The 13th International Workshop on e+e- collisions from Phi to Psi PHIPSI 2022

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

On behalf of the SND Collaboration

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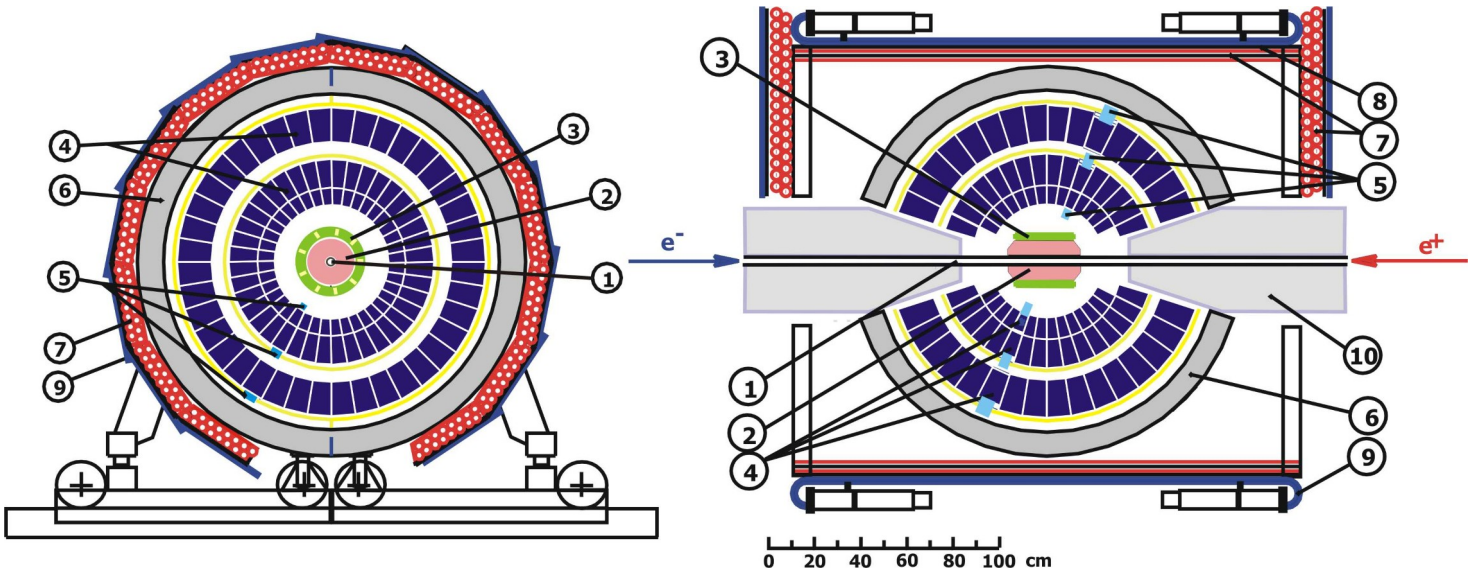
Physical goals

SND experiment at VEPP-2000 collider studies e^+e^- annihilation to hadrons at low energy region ($\sqrt{s}$<2 GeV). These studies include:

- **Measurement of the cross sections $e^+e^- \to$ *hadrons*. Measurement of the cross sections and electromagnetic form-factors, study of many hadron processes dynamics.**
- **Study of the vector mesons ρ, ω, ϕ and their excited states ρ', ρ'', ω', ω'', ϕ', …**
- **Study of e^+e^- annihilation to C-even resonances:**

  $e^+e^- \to$ *S, P, A, T*.

