Study of $e^+e^- \to K^+K^-\eta$ process with the CMD-3 detector at VEPP-2000 collider*

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Abstract: We report the results of the study of $e^+e^- \to K^+K^-\eta$ process with the CMD-3 detector. The analysis is based on an integrated luminosity of 22 pb^{-1} collected by the CMD-3 in 2011–2012. It was established, that only $\phi(1020)\eta$ intermediate state can be recognized at the current level of CMD-3 statistics. The cross section of $e^+e^- \to \phi(1020)\eta$ process was measured at 30 center-of-mass energy points in the range from 1.59 up to 2.0 GeV. The η meson was treated as a recoil particle, and all the modes of η decay were used. The total of 1454±48 events of signal process were selected. The measured cross section was approximated according to Vector Meson Dominance model as a sum of $\phi(1680)$ and nonresonant amplitudes, and the preliminary results for $\phi(1680)$ meson parameters have been obtained.

Key words: hadrons, signal/background separation, cross section

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1 Introduction

The measurement of the cross section of $e^+e^- \to \phi(1020)\eta \to K^+K^-\eta$ process provides an opportunity to refine the parameters of $\phi(1680)$ meson. Also it is need for the improvement of the accuracy of the hadronic contribution to the $(g-2)/2$ of muon. The process has been earlier studied by the BaBar Collaboration in the c.m. energy ($E_{\text{c.m.}}$) range from 1.56 to 3.48 GeV in the $\eta \to 2\gamma$ decay channel [1], and in the energy range from 1.56 to 2.64 GeV in the $\eta \to \pi^+\pi^-\pi^0$ decay channel [2]. It was found that the main intermediate mechanism is $e^+e^- \to \phi(1680) \to \phi(1020)\eta$, whereas the cross section of so-called non$-\phi(1020)\eta$ part of the process (i.e. with kaons, which have the invariant mass $M_{\text{inv}}(K^+,K^-) > 1045\,\text{MeV/c}^2$) is an order of magnitude lower. The statistics was not enough to study the dynamics of non$-\phi(1020)\eta$ contribution.

We performed the study of $e^+e^- \to K^+K^-\eta$ process with the CMD-3 detector. The structure of the detector and its physical programm are described elsewhere [3, 4]. The analysis is based on an integrated luminosity of 22 pb^{-1} collected by the CMD-3 in 2011–2012.

2 Study of $e^+e^- \to K^+K^-\eta$ with CMD-3

2.1 Selection of $K^+K^-\eta$ final state

To select kaons in the $K^+K^-\eta$ final state, we search for a pair of beam-originating tracks, which have zero net charge and ionization losses dE/dx in the drift chamber, typical for kaons with corresponding momenta. For the selected pair we calculate the energy disbalance ΔE:

$$\Delta E \equiv E_{K^+} + E_{K^-} + \sqrt{(-\vec{\mathbf{p}}_{K^+} - \vec{\mathbf{p}}_{K^-})^2 + m_\eta^2} - 2E_{\text{beam}}, \quad (1)$$

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which represents the total energy of the final particles minus twice beam energy under the assumption that the missing particle is η meson. The ΔE distribution peaks at zero for signal events, so it is used to extract the number of these events at each $E_{\rm c.m.}$ point.

To search for non $-\,\phi(1020)\eta$ mechanisms in $\eta \to 2\gamma$ mode, we perform a 4C kinematic fit with all the pairs of photons, and choose the pair having the lowest χ^2. We apply the conditions $M_{\rm inv}(K^+,K^-) > 1045\,{\rm MeV/c^2}$ and $\chi^2 < 25$. We find (see Fig. 1) 10 events in the experiment, whereas 15.2 events of the $e^+e^- \to \phi(1020)\eta \to K^+K^-2\gamma$ process are expected according to the simulation. Thus, on the base of the data collected by CMD-3 in 2011-2012 we cannot recognize the contribution of any other intermediate mechanisms, except $e^+e^- \to \phi(1020)\eta$. Moreover, we suspect that the events, which in BaBar study [1] were considered as non$-\phi(1020)\eta$ part of the process, are in fact the events from the tail of $\phi(1020)$.

To select kaons from $\phi(1020)$ decay, we apply to the selected pair of kaons the condition $M_{\rm inv}(K^+,K^-) < 1070\,{\rm MeV/c^2}$. Also we search for the other beam-originating tracks with dE/dx, typical for pions. Fig. 2 shows the dE/dx for the selected kaons and pions. It is seen, that there is no significant particle misidentification.

