# Recent results from the SND detector

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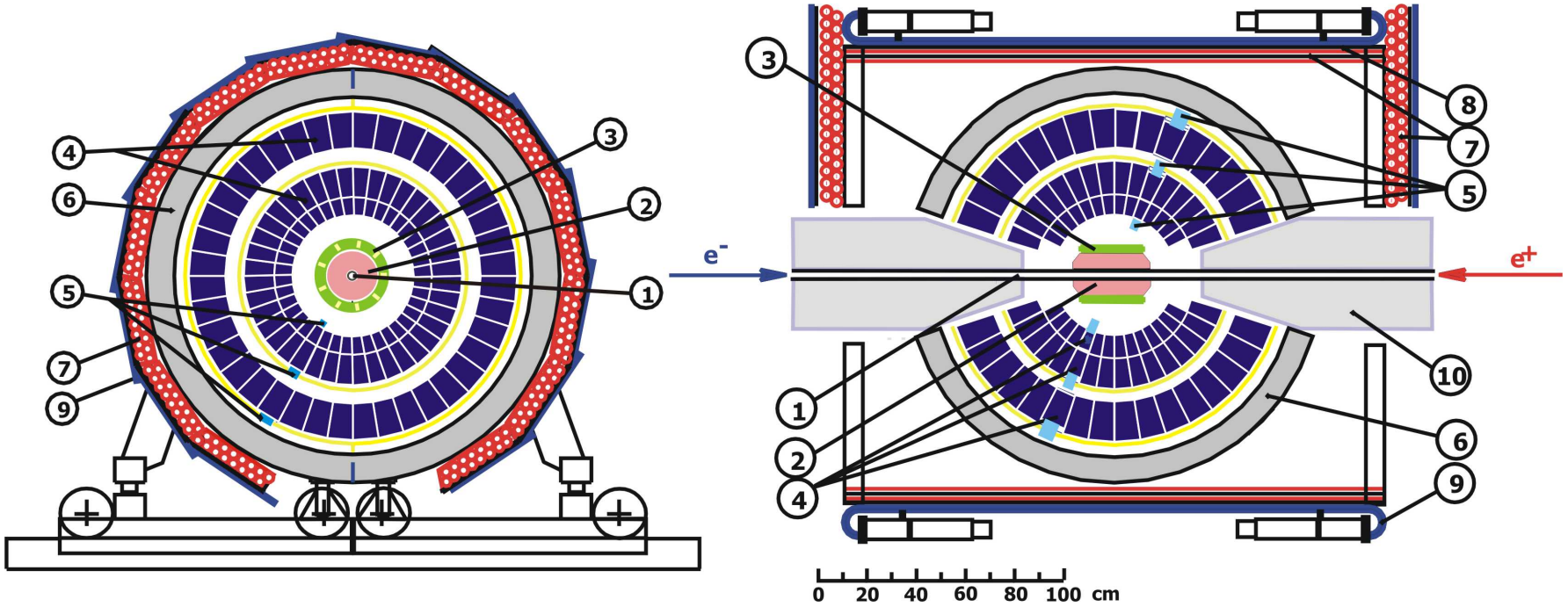
**(on behalf of the SND collaboration)**

*Сессия-конференция Секции ядерной физики ОФН РАН "Физика фундаментальных взаимодействий", посвященная 50-летию БНО*

# SND detector



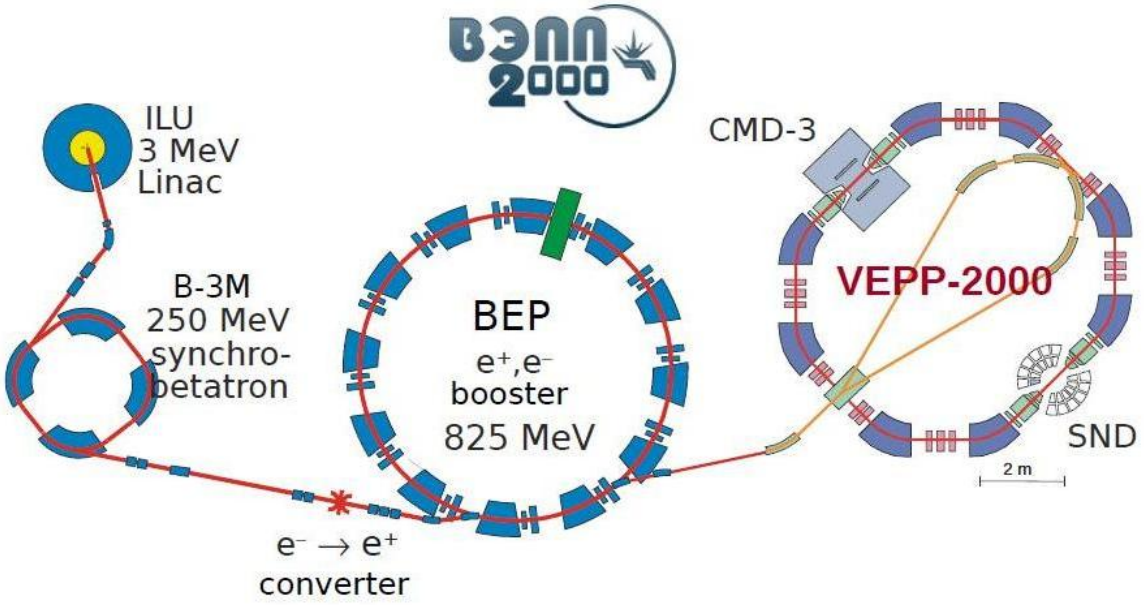

**1 – beam pipe, 2 – tracking system, 3 – aerogel Cherenkov counter , 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron muon absorber, 7–9 – muon detector, 10 – focusing solenoids.**

