IRSTI 29.15.03 https://doi.org/10.26577/RCPh.2023.v85.i2.02

Akbari Jahan* , Diptimonta Neog
Department of Physics, North Eastern Regional Institute of Science and Technology,
India, Arunachal Pradesh, Nirjuli
*email: akbari.jahan@gmail.com

A BRIEF ANALYSIS ON THE BEHAVIOUR OF GLOBAL PARTON DISTRIBUTION FUNCTIONS AT SMALL AND LARGE *x*

Parton distribution functions (PDFs) inscribe details about the hadronic substructure in terms of partons, quarks and gluons collectively, which are the fundamental degrees of freedom of Quantum Chromodynamics (QCD), the theory of strong interactions. Study of PDFs has led to a better comprehension of the partonic structure of hadrons and the proton structure function in deep inelastic scattering. Understanding parton densities within the hadrons is vital to estimate the hard-scattering process results. Owing to theoretical and experimental limitations, PDFs cannot be computed from the first principles. The global analysis of parton distribution functions, therefore, requires an unrelenting endeavour.

The aim ofthe present work is to have a comparative study of the PDFs from the plots obtained using APFEL, which is a PDFs evolution library. We discuss the graphical analyses as well as comparisons of the three global PDFs sets, viz. CT10, MSTW2008 and NNPDF30, in a wide range of momentum fraction x and energy scale Q. A comparative analysis of gluons extracted from these global fits has also been done.

Keywords: Parton distribution functions, Proton structure function, Deep inelastic scattering, Momentum fraction *x.*

Акбари Джахан*, Диптимонта Неог
Кафедра физики Северо-восточного регионального института науки и технологий,
Индия, Аруначал-Прадеш, г. Нирджули
*email: akbari.jahan@gmail.com

Краткий анализ поведения глобальных функций распределения партонов при малом и большом *x*

Функции распределения партонов (PDF) описывают детали адронной подструктуры с точки зрения партонов, кварков и глюонов вместе, которые являются фундаментальными степенями свободы квантовой хромодинамики (КХД) и теории сильных взаимодействий. Изучение функции распределения партонов привело к лучшему пониманию партонной структуры адронов и структурной функции протонов при глубоко неупругом рассеянии. Понимание плотности партонов внутри адронов жизненно важно для оценки результатов процесса жесткого рассеяния. Доказано, что из-за теоретических и экспериментальных ограничений партонные функции распределения нельзя рассчитать из первых принципов. Таким образом, глобальный анализ функций распределения партонов требует огромных усилий исследователей.

Целью настоящей работы является сравнительное исследование функций распределения партонов из графиков, полученных с помощью APFEL, которая представляет собой библиотеку эволюции функций распределения партонов. Мы в данной работе обсуждаем графический анализ, а также проводим сравнение трёх глобальных наборов PDF, а именно CT10, MSTW2008 и NNPDF30 в широком диапазоне доли импульса x и шкалы энергии Q. Также нами был проведен сравнительный анализ глюонов, извлеченных из этих глобальных подгонок.

Ключевые слова: функции распределения партонов, структурная функция протона, глубоконеупругое рассеяние, доля импульса *x*.

Акбари Джахан*, Диптимонта Неог
Солтүстік-шығыс аймақтық ғылым және технология институтының физика кафедрасы,
Үндістан, Аруначал-Прадеш, Нирджули қ.
*email: akbari.jahan@gmail.com

Кіші және үлкен *x* үшін жаһандық партондардың үлестіру функцияларының тәртібіне қысқаша талдау