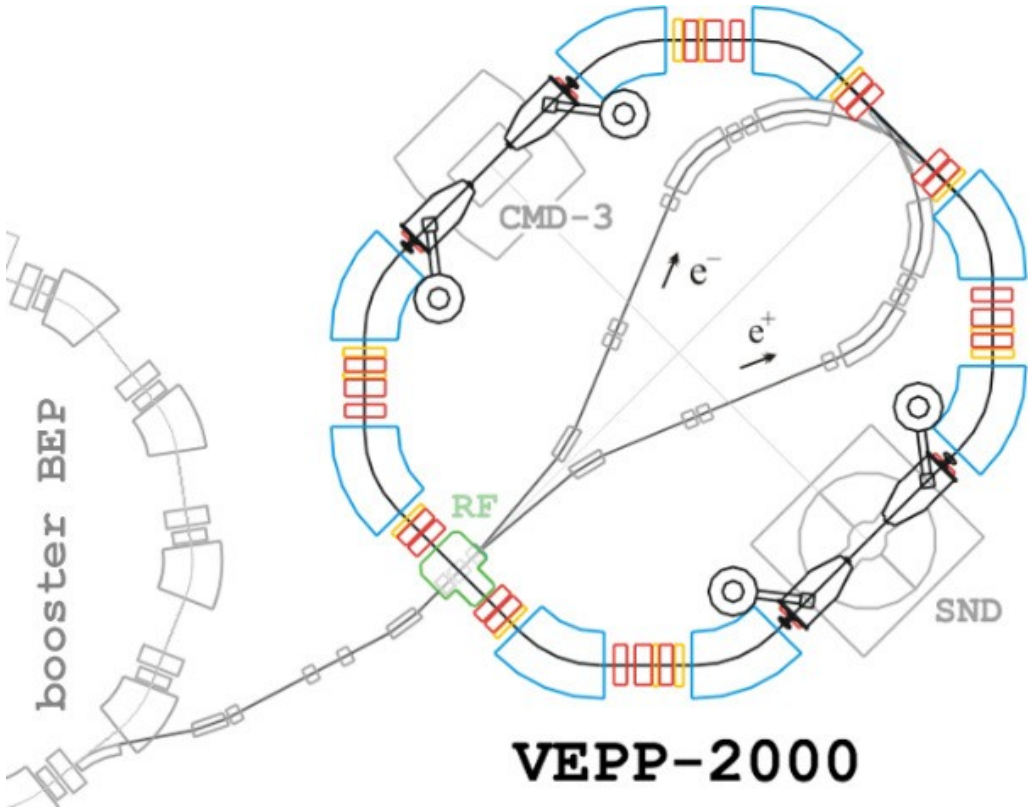
SND detector



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 VEPP-2M (1996-2000) and at VEPP-2000 (2010-2013) and (2017-…).

VEPP-2000 e^+e^- collider

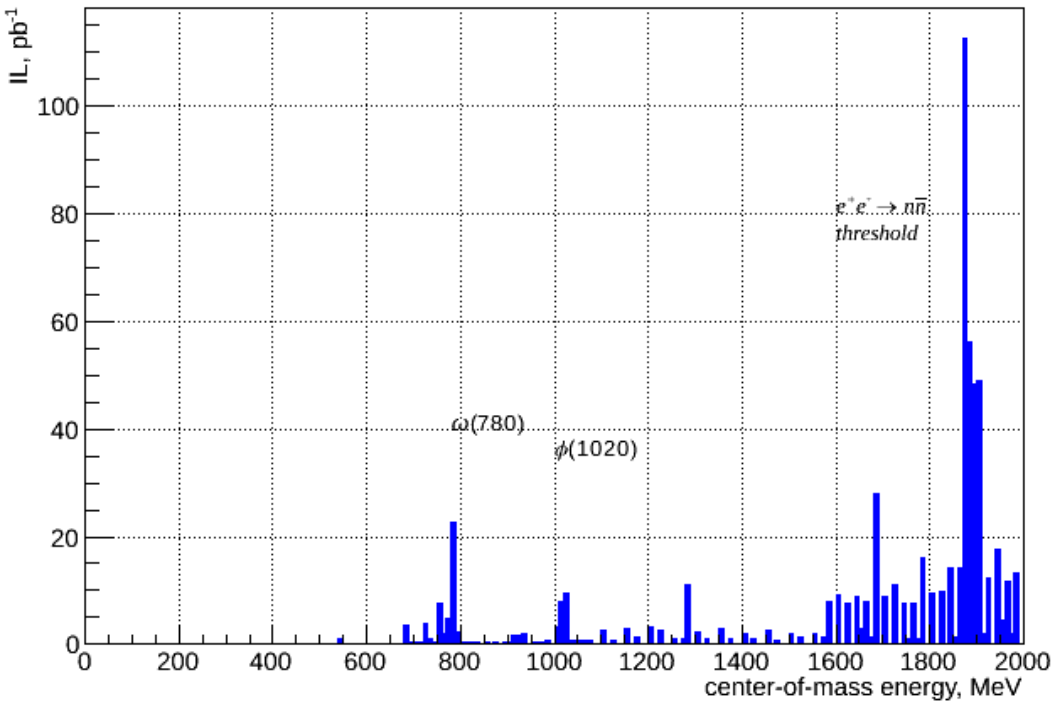


VEPP-2000 parameters:

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

SND data

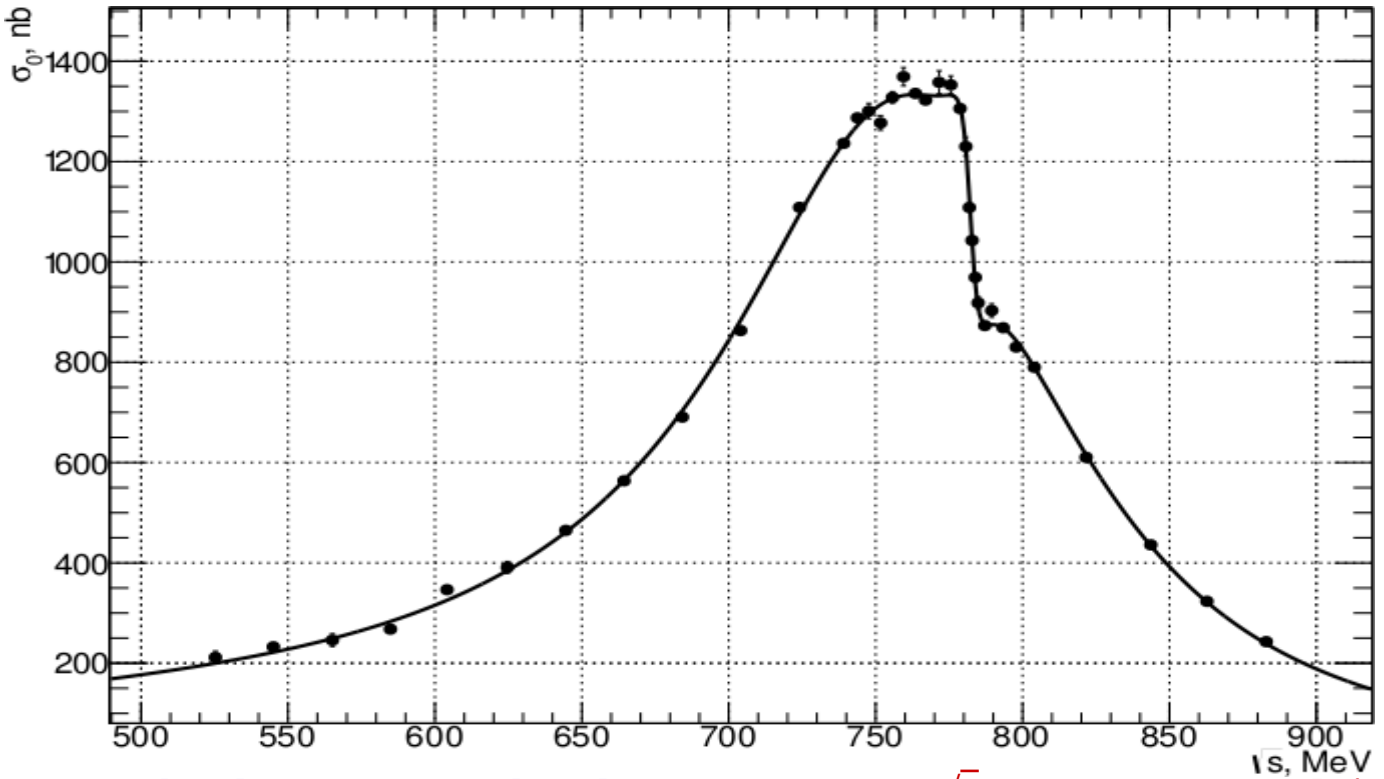
Year	IL (pb^{-1})
2010-2013	70
2017	50
2018	90
2019	65
2020	45
2021	57
2022	360



