Electroweak results from CMS

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1 Introduction

Events with W and Z bosons in high energy pp collisions at LHC produce very clean signals and allow to perform precision measurements. Accurate theoretical standard model (SM) predictions at next-to-next-to-leading order (NNLO) in perturbative QCD for cross section and differential distributions are available with programs like FEWZ, RESBOS, DYNNLO, and next-to-leading order (NLO) programs like POWHEG and MC@NLO provide full event generation. Uncertainties in valence and sea PDF limit the accuracy of theoretical predictions, and, on the other hand, differential distributions of eletcroweak processes are sensitive to PDF and can improve the precision of their current knowledge. Many estimates required to perform measurements of electroweak processes can be done on the large control samples available in data instead of relying on simulations. Events containing W and Z are themselves useful tools to understand and calibrate the detector, and the tag-and-proble (T&P) method is extensively used to determine lepton efficiencies from high-purity samples of $Z \to \ell^+\ell^-$ events, which are also used to study lepton momentum scale and resolution. Many searches for new physics have electroweak processes among their main backgrounds, hence studying electroweak processes is also important to keep backgrounds to such searches under control.

2 Studies of W and Z production

W events are selected using a loose single-lepton trigger [1], and well understood lepton identification cuts are applied. Leptons are required to have $p_{\mathrm{T}} > 25$ GeV and pseudorapidity η within the trigger fiducial volume. Lepton isolation is enforced requiring a small sum of tracker and calorimeter activities within a cone of $\Delta R = \sqrt{(\Delta\varphi)^2 + (\Delta\eta)^2} < 0.3$. Events with a second lepton are vetoed to suppress the Drell–Yan (DY) background. The W signal yield is extracted from a fit to the missing E_{T} distribution of selected events, where parameterized or fixed binned shapes are used to model signal and background distributions. The shape of the QCD background is determined from data inverting lepton identification or isolation selections. Lepton efficiencies are determined as a function of p_{T} and η using a T&P method. The misssing E_{T} distribution is studied using the dilepton recoil in Z events. Separate fits to missing E_{T} spectra in events containing positive and negative leptons allow to extract $\sigma(\mathrm{W}^+)$ and $\sigma(\mathrm{W}^-)$. Alternatively, a simultaneous fit allow to to extract the inclusive cross section $\sigma(\mathrm{W}^\pm)$ and the ratio $\sigma(\mathrm{W}^+)/\sigma(\mathrm{W}^-)$, in which several uncertainties cancel.

The selection of Z events [1] proceeds requiring pairs of isolated leptons having $p_{\mathrm{T}} > 20$ (25 GeV) for Z→ $\mu^+\mu^-$ (Z→$\mathrm{e}^+\mathrm{e}^-$) and η within the fiducial detector and trigger acceptances. The invariant mass range $60 < m_{\ell\ell} < 120$ GeV is used for signal extraction, which is performed via a simultaneous fit of the Z signal yield and efficiencies using different dilepton categories for Z→ $\mu^+\mu^-$, or a simpler cut-and-count analysis using an efficiency determination from a T&P method for Z→$\mathrm{e}^+\mathrm{e}^-$.

Efficiencies as well as background and signal shapes are determined mainly from data, allowing to minimize the experimental systematic uncertainties. Theoretical uncertainties affect acceptance determinations. In particular, the PDF uncertainty, the modeling of initial-state radiation, higher-order QCD effects (studied using the RESBOS generator), electroweak corrections, final-state radiation (studied with HORACE), and factorization and renormalization scale (estimated using FEWZ). The inclusive W and Z production cross sections at a center-of-mass energy of 7 TeV are determined as:

$$\sigma(\mathrm{pp}\to \mathrm{W}X)\times\mathcal{B}(\mathrm{W}\to\ell\nu) = 10.30\pm0.02(\mathrm{stat.})\pm0.10(\mathrm{syst.})\pm0.10(\mathrm{th.})\pm0.41(\mathrm{lumi.})\,\mathrm{nb}\,, \quad (1)$$

$$\sigma(\mathrm{pp}\to \mathrm{Z}X)\times\mathcal{B}(\mathrm{Z}\to\ell^+\ell^-) = 0.974\pm0.007(\mathrm{stat.})\pm0.007(\mathrm{syst.})\pm0.018(\mathrm{th.})\pm0.039(\mathrm{lumi.})\,\mathrm{nb}\,. \quad (2)$$

The study of Z→ $\tau^+\tau^-$ [8] is a benchmark for searches using tau leptons, like $\mathrm{H}^+\to\tau^+\nu$ and $\mathrm{H}\to\tau^+\tau^-$. Tau candidates are reconstructed using the particle flow algorithm that combines tracker and calorimeter measurements to determine particle candidates. The main uncertainty in the measurement comes from the knowledge of the tau identification efficiency, which is determined directly from data. The study of the decay W→ $\tau\nu$ [11] is particularly challenging, requiring a trigger based on the presence of a tau candidate associated to missing E_{T}. The results of W and Z inclusive cross sections measurements using decays to tau are in agreement with the standard-model (SM) predictions and with the measurements performed in the electron and muon channels.

