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Flavor asymmetry of the polarized nucleon sea

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We discuss the flavor asymmetry of polarized light antiquarks in the nucleon, $\Delta\bar{u} - \Delta\bar{d}$. We present a determination of this quantity based on two global QCD analyses of experimental data, `DSSV08` and `NNPDFpol1.1`, in which sea-quark parton distribution functions are determined respectively either from semi-inclusive deep-inelastic scattering or W-boson production data. The latter have become available only very recently, and their effect on the polarized flavor asymmetry is presented here for the first time. We find that the flavor asymmetry of polarized antiquarks in the nucleon is definitely positive, and has almost the same absolute size of its unpolarized counterpart. We compare this result with various theoretical models of the nucleon structure in order to test their validity. We show that some of them are clearly disfavored.

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The flavor dependence of quark and antiquark Parton Distribution Functions (PDFs) in the nucleon is presently recognized to play a leading role in unraveling the non-perturbative chiral dynamics of Quantum Chromodynamics (QCD) [1]. A sizable flavor asymmetry $\bar{u}-\bar{d}>0$ is observed between light helicity-averaged antiquark distributions from charged-current Deep-Inelastic Scattering (DIS) and Drell-Yan (DY) measurements [2]. This leads to the question whether their helicity-dependent counterparts, $\Delta\bar{u}$ and $\Delta\bar{d}$, would be asymmetric as well. The knowledge of such a behavior is of particular relevance in the polarized case, since it could provide additional insight into the decomposition of the proton's spin into quark and antiquark contributions.

Polarized light-sea distributions can be accessed experimentally in different hard-scattering processes: polarized Semi-Inclusive DIS (SIDIS), polarized DY [3], single-spin asymmetry in W-boson production in polarized proton-proton (pp) collisions [4], and charged-current DIS using both neutrino beam, at a neutrino factory [5], or electron beam, at an Electron-Ion Collider [6]. Among these processes, only SIDIS and W-boson production have been actively pursued so far, and some of the corresponding experimental data have been included in global QCD analyses of polarized PDFs. The `DSSV08` [7] and `LSS10` [8] determinations of PDFs include SIDIS data, while the `NNPDFpol1.1` [9] determination of PDFs includes W-boson production data.

Various theoretical models have also been developed for predicting the unpolarized and polarized flavor structure of the nucleon sea (for a review, see *e.g.* [10]). Computations based on different models lead to similar results for the unpolarized distributions $\bar{u}$ and $\bar{d}$, while they often differ significantly for the polarized distributions $\Delta\bar{u}$ and $\Delta\bar{d}$. Therefore, a comparison between the latter predictions and the corresponding PDFs determined from a fit to experimental data allows for testing the validity of the various theoretical models.

In this contribution we present such a comparison in a systematic way. We consider for reference the `NNPDFpol1.1` [9] and the `DSSV08` [7] parton sets. They both provide polarized PDFs at next-to-leading-order (NLO) accuracy, but they differ in two main aspects: first, the methodology used for PDF determination, and, second, the experimental information included for constraining $\Delta\bar{u}$ and $\Delta\bar{d}$ distributions.

Concerning the methodology used for PDF determination, the `DSSV08` analysis is based on the *standard* Hessian methodology. Conversely, the `NNPDFpol1.1` analysis is based on the NNPDF methodology. This uses a parametrization of PDFs based on neural networks with a very large number of free parameters, and Monte Carlo sampling and representation of PDFs. The first feature allows for reducing as much as possible the theoretical bias due to PDF parametrization. The second feature allows in particular for including new experimental information into a given PDF determination via Bayesian reweighting [11, 12]. This consists of updating the representation of the probability distribution in the space of PDFs, provided by an available PDF set, by means of Bayes' theorem, in such a way that the information contained in the new data sets is included. Indeed, the `NNPDFpol1.1` parton set was obtained via reweighting (see Refs. [9, 13] for details).

