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DIQUARKS AS A SOURCE OF LARGE-P⊥ BARYONS IN HARD NUCLEON COLLISIONS

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1. INTRODUCTION

The QCD, a pretending theory of strong interaction having a conventional success in the hard-process description has some uncertainty in an intermediate Q^2 region. This uncertainty arises because it is difficult to separate exactly the gluon bremsstrahlung contribution (logarithmic corrections) and nonperturbative higher-twist contribution (power corrections). Up to-day an experimental separation of such contributions is extremely hard, as is obvious from uncertainties of experimental values of Λ_{QCD}. On the other hand, the higher-twist theoretical analysis is rather complicated /1/ and the main question is whether a factorization property conserves in higher twists/2/ . Therefore, a consideration of higher-twist effects in terms of phenomenological models (a constituent interchange model (CIM)/3/ , diquarks/4-14/etc. /15/) seems to be interesting now.

The nucleon diquark model with a dominating scalar (ud)-diquark /5-9/ developed in general by the Stockholm group/5-7/ for explaining the scaling breaking in different hard leptonic and hadronic processes is, as we think, more attractive and fruitful.

Available experimental data on proton production in hard-proton collisions/16-20/ indicate an important dynamical role of diquarks /10-14/ . A large-$p_\perp$ deuteron production in pp-collisions/21/ , which can be interpreted as a result of simultaneous double quark-diquark collisions/22/, is also interesting.

There are also indications to a significant diquarks role in realistic hadronic models/23/ (where hadron statical properties in QCD-vacuum are defined by quark-, gluon-condensates and instantons) and in lattice calculations as well/24/ . There the mass differences in scalar and vector channals are in practice fully determined by instanton contributions (e.g., the mass differences $m_\Delta - m_p$, $m_\rho - m_\pi$ etc./23/). It is also important that in a nucleon the diquark produced by instantons can be only scalar and isoscalar, and the radius of such a scalar diquark is $r_d \simeq r_{inst} = 0.2 \div 0.3$ Fm/25/ , close to the value r_d = 0.2 Fm obtained from experimental data on hard processes/12-14/ .

The differences of u - and d -quarks distributions in a nucleon can be equally explained by the quark clusterization to a (ud)-diquark/9/ .

In this letter we consider the dynamical role of diquarks in production of single nucleons, symmetric nucleon pairs, and Λ^0 -hyperons in hard proton collisions. As we will see, the presence of a scalar (ud)-diquark in a nucleon allows us to describe the p/π^+ -ratio and the absolute values of production cross sections of protons and protons pairs in pp -collisions in a wide energy region, as well.

2. LARGE-$p_\perp$ BARYON PRODUCTION AND p/π^+-RATIO

It is known that the problem of large-$p_\perp$ baryon production in hadronic collisions cannot be solved in the framework of the elastic quark scattering model/26/ . As a result, phenomenological higher twists models appear: CIM/3/ , diquarks/10-14/, etc./15/ .

It seems that one of the main tests for these models in hard nucleon collisions is the $R = p/\pi^+$-ratio at large angles in CM-system.

An $R = p/\pi^+$-ratio analysis was already made in the region ($19.4 \leq \sqrt{s} \leq 62$ GeV). Strong scaling breaking with respect to $R = p/\pi^+ \sim 1/p_\perp^4$ (proton production $\sim 1/p_\perp^{12}$ and that of π^+-mesons $\sim 1/p_\perp^8$) was explained by power corrections, i.e. in general by diquark/10-14/ , subproton in CIM /3/ form factors or by triple quark collision process/15/ .

Reduction to the IHEP (Serpukhov) energy region gives a more extraordinary effect: the scaling breaking becomes so strong that the R -ratio increases rather than decreases with $p_\perp$ increasing (Sulyaev's group data:/19,20/)! In fact, $R = p/\pi^+ > 1$ beginning from $p_\perp \simeq 1.8$ GeV/c ($X_\perp = 0.3$, $\theta_{CM} = 90^0$), i.e. a number of protons becomes greater than that of π^+ -mesons (Fig. 1a)!

