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A DUAL RESONANCE MODEL FOR HIGH ENERGY
DIFFRACTION DISSOCIATION

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ABSTRACT

Diffraction dissociation (Pomeron exchange) is combined with a dual resonance description for the dissociated system. The model is applied to single pion production in high energy proton-proton collisions and shown to give quite good agreement with experimental data.

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1. INTRODUCTION

For the study of hadronic multiparticle production, a certain class of reactions gains particular importance with increasing incident energy : the so-called diffraction dissociation processes ^{1),2)}. In general, production cross-sections decrease quite rapidly with increasing energy; however, reactions of the type

approach constant asymptotic cross-sections, when the system X has, apart from possible spin and parity changes, the same quantum numbers as B . Such diffraction dissociation processes will thus provide a significant contribution even at very high energies and may perhaps build up a considerable fraction of the asymptotic total inelastic cross-section ³⁾.

Experimental investigations ⁴⁾⁻⁶⁾ of diffraction dissociation show generally a rather low invariant mass with strong resonance structure for the system X . Together with the asymptotic constancy of the cross-sections, this property has led to theoretical descriptions ^{7),8)} in terms of two-body processes (i.e., $PP \rightarrow PN^*$, etc.) in a Regge picture with Pomeron exchange between A and B .

On the other hand, diffraction dissociation processes contribute significantly in single and double pion production ^{9),10)} and it is therefore desirable to obtain a description for them in the framework of multiparticle production dynamics.

The first step in this direction is provided by the one-pion exchange model (OPE) (cf., Fig. 1), where the elastic πA scattering (with off-shell incident π) is dominated by $\mathbb{P}$ exchange at high energies. While this model in its simplest form deviates strongly from experimental high energy results, modified versions [cf., e.g., Refs. 10)-12)] which introduce additional form factors, etc., have yielded a fairly good quantitative description of many experimental features. Besides the necessity of introducing such modifications, the essential

shortcoming of this type of model is that it describes the system X , which is of low mass and exhibits a strong resonance structure, at best in some kind of average sense.

This situation is not significantly improved (and results are not greatly altered) by reggeization of the π exchange ¹³⁾; moreover, one is faced with the difficulty of justifying the high energy Regge form for the low mass of the system X . The fact that these models nevertheless provide fairly good average descriptions appears understandable in the context of duality arguments ¹⁴⁾, which indeed indicates that in many cases high energy Regge amplitudes yield an averaged description of low energy resonance behaviour.

The further development of duality concepts has recently led to the construction of a two-body amplitude ¹⁵⁾ which describes "locally" (i.e., not only averaged) both the low energy resonance and high energy Regge behaviour in terms of the relevant trajectories for the s , t and u channels. This Veneziano amplitude was then generalized to describe more than two outgoing particles ^{16), 17)}; such generalizations have been employed ¹⁸⁾ with remarkable success in the analysis of $PK \rightarrow \Lambda \pi \pi$.

In all multiparticle applications so far, however, the Pomeron [as presumably not dual to low energy resonances ¹⁹⁾] had to be excluded, either by studying processes at very low energies ^{20), 21)} or by selecting reactions (such as the above KP case) where $\mathbb{P}$ exchange cannot occur.

The aim of the present paper is to propose and apply a model combining high energy diffraction dissociation (i.e., $\mathbb{P}$ exchange : $I^G = 0^+$, $J^P = 0^+$) with a dual resonance description for the excitation of the composite system X in the case of single pion production.

2. FORMULATION OF THE MODEL

In the following, we shall consider the $\mathbb{P}$ exchange dissociation of a nucleon into a πN final state

$$A N \rightarrow A (\pi N) \quad (2.1)$$

where A can be any meson or baryon (cf., Fig. 2). We define the relevant variables as follows :

$$\bar{s} = (p_A + p_N)^2 \quad (2.2)$$

$$t_{AA} = (p_A - p'_A)^2 \quad (2.3)$$

$$s = (p'_N + q)^2 \quad (2.4)$$

$$t = (p_N - p'_N)^2 \quad (2.5)$$

$$u = (p_N - q)^2 \quad (2.6)$$

We assume now the matrix element for (2.1) to factorize into an $AA\bar{P}$ vertex determined by asymptotic elastic scattering $AA \rightarrow AA$ and a "two-body" amplitude V describing the process $\bar{P}N \rightarrow \pi N$:

$$M \sim e^{\frac{i}{2} t_{AA}} \bar{s} V \quad (2.7)$$

For the Pomeron we have taken unit intercept and zero slope.

