TO LEARN PRODUCTION OF SCALARS VS. TENSORS IN e^+e^- COLLISIONS

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The intensity of scalar $a_0(980)$, $f_0(980)$ and tensor $a_2(1320)$, $f_2(1270)$ mesons production at VEPP-2000 (BINP, Novosibirsk) and the upgraded DAΦNE (Frascati, Italy) in the processes $e^+e^- \rightarrow a_0(f_0, a_2, f_2)\gamma$ is calculated.

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1. Introduction

Study of the nature of light scalar resonances is one of the central problems of nonperturbative QCD, it is important for understanding the way chiral symmetry is realized in the low energy region and, consequently, for the understanding of confinement. The $a_2(1320)$ and $f_2(1270)$ tensor mesons are well-known P-wave $q\bar{q}$ states, while the exotic nature of the scalar $a_0(980)$ and $f_0(980)$ mesons is usually not questioned now. There are many indications that the above scalars are four quark states.

Comparative study of the production of scalar and tensor mesons is proposed to investigate the nature of light scalar mesons. For this purpose the intensity of scalar $a_0(980)$, $f_0(980)$ and tensor $a_2(1320)$, $f_2(1270)$ mesons production at the colliders VEPP-2000 (BINP, Novosibirsk) and DAΦNE (LNF, Frascati) in the processes $e^+e^- \rightarrow S\gamma, T\gamma$ (here and hereafter $S = a_0, f_0$; $T = a_2, f_2$) is calculated.

This paper is based on the article of Ref. 1, where detailed discussions and references may be found. Photon angle distribution and the spin density matrices of a_2 and f_2 are presented in Ref. 1 also.

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2. The reactions $e^+e^- \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma$ and $e^+e^- \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$

According to the kaon loop model Ref. 2, 3, the dominant process is $e^+e^- \rightarrow \sum_V V \rightarrow K^+K^- \rightarrow a_0(f_0)\gamma \rightarrow \eta(\pi^0)\pi^0\gamma$, where V are vector mesons. The cross-section of the $e^+e^- \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ reaction is of forms

$$\begin{aligned} & \frac{d\sigma_{e^+e^- \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma}(s, m)}{dm} \\ &= \frac{g_{f_0\pi^0\pi^0}^2 p_{\pi\pi}(m)}{4\pi^2 |D_{f_0}(m)|^2} \sigma_{e^+e^- \rightarrow f_0\gamma}(s, m) \\ &= \frac{e^4 (s - m^2) p_{\pi\pi}(m)}{96\pi^3 s^3} |A_{K^+K^-}(s) \bar{g}(m)|^2 \left| \frac{g_{f_0K^+K^-} g_{f_0\pi^0\pi^0}}{D_{f_0}(m)} \right|^2, \end{aligned} \quad (1)$$

where $p_{\pi\pi}(m) = \frac{\sqrt{m^2 - 4m_\pi^2}}{2}$.

Here m is the $\pi^0\pi^0$ invariant mass correspondingly, $A_{K^+K^-}(s)$ is the amplitude of the $\gamma^* \rightarrow K^+K^-$ transition. We use this amplitude taking into account mixing of the resonances according to Ref. 4, see Ref. 1. The $\bar{g}(m) = g_R(m)/(eg_{\phi K^+K^-} - g_{RK^+K^-})$ is the integral on the kaon loop.² The Eq. (1) is proportional to $\sigma_{e^+e^- \rightarrow K^+K^-}(s)$, see Ref. 1.

After integration over m one obtains the full cross-section $\sigma_{e^+e^- \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma}(s)$. Results for the $e^+e^- \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma$ process are similar. Numerical results with $a_0(980)$ and $f_0(980)$ parameters used in Ref. 1 are shown in Fig. 1. Note that mere VDM prediction for the point-like $VS\gamma$ interaction is obtained by the removal of the loop integral $\bar{g}(m)$ in Eq. (1) and normalization of the cross-section to the signal one at $\sqrt{s} = m_\phi$. The kaon model prediction is less than this prediction because of additional suppression $\sim \frac{(2m_K)^2}{s} \ln^2 \frac{s}{m_K^2}$.⁵

Fig. 1. The a) $\sigma_{e^+e^- \rightarrow f_0\gamma}(s, m = m_{f_0})$ and b) $\sigma_{e^+e^- \rightarrow a_0\gamma}(s, m = m_{a_0})$. Solid lines show the kaon loop model prediction, dashed lines show 1/10 of the cross-sections in case of the mere VDM prediction. Points are result of using the experimental data on the $\sigma_{e^+e^- \rightarrow K^+K^-}(s)$.

