STUDY OF THE REACTION $\pi^- + \text{Xe} \rightarrow \pi^- + \pi^0 + \text{Xe}$ *FOR 9-BeV/c PRIMARY* π^- *MESONS*

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Reaction (2) for 9 BeV/c primary π^- mesons was studied in a xenon bubble chamber. The upper limit of the cross section for production of π^0 mesons in the Coulomb field of the Xe nucleus is estimated to be 1.0 ± 0.2 mb.

In this investigation we have studied the formation of π^- and π^0 mesons in the interaction of π^- mesons with nuclei for small momentum transfer to the recoil nucleus. Several possibilities exist for this process:

a) interaction of a π^- meson with a quasifree neutron:

$$\pi^- + n \rightarrow \pi^- + \pi^0 + n; \tag{1}$$

b) nuclear interaction of a π^- meson with the xenon nucleus as a whole;

c) creation of a π^0 meson in the Coulomb field of the nucleus.

The last two possibilities correspond to the reaction

$$\pi^- + \text{Xe} \rightarrow \pi^- + \pi^0 + \text{Xe}. \tag{2}$$

In the study of these reactions the greatest interest clearly is presented by the process of producing a π^0 meson in a Coulomb field. Study of this reaction could yield information on the interaction of π mesons with γ rays. Theoretical treatment of the production of particles in a Coulomb field has been given by Pomeranchuk and Shmushkevich [1] and by Good and Walker [2]. Barmin et al. [3,4], who carried out experiments with a xenon bubble chamber for a π^- momentum of 2.8 BeV/c, give data on the evaluation of the cross section for reaction (2).

For separation of type (1) and (2) events with low momentum transfer to the nucleus, in photographs obtained with a 24-liter xenon bubble chamber irradiated by 9 BeV/c π^- mesons, we selected cases of π^- scattering at an angle $\varphi \geq 2°$, accompanied by two γ rays converted in the chamber. In double scanning of 54,000 photographs we obtained 290 such cases located in the working region of the chamber. The average efficiency of the double scanning was 92 ± 2%.

For all events selected, measurements were made of the emission angles of the γ rays and the π^- meson. In addition the γ-ray energies were measured by the method described by Danysh et al [6]. The energy was determined from the total electron path length R for a given length of shower development d, i.e., distance from the point of production of the first pair of the shower to the point of exit of the shower from the chamber. The curves of $E_\gamma(R, d)$ taking into account the fraction of the electron energy leaving the chamber, given by Danysh et al, permit determination of the energy with an accuracy of 20–25% up to about 600 MeV. At higher energies the estimate is less accurate. For showers produced by high-energy γ rays ($E_\gamma \geq 2$ BeV), a calculation was made of the number of particles at the peak of the shower development, and their energy was evaluated from the shower curve.

γ-ray energies were measured in 190 events.[1)] From the data obtained, after application of geometrical corrections, we plotted the γ-ray energy spectrum shown in Fig. 1. We can see that the spectrum has a peak in the region 50–100 MeV, corresponding to the decay $\pi^0 \rightarrow 2\gamma$, and beyond that falls rather slowly without any anomalies.

In addition we computed the effective mass of the two γ rays:

$$m_{\gamma\gamma} = 2 \sin \frac{\theta}{2} \sqrt{E_1 E_2}, \tag{3}$$

where E_1 and E_2 are the γ-ray energies and θ is the angle between them. The distribution of $m_{\gamma\gamma}$ is shown in Fig. 2, where the abscissa is log $m_{\gamma\gamma}$ with an interval corresponding to a constant error

1)In a fraction of the events with small lengths of shower development (d < 10 cm), the γ-ray energy was not measured.

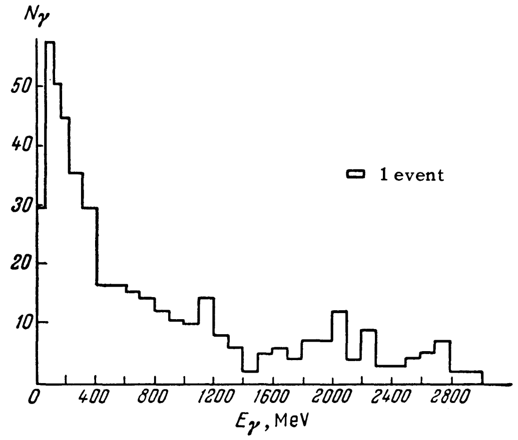

FIG. 1. γ-ray energy spectrum.

