π^-p *INTERACTION AT 7 BEV*

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A method developed earlier[3] is employed to describe the π^-p interaction at 7 Bev. The results of the calculations are compared with the experimental data. The comparison shows that the main characteristics of recoil nucleons (their energy spectrum, angular distribution, etc.) satisfactorily agree with the calculations. The problem of obtaining information on the $\pi\pi$-interaction cross section at energies for which it is mainly inelastic and, in particular, on the $\pi\pi$ diffraction cross section is discussed. It is shown that suitable events can be chosen from the experimental material on the π^-p interaction and can be used for determining the $\pi\pi$ diffraction cross section.

EXPERIMENTAL data have recently been obtained on the π^-p interaction at a laboratory energy $E_L = 7$ Bev.[1] Some of the data (for example, the angular and energy distributions of the nucleons) indicate that peripheral interactions play an important role.

In this connection, we studied this process in the one-meson approximation on the basis of the diagram shown in Fig. 1. This method has already been used for the calculation of the πp interaction at 5 Bev[2]* and of the nucleon-nucleon interaction at 9 Bev.[3] The conditions of applicability have been discussed earlier.[3] We note that for the calculation of the π^-p interaction at 7 Bev, the method requires knowledge of the $\pi\pi$ interaction cross section $\sigma_{\pi\pi}$, the dependence of this cross section on the pion energy (in the c.m.s. of the pions, hereafter referred to as the $\pi\pi$ system), and on their isotopic spin (here the three possible states are T = 0, 1, 2).

One of the authors[2] has shown that the best description is probably given by the variant in which all three isostates of the $\pi\pi$ system occur with equal probability. Using this variant, we can readily write the cross section of the π^-p interaction in the form

$$\sigma_{\pi p} = \frac{1}{4\pi^3 m^2 E_L^2}\int dz \int dy \sqrt{(z^2 - m^2\mu^2)(y^2 - \mu^4)}\left[\frac{1}{\varkappa^2 + \mu^2} - \frac{1}{\varkappa^2 + \mu^2 + 4p_0 P_1}\right]\sigma_{\pi\pi}(y)\,\{2\sigma_{3/2}(z) + \sigma_{1/2}(z)\}, \qquad (1)$$

where $z = \frac{1}{2}(\mathfrak{M}_1^2 - m^2 - \mu^2)$, $y = \frac{1}{2}(\mathfrak{M}_2^2 - 2\mu^2)$,

*In[2] one of the authors considered mainly the isotopic relations in the $\pi\pi$ interaction.

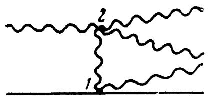

FIG. 1. One-meson diagram of inelastic πp interactions.

$\mathfrak{M}_2$ is the pion energy in the $\pi\pi$ system; $\mathfrak{M}_1$ is the total energy of the pion and nucleon emitted from node 1 (Fig. 1) in their c.m.s.; E_0 and p_0 are the c.m.s. energy and momentum of the nucleon prior to the interaction; E_1 and P_1 are the total energy and momentum of the particles emitted from node 1 in the c.m.s. of the process; E_L is the pion energy in the laboratory system (l.s.); and $\kappa^2 = 2(E_0E_1 - p_0P_1) - \mathfrak{M}_1^2 - m^2$. The number of pions emitted from node 2 is even. In other respects, the number of pions (at both nodes 1 and 2) is arbitrary. The total number is limited by the conservation laws.

To see how well this picture agrees with the experimental data,[1,4] we calculated the transverse momentum distribution, the c.m.s. angular distribution, and the l.s. energy distribution of the nucleons. We note that it is necessary to know for the calculation of these characteristics the value of $\sigma_{\pi\pi}(\mathfrak{M}_2)$ in the interval $0.3 < \mathfrak{M}_2 < 2$ Bev. The details of the $\pi\pi$ interaction (multiplicity in inelastic $\pi\pi$ interactions, angular and energy distributions of the pions in the $\pi\pi$ system) do not affect the results of this calculation.

We carried out the calculations under the following limiting assumptions: a) the quantity $\sigma_{\pi\pi}(\mathfrak{M}_2)$ depends weakly on the energy $\mathfrak{M}_2$, it can be assumed constant and equal to $\overline{\sigma}_{\pi\pi}$; b) the quantity $\sigma_{\pi\pi}(\mathfrak{M}_2)$ has a sharp maximum at $\mathfrak{M}_2 \sim 0.4 - 1$ Bev. It is equal to $\sigma_{\pi\pi}^{(r)}$ inside this region and is very small outside it. (Fraser and

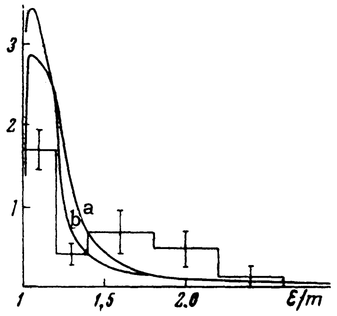

FIG. 2. Energy distribution of the nucleons in the l.s. Curves a and b are calculated by variants a and b, respectively; ε is the l.s. energy of the nucleon. The curves and histogram are normalized to the same area. The histogram represents the experimental data.

