Resent results on e^+e^- annihilation to hadrons from the SND experiment

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on behalf of the SND collaboration

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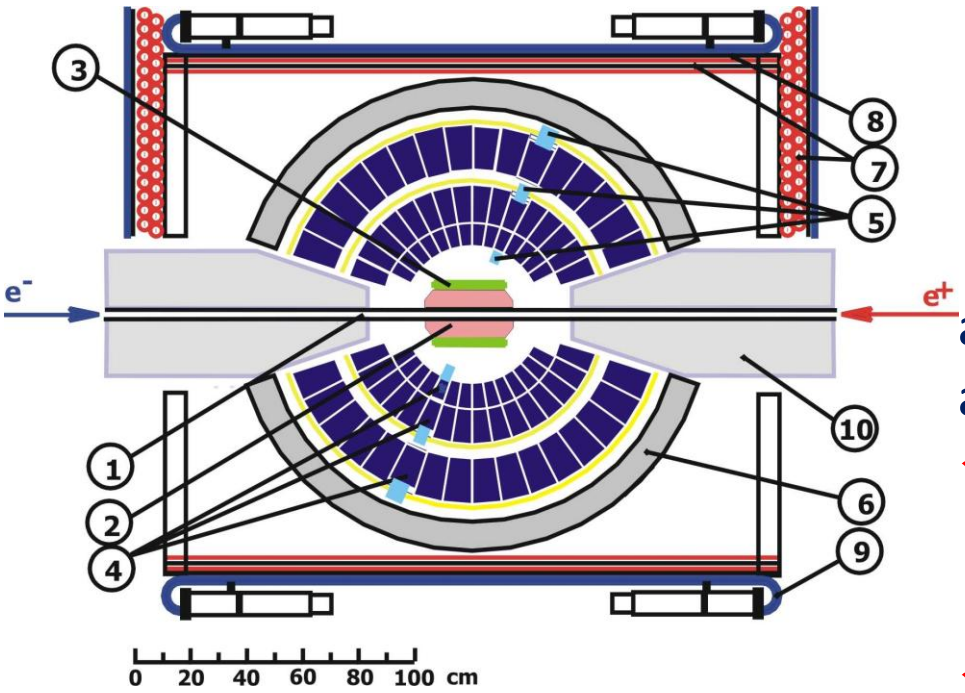
SND detector



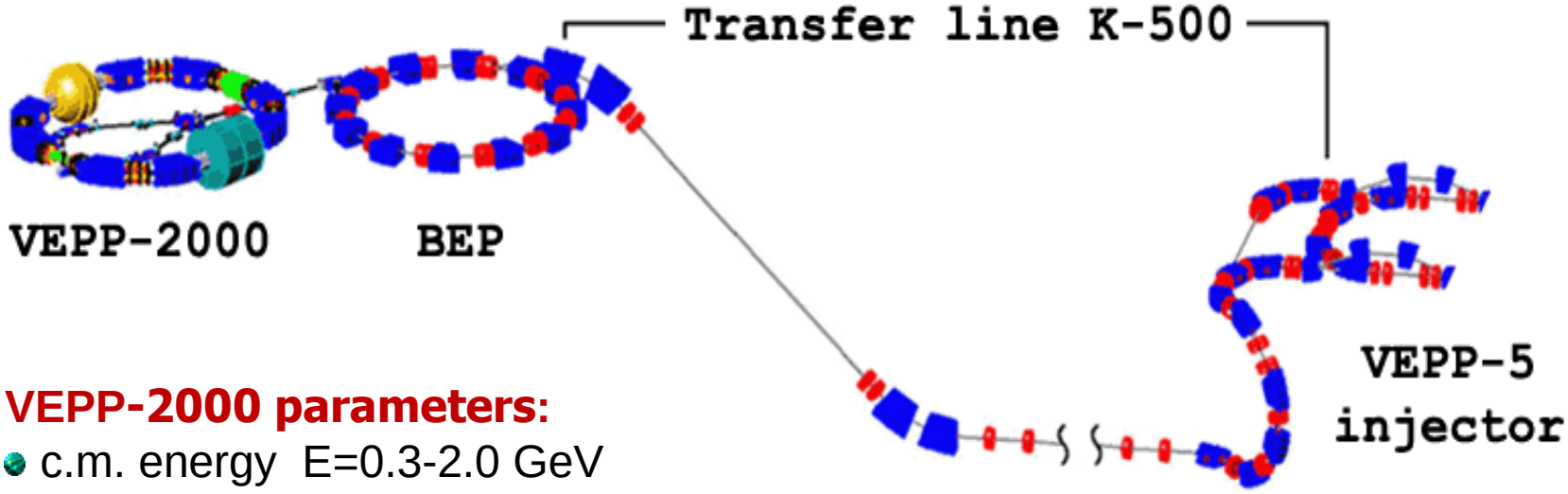
1 – beam pipe, 2 – tracking system, 3 – aerogel Cherenkov counter , 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron muon absorber, 7–9 – muon detector, 10 – focusing solenoids.

SND collected data at the VEPP-2M (1996-2000) and VEPP-2000 (2010-2013,2016-…)

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).
  - Properties of excited vector mesons of the ρ, ω, ϕ families
  - Development of MC event generator for $e^+e^- \rightarrow$ hadrons below 2 GeV.

