Impact of the top quark cross section data on parton distribution functions

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Abstract

Recent measurements of top quark pair production cross section, which is performed at the LHC and the Tevatron collider, are studied using Hessian profiling technique to obtain their impact on the parton distribution functions (PDFs). The top quark production data covers different center-of-mass energies $\sqrt{s}= 1.96, 5.02, 7, 8$ and 13 TeV in either $pp$ or $p\bar{p}$ collisions. It is explained how the Hessian profiling method may be used to assess the impact of these new data on PDFs and consequently on their predictions. In this research, the impact of recent measurements of top quark pair cross sections on different CT14, MMHT2014, and NNPDF3.0 PDF sets is investigated. The analysis results show that the recent top quark production at the LHC and Tevatron data provide significant constraints in particular on the central value, relative uncertainties or both for the s-quark distribution and the gluon PDFs in both of CT14, MMHT2014 PDF sets and are insensitive to valence-quark PDFs. A small constraint on the $\bar{u}$-sea quark distribution for CT14 PDF is also observed. There is no impact on the NNPDF3.0 PDF set in presence of these data.

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I. INTRODUCTION

Parton distribution functions (PDFs) are a fundamental input into lepton-hadron and hadron-hadron collider physics for both the experimental and theoretical high energy particle physics. A recent review of the progress in determination of PDFs, with the main emphasis on the usages for accurate phenomenology at the Large Hadron Collider (LHC), is reported in Ref. [1]. Since PDFs and their associated uncertainties play an important role in various LHC applications, so there are enough motivations to improve our understanding of the internal structure of the proton.

By utilizing experimental data, physical theories and proper mathematical methods implemented in computational tools, we are able to find better descriptions for PDFs inside the nucleons [2, 3]. As it is expected, released data by experimental groups in colliders have played a prominent role in increasing our understanding of hadrons. Almost all of the theoretical predictions in a hadron collider depend on the choice of PDFs. On the other hand, the measurements from the colliders can be used to improve the PDFs.

In the recent years, variety of PDF sets [4–9] are extracted and published by various research groups. There are continuous efforts to improve PDFs, either by fitting new experimental data or by using new computational methods.

Top quark is the heaviest elementary particle ($m_t > 170$ GeV) [10], which was discovered in CDF [11] and DØ [12] experiments in 1995. It is expected that top quark plays an important role in the electroweak symmetry breaking because it is the only fermion which is close to its scale.

Knowing top quark properties provides a unique opportunity to test the predictions of the standard model (SM) of the particles physics. Top quark is considered as a window to physics beyond the standard model (BSM). In hadron colliders, top quark is produced dominantly in pairs via QCD interactions, where quark-antiquark or gluon-gluon are fused to a high energy gluon that mediates the momentum to a top-antitop ($t \bar{t}$) pair. Top quark pair production can be considered as a motivation of many researches [13–20] seeking a deviation from the SM predictions as a signature of BSM. The total and differential $t \bar{t}$ production cross section are among the important observables at the hadron colliders, which have been measured with a high precision. The recent measurements of the total $t \bar{t}$ pair production cross section are reported by ATLAS [21, 23] and CMS [24, 29] collaborations at
LHC, and DØ [30] collaboration at Tevatron. The measurements of the differential $t\bar{t}$ cross section is provided by ATLAS [31] and CMS [32] collaborations at LHC. Both experimental measurements are used in this analysis to constrain the PDF’s.

In order to obtain the most comprehensive PDF constraints, different theoretical groups perform the global QCD fits of the experimental data. To study the impact of new experimental measurements, one can perform a QCD global analysis with including the new data to the base data.

To estimate the impact of new experimental measurements on the PDFs, we can use the approximate methods that can be used instead of a complete QCD fit, as an alternative approach. In this regard, one can use the Bayesian Monte Carlo reweighting and Hessian profiling techniques, as the approximate methods. As an example, the impact of the W-boson charge asymmetry and of Z-boson production cross sections data based on the Bayesian Monte Carlo reweighting and Hessian profiling techniques are reported in Refs. [33–36].

