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INVESTIGATION OF REACTIONS AT A MOMENTUM OF 2.94 GeV/c

V.V. Barmin, V.M. Golubchikov, G.V. Davidenko,
A.G. Dolgolenko, V.A. Ergakov, A.G. Meshkovskij,
L.S. Novikov, I.I. Pershin, S.V. Skachkov, Yu.V. Trebukhovskij,
T.A. Chistyakova and V.A. Shebanov

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A B S T R A C T

The systems of π^0-mesons and γ -quanta were studied in $\pi^- + p \rightarrow n + m\gamma$ reactions at π^--meson momenta of 2.94 GeV/c. In the effective mass distributions of the $\pi^0\gamma$ and $2\pi^0$ systems, maxima are observed which correspond to the production of ω and f mesons. In the $2\pi^0$ system a large excess of events is found above the phase shift curve at a mass of $\sim$ 700 MeV and at a width of $\sim$ 300 MeV. The values of the elements of the spin matrix of density ρ_{00} , ρ_{1-1} , and $Re\,\rho_{10}$ are obtained for the ω -meson in the $\omega \rightarrow \pi^0 + \gamma$ decay. The distributions of the squared 4-momentum transfer and the angular distributions for various parts of the spectrum of the $\pi^0\gamma$ and $2\pi^0$ systems were obtained. The cross sections of $\pi^- + p \rightarrow n + m\gamma$ reactions at m = 3, 4, 6, 8, 10 and of certain other reactions involving π^0-meson and γ -quanta production are given.

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1. Experimental Section

In the present work, a study was made of the $\pi^- + p \rightarrow n + m\gamma\ (m \geq 3)$ reactions by means of a 120-litre bubble chamber [1] placed in a magnetic field of 18 kG and exposed to the 2.94 GeV/c beam of π^--mesons from the IHEP proton synchrotron. For the purposes of this experiment the chamber was filled with a mixture of propane and xenon. The xenon content was 57% (by weight). As already shown [2], this mixture provides a most efficient way of recording radiation processes and enables the reactions occurring in the hydrogen to be isolated.

A total of 250'000 stereophotographs were taken and later scanned. During scanning, a search was made for cases of zero-ray stars accompanied by one or more electron-position conversion pairs of γ-quanta, directed to the point at which the track of the π^--meson disappeared. All the events found during scanning were checked with a stereo-projector on which the spatial diagram of the event was reconstituted. During a check, the number of conversion pairs for each event was accurately determined.

The distribution of the events found, according to the number of recorded γ-quanta is given in Table I.

Table I

Number of γ-quanta	I	2	3	4	5	6	7	8	9	I0
Number of Nm cases found	2205	3258	I982	II66	470	I94	75	23	5	6

The efficiency of recording a solitary γ-quantum P, and the number of events of the $\pi^- + p \rightarrow n + m\gamma$ reactions occurring in the chamber $n_{m\sigma}$ were calculated from the following system of equations:

$$
\begin{aligned}
p_{12}n_2 + p_{13}n_3 + p_{14}n_4 + p_{16}n_6 + p_{18}n_8 + p_{110}n_{10} &= N_1\\
p_{22}n_2 + p_{23}n_3 + p_{24}n_4 + p_{26}n_6 + p_{28}n_8 + p_{210}n_{10} &= N_2\\
p_{33}n_3 + p_{34}n_4 + p_{36}n_6 + p_{38}n_8 + p_{310}n_{10} &= N_3\\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots &\\
p_{88}n_8 + p_{810}n_{10} &= N_8\\
p_{910}n_{10} &= N_9\\
p_{1010}n_{10} &= N_{10},
\end{aligned}
$$

where N_m is the observed number of events with m γ-quanta and P_{ik} is the efficiency of recording i of γ-quanta from $P_{ik} = C_k^i p^i (1-p)^{k-i}$.

The result obtained was $p = 0.67 + 0.01$. The number of reaction events n_m is shown in Table 2.

Table 2.

