# 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 $\sqrt{s}=0.36-1.38 \mathrm{GeV}$ is given. The presented results include the following items: studies of the light vector mesons radiative decays, OZI-rule and G-parity suppressed $\phi$ meson rare decays, $\phi$-meson parameters measurements, studies of $e^{+} e^{-} \rightarrow$ $\pi^{+} \pi^{-} \pi^{0}$ process dynamics, $\eta$ and $K_{S}$ mesons rare decays, $\eta$ and $\phi$ 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 $30 \mathrm{pb}^{-1}$.

## Radiative decays of the $\phi, \omega, \rho$ mesons

Electric dipole transitions of the $\phi$ meson. Till recently $\phi$ 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 $\phi \rightarrow f_{0} \gamma$,

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Figure 1: The $\pi^{0} \pi^{0}$ mass in the decay $\phi \rightarrow \pi^{0} \pi^{0} \gamma$ (a) and the $\eta \pi^{0}$ mass in the decay $\phi \rightarrow \eta \pi^{0} \gamma$ (b)
$a_{0} \gamma$ decays search appeared 4 . In 1997 the $\phi \rightarrow \pi^{0} \pi^{0} \gamma, \eta \pi^{0} \gamma$ decays were observed with SND 5]. The SND results based on the full data sample look as follows [6]: $B\left(\phi \rightarrow \pi^{0} \pi^{0} \gamma\right)=(1.22 \pm 0.10 \pm 0.06) \cdot 10^{-4}, B\left(\phi \rightarrow \eta \pi^{0} \gamma\right)=(0.88 \pm$ $0.14 \pm 0.09) \cdot 10^{-4}$. Studies of the $\pi^{0} \pi^{0}$ and $\eta \pi$ invariant mass spectra (Fig.11) demonstrate that $f_{0} \gamma$ and $a_{0} \gamma$ mechanisms dominate in these decays [6]. So the following branching ratios were obtained: $B\left(\phi \rightarrow f_{0} \gamma\right)=\left(3.5 \pm 0.3 \pm{ }_{0.5}^{1.3}\right) \cdot 10^{-4}$, $B\left(\phi \rightarrow a_{0} \gamma\right)=(0.88 \pm 0.14 \pm 0.09) \cdot 10^{-4}$. 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 99.

The decays $\rho, \omega \rightarrow \pi^{0} \pi^{0} \gamma$. In VDM model these decays proceed through the $\rho \rightarrow \omega \pi^{0} \rightarrow \pi^{0} \pi^{0} \gamma$ and $\omega \rightarrow \rho \pi^{0} \rightarrow \pi^{0} \pi^{0} \gamma$ 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 $\omega \rightarrow \pi^{0} \pi^{0} \gamma$ 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 $9 \mathrm{pb}^{-\mathrm{I}}$ are presented here.

We cannot extract any information about $\omega$ 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 $\sigma$ 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 $\rho, \rho^{\prime} \rightarrow \omega \pi^{0}$ 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 $\omega$ 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.
$\omega \rightarrow \pi^{0} \pi^{0} \gamma$ decay in VDM model and through $V \rightarrow S \gamma$ transitions. The strong difference in the energy dependences of the phase space for $\rho \rightarrow \omega \pi^{0}$ and $\rho \rightarrow$ $S \gamma$ mechanisms allows to distinguish the different models. The model without $\rho \rightarrow S \gamma$ contribution gives $P\left(\chi^{2}\right) \simeq 1 \%$. Inclusion of the scalar mechanism to the fit improves $P\left(\chi^{2}\right)$ to $30 \%$. The results of the fit follows: $B\left(\omega \rightarrow \pi^{0} \pi^{0} \gamma\right)=$ $(6.3 \pm 1.4 \pm 0.8) \cdot 10^{-5}, B\left(\rho \rightarrow \pi^{0} \pi^{0} \gamma\right)=(4.0 \pm 0.9 \pm 0.4) \cdot 10^{-5}, B(\rho \rightarrow S \gamma \rightarrow$ $\left.\pi^{0} \pi^{0} \gamma\right)=(2.0 \pm 0.7 \pm 0.3) \cdot 10^{-5}$. So we confirm the value of $\omega$ decay obtained by GAMS. The $\rho$ 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 $\phi \rightarrow \eta^{\prime} \gamma$ was not observed till recently. This decay was observed with CMD2 detector 155 and then confirmed by SND [16]. The results of SND studies of the $\phi \rightarrow \eta^{\prime} \gamma$ in comparison with CMD2 and KLOE measurements are listed in Table 1.

