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SCALING ONSET IN THE REACTIONS $dd \to p^3H$ AND $pd \to pd$ IN THE GEV REGION

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Abstract

Constituent Counting Rules (CCR) can give a definite signal for transition from meson-baryon to valence quarks level in nuclear structure. The CCR behaviour of the reactions $\gamma d \to pn$, $dd \to {}^3Hp$ and $pd \to pd$ is considered.

1 Introduction

The main goal of many experiments on deep inelastic nuclear reactions at high transferred momenta was to search for dense fluctuations of nuclear matter (multiquark configurations). Very interesting features were observed in inclusive spectra of these reactions which can be interpreted as a manifestation of "drops" of the quark phase in nuclei (see for review Ref. [1]). However, a quantitative theory of this phenomena is still not available and, therefore, other independent signals for the transition region are necessary.

A definite signature for transition to the valence quark region is given by the constituent counting rules (CCR) [2, 3]. According to the dimensional scaling [2, 3] the differential cross section of a binary reaction $AB \to CD$ at high enough energy $\sqrt{s}$ and transferred momentum $|t|$ can be parameterized for a given c.m.s. scattering angle θ_{cm} as

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

where $n = N_A + N_B + N_C + N_D$ and N_i is the minimum number of point-like constituents in the *i-th hadron* (for a lepton and gamma one has $N_l = 1$), $f(s/t)$ is a function of θ_{cm}. The CCR follows from a self-similarity hypothesis [2] and perturbative QCD (pQCD) [3].

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2 Existing CCR Data on Nuclear Reactions

High energy data for many hard processes with free baryons and mesons appear to be consistent with the CCR [4]. CCR properties were also observed in electromagnetic interactions with the deuteron. So, the reaction $\gamma d \to pn$ follows the s^{-11} scaling behaviour at photon energies $E_\gamma = 1 - 4$ GeV and high transversal momenta $p_T > 1.1$ GeV/c corresponding to large scattering angles $\theta_{cm} \sim 90°$ (see Refs. [5, 6] and references therein). Meson-exchange models fail to explain the $\gamma d \to pn$ data at $E_\gamma > 1$ GeV, and therefore several nonperturbative theoretical models were suggested (see Ref. [7] and references therein).

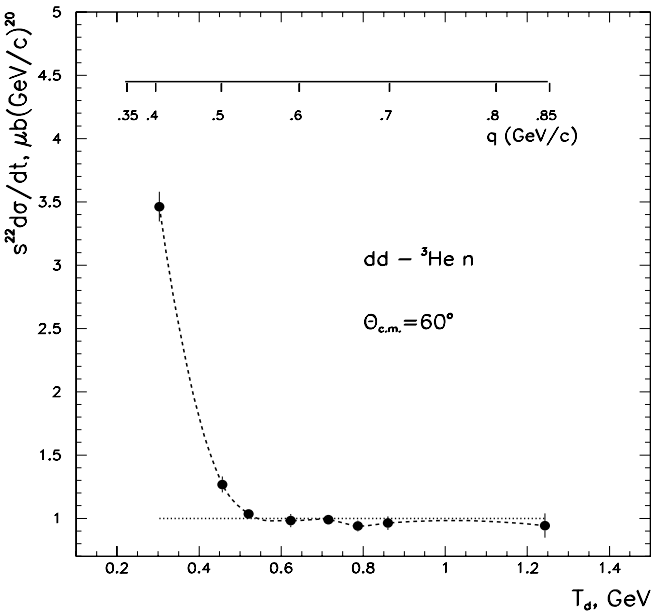

Figure 1: The cross section of the reaction $dd \to {}^3Hp$ [9] multiplied by s^{22} versus the beam energy (T_d) and internal momentum in the deuteron (q).

