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Measurement of the Muon Charge Asymmetry from W Bosons Produced in pp Collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

The ATLAS Collaboration

Abstract

This letter reports a measurement of the muon charge asymmetry from W bosons produced in proton-proton collisions at a centre-of-mass energy of 7 TeV with the ATLAS experiment at the LHC. The asymmetry is measured in the $W \to \mu\nu$ decay mode as a function of the muon pseudorapidity using a data sample corresponding to a total integrated luminosity of 31 pb^{-1}. The results are compared to predictions based on next-to-leading order calculations with various parton distribution functions. This measurement provides information on the u and d quark momentum fractions in the proton.

1. Introduction

The measurement of the charge asymmetry of leptons originating from the decay of singly produced W bosons at pp, $p\bar{p}$ and ep colliders provides important information about the proton structure as described by parton distribution functions (PDFs). The W boson charge asymmetry is mainly sensitive to valence quark distributions [1] via the dominant production process $u\bar{d}(\bar{u}d) \to W^{+(-)}$ and provides complementary information to that obtained from measurements of inclusive deep inelastic scattering cross-sections at the HERA electron-proton collider [2, 3, 4, 5]. The HERA data do not strongly constrain the ratio between u and d quarks in the kinematic regime of low x, where x is the proton momentum fraction carried by the parton [6]. A precise measurement of the W asymmetry at the Large Hadron Collider (LHC) [7] on the other hand, can contribute significantly to the understanding of PDFs and quantum chromodynamics (QCD) in the parton momentum fraction range $10^{-3} \lesssim x \lesssim 10^{-1}$.

In pp collisions the overall production rate of W^+ bosons is significantly larger than the corresponding W^- rate, since the proton contains two u and one d valence quarks. The first measurements of the inclusive $W^\pm$ cross-sections at the LHC by the ATLAS [8] and the CMS [9] Collaborations confirmed the difference predicted by the Standard Model. The asymmetry in pp collisions is symmetric with respect to the W rapidity, whereas in $p\bar{p}$ collisions it is anti-symmetric; the small sensitivity to sea quark contributions is strongly suppressed in $p\bar{p}$ compared to pp collisions [10]. Measurements in $p\bar{p}$ collisions have been performed at the Tevatron by both the CDF [11, 12] and DØ [13, 14] Collaborations, and the data have been included in global fits of parton distributions [15, 16].

This letter presents a differential measurement of the muon charge asymmetry from the decay of $W^\pm$ bosons in pp collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV at the LHC. The asymmetry varies significantly as a function of the pseudorapidity[1] η_μ of the charged decay lepton owing to its strong correlation with the momentum fraction x of the partons producing the W boson. It is defined from the cross sections for $W \to \mu\nu$ production $d\sigma_{\mathrm{W}\mu^\pm}/d\eta_\mu$ as:

$$A_\mu = \frac{d\sigma_{\mathrm{W}\mu^+}/d\eta_\mu - d\sigma_{\mathrm{W}\mu^-}/d\eta_\mu}{d\sigma_{\mathrm{W}\mu^+}/d\eta_\mu + d\sigma_{\mathrm{W}\mu^-}/d\eta_\mu}\,, \tag{1}$$

where the cross sections include the event kinematical cuts used to select $W \to \mu\nu$ events. No extrapolation to the

[1] The nominal pp interaction point at the centre of the detector is defined as the origin of a right-handed coordinate system. The positive x-axis is defined by the direction from the interaction point to the centre of the LHC ring, with the positive y-axis pointing upwards. The azimuthal angle ϕ is measured around the beam axis and the polar angle θ is the angle from the z-axis. The pseudorapidity is defined as $\eta = -\ln\tan(\theta/2)$.

full phase space is attempted in order to reduce the dependence on theoretical predictions.

Systematic effects on the W-production cross-section measurements are typically the same for positive and negative muons, mostly canceling in the asymmetry. The ATLAS detector measures muons with two independent detector systems. These two independent measurements allow systematic uncertainties to be controlled. The results presented are based on data collected in 2010 with an integrated luminosity of 31 pb^{-1}. These results significantly improve on the previous measurement by the ATLAS Collaboration [8], which is based on a data set approximately 100 times smaller.

2. The ATLAS Detector

The ATLAS detector [17, 18] consists of an inner tracking system (inner detector, or ID) surrounded by a superconducting solenoid providing a 2T magnetic field, electromagnetic and hadronic calorimeters and a muon spectrometer (MS). The ID consists of pixel and silicon microstrip (SCT) detectors, surrounded by a transition radiation tracker (TRT). The electromagnetic calorimeter is a lead liquid-argon (LAr) detector in the barrel and the endcap, and in the forward region copper LAr technology is used. Hadron calorimetry is based on two different detector technologies, with scintillator tiles or LAr as the active media, and with either steel, copper, or tungsten as the absorber material. There is a poorly instrumented transition region between the barrel and endcap calorimeter, $1.37 < |\eta| < 1.52$, where electrons cannot be precisely measured. In view of a later combination, this motivates the binning in that region for the present muon analysis. The MS is based on three large superconducting toroids, and a system of three stations of chambers for trigger and precise tracking measurements. There is a transition between the barrel and endcap muon detectors around $|\eta| = 1.05$.

