**MODEL-INDEPENDENT MEASUREMENT OF $\omega \rightarrow \eta\gamma$
DECAY BRANCHING RATIO**

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Abstract

The rare $\eta\gamma$ decay width of the ω -meson has been measured in a model-independent way, with ω produced in 38 GeV/c π^-p charge-exchange. Large momentum transfer events have been selected in order to eliminate ω - ρ interference contribution. $BR(\omega \rightarrow \eta\gamma) = (8.3 \pm 2.1) \cdot 10^{-4}$. The gammas from $\omega \rightarrow \eta\gamma \rightarrow 3\gamma$ decay have been detected with the multiphoton spectrometer GAMS-2000 at the IHEP 70 GeV proton accelerator.

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A measurement of the partial width of rare radiative decay of the ω meson

$$\omega \rightarrow \eta\gamma \quad (1)$$

is reported here by the GAMS collaboration.

The value of this quantity had been determined in earlier experiments with ω mesons produced either in diffractive photoproduction [1] or in e^+e^- annihilation [2]. In these electromagnetic processes, two vector mesons with close masses, ω and ρ^0 , are simultaneously produced; they decay further through the same $\eta\gamma$ channel with similar intensities. As a result, experimentally measured rates are strongly influenced by their mixing [3]. It increases (or decreases) the signal of ω meson by a factor 2-3 in the overall $\eta\gamma$ mass spectrum in the case of constructive (destructive) interference. According to [4], $BR(\omega \rightarrow \eta\gamma) = (5 \pm 2) \times 10^{-4}$ in the assumption of constructive ω - ρ interference (favored by the quark model). This value would be larger by an order of magnitude, would the interference be destructive.

The use of high energy π^-p charge-exchange

$$\pi^-p \rightarrow \omega n \quad (2)$$

as a source of monoenergetic ω mesons opens a possibility to measure the decay (1) rate in a model-independent way. Although reaction (2) is accompanied by an analogous reaction of ρ^0 production

$$\pi^-p \rightarrow \rho^0 n, \quad (3)$$

with ρ^0 decaying also into $\eta\gamma$, both processes can be largely separated on kinematical ground, due to the difference in production mechanisms. Reaction (3) is dominated by the one-pion exchange mechanism. Corresponding events are concentrated at small momentum transfers. On the other hand, the differential cross-section of reaction (2) has a comparatively flat t -dependence [5]. This allows to choose a region of sufficiently high $|t|$ in order to get rid of most of the ω - ρ interference influence on the ω signal in reaction

$$\pi^-p \rightarrow \eta\gamma n \quad (4)$$

without a big loss of $\omega \rightarrow \eta\gamma$ events. Also the interference correction to the value of $BR(\omega \rightarrow \eta\gamma)$ determined in this reaction decreases fast with increasing energy due to a lesser unnatural parity exchange contribution, which practically vanishes in reaction (2) above 20 GeV/c [5,6].

The data have been collected by the GAMS collaboration at the IHEP 70 GeV proton accelerator during a 1984 run [7]. The photons from $\omega \rightarrow \eta\gamma \rightarrow 3\gamma$ decay were detected with the multiphoton GAMS-2000 hodoscope spectrometer in a 38 GeV/c pion beam. A detailed description of the experiment, of the detectors, of their calibration and of the event reconstruction procedures has been given elsewhere [7,8].

During the same experiment the intense competing decay

$$\omega \rightarrow \pi^0\gamma \quad (5)$$

with a topology similar to that of decay (1), has also been measured and used for normalization (fig. 1). This helps to reduce the systematic errors in the determination of the partial width of the $\eta\gamma$ decay mode.

The observation of the $\omega \rightarrow \eta\gamma$ decay is experimentally difficult as this rare process must be disentangled from the background due to other charge-exchange reactions which occur simultaneously with several orders of magnitude higher intensity.

The analysis of the data (35 million neutral events written on magnetic tapes) has been performed in several steps. Of these, $3 \cdot 10^5$ 3γ -events are selected by the GAMS shower reconstruction program. Further, a series of criteria are applied in order to suppress physical and instrumental backgrounds without any substantial loss in detection efficiency of the studied reaction (1), (2) :

- the distance between the shower axes in GAMS is larger than 6 cm;
- the distance between γ -impacts on GAMS and the beam axis is larger than 4.5 cm (this criterion allows one to suppress the background in the central GAMS counters which are heavily loaded because of the high beam intensity (up to 10^7 π^- /s traversing the spectrometer);
- the total energy deposited in GAMS is limited to the range 35 to 40 GeV;
- the energy of each gamma is larger than 0.6 GeV;
- the energy of the single gamma, emitted with the η meson, is larger than 2.5 GeV;
- the invariant mass of the γ -pair from an η decay lies between 490 MeV and 620 MeV;
- $\cos \theta_\gamma^* < 0.8$, where θ_γ^* is the polar angle in the η rest frame of one of its decay gammas, relatively to the η momentum direction in the laboratory.

