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BINARY PROCESSES AT HIGH ENERGIES: REGULARITIES OF BEHAVIOUR

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Abstract

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Dynamical properties of inelastic binary reaction $a+b \to c+d$ have been considered. Universal regularities which should obey the behaviour of angular distributions and polarization parameter in these reactions at $-t \gtrsim 1$ $(GeV/c)^2$ have been found. These regularities are a dynamical manifestation of the effects connected with unitarity of the scattering matrix. Comparison with experimental data has been made.

Аннотация

Трошин С.М., Тюрин Н.Е. Бинарные процессы при высоких энергиях: универсальность поведения: Препринт ИФВЭ 86-79. – Серпухов, 1986. – 7 с., 2 рис., библиогр.: 7 назв.

Рассмотрены динамические свойства неупругих бинарных реакций $a+b \to c+d$. Установлены универсальные закономерности, которым должно подчиняться поведение угловых распределений и параметра поляризации в этих реакциях при $-t \geqslant 1$ $(ГэВ/c)^2$. Эти закономерности являются динамическим проявлением эффектов, связанных с унитарностью матрицы рассеяния. Проведено сравнение с экспериментальными данными.

INTRODUCTION

Inelastic binary reactions play a particular role among hadron interaction processes. The study of inelastic binary reactions may serve as a test of hadron interaction mechanisms at the level of their structure constituents. As was shown on the basis of the quark model for the U-matrix /1/, the dynamics of such processes at fixed momentum transfers is connected with the range of distances $r < R(s)$, where $R(s)$ is an effective radius of elastic process.

Though the cross sections for inelastic binary processes $a+b \to c+d$ and the polarization parameter have different values depending on the type of hadron in the final state, universal regularities should be observed in the behaviour of these quantities /1/.

The present work is devoted to the discussion of such regularities.

1. REGULARITIES OF THE BEHAVIOUR OF ANGULAR DISTRIBUTIONS AND POLARIZATION IN INELASTIC BINARY REACTIONS AS A CONSEQUENCE OF UNITARITY CONDITION

Our consideration will be based on the approach which uses three-dimensional dynamical equations in QFT, which connect the amplitude with a generalized matrix of the reaction (U-matrix). These equations /2,1/ are transformed to algebraic ones in the partial waves or in the impact parameter representation, which allows one to represent the amplitude of the reaction $a+b \to c+d$ in the form

$$f_r(s,b)=u_r(s,b)/(1-iu(s,b)), \qquad (1)$$

where u_r is a corresponding generalized matrix of the reaction, and the function u corresponds to the elastic scattering process $a+b \to a+b$.

Solution (1) is a consequence of taking into account the unitarity relation in the direct channel. The representation (1) corresponds to the approximation, which was made in the initial equations for high energy region. This assumption implies that K-matrix is approximated by the diagonal matrix. The form of representation (1), as it is, generates singularities in the b-plane. The analytical structure of the amplitudes for different processes turns out to be similar . An effective use of this circumstance was proposed in ref.[3] devoted to the development of the method of analytical calculations of the amplitudes.

For the helicity amplitudes of a binary process $0+1/2 \to 0+1/2$, designated as F_o and F_f, we have

$$F_o(s,t)=\frac{s}{\pi^2}\int_o^\infty bdbJ_o(b\sqrt{-t})\frac{u_o(s,b)}{1-iu(s,b)},$$
$$F_f(s,t)=\frac{s}{\pi^2}\int_o^\infty bdbJ_1(b\sqrt{-t})\frac{u_f(s,b)}{[1-iu(s,b)]^2}, \qquad (2)$$

where we assume, that in the elastic scattering $a+b \to a+b$ the generalized matrix of the reaction, describing hadron scattering process with helicity flip, is suppressed, as compared with $u(s,b)$ describing the scattering without helicity flip.

