Measurements of Four-Lepton Production at the Z Resonance in pp Collisions at $\sqrt{s} = 7$ and 8 TeV with ATLAS

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Measurements of four-lepton (4ℓ, $\ell = e, \mu$) production cross sections at the Z resonance in pp collisions at the LHC with the ATLAS detector are presented. For dilepton and four-lepton invariant mass regions $m_{\ell^+\ell^-} > 5$ GeV and $80 < m_{4\ell} < 100$ GeV, the measured cross sections are $76 \pm 18(\text{stat}) \pm 4(\text{syst}) \pm 1.4(\text{lumi})$ fb and $107 \pm 9(\text{stat}) \pm 4(\text{syst}) \pm 3.0(\text{lumi})$ fb at $\sqrt{s} = 7$ and 8 TeV, respectively. By subtracting the nonresonant 4ℓ production contributions and normalizing with $Z \to \mu^+\mu^-$ events, the branching fraction for the Z boson decay to 4ℓ is determined to be $(3.20 \pm 0.25(\text{stat}) \pm 0.13(\text{syst})) \times 10^{-6}$, consistent with the standard model prediction.

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This Letter presents measurements of the cross sections for the inclusive production of four leptons (4ℓ, $\ell = e, \mu$) at the Z resonance in pp collisions at $\sqrt{s} = 7$ and 8 TeV using data recorded by the ATLAS detector [1] at the LHC [2]. In the standard model (SM), 4ℓ production in the Z resonance region occurs dominantly via an s-channel diagram such as that shown in Fig. 1(a) where the Z boson decay to charged leptons includes the production of an additional lepton pair from the internal conversion of a virtual Z or γ. A small fraction of 4ℓ events is produced in a t-channel process such as that shown in Fig. 1(b), which includes Z production with internal conversion of initial-state radiation. The process $gg \to Z^{(*)}Z^{(*)} \to 4\ell$ accounts for only about 10^{-3} of the total 4ℓ event rate around the Z resonance [3]. A resonant peak around the Z mass in the 4ℓ invariant mass spectrum is observed along with the nearby peak from the Higgs boson decay $H \to 4\ell$ [4,5]. A measurement of the 4ℓ production cross section at the Z resonance provides a test of the SM and a cross-check of the detector response to the 4ℓ final state from Higgs decays.

Since the interference between the resonant and nonresonant (t-channel and gg) production mechanisms is expected to be small around the Z resonance, the branching fraction of the rare decay $Z \to 4\ell$ can be determined by subtracting the expected nonresonant 4ℓ contributions from the measured 4ℓ rate. For simplicity, inclusive 4ℓ production around the Z resonance, including the nonresonant contributions, is denoted as $Z \to 4\ell$ from here on, except that the branching fraction $\Gamma_{Z\to4\ell}/\Gamma_Z$ refers to the s-channel contribution alone. The CMS Collaboration has observed the $Z \to 4\ell$ resonance in $\sqrt{s} = 7$ TeV data and determined a branching fraction, summed over the $4e$, 4μ, and $2e2\mu$ final states, of $\Gamma_{Z\to4\ell}/\Gamma_Z = (4.2^{+0.9}_{-0.8}(\text{stat}) \pm 0.2(\text{syst})) \times 10^{-6}$, where $80 < m_{4\ell} < 100$ GeV and $m_{\ell\ell} > 4$ GeV for all pairs of leptons [6]. The results presented here include the first cross-section measurement of the 4ℓ production at the Z resonance at $\sqrt{s} = 8$ TeV, and a determination of $\Gamma_{Z\to4\ell}/\Gamma_Z$ with improved statistical precision in a final phase-space region defined by the dilepton and four-lepton invariant mass requirements $m_{\ell^+\ell^-} > 5$ GeV and $80 < m_{4\ell} < 100$ GeV, where $\ell^+\ell^-$ denotes all same-flavor lepton pairs with opposite charge.

