Inclusive and differential W/Z at CMS and ATLAS

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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 center-of-mass energies of 8 and 13 TeV.

The ATLAS[1] and CMS[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 ($pp \to Z/\gamma^* + X \to \ell^+\ell^- + X$) 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 ($pp \to W + X \to \ell\nu + X$) a lepton and missing transverse energy ($\not{E}_T$) 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[3].
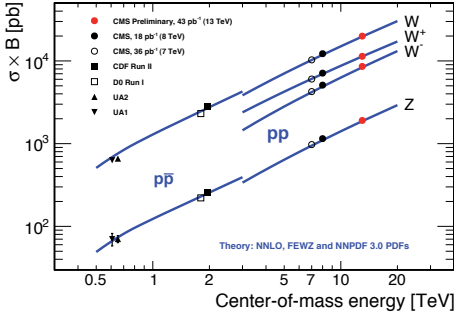

Figure 1 – Measurements of the total W^+, W^-, W, and Z production cross sections times branching fractions versus center-of-mass energy for CMS and experiments at lower-energy colliders[3].

The ϕ_η^* distribution is used as a probe for the transverse momentum of the Z boson $(p_T^{\ell\ell})$[4], 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 ϕ_η^*–$y^{\ell\ell}$, $p_T^{\ell\ell}$–$y^{\ell\ell}$, ϕ_η^*–$m^{\ell\ell}$, and $p_T^{\ell\ell}$–$m^{\ell\ell}$ 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[5]. Fig. 2 shows, as an example, the differential measurement of $p_T^{\ell\ell}$–$m^{\ell\ell}$ (left) and the ϕ_η^*–$m^{\ell\ell}$ (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 effective weak mixing angle. Moreover,
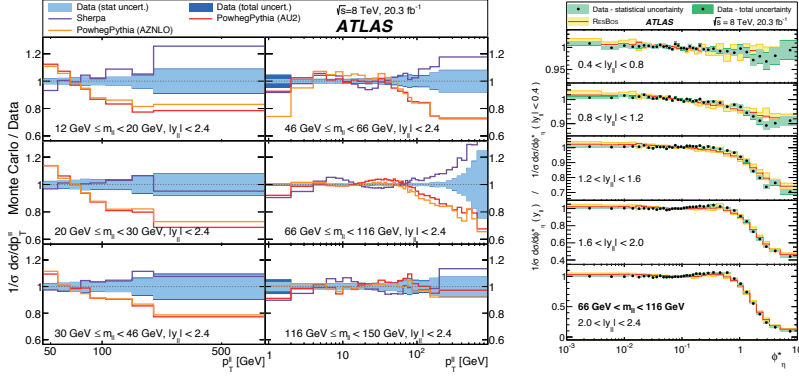
Figure 2 – Left, the distribution of $(1/\sigma)\mathrm{d}\sigma/\mathrm{d}\phi_\eta^*$ at Born level in each region of $y^{\ell\ell}$, shown as a ratio to the central rapidity region ($|y^{\ell\ell}|$<0.4), for events at the Z-boson mass peak at $\sqrt{s} = 8$ TeV measured by ATLAS. Right, the ratio of $(1/\sigma)\mathrm{d}\sigma/\mathrm{d}p_\mathrm{T}^{\ell\ell}$ as predicted by various MC generators to the combined Born-level data, in six different regions of $m^{\ell\ell}$ for $|y^{\ell\ell}| < 2.4$ at $\sqrt{s} = 8$ TeV measured by ATLAS[5].

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 $y^{\ell\ell}$ and $m^{\ell\ell}$ has been reported[6], and the central rapidity ($y^{\ell\ell}$<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 (η) region. The differential measurement of the W asymmetry in η^μ has been presented[7], and shown in fig. 3-right.
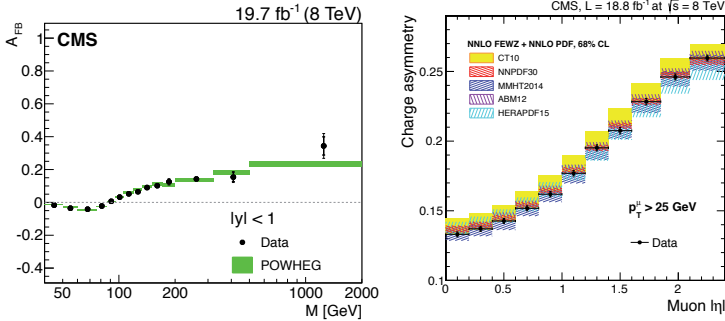

