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ON THE NUCLEON WAVE FUNCTION

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On the Nucleon Wave Function

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ABSTRACT

The nucleon wave function $\varphi_N(x_1, x_2, x_3)$ describes the distribution of three quarks in the nucleon in longitudinal momentum fractions $0 \leqslant x_i \leqslant 1$, $i=1, 2, 3$ at $p_z \to \infty$. The values of all its first, second and third moments, $(n_1, n_2, n_3) = \int_0^1 d_3x \cdot x_1^{n_1} x_2^{n_2} x_3^{n_3} \varphi_N(x)$, $n = n_1 + n_2 + n_3$, $n=0, 1, 2, 3$ are found by using the QCD sum rules. The results show unambigously the large assymetry in the distribution of the nucleon longitudinal momentum between three quarks at $p_z \to \infty$. Roughly, one u-quark with its spin parallel to the proton spin carries $\simeq 60\%$, and each of two other quarks carries $\simeq 20\%$ of the proton momentum.

The simple model wave function which satisfy the sum rules requirements is proposed. The comparison with the results of previous papers is made.

1. INTRODUCTION

The theory of the asymptotic behaviour of exclusive processes in QCD is well developed at present [1] (the review see in [2]). According to this theory, the hard exclusive amplitude can be expressed as a convolution of the «hard kernel» $T_H(x, y)$ (which is calculated in perturbative QCD) with $\varphi(x)$, $\tilde{\varphi}(y)$, the nonperturbative wave functions of hadrons participating in the process. The wave function (w.f.) $\varphi(x_i)$ is the fundamental object of the theory and it describes the distribution of quarks in the hadron in longitudinal momentum fractions $0 \leqslant x_i \leqslant 1$, $\Sigma x_i = 1$ (at $|p_z| \to \infty$).

The expressions for the nucleon magnetic form factors $G_M^{p,n}(Q^2)$ in terms of the nucleon w.f. $\varphi_N(x)$ and their formal asymptotic limit at $Q^2 \to \infty$, $\ln(Q^2/\mu^2) \gg 1$ were obtained for the first time in papers [3, 4] (see also [5], the overall signs obtained in [4] for G_M^p and G_M^n should be reversed).

The properties of the nonperturbative nucleon w.f. $\varphi_N(x_1, x_2, x_3)$ were investigated in [6] with the help of the QCD sum rules [7]. It has been shown that the distribution of the proton momentum between three quarks is very asymmetrical at $p_z \to \infty$: $\simeq 63\%$ of proton momentum carries one u-quark with its spin parallel to the proton spin, while each of two rest quarks carries $\simeq 15-20\%$ of the total momentum.

Using the results obtained in [6] for the first and second moments of $\varphi_N(x)$, the model w.f. was proposed (denoted hereafter as $\varphi_N^{\mathrm{I}}(x)$). It was shown that this w.f. leads to the predictions for the nucleon magnetic form factors and the decay widths $J/\Psi \to \bar{p}p$, $\chi_2 \to \bar{p}p$ in a reasonable agreement with the experiment.

The sum rules for the first and second moments of $\varphi_N(x)$ were considered also in the recent paper [8]. The results obtained in [8] for the contributions into the sum rules from the perturbative theory Fig. 1, and from the quark condensate, Fig. 3, coincide with the results obtained in [6]. Let us emphasize that just these contributions are the dominant ones in the sum rules. At the same time, the results obtained in [8] for the contributions of the gluonic condensate, Fig. 2, and the quark condensate, Fig. 4, don't coincide with [6]. Let us point that, as a rule, these contributions into sum rules play no significant role. For this reason the results obtained in [8] for the values of the w.f. moments are close to those from [6]. (For instance, the first u-quark carries $\simeq 63\%$ and $\simeq 55\%$ of the proton momentum in [6] and [8] correspondingly). The model w.f., $\varphi_N^{KS}(x)$, proposed in [8] is much like in all its properties to those from [6].

Because of importance of investigation the nucleon wave function properties, we have recalculated once more the sum rules for all first $(n_1+n_2+n_3=n=1)$ and second $(n=2)$ moments of w.f. Moreover,— we have derived new sum rules for all third $(n=3)$ moments which have not been investigated before, and this is the main result of this paper. Based on the treatment of all these sum rules we propose the new model wave function $\varphi_N^{II}(x)$.

As for the first $(n=1)$ and second $(n=2)$ moments, let us point here the following:

a) we confirm the results obtained in [6] and [8] for the contributions of Fig. 1 and Fig. 3 diagrams which dominate in the sum rules;

b) we confirm the results obtained in [8] for the contributions of Fig. 2 diagrams;

c) the results obtained in this paper for the contributions of Fig. 4 diagrams differ from both [6] and [8].