Distribution of integrated luminosity **IL≈670 pb^{-1}** collected in **2017-2022** over c.m. energy.

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

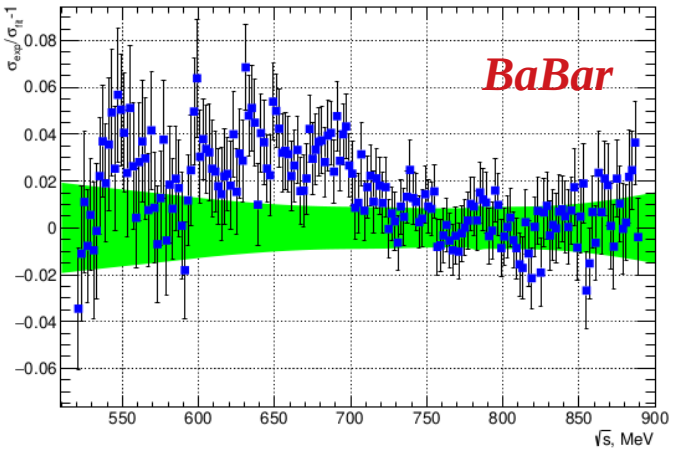
m_ρ	775,3±0,5±0,6 MeV
Γ_ρ	145,6±0,6±0,8 Mev
$B(\rho\to e^+e^-)B(\rho\to\pi^+\pi^-)$	$(4,89\pm0,02\pm0,06)\times10^{-5}$
$B(\omega\to e+e-)B(\omega\to\pi^+\pi^-)$	$(1,32\pm0,06\pm0,02)\times10^{-6}$
$\phi_{\rho\omega}$	(110,7±1,5±1,0)°
	$a_\mu\times10^{10}$
SND VEPP-2000	409,79±1,44±3,87
SND VEPP-2M	406,47±1,74±5,28
BaBar	413,58±2,04±2,29
KLOE	403,39±0,72±2,50

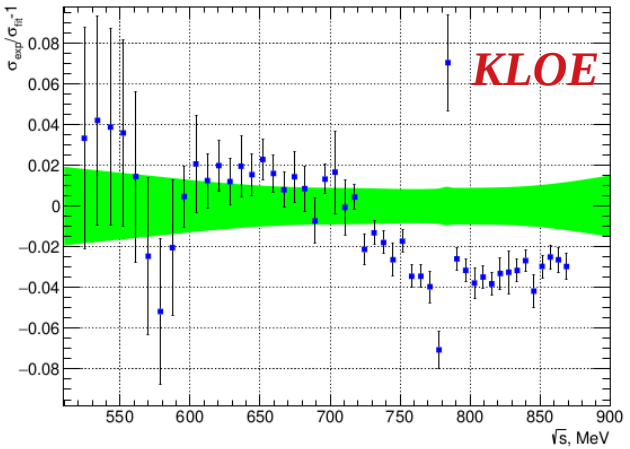


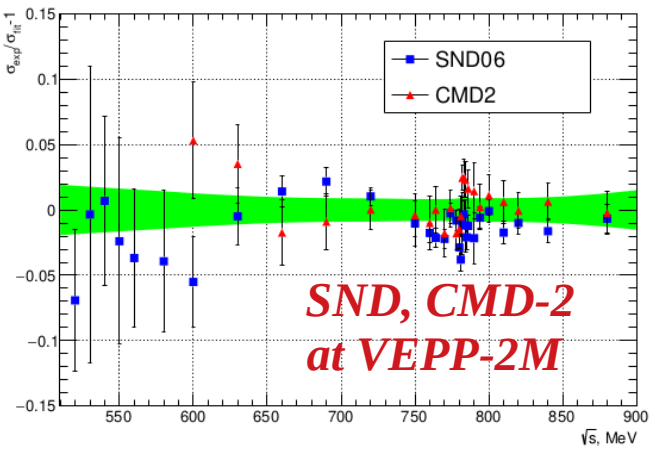
The cross section of the process $e^+e^-\to\pi^+\pi^-$ has been measured in the energy region $\sqrt{s}$ **<1 GeV**, **IL≈5 pb^{-1}**, systematic error is – **0,8 %**. Result is in agreement with **CMD-2** and **SND** at **VEPP2-2M**.

