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Search for resonant WZ production in the $WZ \to \ell\nu\ell'\ell'$ channel in $\sqrt{s} = 7$ TeV pp collisions with the ATLAS detector

The ATLAS Collaboration

Abstract

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I. INTRODUCTION

The study of electroweak boson pair production is a powerful test of the spontaneously broken gauge symmetry of the Standard Model (SM) and can be used as a probe for new phenomena beyond the SM. Heavy particles that can decay to gauge boson pairs are predicted by many scenarios of new physics, including the Extended Gauge Model (EGM) [1], Extra Dimensions [2, 3], and Technicolor models [4–6].

This paper describes the search for a resonant structure in $WZ \to \ell\nu\ell'\ell'$ ($\ell, \ell' = e, \mu$) production above 200 GeV. The dataset used corresponds to an integrated luminosity of 1.02 fb^{-1}, collected by the ATLAS detector at the Large Hadron Collider in pp collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV during the 2011 data taking. Events are selected with three charged leptons (electrons or muons) and large missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) due to the presence of a neutrino in the final state. Two benchmark models, which predict the existence of narrow heavy particles decaying into WZ, are used to interpret the results: the EGM, through heavy vector boson W' production, and the Low Scale Technicolor model (LSTC) [4], through technimeson production.

The couplings of the EGM W' boson to the SM particles are the same as those of the W boson, except for the coupling to WZ, whose strength is $g_{W'WZ} = g_{WWZ} \times m_W m_Z / m_{W'}^2$, where g_{WWZ} is the SM WWZ coupling strength, and m_W, m_Z and $m_{W'}$ are the masses of the W, Z and W' particles, respectively. Strong bounds exist on $m_{W'}$ from $W' \to \ell\nu$ searches [7–10] assuming the Sequential Standard Model (SSM) as the benchmark model, in which the W' coupling to WZ is strongly suppressed. The $W' \to WZ$ search presented in this paper is thus independent of, and complementary to, $W' \to \ell\nu$ searches. Searches for the EGM W' boson in the WZ channel have been performed at the Tevatron and W' bosons with a mass between 180 GeV and 690 GeV are excluded at 95% confidence level (CL) [11, 12].

In the LSTC model, technimesons with narrow widths are predicted which decay to WZ. Examples are the lightest vector technirho ρ_{T} and its axial-vector partner techni-a a_{T}. A previous search in the WZ decay channel has been performed by the D0 experiment and ρ_{T} technimesons with a mass between 208 GeV and 408 GeV are excluded at 95% CL under the specific mass hierarchy assumption $m_{\rho_{\mathrm{T}}} < m_{\pi_{\mathrm{T}}} + m_W$, where $m_{\rho_{\mathrm{T}}}$, $m_{\pi_{\mathrm{T}}}$ are the masses of the technirho and technipion, respectively [13].

II. THE ATLAS DETECTOR

The ATLAS detector [14] is a general-purpose particle detector with an approximately forward-backward symmetric cylindrical geometry, and almost 4π coverage in solid angle [15]. The inner tracking detector (ID) covers the pseudorapidity range of $|\eta| < 2.5$ and consists of a silicon pixel detector, a silicon microstrip detector, and a transition radiation tracker. The ID is surrounded by a thin superconducting solenoid providing a 2 T magnetic field, and by a calorimeter system covering an η range up to 4.9, which provides three-dimensional reconstruction of particle showers. For $|\eta| < 2.5$, the electromagnetic calorimeter is finely segmented and uses lead as absorber and liquid argon (LAr) as active material. The hadronic calorimeter uses steel and scintillating tiles in the barrel region, while the endcaps use LAr as the active material and copper as absorber. The forward calorimeter also uses LAr as active medium with copper and tungsten as absorber. The muon spectrometer (MS) is based on one barrel and two endcap air-core toroids, each consisting of eight superconducting coils arranged symmetrically in azimuth, and surrounding the calorimeter. Three layers of precision tracking stations, consisting of drift tubes and cathode strip chambers, allow a precise muon momentum measurement up to $|\eta| < 2.7$. Resistive plate and thin-gap chambers provide muon triggering capability up to $|\eta| < 2.4$.

III. MONTE CARLO SIMULATION

Monte Carlo (MC) simulated samples are used to model signal and background processes. Events are generated at $\sqrt{s} = 7$ TeV and the detector response simulation [16] is based on the GEANT4 program [17].

The simulation of the signals, both for the EGM W' and the LSTC ρ_{T} production, is based on the leading-order (LO) PYTHIA [18] event generator, with modified leading-order (LO*) [19] parton distribution function (PDF) set MRST2007 LO* [20]. By default, PYTHIA also includes a_{T} production, as discussed below. A mass-dependent k-factor is used to rescale the LO* PYTHIA prediction to the next-to-next-to-leading order (NNLO) cross section. The k-factor is computed using the ZWPROD program [21] in the approximation of zero-width for the resonance; its value decreases with the resonance mass from 1.17 at $m_{W'} = 200$ GeV to 1.08 at $m_{W'} = 1$ TeV.