Concerning the experimental information included for constraining $\Delta\bar{u}$ and $\Delta\bar{d}$ distributions, the `NNPDFpol1.1` PDF determination uses W-boson production measurements in polarized pp collisions. Specifically, the data sets on both W^+ and W^- single- and double-spin asymmetries recently provided by the STAR collaboration [14] were included. Unlike `NNPDFpol1.1`, in the `DSSV08` analysis sea-quark densities are determined from SIDIS data, since W-boson production data were not available at the time this global fit was performed. However, in this case additional

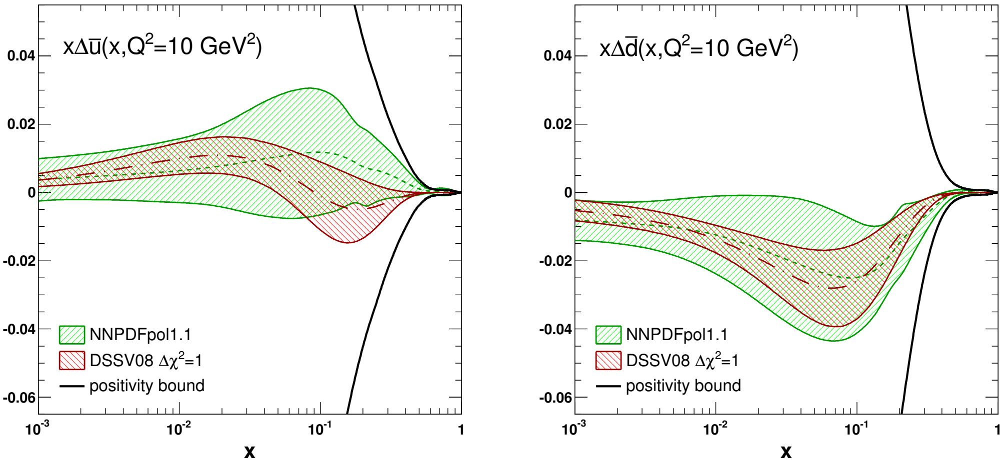

Figure 1: The $\Delta\bar{u}$ and $\Delta\bar{d}$ distributions from the `NNPDFpol1.1` [9] parton set compared to those from the `DSSV08` [7] parton set at $Q^2 = 10$ GeV^2. The positivity bound is also shown (see Refs. [9, 13] for details).

knowledge of the fragmentation functions for light quarks is required. Indeed, fragmentation functions are on the same footing as PDFs: they can only be determined from a fit to experimental data (see *e.g* [15] and references therein), and as such they are subject to the same potential sources of bias. Because the NNPDF methodology aims at reducing possible such bias, and a determination of fragmentation functions based on this methodology is not yet available, in `NNPDFpol1.1` sea-quark distributions were determined from collider data only, which do not require the usage of fragmentation functions.

Light sea-quarks from the `NNPDFpol1.1` parton set are shown in Fig. 1, together with those from the `DSSV08` parton set; the `NNPDFpol1.1` uncertainty corresponds to the one-σ band, while the `DSSV08` uncertainty is the Hessian uncertainty computed assuming $\Delta\chi^2 = 1$. This choice may lead to somewhat underestimated uncertainties: it is well known that, in global fits based on Hessian methodology, a tolerance $\Delta\chi^2 = T > 1$ is needed for faithful uncertainty estimation. Indeed, in Ref. [7] uncertainty estimates obtained from the Lagrange multiplier method with $\Delta\chi^2/\chi^2 = 2\%$ (roughly corresponding to $T \sim 8$) were recommended as more reliable. In this case, `DSSV08` uncertainties would be larger than those shown in Fig. 1 by a factor $\sqrt{T}$.

The two results show a slightly different behavior of the $\Delta\bar{u}$ distribution above $x \sim 3 \cdot 10^{-1}$, while they nicely agree for the $\Delta\bar{d}$ distribution. Since light sea-quarks are obtained from different hard-scattering processes in the two determinations, W-boson production in `NNPDFpol1.1` and SIDIS in `DSSV08`, the discrepancy in the $\Delta\bar{u}$ distribution may suggest some tensions between the corresponding experimental data. Also, the `DSSV08` result could have been biased by an imperfect knowledge of the fragmentation functions used in the analysis of SIDIS data.