***Calorimeter: 0.95×4π, 13.4X0, δE/E= 0.042/$\sqrt[4]{E(GeV)}$, δφ=1.5°.***

***Tracking system: 0.94×4π, δφ=0.45°, δθ=0.8°***

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 0.3-2.0 GeV
- circumference – 24.4 m
- round beam optics
- luminosity at 2 GeV:

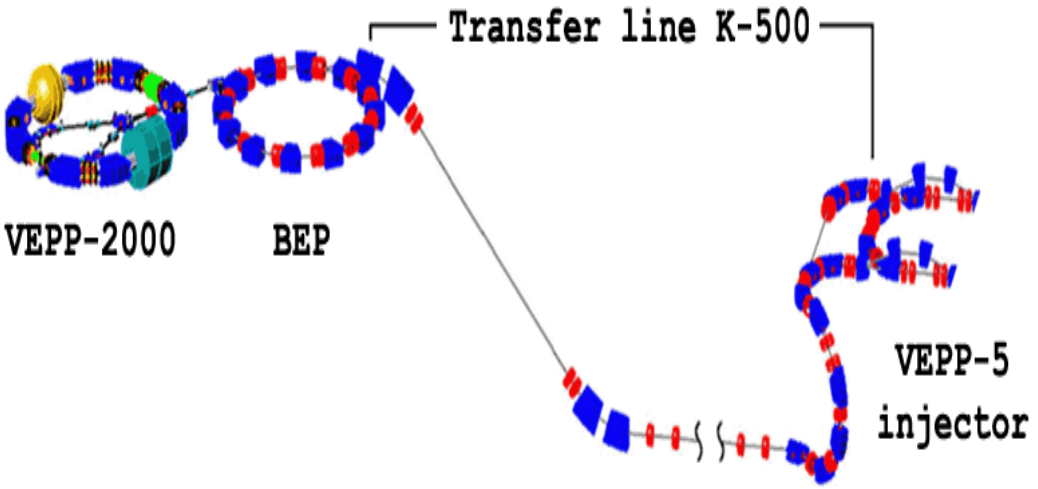
  $1\times10^{32}$ cm$^{-2}$ sec$^{-1}$ (project)

  $2\times10^{31}$ cm$^{-2}$ sec$^{-1}$ (achieved)

During 2010-2013 the luminosity was limited by shortage of positrons.

Upgrade of the VEPP-2000 complex:

- Electrons and positrons are transported from the VEPP-5 injection complex.
- Experiments at upgraded VEPP-2000 has begun at the end of 2016.



# SND data

| VEPP-2M | | | |
|---|---|---|---|
| | Below $\phi$ | Arround $\phi$ | Above $\phi$ |
| **IL, pb-1** | 9.1 | 13.2 | 8.8 |
| **√s, GeV** | 0.36 – 0.97 | 0.98 – 1.06 | 1.06 – 1.38 |
| VEPP-2000 | | | |
| **IL, pb-1** | 15.4 | 6.9 | 47.0 |
| **√s, GeV** | 0.30 – 0.97 | 0.98 – 1.05 | 1.05 – 2.00 |

About 15 hadronic processes are currently under analysis.

Here we report three new measurements.

## Precision measurement

$e^+e^- \to \pi^\circ\gamma$ (VEPP-2M, VEPP-2000 data)

## First measurements

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

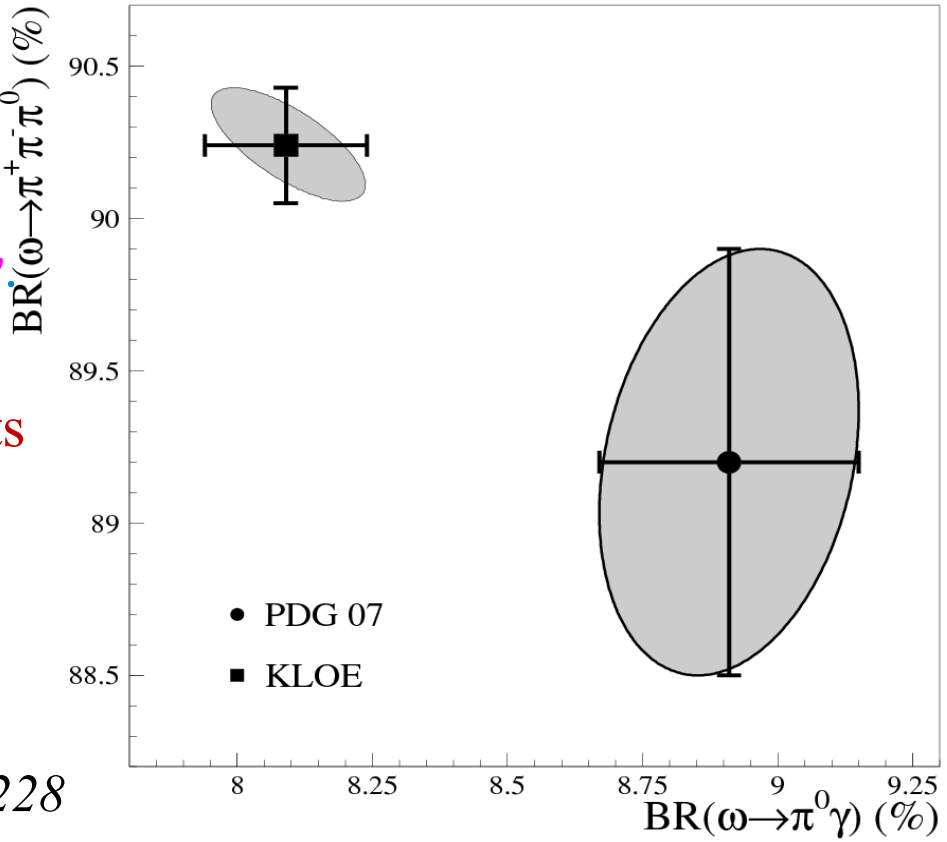
$e^+e^- \to \omega\pi^\circ\eta$

# Process $e^+e^- \to \pi^\circ\gamma$ (VEPP-2M data)

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

  KLOE have studied the $e^+e^-\to\omega\pi^\circ$ process near the $\phi$-meson resonance in two decay modes $\omega\to\pi^+\pi^-\pi^\circ$ and $\omega\to\pi^\circ\gamma$.

