PROCEEDINGS OF SCIENCE

Searches for new phenomena in final states involving 'leptons and jets' or involving leptons using the ATLAS detector

Yanlin Liu* **on behalf of the ATLAS Collaboration**
University of Michigan, University of Science and Technology of China
E-mail: yanlin.liu@cern.ch

Many theories beyond the standard model predict new phenomena which can result in final states containing leptons and jets or purely leptons. Searches for new physics models with these signatures are performed using the ATLAS detector at the LHC. This talk presents the corresponding results using the pp collision data sample collected in 2015 and 2016 by the ATLAS detector at the LHC with a center-of-mass energy of 13 TeV.

XXV International Workshop on Deep-Inelastic Scattering and Related Subjects
3-7 April 2017
University of Birmingham, UK

*Speaker.

PoS(DIS2017)263

1. Introduction

Many theories beyond the Standard Model (BSM) predict the existence of heavy resonances, and among which are spin-0 high mass Higgs boson, spin-1 new gauge bosons like W' or Z', spin-2 graviton and so on. The ATLAS detector at Large Hadron Collider (LHC) provides a platform to detect and search for these new resonances. After the center-of-mass energy of LHC was increased to 13 TeV, various related searches have been performed with the data recorded in 2015 and 2016 using the ATLAS detector [1]. The following sections include searches for VV (V is Z or W boson) [2, 3] in the subsequent semi-leptonic decay final states, and for W' [4] and Z' [5] with their leptonic decay final states.

2. WV resonance search with $\ell\nu qq$ final states

The WV resonance search is sensitive to detecting many new particles predicted by BSM, including Z' or W' from the heavy vector triplet (HVT) model, the Kaluza-Klein (KK) graviton (G^*) and also heavy Higgs bosons. The heavy resoances are searched in the $\ell\nu qq$ final state, where one W boson decays leptonically ($W \to \ell\nu$ with $\ell = e, \mu$) and the other W or Z boson decays hadronically ($W/Z \to qq$). This search is performed with a total integrated luminosity of 13.2 fb^{-1} recorded in 2015 and early 2016. Since this search is dedicated for high-mass resonance, and the two jets from boson decay have a small opening angle, therefor only one large radius (large-R) jet is reconstructed.

In this analysis, events are required to have exactly one electron (muon) with $p_T > 27$ (25) GeV, to have at least one large-R jet (anti-k_t algorithm with distance parameters of $R = 1.0$) with $p_T > 200$ GeV and to satisfy the requirement of $E_T^{miss} > 100$ GeV. Events selected are further divided into high-purity and low-purity categories depending on whether the large-R jet satisfies a selection cut on the jet substructure variable $D_2^{(\beta=1)}$ [6], which can help to distinguish the boosted hadronically decaying W/Z bosons from jets originated from non-top quarks or gluons. For this search, major background resource comes from W+jets and $t\bar{t}$, which are estimated from simulation. The invariant mass of the full final state system $m_{\ell\nu J}$ is the final discriminant to examine whether there is any data excess above the SM expectation, which is consistent with the BSM predictions of heavy resonances. Figure 1 shows the $m_{\ell\nu J}$ distributions in WW and WZ signal regions (large-R jet within 15 GeV of the W/Z mass peak) after passing full selection criteria.

In the absence of any obvious excess in the data, a simultaneous binned likelihood fit to $m_{\ell\nu J}$ distributions in different lepton flavor channels is performed to derive the upper limits on the production cross section times the branching fraction ($\sigma \times B$) for various benchmark models. Both the observed and expected limits as well as the BSM predictions are shown in Figure 2. At the 95% CL, for HVT Z' (W'), masses below $2500 - 2810$ ($2400 - 2540$) GeV are excluded depending on the model; while resonance masses below 1240 GeV are excluded for a spin-2 Randall-Sundrum bulk graviton.

3. ZV resonance search with $\ell\ell qq$ and $\nu\nu qq$ final states

Many BSM models predict a resonance decaying into the ZV ($V = W$ or Z) final state, such as heavy neutral Higgs boson, HVT W' and graviton. In this search, the Z boson can either decays

