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Determination of Parton Distribution Functions with Jets at Forward Rapidity Region Using xFitter Analysis Framework

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Abstract

Parton distribution functions (PDF), which have to be determined from the measurements, are one of the main components to define the physics that occurs at the hadron colliders. In this study, a quantum chromodynamics (QCD) analysis was performed at the next-to-leading order (NLO) in the xFitter framework which is an open source QCD fit platform. Along with the HERA1+2 DIS and the jet differential cross-section data measured in the forward rapidity region ($3.2 < |y| < 4.7$) of the CMS detector in the LHC in proton-proton collisions at $\sqrt{s} = 8$ TeV were used in xFitter analysis framework. Particularly gluon distribution functions were emphasized.

Keywords: Jets, PDF, xFitter, gluon

xFitter Analiz Çerçevesi Kullanılarak İleri Rapidite Bölgesinde Jetler ile Parton Dağılım Fonksiyonlarının Belirlenmesi

Öz

Ölçümlerden belirlenmesi gereken parton dağılım fonksiyonları (PDF), hadron çarpıştırıcılarında meydana gelen fiziği tanımlayan ana bileşenlerden biridir. Bu çalışmada, açık kaynak kodlu bir kuantum renk dinamiği (QCD) fit platformu olan xFitter çerçevesinde ikincil mertebeden (NLO) bir QCD analizi yapılmıştır. HERA1+2 DIS ile birlikte $\sqrt{s} = 8$ TeV'de proton-proton çarpışmalarında LHC'deki CMS dedektörünün ileri rapidite bölgesinde ($3.2 < |y| < 4.7$) ölçülen jetlerin diferansiyel tesit kesit verileri xFitter analiz çerçevesinde kullanılmıştır. Özellikle gluon dağılım fonksiyonları üzerinde durulmuştur.

Anahtar Kelimeler: Jetler, PDF, xFitter, gluon

INTRODUCTION

The jets, collimated spray of particles produced in the forward rapidity region of the CMS detector at the LHC provide important information about the inner world of the protons structures, i.e. partons. Such information may help to reduce the uncertainties on the density of gluons in protons. The structure function variable of the proton, bjorken-*x*, is the ratio of the parton momentum to the hadron momentum and can be expressed as $x = p_{parton} / p_{hadron}$. Quantum Chromodynamics (QCD) describes the interaction between quarks mediated by eight gluon fields. Quarks and gluons have a new degree of freedom called color, which obeys the Pauli exclusion principle (Han and Nambu, 1965). Quantitative estimates describing the rates (cross sections) of strong interactions can be obtained using lattice gauge theory (Wilson, 1974) or perturbative QCD (pQCD). The pQCD can be used in the asymptotically free system, which is characterized by small distances and high energies where quarks and gluons are weakly bonded. This phenomenon is called asymptotic freedom and is a result of the nature of the strong nuclear force. The force between quarks and gluons increases with distance. We can imagine this freedom as the "leakage" of the color charge of virtual gluons into the surrounding space (Stirling et al., 2003). However, low-energy quarks sense a very high color space, and it becomes energetically favorable for a new quark-antiquark pair to arise and form colorless hadrons. As a result, quarks and gluons are bound or confined to color neutral hadrons. The strong coupling constant α_s is a key parameter of QCD.

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Therefore, its value is often determined from experimental measurements. A suitable reference scale large enough to allow a perturbative approximation is the *Z*-boson mass M_z. The world average value of strong coupling measured on the Z-boson mass scale is α_s (M_Z) = 0.1181 ± 0.0011 (Particle Data Group, 2016). This value was determined from various measurements such as hadronic τ-decays, pQCD calculations, e^+e^- processes, Deep Inelastic Scattering (DIS) and LHC data (Tanabashi et al., 2018). Figure 1 shows the α_s values determined using data from different experiments. Jet production in the CMS experiment at the LHC provides important information for the determination and investigation of varying α_s (running coupling constant) values.

MATERIAL AND METHODS

To determine how the partons are connected to one another and the internal property of the proton, it is necessary to understand the proton structure very well. The structure of the proton is characterized by the parton distribution functions (PDFs) which represent the probability density of finding a parton that carries as much as *x* of the proton's momentum. Even though the scale of PDFs is estimated by pQCD, the dependency on *x* should be determined by experimental results. PDFs are extracted by various groups such as ABMP (Alekhin et al., 2016), NNPDF (Ball et al., 2017), MMHT (Luthe et al., 2017), HERAPDF (Abramowicz and et al., 2015) and CT (Dulat et al., 2016) making universal adaptations to a wide range of measurements from different experiments.

