PHENOMENOLOGY OF HIGH ENERGY EXCHANGE PROCESSES*†

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INTRODUCTION

In this review I will first try to give the interested reader a feeling for the kinds of work going on in this field, the kinds of models people are considering and why. The level will be qualitative and vague, meant to give a framework to classify present and future efforts.

In addition to a general survey a number of current subjects with interesting possibilities or implications will be discussed. These are:

--remarks on amplitude analysis

--zeros of s-channel helicity amplitudes; fixed t or fixed u?

--$np \to pn$, $\bar{p}p \to \bar{n}n$, $d\sigma/dt$ and polarizations; important test for models

--energy dependence; comparison of different reactions with the same exchange and different observables in the same reaction

--production of higher spin resonances; especially the B and external Regge recurrences

--expectations for higher energy data soon to come; especially concerning relative energy dependence of different Reggeons, shrinkage, and line reversed reactions.

In preparing this review I looked back at several recent reviews[1] and rapporteur's talks about high energy particle exchange phenomena and two body reactions. They are noteworthy for extensive treatment of the details of experimental data and the description of data in lots of models, for diligently searching out possible puzzles and contradictions, and for a lack of optimism about our hopes for progress in this field.

Hadron exclusive reactions is not a field where questions have simple yes/no answers any more. Rather we have to look for insights to the pattern of much data. The situation appears to be complicated. Even so, I think that there has been slow but steady increase in insight, and that it is appropriate here to try to give a broad overview of the general ideas at hand. In the general survey, rather than present details of many

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models I will simply try to discriminate among the basic approaches people use. At the present time only one model, essentially a classical absorption approach, has succeeded in describing a large body of data and has presented a large number of predictions for higher energy data; so its results are used in several sections.

HISTORICAL AND GENERAL SURVEY

To understand the present situation concerning models relevant to two body hadron reactions it is useful to briefly recall some history.

For a long time it has been apparent that it is useful to imagine that the reactions proceed via exchange of a system carrying appropriate quantum numbers. This is clear from a study of energy dependence, phase, and quantum numbers (SU(3), etc.). It was also realized early that for theoretical reasons the exchange of many partial waves must be correlated in a t-dependent way, giving Regge energy dependence $s^{\alpha(t)}$ and the associated phase from analyticity $e^{-i\alpha(t)/2}$.

On the other hand, the behavior of the Regge residues, essentially interpretable as form factors, has remained unknown. This has allowed an unhappy amount of freedom in describing data and has led to ambiguities and misunderstandings concerning Regge ideas. The Regge energy dependence and phase are unambiguous; the determination of the residue remains one of the major theoretical or phenomenological problems in hadron physics.

Still ten years ago it was realized that the external particles, being strongly interacting, must undergo important final state and initial state interactions, called absorption corrections. Much of the work in this field in the past ten years can be understood as the attempt to take account of the hadronic nature of the external particles--how should one perform absorption corrections? It has not been emphasized enough that the question should not be whether to take account of absorption but how, because it would be extraordinary if absorption did not occur when hadrons interact. To neglect absorption may turn out to be correct in some situation or amplitude, but it will require extensive theoretical justification.

Next it was realized that the absorption question had still another complication, the sum over intermediate states. This is one of the most interesting theoretical questions in the whole area. Basically the situation can be pictured as in Fig. 1. The full amplitude is given by a Reggeon exchange (wavy line) plus the elastic absorption correction plus a sum over non-elastic intermediate states c* and d* (plus appropriate contributions with intermediate

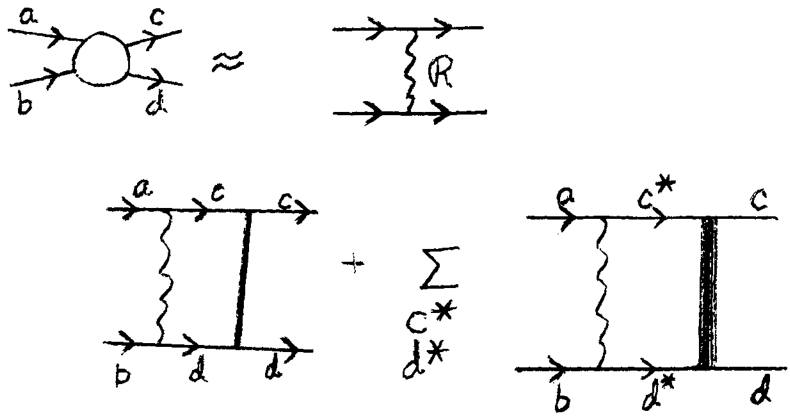

Fig. 1

states a and b, etc.). How does one calculate the sum over intermediate states?

Until recently two methods have been used to represent its value; neither can be considered a calculation. One common procedure, often used for helicity flip amplitudes, was to set sum = 0. So far this has no significant theoretical justification, and it is probably inadequate phenomenologically. It is somewhat like the situation used to be with phase shift analyses, where all phase shifts beyond a certain partial wave were set to zero; now we know that it is better to use a reasonable model for the high partial waves. On the other hand, if the Mystical Models described below turned out to be on the right track it would not be surprising if sometimes one should have sum = 0.

The second method was to assume that the sum had the same dependence on its variables as the elastic intermediate state contribution, so that elastic + sum = λ(elastic) where $\lambda \geqslant 1$. This method, a useful approximation in the earliest models (e.g., "SCRAM"), is known to be inadequate in that the sum should have a different shape in impact parameter than the elastic term (peripheral vs. central) and since absorption has to do with affecting the partial wave structure that is an important thing to get right. A recent attempt along these lines is described in the Classical Absorption Model mentioned in the text.

Fortunately there will be experimental hints about how to calculate intermediate state sums; it is not merely a question of theorist's games. In addition to the absorption phenomenology itself, which provides one check, three other possible experimental tools are described in Appendix 1.

On the whole one can put the huge proliferation of models for hadron two body reactions into one of three classes; Romantic, Mystical, or Classical. The first two of these have as a basic, underlying (sometimes not explicit) assumption that the ideas and tools we currently have at hand are not adequate to arrive at a description of the data. Some new concept, possibly a dramatic one, is needed; at the minimum, it is felt that the results might come from an existing theory if we could calculate with it, but since we cannot the best we can do is look for regularities in the data. The Romantic Models, while requiring behavior we are not able to understand (such as Regge pole phases for amplitudes with strong Regge cuts) attempt to give theoretical arguments which might lead to the behavior. The Mystical models go even further, postulating models where accepted physical principles are violated (such as analyticity) to obtain agreement with data, or where the modifications are entirely ad hoc. This characterization should not be interpreted as critical; if in fact the intuition that new ideas are needed is correct it may be the right approach to search them out. The Mystical Models have as an additional implicit assumption that exchange degenerate poles must be the starting point. It is well known that this leads to considerable phenomenological difficulty, and has led to some of the clever modifications which have been introduced to allow one to fit data.

In theClassical Models, on the other hand, the basic point of view is that no fundamental physics is lacking to understand the behavior of hadron experimental data. Although the very simple models formulated in the past have not described the data well, the difficulty, it is argued, has mainly been in subtleties concerning phases, and can be dealt with by a slight increase in realism such as properly interpreting the initial or final state rescattering phase in terms of real elastic scattering at the same energy.

At the present time most models are capable of describing $0^-\frac{1}{2}^+\to 0^-\frac{1}{2}^+$ reactions, so one cannot conclude much from such applications. In addition to these, one Classical absorption model[2] (referred to as CAM in the following) has been able to describe in considerable detail a number of $0^-\frac{1}{2}^+\to 1^-\frac{1}{2}^+$ [3] and $\frac{1}{2}^+\frac{1}{2}^+\to\frac{1}{2}^+\frac{1}{2}^+$ [4] reactions. These involve subtle and relevant tests of the details of amplitudes, so to the extent that describing data can lead us to physical insight the CAM must currently be considered acceptable and the leading contender for a good model. From describing a finite amount of data alone one can never, of course, confirm a given model or theory; the reader must decide for himself whether he is prepared to accept the underlying physics.

TABLE 1

Model	Philosophy	Applicability: Exchanges	Applicability: Reactions	Validity
Dual Absorption Model (Harari)	"Romantic" ImM "absorbed" because of duality but ReM unknown or given by Regge phase. Believe we still lack important concepts	Not applicable to cross sections but only to some parts of some amplitudes Vector, tensor mesons; baryon Not π	$0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ (some qualitative features of $1^-\frac{1}{2}^+$ production)	Dubious though not proved wrong (certainly inapplicable for π exchange; tensor exchange imaginary parts probably not peripheral; energy dependence)
Modified Exchange Degenerate Pole Models (Rutherford/Orsay; Saclay; etc.) Not Absorption Models	"Mystical" Begin with Ex. Deg. poles and introduce various ad hoc modifications to get agreement with data. Sometimes appear to violate accepted physics such as analyticity. Current ideas considered fundamentally inadequate to understand data.	Vector, tensor mesons Others?	$0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$	Consistent with data for all or some of these reactions (depending on model). Not known how to apply elsewhere, or unsuccessful.
Classical Absorption Model (Hartley, Kane, Vaughn)	"Classical" Absorb simple Regge pole in standard way, locally in b, with elastic rescattering amplitude which must have structure of data, e.g., shrinkage, small t break, phase, correct shape in b, even signature, etc. Include sum over intermediate states peripheral in impact parameter. Believe no basic obstacle to understanding data.	Vector, tensor π mesons Can be applied to any exchange	$0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ $\frac{1}{2}^+\frac{1}{2}^+ \to \frac{1}{2}^+\frac{1}{2}^+$ $0^-\frac{1}{2}^+ \to 1^-\frac{1}{2}^+$ (Field and Sidhu)	So far consistent with all data above few GeV/c. Amplitudes are very Ex. Deg. at high energies but the low energy continuation is not dual
		[for vector meson exchange CAM and DAM have the same t dependence and phase; elsewhere they differ]		

The situation is summarized in capsule form in Table 1. Several of the detailed subjects mentioned below give further particulars of model behavior. A numer of references are given[5] to specific models which have been applied in a limited set of reactions so the interested reader can look them up.

This short survey should leave the non-expert reader in a position to find the sort of model which he finds attractive and examine it further, or give him a framework to evaluate future work. The expert reader will not have learned much but may have been stimulated to some useful controversy.

Now we turn to specialized subjects. These have been selected because I feel that in the next year or two they are likely to be the main areas which lead us to new insights or change our present attitudes.

REMARKS ON AMPLITUDE ANALYSIS

For about two years, following the work of Halzen and Michael, who noticed that sufficient data existed for πN scattering at 6 GeV/c to extract the actual scattering amplitudes at a few angles, considerable enthusiasm has been expressed for "amplitude analysis". This in turn has stimulated extensive efforts to do "model independent" work. Laudable though these tendencies may be, there is now some evidence that a certain amount of caution is necessary. It will be very nice to know actual scattering amplitudes when it is possible to measure them. But as soon as assumptions are needed, possibly even normalization or continuity assumptions about data, the amplitude analyses become "amplitude models" and should be studied as such.

The main point can be stated as a "theorem" (it deserves that title about as much as most amplitude analyses are really amplitude analyses):

> One can rarely learn enough from model independent work involving data.

Two examples will illustrate the point.

(1) In the standard πN case one can, given certain continuity assumptions about the data and a knowledge of the $\pi^- p \to \pi^\circ n$ polarization, extract the amplitudes up to the well known overall phase. To compare with predictions of models, however, one needs the absolute phase. For example, the Dual Absorptive Model makes a precise statement only about the imaginary parts of the amplitudes. Thus in most cases of interest, the actual use of the amplitude knowledge requires assumptions about the (t-dependent) overall phase and is highly model dependent.

(2) A number of authors have extracted amplitudes from incomplete sets of data on hypercharge exchange (and backward reactions). It is instructive to compare the

results of different analyses. (For the backward case the amplitudes are surprisingly not explicitly published and obtaining them is sometimes difficult.) For the hypercharge exchange case Fig. 2 shows a compilation from the recent review of Fox and Quigg. If the results were not sensitive to the assumptions all of the dashed lines would lie on top of one another, and all of the solid lines on top of one another. It is hard to imagine bigger disagreements. Further, SU(3) plus the constancy of $\sigma_T(K^+p)$ imply near equality of the imaginary parts of the vector and tensor exchanges in the nonflip amplitude at $t = 0$, a condition satisfied by none of the analyses shown.

(3) Another way to get at the amplitudes is to calculate them directly from the phase shifts at lower energies and then use Regge pole FESR relations to get at the high energy amplitudes, or simply invoke duality to argue that the high and low energy s-channel helicity amplitudes will have the same t-dependence. However, Fukugita and Inami[6] have remarked that when full account is taken of the zero structure of amplitudes, including forward fixed t and backward fixed u zeros, it may happen for some ranges of FESR cutoffs that the backward zeros cause the amplitude to behave as if it had additional forward zeros. They explicitly suggest that some second zeros found in previous FESR calculations may be reinterpreted this way.

All this is not to imply that the attempts to get at amplitudes are not valuable, or that they are not correct. Indeed it would be very useful if analyses such as that of Elvekjaer, Inami, and Ringland[7] which show interesting zero structure out to $-t \sim 3$ GeV^2 from phase shift and FESR analyses, prove to be correct because such regularities will be useful in searching for underlying dynamics. However, as might be expected the initial rash of enthusiasm for getting amplitudes at any cost must now be tempered with some critical evaluation, and the full model dependence of much of the work should be recognized. That is all right; model dependence is fine when the model is a good one.

