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Letter

ATLAS search for a heavy gauge boson decaying to a charged lepton and a neutrino in pp collisions at $\sqrt{s} = 7$ TeV

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Abstract The ATLAS detector at the LHC is used to search for high-mass states, such as heavy charged gauge bosons (W'), decaying to a charged lepton (electron or muon) and a neutrino. Results are presented based on the analysis of pp collisions at a center-of-mass energy of 7 TeV corresponding to an integrated luminosity of 4.7 fb^{-1}. No excess beyond Standard Model expectations is observed. A W' with Sequential Standard Model couplings is excluded at the 95 % credibility level for masses up to 2.55 TeV. Excited chiral bosons (W^*) with equivalent coupling strength are excluded for masses up to 2.42 TeV.

1 Introduction

High-energy collisions at the CERN Large Hadron Collider provide the opportunity to search unexplored regions for physics beyond the Standard Model (SM) of strong and electroweak interactions. One extension common to many models is the existence of additional heavy gauge bosons, the charged ones commonly denoted W'. Such particles are most easily searched for in their decay to a charged lepton (electron or muon) and a neutrino.

This letter describes such a search performed using 7 TeV pp collision data collected with the ATLAS detector during 2011 corresponding to a total integrated luminosity of 4.7 fb^{-1}. The data are used to extend current limits [1–4] on σB (cross section times branching fraction) for $W' \to \ell\nu$ ($\ell = e$ or μ) as a function of W' mass. Limits are evaluated in the context of the Sequential Standard Model (SSM), i.e. the extended gauge model of Ref. [5] with the W' coupling to WZ set to zero. In this model, the W' has the same couplings to fermions as the SM W boson and a width which increases linearly with the W' mass. A previous letter [4] described a similar search with a subset (1.0 fb^{-1}) of the data used in this study. Here the mass range of the search is extended and the limits in the previously covered region are significantly improved because of the fivefold increase in integrated luminosity. An improved lower mass limit assuming SSM coupling strength is also reported.

A search is also performed for the charged partners, denoted W^*, of the chiral boson excitations described in Ref. [6] with theoretical motivation in Ref. [7]. The anomalous (magnetic-moment type) coupling of the W^* leads to kinematic distributions significantly different from those of the W'. The previous search for this resonance [3] was performed using data acquired in 2010 with an integrated luminosity less than 1 % of that used here. The search region is expanded to both lower and higher masses and the limits are considerably improved in the region covered by the previous search. A lower mass limit is evaluated by fixing the W^* coupling strengths to give the same partial decay widths as the SSM W'.

The analysis presented here identifies event candidates in the electron and muon channels, sets separate limits for $W'/W^* \to e\nu$ and $W'/W^* \to \mu\nu$, and then combines these assuming a common branching fraction for the two channels. The kinematic variable used to identify the W'/W^* is the transverse mass

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\varphi_{\ell\nu})}, \qquad (1)$$

whose distribution has a Jacobian peak and falls sharply above the resonance mass. Here p_{T} is the lepton transverse momentum, $E_{\mathrm{T}}^{\mathrm{miss}}$ is the magnitude of the missing transverse momentum (missing E_{T}), and $\varphi_{\ell\nu}$ is the angle between the p_{T} and missing E_{T} vectors. Throughout this letter, transverse refers to the plane perpendicular to the colliding beams, longitudinal means parallel to the beams, θ and φ are the polar and azimuthal angles with respect to the longitudinal direction, and pseudorapidity is defined as $\eta = -\ln(\tan(\theta/2))$.

Figure 1 shows the electron η and the m_{T} spectra for $W' \to e\nu$ and $W^* \to e\nu$, with $m_{W'} = m_{W^*} = 2.0$ TeV, from

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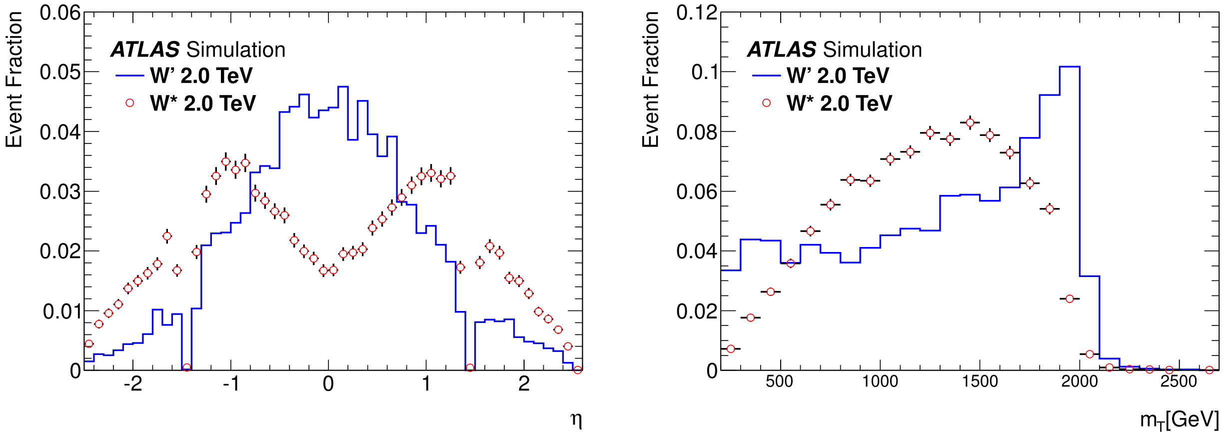

Fig. 1 Reconstructed electron η (*left*) and m_{T} (*right*) distributions for $W' \to e\nu$ and $W^* \to e\nu$ with $m_{W'} = m_{W^*} = 2.0$ TeV. All distributions are normalised to unit area

the event generation, detector simulation and reconstruction described below. The difference in kinematic shape is evident: the W' is more central in pseudorapidity and has a sharper m_{T} spectrum.

