COHERENT PRODUCTION OF PIONS 17·2 GeV PION-NUCLEUS INTERACTIONS IN EMULSION NUCLEI

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Abstract

The coherent production of pions at 17·2 GeV in pion interactions with nuclei has been studied using Nuclear Emulsion Technique. The kinematical selection of such events was made out of three prong events in which all the prongs were identified as pions. The mean free path of coherent events was 65 meters. It was found that diffraction dissociation takes place with lighter nuclei, whereas the Coulomb dissociation plays a major role in the case of heavier emulsion nuclei.

1. Introduction

The inelastic interaction of high energy pions with nucleus can be broadly divided into two groups. One, in which the pion interacts with individual nucleons in the nucleus, as the wavelength of high energy pions is of the order of the size of the nucleon. This results in pion production, excitation and subsequent evaporation of the nucleus. The other kind of interaction is that in which interaction takes place with the nucleus as a whole. The later process is known as the coherent interaction. It was suggested by Feinberg and Pomeranchuk,[1] and Good and Walker[2, 3] that coherent interaction of pions with nucleus can result in emission of pions. The inelastic coherent interaction with nuclear field is called diffraction dissociation whereas the interaction with Coulomb field is termed as Coulomb dissociation. Detailed theoretical analysis of these interactions have been reported by Drell,[4] Mathews and Salam,[5] Zhizhin *et al.*[6] and Belenkii.[7] It has been suggested that the cross section for production of these events is a function of the charge of the target nucleus. Nuclear emulsion has an advantage of providing targets of high charge and is quite a convenint technique for the study of these coherent events. The production of pions by the diffraction and Coulomb dissociation of pions at energies ranging between 14–18 GeV has been studied in Nulcear Emulsion[8–11] and heavy liquid Bubble Chamber.[12–13]

In this paper we report the analysis of 3 prong events identified as coherent interaction selected from the events of the type

$$\pi^- + \text{Nucleus} \rightarrow \pi^- + \pi^+ + \pi^- + n\pi^\circ + \text{Nucleus}.$$

The results obtained have further been compared with the values reported by various workers using Nuclear Emulsion and Bubble Chamber techniques.

2. Experimental Details

A stack of Ilford G.5 emulsions of thickness 600 μ and of the size 23 cm. $\times$ 15 cm. was exposed to 17·2 GeVπ^- beam at CERN. The average flux was 4×10^4 cm.$^{-2}$. 471 meters of track length was followed and 1166 events were picked up. The total magnification used for line scanning was 1000$\times$ and the scanning rate was 25 cm./hr.

There were 27 events which satisfied the following criteria:

(*a*) no heavy prong ($N_h = n_b + n_g$) associated with the event,

(*b*) the number of charged relativistic secondaries was three,

(*c*) no electron track or recoil associated with the event.

These 27 events have been termed as 'clean' events. There is another sample of 45 events with $N_h \leqslant 3$ and $n_s = 3$. These events do not include the 'clean' events and are called 'dirty' events. These events are essentially not due to coherent production of pions.

The angular and energy measurements have been carried on Koristka R-4 microscope. The tracks having minimum projected length equal to 5 mm. in the scanned plate have been accepted for scattering measurements. The remaining tracks were assigned energies from the consideration of emission angles alone. The number of such tracks was, however, less than 20% of all the charged secondaries.

3. Search for Coherent Events

3.1. *Σ sin a_i distribution.*—Since the nucleus remains in the ground state before and after the interaction, the momentum transfer to it, is small and also the point of momentum transfer is localised outside the nucleus. This condition roughly puts an upper limit to the longitudinal component of the momentum transfer (q_{11}). From uncertainty principle one finds that the value of q_{11} should be less than or equal to $R^{-1} = (m_\pi/A^{\frac{1}{3}})$, where R is the radius of the nucleus and A its mass number. For carbon nucleus q_{11} should be less than or equal to 60 MeV/c and its value is still smaller in case of heavier nuclei (A_gB_r).

It can be shown[14] that this condition can be satisfied only by the events which undergo the following conditions:

$$\sum_{i=1}^{3} \sin \alpha_i \leqslant \frac{1}{m_\pi} q_{11} \max. \tag{1}$$

where α_i is the angle between the direction of the incident pion and the i-th particle in the laboratory system.

