PHENOMENOLOGY OF DIFFRACTIVE REACTIONS

BY G. L. KANE*

Rutherford Laboratory, Chilton, Didcot, Berkshire**

(Presented at the XII Cracow School of Theoretical Physics, Zakopane, June 8–18, 1972)

In these lectures I want to consider diffractive production reactions with very close attention to the constraints that experimental data at accelerator energies (say below 30 GeV/c) imposes on any relevant theory. Because of three "problems" I argue that most of the traditional views of diffractive production are of limited value in describing the actual data.

These problems are (i) The existence of crossovers for diffractive production, which implies contributions which change sign between processes such as $Kp \to Q^0 p$ and $Kp \to \overline{Q}_0 p$, or $\pi^{\pm}N \to A_1^{\pm}N$; ($ii$) Miettinen and Pirilä have recently pointed out that the dramatic decrease in production momentum transfer slope with increasing M^2 must be a property of the matrix element rather than induced by kinematic effects, but the traditional models for diffractive production generally have a constant slope in the matrix elements; (iii) Detailed arguments concerning sizes of diffractive cross-sections as compared with non-diffractive ones.

The form which a model capable of describing the data might take is indicated by constructing an example. It uses important contributions from a number of the available s-channel helicity amplitudes, with t dependences analogous to those found in conventional two-body reactions. In addition to allowing us to describe all the qualitative features of the data, the model suggests an interpretation of t-channel helicity "conservation" and shows how to predict the helicity properties of the reaction from the shape of the differential cross-section.

A brief discussion is given of the energy dependence of resonances and background in the diffractive mass spectrum.

CONTENTS

1. Introduction

2. Traditional views

* J. S. Guggenheim Foundation Fellow, on Sabbatical leave from the University of Michigan.
** Address: Rutherford Laboratory, Chilton, Didcot, Berkshire, England.

1. Introduction

In these lectures I want to look at the diffractive reactions with very close attention to the detailed features of relevant experimental data. I will argue that the traditional views are not adequate to describe the actual data at energies where it is currently available.

Many important aspects of diffractive production will not be covered here; they can be studied in the reviews of Morrison at Kiev, Satz and Schilling at the Helsinki multiparticle meeting, and Berger at the Cal. Tech. Phenomenology Conference.

Although I do not know, of course, how to construct a theory of diffractive processes, I will at least exhibit one model that is capable of describing in detail most of the diffractive data. Whether there is any truth in the model or not, it will provide a useful framework to correlate the diverse properties of the data, and to see what must be some of the properties of a successful theory.

A good deal of the following is in or implicit in Ref. [1].

Let us begin by talking about the size of various cross-sections and the definition of diffractive reactions.

What makes up σ_{total} at fairly high energies, and what is the energy dependence of the various pieces? For most particles the integrated elastic cross-section is about 15–20% of σ_T, ranging from about 4 mb for Kp to about 10 mb for $\bar{p}p$.

Next consider the diffractive part of the cross-section. The word "diffractive" means many things to many people, and we will try to distinguish some interpretations.

Consider a typical inclusive process such as

$$a+b \to c+X \tag{1}$$

where X represents summing over all contributions. We can describe this by giving the total energy (s), the momentum transfer to the proton (t) and the mass of $X(M^2)$.

Some people have used the name σ_{DIFF} for the cross-section for (1) differential in M^2 but integrated over t,

$$\sigma_{DIFF} = \frac{d\sigma}{dM^2} = \int dt \frac{d\sigma}{dM^2 dt}$$

σ_{DIFF} is rather large; for a reasonable size M^2 bin one has a cross-section comparable to σ_{EL}. The essential property of σ_{DIFF} is that it is expected to be independent of energy.

Sometimes σ_{DIFF} is a rather strange quantity in terms of traditional viewpoints; *e.g.* for $\pi^- p \to \pi^+ + X$ one has a very small cross-section where π^+ is produced with a small momentum transfer from π^- (including reactions such as $\pi^- p \to A_1^- p$, $A_1^- \to \pi^+\pi^-\pi^-$), but a large σ_{DIFF}. The study of σ_{DIFF} is essentially a many-body or inclusive theory problem and we will not pursue it further.

We will mainly be interested in reactions that fall less rapidly with energy than $1/p_L$ and have $d\sigma/dtdM^2$ peripheral in t; we will call them Quasi-Elastic. This includes examples such as $\pi^- p \to \pi^- p^*$ (1690) with $-t_{\pi^-\pi^-} \lesssim 1$ (GeV/c)^2, $pp \to p+X$ with M_X^2 fixed and $t_{pp} \lesssim 1$ (GeV/c)^2. Our interest in them is mainly from the point of view of two-body reactions. They are a meeting place between elastic scattering and Reggeon exchange reactions and could help us to understand either of these better. Since σ_{QE} can get significant contributions from Reggeon exchange as well as some energy independent production process we expect that σ_{QE} will fall with energy but significantly slower than $1/p_L$; it need not be constant in s, although it could be. For a typical process

$$\int dm^2 \sigma_{QE} \sim \tfrac{1}{2}\sigma_{EL}.$$

When we discuss elastic scattering we can speak of it as due to an exchange process. The normal Reggeons can be exchanged, and the main contribution (whose nature is still mysterious) is called the Pomeron. It is the exchange language analogue of diffraction or shadow scattering; it carries vacuum quantum numbers, though possibly it can change parity. Thus when we speak of Pomeron exchange we can mean several things, depending on the context: a t-channel J-plane singularity, or the sum over all s-channel intermediate states, *etc.* Whatever the interpretation we mean that Pomeron exchange gives a cross--section that is asymptotically essentially constant with energy (up to ln s terms).

Probably the main reason for studying QE reactions is to find out the nature of the Pomeron-like contributions there. What is their energy dependence, spin dependence, phase, size? There are currently no compelling theoretical answers to these questions at energies where experiments can be done.

For a given process like (1) one sees a mass spectrum with occasional peaks, as in Fig. 1[2]. One of the things we would most like to understand is this mass spectrum — can one produce both definite quantum number states (such as N^* (1690)) and a rather featureless background, both by Pomeron exchange (in some sense, not necessarily the same for both)? Particularly the energy dependence is interesting, and the question can probably only be resolved by rather careful experiments.

Consider here only the question of how the resonance production falls with energy relative to the whole process. Fig. 2 shows the same data as Fig. 1. The black square boxes at the bottom are the mass spectrum obtained by Frampton and Ruuskanen [3] by an extrapolation of the numbers shown to infinite energy, using a form $d\sigma/dtdm = a(m)+b(m)s^{-p(m)}$; the solid line is the contribution they find from resonances alone. On the other hand, under exactly the same conditions but assuming $d\sigma/dtdm = A(m)s^{2\alpha_{\mathscr{P}}-2}+B(m)s^{2\alpha_m-2}$,

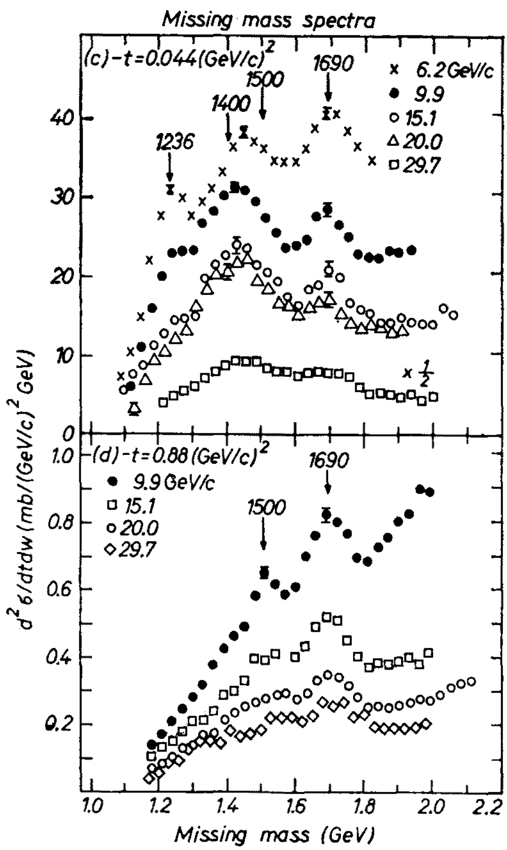


Fig. 1. From Ref. [2], this shows typical missing mass spectra in an experiment such as $pp \to p + X$

with $\alpha_{\mathscr{P}} = 1+t/2$, $\alpha_m = \frac{1}{2}+t$, and $t = -0.044$, Roberts and Roy [4] find the results shown by circuled x's for the infinite energy mass spectrum.

Still proceeding directly from the spectra shown, Van der Velde [5], motivated by the Princeton-Michigan experiment mentioned just below which sees no resonance structure in the mass spectrum, conjectures that the resonances go away with energy relative to the "background". He argues that this is not ruled out by the data, and plots the data vs $1/p_L$ to suggest that it is not at all out of the question to see the resonances going away faster than the background.

However, all three of the above analyses use the data directly without unfolding the experimental resolution. The resolution is known [2] to increase considerably with increasing energy, so it is probably essential to consider it.

The experimenters themselves [2, 6] after a careful analysis including resolution effects, conclude that the background disappears relative to the resonances, so at infinity

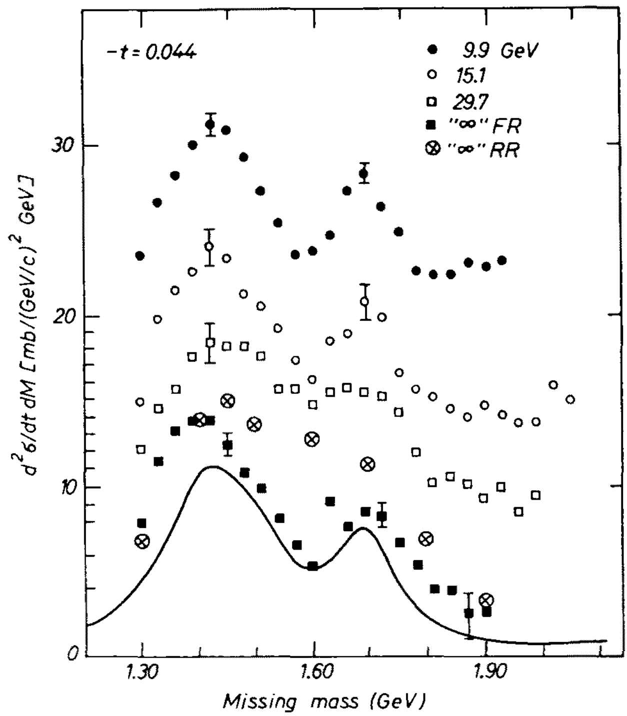


Fig. 2. Extrapolation to $s \to \infty$ of missing mass spectrum of Fig. 1; see text for interpretation

one has essentially a pure resonance spectrum. Similar conclusions are reached by Einhorn and collaborators [7], also by including resolution.

The only other places we can look for relevant data are $\pi N \to A_1 N$ and $KN \to QN$. Fig. 3 shows the A_1 cross-section *vs* energy and Fig. 4 the total 3π cross-section; on the surface it would appear that the resonance production (if A_1 is a resonance) goes down relative to background. On the other hand, Fig. 5 shows the opposite result up to 12 GeV/*c* for the Q. In the A_1 case normalizations and cross-section definitions have probably not been done consistently yet at different energies, and much care is necessary to take these results seriously.

The relative behavior of background and resonances with energy is clearly a very important question. Considerably more work, both experimental and phenomenological, needs to be done to sort it out. Of course, good resolution mass spectra at very high energies could settle it; to be certain we need both missing mass spectra and the spectrum for a definite (*e.g.* two body) final state.

