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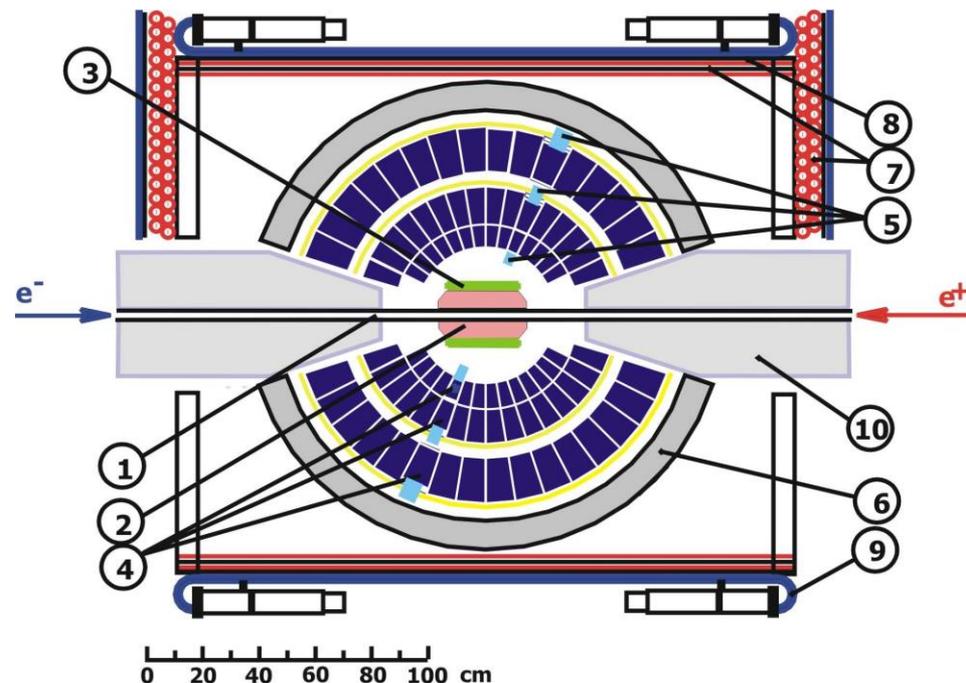
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on behalf of the SND collaboration

EPS HEP2019, Ghent, Belgium, 10-17 July 2019

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
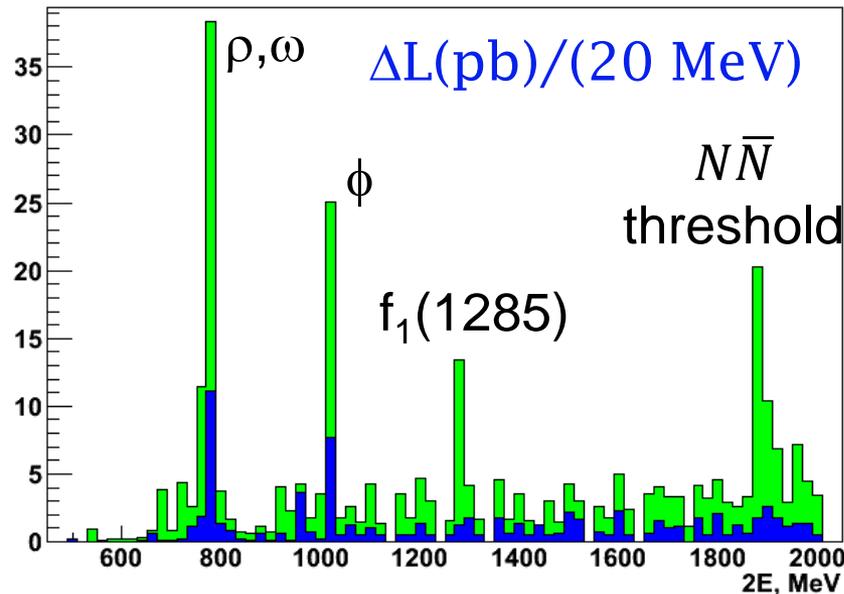- Development of MC event generator for $e^+e^- \rightarrow$ hadrons below 2 GeV.

SND data

~15 hadronic processes are currently under analysis

VEPP-2M

	Below ϕ	Near ϕ	Above ϕ
IL, pb^{-1}	9.1	13.2	8.8
E$_{cm}$, GeV	0.36-0.97	0.98-1.06	1.06-1.38

