Recent results from the SND experiment at the VEPP-2000 collider

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on behalf of the SND collaboration

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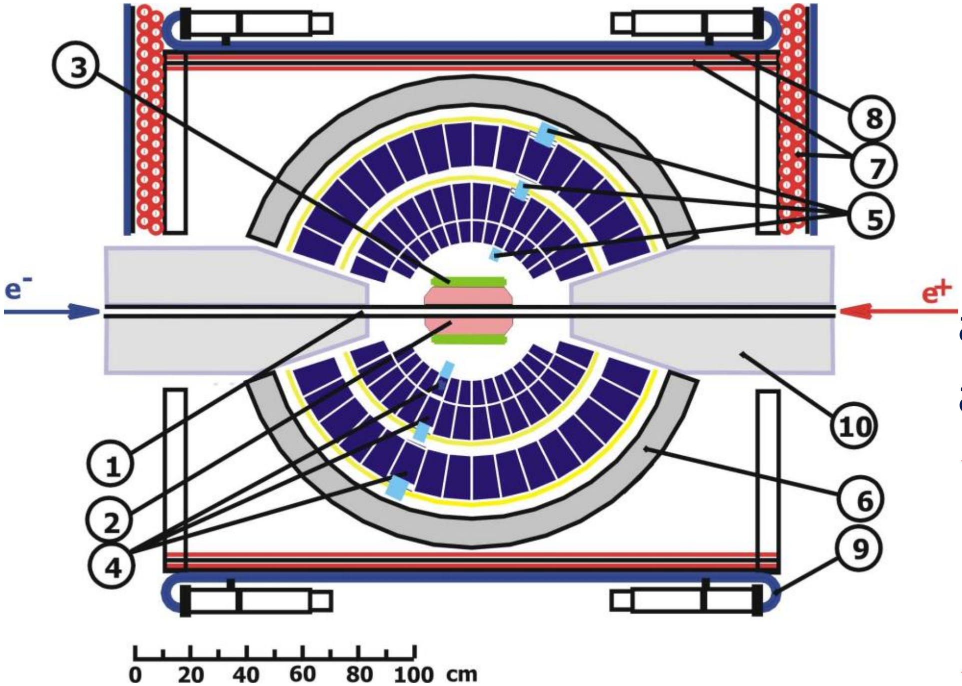
SND detector



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-…)

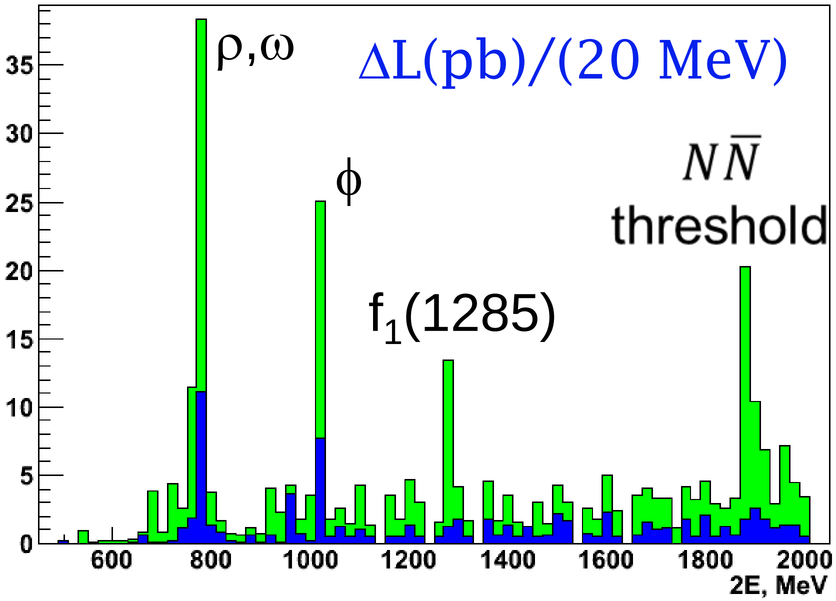
Main physics task of SND is study of all possible processes of e^+e^- annihilation into hadrons below 2 GeV.

- ✓ 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 $e^+e^- \to$ hadrons below 2 GeV.

