Overview of SND Hadronic Cross Section Measurements

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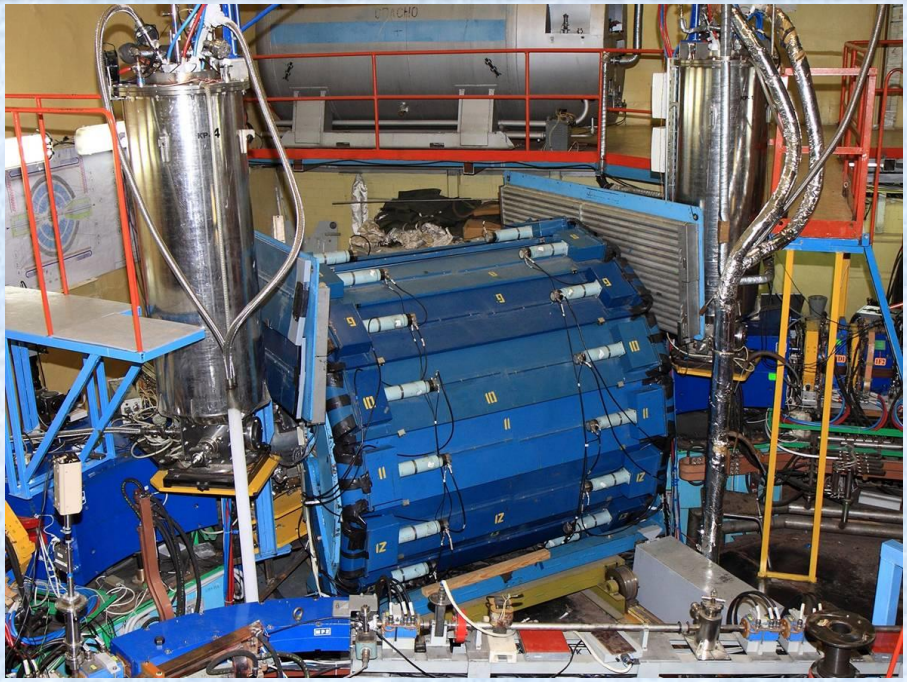
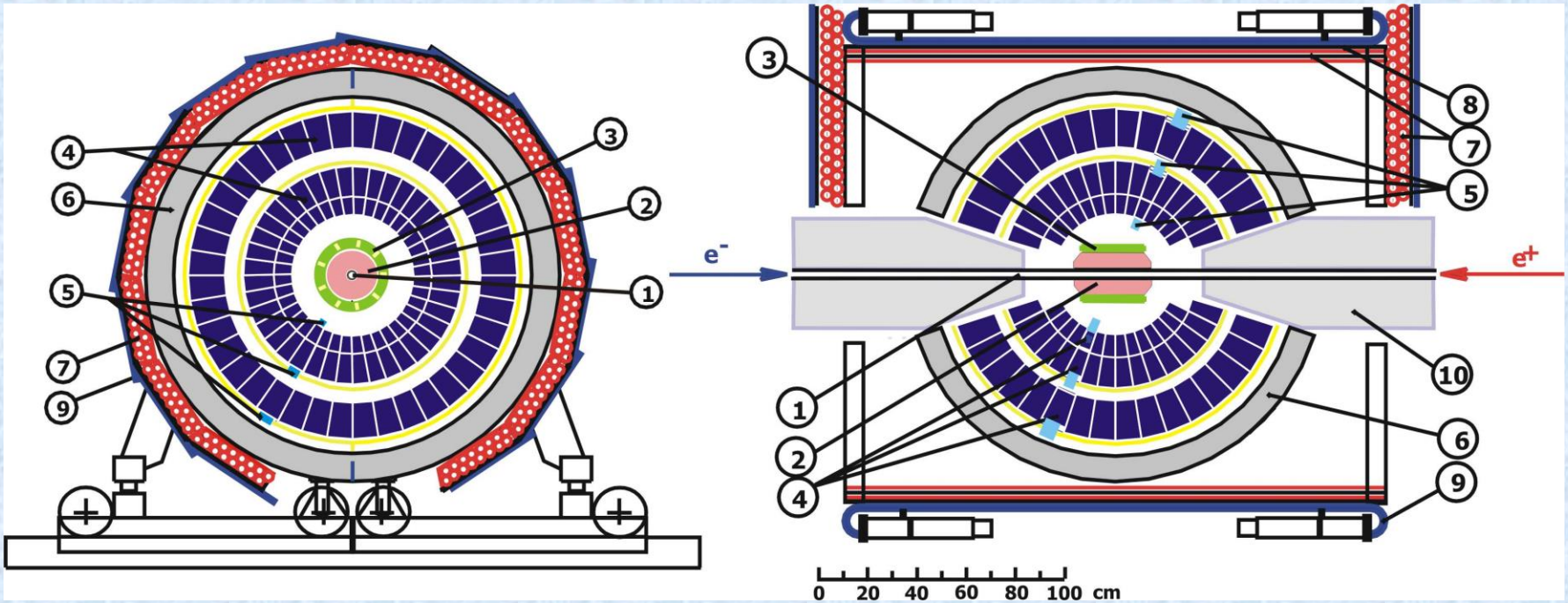


SND detector

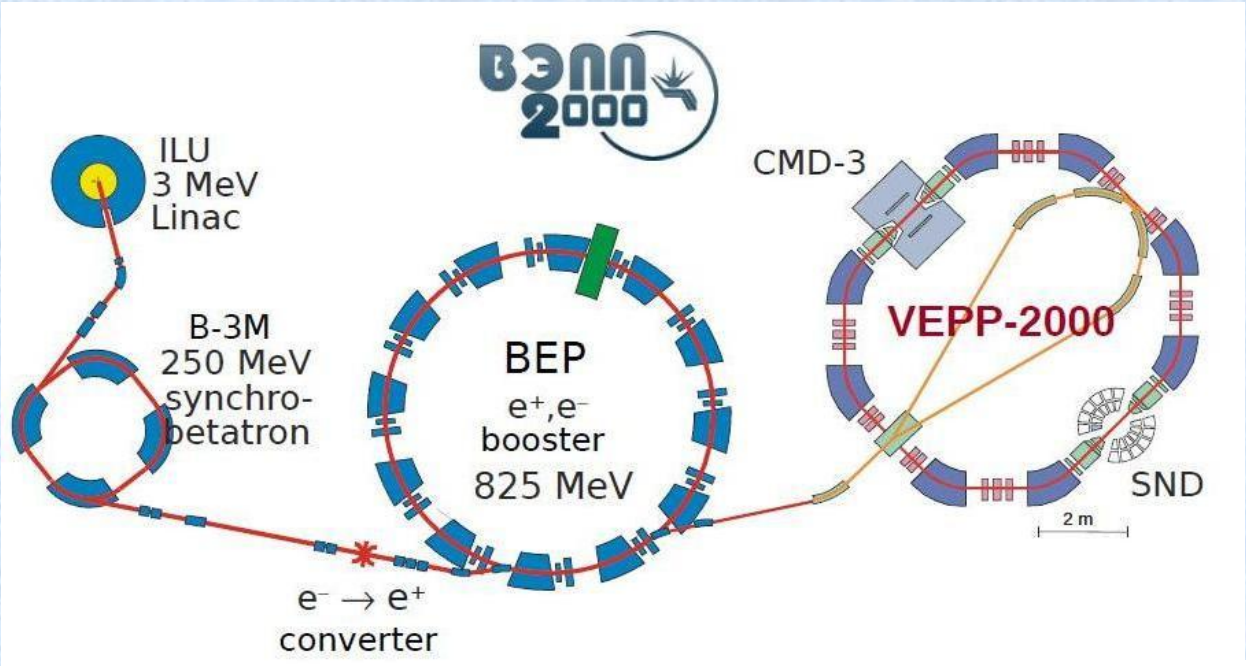
NIM A449 (2000) 125-139



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

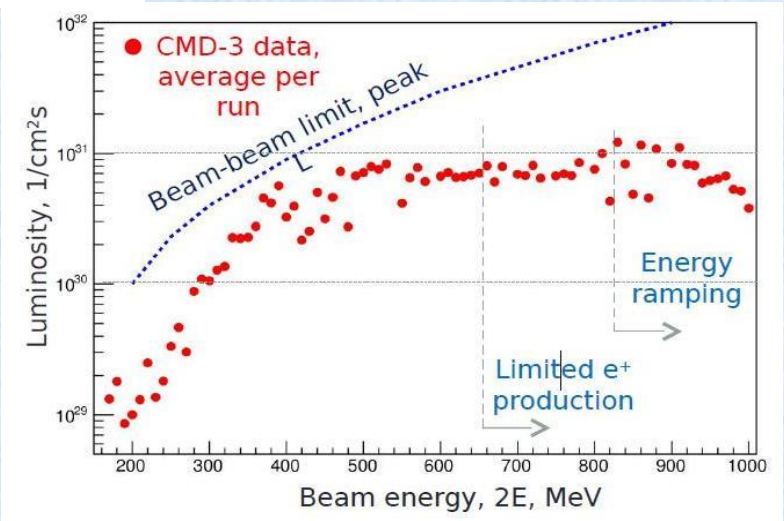
SND collected data at VEPP-2M (1996-2000) and at VEPP-2000 (2010-2013, 2016 - …)