FIXED t (t') ZEROS

In the past few years it has been increasingly realized how important the zero structure of amplitudes can be for understanding the basic physics. Odorico, basing his ideas on the Veneziano Model zero structure, has shown that a great deal of data has structure suggesting zeros often reminescent of the double pole killing zeros, and has suggested ways to understand much of this structure in the real world.

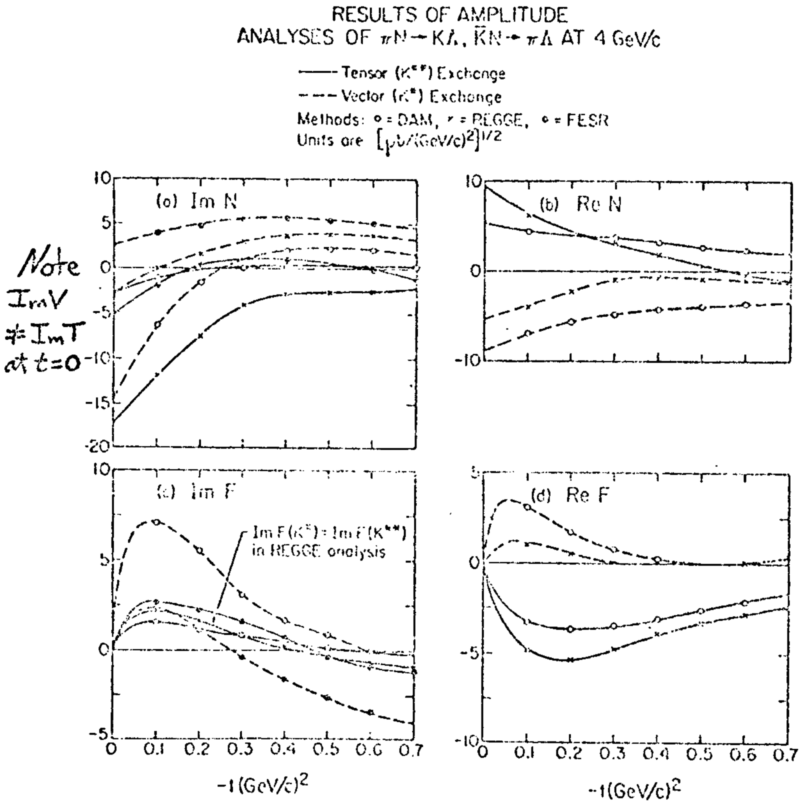

Fig. 17 FOX + QUIGG

Figure 2. From the review of Ref. 1 . This shows results for hypercharge exchange amplitudes obtained by using different sorts of assumptions to compensate for the absence of a complete set of data. The reader need only note that if the results were not model dependent all of the dashed lines would give identical results for the vector exchange and all of the solid lines would give identical results for the tensor exchange. One of the methods used may be valid, although the fact that none would give a constant $\sigma_T(K^+p)$ using SU(3) for the t=0 Im(nonflip) since vector $\neq$ tensor, tends to cast doubt on all of them.

For the past year or so data and theoretical information have been accumulating which suggest that the situation may be different; in addition there is data for π exchange reactions which has never been brought to bear on this question. It is not clear what the answer is at present, but it now seems possible to state the problem rather clearly and suggest directions of attack to fully understand the zero structure of hadron amplitudes.

First we remind the reader of the simplest situation and expectations, presenting two contrasting views to provide a frame of reference to view the data. Then we examine a large number of reactions for the zero structure which the data suggests might be found in their amplitudes. A useful recent review on amplitude zeros, particularly for $\pi\pi$ scattering, is given by Pennington.

Consider $\pi^+\pi^-\rightarrow\pi^+\pi^-$. The most popular view, based on the Lovelace-Veneziano model and discussed in detail by Odorico,[9] is that zeros will occur at fixed u values as the energy s is changed. Very crudely, this is because one can have s and t channel resonances, so $M(s,t)\sim 1/(m^2-s)+1/(m^2-t)$, with equal residues by crossing symmetry. This can be written

$$M(s,t) \sim (2m^2-s-t)/(m^2-s)(m^2-t)$$

and one avoids a double pole at $s=m^2$, $t=m^2$ by the numerator zero at $s+t = 2m^2$, i.e., at fixed u. Thus it was conjectured that in the real world amplitudes would show isolated zeros at the intersection of resonance pole lines on the Mandelstam diagram.

Note that at least two matters of judgement must be settled before one can test such ideas against data. First, one must decide whether the zeros should appear only in the imaginary parts of the amplitudes where the resonance poles are; or whether the entire amplitude has a zero nearby in which case it should be observable in cross sections. Second, one must decide what paths the zeros follow between resonance lines intersections. For example, everyone agrees, as first noted by Dolen, Horn, Schmid, that the first zeros of the imaginary parts of the πN amplitudes are at $-t \approx 0.3$ at the positions of the dominant s-channel N*'s. Are these successive fixed u zeros each moving on to become a higher Legendre zero at the next resonance as the energy increases,[10] or a single fixed t zero?

A different point of view, with different answers to the above questions, suggests itself if one begins from the regularities in the high energy data rather than the resonances. Then (consider πN nonflip scattering or (presumably) $\pi\pi$ scattering) the dominant feature is the crossover zero near $-t = 0.25$ GeV^2. The crossover zero stays at the same t value (not u) over a large range of energies. In addition we know that there is a zero at a similar t value at the dominant resonances. Thus one is

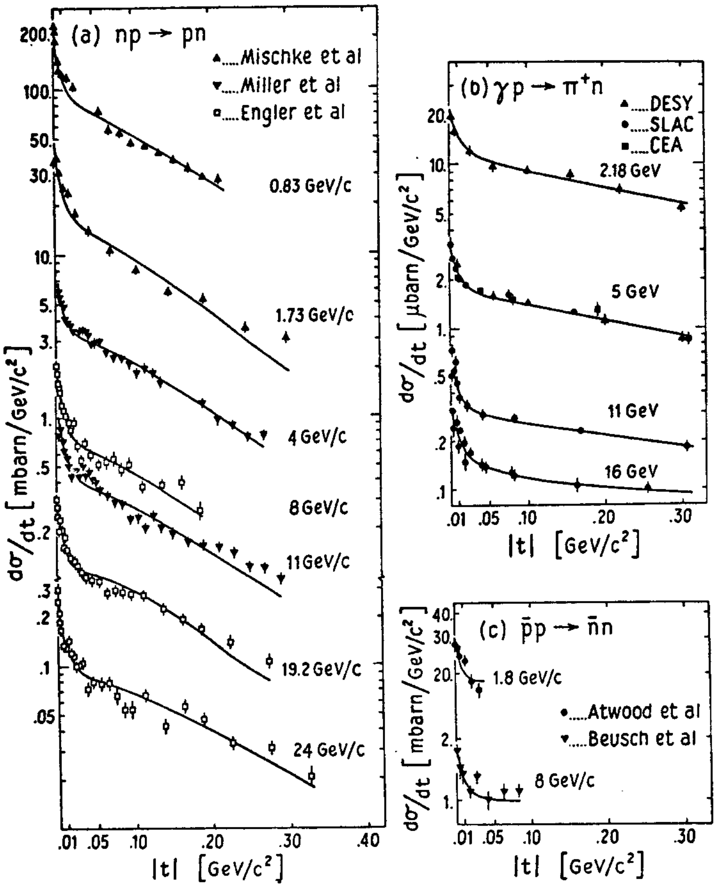

Fig. 3. Differential cross sections are shown for several cross sections with important π exchange contributions. The sharp peak for $-t \leqslant m_\pi^2$ corresponds to a zero at $-t \approx m_\pi^2$ in the amplitude with net helicity flip zero and s-channel helicity flip at the nucleon vertex. The position of the zero is apparently approximately fixed in t over a large range of energies. Further, the zero occurs whether the s-channel is exotic or not (i.e., whether there are s-channel resonances). Any interpretation of amplitude zeros should account for the existence of this zero, in the dominantly real π exchange contribution, at approximately fixed t, present whether there are s-channel resonances or not, and a zero of the full amplitude giving structure in $d\sigma/dt$. The interpretation of Ref.10 extrapolated to this situation attributes the zero to unitarity effects (absorption at higher energies).

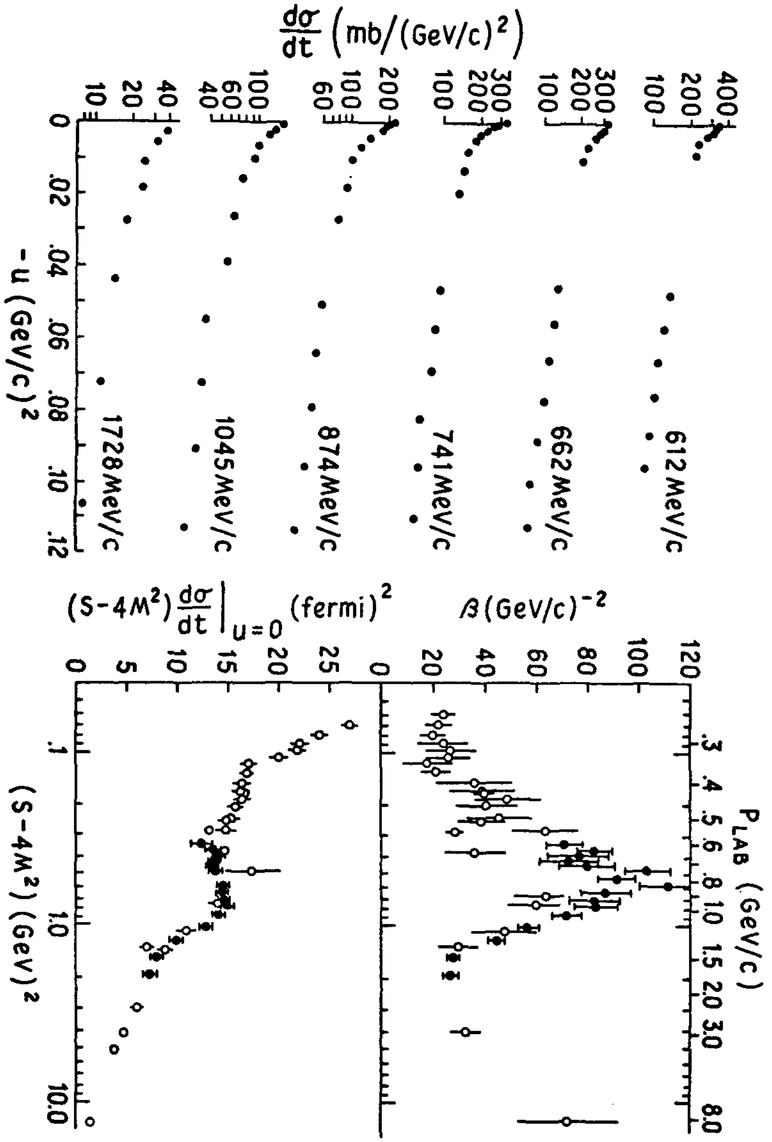

Fig. 4. For np→pn this shows more precisely the extent to which the zero can be considered fixed in t[11]. From its high energy value of about 50 GeV^{-2} the slope β (upper right hand corner) varies up or down by about a factor of 2 as one passes pion production thresholds. From the cross section alone one cannot tell if the shift is due to changes in the other incoherent amplitudes or to shifts of order 50% in the zero position. Data from Devlin et al. Ref. 12 .

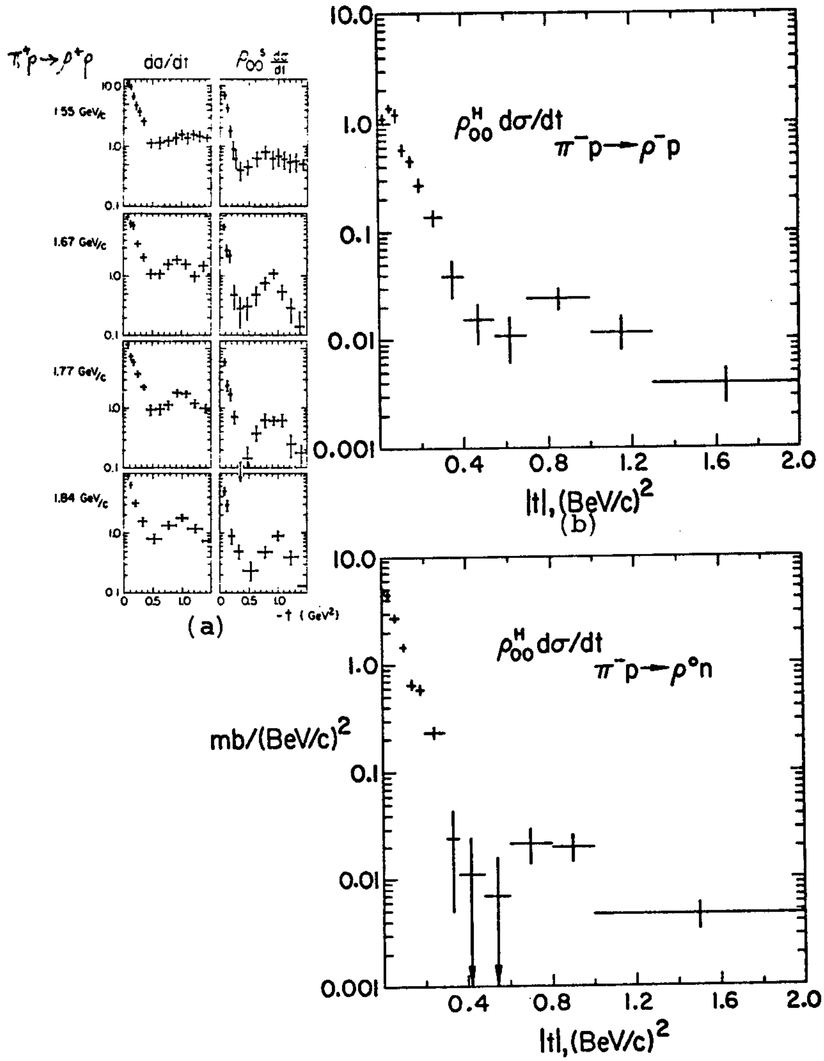

Fig. 5. Shows another fixed t zero, in ρ^H_{oo} dσ/dt for $\pi N \to \rho N$. This quantity isolates unnatural parity exchange, presumably π exchange. The zero, at $-t \sim 0.5$ GeV^2, persists over a large range of energies. Data for (a) are from Ref. 13, for (b) from Ref. 14, at 4.5 GeV/c.