Партонның үлестіру функциялары (PDF) адрондық ішкі құрылымның бөлшектерін партондар, кварктар және глюондар тұрғысынан сипаттайды, олар кванттық хромодинамиканың (КХД) және күшті өзара әрекеттесу теориясының негізгі еркіндік дәрежесі болып табылады. Партонның таралу функциясын зерттеу адрондардың партондық құрылымын және терең серпімді емес шашыраудағы протондардың құрылымдық қызметін жақсырақ түсінуге әкелетіні белгілі. Адрондар ішіндегі партондардың тығыздығын түсіну қатты шашырау процесінің нәтижелерін бағалау үшін өте маңызды екені түсінікті. Теориялық және эксперименттік шектеулерге байланысты партондық үлестіру функцияларын бірінші принциптерден есептеу мүмкін еместігі дәлелденді. Осылайша, партондық үлестіру функцияларын жаһандық талдау зерттеушілердің үлкен күш-жігерін талап етеді.

Бұл ұсынылған жұмыстың мақсаты партондық үлестіру функцияларының эволюциясының кітапханасы болып табылатын APFEL көмегімен алынған графиктерден партондық үлестіру функцияларын салыстырмалы зерттеу болып табылады. Бұл мақалада біз графикалық талдауды талқылаймыз, сонымен қатар CT10, MSTW 2008 және NNPDF30 сияқты үш жаһандық партонның үлестіру функциялар жиынын *x* импульс бөлігінің кең диапазоны мен *Q* энергетикалық шкаласы бойынша салыстырамыз. Сондай-ақ біз осы жаһандық сәйкестіктерден алынған глюондардың салыстырмалы талдауын жасадық.

Түйін сөздер: партонның таралу функциялары, протонның құрылымдық функциясы, терең серпімді емес шашырау, импульстік бөлшек *x*.

Introduction

The explanation of proton in terms of its elementary components, viz. quarks and gluons, remains one of the major difficulties of elementary particle physics. It is due to the fact that quarks and gluons are subject to confinement at proton energy scale (Λ_{QCD}), which is of the order of 200 MeV.

Parton distribution functions (PDFs) inscribe details about the hadronic substructure in terms of partons, quarks and gluons collectively, which are the fundamental degrees of freedom of Quantum Chromodynamics (QCD), the theory of strong interactions. With the advent of the Large Hadron Collider (LHC) to study the fundamental interactions, precise understanding of the PDFs hasbecome crucial owing to the fact that they are essential components in the cross section calculations of collider experiments [1]. Essentially, it is the partons that are experiencing hard collisions when proton-proton collision takes place. The rates of such collisions can only be determined if the PDFs in the proton are accurately understood. Studies of PDFs [2, 3] have led to understand the partonic structure in a more precise way. The dynamics of quark-gluon interaction inside the proton brings about momenta distribution, which are expressed in terms of PDFs, and thus display the underlying structure of proton. They are best ascertained by global fits to the available deep inelastic scattering (DIS) data. The DIS data from HERA (Hadron Electron Ring Accelerator) provided a considerable increase in both accuracy and kinematics. Besides, the HERA data also provides sufficient information about the large gluon density at very small *x* [4]. Determination of PDF uncertainties have been done using the global fits of MSTW (Martin-Stirling-Thorne-Watt) [5] and CTEQ/CT (Coordinated Theoretical Experimental project on QCD) [1] collaborations. NNPDF (Neural Network PDF) collaboration [6] is another global fit [7] based on DIS data [8].

As PDFs are functions and immeasurable from the first principles, they must be extricated using discrete experimental data fits, followed from some serious theoretical presumptions. A functional form for PDFs is, therefore, usually assumed and parameterized by a few number of parameters for *x*at some reference scale, say Q_0^2. Presently, three sets of PDFs, viz. CTEQ/CT, MSTW and NNPDF collaborations, support these characteristics and the conventional assumption of PDF fitting groups is usually given as [3, 9]

$$f_i(x, Q_0^2) = x^{\alpha_i}(1-x)^{\beta_i} g_i(x),$$

where $g_i(x) \rightarrow$ is a constant for both $x \rightarrow 0$ and $x \rightarrow 1$. Regge theory and quark counting rules respectively explain the behavior of PDFs as power of *x* when $x \rightarrow 0$ and as power of $(1-x)$ as $x \rightarrow 1$ [3, 10].

