Parton distributions and Tevatron jet data

S. Alekhin*,†, J. Blümlein* and S. Moch*

* Deutsches Elektronensynchrotron DESY, Platanenallee 6, D–15738 Zeuthen, Germany
† Institute for High Energy Physics, 142281 Protvino, Moscow region, Russia

Abstract. We study the impact of Tevatron jet data on a global fit of parton distribution functions and on the determination of the value of the strong coupling constant $\alpha_s(M_Z)$. The consequences are illustrated for cross sections of Higgs boson production at Tevatron and the LHC.

Keywords: High-energy scattering, parton distribution functions, jet cross sections

PACS: 13.85.-t, 13.87.-a, 12.38.-t

Parton distribution functions (PDFs) are indispensable ingredients in any prediction of hard scattering cross sections at hadron colliders. Since they cannot be calculated within perturbative QCD, they have to be determined in global fits to scattering data from fixed-target and collider experiments in order to cover the wide kinematical plane in parton momentum fractions $x$ and scales $Q^2$. Much of the experimental information needed in this procedure originates from neutral- and charged-current deep-inelastic scattering (DIS) with complementary input provided by off-resonance Drell-Yan data in proton-nucleon collisions and, possibly, collider data from $W^\pm$-boson production. For all these processes, the perturbative corrections are known at least through next-to-next-to-leading order (NNLO) in QCD (see e.g. [1]) and the inclusion of NNLO contributions at hadron colliders is mandatory for cross section predictions accurate to about 10% or better.

The Tevatron experiments CDF and D0 provide data for the jet production, both for the $E_T$ distribution in the 1-jet inclusive production [2, 3, 4] using different jet algorithms as well as for the di-jet invariant mass spectrum [5]. The cross sections for hadronic jet production are currently only known up to next-to-leading order (NLO) in QCD, see e.g. [6, 7], along with certain soft corrections beyond NLO for the $E_T$ distribution in the 1-jet inclusive case [8]. This leads to comparably larger theoretical uncertainties in the jet production cross sections due to possible variations of the renormalization and factorization scales $\mu_r$ and $\mu_f$.

Considering Tevatron jet data in connection to PDFs gives rise to a number of interesting questions:

• Do global PDF fits based on DIS and other fixed-target data also give a satisfactory description of Tevatron jet data, even if these data are not included in the fit?
• Which Tevatron jet data provide additional constraints on PDFs, especially on the gluon distribution at $x \sim 0.1$, and on the value of $\alpha_s(M_Z)$?

The latter aspect is of particular importance given that both these quantities, $\alpha_s(M_Z)$ and the gluon PDF, have direct impact on cross section predictions for Higgs boson production in gluon-gluon fusion both at the Tevatron and the LHC. This is the dominant
TABLE 1. The values of the strong coupling $\alpha_s(M_Z)$ obtained in global fits of PDFs at various orders of perturbation theory as indicated in the first column. The second column gives the results of the ABKM09 fit [11], the other columns are obtained from variants of the ABKM09 fit including data either for 1-jet inclusive or for di-jet production from the collaborations D0 [4, 5] or CDF [2, 3]. The value in bold corresponds to the published result in [11].

| $\alpha_s(M_Z)$ | ABKM09 | D0 1-jet inc. | D0 di-jet | CDF 1-jet inc. (cone) | CDF 1-jet inc. ($k_T$) |
|-----|--------|--------------|-----------|-----------------------|-----------------------|
| NLO | 0.1179(16) | 0.1190(11) | 0.1174(9) | 0.1181(9) | 0.1181(10) |
| NNLO | 0.1135(14) | 0.1149(12) | 0.1145(9) | 0.1134(9) | 0.1143(9) |

TABLE 2. The predicted cross sections for Higgs boson production in gluon-gluon fusion with $M_H = 165$ GeV at Tevatron ($\sqrt{s} = 1.96$ TeV) from variants of the ABKM09 fit [11] corresponding to Tab. 1. The uncertainty in brackets refers to 1 $\sigma$ standard deviation for the combined uncertainty on the PDFs and the value of $\alpha_s(M_Z)$. The value in bold corresponds to the published result [1].

| $\sigma(H) [pb]$ | ABKM09 | D0 1-jet inc. | D0 di-jet | CDF 1-jet inc. (cone) | CDF 1-jet inc. ($k_T$) |
|-----|--------|--------------|-----------|-----------------------|-----------------------|
| NLO | 0.206(17) | 0.235(10) | 0.212(10) | 0.229(8) | 0.229(8) |
| NNLO | 0.253(22) | 0.297(12) | 0.281(12) | 0.283(10) | 0.292(10) |

production mode at those colliders and the largest differences between the currently available theory predictions are of precisely this origin [1, 9]. It has recently been found that the primary source responsible for these deviations in cross section predictions is due to a consistent treatment of the DIS data, in particular higher-order radiative corrections to the fixed-target DIS data from NMC [10].

