ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E1-2000-258

A.Yu.Illarionov, A.G.Litvinenko, G.I.Lykasov

POLARIZATION PHENOMENA BY FRAGMENTATION OF DEUTERONS TO PIONS

Submitted to «European Physical Journal A»

2000

1 INTRODUCTION

One of the main sources of information about the deuteron structure at small distances is the reactions of hadron production by proton-deuteron and deuteron-deuteron collisions in the kinematical region forbidden for the free nucleon-nucleon interaction [1, 2], the so called cumulative processes. This kinematical region corresponds to the values of the light-cone variable $x = 2(E' + p')/(E_D + p_D) \geq 1$ where E', E_D and p', p_D are the energies and momenta of the final hadron and deuteron respectively. The nucleon momentum distributions in a deuteron, extracted from the reaction $Dp \to pX$ at forward emission of proton and eD-inelastic scattering [3] actually coincide with each other (see, for example, [4]). So, one can conclude hadron and lepton probes result in the same information about the deuteron structure. The so called Paris [5] and Reid [6] deuteron wave functions (DWF) reproduce rather well the experimental data about $Dp \to pX$ reaction at internal momenta $k = \sqrt{m^2/(4x(1-x)) - m^2}$ up to 0.25 GeV/c within the framework of impulse approximation (IA) [4]). The inclusion of corrections to IA related to the secondary interactions allows to describe the experimental data about the deuteron fragmentation $Dp \to pX$ at $k > 0.25$ GeV/c [7].

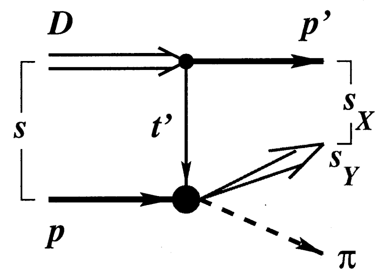
The investigation of polarization phenomena by fragmentation of deuterons at middle and high energies in the kinematical region forbidden for the emission of hadrons by free $N - N$ scattering has recently become very topical. The cumulative proton production by the collision of the polarized deuterons with the target results in the information about the deuteron spin structure at small internuclear distances. It can be seen from the experimental and theoretical study of deuterons fragmentation into protons at zero angle [8, 9, 7]. The theoretical analysis of this reaction has shown that tensor analyzing power T_{20} and polarization transfer coefficient κ are more sensitivity to the used deuteron wave function (DWF) and especially to the reaction mechanism than inclusive spectrum [7]. At the present time not one relativistic form of the DWF can describe T_{20} at $x \geq 1.7$ measured by $Dp \to pX$ striping. On the other hand, the inclusion of the reaction mechanism: the impulse approximation and the secondary interaction of produced hadrons can describe both the inclusive spectrum and T_{20} at $x \leq 1.7$ using only the nucleon degrees of freedom [7]. One of the cause for the explanation of this phenomena can be the point that the deuteron structure at high ($>$ 0.20 GeV/c) internal momentum (short internuclear distances $<$ 1 fm) are determined by non-nucleon degrees of freedom. The inclusion of the non-nucleon degrees of freedom, it can be either six-quark state or the composition of $\Delta\Delta$, NN^*, $NN\pi$, etc. states in the deuteron, allowed to describe the experimental data about the inclusive proton spectrum at $x \geq 1.7$ [7]. Many papers were dedicated to the theoretical analysis o the deuteron striping to protons, see for example Refs. in [2, 7]. However till now there is not the unified theoretical description of T_{20} at the whole kinematic region of protons emitted forward by the $Dp \to pX$ striping.

If we try to study the manifestation of non-nucleon degrees of freedom it is natural to investigate the cumulative production of different hadrons which have different quarks contents. Recently the interesting experimental data about T_{20} in the reaction $Dp \to \pi X$ when the pion is emitted forward have been published [10]. They show very small, approximately constant, value of the tensor analyzing power T_{20} for the fragmentation of deuteron to pions $Dp \to \pi X$ at $x \geq 1$. The mechanism of this reaction is mainly impulse approximation, as it is shown in [11] the secondary interaction or the final state interaction (FSI) is very small and can be neglected. The quite big yield of high momentum pions produced by $p - D$ and $p - A$ collisions in the kinematical region forbidden for the free $N - N$ scattering was explained by both few-nucleon correlation models [2] and [12] or multiquark bags one [13, 14]. However the polarization phenomena by deuteron fragmentation to pions were out side of these models.

In this paper we present a relativistic invariant analysis of the deuteron tensor analyzing power T_{20} and unpolarized pion spectrum in backward inclusive $p+D \to \pi(180^0)+X$ reaction. The main goal is to describe this reaction in a consistent relativistic approach using nucleon model of deuteron. A fully covariant expression for all quantities is obtained within the Bethe-Salpeter (BS) formalism. This way results in the general conclusions about the amplitude of the process which can't be seen in the non-relativistic approach. On the other hand, the non-relativistic limit will be recovered and some links to the non-relativistic corrections can be established. This analysis of the deuteron models can be very important for the searching for nuclear quarks phenomena.

2 RELATIVISTIC IMPULSE APPROXIMATION

Let us consider the inclusive reaction $D+p \to \pi(0^0)+X$, within the framework of the impulse approximation.



The amplitude of this process $\mathcal{T}^{\pi}_{pD}$ can be written in the following relativistic invariant form:

$$\mathcal{T}^{\pi}_{pD} \equiv \mathcal{T}(Dp \to \pi X) = \left(\bar{\mathcal{U}}_Y \Gamma_{NN}\right)_{\alpha\beta} \bar{u}^{(\sigma_{p'})}_{\gamma}(p') \left(\frac{\hat{n}+m}{n^2-m^2}\right)_{\beta\delta} u^{(\sigma_p)}_{\alpha}(p) \left(\Gamma_\mu(D,q)\mathcal{C}\right)_{\delta\gamma} \xi^{\mu}_{M}(D) \ . \quad (1)$$

where $(\bar{\mathcal{U}}_Y \Gamma_{NN})$ is the truncated $NN \to \pi Y$ vertex, α, β, γ and δ are the Dirac indices (with summation over twofold indices), μ is a Lorentz index and $\mathcal{C} = i\gamma_2\gamma_0$ is a charge conjugation Dirac matrix, M is the deuteron spin projection. Here the deuteron vertex $(\Gamma_\mu(D,q)\mathcal{C})$ satisfies to the BS equation and depends on the relative momentum $q = (n-p')/2$ and total momentum $D = n+p'$ of the deuteron, $\xi^{\mu}_{M}(D)$ is the four-vector of the deuteron polarization. It satisfies to the following equations:

$$\xi^{\mu M}(D) D_\mu = 0 \ , \quad \xi^{\mu M}(D)\xi_{\mu M'}(D) = -\delta^{M}_{M'}$$
$$\sum_M \left(\xi_{\mu M}(D)\right)^* \xi_{\nu M}(D) = -g_{\mu\nu} + \frac{D_\mu D_\nu}{M^2}, \quad (2)$$