Comparing theoretical predictions and experimental measurements can be used to constrain the PDFs, strong coupling constant ($\alpha_s$) and top quark mass ($m_t$). The central values and theoretical uncertainties for CT14, MMHT2014 and NNPDF3.0 are not all close to each other, except in the certain regions of $x$. The goal of this analysis is finding the impact of the new measurements of the production cross section of the top quark pair ($t\bar{t}$) [21–32] on the modern CT14 [4], NNPDF3.0 [6] and MMHT2014 [5] PDF sets using the Hessian profiling technique [37], without need of having a complete baseline global PDF fit procedure.

In this article, the QCD analysis is performed based on xFitter open source framework [38, 39]. The recent top quark production data which are not included in the main xFitter package are added. In Refs. [40–45], we used xFitter for different QCD analyses, such as the study of different schemes in the QCD analysis and determination of the strong coupling constant.

The focus of this paper is to show how top quark new data can be used to constrain the PDFs (especially in the central value) and uncertainties or both for $s$-quark PDF and the gluon PDF at the large-$x$. In Ref. [36], the impact of the Tevatron $W$ and $Z$ data on the MMHT2014 NLO set is reported that shows a reduction of the PDF uncertainties in the $d$-valence PDF.

The outline of the paper is as follows. In Sec. [II] the data samples are introduced and in Sec. [III] a brief review of Hessian profiling method is described. In Sec. [IV] the theoretical
calculation and tools of the present analysis are explained. The impact of the new data on the central value and uncertainty of the PDFs is shown in Sec. V. Finally, the results obtained in the paper are summarized in Sec. VI.

II. THE TOP CROSS-SECTION MEASUREMENTS AND UNCERTAINTIES

Before remarking the general impact of the t\bar{t} pair production cross section data, a brief explanation about these data is useful. The detailed discussion is given in Ref. [17, 46] for the t\bar{t} pair production cross section data, but for completeness we present a summary below with only focusing to recent t\bar{t} pair production cross section measurements.

The recent measurements of t\bar{t} pair production cross section by ATLAS [21–23, 31] and CMS [24–29, 32] collaborations at LHC and DØ [30] collaboration at Tevatron, are considered in the present study. The ATLAS experiment [21] at LHC has measured the t\bar{t} production cross section in events containing an opposite-charge electron-\mu (e\mu) pair. The measurement uses 4.6 (20.3) fb\(^{-1}\) of data in \(\sqrt{s} = 7\) TeV (8 TeV). The corresponding measurement in \(\sqrt{s} = 13\) TeV uses 3.2 fb\(^{-1}\) of data [23]. The same experiment, has also measured the cross section in lepton+jets final state in \(\sqrt{s} = 8\) TeV with 20.2 fb\(^{-1}\) of data [22]. In another analysis, the ATLAS experiment has reported a measurement for the differential t\bar{t} cross section as a function of the top-quark transverse momentum [31]. The analysis uses 4.6 fb\(^{-1}\) of data in \(\sqrt{s} = 7\) TeV in lepton+jets final state.

The other main experiment at LHC, the CMS experiment, has also provided several results for the t\bar{t} cross section measurement. In a unique analysis, the cross-section is measured in \(\sqrt{s} = 5.02\) TeV, using 0.026 fb\(^{-1}\) of data. The events are required to have an opposite-charge e\mu pair and at least two jets. The same final state is used in \(\sqrt{s} = 7\) TeV (8 TeV) with 5 (19.7) fb\(^{-1}\) of data to measure the cross section [25]. The measurement in \(\sqrt{s} = 13\) TeV uses 2.2 fb\(^{-1}\) of data collected in 2015 [27]. The CMS experiment has measured the cross section also in lepton+jets final state [26]. The analysis uses 5 (19.6) fb\(^{-1}\) of data in \(\sqrt{s} = 7\) TeV (8 TeV). The measurement in this final state in \(\sqrt{s} = 13\) TeV using 3.2 fb\(^{-1}\) of data is reported in Ref. [28]. The CMS experiment has also published a result for the t\bar{t} cross section measurement in the fully hadronic final state based on 2.53 fb\(^{-1}\) of data collected in \(\sqrt{s} = 13\) TeV [29]. This experiment has combined the data from dilepton and lepton+jets final states to measure the differential t\bar{t} cross section as a function of different
kinematic variables \[32\]. The analysis uses 5 fb\(^{-1}\) of data in \(\sqrt{s} = 7\) TeV.