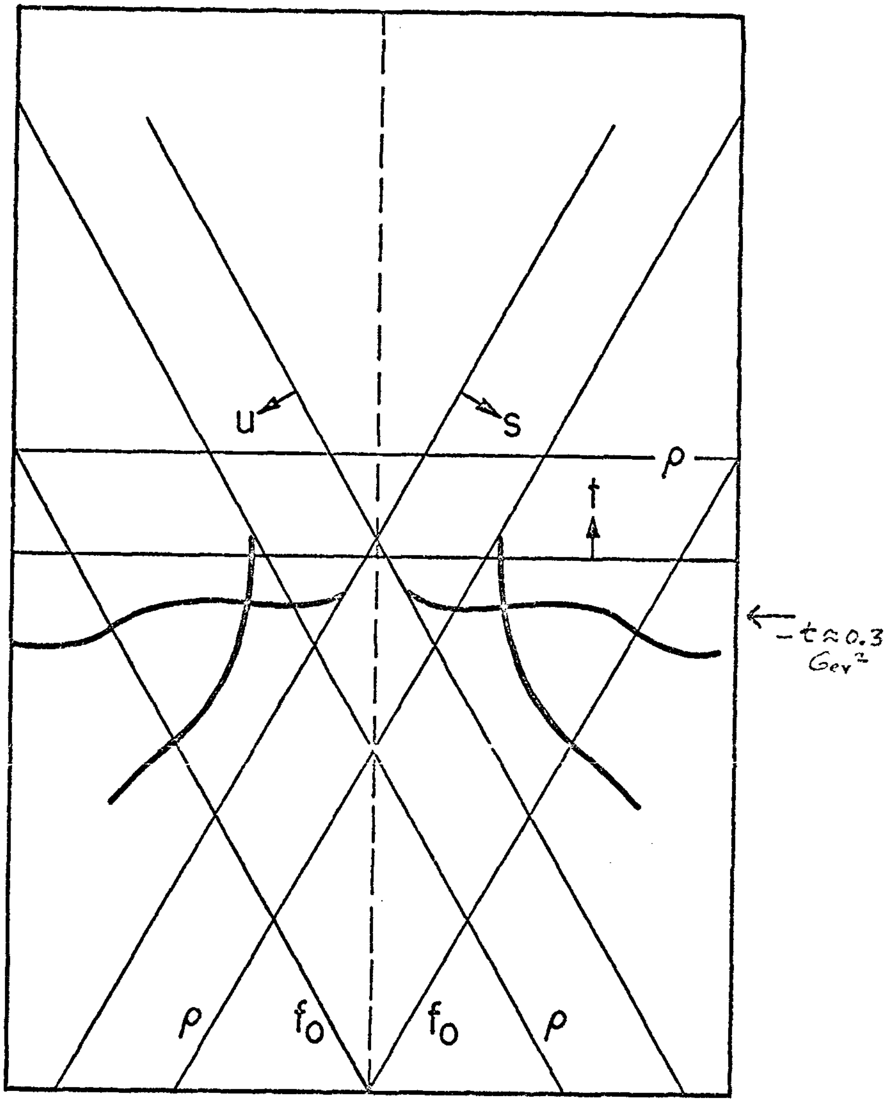

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Fig. 6. The zero contours for ππ scattering with <u>t-channel isospin one only</u> can be interpreted as fixed t zeros at about the position of the crossover zero. Such a result would only be expected in the picture of Ref. 10 for the amplitudes corresponding to exchange of a definite Reggeon (not the Pomeron). Figure from Eguchi et al., Ref. 15 and 18

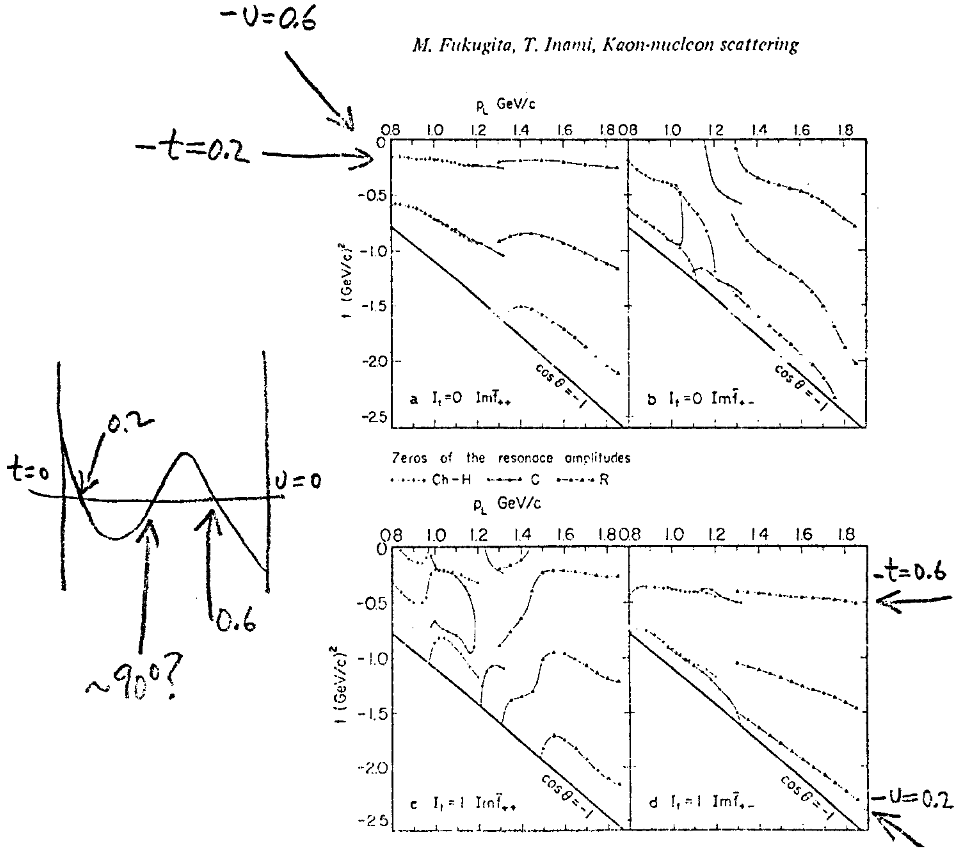


Fig. 7. Plots for KN scattering of the zeros of amplitudes with definite t-channel quantum numbers, from Ref. 6 . A background or Pomeron contribution is subtracted from I_t = 0. Again, the results can be interpreted as fixed t zeros (as noted by the authors). As shown in the insert on the left the third zero may be "trivial" in origin to allow the amplitude to have the dynamical zeros at 0.2 and 0.6 while having the sign of the pole residue at the forward and backward directions. However, there may be some inconsistency between the results of this analysis and that of Fig. 8.

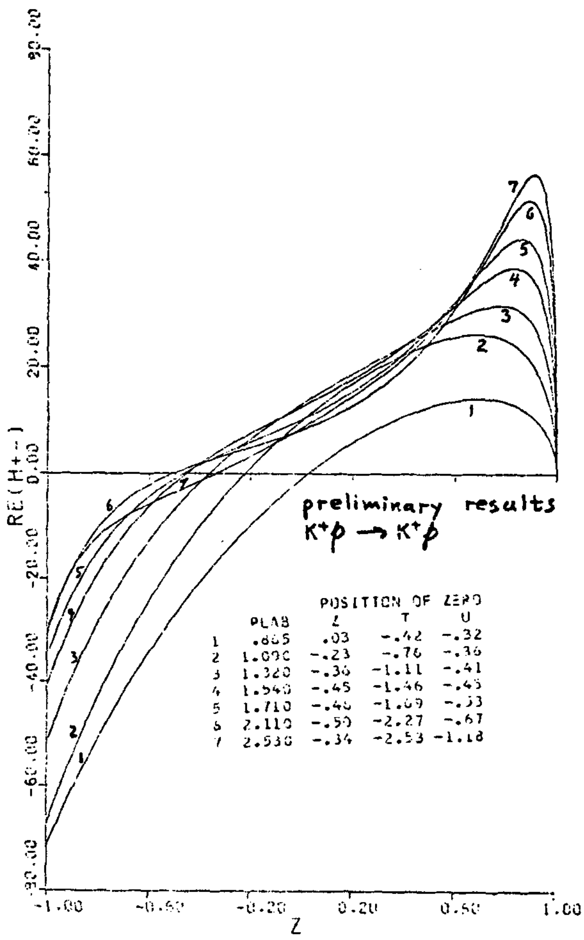


Fig. 8. Shows zero structure of the s-channel helicity flip amplitude for $K^+p \to K^+p$; there should be no Pomeron background present so the amplitude could have forward V and T exchanges of both isospins and backward baryon and decuplet exchanges. The interpretation of the results with only one zero is not clear, and it is not clear how to relate these results to those of Fig. 7. The situation is complicated by the dominance of the real amplitude (for K^+p) where zero structure is often more complicated. Results presented at this conference by R. Kelly.[16]

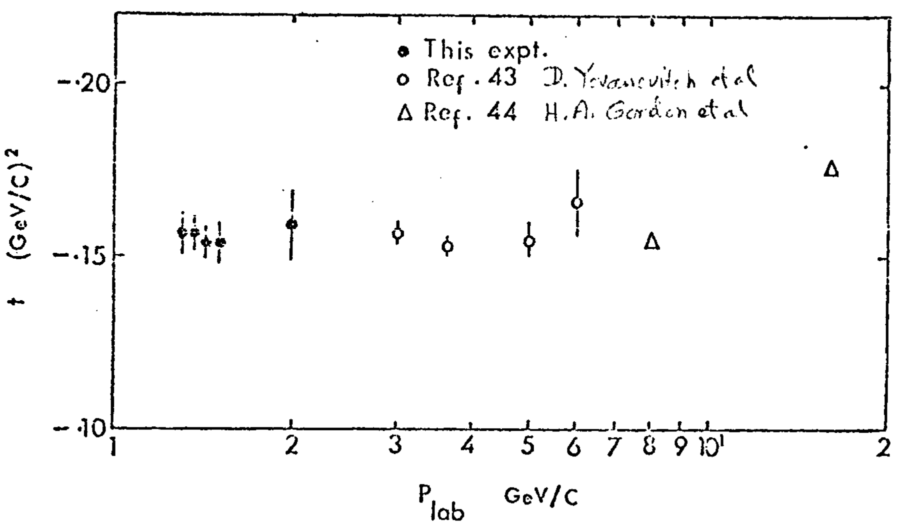


Fig. 9. Shows the[19] t value of the $p^{\pm}p$ crossover zero (presumably due to a zero in the imaginary part of the ω nonflip amplitude) essentially fixed in t over a large range of energies. The connection of the fixed t zero with s-channel resonances is obscure here; the interpretation in terms of absorption ideas may make sense here. Low energy data from the QMC, Liverpool, DNPL, RHEL CERN P.S. Experiment 599, C. Hojvat private communication.

