Study of the $e^+e^-\to VP$ reactions at the VEPP-2000 e^+e^- collider with the SND detector

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Abstract:The reactions $e^+e^-\to\rho\pi$, $\omega\pi$, $\rho\eta$, $\omega\eta$ have been studied in the energy region 1.05-2.00 GeV. The experiment has been carried out at the VEPP-2000 e^+e^- collider with the SND detector. The measured cross sections have been fitted in the vector meson dominance model.

Key words:VEPP-2000; SND detector

用 SDN 探测器研究 VEPP-2000 对撞机上 $e^+e^-\to VP$ 的反应

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摘要:研究了 1.05-2.00 GeV 能区 $e^+e^-\to\rho\pi$, $\omega\pi$,$\rho\eta$, $\omega\eta$ 的反应,用 SDN 探测器在 VEPP-2000 对撞机上进行了实验,测量的截面适合用矢量介子模型来拟合.

关键词:强子;信号/本地分离;截面

0　Introduction

The transitions into the *VP* final states, where *V* and *P* denote vector and pseudoscalar mesons, respectively, are dominant decay modes for excited states of the vector ρ, ω, and ϕ mesons. In the center-of-mass(c. m.) energy region $\sqrt{s}$ = 1-2 GeV, where these vector resonances are located, the reactions $e^+e^-\to VP$ constitute a significant part of the cross section $e^+e^-\to$ hadrons. In this paper we study the reactions of this type with $VP=\rho\pi$, $\omega\pi$, $\rho\eta$, $\omega\eta$ in the c. m. energy region 1.05-2.00 GeV with the SND detector[1] at the VEPP-2000 e^+e^- collider[2]. The measured cross sections are fitted with the vector meson dominance (VMD) model.

1　Processes overview

1.1　$e^+e^-\to\rho\pi$

The cross section of the process $e^+e^-\to\rho\pi$ with the decay $\rho\to\pi\pi$ has been measured in the energy

range $1.05 \leqslant \sqrt{s} \leqslant 2.00$ GeV[3]. The following criteria are applied to selected $\pi^+ \pi^- \pi^0$ events.

（Ⅰ）Exactly 2 charged tracks originating from the $e^+ e^-$ interaction region.

（Ⅱ）Exactly 2 photons with energies $E_\gamma > 30$ MeV

（Ⅲ）The total energy deposition in the detector calorimeter $0.3 < E_{tot}/\sqrt{s} < 0.8$.

Selected events are fitted to a common vertex. The quality of the vertex fit is characterized by the parameter χ_R^2, which is required to be less than 40. Then the kinematic fit to the hypothesis $e^+ e^- \rightarrow \pi^+ \pi^- \gamma\gamma$ is performed with requirements of the energy and momentum balance, and events are further selected with the following conditions:

（Ⅰ）$\chi_E^2 < 30$, where χ_E^2 is the χ^2 of the kinematic fit.

（Ⅱ）z coordinate of the vertex $|z_{vertex}| < 10$ cm.

（Ⅲ）The polar angles of the charged tracks $30° < \theta_{track} < 150°$.

（Ⅳ）the difference of charged track azimuthal angles $|\Delta\phi_{track}| > 10°$.

（Ⅴ）The energy deposition in the calorimeter associated with the charged pions $(E_{\pi^+} + E_{\pi^-})/\sqrt{s} < 0.6$.

（Ⅵ）The total energy deposition in the calorimeter not associated with two charged particles and two photons $E_{tot}^{outer} < 70$ MeV.

The number of signal events is determined from the fit to the two-photon mass spectrum with a sum of signal（π^0 resolution function）and background distributions, whose shapes are obtained using signal and background（$e^+ e^- \rightarrow \pi^+ \pi^- \pi^0\pi^0$, $e^+ e^- \rightarrow \pi^+ \pi^- \gamma$, etc.）simulation. The measured $e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$ cross section is shown in Fig. 1. Our results is in agreement with SND at VEPP-2M and BABAR measurements, but has better accuracy. The curve in Fig. 1 represents the result of the VMD fit with $\omega(782)$, $\phi(1020)$, $\omega(1450)$, and $\omega(1680)$ resonances.

