Recent results from SND detector at VEPP-2000 collider. Measurement of pion formfactor.

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on behalf of the SND collaboration

Tau and QCD physics at present and future electron-positron colliders.
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VEPP-2000 $e^+e^-$ collider

**VEPP-2000 parameters**

- c.m. energy $E = 0.3-2.0$ GeV
- Luminosity at $E = 1.8$ GeV
  - $10^{32} cm^{-2} sec^{-1}$ (project)
  - $4 \times 10^{31} cm^{-2} sec^{-1}$ (achieved)
- Beam energy spread - 0.6 MeV at $E = 1.8$ GeV

- 10 times more intense positron source
- Experiments at upgraded VEPP-2000 was restarted by the end of 2016
SND data

Timeline
2010-2013 – experiments, 70 pb\(^{-1}\)
2013-2016 – upgrade, new injector
2016 - . . . – experiments, 210 pb\(^{-1}\)

15 hadronic processes are currently under analysis

- \(e^+ e^- \rightarrow \eta \pi^0 \gamma\)
- \(e^+ e^- \rightarrow \pi^+ \pi^- \pi^0 \eta\)
- \(e^+ e^- \rightarrow n \bar{n}\)
- \(e^+ e^- \rightarrow \pi^+ \pi^-\)
- \(e^+ e^- \rightarrow f_1(1285)\)
- \(e^+ e^- \rightarrow \eta\)

Main physics task of SND is study of all possible processes of $e^+e^-$ annihilation into hadrons below 2 GeV.

- The total hadronic cross section, which is calculated as a sum of exclusive cross sections.
- Study of hadronization (dynamics of exclusive processes).

Analysis is based on the $4.6 \text{ pb}^{-1}$ statistics, collected in 2012 – 2013, that corresponds to the $2.3 \times 10^6$ collinear events, with $10^6 e^+e^- \rightarrow \pi^+\pi^-\mu^+\mu^-$ and $1.3 \times 10^6 e^+e^- \rightarrow e^+e^-$.
1. $N_{ch} \geq 2$. The events can contain neutral particles due to nuclear interactions of charged pions with detector material or due to electromagnetic showers splitting.

2. $|\Delta \theta| = |180^\circ - (\theta_1 + \theta_2)| < 12^\circ$ and $|\Delta \phi| = |180^\circ - |\phi_1 - \phi_2|| < 4^\circ$, where $\phi$ is the particle azimuthal angle.

3. $E_{1,2} > 40$ MeV, where $E_i$ is the $i$th particle ($i = 1, 2$) energy deposition.

4. $50^\circ < \theta_0 = (\theta_1 - \theta_2 + 180^\circ) \times 0.5 < 130^\circ$.

5. $|d0_1| < 1$ cm, $|d0_2| < 1$ cm, where $|d0_i|$ is a distance between the $i$th particle track and the beam axis.

6. $|z0_1| < 8$ cm, $|z0_2| < 8$ cm, where $|z0_i|$ is a distance from the center of the detector to the primary vertex of the $i$th particle track along the beam axis.

7. The muon system veto = 0.
The output signal of the trained BDT network $R$ is a value in the interval from -1.0 to 1.0.

The $e^+ e^- \rightarrow e^+ e^-$ events are located in the region $R < 0$, while $e^+ e^- \rightarrow \pi^+ \pi^-, \mu^+ \mu^-$ events in $R > 0$. 
Non-collinear and cosmic backgrounds

\[ N_{\text{cosm}} = N_{\text{exp}}[\text{veto} = 1] \times \frac{N_{\text{cosm}}[\text{veto} = 0]}{N_{\text{cosm}}[\text{veto} = 1]} \]

- \( N_{\text{exp}}[\text{veto} = 1] \) – number of data events selected with 2\( \pi \) cuts but with veto=1;
- \( N_{\text{cosm}}[\text{veto} = 0(1)] \) – number of special cosmic events

Two types of cosmic events are used:

- Non-central (\( |d0_1| > 0.5 \text{ cm} , |d0_2| > 0.5 \text{ cm} , |z0_1| > 5 \text{ cm} \) and \( |z0_2| > 5 \text{ cm} \)) events from the same data sample.
- Events from special cosmic runs without beams

