

INELASTIC INTERACTIONS BETWEEN 6.8 Bev/c π^- MESONS AND NUCLEONS*

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An analysis was made of 355 interactions between π^- mesons and nucleons. The momentum and angular distributions of the secondary charged particles were measured. Information on π^0 mesons produced in the interactions has been obtained. The experimental data are compared with the statistical theory. The results suggest that peripheral interactions may exist. In events of low multiplicity (two-prong cases) "one-meson" peripheral interactions play an important role, while in events of large multiplicity an important role is played by interactions not of the one-meson type, among which also central collisions are possible.

I. EXPERIMENTAL RESULTS

IN this experiment we used photographs obtained with a 24-liter propane bubble chamber^[2] placed in a magnetic field of 13 700 oe. The arrangement in which the chamber was located in a beam of (6.8 ± 0.6) Bev/c negative pions from the proton synchrotron of the Joint Institute for Nuclear Research has been described previously.^[3] We scanned 870 pictures, on which we found 777 interactions of π^- mesons with hydrogen and carbon nuclei. The pictures were scanned twice. The overall efficiency of the scanning was close to unity.

1. To measure the momenta and angles we selected visually 456 interactions. The remaining 321 events were rejected on the basis of the following criteria: a) the sum of the charges of the secondary particles was not equal to 0 or -1; b) the presence of a short track of length $\lesssim 2$ mm; c) the number of slow-particle tracks stopping in the chamber was ≥ 2 .

Moreover, we discarded 28 elastic π^-p scatterings which were used in^[3].

On stereoscopic pairs of pictures of the selected events we measured under a microscope the coordinates of 8-20 points of each track. From the coordinates we calculated the momenta of the particles, the error of the momentum measurement,

*The value of M is equal to the nucleon mass for interactions with a free nucleon. For interactions with quasi-free nucleons, the value of M depends on the state of motion of the target nucleon and lies within the limits 0.76-1.16 Bev. The events were considered to be πN interactions if $\Sigma \Delta_i < 1.16$ Bev.

and also the direction cosines of the track at the point of interaction. The calculations were made on an electronic computer. For tracks of primary pions producing the interactions we obtain a mean momentum $\bar{p}_{\pi^-} = 6.9 \pm 0.4$ Bev/c, which agrees, within the limits of error, with the mean momentum calculated from the data of^[3] $(6.7 \pm 0.2$ Bev/c).

2. All secondary negative particles were assumed to be π^- mesons. For positive particle tracks we measured the ionization by a gap-counting method similar to that used in^[4]. For each interaction we measured the ionization of the primary pion, and the ionization of all secondary particles was referred to this value. We separated the protons and π^+ mesons for the momenta up to 1.2 Bev/c. In addition, part of the particles were also identified by their range. In all, it proved to be possible to identify 99% of the positive particle tracks of momentum ≤ 1.2 Bev/c.

3. As a result of the momentum and ionization measurements, we discarded 37 cases not satisfying the foregoing criteria and also cases of "scattering" by angles $< 5^\circ$.

As was shown earlier in^[5], for each πN interaction the relation

$$\sum \Delta_i \equiv \sum (E_i - p_i \cos \theta_i) \leq M$$

should be satisfied, where M is the nucleon mass.* The summation is carried out over all secondary particles of total energy E_i , momentum p_i , and angle θ_i relative to the direction of motion of the

*Similar interactions with neutrons are included in the group of "scatterings" by an angle $< 5^\circ$, and therefore were also excluded from the final statistics.

Table I

Reference	Primary π^- energy, Bev	$\sigma_{\text{tot}}(\pi^-p)$, mb
[1]	9.2	25 ± 4
Present expt.	6.8	~ 31
[7]	5.2	29.1 ± 2.9
[8]	4.7	28
[9]	4.4	30 ± 5
[10]	4.3	30 ± 5

primary particle. The inequality sign refers to cases in which not all neutral secondary particles are known. We discarded another 24 cases as a result of the application of this relation.

Moreover we discarded 12 two-prong events whose kinematics corresponded to cases of elastic interactions of a π^- meson with a quasi-free proton.*

4. We ultimately selected 262 cases of inelastic interactions of a π^- meson with a proton and 93 cases of interaction with a neutron. We estimated the inelastic π^-p interaction cross section and obtained the value $\sigma_{\text{in}}(\pi^-p) = 25 \pm 3$ mb. In the calculation of the cross section we assumed that the interactions with quasi-free protons and quasi-free neutrons are of the same frequency. The corresponding value for inelastic interactions of a π^- meson with a carbon nucleus turned out to be $\sigma_{\text{in}}(\pi^-C) = 194 \pm 13$ mb. The elastic π^-p cross section obtained in [3] was 5.5 mb. Hence the total π^-p interaction cross section was $\sigma_{\text{tot}}(\pi^-p) = 31$ mb. Tables I and II give a summary of the data on the cross sections $\sigma_{\text{tot}}(\pi^-p)$ and $\sigma_{\text{in}}(\pi^-C)$ obtained in our and other experiments.

