Article ID:0253-2778(2016)06-0502-05

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

IVANOV V. L.[1,2], AMIRKHANOV A. N.[1,2], ANISENKOV A. V.[1,2], AULCHENKO V. M.[1,2], BANZAROV V. S.[1], BASHTOVOY N. S.[1], BERKAEV D. E.[1], BONDAR A. E.[1,2], BRAGIN A. V.[1], EIDELMAN S. I.[1,2], EPIFANOV D. A.[1], EPSHTEYN L. B.[1,2,3], EROFEEV A. L.[1,2], FEDOTOVICH G. V.[1,2], GAYAZOV S. E.[1,2], GREBENUK A. A.[1,2], GRIBANOV S. S.[1,2], GRIGORIEV D. N.[1,4], IGNATOV F. V.[1], KARPOV S. V.[1], KAZANIN V. F.[1], KOROBOV A. A.[1,2], KOVALENKO O. A.[1,2], KOZYREV A. N.[1],KOZYREV E. A.[1,2], KROKOVNY P. P.[1,2], KUZMENKO A. E.[1,2], KUZMIN A. S.[1], LOGASHENKO I. B.[1,2], LUKIN P. A.[1,2], MIKHAILOV K. YU.[1,2], OKHAPKIN V. S.[1], PESTOV YU. N.[1], POPOV A. S.[1,2], RAZUVAEV G. P.[1,2], RUBAN A. A.[1], RYSKULOV N. M.[1], RYZHENENKOV A. E.[1,2], SHEBALIN V. E.[1], SHEMYAKIN D. N.[1,2], SHWARTZ B. A.[1,2], SIBIDANOV A. L.[4], SHATUNOV YU. M.[1], SOLODOV E. P.[1,2], TITOV V. M.[1], TALYSHEV A. A.[1,2], VOROBIOV A. I.[1], YUDIN YU. V.[1,2]

(1. *Budker Institute of Nuclear Physics*, *Novosibirsk* 630090, *Russia*; 2. *Novosibirsk State University*, *Novosibirsk* 630090, *Russia*; 3. *Novosibirsk State Technical University*, *Novosibirsk* 630092, *Russia*; 4. *Falkiner High Energy Physics Department*, *University of Sydney*, *Australia*)

Abstract: The results of the study of $e^+e^- \to K^+K^-\eta$ process with the CMD-3 detector are reported. 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. A 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

CLC number: O572.3 **Document code**: A doi:10.3969/j.issn.0253-2778.2016.06.009

Citation: IVANOV V L, AMIRKHANOV A N, ANISENKOV A V, et al. Study of $e^+e^- \to K^+K^-\eta$ process with the CMD-3 detector at VEPP-2000 collider[J]. Journal of University of Science and Technology of China, 2016, 46(6): 502-506.

IVANOV V L, AMIRKHANOV A N, ANISENKOV A V, 等. 用CMD-3谱仪研究VEPP-2000对撞机上的$e^+e^- \to K^+K^-\eta$过程[J]. 中国科学技术大学学报,2016, 46(6): 502-506.

Received:2015-11-30; **Revised**:2016-04-20

Foundation item: Supported in Part by the Russian Science Foundation(14-50-00080), Russian Foundation for Basic Research(RFBR 13-02-00215-a, RFBR 13-02-01134-a, RFBR 14-02-00580-a, RFBR 14-02-31275-mol-a, RFBR 14-02-00047-a, RFBR 14-02-31478-mol-a, RFBR 14-02-91332, RFBR 15-02-0567).

Biography: VANOV V. L. (corresponding author), PhD. Research field: electro-positron annihilation into hadrons. E-mail: vyacheslav_lvovich_ivanov@mail.ru