The purpose of this paper is twofold. First, it aims to provide a succinct and didactic review of PDFs, relevant for understanding the hard processes of QCD. Second, it analyses the plots obtained using APFEL. Comparisons and combinations of PDFs from such global fitting groups have been discussed.

Methodology

As stated earlier, determination of PDFs cannot be ascertained from the first principles and hence they are computed by making suitable theoretical predictions of hadronic cross sections. In such cases, a confidence interval is often associated in the PDF space that are developed using a proper goodness-of-fit measure. APFEL (A PDF Evolution Library) is a web-based application designed for the graphical representation of PDFs and contains PDF grids from LHAPDF5 and LHAPDF6. LHAPDF stands for the Les Touches Accord PDF and it is a standard interface designed to evaluate and work with PDF sets. In our study, we have examined the three most global PDF sets, viz. CT10, MSTW2008 and NNPDF30 from the LHAPDF library and then created the grids making use of LHAPDF6 [11] format. Based on the PDF set, the uncertainty type, be it the Monte Carlo approach or the Hessian approach [12, 13], is automatically determined by the LHAPDF6 library. Plots of gluon distribution functions for these three global fits have been obtained at different energy scales. A comparative analysis of proton structure function has also been done.

Results and Discussion

We compare the three global PDF sets in the same plot as a function of *x* for a given flavour and energy scale *Q*.

The plots of gluon distribution functions are shown in Figure 1, where PDFs have been shown to evolve from 1.5 GeV to 1000 GeV and they are compared using the APFEL PDF sets. Gluons dominate at small *x* but drop-off sharply with the rise of *x*. At large *Q*, gluon radiates either quark-antiquark pairs or additional gluons, resulting in low parton momenta and thus shifting everything towards small *x*. Consequently, gluon PDF as well as sea quark PDF decline sharply.