The ATLAS detector has a cylindrical geometry [7] and consists of an inner tracking detector (ID) surrounded by a 2 T superconducting solenoid, electromagnetic and hadronic calorimeters, and a muon spectrometer (MS) with a toroidal magnetic field. The ID provides precision tracking for charged particles for $|\eta| < 2.5$. It consists of silicon pixel and strip detectors surrounded by a straw tube tracker that also provides transition radiation measurements for electron identification. The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. For $|\eta| < 2.5$, the liquid-argon electromagnetic calorimeter is finely segmented and plays an important role in electron identification. The MS includes fast-trigger chambers ($|\eta| < 2.4$) and high-precision tracking chambers covering $|\eta| < 2.7$.

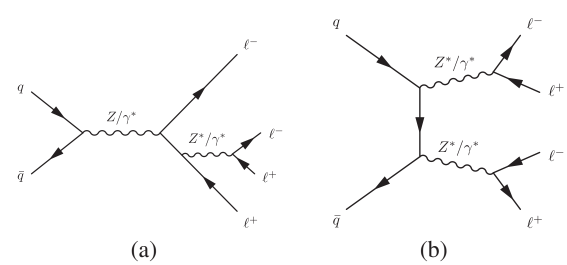

FIG. 1. Examples of (a) s-channel and (b) t-channel Feynman diagrams for 4ℓ production in pp collisions.

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The data sets for this analysis are recorded using single-lepton and dilepton triggers. The transverse momentum (p_T) thresholds of these triggers vary from 20 to 24 GeV for the single-lepton triggers and from 8 to 13 GeV for the dilepton triggers, depending on lepton flavor and data-taking period. The overall trigger efficiency for selected $Z \to 4\ell$ events ranges from 94 to 99%.

After removing the short data-taking periods having problems that affect the lepton reconstruction, the total integrated luminosity used in the analysis is 4.5 fb^{-1} at 7 TeV and 20.3 fb^{-1} at 8 TeV. The overall uncertainty on the integrated luminosity is 1.8% [8] and 2.8% [9] for the $\sqrt{s} = 7$ and 8 TeV data sets, respectively.

The POWHEG Monte Carlo (MC) program [10–12], used to calculate the signal cross sections, includes perturbative QCD corrections to next-to-leading order. The calculation also includes the interference terms between the s-channel and the t-channel as well as the interference terms between the Z and the γ^* diagrams. The CT10 [13] set of parton distribution functions (PDFs) and QCD renormalization and factorization scales of μ_R, $\mu_F = m_{4\ell}$ are used. In the $m_{\ell^+\ell^-} > 5$ GeV and $80 < m_{4\ell} < 100$ GeV phase space, the production cross sections calculated by POWHEG are 53.4 ± 1.2 fb (45.8 ± 1.1 fb) for the sum of the $4e$ and 4μ final states, and 51.5 ± 1.2 fb (44.2 ± 1.1 fb) for the $2e2\mu$ final state at 8 TeV (7 TeV). The cross sections for $4e$ and 4μ are larger than for $2e2\mu$ due to the interference between the two same-flavor lepton pairs. The cross-section uncertainties reflect theoretical uncertainties from the choice of QCD scales and PDFs. The scales are varied independently from 0.5 to 2.0 times the nominal μ_R, $\mu_F = m_{4\ell}$. The PDF uncertainties are estimated by taking the sum in quadrature of the deviations of the cross section for each PDF error set (52 CT10 eigenvectors varied by one standard deviation) and for an alternative PDF set, MSTW2008 [14], with respect to the nominal one. The expected fraction of 4ℓ events produced via the t-channel process is $(3.35 \pm 0.02)\%$ and $(3.90 \pm 0.02)\%$ for same-flavor ($4e$, 4μ) and mixed-flavor ($2e2\mu$) final states, respectively, for both 7 and 8 TeV. The $gg \to ZZ \to 4\ell$ process is modeled by GG2ZZ [15], and the 4ℓ event fraction from this process is calculated to be around 0.1%. The overall nonresonant fraction (f_{nr}) from the t-channel and gg contributions combined is $(3.45 \pm 0.02)\%$ and $(4.00 \pm 0.02)\%$ for the same-flavor and mixed-flavor final states, respectively. To generate MC events with a simulation of the detector to determine the signal acceptance, POWHEG is interfaced to PYTHIA6 [16] or PYTHIA8 [17] for showering and hadronization and to PHOTOS [18] for radiated photons from charged leptons.

