Abstract

The ATLAS and CMS collaborations report the latest measurements and updates on the inclusive and differential cross section of the W and Z bosons production in pp collisions at a center-of-mass energies of 8 and 13 TeV.

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Inclusive and differential W/Z at CMS and ATLAS

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The ATLAS\textsuperscript{1} and CMS\textsuperscript{2} collaborations report the latest measurements of the inclusive and differential W and Z boson production in pp collisions at center-of-mass energies ($\sqrt{s}$) of 8 and 13 TeV. The high rate at the CERN large hadron collider (LHC), the clean signature, and the good understanding of the detectors allow the experiments to perform precision tests of perturbative quantum chromodynamics (pQCD) and further constrain the parton distribution functions (PDFs). Drell–Yan (DY) events (pp → Z/$\gamma^{*}$ + X → $\ell^{+}\ell^{-}$ + X) are characterized by the presence of two hard leptons (where only $\ell$ = $\mu$, $e$ are considered in the presented analyses) with opposite sign and same flavour, while in W events (pp → W + X → $\ell\nu$ + X) a lepton and missing transverse energy ($E_{T}$) is present. The next-to next-to leading order predictions agree with the measurements across the energy ranges probed so far, as shown in fig. 1\textsuperscript{3}.

The $\phi^{*}_{\eta}$ distribution is used as a probe for the transverse momentum of the Z boson ($p_{T}^{\ell}$), but having only angular variables in its definition, a very accurate experimental result can be achieved, allowing for very precise comparison with resummation techniques or with different expansion in the perturbation theory. The double differential cross section measurements in $\phi_{\eta}^{*}$–y$^{*}$, $p_{T}^{\ell}$–y$^{*}$, $\phi_{\eta}^{*}$–m$^{\ell\ell}$, and $p_{T}^{\ell}$–m$^{\ell\ell}$ at $\sqrt{s}$ = 8 TeV, covering a wide phase space in both the DY mass (m$^{\ell\ell}$) and the rapidity (y$^{\ell\ell}$) of the Z boson have been presented\textsuperscript{5}. Fig. 2 shows, as an example, the differential measurement of $p_{T}^{\ell}$–m$^{\ell\ell}$ (left) and the $\phi_{\eta}^{*}$–m$^{\ell\ell}$ (right).

The proton PDFs have a crucial importance in the understanding the standard model (SM), and therefore in putting constrains of new physics phenomena. The forward-backward asymmetry ($A_{FB}$) in DY events can be used to constrain the u- and d-quark weak couplings and the
Preliminary results on the datasets corresponding to the 2015 LHC run have been also shown, and compared to different PDFs sets, and shown in fig. 4. The total inclusive cross section of the DY boson production is extracted ATLAS uses the born level definition while CMS the "level. Detector level plots are shown in fig. 6. The correlation of the W charge asymmetry in \( \eta^W \) has been presented, and shown in fig. 3-right.

Figure 2 – Left, the distribution of \((1/\sigma)d\sigma/dy^*\) at Born level in each region of \(y^*\), shown as a ratio to the central rapidity region (\(|y^*|<0.4\), for events at the Z-boson mass peak at \(\sqrt{s} = 8\) TeV measured by ATLAS. Right, the ratio of \((1/\sigma)d\sigma/dy^*\) as predicted by various MC generators to the combined Born-level data, in six different regions of \(m^\tau\) for \(|y^*| < 2.4\) at \(\sqrt{s} = 8\) TeV measured by ATLAS.

Effective weak mixing angle. Moreover, deviations with respect to the SM predictions can be used to probe beyond the SM physics. The double differential measurements of \(A_{FB}\) at \(\sqrt{s} = 8\) TeV in \(y^*\) and \(m^\tau\) has been reported, and the central rapidity (\(y^* < 1\)) region is shown in fig. 3-left. The W charge asymmetry is sensitive to the different valence and sea quark contributions in the proton PDFs, particularly in the high pseudo-rapidity (\(\eta\)) region. The differential measurement of the W asymmetry in \(\eta^W\) has been presented, and shown in fig. 3-right.

Preliminary results on the datasets corresponding to the 2015 LHC run have been also shown, and are summarized here. Although the experiments use similar definitions, small differences are present in the fiducial phase-space, leptons are required to have both \(p_T > 25\) GeV, and electrons \(|\eta| < 2.5\), but for CMS \(|\eta| < 2.4\) while for ATLAS \(|\eta| < 2.47\). The Z mass window also differs between ATLAS and CMS, being 66–116 GeV for the first and 60–120 GeV for the latter, and finally ATLAS uses the born level definition while CMS the “dressed” level. Detector level plots are shown in fig. 4. The inclusive cross section of the DY boson production is extracted and compared to different PDFs sets, and shown in fig. 5. CMS provides also an updated measurement to the full 2015 datasets in the muon channel \(\sigma_F^{\mu} = 1870 \pm 2\) (stat) \(\pm 35\) (syst) \(\pm 51\) (lumi) and reduced luminosity uncertainty. The W cross section measurements require exactly one lepton in the event. In the signal extraction, CMS uses analytical fit functions to the \(E_T\) distributions, while ATLAS uses template based fit of the transverse mass \(m_T\) but asking for an additional requirement \(E_T > 25\) GeV. Detector level plots are shown in fig. 6.
the systematics effects among the different cross section measurements, e.g. luminosity, allows to extract their ratio very precisely. In fig. 8 shows as example the cross-section ratio for W/Z in the above defined fiducial volume. The same results but distinguishing the charge of the W as well as the inclusive W asymmetry are also presented for the total and fiducial volume.

