Partonic Spin Structure of the Nucleon and QCD

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We present a concise description of our present knowledge of the polarized parton densities extracted from the world data on inclusive deep inelastic lepton-nucleon scattering.

Recently [1] we carried out a next-to-leading order (NLO) QCD analysis of the world data on polarized inclusive deep inelastic scattering (DIS). Since then the SMC group at CERN have reanalyzed their small-x data, using a totally new method of analysis, and published the final results of their experiment [2]. At the same time new data have emerged from the HERMES Collaboration at DESY [3] and very recently from the E155 experiment at SLAC [4].

Given that there are significant changes in the SMC data, and the high precision of the new HERMES and SLAC/E155 data, we have updated our analysis. We have found that the newly incorporated data improve the determination of the polarized parton densities, in particular, of the poorly known gluon density. Here we present a brief summary of the general trends in our new results.

All details of our approach are given in [1]. We carry out our analysis in three different factorization schemes: $\overline{\rm MS}$, AB (Adler-Bardeen) and JET [5] and test the independence of the physical results on the choice of the factorization convention. We prefer to work with separate valence and sea parton densities and we check the stability of our results when we vary the parameter λ corresponding to different flavour decompositions of the sea $\Delta\bar{u} = \Delta\bar{d} = \lambda\Delta\bar{s}$, i.e., we confirm that the non-singlets Δq_3, Δq_8, the singlet $\Delta\Sigma$ and the gluon density ΔG are invariant (do *not* change as λ is varied). Note that this implies that the strange quark density $\Delta\bar{s} = \frac{1}{6}(\Delta\Sigma - \Delta q_8)$ is also invariant and it can be extracted from the data as well as $\Delta\Sigma$. Of course, the valence quark densities Δu_v and Δd_v are sensitive to the different assumptions about the sea.

For the input polarized parton densities at $Q_0^2 = 1\ GeV^2$ we have adopted a very simple parametrization

$$\begin{aligned} x\Delta u_v(x,Q_0^2) &= \eta_u A_u x^{a_u} x u_v(x,Q_0^2)\ , \\ x\Delta d_v(x,Q_0^2) &= \eta_d A_d x^{a_d} x d_v(x,Q_0^2)\ , \\ x\Delta Sea(x,Q_0^2) &= \eta_S A_S x^{a_S} x Sea(x,Q_0^2)\ , \\ x\Delta G(x,Q_0^2) &= \eta_g A_g x^{a_g} x G(x,Q_0^2)\ , \end{aligned} \qquad (1)$$

where on RHS of (1) we have used the MRST unpolarized densities [6]. The normalization factors A_f in (1) are fixed such that η_f are the first moments of the polarized densities. The first moments of the valence quark densities η_u and η_d are fixed by the octet nucleon and hyperon β decay constants [7].

The rest of the parameters in (1), $\{a_u,\ a_d,\ \eta_S,\ a_S\ ,\ \eta_g\ ,\ a_g\}$, have been determined from the fits to the world data on $A_1^N(x,Q^2)$ [2-4, 8-12]. The total (statistical and systematic) errors are taken into account. The results presented below correspond to an SU(3) symmetric sea.

What follows from our analysis is that the NLO QCD predictions are in a very good agreement with the presently available data on A_1^N (g_1^N) in all the schemes, JET, AB and $\overline{\rm MS}$, with the essen-

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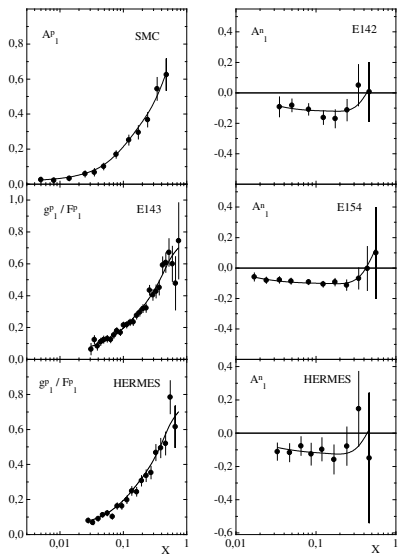

Figure 1. Comparison of our NLO results in the JET scheme for $A_1^N(x,Q^2)$ with the experimental data at the measured x and Q^2 values.

tially the same $\chi^2/DOF \approx 128.5$ for 155 DOF. An example of the quality of the fits is shown in Fig. 1.

Let us now comment briefly upon the state of our knowledge about the individual polarized parton densities. The extracted quark (valence and sea) and gluon densities are shown in Fig. 2 and Fig. 3.

$\Delta u_v(x,Q^2)$ and $\Delta d_v(x,Q^2)$

i) The valence quark densities are practically unchanged if the new data are incorporated in the analysis.

ii) Δu_v and Δd_v in the JET, AB and $\overline{\rm MS}$ schemes coincide within the errors, in excellent agreement with what follows from the theory (they should be the same in the factorization schemes under consideration).

iii) Although the first moment of $\Delta d_v(x,Q_0^2)$, η_d, has been kept fixed in the analysis, Δd_v is not well determined from the present inclusive data.

