New data from SND detector in Novosibirsk

M.N. Achasov, V.M. Aulchenko, K.I. Beloborodov, A.V. Berdyugin,
A.V. Bozhenok, A.D. Bukin, D.A. Bukin, S.V. Burdin, T.V. Dimova,
S.I. Dolinsky, A.A. Drozdetsky, V.P. Druzhinin, M.S. Dubrovin, I.A. Gaponenko,
V.B. Golubev, V.N. Ivanchenko, I.A. Koop, A.A. Korol, M.S. Korostelev,
S.V. Koshuba, G.A. Kukartsev, E.V. Pakhtusova, V.M. Popov, A.A. Salnikov,
S.I. Serednyakov, V.V. Shary, Yu.M. Shatunov, V.A. Sidorov, Z.K. Silagadze,
A.N. Skrinsky, Yu.V. Usov,Yu.S. Velikzhanin, A.V. Vasiljev, A.S. Zakharov
Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia,
Novosibirsk State University, Novosibirsk 630090, Russia

presented by V.P. Druzhinin

The current status of experiments with SND detector at VEPP-2M e^+e^- collider in the energy range $2E_0 = 400 - 1400$ MeV and recent results of data analyses for ϕ, ω and ρ decays and e^+e^- annihilation into hadrons are presented.

1. INTRODUCTION

VEPP-2M is the e^+e^--collider[1], operating since 1974 in the energy range 2E=0.4-1.4 GeV (ρ, ω, ϕ-mesons region). Its maximum luminosity is about $5 \cdot 10^{30}$ $cm^{-2}s^{-1}$ at E=510 MeV. Two detectors SND and CMD2 carry out experiments at VEPP-2M now.

SND was described in detail in [2]. Its main part is the three layers spherical electromagnetic calorimeter consisting of 1620 NaI(Tl) crystals with total weight of 3.6 tons. The solid angle coverage of the calorimeter is 90% of 4π steradian. The energy resolution for photons can be approximated as $\sigma_E(E)/E = 4.2\%/E(\mathrm{GeV})^{1/4}$, angular resolution is about 1.5°. The angles of charged particles are measured by two cylindrical drift chambers covering 95% of 4π solid angle.

In this report we present results of the four SND experiments:

•**PHI96**: 7 scans of energy region 985–1040 MeV were performed with total integrated luminosity of 4.3 pb^{-1}. Number of produced ϕ-mesons is about $8 \cdot 10^6$.

•**PHI98**: 8 pb^{-1} of integrated luminosity were collected in two scans of the energy region 985–1060 MeV. Number of produced ϕ-mesons is about $12 \cdot 10^6$.

•**MHAD97**: the data was collected in the energy region 1040-1380 MeV with the integrated luminosity of 6.3 pb^{-1}.

•**OME98**: the data was collected in the energy region 360-970 MeV with the integrated luminosity of 3.6 pb^{-1}. $1.2 \cdot 10^6$ ω-mesons and $1.9 \cdot 10^6$ ρ-mesons were produced.

2. ϕ-MESON DECAYS

2.1. Magnetic dipole decays $V \to P\gamma$

The radiative decay $\phi \to \eta\gamma$ was studied in three main η decay modes. The obtained results are the following:

$$B(\phi \to \eta\gamma) = \begin{cases} (1.296 \pm 0.024 \pm 0.057)\%, & \eta \to 3\pi^0 \quad [3] \\ (1.338 \pm 0.012 \pm 0.052)\%, & \eta \to 2\gamma \quad [4] \\ (1.259 \pm 0.030 \pm 0.059)\%, & \eta \to \pi^+\pi^-\pi^0 \quad [5] \end{cases}$$

The measured branching ratios are consistent inside systematic errors. The accuracy of our average $\boldsymbol{B(\phi \to \eta\gamma) = (1.304 \pm 0.049)\%}$ is better than world average one[6].

