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Nuclear and Particle Physics Proceedings 287–288 (2017) 89–94

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Strong isospin breaking at production of light scalars

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Abstract

It is discussed breaking the isotopic symmetry as the tool of studying the production and nature of light scalar mesons.

Keywords: Light scalar mesons, isospin breaking decays, $a_0(980) - f_0(980)$ mixing, $K\bar{K}$ loop mechanism

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1. Introduction

The thirty seven years ago we discovered theoretically a threshold phenomenon known as the mixing of $a_0^0(980)$ and $f_0(980)$ resonances that breaks the isotopic invariance considerably, since the effect $\sim \sqrt{2(M_{K^0} - M_{K^+})/M_{K^0}} \approx 0,13$ in the module of the amplitude [1]; see also Ref. [2]. This effect appears as the narrow, $2(M_{K^0} - M_{K^+}) \approx 8$ MeV, resonant structure between the K^+K^- and $K^0\bar{K}^0$ thresholds, $a_0^0(980) \to K\bar{K} \to f_0(980)$ and vice versa. Since that time many new proposals were appeared, concerning both the searching it and estimating the effects related with this phenomenon [3-29].

Nowadays, this phenomenon has been discovered experimentally and studied with the help of detectors VES in Protvino [30, 31] and BESIII in Beijing [32, 33, 34] in the processes

(a) $\pi^- N \to \pi^- f_1(1285) N \to \pi^- f_0(980)\pi^0 N \to$
$\to \pi^-\pi^+\pi^-\pi^0 N$ [30, 31],

(b) $J/\psi \to \phi f_0(980) \to \phi a_0(980) \to \phi\eta\pi^0$ [32],

(c) $\chi_{c1} \to a_0(980)\pi^0 \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0$ [32],

(d) $J/\psi \to \gamma\eta(1405) \to \gamma f_0(980)\pi^0 \to \gamma\, 3\pi$ [33],

(e) $J/\psi \to \phi f_0(980)\pi^0 \to \phi\, 3\pi$ [34],

(f) $J/\psi \to \phi f_1(1285) \to \phi f_0(980)\pi^0 \to \phi\, 3\pi$ [34]

It has become clear [35, 36] that the similar isospin breaking effect can appear not only due to the $a_0^0(980) - f_0(980)$ mixing, but also for any mechanism of the production of the $K\bar{K}$ pairs in the S wave, $X \to K\bar{K} \to f_0(980)/a_0^0(980)$. [1] Thus a new tool to study the production mechanism and nature of light scalars is emerged.

2. The $a_0^0(980) - f_0(980)$ mixing

The main contribution to the $a_0^0(980)-f_0(980)$ mixing amplitude, caused by the diagrams shown in Fig. 1, has the form

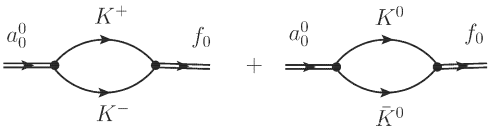

Figure 1: The $K\bar{K}$ loop mechanism of the $a_0^0(980) - f_0(980)$ mixing.

$$\Pi_{a_0^0 f_0}(m) = \frac{g_{a_0^0 K^+K^-}\, g_{f_0 K^+K^-}}{16\pi}\Bigg[i\Big(\rho_{K^+K^-}(m)$$
$$-\rho_{K^0\bar{K}^0}(m)\Big) - \frac{\rho_{K^+K^-}(m)}{\pi}\ln\frac{1+\rho_{K^+K^-}(m)}{1-\rho_{K^+K^-}(m)}$$

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[1] Each such mechanism reproduces both the narrow resonant peak and the sharp jump of the phase of the amplitude between the K^+K^- and $K^0\bar{K}^0$ thresholds.

http://dx.doi.org/10.1016/j.nuclphysbps.2017.03.051

$$+\frac{\rho_{K^0\bar{K}^0}(m)}{\pi}\ln\frac{1+\rho_{K^0\bar{K}^0}(m)}{1-\rho_{K^0\bar{K}^0}(m)}\Bigg]$$

$$\approx\frac{g_{a_0^0K^+K^-}g_{f_0K^+K^-}}{16\pi}\,i\Big(\rho_{K^+K^-}(m)-\rho_{K^0\bar{K}^0}(m)\Big),$$

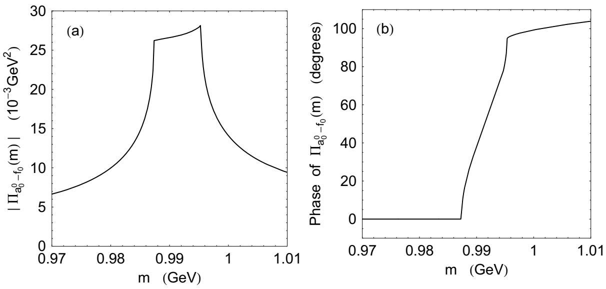

Figure 2: (a) An example of the modulus of the $a_0^0(980)-f_0(980)$ mixing amplitude. (b) The phase of the $a_0^0(980)-f_0(980)$ mixing amplitude.