Both give the same 2.5% ratio between \( N_{\text{cosm}}[\text{veto} = 0] \) and \( N_{\text{cosm}}[\text{veto} = 1] \) in the whole energy spectrum.
Non-collinear and cosmic backgrounds

Background from the $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ is subtracted directly in the $\omega(782)$ region, with a number of background events estimated according to the formula:

$$N_{3\pi} = N_{exp}[3\pi] \times \frac{N_{mc}[2\pi]}{N_{mc}[3\pi]}$$

$N_{exp}[3\pi]$ – number of $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ events in the same data sample selected with a special $3\pi$ cuts:

$$N_{cha} \geq 2, \; N_n \geq 2, \; |\Delta \theta| > 10^\circ, \; |\Delta \phi| > 10^\circ,$$

$$40^\circ < \theta_i < 140^\circ, \chi^2_{\pi^+\pi^-2\gamma} < 50, \; \chi^2_{\pi^+\pi^-\pi^0} < 30$$

**Contribution** of this background to the total $e^+e^- \rightarrow \pi^+\pi^-$ cross section is less than 0.15%, due to the strong suppression by $|\Delta \theta|$ and $|\Delta \phi|$ cuts.
\[ \varepsilon_e = \frac{N^{ee}(R \in [-1; 0])}{N^{ee}(R \in [-1; 1])}, \quad \varepsilon_\pi = \frac{N^{\pi\pi}(R \in [0; 1])}{N^{\pi\pi}(R \in [-1; 1])} \]

\(N^{ee,\pi\pi}(R \in [a; b])\) are the numbers of \(e^+e^- \rightarrow e^+e^-\) or \(\pi^+\pi^-\) events with \(R\) in the interval \([a; b]\)

Identification efficiencies for \(e^+e^- \rightarrow e^+e^-\) and \(e^+e^- \rightarrow \pi^+\pi^-\) simulated events
ID efficiency correction

\[ \delta_x = \frac{\epsilon_x^{\text{exp}}}{\epsilon_x^{\text{mc}}}, \]

\( x = e(\pi) \), \( \epsilon_x^{\text{exp}} \) and \( \epsilon_x^{\text{mc}} \) are identification efficiencies for experimental and simulated pseudoevents respectively. The \( \delta_e \) does not depend on energy, and its average value is \( 1.0006 \pm 0.0001 \).

\[ \delta_{\pi}(\sqrt{s}) = a\left(\sqrt{(\sqrt{s} - b)^2 + 10 - (\sqrt{s} - b)}\right) + c \]

\( \delta_{\pi} = 0.9990 \pm 0.0002 \) at the energy region \( \sqrt{s} > 0.65 \text{ GeV} \) and below \( \delta_{\pi} \) changes upto \( 0.9950 \pm 0.0006 \) at \( \sqrt{s} = 0.52 \text{ GeV} \).
Correction coefficients for ID efficiencies of the $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \pi^+\pi^-$ events. $\delta_\pi$ obtained using pseudo $\pi\pi$ events constructed from $e^+e^- \rightarrow \pi^+\pi^-$ and $e^+e^- \rightarrow \omega, \phi \rightarrow \pi^+\pi^-\pi^0$ events. Lines are the fit results.

Corrected ID efficiencies for the $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \pi^+\pi^-$ events
### Contribution to the cross section uncertainty

<table>
<thead>
<tr>
<th>Error</th>
<th>$\delta_e$, %</th>
<th>$\delta_\pi$ at $\sqrt{s} &gt; 0.65$ GeV, %</th>
<th>$\delta_\pi$ at $\sqrt{s} &lt; 0.65$ GeV, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{stat}$</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02 – 0.06</td>
</tr>
<tr>
<td>$\sigma_{ID}$</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>$\sigma_{bkg}$</td>
<td>0.02</td>
<td>0.02</td>
<td>–</td>
</tr>
<tr>
<td>$\sigma_{tot}$</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03 – 0.06</td>
</tr>
</tbody>
</table>

**Contribution of the ID efficiencies to the relative error of $e^+e^- \rightarrow \pi^+\pi^-$ cross section is less than 0.2% for the most energy points.**
The pseudo-$\pi\pi$ events are used to check the validity of efficiency for the $E_{1,2} > 40$ MeV cut, derived from the simulation.