VEPP-2000 Collider (2010-2013)



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

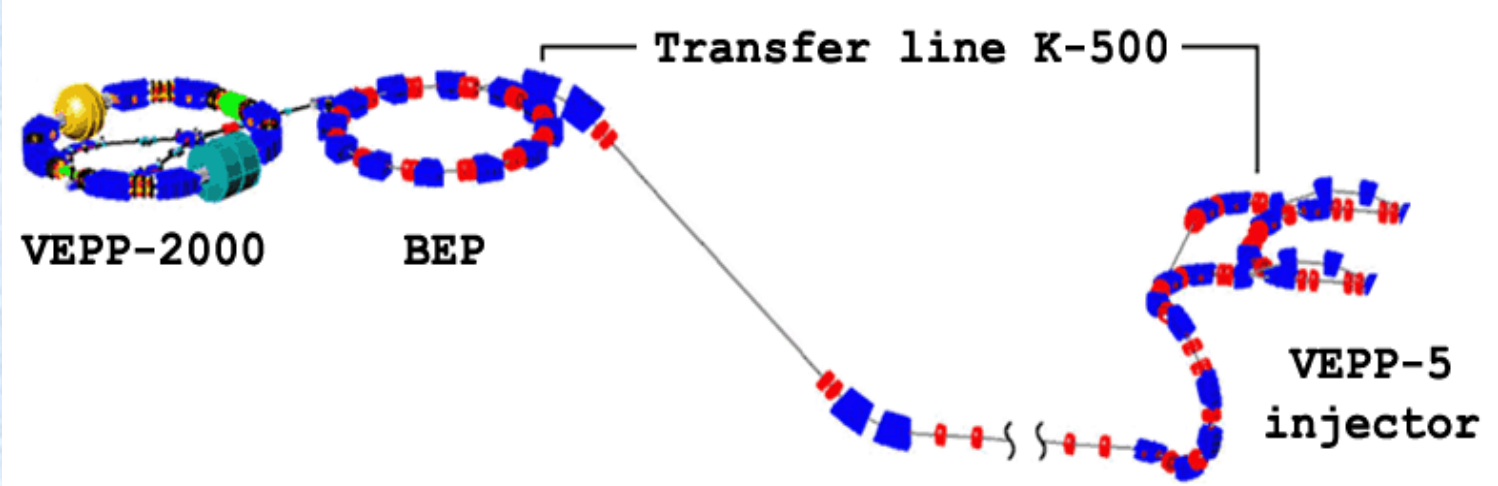
Luminosity vs. energy



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 $L_{max}=2\times10^{31}cm^{-2}c^{-1}$

Upgraded VEPP-2000



✓ The injection system was changed: electrons and positrons are transported from the VEPP-5 injection complex through 250 m beamline.

✓ Experiments at upgraded VEPP-2000 has begun at the end of 2016.

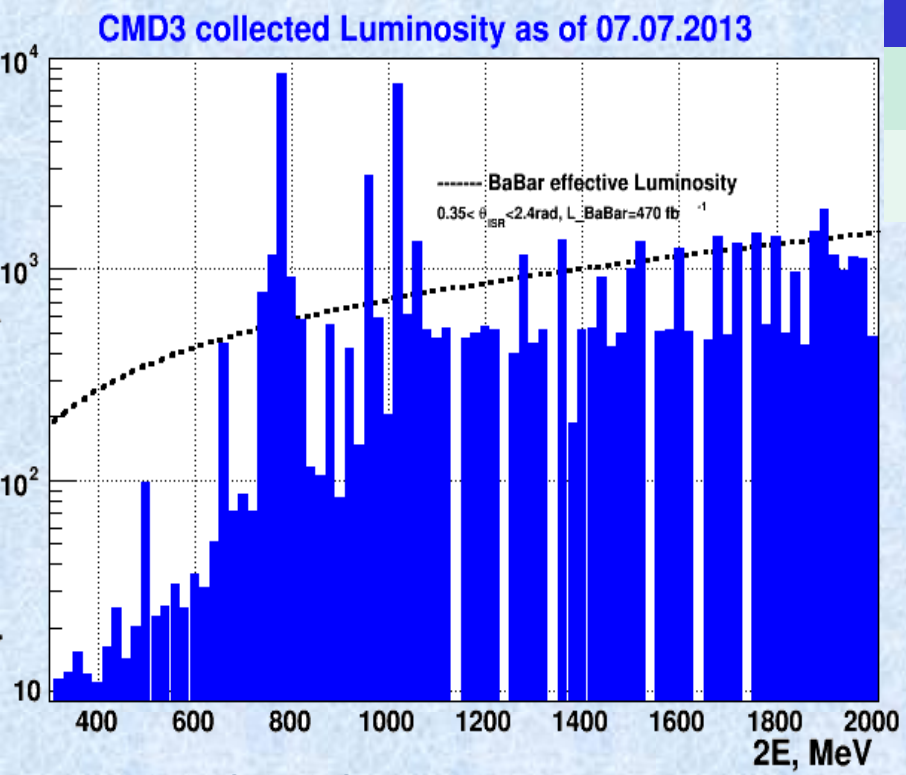
✓Achieved luminosity is about $L_{max}=4\times10^{31}cm^{-2}c^{-1}$

✓About **$50pb^{-1}$** of integrated luminosity has been already collected during the 2017 run

Collected Luminosity

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}	15.4	6.9	47.0
E_{cm}, GeV	0.30-0.97	0.98-1.05	1.05-2.00

SND physical results (journal articles)

1. $e^+e^- \to \pi^0\pi^0\gamma$, Phys.Rev.D, (2013)
2. $e^+e^- \to nn$, Phys.Rev.D,(2014)
3. $e^+e^- \to NN+6\pi$, JETP Lett.,(2014)
4. $e^+e^- \to \eta\gamma$, Phys.Rev.D,(2014)
5. $e^+e^- \to \eta'$, Phys.Lett.B,(2015)
6. $e^+e^- \to \eta\pi^+\pi^-$, Phys.Rev.D,(2015)
7. $e^+e^- \to \pi^+\pi^-\pi^0$, JETP,(2015)
8. $e^+e^- \to \eta$ JETP Lett.,(2015)
9. $e^+e^- \to \omega\eta\pi^0$, Phys.Rev.D,(2016)
10. $e^+e^- \to \omega\eta$, Phys.Rev.D,(2016)
11. $e^+e^- \to \pi^0\gamma$, Phys.Rev.D,(2016)
12. $e^+e^- \to \pi^0\pi^0\gamma$, Phys.Rev.D, (2016)
13. $e^+e^- \to K^+K^-$ Phys. Rev. D, (2016)

~15 hadronic processes are currently under analysis

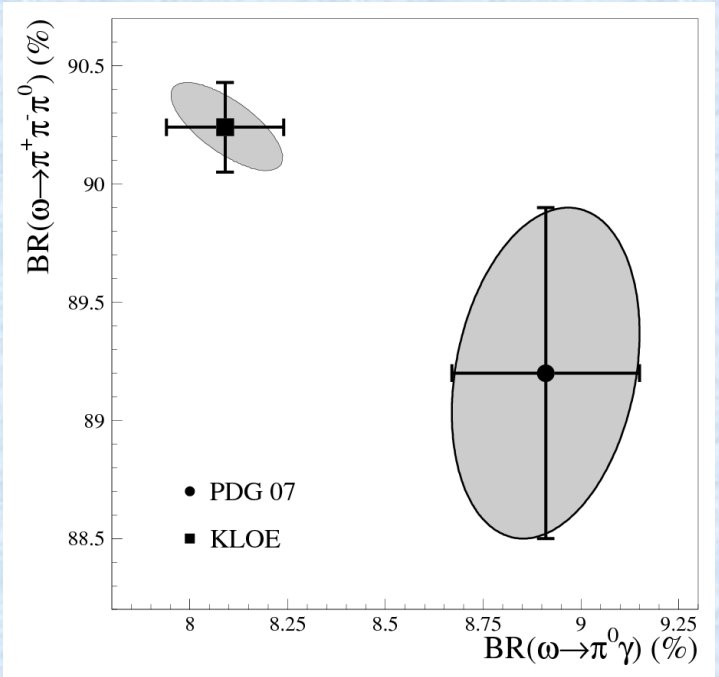
Precise measurements of cross sections

$e^+e^- \to \pi^0\gamma$ (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 $V\to\pi^0\gamma$, $V=\rho, \omega, \phi$ …
- There is a tension between the KLOE measurement of the ratio $\Gamma(\omega\to\pi^0\gamma)/\Gamma(\omega\to\pi^+\pi^-\pi^0)$ and other measurements of ω-meson parameters.