用 CMD-3 谱仪研究 VEPP-2000 对撞机上的 $e^+e^- \to K^+K^-\eta$ 过程

IVANOV V. L.[1,2], AMIRKHANOV A. N.[1,2], ANISENKOV A. V.[1,2], AULCHENKO V. M.[1,2], BANZAROV V. S.[1], BASHTOVOY N. S.[1], BERKAEV D. E.[1], BONDAR A. E.[1,2], BRAGIN A. V.[1], EIDELMAN S. I.[1,2], EPIFANOV D. A.[1], EPSHTEYN L. B.[1,2,3], EROFEEV A. L.[1,2], FEDOTOVICH G. V.[1,2], GAYAZOV S. E.[1,2], GREBENUK A. A.[1,2], GRIBANOV S. S.[1,2], GRIGORIEV D. N.[1,4], IGNATOV F. V.[1], KARPOV S. V.[1], KAZANIN V. F.[1], KOROBOV A. A.[1,2], KOVALENKO O. A.[1,2], KOZYREV A. N.[1],KOZYREV E. A.[1,2], KROKOVNY P. P.[1,2], KUZMENKO A. E.[1,2], KUZMIN A. S.[1], LOGASHENKO I. B.[1,2], LUKIN P. A.[1,2], MIKHAILOV K. YU.[1,2], OKHAPKIN V. S.[1], PESTOV YU. N.[1], POPOV A. S.[1,2], RAZUVAEV G. P.[1,2], RUBAN A. A.[1], RYSKULOV N. M.[1], RYZHENENKOV A. E.[1,2], SHEBALIN V. E.[1], SHEMYAKIN D. N.[1,2], SHWARTZ B. A.[1,2], SIBIDANOV A. L.[4], SHATUNOV YU. M.[1], SOLODOV E. P.[1,2], TITOV V. M.[1], TALYSHEV A. A.[1,2], VOROBIOV A. I.[1], YUDIN YU. V.[1,2]

(1. 俄罗斯布德克尔核物理研究所，新西伯利亚 630090，俄罗斯；2. 国立新西伯利亚大学，新西伯利亚 630090，俄罗斯；
3. 国立新西伯利亚理工大学，新西伯利亚 630090，俄罗斯；4. 悉尼大学物理学院高能物理系，悉尼，澳大利亚)

摘要：报道了用 CMD-3 在 2011-2012 年收集的积分亮度为 22 pb^{-1}的研究结果. 在 CMD-3 当前的统计量下，只能被确定 $\phi(1020)\eta$ 中间共振态. 在 1.59-2.0 GeV能区的 30 个能量点测量了 $e^+e^- \to \phi(1020)\eta$. 分析中，将 η 介子当做反冲粒子，穷尽了 η 衰变的所有模式，选出的事例总数为 1454 ± 48. 测量的截面近似为 $\phi(1680)$和非共振振幅按照矢量介子主导模型的叠加，并得到了 $\phi(1680)$介子共振参数的初步结果.

关键词：强子；信号/本地分离；截面

0　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 needed for the improvement of the accuracy of the hadronic contribution to the $(g-2)/2$ of muon. The process has been studied earlier by the BaBar Collaboration in the c. m. energy ($E_{c.m.}$) 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 $M_{inv}(K^+,K^-) > 1045$ 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.

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

1.1　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:

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

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 $E_{\mathrm{c.m.}}$ 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 $M_{\mathrm{inv}}(K^+, K^-) > 1045$ MeV/c^2 and $\chi^2 < 25$. We find 10 events in the experiment (see Fig. 1, (a) invariant mass of the pair of photons, (b) invariant mass of the pair of kaons, (c) energy disbalance ΔE, (d) χ^2 of the 4C kinematic fit), 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 basis 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 $\phi(1020)$.

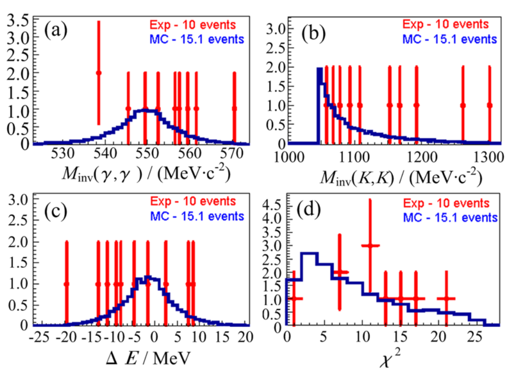

Fig. 1 The experimental (markers with error bars) and simulated (open histograms) distributions

To select kaons from $\phi(1020)$ decay, we apply to the selected pair of kaons the condition $M_{\mathrm{inv}}(K^+, K^-) < 1070$ 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 can be seen, that there is no significant particle misidentification (the selected candidates for kaons (dots) and pions (crosses) in the experiment).