The MC generators used to simulate the reducible background contributions are MC@NLO [19] (to model top productions) and ALPGEN [20] (to model Z boson production in association with jets, referred to as $Z +$ jets). These generators are interfaced to HERWIG [21] and JIMMY [22] for parton showering and underlying-event simulations. The diboson background processes WZ and $Z\gamma$, and $Z^{(*)}Z^{(*)} \to 4\ell$ decays involving $\tau \to e/\mu + 2\nu$, are modeled by POWHEG (interfaced to PYTHIA for parton showering) and SHERPA [23].

The detector response simulation [24] is based on the GEANT4 program [25]. Additional inelastic pp interactions (referred to as pile-up) are included in the simulation, and events are reweighted to reproduce the observed distribution of the average number of collisions per bunch crossing in the data.

The $Z \to 4\ell$ event selection closely follows the $H \to ZZ^* \to 4\ell$ analysis [26] with muon p_T and dilepton invariant mass requirements loosened to increase the acceptance for the $Z \to 4\ell$ process.

Muons are identified by tracks reconstructed in the MS and are matched to tracks reconstructed in the ID ($|\eta| < 2.5$). The muon momentum is calculated by combining the information from the tracking systems, correcting for the energy lost in the calorimeters. In the region $2.5 < |\eta| < 2.7$, muons can also be identified by an MS track alone (denoted stand-alone muons). The identified muons described above are required to have $p_T > 4$ GeV. In the MS gap region ($|\eta| < 0.1$) muons are identified by an ID track with $p_T > 15$ GeV associated with a compatible calorimeter energy deposit (denoted calorimeter-tagged muons).

Electrons are reconstructed from energy deposits in the electromagnetic calorimeter matched to a track in the ID [27]. Tracks associated with electromagnetic clusters are fitted using a Gaussian sum filter [28], which allows bremsstrahlung energy losses to be taken into account. For $\sqrt{s} = 8$ TeV data, improved electron discrimination from jets is obtained using a likelihood function formed from parameters characterizing the shower shape and track association, resulting in a reduction of the electron misidentification rate by more than a factor of two compared to that at 7 TeV. Electron candidates are required to have $p_T > 7$ GeV and $|\eta| < 2.47$.

Collision events are selected by requiring at least one reconstructed vertex with at least three charged particle tracks with $p_T > 0.4$ GeV. If more than one vertex satisfies the selection requirement, the primary vertex is chosen as the one with the highest $\sum p_T^2$, summed over all tracks associated with the vertex.

In order to reject electrons and muons from jets, only isolated leptons are selected, requiring the scalar sum of the transverse momenta, $\sum p_T$, of other tracks inside a cone size of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.2$ around the lepton to be less than 15% of the lepton p_T. In addition, the $\sum E_T$ deposited in calorimeter cells inside a cone size of $\Delta R = 0.2$ around the lepton direction, excluding the transverse energy due to the lepton and corrected for the expected pile-up contribution, is required to be less than 30% of the lepton p_T, reduced to 20% for electrons in the 8 TeV data

