PROCEEDINGS OF SCIENCE

Search for resonant WZ Production in the fully leptonic final state in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector

Benjamin Freund*
Université de Montréal
E-mail: benjamin.freund@cern.ch

A search for a heavy resonance decaying into WZ in the fully leptonic channel (electrons and muons) is performed. It is based on proton–proton collision data collected by the ATLAS experiment at the Large Hadron Collider at a centre-of-mass energy of 13 TeV, corresponding to an integrated luminosity of 36.1 fb^{-1}. Limits are set on the production cross section times branching ratio of a heavy vector particle produced either in quark–antiquark fusion or through vector-boson fusion. Constraints are also obtained on the mass and couplings of a singly charged Higgs boson, in the Georgi–Machacek model, produced through vector-boson fusion.

Sixth Annual Conference on Large Hadron Collider Physics (LHCP2018)
4-9 June 2018
Bologna, Italy

*Speaker.

PoS(LHCP2018)008

1. Introduction

Searches for diboson resonances provide an essential test of theories of electroweak symmetry breaking beyond the Standard Model (BSM). Vector and scalar resonances are predicted in various BSM scenarios. This poster reports on a search for a WZ resonance in the fully leptonic decay channel $\ell\nu\ \ell\ell$ ($\ell = e$ or μ), produced either by quark–antiquark ($q\bar{q}$) fusion or by vector-boson fusion (VBF) [1]. The proton–proton collision data were collected by the ATLAS detector at the Large Hadron Collider (LHC) at a centre-of-mass energy $\sqrt{s} = 13$ TeV.

Two benchmark model hypotheses are tested in this channel. Heavy vector resonances as predicted by parameterised Lagrangians incorporating a heavy vector triplet (HVT) [2] as well as charged Higgs for the VBF channel as predicted by the Georgi-Machacek model (GM) [3]. For HVT two benchmark models are used. In Model A, weakly coupled vector resonances arise from an extension of the SM gauge group with an additional SU(2) symmetry group and the branching fractions to fermions and gauge bosons are comparable. In Model B, the heavy vector triplet is produced in a strongly coupled scenario, as in a Composite Higgs model and fermionic couplings are suppressed. The vector-boson scattering process, which is only sensitive to the gauge boson coupling, uses a benchmark model which assumes no coupling of the heavy vector resonance to fermions. The Georgi–Machacek model is used as a benchmark for a singly charged scalar resonance. The model extends the Higgs sector by including one real and one complex triplet. A parameter $\sin\theta_H$, representing the mixing of the vacuum expectation values, determines the contribution of the triplets to the masses of the W and Z bosons. The ten physical scalar states are organised into different custodial multiplets: a fiveplet H_5 which is fermiophobic but couples to WZ, a triplet, and two singlets, one of which is identified as the 125 GeV SM Higgs boson. Assuming that the triplet states are heavier than the fiveplet scalars, H_5 can only be produced by vector-boson fusion and the cross section is proportional to $\sin^2\theta_H$.

2. Event selection

As a preselection criterion three prompt leptons are required. The Z boson candidate is reconstructed from the two leptons of same flavour and opposite charge, whose invariant mass is closest to the on-shell mass m_Z, and in the range $|m_{\ell\ell} - m_Z| < 20$ GeV. The third lepton is associated with the W boson decay.

Since there is a neutrino in the signal events, $E_T^{miss} > 25$ GeV is also required. The third lepton and the missing transverse momentum E_T^{miss} are assumed to result from the W boson decay. The longitudinal momentum p_z of the neutrino is calculated by requiring that the invariant mass of the lepton–neutrino system be equal to the W mass. The solution results in a quadratic equation which leads to two possible solutions. If they are real, the one with the smaller $|p_z|$ is chosen since it was found to provide a better agreement with the truth. Otherwise, the real part is chosen. The invariant mass, m_{WZ}, of the WZ resonance candidate is then reconstructed using the chosen solution for p_z along with the four-momenta of the three charged leptons.

The selected events are then separated into two categories targeting different production mechanisms: VBF and $q\bar{q}$. The VBF category contains events with two or more jets with $p_T > 30$ GeV which fail b-tagging requirements. The dijet pair defined by the two highest-p_T jets in the event must also have large η separation ($|\Delta\eta| > 3.5$) and an invariant mass m_{jj} above 500 GeV. If more than two jets are found in an event, the two highest-p_T jets are considered.

The remaining events are assigned to the $q\bar{q}$ category signal region. For this category, the W and Z bosons from a resonance produced in the s-channel with m_{WZ} larger than 250 GeV are expected to have transverse momenta close to 50% of its mass. The requirements $p_T^W/m_{WZ} > 0.35$ and $p_T^Z/m_{WZ} > 0.35$ enhance the sensitivity to the signal.

