Search for a heavy gauge boson decaying to a charged lepton and a neutrino in 1 fb-1 of pp collisions at √s = 7 TeV using the ATLAS detector

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Search for a heavy gauge boson decaying to a charged lepton and a neutrino in 1 fb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector ☆

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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 1.04 fb^{-1}. No excess above Standard Model expectations is observed. A W' with Sequential Standard Model couplings is excluded at the 95% confidence level for masses up to 2.15 TeV.

1. Introduction

The high-energy collisions at the CERN Large Hadron Collider provide new opportunities to search 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 [1], 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 and corresponding to a total integrated luminosity of 1.04 fb^{-1}. No W' signal is observed, and the data are used to extend current limits [2–4] on σB (cross section times branching fraction) as a function of W' mass. The significant improvement over the previous ATLAS result [4] comes mostly from the increase in available integrated luminosity, but also reflects optimization of the event selection and increased acceptance in the muon channel. A lower limit on the mass of a W' boson in the Sequential Standard Model (SSM), i.e. the extended gauge model of Ref. [5] with W' coupling to WZ set to zero, is also reported. In this model, the W' has the same couplings to fermions as the SM W boson and thus a width which increases linearly with the W' mass.

The analysis presented here identifies candidates in the electron and muon channels and sets separate limits for $W' \to e\nu$ and $W' \to \mu\nu$. In addition, combined limits are evaluated, assuming the same branching fraction for both channels. The kinematic variable used to identify the W' is the transverse mass

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

which displays a Jacobian peak that 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 $\varphi_{l\nu}$ 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 $\eta = -\ln(\tan(\theta/2))$.

The main background to the $W' \to \ell\nu$ 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 $t\bar{t}$ production which is most important for the lowest W' masses considered here, where it constitutes about 10% 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, again after final selection. These are called QCD background in the following.

2. Data

The ATLAS detector [6] 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 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

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provides three-dimensional reconstruction of particle showers. It uses liquid argon for the inner, electromagnetic compartment followed by a hadronic compartment based on scintillating tiles in the central region ($|\eta| < 1.7$) and additional 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 the events recorded with a trigger requiring the presence of an electron with $p_T >$ 20 GeV. The efficiency of this trigger is 98%. For the muon channel, matching tracks in the muon spectrometer and inner detector with combined $p_T > 22$ GeV are used to identify events. Events are also recorded if a muon with $p_T > 40$ GeV is found in the muon spectrometer. The muon trigger efficiency is 80–90% in the regions of interest.

Each energy cluster reconstructed in the electromagnetic compartment of the calorimeter with $E_T > 25$ GeV and $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$ is considered as an electron candidate if it matches with 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 (less than 2%) η-dependent energy scale correction. The resolution of the energy measurement is 2% for $E_T \approx 50$ 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 electromagnetic part of the calorimeter and 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 give about 90% identification efficiency for electrons with $E_T > 25$ GeV and a 2×10^{-4} probability to falsely identify jets as electrons before isolation requirements are imposed [7].

Muon tracks can be reconstructed independently in both the inner detector and muon spectrometer, and the muons used in this study are required to have matching tracks in both systems. The muons are required to have $p_T > 25$ GeV, where the momentum of the muon is obtained by combining the inner detector and muon spectrometer measurements. 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 currently about 15% at $p_T = 1$ 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 the electron channel is obtained from a vector sum over calorimeter cells associated with topological clusters and using local hadronic calibration [8]:

$$\mathbf{E}_T^{\text{miss}} = \mathbf{E}_{T\,\text{calo}}^{\text{miss}} = -\sum_{\text{topo}} \mathbf{E}_T^{\text{cell}}. \tag{2}$$

The topological clusters reduce contributions from electronic noise. The E_T of cells associated with the electron is corrected so their sum equals the electron E_T. Muons only deposit a small fraction of their energy in the calorimeter, and so, in the muon channel, the missing E_T is obtained from

$$\mathbf{E}_T^{\text{miss}} = \mathbf{E}_{T\,\text{calo}}^{\text{miss}} - \mathbf{p}_T^{\mu} + \mathbf{E}_T^{\mu,\text{loss}}. \tag{3}$$

The second term in this vector sum subtracts the muon transverse momentum and the last corrects for the transverse component of the energy deposited in the calorimeter by the muon, which is included in both of the first two terms. The energy loss is estimated by integrating the amount of material traversed and applying a calibrated conversion from path length to energy for each material type.