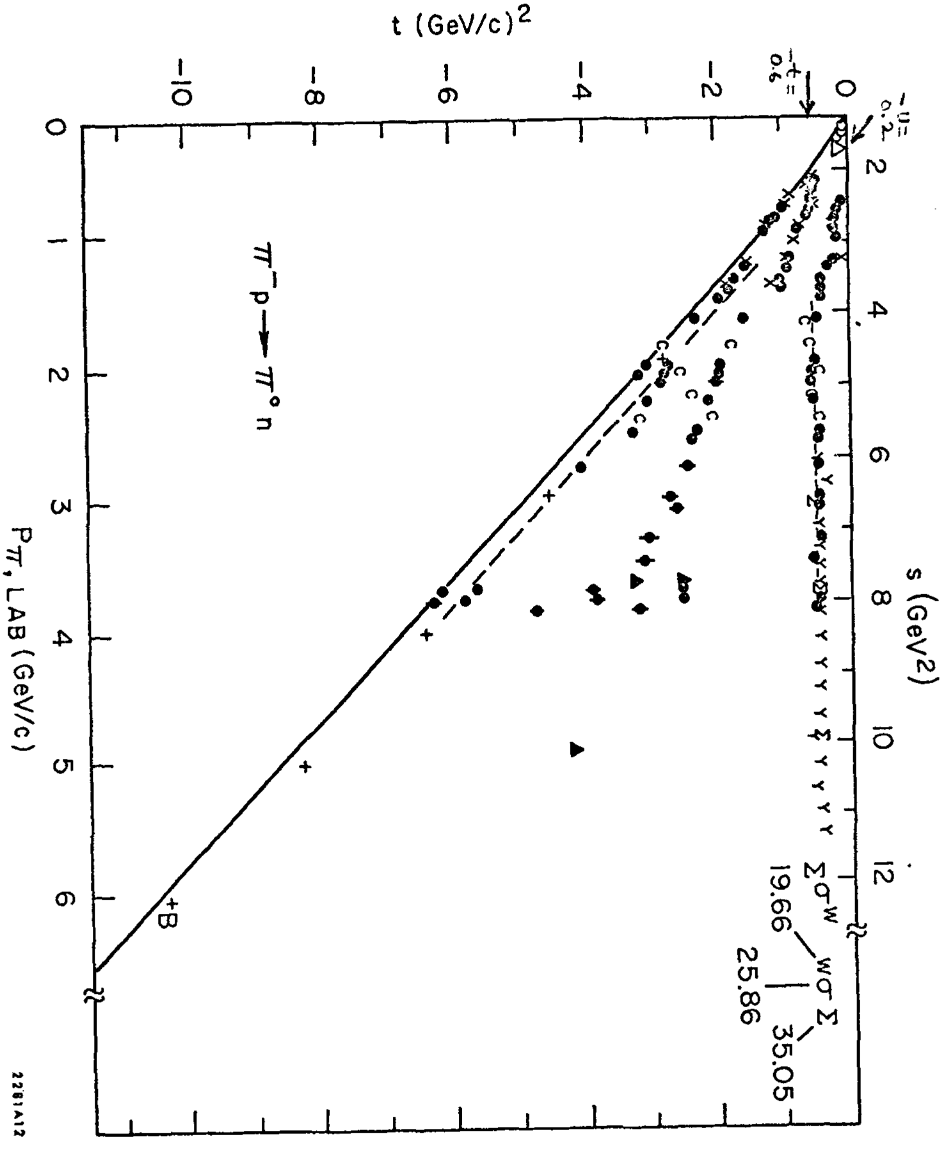


Fig. 10. Position of dips in $d\sigma(\pi^- p \to \pi^\circ n)/dt$. The dips appear in the cross section so they are not obscured by the real parts, and they are approximately fixed regardless of the presence of strong s-channel resonances at a given energy. Data from the review of Ref. 17 .

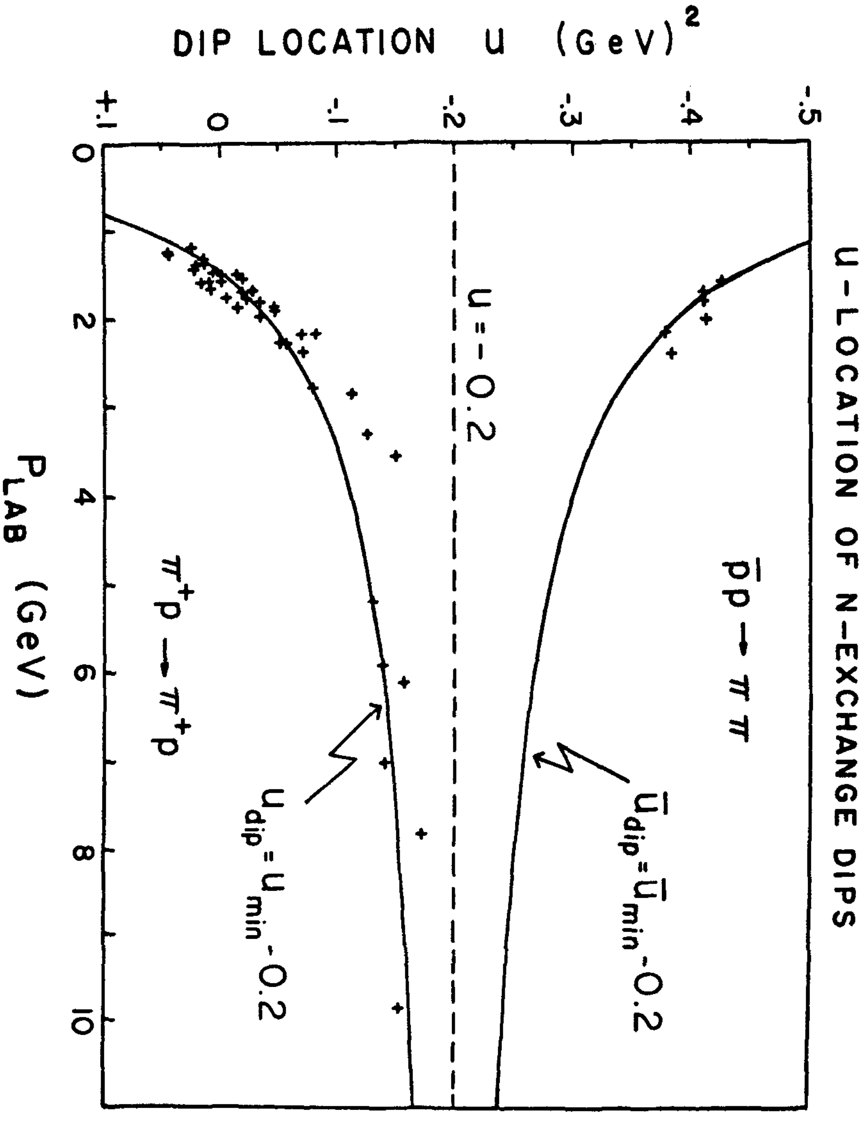


Fig. 11. Dip locations in $\pi^+p \to p\pi^+$ and $\bar{p}p \to \pi^-\pi^+$ from the compilation of Barger, Halzen, and Phillips.[18] Results suggest dips approximately at fixed $t' \approx 0.2$ GeV^2 as in the absorptive mechanism conjecture of Ref. 19 . Deviations from this simple conjecture as one passes resonances or production thresholds should be comparable to those suggested by Fig. 4.

led to conjecture[10] that the imaginary part of the amplitude will have a fixed t zero, given by a single zero trajectory. Further, if the high energy mechanism giving the zero position is absorptive rescattering effects it is likely that these affect the real part of the amplitude in a way similar to the imaginary part, so one is led to expect zeros of the entire amplitude at complex values of t with magnitude near 0.2. Thus the zeros should also appear for π exchange where the amplitude is dominantly real, and in cross sections. For vector and tensor exchanges an explicit model has been constructed[10] for $\pi\pi$ scattering which appears to have such zero trajectories.

A basic aspect of this view is that the fixed t zero structure should arise only when one is considering an s-channel helicity amplitude with definite exchange quantum numbers so the absorption zeros appear. For any other amplitudes the zeros will be mixed up and moved around.

Experimentally the situation is unclear and perhaps more complicated than either of these extreme views. In Figures 3-11 a number of amplitude or cross section zeros are shown which either are based on recent work or are not commonly considered in this context. On the whole they seem morein accord with the idea of a single zero, fixed in t as s increases, than with any other picture, but it is too early to draw any conclusions. (In cases where t and t' differ because of mass differences the high energy point of view where the zeros originate as absorption effects suggests[19] that the zeros should be approximately at fixed t', i.e., at a fixed distance in t from the forward or backward direction). The main point to emphasize is that whatever the final answer it must explain all of the zero structure illustrated in the figures and not just apply to a few spin 0-spin $\frac{1}{2}$ reactions or $\pi\pi$ scattering.

$NP \to PN$, $\bar{P}P \to \bar{N}N$

With the existence of cross section and polarization data[20] for both, this pair of line reversed reactions has now become one of the major tests for models of hadron amplitudes. Essentially all of the features of the amplitudes which are tested in the $0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ reactions are tested here too, sometimes more sensitively, and new features are present as well.

First, of course, these reactions show the absorbed π exchange forward peak. However, even inside the peak the behavior is different for the two reactions. To get the difference correct and the actual magnitude at t = 0 correct one must get a correct description of the exchanges interfering with the π.

The other exchanges should be dominated by the ρ and A_2. Even at $t = 0$ one finds[4,21] important π-A_2 interference, with the forward A_2 amplitude about 40% that of the π. At larger t the $\bar{p}p \to \bar{n}n$ cross section is 1.5-2 times the $np \to pn$ cross section; this must be due to interference with the ρ which changes sign between the two reactions. Thus a knowledge of the normalized cross sections puts stringent restrictions on all the contributions since they all interfere strongly.

In pole models with ρ and A_2 about 90° out of phase none of the three exchanges would interfere. Thus the large interferences observed are sensitive probes of how one departs from pole models.

The cross sections are shown in Fig. 12.

The polarization is also very useful because it is large for $np \to pn$ and very different for the two reactions. (Polarizations, which depend sensitively on phases, are sometimes such sensitive tests that they only teach one about unimportant details.) In addition, apart from quantitative details the polarizations are determined by the ρ and A_2 alone, so they test the same amplitude structure as the more conventional $0^-\frac{1}{2}^+$ reactions.

There are five helicity amplitudes for these reactions, conventionally named φ_1-φ_5. No s-channel helicity flip occurs at either vertex in φ_1 and φ_3; one vertex flips in φ_5 and not the other, so it has net flip of one unit; and flips occur at both vertices in φ_2 and φ_4 giving one with no net flip and one with two units of flip. Since π exchange always flips the s-channel nucleonhelicity, it can only contribute to φ_2 and φ_4, and it contributes a pole term which is the same for both.

The polarization is proportional to

$$\mathrm{Im}(\varphi_1+\varphi_3+\varphi_2-\varphi_4)\varphi_5^*$$

so the pion pole drops out, not contributing to φ_1 or φ_3 or φ_5 and cancelling in $\varphi_2-\varphi_4$. Thus the polarization is largely determined by the ρ and A_2 contributions (quantitatively the pion absorption correction is important at small t but qualitatively it is unimportant); polarizations test ρ-A_2 exchange degeneracy ideas here as well as in $0^-\frac{1}{2}^+$ reactions. It is amusing that the polarization is large in the exotic channel here, small in the non-exotic one. Some polarization data is shown in Fig. 13.

As with the cross sections, the CAM provides an explanation for the polarizations, starting with ρ and A_2 amplitudes which are approximately degenerate at $t = 0$ (as required by the approximate constancy of σ_T, plus SU(3)). For $np \to pn$ the explanation only depends on the properties of the dominant real amplitudes and general properties of the model, and is given in Appendix 2. For $\bar{p}p \to \bar{n}n$ the smaller imaginary parts are important so the explanation is detailed and the reader is referred to Ref. 4 ; although detailed the result is well determined

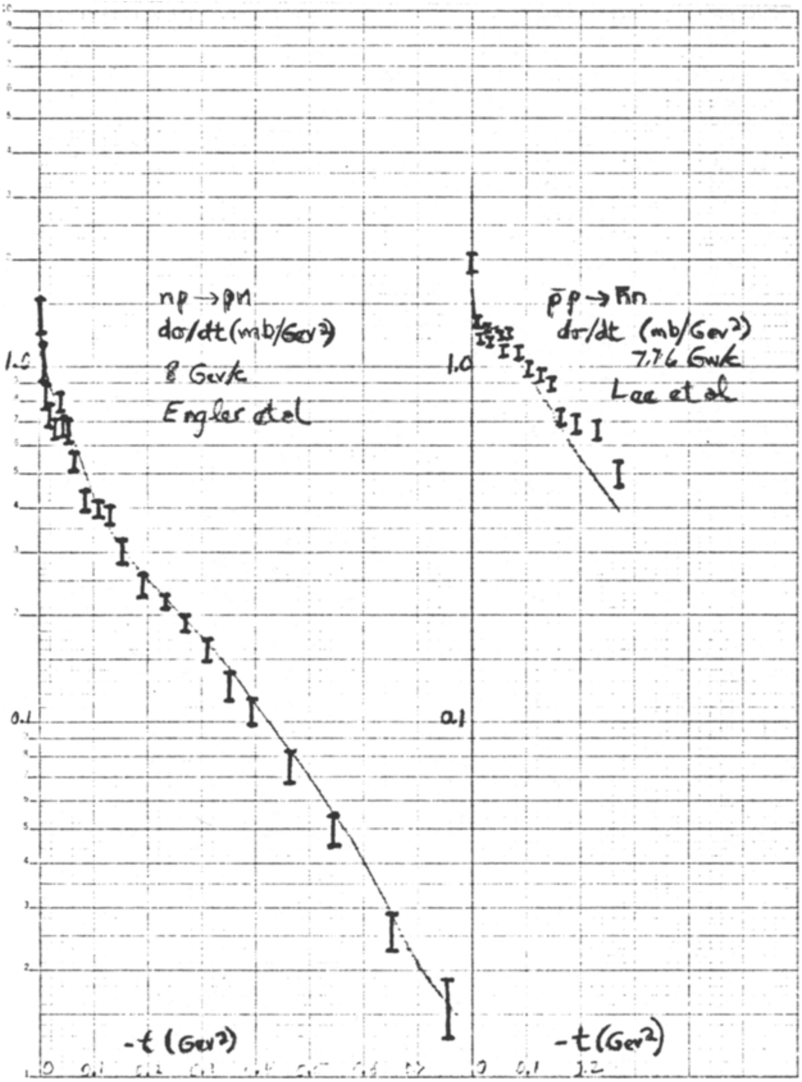


Fig. 12. These show $d\sigma/dt$ for the line reversed pair $np \to pn$ and $\bar{p}p \to \bar{n}n$. Note the latter (non-exotic) channel is larger at $-t \geq 0.02$ GeV^2, just the opposite of the situation for line reversed pairs in $0^-\frac{1}{2}^+$ reactions; an explanation for this is given in the analysis of line reversed reactions in the section on high energy expectations. These reactions, with polarizations also available (See Fig. 13), provide an excellent testing ground for models, containing most of the physics of the $0^-\frac{1}{2}^+$ reactions and much more. The theory lines show results of the CAM, from Ref. 4.