Obtained average correction is equal to 0.992. The maximum difference between corrections derived from the different types of pseudo-events is 0.5%.
Efficiency of the $|\Delta \phi| < 4^\circ$ and $|\Delta \theta| < 12^\circ$ cuts

In order to study the differences between simulation and experimental data at each energy point, an efficiency correction is introduced:

$$R_i(x) = \frac{\epsilon_i^{\text{exp}}(x)}{\epsilon_i^{\text{mc}}(x)} \quad \epsilon_i^{\text{exp}} = \frac{N_i(x \in [A_x; B_x])}{N_i(x \in [C_x; D_x])} \quad \epsilon_i^{\text{mc}} = \frac{M_i(x \in [A_x; B_x])}{M_i(x \in [C_x; D_x])}$$

**Graphs:**
- $e^+ e^- \rightarrow \pi^+ \pi^-$
- $e^+ e^- \rightarrow e^+ e^-$

The average values of $\delta_{\Delta \phi} = R_{\pi \pi}(\Delta \phi)/R_{ee}(\Delta \phi)$ and $\delta_{\Delta \theta} = R_{\pi \pi}(\Delta \theta)/R_{ee}(\Delta \theta)$ differ from 1 by 0.1 % and 0.2 %, respectively.

The overall contribution to the systematic uncertainty from the conditions on the $\Delta \phi$ and $\Delta \theta$ is equal to $0.001 \oplus 0.002 = 0.002$.
Efficiency of the $50^\circ < \theta_0 < 130^\circ$ cut

$$R_i(z) = \frac{\varepsilon_i^{\exp}(z)}{\varepsilon_i^{mc}(z)} \varepsilon_i^{\exp}(z) = \frac{N_i(\theta_0 \in [x; 180^\circ - z])}{N_i(\theta_0 \in [50^\circ; 130^\circ])} \varepsilon_i^{mc}(z) = \frac{M_i(\theta_0 \in [x; 180^\circ - z])}{M_i(\theta_0 \in [50^\circ; 130^\circ])}$$

The statistically significant deviation of $\delta_{\theta_0} = R_{\pi\pi}/R_{ee}$ from unity does not exceed 0.5 %
Track reconstruction efficiency

Probability of the $\pi$ (e) track loss due reconstruction inefficiency is estimated from the $R_{\pi\pi}$ ($R_{ee}$):

the ratio of the number of events with one track, but the total number of particles $> 1$ and loosen $\Delta \phi$ and $\Delta \theta$ cuts, to the number of events with two or more tracks.

The ratio of $R_{\pi\pi}$ to $R_{ee}$ is taken as a correction to the measured cross section. It does not show a significant deviation from unity.
Muon system veto efficiency

\[ \delta_{\text{veto}} = \frac{\sigma_{\pi\pi}((\phi_1 + \phi_2 - 180^\circ)/2 > 166^\circ \text{or} < 14^\circ; \text{veto} \geq 0)}{\sigma_{\pi\pi}((\phi_1 + \phi_2 - 180^\circ)/2 > 166^\circ \text{or} < 14^\circ; \text{veto} = 0)} \]

In case of the veto \( \geq 0 \) selection the certain number of the residual cosmic background events, derived from the fit of the \((z_0_1 + z_0_2)/2\) with a sum of uniform and normal distributions, is subtracted from the total number of the \( e^+ e^- \rightarrow \pi^+ \pi^- \) events.

\( \delta_{\text{veto}} \) shows no significant energy dependence.