The main background to the $W'/W^* \to \ell\nu$ signal comes from the high-m_{T} tail of SM W boson decay to the same final state. Other backgrounds are Z bosons decaying into two leptons where one lepton is not reconstructed, W or Z decaying to τ leptons where a τ subsequently decays to an electron or muon, and diboson production. These are collectively referred to as the electroweak (EW) background. In addition, there is a background contribution from $t\bar{t}$ and single-top production which is most important for the lowest W' masses considered here, where it constitutes about 15 % of the background after event selection. Other strong-interaction background sources, where a light or heavy hadron decays semileptonically or a jet is misidentified as an electron, are estimated to be at most 10 % of the total background in the electron channel and a negligible fraction in the muon channel. These are called QCD background in the following.

2 Detector, trigger and reconstruction

The ATLAS detector [8] has three major components: the inner tracking detector, the calorimeter and the muon spectrometer. Charged particle tracks and vertices are reconstructed with silicon pixel and silicon strip detectors covering $|\eta| < 2.5$ and straw-tube transition radiation detectors covering $|\eta| < 2.0$, all immersed in a homogeneous 2 T magnetic field provided by a superconducting solenoid. This tracking detector is surrounded by a finely segmented, hermetic calorimeter system that covers $|\eta| < 4.9$ and provides three-dimensional reconstruction of particle showers. It uses liquid argon for the inner EM (electromagnetic) compartment followed by a hadronic compartment based on scintillating tiles in the central region ($|\eta| < 1.7$) and liquid argon for higher $|\eta|$. Outside the calorimeter, there is a muon spectrometer with air-core toroids providing a magnetic field, whose integral averages about 3 Tm. The deflection of the muons in the magnetic field is measured with three layers of precision drift-tube chambers for $|\eta| < 2.0$ and one layer of cathode-strip chambers followed by two layers of drift-tube chambers for $2.0 < |\eta| < 2.7$. Additional resistive-plate and thin-gap chambers provide muon triggering capability and measurement of the φ coordinate.

The data used in the electron channel are recorded with a trigger requiring the presence of an EM cluster (i.e. an energy cluster in the EM compartment of the calorimeter) with energy corresponding to an electron with $p_{\mathrm{T}} > 80$ GeV. This substantial increase over the p_{T} threshold used in the previous analysis [4] is required to maintain high efficiency (above 99 %) and keep the trigger rate at a tolerable level for the high luminosity used to acquire the bulk of the data. For the muon channel, matching tracks in the muon spectrometer and inner detector with combined $p_{\mathrm{T}} > 22$ GeV are used to select events. Events are also recorded if a muon with $p_{\mathrm{T}} > 40$ GeV is found in the muon spectrometer. These are the same p_{T} thresholds used in the previous analysis and, despite stricter hit requirements imposed for the higher-luminosity data, the muon trigger efficiency remains 80–90 % in the regions of interest.

Each EM cluster with $E_{\mathrm{T}} > 85$ GeV and $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$ is considered as an electron candidate if it matches an inner detector track. The electron direction is defined as that of the reconstructed track and its energy as that of the cluster, with a small η-dependent energy scale correction. The energy resolution is 2 % for $E_{\mathrm{T}} \approx 50$ GeV and approaches 1 % in the high-E_{T} range relevant to this analysis. To discriminate against hadronic jets, requirements are imposed on the lateral shower shapes in the first two layers of the EM compartment of the calorimeter and on the fraction of energy leaking into the hadronic compartment. A hit in the first pixel layer is required to reduce background from photon conversions in the inner detector material. These requirements result in about 90 % identification efficiency for electrons with $E_{\mathrm{T}} > 85$ GeV and a 2×10^{-4} probability to falsely identify jets as electrons before isolation requirements are imposed [9].

Muons are required to have $p_{\mathrm{T}} > 25$ GeV, where the momentum of the muon is obtained by combining the inner detector and muon spectrometer measurements. The p_{T} threshold allows the high trigger efficiency. To ensure precise measurement of the momentum, muons are required to have hits in all three muon layers and are restricted to those η-ranges where the muon spectrometer alignment is best understood: approximately $|\eta| < 1.0$ and $1.3 < |\eta| < 2.0$. The average momentum resolution is about 15 % at $p_{\mathrm{T}} = 1$ TeV. About 80 % of the muons in these η-ranges are reconstructed, with most of the loss coming from regions with limited detector coverage.

The missing E_{T} in each event is evaluated by summing over energy-calibrated physics objects (jets, photons and leptons) and adding corrections for calorimeter deposits away from these objects [10]. This is an improvement over the previous analysis which did not include the energy calibration.

This analysis makes use of all the $\sqrt{s} = 7$ TeV data collected in 2011 for which the relevant detector systems were operating properly. The integrated luminosity for the data used in this study is 4.7 fb^{-1} in both the electron and muon decay channels. The uncertainty on this measurement is 3.9 % [11, 12].

3 Simulation

Except for the QCD background, which is measured with data, expected signal and background levels are evaluated using simulated samples, normalised with calculated cross sections and the integrated luminosity of the data.

The W' signal and the W/Z boson backgrounds are generated with PYTHIA 6.421 [13] using the modified leading-order (LO) parton distribution functions (PDFs) of Ref. [14]. PYTHIA is also used for the $W^* \to \ell\nu$ event generation, but with initial kinematics generated at LO with COMPHEP [15] using the CTEQ6L1 PDFs [16]. The $t\bar{t}$ background is generated with MC@NLO 3.41 [17] using the CTEQ6.6 [18] PDFs. For all samples, final-state photon radiation is handled by PHOTOS [19]. The ATLAS full detector simulation [20] based on GEANT4 [21] is used to propagate the particles and account for the response of the detector.

The PYTHIA signal model for W' has $V-A$ SM couplings to fermions but does not include interference between W and W'. For both W' and W^*, decays to channels other than $e\nu$ and $\mu\nu$, including $\tau\nu$, ud, sc and tb, are included in the calculation of the widths but are not explicitly included as signal or background. At high mass ($m_{W'} > 1$ TeV), the branching fraction to each of the lepton decay channels is 8.2 %.