The main features of the quark model for the U-matrix[4] are as follows:

- quasi-independence of the valence quark scattering by the effective field created by hadron structure overlapping (gluon clouds);
- a short-range character of the valence quark interaction with the effective field, in this $r_q \sim m_q^{-1}$ in accordance with the assumption on the localization of the quark color field;
- qualitative difference of the mechanisms of valence quark scattering with and without helicity flip.

The expression for the U-matrix is represented as a product of quark amplitudes

$$u(s,b)=\prod_{q=1}^{N} f_q(s_q,b), \qquad (3)$$

and the expression for $f_q(s_q,b)$ has the form[4]:

$$f_q(s_q,b)=g_q\sqrt{s}\,\exp[-m_q b+i\phi_q(s)] \quad (4)$$

In formula (3) N is a total number of valence quarks in hadrons a and b: $N=n_a+n_b$. The expression for u(s,b), thus, has the form

$$u(s,b)=iC\left(\frac{s}{M^2}\right)^{N/2}\exp(-Mb), \quad (5)$$

where $M=\sum_{q=1}^{N} m_q$. When deriving (5) we single out the imaginary unit for the conveniency.

Let us now consider the construction procedure for the expressions for the function $u_o(s,b)$ and $u_f(s,b)$, connected with the dynamics of the binary reaction $a+b\to c+d$. As was shown in work[6] the helicity flip of hadron in inelastic binary processes takes place due to the helicity flip of valence quarks in inelastic quark transitions $q(\uparrow)\to q'(\downarrow)$. The contribution from the transitions $q(\uparrow)\to q(\downarrow)$ turns out to be suppressed over energy. Then with the notions adopted in the model about hadron structure and their interactions being taking into consideration, one may present the functions $u_o(s,b)$ and $u_f(s,b)$ as a product of the quark elastic scattering factors f_q and the function $\varkappa_o$ and $\varkappa_f$ which describe quark inelastic transitions. These processes have a smaller radius, and therefore an inelastic binary process is connected with the interactions in the region of distances smaller than in the case of elastic scattering. In accordance with what was said above, one has

$$u_{o,f}(s,b)=\varkappa_{o,f}(\{s_{q'}\},b)\prod_{q=1}^{N-N'} f_q(s_q,b), \quad (6)$$

where N' is the number of valence quarks, participating in inelastic quark transitions, the ratio of the functions $\varkappa_o/\varkappa_f=1$, which is connected with an equal probability of transitions $q(\uparrow)\to q'(\downarrow)$ and $q(\uparrow)\to q'(\uparrow)$[5].

Let us now introduce the functions $\phi_o(s,b)$ and $\phi_f(s,b)$ by the relations:

$$\phi_{o,f}(s,b)=\frac{u_{o,f}(s,b)}{u(s,b)}=\frac{\varkappa_{o,f}(\{s_{q'}\},b)}{\prod_{q'=1}^{N'} f_{q'}(s_{q'},b)}, \quad (7)$$

For simplicity we shall use for ϕ_o and ϕ_f expressions in a factorized form

$$\phi_{o,f}(s,b)=gs^{-\lambda}\,\gamma(b)e^{i\alpha_{o,f}(s)}, \qquad (8)$$

which with an account of the relation between $\varkappa_o$ and $\varkappa_f$ differ from each other in the phases α_o and α_f. The choice of the energy dependence of these functions in form (8) corresponds to the power-law decrease of the cross sections $\sigma_{ab\to cd}(s)\sim s^{-2\lambda}(\ln s)^{\delta}$, $\delta < 2$ [1].

The quantity $\gamma(b)$ decreases with the growth of b, but slower than any exponential [1].

