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

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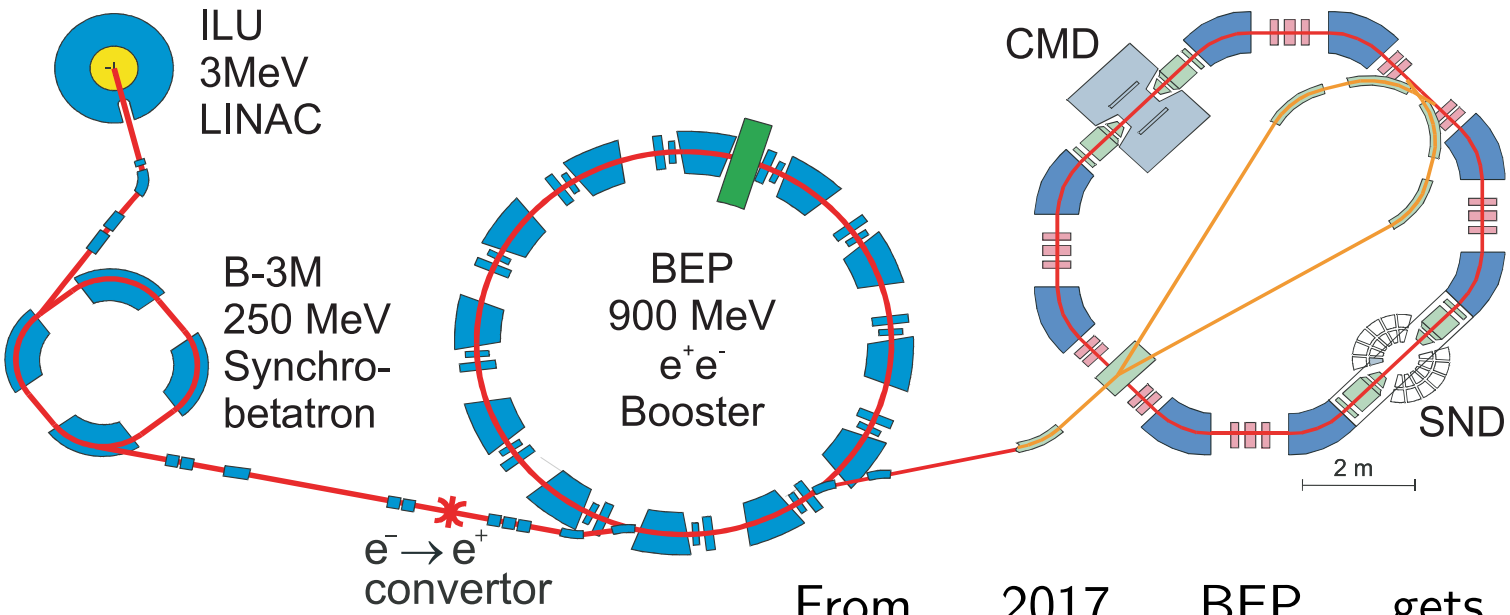
VEPP2000 Layout (2010-2013)

