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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 were carried out at the e^+e^--collider VEPP-2000 in the energy range 0.3~2.0 GeV. New results on the 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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SND上质心能量2 GeV以下正负电子淹没到强子过程的研究

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摘要:从 2010 年开始,VEPP-2000 正负电子对撞机上的 SND 探测器在质心能量区间 0.3～2.0 GeV 正式运行. 基于已获取数据,得到了正负电子淹没到强子过程研究的新结果.

关键词:通用探测器;强子;截面;数据分析

0 Introduction

The VEPP-2000 e^+ e^- collider[1] (Fig. 1) operates in the center-of-mass (c. m.) energy range from 0.3 to 2.0 GeV. Experiments at VEPP-2000 were carried out in 2010～2013. The maximal luminosity achieved during these experiments was 2×10^{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 an increase of 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.

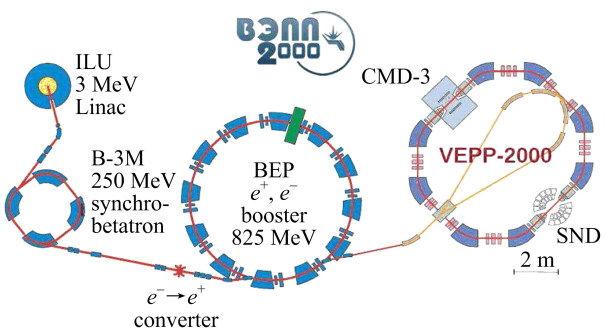
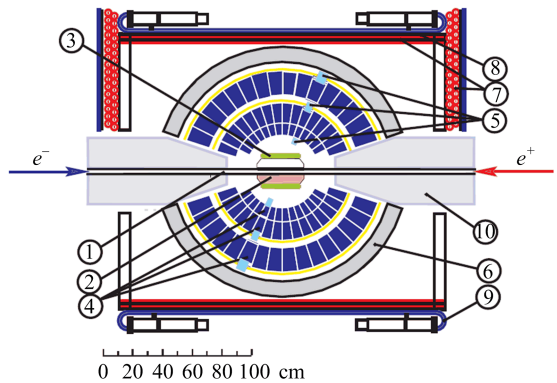


Fig. 1　The layout of the VEPP-2000 e^+ e^- collider

The Spherical Neutral Detector (SND)[2-3] (Fig. 2) is the universal nonmagnetic detector, which consists of a nine-layer drift chamber, an aerogel Cherenkov counter, 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}.



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.

Fig. 2　The SND detector

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 the accuracy of $R=\sigma(e^+e^-\rightarrow\text{hadrons})/\sigma(e^+e^-\rightarrow\mu^+\mu^-)$, which is used for calculating 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 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.

1 Multihadron processes

1.1　$e^+e^-\rightarrow\pi^+\pi^-\pi^0$ [4]

The $e^+e^-\rightarrow\pi^+\pi^-\pi^0$ 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 needs to be added to describe cross section energy dependence.

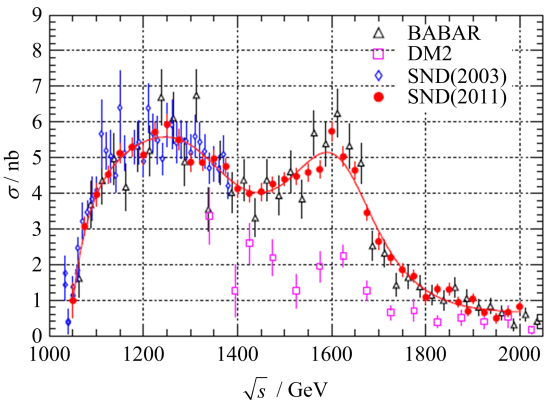


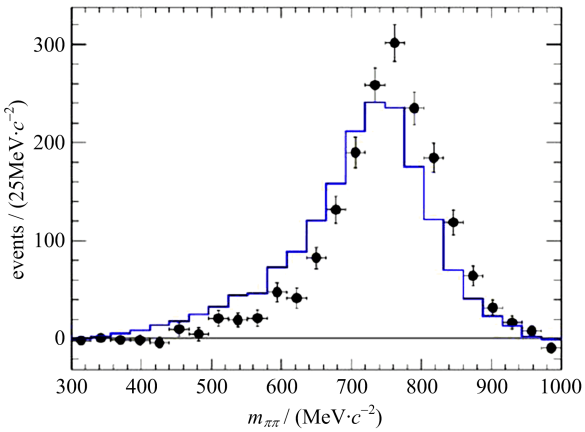
Fig. 3 The cross section for $e^+e^-\to\pi^+\pi^-\pi^0$ obtained by SND at VEPP-2000 in comparison with the previous SND[5] and BABAR[6] data

1.2 $e^+e^-\to\pi^+\pi^-\eta$[7]

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 can be 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. $\rho(1450)\eta$.