VEPP-2000

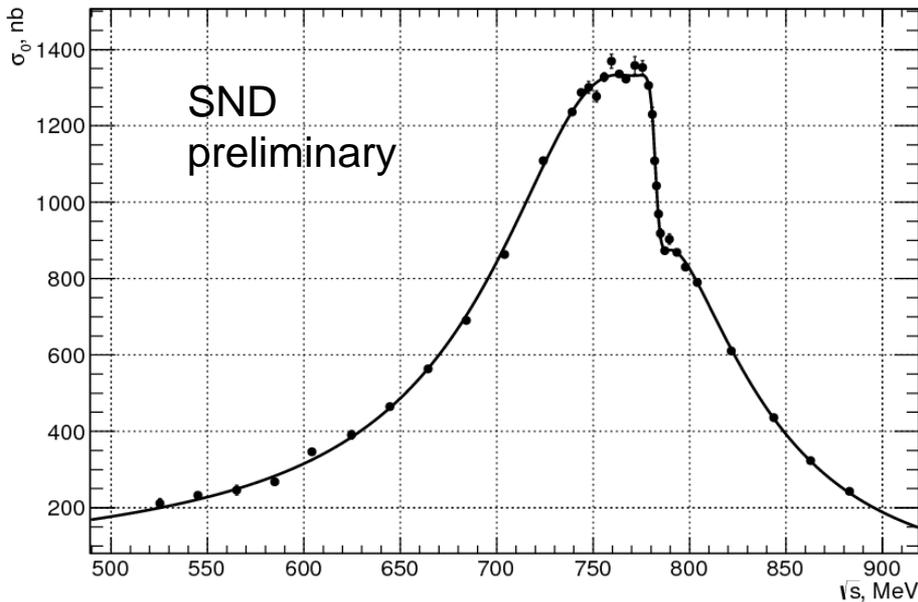|	Below ϕ	Near ϕ	Above ϕ
IL, pb^{-1}	77	31	168.0
E$_{cm}$, GeV	0.30-0.97	0.98-1.05	1.05-2.00

ρ,ω

$\Delta L(pb)/(20\ MeV)$

ϕ

$N\bar{N}$ threshold

f$_1$(1285)

- $e^+e^- \to \pi^+\pi^-$
- $e^+e^- \to n\bar{n}$
- $e^+e^- \to \pi^+\pi^-\pi^0\eta$
- $e^+e^- \to \pi^+\pi^-4\pi^0$

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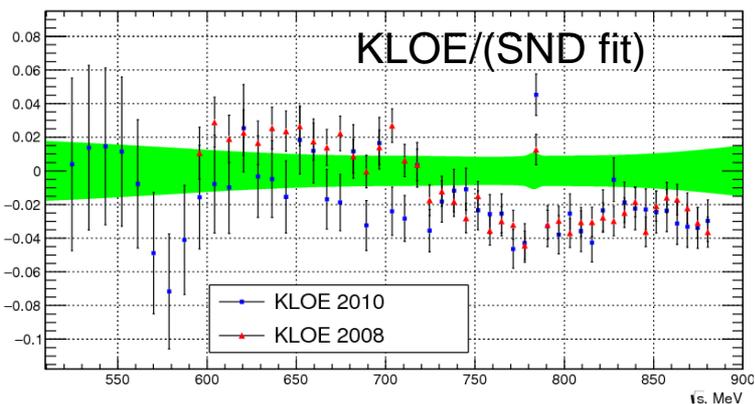- $e^+e^- \to f_1(1285)$

$e^+ e^- \rightarrow \pi^+ \pi^-$

SND preliminary

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**

|	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
$B_{\rho ee} \times 10^5$	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

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

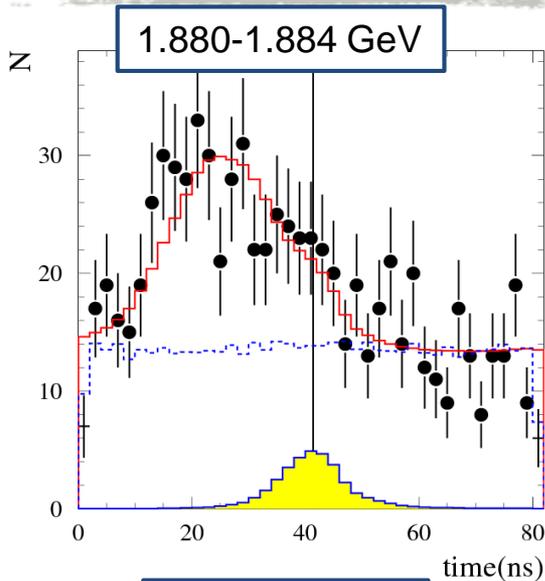# $e^+e^- \rightarrow \pi^+\pi^-$

SND/(SND fit)

BABAR/(SND fit)

preliminary

KLOE/(SND fit)

KLOE 2010
KLOE 2008

VEPP2M/(SND fit)

