Measurement of the Electron Charge Asymmetry in Inclusive W Production in pp Collisions at √s = 7 TeV

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A measurement of the electron charge asymmetry in inclusive pp → W + X → eν + X production at √s = 7 TeV is presented based on data recorded by the CMS detector at the LHC and corresponding to an integrated luminosity of 840 pb⁻¹. The electron charge asymmetry reflects the unequal production of W⁺ and W⁻ bosons in pp collisions. The electron charge asymmetry is measured in bins of the absolute value of electron pseudorapidity in the range of |η| < 2.4. The asymmetry rises from about 0.1 to 0.2 as a function of the pseudorapidity and is measured with a relative precision better than 7%. This measurement provides new stringent constraints for parton distribution functions.

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The dominant mechanism for W boson production in pp collisions at the Large Hadron Collider (LHC) is the annihilation of a valence quark from one proton with a sea antiquark from the other. Because the proton contains two valence u quarks and one valence d quark, W⁺ bosons are produced more frequently than W⁻ bosons. The Compact Muon Solenoid (CMS) Collaboration measured the ratio of the inclusive W⁺ and W⁻ production cross sections at √s = 7 TeV at the LHC [1] to be in good agreement with the prediction of the standard model based on various parton distribution functions (PDFs) [2–7]. In this Letter, we present a further investigation of inclusive W⁺ and W⁻ production in the W → eν decay channel. We measure the electron charge asymmetry, defined as

\[ A(\eta) = \frac{dσ/dη(W⁺ → e⁺ ν) - dσ/dη(W⁻ → e⁻ \bar{ν})}{dσ/dη(W⁺ → e⁺ ν) + dσ/dη(W⁻ → e⁻ \bar{ν})}, \]

where η is the electron pseudorapidity in the CMS lab frame [η = −ln(tan(θ/2)], θ is the polar angle, measured from the anticlockwise beam direction, and dσ/dη is the differential cross section for electrons from W boson decays. Within the CMS tracker acceptance (|η| < 2.5), the asymmetry is expected to rise with increasing |η| because the valence u quarks that produce the W⁺ bosons tend to carry a higher fraction x of the proton momentum [8] than the valence d quarks that produce the W⁻ bosons. Measurements of the asymmetry provide constraints on the u, d, ̅u, and ̅d PDFs in the range 10⁻³ < x < 10⁻¹ and are complementary to measurements of deep inelastic scattering at HERA [4].

The lepton charge asymmetry and the W charge asymmetry have been studied in pp collisions by the CDF and D0 Collaborations at the Fermilab Tevatron collider [9,10]. The ATLAS and CMS Collaborations at the LHC reported measurements of the lepton charge asymmetry in the region |η| < 2.5 using the data collected during the 2010 LHC runs [11,12]. The LHCb Collaboration recently extended the measurement of the lepton charge asymmetry at the LHC to the 2.0 < η < 4.5 region [13]. The NNPDF Collaboration estimated the impact of the CMS and ATLAS results on the PDFs [5]; the uncertainty on the light flavor and antiflavor distributions is reduced by 20% at x ~ 10⁻³ and by 10%–25% at larger x values.

The results presented in this Letter significantly improve the measurement of the electron charge asymmetry in inclusive pp → W + X → eν + X production at √s = 7 TeV and are based on a data sample corresponding to 840 pb⁻¹ collected in spring 2011. This analysis uses the portion of the 2011 data set for which the single-electron trigger threshold was relatively low. Compared to the analysis performed in 2010 [12], the threshold on the electron transverse momentum (p_T) is increased from 25 to 35 GeV to match the higher trigger threshold for single electrons. The data sample is ~25 times larger than in 2010 and allows a reduction of many systematic uncertainties.