SND data

2010-2013 – experiments, 70 pb^{-1}
2013-2016 – upgrade, new injector
2016- … – experiments, 210 pb^{-1}

~15 hadronic processes are currently under analysis

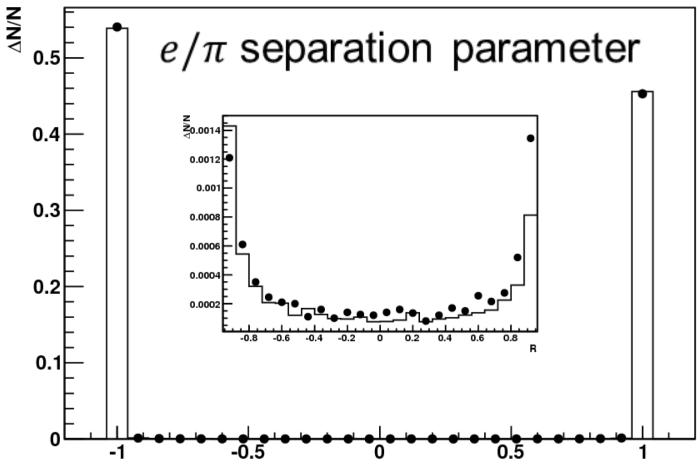


	Below ϕ	Near ϕ	Above ϕ
IL, pb^{-1}	77	31	168.0
E_{cm}, GeV	0.30-0.97	0.98-1.05	1.05-2.00

- $e^+e^- \to \pi^+\pi^-$
- $e^+e^- \to n\bar{n}$
- $e^+e^- \to \pi^+\pi^-\pi^0\eta$

- $e^+e^- \to \pi^0\eta\gamma$
- $e^+e^- \to \eta$
- $e^+e^- \to f_1(1285)$

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

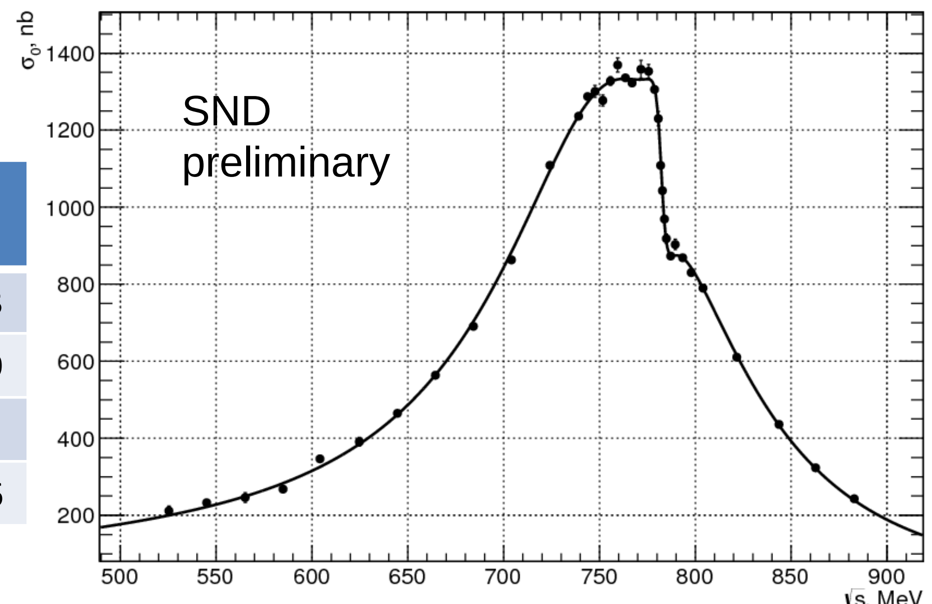


Systematic uncertainty on the cross section (%)

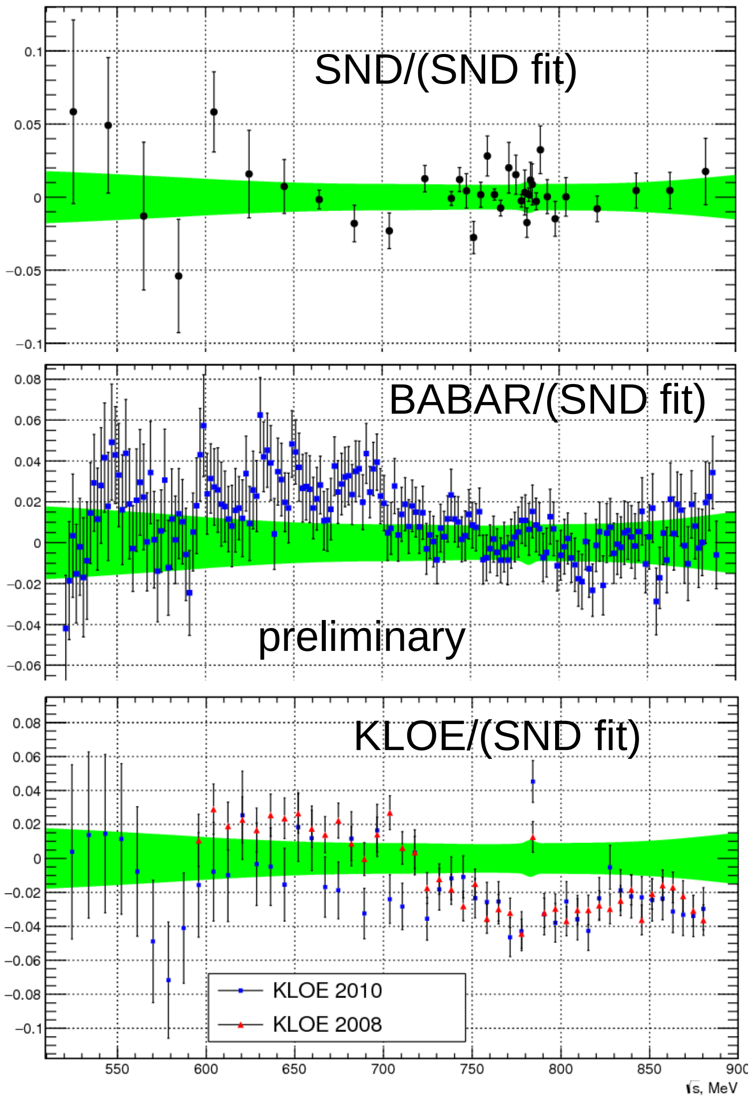
Source	**< 0.6GeV**	**0.6 - 0.9 GeV**
Trigger	0.5	0.5
Selection criteria	0.6	0.6
e/π separation	0.5	0.1
Nucl. interaction	0.2	0.2
Theory	0.2	0.2
Total	**0.9**	**0.8**

