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# W and Z studies at CMS

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**Summary.** — Selected measurements done with W and Z bosons detected in the CMS detector, based on samples of events collected during 2011 at 7 TeV and 2012 at 8 TeV physics runs, are presented. Results on the inclusive W and Z cross sections and the lepton charge asymmetry in the reconstructed W events decaying to a lepton and a neutrino, obtained in the electron and muon decay channels, are presented. Differential cross section, forward-backward asymmetry and electroweak couplings of events coming from the Drell-Yan process are compared with the corresponding theoretical QCD prediction comparison.

PACS 12.38.Aw – General properties of QCD (dynamics confinement, etc.).
PACS 12.15.-y – Electroweak interactions.
PACS 14.70.Fm – $W$ bosons.
PACS 14.70.Hp – $Z$ bosons.

## 1. – Introduction

The study of W and Z vector boson production in proton-proton collisions represents an important test of perturbative QCD calculations, and can be used to constrain the parton density functions (PDF) inside the proton. The NLO theoretical predictions with different generators and QCD tunings are tested using several W and Z measurements with 2011 CMS collision data, with a center of mass energy of 7 and 8 TeV. Processes involving vector bosons may play an important role in the field of the Higgs boson studies, since they appear as a dominant background for many Higgs decay channels, as well as in the searches of new physics phenomena. Precise measurements of W and Z properties are essential for understanding and testing the Standard Model at the LHC energy with a precision never reached before in hadronic colliders. Measurements performed in proton-proton collisions with a center of mass energy $\sqrt{s} = 7$ TeV presented in this report are the Drell-Yan differential and double-differential cross section, as a function of dilepton rapidity, the charge asymmetry in W decay to electrons and muons and the Z forward-backward asymmetry, the electroweak mixing angle and the boosted Z boson momentum differential cross section. Vector bosons productions with $\sqrt{s} = 8$ TeV data are analyzed by measuring the W and Z inclusive production cross section, using special LHC proton fills in 2012, for a total integrated luminosity of $19\,\mathrm{pb}^{-1}$ with low pile-up and dedicated triggers. The measurement of the ratio between W and Z cross section is also performed. All the results are compared with NNLO theoretical prediction and different Monte Carlo generators.

## 2. – W, Z measurements at $\sqrt{s} = 7\,\mathrm{TeV}$

**2**·1. *Drell-Yan cross section measurements.* – The Drell-Yan differential cross section $\mathrm{d}\sigma/\mathrm{d}M$ for Z bosons decaying into electrons and muons pair in the mass range $15 < M < 1500\,\mathrm{GeV}$, and the double-differential cross section for the dimuon final state in rapidity bins within the mass range of $20 < M < 1500\,\mathrm{GeV}$, $\mathrm{d}^2\sigma/\mathrm{d}M\mathrm{d}Y$ is performed using a total integrated luminosity of $4.5\,\mathrm{fb}^{-1}$ in dimuons final state and $4.8\,\mathrm{fb}^{-1}$ for dielectrons [1]. Dileptons are selected by requiring high transverse momentum, opposite charge and passing some quality cuts. Dilepton candidates must be matched with a double lepton unprescaled trigger, and efficiency is evaluated by data-driven methods. The cross section is normalized to the Z boson cross section in order to cancel the systematic uncertainty of the luminosity, and reduce the contribution of the pile-up and the PDFs. The dilepton mass is corrected for the leptons final state radiation (FSR). Finally the results, presented in fig. 1, are compared with the NLO theoretical prediction with POWHEG [2] with CT10 NLO [3] pdf set, and the NNLO prediction with FEWZ [4] using MSTW08 [5] as PDF.

