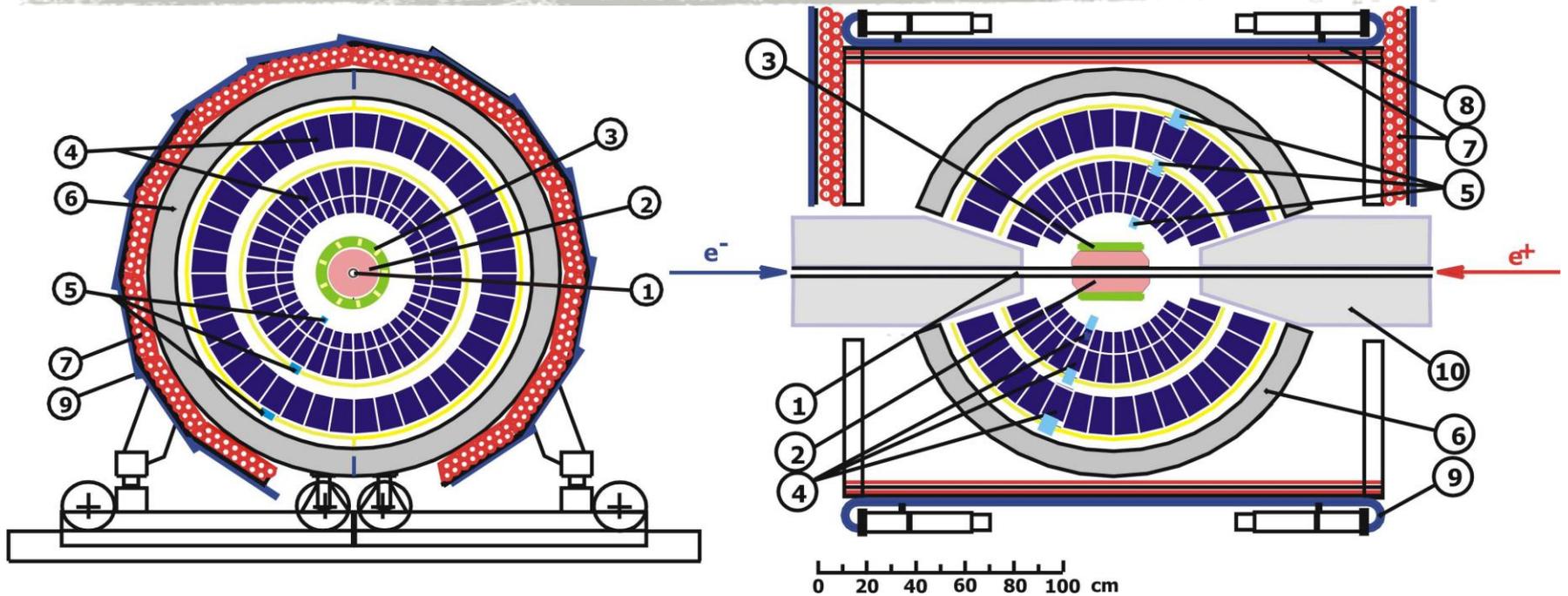


Measurement of hadron cross sections with the SND detector

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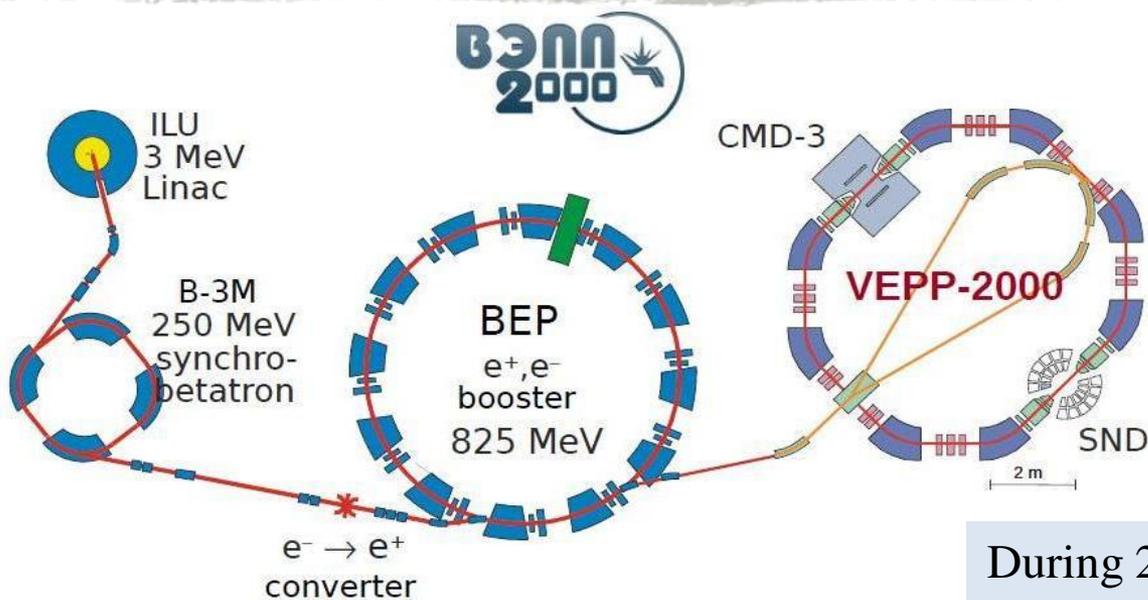
SND detector