For V we now want to introduce a dual resonance amplitude analogous to that proposed by Veneziano ¹⁵⁾, i.e., it will be a function only of the relevant (linear) trajectories in the s , t and u channels and will not contain any further dependence on external masses (in particular that of the Pomeron). In our case, we consider two non-degenerate trajectories for both s and u channels, one (N^+) containing the nucleon and one (N^-) the $N^*(1518)$, and the (degenerate) π and A_1 trajectories for the t channel. The amplitude V can now be decomposed into the invariant amplitudes $A(s,t,u)$ and $B(s,t,u)$

$$V \sim \bar{u}(p'_N) \gamma_5 (A + \frac{1}{2} B \gamma_\mu [q^\mu + k^\mu]) u(p_N) \quad (2.8)$$

Since present experimental evidence ^{13),22)} seems to favour a much weaker coupling for the A_1 trajectory than for the π , we shall try to simply

neglect it as a first approximation and, hence ²²⁾, set $B=0$. Using the known N^+ , N^- and π trajectories we now write for the remaining invariant amplitude A the Veneziano form

$$\begin{aligned}
 A \sim & [B(\tfrac{1}{2} - \alpha_N^+(s), -\alpha_\pi(t)) + B(\tfrac{1}{2} - \alpha_N^+(s), \tfrac{1}{2} - \alpha_N^+(u)) \\
 & + B(\tfrac{1}{2} - \alpha_N^+(u), -\alpha_\pi(t))] \\
 & + \beta [B(\tfrac{1}{2} - \alpha_N^-(s), -\alpha_\pi(t)) - B(\tfrac{1}{2} - \alpha_N^-(s), \tfrac{1}{2} - \alpha_N^-(u)) \\
 & + B(\tfrac{1}{2} - \alpha_N^-(u), -\alpha_\pi(t))] \quad (2.9)
 \end{aligned}$$

with $B(x,y) = \Gamma(x)\Gamma(y)/\Gamma(x+y)$ and $\alpha_N^\pm$ denoting respectively the $N^\pm$ trajectory. The arguments of the B functions, as chosen, give the correct pole structure and Regge behaviour in all three channels (this is a direct consequence of not neglecting baryon spins); A moreover has the correct s - u crossing symmetry. Requiring the N^+ term to contribute on the parent level only to resonances $1/2, 5/2, \dots$ and N^- only to $3/2, 7/2, \dots$, together with the condition of no A_1 exchange in the t channel, uniquely fixes the relative weights and signs of the various $B(x,y)$ terms. Apart from the over-all normalization, this leaves only one open parameter, namely the relative coupling strength β of the N^+ and N^- trajectories.

Our amplitude, as constructed, gives rise to resonances of both parities at each spin value; this "parity doubling" seems so far to be a general property ²³⁾ of (linear trajectory) Veneziano amplitudes involving particles of spin one-half. While experimentally many nucleon resonances exhibit such a doublet structure, it is not clear at present if both partners can be produced by high energy diffraction dissociation. It has been proposed ²⁴⁾ that such processes obey the spin parity selection rule $\Delta P = (-1)^{\Delta J}$, J and P denoting, respectively, spin and parity of the system X . For the dissociation of a pseudoscalar meson (e.g., $K \rightarrow K\pi$) such a rule follows already from our $J^P = 0^+$ assignment for the Pomeron, whereas this is not true in the case of meson-baryon systems.

In the application we shall not be interested in polarization effects; we then have

$$|\overline{M}|^2 \sim e^{a t_{AA}} \int dt |V|^2 \quad (2.10)$$

for the squared matrix element $[(2.7)/(2.8)]$ summed over final and averaged over initial nucleon spins.

