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SEA STRUCTURE FUNCTIONS WITHIN THE FRAMEWORK OF NONPERTURBATIVE APPROACH

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Recently the experimental data of extreme importance concerning the sea quark structure function measurements have been appeared[1]–[3]. The EMC group[1] has measured the DIS proton spin-dependent structure function , $g_1^p(x)$, with high accuracy. The data analysis has given the following estimation of the helicity carried by sea quarks:

$$\Delta u^s + \Delta d^s + \Delta s^s = -0.95 \pm 0.16 \pm 0.23, \quad (1)$$

where

$$\Delta q^s = \int_0^1 dx\ [q_+^s(x) - q_-^s(x)],$$

$q_+^s(x)(q_-^s(x))$ being the quark of flavour q distribution with the helicity parallel (antiparallel) to the parent helicity of the proton.

The independent estimation for the helicity of strange quarks obtained from the neutrino experiment[2] is as follows:

$$\Delta s^s = -0.15 \pm 0.09. \quad (2)$$

Thus, the contributions of sea quarks to the proton helicity can be deduced

$$\Delta u^s \approx \Delta d^s \approx -0.4;\ \Delta s^s \approx -0.15. \quad (3)$$

These values are about one order higher than the fractions of the proton momentum carried by sea quarks[3]:

$$u^s \approx d^s \approx 0.05;\ s^s \approx 0.02, \quad (4)$$

where $q^s = \int_0^1 dx\ [q_+^s(x) + q_-^s(x)]$. The anomalously large contribution of sea quarks to the proton helicity has given rise to the so-called "spin crisis" (see for the details[4]) because it canceles almost completely the helicity carried by valence quarks.

In our works[5] (see also[6]) the nonperturbative mechanism of appearence of the negative helicity of sea quarks has been suggested. It is based on the model of the QCD vacuum as an instanton liquid[7]. The matter is that in an instanton field, a strong nonperturbative gluon fluctuation, a quark being in the t'Hooft zero mode[8] changes its chirality to the opposite one. This phenomenon is quite anologous to the appearence of the baryon number from the Dirac vacuum in the field of a strong topological fluctuation of the chiral field in the Skyrme-like models of the nucleon[9].

In the recent paper[10] the idea of works[5,6] on a dominant role of the instanton mechanism in arising the helicity of sea quarks has been used to construct manifestly the quark structure functions. Therein, within the dilute instanton gas approximation the contribution of instantons into the proton axial form factor has been determined (fig. 1) as follows:

$$G_A^5(Q^2) \propto (1/Q^2)^n, \quad n \geq 5. \tag{5}$$

Then, by using the Drell-Yan-West relation one can derive the x-dependence of the polarized structure functions:

$$\Delta q(x) \approx B(1-x)^p, \quad p \geq 10. \tag{6}$$

Note, that the Drell-Yan-West relation is obtained as a result of squaring

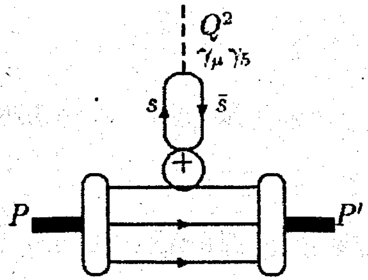


Fig. 1 The instanton contribution to the proton axial formfactor (+(−)-(anti)instanton).

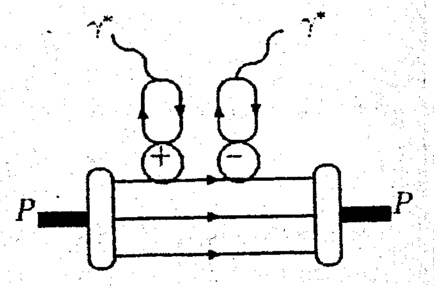


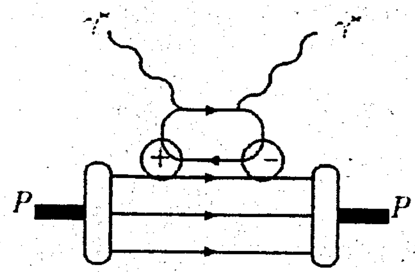
Fig. 2

of the diagram of Fig. 1 (see Fig. 2). Evidently, then a large momentum passes through a nonperturbative fluctuation leading to a very strong Q^2-dependence ($\Delta q(x) \propto (1/Q^2)^{2n}$) of the structure function eq. (6). This means that expression eq. (6) probably bears no relation to the structure function of leading twist.