1.2 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 that two charged pions were found, we use a distribution of $M_{\mathrm{missing}2K2\pi}$ 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 $M_{\mathrm{missing}2K2\pi} > 100$ MeV/c^2. If in the event that only one charged pion was found, we use a distribution of $M_{\mathrm{missing}2K\pi}$ 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 $M_{\mathrm{missing}2K\pi} > 300$ MeV/c^2.

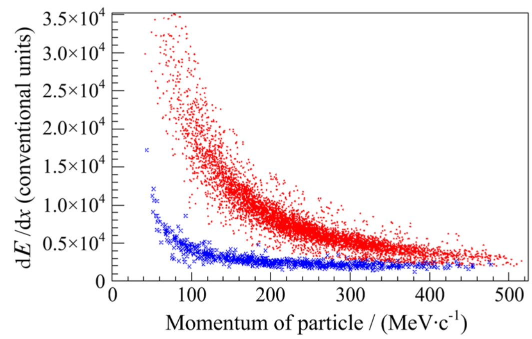

Fig. 2 The distribution of energy losses vs particle momentum

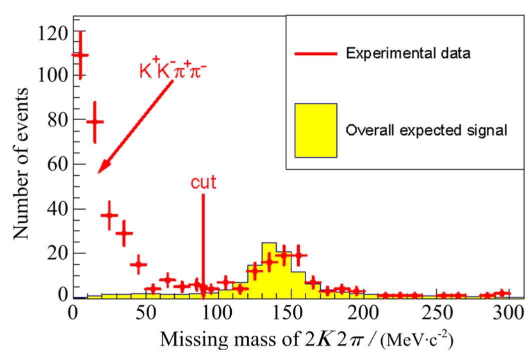

Fig. 3 The distributions of the $M_{\mathrm{missing}2K2\pi}$ parameter

In the experiment (markers with error bars); for the MC of the signal process (filled histogram). The 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.

The distributions of the missing mass $M_{\mathrm{missing}2K}$ and

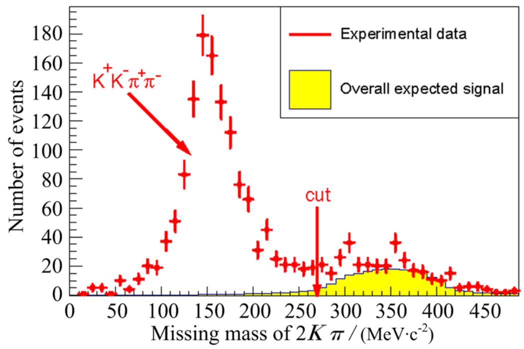

Fig. 4　The distributions of the $M_{missing2K2\pi}$ parameter

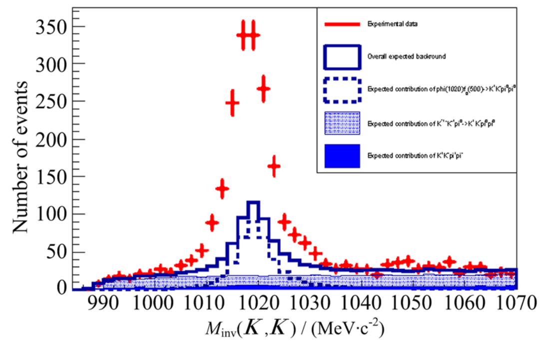

Fig. 6　The distributions of the $M_{inv}(K^+,K^-)$ parameter

the invariant mass $M_{inv}(K^+, K^-)$ of two kaons for the experimental and simulated background events are shown in Figs. 5 and 6 correspondingly. 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 backronds (solid line). All energy points $E_{c.m.}$ are combined.