SND VEPP2M
CMD2

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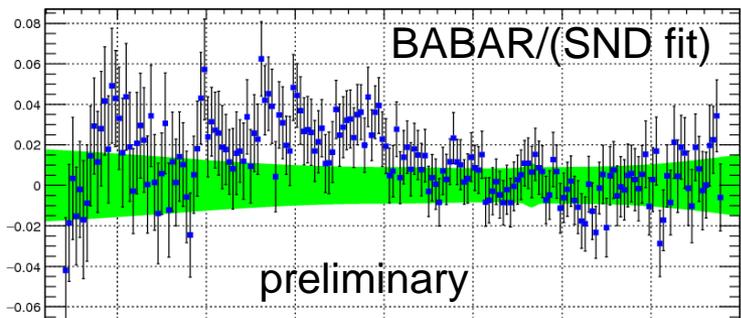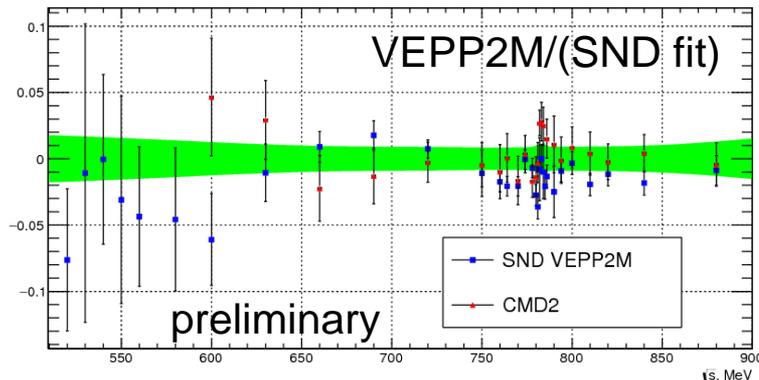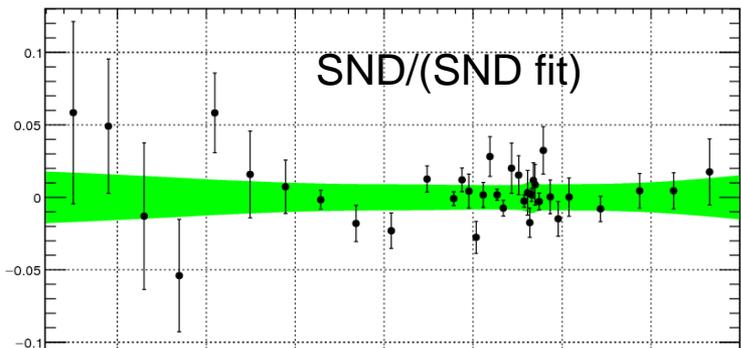
$0.53 < \sqrt{s} < 0.88$ GeV

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

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

1.880-1.884 GeV

1.90-1.94 GeV

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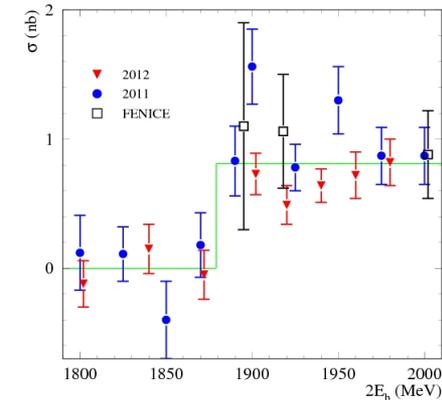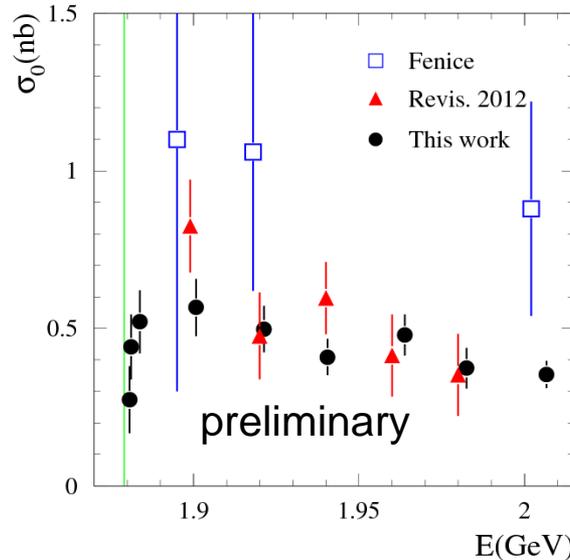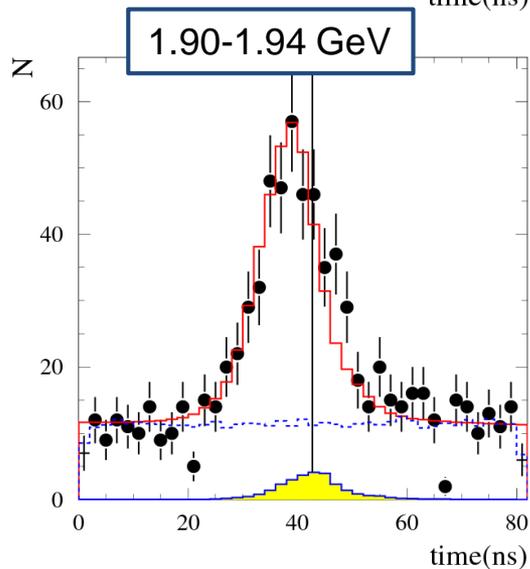
This process was previously measured by FENICE and SND using the 2011-2012 dataset.

❑ 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.

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

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

➢ The $e^+e^- \rightarrow n\bar{n}$ 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 becomes lower than the proton one with increase of the energy.