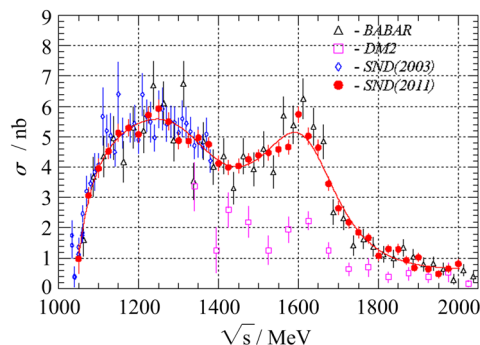In Fig. 1, The cross section for the process $e^+ e^- \rightarrow \rho\pi$ measured in this work［SND（2011）］

Fig. 1　The cross section for the process $e^+ e^- \rightarrow \rho\pi$

together with previous measurements in the DM2[4], SND at VEPP-2M（［SND（2003）］[5], and BABAR[6] experiments. The curve is the result of the VMD fit described in the text.

1.2　$e^+ e^- \rightarrow \omega\pi$

The process $e^+ e^- \rightarrow \omega\pi^0$ is studied in the decay mode $\omega \rightarrow \pi^0\gamma$ in the same energy range. Five-photon events are selected using the following conditions.

（Ⅰ）At least 5 photons.

（Ⅱ）No charged particles.

（Ⅲ）Less than 6 hits in the detector drift chamber.

（Ⅳ）The total energy deposition in the calorimeter $E_{tot}/\sqrt{s} > 0.5$.

For selected events the kinematic fits to the hypotheses $e^+ e^- \rightarrow 5\gamma$ and $e^+ e^- \rightarrow \pi^0\pi^0\gamma$ are performed, whose qualities are characterized by the parameters $\chi_{5\gamma}^2$ and $\chi_{\pi^0\pi^0\gamma}^2$, respectively. Further selection is based on the following criteria.

（Ⅰ）$\chi_{5\gamma}^2 < 30$.

（Ⅱ）$\chi_{\pi^0\pi^0\gamma}^2 - \chi_{5\gamma}^2 < 10$.

（Ⅲ）At least one of the two $\pi^0\gamma$ invariant masses $|m_{\pi^0\gamma} - M_\omega| < 200$ MeV.

The invariant masses in the latter condition is calculated using photon parameters obtained in the $e^+ e^- \rightarrow \pi^0\pi^0\gamma$ fit. The number of signal events is obtained from the fit to the $m_{\pi^0\gamma}$ spectrum with a sum of signal and background distributions. The measured cross section is shown in Fig. 2. It should be noted that the CLEO cross section is calculated under the CVC hypothesis from the $\omega\pi$ spectral function in the $\tau \rightarrow$

$\omega\pi\nu_\tau$ decay. In Fig. 2, we present the result based on SND data collected in 2010-2012 runs. Our previous measurement based on 2010-2011 data was published in Ref. [7]. From the measured cross section the $\gamma^* \to \omega\pi$ transition form factor shown in Fig. 3 is extracted. The curves in Figs. 2 and 3 are the results of the SND data VMD fit with the $\rho(770)$, $\rho(1450)$ and $\rho(1700)$ resonances. The dashed curve in Fig. 3 is the fit result with the $\rho(770)$ only. It is seen that the VMD model cannot describe simultaneously our data on the transition form factor and data obtained in the NA60 from the $\omega \to \pi^0\mu^+\mu^-$ decay also shown in Fig. 3.

