Measurement of the differential cross section and charge asymmetry for inclusive pp to W + X production at s = 8 TeV postprint

Authors: Khachatryan, Vardan and others

Date: 2016-08-22T00:00:00+00:00

Abstract

The differential cross section and charge asymmetry for inclusive pp to W + X to mu-nu + X production at sqrt(s) = 8 TeV are measured as a function of muon pseudorapidity. The data sample corresponds to an integrated luminosity of 18.8 inverse-femtobarns recorded with the CMS detector at the LHC. These results provide important constraints on the parton distribution functions of the proton in the range of the Bjorken scaling variable x from 10 to the minus 3 to 10 to the minus 1.

Full Text

Preamble

Measurement of the differential cross section and charge asymmetry for inclusive pp → W± + X production at √s = 8 TeV
The CMS Collaboration∗

Abstract

The differential cross section and charge asymmetry for inclusive pp → W± + X → μ± + X production at √s = 8 TeV are measured as a function of muon pseudorapidity. The data sample corresponds to an integrated luminosity of 18.8 fb [1] recorded with the CMS detector at the LHC. These results provide important constraints on the parton distribution functions of the proton in the range of the Bjorken scaling variable x from 10 [3] to 10 [1].

Submitted to the European Physical Journal C

∗See Appendix A for the list of collaboration members

1 Introduction

We present measurements of the pp → W± + X → μ± + X differential cross section and the muon charge asymmetry that provide important constraints on the valence and sea quark distributions in the proton. Uncertainties in the parton distribution functions (PDF) have become a limiting factor for the precision of many inclusive and differential cross section calculations, given the development of precise theoretical tools describing hard scattering processes in pp collisions.

For each charge of the W boson, the differential cross section, (pp → W± + X → μ± + X), is measured in bins of muon pseudorapidity = -ln tan(/2) in the laboratory frame, where is the polar angle of the muon direction with respect to the beam axis. Current theoretical calculations predict these cross sections with next-to-next-to-leading-order (NNLO) accuracy in perturbative quantum chromodynamics (QCD). The dominant W± boson production occurs through the annihilation of a valence quark from one of the protons with a sea antiquark from the other: ud → W and dū → W . Because of the presence of two valence u quarks in the proton, W bosons are produced more often than W bosons. Precise measurement of the charge asymmetry as a function of the muon , A( ) = (_ - _)/(_ + _), provides significant constraints on the ratio of u and d quark distributions in the proton for values of x, the Bjorken scaling variable [1], between 10 ^{3} and 10 ^{1}.

The W± boson production asymmetry was previously studied in pp collisions by the CDF and D0 collaborations [2-6]. At the LHC, the first measurements of the lepton charge asymmetries were performed by the CMS, ATLAS, and LHCb experiments using data collected in 2010 [7-9]. The CMS experiment has further improved the measurement precision in both the electron and muon decay channels using data from pp collisions at $\sqrt{s}$ = 7 TeV corresponding to integrated luminosities of 0.84 fb ^{1} and 4.7 fb ^{1} in the electron [10] and muon [11] decay channels, respectively. This measurement is based on a data sample of pp collisions at $\sqrt{s}$ = 8 TeV collected by CMS during 2012, corresponding to an integrated luminosity of 18.8 fb ^{1}. At $\sqrt{s}$ = 8 TeV the average value of the Bjorken scaling variable for the interacting partons in W± boson production is lower than at $\sqrt{s}$ = 7 TeV, which is expected to result in a lower W± boson production charge asymmetry. This measurement provides important constraints on the proton PDFs, which is illustrated by the QCD analysis also presented in this paper.

2 CMS Detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [12].

3 Data Selection and Simulation

A W± → μ± event is characterized by an isolated muon with a high transverse momentum p_T and a large missing transverse energy E_T^miss associated with an undetected neutrino. Events in this sample are collected with an isolated single-muon trigger with a p_T threshold of 24 GeV.

To reduce the background, identification and isolation criteria are applied to the reconstructed muons. These requirements are similar to those used in the previous measurement [11]. Muon tracks must be reconstructed in both the silicon tracker and the muon detectors. The global muon fit is required to have a ^{2} per degree of freedom less than 10. The pseudorapidity coverage for reconstructed muons is restricted to | | < 2.4. Cosmic ray contamination is largely reduced by rejecting muon candidates with a large (>0.2 cm) distance of closest approach to the primary vertex in the transverse plane. The isolation criterion is based on additional tracks reconstructed in a cone of √(Δ)^2 + (Δ)^2 < 0.3 around the muon, where is the azimuthal angle (in radians) in the laboratory frame. The muon candidate is rejected if the scalar p_T sum of these tracks exceeds 10% of the muon p_T. The selected muon candidate with the largest p_T, identified as a signal muon from the W boson decay, is required to have p_T > 25 GeV and must be the particle that triggered the event. To reduce background from Drell–Yan (DY) dimuon production, events containing a second identified muon with p_T > 15 GeV are rejected.

A total of about 61 million W → μ and 45 million W → μ candidate events are selected.