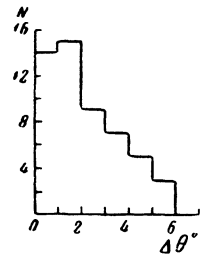
Table II

Reference	Primary π^- energy, Bev	$\sigma_{\text{in}}(\pi^-C)$, mb
[11]	1.5	219 ± 11
[12]	4.2	218 ± 7
[13]	2-4	210^{+59}_{-68}
	4-66	208^{+97}_{-120}
Present expt.	6.8	$194 \pm 13^*$

*Only the statistical error is shown. No special estimate of possible systematic errors was made.

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FIG. 1. Distribution of angles between electron and positron tracks.



Tables III and IV show the distributions of the observed cases for different values of the multiplicity n of charged particles and the values of the mean multiplicity \bar{n} of charged particles. Also shown are the emulsion data [14] and the results of calculations made with the statistical theory in which the isobaric states [15,16] were taken into account.

As seen from these tables, the charged-particle multiplicity distribution is in agreement with the results obtained by the emulsion technique. The calculations with the statistical theory give values close to the experimental.

5. During the scanning, we recorded all electron-positron pairs which appeared to be emitted from the point of interaction.* After the measurements, we separated 74 γ quanta (for a total number of 355 π^-N interactions) which gave pairs satisfying the condition

$$|\theta_\gamma - \theta_i| \leq 2\Delta\theta \quad (i = 1, 2).$$

Here θ_γ , θ_1 , θ_2 are the angles between the direction of flight of the γ quantum, electron, positron, respectively, and the direction of the primary track; $\Delta\theta$ is the angle between the electron and positron tracks. The quantity $\Delta\theta$ characterizes the accuracy in the measurement of the angles for a given event; the distribution of these values is shown in Fig. 1.

Fulfillment of this condition did not exclude the possibility of recording γ quanta from background interactions. However, it was estimated that the number of such γ quanta cannot exceed 2%.

We determined for each γ quantum the "potential" range in the effective region of the chamber and calculated the "statistical" weight

$$W_i = (1 - \exp[-l_i \mu(E_\gamma)])^{-1}.$$

Here l_i is the "potential" range of the γ quantum in radiation lengths (100 cm for propane of density 0.43 g/cm³), W_i is the total probability for the production of pairs per radiation length. The sum of all values of W_i is equal to the total num-

*A special check showed that the efficiency of detection of pairs was close to 100%.

Table III.

Multiplicity, n	Present experiment		[14]		Statistical theory
	Number of interactions	%	Number of interactions	%	%
0	7	2.7±1.0	13	4.4±1.2	3.7
2	119	45.4±4.2	142	48.5±4.1	45.1
4	115	43.9±4.3	122	41.6±3.8	46.5
6	20	7.7±1.7	14	4.8±1.3	4.7
8	1	0.4±0.4	2	0.7±0.5	0.05
0-8	262		293		
\bar{n}	3.15±0.09		2.98±0.08		3.05

Table IV.

Multiplicity, n	Present experiment		[14]		Statistical theory
	Number of interactions	%	Number of interactions	%	%
1	16	17.2±4.6	56	23.1±3.1	18.5
3	53	57±9.8	143	59.1±4.9	59.5
5	21	22.6±5.4	36	14.9±2.5	20
7	3	3.2±1.9	7	2.9±1.1	2.0
1-7	93		242		
\bar{n}	3.24±0.15		2.95±0.09		3.0

ber of γ quanta emitted in the observed interactions. It turned out that $\sum_{i=1}^{74} W_i = 743 \pm 90$ γ quanta, i.e., the mean efficiency of recording γ quanta under our conditions was $(10 \pm 1)\%$.

6. The most complete information is obtained for the properties of the secondary π^- mesons. Figure 2 shows the c.m.s. angular distribution of π^- mesons from all π^-p and π^-n interactions. It proved to be asymmetric with respect to the angle $\theta^* = \frac{1}{2}\pi$. The forward-peaked anisotropic part of the angular distribution is associated primarily with fast π^- mesons ($P_{lab} \geq 2$ Bev/c. Angular distributions of such a nature are in sharp contradiction with the statistical theory. It is natural to associate the "anisotropic" π^- mesons with peripheral interactions (see, for example, [14, 15]). The percentage of

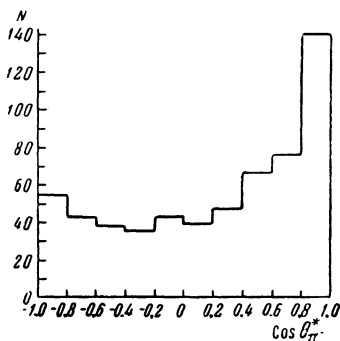


FIG. 2. C.m.s. angular distribution of π^- mesons from all π^-p and π^-n interactions.

such π^- mesons decreases with the multiplicity (see Fig. 3).

Figure 4 shows the c.m.s. momentum distribution of π^- mesons for different multiplicities and

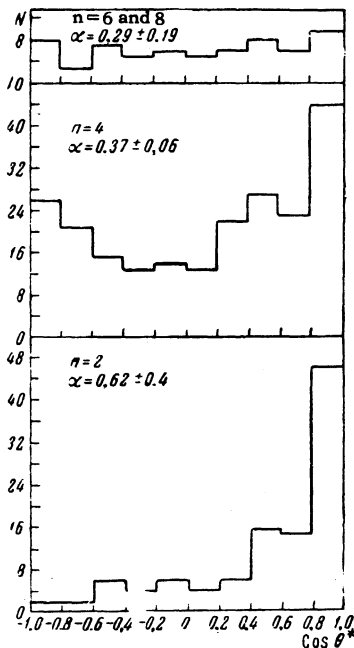


FIG. 3. C.m.s. π^- -meson angular distribution for interactions of even multiplicity; $\alpha = (N_2 - N_1)/n_{int}$, where N_2 and N_1 are the number of π^- mesons emitted forward and backward, n_{int} is the number of interactions.

