PROCEEDINGS OF SCIENCE

α_s from parton densities

Joey Huston[*]
Dept. of Physics and Astronomy, Michigan State University, East Lansing, MI 48824-1116, USA
E-mail: huston@pa.msu.edu

The sensitivity of global parton distribution function (PDF) fits to determine the value of $\alpha_s(m_Z)$ is reviewed.

α_s(2019): Workshop on precision measurements of the QCD coupling constant
11-15 February, 2019
Trento, Italy

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[*] Speaker.

PoS(ALPHAS2019)015

There are over 3500 data points in modern global PDF fits, including data from deep-inelastic scattering (DIS), Drell–Yan (DY) production, inclusive jet and dijet production, and from top production, the latter both singly differential and double-differential in the relevant kinematic variables. The state-of-the art is the production of parton distribution functions (PDFs) at NNLO, although it is common to also produce sets at NLO and LO. The NLO and NNLO PDFs are typically very similar to each other, while the LO PDFs deviate substantially due to the absence of critical higher order corrections. All of the processes in a global PDF fit are sensitive to the value of $\alpha_s(m_Z)$, with the power of $\alpha_s(m_Z)$ in the prediction depending on the process (and the order). Thus, a global PDF fit can be used in the determination of $\alpha_s(m_Z)$.

There are two philosophies in global PDF fitting; either allow $\alpha_s(m_Z)$ to be free in the fit, or to to fix its value at some standard, typically the value quoted by the Particle Data Group. The widespread standard is to use a central value of $\alpha_s(m_Z)$ of 0.118 (basically an approximation/truncation of the PDG result) and an uncertainty (at the 90% confidence level) of ±0.002, or ±0.0012 at the 68% CL. This central value and uncertainty is typically used for both NLO and NNLO global PDF fits. In LO PDF fits, a much larger value is needed, typically in the range 0.130-0.140. (It is difficult to quote an uncertainty for $\alpha_s(m_Z)$ for LO PDF fits, just as it is difficult to quote an uncertainty for the PDFs themselves, again due to the deficiencies of the LO matrix elements.) Thus, for example, the PDF4LHC15 PDFs, a combination of the PDFs from the CT, MMHT and NNPDF groups, uses this standard [1].

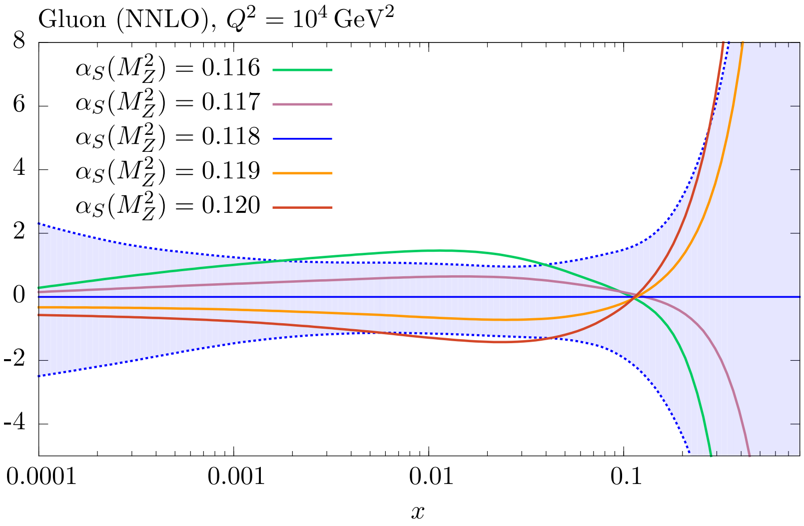

Figure 1: The MMHT NNLO gluon distribution plotted for several values of $\alpha_s(m_Z)$, from Ref. [2]. Also shown is the PDF uncertainty for the gluon distribution.

But, as stated earlier, a global PDF fit can be used for the determination of the $\alpha_s(m_Z)$. In fact, previous determinations of $\alpha_s(m_Z)$ from the PDG have included the input from PDF fits, though mostly using DIS data [6]. One difficulty, though, is that there is a correlation (or anti-correlation depending on the parton x range) between the value of $\alpha_s(m_Z)$ and the strength of the gluon distribution. As the gluon distribution remains with one of the largest uncertainties among the PDFs, this can result in a relatively large uncertainty in the extracted value of $\alpha_s(m_Z)$, and thus the philosophy among some groups of instead using the PDG standard value. In any case, it has become the standard among PDF fitting groups to produce PDFs with alternate values of $\alpha_s(m_Z)$, in intervals of a multiple of 0.001 above and below the central value, allowing the impact of a different value of $\alpha_s(m_Z)$ to be calculated, and thus a determination of the $\alpha_s(m_Z)$ uncertainty to go along with the PDF uncertainty.

The gluon distribution at NNLO from MMHT2014 is shown in Fig. 1 for five different values of $\alpha_s(m_Z)$, along with the PDF uncertainty for the central value of $\alpha_s(m_Z)$ [2]. As stated previously, there is a correlation between the value of $\alpha_s(m_Z)$ and the size of the gluon distribution for x values below 0.1, and an anti-correlation for higher x.