VEPP-2000 e^+e^- collider



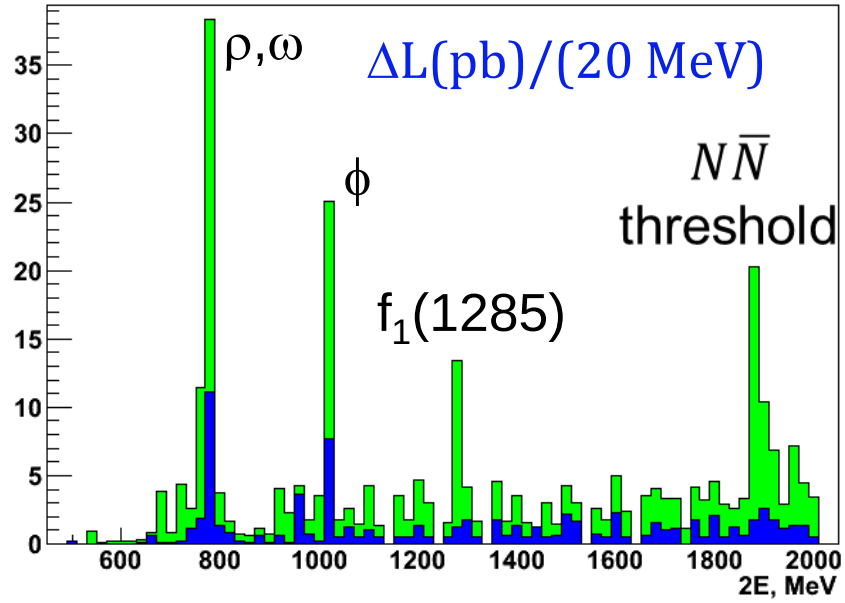
VEPP-2000 parameters:

- c.m. energy E=0.3-2.0 GeV
- circumference – 24.4 m
- round beam optics
- Luminosity at E=1.8 ГэВ
  1×10^{32} cm^{-2} sec^{-1} (project)
  4×10^{31} cm^{-2} sec^{-1} (achieved)
- Two detectors: SND and CMD-3

2010-2013 – experiments, 70 pb^{-1}
2013-2016 – upgrade, new injector
2016- … – experiments, 250 pb^{-1}

SND data

~15 hadronic processes are currently under analysis

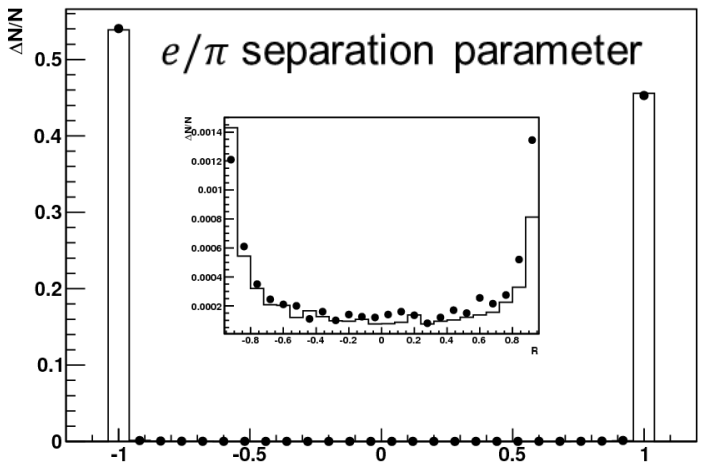


VEPP-2000

	Below ϕ	Near ϕ	Above ϕ
IL, pb^{-1}	77	31	209
E_{cm}, GeV	0.30-0.97	0.98-1.05	1.05-2.00

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

$e^+e^- \to \pi^+\pi^-$

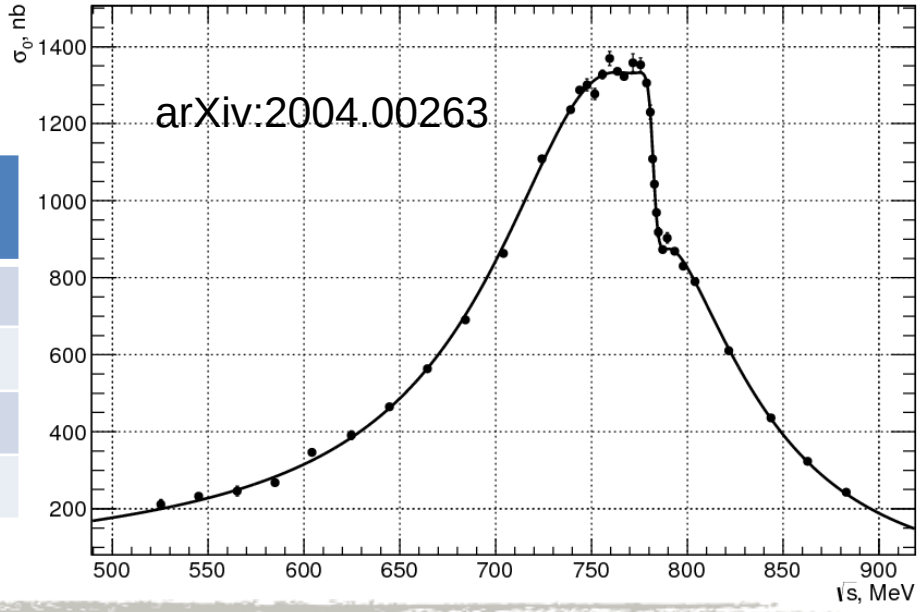


Systematic uncertainty on the cross section (%)

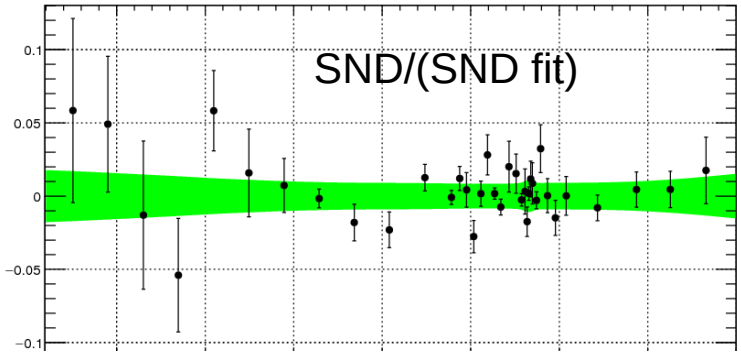
Source	< 0.6 GeV	0.6 - 0.9 GeV
Trigger	0.5	0.5
Selection criteria	0.6	0.6
e/π separation	0.5	0.1
Nucl. interaction	0.2	0.2
Theory	0.2	0.2
Total	**0.9**	**0.8**