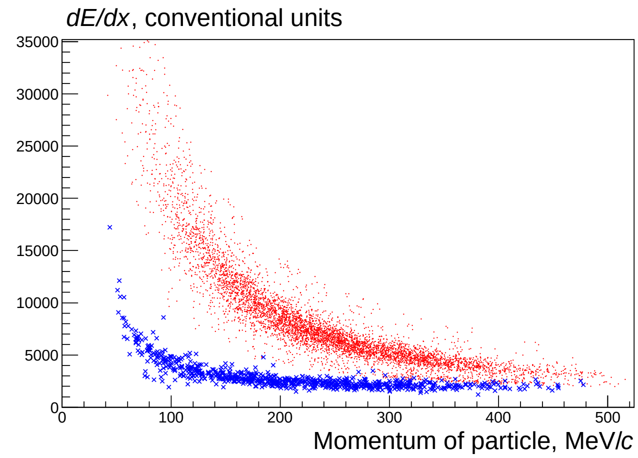

Fig. 2. The distribution of energy losses dE/dx vs particle momentum of the selected candidates for kaons (dots) and pions (crosses) in the experiment.

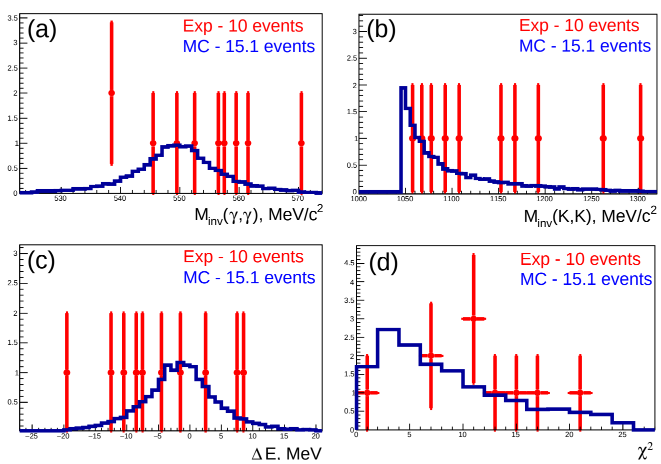

Fig. 1. The experimental (markers with error bars) and simulated (open histograms) distributions: of the invariant mass of the pair of photons (a); of the invariant mass of the pair of kaons (b); of the energy disbalance ΔE (c); of the χ^2 of the 4C kinematic fit (d).

2.2 Background processes

If the parameter ΔE belongs to the range from -180 to 150 MeV, the estimations of the expected number of events (according to the cross sections measured by BaBar [1, 5]) show that the only significant background processes are: $e^+e^- \to \phi(1020) f_0(500)$, $K^{*\pm}(892)K^{\mp}\pi^0 \to K^+K^-\pi^0\pi^0$, $e^+e^- \to K^+K^-\pi^+\pi^-$. As for the latter process, its contribution can be almost completely suppressed. Indeed, if in the event two charged pions were found, we use a distribution of $M_{{\rm missing}\,2K2\pi}$ parameter (Fig. 3), representing the missing mass for the two kaons and two pions. The events of $e^+e^- \to K^+K^-\pi^+\pi^-$ process are concentrated near the origin of coordinates, and for the suppression of the background we apply the condition $M_{{\rm missing}\,2K2\pi} > 100\,{\rm MeV}/c^2$. If in the event only one charged pion was found, we use a distribution of $M_{{\rm missing}\,2K\pi}$ parameter (Fig. 4), representing the missing mass for the two kaons and one pion. In this case for the background suppression we apply the condition $M_{{\rm missing}\,2K\pi} > 300\,{\rm MeV}/c^2$.

The distributions of the missing mass $M_{{\rm missing}\,2K}$ and the invariant mass $M_{\rm inv}(K^+,K^-)$ of two kaons for the experimental and simulated background events are shown in Fig. 5 and 6 correspondingly.

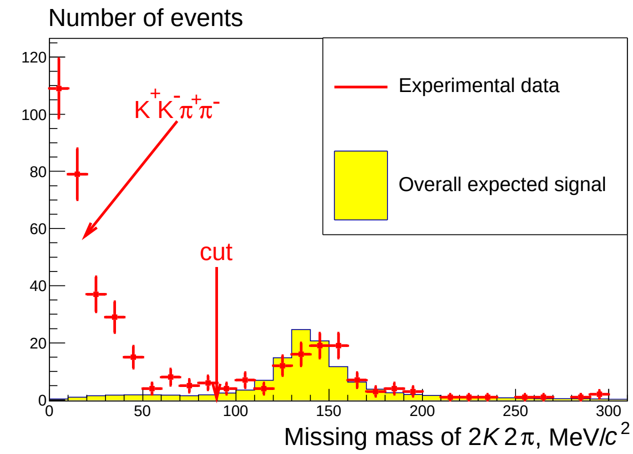

Fig. 3. The distributions of the $M_{\mathrm{missing}\,2K2\pi}$ parameter: in the experiment (markers with error bars); for the MC of signal process (filled histogram). Number of events at each bin of the simulated histogram corresponds to the expected number of events in this bin. All the energy points $E_{\mathrm{c.m.}}$ are combined.