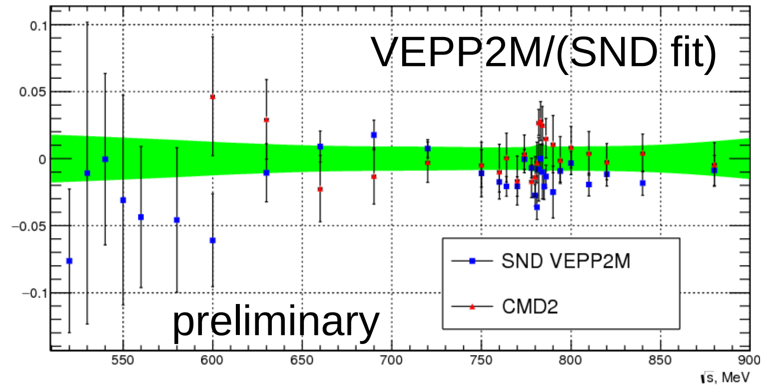
The analysis is based on 4.7 pb^{-1} data recorded in 2013 (1/10 full SND data set)

	SND @ VEPP-2000	**SND @ VEPP-2M**	**PDG**
M_ρ, MeV	775.4±0.5±0.4	775.6±0.4±0.5	775.3±0.3
Γ_ρ, MeV	145.7±0.7±1.0	146.1±0.8±1.5	147.8±0.9
$B_{\rho ee}\times10^5$	4.89±0.2±0.4	4.88±0.2±0.6	4.72±0.5
$B_{\omega\pi\pi}$, %	1.77±0.08±0.02	1.66±0.08±0.05	1.53±0.06