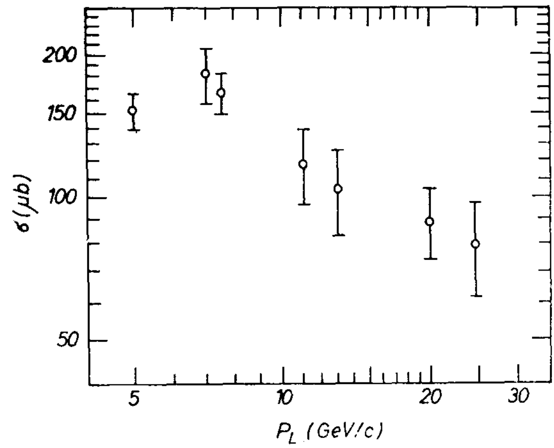


Fig. 3. Cross-section for $\pi^- p \to A_1^- p$ as a function of π^- momentum with A_1^- of spin parity 1^+ and mass between 1.0 and 1.2 GeV. From Kruse, proceedings of the Cal. Tech. Phenomenology Conference

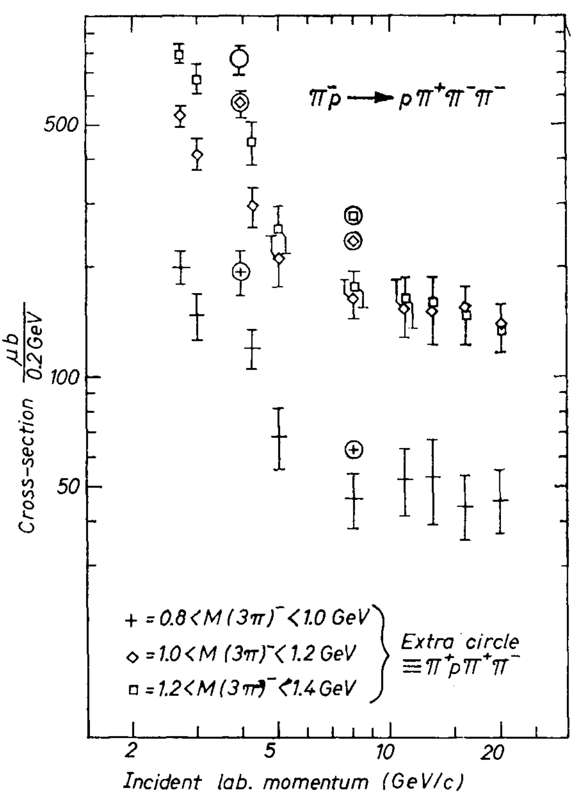


Fig. 4. From Paler, *Nuclear Phys.*, **B18**, 211 (1970),

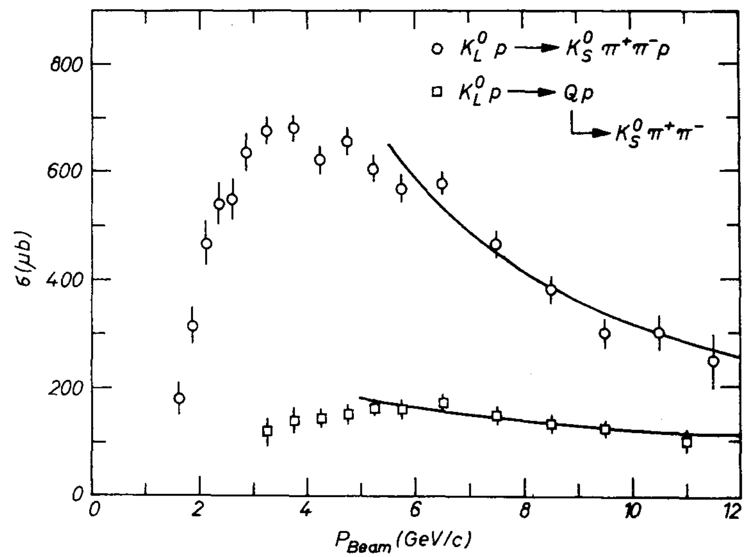


Fig. 5. Energy dependence of Q and $K_S\pi^+\pi^-$ production, from Brandenberg *et al.*, Ref. [11]

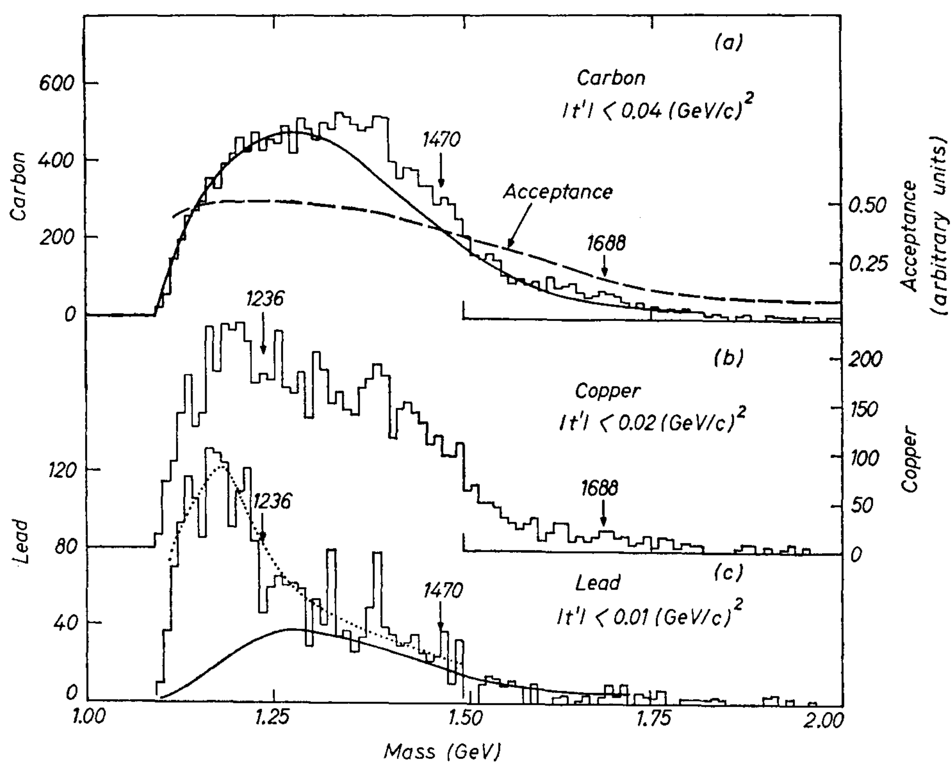


Fig. 6. Mass spectra for neutron dissociation $n \rightarrow p\pi^-$ on nuclei; note the carbon data and the absence of resonances. From Ref. [8]

To conclude the introduction we note a first indication that things might be much more complicated than is usually supposed. In a Brookhaven experiment at 30 GeV/c a Michigan, Princeton [8, 9] group has found for the two body dissociation $n \to p\pi^-$ on carbon a mass spectrum shown in Fig. 6 and a "decay" angular distribution shown in Fig. 7. For small t where one is surely in the coherent peak on carbon the mass spectrum

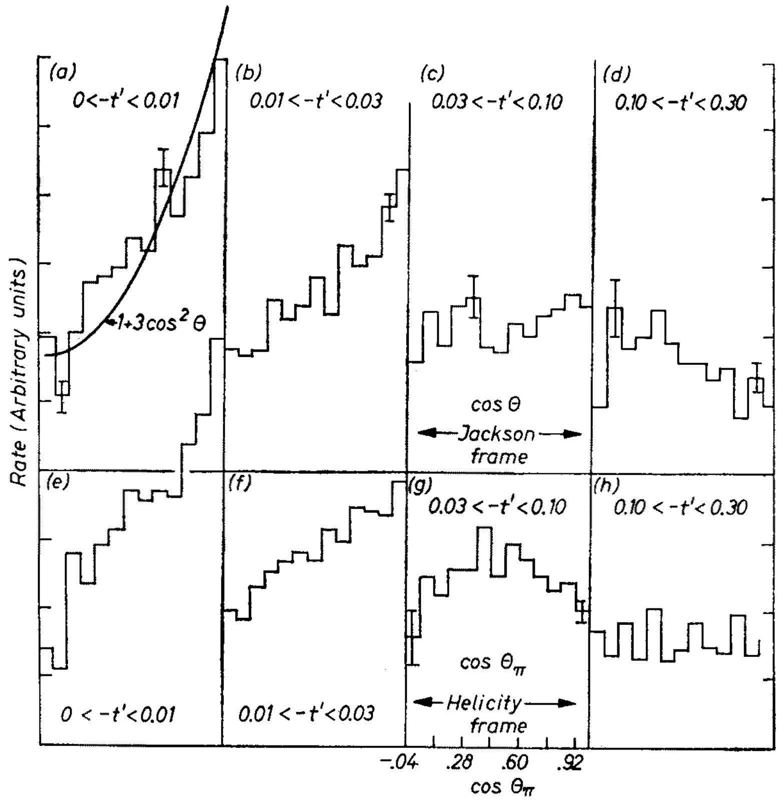


Fig. 7a. Angular distribution from the two-body dissociation $n \to p\pi^-$ on carbon, from the experiment of references [8, 9]. (Distributions in the cosine of the polar angle of the π^- in the $p\pi^-$ rest frame; *a–d* are for various t' bins as indicated and θ is measured in the Jackson frame; *e–h* are for the same t' bins with θ measured in the helicity frame. Note that all distributions only cover the angular range $-0.04 < \cos\theta < 1.0$. The $p\pi^-$ invariant mass is restricted to the interval 1.10–1.32 GeV. The higher mass region gives similar results.) Naively, the results imply that even in the smallest mass region the dissociation has important or dominant contributions from $J = 3/2$ $p\pi^-$ systems

shows a very low mass broad enhancement and no sign of resonance production. It is not clear how strong a signal should have been seen for (say) $N^*(1690)$ production, but one would have liked some signal (the branching ratio for $N^*(1690) \to p\pi^-$ is about 40%). The peaking of the spectrum at about 1300 MeV may be due to the two-body decay, with higher mass final states peaking higher and giving a peak at about 1450 MeV in the missing-mass experiment — see the discussion by Morrison [10].

This experiment only observes events in the "backward" half of the two body decay (see caption for Fig. 7); it is not clear what effect that has on the mass spectrum in practice, when there can be production of interfering states.

Even more amusing than the absence of resonances is the angular distribution (Fig. 7b), which is not isotropic (as it would be if $J(p\pi^-) = \frac{1}{2}$) even in the lowest mass region $1100 < M < 1300$ MeV. There is no model which has an important (let alone dominant) amount of production of $J = 3/2$ dissociation states right at threshold. The data would be consistent with production of states with $J = 3/2$ and helicity $\frac{1}{2}$. It is important

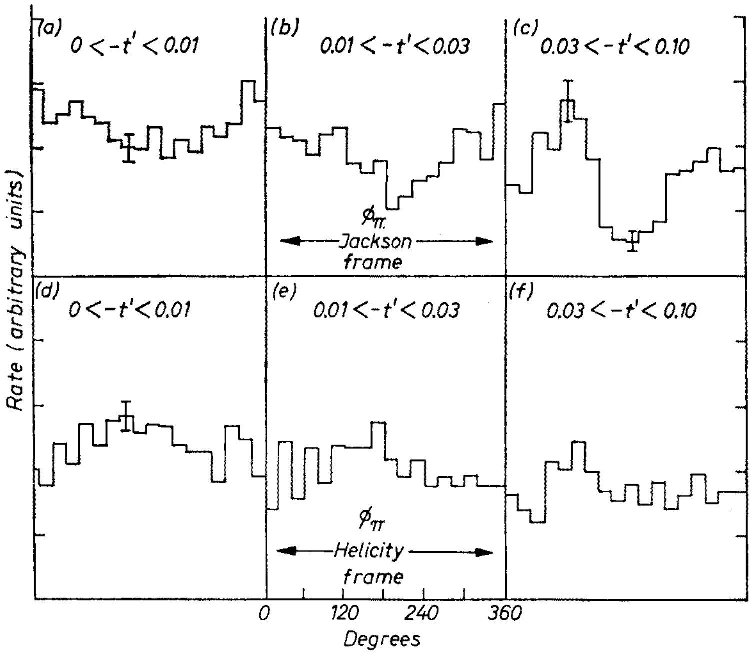


Fig. 7b. Distributions in the azimuthal angle of the π^- in the $p\pi^-$ rest frame; *a–c* are for the Jackson frame and *d–f* for the helicity frame in various t' bins as noted. In *a–c* only those events with $\cos\theta$ (Jackson) ≥ 0 are plotted and in *d–f* only those events with $\cos\theta$ (helicity) ≥ 0 are plotted. The $p\pi^-$ mass is in the interval 1.10–1.32 GeV. The higher mass region gives similar results. Also from Ref. [8, 9]

to have these results confirmed in an experiment with different sorts of background and biases — presumably with a hydrogen target. In interpreting these results it may be important to note that only events are detected with π^- going forward in the CM relative to the beam direction. Altogether then, so far we have seen qualitatively what the data show, and some hints explicitly in the data about possible complications to a simple picture.