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

VEPP-2000 e^+e^- collider

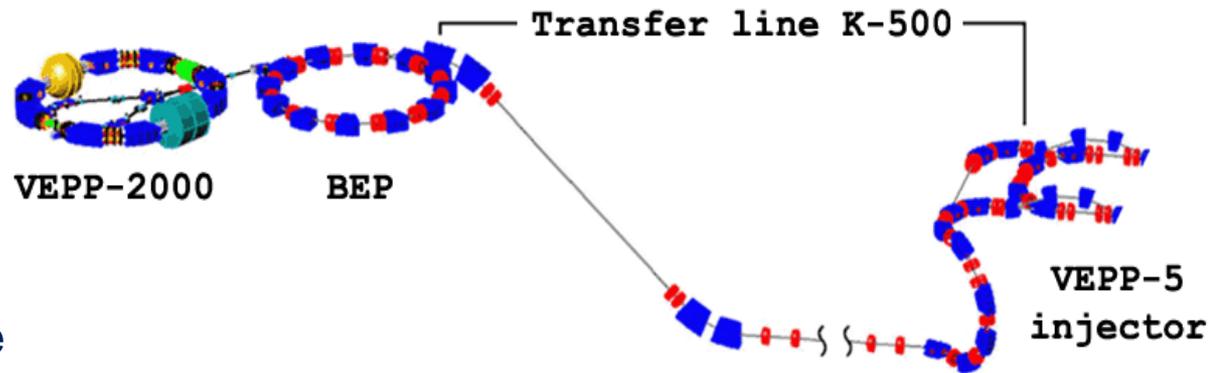


VEPP-2000 parameters:

- c.m. energy $E=0.3-2.0$ GeV
- circumference – 24.4 m
- round beam optics
- Luminosity at $E=1.8$ ГэВ
 $1 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ (project)
 $2 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$ (achieved)

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

- ✓ Currently the VEPP-2000 complex is upgrading
- ✓ Electrons and positrons are transported from the VEPP-5 injection complex through 250 m beamline.
- ✓ Experiments at upgraded VEPP-2000 are expected to be started in the end of 2016.



SND data

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

~15 hadronic processes are currently under analysis

VEPP-2000

	Below ϕ	Near ϕ	Above ϕ
IL, pb ⁻¹	15.4	6.9	47.0
E _{cm} , GeV	0.30-0.97	0.98-1.05	1.05-2.00

Precision measurements:

- $e^+e^- \rightarrow \pi^0\gamma$ (VEPP-2M data)
- $e^+e^- \rightarrow K^+K^-$

First measurements

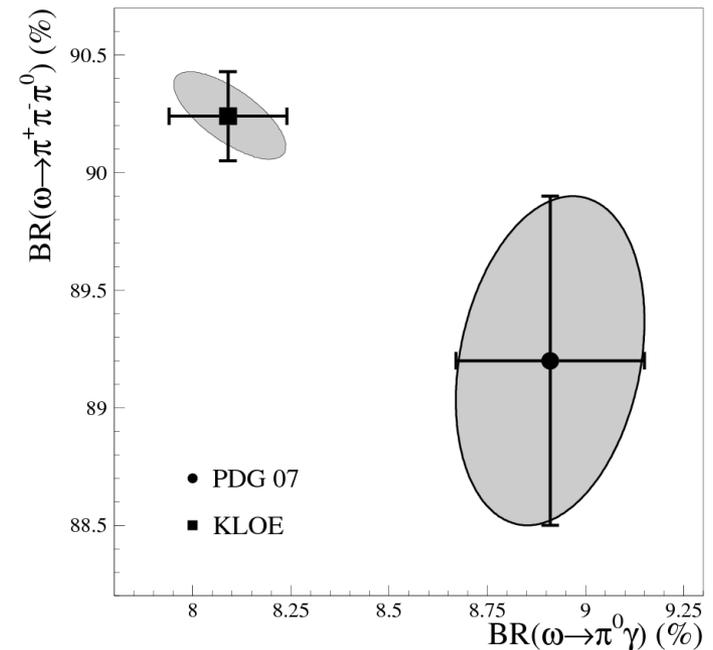
- $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$
- $e^+e^- \rightarrow \omega\pi^0\eta$

$e^+e^- \rightarrow \pi^0\gamma$ (VEPP-2M data)

- ❑ Third largest cross section (after 2π and 3π) below 1 GeV
- ❑ Measurement of the $\pi^0\gamma^*\gamma$ transition form factor
- ❑ Measurement of the radiative decays $V \rightarrow \pi^0\gamma$, $V = \rho, \omega, \phi \dots$
- ❑ There is a tension between the KLOE measurement of the ratio $\Gamma(\omega \rightarrow \pi^0\gamma) / \Gamma(\omega \rightarrow \pi^+\pi^-\pi^0)$ and other measurements of ω -meson parameters.

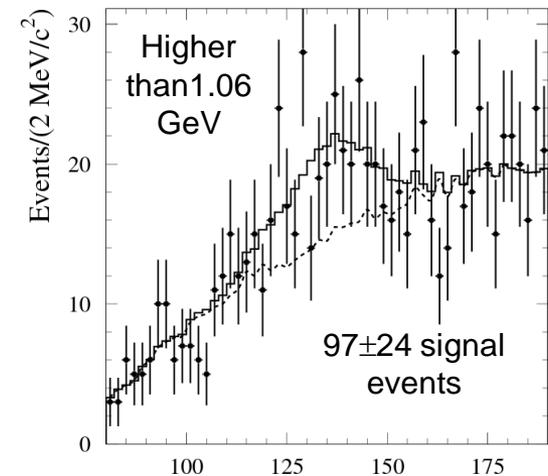
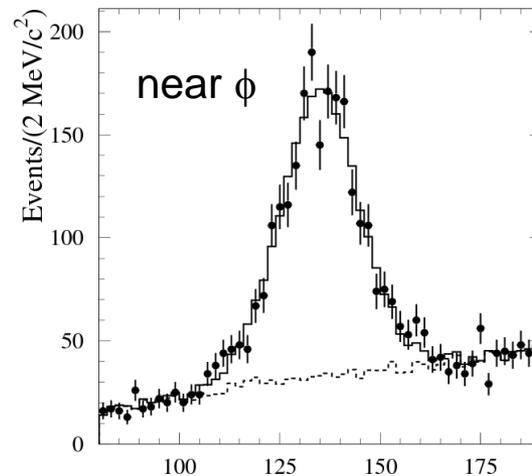
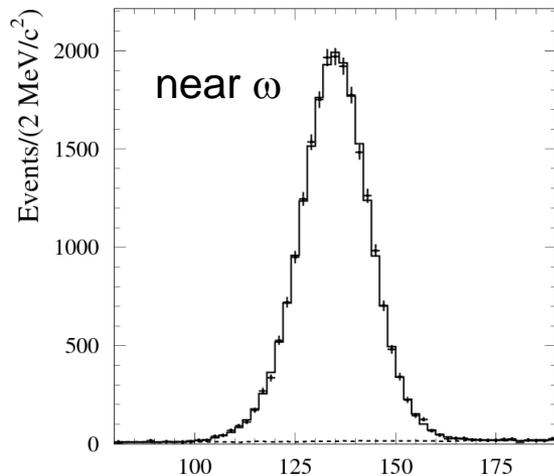
KLOE studies the $e^+e^- \rightarrow \omega\pi^0$ process near the ϕ -meson resonance in two ω decay modes.