3. Data and Simulated Event Samples

The data used in this analysis were collected from the end of September to the end of October 2010. Basic requirements on beam, detector, stable trigger conditions and data-quality were used in the event selection, resulting in a total integrated luminosity of 31 pb^{-1}. Events in this analysis are selected using a single-muon trigger with a requirement on the momentum transverse to the beam (p_{T}) of at least 13 GeV. The trigger includes three levels of event selection: a first level hardware-based selection using hit patterns in the MS and two higher levels of software-based requirements.

Simulated event samples are used for the background estimation, the acceptance calculation and for comparison of data with theoretical expectations. The processes considered are the $W \to \mu\nu$ signal, and backgrounds from $W \to \tau\nu$, $Z \to \mu\mu$, $Z \to \tau\tau$, $t\bar{t}$ and jet production via QCD processes (referred to as "QCD background" in the text). The signal and background samples (except $t\bar{t}$) were generated with PYTHIA 6.421 [19] using MRST 2007 LO* [20] PDFs. The $t\bar{t}$ sample was generated with POWHEG-HVQ v1.01 patch 4 [21]; the PDF set was CTEQ 6.6M [22] for the NLO matrix element calculations, while CTEQ 6L1 was used for the parton showering and underlying event via the POWHEG interface to PYTHIA. The radiation of photons from charged leptons was treated using PHOTOS v2.15.4 [23] and TAUOLA v1.0.2 [24] was used for tau decays. The underlying and pile-up events were simulated according to the ATLAS MC09 tune [25]. The generated samples were passed through the GEANT4 [26] simulation of the ATLAS detector [27], reconstructed and analysed with the same analysis chain as the data. The cross-section predictions for W and Z were calculated to next-to-next-to-leading-order (NNLO) using FEWZ [28] with the MSTW 2008 [29] PDFs. The $t\bar{t}$ cross-section was obtained at next-to-leading-order (plus next-to-next-to-leading-log, NNLL) using POWHEG [30]. The Monte Carlo (MC) were generated with, on average, two soft inelastic collisions overlaid on top of the hard-scattering event. Events in the MC samples were weighted so that the distribution of the number of inelastic collisions per bunch crossing matched that in data, which has an average of 2.2.

4. Event Selection

The criteria for the event selection and muon identification follow closely those used for the W boson inclusive cross-section measurement [8], with an improved muon quality selection [31]. Events from pp collisions are selected by requiring a collision vertex with at least three tracks each with transverse momentum greater than 150 MeV. A beam-spot constraint has been applied in the collision vertex reconstruction stage significantly improving the resolution on the collision vertex position in the transverse plane. To reduce the contribution of cosmic-ray and beam-halo events, induced by proton losses from the beam, the analysis requires the collision vertex position along the beam axis to be within 20 cm of the nominal interaction point.

Events with a high transverse momentum muon are selected by imposing stringent requirements to ensure good discrimination of $W \to \mu\nu$ events from background. The muon parameters are first reconstructed separately in the MS and ID. Subsequently, the tracks from the ID and MS are matched. Their parameters are then combined, weighted by their respective errors, to form a combined muon. The W candidate events are required to have at least one combined muon track with $p_{\mathrm{T}} > 20$ GeV and p_{T} measured by the MS alone greater than $p_{\mathrm{T}}^{\mathrm{MS}} > 10$ GeV, within the range $|\eta_{\mu}| < 2.4$. The difference between the ID and MS p_{T}, corrected for the mean energy loss in the material traversed between the ID and MS, is required to be less than 0.5 times the ID p_{T},

$$p_{\mathrm{T}}^{\mathrm{MS}}(\text{energy loss corrected}) - p_{\mathrm{T}}^{ID} < 0.5\ p_{\mathrm{T}}^{\mathrm{ID}}.$$

This requirement increases the robustness against track reconstruction mismatches, including decays-in-flight of hadrons. In addition, a minimum number of hits in the ID is required to ensure high quality tracks [31]. In order to further reduce non-collision backgrounds, the difference between the z position of the muon track extrapolated to the beam line and the z coordinate of the collision vertex is required to be less than 1 cm. A track-based isolation for the muon is defined as $\sum p_{\mathrm{T}}^{\mathrm{ID}}/p_{\mathrm{T}} < 0.2$, where $\sum p_{\mathrm{T}}^{\mathrm{ID}}$ is the scalar sum of transverse momenta of all other tracks measured in the ID within a cone[2] $\Delta R < 0.4$ around the muon direction excluding the ID track associated with the muon, and p_{T} is the transverse momentum of the muon combined track.