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

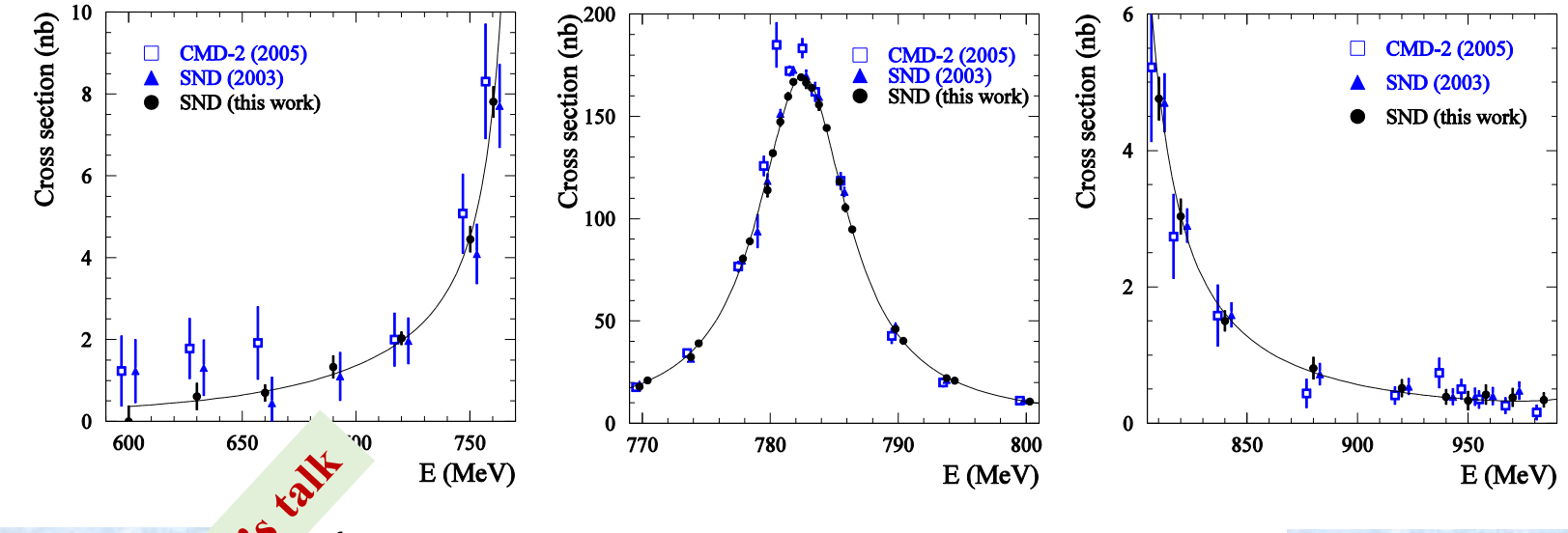
The KLOE measurement led to a large shifts of the previously measured ω-meson parameters, especially for $\omega\to\pi^0\gamma$.



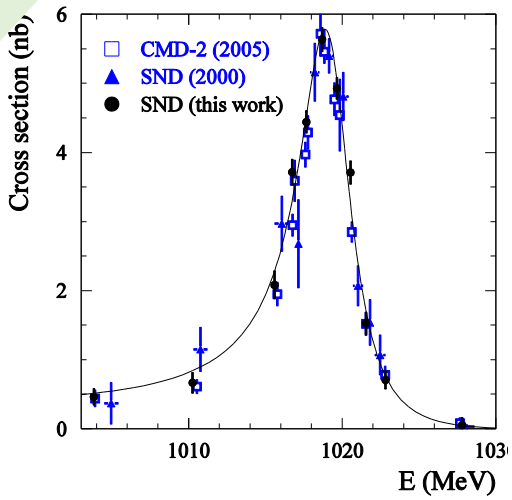
$e^+e^- \to \pi^0\gamma$ (from VEPP-2M)

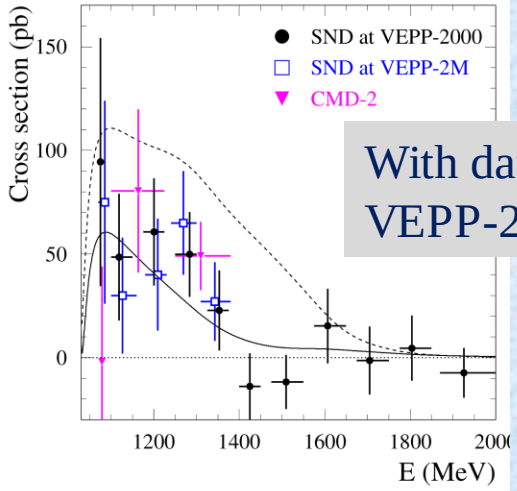
Cross section in 5 energy regions

Phys.Rev.D93,092001(2016)



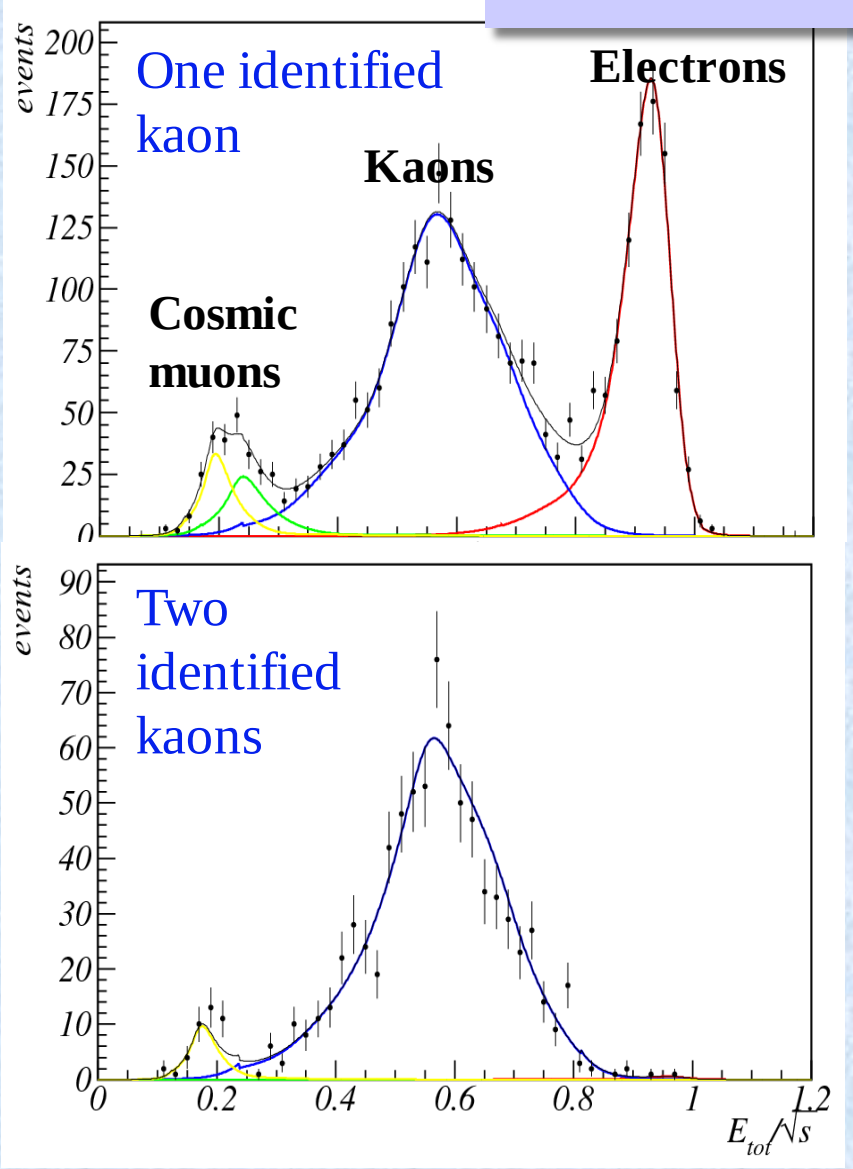
Details in Kardopoltzev's talk





With data from VEPP-2000

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



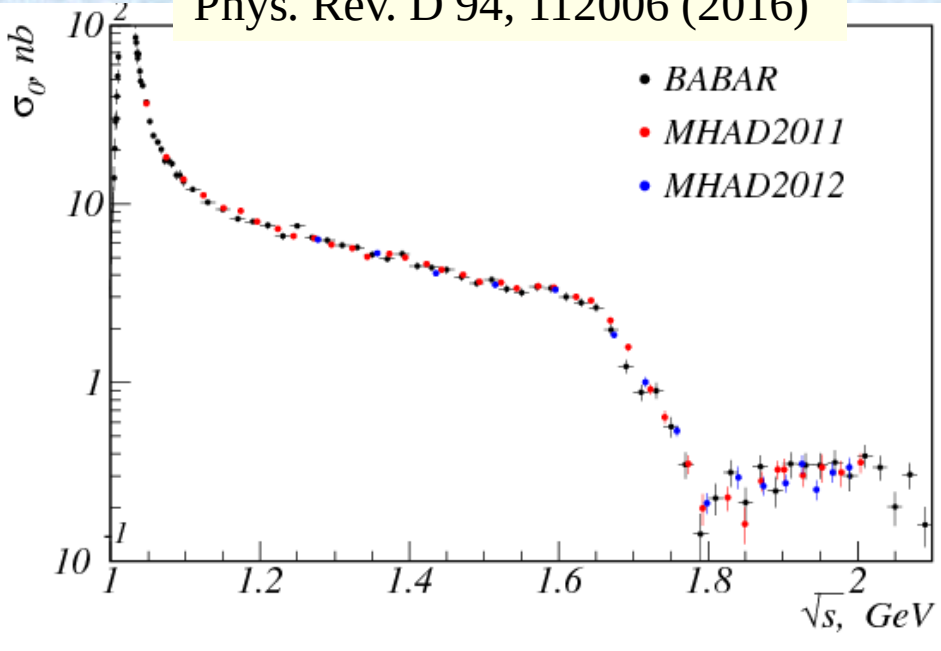
Kaon identification is based on information from Cherenkov aerogel counters.

