THE PHENOMENON OF DIFFRACTION DISSOCIATION

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This is a report on some work done by W.D. Walker and myself about a year ago[1]; we have carried it only a little further since that time.

I will try to present the idea, that a particular type of low momentum transfer collision should exist. Next, I will explain why we might be interested in such a process. Then I will attempt to relate this process to more conventional ideas, involving single pion exchange; and, finally, I will present some crude preliminary data.

I begin with a point in kinematics. Let us consider a collision of a particle of mass M with a nucleus, the particle transforming into a system of mass M* as a result of the collision. Let us assume that the nucleus absorbs only a small amount of momentum, $(\vec{q})$, and no energy. We then have

$$E^2 = p^2 + M^2$$

(E, p = energy, momentum of incident particle)

and, also

$$E^2 = (\vec{p} - \vec{q})^2 + M^{*2}$$

to first order in the scattering angle,

$$q_{//} = \frac{M^{*2} - M^2}{2p} = (M^* - M)\left(\frac{M^* + M}{2p}\right)$$

where $q_{//}$ is the component of $\vec{q}$ in the beam direction.

The kinematical point is that $q_{//}$ will, for relativistic particles, be small compared to $M^* - M$; and, also, $q_{//}$ can be small compared to $\frac{m_\pi}{A^{1/3}}$, the reciprocal of the nuclear size. It is feasible, then, for the nucleus to remain in its ground state, provided that

$$q_{//} \simeq \frac{M^{*2} - M^2}{2p} << \frac{m_\pi}{A^{1/3}} . \qquad (1)$$

Another useful fact is that when Eq. (1) is satisfied, the state M and the state M* are degenerate as far as the nucleus is concerned. That is to say, the difference in phase of the de Broglie oscillations of M and M* in travelling a distance of one nuclear radius, $R = \frac{A^{1/3}}{m_\pi}$, is small compared to one radian:

$$\varphi_2 - \varphi_1 = \left[\frac{\partial\varphi_2}{\partial t} - \frac{\partial\varphi_1}{\partial t} + \left(\frac{\partial\varphi_2}{\partial x} - \frac{\partial\varphi_1}{\partial x}\right)\frac{dx}{dt}\right]\Delta t$$

$$= [(\omega_2 - \omega_1 = 0) - (k_2 - k_1)(\beta \simeq 1)]\left(\Delta t \simeq \frac{A^{1/3}}{m_\pi}\right) \qquad (\hbar = c = 1)$$

hence

$$\varphi_2 - \varphi_1 \simeq q_{//} \; R \qquad (2)$$

but, according to Eq. (1),

$$q_{//} \; R << 1 .$$

Thus the state M and M* are effectively degenerate.

Now, when a degeneracy exists, we know that one can, by differential absorption, create a new state. Thus, in the $K_2^0 \to K_1^0$ regeneration phenomenon, differential absorption of the K^0, $\bar{K}^0$ components creates some

K_1^0 amplitude in the unscattered beam; the scattering nucleus remains unchanged.

We may apply this same concept to the present situation. Suppose, for purposes of illustration, we express the initial state of the incident particle, which is a "dressed" or real particle, as a series expansion in the "bare particle" states of perturbation theory. Then the incident wave is:

$$| I > \; = \; e^{ikz} \; | \tilde{N} > \; = \; e^{ikz} \; (\sum_i C_{Ni} \; | B_i >)$$

where $| \tilde{N} >$ represents a real nucleon (for instance), and $| B_i >$ are the states comprised of a bare nucleon and bare pions, of the same quantum numbers as $| \tilde{N} >$. We are concerned only with those parts of the summation for which $M^* = M \, (B_i)$ is such that Eq. (1) is fulfilled.

Let us suppose now that the B_i are absorbed differently in going through the nucleus.

The transmitted wave is then

$$| T > \; = \; \sum_i C_{Ni} \; \eta_i \; | B_i > \; .$$

The point is simply that this is, in general, not a pure nucleon wave: $| T > \; \neq \; | \tilde{N} >$.

A scattering therefore results. The scattered wave $| S >$ is given by:

$$\Big| \, | S > \Big|_{z=0} = \Big| \, | I > \Big|_{z=0} - \Big| \, | T > \Big|_{z=0} = \sum_i (1 - \eta_i) \; C_{Ni} \; | B_i > \; .$$

It is also true that, in general, $| S > \neq | \tilde{N} >$. Thus the scattered beam contains components corresponding to real ("dressed") two or more particle states such as: $| \tilde{N} \tilde{\pi} >$, $| \tilde{N}, 2\tilde{\pi} >$, ... It is these amplitudes which we call diffraction dissociation.

