Study of the process $e^+e^- \to 4\pi$ at energies 1.05–1.38 GeV

N.I. Root
for CMD-2 Collaboration

1. INTRODUCTION

In this work, we present results of a model-dependent analysis of both possible channels in e^+e^- annihilation into four pions based on 5.8 pb^{-1} of e^+e^- data collected with the CMD-2 detector [1] at center-of-mass energies $\sqrt{s}$ from 1.05 to 1.38 GeV. The data were recorded in 1997 at the VEPP-2M e^+e^- collider of the Budker Institute of Nuclear Physics in Novosibirsk, Russia.

2. DATA ANALYSIS

The process $e^+e^- \to \pi^+\pi^-2\pi^0$ was studied using 22128 completely reconstructed events with two oppositely charged tracks and four or more photons.

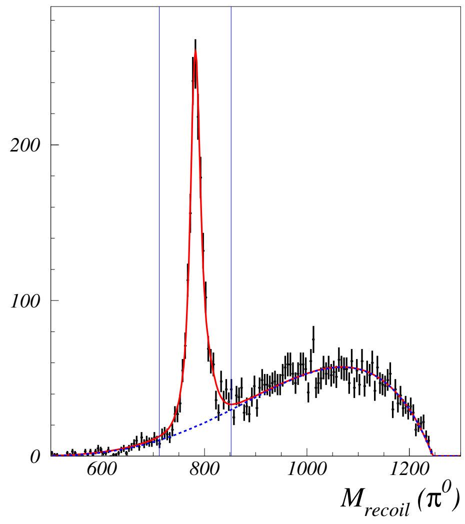

Figure 1. Distribution of the π^0 recoil mass for $\pi^+\pi^-2\pi^0$

To understand the dynamics of the process we studied the distribution of the recoil mass for one of the π^0's. Figure 1 shows this distribution at $\sqrt{s}$ = 1.38 GeV. Each event gives two entries to the histogram corresponding to two π^0. A signal from the $\omega\pi^0$

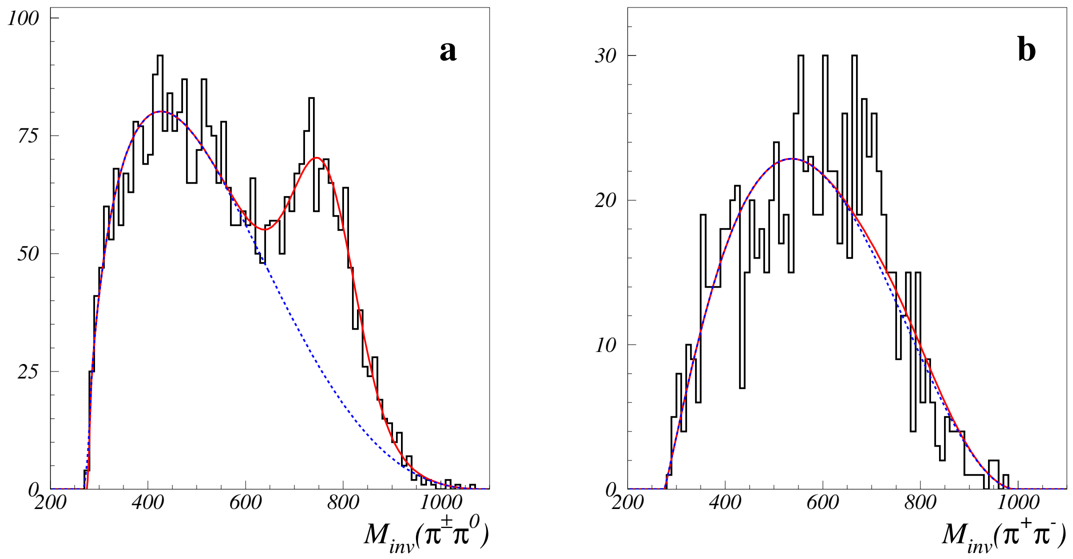

Figure 2. Distributions of (a) $M_{inv}(\pi^{\pm}\pi^{0})$ and (b) $M_{inv}(\pi^{+}\pi^{-})$ for $\pi^{+}\pi^{-}2\pi^{0}$ events from the class (II)

intermediate state is clearly seen. Points with errors are the data while the smooth line is our fit corresponding to the sum of a combinatorial background and a Breit-Wigner ω signal convoluted with detector resolution. The number of events under the ω peak accounts for only $\sim 60\%$ of the observed events.

For further analysis the data sample was subdivided into two classes: (I) $min(|M_{recoil}(\pi^{0})-M_{\omega}|) < 70\ MeV$ and (II) $min(|M_{recoil}(\pi^{0})-M_{\omega}|) > 70\ MeV$ where M_{ω} is the ω mass. The first class contains mostly $\omega\pi^{0}$ events while their admixture in the second class is relatively small.

Fig. 2 shows distributions of invariant masses $M_{inv}(\pi^{\pm}\pi^{0})$ and $M_{inv}(\pi^{+}\pi^{-})$ for events in the second class. The spectrum of $M_{inv}(\pi^{\pm}\pi^{0})$ contains a clear signal of $\rho^{\pm}$ while that for $M_{inv}(\pi^{+}\pi^{-})$ is relatively smooth and no signal from the ρ^{0} is observed. The solid lines show our fit including smooth combinatorial background and gaussian ρ signals. Presence of the $\rho^{\pm}$ signal and absence of the ρ^{0} signal lead us to the natural conclusion that ρ mesons originate from an isospin 1 resonance since for the $I = 0$ resonance one expects production of both neutral and charged ρ's.