Number of γ-quanta	2	3	4	6	8	I0
Number of n_m reactions	3700±I87	I098±270	34I8±233	I2I9±I30	362±78	59±27

The events found were measured with a stereoprojector and a semi-automatic digital unit (PTsS). By means of the stereoprojector, measurements were made, for each event, of the polar and azimuthal escape angles of the γ-quanta, the angles between the γ-quanta, the radii of curvature of the electron and positron tracks and the potential lengths of the γ-quanta. Measurements were also made, on the digital unit, of the coordinates of the points on the π^--meson and electron tracks. The data from the digital unit were used for calculations with the "Heavy chamber" programme (3). The corrections to the γ-quanta momenta for radiation losses of electrons were calculated by the Behr and Mittner method [4] with a cut-off parameter of 0.7. Both measurement methods, the stereo-projector and the digital unit, gave results which were identical in accuracy: $\pm$ 30% for the energy of the γ -quanta and $\pm 2^{\circ}$ for the angles.

The Behr and Mittner method presupposes the measurement of the curvature radii of the tracks over a certain optimum length related to the intensity of the magnetic field and the cut-off parameter. Measurement over lengths shorter than the optimum considerably increases the error. Consequently, a large number of events which, as a result of Coulomb scattering and Bremsstrahlung, showed kinks in the electron and position tracks at short distances from the conversion point, were unsuitable for measurement. As a result, the number of events with a γ -quantum number of 3, 4, 5 and 6 selected for measurement and subsequent scanning was 742, 433, 176 and 67 respectively.

2. The $\pi^- + p \to n + 3\gamma$ reaction

All of the events measured having three γ -quanta were scanned for the missing mass in the 3 γ -quanta. The events selected were those having a missing mass of less than 1500 MeV, in order to decrease considerably the number of events which did not belong to the $\pi^- + p \to n + 3\gamma$ reaction. As a result, 397 events were left. For these, calculations were made of the effective masses of the 3 γ -quanta systems and of all the combinations with two γ -quanta, after which a selection was made of those events for which at least one of the combinations with two γ -quanta had an effective mass in the 70-200 MeV range, i.e. in the region of the mass of the π^0-meson (account being taken of experimental error). After this selection had been made, there remained 332 events which included events of the reaction $\pi^- + p \to n + \pi^0 + \gamma$ and the background from the events having a larger number of γ -quanta.

To determine the shape of the background distributions, combinations were made with three γ -quanta from all measured events with 4, 5 and 6 γ -quanta; to these were applied the selection procedures for the missing mass and the mass of the π^0 -meson, as described above. The $\pi^- + p \rightarrow n + \pi^0 + \gamma$ reaction was isolated by deducting the background. The effective mass distribution of the $\pi^0\gamma$ system is given for this reaction in figure 1.

As can be seen from the block diagram in Figure 1, the distribution shows a pronounced peak at a mass of about 800 MeV. This maximum is the result of the production of an ω -meson in the $\pi^- + p \rightarrow n + \omega$ reaction with its subsequent decay according to $\omega \rightarrow \pi^0 + \gamma$. Furthermore, the distribution shows a marked surplus of events in the 1000 - 1400 MeV range of masses. A similar phenomenon had already been noted in the paper by Barmin et al (5).

As for the events relating to the ω -meson (mass range: 600 - 900 MeV) calculations of the elements of the spin matrix of density ρ_{00}, ρ_{1-1} n $Re\,\rho_{10}$ showed these to be: $\rho_{00} = 0.74 \pm 0.32$, $\rho_{1-1} = 0.11 \pm 0.20$ and $Re\,\rho_{10} = 0.12 \pm 0.13$. These values correspond with those predicted with the OMAE model for the case when it is assumed that there is an exchange of a ρ -meson as the fundamental mechanism of the reaction $\pi^- + p \rightarrow n + \omega$ (8) and agrees with the experimental results obtained for the reaction $\pi^+ + n \rightarrow p + \omega\ (\omega \rightarrow \pi^+ + \pi^- + \pi^0)$ at momenta similar to those of our experiment (6,7).

There is also agreement between the OMAE model and the distribution we obtained for the square of the 4-momentum transfer for events from the same mass range, 600 - 900 MeV, as is shown in figure 2. The theoretical curve calculated by Jeckson has been plotted on the distribution (8).