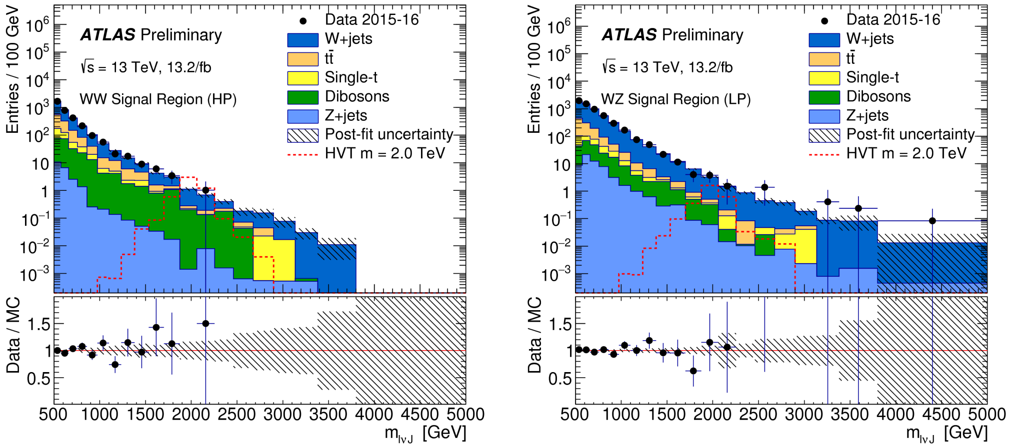

Figure 1: The $m_{\ell\nu J}$ distributions for WW (left) and WZ (right) signal regions corresponding to 13.2 fb^{-1} integrated luminosity [2]. The lower panels show the ratio of the observed data to the SM background estimation.

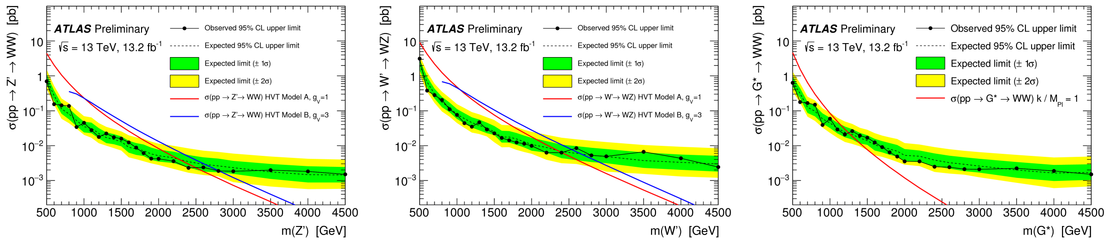

Figure 2: Observed and expected 95% CL upper limits on the production cross section times the branching fraction for HVT Z' (left), W' (middle) and Randall-Sundrum bulk graviton (right) as a function of resonance mass [2].

to two charged leptons ($\ell\ell$, $\ell = e$ or μ) or two neutrinos ($\nu\nu$), while the other vector boson decays hadronically into a qq final state. The search is therefore conducted in these two final states, denoted as $\ell\ell qq$ and $\nu\nu qq$ in the following. For the $\ell\ell qq$ analysis, events are selected by requiring the invariant mass of two selected leptons to be within a Z boson mass window. Events with at least one large-R jet (anti-k_t algorithm with a radius parameter of R = 1.0) with $p_{\mathrm{T}} > 200$ GeV are sorted into the so-called merged signal region, while the remaining events with two central small-R jets (anti-k_t algorithm with a radius parameter of R = 0.4) are categorized into the resolved signal region. For the $\nu\nu qq$ analysis, events are required to have a large-R jet and also satisfy $E_{\mathrm{T}}^{\mathrm{miss}} >$ 250 GeV. The discriminants for these two final states are invariant mass $m_{\ell\ell qq}$ and transverse mass $m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T,J}} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{\mathrm{T,J}} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}})^2}$ respectively, where $E_{\mathrm{T,J}} = \sqrt{m_{\mathrm{J}}^2 + p_{\mathrm{T,J}}^2}$.

This search is performed with 13.2 fb^{-1} integrated luminosity and the major background contributions are from Z+jets, top-quark and diboson. Figure 3 shows the distributions for $m_{\ell\ell qq}$ and m_{T} after applying full selection criteria. Since no significant data excess is observed in the discriminant distributions, a profile-likelihood-ratio test statistic is used to measure the compatibility of the background-only hypothesis with the observed data and to test the hypothesis of a heavy resonance. Figure 4 shows the upper limits on various models' production $\sigma \times B$ as a function of the resonance mass. At the 95% CL, for HVT W', masses below 2225 (2400) GeV are excluded for the $\ell\ell qq$ ($\nu\nu qq$) scenario while resonance masses below 1035 GeV and 1100 GeV are excluded for the $\ell\ell qq$ and $\nu\nu qq$ search respectively in terms of the graviton model.