The reconstruction of the missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) and the transverse mass (m_{T}) follows the prescription in [8]. The $E_{\mathrm{T}}^{\mathrm{miss}}$ is determined from the energy deposits of calibrated calorimeter cells in three-dimensional clusters and is corrected for the momentum of all muons reconstructed in the event. Jet-quality requirements are applied to remove a small fraction of events where sporadic calorimeter noise and non-collision backgrounds can affect the $E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction [32]. The transverse mass is defined as

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\mu}p_{\mathrm{T}}^{\nu}(1-\cos(\phi^{\mu}-\phi^{\nu}))}, \qquad (2)$$

where the highest p_{T} muon is used and the (x, y) components of the neutrino momentum are inferred from the corresponding $E_{\mathrm{T}}^{\mathrm{miss}}$ components. Events are required to have $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV and $m_{\mathrm{T}} > 40$ GeV, yielding 129572 W candidates.

5. $W^{\pm}$ Signal Yield and Background Estimation

Many components in the W cross-section measurement, such as the luminosity or detector efficiencies, are in principle the same for positive and negative muons and therefore mostly cancel in the asymmetry calculation. The main experimental biases on the asymmetry measurement come from possible differences in the reconstruction of positive and negative muons. Each effect (trigger and reconstruction efficiency and momentum scale) is examined to check that the two charges behave in the same way within the systematic uncertainties. These studies are performed in absolute pseudorapidity in order to reduce the uncertainty associated with the limited size of the data samples used.

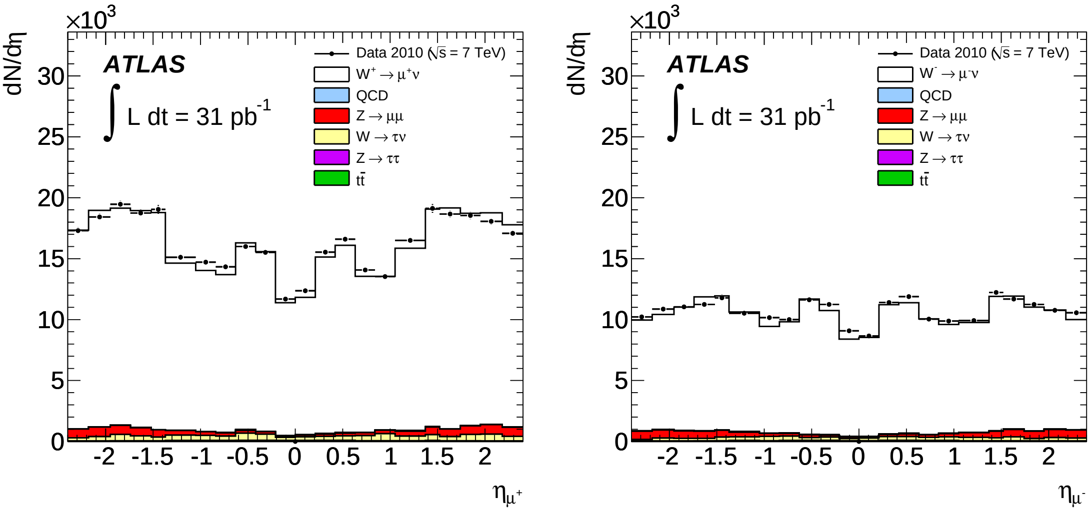
As in past W analyses, trigger [31] and muon reconstruction [8, 31] efficiencies as a function of muon η_μ have been measured in data using a sample of unbiased muons from $Z \to \mu\mu$ decays, which provides a source of muons with small background. The trigger efficiency is determined relative to a reconstructed muon satisfying the selection criteria of the analysis. The average trigger efficiencies after the full W selection are $(81 \pm 2)\%$ in the central detector region, $|\eta_\mu| < 1.05$, and $(94 \pm 1)\%$ in the forward detector region, $1.05 < |\eta_\mu| < 2.4$, where the differences are due to the geometrical acceptance of the muon trigger chambers. In the same muon sample, the muon reconstruction efficiency relative to an ID track is measured to be $(93 \pm 1)\%$ overall. The efficiency for reconstructing an ID track is $(99 \pm 1)\%$ [8]. The quoted uncertainties on these efficiencies are statistical.

Corrections have been applied to the simulated samples to account for differences in the trigger and reconstruction efficiencies between data and simulation. These are based on the ratio of the efficiency in data and in simulation, and are computed as a function of the muon η_μ and charge. The corrections for each charge agree within the statistical uncertainties, so the charge-averaged result is applied. For the trigger, the corrections are 0.98 and 1.03 in the central and forward MS regions, respectively. For the reconstruction efficiency, the correction factors are about 0.99 per η_μ bin except for the central-forward MS transition region ($|\eta_\mu|$ about 1.05) where the correction factor is 0.94.

