# PDFs, $\alpha_s$, and quark masses from global fits

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The strong coupling constant $\alpha_s$ and the heavy-quark masses, $m_c$, $m_b$, $m_t$ are extracted simultaneosly with the parton distribution functions (PDFs) in the updated ABM12 fit including recent data from CERN-SPS, HERA, Tevatron, and the LHC. The values of

$$\begin{aligned}
\alpha_s(M_Z) &= 0.1147 \pm 0.0008 \text{ (exp.)}, \\
m_c(m_c) &= 1.252 \pm 0.018 \text{ (exp.) GeV}, \\
m_b(m_b) &= 3.83 \pm 0.12 \text{ (exp.) GeV}, \\
m_t(m_t) &= 160.9 \pm 1.1 \text{ (exp.) GeV}
\end{aligned}$$

are obtained with the $\overline{MS}$ heavy-quark mass definition being employed throughout the analysis.

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With the form of the Standard-Model (SM) Lagrangian widely validated after the experimental discovery of the Higgs boson its fundamental parameters play increasing role in search of physics beyond SM and related topics in cosmology [1]. These parameters can be extracted from the various experimental data with an accuracy of O(1%) achieved for the heavy-quark masses and the strong coupling constant $\alpha_s$ [2]. The latter was obtained in particular in the ABM12 fit [3] aimed to determine the parton distribution functions (PDFs) from the combination of lepton-nucleon deep-inelastic-scattering (DIS) and Drell-Yan (DY) data. The value of $\alpha_s$ obtained in this way is mainly driven by the DIS sample, while the DY part is employed to facilitate the disentangling of the quark species. The input for the ABM12 fit has been recently updated with the latest DIS and DY data from CERN-SPS, HERA, Tevatron, and the LHC [4, 5, 6]. The main impact of this input on $\alpha_s$ stems from the new inclusive DIS data set representing a Run I+II combination of the results obtained by the H1 and ZEUS experiments during the whole period of the HERA collider operation. This tendency was checked by performing a variant of the present analysis with no other DIS data included. The value of $\alpha_s$ obtained in this way is displayed in Fig. 1 in comparison with the one preferred by the earlier Run I combination of the H1 and ZEUS data accumulated in the first HERA run. The Run I+II value of $\alpha_s$ moves up by $1\sigma$ which causes a corresponding shift in the results of the combined analysis including all DIS data, although the combined value of

$$\alpha_s(M_Z) = 0.1145 \pm 0.0009 \text{ (exp.)} \tag{1}$$

obtained is still lower than the PDG average, cf. Fig. 1. Other DIS experiments included into our analysis, SLAC, BCDMS and NMC, also prefer relatively small $\alpha_s$ values, however, for the case of SLAC it is achieved only if the higher-twist (HT) terms are taken into account properly. The BCDMS, NMC, and HERA Run I+II data are less sensitive to HT terms, while the HERA Run I ones are not sensitive at all. Indeed, in the region of small $x$, which is controlled by the HERA Run I data in the ABM12 fit, the HT values obtained are fully negligible within the uncertainties and in the present analysis a non-zero HT contribution to the longitudinal structure function $F_L$ is found due to the better accuracy of the Run I+II combination [4, 7, 8].

In addition to the inclusive HERA sample we also employ the data on the $c$- and $b$-quark DIS production, cf. Fig. 2. They span the region of momentum transfer $Q^2$ down to few GeV$^2$ and therefore are sensitive to the values of heavy quark masses $m_{c,b}$. In our analysis the DIS process is described within the 3-flavour fixed-flavor-number (FFN) factorization scheme with the QCD corrections up to NNLO both for the massless and massive contributions taken into account. The NNLO terms in the neutral-current massive Wilson coefficients are derived from the high-energy asymptotic expressions and the threshold-resummation results matched using available NNLO terms in the massive operator matrix elements (OMEs) [12, 13]. For the first time such a parameterization [14] was used in the ABM12 analysis. In the present analysis we take an improved form of the parameterization [14] employing the NNLO pure-singlet terms in the massive OMEs [12]. The NNLO corrections to charged-current $c$-quark production are taken in the asymptotic form [16, 6] valid for $Q^2 \gg m_c^2$ which are therefore applied only to the HERA data occupying the region of $Q^2 > 300$ GeV$^2$. All massive terms in the scheme adopted are considered in the $\overline{MS}$-scheme for the heavy-quark mass since this approach was shown to provide better perturbative stability if compared to the pole-mass case [15]. Furthermore, the fit based on this framework provides a good agreement with the HERA data on the heavy-quark production up to the largest values of

