Study of e^+e^- annihilation to hadrons below 2GeV with SND

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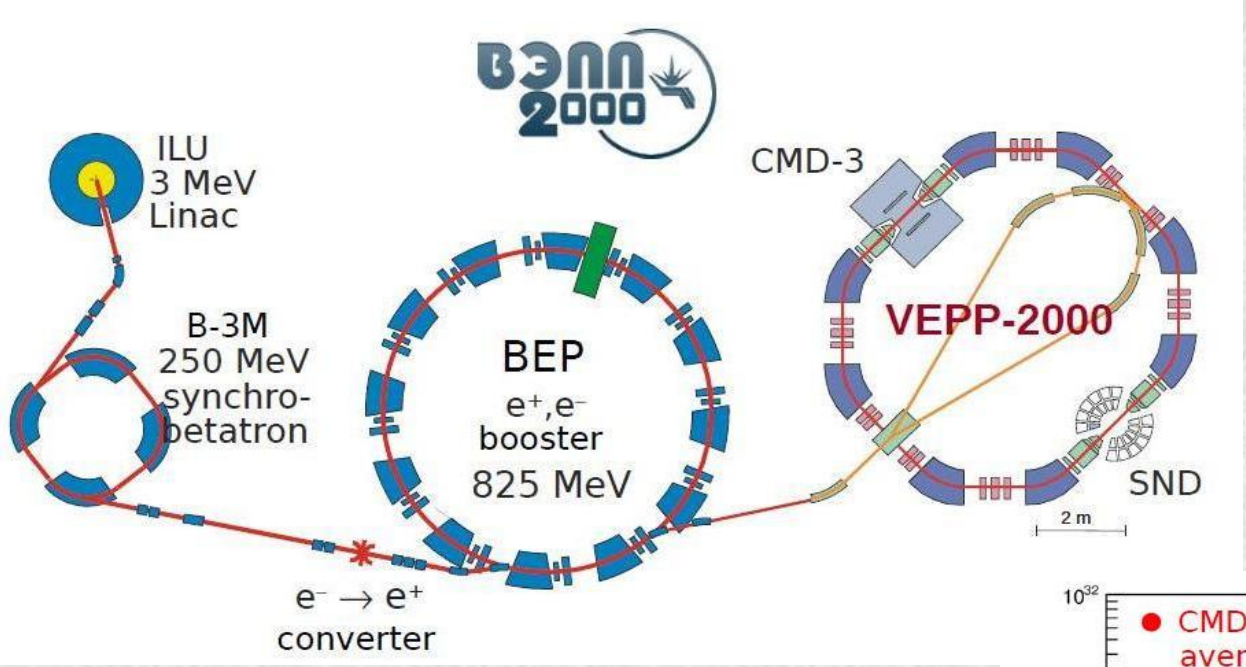
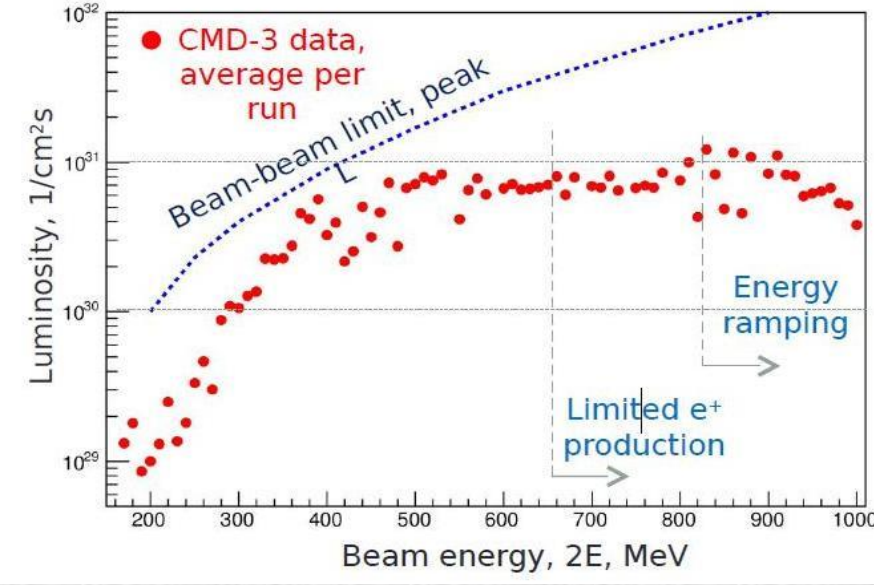
VEPP-2000 e^+e^- collider



During 2010-2013 data taking period the luminosity was limited by the deficit of positrons

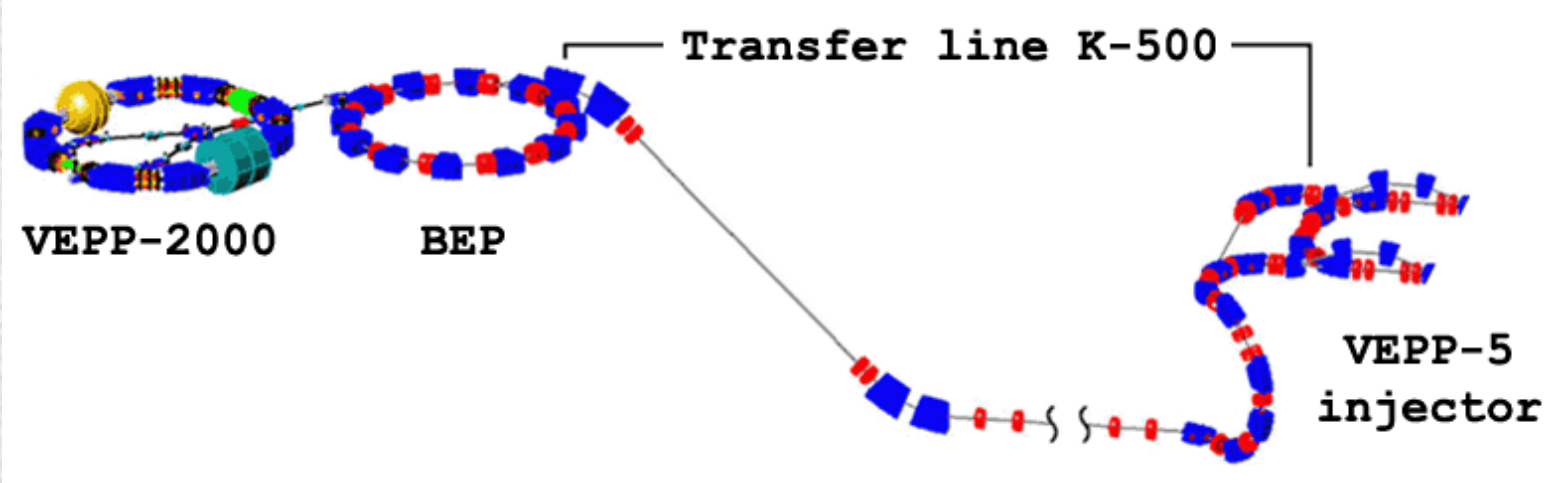
Luminosity vs. energy



Main parameters:

- center-of-mass energy E=0.3-2.0 GeV
- circumference – 24.4 m
- round beam optics
- beam energy spread – 0.6 МэВ at E=1.8 GeV
- achieved luminosity $L_{max}=2\times10^{31}cm^{-2}c^{-1}$

