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W and Z boson production at CMS

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We present selected measurements done with W and Z bosons performed with the CMS detector, based on samples of events collected during 2011 and 2012 physics runs. Measurements include W and Z inclusive cross sections, the lepton charge asymmetry in W events, and differential cross sections of Z and Drell-Yan production.

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1. Introduction

The production of W and Z bosons in proton proton collisions, which are typically identified through their leptonic decays, are not only very useful experimental candles at the LHC, they are theoretically described very well within the framework of the standard modle (SM). In this proceeding, several vector boson measurements such as Muon charge asymmetry, Drell-Yan cross setion, W and Z boson cross section, and transverse momentum distribution of Z bosons are reported.

2. Measurement of the muon charge asymmetry in inclusive $pp \to W$ production at $\sqrt{s} = 7$ TeV

The overall excess of W^+ over W^- bosons is due to the presence of two valence u-quarks in the proton. Measurements of the production asymmetry between W^+ and W^- bosons as a function of boson rapidity provide additional constraints on u/d ratio and on the sea antiquark densities in the proton. But we measure muon charge instead of boson one for the difficulty from neutrions at W decays.

$$A_{exp}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to l^+\nu) - \frac{d\sigma}{d\eta}(W^- \to l^-\bar{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to l^+\nu) + \frac{d\sigma}{d\eta}(W^- \to l^-\bar{\nu})} \tag{2.1}$$

where l is the daughter charged lepton, η is the charged lepton pseudorapidity in the CMS lab frame. The muon charge asymmetry is measured with events in inclusive $pp \to W + X$ production at $\sqrt{s} = 7$ TeV using a data sample corresponding to an integrated luminosity of 4.7 fb^{-1} collected with the CMS detector at the LHC in 2011 (a sample of more than 20 M $W \to \mu\nu$ events). Both W lepton charge asymmetry and the W production charge asymmetry were studied in $p\bar{p}$ collisions by the CDF and D0 experiments at the Fermilab Tevatron Collider [1, 2]. The ATLAS, CMS and LHCb experiments also reported measurements of the lepton charge asymmetry using data collected during 2010 LHC run. Earlier measurements of the W lepton charge asymmetry extracted from CMS data used data samples of 840 pb^{-1} [4] and 234 pb^{-1} [5] for electron and muon decay channel respectively. The asymmetry is measured in 11 bins in absolute muon pseudorapidity (η) ranging from 0 to 2.4 for two different muon p_T thresholds: 25 GeV and 35 GeV. Other physics process, such as multijet production (QCD background), Drell-Yan ($Z/\gamma^* \to l^+l^{-1}$) production, $W \to \tau\nu$ production (EWK background), and top quark pair ($t\bar{t}$) production can produce high-p_T muons and mimic $W \to \mu\nu$ signal candidates. In addition, cosmic ray muons can mimic $W \to \mu\nu$ candidates. The expected backgrounds from QCD, EWK and $t\bar{t}$ events in the $W \to \mu\nu$ data sample are about 8.0%, 8.0%, and 0.5%, respectively. Binned maximum likelihood fits of the binned $\not{E}_T$ (missing transverse energy) distributions are simultaneously done for W^+ and W^- candidate events to extract the W^+ yield and the W^- yield for each $|\eta|$ bin. The $\not{E}_T$ distributions for the $W \to \mu\nu$ signal and backgrounds are obtrained from simulations which are corrected for the hadronic recoil as measured in $Z/\gamma^* \to \mu^+\mu^-$ events to improve data-MC agreement for $\not{E}_T$ distribution [6]. We also repeat the analysis with a higher muon p_T threshold of 35 GeV. We investigate possible additional corrections to the raw charge asymmetry (A^{raw}) from detector bias that results in a difference from the true charge asymmetry (A^{true}).