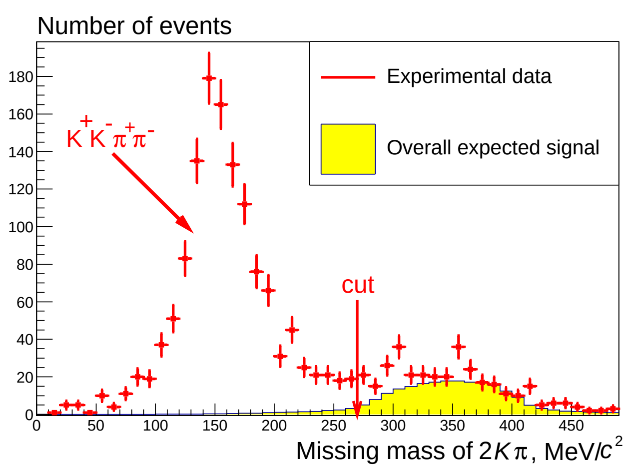

Fig. 4. The distributions of the $M_{\mathrm{missing}\,2K\pi}$ parameter: in the experiment (markers with error bars); for the MC of signal process (filled histogram). Number of events at each bin of the simulated histogram corresponds to the expected number of events in this bin. All the energy points $E_{\mathrm{c.m.}}$ are combined.

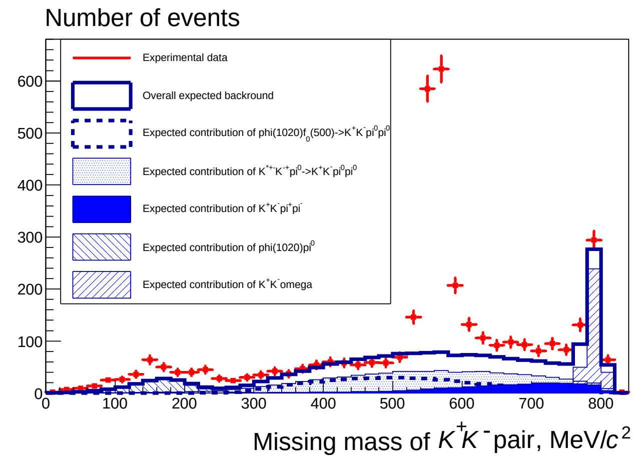

Fig. 5. The distributions of the $M_{\mathrm{missing}\,2K}$ parameter: in the experiment (markers with error bars); for the MC of $\phi(1020)\pi^0$ (cross-hatched histogram), $K^+K^-\omega$ (hatched histogram), $\phi(1020)f_0(500)\to K^+K^-\pi^0\pi^0$ (dotted line), $K^{*\pm}(892)K^{\mp}\pi^0\to K^+K^-\pi^0\pi^0$ (dotted histogram), $K^+K^-\pi^+\pi^-$ processes (filled histogram), sum of backrounds (solid line). All energy points $E_{\mathrm{c.m.}}$ are combined.

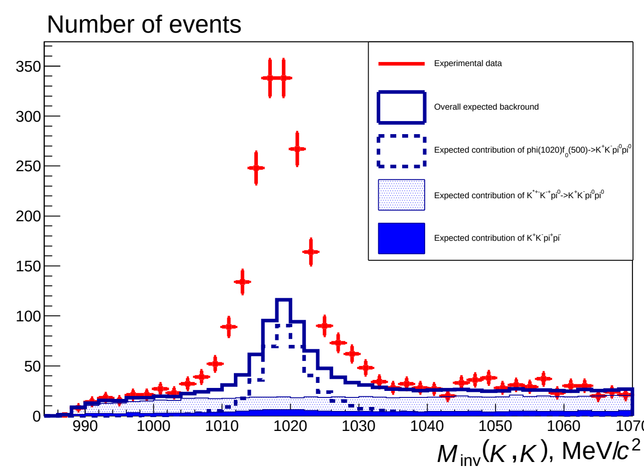

Fig. 6. The distributions of the $M_{\mathrm{inv}}(K^+,K^-)$ parameter for kaons with $\Delta E \in (-180\ \mathrm{MeV}; 150\ \mathrm{MeV})$: in the experiment (markers with error bars); for the MC of $\phi(1020)\pi^0$ (cross-hatched histogram), $K^+K^-\omega$ (hatched histogram), $\phi(1020)f_0(500)\to K^+K^-\pi^0\pi^0$ (dotted line), $K^{*\pm}(892)K^{\mp}\pi^0\to K^+K^-\pi^0\pi^0$ (dotted histogram), $K^+K^-\pi^+\pi^-$ processes (filled histogram), sum of backrounds (solid line). All energy points $E_{\mathrm{c.m.}}$ are combined.

