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TREIMAN-YANG CRITERION AND PERIPHERAL NUCLEON-NUCLEON COLLISIONS

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It has been recently proposed by Treiman and Yang¹⁾ that the hypothesis of the dominance of the peripheral (i.e., one-pion exchange) mechanism of interaction is subjected to a very simple experimental test, valid also in the presence of any "structure" of the interaction of the virtual intermediate pion with the initial particles²⁾. If a reaction is described by the diagram of Fig. 1 (where p_1 is the incident particle, p_2 the target particle, Q and Q' the final particles), the intermediate spinless pion carries no angular momentum from one vertex to the other, and all the distributions predicted are unchanged under any rotation of the systems of particles (p_1+Q) and (p_2+Q') around the axis given by the direction of propagation of the virtual pion. In particular, no correlation is predicted between the mutual orientation in space of these two systems, once their internal degrees of freedom have been fixed.

The above idea takes a particularly simple form for a three final particle state. Consider the reaction

$$p_1 + p_2 \rightarrow q_1 + q_2 + q \quad (1)$$

in the laboratory (L) system, defined by $\vec{p}_2^L = 0$. If the reaction is described by the diagram shown in Fig. 2, no correlation must be found in this system in the relative orientation of the planes $\vec{q}_1 \vec{p}_1$ and $\vec{q}_2 \vec{q}$. On the other hand, if the reaction is described by the diagram of Fig. 3, no correlation must be found in the relative orientation of the planes $\vec{p}_2 \vec{q}_2$ and $\vec{q}_1 \vec{q}$ in the system where the incident particle p_1 is at rest. We call this system the antilaboratory ($\bar{L}$) system, defined by $\vec{p}_1^{\bar{L}} = 0$.

This argument applies fairly well to peripheral single pion production in pion-nucleon collisions, where only one peripheral diagram (of the type of Fig. 3, where q_2 is the final nucleon) can be constructed. In fact, applications of the criterion in this case have given the expected azimuthal isotropy in the region where the peripheral model is more reliable (i.e., for low momentum transfers of the nucleon)³⁾.

There have also been recent indications ^{4),5)} that the peripheral model works fairly well for the processes of single pion production in nucleon-nucleon collisions at incident energies of 1 - 3 GeV. It seems that the model can be extended in this case also to the region of high momentum transfers carried by the intermediate pion ⁵⁾. It would seem then desirable to apply the above criterion also to these reactions, in order to have a further check of a hypothesis already explaining other aspects of the phenomenon.

However, the application of the TY criterion to this case must be done with some care. In fact, it is easily seen that the processes under consideration can be described by four different peripheral graphs, obtained the one from the other by suitable exchanges of the initial and/or final nucleons. These diagrams are shown in Fig. 4.

The TY argument states that, e.g., for diagram a) no correlation must be found in the $\bar{L}$ -system between the planes $\vec{p}_2\vec{q}_2$ and $\vec{q}_1\vec{q}_2$; however, such a correlation is introduced by the occurrence of the other diagrams. The aim of this note is to examine this situation more carefully, and to look whether it is possible to isolate the contribution due to a single diagram so as to allow an unambiguous application of the TY criterion.

For the separation of the effects due to diagrams lying on the same row in Fig. 4, the procedure to be used comes out very naturally. In fact, one can easily see [e.g., from the experimental spectra reported in Ref. ⁵⁾ and measured at Cambridge and Yale ⁶⁾, and the analogous ones at 2 GeV measured at Brookhaven ⁷⁾] that at not too low energies ($\gtrsim 2$ GeV) the events are practically all grouped into two classes, the one showing fast q_2 (and slow q_1), the other slow q_2 (and fast q_1) in the lab. system. These classes correspond to the emission of q_2 in the forward or backward direction in the c.m. system, which are both favoured by the peripheral model and for proton-proton collisions are equally likely. The backward events are associated to diagrams a) and c), the forward events to b) and d). It is then sufficient to consider only the events for which the lab. kinetic energy of q_2 is smaller (larger) than a suitable value, for having two of the four possible contributions practically ruled out.

Also in this case, however, the distribution of the events chosen will be reminiscent of the neglected diagrams through the interferences between a) and b), and between c) and d) ⁸⁾. However, such effects are decreasing with increasing incident energy, especially if the off-shell pion effects are taken into account, and can be considered as a small perturbation. We also point out that the contamination of b) on a) [and of d) on c)] can occur only through the angular distribution of q_1 and q in their centre of mass, i.e., through the decay of the "isobar" produced in the lower vertex of b); for isotropic isobar decay, and pure s wave interference term, the whole system a) + b) shows isotropy in the TY angle.