|  | SND [16] <br> $\eta^{\prime} \rightarrow \pi^{+} \pi^{-} \eta$ | $\eta^{\prime} \rightarrow \pi^{0} \pi^{0} \eta$ | SND <br> (average) | CMD2 | KLOE |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $[17]$ | $[18]$ |  |  |  |  |
| $B\left(\phi \rightarrow \eta^{\prime} \gamma\right) \cdot 10^{5}$ | $6.7 \pm_{2.9}^{3.4}$ | $4.3 \pm 1.6 \pm 0.9$ | $4.9 \pm_{1.5}^{1.6}$ | $6.4 \pm 1.6$ | $6.8 \pm 0.8$ |

Table 1: The comparison of the $B\left(\phi \rightarrow \eta^{\prime} \gamma\right)$ 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 $\rho$ and $\omega$ energy region (a) and above $\phi$ meson (b)
data set. It was found that cross section (Fig.3) can be described by sum of $\rho, \omega$ and $\phi$ 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 $\phi \rightarrow \eta \gamma$ decay was measured by SND in two other $\eta$ meson decay modes: $\eta \rightarrow \pi^{+} \pi^{-} \pi^{0}$ [21] and $\eta \rightarrow \gamma \gamma$ [22]. Combining the results of the three different modes the SND average was obtained: $B(\phi \rightarrow \eta \gamma)=$ $(1.310 \pm 0.045) \%$. It is the most precise measurement of this value.

The process $e^{+} e^{-} \rightarrow \pi^{0} \gamma$ was studied in the vicinity of $\phi$-meson 22] and in the $\rho, \omega$ energy region [23]. As in previous case the cross section can be described by sum of $\rho, \omega$ and $\phi$ mesons only. The obtained branching ratios are listed in Table 2. The $\rho$ and $\omega$ 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 $\rho$ meson branching ratio. We also hope that combined analysis of data from $\phi$ and $\rho, \omega$ energy regions could reduce the systematic error of $\phi \rightarrow \pi^{0} \gamma$ branching ratio caused by the model dependence of $\phi-\omega$ interference description.

## $\phi$ meson energy region study

OZI rule and G-parity suppressed $\phi \rightarrow \omega \pi^{0}$ and $\pi^{+} \pi^{-}$decays. Till recently only one decay of this type $\phi \rightarrow \pi^{+} \pi^{+}$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 $\phi \rightarrow \pi^{+} \pi^{+}$decay was studied
[28] and the decay $\phi \rightarrow \omega \pi$ was observed for the first time [29].
These decays are seen as interference patterns around $\phi$-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 $\sigma_{0}$ 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: $\operatorname{Im}\left(Z_{\pi \pi}\right)=-0.041 \pm 0.007, \operatorname{Im}\left(Z_{\omega \pi}\right)=-0.125 \pm 0.020$ agree with theoretical predictions based on standard $\omega-\phi$ mixing, while the expected values of the real parts exceed our results: $\operatorname{Re}\left(Z_{\pi \pi}\right)=0.061 \pm 0.006, \operatorname{Re}\left(Z_{\omega \pi}\right)=$ $0.108 \pm 0.16$. The possible cause of this disagreement could be a nonstandard $\omega-\phi$ mixing or direct decays.
$\phi$ meson parameters study. The main parameters of the $\phi$ meson were measured through studies of the processes $e^{+} e^{-} \rightarrow K^{+} K^{-}, K_{S} K_{L}$ and $\pi^{+} \pi^{-} \pi^{0}$ [30]. The measured cross sections were approximated within the VDM, taking into account $\rho, \omega$ and $\phi$ mesons. Contributions from higher resonances $\rho^{\prime}, \omega^{\prime}, \phi^{\prime}$ were included in each cross section as constant terms. The $K^{+} K^{-}$and $K_{S} K_{L}$ cross sections can be fitted by a sum of $\rho, \omega$ and $\phi$ contributions only, while for a good approximation of the $e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} \pi^{0}$ cross section the additional contribution, which can be attributed to the higher resonances, is strongly required. The obtained $\phi$-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 $\phi$-meson width. The world average $\Gamma_{\phi}$ value is strongly based on CMD2 measurement $\Gamma_{\phi}=4.477 \pm 0.036 \pm 0.022 \mathrm{MeV}$ 31 which contradict to the SND one. But the recent CMD2 result $\Gamma_{\phi}=4.280 \pm 0.033 \pm 0.025 \mathrm{MeV}$ 32] agreed with SND measurement.