Kaons do not produce Cherenkov signal in the counter, while electron, muon and pions do.

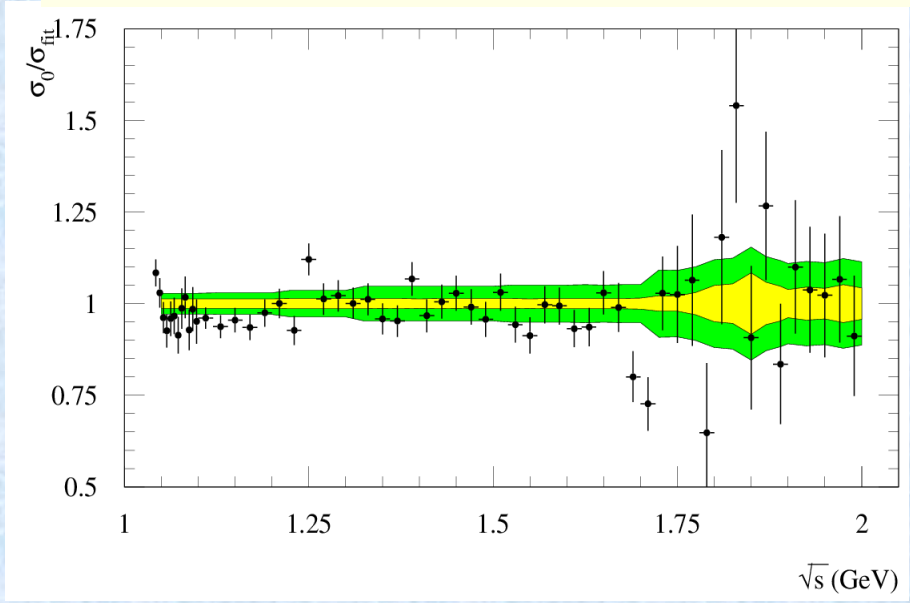
The kaon ID requirement suppresses background from $e^+e^- \rightarrow e^+e^-$ by a factor of 300.

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

Phys. Rev. D 94, 112006 (2016)



(BABAR data)/(SND fit) ratio

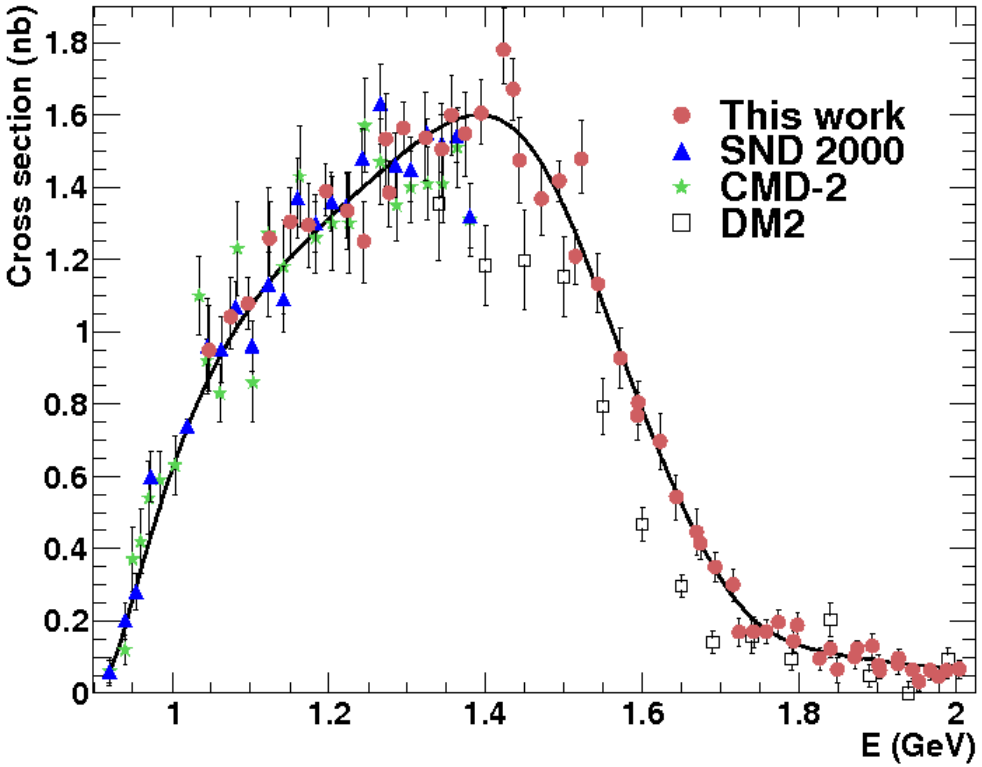


Our measurement agrees with the BABAR data and has comparable or better accuracy.

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

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

Phys.Rev.D94(2016) 112001

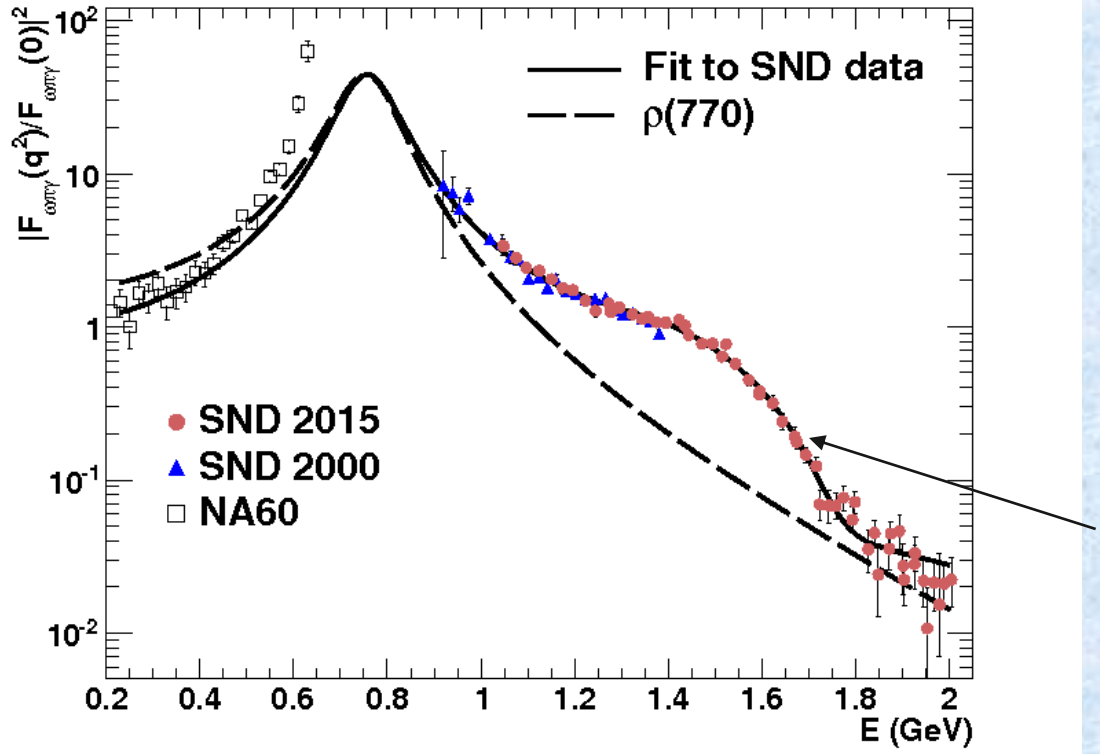


- Our previous result based on 2010-2011 data has been updated using the **full** SND data set.
- The mistake has been fixed in the radiative correction calculation.
- The cross section is described by a sum of the ρ(770), ρ(1450), and ρ(1700) contributions.

