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ON THE MASS DEPENDENCE OF MOMENTUM TRANSFER DISTRIBUTIONS
IN DIFFRACTION DISSOCIATION ^{*)}

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A B S T R A C T

We investigate peripheral diffraction dissociation mechanisms together with diffractive resonance production and obtain predictions for structure in the mass dependence of the inelastic diffraction slope.

*) A preliminary report of this work was given at the Colloquium on High Multiplicity Hadronic Interactions, Paris, May 13-15, 1970.

The inelastic hadron process

$$A+B \rightarrow A+C+D+\dots$$

(1)

exhibits a striking similarity with elastic scattering whenever the system $X=C+D+\dots$ has, apart from a possible spin and natural parity changes, the same quantum numbers as B ("diffraction dissociation"): both processes give an exponential distribution for small momentum transfers as well as an integrated cross-section reaching a non-vanishing constant value with growing energy¹⁾. This suggests for (1) Pomeron exchange (cf., Fig. 1) as the dynamical mechanism at high energies. By assuming factorization, the $\mathbb{P}AA$ form factor $G(t_{AA})$ can be determined from elastic processes, e.g., from $d\sigma(AA \rightarrow AA)/dt \sim \exp 2at$ we get $G(t_{AA}) = \exp(at_{AA}/2)$. At the dissociation vertex V_X we shall treat the Pomeron essentially as a particle²⁾, i.e., we take V_X to be the amplitude for the process $\mathbb{P}+B \rightarrow C+D+\dots$, with $m_{\mathbb{P}}^2 = t_{AA}$. In the present note we want to employ this picture to study the behaviour of the inelastic diffraction slope $R(M_X)$

$$\frac{d^2\sigma}{dt_{AA} dM_X} \sim e^{R(M_X)t_{AA}}; \quad M_X = \sqrt{(p_C + p_D + \dots)^2}$$

(2)

as function of M_X .

Consider first the limit of large M_X [keeping of course $M_X^2 < (p_A + p_B)^2$]. Since in our picture V_X contains t_{AA} only as external mass, that of the Pomeron, and since this is moreover bounded by $G(t_{AA})$, we find V_X (for X going to a definite final state $X \rightarrow C+D+\dots+L$) becoming independent of t_{AA} as $M_X \rightarrow \infty$ ("high energy limit" for $\mathbb{P}+B \rightarrow C+D+\dots+L$). With $G(t_{AA}) = \exp(at_{AA}/2)$ we thus find

$$\lim_{M_X \rightarrow \infty} R(M_X) = a \quad (3)$$

with the value of a determined from elastic scattering.

To investigate the low M_X region, we restrict ourselves for simplicity to $X \rightarrow C+D$, the arguments being easily extendable to general X . At threshold $M_X = m_C + m_D$, we have

$$t_{BC} = t_{AA} \left(\frac{m_C}{m_C + m_D} \right) + \text{const.} \quad (4)$$

with an analogous relation between t_{BD} and t_{AA} . Hence, any peripherality (momentum transfer damping in t_{BC} or t_{BD}) for $\mathbb{P} + B \rightarrow C+D$ will, for small M_X , give rise to an additional t_{AA} damping as well ^{2), 3)}. We thus expect $R(M_X)$, starting from large threshold values, to decrease with increasing M_X towards its asymptotic value of one-half the elastic slope.

This over-all picture is indeed in agreement with the present experimental results ($\pi\mathcal{N} \rightarrow \mathcal{N} 2\pi$ ⁴⁾, $\mathcal{N}\mathcal{N} \rightarrow \mathcal{N}\mathcal{N}\pi$ ⁵⁾, $\mathcal{N}\mathcal{N} \rightarrow \mathcal{N}\text{MM}$ ⁶⁾, $\gamma^* P \rightarrow \pi^+ \pi^- P$ ^{7), 8), 9)}, $\pi\mathcal{N} \rightarrow 3\pi\mathcal{N}$ ¹⁰⁾, $\bar{K}\mathcal{N} \rightarrow \bar{K} 2\pi\mathcal{N}$ ¹⁰⁾), which all give slopes starting at about $R \simeq 10-15 \text{ GeV}^{-2}$ at threshold and decreasing to about $R \simeq 3.5-5 \text{ GeV}^{-2}$ for M_X , one to two GeV above threshold, in accord with the measured elastic $\pi\mathcal{N}$ and $\mathcal{N}\mathcal{N}$ slopes of about $7-10 \text{ GeV}^{-2} = 2a$. As illustration we show in Fig. 2 the R behaviour for $\pi^- P \rightarrow N \pi^+ \pi^-$ ⁴⁾ and for $\gamma^* P \rightarrow \pi^+ \pi^- P$ ⁸⁾.