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



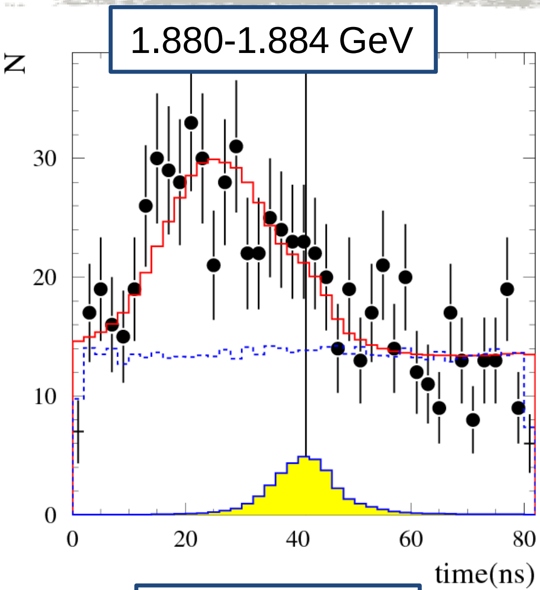


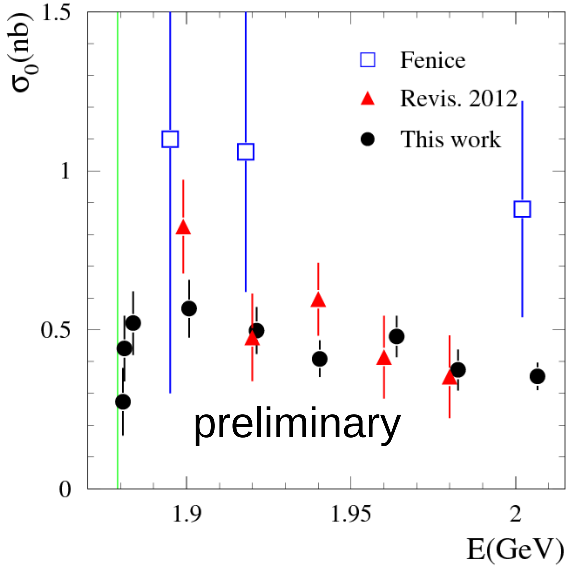
$$0.53 < \sqrt{s} < 0.88 \text{ GeV}$$

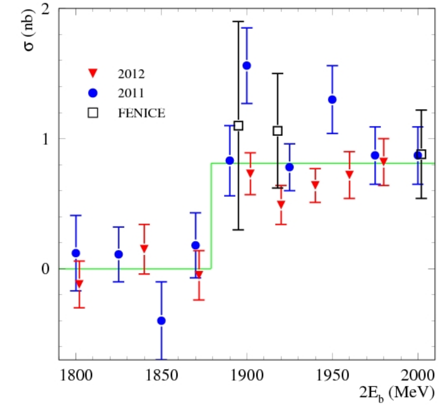
	$a_\mu(\pi^+\pi^-) \times 10^{10}$
SND & VEPP-2000	$411.8 \pm 1.0 \pm 3.7$
SND & VEPP-2M	$408.9 \pm 1.3 \pm 5.3$
BABAR	$414.9 \pm 0.3 \pm 2.1$

More details in plenary talk of Fedor Ignatov

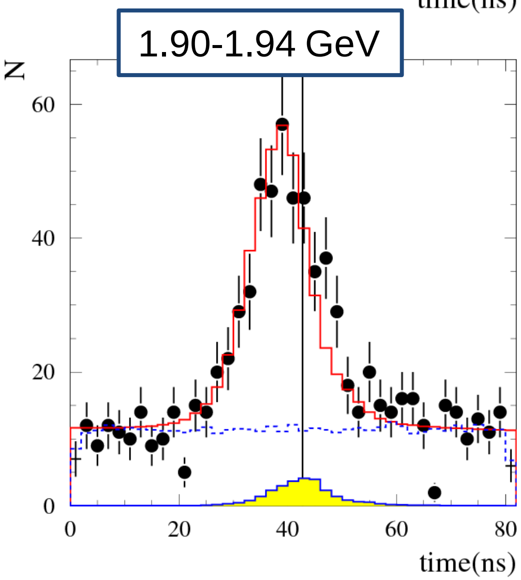
$e^+e^- \to n\bar{n}$





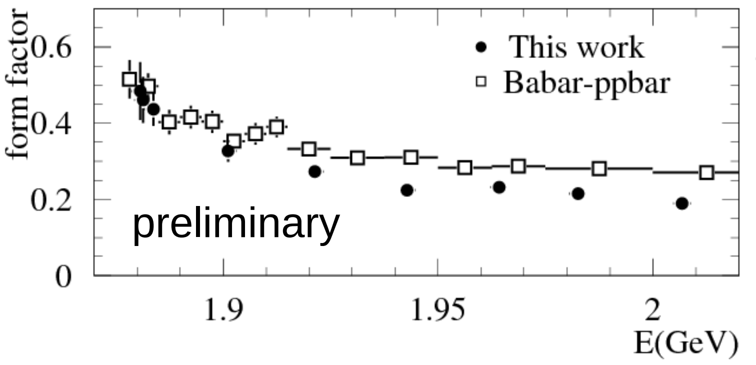


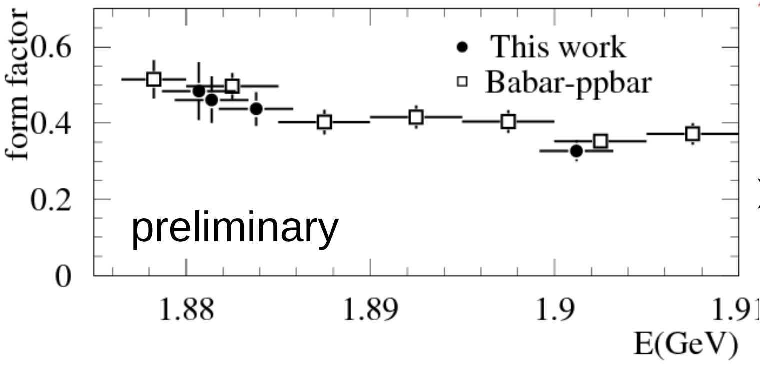
This process was previously measured by FENICE and SND using the 2011-2012 dataset.



- 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.