Table V. Mean Value of p_{\perp} (Bev/c)

Particles	$n=2$	$n=4$	$n=6, 8$	$n=2, 4, 6, 8$
π^- mesons	0.38 ± 0.03	0.38 ± 0.02	0.28 ± 0.03	0.36 ± 0.01
All positive particles	0.42 ± 0.03	0.36 ± 0.02	0.28 ± 0.03	0.36 ± 0.01
Identified π^+ mesons	0.35 ± 0.04	0.26 ± 0.01	0.19 ± 0.02	0.26 ± 0.04
Identified protons	0.26 ± 0.03	0.37 ± 0.04	0.28 ± 0.07	0.31 ± 0.04
π^0 mesons	—	—	—	0.34 ± 0.07

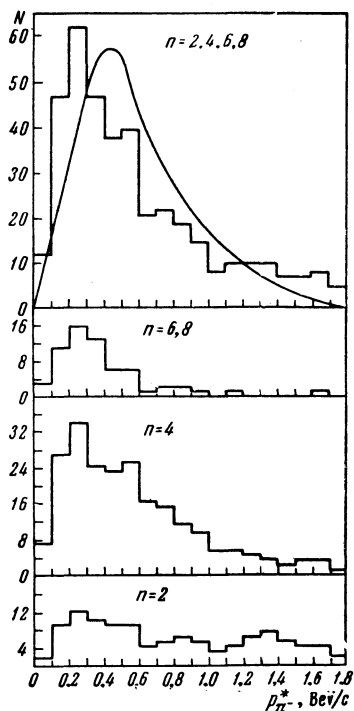


FIG. 4. C.m.s. π^- -meson momentum distribution for π^-p interactions of even multiplicity. The smooth curve was calculated from statistical theory.^[15]

the overall distribution together with the theoretical curve calculated from statistical theory.^[15] As we see, the calculations based on statistical theory

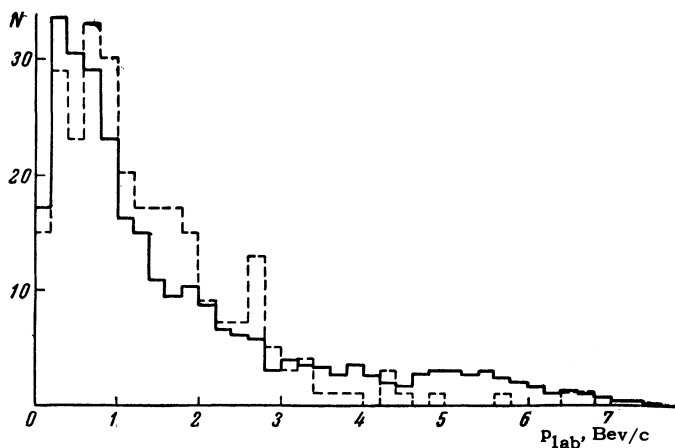


FIG. 5. L.s. π^- -meson momentum distribution for π^-p interactions. The dotted-line histogram represents the statistical theory distribution obtained with the aid of tables of random stars.^[15]

are not in qualitative contradiction with the experimental histogram.

Shown in Fig. 5 are the l.s. momentum distributions of the π^- mesons. The theoretical distributions were obtained from tables of random stars.^[15]

The c.m.s. γ -quantum angular distribution (from π^-p and π^-n interactions), which reflects the angular distribution of π^0 mesons is asymmetric (Fig. 6), i.e., it is apparently similar to the angular distribution of the charged π^- mesons. The mean number of π^0 mesons in π^-p interactions is 1.3 ± 0.2 and agrees with the calculations based on statistical theory.^[16]

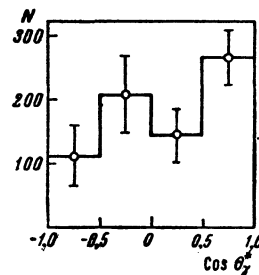


FIG. 6. C.m.s. angular distribution of γ quanta from all π^-n and π^-p interactions.

The observed l.s. γ quantum energy distribution is shown in Fig. 7. The mean π^0 energy for one π^-p interaction is 1.12 ± 0.15 Bev. This is less than the mean energy of the π^- mesons $E_{\pi^-} = 2.7 \pm 0.15$ Bev.