The W± → μ± signal is contaminated with backgrounds that also produce a muon with high p_T. The major background sources are (i) multijet (QCD) events with high-p_T muons produced in hadron decays (about 10% of the selected sample), and (ii) Z/ * → μ μ events (5% of the sample). The contribution from other backgrounds, such as W± → ± (2.6%), Z/ * → (0.5%), and t t (0.5%) events, is relatively small. The contributions from single top quark (0.14%) and diboson (0.07%) events, as well as from cosmic muons (10), are negligible.

Simulated samples are used to model the signal and background processes. The signal, as well as the electroweak and t t background samples, is based on next-to-leading-order (NLO) matrix element calculations implemented in the POWHEG Monte Carlo (MC) event generator [13–16], interfaced with PYTHIA6 [17] for parton showering and hadronization, including electromagnetic final-state radiation (FSR). The CT10 NLO PDFs [18] are used. The lepton decays in relevant processes are simulated with TAUOLA [19].

The QCD background is generated with PYTHIA6 using CTEQ6L PDF [20]. The detector response to all generated particles is simulated with GEANT4 [21]. Final-state particles are reconstructed with the same algorithms used for the data sample. To match the distribution of the number of additional interactions per bunch crossing (pileup) observed in data, weight factors are applied to all simulated events in signal and background samples. The weight factors are based on the instantaneous luminosity and the total inelastic cross section of 69.4 mb measured by CMS [22].

4 Corrections to the Data and Simulations

The fiducial cross sections are measured for muon $p_T > 25$ GeV in 11 bins of absolute pseudorapidity, covering the range $| \ | < 2.4$. The $| \ |$ binning is such that migration effects due to finite resolution are negligible. In each $| \ |$ bin, the number of W → μ and W → μ events is extracted by fitting the E_T^{miss} distributions with signal and background templates. The template shapes and initial normalizations are derived from MC simulations. To improve the simulation, several corrections are applied to the MC samples, which are briefly summarized below.

Accurate calibration of the muon momentum is important for proper modeling of W± event yields and E_T^{miss} template shapes. Dominant sources of muon momentum mismeasurement are mismodeling of tracker alignment and magnetic field. Muon momentum correction factors are derived using Z/ * → μ μ events in several iterations [23]. First, "reference" distributions are defined based on MC generated muons with momenta smeared by reconstruction resolution. Then, corrections to muon momentum in bins of and are extracted separately for positively and negatively charged muons. These corrections match the mean values of reconstructed $1/p_T$ spectra to corresponding reference values. Finally, correction factors are tuned further by comparing reconstructed dimuon invariant mass spectra in each μ and μ pseudorapidity bin with the reference. The correction factors are determined separately for data and simulated events following the same procedure.

The overall muon selection efficiency includes contributions from reconstruction, identification, isolation, and trigger efficiencies. Each component is measured from Z/ * → μ μ events using the "tag-and-probe" method [24, 25]. The efficiencies are measured in bins of and p_T for μ and μ separately. Each bin of the efficiency measurement is fully contained in a single $| \ |$ bin used for the asymmetry measurement. The total average efficiency is about 85% at central rapidities and drops to about 50% in the last $| \ |$ bin. The ratio of average μ and μ efficiencies varies within 0.6% of unity in the first 10 $| \ |$ bins; in the last bin the ratio is 0.98. The same procedure is used in data and MC simulation, and scale factors are determined to match MC simulation efficiencies to data.

Template shapes used in the fits are based on missing transverse momentum (p_T^miss) reconstructed with the particle-flow algorithm [26, 27]. The p_T^miss is defined as the projection on the plane perpendicular to the beams of the negative vector sum of momenta of all reconstructed particles in an event. A set of corrections is applied to p_T^miss to improve modeling of E_T^miss = |p_T^miss| distributions in data and MC templates. First, the average bias in the p_T^miss component along the direction of p_T-sum of charged particles associated with pileup vertices is removed [28]. Second, the muon momentum correction to p_T, described above, is added vectorially to p_T^miss. In addition, " -modulation" corrections, which increase linearly as a function of pileup, make the (p_T^miss) distributions uniform [28].

These corrections are applied to both data and simulated events. The final set of corrections, derived from the "hadronic recoil" technique [29, 30], is applied to simulated W± → µ± , Z/ * → µ µ , and QCD events to match the average p_T^miss scale and resolution to data.

The modeling of multijet events is further improved with corrections derived from a QCD control sample selected by inverting the offline isolation requirement for events collected using a prescaled muon trigger with no isolation requirement. Muon p_T-dependent weight factors are determined for the QCD simulation to match muon p_T distributions with data.

5 Signal Extraction

In each of the 11 muon | | bins, yields of W and W events are obtained from simultaneous ² fits of the E_T^miss distributions of µ and µ events. The ² definition used in the fit takes into account statistical uncertainties in simulated templates. The shapes of E_T^miss distributions for W± → µ± signal and backgrounds are taken from MC simulation after correcting for detector response mismodeling and W boson p_T distribution. All electroweak and t t background samples are normalized to integrated luminosity using theoretical cross sections calculated at NNLO. Each simulated event is also weighted with scale factors to match average muon selection efficiencies in data. Additionally, mass-dependent correction factors are applied to Z/ * → µ µ simulated events to match observed dimuon mass distributions in data.