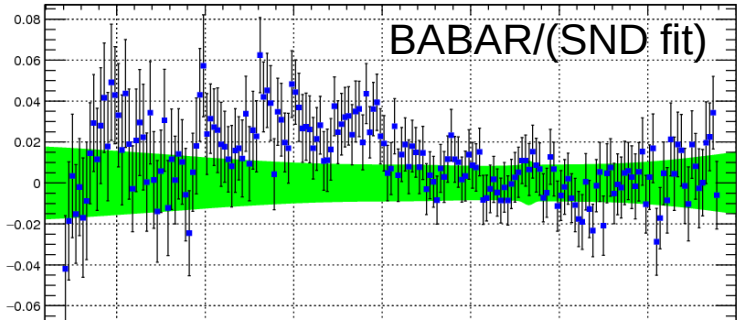
The analysis is based on 4.7 pb^{-1} data (1/10 full SND data set) recorded in 2013

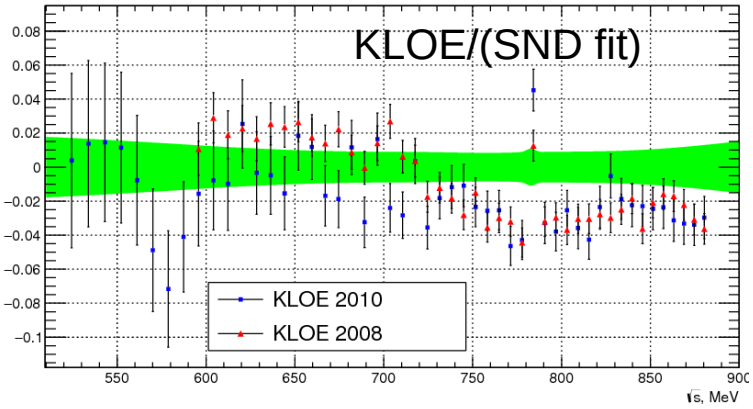
	SND @ VEPP-2000	SND @ VEPP-2M	PDG
M_ρ, MeV	775.3±0.5±0.6	775.6±0.4±0.5	775.3±0.3
Γ_ρ, MeV	145.6±0.6±0.8	146.1±0.8±1.5	147.8±0.9
$B_{\rho ee}\times 10^5$	4.89±0.02±0.04	4.88±0.02±0.06	4.72±0.05
$B_{\omega\pi\pi}$, %	1.77±0.08±0.02	1.66±0.08±0.05	1.53±0.06