The much more intense decay $\omega \rightarrow \pi^0\gamma$ is the source of a combinatorial background which simulates $\eta\gamma$ events. All events that might contain a π^0 have been rejected (any γ -pair mass must be outside $30 \div 240$ MeV interval).

Another strong background reduction is achieved by selecting showers in GAMS according to their shape (GAMS cell signals are fitted to the experimentally determined distribution, for details see [9]).

Fig. 2 shows the quality of η identification after applying the above listed criteria¹ (obviously except the mass cut). The peak width corresponds to the intrinsic GAMS resolution ($\sigma_M/M \approx 3\%$). The peak exceeds the continuum by an order of magnitude in the whole $\eta\gamma$ mass region.

The next stage of data treatment starts with event selection on the basis of a 2C kinematical fit (masses of η and recoil neutron in reaction (4) being fixed). In this fit, χ^2 values are computed for each possible γ -combination (up to three) in which the invariant mass of the γ -pair lies inside the η interval ($490 \div 620$ MeV). Events are retained for further analysis if at least one combination satisfies the condition

$$\chi^2 < \chi_{\max}^2 \quad (6)$$

The $\chi_{\max}^2$ value has been varied between 4 (strong cut, $1 - \text{CL} = 0.15$) and 8 (soft cut, $1 - \text{CL} = 0.02$), the final choice being made at the end of analysis.

¹ At the final stage of the data treatment all these selection criteria were varied in order to check the stability of the results and to estimate the systematic errors.

Next, small momentum transfer events, $|t| < 0.15 \text{ (GeV/c)}^2$, have been excluded since the p^0 background is high, ω production is reduced (its cross-section vanishes with $t \rightarrow 0$) and ω - p interference may be large in this region (see above).

These procedures have been analyzed by a Monte Carlo simulation of the experiment, making use of a bank of real showers [10]. The $\omega \rightarrow \eta\gamma$ events have been generated using the production t -dependence and the angular distribution in the Gottfried-Jackson frame of $\omega \rightarrow \pi^0\gamma$ as measured in the present experiment (they are in a good agreement with previous data [5,6]). For the simulation of events outside the ω -peak, the measured $\eta\gamma$ distribution has been used.

The spectrometer efficiency ϵ has been parametrized as described in [11]. For ω decaying into $\eta\gamma$ and $\pi^0\gamma$, ϵ values are close. Their ratio depends only weakly on t , it stays within a few percent.

The very same programs and selection criteria, that are used in the experimental data analysis, have been applied to the Monte Carlo generated $\eta\gamma$ events. The majority (96% at $\chi^2_{\max} = 5$) have only one γ -combination compatible with the limiting χ^2 (6). Only in one percent of the cases this reconstructed combination differs from the initial one (fig. 3). Four percent of $\eta\gamma$ events admit two solutions which are both compatible with this condition. If one keeps the solution with the smallest χ^2 , a wrong combination is found in one tenth of the cases only (fig. 4). Thus, 99% of events with a single solution pass the selection; if the number of solutions is not restricted and if events with the least significant χ^2 are ignored, the overall selection gets up to 98.6% of the simulated events (at $\chi^2_{\max} = 5$). By relaxing the strength of the selection, the contribution of wrongly identified events increases but still remains small (2.3% at $\chi^2_{\max} = 8$).

Double solutions start to occur for $\eta\gamma$ masses larger than $\sqrt{2} m_\eta$ which is, by chance, equal to m_ω . Their number increases rapidly with mass and reaches 50% for $\chi^2_{\max} = 5$ and more for larger $\chi^2_{\max}$. These simulated events are concentrated in the $800 \div 900 \text{ MeV}$ region. At $M_{\eta\gamma} \approx 800 \text{ MeV}$ the second (wrong) solution is shifted by about 40 MeV towards larger masses (fig. 4) while at $M_{\eta\gamma} \approx 900 \text{ MeV}$ it moves as much but towards smaller masses. At $M_{\eta\gamma} \approx 850 \text{ MeV}$ both solutions give practically the same mass. In summary, in the whole double solution region (fig. 5) $\eta\gamma$ events are reconstructed with high efficiency ($> 95\%$) if the γ -combination with the smallest χ^2 is retained.

An analogous concentration of events with a double solution is observed in the case of $\pi^0\gamma$ decay but it happens for $\pi^0\gamma$ systems of small mass ($< 400 \text{ MeV}$). In the ω region, the contribution of $\pi^0\gamma$ events with a double solution amounts to 5% only.

