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THE PERIPHERAL IMPACT PARAMETER DESCRIPTION

OF INELASTIC DIFFRACTION DISSOCIATION

AT VERY HIGH ENERGIES

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ABSTRACT

A simple peripheral impact parameter model for inelastic diffraction dissociation is used to describe both the very high energy exclusive process $pp \rightarrow p\pi^+n$ and the inclusive process $pp \rightarrow pX$.

It is found that the width of the impact parameter profile has a small dependence on s/M^2 which is compatible with a Regge shrinkage factor of the form $(s/M^2)^{0.17t}$. It is suggested that the profile is independent of the number of particles produced; and that the non-vanishing of the triple Pomeron coupling and the sharp t -behaviour of the inclusive distributions at small M^2 values is the generalisation of the slope-mass correlation effect observed in exclusive processes.

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1. INTRODUCTION

In a previous paper [1] a simple peripheral impact parameter model of inelastic diffraction scattering was proposed to account for the observed correlation between the slope of the momentum transfer distributions and the mass M of the dissociated system. In describing some few body exclusive diffraction reactions at laboratory energies below 20 GeV/c it was found that the data are compatible with the following general features:

- i) Each helicity amplitude has the same peripheral impact parameter profile (except for a necessary, but trivial modification so that the profile behaves like $b^{\Delta\lambda}$ near $b = 0$). This is the universal impact parameter (UIP) hypothesis [1] or "b-universality" [2].
- ii) The relative strength of each helicity amplitude profile reaches a universal limiting value. This limiting value is independent of the type of particles involved, though the way the limit is approached depends on the structure of the dissociating system and the amount of net helicity flip $\Delta\lambda$. This is the universal limiting strength (ULS) hypothesis.

Besides these two features it was also observed that for the reactions considered the impact parameter profile depended only on the particles in the initial state. That is to say the data did not demand any large variation of the profile, either with the mass M of the dissociated system or with the number of particles n in the final state. However, in Ref. 1 the ranges of M and n were too limited to examine this feature in detail. Moreover, the range of incident particle momentum considered in [1] was also too limited to examine the behaviour of the universal impact parameter profile as a function of the centre-of-mass energy $\sqrt{s}$.

In order to study a much larger range of s and M^2 therefore, in this paper we use the same model to describe the very high energy $pp \rightarrow p\pi^+n$ diffraction dissociation data obtained recently at the ISR [3] and the inclusive diffraction dissociation data from both NAL and ISR [4-7]. We find that the same model parameter which described the 19 GeV/c

$pp \rightarrow p\pi^+ n$ data [1] can also describe these very high energy data, provided we introduce a typical Regge shrinkage factor

$$(s/M^2)^{\alpha_{\mathbb{P}}(t)}$$

where the effective Pomeron trajectory $\alpha_{\mathbb{P}}(t)$ has a small slope $\alpha' \lesssim 0.17$ $(\text{GeV}/c)^{-2}$. We shall argue below that this result suggests that for larger values of M the momentum transfer distributions $d\sigma/dt'$ for diffraction dissociation are independent of the number of particles in the final state. For small values of M however, these distributions will depend on the properties of the diffractively produced system, in particular on n . Moreover, we stress that the non-vanishing of the triple-Pomeron coupling, and the corresponding "spike" in the small t -region of the inclusive distributions has a very natural explanation in terms of this model.

2. THE MODEL

Let us write the differential cross-section for the process $p+p \rightarrow p+X(M)$ in terms of the s -channel helicity amplitudes $t_{\Delta\lambda}(s, t', M)$ such that

$$\frac{d\sigma}{dt'} = \sum_{\Delta\lambda} |t_{\Delta\lambda}(s, t', M)|^2 \quad (1)$$

where $t' = t - t_{\min}$ and $\Delta\lambda = |\lambda_{\text{initial}} - \lambda_{\text{final}}|$. The "b-universality" hypothesis suggests that if we transform these helicity amplitudes to b -space such that

$$H_{\Delta\lambda}(s, b, M) = \int_0^\infty T_{\Delta\lambda}(s, t', M) T_{\Delta\lambda}(b\sqrt{-t'}) d(-t') \quad (2)$$

then $H_{\Delta\lambda}(s, b, M)$ has the same b dependence, away from $b = 0$, for all values of $\Delta\lambda$; i.e.

$$H_{\Delta\lambda}(s, b, M) \sim H(s, b, M), \quad b > 0. \quad (3)$$

Near $b = 0$ of course, $H_{\Delta\lambda}(s, b, M)$ must behave like $b^{\Delta\lambda}$ in order that the corresponding helicity amplitudes have the correct $(-t')^{\Delta\lambda/2}$ structure near $t' = 0$.

