Statistical Polarized Parton Distributions at Large-x

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Abstract. We present a new set of polarized parton distributions constructed in a statistical physical picture of the nucleon. The chiral peoperties of QCD lead to precise relations between quarks and antiquarks distributions and the importance of the Pauli exclusion principle is also emphasized. The model involves a small number of free parameters which are determined by a global next-to-leading order QCD analysis of unpolarized and polarized deep-inelastic scattering data. We discuss the implications of experimental data on the structure of polarized distributions.

INTRODUCTION

An experimental study of deep-inelastic scattering (DIS) of leptons on hadrons during the last twenty years has produced measurements of cross sections and structure functions over a large kinematic domain, and as a consequence a better knowledge of the partons distributions functions (PDF) in the unpolarized and polarized cases. Although, we have no theory to compute the PDF, a large variety of phenomelogical functions has been proposed in the literature [1], and their success in describing experimental data has provided a better explanation of the hadrons structure and a test of pQCD.

The above *classic* PDF are generally parametrized as a polynomial in the Bjorken variable x at an input scale Q_0, in order to introduce more physical aspects in the description of PDF, we propose a new statistical approach where the nucleon is viewed as a gas of massless partons (quarks, antiquarks, gluons) in equilibrium at a given temperature in a finite size volume. Moreover, in contrast with other parametrizations, we consider from the beginning that the fundamental entities are polarized parton distributions defined by their helicities. In the process of building our PDF, we take into account experimental informations well established by now. For instance, data exhibit a clear evidence for a flavor-asymmetric light sea, *i.e.*, $\bar{d} > \bar{u}$, which can be understood in terms of the Pauli exclusion principle, based on the fact that the proton contains two u quarks and only one d quark. The signs of the polarized light quarks distributions are essentially well established, $\Delta u > 0$ and $\Delta d < 0$, while we just begin to uncover a flavor asymmetry,

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for the polarized light sea, namely $\Delta\bar{u} \neq \Delta\bar{d}$.

CONSTRUCTION OF THE STATISTICAL PDF

Our motivation is to use the statistical approach to build up : $q_i, \Delta q_i, \bar{q}_i, \Delta\bar{q}_i, G$ and ΔG, by means of a very small number of free parameters. We propose a simple description of the parton distributions $p(x)$, at an input energy scale Q_0^2, proportional to $1/\left[\exp\left[(x - X_{0p})/\bar{x}\right] \pm 1\right]$, the *plus* sign for quarks and antiquarks, corresponds to a Fermi-Dirac distribution and the *minus* sign for gluons, corresponds to a Bose-Einstein distribution. Here, X_{0p} is a constant which plays the role of the *thermodynamical potential* of the parton p and $\bar{x}$ is the *universal temperature*, which is supposed to be the same for all partons. Since quarks carry a spin-1/2, it is natural to consider that the basic distributions are $q_i^{\pm}(x)$, corresponding to a quark of flavor i and helicity parallel or antiparallel to the nucleon helicity. Clearly one has : $q_i = q_i^+ + q_i^-$ and $\Delta q_i = q_i^+ - q_i^-$ and similarly for antiquarks and gluons.

From the chiral structure of QCD, we have two important properties which allow to relate quark and antiquark distributions and to restrict the gluon distribution :

- The potential of a quark q_i^h of helicity h is opposite to the potential of the corresponding antiquark $\bar{q}_i^{-h}$ of helicity -h,

$$X_{0q}^{h} = -X_{0\bar{q}}^{-h}. \tag{1}$$

- The potential of the gluon G is zero, $X_{0G} = 0$.

From well established features of the u and d quark distributions extracted from DIS data, we anticipate some simple relations between the potentials:

- $u(x)$ dominates over $d(x)$, therefore one can expect: $X_{0u}^+ + X_{0u}^- > X_{0d}^+ + X_{0d}^-$
- $\Delta u(x) > 0$, therefore $X_{0u}^+ > X_{0u}^-$
- $\Delta d(x) < 0$, therefore $X_{0d}^- > X_{0d}^+$.

So we expect X_{0u}^+ to be the largest thermodynamical potential and X_{0d}^+ the smallest one. In fact, we have the following ordering $X_{0u}^+ > X_{0d}^- \sim X_{0u}^- > X_{0d}^+$, these inequalities are consistent with the previous determinations of the potentials [2]. By using Eq. (1), this ordering leads immediately to some important consequences for antiquarks, namely, $\bar{d}(x) > \bar{u}(x)$, the flavor symmetry breaking which also follows from the Pauli exclusion principle, as recalled above. This was already confirmed by the violation of the Gottfried sum rule [3, 4]. Notice that since $\bar{u}^+(x) \sim \bar{d}^+(x)$, we have $\Delta\bar{u}(x) - \Delta\bar{d}(x) \sim \bar{d}(x) - \bar{u}(x)$, so the flavor symmetry breaking is almost the same for unpolarized and polarized distributions.