However, because the contributions of the Fig. 2 and Fig. 4 diagrams into the sum rules are, as a rule, not of great importance, the w.f. $\varphi_N^{II}(x)$ obtained in this paper is much like to both $\varphi_N^{I}(x)$ and $\varphi_N^{KS}(x)$.

2. THE SUM RULES FOR THE NUCLEON WAVE FUNCTION

The definition of the leading twist nucleon w.f. and the choise of correlators for obtaining the sum rules have been given in [3, 6]. We reproduce below in short the required formulae for a reader

convenience and because these formulae are needed for obtaining the sum rules for other baryons from the nucleon octet [11]

The leading twist proton w.f. is defined by the matrix element of the three-local operator (taken on the light-cone) [3]:

$$\langle 0|\varepsilon^{ijk} u^i_\alpha(z_1)\, u^j_\beta(z_2)\, d^k_\gamma(z_3)|\, N(p)\rangle = \frac{1}{4} f_N \{(\hat{p}C)_{\alpha\beta}(\gamma_5 N)_\gamma V(z_i p) +$$

$$+(\hat{p}\gamma_5 C)_{\alpha\beta} N_\gamma A(z_i p) - (\sigma_{\mu\nu} p_\nu C)_{\alpha\beta}(\gamma_\mu\gamma_5 N)_\gamma T(z_i p)\}, \quad (1)$$

$$\hat{p} = p_\mu\gamma_\mu, \quad \sigma_{\mu\nu} = \frac{1}{2}[\gamma_\mu, \gamma_\nu], \quad V(0) = T(0) = 1;$$

$$V(z_i p) = \int_0^1 d_3x \exp\{-i\Sigma x_i (z_i p)\}\, V(x_i),$$

$$d_3x = dx_1\, dx_2\, dx_3\, \delta(1-\Sigma x_i), \text{ (and analogously for } A(z_i p) \text{ and } T(z_i p)). \quad (2)$$

Here: i, j and k are colour indices, α, β and γ are spinor indices, $u^i_\alpha(z)$ and $d^k_\gamma(z)$ are quark field operators, $|p\rangle$ is the proton state with the momentum $p\,(p_z\to\infty)$, N_γ is the proton spinor, $\bar{N}N=2M_N$, C is the charge conjugation matrix. The constant f_N determines the value of the nucleon w.f. at the origin. The dimensionless w.f. $V(x)$, $A(x)$ and $T(x)$ describe the distribution of three quarks in the proton in longitudinal momentum fractions $0\leqslant x_i\leqslant 1$, $\Sigma x_i=1$.

Requiring the total isospin of three quarks to be equal 1/2, one obtains the relation:

$$2T(1,2,3) = \varphi_N(1,3,2) + \varphi_N(2,3,1),$$

$$\varphi_N(1,2,3) = V(1,2,3) - A(1,2,3). \quad (3)$$

Besides:

$$V(1,2,3) = V(2,1,3), \quad T(1,2,3) = T(2,1,3),$$

$$A(1,2,3) = -A(2,1,3). \quad (4)$$

The formulae (1) — (2) are equivalent to the following form of the proton state (at $p_z\to\infty$) [3]:

$$|p^\uparrow\rangle = f_N \int \frac{d_3x}{4\sqrt{6}} \left\{ \frac{V(x)-A(x)}{2}\, |u^\uparrow(x_1)\, u^\downarrow(x_2)\, d^\uparrow(x_3)\rangle + \right.$$

$$\left. + \frac{V(x)+A(x)}{2}\, |u^\downarrow(x_1)\, u^\uparrow(x_2)\, d^\uparrow(x_3)\rangle - T(x)|\, u^\uparrow(x_1)\, u^\uparrow(x_2)\, d^\downarrow(x_3)\rangle \right\}. \quad (5)$$