The W and W signal yields and QCD background normalization are free parameters in the fit. Relative contributions of QCD background events in W and W samples are constrained to values obtained from the QCD control sample. The W± → ± background is normalized to W± → µ± signal, for each charge, using scale factors corresponding to free parameters of the signal yield. Normalizations of remaining electroweak and t t backgrounds are fixed in the fit.

Table 1 summarizes fitted yields of W (N) and W (N) events, correlation coefficients (,), and ² values for each fit. Examples of fits for three | | ranges are shown in Fig. 1 [Figure 1: see original paper]. The ratio of data to final fit, shown below each distribution, demonstrates good agreement.

For each muon charge and | | bin, the fiducial cross section is calculated as:

_ = N _ / (_ × _FSR × L_int)

where _ is the average μ± selection efficiency per | | bin, _FSR accounts for event loss within the muon p_T acceptance due to final-state photon emission, and L_int is the integrated luminosity of the data sample. The average _ in each bin is based on scale factors measured from Z/ * → μ μ events for each charge that match muon selection efficiencies between simulation and data. Each _FSR factor, defined as the ratio of numbers of events within the p_T acceptance after and before FSR, is evaluated using signal MC samples.

6 Systematic Uncertainties

To estimate systematic uncertainties in muon selection efficiencies, several variations are applied to measured efficiency tables. First, efficiency values in each -p_T bin are varied within their statistical errors for data and simulation independently. In each pseudo-experiment, the varied set of efficiencies is used to correct MC simulation templates and extract cross sections using Eq. (3). The standard deviation of the resulting distribution is taken as systematic uncertainty for each charge and | | bin. Statistical uncertainties between the two charges and all -p_T bins are uncorrelated. Second, offline muon selection efficiency scale factors are varied by ±0.5% coherently for both charges and all bins. Trigger selection efficiency scale factors are varied by ±0.2%, assuming no correlations between bins but +100% correlations between charges and p_T bins. These systematic variations account for uncertainties associated with the tag-and-probe technique, assessed by varying signal and background dimuon mass shapes, background levels, and dimuon mass range and binning used in fits. Finally, an additional ±100% correlated variation is applied based on bin-by-bin differences between true and measured efficiencies in Z/ * → μ μ MC samples. This difference changes gradually from about 0.5% in the first bin to about -2% in the last bin. This contribution is the main source of negative correlations in systematic uncertainties between central and high rapidity bins. The total systematic uncertainty in efficiency is obtained by adding the four covariance matrices corresponding to these variations.

A possible mismeasurement of muon charge could bias observed asymmetry between W and W event rates. The muon charge misidentification rate has been studied in detail and found to be negligible (10) [7].

Muon momentum correction affects yields and shapes of E_T^miss distributions in both data and MC simulation. To estimate systematic uncertainty, muon correction parameters in each - bin and overall scale are varied within their uncertainties. The standard deviation of resulting cross section distribution for each charge and muon | | bin is taken as systematic uncertainty, with corresponding correlations calculated. Finite detector resolution effects, which cause migration of events around the p_T threshold and between | | bins, have been studied with signal MC samples and found to have negligible impact on measured cross sections and asymmetries.

Two sources of systematic uncertainty are associated with QCD background estimation. One is uncertainty in the ratio of QCD background events in W and W samples (R_QCD^±). While total QCD normalization is a free parameter in the fit, R_QCD^± is constrained to values observed in the QCD control sample, which vary within 3% of unity depending on | | bin. Corresponding systematic uncertainty is evaluated by changing it by ±5% in each | | bin. This variation covers maximum deviations indicated by QCD MC simulation. Resulting systematic uncertainties are assumed uncorrelated between | | bins. Additionally, the average difference of this ratio between signal and QCD control regions is evaluated using QCD MC simulation. This difference of about 3% is taken as an additional 100%-correlated systematic uncertainty in R_QCD^±. As a check, using the same shape for QCD background in µ and µ events, its normalization is allowed to float independently for the two charges. Resulting R_QCD^± values are covered by these systematic uncertainties.

The other component of systematic uncertainty associated with QCD background is the E_T^miss shape. To estimate systematic uncertainty in modeling E_T^miss distributions in QCD events, additional fits are performed using E_T^miss distributions without hadronic recoil corrections and p_T-dependent scale factors, resulting in about 2% variation in average E_T^miss resolution. Resulting shifts in extracted cross section values in each | | bin are taken as systematic uncertainties. Correlations between | | bins and the two charges are assumed to be 100%.

Normalization of Z/ * → µ µ background in the signal region is corrected with mass-dependent scale factors that match dimuon mass distributions in MC simulation with data. Systematic uncertainty is the difference between cross sections calculated with and without these corrections to DY background normalizations. A 7% uncertainty is assigned to the t t theoretical cross section [31], used to normalize t t background to data sample integrated luminosity. In fits, W± → ± background is normalized to W± → µ± yields in data with a ratio obtained from simulation. A ±2% uncertainty is assigned to the W± → ± to W± → µ± ratio [32]. Each variation is assumed fully correlated across bins and charges.