Next we briefly review traditional models, then discuss why we feel they are inadequate by themselves to account for data for $p_L \lesssim 30$ GeV/c (at least). Then we present a model which can describe most of the data, and finally we look at some of the experiments the next few years might bring.

2. *Traditional views*

Since all of these will be described in detail in other lectures I will be very brief here.

Fig. 8a shows the classic view of diffraction dissociation. Among the many people who have looked at its consequences we should note Good and Walker over ten years ago, Ross and Yam who performed detailed calculations to compare with data in the middle 1960's, and more recently Białas, Czyż and Kotański who have extended the formalism and studied it in most detail. The behaviour in t is taken as the t dependence of the elastic scattering and must be peripheral; in t' it is not clear but a fall off is needed for a finite cross-section. This is the "Deck effect".

Fig. 8b shows the multiperipheral version equivalent to a. Generally it is calculated with Reggeized exchanges. It has been most often compared with data by Berger. It is peripheral in t and t'.

Fig. 8c shows a more direct point of view for N^* production — an N^* is excited by some mechanism. (We have drawn it as an exchange but that is not essential — it could be an s-channel mechanism such as partially coherent unitarity effects). This picture is

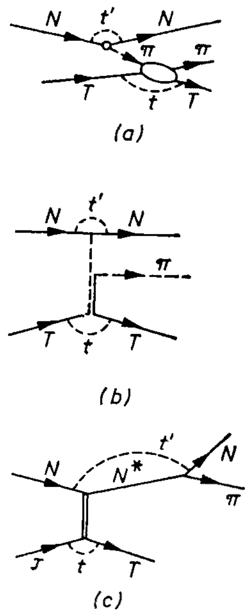


Fig. 8. Traditional views of dissociation processes

probably closest to the work of Chou and Yang, extended by Byers and Frautschi. Here the result is peripheral in t and the t' dependence comes from the N^* decay; it is peripheral in t' if only helicities small compared to its spin are populated for the N^*.

For all of these one takes $d\sigma/dt\, dM^2$ constant in s. We have labeled the lines in Fig. 8 only as an example of course; one can draw similar figures for any particles.

As $s \to \infty$ some pictures such as these may actually be valid. But we want to discuss experiments below (say) 100 GeV/c or so and in that region I feel that only a fairly small part of the cross-sections is coming from such contributions. Unless we complicate these pictures considerably, I do not think they will allow us to understand the data in the 10–20 GeV/c range very well; the energy dependence available suggests to me that the problems will persist for a while with increasing s. In addition to the problems which are associated with mass and angular distributions from the Michigan-Princeton experiment mentioned above, we consider three possible problems.

3. Problems

1. Crossovers [1]. In elastic scattering one observes a crossover of particle-antiparticle cross-sections. All three quantities

$$\Delta(Kp) = \frac{d\sigma}{dt}(K^- p) - \frac{d\sigma}{dt}(K^+ p)$$

$$\Delta(\pi p) = \frac{d\sigma}{dt}(\pi^- p) - \frac{d\sigma}{dt}(\pi^+ p)$$

$$\Delta(pp) = \frac{d\sigma}{dt}(\bar{p}p) - \frac{d\sigma}{dt}(pp)$$

have a zero near $-t = 0.15$, at least at energies $p_L \gtrsim 3$ GeV/c. If any process were completely dominated by Pomeron exchange one would have $\Delta = 0$ at all t. To have a crossover one needs a contribution of odd charge-conjugation eigenvalue so that it changes sign between the two reactions. For elastic scattering one only needs to consider one amplitude, so naively we can write, for example,

$$\Delta(Kp) = |\mathscr{P}+\omega|^2 - |\mathscr{P}-\omega|^2 = 2\,\mathrm{Re}\,\mathscr{P}\omega^*$$

where $\mathscr{P}$ denoted Pomeron and ω denotes omega exchange, which is known to be important in that reaction and changes sign between $K^{\pm}p$. Since the Pomeron is mainly imaginary it is mainly the imaginary part of the ω amplitude that interferes; this is expected to have a zero near $-t \sim 0.2$ from the strong absorption model, or by analogy with the ϱ whose zero can be understood either from the absorption model or duality. In fact, the zeros in the ω and ϱ are at $-t$ in the range 0.2 to 0.3 and the crossover zero in Δ is closer to $t = 0$ because $\mathscr{P}$ has a negative real part and ω or ϱ a positive real part, shifting the zero in.

For diffractive reactions so far three crossovers have been reported [11]:

$$\Delta(Qp) = \frac{d\sigma}{dt}(K_2 p \to \bar{Q}p) - \frac{d\sigma}{dt}(K_2 p \to Q^0 p)$$

$$\Delta(A_1 p) = \frac{d\sigma}{dt}(\pi^- p \to A_1^- p) - \frac{d\sigma}{dt}(\pi^+ p \to A_1^+ p)$$

$$\Delta(N^* p) = \frac{d\sigma}{dt}(\bar{p}p \to \bar{p}N^*) - \frac{d\sigma}{dt}(pp \to pN^*).$$

All three are consistent with a crossover in the same place as the elastic reactions. The A_1 crossover is actually observed not only for 3 pions at the A_1 mass but for all peripheral 3 pion states — that could be important. The crossovers are shown in Fig. 9.

In the A_1 region the data is consistent with $d\sigma/dt(A_1^- p) = 1.2e^{11.5t}$, $d\sigma/dt(A_1^+ p) = 0.8e^{9.6t}$, in mb/GeV². The errors are ± 0.1 on the intercepts and 7% on the slopes. The size of this crossover is even larger than the elastic πN one; that is reasonable if the ϱ plays a larger role here than in the elastic case; but that may contradict the apparent absence of charge exchange production, so a careful quantitative analysis of the combined crossover and charge exchange data is needed. Very naively, ignoring errors and putting

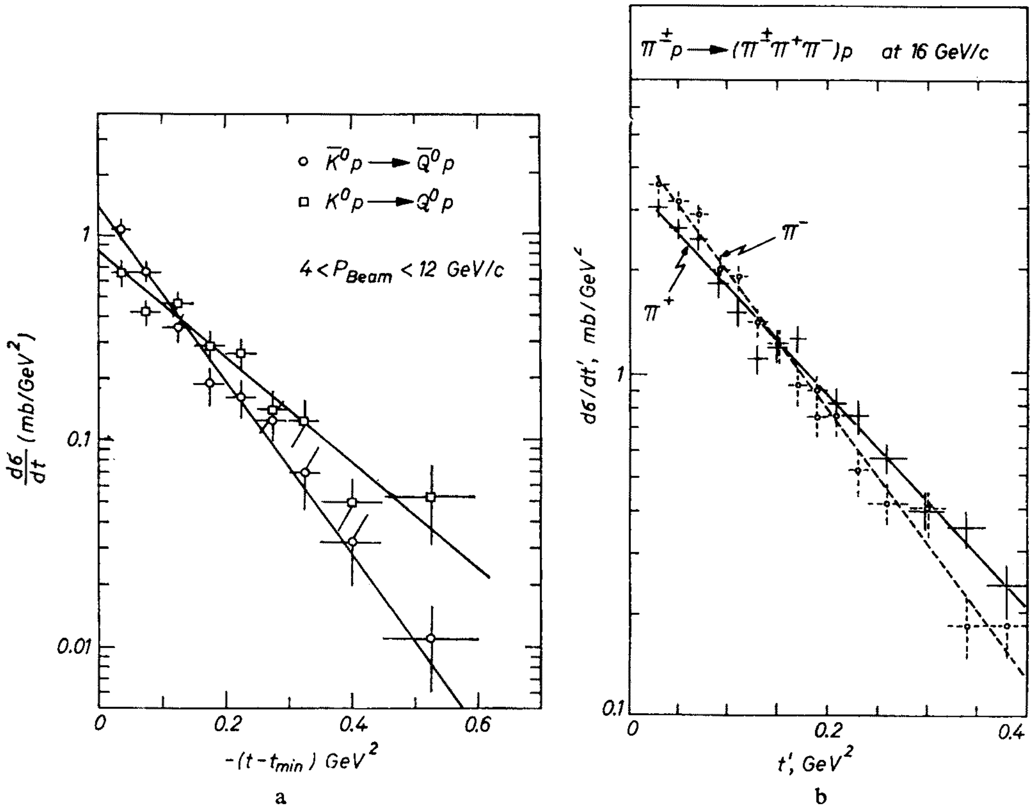


Fig. 9a. Q crossover, from Ref. [11]. See text; b. A_1 crossover, from Ref. [11]. See text

$d\sigma/dt(A_1 p) = |\mathscr{P} \pm \varrho|^2$ and taking $\mathscr{P}$ purely imaginary we get $|\mathscr{P}| = 1$, $|\varrho| = 0.1$ at $t = 0$. Then (using isospin and a typical ϱ phase) we have $d\sigma/dt(\pi^- p \to A_1^0 n) \sim 0.04$ mb/GeV² at $t = 0$. Since this is of order $\frac{1}{4}$ of the $\pi^- p \to \pi^0 n$ cross-section at 16 GeV/c, and A_1 CEX is known to be much smaller than that, something appears wrong. But a careful analysis including errors and phases may be needed.

The QN crossover is the most important for two reasons. The first is the practical one that it is not subject to normalization problems as the other two might be, since Q^0

and $\overline{Q^0}$ come from the same beam (in practice establishing a difference in slope is adequate to find the effect; one needs the normalization to see at what t value $\Delta = 0$).

Second, it tells us a very important piece of information about the dynamics. Suppose that the Deck effect contribution was important here for Q production. Then the situation would be as in Figure 10. Since the πN crossover has $\pi^- p$ larger at small t and steeper, one would expect from the Deck effect that the Qp crossover would have $Q^0 p$ larger at small t and steeper than $\overline{Q^0}p$, just the opposite of the data! Thus, whatever is going on, if there is a Deck contribution there is at least one other large contribution changing the relative size and shape.

One could argue here that the contribution equivalent to Fig. 10 but with K^* exchange, which goes the right way for a crossover, could fix things up. But then one quickly sees that for the $K^\pm p \to Q^\pm p$ crossover all such contributions are in the "right" direction, so one expects a very large effect for $Q^\pm p$ compared to Q^0, $Q^0 p$. Since the latter is already quite large it seems unlikely that this is a way out, although the $K^\pm$ data is not available. On the other hand, accounting for crossovers with ω exchange here we would predict an equal effect for $Q^\pm p$ and Q^0, $\overline{Q^0}p$. A comparison of these crossovers is essential to complete the systematics.

The Qp data are consistent with $d\sigma/dt(K_2 p \to \overline{Q^0}p) = 1.3e^{9.7t}$ and $d\sigma/dt(K_2 p \to Q^0 p) = 0.83e^{5.9t}$, in mb/GeV^2. The integrated cross-sections are equal within 10% for $Q^0 p$ and $\overline{Q^0}p$.