A detailed description of the CMS experiment can be found elsewhere [14]. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, 13 m in length, providing an axial field of 3.8 T. Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL), and the brass-scintillator hadron calorimeter. Muons are measured in gas-ionization detectors embedded in the steel return yoke of the solenoid. The most relevant subdetectors for this measurement are the ECAL and the tracking system. The electromagnetic calorimeter consists of nearly 76000 lead tungstate crystals, which provide coverage in pseudorapidity |η| < 1.48 in the barrel region and...
A large fraction of electrons radiate photons, owing to the substantial amount of material in front of the ECAL detector. These photons may convert close to the original electron trajectory, leading to a non-negligible charge misidentification probability. Three different methods are used to determine the electron charge. First, the electron charge is determined by the signed curvature of the associated GSF track. Second, the charge is determined from the associated trajectory reconstructed in the silicon tracker using a Kalman filter algorithm [21]. Third, the electron charge is determined from the azimuthal angle between the vector joining the nominal interaction point and the ECAL cluster position and the vector joining the nominal interaction point and the innermost hit of the GSF track. It is required that all three charge determinations from these methods agree. This procedure significantly reduces the charge misidentification probability to 0.01% in the ECAL barrel and to 0.3% in the ECAL end caps. The electron pseudorapidity is measured from the GSF track at the $pp$ interaction point; the uncertainty on $\eta$ is negligible for this analysis.

The $W \rightarrow e\nu$ candidates are selected by requiring electrons to have transverse momentum $p_{T} > 35$ GeV, $|\eta| < 2.4$, and to be associated with one of the electron trigger candidates used to select the electron data set. The Drell-Yan production and $t\bar{t}$ backgrounds are suppressed by rejecting events that contain a second isolated electron or muon with $p_{T} > 15$ GeV and $|\eta| < 2.4$. According to MC simulations, the data sample of selected electrons consists of about 16% QCD background events, about 7.4% EW background events, and about 0.4% $t\bar{t}$ background events.

As the forward and backward hemispheres are equivalent in $pp$ collisions, the asymmetry results are presented as a function of the absolute value of the electron pseudorapidity. The selected events are divided into bins of $|\eta|$ with bin width 0.2. The region of $|\eta|$ between 1.4 and 1.6 is excluded because the cables and services in the transition region between the ECAL barrel and end caps cause a significant reduction in the efficiency and purity of the $W$ selection. A total of 1 229 315 $W^{+} \rightarrow e^{+}\nu$ candidates and 991 256 $W^{-} \rightarrow e^{-}\bar{\nu}$ candidates are selected in the 11 bins of $|\eta|$.

A binned extended maximum-likelihood fit is performed to the $E_{T}$ distribution to estimate the $W \rightarrow e\nu$ signal yield for electrons ($N^{-}$) and positrons ($N^{+}$) in each pseudorapidity bin. The signal $E_{T}$ shape is derived from MC simulations with an event-by-event correction to account for differences in the energy scale and resolution between data and simulation inferred from the hadronic recoil energy distributions in $Z/\gamma^{*} \rightarrow e^{+}e^{-}$ events selected from data [22]. The shape of the QCD background is determined, for each charge, from a signal-free control sample obtained by inverting a subset of the electron identification criteria [1]. The $E_{T}$ shapes for other backgrounds...
FIG. 1 (color online). Signal plus background fit to data $E_T$ distributions for positrons (left) and electrons (right) in data. Results are shown for the first pseudorapidity bin ($|\eta| < 0.2$, top) and for the tenth pseudorapidity bin ($2.0 < |\eta| < 2.2$, bottom). The hatched area represents the statistical and systematic uncertainties associated with the fitting procedure.

such as the Drell-Yan process, $\vec{t}\vec{t}$, and $W \rightarrow \tau\nu$ are taken from MC simulations with a fixed normalization relative to the $W \rightarrow e\nu$ yields. The normalization factors are calculated from the predicted values of the cross sections at next-to-leading order (NLO). The yield of the QCD background and the yield of the $W \rightarrow e\nu$ signal ($N^\pm$) are free parameters in the fit. The results of the fits to the data are shown for the first ($|\eta| < 0.2$) and the tenth ($2.0 < |\eta| < 2.2$) pseudorapidity bins in Fig. 1. The uncertainty in each bin represents the systematic and statistical components associated with the $N^\pm$ extraction procedure. The ratio of the QCD background yields estimated from the fit to the $E_T$ distributions for positive and negative electrons is consistent with unity. The EW background yield for positive electrons is larger than for negative electrons because of the contribution of $W \rightarrow \tau\nu$ events. The charge asymmetry is obtained from the $(N^+ - N^-)/(N^+ + N^-)$ ratio.