In the ratios of $\mathrm{W}^+/\mathrm{W}^-$ and W/Z cross sections, luminosity and other uncertainties cancel. The W^+/W ratio is potentially sensitive to PDFs, while the W/Z ratio provides the most stringent test of the SM. The following inclusive production cross-section ratios have been measured:

$$\frac{\sigma(\mathrm{pp}\to \mathrm{W}^+X)\times\mathcal{B}(\mathrm{W}^+\to\ell\nu)}{\sigma(\mathrm{pp}\to \mathrm{W}^-X)\times\mathcal{B}(\mathrm{W}^-\to\ell\nu)} = 1.421\pm0.006(\mathrm{stat.})\pm0.014(\mathrm{syst.})\pm\pm0.014(\mathrm{th.})\,, \quad (3)$$

$$\frac{\sigma(\mathrm{pp}\to \mathrm{W}X)\times\mathcal{B}(\mathrm{W}\to\ell\nu)}{\sigma(\mathrm{pp}\to \mathrm{Z}X)\times\mathcal{B}(\mathrm{Z}\to\ell^+\ell^-)} = 10.54\pm0.07(\mathrm{stat.})\pm0.08(\mathrm{syst.})\pm\pm0.16(\mathrm{th.})\,. \quad (4)$$

Good overall agreement of the inclusive cross section measurements and their ratios with theoretical predictions at NNLO is found.

The W^+/W ratio is also measured as a function of the lepton pseudorapidity η [2], in order to achieve a larger sensitivity to PDFs, using a similar selection to the inclusive cross section analysis. Two p_T thresholds (25, 30 GeV) are used to probe different phase-space regions. The achieved precision is better than 1.6% in most of the η bins for both electron and muon channels, thanks to the small charge mis-identification, which is 0.1(barrel)-0.4(endcap)% for electrons and less than 10^{-4} for muons. The large collected data samples allows to study the differential Z production cross sections as a function of the Z boson rapidity and transverse momentum [4], and the full DY cross section as a function of the lepton pair invariant mass [3].

Good agreement is found with theoretical NNLO predictions after an unfolding correction of both resolution and final-state radiation, not included in the theoretical calculation. The study of the lepton forward-backward asymmetry as a function of the dilepton invariant mass allows to perform a measurement of the Weinberg angle:

$$\sin^2\theta_{\mathrm{eff}} = 0.2287 \pm 0.0077(\mathrm{stat.}) \pm 0.0036(\mathrm{syst.})\,. \tag{5}$$

The study of W and Z production in association with hadronic jets is an important test of perturbative NLO predictions and provides an estimate of one of the main backgrounds to searches for the Higgs boson and other new physics. The ratios $\sigma(V + n\,\mathrm{jets})/\sigma(V)$ of the prodiction cross section of W and Z associated with n jets and the inclusive boson's production cross section are determined, considering jets with $E_T > 30$ GeV [6]. The measurements are dominated by systematic uncertainties, one of the main uncertainty being the knowledge of the jet energy scale. Agreement with MadGraph is found while discrepancies with the PYTHIA parton shower approximation are observed. The Berends–Giele scaling [7] has been tested measuring the ratios $\sigma(V + n\,\mathrm{jets})/\sigma(V + (n-1)\,\mathrm{jets})$, confirming that the ratio is approximatly indepedent on the number of jets n. The ratio as a function of n has been parametrized as $\alpha + \beta \times n$, and the fitted values for α and β, the latter close to zero, as expected, are compared with the simulation predictions.

Z production has been studied in association with at least one jets identified as produced by a b quark [10]. A small missing E_T must accompany the presence of the lepton pair from the Z decay, in order to suppress the background due to top-quark production. The purity of the b-tag selection is determined from data using a fit to the distribution of the invariant mass of tracks associated to the secondary vertex. This study allows to probe the two main production mechanism: a b pair produced from quark-quark or gluon-gluon scattering (fixed flavour), or a single b quark produced at partonic level (variable flavour). The ratio of Z production cross section in association with a b jet and in association with a generic jet has been fonund to be in agreement with NLO theoretical predictions:

$$\sigma(\mathrm{Z}+\mathrm{b})/\sigma(\mathrm{Z}+\mathrm{jet}) = 0.054 \pm 0.016\,,\ \text{with } \mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-\,, \tag{6}$$

$$\sigma(\mathrm{Z+b})/\sigma(\mathrm{Z+jet}) = 0.046 \pm 0.014\,, \text{ with } \mathrm{Z} \to \mu^+\mu^-\,. \tag{7}$$