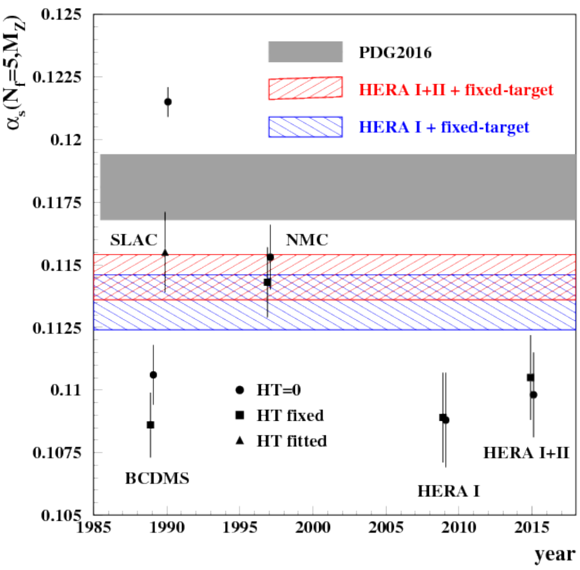


**Figure 1:** The value of $\alpha_s(M_Z)$ preferred by various DIS data samples employed in the present analysis w.r.t. the year of the data publication. Three variants of the fit with different treatment of the HT terms are presented: The HT set to 0 or to the ones obtained in the combined fit (circles and squares, respectively) and fitting to the one particular data set (triangles). The $\alpha_s$ bands obtained by using the combination of the fixed-target SLAC, BCDMS, and NMC samples with those from HERA Run I (left-tilted hatches) and Run I+II (right-tilted hatches), as well as the PDG average [2], are given for comparison.

$Q^2$ available, cf. Fig. 2. The $\overline{MS}$-values of the $c$- and $b$-quark masses are determined from the fit simultaneously with the PDFs as

$$m_c(m_c) = 1.252 \pm 0.018 \text{ (exp.) GeV}, \qquad m_b(m_b) = 3.83 \pm 0.12 \text{ (exp.) GeV}. \tag{2}$$

They are in a good agreement with other NNLO determinations based on a variety of different experimental data [2]. On the other hand, a value of the $c$-quark pole mass $m_c^{pole} \sim 1.3$ GeV is commonly set in the PDF fits based on the variable-flavor-number (VFN) factorization scheme [17, 18, 19]. This setting is dramatically different from ours since the value of $m_c(m_c)$ Eq. (2) corresponds to $m_c^{pole} = 2.4$ GeV with account of the 4-loop corrections to the matching relations [20]. We note that the values of $\chi^2$ obtained for the HERA inclusive and semi-inclusive data in the VFN-based PDF fits are in general larger than the FFN ones. This also demonstrates the benefit of the FFN approach [21].

The data on single-top and $t\bar{t}$ hadro-production cross sections from Tevatron and the LHC included in the present analysis allow to determine the $t$-quark mass $m_t$ once it is considered as a fit parameter. The value of $m_t$ determined in such a way is a well-defined quantity, in contrast to experimental determinations commonly sensitive to details of Monte-Carlo modeling. Similarly to the case of $c$- and $b$-quark DIS production we employ the $\overline{MS}$ definition for the $t$-quark hadro-production that provides better perturbative stability here again [3]. For this purpose we run the Hathor code [22, 23] with the full NNLO corrections to the $t\bar{t}$ [24] and the $t$-channel single-top production [25], while the NNLO terms for the $s$-channel single-top production are computed using the threshold-resummation approximation [26]. The $t$-quark data collected in a wide range of the c.m.s. energy are well accommodated in the fit, cf. Figs. 3,4. The value of

$$m_t(m_t) = 160.9 \pm 1.1 \text{ (exp.) GeV} \tag{3}$$

preferred by the data is in a broad agreement with other determinations based on the $t$-production cross section [2] and the value of $m_t(m_t) = 158.9 \pm 3.4$ (exp.) GeV extracted from the single-top production data only and the ABM12 PDFs used [26]. The value of $\alpha_s(M_Z) = 0.1147 \pm$