Several sources of systematic uncertainty affect E_T^miss shapes. Uncertainty associated with modulation of p_T^miss is evaluated by removing corresponding correction to p_T^miss. Effect of mismodeling pileup in simulation is estimated by varying minimum bias cross section by 5% and reweighting MC events to match expected pileup distributions in data. To improve agreement between data and simulation, W boson p_T spectrum is weighted using factors determined from ratios of p_T distributions in Z/ * → µ µ events in data and MC simulation. Difference in measured cross sections with and without this correction is taken as systematic uncertainty.

Each source above is assumed fully correlated between charges and bins. Systematic uncertainties associated with recoil corrections are evaluated by varying average recoil and resolution parameters within their uncertainties. Standard deviation of resulting cross section distribution is taken as systematic uncertainty, with correlations between charges and bins calculated.

Emission of FSR photons tends on average to reduce muon p_T. Observed post-FSR cross sections within p_T acceptance are corrected using _FSR factors derived from signal MC samples. Differences between p_T spectra of positive and negative muons result in smaller charge asymmetries after FSR compared with before FSR within the same p_T > 25 GeV acceptance. These differences, varying between 0.07% and 0.11% depending on | | bin, are corrected by charge-dependent _FSR efficiency factors. Systematic uncertainty in FSR modeling is estimated by reweighting events with radiated photons using correction factors that account for missing electroweak corrections in parton shower [33, 34]. _FSR correction factors are reevaluated after such reweighting, and difference between cross sections calculated with new and default _FSR values is taken as systematic uncertainty. Correlations between charges and | | bins are assumed 100%. Effects of migration between | | bins due to final-state photon emission have been evaluated with signal MC samples and found negligible.

PDF uncertainties are evaluated using NLO MSTW2008 [35], CT10 [18], and NNPDF2.1 [36] PDF sets. All simulated events are weighted according to a given PDF set, varying both template normalizations and shapes. For CT10 and MSTW2008 PDFs, asymmetric master equations are used [18, 35]. For NNPDF2.1 PDF set, standard deviation of extracted cross section distributions is taken as systematic uncertainty. For CT10, the 90% confidence level (CL) uncertainty is rescaled to 68% CL using a factor of 1.645. Half-width of the total envelope of all three PDF uncertainty bands is taken as PDF uncertainty. CT10 error set is used to estimate correlations between charges and | | bins.

Finally, a $\pm 2.6\%$ uncertainty [37] is assigned to integrated luminosity of the data sample. Luminosity uncertainty is fully correlated between | | bins and charges, therefore canceling in measured charge asymmetries. Uncertainty in normalization of electroweak backgrounds due to luminosity uncertainty has negligible impact on measurements.

Table 2 summarizes systematic uncertainties in measured cross sections and asymmetries. For comparison, statistical and luminosity uncertainties are also shown. Uncertainty in integrated luminosity dominates total uncertainties in measured cross sections, while uncertainty in QCD background estimation dominates uncertainties in charge asymmetries. Uncertainties for muon charge asymmetries are calculated from those in differential cross sections, accounting for correlations between charges.

Correlations in systematic uncertainty between charges and | | bins are shown in Table 3 . The full 22×22 correlation matrix C is split into four 11×11 blocks as:

C = [C C C C]

where C and C matrices represent bin-to-bin correlations of systematic uncertainties in _ and _ respectively, and C describes correlations between charges.

To construct total covariance matrix, covariance matrix of systematic uncertainties should be added to those of statistical and integrated luminosity uncertainties. The latter are fully correlated between charges and | | bins. For statistical uncertainties, bin-to-bin correlations are zero; correlations between charges are shown in Table 1.

7 Results

Measured cross sections and charge asymmetries are summarized in Table 4 and displayed in Fig. 2 [Figure 2: see original paper]. Error bars represent both statistical and systematic uncertainties, including integrated luminosity uncertainty. Measurements are compared with theoretical predictions based on several PDF sets. Predictions are obtained using FEWZ 3.1 [38] NNLO MC calculation interfaced with CT10 [18], NNPDF3.0 [39], HERAPDF1.5 [40], MMHT2014 [41], and ABM12 [42] PDF sets. No electroweak corrections are included. Error bars of theoretical predictions represent PDF uncertainty, which dominates uncertainty in these calculations. For CT10, MMHT, HERA, and ABM PDFs, uncertainties are calculated with eigenvector sets using asymmetric master equations where applicable. For NNPDF set, standard deviations over its 100 replicas are evaluated.

Numerical values of predictions are also shown in Table 4. Previous CMS lepton charge asymmetry measurements at $\sqrt{s} = 7$ TeV have been included in global PDF fits for NNPDF3.0, MMHT2014, and ABM12 PDFs. Measured cross sections and charge asymmetries are well described by all considered PDF sets within their uncertainties.