  The $\omega$-meson parameters obtained through KLOE studies have a large shifts from the previously measurements, especially for $\omega\to\pi^\circ\gamma$ decay.




*F. Ambrosino, et. al.,*
*Phys. Lett. B 665 (2008) 223-228*

# $e^+e^- \to \pi^\circ\gamma$: analysis features

The process $e^+e^- \to \gamma\gamma$ is used for normalization.

**Common selection criteria for $2\gamma$ and $3\gamma$ final states:**

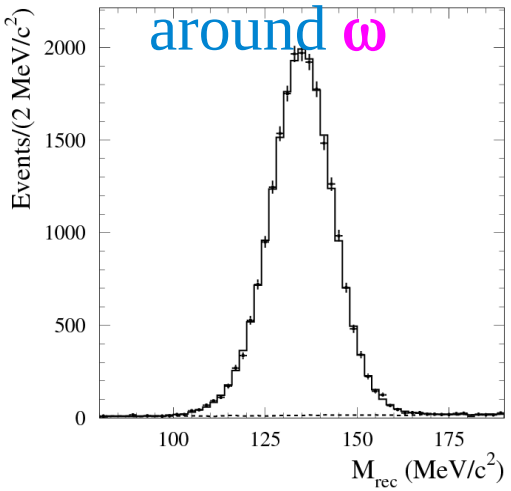
- trigger, no charged tracks, total energy deposition and momentum, muon system veto.

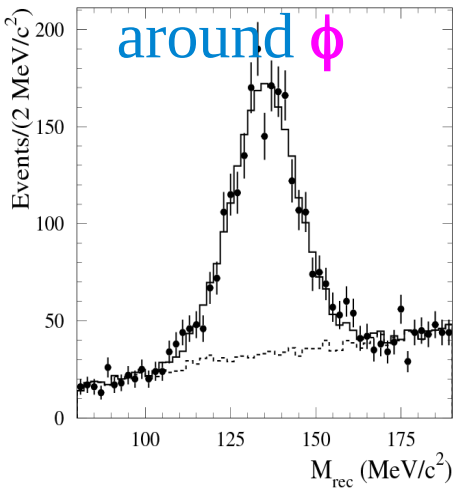
Final selection is **based on 4C kinematic fit:**

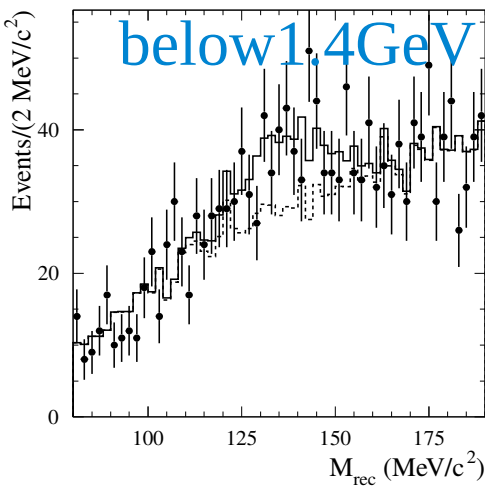
$$\chi^2_{3\gamma} < 30, \quad 36^\circ < \theta_\gamma < 144^\circ, \; 80 < M_{rec} < 190 \text{ MeV},$$

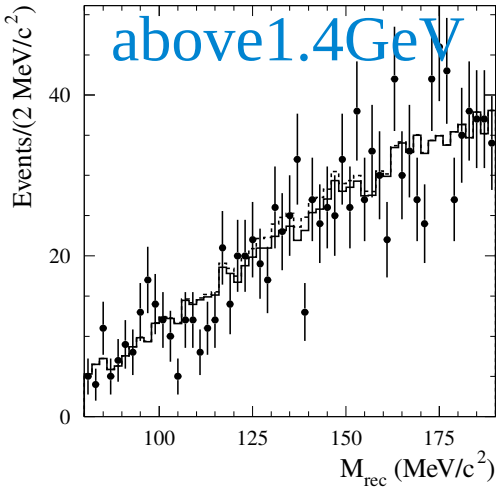
here $M_{rec}$ is the mass recoiling against largest energy photon.

The number of signal events is determined from **the fit of $\pi^\circ$ in $M_{rec}$ spectrum.**