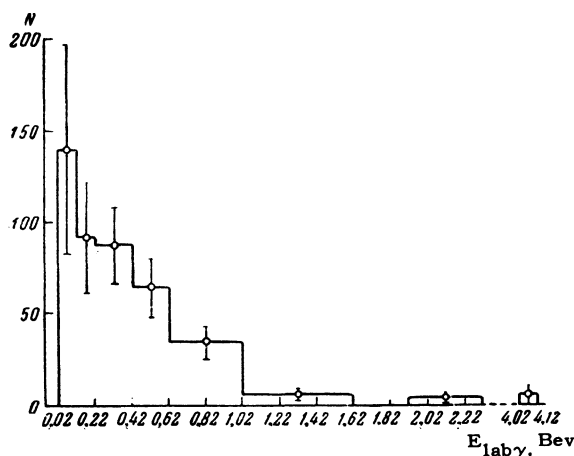


FIG. 7. L.s. energy distribution of γ quanta from all π^-n and π^-p interactions. The ordinate axis gives the number of γ quanta for intervals of $E_{lab, \gamma} = 0.10$ Bev.

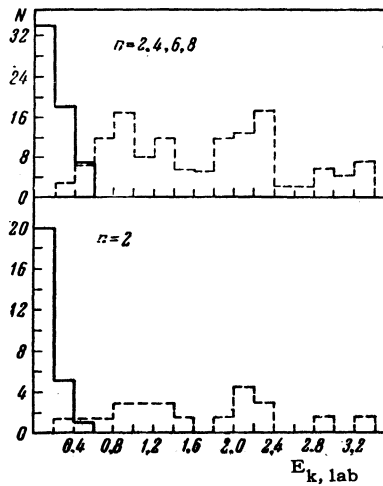


FIG. 8. L.s. energy distribution of protons in π^-p interactions; the histograms expected from statistical theory (table of random stars^[18]) are shown dotted.

7. Table V lists the mean values of the transverse momenta calculated for particles produced in π^-p interactions of different multiplicity. The observed mean transverse momenta are close to the mean transverse momenta of Λ^0 and K^0 particles produced in π^-p interactions for the same primary π^- -meson energy.^[17] The value of the transverse momenta for π^- mesons, within the limits of error, depends weakly on the multiplicity, which, perhaps, reflects the approximate equality of the interaction range

$$(\Delta r^2)^{1/2} \geq \hbar/2 (\bar{p}_\perp^2)^{1/2} = 3.2 \cdot 10^{-14} \text{ cm.}$$

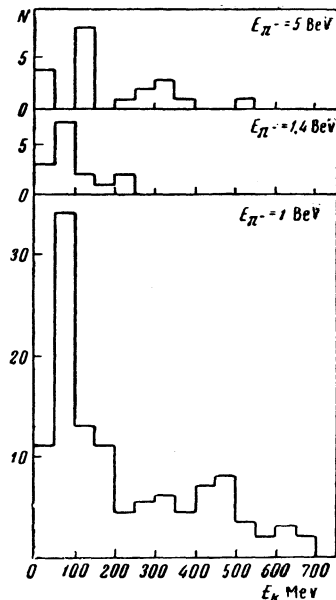


FIG. 9. L.s. proton energy distribution for π^-p interactions produced by π^- mesons of energy 1, 1.4, and 5.0 BeV. The distributions were constructed from the data of^[22-24].

Table VI.

n	Number of cases	$\bar{p}_{1ab'}$ BeV/c	$\bar{\theta}_{1ab'}$ deg
2	26	0.41 ± 0.05	53 ± 5
4	26	0.62 ± 0.05	42 ± 4
6; 8	7	0.88 ± 0.08	19 ± 4
2-8	59	0.56 ± 0.04	44 ± 3

8. Figure 8 shows the experimental l.s. energy distribution of the identified protons and the distribution of protons of any momentum expected from statistical theory for the observed interactions (obtained with the aid of tables of random stars^[18]). As seen from the figure, a maximum in the proton distribution occurs for energies of 100-200 Mev, while in the case of statistical theory hardly any such protons should occur.

The presence of a maximum indicates that there is a definite group of interactions in which there is a small energy transfer to the target nucleon. One may suspect that these cases are connected mainly with peripheral interactions of the incident π^- mesons. Theoretical investigations of peripheral interactions^[19-21] also predict the existence of such a maximum in the region of low proton kinetic energies. Similar results were also obtained in^[22-24] for primary π^- -meson energies of 1, 1.4, and 5 BeV (see Fig. 9). The fraction of cases with a very slow proton ($E_k < 200$ Mev) at each of these energies (1, 1.4, 5.0, 6.8 BeV) is approximately constant and equal to $\sim 10\%$ of the total

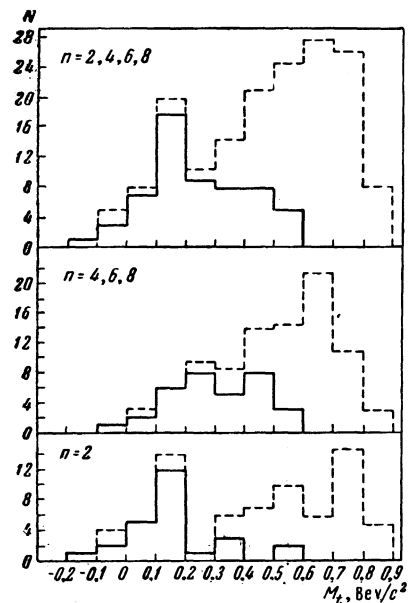


FIG. 10. Distribution of the "target mass" M_t for π^-p interactions in which an identified proton is among the secondary particles. The dotted-line histograms represent events with an unknown positive particle, which is assumed to be a proton.