The LSTC simulated samples correspond to the following set of parameters: number of technicolors $N_{TC} = 4$, charges of up-type and down-type technifermions $Q_U = 1, Q_D = 0$, mixing angle between technipions and electroweak gauge boson longitudinal component $\sin\chi = 1/3$. The ρ_{T} can decay both to WZ and $\pi_{\mathrm{T}}W$; if the ρ_{T} and π_{T} masses are degenerate, the branching ratio $BR(\rho_{\mathrm{T}} \rightarrow WZ)$ is 100%. Two-dimensional exclusion regions are set on the technicolor production in the ($m_{\rho_{\mathrm{T}}}$, m_{π_T}) plane. In addition, for comparison purpose with previous results [13], the relation $m_{\rho_{\mathrm{T}}} = m_{\pi_{\mathrm{T}}} + m_W$ is used when extracting one-dimensional limits on the ρ_{T} mass, which entails a value of $BR(\rho_{\mathrm{T}} \rightarrow WZ) = 98\%$. The axial-vector partner of the ρ_{T}, the a_{T}, also decays to WZ, and depending on its mass, contributes to the WZ production cross section. Two scenarios for the value of the mass of the a_{T} technimeson are considered: $m_{a_{\mathrm{T}}} = 1.1 \times m_{\rho_{\mathrm{T}}}$, which is the standard value implemented in PYTHIA, and $m_{a_{\mathrm{T}}} \gg m_{\rho_{\mathrm{T}}}$, which is simulated by removing the a_{T} contribution at the generator level.

The SM WZ production, which is an irreducible background for this search, is modeled by the MC@NLO event generator [22], which incorporates the next-to-leading-order (NLO) matrix elements into the parton shower by interfacing to the HERWIG program [23]. The underlying event is modeled with JIMMY [24]. Other SM processes that can mimic the same final state include: $ZZ \rightarrow \ell\ell\ell'\ell'$, where one of the leptons is not detected or fails the selection requirements; $Z(\rightarrow \ell\ell) + \gamma$, where the photon is misidentified as an electron; and processes with two identified leptons and jets, namely Z production in association with jets (Z+jets), $t\bar{t}$ and single top events, where leptons are present from b- or c-hadron decays or one jet is misidentified as a lepton. SM ZZ events are simulated at LO using HERWIG and $W/Z + \gamma$ production is modeled with SHERPA [25]. The cross sections for these two processes are corrected to the NLO calculation computed with MCFM [26, 27]. The W/Z+jets process is modeled at LO using ALPGEN [28], and then corrected to the NNLO cross section computed with FEWZ [29]. Single top and $t\bar{t}$ events are simulated at NLO using MC@NLO. The backgrounds due to the Z+jets, $t\bar{t}$ and single top processes (called the "$\ell\ell'$+jets" background in this paper) are estimated using data-driven methods and the corresponding MC samples mentioned above are used only for cross-checks.

IV. EVENT SELECTION

The data analyzed are required to have been selected online by a single-lepton (e or μ) trigger with a threshold of 20 GeV on the transverse energy (E_{T}) in the electron case and 18 GeV on the transverse momentum (p_{T}) in the muon case. After applying data quality requirements, the total integrated luminosity of the dataset used in this analysis is 1.02 ± 0.04 fb^{-1} [30, 31].

Due to the presence of multiple collisions in a single bunch-crossing, about 6 on average, each event can have multiple reconstructed primary vertices. The vertex having the largest sum of squared transverse momenta of associated tracks is selected as the primary vertex of the hard collision and it is used to compute any reconstructed quantity referred to the primary interaction vertex. To reduce the contamination due to cosmic rays, only events where the primary vertex of the hard collision has at least three associated tracks with $p_{\mathrm{T}} > 0.5$ GeV are considered.

Electrons are reconstructed from a combination of an ID track and a calorimeter energy cluster, with $E_{\mathrm{T}} > 25$ GeV and $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$, avoiding the transition region between the barrel and the end-cap electromagnetic calorimeters. Candidate electrons must satisfy the *medium* [32] quality definition, which is based on the calorimeter shower shape, track quality, and track matching with the calorimeter cluster. To make sure candidate electrons originate from primary interaction vertex, they are also required to have a longitudinal impact parameter ($|z_0|$) smaller than 10 mm and a transverse impact parameter (d_0) with significance ($|d_0|/\sigma_{d_0}$) smaller than 10, both with respect to the selected primary vertex. In addition, the electron is required to be isolated in the calorimeter such that the sum of the E_{T} of the clusters around the electron within a cone of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.3$ is less than 4 GeV. Corrections are applied to account for the energy deposition inside the isolation cone due to electron energy leakage and additional pile-up collisions.

