Measurement of the $e^+e^- \to \pi^0\gamma$ cross section at SND

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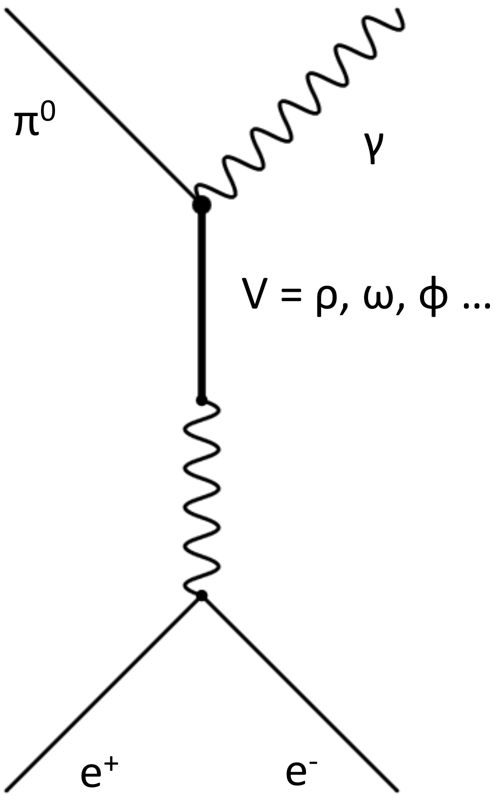
Outline

- Motivation to study $e^+e^- \to \pi^0\gamma$ process
- Measurement from SND@VEPP-2M
- Measurement from SND@VEPP-2000 (preliminary)

Radiative decays



• $e^+e^- \to \pi^0\gamma$ cross section is the third largest cross section below 1 GeV (after 2π and 3π)

• branching fraction of radiative decays of ρ, ω, ϕ and their excitations can be extracted from the fit to the cross section

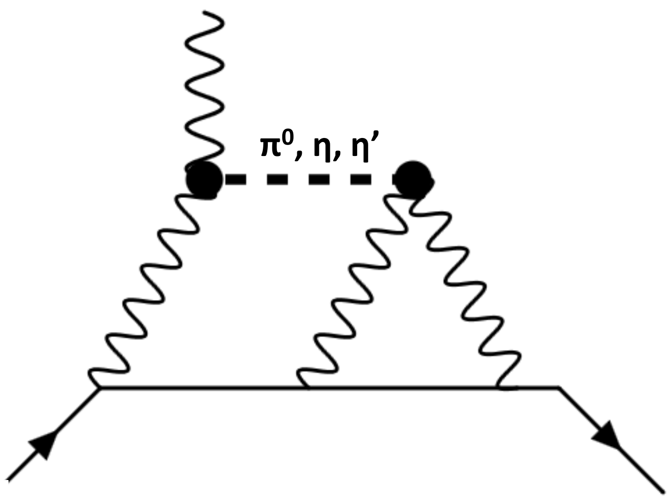
• this information is important for different phenomenological models

[1] Eur.Phys.J. A16 (2003) 209
[2] Eur.Phys.J. C22 (2001) 503
[3] Phys.Rev. D65 (2002) 092003

Hadronic light-by-light scattering

- The anomalous magnetic moment of the muon serves as an important test of SM

- One of the main sources of (g_μ-2) uncertainty originates from the hadronic light-by-light scattering



- The only way to calculate it is to use models

- Pseudo-scalar pole contribution is numerically dominant according to the most of model calculations

- Measurement of $e^+e^- \to \pi^0\gamma$ cross section can help to improve phenomenological models describing $\pi^0\gamma^{(*)}\gamma^{(*)}$ transition form factor ($F\pi\gamma^*\gamma^*$)