Note that in the case of $\Delta(A_1\, N)$ or $\Delta(\pi N^*)$ a crossover would be due to ϱ exchange and imply a lower limit (somewhat hard to get because of spin effects) on charge exchange

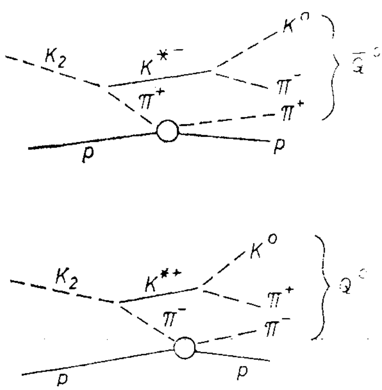


Fig. 10. Shows what the Deck effect would give for the Qp crossover. Since the πN crossover has $\pi^- p$ larger at small t and with steeper slope, the Qp crossover should have $Q^0 p$ larger and steeper, just the opposite of the data!

production, while in $\Delta(Qp)$ or $\Delta(KN^*)$ or $\Delta(pN^*)$ the crossover is due to ω exchange (presumably) and has no simple implications for charge or hypercharge exchange cross-sections.

The systematics of crossovers in diffractive production may be essential to untangling the underlying physics. The apparent result that the crossovers occur for continuum as well as resonance production should be verified. The comparison of K and $\overline{K}$ crossovers, with the results in the opposite direction to Deck or multiperipheral models, will be a very hard constraint to satisfy for traditional models. The t dependence will tell us a lot about which helicity states are populated. The comparison of crossovers in elastic processes and associated diffractive ones may tell us a lot about the basic diffractive process if we can assume we understand the odd-C exchange from the elastic processes.

2. Slope-mass correlation. It is well known that in a dissociation such as $pp \to p+X$ one finds $d\sigma/dt\, dM^2$ having a much steeper slope in t (at small t) for small M^2 than for large M^2, the slope falling monotonically (on average) for increasing M^2. Recently Miettinen and Pirilä [12] have pointed out that the traditional explanation in terms of

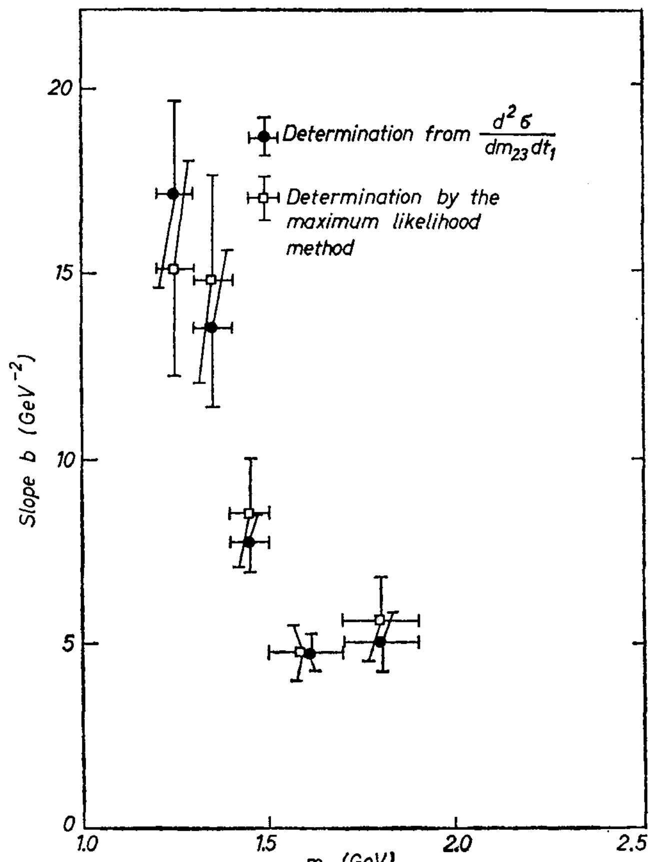


Fig. 11. Slope-mass correlation for $pp \to pn\pi^+$, from Ref. [12]

Deck effect or multiperipheral dynamics, plus kinematical correlations, is not actually consistent with the data. The slope-mass correlation for $pp \to pn\pi^+$ is shown in Fig. 11.

Miettinen and Pirilä have two points; one is that a careful analysis of the data for $pp \to pn\pi^+$ as a function of all four variables shows that the data simply does not show the correlations with momentum transfers usually assumed to produce the slope-mass correlation. The second is that the kinematic correlations induced by multiperipheral or Deck dynamics is far too weak quantitatively to produce the observed effect. Previous work has

TABLE 1

Various cross-section sizes, meson beams

Reaction	p_L	$d\sigma/dt$ ($t = 0$) or peak value μb/GeV²	$\int dt\, d\sigma/dt$ μb
$\pi^- p \to \pi^0 n$	6	400	80
	18	120	—
	20	—	20
	40	—	11
$K^+ p \to K^+ p$	~7	20 000	3 300
$K_2 p \to K_1 p$	~7	400	50
$K_2 p \to Q^0 p$	~7	3 900	650
$\pi^- p \to \varrho^0 n$	7	3 500	400
	16	400	50
$p^- \to g^0 \pi$	~ 7	—	80
	16	—	15
$\pi^+ p \to B^+ p$	8	150	30
$\pi^- p \to \pi^- p$	16	—	4 100
	6	40 000	5 000
f contribution	6	2 900	—
ϱ contribution	6	130	—
$\mathscr{P}$ contribution	6	2 4000	—
$\pi^- p \to A_1^- p$	8	1 400	180
	20	700	90
$\pi^- p \to A^0{}_1 n$			< few μb
$\pi N \to \pi N^*(1410)$	8		
	16	2 500	200
$\pi^- p \to \pi^0 N^*(1410)$	6	—	$\lesssim$10
$\pi N \to \pi N^*(1690)$	8	600	200
	16		150
$\pi N \to \pi N^{*0}(1690)$	6	—	~ 10
$\pi N \to \pi N^*(2190)$	16	100	—
$K^+ n \to K^{*0} p$	9	—	90
$K^+ n \to K^{*0}$ (1750)p	9	—	40

TABLE II

Various cross-section sizes, baryon beams

Reaction	p_L GeV/c	$d\sigma/dt$ ($t = 0$) or peak value μb/GeV²	$\int dt\, d\sigma/dt$ μb
$pp \to n\Delta^{++}$	7	—	2 000
	10	—	1 180
	19	—	270
	28.5	—	115
$pp \to n\Delta^{++}(1950)$	6	—	300 ± 200
	10	—	380 ± 100
	19	—	31
$pp \to n^0(1690)\Delta^{++}$	~7	—	~250
$pp \to pp$	16		8 000
$pp \to p+X$	30		
$1.3 \leqslant m_x \leqslant 1.5$		25 000	2 000
$1.5 \leqslant m_x \leqslant 1.7$		20 000	2 000
$pp \to pp^*(1410)$	all	~6 000	400–600
$pp \to pp^*(1690)$	8,16	1 500	300–500

been incomplete in that averaging over some variables obscured what was really in the model.

Explicitly, they consider models which can be written in the form (in the notation of Fig. 8, with S_1, S_2 the final subenergies)

$$|M|^2 = e^{bt} g(S_1, S_2, t').$$

Then they perform Monte Carlo calculations and show that a careful 4-dimensional analysis (in terms of t, t', S_1, S_2) will allow one to extract constant b from Monte Carloed events independent of the amount of peripherality in t'. Then they take explicit examples and show that even with extremely peripheral coupling in t' one does not obtain sufficient variation of b, with M^2.

Finally, they demonstrate that even in the careful 4-dimensional analysis of $pp \to pn\pi^+$ data one finds a slope which increases rapidly at small M^2, so that this increase must be in the dynamics of the matrix element and very little due to the traditional explanation; that is, the data does not arise from a slope b which is independent of M^2.

Any models similar to the Deck effect or multiperipheral models have a constant slope with M^2 so they cannot contribute very much of the QE amplitude.

Thus again we find that a basic feature of the data (the slope-mass correlation) is not present in the traditional models.

3. Size. The next problem has to do with the size of the diffractive cross-sections. The essential point is that at energies in the 8–16 GeV/c range or so there are many processes which have similar cross-sections. Some of them are Reggeon exchange and some are diffractive; the latter are no larger than the former. The diffractive processes are no larger than, and sometimes smaller than, just the magnitude one would expect from Reggeon exchange alone.

The numbers I quote above in Tables I, II have been taken or estimated from many sources and often have large errors. The results do not depend on any specific number but on the general trends. Some of the numbers are interpolations I have made. Many of the integrated cross-section values come from the CERN-HERA compilations. The following remarks are based on these numbers.

We can look at several separate but related points.

A. Quasi-Elastic cross-sections are usually more than an order of magnitude smaller than elastic cross-sections.

B. Below 10 GeV/c or so QE cross-sections are about the same size as normal Reggeon exchange processes. More specifically, QE processes are usually a little larger than the charge exchange processes, though they are smaller than π exchange. But it is generally accepted that the isoscalar exchanges (ω, f) give cross-sections a few times larger than the isovector (ϱ, A_2) even though it is hard to separate out the ω, f contributions. For example, the f contribution [13] to $\pi^- p$ elastic at 6 GeV/c is larger than any of the QE processes there. Thus in this energy region normal Reggon exchange alone could account for the sizes of the observed QE cross-sections.

C. If Q, A_1, N^* (1410) are resonances their charge exchange production should be in a certain size region. Considering $\pi^+ p \to B^+ p$, $\pi^- p \to \pi^0 n$, $K_2 p \to K_1 p$, $\pi^- p \to \pi^0 N^*$ (1690), and other similar processes, it would seem unreasonable if the charge exchange cross--sections for these are less than (say) 20 μb in the 6–8 GeV/c range, but in each case no signal has been seen at that level or considerably below it.

D. From a number of examples in the tables one can see that for Reggeon exchange one expects a cross-section ratio of order 1/3 to 1/8 for $\sigma(a+b \to c+d^*)/\sigma(a+b \to c+d)$ where d^* is the Regge recurrence of d. To be conservative, use 1/8 and ask what just the f exchange contribution should give to $\pi^- p \to \pi^- N^*(1690)$; this is about 300 μb/GeV^2 at 8 GeV/c. Adding a ϱ contribution, we see that these alone can essentially account for the observed $N^*(1690)$ cross-sections at that energy. A similar calculation for ω exchange in $pp \to pN^*(1690)$ gives even a stronger result.

We could summarize these points by saying that either the Pomeron, or the Reggeon, contributions seem to be suppressed in QE reactions below about 10 GeV/c. One might expect the Pomeron contribution to be larger than the Reggeon one; certainly all the traditional models have had that property. If both were present we would simply expect bigger cross-sections. We cannot, of course, make these arguments rigorous or unique, but I find them compelling. On the other hand, at considerably higher energies the QE cross--sections are still "large" and falling considerably slower with energy than the Reggeon ones.

Altogether then, there are clearly large difficulties in saying that the traditional Deck or multiperipheral models give important contributions to diffractive production. But of course, as will be often spelled out in other lectures, these models are around because they are both theoretically reasonable and because they do a good job of describing some effects. It is not clear what is going wrong or how to reconcile the problems. Perhaps the traditional models are really for very high energies.

