PROCEEDINGS OF SCIENCE

α_s, ABM PDFs, and heavy-quark masses

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The value of α_s is extracted from a global QCD analysis of experimental data on inclusive neutral-current (NC) and charged-current (CC) deep-inelastic scattering (DIS), c- and b-quark production in the NC DIS, c-quark production in the CC DIS, and W-, Z-boson, and t-quark production in (anti)proton-proton collisions with a simultaneous extraction of parton distribution functions (PDFs). The NNLO value of $\alpha_s^{(n_f=5)}(m_Z) = 0.1147 \pm 0.0008\,(\mathrm{exp.}) \pm 0.0022\,(\mathrm{h.o.})$ is obtained with the uncertainty due to missing higher-orders (h.o.) being estimated as one half of the difference between the values of α_s obtained in the NNLO and NLO variants of this fit. The masses of the heavy-quarks, charm, beauty and top, which are determined in parallel, are employed for cross-check of the theoretical framework consistency of the analysis.

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The ABMP16 PDF fit [1] is based on a combination of experimental data on hadronic hard-scattering processes: inclusive neutral-current (NC) and charged-current (CC) deep-inelastic scattering (DIS), c- and b-quark production in the NC DIS, c-quark production in the CC DIS, and W-, Z-boson and t-quark production in (anti)proton-proton collisions. A variety of processes provides a complementary set of constraints on the PDFs and the parameters of QCD Lagrangian, which are required for a consistent interpretation of the data, in particular, the heavy-quark masses and α_s. The value of α_s determined from this fit is predominantly driven by the NC DIS data, which cover a wide range of the momentum transfer squared $Q^2 = 2.5 \div 50000\mathrm{GeV}^2$ and can be nicely described by perturbative QCD with the corrections up to next-to-next-to-leading-order (NNLO) taken into account [2] and the heavy flavor corrections [3]. However, at the lowest end of this range the leading-twist (LT) PDF term is accompanied by substantial contributions from the higher-twist (HT) operators [4]. The latter introduce an additional power-like dependence on Q^2, which spoils the purely logarithmic behavior of the leading-twist part and, as a result, shifts the fitted value of α_s upwards [5]. Therefore in order to provide an unbiased determination one has to eliminate the impact of the HT terms either by cutting on the potentially problematic kinematic region or by parameterizing and fitting them in parallel with the LT PDFs. The ABMP16 fit is based on the latter approach, while it has also been checked that the former one provides a consistent value of α_s, cf. Table 1. The HT terms appear at large Bjorken x therefore their isolation can be performed with a cut of $W^2 > 12.5\ \mathrm{GeV}^2$, where W is the invariant mass of the hadronic system. However, such a cut does not affect the small-x part of the HT terms, which manifests itself in the NMC and the HERA data [7]. Thus, in order to allow for a pure leading-twist theoretical treatment of the available DIS data an additional cut of $Q^2 > 10\ \mathrm{GeV}^2$ is also required.

Table 1: The values of $\alpha_s^{(n_f=5)}(m_Z)$ obtained in the NLO and NNLO variants of the ABMP16 fit with various kinematic cuts on the DIS data imposed and different modeling of the higher twist terms. Table from Ref. [6].

fit ansatz		$\alpha_s(m_Z)$	
higher twist modeling	cuts on DIS data	NLO	NNLO
higher twist fitted	$Q^2 > 2.5\ \mathrm{GeV}^2$, $W > 1.8$ GeV	0.1191(11)	0.1147(8)
higher twist fixed at 0	$Q^2 > 10\ \mathrm{GeV}^2$, $W^2 > 12.5\ \mathrm{GeV}^2$	0.1212(9)	0.1153(8)
	$Q^2 > 15\ \mathrm{GeV}^2$, $W^2 > 12.5\ \mathrm{GeV}^2$	0.1201(11)	0.1141(10)
	$Q^2 > 25\ \mathrm{GeV}^2$, $W^2 > 12.5\ \mathrm{GeV}^2$	0.1208(13)	0.1138(11)

The values of α_s preferred by four groups of the inclusive DIS data, SLAC, BCDMS, NMC, and HERA, which are used in the ABMP16 fit, are displayed in Fig. 1 in their historical perspective. The earliest experiments, which were performed in SLAC, prefer somewhat larger α_s, while they are also more sensitive to the HT contribution because of the kinematic limitations caused by the relatively low beam energy. The most recent HERA data prefer a smaller value of α_s with a marginal sensitivity to the HT contribution. It is worth noting that α_s extracted from the combined Run I+II HERA data is somewhat larger than the one obtained from the earlier Run I sample, which was employed in the earlier version of the ABMP16 PDF fit [8]. Due to the update of the HERA data the value of α_s moves somewhat up, although still lower than the world average, cf. Fig. 1.

