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Unbiased polarized PDFs upgraded with new inclusive DIS data

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Abstract. I present a determination of longitudinally-polarized parton distribution functions of the proton from inclusive deep-inelastic scattering data: `NNPDFpo11.0+`. This determination, based on the `NNPDF` methodology, upgrades a previous analysis, `NNPDFpo11.0`, in two respects: first, it includes all new data sets which have recently become available from the COMPASS experiment at CERN and from the E93-009, EG1-DVCS and E06-014 experiments at JLAB; second, it uses the state-of-the-art unpolarized parton set `NNPDF3.0` as a baseline for the reconstruction of fitted observables and for the determination of positivity constraints. I discuss the impact of both these new inputs on the uncertainty of parton distribution functions.

In the last years, the `NNPDF` collaboration put a great deal of effort into the determination of minimally biased longitudinally-polarized Parton Distribution Functions (PDFs) of the proton and their associated uncertainties. Two sets of longitudinally-polarized PDFs based on the `NNPDF` methodology have been released so far: `NNPDFpo11.0` [1] and `NNPDFpo11.1` [2]. The former was obtained only from inclusive Deep-Inelastic Scattering (DIS) data with longitudinally-polarized beams and targets; the latter was obtained, in addition to the DIS data included in `NNPDFpo11.0`, also from open-charm production data by the COMPASS experiment at CERN and from W^\pm and high- p_T jet production data by the STAR and PHENIX experiments at RHIC. Respectively, RHIC data sets have been proven to provide a first hint of flavor symmetry breaking for polarized sea quarks, and a first evidence of a sizable, positive gluon polarization in the proton [2].

Despite very promising, available RHIC data are not so many, and they cover a rather small kinematic range so far. Hence, the bulk of the experimental information on the longitudinally-polarized PDFs is still provided by inclusive DIS data: the leading observable, reconstructed from spin asymmetries, *i.e.*, differences between cross sections with opposite target polarizations, is the polarized structure function of the nucleon $g_1(x, Q^2)$. Following factorization, this reads, up to power-suppressed corrections, as

$$g_1(x, Q^2) = \frac{\sum_{q=1}^{n_f} e_q^2}{2n_f} [\mathcal{C}_{\text{NS}} \otimes \Delta q_{\text{NS}} + \mathcal{C}_S \otimes \Delta \Sigma + 2n_f \mathcal{C}_g \otimes \Delta g] + \frac{h^{\text{TMC}}}{Q^2} + \frac{h}{Q^2} + \mathcal{O}\left(\frac{1}{Q^4}\right), \quad (1)$$

where: n_f is the number of active flavors; e_q is the fractional electric charge for the q^{th} quark flavor; \otimes denotes the usual convolution product; $\Delta q_{\text{NS}} \equiv \sum_q^{n_f} \left(n_f e_q^2 / \sum_{q=1}^{n_f} e_q - 1 \right) (\Delta q + \Delta \bar{q})$, $\Delta \Sigma = \sum_{q=1}^{n_f} (\Delta q + \Delta \bar{q})$ and Δg are the nonsinglet, singlet and gluon longitudinally-polarized PDFs; \mathcal{C}_{NS} , \mathcal{C}_S and \mathcal{C}_g are the corresponding leading-twist coefficient functions; and h^{TMC} and

Figure 1. Kinematic coverage of data.

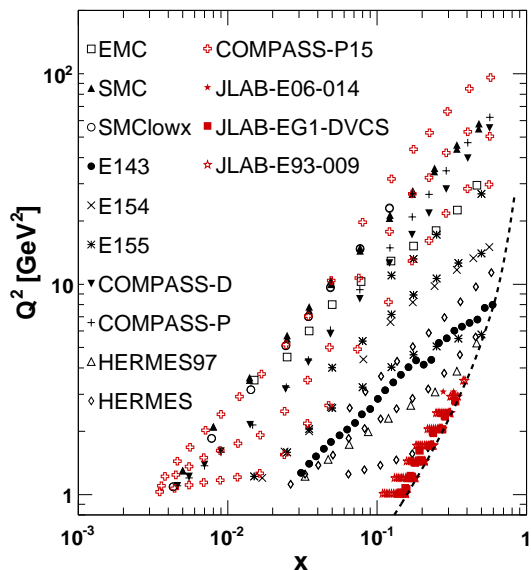


Table 1. Values of χ^2/N_{dat} for each data set.