➢ The ratio of the form factors can be determined from the analysis of the cos θ distribution

➢ The cos θ distribution is well described by 1+cos²θ, i.e. G_E=0.
➢ The dominance of the G_E term in the cross section is excluded.
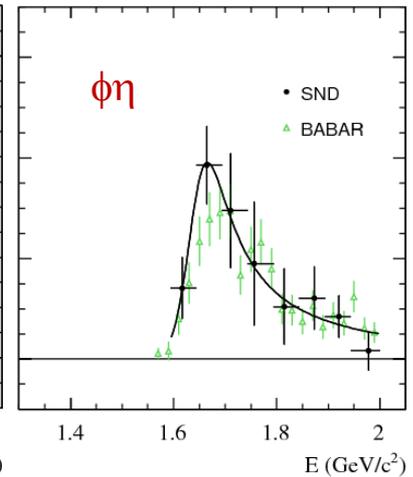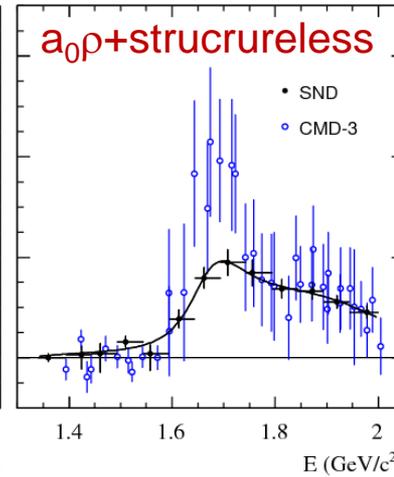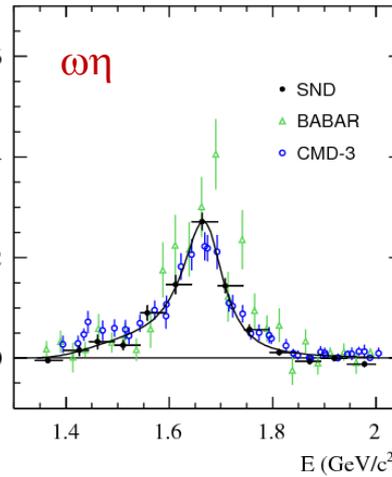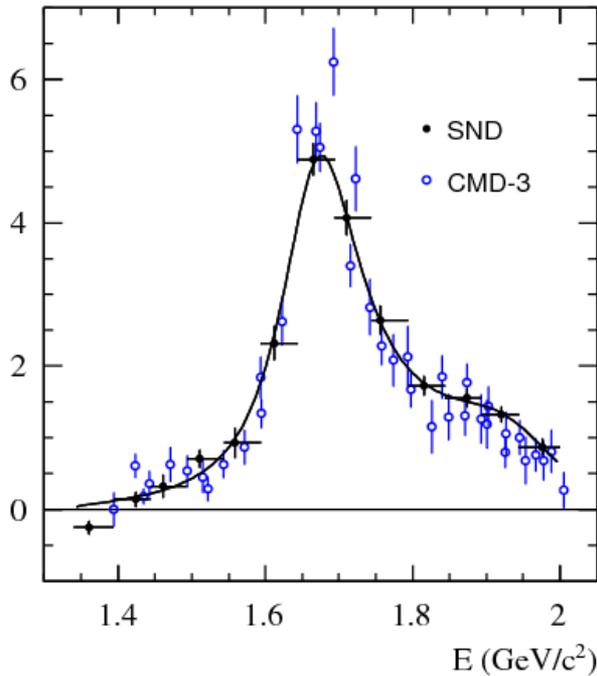➢ For proton $|G_E/G_M|\approx1.5$ in this energy region.

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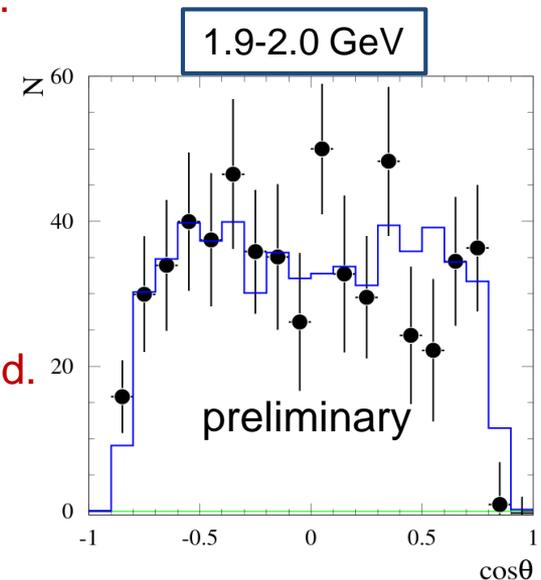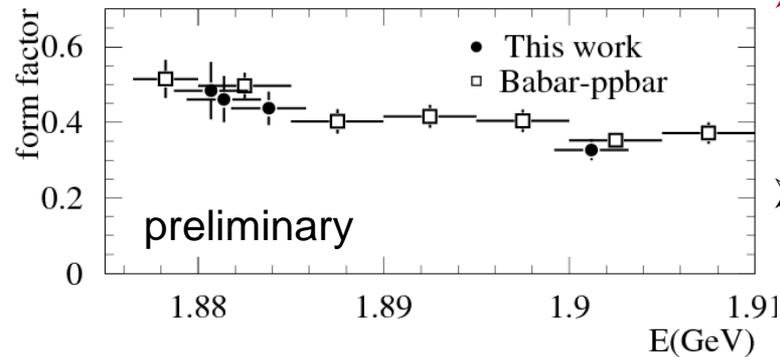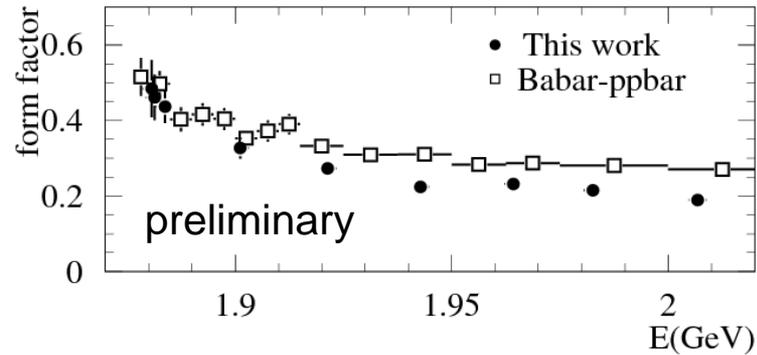
$e^+e^- \to \pi^+\pi^-\pi^0\eta$