The $W \to \ell\nu$ events are reweighted to have the NNLO (next-to-next-to-leading-order) QCD mass dependence of ZWPROD [22] following the G_μ scheme [23] and using the MSTW2008 PDFs [24]. Higher-order electroweak corrections (in addition to the photon radiation included in the simulation) are calculated using HORACE [23, 25]. In the high-mass region of interest, the electroweak corrections reduce the cross sections by 11 % at $m_{\ell\nu} = 1$ TeV and by 18 % at $m_{\ell\nu} = 2$ TeV.

The $W \to \ell\nu$ and $Z \to \ell\ell$ cross sections are calculated at NNLO using FEWZ [26, 27] with the same PDFs, scheme and electroweak corrections used in the ZWPROD event reweighting. The $W' \to \ell\nu$ cross sections are calculated in the same way, except the electroweak corrections beyond final-state radiation are not included because the calculation for the SM W cannot be applied directly. The $t\bar{t}$ cross section is calculated at approximate-NNLO [28–30] assuming a top-quark mass of 172.5 GeV. The $W^* \to \ell\nu$ cross-section evaluation is performed with COMPHEP using the CTEQ6L1 PDFs (i.e. same as the event generation). The signal and most important background cross sections are listed in Table 1.

Cross-section uncertainties for $W' \to \ell\nu$ and the W/Z [9] and $t\bar{t}$ [31] backgrounds are estimated from the MSTW2008 PDF error sets, the difference between the MSTW2008 and CTEQ6.6 PDFs, and variation of renormalization and factorization scales by a factor of two. The estimates from the three sources are combined in quadrature. Most of the net uncertainty comes from the PDF error sets and the MSTW-CTEQ difference, in roughly equal proportion. The $W^* \to \ell\nu$ cross-section uncertainties are evaluated with the CTEQ61 [16] PDF error sets.

4 Event selection

The primary vertex for each event is required to have at least three tracks with $p_{\mathrm{T}} > 0.4$ GeV and to have a longitudinal distance less than 200 mm from the center of the collision region. Due to the high luminosity, there are an average of more than ten additional interactions per event in the data used for this analysis. The primary vertex is defined to be the one with the highest summed track p_{T}^2. Spurious tails in missing E_{T}, arising from calorimeter noise and other detector problems are suppressed by checking the quality of

Table 1 Calculated values of σB for $W' \to \ell\nu$, $W^* \to \ell\nu$ and the leading backgrounds. The value for $t\bar{t} \to \ell X$ includes all final states with at least one lepton (e, μ or τ). The others are exclusive and are used for both $\ell = e$ and $\ell = \mu$. All calculations are NNLO except W^* which is LO and $t\bar{t}$ which is approximate-NNLO

Process	Mass [GeV]	σB [pb]
$W' \to \ell\nu$	300	130.5
	400	41.6
	500	17.25
	600	8.27
	750	3.20
	1000	0.837
	1250	0.261
	1500	0.0887
	1750	0.0325
	2000	0.0126
	2250	0.00526
	2500	0.00235
	2750	0.001156
	3000	0.000643
$W^* \to \ell\nu$	400	29.6
	500	12.6
	750	2.34
	1000	0.610
	1250	0.188
	1500	0.0636
	1750	0.0226
	2000	0.00819
	2250	0.00299
	2500	0.000109
	2750	0.000391
	3000	0.000138
$W \to \ell\nu$		10460
$Z/\gamma^* \to \ell\ell$ ($m_{Z/\gamma^*} > 60$ GeV)		989
$t\bar{t} \to \ell X$		89.4

each reconstructed jet and discarding events where any jet has a shape indicating such problems, following Ref. [32]. In addition, the inner detector track associated with the electron or muon is required to be compatible with originating from the primary vertex, specifically to have transverse distance of closest approach $|d_0| < 1$ mm and longitudinal distance at this point $|z_0| < 5$ mm in the electron channel. For the muon channel, the requirements are $|d_0| < 0.2$ mm and $|z_0| < 1$ mm. Events are required to have exactly one candidate electron or one candidate muon satisfying these requirements.

Table 2 Expected numbers of events from the various background sources in each decay channel for $m_T > 794$ GeV, the region used to search for a W' with a mass of 1000 GeV in the electron and muon channels. The $W \to \ell\nu$ and $Z \to \ell\ell$ entries include the expected contributions from the τ-lepton. The uncertainties are those from the Monte Carlo statistics

	$e\nu$	$\mu\nu$
$W \to \ell\nu$	14.2±0.5	11.2±0.5
$Z \to \ell\ell$	0.022±0.001	0.76±0.01
diboson	1.2±0.2	0.71±0.15
$t\bar{t}$	0.24±0.11	0.09±0.05
QCD	0.8±0.3	–
Total	16.5±0.6	12.8±0.5

To suppress the QCD background, the lepton is required to be isolated. In the electron channel, the isolation energy is measured with the calorimeter in a cone $\Delta R < 0.4$ ($\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$) around the electron track, and the requirement is $\sum E_T < 9$ GeV, where the sum includes all calorimeter energy clusters in the cone excluding the core energy deposited by the electron. The sum is corrected to account for additional interactions and leakage of the electron energy outside this core. In the muon channel, the isolation energy is measured using inner detector tracks with $p_T^{\text{trk}} > 1$ GeV in a cone $\Delta R < 0.3$ around the muon track. The isolation requirement is $\sum p_T^{\text{trk}} < 0.05\ p_T$, where the muon track is excluded from the sum. The scaling of the threshold with the muon p_T reduces efficiency losses due to radiation from the muon at high p_T.

Missing E_T thresholds are imposed to further suppress the background from QCD and W+jets (events where the SM W recoils against hadronic jets). In both channels, the threshold used for the charged lepton p_T is also applied to the missing E_T: $E_T^{\text{miss}} > 85$ GeV for the electron channel and $E_T^{\text{miss}} > 25$ GeV for the muon channel.

The above constitute the event preselection requirements. An m_T threshold varying with W' or W^* mass and decay channel is applied after preselection to establish the final event counts.

