Study of e^+e^- annihilation into hadrons below 2 GeV with SND

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Abstract: Beginning from 2010 experiments with the SND detector are carrying out at the e^+e^- -collider VEPP-2000 in the energy range 0.3-2.0 GeV. New results on study of the processes of e^+e^- annihilation into hadrons based on data collected in these experiments are presented.

Key words: universal detector, hadrons, cross section, data analysis

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1 Introduction

The VEPP-2000 e^+e^- collider [1] (Fig. 1) operates in the center-of-mass (c.m.) energy range $E_{cm} = 0.3 - 2.0$ GeV. Experiments at VEPP-2000 were carried out in 2010-2013. The maximal achieved luminosity during these experiments was $2 \times 10^{31} cm^{-2} s^{-1}$. The luminosity was limited by deficit of positrons. Currently the VEPP-2000 complex is being upgraded. This upgrade is expected to provide increase of the VEPP-2000 luminosity at 2 GeV up to $10^{32} cm^{-2} s^{-1}$ and should result in a more stable operation of the accelerator complex.

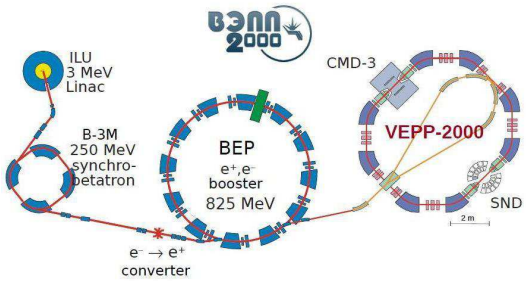

Fig. 1. The layout of the VEPP-2000 e^+e^- collider

The Spherical Neutral Detector (SND) [2](Fig. 2) is the universal nonmagnetic detector, which consists of a nine-layer drift chamber, an aerogel Cherenkov counters, a three-layer spherical electromagnetic calorimeter with 1640 NaI(Tl) crystals, and a muon system. During 2010-2013 a data sample with an integrated luminosity of about 69 pb^{-1} was recorded with the SND detector in the energy range from 0.32 to 2.00 GeV. Data accumulated in the energy region above the ϕ-meson resonance correspond to an integrated luminosity of 45 pb^{-1}.

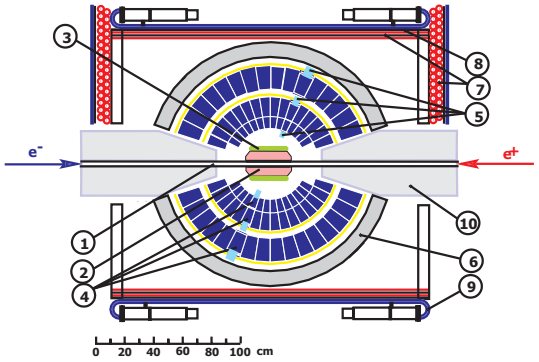

Fig. 2. The SND detector: 1 - beam pipe, 2 - tracking system, 3 - aerogel Cherenkov counters, 4 - NaI(Tl) crystals, 5 - phototriodes, 6 - iron muon absorber, 7-9 - muon detector, 10 - focusing superconducting solenoids.

The physical program for VEPP-2000 includes precise measurements of all major channels of e^+e^- annihilation to hadrons from threshold up to 2 GeV. The main goal of these measurements is to improve accuracy of $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$, which is used in calculation of the muon anomaly $(g-2)_\mu$ and the fine structure constant at Z-mass $\alpha_{em}(s = M_Z^2)$. Other items of the program are: study of the production, dynamics

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and decays of the excited vector states ρ', ρ'', ω', ω'',and ϕ', the comparison of the isovector cross sections with the corresponding spectral functions in τ decays, study of the nucleon pair production near threshold and some others.

2 Multihadron processes

2.1 $e^+e^- \to \pi^+\pi^-\pi^0$ [3]

The $e^+e^- \to \pi^+\pi^-\pi^0$ cross section measured by SND is shown in Fig. 3 in comparison with data of previous experiments. This is the most precise measurement in the energy range 1.05–2.00 GeV. For energies below 1.8 GeV the cross section data are well described by the VMD model with the contributions of ω, ϕ, $\omega(1420)$ and $\omega(1650)$ resonances. Above 1.8 GeV, an extra resonance or a non-resonant contribution is needed to be added to describe cross section energy dependence.