The method of calculating the amplitudes F_o and F_f is based on the analysis of the singularities in the complex plane of the impact parameter [3]. At fixed momentum transfers the behaviour of the amplitudes F_o and F_f is determined by the poles in the impact parameter plane. The position of the poles is given by the solution of equation $1-iu(s,\beta)=0$, where $\beta=b^2$. The representation (1) takes into account effects of interaction in the initial state. This is reliable approximation for the states ab and cd (for the ab→cd processes), which have nearly the same quark composition. Here contrary to the elastic scattering amplitude, the main role in inelastic binary processes is played by the poles whose imaginary part is minimal $\beta_{\pm}(s)=$ $=[R(s)\pm i\frac{\pi}{M}]^2$ where R(s) is an effective radius of elastic scattering: $R(s)=\frac{N}{M}\ln s$ at $s\to\infty$. Thus for the momentum transfers, $-t>1$ and at large values of s for the amplitudes, $F_o(s,t)$ and $F_f(s,t)$ one will have

$$F_{o,f}(s,t)=g_{o,f}(s)\exp(-\frac{\pi}{M}\sqrt{-t})\,\Phi_{o,f}(R(s),\sqrt{-t}), \qquad (9)$$

where Φ_o and Φ_f are the known functions of R(s) and $\sqrt{-t}$.

Hence the angular distributions in inelastic binary processes decrease according to Orear law:

$$\frac{d\sigma}{dt}\sim \exp(-\frac{2\pi}{M}\sqrt{-t}) \qquad (10)$$

and may have oscillations depending on the concrete form of the function $\gamma(\beta)$.

As is seen from relation (10), the law of angular distribution decreases in inelastic binary reactions $a+b\to c+d$ and in the corresponding elastic process at sufficiently large $-t$ coincides. The value for the universal slope is determined by the quantity $M = \sum_{q=1}^{N} m_q$. Note, that the conclusion on the universality of the slope is valid in the case considered, and for the reaction with arbitrary spin of hadrons, since in this case as well the behaviour of the helicity amplitudes will, as before, be determined by pole position in the β-plane, which is connected with the dynamics of elastic scattering.

Function (10) in the case when $m_u = m_d = m_q$ is compared with the angular distributions in the reactions $\pi^- p \to (\pi^0, \eta, \eta', \omega) n$ measured at p_L=40 GeV/c /6/ (see fig. 1). As is seen from the figure, the experimental data available are in a good agreement with universal dependence (10). Here the value for m_q= 190 MeV, which follows from the analysis of the angular distributions in elastic pp-scattering at high energies, is used.

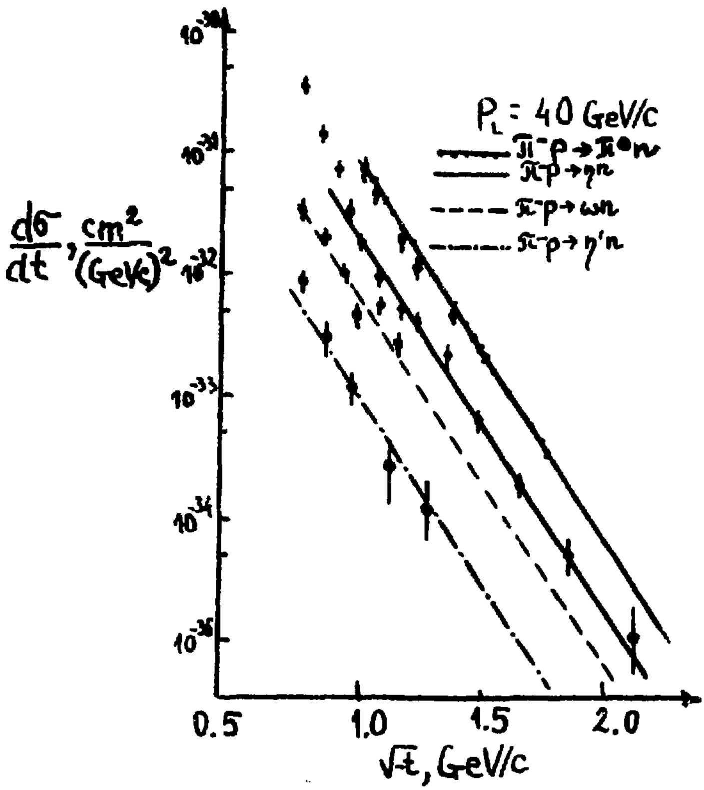

Fig. 1.

