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DIFFRACTIVE EXCITATION OF NUCLEON INTO HIGH-MASS STATES AND A QUARK MODEL

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Дифракционное возбуждение нуклонов в состояния с большой массой и модель кварков

На основе кварк-реджеонной модели [1] вычислено сечение дифракционного возбуждения нуклонов при малых переданных импульсах и найдены значения трехреджеонных вершин. Показано, что модель, содержащая лишь один свободный нормировочный параметр, успешно описывает экспериментальные данные в широкой области энергий и масс возбужденной системы. Наилучшее согласие получено в предположении кварк-дикварковой структуры нуклона.

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Diffractive Excitation of Nucleon into High-Mass States and a Quark Model

The inclusive cross section of diffractive excitation of nucleon at small momentum transfers and the triple Regge couplings have been calculated using the quark-reggeon model [1]. It is shown that the model with only one free parameter successfully describes experimental data in a wide range of energies and masses of the excited system. The best agreement has been found for the quark-diquark structure of the nucleon.

The investigation has been performed at the Laboratory of High Energies, JINR.

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1. INTRODUCTION

Triple Regge formalism [2] is widely used for analysis of inelastic diffractive hadron scattering with excitation into high-mass states $W \gg m$ in the region $s \gg m^2$ and $s/W^2 \gg 1$. This allows the inclusive cross section to be related to the triple Regge couplings g_{ijk} (Fig. 1):

$$\frac{d\sigma}{dt\, d(W^2/s_0)} = \sum_{ijk} G_{ijk}(t)\left(\frac{s}{s_0}\right)^{a_i(t)+a_j(t)+2} \times \tag{1}$$

$$\times \left(\frac{W^2}{s_0}\right)^{a_k(0)-a_i(t)-a_j(t)},$$

$G_{ijk} = (16\pi)^{-1}\beta_i(t)\beta_j(t)X_i(t)X_j(t)\mathrm{Im}X_k(0)\beta_k(0)g_{ijk}$ ($X_j(t) = -[1 + r_j \exp(-i\pi\alpha_j(t))]/\sin\pi\alpha_j(t)$ is the signature factor) and gives a phenomenological ground for the experimental data systematics.

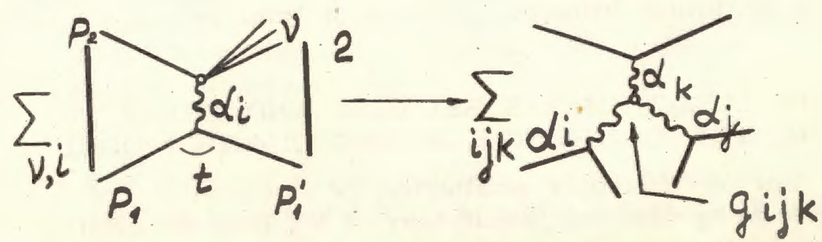

Fig. 1. Inclusive cross section in triple Regge formalizm.

However, this approach stands aside from one of the most interesting aspects of the inelastic diffraction phenomenon: its relation to hadron structure. From the practical point of view, this approach suffers from the abundance of free phenomenological parameters. For example, if one takes into account only leading Regge poles: Pomeron P, vector and tensor exchanges R, then, in general, six unknown functions (G_{PPP}, G_{PPR}, G_{RRR}, G_{RRP}, G_{PRP} and G_{RPR}) are needed to describe the cross section. As many as twelve free parameters are required even for narrow t-region where simple parametrization of the $g_{ijk}(t) = g_{ijk}(0)\exp(b_{ijk}t)$ type can be sufficient.

It has been suggested /1/ to use the quark model for calculation of the inclusive diffraction cross section. In this case triple Regge couplings g_{ijk} can be expressed in terms of hadron-reggeon couplings β_i which are known from an analysis of elastic hadron scattering. Normalization constant λ is the only unknown quantity in this model. To calculate λ, one needs to know details of the quark structure of hadrons, off-shell effects, and the value of absorptive corrections. In this paper we calculate the triple Regge couplings in the framework of the quark-reggeon model /1/ and compare results with experimental data on the diffractive excitation of nucleon $p + p \to X + p$ /3/. We restrict ourselves to a low t region where results are especially simple. In this case to find the inelastic cross section, one needs only the slope parameter for elastic pp scattering and the values of $\beta_P(0)$, $\beta_f(0)$ and $\beta_\omega(0)$ which can be found from the pp and $\bar{p}p$ total cross sections.

