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PROTON STRUCTURE FUNCTIONS AT LARGE TRANSFER MOMENTA AND ITS DESCRIPTION IN A MODEL WITH THE QUARK-AMPLITUDE FACTORIZABILITY ASSUMPTION

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Recently new results of the experiment on the deep inelastic muon-nucleon scattering in the kinematical region $0.35 \leq x \leq 0.65$, $27.5 \leq Q^2 \leq 170$ GeV^2 have been obtained [1]*. A very small violation of the Bjorken scaling [2], studied earlier in Ref. [3] on the basis of general principles of the quantum field theory, is a characteristic peculiarity of the data on the structure function $F_2(x,Q^2)$ (obtained with the assumption $R = \sigma_L/\sigma_T = 0$).

Since a field-theoretical description of the system composed from three and more particles (quarks) is a rather complicated and yet far to be solved problem, then to obtain an explicit form of the structure functions, it is necessary to use model representations.

In this paper it is shown that the NA-4 experimental data as well as the data of the earlier SLAC experiment [4] are well described by the simple quark model with the factorizability hypothesis namely the dynamical model of factorizing quarks (DMFQ) [5].

DMFQ is an extension of the model of factorizing quarks [6] assuming that in a hadron collision a some effective self-consistent field V_{eff} is produced and quarks of the hadrons scatter as quasi-independent objects on this field. DMFQ supplement this picture by the hypothesis that at a large-angle scattering the range of a quark interaction is characterized by an effective size to be equal to the quark Compton wave length M_q^{-1} (M_q is an effective quark mass). Under this assumption a technique of the expansion over the unitary finite-dimensional irreducible representations of the Lorentz group realized by the functions $(\hbar = c = 1)$ [7]

$$\xi(\vec{p},\vec{r}) = \left(\frac{p_0 - \vec{p}\vec{n}}{M_q}\right)^{-1-irM_q} \quad ; \quad \vec{r} = r\vec{n} \qquad (1)$$

permits us to find an explicit expression for the amplitude of the scattering of an individual quark $g_q(\theta)$ at an angle θ

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*We use the standard variables: $Q^2 = -t = -q^2$, $\nu = Pq/M$, $x = 1/\omega = Q^2/2M\nu$, $W^2 = (P+q)^2$, where P is a momentum of the initial nucleon, M is its mass, q is a transfer momentum.

in the potential V_{eff} [5]:

$$g_q(\theta)=\chi_q/\mathrm{sh}\,\chi_q \,. \tag{2}$$

There $\chi_q=\mathrm{Arch}(1-t_q/2M_q^2)$ is the rapidity corresponding to the transfer momentum $t_q=t/n^2$, n is the number of the quarks in the hadrons. Products of the quark amplitudes (2) determine, in the DMFQ, amplitudes of binary processes and the electrical form factor of the hadron A composed of n valence quarks [5]:

$$G_A(t)=b_A\left(\frac{\chi_q}{\mathrm{sh}\,\chi_q}\right)^n \approx \left(\frac{\ln|t|\,n^{-2}M_q^{-2}}{|t|\,n^{-2}M_q^{-2}}\right)^n. \tag{3}$$

To find a form of the structure functions in the threshold region, in Ref. [8] there were used the formula (3) and the Bloom-Gilman relation of a local duality [9], that for the proton structure function F_2 has the form

$$F_2(\omega_s)=\frac{t}{1-\omega_s}\,\frac{d}{dt}\,\frac{G_E^2(t)-t/4M^2\cdot G_M^2(t)}{1-t/4M^2}. \tag{4}$$

In (4) G_E and G_M are the Sach electric and magnetic form factors. The Bloom-Gilman scaling variable in (4), ω_s, is given by the expression

$$\omega_s=\omega-\frac{M_s^2}{t}\xrightarrow[\omega\to 1]{}1-\frac{W_{in}^2+M_s^2-M^2}{t}\,, \tag{5}$$

where $W_{in}^2=(M+m_\pi)^2$ is the inelastic threshold of the lepton-proton scattering (m_π is the pion mass), M_s^2 is parameter that takes into account the resonance contribution. Substituting (3) into (4) and taking into account the scaling relation between the electric and magnetic proton form factors $G_M=\mu G_E$ (μ is the proton magnetic moment) we find [8]