By squaring this amplitude one can write the relativistic invariant inclusive pion spectrum of the reaction $Dp \to \pi X$ in the following form:

$$\rho_{pD}^{\pi} = \varepsilon_{\pi}\frac{d\sigma}{d^3p_{\pi}} = \frac{1}{(2\pi)^3}\int \frac{\sqrt{\lambda(p,n)}}{\sqrt{\lambda(p,D)}}\rho_{\mu\nu}(D)\left[\rho_{pN}^{\pi}\cdot\Phi^{\mu\nu}(D,q)\right]\frac{m^2d^3p'}{E'}\ , \tag{3}$$

where $\lambda(p_1,p_2) \equiv (p_1p_2)^2 - m_1^2m_2^2 = \lambda(s_{12},m_1^2,m_2^2)/4$ is the flux factors, p, n are four-momenta of the proton-target and intra-deuteron nucleon respectively, $\rho_{pN}^{\pi} \equiv \varepsilon_{\pi}\cdot d\sigma/d^3p_{\pi}$ is the relativistic invariant inclusive spectrum of pions produced by interaction of the intra-deuteron nucleon with the proton-target. In general case this spectrum can be written as a three variables function $\rho_{pN}^{\pi} = \rho(x_f,\pi_{\perp},s_{NN})$. Feynman's variable, x_f, is defined as $x_f = 2\pi_{||}/\sqrt{s_{NN}}$, where π is the pion momentum in the center of mass of the two interacting nucleons and $s_{NN} = (p+N)^2$.

$\rho_{\mu\nu}(D)$ is the density matrix of the deuteron [15]:

$$\rho_{\mu\nu}(D) = (\xi_{\mu M}(D))^*\,\xi_{\nu M}(D) = \frac{1}{3}\left(-g_{\mu\nu}+\frac{D_{\mu}D_{\nu}}{M^2}\right)+\frac{1}{2}(W_{\lambda})_{\mu\nu}s_D^{\lambda} -$$
$$\left[\frac{1}{2}\Big((W_{\lambda_1})_{\mu\rho}(W_{\lambda_2})^{\rho}{}_{\nu}+(W_{\lambda_2})_{\mu\rho}(W_{\lambda_1})^{\rho}{}_{\nu}\Big)+\frac{2}{3}\left(-g_{\lambda_1\lambda_2}+\frac{D_{\lambda_1}D_{\lambda_2}}{M^2}\right)\left(-g_{\mu\nu}+\frac{D_{\mu}D_{\nu}}{M^2}\right)\right]p_D^{\lambda_1\lambda_2} \tag{4}$$

with $(W_{\lambda})_{\mu\nu} = i\varepsilon_{\mu\nu\gamma\lambda}D^{\gamma}/M$; s_D is the spin vector and p_D is the alignment tensor of the deuteron.

The full symmetrical tensor $\Phi_{\mu\nu}(D,q)$ in Eq.(3) reads

$$\Phi_{\mu\nu}(D,q) = \frac{1}{4}Tr\left[\bar{\Psi}_{\mu}\left(\frac{\widehat{n}+m}{m}\right)^2\Psi_{\nu}\frac{\widehat{p'}-m}{m}\right] = -f_0(n^2)g_{\mu\nu}+f_1(n^2)\frac{q_{\mu}q_{\nu}}{m^2}\ . \tag{5}$$

By the proof of eq.(5) we introduced the modified vertex, $\Psi_{\mu}(D,q)$:

$$\Psi_{\mu}(D,q) = \frac{\Gamma_{\mu}(D,q)}{m^2-n^2-i0} = \varphi_1(n^2)\gamma_{\mu}+\varphi_2(n^2)\frac{n_{\mu}}{m}+\frac{\widehat{n}-m}{m}\left(\varphi_3(n^2)\gamma_{\mu}+\varphi_4(n^2)\frac{n_{\mu}}{m}\right)\ . \tag{6}$$

By substituting Eq.(6) into Eq.(5) and calculating the trace, one can find the explicit forms of the invariant functions $f_{0,1}$

$$f_0(n^2) = \frac{M^2}{m^2}\left(\varphi_1-\frac{m^2-n^2}{m^2}\varphi_3\right)\varphi_1-\left(\frac{m^2-n^2}{m^2}\right)^2(\varphi_1-\varphi_3)\,\varphi_3\ ;$$
$$f_1(n^2) = -4\left\{\varphi_1+\varphi_2-\frac{m^2-n^2}{m^2}\left(\frac{\varphi_2}{2}+\varphi_3+\varphi_4\right)\right\}(\varphi_1+\varphi_2)$$
$$+\frac{M^2}{m^2}\left(\varphi_2-\frac{m^2-n^2}{m^2}\varphi_4\right)\varphi_2-\left(\frac{m^2-n^2}{m^2}\right)^2(\varphi_2+2\varphi_3+\varphi_4)\,\varphi_4\ . \tag{7}$$

The corresponding invariant scalar functions $\varphi_i(n^2)$ of the deuteron vertex with one on-shell nucleon may be computed in any reference frame. Let us note that in our case, when one particle is the on-mass shell, only four partial amplitudes contribute to the process, namely, with the ρ spin classification, $u = {}^3\mathcal{S}_1^{++}, w = {}^3\mathcal{D}_1^{++}, v_s = {}^1\mathcal{P}_1^{-+}$ and $v_t = {}^3\mathcal{P}_1^{-+}$. We can write φ_i in the deuteron rest frame in order to relate them to the non-relativistic S-, D- and

$\mathcal{P}$-waves of deuteron. In this case the invariant functions have the following forms:

$$
\begin{aligned}
\mathcal{N}\varphi_1 &= u - \frac{w}{\sqrt{2}} - \sqrt{\frac{3}{2}}\frac{m}{|\boldsymbol{q}|}v_t \ ; \\
\mathcal{N}\varphi_2 &= -\frac{m}{(E_{\boldsymbol{q}}+m)}u - \frac{m(2E_{\boldsymbol{q}}+m)}{|\boldsymbol{q}|^2}\frac{w}{\sqrt{2}} + \sqrt{\frac{3}{2}}\frac{m}{|\boldsymbol{q}|}v_t \ ; \\
\mathcal{N}\varphi_3 &= -\sqrt{\frac{3}{2}}\frac{mE_{\boldsymbol{q}}}{|\boldsymbol{q}|(2E_{\boldsymbol{q}}-M)}v_t \ ; \\
\mathcal{N}\varphi_4 &= \frac{m^2}{M(E_{\boldsymbol{q}}+m)}u - \frac{m^2(E_{\boldsymbol{q}}+2m)}{M|\boldsymbol{q}|^2}\frac{w}{\sqrt{2}} - \sqrt{3}\frac{m^2}{|\boldsymbol{q}|(2E_{\boldsymbol{q}}-M)}v_s \ ,
\end{aligned} \tag{8}
$$

where all the vertex functions are determined in the deuteron rest frame and all the kinematical variables in eqs.(8) have to be evaluated in this system; $E_{\boldsymbol{q}} = \sqrt{|\boldsymbol{q}|^2+m^2}$. The normalization factor $\mathcal{N}^{-1} = \pi\sqrt{2/M}$ has been chosen according to the non-relativistic normalization of the DWF: [1]

$$
\int\limits_0^\infty |\boldsymbol{q}|^2 d|\boldsymbol{q}| \left(u^2(|\boldsymbol{q}|) + w^2(|\boldsymbol{q}|)\right) = 1
$$