The $\phi \to \pi^0\gamma$ decay was studied in 3-gamma final state. The result $\boldsymbol{B(\phi \to \pi^0\gamma) = (1.226 \pm 0.036^{+0.096}_{-0.089}) \cdot 10^{-3}}$[4] is the most precise measurement of the $\phi \to \pi^0\gamma$ decay. The main problem of this measurement is the large systematic error coming from uncertainty in the relative ϕ-ω phase. The improvement can be achieved with the precise measurement of non-resonant cross section in the energy region between ω and ϕ.

2.2. $\phi \to \pi^0\pi^0\gamma, \eta\pi^0\gamma$ decays

First observation of the $\phi \to \pi^0\pi^0\gamma, \eta\pi^0\gamma$ decays was reported in 1997 by SND[7]. Results of completed analyses of PHI96 experiment were published in [8,9]. These results were confirmed by CMD-2 [10]. The $\phi \to \pi^0\pi^0\gamma, \eta\pi^0\gamma$ decays are interesting for clarification of the nature of $f_0(980)$ and $a_0(980)$ mesons. The theoretical estimations of $\phi \to f_0\gamma, a_0\gamma$ branching ratios vary from about 10^{-5} in two-quark and $K\bar{K}$ molecular models up to 10^{-4} in four-quark model[11].

We studied the $\phi \to \pi^0\pi^0\gamma, \eta\pi^0\gamma$ decays in five photons final state. The energy-momentum balance and existence of $\pi^0\pi^0$ or $\eta\pi^0$ intermediate state were required for each event. Additional cuts were imposed to suppress background from $e^+e^- \to \omega\pi^0$ and $\phi \to \eta\gamma \to 3\pi^0\gamma$ processes. The detection efficiencies for both decays under study strongly depended on recoil photon energy. The efficiency averaged over photon spectrum was about 15% for $\pi^0\pi^0\gamma$ and 3.5% for $\eta\pi^0\gamma$ events.

The $\pi^0\pi^0$ and $\eta\pi^0$ mass spectra are presented in Fig.1, 2. For both spectra significant part of events is placed at large masses supporting assumption about $f_0(980)$ and $a_0(980)$ intermediate states. The obtained branching ratios for $\phi \to \pi^0\pi^0\gamma$ decay [8] are

$$B(\phi \to \pi^0\pi^0\gamma) = (1.14 \pm 0.10 \pm 0.12) \cdot 10^{-4},$$
$$B(\phi \to \pi^0\pi^0\gamma) = (0.50 \pm 0.06 \pm 0.06) \cdot 10^{-4}, \quad \text{for } m_{\pi\pi} > 900\,\text{MeV}$$

This result is based on analysis of only PHI96 experiment. For $\phi \to \eta\pi^0\gamma$ decay we present the preliminary result of analyses of full ϕ meson data sample:

$$B(\phi \to \eta\pi^0\gamma) = (0.87 \pm 0.14 \pm 0.07) \cdot 10^{-4},$$
$$B(\phi \to \eta\pi^0\gamma) = (0.36 \pm 0.11 \pm 0.03) \cdot 10^{-4}, \quad \text{for } m_{\eta\pi} > 950\,\text{MeV}.$$

The new branching ratio value is in good agreement with our previous result $(0.83 \pm 0.23) \cdot 10^{-4}$[9], but its statistical error is two times smaller.

Our conclusions on $\phi \to \pi^0\pi^0\gamma$ and $\phi \to \eta\pi^0\gamma$ decays are that greater part of events for both decays originate from $f_0\gamma$ or $a_0\gamma$ intermediate states. The relatively large values

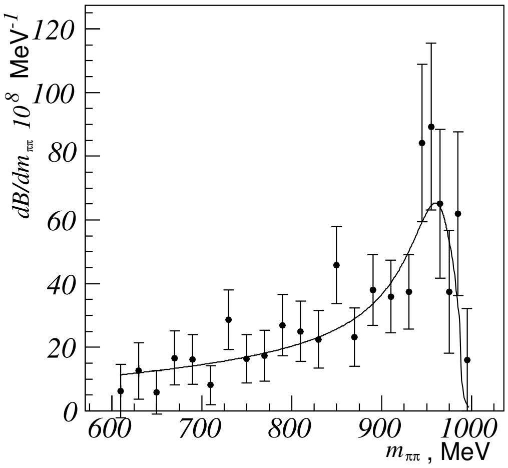

Figure 1. The $\pi^0\pi^0$ invariant mass spectrum for $\phi \to \pi^0\pi^0\gamma$ decay.