3. The $\pi^- + p \rightarrow n + 4\gamma$ reaction

Out of all of the events measured with 4 γ -quanta, 304 events were chosen for which the missing mass with 4 γ -quanta was less than 1500 MeV. For these, calculations were made of the effective masses of the system with 4 γ -quanta and of all combinations with two γ -quanta. It appeared that for 185 events, the masses of two independent combinations with two γ -quanta were in the mass range of the π^0-meson (700 - 200 MeV). After subtracting the background from the events which had a larger number of γ -quanta for such events, a reaction was isolated which, in its final state, gave rise to two π^0-mesons.

The effective mass spectrum of the $2\pi^0$ system is shown in figure 3. By means of an arbitrary normalisation, the graph has been plotted with the phase curve for the reaction $\pi^- + p \rightarrow n + \pi^0 + \pi^0$, which, as we see, does not describe the experimental distribution obtained. On the bar-chart two maxima are clearly visible, one for a mass of $\sim$ 700 MeV, with a width of $\sim$ 300 MeV, and the other is apparently an f -meson, which decays according to $f \rightarrow \pi^0 + \pi^0$.

Figure 4 shows distributions for the cos θ of the events from two mass ranges of the spectrum (θ = angle between the π^- and π^0-mesons in the rest system of two π^0 -mesons). The distributions are given for both π^0-mesons and events have been selected in which the square of the 4-momentum transfer $\Delta^2 < 0.5$ $(GeV/c)^2$. The distribution in figure 4-b agrees well with similar experimental results obtained in those papers in which the $f \rightarrow \pi^+ + \pi^-$ decay was studied [9]. The angular distribution of the events from the 600 - 900 MeV range is described well by the curve $y = 8.0 + 33.2 \cos^2\theta + 9.8 \cos^4\theta$, selected by the least squares method and plotted on the graph.

Figure 5 shows the distribution of events from the 600 - 900 MeV range depending on the square of the momentum transfer. As can be seen, the majority of events are within $\Delta^2 < 1.0$ $(GeV/c)^2$.

4. Cross-sections of the reactions

The cross-sections of the $\pi^- + p \to n + m\gamma$ reactions were calculated with the formula $\sigma_m = \sigma_0 \, n_m / \sum_2^{10} n_m$, where n_m is the number of reactions from Table 2 and σ_0 is the cross-section of the reaction $\pi^- + p \to$ neutrals (with no strange reactions), taken to be 2.0 mbarn at 2.94 GeV/c [10]. In this way the cross-sections of the reactions were determined in which the final states $\pi^0\gamma$ and $2\pi^0$ occur, the number of these reactions being calculated from the solution of systems of equations similar to the system shown in section I, but based on the scanning of events according to the missing mass and the mass of the double combinations of γ -quanta. A summary of the cross-sections obtained is given in Table 3, which also includes the estimates of the cross-sections of the $\pi^- + p \to n + \omega(\omega \to \pi^0 + \gamma)$ and $\pi^- + p \to n + f\,(f \to 2\pi^0)$ reactions which can be made on the basis of Figures 1 and 3.

The cross-sections given in Table 3 for the $\pi^- + p \to n + m\gamma$ reactinns when m = 4, 6, 8 and 10 agree satisfactorily with the papers referred to, where these sections were measured at momenta similar to that of our experiment, [10,11]. The cross-section of the reaction $\pi^- + p \to n + \omega$ according to the interpolation of the data obtained for the charge-symmetry reaction $\pi^+ + n \to p + \omega$ for various momenta [12,13] should be 0.8 mbarn at 2.94 GeV/c. The estimate given in Table 3 agrees well with the value if the relation $\Gamma(\omega \to \pi^0 + \gamma)/\Gamma(\omega \to \text{all}) = 0.094$ [14]. Our estimate of the production-section of the f -meson is also in agreement with the data obtained for similar momenta described in other papers [15].

