PROCEEDINGS OF SCIENCE

Study of the e^+e^- annihilation into hadrons with the SND detector at the VEPP-2000 collider

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Recent results on study of exclusive processes of e^+e^- annihilation into hadrons below 2 GeV obtained at the SND detector are presented. The analysis are based on data collected at the VEPP-2M and VEPP-2000 colliders. In particular, we present the measurements of the $e^+e^- \to \eta\pi^+\pi^-$, $e^+e^- \to \eta K^+K^-$, $e^+e^- \to K_S K_L \pi^0$ cross sections, the preliminary results on study of the $e^+e^- \to \pi^+\pi^-$, $e^+e^- \to n\bar{n}$ and $e^+e^- \to \pi^0\gamma$, and the upper limit for $\eta \to e^+e^-$ decay branching fraction

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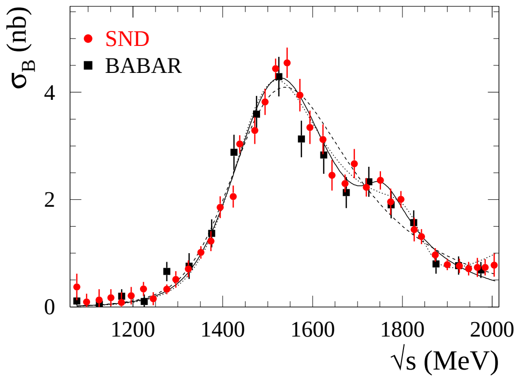

Figure 1: Born cross section for $e^+e^- \to \eta\pi^+\pi^-$ process. The solid, dashed, and dotted curves at the right plot are the results of the VMD fit with models 1,2 and 3 described in the text

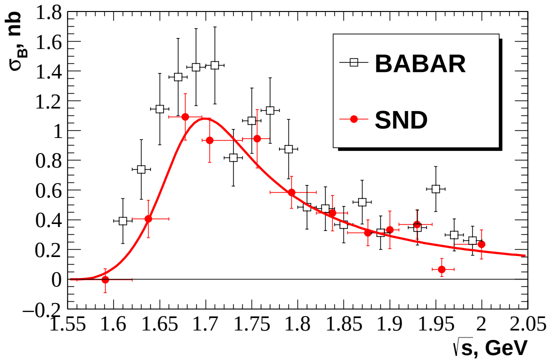

Figure 2: Born cross section (right) for $e^+e^- \to \eta K^+K^-$ process

1. Detector and Experiment

The VEPP-2000 e^+e^- collider works in the center-of-mass (c.m.) energy range 0.32–2.00 GeV. Its maximum achieved luminosity at 2 GeV is $3{\cdot}10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (during 2010–2013 years). Two detectors, CMD-3 and SND, collect data at VEPP-2000 simultaneously.

Spherical Neutral Detector (SND) consists of a tracking system based on a drift chamber, an aerogel Cherenkov threshold counter, a spherical three-layer electromagnetic calorimeter and a muon system. The calorimeter based on NaI(Tl) crystals covers a solid angle of 95% of 4π.

The physics program of experiments at VEPP-2000 includes measurement of exclusive hadronic cross sections below 2 GeV to obtain the total cross section for $e^+e^- \to hadrons$, study of dynamics of hadron production, i.e. separation between different intermediate states, spectroscopy of light-vector-meson excitations, search for rare and forbidden decays of the ρ, ω, and ϕ mesons, study of nucleon-antinucleon pair production, search for production of C-even resonances.

2. Recent Results

Presented results are obtained using data of 2010–2013 years. In 2017–2018 data taking was continued with greater luminosity.

The process $e^+e^- \to \eta\pi^+\pi^-$ was studied in two η-meson decay modes: $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ [1]. The results (fig. 1) in two modes are compatible and are in agreement with previous (BABAR) measurements [2], but have better accuracy. The dominant mechanism of the $e^+e^- \to \eta\pi^+\pi^-$ process is $e^+e^- \to V \to \eta\rho(770) \to \eta\pi^+\pi^-$, where V is $\rho(770)$, $\rho(1450)$, $\rho(1700)$ and (probably) $\rho(1250)$.

