

PROGRESS IN THE NNPDF GLOBAL ANALYSIS

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We report on recent progress in the NNPDF framework of global PDF analysis. The NNPDF2.3 set is the first and only available PDF set which includes LHC data. A recent benchmark comparison of NNPDF2.3 and all other modern NNLO PDF sets with LHC data was performed. We have also studied theoretical uncertainties due to heavy quark renormalization schemes, higher twists and deuteron corrections in PDFs. Finally, we report on the release of positive definite PDF sets, based on the NNPDF2.3 analysis, specially suited for use in Monte Carlo event generators.

Introduction In this age of precision QCD at the LHC, the determination of the parton distribution functions which characterize the structure of the proton is becoming increasingly important. For some measurements the size of PDF uncertainties approaches that of experimental uncertainties. However, the LHC also offers a great opportunity to constrain PDFs. Some LHC observables important to PDFs have already been released using 2010 and 2011 data, and many others are now being analysed with the full 2012 data. NNPDF2.3 is the first and only publicly available PDF set which includes LHC data¹, extending the dataset from NNPDF2.1^{2,3} with data on jet and electroweak boson production from the ATLAS, CMS and LHCb collaborations. The impact of the data was found to be moderate, but it will certainly increase with the release of more data with greater precision and including a wider range of different physical observables.

Here we will discuss recent work involving members of the NNPDF collaboration: a benchmarking of NNLO PDF sets, investigation of sources of theoretical uncertainties on PDF determinations, and the release of a NNPDF2.3 set for NLO Monte Carlo generators.

PDF benchmarking with LHC data An extensive benchmarking exercise comparing the modern NNLO PDFs was carried out in Ref. ⁴. It benchmarked both PDFs and parton luminosities for NNPDF2.3, ABM11, HERAPDF1.5, CT10 and MSTW08, and also compared the predictions of these sets to LHC data both at the level of inclusive cross sections and of differential distributions. The comparisons to data were made quantitative using a variety of χ^2 estimators. The gluon–gluon luminosities for the PDF sets in the benchmark are shown as a ratio to NNPDF2.3 in Fig. 1 for $\alpha_S = 0.119$.

There is good agreement between the three global PDF sets (NNPDF2.3, MSTW08 and CT10), which is at least as good at NNLO as was previously found for NLO. For several LHC processes the combined PDF+ α_S uncertainties determined from the envelope of MSTW, NNPDF and CT sets are found to be smaller in the 2012 PDF sets than for the 2010 sets. The HERAPDF1.5 central values also show good agreement with the global sets, with larger uncertainties due to the smaller dataset used. For ABM11, however, disagreement was found for several PDFs

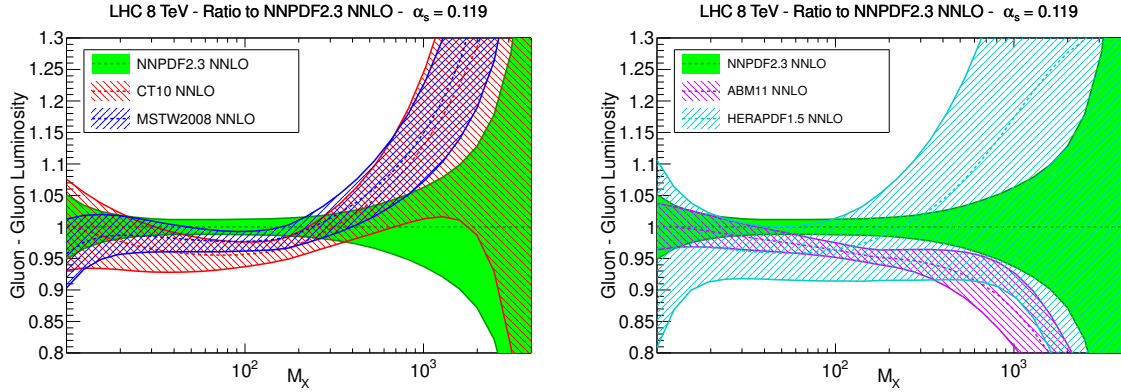


Figure 1: The gluon–gluon parton luminosity at $\sqrt{s} = 8$ TeV for $\alpha_s(M_Z) = 0.119$ as a function of the invariant mass of the final state M_X , for various NNLO PDF sets.

and LHC cross sections. Possible reasons for this disagreement are the use of an FFN scheme or the inclusion of higher twist corrections in ABM11, discussed below, but the situation will become more clear with the release of further precise LHC measurements, particularly top pair production⁵.