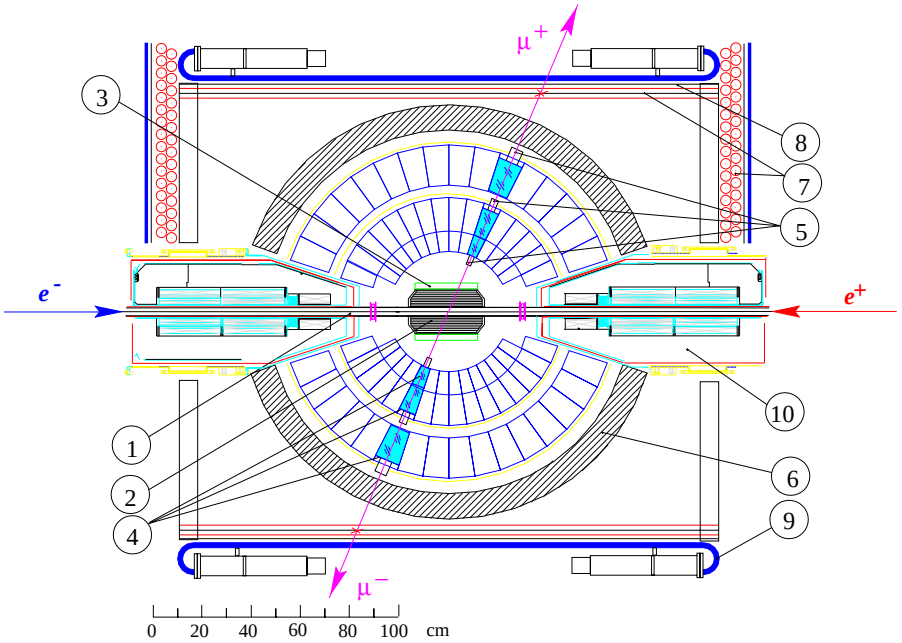


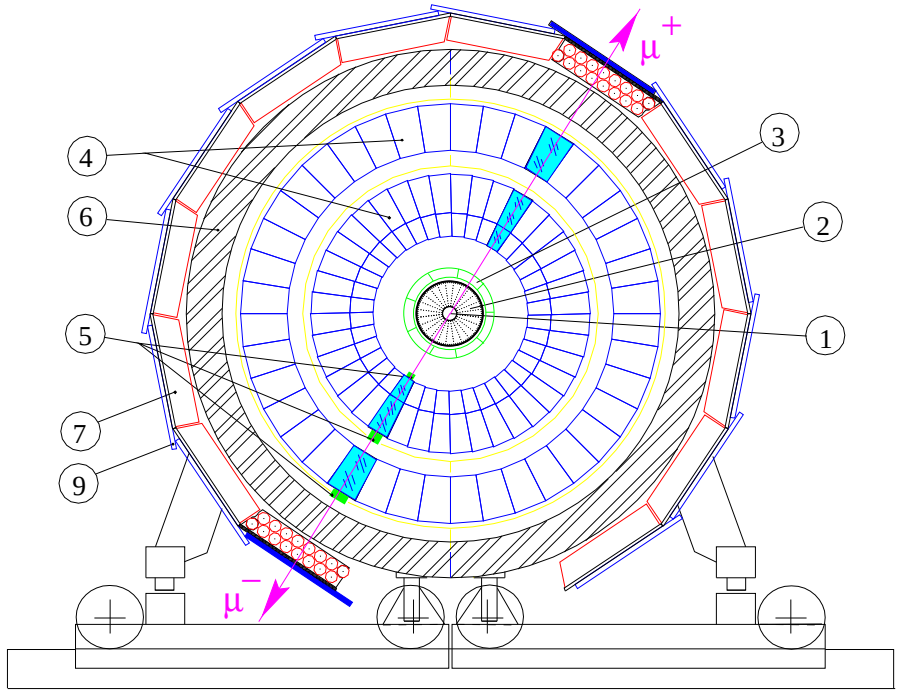
From 2017 BEP gets electrons/positrons from new VEPP-5 source

- Circumference 24.4 m
- $\sqrt{s} = 0.3 - 2.0$ GeV
- Beam energy spread 0.6 MeV at $\sqrt{s} = 1.8$ GeV
- Achieved luminosity $L_{max} = 2 \times 10^{31}$ cm^{-2}s^{-1}

Collected luminosity in 2010–2013:	
ω-region	8.3 pb^{-1}
Below 1 GeV (except ω)	9.4 pb^{-1}
ϕ-region	8.4 pb^{-1}
Above ϕ	41 pb^{-1}

Spherical Neutral Detector





SND detector: 1 – beam pipe, 2 – tracking system, 3 – aerogel Cherenkov counters, 4 – NaI(Tl) calorimeter counters, 5 – vacuum phototriodes, 6 – iron absorber, 7-9 – muon systems, 10 – VEPP2000 superconducting focusing solenoids.