The DØ experiment at Tevatron has recently published a paper \[30\] on \(t\bar{t}\) cross section measurement in \(p\bar{p}\) collisions in \(\sqrt{s} = 1.96\) TeV. The analysis uses 9.7 fb\(^{-1}\) of data and each event is forced to have either one or two leptons.

In Tables I and II, the differential cross sections of top quark reported by ATLAS \[31\] and CMS \[32\] are summarized.

| \(p_T\) [GeV] | \(\frac{1}{\sigma} \frac{d\sigma}{dp_T}\) [GeV\(^{-1}\)] | Stat. [%] | Sys. [%] |
|---------------|----------------------------------|-----------|---------|
| 0 to 50       | \(3.4 \cdot 10^{-3}\)            | ± 2.4     | ± 5.1   |
| 50 to 100     | \(6.7 \cdot 10^{-3}\)            | ± 1.2     | ± 1.9   |
| 100 to 150    | \(5.3 \cdot 10^{-3}\)            | ± 2.5     | ± 2.6   |
| 150 to 200    | \(2.6 \cdot 10^{-3}\)            | ± 2.0     | ± 4.8   |
| 200 to 250    | \(1.12 \cdot 10^{-3}\)           | ± 2.4     | ± 4.8   |
| 250 to 350    | \(0.32 \cdot 10^{-3}\)           | ± 3.5     | ± 5.5   |
| 350 to 800    | \(0.018 \cdot 10^{-3}\)          | ± 6.1     | ± 11    |

TABLE I: Normalized differential cross-sections as a function of the transverse momentum measured by the ATLAS collaboration. The statistical and systematic uncertainties are also reported.

| \(p_T\) [GeV] | \(\frac{1}{\sigma} \frac{d\sigma}{dp_T}\) [GeV\(^{-1}\)] | Stat. [%] | Sys. [%] |
|---------------|----------------------------------|-----------|---------|
| 0 to 60       | \(4.54 \cdot 10^{-3}\)            | ± 2.5     | ± 3.6   |
| 60 to 100     | \(6.66 \cdot 10^{-3}\)            | ± 2.4     | ± 4.9   |
| 100 to 150    | \(4.74 \cdot 10^{-3}\)            | ± 2.4     | ± 3.2   |
| 150 to 200    | \(2.50 \cdot 10^{-3}\)            | ± 2.6     | ± 5.1   |
| 200 to 260    | \(1.04 \cdot 10^{-3}\)            | ± 2.9     | ± 5.5   |
| 260 to 320    | \(0.38 \cdot 10^{-3}\)            | ± 3.7     | ± 8.2   |
| 320 to 400    | \(0.12 \cdot 10^{-3}\)            | ± 5.8     | ± 9.5   |

TABLE II: Normalized differential cross-sections as a function of the transverse momentum measured by the ATLAS collaboration. The statistical and systematic uncertainties are also reported.

In Table III, the specifications of the recent experimental measurements of the top quark
The recent measurements of top quark pair production total cross section in different center-of-mass energies with corresponding uncertainties are summarized.

