DEUTERON STRUCTURE AT SMALL $N - N$ DISTANCES FROM INELASTIC $e - D$ AND $p - D$ REACTIONS

A.Yu. Illarionov$^{1,\ast}$ and G.I. Lykasov$^{1,\dagger}$

$^{1}$141980, JINR, Dubna, Moscow region, Russia

The outline of the presentation is as follows:
I. Nucleon Distribution in the Deuteron from $e - D$ and $p - D$ Processes.
II. Quark Distribution in Deuteron from its Fragmentation to Pions and Deep Inelastic $e - D$ scattering.
III. Difference of These Two Distributions and Its Possible Understanding.
IV. Conclusions.

1. NUCLEON DISTRIBUTION IN THE DEUTERON FROM $e - D$ AND $p - D$ PROCESSES

Over the past decades the study of the short range structure of atomic nuclei attracts attention of theorists and experimentalists. In the more conventional picture, the basic degrees of freedom are point-like non-relativistic nucleons. The distribution of these nucleons in nuclei can be calculated within the many-body approach by introducing the phenomenological Hamiltonian fitted to the nucleon-nucleon scattering data and to the properties of the few-nucleon bound states. The nucleon distribution in a deuteron or the square of the deuteron wave function (DWF) magnitude $n_D(k) = |\Psi_D(k)|^2$ can be obtained by solving the Schrödinger equation for DWF with different $N - N$ potentials.

Experimentally $\Psi_D(k)$ is extracted usually from the elastic $e - D$ scattering and there is a satisfactory theoretical description of these data at small and moderate nucleon momenta $k$. This information can be obtained also in experiments about the deuteron stripping $Dp \to pX$ or semi-inclusive $eD \to e'pX$ processes. The data about $|\Psi_D(k)|^2$ obtained from the experiments on $e - D$ scattering and $Dp \to pX$ stripping are presented in Fig. 1.

The solid and dashed lines correspond to the calculations performed within the impulse approximation. As it has been shown in [2], the discrepancy between this lines in Fig. 1 and experimental points at $0.3<$ (GeV/c)$< k < 0.45$ (GeV/c) can be due to the secondary interactions, namely the contribution of the so called triangle graphs with the virtual exchange meson. Therefore this difference can not be interpreted as a contribution of the non nucleon degrees of freedom. However the high momentum tail of nucleon distribution in a deuteron, e.g., $|\Psi_D(k)|^2$ at $k > 0.65$ (GeV/c) extracted from the experimental data about $Dp \to pX$ stripping [4] can not be described by using the standard degrees of freedom in a deuteron, point-like non-relativistic nucleons. There are models including a possible $2(3q)$ admixture in the DWF, see for example [3], or non-nucleon degrees of freedom as like as $NN^*, \Delta\Delta$, etc., [2] [3], which allow to describe the experimental data about $Dp \to pX$ stripping at $k > 0.65$ (GeV/c).

The Fig. 1 shows the identity for $|\Psi_D(k)|^2$ extracted from $e - D$ scattering at not large $Q^2$ [7] and $Dp \to pX$ stripping data [4]. However the SLAC data allow to extract the nucleon distribution in a deuteron at $k \leq 0.75$ (GeV/c). Only experimental data about the deuteron stripping $Dp \to pX$ [4] result in an information about the high momentum tail of this distribution.

*Electronic address: Alexei.Illarionov@jinr.ru URL: http://thsun1.jinr.ru/~illar
†Electronic address: lykasov@nusun.jinr.ru
The additional information about the deuteron structure at small $N-N$ distances can be obtained from the analysis of the fragmentation processes of a deuteron to pions emitted, mainly, backward, e.g., $Dp \to \pi X$ at large pion momenta or big values of the light-front variable

$$z = \frac{p_{\pi}p_{D}}{p_{p}p_{D}} > 1.$$ 

where $p_{\pi}, p_{D}$ and $p_{p}$ are four-momenta of pion, moving initial deuteron and proton-target at rest. For this type of the fragmentation process the inclusive pion spectrum $\rho_{Dp \to \pi X}(z)$ at large $z$ can give us information about the valence quark distribution in a deuteron $q_{D}(z)$ because at $z \to 2$:

$$\rho_{Dp \to \pi X}(z) \propto q_{D}(z).$$

In Fig. 2 the pion inclusive spectrum $\rho_{Dp \to \pi X}(z)$ is presented. This figure shows the main contribution to the spectrum at $z > 1.6$ is coming from the high momentum tail of the nucleon like objects in a deuteron $G_{2}(3q)$. This function $G_{2}(3q)$ effectively includes the Fock columns $NN^{*}, \Delta\Delta, \pi NN, \ldots$ of the deuteron state $[3, 4]$ and $[12]$. According to this approach the valence quark distribution in a deuteron at $z > 1$, for example $u_{D}(z)$ has the following form:

$$u_{D}(z) = \frac{C_{uD}}{\sqrt{z}}(2-z)^{4.5},$$

where $C_{uD}$ is the normalized constant. On the other hand, the quark counting rule results in at large $z$ the following $[10]$:

$$u_{D}^{q.c.}(z) \sim \frac{1}{\sqrt{z}}(2-z)^{10}.$$  

Really, the $z$-behavior for $q_{D}(z)$ given by Eq.(2) is predicted by the perturbative QCD $[10]$. This $z$-dependence of $q_{D}(z)$ or the deuteron structure function $F_{2D}(z)$ at $z > 1$ has coincided with the measurements of the BCDMS $[13]$ and CCFR $[14]$ (exp. E770) collaborations, Fig. 3.

**Q U E S T I O N**

Why is there a big difference between quark distribution in a deuteron at large $z$ obtained from the deuteron fragmentation to pions and from deep inelastic scattering?

It can be understood within the quark model suggested in $[12]$.

**3. DIFFERENCE OF THESE TWO DISTRIBUTIONS AND ITS POSSIBLE UNDERSTANDING**

According to $[12]$, one can construct the quark distribution in a deuteron at $z > 1$ calculating the relativistic invariant phase space volume available to a quark when the quark distributions of
different nucleons overlap. Let us shortly present a scheme of this approach. The quark distribution in a nucleon can be written in the following form:

$$q_N(z) \sim z^{a_N}(1 - z)^{b_N},$$

(3)

where $a_N, b_N$ are some values which will be discussed little bit later. Calculating the overlap of the quark distributions of different nucleons, according to [12], one can get the quark distribution in the overlapping region which at $z > 1$ coincides with $q_D(z)$,

$$q_D(z) \sim z^{a_N}(2 - z)^{2b_N + 2 + a_N},$$

(4)

In principle, the $z$-dependence of distributions of the constituent quarks in nucleon participating at soft hadron processes is different from distributions of current valence quarks interacting with lepton beam in deep inelastic lepton-nucleon scattering (DIS). This difference is determined mainly by the value of $b_N$. So, for current quarks $b_N \simeq 3.5 \div 4.5$ at $Q^2 = Q_{0}^2 \simeq 2. \div 3 (\text{GeV}/c)^2$, according to experimental data on DIS, but the constituent quarks have to have the true Regge asymptotic at large $z$ [15] and for them $b_N = \alpha_R(0) - 2\alpha_B(0) = 3/2$; here $\alpha_R(0)$ and $\alpha_B(0)$ are the intercepts of meson and average baryon Regge trajectory $\alpha_B(0) = -0.5$ and $\alpha_R(0) = 1/2$. The value of $a_N$ determines the quark distribution in a nucleon at $z \to 0$ and $a_N = -\alpha_R(0) = -0.5$ for the constituent and current quark except the region of too small $x$ corresponding to last HERMES data.

Therefore inputting the different values of $b_N$ to the Eq. (4) we get the distribution for constituent quarks in a deuteron at $z > 1$:

$$q_{D}^{\text{cons}}(z) \sim \frac{1}{\sqrt{z}}(2 - z)^{4.5},$$

(5)

and current valence quarks in a deuteron at $z > 1$:

$$q_{D}^{\text{cur}}(z) \sim \frac{1}{\sqrt{z}}(2 - z)^{8.5 \div 9.5}.$$ 

(6)

Actually, the $Q^2$ evolution of the current quark distributions in a nucleon using the Altarelli-Parisi-Dokshicer-Gribov-Lipatov (DGLAP) equation [16, 17] has to be included by more careful calculation of $q_{D}^{\text{cur}}(z)$.

4. CONCLUSIONS

I. One can extract the nucleon distribution in a deuteron over momentum $k$ from experimental data about $e - D$ scattering and $Dp \to pX$ stripping within the impulse approximation at small $k < 0.25(\text{GeV}/c)$ only.

II. This procedure is incorrect at larger momenta up to 0.5(\text{GeV}/c) because the secondary graphs have to be included.

III. The conventional deuteron wave function of type, for example the Paris one, doesn’t describe the high momentum tail of protons in the deuteron stripping $Dp \to pX$ at $k > 0.5(\text{GeV}/c)$.

IV. Additional information about the deuteron structure at small $N - N$ distances can be obtained from the deuteron fragmentation to pions.

V. The quark distribution in a deuteron describing the inclusive pion spectrum in the process $Dp \to \pi X$ at $z > 1$ is different from the analogous distribution describing the DIS $e - D$ scattering at $x = Q^2/(2m\nu) > 1$.
VI. This difference can be understood within the approach which is based on the calculation of the relativistic invariant phase space volume available to a quark when the quark distributions of different nucleons overlap.