Fulco[5] have discussed the possibility that such a "resonance" occurs.) We note that the characteristic values of the virtualness k^2 (k is the 4-momentum of the intermediate meson), as in [1], are $k^2 \sim (6\mu - 7\mu)^2$.

The total cross section of the inelastic πp interaction turned out to be $\sigma_{\pi p} = 0.3\,\overline{\sigma}_{\pi\pi}$ in variant a and $\sigma_{\pi p} = 0.12\,\sigma_{\pi\pi}^{(r)}$ in variant b. The experimental value of the inelastic cross section $\sigma_{\pi p}$ has been estimated earlier.[3] (It should, of course, be borne in mind that this is a very preliminary estimate.) The estimate gave $\sigma_{\pi p} \approx 20$ mb. It can therefore be concluded that either $\overline{\sigma}_{\pi\pi} \approx 66$ mb in variant a or $\sigma_{\pi\pi}^{(r)} \approx 160$ mb in variant b. These values do not contradict other very approximate estimates.[6,7]

The l.s. energy distribution of the nucleons, their c.m.s. angular distribution, and the transverse momentum distribution (in arbitrary units) are shown in Figs. 2, 3, and 4, respectively.

The angular distribution and the $p_\perp$ distribution calculated by variants a and b are practically the same. The energy distributions of the nucleons

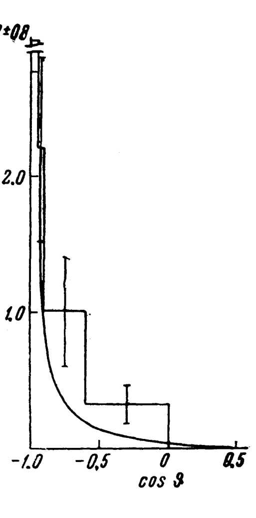

FIG. 3. Angular distribution of the nucleons in the c.m.s.

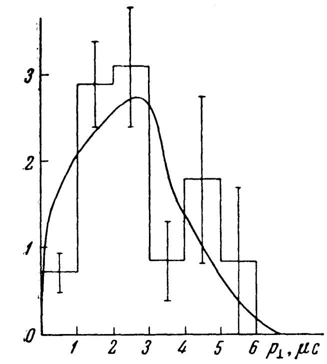

FIG. 4. Transverse momentum distribution of the nucleons in the c.m.s.

differ little. Hence from a comparison of these characteristics with experiment we can draw no conclusions as to the dependence of $\sigma_{\pi\pi}$ on the energy $\mathfrak{M}_2$.

The experimental data are represented in the figures by the histograms. Comparing these data, we see that: 1) the transverse momentum distribution is in satisfactory agreement with the experimental data; 2) the calculated energy distribution of the recoil nucleon and the angular distribution are in somewhat poorer agreement with the experimental data.

In the experimental distributions, cases with larger angles of the nucleons (in the c.m.s.) and high recoil-nucleon energies (in the l.s.) have greater weight.* Possibly, this is due to the insufficient accuracy of the experiment and will change when the accuracy is improved. On the other hand, it is possible that the entire process does not take place here in accordance with the foregoing scheme and that there is a mixture of cases occurring through other channels.

It is possible, for example, that part of the cases correspond to diagrams in which the nucleon is not excited and its interaction with the pion is proportional to $g(\psi\gamma_5\psi)\varphi$. (This scheme has been suggested by Chew and Low[8] and has been considered several times[6,7] at lower energies — $E_L \approx 1 - 3$ Bev.) Calculation shows† that in this case the angular and energy distributions of the nucleons are quite broad. However, this calculation cannot be made at 7 Bev, since the values of the virtualness k^2 and of the quantity $\mathfrak{M}_2$ are appreciably larger here than in the process pictured in Fig. 1. In fact, the values of k^2 which contribute significantly to the Chew-Low process are of the

*We note that the experimentally found angular and energy distributions of the nucleons in the case of the πp interaction at 7 Bev is appreciably broader than the similar characteristics of NN interactions at 9 Bev.[3]

†We do not reproduce this calculation here, since it has been given in detail elsewhere.[6-8]

order $k^2 \approx (13\mu)^2$ and $\mathfrak{M}_2 \approx 2-3$ Bev. It was shown earlier[9] that restrictions on the virtualness must be introduced for such values of k^2 and $\mathfrak{M}_2$. Since the restricting procedure is not unique, this process cannot, at present, be calculated correctly.