Averaged value is applied and it is consistent with 1.
The main sources of systematic uncertainty

- $\Delta \theta, \Delta \phi, \theta_0$ cuts: $0.001 \oplus 0.002 \oplus 0.005 = 0.55\%$
- $E_{1,2} > 40$ MeV condition: $0.5 \%$
- $e/\pi$–separation for the $\sqrt{s} \leq 600$ MeV: $0.3 – 0.5\%$
- muon subtraction for the $\sqrt{s} \leq 600$ MeV: $0.3 – 0.7\%$

Additional sources of systematic uncertainty

- 0.2 \% is taken as a systematic error from modeling of the pion loss due to nuclear interaction
- Contributions from the $N_{cha} \geq 2$ and veto = 0 cuts are considered to be negligible
- Calculation of the radiative correction gives 0.2 \%
- 0.1 \% from variation of the trigger cuts
<table>
<thead>
<tr>
<th>Source</th>
<th>$\sqrt{s} &gt; 600$ MeV</th>
<th>$\sqrt{s} \leq 600$ MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID $e/\pi$</td>
<td>0.1-0.2</td>
<td>0.3-0.5</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.0-0.2</td>
<td>0.3-0.7</td>
</tr>
<tr>
<td>$\Delta \theta$</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>$\Delta \phi$</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>$\theta_0$</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>$E_{1,2}$</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>rad</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>trig</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>nucl</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>0.8</td>
<td>0.9-1.2</td>
</tr>
</tbody>
</table>
Calculating $e^+ e^- \rightarrow \pi^+ \pi^-$ cross section

\[ N_a = L(\sigma_{\pi\pi} \varepsilon_{\pi\pi}^a + \sigma_{\mu\mu} \varepsilon_{\mu\mu}^a + \sigma_{ee} \varepsilon_{ee}^a) + N_{nc}^a \]

$a = 1,2$ correspond to the $R_{e/\pi} \in [0,1]$ and $R_{e/\pi} \in [-1,0]$ respectively; $\sigma_{jj}$ and $\varepsilon_{jj}^a$, with $jj = \pi^+ \pi^-, \mu^+ \mu^-$, $e^+ e^-$ in the final state; $N_{nc}^a$ is the number of non-collinear and cosmic background events; $L$ is the IL collected at $s_i$.

From these equations $e^+ e^- \rightarrow \pi^+ \pi^-$ cross section and $L$ can be deduced:

\[ L(s_i) = \frac{(N_2 - N_{nc}^2)\varepsilon_{\pi\pi}^1 - (N_1 - N_{nc}^1)\varepsilon_{\pi\pi}^2}{\sigma_{ee}(\varepsilon_{ee}^2 \varepsilon_{\pi\pi}^1 - \varepsilon_{ee}^1 \varepsilon_{\pi\pi}^2) + \sigma_{\mu\mu}(\varepsilon_{\mu\mu}^2 \varepsilon_{\pi\pi}^1 - \varepsilon_{\mu\mu}^1 \varepsilon_{\pi\pi}^2)} \]

\[ \sigma_{\pi\pi}(s_i) = \frac{N_1 - N_{nc}^1 - L(s_i)\sigma_{\mu\mu} \varepsilon_{\mu\mu}^1(s_i) - L(s_i)\sigma_{ee} \varepsilon_{ee}^1}{L(s_i)\varepsilon_{\pi\pi}^1} \]
Born cross section

\[ \sigma^0_{\pi\pi}(s_i) = \frac{\sigma_{\pi\pi}(s_i)}{1 + \delta_{rad}(s_i)} \]

1 + \delta_{rad}(s_i) is a **radiative correction**, that accounts for radiation from the initial and final states, calculated using the **MCGPJ** code.

\[ \delta_{rad}(s_i) \]

has to be calculated iteratively, by fitting measured cross sections with a model from the MCGPJ code.

JHEP 9710, 006 (1997)
$$\sigma_{\pi\pi}(s) = \frac{2}{3} \frac{\alpha^2}{s^{5/2}} P_{\pi\pi}(s) |A_{\pi\pi}(s)|^2$$

$$P_{\pi\pi}(s) = q^3_\pi(s), \quad q_\pi(s) = \frac{1}{2} \sqrt{s - 4m^2_\pi}$$

$$|A_{\pi\pi}(s)|^2 = \left| \sqrt{\frac{3}{2}} \frac{1}{\alpha} \sum_{V=\rho,\omega,\rho'} \Gamma_V m^3_V \sqrt{m_V \sigma(V \to \pi^+\pi^-)} \frac{e^{i\phi_{\rho'}} \Gamma_{\omega}(s)}{\sqrt{q^3_\pi(m_V)}} \right|^2$$

