PROCEEDINGS OF SCIENCE

The role of intrinsic charm in the proton via photon production in association with a charm quark

S. Rostami
Physics Department, Semnan University, Semnan, Iran
E-mail: asalrostami.phy@gmail.com

A. Khorramian*
Physics Department, Semnan University, Semnan, Iran
School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM), P.O.Box 19395-5531, Tehran, Iran
E-mail: khorramiana@theory.ipm.ac.ir

A. Aleedaneshvar
Physics Department, Semnan University, Semnan, Iran
E-mail: alireza.daneshvar@gmail.com

In this paper, we carry out a comparative analysis of the impact of intrinsic charm on differential cross section of photon c-jet production in pp collision at the LHC and $p\bar{p}$ collision at the Tevatron. For this aim, we use the non-singlet evolution of the intrinsic heavy quark distribution technique which allows us to evolve intrinsic heavy quark distribution independently from the gluon and other parton distribution functions.

The European Physical Society Conference on High Energy Physics
22-29 July 2015
Vienna, Austria

*Speaker.

PoS(EPS-HEP2015)511

1. Introduction

Interaction of hadrons at high energy such as pp scattering at the Large Hadron Collider (LHC) and $p\bar{p}$ scattering at the Tevatron can be a useful tool to investigate the parton distribution functions (PDFs). Precise knowledge of PDFs is absolutely important to test the standard model and search new physics.

The PDF $f_i(x,Q^2)$ is the number density of parton i (quark or gluon) carrying a momentum fraction x at the scale of Q^2. These functions $f_i(x,Q^2)$ can be determine from the QCD global analysis [1–11] of the accessible hard scattering data. In the most of analyses, only the light quark distributions are non zero at the scale of Q_0^2 and the heavy quark distributions are generated perturbatively through the splitting of gluon into quark anti-quark pairs in the DGLAP evolution equations. In this way, we do not need any functional form for heavy quark distributions. However, there are some models that suggest the existence of an intrinsic heavy component in the proton. These types of quarks are certainly non-perturbative and play an important role at large x. For the first time, the intrinsic quark component was suggested by Brodsky, Hoyer, Peterson, and Sakai (BHPS) in 1980 [12]. In the recent years this non-perturbative intrinsic quark components in addition to perturbative extrinsic one have been studied by many articles [13–26]. There are remarkable differences between the extrinsic and intrinsic sea quarks. The extrinsic sea quarks are generated in the proton perturbatively through the splitting of gluons into quark-antiquark pairs in the DGLAP Q^2 evolution [27]. They produce more and more when the Q^2 scale increases. Meanwhile extrinsic sea quarks dominate at very low parton momentum fraction x and so have a "sealike" characteristics. In contrast, the intrinsic sea quarks arise through the non-perturbative fluctuations of the nucleon state to five-quark states in the light-cone Fock space picture [28] and exist over a time scale which is independent of any probe momentum transfer (infinite momentum frame). Moreover, the intrinsic sea quarks behave as "valencelike" quarks and then their distributions peak at relatively large x.

To investigate for evidence of the intrinsic heavy quark components in the proton, it is useful to focus on the processes which are sensitive to the intrinsic heavy quark distributions specially intrinsic charm. The prompt photon production in association with a charm quark at hadron colliders ($pp(\bar{p}) \to \gamma + c$-jet) [29, 30] are dependent on the charm quark distribution. In this paper, we present predictions for production of differential $\gamma + c$-jet cross section in pp and $p\bar{p}$ collisions. We compare our results with the recent experimental data from D0 $\sqrt{s} = 1.96$ TeV at the Tevatron. Also we present some predictions for pp collisions at $\sqrt{s} = 8$ TeV for the LHC.

2. Intrinsic charm distribution and its evolution

According to the BHPS model the probability distribution for the five-quark state, $|uudQ\bar{Q}\rangle$, assuming that the effect of transverse momentum is negligible, can be written as [12]

$$P(x_1,...,x_5) = \mathscr{N}\delta(1-\sum_{i=1}^{5}x_i)[M^2 - \sum_{i=1}^{5}\frac{m_i^2}{x_i}]^{-2}, \tag{2.1}$$

where m_i and M are the mass of the parton i in the Fock state and mass of proton respectively. As well as x_i is the momentum fraction carried by partons. $\mathscr{N}$ normalizes the five-particle Fock state probability and can be determined from