In the electron channel, the QCD background is estimated from data using the *ABCD* technique [33] with the isolation energy and missing E_T serving as discriminants. Consistent results are obtained using the *inverted isolation* technique described in Ref. [3].

The QCD background for the muon channel is evaluated using the *matrix method* [31]. This background is less than 1 % of the total background, and so it is neglected in the following.

The same reconstruction and event selection are applied to both data and simulated samples. Figure 2 shows the charged lepton p_T, missing E_T, and m_T spectra for events with $m_T > 200$ GeV in each channel after event preselection. The data, the expected background, and three examples of W' signals at different masses are shown. The m_T threshold, which is below that used in all of the final selections, discriminates against the W+jets and QCD backgrounds.

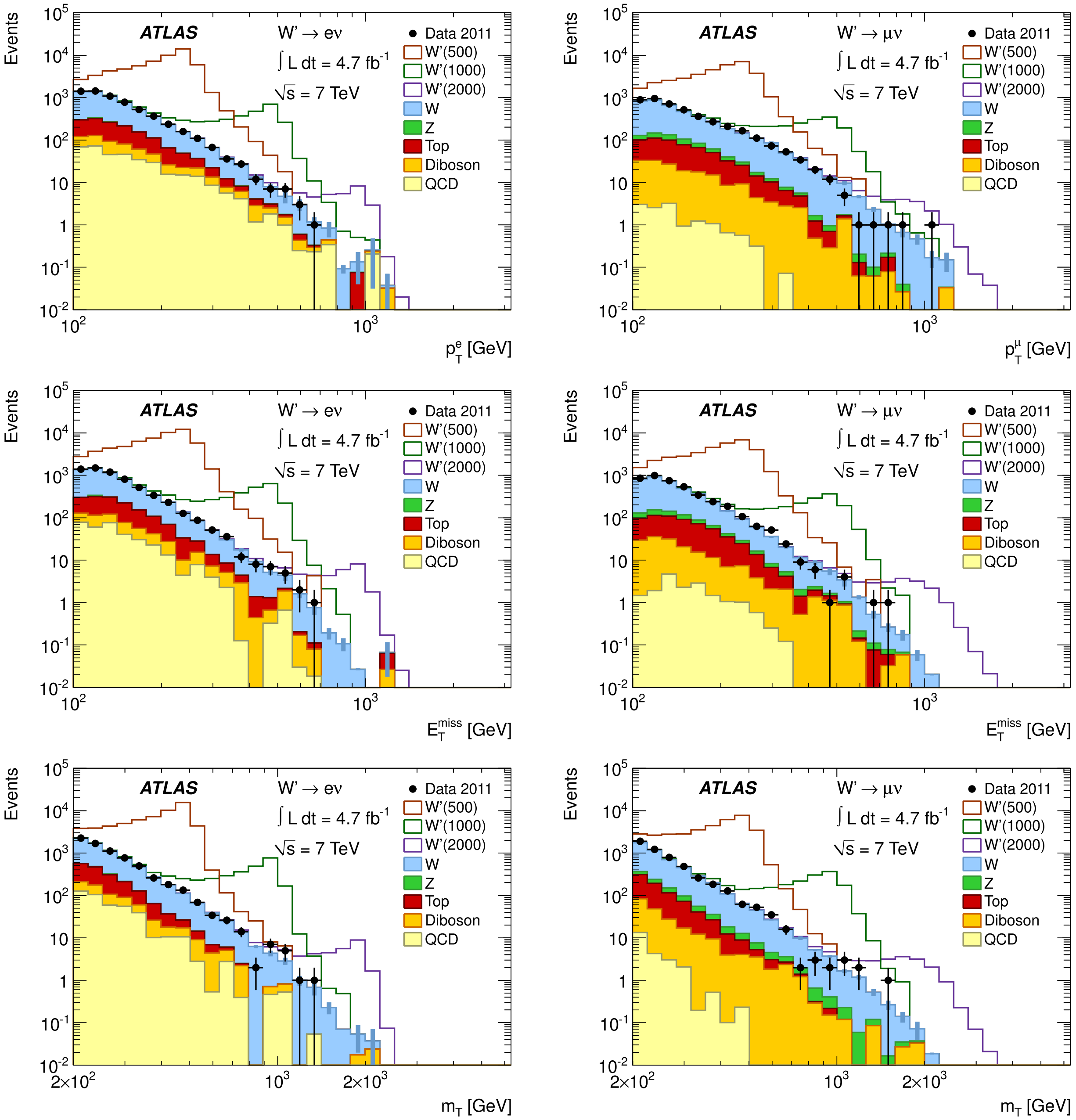

Fig. 2 Spectra of charged lepton p_T (*top*), missing E_T (*center*) and m_T (*bottom*) for the electron (*left*) and muon (*right*) channels for events with $m_T > 200$ GeV after event preselection. The points represent data and the filled histograms show the stacked backgrounds. Open histograms are $W' \to \ell\nu$ signals added to the background with masses in GeV indicated in parentheses in the legend. The QCD backgrounds estimated from data are also shown. The signal and other background samples are normalised using the integrated luminosity of the data and the NNLO (approximate-NNLO for $t\bar{t}$) cross sections listed in Table 1. The error bars on the data and background sums are statistical, i.e. the latter do not include the systematic uncertainties used in the statistical analysis

The m_T spectra for the data and expected background are consistent within statistical and systematic uncertainties.

Table 2 shows the contributions to the background for $m_T > 794$ GeV, the region used to search for a W' with a mass of 1000 GeV. The $W \to \ell\nu$ background dominates and the background for the electron channel is higher than that for muons because of the difference in acceptance.

