Review of results from SND detector

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Abstract

The review of experimental results obtained with SND detector at VEPP-2M e^+e^- collider in the energy region $\sqrt{s} = 0.36 - 1.38$ GeV is given. The presented results include the following items: studies of the light vector mesons radiative decays, OZI-rule and G-parity suppressed ϕ -meson rare decays, ϕ -meson parameters measurements, studies of $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ process dynamics, η and K_S mesons rare decays, η and ϕ mesons conversion decays, and study of the e^+e^- annihilation into hadrons.

The Spherical Neutral Detector (SND) operated since 1995 up to 2000 at VEPP-2M [1] e^+e^- collider in the energy range from 0.36 to 1.38 GeV. SND was described in detail in Ref.[2]. During six experimental years SND had collected data with integrated luminosity about 30 pb⁻¹.

Radiative decays of the ϕ , ω , ρ mesons

Electric dipole transitions of the ϕ meson. Till recently ϕ meson electric dipole transitions were not observed. A search for such decays was first performed with ND detector at VEPP-2M and the upper limits of about 10^{-3} were obtained [3]. About the same time the theoretical proposal of the $\phi \to f_0 \gamma$,

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Figure 1: The $\pi^0 \pi^0$ mass in the decay $\phi \to \pi^0 \pi^0 \gamma$ (a) and the $\eta \pi^0$ mass in the decay $\phi \to \eta \pi^0 \gamma$ (b)

 $a_0\gamma$ decays search appeared [4]. In 1997 the $\phi \to \pi^0\pi^0\gamma$, $\eta\pi^0\gamma$ decays were observed with SND [5]. The SND results based on the full data sample look as follows [6]: $B(\phi \to \pi^0\pi^0\gamma) = (1.22\pm0.10\pm0.06)\cdot10^{-4}$, $B(\phi \to \eta\pi^0\gamma) = (0.88\pm0.14\pm0.09)\cdot10^{-4}$. Studies of the $\pi^0\pi^0$ and $\eta\pi$ invariant mass spectra (Fig.1) demonstrate that $f_0\gamma$ and $a_0\gamma$ mechanisms dominate in these decays [6]. So the following branching ratios were obtained: $B(\phi \to f_0\gamma) = (3.5\pm0.3\pm^{1.3}_{0.5})\cdot10^{-4}$, $B(\phi \to a_0\gamma) = (0.88\pm0.14\pm0.09)\cdot10^{-4}$. These relatively large values point out the exotic four-quark structure of a_0 and f_0 mesons [7]. CMD2 measurements reported in Ref. [8] agree with SND results. Also results of such measurements were recently reported by KLOE [9].

The decays ρ , $\omega \to \pi^0 \pi^0 \gamma$. In VDM model these decays proceed through the $\rho \to \omega \pi^0 \to \pi^0 \pi^0 \gamma$ and $\omega \to \rho \pi^0 \to \pi^0 \pi^0 \gamma$ transitions with the relative probability about 10^{-5} [10]. The same final state is also possible through the vector mesons radiative transitions to the $\pi^0 \pi^0$ scalar state with expected branching ratio about $1.4 \cdot 10^{-5}$ [11, 12]. The only measurement of $\omega \to \pi^0 \pi^0 \gamma$ decay by GAMS [13] gives value of $(7.2 \pm 2.5) \cdot 10^{-5}$. The SND studies of these decays based on the one third of the accumulated statistics were already reported in Ref. [14]. The results of a new analysis based on the full data sample of about 9 pb⁻¹ are presented here.

We cannot extract any information about ω decay mechanisms from the energy or angular distributions due to insufficient statistics. The photon energy spectrum shape agrees with VDM as well as with the sum of VDM and $V \rightarrow S\gamma$ (V denotes vector meson and S – the scalar one, for example σ meson) radiative decays mechanisms in case of constructive interference between them (Fig.2 (a)). The destructive interference is ruled out experimental distribution.