$$\mathscr{P}_5^{Q\bar{Q}} = \int_0^1 dx_1 ... dx_5 P(x_1, ..., x_5), \tag{2.2}$$

where $\mathscr{P}_5^{Q\bar{Q}}$ is the $|uudQ\bar{Q}\rangle$ Fock state probability. BHPS assumed the light quarks and proton masses are negligible compared to the heavy quark mass. Therefore, in this limit Eq. 2.1 becomes

$$P(x_1, ..., x_5) = \mathscr{N}_5 \delta(1 - \sum_{i=1}^{5} x_i) \frac{x_4^2 x_5^2}{(x_4 + x_5)^2} , \tag{2.3}$$

where $\mathscr{N}_5 = \mathscr{N}/m^4_{Q,\bar{Q}}$ and its value is determined by integrating of Eq. (2.2) over x_i so that $\mathscr{N}_5 = 3600\mathscr{P}_5^{Q\bar{Q}}$. Finally, the probability distribution for the intrinsic heavy quark in the proton obtained by integrating over $dx_1 ... dx_4$ is given by

$$P(x_5) = \mathscr{P}_5^{Q\bar{Q}} 1800\, x_5^2 \Big[\frac{(1-x_5)}{3}\left(1 + 10x_5 + x_5^2\right) + 2x_5(1 + x_5)\ln(x_5)\Big]. \tag{2.4}$$

According to Eq. (2.1), BHPS model has equal probability distributions for Q and $\bar{Q}$ in the five-quark state of the proton. Assuming with 1% probability for intrinsic charm in the proton we have [12]

$$c(x) = 18x^2 \Big[\frac{(1-x)}{3}\left(1 + 10x + x^2\right) + 2x(1 + x)\ln(x)\Big], \tag{2.5}$$

where for convenience, we used x in place of x_5. Although an estimation of the order of 1% for the probability of finding intrinsic charm have been found before, but several studies have been indicated that it can be even 2-3 times larger [19, 20, 31, 32].

In order to investigate the impact of intrinsic charm quarks on the physical observables, the study of the evolution of intrinsic charm distributions together with extrinsic ones can be interesting and useful. If we adopt the intrinsic charm component in the proton, then the total heavy quark distribution in any x and Q^2 values can be obtained by adding the intrinsic contribution (non-perturbative) xc_{int} to the extrinsic component (perturbative) xc_{ext} as follows

$$xc(x, Q^2) = xc_{ext}(x, Q^2) + xc_{int}(x, Q^2). \tag{2.6}$$

In the case of heavy quark, the evolution equation can be separated into two parts [33]. The first part is evolution of the extrinsic heavy quark. The PDFs for the extrinsic heavy component can be taken from a global analysis result of various groups, which are available in the Les Houches Accord PDF Interface (LHAPDF [34]) in arbitrary x and Q^2, for example CTEQ66 [32]. The second part is evolution of the intrinsic heavy quark distribution Q_{int} (where $Q = c$ or b). The Q^2-evolution of the intrinsic heavy quark distribution is controlled by non-singlet evolution equation [33]

$$\dot{Q}_{int} = P_{QQ} \otimes Q_{int}, \tag{2.7}$$

with the splitting function P_{QQ}. This technique allows us to evolve intrinsic heavy quark distribution without performing a new global analysis. In this way, the intrinsic heavy quark evolves independently from the gluon and from other PDFs. In recent years the CTEQ collaboration has performed global analysis of PDFs with an intrinsic charm contribution in $Q \geqslant m_c$ and presented CTEQ66c PDF sets [32]. However, using their results we have only the total charm distribution in any x and Q^2 and not the intrinsic contribution separately. For that reason, there is no source giving the evolution of IC distribution itself at arbitrary x and Q^2. But non-singlet evolution of the intrinsic heavy quark component of the parton allows us to study the impact of this nonperturbative contribution on physical observable without performing a complete global analysis of PDFs. In other words, this technique gives us evolution of the intrinsic charm distribution in any x and Q^2 and can be added to any extrinsic PDFs. To check the results, one can extract the extrinsic charm distribution at fixed Q^2 using CTEQ66 PDFs and then add it to IC contribution using our grids to compare this total charm distribution with extracted results from CTEQ66c1 (which includes BHPS with 1% IC) [32]. This comparison shows that, there is a very good agreement between our result and CTEQ66c1. We carried out our calculation by QCDNUM package [35] using its ability for the evolution of the non-singlet PDFs.