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 a0ρ+strucrureless final state.
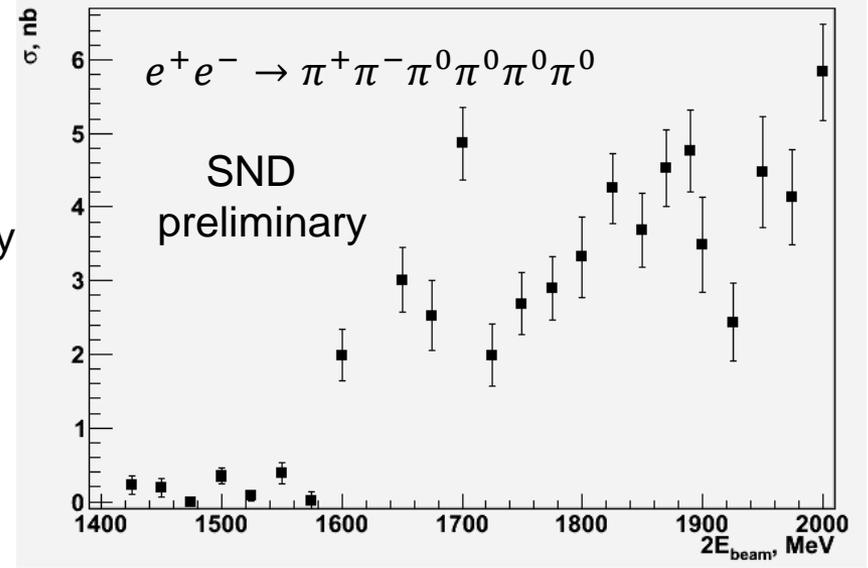
$e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0\pi^0\pi^0$

The process $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0\pi^0\pi^0$ was not studied before.
The measurement is hard due to large multiplicity of the final particles, 2 charged particles and 8 photons.
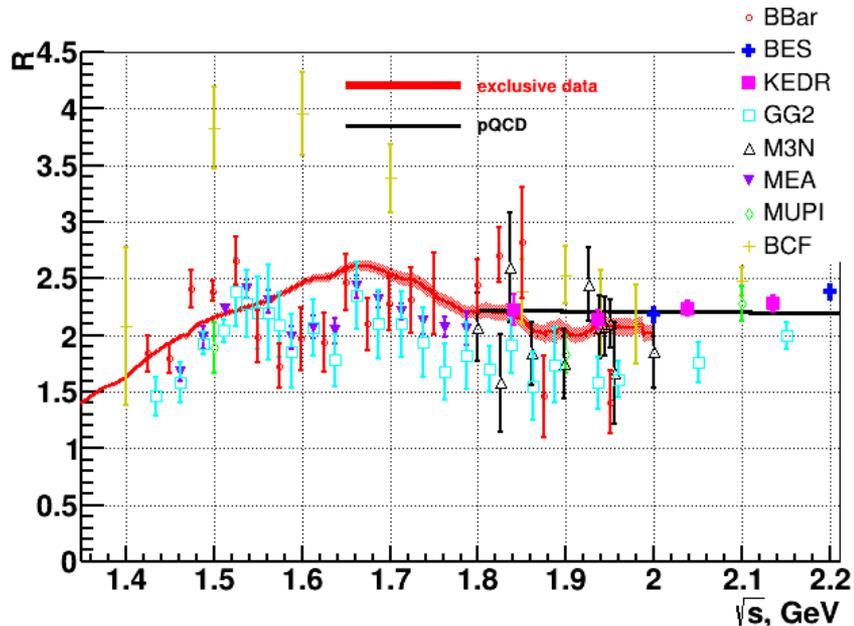
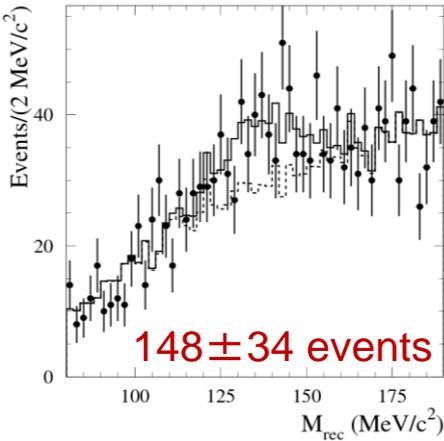