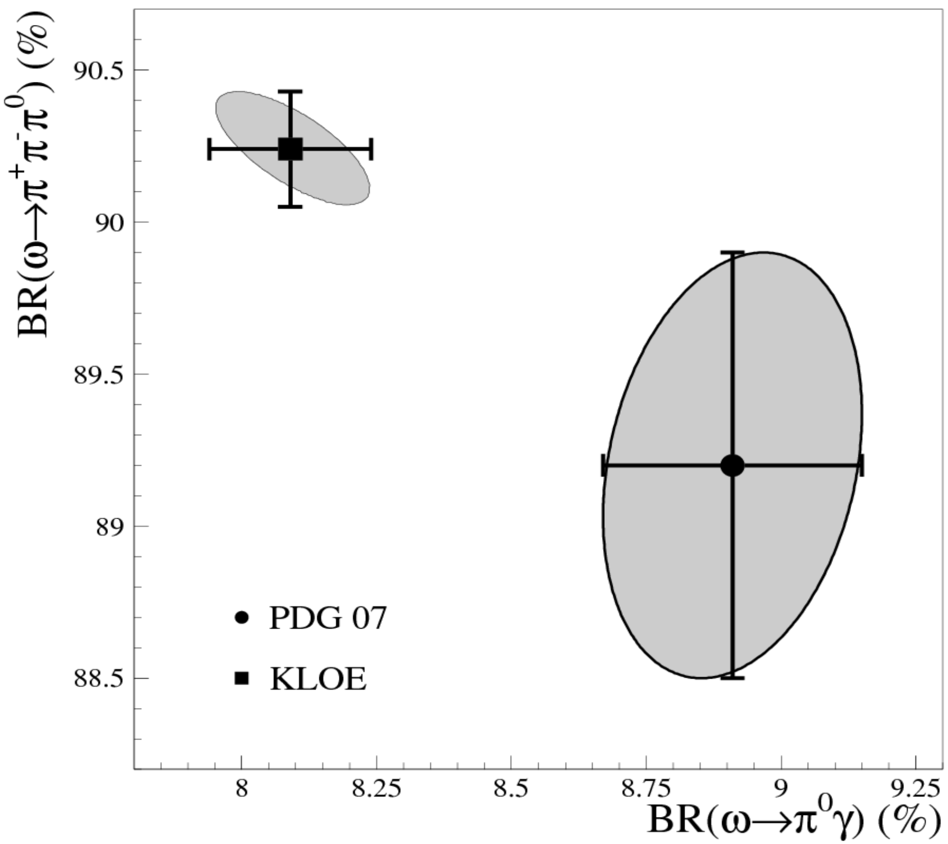
KLOE measurement

• There is an inconsistency between KLOE measurement of the ratio $\Gamma(\omega \to \pi^0 \gamma)/\Gamma(\omega \to \pi^+ \pi^- \pi^0)$ [1] and other measurements of ω-meson parameters

• KLOE has studied the $e^+e^- \to \omega \pi^0$ process near φ-meson resonance in two decay modes $\omega \to \pi^+\pi^-\pi^0$ and $\omega \to \pi^0\gamma$

•The ω -meson parameters obtained from KLOE studies have large shift from the previous measurement, especially for $\omega \to \pi^0\gamma$

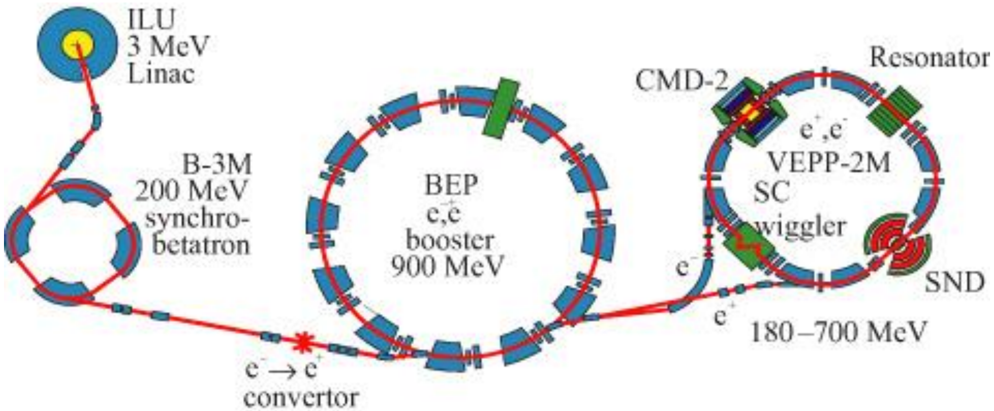
•new measurement of $e^+e^- \to \pi^0\gamma$ cross section will help to resolve or enhance this inconsistency



[1] F. Ambrosino at al. Phys. Lett. B 669, 223 (2008)

SND@VEPP-2M

e^+e^- collider VEPP-2M

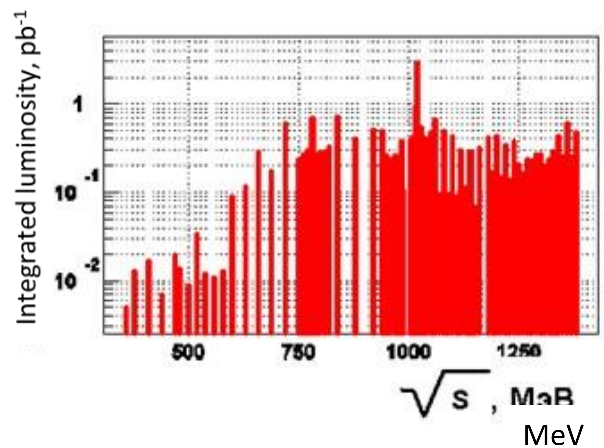


Year	Energy range (MeV)	Integrated luminosity (pb^{-1})
1997	1016-1380	5.7
1998	984-1060	7.8
1998	360-970	3.5
1999	1060-1360	3.0
2000	600-940	5.9
Total	360-1380	25.9