2. INCLUSIVE CROSS SECTION AND TRIPLE REGGE COUPLINGS IN THE QUARK MODEL

Let us consider scattering of nucleon N_1 off nucleon N_2 with the excitation of N_2 into the state with high mass $W \gg m$. We suppose the energy $s=(p_1+p_2)^2$ is large ($s \gg W^2$) and scattering is "soft",

i.e., the invariant momentum transfer is small: $t=(p_1'-p_1)^2 \equiv k_1^2 \simeq \vec{k}_\perp^2 \simeq 0$. In the lab. system, where N_2 is at rest, this process occurs with a large longitudinal (along $\vec{p}_1$- direction) momentum transfer $k_\parallel \simeq k_0 \simeq (W^2 - m^2)/2m$. The idea of utilization of the quark model for calculation of the cross section for this process /1/ can be traced from Fig. 2. We assume

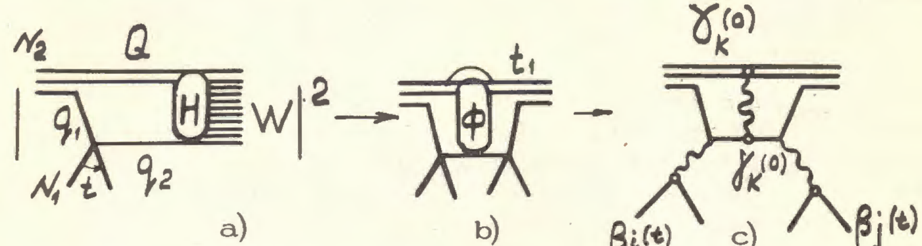

Fig. 2. Inclusive cross section in the quark model.

that at first, one of the constituent ("dressed") quarks from nucleon N_2 scatters off nucleon N_1 (scattering amplitude T) and receives momentum k which results in a high effective mass of the excited state. We as usually assume that the large values of quark momentum $\vec{q}^2$ in the nucleon are suppressed and quark virtual masses $q_i^2 \equiv \mu_i^2$ are bounded. Then, it is easy to see that a large value of $k_\parallel$ can be transferred only to the quark which has a small virtual mass μ_1^2: $q_\parallel = k_\parallel \mu_1^2 (\mu_1^2 + q^2 - \mu_2^2)^{-1}$. Then the hadronization (i.e., transformation of quarks into a final hadronic system of mass W) occurs, shown by blobs H in Fig. 2. At high values of W one can neglect a relative quark momentum in the initial nucleon N_2 and write the amplitude in factorized form

$$F = NTH, \tag{2}$$

where N is related to the nucleon wave function at $q^2 \to 0$ and is independent of W and t at large W and small $|t|$ /1/.

The next step is to calculate the inclusive cross section. Using the generalized optical theorem and eq. (2), one can write the cross section (see Fig. 2) as

$$\frac{d\sigma}{dt\,d(W^2/s_0)} = \frac{1}{16\pi(s/s_0)^2} N^2 |T|^2 \mathrm{Im}\,\phi(W^2, t_1 = 0), \qquad (3)$$

where ϕ is the amplitude of quark-"diquark" scattering. Here, we shall not consider the problems connected with unitarity for the quark amplitudes, because they have been thoroughly discussed already in the case of a deep inelastic lepton-hadron scattering (see, for example /4/, and the references therein). Thus, the inclusive approach permits quark "soft" scattering (i.e., scattering at high energies and small $|t|$) amplitude to be used instead of the totally unknown hadronization amplitude. To calculate this amplitude and the amplitudes T of the soft scattering of quarks off the nucleon N_1 (which enters into diagram 2b), we use the Regge pole model. It is well-known that this model gives a reasonable phenomenological description of soft two- and quasi-two-body hadron reactions. The quark model supplemented with the additivity assumption means that the Regge poles can be also used to describe the soft scattering of constituent quarks on quarks and hadrons as shown in diagram 2c.

