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THE CONTRIBUTION OF $(t(\tau) + N)$-COMPONENT TO THE α-PARTICLE WAVE FUNCTION FROM THE DATA ON THE REACTIONS $p(\alpha, pp)t$ AND $p(\alpha, pn)\tau$ AT THE INCIDENT α-PARTICLE MOMENTUM 5 GeV/c

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The 2-meter liquid-hydrogen bubble chamber was exposed to a separated beam of α-particles from ITEP synchrotron. Averaged over the fiducial volume of the chamber the momentum of the incident ^{4}He nuclei was 5 GeV/c (the kinetic energy of initial protons in the nucleus rest frame was T_p = 620 MeV). The spectral functions of decays $\alpha \to tp$ and $\alpha \to \tau n$ were extracted in 4π-geometry (the last one was extracted for the first time) from the exclusive reactions $\alpha p \to tpp$ and $\alpha p \to \tau pn$ in the spectator momenta region $0 < q < 0.3$ GeV/c. The pole dominance criteria were checked carefully. By extrapolating the nuclear vertex function to the pole the lower bound of the nuclear vertex constant was obtained. Our experimental data are compared with the results of other studies and the theoretical calculations as well.

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The momentum distributions (spectral functions (SF's)) are one of the most important characteristic of ^{4}He nucleus. They are defined as the square of overlap integrals between the nucleus wave function (WF) and the spectator nuclear fragments ones ($t(\tau)$, dN, 3N).

In [1] we have extracted SF's of virtual two-particle decays $\alpha \to t(\tau)N$ ($t \equiv {}^3$H, $\tau \equiv {}^3$He) from the reactions

$$p(\alpha, pp)t, \qquad (1)$$

$$p(\alpha, pn)\tau, \qquad (2)$$

at the initial α-particle momentum 2.7 GeV/c in the spectator momenta region $0 < q < 0.16$ GeV/c (in this case due to small phase space value the contribution

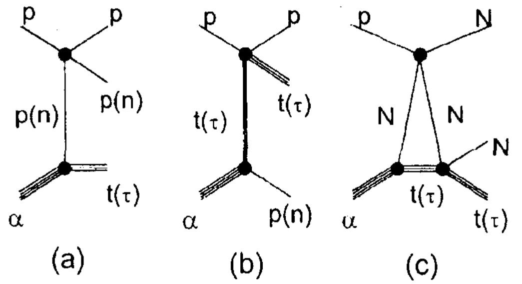

Fig.1. The simplest diagrams for the reactions pα → t(τ)pN

of the diagram with three-nucleon nucleus exchange (Fig.1*b*) becomes already significant at $q \sim 0.2$ GeV/*c*).

The particular attention was given to the accurate selection of quasifree pN-scattering (QFS) events, which correspond to the diagram of Fig.1*a*. The criteria of pole dominance described in [2] were checked, in particular, Treiman - Yang criterion which is very sensitive to the contribution of mechanisms other than pole one (especially, to the final-state-interaction (FSI) mechanism of Fig.1c).

In the present paper the preliminary data (70% of expected statistic) on SF's from the reactions (1) and (2) at the initial α-particle momentum 5 GeV/*c* are presented. There are two main goals here: a) the verification of the SF's independence on initial momentum of incident α-particle, which confirms the validity of SF's extraction, and b) the expansion of phase space so that the contribution of the diagram of Fig.1*b* could be neglected up to the momentum value $q \sim 0.3$ GeV/*c*.

The experimental data were obtained by using of 2-meter liquid-hydrogen bubble chamber of ITEP. It was exposed to a separated beam of α-particles; their momentum averaged over the fiducial volume being 5 GeV/*c* (such experimental technique allows the nuclear fragments to be fast particles and thus be measured with high accuracy). 1445 events of the reaction αp → tpp and 1824 events of the reaction αp → τpn were selected. The method of spectral functions extraction from experimental data was described in our papers [3, 4] in detail.