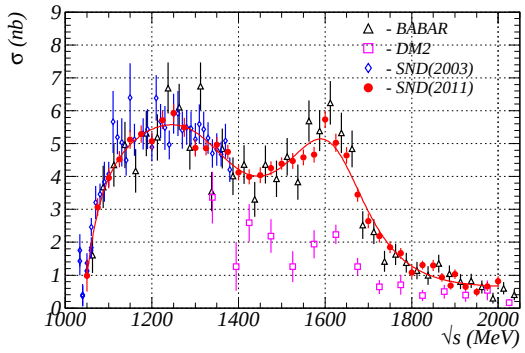

Fig. 3. The cross section for $e^+e^- \to \pi^+\pi^-\pi^0$ obtained by SND at VEPP-2000 in comparison with the previous SND [4] and BABAR [5] data.

2.2 $e^+e^- \to \pi^+\pi^-\eta$ [6]

It is usually assumed that the dominant mechanism for this reaction is the transition via the $\rho(770)\eta$ intermediate state. The measured $\pi^+\pi^-$ invariant mass spectrum is shown in Fig. 4. It is seen that it differs from the spectrum calculated under the $\rho(770)\eta$ assumption. The observed deviation may be a result of a contribution of other intermediate state, e.g. $\rho(1450)\eta$.

The $e^+e^- \to \pi^+\pi^-\eta$ cross section measured by SND at VEPP-2000 in comparison with previous measurements is shown in Fig. 5. The fit to the cross section data was performed for two models: (i) a sum of the $\rho(770)$, $\rho(1450)$ and $\rho(1700)$ resonance contributions and (ii) a sum of the $\rho(770)$ and $\rho(1450)$ contributions. The value of the $\rho(1700)$ amplitude obtained in the first model deviates from zero by 2σ. So, we cannot set a definite conclusion that the $\rho(1700)$ contribution is needed for data description.

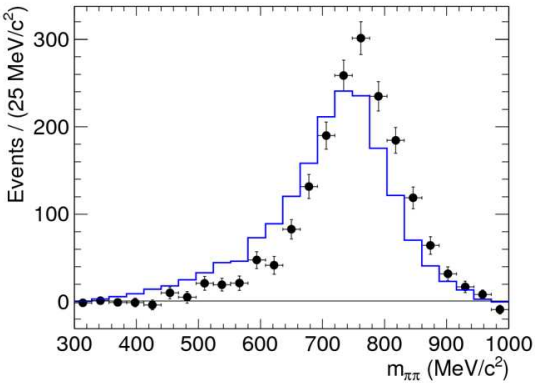

Fig. 4. The $\pi^+\pi^-$ invariant mass spectrum for $e^+e^- \to \pi^+\pi^-\eta$ data events (points with error bars). The histogram is the simulated spectrum for the $\rho\eta$ mechanism.

Using our data on the $e^+e^- \to \eta\pi^+\pi^-$ cross section under the CVC hypothesis, the branching fraction of the decay $\tau \to \eta\pi^-\pi^0\nu_\tau$ is calculated to be $(0.156 \pm 0.011)\%$. This value is in a reasonable agreement with the PDG [7] value $B(\tau \to \eta\pi^-\pi^0\nu_\tau) = (0.139 \pm 0.01)\%$.

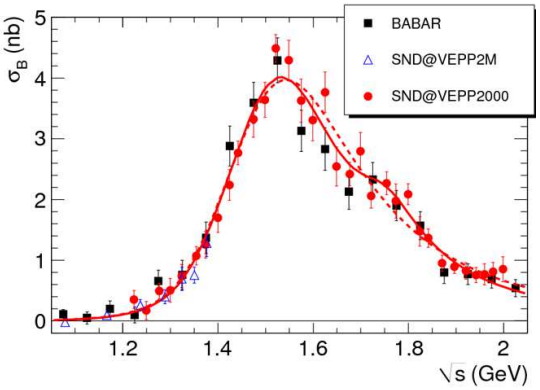

Fig. 5. The $e^+e^- \to \pi^+\pi^-\eta$ cross section obtained by SND at VEPP-2000 in comparison with the previous SND[8] and BABAR[9] measurements. The solid curve is the result of the fit with ρ, $\rho(1450)$ and $\rho(1700)$ contributions. The dashed line is the result of the fit with ρ and $\rho(1450)$ contributions.

