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ON THE KINEMATIC ENHANCEMENT OF RESONANCE PRODUCTION IN CERTAIN TWO BODY REACTIONS

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ABSTRACT

An explanation is given of the fact that certain quasi two body reactions have a constant cross section with respect to incident momentum. It is supposed that there is a diffraction scatter at one vertex followed by a final state interaction. This mechanism is applied to reactions produced by incident protons, pions, kaons and gammas.

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The cross section for two body inelastic reactions :

$$A + B \rightarrow C + D \qquad (1)$$

in general decreases rapidly with incident momentum, as is shown, for example in the preceding letter[1]. However, Anderson et al[2] have extended the earlier work of Cocconi et al[3] to show that in the reaction

$$p + p \rightarrow p + N^{*} , \qquad (2)$$

where N has isotopic spin $T = \frac{1}{2}$, the cross section is essentially constant over the range 6 to 30 GeV/c. In this letter we attempt to explain this surprising result as being due to a diffraction scattering process at one vertex followed by a final state interaction. The importance of the relative velocity of the particles in this process is stressed. This concept is then extended to reactions involving incident pions, kaons antiprotons and gammas. It is suggested, for example, that the reactions of the type :

$$\pi^{\pm} + p \rightarrow p + M^{\pm} \qquad (3)$$

and

$$K^{\pm} + p \rightarrow p + L^{\pm} \qquad (4)$$

will have a constant cross section when M and L are resonances which decay into another resonance and a meson, and when the reaction may be described in terms of a Feynmann diagram with a diffraction scatter at the baryonic vertex, e.g. M might be A_1 or A_2 and L could be the $(K\pi\pi)$ resonances at 1320 or at 1790 MeV[4].

It is assumed that two body inelastic reactions (1) can be interpreted in terms of Feynmann diagrams in which a "particle" carrying definite quantum numbers is exchanged between the two vertices. Cocconi et al[5] showed in counter experiments that reaction (2) gave a strong forward diffraction-like peak and Morrison[6] showed in bubble chamber experiments with incident π^- and protons that diffraction-like distributions for outgoing π^- and protons are obtained. Amati and Prentki[7] and Drell and Hiida[8] suggested that diffraction scattering at one vertex could be responsible for these effects. The idea of diffraction dissociation on nuclei, previously proposed by Good and Walker[9], is equivalent to this idea.

The conventional Feynmann diagram of reaction (2) is shown in Fig. 1a where the virtual pion from the top vertex undergoes diffraction scattering at the bottom vertex. It is, however, perhaps easier to understand this process if we consider Fig. 2. Here a proton, p_A, entering from the left, dissociates at A into a virtual pion (shown dotted) and a nucleon, N_A. At B, the other proton, entering from the right, which we will call p_B, makes an elastic interaction; the nucleon leaving B must be the same as the proton p_B. The pion leaving B then interacts with the nucleon from A and may, in some cases, produce an isobar. There are a number of important points about this mechanism.

(1) The virtual pion and N_A have about the same velocity as p_A.

(2) The differential cross section for the dissociation $p_A \rightarrow N_A + \pi$ may be taken as independent of the momentum of p_B.

(3) In the rest system of p_B, the virtual pion is a high energy particle, thus the elastic scattering process at B is a high energy process.

(4) In a high energy elastic reaction, the scattering is of a diffraction type, so that the outgoing π and proton will have almost the same momentum as before, but the direction will be slightly different - this is independent of the momentum of p_B.

(5) From (1) and (4), N_A and the pion leaving B have approximately the same velocity, and therefore the cross section for them to combine together to form an isobar will be large, this being a low energy effect, and will be approximately independent of the momentum of p_B.

(6) For a high energy elastic reaction, the cross section is approximately independent of energy. Thus the cross section for the reaction at B is independent of the momentum of p_A and p_B.

We may draw the following conclusions :

(a) Since the 3 cross sections for the interactions at A, at B and for the final state formation of the isobar are all independent of the incident momentum, then the overall cross section for the reaction (2) may be expected to be approximately constant with respect to the incident momentum.

(b) In elastic scattering, charge baryon number, strangeness number and isotopic spin cannot be exchanged between the vertices. Since at vertex B these quantum numbers cannot be exchanged as we postulate an elastic scattering, then the N^* will have the same value of these quantum numbers as the incident proton. In particular the isotopic spin of the isobar must be 1/2. The spin and parity of the isobar may however change (as can be seen experimentally from the fact that the isobars produced in reaction (2) can have different spins and different parity from that of the proton.)