The Coulomb dissociation is more prominent when the charge of the target nucleus is very high. So the main contribution to the cross-section for such events is due to the collisions with heavier nuclei (A_gB_r) for which $q_{11} \simeq 30$ MeV/c. Thus, for Coulomb dissociation, we expect

$$\sum_{i=1}^{3} \sin \alpha_i \lesssim 0{\cdot}22. \tag{2}$$

On the other hand the diffraction dissociation is expected to take place with semi-transparent nuclei (CNO). In this case q_{11} max. $=$ 60 MeV/c and hence the geometrical condition for such events is

$$\sum_{i=1}^{3} \sin \alpha_i \leqslant 0{\cdot}43 \tag{3}$$

These conditions are necessary but not sufficient.

Figure 1 shows the $\sum_{i=1}^{3} \sin \alpha_i$ normalised distribution for 'clean' and 'dirty' events. There lies a marked difference in the two distributions. The 'clean' events are concentrated towards the lower values of $\sum_{i=1}^{3} \sin \alpha_i$, whereas the 'dirty' events show an all-round spread. Out of 27 clean events, there are 19 events with $\sum_{i=1}^{3} \sin \alpha_i \leqslant 0{\cdot}45$, whereas out of 45 dirty events, there are 14 events which satisfy this condition.

The value of γ defined as the ratio of the number of events with $\sum_{i=1}^{3} \sin \alpha_i \leqslant 0{\cdot}45$ to the events with $\sum_{i=1}^{3} \sin \alpha_i > 0{\cdot}45$ for clean and dirty events are 2·38 and 0·45 respectively.

3.2.—*Total energy carried by secondary pions.*—As the energy transfer to the target nucleus is very small, the total energy of the secondaries other than the recoiling target is almost equal to the energy of the primary pion. Figure 2 shows $\sum_{i=1}^{3} E_i$ plotted against $\sum_{i=1}^{3} \sin \alpha_i$ for all the 'clean' and 'dirty'

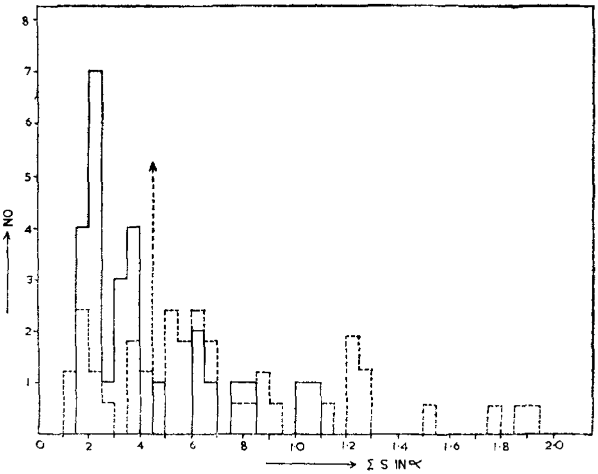

FIG. 1. Normalised $\sum_{i=1}^{3} \sin \alpha_i$ distribution in the case of 'clean' (————) and dirty (- - - - -) events.

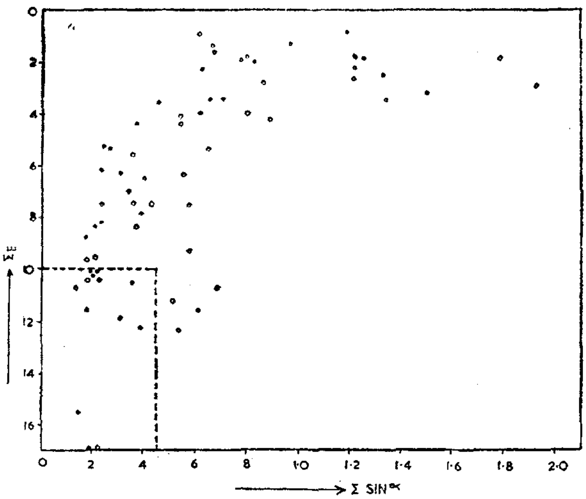

FIG. 2. $\sum_{i=1}^{3} E_i$ plotted against $\sum_{i=1}^{3} \sin \alpha_i$ for both 'clean' and 'dirty' events. The points marked (⊙) and (○) belong to 'clean' and 'dirty' events respectively.