**2**·2. *Charge asymmetry in inclusive W decay.* – The W charge asymmetry at the LHC arises because of the structure of the protons collision. Since inside a proton there are two up-type quarks, it's easier to produce a $\mathrm{W}^+$ than a $\mathrm{W}^-$, and so the asymmetry in the W production can be estimated by the number of positive and negative charged leptons in the final state, as a function of the pseudorapidity $\eta$ of the charged lepton: $A(\eta) = \frac{\mathrm{d}\sigma/\mathrm{d}\eta(W^+)-\mathrm{d}\sigma/\mathrm{d}\eta(W^-)}{\mathrm{d}\sigma/\mathrm{d}\eta(W^+)+\mathrm{d}\sigma/\mathrm{d}\eta(W^-)}$. This measurement provides information about the ratio between the u-type and the d-type quarks and the sea antiquark inside protons in the Bjorken $x$ range of the $7\,\mathrm{TeV}$ energy. Therefore, the charge asymmetry gives a significant contribution to PDFs tuning. In the electrons final state, this measurement exploits a total integrated CMS luminosity of $0.234\,\mathrm{fb}^{-1}$ [6], and the selection imposes a high energy isolated electron passing a single electron trigger. The presence of a neutrino in the final state implies that the signal has to be extracted from a binned maximum likelihood fit to the missing transverse energy distribution, calculated for electrons and positrons separatly in order to obtain the $N^+$ and $N^-$ contribution to the asymmetry. A similar strategy is applied for muons final state, after selecting a sample of high energy isolated and triggered muons. Final results are finally compared to the theoretical calculation obtained with MCFM and using different set of PDFs: MSTW2008NLO, CT10W, NNPDF2.1 (NLO) [7] and HERAPDF1.0 [8]. As can be seen in fig. 2 very good agreement is shown with the different set of PDFs, except for the MSTW2008NLO, that exibits a slight discrepancy with data in both electrons and muons results.

**2**·3. *Forward-backward asymmetry in Z decays.* – The $V - A$ structure of the electroweak interactions can be tested at the LHC by measuring the forward-backward asymmetry that characterizes the Z boson decay to leptons. The asymmetry is defined as ratio between the number of events selected in dilepton final state in the forward region and the number of events in the backward region, discriminated by positive and negative

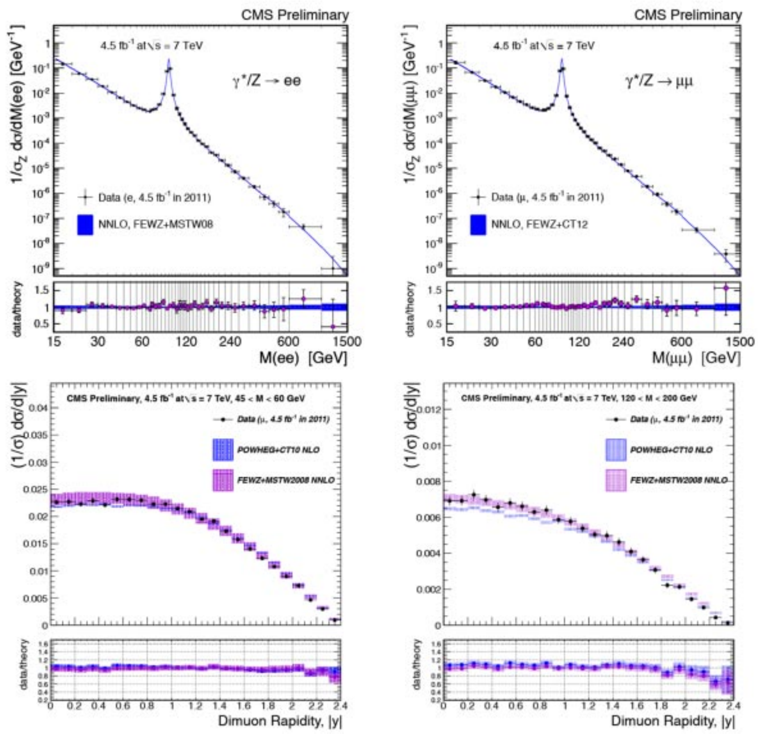


Fig. 1. – The Drell-Yan cross section shape in the dielectron final state (top-left), and in the dimuon final state (top-right), and the double-differential cross section in the mass range $45 < M < 60\,\mathrm{GeV}$ (bottom-left) and $60 < M < 120\,\mathrm{GeV}$ (bottom-right).

values of lepton pseudorapidity. Leptons are selected by requiring $p_T > 20\,\mathrm{GeV}$, and results are presented as a function of leptons rapidity after unfolding the Born level. The ratio between data and Monte Carlo is shown within $1\sigma$ and $2\sigma$ error bands, using the POWHEG + Pythia Z2 tune event generator with CT10 pdf set using an integrated luminosity of $5\,\mathrm{fb}^{-1}$ [9]. The results are presented in fig. 3. An overall good agreement is seen in the comparison between data and theoretical predictions.

