W and Z boson production at CMS at $\sqrt{7}$ TeV

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We present the first measurements of inclusive W and Z production cross sections in muon and electron decay channels at $\sqrt{s} = 7$ TeV, obtained using an integrated luminosity of 198 nb^{-1} of proton proton collisions recorded by the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC).

These production cross-sections at $\sqrt{s} = 7$ TeV have been measured to be $\sigma(W \to \ell\nu) = 9.22 \pm 0.24(\text{stat.}) \pm 0.47(\text{syst.}) \pm 1.01(\text{lumi.})$ nb and $\sigma(Z \to \ell^+\ell^-) = 0.882^{+0.077}_{-0.073}(\text{stat.})^{+0.042}_{-0.036}(\text{syst.}) \pm 0.097(\text{lumi.})$ nb, limited to the di-lepton invariant mass range: $60 < m_{l^-l^+} < 120 \, \text{GeV}/c^2$.

The measurement of W cross-section has also been split by charge, obtaining $\sigma(W^+ \to \ell^+\nu) = 5.50 \pm 0.18(\text{stat.}) \pm 0.29(\text{syst.}) \pm 0.61(\text{lumi.})$ nb and $\sigma(W^- \to \ell^-\overline{\nu}) = 3.60 \pm 0.13(\text{stat.}) \pm 0.19(\text{syst.}) \pm 0.40(\text{lumi.})$ nb. The luminosity independent cross section ratios are $\sigma(W \to \ell\nu)/\sigma(Z \to \ell^+\ell^-) = 10.46^{+0.99}_{-0.88}(\text{stat.})^{+0.65}_{-0.56}(\text{syst.})$ and $\sigma(W^+ \to \ell^+\nu)/\sigma(W^- \to \ell^-\overline{\nu}) = 1.51^{+0.08}_{-0.07}(\text{stat.}) \pm 0.04(\text{syst.})$.

All the measurements are in good agreement with NNLO QCD cross section calculations and current parton distribution functions.

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The inclusive production of vector gauge bosons W and Z with their subsequent leptonic decay is the first electroweak process observed at CMS. Characterized by relatively large cross-sections and clean and simple experimental signatures, together with precise theoretical predictions, they are a benchmark process for many LHC early measurements. They are essential for the calibration of the detectors and to establish their performance. These $pp \rightarrow W + X$ and $pp \rightarrow Z + X$ events also constitute one of the main sources of background for many searches beyond the Standard Model to be carried out at the LHC, and therefore a precise understanding of these processes is critical before any discovery can be made. Their study represents a first step in the detailed understanding of reference physics processes at the LHC.

W $\rightarrow \ell \nu$ and Z $\rightarrow \ell^+ \ell^-$ are characterized by the presence of one or two high-momentum leptons in the detector. Since neutrinos escape detection, W events exhibit a significant imbalance in the transverse energy of the event (E_T^{miss}). Given the limited statistics available at the time of this conference and the early phase of the experiment, simple and robust methods for signal yield extraction were devised [2].

Muons and electrons are selected online through High Level Trigger algorithms. Muon triggers are based both on the muon spectrometers and the inner tracker, while electrons are triggered based exclusively on the electromagnetic calorimeter.

Leptons coming from W and Z decays are typically isolated in the detector, with little detector activity in tracker and calorimeters ($\sum p_T^{track}$ or $\sum E_T^{cal}$), in a cone of radius $\Delta R = \sqrt{(\Delta \phi)^2 + (\Delta \eta)^2} < 0.3$ around the lepton direction. This is one of their key distinguishing features against hadronic backgrounds.

W $\rightarrow \ell \nu$ events are selected requiring an identified, isolated lepton in the fiducial volume and with $p_T > 20$ GeV/c (muons) or $E_T > 20$ GeV (electrons) (events with another lepton of $p_T > 10$ GeV/c (or $E_T > 10$ GeV) are vetoed as Z candidates). Particle flow techniques [2] are used to reconstruct E_T^{miss}.

Several sources of background events are identified after selection. The dominant background contribution is hadronic QCD (mostly decays of b-hadrons in the muon channel and fake electrons in the electron channel). Other electroweak processes also contribute to the residual background, mainly Z $\rightarrow \ell^+ \ell^-$ events with one of the leptons beyond the detector acceptance, and W $\rightarrow \tau \nu$ events where the τ decays leptonically. Other remaining backgrounds, such as Z $\rightarrow \tau^+ \tau^-$, $t\bar{t}$ and VV (V=W, Z) production are significantly smaller.

