Production of W/Z bosons at LHC

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Studies from the Atlas and CMS experiments about the production mechanism of the heavy bosons Z and W at the LHC are presented. Results are compared to predictions from theory and an overall good agreement is found between expectations and observations.

Data collected in 2010 and 2011 by the CMS [1] and Atlas [2] experiments provided very useful information about the production at the LHC of the massive bosons W and Z in pp collisions with a center of mass energy of 7 TeV. Results about the measurement of absolute W and Z cross sections (Section 1), differential W and Z cross sections (Section 2), lepton charge asymmetry from W (Section 3) and results about W polarization(Section 4) are presented.

1 W/Z cross section measurement

Measurement of the cross section of the W and Z production in pp collisions is a fundamental test to probe the accuracy of QCD theory for hadronic interaction at high momentum. Both CMS and Atlas published the results on the cross sections using the data collected in 2010 [3,4]. In order to have a very clean sample of events with heavy bosons, only the decay of W and Z to muons and electrons are considered. Atlas selects Z candidates requesting two isolated leptons with transverse momentum (pt) above 20 GeV and W candidates are selected by requesting a lepton with pt $>$ 20 GeV and missing transverse energy (MET) above 25 GeV. CMS selects W candidates requesting one isolated lepton with pt $>$ 25 GeV and no cut on MET while Z candidates are selected by requesting two isolated muons(electrons) with pt$>$ 20(25) GeV. The number of Z signal events is extracted from a fit to the invariant mass of the two leptons while the number of W signal events is from a fit to the MET distribution. The agreement between the measured cross sections in the fiducial region and the theory predictions is at the level of few percent. A theory estimation of the detector acceptance is needed to extrapolate the measurement of the cross section in the fiducial region to the full kinematic range. Since the fiducial region of CMS and Atlas is different, in Table 1 only the cross sections in the full kinematic range are reported.

2 Differential cross section measurements

Additional information on the QCD theory describing the Drell–Yan production in pp collisions are obtained by comparing the differential cross section measurements to the calculations at

$\sigma \pm d\sigma(stat) \pm d\sigma(syst) \pm d\sigma(lumi) \pm d\sigma(theory)$		
	Atlas	CMS
$\sigma_W^{tot} \times BrW \to \ell\nu$ (nb)	$10.207 \pm 0.016 \pm 0.072 \pm 0.206 \pm 0.096$	$10.31 \pm 0.02 \pm 0.09 \pm 0.41 \pm 0.10$
$\sigma_Z^{tot} \times BrZ \to \ell\ell$ (nb)	$0.937 \pm 0.006 \pm 0.009 \pm 0.032 \pm 0.016$	$0.974 \pm 0.007 \pm 0.007 \pm 0.039 \pm 0.018$

Table 1: Cross section in the full kinematic region of W and Z production in pp collisions at 7 TeV.

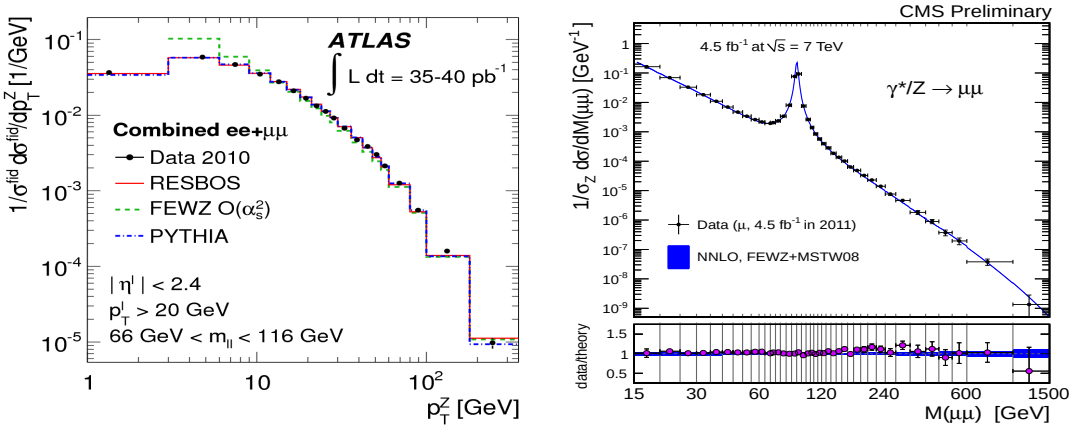

Figure 1: Left: Pt distribution of Z events observed by Atlas and compared to predictions from RESBOS, FEWZ and PYTHIA. Right: $M_{\ell\ell}$ distribution of Drell-Yan events observed by CMS and compared to predictions from FEWZ.

