PROCEEDINGS OF SCIENCE

Study of $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ in the energy range 1.05–2.00 GeV with SND

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The cross section for the process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ has been measured in the center-of-mass energy range 1.05–2.00 GeV. The experiment has been performed at the e^+e^- collider VEPP-2000 with the SND detector. The measured $e^+e^- \to \omega\pi^0$ cross section above 1.4 GeV is the most accurate to date. Below 1.4 GeV our data are in good agreement with the previous SND and CMD-2 measurements. Data on the $e^+e^- \to \omega\pi^0$ cross section are well described by the Vector Meson Dominance (VMD) model with two excited ρ-like states. From the measured cross section we have extracted the $\gamma^* \to \omega\pi^0$ 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. We have also tested Conserved Vector Current (CVC) hypothesis comparing our results on the $e^+e^- \to \omega\pi^0$ cross section with data on the $\tau^- \to \omega\pi^-\nu_\tau$ decay and have found that the CVC hypothesis works well within reached experimental accuracy of about 5%.

XV International Conference on Hadron Spectroscopy-Hadron 2013
4-8 November 2013
Nara, Japan

*Speaker.

PoS(Hadron 2013)103

1. Introduction

Experiments with the SND detector [1] at the e^+e^- collider VEPP-2000 [2] started in 2010. The main goals of these experiments are a high precision measurement of the total cross section of $e^+e^- \to hadrons$ in the center-of-mass (c.m.) energy range up to 2 GeV and investigation of the vector meson excitations with masses between 1 and 2 GeV/c^2. In this connection, a study of the process

$$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma \tag{1.1}$$

is very topical. The process $e^+e^- \to \omega\pi^0$ is one of the dominant hadronic processes contributing to the total hadronic cross section at the c.m. energy between 1 and 2 GeV. As one of the important decay modes of the isovector vector states $\rho(1450)$ and $\rho(1700)$, it can provide a lot of information about their properties.

More details about this work one can find in reference [3].

2. Experiment

SND [1] is a general purpose non-magnetic detector. Its main part is a spherical three-layer NaI(Tl) calorimeter with 560 individual crystals per layer and 90% solid angle coverage. The calorimeter energy resolution for photons is $\sigma_E/E_\gamma = 4.2\%/\sqrt[4]{E_\gamma(GeV)}$, the angular resolution $\simeq 1.5°$. There is a tracking system around the collider beam pipe based on a nine-layer drift chamber and a one-layer proportional chamber with cathode-strip readout. Outside the calorimeter a muon detector consisting of proportional tubes and scintillation counters is placed. An aerogel Cherenkov counter located between the drift chamber and the calorimeter is used for particle identification.

Experiments at VEPP-2000 started in 2010. During 2010–2012 the c.m. energy range E = 1.05–2.00 GeV was scanned several times with a step of 20–25 MeV. The total integrated luminosity collected by SND in this energy range is about 40 pb^{-1}. This work is based on data (27 pb^{-1}) recorded in 2010–2011.

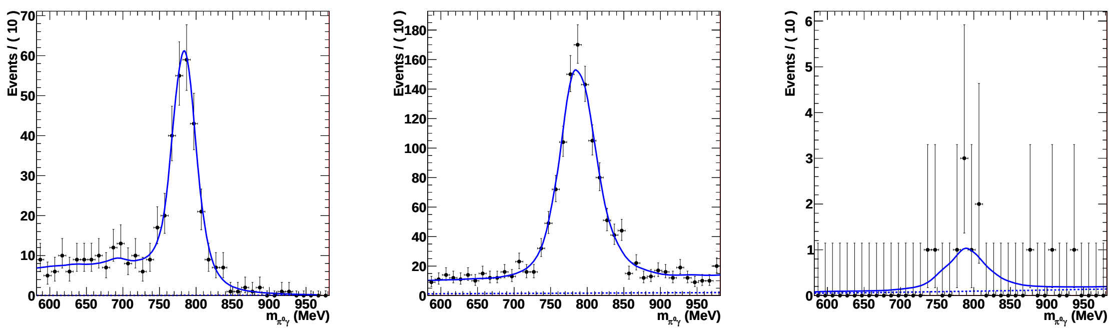

Figure 1: The distribution of the $\pi^0\gamma$ invariant mass for selected data events (points with error bars) with E = 1.1 GeV (left), E = 1.5 GeV (center) and E = 1.9 GeV (right). The curves are the result of the fit by a sum of signal and background distributions. The dashed line represents the linear-background contribution.