There were two detectors on VEPP-2M : SND and CMD-2

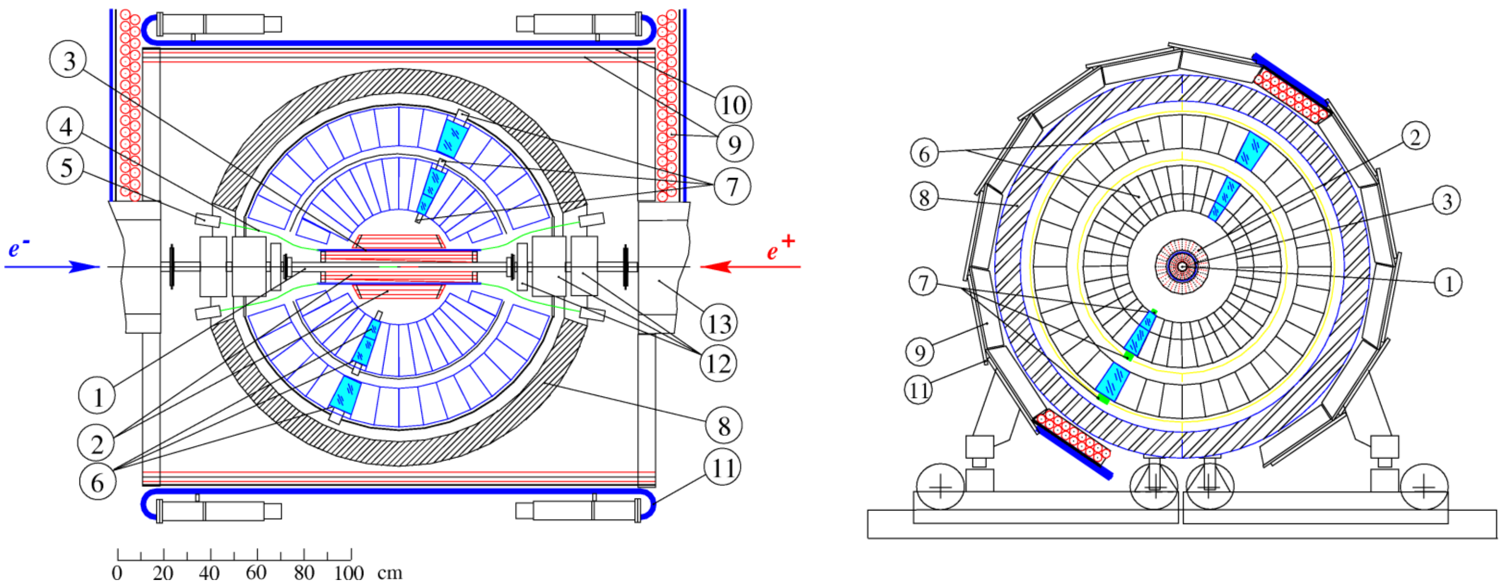
$2E = 0.36\text{-}1.38$ GeV

$L \sim 3 \cdot 10^{30}\ cm^{-2}s^{-1}$ (2E = 1GeV)



Integrated luminosity distributed over energy region

The Spherical Neutral Detector (SND)



1 - vacuum pipe, 2 - drift chambers, 3 - scintillation counter, 4 – light guides, 5 -PMTs, 6 - NaI(Tl) crystals, 7 - vacuum phototriodes, 8 - iron absorber, 9 - streamer tubes, 10 - 1cm iron plates, 11 - scintillation counters, 12 - storage ring lens, 13 - bending magnets.

Analysis features

We use $e^+e^- \to \gamma\gamma$ process for normalization

Common selection criteria for 2g and 3g final states:

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

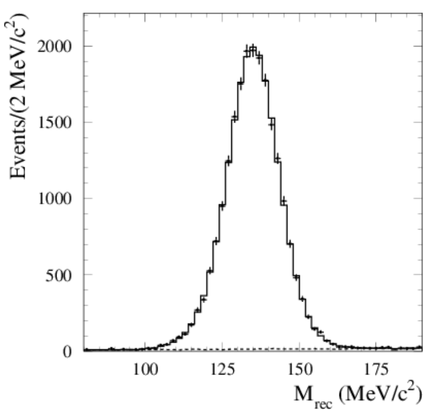
Final selection is based on kinematic fit to $e^+e^- \to 3\gamma$ hypothesis

$\chi^2 < 30$ and $80 < M_{rec} < 190$ MeV

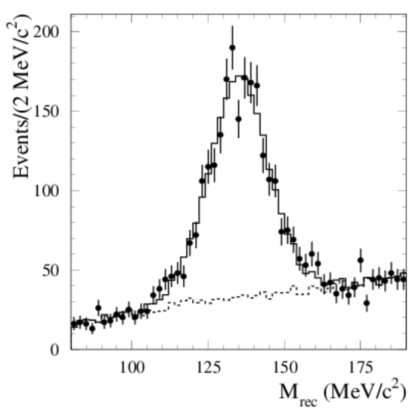
The number of signal events was determined from the fit of π^0 in the spectrum of recoil mass against most energetic photon (M_{rec}).