2.3 Number of signal events

The distributions of simulated signal and background events in ΔE are fitted at every point of energy. For the signal events the fitting function is the sum of three Gaussian functions with different mean values and widths, the widest of which describes the radiative tail of the distribution. The simulated sum of backgrounds is fitted by a second-degree polynomial. The functions found are used to fit the distribution of experimental events in ΔE with three free parameters: the amplitude and position of the signal function, and the amplitude of the background function. The integral of the signal function gives the number of signal events at a given energy point ($N_{\text{signal}}(E_{\text{c.m.}})$). So we get the total number of signal $N_{\text{signal,total}} \approx 1454 \pm 48$ events in the experiment. As an example the procedure of signal-background separation at $E_{\text{c.m.}} = 1.96\,\text{GeV}$ is shown in Fig. 7.

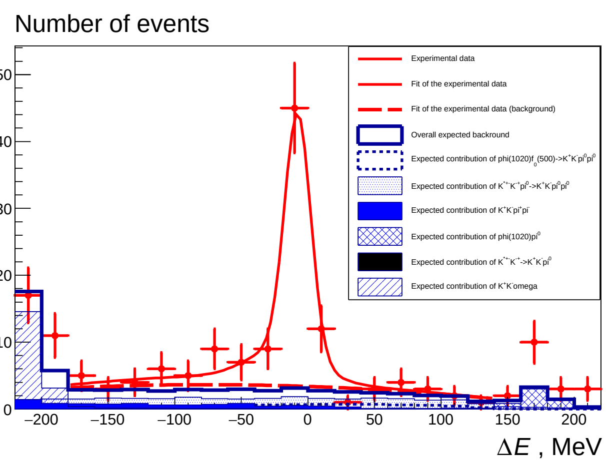

Fig. 7. The distribution of ΔE parameter at $E_{\text{c.m.}} = 1.96\,\text{GeV}$: in the experiment (markers with error bars); for the MC of $\phi(1020)\pi^0$ process (cross-hatched histogram); for the MC of $K^+K^-\omega$ process (hatched histogram); for the MC of $\phi(1020)f_0(500) \to K^+K^-\pi^0\pi^0$ process (dotted line); for the MC of $K^{*\pm}(892)K^{\mp}\pi^0 \to K^+K^-\pi^0\pi^0$ process (dotted histogram); for the MC of $K^+K^-\pi^+\pi^-$ process (filled histogram). Also the fit of the experimental distribution (solid line) and the fit of background (dashed line) are shown.

2.4 Cross section of $e^+e^- \to \phi(1020)\eta$ process

The cross section of the $e^+e^- \to \phi(1020)\eta$ process was calculated at each $E_{\text{c.m.}}$ according to the expression:

$$\sigma_{\phi(1020)\eta} = \frac{N_{\text{signal}} \cdot (1+\delta_{eff})}{L \cdot \varepsilon_{\text{MC}} \cdot \varepsilon_{\text{trig}} \cdot (1+\delta_{\text{rad}}) \cdot \mathcal{B}(\phi(1020) \to K^+K^-)}, \quad (2)$$

where L is the collected luminosity at the fixed energy point, ε_{MC} is the efficiency of registration of the events of signal process, determined from simulation, $1+\delta_{eff}$ is the correction to the efficiency of registration, $\varepsilon_{\text{trig}}$ is the efficiency of trigger, $(1+\delta_{\text{rad}})$ is the radiative correction. The results of calculation are presented in Fig. 8 along with the BaBar data.

