New experimental data for the decays $\phi \to \mu^+\mu^-$ and $\phi \to \pi^+\pi^-$ from SND detector.

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The processes $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \pi^+\pi^-$ have been studied with SND detector at VEPP-2M e^+e^- collider in the vicinity of $\phi(1020)$ resonance. The branching ratios $B(\phi \to \mu^+\mu^-) = (3.30 \pm 0.45 \pm 0.32) \times 10^{-4}$ and $B(\phi \to \pi^+\pi^-) = (0.71 \pm 0.11 \pm 0.09) \times 10^{-4}$ were obtained.

1. INTRODUCTION

The both decays $\phi \to \mu^+\mu^-$ and $\phi \to \pi^+\pi^-$ give interference patterns in the energy dependences of the cross sections of the processes

$$e^+e^- \to \mu^+\mu^-, \qquad (1)$$
$$e^+e^- \to \pi^+\pi^- \qquad (2)$$

in the region of ϕ resonance. The interference amplitude is determined by the branching ratio of the corresponding decay. The table value of the branching ratio BR($\phi \to \mu^+\mu^-$) $= (2.5 \pm 0.4) \times 10^{-4}$ [1] is based on the experiments in photoproduction [2]. In e^+e^- collisions one can measure the leptonic branching ratio of ϕ meson $B_{e\mu} = \sqrt{B(\phi \to \mu^+\mu^-) \cdot B(\phi \to e^+e^-)}$. Such measurements were performed in Orsay [3] and Novosibirsk [4], but their accuracy was not too high.

The experimental result on the decay $\phi \to \pi^+\pi^-$ [1] does not agree well with the theoretical predictions (see for example [5]), but the improvement of the accuracy is needed.

Data collected at VEPP-2M [6] with SND detector [7] in the vicinity of ϕ resonance allow to improve the accuracy of the measurements of these decays. The result on the decay $\phi \to \mu^+\mu^-$ [8] was obtained using 1996 data sample with the total integrated luminosity 2.61 pb^{-1} and corresponding number of ϕ mesons about 4.6×10^6. The 1998 data were used to measure the decay $\phi \to \pi^+\pi^-$. During 1998 about 13.2×10^6 ϕ mesons were produced with the integrated luminosity 8.6 pb^{-1}.

2. EVENT SELECTION

The preliminary selections were the same for the both processes. The events with two collinear charged tracks were selected. The cuts on the angles of acollinearity in azimuth and polar directions were following: $\mid \Delta\varphi \mid < 10°$, $\mid \Delta\theta \mid < 25°$. To suppress the beam and cosmic background the production point of charged particles was required to be within 0.5 cm from the interaction point in the azimuth plane and ± 7.5 cm along the beam direction (the longitudinal size of the interaction region σ_z is about 2 cm). The polar angles of the charged particles were limited in the range $45° < \theta < 135°$, corresponding to the acceptance angle of the outer system [7]. The outer system allows to distinguish between the processes (1) and (2) due to the difference in the probability to hit the outer system for muons and pions. These probabilities are shown in Fig. 1 and 2. The data

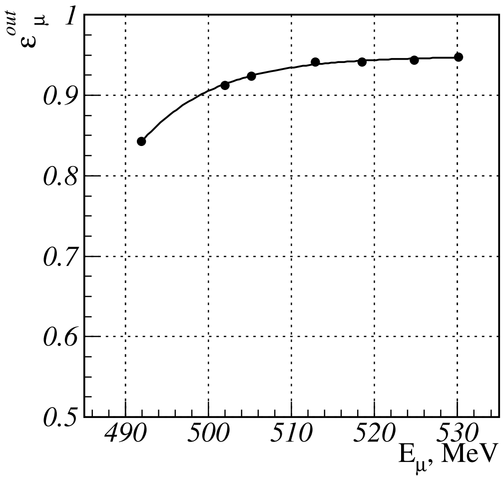

Figure 1. The energy dependence of the probability to hit the outer system for muons.