For analysing large-$p_\perp$ hadron production processes we use the "black-box" model by Field and Feynman/26/ . Similarly to works/10--13/ , we consider that

$$\left(\frac{d\sigma}{dt}\right)_{qd} = \left(\frac{d\sigma}{dt}\right)_{qq} \cdot f^2(Q^2) ,$$
$$f(Q^2) = \frac{1}{1 + Q^2/M^2} , \quad Q^2 = 2\,\frac{\hat{s}\,\hat{t}\,\hat{u}}{\hat{s}^2 + \hat{t}^2 + \hat{u}^2} . \tag{1}$$

The diquark distribution function is chosen in the following form

$$G_d(x) = 6\,X(1-X) , \quad \int_0^1 G_d(X)\,dX = 1. \tag{2}$$

At small X this distribution function differs from that of the Stockholm diquark model and from that of ref./14/ where $G_d(x) \sim 1/x, 1/\sqrt{x}$ with $X \to 0$.

The fragmentation function of a (ud)-diquark to a nucleon is chosen according to the Field and Feynman jet model/27/ :

$$D^p_{(ud)}(z) = D^n_{(ud)}(z) = 0.4\,[1 - a + 3a(1-z)^2] ,$$
$$\int_0^1 dz\, D^p_{(ud)}(z) = \langle n_p \rangle = \langle n_n \rangle = 0.4 ,$$

where the parameter a = 0.57/28/ , $\langle n_p \rangle$ ($\langle n_n \rangle$) is the mean multiplicity of protons (neutrons) in a diquark jet.

To describe π^+ inclusive production in pp -collisions, Field -Feynmann jet model fragmentation functions/27/ were also used, where a = 0.74 at $\sqrt{s}$ = 11.5 GeV and a = 0.94 at $\sqrt{s} \gtrsim 20$ GeV.

It is well seen from Fig.1 and Fig.2 that the main contribution to the large-$p_\perp$ proton production is made by a quark-diquark subprocess; at $\sqrt{s}$ = 11.5 GeV energy diquark-diquark scattering becomes also important.

Sulyaev's group data/19,20/confirm the hypothesis/5-7/ of a small diquark size (the form factor parameter M^2 = 12 (GeV/c)^2). But our choice of the diquark distribution is, as one can see from data (Fig.1), especially for $X_\perp \lesssim 0.25$, more preferable than in/6,13,14/ . The use of the diquark distribution /6,13,14/ results in a permanent-decreasing p/π^+ - ratio/12-14/ with $X_\perp$ increasing, while at $\sqrt{s}$ = = 11.5 GeV $R = p/\pi^+$ is a growing function of $X_\perp$.

The quark-diquark configuration probability in a nucleon, obtained by us, is equal to about 70%; note, however, that the value of this probability is defined by approximate relationship (1) between elastic cross sections of qq - and qd - subprocesses/14/ .

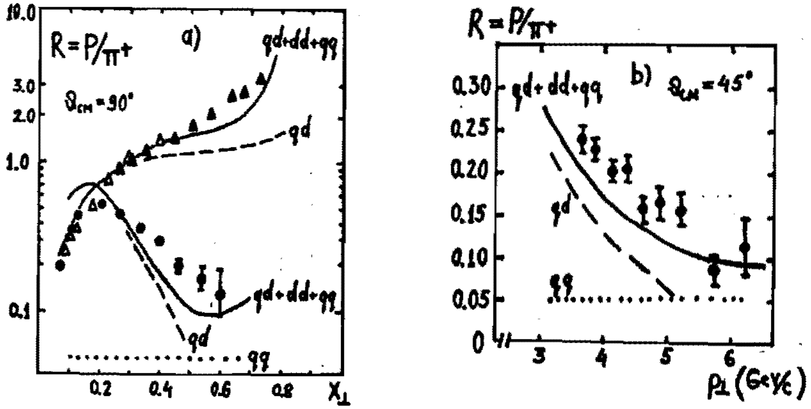

Fig. 1. $R = P/\pi^+$ -ratio in pp-collisions.a) $\vartheta_{CM} = 90^\circ$: ● – FNAL data /16/ at $\sqrt{s} = 23.4$ GeV (E_L = 300 GeV); Δ , ▲ – IHEP (Serpukhov) data/19,20/ at $\sqrt{s}$ = 11.5 GeV (E_L = 70 GeV). b) $\vartheta_{CM} = 45^\circ$: ● – ISR CERN data /18/ at $\sqrt{s}$ = 62 GeV ($E_L \simeq$ 1900 GeV).