8 QCD Analysis

Muon charge asymmetry measurements at 8 TeV are used in a QCD analysis at NNLO together with combined measurements of neutral- and charged-current cross sections of deep inelastic electron(positron)-proton scattering (DIS) at HERA [43]. Correlations of experimental uncertainties for muon charge asymmetry and inclusive DIS cross sections are accounted for. Theoretical predictions are calculated at NLO using MCFM 6.8 [44, 45], interfaced to APPLGRID 1.4.56 [46]. NNLO corrections are obtained using k-factors defined as ratios of predictions at NNLO to NLO, both calculated with FEWZ 3.1 [38] using NNLO CT10 [18] PDFs.

Version 1.1.1 of the open-source QCD fit framework HERAFitter [47, 48] is used with partons evolved using Dokshitzer-Gribov-Lipatov-Altarelli-Parisi equations [49–54] at NNLO, as implemented in QCDNUM 17-00/06 [55].

The Thorne-Roberts [35, 56] general mass variable flavor number scheme at NNLO is used for heavy-quark contributions with masses $m_c = 1.43$ GeV and $m_b = 4.5$ GeV. Renormalization and factorization scales are set to Q, denoting four-momentum transfer for DIS data and W boson mass for muon charge asymmetry, respectively.

The strong coupling constant is set to $_s(m_Z) = 0.118$. The Q^2 range of HERA data is restricted to $Q^2 \quad Q^2_{min} = 3.5$ GeV^2 to assure applicability of perturbative QCD over the kinematic range of the fit.

The PDF determination procedure follows the approach used in Ref. [11]. Parameterized PDFs are the gluon distribution xg, valence quark distributions xu_v and xd_v, and u-type and d-type anti-quark distributions xU and xD. At the initial QCD evolution scale $Q^2 = 1.9$ GeV^2, PDFs are parameterized as:

$$xg(x) = A_g x^{B_g} (1 - x)^{C_g} (1 + D_g x)$$
$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1 - x)^{C_{u_v}} (1 + E_{u_v} x^2)$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1 - x)^{C_{d_v}}$$
$$xU(x) = A_U x^{B_U} (1 - x)^{C_U} (1 + E_U x^2)$$
$$xD(x) = A_D x^{B_D} (1 - x)^{C_D}$$

with relations $xU = x\bar{u}$ and $xD = x\bar{d} + xs$ assumed.

Normalization parameters A_{u_v}, A_{d_v}, and A_g are determined by QCD sum rules. The B parameter governs small-x behavior, while C describes the shape as $x \to 1$. Additional constraints $B_U = B_D$ and $A_U = A_D(1 - f_s)$ are imposed, with f_s being the strangeness fraction $f_s = s/(\bar{d} + s)$, fixed to $f_s = 0.31 \pm 0.08$ as in Ref. [35], consistent with CMS W + charm production measurements [11]. The ^{2} definition follows Eq.(32) of [43] without the logarithmic term. Parameters were selected by first fitting with all D and E parameters set to zero, then adding other parameters one at a time, monitoring ^{2} improvement until no further improvement was observed, resulting in a 13-parameter fit.

PDF uncertainties are estimated according to the HERAPDF1.0 approach [57], accounting for experimental, model, and parametrization uncertainties. A tolerance criterion of $\Delta ^2 = 1$ defines experimental uncertainties from measurements. Model uncertainties arise from variations in heavy-quark masses ($4.25 \quad m_b \quad 4.75$ GeV, $1.37 \quad m_c \quad 1.49$ GeV) and Q^2_{min} ($2.5 \quad Q^2_{min} \quad 5.0$ GeV^2) for HERA data. The strangeness fraction f_s is varied by its uncertainty. Parametrization uncertainty is estimated by extending functional forms with additional parameters, constructing an envelope from maximal differences between varied PDFs and central fit at each x value. Total PDF uncertainty is obtained by adding experimental, model, and parametrization uncertainties in quadrature. Quoted uncertainties correspond to 68% CL.

Table 5 shows partial ^{2} per number of data points and global ^{2} per degrees of freedom, illustrating consistency among data sets. The somewhat high ^{2}/ndof values for combined DIS data are similar to those observed in Ref. [43].

In the kinematic range probed, final combined HERA DIS data currently provide the most significant constraints on valence distributions. Adding these muon charge asymmetry measurements significantly improves constraints, as shown in Fig. 3 [Figure 3: see original paper] where xu_v and xd_v distributions are displayed at $Q^2 = m^2\_W$, relevant for W boson production. Changes in shapes and reduced uncertainties of valence quark distributions relative to HERA-only fits are evident.

