# $f_0(1370)$ and $f_0(1520)$ resonances found in $\bar{N}N$ annihilation at rest

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It is shown that (i) to describe the $(4\pi)^0$ mass spectra in $\bar{N}N\to(4\pi)^0\pi$ at rest by an $f_0$ resonance with an energy-dependent total width, the mass of the resonance cannot equal 1370 MeV but has to lie above 1500 MeV, (ii) the shape of these mass spectra is only weakly sensitive to the value of the $f_0$ resonance mass if this is high, and (iii) they also readily tolerate a nonresonant interpretation. A possible relation between a heavy $f_0$ resonance dominating the $4\pi$ channel and the $f_0(1520)$ state observed in the reactions $\bar{N}N\to3\pi$ and $\bar{N}N\to2\eta\pi$ is pointed out.

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## I. INTRODUCTION

Over the last several years new resonancelike structures in two- and four-body mass spectra were discovered and studied in $\bar{N}N$ annihilation at rest into $3\pi$, $5\pi$, $\eta\eta\pi$, $\eta\pi\pi$, and $\eta\eta'\pi$ [1–15]. So far no information on these states in other reactions has been published. Some of them have had a rather dramatic history [8–13]. For example, the states originally classified as tensors, $AX(1565,I^G\,J^P=0^+2^+)\to\pi\pi$ [1,2] and $\zeta(1480,I^GJ^P=0^+2^+)\to\rho\rho$ [4], turned out after all to be scalars [8–13]. In brief, the present situation appears to be as follows. The reactions $\bar{p}n\to3\pi^-2\pi^+$ [8], $\bar{n}p\to3\pi^+2\pi^-$ [9], and $\bar{p}p\to\pi^+\pi^-3\pi^0$ [10] are dominated by the production of an $X(I^GJ^P=0^+0^+)$ intermediate state with a mass in the 1300–1400 MeV region and width of about 300–400 MeV [11]: $\bar{N}N\to X\pi\to(4\pi)^0\pi$. The $X\to4\pi$ decay is dominant ($\gtrsim$80%) and proceeds through the $\rho\rho$ and $\sigma\sigma$ intermediate states [8–13]: $X\to\rho\rho+\sigma\sigma\to4\pi$. Following Ref. [12], we shall name this state the $f_0(1370)$ resonance. It is considered that rare decay of the $f_0(1370)$ resonance into $\pi\pi$ and $\eta\eta$ are observed in the reactions $\bar{p}p\to\pi^0\pi^0\pi^0$ and $\bar{p}p\to\eta\eta\pi^0$ [11–13]. Furthermore, one more state, the $f_0(1520)$ with $I^GJ^P=0^+0^+$ and width of 100–250 MeV, decaying to $\pi^0\pi^0$, $\eta\eta$, and $\eta'\eta$, is observed in $\bar{p}p\to\pi^0\pi^0\pi^0$, $\bar{p}p\to\eta\eta\pi^0$, and $\bar{p}p\to\eta\eta'\pi^0$, respectively [6,7,11–13,15]. The ratios of the decays into various channels for the $f_0(1370)$ and $f_0(1520)$ resonances are not very accurately determined for the present. The data are, for $f_0(1370)$,

$$4\pi(\rho\rho+\sigma\sigma)/\pi\pi/\eta\eta/K\bar{K}\approx10/1/1/? \quad \text{from [12]}, \tag{1}$$

$$4\pi/\pi\pi\approx5/1 \quad \text{from [13]}, \tag{2}$$

and, for $f_0(1520)$,

$$\pi^0\pi^0/\eta\eta/\eta\eta'\approx1/0.72/1.05(\pm0.25) \quad \text{from [12]}, \tag{3}$$

$$\pi\pi/\eta\eta\approx5/1 \quad \text{from [13]}, \quad \eta\eta'/\eta\eta<0.29 \quad \text{from [7]}. \tag{4}$$

Since the $f_0(1520)$ is practically unobservable in $\pi\pi$ elastic scattering,[1] other decay channels are expected to be dominant [13] [i.e., the $f_0(1520)$, just like the $f_0(1370)$ [12,13], has to be highly inelastic]. If $4\pi$ decay is the dominant channel, the $f_0(1520)$ should be seen in the reactions $\bar{N}N\to f_0(1520)\pi\to(4\pi)^0\pi$. However, at present it is considered that such a signal is absent in the available data [8–12].