To suppress 5γ background above 1.06 GeV we selected exactly 3 photons and use a tighter cut on χ^2 of kinematic fit

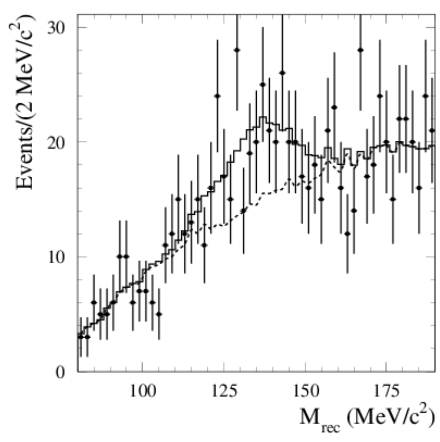
around ω



around ϕ



1.1 - 1.4 GeV



Systematic uncertainties

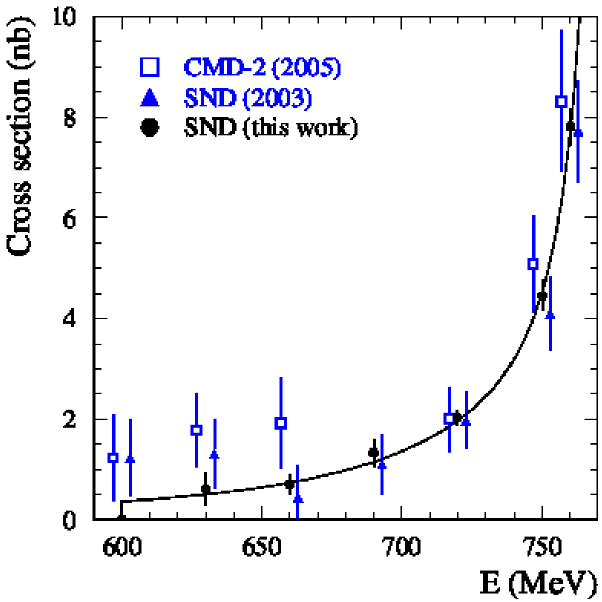
Total systematic uncertainty below 1.06 GeV is 1.4 %
- luminosity measurement – 1.2 %
- selection criteria – 0.6 %

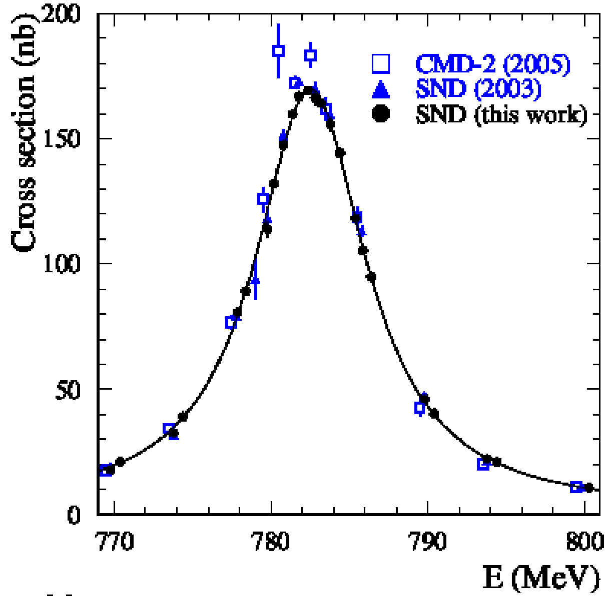
Systematic uncertainty of luminosity measurement includes theoretical error of cross section calculation (1%) and selection criteria (0.7 %)

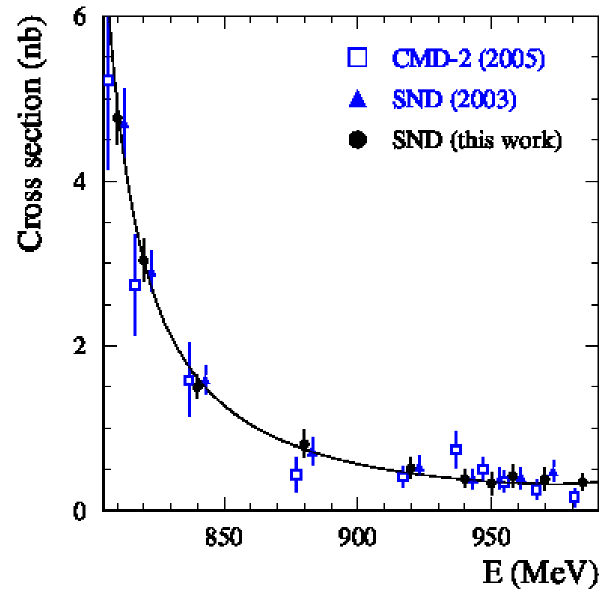
In ω-meson peak energy region the accuracy is mostly determined by systematic uncertainty