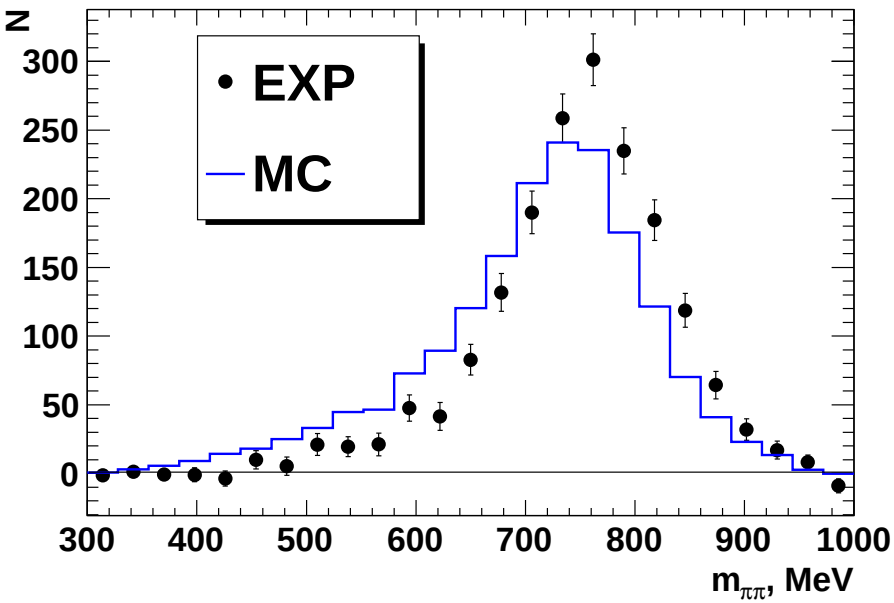
SND Physics program

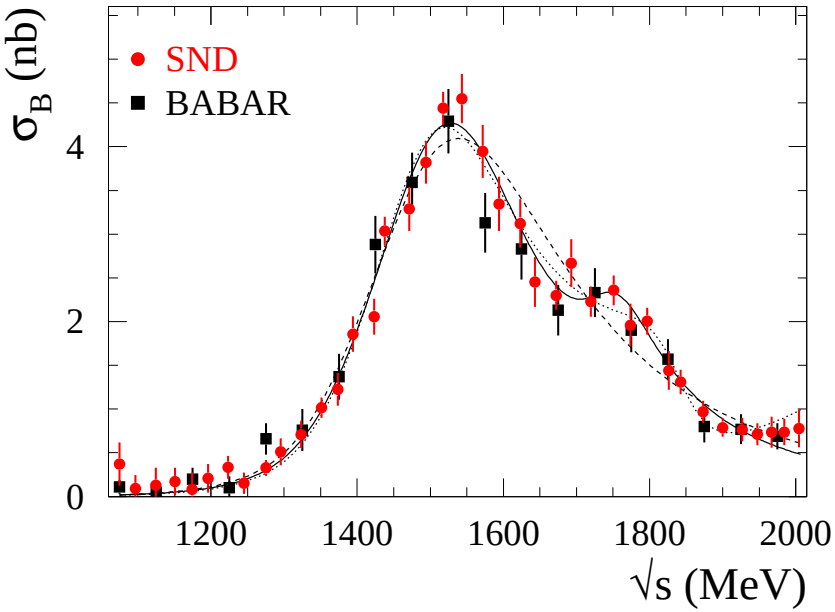
The physics program of experiments at VEPP-2000 includes the following main topics:

1. Measurement of exclusive hadronic cross sections below 2 GeV for calculation HVP contribution to $(g-2)_\mu$
2. Study of dynamics of hadron production, i.e. separation between different intermediate states , for example, $\omega\eta$, $\phi\eta$, ρa^0, etc.
3. Hadron spectroscopy: study of light-vector-meson excitations
4. Search for rare and forbidden decays of the ρ, ω, and ϕ mesons.
5. Study of nucleon-antinucleon pair production, extraction of the proton and neutron electromagnetic form factors.
6. Search for production of C-even resonances: $e^+e^- \to \eta$, η', f_1, f_2, a_2, etc.
7. Using the radiative return technique as alternative method for measurement of hadronic cross sections.

The process $e^+e^- \to \eta\pi^+\pi^-$

- Process was studied in two η-meson decay modes: $\eta \to \gamma\gamma$ (39.41%) and $\eta \to 3\pi^0$ (32.68%)
- The dominant mechanism of the 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) $\rho(2150)$.
- Measured $\pi^+\pi^-$ mass spectrum differs from MC, based on $\eta\rho(770)$ mechanism





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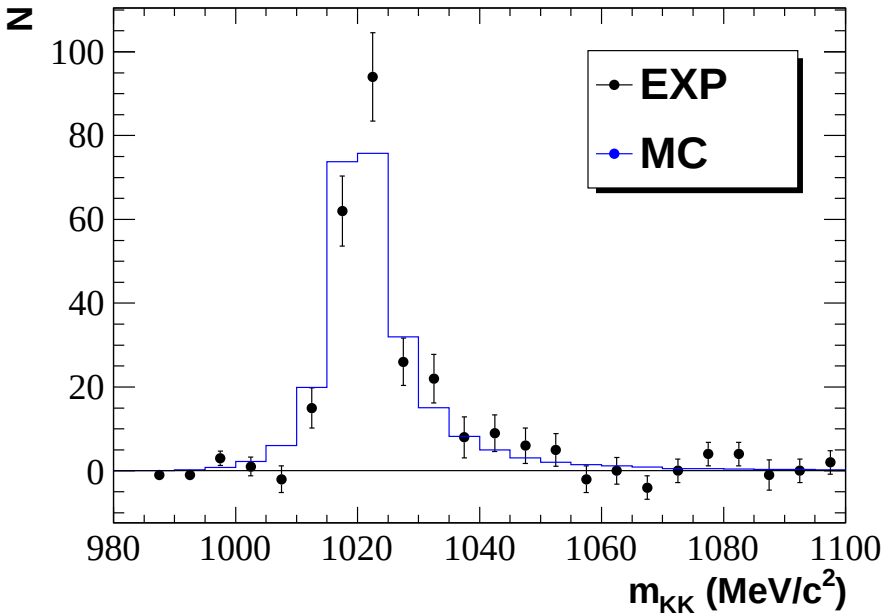
The process $e^+e^- \to \eta\pi^+\pi^-$