$\Delta\bar{s}(x,Q^2)$ and $\Delta\Sigma(x,Q^2)$

Note that these quantities are scheme dependent.

i) $\Delta\bar{s}$ and $\Delta\Sigma$ are well determined from the data now (see Fig. 2).

ii) The first moment of $\Delta\bar{s}$ in the $\overline{\rm MS}$ scheme, $(\eta_{\bar{s}})_{\overline{\rm MS}}$, is almost twice as big as it is in the JET(AB) schemes, $(\eta_{\bar{s}})_{\rm JET(AB)}$:

$$\begin{aligned}(\eta_{\bar{s}})_{\overline{\rm MS}} &= -0.051 \pm 0.006,\\ (\eta_{\bar{s}})_{JET} &= -0.032 \pm 0.005. \end{aligned} \quad (2)$$

The polarized strange quark density is significantly different from zero independently of the factorization schemes used in the analysis. The result (2) demonstrates the extent to which the strange quark densities in different schemes can differ in the polarized case.

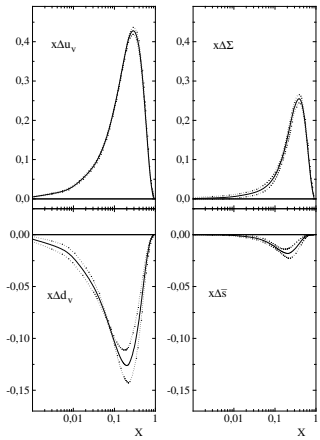

Figure 2. Polarized valence, strange and singlet quark distributions at $Q^2 = 1\ GeV^2$ with their error bands (JET scheme).

Gluons $\Delta G(x,Q^2)$

i) The new set of data allows a better determination of the polarized gluon density in the JET and AB schemes.

In previous studies χ^2 was quite insensitive to the value of a_g in all factorization schemes under consideration, and the results of the fits corresponding to fixing $a_g = 0.6$ were presented in [1]. The results when a_g is a free parameter are summarized in Table 1. It is clear from the Table 1 that now both the value of a_g and η_g, i.e., the shape and the normalization of the gluon density are much better constrained in the JET and AB schemes. The progress in extracting the polarized gluon density from the new data set is illustrated in Fig. 3 (JET scheme).

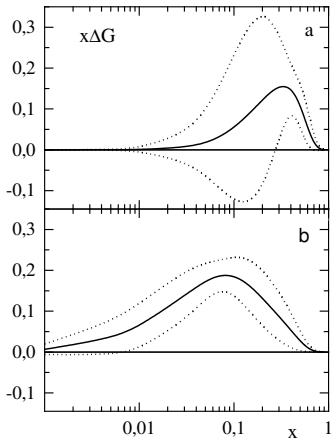

Figure 3. The polarized gluon density at $Q^2 = 1\ GeV^2$ determined from the old (a) and the new (b) world sets of data. The error bands account for the statistical and systematic uncertainties.

Table 1
The values of the parameters associated with the input polarized gluon density in the JET, AB and $\overline{\text{MS}}$ schemes for the new and old sets of data.

	JET	AB	$\overline{\text{MS}}$
Old data			
a_g	1.8 ± 2.1	1.7 ± 1.8	1.6 ± 1.9
η_g	0.24 ± 0.35	0.28 ± 0.40	0.30 ± 0.50
New data			
a_g	0.18 ± 0.45	0.14 ± 0.42	3.6 ± 3.8
η_g	0.57 ± 0.14	0.58 ± 0.12	0.07 ± 0.10

ii) In the $\overline{\text{MS}}$ scheme the gluons are still poorly constrained. χ^2 continues to be insensitive to a large range of possible values for a_g (see Table 1). The obtained value of η_g in this case is consistent with zero. However, if we fit the data with a fixed value of $a_g = 0.2$ (in accord with the values obtained in the JET, AB schemes), we find $\eta_g = 0.62 +/- 0.42$, in agreement with the values of this quantity in the JET and AB schemes, as expected theoretically.

Axial charge $\mathbf{a_0(Q^2)}$

i) A good agreement between the values of $a_0(Q^2)$ at $Q^2 = 1\ GeV^2$ determined in the different schemes is achieved

$$(a_0)_{\text{JET}} = 0.26 \pm 0.05, \quad (a_0)_{\overline{\text{MS}}} = 0.28 \pm 0.04, \quad (3)$$

which illustrates how our analysis respects the scheme-independence of physical quantities.

ii)The central values of a_0 are slightly smaller than the corresponding values obtained from our previous analysis.

In conclusion, we have found that the main effect of the newly incorporated data is a better determination of the polarized gluon density, but in comparison with the other densities the uncertainty is still large. To know more precisely both the quark and the gluon polarized densities in the nucleon, accurate data from inclusive and semi-inclusive processes in a larger kinematic region as well as a direct measurement of the polarized gluon density at RHIC and HERA are needed.

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