$$A^{true} = A^{raw} - \frac{1 - (A^{raw})^2}{2}(r^{W^+/W^-} - 1), \tag{2.2}$$

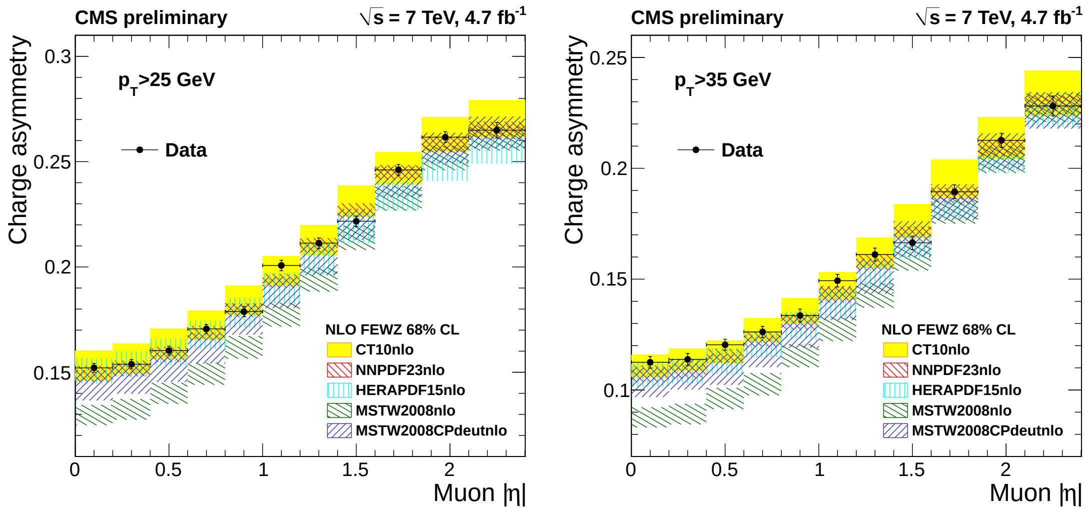

Figure 1: Comparison of the measured muon charge asymmetries to predictions with MSTW2008, CT10, NNPDF2.1, and HERAPDF1.5 NLO PDF models. Results for muon $p_T > 25$ GeV and muon $p_T > 35$ GeV are shown on the left and right panels, respectively.

where r^{W^+/W^-} is the ratio of the selection efficiency between W^+ and W^- events. The dominant systematic errors are comming from the efficiency correction and QCD shape and nomalization. The measured asymmetries after all corrections are shown in Fig. 1, including statistical and systematic uncertainties both.

Compared to the previous CMS measurement, this measurement significantly reduces both the statistical and systematic uncertainties. The per bin total uncertainty is 0.2-0.4%. The data are in good agreement with the CT10 PDF parametrization, and in better agreement with the new MSTW2008 parametrization after flexible input parameterisation and deuteron correction. The experimental errors are smaller than the uncertainties in the PDF parametrization. Therefore, this measurements can be used to improve the parametrization and reduce the PDF uncertainties.

3. Measurement of the differential and double-differential Drell-Yan Cross sections at 7 TeV

The theoretical calculations of the differential cross section $d\sigma/dm$ and the double-differential cross section $d^2\sigma/dmd|y|$, where m is the dilepton invariant mass and $|y|$ is the absolute value of the dilepton rapidity (y), are well established up to the next-to-next-leading order (NNLO) in quantum chromodynamics (QCD). The rapidity and the invariant mass of the dilepton system produced in proton-proton collisions are related at leading order (LO) to the momentum fraction $x_+(x_-)$ carried by the parton in the forward-going (backward-going) proton as described by the formula $x_\pm = \frac{m}{\sqrt{s}} \exp^{\pm y}$. Therefore, the rapidity and mass distributions are sensitive to the PDFs of the interacting partons.

The measurements reported in this paper [7] are based on pp collision data recorded in 2011 with the CMS detector at the LHC at $\sqrt{s} = 7$ TeV, corresponding to an integrated luminosity of

4.5 fb^{-1} (dimuon channel) and 4.8 fb^{-1} (dielectron channel). The fiducial volumes of detection are $p_T > 14$, 9 GeV/c, and $|\eta| < 2.4$ for muon, and $p_T > 20$, 10 GeV/c, and $|\eta| < 2.5$ for electron. The cross section measurements are calculated using the following formula:

$$\sigma = \frac{N_u}{A \cdot \varepsilon \cdot \rho \cdot L_{int}}, \tag{3.1}$$

where N_u denotes the background-subtracted yield obtained using a matrix inversion unfolding technique. The acceptance A and the efficiency ε are both estimated from MC simulation, while ρ, the scale factor accounting for the differences in the efficiency between data and simulation. The cross sections for these measurements are normalized to the Z-peak region (60<m<120 GeV). The differential differential $d\sigma/dm$ cross section measurements are performed over a mass range from 15 to 1500 GeV in 40 variable-width mass bins chosen to provide reasonable statistics per bin.