The fit of the cross section (Fig.2 (b)) included $\rho, \rho' \to \omega \pi^0$ transitions and



Figure 2: (a) – the photon energy spectrum in the reaction $e^+e^- \rightarrow \pi^0\pi^0\gamma$ in the energy range near ω meson mass. Solid curve – VDM model, dashed curve – sum of VDM and $\sigma\gamma$ mechanisms in case of destructive interference between them. (b) – cross-section for the $e^+e^- \rightarrow \pi^0\pi^0\gamma$ reaction. Solid line – fit in VDM model, dashed line – fit with sum of VDM and $\rho \rightarrow S\gamma$ decay.

 $\omega \to \pi^0 \pi^0 \gamma$ decay in VDM model and through $V \to S \gamma$ transitions. The strong difference in the energy dependences of the phase space for $\rho \to \omega \pi^0$ and $\rho \to S \gamma$ mechanisms allows to distinguish the different models. The model without $\rho \to S \gamma$ contribution gives $P(\chi^2) \simeq 1\%$. Inclusion of the scalar mechanism to the fit improves $P(\chi^2)$ to 30%. The results of the fit follows: $B(\omega \to \pi^0 \pi^0 \gamma) = (6.3 \pm 1.4 \pm 0.8) \cdot 10^{-5}, B(\rho \to \pi^0 \pi^0 \gamma) = (4.0 \pm 0.9 \pm 0.4) \cdot 10^{-5}, B(\rho \to S \gamma \to \pi^0 \pi^0 \gamma) = (2.0 \pm 0.7 \pm 0.3) \cdot 10^{-5}$. So we confirm the value of ω decay obtained by GAMS. The ρ meson decay to $\pi^0 \pi^0 \gamma$ was observed for the first time.

The magnetic dipole transitions of the light vector mesons. The magnetic dipole radiative decays are traditional objects in the light meson spectroscopy. Only one decay of this type $\phi \rightarrow \eta' \gamma$ was not observed till recently. This decay was observed with CMD2 detector [15] and then confirmed by SND [16]. The results of SND studies of the $\phi \rightarrow \eta' \gamma$ in comparison with CMD2 and KLOE measurements are listed in Table 1.

	SND [16]	SND	SND	CMD2	KLOE
	$\eta' \to \pi^+ \pi^- \eta$	$\eta' ightarrow \pi^0 \pi^0 \eta$	(average)	[17]	[18]
$B(\phi \to \eta' \gamma) \cdot 10^5$	$6.7\pm^{3.4}_{2.9}$	$4.3\pm1.6\pm0.9$	$4.9\pm^{1.6}_{1.5}$	6.4 ± 1.6	6.8 ± 0.8

Table 1: The comparison of the $B(\phi \to \eta' \gamma)$ obtained with SND and results of the other experiments [17, 18]

The process $e^+e^- \rightarrow \eta\gamma$ in the seven photon final state was studied in full available energy region. The results based on the part of accumulated statistics were already published [19]. Here we present the result obtained using full



Figure 3: The cross section of the reaction $e^+e^- \rightarrow \eta\gamma$ in the ρ and ω energy region (a) and above ϕ meson (b)

data set. It was found that cross section (Fig.3) can be described by sum of ρ, ω and ϕ resonances contributions only. The branching ratios obtained from the fit are presented in Table 2. The experimental ratio of the partial width $\Gamma_{\omega\eta\gamma}: \Gamma_{\rho\eta\gamma}: \Gamma_{\phi\eta\gamma} = 1: (11.7 \pm 1.9): (15.9 \pm 1.9)$ is consistent with a prediction of the simple quark model 1:8:12.

The probability of the $\phi \to \eta \gamma$ decay was measured by SND in two other η meson decay modes: $\eta \to \pi^+ \pi^- \pi^0$ [21] and $\eta \to \gamma \gamma$ [22]. Combining the results of the three different modes the SND average was obtained: $B(\phi \to \eta \gamma) = (1.310 \pm 0.045)\%$. It is the most precise measurement of this value.

