Could the decay $\phi \to \gamma K_S K_S$ hinder research on CP-invariance violation at ϕ factories?

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There is no basis for the fairly widespread belief that the decay $\phi \to \gamma K_S K_S$ might be an obstacle to research on the violation of *CP* invariance in the decay $\phi \to K_L K_S$.

It is believed by some that the decay $\phi \to \gamma K_S K_S$ might prove an obstacle to research on $\mathcal{T}(\epsilon'/\epsilon)$ in the decay $\phi \to K_L K_S$ (Ref. 1, for example).[1)]

It was shown[3] in 1987 that the branching ratio for the decay $\phi \to \gamma K_S K_S$ is low,

$$BR(\phi \to \gamma(f_0(975) + a_0(980)) \to \gamma K_S K_S) \simeq 0.65 \times 10^{-8}, \tag{1}$$

in the case which is the worst case from the standpoint of research on the violation of *CP* invariance, i.e., the case in which the $a_0(980)$ and $f_0(975)$ resonances are of a four-quark nature ($q^2\bar{q}^2$). The contributions of these resonances interfere destructively in both the $q^2\bar{q}^2$ model and the $q\bar{q}$ model.

Let us just arbitrarily change the sign of the interference. Making use of the results of Ref. 3, we can then replace (1) by

$$BR(\phi \to \gamma(f_0(975) + a_0(980)) \to \gamma K_S K_S) \simeq 3.6 \times 10^{-7}. \tag{2}$$

In a Pickwickian sense, the right side of (2) can be thought of as an upper limit. Then why would it be difficult to obtain a significantly larger number? The reason is that according to gauge invariance, the decay amplitude is, proportional to the tensor of the electromagnetic (or electric) field, i.e., to the photon energy ($\sim \omega$), since in our case a fairly soft γ ray is emitted. We thus write

$$\frac{d}{d\omega}\Gamma(\phi \to \gamma K_S K_S) \sim \frac{\alpha}{\pi}\omega^3 P_S \sim \frac{\alpha}{\pi}\omega^3\sqrt{\omega_0 - \omega}, \tag{3}$$

where $\omega_0 = (m_\phi^2 - 4m_{K_S}^2)/2m_\phi = 24$ MeV is the maximum photon energy in the decay, $P_S = [m_\phi(\omega_0 - \omega)/2]^{1/2}$ is the momentum of the K_S meson, and $\alpha = 1/137$ is the fine-structure constant.

From (3) follows[4]

$$\Gamma(\phi \to K_S K_S) \sim \frac{\alpha}{\pi}\ 0.1\omega_0^4\sqrt{\omega_0}. \tag{4}$$

This factor of $\omega_0^4\sqrt{\omega_0}$, which is exceedingly small at the scale of strong interactions, rules out a value significantly greater than that in (2) for the branching ratio of this decay.

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The very strong (ω^3) dependence in spectrum (3) suggests determining and eliminating the background under discussion here by introducing a cutoff in the photon energy:

$$\Gamma(\phi \to \gamma K_S K_S | \omega < \omega_{cut} \sim \frac{\alpha}{\pi} \cdot \frac{32}{315} \omega_0^4 \sqrt{\omega_0} f(\omega_{cut}/\omega_0)) , \quad (5)$$

$$f(x) = 1 + \frac{1}{16}[35(1-x)^{9/2} - 135(1-x)^{7/2} + 189(1-x)^{5/2} - 105(1-x)^{3/2}], \quad (6)$$

where $\omega_{\rm cut} \leqslant \omega_0$ is the cutoff energy.

The function $f(x)$ is a strong cutting factor. In the limit $x \to 0$ we have $f(x) \to x^4$. If we assume (for example) $x = 1/3$ ($\omega_{\rm cut} = 8$ MeV), we find that $BR(\phi \to \gamma K_S K_S)$ is suppressed by a factor of 40 in comparison with (4): $f(1/3) = 0.026$.

A cutoff in the energy of the γ ray thus makes it possible to eliminate the background due to the decay $\phi \to \gamma K_S K_S$ almost completely.[2)] Furthermore, the characteristic dependence of the branching ratio for the decay $\phi \to \gamma K_S K_S$ on the cutoff photon energy [see (5) and (6)] could be exploited to determine this energy.

[1)]In measurements of $\mathscr{R}(\epsilon'/\epsilon)$, on the other hand, this background could evidently be eliminated by simple cutoffs in the range of the decaying particles.[2]

[2)]It now appears[5] that even the value in (2) would not be a hindrance to measurements of $\mathscr{T}(\epsilon'/\epsilon)$.

[1]P. Franzini, *Proc. DAFNE Workshop*, Frascati, Italy, 1991, 733.

[2]D. Cocoliccio, Laboratori Nazionali di Frascati Report No. LNF-90/031(*R*), 1990.

[3]N. N. Achasov and V. N. Ivanchenko, Nucl. Phys. B **315**, 465 (1989); Preprint INP 87–89, Novosibirsk, 1987.

[4]N. N. Achasov, *Proc. DAFNE Workshop*, Frascati, Italy, 1991, 421.

[5]V. Patera, *Proc. DAFNE Workshop*, Frascati, Italy, 1991, 499.

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