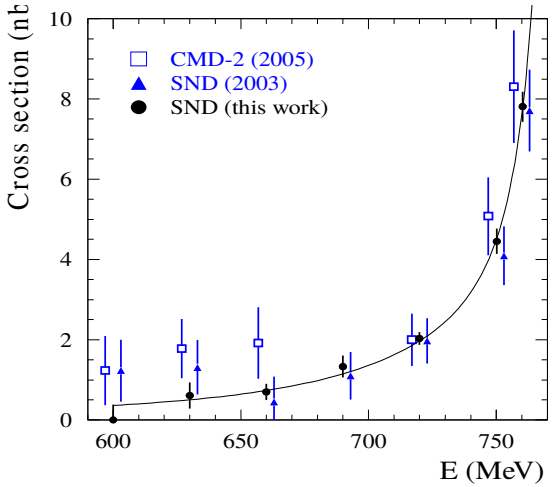


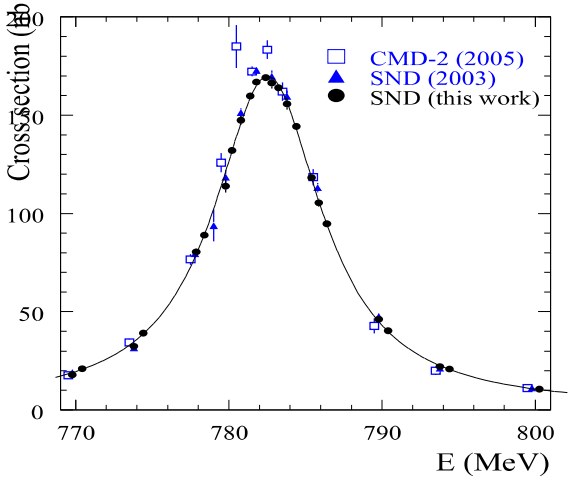



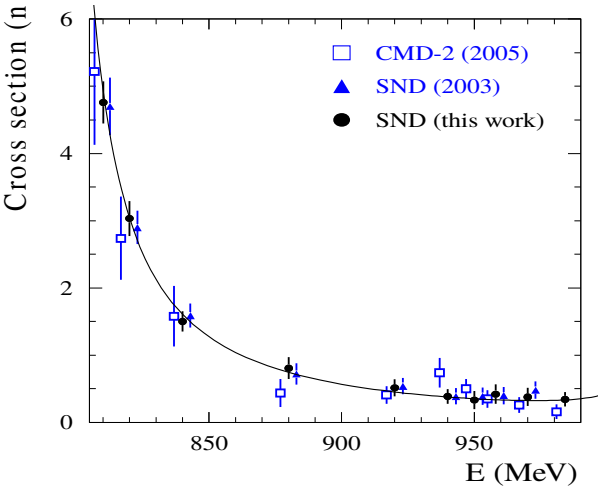



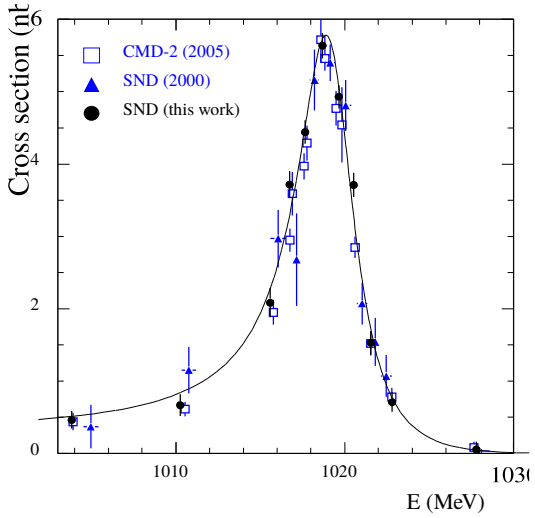



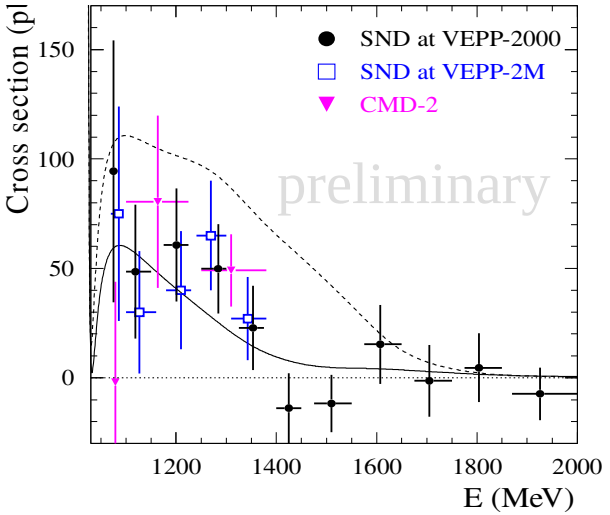
# $e^+e^- \to \pi^\circ\gamma$: cross-section




The most precise measurement of the $e^+e^- \to \pi^\circ\gamma$ cross section.

Systematic uncertainty at the ω peak is **1.4%**:

- luminosity **1.2%**
- selection criteria **0.6%**

***M.N. Achasov, et. al., Phys. Rev. D 93 092001 (2016)***

# Results on radiative decays

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

Using PDG value for **$B(\omega\to\pi^+\pi^-\pi^\circ)\times B(\omega\to e^+e^-)$** we have obtained **$\Gamma(\omega\to\pi^\circ\gamma)/\Gamma(\omega\to\pi^+\pi^-\pi^\circ)=0.0992\pm0.0023$**,
which is higher than the KLOE value **$0.0897\pm0.0016$** by **$3.4\sigma$ .**

