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An Update of the ABM16 PDF Fit

Sergey Alekhin[*†]
II. Institut für Theoretische Physik, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany;
Institute for High Energy Physics,142281 Protvino, Russia
E-mail: sergey.alekhin@desy.de

Johannes Blümlein
Deutsches Elektronensynchrotron DESY, Platanenallee 6, D–15738 Zeuthen, Germany
E-mail: Johannes.Bluemlein@desy.de

Sven-Olaf Moch
II. Institut für Theoretische Physik, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany
E-mail: sven-olaf.moch@desy.de

We present an updated version of the ABMP16 nucleon PDFs, which is tuned by using recent precise data on W- and Z/γ^*-production at the LHC and the final HERA data on DIS c- and b-quark production and by imposing a stringent Q^2-cut on the inclusive DIS data in order to avoid the impact of higher twist terms at small x at HERA. The new W- and Z-boson production data, in particular the updated version of the ATLAS data at the c.m.s. energy 7 TeV, are well accommodated into the present fit. The strange sea distribution obtained is consistent with the average of the up and down quark ones at small x. However, it is still suppressed with respect to the non-strange one by a factor of ~ 0.5 at moderate x. The small-x gluon distribution is enhanced as compared to the previous ABMP16 fit, in line with updated data on the DIS c-quark production. Finally, a good description of the non-resonant γ^*/Z-production data, which are included into the ABM analysis for the first time, is achieved provided the photon-initiated lepton pair production is taken into account.

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[*]Speaker.

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The ABMP16 proton parton distribution functions (PDFs) [1] are extracted from a combination of data on inclusive neutral-current (NC) deep-inelastic scattering (DIS), semi-inclusive c- and b-quark for NC and charged-current (CC) DIS data and W-, Z-boson and single/double t-quark production in (anti)proton-proton collisions. The data set used has a high accuracy of typically $\mathscr{O}(1\%)$ and allows the precise determination of the quark distributions in a wide range of parton momentum fractions x and of the gluon distribution at small and moderate x. Nonetheless, the analysis can still be improved by using the advantage of the fast growing statistics of the LHC experiments. In this paper we describe such an update with the focus on the impact of recent W- and Z/γ^*-boson production data. We also check updated measurements of the c- and b-quark production at HERA and consider a new treatment of the power corrections (higher twist) to the DIS cross sections.

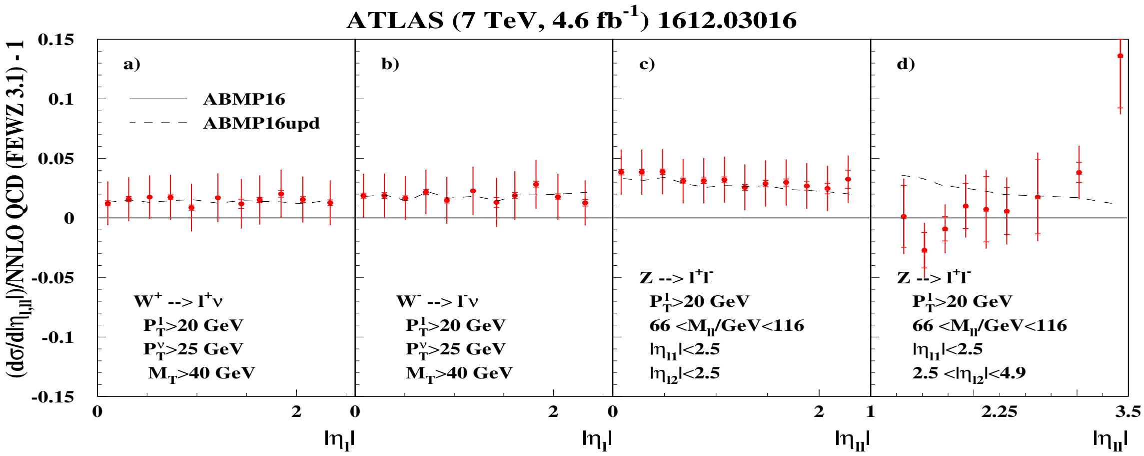

Figure 1: The pulls of the W- and Z-boson production ATLAS data of Ref. [2] in various boson-rapidity regions w.r.t. the NNLO QCD predictions obtained by using `FEWZ 3.1` in combination with the ABMP16 PDFs [1] (solid lines) and the ABMP16upd ones obtained in the present analysis (dashed) (**a**): W^+ (central), **b**): W^- (central), **c**): Z (central), **d**): Z (forward).

