

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

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**Abstract.** Recent SND results on the study of the process  $e^+e^- \rightarrow \pi^0\gamma$  are presented. The study is based on data collected with the SND detector on the VEPP-2M and VEPP-2000  $e^+e^-$  colliders with an integrated luminosity of 25 and 46 pb<sup>-1</sup>, respectively. The VEPP-2M data used in this analysis are recorded in the center-of-mass energy range 0.60-1.38 GeV, while the VEPP-2000 data in the range 1.05-2.00 GeV.

### 1 Introduction

The  $e^+e^- \rightarrow \pi^0\gamma$  cross section is the third largest hadronic cross section (after  $e^+e^- \rightarrow \pi^+\pi^-$  and  $\pi^+\pi^-\pi^0$ ) below 1 GeV. It provides a lot of experimental information about properties of vector mesons produced in  $e^+e^-$  collisions. From the analysis of  $e^+e^- \rightarrow \pi^0\gamma$  data in the vector meson dominance (VMD) model, the widths of radiative decays of vector mesons can be extracted. Also measurement of  $e^+e^- \rightarrow \pi^0\gamma$  cross section can help to improve phenomenological models describing  $\pi^0\gamma^{(*)}\gamma^{(*)}$  transition form factor. This is important for calculation of light-by-light scattering contribution into  $(g-2)_\mu$ . New measurement of the  $e^+e^- \rightarrow \pi^0\gamma$  can also resolve the contradiction between the KLOE measurement of the ratio  $\Gamma(\omega \rightarrow \pi^0\gamma)/\Gamma(\omega \rightarrow \pi^+\pi^-\pi^0)$  [1] and other measurements of  $\omega$ -meson parameters [2].

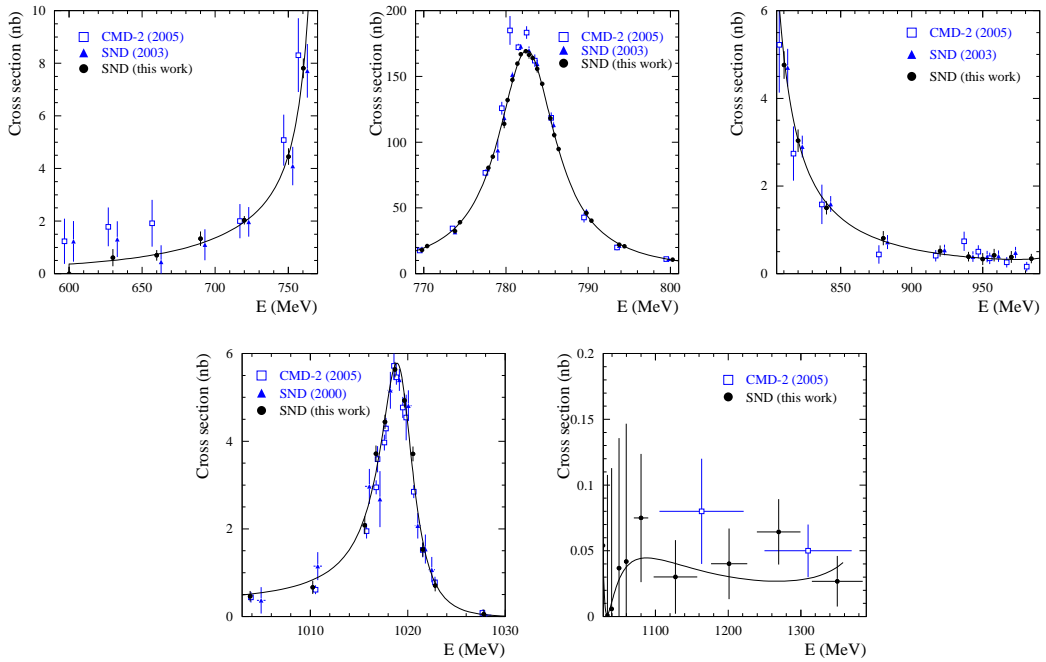
### 2 Measurement at VEPP-2M

SND is a general-purpose nonmagnetic detector [3]. From 1996 to 2000 it collected data at the VEPP-2M  $e^+e^-$  collider [4]. In this analysis a data sample with an integrated luminosity of 25 pb<sup>-1</sup> recorded in the center-of-mass (c.m.) energy range 0.6–1.38 GeV is used. The data were collected during several c.m. energy scans. The step of the scans varied from 0.5 MeV near the peaks of the  $\omega$  and  $\phi$  resonances to 10–20 MeV far from them. The measured  $e^+e^- \rightarrow \pi^0\gamma$  cross section [5] is presented in Fig. 1.