Leading Regge poles coupled with nucleon are Pomeron P, vector and tensor poles $R = f, \omega, \rho, A_2$ and pole π. We neglect ρ and A_2 weakly coupled with nucleon and calculate the contribution in Fig. 2c only from P and $R = f, \omega$ assuming that $\alpha_f(t) = \alpha_\omega(t) \doteq \alpha_R(t)$. In this approximation neutron and proton interact equally, so u and d quarks can be considered identical $u = d \equiv q$.

Using the additivity one can express hadron-reggeon vertex function $\beta_i(t)$ in terms of quark-reggeon vertices $\gamma_i(t)$

$$\beta_i(t) = \left(\frac{m}{\mu}\right)\gamma_i(t)\, f(t) \left(\frac{s_0 \mu^2}{s_q m^2}\right)^{\alpha_i(t)/2} . \qquad (4)$$

Here m and $\mu \simeq m/3$ are the masses of the nucleon and of constituent quark, $f(t)$ is the quark form-factor of the nucleon, $\alpha(t)$ is the Regge trajectory, s_0 and s_q are the scale factors for the NN and qq scattering amplitudes which, in general, can be different. Factor $m/\mu \simeq 3$ takes into account the number of diagrams and the last factor in (4) arises as a result of recalculation of energy from qq to NN scattering. The radius of the constituent quark is usually expected to be much smaller than that of the nucleon so we can approximate $\gamma_i(t)$ by constant γ_i and determine its value from eq. (4). Then the resultant expression for the inclusive cross section, which corresponds to Fig. 2c, can be written precisely in the same form as triple Regge formula (1) and we obtain the following expression for g_{ijk} /1/

$$q_{ijk}(t) = \lambda g^{\circ}_{ijk} \Delta_{ijk} ,$$

$$g^{\circ}_{ijk} = \beta_i(0)\beta_j(0)\beta_k(0), \qquad (5)$$

$$\Delta_{ijk} = \left(\frac{m^2}{\mu(m-\mu)}\right)^{\alpha_k(0)} \left(\frac{\mu^2}{\sqrt{s_0 s_q}}\right)^{\alpha_i(t)+\alpha_j(t)} \times$$

$$\times \left(\frac{\sqrt{s_q}\, m}{\sqrt{s_0}\, \mu}\right)^{\alpha_i(0)+\alpha_j(0)} ,$$

where λ is a normalization factor.

In derivation of (5) we suggested that the vertices γ_i entering Fig. 2c at $q^2 \to 0$ are identical with vertices γ_i of elastic scattering or differs from them by a factor common for all $i = P, f, \omega$. It is worth noting that triple Regge vertices do not arise literally in the quark model (Fig. 2c). However, a similar structure of the expression for the cross section in the triple Regge and quark model makes it possible to identify (5) with triple coupling g_{ijk}.

Equation (5) has been derived assuming that the quarks in nucleon are symmetric (qqq -model) and

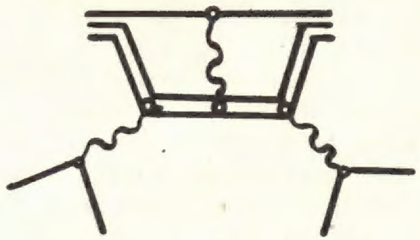

Fig. 3. Diagram with diquark scattering.

the term "diquark" has been used simply to identify two spectator quarks. We also consider as an alternative the quark-diquark model [5], where two of three quarks in the nucleon form "quasi-particle" (diquark; Qq -model). In this case, in addition to Fig. 2c, one needs to take into account also the diagram shown in Fig. 3. Assuming that $m_Q \simeq 2m_q$ and $\sigma_{Qh} \simeq \sigma_{qh}$, this leads to the following additional factor in the cross section

$$\left(\frac{\mu}{m}\right)^2 \left[1 + \left(\frac{m-\mu}{\mu}\right)^{\alpha_i(t)+\alpha_j(t)+2}\right]. \qquad (6)$$