The study of W polarization in events with a W associated to hadronic jets [9] is a stringent test of detailed features of QCD prediction in a final state that is common to searches for new physics that would present different distribution of the final-state lepton's kinematic variables. The W polarization fractions f_L, f_R and f_0 are determined from the distributions of the lepton projection on the reconstructed W momentum in the transverse plane for positive and negative leptons. The differences of L and R polarization fraction for negative and positive W production are: $(f_L - f_R)^- = 0.240 \pm 0.036(\mathrm{stat.}) \pm 0.031(\mathrm{syst.})$ and $(f_L - f_R)^+ = 0.310 \pm 0.036(\mathrm{stat.}) \pm 0.017(\mathrm{syst.})$ for negatively and positively charged leptons respectively, and confirm the SM prediction of a predominantly left-handed W production.

3 Diboson production

The study of Z and W production in association with a photon [12] probes final states common to new physics searches, as well as the triple gauge coupling predictions in the SM. The estimate of the misidentified photon background is very important for this analysis, and is performed mainly from data. The measured cross sections agree with the SM predictions:

$$\sigma(\mathrm{pp} \to \mathrm{W}\gamma + X) \times \mathcal{B}(\mathrm{W} \to \ell\nu) = 56.3 \pm 5.0(\mathrm{stat.}) \pm 5.0(\mathrm{syst.}) \pm 2.3(\mathrm{lumi.})\,, \tag{8}$$

$$\sigma(\mathrm{pp} \to \mathrm{Z}\gamma + X) \times \mathcal{B}(\mathrm{Z} \to \ell\ell) = 9.4 \pm 5.0(\mathrm{stat.}) \pm 1.0(\mathrm{syst.}) \pm 0.6(\mathrm{lumi.})\,. \tag{9}$$

First limits are set on anomalous trilinear WWγ, ZZγ and Z$\gamma\gamma$ gauge couplings at $\sqrt{s}$=7 TeV. The study of WW production [13] is a challenging task, and a benchmark for the search for the Higgs boson with the decay $\mathrm{H} \to \mathrm{W}^+\mathrm{W}^-$. Using W decays to electrons and muons, part of the $\mathrm{W} \to \tau\nu$ contribution is also included in the selected sample. The selection is based on a DY veto, requiring the presence of a missing E_{T}, and removing same-flavour dilepton events with an invariant mass close to the Z mass. $\mathrm{Z} \to \tau^+\tau^-$ suppression is achieved requiring the missing E_{T} projection transverse to closest leptons to be greater than 35 GeV, and events containing a top quark are vetoed using the number of jets present in the event and applying soft muon and b-tagging vetos. 13 events selected against a background estimate of 3.3 ± 1.2, and the WW cross section is measured as:

$$\sigma(\mathrm{WW}) = 41.1 \pm 15.3(\mathrm{stat.}) \pm 5.8(\mathrm{syst.}) \pm 4.5(\mathrm{lumi.})\,. \tag{10}$$

Limits to anomalous WWγ and WWZ couplings are also set from this study. Spin correlation determines the distribution of the azimuthal angular separation of the two leptons, which is used to discriminate a possible signal due to a Higgs boson decay to WW, resulting in limits to the production of the Higgs boson in the presence of a fourth generation.

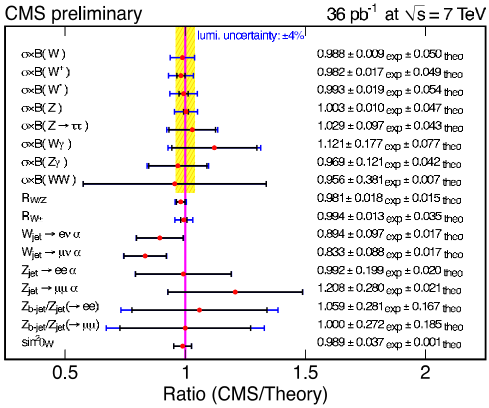

Figure 1: Ratio of CMS electroweak measurements to SM theoretical predictions.

4 Summary

CMS produced many EWK measurements with the first 36 pb^{-1} of LHC data at 7 TeV. Precision measurements of inclusive W and Z production cross sections with large statistics provide a test of the SM at the new energy scale explored by the LHC. W and Z production associated to jets, including Z plus b-jets, is studied, and W polarization is been measured in events containing a W plus jets. Detailed studies of differential cross sections and many observables, like asymmetries, have been reported, as well as studies of diboson production: Wγ, Zγ, WW. All measurements are so far in agreement with theoretical predictions from the SM. A summary of the ratios of CMS measurement to the SM predictions is shown in Fig. 1. While many measurements are already limited by systematic uncertainties, the increase of integrated luminosity will benefit many other measurements and will allow to access more rare SM processes.

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