next-to-leading order (NLO) and next-to-next-to-leading order (NNLO). The CMS collaboration presented results about the distribution of the rapidity and of the transverse momentum of the neutral Z bosons [5] using 36 pb^{-1}collected in 2010 and the invariant mass distribution of the Drell-Yan events in the range $15 < M_{\ell\ell} < 1500GeV$ with 4.5 fb^{-1}collected in 2011 [6]. POWHEG [7](NLO) and FEWZ [8] (NNLO) describe correctly the Z rapidity and pt distribution. FEWZ describes better than POWHEG the mass distribution of Drell–Yan events especially in the low mass region. The Atlas collaboration presented results about the pt distribution of W [9] and Z [10] using the 33-36 $pb^{-1}$of data collected in 2010. The distributions are compared with the generators SHERPA [11], ALPGEN [12], PYTHIA [13] MC@NLO [14], POWHEG [7], FEWZ [8], and RESBOS [15]. The first three generators in the list provide the most accurate description of the pt distributions for heavy bosons. A subset of differential cross section results from Atlas and CMS are shown in Fig. 1 .

3 Lepton Charge Asymmetry

The lepton charge asymmetry is defined as:

$$\mathcal{A} = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})} \quad (1)$$

where η is the lepton pseudorapidity in the lab frame and $d\sigma/d\eta$ is the differential cross section for leptons from W decay. $\mathcal{A}$ provides constraints on the u, d, $\bar{u}$, and $\bar{d}$ parton distribution functions(PDF) in the range $10^{-3} < x < 10^{-1}$ where x is the fraction of momentum carried by the interacting quarks. Atlas measured the asymmetry [3] in both the electron and muon channels (Fig. 2 left) with 33–36 $pb^{-1}$of data collected in 2010. The kinematic cuts on the events are $pt_\ell > 20$ GeV, $MET > 25$ GeV and transverse mass(M_T) above 40 GeV. Using the data collected in 2010, CMS measured the asymmetry for electrons and muons above 25 GeV [16] with

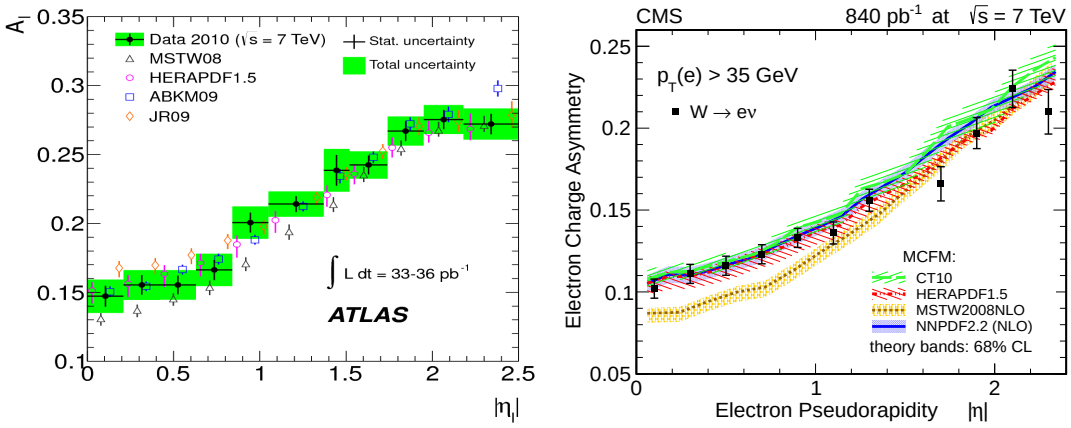

Figure 2: Left: Lepton charge asymmetry measured by Atlas for events with $pt_\ell > 20$ GeV , $MET > 25$ GeV and $M_T > 40$ GeV. Right: Electron charge asymmetry measured by CMS for events with $pt_e > 35$ GeV.

a luminosity of $36pb^{-1}$. In 2011 the CMS muon asymmetry has been updated with additional 200 pb^{-1} [17]. In spring 2012 CMS released a measurement of the charge asymmetry with $840pb^{-1}$for electrons (Fig. 2 right) with transverse momentum above 35 GeV [18]. The results are compared to theory predictions. Atlas considered the DYNNLO [19] generator interfaced with the ABKM09 [20], HERAPDF [21], MSTW [22], and JR09 [23] PDF models while CMS evaluated the compatibility of the experimental results with the prediction from the MCFM [24] generator interfaced with CT10 [25], HERAPDF [21], NNPDF [26], MSTW [22]. There is a general good agreement between the predictions and the experimental results. Only the MSTW predictions are systematically lower than the measurements in the region $|\eta| < 1.4$.

