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Conversion decays of ϕ(1020) decays into $\pi^0 e^+e^-$, η(550) e^+e^- and η(550) into $e^+e^-\gamma$ from SND detector at VEPP-2M

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Abstract: The conversion decays $\phi \to \eta e^+e^-, \phi \to \pi^0 e^+e^-$ and $\eta \to \gamma e^+e^-$ were studied by the SND detector using ϕ-meson production in e^+e^--annihilation at VEPP-2M collider. The e^+e^--pair mass spectra and transition form factors for $\phi \to \eta e^+e^-$ and $\eta \to \gamma e^+e^-$ were also studied.

1. Introduction

Conversion decays of vector and pseudoscalar mesons are closely related to corresponding radiative decays. But in conversion decays a radiated photon is virtual and its squared mass q^2 (equal to invariant mass of lepton pair $M^2_{l^+l^-}$) is not equal to zero. So studying lepton pair invariant mass spectrum it is possible to learn more about mesons structure and underlying quark dynamics and to measure a so-called transition form factor. In general case of meson V decay into meson P this spectrum is described by the following formula[1]:

$$\frac{d}{dq^2}\frac{B(V \to Pe^+e^-)}{B(V \to P\gamma)} =$$

$$\frac{\alpha}{3\pi}\frac{|F_{VP}(q^2)|^2}{q^2} \cdot \sqrt{1-\frac{4m^2}{q^2}}\left(1+\frac{2m^2}{q^2}\right) \cdot \left[\left(1+\frac{q^2}{m_V^2-m_P^2}\right)^2 - \frac{4m_V^2 q^2}{(m_V^2-m_P^2)^2}\right]^{3/2}, \quad (1.1)$$

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where F_{VP} - transition form factor, m - electron mass, m_V, m_P - masses of V and P mesons respectively. In one-pole approximation transition form factor can be written in the following way:

$$F_{VP} = \frac{1}{1 - q^2/\Lambda^2}, \tag{1.2}$$

were $b^2 = 1/\Lambda^2$ is a transition form factor slope, which is usually measured in experiments.

In this work three different conversion decays were studied: $\phi \to \eta e^+ e^-$, $\phi \to \pi^0 e^+ e^-$, $\eta \to \gamma e^+ e^-$. As a source of η mesons the decay $\phi \to \eta\gamma$ was used. The available experimental data about these decays before the experiments at VEPP-2M with SND and CMD2 detectors are shown in Table 1.

Decay	experimental status	PDG [8]
$\phi \to \eta e^+ e^-$	ND (5 events) (BINP,Novosibirsk[2])	$(1.3^{+0.8}_{-0.6}) \cdot 10^{-4}$
$\eta \to e^+ e^- \gamma$	optical spark chamber (Rutherford Laboratory)	$(4.9 \pm 1.1) \cdot 10^{-3}$
	transition form factor study[3]	$b_\eta = (-0.7 \pm 1.5)$ GeV^{-2}
$\phi \to \pi^0 e^+ e^-$	not seen	$< 1.2 \cdot 10^{-4}$

Table 1: Experimental status of conversion decays before experiments at VEPP-2M.

2. Detector and experiment

The experiments with Spherical Neutral Detector (SND) were held at VEPP-2M e^+e^--collider from 1995 to 2000. SND [4] has the following parts: tracking system consisting of two drift chambers, three layers NaI(Tl) crystal calorimeter and a muon system. Angular resolution of the tracking system is $\sigma_\varphi = 0.5^\circ, \sigma_\vartheta = 2.5^\circ$. The energy and angular resolutions of the calorimeter for photons with energy E are $\sigma_E/E = \frac{4.2\%}{\sqrt[4]{(E(GeV)}}$ and $\sigma_\varphi = \frac{0.82^\circ}{\sqrt{E(GeV)}} \oplus 0.63^\circ$.

The analysis was based on full statistics accumulated near ϕ-meson resonance which is equal to 8.8 pb^{-1} at the energy range 1016 MeV$< \sqrt{s} <$1024 MeV and corresponds to $2. \cdot 10^7$ of ϕ mesons decays.