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

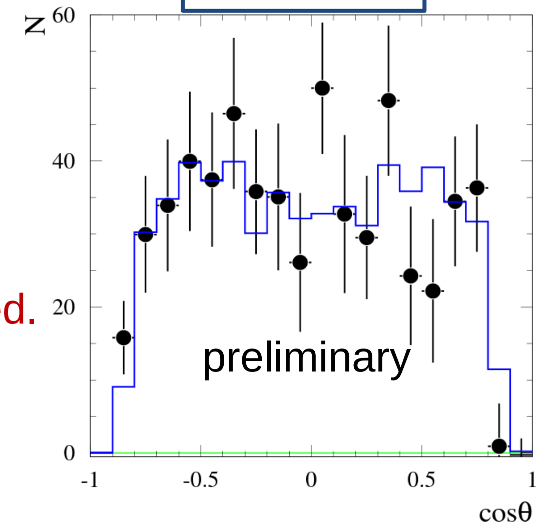




$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{1}{\tau}|G_E(s)|^2\sin^2\theta\right] \quad \tau = \frac{s}{4m_n^2}$$

- 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

1.9-2.0 GeV

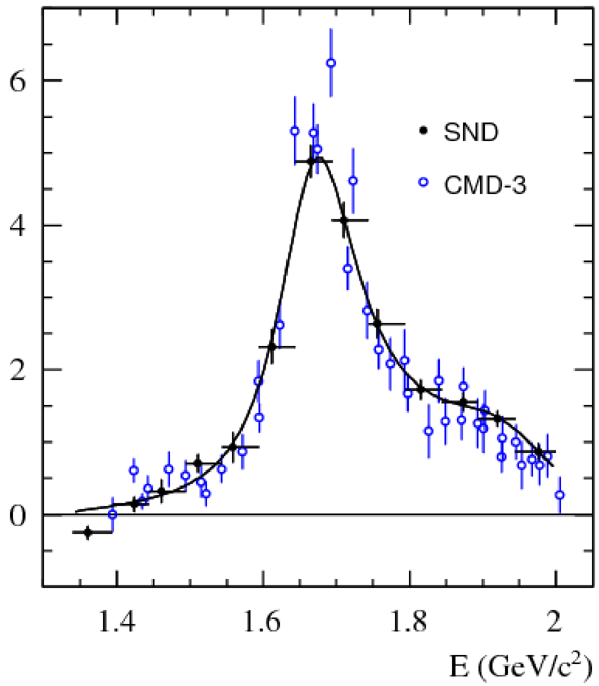


- The cosθ distribution is well described by $1+\cos^2\theta$, i.e. $G_E=0$.
- The dominance of the G_E term in the cross section is excluded.
- For proton $|G_E/G_M| \approx 1.5$ in this energy region.

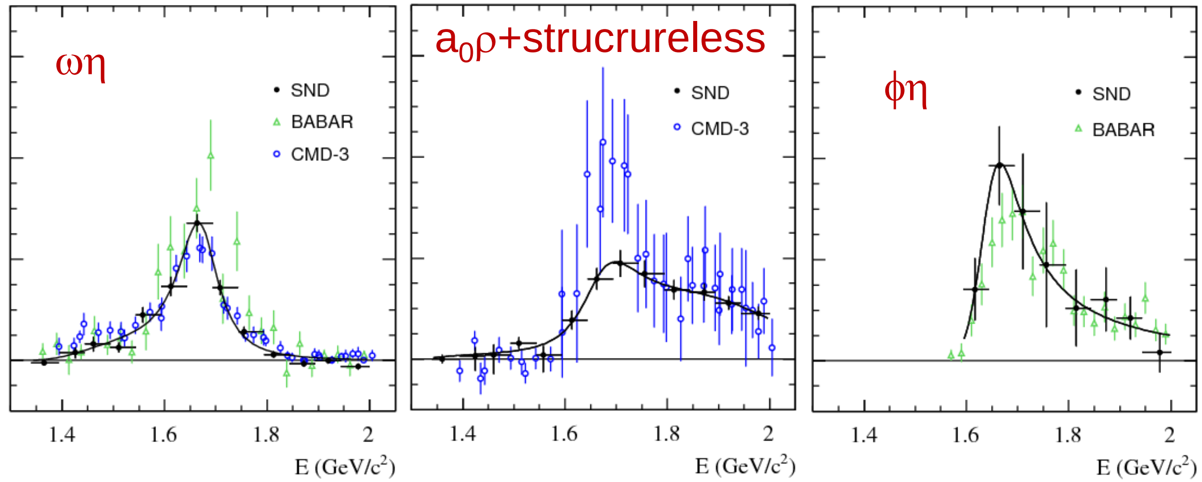
$e^+e^- \to \pi^+\pi^-\pi^0\eta$

Phys. Rev. D 99, 112004 (2019)