Thanks to F. Ignatov for this plot

There is a difference between the sum of exclusive cross sections near 2 GeV and pQCD prediction, which agrees well with inclusive measurement above 2 GeV.
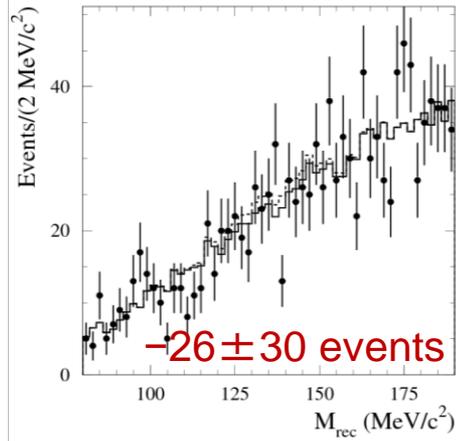The SND preliminary measurement shows that the process $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0\pi^0\pi^0$ fully compensates this difference.

$$e^+ e^- \rightarrow \pi^0 \gamma$$

1075−1375 MeV

1400−2000 MeV

148±34 events

−26±30 events

❑ Below 1.4 GeV the process $e^+ e^- \rightarrow \pi^0 \gamma$ was carefully studied at VEPP-2M with SND and CMD-2.

❑ In these experiments the evidence of the nonzero contribution of excited vector resonances was obtained.

❑The new analysis is based on data 41 pb^{-1} dataset recorded by SND in 2010–2012 in the range $\sqrt{s} = $1.075 − 2 GeV.

- SND VEPP-2000
- □ SND VEPP-2M
- ▼ CMD-2
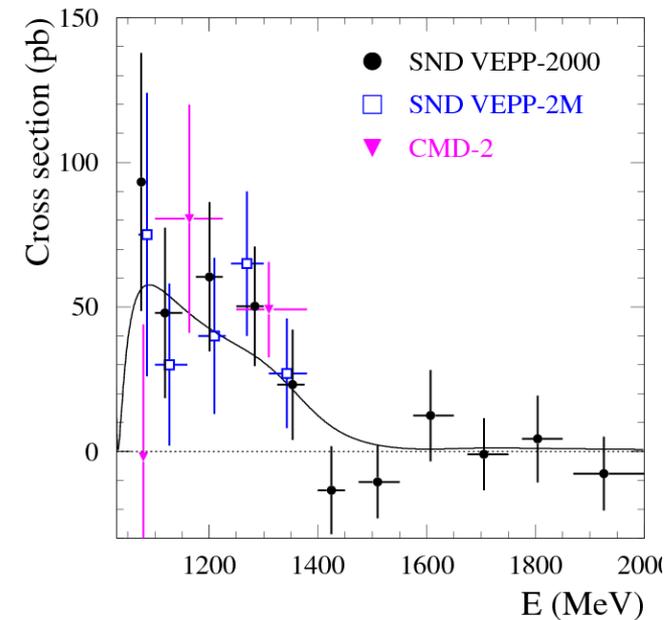
✓ Below 1.4 GeV the obtained cross section is about 50 pb in agreement with the previous SND and CMD-2 results.

✓ To explain this cross section value, the contribution of the ρ(1450) and ω(1420) resonances is required with a significance of 4σ (fit to SND+CMD-2 data).

✓ In the region 1.4–2.0 GeV the process $e^+ e^- \rightarrow \pi^0 \gamma$ has been studied for the first time.

✓ The cross section in this region has been found to be consistent with zero within the statistical errors of about 15 pb.

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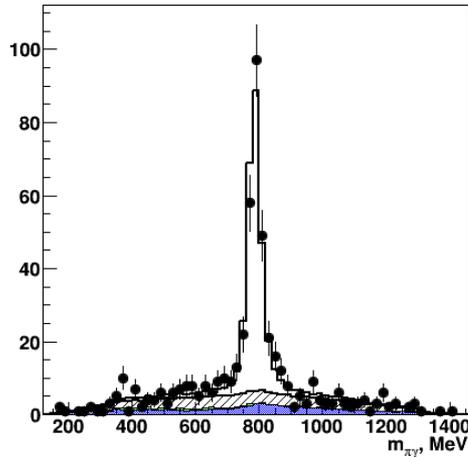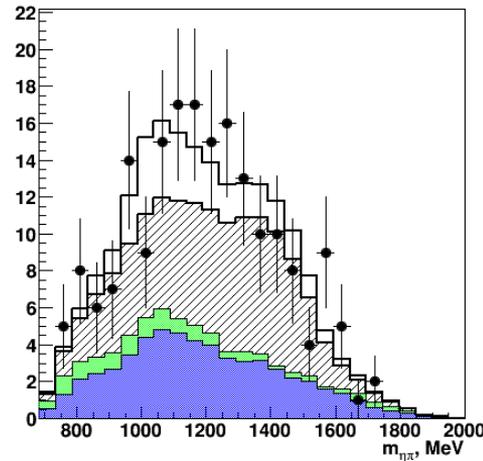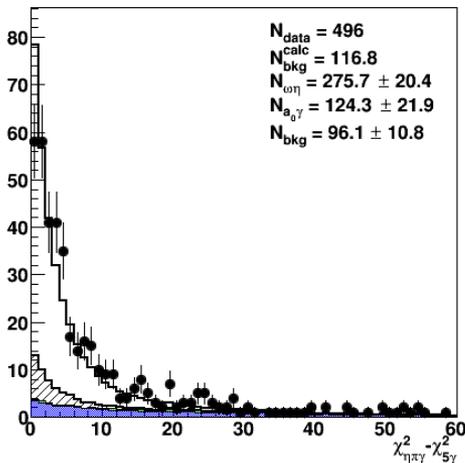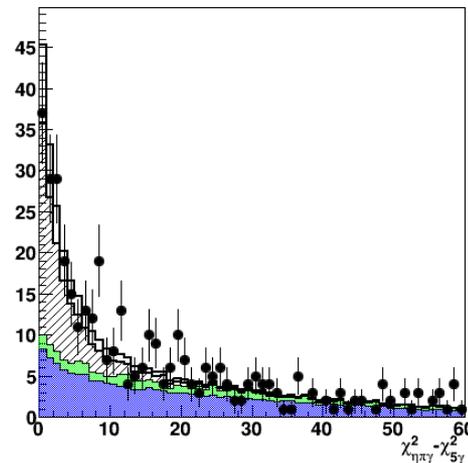