0.0008 (exp.) obtained in the latter variant of the fit with the $t$-quark data included comes out somewhat bigger than the value of Eq. (1), however, the difference lays within the uncertainties.

## References


[1] M. Shaposhnikov and C. Wetterich, Phys. Lett. B **683** (2010) 196.

[2] K. A. Olive *et al.* [Particle Data Group Collaboration], Chin. Phys. C **38** (2014) 090001.

[3] S. Alekhin, J. Blümlein and S. Moch, Phys. Rev. D **89** (2014) no.5, 054028.

[4] S. Alekhin, J. Blümlein, S. Moch and R. Placakyte, arXiv:1609.03327 [hep-ph].

[5] S. Alekhin, J. Blümlein, S. Moch and R. Placakyte, arXiv:1508.07923 [hep-ph].

[6] S. Alekhin, J. Blümlein, L. Caminada, K. Lipka, K. Lohwasser, S. Moch, R. Petti and R. Placakyte, Phys. Rev. D **91** (2015) no.9, 094002.

[7] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, Eur. Phys. J. C **76** (2016) no.4, 186.

[8] I. Abt, A. M. Cooper-Sarkar, B. Foster, V. Myronenko, K. Wichmann and M. Wing, Phys. Rev. D **94** (2016) no.3, 034032.

[9] H. Abramowicz *et al.* [H1 and ZEUS Collaborations], Eur. Phys. J. C **73** (2013) no.2, 2311.

[10] F. D. Aaron *et al.* [H1 Collaboration], Eur. Phys. J. C **65** (2010) 89.

[11] H. Abramowicz *et al.* [ZEUS Collaboration], JHEP **1409** (2014) 127.

[12] J. Ablinger, A. Behring, J. Blümlein, A. De Freitas, A. von Manteuffel and C. Schneider, Nucl. Phys. B **890** (2014) 48.

[13] A. Behring, I. Bierenbaum, J. Blümlein, A. De Freitas, S. Klein and F. Wißbrock, Eur. Phys. J. C **74** (2014) no.9, 3033.

[14] H. Kawamura, N. A. Lo Presti, S. Moch and A. Vogt, Nucl. Phys. B **864** (2012) 399.

[15] S. Alekhin and S. Moch, Phys. Lett. B **699** (2011) 345.

[16] J. Blümlein, A. Hasselhuhn and T. Pfoh, Nucl. Phys. B **881** (2014) 1.

[17] S. Dulat *et al.*, Phys. Rev. D **93** (2016) no.3, 033006.

[18] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, Eur. Phys. J. C **75** (2015) no.5, 204.

[19] R. D. Ball *et al.* [NNPDF Collaboration], JHEP **1504** (2015) 040.

[20] P. Marquard, A. V. Smirnov, V. A. Smirnov and M. Steinhauser, Phys. Rev. Lett. **114** (2015) no.14, 142002.

[21] A. Accardi *et al.*, Eur. Phys. J. C **76** (2016) no.8, 471.

[22] M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer and M. Wiedermann, Comput. Phys. Commun. **182** (2011) 1034.

[23] P. Kant, O. M. Kind, T. Kintscher, T. Lohse, T. Martini, S. Mölbitz, P. Rieck and P. Uwer, Comput. Phys. Commun. **191** (2015) 74.

[24] M. Czakon, P. Fiedler and A. Mitov, Phys. Rev. Lett. **110** (2013) 252004.

[25] M. Brucherseifer, F. Caola and K. Melnikov, Phys. Lett. B **736** (2014) 58.

[26] S. Alekhin, S. Moch and S. Thier, arXiv:1608.05212 [hep-ph].


