Conversion decays $\phi \to \eta e^+e^-$, $\phi \to \pi^0 e^+e^-$ and $\eta \to e^+e^-\gamma$ at CMD-2

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1. Introduction

Conversion decays are closely related to corresponding radiative decays. In conversion decays a virtual photon is converted into a lepton pair.

This work is devoted to determination of the branching ratios for conversion decays $\phi \to \eta e^+e^-$, $\phi \to \pi^0 e^+e^-$ as well as Dalitz decay $\eta \to e^+e^-\gamma$. A data sample corresponding to the integrated luminosity of 15.5 pb^{-1} has been used which was collected with the CMD-2 detector at VEPP-2M collider during the runs PHI-93, PHI-96 and PHI-98. The decay $\eta \to e^+e^-\gamma$ was detected via the mode $\phi \to \eta\gamma$, $\eta \to e^+e^-\gamma$, the decay $\phi \to \pi^0 e^+e^-$ via the $\pi^0 \to \gamma\gamma$ and the decay $\phi \to \eta e^+e^-$ via the $\eta \to \gamma\gamma$. The process $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-\gamma$ was used to determine the number of ϕ-mesons.

All processes have two charged particles and two photons in the final state.

The decay $\phi \to \eta e^+e^-$ was also detected via the $\eta \to 3\pi^0$, $\pi^0 \to \gamma\gamma$ with 6 photons in the final state.

The primary selection criteria are:

- the number of vertices in the drift chamber $N_{vert} = 1$;
- the number of tracks from this vertex $N_{track} = 2$;
- total charge of tracks = 0;
- the impact parameter of tracks $r_{min} < 1.0\ cm$;
- the number of photons in calorimeter $N_\gamma \geq 1$.

Selected events were subject to kinematic reconstruction taking into account energy-momentum conservation.

Detection efficiencies were calculated from the Monte Carlo simulation of the experiment [1].

2. Selection of $\eta \to \pi^+\pi^-\gamma$ events

The main selection criteria are:

- two photons in final state $N_\gamma = 2$;
- invariant mass of two gammas $M_{inv}(\gamma\gamma) > 250\ MeV$, to suppress $\phi \to \pi^+\pi^-\pi^0$ events;

In Fig. ?? *a*) we plot the invariant mass of the $\pi^+\pi^-\gamma_{min}$ system for the data of PHI-98 where γ_{min} is a photon with the minimal energy.

The number of ϕ-mesons was determined from the formula

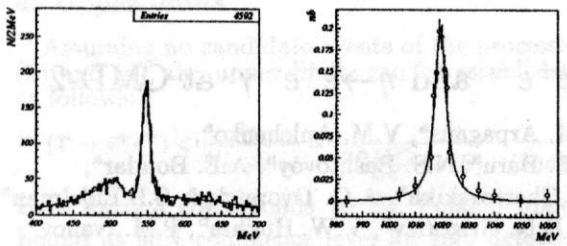
$$N_\phi = \frac{N_0}{B(\phi \to \eta\gamma) \cdot B(\eta \to \pi^+\pi^-\gamma) \cdot \varepsilon_0} \qquad (1)$$

where N_0 is the number of $\pi^+\pi^-\gamma$ events, ε_0 is the detection efficiency determined from simulation.

3. Selection of $\eta \to e^+e^-\gamma$ events

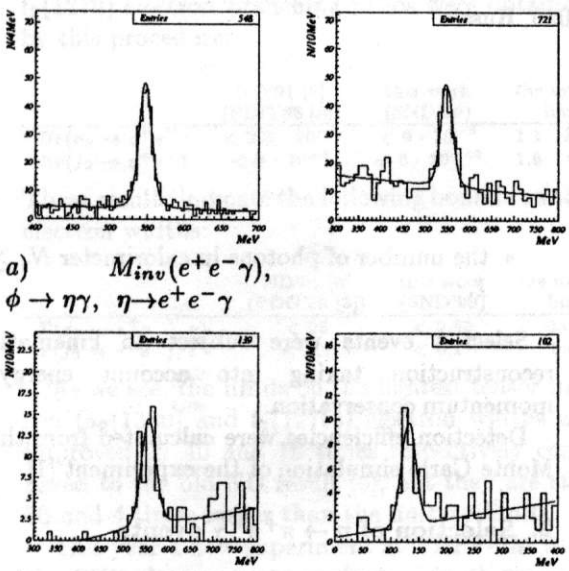
To select conversion decays one used the peculiar feature of their kinematics: the angle between e^+ and e^- is as a rule close to zero.