Figure 3 – Left, the combined ($\mu^+\mu^-$ and e^+e^-) unfolded A_{FB} distributions in the central rapidity region differentially in $m^{\ell\ell}$ at $\sqrt{s} = 8$ TeV measured by CMS[6]. Right, comparison of the measured W charge asymmetry differentially in η^μ at $\sqrt{s} = 8$ TeV measured by CMS[7].

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 $|\eta^e|$<2.5, but for CMS $|\eta^\mu|$<2.4 while for ATLAS $|\eta^\mu|$<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 total inclusive cross section of the DY boson production is extracted and compared to different PDFs sets[3,8,9] (fig. 5). CMS provides also an updated measurement to the full 2015 datasets in the muon channel $\sigma_{\mathrm{tot}}^{\mathrm{Z}}$=1870±2(stat)±35(syst)±51(lumi) and reduced luminosity uncertainty[10].
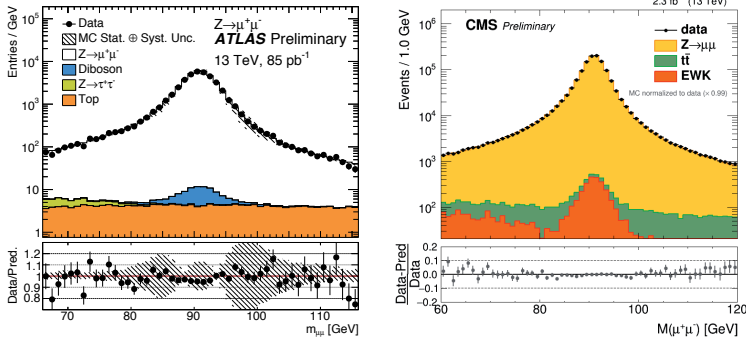
Figure 4 – Detector level mass distribution for DY di-muon candidates at $\sqrt{s} = 13\,\text{TeV}$ recorded by ATLAS[8] (left) and CMS[10] (right) detectors. Data are compared to MC simulations for signal and backgrounds.
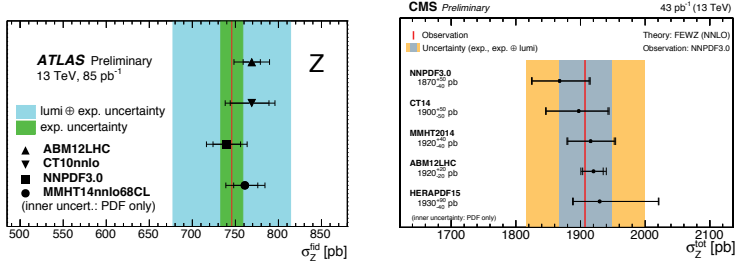

Figure 5 – The total inclusive cross section for the DY production at $\sqrt{s} = 13\,\text{TeV}$ measured by ATLAS[8] (left) and CMS[3] (right) compared to different PDF sets.
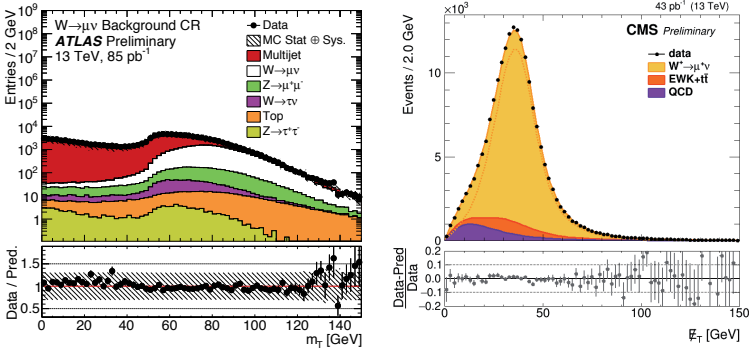

Figure 6 – Detector level m_T and $\not{E}_T$ distribution for W candidates in the muon channel at $\sqrt{s} = 13\,\text{TeV}$ recorded by ATLAS[8] (left) and CMS[3] (right) detectors. Data are compared to MC simulation for signal and backgrounds.