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Table 3

Final state	3γ	4γ	6γ	8γ	10γ	$\pi^0\gamma$	$2\pi^0$	ω ($\omega \to \pi^0\gamma$)	f ($f \to 2\pi^0$)
Cross-section in microbarn	223±55	694±47	247±26	73±I6	I2±51	205±5I	480±I50	80	90

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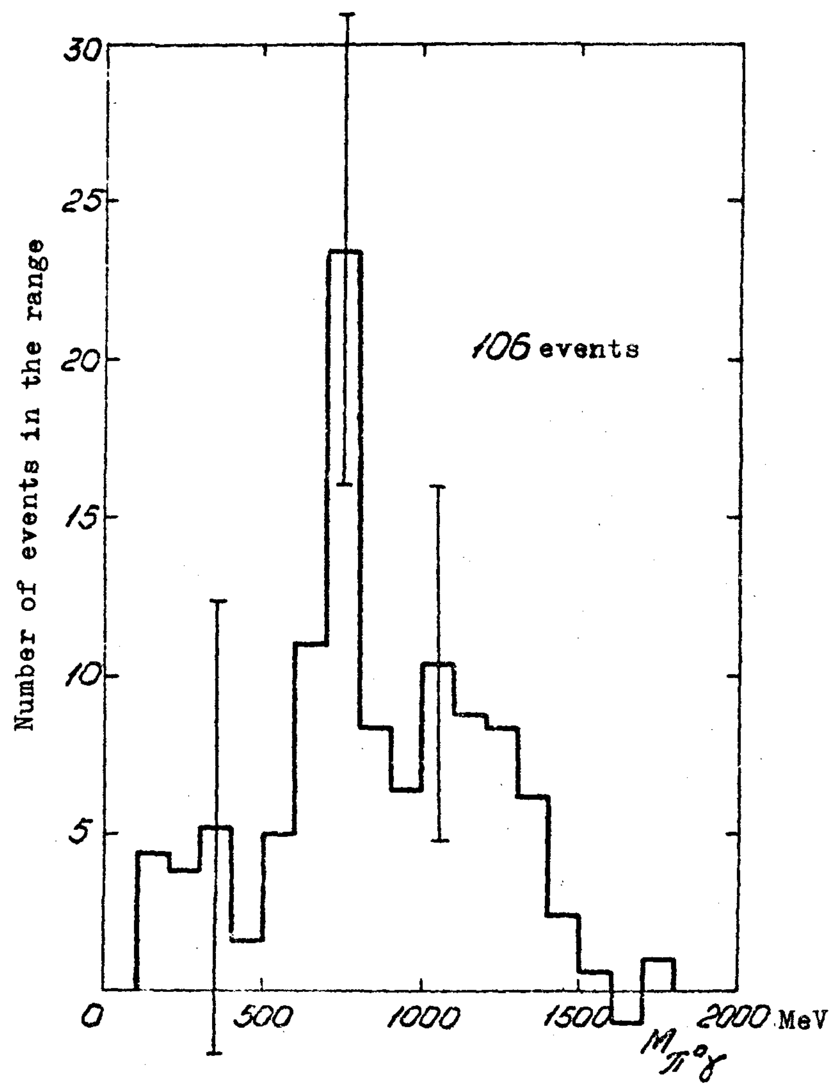

Fig. 1 Effective mass distribution of the $\pi^{0}\gamma$ system.