An important component of the present update are recent high-statistics Drell-Yan data collected at the LHC. In particular, the ATLAS collaboration greatly improved the accuracy of their 7 TeV W- and Z-boson sample [2], which now supersedes the earlier data set released in 2011 [3]. Besides, the data of Ref. [2] cover the non-resonant γ^* channel, which provides an additional independent constraint on the PDFs. The whole ATLAS data set is very well accommodated into the ABMP16 fit with the value of $\chi^2/NDP = 69/61$ obtained at next-to-next-to-leading order (NNLO) QCD. The irreducible background from the process $\gamma\gamma \to l^+l^-$, where $l^\pm$ denotes charged leptons, significantly improves the agreement of the fit with the data, cf. Fig. 2. In the present analysis leading-order QED corrections are used and the photon distribution is included into the present PDF fit. The photon distribution preferred by the non-resonant DY data within this approach are evidently larger than MRST2004qed ones [4] employed to correct the ATLAS data [2] for photonic initial-state contribution. No statistically significant trends are seen in the pulls, cf. Figs. 1, 2, except of the forward Z-boson production case. Due to large uncertainties in the data the value of χ^2 for this sample is still considered to be reasonable.

It is worth mentioning that, given the experimental accuracy achieved by now, a comparison of the data with the QCD predictions is sensitive to the choice of the theoretical tool used. It

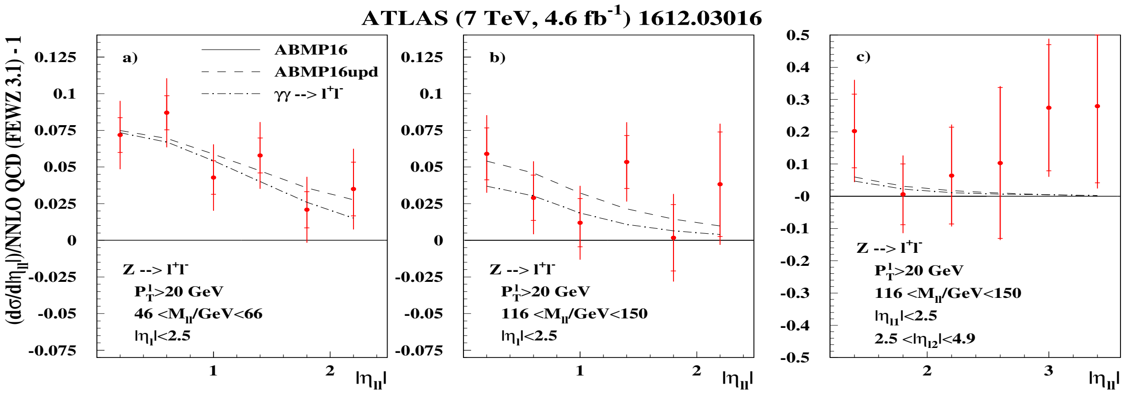

Figure 2: The same as Fig. 1 for the non-resonant DY data in various bins on the lepton pair invariant mass M_{ll} and pseudo-rapidity η_{ll} (**a**): $46 < M_{ll}/\mathrm{GeV} < 66$ (central), **b**): $116 < M_{ll}/\mathrm{GeV} < 150$ (central), **c**): $116 < M_{ll}/\mathrm{GeV} < 150$ (forward)). The LO contribution of the photon-induced channel $\gamma\gamma \to l^+l^-$ computed with the photon distributions obtained n the present analysis is given for comparison (dashed dots).

is particularly relevant for the data on the charged lepton asymmetry A_l, where many systematic uncertainties cancel in the ratio. Indeed, a comparison of the NNLO QCD predictions with the ATLAS data on A_l collected at 7 and 8 TeV collision energy [2, 5] demonstrate different trends for two publicly available tools, `FEWZ 3.1` [6] and `DYNNLO 1.4` [7]. The FEWZ predictions do somewhat overshoot the data at 7 TeV, while the DYNNLO ones go lower and are in better agreement with the measurements. At 8 TeV the tendency is different: The FEWZ predictions somewhat undershoot the data and the DYNNLO ones go essentially lower, cf. Fig. 3. In summary, the FEWZ predictions demonstrate a better overall agreement with the data. Therefore this tool is routinely used in our fit.