The process $e^+e^- \to \pi^0\gamma$ was studied in the vicinity of ϕ -meson [22] and in the ρ, ω energy region [23]. As in previous case the cross section can be described by sum of ρ, ω and ϕ mesons only. The obtained branching ratios are listed in Table 2. The ρ and ω branching ratios are in good agreement with both PDG values and prediction of a simple quark model. These results are based on a one third of available statistics. For full data sample we expect improvement of accuracy of the ρ meson branching ratio. We also hope that combined analysis of data from ϕ and ρ, ω energy regions could reduce the systematic error of $\phi \to \pi^0 \gamma$ branching ratio caused by the model dependence of $\phi - \omega$ interference description.

ϕ meson energy region study

OZI rule and G-parity suppressed $\phi \to \omega \pi^0$ and $\pi^+ \pi^-$ decays. Till recently only one decay of this type $\phi \to \pi^+ \pi^+$ was observed by detectors OLYA [24] and ND [27]. Such decays are possible through the $\omega - \phi$ mixing or direct transition [25, 26]. In the SND experiment the $\phi \to \pi^+ \pi^+$ decay was studied [28] and the decay $\phi \to \omega \pi$ was observed for the first time [29].

These decays are seen as interference patterns around ϕ -resonance in the energy dependence of the cross section. The Born cross section can be written as follows [25]:

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

where σ_0 is nonresonant cross section and Z is complex interference amplitude. The measured branching ratios are listed in Table 2. The imaginary parts of Z amplitudes: $\text{Im}(Z_{\pi\pi}) = -0.041 \pm 0.007$, $\text{Im}(Z_{\omega\pi}) = -0.125 \pm 0.020$ agree with theoretical predictions based on standard $\omega - \phi$ mixing, while the expected values of the real parts exceed our results: $\text{Re}(Z_{\pi\pi}) = 0.061 \pm 0.006$, $\text{Re}(Z_{\omega\pi}) = 0.108 \pm 0.16$. The possible cause of this disagreement could be a nonstandard $\omega - \phi$ mixing or direct decays.

 ϕ meson parameters study. The main parameters of the ϕ meson were measured through studies of the processes $e^+e^- \to K^+K^-$, K_SK_L and $\pi^+\pi^-\pi^0$ [30]. The measured cross sections were approximated within the VDM, taking into account ρ , ω and ϕ mesons. Contributions from higher resonances ρ' , ω' , ϕ' were included in each cross section as constant terms. The K^+K^- and K_SK_L cross sections can be fitted by a sum of ρ , ω and ϕ contributions only, while for a good approximation of the $e^+e^- \to \pi^+\pi^-\pi^0$ cross section the additional contribution, which can be attributed to the higher resonances, is strongly required. The obtained ϕ -meson parameters (Table 2) mainly agree with PDG data and have accuracies comparable with the world averages. The only measured value which is in conflict with the now days world average is ϕ -meson width. The world average Γ_{ϕ} value is strongly based on CMD2 measurement $\Gamma_{\phi} = 4.477 \pm 0.036 \pm 0.022$ MeV [31] which contradict to the SND one. But the recent CMD2 result $\Gamma_{\phi} = 4.280 \pm 0.033 \pm 0.025$ MeV [32] agreed with SND measurement.

The ϕ -meson leptonic branching ratio was also measured using $e^+e^- \rightarrow \mu^+\mu^-$ reaction [33]: $\sqrt{B(\phi \rightarrow e^+e^-)B(\phi \rightarrow \mu^+\mu^-)} = (2.93 \pm 0.11) \cdot 10^{-4}$, which is in a good agreement with branching value of $\phi \rightarrow e^+e^-$ decay. Using SND value of $\phi \rightarrow e^+e^-$ decay width we obtained the following leptonic branching ratio: $B(\phi \rightarrow l^+l^-) = (2.93 \pm 0.09) \cdot 10^{-4}$.