Upgrade of VEPP-2000 e^+e^- collider



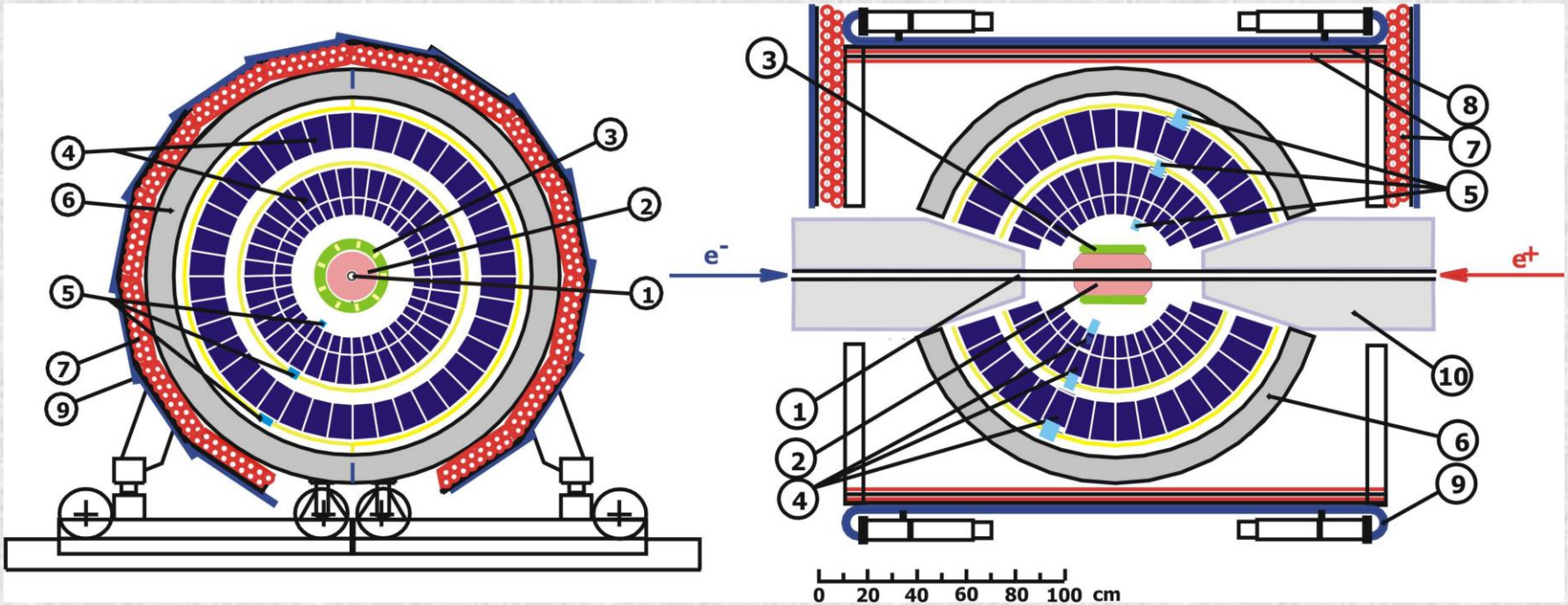
✓The maximum BEP energy will be increased up to 1 GeV.

✓The injection system will be changed. Electrons and positrons will be transported to BEP from the VEPP-5 injection complex through 250 m beamline.

✓Expected maximal luminosity $L_{max}=10^{32}cm^{-2}c^{-1}$

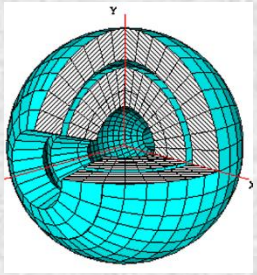
✓Experiments at upgraded VEPP-2000 is expected to be started in 2016.

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 parameters



Calorimeter:
1632 NaI(Tl) crystals
VPT reading
13.5 X_0
solid angle - 90% from 4π
$\Delta\varphi \times \Delta\theta$ =9° x 9°

Tracking system:
9-layer cylindrical drift chamber with 24 jet-type cells
solid angle - 94% from 4π
90% Ar + 10% CO_2 gas mixture
particle identification at p<300 MeV/c using dE/dx

Cherenkov counter:
9 counters with n=1.13 or n=1.05 for different energy ranges
PMT reading
0.09 X_0
solid angle - 60% from 4π

Energy resolution:

$$\frac{\sigma_E}{E} = \frac{4.2\%}{\sqrt[4]{E(GeV)}}$$

Angular resolution:

$$\sigma_\varphi = 0.55^\circ,\ \sigma_\theta = 1.2^\circ$$

Angular resolution:

$$\sigma_\phi = \frac{0.82^\circ}{\sqrt{E\,(\mathrm{GeV})}} \oplus 0.63^\circ$$

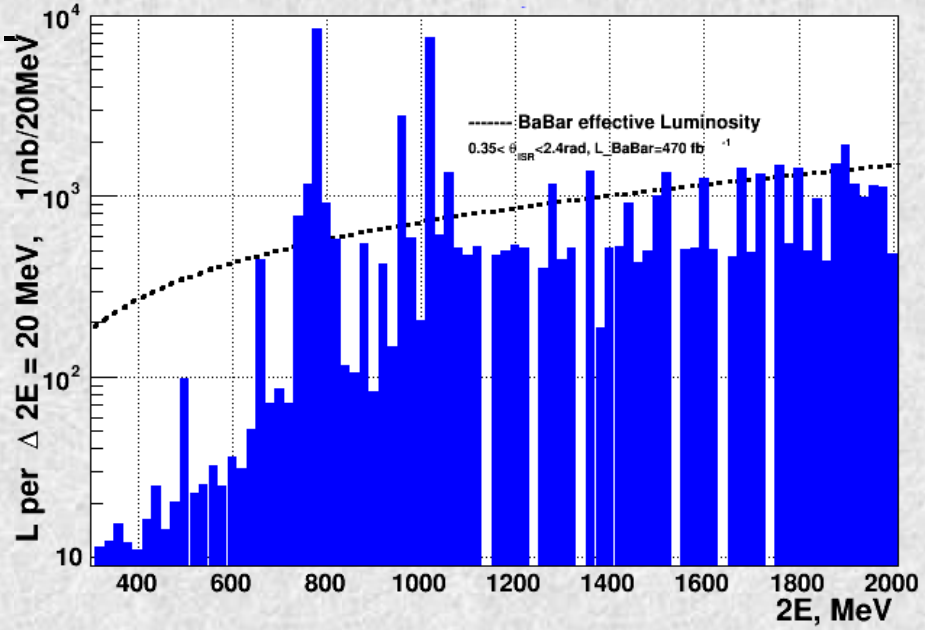
π- threshold: 300MeV/c (n=1.13)
450MeV/c (n=1.05)
e/ π separation for E_p< 450 MeV (for n=1.05);
No signal from charged K in all energy range for n=1.13 - there is π/K separation

Collected Luminosity

Experimental runs at VEPP-2000

Year	Energy(GeV)	L(pb^{-1})
2010	1.05-2.0	5
2011	1.05-2.0	25
2012	1.05-2.0	17
2013	0.32-1.06	22
Total	0.32-2.0	69

VEPP-2000 collected luminosity



Physics program

1. Measurement of exclusive hadronic cross sections below 2 GeV. The goal is to obtain the total cross section for $e^+e^- \to hadrons$, which used for calculation HVP contribition to the muon (g-2) and the running α_{QED}.
2. Study of dynamics of hadron production, i.e. separation between different intermediate states , for example, $\omega\eta$, $\phi\eta$, ρa_0 etc. in the reaction $e^+e^- \to \pi^+\pi^-\pi^0\eta$. This is needed for understanding hadronization mechanisms.
3. Hadron spectroscopy: study of light-vector-meson exitations., in particular, search for their radiative decays.
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 formfactors.
6. Two-photon physics, in particular, measurement of the photon-meson transition form factors for π^0, η, η'.
7. Search for production of C-even resonances: $e^+e^- \to \eta, \eta', f_1, f_2, a_2 \ldots$
8. Using radiative return technique as alternative method for measurement of hadronic cross sections.
9. Test of high-order QED: $2 \to 4,5$.
10. etc.