4 W polarization

At the LHC the quarks generally carry a larger fraction of the momentum of the initial-state protons than the antiquarks. This causes the W bosons to be boosted in the direction of the initial quark. In the massless quark approximation, the quark must be left-handed and the antiquark right-handed resulting in purely left-handed W at high rapidity and in a mixture of left-handed and right-handed W in the more central regions. Predictions of the polarization distribution requires detailed calculation of all the W production mechanisms. The helicity angle of W cannot be measured in leptonic decays because of the undetected neutrinos. Both Atlas and CMS defined an observable largely correlated with the helicity angle of the W:

$$CMS : LP = \frac{\vec{pt}^{\,\ell} * \vec{pt}^{\,W}}{|\vec{pt}^{\,W}|^2} \qquad Atlas : \cos\theta_{2D} = \frac{\vec{pt}^{\,\ell *} * \vec{pt}^{\,W}}{|\vec{pt}^{\,\ell *}||\vec{pt}^{\,W}|} \tag{2}$$

where pt^W and pt^ℓ are the transverse momentum of the W and the lepton in the lab frame and $pt^{\ell *}$ is the transverse momentum in the W rest frame. CMS measured the W polarization [27] separately for positive and negative leptons above 25 GeV. Atlas measured the W polarization [28] for leptons in the $35 < pt < 50$ GeV region and for leptons with pt above 50 GeV. The results are in good agreement with the NLO generators POWHEG [7] and MC@NLO [14]. Atlas and CMS measurements have been performed with the data collected in 2010 and are shown in Fig. 3 .

5 Summary

The CMS and Atlas collaborations have analyzed the data collected in 2010 and 2011 to study the production of W and Z bosons at LHC. The measured absolute and differential cross sections

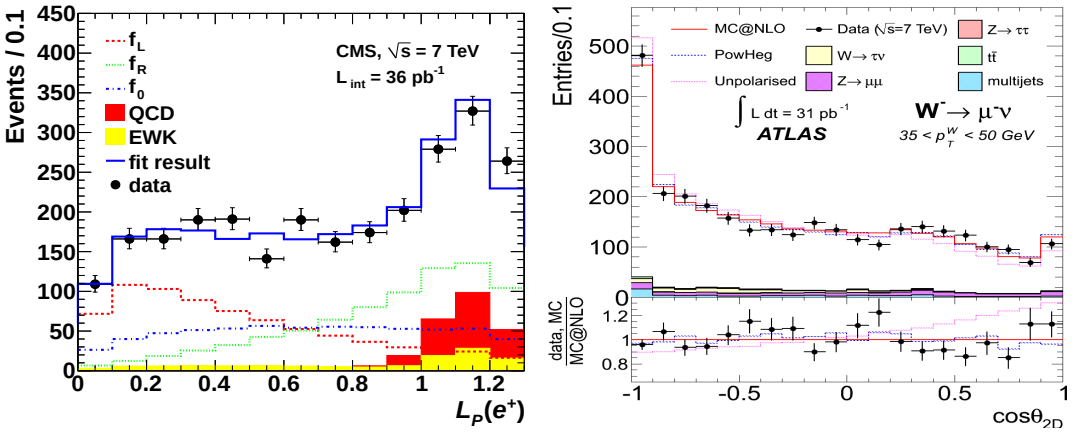

Figure 3: Left: Fit to the LP distribution in data for positive electrons. Right: Fit to the $cos\theta_{2D}$ distribution for negative muons with $35 < pt < 50$ GeV

are in agreement with most of the NLO and NNLO generators describing the Drell-Yan processes in pp collisions. The NNPDF collaboration estimated the charge asymmetry results improves the accuracy of light quarks PDFs by $10 - 25\%$.

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