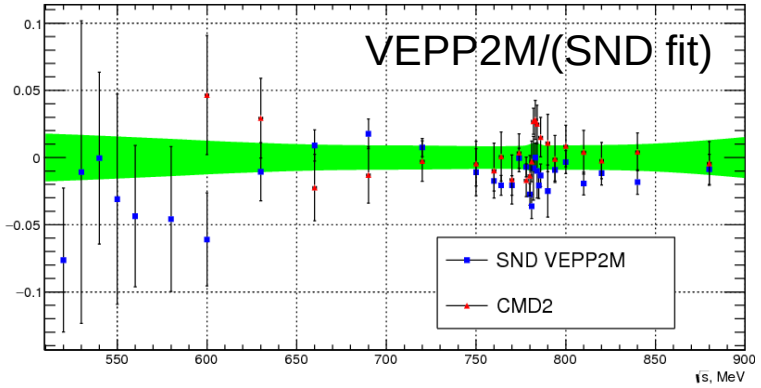


$e^+e^- \to \pi^+\pi^-$





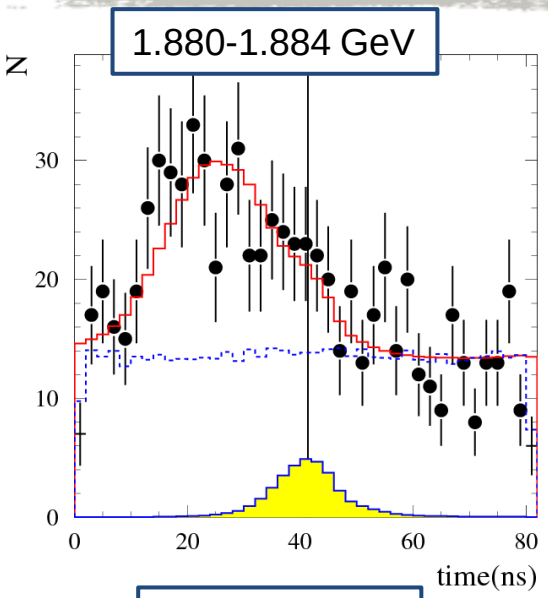


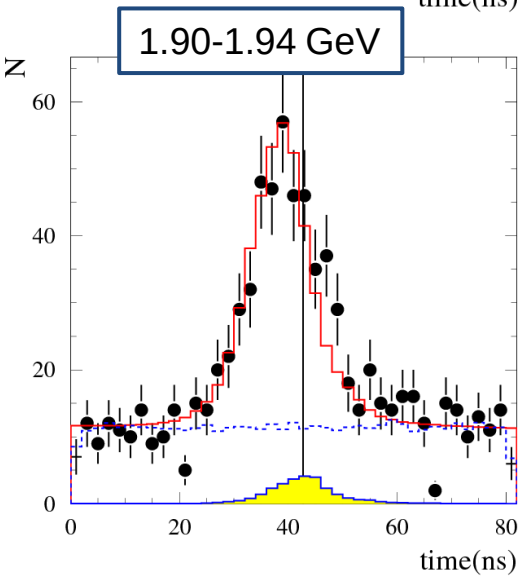


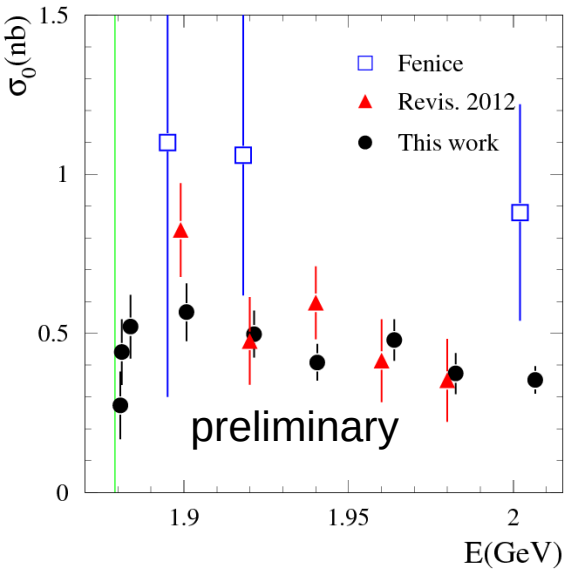
$$0.53 < \sqrt{s} < 0.88 \text{ GeV}$$

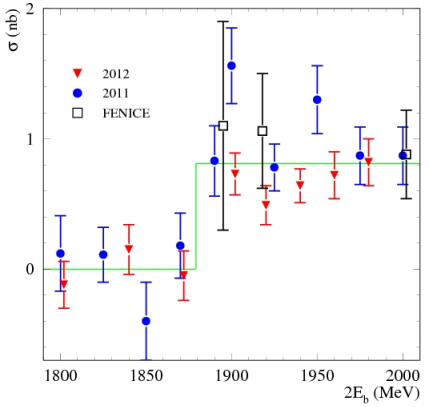
	$a_\mu(\pi^+\pi^-) \times 10^{10}$
SND & VEPP-2000	$409.79 \pm 1.44 \pm 3.87$
SND & VEPP-2M	$406.47 \pm 1.74 \pm 5.28$
BABAR	$413.58 \pm 2.04 \pm 2.29$
KLOE	$403.39 \pm 0.72 \pm 2.50$

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





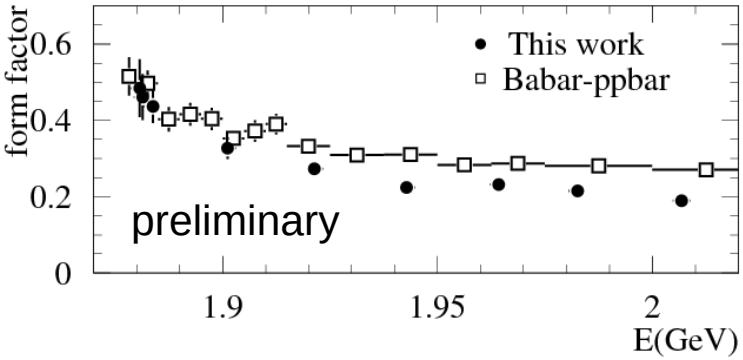


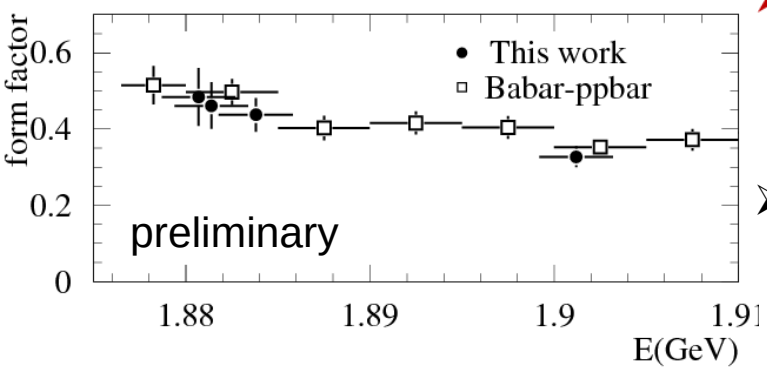


This process was previously measured by FENICE and SND using the 2011-2012 dataset.

- The new measurement is based on the 2017 dataset and uses a different method. The calorimeter-trigger-time distribution is analyzed.
- The time distribution is fitted by a sum of distributions for signal, cosmic background, and beam + e^+e^- annihilation background.
- 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.