It is interesting/important that even though the gluon distribution and the value of $\alpha_s(m_Z)$ are correlated (or anti-correlated), the uncertainties for those two quantities are un-correlated [3]. Thus, the combined PDF+$\alpha_s(m_Z)$ uncertainty can be calculated by computing the one sigma uncertainty with $\alpha_s(m_Z)$ fixed at its central value, and adding in quadrature the one-sigma uncertainty in $\alpha_s(m_Z)$, and this is the standard that the PDF4LHC working group advocates.

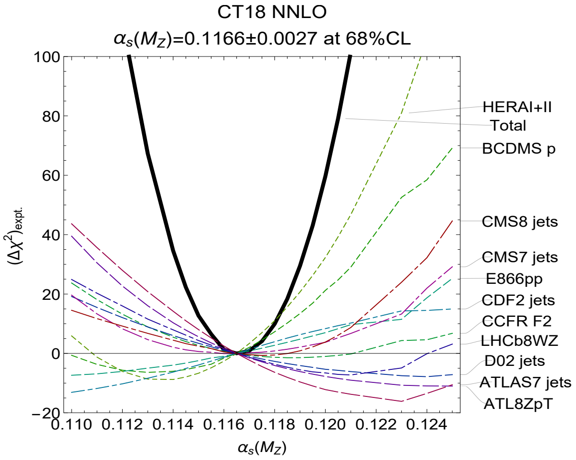

Figure 2: The Lagrange Multiplier study of the sensitivity of the data sets included in the CT18 PDF to the value of $\alpha_s(m_Z)$.

To make matters more complicated, all of the experiments in a global PDF fit do not speak with one voice, i.e. their preference for the value of $\alpha_s(m_Z)$ is not necessarily the same. In Fig. 2 is shown a Lagrange Multiplier study of the preference for the value of $\alpha_s(m_Z)$ for some of the data sets included in the CT18 global PDF fit. The χ^2 distribution for the total CT18 data set has a fairly quadratic shape, and a reasonable uncertainty of ±0.0018 (about 1.5 times the uncertainty assumed by the PDF4LHC working group), but the different data sets often prefer a different value, and in some cases the χ^2 distributions are not even quadratic. Some of the strongest constraints come from the LHC jet data and from the HERA Run 1+2 combined data. The former are sensitive to $(\alpha_s(m_Z))^2$ at the Born level and have relatively small statistical and systematic errors over a broad kinematic range. The latter have a small sensitivity per point to the value of $\alpha_s(m_Z)$ but the large number of points in that data set lead to a significant impact on the value of $\alpha_s(m_Z)$ preferred by the CT18 fit. Note that the central value (0.1168) is smaller than the value of 0.118 noted earlier, for both NLO and NNLO. The preference for a smaller value of $\alpha_s(m_Z)$ at NNLO compared to NLO has also been observed by MMHT [2].

NNPDF has recently determined a value of $\alpha_s(m_Z)$ from their global PDF fit of 0.1185 ± 0.0012, or slightly above the world average [5]. See Fig. 3. Their uncertainty is similar to that obtained by the PDG world average. Some care has to be taken, though, for it is difficult to exactly determine a one-sigma error for $\alpha_s(m_Z)$ in global PDF fits, due to the issue of tolerance. CT18, for example, has a tolerance in $\Delta\chi^2$ of 100, corresponding to the 90% confidence level, or about 37 at the 68% confidence level. This increased tolerance is motivated by tensions within the data sets (as noted above for the individual experimental sensitivities to the value of $\alpha_s(m_Z)$). A decreased tolerance would lead to a decreased uncertainty.

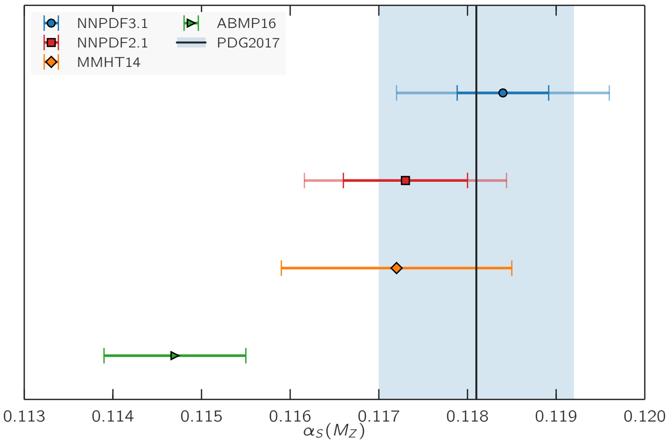

Figure 3: The value of $\alpha_s(m_Z)$ and its uncertainty is shown for several PDF fits, and compared with the central value and uncertainty from the world average. From Ref. [5].

To summarize: global PDF fits have a sensitivity to the value of $\alpha_s(m_Z)$, somewhat clouded by the remaining sensitivity to the gluon distribution. The deep-inelastic data from HERA will continue to be the most important data set in modern global PDF fits for some time, but the growing number of data sets from the LHC will increase the importance of collider data both for the determination of PDFs and for the determination of $\alpha_s(m_Z)$, especially as the full results from the 13 TeV LHC data sets are published in the next few years.

References

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