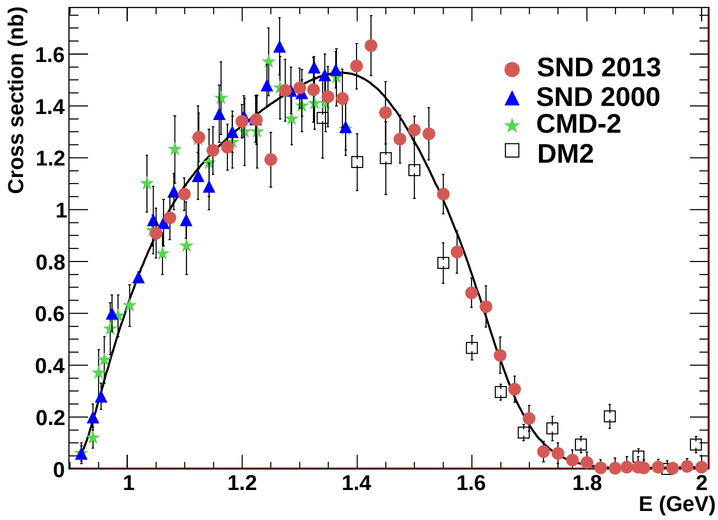

Figure 2: The cross section for $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ measured in this work (circles), and in SND [4] (triangles), CMD-2 [5] (stars), and DM2 [6] (squares) experiments. Only statistical errors are shown. The curve is the result of the fit to SND 2000 and SND 2013 data described in the text.

3. Analysis

At the first stage of the analysis events with at least five photons and without charged particles were selected. For events passing the preliminary selection, kinematic fits to the $e^+e^- \to 5\gamma$ and $e^+e^- \to \pi^0\pi^0\gamma$ hypotheses are performed with requirements of energy and momentum conservation and π^0 mass constraints for the second hypothesis. To select $\pi^0\pi^0\gamma$ candidates additional conditions on the goodness of the fits were applied.

To determine the number of signal events, the $\pi^0\gamma$ mass spectrum in the range $|m_{\pi^0\gamma} - M_\omega| < 200$ MeV/c^2 is fitted by a sum of signal and background distributions. The results of the fit is shown in Fig. 1 for three energy points.

The total systematic uncertainty is 3.4% in the energy range $E \leq 1.55$ GeV and 4.5% in the energy range $1.55 < E < 1.6$. Above 1.6 GeV the uncertainty increases due to the model dependence of the radiative correction.

4. Results and discussion

The Born cross section for $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ is shown in Fig. 2 in comparison with the results of previous measurements. Our data are in good agreement with the measurements [4, 5] performed by SND and CMD-2 at the VEPP-2M collider at energies below 1.4 GeV, but significantly (by 20–30%) exceed the DM2 data [6]. The DM2 data were obtained in the $\pi^+\pi^-\pi^0\pi^0$ mode and have been rescaled using the ratio of the $\omega \to \pi^0\gamma$ and $\omega \to 3\pi$ decay probabilities [7].

The cross section measured in this work is fitted together with the SND data obtained in experiments at VEPP-2M [4] using the model based on VMD with $\rho(770)$, $\rho(1450)$, $\rho(1700)$. For simplicity we use energy-independent $\rho(1450)$ and $\rho(1700)$ widths.

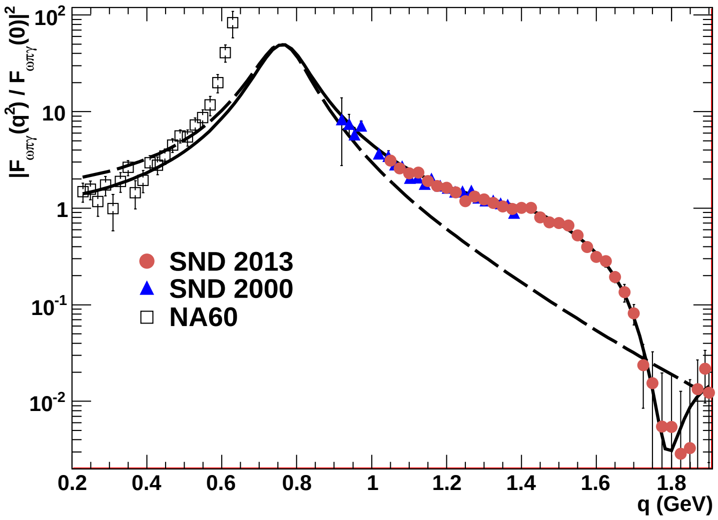

Figure 3: The $\gamma^* \to \omega\pi^0$ transition form factor. The points with error bars represent data from this work (circles), Ref. [4] (triangles), and Ref. [10] (squares). Only statistical errors are shown. The curve represent the result of model prediction. The dashed curve shows the $\rho(770)$ contribution.