5 Statistical analysis and systematics

Discovery significance and σB limits are evaluated independently for W' and W^* following the same procedure as for the previous analysis [4]. The observed number of events N_{obs} is the count after final selection including the requirement $m_T > m_{T_{\text{min}}}$, with that threshold chosen sepa-

Table 3 Event selection efficiencies for the $W' \to e\nu$ and $W' \to \mu\nu$ searches. The first three columns are the W' mass, m_T threshold and decay channel. The next two are the signal selection efficiency, ε_{sig}, and the prediction for the number of signal events, N_{sig}, obtained with this efficiency. The uncertainty on N_{sig} includes contributions from the uncertainty on the cross sections but not from that on the integrated luminosity

$m_{W'}$ [GeV]	$m_{T_{\text{min}}}$ [GeV]		ε_{sig}	N_{sig}
300	251	$e\nu$	0.288 ± 0.023	176000±19000
		$\mu\nu$	0.186 ± 0.016	114000±13000
400	355	$e\nu$	0.237 ± 0.023	46200±5600
		$\mu\nu$	0.153 ± 0.018	30000±4100
500	447	$e\nu$	0.237 ± 0.023	19200±2300
		$\mu\nu$	0.145 ± 0.019	11700±1800
600	501	$e\nu$	0.307 ± 0.024	11900±1300
		$\mu\nu$	0.195 ± 0.017	7600±900
750	631	$e\nu$	0.297 ± 0.023	4470±470
		$\mu\nu$	0.189 ± 0.016	2840±320
1000	794	$e\nu$	0.339 ± 0.023	1330±130
		$\mu\nu$	0.223 ± 0.015	877±90
1250	1000	$e\nu$	0.323 ± 0.024	395±47
		$\mu\nu$	0.212 ± 0.019	259±34
1500	1122	$e\nu$	0.351 ± 0.026	146±20
		$\mu\nu$	0.237 ± 0.021	99±14
1750	1413	$e\nu$	0.280 ± 0.024	42.7±6.8
		$\mu\nu$	0.179 ± 0.024	27.3±5.2
2000	1413	$e\nu$	0.317 ± 0.025	18.8±3.2
		$\mu\nu$	0.215 ± 0.022	12.7±2.3
2250	1413	$e\nu$	0.315 ± 0.022	7.8±1.5
		$\mu\nu$	0.218 ± 0.017	5.4±1.0
2500	1413	$e\nu$	0.276 ± 0.024	3.1±1.4
		$\mu\nu$	0.184 ± 0.024	2.0±1.0
2750	1413	$e\nu$	0.217 ± 0.020	1.18±0.59
		$\mu\nu$	0.149 ± 0.020	0.81±0.41
3000	1413	$e\nu$	0.143 ± 0.027	0.43±0.25
		$\mu\nu$	0.106 ± 0.031	0.32±0.20

Table 4 Event selection efficiencies for the $W^* \to e\nu$ and $W^* \to \mu\nu$ searches. The first three columns are the W^* mass, m_T threshold and decay channel. The next two are the signal selection efficiency, ε_{sig}, and the prediction for the number of signal events, N_{sig}, obtained with this efficiency. The uncertainty on N_{sig} includes contributions from the uncertainty on the cross sections but not from that on the integrated luminosity

m_{W^*} [GeV]	$m_{T_{\text{min}}}$ [GeV]		ε_{sig}	N_{sig}
400	316	$e\nu$	0.189 ± 0.021	26300±3200
		$\mu\nu$	0.118 ± 0.020	16400±2900
500	398	$e\nu$	0.182 ± 0.020	10800±1300
		$\mu\nu$	0.114 ± 0.021	6740±1300
750	562	$e\nu$	0.224 ± 0.021	2460±270
		$\mu\nu$	0.143 ± 0.019	1570±230
1000	708	$e\nu$	0.267 ± 0.022	766±83
		$\mu\nu$	0.172 ± 0.017	493±60
1250	891	$e\nu$	0.254 ± 0.021	225±26
	794	$\mu\nu$	0.216 ± 0.015	192±21
1500	1122	$e\nu$	0.212 ± 0.021	63.5±9.0
	1000	$\mu\nu$	0.192 ± 0.016	57.5±7.5
1750	1122	$e\nu$	0.330 ± 0.023	35.0±5.0
		$\mu\nu$	0.208 ± 0.016	22.1±3.2
2000	1413	$e\nu$	0.258 ± 0.021	9.9±1.7
		$\mu\nu$	0.156 ± 0.018	6.0±1.2
2250	1413	$e\nu$	0.338 ± 0.024	4.8±1.0
		$\mu\nu$	0.211 ± 0.016	2.97±0.63
2500	1413	$e\nu$	0.397 ± 0.025	2.03±0.53
		$\mu\nu$	0.241 ± 0.016	1.23±0.32
2750	1413	$e\nu$	0.449 ± 0.027	0.83±0.28
		$\mu\nu$	0.260 ± 0.016	0.48±0.16
3000	1413	$e\nu$	0.475 ± 0.029	0.31±0.13
		$\mu\nu$	0.276 ± 0.016	0.179±0.077

rately for each mass and decay channel to maximize sensitivity. A Bayesian posterior probability distribution for the signal σB is evaluated with a Poisson likelihood at each mass for each decay channel and for the combination of the two channels. A positive, flat prior is used for the signal σB, and Gaussian distributions are used for the three nuisance parameters: ε_{sig}, the efficiency to select signal events, N_{bg}, the expected number of background events and L_{int}, the integrated luminosity. For each observed posterior, an ensemble of expected posteriors is generated assuming no signal and the same prior distributions for N_{bg} and L_{int}.

Each of the observed posteriors is used to evaluate an observed limit on σB, and the ensemble of expected posteriors provides the corresponding expected limit distribution. All limits are at 95 % CL (credibility level). Discovery significance is assessed from the fraction of the expected posteriors that are more signal-like than the observation.

The values and uncertainties for ε_{sig} are presented in Tables 3 and 4, and those for N_{bg} and N_{obs} in Table 5. The ε_{sig} tables also give the predicted numbers of signal events, N_{sig}, with their uncertainties accounting for the uncertainties in both ε_{sig} and the cross-section calculations.