$$D_V(s) = m^2_V - s - i\sqrt{s} \Gamma_V(s), \quad \Gamma_V(s) = \sum_{f} \Gamma(V \to f, s)$$

$$\Gamma_\omega(s) = \frac{m^2_\omega}{s} \frac{q^3_\pi(s)}{q^3_\pi(m_\omega)} \Gamma_\omega B_{\omega \to \pi^+\pi^-} + \frac{q^3_\pi \gamma(s)}{q^3_\pi \gamma(m_\omega)} \Gamma_\omega B_{\omega \to \pi^0\gamma} + \frac{W_\rho_\pi(s)}{W_\rho_\pi(m_\omega)} \Gamma_\omega B_{\omega \to 3\pi}$$

$$\Gamma_V(s) = \frac{m^2_V}{s} \frac{q^3_\pi(s)}{q^3_\pi(m_V)} \Gamma_V \quad (V = \rho, \rho')$$
The relative difference between the $e^+e^- \rightarrow \pi^+\pi^-$ cross section, measured by SND and fit of the SND experimental data. The green bar depicts systematic and statistical errors of the SND fit, folded quadratically.

Cross section values in the $\sqrt{s} = 352.02$, 375.85 and 389.36 MeV energy points shows non-statistical deviation from the fit.
### Fit results

<table>
<thead>
<tr>
<th>parameter</th>
<th>SND VEPP-2000</th>
<th>SND VEPP-2M</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_\rho$, MeV</td>
<td>$775.4 \pm 0.5 \pm 0.4$</td>
<td>$774.6 \pm 0.4 \pm 0.5$</td>
</tr>
<tr>
<td>$\Gamma_\rho$, MeV</td>
<td>$145.8 \pm 0.7 \pm 1$</td>
<td>$146.1 \pm 0.8 \pm 1.5$</td>
</tr>
<tr>
<td>$\sigma(\rho \to \pi^+\pi^-)$, nb</td>
<td>$1189.25 \pm 4.6 \pm 9.5$</td>
<td>$1193 \pm 7 \pm 16$</td>
</tr>
<tr>
<td>$\sigma(\omega \to \pi^+\pi^-)$, nb</td>
<td>$31.3 \pm 1.3 \pm 0.3$</td>
<td>$29.3 \pm 1.4 \pm 1.0$</td>
</tr>
<tr>
<td>$\phi_{\rho\omega}$, deg.</td>
<td>$110.9 \pm 1.5 \pm 0.7$</td>
<td>$113.7 \pm 1.3 \pm 2.0$</td>
</tr>
<tr>
<td>$\sigma(\rho' \to \pi^+\pi^-)$, nb</td>
<td>$2.3 \pm 0.6$</td>
<td>$1.8 \pm 0.2$</td>
</tr>
<tr>
<td>$\chi^2/ndf$</td>
<td>$43/30$</td>
<td>$-$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>parameters</th>
<th>SND VEPP-2000</th>
<th>SND VEPP-2M</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{\rho \to e^+e^-} \times B_{\rho \to \pi^+\pi^-}$</td>
<td>$(4.888\pm 0.02\pm 0.04) \times 10^{-5}$</td>
<td>$(4.876\pm 0.02\pm 0.06) \times 10^{-5}$</td>
</tr>
<tr>
<td>$B_{\omega \to e^+e^-} \times B_{\omega \to \pi^+\pi^-}$</td>
<td>$(1.312\pm 0.06\pm 0.01) \times 10^{-6}$</td>
<td>$(1.225\pm 0.06\pm 0.04) \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Fit results