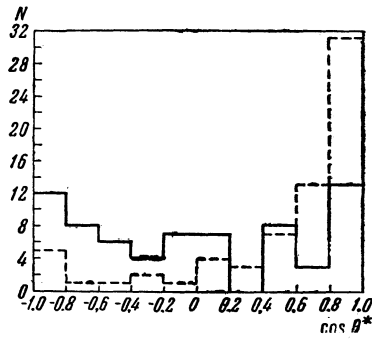


FIG. 11. Angular distribution of charged pions in the system of two pions for π^-p interactions with a "target mass" $M_t < 0.3 \text{ BeV}/c^2$ calculated from the identified proton. The dotted-line histogram represents the distribution of these pions in the c.m.s. (pion-nucleon system).

π^- -nucleon cross section. This is also in qualitative agreement with the picture of peripheral interactions.

In the present experiment a maximum occurs in the proton energy distribution from two-prong interactions and is not evident in interactions of large multiplicity. This can be connected with a decrease in the fraction of peripheral interactions as the multiplicity increases. Shown in Table VI are the values of the mean momentum and mean angle of emission of the protons in the l.s. for cases of different multiplicity. It is seen that both the energy characteristics and the mean angle of emission of the proton change with the multiplicity.

II. ANALYSIS OF EXPERIMENTAL DATA

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THE data obtained on π^- -meson interactions with nucleons at 6.8 BeV and the data at lower energies lead to the conclusion that the statistical theory cannot explain a number of important characteristics of the angular and momentum distributions of the secondary particles. In this connection, one can conclude that an appreciable role is played by the so-called peripheral interactions.

We shall consider this question from a somewhat different viewpoint. We introduce the quantity^[25]

$$M_t = M - (E_p - p_p \cos \theta_p),$$

where M is the nucleon mass, E_p and p_p are total energy and momentum of the secondary proton in the l.s., θ_p is its angle of emission. It is known that, qualitatively, M_t can be regarded as

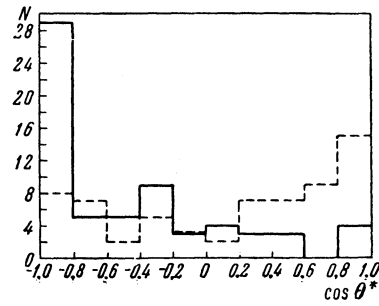


FIG. 12. Angular distribution of charged pions in the system of two-pions from π^-p interactions in which the "target mass" M_t calculated from the identified proton was greater than $0.3 \text{ BeV}/c^2$. The dotted-line histogram represents the angular distribution of these pions in the pion-nucleon c.m.s.

the "effective mass" of that part of the target nucleon with which the primary meson collides. Figure 10 shows the experimental distribution of M_t for π^-p interactions of different multiplicity and calculated for the group of interactions in which there is either a secondary proton or an unidentified positive particle of momentum $> 1.2 \text{ BeV}/c$, which we shall assume to be a proton.

As seen from Fig. 10, there is a maximum at the mass M_t close to the pion mass in the case of two-prong interactions. One may therefore assume that among the two-prong events is a sizable group of so-called one-meson interactions corresponding to the collision of a primary π^- meson with a single virtual pion emitted by the target nucleon. Interactions of this type associated with small values of M_t possibly occur also in events of large multiplicity.

Figure 11 shows the angular distributions of charged pions from interactions in which the mass M_t calculated from the identified proton was less than $0.3 \text{ BeV}/c^2$. The distributions are shown in the c.m.s. of two pions ($\pi\pi$ system) and in the pion-nucleon c.m.s. The first angular distribution is symmetric with respect to the angle 90° and the second is asymmetric. This result appears to agree with the suggestion that the primary π^-

Table VII.

	Events with $M_t < 0.3 \text{ BeV}/c^2$	Events with $M_t > 0.3 \text{ BeV}/c^2$	Total
Number of cases	38	21	59
Number of cases with $p_{\text{lab}} \geq 0.3 \text{ BeV}/c$	19	5	24
Mean momentum of π^- mesons in l.s., BeV/c	2.6 ± 0.3	1.3 ± 0.2	2.0 ± 2.0

meson interacts with a virtual pion of the nucleon. In this connection, it is interesting to note that, in cases with $M_t > 0.3$ Bev/c², the angular distribution of the secondary pions in the $\pi\pi$ system is strongly asymmetric, with a predominance of angles greater than 90° (see Fig. 12).

There is also a clear correlation between the value of M_t and the number of high-momentum secondary pions (see Table VII). It is possible that the π^- mesons are associated with elastic scattering of a primary π^- meson on a virtual pion.