Because of the size of the source, these scattered amplitudes should have an angular distribution characteristic of diffraction scattering from the nucleus. The nucleus remains in its ground state throughout, for the processes under consideration.

It is useful to recognize at this point that the diffraction dissociated amplitude represents, from another point of view, the coherent sum of the corresponding amplitude from each of the nucleons in the nucleus. We therefore, by observing this particular process, use the nucleus as a sort of interferometer to single out the non-spin flip part of the appropriate forward inelastic amplitude.

I now want to state why we should be interested in this process. It is simply that the state of mass M* is, under favourable circumstances, a state of known quantum numbers, and so is amenable to detailed study.

To see this, consider first the angular momentum of M or M* relative to the nucleus. If $q_{\parallel} R \ll 1$ (Eq. (1)), and also

$$q_{\perp} R \ll 1 \quad , \tag{3}$$

then the classically-computed angular momentum change is small compared to 1. Thus, when Eq. (1) is satisfied, and if we observe diffraction dissociation events near the centre of their angular distribution so as to fulfil Eq. (3), the angular momentum change will be, to good approximation, zero. Thus, if we write

$$\vec{J} = \vec{L} + \vec{S}_{TARGET} + \vec{S}_{PROJECTILE}$$

we have

$$\Delta \vec{J} = 0 \qquad \text{(always)}$$

$$\Delta \vec{L} = 0 \qquad \text{(by the above arguments)}$$

$$\Delta \vec{S}_{TARGET} = 0 \qquad \text{(by the requirement of nuclear coherence)}$$

and, therefore,

$$\Delta \vec{S}_{PROJECTILE} = 0.$$

This means that the system M* must have the same spin (and parity) as does the projectile, M.

Similarly, if the nucleus has isotopic spin zero, and remains in its ground state, the I-spin of M* must equal that of M.

We have thus the following list of quantum numbers which must be the same for M* and M:

Q	charge
N	baryon number
S	strangeness
$\vec{S}$	spin
S_z	spin z component
T	I-spin
T_3	I-spin 3-component
P	parity .

The state M* is thus one of known quantum numbers, and its internal structure, i.e. the distribution in internal momenta and angles, might be studied profitably.

I would now like to try to relate this predicted process, which is a small 3-momentum transfer one (as well as small 4-momentum transfer), to more familiar ideas of peripheral collisions. The task is to try to identify the diffraction-production amplitude from the individual nucleons (a forward, non-spin flip, inelastic amplitude) with that of one or more of the various peripheral collision processes previously discussed by other people.

It will readily be seen that any of the diagrams (A), (B), (C) ... (Fig. 1) will fill the bill. (In each case the square box represents a diffraction scatter.) The trouble is that they must be added coherently, and whether any one of them dominates is something we (the authors) do not know how to answer. If it could be shown that (A) dominated, this would be a single pion exchange of the Salzman type, but with the "book-keeping" done differently, i.e. the outgoing π would be lumped with the nucleon that <u>first</u> emitted it, rather than with the one which scattered it. In other words, the connection is not clear at the present time, but there may be one.

This raises the important question: is it necessary to use anything as complicated as a nucleus to produce states with controlled quantum numbers, or will a nucleon target suffice?

First, note that if Eq. (1) is satisfied (for A = 1), and the angle of scattering is small enough, then $\Delta \vec{L} = 0$ as before. But now all we can conclude is that $\vec{\Delta} S_{TARGET} + \vec{\Delta} S_{PROJECTILE} = 0$ (rather than having them separately zero, as desired). In other words, the target spin flip can cause trouble. Similarly, the I-spin of M* can now differ from that of M. (For instance, a π^- (T = 1) incident on a proton (T = $\frac{1}{2}$) can scatter into an isospin system (M*) of T = 2, (plus a proton), in the channel of total I-spin $\frac{3}{2}$.)

If (and only if), as has been suggested several times at this meeting, diffraction elastic scattering amplitudes become independent of spin, and independent of I-spin at high energy, then these undesired things will not happen*). In that case, the system M* would have the same quantum numbers as M for scattering angles small enough so that Eq. (3) is fulfilled, and M* small enough so that Eq. (1) is fulfilled.