VII. The constituent quarks participate at the deuteron fragmentation to protons or pions, on the other hand lepton interacts with current quarks by the DIS $e - D$ scattering. They have completely different $x$-distributions in a nucleon especially at large $x$. It leads to the different distributions of these sorts of quarks in a deuteron.

Acknowledgments

This work has been supported by RFFI grants N 99-02-17727.

[1] V.G. Ableev et al., Pis'ma Zh.Eksp.Teor.Fiz. 37, 196 (1983).
[2] G.I. Lykasov, EPAN 24, 59 (1993).
[3] A.V. Efremov, A.B. Kaidalov, V.T. Kim, G.I. Lykasov and N.V. Slavin, Sov.J.Nucl.Phys. 47, 868 (1988).
[4] A.V. Efremov, A.B. Kaidalov, G.I. Lykasov and N.V. Slavin, Sov.J.Nucl.Phys. 57, 874 (1994).
[5] V.V. Burov, V.K. Lukyanov and A.I. Titov, Sov.J.Part.Phys. 15, 558 (1984).
[6] A.P. Kobushkin and L. Vizireva, J.Phys.G: Nucl.Phys. 8, 893 (1982).
[7] P. Bosted et al., Phys.Rev.Lett. 49, 1380 (1982); V.L. Agranovich, V.S. Kuz’menko, and P.V. Sorokin, Sov.J.Nucl.Phys. 25(5), 595 (1977).
[8] V.S. Stavinski, Sov.J.Part.Nucl. 10, 373 (1979).
[9] A.Yu. Illarionov et al., Czech.J.Phys. 51 (2001), [hep-ph/0007358], [hep-ph/0012290].
[10] L.L. Frankfurt and M.I. Strikman, Phys. Rep. 76, 215 (1981); 160, 236 (1988).
[11] A.M. Baldin, Nucl.Phys. A434, 695c (1985).
[12] O. Benhar, S. Fantoni, G.I. Lykasov and N.V. Slavin, Phys.Rev. C55, 244 (1997); C57, 1532 (1998).
[13] A.C. Benvenuti et al., (BCDMS Collaboration), Z.Phys. C63, 29 (1994).
[14] M. Vakili et al., (CCFR Collaboration), Phys.Rev. D61, 052003 (2000).
[15] A.B. Kaidalov, Phys.Lett. B116, 459 (1982); JETP Lett. 32, 494 (1980).
[16] V.N. Gribov and L.N. Lipatov, Sov.J.Nucl.Phys. 15, 438, 675 (1972); L.N. Lipatov, Sov.J.Nucl.Phys. 20, 94 (1974).
[17] G. Altarelli and G. Parisi, Nucl.Phys. B126, 298 (1977).
FIG. 1: The nucleon distribution in the deuteron, $n_D(k) = |\Psi_D(k)|^2$ extracted from the $e - D$ scattering and $Dp \to pX$ stripping data [V.G. Ableev et al., Pis'ma Zh.Eksp.Teor.Fiz. 37, 196 (1983)]. The solid and dashed lines correspond to the calculations performed within the impulse approximation. The dash-dotted line show the effect of including of the non-nucleon component in the DWF [G.I. Lykasov, EPAN 24, 59 (1993); A.V. Efremov et al., Sov.J.Nucl.Phys. 47, 868 (1988)].
FIG. 2: The invariant spectrum of the backward pions in the deuteron fragmentation reaction via the cumulative variable \( x_C \sim z = (\pi D)/(pD) > 1 \), calculated in the relativistic impulse approximation with including of the non-nucleon component in the DWF [9] A.Yu. Illarionov et al., Czech.J.Phys. 51 (2001), hep-ph/0007358, hep-ph/0012290; its probability \( \alpha_{2(3q)} \) is 2% - 4% (dot-dashed and dashed curves, respectively). The long-dashed and solid lines correspond to the calculation using nonrelativistic DWF and DWF obtained by the minimal relativization scheme (MRS) [10] L.L. Frankfurt and M.I. Strikman, Phys.Rep. 160, 236 (1988), respectively. The calculated results are compared with the experimental data from [11] A.M. Baldin, Nucl.Phys. A434, 695c (1985) for a the projectile proton momentum of \( P_p = 9 \) GeV/c. One can see the good description of the experimental data for all cumulative \( x_C \).
FIG. 3: This $x$-dependence of the structure function $F^A_2(x,Q^2)$ at $x > 1$ from the deep-inelastic scattering (DIS). The experimental data are taken from [13] (BCDMS muon DIS experiment) and [14] (CCFR E770 neutrino DIS experiment).