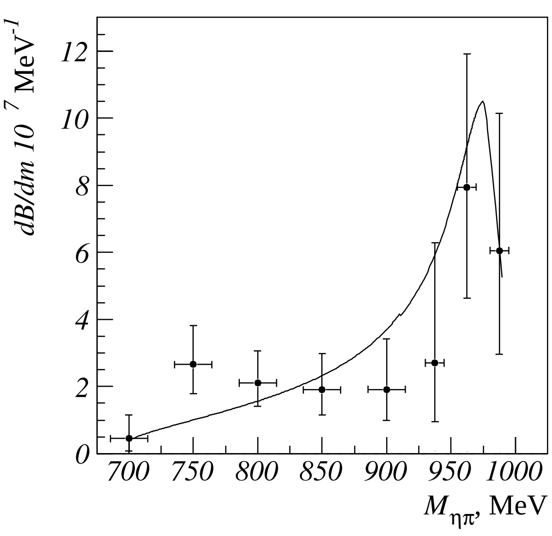

Figure 2. The $\eta\pi^0$ invariant mass spectrum for $\phi \to \eta\pi^0\gamma$ decay.

of measured branching ratios contradict conventional two-quark structure of $f_0(980)$ and $a_0(980)$ mesons, but support their exotic four-quark structure.

2.3. $\phi \to \omega\pi$ and $\phi \to \pi^+\pi^-$ decays

These double suppressed by QZI rule and G-parity decays can be seen as interference patterns in the cross sections of $e^+e^- \to \omega\pi$ and $e^+e^- \to \pi^+\pi^-$ processes. The Born cross section for such processes is described as the following formula:

$$\sigma(E) = \sigma_0(E) \cdot \left|1 - Z\frac{m_\phi \Gamma_\phi}{D_\phi(E)}\right|^2,$$

where $\sigma_0(E)$ is nonresonant cross section, Z is complex interference amplitude, $D_\phi(E)$ is ϕ meson propagator. One can extract from experimental data both real and imaginary parts of the decay amplitude.

The decay $\phi \to \omega\pi$ was studied in two main ω decay modes: $\pi^+\pi^-\pi^0$ and $\pi^0\gamma$. The results of analyses of PHI96 data were first measurement of the probability of this decay in 4π final state[12] and observation of the interference pattern in $2\pi^0\gamma$ final state[13]. In this report we present results of PHI98 experiment. The visible cross section for $e^+e^- \to \omega\pi \to \pi^+\pi^-\pi^0\pi^0$ process is shown in Fig.3. The measured real and imaginary parts of interference amplitude and corresponding branching ratio are following:

$$Re(Z) = 0.112 \pm 0.015,\ Im(Z) = -0.104 \pm 0.022,$$

$$B(\phi \to \omega\pi^0) = (4.6 \pm 1.0 \pm 0.6) \cdot 10^{-5}.$$

This result can be compared with our first measurement:$B(\phi \to \omega\pi^0) = (4.8^{+1.9}_{-1.7} \pm 0.8) \cdot 10^{-5}$ [12]. The value of interference amplitude is sensitive to mechanism of $\phi - \rho$ and

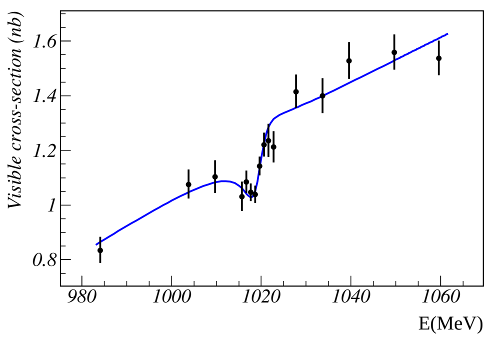

Figure 3. The visible cross section of $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$ reaction.