Consequently, we did not analyze this process in detail in the present study and considered only the process of Fig. 1.

We return to the question of the dependence of $\sigma_{\pi\pi}$ on the energy $\mathfrak{M}_2$. As we have already mentioned, the observed characteristics of the recoil nucleons are not sensitive to this energy and do not provide the required information. In order to find the value of $\sigma_{\pi\pi}(\mathfrak{M}_2)$ in the region $\mathfrak{M}_2 > 1$ Bev, it is necessary to consider in greater detail the characteristics not of the nucleons, but of the secondary pions in the given process.

It can be expected that for $\mathfrak{M}_2 < 1.2$ Bev the $\pi\pi$ interaction will be primarily elastic. In fact, the inelastic interaction will be important only if all the secondary pions in the $\pi\pi$ system are relativistic, i.e., if they have an energy $\epsilon \gtrsim 2\mu$.

The minimum number of secondary particles in an inelastic collision is four. Hence it can be assumed that the interaction is elastic up to the energy $\mathfrak{M}_2 \approx 1.2$ Bev; for $\mathfrak{M}_2 > 1.2$ Bev the inelastic part will be important; in this case the elastic part will have a diffractive character.

The cross section of the inelastic πp interaction $\sigma^{(i)}_{\pi p}$ due to the inelastic $\pi\pi$ interaction in the process under consideration (Fig. 1) and calculated according to formula (1) turns out to be $\sigma^{(i)}_{\pi p} = 0.15\,\sigma^{(i)}_{\pi\pi}$, where $\sigma^{(i)}_{\pi\pi}$ is the inelastic $\pi\pi$ cross section averaged over the energy interval $1.2 < \mathfrak{M}_2 < 2$ Bev. To separate such interactions, we can select cases in which more than two secondary pions are emitted forward in the c.m.s.

Of basic interest here is the elastic (diffractive) $\pi\pi$ interaction (resulting from the existence of the inelastic $\pi\pi$ interaction). It leads to specific characteristics of the experimentally observed phenomena which allow it to be separated quite distinctly.

First, the sign of the diffraction-scattered pion should be negative.

Second, for $\mathfrak{M}_2 > 1.2$ Bev the l.s. energy of the fastest diffraction-scattered pion is $\epsilon_L \gtrsim 5$ Bev, according to the calculations with formula (1). In interactions of another type, the energy of the fastest pions is appreciably less. For example, in an elastic, but nondiffractive interaction (for $\mathfrak{M}_2 < 1.2$ Bev), $\epsilon_L \approx 3.8$ Bev; for an inelastic $\pi\pi$ interaction (with $\mathfrak{M}_2 > 1.2$ Bev) $\epsilon_L \approx 2$ Bev.

Third, the angle at which the diffraction-scattered pions of l.s. energy $\epsilon_L \sim 5$ Bev are emitted is small. It can be estimated in the following way. The basic contribution to the transverse component of these pions comes from the quantity $k_\perp$ (transverse momentum of the intermediate virtual pions). The $k_\perp$ distribution was calculated on the basis of expression (1). The curve of $d\sigma/dk_\perp$ has a maximum at $k_\perp = 2\mu$ and reaches half the maximum value at $k_\perp = 0.5\mu$ and $k_\perp = 4.5\mu$. Therefore the l.s. angles of the diffraction-scattered pions will lie within the limits $0.014 < \vartheta_L < 0.13$ $(1° < \vartheta_L < 9°)$.

Using formula (1) and taking $\sigma^{(d)}_{\pi\pi}$ to be constant, we find the πp interaction cross section due to the diffractive $\pi\pi$ interaction:

$$\sigma^{(d)}_{\pi p} = 0.15\,\sigma^{(d)}_{\pi\pi}. \tag{2}$$

Summing up, we can state that the diffractive interaction between the incident pion and a virtual pion can be separated experimentally if we select cases in which a negative pion is emitted in the forward direction with an energy greater than 5 Bev at an angle less than 9° l.s.

According to the experimental data,[4] the fraction of such cases in πp interactions at 7 Bev is 0.15, i.e., the cross section of this process is $\sigma^{(d)}_{\pi p} \approx 3$ mb. We can thus conclude that the elastic diffraction-scattering $\pi\pi$ cross section is, according to (2), $\sigma^{(d)}_{\pi\pi} \approx 20$ mb in the energy region $1.2 < \mathfrak{M}_2 < 2$ Bev. We note that according to [4] the greater part of the pions of energy $\epsilon_L \gtrsim 5$ Bev proved to be negative. This indicates that the elastic $\pi\pi$ scattering in this energy region occurs in most cases without the pion experiencing charge exchange, which is in agreement with the proposed picture of the interaction.

In conclusion, the authors express their gratitude to E. L. Feĭnberg for fruitful discussions and to the authors of [1,4] for making their data available to us and for discussions.

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