9 Summary

We have measured the differential cross section and charge asymmetry of $W\pm \rightarrow \mu\pm$ production in pp collisions at $\sqrt{s} = 8$ TeV using a data sample corresponding to 18.8 fb ^{1} collected with the CMS detector at the LHC. Measurements were performed in 11 bins of absolute muon pseudorapidity | | for muons with p_T > 25 GeV. Results have been incorporated into a NNLO QCD analysis with inclusive deep inelastic scattering data from HERA. Significant improvement in valence quark distribution accuracy is observed in the range $10\ ^{3} < x < 10\ ^{1}$, demonstrating the power of these muon charge asymmetry measurements to enhance main constraints from HERA data in the probed kinematic range. This strongly suggests using these measurements in future PDF determinations.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and other CMS institutes for their contributions. We gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering essential computing infrastructure. Finally, we acknowledge enduring support for LHC and CMS construction and operation from funding agencies: BMWFW and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, NSFC (China); COLCIENCIAS (Colombia); MSES, CSF (Croatia); RPF (Cyprus); MoER, ERC IUT, ERDF (Estonia); Academy of Finland, MEC, HIP (Finland); CEA, CNRS/IN2P3 (France); BMBF, DFG, HGF (Germany); GSRT (Greece); OTKA, NIH (Hungary); DAE, DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP, NRF (Korea); LAS (Lithuania); MOE, UM (Malaysia); CINVESTAV, CONACYT, SEP, UASLP-FAI (Mexico); MBIE (NZ); PAEC (Pakistan); MSHE, NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR (Russia); MESTD (Serbia); SEIDI, CPAN (Spain); Swiss Funding Agencies; MST (Taipei); ThEPCenter, IPST, STAR, NSTDA (Thailand); TUBITAK, TAEK (Turkey); NASU, SFFR (Ukraine); STFC (UK); DOE, NSF (USA).

Individuals received support from Marie-Curie programme, European Research Council, EPLANET (EU); Leventis Foundation; A.P. Sloan Foundation; Alexander von Humboldt Foundation; Belgian Federal Science Policy Office;

FRIA (Belgium); IWT-Belgium; MEYS (Czech Republic); CSIR (India); HOMING PLUS (Poland); National Science Center (Poland); Compagnia di San Paolo (Torino); MIUR project 20108T4XTM (Italy); Thalis, Aristeia programmes (Greece); Qatar National Research Fund; Rachadapisek Sompot Fund (Thailand); Chulalongkorn Academic Advancement Project (Thailand); Welch Foundation (contract C-1845).

References

[1] J. D. Bjorken and E. A. Paschos, "Inelastic electron-proton and -proton scattering and the structure of the nucleon" , Phys. Rev. 185 (1969) 1975, doi:10.1103/PhysRev.185.1975.

[2] CDF Collaboration, "Measurement of the lepton charge asymmetry in W boson decays produced in pp collisions" , Phys. Rev. Lett. 81 (1998) 5754, doi:10.1103/PhysRevLett.81.5754, arXiv:hep-ex/9809001.

[3] CDF Collaboration, "Direct measurement of the W production charge asymmetry in pp Collisions at $\sqrt{s} = 1.96$ TeV" , Phys. Rev. Lett. 102 (2009) 181801, doi:10.1103/PhysRevLett.102.181801, arXiv:0901.2169.

[4] D0 Collaboration, "Measurement of the muon charge asymmetry from W boson decays" , Phys. Rev. D 77 (2008) 011106, doi:10.1103/PhysRevD.77.011106, arXiv:0709.4254.

[5] D0 Collaboration, "Measurement of the electron charge asymmetry in pp $\rightarrow$ W + X $\rightarrow$ e + X events at $\sqrt{s} = 1.96$ TeV" , Phys. Rev. Lett. 101 (2008) 211801, doi:10.1103/PhysRevLett.101.211801, arXiv:0807.3367.

[6] D0 Collaboration, "Measurement of the muon charge asymmetry in pp $\rightarrow$ W + X $\rightarrow$ μ + X events at $\sqrt{s} = 1.96$ TeV" , Phys. Rev. D 88 (2013) 091102, doi:10.1103/PhysRevD.88.091102, arXiv:1309.2591.

[7] CMS Collaboration, "Measurement of the lepton charge asymmetry in inclusive W production in pp collisions at $\sqrt{s} = 7$ TeV" , JHEP 04 (2011) 050, doi:10.1007/JHEP04(2011)050, arXiv:1103.3470.

[8] ATLAS Collaboration, "Measurement of the inclusive W± and Z/ cross sections in the e and μ decay channels in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector" , Phys. Rev. D 85 (2012) 072004, doi:10.1103/PhysRevD.85.072004, arXiv:1109.5141.

[9] LHCb Collaboration, "Inclusive W and Z production in the forward region at $\sqrt{s} = 7$ TeV" , JHEP 06 (2012) 058, doi:10.1007/JHEP06(2012)058, arXiv:1204.1620.

[10] CMS Collaboration, "Measurement of the Electron Charge Asymmetry in Inclusive W Production in pp Collisions at $\sqrt{s} = 7$ TeV" , Phys. Rev. Lett. 109 (2012) 111806, doi:10.1103/PhysRevLett.109.111806, arXiv:1206.2598.

[11] CMS Collaboration, "Measurement of the muon charge asymmetry in inclusive pp $\rightarrow$ W + X production at $\sqrt{s} = 7$ TeV and an improved determination of light parton distribution functions" , Phys. Rev. D 90 (2014) 032004, doi:10.1103/PhysRevD.90.032004, arXiv:1312.6283.