During last two decades, in a nuclei sector only electromagnetic processes and only on the deuteron were considered to be compatible with the CCR. However, recently it was shown [8] that the cross section of the reaction $dd \to {}^3Hp$ (and $dd \to {}^3Hen$), measured at SATURNE in 80's [9], also perfectly follows the scaling behaviour at transversal momenta $p_T \sim 0.6 - 0.9$ GeV/c (Fig.1). At the beam energy $T_d = 0.5 - 1.25$ GeV the differential cross section $d\sigma/dt$ for the maximum measured scattering angles $\theta_{cm} = 50° - 60°$ demonstrates the s^{-22} dependence with $\chi^2_{n.d.f.} = 1.18$. In this reaction $n =$

$6+6+9+3=24$. Up to now, the reaction $dd \to {}^3Hen$ (${}^3Hp$) is the only pure hadronic process which involves the deuteron and ${}^3He({}^3H)$ nuclei and found to follow the CCR. As shown in [8], the cross section of the reaction $dp \to dp$ also demonstrates the CCR behaviour $\sim s^{-16}$ at $T_d = 2T_p = 1-5$ GeV and $\theta_{cm} = 120° - 130°$, however the χ^2-value is not good in this case, perhaps, due to different sets of the data included into analysis [8]. For other reactions with the lightest nuclei, as $dd \to dd$, $dd \to {}^4He\eta$, $d^3He \to {}^4Hep$ and $pd \to {}^3H\pi^+$, systematic experimental data at beam energies above 1 GeV and large scattering angles are absent.

3 Models

Presumably, the observed in the GeV region scaling is non-perturbative by its origin. Indeed, the pQCD is expected to be valid at very high transferred momenta and energies about hundreds GeV [10]. Furthermore, the hadron helicity conservation predicted by the pQCD was not confirmed experimentally in the scaling region of the reaction $\gamma d \to pn$ [11]. On the other hand, in these reactions the 3-momentum transfer $Q > 1$ GeV/c is large enough to probe very short distances between nucleons in nuclei, $r_{NN} \sim 1/Q$. So, one can find within the impulse approximation that at $E_\gamma = 1$GeV and $\theta_{cm} = 90°$, i.e. in the scaling onset region, the internal momentum of the nucleon in the deuteron is $q \sim 1$ GeV/c. This is very high momentum corresponding to the relative distance between nucleons $r_{NN} \sim 0.2$ fm. In the reaction $dd \to {}^3Hp$ at $T_d = 0.5 - 1.2$ GeV and $\theta_{cm} = 90°$ one has $q = 0.7 - 1.1$ GeV/c. Nucleons can lose their separate identity in this overlapping region and form multi-quark configurations, which can reveal itself in the CCR scaling.

Within the constituent quark model, the observed s^{-22} behaviour shows that all constituent quarks in the initial and final state are active in the reaction $dd \to {}^3Hp$. Indeed, the nuclear matter density in the short-range configurations with high internal momenta of nucleons $q \sim 1GeV/c$ probed in this reaction, is close to the critical one, $\varepsilon_c \sim 1GeV/fm^3$, that corresponds to the phase transition [12]. On the whole, interpretation of such phenomena can be associated with the *quark-hadron duality*. So, the most accurate phenomenological description of the $\gamma d \to pn$ data was achived within the Quark-Gluon String model formulated in terms of the Reggeon exchanges [7]. In Ref. [8] the Reggeon model [7] with some modifications was also used to describe the $dd \to {}^3Hen$ and $dp \to dp$ reactions.

One should note that the scaling behaviour s^{-11} in the reaction $\gamma d \to pn$ starts at $p_T > 1.1$ GeV/c [6], whereas the data [13] on reaction $pp \to d\pi^+$ do not follow to the expected CCR scaling regime s^{-12} at almost the same p_T

(1.0−1.4 GeV/c) at beam energy 2 - 4 GeV. The reason for absence of scaling in the reaction $pp \to d\pi^+$ can be excitation of baryon resonances in πN-interaction [14]. On the other hand, in the meson-less reaction $dd \to {}^3Hp$ the s^{-22} behaviour is appeared [8] at lower p_T, $0.6 - 0.9$ GeV/c.

In conclusion, the dimensional scaling is observed in several binary reactions in the few GeV region. Most likely, this behaviour is not related to the pQCD. However, this interesting phenomenon occurs at high p_T and, therefore, is certainly related to the short-range structure of the lightest nuclei. New systematic data on exclusive reactions with the lightest nuclei are required to get more insight on the origin of this scaling.

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