PROCEEDINGS OF SCIENCE

Search for a W' decaying to $\mathrm{t\bar{b}}$ in the lepton plus jets final state with the ATLAS detector using 36.1 fb^{-1} of pp collision data at $\sqrt{s}$ = 13 TeV

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A search for new charged massive gauge bosons, called W', decaying to $t\bar{b}$, is performed with the ATLAS detector in the decay channel leading to final states with an electron or muon, 2 or 3 jets and missing transverse momentum. This search uses a dataset corresponding to an integrated luminosity of 36.1 fb^{-1} of pp collisions produced at the LHC and collected during 2015 and 2016. The data is found to be consistent with the Standard Model expectation. Therefore limits are set on the $W' \rightarrow t\bar{b}$ cross section times branching ratio and on the W' boson effective couplings as a function of the W' boson mass.

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1. Motivation

Many theories of new physics introduce new heavy charged gauge bosons, usually referred to as W′. For example they are predicted by Kaluza- Klein [1] excitations of the Standard Model (SM) W boson or in models that extend the fundamental symmetries of the SM and propose a massive right-handed counterpart to the W boson [2]. This search [3] for a W′ boson decaying into a top quark and a $\bar{b}$-quark (illustrated in Figure 1 on the left) performed with the ATLAS detector [4] considers only W′ bosons with right-handed couplings (W'_{R}).

2. Event reconstruction and signal selection efficiency

The W'_{R} boson search is performed in the semileptonic decay channel so the final-state signature consists of two b-quarks, one charged lepton and a neutrino, which is undetected and results in missing transverse momentum, $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$. The dominant background processes are the production of W/Z+jets, single top quarks, $t\bar{t}$ pairs and dibosons, all modelled with Monte Carlo (MC) simulated events. An instrumental background due to multijet production, where a hadronic jet is misidentified as a lepton, is also present and it is derived using data.

The reconstruction of the W′ candidate starts with the calculation of the z component of the neutrino momentum from the invariant mass of the lepton–$\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ system with the constraint that $m_W = 80.4$ GeV. The four-momentum of the top-quark candidate is reconstructed by adding the four-momenta of the W-boson candidate and of the jet, that yields the invariant mass closest to the top-quark mass. This jet is referred to as "b_{top}". Finally, the four-momentum of the candidate W′ boson is reconstructed by adding the four-momentum of the reconstructed top-quark candidate and the four-momentum of the highest-p_{T} remaining jet (referred to as "b_1"). The invariant mass of the reconstructed $W' \to t\bar{b}$ system ($m_{t\bar{b}}$) is the discriminating variable of this search.

The phase space is divided into a signal region (SR), a validation region enriched with the W+jets background ($\mathrm{VR}_{\mathrm{pretag}}$), a validation region enriched with the $t\bar{t}$ background ($\mathrm{VR}_{t\bar{t}}$), and a validation region enriched with the W+heavy-flavour jets background ($\mathrm{VR}_{\mathrm{HF}}$). The signal and validation regions are defined by the number of jets and b-tagged jets, and are labelled as "X-jet Y-tag" where $X = 2,3,4$ and $Y = 1,2$. They are further separated into electron and muon channel. The pretag region has no requirement on the number of b-tagged jets. The event selection criteria for each region are summarized in Table 1. Figure 2 shows the distributions of the reconstructed invariant mass of the W′ boson candidate in the 2-jet 1-tag $\mathrm{VR}_{\mathrm{HF}}$ and 4-jet 2-tag $\mathrm{VR}_{t\bar{t}}$ regions.

The signal selection efficiency (defined as the number of events passing all selection requirements divided by the total number of simulated $W' \to t\bar{b} \to \ell\nu b\bar{b}$ events) in the signal region is shown, as a function of the simulated W'_{R} mass, in Figure 1 on the right. The application of the b-tagging requirement has a larger impact on the signal efficiency at high W'_{R} boson mass values. In the electron channel the electron–jet overlap criterion does not allow the electron to be close ($\Delta R(\ell,\mathrm{jet}) < 0.4$) to the jet. In the muon channel, this criterion is relaxed by using a variable ΔR cone size, resulting in an improved signal acceptance.

3. Results and interpretations

In order to test for the presence of a massive resonance, the $m_{t\bar{b}}$ templates obtained from the

Table 1: Summary of the event selection criteria used to define signal and validation regions [3]. The E_T^{miss} selection cut is harder for events with electrons than with muons.