The KLOE measurement led to a large shift of the previously measured ω -meson parameters, especially for $\omega \rightarrow \pi^0\gamma$.

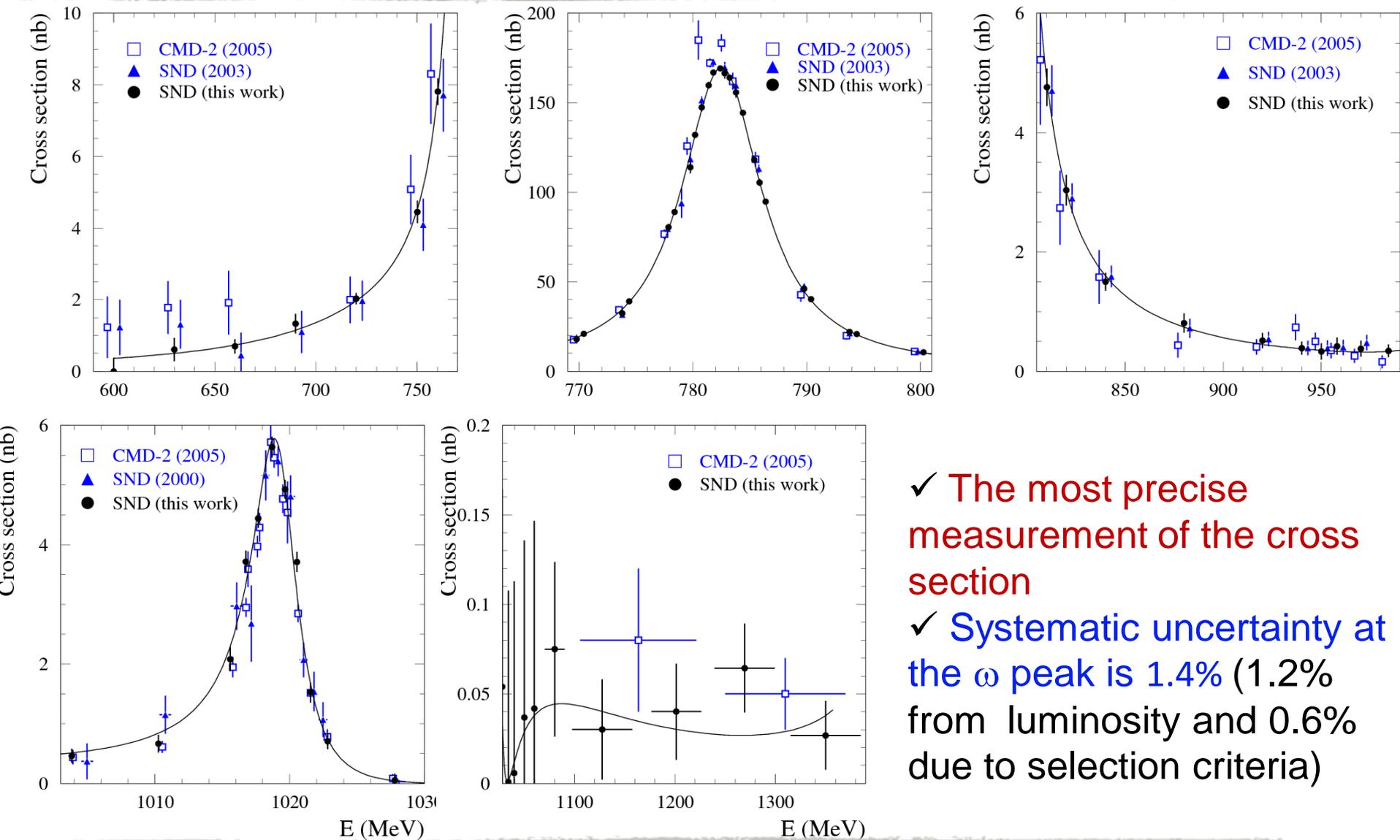


Analysis features

- ❑ The process $e^+e^- \rightarrow \gamma\gamma$ is used for normalization. Many selection criteria are **common for 2γ and 3γ** .
 - trigger, absence of charged tracks, cuts on the total energy deposition and event momentum, muon system veto.
- ❑ Final selection is **based on 4C kinematic fit** ($\chi^2_{3\gamma} < 30$, $36^\circ < \theta_\gamma < 144^\circ$, $80 < M_{\text{rec}} < 190$ MeV, where M_{rec} is the mass recoiling against largest energy photon).
- ❑ The number of $e^+e^- \rightarrow \pi^0\gamma$ events is determined from **the fit to the M_{rec} spectrum**



Born cross section



- ✓ The most precise measurement of the cross section
- ✓ Systematic uncertainty at the ω peak is 1.4% (1.2% from luminosity and 0.6% due to selection criteria)

Results on radiative decays

■ $B(\omega \rightarrow \pi^0 \gamma)B(\omega \rightarrow e^+ e^-) = (6.336 \pm 0.056 \pm 0.089) \times 10^{-6}$