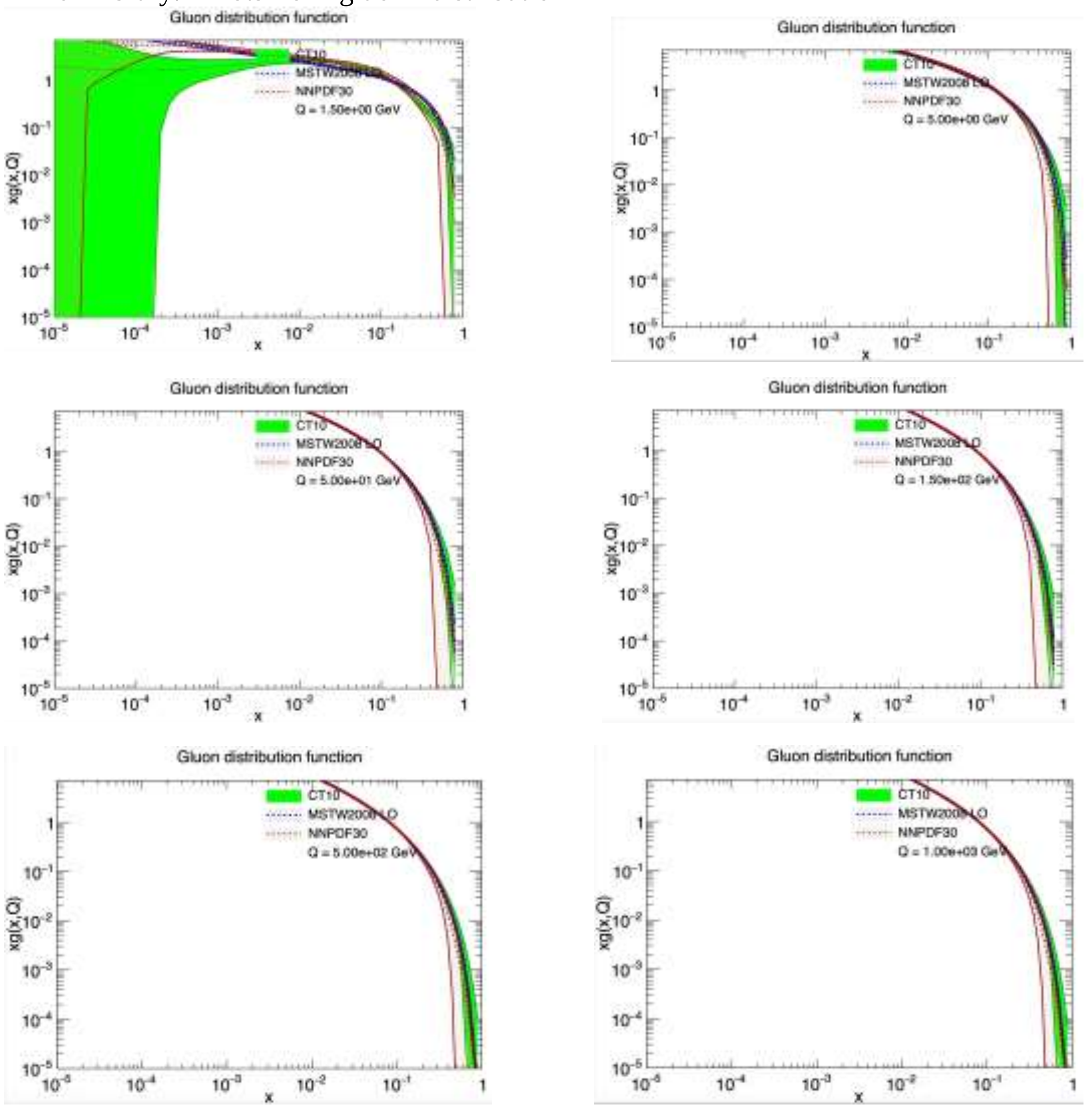

Figure 1. Comparison of gluon distribution function from CT10, MSTW2008 and NNPDF30 collaborations at *Q* values of 1.5, 5, 50, 150, 500 and 1000 GeV using a linear scale in *x*.