The process $e^+e^- \to \eta K^+K^-$ was studied in $\eta \to \gamma\gamma$ decay mode. The results (fig. 2) are compatible with previous (BABAR) measurements [3] and have comparable accuracy. The known mechanism of the process is $e^+e^- \to \phi(1680) \to \eta\phi \to \eta K^+K^-$, no other significant mechanism were found [4].

The process $e^+e^- \to K_SK_L\pi^0$ was studied in the $K_S \to \pi^0\pi^0$ decay mode [5]. The events were selected by kinematic reconstruction of K_L by recoil mass of $K_S\pi^0$ system. Measured cross

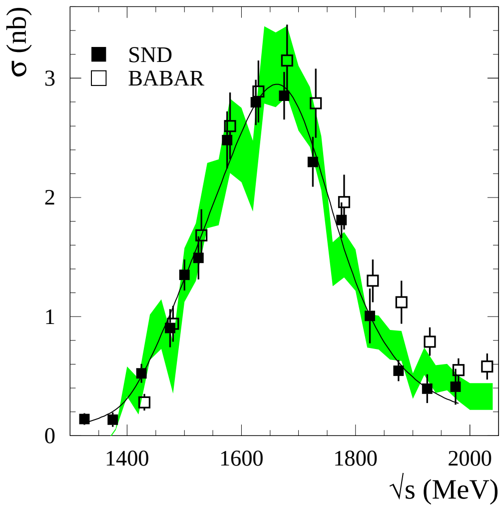

Figure 3: Born cross section for $e^+e^- \to \eta K_S K_L \pi^0$ process in comparison with BABAR data [6]. The band shows the theoretical prediction described in the text