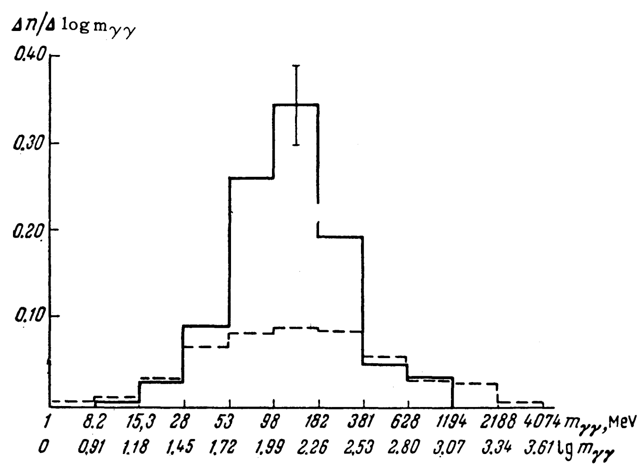

FIG. 2. Spectrum of the mass $m_{\gamma\gamma}$ (the dashed line gives the distribution of $m_{\gamma\gamma}$ calculated by the Monte Carlo method).

$\Delta m_{\gamma\gamma}/m_{\gamma\gamma} = 30\%$, and the ordinate is the fraction of the events in an interval. The distribution obtained can be used for determination of the cross section for production of a single π^0 meson. It is necessary, however, to consider the background associated with interactions in which more than one π^0 meson are formed and for which only two γ rays belonging to different π^0 mesons are counted in the working volume of the chamber. For calculation of this background we plotted a distribution of $m_{\gamma\gamma}$ obtained by the Monte Carlo method. In this calculation we used the γ-ray energy spectrum and the distribution of angles between the γ rays obtained experimentally. From these distributions we determined a set of random values of E_1, E_2, and θ which were used for computing values of $m_{\gamma\gamma}$ corresponding to background events.

In order to subtract the background, the distribution obtained by the Monte Carlo method was normalized to the experimental distribution in the intervals $\log m_{\gamma\gamma} < 1.72$ and $\log m_{\gamma\gamma} > 2.53$, i.e., in those parts of the experimental distribution where there can be only background events. The distribution normalized in this way is plotted in Fig. 2 (dashed line). After subtraction of the background and correction for γ-ray counting efficiency, the cross section turned out to be 4.9 ± 0.5 mb (the statistical error is given).

As we have pointed out above, considerable interest is attached to the study of π^0-meson production in the Coulomb field of a nucleus. If we assume that this process results from exchange of one virtual photon, then we must expect that at very high momentum transfers its cross section will be large compared to the cross section for reactions occurring with exchange of virtual π mesons. According to estimates given by Barmin et al. [3], these cross sections are equal for $q^2 \approx (m_\pi/2)^2$. In the same paper a criterion is proposed for separation of the events of reaction (2) with small momentum transfer, based on analysis of the emission angles of the secondary π^- mesons and γ rays.

On the basis of the results obtained for 2.8 BeV/c π^- mesons, we could expect the angular distribution of secondary π^- mesons to be narrower for cases satisfying this criterion than for

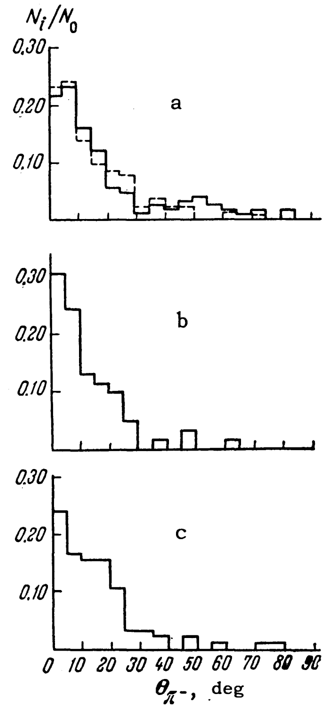

FIG. 3. Angular distribution of π^--mesons: a) in events with two γ-rays (the solid line gives the distribution for events satisfying the small-momentum-transfer criterion; the dashed line – for events not satisfying this criterion), b) in events with two γ-rays for which 98 MeV < $m_{\gamma\gamma}$ < 182 MeV, c) in events with three γ-rays.