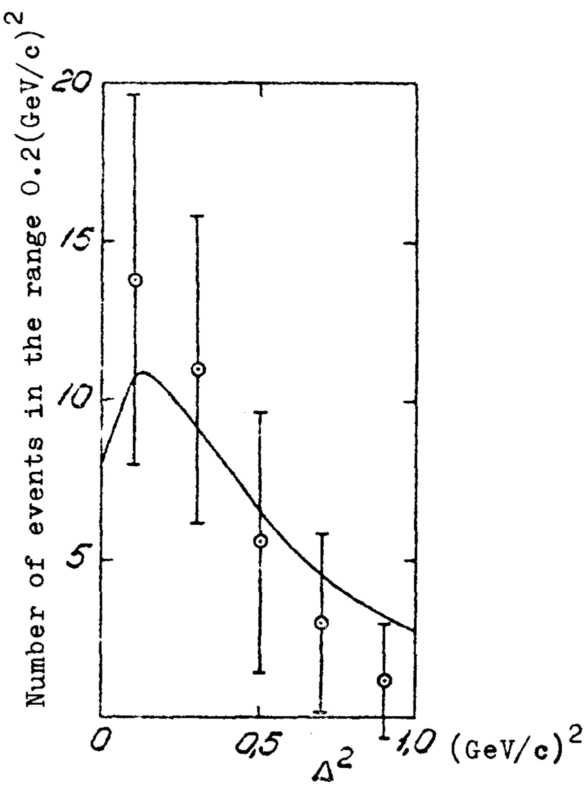

Fig. 2 Distribution of events in the range $600 \leq M_{\pi^0\gamma} \leq$ 900 MeV according to the square of the 4-momentum transfer.

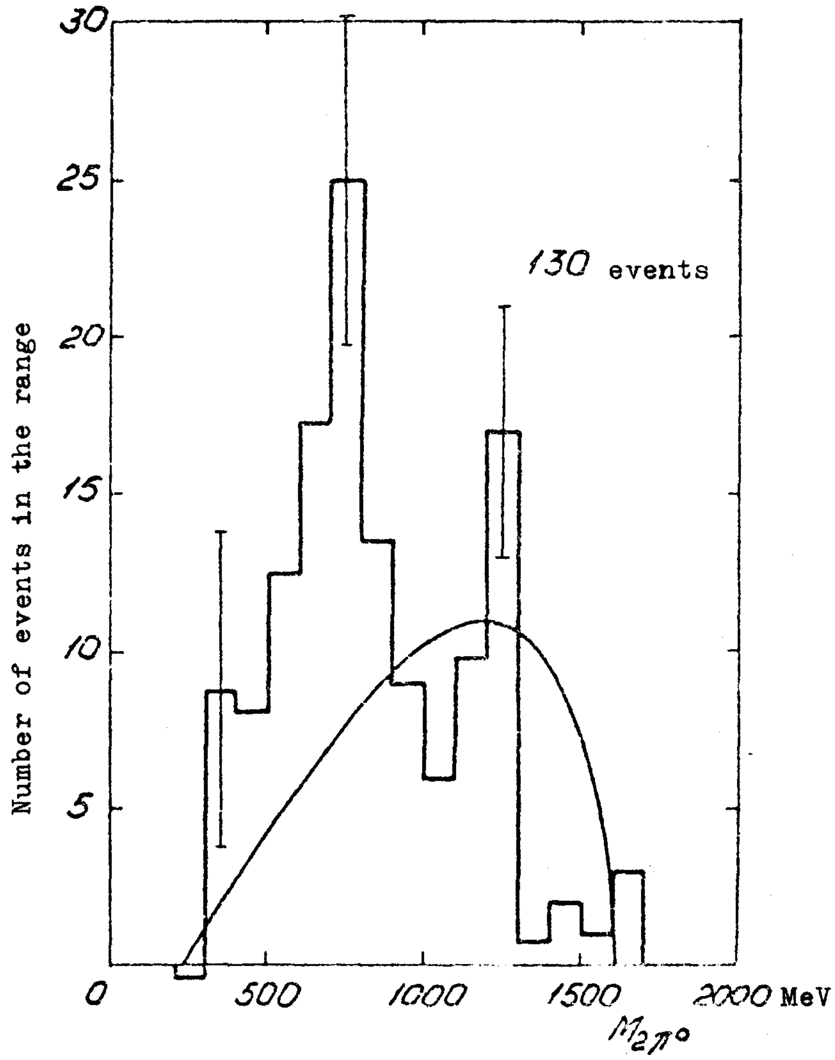

Fig. 3 Effective mass distribution of the $2\pi^0$ system.