The discussion of various properties and the probable nature of new resonant states (see, for example, Refs. [10–13, 16]) in any case are tied to the masses and widths obtained in the original experimental work. Here we should like to draw attention to the fact that the mass of the $f_0(1370)$ resonance decaying to $4\pi$ was determined under one, in our opinion, crucial and mistaken assumption; namely, in all analyses [8–10], the $(4\pi)^0$ mass spectra in $\bar{N}N\to(4\pi)^0\pi$ at rest were described by a Breit-Wigner resonance with constant total width. In Sec. II, we show that if one describes these spectra by an $f_0$ resonance with an energy-dependent total width its mass has to lie above 1500 MeV, and that no appreciable coupling of the $f_0(1370)$ resonance to the $4\pi$ channel is required. A nonresonant interpretation of the $(4\pi)^0$ mass spectra is also possible. In Sec. III, we discuss briefly a possible relation of a heavy $f_0$ resonance dominating in the $4\pi$ channel to the $f_0(1520)$ state observed in the reactions $\bar{N}N\to3\pi$ and $\bar{N}N\to2\eta\pi$.

## II. DOES THE $f_0(1370)$ RESONANCE EXIST IN THE $4\pi$ CHANNEL?

Let us ignore all complications connected with identical pions in the final state. Then the formula which was essentially used in Refs. [8–10] for the description of the resonant four-pion mass spectra in the reaction $\bar{N}N\to f_0\pi\to(4\pi)^0\pi$

[1] D. V. Bugg, A. V. Sarantsev, and B. S. Zou reported at Hadron '95 (Manchester, England, 1995) a new amplitude analysis combining $\pi\pi$ scattering information with data on central production and $\bar{N}N$ annihilation at rest, which points to a signal for $f_0(1520)\to\pi\pi$. Note that they used and cited our result on the $4\pi$ channel obtained in the present paper.

 

can be written in the following form:[2]

$$\frac{dN_{4\pi}}{dm}=C\rho(\sqrt{s},m,m_\pi)\;\frac{2m}{\pi}\left(\frac{m\Gamma_{f_0\to4\pi}(m)}{(m_{f_0}^2-m^2)^2+(m_{f_0}\Gamma_{f_0}^{\rm tot})^2}\right), \tag{5}$$

where $\rho(\sqrt{s},m,m_\pi)=(\{1-[(m-m_\pi)/\sqrt{s}]^2\}\{1-[(m+m_\pi)/\sqrt{s}]^2\})^{1/2}$, $m$ is the invariant mass of the four-pion system, $s=4m_N^2$, and $\Gamma_{f_0}^{\rm tot}$ is the constant total width of the $f_0$ resonance, which was determined from a fit to the data. Models incorporating the $\rho\rho$ and $\sigma\sigma$ intermediate states were constructed for the $f_0\to4\pi$ decay in Refs. [8–10]. In the framework of these models, the function $m\Gamma_{f_0\to4\pi}(m)$ in the numerator of Eq. (5) increases by several tens of times as $m$ varies from 1200 to 1740 MeV. The observed enhancement in the $(4\pi)^0$ mass spectra in $N\bar{N}\to(4\pi)^0\pi$ at rest is concentrated entirely in the range $1200<m<1740$ MeV and has a visible maximum at $m\approx1500$ MeV [8–10]. Owing to the strong increase of $m\Gamma_{f_0\to4\pi}(m)$, the maximum of the Breit-Wigner distribution in Eq. (5) is shifted from $m=m_{f_0}$ to a higher mass region. Therefore, Eq. (5) gives a quite satisfactory description of the empirical mass spectra for the $m_{f_0}$ values lying in the range 1330 to 1400 MeV [8–10].

