Determination of the probability for the decay $\rho^0 \to \mu^+\mu^-$

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The events corresponding to the formation of the 1^+S state of the $\rho^0\pi^-$ system have been identified in the study of the coherent dissociation reaction $\pi^- + \mathrm{Cu} \to \mathrm{Cu} + \rho^0 + \pi^-$ with a subsequent decay of a ρ^0 meson into a $\mu^+\mu^-$ pair at 50 GeV/c. The cross section of this process and the probability for the decay $\rho^0 \to \mu^+\mu^-$ have been determined. The measured probability value in the mass interval of the $\rho^0\pi^-$ system 1.0–1.4 GeV/c^2 is $\mathrm{Br}_{\rho^0 \to \mu^+\mu^-} = (4.6 \pm 0.2_{\rm stat} \pm 0.2_{\rm syst}) \times 10^{-5}$.

On the basis of the $\mu - e$ universality hypothesis, the probabilities for the decay of particles into $\mu^+\mu^-$ and e^+e^- should be the same within the corrections to the phase space. This situation in fact occurs in the case of most mesons with such decay modes. Until now, however, the measured probabilities for the decays $\rho^0 \to \mu^+\mu^-$ (Refs. 2–4) and $\rho^0 \to e^+e^-$ differed markedly from each other. The ratio of these probabilities is[1]

$$\mathrm{Br}_{\rho^0 \to \mu^+\mu^-} / \mathrm{Br}_{\rho^0 \to e^+e^-} = (6.7 \pm 1.2) \cdot 10^{-5} \,/\, (4.5 \pm 0.2) \cdot 10^{-5} = 1.5 \pm 0.3.$$

We have carried out an experimental study in order to determine more accurately the probability for the decay $\rho^0 \to \mu^+\mu^-$. This study was based on the data obtained in a study of the coherent dissociation of a π^- meson into $\mu^+\mu^-\pi^-$ system on a copper nucleus at 50 GeV/c:

$$\pi^- + \mathrm{Cu} \to \mathrm{Cu} + \mu^+ + \mu^- + \pi^-. \qquad (1)$$

This reaction is especially useful for the solution of this problem: As was shown in Ref. 5, this reaction involves primarily the production of a ρ^0 meson which subsequently decays into a $\mu^+\mu^-$ pair.

The probability for the decay $\rho^0 \to \mu^+\mu^-$ was defined as the ratio of the cross section for reaction (1) to the cross section for the coherent dissociation of a π^- meson into the system $\pi^+\pi^-\pi^-$ in the interaction

$$\pi^- + \mathrm{Cu} \to \mathrm{Cu} + \pi^+ + \pi^- + \pi^- \qquad (2)$$

for the $l^+S\rho^0\pi^-$ state of the final reaction products in the mass interval (1.0–1.4) GeV/c^2.

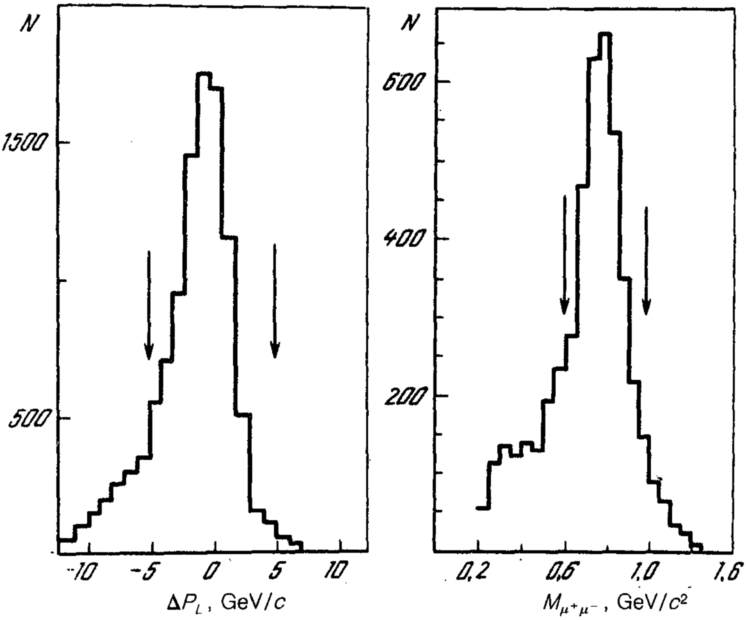

FIG. 1. (a) Longitudinal momentum profile of the $\mu^+\mu^-\pi^-$ system and of the beam particles; (b) effective mass spectrum of the $\mu^+\mu^-$ pairs.