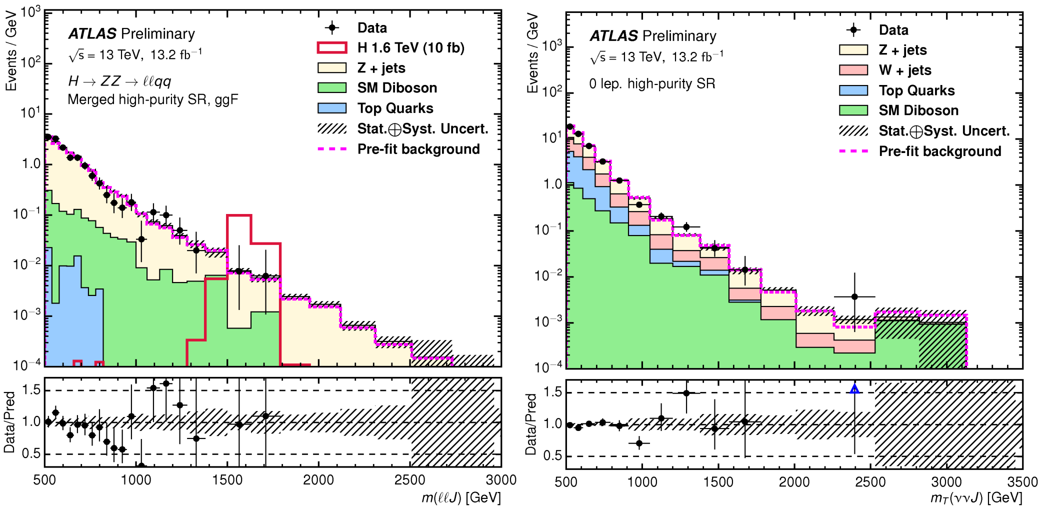

Figure 3: The $m_{\ell\ell qq}$ (left) and $m_{\rm T}$ (right) distributions in high-purity signal regions corresponding to 13.2 fb^{-1} integrated luminosity [3]. The lower panels show show the ratio of the observed data to the SM background estimation.

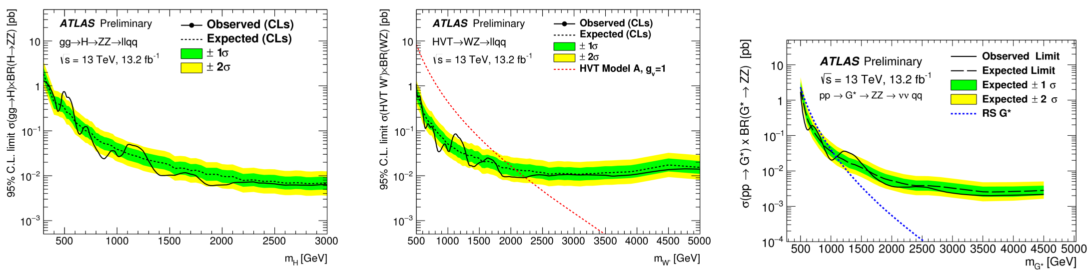

Figure 4: Observed and expected 95% CL upper limits on the production cross section times the branching fraction for heavy neutral Higgs (left), HVT W' (middle) and Randall-Sundrum bulk graviton (right) as a function of resonance mass [3].

4. Search for W' with a lepton and missing transverse momentum final state

The Sequential Standard Model (SSM) predicts a new heavy gauge boson W' with couplings to fermions that are identical to those of the SM W boson. The final state containing a charge lepton and a neutrino is a relatively clean channel to detect this signature. The search for W' with this channel is carried out using the data recorded in 2015 and 2016 corresponding to an integrated luminosity of 36.1 fb^{-1}.

Events are required to have one electron (muon) with $p_{\mathrm{T}} > 65$ (55) GeV, and to have $E_{\mathrm{T}}^{\mathrm{miss}} > 65$ GeV. The discriminant for this analysis is the transverse mass $m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}} (1 - cos\phi_{\ell\nu})}$, where $\phi_{\ell\nu}$ is the azimuthal angle differences between lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$. The main backgrounds for this analysis are W+jets, top and diboson, which are estimated from simulation. Figure 5 shows the m_{T} distributions after the entire selection requirement applied.