It is interesting to note that the ratio of the number of π^- mesons to the number of positive particles changes rapidly with the momentum. Thus, for example, among positive particles with $p_{lab} \geq 2.0$ Bev/c the ratio of the number of positive particles to the number of negative particles is $n_+/n_- = 0.6 \pm 0.1$, while for $p_{lab} \geq 4.5$ Bev/c we have $n_+/n_- = 0.2 \pm 0.1$. The number of π^+ mesons apparently decreases still more rapidly. Comparison of the energy characteristics of the π^- , π^+ , and π^0 mesons leads to the same qualitative result. In particular, the mean energy of the π^- mesons in π^-p interactions is $\bar{E}_{lab} \pi^- = 1.69 \pm 0.08$ Bev, while for π^0 mesons this value is $\bar{E}_{lab} \pi^0 = 0.90 \pm 0.12$ Bev. For π^-p interactions in which slow protons are produced, the mean π^- momentum is $\bar{p}_{lab} = 2.04 \pm 0.19$ Bev/c, while for π^+ mesons $\bar{p}_{lab} = 1.2 \pm 0.16$ Bev/c. Thus the secondary π^- mesons stand out with respect to the π^+ and π^0 mesons. This circumstance cannot be explained from the viewpoint of statistical theory and is in good agreement with the views on the important role of peripheral interactions. In pp interactions no such difference among π^- , π^0 , and π^+ mesons is observed.*

In this connection, one might suppose that the greater part of the high-momentum π^- mesons (say, for $p_{lab} > 4.0$ Bev/c) is produced as a result of $\pi\pi$ diffraction scattering. Such a conclusion appears to correspond fully with the general views on the mechanism of elementary particle interactions at high energies (see^[26-28]). If this is so, then the cross sections for elastic and inelastic $\pi\pi$ interactions should not depend on the charge state of the colliding pions. It thus follows that the number of fast π^- mesons in π^-p interactions should, on the average, be the same as for π^-n interactions. The experimental data does not con-

*Similar conclusions can be made on the basis of an analysis of the angular distribution of secondary protons, which are emitted primarily backward in the c.m.s. (see, for example, ^[29,30,14]).

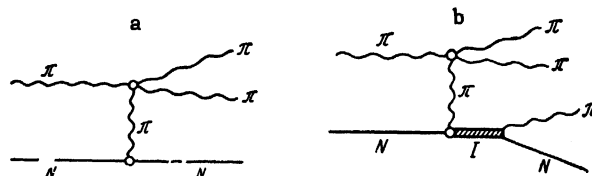


FIG. 13

tradict this statement. For example, for $p_{lab} \geq 4.0$ Bev/c the corresponding ratio is

$$n_{\pi^-}(\pi^-n)/n_{\pi^-}(\pi^-p) = 0.9 \pm 0.3.$$

The mean value of the transverse momentum p_\perp in diffraction scattering directly characterizes the range of interaction. For π^- mesons with $E_{\pi^-} \geq 4$ Bev produced in two-prong events, the mean value of the transverse momentum is $\bar{p}_\perp = 0.44 \pm 0.05$ Bev/c. It should be borne in mind here that the virtual pion, before the collision with the primary pion, also has a transverse momentum which is reasonably taken equal to the transverse momentum of the recoil protons in the considered group of interactions ($\sim 0.26 \pm 0.03$ Bev/c). If we take this into account, the interaction range in $\pi\pi$ diffraction scattering* proves to be $(1-2)\hbar/m_\pi c$.

We shall now present some remarks with a view to establishing more accurately the character of the peripheral interactions. The possibility of the existence of a group of interactions described by the diagram of Fig. 13a has been indicated several times. In this case we shall speak of "nucleonic dissociation" of the target nucleon. On the other hand, Gramenitskii, Dremin, and Chernavskii^[21] have indicated the important role played by processes with the so-called "isobaric dissociation" of the nucleon (see Fig. 13b). For the following analysis we shall consider only events in which a fast π^- meson is produced ($p_{lab} \geq 3.0$ Bev/c),[†] and assume that in these cases the upper vertex of each diagram corresponds to $\pi\pi$ diffraction scattering. Under these conditions, there are, within the framework of each of the schemes, single-valued isotopic relations connecting the cross sections of these reactions. One may expect that a

*It should be noted that the entire picture of $\pi\pi$ diffraction scattering has not been fully established. In particular, one cannot exclude the possibility that part of the $\pi\pi$ scattering is accompanied by charge exchange. This can be connected with the existence of a certain amount of fast π^0 mesons as well as π^+ mesons.

[†]Such a choice is partly connected with the absence of interactions with 5, 6, 7, and 8 prongs in which a π^- meson with $p_{lab} \geq 3.0$ Bev/c is produced. The presence of such interactions would be in contradiction with the scheme being considered.

Table VIII.

Multi- plicity n	\bar{M}_t , Bev/c ² —calculated only from charged secondary particles		\bar{M}_t , Bev/c ² —calculated with allowance for the contribution from π^0 mesons		\bar{k}	
	min	max	min	max		
2	0.18	0.41	0.30±0.06	0.44±0.06	0.32±0.06	0.47±0.06
4	0.38	0.53	0.54±0.12	0.59±0.09	0.57±0.13	0.63±0.09
6; 8	0.49	0.58	0.71±0.30	0.80±0.30	0.76±0.32	0.85±0.32
2—8	0.30	0.48	0.44±0.06	0.54±0.05	0.47±0.07	0.57±0.05

comparison of these relations with the experimental data will permit some conclusions on the relative role of peripheral interactions with nucleonic and isobaric dissociation (if, of course, we are dealing with $\pi\pi$ diffraction scattering).