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

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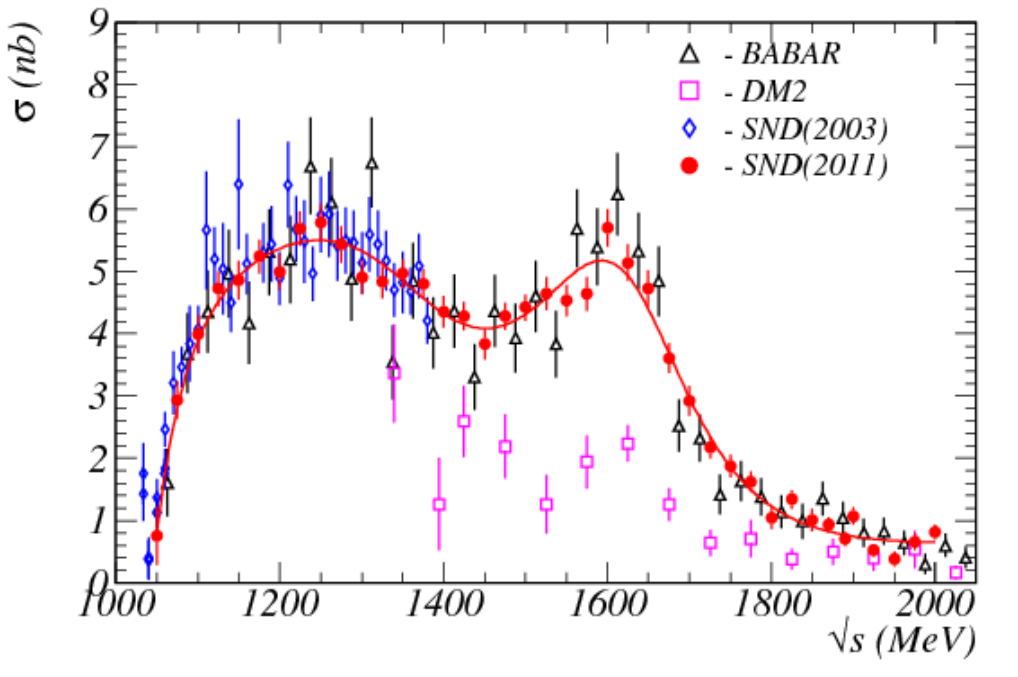

✓Our results are in agreement with the SND measurements at VEPP-2M and the BABAR data, but disagree with DM2

✓This is the most precise measurement to date.

- ✓ The two maxima in the cross section correspond to the ω(1420) and ω(1650) resonances. Their amplitudes interfere with the tails of ω(782) and ϕ(1020) resonances, and with each other.
- ✓ $e^+e^- \to \pi^+\pi^-\pi^0$ is the only process, in which the ω(1420) resonance is clearly seen.
- ✓ Above 1.8 GeV the cross-section energy dependence cannot be described by contributions of known resonances.

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

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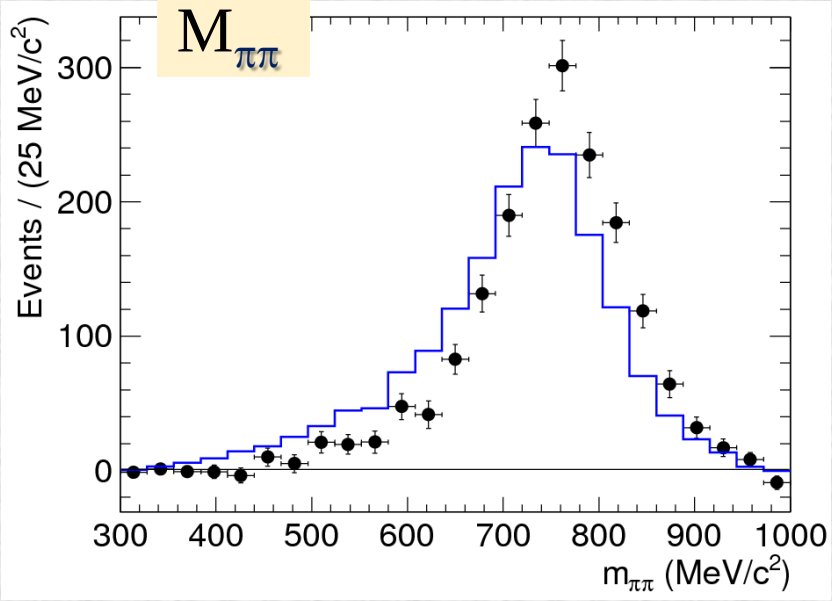
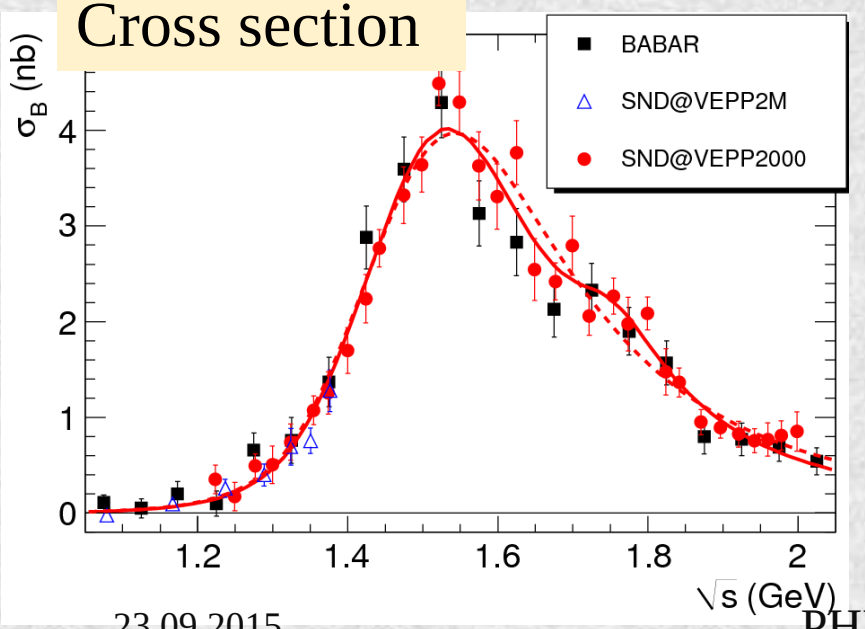


- It was assumed that the dominant reaction mechanism is ρ(770)η.
- We observe contribution of other mechanism, presumably ρ(1450)η.



- Our result agrees with the BABAR measurement, but has better accuracy.
- The ρ(1450) (or ρ′) contribution dominates. The ρ(1700) contribution is small.