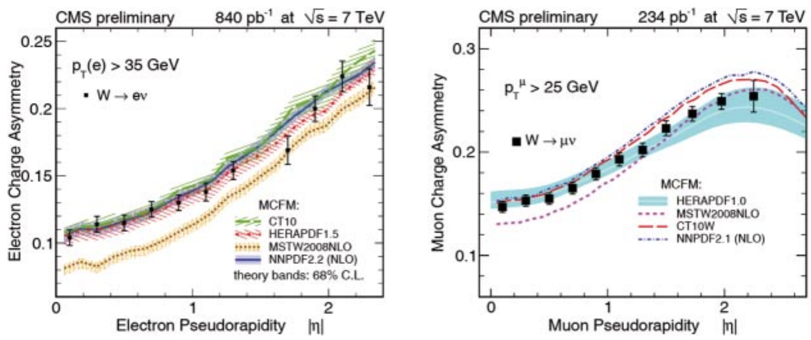


Fig. 2. – The charge asymmetry in W decaying to electrons (left) and muons (right). Results are compared with different theoretical predictions at NLO.

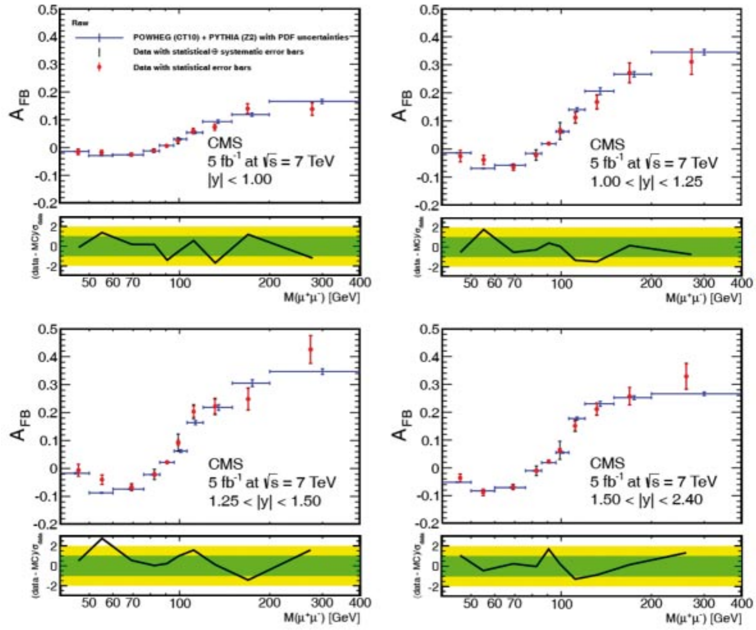


Fig. 3. – The Z boson forward-backward asymmetry as a function of the dilepton invariant mass in different lepton rapidity bins. Yellow and green bands represent the 1$\sigma$ and 2$\sigma$ error bands, and the blue line shows the theoretical prediction.

**2**˙4. *Electroweak mixing angle measurement.* – The electroweak mixing angle has been previously measured in electron-positron collisions at LEP with a precision of 0.1% and in proton-antiproton collisions at 1% of precision. At the LHC this measurement has been performed using 1.1 $\text{fb}^{-1}$ in proton-proton collision at 7 TeV [10]. The Drell-Yan process with a Z boson decaying into muons is used in order to extract the value of the mixing angle by a simultaneous unbinned maximum likelihood fit to the dimuon decay angle, invariant mass and rapidity. The final results for the squared sine of the mixing angle is

$$\sin^2\theta_W = 0.2287 \pm 0.0020(\text{stat.}) \pm 0.0025$$

in agreement with the previous measurements and with an overall precision of around 1%.

**2**˙5. *Z boson momentum differential cross section.* – At the LHC, the dilepton pair coming from a Z boson decay can be boosted because of many QCD process, such as the initial hard radiation from a gluon or the underlying event activity. For this reason, measuring the Z boson momentum can be very useful to understand the hard scattering modelization in the event generators, and the proton dynamics. This measurement is performed using a luminosity of 36 $\text{pb}^{-1}$ recorded by CMS [11], by selecting dimuon pairs coming from the Z boson decay in Drell-Yan process. Results are compared to the theoretical prediction of POWHEG with CT10 PDFs, and using different tunes of Pythia to describe the low momentum region (below 30 GeV), to account the non-perturbative processes, and FEWZ at NNLO to describe the high momentum region (from 30 to 300 GeV) (fig. 4). A good agreement between data and theoretical prediction is found.