Thus, the answer to our question seems to be that maybe a nucleon will do. It would seem worthwhile to examine small momentum transfer inelastic events in hydrogen with this in mind.

The conclusion thus far would seem to be that in nuclei, small momentum transfer inelastic collisions which leave the nucleus in the ground state and in which the other particles are simply dissociation products of the beam particle, should exist (and may not be at all rare). In the case where the target is a nucleon, such processes either will or will not dominate all collisions of sufficiently low momentum transfer, depending on whether or not the diffraction elastic scattering amplitudes are independent of spin and isospin at high energy.

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*) I am indebted to Charles Goebel for clarifying some of these points.

In conclusion, I would like to show some extremely crude and preliminary data on a search for this process. The hoped-for reaction is

$$\pi^- + C^{12} \rightarrow (\pi^- + \pi^- + \pi^+) + C^{12}$$

at $p_\pi \simeq 4.5$ GeV/c. The film was kindly loaned to us by Professor Wilson Powell. Messrs. Neal Cason and Thornton Murphy did most of the data reduction.

Fig. 2 shows the differential cross-section vs. transverse momentum, for all events with a reasonable longitudinal momentum balance and no recoil proton tracks visible. The mean transverse momentum is ~ 3 - 400 MeV/c as in many other reactions. This is consistent with diffraction production from a nucleon.

If coherence from the carbon nucleus is observed, a much narrower peak would be produced. As you can see, there is no evidence yet for such a peak, but both the statistics and the angular resolution are here quite poor.

If we cheerfully assume that the diffraction elastic amplitudes are spin- and I-spin independent, then we do not near the carbon coherence. In that case, we are already looking at a 3π state of the same quantum numbers as the pion, i.e. $T = 1$, $J = 0$, $P = -1$. This is the same 3-pion state reached in τ decay. What we have here, then, (if one believes all this) is a "τ meson with a knob on it"; turning the knob varies the mass. Fig. 3 shows the mass distribution obtained. These masses correspond (Eq. (1)) to longitudinal momentum transfers of one to four hundred MeV/c. Fig. 4 shows the internal structure, in the form of two-pion mass distributions, for $\pi^-\pi^-$ and $\pi^+\pi^-$ separately. There may be some evidence for a difference in shape, there being perhaps more $\pi^-\pi^-$ around 500 MeV.

These data are shown only as an indication of the sort of things one might hope to do, rather than as definite results. We hope to be able to investigate it more thoroughly in the future.

REFERENCE

1) M.L. Good and W.D. Walker, Phys. Rev. 120, 1857 (1960).