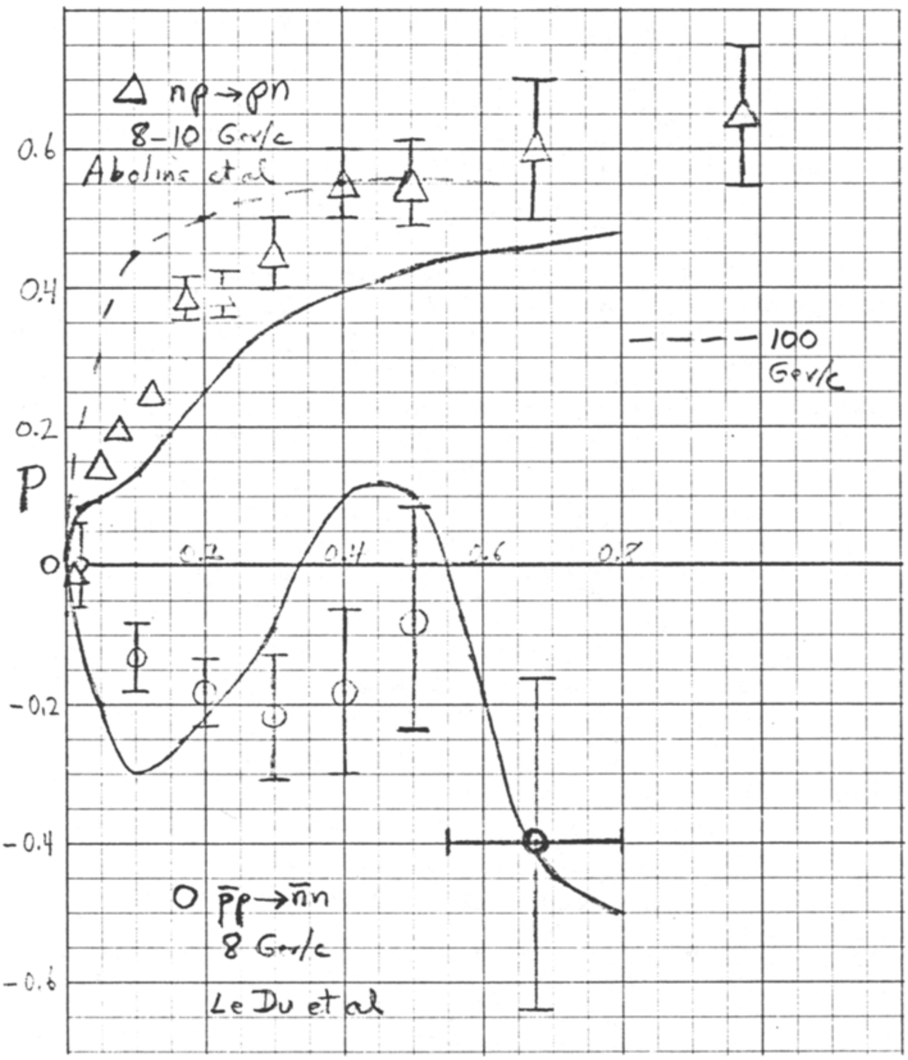


Fig. 13. Polarizations for the line reversed reactions np→pn, p̄p→n̄n. Note that the exotic channel has the larger polarization. The signs are Basel convention. The theory curves for the CAM show that the data can be understood; the p̄p→n̄n result was a prediction. In Appendix 2 a mechanism which gives the large essentially constant np→pn polarization is given. Note, as described in the text, that the polarizations are essentially determined by $\pm\rho+A_2$ exchange and so they test largely the same ideas as the $0^-\frac{1}{2}^+$ reactions.

and the curve shown in Fig. 13 was a prediction before the data were available.

From now on it would seem reasonable that models which base a claim for recognition even partially on their relation to data should have to show that they can deal with the $np \to pn$, $\bar{p}p \to \bar{n}n$ data.

ENERGY DEPENDENCE

Basically the energy dependence of exchange processes seems to be consistent with a Regge-like s^{α} (see further remarks on the section on high energy expectations). But the present data hints[22] at some rather detailed but significant departures from this, (1) Quantities which should be dominated by the same exchange such as $\Delta\sigma_T(\pi N) = \sigma_T(\pi^- p) - \sigma_T(\pi^+ p)$ and $d\sigma(\pi^- p \to \pi^\circ n)/dt$ at $t = 0$, both ρ exchange, show rather different energy dependence, with $\Delta\sigma_T$ giving an effective trajectory $\alpha_{eff} \approx 0.65$, considerably above the conventional ρ intercept of about $\frac{1}{2}$. (2) Different reactions which would naively be expected to show the same energy dependence do not; in particular, $\Delta\sigma_T(KN)$ and $\Delta\sigma_T(NN)$ fall about equally fast with energy and both fall faster than $\Delta\sigma_T(\pi N)$.

Although it will not be easy to establish a quantitative agreement between theory and data here, effects such as these are expected in any model with important absorptive effects and can be simply understood. The basic situation is that the full amplitude at $t = 0$ can be approximately written

$$M(s,t) \sim s^{\alpha_o}(1-C/(B+\alpha' \ell n s)) \qquad (1)$$

where the s^{α_o} is from the Reggeon and the correction is due to absorption. The constant C is proportional to σ_T and B is a sum of t-independent slopes of both the diffractive elastic amplitude describing the absorption and the Reggeon. The key point to note is that the absorption correction is destructively interfering (C,B are positive) so as s increases the quantity in brackets is an increasing function of s. Thus if we were to parameterize M as $s^{\alpha_{eff}}$, we would find

$$M(s,t) \sim s^{\alpha_{eff}} \qquad (2)$$

$$\alpha_{eff} > \alpha_o \qquad (3)$$

Note that the larger C is (i.e., σ_T) the greater the difference between α_{eff} and α_o, while the larger B is the less the difference.

From this we can make several observations. First we consider a single exchange, relevant to (1) above. Then note:

(a) For small t, amplitudes with net helicity flip $n = 0$ feel absorption much more than those with $n > 0$

since the latter have their small b components (where absorption is strongest) kinematically suppressed. Thus

$$\alpha_{eff}(\text{nonflip}) > \alpha_{eff}(\text{flip})$$

(b) For vector exchanges (e.g., ρ,ω) it is observed that the imaginary parts of the amplitudes are more strongly absorbed than the real parts, so

$$\alpha_{eff}(\text{ImM, vector exchange}) > \alpha_{eff}(\text{ReM, vector exchange})$$

Combining these we can relate several energy dependences; e.g., <u>for πN</u>

$$\alpha_{eff}(\Delta\sigma_T) > \alpha_{eff}(d\sigma(\pi^- p \to \pi^\circ n)/dt, t=0) > \alpha_{eff}(\sigma(\pi^- p \to \pi^\circ n)).$$

Next consider Point (2). What is observed is that

$$\alpha_{eff}(\Delta\sigma_T(\pi N)) > \alpha_{eff}(\Delta\sigma_T(KN)) \approx \alpha_{eff}(\Delta\sigma_T(NN)).$$

Can we understand this? If it was only a matter of the first relation we could claim that πN feels absorption more than KN since $\sigma_T(\pi N) > \sigma_T(KN)$. But $\sigma_T(NN)$ is still larger and it behaves as KN. Since πN is dominated by ρ exchange while KN and NN are dominated by ω exchange one could claim that ω simply lies lower than ρ; while that might be true, it is no explanation and in addition the fact that crossover positions appear to show the same qualitative effect, with the πN crossover closer to $t = 0$ than KN or NN, strongly suggests that the explanation is a dynamical one.

It does in fact appear that the absorption dynamics gives the right effect, but to be sure we must have confidence in our knowledge of Regge residues, which is hardly justified. Thus here we can indicate how the effect probably arises, and we can await a more certain knowledge of the Regge residues to be confident. In any case, to my knowledge this is the only explanation of the data so far. The argument is simple; we assume the ρ and ω have the same trajectory intercept, by SU(3) (any difference in intercept would just add to this effect), and use Eqns. 1 and 2. Then using the numbers in the first two rows of Table 2 we get the results in the third row for the amount α_{eff} exceeds α_o. As desired, πN lies above KN and NN by a significant amount, and the latter two are about equal. With an input $\alpha_o = 0.43$, for example, the results are consistent with the Serpukhov data. Whether the numbers used for C,B are realistic is not something we can be confident of at the present time, but they are reasonable and might be sufficiently correct.

TABLE 2

	KN	πN	NN
C	3	4.5	7
B	3.15	4	8.5
$\alpha_{eff}-\alpha_o$	0.10	0.18	0.11

Physically what is happening is clear. The effect of absorption depends not only on the strength of the interaction (σ_T), but on the partial wave structure. An amplitude which is sharper in t is more spread out in b and feels the removal of its lowest partial waves relatively less. Thus the net effect depends on some function of ‿/B.

At the present time, then, the pattern of energy dependences exhibited by the data can be accommodated by models with strong absorptive effects so that the effective energy dependence of the nonflip amplitude is considerably different from that of the input trajectory. The effect depends on the amount of net helicity flip and on the reaction considered. Similar effects will appear in the phases of the amplitudes and the crossover behavior and can be correlated with the energy dependence. It will be important to find out whether other models, particularly those which insist on maintaining a phase as close to the Regge phase as possible, can accommodate the present data, and of course to confirm the data and observe the energy dependence over even a wider range.

HIGH ENERGY EXPECTATIONS

What can we learn from higher energy data? What behavior should surprise us? What general behavior should make us feel that we understand what is happening?

Two body hadron reactions have been around for some time, and we have become somewhat numbed to the broad implications of the data. In fact, there are important general features to be studied as well as a lot of detailed results. We are indeed at a stage of describing a very large amount of data in real detail, without averaging over lots of variables. We are really looking at the energy and angular dependence including phase of lots of individual spin amplitudes for lots of related reactions. On the other hand, the general features will be tested much better with higher energy data than ever before.

There are at least three important questions which will be resolved by the data soon to come. The first two are of extremely general significance; the third is important because we understand two body data well enough to study interference effects and it may be able to distinguish between existing points of view.

(1) It is generally thought that hadron states are composite systems and that the hadrons will lie on Regge trajectories just as bound states always do in quantum mechanics. This implies that the contribution of a given exchange will be proportional to s^{α}, where α is a power related to the particle's spin and mass, $J = \alpha(m^2)$. For example, if $\alpha \approx a+bt$ at small t, then $\alpha_\pi, \alpha_B \approx 0$ and $\alpha_\rho, \alpha_\omega, \alpha_f, \alpha_{A_2} \approx 1/2$.

Since $d\sigma/dt \sim s^{2\alpha}$ one expects approximately a 1/s suppression of π, B exchanges relative to ρ, ω, f, A_2 ($s \approx 2p_L$). Similarly, for backward reactions one expects N exchange to decrease relative to Δ by about 1/s. Many processes which have important π or B or N contributions will change their character considerably as the energy increases.

Note that this is a deeper question than a power law falloff for general exchange processes. That could arise, for example, form the presence of large numbers of competing channels via unitarity and have nothing to do with compositeness and Regge trajectories. But then one would expect all the exchanges in a given reaction to show the same falloff and the shape or spin dependence should not change with energy. Several examples are:

(a) π exchange peaks. In $np \to pn$, $\gamma N \to \pi N$, $\pi N \to \rho N$, the π exchange contribution will go away relative to the other isovector exchanges ρ and A_2. A reasonable behavior is shown for $np \to pn$ in Fig. 14.