The double-differential cross section measurement is performed in dimuon rapidity y space. The mass bin edges are 20, 30, 45, 60, 120, 200, and 1500 GeV. For each mass bin, 24 equidistant bins of width 0.1 in absolute dimuon rapidity are defined.

The main backgrounds in the region of high invariant mass (above the Z peak) are due to $t\bar{t}$ and diboson production followed by leptonic decays, while the DY production of $\tau^+\tau^-$ pairs is the dominant source of background in the region just below the Z peak. At low values of the dimuon invariant mass (up to 40 GeV), most of the background events are due to QCD events with multiple jets (QCD multijet). The situation is slightly different for electrons in the final state. At low values of dielectron invariant mass most of the background events are from $\tau^+\tau^-$ and $t\bar{t}$ processes.

The major uncertainty in the dimuon signal comes from the efficiency scale factor ρ that reflects systematic deviations that vary up to 2% between the data and the simulation. In the dielectron channel, the leading systematic uncertainty is associated with the energy scale corrections for individual electrons upto 17.6 %.

The results of two channels (muon and electron) are compatible within uncertainty and combined. The left plot of Fig. 2 shows the DY cross section measurement normalized to the Z-boson mass peak region. We perform a comparison with the theoretical expectations calculated with various PDF sets. The right plot of Fig. 2 shows the comparison with currently available NNLO PDFs, most of which are from the pre-LHC era: CT10, CT10W, NNPDF2.1, HERAPDF15, MSTW2008, JR09, and ABKM09.

Given the uncertainties, the measurements provide sufficient sensitivity to different PDFs and can be used to calculate a new generation of PDFs, and extend out knowledge of perturbative QCD and the parton contents of the proton.

4. Measurement of inclusive W and Z boson cross section in pp collisions at $\sqrt{s} = 8$ TeV

The data sample in this analysis collected in 2012 corresponding to an integrated luminosity of 18.7±0.9 pb^{-1}. In order to perform a precision measurement of the inclusive W and Z boson cross sections at $\sqrt{s} = 8$ TeV, a dedicated LHC configuration was deployed to accumulate a dataset with low pileup and low transverse momentum trigger thresholds.