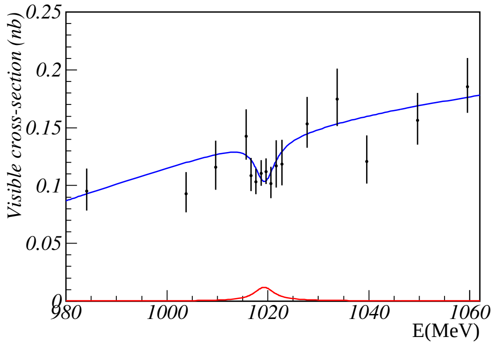

Figure 4. The visible cross section of $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ reaction.

$\phi - \omega$ mixing. The VDM prediction with conventional mixing of vector mesons $B(\phi \to \omega\pi^0) = (8 \sim 9) \cdot 10^{-5}$[14], that is about two times more than measured value. Possible explanations of this deviation could be the nonstandard mixing or the existence of direct $\phi \to \omega\pi^0$ transition.

The interference pattern for $e^+e^- \to \omega\pi \to \pi^0\pi^0\gamma$ process (Fig.4) has another shape:

$$Re(Z) = 0.02 \pm 0.03, \; Im(Z) = -0.24 \pm 0.05$$

In this final state there is an additional contribution of $\phi \to \rho^0\pi^0 \to \pi^0\pi^0\gamma$ transition which interferes with $e^+e^- \to \omega\pi^0$ amplitude. The difference between interference amplitudes measured in $2\pi^0\gamma$ and 4π modes is in a qualitative agreement with VDM estimation for $\phi \to \rho^0\pi^0$ transition[13]: $Re(Z) = -0.079, \; Im(Z) = -0.053$.

Detailed description of study of $\phi \to \pi^+\pi^-$ decay is in report presented at this conference by S.Burdin. The result is $Re(Z) = 0.061 \pm 0.005, \; Im(Z) = -0.042 \pm 0.06$, $B(\phi \to \pi^+\pi^-) = (0.71 \pm 0.10 \pm 0.10) \cdot 10^{-4}$.

3. ρ and ω DECAYS

The $e^+e^- \to \eta\gamma$ reaction was studied in energy region of ρ and ω resonances in 7 photons final state. This state was chosen due to absence of any physical background. The preliminary results of this study

$$B(\omega \to \eta\gamma) = (5.9 \pm 1.0) \cdot 10^{-4}, \; B(\rho \to \eta\gamma) = (2.0 \pm 0.4) \cdot 10^{-4}.$$

have statistical accuracy comparable to or better than world average one. The work is in progress.

The experimental data on $e^+e^- \to \pi^0\pi^0\gamma$ process in ρ, ω mesons energy region are poor. Only one measurement of $\omega \to \pi^0\pi^0\gamma$ decay was done: $B(\omega \to \pi^0\pi^0\gamma) = (7.2 \pm 2.5) \cdot 10^{-5}$[15]. In VDM this process is described by sum of two amplitudes: $\rho \to \omega\pi^0$, $\omega \to \pi^0\gamma$ and $\omega \to \rho\pi$, $\rho \to \pi^0\gamma$. The VDM estimation $B(\omega \to \pi^0\pi^0\gamma) = 2.6 \cdot 10^{-5}$ contradicts to the experimental value. There are no works explaining this discrepancy.

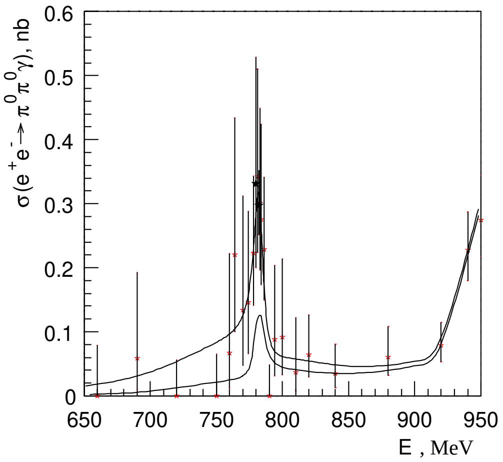

Figure 5. The Born cross section of $e^+e^- \rightarrow \pi^0\pi^0\gamma$ process. Points – data. Lower curve – VDM calculation. Upper curve – fit result.