In [1] a suitable peripheral b-space profile was found to be

$$H_{\Delta\lambda}(s,b,M) \propto \frac{1}{2a} e^{-(b+b_0)^2/4a} I_n(bb_0/2a) \quad (4)$$

which for $b > 2ab_0$ becomes

$$H_{\Delta\lambda}(s,b,M) \propto \frac{1}{\sqrt{4\pi b b_0 a}} e^{-(b-b_0)^2/4a}; \quad (5)$$

i.e. approximately Gaussian, centred around $b=b_0$ with a width $2\sqrt{a}$ and independent of n . This form is particularly convenient since it transforms back to give the simple Bessel function parameterisation

$$T_{\Delta\lambda}(s,t',M) \propto e^{at'} J_{\Delta\lambda}(b_0\sqrt{-t'}). \quad (6)$$

In order to investigate the M dependence of these amplitudes let us note that the maximum value of $\Delta\lambda$ in the sum in Eq (1) is determined by the maximum spin, $j_{\max}$, of the dissociated system X . For low values of M therefore, where $j_{\max}$ is likely to be very small, only one or two helicity amplitudes can contribute. As the mass M increases however, so will $j_{\max}$ and there is a good probability that several helicity amplitudes are populated*. In [1] it was found satisfactory to parameterise this M dependence of the helicity amplitudes solely by means of multiplicative strength functions, such that,

$$T_{\Delta\lambda}(s,t',M) = e^{at'} J_{\Delta\lambda}(b_0\sqrt{-t'}) h_{\Delta\lambda}(M) \quad (7)$$

$$\begin{aligned} \text{where } h_{\Delta\lambda}(M) &= 0, & M < M_R^{(\Delta\lambda)} - \Delta_R^{(\Delta\lambda)} \\ h_{\Delta\lambda}(M) &= h_{\Delta\lambda}^{\infty} (M^2)^{\gamma}, & M > M_R^{(\Delta\lambda)} \end{aligned} \quad (8)$$

with $M_R^{(\Delta\lambda)}$, $\Delta_R^{(\Delta\lambda)}$ are certain (resonance) parameters, and $h_{\Delta\lambda}(M)$ increases smoothly from $M_R^{(\Delta\lambda)} - \Delta_R^{(\Delta\lambda)}$ to $M_R^{(\Delta\lambda)}$. While these parameters may change from one diffractive process to another it was found that the relative

*) It was argued in [1] that it was this feature together with the distinctive t' -dependence of the J_n Bessel functions which gave rise to the slope mass correlation.

strengths of the helicity amplitudes, h_m^∞/h_o^∞ , appeared to have little or no dependence on the particular process considered; i.e. they satisfied the ULS hypothesis.

3. DESCRIPTION OF INELASTIC DIFFRACTION DISSOCIATION AT VERY HIGH ENERGIES

If the universal limiting strength hypothesis is indeed satisfied, then the model defined by Eqs (1), (7) and (8) together with the limiting values of h_n^∞/h_o^∞ obtained from fitting say the process $pp \rightarrow p\pi^+n$ at 19 GeV/c, i.e.

$$\begin{aligned} h_1^\infty/h_o^\infty &= 1.24 \\ h_2^\infty/h_o^\infty &= 1.48 \\ h_3^\infty/h_o^\infty &= 1.98 \\ h_4^\infty/h_o^\infty &= 0.132 \\ h_n^\infty/h_o^\infty &\sim 0.0, \quad n \geq 5 \end{aligned} \tag{9}$$

should also describe the very high energy inelastic diffraction dissociation data for both exclusive and inclusive processes. Of course, for small values of the dissociated mass M we must also specify the way in which the limiting values of Eq (9) are approached. However, since the very high energy exclusive reaction $pp \rightarrow p\pi^+n$ we consider is one of the processes considered in [1] we shall take the same $M_R^{(\Delta\lambda)}$ and $\Delta_R^{(\Delta\lambda)}$ parameters of the (π^+n) system as we did there. For the inclusive process $pp \rightarrow p+X$ on the other hand we shall have to modify this parameterisation as discussed below; or confine our attention to large values of M^2 where we believe the helicity amplitudes should have reached their limiting strengths.