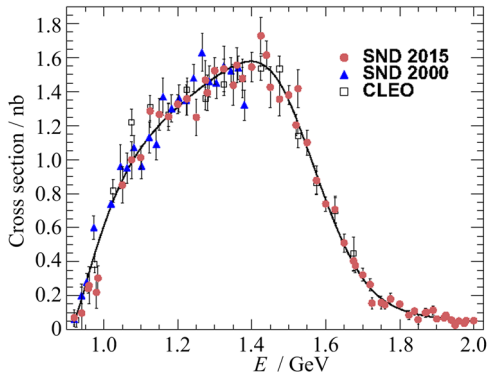**Fig. 2　The cross section for the process $e^+e^- \to \omega\pi$**

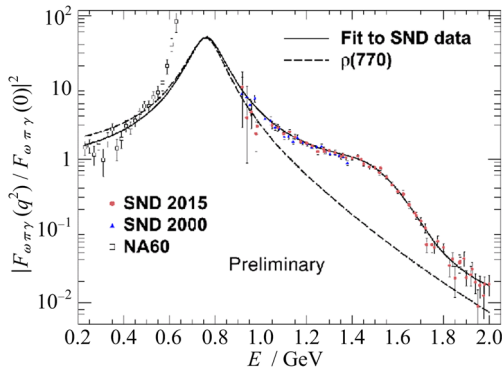**Fig. 3　The $\gamma^* \to \omega\pi$ transition**

In Fig. 2, the cross section for the process $e^+e^- \to \omega\pi$ measured in this work (SND 2015) in comparison with previous measurements in the SND at VEPP-2M (SND 2000)[8] and CLEO[9] experiments. The curve is the result of the VMD fit described in the text. In Fig. 3, the $\gamma^* \to \omega\pi$ transition form factor measured in this work (SND 2015) in comparison with

previous measurements in the SND at VEPP-2M (SND 2000)[8] and NA60[10] experiments. The curves are the result of the fit described in the text.

1.3　$e^+e^- \to \rho\eta$

The process $e^+e^- \to \rho\eta \to \pi^+\pi^-\eta$ has been studied in the decay mode $\eta \to \gamma\gamma$ in the energy range 1.22-2.00 GeV[11]. The following criteria are used to select $\pi^+\pi^-\eta$ events.

（Ⅰ）Exactly 2 charged tracks originated from the interaction region.

（Ⅱ）Exactly 2 photons with polar angles $36° < \theta < 144°$.

（Ⅲ）The total energy deposition in the calorimeter $0.4 < E_{\text{tot}}/\sqrt{s} < 0.9$.

（Ⅳ）The energy deposition of charged particles $E_{\text{track}}/\sqrt{s} < 0.65$.

The vertex fit and kinematic fit to the $e^+e^- \to \pi^+\pi^-\gamma\gamma$ hypothesis are performed for selected events. The final selection uses the following conditions.

（Ⅰ）$\chi_R^2 < 200$ and $\chi_E^2 < 60$.

（Ⅱ）The $\gamma\gamma$ invariant mass 400 MeV $< m_{\gamma\gamma} < 700$ MeV.

The number of signal events is obtained from the fit to the $m_{\gamma\gamma}$ spectrum with a sum of signal and background distributions. The measured cross section is shown in Fig. 4. Our result agrees with BABAR data, but has better accuracy. The solid curve in Fig. 4 is the result of the VMD fit with $\rho(770)$ and $\rho(1450)$ resonances, while the dashed curve represents the fit with the $\rho(1700)$ contribution added. It is seen that the $\rho(1700)$ contribution is small. It is usually assumed that the dominant mechanism of the $e^+e^- \to \pi^+\pi^-\eta$ reaction is transition via $\rho^0(770)\eta$ intermediate state. We however observe a contribution of other mechanism, presumably $\rho^0(1450)\eta$[11]. From our cross section measurement, using the CVC hypothesis the branching ratio $B_{\text{CVC}}(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.156 \pm 0.011)\%$ is calculated, which is in agreement with the measured value $B_{\text{exp}}(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.139 \pm 0.010)\%$.