2.3 $e^+e^- \to K^+K^-\eta$

This process is studied in the $\eta \to \gamma\gamma$ decay mode. The measured cross section in comparison with BABAR data is shown in Fig. 6. The fit to the cross section data is performed in hypothesis that main mechanism of this reaction is $e^+e^- \to \phi(1680) \to \phi(1020)\eta$. The result of the fit is in agreement with the data.

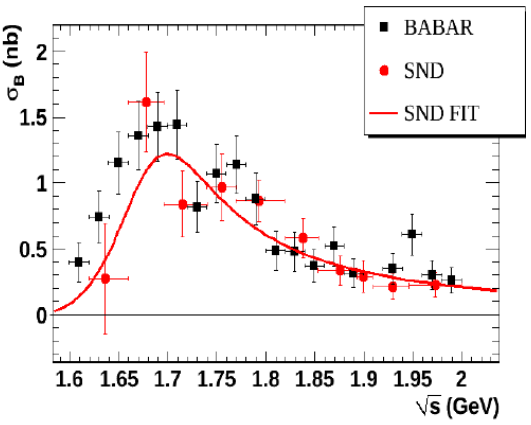

Fig. 6. The $e^+e^- \to K^+K^-\eta$ cross section obtained by SND in comparison with the BABAR measurement [10]. The solid curve is the result of the fit described in the text.

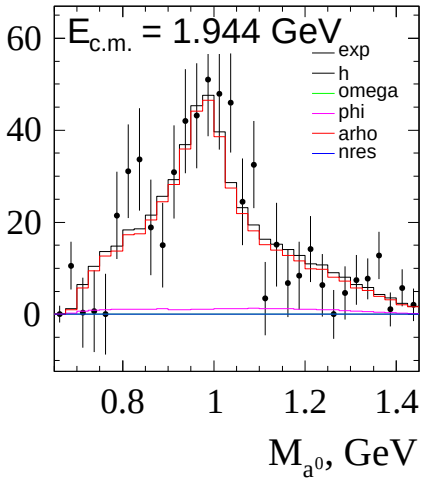

Fig. 8. The $\eta\pi$ invariant mass spectrum for $e^+e^- \to \pi^+\pi^-\pi^0\eta$ data events (points with error bars) at $E_{cm} = 1.944$ GeV.

2.4 $e^+e^- \to \pi^+\pi^-\pi^0\eta$

This process proceed through different intermediate states. The contributions of the $\omega\eta$ and $\phi\eta$ intermediate states is clearly seen in the spectrum of the $\pi^+\pi^-\pi^0$ invariant mass shown in Fig. 7. The contribution of $a\rho$ intermediate state is seen in the $\eta\pi$ invariant mass spectrum shown in Fig. 8. There is also a non-resonant contribution.

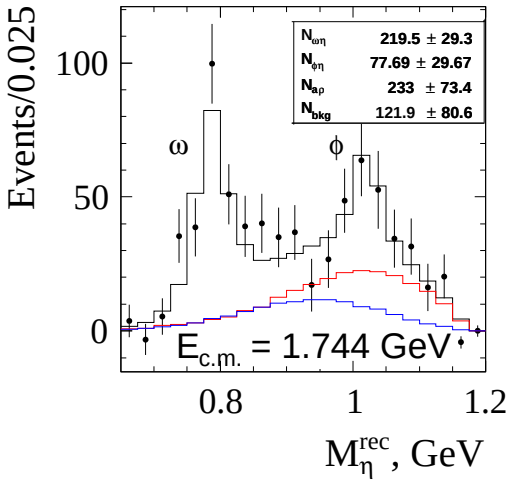

Fig. 7. The $\pi^+\pi^-\pi^0$ invariant mass spectrum for $e^+e^- \to \pi^+\pi^-\pi^0\eta$ data events (points with error bars) at $E_{cm} = 1.794$ GeV.