JHEP 2101 (2021) 113

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







The relative difference between the $e^+e^- \to \pi^+\pi^-$ cross section measured by BaBar, KLOE, SND and CMD-2 at VEPP-2M and the fit to the SND data at VEPP-2000.

Process $e^+e^- \to \eta\pi^0\gamma$ in energy region $\sqrt{s}$ >1 GeV

Process $e^+e^- \to \eta\pi^0\gamma$ was studied in energy region $\sqrt{s}$ =1,05–2 GeV, IL=95 pb^{-1}.

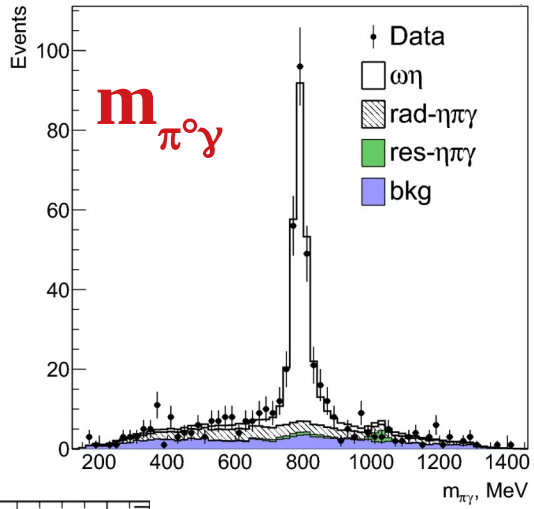
Following intermediate mechanisms give contribution to $e^+e^- \to \eta\pi^0\gamma$ process:

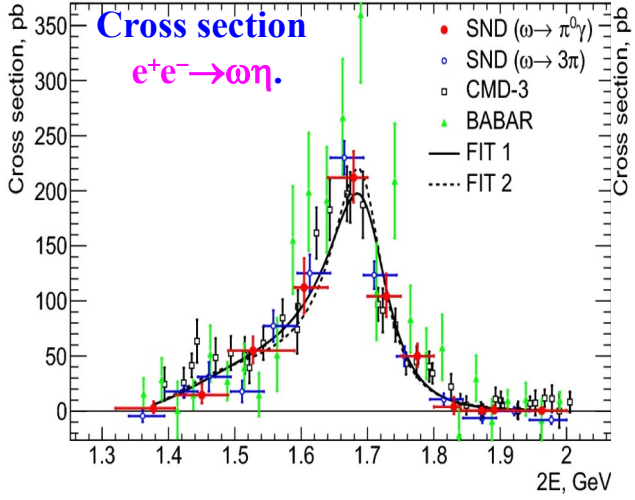
$e^+e^- \to \omega\eta$ (main contribution),

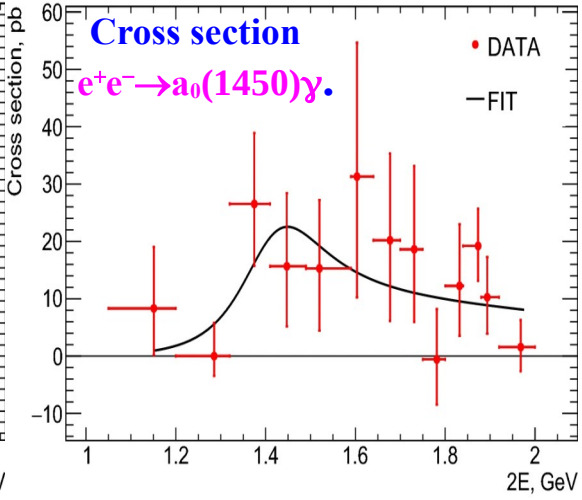
$e^+e^- \to \phi\eta$, $\rho\eta$, $\phi\pi^0$, $\omega\pi^0$ (significantly smaller contribution),

Assumed contribution from radiative processes:

$e^+e^- \to V', V'' \to a_0(980)\gamma$, $a_0(1450)\gamma$, $a_2(1270)\gamma$.







We need to take into account **ω(1420)** and **V''(1680)** resonances to fit measured cross section of the $e^+e^- \to \omega\eta \to \eta\pi^0\gamma$ process.

It has been found, with a significance of **5,6σ** that the process $e^+e^- \to \eta\pi^0\gamma$ is not completely described by the hadronic intermediate states $e^+e^- \to$ **VP**. Missing contribution arises from radiative processes, with the dominance of intermediate mechanism $e^+e^- \to a_0(1450)\gamma$.

Eur. Phys. J. C80 (2020) no.11, 1008.

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

Cross section of the $e^+e^- \to \eta\eta\gamma$ process was measured in the energy region $\sqrt{s}$ =1,17–2 GeV, IL=200 pb^{-1}.