Muon candidates must be reconstructed in both the ID and the MS, and the combined track is required to have $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.4$. Good quality is ensured by requiring a minimum number of silicon strip and pixel hits associated to the track. To suppress the contribution of muons coming from hadronic jets, the p_{T} sum of other tracks with $p_{\mathrm{T}} > 1$ GeV, within a cone of $\Delta R = 0.2$ around the muon track, is required to be less than 10% of the muon p_{T}. The muon candidate is required to be compatible with the selected primary vertex, with $|z_0| < 10$ mm and $|d_0|/\sigma_{d_0} < 10$.

The missing transverse momentum, $E_{\mathrm{T}}^{\mathrm{miss}}$, is reconstructed, in the range $|\eta| < 4.5$, as the negative vector sum of calorimeter cell transverse energies, calibrated to the electromagnetic scale [33], to which the transverse momenta of identified muons are added.

The $WZ \to \ell\nu\ell'\ell'$ candidate events are selected by requiring two oppositely-charged same-flavor leptons with an invariant mass within 20 GeV of the Z boson mass, plus a third lepton and $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV. The transverse mass of the reconstructed W boson, i.e. $m_{\mathrm{T}}^{W} = \sqrt{2p_{\mathrm{T}}^{\ell}E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi)}$, where p_{T}^{ℓ} is the transverse momentum of the charged lepton and $\Delta\phi$ is the opening angle between the lepton and the $E_{\mathrm{T}}^{\mathrm{miss}}$ direction in the plane transverse to the beam, is required to be greater than 15 GeV to suppress multijet background. Selected events are also required to have exactly three charged leptons to suppress the $ZZ \to \ell\ell\ell'\ell'$ background. These selection criteria define the signal region. Four decay channels $e\nu ee$, $e\nu\mu\mu$, $\mu\nu ee$ and $\mu\nu\mu\mu$ are analyzed separately and then combined. The measurement of the inclusive $pp \to WZ \to \ell\nu\ell'\ell'$ cross section has previously been reported by ATLAS [34]. This analysis goes further by using the reconstructed event properties to probe for new phenomena.

After the final selection, the transverse mass of the WZ candidates (m_{T}^{WZ}) is examined for any resonant structure. Here m_{T}^{WZ} is calculated as $m_{\mathrm{T}}^{WZ} = \sqrt{(E_{\mathrm{T}}^{Z}+E_{\mathrm{T}}^{W})^2-(p_x^Z+p_x^W)^2-(p_y^Z+p_y^W)^2}$, where E_{T}^{Z} and E_{T}^{W} are the scalar sums of the transverse energies of the decay products of the Z and W candidates, respectively. The $E_{\mathrm{T}}^{\mathrm{miss}}$ vector is used as the estimator of the transverse momentum of the neutrino arising from the W boson decay.

V. BACKGROUND ESTIMATION

The dominant background for the WZ resonance search comes from SM WZ production. Its contribution is estimated using MC simulation. Simulated events are required to pass the event selection criteria and the final yield is normalized to the integrated luminosity. Lepton reconstruction and identification efficiencies, energy scale and resolution in the MC simulation are corrected to the corresponding values measured in the data in order to improve the overall modeling. Other diboson processes such as ZZ and $Z\gamma$ are also estimated using MC simulation.

A data-driven approach is used to estimate the contribution of the $\ell\ell'$+jets background in the signal region. It is estimated by selecting a data sample containing two leptons that pass all the quality criteria requested in the lepton selection, and a lepton-like jet, which is defined as a reconstructed object that satisfies all quality criteria but fails the electron *medium* quality or the muon isolation requirement. The overall contribution is obtained by scaling each event by a correction factor f. The factor f is the ratio of the probability for a jet to satisfy the full lepton identification criteria to the probability to satisfy the lepton-like jet criteria. The factor f is measured both for muons and electrons in a dijet-enriched data sample as a function of the lepton p_{T}, and corrected for the small contribution of leptons coming from W and Z bosons decays using MC simulation.