The experiment was carried out at the Institute of High Energy Physics using a "Sigma" spectrometer in a beam of π^- mesons with a momentum of 50 GeV/c. A detailed description of the experimental setup and the procedure used to identify the coherent dissociation events can be found in Refs. 5, 6, and 13.

Figure 1a shows the longitudinal momentum profile of the beam particles and of the $\mu^+\mu^-\pi^-$ system, ΔP_L. The peak at $\Delta P_L = 0$ corresponds to the dissociation of a pion incident on the $\mu^+\mu^-\pi^-$ system. The mass spectrum of dimuons for the events from the region of the peak with the imposition of the constraint $1.0 < M_{\mu^+\mu^-\pi^-} < 1.4$ GeV/c^2 is shown in Fig. 1b. As can be seen in this figure, the dimuons are primarily the decay products of the ρ^0 meson. The dissociation of π^- mesons into $\mu^+\mu^-\pi^-$ system was subsequently assumed to be such an event for which the total momentum of the $\mu^+\mu^-\pi^-$ system matched the momentum of the beam within the experimental resolution ($|\Delta P_L| \leqslant 5$ GeV/c) and for which the dimuon mass was situated in the mass region of the ρ^0 meson ($0.6 \leqslant M_{\mu^+\mu^-} < 1.0$ GeV/c^2).

To account for the geometric acceptance of the installation, we calculated by the Monte Carlo method the weight for each event of the dissociation $\pi^- \to \rho^0\pi^-$. The azimuthal angles of the π^- meson in the rest frame of the $\mu^+\mu^-\pi^-$ system and of the positive muon in the rest frame of the $\mu^+\mu^-$ pair were simulated isotropically. The polar angle of the μ^+ meson relative to the direction of motion of the incident pion in the dimuon rest frame was simulated proportionally to $\sin^2\theta$ in accordance with Ref. 7.

The square of the transverse momentum profile of the $\mu^+\mu^-\pi^-$ system is described well by the sum of the two exponential functions. A sharp rise at $P_{t^2} < 0.05$ $(\mathrm{GeV}/c)^2$ stems from the coherent dissociation of pions into the $\rho^0\pi^-$ system and corresponds to the exponential function with the slope parameter $b_1 = 50 \pm 2$ $(\mathrm{GeV}/c)^{-2}$. The other exponential function with the slope $b_2 = 8 \pm 0.5$ $(\mathrm{GeV}/c)^{-2}$ describes the incoherent part of the spectrum. The small measured value of the slope parameter b_1 in comparison with the typical value[8] for the processes under consideration is attributable to the resolution of the spectrometer.

The number of coherent events, N_c, and incoherent events, N_{ic}, of the dissociation $\pi^- \to \pi^-\mu^+\mu^-$ was determined in the solution of the following two equations for N_c and N_{ic}:

$$N_c b_1 \int_0^{0.05} \exp(-b_1 x)dx + N_{ic} b_2 \int_0^{0.05} \exp(-b_2 x)dx = I_1 ,$$

$$N_c b_1 \int_0^{0.5} \exp(-b_1 x)dx + N_{ic} b_2 \int_0^{0.5} \exp(-b_2 x)dx = I_2 ,$$

where I_1 and I_2 are the intensities of the 1^+S wave of the $\rho^0\pi^-$ system in the P_{t^2} intervals (0–0.05) $(\mathrm{GeV}/c)^2$ and (0–0.5) $(\mathrm{GeV}/c)^2$, respectively. The intensities I_1 and I_2 were calculated as a result of partial-wave analysis[6] of various mass intervals of the $\rho^0\pi^-$ system. The experimental cross section of the dissociation was calculated from the equation

$$\sigma = N_c \times W, \tag{3}$$

where N_c is the number of coherent $\mu^+\mu^-\pi^-$ events which satisfy all the selection rules. The value of W was determined from the expression

$$W = 1/(N_T \times A_T \times N_{Mon} \times \epsilon), \tag{4}$$

where N_T is the number of target nuclei per unit area, A_T is the correction for N_T due to the length of the target and its absorption of the primary and secondary pions, N_{Mon} is the number of beam particles that passed through the detectors, which corresponds to the number of events of the coherent dissociation $\pi^- \to \rho^0\pi^-$, and ϵ is the correction which takes into account the number of lost coherent events because of the inefficiency of the detectors and the reconstruction programs. Table I gives the results of the

TABLE I.

