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Abstract

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ANALYSIS OF PHOTOPRODUCTION OF POSITIVE PIONS AT PHOTON ENERGIES OF 175–230 MeV

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During the last several years, experiments on the photoproduction of positive pions on hydrogen near threshold ($E_\gamma \leq 230$ MeV) have pursued the aim of increasing the accuracy of the experimental data. This is due to the fact that, on the one hand, quantitative measurements are necessary for carrying out a phase analysis of photoproduction processes, while, on the other hand, such measurements can provide information on how well the modern theory, based on dispersion relations, describes experiment. The uncertainties of theoretical estimates in the energy region near threshold are minimal. Therefore, comparison of experimental data with the results of correct theoretical calculations makes it possible to assess the role of various effects in pion photoproduction processes, including the influence on photoproduction of the resonant $\pi - \pi$ interaction (the ρ-meson). The purpose of the present communication is to compare new experimental data, obtained over a wide range of angles and energies, with the results of new calculations performed on the basis of dispersion relations ([1]).

The experiment was carried out on the 260 MeV synchrotron of the P. N. Lebedev Physical Institute of the Academy of Sciences of the USSR. A bremsstrahlung photon beam, after passing through a system of collimators and a cleaning magnet, entered a liquid-hydrogen target. Stacks of nuclear photographic emulsions NIKFI BK-400 served as the pion detector. All cases of $\pi - \mu$ decays were recorded, and also, for additional control, the ends of muon tracks and pion tracks near stopping. Tracking the tracks in adjacent layers made possible the unambiguous identification of each event and the elimination of accidental background. The background of pions from the target walls amounted to about 1.5%. The photon energy flux was measured with a quantameter. The correction for pion decay in flight and nuclear interaction amounted to from 6 to 19%, depending on the pion energy.

Differential cross sections $d\sigma/d\Omega$ for photoproduction of positive pions were measured for 9 angles at photon energies, in steps of 5 MeV, from 175 to 230

Figure 1

Figure 1: Figure 1

MeV. Below, the cross sections are given with only the statistical standard errors indicated, whose average value was $\sim 6\%$.

Figure 1 shows the dependence of the quantity $\frac{k}{q}\frac{d\sigma}{d\Omega}$ $(\theta = 90^\circ)$ on q^2, where θ is the pion emission angle in the center-of-mass system (c.m.s.); k, q are the momenta of the photon and pion in the c.m.s., expressed in units $\hbar = \mu = c = 1$. The observed agreement of our data (including the results of work (3)) with the data obtained in other laboratories (2,4–6) also holds for other angles. The solid line represents the dependence of $\frac{k}{q}\frac{d\sigma}{d\Omega}$ $(\theta = 90^\circ)$ on q^2, calculated from one-dimensional dispersion relations.

In calculating the cross sections, in addition to the contribution to the dispersion integrals of the first resonance in the $\pi{-}N$ system, the contribution of the second resonance was taken into account.

and nonresonant S- and P-wave amplitudes. The imaginary parts of the resonant amplitudes were determined from experimental data on photoproduction and meson scattering. The imaginary parts of the nonresonant amplitudes were calculated from static dispersion relations using

Fig. 1. 1 –according to (2); 2 –according to (3); 3 –our data

for the description of small pion-nucleon scattering phases the results of the analysis by Hamilton et al. (7). As follows from the figure, satisfactory agreement is observed between the experimental data for $\theta = 90^\circ$ and the theory. The value of the S-wave amplitude obtained by extrapolation to threshold, $F_{10} = (3.99 \pm 0.17) \cdot 10^{-15}$ cm, agrees within the errors with the theoretical value $F_{10} = 4.03 \cdot 10^{-15}$ cm.

However, such agreement is not observed for all amplitudes. In Fig. 2a the quantity

$$\Phi = \frac{1}{2}\sqrt{\frac{k}{q}}\left[\sqrt{\frac{d\sigma}{d\Omega}(165^\circ)} - \sqrt{\frac{d\sigma}{d\Omega}(20^\circ)}\right]$$

is presented; it is proportional to the sum of two amplitudes for pion photoproduction in the P-state. As can be seen from the figure, the experimental points lie above the curve calculated from one-dimensional dispersion relations. This discrepancy cannot be due to uncertainty in the calibration of the photon flux, since eliminating the discrepancy would require changing the calibration by a factor of 1.5, which contradicts the calibration accuracy of 5-10%.