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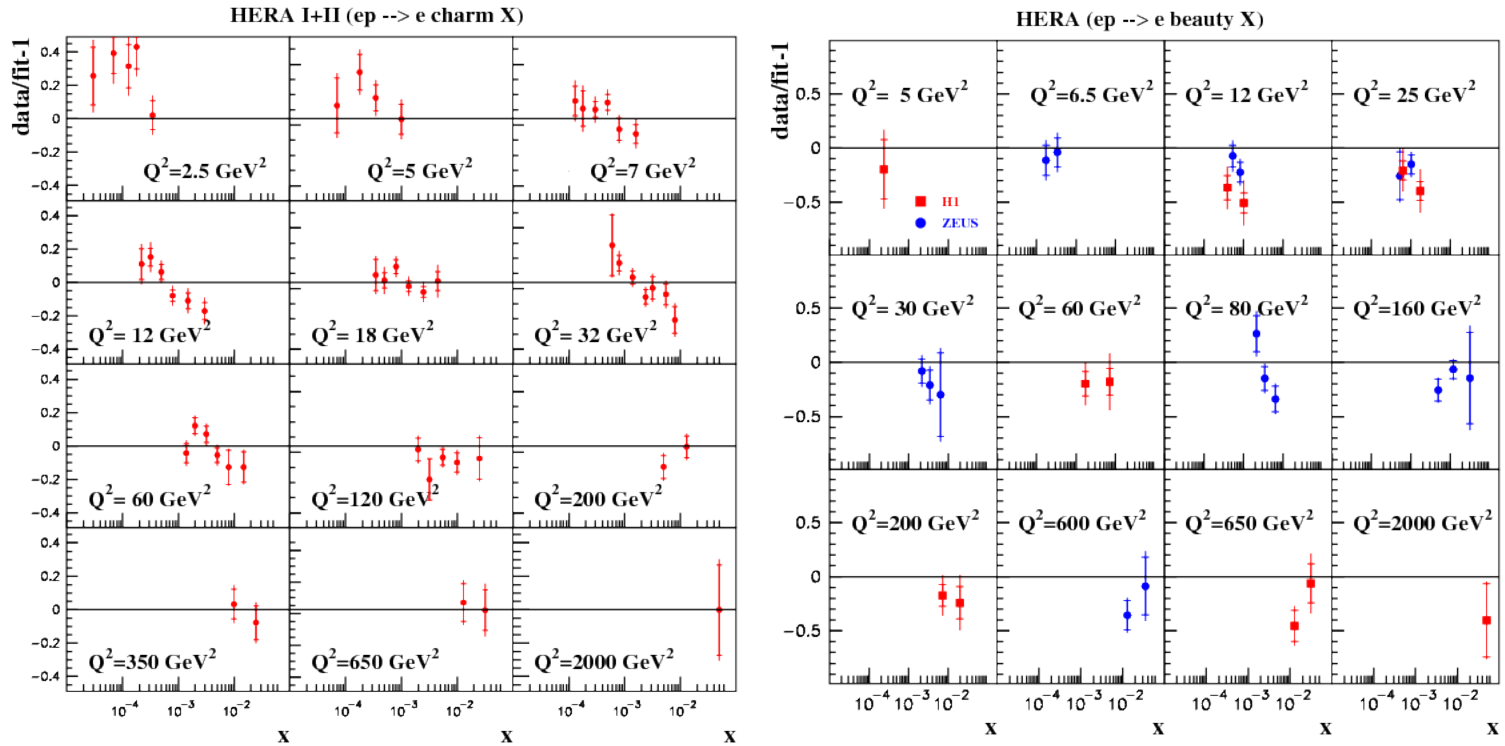


**Figure 2:** Left panel: The pulls versus Bjorken $x$ in bins of the momentum transfer $Q^2$ for the combination of NC DIS inclusive charm-quark production data from the H1 and ZEUS experiments at HERA [9]. Right panel: The same for the separate bottom-quark production data from H1 [10] (squares) and ZEUS [11] (circles).

