Experimental study of the decay $\phi \to \eta\gamma$ in multi-photon final state

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Abstract

In the SND experiment at VEPP-2M e^+e^- collider the $\phi(1020) \to \eta\gamma \to 3\pi^0\gamma$ decay was studied. The branching ratio $B(\phi \to \eta\gamma) = (1.246 \pm 0.025 \pm 0.057)$ % was measured.

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The $\phi \to \eta\gamma$ decay is a classical magnetic dipole transition from ϕ to η meson which was studied in many experiments [1]. In this work we describe the measurement of the $\phi \to \eta\gamma$ branching ratio in the SND experiment at the VEPP-2M e^+e^- collider in Novosibirsk. Spherical non-magnetic detector SND [2] was designed for the experimental study of e^+e^--annihilation at center of mass energy about 1 GeV. Its main part is a three layer electromagnetic calorimeter consisted of 1630 NaI(Tl) crystals [3, 4]. The experiment was performed at VEPP-2M in 1996 [5]. It consists of 6 successive runs at 14 different beam energies in the region $2E_0 = (980 - 1050)$ MeV covering the peak and close vicinity of the ϕ resonance. The total integrated luminosity is equal to 3.7 pb^{-1} which corresponds to $7.6 \cdot 10^6$ ϕ-mesons produced. The luminosity was determined using events of the two-quantum annihilation process.

The following reaction was studied:

$$e^+e^- \to \phi \to \eta\gamma \to 3\pi^0\gamma \to 7\gamma.$$

The events were selected with 6–8 photons emitted at angles of more than 27 degrees with respect to the beam and no charged particles. Standard SND cuts [5] on energy-momentum balance in an event were used. As a result of such selection cosmic background is excluded and the main background process $e^+e^- \to \phi \to K_SK_L \to \pi^0\pi^0K_L$ is suppressed. It is seen from Fig.1, where spectrum is shown for the recoil mass $m_{rec\gamma}$ of

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the most energetic photon in an event. The peak on the mass of the η meson dominates. For final selection of $\eta\gamma$ events a soft cut $400\ MeV < m_{rec\gamma} < 620\ MeV$ was used. The $\phi \to K_S K_L$ background contribution is about 1 %, which was evaluated using number of events from the $m_{rec\gamma}$ interval from 620 to 840 MeV. It worth noting that number and spectrum of $K_S K_L$ events are in a good agreement with Monte Carlo simulation.

The number of thus selected events in each energy point for each run allows to determine the visible cross section σ_{vis}, which was fitted for each of 6 runs separately according to following expression:

$$\sigma_{vis}(s) = \sigma_0 \beta(s) \varepsilon \sqrt{\frac{1 - m_\eta^2/s}{1 - m_\eta^2/m_\phi^2}} \cdot \left| \frac{\Gamma_\phi m_\phi}{m_\phi^2 - s - i m_\phi \Gamma_\phi(s)} + A \right|^2, s = 4E^2,$$

where E is a beam energy, σ_0 – cross section in the ϕ-meson pole (free parameter of the fit), $\beta(s)$ – radiative correction which was calculated according to Ref.[6], ε – detection efficiency, A – interference term. In the fit procedure the beam energy spread of 300 keV and the instability of average beam energy of 100 keV were taken into account. The shifts in the beam energy scale for each run were determined using the decay mode $\phi \to K_S K_L$ [5].

The results of the fit are shown in Table 1. The detection efficiency is individual for each run because of small differences in trigger settings and in number of broken or noisy calorimeter channels. The value A describes the interference between ϕ meson and tails of ρ, ω resonances and with a possible anomaly contribution [7]. The results shown in Table 1 were obtained for $A = 0$. If the fit is performed with A as a free parameter the result coincides with the previous assumption. If A is calculated according to Ref.[7], then the results are practically the same. If standard vector dominance model is used as in the analysis of previous experiments [8], then value of σ_0 decreases by only 1.5 %. We include described model uncertainty in the systematic error.

Averaging the data from the Table 1, one can found

$$\sigma_0 = (16.95 \pm 0.34 \pm 0.59)\ nb,$$

where the first error is a statistical one and the second is systematic. Because the results in Table 1 demonstrate some difference, the scale factor for these measurements was calculated according to PDG recommendations. It was found to be 1.5 and was taken into account in the presented statistical error. The systematic error was estimated to be 3.5 %. It is mainly determined by the the systematic uncertainty in normalization (3 %), the background subtraction error (1 %), the error in the detection efficiency estimation (0.5 %), the error in the value of the interference term (1.5 %).

Using the following expression:

$$\sigma_0 = \frac{12\pi B(\phi \to \eta\gamma) B(\phi \to e^+e^-) B(\eta \to 3\pi^0)}{m_\phi^2}$$

and PDG data [1] one can find the value of the branching ratio

$$B(\phi \to \eta\gamma) = (1.246 \pm 0.025 \pm 0.057)\ \%,$$

where first error is a statistical one and the second is systematic. Taken into account were systematics in σ_0 and in PDG data for $B(\phi \to e^+e^-)$ (2.7 %) and $B(\eta \to 3\pi^0)$ (1.2 %).

The result is in agreement with average PDG value (1.26 ± 0.06) % and with each previous experiment [1]. At the moment it is the most accurate single measurement

Table 1: The results of the study of $\phi \to \eta\gamma$ decay for 6 independent runs.

Experiment	Events	$N_\phi \cdot 10^{-6}$	ε, %	σ_0, nb	χ^2/n_D
PHI9601	1064	0.867	32.15	16.14 ± 0.59	11/8
PHI9602	1465	1.143	32.12	16.79 ± 0.53	13/8
PHI9603	2171	1.721	31.69	16.85 ± 0.45	16/10
PHI9604	1258	1.025	31.33	16.05 ± 0.57	16/11
PHI9605	2286	1.607	32.05	17.92 ± 0.56	16/11
PHI9606	1770	1.227	31.73	18.30 ± 0.66	5/9

of $B(\phi \to \eta\gamma)$ based on 10^4 selected events. Precision can be improved if systematic uncertainty is decreased. Note that the limiting factors for this measurement are the accuracy of normalization and the accuracy of the $\phi \to e^+e^-$ branching ratio.

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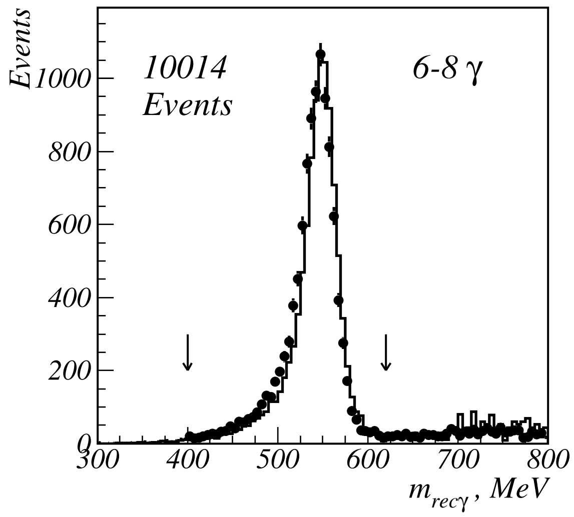

Figure 1: The recoil mass of the most energetic photon in an event. Points – data, histogram – simulation.