where m (invariant virtual mass of scalar resonances) $\geq 2m_{K^0}$ and $\rho_{K\bar{K}}(m)=\sqrt{1-4m_K^2/m^2}$; in the region $0\leq m\leq 2m_K$, $\rho_{K\bar{K}}(m)$ should be replaced by $i|\rho_{K\bar{K}}(m)|$. The modulus and the phase of $\Pi_{a_0^0f_0}(m)$ are shown in Fig. 2. In the region between the K^+K^- and $K^0\bar{K}^0$ thresholds, which is the 8 MeV wide,

$$|\Pi_{a_0^0f_0}(m)|\approx\frac{|g_{a_0^0K^+K^-}g_{f_0K^+K^-}|}{16\pi}\sqrt{\frac{2(m_{K^0}-m_{K^+})}{m_{K^0}}}$$

$$\approx 0.127\frac{|g_{a_0K^+K^-}g_{f_0K^+K^-}|}{16\pi}\simeq 0.03\ \mathrm{GeV}^2$$

$$\approx m_K\sqrt{m_{K^0}^2-m_{K^+}^2}\approx m_K^{3/2}\sqrt{m_d-m_u}\,.$$

Note that $|\Pi_{\rho^0\omega}|\approx|\Pi_{\pi^0\eta}|\approx 0.003\ \mathrm{GeV}^2\approx(m_d-m_u)\times$ 1 GeV.

The branching ratios of the isospin-breaking decays $f_0(980)\to\eta\pi^0$ and $a_0^0(980)\to\pi^+\pi^-$, caused by the $a_0^0(980)-f_0(980)$ mixing, are [36]

$$BR(f_0(980)\to K\bar{K}\to a_0^0(980)\to\eta\pi^0)$$
$$=\int\left|\frac{\Pi_{a_0^0f_0}(m)}{D_{a_0^0}(m)D_{f_0}(m)-\Pi^2_{a_0^0f_0}(m)}\right|^2$$
$$\times\frac{2m^2\Gamma_{a_0^0\to\eta\pi^0}(m)}{\pi}dm\approx 0.3\%\,,$$

$$BR(a_0^0(980)\to K\bar{K}\to f_0(980)\to\pi\pi)$$
$$=\int\left|\frac{\Pi_{a_0^0f_0}(m)}{D_{a_0^0}(m)D_{f_0}(m)-\Pi^2_{a_0^0f_0}(m)}\right|^2$$
$$\times\frac{2m^2\Gamma_{f_0\to\pi\pi}(m)}{\pi}dm\approx 0.2\%\,,$$

where $D_{a_0^0}(m)$ and $D_{f_0}(m)$ are the propagators of the $a_0^0(980)$ and $f_0(980)$ resonances, respectively. Figure 3 shows the mass spectra correspond to the integrands in the above equations. [2]

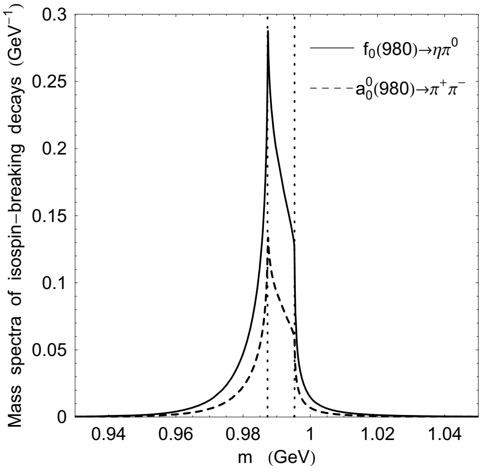

Figure 3: Mass spectra in the isospin-violating decays $f_0(980)\to\eta\pi^0$ and $a_0^0(980)\to\pi^+\pi^-$, caused by the $a_0^0(980)-f_0(980)$ mixing. The solid and dashed lines are generally similar each other. The dotted vertical lines show the locations of the K^+K^- and $K^0\bar{K}^0$ thresholds.

3. Polarization phenomena

The phase jump (see Fig. 2(b)) suggests the idea to study the $a_0^0(980)-f_0(980)$ mixing in polarization phenomena [17, 18]. If the process amplitude with the spin configuration is dominated by the $a_0^0(980)$–$f_0(980)$ mixing then the spin asymmetry of the cross section jumps near the $K\bar{K}$ thresholds. An example is the reaction $\pi^-p_\uparrow\to\big(a_0^0(980)+f_0(980)\big)n\to a_0^0(980)n\to\eta\pi^0\,n$ on a polarized proton target. The corresponding differential cross section has the form

$$\frac{d^3\sigma}{dtdmd\psi}=\frac{1}{2\pi}\Big[\,|M_{++}|^2+|M_{+-}|^2$$
$$+2\,\Im(M_{++}M^*_{+-})\,P\cos\psi\,\Big]\,,$$

and the dimensionless normalized spin asymmetry is $A(t,m)\;=\;2\,\Im(M_{++}M^*_{+-})/(|M_{++}|^2+|M_{+-}|^2)$, $-1\;\leq$

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[2] Here we use the values of the coupling constants of the $f_0(980)$ and $a_0^0(980)$ resonances with the $\pi\pi$, $K\bar{K}$, and $\eta\pi$ channels obtained in Ref. [36] from the BESIII data on the intensities of the $f_0(980)\to a_0^0(980)$ and $a_0^0(980)\to f_0(980)$ transitions measured in the reactions (b) and (c) [32].