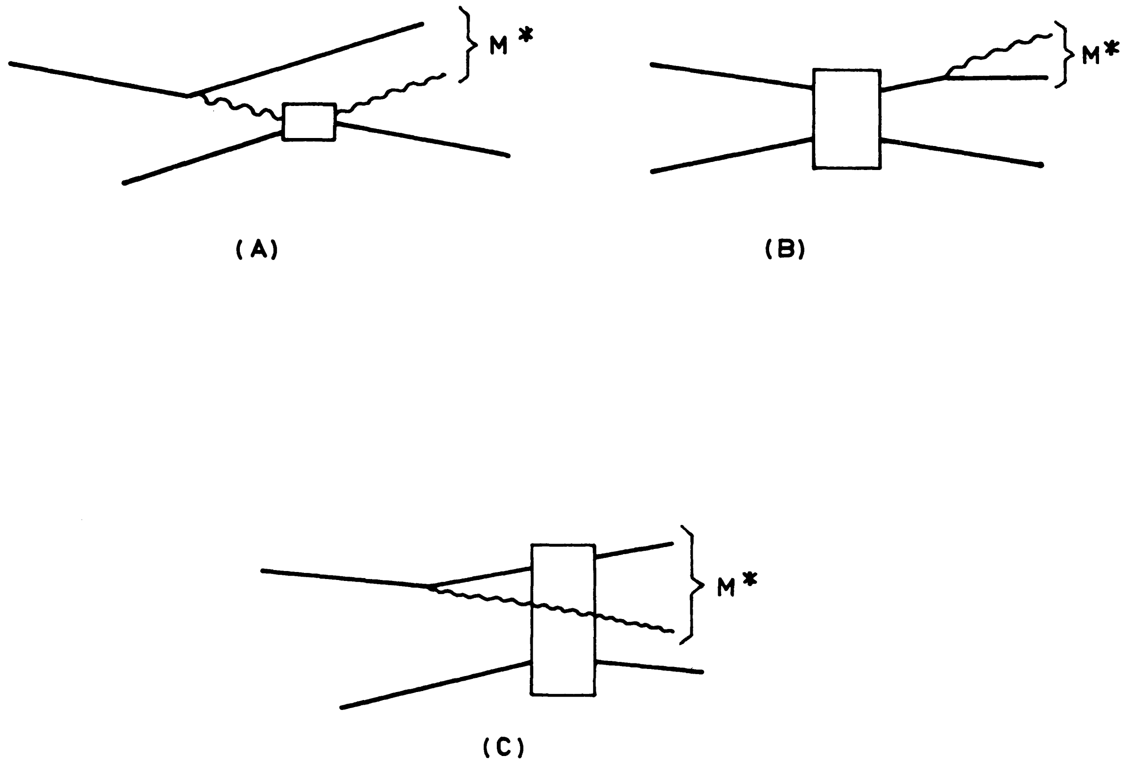

Fig. 1. Possible diagrams leading to diffraction dissociation. The boxes represent diffraction scattering.

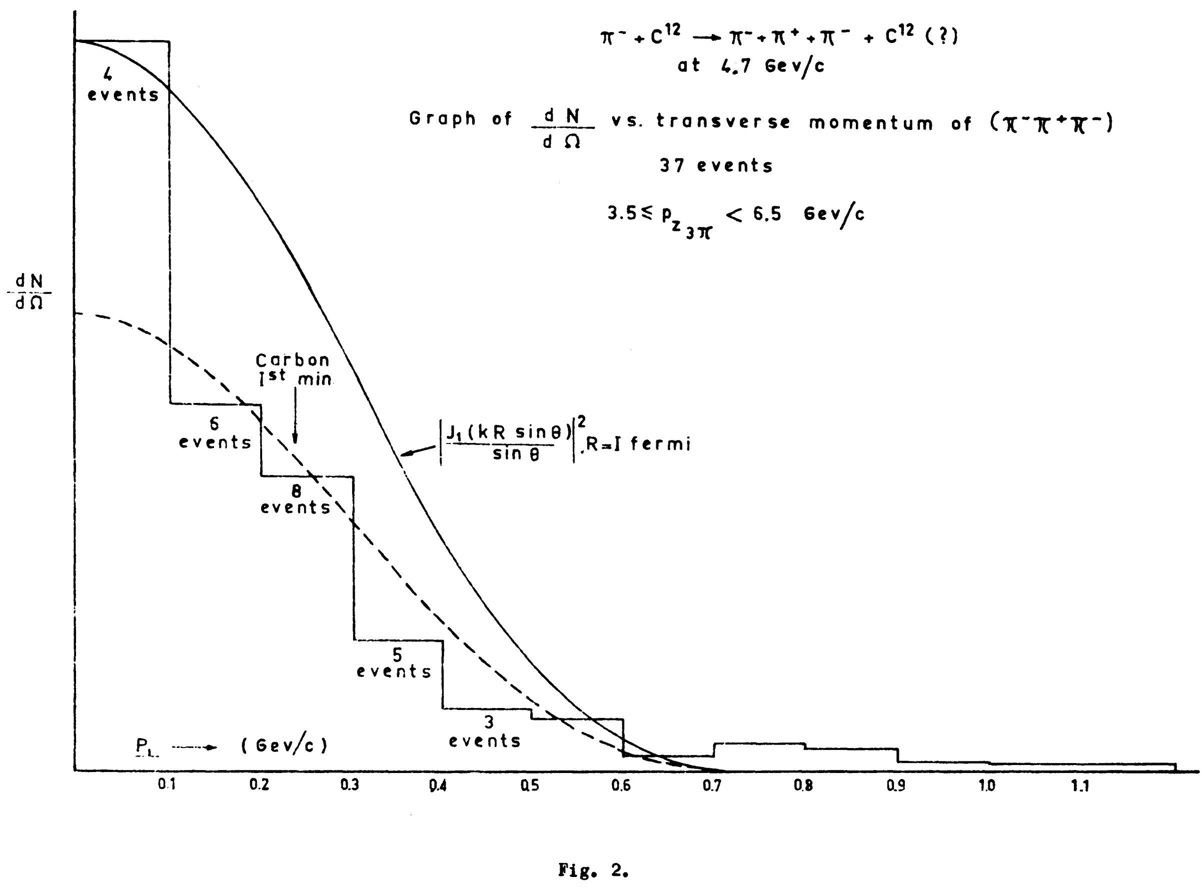

Fig. 2.