The $e^+e^- \to \pi^+\pi^-\pi^0$ dynamics study and other results. In SND experiment the dipion mass spectra were studied in the $e^+e^- \to \pi^+\pi^-\pi^0$ process in the energy region around ϕ -meson [34]. Such studies provide the information about reaction dynamics as well as about ρ -meson parameters – mass and width, ρ^{\pm} and ρ^0 mass difference [35]. Spectra were analyzed within the VDM framework taking into account $\rho\pi$ transition, $\rho - \omega$ mixing and possible transition through intermediate states different from $\rho\pi$ (for example, via $\rho'\pi$). It was found that the experimental data can be described as a pure $\rho\pi$ transition. Upper limit on the branching ratio of the non $\rho\pi \phi(1020) \to 3\pi$ decay was obtained: $B(\phi \to \pi^+\pi^-\pi^0) < 6 \cdot 10^{-4}$. This result agrees with CMD2 similar studies [36]. Also the result of such studies was reported by KLOE [37], but unfortunately the information given there is insufficient to do the comparison

Table 2: The results of the $\rho, \omega, \phi \to \eta \gamma$ decays studies using the seven photon final state, results of $\rho, \omega, \phi \to \pi^0 \gamma, \phi \to \pi^+ \pi^-, \omega \pi$ decays measurements, the obtained ϕ -meson parameters, results on η and K_s mesons rare decays and conversion decays of η and ϕ mesons

	SND	Other data	
$B(\rho \to \eta \gamma) \cdot 10^4$	$2.77 \pm 0.26 \pm 0.16$	$3.28 \pm 0.37 \pm 0.23$	(CMD2 [20])
$B(\omega \to \eta \gamma) \cdot 10^4$	$4.22 \pm 0.47 \pm 0.17$	$5.10 \pm 0.72 \pm 0.34$	(CMD2 [20])
$B(\phi \to \eta \gamma) \cdot 10^2$	$1.34 \pm 0.01 \pm 0.05$	$1.287 \pm 0.013 \pm 0.063$	(CMD2 [20])
$B(\rho \to \pi^0 \gamma) \cdot 10^4$	$5.03 \pm 1.17 \pm 0.83$	6.8 ± 1.7	(PDG-2000)
$B(ho o \pi^{\pm} \gamma) \cdot 10^4$		4.5 ± 0.5	(PDG-2000)
$B(\omega o \pi^0 \gamma) \cdot 10^2$	$9.17 \pm 0.16 \pm 0.46$	8.5 ± 0.5	(PDG-2000)
$B(\phi o \pi^0 \gamma) \cdot 10^3$	$1.23 \pm 0.04 \pm 0.09$	1.26 ± 0.10	(PDG-2000)
$B(\phi \to \pi^+\pi^-) \cdot 10^5$	7.1 ± 1.4	$8\pm_{4}^{5}$	[24, 27]
$B(\phi \to \omega \pi^0) \cdot 10^5$	$5.2 \pm ^{1.3}_{1.1}$		
m_{ϕ}, MeV	$1019.42 \pm 0.02 \pm 0.04$	1019.417 ± 0.014	(PDG-2000)
$\Gamma_{\phi}, \mathrm{MeV}$	$4.21 \pm 0.03 \pm 0.02$	4.458 ± 0.032	(PDG-2000)
$B(\phi \rightarrow e^+ e^-) \cdot 10^4$	$2.93 \pm 0.02 \pm 0.14$	2.91 ± 0.07	(PDG-2000)
$B(\phi \to K^+ K^-), \%$	$47.6 \pm 0.3 \pm 1.6$	49.2 ± 0.7	(PDG-2000)
$B(\phi \to K_S K_L), \%$	$35.1 \pm 0.2 \pm 1.2$	33.8 ± 0.6	(PDG-2000)
$B(\phi \to \pi^+ \pi^- \pi^0), \%$	$15.9 \pm 0.2 \pm 0.8$	15.5 ± 0.6	(PDG-2000)
$B(\phi \to \eta \gamma), \%$	$1.33 \pm 0.03 \pm 0.05$	1.297 ± 0.033	(PDG-2000)
$B(\eta \to \pi^0 \pi^0) \cdot 10^4$	< 6 [38]	< 4.3	(CMD2 [8])
$B(\eta \to \pi^0 \gamma \gamma) \cdot 10^4$	< 8.4 [39]	7.1 ± 1.4	(PDG2000)
$B(K_S \to 3\pi^0) \cdot 10^5$	$< 1.4 \ [40]$	< 1.9	(CPLEAR [41])
$B(\phi \to \eta e^+ e^-) \cdot 10^4$	1.19 ± 0.22 [42]	1.17 ± 0.12	(CMD2 [43])
$B(\eta \rightarrow e^+ e^- \gamma) \cdot 10^3$	5.15 ± 0.96 [42]	7.10 ± 0.79	(CMD2 [43])
$B(\phi \to \pi^0 e^+ e^-) \cdot 10^5$	1.05 ± 0.37	1.22 ± 0.40	(CMD2 [44])