$$F_2(\omega_s)=C\frac{\mu^{-2}-r}{1-r}\Phi(\chi_s)+C\,b_p^2\mu^2\frac{\lambda(\mu^{-2}-1)}{4M^2(1-r)}\left(\frac{\chi_s}{\mathrm{sh}\,\chi_s}\right)^{2n}, \tag{6}$$

where

$$\Phi(\chi_s)=4b_p^2\mu^2M_q^2n^3(W_{in}^2+M_s^2-M^2)(\chi_s\mathrm{ch}\,\chi_s-\mathrm{sh}\,\chi_s)\times$$

$$\times(\mathrm{ch}\,\chi_s-1)^2(\mathrm{sh}\,\chi_s)^{-3}(\chi_s/\mathrm{sh}\,\chi_s)^{2n-1},$$

$$r=\frac{W_{in}^2+M_s^2-M^2}{4M^2(1-\omega_s)},\quad \lambda=\frac{W_{in}^2+M_s^2-M^2}{(1-\omega_s)^2}.$$

Table

The results of fitting the NA-4 [1] and SLAC [4] data by formula (6)

	Experi-ment	Number of points	Number of droped points	$\chi^2_{d.f.}$	M_q (GeV)	C	M_s^2 (GeV^2)
			-	1.424			
1	NA-4	69	1	1.207	0.125 ± 0.011	11.09 ± 0.42	1.982 ± 0.006
			4	0.973			
2	SLAC	36	-	1.035	0.125 ± 0.002	8.35 ± 0.27	1.502 ± 0.028
			-	1.429			
3	NA-4	69	1	1.213	0.124 ± 0.11	11.09 ± 0.41	1.939 ± 0.006
		5	5	0.902			
4	SLAC	36	-	0.945	0.124 ± 0.003	8.36 ± 0.28	1.462 ± 0.028
			-	1.419			
5	NA-4	69	1	1.202	0.126 ± 0.011	11.06 ± 0.44	2.022 ± 0.04
			4	0.966			
6	SLAC	36	-	1.136	0.126 ± 0.002	8.34 ± 0.27	1.542 ± 0.029
			-	1.414			
7	NA-4	69	1	1.195	0.127 ± 0.011	10.99 ± 0.44	2.061 ± 0.036
			4	0.957			
8	SLAC	36	-	1.255	0.127 ± 0.003	8.33 ± 0.27	1.583 ± 0.03

The variable

$$\chi_s = \mathrm{Arch}\left(1 + \frac{W_{in}^2 + M_s^2 - M^2}{2n^2 M_q^2(\omega_s - 1)}\right) \qquad (7)$$

is found from $\chi_q = \mathrm{Arch}(1 - t_q/2M_q^2)$ according to (5) by the change $n^2 t_q \to -(W_{in}^2 + M_s^2 - M^2)/(1-\omega_s)$. Formulae (6) contain the three parameters: the quark mass M_q, proportionality coefficient C, and parameter M_s^2. As is shown in Ref. [8], the formulae (6) well describe the SLAC data [4] not only in the threshold region $x \geq 0.75$ but also all the data completely. Still better agreement with the experiment is achieved when in formulae (6) a Regge-like behaviour of the structure functions at $x \to 0$ is taken into account. A use of the formulae for the form factor (3) and the Bloom-Gilman relation for the determination of the proton structure functions F_1 led also to a well description of experimental data [8].

Results of our analysis of the NA-4 experiment data [1] by formulae (6) are represented in the table in four first rows (N=1,2) that contains also results of comparison of (8) with the SLAC data with $x \geq 0.35$ [4]. The difference of values of the proportionality coefficient C is caused by the need of introducing the normalization factor for the NA-4 data. A natural increase in magnitude of the parameter M_s^2 at the transition from the SLAC data to the NA-4 data reflects the fact that a number of resonances produced in the scattering process increases with Q^2. The listed under N=1,2 in the table set of parameter values is not unique one. A description of the data with the value χ^2 per one degree of freedom ($\chi^2_{d.f.}$) of an order of unity is achieved also at some other parameter values; part of them is listed in the table. Note that the parameter values are stable and the quark mass is consistent in magnitude with the values obtained in Refs. [5,8] and other papers on the description of the processes in the framework of the DMFQ.

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