The $\phi$-meson leptonic branching ratio was also measured using $e^{+} e^{-} \rightarrow$ $\mu^{+} \mu^{-}$reaction 33]: $\sqrt{B\left(\phi \rightarrow e^{+} e^{-}\right) B\left(\phi \rightarrow \mu^{+} \mu^{-}\right)}=(2.93 \pm 0.11) \cdot 10^{-4}$, 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: $B\left(\phi \rightarrow l^{+} l^{-}\right)=(2.93 \pm 0.09) \cdot 10^{-4}$.

The $e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} \pi^{0}$ dynamics study and other results. In SND experiment the dipion mass spectra were studied in the $e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} \pi^{0}$ process in the energy region around $\phi$-meson [34]. Such studies provide the information about reaction dynamics as well as about $\rho$-meson parameters - mass and width, $\rho^{ \pm}$and $\rho^{0}$ 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 $\rho^{\prime} \pi$ ). 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 $\rho \pi \phi(1020) \rightarrow 3 \pi$ decay was obtained: $B\left(\phi \rightarrow \pi^{+} \pi^{-} \pi^{0}\right)<6 \cdot 10^{-4}$. 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 $\rho, \omega, \phi \rightarrow \eta \gamma$ decays studies using the seven photon final state, results of $\rho, \omega, \phi \rightarrow \pi^{0} \gamma, \phi \rightarrow \pi^{+} \pi^{-}, \omega \pi$ decays measurements, the obtained $\phi$-meson parameters, results on $\eta$ and $K_{s}$ mesons rare decays and conversion decays of $\eta$ and $\phi$ mesons

