ELASTIC SCATTERING OF 2.8 Bev/c PIONS ON NEUTRONS

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The differential cross sections for 2.8-Bev π^-n scattering are determined for c.m.s. angles from 10 to 180°. The probability for nondiffractional scattering of π^- mesons is found to be small and to drop sharply with increasing incident meson energy.

INTRODUCTION

THERE is now much experimental material [1-8] on the elastic scattering of pions in πN collisions at energies above 1 Bev. These data deal mostly with scattering in the region of the first diffraction maximum. Appreciable interest is attached, however, to scattering of pions by nucleons at larger angles, called arbitrarily non-diffraction scattering. We have obtained earlier [9] certain information on the cross section for the elastic scattering of negative 2.8-Bev/c pions by neutrons at 140—180° in the c.m.s. In the present work the measurements have been continued to determine the differential cross section of elastic π^-n scattering at all angles outside the diffraction-scattering region.

There is only one published paper [1] devoted to a study of π^+p scattering (which is isotopically symmetrical to π^-n scattering) at 1.8 Bev in the entire angle interval. However, if it is assumed that in this energy range the character of scattering of positive and negative pions by nucleons is the same, the results of the present investigation can be compared with the results of [2-5] which deal with non-diffraction elastic π^-p scattering. In particular, a study was made [2,3] of the angular distribution for elastic scattering of 1.2- and 1.3-Bev negative pions in the c.m.s. angle interval up to 180°. Approximately 100—200 cases each of elastic scattering outside the diffraction region were registered. For 5-Bev negative-pion energies, seven [4] and two [5] cases of non-diffraction elastic scattering were found. In [2] a comparison was made of the angular distributions for elastic π^-p scattering at energies 0.97 Bev, [10] 1.2 Bev, [2] and 1.3 Bev. [3] The differential backward scattering cross section curves for 1.2 and 1.3 Bev do not differ from each other, within the limits of experimental error, but lie somewhat lower than the corresponding curve for π^-p scattering at 970 Mev. The authors call attention to this tendency. The presence of non-diffraction scattering at 1.3 Bev is emphasized in [5], where it is indicated that it apparently interferes with the diffraction scattering. Not much attention has been paid to non-diffraction scattering at high energies, nor have any deductions been drawn concerning its character and its variation with energy.

EXPERIMENTAL SETUP

To study elastic π^-n scattering we scanned approximately 5000 stereo pairs, obtained with a 17-liter freon bubble chamber [11] 50 cm long. The negative-pion beam had a momentum 2.8 ± 0.3 Bev/c. The bubble chamber was operated without a magnetic field. The freon working mixture (CF_3Cl and CF_2Cl_2) contains light nuclei and has at the same time a sufficiently high specific gravity (1.12 g/cm^3) and low conversion length (30 cm); the latter is particularly important, since the main source of the background was a process involving the creation of neutral pions, which were effectively registered in the chamber via the decay γ quanta.

In scanning the stereo pairs we selected the single-prong stars. These were assumed to occur upon interaction between the negative pions and the quasi-free neutrons of the nuclei contained in the freon. Additional selection criteria, taking the kinematics of elastic π^-n scattering into account, were the conditions that a) the scattered particle must not stop in the chamber substance, b) the ionization of the scattered particle must not differ by more than a factor of three from the ionization of the primary particle, and c) the track of the scattered particle must not have a deflection greater than three bubbles ($\sim$2 mm), and consequently the angle of multiple scattering of the particle should be less than that for 200-Mev/c pions.

The film was scanned by two observers independently. The efficiency of detecting a single-prong star with secondary-particle emission angle > 15° in the laboratory system of coordinates (l.s.) is close to unity. Information on the scattering in the ~ 5—15° range in the l.s. were obtained after an additional thorough examination of approximately one tenth of the entire material. This is necessary because, on the one hand, scattering at small angles is frequently encountered, and on the other, it is more difficult to search for such scattering on the film than for scattering at larger angles. Scattering at angles < 5° in the l.s. was not investigated, for in this range of angles scattering on the nucleus as a whole begins to compete with scattering on the quasi-free nucleons.