events. There are 9 'clean' and 4 'dirty' events which satisfied both the conditions simultaneously, *i.e.*, (1) $\sum_{i=1}^{3} E_i \geqslant 10$ GeV and (ii) $\sum_{i=1}^{3} \sin \alpha_i \leqslant 0{\cdot}45$. Some authors[10, 13] have used the energy limit $\sum_{i=1}^{3} E_i \geqslant 0{\cdot}75\, E_0$, where E_0 is the energy of the incident pion. We have put the energy limit of 10 GeV due to errors involved in the energy measurements. The events with energy balance in case of clean sample is 33% and is in good agreement with the value 36% obtained in bubble chambers.[13]

3.3. *The distribution in transverse momentum transfer.*—Figure 3 shows the $q_\perp$ distribution for all the 9 observed 'clean' events. The total histogram is due to combined data of Caforio *et al.*[9] and that of the present work. The smooth curve is due to Belenkii[7] and is given by

$$f(q_\perp)\, dq_\perp = q_\perp \exp. \left(-\frac{q_\perp R}{2}\right)^2 dq_\perp. \tag{4}$$

Here the relative contribution of all the emulsion nuclei in proportion to their geometrical cross-sections have been considered.

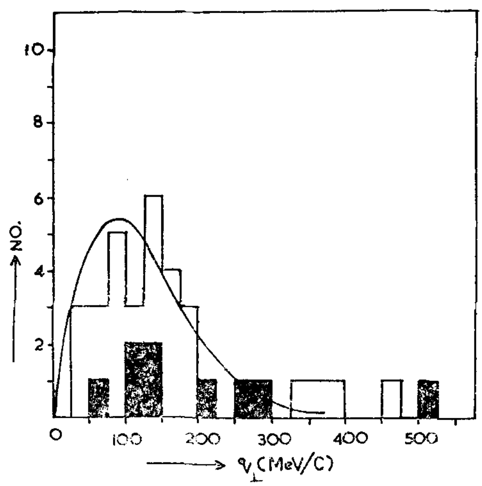

FIG. 3. Distribution of $q_\perp$ for the all probable coherent events (shaded portion). The total histogram is due to the combined results of Caforio *et al.* and due to present investigation. Smooth curve is due to Eq. (4).

For carbon nuclei the most probable value of $q_\perp$ is 85 MeV/c and 95% of all the events should have $q_\perp$ less than 210 MeV/c. One may stretch the upper limit to 300 MeV/c in order to take into account the errors in the momentum measurements, There is one event out of 9 'clean' events with energy balance which has $q_\perp > 300$ MeV/c. Out of 4 'dirty' events, there are two events which have $q_\perp > 300$ MeV/c. After excluding these events one is left with 8 'clean' and 2 'dirty' events which satisfy the above-mentioned condition for the production of coherent events.

3·4. *Invariant mass distribution.*—Figure 4 shows the invariant mass distribution M* for all the eight most probable coherent events along with the combined results of Caforio *et al.*[9] and the present investigation. All the values of M* lies between 0·5 and 1·5 GeV.

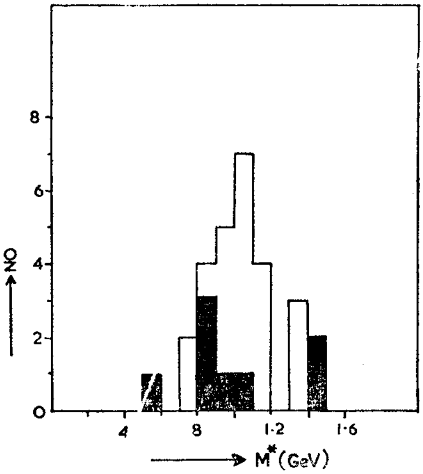

FIG. 4. Invariant mass distribution for the eight coherent events observed in the present investigation (shaded portion) along with the combined histogram due to Caforio *et al.* and present investigation.