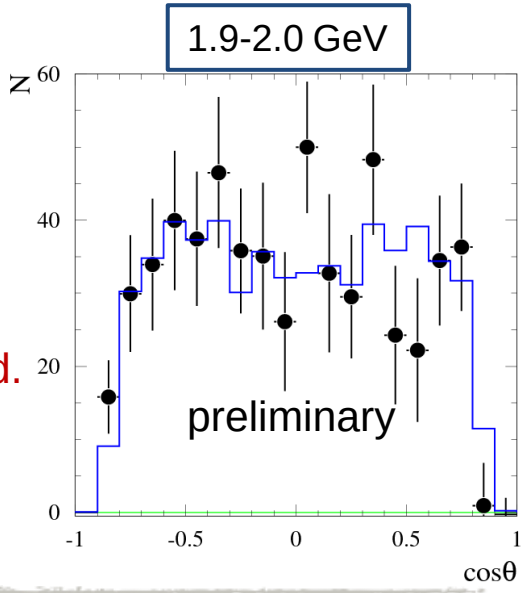
$e^+e^- \to n\bar{n}$





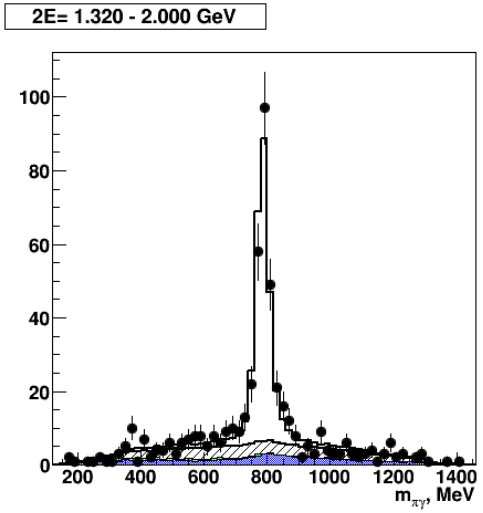
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{1}{\tau}|G_E(s)|^2\sin^2\theta\right] \quad \tau = \frac{s}{4m_n^2}$$

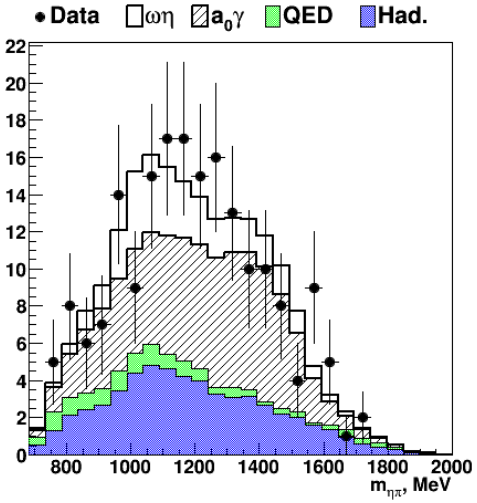
- The $e^+e^- \to n\bar{n}$ cross section depends on two form factors.
- From the measured cross section we determine the effective form factor $|F|^2 = |G_M|^2 + \frac{1}{2\tau}|G_E|^2$
- Near threshold the proton and neutron effective form factors are close to each other. The neutron form factor become lower than the proton one with increase the energy.
- The ratio of the form factors can be determined from the analysis of the cosθ distribution



- The cosθ distribution is well described by $1+\cos^2\theta$, i.e. $G_E=0$.
- The dominance of the G_E term in the cross section is excluded.
- For proton $|G_E/G_M| \approx 1.5$ in this energy region.

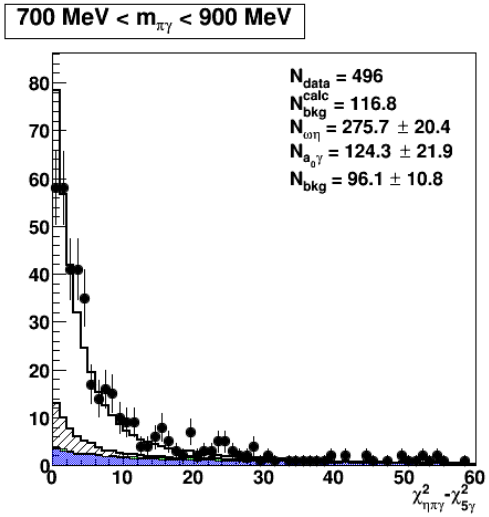
$e^+e^- \to \eta\pi^0\gamma$ arXiv:2006.05465

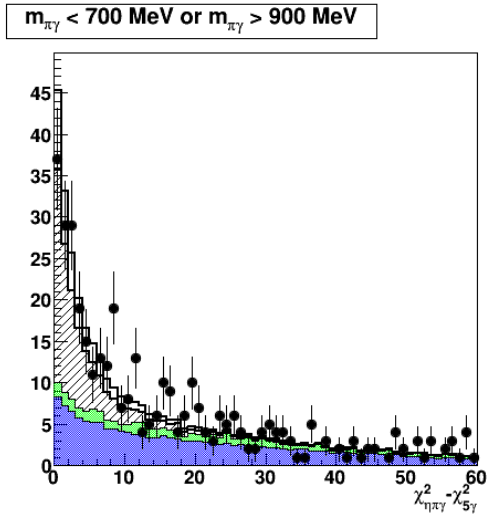




The process $e^+e^- \to \eta\pi^0\gamma$ above 1.05 GeV is studied for the first time.
Data set with IL≈100 pb^{-1} recorded in 2010-2012 and 2017
The five-photon final state is used.

There is a significant contribution of the ωη intermediate state, which is seen as a peak in the $\pi^0\gamma$ mass distribution.