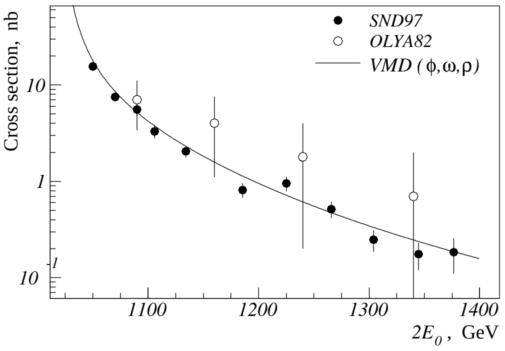

Figure 6. The Born cross section of $e^+e^- \rightarrow K_SK_L$ process. Points – data. Curve – the result of VDM calculation with ρ, ω and ϕ mesons.

About 300 events of $e^+e^- \rightarrow \pi^0\pi^0\gamma$ process were selected in the OME98 experiment. The measured cross section together with the result of VDM calculation are shown in Fig.5. The experimental data significantly exceeds the calculated curve. The measured cross section was fitted by sum of amplitudes of $\rho \rightarrow \omega\pi^0$, $\omega \rightarrow \pi^0\pi^0\gamma$ and $\rho \rightarrow \pi^0\pi^0\gamma$ decays. We check $\rho^0\pi^0$, LIPS, $\sigma(700)\gamma$ models for description of ω decay and LIPS, $\sigma(700)\gamma$ for ρ decay. The analyses of energy and angular distributions did not allow to choose any decay model on our statistical level. The model dependence of the fit parameters was included into systematic errors. The following branching ratios were obtained as the fit results:

$$B(\omega \rightarrow \pi^0\pi^0\gamma) = (8.4^{+4.9}_{-3.1} \pm 3.5) \cdot 10^{-5},\ B(\rho \rightarrow \pi^0\pi^0\gamma) = (4.2^{+2.9}_{-2.0} \pm 1.0) \cdot 10^{-5}.$$

The branching ratio of ρ decay does not include $\omega\pi^0$ intermediate state contribution.

The obtained probability of $\omega \rightarrow \pi^0\pi^0\gamma$ decay significantly exceeds VDM predictions and is in a good agreement with result of previous measurement. The relatively large value of the $\rho \rightarrow \pi^0\pi^0\gamma$ branching ratio also can not be explained in VDM framework. We consider this result as the first evidence of $\rho \rightarrow \pi^0\pi^0\gamma$ decay.

4. HADRON PRODUCTION CROSS SECTIONS

The main goal of MHAD97 experiment was study of hadron production cross sections. In energy region of MHAD97 experiment the level of hadron cross sections is mainly defined by contribution of the excited ρ and ω state, parameters of which are not well established.

The good reconstruction of K_S meson from four photons allowed to select events of $e^+e^- \rightarrow K_SK_L$, $K_S \rightarrow 2\pi^0$ process. The measured cross section of this process is shown

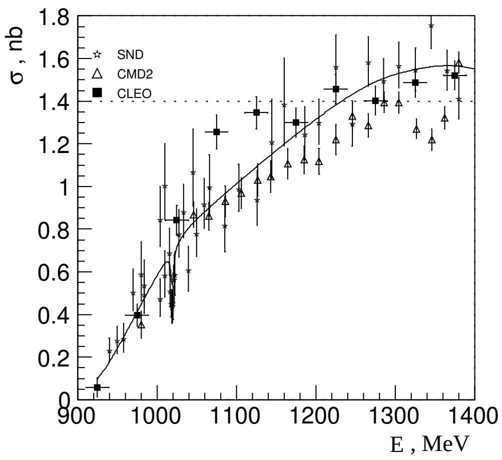

Figure 7. The Born cross section of $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ process.