The process $e^+e^- \rightarrow \eta\pi^0\gamma$ above 1.05 GeV is studied for the first time.
Data set with IL≈100 pb⁻¹ recorded in 2010-2012 and 2017
The five-photon final state is used.

There is a significant contribution of the ωη intermediate state, which is seen as a peak in the $\pi^0\gamma$ mass distribution.
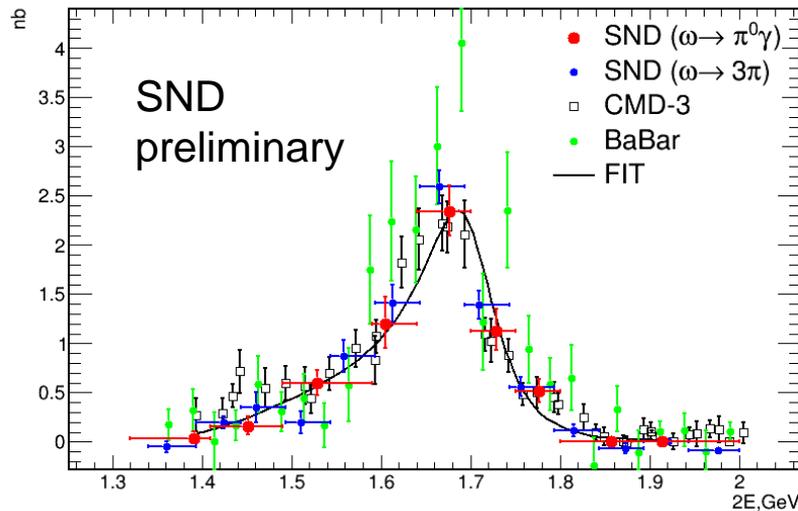
The main background processes are $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ and QED $e^+e^- \rightarrow 4\gamma, 5\gamma$. The background contribution is estimated from the kinematic fit χ^2 distribution.

The non-ωη signal is observed with a wide $\eta\pi^0$ mass distribution. It may arise from the processes $e^+e^- \rightarrow a_0(1450)\gamma$ and a₂(1320)γ.
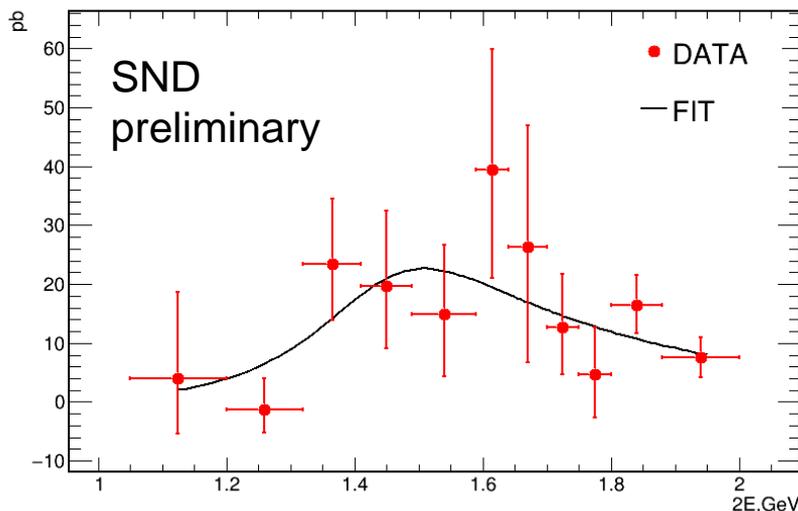
$e^+e^- \to \eta\pi^0\gamma$

Cross section $e^+e^- \to \omega\eta$

SND preliminary

Legend:
- SND ($\omega \to \pi^0\gamma$) — red filled circle
- SND ($\omega \to 3\pi$) — blue filled circle
- CMD-3 — open square
- BaBar — green filled circle
- FIT — line

Cross section $e^+e^- \to$ non-$\omega\eta \to \eta\pi^0\gamma$

SND preliminary

- DATA — red filled circle
- FIT — line

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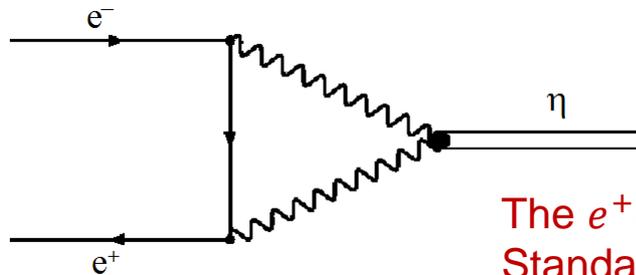
The radiative process $e^+e^- \to \eta\pi^0\gamma$ was studied previously only in the $\phi(1020)$ region.