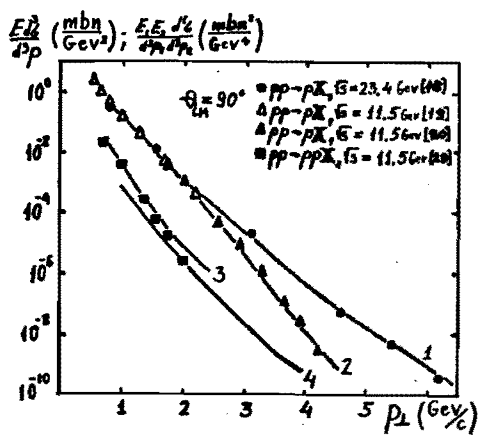

Fig. 2. Invariant cross sections of protons and symmetric-proton-pairs production. Calculated curves: 1 – pp → pX at $\sqrt{s}$ = 23.4 GeV; 2 – pp → pX, 3 – pp → ppX at $\sqrt{s}$ = 11.5 GeV; 4 – a prediction for pp → ppX at $\sqrt{s}$ = 23.4 GeV.

The result of calcuations of $pp \to ppX$ processes/29/ (symmetric -proton-pair production) according to the formula in work/30/ for the double inclusive cross section, which in general must be applied carefully/31/ , is shown in Fig.2. The main contribution to the cross section of production of proton pairs with transverse momenta opposite and equal in values is given by diquark-diquark scattering.

Thus, a simple diquark model describes absolute values of $pp \to pX$, $pp \to ppX$ cross sections in a wide energy region rather good and also correctly reproduces the scaling breaking for the $R = P/\pi^+$ -ratio.

Calculations for the $R = P/\pi^+$ -ratio by a modified CIM /32/ made in/20/ show only qualitative agreement with experimental data /16,19,20/. Through, quantitative agreement in CIM can be reached by an appropriate choice parameters, but correlations measured by ABCDHW and R608 collaborations in CERN ISR between forward and trigger protons (ϑ_{CM} = 10÷40°/33/ , ϑ_{CM} = 90°/34/) require a large angle scattering of two valence quarks, rather than that of three valence quarks as in the CIM/3/ and triple quark collision model/15/ . This is probably indicated/22/ by data /21/ on large-$p_\perp$ deuteron production in pp -collisions.

Another test may be done by measuring large-$p_\perp$ Λ^0-hyperon cross sections in proton collisions. In the dominating scalar (ud)-diquark model the ratio $\Lambda^0/p \propto K^+/\pi^+$ = 0.3÷0.5 must almost be independent of $p_\perp$ and $\sqrt{s}$.

3. SUMMARY

The simple nucleon model with a scalar (ud)-diquark rather well describes absolute values of cross sections of processes of the inclusive production of single protons and symmetric proton pairs with large-$p_\perp$ in pp -collisions in a a wide energy region ($\sqrt{s}$ = 11.5÷÷62 GeV) and also correctly reproduces the strong scaling breaking for the $R = P/\pi^+$ -ratio. The data at $\sqrt{s}$ = 11.5 GeV/19,20/ confirm the hypothesis/5-7/ of small diquark size.

The measurement of the Λ^0/p -ratio at large $p_\perp$ would be a good test for distinguishing between the scalar (ud)-diquark model and other higher-twist models.

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Ким В.Т. E2-87-75

Дикварки как источник барионов с большими $p_\perp$ в жестких нуклонных соударениях

Обсуждается образование нуклонов, симметричных нуклонных пар и Λ^o-гиперонов с большими $p_\perp$ в pp-соударениях в рамках модели нуклона с доминирующим скалярным (ud)-дикварком. Показано, что для объяснения сильного нарушения скейлинга в отношении p/π^+ необходим учет высших твистов - дикварков. В данной модели предсказывается приближенное равенство $\Lambda^o/p \simeq k^+/\pi^+$.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Kim V.T. E2-87-75

Diquarks as a Source of Large-$P_\perp$ Baryons in Hard Nucleon Collisions

The production of nucleons, symmetric nucleon pairs, and Λ^o-hyperons with large $p_\perp$ in pp-collisions is discussed in the framework of a dominatiing scalar (ud)-diquark nucleon model. The necessity of making allowance for higher twists-diguarks for explaining strong scaling breaking in p/π^+ ratio is shown. The approximate equation $\Lambda/p \simeq k^+/\pi^+$ is predicted in this model.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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