Study of the reaction $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$ at $2E$ up to 1.4 GeV

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The reaction $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$ has been studied over the energy range 0.64–1.40 GeV. The reaction cross section can be described well by a vector-dominance model with $\rho(770)$ and $\rho(1600)$. Upper limits are found on the lepton width of $\rho(1250)$ and on the branching ratios for the decays $\rho,\omega\to\pi^+\pi^-\pi^0\pi^0$.

This letter reports a study of the reaction $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$, with the OLY*a* detector at the VÉPP-2M storage ring.[1] The statistical base was obtained by scanning the energy range 0.64–1.40 GeV at a step equal to the energy spread in the c.m. frame (0.5–0.7 MeV). The luminosity acquired experimentally is 1540 nb^{-1}. Preliminary results on the energy interval 1.0–1.4 GeV were published previously.[2]

To study this reaction, we selected events with two noncollinear tracks ($|\Delta\phi|>10°$ or $|\Delta\theta|>10°$) emerging from the region in which the beams interact and with at least two γ rays in the shower chambers of quadrants without tracks. We did not consider events with a single γ ray since they are mostly radiative events $e^+e^-\to e^+e^-\gamma$. Under these selection conditions we obtained 1527 events with two γ rays and 223 with three γ rays. The pulse-height spectra in the scintillation sandwiches provide evidence that the charged particles in the selected events are for the most part π mesons.

The main component of the background for the process under study is the reaction $e^+e^-\to\pi^+\pi^-\pi^0$. Analysis of the ratio of the numbers of events with three and two γ rays in a simulation and experimentally shows that the channel $\pi^+\pi^-\pi^0$ is predominant below 1.1 GeV, while the production of four π mesons is predominant at higher energies. A detailed calculation of the total background from the processes $e^+e^-\to\pi^+\pi^-\pi^0$, $e^+e^-\gamma$, K_SK_L shows that the observed cross section can be described well at energies up to 0.96 GeV by means of the background processes ($\pi^+\pi^-\pi^0$, $e^+e^-\gamma$), while at higher energies the cross section exceeds the background, with the difference increasing with increasing energy. This result is evidence of a new channel, $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$.

In the vector-dominance model the production of four π mesons can go by the following intermediate mechanisms[3,4]: $\omega\pi^0$, $\rho^0\pi^0\pi^0$, $A_1^{\pm}\pi^{\mp}$. In the case of the $\rho^0\pi^0\pi^0$ mechanism, charged π mesons are produced in the decay of a slow ρ meson and tend toward collinearity; for $\omega\pi^0$ and $A_1^{\pm}\pi^{\mp}$, there are no mechanisms for such a preference. Analysis of the distribution of events in the angle between the charged π mesons shows that this distribution agrees well with that expected for the $\omega\pi^0$ mechanism, and the relative importance of the $\rho^0\pi^0\pi^0$ state does not exceed 20% (Fig. 1). In calculating the total cross section we made use of the detection probability for the process

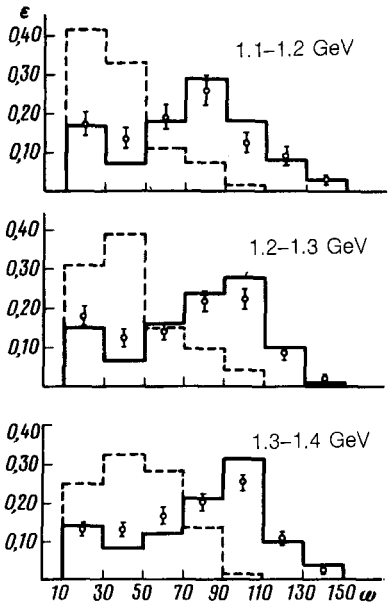

FIG. 1. Distribution in the solid angle which is a measure of the deviation from collinearity. Points—experimental; solid histogram—simulation of the $\omega\pi^0$ mechanism; dashed histogram—simulation of $\rho^0\pi^0\pi^0$.

$e^+e^-\to\omega\pi^0$, which amounts to a significant fraction of the cross section, according to the data of Ref. 5. The radiative corrections were found in accordance with Ref. 6; they varied smoothly from -13% to -2%. The systematic error in the cross section does not exceed 20% and stems from the uncertainty regarding the production mechanism.