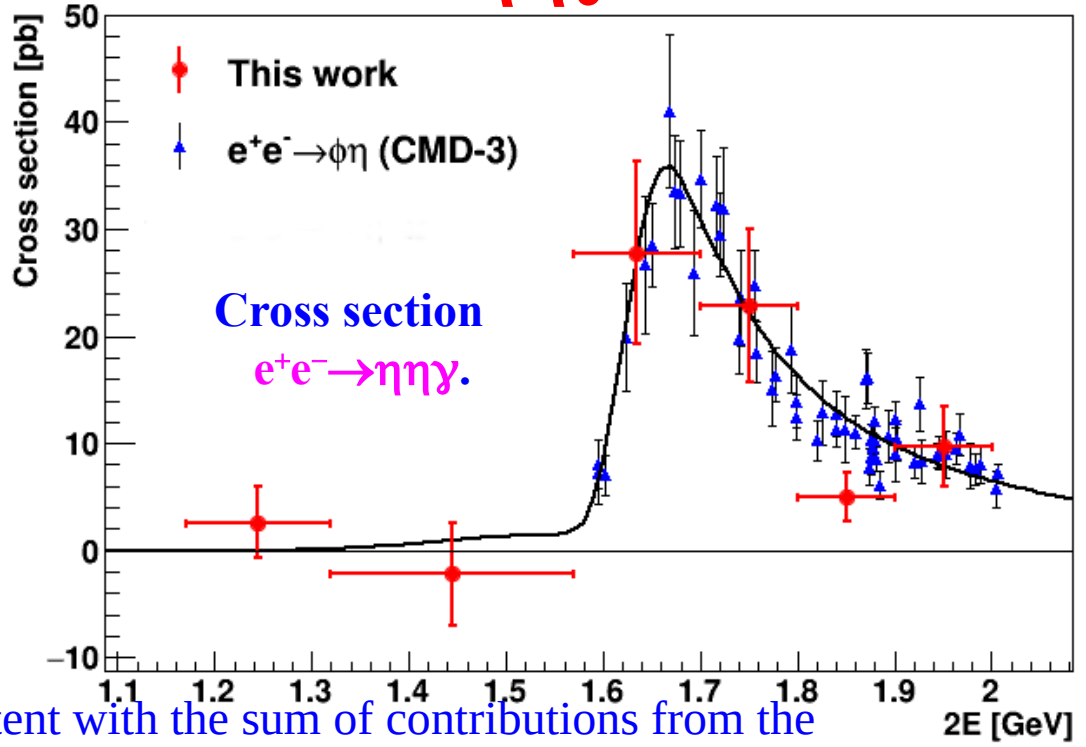
Intermediate mechanisms that make contribution to the $e^+e^- \to \eta\eta\gamma$ process:

$e^+e^- \to \phi\eta$ (main contribution),

$e^+e^- \to \omega\eta, \rho\eta$ (small contribution),

possible contribution from radiative decays:

$e^+e^- \to V \to f_0(1500)\gamma, f_2'(1525)\gamma$.



Measured $e^+e^- \to \eta\eta\gamma$ cross section is consistent with the sum of contributions from the $e^+e^- \to \phi\eta$, $e^+e^- \to \omega\eta$ и $e^+e \to \rho\eta$ processes. No significant contribution from the radiative decays has been found. In the energy region of $\phi(1680)$ and $\rho(1700)$ resonances the upper limit for the radiative decays is **11 pb (90% *CL*)**.

Theoretical predictions for this decays are $\sigma(e^+e^- \to \phi(1680) \to f_2'(1525)\gamma \to \eta\eta\gamma)$=1,7 pb, $\sigma(e^+e^- \to \rho(1700) \to f_0(1500)\gamma \to \eta\eta\gamma)$=0,4 – 1,9 pb. ***Eur. Phys. J. C 82 (2022).***

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

Differential cross section:

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

G_E and **G_M** – electric and magnetic form factors, **$|G_E|=|G_M|$** at the threshold,
C – Coulomb form factor.

Total cross section:

$$\sigma_0(s) = \frac{4\pi\alpha^2\beta C}{3s}\left[|G_M(s)|^2 + \frac{1}{\tau}|G_E(s)|^2\right].$$

From the measured **$e^+e^- \to n\bar{n}$** cross section we determine effective form factor.

