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Measurement of the high-mass Drell-Yan differential cross-section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector
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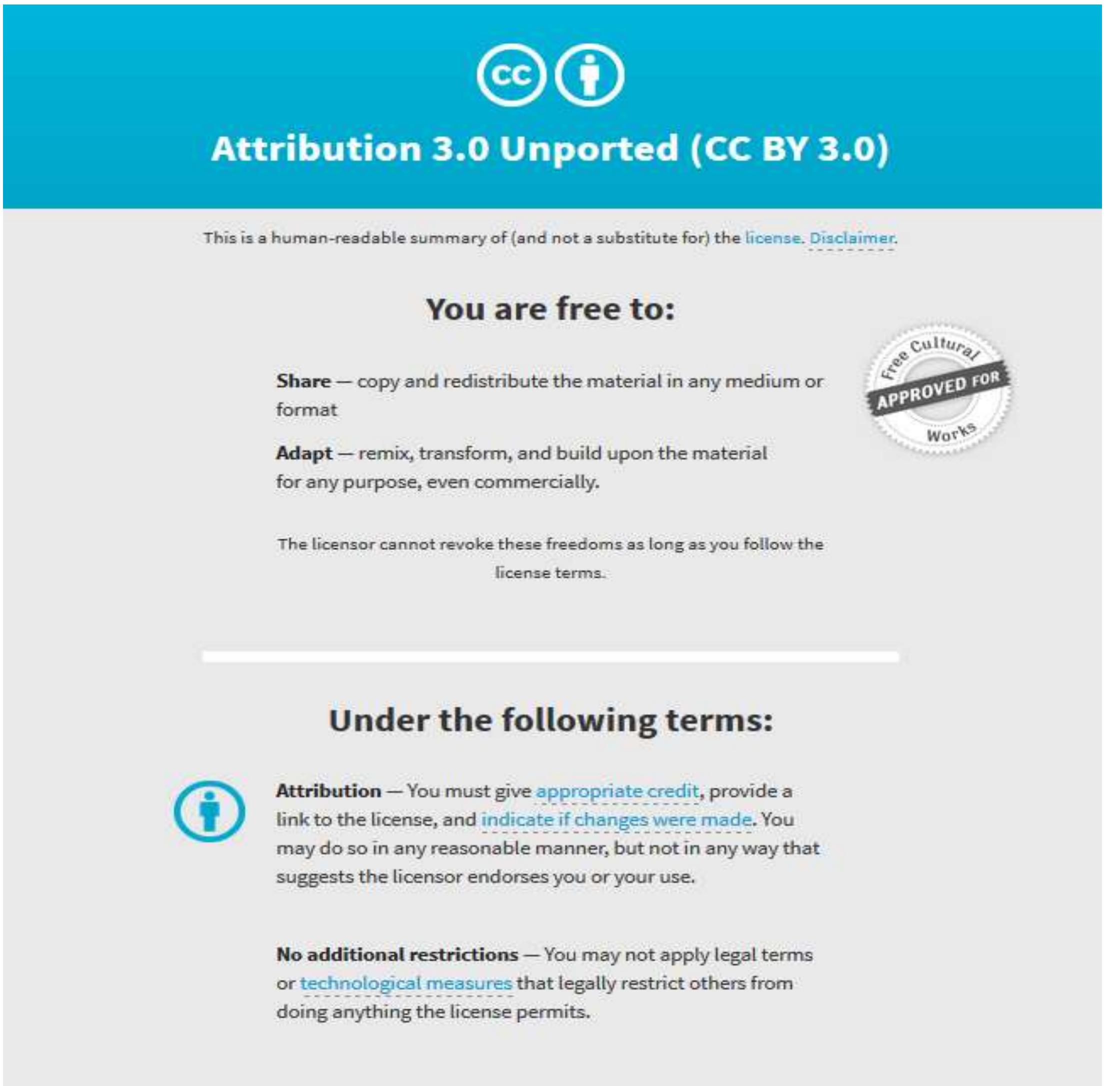

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Measurement of the high-mass Drell–Yan differential cross-section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector ☆

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ABSTRACT

This Letter reports a measurement of the high-mass Drell–Yan differential cross-section in proton–proton collisions at a centre-of-mass energy of 7 TeV at the LHC. Based on an integrated luminosity of 4.9 fb^{-1}, the differential cross-section in the $Z/\gamma^* \to e^+e^-$ channel is measured with the ATLAS detector as a function of the invariant mass, m_{ee}, in the range $116 < m_{ee} < 1500$ GeV, for a fiducial region in which both the electron and the positron have transverse momentum $p_T > 25$ GeV and pseudorapidity $|\eta| < 2.5$. A comparison is made to various event generators and to the predictions of perturbative QCD calculations at next-to-next-to-leading order.