Let us now complete the description of our parametrization. The small x region is characterized by a rapid rise of the distributions as $x \to 0$, so they should be dominated by a universal diffractive term, flavor and helicity independent, coming from the Pomeron universality. Therefore we must add a term of the form $\tilde{A}x^{\tilde{b}}/[\exp(x/\bar{x}) + 1]$, where $\tilde{b} < 0$

and $\tilde{A}$ is a normalization constant. In summary, for the light quarks $q = u, d$ of helicity $h = \pm$, at the input energy scale $Q_0^2 = 4\text{GeV}^2$, we take

$$xq^h(x, Q_0^2) = \frac{AX_{0q}^h x^b}{\exp[(x - X_{0q}^h)/\bar{x}] + 1} + \frac{\tilde{A}x^{\tilde{b}}}{\exp(x/\bar{x}) + 1} , \tag{2}$$

and similarly for the light antiquarks

$$x\bar{q}^h(x, Q_0^2) = \frac{\bar{A}(X_{0q}^{-h})^{-1} x^{2b}}{\exp[(x + X_{0q}^{-h})/\bar{x}] + 1} + \frac{\tilde{A}x^{\tilde{b}}}{\exp(x/\bar{x}) + 1} . \tag{3}$$

For the strange quarks and antiquarks, we take the particular choice

$$xs(x, Q_0^2) = x\bar{s}(x, Q_0^2) = \frac{1}{4}[x\bar{u}(x, Q_0^2) + x\bar{d}(x, Q_0^2)] , \tag{4}$$

$$x\Delta s(x, Q_0^2) = x\Delta\bar{s}(x, Q_0^2) = \frac{1}{3}[x\Delta\bar{d}(x, Q_0^2) - x\Delta\bar{u}(x, Q_0^2)] . \tag{5}$$

This choice gives rise to a large negative $\Delta s(x, Q_0^2)$. The charm quarks c , both unpolarized and polarized, are set to zero at $Q_0^2 = 4\text{GeV}^2$. Finally concerning the gluon distribution, as indicated above, we use a Bose-Einstein expression given by

$$xG(x, Q_0^2) = \frac{A_G x^{\tilde{b}+1}}{\exp(x/\bar{x}) - 1} , \tag{6}$$

with a vanishing potential and the universal temperature $\bar{x}$. For the sake of completeness, we also need to specify the polarized gluon distribution where we take the particular choice, $x\Delta G(x, Q_0^2) = 0$.

To summarize our parametrization involves a total of *eight* free parameters

$$\bar{x} , X_{0u}^+ , X_{0u}^- , X_{0d}^- , X_{0d}^+ , b , \tilde{b} \text{ and } \tilde{A} .$$

These parameters, are determined at NLO by a fitting procedure described in Ref. [5, 6].

We have defined the PDF in terms of Fermi functions at the input scale Q_0^2, does this property still persist at any given Q^2. We have proven in Ref. [7] that the statistical PDF can be approximated by a linear combination of Fermi functions which depend explicitely on x and Q^2. In the next section we will concentrate on the large x results obtained at NLO with the statistical PDF.

EXPERIMENTAL TESTS FOR (UN)-POLARIZED DIS

We first consider μp and ep DIS for which several experiments have yielded a large number of data points on the structure function $F_2^p(x, Q^2)$. In Fig. 1 (left) we compare our calculations with measurements made by NMC, BCDMS, ZEUS and H1 collaborations,

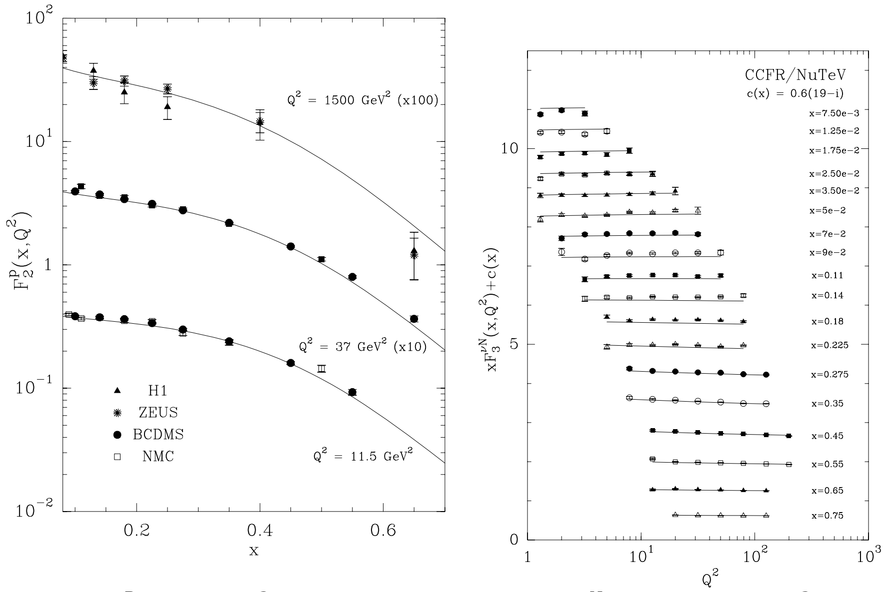

FIGURE 1. Left, F_2^P for fixed Q^2 as a function of x. Right, $xF_3^{\nu N}$ as a function of Q^2 for fixed x bin .