ΔM, GeV/c^2	$\sigma_{\pi^- \to \mu^+\mu^-\pi^-}$, nb	$\sigma_{\pi^+\pi^-\pi^-}$, mb	$\mathrm{Br}_{\rho^0 \to \mu^+\mu^-} \cdot 10^5$
1.0 ÷ 1.2	79 ± 2 ± 5	1.71 ± 0.08	4.7 ± 0.3 ± 0.3
1.2 ÷ 1.4	43 ± 2 ± 3	1.01 ± 0.05	4.3 ± 0.3 ± 0.3
1.0 ÷ 1.4	122 ± 3 ± 6	2.68 ± 0.11	4.6 ± 0.2 ± 0.2

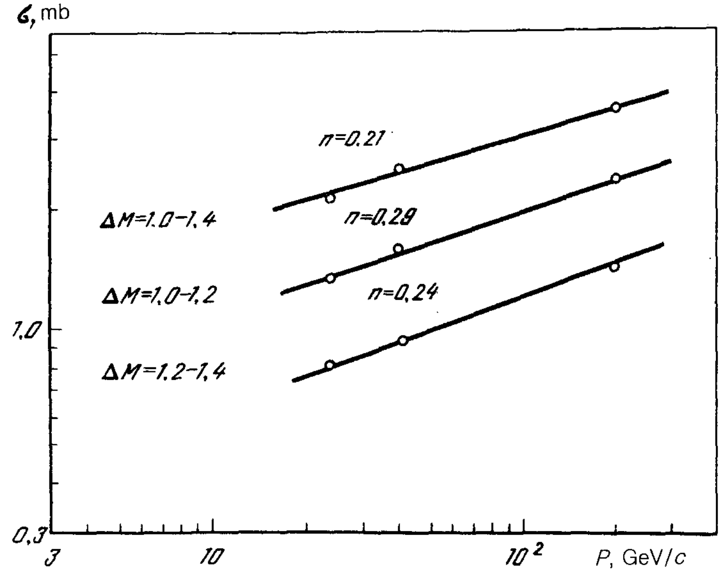

FIG. 2. Cross sections for the coherent production of the $\pi^+\pi^-\pi^-$ system in the 1^+S state in the π^-Cu interactions at various energies in various mass intervals of the $\pi^+\pi^-\pi^-$ system. The straight lines correspond to the results of interpolations of the form $\sigma \sim p^{-n}$. The data were taken from the following references: 23 GeV/c (Ref. 11), 40 GeV/c (Ref. 8), and 200 GeV/c (Ref. 12).

calculation of the cross sections for the coherent dissociation of $\pi^- \to \mu^+\mu^-\pi^-$ for various effective-mass intervals of the $\mu^+\mu^-\pi^-$ system (the first error is statistical and the second is a systematic error).

In our experiment we did not study the coherent dissociation of $\pi^- \to \pi^+\pi^-\pi^-$, whose cross section must be normalized in order to determine the probability which we are seeking. The results of several experimental studies of reaction (2) at various energies have, however, been published. Figure 2 shows data of Refs. 8, 11, and 12 for the mass intervals of interest. We used the relation $\sigma = AP_{\text{inc}}^{-n}$ to interpret the data, from which we found the cross sections for the coherent dissociation $\pi^- + \text{Cu} \to \text{Cu} + \pi^+ + \pi^- + \pi^-$ (1^+S) at an initial momentum 50 GeV/c for the mass intervals which we are considering (see Table I). The ratios of the cross sections obtained by us to those calculated by interpolation yield the probability values for the decay $\rho^0 \to \mu^+\mu^-$.

We see that all the probability values are in good agreement with each other. To obtain the final result, however, we used the total mass interval (1.0–1.4) GeV/c^2, i.e.,

$$\text{Br}_{\rho^0 \to \mu^+\mu^-} = (4.6 \pm 0.2_{\text{stat}} \pm 0.2_{\text{syst}}) \times 10^{-5}.$$

This value agrees, within experimental error, with the probability for the decay $\rho^0 \to e^+e^-$.

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