4. Solutions?

All of the preceding discussions suggest that we try to form a new picture of QE processes along the following lines. We make the following assumptions:

1. QE processes have a typical amount of Reggeon exchange. We can use normal two-body phenomenology to describe these.

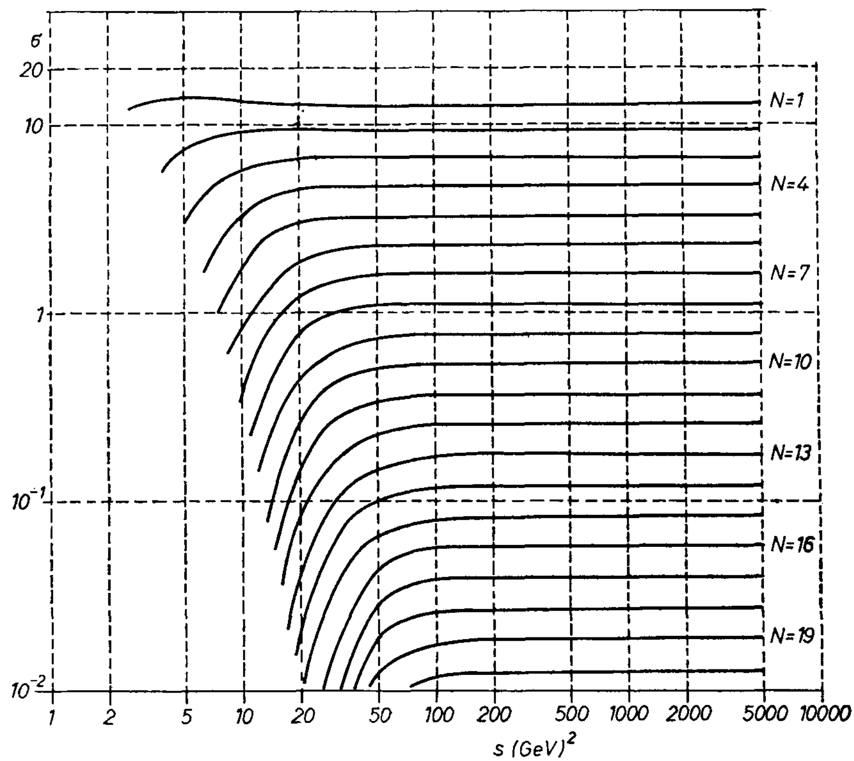


Fig. 12. Shows the rise with energy to an asymptotic value, due to angular momentum barrier effects when producing high spin particles, for integrated cross-sections

2. The Pomeron contribution for $d\sigma/dtdM^2$ for each process rises with increasing energy to a constant value at some energy where $s \gg M^2$.

The reasons I believe this increase with energy occurs are as follows:

(*i*) We are producing final states with higher angular momentum particles in most of these reactions. Simple angular momentum barrier effects for these will produce this effect. For example, Fig. 12 shows cross-sections for recurrences computed in the Veneziano model by Tsou [14]; their rise with energy is apparent and quantitatively large. For the state spin two above the ground state the rise is at least 20% from $s = 10\ \text{GeV}^2$ to the asymptotic value.

(*ii*) Some effect such as absorptive cuts may be making σ_T rise for πN, KN reactions. If so there will be a similar effect in QE processes, and in one model (Cohen-Tannoudji, private communication) the rise is twice as large for the diffractive production as for the elastic process. This might contribute a 10—20% rise.

(*iii*) At a more conjectural level I think that in any theory one will find a kind of "coherence" effect keeping diffractive production processes from reaching their full strength until higher energies. In models of diffractive production on nuclei [15] the effect will explicitly appear as a partial cancellation in the overlap integral of initial and final states. One would need a theory to know whether this effect is present and how big it is — I would be surprised if there were not a 10–20% increase above $s = 10\ \text{GeV}^2$.

The minimal effect of this kind is given by "form factors" not reaching their maximum for $t_{\min} < 0$, but it could be much larger, with important effects due to the presence of real parts in the amplitudes.

Perhaps it should be emphasized that if this assumption (rising Pomeron contribution – perhaps as much as 30%) is correct it is not possible to conclude from energy behavior alone anything about the production mechanism. A considerable Reggeon contribution could be present, with its fall off as s increases masked by the rise of the Pomeron part. One can measure the contribution of isovector (ϱ, A_2, π, ...) exchanges from the size of charge-exchange cross-sections, but it is much harder to obtain a fairly model-independent estimate of the contribution of isoscalar exchange; from normal ideas about Reggeons the isoscalar exchanges are expected to be more important than isovector.

For the odd-C isoscalar exchange (mainly ω) one has two techniques available. First, one can measure the energy dependence of $\Delta(KN)$ or $\Delta(NN)$ at $t = t_{\min}$; this is proportional to the ω amplitude and when combined with the energy dependence of the cross-sections will allow an estimate of the strength of the ω contribution. It is essentially a matter of measuring the energy dependence of the "cross over effect".

Second, one can measure the cross-sections for $K_2 p \to K_1 p^*$, dominated by ω exchange. With monoenergetic beams one could do the inclusive experiment and compare mass spectra with $(\pi)pp \to (\pi)pp^*$. One could also obtain the ω contribution to each specific final N^* state in the exclusive processes. It would be very nice to know the cross-section (and density matrices) for

$$K_2 p \to K_1 p^*(1690)$$
$$\quad\quad\quad\quad\quad \lfloor\!\longrightarrow n\pi^+,\, p\pi^0,\, \Lambda K^+.$$

For even-C isoscalar exchange (mainly f) one can only get numbers with theoretical input and models. One experiment (for the future) is to measure the real part at $t_{\min}$ in a Coulomb interference experiment, which can be done for the QE processes as well as for the elastic ones; then one has a fairly good handle on the f.

By comparing different processes one may be able to get some clues; for example, if the amount of Pomeron and the amount of ω in Kp and in pp processes are in different ratios then knowing the energy dependence of both will allow one to extract some information.

General model. Here I will sketch the ingredients of a general model that allows us to go a bit further in discussing the data. Below I will remark briefly on the possibility of more detailed calculations.

Consider as examples $KN \to KN^*(1690)$, or $KN \to QN$. Both have six independent helicity amplitudes. To make a complete model we must tell how each amplitude behaves as a function of s and t, and how much of each amplitude is present.

To have a useful discussion one only needs to add one more assumption to the two above, namely:

3. For each diffractive process several of the helicity amplitudes are significantly populated.

In conventional analysis of two-body reactions it has proved much more fruitful to see simple physical behavior by studying data in terms of s-channel helicity amplitudes than any other. This is not a statement about helicity conservation or any such game; it is a claim that the dependence of the amplitudes on s and t, and their sizes, is simpler to describe and understand for the s-channel amplitudes than any others.

The formalism we need is simple and concise. Consider a process $a+b \to c+d$ with s-channel centre-of-mass helicities λ_a, *etc.* Define the quantity

$$n = |(\lambda_a-\lambda_b)-(\lambda_c-\lambda_d)| = |(\lambda_a-\lambda_c)-(\lambda_b-\lambda_d)|;$$

n is referred to as the net helicity flip. In the forward direction n is the change in J_z.

From general arguments (angular momentum) one can see that for any s-channel helicity amplitude

$$M_{(\lambda)} \underset{\theta\to 0}{\to} (\sin\theta/2)^n$$

(*e.g.* use the small angle form for the $d^J_{\lambda\mu}$ in the Jacob-Wick partial wave expansion).

We can enumerate the full set of helicity amplitudes for any process by letting all λ_i run over their possible values. Parity conservation says that putting all λ_i into minus themselves one gets back $\pm$ what one started with. Thus for $KN \to QN$ one has for $M^Q_{N'N}$ the independent possibilities

$$M^1_{++}(1),\ M^1_{-+}(2),\ M^0_{++}(0),\ M^0_{-+}(1),\ M^{-1}_{++}(1),\ M^{-1}_{-+}(0)$$

where $\pm$ stands for $\pm\frac{1}{2}$ and the n value is given in parenthesis; for $KN \to KN^*(1690)$ there are

$$M_{5+}(2),\ M_{3+}(1),\ M_{1+}(0),\ M_{-1+}(1),\ M_{-3+}(2),\ M_{-5+}(3),$$

where the first subscript is twice $\lambda(1690)$.

If we knew the probability of various exchanges changing meson or baryon helicities by 0, 1, 2, 3 units we could say how important the various terms are.

The cross-section is just the sum of absolute squares of the independent amplitudes,

$$\frac{d\sigma}{dt} = \sum_{\substack{\text{independent} \\ (\lambda)}} |M^{\lambda c \lambda d}_{\lambda a \lambda b}|^2$$

and the density matrices are given by (unnormalized)

$$\varrho_{\mu'\mu}(Q) = \sum_{\lambda'\lambda} M^{\mu'}_{\lambda'\lambda} M^{\mu *}_{\lambda'\lambda}$$

$$\varrho_{\mu'\mu}(N^*) = \sum_{\lambda} M_{\mu'\lambda} M^*_{\mu\lambda}.$$

General observations on t-dependence. The main problem in making a model is that we do not know what exchanges populate which helicity amplitudes how much. As an increasing number of amplitudes with $n > 0$ are populated, one will find a less sharp forward peak and then a forward turnover because all amplitudes with $n > 0$ vanish in the forward direction. Thus observation of forward turnovers could be interpreted simply as evidence for the presence of amplitudes with $n > 0$. It could also be interpreted as the presence of a dynamical forward zero in the amplitude with $n = 0$ that would normally give a peak; one of the first jobs experimentally, if turnovers are observed, will be to distinguish between these explanations by measuring the density matrices.

The presence of forward turnovers could account [1] for the failure of the Michigan--Princeton experiment [8, 9] to see any N^*'s; the coherent cross-section depends on the small t cross-section, which could be much smaller than a simple extrapolation from larger t would give.

In Figs 13–16 the t dependence is shown for several N^* states [2]. The values of the slopes and their energy dependence are shown in Fig. 17, and the ratio of $N^*(1690)$ to elastic in Fig. 17. For the N^* states beyond $N^*(1411)$ there is at least considerable flattening at small t.

If amplitudes with $n > 0$ are important in N^* production then it will be much harder to see crossovers; this was predicted in reference [1] and seems to be observed by Kittel *et al.* [11] who see a crossover in $\pi N \to A_1 N$ but not in $\pi N \to N^*$.

Similarly, the more amplitudes with $n > 0$ the smaller the slope one gets for $-t \lesssim 1$ since the t distribution for higher n amplitudes peaks at larger t.

Thus a lot of the behavior of QE reactions can be correlated by assuming important contributions from amplitudes with $n > 0$.

We can go further with some dynamical conjectures. For Reggeon exchange it is known that the magnitude of the $n = 0$ amplitude has a forward peak and then a dip at a $-t$ value of about 0.25 for ω, ϱ exchange, somewhat further out for f, A_2 exchange. Very crudely, this can be described by a t-dependence for the amplitude proportional to $J_0(R\sqrt{-t})$, where R is about a fermi for vector meson exchange; the tensor exchange is a shorter range force, with $R \sim 2/3$ fermi. Recently I have argued [16] that a similar view of the Pomeron amplitude is useful and I think a similar approach [17] is appropriate for the diffractive reactions as well.

Here we want to concentrate on the diffractive production. Essentially the argument I want to make is that diffractive production of hadrons comes mainly from the more peripheral part of the interaction, the smallest partial waves being absorbed away. There may still be a central piece, though it will be less important here than for elastic processes. The amplitude arises not as a simple exchange of some sort, but as the end result of some underlying "Born" term, modified considerably by unitarity (absorptive) effects. Thus I expect that the $n = 0$ amplitude for QE processes will be of the form

$$M \sim Ae^{Bt} + A_0 e^{b_0 t} J_0(R\sqrt{-t})$$

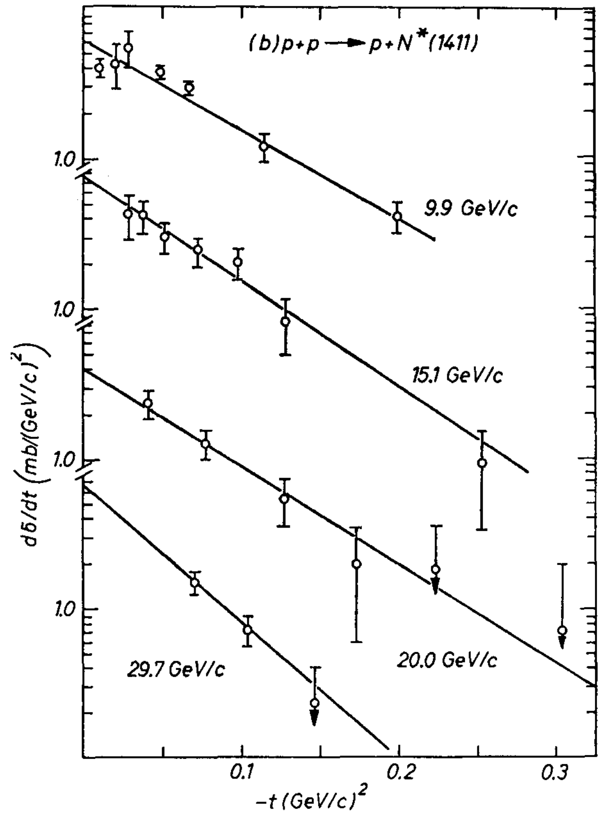


Fig. 13. t-dependence for $N^*(1411)$. From Ref. [2]

with the second term dominating at small t. Then $|M|^2$ will have a dip near $-t \sim 0.25$, and a steep slope at small t. A is imaginary and A_0 at least half imaginary. Similarly, amplitudes with $n > 0$ will be proportional to $J_n(R\sqrt{-t})$; they could arise from Pomeron or Reggeon contributions.