3. Data analysis

3.1 Branching ratios measurement

Selection of events was performed in two steps. At the first step common for all processes criteria were used:

- number of charged particles is $N_{cp} = 1$; number of photons is $N_{np} = 2$;
- the origin of charged track is located at interaction point;
- polar angle of all particles is limited $36^\circ < \theta < 144^\circ$;

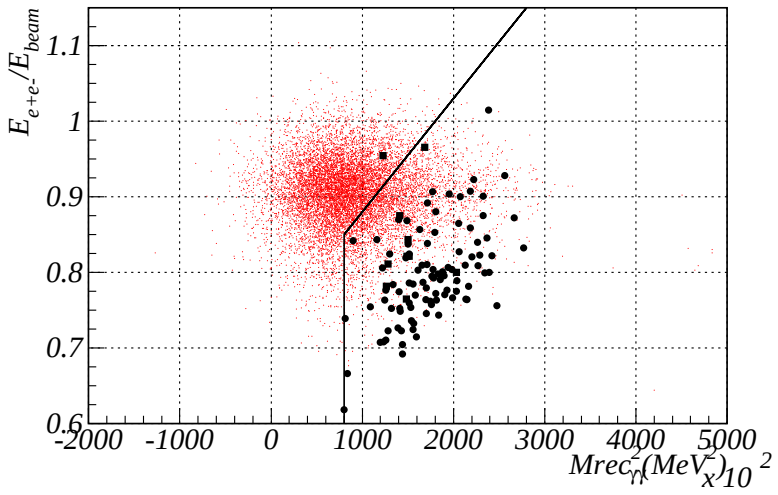

Figure 1: Graphical cut used for $e^+e^- \to \pi^+\pi^-\pi^0$ background suppression in $\phi \to \pi^0 e^+e^-$ analysis

- total energy deposition in the calorimeter is $E_{tot}/2E_0 > 0.8$;
- total normalized momentum in an event is $P_{tot}/E_{tot} < 0.15$;
- $\chi^2 < 15$, where χ^2 is a parameters of the kinematic fit assuming energy-momentum conservation.

At the second step the analysis of $\phi \to \eta e^+e^-$ and $\eta \to e^+e^-\gamma$ decays was performed separately from that of $\phi \to \pi^0 e^+e^-$. For the first two processes the following additional selection criteria were used:

- acollinearity angle in R-ϕ plane $|\Delta\phi_{e\gamma}| = |180^\circ - |\phi_e - \phi_\gamma|| > 5^\circ$;
- minimum photon energy $E_\gamma > 150MeV$;
- invariant mass of two photons $m_{\gamma\gamma}$ is outside 110÷170 MeV interval.

For the last decay the following additional criteria were used:

- minimum photon energy $E_\gamma > 50MeV$;
- graphical cut on 2 dimensional distribution on recoil mass of two photons $M^{rec}_{\gamma\gamma}$ vs. e^+e^--pair energy was used (fig.1).

For thus selected events the following invariant mass distributions were constructed (fig.2): invariant mass of two photons for $\phi \to \eta e^+e^-$ and $\phi \to \pi^0 e^+e^-$ decays and invariant mass of $e^+e^-\gamma$ system for $\eta \to e^+e^-\gamma$. Number of events for each process were obtained via approximation of these spectra by a sum of Gaussian and a polynomial.

Numbers of background events of corresponding radiative decays with conversion of the photon on the material before drift chamber were determined by simulation. For the process $\phi \to \pi^0 e^+e^-$ the tails of ρ and ω resonances were taken into account: correction coefficient was calculated from experimental data on $e^+e^- \to \pi^0\gamma$ cross section. The systematic errors were estimated to be 10% for $\phi \to \eta e^+e^-$, 14% for$\eta \to \gamma e^+e^-$ and 25% for $\phi \to \pi^0 e^+e^-$. Final results for branching ratios are shown in Table 2.

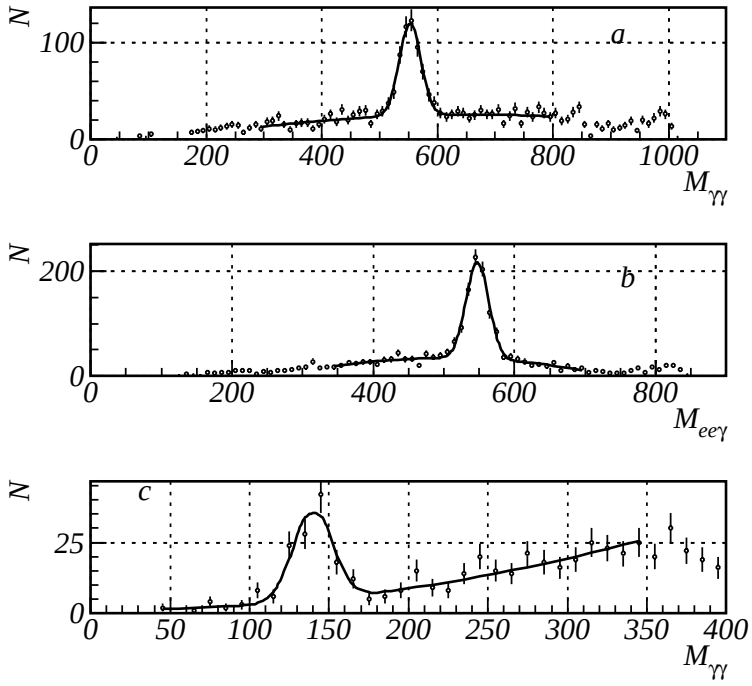

Figure 2: Invariant mass spectra: a – $M_{\gamma\gamma}$ for $\phi \to \eta e^+e^-$, b – $M_{e^+e^-\gamma}$ for $\eta \to e^+e^-\gamma$, c – $M_{\gamma\gamma}$ for $\phi \to \pi^0 e^+e^-$