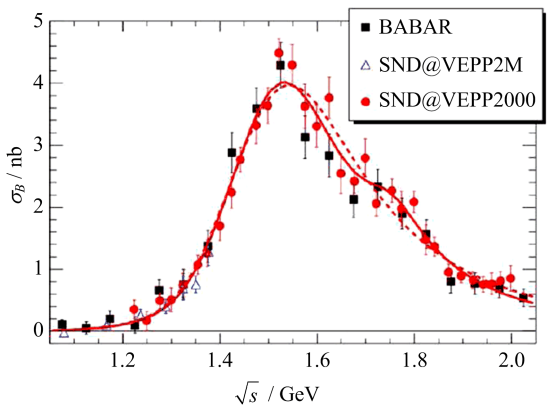
The $e^+e^-\to\pi^+\pi^-\eta$ cross section measured by SND at VEPP-2000 in comparison with previous measurements is shown in Fig. 5. The fit to the cross section data was performed for two models: ① a sum of the $\rho(770)$, $\rho(1450)$ and $\rho(1700)$ resonance contributions and ② a sum of the $\rho(770)$ and $\rho(1450)$ contributions. The value of the $\rho(1700)$ amplitude obtained in the first model deviates from zero by 2σ. So, we cannot come to a definite conclusion that the $\rho(1700)$ contribution is needed for data description.

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 $(0.156\pm0.011)\%$. This value is in reasonable agreement with the PDG[8] value $B(\tau\to\eta\pi^-\pi^0\nu_\tau)=(0.139\pm0.01)\%$.



The histogram is the simulated spectrum for the $\rho\eta$ mechanism.

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



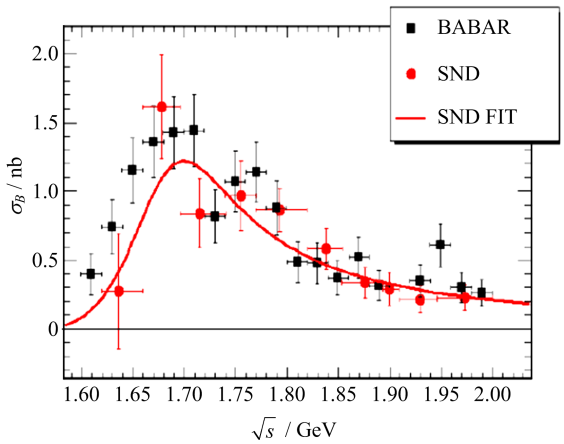
The solid curve is the result of the fit with ρ, $\rho(1450)$ and $\rho(1700)$ contributions. The dashed line is the result of the fit with ρ and $\rho(1450)$ contributions.

Fig. 5 The $e^+e^-\to\pi^+\pi^-\eta$ cross section obtained by SND at VEPP-2000 in comparison with the previous SND[9] and BABAR[10] measurements

1.3 $e^+e^-\to K^+K^-\eta$

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 the hypothesis that the 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.



The solid curve is the result of the fit described in the text.

Fig. 6　The $e^+e^-\to K^+K^-\eta$ cross section obtained by SND in comparison with the BABAR measurement[11]

1.4　$e^+e^-\to\pi^+\pi^-\pi^0\eta$

This process runs through different intermediate states. The contributions of the $\omega\eta$ and $\phi\eta$ intermediate states are 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.

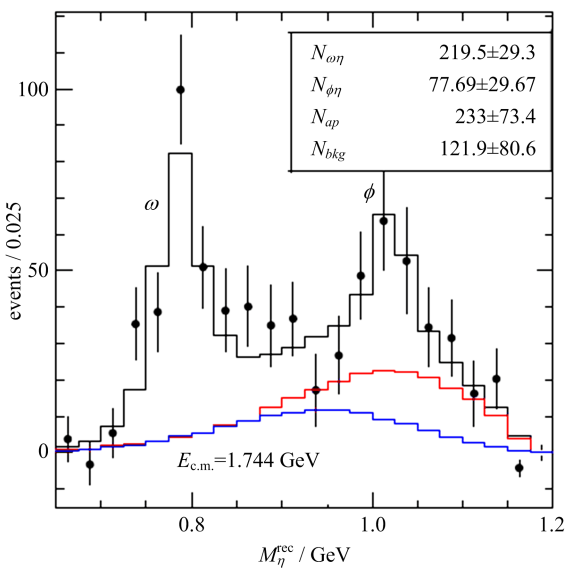


Fig. 7　The $\pi^+\pi^-\pi^0$ invariant mass spectrum for $e^+e^-\to\pi^+\pi^-\pi^0\eta$ data events (points with error bars) at $E_{cm}=1.794$ GeV