This analysis makes use of all the $\sqrt{s} = 7$ TeV data collected in March–June 2011 that satisfy data quality requirements which guarantee the relevant detector systems were operating properly. The integrated luminosity for the data used in this study is 1.04 fb^{-1} in both the electron and muon decay channels. The uncertainty on this estimate is 3.7%.

3. Simulation

Except for the QCD background, which is estimated from data, expected signal and background levels are evaluated with simulated samples and normalized using 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 [9] using MRST LO* [10] parton distribution functions (PDFs). The $t\bar{t}$ background is generated with MC@NLO 3.41 [11]. For all samples, final-state photon radiation is handled by Photos [12]. ATLAS full detector simulation [13] based on Geant4 [14] 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 but does not include interference between 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 W' widths but are not explicitly included as signal or background. At high mass ($m_{W'} > 1$ TeV), the branching fraction to any 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 [15] with MSTW2008 PDFs [16] and following the G_μ scheme [17]. Higher-order electroweak corrections (in addition to the photon radiation included in the simulation) are calculated using Horace [17,18]. 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 [19,20] 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 [21–23] assuming a top-quark mass of 172.5 GeV. The signal and most important background values for σB are listed in Table 1.

Cross-section uncertainties for $W' \to \ell\nu$ and the W/Z [7] and $t\bar{t}$ [24] backgrounds are estimated from the MSTW2008 PDF error sets, the difference between MSTW2008 and CTEQ6.6 [25] PDF sets, 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 error sets and the MSTW–CTEQ difference, in roughly equal proportion. The uncertainty on the cross section for the $W \to \ell\nu$ background varies from 5% at $m_{\ell\nu} = 500$ GeV to 19% at $m_{\ell\nu} = 2500$ GeV.

4. Event selection

Events are required to have their primary vertex reconstructed from at least three tracks with $p_T > 0.4$ GeV and longitudinal distance less than 200 mm from the center of the collision region. Due to the high luminosity, there were typically five additional interactions per event and the primary vertex is defined to be the

Table 1
Calculated values of σB for $W' \to \ell\nu$ 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 $t\bar{t}$ which is approximate-NNLO.

Process	Mass [GeV]	σB [pb]
$W' \to \ell\nu$	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	0.00234
$W \to \ell\nu$		10 460
$Z/\gamma* \to \ell\ell$ ($m_{Z/\gamma*} > 60$ GeV)		989
$t\bar{t} \to \ell X$		89.4

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 each reconstructed jet and discarding events where any jet has a shape indicating such problems, following Ref. [26]. Events are required to have exactly one candidate electron or one candidate muon satisfying the requirements described above. 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.

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 $p_T^{\mathrm{trk}} > 1$ GeV in a cone $\Delta R < 0.3$ around the muon track. The isolation requirement is $\sum p_T^{\mathrm{trk}} < 0.05 p_T$, 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.

Finally, missing E_T requirements are imposed to further suppress the QCD background. In both channels, a fixed threshold is applied: $E_T^{\mathrm{miss}} > 25$ GeV. In the electron channel, where hadronic jets may be misidentified as electrons, a threshold proportional to the electron E_T is also applied: $E_T^{\mathrm{miss}} > 0.6 E_T$.

In the electron channel, the QCD background is estimated from data using the ABCD technique [27] with the isolation energy and missing E_T serving as discriminants. Consistent results are obtained using the "inverted isolation" technique described in Ref. [4]. In the higher mass bins ($m_T > 700$ GeV) where no events remain in the estimate, the QCD background level is set to zero and assigned an uncertainty equal to 10% of the total background level, a conservative upper limit based on the QCD contribution to the electron m_T distribution.