1. Introduction

At hadron colliders, the Drell–Yan (DY) process [1], proceeding at tree level via the s-channel exchange of a virtual photon or Z boson, can produce charged lepton pairs over a wide range of invariant mass. The differential cross-section as a function of the invariant mass is described by perturbative QCD (pQCD) calculations at next-to-next-to-leading order (NNLO). Given the simple experimental signature and the low backgrounds, a small experimental uncertainty can be achieved on the measured invariant mass distribution allowing for a precision test of pQCD. The mass spectrum is also sensitive to the parton distribution functions (PDFs), in particular to the poorly known distribution of antiquarks at large x [2], where x can be interpreted, at leading order, as the fraction of the proton momentum carried by the interacting parton. Additionally, the production of DY dilepton pairs is a source of background for other Standard Model (SM) measurements, and the mass spectrum may be modified by new physics phenomena giving rise to, e.g., narrow resonances or an excess of high-mass pairs inconsistent with the known PDFs.

The differential cross-section for DY dilepton pair production in the high-mass range has been reported previously by the CMS [3], CDF [4] and D0 [5] Collaborations. With the ATLAS detector, total and differential cross-sections in a mass window of 66–116 GeV have been measured using the 2010 dataset [6]. In addition, searches for new physics in the high-mass range have been performed [7–9] and no deviations from the SM expectation were observed. This Letter reports an extension of these previous analyses by providing a measurement of the DY cross-section, fully corrected for detector effects, in the dielectron channel as a function of the e^+e^- invariant mass, m_{ee}, up to 1500 GeV. To minimise model-dependent theoretical uncertainties, the cross-section is not extrapolated to the full phase space but is reported in a phase space only slightly extended with respect to the fiducial acceptance of the e^+ and e^-. The results are compared to NNLO pQCD calculations with next-to-leading-order (NLO) electroweak corrections from the `FEWZ 3.1` [10,11] framework and to the predictions from three event generators.

2. The ATLAS detector

The ATLAS detector is described in detail in Ref. [12]. The two systems most relevant to this analysis are the inner tracking detector, surrounded by a superconducting solenoid providing a 2 T axial magnetic field, and the calorimeter. Charged-particle tracks and vertices are reconstructed with silicon pixel and microstrip detectors covering the pseudorapidity[1] range $|\eta| < 2.5$ and a straw-tube transition-radiation tracker covering $|\eta| < 2.0$. Within the region $|\eta| < 3.2$, electromagnetic calorimetry is provided by barrel and endcap detectors consisting of lead absorbers and liquid argon (LAr) as the active material, with fine lateral and longitudinal

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[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point in the centre of the detector and the z-axis coinciding with the axis of the beam pipe. The x-axis points from the interaction point to the centre of the LHC ring, and the y-axis points upward. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$, and ϕ is the azimuthal angle around the beam pipe with respect to the x-axis. The angular distance is defined as $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum and energy are defined as $p_T = p \times \sin\theta$ and $E_T = E \times \sin\theta$, respectively.

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segmentation within $|\eta| < 2.5$. The hadronic calorimeter is based on steel/scintillator tiles in the central region ($|\eta| < 1.7$) while the hadronic endcap calorimeters ($1.5 < |\eta| < 3.2$) use copper/LAr.

A three-level trigger system is used to select events. The first level is implemented in custom electronics and is followed by two software-based trigger levels. In 2011 the total output rate of events recorded for physics analysis was 200–300 Hz.

3. Simulated samples

Simulated data samples were generated in order to estimate backgrounds and correct the signal for the detector resolution, efficiency and acceptance. The `PYTHIA 6.426` [13] and `MC@NLO 4.02` [14] Monte Carlo (MC) generators were used to model the DY signal. In addition, `SHERPA 1.3.1` [15] was used to produce signal samples with up to three additional partons, and the final result of the analysis is compared to the generator-level predictions from all three programs. `MC@NLO` was also used to simulate the $t\bar{t}$ background, while `HERWIG 6.520` [16] was used for the diboson (WW, WZ or ZZ) backgrounds. `MC@NLO` was interfaced to `HERWIG` to model parton showers and fragmentation processes, and to `JIMMY 4.31` [17] for underlying event simulation. All event generators were interfaced to `PHOTOS 3.0` [18] to simulate QED final-state radiation (FSR), except for `SHERPA` which uses the method of Ref. [19].

The `PYTHIA` and `HERWIG` samples were generated using the modified leading-order (LO**) PDF set `MRSTMCal` [20] following the recommendations of Ref. [21], while the `MC@NLO` samples used the NLO `CT10` [22] set. The `SHERPA` samples used the default `CTEQ6L1` [23] PDF set of the generator.

All MC events were generated at $\sqrt{s} = 7$ TeV and include the full ATLAS detector simulation [24] based on `GEANT4` [25]. Settings of MC parameters that describe properties of minimum bias events and the underlying event were chosen based on results from previous ATLAS measurements [26]. The effects of having on average nine interactions per bunch crossing (“pile-up”) were accounted for by overlaying simulated minimum bias events. To match the measured instantaneous luminosity profile of the LHC, MC events were reweighted to yield the same distribution of the mean number of interactions per bunch crossing as measured in data.