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

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

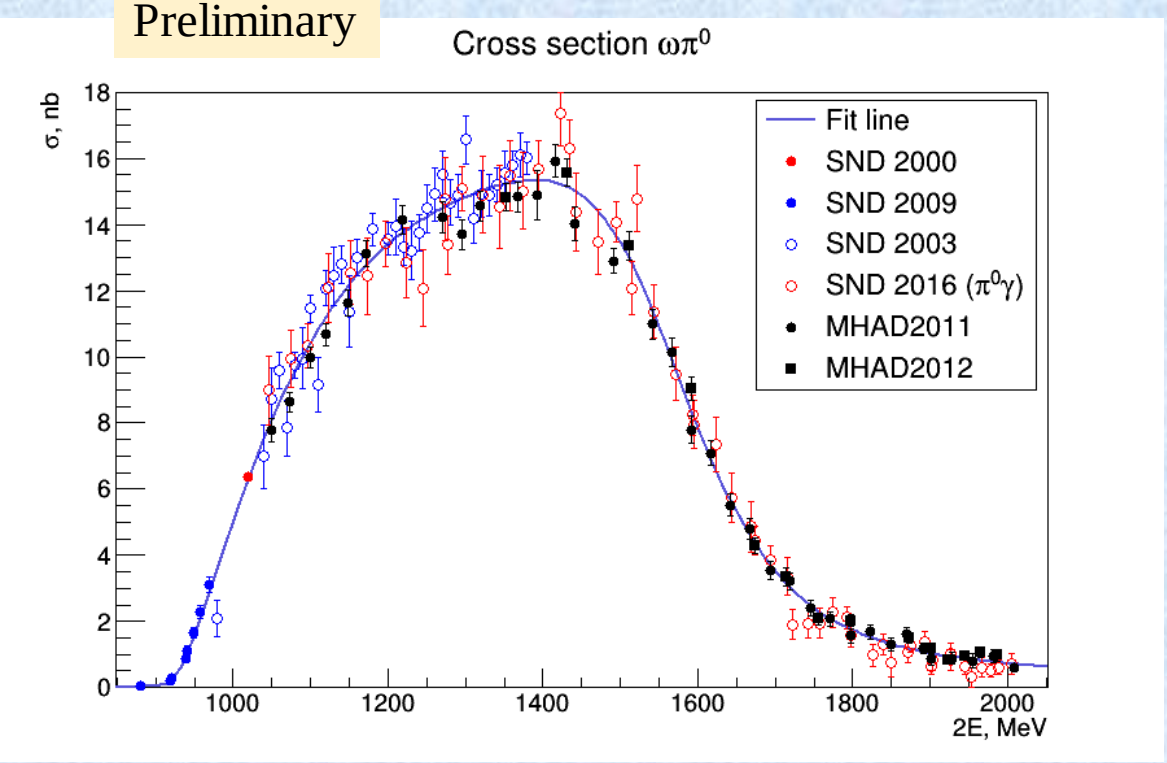
$$\sigma_{\omega\pi^\circ} = \frac{4\pi\alpha^2}{E^3}\left|F_{\omega\pi\gamma}(E^2)\right|^2 P_f(E),\ P_f(E) - \text{phase space factor}$$



- 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 $\rho(1450)$ contribution

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

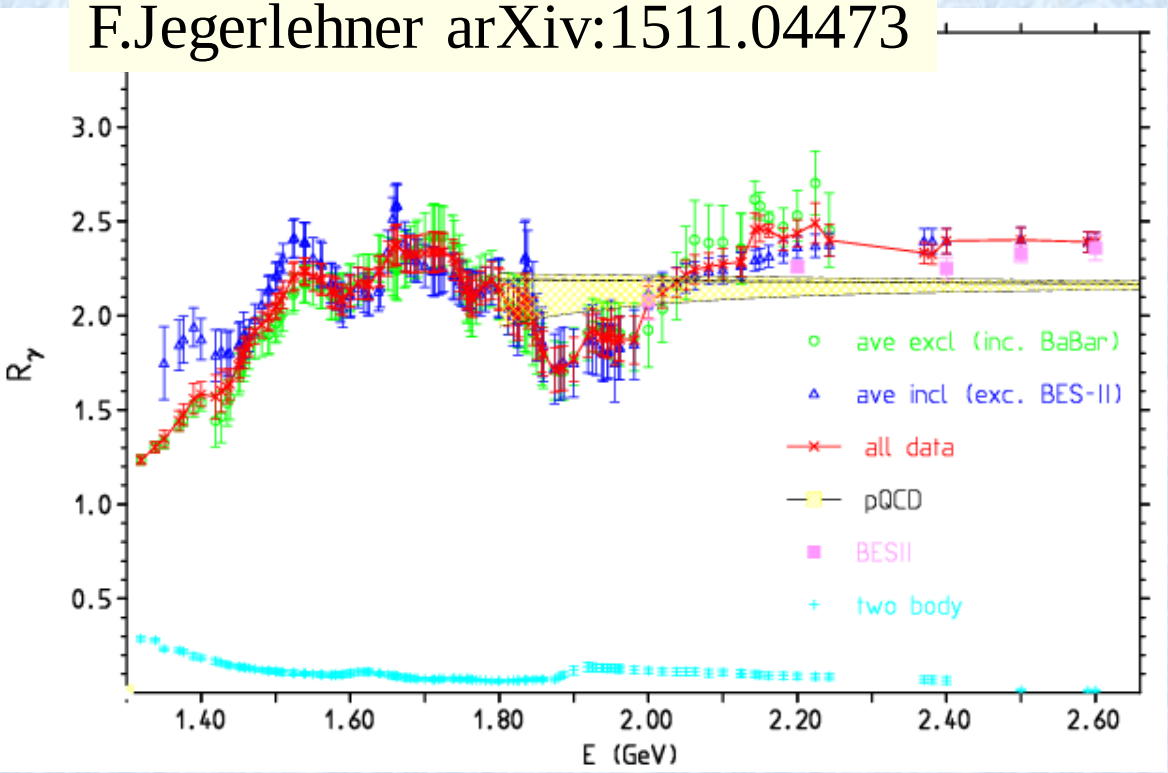
Preliminary



- This result is based on 2011-2012 data set.
- Statistical error varies from 2 to 16 % depending on energy
- Systematic error varies from 1 to 9%

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
- Currenly the exclusive and inclusive data below 2 GeV are in reasonable agreement.
- But the exclusive data are incomplete in the region $1.6<E<2.0$ GeV.

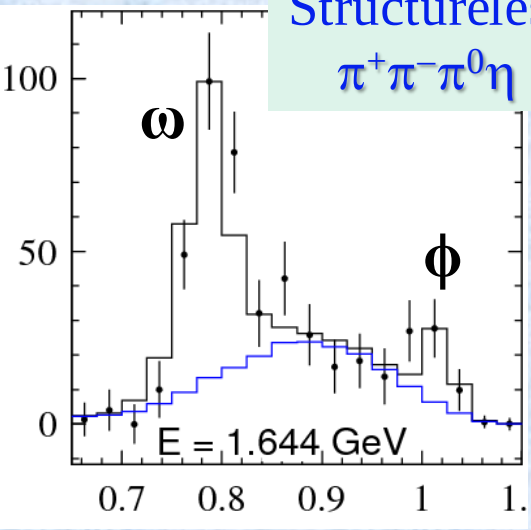
There is no experimental data on the final states $\pi^+\pi^-\pi^0\eta$, $\pi^+\pi^-\eta\eta$, $\pi^+\pi^-\pi^0\,\pi^0\pi^0$, $\pi^+\pi^-\pi^0\pi^0\eta$ …