The maximum value for the $W' \to \ell\nu$ signal selection efficiency is at $m_{W'} = 1500$ GeV. For lower masses, the efficiency falls because the relative m_T threshold, $m_{T_{\text{min}}}/m_{W'}$, is increased to reduce the background level. For higher masses, the efficiency falls because a large fraction of the cross section goes via off-shell production with $m_{\ell\nu} \ll m_{W'}$. This effect is not seen for $W^* \to \ell\nu$ because its derivative couplings [6] suppress off-shell production at low mass.

The fraction of fully simulated signal events that pass the event selection and are above the m_T threshold provides the initial estimate of ε_{sig} for each channel and mass. For W',

Table 5 Background levels and observed counts for the $W' \to \ell\nu$ and $W^* \to \ell\nu$ searches in both the electron and muon channels. The first two columns are the m_T threshold and decay channel, followed by the expected number of background events, N_bg, and the number of events observed in data, N_obs. The uncertainty on N_bg includes contributions from the uncertainties on the cross sections but not from that on the integrated luminosity

$m_{\mathrm{T}_\mathrm{min}}$ [GeV]		N_bg	N_obs
251	$e\nu$	3190±260	3105
	$\mu\nu$	1950±190	2023
316	$e\nu$	1240±100	1229
	$\mu\nu$	773±72	750
355	$e\nu$	761±64	734
	$\mu\nu$	492±44	491
398	$e\nu$	467±39	474
	$\mu\nu$	285±26	307
447	$e\nu$	277±24	293
	$\mu\nu$	178±15	179
501	$e\nu$	164±14	159
	$\mu\nu$	113±10	117
562	$e\nu$	95.8±8.4	90
	$\mu\nu$	66.2±5.8	64
631	$e\nu$	54.5±5.2	56
	$\mu\nu$	40.0±3.7	29
708	$e\nu$	30.7±3.0	30
	$\mu\nu$	22.7±2.2	13
794	$e\nu$	16.5±1.7	16
	$\mu\nu$	12.8±1.4	11
891	$e\nu$	9.0±1.0	14
1000	$e\nu$	5.15±0.69	7
	$\mu\nu$	3.86±0.58	6
1122	$e\nu$	2.57±0.42	2
	$\mu\nu$	2.21±0.34	3
1413	$e\nu$	0.64±0.18	0
	$\mu\nu$	0.51±0.12	1

small corrections are then made to account for the difference in acceptance at NNLO (obtained from FEWZ) and that in the LO simulation. These vary from a 10 % increase for $m_{W'} = 500$ GeV to an 11 % decrease for $m_{W'} = 2500$ GeV. Contributions from $W' \to \tau\nu$ with the τ-lepton decaying leptonically have been neglected. These would increase the W' signal strength by 3–4 % for the highest masses. The background level is estimated for each mass by summing the EW and $t\bar{t}$ event counts from simulation, and adding the small QCD contribution in the electron channel.

The uncertainties on ε_sig, N_bg and L_int account for experimental and theoretical systematic effects as well as the statistics of the simulation samples. The uncertainty on L_int is included separately to allow for the correlation between signal and background. The experimental systematic uncertainties include efficiencies for the electron or muon trigger, reconstruction and selection. Lepton momentum and missing E_T response, characterised by scale and resolution, are also included. Most of these performance metrics are measured at relatively low p_T and their values are extrapolated to the high-p_T regime relevant to this analysis. The uncertainties in these extrapolations are included but their contributions are small compared to the total uncertainty on ε_sig or N_bg. The uncertainty on the QCD background estimate also contributes to the background-level uncertainties for the electron channel. Theoretical uncertainties include those from the cross-section calculations (see Sect. 3) and from the W' acceptance corrections. The values for the uncertainties are similar to those obtained in the previous analysis. Table 6 summarizes the uncertainties on the event selection efficiencies and background levels for the $W' \to \ell\nu$ signal with $m_{W'} = 1500$ GeV using $m_\mathrm{T} > 1122$ GeV.

Table 6 Relative uncertainties on the event selection efficiency and background level for a W' with a mass of 1500 GeV. The efficiency uncertainties include contributions from the trigger, reconstruction and event selection. The cross-section uncertainty for ε_sig is that assigned to the acceptance correction described in the text. The cross-section uncertainty on N_bg is that from the cross-section calculations. The last row gives the total uncertainties

Source	ε_sig		N_bg	
	$e\nu$	$\mu\nu$	$e\nu$	$\mu\nu$
Efficiency	5 %	2 %	4 %	2 %
Energy/momentum resolution	–	1 %	3 %	–
Energy/momentum scale	2 %	–	4 %	–
Missing E_T	–	–	2 %	4 %
QCD background	–	–	4 %	–
Monte Carlo statistics	5 %	9 %	10 %	9 %
Cross section (shape/level)	3 %	3 %	12 %	12 %
Total	7 %	9 %	17 %	16 %

6 Results

None of the observations for any mass point in either channel or their combination shows an excess with significance above three sigma, so there is no evidence for the observation of $W' \to \ell\nu$ or $W^* \to \ell\nu$. Tables 7 and 8 and Fig. 3 present the 95 % CL observed limits on σB for both $W' \to \ell\nu$ and $W^* \to \ell\nu$ in the electron channel, the muon channel and their combination. The tables also give the limits obtained without systematic uncertainties and with various subsets. The uncertainties on the signal efficiency have very little effect on the final limits, and the background-level and luminosity uncertainties are important only for the lowest masses. The figure also shows the expected limits and the

Table 7 Observed upper limits on σB for $W' \to e\nu$, $W' \to \mu\nu$ and the combination of the two. The *first two columns* are the W' mass and decay channel. The *following columns* are the 95 % CL limits with headers indicating the nuisance parameters for which uncertainties are included: S for the event selection efficiency (ε_{sig}), B for the background level (N_{bg}), and L for the integrated luminosity (L_{int}). These values neglect correlations between the two channels for the combined limit. The only important correlation, that from the background cross section, is included in the column $\text{SB}_\text{c}\text{L}$. The last column in each row (SBL for e and μ and $\text{SB}_\text{c}\text{L}$ for $e\mu$) is the final limit (including all systematic uncertainties) for the mass listed in the first column. These are the limits shown in Fig. 3 (left)

