ee and $\mu e + e\mu$. Transverse mass distribution for each channel are presented in Figure 1. The $\mu\mu$ and ee channels have smaller statistics, and suffer from large Z+jets backgrounds. This is especially relevant in the high mass tail of the $\mu\mu$ channel, where high momentum muons from $Z \to \mu\mu$ events can be mismeasured, giving rise to $E_{\mathrm{T}}^{\mathrm{miss}}$ consistent with $W \to \mu\nu$ decays. The $\mu e + e\mu$ combination benefits from the largest statistics and smallest backgrounds. Good agreement between data and the SM expectations is observed in all channels, and 95% confidence level (CL) limits on the G^* and G^*_{Bulk} cross-sections are extracted, as shown in Figure 2, as a function of the resonance mass. For a coupling parameter $k/\bar{\mathrm{M}}_{\mathrm{Pl}}$ set to 0.1 [7], these correspond to observed (expected) lower limits of 1230 (1130) GeV for the G^* mass and 840 (740) GeV for the G^*_{Bulk} mass.

The search for ZZ resonances [8] uses 1.02 fb^{-1} of integrated luminosity and is divided into two channels, $\ell\ell\ell\ell$ and $\ell\ell jj$. To reduce the Z+jets background in the $\ell\ell jj$ channel, the reconstructed Z candidates are required to have large transverse momenta, with the highest sensitivity obtained when $p_{\mathrm{T}}^{Z} > 200$ GeV. The data and Standard Model mass distributions in the $\ell\ell\ell\ell$ channel and in the $\ell\ell jj$ ($p_{\mathrm{T}}^{Z} > 200$ GeV) channel are presented in Figure 3. Good agreement is observed, and limits on the G^* cross-section times branching ratio as a function of its mass are extracted (Figure 4). The limits obtained in the $\ell\ell\ell\ell$ channel are more sensitive to resonance masses smaller than 500 GeV, while the $\ell\ell jj$ channel is more sensitive at higher resonance masses. For a coupling parameter $k/\bar{\mathrm{M}}_{\mathrm{Pl}} = 0.1$, the combined observed (expected) lower limit on the G^* mass is 810 (740) GeV. In addition, the number of $\ell\ell\ell\ell$ events with $m_{\ell\ell\ell\ell} > 300$ GeV is used to set a model-independent limit of 0.92 pb on the fiducial cross-section[2] of any new sources of ZZ production with masses larger than 300 GeV.

The WZ resonance search [5] uses 1.02 fb^{-1} of integrated luminosity, and focuses on the $\ell\nu\ell\ell$ final state. The data and SM transverse mass distributions are shown in Figure 5 and found to be in good agreement. Limits as a function of resonant mass are extracted for production cross-section times branching ratio of the LSTC ρ_{T} (shown in Figure 5) and the SSM W'. The SSM limits assume a coupling parameter $c_{\mathrm{EGM}} = 1$ and exclude (expect to exclude) W' bosons with masses below 760 (776) GeV. The LSTC limits assume the mass relation $m_{\rho_{\mathrm{T}}} = m_{\pi_{\mathrm{T}}} + m_W$, which

[2] The fiducial cross-section is defined in a fiducial region which contains events with four charged leptons (e or μ) each with $p_{\mathrm{T}} > 15$ GeV and $|\eta| < 2.5$, forming two pairs each with $m_{\ell\ell}$ in the range 66–116 GeV and $m_{\ell\ell\ell\ell} > 300$ GeV.