Several independent corrections were applied to the simulated samples, for the detector response, missing higher order terms in the generation of the signal events and for the modelling of the transverse momentum spectrum of the lepton pair. The electron[2] energy resolution was corrected to match that observed in data, following Ref. [27]. In addition, the efficiencies for electrons to pass requirements on the trigger, the reconstruction, and the particle identification in the MC simulation were corrected by scale factors, defined as the ratio of the measured efficiency in data to that in the simulation. The `PYTHIA` and `MC@NLO` signal predictions were reweighted to a NNLO pQCD calculation with m_{ee}-dependent K-factors obtained from a modified version of `PHOZPR` [28]. Additionally, NLO electroweak corrections, calculated using `HORACE 3.1` [29], were applied to the `PYTHIA` MC sample. The $t\bar{t}$ sample was rescaled to its inclusive near-NNLO cross-section prediction [30,31] and the diboson samples were normalised to NLO cross-sections calculated using `MCFM` [32]. The `PYTHIA` signal MC sample was reweighted at generator level to a version that used an ATLAS tune found to yield a good agreement with the transverse momentum distribution of the Z boson observed in data [33]. This procedure gives an adequate description of the transverse momentum distribution for the high m_{ee} region studied in this analysis.

4. Event selection

The analysis is based on the full 2011 data sample collected at $\sqrt{s} = 7$ TeV. The data were selected online by a trigger that required two electromagnetic (EM) energy deposits each with a transverse energy greater than 20 GeV. Applying trigger and data-quality requirements yields an integrated luminosity of $4.9 \pm 0.1\ \text{fb}^{-1}$. Events from these pp collisions are selected by requiring a collision vertex with at least three associated tracks, each with transverse momentum greater than 400 MeV. Events are then required to have at least two electron candidates as defined below.

Electron candidates are reconstructed from the energy deposits in the calorimeter matched to inner-detector tracks. The electron energy is measured in the calorimeter and its direction from the associated track. The calorimeter energy resolution is between 1% and 2% for high-energy electrons [27]. An energy scale correction obtained from an *in situ* calibration, using W/Z boson and J/ψ meson decays, following the recipe of Ref. [27], is applied to the data. The electron candidates are required to have a transverse energy $E_T > 25$ GeV and pseudorapidity $|\eta| < 2.47$, excluding the transition regions between the barrel and endcap calorimeters at $1.37 < |\eta| < 1.52$. They must satisfy the “medium” identification criteria based on shower shape, track-quality and track–cluster matching variables, which are inclusive of the shower shape criteria applied as part of the “loose” identification [27]. Additionally, the electron candidates must have an associated hit in the innermost pixel layer to suppress background from photon conversions.

If an event contains more than two electron candidates passing the above selection, the two with highest E_T are chosen. To further reduce the background from jet production, the leading (highest E_T) electron is required to be isolated by demanding that the sum of the transverse energy in the calorimeter cells in a cone of $\Delta R = 0.2$ around the electron direction is less than 7 GeV. This sum excludes the core of the electron energy deposition and is corrected for the E_T-dependent transverse shower leakage from the core, as well as for pile-up contributions.

After all selection requirements, a total of 26 844 candidate events are found in the m_{ee} range considered. The dominant backgrounds are events containing one or two misidentified electron candidates, denoted $W+$jets and dijet. Other backgrounds arise from events containing two real electrons, originating from the dileptonic decays of pair-produced top quarks (denoted $t\bar{t}$) and from diboson production processes.

Of the dijet and $W+$jets background, the dijet component additionally contains multi-jet, heavy-flavour quark and $\gamma+$jet production. The $W+$jets includes pair-produced top quarks and single-top-quark production, where at least one electron comes from the misidentification of a jet or a heavy quark. A data-driven method is used to evaluate the sum of these components. The probability for a jet to be misidentified as an electron (the *fake rate*) is determined in an E_T- and η-dependent way from nine background-enriched samples recorded by different inclusive jet triggers. These triggers had E_T thresholds in the range 20–240 GeV, each with a different predefined rate achieved via the automatic rejection of a certain fraction of events, such that the nine samples were needed to collect sufficient background events over the full E_T range. In each of these jet-triggered samples, the fake rate is calculated as the fraction of electron candidates passing the “loose” identification requirement that also pass the “medium” requirement. Events containing electron candidates from W or Z boson decays are first removed by dedicated cuts in order to avoid bias from real electron contamination: W candidates are rejected by

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[2] In the following electron can mean either electron or positron.