Figure 2

Figure 2: Figure 2

Fig. 2

The quantity Φ is sensitive to the contribution of the ρ-meson to the photoproduction amplitudes, characterized by the constant of the $\gamma - \pi - \rho$ interaction Λ. If the discrepancy is attributed to this contribution, then for Λ, according to a χ^2-analysis, one should choose the value $\Lambda = 0.6ef$ $(e^2 = 1/137,\ f^2 = 0.08)$. The confidence interval for Λ lies between 0.4 and $0.8ef$ at a confidence level of 95%. It should be noted that the subtraction constant of the process $\gamma + \pi \to \pi + \pi \to N + \widetilde{N}$ affects the value of Φ comparatively weakly, and for estimating the value of Λ we used the bipion approximation [8].

In Fig. 2b the quantity

$$\Psi = \frac{1}{2}\sqrt{\frac{k}{q}}\left[\sqrt{\frac{d\sigma}{d\Omega}(165^\circ)} + \sqrt{\frac{d\sigma}{d\Omega}(20^\circ)}\right],$$

is shown; it is proportional to the sum of the pion-production amplitudes in the S- and D-states. In contrast to Φ, the quantity Ψ depends not only on Λ, but is also determined to a considerable degree by the subtraction constant. If the value $\Lambda = 0.6ef$ found above is used to estimate A, then we find that the subtraction constant is small and equal to -0.014. In the subsequent analysis of the angular distributions we shall discuss the contribution of the $\gamma - \pi - \rho$ interaction only in the bipion approximation.

In Figs. 3a and 3b the angular distributions of pions are shown for photon energies of 185 and 215 MeV. For $E_\gamma = 185$ MeV, unlike the other energies, differential cross sections were obtained for 12 angles, which made it possible, by the least-squares method, to approximate the shape of the angular distribution in the form of a series in powers of $\cos\theta$ (β is the pion velocity):

$$(1 - \beta\cos\theta)^2\, d\sigma/d\Omega = A + B\cos\theta + C\cos^2\theta + D\cos^3\theta + E\cos^4\theta + F\cos^5\theta.$$

It turned out that $\chi^2 = 21.1$ for an expansion up to and including $\cos^4\theta$, and $\chi^2 = 4.9$ for an expansion up to and including $\cos^5\theta$. It follows from this that, in photoproduction of pions near threshold, the formation of pions in the D-state probably makes a contribution. One possible explanation for the nature of this contribution may be the influence of the ρ-meson.

Fig. 3

If the angular distribution for $E_\gamma = 185$ MeV is compared with the results of calculations performed with allowance for the $\gamma - \pi - \rho$ interaction, the best

Fig. 3

Figure 3: Fig. 3

agreement is achieved at $\Lambda \approx 1\,ef$. The same value of Λ is obtained from the angular distribution at $E_\gamma = 190$ MeV. At higher energies the experimental data indicate smaller values of Λ.

It is useful to compare all the experimental data with theoretical calculations, taking as parameters the constant Λ and the beam-calibration coefficient K. Table 1 gives the values of χ^2 as a function of Λ and K. The number of free parameters is $N = 102$. As can be seen from the table, the best agreement of theory with experiment is observed at $\Lambda = 0.4\,ef$ and $K = 1$. It should be noted that the value $\chi^2 = 150$ for $N = 102$ indicates that the agreement achieved between experiment and theory is not the best possible. If the uncertainty in the theoretical estimates is taken into account, the situation improves considerably. For the best comparison of experiment with theory, it is necessary both to further increase the accuracy of the experimental data and, in the theoretical calculations, to refine the values of the dispersion integrals.

Table 1

K	$\Lambda = 0$	$\Lambda = 0.2$	$\Lambda = 0.4$	$\Lambda = 0.6$
1	211	177	150	175
0.95	174	178	205	262
0.90	310	389	–	–

In conclusion, it should be emphasized that photoproduction of positive pions can provide more reliable information on the constant of the $\gamma-\pi-\rho$ interaction than photoproduction of neutral pions, since the latter process is influenced not only by the ρ- but also by the ω-meson.

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Note: Figure translations are in progress. See original paper for figures.