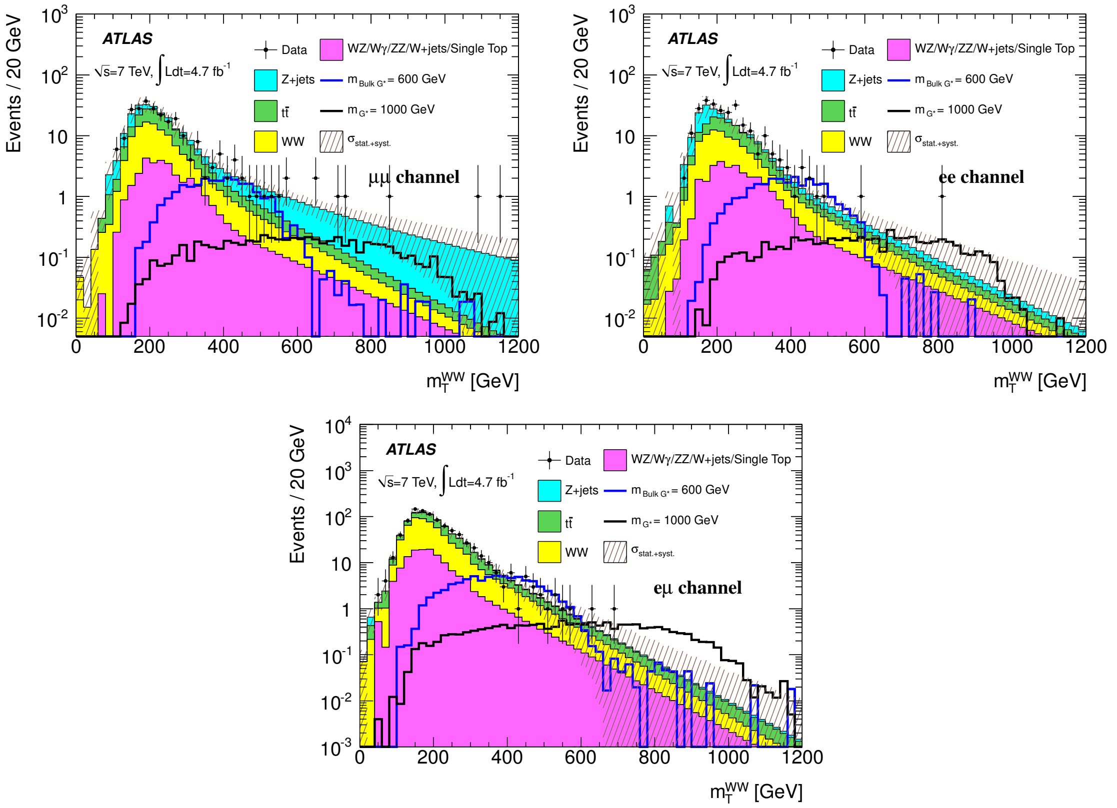

Figure 1: Observed and predicted transverse mass distribution after event selection in the $\mu\mu$ (top left), ee (top right) and $\mu e+e\mu$ (bottom) lepton flavor combinations of the WW resonance search [6]. Predictions for an RS graviton with a mass of 1000 GeV and a bulk RS graviton with a mass of 600 GeV are also shown for $k/\bar{M}_{\rm Pl}=0.1$. The shaded area represents the total statistical and systematic uncertainty on the background.

maximizes the $\rho_T \to WZ$ branching fraction. The observed (expected) limits on ρ_T technimesons are 467 (506) GeV for $m_{a_T} = 1.1\ m_{\rho_T}$ and 456 (482) GeV for $m_{a_T} \gg m_{\rho_T}$.

4. Conclusion

We have reviewed ATLAS results for the search of new particles in diboson final states with 1–4.7 fb^{-1} of 7 TeV pp collisions. No excesses above the Standard Model expectations are observed in the high mass regions of the WW, WZ and ZZ channels. Mass-dependent 95% CL limits are set on the cross-sections times branching ratios of RS gravitons, technimesons, and W' bosons, with sensitivities at the picobarn level or lower. These limits are also expressed as lower mass limits, ranging from 452 GeV to 1230 GeV, for new particles in specific models.

ATLAS searches for high-mass diboson resonances are ongoing, both using the growing 8 TeV dataset, and exploring other W and Z decay channels including neutrinos and jets.

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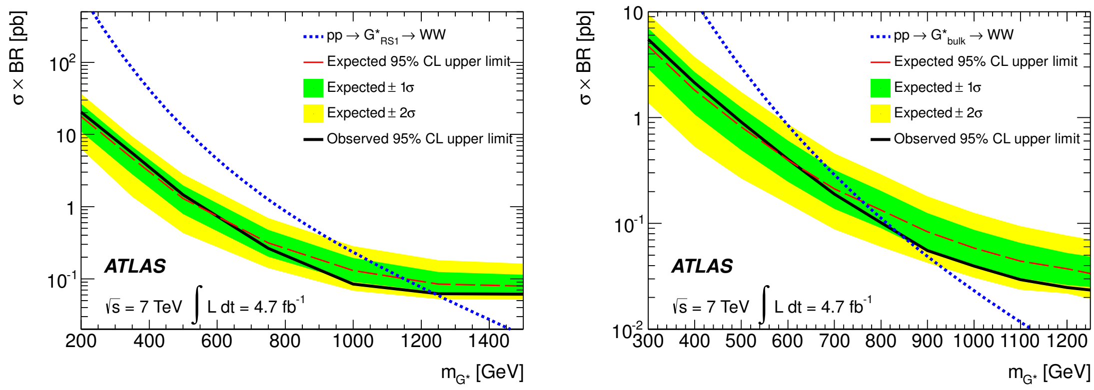

Figure 2: The observed and expected 95% CL upper limits on $\sigma(pp \to G^*) \times \mathrm{BR}(G^* \to WW)$ for the RS graviton (left) and for the bulk RS graviton (right) with the theoretical predictions at LO for $k/\bar{\mathrm{M}}_{\mathrm{Pl}} = 0.1$ (dotted line). The inner and outer bands represent respectively the 1σ and 2σ uncertainty on the expected limit [6].