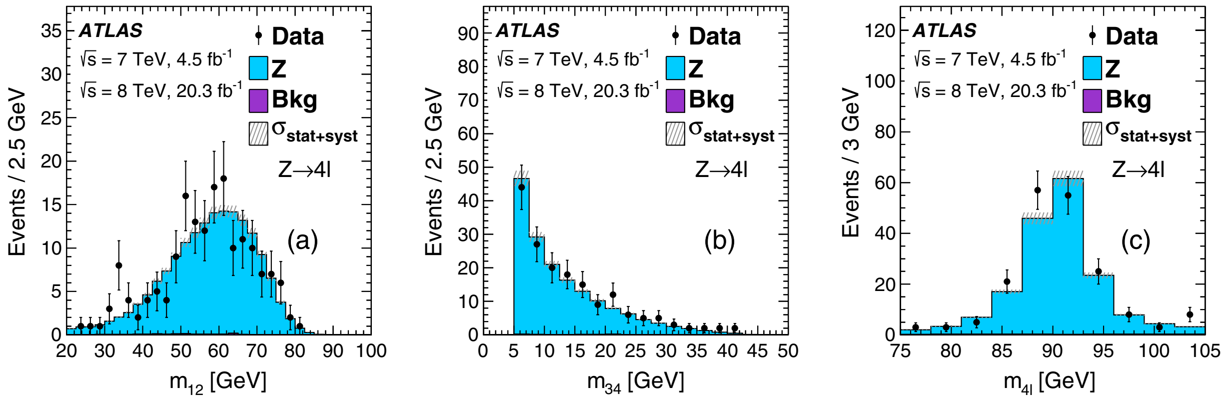

FIG. 2 (color online). Data and MC invariant mass distributions of (a) the leading lepton pair, m_{12}, (b) the subleading lepton pair, m_{34}, and (c) the four-lepton system, $m_{4\ell}$. All selections are applied except in (c) there is no $m_{4\ell}$ requirement. The background contributes $< 1\%$ of the total expected signal (invisible in the plots).

set and 15% for stand-alone muons. The impact parameter relative to the primary vertex is required to be less than 3.5 (6.0) standard deviations for all muons (electrons), where the looser electron requirement allows for tails in the electron impact parameter distribution due to bremsstrahlung in the ID.

Candidate quadruplets are formed by selecting two opposite-sign, same-flavor dilepton ($\ell^+\ell^-$) pairs in an event. The four leptons of a quadruplet are required to be well separated: $\Delta R > 0.1$ for same-flavor lepton pairs and $\Delta R > 0.2$ for $e\mu$ pairs. At most one muon is allowed to be a stand-alone muon or a calorimeter-tagged muon. The two leading leptons must have $p_T > 20$ and 15 GeV. The third lepton must have $p_T > 10\,(8)$ GeV if it is an electron (muon). One quadruplet is selected for each event, formed from the $\ell^+\ell^-$ pair with greatest invariant mass (the leading lepton pair, with mass m_{12}) and the $\ell^+\ell^-$ pair with the largest invariant mass among the remaining possible pairs (the subleading pair, with mass m_{34}). The dilepton masses must satisfy $m_{12} > 20$ GeV and $m_{34} > 5$ GeV. In the $4e$ and 4μ channels all the $\ell^+\ell^-$ pairs are required to have $m_{\ell^+\ell^-} > 5$ GeV, to reject events containing $J/\psi \to \ell^+\ell^-$ decays. The 4ℓ invariant mass is restricted to $80 < m_{4\ell} < 100$ GeV. A total of 21 and 151 $Z \to 4\ell$ candidate events are selected in the 7 and 8 TeV data sets, respectively. The distributions of m_{12}, m_{34}, and $m_{4\ell}$ are shown in Fig. 2. The number of events observed in each channel is shown in Table I, where the labeling $\ell\ell + \ell'\ell'$ indicates the leading and subleading lepton pairs.

The overall signal selection efficiency is the product of efficiency and acceptance factors, $C_{4\ell}$ and $A_{4\ell}$, respectively. The efficiency factor $C_{4\ell}$ is the ratio of the number of $Z \to 4\ell$ events passing the reconstructed event selections to the number in the fiducial region, and is determined using the signal MC samples after the detector simulation. The fiducial region, defined at the MC generator level using the lepton four-momenta, requires $p_T > 20$, 15, 10 (8), 7(4) GeV and $|\eta| < 2.5(2.7)$ of the p_T-ordered $e(\mu)$, $\Delta R(\ell, \ell') > 0.1(0.2)$ for all same(different)-flavor lepton pairs, $m_{\ell^+\ell^-} > 20$ GeV for at least one lepton pair, $m_{\ell^+\ell^-} > 5$ GeV for all same-flavor lepton pairs, and $80 < m_{4\ell} < 100$ GeV. The four-momenta of all final-state photons within $\Delta R = 0.1$ of a lepton are summed into the four-momentum of that lepton. The acceptance factor $A_{4\ell}$ is the fraction of $Z \to 4\ell$ events in the final phase space which falls into the fiducial region. The $C_{4\ell}$ uncertainty is mostly experimental and the $A_{4\ell}$ uncertainty is entirely theoretical. The $A_{4\ell}$ and $C_{4\ell}$ values are listed in Table I for each channel and data set. The $C_{4\ell}$ values for 8 TeV are larger than for 7 TeV due to a variety of factors, including electron identification improvements with better bremsstrahlung treatment and additional muon detector coverage.