### TABLE III

| $\sqrt{s}$ | Ref. | $\sigma_{\text{Exp.}}^{\text{tot}}(t \bar{t})$ [pb] |
|------------|------|------------------------------------------|
| ATLAS Experiment at LHC |
| 7 TeV [21] | $182.9 \pm 3.1\text{(stat.)} \pm 4.2\text{(syst.)} \pm 3.6\text{(lumi.)} \pm 3.3\text{(beam)}$ |
| 8 TeV [21] | $242.9 \pm 1.7\text{(stat.)} \pm 5.5\text{(syst.)} \pm 5.1\text{(lumi.)} \pm 4.2\text{(beam)}$ |
| 8 TeV [22] | $248.3 \pm 0.7\text{(stat.)} \pm 13.4\text{(syst.)} \pm 4.7\text{(lumi.)}$ |
| 13 TeV [23] | $818 \pm 8\text{(stat.)} \pm 27\text{(syst.)} \pm 19\text{(lumi.)} \pm 12\text{(beam)}$ |
| CMS Experiment at LHC |
| 5.02 TeV [24] | $82 \pm 20\text{(stat.)} \pm 5\text{(syst.)} \pm 10\text{(lumi.)}$ |
| 7 TeV [25] | $173.6 \pm 2.1\text{(stat.)} \stackrel{+4.5\text{(syst.)}}{-4}\pm 3.8\text{(lumi.)}$ |
| 7 TeV [26] | $161.7 \pm 6\text{(stat.)} \pm 12\text{(syst.)} \pm 3.6\text{(lumi.)}$ |
| 8 TeV [26] | $227.4 \pm 3.8\text{(stat.)} \pm 13.7\text{(syst.)} \pm 6\text{(lumi.)}$ |
| 8 TeV [25] | $244.9 \pm 1.4\text{(stat.)} \stackrel{+6.3\text{(syst.)}}{-5.5}\pm 6.4\text{(lumi.)}$ |
| 13 TeV [27] | $815 \pm 9\text{(stat.)} \pm 38\text{(syst.)} \pm 19\text{(lumi.)}$ |
| 13 TeV [28] | $888 \pm 2\text{(stat.)} \stackrel{+26\text{(syst.)}}{-28}\pm 20\text{(lumi.)}$ |
| 13 TeV [29] | $834 \pm 25\text{ (stat.)} \stackrel{+118\text{(syst.)}}{-104}\pm 23\text{(lumi.)}$ |
| DØ Experiment at Tevatron |
| 1.96 TeV [30] | $7.26 \pm 0.13\text{ (stat.)} \stackrel{+0.57\text{(syst.)}}{-0.50}$ |

III. HESSIAN PROFILING TECHNIQUE

To study the impact of new experimental measurements on the PDFs, one can perform a QCD global fit analysis using the experimental data. As an alternative approach, an approximate method can be used instead of a complete QCD fit. The profiling technique is the approximate method that can be applied for PDFs extracted by Hessian method [38].

Generally, there are two approximate methods such as Bayesian Monte Carlo reweighting.
and Hessian profiling techniques. The main benefit of using these two techniques is that they can be applied to find the impact of new experimental data on a preexisting PDF. It should be noted that these approximate methods have a number of limitations. For example, if the impact of new measurements is very large, these methods can not be useful and in particular are not able to explain the effect on the input PDF parametrization, or in the theoretical calculations. Therefore, not only when using these approximate methods some care should be taken but also we should care when interpreting their results.

The Hessian profiling technique is based on the $\chi^2$ minimization method using a comparison between the theoretical predictions extracted with a given input Hessian PDF set and the new experimental data. According to this method, the $\chi^2$ definition with taking into account the uncertainties of experimental data and the effects from the variations of PDF which is encoded by the Hessian eigenvectors, is as following

$$\chi^2(\beta_{\text{exp}}, \beta_{\text{th}}) = \sum_{i=1}^{N_{\text{data}}} \left( \frac{[\sigma_i^{\text{exp}} + \sum_j \Gamma_{ij}^{\text{exp}} \beta_{j, \text{exp}}] - [\sigma_i^{\text{th}} + \sum_k \Gamma_{ik}^{\text{th}} \beta_{k, \text{th}}]}{\delta_i^2} \right)^2 + \sum_j \beta_{j, \text{exp}}^2 + \sum_k \beta_{k, \text{th}}^2(1)$$

where $\delta_i$ is the total experimental uncorrelated uncertainty, $\beta_{j, \text{exp}}$ and $\beta_{k, \text{th}}$ are the parameters corresponding to the set of fully correlated experimental systematic uncertainties and the PDF Hessian eigenvectors, respectively. Also in above equation, $N_{\text{data}}$ is the number of experimental data points which is being added into the fit, and finally the matrices $\Gamma_{ij}^{\text{exp}}$ and $\Gamma_{ik}^{\text{th}}$ encode the effects of the corresponding $\beta_{j, \text{exp}}$ and $\beta_{k, \text{th}}$ parameters on the experimental data and on the theory predictions, respectively.