The muon momentum resolution is affected by the amount of material traversed by the muon, the spatial resolution of the individual track points and the degree of internal alignment of the ID and MS [33]. This resolution has been measured as a function of η_μ for the main detector regions (in η_μ ranges delimited by $1.05, 1.7, 2.0$ and 2.4) from the width of the di-muon invariant mass distribution in $Z \to \mu\mu$ decays and from the comparison of the momentum measurements in the ID and MS in $Z \to \mu\mu$ and $W \to \mu\nu$ decays. The measured resolution is worse than expected from simulation by $1-5\%$, with the maximum discrepancy reached in the high-η_μ region of the detector. The discrepancy is due to residual mis-alignments in the ID and MS, imperfections in the description of the inert material in simulation and an imperfect mapping of the magnetic field in the MS transition region where the field is highly non-uniform. Smearing corrections are therefore applied to the simulation in order to improve the agreement with data.

If the accuracy of the muon momentum measurement is different for positive and negative muons, this difference can produce a bias in the acceptance of μ^+ with respect to μ^-. Differences in the muon p_{T} measurement between data and simulation have been evaluated comparing the curvature of muons from W candidates in data and in templates derived from simulation. A binned likelihood fit for a momentum-scale correction that yields the best agreement between data and simulation is performed as a function of η_μ separately for positive and negative charges. The measured biases in the p_{T} scale between the two charges are $< 1\%$, but they increase to about 3% in the transi-

[2] ΔR is defined as $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$.



(a) (b)

Figure 1: Distribution of the muon pseudorapidity η_μ of W^+ (a) and W^- (b) candidates, after final selection. The data are compared to MC simulation, broken down into the signal and various background components. The MC distributions are normalised to the total number of events in data.

tion and high-η_μ regions due to residual mis-alignments in the ID and MS. These corrections are applied to the muon momenta in the simulated samples.

Figure 1 shows the pseudorapidity distribution of the selected positive and negative muons. Data distributions are compared to the MC simulation, normalised to the total number of events in data. The shape of the simulation agrees well with the shape of the data after the corrections for the reconstruction and trigger efficiencies, and the muon-momentum scale and resolution.

The main backgrounds to $W \to \mu\nu$ arise from heavy flavour decays in multijet events and from the electro-weak background from $W \to \tau\nu$ where the tau decays to a muon, $Z \to \mu\mu$ where one muon is not reconstructed and $Z \to \tau\tau$ where one tau decays to a muon, as well as semileptonic $t\bar{t}$ decays in the muon channel. Di-boson and single top backgrounds are found to be negligible. The $W \to \tau\nu$ contribution is treated as a background. While this contribution presents the same asymmetry as the $W \to \mu\nu$ signal, it is difficult to include in PDF fits, which assume that the asymmetry is a function of η_ℓ for $W \to l\nu$.

The background estimates of the electro-weak and $t\bar{t}$ backgrounds and the QCD background closely follow the methods used in the W inclusive cross-section measurement [8]. They are determined separately for positive and negative muons as a function of η_μ. The electro-weak and $t\bar{t}$ backgrounds are estimated using MC simulation. The QCD background comes primarily from b and c quark decays, with a smaller contribution from pion and kaon decays in flight. This background is estimated using a data-driven method similar to the one described in [8]. The sample of events fulfilling the full W selection criteria with the exception of the muon isolation requirement is compared before and after the isolation requirement. The isolation efficiency for non-QCD events is measured in data with the $Z \to \mu\mu$ sample. The efficiency for QCD events is estimated in a control sample of low-p_{T} muons extrapolated to the high-p_{T} and high-$E_{\mathrm{T}}^{\mathrm{miss}}$ signal region using the simulated jet sample. Since the samples before and after isolation can be defined in terms of a QCD and non-QCD component, the expected number of QCD events can thus be determined.

The expected background amounts to 7% of the selected events; 6% is the electro-weak and $t\bar{t}$ contribution (3% $Z \to \mu\mu$, 2% $W \to \tau\nu$, and 1% for the sum of $t\bar{t}$ and $Z \to \tau\tau$) and the remainder is the QCD background. The cosmic ray background contamination is estimated to be smaller by a factor of 10^5 compared to the signal and thus negligible. The $W^\pm$ candidate events and expected background contributions are summarised in Table 1.

Figure 2 shows the transverse momentum distribution for positive and negative muons after the full event selection. They are compared with the distributions predicted by the corrected MC simulation normalised to the total number of events in data. The correction factors, $C_{\mathrm{W}\mu^\pm}$, corresponding to the ratio of reconstructed over generated events in the simulated W sample, satisfying all kinematic requirements of the event selection, $p_{\mathrm{T}}^{\mu} > 20$ GeV, $p_{\mathrm{T}}^{\nu} > 25$ GeV, $m_{\mathrm{T}} > 40$ GeV, are also listed in Table 1. No correction is made to the full acceptance. The $C_{\mathrm{W}\mu^\pm}$ factors include trigger and muon reconstruction scale factors to correct for observed deviations between data and MC efficiencies. Due to a reduced geometric acceptance in the trigger, the $C_{\mathrm{W}\mu^\pm}$ factors for the lowest $|\eta_\mu|$ bins are significantly smaller than those for the higher $|\eta_\mu|$ regions.