Calculating bare $e^+ e^- \rightarrow \pi^+ \pi^-$ cross section

$$\sigma_{\pi\pi}^{\text{bare}}(s) = \sigma_{\pi\pi}^0(s) \times |1 - \Pi(s)|^2 \times \left(1 + \frac{\alpha}{\pi} a(s)\right)$$

$$a(s) = \frac{1 + \beta^2}{\beta} \left[ 4 \text{Li}_2\left(\frac{1 - \beta}{1 + \beta}\right) + 2 \text{Li}_2\left(-\frac{1 - \beta}{1 + \beta}\right) - ight.$$ 

$$3 \ln \frac{2}{1 + \beta} \ln \frac{1 + \beta}{1 - \beta} - 2 \ln \beta \ln \frac{1 + \beta}{1 - \beta} - 3 \ln \frac{4}{1 - \beta^2} - 4 \ln \beta + \frac{1}{\beta^3} \left[ \frac{5}{4} (1 + \beta^2)^2 - 2 \right]$$

$$\times \ln \frac{1 + \beta}{1 - \beta} + \frac{3}{2} \frac{1 + \beta^2}{\beta^2}.$$ 

$$\text{Li}_2(x) = - \int_0^x dt \ln(1-t)/t, \quad \beta = \sqrt{1 - \frac{4m_{\pi}^2}{s}}$$
Contribution to $a_\mu$

$$a_\mu(\pi\pi, s_{\min} \leq \sqrt{s} \leq s_{\max}) = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{s_{\min}}^{s_{\max}} \frac{R(s)K(s)}{s^2} ds$$

$K(s)$ is a known kernel (J. Phys. G 38, 085003 2011) and

$$R(s) = \frac{\sigma_{\pi\pi}^{bare}}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}, \quad \sigma(e^+e^- \rightarrow \mu^+\mu^-) = \frac{4\pi\alpha^2}{3s}$$

Trapezoid integration allows to compute $a_\mu$ using measured cross sections

<table>
<thead>
<tr>
<th></th>
<th>SND VEPP-2000</th>
<th>SND VEPP-2M</th>
<th>BaBar</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_\mu(\pi\pi) \times 10^{10}$</td>
<td>410.88 ± 1.02± 3.75</td>
<td>408.88±1.30±5.31</td>
<td>414.93±1.02±2.07</td>
</tr>
</tbody>
</table>
The relative difference between the $e^+e^- \rightarrow \pi^+\pi^-$ cross section, measured by BABAR and fit of the SND experimental data

- $\sigma_{sys} \oplus \sigma_{stat}$ errors are shown for the BABAR data
- The green bar depicts systematic and statistical errors of the SND fit, folded quadratically


The relative difference between the $e^+e^- \rightarrow \pi^+\pi^-$ cross section, measured by KLOE and fit of the SND experimental data.
The relative difference between the \( e^+e^- \rightarrow \pi^+\pi^- \) cross section, measured in experiments at VEPP-2M and fit of the SND experimental data.

The difference between the value of \(a_\mu(\pi\pi, 525\text{MeV} \leq \sqrt{s} \leq 883\text{MeV})\) obtained from the SND data, and ones derived from the previous measurements < 1\(\sigma\).

The parameters of the \(\rho\) and \(\omega\) mesons in this analysis are consistent with ones obtained by SND in experiments at VEPP-2M.

Comparison with VEPP-2M results indicates no significant contradictions in the whole energy spectrum.

In the \(0.6 \geq \sqrt{s} \leq 0.7\) GeV energy range there is a 3\% discrepancy between the SND and BABAR data, but for the rest of the spectrum SND data is in agreement with the BABAR results.

There is 1–3 \% deviation between KLOE and SND data for \(\sqrt{s} \geq 0.7\) GeV.
The new measurement is based on the 2017 dataset and uses a different method. The calorimeter-trigger-time distribution is analyzed.

Our new result is lower than the previous SND measurement. The reasons are underestimated beam background and incorrect MC simulation.

The systematic uncertainty on the cross section is estimated to be about 20%, mainly due to MC simulation.
The cross section depends on two form factors. From the measured cross section we determine the effective form factor. Near threshold the proton and neutron effective form factors are close to each other. The neutron form factor become lower than the proton one with increase the energy. The ratio of the form factors can be determined from the analysis of the $\cos(\theta)$ distribution.