After minimizing the $\chi^2$ in Eq. (1), the corresponding values of the theoretical $\beta_{k, \text{th}}^{\min}$ parameters can be interpreted as leading to optimized PDFs (“profiled”) to explain the new specific measurement. In the next sections it will be seen how profiling method modifies both central values and total PDF uncertainties.

IV. THEORETICAL PREDICTIONS OF TOP QUARK PRODUCTION

The cross-section of the $t\bar{t}$ production is one of the most important measurements among different top quark measurements. The SM predictions for this measurement involve both the QCD calculations of the partonic processes and also PDF used to integrate the partonic cross section. The next-to-leading-order (NLO) production cross section of un-polarized
and polarized top quark pair are calculated in Refs. [47–49]. Beyond the NLO accuracy, the resummation of the soft gluon emission at next-to-leading-logarithmic (NNL) correction is investigated in Refs. [50, 51]. At this time, the next-to-next-to-leading-order (NNLO) corrections to inclusive production of $t\bar{t}$ pair, accomplished in Refs. [52–55], are needed to improve the computational tools [56–63].

There are many different computational tools to calculate the $t\bar{t}$ production cross section such as HATHOR [64], Top++ [65], DiffTop [66] and MCFM [67]. Although DiffTop is capable to calculate both total and differential cross section of $t\bar{t}$ pair production.

As it is expected from the PDFs of proton and antiproton, gluon-gluon fusion is dominant in $t\bar{t}$ production in proton-proton colliders like LHC. About 80% of $t\bar{t}$ pairs in LHC at the center-of-mass energy of ($\sqrt{s} = 7$) TeV are from gluon-gluon fusion. The fraction grows with $\sqrt{s}$ and can reach 90% in $\sqrt{s} = 14$ TeV [10]. So the $t\bar{t}$ production cross section measurement from LHC can mainly constrain the gluon PDF. Due to high mass of the top quark, the $t\bar{t}$ production cross section receives the main contribution from high-$x$ gluon distribution which is affected by considerable uncertainty.

In this analysis, the HATHOR and DiffTop computational programs at NNLO which are implemented in xFitter [38], the new version of HeraFitter [39], is used to include the $t\bar{t}$ cross section measurements, following the profiling method.

V. RESULTS AND DISCUSSION

To study the impact of top quark cross section measurements on a given PDF set, the Hessian profiling method is used. This approximate method incorporates the information contained in new measurements into an existing specific PDF sets without the need for refitting.

The top cross section from LHC and Tevatron are used to update the proton PDFs using the profiling method, utilized by the Thorne-Roberts (TR) scheme [68] of General-Mass Variable Flavour Number (GM-VFN) scheme. The values of top quark mass, $m_t$, and strong coupling constant at Z boson mass, $\alpha_s(M_Z)$, are set to 173.3 GeV and 0.118, respectively.

The CT14, MMHT2014 and NNPDF3.0 parton distribution functions, in different confidence level are available in LHAPDF library [69] which is interfaced to xFitter. The
theoretical calculation of the total top quark cross section and the relevant uncertainty using different PDF sets for LHC and Tevatron center of mass energies are presented in Table IV.

| PDF Sets     | LHC [TeV] | Tevatron [TeV] |
|--------------|-----------|----------------|
|              | 5.02      | 7              | 8              | 13             | 1.96          |
| CT14         | 66.16 +6.4| 172.45 +12.68  | 246.36 +16.14  | 806.52 +34.94  | 7.24 +0.41    |
|              |           | +10.65         | +14.1          | -35.5          | -0.26         |
| MMHT2014     | 66.36 +1.8| 172.07 +3.83   | 245.62 +5.1    | 804.21 +13.33  | 7.33 +0.206   |
|              |           | -2.62          | -5.37          | -7             | -17.08        |
| NNPDF3.0     | 64.88 ±4.8| 170.16 ±4.26   | 243.66 ±5.53   | 803.26 ±14.19  | 7.16 ±0.132   |

TABLE IV: The total NNLO top quark total cross section [pb] prediction and total theoretical uncertainties calculated by Hathor at LHC and Tevatron run II energies for CT14, MMHT2014 and NNPDF3.0 PDF sets.