$e^+e^- \to \pi^+\pi^-\eta$ (II)

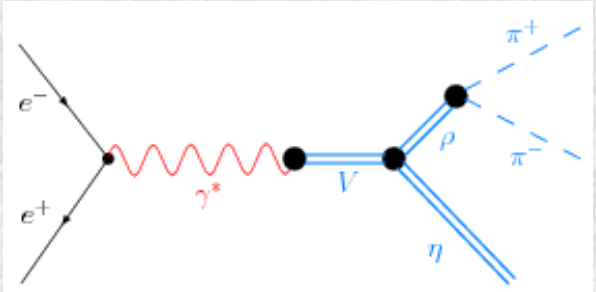
- The product $B(\rho' \to e^+e^-)B(\rho' \to \pi^+\pi^-\eta) = (4.3 \pm 1.1) \times 10^{-7}$ is obtained from the fit of the cross section
- From comparison with ρ(1450) measurements in other decay modes we extract the ratio

$B(\rho' \to \omega\pi) : B(\rho' \to \pi^+\pi^-\eta) : B(\rho' \to \pi^+\pi^-) = (12.3 \pm 3.1) : 1 : (1.3 \pm 0.4)$,

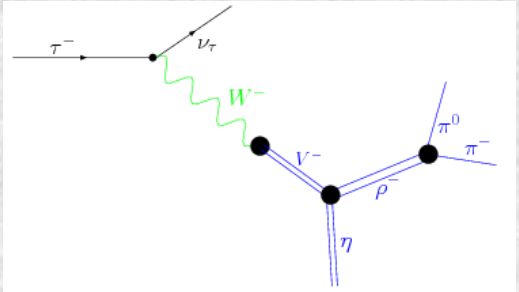
which can be compared with predictions (7-8) : 1 : (4-10).

- Using CVC hypothesis we calculate $B_{CVC}(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.156 \pm 0.011)\%$,

which is in agreement with the measured value $B_{exp}(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.139 \pm 0.010)$.



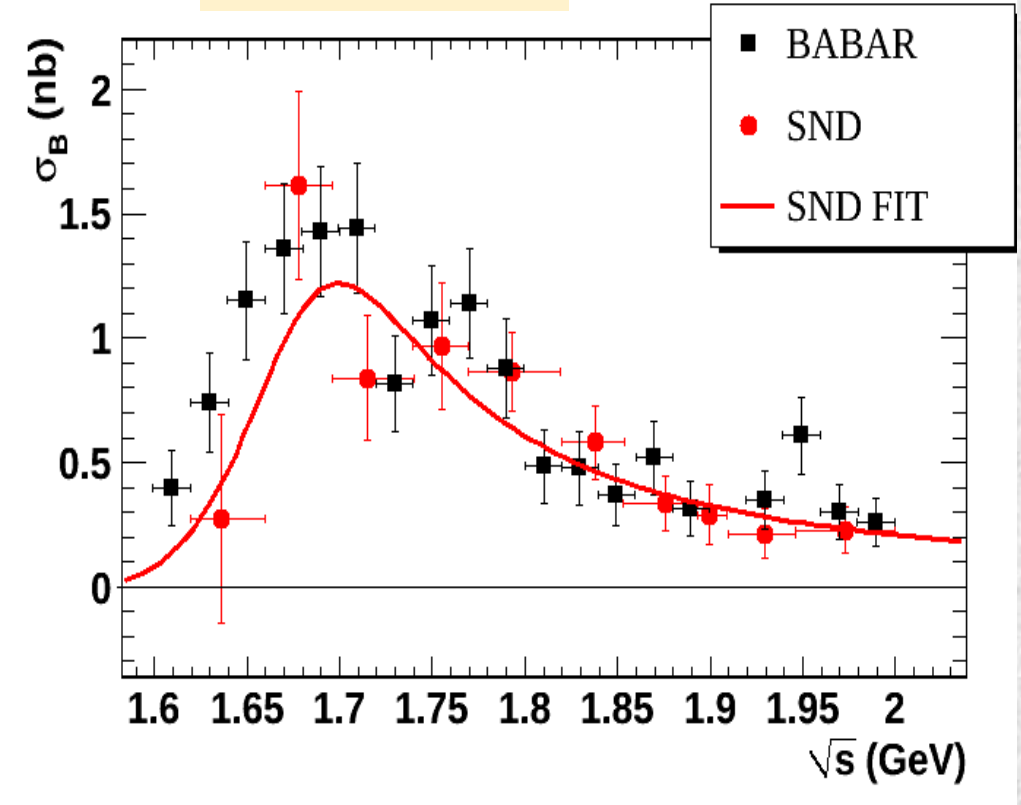
$e^+e^- \to \eta\pi^+\pi^-$



$\tau^- \to \eta\pi^-\pi^0\nu_\tau$

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

Very preliminary

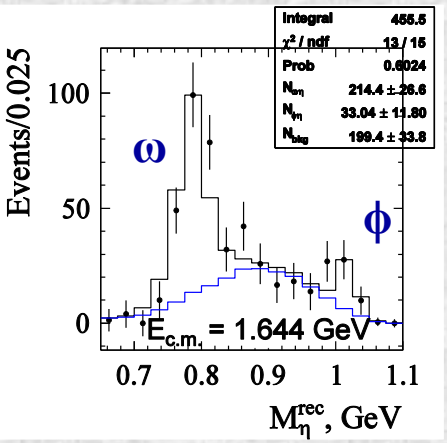


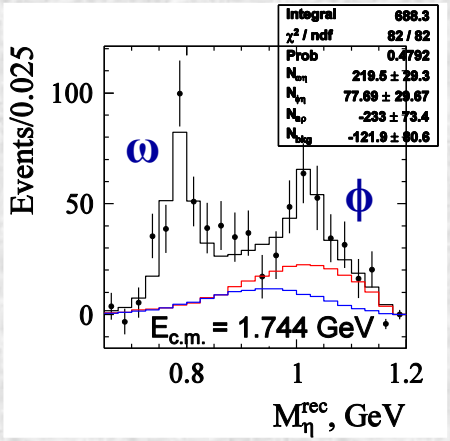
- It is assumed that the dominant reaction mechanism is **$\varphi(1680) \to \varphi(1020)\eta$.** This hypothesis is in agreement with the data.
- Our result agrees with the BABAR measurement.

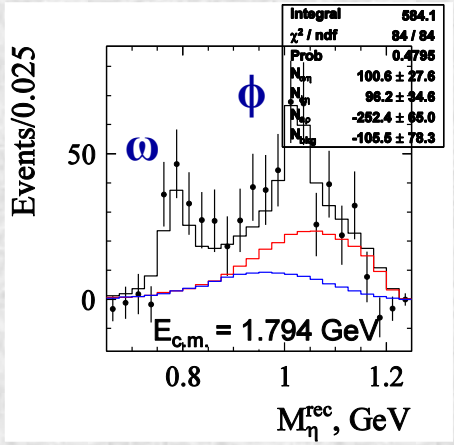
$e^+e^- \to \pi^+\pi^-\pi^0\eta$

Preliminary

η recoil mass spectra

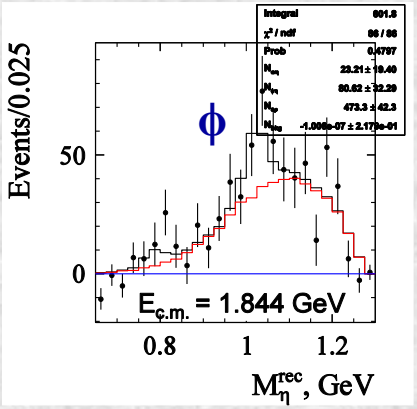


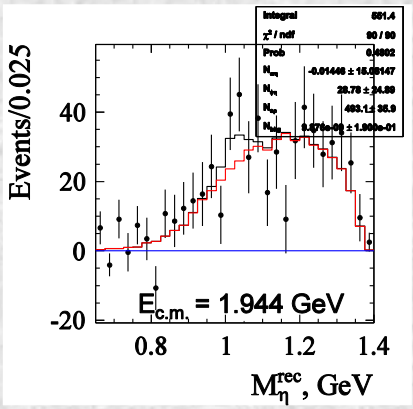




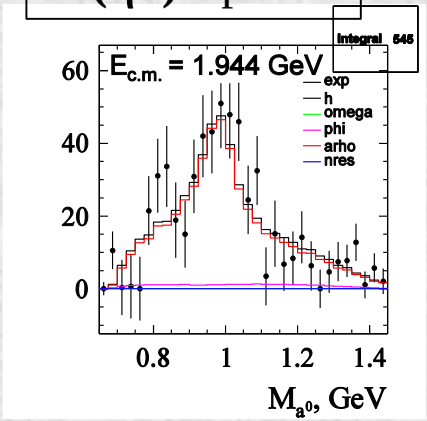
- in red - αρ contribution;
- in blue – non-resonant contribution