The measured $e^+e^- \to \pi^+\pi^-\pi^0\eta$ cross section is shown in Fig. 9. This is the first measurement of the cross section. We suppose that the dominant contributions into the $e^+e^- \to \pi^+\pi^-\pi^0\eta$ cross section comes from the $\phi(1680)$ and $\omega(1650)$ resonances. The cross section for the $\omega\eta$ component is shown in Fig. 10 in comparison with BABAR data. The fit to cross section data takes into account contributions of the $\phi(1680)$ and $\omega(1420)$ resonances. The sharp decrease of the cross section to zero above $E_{cm} > 1.8$ GeV is explained by destructive interference of the two resonance amplitudes.

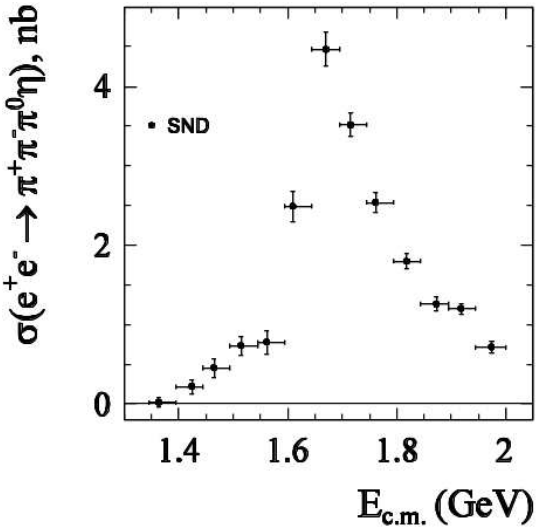

Fig. 9. The $e^+e^- \to \pi^+\pi^-\pi^0\eta$ cross section measured by SND.

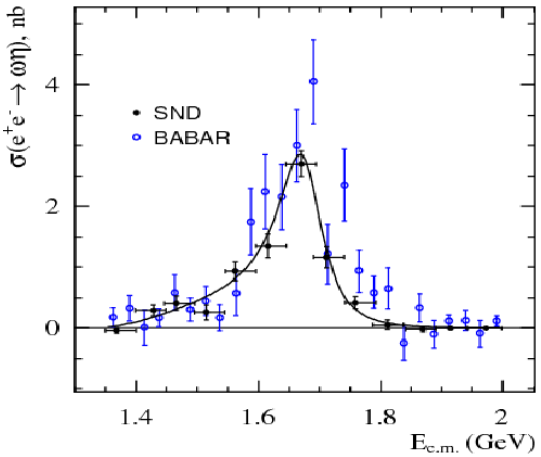

Fig. 10. The $e^+e^- \to \omega\eta$ cross section obtained by SND in comparison with BABAR data [11].

2.5 $e^+e^- \to \omega\pi^0$

The update our previous measurement of the $e^+e^- \to \omega\pi^0$ cross section [12] based on the full SND data set collected at VEPP-2000 is presented in Fig. 11 in comparison with the SND at VEPP-2M result (SND 2000) and CLEO data. The CLEO cross section is calculated under the CVC hypothesis from the spectral function in the $\tau \to \omega\pi\nu_\tau$ measured in Ref. [14]. The cross-section energy dependence is well described by contributions of the ρ, $\rho(1450)$ and $\rho(1700)$ resonances. The transition form factor $F_{\omega\pi\gamma}$ for $\gamma^* \to \omega\pi^0$ vertex $F_{\omega\pi\gamma}$ obtained from the measured cross section is shown in Fig.12. Below 0.7 GeV the same form factor measured in the $\omega \to \pi^0\mu^+\mu^-$ decay [15] is shown. The solid curve represents the results of the VMD prediction with the parameters obtained from our cross section fit. The dashed curve shows the $\rho(770)$ contribution only. One can see that the data from e^+e^- annihilation and $\omega \to \pi^0\mu^+\mu^-$ decay cannot be described within the VMD model.

