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Weak boson production from D0 and LHCb in the NNPDF global analysis

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High-precision electroweak production measurements from the Tevatron and the LHC provide important constraints on the quark flavor separation in global PDF fits. In this contribution, we study the impact of the recent D0 W asymmetry measurements and of the LHCb W and Z Run I combination in the global NNPDF analysis. We find that these measurements can be described by NLO QCD theory and that they lead to a significant reduction of PDF uncertainties.

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Towards NNPDF3.1. NNPDF3.0 [1] is the most updated version of the NNPDF family of global analysis. NNPDF3.0 was the result of a complete rewrite of the NNPDF fitting code from `Fortran` to `C++` and `Python`, and for the first time the entire fitting methodology was robustly validated by means of closure tests. Subsequently, a number of studies based on NNPDF3.0 have been presented, including the constraints on NNPDF3.0 from the final HERA I+II combined inclusive dataset [2] and those from forward charm production at LHCb [3]. The NNPDF3.0 fits have also been the baseline to construct PDF sets with NLO+NLL and NNLO+NNLL threshold resummation [4], used as input for updated NLO+NLL calculations of squark and gluino production at the LHC 13 TeV [5]. NNPDF3.0 is also part of the PDF4LHC recommendations for PDF usage at Run II [6].

In this contribution, we review recent progress towards the next major update of the NNPDF family of global analysis, NNPDF3.1. First of all, we review the new fit settings, including improvements in data, theory and methodology, and then study the impact of some selected datasets. In particular, we will consider the impact of the D0 legacy measurements on W leptonic asymmetries and of the LHCb combination of W and Z production in the muon final state from Run I. We will show that these datasets provide important constraints in the global analysis, in particular regarding quark flavor separation.

Data, theory and fitting methodology. As compared to the NNPDF3.0 analysis, the NNPDF3.1 fit introduces a number of improvements in terms of the input dataset, theory calculations and the fitting methodology. Concerning the fitted dataset, in addition to the combined HERA inclusive data, NNPDF3.1 will include, among others, the Tevatron D0 Run II W lepton asymmetries, the complete Run I W,Z production dataset from LHCb, new inclusive jet and electroweak production measurements from ATLAS and CMS, as well as the differential distributions for top pair quark production and the Z transverse momentum at 8 TeV from ATLAS and CMS, exploiting recent progress in NNLO calculations [7, 8, 9].

From the point of view of the theory calculations, structure functions and PDF evolution are now evaluated using the public PDF evolution code `APFEL` [10], suitably benchmarked with the internal code `FKgenerator` [11] used in previous NNPDF fits. Among other recent improvements, `APFEL` allows for calculations using both the pole and the running heavy quark mass schemes, as well as the calculation of FONLL general-mass scheme structure functions with massive charm-initiated contributions [12].

In terms of the fitting methodology, the main difference as compared to NNPDF3.0 is the treatment of the charm PDF on an equal footing as the light quark PDFs and the gluon, following the strategy presented in Ref [13]. Fitting the charm PDF has a number of conceptual advantages, including an increased stability of the PDFs with respect the value of the charm mass m_c. Other updates include an improved treatment of the PDF positivity constraints, specially relevant for the production of BSM high-mass resonances, as well as a more refined determination of the asymptotic behaviour of PDFs at small and large-x relevant for the determination of the preprocessing ranges [14].