Further tests on the pQCD are performed by looking at the associate jet production with the Z boson. ATLAS and CMS use both the anti-\(k_T\) algorithm with radius parameter \(R=0.4\) and \(p_T>30\) GeV requirement, but slightly different rapidity acceptance: \(|y^{\text{jet}}|<2.5\) for the first and \(|y^{\text{jet}}|<2.4\) for the latter\(^{11,12}\). The probing of the jet kinematics can be performed by looking at the number of associated jets (fig. 9), their \(p_T\), or the \(H_T=\sum_{j \in \text{jet}} p_T\cdot j\) of the event (fig. 10). Jet kinematics in Monte Carlo (MC) is sensible to both to the matrix element and the parton shower simulation.

Differential distributions in \(p_T^{\ell\ell}, \phi_\eta^{\ell\ell}, y^{\ell\ell}\), and lepton \(p_T\) (\(p_T^\ell\)), are also presented\(^{10}\) and shown in figs. 11–14. MCs that don’t have resummation are expected to fail in the low \(p_T^{\ell\ell}\) region, while high order corrections show their importance in the high \(p_T^{\ell\ell}\) regime. High \(y^{\ell\ell}\) region is sensitive to different PDFs contribution, and \(p_T^\ell\) is sensitive to Sudakov shoulder logarithms.

A impressive effort is made by the two collaborations to produce new results at the highest available center-of-mass energies, and to consolidate the one with previous datasets. Data are compared to the most recent theory calculations, in order to exploit limitations and deviations of the current available models.

References

2. CMS Collaboration. The CMS experiment at the CERN LHC. *JINST*, 3(08), 2008.
Figure 4 – Detector level mass distribution for DY di-muon candidates at $\sqrt{s} = 13$ TeV recorded by ATLAS$^8$ (left) and CMS$^9$ (right) detectors. Data are compared to MC simulations for signal and backgrounds.

Figure 5 – The total inclusive cross section for the DY production at $\sqrt{s} = 13$ TeV measured by ATLAS$^8$ (left) and CMS$^9$ (right) compared to different PDF sets.

Figure 6 – Detector level $m_{\mu\mu}$ and $E_T$ distribution for W candidates in the muon channel at $\sqrt{s} = 13$ TeV recorded by ATLAS$^8$ (left) and CMS$^9$ (right) detectors. Data are compared to MC simulation for signal and backgrounds.

Figure 7 – The total inclusive cross section for the W production at $\sqrt{s} = 13$ TeV measured by ATLAS$^8$ (left) and CMS$^9$ (right) compared to different PDF sets.
Figure 8 – Comparison of measured total inclusive cross section ratios between Z and W productions at $\sqrt{s} = 13$ TeV with predictions for different PDF sets.

Figure 9 – Inclusive jet multiplicity distribution in DY events measured by ATLAS (left) and CMS (right) at $\sqrt{s} = 13$ TeV, compared to different LO and NLO MC predictions.

Figure 10 – $p_T$ of the leading jet (left) and $H_T$ distribution (right) in DY events at $\sqrt{s} = 13$ TeV measured by CMS compared to NLO MC predictions.
Figure 11 – $p_T^{\ell\ell}$ distribution in DY events at $\sqrt{s} = 13$ TeV measured by CMS. Data are compared to NLO and NNLO MC predictions\textsuperscript{10}.

Figure 12 – $\phi_y^\ell$ distribution in DY events at $\sqrt{s} = 13$ TeV measured by CMS. Data are compared to NLO and NNLO MC predictions\textsuperscript{10}.

Figure 13 – $y^{\ell\ell}$ distribution in DY events at $\sqrt{s} = 13$ TeV measured by CMS. Data are compared to NLO and NNLO MC predictions\textsuperscript{10}.

Figure 14 – $p_T^\ell$ distribution in DY events at $\sqrt{s} = 13$ TeV measured by CMS. Data are compared to NLO and NNLO MC predictions\textsuperscript{10}. 

\textsuperscript{10} CMS Preliminary, CMSPDF set: NNPDF3.0, $>25$ GeV, $T|<2.4, p_\eta|>25$ GeV, $\phi_y^\ell$, $y^{\ell\ell}$, $p_T^\ell$. Data are compared to NLO and NNLO MC predictions.