	μ^+			μ^-		
	Observed	Exp. Background	$C_{W\mu^+}$	Observed	Exp. Background	$C_{W\mu^-}$
$0.00 < \lvert\eta_\mu\rvert < 0.21$	5052	272 ± 51	0.594 ± 0.005	3726	236 ± 55	0.584 ± 0.004
$0.21 < \lvert\eta_\mu\rvert < 0.42$	6519	385 ± 70	0.779 ± 0.009	4757	334 ± 70	0.759 ± 0.008
$0.42 < \lvert\eta_\mu\rvert < 0.63$	6845	481 ± 88	0.808 ± 0.009	4936	357 ± 70	0.800 ± 0.009
$0.63 < \lvert\eta_\mu\rvert < 0.84$	5963	366 ± 76	0.686 ± 0.008	4212	329 ± 64	0.691 ± 0.008
$0.84 < \lvert\eta_\mu\rvert < 1.05$	5933	395 ± 63	0.672 ± 0.007	4207	358 ± 63	0.681 ± 0.008
$1.05 < \lvert\eta_\mu\rvert < 1.37$	10114	627 ± 93	0.735 ± 0.007	6544	585 ± 101	0.752 ± 0.007
$1.37 < \lvert\eta_\mu\rvert < 1.52$	5726	363 ± 57	0.905 ± 0.009	3601	348 ± 59	0.914 ± 0.009
$1.52 < \lvert\eta_\mu\rvert < 1.74$	8228	542 ± 89	0.905 ± 0.008	5043	518 ± 82	0.925 ± 0.008
$1.74 < \lvert\eta_\mu\rvert < 1.95$	7982	605 ± 114	0.896 ± 0.009	4688	456 ± 80	0.898 ± 0.008
$1.95 < \lvert\eta_\mu\rvert < 2.18$	8392	647 ± 100	0.903 ± 0.009	4971	548 ± 91	0.910 ± 0.009
$2.18 < \lvert\eta_\mu\rvert < 2.40$	7562	534 ± 81	0.881 ± 0.010	4571	492 ± 82	0.896 ± 0.010

Table 1: Summary of observed number of events, expected background and correction factor $C_{W\mu^\pm}$ for positive and negative muons in bins of $|\eta_\mu|$. The errors given for the background estimates include systematic uncertainties, including the uncertainty due to the luminosity, used in the normalization of the electro-weak and $t\bar{t}$ components. The $C_{W\mu^\pm}$ factors include trigger and muon reconstruction scale factors; they include the statistical uncertainty from the MC sample and the trigger and reconstruction scale factors.

6. Systematic Uncertainties

All systematic uncertainties on the asymmetry measurement are determined in each $|\eta_\mu|$ bin accounting for correlations between the charges and are summarised in Table 2. The dominant sources of systematic uncertainty on the asymmetry come from the trigger and reconstruction efficiencies. The determination of these efficiencies is affected by the statistical uncertainty due to the small available sample of $Z \to \mu\mu$ events. Systematic uncertainties on the efficiencies are determined from studies of the impact of the selection criteria and backgrounds, and no significant charge biases are found. There is a loss of trigger efficiency in the low pseudorapidity region due to reduced geometric acceptance, resulting in a larger statistical error. As a result, the trigger systematic uncertainty on the asymmetry is largest in the low pseudorapidity bins (6-7% for central $|\eta_\mu|$ and 2-3% for forward $|\eta_\mu|$). Similarly, the uncertainties associated with the reconstruction efficiency are larger in the lowest pseudorapidity bin (about 7%), and in the MS central-forward transition region (about 3%), due to geometrical acceptance effects associated with reduced chamber coverage. In the remaining regions, the uncertainty is about 1-2%.

The muon momentum scale and resolution corrections contribute to the uncertainty primarily due to the limited statistics for the fitting procedures used to measure the differences between the data and simulation. An additional source of uncertainty arises from potential biases in the template shapes. The size of this effect is determined by using different templates created by shifting the resolution parameters in opposite directions to account for possible charge biases. Uncertainties associated with the modelling of the background contributions to the templates, particularly the QCD background, are also included. The resulting uncertainty on the asymmetry is in the 1-2% range, with little dependence on η_μ. The redundant ID and MS momentum measurements result in a rate of charge misidentification smaller than 10^{-4} in the p_{T} range considered, resulting in a negligible impact on the asymmetry.