In (5): $|p^\uparrow\rangle$ is the proton state with its spin along the z-axes,

$$(p_z \to \infty), \qquad \langle p', \lambda' | p, \lambda \rangle = (2\pi)^3 \delta_{\lambda'\lambda}\, \delta(\vec{P}' - \vec{P}),$$

$$|u_1^{\uparrow}\, u_2^{\downarrow}\, d_3^{\uparrow}\rangle \equiv \frac{\varepsilon^{ijk}}{\sqrt{6}} b_u^i(x_1, \uparrow)\, b_u^j(x_2, \downarrow)\, b_d^k(x_3, \uparrow)|0\rangle ,$$

where b_u and b_d are the creation operators of free quarks,

$$\langle 0|\, u_\alpha^i(z)|\, u^j(x_1, \uparrow)\rangle = \exp\{-ix_1\, pz\}\, \delta^{ij} u_\alpha^{\uparrow}(x_1),$$

and $u_\alpha(x)$ is the free quark spinor:*)

$$u_\alpha^{\uparrow}(x) \simeq \sqrt{xE}\begin{pmatrix}\varphi_+\\ \varphi_+\end{pmatrix}, \quad \varphi_+ = \begin{pmatrix}1\\ 0\end{pmatrix}; \qquad u_\alpha^{\downarrow}(x) \simeq \sqrt{xE}\begin{pmatrix}\varphi_-\\ -\varphi_-\end{pmatrix}, \quad \varphi_- = \begin{pmatrix}0\\ 1\end{pmatrix}.$$

Using (3) and (4) one can rewrite (5) in the form $(\int_0^1 d_3x\varphi_N(x) = 1)$:

$$|p^{\uparrow}\rangle = f_N \int_0^1 \frac{d_3x\, \varphi_N(x)}{4\sqrt{6}}\, |u^{\uparrow}(x_1)(u^{\downarrow}(x_2)\, d^{\uparrow}(x_3) - d^{\downarrow}(x_2)\, u^{\uparrow}(x_3))\rangle . \qquad (6)$$

To find f_N and the values of moments

$$(n_1\, n_2\, n_3) \equiv \int_0^1 d_3x\, x_1^{n_1} x_2^{n_2} x_3^{n_3}\, \varphi_N(x) \qquad (7)$$

we use the following correlators:

$$I^{(n)}(q, z) = i\int dx\, e^{iqx}\langle 0|\, T\{J_\tau^{(n)}(x)\, \bar{J}_{\tau'}^{(1)}(0)\}\, |0\rangle \hat{z}_{\tau'\tau} =$$
$$= (zq)^{n_1+n_2+n_3+4} I^{(n)}(q^2), \qquad (n) = (n_1, n_2, n_3); \qquad (8)$$

$$J_\tau^{(n)}(x) = \varepsilon^{ijk}[D^{n_1}u(x)]^i C\hat{z}\{[D^{n_2}u(x)]^j\, [D^{n_3}\gamma_5\, d(x)]_\tau^k - [D^{n_2}\gamma_5\, u(x)]^j\, [D^{n_3} d_\tau(x)]^k\},$$
$$J_{\tau'}^{(1)}(0) = \varepsilon^{ijk}[Du(0)]^i C\hat{z}\ \{u^j(0)(\gamma_5\, d^k(0))_{\tau'} - d^j(0)(\gamma_5\, u^k(0))_{\tau'}\},$$
$$D = z_\mu(i\partial_\mu - gA_\mu), \qquad z^2 = 0. \qquad (9)$$

Let us point out that the current $J_{\tau'}^1(0)$ has the isospin 1/2.

The spectral density of the correlator (8) is chosen in the standard form:

$$\frac{1}{\pi}\ \mathrm{Im}\ I^{(n)}(s) = 4r^{(n)}\delta(s - M_N^2) + \begin{pmatrix}\text{next}\\ \text{resonance}\end{pmatrix} + \theta(s - s_n)\, \frac{\beta_1^{(n)}}{480\pi^4}\, s, \qquad (10)$$

*) At such a normalization convention one should to replace in (5): $d_3x \to d_3x/\sqrt{x_1x_2x_3}$. We omit this factor, however, because it always cancels in the matrix elements.

where $r^{(n)} = |f_N|^2(n_1n_2n_3)[(100) + \frac{1}{2}(001)]$ is the nucleon contribution and the last term in (10) is the perturbation theory contribution (the coefficients $\beta_1^{(n)}$ are given in Table 1). The quantities s_n determine the beginning of the smooth continuum in correlators.

The sum rules obtained from (8), (9) have the form:

$$4r^{(n)}\exp\{-M_N^2/M^2\} + R^{(n)}\exp\{-\mathring{M}^2/M^2\} =$$
$$= \frac{\beta_1^{(n)}}{480\pi^4} M^4\{1 - (1 + H)e^{-H}\} + \frac{\beta_2^{(n)}}{48\pi^2}\langle 0\left|\frac{\alpha_s}{\pi}G^2\right|0\rangle +$$
$$+ \frac{4}{81}\, \frac{\beta_3^{(n)}}{\pi M^2}\langle 0|\sqrt{\alpha_s}\, \bar{u}u|0\rangle^2, \qquad H = s_n/M^2, \qquad (11)$$