The W cross section measurements require exactly one lepton in the event. In the signal extraction, CMS uses analytical fit functions to the $\not{E}_T$ distributions, while ATLAS uses template based fit of the transverse mass (m_T) but asking for an additional requirement $\not{E}_T > 25\,\text{GeV}$ (fig. 7). Detector level plots are shown in fig. 6. The correlation of 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.

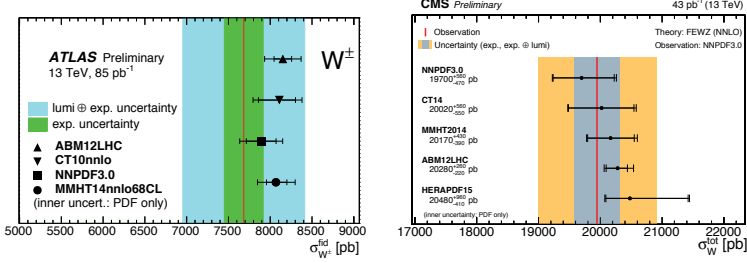The same results but distinguishing the charge of the W as well as the inclusive W asymmetry

Figure 7 – The total inclusive cross section for the W production at $\sqrt{s} = 13\,\mathrm{TeV}$ measured by ATLAS[8] (left) and CMS[3] (right) compared to different PDF sets.
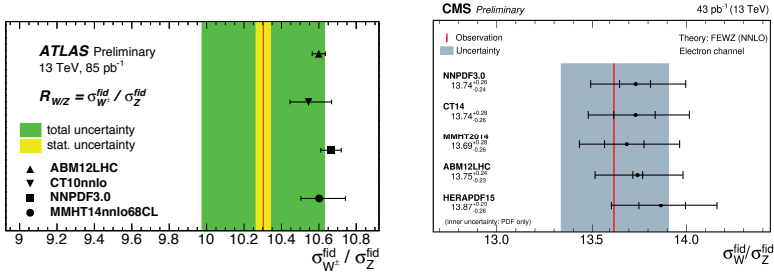

Figure 8 – Comparison of measured total inclusive cross section ratios between Z and W productions at $\sqrt{s} = 13\,\mathrm{TeV}$ with predictions for different PDF sets[8,3].

are also presented for the total and fiducial volume[3,8]. 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: $|y^\mathrm{jet}|$<2.5 for the first and $|y^\mathrm{jet}|$<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=$\sum_{j\in\mathrm{jet}} p_{\mathrm{T}j}$ of the event (fig. 10). Jet kinematics in Monte Carlo (MC) is sensible to both to the matrix element and the parton shower simulation.
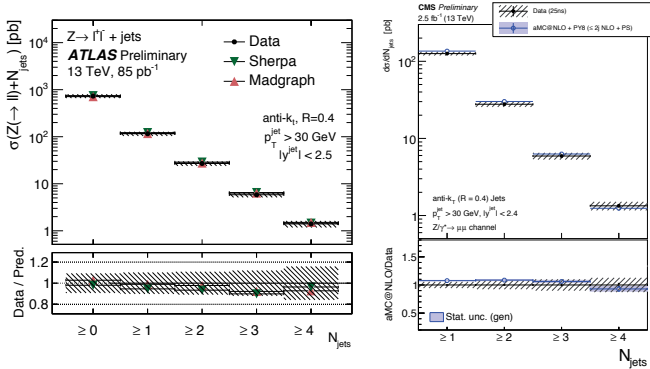

Figure 9 – Inclusive jet multiplicity distribution in DY events measured by ATLAS (left) and CMS (right) at $\sqrt{s} = 13\,\mathrm{TeV}$, compared to different LO and NLO MC predictions[12,11].
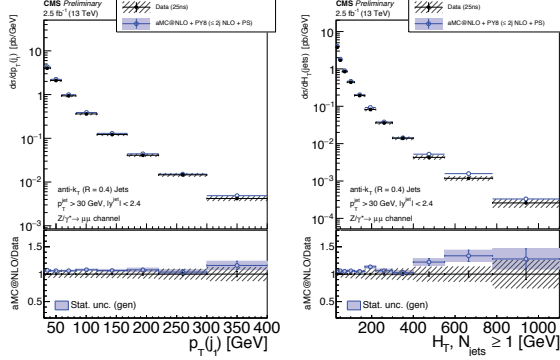
Figure 10 – p_T of the leading jet (left) and H_T distribution (right) in DY events at $\sqrt{s} = 13\,\text{TeV}$ measured by CMS compared to NLO MC predictions[11].