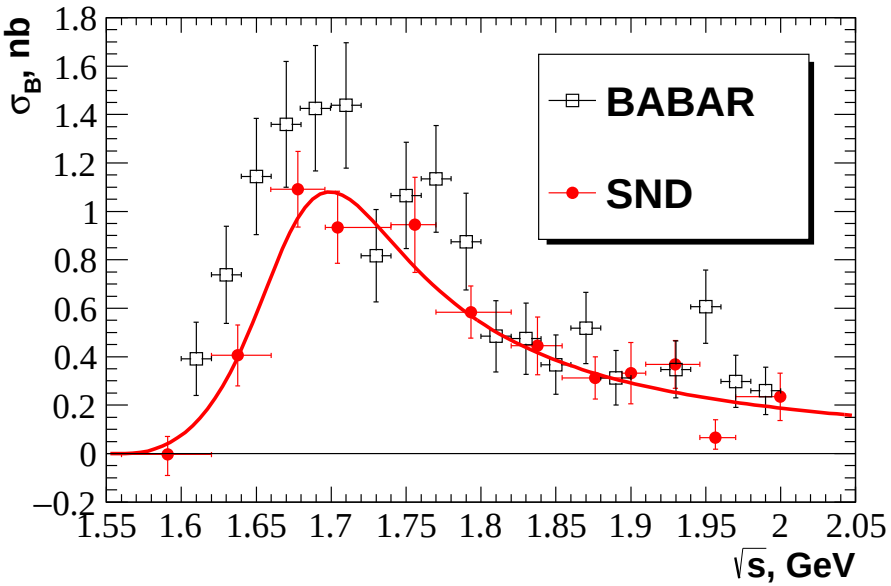
- Model 1: $\rho(770)$, $\rho(1450)$ and $\rho(1700)$, $\phi_{\rho(1700)} = \pi$
- Model 2: $\rho(770)$ and $\rho(1450)$
- Model 3: $\rho(770)$, $\rho(1450)$, $\rho(1700)$ and $\rho(2150)$, $\phi_{\rho(1700)} = \phi_{\rho(2150)} = 0$

Parameter	Model 1	Model 2	Model 3
$g_{\rho(1450)}$ (GeV^{-1})	0.44 ± 0.5	0.56 ± 0.2	0.45 ± 0.3
$\phi_{\rho(1450)}$	π	π	π
$m_{\rho(1450)}$ (MeV/c^2)	1520 ± 10	1510 ± 10	1500 ± 10
$\Gamma_{\rho(1450)}$ (MeV)	320 ± 30	390 ± 10	280 ± 20
$g_{\rho(1700)}$ (GeV^{-1})	$0.024^{+0.019}_{-0.011}$	–	$0.025^{+0.014}_{-0.009}$
$\phi_{\rho(1700)}$	π	–	0
$m_{\rho(1700)}$ (MeV/c^2)	1750 ± 10	–	1840 ± 10
$\Gamma_{\rho(1700)}$ (MeV)	135 ± 50	–	132 ± 40
$g_{\rho(2150)}$ (GeV^{-1})	–	–	0.084 ± 0.008
χ^2/ν	33/33	55/36	29/32
P,%	47	2.2	62

The process $e^+e^- \to \eta K^+K^-$

- The process $e^+e^- \to \eta K^+K^-$ was studied in $\eta \to \gamma\gamma$ decay mode.
- The results are compatible with previous (BABAR) measurements and have comparable accuracy.
- The data on K^+K^- invariant mass spectrum is compatible with spectrum from MC simulation based on $e^+e^- \to \phi(1680) \to \eta\phi \to \eta K^+K^-$ mechanism of the process.





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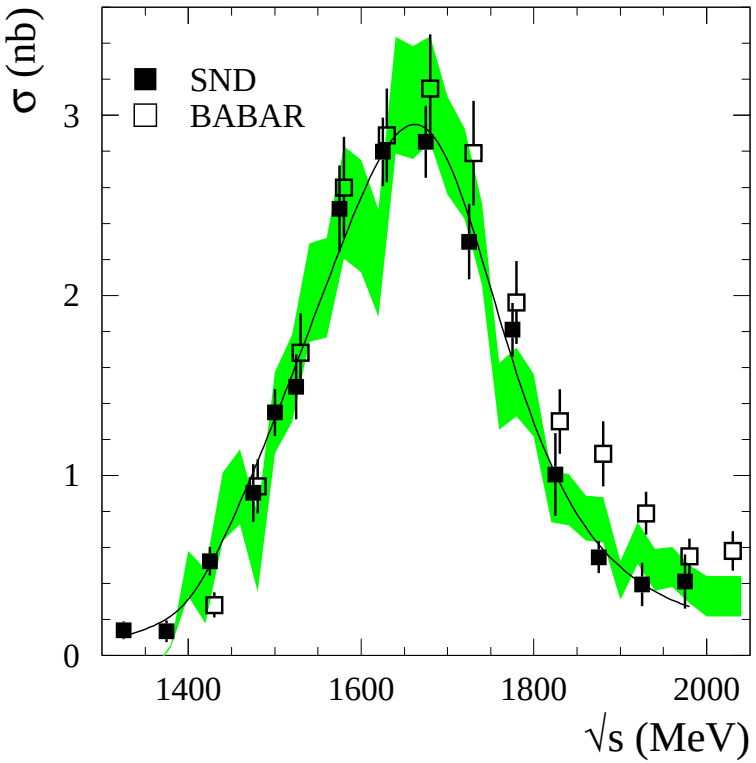
The process $e^+e^- \to K_S K_L \pi^0$



Born cross section of $e^+e^- \to K_S K_L \pi^0$ process, measured in this work (filled squares) in comparison with the BABAR data (open squares), and prediction from isospin relations (green band)