where the term $\sim r^{(n)}$ is the proton contribution and the term $\sim R^{(n)}$ is the next resonance contribution. The coefficients $\beta_1^{(n)}$ are determined by the perturbation theory contributions, Fig. 1; $\beta_2^{(n)}$ is the gluonic condensate contributions, Fig. 2; $\beta_3^{(n)}$ is the quark condensate contributions, Fig. 3 and 4. The coefficients $\beta_1^{(n)}$ are presented in Table 1. As was pointed out above, for $n_1 + n_2 + n_3 \leqslant 2$ they coincide with that from [6] and [8]. The coefficients $\beta_2^{(n)}$ are given in Table 2 and for $n \leqslant 2$ they coincide with that from [8]. The coefficients $\beta_{33}^{(n)}$ and $\beta_{34}^{(n)}$ $(\beta_3^{(n)} = \beta_{33}^{(n)} + \beta_{34}^{(n)})$ are given in Tables 3 and 4 correspondingly and are the contributions of Fig. 3 and Fig. 4 diagrams. As was pointed out above, for $n \leqslant 2$ $\beta_{33}^{(n)}$ coincide with [6] and [8]. In Table 4 the results for $\beta_3^{(n)}$ from [6] and [8] are presented for comparison.

The comparison of the coefficients $\beta_3^{(n)}$ (Table 4) obtained in this work and in [8] shows that the results [8] for the moments (010), (001) and (020) are overestimated. Because of this, the values of these moments obtained in [8] are larger than in this work.

THE RESULTS

The sum rules (11) for all moments with $n_1 + n_2 + n_3 \leqslant 3$ have been treated in the standard way (see [6], the mass of the next resonance was taken $M_R = 1.5$ GeV). The results are presented in Table 5. The results obtained in [6] and [8] are also presented for a comparison. (Let us point out that for $n \leqslant 2$ there are no large differences between the sum rules obtained in this paper and in [6]. Some difference in the $n \leqslant 2$ moment values obtained here and in [6] is due to more careful treatment of sum rules in this paper).

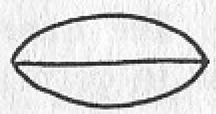

Fig. 1.

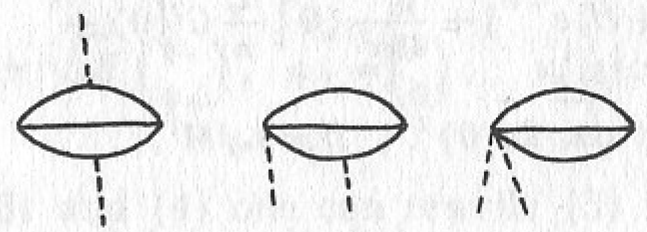

Fig. 2.

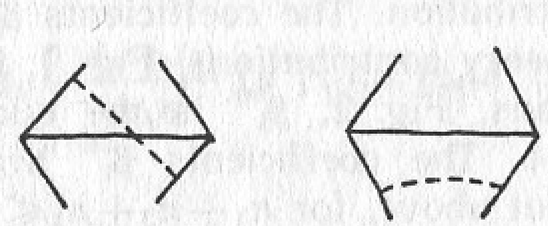

Fig. 3.

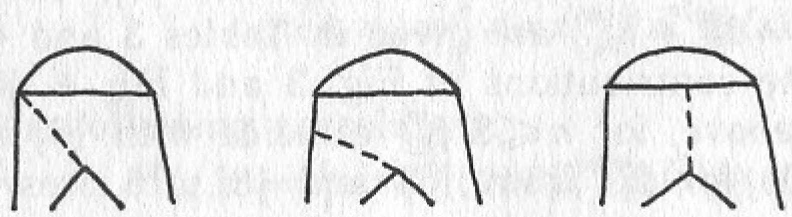

Fig. 4.

We have obtained

$$|f_N| = (5.0 \pm 0.3) \cdot 10^{-3}\ \mathrm{GeV}^2 \qquad (12)$$

for the value of the nucleon w.f. at the origin, and this agrees with the results [6] and [8].

Let us point out also the following. In addition to the sum rules (11) we have considered also the independent sum rules which follow from the correlator (8) with the current $J_{\tau'}^{(1)}(0)$ replaced by

$$J_{\tau'}^{(2)} = \varepsilon^{ijk} [D^2 u]^i\, C\hat{z} \{u^j (\gamma_5 d)^k_{\tau'} - d^j (\gamma_5 u)^k_{\tau'}\}.$$

This current includes two derivatives acting on the first quark. Because this quark carries $\simeq 60\%$ of the proton momentum, the role of the proton contribution into the correlators containing this current is further increased. In other words, the correlators containing

the current $J_{\tau'}^{(2)}(0)$ are even more sensitive to the proton contribution than those in (8). This is especially useful for a more precise determination of those moments which are connected with the second and third quarks; (010), (020), (002) etc., because these quarks carry only a small fraction of the proton momentum.