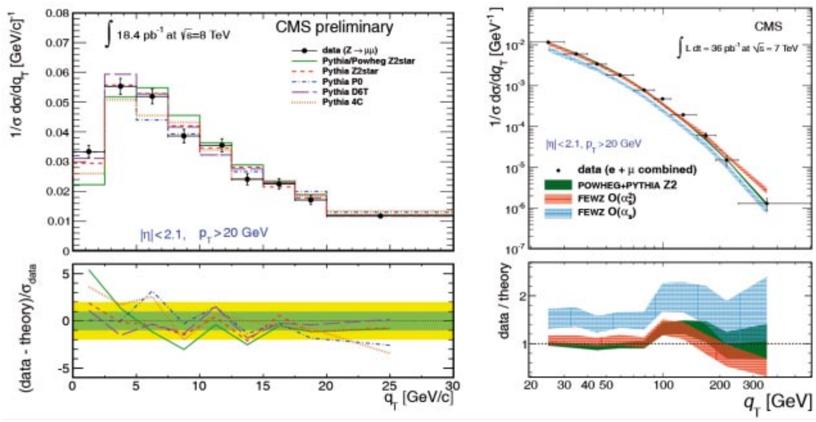


Fig. 4. – The Z momentum distribution in the low momentum range $0 < q_T < 30$ compared with different Pythia tunes prediction (left), and the high momentum range ($30 < q_T < 300$) compared to the FEWZ prediction at NNLO (right).

## 3. – W, Z measurements at $\sqrt{s} = 8\,\text{TeV}$

From QCD calculations, we expect that increasing the center of mass energy of the LHC pp system from 7 to 8 TeV will raise the W and Z boson production cross section by 15–20%. For this reason this measurement is an important test of the Standard Model at 8 TeV and also gives important contributions to the pQCD calculations. The inclusive vector boson cross section was previously measured by CMS at 7 TeV [12]. The measurement is performed using an integrated luminosity of $19\,\text{pb}^{-1}$ [13]. Z boson inclusive cross section is measured by the invariant mass distribution of the dilepton final state in the range $[60, 120]$ GeV for high $p_T$ electrons and muons in the range of $|\eta| < 2.4$. W boson cross inclusive cross section is extracted by means of a binned maximum likelihood fit to the missing transverse energy distribution for single isolated leptons in the range $|\eta| < 2.1$. Leptons are required to pass a single/double lepton trigger and the efficiencies are evaluated by data-driven methods. Final results are then compared to the theoretical NNLO FEWZ+MSTW2008 predictions within 68% CL uncertainty for muons and electrons final state, and for the dilepton combination(fig. 5).

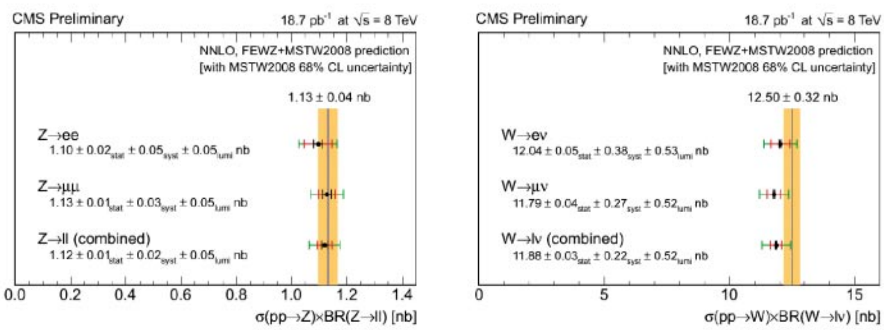


Fig. 5. – The results of the Z boson (left side) and W boson (right side) cross section in dilepton final state, compared with the NNLO FEWZ+MSTW2008 theoretical predictions, within 68% CL uncertainty.

## 4. – Conclusions

Standard Model W, Z boson measurements in LHC proton-proton collision at a center of mass energy of 7 TeV and 8 TeV with the CMS experiment have been presented. Results on the Drell-Yan process cross section, forward-backward asymmetry in Z boson decay, W charge asymmetry, electroweak mixing angle and Z boson momentum measurements at 7 TeV have been measured and compared with different theoretical expectation from several Monte Carlo generators and PDF tunings. W and Z boson inclusive production cross section and W/Z cross section ratios have been measured with 8 TeV, and compared to NNLO prediction. With the available amount of data, no evidence of significative deviations from the theoretical predictions are observed. All results are in good agreement with the Standard Model predictions.

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