for fixed Q^2 and large x values. We have also a quite good description of the neutron structure function $F_2^n(x,Q^2)$ data [5]. The high statistic νN DIS data from CCFR/NuTeV allows to extract the $xF_3^{\nu N}(x,Q^2)$ structure function, which is successfully compared to our results on Fig. 1 (right), we have also a very good description of the ZEUS and H1 data in the range $1500 \leq Q^2 \leq 310^5$ [8, 9].

Since our approach is based on the direct construction of quarks and antiquarks PDF of a given helicity, we immediately obtained Δq_i and $\Delta \bar{q_i}$ for each flavor. We display in Fig. 2 (left) the polarized structure functions $g_1^{p,n,d}$ at large x, from different experiments on proton, deuterium and helium targets, evolved at a fixed value $Q^2 = 5\text{GeV}^2$. The x dependence is in fair agreement with our results. We notice, in particular, for g_1^n, the perfect agreement with the 3 very precise data points recently measured at Jefferson Lab (Jlab-E99).

In Fig. 2 (right) the asymmetries $A_1^{p,n}$ are displayed with the world data at $Q^2 = 4\text{GeV}^2$ and restricted to $x > 0.1$. An interesting feature is the behavior of the asymmetries when $x \to 1$, in our model we find that $A_1^{p,n} < 1$ due to the fact that $\Delta u/u = 0.77$ and $\Delta d/d = -0.46$. For the A_1^n asymmetry measured by JLab-E99 at $x = 0.33, 0.47, 0.6$, our model agrees with their data at the two extreme points, but at $x = 0.47$ its value is above by 1σ. We have also computed the $g_2^{p,n}$ asymmetries using the Wandzura-Wilczek relation, a comparison with data from SLAC and Jefferson Lab. show a reasonable agreement owing to the experimental errors.

Recently, HERMES collaboration has obtained a set of polarized PDF at $Q^2 = 2.5\text{GeV}^2$, (see L. De Nardo, these proceedings) a comparison with our results is displayed in Fig. 3 (left), the agreement is satisfactory within the experimental errors.

Let us comme back to the important question of the flavor asymmetry of the light antiquarks. Our determination of $\bar{u}(x,Q^2)$ and $\bar{d}(x,Q^2)$ is perfectly consistent with the violation of the Gottfired sum rule, for which we found $I_G = 0.2493$ for $Q^2 = 4\text{GeV}^2$.

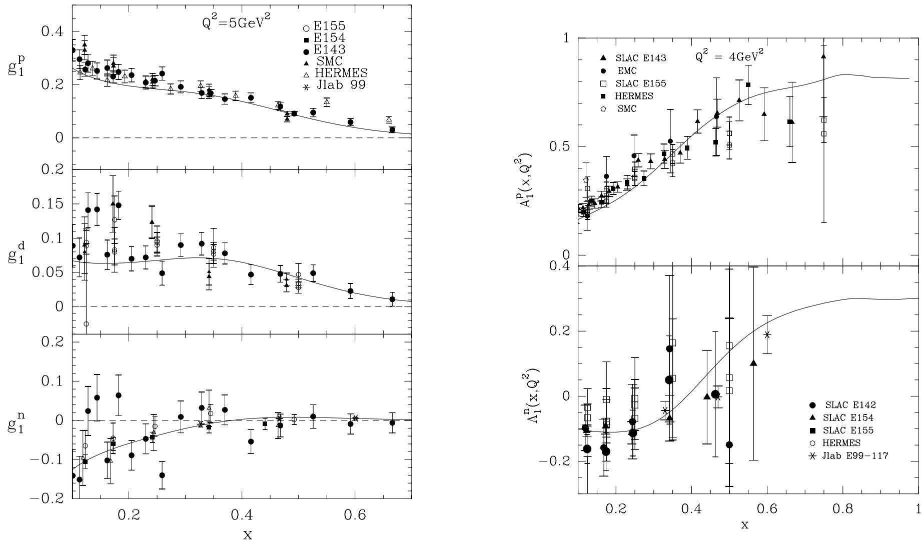

FIGURE 2. $g_1^{p,n,d}$ and $A_1^{p,n}$ for fixed Q^2 as a function of x.