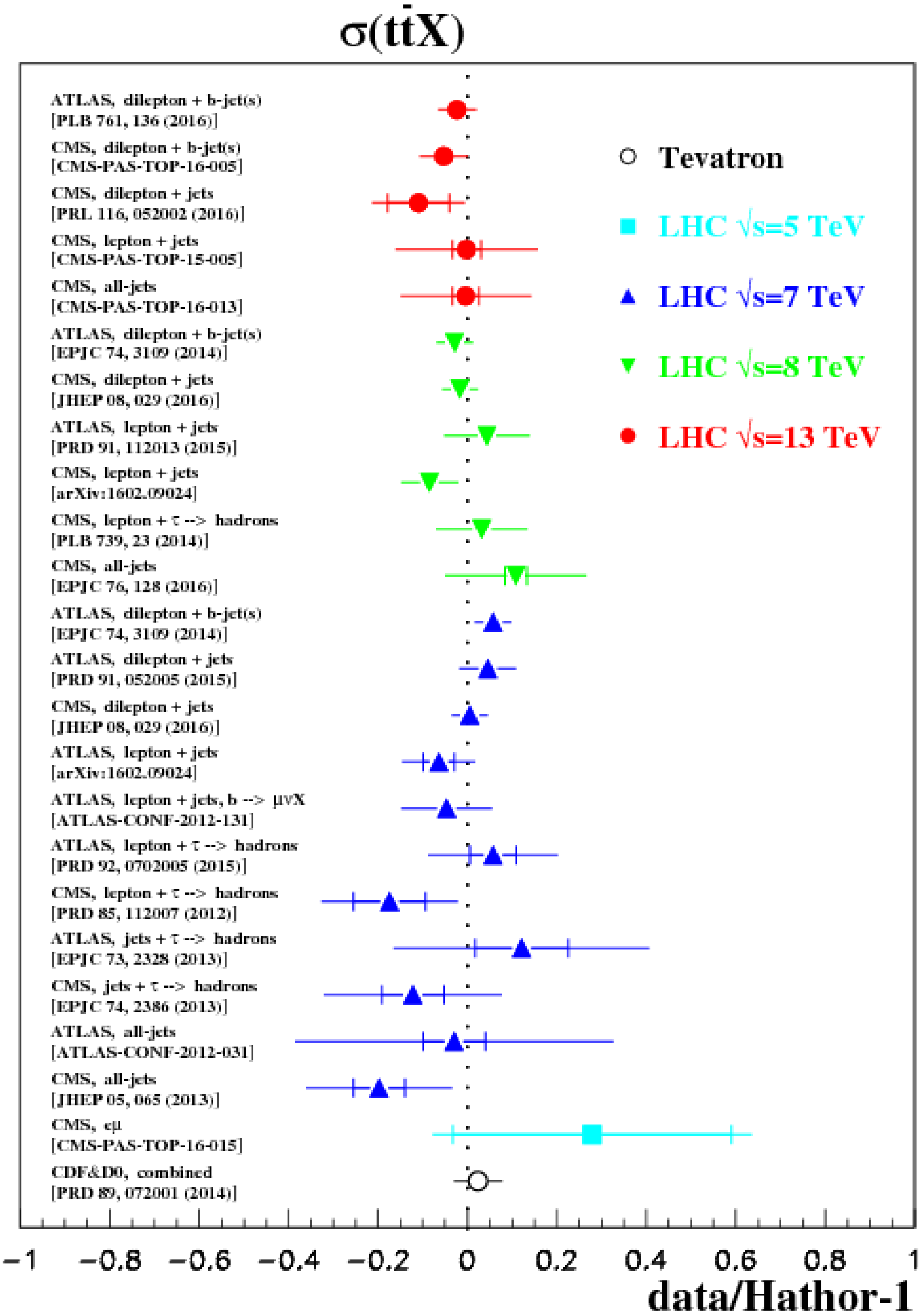


**Figure 3:** The pulls for data on top-quark pair production from the Tevatron (CDF and D0) at $\sqrt{s} = 1.96$ TeV and the LHC (ATLAS and CMS) at $\sqrt{s} = 5, 7, 8$ and 13 TeV with respect to our NNLO fit. The NNLO QCD predictions have been obtained with Hathor [22].