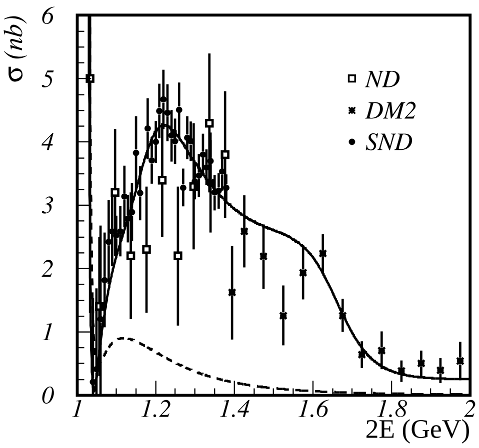

Figure 8. The Born cross section of $e^+e^- \to \pi^+\pi^-\pi^0$ process.

in Fig.6. In the energy region below 1.4 GeV the contributions of only ρ, ω and ϕ mesons describe the cross section well.

The $e^+e^- \to \omega\pi^0$ cross section was measured in neutral mode from threshold to maximum VEPP2-M energy. Obtained cross section together with results of other experiments is presented in Fig.7. One can see that there are systematic difference between results of different experiments. Our systematic error is not more than 10%.

The measured cross section of $e^+e^- \to \pi^+\pi^-\pi^0$[16] is shown in Fig.8. The broad peak in cross section is seen near 1.2 GeV and there is no visible confirmation of the existence of the $\omega(1420)$[6] state. We fit SND, CMD2 and DM2 data by sum of contributions of ϕ, ω and two excited states: ω' and ω''. The Breit-Wigner shape with constant width was used for description of excited ω. The parameters of $\omega''(1600)$ were obtained from DM2 data on the reaction $e^+e^- \to \omega\pi^+\pi^-$. The best fit of experimental data was obtained with the following resonance phases choice: $\phi_\omega = 0$, $\phi_{\omega'} = \pi$ and $\phi_{\omega''} = 0$. The resulting curve is shown in Fig.8. The mass about 1200 MeV was obtained for ω' state instead of table 1420 MeV value. The inclusion of mass-dependent widths of ω' and ω'' into the fit can significantly shift ω' position from visible one. But in any case the reexamination of table $\omega(1420)$[6] state based on analyses of all available data is required.

ACKNOWLEDGMENT

The authors are grateful to N.N.Achasov for useful discussions. The work is partially supported by RFBR (Grants No 96-15-96327, 99-02-17155, 99-02-16815, 99-02-16813) and STP “integration” (Grant No 274).

REFERENCES

1. G.M.Tumaikin, Proc. of the 10-th Int. Conf. on High Energy Particle Accelerators. Serpukhov, 1977, vol.1, p.443.

2. M.N. Achasov et al., e-print hep-ex/9909015, submitted to Nucl. Instr. and Meth.
3. A.A. Salnikov, Talk given at Int. Workshop on e^+e- Collisions from ϕ to J/ψ. Novosibirsk, March, 1999.
4. M.N. Achasov et al., Budker INP 99-39, Novosibirsk, 1999.
5. M.N. Achasov et al., to be published in JETP Lett.
6. C. Caso et al. (Particle Data Group), Europ. Phys. Jour. C3 1 (1998).
7. M.N. Achasov et al., Proc. of HADRON'97, p.783., e-print hep-ex/971102
8. M.N. Achasov et al., Phys. Lett. B 440 442 (1998)
9. M.N. Achasov et al., Phys. Lett. B 438 441 (1998)
10. R.R. Akhmetshin et al., Budker INP 99-11, Novosibirsk, 1999.
11. N.N. Achasov, V.N. Ivanchenko, Nucl. Phys. B 315, 465 (1989).
12. M.N. Achasov et al., Phys. Lett. B 449 122 (1999)
13. M.N. Achasov et al., e-print hep-ex/9907026, to be published in Nucl.Phys. B
14. H. Genz, S. Tatur, Phys.Rev. D 50 3263 (1994)
15. D. Alde et al., Phys. Lett. B 340 122 (1994)
16. M.N. Achasov et al., Phys. Lett. B 462 365 (1999)