3. APPLICATION TO THE REACTION $PP \rightarrow PN \pi^+$

The model, as described above, is applicable to $\pi^\pm$, $K^\pm$, P or N incident on nucleons; since it is constructed for high energy diffraction scattering, it is however necessary for a comparison with experimental results to have a sample of data which with reasonable certainty contains only $\mathbb{P}$ exchange. While this exchange contributes significantly even at quite low energies ⁹⁾, it is (e.g., in PP collisions) only for $P_{\text{Lab}} \sim 20-30$ GeV/c that one can be fairly sure of essentially only $\mathbb{P}$ exchange ^{10), 25)}, without making any cuts in sub-system masses (or other separation techniques). Since extensive data at such high energies are presently available only for PP collisions, we shall in the following consider the reaction $PP \rightarrow PN \pi^+$ at 28.5 GeV/c ⁶⁾.

The parametrization of the trajectories is used as follows

$$\begin{aligned} \alpha_n^+ &= -0.4 + s + i 0.16(s - s_0) \\ \alpha_n^- &= -0.95 + s + i 0.16(s - s_0) \\ \alpha_\pi &= -0.02 + s \\ s_0 &= (m + \mu)^2 \end{aligned} \quad (3.1)$$

which gives rise to poles at the observed masses and of the observed widths with the imaginary part as chosen. Writing elastic PP scattering in the form $\partial \sigma_{el} / \partial t \sim e^{2at}$, we obtain $a \simeq 5(\text{GeV})^{-2}$.

As mentioned, our formula (2.10) contains besides the over-all normalization, one open parameter β , the relative coupling strength

of N^+ and N^- . We have not attempted a fit for this parameter, but instead have chosen a value which fairly well reproduces the relative importance of N^+ to N^- trajectory effects in the dominant region in the over-all $N\pi^+$ mass distribution : $\beta = 1.5$.

The available 28.5 GeV/c results ⁶⁾ consist of $N\pi^+$ mass distributions in various t_{pp} intervals and of t_{pp} distributions for various $N\pi^+$ mass intervals. These data, together with the results from our model, are shown in Figs. 3-10. There is, moreover, experimental information published ¹³⁾ on the PN momentum transfer distribution (t) , which we give in Fig. 11 together with our results.

The over-all mass distribution (Fig. 3) clearly exhibits the experimentally observed resonance structure as well as a reasonable decrease with growing $N\pi^+$ mass. The 1400 MeV peak is in our case essentially provided by the first daughter of the N^+ trajectory at $J = \frac{3}{2}$ (the parent vanishing by construction at this point), together with the low mass "background" enhancement provided by the peripherality of the reaction; the effect at 1550 MeV is due to the $J = \frac{3}{2}$ pole (parent and daughter) from the N^- trajectory. As seen from Figs. 4 and 5, our amplitude also reproduces correctly the trend shown by the mass distributions in various t_{pp} intervals : with increasing t_{pp} higher mass resonances come more strongly into play.

Related to this effect is the most striking feature seen in the t_{pp} distributions (Figs. 6-10); with increasing $N\pi^+$ mass the slope of the t_{pp} distribution becomes flatter and flatter. Our calculations give the form $e^{bt_{pp}}$ with $b \simeq 11(\text{GeV})^{-2}$ for very small $N\pi^+$ masses and asymptotic convergence to $b = 5(\text{GeV})^{-2}$ as the $N\pi^+$ mass grows large, i.e., then $b \rightarrow a$. The experimental results exhibit the same effect, although apparently with somewhat larger slope for very small masses ($b \simeq 14 \pm 2 \text{ GeV}^{-2}$) and with possible fluctuations in the first peak.