To apply the profiling technique for a PDF set, only the new top quark measurements which are not included in that PDF sets are considered. The compatibility of the new measurements with the CT14, MMHT2014 and NNPDF3.0 sets is tested by computing the $\chi^2$ function of Eq. (1).

In Fig. 1, the original and profiled CT14, MMHT2014 and NNPDF3.0 parton distribution functions for $xg$ gluon PDF at the NNLO are presented. It can be seen that the recent top quark measurements at the LHC and Tevatron provide significant constraints in particular on the central value and the uncertainties of $xg$ for CT14, MMHT2014. There is no impact on the NNPDF3.0 PDF set. So, we study the impact of these data on the CT14, MMHT2014 PDF sets only.

The comparison between original and profiled parton distribution of $xu_v, xd_v, x\bar{u}, x\bar{d}, xs, xg$ extracted from CT14 PDFs are presented in Fig. 2. According to this figure, the new top quark cross section data provide significant constraints on the central values and their uncertainties of $xs$, and $xg$ PDFs. In Fig. 3 the most significant impact of new measurements are observed only on the gluon PDF ratio.

The impact of the recent measurements of top quark cross section on the parton distribution ratio $xu_v/x_{u_{rel}}$, $xd_v/x_{d_{rel}}$, $x\Sigma/x_{\Sigma_{rel}}$, and $xg/x_{g_{rel}}$ for CT14 PDFs are represented in Fig. 4.
same as figures 2 and 3, the results for MMHT2014 are shown in Figs. 5 and 6. It is seen
that the new top quark cross section data provide significant changes on the central values
and the uncertainties of $xs$ and $xg$ PDFs.

According to Fig. 6, the relative PDF uncertainty of $x\delta u_v/xu_v$ is affected at low and
large-$x$. Also, the relative PDF uncertainty of $x\delta \Sigma/x\Sigma$ is affected at medium-$x$, but the
relative PDF uncertainty of $x\delta g/xg$ decreases significantly at high $x$. Finally, in Fig. 7 the
impact of the recent top quark cross section data on the parton distribution ratio $xu_v/xu_{v,ref}$,
$xd_v/xd_{v,ref}$, $x\Sigma/x\Sigma_{ref}$, and $xg/xg_{ref}$ for MMHT2014 PDFs are presented.

The profiling procedure using new set of top quark pair production data improves agree-
ment of the strange $xs$ and gluon distributions between the CT14 and MMHT2014 PDF sets. Figures 8 and 9 show a direct comparison between CT14 and MMHT2014 sets.

VI. CONCLUSION

In fact, a large part of high energy collider physics depends on the knowledge of PDFs in
QCD. The PDFs determination in global analyses is a complex procedure, which needs the
parametrization using the fits of experimental data. Although different PDF parameteriza-
tions are available for a general user, finding the impact of new measurements of the data
on PDFs without doing a global QCD analysis would be worthwhile. For example, we can find
which kind of PDFs can be affected in the presence of a specific new data. In this regard,
the Hessian profiling technique is a good choice.

We have discussed how to investigate the effects that a new set of top quark pair produc-
tion measurements have within an existing PDF set. Using the profiling formalism we have
determined the impact of the recent top quark pair production data on the different PDFs.
The gluon PDF is one of the worth known parton distribution functions and deep inelastic
scattering data constrain the gluon only indirectly, and direct information comes only from
the inclusive jet production measurements.

The CT14 and MMHT2014 PDFs are profiled according to Eq. (1). The results of the
profiling on $s$ and gluon PDFs, their relative uncertainties, and on the PDF ratios with
respect to before profiling procedure are shown. The profiling affects the shape of the PDF
more for the CT14 when compared to MMHT2014 PDF set. In the present paper, we
observed a small impact on $x\bar{u}$, a significant on both central values and uncertainties of $xs$
and gluon PDFs for CT14 and MMHT2014.