Using PDG value for $B(\omega \rightarrow \pi^+ \pi^- \pi^0)$ $B(\omega \rightarrow e^+ e^-)$ we obtain

$$\Gamma(\omega \rightarrow \pi^0 \gamma) / \Gamma(\omega \rightarrow \pi^+ \pi^- \pi^0) = 0.0992 \pm 0.0023,$$

which is higher than the KLOE value 0.0897 ± 0.0016 by 3.4σ

■ $B(\rho \rightarrow \pi^0 \gamma) = (4.20 \pm 0.47 \pm 0.22) \times 10^{-4}$

By 1.8σ lower than the current PDG value $(6.0 \pm 0.8) \times 10^{-4}$,

but agrees with the branching fraction for the charged

mode $B(\rho^\pm \rightarrow \pi^\pm \gamma) = (4.5 \pm 0.5) \times 10^{-4}$

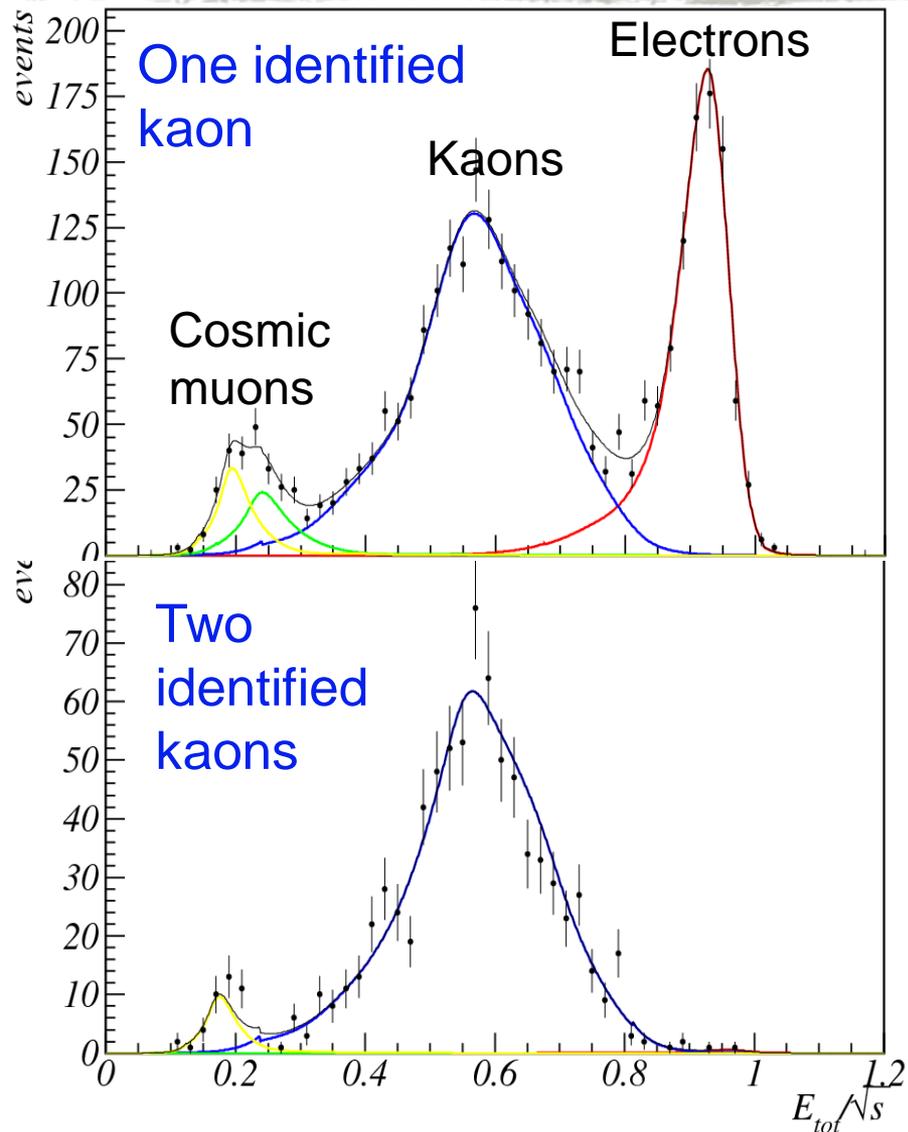
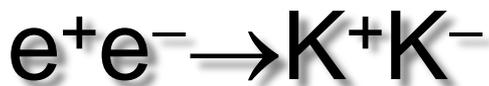
■ $B(\phi \rightarrow \pi^0 \gamma)B(\phi \rightarrow e^+ e^-) = (3.92_{-0.40}^{+0.71} \pm 0.51) \times 10^{-7}$

The model uncertainties of the previous measurements

($\sim 8\%$) were underestimated. For φ_ϕ fixed at the value

$(163 \pm 7)^\circ$ obtained in the VMD fit to $e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$ data

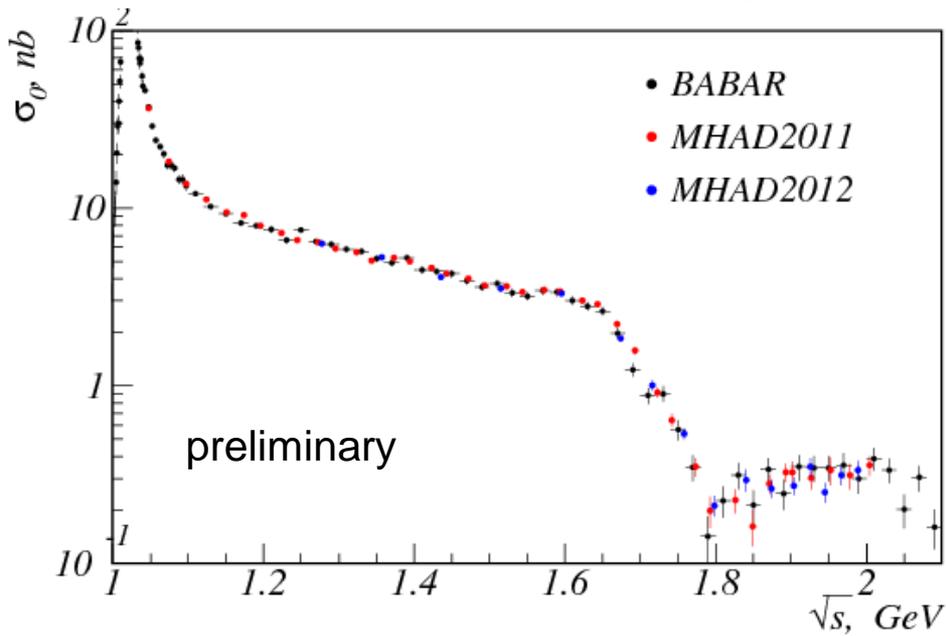
$$B(\phi \rightarrow \pi^0 \gamma)B(\phi \rightarrow e^+ e^-) = (4.04 \pm 0.09 \pm 0.19) \times 10^{-7}$$