Common selection			
$p_T(\ell) > 50$ GeV, $p_T(b_1) > 200$ GeV, $p_T(\text{top}) > 200$ GeV			
$E_T^{miss} > 30$ (80) GeV, $m_T^W + E_T^{miss} > 100$ GeV			
Signal Region	**VR_{pretag}**	**$VR_{t\bar{t}}$**	**VR_{HF}**
2 or 3 jets	2 or 3 jets	4 jets	2 or 3 jets
1 or 2 b-jets	pretag	1 or 2 b-jets	1 b-jet
$\Delta R(\ell, b_{top}) < 1.0$			$\Delta R(\ell, b_{top}) > 2.0$
$m_{tb} > 500$ GeV			$\Delta R(b_1, b_{top}) > 1.5$

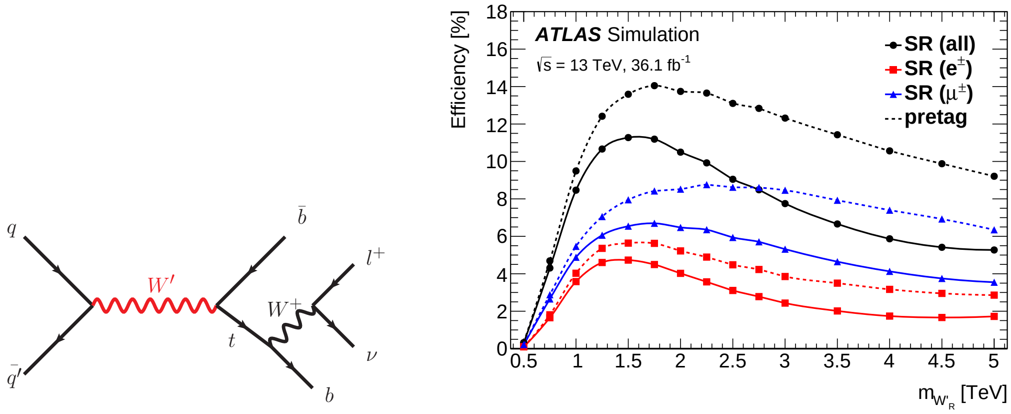

Figure 1: On the left, Feynman diagram for W′ boson production with the subsequent decay into $t\bar{b}$ and a leptonically decaying top quark. On the right, signal selection efficiencies are shown [3].

signal and background simulated event samples are fit to data in the SR using a binned maximum-likelihood approach. Each signal region is considered simultaneously as an independent search channel, for a total of eight regions corresponding to mutually exclusive categories of electron and muon, 2-jet and 3-jet, and 1-b-tag and 2-b-tags.

The normalizations of the $t\bar{t}$ and W+jets backgrounds are free parameters in the fit. The systematic uncertainties are incorporated in the fit as nuisance parameters with correlations across regions and processes taken into account. The fitted $t\bar{t}$ and W+jets rates relative to their nominal predictions are found to be 0.98 ± 0.04 and 0.78 ± 0.19, respectively. Figure 3 presents the post-fit distributions of the reconstructed mass of the W'_R boson candidate in the 2-jet 1-tag signal regions, for (left) electron and (right) muon channel.

For a W'_R boson with a mass of 2 TeV the total expected uncertainty in estimating the signal strength[1] is 12%. The total systematic uncertainty is 9%, and the largest uncertainties are due to the $t\bar{t}$ generator and jet energy scale uncertainties. For resonances with a mass of 2.5 TeV or above,

[1]The signal strength is defined as the ratio of the signal cross section estimated using the data to the predicted signal cross section.

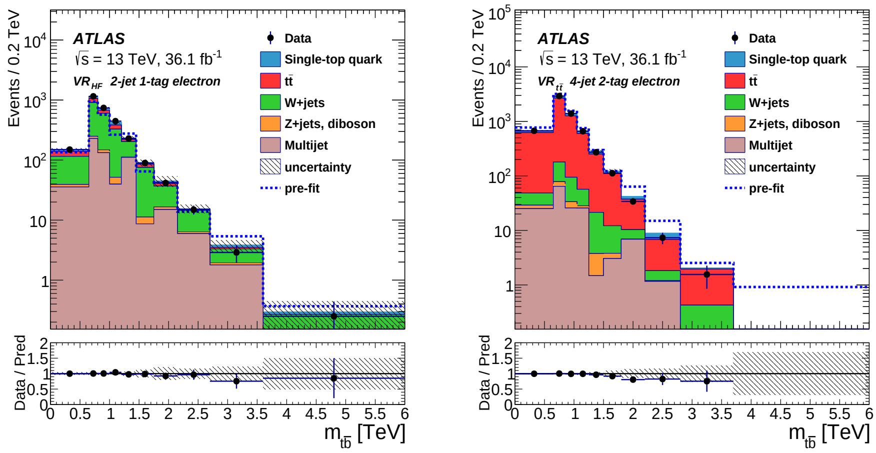

Figure 2: Distributions of the reconstructed invariant mass of the W′ boson candidate in the 2-jet 1-tag $\mathrm{VR_{HF}}$ and 4-jet 2-tag $\mathrm{VR}_{t\bar{t}}$ validation regions [3]. Uncertainty bands include all the systematic and statistical uncertainties.

the data Poisson uncertainty becomes the largest uncertainty, while the total systematic uncertainty is dominated by the uncertainty on the b-tagging efficiency.