As follows from the analysis of the matrix element of QFS diagram of Fig.1*a*, there is a simple relation between spectral functions $\rho_{\rm tN}$ of two-particle decays $\alpha \to {\rm t}(\tau){\rm N}$ and the differential cross sections of reactions (1) and (2) $d\sigma/dq^2$:

$$\rho_{\rm tN}(q) = \frac{8m\pi^2\lambda(s,m^2,m_\alpha^2)}{m_\alpha^2\Phi(t_1)}\frac{d\sigma}{dq^2}. \tag{3}$$

Here q is three-particle nucleus momentum in the ^{4}He nucleus rest frame, m is the mass of the nucleon, m_α is the mass of ^{4}He nucleus, $\lambda(x,y,z) = (x+y+z)^2 - xyz$, s is the square of the total invariant mass, t_1 is the square of the 4-momentum transferred from ^{4}He nucleus to the three-nucleon nucleus, $\Phi(t_1)$ is defined as follows:

$$\Phi(t_1) = \int\limits_{\max\{s_-(t_1),4m^2\}}^{s_+(t_1)} ds_1\sigma_{el}^{(\rm pN)}(s_1,t_1)\lambda^{1/2}(s_1,m^2,m^2). \tag{4}$$

Here s_+ and s_- are calculated using the formulae given in [3] with the corresponding mass substitution, s_1 is the square of the total pN-system mass, $\sigma_{el}^{(\rm pN)}$

is determined by the following formulae:

$$\sigma_{el}^{(\mathrm{pN})}(s_1,t_1) = 2\pi(1 - I_z^{\mathrm{pN}}/2) \int\limits_{-c_1}^{c_2} \frac{d\sigma^{(\mathrm{pN})}(s_1,t_1)}{d\Omega^*} d\cos\theta^* . \qquad (5)$$

Here $I_z^{(\mathrm{pN})}$ is the third isospin projection of pN-system, $d\sigma^{(\mathrm{pN})}(s_1,t_1)/d\Omega^*$ is off-shell cross section of elastic pN-scattering, θ^* is the scattering angle between the initial and outgoing protons in the pN-pair center-of-mass system. As for the limits of integration c_1 and c_2, their choice will be discussed below.

Two constraints were imposed to select the events corresponding to the QFS diagram (Fig.1*a*): I)$q < 0.3$ GeV/c and II)$-c_1 < \cos\theta^* < c_2$. For the reaction (1) $c_1 = c_2 = 0.7$, and for the reaction (2) $c_1 = c_2 = 0.8$. After imposing these constraints 968 events of the reaction (1) and 1106 events of the reaction (2) left.

First constraint is needed to exclude the contribution of diagram of Fig.1*b* (with three-nucleon nucleus exchange). This contribution is shown by our calculations to be negligible at the initial energy $T_p = 620$ MeV and $q < 0.3$ GeV/c (Monte-Carlo calculations were performed; the elastic cross sections pN, pt and pτ have being taken on the mass shell in all kinematic permitted region, Glauber – Sitenko model has being used for the calculation of pt and pτ elastic cross sections and pN-amplitudes being taken from phase space analysis; SF's ρ_{tN} were taken from the theoretical calculations [5, 6]).

Second constraint gives the possibility to exclude significantly the phase space region where the FSI is substantial [3, 4, 7].

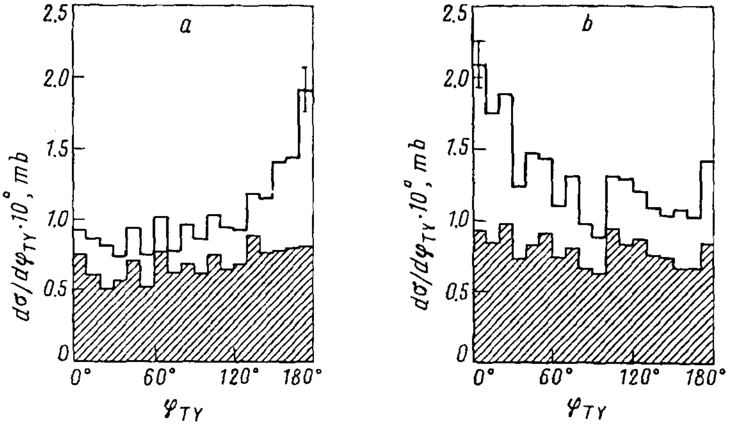

Fig.2. Treiman – Yang angle distributions for the reactions: (*a*) – $\alpha\mathrm{p} \to \mathrm{tpp}$ and (*b*) – $\alpha\mathrm{p} \to \tau\mathrm{pn}$. Clear histograms correspond to the total number of events, shaded histograms correspond to the events leaving after two constraints are imposed (see text above)