The maximum value of M* produced by diffraction or Coulomb dissociation by a nucleus of mass number A and an incident momentum p_0 is given by

$$M^*_{\max.} = m_\pi \left[\frac{2p_0}{m_\pi A^{\frac{1}{3}}} + 1 \right] \simeq 1 \cdot 5 \text{ GeV}. \tag{5}$$

The lower limit of the invariant mass may be simply the rest mass of the three pions (420 MeV) or it may be the rest mass of ρ meson and a pion combined (900 MeV).

3.5. *The distribution in longitudinal momentum transfer.*—Purely from the consideration of conservation laws of energy and momentum, the value of q_{11} is given by[9]

$$q_{11} = \left(\frac{M_A + p_0}{2M_A p_0} \right) q_\perp^2 + \frac{M^{*2} - m_\pi^2}{2p_0} + T_{exc}, \tag{6}$$

where T_{exc} is the excitation energy of the target nucleus and is quite small. M^* is the invariant mass of the emitted pions.

Figure 5 shows the q_{11} differential distribution of all the eight most probable coherent events. Combined distribution of these events along with the results of Caforio *et al.* has also been plotted. There lies a general agreement with both the results and all the values of q_{11} are confined between 10 and 80 MeV/c.

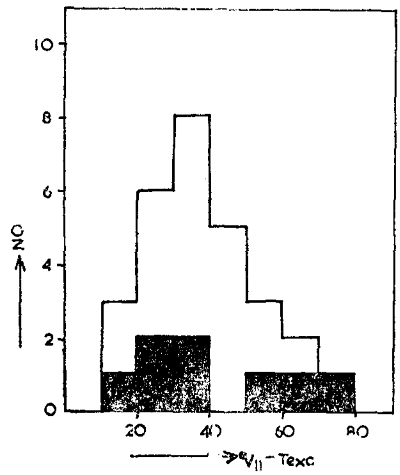

FIG. 5. q_{11}-T_{exc} distribution of eight most probable coherent events in the present investigation (shaded part) along with the combined distribution due to Caforio *et al.* and present investigation.

4. Discussion of Results

Out of 471 meters of track length followed, there are eight 'clean' events and two 'dirty' events, which satisfy all the accepted conditions for coherent production. Since out of 45 'dirty' events, there are two events which satisfy all the conditions for coherent events, one may expect that out of these eight events, there is a small contribution (1·20) of incoherent events. For the maximum 6% contamination due to electrons and muons in the incident beam, we have the total mean free path equal to 65 meters. This value of mean free path is comparable with $\left(51 \begin{smallmatrix} +18 \\ -11 \end{smallmatrix}\right)$ meters reported by Caforio *et al.*[9] at almost the same incident energy.

If it were assumed that all these coherent events are due to Coulomb and diffraction dissociation on CNO nuclei only, the cross-section for such process is $(6 \cdot 1 \pm 2 \cdot 3)$ mb. Further if it were assumed that all the emulsions nuclei contributed equally, the cross-section is $(3\cdot4 \pm 1\cdot3)$ mb. and finally if it were assumed that the cross-section is proportional to $A^{2/3}$, its value would be $(1\cdot4 \pm 0\cdot5)$ mb. The cross-section obtained in the case of coherent events produced on carbon nuclei with bubble chamber[13] is $\left(1\cdot7 {}^{+\ \cdot6}_{-\ 1\cdot3}\right)$ mb. and in nuclear emulsions obtained by Caforio *et al.*[9] is $(1\cdot7 \pm 0\cdot5)$ mb. on the assumption that cross-section is proportional to $A^{2/3}$. Therefore, it follows that a majority of these events is due to A_gB_r nuclei. It has been discussed in Sec. 3.1, that all the events having $\Sigma \sin \alpha_i \leqslant 0\cdot22$ are mainly attributed to Coulomb dissociation. There are six such events. The remaining two events may be due to diffraction dissociation. The cross-section based upon these events for the diffraction dissociation on CNO nuclei is $1\cdot8$ mb. and is in good agreement with the value $1\cdot7$ mb. reported by C. Bellini on carbon nuclei. So one may conclude that the diffraction dissociation takes place on lighter semi-transparent nuclei, whereas the Coulomb dissociation plays a major role in the case of heavier A_gB_r nuclei.

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