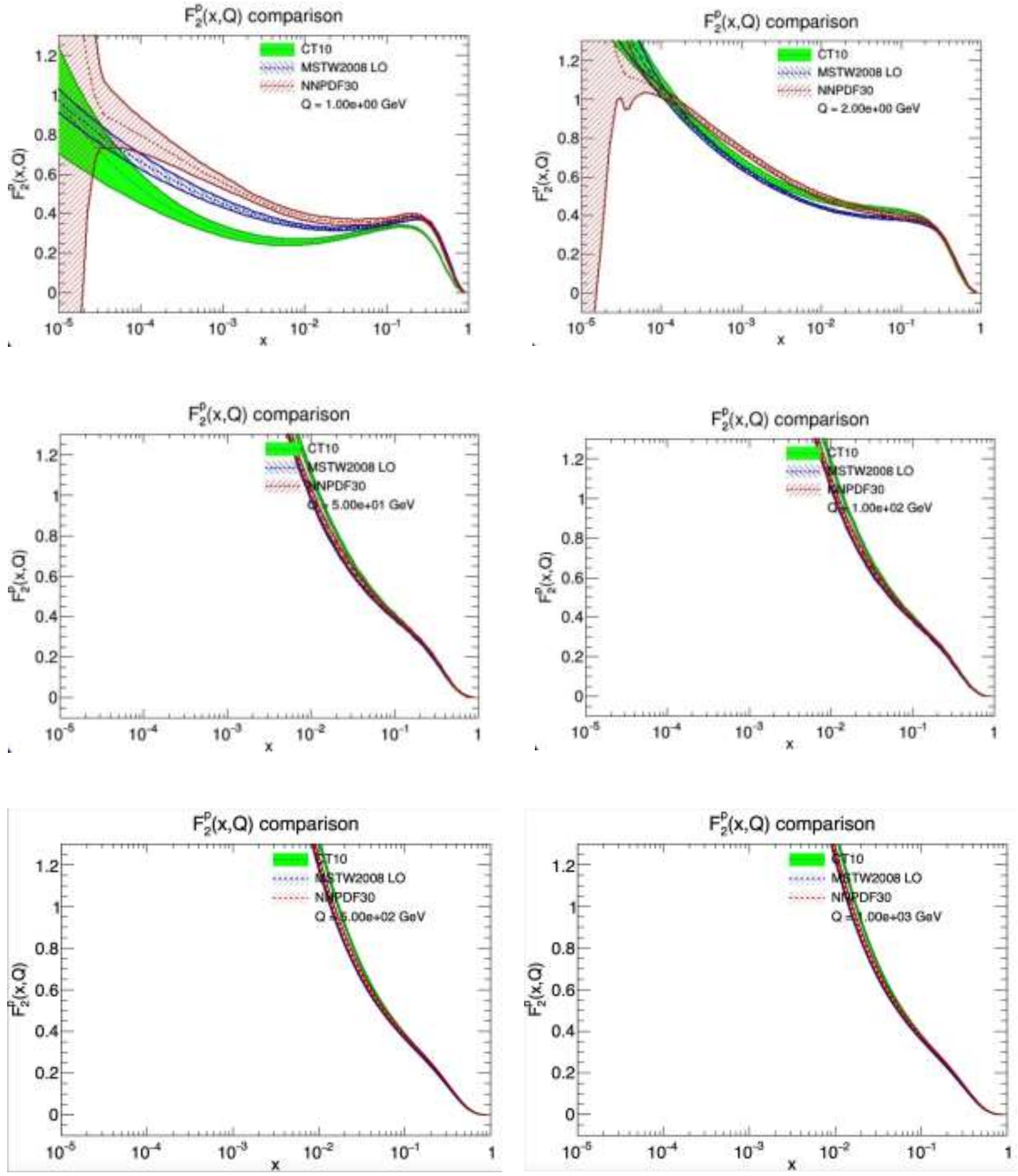

Figure 2. Comparison of proton structure function from CT10, MSTW2008 and NNPDF30collaborations at Q values of 1, 2, 50, 100, 500 and 1000 GeV using a linear scale in x

The plots of proton structure function are shown in Figure 2, where the function has been compared using the APFEL PDF sets with the energy scale evolving from 1 GeV to 1000 GeV. In all the cases, the structure function of proton undergoes a gradual fall towards large x. The fall is also sharper for large Q. This behaviour of the structure function agrees well with theory.

Conclusion

In this paper, analyses of PDFs have been done graphically using APFEL PDF sets. The behaviour of these PDFs have been studied for both small x as well as large x. Gluon distribution function *vs* x as well as proton structure function *vs* x for a few representative values of energy scale Q have been plotted in figure 1 and Figure 2. The three most global data sets, viz. CT/CTEQ, MSTW and NNPDF have been compared in these figures. It can be observed that the PDFs descend at large *x*, which is quite expected [4]. At large *x*, the cross section declines with the increase in energy scale because the PDFs fall as the partons capitulate their momenta by radiating gluons that split into quark-antiquark pairs. These pairs also radiate again and consequently, the small *x* PDFs rise. In Figure 2, it can be observed that the intermediate *x* range shows the drop of PDFs at first, then ascend and again descends towards large *x*. The reason for such behaviour may be due to the dynamics of the NLO (next-to-leading order) and also the NNLO (next-to-next-to-leading order) in this intermediate range.

Declarations

No funding has been received for conducting this study. The authors have no competing interests to declare that are relevant to the content of this manuscript.