The distribution of selected single-prong stars by the secondary-particle l.s. emission angles is shown by the smooth curve of Fig. 1. The dashed curve on the same figure shows the angular distribution of those single-prong stars, from among the total number selected, which were accompanied by 1, 2, or 3 electron-positron pairs directed toward the interaction point. These events were due to the reaction

$$\pi^- + n \to \pi^- + n + m\pi^0, \tag{1}$$

where m = 1, 2, ... is the number of mesons produced in the given process. This distribution includes five single-prong stars connected with creation of strange particles: one Λ^0 (or Σ^0) and four K^0 mesons. In two cases the creation of the K^0 meson was accompanied by emission of pions, since electron-positron pairs due to conversion of the γ quanta from the neutral pion decay were registered. It is natural to assume that the Λ^0 and K^0 particles were created in interactions of the type

$$\pi^- + n \to \pi^- + \Lambda^0(\Sigma^0) + K^0 + m\pi^0, \tag{2}$$

$$\pi^- + n \to K^- + K^0 + n + m\pi^0, \tag{3}$$

$$\pi^- + n \to \pi^- + n + K^0 + \overline{K}^0 + m\pi^0, \tag{4}$$

where m = 0, 1, 2 ....

We note that seven single-prong stars were registered in the interval of negative-pion emission angles from 90 to 180° in the l.s. Five of these were accompanied by electron-positron pairs or a K^0 meson. This fact is in good agreement with the result of the preceding investigation.[9]

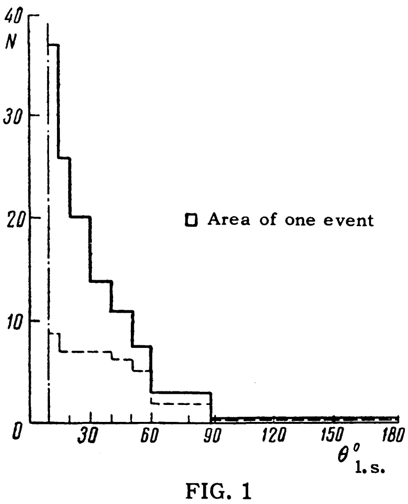

FIG. 1

SUBTRACTION OF BACKGROUND

The reactions (1)—(4) are background reactions relative to the investigated process, and the single-prong stars due to these reactions must be eliminated from the total number of selected cases. There exists a finite probability of not registering a π^0, K^0, or Λ^0 particle. The registration efficiencies of the neutral particles must therefore be taken into account in the subtraction of the background.

Let us consider reaction (1). It is first necessary to estimate the efficiency of registration of the γ quanta from the neutral-pion decay. For each γ quantum producing a pair directed toward the selected single-prong star we measured the distance L along the direction of motion of the γ quantum, from the point of interaction to the boundaries of that region of the chamber in which the conversion pair could still be registered in the scanning. This distance, for a known conversion length L_K = 30 cm, enables us to determine by means of the formula $\epsilon = 1 - \exp(-L/L_K)$ the efficiency ϵ of registering a γ quantum emitted from a given point in a given direction. The average efficiency of registration of the γ quantum from reaction (1) was calculated from the formula $\bar{\epsilon} = n/\Sigma\epsilon_i^{-1}$, where n is the number of registered electron-positron pairs.

Within the limits of statistical errors, the average efficiency of registering the γ quanta remains the same for neutral-pion emission in different angular ranges. This enabled us to calculate the average γ-quantum registration efficiency for the entire chamber, independently of the angle of emission of the neutral pion. The average registration efficiency of the γ quantum produced by reaction (1) is 0.33 ± 0.03.