The impact of the D0 Run II W lepton asymmetry data. The D0 collaboration at the Tevatron has presented their legacy measurements for the W leptonic asymmetries in the electron [15] and

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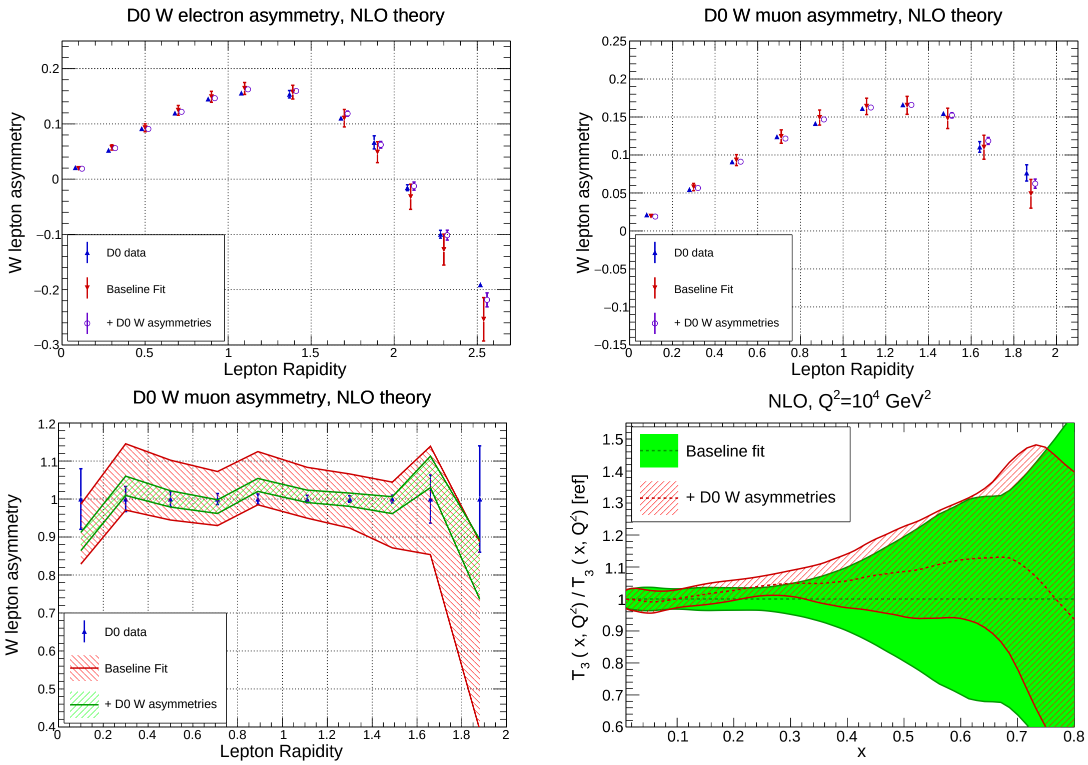

Figure 1: Upper plots: comparison between data and NLO QCD theory for the D0 electron (left) and muon (right) W asymmetries as a function of the lepton rapidity. The experimental data is compared with a baseline fit, with NNPDF3.1 methodology and NNPDF3.0 dataset, as well as with the same fit now including the D0 W asymmetries. Lower left plot: the ratio between theory and data for the D0 W muon asymmetry data. Lower right plot: the isotriplet quark PDF, $T_3 = u + \bar{u} - d - \bar{d}$, in the baseline fit and in the fit with the D0 data included, normalized to the central value of the former.

muon [16] final states using the complete Run II luminosity. The impact of these data was demonstrated in the HERAfitter (now xFitter) analysis of Ref. [17], and some of these D0 measurements are already included in other global PDF fits. Here we show the impact of the D0 W asymmetry data when added on top of a baseline fit using the NNPDF3.1 settings, but with the NNPDF3.0 dataset. NLO QCD cross-sections have been computed with `MCFM` interfaced to `APPLgrid` [18], using the same settings as in [17].

In Fig. 1 we show a comparison between the D0 data and NLO theory for the electron and muon W asymmetries, as a function of the lepton rapidity. The experimental data is compared with the baseline fit and with the same fit now including the D0 W asymmetries. The PDF uncertainties in the theory predictions are substantially reduced once the D0 data is included in the fit, highlighting the constraining power of these measurements. In Fig. 1 we also show the same comparisons for the muon asymmetry, this time normalizing the theory predictions to the experimental data. This illustrates the substantial reduction of PDF uncertainties in the entire kinematical range, but specially for forward rapidities, sensitive to the poorly-known large-x antiquarks. The good agreement between data and theory after the fit is also indicated by the $\chi^2/N_{\rm dat}$ estimator, which is $\simeq 1.5$ for the electron data and $\simeq 1.4$ for the muon data.