Kaon identification is based on information from Cherenkov aerogel counters. Kaons do not produce Cherenkov signal in the counter, while electron, muon and pions do.

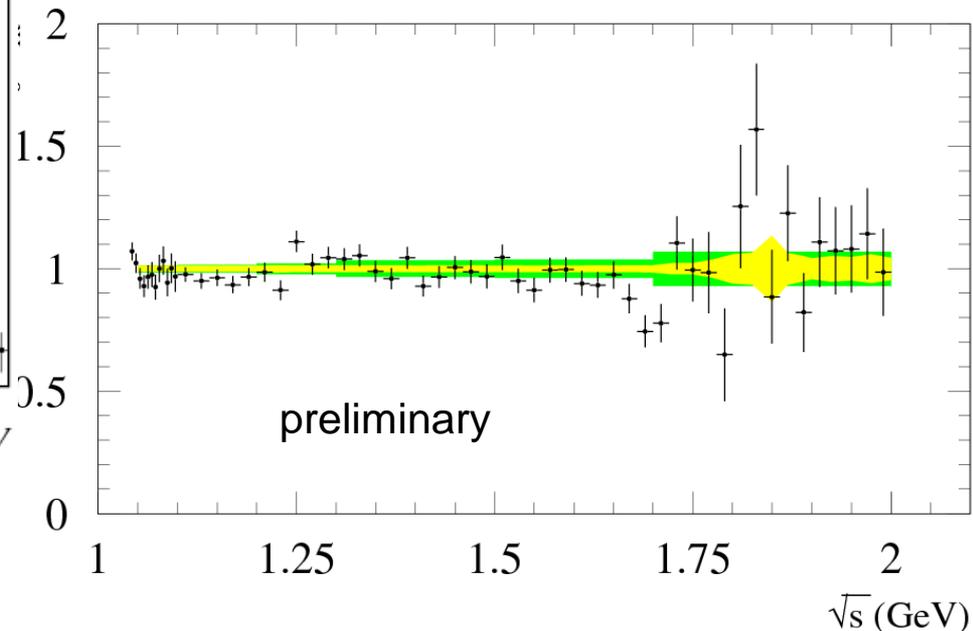
The kaon ID requirement suppresses background from $e^+e^- \rightarrow e^+e^-$ by a factor of 300.

$e^+e^- \rightarrow K^+K^-$



Our measurement agrees with the BABAR data and has comparable or better accuracy.