of the results. Neutral and charged ρ -mesons mass difference was found to be consistent with zero: $m_{\rho^{\pm}} - m_{\rho^{0}} = -1.3 \pm 2.3$ MeV. The ρ -meson mass and width were measured equal to $m_{\rho} = 775.0 \pm 1.3$ MeV, $\Gamma_{\rho} = 150.4 \pm 3.0$ MeV. The ρ mass values obtained by using different reactions contradict each other. SND ρ -mass value support the results of the e^+e^- annihilation and τ decay experiments: $m_{\rho} = 776 \pm 0.9$ MeV. But the PDG value 769.3 ± 0.8 MeV, which takes into account all experiments in which the ρ -meson mass was measured, contradicts our result.

Some other results obtained using statistics collected in the ϕ -meson energy region are presented in Table 2.

e^+e^- annihilation into hadrons above 1 GeV

The light vector mesons are studied rather well. They are 2 quark states, their masses, widths and the main decays are measured with high accuracy. The experimental data also point out the existence of the states with vector meson quantum numbers $I^G(J^{PC}) = 0^+(1^{--}), 0^-(1^{--})$ and masses above 1 GeV. Parameters of these states are not well established due to the poor accuracy and conflicting of experimental data. The nature of these states is not clear.



Figure 4: (a) – the cross section of the reaction $e^+e^- \rightarrow K_S K_L$. The results of the SND, OLYA [53] and DM1 [54] are shown. Curve is theoretical cross section in conventional VDM. (b) – the cross section of the reaction $e^+e^- \rightarrow \omega\pi \rightarrow \pi^0\pi^0\gamma$. The results of the SND [47], DM2 [48], CMD2 [49] and CLEO2 [50] are shown. Curves are results of fitting in models described in Ref.[47]

They are considered as a mixture of two quark, four quark and hybrids states [45] or as a two quark states – radial and orbital excitations of the ρ , ω and ϕ mesons [46]. In this context the main experimental task is the improvement of the cross sections measurement accuracy. In SND experiment the following processes were studied.

The $e^+e^- \rightarrow K_S K_L$ cross section was measured using $K_S \rightarrow \pi^0 \pi^0$ decay mode. Our measurements in comparison with OLYA and DM1 results are shown in Fig.4 (a). The curve is theoretical cross section with ρ , ω and ϕ contributions only. Experimental data above 1.2 GeV exceed the conventional VDM prediction.

The process $e^+e^- \rightarrow \omega\pi$ was studied in the $\pi^0\pi^0\gamma$ final state [47]. Measured cross section in comparison with the other results is shown in Fig. 4 (b). The systematic error of SND measurement is about 5%. The CLEO2 results¹ are in good agreement with ours, while CMD2 measurements are about 10% lower, but this difference is smaller than the 15% systematic error quoted in Ref.[49]. The same process was also studied in the $\pi^+\pi^-\pi^0\pi^0$ final state [51]. Obtained cross section agrees with our result in $\pi^0\pi^0\gamma$ mode. Its systematic error was estimated to be 20% for $\sqrt{s} < 1150$ MeV and 15% at $\sqrt{s} > 1150$.

The $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ cross section with subtracted contribution from $\omega\pi^0$ is shown in Fig.5 (a). The systematic error of SND measurements is about 20%. The SND result is compared with CLEO2, CMD2 and DM2 data². The two groups are seen: CMD2 dots better agree with DM2 while SND ones – with

 $¹e^+e^-$ annihilation cross section was calculated from $\tau\to 3\pi\pi^0$ decay data using CVS hypothesis

²While extracting cross section data from CLEO2 results the ratio $\sigma_{e^+e^- \to \pi^+\pi^-\pi^+\pi^-}/\sigma_{e^+e^- \to \pi^+\pi^-2\pi^0} = 2$ was assumed, which is confirmed by SND measurements [51]



Figure 5: (a) – the cross section of the reaction $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ with subtracted contribution from $\omega\pi^0$. (b) – the cross section of the reaction $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$. The results of the SND [51], DM2 [52], CMD2 [49] and CLEO2 [50] are shown.