Thus we have the following situation. Amplitudes characterized by $n = 0$, 1, 2 (for example) are sketched in Fig. 18a—c respectively, and a possible cross-section with about equal amounts of $n = 0$, 1 present in Fig. 18d. A pure $n = 0$ cross-section would show

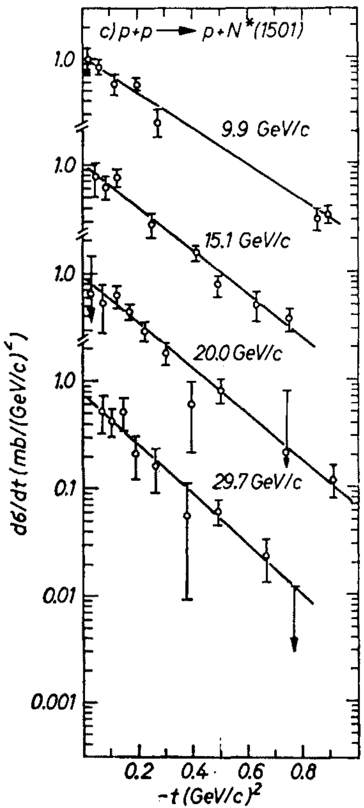


Fig. 14. t-dependence for $N^*(1501)$. From Ref. [2]

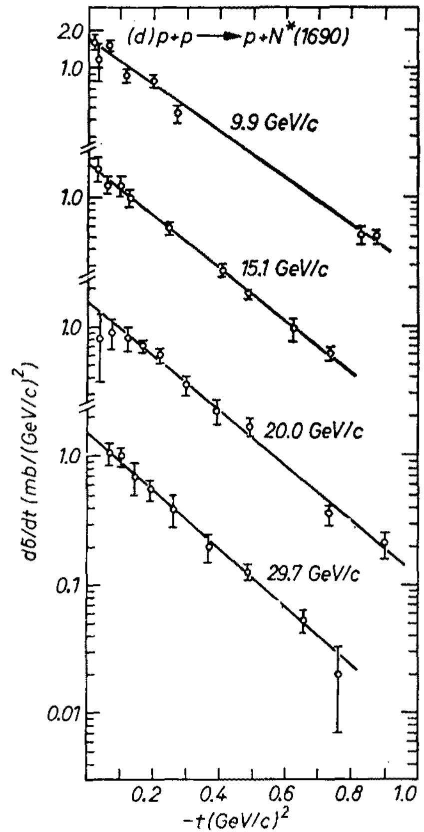


Fig. 15. t-dependence for $N^*(1690)$. From Ref. [2]

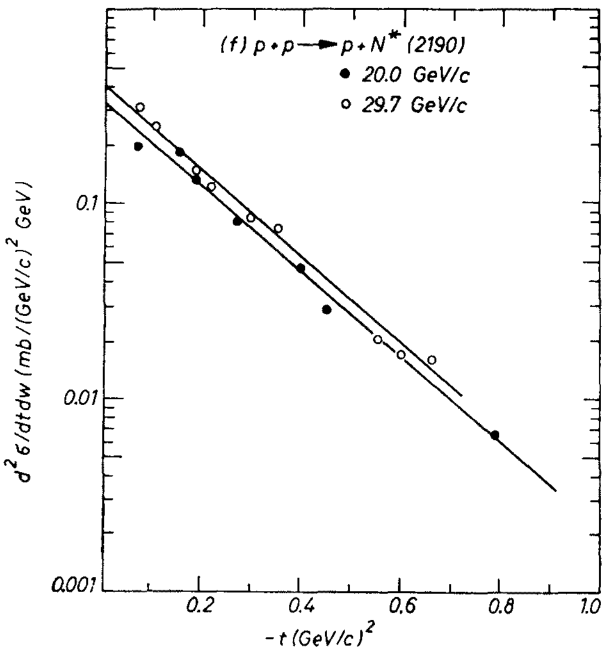


Fig. 16. t-dependence for $N^*(2190)$. From Ref. [2]

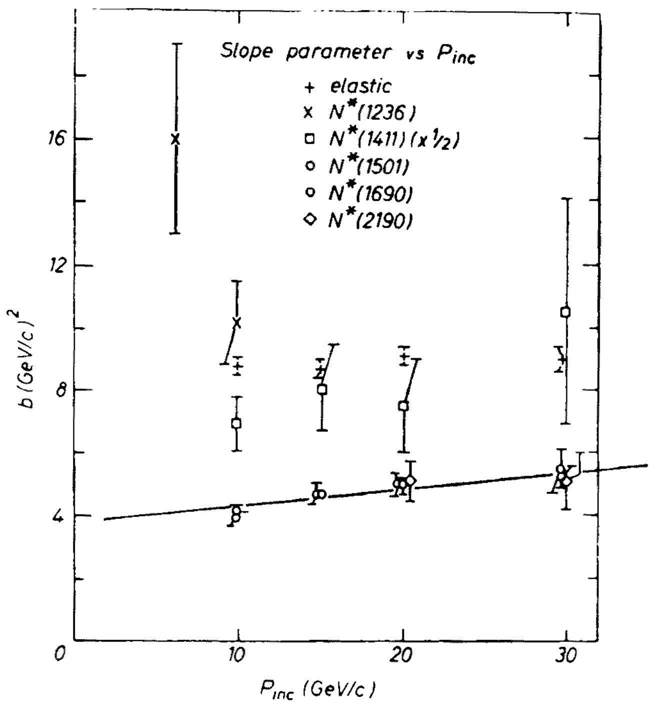


Fig. 17. Values and energy dependence of slopes, showing shrinkage; from Ref. [2]

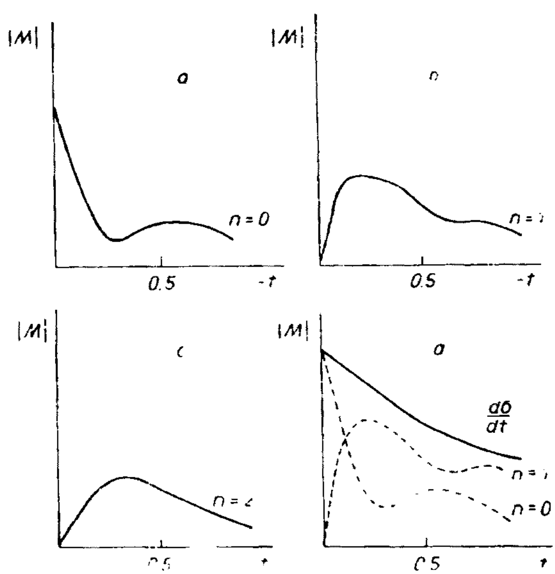
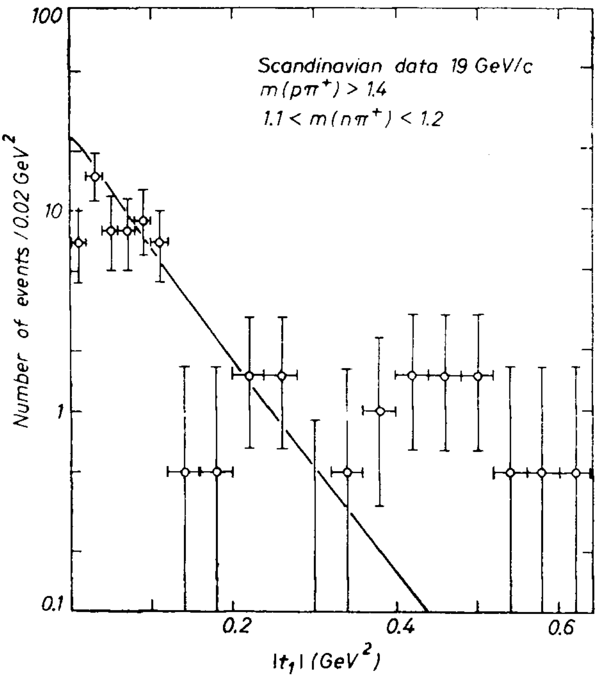
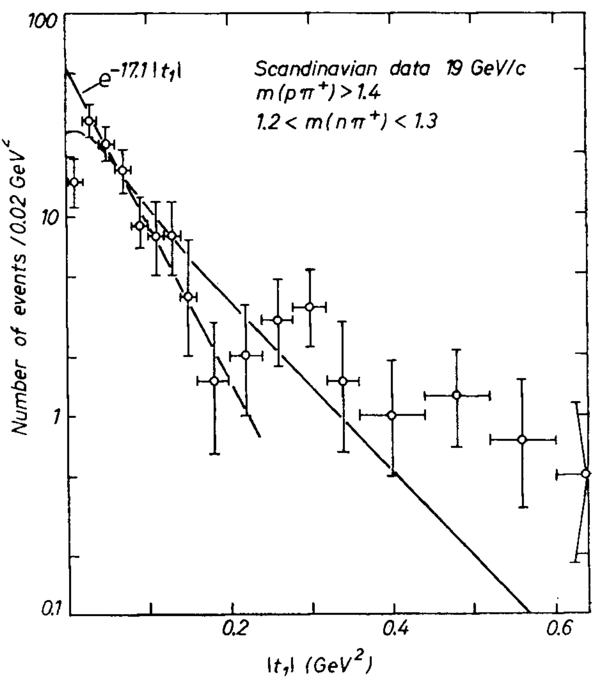


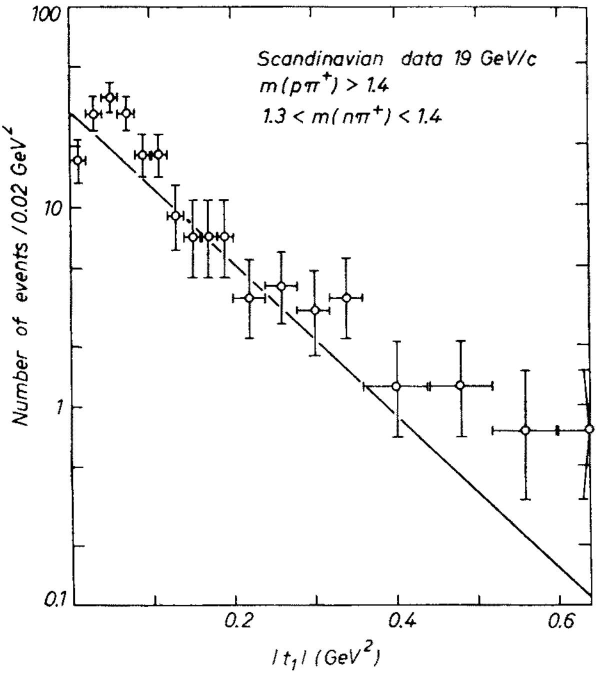
Fig. 18. Parts a—c show magnitudes of $n = 0,1,2$ amplitudes respectively, sketched on a semilog scale *vs* $-t$; part d shows a possible cross-section, with about equal $n = 0$ and $n = 1$ contributions. The $n = 0$ cross-section would have a slope ~ 15—20 GeV^{-2} at small t


Scandinavian data 19 GeV/c
m(pπ⁺) > 1.4
1.1 < m(nπ⁺) < 1.2
Number of events /0.02 GeV²
|t₁| (GeV²)
100
10
1
0.1
0.2
0.4
0.6