Experiment	N_{dat}	χ^2/N_{dat}		
		1.0	1.1	1.0+
EMC	10	0.44	0.43	0.43
SMC	24	0.93	0.90	0.92
SMC_lowx	16	0.97	0.97	0.94
E143	50	0.64	0.67	0.63
E154	11	0.40	0.45	0.34
E155	40	0.89	0.85	0.98
COMPASS-D	15	0.65	0.70	0.57
COMPASS-P	15	1.31	1.38	0.93
HERMES97	8	0.34	0.34	0.23
HERMES	56	0.79	0.82	0.69
COMPASS-P15	51	0.68*	0.69*	0.65
JLAB-E93-009	148	1.26*	1.23*	0.94
JLAB-EG1-DVCS	18	0.45*	0.59*	0.29
JLAB-E06-014	2	2.81*	3.20*	1.33
* Experiment not included		0.77	0.78	0.74

h denote respectively (kinematic) target-mass corrections (TMCs) and (dynamic) higher-twist corrections. In Eq. (1), the dependence of PDFs, coefficient functions, TMCs and higher-twist terms on both the scaling variable x and the energy Q^2 has been omitted for brevity.

In this write-up, I present NNPDFpo11.0+, an update of the analysis in Ref. [1], in which:

- new data sets for the polarized structure function of the proton g_1^p from COMPASS (COMPASS-P15 [3]), for the ratio of polarized to unpolarized structure functions of the proton and deuteron $g_1^{p,d}/F_1^{p,d}$ from CLAS (JLAB-E93-009 [4, 5] and JLAB-EG1-DVCS [6]), and for the virtual photoabsorption asymmetry of the neutron A_1^n from HALL-A (JLAB-E06-014 [7]) are fitted;
- the unpolarized PDF set used as a baseline both for the reconstruction of the structure function $g_1(x, Q^2)$ from experimental asymmetries and for the determination of positivity constraints (see respectively Secs. 2.1 and 4.4 in Ref. [1]) is updated from NNPDF2.1 [8] to NNPDF3.0 [9]; the unpolarized structure functions, if needed, are obtained with APFEL [10].

I will concentrate only on DIS data here; the NNPDFpo11.0+ parton set could then be reweighted with proton-proton collision data from RHIC along the lines of the analysis of Ref. [2]. However, this will require an additional study which is beyond the scope of this write-up.

Except for the improvements listed above, the analysis presented here proceeds exactly as in Ref. [1]. The kinematic coverage of experimental data is shown in figure 1 (new data sets are listed in the right column), together with the kinematic cut $W^2 = m^2 + Q^2(1-x)/x \geq 6.25$ GeV², with m the nucleon mass. This was chosen so that the dynamic higher twist h in Eq. (1) become compatible with zero once fitted to experimental data, and can then be neglected; TMCs instead are included exactly, see Sec. 3.2 in Ref. [1] for details. The structure function $g_1(x, Q^2)$ is reconstructed from the measured observables according to the available experimental information: referring to Sec. 2.1 of Ref. [1], the COMPASS-P15 data set is treated as the EMC data set, JLAB-E93-009 and JLAB-EG1-DVCS as E155, and JLAB-E06-014 as E143.

The quality of the NNPDFpo11.0+ analysis is assessed by the values of the χ^2 per data point, χ^2/N_{dat} , which are reported in table 1 for each data set, together with the number of included data points N_{dat} . In table 1, I also show the values of χ^2/N_{dat} obtained from the NNPDFpo11.0 [1] and NNPDFpo11.1 [2] parton sets. Inspection of table 1 allows for the following remarks.