	$\phi \to \eta e^+e^-$ $(\cdot 10^{-4})$	$\eta \to e^+e^-\gamma$ $(\cdot 10^{-3})$	$\phi \to \pi^0 e^+e^-$ $(\cdot 10^{-5})$
SND	1.19 ± 0.22	5.15 ± 0.96	1.05 ± 0.37
CMD-2	1.17 ± 0.12[5]	7.10 ± 0.79[5]	1.22 ± 0.40 [6]
SND&CMD-2	1.18 ± 0.11	6.31 ± 0.61	1.13 ± 0.27
Theory[1, 7]	1.10 ± 0.1	6.5–6.8	1.3–1.6
PDG(2000)[8]	$1.3^{+0.8}_{-0.6}$	4.9 ± 1.1	$< 1.2 \cdot 10^{-4}$

Table 2: Experimental results for branching ratios

3.2 Transition form factors measurement

Study of electromagnetic transition form factors was performed for the processes $\phi \to \eta e^+e^-$ and $\eta \to e^+e^-\gamma$. In this analysis the selection criteria were similar to those described in 3.1. The only difference was that two charged tracks were required. For selected events the final criteria were used: for $\phi \to \eta e^+e^-$ decay invariant mass of two photons was required to be within 500÷600MeV interval and invariant mass of $e^+e^-\gamma$ system closest to η-meson was required to be ouside 500÷600MeV interval. For $\eta \to e^+e^-\gamma$ decay — opposite criteria were used. For thus selected events the e^+e^- invariant mass M_{ee} spectra was plotted. The background from QED process $e^+e^- \to e^+e^-\gamma\gamma$ was substracted using simulation. From these spectra using formulas from [1] the transition form factors were extracted (fig.3). The distributions were fitted by function (1.2), obtained form factors slopes are shown at Table 3.

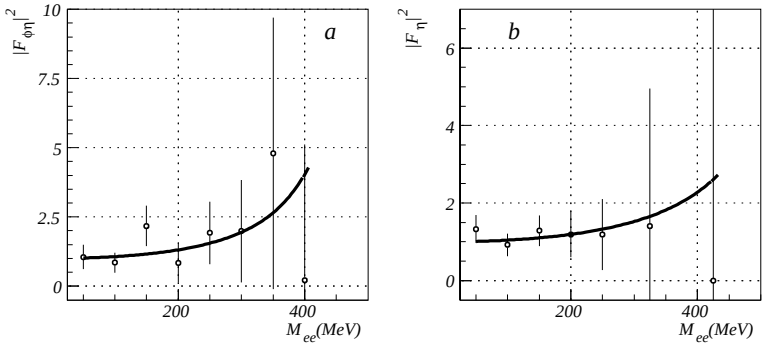

Figure 3: Transition form factors for the processes $\phi \to \eta e^+e^-$ (a) and $\eta \to e^+e^-\gamma$ (b); points - experimental data, solid line - one-pole approximation fit.

	$\phi \to \eta e^+e^-$ $b_{\phi\eta}$,GeV^{-2}	$\eta \to e^+e^-\gamma$ b_η,GeV^{-2}	$\phi \to \pi^0 e^+e^-$ $b_{\phi\pi}$,GeV^{-2}
SND	3.8 ± 1.8	1.6 ± 2.0	—
Theory (VDM)[1]	1.0	1.8	
Previous measurement[3]	—	-0.7 ± 1.5	—

Table 3: Experimental results for transition form factors slopes

4. Conclusions

As a result of experiments with SND detector at VEPP-2M e^+e^--collider the knowledge about conversion decays of ϕ and η mesons was significantly improved. The branching ratios were measured with the accuracy $\sim 20\%$ – for $\phi \to \eta e^+e^-$ and $\eta \to e^+e^-\gamma$ and 35% – for $\phi \to \pi^0 e^+e^-$. The measured values are in good agreement with theoretical predictions, recent CMD-2 results and previous measurements. The measured transition form factor slopes are consistent with VDM predictions.

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