It is readily shown that in the case of isobaric dissociation the number of slow protons in π^-p interactions should be 3.5 times as great as in π^-n interactions; on the other hand, in the case of nucleonic dissociation, slow protons should be encountered in π^-n interactions twice as often as in π^-p interactions. Experimentally, we observe in 51 two- and four-prong π^-p interactions containing π^- mesons of momentum ≥ 3.0 Bev/c a total of 24 slow protons (with $p \leq 1.2$ Bev/c) and only two slow protons in 17 three-prong π^-n interactions.

The number of slow π^+ mesons in π^-n interactions should be $\frac{5}{7}$ of the number of slow π^+ mesons in π^-p interactions if the dissociation is isobaric. Experimentally, this ratio is 0.9 ± 0.5 for π^+ mesons of momentum ≤ 1.2 Bev/c, while for the case of nucleonic dissociation in π^-n interactions, the slow π^+ mesons should be entirely absent. On the other hand, for two-prong interactions in which π^- mesons are produced with energy near the upper limit, there is an appreciable mixture of nucleonic dissociation. In fact, for isobaric dissociation the ratio of the number of two-prong interactions with fast π^- mesons to the number of analogous four-prong interactions should be $\frac{4}{5}$. Actually, this ratio turns out to be dependent on the π^- -meson energy, as is seen from the following data:

E_{π^-} , Bev:	2.0	3.0	4.0
$N_{n=2}/N_{n=4}$:	1.4±0.3	2.6±0.8	3.2±1.3

If the dissociation were to take place only by the nucleonic scheme, then the ratio would be infinite, since the four-prong interactions cannot occur.*

*If "nucleonic dissociation" were to play the basic role in peripheral interactions, then the foregoing conclusion on the absence of slow protons in π^-n interactions could be understood if it were assumed that $\sigma(\pi\pi^0) > \sigma(\pi\pi^-)$ and, consequently, that charge-exchange scattering occurs in $\pi\pi$ interactions.

Apart from the one-meson interactions considered above, an important role is apparently played by interactions with a larger number of virtual pions. As has already been noted, the momentum and angular distributions of the secondary protons change with an increase in multiplicity. Table VIII lists the estimates of the value of \bar{M}_t for π^-p interactions of different multiplicity. For events in which there are no identified protons and all positive particles are assumed to be π^+ mesons, the value of M_t was calculated from the formula

$$M_t = \Sigma (E_i - p_i \cos \theta_i).$$

Here the summation is carried out over all charged pions and γ quanta from the π^0 -meson decay for a given event. The minimum and maximum estimates of M_t are obtained under the assumption that the unidentified positive particles are π^+ mesons or protons, respectively.* It is known that the quantity M_t/M is equal to the fraction of energy k lost by a proton in a collision with a π^- meson if we consider the π^-p interaction in the S system, in which the initial π^- meson is at rest.^[5] (The proton energy in this system is ~ 46 Bev.) The values obtained for the mean loss \bar{k} are also shown in Table VIII. As seen from this table, the quantities \bar{M}_t and \bar{k} evidently depend on the multiplicity, which indicates the different nature of the interaction (decrease in the "degree of peripheralness" with an increase in the multiplicity). For the π^-p interactions considered as a whole, the quantity $\bar{M}_t(\bar{k})$ proves to be rather large. It thus apparently follows that there is a large group of interactions which are not of the one-meson type. In fact, it follows from the consideration of a very rough model that for one-meson interactions the energy losses in the S system should be close to the value $m_\pi/M \approx 0.15$,

*The errors in Table VIII were calculated directly only for the resultant mean numbers. From the values obtained with allowance for the observed number of γ quanta, we estimated the errors of the quantities corresponding to each multiplicity.

while the experimental value is $\bar{k} = 0.47 - 0.57$.* As regards "truly central" interactions accompanied by the production of a very high energy secondary nucleon (in the l.s.) we cannot, at present, say anything definite about their relative role and properties.

One may, however, estimate the l.s. nucleon energy from the mean energy loss in the S system for all π^-p interactions, apart from those for which M_t determined from the slow proton is $\leq 0.3 \text{ BeV}/c^2$ (i.e., for 87% of the interactions). In this case $\bar{k} = 0.54 - 0.66$, and for the mean l.s. nucleon energy we obtain the estimate $\bar{E}_{\text{lab } p} = 1.2 - 1.8 \text{ BeV}$ if we assume that for nucleons $p_{\perp} = 0.31 - 0.47 \text{ BeV}/c$. In this connection it is interesting to note that the energy of the nucleon which, after interaction, comes to rest in the c.m.s. is $E_{\text{lab}} = 2.0 \text{ BeV}$.

It is known (see, for example^[31,32]) that in the interaction of a fast proton with a proton the energy loss is $k_{pp} \approx 0.4$; in any case it does not exceed the value of the energy loss in collisions of a fast proton with a π^- meson ($\bar{k}_p = 0.47 - 0.57$). If we roughly represent each of the nucleons as consisting of a "core" and a pion cloud, then the above-mentioned circumstance can be considered to mean that the basic role in pp interactions is played by collisions of the "cloud"- "core" type, while there are practically no collisions of the "core"- "core" type, which, of course, lead to a large energy loss (see also^[25]). Further investigations are necessary before a more accurate picture can be formed.

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¹V. Petrzilka, Proc. of the 1960 Ann. Intern. Conf. on High Energy Physics at Rochester, Interscience Publ. 1960, p. 82.