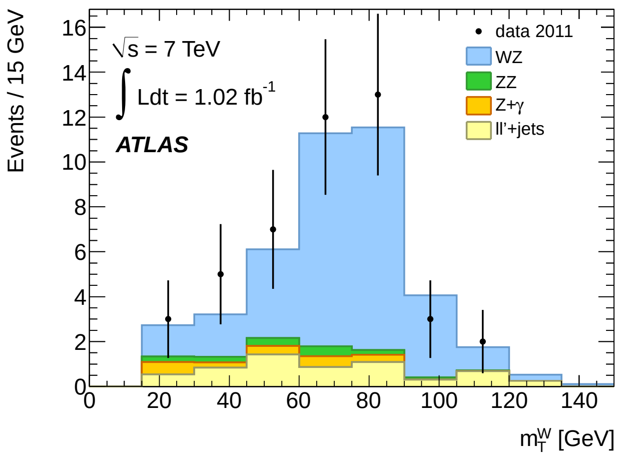
Data and SM predictions are compared in two dedicated signal-free control regions, selected by requiring the same selection criteria as used for the signal region except requiring $m_{\mathrm{T}}^{WZ} < 300$ GeV for the "SM WZ control region", and requiring $E_{\mathrm{T}}^{\mathrm{miss}} < 25$ GeV for the "$\ell\ell'$+jets control region". The SM WZ control region is used to test the modeling of the irreducible background from non-resonant WZ production, and the $\ell\ell'$+jets control region is used to assess the modeling of the $\ell\ell'$+jets background. Good agreement between data and SM predictions is found in both control regions, as shown by the transverse mass distribution of the W boson in the SM WZ control region and by the invariant mass distribution of the two leptons coming from the Z boson decay in the $\ell\ell'$+jets control region displayed in Fig. 1.

VI. SYSTEMATIC UNCERTAINTIES

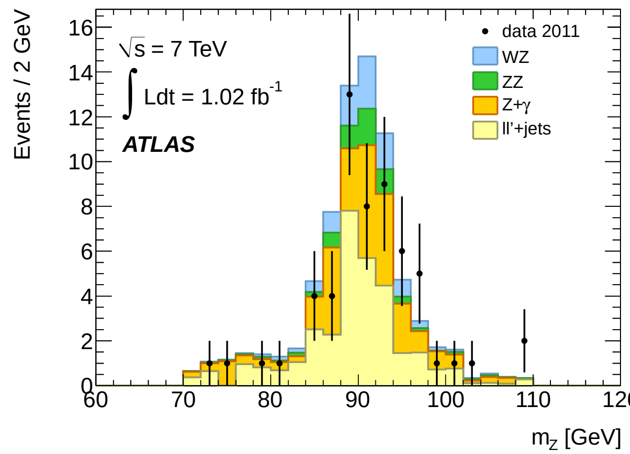
Different sources of systematic uncertainties have been considered. The first source is related to the lepton trigger, reconstruction and identification efficiencies. These efficiencies are evaluated with tag-and-probe methods using $Z \to \ell\ell$, $W \to \ell\nu$ and $J/\psi \to \ell\ell$ events [35]. Scale factors are used to correct for differences between data and MC simulation. The lepton trigger efficiency scale factors are compatible with unity and a systematic uncertainty of 1% is considered. The lepton reconstruction and identification scale factors are close to one and have a systematic uncertainty of 1.2% for the electrons and 0.5% for muons [35]. The lepton isolation efficiency uncertainties are estimated to be 2% for electrons and 1% for muons.

The second source of uncertainty is related to the lepton energy, momentum and $E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction. Additional smearing is applied to the muon p_{T} and to the electron cluster energy in the simulation, so that they replicate the $Z \to \ell\ell$ invariant mass distributions in data. The uncertainty due to the lepton resolution smearing is of the order of 0.1% [35]. The uncertainty on the $E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction receives contributions from different sources: energy deposits due to additional pp collisions which are in-time and out-of-time with respect to the bunch-crossing; energy deposits around clusters associated to reconstructed jets and electrons; energy deposits not associated to any reconstructed objects; and muon momentum uncertainties. The total systematic uncertainty on the dominant SM WZ background estimation due to the $E_{\mathrm{T}}^{\mathrm{miss}}$ uncertainties lies between (2−3)%, depending on the channel considered.

The third source of uncertainty is due to the limited knowledge of the theoretical cross sections of SM processes, used both to evaluate WZ, ZZ and $Z\gamma$ background contributions, and for subtracting contributions of W and Z leptonic decays from the dijet sample used for the measurement of the correction factor f. An un-



(a)



(b)

FIG. 1: (color online) Observed and predicted W boson transverse mass (m_{T}^{W}) distribution in the SM WZ control region (a), and dilepton invariant mass (m_Z) distribution in the $\ell\ell'$+jets control region (b).

certainty of 7% is assigned for the WZ process, 5% for the ZZ process and 8% for the $Z\gamma$ process [27], to which the MC statistical uncertainty is added in quadrature.

The fourth source of uncertainty is related to the uncertainty on the $\ell\ell'$+jets background estimation. The systematic uncertainty comes mainly from the uncertainty on f due to differences in the kinematics and flavor composition of the QCD dijet events with respect to the $\ell\ell'$+jets processes, and differences in event selection criteria for QCD dijet events and WZ candidates. The factor f is around 0.15 for muons and 0.07 for electrons over the full range of p_{T} and η, with a relative uncertainty between 5% and 20%. The estimated number of events from the $\ell\ell'$+jets background in the signal region using the data-driven method is $6.4\pm1.0(\mathrm{stat.})^{+3.2}_{-4.0}(\mathrm{syst.})$. A MC-based cross-check gives a consistent estimation of 4.3 ± 1.1(syst.) events.