The $\cos(\theta)$ distribution is well described by $1 + \cos^2(\theta)$, i.e. $G_E = 0$. For proton $|G_E/G_M| \approx 1.5$ in this energy region.
The total $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$ cross section measured by SND is, in general, consistent with the CMD-3 result. The $\approx 15\%$ difference in the cross section maximum is within the systematic uncertainties, which are 7\% for SND and 11\% for CMD-3.

**Exclusive channels**

- The obtained $\omega\eta$ cross section agrees with the CMD-3 measurement. Both the SND and CMD-3 results lie below the BABAR data.
- The SND and BABAR $\phi\eta$ measurements are in reasonable agreement.
- The significant difference between the SND and CMD-3 measurements is observed for the $a_0\rho+structureless$ final state.
The measured $e^+e^- \rightarrow \omega \eta \rightarrow \eta \pi^0 \gamma$ cross section is in good agreement with the SND and CMD-3 measurements in the $\omega \rightarrow 3\pi$ decay mode.

- The radiative $e^+e^- \rightarrow \eta \pi^0 \gamma$ process was studied previously only in the $\phi(1020)$ region.
- We perform the first measurement in the energy range 1.05-2.00 GeV.
- The value of the cross section is about 15-20 pb in the region 1.4-1.9 GeV.
$e^+e^- \rightarrow \eta$ and $e^+e^- \rightarrow f_1(1285)$

- The 650 $nb^{-1}$ data sample was recorded in 2018 at $\sqrt{s} = m_\eta$.
- The decay mode $\eta \rightarrow 3\pi^0$ is used, in which the single photon annihilation background is absent.
- Zero signal events have been selected.
- The upper limit $B(\eta \rightarrow e^+e^-) < 7 \times 10^{-7}$ at 90% CL has been set.

$e^+e^- \rightarrow f_1(1285)$

- About 4 $pb^{-1}$ of data were collected in the resonance maximum.
- The $f_1(1285) \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$ decay mode is used.
- The main background sources are $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$, $e^+e^- \rightarrow \eta\gamma$ and $e^+e^- \rightarrow \pi^0\pi^0\omega$.
- After applying the selection criteria, two events have been observed at the peak.
- These two events correspond to $B(f_1(1285) \rightarrow e^+e^-) = 6.1^{+3.6}_{-2.6} \times 10^{-9}$
The $e^+e^- \rightarrow \pi^+\pi^-$ cross section is measured with systematic uncertainty better than 1%

The accuracy of $e^+e^- \rightarrow n\bar{n}$ measurement is significantly improved

The $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$ cross section has been measured

Rare radiative process $e^+e^- \rightarrow \eta\pi^0\gamma$ have been measured for the first time in the energy range 1.05-2.00 GeV