In Fig. 1 we also show the impact of the D0 W asymmetries on the isotriplet quark PDF combination, $T_3 = u + \bar{u} - d - \bar{d}$, for $Q^2 = 100$ GeV^2. The most significant effect appears to be for $x \gtrsim 0.3$, where the D0 data prefer a harder central value for T_3, as well as a reduction of the PDF uncertainties that can be as large as 50%, for example for $x \simeq 0.6$. Similar constraints are observed for other quark combinations.

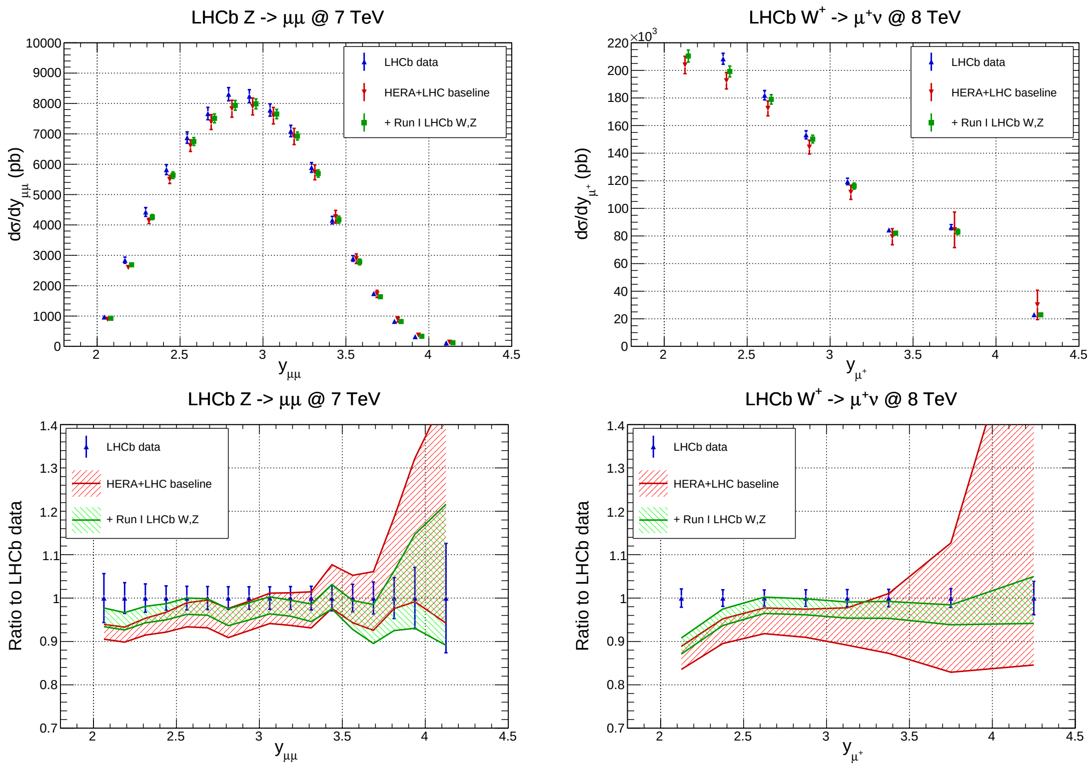

Figure 2: Upper plots: the differential cross-sections for Z production at 7 TeV and W^+ production at 8 TeV in the muon final state, measured by the LHCb experiment in the forward region. We compare a baseline HERA+LHC NLO QCD fit to the same fit once the LHCb data has been included. Lower plots: same comparison, now normalized to the LHCb measurements.