The relativistic invariant functions $f_{0,1}(|\boldsymbol{q}|)$ (7) can be rewritten in terms of this spin-orbit momentum wave functions as

$$
\begin{aligned}
f_0(|\boldsymbol{q}|) &= \mathcal{N}^{-2}\frac{M^2}{m^2}\left\{\left(u-\frac{w}{\sqrt{2}}\right)^2 + \sqrt{6}\frac{|\boldsymbol{q}|}{m}\left(u-\frac{w}{\sqrt{2}}\right)v_t - \frac{3}{2}v_t^2\right\} \ ; \\
\frac{2}{3}\frac{|\boldsymbol{q}|^2}{m^2}f_1(|\boldsymbol{q}|) &= \mathcal{N}^{-2}\frac{M^2}{m^2}\left\{2\sqrt{2}uw + w^2 + v_t^2 - 2v_s^2 - \frac{4}{\sqrt{3}}\frac{|\boldsymbol{q}|}{m}\left[\left(u-\frac{w}{\sqrt{2}}\right)\frac{v_t}{\sqrt{2}} + \left(u+\sqrt{2}w\right)v_s\right]\right\} \ .
\end{aligned} \tag{11}
$$

Then all the observables can be computed in terms of positive- and negative-energy wave functions, u, w and v_s, v_t respectively. The contribution of the positive-energy waves u, w to the observables results in the non-relativistic limit. The parts containing the negative-energy waves v_s, v_t have a purely relativistic origin and consequently they manifest genuine relativistic correction effects.

Using the explicit form of the density matrix (4) one can write

$$
\Phi \equiv \rho_{\mu\nu}\Phi^{\mu\nu} = \Phi^{(u)} + \Phi^{(v)}_\lambda s_D^\lambda + \Phi^{(t)}_{\lambda_1\lambda_2}p_D^{\lambda_1\lambda_2} \ . \tag{12}
$$

[1]Note, the Gross definition [16] of the DV $\widetilde{\Psi}_\mu(q)$ is related to the BS vertex $\Psi_\mu(q)$ (6) by the following:

$$
\widetilde{\Psi}_\mu(q) = \Psi_\mu(-q) \ . \tag{9}
$$

Comparing it with eqs.(46) of reference [16] one can see the Gross wave functions $\widetilde{u}(q), \widetilde{w}(q)$ and $\widetilde{v}_s(q), \widetilde{v}_t(q)$ are connected with our wave functions (8) as

$$
\begin{aligned}
&\widetilde{u}(q_0,|\boldsymbol{q}|) = u(-q_0,|\boldsymbol{q}|) \ ; \ \ \widetilde{w}(q_0,|\boldsymbol{q}|) = w(-q_0,|\boldsymbol{q}|) \ ; \\
&\widetilde{v}_s(q_0,|\boldsymbol{q}|) = -v_s(-q_0,|\boldsymbol{q}|) \ ; \ \ \widetilde{v}_t(p_0,|\boldsymbol{p}|) = -v_t(-q_0,|\boldsymbol{p}|) \ ,
\end{aligned} \tag{10}
$$

where in our case $q_0 = M/2 - E_{\boldsymbol{q}}$.

The superscripts (u, v, t) denote unpolarized, vector polarized and tensor polarized cases, respectively:

$$\begin{aligned}
&\Phi^{(u)}(\boldsymbol{q}) = f_0 + \frac{1}{3}\frac{|\boldsymbol{q}|^2}{m^2} f_1 \ ; \\
&\Phi^{(v)}_{\lambda}(\boldsymbol{q}) = 0 \ ; \\
&\Phi^{(t)}_{\lambda_1\lambda_2}(\boldsymbol{q}) = \left[\frac{1}{3}\frac{|\boldsymbol{q}|^2}{m^2}\left(-g_{\lambda_1\lambda_2} + \frac{D_{\lambda_1}D_{\lambda_2}}{M^2}\right) - \left(-g_{\lambda_1\mu} + \frac{D_{\lambda_1}D_{\mu}}{M^2}\right)\left(-g_{\lambda_2\nu} + \frac{D_{\lambda_2}D_{\nu}}{M^2}\right)\frac{q^\mu q^\nu}{m^2}\right] f_1 \ .
\end{aligned} \tag{13}$$

Let us consider now the case when the deuteron has the tensor polarization. If the initial deuteron is only aligned due to p_D^{zz} component, then the inclusive spectrum of the reaction $\boldsymbol{D} + p \to \pi + X$ (3) can be written in the form:

$$\rho^{\pi}_{pD}\left(p^{zz}_{D}\right) = \rho^{\pi}_{pD}\left[1 + \mathcal{A}_{zz}\cdot p^{zz}_{D}\right] \ , \tag{14}$$

where ρ^{π}_{pD} is the inclusive spectrum for the case of unpolarized deuterons and $\mathcal{A}_{zz} \equiv \sqrt{2}T_{20}$ $(-\sqrt{2} \leq T_{20} \geq 1/\sqrt{2})$ is the tensor analyzing power. One can write:

$$\rho^{\pi}_{pD} = \frac{1}{(2\pi)^3}\int \frac{\sqrt{\lambda(p,n)}}{\sqrt{\lambda(p,D)}}\left[\rho^{\pi}_{pN}\cdot\Phi^{(u)}(|\boldsymbol{q}|)\right]\frac{m^2 d^3q}{E_{\boldsymbol{q}}} \ ; \tag{15}$$

$$\rho^{\pi}_{pD}\cdot\mathcal{A}_{zz} = -\frac{1}{(2\pi)^3}\int \frac{\sqrt{\lambda(p,n)}}{\sqrt{\lambda(p,D)}}\left[\rho^{\pi}_{pN}\cdot\Phi^{(t)}(|\boldsymbol{q}|)\right]\left(\frac{3Cos^2\vartheta_{\boldsymbol{q}} - 1}{2}\right)\frac{m^2 d^3q}{E_{\boldsymbol{q}}} \ . \tag{16}$$

where

$$\begin{aligned}
\Phi^{(u)}(|\boldsymbol{q}|) &= f_0(|\boldsymbol{q}|) + \tfrac{1}{3}\tfrac{|\boldsymbol{q}|^2}{m^2} f_1(|\boldsymbol{q}|) = \\
&\mathcal{N}^{-2}\frac{M^2}{m^2}\left\{u^2 + w^2 - v_t^2 - v_s^2 + \frac{2}{\sqrt{3}}\frac{|\boldsymbol{q}|}{m}\left[\left(\sqrt{2}v_t - v_s\right)u - \left(v_t + \sqrt{2}v_s\right)w\right]\right\}
\end{aligned} \tag{17}$$

$$\begin{aligned}
\Phi^{(t)}(|\boldsymbol{q}| &= \tfrac{2}{3}\tfrac{|\boldsymbol{q}|^2}{m^2} f_1(|\boldsymbol{q}|) = \\
&\mathcal{N}^{-2}\frac{M^2}{m^2}\left\{2\sqrt{2}uw + w^2 + v_t^2 - 2v_s^2 - \frac{4}{\sqrt{3}}\frac{|\boldsymbol{q}|}{m}\left[\left(u - \frac{w}{\sqrt{2}}\right)\frac{v_t}{\sqrt{2}} + \left(u + \sqrt{2}w\right)v_s\right]\right\} \ .
\end{aligned} \tag{18}$$

It is intuitively clear that the two nucleons in the deuteron are mainly in states with angular momenta $L = 0, 2$ (see also numerical analysis of the solutions of the BS equation in terms of amplitudes within the ρ-spin basis [17]), so the probability of states with $L = 1$ $(v_{s,t})$ in eqs.(17,18) is much smaller in comparison with the probability for the u, w configurations. Moreover, it can be shown that the u and w waves directly correspond to the non-relativistic $\mathcal{S}$ and $\mathcal{D}$ ones. Therefore, eqs.(17,18) with only u, w waves can be identified as the main contributions to the corresponding observables and they may be compared with their non-relativistic analogues. The other terms posses contributions from the $\mathcal{P}$-waves and they are proportional to $\boldsymbol{q}/m$ (the diagonal terms in $v_{s,t}$ are negligible). Due to their pure relativistic origin one can refer to them as relativistic corrections.