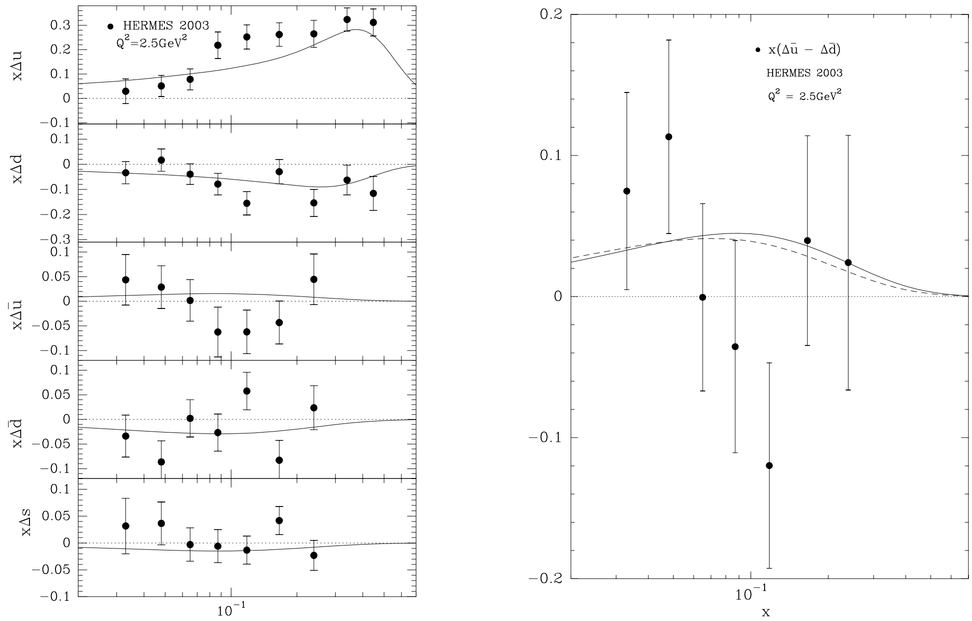

FIGURE 3. Left, comparison between polarized PDF and Hermes data, Right, $x(\Delta\overline{u} - \Delta\overline{d})$ compared with Hermes data at $Q^2 = 2.5\text{GeV}^2$ solid line and $Q^2 = 54\text{GeV}^2$ dashed line. .

Nervertheless there remains an open problem with the x distribution of the ratio $\bar{d}/\bar{u}$ for $x > 0.2$, in connection with the E866/NuSea collaboration. They have found at $Q^2 = 54\text{GeV}^2$ that $\bar{d}/\bar{u}$ is decreasing above $x > 0.2$ while in our model this ratio is, according to the Pauli principle, above 1 for any value of x. One possibility to clarify the situation is to measure the ratio of the unpolarized cross sections for the production of $W^\pm$ in pp collisions, which will directly probe the behavior of $\bar{d}/\bar{u}$ ratio. As an illustration, we have computed this ratio using MRST2002 PDF, where $\bar{d}/\bar{u} < 1$ for $x > 0.2$, and compare with our result, a significant gap at $y = 0$ exists. An other test is to consider the polarized difference $x[\Delta\bar{u}(x) - \Delta\bar{d}(x)]$, taking into account the properties of the polarized PDF in our model, we can show that if $\bar{d}/\bar{u} > 1$ for $x > 0.2$, the previous difference is positive, in the opposite case it becomes negative. The HERMES collaboration has released some values of this difference shown in Fig. 3 (right), however, no definite conclusion can be drawn due the large errors, nevertheless, above $x > 0.1$, it seems that the trend of data favor positive values. In the figure, the solid curve corresponds to $Q^2 = 2.5\text{GeV}^2$, the dashed curve to $Q^2 = 54\text{GeV}^2$, showing a small variation. An extended measurement is scheduled by the E906 collaboration (see A. Towell, these proceedings).

Let us mention an other way to obtain a good flavor separation by measuring the parity-violating asymmetry in $W^\pm$ production at RHIC-BNL. Calculations in the statistical model at $\sqrt{s} = 500\text{GeV}$ near a rapidity $y = +1$ show that $A_L^{PV}(W^+) \sim \Delta u/u$ and that $A_L^{PV}(W^-) \sim \Delta d/d$ (evaluated at $x = 0.435$). Similarly, near $y = -1$, $A_L^{PV}(W^+) \sim -\Delta\bar{d}/\bar{d}$ and $A_L^{PV}(W^-) \sim -\Delta\bar{u}/\bar{u}$ (see Ref. [5] for more details).

We have presented a few samples of the predictions obtained with the statistical model, a full set of results is available in Ref. [9].

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