3. Background estimation

The dominant background in the resonance search is the SM production of WZ. Its normalisation and shape are estimated from MC and validated in dedicated validation regions by comparing the data and MC distributions. Events in the validation regions are selected in exactly the same way as those in their corresponding signal categories except for the following requirements. The VBF WZ validation region is defined by inverting the requirements on the dijet variables: $100 < m_{jj} < 500$ GeV and $|\Delta\eta| < 3.5$ The WZ $q\bar{q}$ validation region requires the events to have $p_T^Z/m_{WZ} < 0.35$ or $p_T^W/m_{WZ} < 0.35$. Good agreement of data with the background prediction is observed.

Events from Z+jets, $Z\gamma$, $W\gamma$, $t\bar{t}$, single top or WW where jets or photons were misidentified as leptons (here called *fake/non-prompt* leptons), can also satisfy the selection criteria. The distribution shapes and number of fake/non-prompt lepton events are estimated for both the $q\bar{q}$ and VBF categories by a data-driven method using a global matrix which exploits differences in object characteristics between real and fake/non-prompt leptons on a statistical basis.

Other backgrounds include $t\bar{t}V$, ZZ, tZ, $WZbj$ and triple boson production. They are estimated by Monte Carlo simulation. The tZ, $WZbj$ and VVV backgrounds, where V refers to either the W or Z boson, are added as a single contribution, here called tZ+VVV.

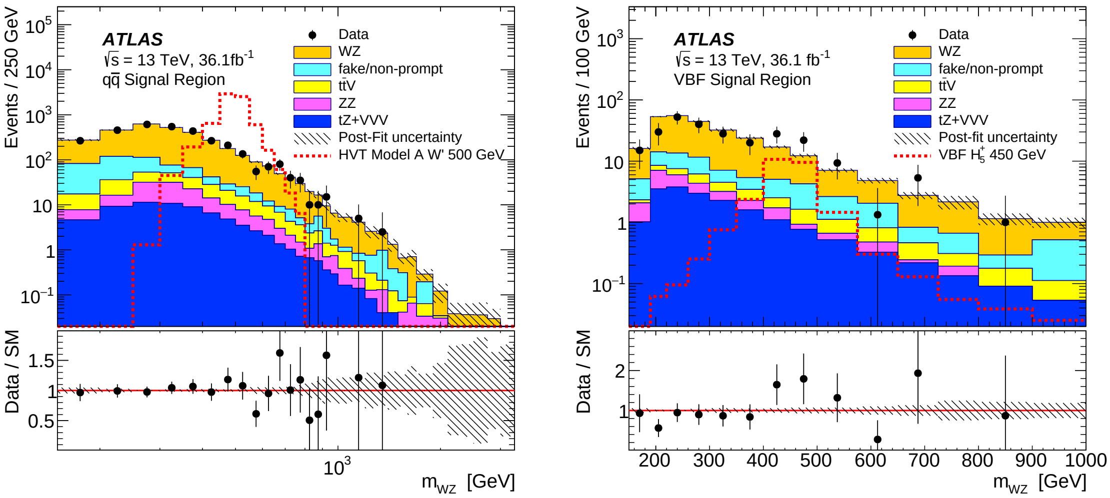
4. Results

The WZ invariant mass distribution, m_{WZ} is used as the discriminating variable, with bin widths comparable to the expected resolution of a narrow resonant signal. A binned likelihood function, constructed from the Poisson probability of the sum, in each bin, of the contributions of the background and of a hypothetical signal of strength μ relative to the benchmark model, is used to set limits on the presence of a signal. The fit is performed in the signal region for the $q\bar{q}$ and VBF categories separately. Apart from the statistical uncertainties in the data, the uncertainty with the largest impact on the sensitivity of the searches is related to the WZ background modelling.

The numbers of background events are extracted through a background-only fit of the data in each category. Background contributions from prompt leptons, including their shapes, are taken from MC simulations. In the case of non-prompt leptons the background shapes are taken from the Matrix Method. In the fit, the normalisation of all backgrounds are allowed to vary with in their uncertainties.

Figure 1 shows the post-fit m_{WZ} distribution for the $q\bar{q}$ and VBF categories. The largest difference between the observed data and the SM background prediction is in the VBF category. A local excess of events at a resonance mass of around 450 GeV can be seen in Figure 1b. The local significances for signals of $H_5^{\pm}$ and of a heavy vector W' are 2.9 and 3.1 standard deviations, respectively. The respective global significances calculated using the Look Elsewhere method and evaluated up to a mass of 900 GeV, are 1.6 and 1.9 standard deviations.

Upper limits are set on the product of the production cross section of new resonances and their decay branching ratio into WZ. The limit set on the signal strength μ is then translated into a limit on the signal cross section times branching ratio, $\sigma \times \mathscr{B}(W' \to WZ)$, using the theoretical cross section and branching ratio for the given signal model.