(b) Currently in ω production reactions, $\pi N \to \omega N$ and $\pi N \to \omega\Delta$, there are a large number of ω's produced with s-channel helicity zero, especially at small t. The (natural parity)

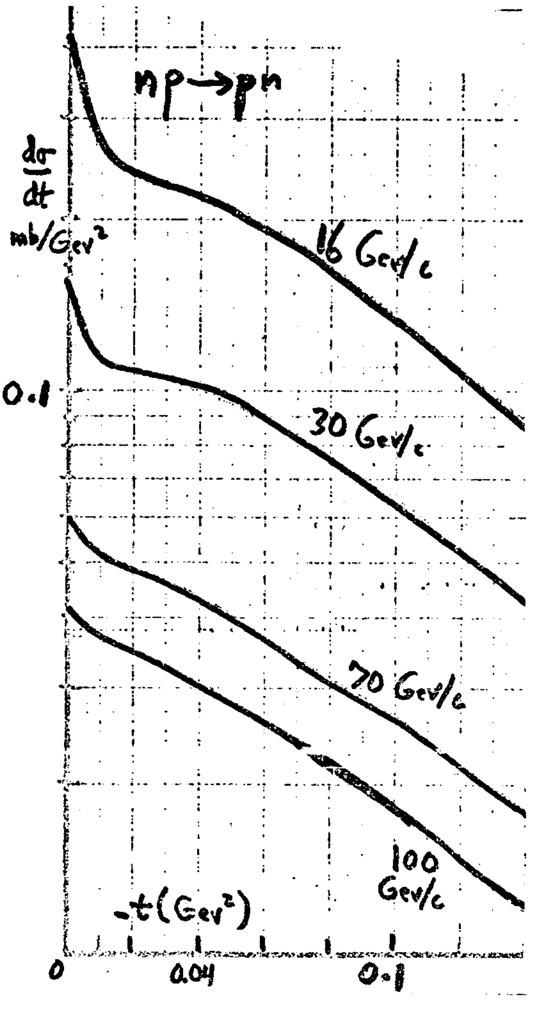


Fig. 14 . Shows predictions for high energy dσ/dt for np→pn from Ref. 4 . The π exchange peak is expected to disappear with energy relative to the other isovector exchanges ρ and A_2 if hadrons lie on simple Regge trajectories. The effect should be clearly observable at NAL energies, and possibly at Serpukhov. Other reactions where similar effects will occur are mentioned in the text.

ρ exchange cannot produce such helicity states, and they are presumably due to B exchange at larger t, π exchange via ρ-ω mixing at small t. Therefore as the energy increases they should go away relative to helicity 1 ω's. To see that one could, for example, plot $\rho^s_{oo} d\sigma/dt$ (which isolates the unnatural parity exchange) vs. s at fixed t.
(c) Since photon exchange has a constant cross section in energy while hadron exchanges presumably fall as a power of s, at some energy (about 1500 GeV/c) one will find $\sigma_\gamma \sim \sigma$(hadron). But at much lower energies one should see effects of the γ exchange, such as isospin violations.[23] For example, by comparing $K^+p \to K^{*+}\Delta^+$ and $K^+p \to K^{*o}\Delta^{++}$ or similar K^- reactions one can see isospin violations. In addition,[24] since the γ exchange is mainly real, the interference effects should be larger and appear at a lower energy in the K^+ reactions than in the K^- if exchange degeneracy ideas hold[25] for K* reactions as well as for $0^-\frac{1}{2}^+$ processes.

If the higher lying exchanges do not dominate as the energy increases our ideas about composite states will need fundamental revision. If, on the other hand, things go about as expected, then we can use the detailed information to confirm or improve our present detailed ideas.

(2) Shrinkage must occur; i.e., if there is a dominant exchange and the amplitude goes as s^α where α is a function of t, then the t dependence will change with energy. If α is linear in t at small t, then

$$s^{a+bt} \sim e^{(b\ell n s)t}$$

and the slope will increase approximately as ℓn s. Absorptive effects and lower lying exchanges which go away will modify the simple behavior in detail, but over a large energy range the qualitative features should appear in all particle exchange processes.

However, unless some care is taken one can hide the effects in processes where structure is present. For example, Fig.15 shows the $\pi^-p \to \pi^o n$ cross section from Ref.2,26 as a function of energy. The dip moves with energy. Depending on the t region chosen one would predict shrinkage or not. For example, Fig. 16 shows the ratio of cross sections at two t values vs. energy. In part a the shrinkage is apparent, when the t range is .15 to .4; in part b the shrinkage is obscured by choosing a range including -t = .5 which senses the dip motion.

In general it is more precise and interpretable to plot cross section ratios such as in Fig. 16 rather than fitted slopes. It would be helpful if data was presented this way.

(3) Line reversal at high energies. In general one cannot find definitive tests of models or ways to decide between models with one experiment. However, as far as I

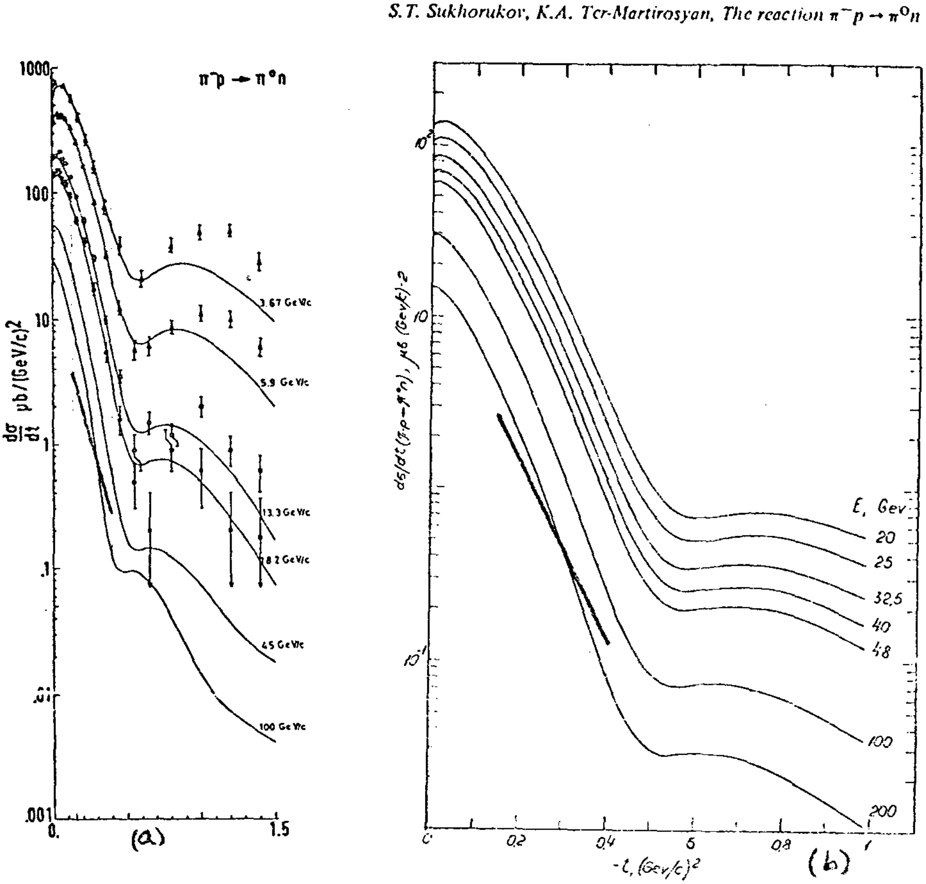


Fig. 15. Shrinkage predictions for $\pi^- p \to \pi^\circ n$ from (a) Ref. 2 , (b) Ref.26. The lines drawn in on the high energy curves are the slope the low energy region shows and illustrate the amount of shrinkage expected in the t-region (0.15-0.4) shown by the vertical lines. If the t region were to include 0.5 the shrinkage would essentially disappear as shown on the next figure.

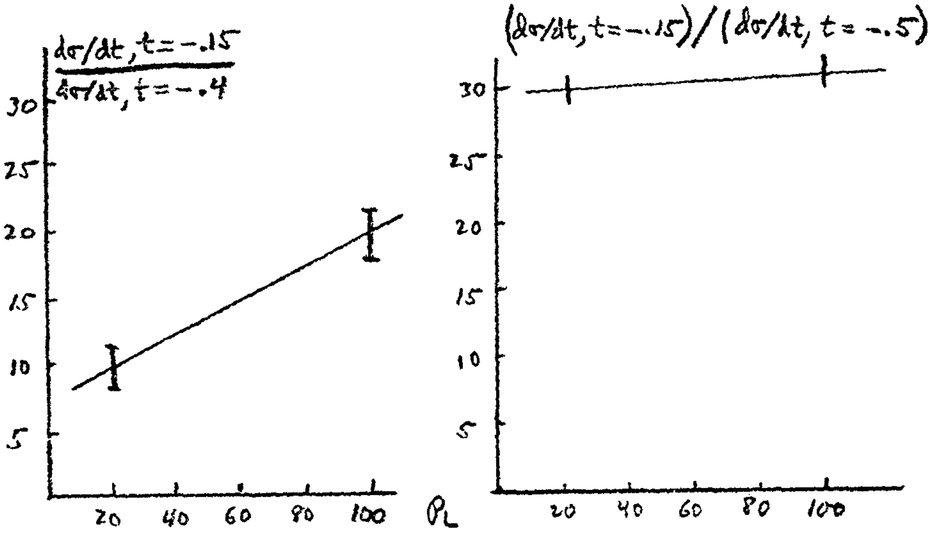


Fig.16 . Illustrates how one's perception of shrinkage depends on the t region when structure is present. Plotting cross section ratios as shown is a good way to present the data. Numbers read off from Fig.15 a.

can see at the moment there is one type of experiment which can rule out either the Classical or the Mystical plus Romantic models depending on the results, namely a high energy comparison of $0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ line reversed reactions such as $K^-p \to K^\circ n$ vs. $K^+n \to K^\circ p$, $\pi^+p \to K^+\Sigma^+$ vs. $K^-p \to \pi^-\Sigma^+$ etc.

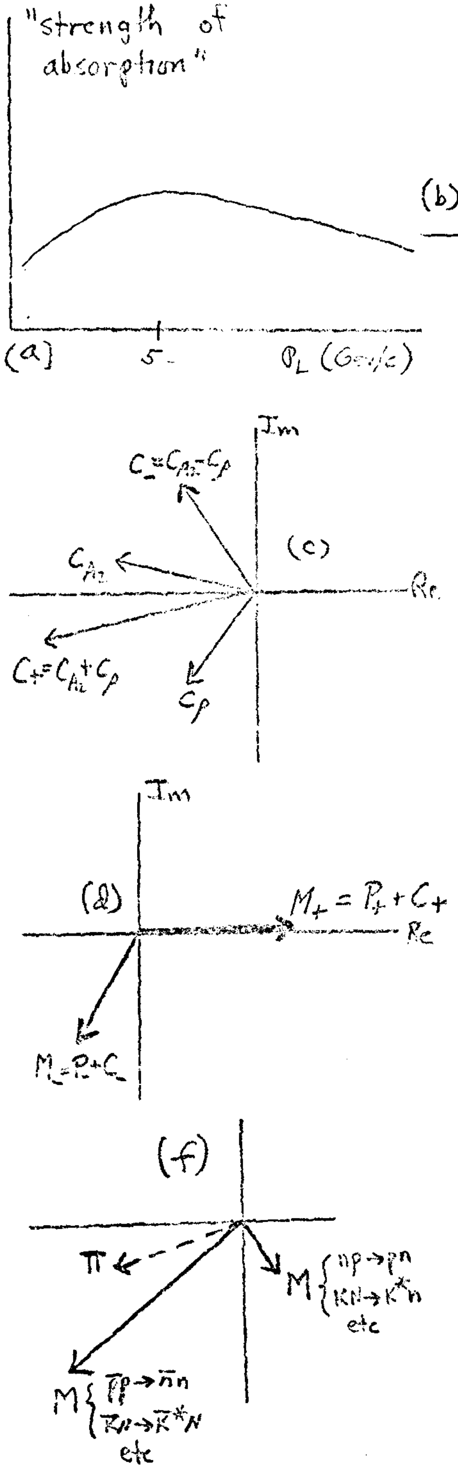
As far as I know, all models which have exchange degenerate pole terms, regardless of details, will have to have the line reversed processes with equal differential cross sections to a few percent at energies above 10-15 GeV/c. In particular, it seems clear that however close the line reversed cross sections are at a given energy, they will be closer as the energy increases, never farther apart.

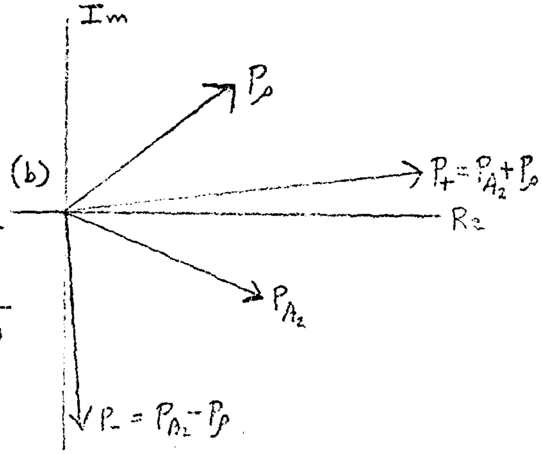
On the other hand, the Classical Absorption Model for quite general reasons requires that the line reversed reactions differ by amounts of order 50% at energies above 25 GeV/c, after having been closer together at lower energies. Again, I see at present no way to avoid this result. The direction of the result is fixed by general arguments too; the "real" process must be larger.

It is easy and instructive to see how this result comes about in the CAM. The input is the one phenomenological result[2] that the tensor trajectories (A_2 or K^{**}) lie lower in the J plane near $t = 0$ than the vector trajectories (ρ or K^*) by an amount $\Delta\alpha \approx 0.15$. (the precise value is not important to establish the effect but affects the size of the result). Next, observe that tensor exchanges are more central in impact parameter than vector ones, so tensor exchanges will feel absorption more than vector exchanges (since absorption modifies central partial waves most). As an aside, note that this raises α_{eff} above α_0 more for tensor than vector exchange, so the final α_{eff}'s are closer together than the input α's.