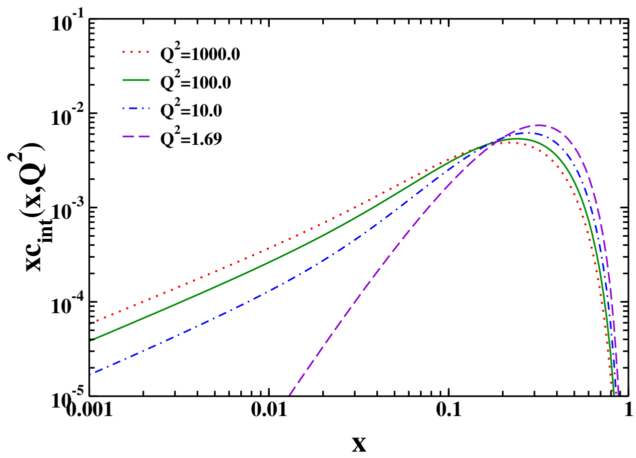

Figure 1: Q^2 evolution of IC according to the non-singlet evolution at $Q^2 = 1.69, 10, 100$ and 1000 GeV^2.

In Fig. 1 we show the evolution of the intrinsic charm distribution for different values of $Q^2 = 1.69, 10, 100$ and 1000 GeV^2. As a result, we can see that its peak decreases in magnitude with increasing Q^2 value and also shifts to the smaller values of x just like the valence quark behavior as expected.

Fig. 2 shows the Q^2-evolution of $xc_{int}(x,Q^2)$ and total charm distribution $xc(x,Q^2)$. The charm distribution of CTEQ66c1 [32] is shown for two values of $Q^2 = 100$ and 10000 GeV^2 (blue dashed curves). The intrinsic charm distribution that evolved according to the non-singlet evolution equation is shown by dotted-dotted-dashed curves and the dotted curves have been obtained as the sum of the extrinsic charm contribution from CETQ66 [32] and intrinsic ones from our result. One can see that there is a very good agreement between adding an intrinsic charm distribution to CTEQ66 PDFs and CTEQ66c.

3. Production of photon with charm quark jet

The prompt photon production in association with charm quark at the leading order (LO),

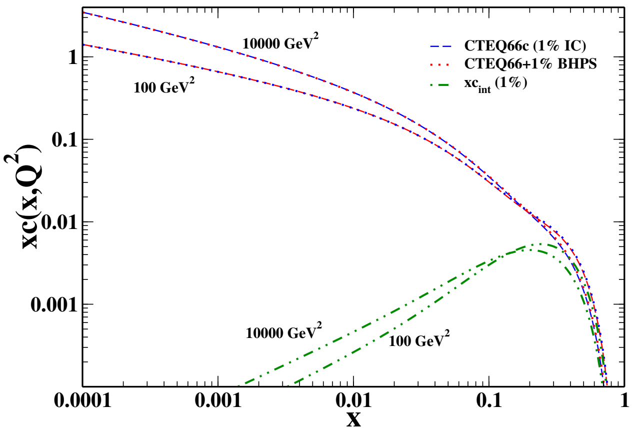

Figure 2: The distributions of charm quark; the dotted-dotted-dashed curves are the intrinsic charm distributions, the dashed curves are CTEQ66c1 and the sum of the extrinsic charm contribution from CETQ66 and intrinsic charm distribution are presented by dotted curves. The result shown for two values of $Q^2 = 100$ and 10000 GeV^2.

arises from the Compton sub-process $gc \to \gamma c$ [30]. At the LHC, the Compton process dominates for all energies but at the Tevatron the annihilation process $q\bar{q} \to \gamma g \to \gamma c\bar{c}$ dominates for photons with high transverse momentum p_T^γ [36]. At the next-to-leading order (NLO), the number of contributing sub-processes increases. For example, contributions from diagrams like $gg \to \gamma c\bar{c}$ and $gc \to \gamma qc$ should be included [36,37]. Therefore, almost all the PDFs dependence in $\gamma + c$-jet cross section come from the gluon and charm distributions [37].