To complete the model we must also specify the parameters b_o and a which determine the universal impact parameter profile. For simplicity, initially we take the value of $b_o = 5.68 \text{ (GeV/c)}^{-2}$ which was obtained in [1] for pp reactions. Hence, the only remaining free parameters besides

the overall normalisation, are the width parameter a and the parameter γ which determines the absolute M^2 dependence of all helicity amplitudes.

A) $pp \rightarrow p\pi^+n$ at $s = 2809 \text{ GeV}^2$

The data we consider for this process come from the recent ISR experiment using the Split-Field-Magnet Facility which was augmented with special neutron detectors [3]. The diffractively produced π^+n mass distribution at this energy is found to be very little different to that observed at lower energies. Hence, we should expect the value of γ which determines the high M dependence of this distribution should be little different to the value of 1.0 obtained in [1]. However, as noted in [3] the slope of the momentum transfer distributions at various values of M is approximately two units larger than for the corresponding distributions at 12 and 24 GeV/c [9]. We might expect therefore that the width parameter a must increase by approximately one unit from its value of 2.86 GeV^{-2} obtained at 19 GeV/c.

Allowing only this one parameter a to vary from its value obtained in [1], therefore, we see in Fig. 1 that the model can also very satisfactorily describe the very high energy $pp \rightarrow p\pi^+n$ differential cross-sections^{*)}. The dramatic change of slope and structure in the t' distributions with increasing M is again well accounted for by the increasing contribution of higher helicity amplitudes, and the assumption of a peripheral impact parameter. In particular the pronounced structure in the lowest mass bin is found to be the residual effect of the dip near $t' \approx 0.2$ of the J_0 Bessel function which parameterises the $\Delta\lambda = 0$ amplitude [1].

*) In the lowest mass region, as in [1] we again include a small background term $\frac{g}{M^{0.5}} e^{2t'}$ in order to partially fill in the deep dip of the J_0 Bessel function at $t' = -0.2 \text{ (GeV/c)}^2$. However, as discussed there, this is not necessary if one changes slightly the form of the strength functions $h_n(M)$.

The actual value of $a = 3.6$ used in Fig. 1 compared with the value of 2.86 at 19 GeV/c corresponds to a Regge shrinkage factor^{*)}

$$\left(\frac{s}{M_o^2} \right)^{\alpha' t} \quad (10)$$

with $\alpha' \approx 0.17 \text{ (GeV/c)}^{-2}$. Thus we see that both the 19 GeV/c data and the ISR data can be quite compatible with our two basic hypotheses:

- i) b-universality
- ii) universal limiting strengths.

provided that the universal input parameter profile, while still being centred around 1.1 fm (i.e. $b_o \approx 5.68 \text{ GeV}^{-2}$), has a (width)² which increases logarithmically with the c.m. energy, i.e.

$$a = 2.4 + 0.17 \log \left(\frac{s}{M_o^2} \right) \quad (11)$$

(In fact although we also tried other fits in which the profile position b_o was allowed to vary, no significant improvement could be found for any different value of b_o).

It is interesting to note that, because of this s-dependence of a , the ratios $\sigma_{\Delta\lambda} / \sigma_o$ of the helicity flip cross-sections change quite appreciably between 19 GeV/c and ISR energies - as much as 50% for the high values of $\Delta\lambda$. Hence, if we had used these ratios instead of the ratios $h_{\Delta\lambda} / h_o$ in the ULS hypothesis, the curves in Fig. 1 would not have described the data so well, at least without further changes in the parameterisation.