(c) The scattered pion may or may not interact with N_A to produce an isobar. Hence, one expects there to be an appreciable background below the isobar peak and one expects this background to be constant with respect to variation of the incoming momentum.

(d) The production of the isobar and the background should both be of a peripheral nature with a differential cross section similar to that for π-p elastic scattering.

(e) If in reaction (2), the N^* produced has $T = \frac{3}{2}$, then the model discussed here does not apply and the cross section may be expected to decrease with incident energies, with the normal exponent, 1.5, characteristic of most inelastic processes[1].

In general, the experimental results of Cocconi et al[3] and Anderson et al[2] seem to agree with these predictions except that the slope of the $d\sigma/dt$ distribution for the production of $N^*(1400)$ is different from those of the other $T = \frac{1}{2}$ isobars. It may however be noted that only the $N^*(1400)$ has the same spin and parity as has the proton.

The interaction mechanism described in Fig. 1a or 2 can be applied to other incoming particles such as π or K-mesons, antiprotons or gammas, i.e., to the reactions :

$$\pi + p \rightarrow \pi + N^* \qquad (5)$$

$$K + p \rightarrow K + N^* \qquad (6)$$

$$\bar{p} + p \rightarrow p + \bar{N}^* \qquad (7)$$

$$\bar{p} + p \rightarrow N^* + \bar{p} \qquad (8)$$

where N^* and $\bar{N}^*$ have $T = \frac{1}{2}$, or to the reactions :

$$\pi + p \rightarrow p + A \qquad (9)$$

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where A is a resonance with T = 1 which has a $\pi\rho$ decay mode e.g. A_1, A_2. Also if there exists a (πf^0) resonance, P say, with T = 1, then the reaction:

$$\pi + p \rightarrow p + P \qquad (10)$$

may also be considered.

$$K + p \rightarrow p + L \qquad (11)$$

where L may be taken as a general name for $(K\pi\pi)$ resonances with $T = \frac{1}{2}$ which decay into $K^*\pi$ and/or $K\rho$. One may extend reaction(11) further to include possible resonances of $K^*(1400)\pi$ or Kf^0.

$$\gamma + p \rightarrow p + \rho \qquad (12)$$

Similarly for the reaction $\gamma p \rightarrow pf^0$.

The Feynmann diagrams corresponding to reactions (5) and (6) are the same as that of Fig. 1a, but with the proton at the bottom vertex replaced by a π (or K) meson. The Feynmann diagrams corresponding to reactions (7), (9), (10)and (12)are shown in Figs. 1b, 1c, 1d and 1g respectively, while that for reaction (11)is shown in Fig. 1e and 1f. Other variations can be imagined, e.g., in Fig. 1c, one could consider the π and ρ being interchanged so that the ρ undergoes the diffraction scattering on the proton.

In all these reactions (2) to (12),it is required that the resonance produced has the same isospin as that of the corresponding incident particle. It is then predicted that the cross section will be approximately constant with incident momentum, and that there will be an appreciable background under this resonance which will also be approximately constant with the incident momentum. For reactions (5), (6), (7) and (8) there are insufficient data to test this prediction, but it may be noted that the reaction $p\bar{p} \rightarrow N\bar{N}\pi$ varies little with incoming momentum over the range 3 to 6.9 GeV/c, unlike other 3-body reactions. The cross section for the production of the A_1 and A_2 mesons which have the same isospin as the π-meson, is approximately constant over the range 4 to 11 GeV/c[10], though it should be noted that the background is difficult to determine. The resonance in the $(K\pi\pi)$ system from reaction (11) observed near 1320 has approximately the same cross section at 10 GeV/c[4] as that observed near 5 GeV/c[11], instead of being $(5/10)^2 = 1/4$ of that at 5 GeV/c as would be expected for most inelastic reactions (the background is not well understood also in this reaction). The peaks in the $K^*\pi$ and $K\rho$ systems near 1320 and 1800 MeV[4] are believed to have $T = \frac{1}{2}$ as has the K meson.

