

# Update on Neural Network Parton Distributions: NNPDF1.1

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## Abstract

We present recent progress within the NNPDF parton analysis framework. After a brief review of the results from the DIS NNPDF analysis, NNPDF1.0, we discuss results from an updated analysis with independent parametrizations for the strange and anti-strange distributions, denoted by NNPDF1.1. We examine the phenomenological implications of this improved analysis for the strange PDFs.

**Introduction** PDFs and their associated uncertainties will play a crucial role in the full exploitation of the LHC physics potential. However, it is known that the standard approach to PDF determination [1, 2] suffers from several drawbacks, mainly related to the lack of control on the bias introduced in the choices of specific PDF parametrizations and flavour assumptions, as well as to the difficulty in providing a consistent statistical interpretation of PDFs uncertainties in the presence of incompatible data.

Motivated by this situation, a novel method has been introduced which combines a MC sampling of experimental data with neural networks as unbiased interpolators for the PDF parametrization. This method, proposed by the NNPDF Collaboration, was first successfully applied to the parametrization of DIS structure functions [3, 4] and more recently to the determination of PDFs [5, 6]. In this contribution we present recent results within this NNPDF analysis framework.

**The NNPDF1.0 analysis** NNPDF1.0 [6] was the first DIS PDF analysis from the NNPDF Collaboration. The experimental dataset used in the NNPDF1.0 analysis consists of all relevant fixed target and collider deep-inelastic scattering data: structure functions from NMC, SLAC and BCDMS, CC and NC reduced cross-sections from HERA, direct  $F_L(x, Q^2)$  from H1 and neutrino CC reduced cross sections from CHORUS.

In NNPDF1.0, five PDFs are parametrized with neural networks at the initial evolution scale, which is taken to be  $Q_0^2 = m_c^2 = 2 \text{ GeV}^2$ :  $\Sigma(x, Q_0^2)$ ,  $V(x, Q_0^2) \equiv (u_v + d_v + s_v)(x, Q_0^2)$ ,

$T_3(x, Q_0^2) \equiv (u + \bar{u} - d - \bar{d})(x, Q_0^2)$ ,  $\Delta_S(x, Q_0^2) \equiv (\bar{d} - \bar{u})(x, Q_0^2)$ , and  $g(x, Q_0^2)$ . The strange distributions are fixed by the additional assumption:

$$s(x, Q_0^2) = \bar{s}(x, Q_0^2) = C_S/2 \left( \bar{u}(x, Q_0^2) + \bar{d}(x, Q_0^2) \right) . \quad (1)$$

The fraction of (symmetric) strange over non-strange sea is taken to be  $C_S = 0.5$ , as suggested by di-muon data. While recent analysis (see [7] and references therein) suggest a somewhat smaller central value, Eq. 1 is a very crude approximation and therefore uncertainties in  $C_S$  are expected to be rather large, as the new NNPDF1.1 analysis confirms below.

The overall normalization of  $g(x)$ ,  $\Delta_S(x)$  and  $g(x)$  is fixed by imposing the momentum and valence sum rules. The NNPDF NLO evolution program employs a hybrid N-space and x-space method [5], whose accuracy has been checked with the Les Houches benchmark tables [8], obtained from a comparison of the HOPPET [9] and PEGASUS [10] evolution programs.

The NNPDF1.0 gluon and singlet PDFs are shown in Fig. 1, compared with the results of other sets. We observe that our analysis produces results consistent with those obtained by other collaborations [1, 2] while our error bands tend to get bigger in the region where data do not constrain PDFs behavior. Interestingly, this happens without any error blow-up from the use of large tolerance factors [1, 2] in the PDF error definition.

**The NNPDF1.1 analysis** NNPDF1.1 is an update of the previously described NNPDF1.0 analysis which introduces independent parametrizations in the strange PDF sector and a randomization of the preprocessing. The motivations for this update are twofold. First of all, the stability analysis of [6], where the preprocessing exponents were varied their optimal values, indicated that uncertainties might have been slightly underestimated for some PDFs in some restricted  $x$ -regions, like for example the valence PDF in the large- $x$  region. On the other hand, the restrictive assumptions on the strange distributions Eq. 1 should also lead to an uncertainty underestimation for some PDFs and some observables, especially those directly sensitive to the strange sector.

Instead of the simplified assumptions in Eq. 1, in NNPDF1.1 both  $s_+(x, Q_0^2)$  and  $s_-(x, Q_0^2)$  are parametrized with independent neural networks. The architecture is the same as in [6], so that each PDF is described by 37 free parameters. The  $s_-(x)$  distribution is forced to satisfy the strange valence sum rule following the method of [6]. These strange PDFs are mostly constrained in our analysis by the CHORUS data as well as by the HERA CC data.

Another improvement in NNPDF1.1 with respect to NNPDF1.0 is a randomization of the preprocessing exponents, which were kept fixed at their optimal values in [6]. In the present analysis for each replica the PDF preprocessing exponents are allowed to vary at random within a given range, which is given in Table 1. This range is determined as the range in which variations of the preprocessing exponents produce no deterioration of the fit quality, see Table 11 in [6].