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



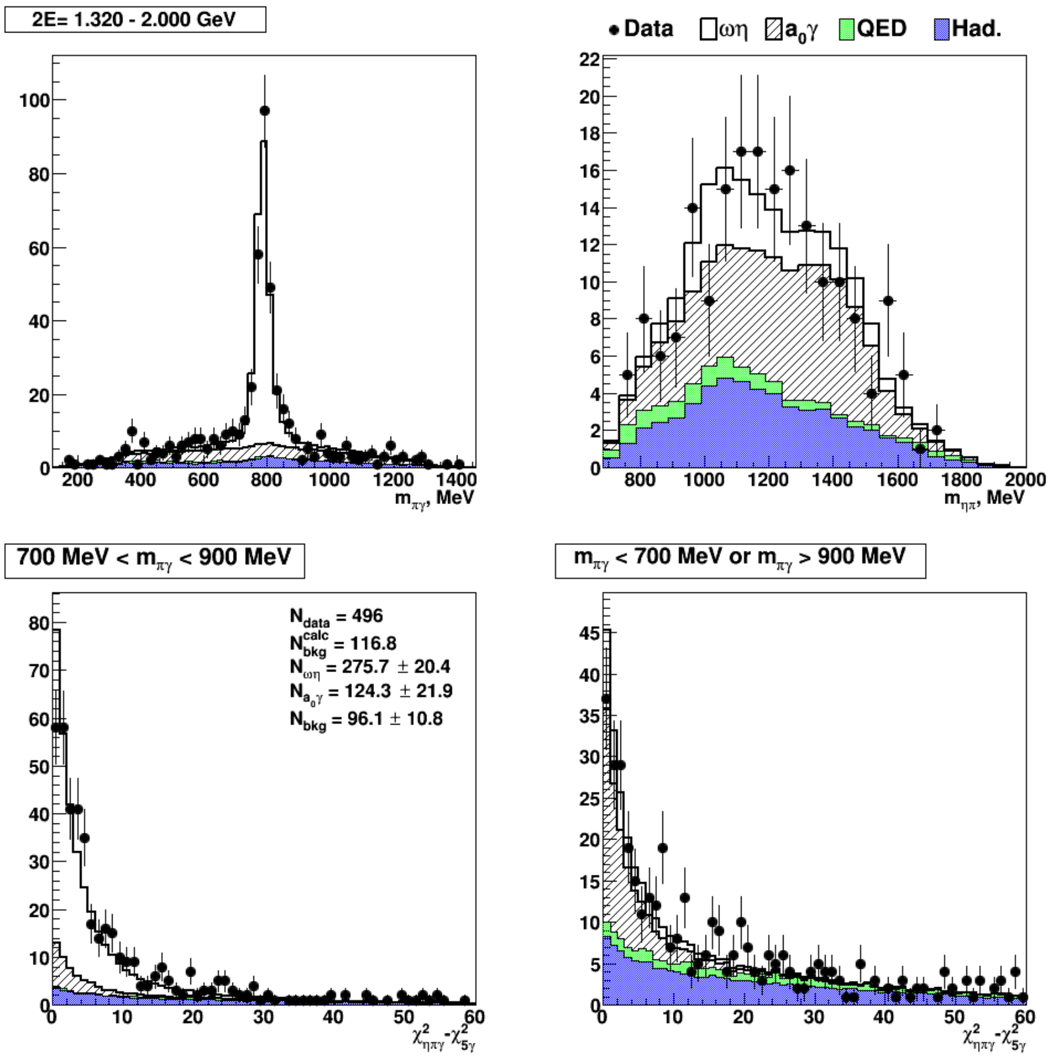
Cross sections in nb



The total $e^+e^- \to \pi^+\pi^-\pi^0\eta$ cross section measured by SND is, in general, consistent with the CMD-3 result. The~15% difference in the cross section maximum is within the systematic uncertainties, which are 7% for SND and 11% for CMD-3.

- The obtained $e^+e^- \to \omega\eta$ 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 $a0\rho$+strucrureless final state.