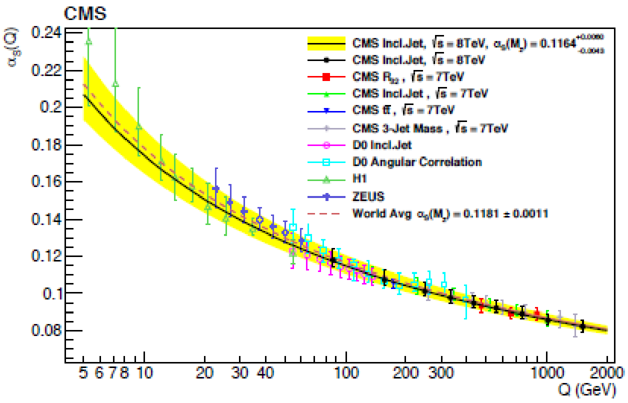

Figure 1. The variation of α_s (*Q*) as a function of the *Q* scale is shown, along with determinations from different experiments and observables. The black dots in the figure are determined from the CMS experiment using inclusive jet measurement at $\sqrt{s}$ = 8 TeV (Khachatryan et al., 2017).

2.1. Jet Production

As a result of the confinement property of QCD, single quarks and gluons cannot be observed as free particles. Instead, partons produced in high-energy collisions emit other partons that cause hadron showers called “jets”. The properties of the first parton are closely related to the properties of an emerging jet. Thus, jets provide the link between the observed final state hadrons and the essential information on PDFs and QCD parameters.

2.2. xFitter QCD Analysis Package

The rapid flow of data from LHC experiments and corresponding theoretical developments provide predictions for increasingly complex processes of higher orders. The improvements in the amount of data and in theory calculations motivated the development of a tool to bring them together in a fast, efficient, and open source framework called xFitter (formerly HERAFitter) (Alekhin et al., 2015, Bertone et al., 2017) which includes a set of tools to facilitate complete QCD analysis of *pp*, $p\bar{p}$ and *ep* scattering data. It is developed to extract fundamental parameters of QCD and heavy quark masses and strong coupling constant for the determination of PDFs. It also provides a common framework for comparing different theoretical approaches. It can also be used to test the effect of new experimental data on PDFs in Standard Model (SM) parameters. The structure and functionality of xFitter can be

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divided into four main blocks: data, theory, QCD analysis, and results, as illustrated in Figure 2.

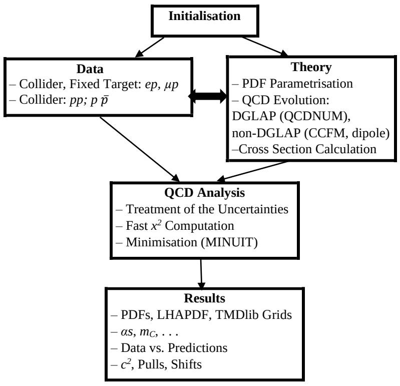

Figure 2. An illustration of xFitter's structure and functionality with four main blocks data, theory, QCD analysis, and results.

RESULTS AND DISCUSSION

Proton PDFs are parameterized with a large number of parameters depending on the analysis performed. Parameterization becomes difficult, since PDFs cannot yet be calculated directly and must be determined from experimental data. PDF constraint requires a large amount of experimental data covering a wide range of kinematics sensitive to different kinds of partons inside the proton. PDFs are fundamental components that allow us to make theoretical predictions for experimental measurements of protons and hadrons. xFitter is an open source QCD analysis platform for determining PDFs and related key parameters of SM by fitting them to experimental data. The comparison of the theory with the CMS forward rapidity jet data obtained at $\sqrt{s}$ = 8 TeV corresponding to 5.6 pb^{-1} integrated luminosity using the xFitter analysis framework. The distributions of valence up (u_V) and down (d_V) quarks and total sea (Σ *:quark-antiquark pairs*) quark at the initial energy scale Q^2 = 1.9 GeV^2 are shown in Figure 3. PDFs obtained with HERA1+2 DIS and CMS forward region inclusive jet data are represented by a blue band, and those obtained without CMS jet data are represented by a red band.

A QCD analysis was performed by adding the forward region CMS inlcusive jet data at $\sqrt{s}$ = 8 TeV to the HERA1+2 DIS data. As a result of the present analysis, it is clearly seen that the addition of forward region jet data does not differ from the distributions of the up (u_V), down (d_V) quark and total sea distributions obtained only from the HERA1+2 DIS data. However, when we look at the gluon distributions obtained at two different values of $\alpha_S = 0.118$ (left graph) and $\alpha_S = 0.121$ (right graph) at Q^2 = 1.9 GeV^2 in Figure 4, a decrease in uncertainty of gluon PDF is observed. In the case of $\alpha_S = 0.118$, a slight improvement is obtained on the gluon PDF uncertainty whereas only a shift in the uncertainty band for $\alpha_S = 0.121$. The gluon PDF is also sensitive to the chosen α_S value. The ratio of gluon to the total sea quark distribution is shown in Figure 5. A decrease in the uncertainty band is observed when the CMS forward region inclusive jet data is used together with the HERA1+2 DIS data, particularly in regions where x is close to the value of 1.