One more improvement is an update of the HERA data on semi-inclusive c- and b-quark DIS production [8]. This process is dominantly initiated by gluons. Therefore these data impose an additional constraint on the gluon distribution at small x, which is otherwise predominantly driven by the slope of the DIS inclusive structure function F_2 w.r.t. $\ln(Q^2)$. As we have shown earlier, the factorization scheme with three light quarks in the initial state provides a solid theoretical framework for the description of the DIS heavy-flavor production [9]. Furthermore, the value of the c-quark mass in the $\overline{\mathrm{MS}}$-scheme extracted from the experimental data within this framework is in very good agreement with other determinations. This gives us additional confidence in the validity of this approach. The HERA data on the DIS c-quark production [8] are also in a reasonable agreement with our updated fit with the value of $\chi^2/NDP = 134/79$ obtained for the whole sample. The pulls of these data w.r.t. the present fit have no systematic trend and look rather like statistical fluctuations, which sometimes go beyond the uncertainties and therefore pull up the value of χ^2. For example, the slope in Bjorken x observed for the bins with momentum transfer $Q^2 = 12, 32$ GeV^2 is not confirmed in the neighbor bins with $Q^2 = 7, 18$ GeV^2, cf. Fig. 4.

It is worth noting that the charm production data prefer a steeper small-x gluon distribution as compared to the one obtained in the ABMP16 fit. A detailed examination shows that the tension is driven by the inclusive HERA data at small x and Q^2. This kinematic region is potentially problematic w.r.t. perturbative QCD analyses in view of the relatively large value of strong coupling

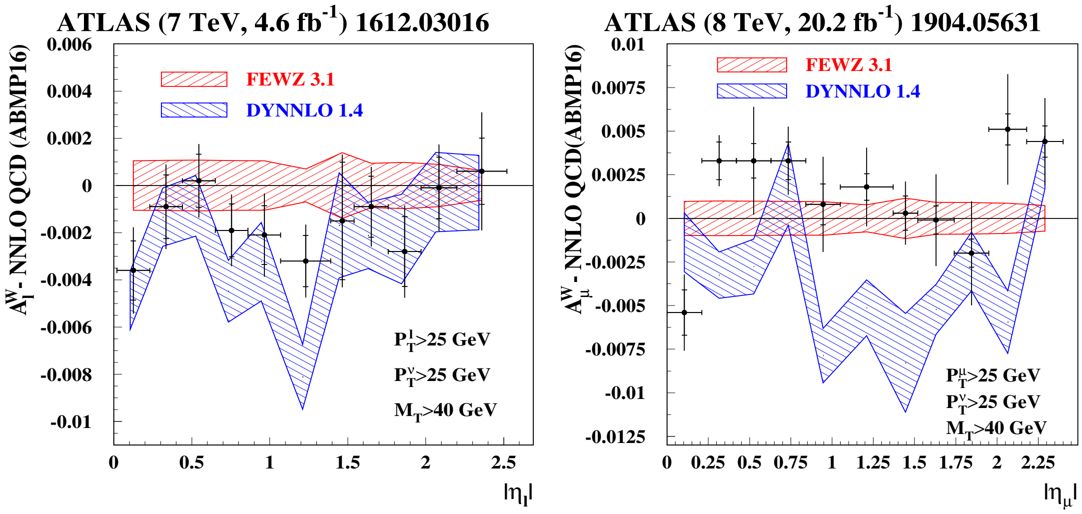

Figure 3: The same as Fig. 1 for the ATLAS data on the lepton asymmetry A_l collected at c.m.s. energy 7 TeV [2] (left panel) and muon asymmetry A_μ collected at c.m.s. energy 8 TeV [5] (right panel) and with various NNLO tools: `FEWZ 3.1` [6] (right-tilted hatch) and `DYNNLO 1.4` [7] (left-tilted hatch). The bands in theory predictions represent computational uncertainties obtained with $\mathcal{O}$(month) computer wall time.

constant α_s and singularities in the anomalous dimensions and Wilson coefficients at small x. A phenomenological description of this part of the inclusive data in the ABMP16 fit includes power corrections in form of a higher twist contribution parameterized in a model-independent form and fitted to the data simultaneously with the leading twist PDFs. The twist-4 term preferred by the inclusive HERA data is negative at small x [1, 10], which demonstrates a trend of damping the Q^2-slope in F_2 driven by the small x, Q^2 part of this sample. In the updated version of our fit a more stringent cut $Q^2 > 10$ GeV^2 is imposed on the inclusive DIS data, cf. also [11]. This allows to neglect the higher twist contributions and circumvents in such a way potential problems of small-Q^2 phenomena. This approach leads also to a better agreement between inclusive and semi-inclusive HERA data sets. In particular, this results in the gluon distribution, which is consistent to the one extracted from the c- and b-quark production data without taking into account the inclusive ones, cf. Fig. 5.