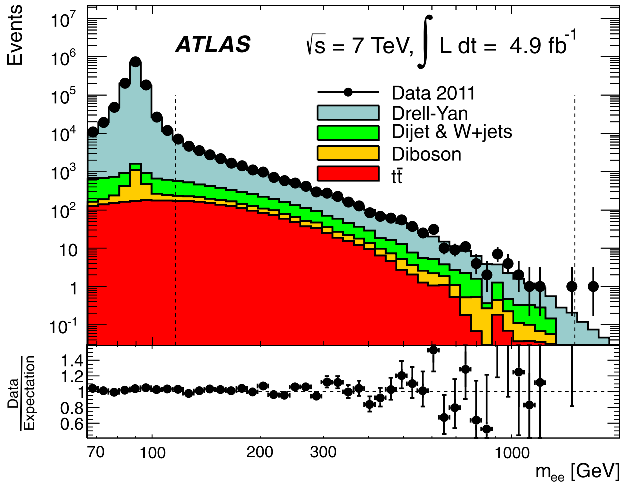

Fig. 1. Distribution of m_{ee} in data compared to the summed signal and background predictions, where the bin width is constant in $\log(m_{ee})$. The Drell–Yan signal is predicted from PYTHIA simulation and the combined dijet and $W+$jets contribution is estimated from data as described in the text. The dashed vertical lines indicate the mass range used for the differential cross-section measurement.

requiring low missing transverse energy and low transverse mass; and Z candidates are rejected if they contain two "medium" electrons. A weighted average of the fake rates obtained from the nine jet samples is then calculated. To estimate the total dijet plus $W+$jets background, a factor derived from the averaged fake rate is applied to events that pass the signal selection but with one or both electron candidates passing only the "loose" identification requirement and failing the "medium" requirement.

The $t\bar{t}$ and diboson backgrounds are estimated from MC simulation and account for up to 5% and 9% of the selected events, respectively. The overall level of agreement between data and the sum of the signal and background predictions is shown in Fig. 1.

5. Cross-section measurement

The differential cross-section, $\mathrm{d}\sigma/\mathrm{d}m_{ee}$, is measured in 13 bins of m_{ee} from 116 GeV to 1500 GeV in a fiducial region in which both electrons have transverse momentum $p_{\mathrm{T}} > 25$ GeV and lie within $|\eta| < 2.5$. The cross-section and fiducial region are determined for two conventions regarding QED FSR corrections. For the Born-level result, the true (meaning without detector simulation) m_{ee} and electron kinematics are defined by the electrons originating from the Z/γ^* decay before FSR. At the *dressed* level, true final-state electrons after FSR are recombined with radiated photons within a cone of $\Delta R = 0.1$.

The cross-section is calculated from

$$\frac{\mathrm{d}\sigma}{\mathrm{d}m_{ee}} = \frac{N_{\mathrm{data}} - N_{\mathrm{bkg}}}{C_{\mathrm{DY}} L_{\mathrm{int}}} \frac{1}{\Gamma_{\mathrm{bin}}}, \tag{1}$$

where N_{data} is the number of candidate events observed in a given bin of m_{ee} (of width Γ_{bin}), N_{bkg} is the total background in that bin and L_{int} is the integrated luminosity. The correction factor, C_{DY}, takes into account the efficiency of the signal selection and bin migration effects. It also includes the small extrapolation (about 10% to 13%) over the small region in $|\eta|$ that is excluded for reconstructed electron candidates ($1.37 < |\eta| < 1.52$ and $2.47 < |\eta| < 2.5$). The correction factor is defined as the number of MC-generated events that pass the signal selection in a bin of reconstructed m_{ee}, divided by the total number of generated events within the fiducial region, at the Born or dressed level, in the corresponding bin of true m_{ee}. It is obtained from the PYTHIA MC signal sample and corrected for differences in the reconstruction, identification and trigger efficiencies between data and MC simulation. The value of C_{DY} varies from 0.55 (0.57) in the lowest bin to 0.70 (0.73) in the highest bin at the Born (dressed) level.

The m_{ee} resolution varies from approximately 3% at low m_{ee} to 1% at high m_{ee}. The purity, defined as the fraction of simulated events reconstructed in a given m_{ee} bin that have true m_{ee} in the same bin, ranges from 79% (82%) to 98% (98%) at the Born (dressed) level.

6. Systematic uncertainties

The main contributions to the systematic uncertainties are given in Table 1 and described below.

6.1. *Background estimation*

In the estimation of the dominant dijet and $W+$jets background, a systematic uncertainty of 11% is assigned to the E_{T}- and η-dependent fake rate, corresponding to the spread of this quantity as measured in the nine independent jet samples, in order to cover any possible bias introduced in the triggering of these background events. A further uncertainty on the fake rate of up to 11% arises due to the presence of remaining signal contamination in the background-enriched sample.

The total systematic uncertainty on the fake rate combines with a smaller effect (around 5%) from signal contamination in the sample where the fake rate is applied, to give a total uncertainty on the resulting background estimate of up to 16%. An additional systematic uncertainty can arise if the fake rate differs for different sources of fake electrons and the relative contribution of the different sources is not the same in the data sample where the fake rate is measured and the sample of events to which it is applied. It is found that b-jets have a higher fake rate than jets initiated by gluons or light quarks, but that the fraction of b-jets is small and similar in both samples. Conservatively taking this additional source of uncertainty into account, the overall uncertainty on the background is enlarged to 20%.