Significant background to events of conversion decays comes from the γ-quantum conversion in



a) invariant mass $M_{inv}(\pi^+\pi^-\gamma)$ *b*) visible cross section

Figure 1. Monitoring process $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-\gamma$, PHI-98 data



a) $M_{inv}(e^+e^-\gamma)$, $\phi \to \eta\gamma$, $\eta \to e^+e^-\gamma$

c) $M_{inv}(\gamma\gamma...)$, $\phi \to \eta e^+e^-$, $\eta \to 3\pi^0$, $\pi^0 \to \gamma\gamma$ *d*) $M_{inv}(\gamma\gamma)$, $\phi \to \pi^0 e^+e^-$, $\pi^0 \to \gamma\gamma$

Figure 2. Invariant masses for conversion decays, PHI-98 data

the detector material. The detection efficiency for this process was also determined from the simulation. The number of conversion events was calculated from the formula:

$$N_{conv} = N_\phi \cdot B(\phi \to P\gamma) \cdot B(P \to \gamma\gamma) \cdot \varepsilon_{conv} \quad (2)$$

where P stands for η (for $\eta \to e^+e^-\gamma$ and $\phi \to \eta e^+e^-$) or π^0 (for $\phi \to \pi^0 e^+e^-$).

The number of events of $\phi \to \eta\gamma$, $\eta \to e^+e^-\gamma$ was determined from the spectrum of the invariant mass of the $e^+e^-\gamma$ state (Fig. 2 *a*).

The main selection criteria are:

- spatial angle between two tracks $\Delta\psi < 0.5\ rad$;
- two photons in the final state $N_\sim = 2$:
- invariant mass $M_{inv}(\gamma\gamma) > 250\ MeV$, to suppress $\phi \to \pi^+\pi^-\pi^0$ events.

The following criterion was used to select a photon:

- γ_{max}, if $(M_{inv}(e^+e^-\gamma_{max}) + M_{inv}(e^+e^-\gamma_{min})) < 2 \cdot M_\eta$;
- γ_{min}, if $(M_{inv}(e^+e^-\gamma_{max}) + M_{inv}(e^+e^-\gamma_{min})) > 2 \cdot M_\eta$,

where γ_{max} is a photon with the maximum energy, γ_{min} is a photon with the minimum energy.

The detection efficiency of the effect and for conversion events was determined from simulation.

4. Selection of $\phi \to \eta e^+e^-$ events

The number of events of $\phi \to \eta e^+e^-$, $\eta \to \gamma\gamma$ was determined from the spectrum of the invariant mass of the $\gamma\gamma$ state (Fig. 2 *b*)). The number of events of $\phi \to \eta e^+e^-$, $\eta \to 3\pi^0$, $\pi^0 \to \gamma\gamma$ – from the spectrum of the invariant mass of the $(\gamma\gamma...)$ state (Fig. 2 *c*)). These processes also have background from the conversion of γ on the material.

The main selection criteria are:

- $\Delta\psi < 0.5\ rad$;
- $N_\gamma = 2$, for the mode $\eta \to \gamma\gamma$ with 2 photons in the final state;
- $N_\gamma \geq 5$, for the mode $\eta \to 3\pi^0$, $\pi^0 \to \gamma\gamma$ with 6 photons.

5. Selection of $\phi \to \pi^0 e^+e^-$ events

The number of $\phi \to \pi^0 e^+e^-$, $\pi^0 \to \gamma\gamma$ events was also determined from the spectrum of the invariant mass of the $\gamma\gamma$ state (Fig. 2 *d*)). The main background for this process comes from the events of $\phi \to \pi^+\pi^-\pi^0$, $\pi^0 \to \gamma\gamma$. But for this process the angle between charged particles does not have a peak around zero, therefore this background can be suppressed by making more strict the criterion for the angle between charged particles.

$$N_{3\pi} = N_\phi \cdot B(\phi \to \pi^+\pi^-\pi^0) \cdot B(\pi^0 \to \gamma\gamma) \cdot \varepsilon_{3\pi} \quad (3)$$

This process also has background from the conversion of γ on the material from process $\phi \to \pi^0\gamma$. All detection efficiencies (effect, conversion events, $\phi \to \pi^+\pi^-\pi^0$- events) were determined from simulation.

The main selection criteria are:

Table 1
The relative branching ratios at some runs

	N_ϕ $(\times 10^6)$	$B(\eta \to e^+e^-\gamma)$ $(\times 10^{-4})$	$B(\phi \to \eta e^+e^-)$ $(\times 10^{-4})$	$B(\phi \to \pi^0 e^+e^-)$ $(\times 10^{-5})$
PHI-93	1.19 ± 0.18	8.36 ± 3.57	1.68 ± 0.74	$2.4^{+1.7}_{-1.4}$
PHI-96	2.51 ± 0.21	6.31 ± 1.39	1.32 ± 0.28	2.00 ± 0.96
PHI-98	9.80 ± 0.60	7.40 ± 0.90	1.06 ± 0.14	1.20 ± 0.38
PHI-98*		7.12 ± 0.99	1.00 ± 0.15	1.04 ± 0.34
Total	13.50 ± 0.66	7.18 ± 0.74	1.13 ± 0.12	1.40 ± 0.33