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

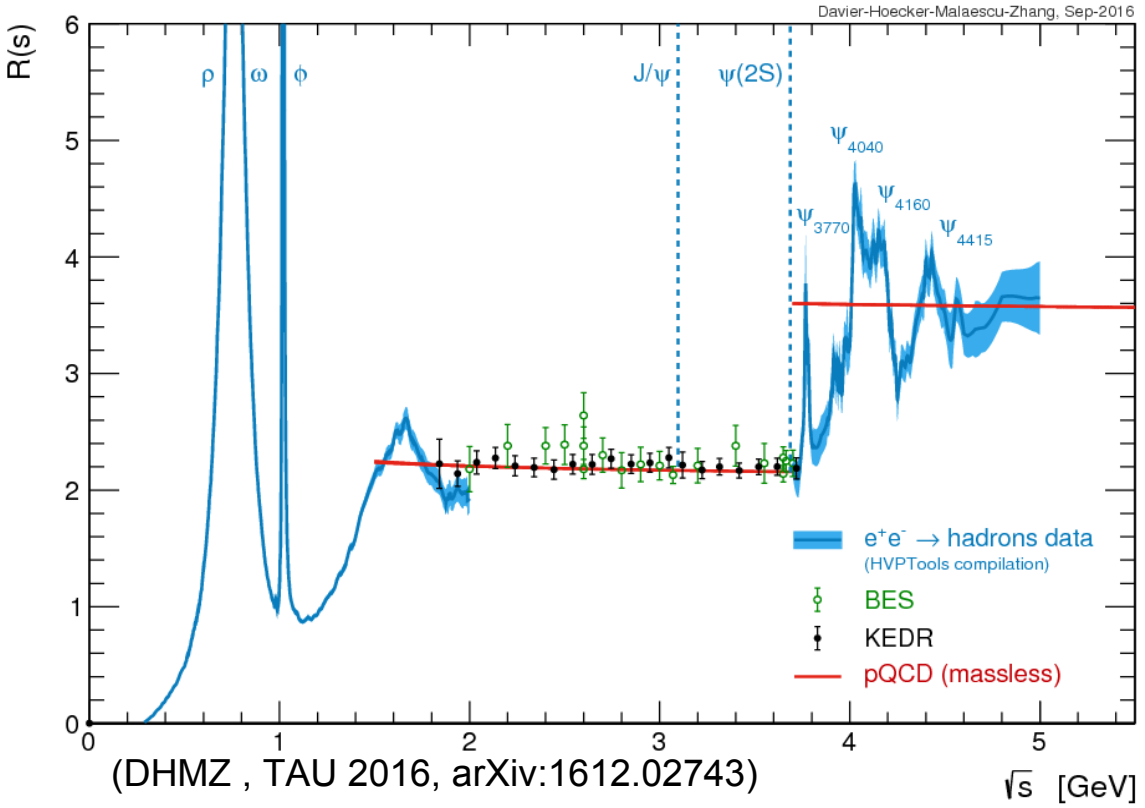
By **$1.8\sigma$** lower than the current PDG value **$(6.0\pm0.8)\times10^{-4}$**, but agrees with the branching fraction for the charged mode **$B(\rho^\pm\to\pi^\pm\gamma) = (4.5\pm0.5)\times10^{-4}$.**

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

The model uncertainties of the previous measurements (**~8%**) were underestimated. For $\phi_\phi$ fixed at the value **$(163\pm7)^\circ$** obtained in the VMD fit to **$e^+e^-\to\pi^+\pi^-\pi^\circ$** data

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

# Exclusive vs inclusive measurements



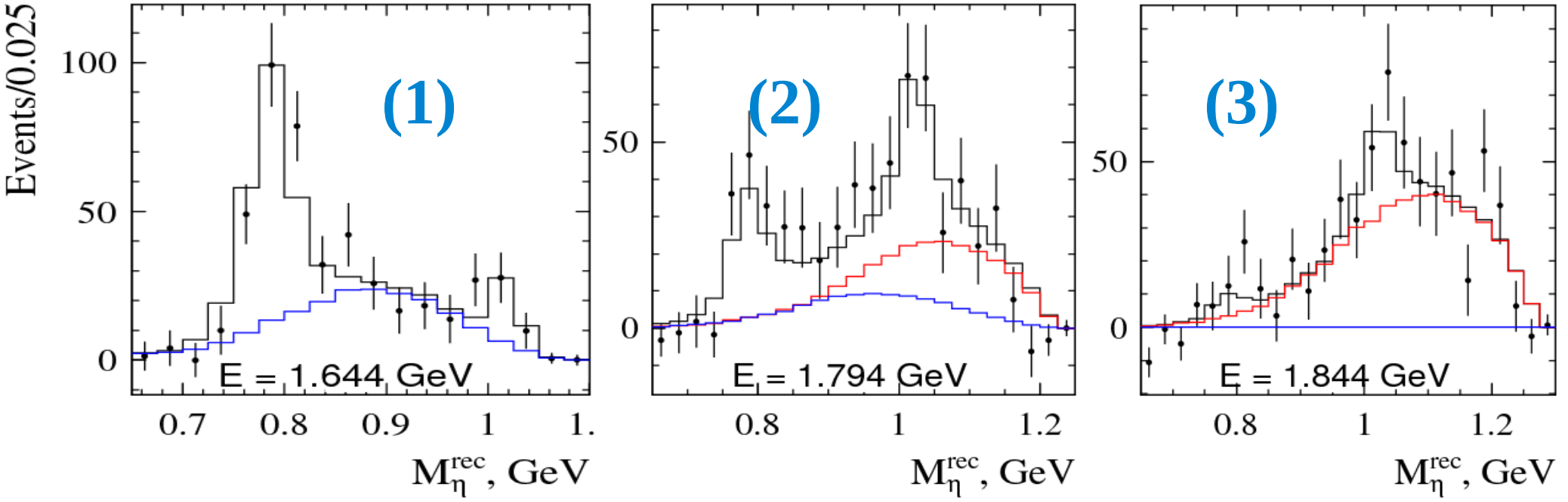

Below **2 GeV** the total hadronic cross section is calculated as a sum of exclusive cross sections.

Currenly 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 are no experimental data on the final states $\pi^+\pi^-\pi^\circ\eta$, $\pi^+\pi^-\eta\eta$, $\pi^+\pi^-\pi^\circ\pi^\circ\pi^\circ$, $\pi^+\pi^-\pi^\circ\pi^\circ\eta$, ...