$$F(s)^2 = \frac{2\tau|G_M(s)|^2 + |G_E(s)|^2}{2\tau+1}.$$

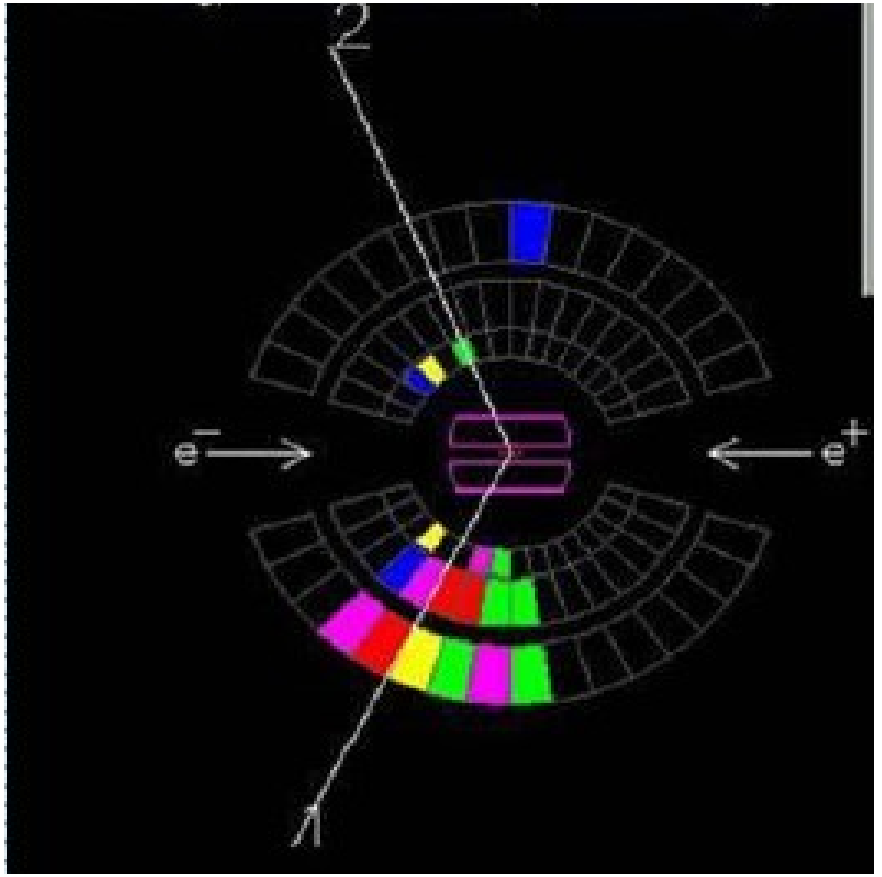
From analysis of antineutron **cosθ** distribution we determine **$|G_E / G_M|$** ratio.

arXiv:2206.13047

$e^+e^- \to n\bar{n}$ events in SND

$e^+e^- \to n\bar{n}$ events in SND.

- $\bar{n}$ annihilates in electromagnetic calorimeter with big energy deposition.
- n has low energy deposition in calorimeter.
- $\bar{n}$ has low velocity, it's signal in EMC is delayed with respect to typical e^+e^- annihilation event.



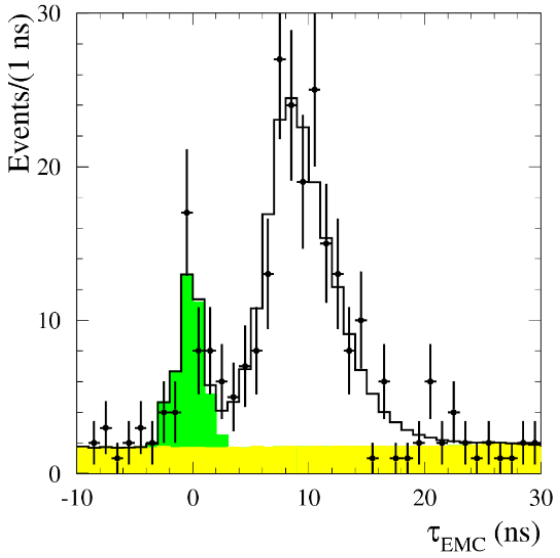
Process $e^+e^- \to n\bar{n}$

Calorimeter signal time (event time) is used for the selection of $e^+e^- \to n\bar{n}$ events:

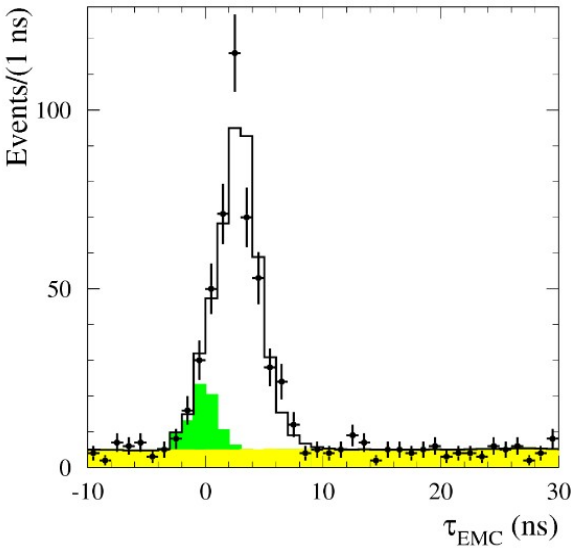
$$T = \frac{\sum t_i E_i}{\sum E_i}$$

t_i – EMC crystal arrival time,
E_i – energy deposition in EMC crystal.