Let us consider the minimal relativisation scheme which describes rather well the differential cross section for such process as deuteron break-up $A(D,p)X$. The minimal relativisation procedure [18, 2] consist of (i) a replacement of the argument of the non-relativistic wave functions by a light-cone variable $\boldsymbol{k} = (\boldsymbol{k}_\perp, \boldsymbol{k}_{||})$

$$\boldsymbol{k}^2 = \frac{m^2 + \boldsymbol{k}_\perp^2}{4x(1-x)} - m^2 \; ; \quad k_{||} = \sqrt{\frac{m^2 + \boldsymbol{k}_\perp^2}{x(1-x)}} \left(\frac{1}{2} - x\right) \; . \tag{19}$$

where $x = (E_{\boldsymbol{q}} + |\boldsymbol{q}| Cos\vartheta_{\boldsymbol{q}})/M = (\varepsilon' - p'_{||})/M$; $|\boldsymbol{k}_\perp| = p'_\perp$ in the deuteron rest frame, and (ii) multiplying the wave functions by the factor $\sim 1/(1-x)$. It results in the shift of the argument towards larger values and the wave function itself decreases more rapidly. This effect of suppressing the wave function is compensated by the kinematical factor $1/(1-x)$.

In the BS approach the relativistic effects are of dynamical nature [19] and not reduced to a simple shift in arguments and, in addition to $\mathcal{S}$ and $\mathcal{D}$ waves, it contains negative energy components, i.e., $\mathcal{P}$ waves which allows for a more refined analysis of the date. One can see that in the polarization case they play a more important role and lead to an improvement of the description of the data.

3 RESULTS AND DISCUSSION

Below the calculation results of the inclusive relativistic invariant pion spectrum and the tensor analyzing power in the fragmentation process $Dp \to \pi X$ are presented and compared with the available experimental data [1, 10]. These experimental data were presented in the dependence on the so called cumulative scaling variable x_C ("cumulative number") [20]. For our reaction, this variable is defined as the following:

$$x_C = 2\frac{(p\pi) - \mu^2/2}{(Dp) - Mm - (D\pi)} = 2\frac{t - m^2}{(t - m^2) + (M+m)^2 - s_X} \leq 2 \; . \tag{20}$$

In the rest frame of the deuteron $D = (M, \mathbf{0})$, it can be rewrited in the form:

$$x_C = 2\frac{EE_\pi - pp_\pi Cos\vartheta_\pi - \mu^2/2}{M(E - E_\pi - m)} \to 2\frac{E}{T_p}\frac{\alpha}{1 - E_\pi/T_p} \; , \tag{21}$$

where $\alpha = (E_\pi - \pi Cos\vartheta_\pi)/M$ is a light-cone variable. The value of x_C corresponds to the minimum mass (in nucleon mass units) of part of the projectile nucleus (deuteron) involved in the reaction. The value x_C larger than 1 correspond to the a cumulative pion.

One of the more intensively studied reaction with hadronic probe is the deuteron (polarized and unpolarized) fragmentation into proton $D + A \to p(0^o) + X$. The reason of this study is firstly, a big cross-section and secondly, rather simple relation of the inclusive spectrum and polarization observables to the $\mathcal{S}$- and $\mathcal{D}$-waves of DWF obtained within IA. For example, the tensor analyzing power T_{20} within IA can be written in the following simple form:

$$T_{20} = -\frac{1}{\sqrt{2}}\,\frac{2\sqrt{2}\; u\; w \;+\; w^2}{u^2 \;+\; w^2} \; . \tag{22}$$

This relation doesn't depend on the amplitude of elementary reaction $pn \to pX$, which in IA is taken as the off mass shell. As it has been shown in [7] both the differential cross section and T_{20} for the fragmentation $D+p \to p(0^o)+X$ can be described within the IA at $k \leq 0.2$ GeV/c only. At larger momenta k the secondary interactions, in particular the triangle graphs with the virtual pion, have to be taken into account in order to describe these observebles more less satisfactory.

However by the pion production $D+p \to \pi(0^o)+X$ at the cumulative region the rescattering mechanism is kinematically suppressed as it has been shown in [21]. Therefore one can be limited to the IA only by the theoretical calculus of the differential cross section and tensor analyzing power T_{20} for this reaction.

The calculation results of the invariant spectrum of pions produced by $D+p \to \pi(0^o)+X$ reaction are presented in FIG.(1-2). The vertex $NN \to \pi Y$ has been taken as the on-mass shell and fit of the corresponding differential cross section used from [22].

One can see from FIG.1 the large sensitivity of the inclusive spectrum to this vertex and the small one to the type of the nonrelativistic DWF. The FIG.2 shows that the inclusion of the $\mathcal{P}$-waves contribution to the DWF within the Bethe-Salpeter or Gross approaches results in a better description of the experimental data at the cumulative region, but not satisfactory. From FIG.3 one can see the effects of the minimal relativization of the DWF [2].

The calculation results of T_{20} for the reaction of polarized deuteron fragmentation into cumulative pions are shown in FIG.(4-6). From these figures one can see a small sensitivity of T_{20} to the vertex corresponding to $NN \to \pi Y$ process. It is also seen that T_{20} is more sensitive to the form of the DWF than the invariant spectrum. The experimental data about T_{20} are not described by any DWF used in this paper. Note, there can be an alternative approach to study the deuteron structure at small distances which assumes a possible existence of non-nucleon or quark degrees of freedom [7, 23, 24] in a deuteron and nucleus. For example, according to [2], large momenta of nucleons can be caused by few nucleon correlations in a nucleus. The deuteron structure can then described by assuming the quark degrees of freedom [13, 14]. On the other hand, the shape of the high momentum tail of the nucleon distribution in a deuteron can be constructed on the basis of its true Regge asymptotic [12] and the corresponding parameters can be found from the good description of the inclusive proton spectrum in deuteron fragmentation $Dp \to pX$ [12, 7]. According to [12, 7] one can write the following form for $\widetilde{\Phi}^{(u)}(|\boldsymbol{q}|)$, see eq.(17):

$$\widetilde{\Phi}^{(u)}(|\boldsymbol{q}|) = \mathcal{N}^{-1}\frac{M^2}{m^2}\left\{(1-\alpha_{6q})\cdot\left[u^2(|\boldsymbol{q}|)+w^2(|\boldsymbol{q}|)\right]+\alpha_{6q}\frac{4\pi x}{E_{\boldsymbol{q}}}\cdot G_{6q}(x,\boldsymbol{k}_\perp)\right\}\ , \tag{23}$$

where the parameter α_{6q} is the probability for the non-nucleon component in the deuteron which is a state of two colorless $(3q)$ systems.

$$G_{6q}(x,\boldsymbol{k}_\perp) = \frac{b^2}{2\pi}\cdot\frac{\Gamma(A+B+2)}{\Gamma(A+1)\Gamma(B+1)}\cdot x^A(1-x)^B\cdot e^{-bk_\perp}\ . \tag{24}$$

On FIG.7 we present the invariant pion spectrum calculated within the relativistic impulse approximation by inclusion of the non-nucleon component in the DWF [12, 7], its probability α_{6q} is 0.2 - 0.4 (dot-dashed and dashed curves respectively). One can see the good description of the experimental data [1] at all x_C.