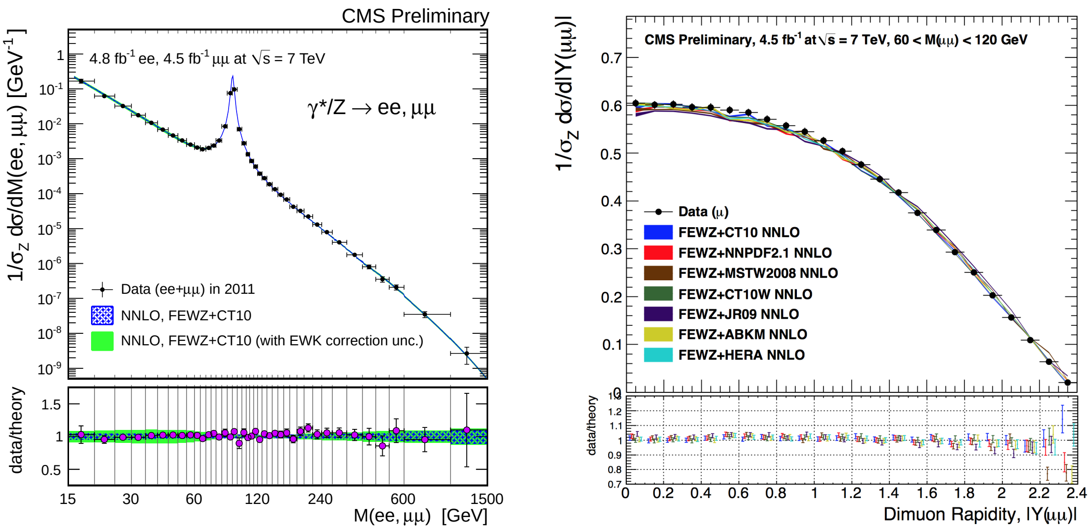

Figure 2: Left: Combined DY differential cross section measurement in dimuon and dielectron channels normalized to the Z-peak region. Including the correlations between the two channels, the normalized χ^2 calculated with total uncertainties on the combined results is 1.1 between data and theoretical expectation with the number of degrees of freedom, 40. The corresponding χ^2 probability is 36.8%. Right: A comparison with theoretical expectations using various PDF sets in the dimuon mass range from 60 to 120 GeV. The six bottom plots show the ratio of data to theoretical expectation.

The fiducial volume of electron selection is within $p_T > 25$ GeV and $|\eta|$<2.5. And it is within $p_T > 25$ GeV and $|\eta|$<2.1 for muon. The background processes as QCD multijet, Drell-Yan, $W \to \tau\nu$ and $Z \to \tau\tau$, $t\bar{t}$, and diboson production are considered by MC or data driven techniques.

The $\not{E}_T$model is fitted to the observed distribution as the sum of three contributions: the W signal, the QCD backgrounds, and EWK backgrounds. The shape of the $\not{E}_T$distribution for the QCD background is modeled by a parametric function. To extract the Z boson yield, the events in the Z mass peak are counted. Most of the systematic is from lepton reconstruction and identification which is upto 3.8% for electron channel, and 1.5% for muon case. Figure 3 shows the measured and predicted W versus Z and W^+ versus W^- cross sections. The measured inclusive cross sections are $\sigma(pp \to WX) \times B(W \to l\nu) = 11.88 \pm 0.03\ (stat.) \pm 0.22\ (syst.) \pm 0.52\ (lumi.)\ nb$ and $\sigma(pp \to ZX) \times B(Z \to l^+l^-) = 1.12 \times 0.01(stat.) \pm 0.02(syst.) \pm 0.05(lumi.)\ nb$, limited to a dilepton mass range of 60 to 120 GeV. These measurements are consistent between the electron and muon channels, and in agreement with next-to-next-to-leading order cross section calculations.

5. Measurement of the transverse momentum distribution of Z bosons decaying to dimuons in pp collisions at $\sqrt{s} = 8$ TeV

A measurement of the transverse momentum distribution of the dimuon system, produced in the Drell-Yan process is reported for the Z boson mass range of 60 to 120 GeV/c^2. The results are obtained using a data sample of pp collisions corresponding to an integrated luminosity of

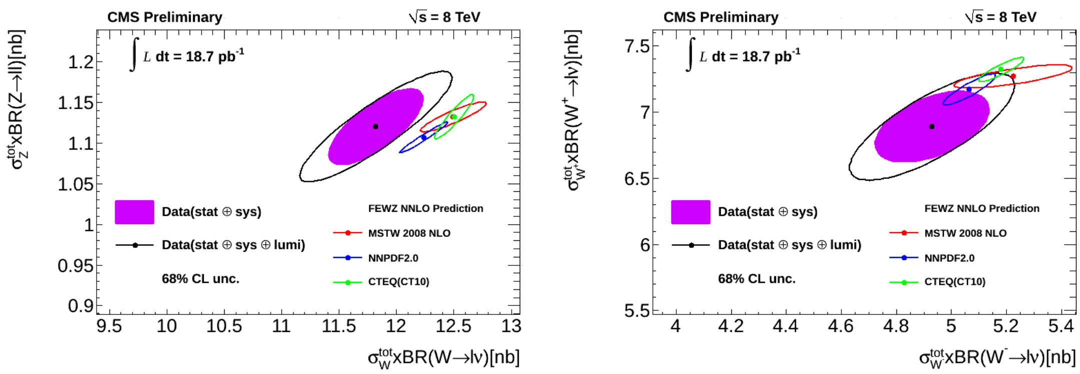

Figure 3: Measured and predicted W versus Z production and W^+ versus W^- cross sections. The ellipses illustrate the 68% coverage for total uncertainties (open black) and excluding the luminosity uncertainty (purple filled). The uncertainties of the theoretical predictions correspond to the PDF uncertainties only.

18.4 pb^{-1}. A study of the q_T spectrum over a similar range at $\sqrt{s} = 7$ TeV has been reported by the ATLAS and CMS experiments [8, 9].