η recoil mass spectra





M(ηπ) spectra

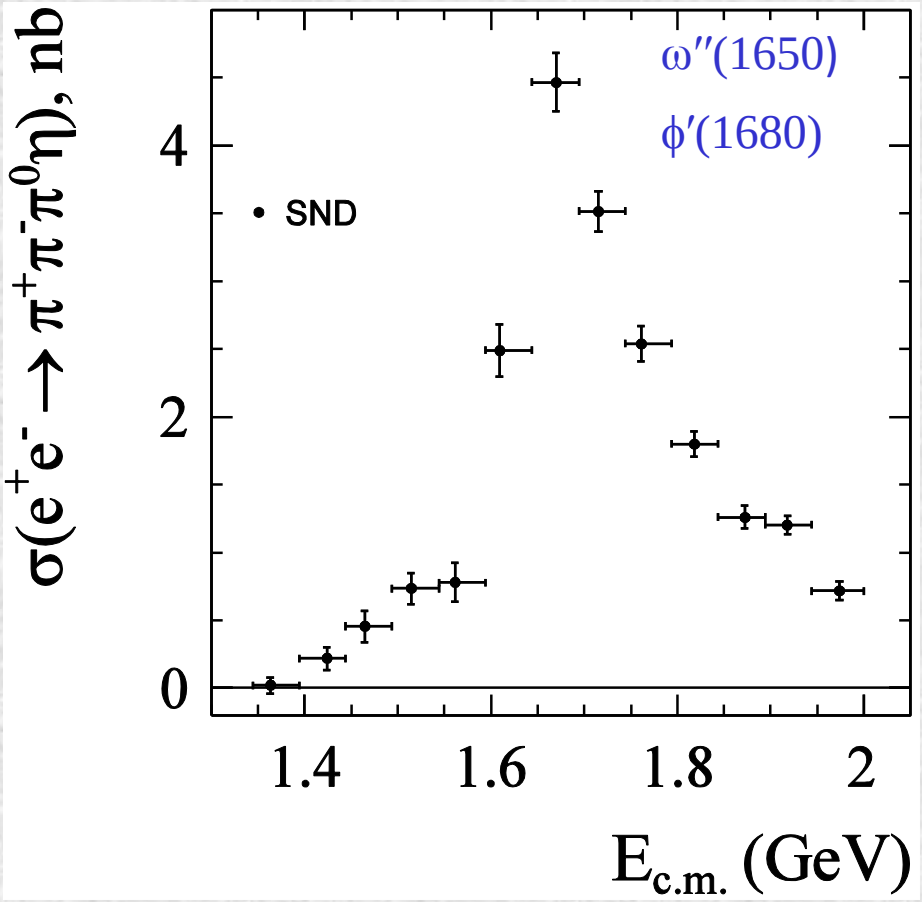


- **intermediate states ωη and ϕη are clearly seen in η recoil mass spectra;**
- **state αρ is seen in ηπ spectra**

$e^+e^- \to \pi^+\pi^-\pi^0\eta$ (II)