More details in poster of A.Botov

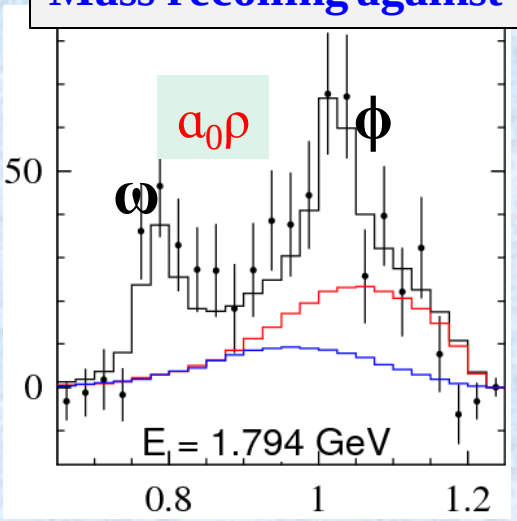
$e^+e^- \to \pi^+\pi^-\pi^0\eta$

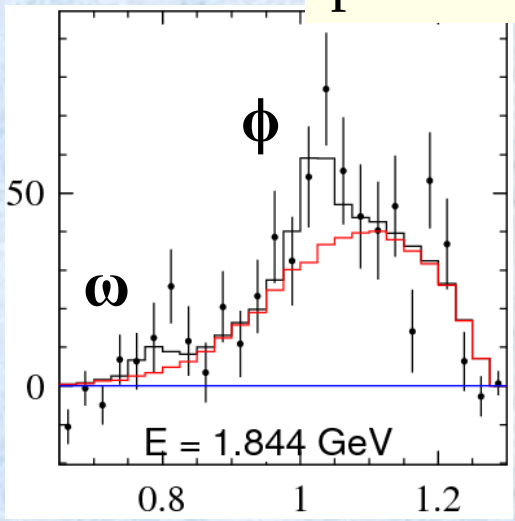
preliminary

Structureless $\pi^+\pi^-\pi^0\eta$

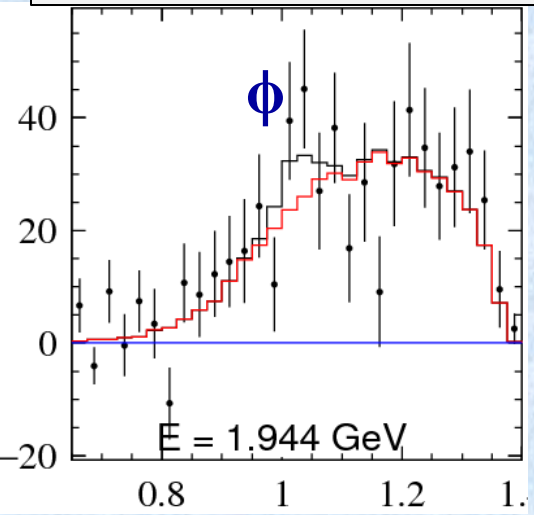


Mass recoiling against η

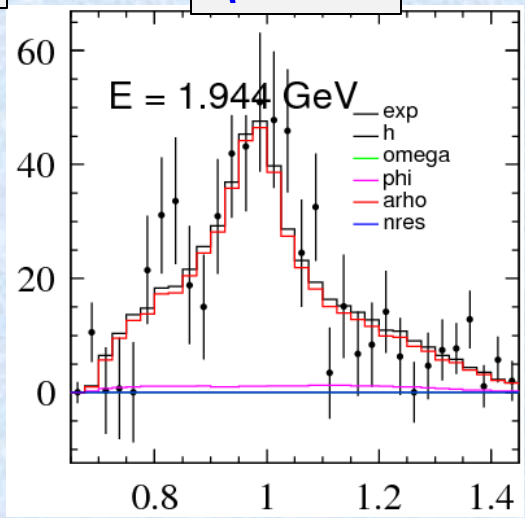




Mass recoiling against η

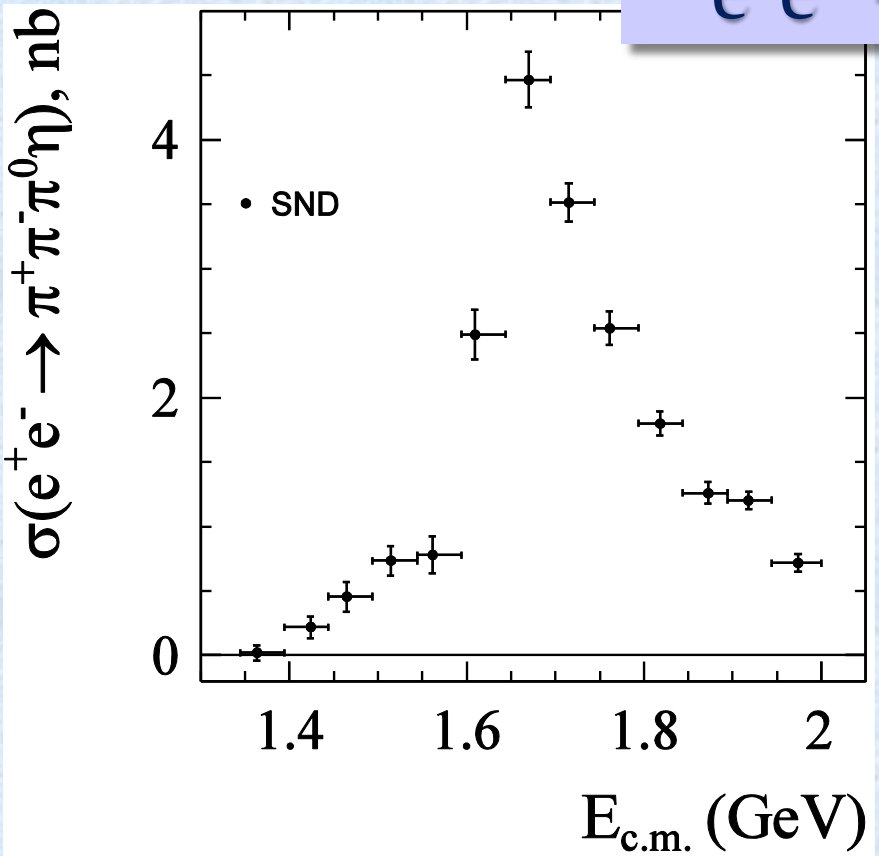


ηπ mass



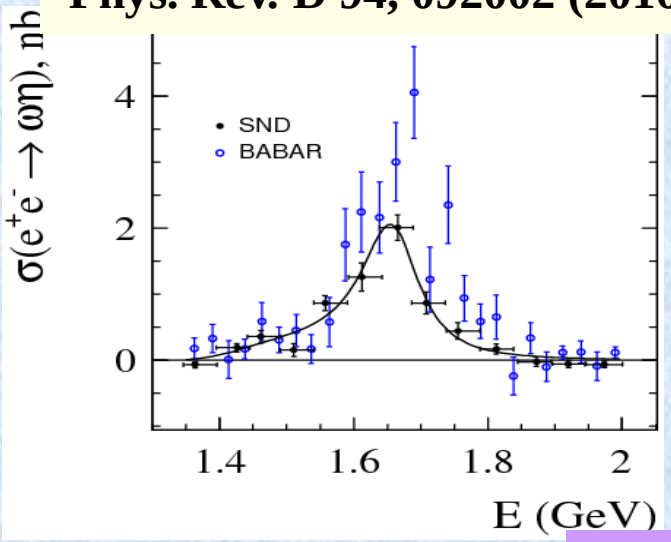
- **ωη** and **ϕη** intermediate states are clearly seen in the spectrum of the mass recoiling against **η**
- **a_0 (980)ρ** intermediate state is seen in the **ηπ** spectrum
- Some fraction of events at E below 1.8 GeV do not have any clear structure.

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



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

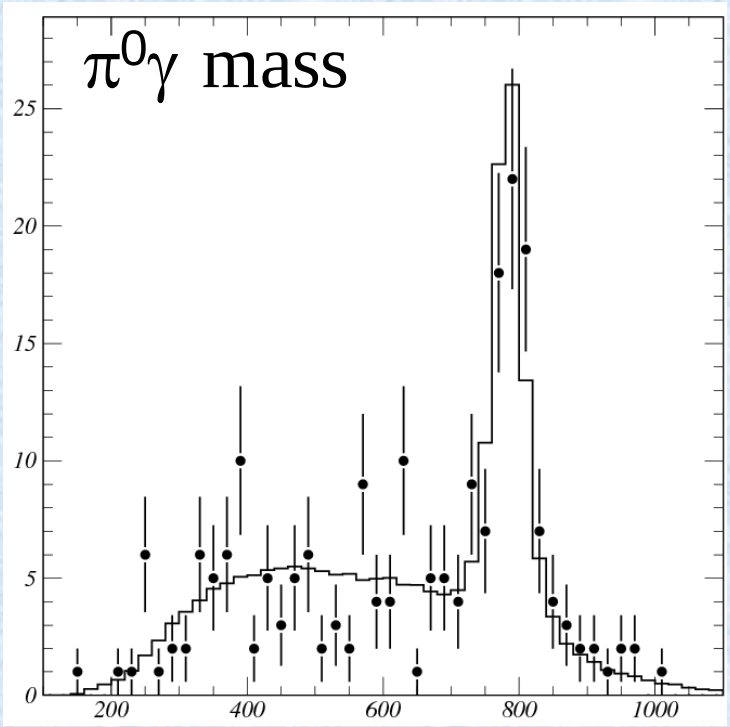
Phys. Rev. D 94, 092002 (2016)



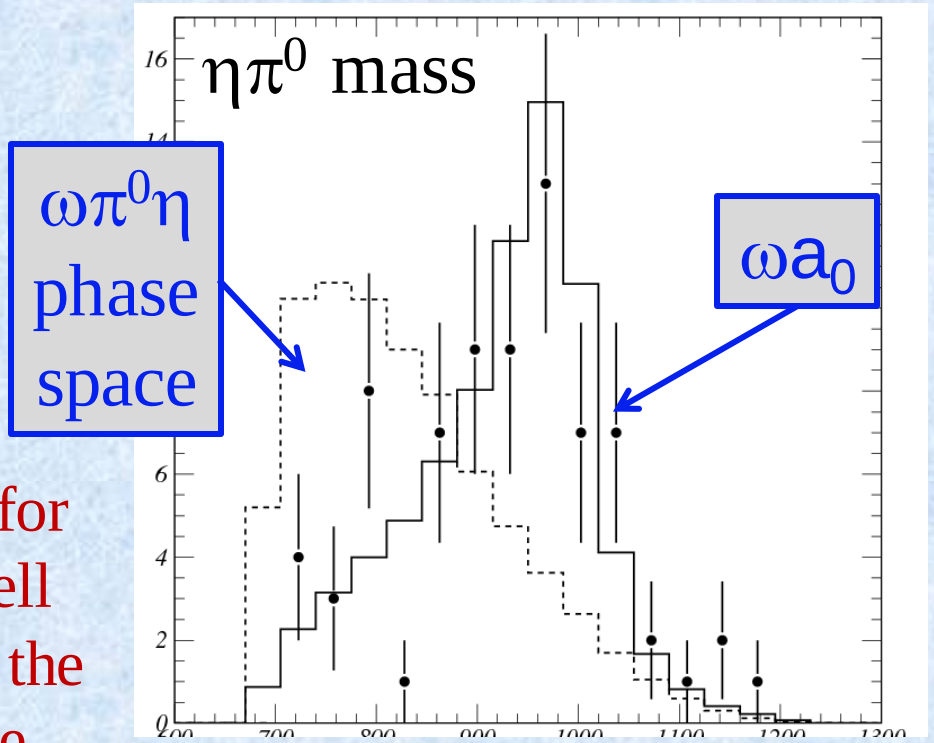
- The process **$e^+e^- \to \omega\eta$** has been measured separately.
- There is a significant difference between our result and the previous BABAR measurement.