cases not satisfying it. However, both classes of events actually have the same angular distribution of secondary π^- mesons (see Fig. 3a). Moreover, for events with large momentum transfer in which at least two π^0 mesons were produced (i.e., cases of scattering accompanied by three γ rays), the π^--meson angular distribution turned out to be the same (Fig. 3c). The π^--meson angular distribution shown in Fig. 3b for events with two γ rays in which $m_{\gamma\gamma}$ is close to the π^0-meson mass is in no way different from the distribution shown in Figs. 3a and 3c. It should be noted also that in events with one π^0 meson, the fraction of the cases satisfying the small-momentum-transfer criterion[3] is the same as for cases where the number of π^0 mesons is clearly more than one; this fraction is 0.43 ± 0.08 and 0.45 ± 0.06, respectively, for the two cases. Thus, the criterion proposed by Barmin et al.[3] is not satisfactory for primary π^- mesons of 9 BeV energy.

In order to select cases of π^0-meson formation with low momentum transfer, we plotted curves of the emission angle of a secondary π meson as a function of its momentum in the laboratory system for different values of the longitudinal component of momentum transfer:

$$\cos\theta_\pi = \frac{2E_0E - 2E_0q_\parallel - m^2}{2\left[(E^2 - m^2)(E_0^2 - 2E_0q_\parallel - m^2)\right]^{1/2}}, \qquad (4)$$

where $E_0 = 9$ BeV is the energy of the incident π^- meson, m and E are the mass and energy of the secondary meson, and $q_\parallel$ is the longitudinal component of the momentum transferred to the Xe nucleus in the π^-Xe interaction. From these curves we evaluated $q_\parallel$ for events having a mass $m_{\gamma\gamma}$ close to the π^0-meson mass. In this evaluation we assumed that the direction of the combined momentum of the secondary π^- and π^0 mesons was not appreciably different from the direction of the primary π^- meson. Estimates show that this assumption is practically always correct in our case.

According to Barmin et al.[3] production in the Coulomb field is the main process when $q^2 < (m_\pi/2)^2$. Therefore for evaluating the Coulomb production cross section σ_C, we must select the events satisfying this condition. The procedure used by us permits determining only the longitudinal component of momentum transfer, and in particular determining the production cross section of a single π^0 meson σ_1 for $q_\parallel \leq 70$ MeV/c, which turned out to be 1.0 ± 0.2 mb. Since $q_\parallel \leq q$, then among the events selected for the determination there can be cases with a squared momentum transfer $q^2 > (m_\pi/2)^2$. Taking this into account, we can conclude that the cross section σ_C is less than or equal to $\sigma_1 = 1.2 \pm 0.2$ mb.

In the work of Barmin et al.[4] carried out in a xenon chamber with a π^--meson momentum of 2.8 BeV/c, the Coulomb production cross section was found to be 2.65 ± 0.90 mb. If we take this value of σ_C and use the energy dependence of σ_C obtained by Pomeranchuk and Shmushkevich[1] and by Barmin et al.[3], then we should expect a value of σ_C for 9-BeV/c π^- mesons of 7 mb. This assumes, as in the paper of Barmin et al.[4], that the cross section σ_p for the process $\gamma + \pi \rightarrow \pi + \pi$ is practically independent of energy.

The value of σ_C calculated in this way does not agree with the results of the present investigation. The observed discrepancy may be due to the fact that the assumption of the constancy of σ_p is not fulfilled. It also cannot be excluded that at an energy of 9 BeV the interaction of π^- mesons with the Coulomb field of the Xe nucleus leads to production of more than one π^0 meson.

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