The LHCb Run I W,Z production combination. Now we discuss the impact of the recent LHCb electroweak gauge boson production data in the forward region at 7 TeV [19] and 8 TeV [20] in the muon final state. These measurements are provided including the full experimental covariance matrix with the correlations between the Z^0, W^+ and W^- rapidity distributions at the two center of mass energies. They supersede previous LHCb Run I measurements of W,Z production in the muon final state, and represent the LHCb legacy measurements at 7 and 8 TeV. For the study of the impact of these datasets, the baseline PDF fit is provided by a HERA+LHC fit, including the same LHC experiments as in NNPDF3.0. Then on top of this we have added the LHCb 7 and 8 TeV combined W and Z data. As in the case of the D0 W asymmetries, NLO QCD predictions have been computed using `MCFM` interfaced to `APPLgrid`.

In Fig. 2 we show, in the upper plots, the differential cross-sections for Z production at 7 TeV and W^+ production at 8 TeV. We compare the baseline HERA+LHC fit to the same fit once the LHCb data has been included. The lower plots then represent the same comparison, now

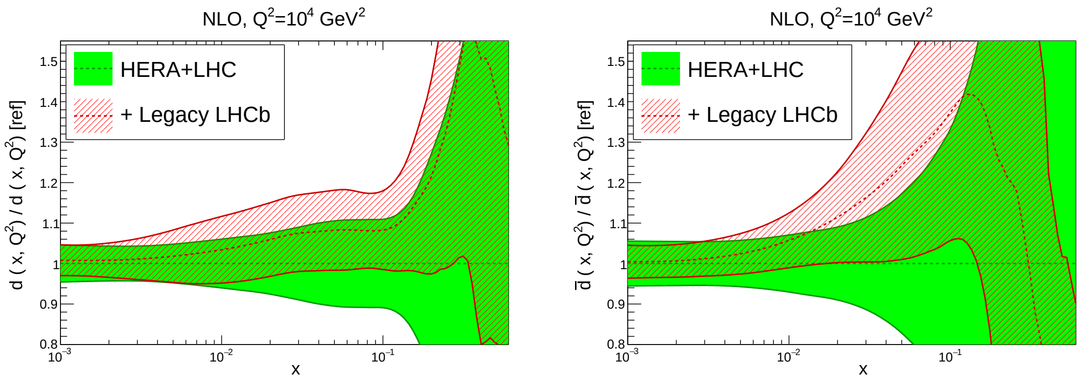

Figure 3: Comparison of the down (left) and anti-down (right plot) quark PDFs between the HERA+LHC baseline fit and the same fit including the LHCb Run I W and Z production data. Results are shown at $Q^2 = 100$ GeV^2, normalized to the central value of the baseline fit.

normalized to the LHCb measurements. As we can see, the agreement between data and theory is in general good after the fit, and a substantial reduction of the PDF uncertainties is obtained, specially for the charged-current Drell-Yan data. The only exception is the most central rapidity bin at 8 TeV, which seems to overshoot the theory for all final states (Z, W^+ and W^-).

Then in Fig. 3 we show a comparison of the down (left) and anti-down (right plot) quark PDFs between the HERA+LHC baseline fit and the same fit including the LHCb Run I W and Z production data. Results are shown at $Q^2 = 100$ GeV^2, normalized to the central value of the baseline fit. We find that the LHCb Run I electroweak data prefer a harder down and anti-down quarks at medium and large-x, except for $x \gtrsim 0.4$ where the anti-down quark tends to become smaller than in the baseline.

Outlook. NNPDF3.1 is the forthcoming update of the NNPDF family of global analysis. Significant improvements in terms of experimental data, theory calculations, and fitting methodology have been implemented. Here we have discussed the significant constraints that the updated D0 and LHCb electroweak production measurements appear to provide in the global PDF fit. These measurements help disentangling the quarks and anti-quarks of different flavor, and thus represent a useful addition to the next generation of global PDF analysis.

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