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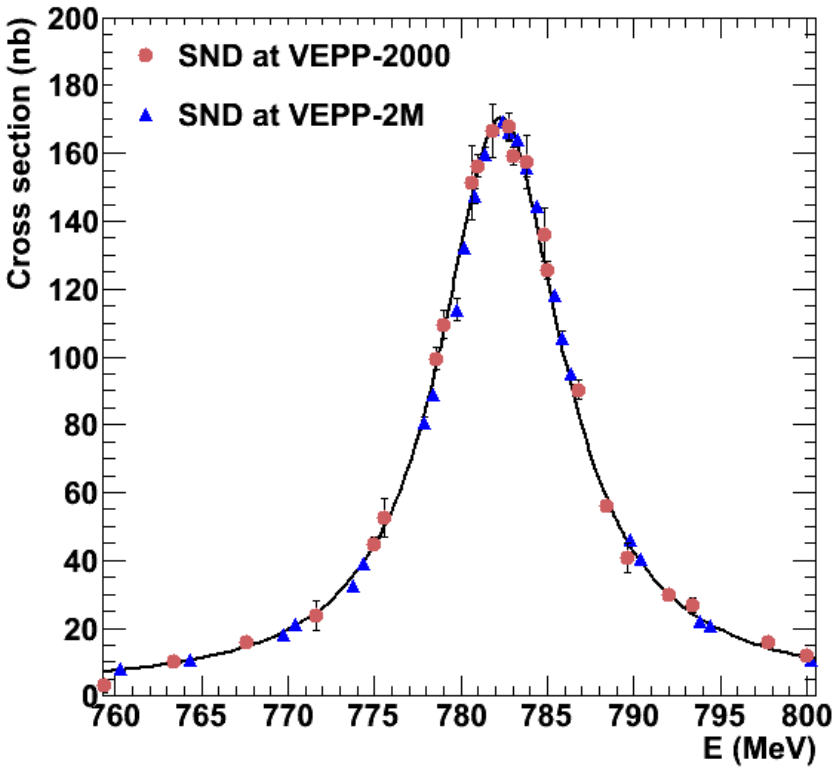
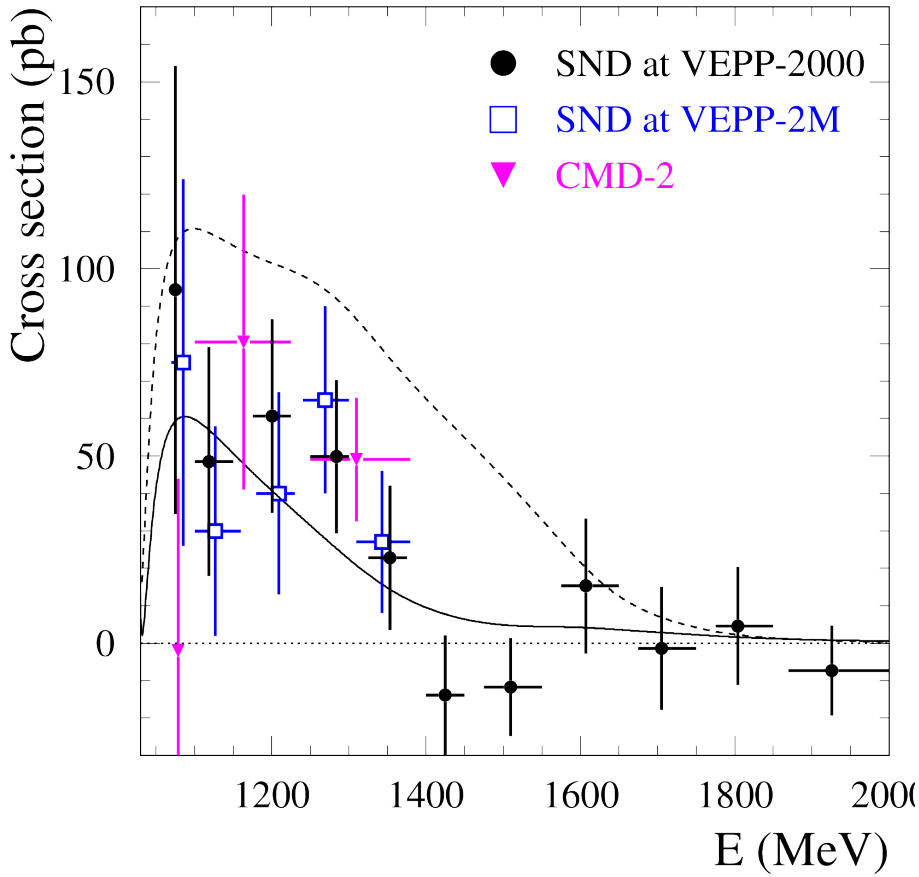
- The process was studied in the $K_S \to \pi^0\pi^0$ decay mode.
- Assuming that the dominant mechanism of this process is the transition via $K^*(892)^0\overline{K^0}$, using the isospin relations and data of the cross sections for the $e^+e^- \to K_S\pi^\pm\pi^\mp$, $e^+e^- \to K^+K^-\pi^0$ and $e^+e^- \to \phi\pi^0$ processes one can predict of the $e^+e^- \to K_S K_L \pi^0$ cross section
- Since prediction is in good agreement with SND measurement, we can conclude that transition via $K^*(892)^0\overline{K^0}$ is the main process mechanism