The fifth source of uncertainty is related to the estimation of the signal acceptance based on MC simulation. The systematic uncertainty is mainly due to the choice of PDF and is found to be 0.6% when comparing the differences between the predictions of the nominal PDF set MRST2007 LO* and the ones given by MSTW2008 LO [36], using the standard LHAPDF framework [37]. A cross-check has been done using the NNPDF LO* [38], CT09MCS, CT09MC1 and CT09MC2 [39] PDF sets, leading to a compatible uncertainty.

Finally the luminosity uncertainty is 3.7% [30, 31].

VII. RESULTS AND INTERPRETATION

The numbers of events expected and observed after the final selection are reported in Table I. A total of 48 $WZ \to \ell\nu\ell'\ell'$ candidate events are observed in data, to be compared to the SM prediction of $45.0 \pm 1.0(\mathrm{stat.})^{+4.6}_{-5.2}(\mathrm{syst.})$ events. The expected numbers of events for a W' with a mass of 750 GeV and a ρ_{T} with a mass of 500 GeV are also reported.

The overall acceptance times trigger, reconstruction and selection efficiencies ($A \times \epsilon$) for EGM $W' \to WZ \to \ell\nu\ell'\ell'$ and the LSTC $\rho_{\mathrm{T}} \to WZ \to \ell\nu\ell'\ell'$ events as implemented in PYTHIA is shown in Table II for various WZ resonance masses. The value of $A \times \epsilon$ is 6.2% for $m_{W'} = 200$ GeV and increases to 20.5% for $m_{W'} = 1$ TeV. The corresponding $A \times \epsilon$ for the LSTC ρ_{T} is found to be slightly lower than that of the EGM W' due to the fact that the PYTHIA implementation of the $\rho_{\mathrm{T}} \to WZ$ process does not account for the polarizations of vector bosons in their decay. A massive W' boson is expected to decay predominantly to longitudinally polarized W and Z bosons, as is the ρ_{T} technimeson. While the production and decay with spin correlations is fully implemented in PYTHIA for W', spin correlation information is not considered in the decay of the W and Z bosons in the ρ_{T} case, hence they each decay isotropically in their respective rest frames. This leads to a softer lepton p_{T} spectrum and consequently lower $A \times \epsilon$. The interpretation of the data in terms of ρ_{T} production is performed in two different manners: the first uses the PYTHIA implementation of ρ_{T} production and decay, and the second assumes that $A \times \epsilon$ for the ρ_{T} is equal to that of the W'.

The transverse mass distribution of the WZ candidates is presented in Fig. 2 for data and background expectations together with possible contributions from W' and ρ_T using PYTHIA. The $\ell\ell'$+jets and $Z\gamma$ background contributions to the m_{T}^{WZ} distribution are extrapolated using exponential functions to extend over the full m_{T}^{WZ} signal region. The transverse mass distribution is used to build a log-likelihood ratio (LLR) test statistic [40], which allows the compatibility of the data with the presence of a signal in addition to the background

TABLE I: The estimated background yields, the observed number of data events, and the predicted signal yield predicted by PYTHIA for a W' boson with a mass of 750 GeV and a ρ_{T} technimeson with a mass of 500 GeV, are shown after applying all signal selection cuts, for each of the four channels considered and for their combination. For the ρ_{T} production, the relation $m_{a_{\mathrm{T}}} = 1.1 \times m_{\rho_{\mathrm{T}}}$ is used. Where one error is quoted, it includes all sources of systematic uncertainty. Where two errors are given, the first comes from the limited statistics of the data and the second includes systematic uncertainties.

	$e\nu ee$	$\mu\nu ee$	$e\nu\mu\mu$	$\mu\nu\mu\mu$	Combined
WZ	6.2 ± 0.7	7.6 ± 0.7	9.2 ± 0.8	11.6 ± 1.0	34.6 ± 3.1
ZZ	$0.25\,^{+0.07}_{-0.11}$	$0.48\,^{+0.14}_{-0.11}$	$0.37\,^{+0.15}_{-0.11}$	$0.63\,^{+0.16}_{-0.11}$	$1.7\,^{+0.5}_{-0.3}$
$Z\gamma$	1.3 ± 0.7	–	1.0 ± 0.9	–	2.3 ± 1.1
$\ell\ell'$ + jets	$1.1 \pm 0.4 \pm 0.7$	$1.3 \pm 0.5\,^{+0.6}_{-0.8}$	$3.0 \pm 0.7\,^{+1.6}_{-1.9}$	$1.0 \pm 0.4\,^{+0.5}_{-0.6}$	$6.4 \pm 1.0\,^{+3.2}_{-4.0}$
Overall backgrounds	$8.9 \pm 0.4 \pm 1.2$	$9.4 \pm 0.5\,^{+0.9}_{-1.1}$	$13.6 \pm 0.7\,^{+2.0}_{-2.3}$	$13.2 \pm 0.4\,^{+1.3}_{-1.2}$	$45.0 \pm 1.0\,^{+4.6}_{-5.2}$
Data	9	7	16	16	48
$W' \to WZ$ ($m_{W'} = 750$ GeV)	0.74 ± 0.07	0.82 ± 0.06	0.97 ± 0.06	1.10 ± 0.08	3.64 ± 0.21
$\rho_{\mathrm{T}} \to WZ$ ($m_{\rho_{\mathrm{T}}} = 500$ GeV)	0.68 ± 0.08	0.79 ± 0.08	0.97 ± 0.09	1.11 ± 0.10	3.55 ± 0.24