Signal yield is extracted using a fit of the experimental distribution of E_T^{miss} for the electron channel and transverse mass ($M_T = \sqrt{2 p_T(\mu) E_T^{miss} * (1 - \cos(\Delta \phi_{\mu, E_T^{miss}}))}$) for the muon channel, to a sum of three different components: signal, electro-weak background and QCD backgrounds.

Given the limited event sample, the shapes of the signal and EWK background components are taken from Monte Carlo (PYTHIA and POWHEG [2]) predictions. In the muon channel analysis the QCD background is modeled from data, using the M_T distribution of non-isolated events. In the electron channel analysis it is parametrized through a modified Rayleigh distribution. This fit provides as output parameters the W $\rightarrow \ell \nu$ yields and the normalization of the QCD contribution as shown in Figure 1. EWK backgrounds are normalized to the W yield through their ratio of theoretical cross sections.

Z $\rightarrow \ell^+ \ell^-$ channels, for which backgrounds are negligible, are treated as counting experi-

ments. For each event, we consider pairs of isolated leptons with $p_T(\mu) > 20$ GeV$/c$ or $E_T(e) > 20$ GeV with an invariant mass in the range $60 < m_{ll} < 120$ GeV$/c^2$. Muons pairs are required to be of opposite charge.

The position and width of the dimuon in Figure 1 peak agrees with the MC prediction better than 0.5%. The dielectron peak exhibits a small shift (-2%) relative to simulation, due to electron energy scale factors well-covered by systematic uncertainties.
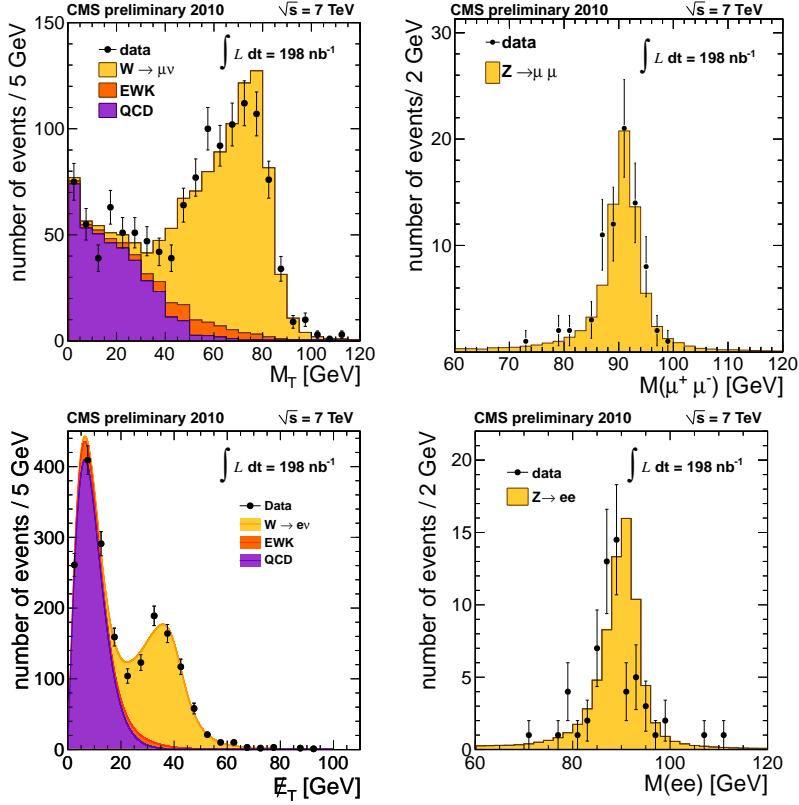

Figure 1: $W \to \ell\nu$ (left) and $Z \to \ell^+\ell^-$ (right) distributions. Experimental distributions (points) are compared to the predictions for signal and background components, normalized to the theoretical cross-sections in the Z channels and to the fitted cross-sections for W channels.

The measured signal yields are $N(W^+ \to \mu^+\nu) = 529 \pm 24$, $N(W^- \to \mu^-\overline{\nu}) = 289 \pm 13$, $N(W^+ \to e^+\nu) = 458 \pm 23$, $N(W^- \to e^-\overline{\nu}) = 339 \pm 20$, $N(Z \to \mu^-\mu^+) = 77$ and $N(Z \to e^-e^+) = 61$. Cross-sections are calculated from these yields correcting by the lepton selection efficiencies and the acceptance of the phase space used, computed using a NLO generator (POWHEG).