$m_{W'}$ [GeV]		95 % CL limit on σB [fb]				
		none	S	SB	SBL	$\text{SB}_\text{c}\text{L}$
300	e	50	51	356	500	
	μ	173	179	514	557	
	$e\mu$	61	62	295	329	389
400	e	36	37	111	124	
	μ	62	65	140	153	
	$e\mu$	30	30	84	92	110
500	e	43	44	65	70	
	μ	42	44	64	69	
	$e\mu$	32	32	47	50	56
600	e	16	17	25	27	
	μ	28	29	36	39	
	$e\mu$	14	14	21	22	24
750	e	12	13	15	15	
	μ	9.0	9.2	11	11	
	$e\mu$	6.8	6.8	8.1	8.4	9.2
1000	e	5.6	6.0	6.3	6.5	
	μ	7.1	7.2	7.5	7.7	
	$e\mu$	4.1	4.1	4.4	4.4	4.6
1250	e	5.5	5.5	5.6	5.7	
	μ	8.2	8.4	8.5	8.6	
	$e\mu$	4.7	4.7	4.8	4.9	4.9
1500	e	2.8	2.8	2.9	2.9	
	μ	5.2	5.4	5.4	5.4	
	$e\mu$	2.3	2.3	2.3	2.4	2.4
1750	e	2.3	2.3	2.3	2.3	
	μ	5.2	5.5	5.5	5.5	
	$e\mu$	1.9	1.9	1.9	1.9	1.9
2000	e	2.0	2.0	2.0	2.1	
	μ	4.3	4.4	4.5	4.5	
	$e\mu$	1.6	1.6	1.6	1.6	1.6
2250	e	2.0	2.1	2.1	2.1	
	μ	4.2	4.3	4.3	4.4	
	$e\mu$	1.6	1.6	1.6	1.6	1.6
2500	e	2.3	2.4	2.4	2.4	
	μ	5.0	5.3	5.3	5.3	
	$e\mu$	1.9	1.9	1.9	1.9	1.9
2750	e	2.9	3.0	3.0	3.0	
	μ	6.2	6.6	6.6	6.7	
	$e\mu$	2.3	2.4	2.4	2.4	2.4
3000	e	4.5	5.0	5.0	5.0	
	μ	8.7	15	15	15	
	$e\mu$	3.5	3.7	3.7	3.7	3.7

Table 8 Observed upper limits on σB for $W^* \to e\nu$, $W^* \to \mu\nu$ and the combination of the two. The columns are as for Table 7. The final (rightmost) limits are shown in Fig. 3 (right)

m_{W^*} [GeV]		95 % CL limit on σB [fb]				
		none	S	SB	SBL	$\text{SB}_\text{c}\text{L}$
400	e	68	71	236	264	
	μ	68	75	263	289	
	$e\mu$	47	48	167	186	222
500	e	57	60	114	125	
	μ	93	106	160	171	
	$e\mu$	57	58	96	104	116
750	e	16	17	22	24	
	μ	23	25	30	31	
	$e\mu$	13	13	17	18	19
1000	e	10	10	11	11	
	μ	7.0	7.2	7.8	8.1	
	$e\mu$	5.0	5.1	5.6	5.8	6.2
1250	e	11	11	11	11	
	μ	7.3	7.4	7.8	7.9	
	$e\mu$	6.7	6.7	6.9	7.0	7.2
1500	e	4.6	4.7	4.8	4.8	
	μ	9.0	9.2	9.3	9.4	
	$e\mu$	4.2	4.3	4.3	4.3	4.4
1750	e	3.0	3.0	3.0	3.0	
	μ	6.0	6.1	6.1	6.2	
	$e\mu$	2.5	2.5	2.6	2.6	2.6
2000	e	2.5	2.5	2.5	2.5	
	μ	5.9	6.2	6.2	6.2	
	$e\mu$	2.1	2.1	2.1	2.1	2.1
2250	e	1.9	1.9	1.9	1.9	
	μ	4.4	4.5	4.5	4.5	
	$e\mu$	1.6	1.6	1.6	1.6	1.6
2500	e	1.5	1.5	1.5	1.5	
	μ	3.8	3.9	3.9	3.9	
	$e\mu$	1.3	1.3	1.3	1.4	1.4
2750	e	1.4	1.4	1.4	1.4	
	μ	3.6	3.6	3.6	3.6	
	$e\mu$	1.2	1.2	1.2	1.2	1.2
3000	e	1.3	1.4	1.4	1.4	
	μ	3.4	3.4	3.4	3.4	
	$e\mu$	1.1	1.1	1.1	1.1	1.1