TABLE II: Signal $A \times \epsilon$ for $W' \to WZ \to \ell\nu\ell'\ell'$ and $\rho_{\mathrm{T}} \to WZ \to \ell\nu\ell'\ell'$ samples as implemented in PYTHIA, with statistical uncertainties. Missing values for ρ_{T} correspond to signal samples not considered.

Mass [GeV]	$A \times \epsilon$ for W' (%)	$A \times \epsilon$ for ρ_{T} (%)
200	6.2 ± 0.2	5.7 ± 0.2
250	8.2 ± 0.4	6.1 ± 0.2
300	10.0 ± 0.5	7.6 ± 0.3
350	11.6 ± 0.3	9.4 ± 0.3
400	13.2 ± 0.5	10.8 ± 0.3
450	14.5 ± 0.6	11.8 ± 0.3
500	15.9 ± 0.3	12.6 ± 0.3
550	16.9 ± 0.6	–
600	17.9 ± 0.6	13.8 ± 0.3
650	18.7 ± 0.6	–
700	19.4 ± 0.7	15.6 ± 0.4
750	19.9 ± 0.3	–
800	20.3 ± 0.7	16.1 ± 0.4
850	20.6 ± 0.7	–
900	20.6 ± 0.7	–
950	20.6 ± 0.7	–
1000	20.5 ± 0.3	–

to be assessed, in a modified frequentist approach [41]. Confidence levels for the signal plus background hypothesis, $\mathrm{CL_{s+b}}$, and background-only hypothesis, $\mathrm{CL_b}$, are computed by integrating the LLR distributions obtained from simulated pseudo-experiments using Poisson statistics. The confidence level for the signal hypothesis $\mathrm{CL_s}$, defined as the ratio $\mathrm{CL_{s+b}}/\mathrm{CL_b}$, is used to determine the exclusion limits.

The probability that the background fluctuations give rise to an excess at least as large as that observed in data has been computed as p-value $= 1 - \mathrm{CL_b}$ and is reported in Table III for the signal hypothesis of a W' particle with mass from 200 GeV to 1 TeV. Since no statistically significant excess is observed for any value of the W' mass, limits are derived on the production cross section times branching ratio ($\sigma \times BR(W' \to WZ)$) for a W' decaying to WZ, already corrected for the $A \times \epsilon$ of the leptonic decay $WZ \to \ell\nu\ell'\ell'$. The 95% CL limit on $\sigma \times BR(W' \to WZ)$ is defined as the value giving $\mathrm{CL_s} = 0.05$. The upper limit on $\sigma \times BR(W' \to WZ)$ for $pp \to W' \to WZ$ as a function of the W' mass is shown in Fig. 3(a) and the values are reported in Table III. Simulation of W' bosons is performed for $m_{W'}$ between 200 GeV and 1 TeV with a 150 to 250 GeV mass spacing, and an interpolation procedure provides m_{T}^{WZ} shape templates with a 50 GeV spacing. The m_{T}^{WZ} shapes from the fully simulated signal samples have been fitted with

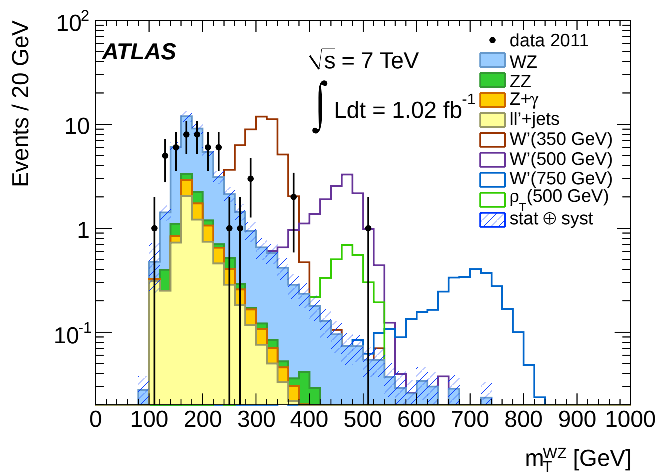


FIG. 2: (color online) Observed and predicted m_{T}^{WZ} distribution for events with all selection cuts applied. Predictions from three W' samples with masses of 350 GeV, 500 GeV and 750 GeV and a ρ_{T} sample with a mass of 500 GeV using PYTHIA are also shown.

a Crystal Ball function using RooFit [42]. The obtained Crystal Ball parameters are fitted as a function of the W' mass and the functional value for these parameters is then used to build the m_{T}^{WZ} templates for the intermediate W' mass points. The observed (expected) exclusion limit on the W' mass is found to be 760 (776) GeV.