In Fig. 1 we show the results from the NNPDF1.1 analysis for the  $\Sigma(x)$ ,  $g(x)$ ,  $s_+(x)$  and  $s_-(x)$  distributions compared to other PDF sets, including NNPDF1.0. First of all, we observe that the central values for both PDFs are reasonably close between NNPDF1.0 and NNPDF1.1, thus ensuring the validity of the flavour assumptions in the former case. Second, we see that the uncertainties in  $s_+(x)$  are large, so that all other PDF sets are included within the NNPDF1.1

PDF	$m$	$n$
$\Sigma(x, Q_0^2)$	[2.7, 3.3]	[1.1, 1.3]
$g(x, Q_0^2)$	[3.7, 4.3]	[1.1, 1.3]
$T_3(x, Q_0^2)$	[2.7, 3.3]	[0.1, 0.4]
$V_T(x, Q_0^2)$	[2.7, 3.3]	[0.1, 0.4]
$\Delta_S(x, Q_0^2)$	[2.7, 3.3]	[0, 0.01]
$s_+(x, Q_0^2)$	[2.7, 3.3]	[1.1, 1.3]
$s_-(x, Q_0^2)$	[2.7, 3.3]	[0.1, 0.4]

Table 1: The range of variation of the preprocessing exponents used in NNPDF1.1.

error band, which turns out to be much larger than for NNPDF1.0, since there the strange sea was fixed by Eq. 1. The situation for the strange valence PDF  $s_-(x)$  is similar: it turns out to be completely unconstrained from the present data set (see Fig. 1), with central value compatible with zero.

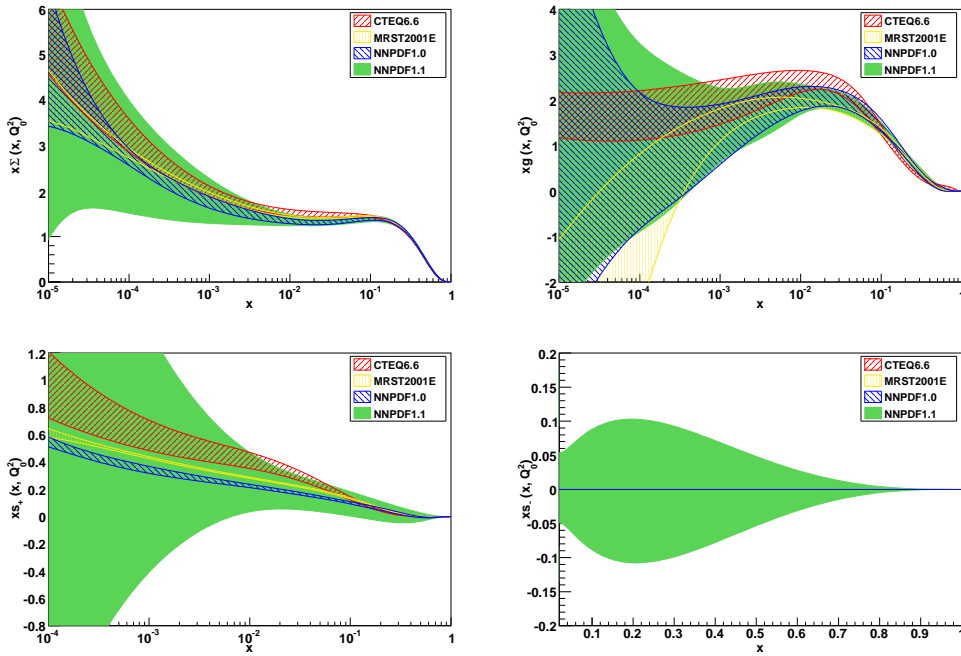


Fig. 1: The NNPDF1.1 PDFs compared with other PDF sets, including NNPDF1.0.

The PDFs from the NNPDF1.1 analysis are seen to be reasonably stable with respect the NNPDF1.0 ones (see  $\Sigma(x)$  and  $g(x)$  in Fig. 1), which is an important result since both two new input PDFs and a randomization of the preprocessing have been incorporated in the new analysis. This stability is quantified by the stability estimators [5], shown in Table 1. The only differences turn out to be for the uncertainty in  $V(x)$  and on the singlet PDF  $\Sigma(x)$  in the extrapolation region. The uncertainty in  $V(x)$ , which was known to be underestimated by a factor 1.5-2 in