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

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

$\sigma_E \approx 200 \, keV$
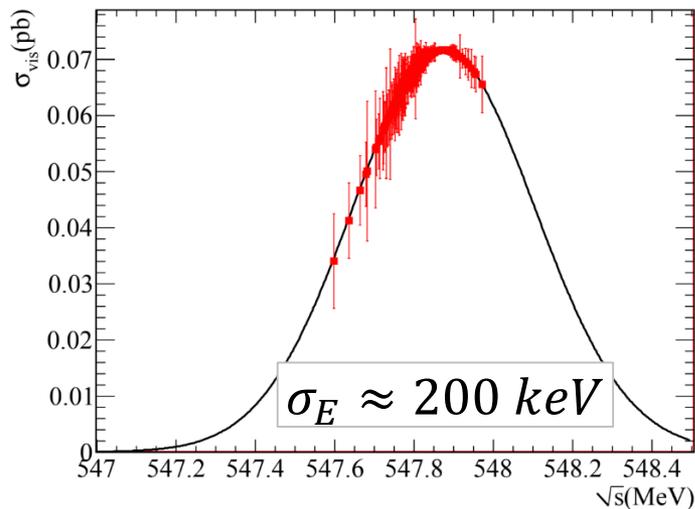
- The 650 nb^{-1} data sample was recorded in 2018 at $\sqrt{s} = m_\eta$.
- The visible η line shape is determined by the energy spread.
- The beam energy and spread were measured with a special system based on Compton backscattering of laser photons off the electron beam.
- The decay mode $\eta \to 3\pi^0$ is used, in which the single photon annihilation background is absent.
- Zero signal events have been selected.
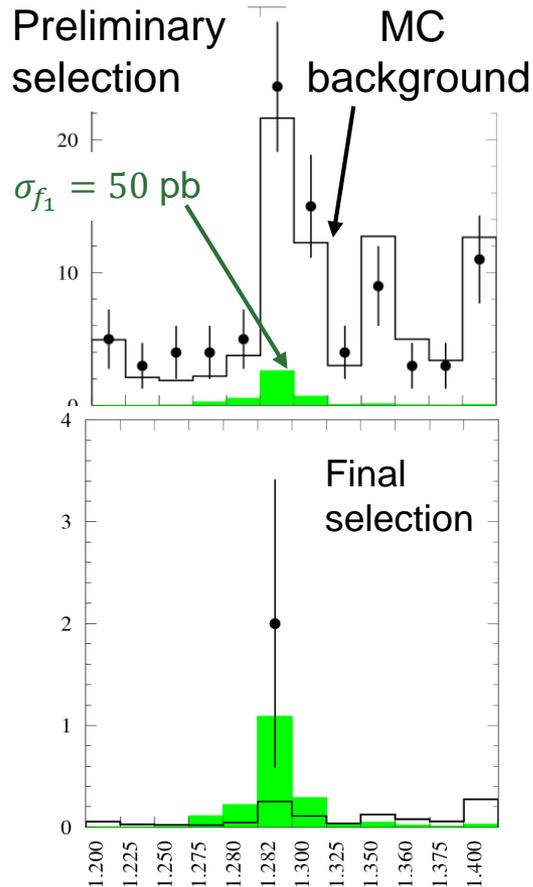
The upper limit $B(\eta \to e^+ e^-) < 7 \times 10^{-7}$ at 90% CL has been set, which improves the previous limit of the HADES Collaboration by a factor of 3.

Search for $e^+ e^- \to f_1(1285)$
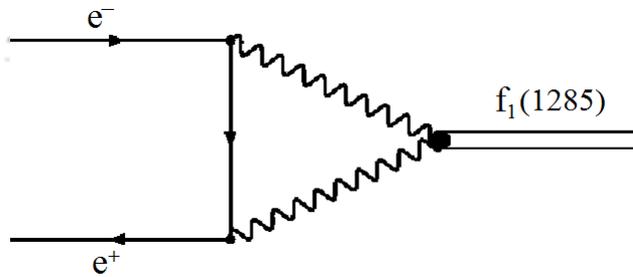
The predicted branching fraction $B(f_1 \to e^+ e^-) = 3{-}8 \times 10^{-9}$ [A. S. Rudenko, Phys. Rev. D96, 076004 (2017)] corresponds to the f_1 production cross section of 30-70 pb.

Preliminary selection

MC background

$\sigma_{f_1} = 50$ pb

Final selection

❑ 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

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

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

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 GeV.
- ✓ The $e^+e^- \rightarrow \pi^+\pi^-$ cross section is measured with a systematic uncertainty better than 1%.
- ✓ The accuracy of the $e^+e^- \rightarrow n\bar{n}$ measurement is significantly improved.
- ✓ The $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$ and $\pi^+\pi^-4\pi^0$ cross sections have been measured, the latter for the first time.
- ✓ Rare radiative processes $e^+e^- \rightarrow \pi^0\gamma$ and $\eta\pi^0\gamma$ have been measured in the energy range 1.05-2 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 $e^+e^- \rightarrow f_1(1285)$ is obtained.