TABLE III: Expected and observed limit on the $\sigma \times BR(W' \to WZ)$ [pb] for W' production decaying to WZ, as a function of the W' mass. The p-values are also reported.

W' Mass [GeV]	Excluded $\sigma \times BR(W' \to WZ)$ [pb]		p-value
	Expected	Observed	
200	7.31	7.62	0.43
250	5.26	6.55	0.34
300	2.74	3.38	0.28
350	1.72	2.06	0.25
400	1.18	1.48	0.25
450	0.92	1.07	0.23
500	0.76	0.93	0.21
550	0.61	0.79	0.19
600	0.54	0.63	0.26
650	0.51	0.56	0.33
700	0.48	0.53	0.34
750	0.49	0.52	0.34
800	0.45	0.50	0.37
850	0.46	0.47	0.38
900	0.50	0.50	0.39
950	0.44	0.44	0.40
1000	0.48	0.46	0.35

The observed (expected) limits on $\sigma \times BR(\rho_{\mathrm{T}} \to WZ)$ for the ρ_{T} technimeson are presented in Fig. 3(b) assuming $m_{a_{\mathrm{T}}} = 1.1 m_{\rho_{\mathrm{T}}}$ and unpolarized W and Z decays. This corresponds to an observed (expected) limit on the ρ_{T} mass of 467 (506) GeV. A limit on the ρ_{T} mass of 456 (482) GeV is obtained if $m_{a_{\mathrm{T}}} \gg m_{\rho_{\mathrm{T}}}$. Assuming $A \times \epsilon$ for the ρ_{T} signal to be equal to that of the W' signal, which is estimated by accounting for predominantly longitudinal W and Z polarization, the observed (expected) limit on the ρ_{T} mass is 483 (553) GeV for $m_{a_{\mathrm{T}}} = 1.1 m_{\rho_{\mathrm{T}}}$, and 469 (507) GeV for $m_{a_{\mathrm{T}}} \gg m_{\rho_{\mathrm{T}}}$. Table IV summarizes these limits, which all assume the relation $m_{\rho_T} = m_{\pi_T} + m_W$.

TABLE IV: Observed (expected) limit on the ρ_{T} mass with two different assumptions about $A \times \epsilon$ for ρ_{T} and two mass hierarchy assumptions between a_{T} and ρ_{T}.

	Excluded ρ_{T} mass [GeV]	
	$m_{a_{\mathrm{T}}} = 1.1 m_{\rho_{\mathrm{T}}}$	$m_{a_{\mathrm{T}}} \gg m_{\rho_{\mathrm{T}}}$
$A \times \epsilon$ from W' sample	483 (553)	469 (507)
$A \times \epsilon$ from ρ_{T} sample	467 (506)	456 (482)

Figure 4 shows the 95% CL expected and observed excluded regions in the (m_{ρ_T}, m_{π_T}) plane for $m_{a_{\mathrm{T}}} = 1.1 m_{\rho_{\mathrm{T}}}$ and $m_{a_{\mathrm{T}}} \gg m_{\rho_{\mathrm{T}}}$, respectively. Results are shown under the two assumptions on $A \times \epsilon$ for the ρ_{T} signal.

VIII. CONCLUSION

A search for resonant production of a pair of WZ bosons with three charged leptons in the final state has been performed using 1.02 fb^{-1} of data collected with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ TeV at the Large Hadron Collider. No significant excess of events is observed and upper limits are derived on the production cross section times branching ratio of new physics using the transverse mass of the WZ system. EGM W' bosons with masses up to 760 GeV are excluded at 95% CL. Using the mass hierarchy assumption $m_{\rho_{\mathrm{T}}} = m_{\pi_{\mathrm{T}}} + m_W$, LSTC ρ_{T} technimesons with masses from 200 GeV up to 467 GeV and 456 GeV are excluded at 95% CL for $m_{a_{\mathrm{T}}} = 1.1 m_{\rho_{\mathrm{T}}}$ and $m_{a_{\mathrm{T}}} \gg m_{\rho_{\mathrm{T}}}$ respectively using the PYTHIA implementation of ρ_{T} production. Assuming the kinematics of the W' production and decay are valid for the ρ_{T} technimeson, ρ_{T} with masses from 200 GeV up to 483 GeV and 469 GeV are excluded for $m_{a_{\mathrm{T}}} = 1.1 m_{\rho_{\mathrm{T}}}$ and $m_{a_{\mathrm{T}}} \gg m_{\rho_{\mathrm{T}}}$ respectively.