Two sources of systematic uncertainty are related to the signal $E_T$ shape, the PDF used to generate the events, and the uncertainty on the correction from the hadronic recoil applied to the signal $E_T$ shape. The PDF uncertainties and their effects on the measured asymmetries are evaluated using the prescription given by the PDF4LHC Working Group [23]. Uncertainties on the correction from the hadronic recoil obtained from data are also propagated to the asymmetry measurements. The systematic uncertainty due to the QCD background shape is evaluated by studying samples from different QCD background control regions.

### Table I. Summary of the systematic uncertainties on the asymmetry. All values are given in units of $10^{-3}$.

| $|\eta|$ bin | Signal yield | Energy scale and res. | Charge MisId. | Efficiency ratio |
|-------------|--------------|-----------------------|---------------|-----------------|
| $0.0 < |\eta| < 0.2$ | 1.8 | 0.6 | <0.1 | 4.5 |
| $0.2 < |\eta| < 0.4$ | 2.5 | 0.6 | <0.1 | 4.4 |
| $0.4 < |\eta| < 0.6$ | 2.7 | 0.3 | <0.1 | 4.4 |
| $0.6 < |\eta| < 0.8$ | 2.5 | 0.3 | <0.1 | 4.4 |
| $0.8 < |\eta| < 1.0$ | 1.9 | 0.6 | <0.1 | 4.4 |
| $1.0 < |\eta| < 1.2$ | 2.4 | 1.0 | <0.1 | 4.9 |
| $1.2 < |\eta| < 1.4$ | 2.6 | 0.8 | 0.1 | 5.4 |
| $1.4 < |\eta| < 1.6$ | 3.1 | 0.8 | 0.1 | 9.2 |
| $1.6 < |\eta| < 1.8$ | 2.0 | 1.6 | 0.2 | 8.7 |
| $1.8 < |\eta| < 2.0$ | 2.0 | 2.6 | 0.3 | 10.0 |
| $2.0 < |\eta| < 2.2$ | 2.9 | 2.4 | 0.3 | 12.5 |

### Table II. Covariance matrix for the systematic uncertainties on the asymmetry. All values are given in units of $10^{-6}$. The matrix is symmetric.

| $|\eta|$ bin | $|\eta|$ bin |
|-------------|-------------|
| [0.0, 0.2]  | 23.7 |
| [0.2, 0.4]  | 2.6 |
| [0.4, 0.6]  | 2.2 |
| [0.6, 0.8]  | 2.5 |
| [0.8, 1.0]  | 2.7 |
| [1.0, 1.2]  | 2.9 |
| [1.2, 1.4]  | 2.9 |
| [1.6, 1.8]  | 2.9 |
| [1.8, 2.0]  | 2.8 |
| [2.0, 2.2]  | 3.1 |
| [2.2, 2.4]  | 4.2 |
The systematic uncertainty due to the modelling of Drell-Yan production, \( t \bar{t} \), and \( W \to \tau \nu \) is estimated by varying the relative normalization of the EW backgrounds to the \( W \to e\nu \) yield by the uncertainty on the Drell-Yan production and \( t \bar{t} \) cross sections, and the effect on the observed asymmetry is negligible. The values of \( N^\pm \) from the fitting procedure are insensitive to the presence of pileup interactions because the \( \mathbf{p}_T \) distributions are obtained from data.

In order to compare our results directly to theoretical predictions, the observed charge asymmetry is corrected for three detector effects: (1) electron energy scale and resolution, (2) relative detection efficiency of positrons and electrons, and (3) electron charge misidentification.

The electron energy scale and resolution can bias the asymmetry because of the effect on electrons on transverse momentum close to the threshold value of 35 GeV. The electron energy scale and resolution are taken as sources for systematic uncertainties due to the modeling of Drell-Yan production, \( t \bar{t} \), and \( W \to e\nu \). The uncertainties due to the electron energy scale and resolution, (2) relative detection efficiency of positrons and electrons, and (3) electron charge misidentification are between 0.96 and 1.03; the statistical uncertainties in all the pseudorapidity bins.

The electron charge misidentification probability is taken as the systematic uncertainty. The charge asymmetry to the predictions of different PDF models for the electron \( p_T \) distributions is estimated using the PDF reweighting technique. All uncertainties shown. The statistical uncertainties in the various pseudorapidity bins are uncorrelated.