In order to do not overload the text, we don't write here the explicit form of these sum rules and the moment values obtained. It is sufficient to say that we have obtained and treated all corresponding sum rules with $n_1 + n_2 + n_3 \leqslant 3$, and all the results agree well with those obtained from the correlators (8).

The results obtained in this paper for all moments with $n_1 + n_2 + n_3 \leqslant 3$ (see Table 5) confirm the conclusions made in [6] and [8]. The distribution of the nucleon momentum (at $p_z \to \infty$) between three quarks is highly asymmetrical. In the wave function component $|u^\uparrow(x_1) u^\downarrow(x_2) d^\uparrow(x_3)\rangle$ the first u-quark with its spin parallel to the proton spin carries $\simeq (56-60)\%$ of the proton momentum, the second u-quark carries $\simeq (18-20)\%$ and the d-quark carries $\simeq (21-25)\%$ of the total momentum.

As was shown in [6, 2], the w.f. $\varphi_N(x, \mu \simeq 1\ \mathrm{GeV})$ has at $x_i \to 0$ and $x_i \to 1$ the same threshold behaviour $\sim x_1 x_2 x_3$ as the asymptotic w.f. $\varphi_{as}(x) = 120 x_1 x_2 x_3$. As usual [2, 6] we confine ourselves by the second order polynomials in the model form of the w.f. We propose the following model w.f.:

$$\varphi_N^{\mathrm{II}}(x) = \varphi_{as}(x) [23.814 x_1^2 + 12.978 x_2^2 + 6.174 x_3^2 + 5.88 x_3 - 7.098],$$

$$T_N^{\mathrm{II}}(x) = \varphi_{as}(x) [10.836 (x_1^2 + x_2^2) + 5.88 x_3^2 - 8.316 x_1 x_2 - 11.256 x_3 (x_1 + x_2)]. \qquad (13)$$

The moment values of the w.f. (13) are given in Table 5. For a comparison the moment values of the w.f.

$$\varphi_N^{\mathrm{I}}(x) = \varphi_{as}(x) [18.06 x_1^2 + 4.62 x_2^2 + 8.82 x_3^2 - 1.68 x_3 - 2.94],$$

$$\varphi_N^{KS}(x) = \varphi_{as}(x) [20.16 x_1^2 + 15.12 x_2^2 + 22.68 x_3^2 - 6.72 x_3 + 1.68 (x_1 - x_2) - 5.04] \qquad (14)$$

proposed in [6] and [8] correspondingly are also presented in Table 5. It is seen from (13), (14) and Table 5 that although the w.f. $\varphi_N^{\mathrm{I}}(x)$, $\varphi_N^{\mathrm{II}}(x)$ and $\varphi_N^{KS}(x)$ differ in their explicit form, they are really much like to each other in their properties.

Let us point out that using an independent sum rules for the three-point Green-function M. Lavelle [10] has obtained the result: $A^{(100)} \simeq -0.18$. This value agrees well with the results presented in

Table 5 for the w.f. $\varphi_N^{II}(x)$: $A^{100}=\frac{1}{2}(\varphi_N^{010}-\varphi_N^{100})\simeq-(0.18-019)$.

We want to emphasize that the model w.f. (13) contains only five parameters (besides, $\varphi_N^{000}\equiv 1$). and describes sufficiently well the values of *ten* independent moments with $n_1+n_2+n_3\leqslant 3$ obtained from the sum rules (see Table 5). This confirms an original supposition that it is sufficient to confine ourselves by two lowest polynomials to reproduce correctly all the main properties of the true w.f. (The small admixture of higher polynomials does not change significantly the large-scale properties of the w.f.).

Let us point out the following. It is seen from Table 5 that the w.f. φ_N^{I}, φ_N^{II} and φ_N^{KS} have close values of first $(n_1+n_2+n_3=1)$ and second $(n_1+n_2+n_3=2)$ moments, while the values of some third $(n_1+n_2+n_3=3)$ moments differ significantly. It will be shown in the next paper [11] that all three w.f. $\varphi_N^{I,II}(x)$ and $\varphi_N^{KS}(x)$ give close (up to a factor 1.5—2) values of the nucleon form factors and the decay widths of the charmonium levels $^3S_1\to\bar{p}p$, $^3P_2\to\bar{p}p$, $^3P_1\to\bar{p}p$. This is an independent argument in favour that the simplest form of the model w.f. (including only the first and second order polynomials) which reproduces obtained from the sum rules $n=1$ and $n=2$ moment values, describes correctly the main properties of the true nucleon w.f.