To determine the number of single-prong stars due to reaction (1), but not accompanied by conversion pairs, we must know the multiplicity of forma-

Angle interval	N_1	N_2	N_3	N	N^*	N_0
0—30°	30	13	0	56	43	29±4
30—60°	24	8	3	49	35	20±3
60—180°	8	6	2	26	16	5±3

tion of neutral pions. The table lists the following data for three negative-pion emission angle intervals: N^* — number of single-prong stars with electron-positron pairs directed towards the interaction point, N_1, N_2, and N_3 — numbers of single-prong stars with 1, 2, and 3 electron-positron pairs, respectively, N — total number of registered γ quanta from reaction (1).

A change in the multiplicity of creation of the neutral pions in reaction (1) influences the sought number of single-prong stars unaccompanied by electron-positron pairs in the chamber (N_0), as well as the ratios N_1/N^*, N_2/N^*, N_3/N^*, and N/N^*. Starting from these experimentally-determined ratios, and assuming that the registration efficiency of the γ quanta is 0.33, we calculated N_0. The resultant values of N_0 are listed in the last column of the table.

The efficiency of registration of reactions (2) —(4) was estimated starting from the following considerations: a) the K^0 and $\bar{K}^0$ mesons behave in half the cases like long-lived K_2^0 mesons and leave the chamber; b) in one-third of the cases the K_1^0 meson decays into two neutral pions, and such cases were not registered in the chamber; c) there is a finite probability that the K_1^0 meson will leave the chamber; d) the Λ^0 particle can decay into a neutral pion and neutron and may thus not be registered; e) the Λ^0 particle can leave the chamber; f) in reactions (2) and (4), the neutral strange particles should be taken into account twice; g) some part of the reactions (2) —(4) are accompanied by the creation of neutral pions, which can be registered in the chamber and accounted for together with reactions (1). The calculated value of the registration efficiency of a single-prong star connected with the observed creation of strange particles in reactions (2)—(4) is approximately 0.4. The error in this quantity is of little significance, since the number of registered events due to reactions (2)—(4) is small.

DISCUSSION OF THE RESULTS

It is assumed that all the single-prong stars remaining after subtracting the background, i.e., not due to reactions (1)—(4), are cases of quasi-elastic π^-n scattering on quasi-free neutrons of the nuclei. In quasi-elastic π^-n scattering, half of the neutrons in each nucleus of the freon mixture effectively participates on the average in the quasi-elastic π^-n scattering. The other half of the neutrons is screened by the remaining nucleons of the nucleus, since the secondary particles produced in the elastic π^-n scattering, initiate a nuclear cascade, which results in stars having > 1 prong. The value of the screening coefficient $n = 0.5$ was discussed earlier.[9]

The angular distribution of elastic π^-n scattering referred to a single free neutron is shown in Fig. 2. The abscissas show the cosines of the angles and the negative-pion emission angles themselves in the c.m.s. of the negative pion and the nucleon. The ordinates represent the differential cross sections of the elastic π^-n scattering. The left-hand scale pertains to angles < 38° in the c.m.s. and the right-hand scale, which has been changed by a factor of one hundred, pertains to scattering angles > 38°. The errors indicated on the figure are statistical. Error bars parallel to the abscissa axis indicate the width of the angle interval over which the average was taken.

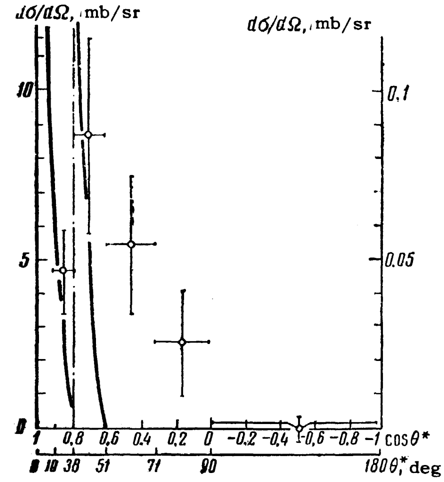

FIG. 2

The continuous curve in Fig. 2 shows the calculated angular distribution of the diffraction scattering of 2.8-Bev/c pions. The calculations were based on the formulas of the optical model, which are customarily used in this case,[12] under the assumption that the nucleon is a sphere with sharp boundary and constant refractive index. The parameters of the optical model were taken from [6], namely: the change in the real part of the wave number K_1 is zero, the coefficient of absorption of the nucleon is $K = 0.71 \times 10^{-13}$ cm^{-1}, and the radius of the sphere is $R = 1.05 \times 10^{-13}$ cm. These parameters agree with all the known experimental data on elastic πN scattering.[1-8] It is seen from