It should perhaps be emphasized that we obtain this effect solely from the (experimental) $PP\pi$ vertex and the Veneziano amplitude for the excited $N\pi^+$ system, without any additional form factors depending on the Pomeron "mass". The obtained $(N\pi^+)$ mass dependence of the t_{pp} slope is essentially a consequence of the peripherality in PN momentum transfer and can be understood as follows. We have

$$\frac{\partial^2 \sigma}{\partial s \partial t_{pp}} \sim e^{at_{pp}} \int_{-1}^1 d(\cos \theta^Q) t |V(s, t)|^2 \quad (3.2)$$

with V depending on t_{pp} only as an external mass; θ^Q denotes the angle between incoming proton and outgoing neutron in the $N \pi^+$ c.m.s. For large $N \pi^+$ energies s the amplitude V becomes independent of all external masses and hence also of t_{pp} ; the dependence of the cross-section on this variable for large s is thus determined solely by the $PP\pi$ vertex and hence becomes $e^{at_{pp}}$. For small $N \pi^+$ masses, it is easy to verify that with $s \rightarrow (m + \mu)^2$

$$t \rightarrow (t_{pp} - \mu^2) m / (m + \mu) \quad (3.3)$$

and hence becomes independent of $\cos \theta^Q$. Since V is peripheral in t , from (3.3) we get an additional t_{pp} damping and hence a large slope b for the t_{pp} distribution. The peripherality of V in the PN momentum transfer t is shown in Fig. 11 and is seen to agree quite well with the experimentally observed dependence.

4. CONCLUSIONS

In the preceding Sections we have tried to formulate a dual resonance model for high energy diffraction dissociation. For the application of this model we have made the simplifying assumption that we have to deal with only one invariant amplitude; this left us with only one open parameter (and over-all normalization) for which we simply chose a value giving roughly the correct relative importance of N^+ to N^- trajectory effects.

Nevertheless, even this simplified form already gives quite good agreement with the available 28.5 GeV/c PP data. We would certainly expect even better agreement if a similar form is also adopted for the B amplitude; since this would however introduce two further parameters,

we considered our simpler version for presently available data as already quite informative. For possible improvement either by keeping a non-vanishing B or by simply performing a genuine fit for the parameter β , a particularly useful experimental quantity seems for us to be the (low mass) $N\pi^+$ angular distribution relative to the incident proton in the $N\pi^+$ c.m.s. ($\cos\theta^Q$), as this quantity seems to depend more critically than others on the choice of parameters. In our case the single parameter β (N^+/N^- coupling) also determines the relative contribution of t channel pion and nucleon exchange - hence the strong dependence of the $\cos\theta^Q$ distribution on β (for non-vanishing B this connection is, however, not as simple).

We thus find that diffraction dissociation processes - here asymptotic single pion production - can well be incorporated into a duality picture. Hopefully such a description can, on the one hand, be combined with the five-point Veneziano amplitude^{16),18)} (for non-Pomeron exchange) to give a model for single pion production also at non-asymptotic energies; on the other hand, Veneziano amplitudes for higher particle numbers in place of V may perhaps also provide us with a form for diffractive multiparticle production.

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FIGURE CAPTIONS

Figure 1 : One-pion exchange diagram.

Figure 2 : $\mathbb{P}$ exchange diagram for the process $A N \rightarrow A(\pi N)$.

Figure 3 : Experimental and theoretical over-all $N \pi^+$ distribution, with $0.02 \leq -t_{pp} \leq 0.8 \text{ (GeV)}^2$.

Figure 4 : Experimental and theoretical $N \pi^+$ distribution with $0.02 \leq -t_{pp} \leq 0.1$.

Figure 5 : Experimental and theoretical $N \pi^+$ distribution with $0.1 \leq -t_{pp} \leq 0.26$.

Figure 6 : Experimental and theoretical over-all t_{pp} distribution.

Figure 7 : Experimental and theoretical t_{pp} distribution for $1.1 \leq M_{N \pi^+} \leq 1.3$.

Figure 8 : Experimental and theoretical t_{pp} distribution for $1.3 \leq M_{N \pi^+} \leq 1.5$.

Figure 9 : Experimental and theoretical t_{pp} distribution for $1.5 \leq M_{N \pi^+} \leq 1.7$.

Figure 10 : Experimental and theoretical t_{pp} distribution for $1.7 \leq M_{N \pi^+} \leq 2.1$.

Figure 11 : Proton-neutron momentum transfer distribution ($t = t_{PN}$).

FIG.1

FIG.2

FIG.3

FIG.6

$$1.5 \leq M_{\pi^+ N} \leq 1.7$$

$$1.7 \leq M_{\pi^+ N} \leq 2.1$$

FIG.11