The process $e^+e^- \to \pi^0\gamma$

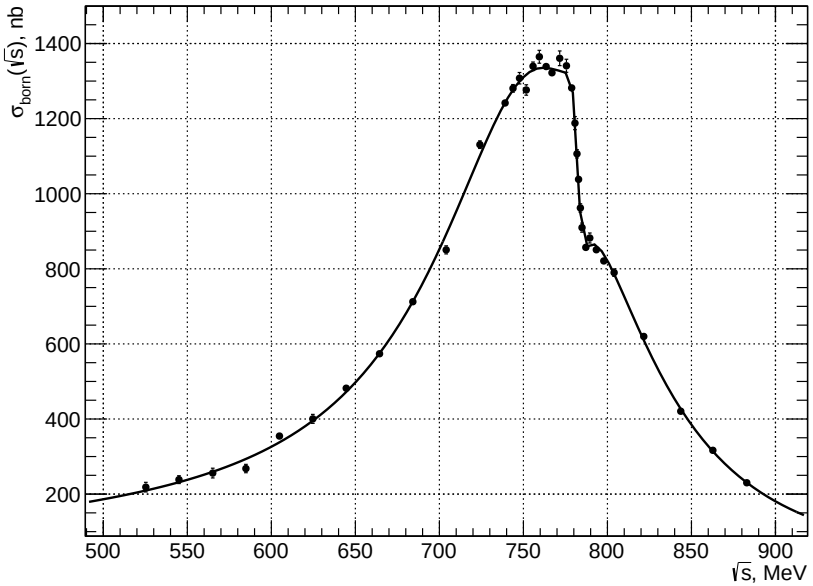
The process $e^+e^- \to \pi^0\gamma$ was studied using events $e^+e^- \to \pi^0\gamma \to 3\gamma$

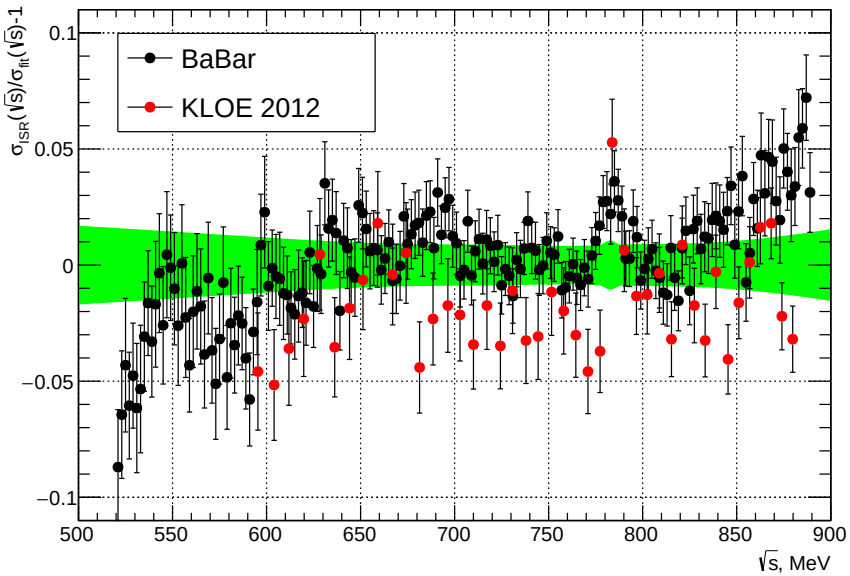




- The third largest hadron cross section below 1 GeV.
- Measurement of the $\pi^0\gamma^\star\gamma$ transition form factor
- Contradiction between $\Gamma(\omega \to \pi^0\gamma)/\Gamma(\omega \to \pi^+\pi^-\pi^0)$ measured by KLOE and by other experiments

The process $e^+e^- \to \pi^+\pi^-$ (preliminary)





Born cross section of $e^+e^- \to \pi^+\pi^-$ process by SND at VEPP2000 and comparison of SND results with BABAR and KLOE data

The process $e^+e^- \to \pi^+\pi^-$ (preliminary)

Fit model includes $\rho(770)$, $\omega(782)$, $\rho(1450)$.

Parameters	SND@VEPP-2000	SND@VEPP-2M
$m_\rho(770)$	$775.9 \pm 0.5 \pm 0.8$	$774.6 \pm 0.4 \pm 0.5$
$\Gamma_\rho(770)$	$145.7 \pm 0.7 \pm 1.6$	$146.1 \pm 0.8 \pm 1.5$
$\sigma(\rho(770) \to \pi^+\pi^-)$, nb	$1188.5 \pm 4.6 \pm 9.5$	$1193.5 \pm 7 \pm 16$
$\sigma(\omega(770) \to \pi^+\pi^-)$, nb	$32.4 \pm 1.3 \pm 0.3$	$29.3 \pm 1.4 \pm 1.0$
$\phi_{\rho(770)\omega}$,$^\circ$	112.5 ± 1.4	$113.7 \pm 1.3 \pm 2.0$
$\sigma(\rho(1450) \to \pi^+\pi^-)$, nb	0.9 ± 0.4	1.8 ± 0.2