The quark distributions are in general not sensitive to this modification of the fit ansatz. However, the updated strange sea distribution is smaller than the one of ABMP16 at small x and consistent with the average of up- and down-quark distributions. Meanwhile, the strange sea is still suppressed w.r.t. the non-strange one by factor of ~ 0.5 at moderate x and this leads to overall strange-sea suppression by an integral factor $\kappa_s(\mu^2 = 20\ \mathrm{GeV}^2) = 0.71(3)$, where

$$\kappa_s(\mu^2) = \frac{\int_0^1 x[s(x,\mu^2) + \bar{s}(x,\mu^2)]dx}{\int_0^1 x[\bar{d}(x,\mu^2) + \bar{u}(x,\mu^2)]dx}.$$

This is in agreement with the ABMP16 result and our earlier study of the impact of the ATLAS data of Ref. [12] on the strange sea determination. Note that the PDFs with such a suppression provide a much better description of ATLAS data as compared to the analysis of Ref. [2] reporting the value of $\chi^2/NDP = 108/61$ for the PDF set, which implies an enhanced strange sea.

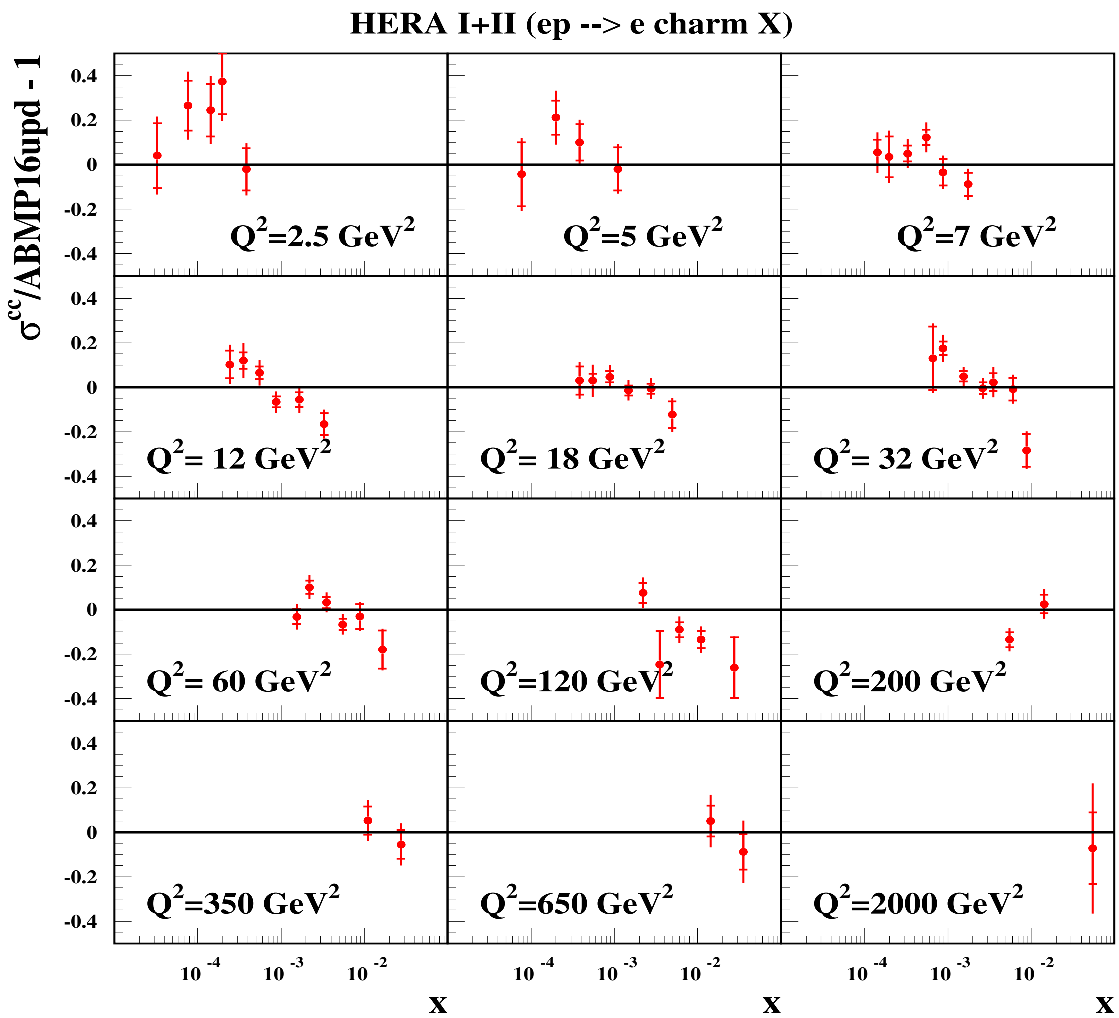

Figure 4: The pulls of the combined HERA data on the DIS c-quark production [8] w.r.t. the ABMP16upd predictions obtained in the present fit versus Bjorken x and for various bins in the virtualities Q^2 .

In summary, we report on an updated version of the ABM PDF fit, which includes recent precise data on W- and Z/γ^*-production at the LHC and final HERA data on DIS c- and b-quark production. Also a stringent cut on Q^2 is imposed on the inclusive DIS data in order to avoid any impact of the higher twist terms at small x, contained in the HERA