The measured $e^+e^-\to\pi^+\pi^-\pi^0\eta$ cross section is shown in Fig. 9. This is the first measurement of

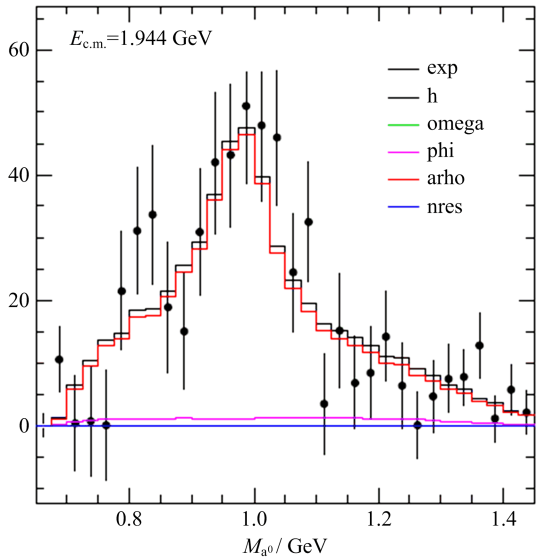


Fig. 8　The $\eta\pi$ invariant mass spectrum for $e^+e^-\to\pi^+\pi^-\pi^0\eta$ data events (points with error bars) at $E_{cm}=1.944$ GeV

the cross section. We suppose that the dominant contributions to 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.

1.5　$e^+e^-\to\omega\pi^0$

The update of our previous measurement of the $e^+e^-\to\omega\pi^0$ cross section[13] 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. [15]. 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 $\omega\to\pi^0\mu^+\mu^-$

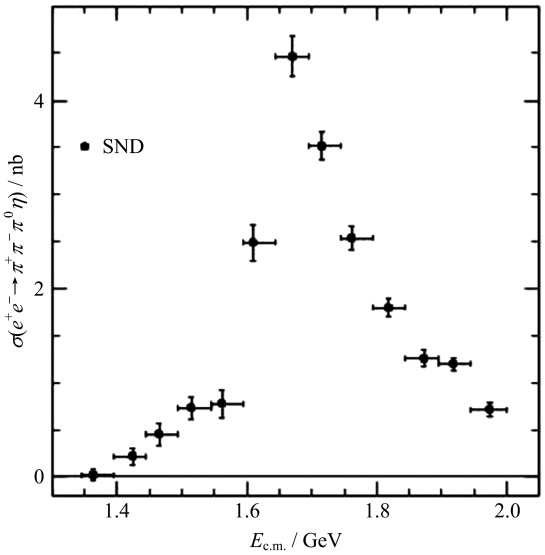


Fig. 9 The $e^+e^-\to\pi^+\pi^-\pi^0\eta$ cross section measured by SND

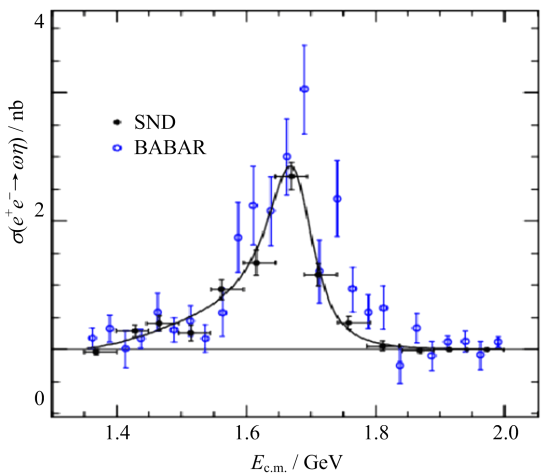


Fig. 10 The $e^+e^-\to\omega\eta$ cross section obtained by SND in comparison with BABAR data[12]

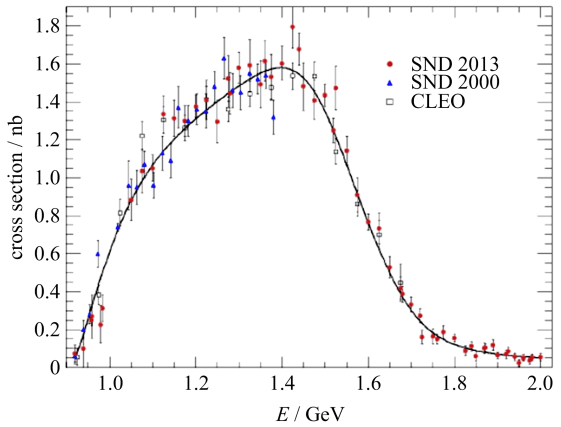
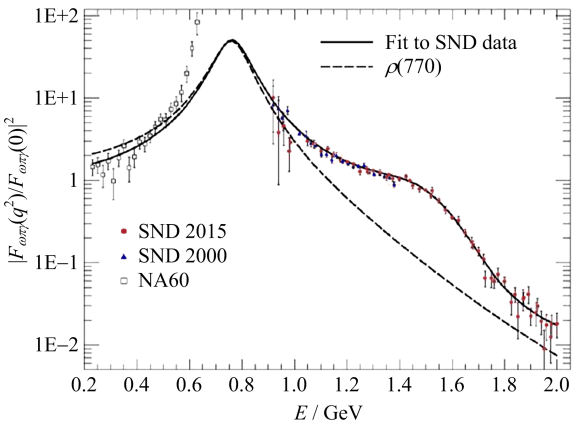