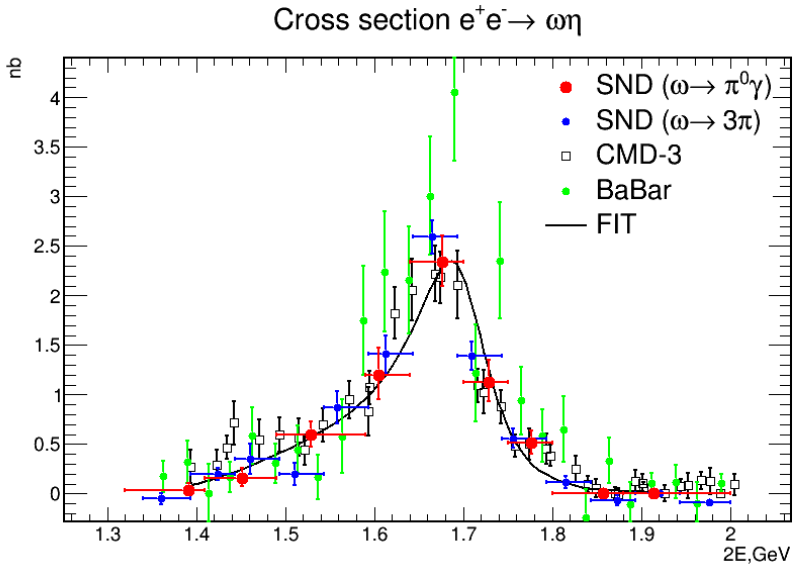


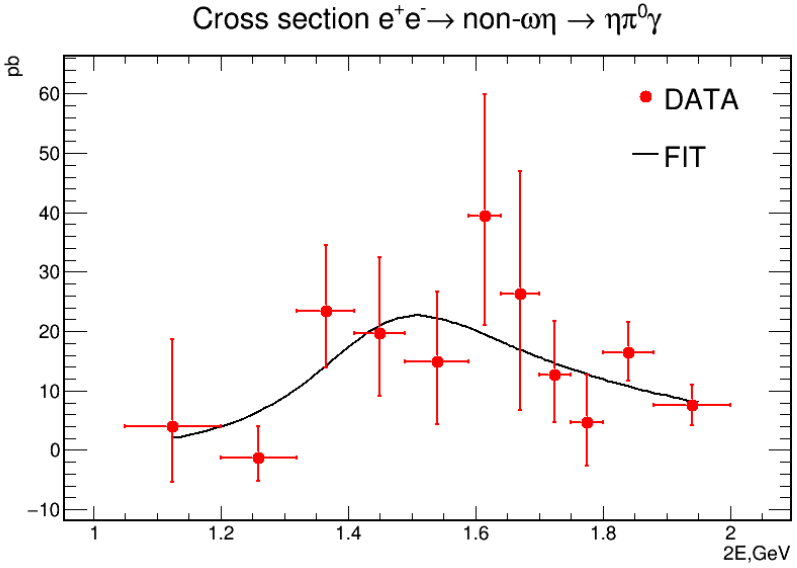


The main background processes are $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ and QED $e^+e^- \to 4\gamma, 5\gamma$. The background contribution is estimated from the kinematic fit χ^2 distribution.

The non-ωη signal is observed with a wide $\eta\pi^0$ mass distribution. It may arise from the processes $e^+e^- \to a_0(1450)\gamma$ and $a_2(1320)\gamma$.

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





The measured $e^+e^- \to \omega\eta$ cross section is in good agreement with the SND and CMD-3 measurements in the $\omega \to \pi^+\pi^-\pi^0$ decay mode.

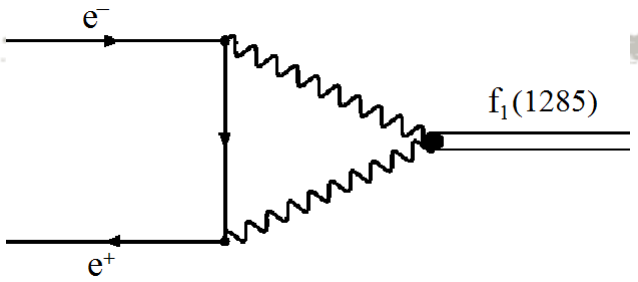
The non-VP $e^+e^- \to \eta\pi^0\gamma$ process is observed with significance of 5.8σ.

We perform the first measurement of the cross section for this process in the energy range 1.05-2.00 GeV.

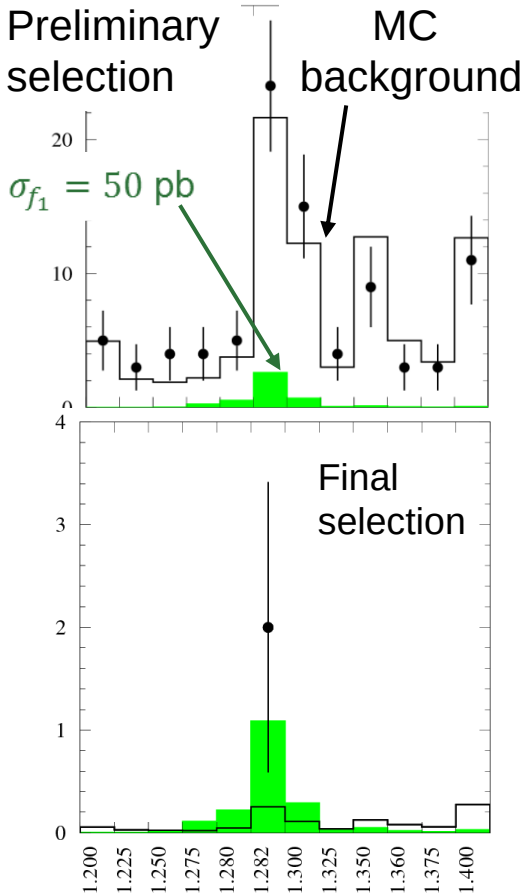
The value of the cross section is about 15-20 pb in the region 1.4-1.9 GeV.

Search for $e^+e^- \to f_1(1285)$

Phys. Lett. B 800, 135074 (2020)



The predicted branching fraction $B(f_1 \to e^+ e^-) = 3\text{-}8 \times 10^{-9}$ [A. S. Rudenko, Phys. Rev. D96, 076004 (2017)] corresponds to the f_1 production cross section of 30-70 pb.