To investigate whether Tevatron jet data plays a distinguished role in global fits of PDFs, we perform several variants of our previous fit ABKM09 [11]. These are based on using D0 data for the $E_T$ distribution in 1-jet inclusive production [4], or the di-jet invariant mass spectrum [5] as well as CDF data on 1-jet inclusive production [2, 3]. In the latter case the $E_T$ distribution has been determined with the cone and $k_T$ jet algorithm. All theoretical predictions for jet cross sections are based on fastNLO [12]. The PDF fit has been performed at NLO and at NNLO in perturbative QCD in a fixed-flavor number scheme with $n_f = 3$ light flavors in the description of DIS data and $n_f = 5$ for the fixed-target Drell-Yan and the Tevatron jet data. We stress, that no complete hard scattering coefficients beyond NLO are available for the jet data. The threshold corrections for the 1-jet inclusive production of Ref. [8] give rise to approximate NNLO corrections, which we denote as NNLO$_{\text{approx}}$. For the di-jet invariant mass spectrum we have to confine ourselves to NLO. Given this incomplete knowledge of higher order perturbative corrections PDF fits including Tevatron jet data implicitly assume the full NNLO corrections to be vanishingly small. Moreover, there exist choices for the QCD evolution linking DIS data at comparably low scales to those of hadronic jet production at high scales and typically ranging over three orders of magnitude. Evolution can either be performed to NLO or to NNLO accuracy and we have chosen the latter option for what we consider as our best fits.

The pulls of the jet data with respect to the ABKM09 predictions and to the variants of ABKM09 fit with the jet data included are shown in Figs. 1 and 2. For the case of the 1-jet inclusive production the data sets have comparable numbers of data points (NDP) and precision and the quoted uncertainties are dominated by systematics. The
TABLE 3. Same as Tab. 2 for the LHC ($\sqrt{s} = 7$ TeV).

|                  | ABKM09 | D0 1-jet inc. | D0 di-jet | CDF 1-jet inc. (cone) | CDF 1-jet inc. ($k_T$) |
|------------------|--------|---------------|-----------|----------------------|------------------------|
| NLO              | 5.73(17) | 5.89(13) | 5.76(10) | 5.76(12) | 5.77(11) |
| NNLO             | 7.05(23) | 7.30(15) | 7.28(14) | 7.02(14) | 7.18(14) |

FIGURE 1. Left: Cross section data for 1-jet inclusive production from the D0 collaboration [4] as a function of the jet’s transverse energy for $\mu_r = \mu_f = \mu_T$ compared to the result of [11] and a re-fit including this data. The order of QCD for the evolution and the hard scattering coefficient functions is indicated. Right: Same for di-jet production data from the D0 collaboration [5] as a function of the di-jet invariant mass for $\mu_r = \mu_f = M_{JJ}$

D0 data are somewhat higher than the ABKM09 predictions and the slope is consistent (Fig. 1 left). The re-fit leads to very good agreement with $\chi^2$/NDP=103/110. For the CDF data the slope in the data is different (Fig. 2). The data set with the cone algorithm displays generally better agreement with the ABKM09 predictions (Fig. 2 right). In the combined fit ($\chi^2$/NDP=78/72) it prefers a lower value of $\alpha_s(M_Z)$ compared to the set with the $k_T$ algorithm ($\chi^2$/NDP=60/76), see Tab. 1. In both cases, however, the apparent disagreement at large $E_T$ can be hardly improved. This disagreement is unrelated to PDFs, because the light quark PDFs, which define the jet cross section in this kinematic range, are very well known. Rather it is a problem of the data suggesting that the Tevatron jet data are not completely understood. The D0 di-jet data is perfectly described by the ABKM09 predictions and the re-fit shows hardly any changes (Fig. 1 right).

The studies demonstrate that the relatively “small” value of the strong coupling constant $\alpha_s(M_Z) = 0.1135(14)$ of ABKM09 is confirmed in the variants of the fit to approximate NNLO accuracy if Tevatron jet data are included. The values in Tab. 1 range between $\alpha_s(M_Z) = 0.1134(9) \ldots 0.1149(12)$. The impact of PDF fits with Tevatron jet data on predictions of the rates for Standard Model Higgs boson production at hadron
colliders is summarized in Tabs. 2 and 3. The results show a slight increase of the order of 1-2 \( \sigma \) in the combined uncertainty on the PDFs and the value of \( \alpha_s(M_Z) \). Note that with account of the missing NNLO corrections impact of the jet data might be even smaller. This supports previous findings, that the bulk of constraints especially on the gluon PDF in the relevant \( x \) range comes from DIS data, in particular from the NMC data [10]. In summary, the studies demonstrate that it is by no means essential to fit Tevatron jets in order to make meaningful predictions for Higgs boson production at hadron colliders. This fact is also supported by independent studies [13].

REFERENCES

1. S. Alekhin, J. Blümlein, P. Jimenez-Delgado, S. Moch, and E. Reya, Phys.Lett. B697, 127–135 (2011), 1011.6259 and references therein.
2. A. Abulencia, et al., Phys.Rev. D75, 092006 (2007), hep-ex/0701051.
3. T. Aaltonen, et al., Phys.Rev. D78, 052006 (2008), 0807.2204.
4. V. Abazov, et al., Phys.Rev.Lett. 101, 062001 (2008), 0802.2400.
5. V. Abazov, et al., Phys.Lett. B693, 531–538 (2010), 1002.4594.
6. Z. Nagy, Phys.Rev.Lett. 88, 122003 (2002), hep-ph/0110315.
7. Z. Nagy, Phys.Rev. D68, 094002 (2003), hep-ph/0307268.
8. N. Kidonakis, and J. Owens, Phys.Rev. D63, 054019 (2001), hep-ph/0007268.
9. J. Baglio, and A. Djouadi, JHEP 1010, 064 (2010), 1003.4266.
10. S. Alekhin, J. Blümlein, and S. Moch (2011), 1101.5261.
11. S. Alekhin, J. Blümlein, S. Klein, and S. Moch, Phys.Rev. D81, 014032 (2010), 0908.2766.
12. T. Kluge, K. Rabbertz, and M. Wobisch pp. 483–486 (2006), hep-ph/0609285.
13. M. Cooper-Sarkar (2011), these proceedings.