The measured $\eta\gamma$ mass spectrum is shown on fig. 6 (all events including the solution with the lowest χ^2 only, when two are possible). A narrow peak which coincides in mass with that of the ω -meson shows up in the spectrum. Its width corresponds to the resolution of GAMS ($\sigma_M/M \approx 1.5\%$, after 2C fit). This figure shows that the selection procedure allows to identify the events of the rare radiative decay $\omega \rightarrow \eta\gamma$ from the background.

In the measured mass spectrum (fig. 6), the kinematical peculiarities elucidated by the analysis of Monte Carlo simulated $\eta\gamma$ systems are observed. The contribution of double solution events being negligible in the ω region becomes important at larger masses. Their spectrum coincides with the simulated one both in numbers and in shape (fig. 6).

The shape of the background that is observed outside the ω -peak is similar to that of the mass spectrum of $\eta\pi^0$ events measured in the same experiment. This essentially reflects the loss of one low energy photon from the π^0 in $\eta\pi^0 \rightarrow 4\gamma$ events because of the detection threshold [7], which confuses a few percent of these $\eta\pi^0$ with 3γ events. This background, a leakage from 4γ events, is practically constant in the $700 \div 1000$ MeV mass region (fig. 6).

The number of observed $\omega \rightarrow \eta\gamma$ decays has been obtained from the number of events in the ω -peak, after subtracting the background inferred from the neighbouring mass intervals (cf. the table). The peak has been fitted to the Gaussian shaped spectrometer resolution. The GAMS resolution as well as the number of free parameters in the polynomial describing the background in the domain of the fit have been varied in order to estimate systematic uncertainties. The number of ω events did not change during these exercises by more than $\pm 5\%$. The precision of the measured ratio of $\omega \rightarrow \eta\gamma$ and $\omega \rightarrow \pi^0\gamma$ decay rates (cf. the table) is mainly determined by the 20% statistical error.

The peak-to-background ratio improves when only single-solution $\eta\gamma$ events are selected (fig. 7). However, an additional uncertainty enters then in the determination of the $\omega \rightarrow \eta\gamma$ event number due to the undetermined normalization of the background on the right side of the ω -peak. As a result, the final precision on the measured ratio of $\omega \rightarrow \eta\gamma$ and $\omega \rightarrow \pi^0\gamma$ widths turns out to be the same as that evaluated on the whole sample (fig. 6) (cf. the table). The latter uncertainty is avoided when the mass spectrum is corrected for efficiency (fig. 8). In this case the background in the neighbourhood of ω -peak is flat for the $\eta\gamma$ events with a single solution also. All above methods do not show systematic differences. A similar procedure has been applied to the events in the lower and upper parts of the t -interval; results are given in the table.

The ratio of both decay widths, $\eta\gamma$ and $\pi^0\gamma$, is

$$\Gamma(\omega \rightarrow \eta\gamma) / \Gamma(\omega \rightarrow \pi^0\gamma) = (9.8 \pm 2.4) \cdot 10^{-3} . \quad (7)$$

Normalizing to the known $\omega \rightarrow \pi^0\gamma$ branching ratio, which is $(8.5 \pm 0.5)\%$ [4], one gets

$$\text{BR}(\omega \rightarrow \eta\gamma) = (8.3 \pm 2.1) \cdot 10^{-4} . \quad (8)$$

The reported error includes the estimated systematic uncertainty ($< 10\%$) which had been obtained by varying the selection criteria (e.g., fig. 9).

Existing high-energy experimental data on reactions (2) and (4) [5,6,12-14] have been used to evaluate a possible influence of ω - ρ interference on the results. The unnatural parity exchange dominates in ρ^0 production (3) at small momentum transfers up to the lower boundary of the chosen interval ($|t| = 0.15$ (GeV/c)²), but it contributes only little to ω production (2) ($\rho_{00} \approx 0.15$, $\rho_{11} - \rho_{1-1} \approx 0$). As a result, the possible

interference correction to the measured number of ω decaying into $\eta\gamma$ is small. With $|t|$ increasing, closer to the upper boundary of the accepted interval ($|t| > 0.5 \text{ (GeV/c)}^2$), the ρ^0 production regime changes and natural parity exchange dominates, as for the ω production (2). This opens a possibility for a strong ω - ρ mixing. However, the fast drop with $|t|$ of the amplitudes of both reactions makes the contribution of this t -region negligible. The eventual interference correction averaged over the considered t -interval is essentially smaller than the statistical uncertainty (cf. the table); it increases the total error in (8) by a small amount (the quoted error is the quadratic sum of all errors).

In addition to the direct determination of the $\omega \rightarrow \eta\gamma$ decay branching ratio, the result of the present work (8) allows to solve an old-standing ambiguity in previously reported results [1,2] by rejecting the solution which corresponds to destructive interference and which produces a $\text{BR}(\omega \rightarrow \eta\gamma)$ value four times larger than (8). It also removes the ambiguity in the determination of $\text{BR}(\rho^0 \rightarrow \eta\gamma)$, the lowest of the two possible values [1,2] is by now the correct one.