B) $pp \rightarrow p+X$ from $s = 400$ to 1000 GeV^2

To test this picture of inelastic diffraction dissociation further, let us now consider the high energy inclusive data accumulated at NAL and the ISR. Here the composition of the missing mass spectrum X will change as the mass increases. Hence, we can no longer assume the same

*) M_o is some typical value of M in the range $1.08 < M < 2.0$. In fact M_o may be equal to M , but over such a small range of values, this can not be established.

parameterisation of the strength functions $h_n(M)$ that was applicable to the π^+n diffractively produced system. However, if the ULS hypothesis is valid, the limiting values given by Eq. (9) should still be applicable for some sufficiently high M values. At lower masses, on the other hand, before these limiting values have been attained, we should expect a stronger variation of the inclusive diffractive slope as a function of M since such a variation is a feature of the exclusive reactions contributing to the inclusive process.

In order to obtain some approximate idea of the range of M over which this phenomenon exists, let us note that an adequate parameterisation of the average charged multiplicity of the dissociating system, even at low M , would seem to be [9]^{*}

$$\langle n_{ch} \rangle = 0.5 + 1.4 \log M^2. \quad (12)$$

Assuming therefore that in this system, $\langle n_{\pi^0} \rangle = \langle n_{\pi^+} \rangle = \langle n_{\pi^-} \rangle$ we obtain the average pion multiplicity of the cluster to be

$$\begin{aligned} \langle n_{\pi} \rangle &= 1.5 (\langle n_{ch} \rangle - 1) \\ &= 4.2 \log M - 0.75 \end{aligned} \quad (13)$$

where we have subtracted 1 from $\langle n_{ch} \rangle$ for a possible proton in the final state system⁺⁾ . If the inclusive distribution is not to show this strong slope-mass correlation effect let us now suppose that all reactions with

$$n_{\pi} \lesssim 2 \langle n_{\pi} \rangle \quad (14)$$

must have reached their limiting helicity strengths. (For a Poisson distribution this value of $2\langle n_{\pi} \rangle$ corresponds to approximately 95% of all contributing processes). However, from a study of some exclusive processes

*) An alternative parameterisation $\langle n_{ch} \rangle = 2 + 0.6 M$ gives very similar results to those discussed here.

+) While it is possible to improve on these simple assumptions the conclusions are not likely to alter very much.

the limiting helicity strengths are apparently reached about 1 GeV above threshold [1]. Hence, for the inclusive process we could estimate that M must be greater by 1 GeV than the threshold for producing a proton and $2\langle n_{\pi} \rangle$ pions; i.e. that

$$M \geq 0.94 + 0.14 (2\langle n_{\pi} \rangle) + 1.0. \quad (15)$$

Inserting Eq (13) in Eq (15) gives us a result that

$$M \geq 3.1 \text{ GeV} \quad (16)$$

For the inclusive diffraction dissociation distributions therefore we consider two regions: (a) with M much greater than this transitioned region; and (b) with M smaller than or equal to this value. In region (a) we can assume that all helicity amplitudes have reached their limiting values and use the value of the strength functions given by $h_{\Delta\lambda}^{\infty}$ of Eq (9). Hence, we fit these high energy, high M^2 inclusive data, as in the case of the exclusive process, by allowing only the two parameters a and γ to vary at any given energy. In practice it was found quite adequate to take the slope parameter a to have the form analogous to Eq (11), i.e.

$$a = 2.4 + 0.17 \log s/M^2. \quad (17)$$

The corresponding fit to the data are shown in Fig. 2. For comparison we also show the triple-Regge parameterisation of these data suggested by Roberts and Roy [10].

It is interesting to note that the lack of a turnover in the distributions at very small t -values, which is indicative of a non-zero triple-Regge coupling, is easily accounted for by our model. It merely represents the characteristic sharp t -behaviour of the $\Delta\lambda = 0$ amplitude, i.e.

$$|e^{at'} J_0(b\sqrt{-t'})|^2$$

which may show up at sufficiently small t' values since all other helicity amplitudes go to zero like $(-t')^{\Delta\lambda/2}$. In fact, in terms of our model,

the observance of this term in the data depends quite considerably on the relative size of each helicity amplitude. For example if h_0^∞ were much greater than h_1^∞, h_2^∞ etc, then the "spike" at small t' would be much more pronounced. If h_0^∞ were much less than the other limiting helicity strengths however, the t -distributions would show a pronounced turn-over in the forward direction. Thus while the fit in Fig. 2 does not ensure the absolute validity of the ULS hypothesis it does at least imply, in the framework of the model, that the relative strengths of the various helicity strengths do not vary too greatly from those given by Eq (9)*.