# Process $e^+e^- \to \pi^+\pi^-\pi^\circ\eta$

Mass recoling against $\eta$




Spectrum contributions:

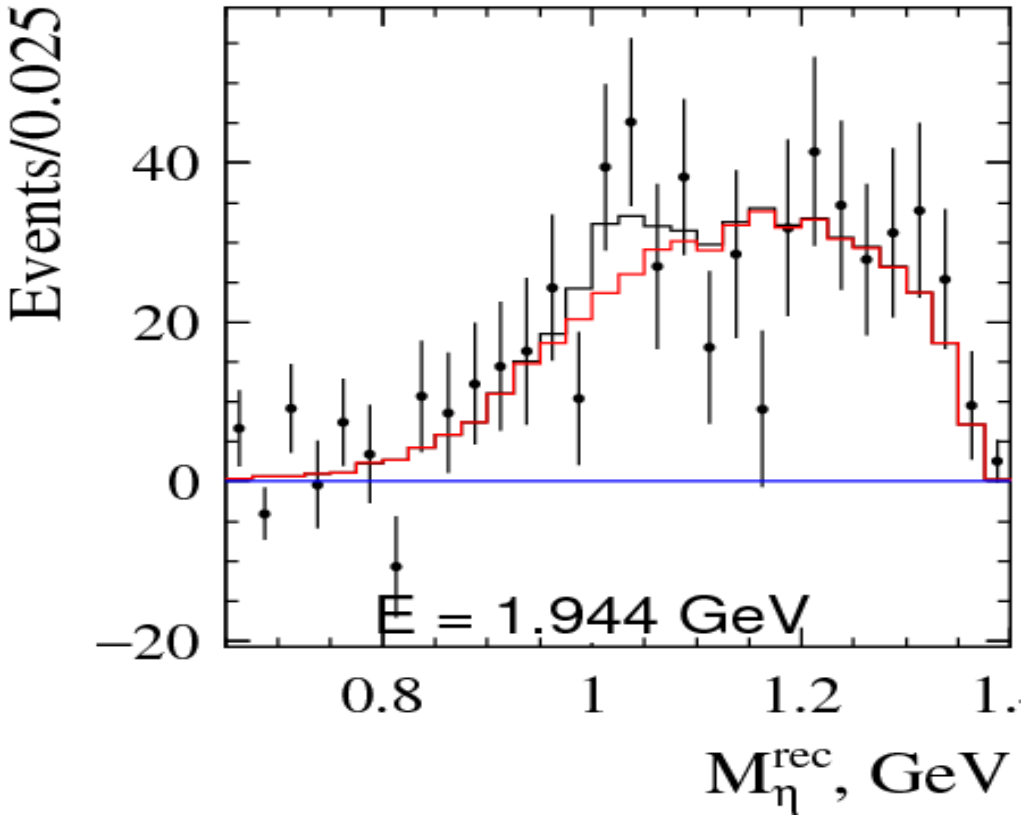
(1) sum of $\omega\eta$, $\phi\eta$ and structureless $\pi^+\pi^-\pi^\circ\eta$ (blue);

(2) sum of $\omega\eta$, $\phi\eta$, structureless $\pi^+\pi^-\pi^\circ\eta$ and $a_0(980)\rho$ (red) ;

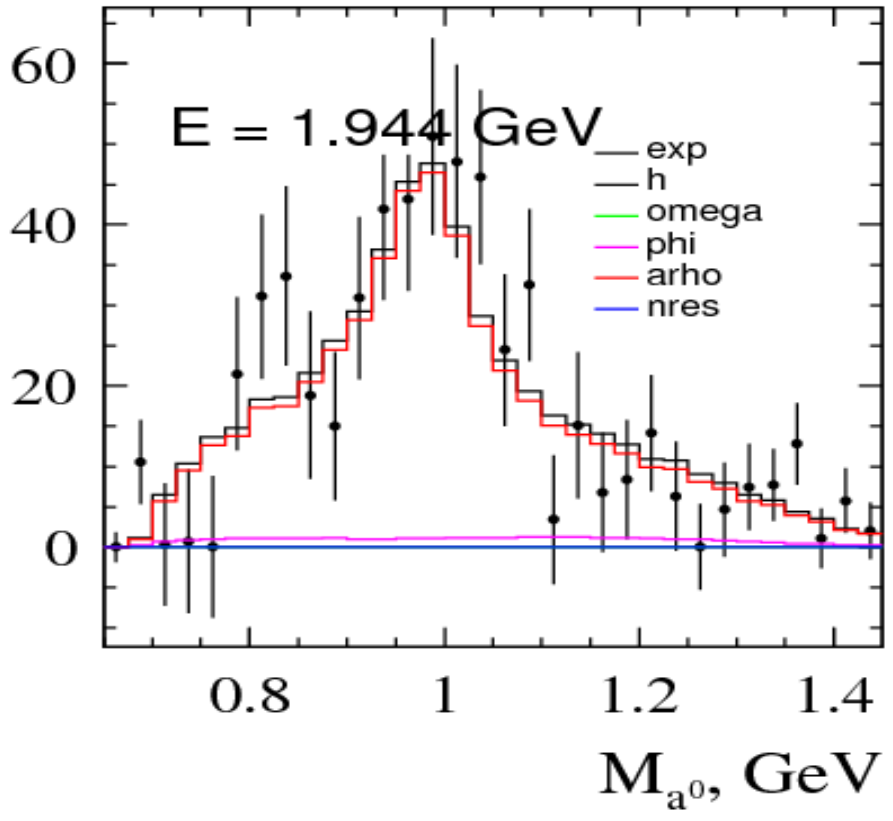
(3) sum of $\phi\eta$ and $a_0(980)\rho$ contributions.

# $e^+e^- \to \pi^+\pi^-\pi^\circ\eta$: mass spectrum

Mass recoling against $\eta$.