[12] CMS Collaboration, "The CMS experiment at the CERN LHC" , JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[13] S. Alioli, P. Nason, C. Oleari, and E. Re, "NLO vector-boson production matched with shower in POWHEG" , JHEP 07 (2008) 060, doi:10.1088/1126-6708/2008/07/060, arXiv:0805.4802.
[14] P. Nason, "A new method for combining NLO QCD with shower Monte Carlo algorithms" , JHEP 11 (2004) 040, doi:10.1088/1126-6708/2004/11/040, arXiv:hep-ph/0409146.
[15] S. Frixione, P. Nason, and C. Oleari, "Matching NLO QCD computations with parton shower simulations: the POWHEG method" , JHEP 11 (2007) 070, doi:10.1088/1126-6708/2007/11/070, arXiv:0709.2092.
[16] S. Alioli, P. Nason, C. Oleari, and E. Re, "A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX" , JHEP 06 (2010) 043, doi:10.1007/JHEP06(2010)043, arXiv:1002.2581.
[17] T. Sjöstrand, S. Mrenna, and P. Skands, "PYTHIA 6.4 physics and manual" , JHEP 05 (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.
[18] H.-L. Lai et al., "New parton distributions for collider physics" , Phys. Rev. D 82 (2010) 074024, doi:10.1103/PhysRevD.82.074024, arXiv:1007.2241.
[19] N. Davidson et al., "Universal Interface of TAUOLA Technical and Physics Documentation" , Comput. Phys. Commun. 183 (2012) 821, doi:10.1016/j.cpc.2011.12.009, arXiv:1002.0543.
[20] J. Pumplin et al., "New generation of parton distributions with uncertainties from global QCD analysis" , JHEP 07 (2002) 012, doi:10.1088/1126-6708/2002/07/012, arXiv:hep-ph/0201195.
[21] GEANT4 Collaboration, "GEANT4—a simulation toolkit" , Nucl. Instrum. Meth. A 506 (2003) 250, doi:10.1016/S0168-9002(03)01368-8.
[22] CMS Collaboration, "Measurement of the inelastic proton-proton cross section at $\sqrt{s} = 7$ TeV", Phys. Lett. B 722 (2013) 5, doi:10.1016/j.physletb.2013.03.024, arXiv:1210.6718.
[23] A. Bodek et al., "Extracting muon momentum scale corrections for hadron collider experiments", Eur. Phys. J. C 72 (2012) 2194, doi:10.1140/epjc/s10052-012-2194-8, arXiv:1208.3710.
[24] CMS Collaboration, "Measurements of inclusive W and Z cross sections in pp collisions at $\sqrt{s} = 7$ TeV with the CMS experiment" , JHEP 10 (2011) 132, doi:10.1007/JHEP10(2011)132, arXiv:1107.4789.
[25] CMS Collaboration, "Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV" , JINST 7 (2012) P10002, doi:10.1088/1748-0221/7/10/P10002, arXiv:1206.4071.
[26] CMS Collaboration, "Particle-flow event reconstruction in CMS and performance for jets, taus, and E_T^miss" , CMS Physics Analysis Summary CMS-PAS-PFT-09-001, CERN, 2009.
[27] CMS Collaboration, "Commissioning of the particle-flow event reconstruction with the first LHC collisions recorded in the CMS detector" , CMS Physics Analysis Summary CMS-PAS-PFT-10-001, CERN, 2010.
[28] CMS Collaboration, "Performance of the CMS missing transverse momentum reconstruction in pp data at $\sqrt{s} = 8$ TeV" , JINST 10 (2015) P02006, doi:10.1088/1748-0221/10/02/P02006, arXiv:1411.0511.