This 20% is added in quadrature to the statistical uncertainty of the sample to which the fake rate is applied; the latter uncertainty dominates in the highest two m_{ee} bins. The resulting overall uncertainty on the cross-section from the dijet and $W+$jets background varies between 1.3% and 7.9%, depending on m_{ee}.

Two alternative methods to estimate the dijet and $W+$jets background are considered as cross-checks. The first of these is similar to the baseline method but uses fake rates derived from loosely selected electrons collected by the EM signal trigger. Here the background-enriched sample is derived by employing a tag-and-probe technique selecting, among other requirements to suppress real electron contamination, a jet-like tag and a probe with the same charge. This method, being correlated to the baseline method due to the overlap of electron candidates passing the EM and jet triggers, yields very similar predictions with comparable systematic uncertainties. In the third method, the combined dijet plus $W+$jets background is estimated by performing a template fit to the isolation of the leading versus sub-leading electron. The background templates are obtained from data by reversing some of the identification requirements on one or both of the electrons, and the signal templates are made from the PYTHIA DY sample. No additional systematic uncertainty is assigned from the two cross-checks, as their results are in agreement with the baseline method.

The uncertainties on the diboson and $t\bar{t}$ background expectations include the theoretical uncertainties on their cross-sections, 5% for the dibosons [30] and 10% for $t\bar{t}$ [31]. At high m_{ee}, the statistical uncertainties on the simulated samples dominate,

Table 1

Summary of systematic uncertainties on the cross-section measurement, shown for the lowest and highest bin in m_{ee}. For some sources the lowest or highest uncertainty may lie in an intermediate bin. The data statistical uncertainties are also given for comparison.

Source of uncertainty	Uncertainty [%] in m_{ee} bin	
	116–130 GeV	1000–1500 GeV
Total background estimate (stat.)	0.1	7.6
Total background estimate (syst.)	1.3	3.1
Electron energy scale & resolution	2.1	3.3
Electron identification	2.3	2.5
Electron reconstruction	1.6	1.7
Bin-by-bin correction	1.5	1.5
Trigger efficiency	0.8	0.8
MC statistics (C_{DY} stat.)	0.7	0.4
MC modelling	0.2	0.3
Theoretical uncertainty	0.3	0.4
Total systematic uncertainty	4.2	9.8
Luminosity uncertainty	1.8	1.8
Data statistical uncertainty	1.1	50

exceeding 50% in the highest bin for both processes. The resulting uncertainty on the cross-section is small compared to the data-driven dijet and $W+$ jets contributions, ranging from less than 0.3% at low m_{ee} to 2.0% in the highest m_{ee} bin. The uncertainty on the cross-section from the total background expectation is between 1.3% and 8.2%.

6.2. *Electron reconstruction and identification*

The reconstruction and identification efficiencies of electrons have been determined previously from data for electrons with E_T up to 50 GeV, using tag-and-probe methods in vector-boson decays, following the prescription of Ref. [27]. To extend the measurement range of the identification efficiency in E_T, a dedicated tag-and-probe measurement is made using $Z \to e^+e^-$ decays. It employs the isolation method, developed in Ref. [27] for $W \to e\nu$ final states, to estimate the background contamination. Here, η- and E_T-dependent background template distributions of the isolation are obtained from data by reversing some of the requirements applied in the electron identification criteria. The isolation quantity is defined in a similar way to that used in the selection of the leading electron in the signal sample. The background isolation templates are then normalised to data in the tail of the distributions where no contribution from signal is expected, both before and after applying the identification requirements, in order to estimate the background fraction in the probe sample. The identification efficiencies are found to be consistent with those obtained by the method of Ref. [27] in the common measurement range, and are stable for electrons with E_T up to 500 GeV.

The differences between the measured reconstruction and identification efficiencies and their values in MC simulation are taken as η- and E_T-dependent scale factors with which the MC-derived C_{DY} is corrected. An additional scale factor for the isolation requirement on the leading electron is also applied. Varying the scale factors for the electron reconstruction (identification) within their systematic uncertainties results in a change in the cross-section of up to 1.7% (2.6%).

6.3. *Energy scale and resolution*

Both the scale and resolution corrections, estimated from $Z \to e^+e^-$ events, are varied in the simulation within their uncertainties. The overall effect on the cross-section is between 1.0% and 3.3%.