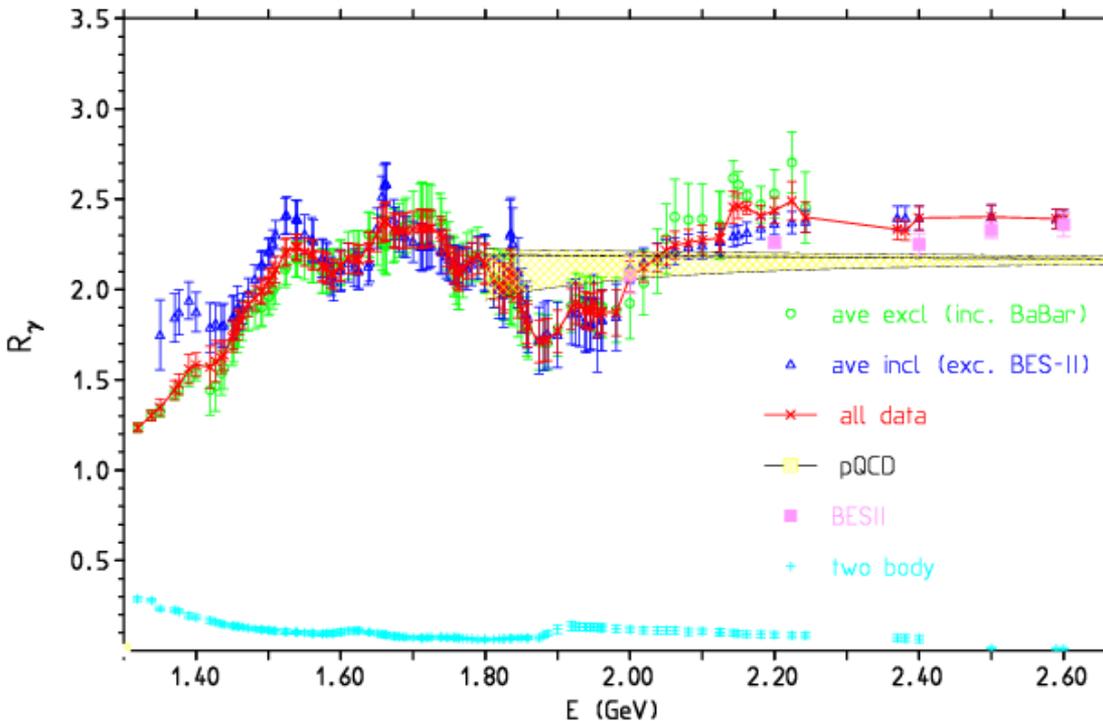
(BABAR data)/(SND fit) ratio



The green and yellow bands represent the BABAR and SND systematic uncertainties

Exclusive vs inclusive measurements

F.Jegerlehner arXiv:1511.04473

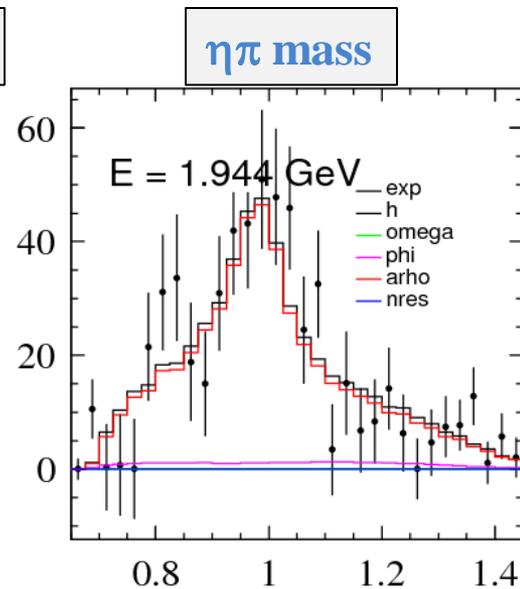
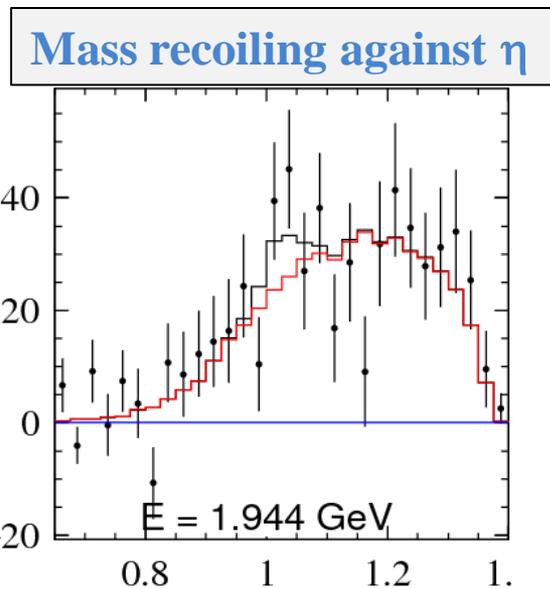
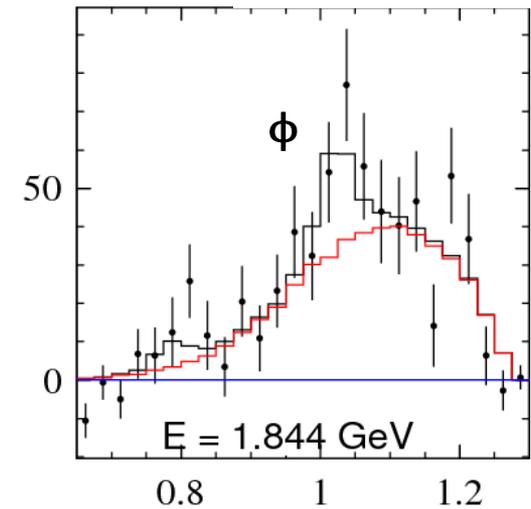
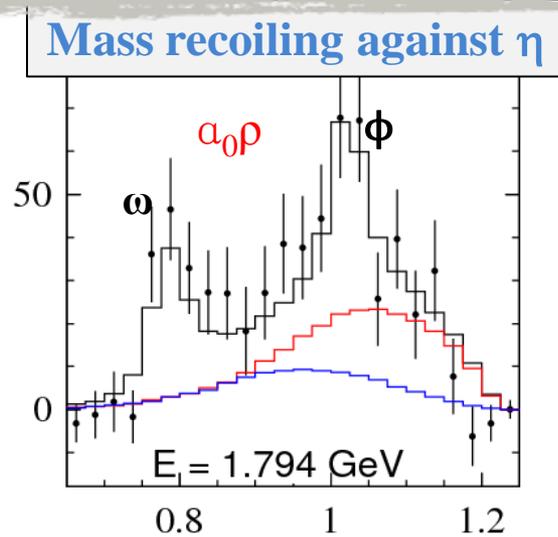
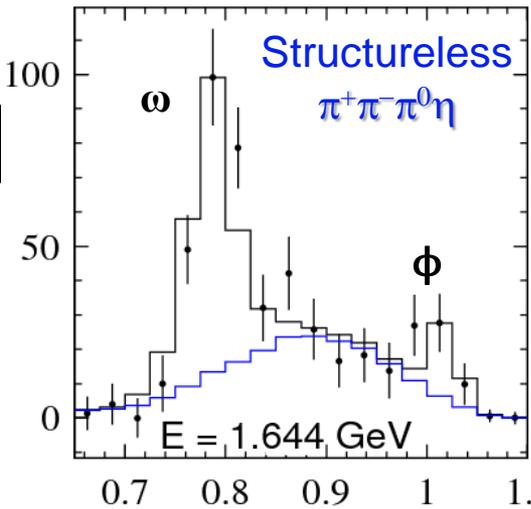


- Below 2 GeV the total hadronic cross section is calculated as a sum of exclusive cross sections
- Currently the exclusive and inclusive data below 2 GeV are in reasonable agreement.

In the energy region 1.5-2.0 GeV exclusive data are incomplete. There is no experimental data on the final states $\pi^+\pi^-\pi^0\eta$, $\pi^+\pi^-\eta\eta$, $\pi^+\pi^-\pi^0\pi^0\pi^0$, $\pi^+\pi^-\pi^0\pi^0\eta$...)