	Data	Extrapolation
$\Sigma(x, Q_0^2)$	$5 \cdot 10^{-4} \leq x \leq 0.1$	$10^{-5} \leq x \leq 10^{-4}$
$\langle d[q] \rangle$	1.6	1.0
$\langle d[\sigma] \rangle$	3.5	2.7
$g(x, Q_0^2)$	$5 \cdot 10^{-4} \leq x \leq 0.1$	$10^{-5} \leq x \leq 10^{-4}$
$\langle d[q] \rangle$	2.9	3.3
$\langle d[\sigma] \rangle$	1.5	1.5
$T_3(x, Q_0^2)$	$0.05 \leq x \leq 0.75$	$10^{-3} \leq x \leq 10^{-2}$
$\langle d[q] \rangle$	1.3	0.9
$\langle d[\sigma] \rangle$	1.4	2.6
$V(x, Q_0^2)$	$0.1 \leq x \leq 0.6$	$3 \cdot 10^{-3} \leq x \leq 3 \cdot 10^{-2}$
$\langle d[q] \rangle$	2.2	2.4
$\langle d[\sigma] \rangle$	5.3	5.3
$\Delta_S(x, Q_0^2)$	$0.1 \leq x \leq 0.6$	$3 \cdot 10^{-3} \leq x \leq 3 \cdot 10^{-2}$
$\langle d[q] \rangle$	1.0	1.4
$\langle d[\sigma] \rangle$	1.9	1.6

Table 2: Stability estimators which compare parton distributions from NNPDF1.0 and NNPDF1.1.

NNPDF1.0 [6], now has correspondingly increased by the expected factor, mainly due to the absence of assumptions on the valence strange PDF  $s_-(x)$ , as can be seen in Fig. 2. A comparable increase in uncertainty is observed in the extrapolation region of  $\Sigma(x)$ , which can be attributed to the extra flexibility induced by the presence of the independent  $s_+(x)$  PDF.

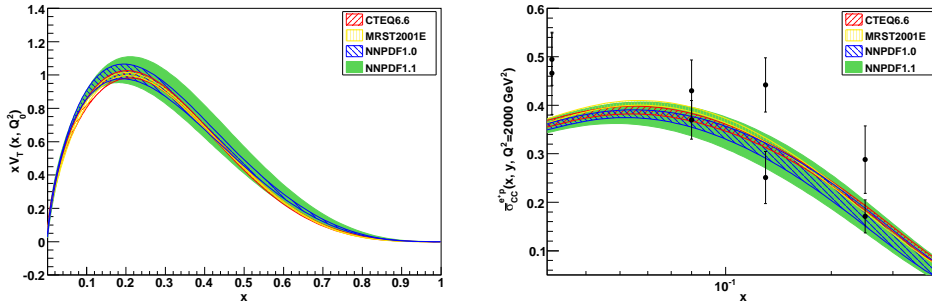


Fig. 2: The valence PDF  $V(x, Q_0^2)$  (left) and the the CC reduced cross section  $\tilde{\sigma}_{CC}$  from HERA (right).

As a consequence of the large uncertainties for  $s_-(x)$ , the uncertainties in the CC DIS observables turn out to be larger than in NNPDF1.0, as can be seen in Fig. 2. This result indicates that the previously determined uncertainties in those observables had been somewhat underestimated, as it should be obvious by the crude assumptions concerning the strange distributions, Eq. 1, introduced in NNPDF1.0.

We can further study the features of the determined strange PDFs by computing their moments. As done for example in [11], the magnitude of the strange sea can be characterized by the following ratio of second moments:

$$K_S(Q^2) \equiv \frac{\int_0^1 dx x s_+(x, Q^2)}{\int_0^1 dx x (\bar{u}(x, Q^2) + \bar{d}(x, Q^2))} = -0.1 \pm 1.7, \quad Q^2 = 20 \text{ GeV}^2, \quad (2)$$

consistent within errors with the value  $C_S = 0.5$  used in Eq. 1. On the other hand, the strange asymmetry can be characterized by the second moment of the  $s_-$  distribution, which turns out to

be:

$$\langle x \rangle_{s_-} \equiv \int_0^1 dx x s_- (x, Q_0^2) = -0.001 \pm 0.04 , \quad (3)$$

that is, consistent with zero within uncertainties. This quantity has important physical implications, for example related the determination of the Weinberg angle and the NuteV anomaly [12]. Both results for the strange PDF moments, Eqns. 2 and 3, further confirm the implicit NNPDF1.0 assumption that, in the absence of further experimental data, a PDF analysis without independent parametrizations for  $s_+$  and  $s_-$  can perfectly describe all available inclusive DIS measurements.

Our results for the moments of the strange PDFs can be compared with related studies of the strange content of the nucleon (see for example [11] and references therein). We observe that our results are compatible with previous determinations of these moments, albeit with large uncertainties. These indicate that a quantitative determination of the strange and anti-strange distributions (and the associated moments) requires a dedicated study which includes experimental data directly sensitive to the strange PDFs. The obvious example is dimuon production from neutrino DIS [7], which is provided in a form in which it can be consistently incorporated into a NLO PDF analysis.

**Outlook** The NNPDF1.0 DIS analysis is the first parton set within the NNPDF framework and is available through the LHAPDF library. The updated NNPDF1.1 analysis includes two main improvements: independent parametrizations for the strange PDFs and a randomization of the preprocessing.

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