It is convenient to make summation over $R = f$ and ω exchanges explicitly [1]. Then excluding triple couplings with an odd number of ω-legs, ruled out by G-parity [6], we have

$$G_{ijk}(t) = \lambda G^{\circ}_{ijk} \Delta_{ijk},$$

$$G^{\circ}_{PPP}(t) = \beta_P^2(t)\beta_P^4(0)\sin^{-2}\frac{\pi\alpha_P(t)}{2}, \qquad (7)$$

$$G^{\circ}_{PPR}(t) = G^{\circ}_{PPf} = \beta_P^2(t)\beta_P^2(0)\beta_f^2(0)\sin^{-2}\frac{\pi\alpha_P(t)}{2},$$

$$G^{\circ}_{RRP}(t) = G^{\circ}_{ffP} + G^{\circ}_{\omega\omega P} = \beta_P^2(0)\left[\beta_f^2(t)\beta_f^2(0)\sin^{-2}\frac{\pi\alpha_R(t)}{2} + \beta_\omega^2(t)\beta_\omega^2(0)\cos^{-2}\frac{\pi\alpha_R(t)}{2}\right],$$

$$G^{\circ}_{RRR}(t) = G^{\circ}_{fff} + G^{\circ}_{\omega\omega f} = \beta_f^2(0)\left[\beta_f^2(t)\beta_f^2(0)\sin^{-2}\frac{\pi\alpha_R(t)}{2} + \beta_\omega^2(t)\beta_\omega^2(0)\cos^{-2}\frac{\pi\alpha_R(t)}{2}\right],$$

$$G^{\circ}_{PRP}(t) = G^{\circ}_{PfP} + G_{fPP} = 2\beta_P(t)\beta_P^3(0)\beta_f(t)\beta_f(0)\left(1 + \mathrm{ctg}\frac{\pi\alpha_P(t)}{2}\mathrm{ctg}\frac{\pi\alpha_R(t)}{2}\right),$$

$$G^{\circ}_{RPR}(t) = G^{\circ}_{fPf} + G^{\circ}_{Pff} + G^{\circ}_{\omega P\omega} + G^{\circ}_{P\omega\omega} = 2\beta_P(t)\beta_P(0)[\beta_f(t)\beta_f^3(0) \times$$

$$\times\left(1+\mathrm{ctg}\frac{\pi\alpha_P(t)}{2}\mathrm{ctg}\frac{\pi\alpha_R(t)}{2}\right) - \beta_\omega(t)\beta_\omega^3(0)\left(-1 + \mathrm{ctg}\frac{\pi\alpha_P(t)}{2}\mathrm{tg}\frac{\pi\alpha_R(t)}{2}\right)].$$

To make a comparison with experiment, one has to take into account the π-exchange contribution as well. Due to the nearness of the pion pole to the physical region, its contribution can be easily estimated [7]

$$G_{\pi\pi k} = -\frac{1}{4\pi}\frac{g^2_{\pi Np}}{4\pi}\sigma_{tot}(\pi^\circ p)\frac{t}{(t-\mu^2)^2}. \qquad (8)$$

Here $k = P$ or R, μ is π-meson mass and $\sigma_{tot}(\pi^\circ p) = \sigma^P s^{\alpha_P(0)-1} + \sigma^R/\sqrt{s}$.

Thus the inclusive cross section for reaction $pp \to Xp$ in the region $s \gg m^2$, $W^2 \gg m^2$, $s/W^2 \gg 1$ can be written as

$$\frac{d\sigma}{dt\,d(W^2/s_0)} = \sum_{ijk} G_{ijk}\left(\frac{s}{s_0}\right)^{\alpha_i(t)+\alpha_j(t)-2}\left(\frac{W^2}{s_0}\right)^{\alpha_k(0)-\alpha_i(t)-\alpha_j(t)} + \qquad (9)$$

$$+\sum_k G_{\pi\pi k}\left(\frac{s}{s_0}\right)^{2\alpha_\pi(t)-2}\left(\frac{W^2}{s_0}\right)^{\alpha_k(0)-2\alpha_\pi(t)},$$

or

$$(1-x)\frac{d\sigma}{dtdx} = \sum_k \left(\frac{s}{s_0}\right)^{\alpha_k(0)-1} (1-x)^{\alpha_k(0)+1} \times$$

$$\times \left[\sum_{ij} G_{ijk}(1-x)^{-\alpha_i(t)-\alpha_j(t)} + G_{\pi\pi k}(1-x)^{-2\alpha_\pi(t)}\right],$$

where G_{ijk} and $G_{\pi\pi k}$ are given by expressions (7) and (8).