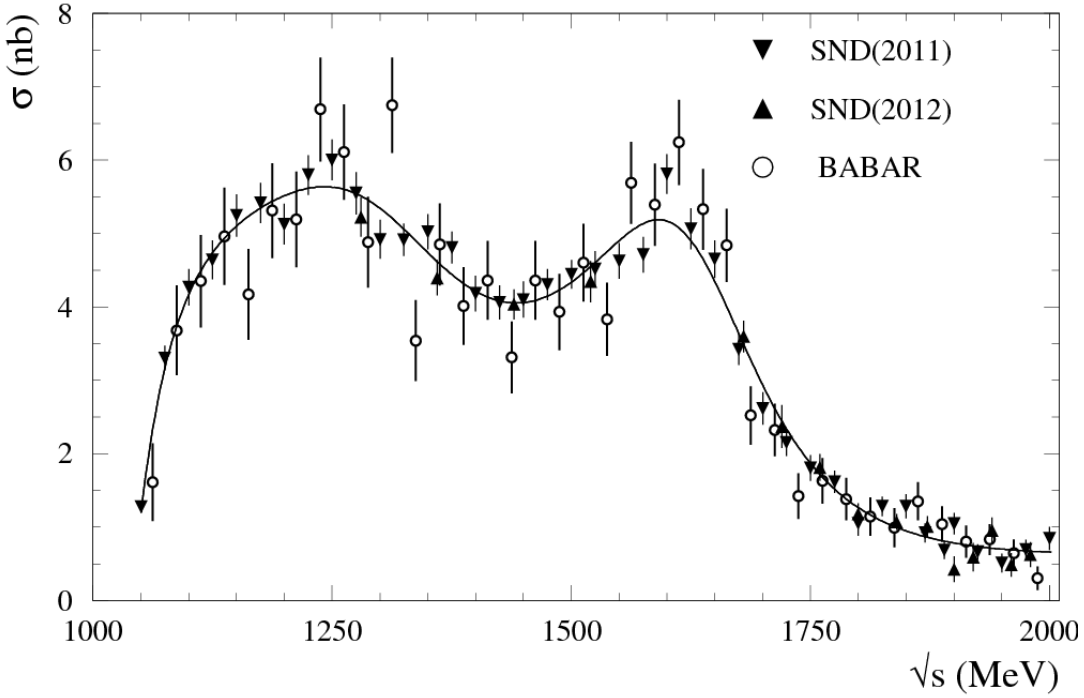
- The 15 pb^{-1} data sample recorded in the energy range $\sqrt{s}$ =1.2-1.4 GeV is analyzed. About 4 pb^{-1} of them were collected in the resonance maximum.
- The decay mode $f_1 \to \eta\pi^0\pi^0 \to 6\gamma$ is used. This final state is not produced in single photon annihilation.
- The main background sources are $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$, $e^+e^- \to \eta\gamma$, and $e^+e^- \to \omega\pi^0\pi^0$.
- After applying the selection criteria, two events have been observed at the peak of the $f_1(1285)$ resonance and zero events beyond the resonance.
- These two events correspond to

$$\sigma(f_1 \to e^+ e^-) = 45^{+33}_{-24}\ \text{pb},$$

$$B(f_1 \to e^+ e^-) = 5.1^{+3.7}_{-2.7} \times 10^{-9}.$$

The significance of the $f_1(1285)$ signal is 2.5σ.

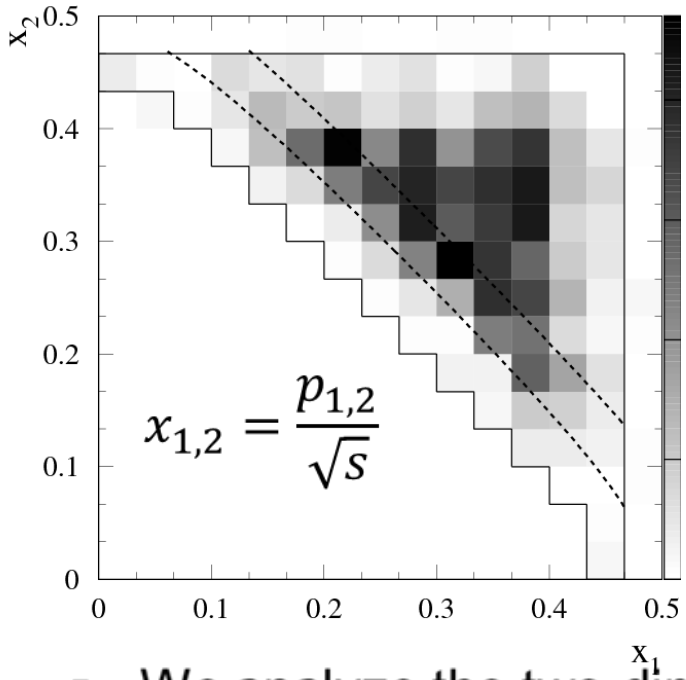
$e^+e^- \to \pi^+\pi^-\pi^0$ cross section