The QCD background for the muon channel is evaluated using a non-isolated data sample following the same procedure used for the 2010 analysis [4]. With the higher statistics now available, it is clear this background is less than 1% of the total background, so it is neglected in the following.

Table 2
Expected numbers of events in 1.04 fb^{-1} from the various background sources in each decay channel for $m_T > 891$ GeV, the region used to search for a W' with a mass of 1500 GeV. The $W \to \ell\nu$ and $Z \to \ell\ell$ entries include the expected contributions from the τ-lepton. No muon events are found in the $t\bar{t}$ sample above this m_T threshold. The uncertainties are statistical.

	$e\nu$	$\mu\nu$
$W \to \ell\nu$	1.59 ± 0.13	1.36 ± 0.13
$Z \to \ell\ell$	0.00010 ± 0.00004	0.095 ± 0.005
diboson	0.08 ± 0.08	0.11 ± 0.08
$t\bar{t}$	0.08 ± 0.08	0
QCD	$0^{+0.17}_{-0}$	$0.01^{+0.02}_{-0.01}$
Total	$1.75^{+0.24}_{-0.18}$	1.57 ± 0.15

The same reconstruction and event selection are applied to both data and simulated samples. Fig. 1 shows the p_T, missing E_T, and m_T spectra for each channel after event selection for the data, for the expected background, and for three examples of W' signals at different masses. The agreement between the data and expected background is good. Table 2 shows as an example how different sources contribute to the background for $m_T > 891$ GeV, the region used to search for a W' with a mass of 1500 GeV. The $W \to \ell\nu$ background dominates. The $Z \to \ell\ell$ background is much larger in the muon channel because most of the energy of the undetected muon is not captured in the calorimeter.

5. Statistical analysis

A Bayesian analysis is performed to determine if there is significant evidence for existence of a $W' \to \ell\nu$ signal above the SM background and to set limits on that process. For each candidate mass and decay channel, events are counted above an m_T threshold, $m_T > m_{T\,\mathrm{min}}$, with the threshold chosen to maximize sensitivity. The expected number of events in each channel is

$$N_{\mathrm{exp}} = \varepsilon_{\mathrm{sig}} L_{\mathrm{int}} \sigma B + N_{\mathrm{bg}}, \tag{4}$$

where L_{int} is the integrated luminosity of the data sample and $\varepsilon_{\mathrm{sig}}$ is the event selection efficiency, i.e. the fraction of events that pass event selection criteria and have m_T above threshold. N_{bg} is the expected number of background events. Using Poisson statistics, the likelihood to observe N_{obs} events is

$$\mathcal{L}(N_{\mathrm{obs}}|\sigma B) = \frac{(L_{\mathrm{int}}\varepsilon_{\mathrm{sig}}\sigma B + N_{\mathrm{bg}})^{N_{\mathrm{obs}}} e^{-(L_{\mathrm{int}}\varepsilon_{\mathrm{sig}}\sigma B + N_{\mathrm{bg}})}}{N_{\mathrm{obs}}!}. \tag{5}$$

Uncertainties are handled by introducing Gaussian nuisance parameters θ_i, each with a probability density function (pdf) $g_i(\theta_i)$, and integrating the product of the Poisson likelihood with the pdfs. The integrated likelihood is

$$\mathcal{L}_B(N_{\mathrm{obs}}|\sigma B) = \int \mathcal{L}(N_{\mathrm{obs}}|\sigma B) \prod g_i(\theta_i)\, d\theta_i. \tag{6}$$

The nuisance parameters are taken to be the explicit dependencies: L_{int}, $\varepsilon_{\mathrm{sig}}$ and N_{bg}, with the latter evaluated at the central value of L_{int}. Correlations between the nuisance parameters are neglected. This is justified by the small effect that the nuisance parameters themselves have on the limits, as demonstrated below.