Now follow the details of Fig. 17. Part a shows qualitatively how some (appropriately defined) strength of absorption will behave with energy. At low energies where there are few open channels there will not be much effect from absorption. At high energies where shrinkage has made the elastic rescattering peak very sharp the amount of absorption will have decreased again. At some energy, perhaps around 5-10 GeV/c, where a large number of inelastic channels are open and high energy shrinkage is beginning to set in, the strength of the absorption will be at a maximum.

Parts b-d show at a given energy how the "real" pole term will be larger in magnitude than the "rotating" one, how the "real" amplitude will be absorbed more than the "rotating" one because its cut will be closer to 180° out of phase, and how the final "real amplitude" will still be larger than the final "rotating" one, but with


"strength of absorption"
(a)
5
p_L (Gev/c)
Im
(c)
Re
$C_- = C_{A_2} - C_\rho$
C_{A_2}
$C_+ = C_{A_2} + C_\rho$
C_ρ
Im
(d)
$M_+ = P_+ + C_+$
Re
$M_- = P_- + C_-$
(f)
π
M {np→pn, KN→K*n, etc}
M {p̄p→n̄n, K̄N→K̄*N, etc}


Im
P_ρ
(b)
$P_+ = P_{A_2} + P_\rho$
Re
P_{A_2}
$P_- = P_{A_2} - P_\rho$

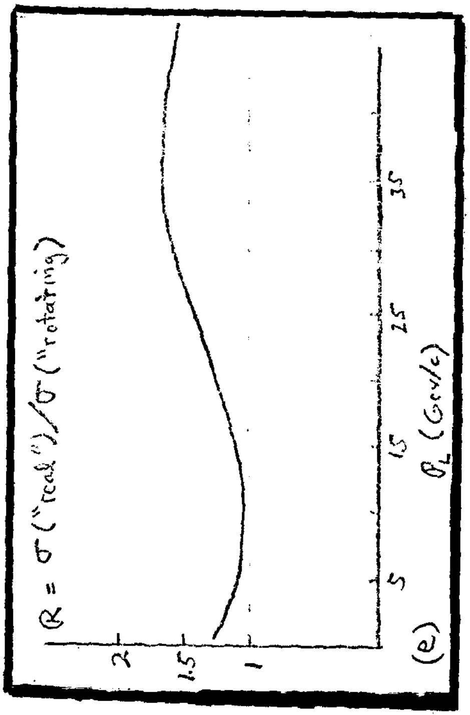

R = σ ("real") / σ ("rotating")
2
1.5
1
5
15
25
35
p_L (Gev/c)
(e)

Fig 17.

(Figure caption)

Fig.17 . To explain the prediction (part (e)) that line reversed reactions do not have equal cross sections at high energies. Part (a) shows an (appropriately defined) "strength of absorption". As the energy increases more inelastic channels open up and the absorption effects increase, until an energy where high energy shrinkage sets in and decreases the effect of absorption. At some energy (e.g.,5-10 GeV/c) the absorption effects are largest. Part (b) shows the ρ and A_2 poles; since $\alpha_{A_2} < \alpha_\rho$ the A_2 pole is a little closer to the real axis. $P_+ = P_{A_2}+P_\rho$ is the pole term for the "real" process (e.g., $K^+n\to K^\circ p$, $K^-p\to\pi^-\Sigma^+$, etc.) and $P_-=P_{A_2}-P_\rho$ is the pole for the "rotating" process (e.g., $K^-p\to\overline{K^\circ}n$, $\pi^+p\to K^+\Sigma^+$,etc.). The angle between P_ρ and P_{A_2} is $\pi/2(1-\alpha_\rho+\alpha_{A_2})$ which is always less than $\pi/2$ since $\alpha_{A_2} < \alpha_\rho$. Thus always $|P_+| > |P_-|$. The "real" process has a larger pole term. Part (c) shows the absorption corrections for the A_2 and ρ and the "real" and "rotating" processes. Since the A_2 is more central than the ρ it feels the absorption more and $|C_{A_2}| > |C_\rho|$. Part (d) shows the complete amplitudes for the "real" and "rotating" processes. The absorption effects are larger for M_+ than for M_- because C_+ is closer to 180° out of phase with P_+ than C_- with P_- (because $|C_{A_2}| > |C_\rho|$). Thus $|M_+|/|M_-| \lessapprox |P_+|/|P_-|$, but for realistic numbers the ratio is still above 1 a little. Part (e) shows the main result, that the ratio of "real" to "rotating" cross sections has a minimum when the absorption strength is maximal and rises to values $R \sim 1.5$ when absorption does not reduce P_+ so much toward P_-. As discussed in the text, this may be one of the few predictions capable of distinguishing among models and ideas. Finally, part (f) shows that the addition of a π contribution (which does not change sign between reactions) just reverses the situation, making the exotic channel have the smaller cross section, as is observed.

$$|P_+|/|P_-| > |M_+|/|M_-| > 1$$

where + stands for "real" and - for "rotating".

At the energy where the absorption is the strongest the ratio is as small as it will get, and the cross section ratio R of part e is down near unity. As s increases the absorption effect decreases and the ratio increases, reaching values such as 1.5 at energies $P_L \sim$ 30 GeV/c. The precise values are model dependent, but the effect must be large.

(Finally, having so many details present it is worth noting that by adding a π exchange contribution to part d one converts to the case of $np \to pn$ vs. $\bar{p}p \to \bar{n}n$ line reversed pairs or vector meson line reversed pairs. The π contribution does not change sign between reactions. As the figure clearly shows, this just reverses the size of the cross sections, making the "rotating" reaction larger than the "real" one. Adding a π interchanges exotic and non-exotic reactions. This is precisely what is observed in the data.)

It will be interesting to see the experimental results on high energy line reversed reactions and to see if in fact it is possible to draw clear conclusions about current models. At the present time the only relevant measurement is the Serpukhov $K^-p \to K^\circ n$ data at 25 and 35 GeV/c, which go in the direction of the CAM prediction, with the observed cross section smaller than expected from an exchange degenerate extrapolation of the low energy data. $K^+n \to K^\circ p$ may also be measured at Serpukhov, making a comparison possible. The Σ reactions may be measurable at NAL within the next year.

(4) Many polarizations will be large at high energies. Predictions for several are shown in Fig. 18 . As lower lying exchanges are less important the polarizations will become more useful tests of models and ideas.

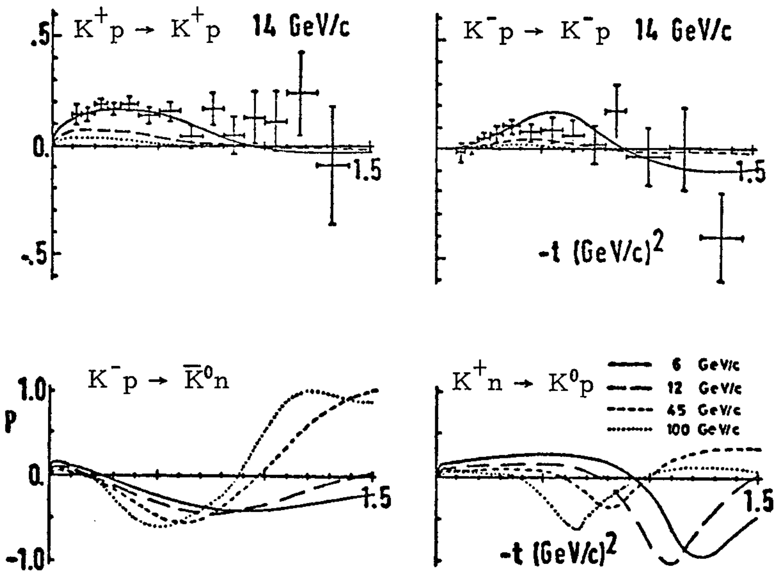


Fig. 18. Typical high energy polarization predictions for elastic and exchange reactions. Similar results hold for πN processes, hypercharge exchange, etc. Theory curves from Ref. 2 . A prediction for P(np→pn) at 100 GeV/c is shown in Fig.[13] .

PRODUCTION OF RESONANCES AND REGGE RECURRENCES

An increasingly important aspect of two body reactions is the production of higher mass and spin resonances. If the production mechanism is understood we can learn about the resonance properties and its role in other areas of hadron physics; equally well, it is a place to further test and improve our understanding of production mechanisms and models. Two kinds of questions are of particular interest.

(a) Are there any data on resonance production mechanisms which indicate that we do not understand what is happening, or do we seem to have a good grasp of all the production data? There is of course a lot of data where the answer is legitimately a matter of opinion at the present time, and these cases must be watched. But I am only aware of one case where a serious claim has been made that the situation is drastic; that is B meson production in $\pi N \to BN$.

Since $B \to \omega\pi$ one expects to produce a lot of B's by ω exchange. That can be done with no need to flip helicity at either vertex. The large nonflip coupling of the nucleon to the ω should allow this amplitude to be important. It should lead to a lot of zero helicity B's.

Fox and Hey[28] have calculated B production and they claim the result is very much too large. To reproduce the data they are then led to some rather surprising assumptions. However, they do not absorb the large nonflip amplitude. They do not give any arguments for this, although one of the few things all workers seemed to agree on in other reactions was that nonflip amplitudes were strongly absorbed; witness, for example, the crossover zero generally agreed to be present in ω exchange in KN and NN reactions because of absorption.

In a typical situation absorption will reduce a nonflip amplitude by about a factor of two in magnitude at $t = 0$, and sharpen the peak. The cross section integrated out to $-t$ about .2 GeV^2 is suppressed about a factor of 7. This would appear to account for most of the missing order of magnitude of Fox and Hey. Using this and assuming that the $B\omega\pi$ coupling is mainly s wave so about equal mixtures of helicity zero and helicity one B's are produced I find cross sections within a factor of two or better agreement with the data. In addition, the absorbed nonflip amplitude has a steep slope at small t because it has a dip near $-t = 0.2$, and then a break due to the secondary maximum of the nonflip amplitude and to the rise of the flip amplitudes. The data is certainly consistent with such a shape, with a small t slope of 10 GeV^2 or more. This approach requires that $\rho^{s}_{00}(B) \gtrsim 1/2$ which does not seem inconsistent with recent data.[29] Basically the situation is as shown in Fig. 19.

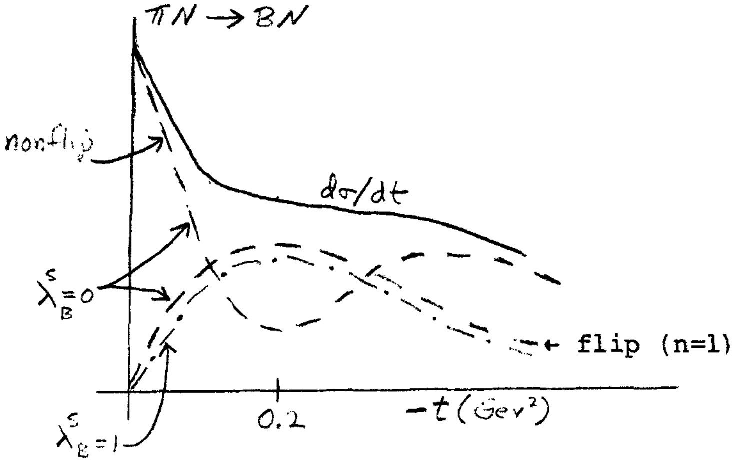


Fig. 19

Thus the rather standard absorption picture of the small t amplitudes appears to give a picture of B production which is not inconsistent with the data. More careful calculations have to be done, of course, to verify that the entire B-ω system, in exchange and production, behaves reasonably. For the present, however, it seems reasonable to believe that there is no worrisome puzzle. It is important to verify for many reactions that the size, s,t, and spin dependence are reasonably understood in terms of our present ideas.

(B) Production of Regge Recurrences. Another way to study the composite nature of hadrons and whether they lie on Regge trajectories is to consider external Reggeon production. In particular, one can produce a particle and its Regge recurrence and compare the behavior, perhaps learning something important in the process. There is quite a lot of data around on Regge recurrence production which is not in very public view because the statistics are not high and one is not sure what to do with it or how to analyze it.

A few reactions which can be studied are:

$\pi N \to \rho N$
$\quad \to fN$ (?)
$\quad \to gN$
$\pi N \to \pi N$
$\quad \to \pi N(1690)$
$\pi N \to \pi \Delta$
$\quad \to \pi \Delta(1920)$

and one can substitute K, K*, Λ, Σ, etc. to generate more.

A full understanding of external Reggeons would allow us to predict the s,t, dependence, which helicity states are populated, and cross section sizes. If one looks, for example, in the s-channel one finds that the ratio of total cross sections in πN scattering at the Δ mass to that at the Δ recurrence mass ($\Delta(1920)$) is a factor of 5. From a different point of view, Veneziano model calculations of Chan and Tsao[30] give a factor of 2 decrease in cross section as one goes from producing a state to producing its recurrence.

The recurrence will have higher spin. Are its higher helicity states populated?

What about energy dependence? In pure pole models the energy dependence does not depend on which amplitudes are populated, while in models with absorption it does.