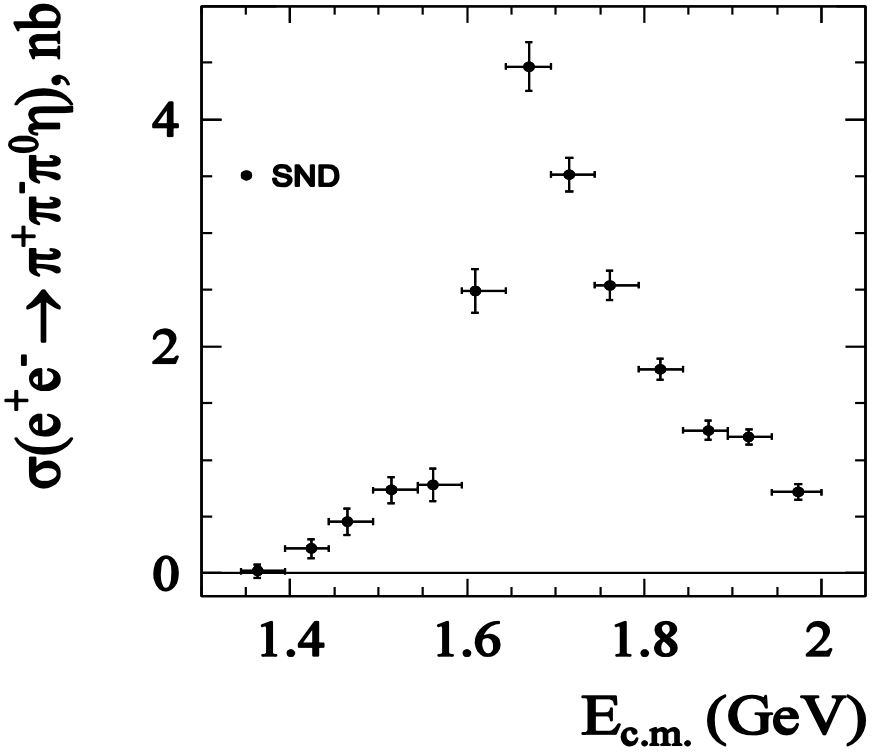



$\eta\pi$ invariant mass.




Above **1.8 GeV** the dominant mechanism of this reaction is $\mathbf{a_0(980)\rho}$.

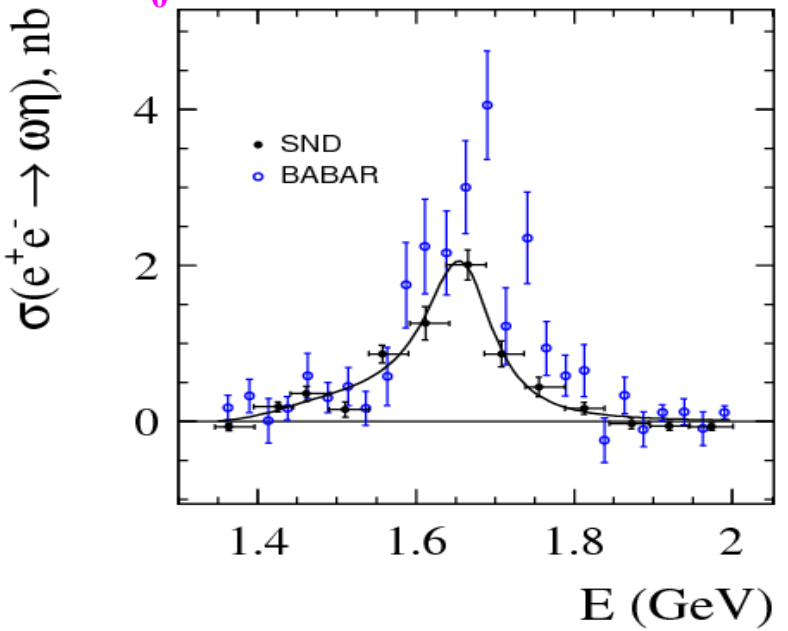
# $e^+e^- \to \pi^+\pi^-\pi^0\eta$: cross-section



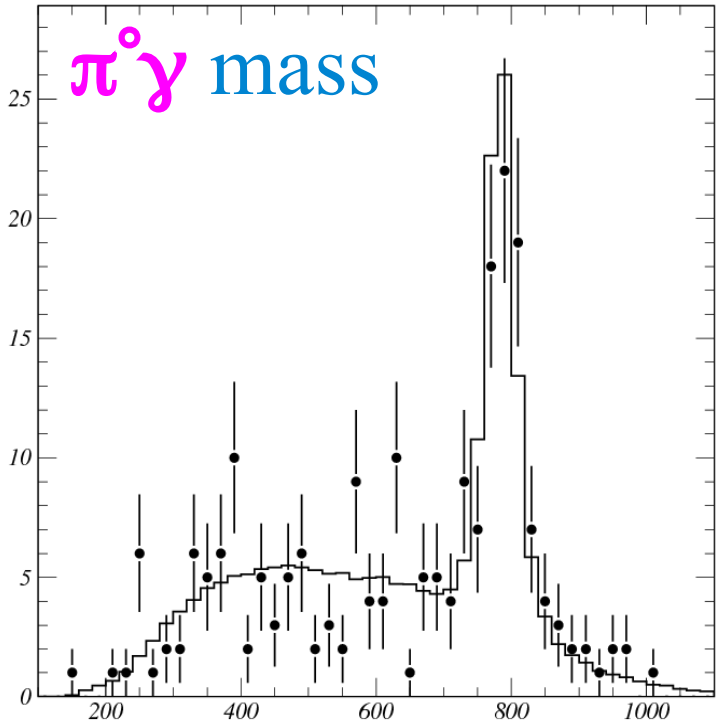

- First measurement of this process.
- The intermediate states are $\omega\eta$, $\phi\eta$, structureless $\pi^+\pi^-\pi^0\eta$ and $a_0(980)\rho$.
- The known $\omega\eta$ and $\phi\eta$ contributions explain about 50-60% of the cross section below **1.8 GeV**.
- Above **1.8 GeV** the dominant reaction mechanism is $a_0(980)\rho$.