Table 2
Comparison with theoretical predictions and other experiments

Decay	$B(\eta \to e^+e^-\gamma)$	$B(\phi \to \eta e^+e^-)$	$B(\phi \to \pi^0 e^+e^-)$
Theory	$(6.60 \pm 0.80) \cdot 10^{-3}$	$(1.10 \pm 0.10) \cdot 10^{-4}$	$(1.44 \pm 0.10) \cdot 10^{-5}$
PDG	$(4.9 \pm 1.1) \cdot 10^{-3}$	$(1.3^{+0.8}_{-0.6}) \cdot 10^{-4}$	$< 1.2 \cdot 10^{-4}$
CMD-2	$(7.18 \pm 0.74 \pm 1.08) \cdot 10^{-3}$	$(1.13 \pm 0.12 \pm 0.17) \cdot 10^{-4}$	$(1.40 \pm 0.33 \pm 0.21) \cdot 10^{-5}$

- $\Delta\psi < 0.15$ *rad*, to suppress $\phi \to \pi^+\pi^-\pi^0$;
- two photons in the final state $N_\gamma = 2$;
- $\pi^\pm/e^\pm$-identification in calorimeter.

6. Branching ratios

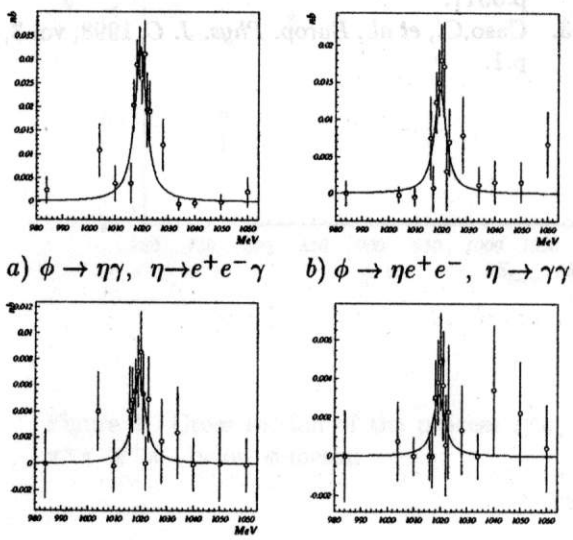
The relative branching ratios B_i were determined from the formula:

$$B_i = \frac{N_{0_i}}{N_\phi \cdot B_{inter_i} \cdot \varepsilon_{0_i}} \qquad (4)$$

where $i = 1,2,3$ corresponds to $\eta \to e^+e^-\gamma$, $\phi \to \eta e^+e^-$ and $\phi \to \pi^0 e^+e^-$; N_{0_i} is the number of events of the effect with N_{conv_i} (2) and $N_{3\pi}$ (3) for $\phi \to \pi^0 e^+e^-$ subtracted; N_{phi} is the number of the ϕ-mesons determined from the (1); B_{inter_i} is the intermediate probability of the decay: $B(\phi \to \eta\gamma)$ for $\eta \to e^+e^-\gamma$, $B(\eta \to \gamma\gamma)$ or $(B(\eta \to 3\pi^0) \cdot B(\pi^0 \to \gamma\gamma)^3)$ for $\phi \to \eta e^+e^-$, $B(\pi^0 \to \gamma\gamma)$ for $\phi \to \pi^0 e^+e^-$; ε_{0_i} is the detection efficiency.

The results are shown in Table 1.

For the PHI-98 data we performed a fit of the energy dependence of the cross sections with the ϕ-meson excitation curve. In Fig. 3 visible cross sections of the processes under the study are shown parametrised with the Breit-Wigner function. At each point the procedure above was used to calculate the visible cross section by dividing the number of events over the integrated luminosity. The relative branching ratios of conversion decays were determined as a ratio of the corresponding maxima of the cross sections to the maximum of the cross section of the monitoring



a) $\phi \to \eta\gamma$, $\eta \to e^+e^-\gamma$ b) $\phi \to \eta e^+e^-$, $\eta \to \gamma\gamma$

c) $\phi \to \eta e^+e^-$, $\eta \to 3\pi^0$, $\pi^0 \to \gamma\gamma$ d) $\phi \to \pi^0 e^+e^-$, $\pi^0 \to \gamma\gamma$

Figure 3. Visible cross sections for conversion decays, PHI-98 data

process $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-\gamma$ (Fig. 1 *b*)) taking into account corresponding detection efficiencies and decay branching ratios. The obtained results (Table 1, line "PHI-98*") are consistent with those from the previous method (Table 1, line "PHI-98").

7. Conclusion

The following sources of the systematic uncertainties were considered: efficiency of reconstruc-

tion and detection of the tracks with a small angle between them, extra photons from the cluster splitting in the calorimeter, extra photons from the noisy crystals and electronics channels in the calorimeter. The overall systematic uncertainty was estimated to be 15%.

The obtained results don't contradict to theoretical predictions [2] and have better statistical accuracy than the previous measurements quoted by the Review of Particle Physics [3] (Table 2).

Investigation of the transition form factors of pseudoscalar mesons will require a detailed study of the efficiencies of reconstruction and detection of tracks at a small angle.

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