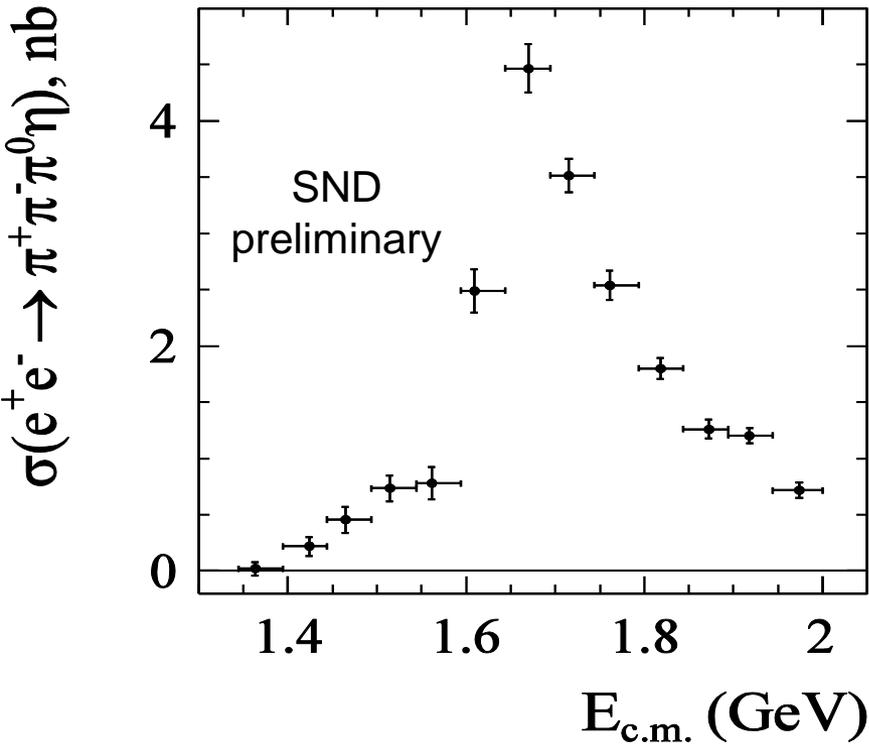
$e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$

preliminary



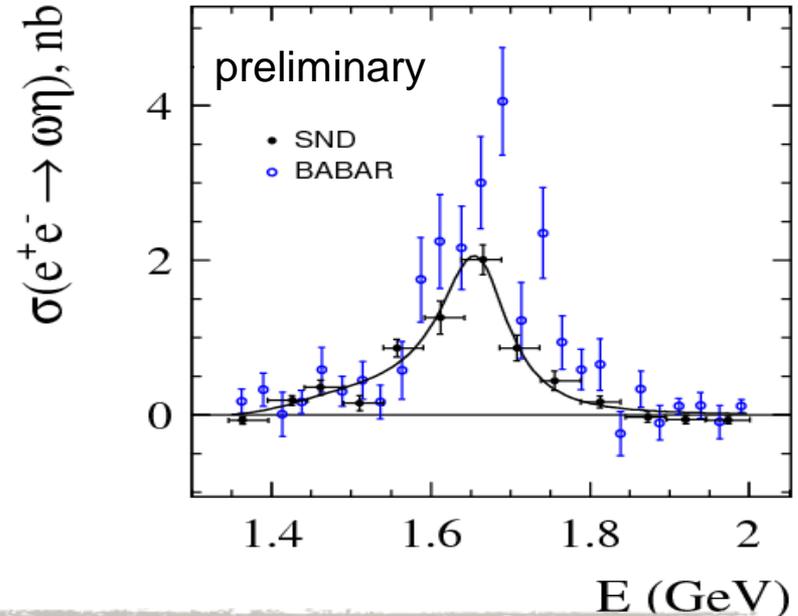
- $\omega\eta$ and $\phi\eta$ intermediate states are clearly seen in the spectrum of the mass recoiling against η
- $a_0(980)\rho$ intermediate state is seen in the $\eta\pi$ spectrum
- Some fraction of events at E below 1.8 GeV do not have any clear structure.

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

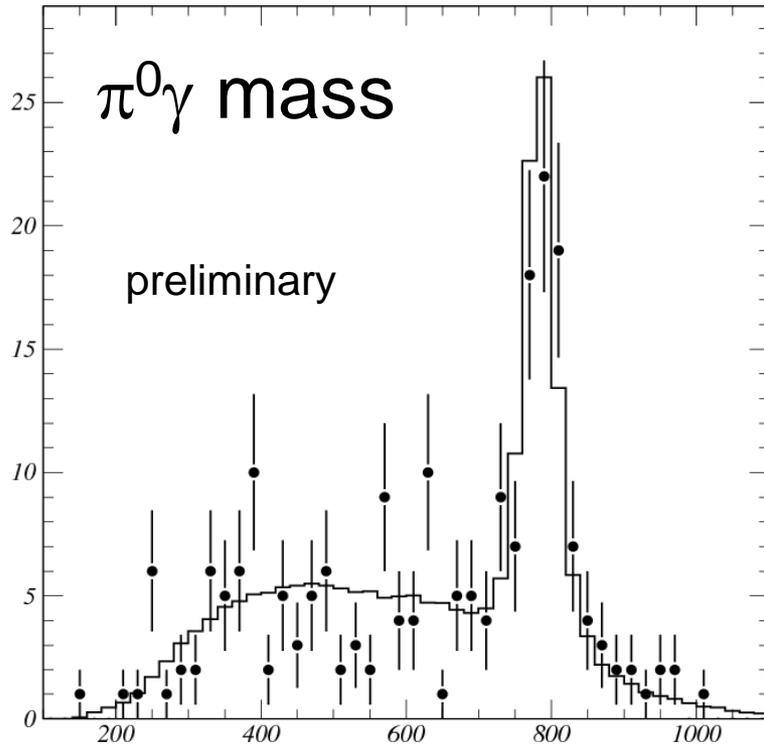


- ✗ First measurement of this process
- ✗ The intermediate states are $\omega\eta$, $\phi\eta$, $\alpha_0\rho$ and structureless $\pi^+\pi^-\pi^0\eta$
- ✗ The known $\omega\eta$ and $\phi\eta$ contributions explain about 50-60% of the cross section below 1.8 GeV.
- ✗ Above 1.8 GeV the dominant reaction mechanism is $\alpha_0\rho$

- The process $e^+e^- \rightarrow \omega\eta$ has been measured separately.
- There is a significant difference between our result and the previous BABAR measurement.