Table 2

Measured differential cross-sections $\frac{d\sigma}{dm_{ee}}$ (in pb/GeV) at the Born and dressed levels for DY production of e^+e^- pairs in the fiducial region (electron $p_T > 25$ GeV and $|\eta| < 2.5$) with statistical (stat.) and systematic (syst.) uncertainties in %. The 1.8% luminosity uncertainty is not included.

m_{ee} [GeV]	$\frac{d\sigma}{dm_{ee}}$ (Born)	$\frac{d\sigma}{dm_{ee}}$ (dressed)	Stat. err. [%]	Syst. err. [%]
116–130	2.24×10^{-1}	2.15×10^{-1}	1.1	4.2
130–150	1.02×10^{-1}	9.84×10^{-2}	1.4	4.3
150–170	5.12×10^{-2}	4.93×10^{-2}	2.0	4.6
170–190	2.84×10^{-2}	2.76×10^{-2}	2.7	4.7
190–210	1.87×10^{-2}	1.82×10^{-2}	3.0	5.3
210–230	1.07×10^{-2}	1.04×10^{-2}	4.4	6.1
230–250	8.23×10^{-3}	7.98×10^{-3}	5.2	5.9
250–300	4.66×10^{-3}	4.52×10^{-3}	4.3	5.8
300–400	1.70×10^{-3}	1.65×10^{-3}	5.1	5.9
400–500	4.74×10^{-4}	4.58×10^{-4}	9.4	6.3
500–700	1.46×10^{-4}	1.41×10^{-4}	11	5.7
700–1000	2.21×10^{-5}	2.13×10^{-5}	24	7.5
1000–1500	2.88×10^{-6}	2.76×10^{-6}	50	9.8

6.4. *Bin-by-bin correction*

The results obtained from the bin-by-bin correction are cross-checked using an iterative Bayesian approach [34] and found to be consistent. In addition, a consistency test is performed by correcting the `MC@NLO` signal sample using the `PYTHIA`-derived C_{DY} factor. The discrepancy between the sample corrected in this way and the true `MC@NLO` sample is about 1.5%. This is due to the slightly different shapes of the m_{ee} distribution from the two generators, considered to represent the possible shape difference between data and the `PYTHIA` simulation. This is conservatively added as a systematic uncertainty on the cross-section in all m_{ee} bins.

6.5. *Trigger efficiency*

Scale factors to account for the difference in the EM signal-trigger efficiency between data and simulation are obtained by measuring the efficiency in data and MC events using a tag-and-probe method. The $Z \to e^+e^-$ events are tagged by selecting events passing a single-electron trigger, thus providing one electron probe free of trigger bias to test against the signal-trigger requirements. The scale factors are very close to unity, and the effect on the cross-section of varying them within their systematic uncertainties is approximately 1%.

6.6. *MC statistics and MC modelling*

The finite number of events in the MC samples from which the C_{DY} factor is derived contribute an uncertainty of up to 2.4% on C_{DY} and the computed cross-section. Systematic uncertainties are associated with the use of the K-factors and with the reweighting of the `PYTHIA` signal MC events in order to better match the transverse momentum distribution of the Z bosons and the mean number of interactions per bunch crossing in the data. The effect of a further reweighting of the vertex position distribution in the z direction, not applied by default when calculating C_{DY}, is also taken as an uncertainty. These uncertainties enter into the calculation of C_{DY} and result in an overall uncertainty on the cross-section of less than 1%. Excellent agreement in the FSR predictions between `PHOTOS` and `SANC` [35,36] has been shown [37] and uncertainties related to the modelling of the detector response to low-energy photons from FSR are negligible.

6.7. *Theoretical uncertainties*

Several theoretical uncertainties apply to the extrapolation of the cross-section in $|\eta|$ from the measured region to the fiducial region and thus contribute to an additional uncertainty on C_{DY}. To evaluate the effect of the choice of PDF, the calculation of C_{DY} using PYTHIA with its default PDF (MRSTMCal) is compared to that obtained after reweighting to CT10 (NLO) and HERAPDF1.5 [38] (NLO). The largest difference between the reweighted results and the default is taken as the systematic uncertainty, and amounts to 0.2%. A further systematic uncertainty is calculated using the MC@NLO sample reweighted to the 52 CT10 eigenvector error sets, the result being 0.5% at most. Finally, comparisons are made between PYTHIA reweighted to the CT10 PDF and MC@NLO (which uses as default CT10), and cross-checked using FEWZ 2.1 at NLO using the CT10 PDF. The effect is at most 0.3%. These systematic uncertainties, which each have a different dependence on m_{ee}, are added in quadrature and together give a 0.2–0.5% uncertainty on the cross-section.

The contributions from the above sources of systematic uncertainty to the uncertainty on the measured cross-section are summarised in Table 1 for the lowest and highest bin in the m_{ee} range considered. The overall systematic uncertainty, excluding the luminosity uncertainty of 1.8% [39], rises from 4.2% in the lowest m_{ee} bin to 9.8% in the highest m_{ee} bin. The data statistical uncertainties increase from 1.1% to 50%.

7. Results and comparison to theory

The cross-sections obtained in the fiducial region (electron $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$) at the Born and dressed levels are given in Table 2. The difference between the two results is at most 4%. The precision of the measurement is limited by the statistical uncertainty on the data for $m_{ee} > 400$ GeV.