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

First observation



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

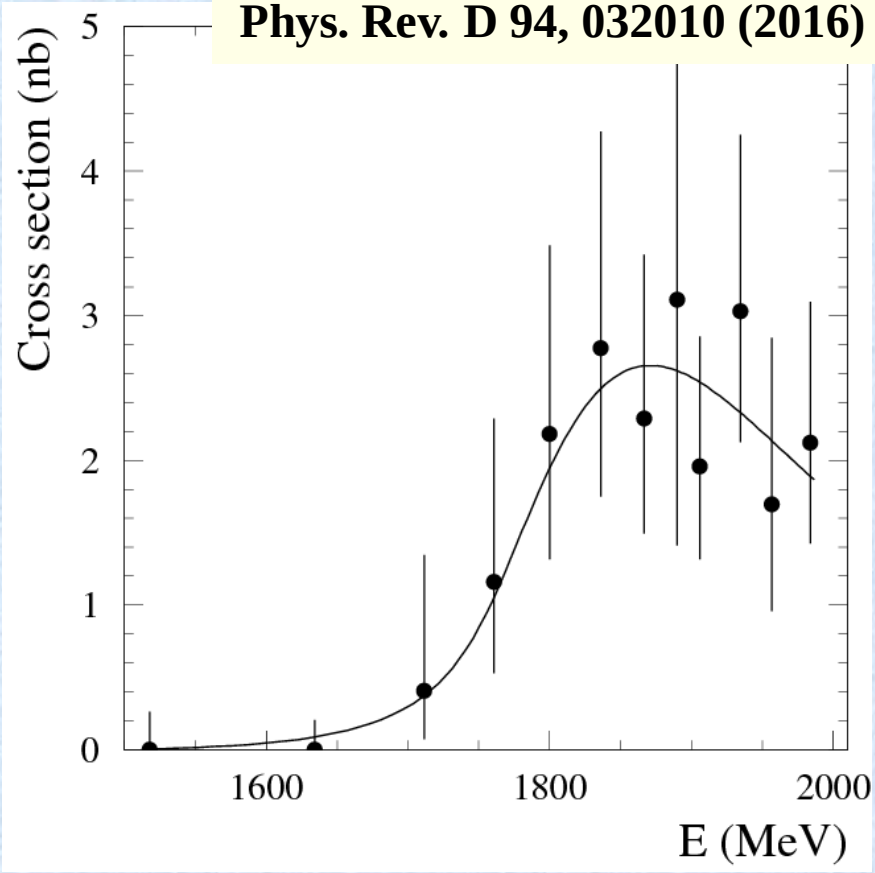


- The $\eta\pi^0$ mass spectrum for selected $\omega\pi^0\eta$ events is well described by the model of the $\omega a_0(980)$ intermediate state

First observation

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

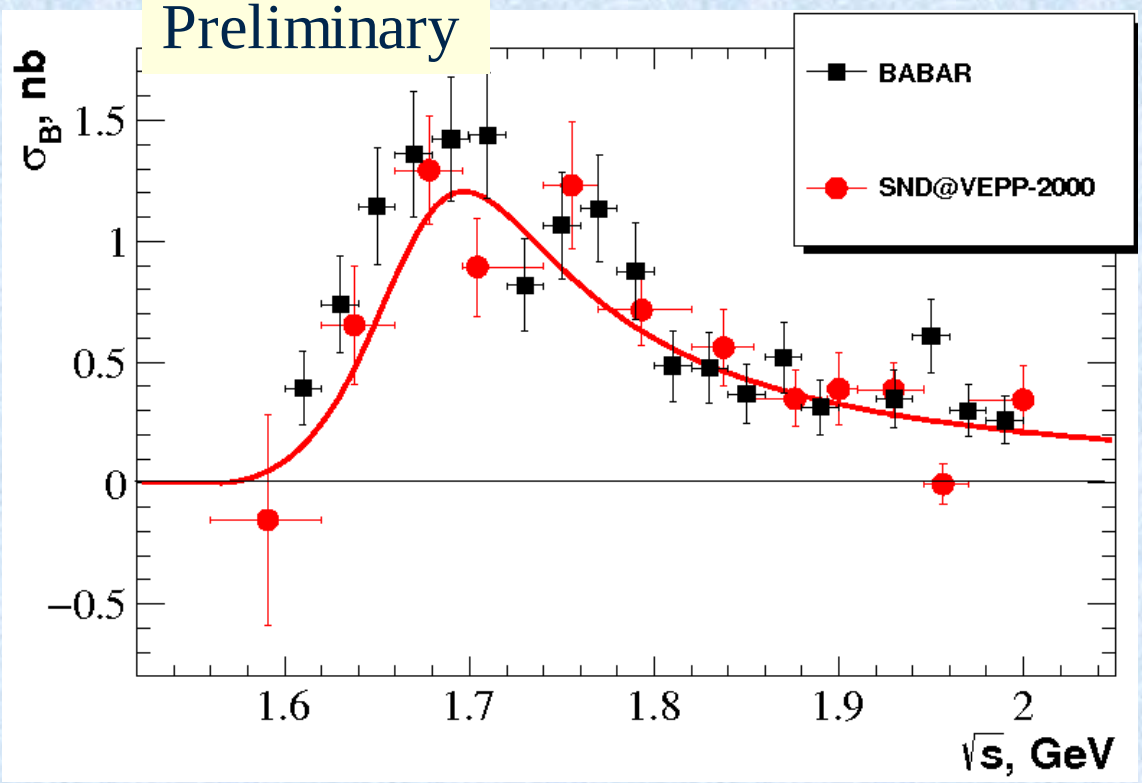
Phys. Rev. D 94, 032010 (2016)



- First measurement of the $e^+e^- \to \omega\pi^0\eta$ 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.

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



- Kaon identification is based on information from Cherenkov aerogel counters and energy deposition in drift chamber

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

Summary

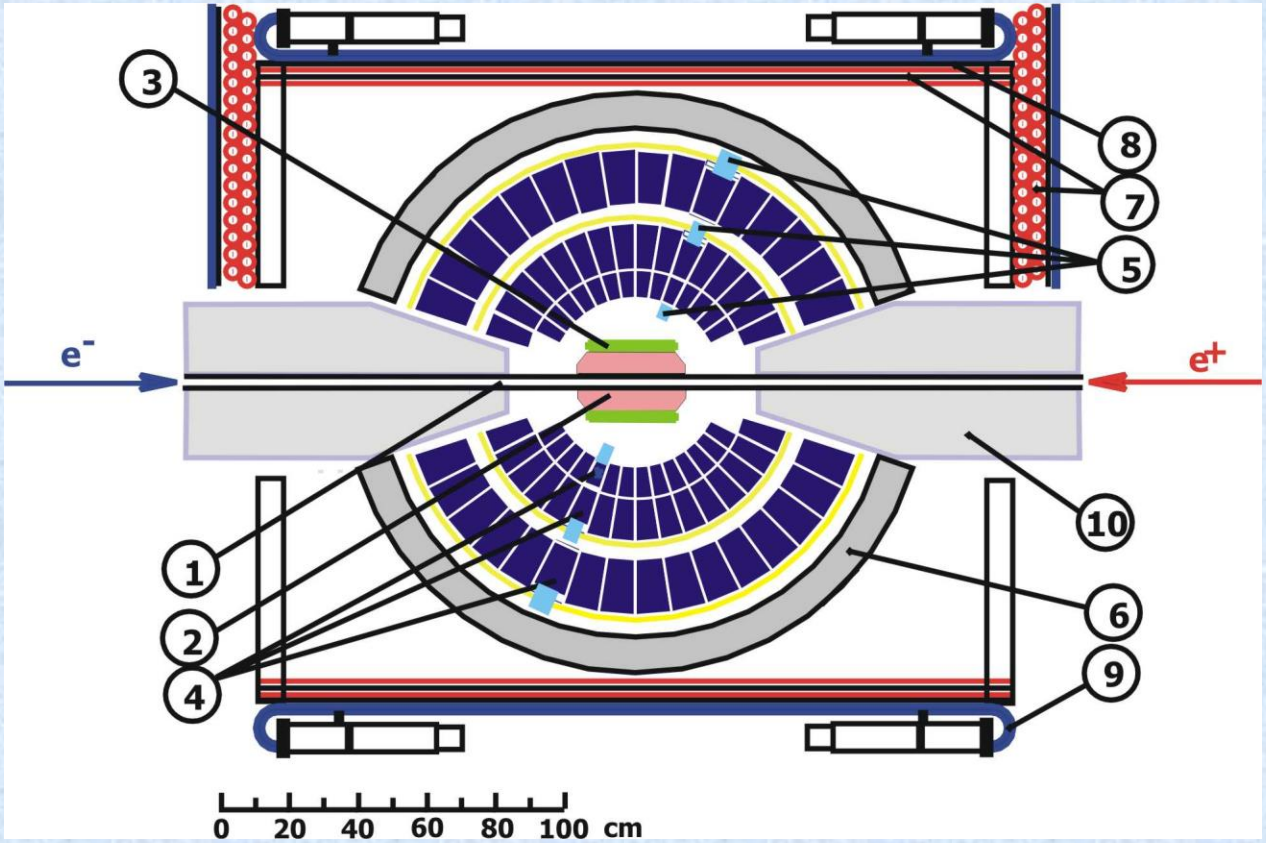
- ✓ During 2010 – 2013 the SND detector accumulated ~70 pb^{-1} of integrated luminosity at the VEPP-2000 e^+e^- collider in the c.m. energy range 0.3 – 2 GeV.
- ✓ Data analysis on hadron production is in progress. The obtained results have comparable or better accuracy than previous measurements (**$\omega\pi^0$**, $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\eta$, **$K^+K^-\eta$**, 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 data taking is resumed with a goal of ~1 fb^{-1} of integrated luminosity.