For reaction (10), it may be noted that the Aachen - Berlin - CERN collaboration observed[12] with 8 GeV/c positive pions that if in the reaction where f^o decays into $\pi^+\pi^-$ or $\pi^o\pi^o$[13] one excludes events having a $(p\ \pi^+)$ effective mass in the $N^*_{3,3}$ mass region (1.12 to 1.34 GeV), then a peak is observed in the $(\pi^+ f^o)$ mass spectrum near 1650 MeV. The present experimental data are not sufficient to establish whether this peak is a resonance or a kinematic effect. The photonuclear reaction (12) is found[14] to have a constant cross section[15], whereas the cross section for other photonuclear reactions such as $\gamma p \rightarrow N^*\pi$ and $\gamma p \rightarrow p\omega$, which cannot be interpreted as having a diffraction scatter at one vertex, are found to decrease rapidly with increasing gamma momentum[16].

In general charge cannot be exchanged in the type of reactions considered here (category one[1]). If charge is exchanged, the reaction is of category two[1] and the cross section will decrease rapidly with energy. Thus at sufficiently high energy a category one reaction will have a larger cross section than the similar reaction with charge exchange. For example with 10 GeV/c K^--mesons, reaction (11) is observed[4] with frequent production of L-mesons of mass $\approx$1320 and 1790 MeV, but in the reaction

$$K^- + p \rightarrow n + K^0 + \pi^+ + \pi^- \qquad (13)$$

no peak is observed in the $(K\pi\pi)^0$ effective mass distribution near 1320 and 1790 MeV.

In the experimental results of reaction (2), there is a smooth background on which are superimposed peaks which correspond to isobars. Here it is suggested that these isobars are not produced directly but only in final state interactions. If there were no isobars to form, then there would be no peaks (other than the broad maximum due to the background).

Deck[17] and Maor and O'Halloran[18] have used the idea of a diffraction scattering at one vertex to calculate the background to reaction (9) and suggest that the A_1 is not a resonance but only the maximum in this background. Here we consider in addition a final state interaction, so that the A_1 (and A_2) are resonances whose production cross section in reaction (3) is enhanced by the special consequences of a diffraction scattering occurring at one vertex. The A_1 (and A_2) can also be produced directly with ρ-meson exchange, but then the cross section would be expected to fall with an exponent $n \approx 1.5$ as described in the previous letter[1]. Maor and O'Halloran[18] also consider the production of the B-meson in the reaction :

$$\pi + p \rightarrow p + B \rightarrow p + \pi + \omega \qquad (14)$$

to be due to a kinematic effect. However, this process, shown in Fig. 1h, does <u>not</u> involve a diffraction scatter at one vertex and hence it is not considered in this letter. We would expect the cross section for reaction (14) to decrease with increasing momentum with an exponent, $n \approx 1.5$[14].

Thus in conclusion, an explanation of the result that the cross section for reaction (2) is constant up to 30 GeV/c has been given in terms of a diffraction scattering at one vertex followed by a final state interaction. A number of other quasi two body reactions which should also have a constant cross section have been discussed.

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Figure Captions

Fig. 1. Feynmann diagrams as discussed in the text for reactions :

(a) $p + p \rightarrow p + N^{*}$, (b) $\bar{p} + p \rightarrow p + \bar{N}^{*}$, (c) $\pi + p \rightarrow p + A$, (d) $\pi^{+}p \rightarrow pP \rightarrow p\pi f^{0}$, (e) $K + p \rightarrow p + L$, (f) $K + p \rightarrow p + L$, (g) $\gamma + p \rightarrow p + \rho$, (h) $\pi + p \rightarrow p + B$.

Fig. 2. Diagram of the reaction $p + p \rightarrow p + N^{*}$ in the CM rest system.