The measurements in the two decay channels are combined assuming the same branching fraction for each. Eq. (6) remains valid with the Poisson likelihood replaced by the product of the Poisson likelihoods for the two channels. The electron and muon integrated luminosity measurements are fully correlated. The selection efficiencies are uncorrelated and the background levels are partly correlated, including only the full correlation between the cross section uncertainties in the two channels. The effect of this correlation is small: if it is not included, the observed σB limits for

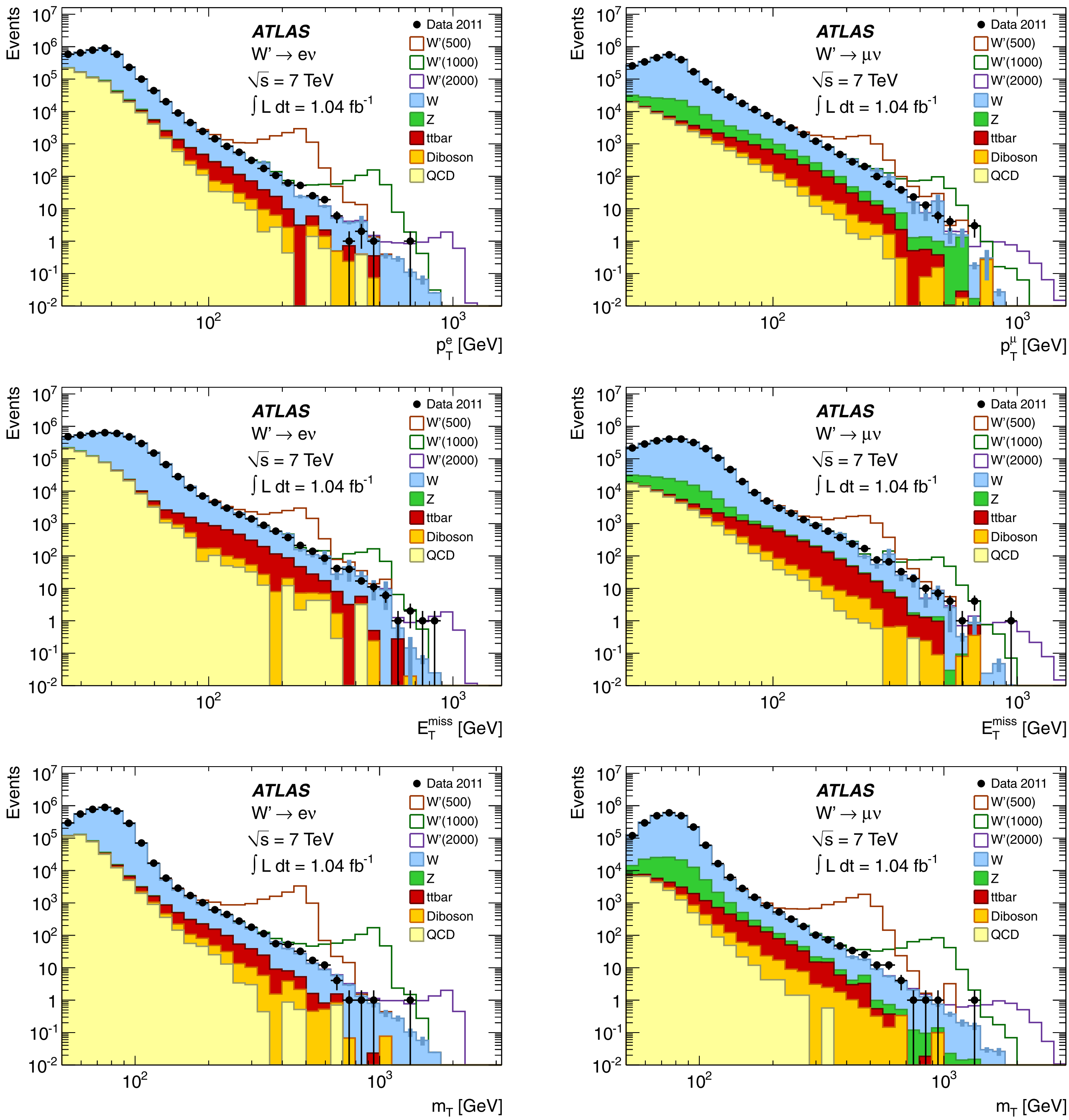

Fig. 1. Spectra of p_T (top), missing E_T (center) and m_T (bottom) for the electron (left) and muon (right) channels after event selection. The points represent data and the filled histograms show the stacked backgrounds. Open histograms are $W' \to \ell\nu$ signals added to the background with masses in GeV indicated in parentheses in the legend. The QCD backgrounds estimated from data are also shown. The signal and other background samples are normalized using the integrated luminosity of the data and the NNLO (approximate-NNLO for $t\bar{t}$) cross sections listed in Table 1.

the lowest mass points improve by 2% and those for the high-mass points are unchanged.

Bayes theorem gives the posterior probability that the $W' \to \ell\nu$ has signal strength σB:

$$P_{\text{post}}(\sigma B|N_{\text{obs}}) = N\mathcal{L}_B(N_{\text{obs}}|\sigma B)P_{\text{prior}}(\sigma B) \quad (7)$$

where $P_{\text{prior}}(\sigma B)$ is the assumed prior probability, here chosen to be one (i.e. flat in σB) for $\sigma B > 0$. The constant factor N normalizes the total probability to one. The posterior probability is evaluated for each mass and each decay channel and their combination, and then used to assess discovery significance and set a limit on σB.

6. Parameter estimation and systematics