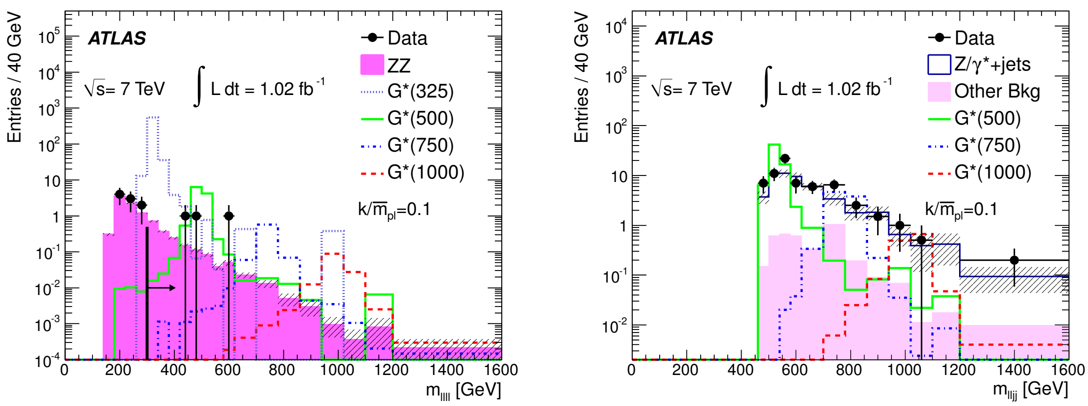

Figure 3: Observed and predicted invariant mass distributions after event selection in the $ZZ \to \ell\ell\ell\ell$ channel (left) and the $ZZ \to \ell\ell jj$ channel with $p_{\mathrm{T}}^{Z} > 200$ GeV (right) . Predictions for RS gravitons with different masse are also shown. The shaded area represents the total statistical and systematic uncertainty on the background [8].

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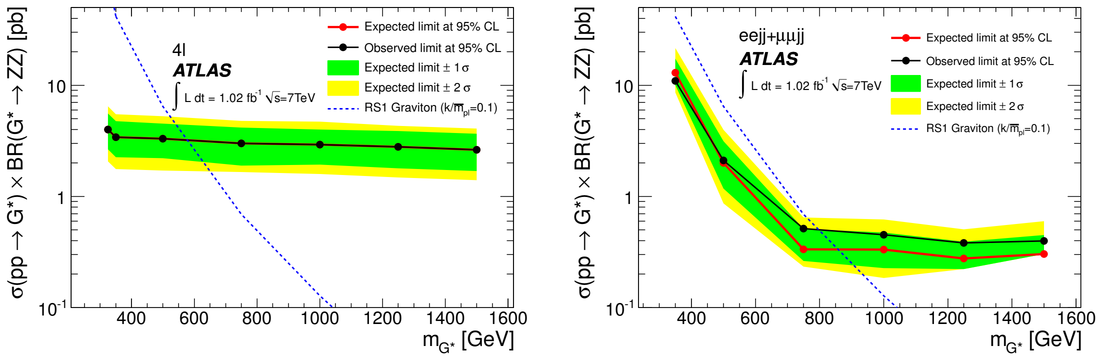

Figure 4: Observed and expected 95% CL upper limits on $\sigma(pp \to G^*) \times \mathrm{BR}(G^* \to ZZ)$ for the RS graviton with the theoretical predictions at LO (dotted line). The limits in the left plot are produced using the $ZZ \to \ell\ell\ell\ell$ analysis, while the right plot uses the $ZZ \to \ell\ell jj$ analysis [8].

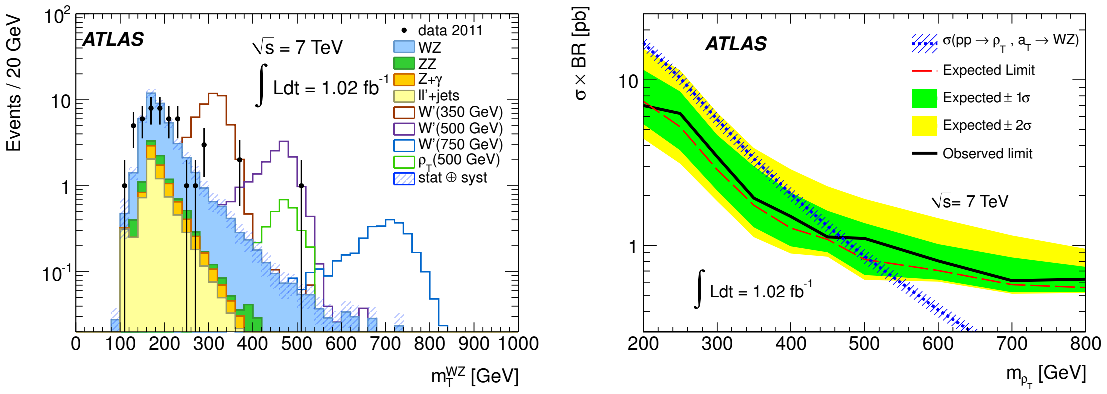

Figure 5: *Left*: Observed and predicted transverse mass distribution after events selection for the $WZ \to \ell\nu\ell\ell$ analysis. Predictions for SSM W' and LSTC ρ_T signals are also shown. *Right*: Observed and expected limits on $\sigma(pp \to \rho_T) \times \mathrm{BR}(\rho_T \to WZ)$ for Low Scale Technicolor. The theoretical prediction (dotted line) assumes $m_{\rho_T} = m_{\pi_T} + m_W$ and $m_{a_T} = 1.1\ m_{\rho_T}$, and it is shown with a band representing the systematic uncertainty due to the choice of parton-distribution functions [5].

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