The momentum-scale correction procedure is further tested by exploiting the redundant muon-momentum measurements offered by the ATLAS detector. The full asymmetry measurement is performed with the ID and MS components of the combined muon separately, including the scale corrections. Figure 3 compares the two independently corrected charge-asymmetry distributions, showing good agreement within the systematic uncertainty associated with the momentum-scale correction.

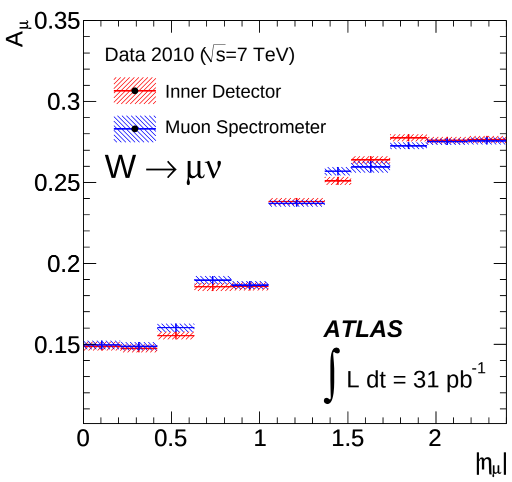


Figure 3: W charge asymmetry measured using the ID and MS separately. The MS measurement is extrapolated to the collision vertex, and corrected for energy-loss in the calorimeters. The two measurements are independently corrected for effects of the muon-momentum scale on the muon acceptance. The two measurements are statistically correlated to a large extent, since they use the same muons reconstructed by different subdetectors and algorithms. The error bar reports therefore only the systematic uncertainty associated with the momentum-scale correction.

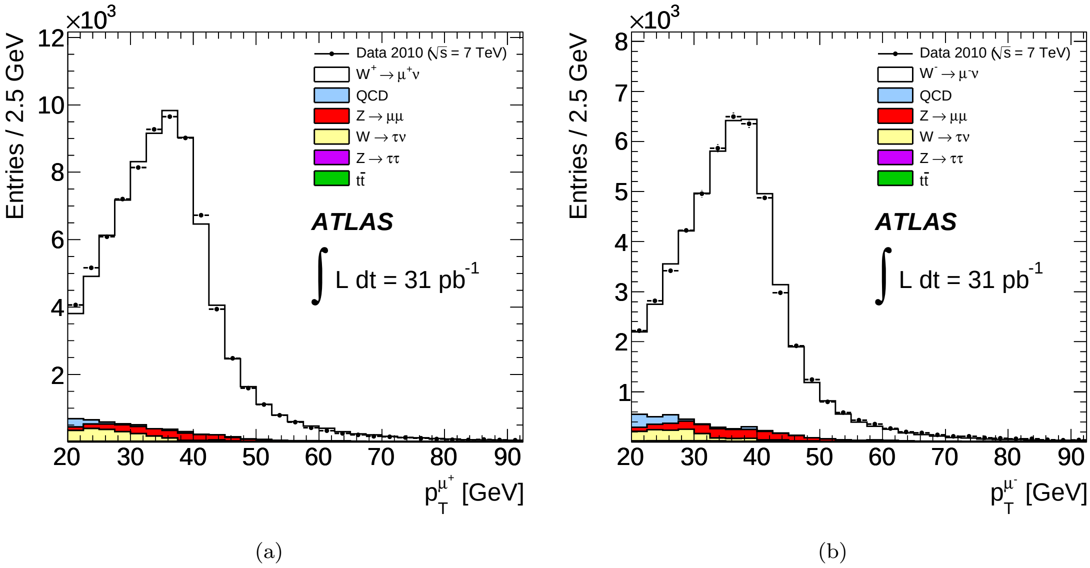


Figure 2: Distribution of the transverse momentum of positive and negative muons after the final selection. The data are compared to MC simulation, broken down into the signal and various background components. The MC distributions are normalised to the total number of entries in data.

The systematic uncertainties on the QCD background arise primarily from the uncertainty on the isolation efficiency for muons in QCD events due to possible mismodellings of the extrapolation of the isolation efficiency to the large p_{T} and $E_{\mathrm{T}}^{\mathrm{miss}}$ region in the QCD simulation (40%). This has been derived from differences in the efficiency predictions between data and simulation in the low muon p_{T} control region and in sideband regions where the muon p_{T} or $E_{\mathrm{T}}^{\mathrm{miss}}$ cuts are reversed. The electro-weak and $t\bar{t}$ background and signal contributions are subtracted from data in these comparisons. Additional uncertainties due to the non-QCD isolation efficiency and the statistical uncertainty are included in the total uncertainty on the QCD background estimate. The corresponding systematic uncertainty on the asymmetry is 1-2%, with little dependence on η_μ.

For the electro-weak and $t\bar{t}$ backgrounds, the uncertainty in the cross-sections includes the PDF uncertainties (3%), and the uncertainties estimated from varying the renormalization and factorization scales: 5% for W and Z, and 6% for $t\bar{t}$ [34, 35, 8]. An additional uncertainty from the luminosity of 11% is included, since the backgrounds are scaled to the luminosity measured in data. The combination of all these contributions results in an uncertainty on the asymmetry of less than 1%.