data. The recent precise W- and Z-boson production data from the LHC, in particular the updated version of the ATLAS data at c.m.s. energy 7 TeV, are well accommodated into the present fit. The latter prefer a strange sea quark distribution, which is consistent with the average of up and down ones at small x and which is suppressed by a factor of ~ 0.5 at moderate x. The small-x gluon distribution is enhanced as compared with the previous ABMP16 fit due to a more stringent cut imposed on the inclusive DIS data and the updated c-quark HERA data are in agreement with such an enhancement that demonstrates a consistent treatment of the DIS data in the present analysis. Finally, a good description of the non-resonant DY γ^*/Z-production data, which are included into our analysis for the first time, is achieved provided photon-initiated lepton pair production is taken into account.

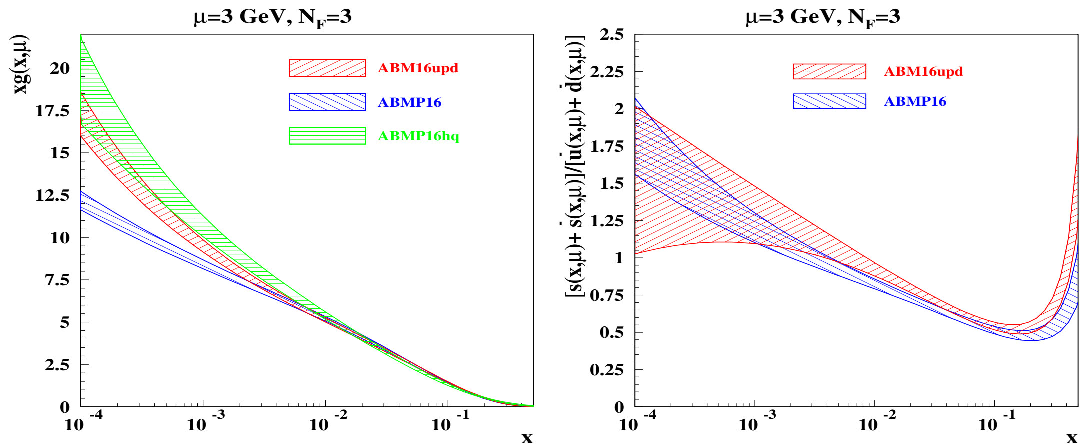

Figure 5: Left: The error band for the ABMP16upd 3-flavor gluon distribution versus x at the factorization scale $\mu = 3$ GeV obtained in the present fit (right-tilted hatch) in comparison with the ABMP16 one (left-tilted hatch) and ABMP16hq one (horizontal hatch), which was obtained in the variant of present analysis with the HERA DIS inclusive data dropped. Right: The same as the left panel for the strange sea suppression factor $[s(x,\mu)+\bar{s}(x,\mu)]/[\bar{u}(x,\mu)+\bar{d}(x,\mu)]$, where $u(x,\mu)$, $d(x,\mu)$ and $s(x,\mu)$ are distributions of the up, down and strange quarks, respectively.

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