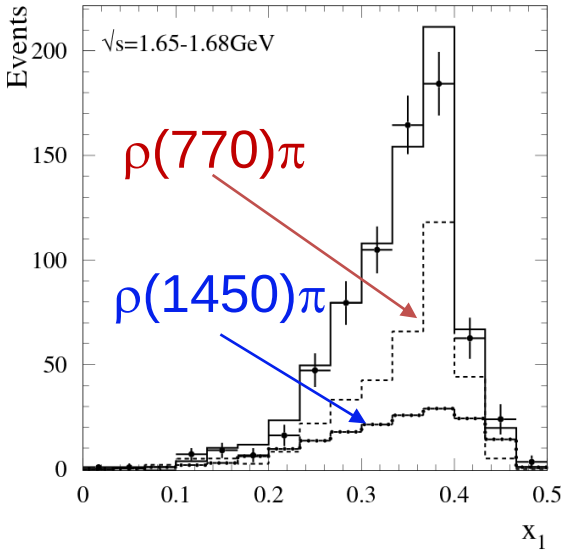


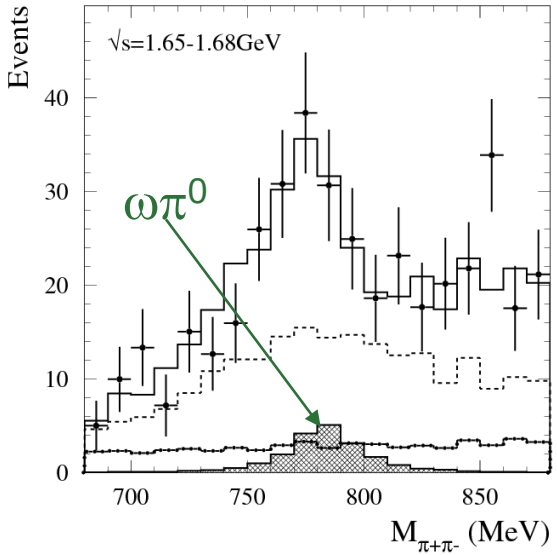
- ✓ Both SND measurements are consistent with each other and with the the BABAR measurement.
- ✓ Two peaks in the cross section corresponds to the ω(1420) and ω(1480) resonances.
- ✓ The systematic uncertainty on the cross section is 4.4%.

The previous SND measurement [J. Exp. Theor. Phys. 121, 27 (2015)] is based on 2011 data set. The 2012 data set has been added.

$e^+e^- \to \pi^+\pi^-\pi^0$ dynamics

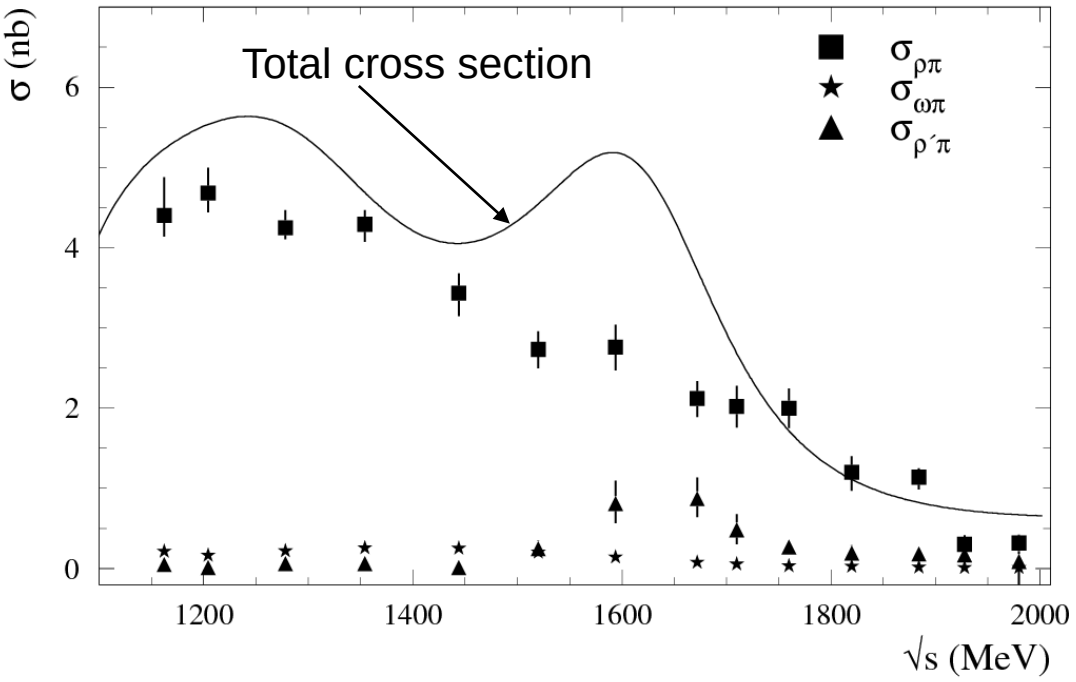






- We analyze the two-dimensional distribution of the charged-pion momenta and the $\pi^+\pi^-$ mass spectrum.
- These distributions are fitted with a model including the ρ(770)π, ρ(1450)π, and $\omega\pi^0$ intermediate states.
- A significant fraction of the ρ(1450)π intermediate state is observed in the energy region 1.55-1.75 GeV.

$e^+e^- \to \pi^+\pi^-\pi^0$ dynamics



- ✓ The cross section for the intermediate state $\rho(1450)\pi$ differs significantly from zero in the range 1.55 - 1.75 GeV, where the resonance $\rho(1680)$ is located.
- ✓ In the $\rho(770)\pi$ cross section the resonance structure near 1680 MeV is not seen.

We conclude that the $\rho(1450)\pi$ intermediate state gives a significant contribution to the decay $\omega(1680) \to \pi^+\pi^-\pi^0$, and that the $\omega(1420) \to \pi^+\pi^-\pi^0$ decay is dominated by the $\rho(770)\pi$ intermediate state.

Summary

- ✓ The SND detector accumulated 320 pb^{-1} of integrated luminosity in the energy range 0.3 – 2 GeV.
- ✓ The $e^+e^- \to \pi^+\pi^-$ cross section has been measured with a systematic uncertainty better than 1%.
- ✓ The accuracy of the $e^+e^- \to n\bar{n}$ measurement has been significantly improved.
- ✓ Rare radiative processes $e^+e^- \to \eta\pi^0\gamma$ have been measured in the energy range 1.05-2 GeV.
- ✓ The first indication of the process $e^+e^- \to f_1(1285)$ has been obtained.
- ✓ The dynamics of the process $e^+e^- \to \pi^+\pi^-\pi^0$ has been studied in the energy range 1.15-2.0 GeV.