In this study, we present predictions of differential cross section for the Tevatron and LHC to investigate the impact of IC component on the cross section. The photon c-jet production in

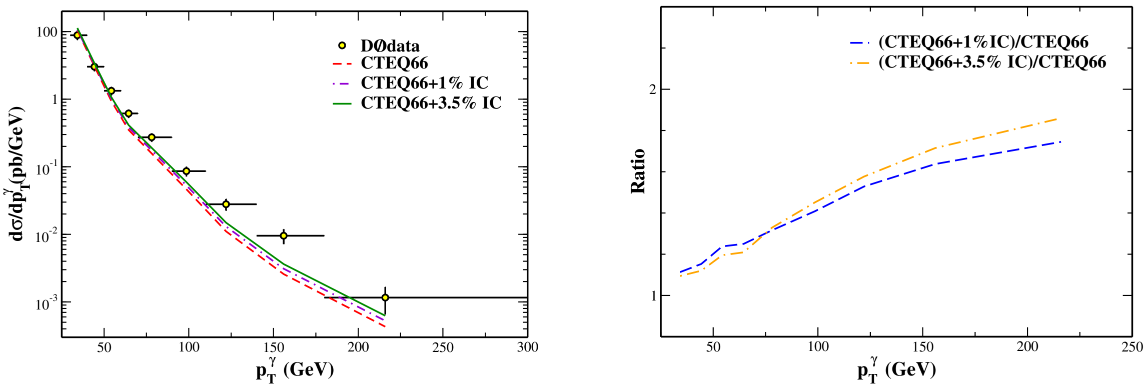

Figure 3: Left: A comparison of D0 measurement of differential $\gamma + c$-jet cross section as a function of p_T^γ at $\sqrt{s} = 1.96$ TeV with CTEQ66 without IC contribution (dashed curve), CTEQ66 plus with 1% IC (dotted-dashed curve), CTEQ66 plus 3.5% IC (solid curve). Right: The ratio of these spectra for 1% (dashed curve) and 3.5% (dotted-dashed curve) IC contribution to CTEQ66.

$p\bar{p}$ collision at $\sqrt{s} = 1.96$ TeV was carried out by the D0 collaborations at the Tevatron [29]. We present prediction of differential cross section $p\bar{p} \to \gamma + c$-jet according specific kinematic cuts for D0 experiment. This calculation was carried out by MadGraph [38]. As one can see in the left panel of Fig. 3, data at large p_T^γ region do not agree with CTEQ66 PDFs [32] without the IC contribution and the inclusion of the IC contribution enhances the cross section at large p_T^γ. In this figure the dotted-dashed and solid curves represent our theoretical results for the cross section using the CTEQ66 plus BHPS with 1% and 3.5% IC, respectively. The ratio of CTEQ66 PDFs adding 1% and 3.5% IC to CTEQ66 PDFs is illustrated in the right panel of Fig. 3. This ratio for 3.5% IC is about 1.5 when p_T^γ reaches 216 GeV, while it is 1.2 for 1% IC.

A similar prediction for the D0 has been done for LHC. The differential $\gamma + c$-jet cross section in pp collisions over the transverse momentum of the photon is presented for the photon rapidity $1.52 < |y^\gamma| < 2.37$ at $\sqrt{s} = 8$ TeV and for transverse momentum $50 < p_T^\gamma < 400$ GeV. The c-jet also has $p_T^c > 20$ GeV and $|\eta^c| < 2.4$. In this kinematical region, the charm momentum fraction is larger than 0.1 ($x_c > 0.1$) where the intrinsic charm distribution is completely considerable in comparison with the extrinsic charm distribution. More information about this kinematic cuts can be found in Ref. [30]. As can be seen from Fig. 4 the difference between the standard PDF (CTEQ66) without considering IC and the results considering IC contribution with 1% and 3.5% are visible specially at large p_T^γ. The difference between the results is visible in right panel of Fig. 4 where the ratio of the spectra including IC contribution with 1% and 3.5% IC probability to CTEQ66 is presented as a function of p_T^γ.