The following results are obtained after imposing the constraints I) and II) to the experimental data of the reactions (1) and (2): 1) as seen from Fig.2 the Treiman – Yang angle distributions are practically isotropic, i.e. the necessary pole dominance criterion is satisfied [2] (ϕ_{TY} is the angle between the planes formed, on one hand, by the momenta of α-particle and t(or τ) nucleus and, on the other hand, by the momenta of the outgoing nucleons, all momenta being taken in the initial proton rest frame); 2) the nuclear vertex function (NVF) will be shown

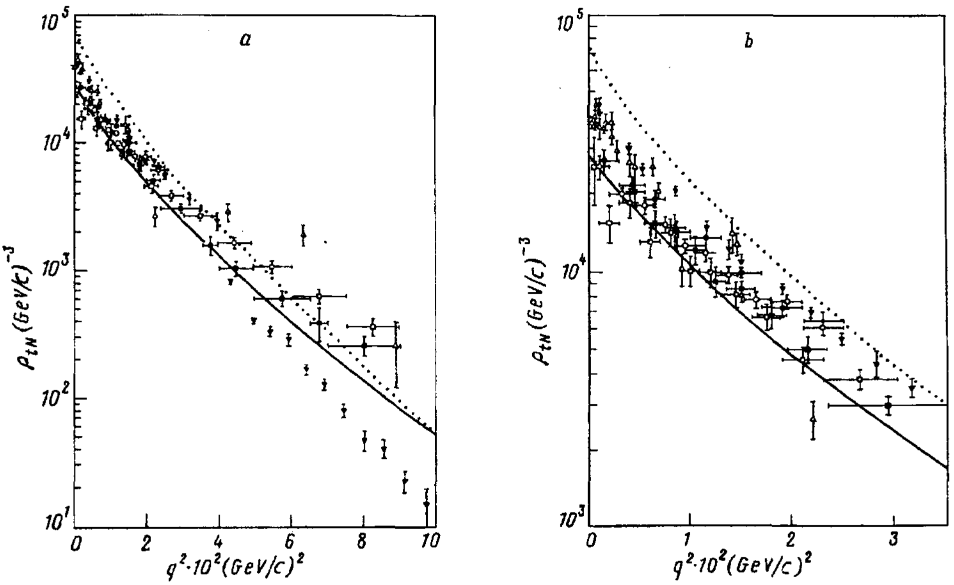

Fig.3. (a) – spectral functions $\rho_{tN}(q)$: o and • – our data (averaged over the corresponding interval of q^2) at T_p = 220 MeV on the reactions p(α,pn)τ and p(α,pp)t respectively [1], □ and ▣ – our data at T_p = 620 MeV on the same reactions respectively (see also Table), ▼ – NIKHEF data [14] on the reaction α(e,e′p)t at T_e = 426 MeV, △ – data of the work [15] on the reaction α(p,pp)t at T_p = 590 MeV. Dotted and solid lines are the theoretical calculations from [5] and [6] respectively; (b) – the scaled part of (a) in the region of small q

below to be linear in q^2 in the region of small q; 3) the average momentum transferred from the initial proton to the fastest outgoing nucleon is ~ 0.8 GeV/c which is sufficiantly greater than the inverse nuclei radius ($\sim$ 0.12 GeV/c); 4) the fraction of events with the relative kinetic energy of Nt(τ)-systems less than 80 MeV (when the FSI-effect is expected to be critical) does not really exceed 25%; 5) the fraction of events with the noncomplanarity angle greater than 6° does not exceed 10%; 6) the stronger constraint ($|\cos\theta^*| < 0.6$) causes no ρ_{tN} changes within the errors while causing the significant improvement of the above characteristics 3) – 5) of the FSI events suppress; 7) SF's are independent on the initial energy within the errors (see Fig.3).

