Search for transition region in exclusive reactions with high p_T at COSY energies

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The structure of the lightest nuclei at short distances ($r_{NN} < 0.5$ fm) or for high relative momenta ($q > 1/r_{NN} \sim 0.4$ GeV/c) constitutes a fundamental problem in nuclear physics. Experimental investigation employ processes where the momentum transfer to the nucleus is large ($Q \sim 1$ GeV/c). One of the most interesting questions is the following: at which values of the Mandelstam variables s and t (or, more precisely, relative momenta q of nucleons in nuclei) does the transition region from the meson-baryon to the quark-gluon picture of nuclei set in? A possible signature for this transition is given by the constituent counting rules (CCR) [1]. According to dimensional scaling [1] the differential cross section of a binary reaction $AB \to CD$ at high enough incident energy can be parameterized for a given c.m.s. scattering angle θ_{cm} as

$$\frac{d\sigma}{dt}(AB \to CD) = \frac{f(t/s)}{s^{n-2}}, \qquad (1)$$

where $n = N_A + N_B + N_C + N_D$ and N_i is the minimum number of point-like constituents in the ith hadron (for a lepton one has $N_l = 1$), $f(s/t)$ is a function of θ_{cm}.

The CCR follows from perturbative QCD (pQCD) [2]. Recently these rules were also obtained within nonperturbative theories which are dual to QCD [3]. Existing high energy data for many measured hard scattering processes with free hadrons appear to be consistent with the CCR [4]. In the nuclei sector only electromagnetic processes and only on the deuteron were found to be compatible with the CCR. So, the deuteron photodisintegration reaction $\gamma d \to pn$ follows the s^{-11} scaling behaviour in the SLAC data [5] at energies $E_\gamma > 0.8 - 2.8$ GeV at $\theta_{cm} \approx 90°$ and in the Jlab data at photon energy $E = 1 - 5$ GeV and high transversal momenta $p_T > 1.1$ GeV/c (see [7, 8] and references therein). Meson-exchange models fail to explain the $\gamma d \to pn$ data at $E_\gamma > 1$ GeV (see, for example, [6]). Recent models based on quark degrees of freedom have become quite successful in describing these data [9].

The pQCD (and, consequently, the scaling behaviour within the pQCD) is expected to be valid at very high transferred momenta which are not yet reached in existing data for nucleon and deuteron form factors [10]. From this point of view the origin of the observed scaling behaviour in the reactions with the deuteron at moderate transferred momenta is unclear. On the other side, in these reactions the 3-momentum transfer $Q = 1 - 5$ GeV/c is large enough to probe very short distances between nucleons in nuclei, $r_{NN} \sim 1/Q < 0.3\,fm$, where $0.3\,fm$ is a size of a constituent quark. One may expect that nucleons loose their separate identity in this overlapping region and, therefore, multi-quark components of a nucleus can be probed in these reactions. In order to get more insight into the underlying dynamics of the scaling behaviour new data are necessary, in particular, for hadron-nuclei interactions.

Very recently it was found [11] that the cross section of the reaction $dd \to {}^3Hen$ (and $dd \to {}^3Hp$), measured in an old experiment at SATURNE [12], also perfectly demonstrates the scaling behaviour s^{-22} at transversal momenta $p_T \sim 0.6 - 0.9$ GeV/c (Fig.1).

In Fig. 1 we show the experimental data from Ref.[12] obtained at SATURNE at beam energies 0.3 – 1.25 GeV for the maximum measured scattering angle $\theta_{cm} = 60°$. Shown on the upper scale is the relative momentum q_{pn} in the deuteron for the one nucleon exchange (ONE) diagram. One can see that at beam energies $0.5 - 1.25$ GeV the data perfectly follow the s^{-22} dependence. (In this reaction $n = 6+6+9+3 = 24$). In Fig. 1 the dashed curve represents the s^{-22} dependence with arbitrary normalization fitted on the data with $\chi^2_{n.d.f.} = 1.18$. *Up to now, the reaction $dd \to {}^3Hen$ (${}^3Hp$) is only purely hadronic process which involves the deuteron and ${}^3He({}^3H)$ nuclei and is found to follow the CCR.* At $\theta_{cm} = 90°$ the ONE mechanism involves higher momenta $q_{pn} = 0.7$ - 1.1 GeV/c and $q_{Nd} = 0.80 – 1.22$ GeV/c for the same beam energies 0.5 – 1.25 GeV. Therefore, continuation of measurements up to $\theta_{cm} = 90°$ is very desirable to confirm the observed s^{-22} behaviour.

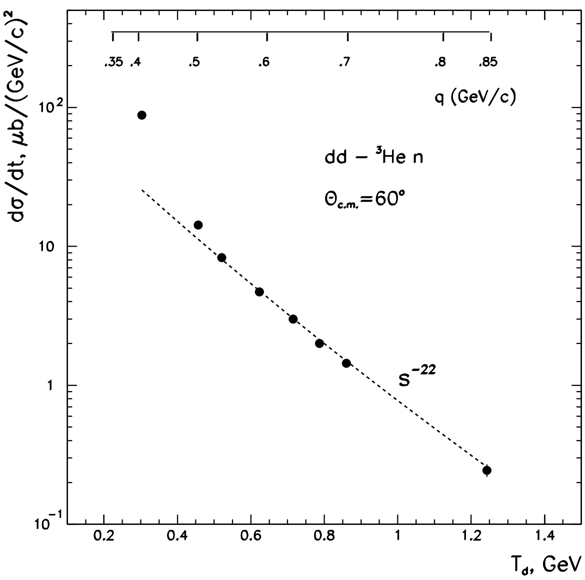

Fig. 1: The differential cross section of the $d + d \to {}^3He + n$ and $d + d \to {}^3H + p$ reactions at $\theta_{c.m.} = 60^o$ (•) [12]. The dashed curve gives the s^{-22} behaviour.

An important task addressed to experiment is to search for similar beaviour of others exclusive reactions with the lightest nuclei at large p_T (> 0.6 GeV/c). As shown in Ref. [11], the cross section of the reaction $pd \to pd$ demonstrates $\sim s^{-16}$ behaviour at $T_p = 1 - 2.5$ GeV and $\theta_{cm} = 120° – 130°$. At these scattering angles a maximum contribution of the three-body forces is expected. The χ^2-parameter is too large, however, for the $pd \to pd$ reaction, probably, because of the data were obtained in various experiments. Others interesting reactions are the following: $d^3He \to {}^4He\,p$, $dd \to dd$, $pd \to {}^3H\pi^+$, $pd \to {}^3He\eta$, $dd \to {}^4He\eta$, $pp \to d\rho^+$, $pp \to \{pp\}({}^1S_0)\gamma$. The last two of them, $pp \to d\rho^+$, $pp \to \{pp\}({}^1S_0)\gamma$, are nontrivial generalization of the $\gamma d \to pn$ reaction.

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