From the measurements of the cross section for the process over the wide energy range from 0.74 to 1.40 GeV, we can search for decays $\rho,\omega\to\pi^+\pi^-\pi^0\pi^0$. A measure of their branching ratio is the difference between the observed number of events and that which would be expected from the processes $e^+e^-\to\pi^+\pi^-\pi^0$,$e^+e^-\gamma$ at $2E\sim m_{\rho,\omega}$. To determine $B(\rho,\omega\to4\pi)$, we used 440 events in the energy interval 0.7–0.9 GeV. A fit of the energy dependence of the experimental data under the assumption of the $\omega\pi^0$ intermediate mechanism yields the following upper limits on the branching ratios of the decay with a 90% confidence level:

$$B(\rho\to\pi^+\pi^-\pi^0\pi^0)<2\times10^{-4}$$
$$B(\omega\to\pi^+\pi^-\pi^0\pi^0)<2\times10^{-2}.$$

This is the first determination of an upper limit on the decay $\omega\to4\pi$. The best limit on the decay $\rho^\pm\to\pi^\pm\pi^+\pi^-\pi^0$ is[7] 2×10^{-3}, i.e., an order of magnitude poorer than that found in the present study. The limit found by us, which corresponds to $\Gamma_{\rho\to4\pi}<30$ keV, should be compared with the value calculated in the vector-dominance model[8]: $\Gamma_{\rho\to4\pi}=0.9$ keV.

Figure 2 shows the total cross section for the reaction $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$ at energies up to 2 GeV as found in the present study and also at Orsay and Frascati.[9–11] The cross section increases rapidly with the energy, and above 1.2 GeV it is significantly higher than the prediction of the vector-dominance model with $\rho(770)$ alone. Clearly,

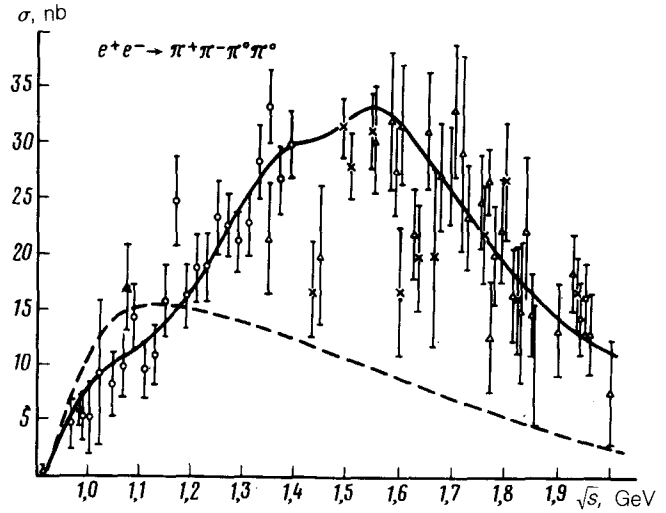

FIG. 2. Total cross section of the reaction $e^+e^-\to\pi^+\pi^-\pi^0\pi^0$. ▲—Reference 9; Δ—Ref. 10; ×—Ref. 11; O—present study; solid line—fit with allowance for an interference of $\rho(770)$ and $\rho(1600)$; dashed line—prediction of Ref. 4.

there is a contribution from $\rho(1600)$ to the observed cross section, but the large scatter in the data at energies above 1.5 GeV hinders an interpretation of the data and also a discussion of the question of $\rho(1250)$.

In fitting the experimental data we used the results of the present study up to 1.4 GeV and Orsay data at higher energies. We assumed that $\rho(1250)$ decays exclusively to $\omega\pi^0$, that $\rho(1600)$ decays exclusively to $A_1^{\pm}\pi^{\mp}$, and that $\rho(770)$ has nonzero coupling constants with both $\omega\pi^0$ and $A_1^{\pm}\pi^{\mp}$. From this fit we found that all the results can be described well even without $\rho(1250)$. The values found for the parameters of $\rho(1600)$ are close to the tabulated values. The incorporation of a nonzero coupling constant between $\rho(1250)$ and $\omega\pi^0$ changes χ^2 only insignificantly. For a resonance with a mass of 1260 MeV and a width of 125 MeV (Ref. 7), we find the upper limit on the product of its lepton width and branching ratio in the reaction $\pi^+\pi^-\pi^0\pi^0$ to be $\Gamma(\rho\to e^+e^-)B(\rho\to\pi^+\pi^-\pi^0\pi^0)<170$ eV, with a 90% confidence level.

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