The lowest diagram contributing into the sea quark structure function of the leading twist is depicted in Fig. 3. The structure function is connected with the wave function on the light cone by the relation[11]:

$$F_{q/p}(x) \propto \sum_n \int [dk_{\perp i}][dx_i]\ \delta(x - x_q) \cdot |\ \Psi_{(n)}(k_{\perp i}, x_i)\ |^2 \cdot \Theta(k_{\perp i}^2 \leq Q^2), \tag{7}$$

Fig. 3 The leading twist contribution to the sea structure functions



where $\Psi_{(n)}(k_{\perp i}, x_i)$ is the contribution of an n-particle intermediate state to the wave function, $x_i = (k^0 + k^3)_i/(p_0 + p_3)$, $\sum_{i=1}^n \vec{k}_{\perp i} = 0$, $\sum_{i=1}^n x_i = 1$. The most general form of the wave function is[11]:

$$\Psi_{(n)}(k_{\perp i}, x_i) = \frac{\Gamma_n(k_{\perp i}, x_i)}{M_p^2 - \sum_{i=1}^n \frac{m_i^2 + k_{\perp i}^2}{x_i}}. \tag{8}$$

Within the model of the QCD vacuum as an instanton liquid $\Gamma_n(k_{\perp i}, x_i)$ are the form factors of quarks in the instanton field which depend exponentially on quark virtualities, so

$$\Psi_{(n)}^{inst}(k_{\perp i}, x_i) \propto \frac{\exp\{-\frac{\rho_c}{p_+}(M_p^2 - \sum_{i=1}^n \frac{m_i^2 + k_{\perp i}^2}{x_i})\}}{M_p^2 - \sum_{i=1}^n \frac{m_i^2 + k_{\perp i}^2}{x_i}}. \tag{9}$$

In the integral eq. (7) the dominant region is

$$M_p^2 \approx \sum_{i=1}^n \frac{m_i^2 + k_{\perp i}^2}{x_i}. \tag{10}$$

Then, one can put down

$$F_{q/p}(x) \propto A \int \frac{[dx_i]\delta(x - x_q)}{|\ M_p^2 - \sum_{i=1}^n \frac{m_i^2 + \langle k_\perp \rangle^2}{x_i}\ |^2}. \tag{11}$$

It should be noted that such nonperturbative structure function provides at $m_i^2, < k_\perp^2 > \ll M_p^2$ correct behaviour of the valence quark structure functions of mesons $(1-x)^2$ and baryons $(1-x)^3$ as $x \to 1$[11].

For the sea structure functions of light (u, d, s) and heavy (c, b) quarks we obtain from eq. (11) :

$$F^s_{q/p}(x)_{x\to 1} \propto (1-x)^5; \quad q = u, d, s; \qquad (12)$$
$$F^s_{q/p}(x)_{x\to 1} \propto (1-x)^3, \quad q = c, b.$$

The behaviour at $x \to 0$ is specified by Regge asymptotics. Usually one assumes (see [12]) that the pomeron exchange with $\alpha_p \approx 1$ dominates in the sum $q^s(x) = q^s_+(x) + q^s_-(x)$, and, hence:

$$\lim_{x\to 0} q^s(x) \propto 1/x, \qquad (13)$$

whereas the difference $\Delta q^s(x) = q^s_+(x) - q^s_-(x)$ is specified by the A_1-meson contribution ($\alpha_{A_1} = 0$), and, so

$$\lim_{x\to 0} \Delta q^s(x) \propto const. \qquad (14)$$

Usually in order to argue eq. (14)[10,12,13] one says that the trajectories with the quantum numbers $\sigma(-1)^I G = -1$ (σ is signature), A_1 being the well-known example with $I = 1$, $\sigma = 1$, $G = 1$ contribute into $\Delta g(x)$. However, to our opinion, such reasoning is not quite correct, because A_1 (the trajectory with $I = 1$) can not contribute into the isosinglet anomalous combination $\Delta u + \Delta d + \Delta s$. The only trajectory capable to contribute into $\Delta q = \Delta u + \Delta d + \Delta s$ is the trajectory with $I = 0$, $\sigma = -1$, $G = 1$.