3. COMPARISON WITH EXPERIMENT

Let us compare expressions (7)-(9) with the data obtained in /8/ at small $|t|$. We use standard parametrization for the Regge trajectories: $\alpha_\pi(t) = t$, $\alpha_R(t) = ½ + t$ and the "bare" Pomeron with intercept larger than one $\alpha_P(t) = 1.06 + \alpha'_P t$, which allows one to describe the rise of σ_{tot}. The values 15 mb and 34.5 mb /8/ are used for $\sigma^P(\pi^\circ p)$ and $\sigma^R(\pi^\circ p)$. The values of $\beta_i(t)$ can be estimated at small $|t|$ from the equation

$$\left(\frac{d\sigma}{dt}\right)_{e\ell} = \frac{1}{16\pi}\left|\sum_i \beta_i^2(t) X_i(t)\left(\frac{s}{s_0}\right)^{\alpha_i(t)-1}\right|^2 = A(s)\, e^{b_{e\ell} t}. \quad (10)$$

For simplicity we neglect the weak t-dependence of X_i and Δ_{ijk} and calculate these values approximately at $\alpha_P(0) = 1$ and $\alpha_R(0) = ½$. Assuming the same t-dependence of $\beta_i(t)$ for all i and using the experimental results of /9/: $b_{e\ell} = b_0 + 0.556 \ln(s/s_0)$, $b_0 = 8.23\ (GeV/c)^2$, we obtain $\beta_i(t) = \beta_i(0)\exp(b_0 t/2)$ and $\alpha'_P \simeq 0.278$. In this approximation the functions G_{ijk} are equal to

$$G_{ijk}(t) = \lambda \bar{G}^\circ_{ijk}(0)\Delta_{ijk}(0)\exp(b_0 t/2). \quad (11)$$

Here

$$\bar{G}^\circ_{PPP}(0) = \beta_P^6(0)\sin^{-2}\frac{\pi\alpha_P(0)}{2},$$

$$\bar{G}^\circ_{PPR}(0) = \beta_P^4(0)\beta_f^2(0)\sin^{-2}\frac{\pi\alpha_P(0)}{2},$$

$$\bar{G}^\circ_{RRP}(0) = 2\beta_P^2(0)[\beta_f^4(0) + \beta_\omega^4(0)],$$

$$\bar{G}^\circ_{RRR}(0) = 2\beta_f^2(0)[\beta_f^4(0) + \beta_\omega^4(0)],$$

$$\bar{G}^\circ_{PRP}(0) = 2\beta_P^4(0)\beta_f^2(0)\left(1 + \mathrm{ctg}\frac{\pi\alpha_P(0)}{2}\right), \quad (12)$$

$$\bar{G}^\circ_{RPR}(0) = 2\beta_P^2(0)\left[\beta_f^4(0)\left(1+\mathrm{ctg}\frac{\pi\alpha'_P(0)}{2}\right) + \beta_\omega^4(0)\left(1 - \mathrm{ctg}\frac{\pi\alpha_P(0)}{2}\right)\right],$$

$$\Delta_{ijk}(0) = \left(\frac{9}{2}\right)^{\alpha_k(0)} \left(\frac{m^2}{3s_0}\right)^{\alpha_i(0)+\alpha_j(0)} \times \begin{cases} 1 & \text{- for the qqq model} \\ \frac{1}{9}\left(1 + 2^{\alpha_i(0)+\alpha_j(0)+2}\right) & \text{- for the qQ model.} \end{cases}$$

Note that the expression for Δ_{ijk} includes only "hadron" scale factors (but not quark scale factor s_q) which is usually chosen as $s_0 = 1\ GeV^2$.

It is seen from (11) that the slope of the t-dependence of the high mass excitation cross section is approximately one half the elastic slope /1/. This is in good agreement with experiment /10/.