The MC lepton identification and trigger efficiencies are corrected based on studies performed in data control regions. The energy and momentum scales and resolutions of the MC events are calibrated to reproduce data from $Z \to \ell^+\ell^-$ and $J/\psi \to \ell^+\ell^-$ decays. The uncertainties on the $Z \to 4\ell$ signal detection efficiency are determined by varying the nominal calibrations (including lepton energy and momentum resolutions and scales, and the trigger, reconstruction, and identification efficiencies) in the MC samples by one standard deviation. For the 8 TeV (7 TeV) analysis, the relative uncertainties on the $C_{4\ell}$ factors are 2.7% (2.7%), 3.7% (4.9%), 6.2% (9.8%), and 9.4% (14.9%) for $\mu\mu + \mu\mu$, $ee + \mu\mu$, $\mu\mu + ee$, and $ee + ee$, respectively. The major uncertainty contributions come from the lepton reconstruction and identification efficiencies. The relative uncertainties on the $A_{4\ell}$ factors, evaluated using POWHEG MC samples with the same approach for QCD scale and PDF uncertainties as described earlier, range from 1.3% to 1.7% depending on the channel.

The overall background in the selected 4ℓ event sample is estimated to be below 1%, as shown in Table I. The background contributions from diboson production are estimated, using MC simulations, to be 0.06 ± 0.01 and 0.49 ± 0.04 events in the 7 and 8 TeV data sets,

TABLE I. Summary of the observed ($N_{4\ell}^{\rm obs}$) and expected ($N_{4\ell}^{\rm exp}$) number of selected $Z\to 4\ell$ candidate events, and the estimated number of background events ($N_{4\ell}^{\rm bkg}$) in each 4ℓ channel for $\sqrt{s}=7$ and 8 TeV. The associated uncertainties are statistical and systematic combined. The central values of the acceptance and efficiency factors ($A_{4\ell}$) and ($C_{4\ell}$), the measured fiducial cross sections ($\sigma_{Z4\ell}^{\rm fid}$), and the total cross sections for $m_{\ell^+\ell^-}>5$ GeV, $80<m_{4\ell}<100$ GeV ($\sigma_{Z4\ell}$) are also presented. The fiducial regions are defined in the text and are different for each channel. The $\sigma_{Z4\ell}$ are given for same-flavor ($4e$ and 4μ), different-flavor ($2e2\mu$), and all channels combined. The uncertainties on $\sigma_{Z4\ell}^{\rm fid}$ and $\sigma_{Z4\ell}$ are the statistical and systematic uncertainties, and the uncertainty due to the luminosity measurement.