The selected muons are within the fiducial volume defined: $p_T > 20$ GeV/c and $|\eta| < 2.1$. The differential cross section is determined in each q_T bin by subtracting the estimated number of background events, from the total number of detected events in a bin. The total background contamination is estimated to less than 1%, consisting primarily of $Z \to \tau\tau$ and $t\bar{t}$ processes with an uncertainty dominated by the statistical uncertainties in the background simulation. The distributions are corrected for the effects of detector resolution using an unfolding technique. The final result is normalized by the measured total cross section in the range of the Z boson ($60 < M_{\mu\mu} < 120$ GeV/c^2). The low q_T region is affected by the underlying event activity in the hadronic collision which is a non-perturbative QCD processe modeled in PYTHIA in terms of few parameters. Several sets of values for these parameters, called "tunes", are available for the LHC, including the Z2*, P0, D6T, and 4C [10]. The shapes predicted with these tunes are compared to the measurement in Fig. 4, where the best data and theory agreement is achieved with PYTHIA Z2*.

A measurement of the shape of the differential cross section for the transverse momentum of the Drell-Yan muon pairs in the Z boson mass region between 60 and 120 GeV/c^2 has been reported as a function of the dimuon transverse momentum within a restricted acceptance for the muons, $p_T > 20$ GeV/c and $|\eta| < 2.1$. This study shows that the PYTHIA generator with Z2* tune is able to describe data well in low q_T region, while MADGRAPH predictions are in general good agreement with data at high q_T. An overall good agreement is observed between the data and the predictions from the theory.

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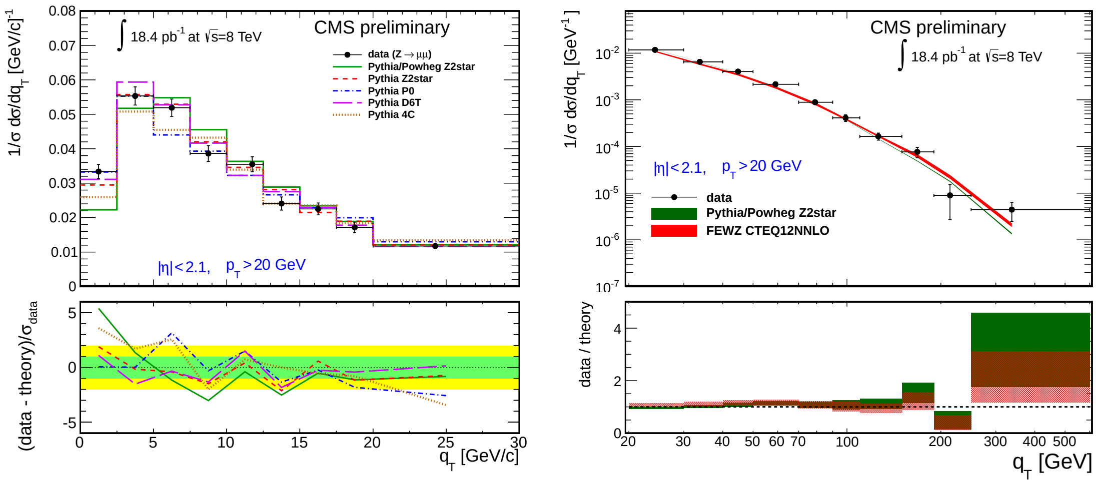

Figure 4: Left: The transverse momentum distribution of the dimuon system from Z boson decay in data (points) compared with the predictions of various tunes in PYTHIA. The lower portion of the figure shows the difference between the data and the simulation predictions divided by the uncertainty (statistical and systematic) on the data, σ_{data}. The green (inner) and yellow (outer) bands are the ranges corresponding to $\pm 1\ \sigma$ and $\pm 2\sigma$ experimental uncertainties. Right: Comparison with the predictions from POWHEG and FEWZ for $q_T > 20$ GeV/c. The bands in the upper plot represent the uncertainty on the predictions from factorization and renormalization scales and PDFs. The lower plot shows the ratio between the data and the theory predictions. The bands in the lower plot represent one standards deviation range for combined theoretical and experimental uncertainties.

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