*In correspondence with the presently accepted phenomenological classification, we consider as peripheral interactions those accompanied by a small energy loss and strongly anisotropic secondary particles. From this point of view, peripheral collisions can include many interactions other than those of the one-meson type. In particular, one may note in this connection that, for interactions with $M_t > 0.3 \text{ BeV}/c^2$ in the c.m.s., the angular distribution of π^- mesons turns out to be anisotropic.

²Wang, Solov'ev, and Shkobin, PTÉ (Instruments and Measurement Techniques) No. 1, 41 (1959); Wang, Ting, Ivanov, Kladnitskaya, Nguyen, Saitov, Solov'ev, and Shafranov, Report, High Energy Laboratory of the Joint Institute for Nuclear Research, 1959.

³Wang, Wang, Ting, Ivanov, Katyshev, Kladnitskaya, Kulyukina, Nguyen, Nikitin, Otwinowski, Solov'ev, Sosnovskii, and Shafranov, JETP **38**, 426 (1960), Soviet Phys. JETP **11**, 313 (1960).

⁴Blinov, Krestinkov, and Lomanov, JETP **31**, 762 (1956), Soviet Phys. JETP **4**, 661 (1957).

⁵N. G. Birger and Yu. A. Smorodin, JETP **36**, 1159 (1959), Soviet Phys. JETP **9**, 823 (1959).

⁶Vovenko, Kulakov, Lubimov, Matulenko, Savin, Smirnov, and Shafranov, Proc. of the 1960 Ann. Int. Conf. on High Energy Phys. at Rochester, Interscience Publ., 1960, p. 443.

⁷R. G. Thomas, Phys. Rev. **120**, 1015 (1960).

⁸G. Maenchen et al., CERN Symposium, 1958. Cited by V. S. Barashenkov, UFN **72**, 53 (1960), Soviet Phys.-Uspekhi **3**, 689 (1960).

⁹Bandtel, Bostick, Moyer, Wallace and Wikner, Phys. Rev. **99**, 673 (1955).

¹⁰N. F. Wikner, UCRL-3639, 1957. Cited by Barashenkov, op. cit. ref. 8.

¹¹Bowen, Di Corato, Moore, and Tagliarferri, Nuovo cimento **9**, 908 (1958).

¹²Wikner, Bostick, and Moyer, Bull. Am. Phys. Soc. **1**, 252 (1956).

¹³Kocharyan, Saakyan, and Kirakosyan, JETP **35**, 1335 (1958), Soviet Phys. JETP **8**, 933 (1959).

¹⁴Belyakov, Wang, Glagolev, Dalkhazhav, Lebedev, Mel'nikova, Nikitin, Petrzilka, Sviridov, Suk, and Tolstov, JETP **39**, 937 (1960), Soviet Phys. JETP **11**, 675 (1960).

¹⁵V. S. Barashenkov, UFN **72**, 53 (1960), Soviet Phys.-Uspekhi **3**, 689 (1960).

¹⁶V. M. Maksimenko, Dissertation, Joint Institute for Nuclear Research, 1961.

¹⁷Wang, Wang, Veksler, Vrana, Ting, Ivanov, Kladnitskaya, Kuznetsov, Nguyen, Nikitin, Solov'ev, and Ch'eng, JETP **40**, 464 (1961), Soviet Phys. JETP **13**, 323 (1961).

¹⁸M. I. Dymant and G. I. Kopylov, Preprint, Joint Institute for Nuclear Research, 1960.

¹⁹G. F. Chew and F. E. Low, Phys. Rev. **113**, 1640 (1959).

²⁰F. Selleri, Phys. Rev. Lett. **6**, 64 (1960).

²¹Gramenitskii, Dremin, and Chernavskii, JETP **41**, 856 (1961), Soviet Phys. **14**, 613 (1962).

²²J. Derado, Nuovo cimento **15**, 853 (1960).

²³Eisberg, Fowler, Lea, Shephard, Shutt, Thordike, and Whittemore, Phys. Rev. **97**, 796 (1955).

²⁴Maenchen, Fowler, Powell, and Wright, Phys. Rev. **108**, 850 (1957).

²⁵N. G. Birger and I. Ya. Smorodin, JETP **37**, 1355 (1959), Soviet Phys. JETP **10**, 964 (1960).

²⁶L. B. Okun' and I. Ya. Pomeranchuk JETP **30**, 424 (1956), Soviet Phys. JETP **3**, 307 (1956).

²⁷S. Z. Belen'kii, JETP **33**, 1248 (1957), Soviet Phys. JETP **6**, 960 (1958).

²⁸V. N. Strel'tsov, Preprint D-472, Joint Institute for Nuclear Research, 1959.

²⁹Grote, Kreckler, Kundt, Lanius, Manske, and Meier, Nuclear Phys. **24**, 300 (1961).

³⁰W. D. Walker, Phys. Rev. **108**, 872 (1957).

³¹Viski, Gramenitskii, Korbel, Nomofilov, Podgoretskii, Rob, Strel'tsov, Tuvdéndorzh, and Khvastunov, JETP **41**, 1069 (1961), Soviet Phys. JETP **14**, 763 (1962).

³²Kalbach, Lord, and Tsao, Phys. Rev. **113**, 330 (1959).

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