4. CONCLUSION

The main purpose of this paper is to investigate in detail the properties of the leading twist nucleon wave function $\varphi_N(x_i, \mu\simeq 1\text{ GeV})$. The main results obtained in this paper are the following.

1. For a determination of values of ten lowest independent w.f. moments

$$(n_1, n_2, n_3)\equiv\int_0^1 d_3x\, x_1^{n_1} x_2^{n_2} x_3^{n_3}\,\varphi_N(x),\quad n_1+n_2+n_3\leqslant 3,\quad \Sigma x_i=1$$

all sum rules with $n_1+n_2+n_3\leqslant 3$ which follow from the correlators (8) have been obtained and treated. (Besides, the same number of independent sum rules which follows from (8) with the replacement $J^{(1)}\to J^{(2)}$, see the text, have also been obtained and treated). It is checked that the treatment of all independent sum rules leads to the results which agree well with each other. The values of ten lowest

independent w.f. moments have been found. The values of these moments characterize the properties of the w.f. themselves and restrict strongly its possible form.

The most characteristic property of the proton w.f. is a highly asymmetric distribution of the proton momentum (at $p_z\to\infty$) between three quarks. The total momentum is distributed in the proportion (58:19:23)%, and the largest part carries *u*-quark with its spin parallel to the proton spin. (For the neutron: $u\leftrightarrow d$). The profile of the w.f. $\varphi_N^{II}(x)$ is shown in Fig. 5.

2. The properties of the nucleon w.f. $\varphi_N(x)$ have been investigated earlier in papers [6] and [8] using the sum rules for moments with $n_1+n_2+n_3\leqslant 2$, i. e. the values of six lowest independent moments have been found. The sum rules with $n_1+n_2+n_3\leqslant 2$ obtained in this paper and in [6] and [8] all differ from each other, but differences are not large. Therefore, the results are close to each other.

3. Based on the knowledge of ten lowest independent moments with $n_1+n_2+n_3\leqslant 3$, we have proposed the new model for the nucleon w.f., $\varphi_N^{II}(x)$ (13). This model w.f. contains five parameters and describes well the values of all ten lowest moments. Comparison with the earlier model w.f. $\varphi_N^{I}(x)$ [6] and $\varphi_N^{KS}(x)$ [8] shows that all these w.f. have close values of six lowest moments with $n_1+n_2+n_3\leqslant 2$, while differences in some third moments are much larger.

4. It will be shown in the next paper [11] that all three model w.f., $\varphi_N^{I}(x)$, $\varphi_N^{II}(x)$ and $\varphi_N^{KS}(x)$, lead to close values for the nucleon form factors $G_M^p(Q^2)$ and $G_M^n(Q^2)$ and for the decay widths $^3S_1$, $^3P_2$, $^3P_1\to\bar{N}N$, in a reasonable agreement with the experiment. This fact shows that simple model wave functions obtained from sum rules and containing only first and second order polynomials are capable to reproduce all the main properties of the true w.f. and, moreover, some differences in values of third $(n=3)$ moments don't lead to significant differences in calculated values of various exclusive amplitudes.

5. The alternative model for the nucleon w.f., $\varphi_N^{GS}(x)$, have been proposed in the recent paper by M. Gari and N.G. Stefanis [12]. We don't understand the reasons which have lead these authors to such a model. Four of six independent moments with $n\leqslant 2$ are chosen in [12] within the limits allowed by sum rules, while the moment (002) is ten times smaller and the moment (101) is two times larger than values allowed by sum rules. It seems that the only goal for such an arbitrary choise was to obtain a small ratio

$(G_M^n / G_M^p \simeq -0.1)$ for the nucleon form factors at $Q^2 \simeq 10-20$ GeV^2.

We want to stress that the moment values: $(002) = 0.008$ and $(101) = 0.23$ chosen arbitrarily in [12], contradict directly to the sum rules requirements (see Table 5). From our point of view, the model w.f. proposed by M. Gari and N.G. Stefanis [12] is unacceptable*).

The application of the w.f. $\varphi_N^{II}(x)$ obtained in this paper for the calculation of the nucleon form factors and $^3S_1$, $^3P_2$, $^3P_1 \to \bar{N}N$, $\bar{\Delta}\Delta$ decay widths, etc., will be described in the next paper.