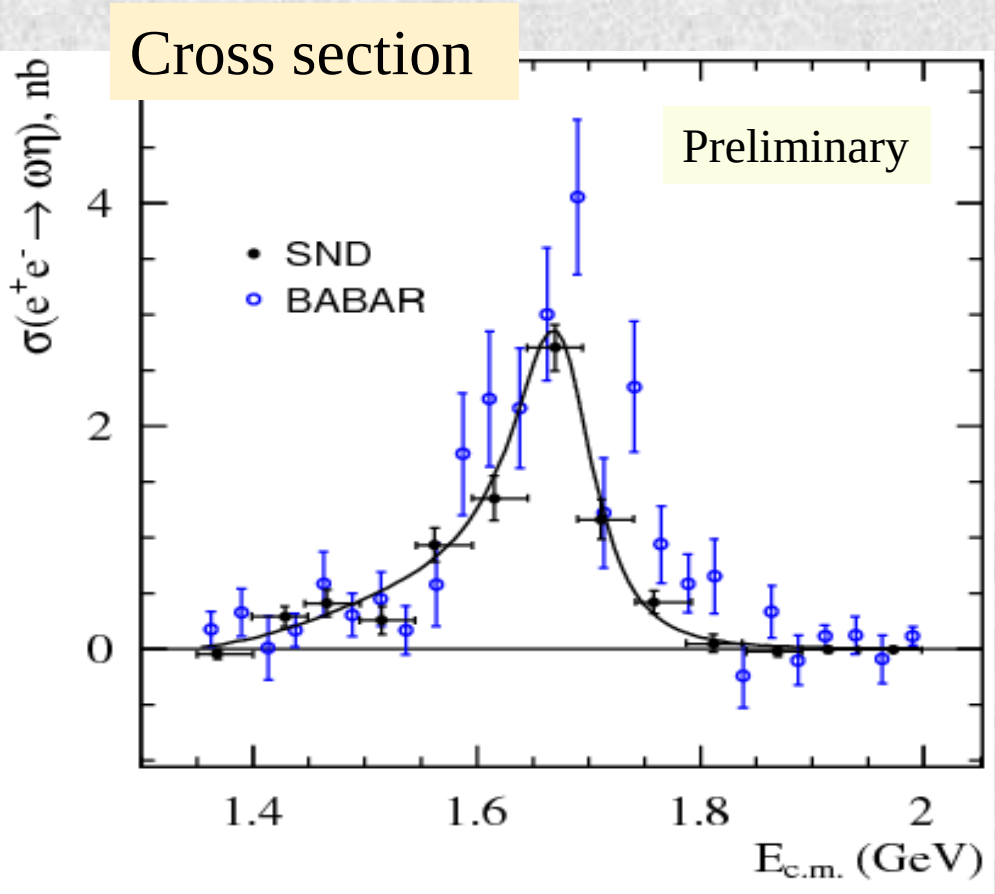
Cross section

Preliminary



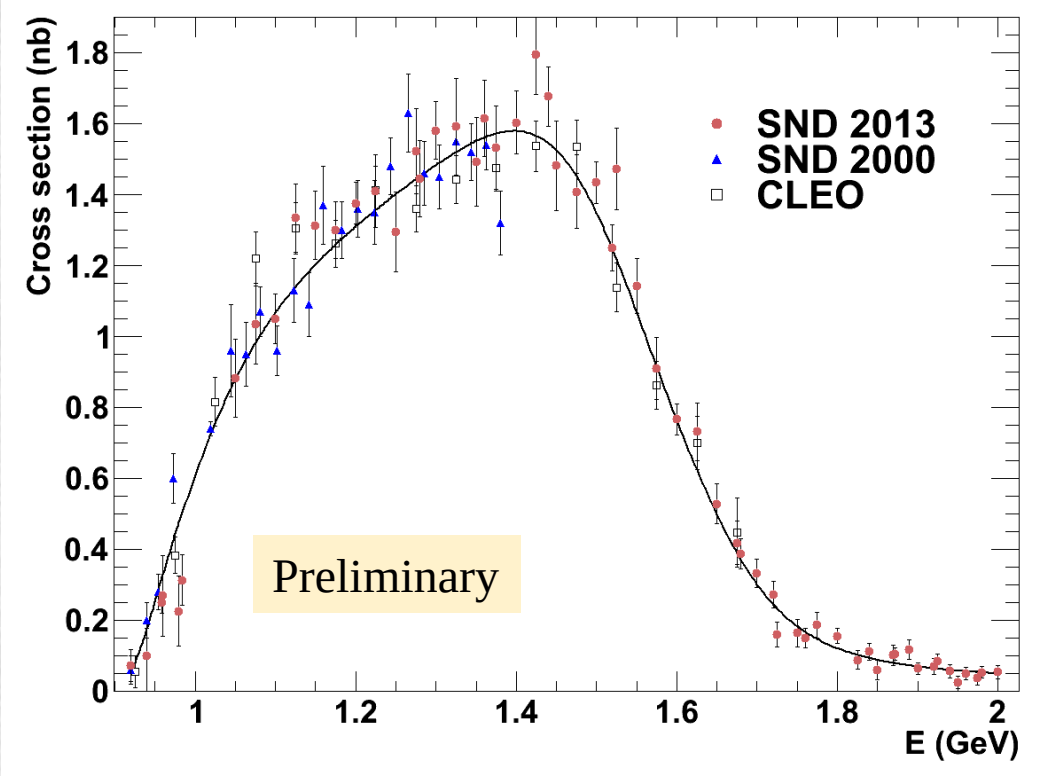
- This is the first measurement
- We assume that the main contributions are the **ϕ(1680)** and **ω(1650)** resonances.

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



- The fit of cross section includes the contributions of the **ϕ(1680)** and **ω(1420)** resonances.
- Zero (within errors) cross-section for E_{cm}>1.8 GeV is due to the resonances interference.

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

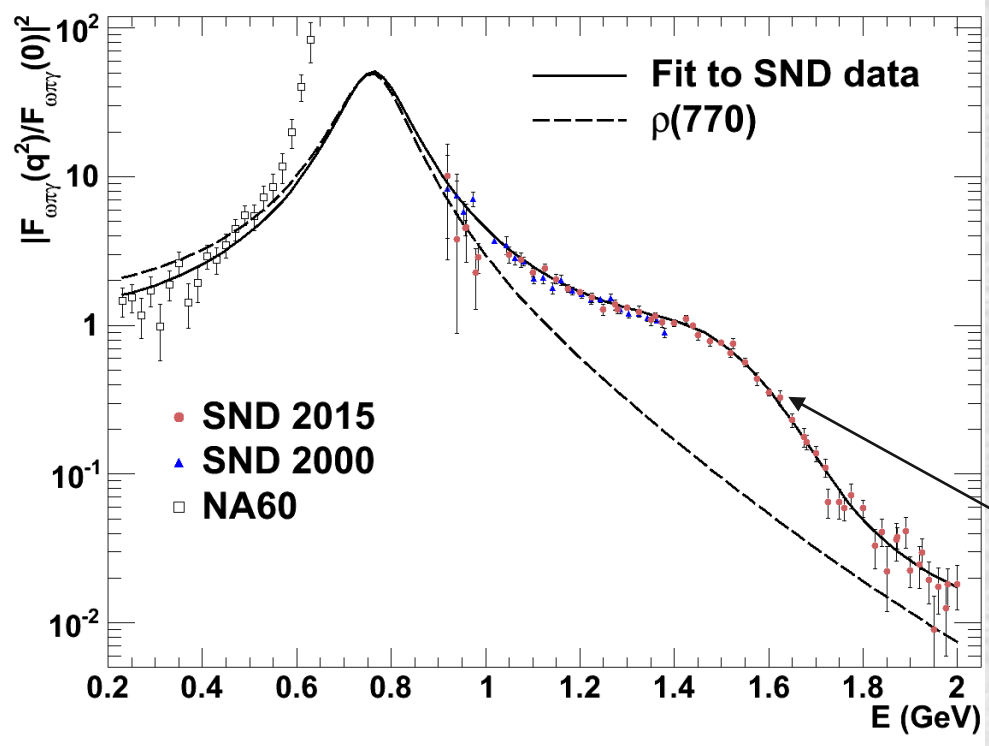


- Our previous result based on 2010-2011 data has been updated using the **full** SND data set.
- The mistake has been fixed in the radiative correction calculation.
- The cross section is described by a sum of the ρ(770), ρ(1450), and ρ(1700) contributions.

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

(Transition form factor $\gamma^* \to \omega\pi^0$, $F_{\omega\pi\gamma}$)

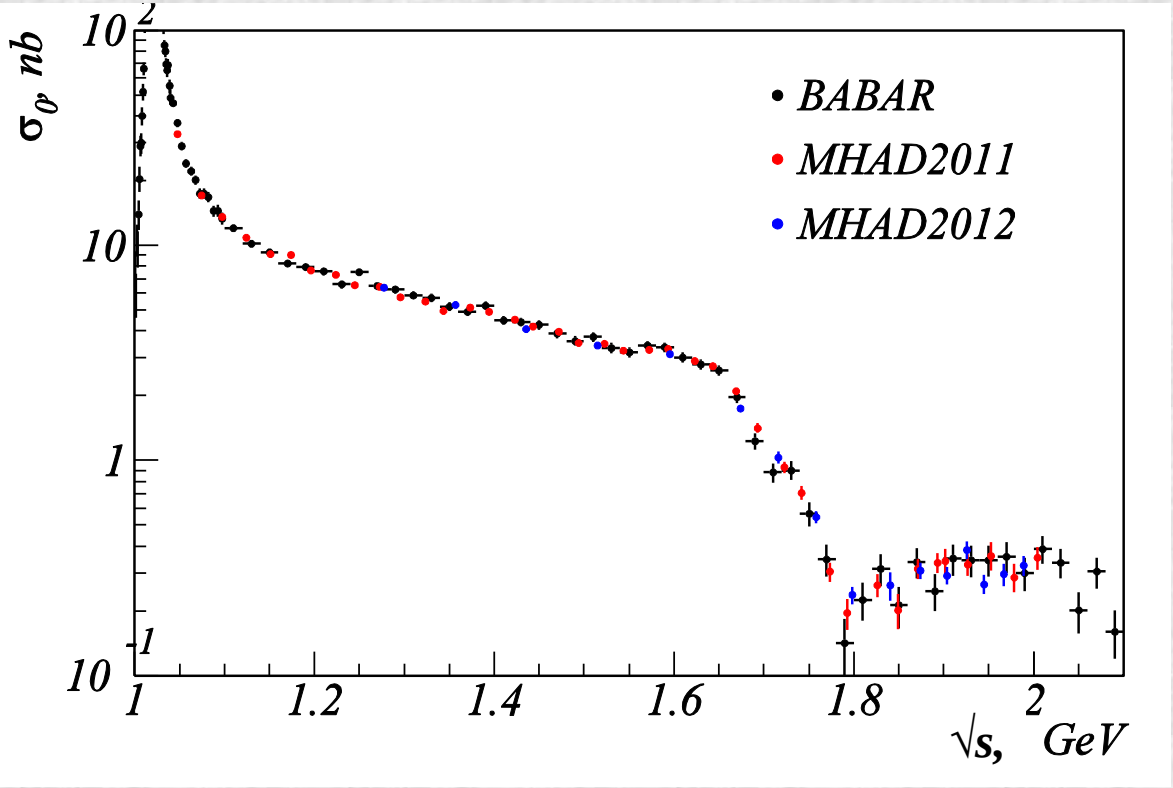
$$\sigma_{\omega\pi^\circ} = \frac{4\pi\alpha^2}{E^3}\left|F_{\omega\pi\gamma}(E^2)\right|^2 P_f(E),\ P_f(E) - \text{phase space factor}$$