The constants $\beta_i(0)$ in (12) can be estimated from the s-dependence of the total pp and $\bar{p}p$ cross sections

$$\sigma\left(\begin{matrix} pp \\ \bar{p}p \end{matrix}\right) = \beta_P^2(0)\left(\frac{s}{s_0}\right)^{\alpha_P(0)-1} + \frac{\beta_f^2(0) \mp \beta_\omega^2(0)}{\sqrt{s/s_0}}. \quad (13)$$

The values $\beta_P^2(0) = 25.75 \pm 0.14$ mb, $\beta_f^2(0) = 70.92 \pm 0.26$ mb and $\beta_\omega^2(0) = 27.60 \pm 0.17$ mb have been found

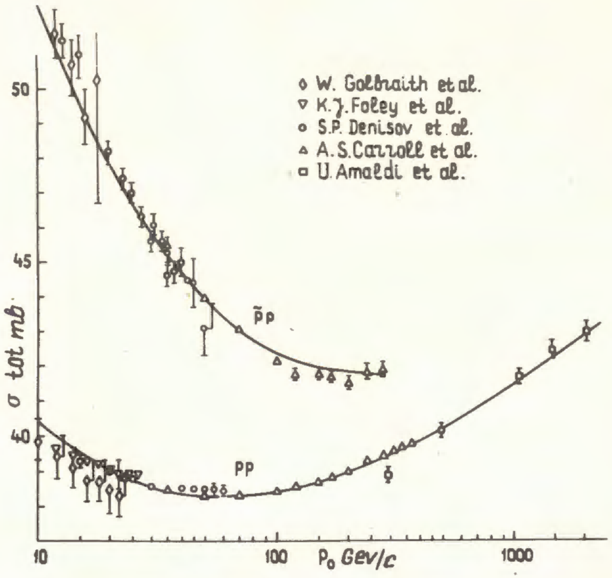

Fig. 4. Total pp and $\bar{p}p$ cross section and the Regge pole model.

from the fit to the data [11] (see Fig. 4.). Now we use these values of $\beta_i(t)$ to calculate G_{ijk} and $d\sigma/dt\,d(W^2/s_0)$. The fit of the data [3] gives the values of parameter λ and, consequently, normalized triple Regge couplings G_{ijk}. The results for the quark (qqq) and quark-diquark (qQ) models are shown in Table 1. The experimental data [3] and the inclusive cross section $(1-x)d\sigma/dt\,dx$ computed using the calculated values of G_{ijk} are plotted in Fig. 5 (here $x = 1 - W^2/s$). Figure 6 displays the contribution of different triple Regge terms to the inclusive cross section calculated in the quark-diquark model at $|t| = 0.05$ $(GeV/c)^2$.