$\sqrt{s}$	4ℓ state	$N_{4\ell}^{\rm obs}$	$N_{4\ell}^{\rm exp}$	$N_{4\ell}^{\rm bkg}$	$C_{4\ell}$	$\sigma_{Z4\ell}^{\rm fid}$ [fb]	$A_{4\ell}$		$\sigma_{Z4\ell}$ [fb]
7 TeV	$ee+ee$	1	1.8 ± 0.3	0.12 ± 0.04	21.5%	$0.9^{+1.4}_{-0.7}\pm 0.14\pm 0.02$	7.5%	$4e, 4\mu$	$32\pm 11\pm 1.0\pm 0.6$
	$\mu\mu+\mu\mu$	8	11.3 ± 0.5	0.08 ± 0.04	59.2%	$3.0^{+1.2}_{-0.9}\pm 0.07\pm 0.05$	18.3%		
	$ee+\mu\mu$	7	7.9 ± 0.4	0.18 ± 0.09	49.0%	$3.1^{+1.4}_{-1.1}\pm 0.16\pm 0.05$	15.8%	$2e2\mu$	$44\pm 14\pm 3.3\pm 0.9$
	$\mu\mu+ee$	5	3.3 ± 0.3	0.07 ± 0.04	36.3%	$3.0^{+1.6}_{-1.2}\pm 0.30\pm 0.06$	8.8%		
	combined	21	24.2 ± 1.2	0.44 ± 0.14					$76\pm 18\pm 4\pm 1.4$
8 TeV	$ee+ee$	16	14.4 ± 1.4	0.14 ± 0.03	36.1%	$2.2^{+0.6}_{-0.5}\pm 0.20\pm 0.06$	7.3%	$4e, 4\mu$	$56\pm 6\pm 1.8\pm 1.6$
	$\mu\mu+\mu\mu$	71	68.8 ± 2.7	0.34 ± 0.05	71.1%	$4.9^{+0.7}_{-0.6}\pm 0.13\pm 0.14$	17.8%		
	$ee+\mu\mu$	48	43.2 ± 2.1	0.32 ± 0.05	55.5%	$4.2^{+0.7}_{-0.6}\pm 0.16\pm 0.12$	14.8%	$2e2\mu$	$52\pm 7\pm 2.4\pm 1.5$
	$\mu\mu+ee$	16	19.3 ± 1.3	0.18 ± 0.04	46.2%	$1.7^{+0.5}_{-0.4}\pm 0.10\pm 0.04$	7.9%		
	combined	151	146 ± 7	1.0 ± 0.11					$107\pm 9\pm 4\pm 3.0$

respectively. Background contributions from $Z+$jets and top-production processes are estimated from data. Such background events may contain two isolated leptons from Z decays or from W decays in top events, together with additional activity such as heavy-flavor jets or misidentified components of jets yielding reconstructed leptons. These backgrounds are estimated using a background-enriched control sample of $\ell\ell j_\ell j_\ell$ events, selected with the standard signal requirements except that lepton-like jets, j_ℓ, are selected in place of two of the signal leptons. Electron-like jets, j_e, in the $\ell\ell j_\ell j_\ell$ control sample are obtained from electromagnetic clusters matched to tracks in the ID that do not satisfy the identification criteria or isolation requirements. Muon-like jets, j_μ, are defined as muon candidates that fail the requirements on isolation. These backgrounds in the signal sample are estimated by scaling each event in the $\ell\ell j_\ell j_\ell$ control sample by $f_1\times f_2$, where the factor f_i ($i=1, 2$) for each of the two lepton-like jets depends on lepton flavor and $p_{\rm T}$. The factor f is the ratio of the probability for a jet to satisfy the signal lepton selection criteria to the probability for the jet to satisfy the lepton-like jet criteria, and is obtained from independent jet-enriched data samples dominated by $Z+$jets or $t\bar{t}$ events. The background from $Z+$jets and top processes, for all 4ℓ channels combined, is estimated to be 0.38 ± 0.14 and 0.49 ± 0.10 events for the 7 and 8 TeV data, respectively.

The numbers of signal events predicted by MC simulation are 23.8 ± 1.2 and 145 ± 7 for 7 and 8 TeV, respectively. The data and MC predictions, as shown in Fig. 2, are in good agreement. Denoting the integrated luminosity by L, the measured fiducial cross sections ($\sigma_{Z4\ell}^{\rm fid}$), determined by $(N_{4\ell}^{\rm obs}-N_{4\ell}^{\rm bkg})/(L\times C_{4\ell})$, are given in Table I. The cross section in the final phase space for each channel is calculated by $\sigma_{Z4\ell}^{\rm fid}/A_{4\ell}$. The cross sections obtained for the $ee+ee$ and $\mu\mu+\mu\mu$ channels, and for the $2e+2\mu$ and $2\mu+2e$ channels, are compatible within errors and are combined using 2×2 covariance matrices. The total 4ℓ cross section is a sum of the two combined cross sections, and the uncertainty includes correlations between the four channels. These cross sections in the final phase space are also given in Table I.