4 SUMMARY AND OUTLOOK

The main goal of this paper was to study the reaction of deuteron fragmentation into pions within the framework of nucleon model of deuteron. The main results can be summarize as the following.

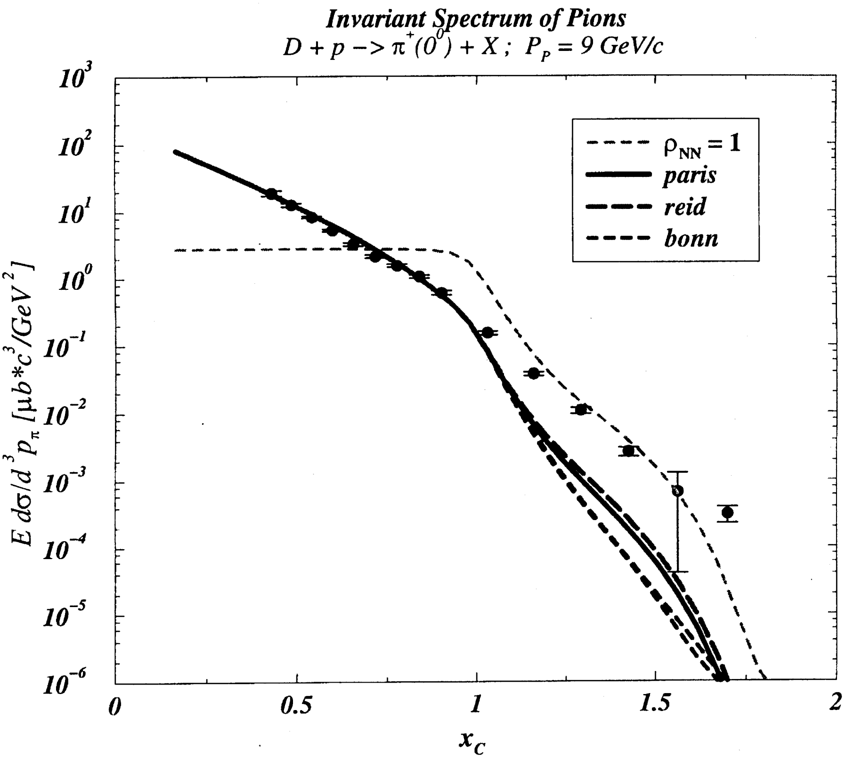


FIG.1. : The invariant spectrum of the backward pions in the deuteron fragmentation reaction calculated in the relativistic impulse approximation using various types of the nonrelativistic DWF. The calculation results are compared with the experimental data from [1] for the value of the projectile proton momentum $P_p = 9$ GeV/c. The thin dashed curve corresponds to the calculus by neglecting the dependence of the elementary vertex $NN \to \pi Y$ on the relativistic invariant variables.

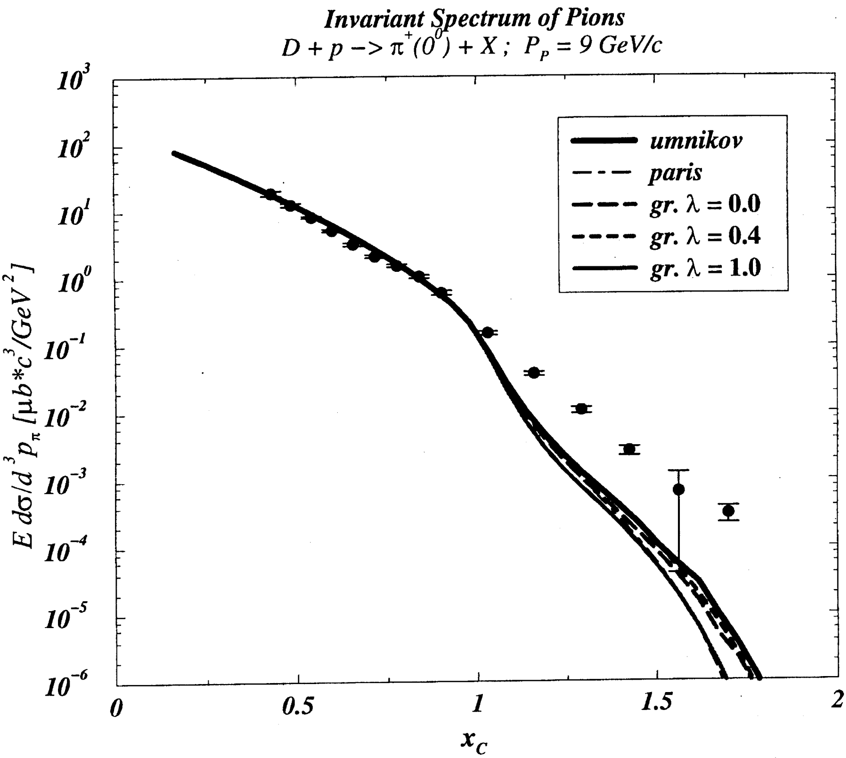


FIG.2. : The invariant spectrum calculated by using two forms of the relativistic DWF's, [25] and [16]. The experimental data are taken from [1]. The thin solid line corresponds to the DWF [25] , where the total probability of the small components: $P_v = \int_0^\infty p^2 dp \cdot [v_t^2 + v_s^2] \simeq 0.2$ %. The long-dashed, dashed and thick solid lines represent the calculations with Gross's DWF by using the mixing parameter $\lambda = 0.0, 0.4$ and 1.0 respectively [26] that correspond to the small component probabilities $P_v = 0.03$ %, 0.44 % and 1.46 %. The dot-dashed line corresponds to the nonrelativistic Paris DWF.