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



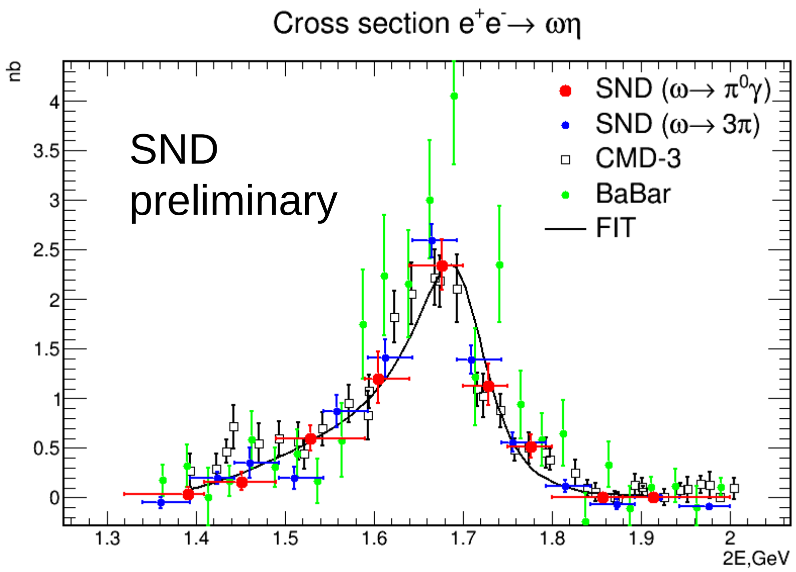
The process $e^+e^- \to \eta\pi^0\gamma$ above 1.05 GeV is studied for the first time.
Data set with IL≈100 pb^{-1} recorded in 2010-2012 and 2017
The five-photon final state is used.

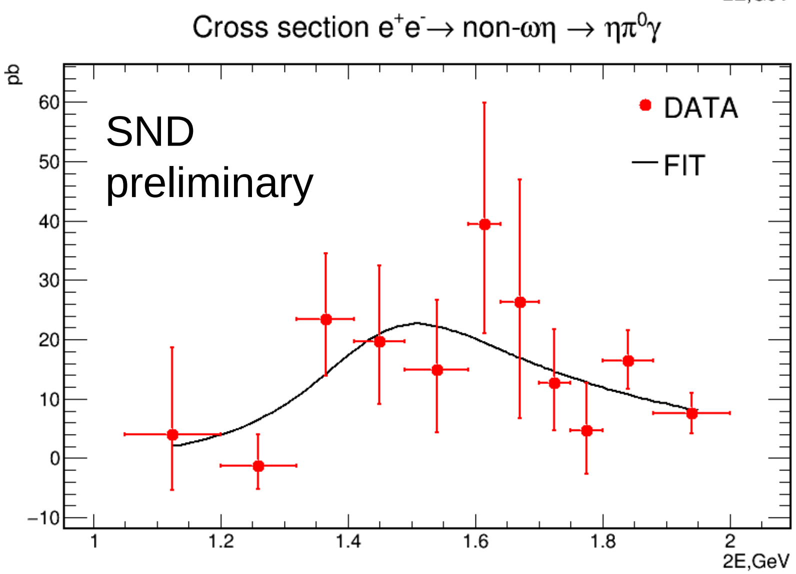
There is a significant contribution of the $\omega\eta$ intermediate state, which is seen as a peak in the $\pi^0\gamma$ mass distribution.

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-$\omega\eta$ 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.

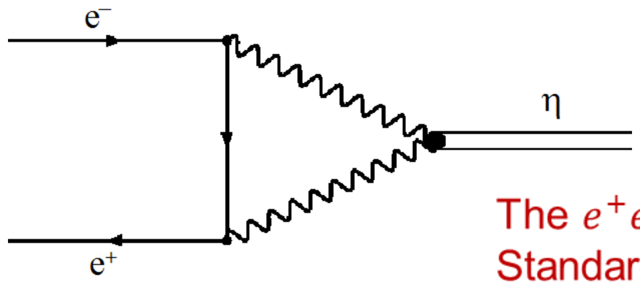
The radiative process $e^+e^- \to \eta\pi^0\gamma$ was studied previously only in the $\phi(1020)$ region.

We perform the first measurement of the $e^+e^- \to \eta\pi^0\gamma$ cross section 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.

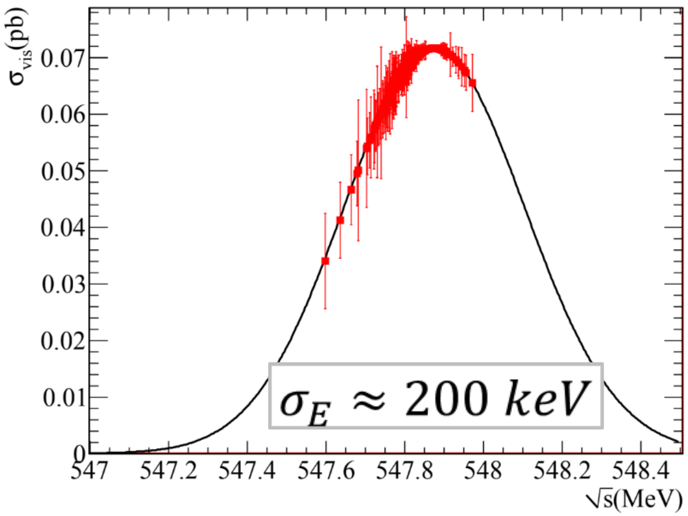
Search for $e^+e^- \to \eta$

Phys. Rev. D 98, 052007 (2018)



The process of production of C-even resonance is rare, suppressed by α^2 compared with single-photon annihilation. For spin-0 resonances there is additional helicity suppression by a factor of $(m_e/m_R)^2$.