Fig. 2 shows the results at the dressed level, where they are compared to the predictions from PYTHIA, MC@NLO and SHERPA. No corrections have been applied to the generator-level predictions; instead, the prediction of each generator has been scaled globally to match the total number of events observed in data. The resulting scale factors are 1.23 for PYTHIA, 1.08 for MC@NLO and 1.39 for SHERPA. As expected, the only prediction at NLO in pQCD, from the MC@NLO generator, yields the scale factor closest to unity. The overall shape of the m_{ee} distribution from all three generators is consistent with the data.

Fig. 3 shows the differential cross-section at the Born level compared to calculations in the FEWZ 3.1 framework using various recent NNLO PDFs. The FEWZ 3.1 framework allows the (N)NLO QCD corrections to lepton pair production to be combined with the NLO electroweak corrections. It has been verified at NLO in QCD that the choice of the electroweak scheme, G_μ or $\alpha(m_Z)$ as introduced in Ref. [40], has an effect of at most 0.4% on the calculated cross-section after applying NLO electroweak corrections. The electroweak-corrected NNLO QCD predictions shown are calculated using the G_μ scheme. The electroweak corrections include a positive contribution from the irreducible, non-resonant photon-induced background, i.e., $\gamma\gamma \to e^+e^-$. This contribution is estimated at leading order (LO) using the MRST2004qed [41] PDF, currently the only set available that includes QED corrections to the proton PDF, by taking the average of the predictions obtained under the current and constituent quark mass schemes. The symmetric difference between the average and either scheme is assigned as the corresponding uncertainty on this additive correction, being approximately 50% and representing a 3% uncertainty on the cross-section prediction in the highest m_{ee} bin. The electroweak and photon-induced corrections were verified by SANC [35,36]. An additional small correction arises from single-boson production in which the final-state charged lepton radiates a real W or Z boson [42]. This is estimated using MADGRAPH 5 [43], following the prescription outlined in Ref. [42], to be at most 2%, in the highest m_{ee} bin.

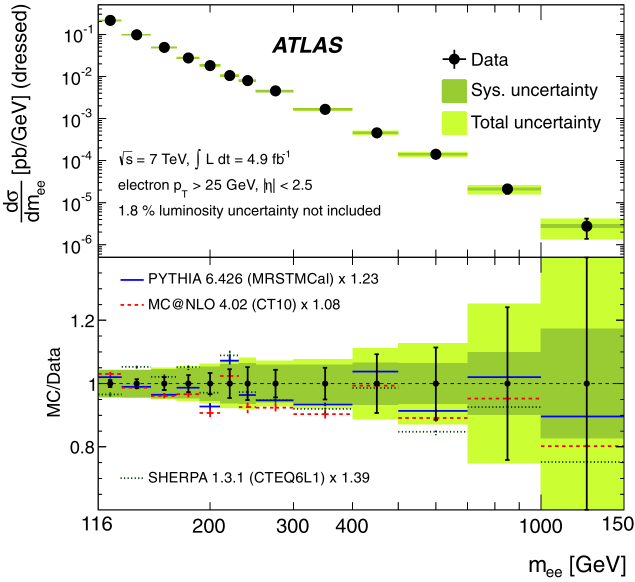

Fig. 2. Measured differential cross-section at the dressed level within the fiducial region (electron $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$) with statistical (error bars), systematic (dark shaded), and combined statistical and systematic (total, light shaded) uncertainties, excluding the 1.8% uncertainty on the luminosity. In the lower panel, the measurement is compared to the predictions of the PYTHIA, MC@NLO and SHERPA MC generators including their statistical uncertainties. No corrections have been applied to the cross-section predictions of the generators. Instead, the predictions of each generator have been scaled by a global factor as indicated on the ratio plots to match the total number of events observed in data.

It can be seen in Fig. 3 that the deviations between the MSTW2008 [2] and the CT10 [22], HERAPDF1.5 [38] and NNPDF2.3 [44] predictions are covered by the total uncertainty band assigned to the MSTW2008 prediction, which is dominated by the combined 68% confidence level (CL) PDF and α_s variation. At low m_{ee} the ABM11 [45] prediction lies above this theoretical uncertainty band, in part due to the ABM11 PDF set using a value of α_s outside of the 68% CL variation. The renormalisation and factorisation scale uncertainties contribute at most 1% to the theoretical uncertainty band in the highest m_{ee} bin, having been evaluated by varying both scales up or down together by a factor of two, using VRAP [46]. The size of the photon-induced contribution is similar to the sum of the PDF, α_s and scale uncertainties as can be seen in the lower panel of Fig. 3(left), where the nominal calculation using the MSTW2008 PDF set is compared to the case where this contribution is not taken into account.

In the region where the precision of the measurement is limited by systematic uncertainties, $m_{ee} < 400$ GeV, the data generally lie above the FEWZ calculations. However, assuming that all systematic uncertainties, except those of statistical origin on the background and on C_{DY} (Table 1), are fully correlated bin-to-bin, the comparison between data and the different predictions over the full mass range yields chi-squared values of 13.9 for MSTW2008, 18.9 for CT10, 13.5 for HERAPDF1.5, 14.7 for ABM11 and 14.8 for NNPDF2.3, for the 13 data points, indicating compatibility between the theory and data.