Theoretical uncertainties in PDF analyses There has also been recent work on several theoretical issues in PDF determination and associated uncertainties which may have some impact on current PDF sets and explain some of the differences between them. In particular, Ref. ⁶ looked at the use of fixed-flavor number (FFN) versus variable-flavor number (VFN) renormalization schemes, higher twist corrections, and nuclear corrections. The analysis was performed in the NNPDF2.3 framework by performing fits with different theoretical assumptions and comparing the results, both in terms of PDFs and LHC cross sections.

The treatment of heavy quarks in PDF fits can potentially have a large impact on the results obtained⁷. Most modern PDF sets, including NNPDF2.3, use a variable flavor number scheme, where fixed order calculations including heavy quark masses are combined with all-orders resummation of contributions from perturbative evolution. Other sets, for instance ABM11, instead use a fixed flavor number scheme where the heavy quarks are not treated as active flavors and do not enter into QCD evolution equations. The effect of scheme dependence was studied by producing versions of the NNPDF2.3 global pdf fit using the FFN scheme, rather than the FONLL VFN which is the default^{8a}.

It was found that first of all the differences between FFN and VFN can be large, and in particular the use of a FFN leads to a suppressed large- x gluon distribution and increased medium and small- x quark distributions. The χ^2 fit quality for the two schemes was also studied, and it was found that FFN provides a systematically poorer description of the data, especially for the high- Q^2 and small- x HERA data, consistent with expectations given that the FFN scheme does not include the resummation of DGLAP logarithms in the PDF evolution which are potentially large in this kinematic region.

In Fig. 2 we show the $t\bar{t}$ total cross section computed at NNLO_{approx} using `top++` for various PDF sets at $\sqrt{s} = 8$ TeV for a common value of $\alpha_s(M_Z) = 0.119$. It is clear that both the use of a reduced DIS-only dataset and of a FFN scheme bring NNPDF2.3 in better agreement with the ABM11 prediction.

Ref. ⁶ also looked at the impact of including corrections for higher twist and deuterium nuclear effects. Higher twist effects arise from power-suppressed contributions to the Wilson expansion, and whilst low-scale data most sensitive to these effects are commonly removed

^aThe NNPDF2.3 sets using the FFN scheme are available on the NNPDF hepforge webpage: nnpdf.hepforge.org/

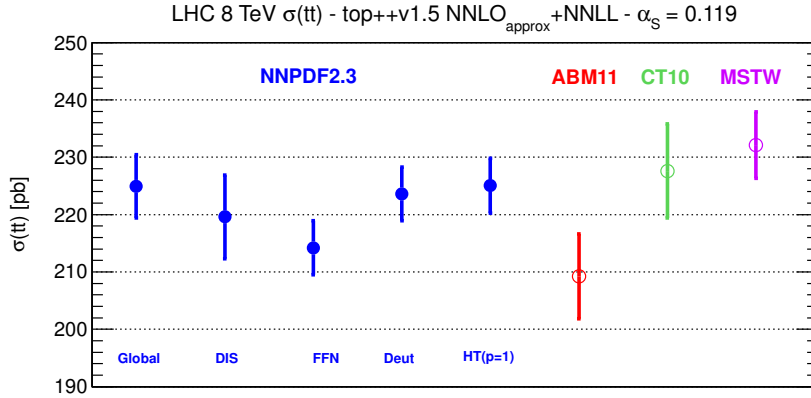


Figure 2: The $t\bar{t}$ computed at NNLO_{approx} using various PDF sets at $\sqrt{s} = 8$ TeV for $\alpha_s(M_Z) = 0.119$.

by kinematic cuts, there may still be some residual effects. An NNPDF2.3 fit was performed with the leading twist DIS structure functions supplemented with a twist four correction taken from Ref. ⁹. It was found that the inclusion of this correction had a negligible effect on the fit within uncertainties, and even when this size of these corrections were doubled the impact was marginal. Fits including nuclear corrections to structure function data on deuterium targets were also performed. Here the corrections do have a moderate impact, however it was limited to the large- x up-down separation. The $t\bar{t}$ total cross section for fits with higher twist and deuterium corrections are also show in Fig. 2, the differences for this particular observable are negligible.