The inputs for the evaluation of $\mathcal{L}_B$ (and hence P_{post}) are L_{int}, ε_{sig}, N_{bg}, N_{obs} and the uncertainties on the first three. Except for L_{int} and its uncertainty, these inputs are all listed in Table 3. The uncertainties on ε_{sig} and N_{bg} account for simulation statistics and all relevant experimental and theoretical effects except for the uncertainty on the integrated luminosity. The latter is included separately to allow for the correlation between signal and background. The table also lists the predicted numbers of signal events, N_{sig}, with their uncertainties accounting for the uncertainties in both ε_{sig} and the cross-section calculation.

Table 3
Inputs for the $W' \to e\nu$ and $W' \to \mu\nu$ σB limit calculations. 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 last two columns are the expected number of background events, N_{bg}, and the number of events observed in data, N_{obs}. The uncertainties on N_{sig} and N_{bg} include contributions from the uncertainties on the cross sections but not from that on the integrated luminosity

$m_{W'}$ [GeV]	$m_{T\min}$ [GeV]		ε_{sig}	N_{sig}	N_{bg}	N_{obs}
500	398	$e\nu$	0.388 ± 0.019	6930 ± 620	101.9 ± 10.8	121
		$\mu\nu$	0.252 ± 0.015	4500 ± 430	63.7 ± 6.5	91
600	447	$e\nu$	0.456 ± 0.022	3910 ± 330	62.1 ± 7.1	69
		$\mu\nu$	0.286 ± 0.016	2450 ± 220	41.8 ± 4.7	57
750	562	$e\nu$	0.429 ± 0.020	1420 ± 110	20.7 ± 3.7	20
		$\mu\nu$	0.293 ± 0.017	970 ± 79	14.3 ± 1.4	20
1000	708	$e\nu$	0.482 ± 0.022	417 ± 35	6.13 ± 0.92	4
		$\mu\nu$	0.326 ± 0.019	282 ± 26	4.98 ± 0.54	4
1250	794	$e\nu$	0.527 ± 0.024	143 ± 14	3.09 ± 0.49	3
		$\mu\nu$	0.367 ± 0.021	99 ± 10	2.87 ± 0.34	3
1500	891	$e\nu$	0.541 ± 0.026	49.6 ± 6.0	1.75 ± 0.32	2
		$\mu\nu$	0.374 ± 0.024	34.4 ± 4.4	1.57 ± 0.23	2
1750	1000	$e\nu$	0.515 ± 0.024	17.3 ± 2.4	0.89 ± 0.20	1
		$\mu\nu$	0.338 ± 0.020	11.4 ± 1.7	0.82 ± 0.14	1
2000	1122	$e\nu$	0.472 ± 0.023	6.16 ± 0.99	0.48 ± 0.10	1
		$\mu\nu$	0.323 ± 0.021	4.21 ± 0.70	0.44 ± 0.09	1
2250	1122	$e\nu$	0.415 ± 0.019	2.84 ± 0.50	0.48 ± 0.10	1
		$\mu\nu$	0.288 ± 0.018	1.97 ± 0.36	0.44 ± 0.09	1
2500	1122	$e\nu$	0.333 ± 0.018	0.81 ± 0.16	0.48 ± 0.10	1
		$\mu\nu$	0.221 ± 0.017	0.53 ± 0.11	0.44 ± 0.09	1