Fig. 11 The $e^+e^-\to\omega\pi^0$ cross section obtained by SND at VEPP-2000 in comparison with previous SND at VEPP-2M results[14] and CLEO data[15]



The circles represent SND at VEPP-2000 data, the triangles of previous SND and VEPP-2M data and squares data from the NA60 experiment[16]

Fig. 12 The transition form factor for the $\gamma^*\to\omega\pi^0$ vertex

decay[16] 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 with the VMD model.

1.6 $e^+e^-\to K^+K^-$

In this measurement charged kaon identification is based on information from the aerogel threshold Cherenkov counters[17]. 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.

1.7 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.

2 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 compared with the two photon decays, where α is

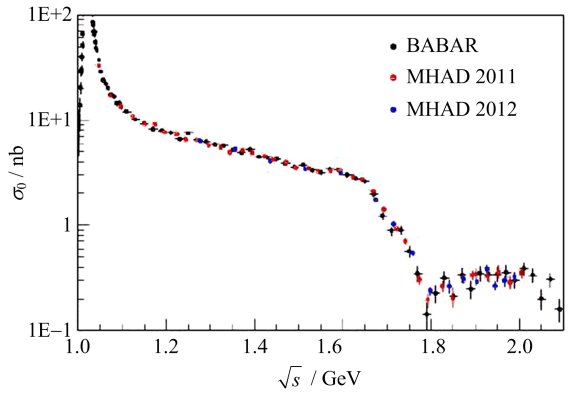


Fig. 13 The $e^+e^-\to K^+K^-$ cross section obtained by SND in comparison with BABAR data[18]

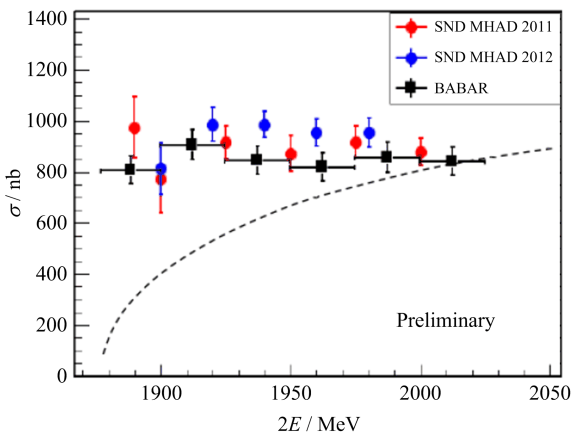


Fig. 14 The $e^+e^-\to p\bar{p}$ cross section obtained by SND in comparison with BABAR data[19]

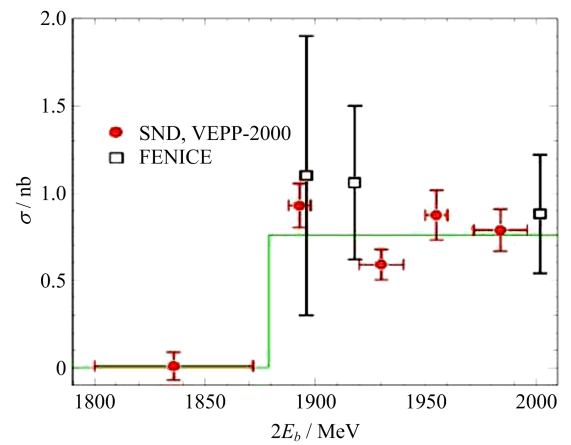


Fig. 15 The $e^+e^-\to n\bar{n}$ cross section obtained by SND in comparison with FENICE data[20]

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 η', $\eta\to e^+e^-$ 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[21]. The upper limit on the η decay $\mathcal{B}(\eta\to e^+e^-)<2.3\times10^{-6}$ was recently set in the HADES experiment[22].

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 $m_{\eta'}=(957.78\pm0.06)$ MeV. Five decay chains with a total branching fraction of 51.5% are used to reconstruct η'. No data events satisfying 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 the 2010～2013 experiments the SND detector didn't collect data at $m_\eta=(548.862\pm0.018)$ 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 $\eta\to\pi^0\pi^0\pi^0$ have 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.

3 Conclusion

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 2 000 MeV. Data with an integrated luminosity of about 69 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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