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

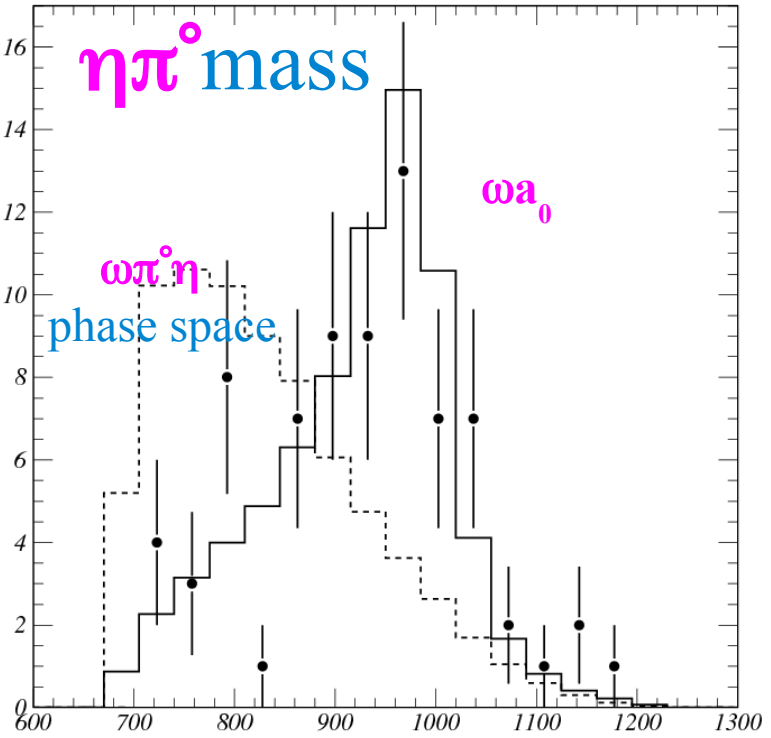
***Phys. Rev. D 94, 092002 (2016)***
***arXiv:1607.00371 [hep-ex]***



# Process $e^+e^- \to \omega\pi^\circ\eta$

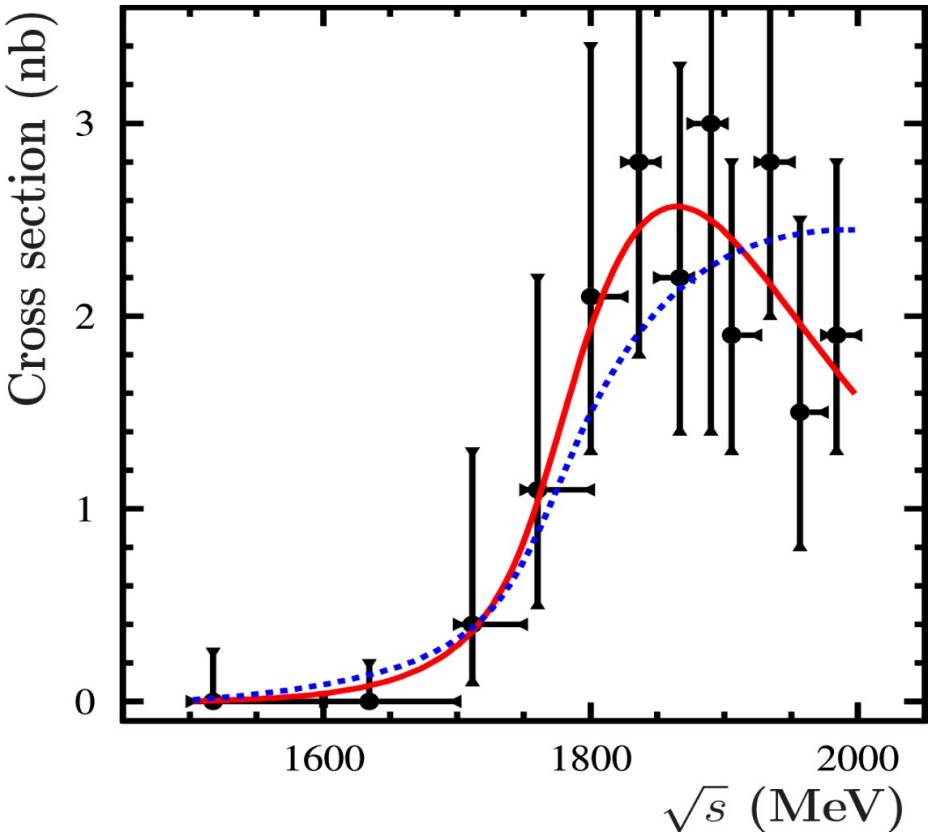



Events of the $e^+e^- \to \pi^\circ\pi^\circ\eta\gamma \to 7\gamma$ process are selected. The dominant intermediate state is $\omega\pi^\circ\eta$. No noticeable $\eta'\gamma$ signal observed.




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

# $e^+e^- \to \omega\pi^\circ\eta$: cross section




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

*and non-resonant is worse at 1.2σ*

***Phys. Rev. D 94, 032010 (2016)***
***arXiv:1606.06481 [hep-ex]***

The cross section is about **2.5 nb.**
**5%** of the total hadronic cross section in the energy region **1.8 – 2.0 GeV**.

# Conclusions

- During **2010 – 2013** the **SND** detector accumulated **~70 pb$^{-1}$** of integrated luminosity at the **VEPP-2000** electron-positron 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 ($\pi^\circ\gamma$).
- For some processes the cross sections have been measured for the first time ($\pi^+\pi^-\pi^\circ\eta$, $\omega\pi^\circ\eta$).
- After **VEPP-2000** upgrade the data taking runs will be continued with a goal of **~1 fb$^{-1}$** of integrated luminosity.