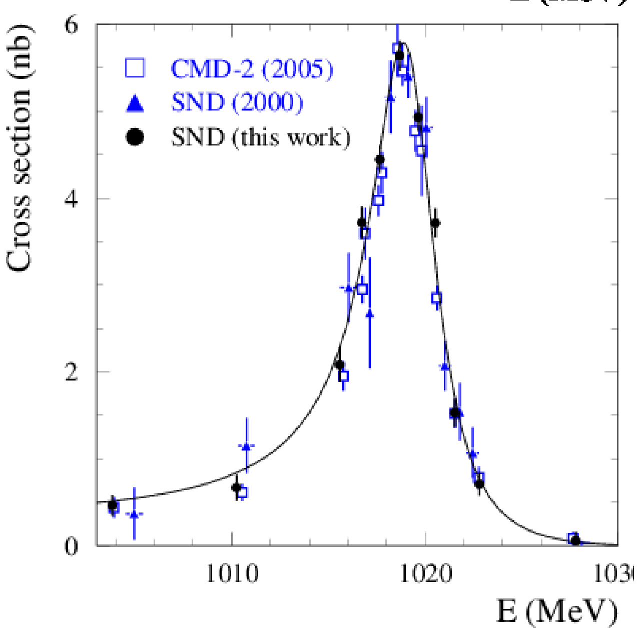
Energy region	Statistical error	Systematic uncertainty
ω-meson peak	1.0 %	1.4 %
ϕ-meson peak	3.2 %	1.4 %

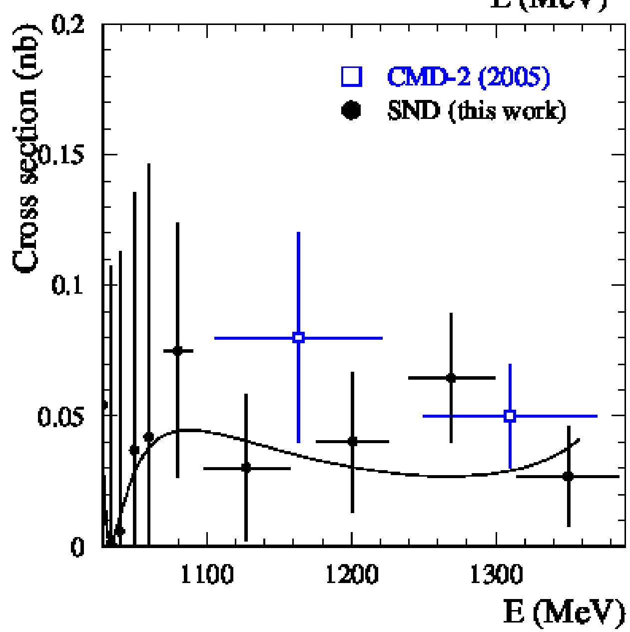
Cross section











The most precise measurement of the $e^+e^- \to \pi^0\gamma$ cross section

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

Branching fractions

From the fit to the cross section we obtain the products of branching fractions

$$B(\rho \to \pi^0\gamma)\, B(\rho \to e^+e^-) = (1.98 \pm 0.22 \pm 0.10)\cdot 10^{-8}$$

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

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

and relative phases

$$\varphi_\rho = (-12.7 \pm 3.4 \pm 3.0)^\circ$$

$$\varphi_\phi = (158^{+31}_{-18} \pm 21)^\circ$$

Our measurement of φ_ρ is in good agreement with theoretical prediction $\varphi_\rho = (-13.5 \pm 0.6)^\circ$ based on [1]

Total uncertainty ~20% for ϕ-meson is caused by strong correlation between σ_ϕ and φ_ϕ. The value of φ_ϕ from $e^+e^- \to \pi^+\pi^-\pi^0$ process study is

$$\varphi^{3\pi}_\phi = (163 \pm 7)^\circ \text{ [2]}$$

We can significantly improve accuracy by fixing φ_ϕ at this value

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

[1] H.B. O'Connell et. al. Prog. Part. Nucl. Phys. 39, 201 (1997)
[2] M.N. Achasov et al. Phys Rev D 68, 052006 (2003)