CLEO2. But the difference is smaller than systematic errors. The measured cross section of the e^+e^- annihilation into four charged pions is shown in Fig.5 (b). Here SND dots better agree with DM2 result. The systematic error of the $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ cross section was estimated to be 12% for $\sqrt{s} < 1150$ MeV and 8% at $\sqrt{s} > 1150$.

Both $e^+e^- \to \rho\pi$ and $e^+e^- \to \omega\pi^0$ mechanisms contribute to the $\pi^+\pi^-\pi^0$ final state. The $\omega\pi$ contribution was predicted in Ref.[55] and observed by SND [56]. SND already reported the total cross section measurements based on the part of the accumulated statistics [57]. The new result of the cross section measurement is presented here. For data analysis we use the following theoretical model, taking into account the $\rho - \omega$ mixing [55]:

$$\frac{d\sigma}{dm_0 dm_+} = \frac{4\pi\alpha}{s^{3/2}} \frac{|\vec{p}_+ \times \vec{p}_-|^2}{12\pi^2 \sqrt{s}} m_0 m_+ \cdot \left| A_{\rho\pi}(s) \sum_{i=+,0,-} \frac{g_{\rho^i \pi\pi}}{D_{\rho}(m_i)} + A_{\omega\pi}(s) \frac{\Pi_{\rho\omega} g_{\rho^0 \pi\pi}}{D_{\rho}(m_0) D_{\omega}(m_0)} \right|^2$$
$$A_{\rho\pi} \sim \sum_{V=\omega,\phi,\omega',\dots} \frac{\Gamma_V m_V^2 \sqrt{m_V \sigma(V \to \rho\pi)}}{D_V(s)} \qquad A_{\omega\pi}(s) = \sum_{V=\rho,\rho',\dots} \frac{g_{\gamma V} g_{V \omega \pi^0}}{D_V(s)}$$
$$\operatorname{Im}(\Pi_{\rho\omega}) \ll \operatorname{Re}(\Pi_{\rho\omega}), \quad \operatorname{Re}(\Pi_{\rho\omega}) = 2m_\omega \delta, \quad \delta = 2.3 \text{ MeV}, \quad \delta \sim \sqrt{B(\omega \to \pi^+ \pi^-)}$$

The combined studies of the total cross section and dipion mass spectra provide the information about relative phase between $A_{\rho\pi}$ and $A_{\omega\pi}$ amplitudes and $\omega \to \pi^+\pi^-$ branching ratio. We performed the combined fit of $\pi^+\pi^-\pi^0$ (Fig.6) and $\omega\pi^+\pi^-$ cross sections. The cross section measured by SND in the ϕ -meson energy region was also included in the fit. The best description of the data was obtained when the cross sections were fitted by a sum of ω , ϕ and three ω^i amplitudes. The obtained ω^i parameters are listed in Table 3.

Table 3: ω^i parameters obtained from the fit. Here ϕ denotes a relative phases between ω and ω^i primes.

	ω^{1}	ω^2	ω^3
m, MeV	1250 ± 29	1400 ± 19	1771 ± 28
Γ , MeV	426 ± 135	626 ± 89	473 ± 76
$\sigma(V \to \rho \pi)$, nb	$0.56{\pm}0.25$	$3.90 {\pm} 0.39$	$2.28 {\pm} 0.46$
$\sigma(V \to \omega \pi \pi)$, nb	0	$0.046{\pm}0.039$	$2.49 {\pm} 0.33$
ϕ	π	π	0
$\Gamma(V \to e^+ e^-), \mathrm{eV}$	~ 25	~ 300	~ 470



Figure 6: (a) – the cross sections of the reactions $e^+e^- \to \pi^+\pi^-\pi^0$. The results of the SND and DM2 [58] are shown. Curve is the fit by a sum of ω , ϕ and three ω^i amplitudes. (b) – the energy dependence of the relative phase between $A_{\rho\pi}$ and $A_{\omega\pi}$ amplitudes.