The measured ratio (7) can be readily compared with the estimation following from the naive quark model²:

$$\text{BR}(\omega \rightarrow \eta\gamma) / \text{BR}(\omega \rightarrow \pi^0\gamma) = \sin^2\delta (p_\eta^* / p_\pi^*)^3 / 9, \quad (9)$$

where $p_{\eta,\pi}^*$ are the momenta of decays (1) and (5). Using in (9) the experimental value of the mixing angle δ for the pseudoscalar meson nonet [4], this ratio is 0.010 ± 0.002 , in good agreement with (7). Other theoretical estimates of ratio (7) are in the limits of 0.002 to 0.014 [15-21].

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² The predictions of this model are usually well satisfied. For example, $\text{BR}(\eta' \rightarrow \omega\gamma) / \text{BR}(\omega \rightarrow \pi^0\gamma) = \cos^2\delta (p_\omega^* / p_\pi^*)^3 (\Gamma_\omega / \Gamma_{\eta'}) / 3 = 0.36 \pm 0.04$, to be compared with the experimental value 0.35 ± 0.04 [4].

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Figure Captions

- Fig. 1 Measured $\pi^0\gamma$ mass spectrum. The peak shows ω produced in $\pi^-p \rightarrow \pi^0\gamma n$. The mass spectrum of γ -pairs in 3γ events is shown in the inset. The arrows point to the tabulated values of ω and π^0 masses.
- Fig. 2 Mass spectrum of γ -pairs amongst 3γ events selected for the analysis of $\pi^-p \rightarrow \eta\gamma n$ (mass interval $760 \div 810$ MeV). The selection criteria are given in the text.
- Fig. 3 Mass spectrum obtained by the analysis of $\omega \rightarrow \eta\gamma$ events generated by Monte Carlo simulation : a) all 3γ events; b) events with a single solution, the hatched part corresponding to the correct reconstruction of the initial combination of photons; c) events in b), which correspond to a wrong reconstruction.
- Fig. 4 Same as in fig. 3, but for double solution 3γ events : a) all events, the hatched part corresponds to the true (initial) combination of photons; b) events in a), which correspond to a wrong combination.
- Fig. 5 The $\eta\gamma$ -mass spectrum reconstructed from an initial simulated flat distribution : a) events with single solution (thin histogram), thick histogram is for all events (in the case of a double solution, the selection is made according to the χ^2 value, cf. text); b) events with two solutions. The dashed curve corresponds to ω production.
- Fig. 6 Measured mass spectrum of 3γ events identified as $\eta\gamma$. The peak corresponds to $\omega \rightarrow \eta\gamma$. Here and further : $0.15 \text{ (GeV/c)}^2 < |t| < 1 \text{ (GeV/c)}^2$. The thick histogram represents all events, the thin histogram shows the contribution of double solution events. The hatched line is the result of Monte Carlo simulation. The arrow points to the tabulated ω mass value.
- Fig. 7 Same as in fig. 6, but for $\eta\gamma$ events with a single solution only. The two curves describing background are normalized in the mass intervals $820 \div 930$ MeV and $800 \div 880$ MeV, respectively (shown by thick lines).
- Fig. 8 Same as in fig. 7, but after efficiency correction. The number of events in the mass bin is $N/\epsilon = \sum_{i=1}^N 1/\epsilon_i$, where ϵ_i is the detection efficiency for the i -th event.
- Fig. 9 $BR(\omega \rightarrow \eta\gamma)$ values obtained with different $\chi_{\max}^2$ cuts.

Table : Results of the data treatment

$ t $ -interval (GeV/c) ²	Number of 3 γ -events $\omega \rightarrow \eta\gamma$	Number of 3 γ -events $\omega \rightarrow \pi^0\gamma$	$\frac{\Gamma(\omega \rightarrow \eta\gamma)}{\Gamma(\omega \rightarrow \pi^0\gamma)}$	Maximum cor- rection due to ω - ρ interference
0.15 - 1.0	a) 58 ± 13 b) 60 ± 13 c) 59 ± 12	15300	0.0095 ± 0.0022 0.0102 ± 0.0022 0.0098 ± 0.0021	± 0.0010
0.3 - 1.0	a) 27 ± 8 b) 30 ± 8	7100	0.0093 ± 0.0027 0.0107 ± 0.0028	± 0.0006
0.15 - 0.3	a) 33 ± 9 b) 31 ± 9	8300	0.0096 ± 0.0026 0.0099 ± 0.0029	± 0.0016

a) all events; b) single solution events; c) single solution events, after efficiency correction.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

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Fig. 9