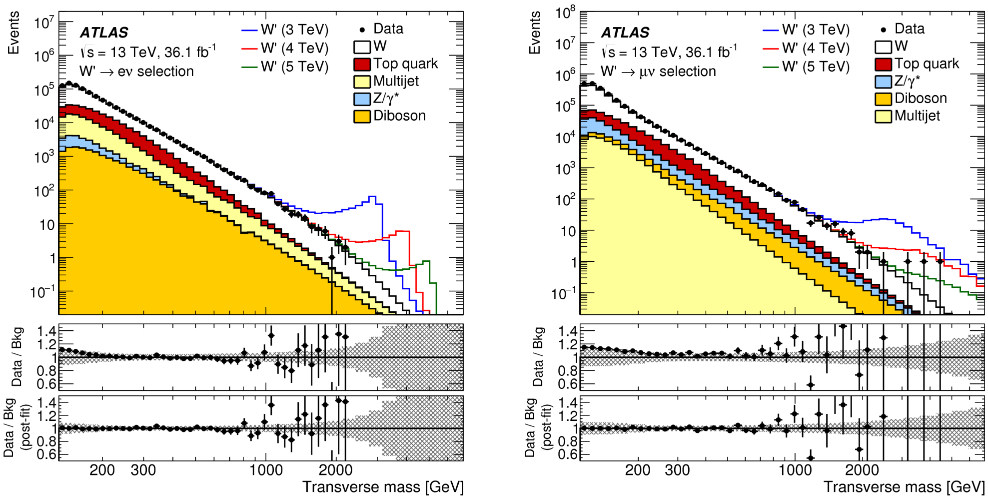

Figure 5: The m_{T} distributions for electron (left) and muon (right) channel, corresponding to 36.1 fb^{-1} integrated luminosity [4]. The middle and lower panels show the ratio of the observed data to the expected background and to adjusted expected background ("post-fit") that results from the statistical analysis.

In the absence of excess observed in the data distributions, the Bayesian method is adopted for statistical analysis. Figure 6 shows the corresponding upper limits on production $\sigma \times B$ as a function of SSM W' pole mass. After combining electron and muon channels, the observed (expected) lower limit on the mass of W'_{SSM} is 5.1 (5.2) TeV at the 95% CL.

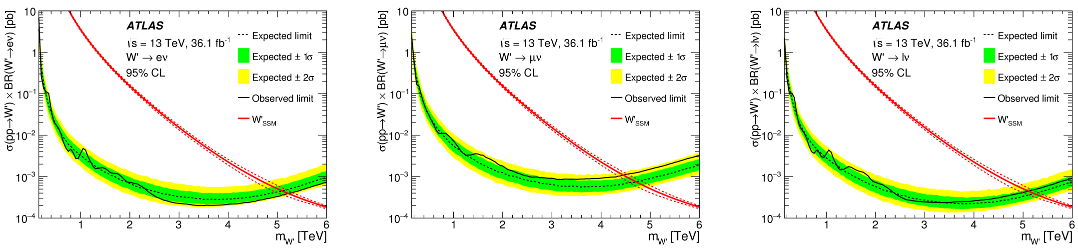

Figure 6: Observed and expected 95% CL upper limits on the production cross section times the branching fraction for SSM W' in electron (left), muon (middle) and combined (right) channels [4].

5. Search for new high-mass phenomena in dilepton final state

Dilepton final states are sensitive to detecting new phenomena in the phase space of large dilepton mass, where the new phenomena can either show up as resonance peaks ("resonance") or as an enhancement to the spectrum without any peaking structures ("non-resonance"). For the resonance scenario, many models predict the existence of a new heavy boson Z'. The SSM model is one of such kind, and it predicts a Z'_{SSM} boson which has couplings to fermions equivalent to those of the SM Z boson. There is another theoretically motivated model, the so-called E_6 model, in which the Z' boson is defined as the mixture of two eigenstates: $Z'(\theta_{E_6}) = Z'_\psi cos\theta_{E_6} + Z'_\chi sin\theta_{E_6}$, where θ_{E_6} is the mixing angle and its specific values lead to Z' signals with different widths between those of Z'_ψ and Z'_χ. Apart from the resonance scenario, some BSM models result in non-resonant deviations from the predicted SM dilepton mass spectrum, which can be represented as a contact interaction between initial-state quarks and final-state leptons.

This analysis is performed using the data corresponding to an integrated luminosity of 36.1 fb^{-1}. Events are selected by requiring two isolated leptons with each lepton $p_T > 30$ GeV. The main backgrounds for this analysis are Drell-Yan, top and diboson, which are estimated from simulation. Figure 7 shows the selected dilepton invariant mass (m_{ll}) distributions.