To obtain relative phase between $A_{\rho\pi}$ and $A_{\omega\pi}$ amplitudes and $\omega \to \pi^+\pi^$ branching ratio the invariant mass distribution and the ratio of $\rho\pi$ to 3π cross sections were fitted together in each energy point. The energy dependence of the relative phase is shown in Fig.6. The obtained branching ratio $B(\omega \to \pi^+\pi^-) =$ $2.46 \pm 0.42 \pm 0.15$ agrees with world average value.

A search for direct production of a_2 and f_2 mesons in e^+e^- annihilation was performed with SND [59]. The following upper limits were obtained $\Gamma(a_2 \rightarrow e^+e^-) < 0.56$ eV and $\Gamma(f_2 \rightarrow e^+e^-) < 0.11$ eV. These upper limits are only four times higher than unitarity limit [60].

Conclusion

The SND detector operated since 1995 up to 2000 at VEPP-2M collider in the energy range $360 < \sqrt{s} < 1380$ MeV and had collected data with integrated luminosity of about 30 pb⁻¹. The ρ , ω , ϕ mesons decays and e^+e^- annihilation into hadrons were studied. New rare decays $\phi \to \pi^0 \pi^0 \gamma$, $\eta \pi^0 \gamma$, $\omega \pi^0$ and $\rho \to \pi^0 \pi^0 \gamma$ were observed. Many other results were obtained. The present work was supported in part by grants RFBR 00-15-96802, 01-02-22003, 01-02-16934-a, 00-02-17478, 00-02-17481, grant no. 78 1999 of Russian Academy of Science for young scientists.

References

- [1] A.N. Skrinsky, in Proc. of Workshop on physics and detectors for $DA\Phi NE$, Frascati, 1995, p.3
- [2] M.N. Achasov et al., Nucl. Instr. and Meth. A449, 125 (2000)
- [3] S.I. Dolinsky et al., Phys. Rep. 202 (1991) 99
- [4] N.N. Achasov, V.N. Ivanchenko, Nucl. Phys. B315 (1989) 465
- [5] M.N.Achasov et al., in Proc. of the 7th Int. Conf. on Hadron Spectroscopy, Brookhaven (BNL), 1997, p.783; Phys. Lett. B436 (1998) 441; Phys. Lett. B440 (1998) 442; Yad. Fiz., 62 (1999) 484
- [6] M.N.Achasov, et al., Phys Lett. B485 (2000) 349; Phys Lett. B479 (2000) 53
- [7] N.N.Achasov and V.V. Gubin, Phys. Rev. D 63 (2001) 094007
- [8] R.R.Akhmetshin et al., Phys. Lett. B 462 (1999) 380; Phys. Lett. B 462 (1999) 371
- [9] A.Aloisio, hep-ex/0107024
- [10] A.Bramon et al., Phys. Lett. B283 (1992) 476
- [11] E.Marco et al., Phys. Lett. B470 (1999) 20
- [12] A.Bramon et al., Phys. Lett. B289 (1992) 97
- [13] D.Albe et al., Phys. Lett. B340 (1994) 122
- [14] M.N.Achasov et al., JETP Letters, 71(9) (2000) 355
- [15] R.R. Akhmetshin et al., Phys. Lett. B415 (1997) 445
- [16] V.M.Aulchenko, et al., JETP Letters 69 (1999), 97
- [17] R.R. Akhmetshin et al., Phys. Lett. B494 (2000), 26
- [18] A.Aloisio, et al., hep-ex/0107022
- [19] M.N.Achasov et al., JETP Letters 72 (2000) 282
- [20] R.R. Akhmetshin et al., Phys. Lett. B509 (2001), 217
- [21] M.N.Achasov et al., JETP 90 (2000) 17