Branching fractions

Using measured $B(\omega \to \pi^0\gamma)$ $B(\omega \to e^+e^-)$ and PDG value for $B(\omega \to \pi^+ \pi^- \pi^0)$ $B(\omega \to e^+e^-)$ we calculated

$$B(\omega \to \pi^0\gamma) / B(\omega \to \pi^+ \pi^- \pi^0) = 0.0992 \pm 0.0023$$

which disagrees with the KLOE measurement (0.0897 ± 0.0016) by 3.4 σ

To calculate ω-meson parameters we use measured $B(\omega \to \pi^0\gamma)$ $B(\omega \to e^+e^-)$, PDG value for $B(\omega \to \pi^+ \pi^- \pi^0)$ $B(\omega \to e^+e^-)$ and branching fraction of other decays

$$B(\omega \to \pi^0\gamma) = (8.88 \pm 0.18)\ \%$$
$$B(\omega \to \pi^+ \pi^- \pi^0) = (89.47 \pm 0.18)\ \%$$
$$B(\omega \to e^+e^-) = (7.13 \pm 0.10) \cdot 10^{-5}$$

PDG values are (8.28 ± 0.28)% , (89.2 ± 0.7)%, $(7.28 \pm 0.14) \cdot 10^{-5}$

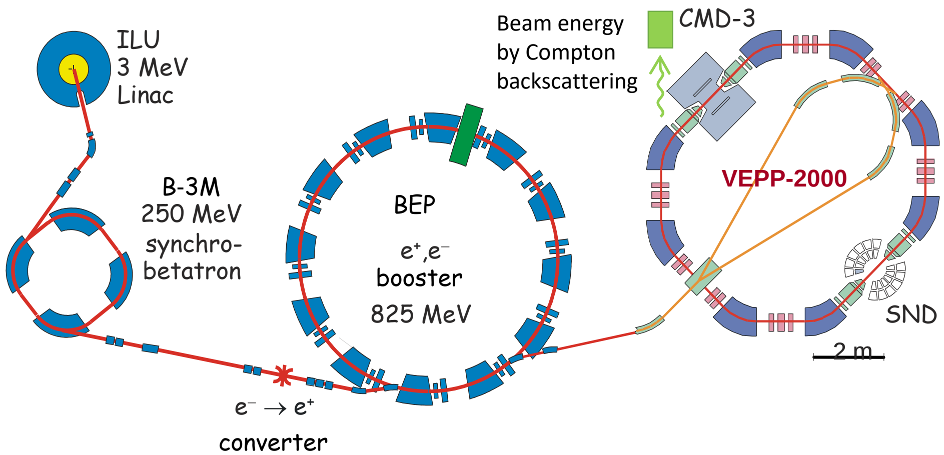
Using PDG value for $B(\rho \to e^+e^-)$ and $B(\phi \to e^+e^-)$

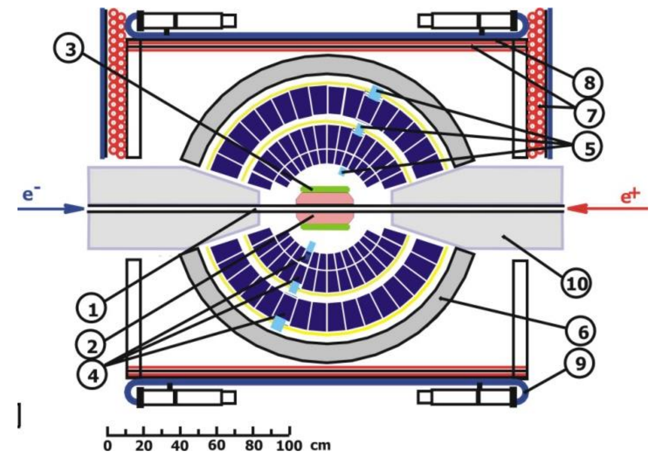
$$B(\phi \to \pi^0\gamma) = (1.367 \pm 0.030 \pm 0.065) \cdot 10^{-3}$$
$$B(\rho \to \pi^0\gamma) = (4.20 \pm 0.47 \pm 0.22) \cdot 10^{-4}$$

PDG values are $(1.27 \pm 0.06) \cdot 10^{-3}$ and $(6.0 \pm 0.8) \cdot 10^{-3}$

SND@VEPP-2000 (preliminary)

VEPP-2000 in 2010-2013





C.m. energy range is E=0.3-2.0 GeV,
round beam optics
Luminosity at E=1.8 GeV is $2\times10^{31}\ cm^{-2}\ s^{-1}$
Two detectors, SND and CMD-3

SND after upgrade:
- new tracking system
- Cherenkov aerogel counters
- EM calorimeter remains the same