A significant reduction of the relative gluon uncertainties is obtained in the large $x$ for MMHT2014 PDF set. However, a significant reduction of the uncertainties is observed in the medium and large $x$ for CT14 PDF set.

The profiling procedure using new set of top quark affected the strange $x$s and gluon distributions at the CT14 and MMHT2014 PDF sets. These findings are interesting and show the significance of the top quark production cross section data to constrain gluon and strange PDFs, and suggest that the data should be used in the future global QCD analyses.

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FIG. 1: The gluon PDFs and relative uncertainties extracted from profiled CT14 [4], MMHT2014 [5], and NNPDF3.0 [6] PDF sets at 1.9 GeV$^2$ as a function of $x$. The results obtained after the profiling procedure compared with corresponding same features before profiling.
FIG. 2: The parton distribution of $xu$, $xd$, $x\bar{u}$, $xd$, $xs$, and $xg$ extracted from CT14 [4] PDFs as a function of $x$ at 4, 10, 100, and 8317 GeV$^2$. The results obtained after the profiling procedure compared with corresponding same features before profiling. Newly added top quark data obviously affected distributions of $xs$, and $xg$. 
FIG. 3: The relative PDF uncertainties $\delta x_u/x_u$, $\delta x_d/x_d$, $\delta x_\Sigma/x_\Sigma$, and $\delta x_g/x_g$ extracted from CT14 PDFs as a function of $x$ at 4, 10, 100, and 8317 GeV$^2$. The results obtained after the profiling procedure compared with corresponding same features before profiling. Newly added top quark data obviously constrained distributions of $\delta x_\Sigma/x_\Sigma$, and $\delta x_g/x_g$. 
FIG. 4: The parton distribution ratio $xu/xu_{\text{ref}}$, $xd/xd_{\text{ref}}$, $x\Sigma/x\Sigma_{\text{ref}}$, and $xg/xg_{\text{ref}}$ with respect to without profiling procedure, extracted from CT14 PDFs as a function of $x$ at 4, 10, 100, and 8317 GeV$^2$. The results obtained after the profiling procedure compared with corresponding same features before profiling.
FIG. 5: The parton distribution of $xu$, $xd$, $\bar{u}$, $\bar{d}$, $x\bar{s}$, and $xg$ extracted from MMHT2014 PDFs as a function of $x$ at 4, 10, 100, and 8317 GeV$^2$. The results obtained after the profiling procedure compared with corresponding same features before profiling.
FIG. 6: The relative PDF uncertainties $\delta x_{u}/x_{u}$, $\delta x_{d}/x_{d}$, $\delta x_{\Sigma}/x_{\Sigma}$, and $\delta x_{g}/x_{g}$ extracted from MMHT2014 PDFs as a function of $x$ at 4, 10, 100, and 8317 GeV$^2$. The results obtained after the profiling procedure compared with corresponding same features before profiling. Newly added top quark data obviously constrained distributions of $\delta x_{\Sigma}/x_{\Sigma}$, and $\delta x_{g}/x_{g}$. 

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FIG. 7: The parton distribution ratio \( xu_\text{v}/xu_{\text{v},\text{ref}} \), \( xd_\text{v}/xd_{\text{v},\text{ref}} \), \( x\Sigma/x\Sigma_{\text{ref}} \), and \( xg/xg_{\text{ref}} \) with respect to without profiling procedure, extracted from MMHT2014 PDFs as a function of \( x \) at 4, 10, 100, and 8317 GeV\(^2\). The results obtained after the profiling procedure compared with corresponding same features before profiling.
FIG. 8: The compression of parton distribution of $x_s$, and $x_g$ extracted from MMHT2014 [5] and CT14 [4] PDFs as a function of $x$ at 4, 10, 100, and 8317 GeV$^2$. The results obtained before profiling.

FIG. 9: The compression of parton distribution of $x_s$, and $x_g$ extracted from MMHT2014 [5] and CT14 [4] PDFs as a function of $x$ at 4, 10, 100, and 8317 GeV$^2$. The results obtained after profiling.