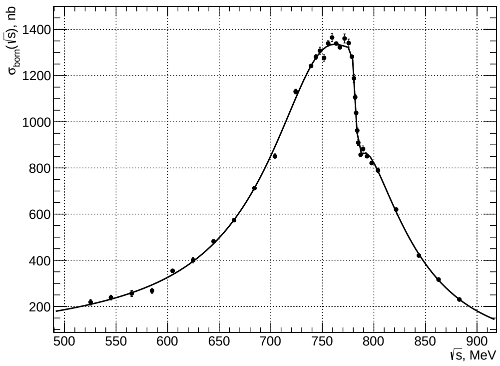

Figure 4: Born cross section for $e^+e^- \to \pi^+\pi^-$ process

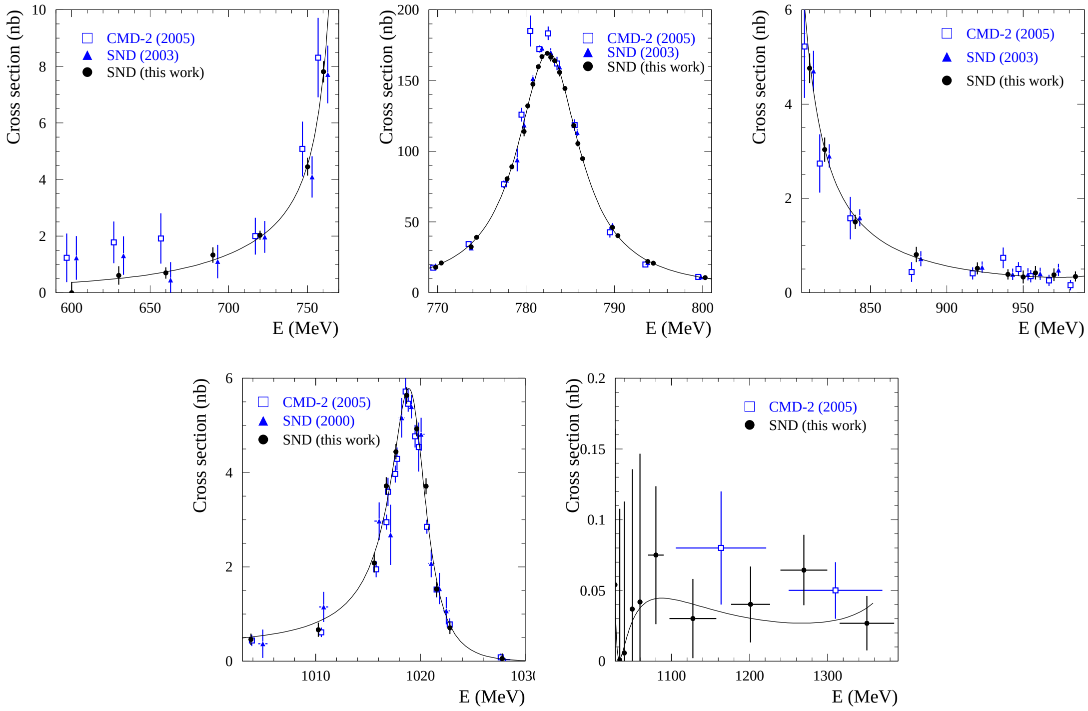

Figure 5: The $e^+e^- \to \pi^0\gamma$ cross section measured in this work in different energy regions in comparison with the previous most accurate measurements: SND (2000) [8], SND (2003) [9], and CMD-2 (2005) [10]. The curve is the result of the fit described in the text.

section is shown at fig. 3. The green band shows the prediction, obtained under assumption that the dominant mechanism of this process is the transition via $K^*(892)^0\overline{K^0}$ intermediate state and using the isospin relations and cross sections of the $e^+e^- \to K_S\pi^{\pm}\pi^{\mp}$, $e^+e^- \to K^+K^-\pi^0$ and $e^+e^- \to \phi\pi^0$ processes. This prediction is in good agreement with SND measurement.

The cross-section of the $e^+e^- \to \pi^+\pi^-$ process is shown on fig. 4. The fit model includes $\rho(770)$, $\omega(782)$ and $\rho(1450)$. From the fit obtained: $B(\rho \to e^+e^-) \times B(\rho \to \pi^+\pi^-) = 4.876 \pm 0.02 \pm 0.06$, $B(\omega \to e^+e^-) \times B(\omega \to \pi^+\pi^-) = 1.225 \pm 0.06 \pm 0.04$

The process $e^+e^- \to \pi^0\gamma$ was studied using events $e^+e^- \to \pi^0\gamma \to 3\gamma$ and events $e^+e^- \to \gamma\gamma$ for normalization. Cross section fit was done using ρ, ω, ϕ and two effective resonances: V' (describing $\omega(1420)$ and $\rho(1450)$) and V'' (describing $\omega(1650)$ and $\rho(1700)$), because their contributions cannot be separated. The cross section of $e^+e^- \to \pi^0\gamma$ is shown on fig. 5 [7].

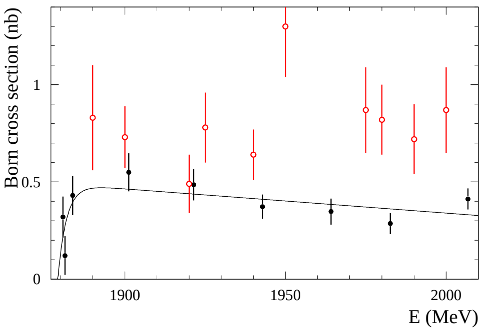

Figure 6: Born cross-section of $e^+e^- \to n\bar{n}$ process: SND2011-2012 (red opened points) and SND2017 (black filled points)

The process $e^+e^- \to \eta$ was searched at energy $\sqrt{s} = m_\eta$ with energy spread $\sigma_E \approx$ 200 KeV in $\eta \to 3\pi^0$ decay channel. No events were found. The upper limit for $\eta \to e^+e^-$ branching ratio is $B(\eta \to e^+e^-) < 7 \times 10^{-7}$ 90% *CL* [13].

Born cross-section for $e^+e^- \to n\bar{n}$ was measured using 2011–2012 and 2017 data. Results are shown on fig. 6. Fit of cross section is done by function:

$$\sigma_B(\sqrt{s}) = c_s\left[1 - e^{-\frac{\sqrt{s}-2m_n}{d}}\right] \cdot \left[1 + a\frac{\sqrt{s}-2m_n}{100}\right],$$

where m_n is neutron mass, $c_s = 0.49 \pm 0.08$ nb^{-1}, $d = 2.7 \pm 1.3$ MeV, $a = -0.25 \pm 0.15$ MeV^{-1}.

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