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NEW STUDY OF $\phi \to \pi^+\pi^-\pi^0$ DECAY WITH CMD-2 DETECTOR

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ABSTRACT

The analysis of a data sample of about 12 pb^{-1} collected with CMD-2 detector at the VEPP-2M collider was performed. The $e^+e^- \to \pi^+\pi^-\pi^0$ cross section in the ϕ-meson energy range was measured, and the value of Br$(\phi \to \pi^+\pi^-\pi^0)\cdot$Br$(\phi \to e^+e^-)$ was determined. The study of the decay dynamics was performed by analyzing the Dalitz plot distribution of 3π events, taking into account the $\rho\pi$ -mechanism as well as contact production.

1 Introduction

Although the $\phi \to \pi^+\pi^-\pi^0$ decay has been numerously studied starting from sixties, the interest to the process is not exhausted. It is one of the main

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ϕ decays providing the substantial contribution to the total hadronic cross section. The detailed study of the composition of the 3π final state shed light on the mechanism of the light quark interaction. It was primarily proposed in [2] that $\phi \to \pi^+\pi^-\pi^0$ decay proceeds through the $\rho\pi$ intermediate state. First experimental evidence of $\rho\pi$ -dominance appeared in [3]. However, direct production of 3π is not excluded and some phenomenological models [4], [5] predict the value of the related contact amplitude in the wide range. More accurate analysis of 3π dynamics was done in Refs. [6], [7] where only upper limits on the value of the contact amplitude were set up. Recently the non-$\rho\pi$ amplitude was studied at KLOE [8] and the contact amplitude was measured with good accuracy.

In this work we study the process $e^+e^- \to \pi^+\pi^-\pi^0$ in the region of the $\phi-$ meson resonance with the CMD-2 detector. This detector is described elsewhere [9], see also the talk of P.A.Lukin in these proceedings. This analysis, based on 12 pb^{-1} of integrated luminosity, is aimed to measure the 3π cross section as well as to study its dynamics.

2 Selection of 3π events

The present analysis is based on completely reconstructed 3π events. At the initial stage events with one positive and one negative charged particle and two or more reconstructed photon clusters were selected. Then the following criteria were applied:

All charged particles and photons are required to hit detector within the solid angle limited by the polar angle $|\pi/2 - \theta| < 0.67$ radians to avoid edge effects for the detection efficiency. For charged particles:

- Tracks should be acollinear in the $(R - \varphi)$ projection $|\pi - |\varphi_2 - \varphi_1|| > 0.1$ to reject Bhabha events and a space angle between tracks should be $0.1 < \psi < 3.0$.
- The distance from each track to the beam axis should be $R_{min} < 0.2$ cm in the $(R-\varphi)$ projection and the distance from a track to the interaction point along the beam direction should be $|Z_{trk}| < 10$ cm.
- The momentum corresponding to each track is required to be 120 MeV/c $<$ $P_\pi < 500$ MeV/c.

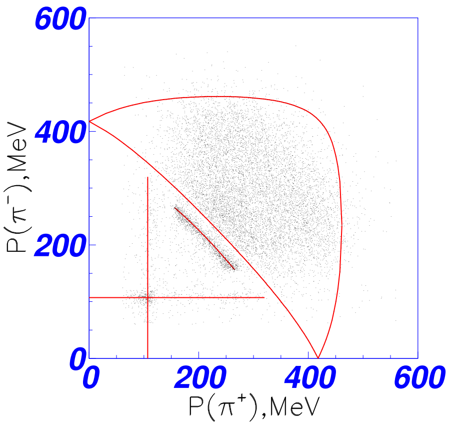

Figure 1: *Experimental 3π events in the 2D-plot* $(|\vec{P_+}|, |\vec{P_-}|)$.

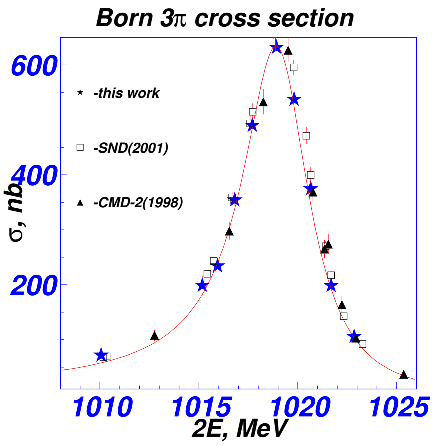

Figure 2: *Born cross section:this work, SND-2001, CMD-1998.*

- Energy losses in the DC for track should be $dE/dx < 4000$ (the dE/dx value for MIP particles is set to 2000) to suppress charged kaons.