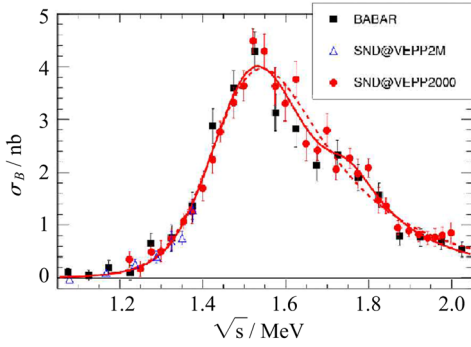In Fig. 4, The cross section for the process $e^+e^- \to \rho\eta$ measured in this work (SND@ VEPP2000)

Fig. 4 **The cross section for the process** $e^+ e^- \to \rho\eta$

in comparison with previous measurements in the SND at VEPP-2M (SND @ VEPP2M)[12] and BABAR[13] experiments. The curves are the results of the VMD fits described in the text.

1.4 $e^+ e^- \to \omega\eta$

The process $e^+ e^- \to \omega\eta$ is studied in the decay mode $\omega \to \pi^+ \pi^- \pi^0$ and $\eta \to \gamma\gamma$ in the energy range 1.34- 2.00 GeV. Events are selected using the following criteria.

(Ⅰ)At least 2 charged tracks originated from the interaction region.

(Ⅱ)At least 4 photons.

(Ⅲ)The total energy deposition in the calorimeter $E_{\text{tot}} > 300$ MeV.

The vertex fit and kinematic fits to the $e^+ e^- \to \pi^+ \pi^- \pi^0 \gamma\gamma$ hypothesis with the additional condition that the two photon invariant mass must be in the range $400 \leqslant m_{\gamma\gamma} \leqslant 700$ MeV and to the $e^+ e^- \to \pi^+ \pi^- \pi^0 \pi^0 (\gamma)$ hypothesis are performed. The quality of the kinematic fits are characterized by the parameters $\chi^2_{\pi^+ \pi^- \pi^0 \gamma\gamma}$ and $\chi^2_{\pi^+ \pi^- \pi^0 \pi^0(\gamma)}$. The $e^+ e^- \to \pi^+ \pi^- \pi^0 \pi^0$ process is the main source of background for the process under study. The following conditions are applied on the parameters obtained in the fits.

(Ⅰ)$\chi^2_{\pi^+ \pi^- \pi^0 \gamma\gamma} < 30$ and $\chi^2_{\pi^+ \pi^- \pi^0 \pi^0(\gamma)} > 200$.

(Ⅱ) The mass recoiling against $\gamma\gamma$, $0.65 < m_{\gamma\gamma}^{rec} < 0.9$ GeV for the $e^+ e^- \to \pi^+ \pi^- \pi^0 \gamma\gamma$ fit.

The $\omega\eta$ signal is extracted from the fit to the $m_{\gamma\gamma}$ and $m_{\gamma\gamma}^{rec}$ distributions. The measured cross section is shown in Fig. 5 in comparison with the previous BABAR measurement. It is fitted with a sum of the $\omega(1420)$ and $\omega (1650)$ contributions. Destructive

interference between these two contributions is responsible for a very low level of the cross section observed above 1.8 GeV.
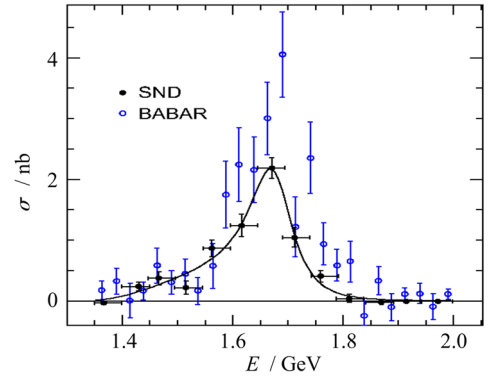

Fig. 5 **The cross section for the process** $e^+ e^- \to \omega\eta$

In Fig. 5, the cross section for the process $e^+ e^- \to \omega\eta$ measured in this work (SND) in comparison with previous measurements in the BABAR[14] experiment. The curve is the result of the VMD fit described in the text.

2 Conclusion

The cross sections for the processes $e^+ e^- \to \rho\pi$, $\omega\pi$, $\rho\eta$, $\omega\eta$ have been measured in the SND experiment at the VEPP-2000 $e^+ e^-$ collider. All of these measurements have the best accuracies to date.

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