In Fig. 2, we show the polarized light sea-quark asymmetry $x(\Delta\bar{u} - \Delta\bar{d})$ computed with the `NNPDFpol1.1` PDFs at $Q^2 = 10$ GeV^2. This result is compared with that obtained from the `DSSV08` PDFs and from various models of nucleon structure, and with the unpolarized sea-quark asymmetry $x(\bar{d} - \bar{u})$ computed with the PDFs from the `NNPDF2.3` parton set [26]. In Tab. 1, we collect the values of the integrated asymmetry $I_\Delta = \int_0^1 dx[\Delta\bar{u}(x) - \Delta\bar{d}(x)]$ for various models, as

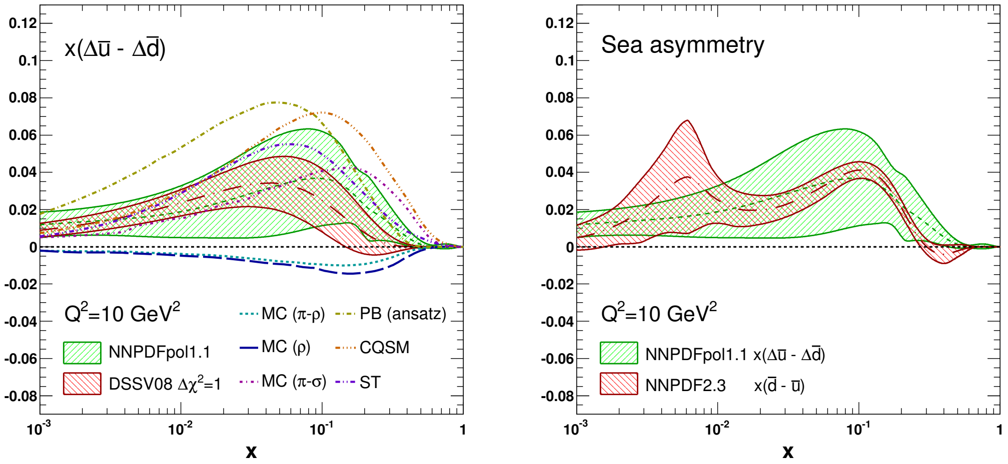

Figure 2: The polarized light sea-quark asymmetry $x(\Delta\bar{u}-\Delta\bar{d})$ computed with the `NNPDFpol1.1` PDFs [9] at $Q^2 = 10$ GeV^2, its comparison with predictions computed with `DSSV08` [7] PDFs and various models of nucleon structure [17, 18, 19, 20, 22, 23, 25] (left plot), and with the unpolarized asymmetry $x(\bar{d}-\bar{u})$ computed with `NNPDF2.3` PDFs [26] (right plot).

	MC (π-meson) [16]	MC (ρ-meson) [18]	PB (bag-model) [17]	PB [21]	IN [24]	`DSSV08` $\Delta\chi^2 = 1$ [7]
I_Δ	$\equiv 0$	< 0	$\simeq 0.09$	$\simeq 0.2$	$\simeq 0.2$	$\mathbf{0.14 \pm 0.05}$
	MC (π-ρ inter.) [17]	MC (π-σ inter.) [19]	PB (ansatz) [20]	CQS [22, 23]	ST [25]	`NNPDFpol1.1` [9]
I_Δ	$[-4\cdot 10^{-3}, -0.033]$	$\simeq 0.12$	$\simeq 0.3$	0.31	> 0.12	$\mathbf{0.17 \pm 0.08}$

Table 1: Prediction for the quantity $I_\Delta = \int_0^1 dx[\Delta\bar{u}(x) - \Delta\bar{d}(x)]$ based on various theoretical models. Results are taken from Ref. [10]. The value of I_Δ at $Q^2 = 10$ GeV^2, obtained using the `NNPDFpol1.1` [9] and the `DSSV08` [7] PDF determinations from experimental data, is shown for comparison.

reported in Ref. [10], compared to that obtained using the `NNPDFpol1.1` and `DSSV08` PDFs. The theoretical models quoted in Fig. 2 and Tab. 1 include several meson-cloud (MC) models [16, 17, 18, 19], various Pauli-blocking (PB) models [17, 20, 21], chiral quark-soliton (CQS) model [22, 23], instanton (IN) model [24] and statistical (ST) model [25]. A description of each of these models has been recently summarized in Ref. [10].