References

1 Lai H.L. et al, New parton distributions for collider physics //Phys. Rev. D. – 2010. – Vol.82. – ArtNo.074024.
2 Forte S. Parton distributions at the dawn of the LHC //Acta Phys. Polon. B. – 2010. – Vol. 41. – P.2859-2920.
3 Forte S. and Watt G. Progress in the determination of the partonic structure of the proton //Ann. Rev. Nucl. Part. Sci. – 2013 – Vol. 63. – P.291-328.
4 Devenish R. And Cooper-Sarkar A. Deep Inelastic Scattering. – Oxford: Oxford University Press, 2004. – 416 p.
5 Martin A. D., Stirling W.J., Thorne R.S. and Watt G., Parton distributions for the LHC. //Eur. Phys. J. C. – 2009. – Vol.63. – P.189-285.
6 Forte S., Garrido L., Latorre J.I. and Piccione A. Neural network parametrisation of deep-inelastic structure functions //JHEP. – 2002. – Vol. 05. – P.062.
7 Ball R.D. and et al, A first unbiased global NLO determination of parton distributions and their uncertainties //Nucl. Phys. B. – 2010. – Vol. 838. – P.136-206.
8 Ball R. D. et al A determination of parton distributions with faithful uncertainty estimation //Nucl. Phys. B. – 2009. – Vol. 809. – P.1-63.
9 Ball R.D., Nocera E.R. and Juan Rojo The asymptotic behaviour of parton distributions at small and large x //Eur. Phys. J. C. – 2016. – Vol. 76 (7). – P.383.
10 Jacob J. Ethier and Emanuele R. Nocera, Parton distributions in nucleons and nuclei //Annu. Rev. Nucl. Part. Sci. – 2020. – Vol.70. – P.43-76.
11 Buckley A. et al, LHAPDF6: parton density access in the LHC precision //Eur. Phys. J. C. – 2015. – Vol.75. – P.132.
12 Mohammad Moosavi Nejad S., Khanpour, H., Tehrani, S.A. and Mahdi Mahdavi, QCD analysis of nucleon structure functions in deep-inelastic neutrino-nucleon scattering: Laplace transform and Jacobi polynomials approach //Phys. Rev. C. – 2016. – Vol.94. – Art.No 045201.
13 Jun Gao and Pavel Nadolsky, A meta-analysis of parton distribution functions //JHEP. – 2014. – Vol.07. – P.035.

References

1 H.L. Lai et al, Phys. Rev. D, 82, 074024 (2010).
2 S. Forte, Acta Phys. Polon. B, 41, 2859-2920 (2010).
3 S. Forte and G. Watt, Ann. Rev. Nucl. Part. Sci., 63, 291-328 (2013).
4 R. Devenish & A. Cooper-Sarkar, Deep Inelastic Scattering, (Oxford: Oxford University Press, 2004), 416 p.
5 A.D. Martin, W.J. Stirling, R.S. Thorne and G. Watt, Eur. Phys. J. C, 63, 189-285 (2009).
6 S. Forte, L. Garrido, J.I. Latorre and A. Piccione, JHEP, 05, 062 (2002).
7 R.D. Ball and et al, Nucl. Phys. B, 838, 136-206 (2010).
8 R.D. Ball and et al, Nucl. Phys. B, 809, 1-63 (2009).
9 R.D. Ball, E.R. Nocera and Juan Rojo, Eur. Phys. J. C, 76 (7), 383 (2016).
10 J. Jacob, Annu. Rev. Nucl. Part. Sci., 70, 43-76 (2020).
11 A. Buckley and et al, Eur. Phys. J. C, 75, 1322015 (2015).
12 Mohammad Moosavi Nejad S., H. Khanpour, S.A. Tehrani, and Mahdi Mahdavi, Phys. Rev. C, 94, 045201 (2016).
13 Jun Gao and P. Nadolsky, JHEP, 07, 035 (2014).