The $e^+e^- \to \eta$ cross section is proportional to $B(\eta \longrightarrow e^+ e^-)$. The Standard Model prediction for this decay is about 5×10^{-9}.

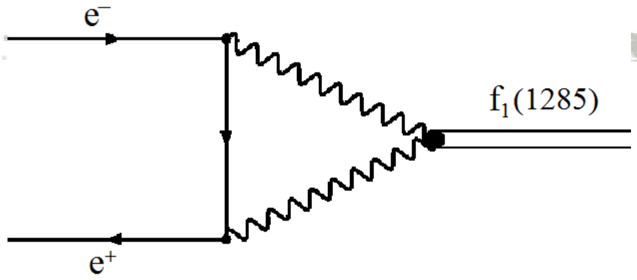


- The 650 nb^{-1} data sample was recorded in 2018 at $\sqrt{s} = m_\eta$.
- The visible η line shape is determined by the energy spread.
- The beam energy and spread were measured with a special system based on Compton backscattering of laser photons off the electron beam.
- The decay mode $\eta \to 3\pi^0$ is used, in which the single photon annihilation background is absent.
- Zero signal events have been selected.

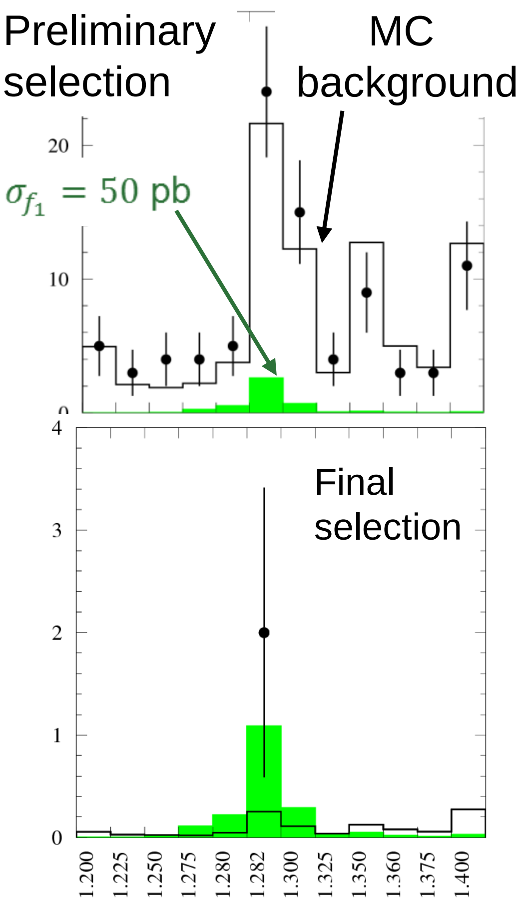
The upper limit $B(\eta \longrightarrow e^+ e^-) < 7 \times 10^{-7}$ at 90% CL has been set, which improves the previous limit of the HADES Collaboration by a factor of 3.

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

arXiv:1906.03838



The predicted branching fraction $B(f_1 \longrightarrow e^+ e^-) = 3\text{-}8 \times 10^{-9}$ [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

$$\sigma(f_1 \longrightarrow e^+ e^-) = 54^{+32}_{-23} \text{ pb},$$

$$B(f_1 \longrightarrow e^+ e^-) = 6.1^{+3.6}_{-2.6} \times 10^{-9}.$$

The significance of the $f_1(1285)$ signal is 2.7σ.

Summary

- ✓ The SND detector accumulated 280 pb^{-1} of integrated luminosity in the energy range 0.3-2.0 GeV
- ✓ The $e^+e^- \to \pi^+\pi^-$ cross section is measured with systematic uncertainty better then 1%
- ✓ The accuracy of $e^+e^- \to n\bar{n}$ measurement is significantly improved
- ✓ The $e^+e^- \to \pi^+\pi^- \pi^0\eta$ cross section have been measured
- ✓ Rare radiative process $e^+e^- \to \eta\pi^0\gamma$ have been measured for the first time in the energy range 1.05-2.00 GeV
- ✓ Search for production of C-even resonances, η and $f_1(1285)$, in e^+e^- annihilation is performed. The first indication of the process $e^+e^- \to f_1(1285)$ is obtained