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ON DEUTERON STRUCTURE AT SMALL $N-N$ DISTANCES[1]

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The nucleon momentum distributions in the deuteron, extracted from the reaction $Dp \to p'X$ at forward proton emission and eD-inelastic scattering, actually coincide with each other. On the other hand, the quark distribution in a deuteron describing the inclusive pion spectrum of the deuteron fragmentation process in the kinematic region forbidden for free nucleon-nucleon collisions is different from the analogous distribution describing the eD-DIS at the Bjorken $x_{Bj} > 1$. It is shown that 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.

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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 $Dp \to p'X$ or semi-inclusive $eD \to e'pX$ processes [1]. The data about $|\Psi_D(k)|^2$ obtained from the experiments on $e-D$ scattering and $Dp \to p'X$ stripping are presented in Fig. 1.

The solid line corresponds to the calculation performed within the impulse approximation. As it has been shown in [2], the discrepancy between these lines in Fig. 1 and experimental

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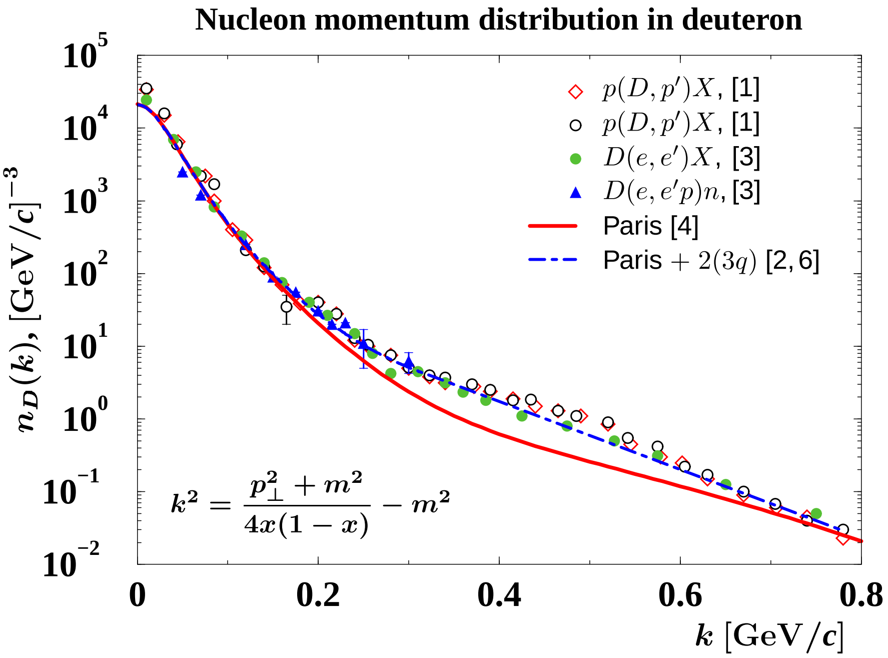

Fig. 1. The nucleon distribution in the deuteron, $n_D(k) = |\Psi_D(k)|^2$ extracted from the $e-D$ scattering [3] and $Dp \to p'X$ stripping data [1]. The solid line corresponds to the calculation performed within the impulse approximation [4]. The dash-dotted curve shows the effect of including of the non-nucleonic component in the DWF [2,6].

points at 0.3 $[\mathrm{GeV}/c] < k < 0.45$ $[\mathrm{GeV}/c]$ 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 $k > 0.6$ $[\mathrm{GeV}/c]$ extracted from the experimental data about $Dp \to p'X$ stripping [1] can not be described by using the standard degrees of freedom in a deuteron, i.e. point-like non-relativistic nucleons. There are models including a possible $2(3q)$ admixture in the DWF, see for example [7–9], or non-nucleon degrees of freedom as like as $NN^\star, \Delta\Delta$, etc. [2,6], which allow one to describe the experimental data about $Dp \to p'X$ stripping at $k > 0.6$ $[\mathrm{GeV}/c]$.

Fig. 1 shows the identity for $|\Psi_D(k)|^2$ extracted from $e - D$ scattering at not too large Q^2 [3] and $Dp \to p'X$ stripping data [1]. However the SLAC data allow us to extract the nucleon distribution in a deuteron at $k \leq 0.75$ $[\mathrm{GeV}/c]$. Only experimental data about the deuteron stripping $Dp \to p'X$ [1] result in an information about the high momentum tail of this distribution.