[29] D0 Collaboration, "A novel method for modeling the recoil in W boson events at hadron collider" , Nucl. Instrum. Meth. A 609 (2009) 250, doi:10.1016/j.nima.2009.08.056, arXiv:0907.3713.
[30] CMS Collaboration, "Missing transverse energy performance of the CMS detector" , JINST 6 (2011) P09001, doi:10.1088/1748-0221/6/09/P09001, arXiv:1106.5048.
[31] M. Czakon and A. Mitov, "Top++: a program for the calculation of the top-pair cross-section at hadron colliders" , Comput. Phys. Commun. 185 (2014) 2930, doi:10.1016/j.cpc.2014.06.021, arXiv:1112.5675.
[32] Particle Data Group Collaboration, "Review of particle physics" , Chin. Phys. C 38 (2014) 090001, doi:10.1088/1674-1137/38/9/090001.
[33] G. Nanava and Z. Was, "How to use SANC to improve the PHOTOS Monte Carlo simulation of bremsstrahlung in leptonic W boson decays" , Acta Phys. Polon. B 34 (2003) 4561, arXiv:hep-ph/0303260.
[34] H. Burkhardt and B. Pietrzyk, "Update of the hadronic contribution to the QED vacuum polarization" , Phys. Lett. B 513 (2001) 46, doi:10.1016/S0370-2693(01)00393-8.
[35] A. D. Martin, W. J. Stirling, R. S. Thorne, and G. Watt, "Parton distributions for the LHC" , Eur. Phys. J. C 63 (2009) 189, doi:10.1140/epjc/s10052-009-1072-5, arXiv:0901.0002.
[36] NNPDF Collaboration, "Impact of heavy quark masses on parton distributions and LHC phenomenology" , Nucl. Phys. B 849 (2011) 296, doi:10.1016/j.nuclphysb.2011.03.021, arXiv:1101.1300.
[37] CMS Collaboration, "CMS luminosity based on pixel cluster counting - Summer 2013 update" , CMS Physics Analysis Summary CMS-PAS-LUM-13-001, CERN, 2013.
[38] Y. Li and F. Petriello, "Combining QCD and electroweak corrections to dilepton production in the framework of the FEWZ simulation code" , Phys. Rev. D 86 (2012) 094034, doi:10.1103/PhysRevD.86.094034, arXiv:1208.5967.
[39] NNPDF Collaboration, "Parton distributions for the LHC Run II" , JHEP 04 (2015) 040, doi:10.1007/JHEP04(2015)040, arXiv:1410.8849.
[40] H1 and ZEUS Collaborations, "Combination and QCD Analysis of the HERA Inclusive Cross Sections" , in Proc. of 35th Int. Conf. of High Energy Physics, vol. 168, 2010. PoS(ICHEP2010)169. Grids at http://www.desy.de/h1zeus/combined_results/index.php?do=proton_structure.
[41] L. A. Harland-Lang, A. D. Martin, P. Motylinski, and R. S. Thorne, "Parton distributions in the LHC era: MMHT 2014 PDFs" , Eur. Phys. J. C 75 (2015) 204, doi:10.1140/epjc/s10052-015-3397-6, arXiv:1412.3989.
[42] S. Alekhin, J. Blumlein, and S. Moch, "The ABM parton distributions tuned to LHC data" , Phys. Rev. D 89 (2014) 054028, doi:10.1103/PhysRevD.89.054028, arXiv:1310.3059.
[43] H1 and ZEUS Collaborations, "Combination of measurements of inclusive deep inelastic e±p scattering cross sections and QCD analysis of HERA data" , Eur. Phys. J. C 75 (2015) 580, doi:10.1140/epjc/s10052-015-3710-4, arXiv:1506.06042.
[44] J. M. Campbell and R. K. Ellis, "Update on vector boson pair

production at hadron colliders" , Phys. Rev. D 60 (1999) 113006, doi:10.1103/PhysRevD.60.113006, arXiv:hep-ph/9905386.
[45] J. M. Campbell and R. K. Ellis, "MCFM for the Tevatron and the LHC" , Nucl. Phys. Proc. Suppl. 205–206 (2010) 10, doi:10.1016/j.nuclphysbps.2010.08.011, arXiv:1007.3492.
[46] T. Carli et al., "A posteriori inclusion of parton density functions in NLO QCD final-state calculations at hadron colliders: the APPLGRID project" , Eur. Phys. J. C 66 (2010) 503, doi:10.1140/epjc/s10052-010-1255-0, arXiv:0911.2985.
[47] S. Alekhin et al., "HERAFitter" , Eur. Phys. J. C 75 (2015) 304, doi:10.1140/epjc/s10052-015-3480-z, arXiv:1410.4412.
[48] HERAFitter website, http://www.herafitter.org.
[49] V. N. Gribov and L. N. Lipatov, "Deep inelastic e-p scattering in perturbation theory" , Sov. J. Nucl. Phys. 15 (1972) 438.
[50] G. Altarelli and G. Parisi, "Asymptotic freedom in parton language" , Nucl. Phys. B 126 (1977) 298, doi:10.1016/0550-3213(77)90384-4.
[51] G. Curci, W. Furmanski, and R. Petronzio, "Evolution of parton densities beyond leading order: The non-singlet case" , Nucl. Phys. B 175 (1980) 27, doi:10.1016/0550-3213(80)90003-6.
[52] W. Furmanski and R. Petronzio, "Singlet parton densities beyond leading order" , Phys. Lett. B 97 (1980) 437, doi:10.1016/0370-2693(80)90636-X.
[53] S. Moch, J. A. M. Vermaseren, and A. Vogt, "The three-loop splitting functions in QCD: the non-singlet case" , Nucl. Phys. B 688 (2004) 101, doi:10.1016/j.nuclphysb.2004.03.030, arXiv:hep-ph/0403192.
[54] A. Vogt, S. Moch, and J. A. M. Vermaseren, "The three-loop splitting functions in QCD: the singlet case" , Nucl. Phys. B 691 (2004) 129, doi:10.1016/j.nuclphysb.2004.04.024, arXiv:hep-ph/0404111.
[55] M. Botje, "QCDNUM: fast QCD evolution and convolution", Comput. Phys. Commun. 182 (2011) 490, doi:10.1016/j.cpc.2010.10.020, arXiv:1005.1481.
[56] R. S. Thorne, "Variable-flavor number scheme for NNLO" , Phys. Rev. D 73 (2006) 054019, doi:10.1103/PhysRevD.73.054019, arXiv:hep-ph/0601245.
[57] H1 and ZEUS Collaborations, "Combined measurement and QCD analysis of the inclusive e±p scattering cross sections at HERA" , JHEP 01 (2010) 109, doi:10.1007/JHEP01(2010)109, arXiv:0911.0884.

A The CMS Collaboration

[Author list and affiliations as provided in original document]

Note: Figure translations are in progress. See original paper for figures.