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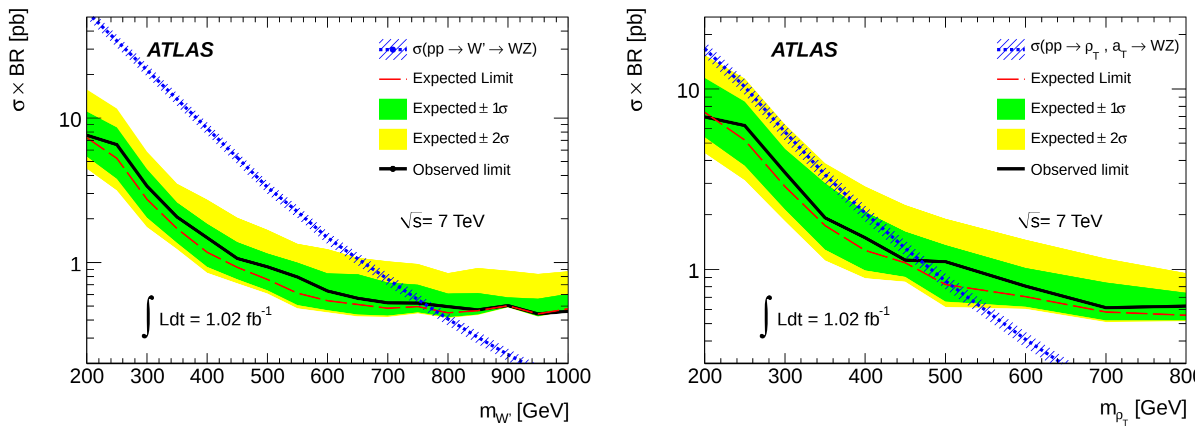
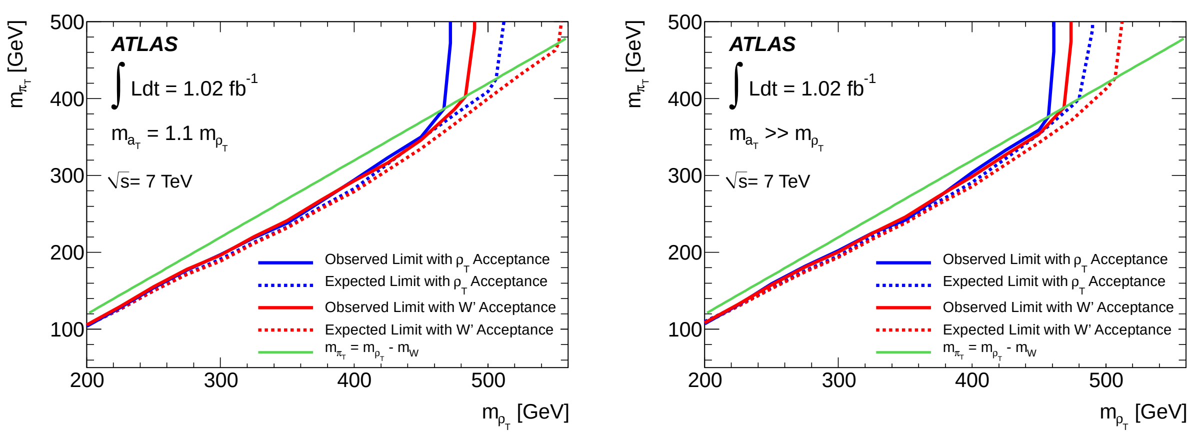


(a) (b)

FIG. 3: The observed and expected limits on $\sigma \times BR(W' \to WZ)$ for $W' \to WZ$ (a) and $pp \to \rho_T, a_T \to WZ$ (b). The theoretical prediction is shown with a systematic uncertainty of 5% due to the choice of PDF and is estimated by comparing the differences between the predictions of the nominal PDF set MRST2007 LO* and the ones given by MSTW2008 LO PDF using the LHAPDF framework. The green and yellow bands represent respectively the 1σ and 2σ uncertainty on the expected limit.



(a) (b)

FIG. 4: The 95% CL expected and observed excluded mass regions in the $(m_{\rho_{\rm T}},\, m_{\pi_{\rm T}})$ plane for $m_{a_{\rm T}} = 1.1 m_{\rho_{\rm T}}$ (a) and $m_{a_{\rm T}} \gg m_{\rho_{\rm T}}$ (b), above the curves. Two different assumptions about the $\rho_{\rm T}$ signal $A \times \epsilon$ are used: assuming a $\rho_{\rm T}$ signal where $A \times \epsilon$ is equal to that of the W' signal and assuming a $\rho_{\rm T}$ signal where $A \times \epsilon$ is obtained through its implementation in PYTHIA.

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