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A Discussion of Some Angular Distributions in the Reactions $\pi+N \to \pi+\pi+N$, $N+N \to 2N+\pi$, $\gamma+N \to \pi+\pi+N$.

G. Morpurgo

Istituto di Fisica dell'Università - Parma
Istituto Nazionale di Fisica Nucleare - Laboratori di Frascati

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Some experiments on the reactions $\pi+N \to \pi+\pi+N$; $N+N \to N+N+\pi$ at high energy have been already done [1]; also experiments on the reaction $\gamma+N \to \pi+\pi+N$ are beginning [2]. Of course we are still very far from statistically significant data but one may expect some increase in the future.

The purpose of the present short discussion is to point out that, in presenting the data from the above mentioned reactions, one should plot also certain angular distributions of the final products (in addition to the ones which are commonly given) which may provide valuable information on some significant aspects of the above reactions.

The aspects which we have in mind are two: *a*) to know whether or not two of the three outgoing particles have a preference for some relative angular momentum state, *b*) to find evidence for parity conservation — or non-conservation — in strong interactions from high energy events.

To illustrate point *a*) we shall consider as an example the reaction [3]:

$$\pi+N \to \pi+\pi+N \,. \tag{1}$$

If, at some energy the relative angular momentum of the two pions shows a preference for some value, this may be an indication for a particularly strong interaction between the two pions when they have that value of the angular momentum. Similarly if the $t=\frac{3}{2}$, $J=\frac{3}{2}$ resonance state of the pion nucleon system has a particularly important

(1) *a*) incident π^-: W. D. Walker, R. Hushfar and W. D. Shephard: *Phys. Rev.*, **104**, 526 (1956); E. Eisberg *et al.*: *Phys. Rev.*, **97**, 797 (1955); W. D. Walker and J. Crussard: *Phys. Rev.*, **98**, 1416 (1955). The Fig. 20 in this paper contains one of the distributions which we shall discuss below. It is the only example we know. *b*) incident p: T. W. Morris *et al.*: *Phys. Rev.*, **103**, 1472 (1956); W. B. Fowler *et al.*: *Phys. Rev.*, **103**, 1479 (1956); W. B. Fowler *et al.*: *Phys. Rev.*, **103**, 1489 (1956); M. M. Block *et al.*: *Phys. Rev.*, **103**, 1484 (1956).

(2) J. Sellen, G. Cocconi, V. T. Cocconi and E. Hart: *Phys. Rev.*, **110**, 779 (1958).

(3) Among the reactions (1) the most convenient is perhaps $\pi^+ + p \to 2\pi + N$.

role (4) in a reaction like (1), in a certain energy interval, one should find the final nucleon and one of the pions (which will be mentioned later) preferentially in a state with total angular momentum $\frac{3}{2}$.

To illustrate point *b*) we notice that, so far, there is no or little evidence for parity conservation in high energy events due to strong interactions. The absence, to a very high degree of accuracy of an electric dipole moment of a nucleon, only depends, as it is well known, on the invariance under T (or CP); and the fact that there is good evidence of parity conservation in strong interactions at low energy (5), does not imply, necessarily, that the same must happen at high energy.

We shall first discuss which angular distributions are important in providing information on point *a*); the same distributions are also of interest for point *b*).

We shall generally call 1, 2, 3, the three outgoing particles from any of the reactions previously mentioned; we are interested in the distribution of angular momentum of the particles 2, 3 in the reference system in which they have opposite momenta; such angular momentum — the relative angular momentum — we call $\boldsymbol{S}$. We may characterize the final state of 1, 2, 3 in the total center of mass system ($\boldsymbol{p}_1+\boldsymbol{p}_2+\boldsymbol{p}_3=0$) giving the momentum $\boldsymbol{p}_1$, the value of S^2 and the component of $\boldsymbol{S}$ along some axis, and the absolute value $|\boldsymbol{p}'|$ of the relative momentum of 2 and 3 in in the reference system in which they have opposite momenta: $\boldsymbol{p}'=\boldsymbol{p}_2'=-\boldsymbol{p}_3'$.

The angular distributions which, we claim, may give information on S are now the following: 1) the distribution in θ, where θ is, for each observed event, the angle between $\boldsymbol{p}_1$ and $\boldsymbol{p}'$; 2) the distribution in φ where φ is the angle between the following two planes: *a*) the plane determined by $\boldsymbol{p}_1$ and the line of flight of the incident particles, *b*) the plane determined by $\boldsymbol{p}_1$ and $\boldsymbol{p}'$. It is apparent that the distributions defined above are the same which have been considered (6) in the reactions of associated production of hyperons and K particles to get information on the spins of the hyperons: we have simply substituted here the K with the particle 1 and the hyperon with the subsystem of the particles 2 and 3. The differences with respect to the case of the associated production are that:

1) the particles 2 and 3 do not generally have, in their rest system, an even approximately unique Q value;

2) the decay of the subsystem 2+3 is almost simultaneous with its production;

3) the subsystem 2+3 is not generally produced with a unique value of the spin S, but will generally bewn superposition of states with different spins, which will generally interfere.

As far as the points 1) and 2) are concerned they should not influence

(4) For a discussion of the isobaric model compare: S. J. LINDENBAUM and R. M. STERNHEIMER: *Phys. Rev.*, **109**, 1722 (1958) for the case of reaction (1) and *Phys. Rev.*, **105**, 1874 (1957) for the case of the reaction N+N → → N+N+π. Our point of view is however somewhat different from that expressed in the above mentioned papers; our question is simply to know whether considering only that subclass of events, which, kinematically could be compatible with the isobaric model, the relative angular momentum of the pion and nucleon from the «decay» of the isobaric state is $\frac{3}{2}$ as it should be; of course it is to be hoped that the subclass of events in question is an appreciable fraction of the total number of the events; it is however difficult to say at present how appreciable it is and the experimental data do not furnish a clear picture.