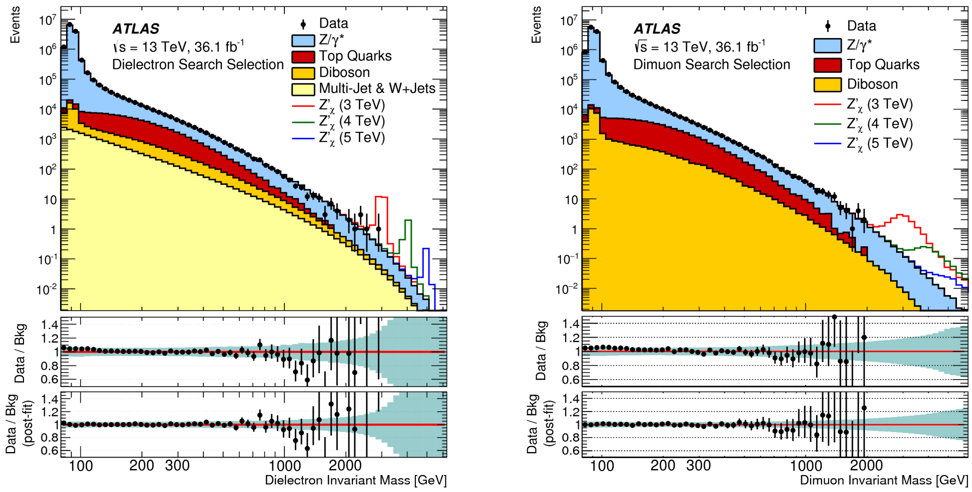

Figure 7: The m_{ll} distributions for electron (left) and muon (right) channel, corresponding to 36.1 fb^{-1} integrated luminosity [5]. The middle and lower panels show the ratio of the observed data to the expected background and to adjusted expected background ("post-fit") that results from the statistical analysis.

Since there is no obvious excess observed in the m_{ll} distributions, the Bayesian analysis is adopted for deriving limit results. Figure 8 shows the corresponding upper limits on production $\sigma \times B$ as a function of Z' pole mass and lower limits on the energy scale Λ for the Contact Interaction model. At the 95% CL, resonance masses below 4.1 TeV are excluded for Z'_χ after the combination of electron and muon channels. The lower limits on contact interaction scale are also set between 23.5 TeV and 40.1 TeV.

6. Summary

This talk presents various searches in final states involving 'leptons and jets' or involving leptons using the ATLAS detector with the data recorded in 2015 and 2016. There are no obvious deviations from the SM predictions observed in data and the most stringent limits are set for corresponding models at the ATLAS experiment. More data will be collected in 2017 and 2018, and

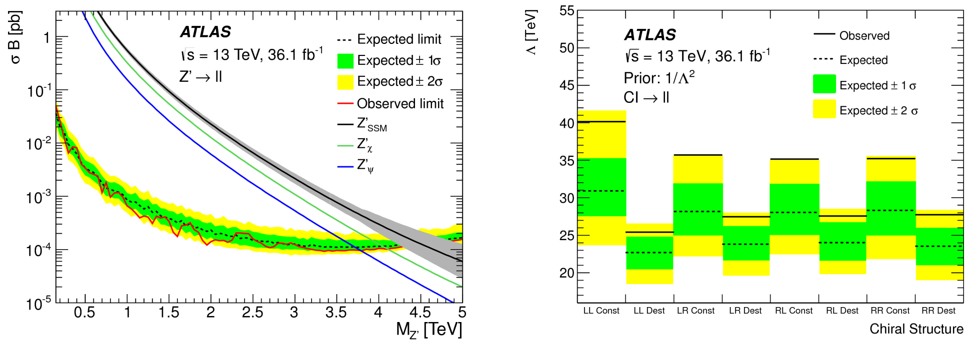

Figure 8: Observed and expected 95% CL upper limits on the production cross section times the branching fraction for Z' (left) and lower limits on the energy scale Λ for the Contact Interaction model with constructive and destructive interference (right) [5].

there is still plenty of room to enlarge the searched phase space for new physics in the relevant channels.

References

[1] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003.

[2] ATLAS Collaboration, Search for diboson resonance production in the $\ell\nu qq$ final state using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector at the LHC, ATLAS-CONF-2016-062.

[3] ATLAS Collaboration, Searches for heavy ZZ and ZW resonances in the $llqq$ and $\nu\nu qq$ final states in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-082.

[4] ATLAS Collaboration, Search for a new heavy gauge boson resonance decaying into a lepton and missing transverse momentum in 36 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS experiment, arXiv:1706.04786.

[5] ATLAS Collaboration, Search for new high-mass phenomena in the dilepton final state using 36.1 fb^{-1} of proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, arXiv:1707.02424.

[6] ATLAS Collaboration, Identification of boosted, hadronically-decaying W and Z bosons in $\sqrt{s}$ = 13 TeV Monte Carlo Simulations for ATLAS, ATL-PHYS-PUB-2015-033.