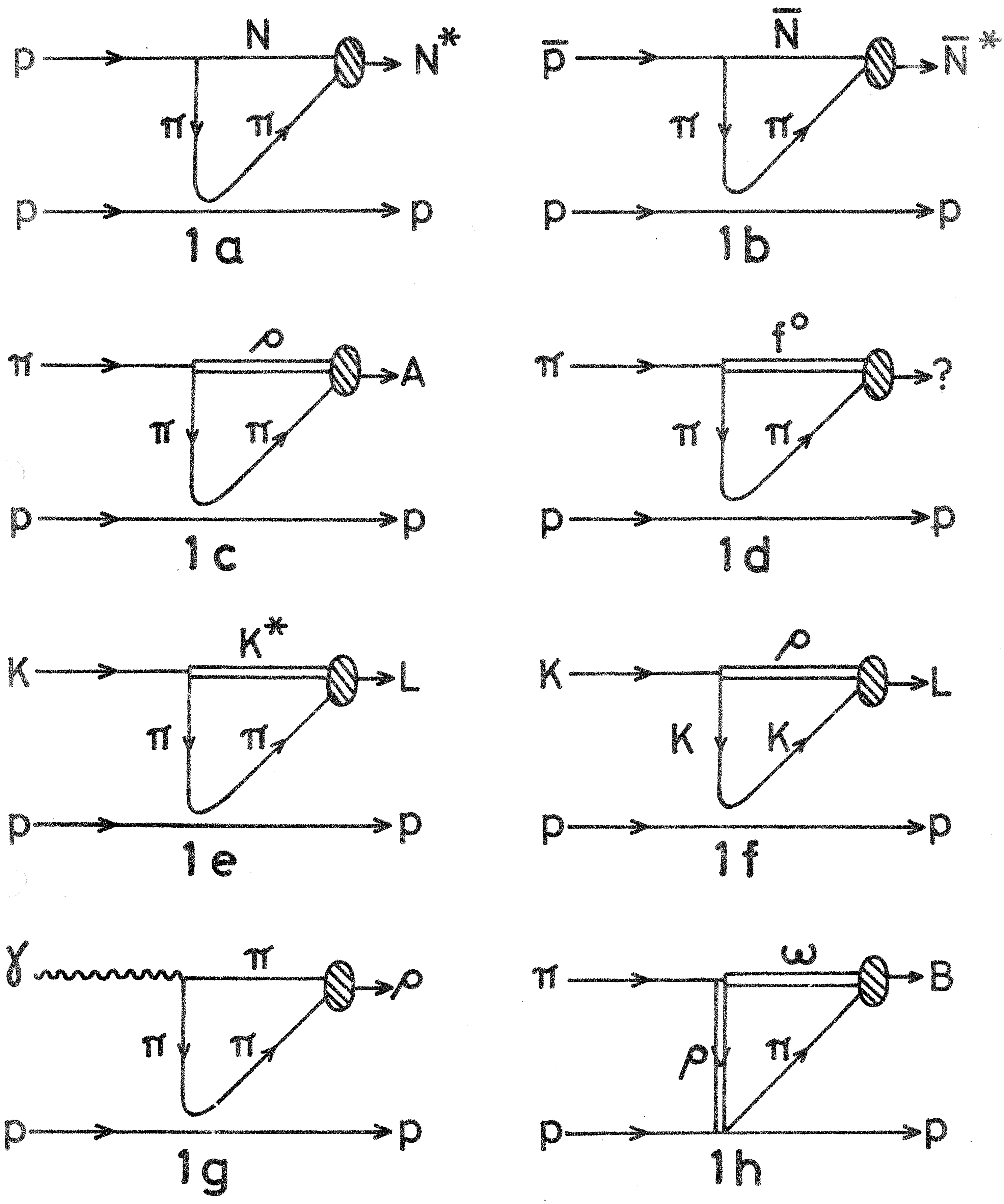
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Fig. 1

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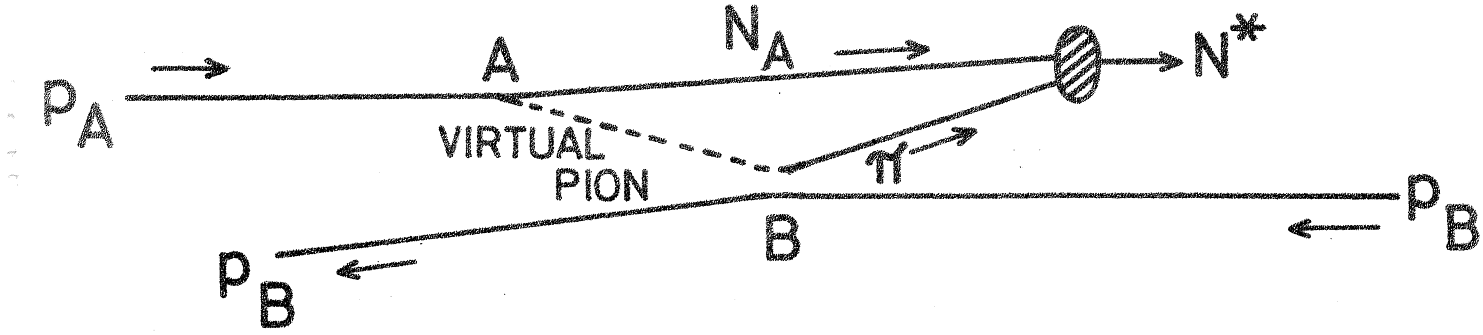

Fig. 2

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