- From the measured cross section we have extracted the $\gamma^* \to \omega\pi$ transition form factor.
- It has been found that the VMD model cannot describe simultaneously our data and data obtained from the $\omega \to \pi^0\mu^+\mu^-$ decay.
- Bump corresponds to ρ(1450) contribution

$e^+e^- \to K^+K^-$

Details in Beloborodov's talk

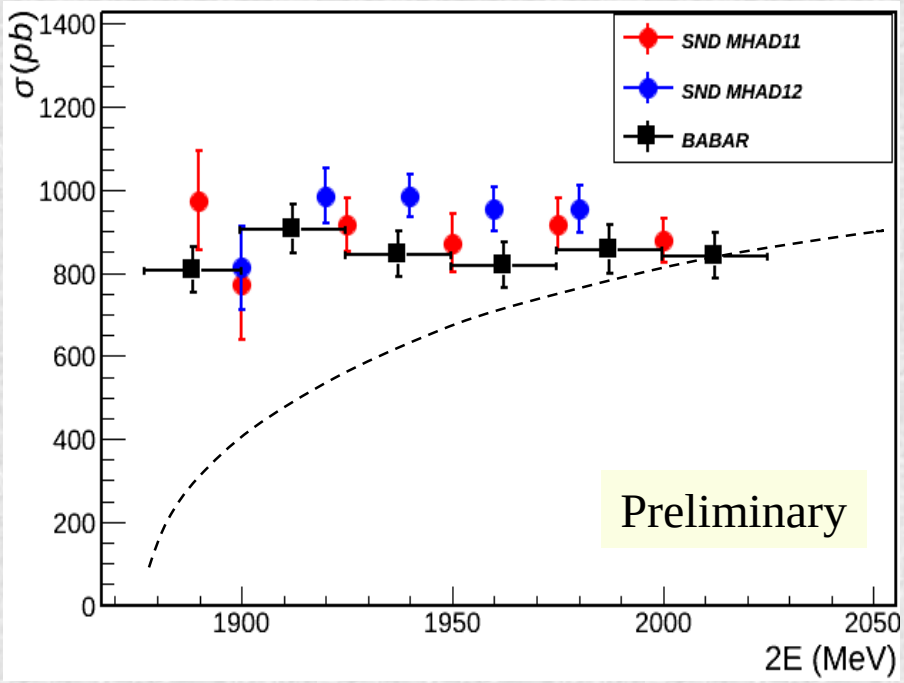


- Our results are in agreement with BABAR measurement and have similar accuracy.
- Both isoscalar and isovector resonances contribute into the cross section. Due to their interference the cross section has complex energy behavior.

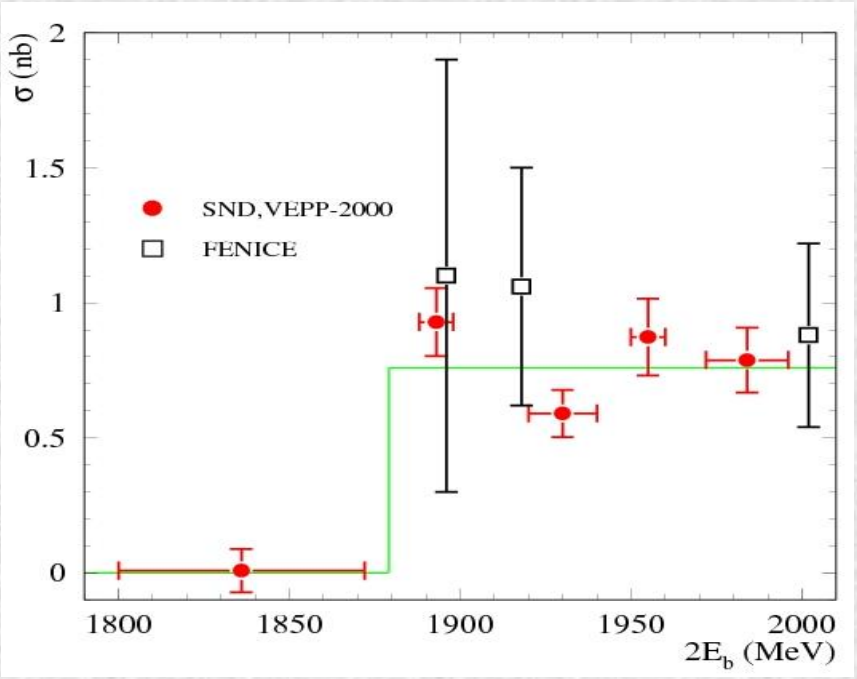
Nucleon production

Details in Korol's talk

$e^+e^- \to$ p anti-p



$e^+e^- \to$ n anti-n



The cross section is constant , through it is natural to expect its decrease as $\beta=(1-4m_p^2/s)^{1/2}$ when approaching threshold.

The $e^+e^- \to$ n anti-n cross section is constant and coincides inside the errors with that for proton anti-proton.

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

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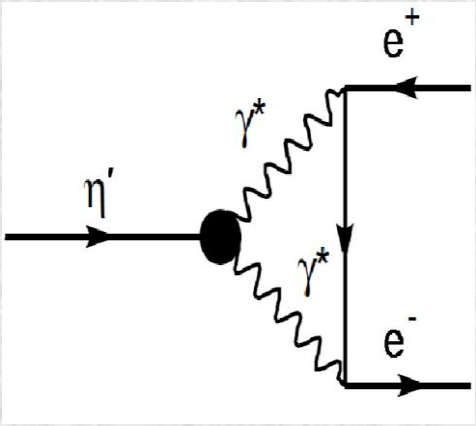


- The rare decay $\eta' \to e^+e^-$ is predicted to have a branching fraction of $(1\text{-}2)\times10^{-10}$.
- Its value is sensitive to the $\gamma^*\gamma^* \to \eta'$ transition form factor.
- The strictest limit on the decay branching fraction $B(\eta' \to e^+e^-) < 1.2 \times10^{-8}$ at 90%CL was set in 2014 by CMD-3 at VEPP-2000.

- The decay is searched for using the inverse reaction $e^+e^- \to \eta'$.
- About 2.9 pb^{-1} was accumulated at the center of mass energy of 957.78±0.06 MeV.
- The collider energy spread (FWHM=0.590 MeV) is significantly larger than the η' width $\Gamma_{\eta'} = 0.198\pm0.009$ MeV.
- The radiative correction and energy spread leads to reduction of the $e^+e^- \to \eta'$ cross section compared to the Born one by a factor of four.