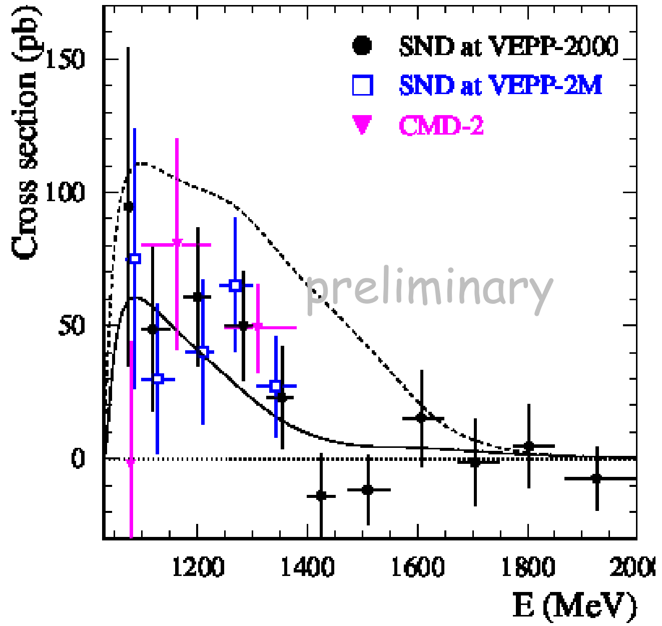
This measurement is based on 45.5 pb^{-1} integrated luminosity collected by SND at VEPP-2000 in 2010-2013

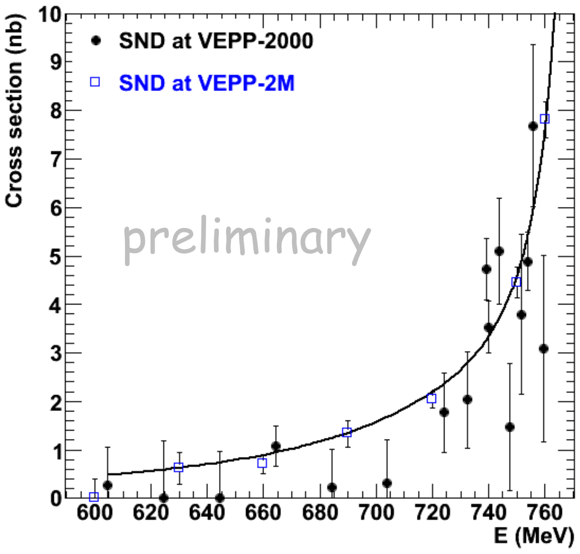
Energy range (MeV)	VEPP-2M Integrated luminosity (pb^{-1})	VEPP-2000 Integrated luminosity (pb^{-1})
360-970	9.4	8.5
1050-1380	8.7	10
1380-2000	-	27

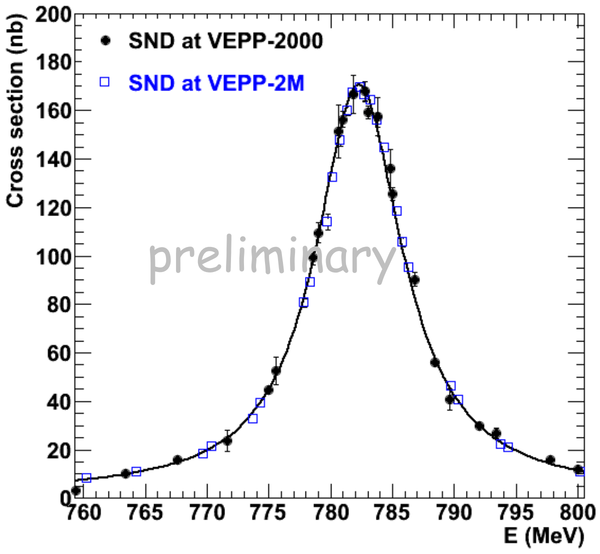
Cross section

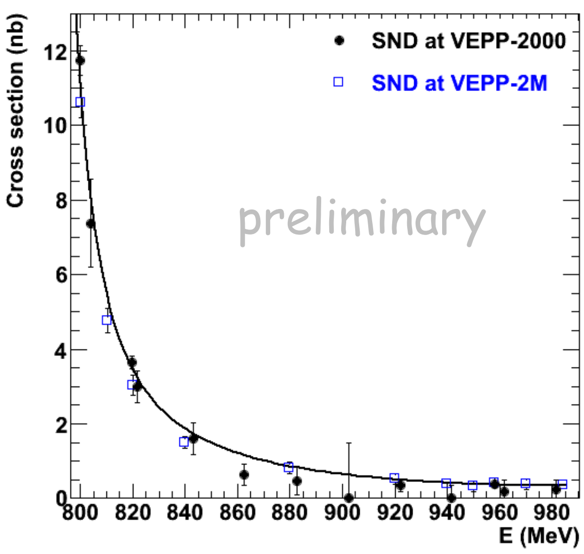
For the analysis we use the same technique as for VEPP-2M data