The cross section data are fitted with the VMD model taking into account the  $\rho$ ,  $\omega$ ,  $\phi$  resonances, and their excitations. From the fit, the products of branching fractions are obtained

$$\begin{aligned} B(\rho \rightarrow \pi^0\gamma)B(\rho \rightarrow e^+e^-) &= (1.98 \pm 0.22 \pm 0.10) \times 10^{-8}, \\ B(\omega \rightarrow \pi^0\gamma)B(\omega \rightarrow e^+e^-) &= (6.336 \pm 0.056 \pm 0.089) \times 10^{-6}, \\ B(\phi \rightarrow \pi^0\gamma)B(\phi \rightarrow e^+e^-) &= (3.92_{-0.40}^{+0.71} \pm 0.51) \times 10^{-7}. \end{aligned} \quad (1)$$

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**Figure 1.** The  $e^+e^- \rightarrow \pi^0\gamma$  cross section measured by SND [5] in different energy regions in comparison with the previous most accurate measurements: SND (2000) [6], SND (2003) [7], and CMD-2 (2005) [8]. The curve is the result of the fit.

The relative phases between the  $\rho$  and  $\omega$  amplitudes, and  $\phi$  and  $\omega$  amplitudes are found to be

$$\begin{aligned}\varphi_\rho &= (-12.7 \pm 3.4 \pm 3.0)^\circ, \\ \varphi_\phi &= (158_{-18}^{+31} \pm 21)^\circ.\end{aligned}\tag{2}$$

The uncertainties in the product  $B(\phi \rightarrow \pi^0\gamma)B(\phi \rightarrow e^+e^-)$  can be reduced by fixing the  $\varphi_\phi$  at the value  $(163 \pm 7)^\circ$  measured in the  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$  reaction [9]:

$$B(\phi \rightarrow \pi^0\gamma)B(\phi \rightarrow e^+e^-) = (4.04 \pm 0.09 \pm 0.19) \times 10^{-7}.\tag{3}$$

Using the measured product  $B(\omega \rightarrow \pi^0\gamma)B(\omega \rightarrow e^+e^-)$  and the PDG value  $B(\omega \rightarrow \pi^+\pi^-\pi^0)B(\omega \rightarrow e^+e^-) = (6.38 \pm 0.10) \times 10^{-5}$  [2], we calculate the ratio

$$\frac{B(\omega \rightarrow \pi^0\gamma)}{B(\omega \rightarrow \pi^+\pi^-\pi^0)} = 0.0992 \pm 0.0023,\tag{4}$$

which disagrees (by  $3.4\sigma$ ) with the KLOE measurement of the same parameter  $0.0897 \pm 0.0016$  [1].

The KLOE measurement strongly influences current PDG values of  $\omega$  meson parameters. Therefore, we calculate  $\omega$  meson parameters based on our measurement  $B(\omega \rightarrow \pi^0\gamma)B(\omega \rightarrow e^+e^-)$ , the PDG values of  $B(\omega \rightarrow \pi^+\pi^-\pi^0)B(\omega \rightarrow e^+e^-)$ , and branching fractions of other decays, which sum is