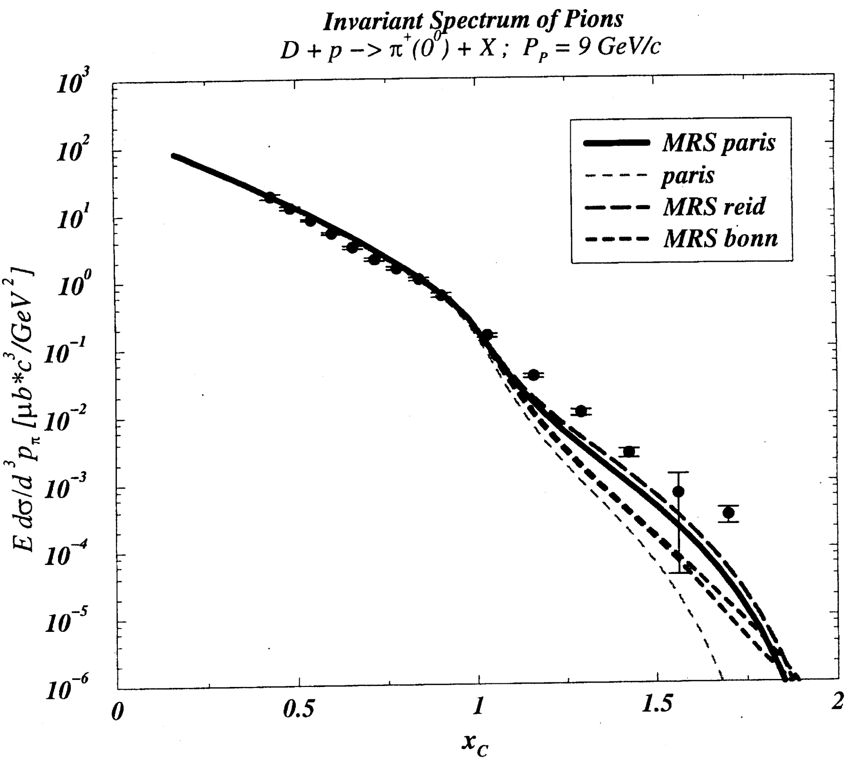


FIG.3. : The invariant pion spectrum calculated by using the nonrelativistic DWF's obtained by the minimal relativisation scheme (MRS) [2, 18]. The solid, dashed and long-dashed lines correspond to the various DWF forms: the Paris one, the RSC and the Bonn DWF. The experimental data are taken from [1].

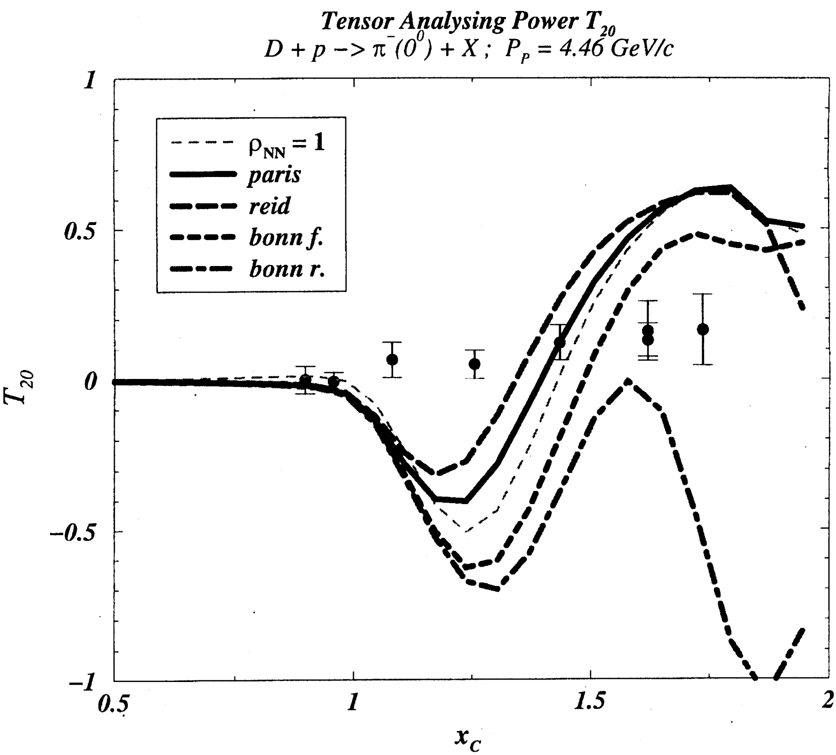


FIG.4. : Tensor analyzing power T_{20} of the deuterons. The calculation results are compared with the experimental data from [10] at the projectile proton momentum $P_p = 4.46$ GeV/c. The thin dashed curve corresponds to the calculus by neglecting of the internal structure of the elementary vertex $NN \to \pi Y$. The solid, long-dashed, dashed and dot-dashed lines correspond to the calculus by using various types of the nonrelativistic DWF: the Paris one, the RSC and two Bonn types, the relativistic Bonn DWF and the full Bonn DWF respectively.

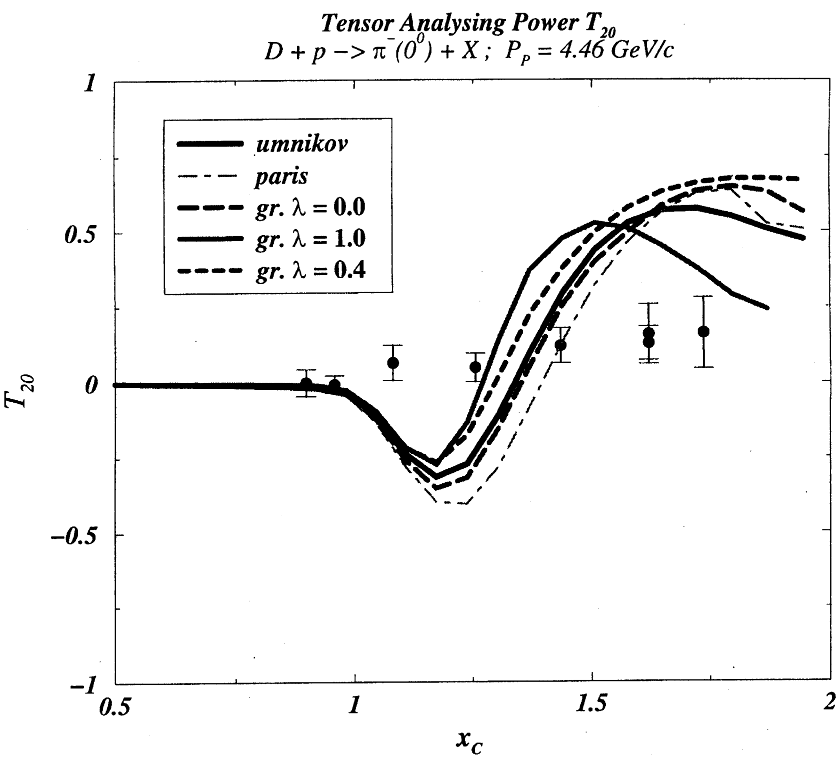


FIG.5. : T_{20} calculated by using two forms of the relativistic DWF's, [25] and [16]. Notation as in FIG. 2. The experimental data are taken from [10].