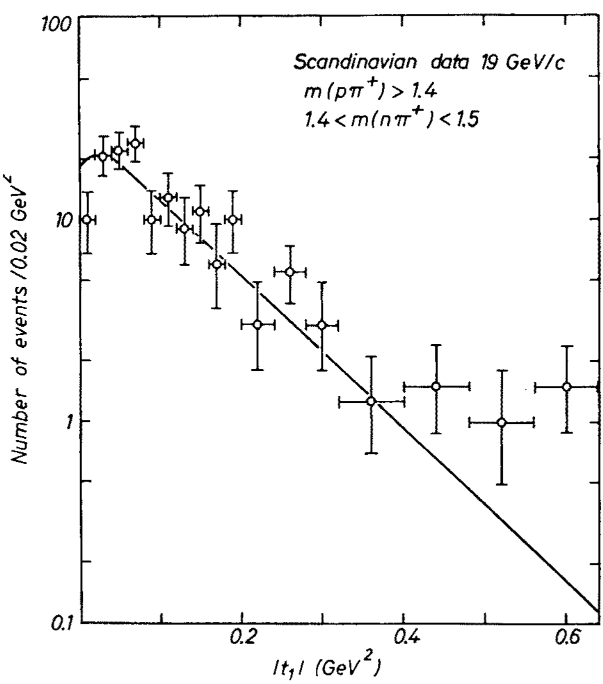
a


Scandinavian data 19 GeV/c
m(pπ⁺) > 1.4
1.2 < m(nπ⁺) < 1.3
e^{-17.1|t₁|}
Number of events /0.02 GeV²
|t₁| (GeV²)
100
10
1
0.1
0.2
0.4
0.6

b


Scandinavian data 19 GeV/c
m(pπ+) > 1.4
1.3 < m(nπ+) < 1.4
Number of events /0.02 GeV2
|t1| (GeV2)
100
10
1
0.1
0.2
0.4
0.6

c


Scandinavian data 19 GeV/c
m(pπ+) > 1.4
1.4 < m(nπ+) < 1.5
Number of events /0.02 GeV2
|t1| (GeV2)
100
10
1
0.1
0.2
0.4
0.6

d

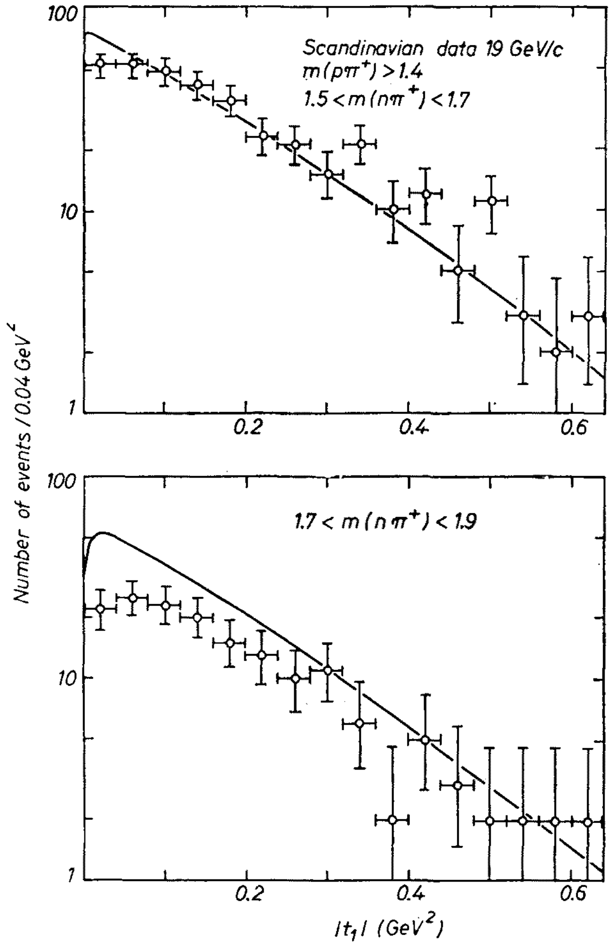


Fig. 19a–e. Showing t distributions for different mass bins, to illustrate the way they change from a dip to a flat slope; from the 19 GeV/c Scandinavian pp data. See Ref. [18]

the dip in Fig. 18a, while a cross-section with about equal mixtures of $n = 0$ and $n = 1$ would give the monotonic curve of Fig. 18d.

Finally, then I propose the following picture of QE reactions. (To avoid confusion, I emphasize that currently it is just a picture within which one can correlate most of the data in a natural way; it has at the moment free parameters in the form of the amounts of different amplitudes present for various processes. It can "fit" most of the data and it can be tested, but it needs input for the coupling strengths before it is really a useful model.)

A given reaction has several amplitudes contributing. At low masses only one or two amplitudes are populated, so that for the low mass region around $N^*(1400)$ one observes a dip near 0.2 because the $n = 0$ amplitude dominates; the steep slope of $N^*(1400)$ is interpreted (not as a steep slope *per se* but) as the approach of a dip. There is some evidence for such a dip [18]. Figs 19a-e show the t-distribution for several mass bins

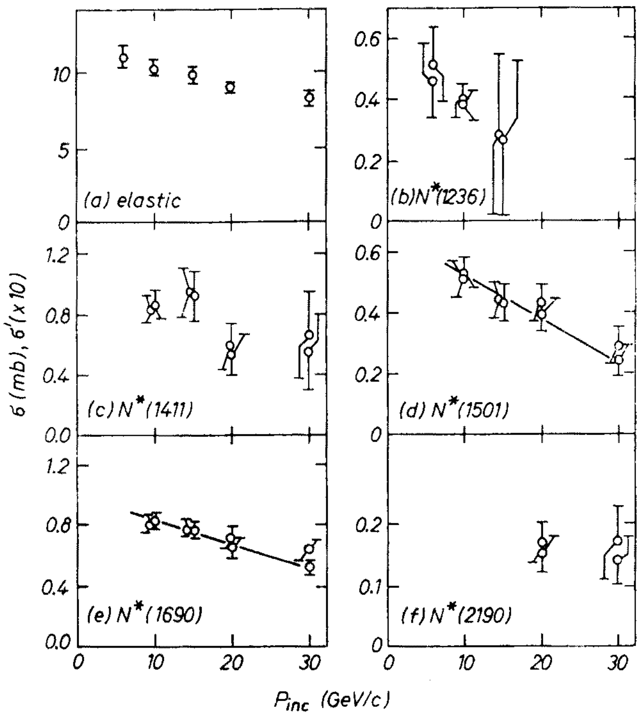


Fig. 20. Energy dependence of N^* production. From Ref. [2]

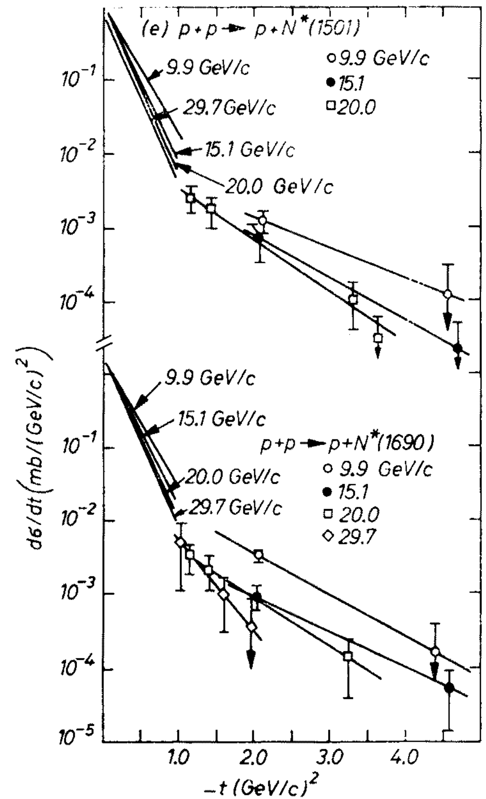


Fig. 21. Shrinkage of N^* production. From Ref. [2]

from the 19 GeV/c Scandinavian collaboration pp data [19]. Note how the dip fills in and the slope decreases as m^2 increases. For the A_1 and Q regions a smaller effect operates giving slopes as steep as, or steeper than, the elastic ones. As the mass goes up, higher helicity states are produced so amplitudes with $n > 0$ are populated giving small slopes in t, and perhaps turnovers. Note that this approach is capable of describing the slope-mass correlation at small t as part of the dynamics. (See above for the importance of this.) Crossovers will arise naturally too here as ω and ϱ contributions will be present in the amplitudes and will interfere.

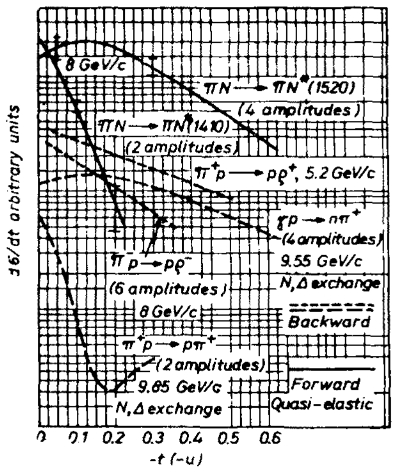


Fig. 22. Shapes of various diffractive and backward cross-sections, to illustrate that those with the same number of amplitudes can look very much alike

The Reggeon exchanges will fall with energy while the Pomeron contribution rises with energy, giving a net contribution which could be constant in s, or fall slowly if the Reggeon contribution is quite large; a slow fall $\sim p_L^{-0.5}$ is usually observed (see Fig. 20, from Ref. [2], for the N^*'s, and Figs 3 and 5 for A_1 and Q). If the $n > 0$ amplitudes are mainly coming from Reggeon exchange one will see a lot of changes as the energy goes up; Fig. 16 does indeed suggest that the QE peaks shrink rather faster than the elastic one, and Fig. 21 from Ref. [2] shows the shrinkage.

In Fig. 22 we make a pedagogical point, to show that the t dependence of the diffractive processes is really quite like that of non-diffractive two-body processes. The solid lines are diffractive and the dashed ones Reggeon exchange; the steep dashed lire for $\pi^+p \to p\pi^+$ is known to be dominated by one $n = 0$ amplitude, while the flatter dashed line for $\gamma p \to n\pi^+$ is known to have four important amplitudes (one with $n = 0$, two with $n = 1$, one with $n = 2$).

Another significant qualitative argument is that slopes $\gtrsim 8$ GeV^{-2} cannot reasonably be associated with diffractive scattering from hadrons with radius ~ 1 fermi unless they arise mainly from edge effects in impact parameter, or dips in momentum transfer. Thus the large slope at small t is most reasonably considered as connected with a dip.

A possible interpretation. My personal view of all the problems of crossovers, slope-mass correlations, size, ... is that we are mainly seeing s-channel unitarity effects. Similar arguments are given for elastic scattering in Ref. [14].

To use the conventional two-body language, I suspect that the Deck or multiperipheral contributions are "absorbed" in some sense. This produces the dip structure and reduces the size. Whether it could help understand the crossover being opposite to the Deck or multiperipheral contribution is unclear; we would need to know how the unitarity corrections depended on the particles in intermediate states.

In this view, whatever the basic structure of the interaction, it is obscured by the very strong interactions of the particles involved. They behave as if there is scattering from a disc with the center absorbed away, a ring — this essentially determines the t dependence. The basic structure can affect the size of the ring, the phase, the selection rules, the main energy dependence. But the superimposed unitarity effects make it hard to extract the basic interaction.

5. *Miscellaneous*

Helicity conservation. It is apparent that we are taking here quite a different view of the dynamics of questions usually discussed under headings like "s-channel *vs* t-channel helicity conservation".