An important aspect of the small-x DIS data interpretation is to account for the heavy-quark

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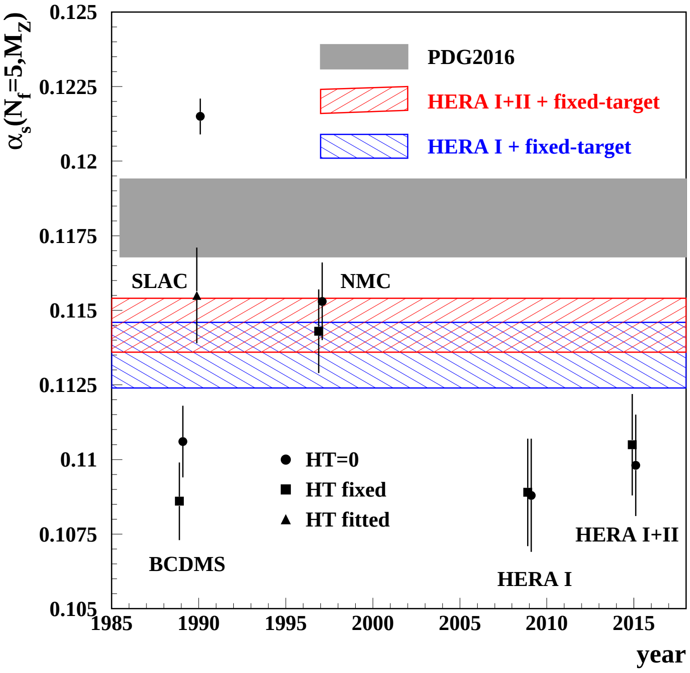

Figure 1: The value of α_s preferred by various DIS data samples employed in the ABMP16 analysis as a function of the year of publication of the data. Three variants of the fit with different treatments of the HT terms are presented: HT set to 0 or to the one obtained in the combined fit (circles and squares, respectively) or fitted to one particular data set (triangles). The α_s bands obtained using combination of the fixed-target SLAC, BCDMS, and NMC samples with the ones from the HERA Run-I (left-tilted hatches) and Run-I+II (right-tilted hatches) as well as the PDG2016 average [9] are given for comparison. Plot from Ref. [1].

contribution. In particular final-state configurations including the c-quark are responsible for an essential part of the NC inclusive cross section in the region of HERA kinematics. Therefore, an accurate treatment of this term is a necessary ingredient of the related phenomenology [10]. This applies also to the extraction of α_s from a combination of the DIS data, which include the small-x HERA sample [11]. In this part the ABMP16 fit is based on the fixed-number-flavor (FFN) scheme, which implies only massless partons, gluon and three light quarks, in the initial state, while the heavy-quark contribution is computed within the photon-gluon fusion mechanism including the higher-order QCD corrections up to the NNLO. Furthermore, the $\overline{\text{MS}}$ definition of the heavy-quark mass, which improves the perturbative convergence, is applied in the ABMP16 fit [12]. The relevance of the FFN approach in such a formulation is supported by a good description of the Run I HERA data on the semi-incisive c-quark production used in the ABMP16 fit and a good agreement with the more recent Run I+II data [13]. Moreover, the $\overline{\text{MS}}$ value of the c-quark mass

$$m_c(m_c) = 1.252 \pm 0.018 \text{ GeV}$$

obtained in the fit simultaneously with α_s and the PDF parameters is in a good agreement with other determinations [9] that also underpins the consistency of the FFN scheme in the application to the analysis of existing data on c-quark DIS production.