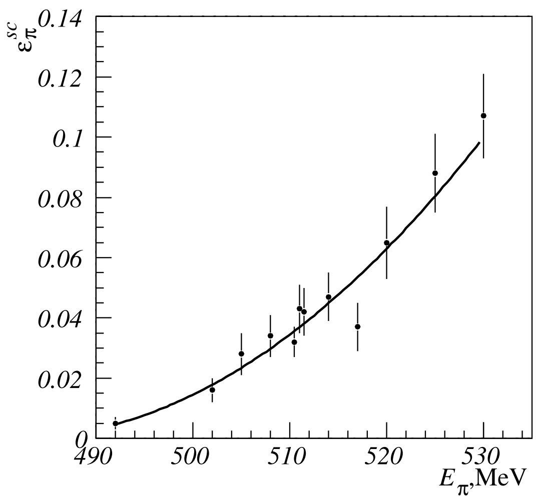

Figure 2. The energy dependence of the probability to hit the outer system for pions.

were divided for two samples ("muons" and "pions") in dependence on the existence of the hit in the outer system. The admixture of the events of the process (2) in the sample "muons" was about 3% at ϕ-resonance energy. The process (1) gave 15% contribution to the sample "pions" at the same energy.

Other sources of background are the cosmic muons and the process $e^+e^- \to e^+e^-$. The cosmic background was significant only for the process (1) and was suppressed by the time of flight system, which is a part of the outer system. The events of the process $e^+e^- \to e^+e^-$ did not contribute to the sample "muons" due to the suppression by the outer system. To reduce the background from these events for the process (2) the procedure of e/π separation based on the energy depositions in the calorimeter layers was used. The events of the process $e^+e^- \to e^+e^-$ were suppressed by factor 3.6×10^{-4}, while only 7% of the events of the process under study were lost. The remaining background from the process $e^+e^- \to e^+e^-$ was about 1.5% at $2E_b = 1020$ MeV.

The processes $e^+e^- \to \phi \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \phi \to K_S K_L$ gave resonance background to the process $e^+e^- \to \pi^+\pi^-$. The events of these decays were suppressed by restrictions on the energy depositions in the calorimeter layers. The contribution of the resonance background remained at the level of 0.5% at $2E_b = 1020$ MeV. Because such background changes the visible interference pattern, special efforts were made to subtract it. The selected events were divided in two parts by the cut on the parameter $\Delta\varphi$: $\mid \Delta\varphi \mid < 5°$ and $\mid \Delta\varphi \mid > 5°$. To obtain the interference parameters the events from the first part were used. The resonance background was determined from the second part, where its level is comparable with the visible cross section of the process (2). The relationship between the quantities of the resonance background in two parts was calculated by Monte Carlo simulation [9].

The detection efficiencies were obtained from the simulated data with using the experimental data for some corrections. The efficiencies for the processes (1) and (2) were 28% and 12% respectively at the region of ϕ resonance.

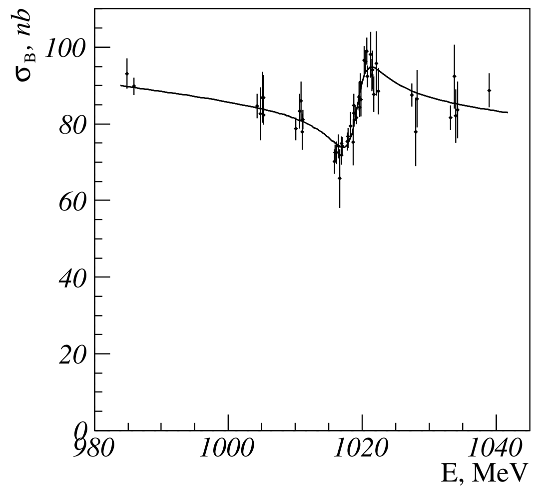

Figure 3. The Born cross section σ_B of the process $e^+e^- \to \mu^+\mu^-$.

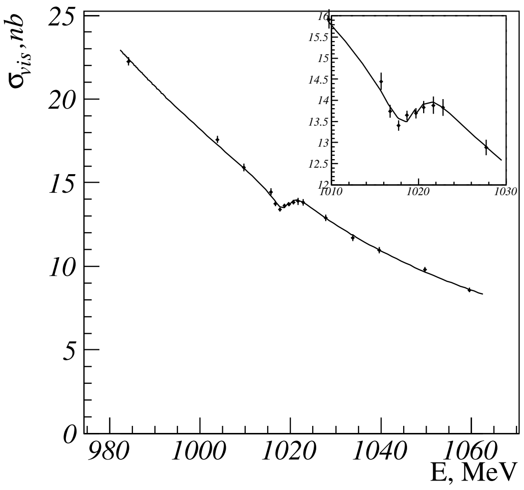

Figure 4. The visible cross section σ_{vis} for the process $e^+e^- \to \pi^+\pi^-$.