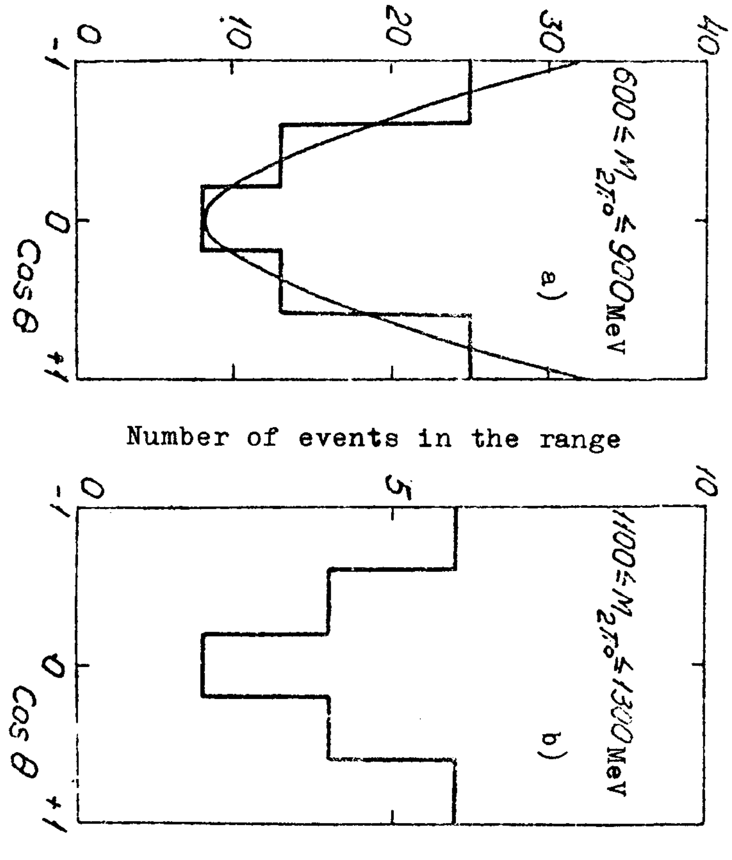

Fig. 4 Angular distribution of the $2\pi^{\circ}$ system for two mass ranges.

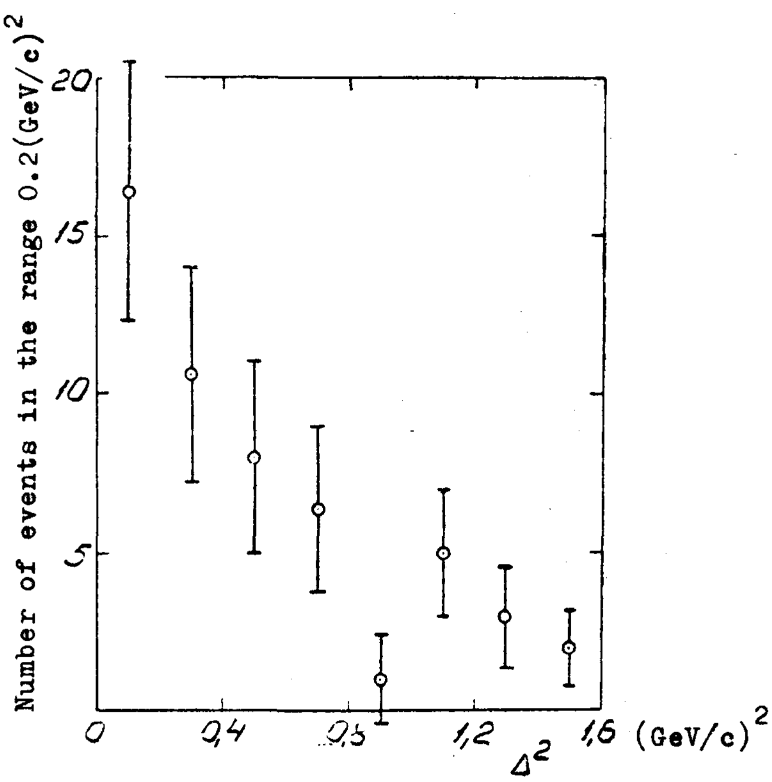

Fig. 5 Distribution of events from the range $600 \leq M_{2\pi^0} \leq 900$ MeV according to the square of the 4-momentum transfer.