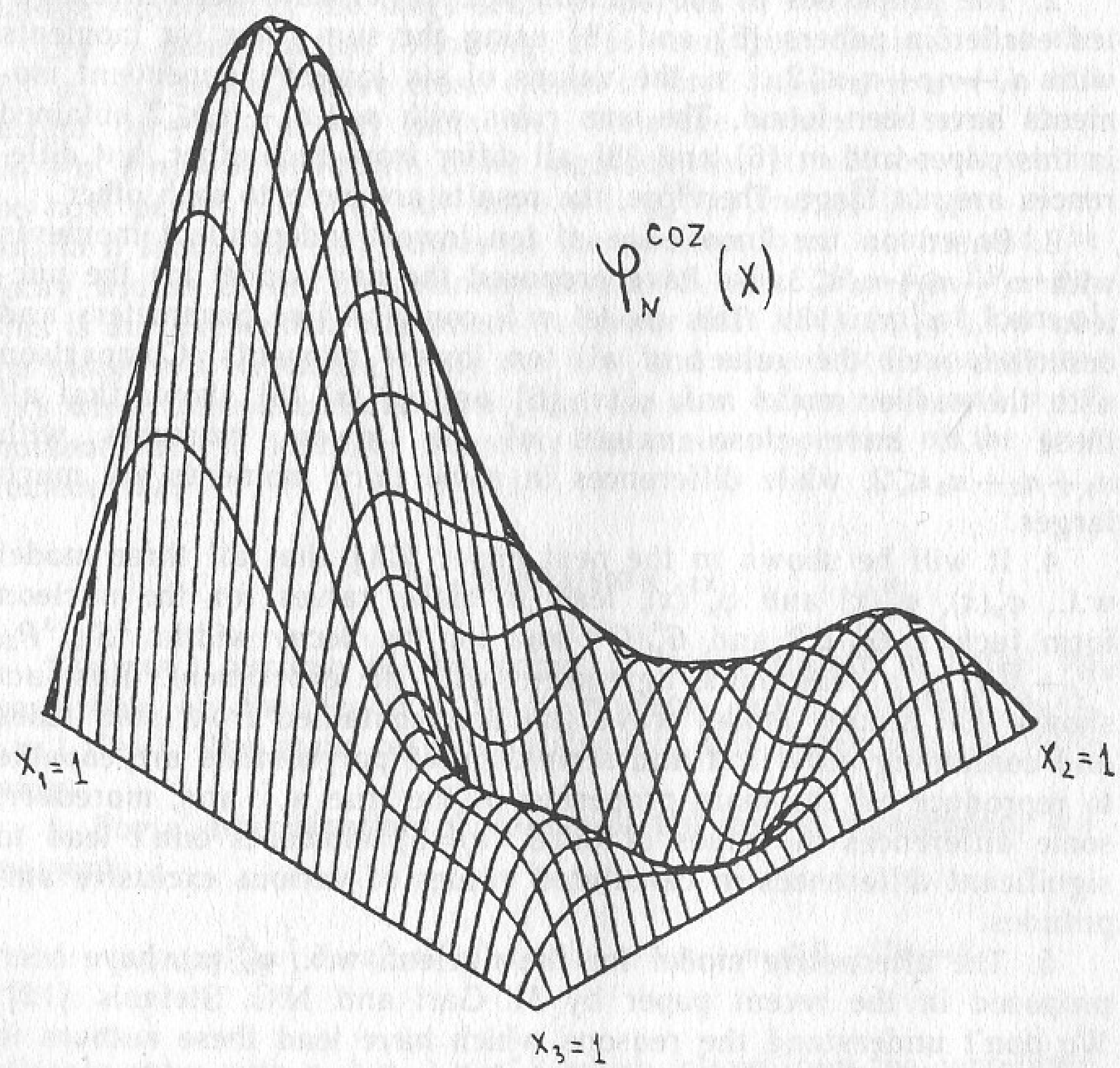

Fig. 5.

*) Besides, as will be shown in our next paper [13] the w.f. $\varphi_N^{GS}(x)$ leads to an unacceptably small prediction for the decay width $J/\Psi \to \bar{p}p$.