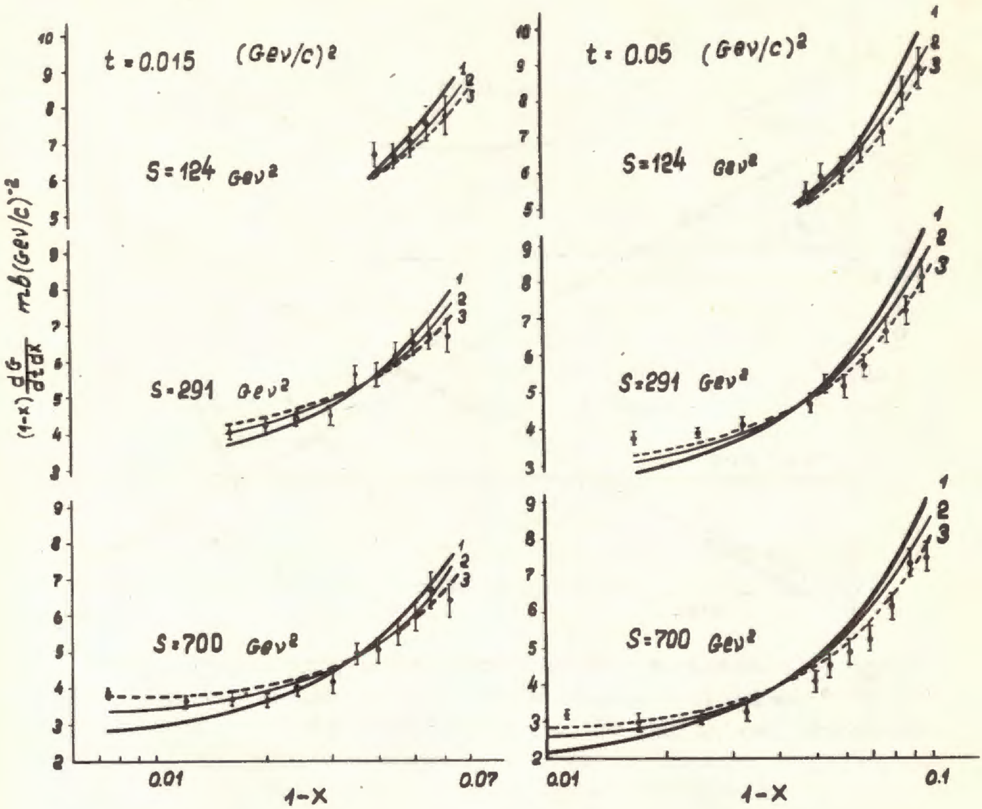

Fig. 5. Comparison with experiment for the reaction $pp \to Xp$; (1) - quark-diquark model, (2) - symmetric quark model, (3) - for both models when the off-shell effects are taken into account.

IV. CONCLUSIONS

1. It is seen from Fig. 5 that the cross section of the diffractive excitation of nucleon calculated in the quark model with reggeon interaction [1] is in reasonable agreement with experimental data [3]. The best results are achieved for the quark-diquark

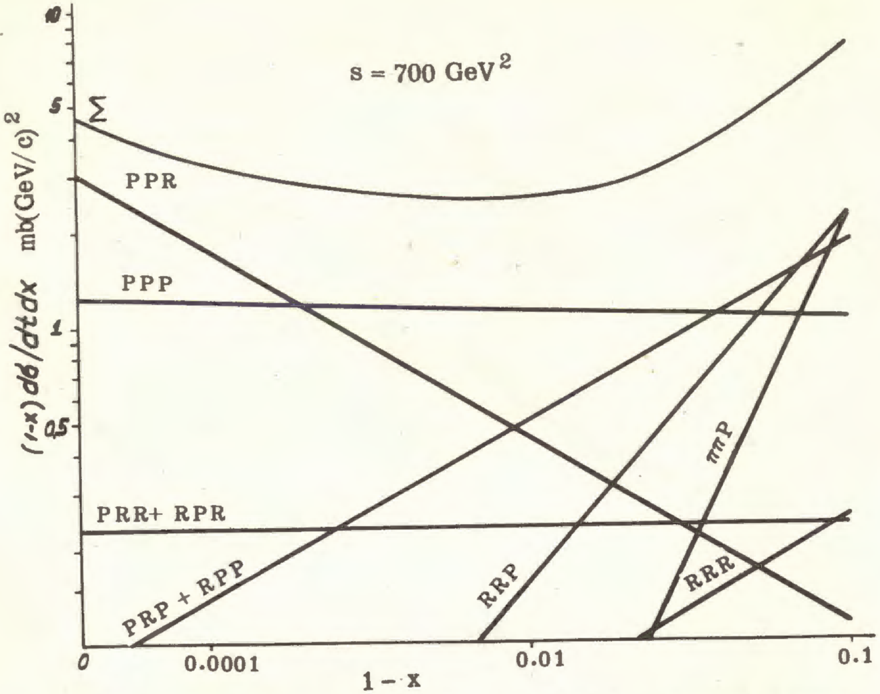

Fig. 6. Contributions of different triple Regge terms to the inclusive cross section calculated by quark-diquark model at $|t| = 0.05$ (GeV/c)^2 .

structure of nucleon ($\chi^2 = 108$ on 54 d.f.), whereas for the quark model the agreement is worse ($\chi^2 = 310$). Thus, the analysis of the diffractive excitation leads to some extra evidence in favour of the quark-diquark model in addition to already known arguments based on spectroscopy, deep inelastic scattering and quark sum. rules for baryon vertices.

We also tried to take into account the off-shell effects for scattered quark by varying its mass $\mu^2 \to \zeta\mu^2$. This leads to the additional factor of $\zeta^{\,\alpha_i(t)+\alpha_j(t)}$ for Δ_{ijk} in (5). The fit of the data with ζ as the second free parameter, shows an equally good agreement with data (χ^2=65) for Qq and qqq models. The results

are presented in the two last columns, Tables 1 and 2, and the dashed curve in Fig. 5.