The data on hadronic t-quark pair production cross sections, which are used in the ABMP16 fit, are also quite sensitive to α_s since the leading order cross section of this process is proportional to α_s^2. At the same time it is also sensitive to the gluon distribution and value of the t-quark mass m_t. Therefore, in order to use the potential of these data in the determination of α_s one has to fix these two ingredients. The gluon distribution at the relevant kinematics is confined by other data employed in the ABMP16 fit, however, none of them are sensitive to m_t. At present, the accurate value of m_t also cannot obtained by direct reconstruction in the experiment due to hadronization effects being still not fully under theoretical control [14]. In view of these limitations the value of m_t is fitted simultaneously with α_s and the PDFs. As a result, impact of the t-quark data on α_s determination is greatly reduced. Indeed, two determinations,

$$\alpha_s^{(n_f=5)}(m_Z) = 0.1145 \pm 0.0009$$

and

$$\alpha_s^{(n_f=5)}(m_Z) = 0.1147 \pm 0.0008,$$

obtained with and without using t-quark data, respectively, are quite similar, both in the central values and uncertainties. An alternative way of illustrating this effect is presented in Fig. 2, which shows a perfect correlation between α_s and m_t obtained in the ABMP16 fit. However, it is worth mentioning that fitting m_t within the ABMP16 framework allows for its consistent independent determination. Using likewise to the case of heavy-quark DIS production the $\overline{\text{MS}}$ definition we obtain

$$m_t(m_t) = 160.9 \pm 1.1 \text{ GeV},$$

which corresponds to the pole mass value of

$$m_t^{\text{pole}} = 170.4 \pm 1.2 \text{ GeV}$$

where the relation between these definitions is known to four loops [15]. The value of m_t^{pole} obtained in this way is smaller than the values of m_t, which are directly measured in experiments by $\mathcal{O}(1\text{GeV})$. Other data sets, on the W-, Z-boson and single t-quark hadronic production, which are used in the ABMP16 fit, demonstrate even less sensitivity to α_s as compared to the t-quark pair production cross sections. Therefore the aggregated value of α_s is essentially determined by the DIS data.

The results of a version of the fit performed with the NLO QCD accuracy [6] can be employed for an estimate of the theoretical uncertainties due to missing higher-order QCD corrections. Taking it as one half of difference between the values obtained in the NNLO and NLO fits we arrive at the following value

$$\alpha_s^{\text{NNLO}}(m_Z) = 0.1147 \pm 0.0008\,(\text{exp.}) \pm 0.0022\,(\text{h.o.}).$$

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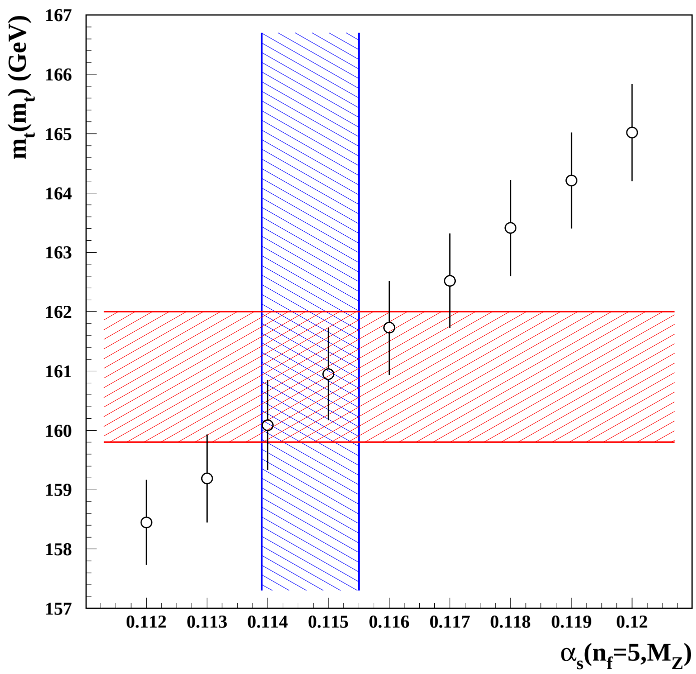

Figure 2: The $\overline{\mathrm{MS}}$ value of the t-quark mass $m_t(m_t)$ obtained in the variants of present analysis with the value of $\alpha_s^{(n_f=5)}(m_Z)$ fixed in comparison with the 1σ bands for $m_t(m_t)$ and $\alpha_s^{(n_f=5)}(m_Z)$ obtained in our nominal fit (left-tilted and right-tilted hatch, respectively). Plot from Ref. [1].

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