The maximum value for the signal selection efficiency is at $m_{W'} = 1500$ GeV. For lower masses, the efficiency falls because the relative m_T threshold, $m_{T\min}/m_{W'}$, increases to reduce the background level. For higher masses, the efficiency falls because a large fraction of the cross section goes to off-shell production with $m_{\ell\nu} \ll m_{W'}$.

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 mass. Small corrections are made to account for the difference in acceptance at NNLO (obtained from FEWZ) and that in the LO simulation. These vary from a 7% increase for $m_{W'} = 500$ GeV to a 10% decrease for $m_{W'} = 2500$ GeV. Contributions from $W' \to \tau\nu$ with the τ-lepton decaying leptonically have been neglected and would increase the W' event selection efficiencies 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 experimental systematic uncertainties include efficiencies for the electron or muon trigger, reconstruction and selection. Lepton momentum and missing E_T response, characterized 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 are too small to significantly affect the results. The uncertainty on the QCD background estimate also contributes to the background level uncertainties for the electron channel. In some cases, e.g. the missing E_T scale and the muon QCD background, the experimental systematic uncertainties are significantly reduced from the previous study [4] because the additional available data allow more precise determination. In other cases they are similar or even larger, but have little effect on the final results.

Table 4
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 trigger, reconstruction and event selection. The cross section uncertainty for ε_{sig} is that assigned to the acceptance correction described in the text. The last row gives the total uncertainties.

Source	ε_{sig}		N_{bg}	
	$e\nu$	$\mu\nu$	$e\nu$	$\mu\nu$
Efficiency	3%	4%	3%	4%
Energy/momentum resolution	-	2%	3%	1%
Energy/momentum scale	1%	1%	5%	3%
QCD background	–	–	10%	1%
Monte Carlo statistics	3%	3%	9%	10%
Cross section (shape/level)	3%	3%	10%	10%
All	5%	6%	18%	15%

Table 4 summarizes the uncertainties on the event selection efficiencies and background levels for the $W' \to \ell\nu$ signal with $m_{W'} = 1500$ GeV using $m_T > 891$ GeV.

7. Results

None of the observations for any mass in either channel or their combination has a significance above three-sigma, so there is no evidence for the observation of $W' \to \ell\nu$. Table 5 and Fig. 2 present the 95% CL (confidence level) observed limits on σB for both $W' \to \ell\nu$ decay channels and their combination. The figure also shows the expected limits and the theoretical σB for an SSM W'. The intersection between the central theoretical prediction and the observed limits provides the 95% CL lower limit on the mass. Table 6 presents the expected and observed W' mass limits for the electron and muon decay channels and for the combination of the two channels. The observed combined mass limit is 2.15 TeV.