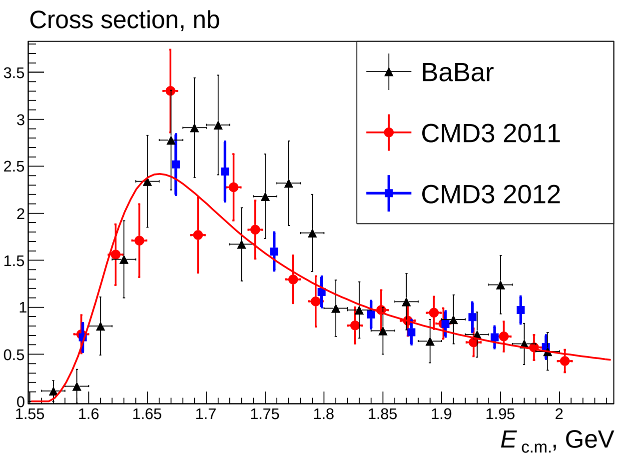

Fig. 8. The cross section of $e^+e^- \to \phi(1020)\eta$ process: CMD-3 results, based on the data collected in 2011 (circular markers) and in 2012 (squared markers) years; BaBar results, measured in $\eta \to 2\gamma$ mode (triangle markers).

2.5 Approximation of the cross section

We fit the cross section using the same parametrization, as that was used in BaBar study [1]:

$$\sigma_{\phi(1020)\eta}(s) = 12\pi \mathcal{P}_{\phi(1020)\eta}(s) \left| \frac{A^{\text{n.r.}}_{\phi(1020)\eta}}{s} + \sqrt{\mathcal{B}^{\phi(1680)}_{\phi(1020)\eta} \Gamma^{\phi(1680)}_{ee}} \frac{\sqrt{\frac{\Gamma_{\phi(1680)}}{\mathcal{P}_{\phi(1020)\eta}(M^2_{\phi(1680)})}} e^{i\Psi_{\phi(1680)}}}{s - M^2_{\phi(1680)} + i\sqrt{s}\Gamma_{\phi(1680)}(s)} \right|^2. \quad (3)$$

Here $\mathcal{P}_{\phi(1020)\eta}$ - the $\phi(1020)\eta$ phase space, $A^{\text{n.r.}}_{\phi(1020)\eta}$ describes the possible contribution of some resonance below the reaction threshold (presumably, it might be $\phi(1020)$), the second term under the module sign describes $\phi(1680) \to \phi(1020)\eta$ contribution in accordance with the Vector Meson Dominance model. We perform a fit of CMD-3 data together with the BaBar data for c.m. energies from 2.3 to 3.46 GeV, taken from [1] (which allows to fix the $A^{\text{n.r.}}_{\phi(1020)\eta}$ term), and a fit of BaBar data. The preliminary results for the $\phi(1680)$ parameters, derived from the fit of CMD-3 and BaBar data, are listed in the Table 1.

Table 1. Results of the cross section approximation.

Parameter	BaBar	CMD-3
χ^2/n.d.f	40.0/44	56.9/54
$\Gamma_{ee}^{\phi(1680)}\mathcal{B}_{\phi(1020)\eta}^{\phi(1680)}$, eV	111.2±17.0	115.4±17.4
$M_{\phi(1680)}$, MeV	1682.3±10.0	1666.6±7.3
$\Gamma_{\phi(1680)}$, MeV	175.8±38.0	222.7±42.6
σ^{peak}, nb	2.92±0.7	2.50±0.67
$\Psi_{\phi(1680)}$	-1.33±0.12	-1.1±0.12
$A_f^{\mathrm{n.r.}}$, nb/GeV	0.11±0.02	0.095±0.016

3 Summary

We established, that in the $e^+e^-\to K^+K^-\eta$ process only $\phi(1020)\eta$ intermediate state can be recognized at the current level of CMD-3 statistics. The cross section of $e^+e^- \to \phi(1020)\eta$ process was measured at 30 center-of-mass energy points in the range from 1.59 up to 2.0 GeV. The total of 1454±48 events of signal process were selected. The measured cross section was approximated according to Vector Meson Dominance model as a sum of $\phi(1680)$ and nonresonant amplitudes, and preliminary results for $\phi(1680)$ meson parameters have been obtained.

References

1 B. Aubert *et al.* [BaBar Collab.], Phys. Rev. D **77**, 092002 (2008), [arXiv:0710.4451 [hep-ex]].
2 B. Aubert *et al.* [BaBar Collab.], Phys. Rev. D **76**, 092005 (2007), [Erratum-ibid. D **77**, 119902 (2008)] [arXiv:0708.2461 [hep-ex]].
3 V. V. Danilov, P. M. Ivanov, I. A. Koop, I. N. Nesterenko, E. A. Perevedentsev, D. N. Shatilov, Yu. M. Shatunov and A. N. Skrinsky, Conf. Proc. C **960610**, 1149 (1996).
4 S. Eidelman, Nucl. Phys. Proc. Suppl. **162**, 323 (2006) 323.
5 B. Aubert *et al.* [BaBar Collab.], Phys. Rev. D **76**, 012008 (2007) [arXiv:0704.0630 [hep-ex]].