Thank you for attention

Backup slides

SND for VEPP-2000

NIM A449 (2000) 125-139



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

Main parameters:

Calorimeter:

Energy resolution:

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

Angular resolution:

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

Tracking system:

Angular resolution:

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

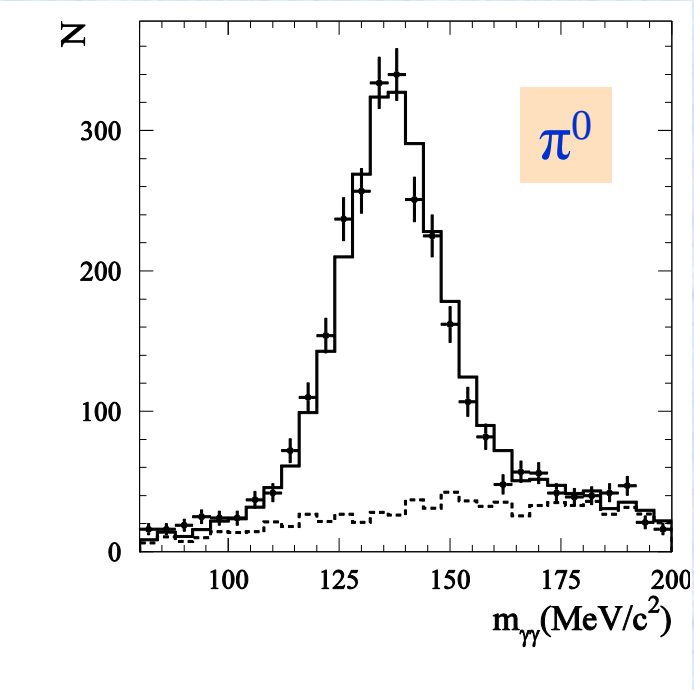
Spatial resolution:

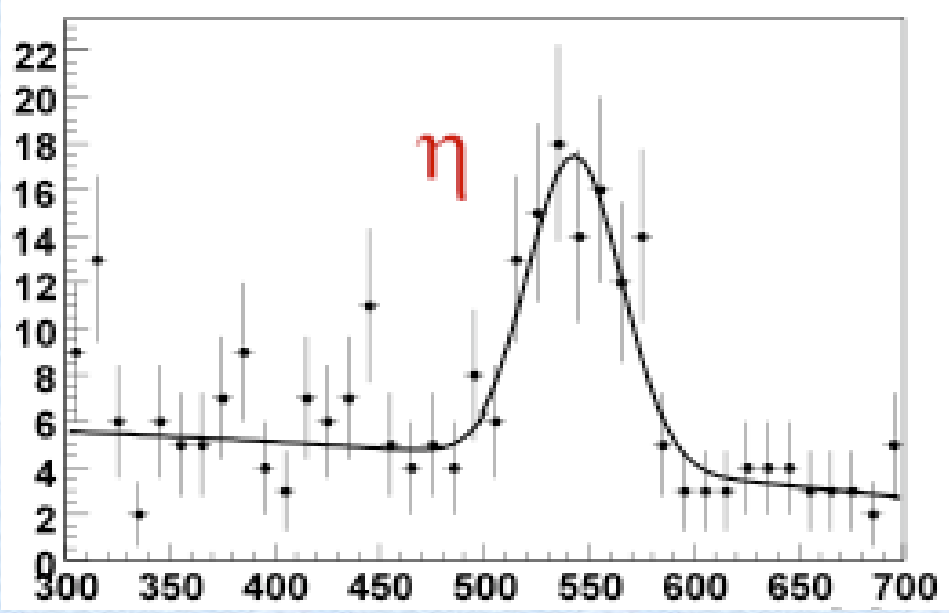
$$\sigma_R = 0.12cm, \sigma_Z = 0.45cm$$

Aerogel counters:

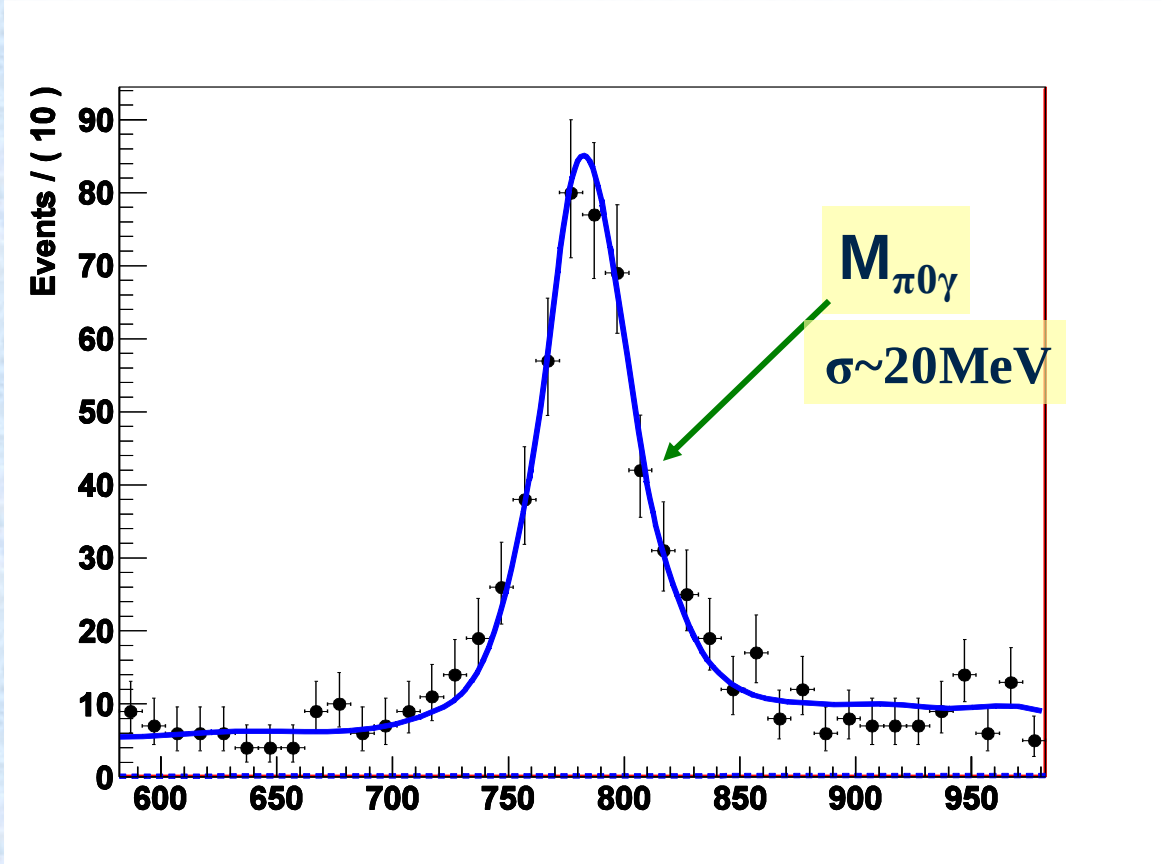
π/K separation E<1 GeV

$\gamma\gamma \rightarrow \pi^0, \eta$





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



Cuts:

- at least 5γ
- no charged particles
- total energy depos. > E_{beam}
- kinemat. reconstruction:

$\chi^2_{5\gamma} < 30$; $\chi^2_{\pi 0\pi 0\gamma} - \chi^2_{5\gamma} < 10$;

$|M_{\pi 0\gamma} - M_{\omega}| < 100$ MeV

Fitting:

sum of ρ(770) and ρ(1450)