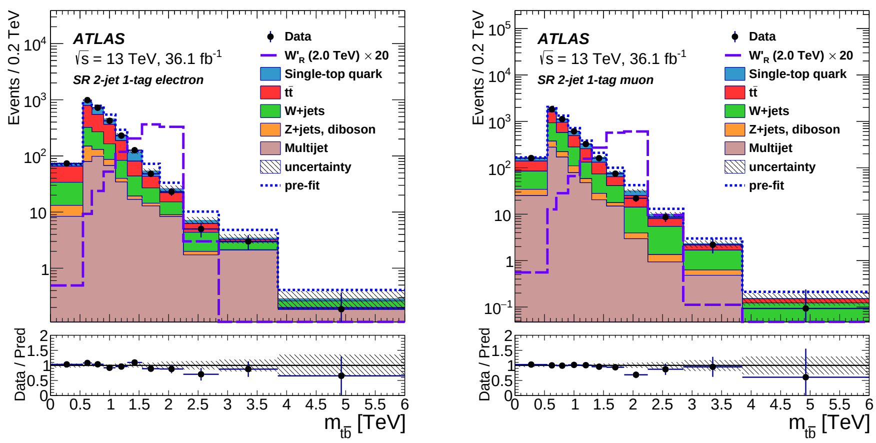

Figure 3: Post-fit distributions of the reconstructed mass of the $\mathrm{W'_R}$ boson candidate in the 2-jet 1-tag signal regions, for (left) electron and (right) muon channel [3]. Uncertainty bands include all the systematic and statistical uncertainties.

As no significant excess over the background prediction is observed, upper limits at the 95% confidence level (CL) are set. The limits on the production cross section multiplied by the branching fraction for $W'_R \to t\bar{b}$ are shown in Figure 4 as a function of the resonance mass. The exclusion limits range between 4.9 pb and 2.9×10^{-2} pb for $\mathrm{W'_R}$ boson masses from 0.5 TeV to 5 TeV.

Limits on the ratio of couplings g'/g as a function of the $\mathrm{W'_R}$ boson mass can be derived from the limits on the $\mathrm{W'_R}$ boson cross section. Figure 4 on the right shows the excluded parameter space as a function of the $\mathrm{W'_R}$ resonance mass, wherein the effect of increasing $\mathrm{W'_R}$ width for coupling values of $g'/g > 1$ is included for signal acceptance and differential distributions. The lowest observed (expected) limit on g'/g, obtained for a $\mathrm{W'_R}$ boson mass of 0.75 TeV, is 0.13 (0.13).

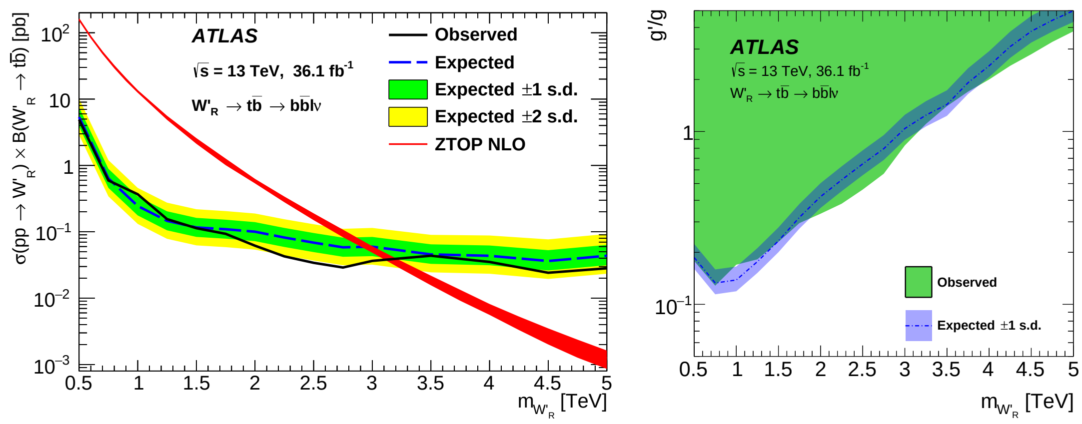

Figure 4: On the left, upper limits at the 95% CL on the W'_R production cross section times branching fraction as a function of resonance mass, assuming $g'/g = 1$ [3]. The solid curve corresponds to the observed limit, while the dashed curve and shaded bands correspond to the limit expected in the absence of signal and the regions enclosing one/two standard deviation (s.d.) fluctuations of the expected limit. The prediction made by the benchmark model generator ZTOP [5], and its width that correspond to variations due to scale and PDF uncertainty, are also shown. On the right, observed and expected 95% CL limit on the ratio g'/g, as a function of resonance mass, for right-handed W' coupling. The filled area corresponds to the observed limit while the dashed line and the one standard deviation (s.d.) band correspond to the expected limit.

4. Conclusion

A search for $W'_R \to t\bar{b}$ in the lepton plus jets final state is performed using 36.1 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV collected with the ATLAS detector at the LHC. No significant excess of events is observed above the SM predictions, so the upper limits are placed at the 95% CL on the cross section times branching fraction and masses below 3.15 TeV are excluded for W'_R bosons. Exclusion limits are also calculated for the ratio of the couplings g'/g and the lowest observed limit, obtained for a W'_R boson mass of 0.75 TeV, is 0.13.

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