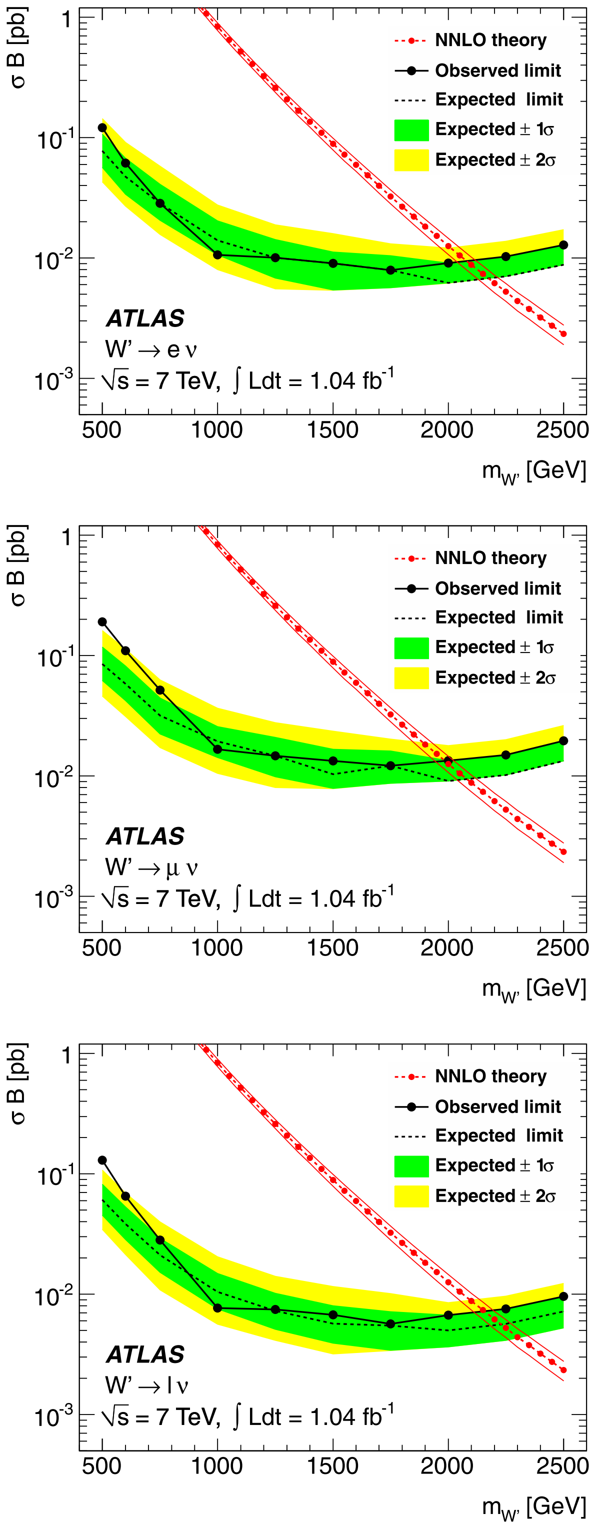

Fig. 2. Expected and observed limits on σB for $W' \to e\nu$ (top), $W' \to \mu\nu$ (center), and the combination (bottom) assuming the same branching fraction for both channels. The NNLO calculated cross section and its uncertainty are also shown.

The above results are obtained using a prior probability flat in σB. If this prior is replaced by one flat in coupling strength, the σB limits improve by 20–28% for $m_{W'} \geqslant 1000$ GeV and by smaller amounts at the lower masses. The reference prior [28,29], which minimizes the information supplied by the prior, gives intermediate results. Limits evaluated with CL_s [30] for the electron and muon channels and including all uncertainties are nearly identical to the corresponding values in Table 5.

Prior to this Letter, the best limits for $500 < m_{W'} < 800$ GeV were established by CDF [2] in $W' \to e\nu$ with $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV using an integrated luminosity of 5.3 fb^{-1}. At higher masses, the best limits were set by CMS [3] and ATLAS [4], each combining electron and muon channels and using pp collisions at $\sqrt{s} = 7$ TeV with 36 pb^{-1} of data acquired in 2010. The CDF and CMS limits were obtained with a Bayesian approach, and the earlier ATLAS results were established with CL_s. Fig. 3 compares the limits obtained here with those earlier measurements. The comparison is made using the ratio of the limit to the calculated value of σB, a quantity that is proportional to the square of the coupling strength. The NNLO cross sections in Table 1 are used

Table 5
Upper limits on σB for $W' \to \ell\nu$. The first two columns are the mass and decay channel and 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}). Columns labeled SBL include all uncertainties and are used to evaluate mass limits. Results are given for the electron and muon channels and both combined.