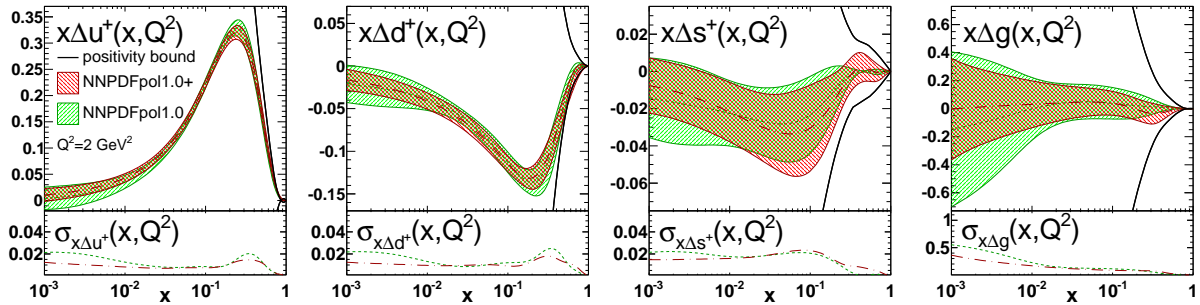


Figure 2. Comparison of $x\Delta u^+$, $x\Delta d^+$, $x\Delta s^+$, $x\Delta g$, and their uncertainties, from NNPDFpo11.0 and NNPDFpo11.0+ at $Q^2 = 2 \text{ GeV}^2$. The positivity bound from NNPDF3.0 is also shown.

- The quality of the NNPDFpo11.0+ PDF determination, as measured by its total χ^2 per data point ($\chi_{\text{tot}}^2/N_{\text{dat}} = 0.74$), is good, and comparable to that achieved in previous determinations, both NNPDFpo11.0 ($\chi_{\text{tot}}^2/N_{\text{dat}} = 0.77$) and NNPDFpo11.1 ($\chi_{\text{tot}}^2/N_{\text{dat}} = 0.78$).
- In comparison to NNPDFpo11.0 and NNPDFpo11.1, the value of χ^2/N_{dat} for new experiments included in NNPDFpo11.0+ improves substantially for all JLAB data sets, while the difference is less significant for the COMPASS data set. This suggests that JLAB data are likely to have a sizable impact on PDFs, while the effects of COMPASS data are expected to be moderate (see also the discussion in the sequel).
- The value of χ^2/N_{dat} for single experiments are often well below the optimal value $\chi^2/N_{\text{dat}} \sim 1$. This is a consequence of the lack of experimental information on correlations among systematics, which cannot be accounted for properly, and ostensibly lead to an overestimation of experimental uncertainties.

In figure 2, I show the total polarized quark distributions $\Delta q^+ = \Delta q + \Delta \bar{q}$ ($q = u, d, s$) and the polarized gluon distribution Δg at $Q^2 = 2 \text{ GeV}^2$, obtained from both NNPDFpo11.0+ and NNPDFpo11.0 PDF sets; their absolute uncertainties, $\sigma_{\Delta q}$, and the positivity bound obtained from the NNPDF3.0 PDF set are also shown. Inspection of figure 2 allows for the following remarks.

- In the small- x region ($x \lesssim 10^{-2}$), the uncertainty of all quark and gluon distributions is reduced by about a factor two. This is due to a better accuracy of the proton and neutron unpolarized structure functions $F_2^{p,n}$ and $F_L^{p,n}$, whose uncertainty is propagated to the polarized structure function $g_1^{p,n}$ when the latter is reconstructed from experimental asymmetries. The improvement between NNPDF2.1 (used in the original NNPDFpo11.0 analysis) and NNPDF3.0 (used in this analysis) is displayed in figure 3, and is due to the significant amount of new LHC data included in NNPDF3.0. The impact of COMPASS-P15, the only new data set which covers the small- x region, is instead rather limited: I performed a fit including COMPASS-P15 data, but using the same unpolarized structure functions as in NNPDFpo11.0, and I found that PDF uncertainties are almost identical to those determined in NNPDFpo11.0.
- In the intermediate-to-large- x region ($10^{-2} \lesssim x \lesssim 0.6$), the uncertainty of Δu^+ and Δd^+ is about two thirds of the uncertainty obtained from NNPDFpo11.0. This is a genuine effect of new JLAB data sets, which attain slightly larger x values and are more accurate than those included in NNPDFpo11.0. The effects of updating the unpolarized structure functions from NNPDF2.1 to NNPDF3.0 are less prominent than in the small- x region: I checked explicitly that results are almost unchanged in this region if a fit including new data but old unpolarized structure functions from NNPDF2.1 is performed. Note that the full potential of JLAB data, which includes the possibility to discriminate among different