On the contrary, the separation of the effects of diagrams lying on the same column in Fig. 4 is expected to be difficult, since the main contributions of such two diagrams overlap in the same kinematical region. This can be visualized also intuitively, by remarking that, e.g., diagrams a) and c) predict both slow q_2 and fast q_1 , irrespectively of the fact whether the pion comes out from the one or from the other vertex ⁹⁾. It seems then that for the reactions where two diagrams of such a kind have a comparable weight, the TY criterion should not be applicable. A relevant example is given by the reaction

But if it occurs that for some reactions diagrams c) and/or d) are small with respect to a) and/or b), the main effect on any experimental distribution will be provided by the latter diagrams, the other contributions appearing only as a perturbation. Such is the case of the reaction

where the magnitude of c) with respect to a) is of the order of $1/9$, if q_2 represents the final neutron. In this case by selecting the low or high energy events a substantial azimuthal isotropy should be found, with possible deviations of minor importance.

In order to conclude, for nucleon-nucleon collisions the application of the TY criterion for checking the validity of the peripheral model should be sensible at not too low energies (where the separation between "low energy" and "high energy" events is a clear cut one), and should be reliable only for reaction (3).

In order to illustrate the arguments we presented, we have calculated a particular TY type distribution, predicted by the peripheral model for reactions (2) and (3) at 2.85 GeV. We have not chosen the L or $\bar{L}$ angle distributions suggested in Ref. ¹⁾, because they are rather complicated for numerical calculations; but it is easy to find another azimuthal correlation, which is subjected to the TY test and allows a simple evaluation. (We think that also its experimental determination should not give too much trouble.) If we put ourselves in the c.m. system of q_1 and q (Q system), p_1 , p_2 and q_2 are coplanar, and we have only four directions in space, which can be used for defining two planes. Diagram a) predicts an isotropic distribution in the azimuthal angle φ^Q between the planes $\vec{q}_2\vec{p}_2$ and $\vec{q}_1\vec{p}_1$. When the other graphs come into play, a certain asymmetry in φ^Q is produced. In order to check the considerations made in this paper, we limit ourselves to the region where a) is important, i.e., $T^L(q_2) \leq 400$ MeV. We use a cut-off procedure of the same type as the one introduced in Ref. ⁵⁾; without cut-off the anisotropy effects would be more pronounced. As far as the decay of the isobar is concerned, we retain the same approximations made in Refs. ⁴⁾ and ⁵⁾ i.e., pure $p_{3/2} 3/2$, $d_{1/2} 3/2$, $f_{1/2} 5/2$ pion-nucleon interaction in appropriate intervals of energy; these assumptions affect mainly the small deviations from isotropy, and not the most important ones [see note ⁹⁾], and do not influence our conclusions appreciably.

The results of the calculation are shown in Fig. 5. It is seen that the qualitative predictions made in this paper are confirmed. The anisotropy predicted by the peripheral model is of the order of 30 % for reaction (2), and less than 10 % for reaction (3). It can be reasonably supposed that the same features are shown also in the TY angular distributions in the L or $\bar{L}$ system.

Fig. 6 contains the same distribution for reaction (3) including all the events; it has been added to stress the importance of the experimental selection. The main discrepancies from isotropy come from graph b) and then from the decay of the isobar; for isotropic isobar decay they would disappear.

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FIGURE CAPTIONS

Fig. 4 The four peripheral diagrams describing single pion production in nucleon-nucleon collisions. Solid lines represent nucleons, wavy lines represent pions.

Fig. 5 Distributions in the azimuthal angle φ^Q (see text) predicted by the peripheral model at 2.85 GeV :

- a) for reaction (3), and for the events where the lab. kinetic energy of the neutron is ≤ 400 MeV;
- b) for reaction (2), and for the events where the lab. kinetic energy of the proton q_2 is ≤ 400 MeV.

Both distributions are symmetrical around 180° .

Fig. 6 Distribution in the azimuthal angle φ^Q predicted by the peripheral model at 2.85 GeV for reaction (3) and all events. The spectrum is symmetrical around 180° .

REFERENCES AND FOOTNOTES

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- 8) These are the only interference terms which may be important; all others are either vanishing or negligible [cf., Da Prato, Ref. ⁴⁾ 7].
- 9) The contamination of c) on a) is of deeper nature than the contamination of b) on a) discussed previously; in fact, through the kinematics, the azimuthal angle in question is connected not only to the decay angle of the isobar, but also to the isobar mass, and then produces an anisotropy also for isotropic isobar decay.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

a)

b)

FIG. 5

FIG.6