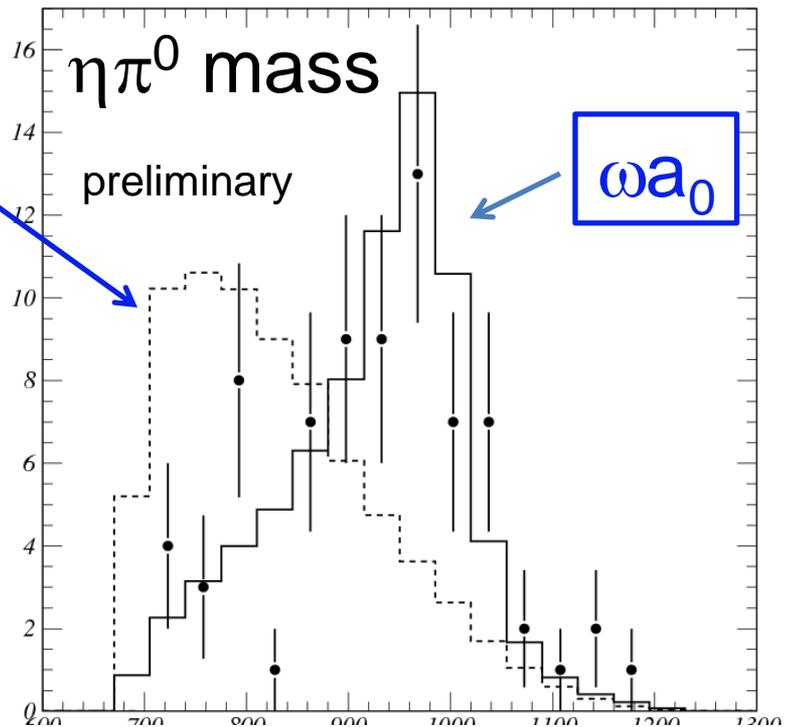
$e^+e^- \rightarrow \omega\pi^0\eta$



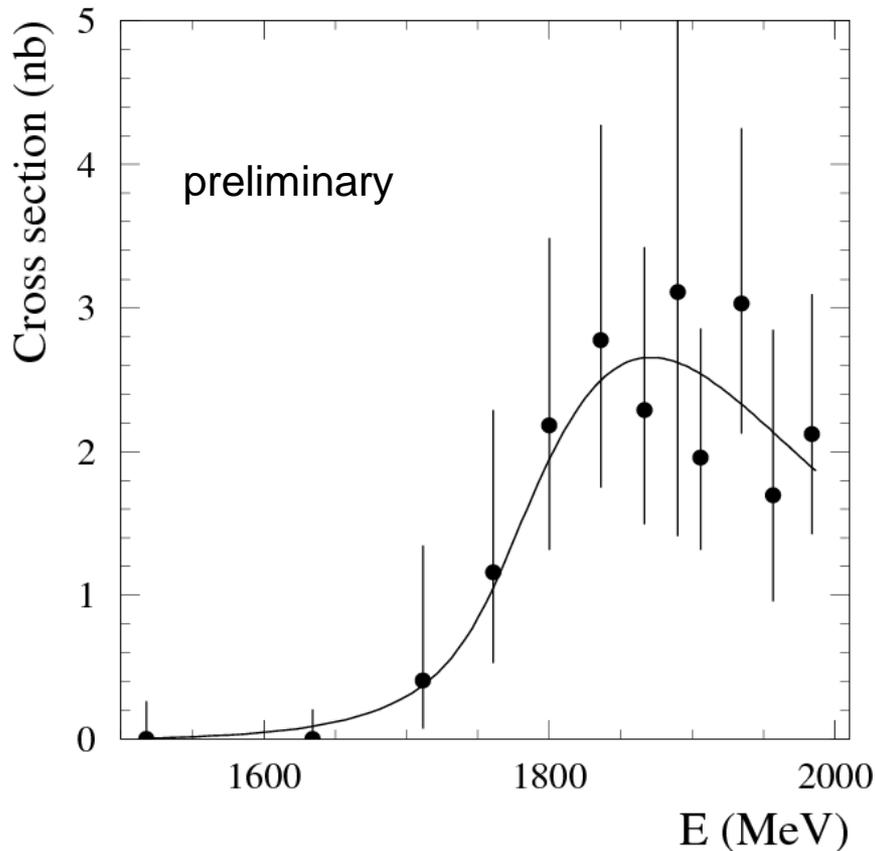
- Events of the $e^+e^- \rightarrow \pi^0\pi^0\eta\gamma \rightarrow 7\gamma$ process are selected.
- The dominant intermediate state is $\omega\pi^0\eta$.

- The $\eta\pi^0$ mass spectrum for selected $\omega\pi^0\eta$ events is well described by the model of the $\omega a_0(980)$ intermediate state

$\omega\pi^0\eta$
phase
space



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



- First measurement of the $e^+e^- \rightarrow \omega\pi^0\eta$ cross section.
- The dominant reaction mechanism is $\omega a_0(980)$.
- The cross-section energy dependence is described by a single-resonance model. The resonance mass and width are consistent with those for $\rho(1700)$.

The cross section is about 2.5 nb, 5% of the total hadronic cross section.

Summary

- ✓ During 2010 – 2013 the SND detector accumulated ~ 70 pb^{-1} of integrated luminosity at the VEPP-2000 e^+e^- collider in the c.m. energy range 0.3 – 2 GeV.
- ✓ Data analysis on hadron production is in progress. The obtained results have comparable or better accuracy than previous measurements ($\omega\pi^0$, $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\eta$, n anti- n , $\pi^0\gamma$, K^+K^-)
- ✓ For several processes the cross sections have been measured for the first time ($\eta\gamma$, $\pi^+\pi^-\pi^0\eta$, $\omega\pi^0\eta$)
- ✓ After VEPP-2000 upgrade the data taking runs will be continued with a goal of ~ 1 fb^{-1} of integrated luminosity.