We shall identify this trajectory with an odderon[14]. having $\alpha_{odd} \approx 1$. There are several ground for such identifications. Firstly, only with such intersept one manages to explain the discrepancy by an order between the magnitudes of eq. (3) and eq. (4). Secondly, the presence of the $I = 0$ signature exchange which does not die out with energy is, seemingly, necessery condition for explanation of the observed differences between the cross-sections of $pp-$ and $p\bar{p}-$reactions at high energies[14]. Thirdly, the exchange in question is to contribute, in general into the large-p_t processes, as large x_i correspond to large $k^2_{\perp i}$ (see eq. (10)), and just in this region the odderon contribution into elastic $pp-$ and $p\bar{p}-$scattering is dominant[14].[1]

[1]The calculated characteristics of the odderon as the state associated with instanton exchange between quarks will be published elsewhere.

So, we believe that an odderon dominates in the difference of distribution functions, and the asymptotics has a form:

$$\lim_{x\to 0} \Delta q^s(x) \propto 1/x. \qquad (15)$$

Thus, the following parametrization of the distribution functions of sea quarks in the proton is proposed:

$$q^s_+(x) \approx \frac{B_q}{x}(1-x)^{k_q} + \frac{A_q}{2x}(1-x)^n, \qquad (16a)$$
$$q^s_-(x) \approx \frac{2B_q}{x}(1-x)^{k_q} + \frac{A_q}{2x}(1-x)^n, \qquad (16b)$$

where the latter terms describe the pomeron contribution as $x \to 0$ and the nonperturbative gluon one as $x \to 1$ ($n \approx 7$ within the quark-countig rule) and $k_q = 5$ for $q = u, d, s$; $k_q = 3$ for $q = c, b$.

The difference between the coefficients in eq. (16a) and eq. (16b) is due to the fact that sea quark helicity is antiparallel to the helicity of the valence quark off which the former is produced. In analogous manner, the substantional breakdown of $SU_f(2)$ and $SU_f(3)$ in the sea quark distribution functions, associated with the fact that the instanton-induced interaction is nonzero only for the quarks of different flavours, occurs. In the proton , for instance, the relation (in the first order in instanton interaction):

$$d^s(x) \approx 2u^s(x) \qquad (17)$$

is to be satisfied.

To our opinion, the difference between the $x-$distributions of valence quarks $u^v_p(x) \propto (1-x)^3$ and $d^v_p(x) \propto (1-x)^4$ observed experimentally is connected with probably incorrect assumptions that $d^s_p(x) \approx u^s_p(x)$. Then some part of sea $d-$quarks, in fact, is taken into account in the valence structure function of $d-$quarks, leading to its softening with respect to the structure function of $u-$quarks.

Further, as the mass of a sea quark grows, the nonperturbative part of structure functions dies out faster than the perturbative one because the interaction proceeds through the quark zero modes in the instanton field (parametrically $B_q \propto 1/m_q^2$, m_q is the constituent quark mass[7]). Then, we may explain the experimentally observed softening of the strange sea[3] as compared to nonstrange one by suppression of the hard nonperturbative sea in eq. (16a), eq. (16b). Note, that in ref. [10] these data were explained by the opposite effect, that is by more stronger dependence of the perturbative sea on the quark mass than that of the nonperturbative one, which is extremely suprising.

As for c and b quarks, the nonperturbative interaction is suppressed by the quantities:

$$\epsilon_c \approx (m_u/m_c)^2 \approx (0.30/1.5)^2 \approx 4\cdot 10^{-2},$$

$$\epsilon_b \approx (m_u/m_b)^2 \approx (0.30/4.7)^2 \approx 4\cdot 10^{-3}.$$

Despite of large suppression ϵ_c of a nonperturbative charm in the proton structure function in the charm production processes already at quite small x due to substantional difference of degrees of $(1-x)$ in eq. (16a), eq. (16b), there begin to dominate the hard nonperturbative component, which can be traced from the data of the experiment[15].

At last note that the degrees of the powers for $1/x$ and $(1-x)$ in eq. (16a), eq. (16b) refer to asymptotics as $x\to 0$ and $x\to 1$. In the intermediate region, evidently, one should take into account more complicated configurations of the proton wave function.

So, we propose the model for structure functions of sea quarks based on the concept of QCD vacuum as an instanton liquid. The model explains the experimental data on the sea structure functions.

We think that further experiments on testing the above-mentioned ideas should be done in the following directions: measerment of Drell-Yan pair production in polarised pp–reactions; measurment of the photon production asymmetry in polarized pp scattering; study of inclusive Λ, Λ_c production in longitudinally polarized pp and pA reactions.

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