Differential distributions in $p_T^{\ell\ell}$, ϕ_η^*, $y^{\ell\ell}$, and lepton p_T (p_T^ℓ), 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 contirbution, and p_T^ℓ is sensitive to Sudakov shoulder logarithms.
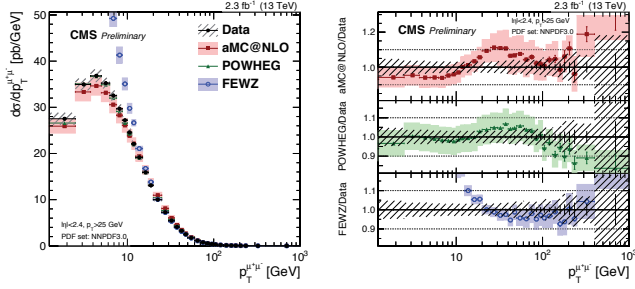

Figure 11 – $p_T^{\ell\ell}$ distribution in DY events at $\sqrt{s} = 13\,\text{TeV}$ measured by CMS. Data are compared to NLO and NNLO MC predictions[10].
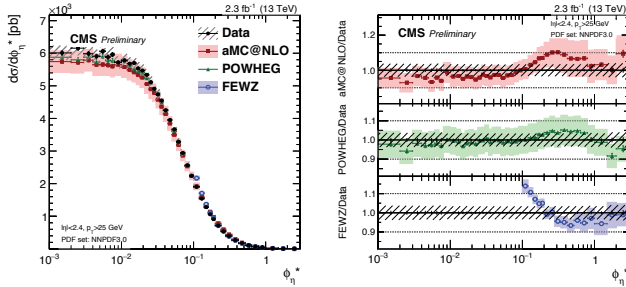

Figure 12 – ϕ_η^* distribution in DY events at $\sqrt{s} = 13\,\text{TeV}$ measured by CMS. Data are compared to NLO and NNLO MC predictions[10].

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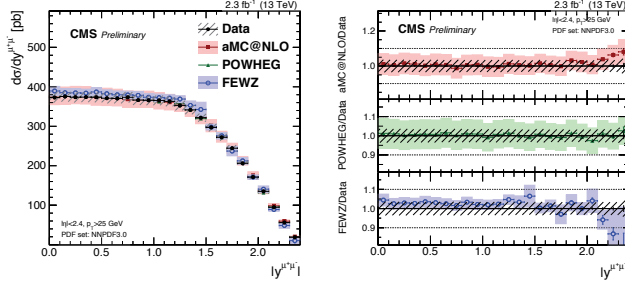
Figure 13 – $y^{\ell\ell}$ distribution in DY events at $\sqrt{s} = 13\,\text{TeV}$ measured by CMS. Data are compared to NLO and NNLO MC predictions[10].
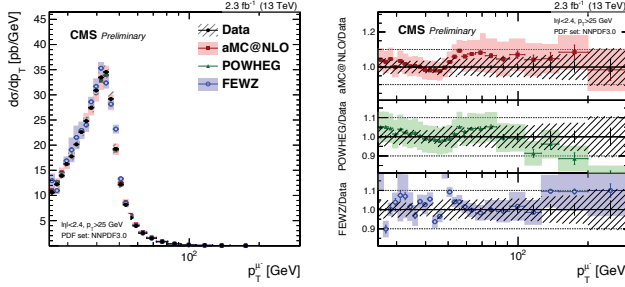

Figure 14 – $p_T^{\ell^-}$ distribution in DY events at $\sqrt{s} = 13\,\text{TeV}$ measured by CMS. Data are compared to NLO and NNLO MC predictions[10].

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