(5) Compare D. H. WILKINSON: *Phys. Rev.*, **109**, 1603, 1610, 1613 (1958) and the references quoted there.

(6) G. MORPURGO: *Nuovo Cimento*, **4**, 1222 (1956); **5**, 1787 (1957); also the chap. 15 in: C. FRANZINETTI and G. MORPURGO: *Suppl. Nuovo Cimento*, **6**, 469 (1957).

the kind of information on S provided by the angular distributions in θ and φ; as far as the point 3) is concerned the knowledge of the spin distribution of the subsystem $2+3$ is precisely one of the objectives of an investigation like the one proposed here; it must be said however that such an investigation is likely to be fruitful only if one value of S is predominant.

To conclude the distributions in θ and φ defined above will give in principle on S the same kind of information which they are capable of providing on the spin of the hyperon in a reaction of associated production. In particular if we take only those events in which particle 1 goes backward or forward with respect to the direction of the incident beam, we may apply a known argument by ADAIR (7) and get a much more significant information (from the θ distribution).

Consider for instance again the reaction (1); and suppose that we ask to test whether the resonance model is valid, as discussed before, at least for an appreciable subclass of the events (4).

We assume that if an event has taken place through the formation of the resonance state $\pi+N \to N^*+\pi_1$ and its subsequent decay $N^* \to N+\pi_2$ we may discriminate between π_1 and π_2 (respectively, the pion directly emitted and the pion in the resonance state), on the basis of their energy being in a certain range. We therefore select, among all the events, those in which a pion, which has an energy appropriate to π_1, is produced backward or forward with respect to the incident beam. If the particles 2 and 3 have then a relative total angular momentum $\frac{3}{2}$ one should find a distribution in θ of the form $1+3\cos^2\theta$.

Similarly, if we have some reason to believe, or if we like to test whether the two pions, in the reaction (1) have dominantly some value of the relative angular momentum, we take those events from reaction (1), in which the final nucleon (particle 1 in this case) goes forward or backward; the distribution in θ is in this case

$$a\cos^{2l}\theta + b\cos^{2l-2}\theta\,.$$

where l is the dominant value of the relative angular momentum for the two pions and a, b arbitrary coefficients.

It has to be pointed out that the above distributions have a determined or almost determined shape because the incident pion is spinless; for photoproduction events or nucleon nucleon collisions the distributions may contain more free parameters.

We now briefly mention the possible effects of parity non conservation (8) on the θ and φ distributions. Again, a discussion similar to that for the associated production may be repeated here (6); we have that, if parity is not conserved, one may expect in general asymmetries both in the θ and in the φ distribution. We recall that an asymmetry in the φ distribution means that the number of events with $0<\varphi<\pi$ is different from that with $\pi<\varphi<2\pi$; which is the same thing as to say that the numbers of events with a positive or with a negative value of $(\boldsymbol{p}_{\text{inc}}\wedge\boldsymbol{p}_1)\cdot\boldsymbol{p}'$ are different. An asymmetry in the θ distribution means that the number of events with $0<\theta<\pi/2$ is different from that of the events with $\pi/2<\theta<\pi$. It has to be remarked

(7) R. K. ADAIR: *Phys. Rev.*, **100**, 1540 (1955).

(8) We are well aware (G. MORPURGO and B. F. TOUSCHEK: circulated report, June 1957) of the fact that to a γ_5 charge independent strong interaction between pions and nucleons it is not possible to add a parity non conserving term simultaneously maintaining the invariance under time reversal, which of course we want to preserve (electric dipole moments). However a strong parity non conserving process between pions and nucleons might be obtained for instance, without violating time reversal and charge independence, through the intermediary of strong parity non conserving interactions involving hyperons and heavy mesons.

that this last kind of asymmetry is not generally considered in the hyperon case because the assumption is usually made that the strong interactions giving rise to the production of the KY pair conserve the parity; if this is true, it follows that the Y can be polarized only normally to the production plane, which implies no θ asymmetry. It is on the other hand clear that if we look for the possible evidence for non conservation of parity in high energy events we have to look also for θ asymmetries, both in the pion-nucleon reactions considered in this paper, and in the reactions with hyperons and heavy mesons; the fact that, so far, no evidence for θ asymmetries is present in this last kind of reactions [9] (*e.g.* $K^- + p \to \Sigma + \pi$; $\Sigma \to N + \pi$ or $\pi + N \to Y + K$; $Y \to N + \pi$) cannot still be considered a proof that parity is conserved in high energy strong interactions involving hyperons and heavy mesons; it may well be that the longitudinal polarizations of the hyperons emitted begin to be significant only for relativistic velocities of the same, which is not the case for the events studied so far.

To conclude we would like to say that we are perfectly aware, particularly having in mind the sequence of the attempts to determine the spins of the hyperons, of the fact that it will not be easy to collect statistically significant information on the points which we have mentioned; but in any case it will be of some interest to have these distributions slowly inproving; we may repeat in particular, that the method suggested here may prove appropriate to establish the role of the $t = \frac{3}{2}$, $J = \frac{3}{2}$ pion nucleon. resonance in a process like (1).

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I would like to thank prof. G. SALVINI for having stimulated my interest in these questions.

(9) For instance in the bubble chamber experiments of the Berkeley group on the reaction $K^- + p \to \Sigma + \pi$ there is, within the errors, no θ asymmetry (by the way, this asymmetry is the same used in testing the parity doublet model and was therefore looked for).