3. DATA ANALYSIS

The energy dependence of the visible cross sections of the processes under study was fitted with the following formula: $\sigma_{vis}(E) = \varepsilon(E)\sigma_B(E)\beta(E) + \sigma_{bg}(E)$, where ε – the detection efficiency, σ_B – the Born cross section of the appropriate process, β – factor taking into account the radiative corrections [10,11], σ_{bg} is the cross section of the background. The Born cross section was factorized into non-resonant and resonant parts: $\sigma_B(E) = \sigma_{nr}(E) \mid Z \mid^2$, $Z = 1 - Q \cdot e^{i\psi} \frac{m_\phi \Gamma_\phi}{m_\phi^2 - E^2 - iE\Gamma(E)}$, where Q, ψ – modulus and phase of the interference amplitude, m_ϕ, Γ_ϕ – mass and width of ϕ meson. Non-resonant cross section was taken in the form $\sigma_{\mu\mu} = 83.50(\mathrm{nb})\frac{m_\phi^2}{E^2}$ for the process (1). A second order polynomial was used to describe the cross section σ_{nr} of the process (2).

The interference amplitude is related to the branching ratio of the decay $\phi \to \mu^+\mu^-$ by the following expression: $Q_\mu = \frac{3 \cdot \sqrt{B(\phi \to \mu^+\mu^-) \cdot B(\phi \to e^+e^-)}}{\alpha}$, where α is the fine structure constant. For the decay $\phi \to \pi^+\pi^-$: $Q_\pi = \frac{6 \cdot \sqrt{B(\phi \to \pi^+\pi^-) \cdot B(\phi \to e^+e^-)}}{\alpha \beta_\pi^{3/2}(m_\phi)|F_\pi|}$, where F_π – the pion form factor at the maximum of ϕ resonance, $\beta_\pi = (1 - 4 \cdot m_\pi^2/E^2)^{1/2}$.

Fig. 3 shows the cross section σ_B of the process (1). The cross section σ_{vis} for the process (2) is shown in Fig. 4. The fit gave the following results: $Q_\mu = 0.129 \pm 0.009$, $\psi_\mu = (4.5 \pm 3.4)^\circ$, $\mid F_\pi \mid^2 = 2.98 \pm 0.02$, $Q_\pi = 0.073 \pm 0.005$, $\psi_\pi = -(34 \pm 4)^\circ$. The systematic errors are not specified in these results. From here the leptonic branching ratio of ϕ meson $B_{e\mu} = (3.14 \pm 0.22 \pm 0.14) \times 10^{-4}$ and the branching ratios $B(\phi \to \mu^+\mu^-) = (3.30 \pm 0.45 \pm 0.32) \times 10^{-4}$, $B(\phi \to \pi^+\pi^-) = (0.71 \pm 0.11 \pm 0.09) \times 10^{-4}$ were obtained. The real and imaginary parts of the interference amplitude of the decay $\phi \to \pi^+\pi^-$ are following: $\Re Z_\pi = (6.2 \pm 0.5 \pm 0.5) \times 10^{-2}$, $\Im Z_\pi = -(4.2 \pm 0.6 \pm 0.4) \times 10^{-2}$.

4. CONCLUSION

The measured value of $B_{e\mu}$ and the branching ratio $B(\phi \to \mu^+\mu^-)$ are in good agreement with the table branching ratio $B(\phi \to e^+e^-) = (2.99 \pm 0.08) \cdot 10^{-4}$ [1]. The accuracy of the result for the decay $\phi \to \mu^+\mu^-$ is comparable with the accuracy of the table value $B(\phi \to \mu^+\mu^-) = (2.5 \pm 0.4) \cdot 10^{-4}$ [1].

The measured value of $B(\phi \to \pi^+\pi^-)$ agrees with the table value $B(\phi \to \pi^+\pi^-) = (0.8^{+0.5}_{-0.4}) \times 10^{-4}$ and has much better accuracy. There is a discrepancy between our result and the preliminary result of CMD-2 [12]. The measured $\Re Z_\pi$ is much lower than VDM prediction with standard $\rho - \omega - \phi$ mixing [5]. Such low real part can be explained by the existence of direct decay of ϕ to $\pi^+\pi^-$ or non-standard $\rho - \omega - \phi$ mixing.

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