Using $\sigma(V \to X) = 12\pi B_{V\to e^+e^-} \cdot B_{V\to X}/m_V^2$:

	SND@VEPP-2000	SND@VEPP-2M
$B(\rho \to e^+e^-) \times B(\rho \to \pi^+\pi^-)$	$4.892 \pm 0.02 \pm 0.04$	$4.876 \pm 0.02 \pm 0.06$
$B(\omega \to e^+e^-) \times B(\omega \to \pi^+\pi^-)$	$1.358 \pm 0.05 \pm 0.01$	$1.225 \pm 0.06 \pm 0.04$

An input to α_μ

SND@VEPP-2000	SND@VEPP-2M	BABAR
$414.48 \pm 1.04 \pm 3.49$	$408.88 \pm 1.30 \pm 5.31$	$414.93 \pm 0.34 \pm 2.07$

The $e^+e^- \to \eta$ process search

- The decay $\eta \to e^+e^-$ was not observed (previous upper limit $B(\eta \to e^+e^-) < 2.3 \times 10^{-6}$ 90% CL from HADES experiment)
- Using $e^+e^- \to \eta$ Born cross section and relation

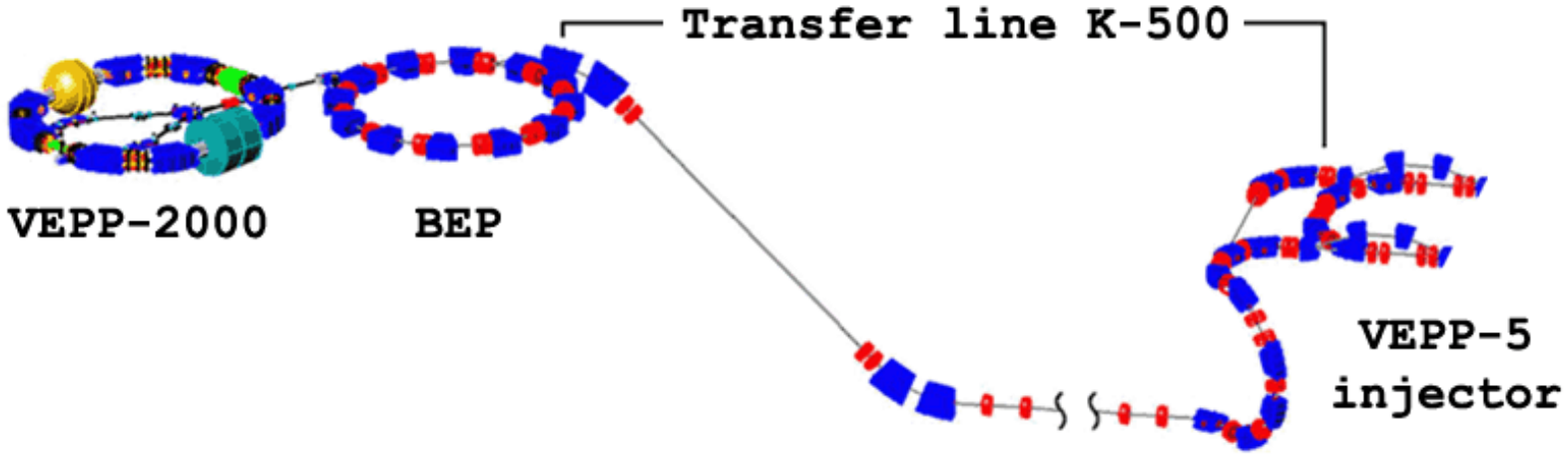
$$\sigma_B = \frac{4\pi}{E^2} B(\eta \to e^+e^-) \frac{m_\eta^2 \Gamma_\eta^2}{(m_\eta^2 - E^2)^2 + m_\eta^2 \Gamma_\eta^2}$$

  one can get $\eta \to e^+e^-$ branching fraction $B(\eta \to e^+e^-)$
- Since beam energy spread $\sigma_E \approx 200$ KeV is much greater then $\Gamma_\eta = 1.31 \pm 0.05$ keV, in fact averaged by energy (around m_η) cross section is measured
- Process was detected in $\eta \to 3\pi^0$ decay channel
- No events of the process were found, so we have branching fraction upper limit:

$$B(\eta \to e^+e^-) < 7 \times 10^{-7} \ 90\% \ CL$$

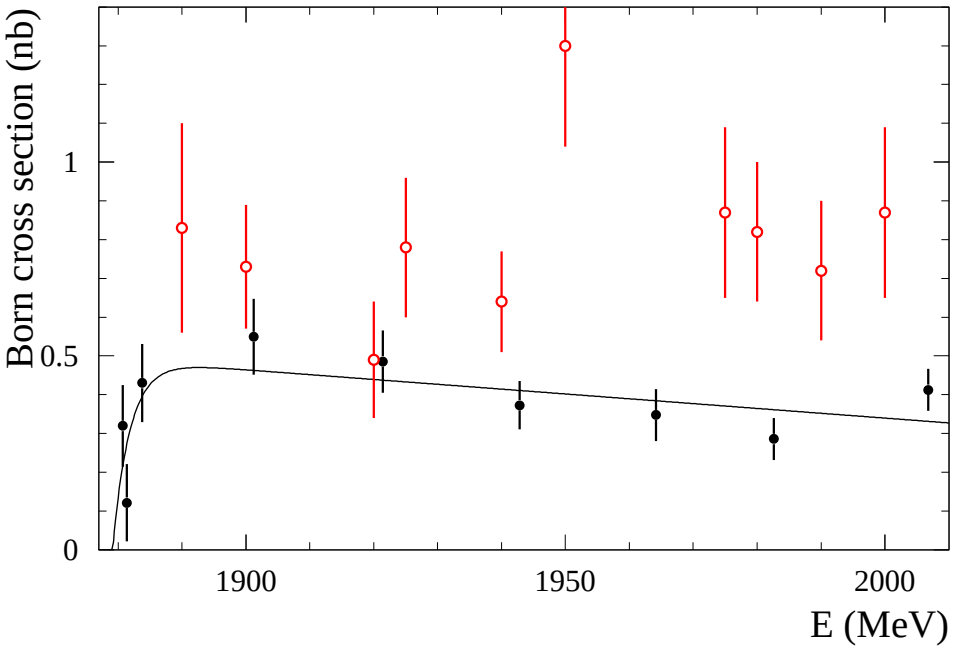
arXiv:1806.07609

VEPP-2000 layout after 2013–2016 upgrade



- New injection system (from VEPP-5 complex)
- Data taking from the end of 2016
- Achieved luminosity $L_{max} = 4 \times 10^{31}$ cm^{-2}s^{-1}
- About 120 pb^{-1} of integrated luminosity has been collected at 2017–2018. Analisys of this data is in progress

The process $e^+e^- \to n\bar{n}$



Born cross-section of $e^+e^- \to n\bar{n}$ process (SND2011-2012 and SND2017)

The difference is due to:

- Incorrect $n\bar{n}$ simulation
- Beam background
- Cosmic background

Systematic uncertancy ~20%, mainly due to MC

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}.

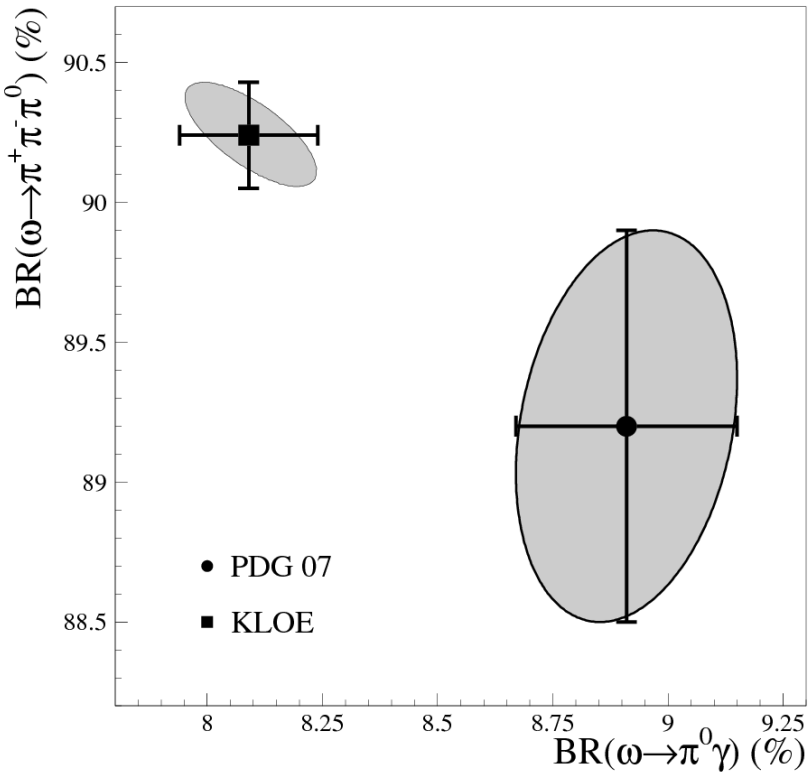
Conclusion

- The cross sections of the following processes are measured:
  - $e^+e^- \to \eta\pi^+\pi^-$
  - $e^+e^- \to \eta K^+K^-$
  - $e^+e^- \to K_S K_L \pi^0$
  - $e^+e^- \to \pi^0\gamma$
  - $e^+e^- \to \pi^+\pi^-$
  - $e^+e^- \to n\bar{n}$

  Precision of most of them is similar or better then worldwide
- Also new upper limit for $\eta \to e^+e^-$ branching fraction is set
- Results from upgraded VEPP-2000 (2017–2018 data taking) are coming soon

BACKUP

The $\Gamma(\omega \to \pi^0\gamma)/\Gamma(\omega \to \pi^+\pi^-\pi^0)$ contradiction



Contradiction between $\Gamma(\omega \to \pi^0\gamma)/\Gamma(\omega \to \pi^+\pi^-\pi^0)$ measured by KLOE (in $\omega \to \pi^0\gamma$ process) and by other experiments