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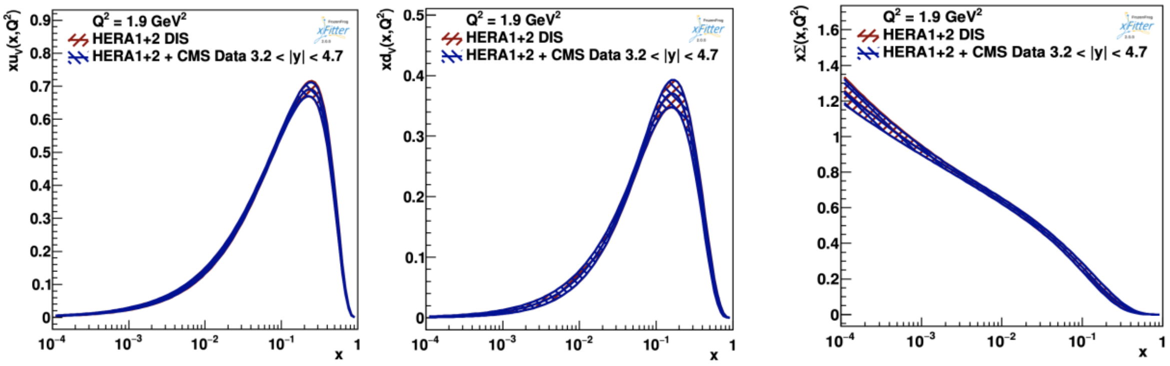

Figure 3. Distributions of valence up (u_V), down (d_V) quarks, and total sea (Σ) quark as functions of x at the starting scale Q^2 = 1.9 GeV^2. PDFs obtained with HERA1+2 DIS and CMS forward region inclusive jet data are represented by blue band, and those obtained without CMS jet data are represented by a red band.

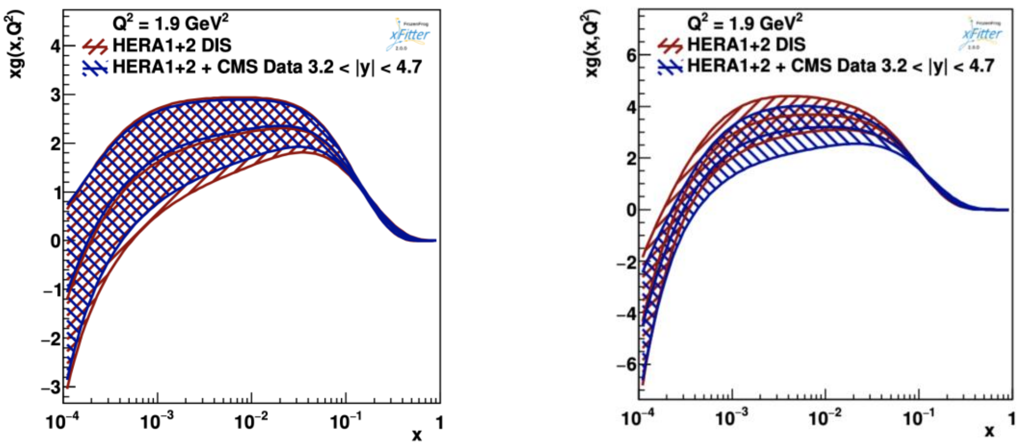

Figure 4. Gluon distributions obtained at two different values of α_S = 0.118 (left) and α_S = 0.121 (right) at Q^2 = 1.9 GeV^2. PDFs obtained with HERA1+2 DIS and CMS forward region inclusive jet data are represented by a blue band, and those obtained without CMS jet data are represented by a red band.

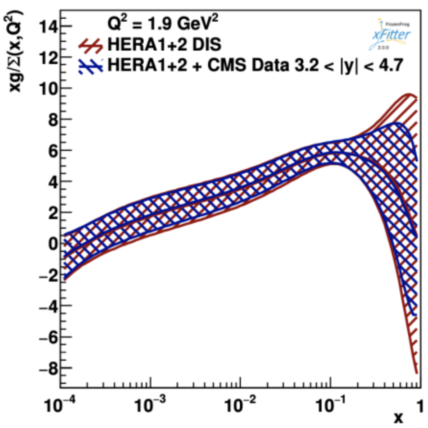

Figure 5. Distribution of the ratio of gluon to total sea quark at Q^2 = 1.9 GeV^2.

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CONCLUSION

Jet-related data, such as differential jet cross-section measurements, allow calculation of PDFs and strong coupling constant if supported by theory calculations with sufficient precision. Based on the results obtained from the present study, it is recommended to use jet production cross-section data obtained at the forward region of the CMS experiment.

As a result of this analysis, it is seen that the addition of forward region jet data does not differ from the distributions of the up (u_V), down (d_V) quark and total sea distributions obtained only from the HERA1+2 DIS data. However, the gluon distributions obtained at two different values of strong coupling constant α_S showed a decrease in uncertainty of gluon PDF. This clearly indicates that the gluon PDF is also sensitive to the value of chosen strong coupling constant α_S. A decrease on the ratio of gluon distribution to the total sea is observed when CMS forward region inclusive jet data is used together with HERA1+2 data, especially in regions where x is close to the value of 1.

CONFLICT OF INTEREST

The authors report no conflict of interest relevant to this article

RESEARCH AND PUBLICATION ETHICS STATEMENT

The authors declare that this study complies with research and publication ethics.

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