Measurements of vector-boson production in ATLAS and CMS

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Vector-boson production in $p-p$ collisions in LHC Run-1 has been extensively studied by ATLAS and CMS. Charged and neutral-current Drell-Yan cross sections are sensitive to the parton distribution functions of the proton and electroweak corrections. The measurements of the neutral-current Drell-Yan process in three distinct kinematic regions, i.e. at the Z boson mass peak, below, and above, are performed. The results are compared to NLO Monte Carlo simulations and to NNLO QCD predictions corrected for NLO EW effects calculated using various parameterisations of the parton distribution functions. An overview of these results is given.

1 Introduction

The proton-proton collisions at the Large Hadron Collider (LHC) are in fact parton-parton collisions, where the momentum fraction x carried by a parton can be described in terms of Parton Distribution Functions (PDFs). These colliding partons may undergo a hard-scattering process producing, for example, a Z boson in the final state. The production cross section for such a process may be factorised into the hard scattering between the partons and the PDF of each of the interacting partons. Via this hard scatter, one can test perturbative QCD (pQCD). Predictions for such processes are available at next-to-next-to-leading order (NNLO).

Drell-Yan (DY) production at the LHC probes the structure of the PDFs over a wide range of x and four-momentum transfer Q^2. The quark and gluon PDFs may be parameterised by functions that describe their shapes as a function of x. One can then use such processes to feed information into global QCD fits to extract these PDFs. The cross-section measurements available at the LHC have differing sensitivity to the proton's PDFs and so much may be gained by including, for example, electroweak boson production as such processes are sensitive to both the valence and sea quark distributions.

The recent measurements presented at this PANIC Conference included the transverse momentum $p_{\mathrm{T}}^{\ell\ell}$ and invariant mass $m_{\ell\ell}$ dependence of the production of $Z/\gamma^* \to \ell\ell$, where the lepton can be either an electron or a muon, as well as the charge asymmetry of $W^{\pm}$ production. The results from QCD analyses extracting PDF information were also discussed. A subset of this presentation is summarised in these proceedings.

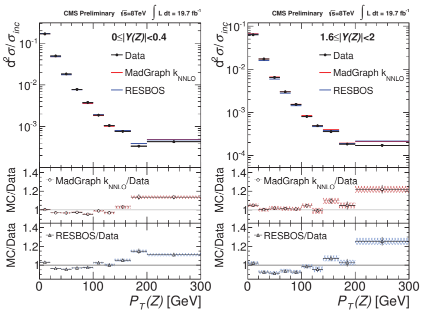

Figure 1: The CMS Z production cross section [1] as a function of $p_{\mathrm{T}}^{\ell\ell}$ in two illustrative bins of $Y_{\ell\ell}$ compared to MADGRAPH [2] normalised to NNLO (red) and RESBOS [4] (blue).

2 $p_{\mathrm{T}}^{\ell\ell}$ dependence of Z/γ^* production

Near the Z pole, single and double-differential cross-section measurements as a function of $p_{\mathrm{T}}^{\ell\ell}$ and Z-boson rapidity $Y_{\ell\ell}$ are reported. The region of low $p_{\mathrm{T}}^{\ell\ell}$ is that of initial state radiation and intrinsic k_{T} of the partons. This region may be modeled through either soft-gluon resummation or parton showers. The high $p_{\mathrm{T}}^{\ell\ell}$ region is that dominated by the radiation of high p_{T} gluons. This region may be modeled by fixed-order calculations available at NNLO. Several measurements have been made by ATLAS and CMS comparing to the predictions for a given choice of PDF. Only one example is illustrated here. Figure 1 shows the CMS measurement [1] of the double-differential cross section for DY dimuon production in two illustrative bins of the dimuon rapidity $Y_{\ell\ell}$. The ratios in these plots show comparisons of data to the leading order MADGRAPH [2] prediction scaled to NNLO with the FEWZ [3] calculation, and the NNLO RESBOS [4] prediction which models soft-gluon resummation at low $p_{\mathrm{T}}^{\ell\ell}$. Both predictions tend to overshoot the data for $p_{\mathrm{T}}^{\ell\ell}$ above approximately 80 GeV. RESBOS also tends to undershoot the data at lower $p_{\mathrm{T}}^{\ell\ell}$.

ATLAS also makes use of its differential cross-section measurements as a function of $p_{\mathrm{T}}^{\ell\ell}$ [5] and an angular variable ϕ_η^* [6] to produce a better tune for the parton shower model used (PYTHIA8 [7]) in conjunction with generators. This new tune called AZNLO is compared to an older tune labelled 4C in Figure 2. The new tune was obtained by modifying, e.g., the values of the primordial k_{T} within the proton and the value of the initial-state radiation cutoff in the parton shower. The tune shows agreement with data to better than 2% up to $p_{\mathrm{T}}^{\ell\ell}$ of 50 GeV.