The impact of using an NLO MC rather than Pythia in the $C_{\mathrm{W}_{\mu^\pm}}$ factor calculation has been evaluated and an additional systematic uncertainty of about 3% is included to account for the small variations observed. Pythia uses a leading-log calculation for W production and is expected to give a reasonably accurate prediction for the low W transverse momentum p_{T}^W region whereas MC@NLO [36] uses higher-order matrix elements and is therefore expected to be more reliable in the high p_{T}^W region. Therefore the differences in the scale factors associated with these two MC calculations gives a reasonable estimate of the associated systematic error.

7. Results and Conclusions

The measured particle-level differential charge asymmetry in eleven bins of muon absolute pseudorapidity is shown in Table 3 and Figure 4. The statistical and systematic uncertainties per $|\eta_\mu|$ bin are included and contribute comparably to the total uncertainty. Table 3 and Figure 4 also show particle-level expectations from W predictions at NLO with different PDF sets: CTEQ 6.6 [16], HERA 1.0 [5] and MSTW 2008 [15]; all predictions are presented with 90% confidence-level error bands. All MC predictions are calculated using MC@NLO, with all kinematic selection criteria applied to the truth particles. The PDF uncertainty bands are obtained by summing in quadrature the deviations of each of the PDF error sets [37] from the respective nominal predictions, according to the specifications of the corresponding PDF collaborations to get 90% C.L. bands. These uncertainties for all predictions include experimental uncertainties as well as model and parametrization uncertainties. The HERA 1.0 [5] set also includes the uncertainty in α_s, which, however, is not the dominant source of uncertainty.

While the predictions with different PDF sets differ within their respective uncertainty bands [38, 39], they follow the same global trend, rising with η_μ. The measured asymmetry agrees with this expectation. As demonstrated graphically in Figure 4, the data are roughly compatible with all the predictions with different PDF sets, though some are slightly preferred to others. A χ^2-comparison using the measurement uncertainty and the central value of the PDF predictions yields values per number of degrees of freedom of 9.16/11 for the CTEQ 6.6 PDF sets, 35.81/11 for the HERA 1.0 PDF sets and 27.31/11 for the MSTW 2008 PDF sets.

In summary, this letter reports a measurement of the W charge asymmetry in pp collisions at $\sqrt{s} = 7$ TeV performed in the $W \to \mu\nu$ decay mode using 31 pb^{-1} of data recorded with the ATLAS detector at the LHC. Until the start of the LHC, it has not been kinematically possible to precisely measure the valence quark distributions and in particular the ratio of u/d quarks below $x \lesssim 0.05$. Whereas none of the predictions with different PDF sets are inconsistent with these data, the predictions are not fully consistent with each other since they are all phenomenological extrapolations in x. The input of the data presented here is therefore expected to contribute to the determination of the next generation of PDF sets, helping reduce PDF uncertainties, particularly the shapes of the valence quark distributions in the low-x region.

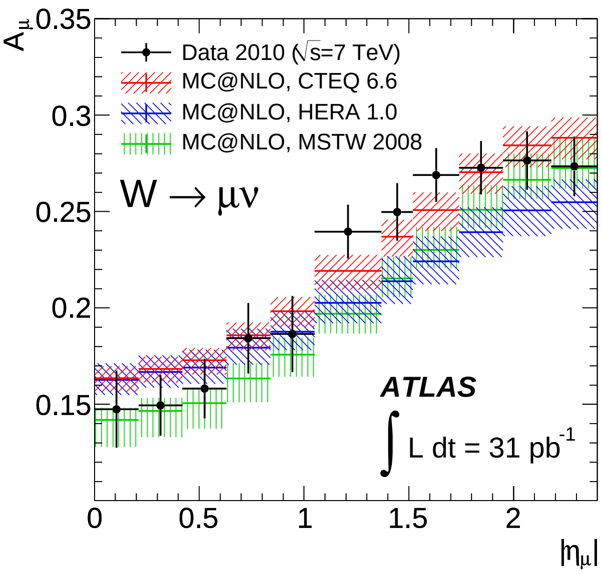


Figure 4: The muon charge asymmetry from W-boson decays in bins of absolute pseudorapidity. The kinematic requirements applied are $p_T^\mu > 20$ GeV, $p_T^\nu > 25$ GeV and $m_T > 40$ GeV. The data points (shown with error bars including the statistical and systematic uncertainties) are compared to MC@NLO predictions with different PDF sets. The PDF uncertainty bands are described in the text and include experimental uncertainties as well as model and parametrization uncertainties.