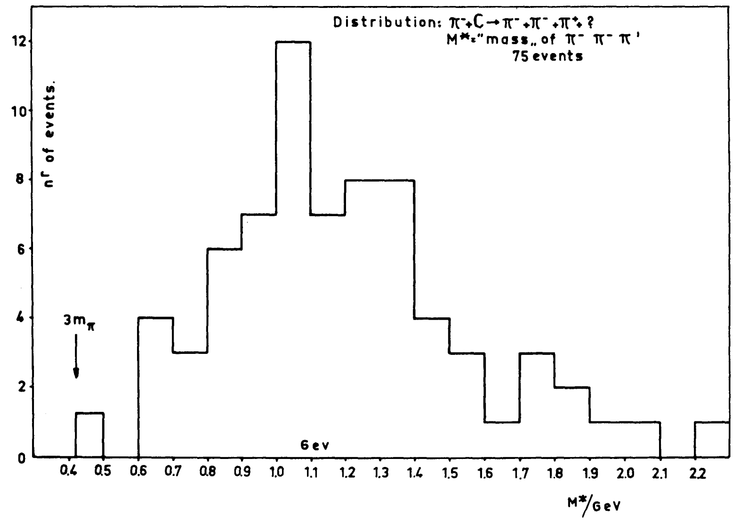
Distribution: π⁻+C→π⁻+π⁻+π⁺+ ?
M*="mass" of π⁻ π⁻ π⁺
75 events
nr of events.
3mπ
Gev
M*/GeV

Fig. 3.

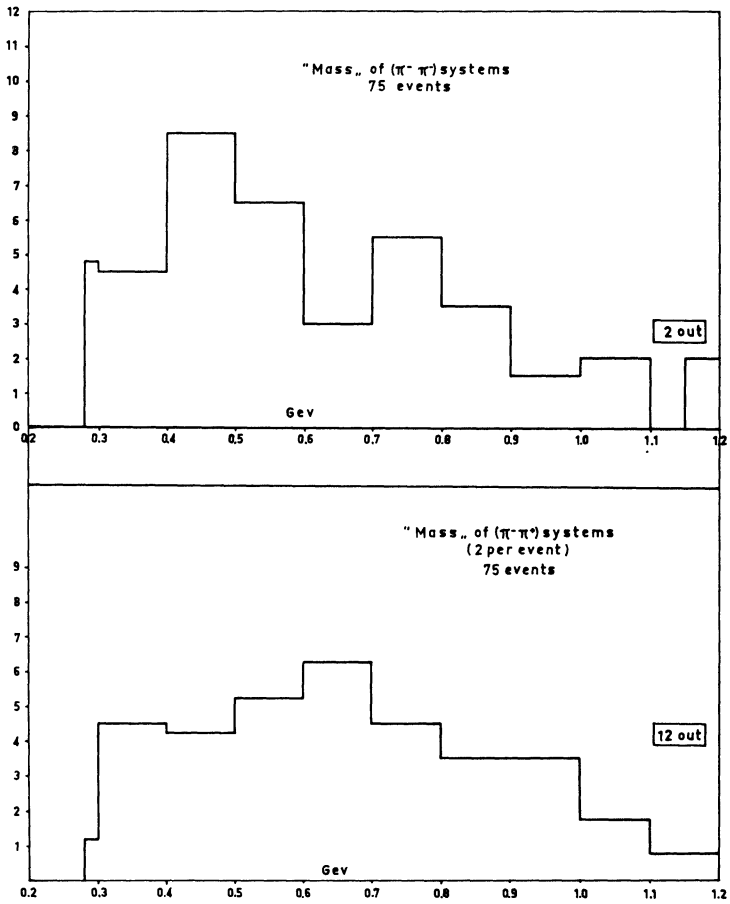
"Mass" of (π⁻ π⁻) systems
75 events
2 out
Gev
"Mass" of (π⁻π⁺) systems
(2 per event)
75 events
12 out
Gev

Fig. 4.