2. Comparison with results of the phenomenological analysis /8/ (Table 1) shows that the presence of the cross terms RPR and PRP (arbitrarily neglected in /8/ in order to reduce the number of free parameters) results in smaller values of the PPP and RRR couplings. It is worth stressing that from comparison with the experimental data we obtain the effective values of triple Regge vertices G_{ijk} reduced by absorptive corrections /8/. In order to find true values of G_{ijk}, a direct calculation of normalization constant N or some estimation of abrosptive corrections is required.

3. Contrary to usual triple Regge phenomenology, in the quark model we can find the contributions of particular reggeons f and ω from the analysis of one reaction. The results are shown in Tables 1 and 2.

4. For further verification of the model it is desirable to make a comparison with nucleon excitation data in a wide t-range (say, up to $|t| \leq 1$ (GeV/c)^2) as well as with data on π- and K-meson excitation. Note that in the model the t-dependence for the $\pi N \to XN$ and $KN \to XN$ cross sections is expected to be close to the t-dependence for $NN \to XN$. A detailed test of the model can involve polarization effects as well.

In the considered model the large value of W mass is a result of the relative motion of quarks after scattering. One can discuss the other possibility shown in Fig. 7a. Here, the nucleon excitation is related to the gluon emission. In this case as well as in the multiperipheral or the Desde-type model /12/ we obtain the triple-Regge vertices explicitly in the triangle form Fig. 7b. Resulting expression for g_{ijk} has the following form:

T A B L E I.

The values of the triple Regge couplings as the result of the fit of the data[3].

Gijk	qQ	qqq	S.Y.Chu e.a.[8]	qQ	qqq
PPP	0,8122	0,5620	1,56	1,006	1,004
PPR	0,9635	0,6667	0,939	1,193	1,192
RRP	27,17	38,42	13,04(28,3*)	19,73	19,67
RRR	32,23	45,57	83,77	23,41	23,33
PRP + RPP	5,551	5,521		5,263	5,280
RPR + PRR	7,791	7,748		7,387	7,441
$K=\sqrt{\beta_P^6}$	1,076+0,009	1,522+0,013		0,486+0,063	0,255+0,033
ξ				1,61+0,12	3,05+0,22
χ^2	108,5	310,0	209,5(57,67)	65,23	65,25

*) Such a change of RRP contribution only gives a considerably better description of the data.

T A B L E II.

The contributions of f and ω exchanges to the triple Regge couplings.

Gijk	qQ	qqq	qQ	qqq
ffP	23,60	33,36	17,14	17,08
ωωP	3,57	5,05	2,60	2,59
fff	28,00	39,58	20,33	20,26
ωωf	4,24	6,00	3,08	3,07
PfP = fPP	2,776	2,760	2,632	2,640
fPf = Pff	3,292	3,274	3,122	3,132
ωPω = Pωω	0,603	0,600	0,572	0,574

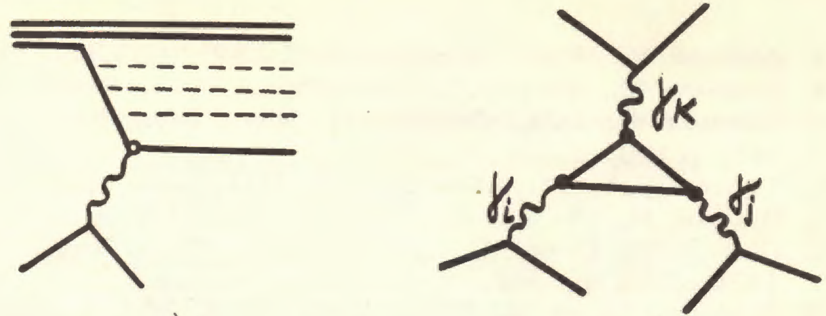

Fig. 7. (a) Diagram with gluon emission. (b) Triangle quark diagram for g_{ijk} .

$$g_{ijk}(0) = [16\pi^3(\alpha_k(0)+1)]^{-1} \int_{-\infty}^{0} dq^2 (-q^2)^{\alpha_k(0)+1} \times$$
$$\times (\mu^2 - q^2)^{\alpha_i(0)+\alpha_j(0)-\alpha_k(0)-3} \gamma_i(\mu^2, q^2, 0)\gamma_j(\mu^2, q^2, 0)\gamma_k(\mu^2, q^2, 0). \quad (14)$$

An analysis of this possibility and comparison with the above-mentioned model will be given elsewhere.

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