- [22] M.N. Achasov et al., Eur.Phys.J. C12 (2000)
- [23] M.N.Achasov et al., Preprint, Budker INP 2001-54, Novosibirsk, 2001 (in Russian)
- [24] I.B.Vasserman et al., Phys. Lett. B99 (1981) 62
- [25] N.N.Achasov, A.A.Kozhevnikov, Int. J. Mod. Phys. A7 (1992) 4825
- [26] J.A. Oller et al., Phys. Rev. D62 (2000) 114017
- [27] V.B.Golubev et al., YAF 44 (1986) 633; Sov. JNP 44 (1986) 409
- [28] M.N.Achasov et al., Phys. Lett. B474 (2000) 188
- [29] M.N.Achasov et al., Phys. Lett. B449 (1999) 122; Nuc. Phys. B569 (2000) 158; V.M.Aulchenko et al., JETP 90 (2000) 927
- [30] M.N.Achasov et al., Phys. Rev. D 63, (2001) 072002
- [31] R.R.Akhmetshin et al., Phys. Lett. B466 (1999) 385
- [32] R.R.Akhmetshin et al., Phys. Lett. B508 (2001) 217
- [33] M.N.Achasov et al., Phys. Lett. B456 (1999) 304; Phys. Rev. Lett. 86 (2001) 1698
- [34] M.N.Achasov et al., hep-ex/0106048
- [35] M.N.Achasov, N.N.Achasov, Pis'ma Zh. Eksp. Teor. Fiz. 69 (1999) 8; JETP Lett. 69 (1999) 7
- [36] R.R.Akhmetshin et al., Phys. Lett. B434 (1998) 426
- [37] M.Adinolfi et al., hep-ex/0006036
- [38] M.N.Achasov et al, Phys. Lett. B425 (1998) 388
- [39] M.N.Achasov et al, Nucl. Phys. B600 (2001) 3
- [40] M.N.Achasov et al, Phys. Lett. B459 (1999) 674
- [41] A.Angelopoulos et al., Phys. Lett. B425 (1998) 391
- [42] M.N.Achasov et al, Phys. Lett. B504 (2001) 275
- [43] R.R.Akhmetshin et al., Phys. Lett. B501 (2001) 191
- [44] R.R.Akhmetshin et al., Phys. Lett. B503 (2001) 237
- [45] A.Donnachie, Yu.S.Kalashnikova Phys. Rev. D60 (1999) 114011; Z. Phys. C60 (1993) 187; Z. Phys. C59 (1993) 621; A.B.Clegg, A.Donnachie Z. Phys. C62 (1994) 455

- [46] N.N.Achasov, A.A. Kozhevnikov Phys. Rev. D55 (1997) 2663; Phys. Rev. D57 (1998) 4334; Phys. Rev. D62 (2000) 117503
- [47] M.N.Achasov et al., Phys. Lett. B486 (2000) 29
- [48] D.Bisello et al., Nucl. Phys. Proc. Suppl. 21 111 (1991)
- [49] R.R.Akhmetshin et al., Phys. Lett. B466 (1999) 392
- [50] K.W.Edwards et al., Phys. Rev. D61 (2000) 072003
- [51] M.N.Achasov et al., Preprint, Budker INP 2000-34, Novosibirsk, 2000 (in Russian)
- [52] L.Stanco, in Proc. of the Int. Conf. on Hadron Spectroscopy, College Park, Maryland, 1991, p.84
- [53] P.M.Ivanov et al., Pis'ma Zh. Eksp. Teor. Fiz. 39 (1982) 91
- [54] F.Mane et al., Phys. Lett. B99 (1981) 261
- [55] N.N. Achasov, A.A.Kozhevnikov, G.N.Shestakov, Phys. Lett. B50 (1974) 448
- [56] M.N. Achasov et al., Preprint Budker INP 98-65 (1998); hep-ex/9809013
- [57] M.N. Achasov et al., Phys. Lett. B462 (1999) 365
- [58] A.Antonelli et al., Z. Phys C56 (1992) 15
- [59] M.N.Achasov et al., Phys. Lett. B492 (2000) 8
- [60] A.I.Vainshtein, I.B.Khriplovich, Yad. Fiz. 13 (1971) 620