With the help of expression (9) one can easily obtain the following expression for the polarization parameter large values for $-t$ ($-t > 1$ $(GeV/c)^2$):

$$P(s,t) = -\sin\Delta(s) 2M\sqrt{-t}\cos[2R(s)\sqrt{-t}] \cdot$$
$$\cdot \{M^2 - t - (M^2+t)\sin[2R(s)\sqrt{-t}]\}^{-1}, \qquad (11)$$

where $\Delta(s)=\alpha_o(s)-\alpha_f(s)$. In contrast with the angular distributions, polarization does not depend on the form of the function $\gamma(b)$. As it follows from formula (11) the polarization for different final states in the reaction $ab \to cd$ has a universal dependence on t (identical position of zeros). Fig. 2 gives the results on comparing the calculational results on polarization made with formula (11), with experimental data at 40 GeV[9]. The parameters R and M were borrowed from the analysis of the elastic scattering R=1f, M=0.95 GeV, and the quantity $\sin\Delta(s)$ was treated as a free parameter.

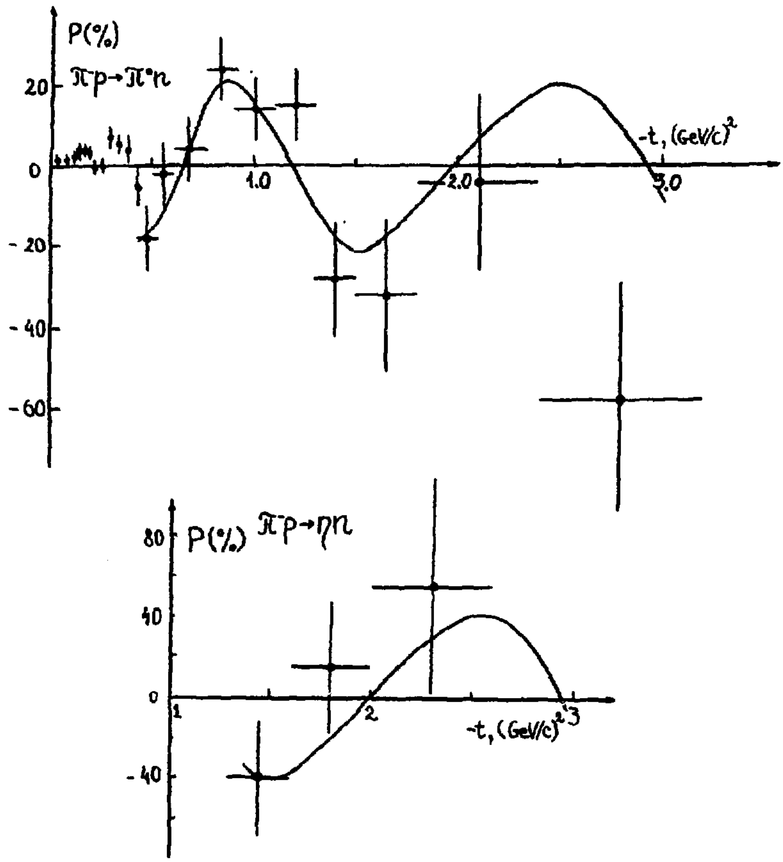

Fig. 2.

2. CONCLUSIONS AND DISCUSSIONS

Thus on the basis of the quark model for the U-matrix it has been shown that the cross sections in the region of fixed momentum transfers in inelastic binary reactions have an equal slope, whose value is determined by the sum of masses of constituent quarks in the initial hadrons. This result is reliable for processes which have nearly the same quark composition in the initial and final states. Such a dependence in the behaviour of the angular distribution is confirmed experimentally. The analysis also shows that polarization in inelastic binary processes reveals an oscillating behaviour and universal position of zeros, which is determined by the effective radius of the corresponding elastic scattering process.

The regularities quoted are a manifestation of dynamic effects connected with the fulfilment of the unitarity condition in the direct channel of the reaction, which is effectively taken into account in the approach treated here.

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