Thus, the results 1) – 7) show the validity of QFS events selection.

To obtain SF's from data on the reactions (1) and (2) the elastic cross sections of pN-scattering were parametrized on the mass shell in all kinematic permitted region using the phase shift analysis [8, 9]. The influence of off-shell effects in the framework of Mongan model [10] was estimated in our previous work [1], where we have extracted SF's from the reactions (1) and (2) at the α-particle momentum 2.7 GeV/c (i.e. at kinetic energy 220 MeV that is nearly the limit of model application). It turns out that the off-shell effects can increase the SF's by 10% in the region $q < 85$ MeV/c and on average by 30% in the region $85 < q < 160$ MeV/c.

It should be mentioned that in the case of two-particle decay of α-particle $\alpha \rightarrow$ t(τ)N the off-shell effects, which depend on the difference between the binding energies $\epsilon_\alpha - \epsilon_{t(\tau)} \approx 20$ MeV, are much greater than for the two-particle decay of three-nucleon nuclei t(τ) $\rightarrow$ Nd where $\epsilon_t(\tau) - \epsilon_d \approx 6$ MeV [3, 7].

Let us define the nuclear vertex function for zero orbital moment l of nucleon and three-nucleon nucleus relative motion ($l = 0$ for $\alpha \to \mathrm{t}(\tau)\mathrm{N}$ unambiguosly) as follows:

$$W(q) = \frac{2}{3m}(q^2 + \kappa^2)\sqrt{\rho_{\mathrm{tN}}(q)}, \quad \kappa^2 = \frac{3m}{2}(\epsilon_\alpha - \epsilon_{\mathrm{t}(\tau)}). \tag{6}$$

The experimental values of NVF $W(q)$ extracted from the full set of our data on the reactions (1) and (2) at the initial momenta 2.7 and 5 GeV/c are well fitted by straight line $W(q) = a_0 + a_1 q^2$ in the region $q < 0.1$ GeV/c (the number of series terms was defined by Fisher criterion). The following parameter values were obtained: $a_0 = (3.51 \pm 0.05)$ $(\mathrm{GeV}/c)^{-1/2}$ and $a_1 = (-44 \pm 2)$ $(\mathrm{GeV}/c)^{-5/2}$ with $\chi^2/DF = 0.86$.

Following our method for Coulomb corrections research for the decay $\tau \to \mathrm{pd}$ [3] the Coulomb screening for the decay $\alpha \to \mathrm{p}\tau$ was found to be less than a few percent.

As mentioned above the linear behaviour of NVF in q^2 in the region of small q verifies the validity of events selection in phase space region where the pole diagram of Fig.1a dominates (see also [11]).

By extrapolating NVF $W(q)$ to the pole at $q^2 = -\kappa^2$ the value of nuclear vertex constant NVC (notation of [12]) was found to be equal $G^2_{\alpha\mathrm{tN}} = (4.5 \pm 0.1)$ fm. The wide spread of NVC values obtained by other phenomenological methods was given in [12] (from 7 fm up to 18 fm). Due to well known statement that NVC is essentially nonlinear in unphysical region, the extracted value must be considered as a lower bound of the real NVC. It should be noted that in the compound quark bag model $G^2_{\alpha\mathrm{tN}} = 5.7$ fm [13].

Spectral function $\rho_{\mathrm{tN}}(q)$ from the reactions p(α,pn)τ and p(α,pp)t at $T_p = 620$ MeV