Search for production of C-even resonances, $\eta$ and $f_1(1285)$, in $e^+e^-$ annihilation is performed. The first indication of the process $e^+e^- \rightarrow f_1(1285)$ is obtained
| $\sqrt{s}$, MeV | $\sigma$, nb  | $\sigma_0$, nb   | $|F(s)|^2$ | $\sigma_{bare}$, nb |
|-----------------|--------------|------------------|-----------|---------------------|
| 525.3           | 203.3$\pm$12.3 | 210.3$\pm$12.7   | 4.4$\pm$0.3 | 209.6$\pm$12.7     |
| 545             | 223.5$\pm$10.1 | 231.7$\pm$10.4   | 5$\pm$0.2  | 231.2$\pm$10.4     |
| 565.1           | 235$\pm$12.3  | 244.4$\pm$12.8   | 5.5$\pm$0.3 | 243.9$\pm$12.8     |
| 584.9           | 254.7$\pm$10.7 | 265.8$\pm$11.2   | 6.2$\pm$0.3 | 265.5$\pm$11.1     |
| 604.8           | 328.5$\pm$8.7  | 344.4$\pm$9.1    | 8.3$\pm$0.2 | 344.5$\pm$9.1      |
| 624.7           | 366.5$\pm$11.1 | 386.2$\pm$11.7   | 9.7$\pm$0.3 | 386.7$\pm$11.7     |
| 644.6           | 438.2$\pm$8.2  | 464.5$\pm$8.7    | 12.1$\pm$0.2 | 465.8$\pm$8.8      |
| 664.4           | 526.4$\pm$3.5  | 561.5$\pm$3.7    | 15.3$\pm$0.1 | 564$\pm$3.7        |
| 684.2           | 642.1$\pm$8.4  | 689.4$\pm$9      | 19.5$\pm$0.3 | 693.1$\pm$9.1      |
| 704             | 797.3$\pm$10.2 | 859.8$\pm$11     | 25.4$\pm$0.3 | 864.6$\pm$11.1     |
| 724.1           | 1029.3$\pm$9.5 | 1111.2$\pm$10.3  | 34.2$\pm$0.3 | 1115.2$\pm$10.3    |
| 739.1           | 1146.5$\pm$5.6 | 1233.5$\pm$6     | 39.1$\pm$0.2 | 1233.7$\pm$6       |
| 743.8           | 1197.9$\pm$9.8 | 1285.8$\pm$10.5  | 41.1$\pm$0.3 | 1284.5$\pm$10.5    |
| 747.7           | 1212.1$\pm$14.4 | 1298.2$\pm$15.4  | 41.9$\pm$0.5 | 1295.3$\pm$15.4    |
| 751.7           | 1195.5$\pm$13.7 | 1277.2$\pm$14.6  | 41.5$\pm$0.5 | 1272.4$\pm$14.6    |
| 755.7           | 1243.9$\pm$10.8 | 1324.7$\pm$11.5  | 43.4$\pm$0.4 | 1318.2$\pm$11.4    |
| 759.5           | 1291.2$\pm$17.3 | 1370.7$\pm$18.4  | 45.3$\pm$0.6 | 1363.1$\pm$18.2    |

| $\sqrt{s}$, MeV | $\sigma$, nb | $\sigma_0$, nb | $|F(s)|^2$ | $\sigma_{\text{bare}}$, nb |
|-----------|-------------|-------------|--------------|------------------|
| 763.5     | 1263.7±5    | 1336.7±5.2  | 44.5±0.2     | 1328.9±5.2      |
| 767       | 1251.9±6.9  | 1320.2±7.3  | 44.3±0.2     | 1312.9±7.2      |
| 771.6     | 1289.8±22.2 | 1355.6±23.3 | 45.9±0.8     | 1350.9±23.2     |
| 775.6     | 1291.3±17.2 | 1353.9±18   | 46.2±0.6     | 1353.5±18       |
| 778.7     | 1251.6±5.3  | 1304.3±5.5  | 44.8±0.2     | 1300.7±5.5      |
| 780.7     | 1198.1±18.4 | 1229±18.9   | 42.4±0.7     | 1212.9±18.6     |
| 781.9     | 1105.1±11.2 | 1111.4±11.2 | 38.4±0.4     | 1081.6±10.9     |
| 782.8     | 1056.2±4.8  | 1041.3±4.7  | 36±0.2       | 1001.4±4.5      |
| 783.9     | 1000.8±11.6 | 967.2±11.2  | 33.5±0.4     | 917.7±10.6      |
| 784.9     | 957.3±12.8  | 915.3±12.2  | 31.8±0.4     | 862.6±11.5      |
| 787.1     | 911.3±5.1   | 872.1±4.8   | 30.4±0.2     | 818.7±4.5       |
| 789.5     | 933±14.1    | 901.8±13.6  | 31.6±0.5     | 849.8±12.8      |
| 793.4     | 891.7±10    | 868.5±9.7   | 30.7±0.3     | 823.3±9.2       |
| 797.8     | 856±10.1    | 833±9.8     | 29.7±0.4     | 792.8±9.3       |
| 804       | 818.3±10.4  | 789.9±10.1  | 28.5±0.4     | 754.1±9.6       |
| 821.6     | 654.4±5.6   | 608.4±5.2   | 22.7±0.2     | 582.6±5         |
| 843.6     | 496±5.8     | 436.9±5.1   | 17±0.2       | 419.5±4.9       |
| 862.7     | 383.4±4.6   | 322±3.9     | 13±0.2       | 309.8±3.8       |
| 882.9     | 303.2±6.7   | 242.3±5.3   | 10.2±0.2     | 233.7±5.1       |