Fig. 2 that the points corresponding to 50° scattering in the c.m.s. lie on the calculated curve, i.e., it can be assumed that the results obtained in the present investigation in the region of diffraction πN scattering do not contradict the aggregate of presently known results.

From the data obtained in this investigation we can conclude that, accurate to 0.006 mb/sr, there is no elastic $\pi^- n$ scattering in the range 90—180° (c.m.s.). This confirms the previous [9] deduction concerning compensation of diagrams with one virtual nucleon (Fig. 3) at high energies in $\pi^- n$ scattering, while the data on the wider angle range confirm the conclusion that the contributions of different phase shifts with small orbital momenta cancel each other in c.m.s. backward scattering, or else that these phase shifts themselves are small.

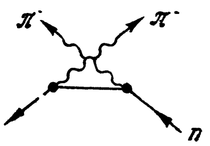

Рис. 3

It is seen from Fig. 2 that elastic $\pi^- n$ scattering is observed at 50—90° in the c.m.s. Strictly speaking, we cannot exclude the possibility of fitting this part of the scattering in the framework of the optical model by suitable choice of the parameters and by increasing their number (for example, by taking account of the diffuse boundary of the nucleon). At the present statistical accuracy of the experimental material, however, such a description is meaningless.

It is interesting to compare the results obtained with the corresponding results from [1–5]. One can hope that the conclusion concerning the compensation of the diagram of Fig. 3 makes a comparison of $\pi^- n$ scattering with $\pi^- p$ scattering valid. Otherwise the scattering of negative pions by neutrons and protons at c.m.s. angles > 90° would be different, since the diagram of Fig. 3, which yields backward scattering at high energies, does not hold for $\pi^- p$ scattering, owing to the charge-conservation law.

The known data on potential, non-diffraction scattering of pions by nucleons are compared in Fig. 4, where the abscissas represent the c.m.s. momentum p* transferred in the scattering and the ordinates are the differential cross sections in terms of the square of the pion wavelengths in the c.m.s. The data of [1,3] have been averaged over the intervals designated by the horizontal

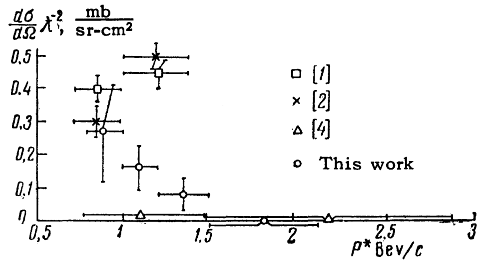

FIG. 4

error bars in the figure. The data of Thomas [4] are given for the seven cases he has noted outside the region of diffraction scattering, with notice of the fact that not a single case of elastic scattering was registered at 90—180° c.m.s. The error shown in the figure for this region corresponds to a single case. As can be seen from the foregoing results, subject to the accuracy indicated in the figure, the nucleon does not acquire a c.m.s. momentum greater than 1.5 Bev in elastic πN scattering, and the probability of acquiring a momentum 1—1.5 Bev decreases with increasing energy of the incoming meson.

The character of scattering at high energies is such that in elastic pp scattering the maximum c.m.s. momentum transfer is 1.6 Bev/c, accurate to 0.01 mb/sr. Such a transfer was registered in the scattering of 4.4-Bev protons in [13]. With increasing energy of incoming protons the probability of transferring a momentum ≥ 1 Bev/c decreases. [13–16] It is interesting to note (see [17]) that the Λ^0 particles produced in the interaction between 2.8-Bev/c negative pions and nucleons also have in the laboratory system a maximum momentum of 1.6 Bev/c.

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