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	Trigger	Reconstruction	p_{T} Scale and Resolution	QCD Normalisation	Electro-weak and $t\bar{t}$ Normalisation	Theoretical Modelling
$0.00 < \lvert\eta_\mu\rvert < 0.21$	0.011	0.010	0.003	0.003	< 0.001	0.007
$0.21 < \lvert\eta_\mu\rvert < 0.42$	0.010	0.004	0.003	0.003	< 0.001	0.005
$0.42 < \lvert\eta_\mu\rvert < 0.63$	0.009	0.004	0.003	0.003	< 0.001	0.006
$0.63 < \lvert\eta_\mu\rvert < 0.84$	0.012	0.004	0.003	0.002	0.001	0.007
$0.84 < \lvert\eta_\mu\rvert < 1.05$	0.013	0.006	0.003	0.003	0.001	0.008
$1.05 < \lvert\eta_\mu\rvert < 1.37$	0.006	0.007	0.002	0.002	0.001	0.006
$1.37 < \lvert\eta_\mu\rvert < 1.52$	0.006	0.005	0.002	0.003	0.002	0.005
$1.52 < \lvert\eta_\mu\rvert < 1.74$	0.005	0.004	0.002	0.003	0.002	0.007
$1.74 < \lvert\eta_\mu\rvert < 1.95$	0.006	0.003	0.002	0.002	0.001	0.006
$1.95 < \lvert\eta_\mu\rvert < 2.18$	0.006	0.004	0.002	0.003	0.002	0.009
$2.18 < \lvert\eta_\mu\rvert < 2.40$	0.007	0.005	0.002	0.003	0.002	0.007

Table 2: Absolute systematic uncertainties on the W charge asymmetry from different sources as a function of absolute muon pseudorapidity that are described in the text.

	Data	MSTW 2008	CTEQ 6.6	HERA 1.0
$0.00 < \lvert\eta_\mu\rvert < 0.21$	$0.147 \pm 0.011 \pm 0.017$	$0.142^{+0.006}_{-0.014}$	$0.164^{+0.006}_{-0.007}$	0.163 ± 0.007
$0.21 < \lvert\eta_\mu\rvert < 0.42$	$0.150 \pm 0.010 \pm 0.012$	$0.147^{+0.007}_{-0.014}$	$0.168^{+0.006}_{-0.007}$	0.167 ± 0.007
$0.42 < \lvert\eta_\mu\rvert < 0.63$	$0.158 \pm 0.010 \pm 0.012$	$0.151^{+0.007}_{-0.013}$	$0.173^{+0.006}_{-0.007}$	0.169 ± 0.007
$0.63 < \lvert\eta_\mu\rvert < 0.84$	$0.184 \pm 0.010 \pm 0.015$	$0.163^{+0.008}_{-0.012}$	$0.186^{+0.007}_{-0.008}$	$0.179^{+0.008}_{-0.007}$
$0.84 < \lvert\eta_\mu\rvert < 1.05$	$0.186 \pm 0.011 \pm 0.017$	$0.176^{+0.009}_{-0.012}$	$0.198^{+0.007}_{-0.008}$	0.188 ± 0.008
$1.05 < \lvert\eta_\mu\rvert < 1.37$	$0.240 \pm 0.008 \pm 0.011$	0.197 ± 0.010	$0.219^{+0.008}_{-0.010}$	$0.203^{+0.009}_{-0.008}$
$1.37 < \lvert\eta_\mu\rvert < 1.52$	$0.250 \pm 0.011 \pm 0.010$	$0.215^{+0.011}_{-0.010}$	$0.237^{+0.009}_{-0.010}$	0.214 ± 0.009
$1.52 < \lvert\eta_\mu\rvert < 1.74$	$0.269 \pm 0.009 \pm 0.010$	$0.230^{+0.012}_{-0.010}$	$0.251^{+0.009}_{-0.011}$	0.224 ± 0.009
$1.74 < \lvert\eta_\mu\rvert < 1.95$	$0.273 \pm 0.009 \pm 0.010$	$0.251^{+0.013}_{-0.009}$	$0.270^{+0.010}_{-0.011}$	$0.239^{+0.010}_{-0.009}$
$1.95 < \lvert\eta_\mu\rvert < 2.18$	$0.276 \pm 0.009 \pm 0.012$	$0.266^{+0.014}_{-0.010}$	$0.284^{+0.010}_{-0.011}$	$0.251^{+0.009}_{-0.010}$
$2.18 < \lvert\eta_\mu\rvert < 2.40$	$0.273 \pm 0.010 \pm 0.012$	$0.272^{+0.015}_{-0.011}$	$0.288^{+0.009}_{-0.010}$	$0.255^{+0.009}_{-0.010}$

Table 3: The muon charge asymmetry from W-boson decays in bins of absolute pseudorapidity. The data measurements are listed with statistical and systematic uncertainties respectively. Predicted asymmetries of the MSTW 2008, CTEQ 6.6, and HERA 1.0 PDF sets are shown for comparison.

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