Inspection of Fig. 2 and Tab. 1 allows us to draw the following conclusions.

- The results obtained using either the `NNPDFpol1.1` or the `DSSV08` PDFs are in fairly good agreement, for both the sea-quark asymmetry and its first moment I_Δ. A slight difference in the size and shape of their central values is observed, especially in the high-x region, as a consequence of the different behavior of the $\Delta\bar{u}$ distribution in the two parton sets, see Fig. 1. This mild discrepancy may be explained by the fact that, in comparison to `NNPDFpol1.1`, the `DSSV08` result could be affected by some sources of bias: these include a poor knowledge of the fragmentations functions used to analyze SIDIS data, and a parametrization of PDFs which is not sufficiently flexible. The uncertainty for both the asymmetry in Fig. 2 and its first moment I_Δ in Tab. 1 corresponds to the one-σ band (for `NNPDFpol1.1`) and to the Hessian uncertainty computed assuming $\Delta\chi^2 = 1$ (for `DSSV08`). We notice that in

Ref. [7] a more faithful estimate for `DSSV08` uncertainties was provided, assuming a tolerance $T = \Delta\chi^2 \sim 8$ (see the discussion after Fig. 1). In this case, `DSSV08` uncertainties are larger than those shown in both Fig. 2 and Tab. 1 by a factor $\sqrt{T}$.

- The polarized sea-quark asymmetry obtained from experimental data is definitely positive, within uncertainties, for both the `NNPDFpol1.1` and `DSSV08` determinations. Hence, predictions from models of nucleon structure which lead to a negative asymmetry are clearly disfavored. This is the case of MC models of Refs. [16, 17, 18]. While all other models are qualitatively consistent with both `NNPDFpol1.1` and `DSSV08` results, predictions from the MC and ST models of Refs. [19, 25] are in better agreement with the `NNPDFpol1.1` result than those from the CQS and PB models of Refs. [22, 23, 20]. A more precise experimental knowledge of the sea-quark asymmetry is needed to reduce its uncertainty and eventually discriminate between these models.

- The polarized sea-quark asymmetry has approximately the same absolute size as its unpolarized counterpart, but it is affected by a larger uncertainty (see right plot in Fig. 2). Even within this uncertainty, it is clear that polarized and unpolarized asymmetries have opposite sign. However, it is difficult to decide whether the expectation $|\Delta\bar{u} - \Delta\bar{d}| > |\bar{u} - \bar{d}|$, predicted for instance by the CQS model, is actually fulfilled. Note that this implies that the Bjorken sum rule (which is proportional to the first moment of the triplet PDF combination $\Delta T_3 = \Delta u + \Delta\bar{u} - \Delta d - \Delta\bar{d}$) is not entirely given by valence quarks: also sea quaks can contribute to it, through their flavor asymmetry.

In conclusion we have shown, for the first time, that W-boson production data favor $\Delta\bar{u} > 0 > \Delta\bar{d}$ and a positive flavor asymmetry of polarized light antiquarks in the nucleon. This agrees with the result obtained using SIDIS, and allows us to conclude that some theoretical models of nucleon structure are disfavored. Ongoing experimental measurements on W asymmetries at the Relativistic Heavy Ion Collider will help to reduce the uncertainties on the polarized antiquarks: more stringent constraints on the validity of theoretical models, and a more clear picture of the flavor asymmetry of light antiquarks in the nucleon could be then achieved.

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