3 $m_{\ell\ell}$ dependence of Z/γ^* production

Single and double-differential DY cross-section measurements as a function of $m_{\ell\ell}$ and $Y_{\ell\ell}$ are available from ATLAS and CMS in the $m_{\ell\ell}$ range of 15 GeV up to 2000 GeV. Low-mass DY production is dominated by the electromagnetic coupling of the photon γ^* to the quark-antiquark pair. This region exhibits different sensitivity to u and d-type quarks than on the Z pole which is dominated by the electroweak coupling of the Z. The measurements are compared to fixed-order calculations and to various generators and PDFs.

Figure 3 (left) shows the ATLAS measurement of the DY differential cross section at low $m_{\ell\ell}$ [8], compared to fixed-order FEWZ [3] calculations at next-to-leading order and NNLO.

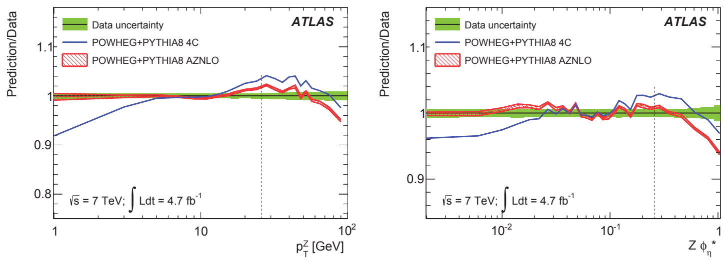

Figure 2: Comparison [5] of the tuned 4C (blue) and AZNLO (red) predictions to the $p_{\mathrm{T}}^{\ell\ell}$ (left) and ϕ_η^* (right) differential cross-section data from ATLAS.

It is evident at low $m_{\ell\ell}$ that NNLO-level calculations are needed to successfully describe the data. In this region of low $m_{\ell\ell}$, the CMS measurement [9] of the differential cross section as a function of $Y_{\ell\ell}$ is shown in Figure 3 (right) compared to a FEWZ prediction with several NNLO PDFs currently available. The agreement is good to the 10% level.

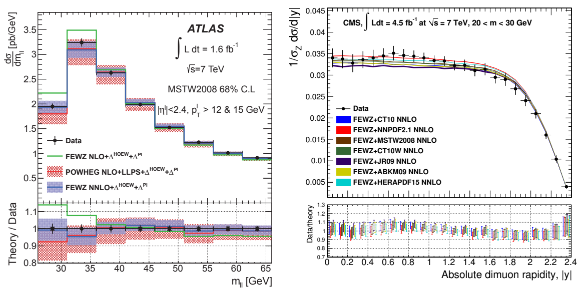

Figure 3: Left: The ATLAS cross-section measurement [8] as a function of $m_{\ell\ell}$ (points) compared to NLO and NNLO predictions. Right: Comparison of the CMS cross-section measurement [9] as a function of $|Y_{\ell\ell}|$ with theory expectations including NNLO PDF sets.

4 $W^{\pm}$ charge asymmetry

The dominant $W^{\pm}$ production mechanisms at the LHC are $d\overline{u} \to W^-$ and $u\overline{d} \to W^+$ and so the differential cross section charge asymmetry of $W^{\pm}$ production as a function of the lepton η can provide additional insight into the d/u PDF ratio as well as sea antiquark PDFs, including the poorly known strange sea. CMS has recently made a measurement of this $W^{\pm}$ charge asymmetry [10], shown in Figure 4 (left) compared to several PDF predictions. Best agreements are obtained with, e.g., the CT10 [11] PDFs while the MSTW2008 [12] family of PDFs shows significant deviations as the lepton η approaches zero. A global QCD fit was made by CMS [10], which used the HERA I inclusive data [13] and these charge-asymmetry results. Figure 4 (right) shows the prediction for d-valence quarks. Adding these new data to the global fit not only better constrains this PDF but also predicts a slight change in the shape of d_v as a function of x.

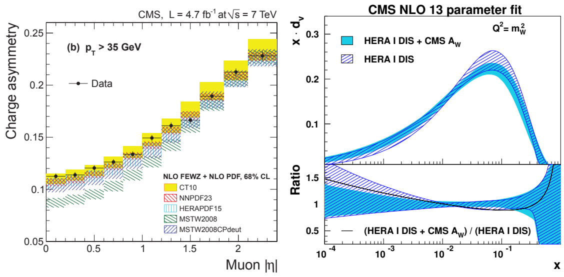

Figure 4: Left: Comparison of the CMS muon charge asymmetry [10] to predictions interfaced with several PDFs. Right: Distribution of d_v resulting from a global fit using HERA I deep inelastic scattering data [13] and CMS muon asymmetry [10] (shaded), and HERA only (hashed).

5 Conclusions

Vector-boson production at the LHC is interesting on many levels. It can be used as a probe of pQCD via the hard-scattering process as well as to better constrain PDFs, particularly valence quarks and poorly-known strange sea quarks. These proceedings presented a very brief overview of some of the ATLAS and CMS measurements that contribute to this new knowledge: the $p_T^{\ell\ell}$ and $m_{\ell\ell}$ dependence of DY production as well as the $W^{\pm}$ production charge asymmetry.

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