For a neutral pion the invariant mass of two photons must be in the range 80 MeV/c^2 < $M_{\gamma\gamma}$ < 170 MeV/c^2. If more than two showers are detected we require only one π^0 candidate to be in the event $N_{\pi^0} = 1$

With the above criteria, 114957 events were selected in total. In Fig.1 the 2D-plot of the selected experimental events (without cut on track momenta) at $E_{beam} = 509.5$ MeV is shown.

Clearly seen are events of three types: $\pi^+\pi^-\pi^0$ inside the allowed kinematic region; $K_L K_S$,$K_S \to \pi^+\pi^-$ along calculated curve of $P_+(P_-)$ dependence; K^+K^- along two lines with P($K^{\pm}$)=107 MeV.

The background for this decay mode can originate from true e^+e^- interactions or from cosmic particles and beam interactions with the residual gas.The main processes which can imitate 3π events are: $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$; $e^+e^- \to \phi \to \eta\gamma$, $\eta \to \pi^+\pi^-\pi^0$ or $\pi^+\pi^-\gamma$; $e^+e^- \to \phi \to K_L K_S$ or K^+K^-; $e^+e^- \to e^+e^-\gamma\gamma$, $e^+e^- \to \pi^+\pi^-\gamma\gamma$, $e^+e^- \to \pi^+\pi^-\gamma$; cosmic particles and beam interaction with the residual gas. The admixture of some background processes was evaluated from experimental data and for the remaining channels relied on luminosity, their cross sections and detection efficiencies taken from MC simulation. We found in total $\simeq$ 1500 background events($\simeq$1.3% of the selected sample).

3 Measurement of cross section

For the cross section measurement 3π events are selected at 10 energy points from 2E=1010 to 1023 MeV. For each energy point the Born cross section is calculated according to the formula:

$$\sigma_B = \frac{N_{3\pi}}{L\varepsilon_{det}\varepsilon_{trig}(1+\delta_{wid})(1+\delta_{rad})(1-\delta_{MC})}, \tag{1}$$

where $N_{3\pi}$ is the number of 3π events, L is the integrated luminosity, ε_{det} is the detection efficiency calculated from Monte Carlo simulation, ε_{trig} is a trigger efficiency, δ_{wid} is a correction for the beam spread, δ_{MC} is a correction to the detection efficiency (it takes into account the difference between experimental and simulated reconstruction efficiencies for $\pi^{\pm}$ and π^0), δ_{rad} is a radiative correction, taking into account the difference between visible and Born cross sections due to the photons radiation by initial e^- and e^+. The calculation of δ_{rad} was done according to Ref. [10].

The Born cross section is approximated by a function incorporating contributions of ω,ϕ mesons and a constant term σ_{BG}:

$$\sigma_{3\pi}(s) = \frac{F_{3\pi}(s)}{s} \cdot |A_\omega + A_\phi e^{i\varphi_{\phi-\omega}}|^2 + \sigma_{BG}, \tag{2}$$

The detailed description of the parametrization can be found in [11]. Fig.2 demonstrates measured Born cross section with an optimal resonance curve. Free parameters of the fit are: peak 3π cross section $\sigma_{3\pi}$, $\omega-\phi$ mixing phase $\varphi_{\phi-\omega}$, mass of the ϕ-meson M_ϕ, total ϕ-meson width Γ_ϕ and constant term σ_{BG}. Parameters of the ω-meson are taken from [1]. The optimal parameters are:

$$\sigma_{\phi 3\pi} = 624 \pm 33 \; nb, \; \varphi_{\phi-\omega} = 160 \pm 17^o$$
$$M_\phi = 1019.3 \pm 0.1 \; MeV, \; \Gamma_\phi = 4.14 \pm 0.13 \; MeV$$
$$\sigma_{bg} = 12 \pm 6 \; nb, \; \chi^2/N = 8.6/5$$

The parameters of the ϕ-meson agree with world average results. Only statistical errors of the fit parameters are presented, systematics studies are in progress.

4 Analysis of $\phi \to \pi^+\pi^-\pi^0$ dynamics

We study $\phi \to \pi^+\pi^-\pi^0$ dynamics analyzing the 3π events distribution over the Dalitz plot with $X = (E_{\pi^-} - E_{\pi^+})/\sqrt{3}$ and $Y = 2E - E_{\pi^-} - E_{\pi^+} - m_{\pi^0}$ as coordinates. For this purpose about 80000 experimental 3π events were selected with CMS energies 2E = $1017 \div 1021$ MeV. After described selections, a kinematic reconstruction was applied using the maximum likelihood method with the constraints of 4-momentum conservation.