Consider, for example, $\pi N \to A_1 N$; a similar description could be given for any QE process. The sharp forward peak is in an $n = 0$ amplitude (presumably M^0_{++} since M^{-1}_{-+} would have an extra evasive factor of t from any definite parity exchange). Thus the amplitude with s-channel A_1 helicity zero, $\lambda_s(A_1) = 0$, is large. But as $-t$ approaches 0.25 or so this amplitude will have a dip, so that one could either have a dip or break in $d\sigma/dt$ near 0.25 or production of $\lambda^s(A_1) = \pm 1$ states filling it in. Since f exchange can produce $\lambda^s = 0$, 1, and if the coupling of A_1 πf is largely s-wave, it means about equal amounts of $\lambda_s = 0$, 1, it is reasonable to expect an increase in $\lambda^s(A_1) = \pm 1$ production in an $n = 1$ amplitude. It is possible too that the Pomeron produces $n > 0$ amplitudes. Thus the decrease in the $\lambda^s(A_1) = 0$ ("helicity conserving") amplitude is from the dynamics of the dip at $-t \sim 0.25$, not due to t-channel helicity conservation. After the dip, for $-t \sim 0.7$, $\lambda^s(A_1) = 0$ will be present again. The important thing is to extract the overall coupling strength of the various amplitudes appropriately defined.

We can then make the following rather strong prediction. For all diffractive processes one finds s-channel helicity conservation if (*i*) the reaction is truly elastic with a very large central Pomeron contribution; or if (*ii*) $d\sigma/dt$ shows a dip near $-t \sim 0.3$ so that only $\lambda_s = 0$ is produced. But for all diffractive production processes where $d\sigma/dt$ does not have the $n = 0$ dip then states with $n > 0$ are being produced. As $-t$ increases away from the forward direction, one finds a region from (say) 0.05—0.25 where $\lambda_s = 0$ and $\lambda_s = 1$ (or $\frac{1}{2}$, 3/2) are about equally produced — this is equivalent to t-channel helicity conservation to a good approximation. For larger $-t$ $\lambda_s = 0$ is small, until near $-t \sim 0.7$ one finds $\lambda_s = 0$ again dominates (see Fig. 18). This picture is currently consistent with all the data on density matrices and on „t-channel conservation" and deviations from it.

We are led, then, to argue that it may be more fruitful to study the spin dynamics by studying the amount of production of different s-channel helicity states as t varies (and s of course). From our point of view the approximate t-channel helicity conservation observed for A_1 and Q is essentially accidental and arises because producing approximately equal amounts of all s-channel helicities is the same as approximately conserving t-channel helicity. It should be fairly easy to distinguish these points of view by comparing different reactions; for example, $K^{\pm}$ dissociations might be rather different since the ω exchange is different for the two and is known to be important for the Q crossovers.

A related point of view has been taken by Gault and Walters [20]. They observe, for example, that for fermion vertices one can conserve helicity in elastic scattering with a γ_μ coupling; assuming that is the universal feature leads to definite predictions for production of higher helicity N^* states, consistent with all existing data for $N^*(1520)$ and N^* (1690).

To avoid confusion I emphasize that it is possible to present information in many equally good ways. But getting at the underlying physics might be much easier one way than another. I would urge experimenters to produce as much information as possible about production of s-channel helicity states, particularly as they vary with t. Observing a dip in the helicity conserving amplitude might tell us more than the fact of t-channel conservation. Then phenomenologists can test simple ideas about the dynamical origin of important amplitudes.

Duality. Essentially no effort has gone into thinking about effects of duality and/or exchange-degeneracy for QE processes. Experimentally it will mainly be comparisons of particle-antiparticle processes that are illuminating, and polarizations.

As an example of an exchange degeneracy prediction [1] we note that it is likely that the Reggeon contribution to $K^+p \to QN$ or KN^* is largely real, while the Reggeon contribution to $K^-p \to \bar{Q}N$ or $\bar{K}N^*$ has a "rotating" phase. If the Pomeron is mainly imaginary it will interfere much more with the Reggeons in the $\bar{K}$ reaction, so the K, $\bar{K}$ reactions will have different energy dependence.

If $K^+p \to Q^+p$ is dominated by a Pomeron which rises with increasing energy it may show such a rise, or fall less rapidly than other processes.

It may be fruitful to study the QE data at high and low energies; perhaps one can see whether mainly peripheral s-channel resonances contribute to the Reggeon exchange part and background to the Pomeron part, or perhaps there will be important central resonances.

Hyperon beams [21]. For a number of reasons we may learn a great deal about QE processes from hyperon beams. Currently there are charged and neutral beams (mainly Λ, $\bar{\Lambda}$, Σ^-, Ξ^-) available at BNL and CERN, with beams to come at ANL and NAL.

Important advantages will include:

1. substantially reduced background;
2. narrower width resonances than for N^*'s;
3. more chance to study selection rules;
4. can get at decay angular distributions and polarizations.

Consider, for example, $\Sigma^- p \to Y_1^* p$ analogous to $pp \to N^* p$. Analogous to $N^*(1690)$ one has $\Sigma(1915)$ and analogous to $N^*(1520)$ one has $\Sigma(1670)$. Both have widths $\sim$ 60 MeV. It will be interesting to see what is analogous to $N^*(1410)$. Cross-sections should be as large as for the pp case.

The presence of Y_1^* (1385) will be of great interest as it involves an $SU(3)$ change and a parity change ($\Delta p \neq (-1)^{\Delta J}$) but not an isospin change; if it is observed ($\Lambda\pi$ decay) or not it will teach us a lot about selection rules. Probably the relevant data would be the relative energy dependence of $pp \to p\Delta(1236)$ and $\Sigma^- p \to Y_1^*(1385)p$; if the ratio Δ/Y^* falls with energy then either $SU(3)$ or the parity selection rule is violated.

Similarly, if the Λ were in an octet and $\Lambda(1405)$ were an $SU(3)$ singlet, $SU(3)$ and the parity selection rule both forbid dissociation into $\Lambda(1405)$. But Λ-mixing should allow the $SU(3)$ transition. Thus here we can separate the $SU(3)$ and parity selection rules. From another viewpoint, the t dependence of dissociation to $\Lambda(1405)$, if it occurs, may tell us about the J_0 $(R\sqrt{-t})$ hypothesis and the steep slope of $N^*(1410)$.

The main new results could come from the possibility of seeing decay angular distributions and polarizations. For example, in

$$
\begin{array}{l}
\Sigma^- p \to Y_1^* p \\
\qquad\quad \llcorner\!\!\to \Lambda\pi \\
\qquad\qquad\quad \llcorner\!\!\to p\pi^-
\end{array}
$$

which might be rather background-free with narrow Y^*'s we can get essentially complete information about which helicity states of the Y^* are populated from the Y^* density matrix, the Λ polarization, and the forward behavior of $d\sigma/dt$. Similar possibilities exist for $\Lambda \to \Sigma^+\pi^-$ with Σ^+ polarized, and for Ξ beams.

Very high energies. As the energy increases the Reggeon contribution goes away and presumably we will have constant QE cross-sections. What about crossovers? If we assume we can only see them $d\sigma/dt$ at $t = 0$ differs by at least 5% (so we are trying hard), then we will still see them if |odd-C Reggeon|/|Pomeron| $\sim$ 2.5% in the amplitude. This is about 1/4 or 1/5 of current values. Assuming this ratio decreases as $1/\sqrt{s}$ approximately, we need s to increase by 16 or so, giving $s \sim 320$ GeV^2 or $p_L \sim 160$ GeV/c when crossovers are too hard to see.

The big puzzle we have is why the traditional views seem rather misleading, and how to replace them. Many authors have speculated on the apparent presence in the mass spectrum of both resonances and low mass enhancements — see particularly Morrison [10]. In the introduction above I discussed the resonance *vs* background energy dependence question currently of considerable interest in inclusive theory. Perhaps the first results from the ISR or NAL will answer these questions for us — the mass spectrum will have prominent resonances or no resonances, and its t dependence will show J_0 behavior or will be smooth and independent of M^2. To be sure, it will be essential not only to have a missing mass spectrum but also dissociation into a definite final state. As we know from inclusive theory, the dissociations into exclusive and inclusive final states may be subtlely related.

One of the main questions certainly must be whether the slope-mass correlation persists as s increases. My own conjecture is that the slope-mass correlation is essentially a unitarity effect, leading through an absorption mechanism to amplitudes which have zeros that give sharp peaks. The effects may be weaker for higher mass dissociation, and amplitudes with $n > 0$ will be more populated for higher spin production, so I suspect the slope-mass correlation is a basic clue; it will flatten a bit as s increases but essentially it will remain.

If all amplitudes with $n > 0$ are populated by Reggeons one will see the $n = 0$ shape approached as s increases and s-channel helicities conserved; if the "Pomeron" can populate $n > 0$ then slopes might change very little with s.

The data of the next two years is likely to have a greater impact on our view of diffractive phenomena than most other aspects of hadron physics.

I am pleased to thank H. I. Miettinen for many stimulating discussions and comments on both the manuscript and its contents; and the organizers of the School for their warm hospitality and effective management.

REFERENCES

[1] G. Cohen-Tannoudji, G. L. Kane, C. Quigg, *Nuclear Phys.* **B37**, 77 (1972).
[2] R. M. Edelstein *et al.*, Carnegie-Mellon University *preprint*, *Isobar Production and Elastic Scattering in p-p Interactions from 6-30 GeV/c.*
[3] P. H. Frampton, P. V. Ruuskanen, *Phys. Letters*, **38B**, 78 (1972).
[4] R. Roberts, D. P. Roy, private communication.
[5] J. C. Van der Velde, *Nuclear Diffraction Dissociation* to be published in the proceedings of the VIIth Rencontre de Moriond, Méribel-des-Allures, France.
[6] R. M. Edelstein, V. Rittenberg, H. R. Rubinstein, *Phys. Letters*, **35B**, 408 (1971).
[7] M. Einhorn, private communication.
[8] M. J. Longo *et al.*, *Phys. Letters*, **36B**, 560 (1971).
[9] J. C. Vand der Velde *et al.*, *Decay Angular Distributions of $p\pi^-$ States Formed in Diffraction Dissociation of Neutrons on Carbon* University od Michigan *preprint* UM-HE 71-31-2.
[10] D. R. O. Morrison, Kiev Conference Proceedings, 1970.
[11] $\Delta(Qp)$ averaged over 4-12 GeV/c giving about 400 events for each, from G. W. Brandenburg *et al.*, *Phys. Rev. Letters*, **28**, 932 (1972); $\Delta(A_1p)$ at 16 GeV/c; W. Kittel, private communication; $\Delta(N^*p)$ at 8 and 16 GeV/c; E. W. Anderson *et al.*, *Phys. Rev. Letters*, **25**, 699 (1970) and preliminary data quoted in Ref. [5].
[12] H. I. Miettinen, P. Pirilä, Rutherford Laboratory *preprint* and *Phys. Letters* to be published. See this paper for references to earlier work.
[13] The numbers quoted for the separate contributions are taken from fits to the πN data (B. J. Hartley and G. L. Kane, *Phys. Letters*, **39B**, 531 (1972)). However, just by assuming that the forward real parts of the πN amplitudes are due to non-Pomeron contributions one can essentially get these numbers. The average real part for πN is about 15%. Squared to give a cross-section, and multiplied by 2 to account for the imaginary part (assume Regge-like phases so $|\mathrm{Re} f| \sim |\mathrm{Im} f|$), we get 4.5% of the full cross-section for the f. This gives 1800 μb/(GeV/c)^2 at $t = 0$. The actual fit gives 2900 as quoted, but 1800 is just as useful a number to make our point. A similar result follows for ω, f exchange in pp collisions.
[14] Tsou Sheung Tsun, *Nuclear Phys.*, **B36**, 472 (1972).
[15] It has been studied for vector meson photoproduction on nuclei by M. Nauenberg, *Phys. Rev. Letters*,

22, 556 (1969); B. Margolis, K. Gottfried, D. R. Yennie, *Phys. Rev.*, **182**, 1595 (1969); S. J. Brodsky, J. Pumplin, *Phys. Rev.*, **182**, 1794 (1969).
[16] G. L. Kane, *Phys. Letters* (to be published).
[17] M. Ross, F. Henyey, G. L. Kane, *Nuclear Phys.*, **B23**, 269 (1970).
[18] H. I. Miettinen, J. Allaby, private communication.
[19] I am grateful to Professor K. Hansen for permission to use this data.
[20] F. D. Gault, P. J. Walters, Durham *preprint*.
[21] These remarks are motivated by correspondence with C. Quigg.