$m_{W'}$ [GeV]		95% CL limit on σB [fb]			
		none	S	SB	SBL
500	$e\nu$	97	98	117	121
	$\mu\nu$	171	174	186	191
	both	109	110	127	130
600	$e\nu$	49	49	59	61
	$\mu\nu$	99	100	108	110
	both	55	55	64	65
750	$e\nu$	23.0	23.1	28.1	28.5
	$\mu\nu$	49.2	49.8	50.9	51.7
	both	23.7	23.8	27.8	28.1
1000	$e\nu$	10.1	10.2	10.5	10.6
	$\mu\nu$	16.1	16.3	16.5	16.7
	both	7.3	7.3	7.6	7.7
1250	$e\nu$	9.8	9.9	10.0	10.1
	$\mu\nu$	14.4	14.5	14.6	14.7
	both	7.3	7.3	7.4	7.5
1500	$e\nu$	8.8	8.9	9.0	9.0
	$\mu\nu$	13.0	13.2	13.2	13.3
	both	6.6	6.6	6.7	6.7
1750	$e\nu$	7.8	7.9	7.9	7.9
	$\mu\nu$	12.0	12.1	12.1	12.2
	both	5.6	5.6	5.7	5.7
2000	$e\nu$	8.9	9.0	9.0	9.1
	$\mu\nu$	13.2	13.3	13.3	13.4
	both	6.6	6.7	6.7	6.7
2250	$e\nu$	10.2	10.2	10.3	10.3
	$\mu\nu$	14.8	14.9	14.9	15.0
	both	7.5	7.5	7.6	7.6
2500	$e\nu$	12.7	12.8	12.8	12.9
	$\mu\nu$	19.2	19.5	19.6	19.7
	both	9.5	9.6	9.6	9.6

Table 6
Lower limits at 95% CL on the SSM W' mass. The first column is the decay channel ($e\nu$, $\mu\nu$ or both combined) and the following columns give the expected (Exp.) and observed (Obs.) mass limits.

	$m_{W'}$ [TeV]	
	Exp.	Obs.
$e\nu$	2.17	2.08
$\mu\nu$	2.08	1.98
both	2.23	2.15

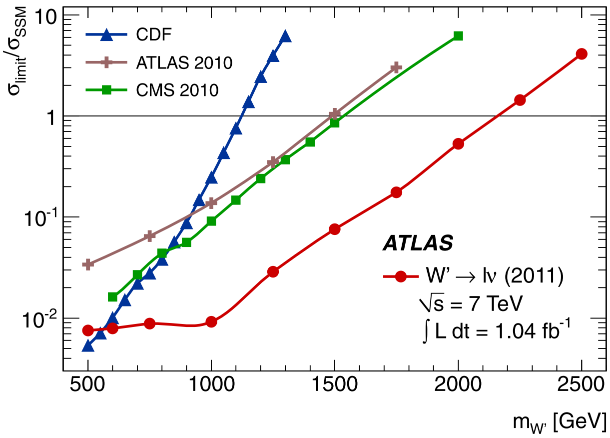

Fig. 3. Normalized cross section limits ($\sigma_{\text{limit}}/\sigma_{\text{SSM}}$) for $W' \to \ell\nu$ as a function of mass for this measurement and from CDF [2], CMS [3] and the previous ATLAS search [4]. The cross section calculations assume the W' has the same couplings as the standard model W boson. The region above each curve is excluded at the 95% CL.

for both the ATLAS and CMS points. The limits presented here provide significant improvement for masses above 600 GeV.

8. Conclusions

The ATLAS detector has been used to search for new high-mass states decaying to a lepton plus missing E_T. The search is performed in pp collisions at $\sqrt{s} = 7$ TeV using 1.04 fb^{-1} of integrated luminosity. No excess above SM expectations is observed. Bayesian limits on σB are shown in Figs. 2 and 3. These are the best published limits for $m_{W'} > 600$ GeV. A W' with SSM couplings is excluded for masses up to 2.15 TeV at the 95% CL.

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