SND@VEPP-2M and SND@VEPP-2000 data are in good agreement with each other









Conclusion

• The cross section for the process $e^+e^- \to \pi^0\gamma$ has been measured in energy range of 0.60 – 1.38 GeV with the SND at VEPP-2M e^+e^- collider

• This is the most accurate measurement of the cross section

• From the fit to the cross section the products of branching fractions was determined

• The values of the three directly measured parameters of ω-meson

$$B(\omega \to \pi^0\gamma)\, B(\omega \to e^+e^-)$$

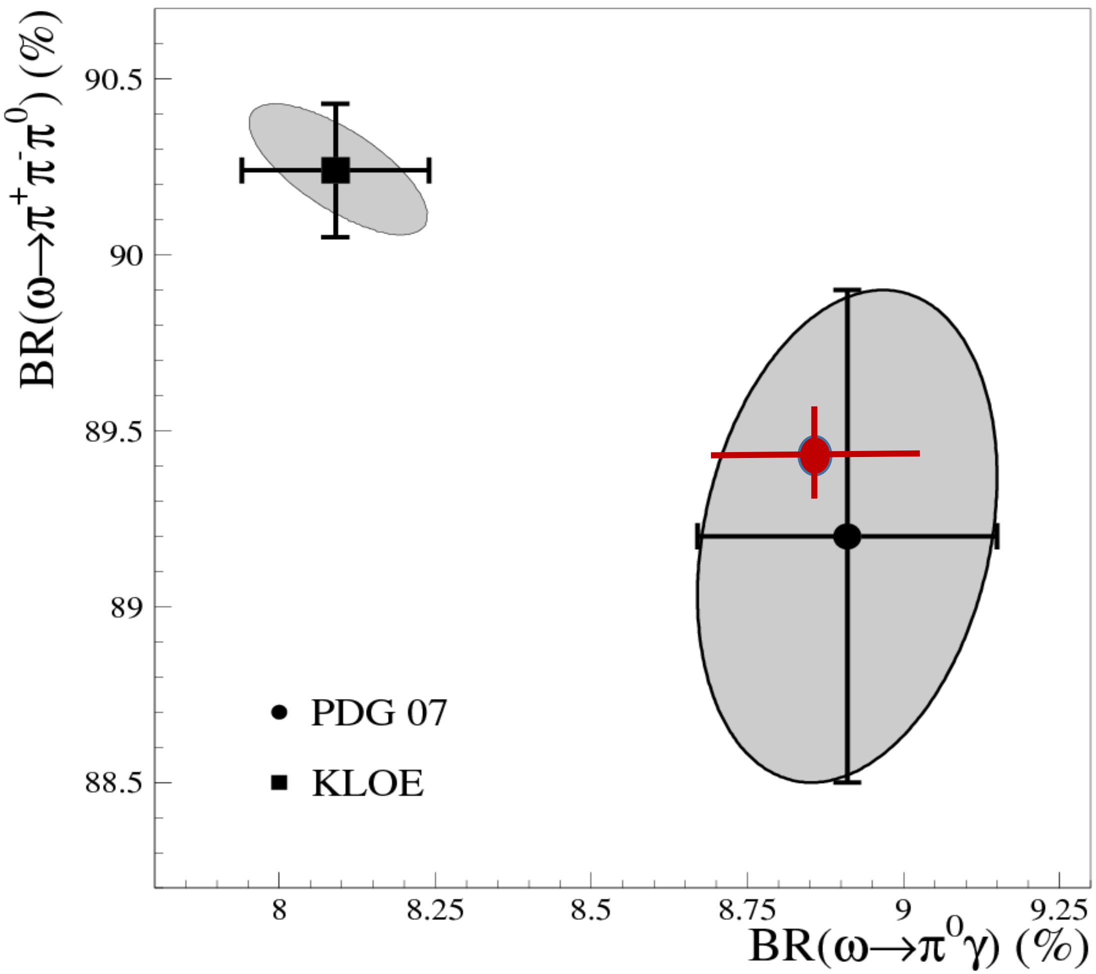
$$B(\omega \to \pi^+\pi^-\pi^0)\, B(\omega \to e^+e^-)$$

$$B(\omega \to \pi^0\gamma)\, /\, B(\omega \to \pi^+\pi^-\pi^0)$$

contradict each other. With our measurement, the level of disagreement between them reaches 3.4σ.

• Preliminary measurement of $e^+e^- \to \pi^0\gamma$ cross section with the SND at VEPP-2000 e^+e^- collider was presented

THANK YOU
FOR YOUR ATTENTION!



90.5
90
89.5
89
88.5
8
8.25
8.5
8.75
9
9.25
BR(ω→π⁺π⁻π⁰) (%)
BR(ω→π⁰γ) (%)
PDG 07
KLOE