We now want to point out that beyond this over-all behaviour $R(M_X)$ should, in fact, exhibit a "fine structure" in its dependence on M_X . Let us again consider a three-body final state, $X \rightarrow C+D$. As the mass M_{CD} of the dissociated system passes from threshold to a few GeV, the two-body process $\mathbb{P} + B \rightarrow C+D$ (for which M_{CD} is

the c.m.s. energy) will in general pass through a more or less "resonant" low energy to a (e.g., "Regge") high energy region. As in most two-body processes ¹¹⁾, one thus expects a very different momentum transfer behaviour in different energy intervals; by the above arguments, such variations in t_{BO} (or t_{BD}) behaviour will then in turn give rise to variations of the t_{AA} behaviour, i.e., to a $R(M_X)$ "fine structure".

To illustrate these effects in more detail, we consider diffractive two-pion photoproduction

$$\gamma P \rightarrow \pi^+ \pi^- P$$

(5)

where one finds for $P + \gamma \rightarrow \pi^+ \pi^-$, t and u channel pion exchange in addition to the very strong s channel ρ production ¹²⁾. The squared matrix element for (5), averaged over photon polarization and nucleon spin, can be written in terms of one invariant amplitude $A(s,t,u)$ ¹³⁾

$$|M|^2 \sim \bar{s}^2 e^{at_{PP}} (s - 4\mu^2) \sin^2 \hat{\theta} |A(s,t,u)|^2$$

(6)

with $\bar{s} = (p_\gamma + p_P^{in})^2$, $s = (p_{\pi^+} + p_{\pi^-})^2$, $t = (p_\gamma - p_{\pi^-})^2$, $u = (p_\gamma - p_{\pi^+})^2$, $p_{\pi^\pm}^2 = \mu^2$, and with $\hat{\theta}$ denoting the angle between γ and $\pi^- \pi^+$ in the two-pion c.m.s.

We can study the effect of a peripheral two-body process $\gamma + P \rightarrow \pi^+ \pi^-$ without direct channel resonances by taking for $A(s,t,u)$ the sum of t and u channel Born terms

$$A(s,t,u) = \left[\frac{1}{t - \mu^2} + \frac{1}{u - \mu^2} \right]$$

(7)

The resulting $R(M_{2\pi})$ is seen in Fig.3a: a smooth monotonic decrease towards the asymptotic $R=a$, here with $a=5 \text{ GeV}^{-2}$. Adding now the direct channel ρ in the form

$$A(s,t,u) = \left[\frac{1}{t-\mu^2} + \frac{1}{u-\mu^2} + \frac{2}{s-m_\rho^2 + i m_\rho \Gamma_\rho} \right] \quad (8)$$

gives rise to Fig.3b, which indeed shows a pronounced dip a little above $M_{2\pi} = m_\rho$: since the strongly t (or u) damped pion exchange terms are almost negligible in the immediate ρ vicinity, R there falls back to the input a . The full dual-resonance amplitude ¹³⁾

$$A(s,t,u) = B(1-\alpha_\rho^s, -\alpha_\pi^t) + B(1-\alpha_\rho^s, -\alpha_\pi^u)$$

$$B(x,y) = \Gamma(x)\Gamma(y)/\Gamma(x+y)$$

(9)

with pion (α_π) and rho (α_ρ) trajectory finally gives Fig.3c, a similar R behaviour as for (8), but with additional high mass variations ^{*)}.

We emphasize here again that structures of this kind in $R(M_X)$ are a direct consequence of the different momentum transfer restrictions of $\pi P \rightarrow C+D$ in resonant and non-resonant M_{CD} regions, and as such of a considerable more general nature than specific dual (or interference) models used here for illustration.

Experimentally, the situation is at present rather curious: while most experiments ^{4), 8), 10)} do, in fact, show dips in the slope near resonance positions, e.g., in Fig.2 near the N_{1470}^*/N_{1520}^* for $\pi^- P \rightarrow \pi^- \pi^+ N$ and near ρ for $\gamma P \rightarrow \pi^+ \pi^- P$, the statistics for each experiment are somewhat too low for any definite conclusion.

*) The amplitude (8), which, in general, gives a good approximation to (9) up to ~ 1 GeV, can be obtained from (9) by the Sivvers-Yellin expansion ¹⁴⁾, keeping only first poles ¹⁵⁾.

Moreover, the lab. momenta of most of the mentioned experiments (usually $P_{\text{lab}} \lesssim 10 \text{ GeV}/c$) may still allow contamination by non-diffractive effects, particularly for large M_X .

We therefore consider further experimental investigation of inelastic diffraction slopes to be of great interest for the understanding of diffraction dissociation dynamics.

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FIGURE CAPTIONS

Figure 1 :

Diffraction dissociation diagram.

Figure 2 :

- a) : Diffraction slope $R(M_{\pi^+N})$ for $\pi^-P \rightarrow \pi^- \pi^+N$
at 11 GeV/c, Ref. 4).
- b) : Diffraction slope $R(M_{\pi^+\pi^-})$ for $\gamma^*P \rightarrow \pi^+ \pi^-P$
at 5 GeV/c, Ref. 8).

Figure 3 :

- $R(M_{CD})$ for
- a) t and u channels exchange only;
 - b) interference model;
 - c) dual resonance model.

FIG.1

FIG.2a

FIG. 2b

FIG.3