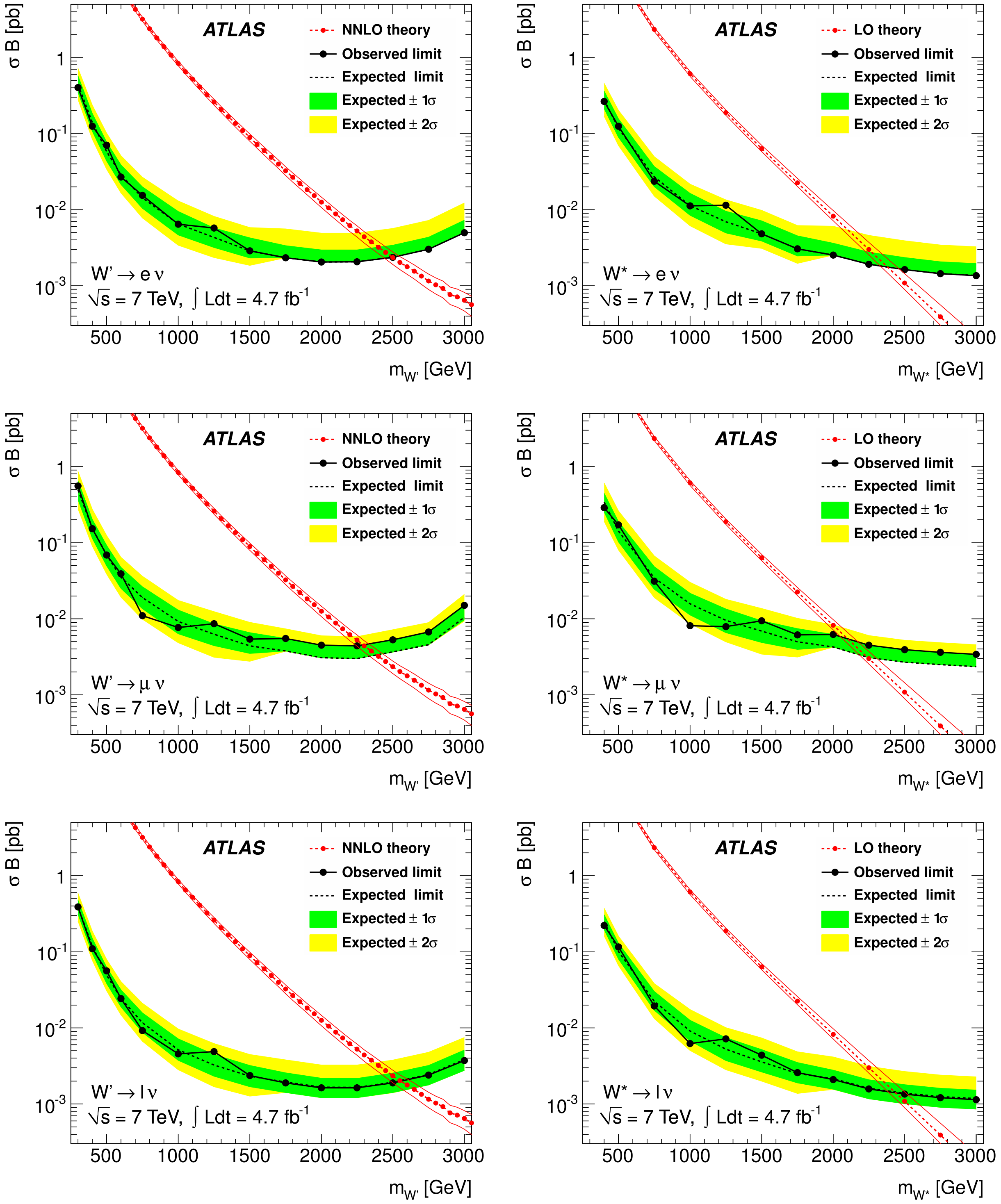

Fig. 3 Expected and observed limits on σB for $W' \to \ell\nu$ (*left*) and $W^* \to \ell\nu$ (*right*) in the electron channel (*top*), muon channel (*center*) and combined (*bottom*) assuming the same branching fraction for both channels. The calculated values for σB (NNLO for W' and LO for W^*) and their uncertainties are also shown

theoretical σB for an SSM W' and for a W^* with quark and gluon coupling strengths normalised to reproduce the W' width.

The intersection between the central theoretical prediction and the observed limits provides the 95 % CL lower limits on the mass. Table 9 presents the expected and ob-

Table 9 W' and W^* mass limits for the electron and muon decay channels and their combination. The first column is the decay channel and the following give the expected (Exp.) and observed (Obs.) mass limits for the SSM W' and for the W^* with equivalent couplings (i.e. chosen to produce the same decay width as the SSM W'). Masses below the reported limit are excluded by this search

	Mass limit [TeV]			
	W'		W^*	
	Exp.	Obs.	Exp.	Obs.
e	2.50	2.50	2.38	2.38
μ	2.38	2.28	2.25	2.09
$e\mu$	2.55	2.55	2.42	2.42

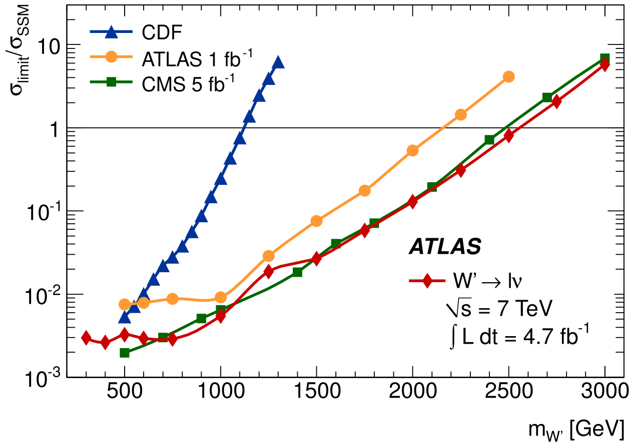

Fig. 4 Normalised cross-section limits ($\sigma_{\text{limit}}/\sigma_{\text{SSM}}$) for $W' \rightarrow \ell\nu$ as a function of mass for this measurement and from CDF, CMS and the previous ATLAS search. The cross-section calculations assume the W' has the same couplings as the SM W boson. The region above each curve is excluded at the 95 % CL

served W' and W^* mass limits for the electron and muon decay channels and their combination.

The limits presented here are a significant improvement over those reported in previous ATLAS analyses. Figure 4 shows the new and previous ATLAS σB limits for $W' \rightarrow \ell\nu$ along with the most recent results from CMS [2] and CDF [1]. Compared with the previous ATLAS results, the limits presented here cover a wider mass range and are about a factor of five lower at the upper end of the range where they overlap. Limits from CMS based on data from the same LHC run period are similar.

7 Conclusions

The ATLAS detector has been used to search for new high-mass states decaying to a lepton plus missing E_T in pp collisions at $\sqrt{s} = 7$ TeV using 4.7 fb^{-1} of integrated luminosity. No excess beyond SM expectations is observed. Bayesian limits on σB are shown in Figs. 3 and 4. A W' with SSM couplings is excluded for $m_{W'} < 2.55$ TeV at the 95 % CL and a W^* with equivalent couplings for $m_{W^*} < 2.42$ TeV.

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