The measured charge asymmetry results are summarized in Table III with both statistical and systematic uncertainties shown. The statistical uncertainties in the various pseudorapidity bins are uncorrelated.

![FIG. 2 (color online). Comparison of the measured electron asymmetry to the predictions of different PDF models for the electron \( p_T \) > 35 GeV. The error bars include both statistical and systematic uncertainties. The data points are placed in the center of the \(|\eta|\) bins. The PDF uncertainty bands are estimated using the PDF reweighting technique and correspond to a 68% confidence level.](image)

**Table III. Summary of the measured charge asymmetry results.** The first uncertainty is statistical and the second is systematic. The theoretical predictions are obtained using MCFM interfaced with four different PDF models. The PDF uncertainties are estimated using the PDF reweighting technique. All values are in units of \( 10^{-3} \).

| \(|\eta|\) bin | Measured Asymmetry \( \mathcal{A} \) | CT10 | HERAPDF | MSTW | NNPDF |
| --- | --- | --- | --- | --- | --- |
| [0.0, 0.2] | 102 ± 3 ± 5 | 109 ± 5 | 106^{+4}_{-3} | 87^{+3}_{-3} | 107 ± 5 |
| [0.2, 0.4] | 111 ± 3 ± 5 | 114 ± 5 | 110^{+4}_{-3} | 89^{+3}_{-3} | 110 ± 5 |
| [0.4, 0.6] | 116 ± 3 ± 5 | 119 ± 5 | 115^{+4}_{-3} | 98^{+3}_{-3} | 116 ± 5 |
| [0.6, 0.8] | 123 ± 3 ± 5 | 126 ± 5 | 123^{+4}_{-3} | 103^{+3}_{-3} | 123 ± 5 |
| [0.8, 1.0] | 133 ± 3 ± 5 | 138^{+5}_{-4} | 132^{+4}_{-3} | 115^{+3}_{-3} | 134 ± 5 |
| [1.0, 1.2] | 136 ± 3 ± 6 | 146 ± 6 | 140^{+5}_{-4} | 128^{+4}_{-3} | 145 ± 5 |
| [1.2, 1.4] | 156 ± 3 ± 6 | 164^{+6}_{-5} | 153^{+5}_{-4} | 144 ± 5 | 158 ± 5 |
| [1.6, 1.8] | 166 ± 3 ± 10 | 195^{+8}_{-7} | 181 ± 5 | 179 ± 5 | 190 ± 4 |
| [1.8, 2.0] | 197 ± 3 ± 9 | 207^{+6}_{-5} | 196^{+4}_{-3} | 200^{+4}_{-3} | 206 ± 4 |
| [2.0, 2.2] | 224 ± 3 ± 11 | 224^{+8}_{-7} | 211^{+5}_{-4} | 213^{+4}_{-3} | 219 ± 4 |
| [2.2, 2.4] | 210 ± 4 ± 13 | 241^{+10}_{-9} | 225^{+5}_{-4} | 231^{+4}_{-3} | 231 ± 5 |

The true charge asymmetry \( \mathcal{A} \) is diluted because of charge misidentification, resulting in an observed asymmetry \( \mathcal{A}^{\text{obs}} = \mathcal{A}(1 - 2w) \). The electron charge misidentification probability \( w \) is measured using \( Z/\gamma^* \to e^+e^- \) events in data. The observed electron charge asymmetry is corrected for the charge misidentification probability as a function of \(|\eta|\). The statistical uncertainty on the charge misidentification probability is taken as the systematic uncertainty.

Table I summarizes the systematic uncertainties in all the electron pseudorapidity bins. The full systematic covariance matrix is given in Table II.
MSTW are systematically lower than the observed asymmetry in the region $|\eta| < 1.4$.

In summary, we have measured the electron charge asymmetry in the $W \rightarrow e \nu$ channel in a sample of proton-proton collisions at 7 TeV, corresponding to an integrated luminosity of 840 pb$^{-1}$. The measured asymmetry rises from about 0.1 to 0.2 as a function of the pseudorapidity, with an uncertainty that ranges from 0.006 in the central region to 0.014 in the ECAL end caps. This precise measurement of the electron charge asymmetry in inclusive $W$ production at the LHC provides stringent constraints for parton distribution functions.

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