Positive definite PDFs for Monte Carlo generators Parton distribution functions are not positive definite quantities beyond leading order, and thus some PDF groups allow for negative PDFs in their NLO and NNLO sets. This is the case in the NNPDF2.3 analysis, where instead the positivity of several physical cross sections is imposed as an additional constraint during the minimization. In practice, negative PDFs then arise only in phase space regions where experimental constraints on a given PDF combination are very scarce, such as the small- x gluon or the large- x antiquarks, and reflect the large PDF uncertainties in such extrapolation regions.

While there are no theoretical issues in dealing with negative PDFs in fixed order computations, some issues can arise in the context of Monte Carlo event generation. For instance, only positive PDFs can be used in the Sudakov form factors that determine the shower probabilities, and negative small- x PDFs may affect the description of the underlying event (UE) and of multiple interactions (MPI) in the event generator. In addition, there can also be practical issues, such as numerical inefficiencies when reweighting events starting from negative PDFs.

None of these issues are insurmountable. For instance the **Sherpa**¹⁰ event generator includes tunes for the default NNPDF2.3 set, which correctly describe UE and MPI at hadron colliders, and NLO event generators such as **aMC@NLO**¹¹ provide exact PDF reweighting without the requirement of positive definite PDFs. In addition, it is a common practice to use separate PDFs for the hard matrix element and for the parton shower, since the latter includes the information from the non-perturbative tunes to the data.

Despite the absence of any conceptual issue, we believe it is useful for the community to have positive definite NLO NNPDF sets for use in event generators at the LHC. To achieve this, we have taken as a starting point the LHAPDF grids for various NNPDF2.3 NLO sets. In the interpolating grid for each PDF, any x, Q point which has a negative value is instead assigned a very small positive number. This defines the NNPDF2.3 MC PDF sets. It was also necessary to modify the LHAPDF wrapper of these sets to ensure that the output is positive definite in

any cases (to avoid negative interpolation between grid points).

Starting from LHAPDF v5.8.9, these Monte Carlo NNPDF2.3 NLO sets are publicly available. In Fig. 3 we show small- x gluon PDF (left plot) and the large- x \bar{d} PDF (right plot), both at $Q^2 = 2 \text{ GeV}^2$, from the NNPDF23_nlo_as_0119_mc.LHgrid PDF set. We have explicitly checked that the good χ^2 quality description of all datasets in the global PDF analysis is unaffected, which was expected given that the PDFs in the default sets only go negative in regions far from experimental constraints.

In summary, the NNPDF2.3 NLO MC PDF sets are positive definite PDF that are specially suited for their use in event generators, while maintaining the excellent description of all hard scattering data, and in particular of all relevant LHC data, which characterizes the default NNPDF2.3 sets.

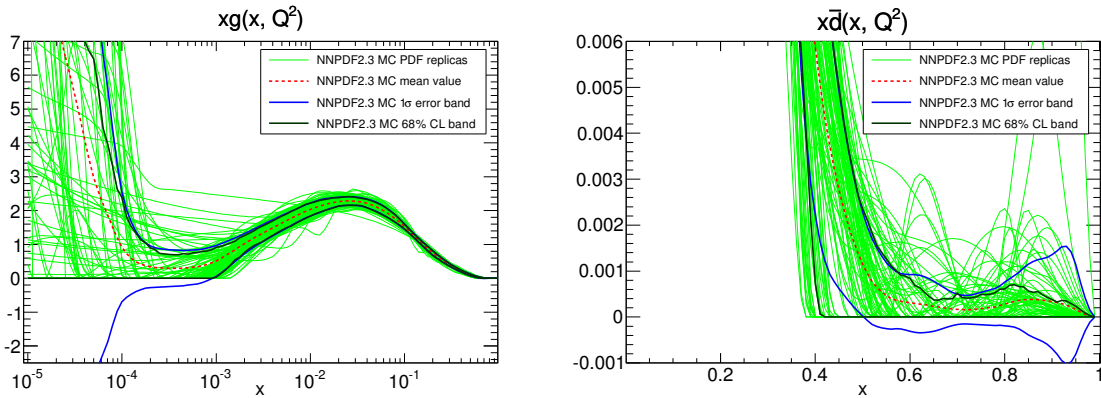


Figure 3: The small- x gluon PDF (left plot) and the large- x \bar{d} PDF (right plot) at $Q^2 = 2 \text{ GeV}^2$ in the NNPDF23_nlo_as_0119_mc.LHgrid PDF set. Each of the green lines is one PDF replica. As can be seen, in these NNPDF2.3 MC sets both the central values and the individual replicas are positive definite.

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