POLARIZATION PHENOMENA IN FRAGMENTATION OF
DEUTERONS TO PIONS AND NON-NUCLEON DEGREES OF
FREEDOM IN THE DEUTERON

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

Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia
† E-mail: Alexei.Illarionov@jinr.ru

Abstract

The fragmentation of deuterons into pions emitted forward in the kinematic region forbidden for free nucleon-nucleon collisions is analyzed. It is shown that the inclusion of the non-nucleon degrees of freedom in a deuteron allows to describe the experimental data about inclusive pion spectrum rather satisfactorily and improves the description of data concerning the deuteron analyzing power $T_{20}$. The experimental data show the positive sign and very small values, less than 0.2, of $T_{20}$ what can’t be reproduced by the calculations ignoring these degrees of freedom.

Let us analyze the inclusive process $Dp \to \pi X$ for the polarized deuteron and pions emitted to forward at initial energies of order few GeV. If the deuteron is tensor analyzed and has $p_{D}^{ZZ}$ component, then the inclusive spectrum of this reaction can be written in the form:

$$\rho_{pD}^{\pi} (p_{D}^{ZZ}) = \rho_{pD}^{\pi} [1 + A_{ZZ} \cdot p_{D}^{ZZ}] ,$$

where $\rho_{pD}^{\pi} \equiv \varepsilon_{\pi} \cdot d\sigma_{pD}^{\pi}/d^{3}p_{\pi}$ is the inclusive spectrum for the case of unpolarized deuterons and $A_{ZZ} = \sqrt{2}T_{20}$ is the tensor analyzing power. They can be written in a fully covariant manner within the Bethe-Salpeter formalism [1]:

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

$$\rho_{pD}^{\pi} \cdot A_{ZZ} = -\frac{1}{(2\pi)^{3}} \int \sqrt{\lambda(p, n)} \sqrt{\lambda(p, D)} \left[ \rho_{pN}^{\pi} \cdot \Phi^{(t)}(|q|) \right] \left( \frac{3\cos^{2}\theta_{q} - 1}{2} \right) \frac{d^{3}q}{E_{q}} ,$$

where $\lambda(p_{1}, p_{2}) \equiv (p_{1}p_{2})^{2} - m_{1}^{2}m_{2}^{2} = \lambda(s_{12}, m_{1}^{2}, m_{2}^{2})/4$ is the flux factor; $p, n$ are the four-momenta of the proton-target and intra-deuteron nucleon, respectively; $\rho_{pN}^{\pi}$ is the relativistic invariant inclusive spectrum of pions produced by interacting the intra-deuteron nucleon with the proton-target. The functions $\Phi^{(u)}(|q|)$ and $\Phi^{(t)}(|q|)$ depends on the relative momentum $q = (n - p')/2$ and contains full information about the structure of deuteron with one on-shell nucleon.

According to [2], the deuteron structure can be described by assuming the possible existence of non-nucleon or quark degrees of freedom. On the other hand, the shape of a high momentum tail of the nucleon distribution in the deuteron can be found from the true Regge asymptotic at $x \to 2$ [3], and the corresponding parameters can be fitted from
a good description of the inclusive proton spectrum in deuteron fragmentation $Dp \rightarrow pX \ [2, \ 3]$. According to [2, 3], one can write the following form for $\Phi^{(u)}(|q|)$:

$$\Phi^{(u)}(|q|) = \frac{E_k/E_q}{2(1-x)} \tilde{\Phi}^{(u)}(|k|) .$$  \hspace{1cm} (4)

where

$$\tilde{\Phi}^{(u)}(|k|) = (1 - \alpha_{2(3q)}) \left[ U^2(|k|) + W^2(|k|) \right] + \alpha_{2(3q)} \frac{8\pi x(1-x)}{E_k} G_{2(3q)}(x, k_\perp) .$$  \hspace{1cm} (5)

The parameter $\alpha_{2(3q)}$ is the probability for a non-nucleon component in the deuteron which is a state of two colorless $(3q)$ systems.

$$G_{2(3q)}(x, k_\perp) = \frac{b^2}{2\pi} \frac{\Gamma(A + B + 2)}{\Gamma(A + 1) \Gamma(B + 1)} x^A (1-x)^B e^{-bk_\perp} .$$  \hspace{1cm} (6)

Fig. 1 presents the invariant pion spectrum calculated within the relativistic impulse approximation including the non-nucleon component in the DWF [2, 3]. One can see a good description of the experimental data [4] at all cumulative variable $x_C$.

However in some sense, the information contained in $T_{20}$ from $Dp \rightarrow pX$ and $Dp \rightarrow \pi X$ processes is redundant, because the main ingredient by analyzing these reactions within the impulse approximation are the same deuteron properties. Therefore calculation of the tensor analyzing power including non-nucleon degrees of freedom in fragmentation of deuteron to pions can give us a new independent information concerning the deuteron structure at small $N-N$ distances. Actually, in [3] a form of $\tilde{\Phi}^{(u)}(|k|)$ has been constructed only. However, to calculate $T_{20}$ it is not enough, the corresponding orbital waves have to be known. Let us assume, the non-nucleon degrees of freedom result in a main contribution to the $S$- and $D$-waves of the DWF. Constructing new forms of these waves by including the non-nucleon degrees of freedom we have to require that the square of the new DWF has to be equal to the one determined by the Eq.(5). Introducing a mixing parameter $\alpha = (\pi/4)a$ one can find the forms of new $S$- and $D$-waves as the following:

$$\tilde{U}(|k|) = \sqrt{1 - \alpha_{2(3q)}} U(|k|) + \cos(\alpha)\Delta(|k|) ;$$  \hspace{1cm} (7)

$$\tilde{W}(|k|) = \sqrt{1 - \alpha_{2(3q)}} W(|k|) + \sin(\alpha)\Delta(|k|) ,$$  \hspace{1cm} (8)
where the function $\Delta$ has been obtained from the equation:

$$\Phi^{(u)}(|k|) = U^2(|k|) + W^2(|k|).$$

Fig. 2 presents the analyzing power $T_{20}$ calculated by using the functions $U, W$ including the non-nucleon components in the DWF, according to [2, 3]. It is shown from Fig. 2 the inclusion of non-nucleon components in the DWF improves the description of the experimental data about $T_{20}$ at $x_C > 1$. The value of the parameter entering the Eqs. (6, 8) $a = 2.3$ results in an optimal description of this observable.

Main results can be summarized as the following. Very interesting experimental data on $T_{20}$ showing approximately zero values at $x_C \geq 1$ are not reproduced by a theoretical calculus using even different kinds of the relativistic DWF [1]. This may indicate a possible existence of non-nucleon degrees of freedom or basically new mechanism of pion production in the kinematic region forbidden for free $N-N$ scattering.

The inclusion of the non-nucleon degrees of freedom within the approach suggested in [3, 2] allows us to describe experimental data about the inclusive pion spectrum at all the values of $x_C$ rather well, Fig. 1, and improve the description of data [5] concerning the analyzing power $T_{20}$ in the fragmentation of deuteron to pions, Fig. 2.

The support from RFFI grant N99-02-17727 is gratefully acknowledged by authors.

References

[1] A.Yu. Illarionov, A.G. Litvinenko, G.I. Lykasov, Preprint JINR E1-2000-258, P2-2001-204; hep-ph/0012290, hep-ph/0007358.

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

[3] A.V. Efremov et al, Sov. J. Nucl. Phys. 47, 868 (1988).

[4] A.M. Baldin, Nucl. Phys. A434, 695 (1985).

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