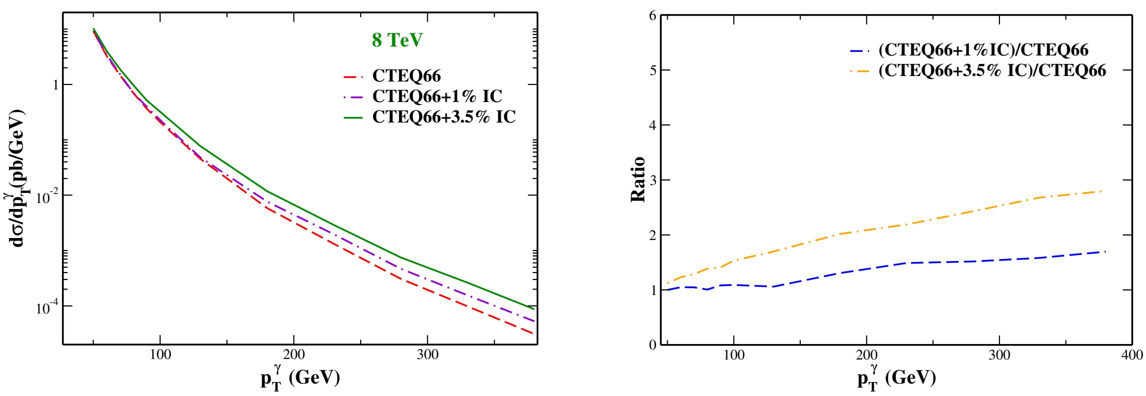

Figure 4: Left: The differential $\gamma + c$-jet cross section in pp collisions as a function of p_T^γ at $\sqrt{s} = 8$ TeV and using CTEQ66 without IC contribution (dashed curve), CTEQ66 plus 1% IC (dotted-dashed curve), CTEQ66 plus 3.5% IC (solid curve). Right: The ratio of these spectra for 1% (dashed curve) and 3.5% (dotted-dashed curve) IC contribution to CTEQ66.

4. Conclusion

In this paper, we present the evolution of intrinsic charm distributions. An important aspect of our calculation is that we present a non-singlet evolution technique for evolution of intrinsic quark distribution for arbitrary $\mathscr{P}_5^{q\bar{q}}$. This allows one to add intrinsic quark distribution to any PDF set without performing a new complete global analysis. The grid files for the evolution of intrinsic charm quarks for arbitrary $\mathscr{P}_5^{c\bar{c}}$ used in this paper are available in Ref. [39]. We have demonstrated the impact of intrinsic charm in the results of the inclusive production of a prompt photon and c-jet in hadron colliders for two values of $\mathscr{P}_5^{c\bar{c}}$. It is worth emphasizing that the IC contribution increases the magnitude of differential cross section of photon c-jet production and has significant contribution in this cross section particularly in high photon transverse momentum.

5. Acknowledgments

We thank S. J. Brodsky for useful discussions and comments. S. R. appreciates O. Mattelaer, G. Lykasov and V. Bednyakov for helpful comments. A.K. thanks the CERN TH-PH division for the hospitality where a portion of this work was performed.

References

[1] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, arXiv:1412.3989 [hep-ph].

[2] J. Gao, M. Guzzi, J. Huston, H. L. Lai, Z. Li, P. Nadolsky, J. Pumplin and D. Stump *et al.*, Phys. Rev. D **89**, no. 3, 033009 (2014) [arXiv:1302.6246 [hep-ph]].

[3] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Eur. Phys. J. C **63**, 189 (2009) [arXiv:0901.0002 [hep-ph]].

[4] R. D. Ball, V. Bertone, S. Carrazza, C. S. Deans, L. Del Debbio, S. Forte, A. Guffanti and N. P. Hartland *et al.*, Nucl. Phys. B **867**, 244 (2013) [arXiv:1207.1303 [hep-ph]].

[5] C. Bourrely and J. Soffer, arXiv:1502.02517 [hep-ph].

[6] S. Alekhin, J. Bluemlein and S. Moch, Phys. Rev. D **89**, no. 5, 054028 (2014) [arXiv:1310.3059 [hep-ph]].

[7] P. Jimenez-Delgado and E. Reya, Phys. Rev. D **89**, no. 7, 074049 (2014) [arXiv:1403.1852 [hep-ph]].

[8] H. Khanpour, A. N. Khorramian and S. A. Tehrani, J. Phys. G **40**, 045002 (2013) [arXiv:1205.5194 [hep-ph]].

[9] A. Kusina, K. KovaÅŹik, T. JeÅ¿o, D. B. Clark, F. I. Olness, I. Schienbein and J. Y. Yu, PoS DIS **2014**, 047 (2014) [arXiv:1408.1114 [hep-ph]].

[10] F. Arbabifar, A. N. Khorramian and M. Soleymaninia, Phys. Rev. D **89**, no. 3, 034006 (2014) [arXiv:1311.1830 [hep-ph]].

[11] A. N. Khorramian, S. Atashbar Tehrani, S. Taheri Monfared, F. Arbabifar and F. I. Olness, Phys. Rev. D **83**, 054017 (2011) [arXiv:1011.4873 [hep-ph]].