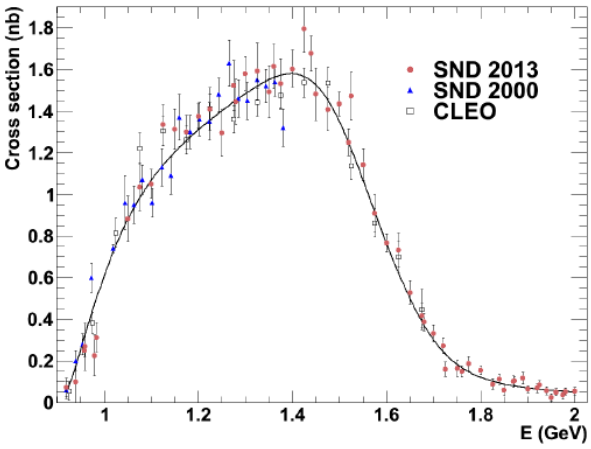

Fig. 11. The $e^+e^- \to \omega\pi^0$ cross section obtained by SND at VEPP-2000 in comparison with previous SND at VEPP-2M results [13] and CLEO data [14].

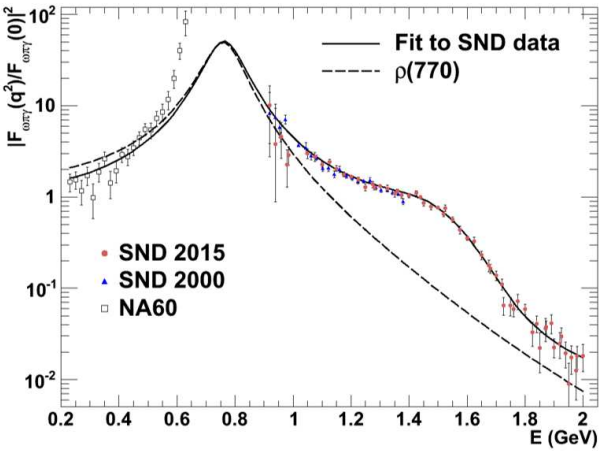

Fig. 12. The transition form factor for the $\gamma^* \to \omega\pi^0$ vertex. The circles represent SND at VEPP-2000 data, the triangles previous SND and VEPP-2M data and squares data from the NA60 experiment [15].

2.6 $e^+e^- \to K^+K^-$

In this measurement charged kaon identification is based on information from the aerogel threshold Cherenkov counters [16]. Our preliminary result on the $e^+e^- \to K^+K^-$ cross section in comparison with BABAR data is shown in Fig.13. The complex energy dependence of the cross section is explained by interference of the amplitudes of all isoscalar and isovector resonances located in the energy region under study.

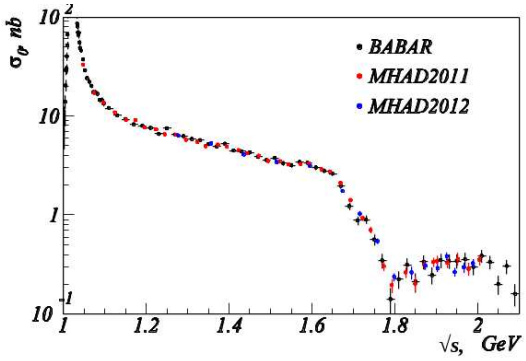

Fig. 13. The $e^+e^- \to K^+K^-$ cross section obtained by SND in comparison with BABAR data [17].

2.7 Production of nucleon-antinucleon pairs

The cross sections for the $e^+e^- \to p\bar{p}$ and $e^+e^- \to n\bar{n}$ processes measured by SND are shown in Figs. 14 and 15. Both cross sections are constant in the energy region under study. The values of the $p\bar{p}$ and $n\bar{n}$ cross sections coincide within errors.

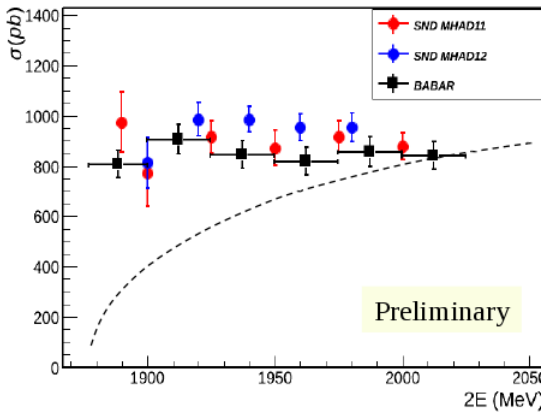

Fig. 14. The $e^+e^- \to p\bar{p}$ cross section obtained by SND in comparison with BABAR data [18].