The t-dependence may change with forward turnovers introduced if higher helicity states are populated.

One can also study symmetry questions; e.g., are SU(3) d/f ratios unchanged? Are K^+ reactions still mainly real at small t?

The situation theoretically has been largely ignored. The most interesting work[31,32] has been done by Hoyer, Roberts, and Roy in a paper based on finite mass sum rules. They argue that

$$X = \left(d\sigma\left(\begin{smallmatrix} a \to c \\ \alpha_i \\ b \to R \end{smallmatrix}\right)/dt\right)\Big/\left(d\sigma\left(\begin{smallmatrix} a \to c \\ \alpha_j \\ b \to R \end{smallmatrix}\right)/dt\right) \sim \left(M_R^2\right)^{2\alpha_j(t)-2\alpha_i(t)}$$

and they give two sorts of predictions. First, if $j = \pi$ and $i = \rho, \omega, f, A_2$ they expect $X \sim (M_R^2)^{-1}$ so π exchanges are predicted to dominate increasingly over natural parity exchanges as the resonance mass increases. There seems to be some evidence that this is occurring. Second,

$$d\sigma\left(\begin{smallmatrix} \alpha_i \\ \to R \end{smallmatrix}\right)/dt\,(M_R^2)^{-2\alpha_i(t)} \sim e^{-2\alpha_i(t)\ln M_R^2}$$

so they expect less falloff in t as M_R^2 increases, an <u>anti-shrinkage</u>. It is not so clear that this is observed.

In fact, consider the following naive kinematical duality argument to compare with their second prediction. Suppose we sit at a fixed s and the cross section is dominated by a peripheral high mass resonance, so we have a Legendre function zero at an angle θ_o, and $s \gg M_R^2 \gg m_a^2, m_b^2$. Then

$$\Delta^2 = -t = \Delta^2_{min} + 2qq'(1-\cos\theta_o)$$

$$\Delta^2_{min} \approx M_R^4\, m_a^2/s^2$$

$$q' \approx (s-M_R^2)/2W$$

Now increase M_R^2. Then $d\Delta^2/dM_R^2 = 2m_a^2M_R^2/s^2 - q(1-\cos\theta_0)/W$ is negative for large s, so the zero is closer to $\Delta^2=0$ and we expect shrinkage as M_R^2 increases. Asymptotically the Δ^2 dependence is independent of M_R^2.

The contradiction presumably has to do with the role of daughter states and lower lying contributions implicit in the two arguments. It will be instructive to see what finally happens in the data, and to try to understand the situation if the first Hoyer, Roberts, Roy prediction is more valid than the second.

(C) Vector meson production. There is a good deal of data submitted to this meeting on vector meson production, and an extensive phenomenologicalanalysis of the data by Field and Sidhu. On the whole their analysis indicates that the properties of the data are well understood. For example, they were able to take the model of Ref. 2 for $0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ reactions and with essentially no changes produce a good description of ρ and ω and K* data. The one place to watch is the detailed phase question of the ρ-ω interference phase for the helicity one natural parity amplitudes, where the model may be in disagreement with the data of the Argonne group at 4-6 GeV/c. However, the higher energy SLAC data suggests that there may not be such a disagreement, and in addition (as Field and Sidhu emphasize), the phase being tested is the same as that giving the line reversal properties for K* reactions which come out all right in the model. Thus it appears likely that the ρ-ω phase at 6 GeV/c is due to a low energy effect such as a lower lying contribution; it should be watched, however, to see that the data changes as the energy is increased. If the higher energy data is the same as the 4-6 GeV/c data then either the phase properties of the models are wrong or unexpected contributions are important or the expected contributions have unexpected energy dependence.

(D) S-Channel helicity Amplitudes. For some time it has been clear that the s-channel helicity amplitudes were likely to be the simplest[19] to interpret and understand. If the Classical absorption approach is basically right this is certainly true. If the Mystical kind of models turn out to be correct, on the other hand, it is not nearly so likely and for some amplitudes a t-channel (or some other) point of view would be more useful. The Romantic models are somewhere inbetween, with s-channel structure at least for the imaginary parts.

The reason s-channel amplitudes are best if absorption is important is that one must rotate the initial Reggeon scattering amplitude to the appropriate z axis to apply the absorption, and that rotation does not mix up amplitudes for s-channel helicity amplitudes, so proper-

A full understanding of external Reggeons would allow us to predict the s,t, dependence, which helicity states are populated, and cross section sizes. If one looks, for example, in the s-channel one finds that the ratio of total cross sections in πN scattering at the Δ mass to that at the Δ recurrence mass ($\Delta(1920)$) is a factor of 5. From a different point of view, Veneziano model calculations of Chan and Tsao[30] give a factor of 2 decrease in cross section as one goes from producing a state to producing its recurrence.

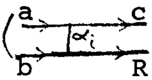
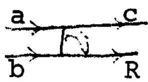
The recurrence will have higher spin. Are its higher helicity states populated?

What about energy dependence? In pure pole models the energy dependence does not depend on which amplitudes are populated, while in models with absorption it does.

The t-dependence may change with forward turnovers introduced if higher helicity states are populated.

One can also study symmetry questions; e.g., are SU(3) d/f ratios unchanged? Are K^+ reactions still mainly real at small t?

The situation theoretically has been largely ignored. The most interesting work[31,32] has been done by Hoyer, Roberts, and Roy in a paper based on finite mass sum rules. They argue that

$X = \Big(d\sigma\Big($  $\Big)/dt\Big)\Big/\Big(d\sigma\Big($  $\Big)/dt\Big) \sim \left(M_R^2\right)^{2\alpha_j(t)-2\alpha_i(t)}$

and they give two sorts of predictions. First, if $j = \pi$ and $i = \rho,\omega,f,A_2$ they expect $X \sim (M_R^2)^{-1}$ so π exchanges are predicted to dominate increasingly over natural parity exchanges as the resonance mass increases. There seems to be some evidence that this is occurring. Second,

$d\sigma\Big($  $\Big)/dt\,(M_R^2)^{-2\alpha_i(t)} \sim e^{-2\alpha_i(t)\ln M_R^2}$

so they expect less falloff in t as M_R^2 increases, an <u>anti-shrinkage</u>. It is not so clear that this is observed.

In fact, consider the following naive kinematical duality argument to compare with their second prediction. Suppose we sit at a fixed s and the cross section is dominated by a peripheral high mass resonance, so we have a Legendre function zero at an angle θ_0, and $s \gg M_R^2 \gg m_a^2, m_b^2$. Then

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The reason s-channel amplitudes are best if absorption is important is that one must rotate the initial Reggeon scattering amplitude to the appropriate z axis to apply the absorption, and that rotation does not mix up amplitudes for s-channel helicity amplitudes, so properties characteristic of an amplitude are not obscured by the absorption. In addition, the absorption is largely helicity independent so the final observable amplitudes preserve many properties of the pole terms. For example, if the pole terms are zero the full amplitudes are zero only for the s-channel helicity amplitudes; one can give many more detailed examples.

Thus however else the data is presented, experimenters should always present s-channel information whenever possible (e.g., density matrices). For resonance production that simply corresponds to choosing a coordinate system in the resonance rest frame with z-axis along the recoil particle direction (rather than along the beam direction, which gives the t-channel information).

APPENDIX 1

Here we just briefly note a few ways to get at the sum over intermediate states experimentally. These are not exactly the same thing needed in the absorption calculation, but they involve such a sum and it is likely that if we can calculate it in one place we will understand it well enough.

(a) In two body double charge exchange reactions all calculations so far which give numerical results use the technique of approximating the sum by one or two lowest states. If we knew from data that that approximation was either adequate, or very bad, it would suggest a similar conclusion for all such sums. In particular, one could compare pairs of reactions such as $\pi^- p \to K^+ \Sigma^-$ or $K^- p \to \pi^+ \Sigma^-$, and $K^- p \to K^+ \Xi^-$. Keeping the spin $\frac{1}{2}$ baryon intermediate states will produce a much larger cross section for $\pi^- p \to K^+ \Sigma^-$ than for $K^- p \to K^+ \Xi^-$ just because there are more intermediate states for the former and they are all coherent. It would be hard to avoid an order of magnitude ratio. Preliminary data[33] indicates that the two cross sections are about equal, which would suggest that the lowest intermediate states are a very bad approximation to the sum. This is a much stronger test than the absolute values of cross sections since the values are sensitive to the coupling constants used. One can find a number of other such comparisons to make when data is available.

(b) As originally suggested by Pumplin and Ross,[34] and Gribov[35] there should be a contribution to the Glauber correction on deuterium from nonelastic intermediate states. This has recently been looked at in detail[36]; there appears to be rather good evidence for the presence of such a contribution, and good data on deuterons will allow one to test our ability to calculate it and its energy dependence.

(c) Very high energy photon exchange is observable in certain nonelastic reactions because the hadron exchanges fall off with energy and the photon does not. In addition, in some cases[24] the photon exchange behaves like a short range force, localized within anfermi. Then it feels the effect of the strong initial and final state interactions, which will receive contributions from inelastic intermediate states. Because the photon pole is known, deviations from it can be studied. With some model dependence, at least at first, the elastic intermediate state can be separated off. In this case the sum encountered is the same one as in the absorption case and will be directly relevant. There will even be such an effect in elastic reactions but it will probably be too small to be seen. In the inelastic short range photon exchange reactions the rescattering effects will dominate the structure and size of the cross sections.

APPENDIX 2

As an example of the behavior of amplitudes we describe briefly here the CAM solution to the long standing puzzle of the large, rather constant $np \to pn$ polarization. Complete details are given in Ref. 4 .

Recall

$$P d\sigma/dt = 2 \mathrm{Im} \varphi_o \varphi_5^*, \qquad \varphi_o \equiv \varphi_1 + \varphi_2 + \varphi_3 - \varphi_4$$

In the simplest case we expect no π contribution and $\rho + A_2$ real so $P = 0$, as discussed in the text. More realistically, at $t = 0$ the situation is approximately as in Fig. A1, with φ_o and φ_5 both approximately real as expected.

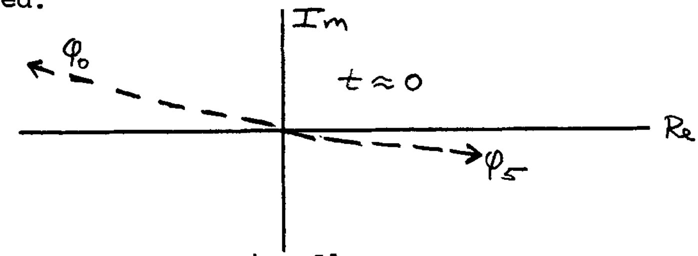
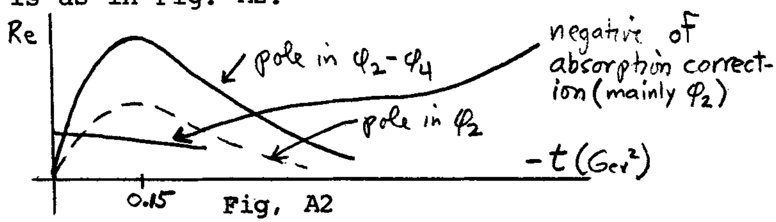


Fig. A1

As $-t$ increases, $\mathrm{Re}\varphi_1$ and $\mathrm{Re}\varphi_3$ (being $n=0$ amplitudes) must have an absorption zero by $-t \sim 0.2$ GeV^2. The natural parity poles add in $\varphi_2 - \varphi_4$, so for ρ and A_2 the behavior is as in Fig. A2.



Fig, A2

So $Re(\varphi_2-\varphi_4)$ has a zero by $-t \simeq 0.05$ (well before the peak of the pole). Thus all parts of φ_0 have a zero at small t, and in fact $Re\varphi_0$ has a zero by $-t \leq 0.1$ GeV^2. Thus Fig. A1 becomes

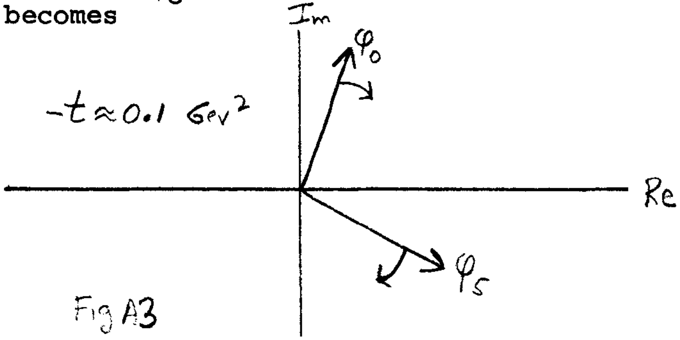


Fig A3

and the polarization is maximal since φ_0, φ_5 are $\pi/2$ out of phase. As -t increases now both φ_0 and φ_5 rotate slowly around staying about 90° apart, so P stays large even though pieces of the amplitudes have zeros.

It appears difficult for other approaches to obtain such a result naturally, because they do not normally have small t zeros in the amplitudes (especially in the real parts) so φ_0 stays in the second quadrant and $P \approx 0$. The CAM zeros in the <u>real parts</u> of ρ and A_2 give both the sign and magnitude of P correctly, assuming exchange degenerate structure at t = 0 and no rapid variation with t except in n = 0 amplitudes where it is implied by the effects of absorption.

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