Lepton reconstruction, identification, online selection and isolation efficiencies are calculated using clean $Z \to \ell^+\ell^-$ data samples as well as random cone techniques for isolation efficiencies and inclusive muon studies for identification and trigger efficiencies. Lepton energy/momentum scale and resolution have been studied using the position and width of reconstructed resonances in data (Z, J/Ψ, Υ) as well as cosmic muons.

E_T^{miss} scale and resolution uncertainties, which only affect the W channel measurement, are estimated from studies in $\gamma + jet$ final states and the recoil distribution against leptons in W events.
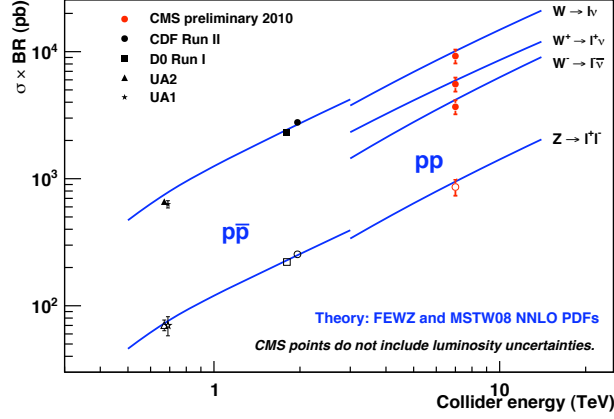
Figure 2: Comparison of the results with the NNLO theoretical predictions and past experiments.

Background subtraction uncertainty has been conservatively assigned to the difference in the fit between the modeling of QCD in each channel and the true Monte Carlo prediction.

Theoretical uncertainties enter in the determination of the acceptance of the detector and selection cuts. The main source of uncertainty comes from the PDF modeling. Remaining theoretical uncertainties are due to the treatment of initial-state radiation, final-state QED radiation, missing electroweak effects and renormalization/factorization scale assumptions. In total they amount to 2.4% for $W \rightarrow \mu\nu$, $W \rightarrow e\nu$ and $Z \rightarrow e^-e^+$ and 2.6% for $Z \rightarrow \mu^-\mu^+$.

These experimental and theoretical sources combine in a final systematic uncertainty of 6.3% for $W \rightarrow \mu\nu$, 3.8% for $Z \rightarrow \mu^-\mu^+$ and 7.7% for $W \rightarrow e\nu$ and $Z \rightarrow e^-e^+$. An additional source of systematic uncertainty comes from the luminosity measurement, currently estimated to be 11%.

This first measurement of production cross-section of W and $Z(\gamma^*)$ bosons and their ratios are in very good agreement with NNLO theoretical predictions and past experiments, as shown in Figure 2:

$$\sigma(pp \rightarrow W + X \rightarrow \ell\nu + X) = 9.22 \pm 0.24(\text{stat.}) \pm 0.47(\text{syst.}) \pm 1.01(\text{lumi.}) \text{ nb.}$$

$$\sigma(pp \rightarrow W^+ + X \rightarrow \ell^+\nu + X) = 5.50 \pm 0.18(\text{stat.}) \pm 0.29(\text{syst.}) \pm 0.61(\text{lumi.}) \text{ nb.}$$

$$\sigma(pp \rightarrow W^- + X \rightarrow \ell^-\overline{\nu} + X) = 3.60 \pm 0.13(\text{stat.}) \pm 0.19(\text{syst.}) \pm 0.40(\text{lumi.}) \text{ nb.}$$

$$\sigma(pp \rightarrow Z(\gamma^*) + X \rightarrow \ell^+\ell^- + X) = 0.882^{+0.077}_{-0.073}(\text{stat.})^{+0.042}_{-0.036}(\text{syst.}) \pm 0.097(\text{lumi.}) \text{ nb..}$$

$$\sigma(pp \rightarrow W + X \rightarrow \ell\nu + X)/\sigma(pp \rightarrow Z(\gamma^*) + X \rightarrow \ell^+\ell^- + X) = 10.46^{+0.99}_{-0.88}(\text{stat.})^{+0.65}_{-0.56}(\text{syst.}).$$

$$\sigma(pp \rightarrow W^+ + X \rightarrow \ell^+\nu + X)/\sigma(pp \rightarrow W^- + X \rightarrow \ell^-\overline{\nu} + X) = 1.51^{+0.08}_{-0.07}(\text{stat.}) \pm 0.04(\text{syst.}).$$

References

[1] CMS Collaboration, 'The CMS experiment at the CERN LHC', JINST 3:S08004,2008

[2] CMS Collaboration, "Measurements of Inclusive W and Z Cross Sections in pp Collisions at $\sqrt{s} = 7$ TeV","EWK-2010-002", 2010 (and references therein)