|  | SND | Other data |  |
| :---: | :---: | :---: | :---: |
| $B(\rho \rightarrow \eta \gamma) \cdot 10^{4}$ | $2.77 \pm 0.26 \pm 0.16$ | $3.28 \pm 0.37 \pm 0.23$ | (CMD2 20]) |
| $B(\omega \rightarrow \eta \gamma) \cdot 10^{4}$ | $4.22 \pm 0.47 \pm 0.17$ | $5.10 \pm 0.72 \pm 0.34$ | (CMD2 20) |
| $B(\phi \rightarrow \eta \gamma) \cdot 10^{2}$ | $1.34 \pm 0.01 \pm 0.05$ | $1.287 \pm 0.013 \pm 0.063$ | (CMD2 [20]) |
| $B\left(\rho \rightarrow \pi^{0} \gamma\right) \cdot 10^{4}$ | $5.03 \pm 1.17 \pm 0.83$ | $6.8 \pm 1.7$ | (PDG-2000) |
| $B\left(\rho \rightarrow \pi^{ \pm} \gamma\right) \cdot 10^{4}$ |  | $4.5 \pm 0.5$ | (PDG-2000) |
| $B\left(\omega \rightarrow \pi^{0} \gamma\right) \cdot 10^{2}$ | $9.17 \pm 0.16 \pm 0.46$ | $8.5 \pm 0.5$ | (PDG-2000) |
| $B\left(\phi \rightarrow \pi^{0} \gamma\right) \cdot 10^{3}$ | $1.23 \pm 0.04 \pm 0.09$ | $1.26 \pm 0.10$ | (PDG-2000) |
| $B\left(\phi \rightarrow \pi^{+} \pi^{-}\right) \cdot 10^{5}$ | $7.1 \pm 1.4$ | $8 \pm_{4}^{5}$ | [24, 27 |
| $B\left(\phi \rightarrow \omega \pi^{0}\right) \cdot 10^{5}$ | $5.2 \pm{ }_{1.1}^{1.3}$ |  |  |
| $m_{\phi}, \mathrm{MeV}$ | $1019.42 \pm 0.02 \pm 0.04$ | $1019.417 \pm 0.014$ | (PDG-2000) |
| $\Gamma_{\phi}, \mathrm{MeV}$ | $4.21 \pm 0.03 \pm 0.02$ | $4.458 \pm 0.032$ | (PDG-2000) |
| $B\left(\phi \rightarrow e^{+} e^{-}\right) \cdot 10^{4}$ | $2.93 \pm 0.02 \pm 0.14$ | $2.91 \pm 0.07$ | (PDG-2000) |
| $B\left(\phi \rightarrow K^{+} K^{-}\right), \%$ | $47.6 \pm 0.3 \pm 1.6$ | $49.2 \pm 0.7$ | (PDG-2000) |
| $B\left(\phi \rightarrow K_{S} K_{L}\right), \%$ | $35.1 \pm 0.2 \pm 1.2$ | $33.8 \pm 0.6$ | (PDG-2000) |
| $B\left(\phi \rightarrow \pi^{+} \pi^{-} \pi^{0}\right), \%$ | $15.9 \pm 0.2 \pm 0.8$ | $15.5 \pm 0.6$ | (PDG-2000) |
| $B(\phi \rightarrow \eta \gamma), \%$ | $1.33 \pm 0.03 \pm 0.05$ | $1.297 \pm 0.033$ | (PDG-2000) |
| $B\left(\eta \rightarrow \pi^{0} \pi^{0}\right) \cdot 10^{4}$ | $<6$ [38] | <4.3 | (CMD2 []) |
| $B\left(\eta \rightarrow \pi^{0} \gamma \gamma\right) \cdot 10^{4}$ | < 8.4 39 | $7.1 \pm 1.4$ | (PDG2000) |
| $B\left(K_{S} \rightarrow 3 \pi^{0}\right) \cdot 10^{5}$ | $<1.4$ 40] | $<1.9$ | (CPLEAR 41) |
| $B\left(\phi \rightarrow \eta e^{+} e^{-}\right) \cdot 10^{4}$ | $1.19 \pm 0.22$ | $1.17 \pm 0.12$ | (CMD2 43) |
| $B\left(\eta \rightarrow e^{+} e^{-} \gamma\right) \cdot 10^{3}$ | $5.15 \pm 0.9642$ | $7.10 \pm 0.79$ | (CMD2 43) |
| $B\left(\phi \rightarrow \pi^{0} e^{+} e^{-}\right) \cdot 10^{5}$ | $1.05 \pm 0.37$ | $1.22 \pm 0.40$ | (CMD2 [44]) |

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

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

## $e^{+} e^{-}$annihilation into hadrons above $1 \mathbf{G e V}$

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 $I^{G}\left(J^{P C}\right)=0^{+}\left(1^{--}\right), 0^{-}\left(1^{--}\right)$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 $\rho, \omega$ and $\phi$ 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 $\rho, \omega$ and $\phi$ 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. (b). The systematic error of SND measurement is about $5 \%$. The CLEO2 results 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 $\sqrt{s}<1150 \mathrm{MeV}$ 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 data. The two groups are seen: CMD2 dots better agree with DM2 while SND ones - with

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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 522, 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 $\sqrt{s}<1150 \mathrm{MeV}$ and $8 \%$ at $\sqrt{s}>1150$.

Both $e^{+} e^{-} \rightarrow \rho \pi$ and $e^{+} e^{-} \rightarrow \omega \pi^{0}$ 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]:

$$
\begin{gathered}
\frac{d \sigma}{d m_{0} d m_{+}}=\frac{4 \pi \alpha}{s^{3 / 2}} \frac{\left|\vec{p}_{+} \times \vec{p}_{-}\right|^{2}}{12 \pi^{2} \sqrt{s}} m_{0} m_{+} \cdot\left|A_{\rho \pi}(s) \sum_{i=+, 0,-} \frac{g_{\rho^{i} \pi \pi}}{D_{\rho}\left(m_{i}\right)}+A_{\omega \pi}(s) \frac{\Pi_{\rho \omega} g_{\rho^{0} \pi \pi}}{D_{\rho}\left(m_{0}\right) D_{\omega}\left(m_{0}\right)}\right|^{2} \\
A_{\rho \pi} \sim \sum_{V=\omega, \phi, \omega^{\prime}, \ldots} \frac{\Gamma_{V} m_{V}^{2} \sqrt{m_{V} \sigma(V \rightarrow \rho \pi)}}{D_{V}(s)} \quad A_{\omega \pi}(s)=\sum_{V=\rho, \rho^{\prime}, \ldots} \frac{g_{\gamma V} g_{V \omega \pi^{0}}}{D_{V}(s)} \\
\operatorname{Im}\left(\Pi_{\rho \omega}\right) \ll \operatorname{Re}\left(\Pi_{\rho \omega}\right), \quad \operatorname{Re}\left(\Pi_{\rho \omega}\right)=2 m_{\omega} \delta, \quad \delta=2.3 \mathrm{MeV}, \quad \delta \sim \sqrt{B\left(\omega \rightarrow \pi^{+} \pi^{-}\right)}
\end{gathered}
$$

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 $\omega \rightarrow \pi^{+} \pi^{-}$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 $\phi$-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 $\omega, \phi$ and three $\omega^{i}$ amplitudes. The obtained $\omega^{i}$ parameters are listed in Table 3.

Table 3: $\omega^{i}$ parameters obtained from the fit. Here $\phi$ denotes a relative phases between $\omega$ and $\omega^{i}$ primes.

|  | $\omega^{1}$ | $\omega^{2}$ | $\omega^{3}$ |
| :--- | :--- | :--- | :--- |
| $m, \mathrm{MeV}$ | $1250 \pm 29$ | $1400 \pm 19$ | $1771 \pm 28$ |
| $\Gamma, \mathrm{MeV}$ | $426 \pm 135$ | $626 \pm 89$ | $473 \pm 76$ |
| $\sigma(V \rightarrow \rho \pi), \mathrm{nb}$ | $0.56 \pm 0.25$ | $3.90 \pm 0.39$ | $2.28 \pm 0.46$ |
| $\sigma(V \rightarrow \omega \pi \pi), \mathrm{nb}$ | 0 | $0.046 \pm 0.039$ | $2.49 \pm 0.33$ |
| $\phi$ | $\pi$ | $\pi$ | 0 |
| $\Gamma\left(V \rightarrow e^{+} e^{-}\right), \mathrm{eV}$ | $\sim 25$ | $\sim 300$ | $\sim 470$ |



Figure 6: (a) - the cross sections of the reactions $e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} \pi^{0}$. The results of the SND and DM2 58] are shown. Curve is the fit by a sum of $\omega, \phi$ and three $\omega^{i}$ 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 $\omega \rightarrow \pi^{+} \pi^{-}$ branching ratio the invariant mass distribution and the ratio of $\rho \pi$ to $3 \pi$ 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 $B\left(\omega \rightarrow \pi^{+} \pi^{-}\right)=$ $2.46 \pm 0.42 \pm 0.15$ 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 $\Gamma\left(a_{2} \rightarrow\right.$ $\left.e^{+} e^{-}\right)<0.56 \mathrm{eV}$ and $\Gamma\left(f_{2} \rightarrow e^{+} e^{-}\right)<0.11 \mathrm{eV}$. 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 $360<\sqrt{s}<1380 \mathrm{MeV}$ and had collected data with integrated luminosity of about $30 \mathrm{pb}^{-1}$. The $\rho, \omega, \phi$ mesons decays and $e^{+} e^{-}$annihilation into hadrons were studied. New rare decays $\phi \rightarrow \pi^{0} \pi^{0} \gamma, \eta \pi^{0} \gamma, \omega \pi^{0}$ and $\rho \rightarrow$ $\pi^{0} \pi^{0} \gamma$ were observed. Many other results were obtained.

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[^1]:    ${ }^{1} e^{+} e^{-}$annihilation cross section was calculated from $\tau \rightarrow 3 \pi \pi^{0}$ decay data using CVS hypothesis
    ${ }^{2}$ While extracting cross section data from CLEO2 results the ratio $\sigma_{e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} \pi^{+}} / \sigma_{e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} 2 \pi^{0}}=2$ was assumed, which is confirmed by SND measurements 51]