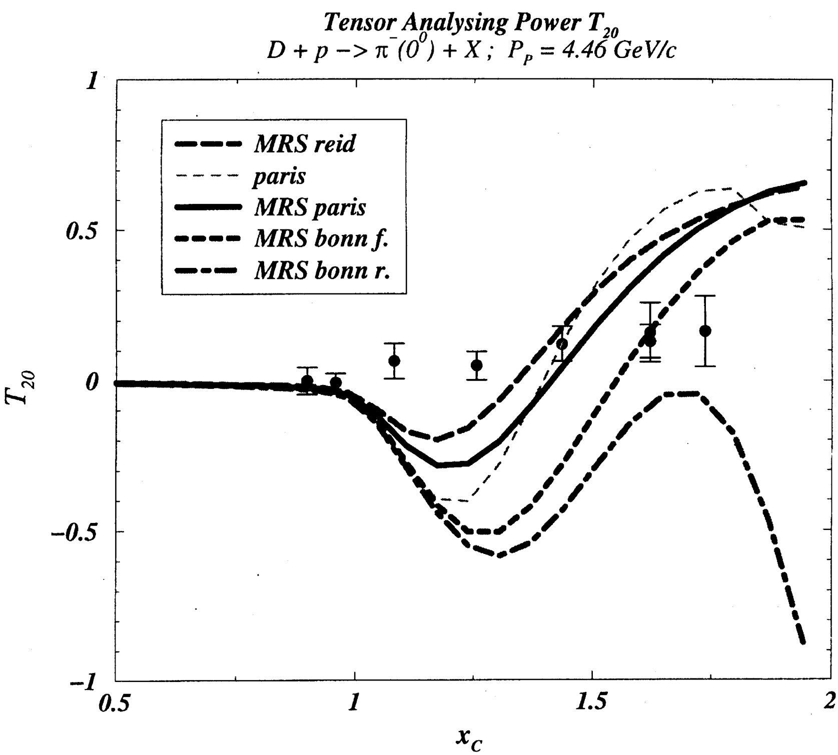


FIG.6. : T_{20} calculated by applying the nonrelativistic DWF's using the minimal relativisation scheme (MRS) [2, 18]. The solid, thick dashed, thin dashed and long-dashed lines correspond to the various DWF forms: the Paris one, the RSC and the two Bonn DWF's, the full Bonn and the relativistic one. The experimental data are taken from [10].

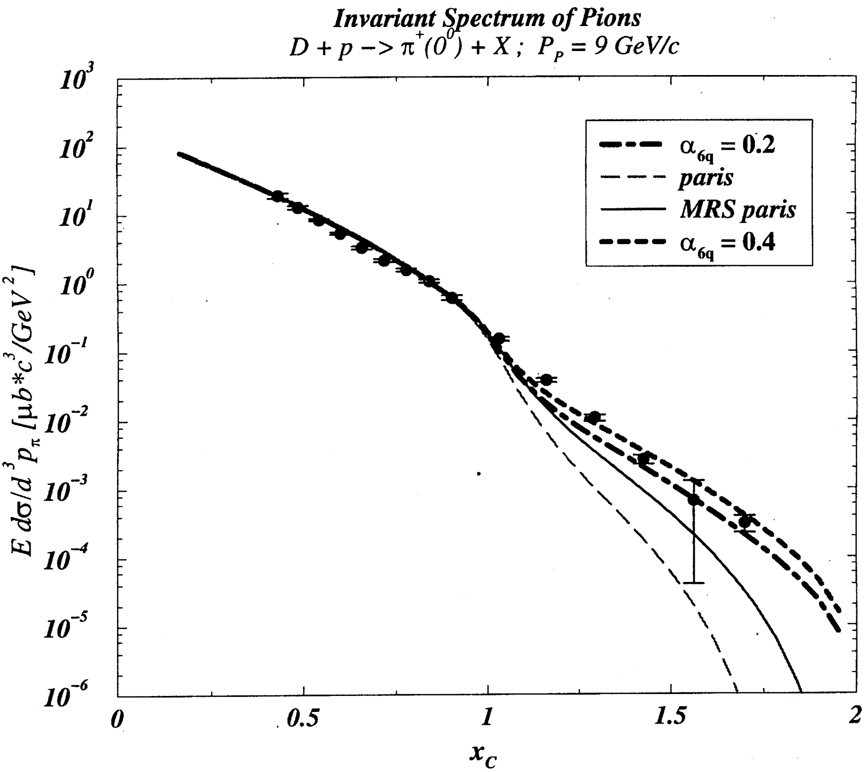


FIG.7. : The invariant pion spectrum calculated within the relativistic impulse approximation by inclusion of the non-nucleon component in the DWF [12, 7], its probability α_{6q} is 0.2 - 0.4 (dot-dashed and dashed curves respectively). One can see the good description of the experimental data [1] at all x_C.

1. It is quite incorrect to use a nonrelativistic deuteron wave function by the analysis of $D-N$ fragmentation to hadrons, in particular pions. Relativistic effects are sizable especially in kinematical region corresponding to short intradeuteron distances or large x. It is seen from the behavior of the inclusive pion spectrum and especially tensor analyzing power T_{20} at large x.

2. At the present time, the state of theory is such that the unique procedure for inclusion of relativistic effects in deuteron has not been yet found. Extreme sensitivity to the different methods of the relativization deuteron wave function is found for T_{20} at $x \geq 1$.

3. The large sensitivity of the inclusive spectrum of pions to the vertex of $NN \rightarrow \pi X$ process can be seen from FIG.1. In the contrast with that the small sensitivity of T_{20} to this vertex is found, what can be seen from FIG.4. This polarization observable is very sensitive to the form of the DWF, what shows FIG.(4-6).

4. The very interesting experimental data about T_{20} showing approximately zero values at $x_C \geq 1$ are not reproduced by theoretical calculus using even different kinds of the relativistic DWF what can indicate to a possible existence of non-nucleon degrees of freedom or principle new mechanism of pion production in the kinematical region forbidden for free $N-N$ scattering.

5. By the fragmentation of deuterons to protons emitted forward the tensor analyzing power T_{20} isn't described by the standard nuclear physics using the nucleon degrees of freedom at $x_C \geq 1.7$ [7]. In the contrary to this T_{20} by the fragmentation $Dp \rightarrow \pi X$ of deuterons to pions can't be described within this physics in the wide interval of x_C, at $x_C \geq 1$. It can be pointed out the more interest to study experimentally and theoretically namely the pion fragmentation of deuteron in order to investigate the deuteron structure at small distances.

References

[1] A.M. Baldin, *Nucl.Phys.* **A434** (1985) 695c.

[2] L.L. Frankfurt and M.I. Strikman, *Phys. Rep.* **76** (1981) 215.

[3] P. Bosted *et al.*, *Phys. Rev. Lett.* **49** (1982) 1380.

[4] Vina Punjabi and Charles F. Perdrisat, in Proc. of the 3rd International Sympozium "DUBNA DEUTERON–95", Dubna, 1996, 304.

[5] M. Lancome *et al.*, *Phys. Lett.* **B101** (1981) 139.

[6] R.V. Reid, *Ann. Phys.* **50** (1968) 411.

[7] G.I. Lykasov, *EPAN* **24** (1993) 59.

[8] V.G. Ableev *et al.*, *Nucl. Phys.* **A393** (1983) 491; **A411** (1983) 541E; *JETP Lett.* **37** (1983), 233; **47** (1988), 279.

[9] V.G. Ableev *et al.*, in Proc. of 7-th Intern. Conf. on Polarization Phenomena in Nuclear Physics (Paris 1990), Vol.1, p.40F.

[10] S.V. Afanasiev *et al.*, *Nucl. Phys.* **A625** (1997) 817; *Phys. Lett.* **B445** (1998) 14; *Preprint JINR E2-98-319*, Dubna, 1998, 10p.

[11] N.S. Amelin and G.I. Lykasov, *Sov.J.Nucl.Phys.* **33** (1981) 100.

[12] A.V. Efremov, A.B. Kaidalov, V.T. Kim, G.I. Lykasov and N.V. Slavin, *Sov.J.Nucl.Phys.* **47** (1988) 868.

[13] V.K. Lukyanov and A.I. Titov, *Sov.J.Part.Nucl.* **10** (1979) 321.

[14] V.V. Burov, V.K. Lukyanov and A.I. Titov, *Sov.J.Part.Nucl.* **15** (1984) 558.