The $Z\to 4\ell$ branching fraction, $\Gamma_{Z\to 4\ell}/\Gamma_Z$, is determined by subtracting the nonresonant contributions to the selected events and normalizing the resulting yield to the observed number of $Z\to\mu^+\mu^-$ events in the same data set,

$$\frac{\Gamma_{Z\to 4\ell}}{\Gamma_Z}=\left(\frac{\Gamma_{Z\to\mu\mu}}{\Gamma_Z}\right)\frac{(N_{4\ell}^{\rm obs}-N_{4\ell}^{\rm bkg})(1-f_{\rm nr})C_{2\mu}\cdot A_{2\mu}}{(N_{2\mu}^{\rm obs}-N_{2\mu}^{\rm bkg})C_{4\ell}\cdot A_{4\ell}},$$

where $\Gamma_{Z\to\mu\mu}/\Gamma_Z=(3.366\pm 0.007)\%$ [29], $N_{2\mu}^{\rm obs}$ is around 1.7 million and 8.9 million in the 7 and 8 TeV data sets, respectively, and $(C\times A)_{2\mu}$ is $(41.4\pm 0.6)\%$ and $(41.8\pm 0.6)\%$, respectively. The background ($N_{2\mu}^{\rm bkg}$) is estimated to be around 0.3% of the selected $Z\to\mu^+\mu^-$ events. The branching fraction for $Z\to 4\ell$, summed over all $\ell=e,\mu$ final states, is determined with both the 7 and 8 TeV data sets. The measured branching fractions for each data set are consistent within uncertainties and are combined, giving

$$\Gamma_{Z\to 4\ell}/\Gamma_Z=(3.20\pm 0.25({\rm stat})\pm 0.13({\rm syst}))\times 10^{-6}$$

in the final phase-space region, where the systematic uncertainty includes a contribution (about 0.2%) due to the interference between the s-channel and t-channel processes, calculated using CALCHEP [30]. The measured branching fraction is consistent with the SM prediction of $(3.33 \pm 0.01) \times 10^{-6}$, calculated using POWHEG. For a larger final phase-space region defined by $m_{\ell^+\ell^-} > 4$ GeV and $80 < m_{4\ell} < 100$ GeV, similar to that used by CMS, the acceptance factors $A_{4\ell}$ and the nonresonant fractions $f_{\rm nr}$, and their uncertainties, are also evaluated (leaving the fiducial region unchanged), and the measured branching fraction becomes $\Gamma_{Z\to 4\ell}/\Gamma_Z = (4.31 \pm 0.34(\text{stat}) \pm 0.17(\text{syst})) \times 10^{-6}$, compared with an SM prediction of $(4.50 \pm 0.01) \times 10^{-6}$. This result is consistent with the CMS result measured with data collected from pp collisions at 7 TeV.

In summary, using data collected by the ATLAS detector corresponding to an integrated luminosity of 4.5 fb^{-1} and 20.3 fb^{-1} at $\sqrt{s} = 7$ and 8 TeV, respectively, the total $Z \to 4\ell$ production cross sections in the phase-space region $m_{\ell^+\ell^-} > 5$ GeV and $80 < m_{4\ell} < 100$ GeV are measured to be $\sigma_{Z4\ell} = 76 \pm 18(\text{stat}) \pm 4(\text{syst}) \pm 1.4(\text{lumi})$ fb at 7 TeV and $107 \pm 9(\text{stat}) \pm 4(\text{syst}) \pm 3.0(\text{lumi})$ fb at 8 TeV, consistent with the SM predictions of 90.0 ± 2.1 fb and 104.8 ± 2.5 fb, respectively. The $Z \to 4\ell$ branching fraction is determined to be $(3.20 \pm 0.25(\text{stat}) \pm 0.13(\text{syst})) \times 10^{-6}$, consistent with the SM prediction of $(3.33 \pm 0.01) \times 10^{-6}$.

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