[12] S. J. Brodsky, P. Hoyer, C. Peterson, N. Sakai, Phys. Lett. B **93**, 451 (1980); S.J. Brodsky, C. Peterson, N. Sakai, Phys. Rev. D **23**, 2745 (1981).

[13] B. W. Harris, J. Smith and R. Vogt, Nucl. Phys. B **461**, 181 (1996) [hep-ph/9508403].

[14] J. Speth and A. W. Thomas, Adv. Nucl. Phys. **24**, 83 (1998).

[15] S. Kumano, Phys. Rep. **303**, 183 (1998).

[16] R. Vogt, Prog. Part. Nucl. Phys. **45**, S105 (2000).

[17] G. T. Garvey and J.-C. Peng, Prog. Part. Nuc. Phys. **47**, 203 (2001).

[18] W.-C. Chang and J.-C. Peng, Phys. Rev. Lett. **106**, 252002 (2011).

[19] J. Pumplin, Phys. Rev. D **73**, 114015 (2006) [hep-ph/0508184].

[20] J. Pumplin, H. L. Lai and W. K. Tung, Phys. Rev. D **75**, 054029 (2007) [hep-ph/0701220].

[21] J.-C. Peng and J.-W. Qiu, Prog. Part. Nucl. Phys. **76**, 43 (2014).

[22] T. J. Hobbs, J. T. Londergan and W. Melnitchouk, Phys. Rev. D **89**, no. 7, 074008 (2014) [arXiv:1311.1578 [hep-ph]].

[23] P. Jimenez-Delgado, T. J. Hobbs, J. T. Londergan and W. Melnitchouk, arXiv:1408.1708 [hep-ph].

[24] S. J. Brodsky and S. Gardner, arXiv:1504.00969 [hep-ph].

[25] S. Dulat, T. J. Hou, J. Gao, J. Huston, J. Pumplin, C. Schmidt, D. Stump and C.-P. Yuan, Phys. Rev. D **89**, no. 7, 073004 (2014) [arXiv:1309.0025 [hep-ph]].

[26] A. Vafaee, A. Khorramian, S. Rostami, A. Aleedaneshvar and M. Goharipour, Nucl. Part. Phys. Proc. (2015)

[27] V. N. Gribov and L. N. Lipatov, Sov. J. Nucl. Phys. **15**, 438 (1972); G. Altarelli and G. Parisi, Nucl. Phys. B **126**, 298 (1997); Yu. L. Dokshitzer, Sov. Phys. JETP **46**, 641 (1977).

[28] S. J. Brodsky, hep-ph/0412101.

[29] V. M. Abazov *et al.* [D0 Collaboration], Phys. Lett. B **719**, 354 (2013) [arXiv:1210.5033 [hep-ex]].

[30] V. A. Bednyakov, M. A. Demichev, G. I. Lykasov, T. Stavreva and M. Stockton, Phys. Lett. B **728**, 602 (2014).

[31] J. F. Donoghue and E. Golowich, Phys. Rev. D **15**, 3421 (1977).

[32] P. M. Nadolsky, H. L. Lai, Q. H. Cao, J. Huston, J. Pumplin, D. Stump, W. K. Tung and C.-P. Yuan, Phys. Rev. D **78**, 013004 (2008) [arXiv:0802.0007 [hep-ph]].

[33] F. Lyonnet, A. Kusina, T. JeÅ¿o, K. KovarÃ■k, F. Olness, I. Schienbein and J. Y. Yu, JHEP **1507**, 141 (2015) [arXiv:1504.05156 [hep-ph]].

[34] D. Bourilkov, R. C. Group and M. R. Whalley, hep-ph/0605240.

[35] M. Botje, Comput. Phys. Commun. **182**, 490 (2011) [arXiv:1005.1481 [hep-ph]].

[36] T. P. Stavreva and J. F. Owens, Phys. Rev. D **79**, 054017 (2009) [arXiv:0901.3791 [hep-ph]].

[37] T. Stavreva, I. Schienbein, F. Arleo, K. Kovarik, F. Olness, J. Y. Yu and J. F. Owens, JHEP **1101**, 152 (2011) [arXiv:1012.1178 [hep-ph]].

[38] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer and T. Stelzer, JHEP **1106**, 128 (2011) [arXiv:1106.0522 [hep-ph]].

[39] Program summary: http://particles.ipm.ir/links/QCD.htm.