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Table 1

Moments	$\beta_1^{(n)}$	Moments	$\beta_1^{(n)}$	Moments	$\beta_1^{(n)}$
(000)	1	(110)	3/28	(111)	1/42
(100)	3/7	(101)	3/28	(210)	1/21
(010)	2/7	(011)	1/14	(201)	1/21
(001)	2/7	(300)	5/42	(120)	1/28
(200)	3/14	(030)	1/21	(021)	1/42
(020)	3/28	(003)	1/21	(102)	1/28
(002)	3/28			(012)	1/42

Table 2

Moments	$\beta_2^{(n)}$	Moments	$\beta_2^{(n)}$	Moments	$\beta_2^{(n)}$
(000)	1/12	(110)	0	(111)	−1/630
(100)	1/30	(101)	1/180	(210)	1/1260
(010)	1/60	(011)	1/180	(201)	1/315
(001)	1/30	(300)	1/42	(120)	1/1260
(200)	1/36	(030)	1/140	(021)	1/315
(020)	1/90	(003)	1/70	(102)	1/252
(002)	1/45			(012)	1/252

Table 3

Moments	$\beta_{33}^{(n)}$	$\beta_{33}^{(n)}$ [6]	$\beta_{33}^{(n)}$ [8]	Moments	$\beta_{33}^{(n)}$	$\beta_{33}^{(n)}$ [6]	$\beta_{33}^{(n)}$ [8]
(000)	3/6	0	4/6	(020)	−6/120	−11/120	0
(100)	45/60	13/60	45/60	(002)	12/120	7/120	18/120
(010)	−15/60	−14/60	−10/60	(110)	0	−1/24	0
(001)	0	1/60	5/60	(101)	12/120	7/120	12/120
(200)	13/20	4/20	13/20	(011)	−12/60	−6/60	−10/60

Table 4

Moments	$\beta_{34}^{(n)}$	$\beta_3^{(n)}$	$\beta_3^{(n)}$ [6]	$\beta_3^{(n)}$ [8]	Moments	$\beta_{34}^{(n)}$	$\beta_3^{(n)}$
(000)	18/6	21/6	18/6	22/6	(300)	45/30	62/30
(100)	135/60	180/60	148/60	180/60	(030)	9/120	5/120
(010)	45/120	15/120	17/120	25/120	(003)	9/120	17/120
(001)	45/120	45/120	47/120	55/120	(111)	0	−1/15
(200)	36/20	49/20	40/20	49/20	(210)	9/60	10/60
(020)	18/120	12/120	7/120	18/120	(201)	9/60	13/60
(002)	18/120	30/120	25/120	36/120	(120)	3/40	5/40
(110)	27/120	27/120	22/120	27/120	(021)	0	−1/15
(101)	27/120	39/120	34/120	39/120	(102)	3/40	7/40
(011)	0	−6/30	−6/60	−5/30	(012)	0	−1/15

Table 5

Moments	Sum rules	Model wave functions			As. wave function
		COZ	CZ	KS	
(000)	1	1	1	1	1
(100)	$0.560^{+0.06}_{-0.02}$	0.579	0.630	0.550	1/3 = 0.333
(010)	$0.192^{+0.008}_{-0.012}$	0.192	0.150	0.210	1/3 = 0.333
(001)	$0.229^{+0.021}_{-0.029}$	0.229	0.220	0.240	1/3 = 0.333
(200)	$0.350^{+0.07}_{-0.03}$	0.369	0.400	0.350	1/7 = 0.143
(020)	$0.084^{+0.004}_{-0.019}$	0.068	0.030	0.090	1/7 = 0.143
(002)	$0.109^{+0.011}_{-0.019}$	0.089	0.080	0.120	1/7 = 0.143
(110)	$0.090^{+0.01}_{-0.01}$	0.097	0.110	0.100	2/21 = 0.952
(101)	$0.102^{+0.008}_{-0.012}$	0.113	0.120	0.100	2/21 = 0.952
(011)	−0.03 — 0.03	0.027	0.030	0.020	2/21 = 0.952
(300)	$0.236^{+0.014}_{-0.026}$	0.2445	0.2433	0.2333	1/14 = 0.071
(030)	$0.032^{+0.008}_{-0.004}$	0.038	0.009	0.057	1/14 = 0.071
(003)	$0.052^{+0.004}_{-0.004}$	0.049	0.041	0.081	1/14 = 0.071
(210)	$0.045^{+0.004}_{-0.004}$	0.059	0.067	0.059	1/28 = 0.036
(201)	$0.050^{+0.005}_{-0.006}$	0.066	0.074	0.057	1/28 = 0.036
(120)	$0.035^{+0.002}_{-0.008}$	0.024	0.027	0.030	1/28 = 0.036
(102)	$0.041^{+0.002}_{-0.004}$	0.033	0.039	0.032	1/28 = 0.036
(021)	−0.004 — 0.007	0.006	−0.006	0.003	1/28 = 0.036
(012)	−0.005 — 0.008	0.007	−0.0007	0.007	1/28 = 0.036

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