Search for $\eta' \to e^+e^-$ decay (II)

- ✓ The process $e^+e^- \to \eta'$ has been searched for in **five** decay chains: $\eta' \to \eta\pi^+\pi^-$ with $\eta \to \gamma\gamma$ and $3\pi^0$, and $\eta' \to \eta\pi^0\pi^0$ with $\eta \to \pi^+\pi^-\pi^0$, $\gamma\gamma$, $3\pi^0$.
- ✓ Total branching fraction of these channels is ~ 51.5%
- ✓ No data events have been observed.
- ✓ The upper limit has been obtained to be $B(\eta' \to e^+e^-) < 1.0 \times 10^{-8}$ at 90%CL
- ✓ The combined SND+CMD-3 limit is $B(\eta' \to e^+e^-) < 5.6 \times 10^{-9}$ at 90%CL.

Plans to search for $\eta \to e^+e^-$ decay

arXiv:1507.02073
JETP Lett.(rus) 102 (2015) 297

VEPP-2000 parameters at $E=m_\eta c^2 \approx 550$ MeV:

- Luminosity – 0.34×10^{30} $cm^{-2}sec^{-1}$.
- Accuracy of the energy setting – 60 keV.
- Energy spread – σ_E=150 keV (Γ_η = 1.31±0.05 keV).

- The inverse reaction $e^+e^- \to \eta$ is proposed for this search
- We have analyzed a data sample with an integrated luminosity of 108 nb^{-1} collected at E=520-580 MeV and found no background events for the reaction $e^+e^- \to \eta$ in the decay mode $\eta \to \pi^0\pi^0\pi^0$.
- In the absence of background, a sensitivity to $B(\eta \to e^+e^-)$ of 10^{-6} can be reached during two weeks of VEPP-2000 operation.
- Such a sensitivity is better than the current upper limit (HADES Collaboration, 2014) by a factor of 2.3.

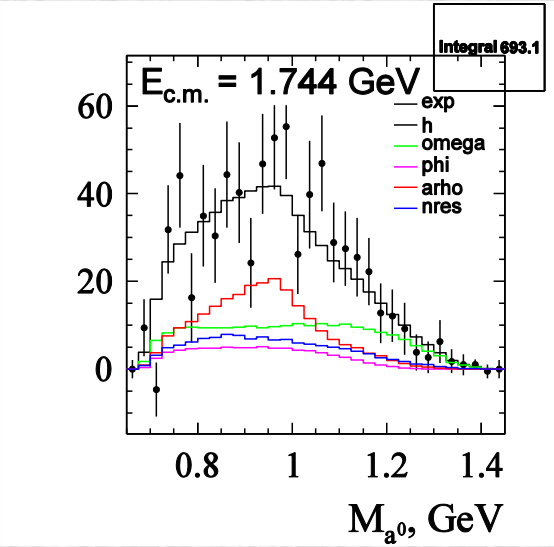
Conclusions

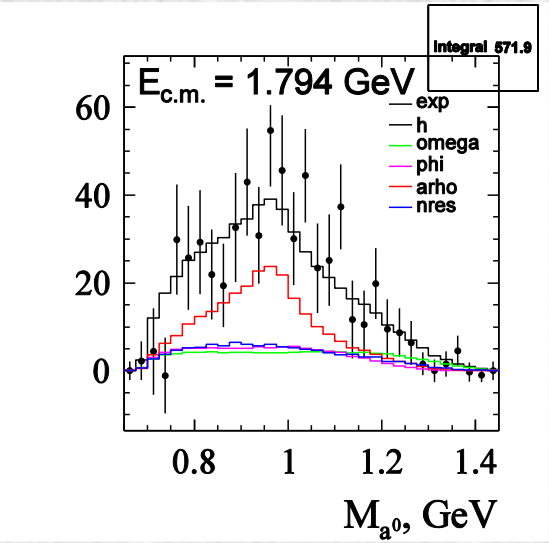
- ✓ **During 2010 – 2013 SND detector accumulated ~70 pb^{-1} of integrated luminosity at VEPP-2000 e^+e^- collider in the energy range E=0.3 – 2 GeV.**
- ✓ **Data analysis on hadron production is in progress. The obtained results have comparable or better statistical precision than previous measurements.**
- ✓ **Six analysis were published. Many more are in preparation for publications.**
- ✓ **After VEPP-2000 upgrade the data taking runs will be continued with a goal of ~1 fb^{-1} of integrated luminosity.**

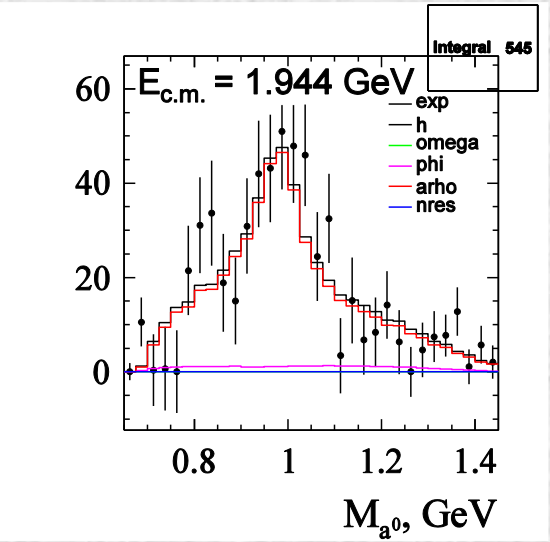
Thank you for attention

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

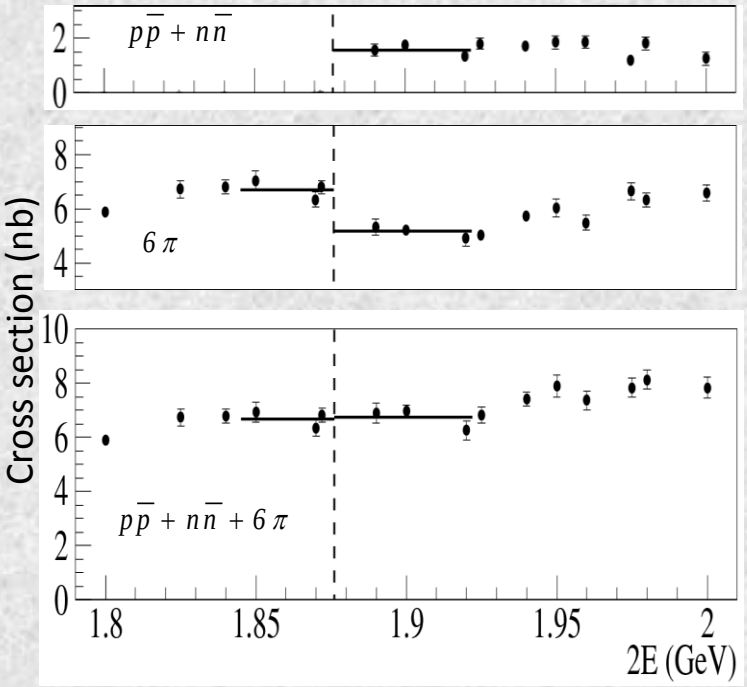
M(ηπ) spectra - **αρ contribution**







The $e^+e^- \to 6\pi$ cross section near N anti-N threshold



A.E. Obrazovsky, S.I. Serednyakov JETP Lett. 99 (2014) 363

- In the total $e^+e^- \to$ hadrons cross section, the appearance of the $e^+e^- \to$ N anti-N processes is fully compensated by the dip in the cross section for the isovector processes $e^+e^- \to 3(\pi^+\pi^-)+2(\pi^+\pi^-\pi^0)$.
- In other cross sections near N anti-N threshold, any features, comparable in magnitude with that for $e^+e^- \to 6\pi$, are not observed.

Angular resolution:

$\sigma_\varphi = 0.55°,\ \sigma_\theta = 1.2°$

Spatial resolution:

$\sigma_R = 0.12cm,$
$\sigma_Z = 0.45cm$