To study the contributions of the $\rho(1450)$ and $\rho(1700)$ resonances, we restrict the energy range to $E \leq 1.9$ GeV. This reduces the model uncertainty due to a possible nonresonant contribution or the ρ''' resonance. Two models have been studied, with a non-zero and zero $\rho(1700)$ contribution. It was found that our data cannot be described by the model with one excited ρ state.

The fitted value of the parameters is used to calculate the products of the branching fractions

$$B(\rho' \to e^+e^-) \cdot B(\rho' \to \omega\pi^0) = (5.3 \pm 0.4) \times 10^{-6}, \quad (4.1)$$

$$B(\rho'' \to e^+e^-) \cdot B(\rho'' \to \omega\pi^0) = (1.7 \pm 0.4) \times 10^{-6}. \quad (4.2)$$

The cross section for $e^+e^- \to \omega\pi^0$ can be expressed in terms of the $\gamma^* \to \omega\pi^0$ transition form factor $F_{\omega\pi\gamma}(q^2)$ [8, 9]. Figure 3 shows the normalized transition form factor squared ($|F_{\omega\pi\gamma}(q^2)/F_{\omega\pi\gamma}(0)|^2$) measured in this work and in Ref. [4] together with most precise data from omega decays obtained in the NA60 experiment [10]. The curve represents the results of the model prediction. The dashed curve shows the $\rho(770)$ contribution. We conclude that it is hard to describe data from e^+e^- annihilation and the $\omega \to \pi^0\mu^+\mu^-$ decay simultaneously with our model based on vector meson dominance (VMD).

The conserved vector current (CVC) hypothesis establishes a relation between the charged hadronic current in the τ decay and the isovector part of the electromagnetic current. A quantitative test of the CVC hypothesis can be made by comparing the measured $\tau \to \omega\pi\nu_\tau$ branching fraction with the value calculated from the $e^+e^- \to \omega\pi^0$ cross section according to the formula [11, 12]

$$\Gamma(\tau^- \to \omega\pi^-\nu_\tau) = \frac{G_F^2|V_{ud}|^2}{64\pi^4\alpha^2 m_\tau^3} \int^{m_\tau} q^3(m_\tau^2 - q^2)^2(m_\tau^2 + 2q^2)\sigma_{\omega\pi^0}(q)dq, \quad (4.3)$$

where $|V_{ud}|$ is the Cabibbo-Kobayashi-Maskawa matrix element, m_τ is the τ lepton mass, G_F is the Fermi constant. We integrate the fitted curve shown in Fig. 2 and obtain the value of the product

$\Gamma(\tau^- \to \omega\pi^-\nu_\tau)B(\omega \to \pi^0\gamma) = (3.68 \pm 0.04 \pm 0.13) \times 10^{-6}$ eV. Using the values of the τ lifetime and $B(\omega \to \pi^0\gamma)$ we calculate the branching fraction

$$B(\tau^- \to \omega\pi^-\nu_\tau) = (1.96 \pm 0.02 \pm 0.10) \times 10^{-2}. \tag{4.4}$$

which is in good agreement with the experimental value $(1.95 \pm 0.08) \cdot 10^{-2}$ obtained as a difference of the PDG [7] values for $B(\tau^- \to \omega h^-\nu_\tau)$ and $B(\tau^- \to \omega K^-\nu_\tau)$. We conclude that the CVC hypothesis for the $\omega\pi$ system works well within the reached experimental accuracy of about 5%.

5. Acknowledgements

This work is supported by the Ministry of Education and Science of the Russian Federation (Contract 14.518.11.7003), the Russian Federation Presidential Grant for Scientific Schools NSh-5320.2012.2, RFBR (grants 11-02-00276-a, 12-02-00065-a, 13-02-00418-a, 13-02-00375-a 12-02-31488-mol-a, 12-02-31692-mol-a, 12-02-31488-mol-a, 12-02-33140-mol-a-ved),the Russian Federation Presidential Grant for Young Scientists MK-4345.2012.2 and the Grant 14.740.11.1167 from the Federal Program ‘Scientific and Pedagogical Personnel of Innovational Russia”.

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