3. The reaction $e^+e^- \rightarrow a_2(f_2)\gamma$

Starting from the effective Lagrangian⁶

$$L = g_{f_2 V V} T_{\mu\nu} F_{\mu\sigma}^V F_{\nu\sigma}^V, F_{\mu\sigma}^V = \partial_\mu V_\sigma - \partial_\sigma V_\mu, \quad (2)$$

where $V = \rho, \rho', \rho''$, $T_{\mu\nu}$ is the tensor f_2 field (see Ref. 1 for motivation) and assuming the VDM mechanism $e^+e^- \rightarrow (\rho + \rho' + \rho'') \rightarrow f_2(\rho + \rho' + \rho'') \rightarrow f_2\gamma$ one obtains

$$\begin{aligned} \sigma_{e^+e^- \rightarrow f_2\gamma}(s) = & \frac{4\pi^2}{9} \alpha^3 \left(1 - \frac{m_{f_2}^2}{s}\right)^3 \left(\frac{s^2}{m_{f_2}^4} + 3\frac{s}{m_{f_2}^2} + 6\right) \\ & \times \left| \frac{m_\rho^2 g_{f_2\rho\rho}}{f_\rho^2 D_\rho(s)} + \frac{m_{\rho'}^2 g_{f_2\rho'\rho'}}{f_{\rho'}^2 D_{\rho'}(s)} + \frac{m_{\rho''}^2 g_{f_2\rho''\rho''}}{f_{\rho''}^2 D_{\rho''}(s)} \right|^2 \end{aligned} \quad (3)$$

Using the experimental value of $\Gamma_{f_2 \rightarrow \gamma\gamma}$ and assuming $g_{f_2\rho\rho} = g_{f_2\rho'\rho'} = g_{f_2\rho''\rho''}$ one arrives to estimates shown in Fig. 2a and Fig. 3a (Fig. 2b and Fig. 3b for analogous treatment of the $e^+e^- \rightarrow a_2\gamma$).

Fig. 2.

Fig. 3. a) The $\pi^0\pi^0$ invariant mass spectra in the reaction $e^+e^- \rightarrow \pi^0\pi^0\gamma$ for $g_{f_2\rho''\rho''} = g_{f_2\rho'\rho'} = g_{f_2\rho\rho}$ at $\sqrt{s} = 2$ GeV. Cuts of 100 MeV around the ω mass in $\pi^0(1)\gamma$ and $\pi^0(2)\gamma$ invariant masses have been applied. The solid line is the sum of the signal with cuts (long-dashed line), of the $\omega\pi^0$ background with cuts (short-dashed line) and of the interference (dashed line). b) The $\eta\pi^0$ invariant mass spectra in the reaction $e^+e^- \rightarrow \eta\pi^0\gamma$ at $\sqrt{s} = 2$ GeV for $g_{a_2\omega''\rho''} = g_{a_2\omega'\rho'} = g_{a_2\omega\rho}$.

Note that Fig.3b of Ref. 1 with $\eta\pi^0$ spectrum in $e^+e^- \rightarrow a_2\gamma \rightarrow \eta\pi^0\gamma$ is mistaken, the $Br(a_2 \rightarrow \eta\pi^0) \approx 0.145$ was missed. The correct spectrum is shown on Fig. 3b of the present paper, it is about 7 times smaller, and the integral is only 0.2 pb, but the $a_2 \rightarrow 3\pi$ may be used to study $e^+e^- \rightarrow a_2\gamma$ instead of $a_2 \rightarrow \eta\pi^0$, because $Br(a_2 \rightarrow 3\pi) \approx 0.7$.

4. Conclusion

Our analysis shows that it should be possible to observe the reactions $e^+e^- \rightarrow a_2\gamma \rightarrow \eta\pi^0\gamma$ and $e^+e^- \rightarrow f_2\gamma \rightarrow \pi^0\pi^0\gamma$ at the energies near 2 GeV in VEPP-2000 after reaching the project luminosity and probably in *DAΦNE* after the planned full upgrade.

As to the reactions $e^+e^- \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma$ and $e^+e^- \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ at the energies 1.7–2 GeV, in the kaon loop model their cross sections are very small, while if the mere VDM (point-like $VS\gamma$ interaction) was correct they would be observed, see Fig. 1. The kaon loop mechanism gives arguments in favour of the four quark nature of light scalar mesons.⁷

Of course, our calculations should be treated as a guide to prove the suppression of the scalar production in comparison to tensor one.

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