8. Summary

Using 4.9 fb^{-1} of data from pp collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV, the invariant mass distribution of e^+e^- pairs from DY production has been measured at ATLAS in the range $116 < m_{ee} < 1500$ GeV, for electrons with $p_{\mathrm{T}} > 25$ GeV and

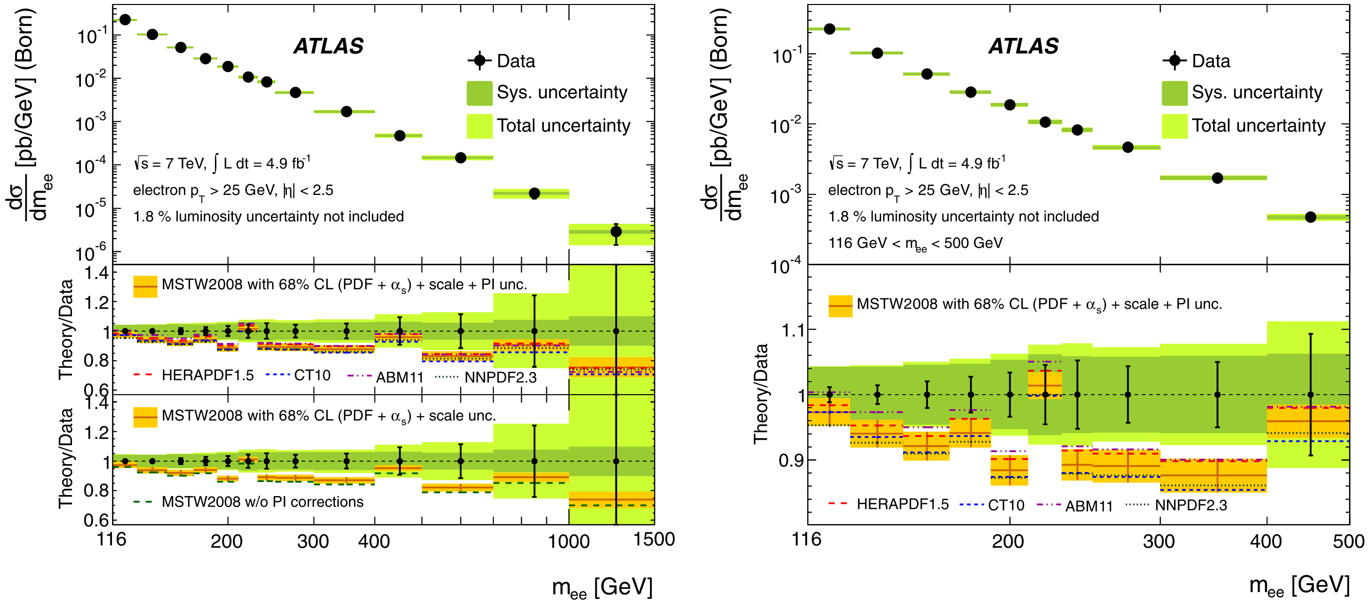

Fig. 3. Measured differential cross-section at the Born level within the fiducial region (electron $p_T > 25$ GeV and $|\eta| < 2.5$) with statistical (error bars), systematic (dark shaded), and combined statistical and systematic (total, light shaded) uncertainties, excluding the 1.8% uncertainty on the luminosity. The measurement is compared to `FEWZ 3.1` calculations at NNLO QCD with NLO electroweak corrections using the G_μ electroweak parameter scheme. The predictions include an additional small correction from single-boson production in which the final-state charged lepton radiates a real W or Z boson. On the left, in the upper ratio plot, the photon-induced (PI) corrections have been added to the predictions obtained from the `MSTW2008`, `HERAPDF1.5`, `CT10`, `ABM11` and `NNPDF2.3` NNLO PDFs, and for the `MSTW2008` prediction the total uncertainty band arising from the PDF, α_s, renormalisation and factorisation scale, and photon-induced uncertainties is drawn. The lower ratio plot shows the influence of the photon-induced corrections on the `MSTW2008` prediction, the uncertainty band including only the PDF, α_s and scale uncertainties. On the right, the results are shown for a restricted range of m_{ee}.

$|\eta| < 2.5$. Comparisons have been made to the predictions of the `PYTHIA`, `MC@NLO` and `SHERPA` MC generators, after scaling them globally to match the total number of events observed in data. The MC predictions are consistent with the shape of the measured m_{ee} distribution. The predictions of the `FEWZ 3.1` framework using five PDF sets at NNLO have also been studied. The framework combines calculations at NNLO QCD with NLO electroweak corrections, to which LO photon-induced corrections and real W and Z boson emission in single-boson production have been added. The resulting predictions for all PDFs are consistent with the measured differential cross-section, although the data are systematically above the theory. The data have the potential to constrain PDFs, in particular for antiquarks at large x, in the context of a PDF fit involving the world data sensitive to the proton structure.

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