To predict observed distributions, a cascade model was developed for MC simulation. Various intermediate states were considered: $e^{+}e^{-} \to a_{1}\pi \to 4\pi$, $e^{+}e^{-} \to \omega\pi \to 4\pi$, $e^{+}e^{-} \to h_{1}\pi \to \rho\pi\pi \to 4\pi$, $e^{+}e^{-} \to \rho^{+}\rho^{-} \to 4\pi$, $e^{+}e^{-} \to \pi'\pi \to \rho\pi\pi \to 4\pi$, $e^{+}e^{-} \to \sigma\rho \to 4\pi$, $e^{+}e^{-} \to a_{2}\pi \to \rho\pi\pi \to 4\pi$ taking into account interference of final pions.

Comparison of MC predictions with the observed spectra (see [2]) showed that the process $e^{+}e^{-} \to \pi^{+}\pi^{-}2\pi^{0}$ is well described by $\omega\pi^{0}$ and $a_{1}(1260)\pi$ intermediate states only. Admixtures of other mechanisms are small. The $a_{1}(1260)\pi$ state saturates the process $e^{+}e^{-} \to 2\pi^{+}2\pi^{-}$. Fig. 3 shows the total cross section vs energy for (a) $\pi^{+}\pi^{-}2\pi^{0}$ and (b) $2\pi^{+}2\pi^{-}$ final states.

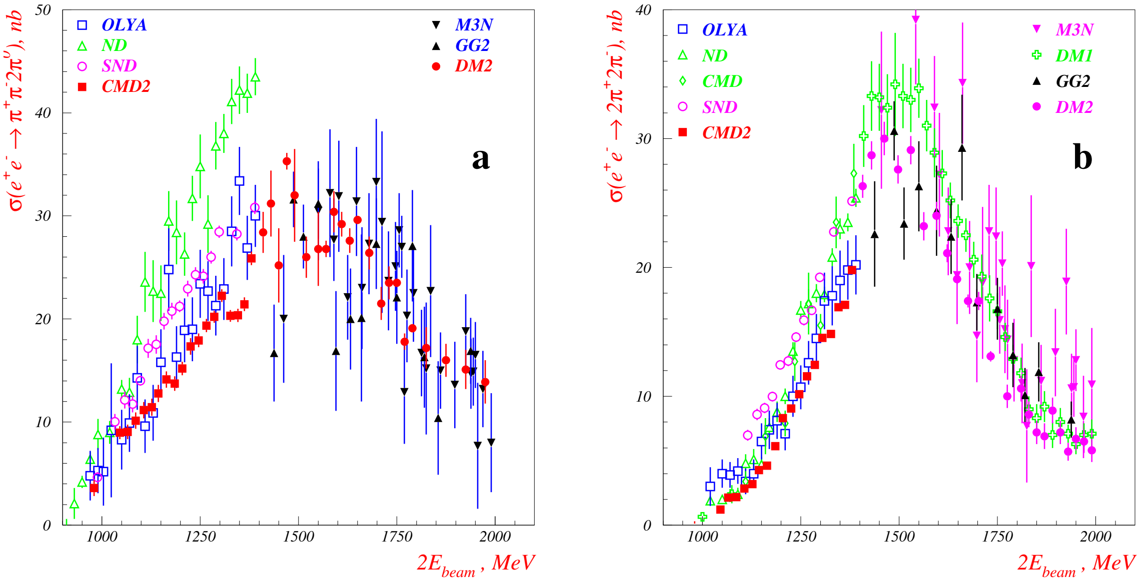

Figure 3. Energy dependence of the (a) $\pi^+\pi^-2\pi^0$ and (b) $2\pi^+2\pi^-$ cross sections

Assuming conservation of vector current (CVC) [3], the cross section of the process $e^+e^- \to 4\pi$ can be related to the probability of the $\tau \to 4\pi\nu_\tau$ decay. Therefore, $\omega\pi^0$ and $a_1(1260)\pi$ states dominating in e^+e^- annihilation should also contribute strongly to τ decays. Within this assumption, we compared [4] distributions of various invariant masses and showed that our model qualitatively describes all available data on $\tau^- \to 2\pi^-\pi^+\pi^0\nu_\tau$ decay (ARGUS [5], ALEPH [6], CLEO-II [7,8]).

3. CONCLUSION

The detailed analysis of the process $e^+e^- \to \pi^+\pi^-2\pi^0$ unambiguously demonstrates that the dominant contribution to the cross section comes from $\omega\pi^0$ and $\rho^\pm\pi^\mp\pi^0$ intermediate states whereas the $\rho^0\pi^0\pi^0$ state is not observed. Moreover, the $\rho^\pm\pi^\mp\pi^0$ state is completely saturated by the $a_1(1260)\pi$ mechanism. The latter also dominates in the cross section of the process $e^+e^- \to 2\pi^+2\pi^-$. Comparison of the experimental data with the calculations shows the importance of taking into account the interference effects.

The model of $\tau \to 4\pi\nu_\tau$ decays developed on the basis of e^+e^- data and CVC reasonably well describes the τ data.

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