2 Quark distribution in a deuteron from its fragmentation to pions

Additional information about the deuteron structure at small $N - N$ distances can be obtained from the analysis of the fragmentation processes of a deuteron where pions are emitted, mainly when in backward direction, e.g. $Dp \to \pi X$ at large pion momenta or big values of the light-front variable

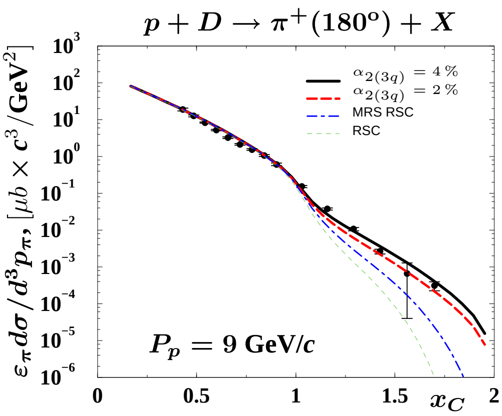

Fig. 2. The invariant spectrum of the backward pions in the deuteron fragmentation reaction via the cumulative variable [10] $x_C \sim z$, calculated in the relativistic impulse approximation where non-nucleonic components in the DWF [2, 6] have been included [11, 12]; its probability $\alpha_{2(3q)}$ is $0.02 \div 0.04$ (long-dashed and solid curves, respectively). One can have a good description of the data [14] for all x_C. The dot-dashed line corresponds to the Reid DWF [5] obtained by the minimal relativistic scheme (MRS) [16].

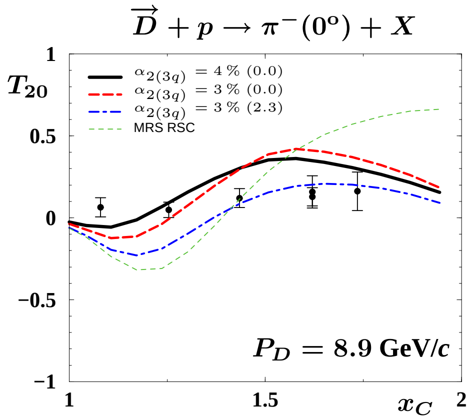

Fig. 3. The tensor analyzing power T_{20} calculated within the relativistic impulse approximation allowing for non-nucleonic components in the DWF [11, 12]. The solid and long-dashed lines represent the calculations with the mixing parameter $a = 0.0$ and the probability $\alpha_{2(3q)} = 4\,\%$, $3\,\%$, respectively. The dot-dashed line corresponds to the calculation with the mixing parameter $a = 2.3$ [13], which gives the curve closest to the data [15] at $x_C \geq 1.5$. The thin dashed curve corresponds to the Reid DWF [5] obtained by the MRS [16].

$$z = (p_\pi p_D)/(p_p p_D) > 1\ , \tag{1}$$

where p_π, p_D and p_p are four-momenta of pion, moving initial deuteron and proton-target at rest, respectively. 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 $z \to 2$:

$$\rho_{Dp\to\pi X}(z) \propto q_D(z)\ . \tag{2}$$

In Fig. 2 the pion inclusive spectrum $\rho_{Dp\to\pi X}(z)$ is presented [11, 12], while Fig. 3 shows the analyzing power T_{20} [13]. It is evident from this figures that the the inclusion of the non-nucleonic degrees of freedom in a deuteron results in a satisfactory description of the data for the inclusive pion spectrum and improves the description of the data about T_{20}. It can be seen that the main contribution at $z > 1.5$ 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 $NN^\star, \Delta\Delta, \pi NN, ...$ of the deuteron state [2, 6, 17]. According to this approach the valence quark distribution in a deuteron at $z > 1$, for example $u_D(z)$ has the following form:

$$u_D(z) = \frac{C_{uD}}{\sqrt{z}}(2 - z)^{4.5}\ , \tag{3}$$

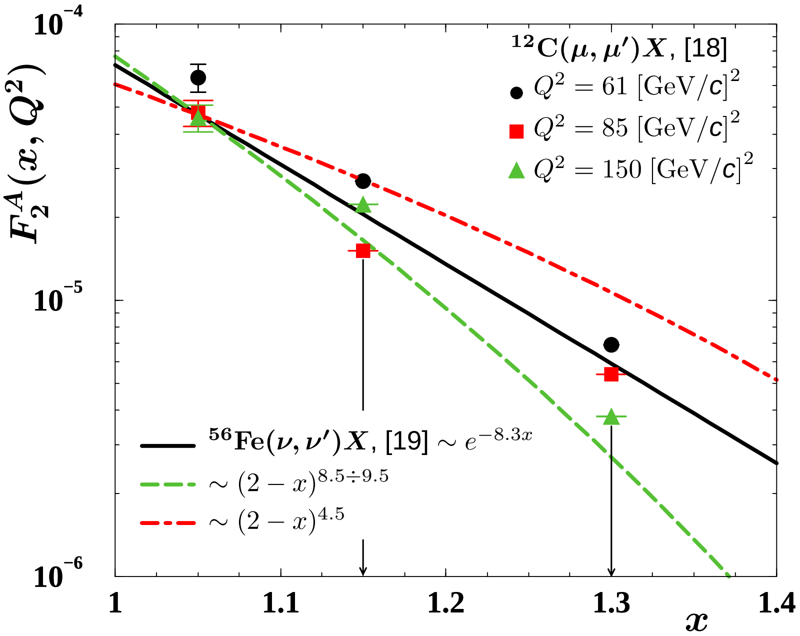

Fig. 4. The x-dependence of the structure function $F_2^A(x, Q^2)$ at $x > 1$ from the deep-inelastic scattering (DIS). The experimental data are taken from [18] (muon DIS) and [19] (neutrino DIS).

where C_{uD} is the normalization constant. On the other hand, at large z the quark counting rule results in

$$u_D^{q.c.}(z) \sim \frac{1}{\sqrt{z}}(2-z)^{10} \, , \tag{4}$$

following ref. [16]. Really, the z-behavior for $q_D(z)$ given by Eq.(4) is predicted by the perturbative QCD [16]. This z-dependence of $q_D(z)$ or the deuteron structure function $F_2^D(z)$ at $z > 1$ has coincided with the measurements of the BCDMS [18] and CCFR [19] (exp. E770) collaborations, as shown in Fig. 4.

The question arises, why there is a big difference between quark distribution in a deuteron at large z obtained from the deuteron fragmentation to pions and from DIS?

It can be understood within the quark model suggested in ref. [17].

3 The difference of the two distributions and its possible explanation [20]

According to ref. [17], 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:

$$q_N(z) \sim z^{a_N}(1-z)^{b_N} \, , \tag{5}$$

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 ref. [17] one can get the quark distribution in the overlapping region which at $z > 1$ coincides with $q_D(z)$,

$$q_D(z) \sim z^{a_N}(2-z)^{2b_N+2+a_N} \ . \tag{6}$$

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 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 $Q^2 = Q_0^2 \simeq 2 \div 3$ $[\mathrm{GeV}/c]^2$, extracted according to experimental data on DIS. But the constituent quarks have to have the true Regge asymptotics at large z [21] 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 the last HERMES data.

Therefore, using the different values of b_N to the Eq.(6) we get the distribution for constituent quarks in a deuteron at $z > 1$:

$$q_D^{\text{cons}}(z) \sim \frac{1}{\sqrt{z}}(2-z)^{4.5} \tag{7}$$

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

$$q_D^{\text{cur}}(z) \sim \frac{1}{\sqrt{z}}(2-z)^{8.5\div 9.5} \tag{8}$$

Actually, the Q^2 evolution of the current quark distributions in a nucleon using the Dokshicer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) equation [22, 23] has to be included by more careful calculation of $q_D^{\text{cur}}(z)$.

4 Conclusions

I. The nucleon distribution in a deuteron over momentum k can be extracted from experimental data about $e-D$ scattering and $Dp \to p'X$ stripping within the impulse approximation at small $k < 0.25$ $[\mathrm{GeV}/c]$ only.

II. This procedure is incorrect at larger momenta up to 0.5 $[\mathrm{GeV}/c]$ because the secondary graphs have to be included.

III. The conventional deuteron wave function, for example of Paris or Reid types, does not describe the high momentum tail of protons in the deuteron stripping $Dp \to p'X$ at $k > 0.5[\mathrm{GeV}/c]$.

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 $e-D$ DIS 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 $e - D$ DIS. 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.

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