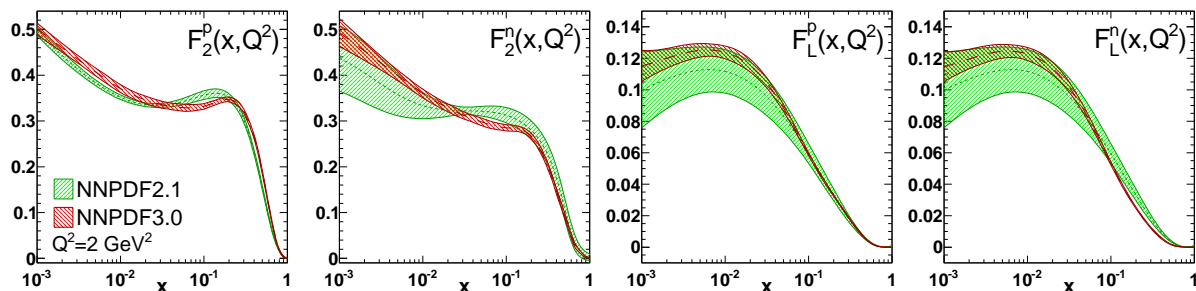


Figure 3. The proton and neutron unpolarized structure functions $F_2^{p,n}$ and $F_L^{p,n}$ from NNPDF2.1 and NNPDF3.0 at $Q^2 = 2 \text{ GeV}^2$, as obtained with APFEL [10].

non-perturbative models of nucleon structure [11], could be exploited only by lowering the kinematic cut on W^2 . However, this will require a systematic inclusion of dynamic higher-twist corrections: I checked that, if h -terms in Eq. (1) are neglected but $W^2 \geq 4 \text{ GeV}^2$ is taken, in principle the PDF uncertainty on Δu^+ and Δd^+ can be reduced even more; however, the value of the χ^2 deteriorates significantly and PDFs become no longer reliable.

- In the large- x region ($x \gtrsim 0.6$), no experimental data are presently available to determine longitudinally-polarized PDFs. However, their behavior is explicitly bounded by their unpolarized counterparts, as it follows from positivity constraints: at leading-order, $|\Delta f(x, Q^2)| \leq f(x, Q^2)$, $f = u^+, d^+, s^+, g$. No significant differences are found in the polarized PDFs by updating the baseline unpolarized PDF set from NNPDF2.1 to NNPDF3.0, except for Δs^+ . For this distribution, the uncertainty is about ten times larger in NNPDFpo11.0+ than in NNPDFpo11.0. Note that $W+c$ data sets, sensitive to the unpolarized strange distribution s^+ , have been included in NNPDF3.0, which lead to a larger s^+ than that found in NNPDF2.1. For this reason, the positivity bound on Δs^+ becomes less stringent, and, in absence of any experimental information, this allows the uncertainty on Δs^+ to grow significantly. A similar effect, though less prominent, can be noticed also for Δg .

In conclusion, longitudinally-polarized PDFs obtained in this analysis are well compatible with those obtained in the previous NNPDF determination based on DIS data, NNPDFpo11.0, but have slightly smaller uncertainties. I have explicitly shown that there is a sizable interplay between unpolarized and polarized PDFs, and that JLAB data are effective in unveiling the large- x behavior of PDFs; however, a determination of higher-twist corrections to g_1 , Eq. (1), will be mandatory to exploit their full potential. In the future, an extensive study will be dedicated to a global determination of longitudinally-polarized PDFs, into which the new DIS data discussed here, the proton-proton collision data included in NNPDFpo11.1 and possibly other new data will be incorporated together.

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