Range of averaging over $q^2 \times 10^3(\mathrm{GeV}/c)^2$	$\rho_{\mathrm{tN}}(q) \times 10^{-4}(\mathrm{GeV}/c)^{-3}$ from the reaction p(α,pn)τ	Range of averaging over $q^2 \times 10^3(\mathrm{GeV}/c)^2$	$\rho_{\mathrm{tN}}(q) \times 10^{-4}(\mathrm{GeV}/c)^{-3}$ from the reaction p(α,pp)t
0 – 1	2.56 ± 0.76	3.5 – 5.5	2.03 ± 0.24
1 – 3	1.54 ± 0.25	5.5 – 7.5	1.53 ± 0.19
3 – 5	1.84 ± 0.23	7.5 – 9.5	1.47 ± 0.18
5 – 7	1.30 ± 0.17	9.5 – 11.5	1.21 ± 0.15
7 – 9	1.41 ± 0.17	11.5 – 13.5	0.91 ± 0.13
9 – 11	1.00 ± 0.13	13.5 – 16.5	0.85 ± 0.10
11 – 13	0.99 ± 0.13	16.5 – 19.5	0.67 ± 0.08
13 – 16	0.81 ± 0.09	19.5 – 23.5	0.50 ± 0.06
16 – 19	0.66 ± 0.08	23.5 – 35	0.30 ± 0.02
19 – 23	0.45 ± 0.05	35 – 39.5	0.15 ± 0.02
23 – 30	0.38 ± 0.03	39.5 – 49.5	0.10 ± 0.01
30 – 39	0.26 ± 0.02	49.5 – 65	0.06 ± 0.01
39 – 49	0.16 ± 0.02	65 – 70	0.04 ± 0.01
49 – 60	0.10 ± 0.01	70 – 90	0.02 ± 0.005
60 – 75	0.06 ± 0.01		
75 – 90	0.03 ± 0.01		

Our results on $\rho_{\mathrm{tN}}(q)$ are shown both in Table and on Fig.3 (where Fig.3b is a scaled part of Fig.3a in the region of small q). Fig.3 includes also our earlier data from [1], the results of experimental works [14, 15] as well as the theoretical calculations for NN-potentials RSCV$_8$ from [5] and Argonne v18 from [6] (the three-particle forces were taken in account in the framework of Urbana IX potential). The data from [16](are not shown) are very close to those of [15] (due to the difference in normalization procedure the data of works [5,6,14-16] must be multiplied by constant value $(2\pi)^3$ to compare with our data). As seen from

Fig.3 the spectral functions $\rho_{tN}(q)$ from the reactions (1) and (2) at the initial α-particle momenta 2.7 and 5 GeV/c are in good agreement within experimental errors.

Our data lie systematically lower than those of experimental works [14-16], discordance reaching 50% in the region $q < 0.05$ GeV/c. By contrast, our data lie higher than NIKHEF results from [14] in the region $0.2 < q < 0.3$ GeV/c, tail discrepancy being nearly an order of magnitude. As for theoretical calculations the results of R. Schiavilla and R.B. Wiringa from [6] are seen from Fig.3 to be in more accordance with our experimental data, especially at small q. It should be mentioned that the theoretical calculations from [5] and [6] are in sharp contradiction with each other at small q, that shows clearly the strong dependence of spectral functions on the NN-potential choice.

Including in analysis all our experimental data on the reactions (1) and (2) at two different initial momentum values we approximated the function $\rho_{tN}(q)$ as follows: $A_1 \exp(-b_1 q^2) + A_2 \exp(-b_2 q^2)$; the following parameter values have being obtained at $\chi^2/DF = 1.45$: $A_1 = (2.5 \pm 0.2) \cdot 10^4$ $(\mathrm{GeV}/c)^{-3}$, $b_1 = 74 \pm 2$ $(\mathrm{GeV}/c)^{-2}$, $A_2 = (6.4 \pm 3.4) \cdot 10^2$ $(\mathrm{GeV}/c)^{-3}$, $b_2 = 12 \pm 4$ $(\mathrm{GeV}/c)^{-2}$.

Finally, after integration of this function with the given above parameters values in the region $0 < q < 0.3$ GeV/c the contribution of $(\mathrm{t}(\tau) + \mathrm{N})$-component

$$N_{\mathrm{tN}} = \frac{1}{(2\pi)^3} \int \rho_{\mathrm{tN}} d^3q$$

to ^{4}He nucleus was found to be 1.05. As follows from our recent work [17] the contribution of (d+d)-component to the wave function of ^{4}He nucleus

$$N_{\mathrm{dd}} = \frac{1}{(2\pi)^3} \int \rho_{\mathrm{dd}} d^3q$$

in the same region of q equals 0.54. These results are very important to check sum rule for the full spectral function which includes the contributions of two-, three- and four-body virtual decays of ^{4}He nucleus.

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