$\sqrt{s}$=1,89 GeV



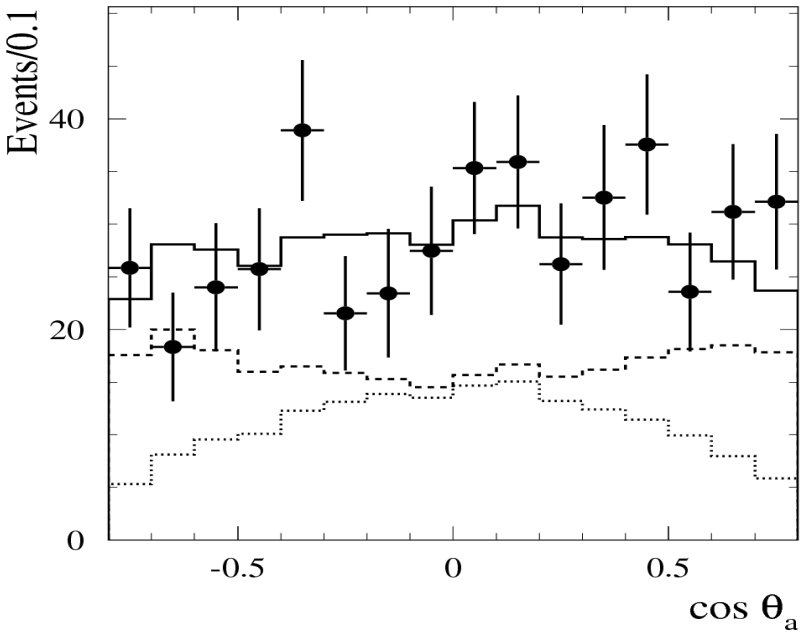
$\sqrt{s}$=1,95 GeV

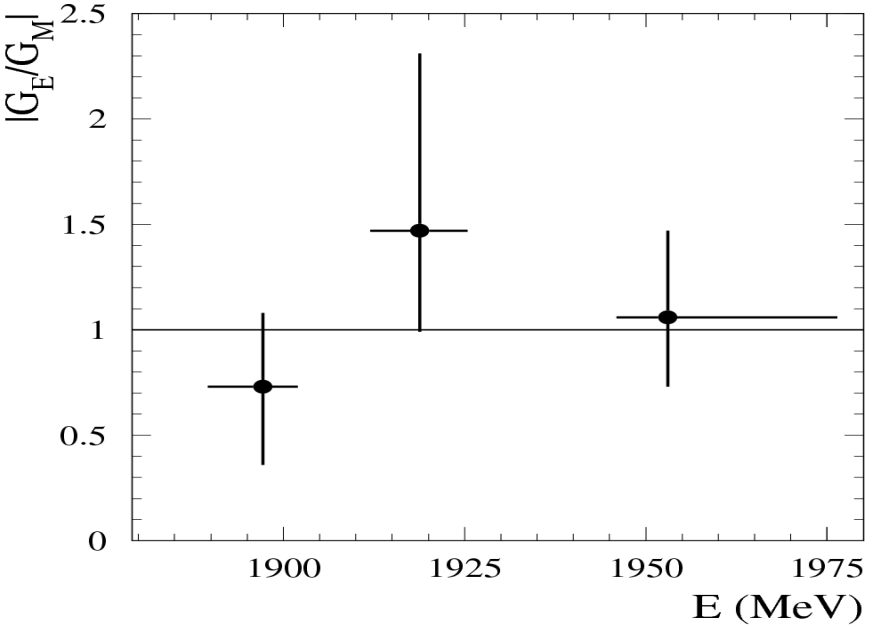


Time distribution for selected data events. Histogram is sum of the signal $e^+e^- \to n\bar{n}$, cosmic ray background (yellow), physical and beam background (green) events.

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

$|G_E / G_M|$ ratio can be extracted from the measured **cosθ** distribution.