(a) (b)

Figure 1: Observed and expected distributions of the WZ invariant mass (a) in the $q\bar{q}$ and (b) in the VBF categories after applying all selection criteria. Signal predictions are overlaid, normalised to the predicted cross sections. The uncertainty in the total background prediction, shown as shaded bands, combines statistical, theory and systematic contributions. The lower panel show the ratios of the observed data to the background predictions.

Figure 2 presents the observed and expected limits on $\sigma \times \mathscr{B}(W' \to WZ)$ at 95% CL for the HVT model in the $q\bar{q}$ category. Masses below 2260 GeV can be excluded for Model A and 2460 GeV for Model B. For resonance masses above 2 TeV the exclusion limits become worse due to the acceptance losses at high mass. For the VBF process, the limit on $\sigma \times \mathscr{B}(W' \to WZ)$ is shown in Figure 3a.

Observed and expected exclusion limits at 95% CL on the mixing parameter $\sin\theta_H$ of the GM Model are shown in Figure 3b as a function of $m_{H_5^{\pm}}$. The shaded regions show the parameter space for which the $H_5^{\pm}$ width exceeds 5% and 10% of $m_{H_5^{\pm}}$.

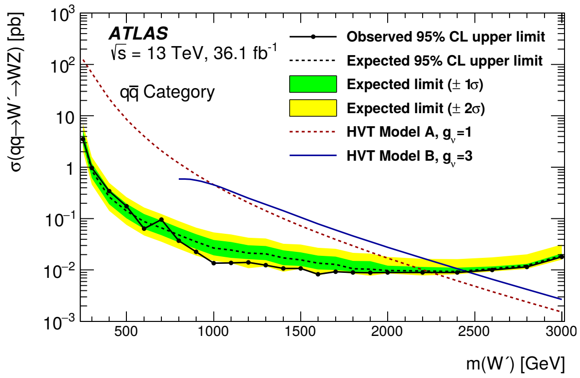
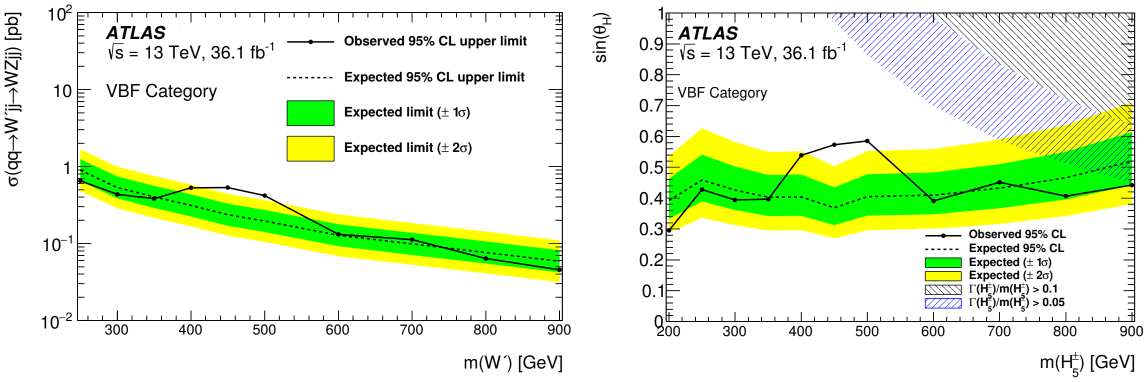


Figure 2: Observed and expected 95% CL upper limits on $\sigma \times \mathscr{B}(W' \to W^{\pm}Z)$ for the $q\bar{q}$ production of a W' boson in the HVT models as a function of its mass. The theoretical predictions for HVT Models A and B are also shown.



(a) (b)

Figure 3: Observed and expected 95% CL upper limits on (a) $\sigma \times \mathscr{B}(W' \to W^{\pm}Z)$ for the VBF production of a W' boson in the HVT Model as a function of its mass and on (b) the parameter $\sin\theta_H$ of the GM Model as a function of $m_{H_5^{\pm}}$. The shaded region shows where the theoretical intrinsic width of the resonance would be larger than 5% or 10% of the mass.

References

[1] The ATLAS Collaboration, “Search for resonant WZ production in the fully leptonic final state in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector”, arXiv:1806.01532 [hep-ex].

[2] D. Pappadopulo, A. Thamm, R. Torre and A. Wulzer, "Heavy vector triplets: bridging theory and data", JHEP 09 (2014) 060, arXiv: 1402.4431 [hep-ph].

[3] H. Georgi and M. Machacek, "Doubly charged Higgs bosons", Nucl. Phys. B 262 (1985) 463.