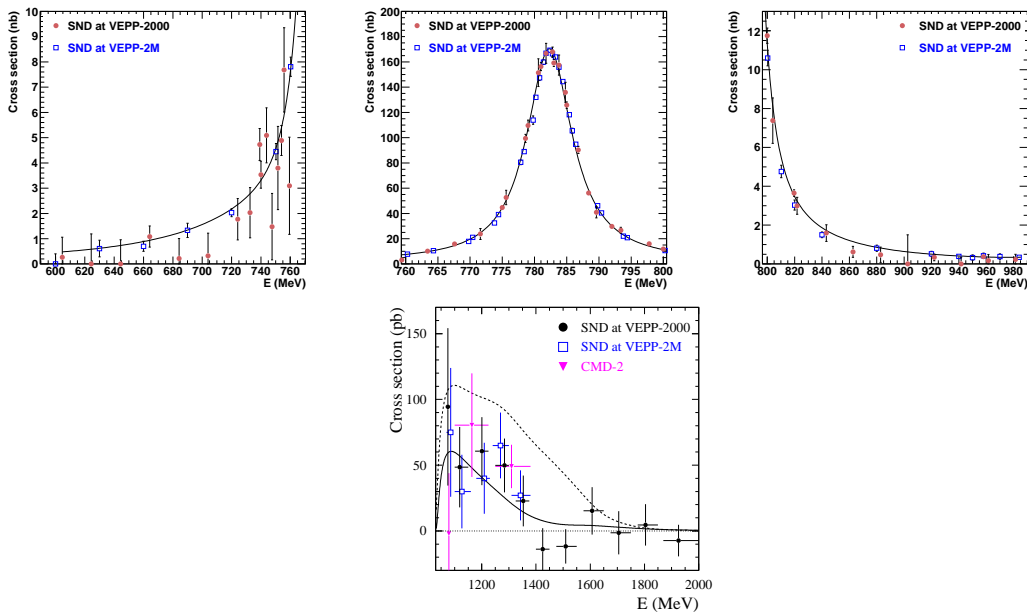
equal to  $0.0165 \pm 0.0013$ . The following parameters are obtained:

$$\begin{aligned}
 B(\omega \rightarrow \pi^0 \gamma) &= (8.88 \pm 0.18)\%, \\
 B(\omega \rightarrow \pi^+ \pi^- \pi^0) &= (89.47 \pm 0.18)\%, \\
 B(\omega \rightarrow e^+ e^-) &= (7.13 \pm 0.10) \times 10^{-5},
 \end{aligned}
 \tag{5}$$

which can be compared with the corresponding PDG values  $(8.28 \pm 0.28)\%$ ,  $(89.2 \pm 0.7)\%$ ,  $(7.28 \pm 0.14) \times 10^{-5}$ . As expected, our result for  $B(\omega \rightarrow \pi^0 \gamma)$  strongly differs from the PDG value.

### 3 Measurement at VEPP-2000

For experiments at VEPP-2000, the SND detector was upgraded [10–13]. In particular, a completely new tracking system and a system of threshold Cerenkov counters were installed. The VEPP-2000  $e^+e^-$  collider operates in a wider energy range. Its maximum c.m. energy is 2 GeV. In this paper we present preliminary SND results based on data with an integrated luminosity of  $45.5 \text{ pb}^{-1}$  collected at VEPP-2000 in 2010–2013. The data are analyzed using the same technique as for the VEPP-2M data. The measured  $e^+e^- \rightarrow \pi^0 \gamma$  cross section is shown on Fig. 2 in comparison with the SND results at VEPP-2M. The VEPP-2000 and VEPP-2M cross section data are in reasonable agreement.



**Figure 2.** The preliminary results on the  $e^+e^- \rightarrow \pi^0 \gamma$  cross section obtained by SND at VEPP-2000 in different energy regions in comparison with the SND data obtained at VEPP-2M [5] and CMD-2 (2005) [8]. The curve is the result of the VMD fit.

## 4 Summary

The cross section for the process  $e^+e^- \rightarrow \pi^0\gamma$  has been measured in the energy range of 0.60-1.38 GeV with the SND detector at the VEPP-2M  $e^+e^-$  collider. This is the most accurate measurement of this cross section. The preliminary results on the  $e^+e^- \rightarrow \pi^0\gamma$  cross section obtained with SND are presented. The VEPP-2000 and VEPP-2M measurement are in agreement. With new data the measurement energy range has been expanded up to 2 GeV.

## 5 Acknowledgments

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