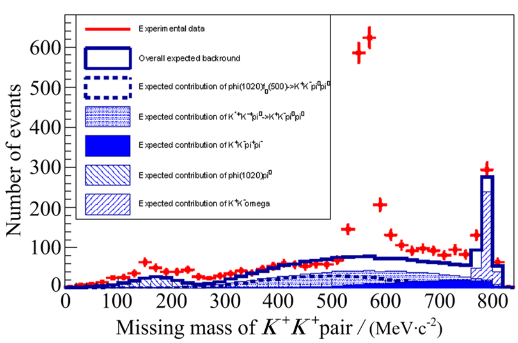

Fig. 5　The distributions of the $M_{missing2K}$ parameter

1.3　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 ($N_{signal}(E_{c.m.})$). So we get the total number of signal $N_{signal,total}\approx 1454\pm 48$ events in the experiment. As an example the procedure of signal-background separation at $E_{c.m.}=1.96$ GeV is shown in Fig. 7.

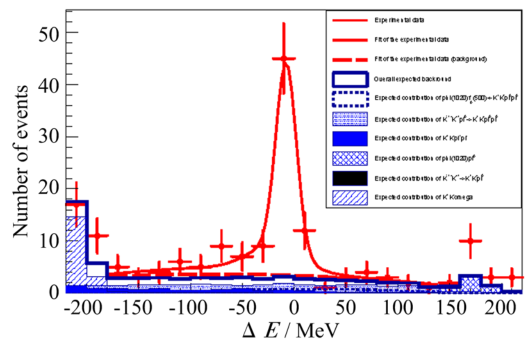

Fig. 7　The distribution of ΔE parameter

In Fig. 7, the distribution of ΔE parameter at $E_{c.m.}=1.96$ 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.

1.4　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 $E_{c.m.}$ according to the expression:

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

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

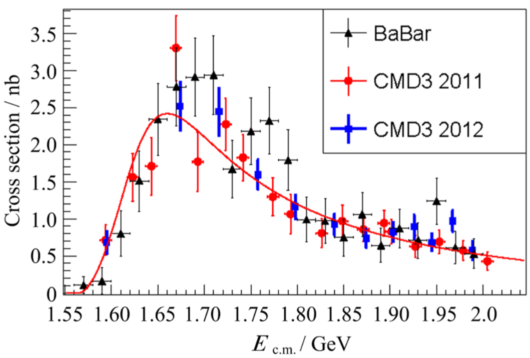

Fig. 8 The cross section of $e^+e^-\to\phi(1020)\eta$ process

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).

1.5 Approximation of the cross section

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

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

Here $P_{\phi(1020)\eta}$ is the $\phi(1020)\eta$ phase space, $A^{n.r.}_{\phi(1020)\eta}$ describes the possible contribution of some resonance below the reaction threshold (presumably, it might be $\phi(1020)$), and 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 Ref. [1] (which allows to fix the $A^{n.r.}_{\phi(1020)\eta}$ 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 Tab. 1.

Tab. 1 Results of the cross section approximation

Parameter	BaBar	CMD-3
χ^2/n. d. f	40.0/44	56.9/54
$\Gamma^{\phi(1680)\eta}_{ee} B^{\phi(1680)}_{\phi(1020)\eta}$/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
$A^{n.r.}_f$/(nb · GeV^1)	0.11 ± 0.02	0.095 ± 0.016

2 Conclusion

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] AUBERT B, BONA M, BOUTIGNY D, et al. Measurements of $e^+e^-\to K^+K^-\eta$, $K^+K^-\pi^0$ and $K^0_S K^\pm\pi^\mp$ cross sections using initial state radiation events [J]. Physical Review D, 2008, 77: 092002.

[2] AUBERT B, BARATE R, BOUTIGNY D, et al. Study of $e^+e^-\to\pi^+\pi^{\pi 0}$ process using initial state radiation with BABAR[J]. Physical Review D, 2007, 76: 092005.

[3] DANILOV V V, IVANOV P M, KOOP I A, et al. The concept of round colliding beams[C]// Proceedings of the 5th European Particle Accelerator Conference. 1996: 1149-1151.

[4] EIDELMAN S. Physics at VEPP-2000[J]. Nuclear Physics B-Proceedings Supplements, 2006, 162(1):323-326.

[5] AUBERT B, BONA M, BOUTIGNY D, et al. Erratum: The $e^+e^-\to 2(\pi^+\pi^-)\pi^0$, $2(\pi^+\pi^-)\eta$, $K^+K^-\pi^+\pi^-\pi^0$ and $K^+K^-\pi^+\pi^-\eta$ cross sections measured with initial-state radiation[J]. Physical Review D, 2007, 76: 092005.