For small M values, we would expect from our preceding arguments that not all the helicity amplitudes for the inclusive process have reached their limiting values. However, rather than trying to parameterize the strength functions $h_{\Delta\lambda}(M)$ by considering each of the exclusive channels which contribute to it, let us here merely make the simple approximation that for $M^2 < 5$ only h_0, h_1 have reached their asymptotic values, h_2 has 75% of its maximum value, and h_3, h_4 etc are put to zero. Similarly for $5 \leq M^2 \leq 10$ we assume that h_2 has now also reached its limiting value and h_3 has 75% of its maximum value. Then using the same form as before for the parameter a , i.e. Eq (17) we see in Fig. 3 that the model can also reproduce the inclusive distributions even in this small M^2 region.

Notice that in terms of a triple Regge analysis, the increasing prominence of the spike at very small t values is described by a sharp t -dependence of the triple Pomeron contribution, which is particularly important for small values of M^2/s . Alternatively, in the present model however, the sharp t -dependence is explained by the rather natural assumption that in the small M^2 region only the lower helicity flip amplitudes will contribute appreciably, which have this characteristic sharp t -behaviour. Hence, we would suggest that this feature of the inclusive data is just the generalisation of the slope-mass correlation effect observed in exclusive diffraction dissociation processes.

*) In view of the large errors on the data considered here and in Ref. 1 this is the only statement one can make about the ULS hypothesis. Clearly the data will be unable to identify any minor changes in these relative strength parameters.

4. DISCUSSION

In the previous section we have seen that the high energy diffraction dissociation data appear to be quite compatible with a peripheral impact parameter description, provided that the width of the profile has a small logarithmic dependence on the ratio s/M^2 . Furthermore, it would seem that this dependence is the same for both inclusive and exclusive processes. However, since the number of particles in the dissociating system in the inclusive process is typically much larger than the two produced in the process $pp \rightarrow p(\pi^+n)$ this would imply that the s/M^2 dependence is a function of the exchange mechanism and does not depend on the number of particles produced. Thus we are led to the conclusion that the universal impact parameter profile for inelastic diffraction dissociation is independent of the number of particles produced. Consequently so long as one considers values of the dissociating mass M which are large enough for all the helicity amplitudes to have reached their limiting values, it makes no difference whether the proton diffractively dissociates into 2 or 12 particles, the slope of the $d\sigma/dt'$ distributions remain the same. Conversely for small values of M the momentum-transfer distributions will be very sensitive to the strength functions $h_{\Delta\lambda}(M)$ which control the contribution of each helicity amplitudes. In turn these functions are likely to depend significantly on the number of particles produced.

In conclusion therefore, let us stress the achievement of this simple model in describing both the low and high energy exclusive and inclusive diffraction dissociation data. Not only does it provide a quantitative description of the slope-mass correlation effect and the observed structure in the $d\sigma/dt'$ distributions at different values of M , but it also relates these effects to the much discussed t -dependence of the inclusive diffraction dissociation data. Moreover it does so in terms of one universal peripheral impact parameter profile for all inelastic diffractive pp collisions at any value of s and M^2 .

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FIGURE CAPTIONS

- Fig. 1 Differential cross sections $d\sigma/dt$ for the inelastic diffractive process $pp \rightarrow p\pi^+n$ at $s = 2809 \text{ GeV}^2$ (Ref. 3). The solid curve is the peripheral impact parameter model fit described in the text.
- Fig. 2 Inclusive diffraction dissociation distributions for $M^2 > 10 \text{ GeV}^2$. The data are taken from Refs. 4-7. (See also Refs 9,10 for a discussion of these data). The solid curve is the calculated peripheral impact parameter model distribution. The broken curve is the triple Regge parameterisation of the data given in Ref. 10.
- Fig. 3 Inclusive diffraction dissociation distributions for $M^2 \lesssim 10 \text{ GeV}^2$. The data are taken from Refs 4-7. The solid and broken curves represent the peripheral impact parameter description and the triple Regge parameterisation of Ref. 10 respectively.

Fig. 1

Fig. 2

Fig. 3