[15] S.G. Bondarenko, V.V. Burov, M. Beyer and S.M. Dorkin, *LANL Preprint nucl-th/9606035.*

[16] W.W. Buck and F. Gross, *Phys. Rev.* **D20** (1979) 2361; *Phys. Lett.* **B63** (1976) 286.

[17] L.P. Kaptari, B. Kaempfer, S.M. Dorkin and S.S. Semikh, *LANL Preprint nucl-th/9612027.*

[18] S.J. Brodsky *et al.*, *Phys. Rev.* **D8** (1973) 4574; J.B. Kogut and D.E. Soper, *Phys. Rev.* **D1** (1970) 2901; S. Weinberg, *Phys. Rev.* **150** (1966) 1313.

[19] L.P. Kaptari, A.Yu. Umnikov, F.C. Khanna and B. Kaempfer, *Phys. Lett.* **B351** *(v.4)* (1995) 400.

[20] V.S. Stavinski, *Sov.J.Part.Nucl.* **10** (1979) 373.

[21] L.A. Kondratyk and V.B. Kopeliovich, *JETF Lett.* **21** (1975) 88.

[22] V.S. Barashenkov and N.V. Slavin, *EPAN* **15** *(v.5)* (1984) 997.

[23] L.Ya. Glozman, V.G. Neudatchin and I.T. Obukhovsky, *Phys. Rev.* **C48** (1993) 389.

[24] A.P. Kobushkin, *J, Phys. G: Nucl. Phys.* **19** (1993) 1993.

[25] A.Yu. Umnikov, *LANL Preprint nucl-th/9605292.*

[26] F. Gross, J.W. VanOrden and Karl Holinde, *Phys. Rev.* **C45** (1992) 2094; **C41** (1990) R1909.

[27] C. Ciofi degli Atti *et al.*, *Phys. Rev.* **C36** (1987) 1208.

[28] J. Benecke *et al.*, *Phys. Rev.* **189** (1969) 2159.

[29] A.M. Baldin *et.al.*, in Proc. Rochester Meeting ADS/OPF, New York, 1971, p.13.

[30] G.A. Leksin, in Proc. IInd ITEP School of Physics, Moscow, 1975, Vol.1, p.90.

[31] A.M. Baldin, *Sov.J.Part.Nucl.* **8** (1977) 429.

[32] V.B. Kopeliovich, *Phys. Rep.* **139** (1986) 52.

[33] A.V. Efremov, *Sov.J.Part.Nucl.* **13** (1982) 254.

[34] E.V. Shuryak, *Sov.J.Nucl.Phys.* **24** (1977) 330.

[35] M.I. Gorenstein, G.M. Zinoviev and V.P. Shelest, *Sov.J.Nucl.Phys.* **26** (1977) 414.

[36] B.Z. Kopeliovich and F. Niedermayer, *Phys.Lett.* **B117** (1982) 101.

[37] D.I. Blokhintsev, *Sov.Phys.JETP* **6** (1958) 995.

[38] G.A.Leksin *et al.*, *Sov. Phys. JETP* **5** (1957) 378.

[39] L.S.Azhgirey *et al.*, *Sov. Phys. JETP* **6** (1958) 911.

[40] G.A. Lobov *et al.*, *JETF Lett.* **23** (1976) 118.

[41] M.V. Tokarev, in The Proceedings of the International Workshop *" Dubna Deuteron – 91 "*, Dubna, 1992.

[42] M.A. Braun and M.V. Tokarev, *EPAN* **22** *(v.6)* (1991) 1237.

[43] L.S. Azhgirey *et al.*, *Preprint JINR P2-87-417*, Dubna, 1987, 16p.

[44] S. Teis *et al.*, *LANL Preprint nucl-th/9609009.*

[45] V.A. Karmanov, *Yad. Fiz.* **18** *(v.5)* (1973) 1133.

[46] V. Dmitriev, O. Sushkov and C. Gaarde, *Nucl.Phys.* **A459** (1986) 503.

[47] B.D. Keister and J.A. Tjon, *Phys. Rev.* **C26** (1982) 578.

[48] L.P. Kaptari, B. Kaempfer, S.M. Dorkin and S.S. Semikh, *LANL Preprint nucl-th/9709071.*

[49] R.G. Arnold, C.E. Carlson and F. Gross, *Phys. Rev.* **C21** (1980) 1426; J. Hornstein and F. Gross, *Phys. Lett.* **B47** (1973) 205; F. Gross, *Phys. Rev.* **C26** (1982) 2203; 2226; **D10** (1974) 223; **186** (1969) 1448; **140** (1965) 410B; **136** (1964) B140.

[50] C. Itzykson, J.B. Zuber, "*Quantum Field Theory*", McGraw-Hill, 1980.

[51] J. Fleisher and J. A. Tjon, *Nucl.Phys.* **B84** (1975) 375.

[52] Yu.L. Dorodnych *et al.*, *Phys. Rev.* **C43** (1991) 2499.

[53] M.A. Franey and W.G. Love, *Phys. Rev.* **C31** (1989) 488; **C24** (1981) 1073.

[54] V.A. Karmanov, *Nucl. Phys.* **A362** (1981) 331.

[55] V.A. Karmanov, *EPAN* **19** (1988) 525 [*Sov. J. Part. Nucl.* **19** (1988) 228].

[56] J. Carbonell and V.A. Karmanov, *Nucl.Phys.* **A581** (1995) 625.

[57] P.L. Chung *et al.*, *Phys. Rev.* **C37** (1988) 2000.

[58] H.J. Melosh, *Phys. Rev.* **D9** (1974) 1095.

Received by Publishing Department
on October 27, 2000.

Илларионов А.Ю., Литвиненко А.Г., Лыкасов Г.И. E1-2000-258
Поляризационные явления во фрагментации дейтронов в пионы

Анализируется фрагментация дейтронов в пионы, испущенные вперед в кинематическую область, запрещенную при столкновении свободных нуклонов. Инклюзивные релятивистски-инвариантные спектры пионов и тензорная анализирующая способность T_{20} исследованы в рамках импульсного приближения с использованием различных волновых функций. Исследовано также влияние P-волны в дейтронной волновой функции. Показано, что инвариантные спектры более чувствительны к выбору амплитуды $NN \to \pi X$-процесса, чем тензорная анализирующая способность T_{20}. Результаты вычислений сравниваются с экспериментальными данными и расчетами, выполненными в релятивистских и нерелятивистских подходах.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2000

Illarionov A.Yu., Litvinenko A.G., Lykasov G.I. E1-2000-258
Polarization Phenomena by Fragmentation of Deuterons to Pions

The fragmentation of deuterons into pions emitted forward at the kinematic region forbidden for the free nucleon-nucleon collision is analyzed. The inclusive relativistic invariant spectrum of pions and tensor analyzing power T_{20} are investigated within the framework of the impulse approximation using the different kinds of the deuteron wave function. The influence of the inclusion of P-wave in the deuteron wave function is studied, too. It is shown that the invariant spectrum is more sensitive to the amplitude of the $NN \to \pi X$ process than the tensor analyzing power T_{20}. Our results are compared with the experimental data and other calculations performed within the both nonrelativistic and relativistic approaches.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 2000

Макет Т.Е.Попеко

Подписано в печать 01.02.2001
Формат 60 × 90/16. Офсетная печать. Уч.-изд. листов 1,9
Тираж 375. Заказ 52481. Цена 2 р. 30 к.

Издательский отдел Объединенного института ядерных исследований
Дубна Московской области