The differential cross section of the process can be presented as:

$$d\sigma = C(s)|\vec{p}_+ \times \vec{p}_-|^2 |A_n a e^{i\varphi} + A_{\rho\pi}|^2 dE_+ dE_-, \tag{3}$$

$$A_{\rho\pi} = \frac{1}{D_{\rho^+}(Q_+^2)} + \frac{1}{D_{\rho^-}(Q_-^2)} + \frac{1}{D_{\rho^0}(Q_0^2)}, \tag{4}$$

where $1/D_{\rho^i}(Q_i^2)$ is a propagator of the ρ-meson; $A_n a e^{i\varphi}$ is the contact term amplitude ($A_n = 7.52$). The case of $a = 1$ corresponds to the equal contributions from $\rho\pi$ and direct 3π final states.

For further analysis the plot was divided into 198 square 20×20 MeV bins as it is shown in Fig.3. Bins near the kinematic boundary were excluded from the analysis. The calculated number of 3π events is given by the expression:

$$N_i^{calc} = \varepsilon_{ij} \varepsilon_{jk}^{rad} N_k^{theory}, \tag{5}$$

where N_k^{theory} is the number of events in bin number "k", calculated according to Eq.3; ε_{jk}^{rad} is a 198×198 matrix taking into account the distortion of the Dalitz distribution due to initial state radiation; ε_{ij} is a 198×198 matrix of the detector apparatus function taken from full 3π Monte Carlo simulation. The graphical example of the ε_{ij} table for one bin is shown in Fig.3. The distribution of experimental 3π events is shown in Fig.4. To approximate it we minimize the χ^2 functional. Free parameters of the fit are: the total number of produced 3π events-N_0, absolute value of a contact amplitude - "a" and phase of the contact amplitude-φ. Obtained optimal parameters are given in tab.1. Also shown are the results on the contact term found by KLOE [8], SND [7],CMD-2 [6] groups.

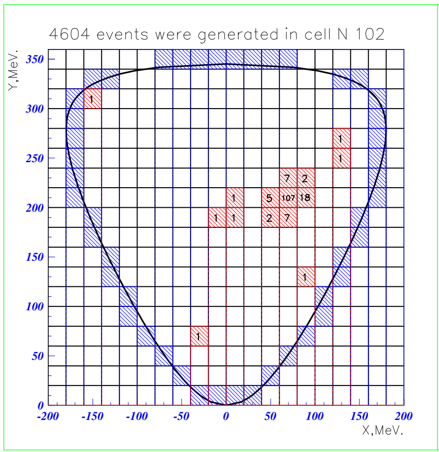

Figure 3: *The spread of events initially simulated in the bin (70,210)*

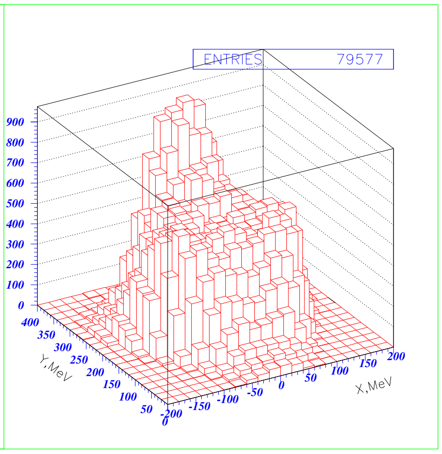

Figure 4: *Dalitz distribution of experimental events*

Our preliminary result is in good agreement with the previous analysis of 3π dynamics at CMD-2, we also agree with KLOE in absolute value of contact amplitude, however the phase is different.

5 Summary

The Born cross section of the $e^+e^- \to \pi^+\pi^-\pi^0$ reaction was measured with a data sample of about 1.15×10^5 3π events in the energy range $2E = 1010 \div 1023$ MeV. Our preliminary result on the 3π peak cross section:

$$\sigma_{3\pi} = 624 \pm 33 \text{ nb}$$
$$Br(\phi \to \pi^+\pi^-\pi^0)Br(\phi \to e^+e^-) = (4.42 \pm 0.23) \times 10^{-5}$$

is in good agreement with previous measurements made by SND and CMD-2 groups.

Analysis of $\phi \to \pi^+\pi^-\pi^0$ dynamics is based on 80000 experimental events. The preliminary result on the absolute value and phase of the contact amplitude:

$$a = 0.103 \pm 0.028,\ \varphi = -2.0 \pm 0.3$$

Table 1: *Results on absolute value and phase of the contact amplitude*

CMD-2 this work	$a = 0.103 \pm 0.028$ $\varphi = -2.0 \pm 0.3$; $P(\chi^2) = 81\%$
KLOE (2003)	$a = 0.104 \pm 0.01 \pm 0.02$ $\varphi = 2.47 \pm 0.08 \pm 0.08$; $P(\chi^2) = 12\%$
SND (2002)	$-0.06 < a < 0.06$ $\varphi = 0$-fixed; 90% CL
CMD-2 (1998)	$-0.15 < a < 0.10$ $\varphi = 0$-fixed; 90% CL

is in good agreement with the previous CMD-2 measurement.

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