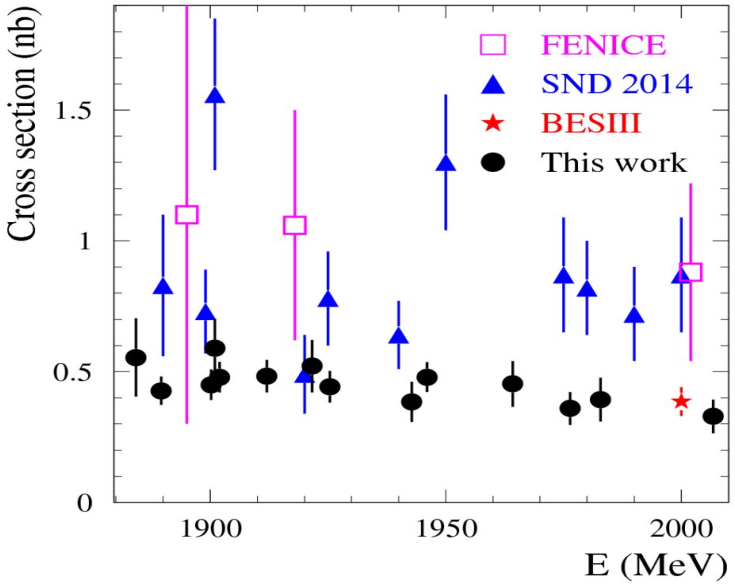


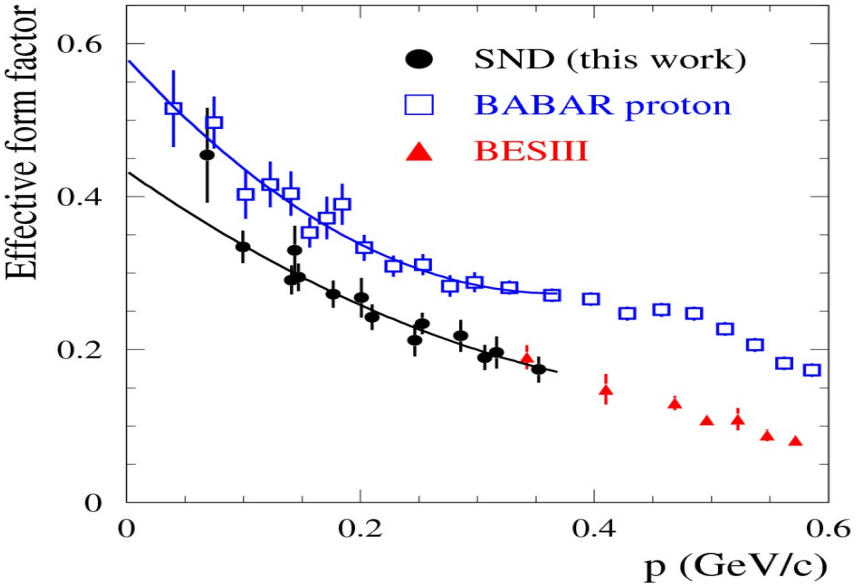


cosθ distribution with $\sqrt{s}$=**1,95 GeV**.
Histogram is result of the fit with **$\sin^2\theta$** for $|G_E|$ and **$1+\cos^2\theta$** for $|G_M|$.

SND results agree with the assumption that $|G_E / G_M|$=**1** , but do not contradict larger values $|G_E / G_M|$≈**1.4-1.5**, observed at BABAR and BESIII.

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

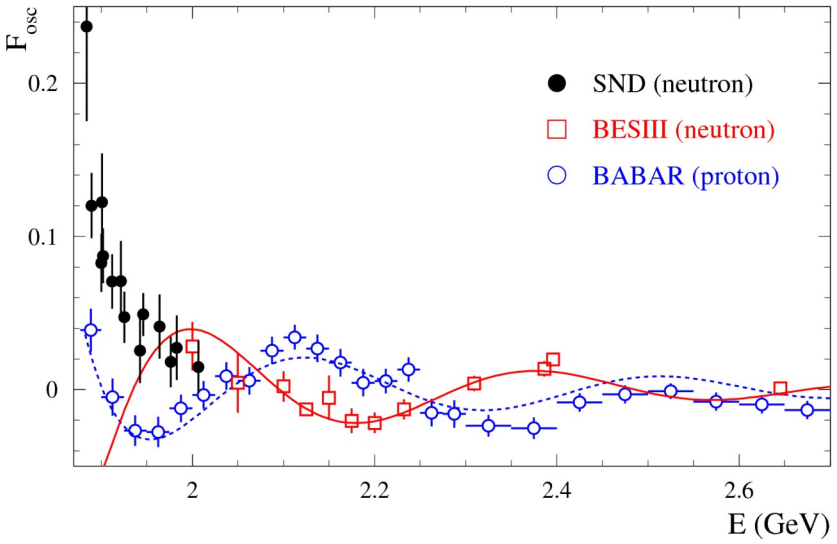


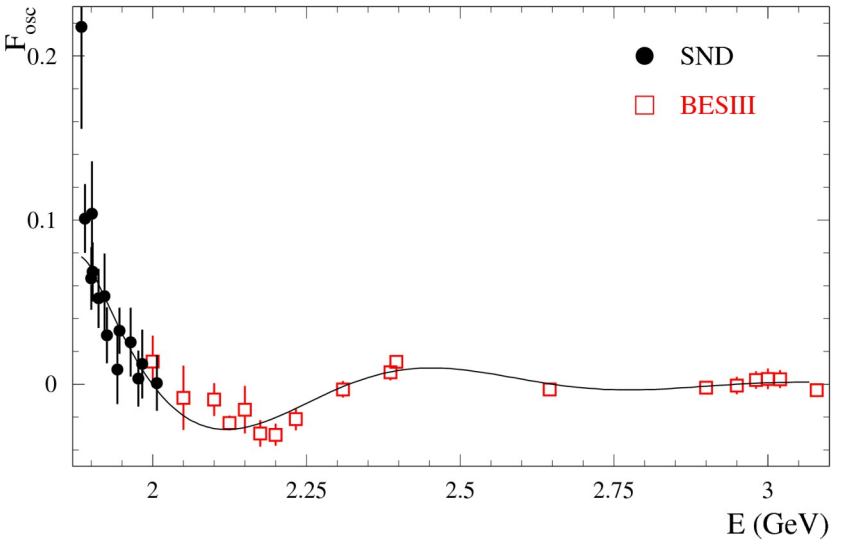


$e^+e^- \to n\bar{n}$ cross section compared with the previous FENICE, SND and BESIII experiments.
The new SND measurement supersedes the previous SND result.

The neutron effective form factor as a function of neutron momentum,
compared with the BESIII measurements,
and the proton effective form factor,
measured by BABAR.

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





Sinusoidal modulation was observed in nucleon effective form factors in BABAR and BESIII experiments. SND and BESIII data fit with significantly lower oscillation frequency.

Summary

- During 2010 – 2022 the SND detector accumulated ~740 pb^{-1} of integrated luminosity at the VEPP-2000 electron-positron collider in the c.m. energy range 0.3 – 2 GeV.
- The data taking runs are continued with a goal of ~1 fb^{-1} of integrated luminosity.
- Data analysis is in progress.
- The $e^+e^- \to \pi^+\pi^-$ cross section has been measured in the energy range 0.53-0.88 GeV with a systematic uncertainty better than 1%.
- Rare radiative processes $e^+e^- \to \eta\pi^0\gamma$ and $\eta\eta\gamma$ have been measured in the energy range 1.05-2 GeV.
- The $e^+e^- \to n\bar{n}$ cross section has been measured, neutron effective form factor and $|G_E / G_M|$ ratio have been determined.

Thank you for your attention!