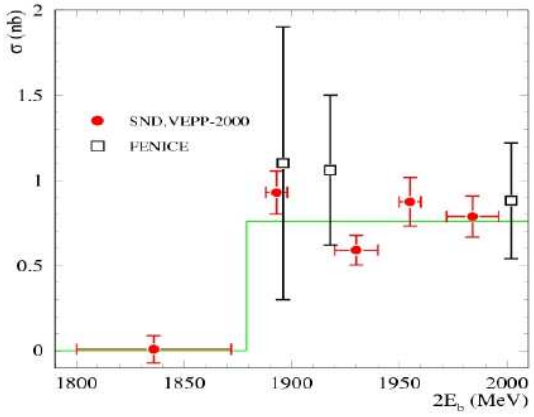

Fig. 15. The $e^+e^- \to n\bar{n}$ cross section obtained by SND in comparison with FENICE data [19].

3 Search for the rare decays $\eta', \eta \to e^+e^-$

In the Standard Model (SM) these decays proceed through the two-photon intermediate state and therefore are suppressed by a factor of α^2 comparing with the two photon decays, where α is the fine structure constant. An additional suppression of $(m_e/m_{\eta',\eta})^2$ arises from the approximate helicity conservation. So, the partial width of $\eta', \eta \to e^+e^-$ decays is less than the corresponding two-photon width by a factor of $\sim \alpha^2(m_e/m_{\eta',\eta})^2$. The low probability makes these decays sensitive to possible contributions of new physics beyond the SM. At the VEPP-2000 e^+e^- collider these decays can be searched for using the inverse reaction $e^+e^- \to \eta', \eta$. The strictest upper limit on the branching fraction $\mathcal{B}(\eta' \to e^+e^-) < 1.2\times10^{-8}$ at the 90% confidence level (CL) was set in the experiment with the CMD-3 detector at VEPP-2000 [20]. The upper limit on the η-decay $\mathcal{B}(\eta \to e^+e^-) < 2.3\times10^{-6}$ was recently set in the HADES experiment [21].

Search for the $\eta' \to e^+e^-$ decay is based on the data set with an integrated luminosity of about 2.9 pb^{-1} collected by SND at c.m. energy close to $m_{\eta'} = 957.78 \pm 0.06$ MeV. Five decay chains with a total branching fraction of 51.5% are used to reconstruct η'. No data events satisfied to η' selection criteria process have been found. As a result the upper limit has been obtained $\mathcal{B}(\eta' \to e^+e^-) < 1.0\times10^{-8}$ at 90%CL. The combined SND and CMD-3 limit is $\mathcal{B}(\eta' \to e^+e^-) < 5.6\times10^{-9}$.

During 2010-2013 experiments the SND detector didn't collect data at $m_\eta = 548.862 \pm 0.018 MeV$. So, we study the possibility to perform $\eta \to e^+e^-$ search after VEPP-2000 upgrade. To do this, data with an integrated luminosity of 108 nb^{-1} collected in the c.m.energy range 520–580 MeV are used. No background events for the reaction $e^+e^- \to \eta$ in the decay mode $\eta \to \pi^0\pi^0\pi^0$ has been found. This means that data with an integrated luminosity of 324 nb^{-1} will provide a sensitivity of 10^{-6} for $\mathcal{B}(\eta \to e^+e^-)$. Such data may be accumulated in two weeks of VEPP-2000 operation.

4 Summary

During 2010-2013, experiments at the VEPP-2000 e^+e^- collider with the SND detector were carried in the c.m. energy range from 320 to 2000 MeV. Data with an integrated luminosity about of 70 pb^{-1} were collected. Analysis of these data is in progress. Obtained results on hadronic cross sections have the same or better statistical precision than previous measurements. After VEPP-2000 upgrade, data taking will be resumed with the goal to collect 1 fb^{-1}.

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