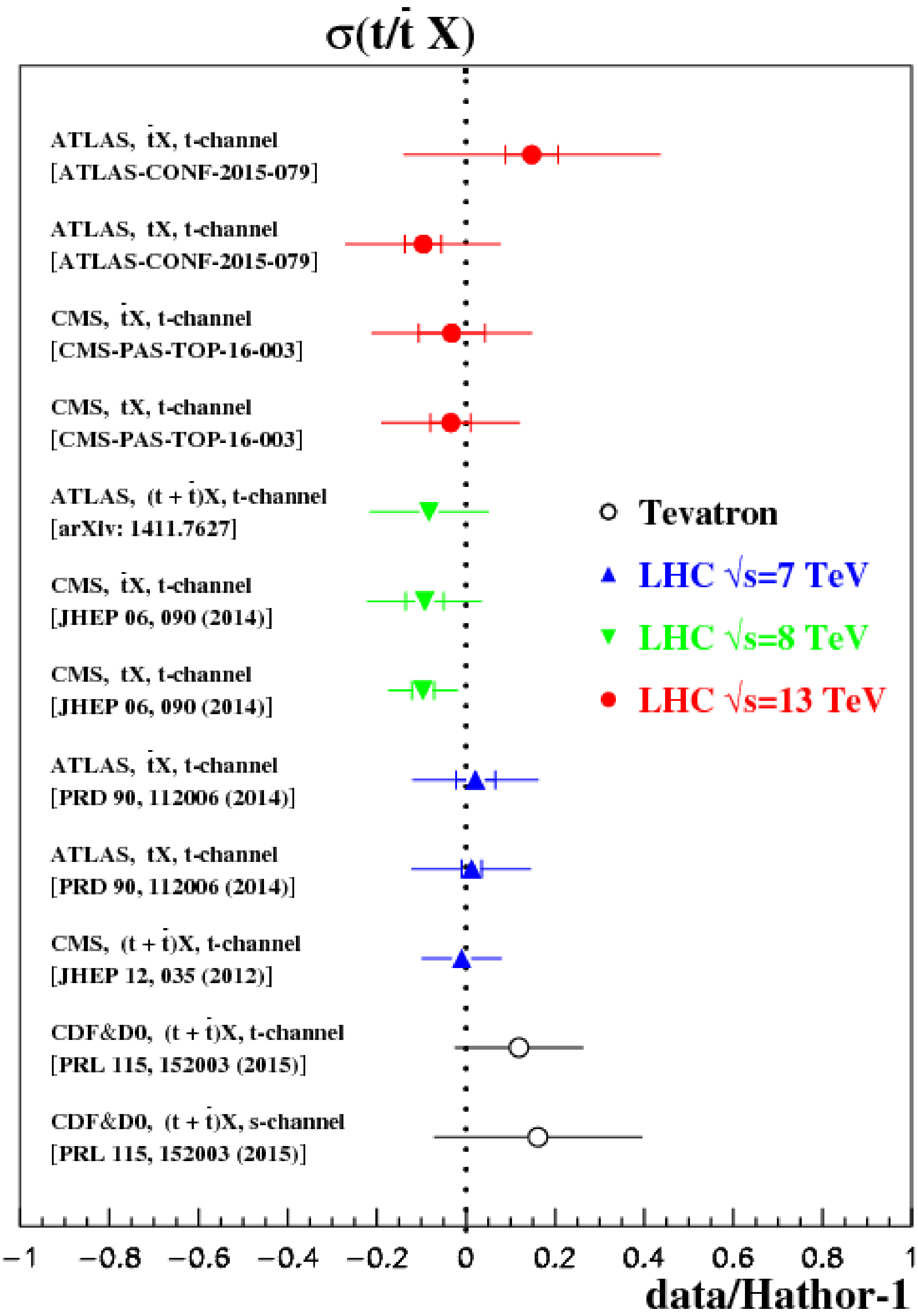


**Figure 4:** Same as Fig. 3 for the data on single-top production in the $s$- and $t$-channel. The NNLO QCD predictions have been computed with Hathor [23] as described in text.