However, in spite of a close agreement with the experimental data, it seems to us that Eq. (5) with a constant total width is not at all justified for determining the resonance mass. The point is that according to the unitarity condition the total width of the $f_0$ resonance has to have an energy dependence practically the same as $\Gamma_{f_0\to4\pi}(m)$ since the $f_0\to4\pi$ decay mode is dominant [8–10] [see the ratios (1) and (2)]. We therefore replace $m_{f_0}\Gamma_{f_0}^{\rm tot}$ in Eq. (5) by

$$m\Gamma_{f_0}^{\rm tot}(m)=m\Gamma_{f_0\to4\pi}(m)+m_{f_0}\Gamma_{f_0\to\rm others}, \tag{6}$$

where $\Gamma_{f_0\to\rm others}$ is the width of the $f_0$ decays into $\pi\pi$, $\eta\eta$, and so on, that is, into all other channels besides the primary four-pion channel. Against the background of a large and rapidly varying $\Gamma_{f_0\to4\pi}(m)$ contribution, the width $\Gamma_{f_0\to\rm others}$ can be considered as a constant. To estimate $\Gamma_{f_0\to\rm others}$ we shall assume in accordance with Eqs. (1) and (2) that the ratio $N_{4\pi}/N_{\rm others}\approx5/1$ [where $N_{4\pi}$ and $N_{\rm others}$ are the numbers of events in the channels $N\bar{N}\to f_0\pi\to(4\pi)^0\pi$ and $N\bar{N}\to f_0\pi\to(\text{others})^0\pi$, respectively]. For the energy dependence of the $f_0\to4\pi$ decay width, we consider two limiting cases (in the following, they will be referred to as case I and case II). For case I, we assume that the function

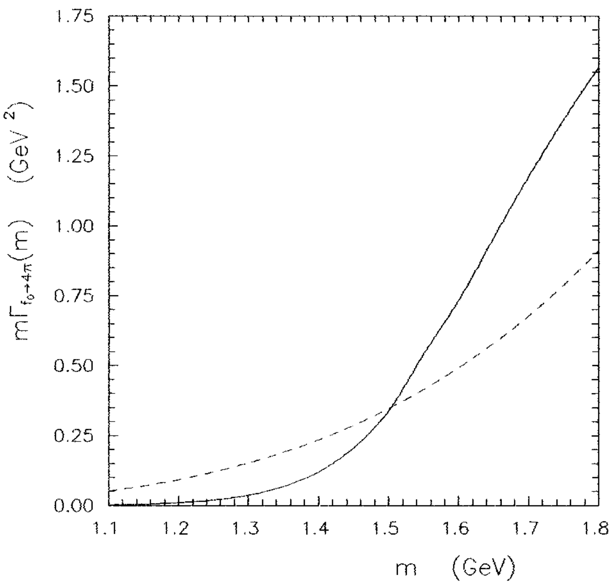


FIG. 1. The product $m\Gamma_{f_0\to4\pi}(m)$ as a function of $m$ for two limiting cases. In the first case (the solid curve), $m\Gamma_{f_0\to4\pi}(m)$ varies with $m$ as the phase space for two unstable $\rho$ mesons [see Eqs. (7), (8), and (9)]. In the second case (the dashed curve), $m\Gamma_{f_0\to4\pi}(m)$ is proportional to the $4\pi$ phase space [the case of pointlike $f_0\to4\pi$ decay, see Eqs. (7) and (10)]. Here, for instance, $G^2/16\pi=5$ GeV$^2$ in the first case [see Eq. (8)] and $G^2/16\pi=0.5$ GeV$^{-2}$ in the second case [see Eq. (10)].

$m\Gamma_{f_0\to4\pi}(m)$ is proportional to the phase space of two unstable $\rho$ mesons,[3] which increases by two orders of magnitude in the region $1200<m<1740$ MeV (by an order of magnitude from 1200 to 1400 MeV and further by one more order of magnitude; see the solid curve in Fig. 1). For case II, we suppose that the $f_0\to4\pi$ decay is pointlike. As $m$ varies from 1200 to 1740 MeV the function $m\Gamma_{f_0\to4\pi}(m)$ increases by a factor of 8 in this case (see the dashed curve in Fig. 1). All models with the $\rho\rho+\sigma\sigma$ intermediate states for the $f_0\to4\pi$ decay considered in Refs. [8–10] lead to an $m$ dependence of the function $m\Gamma_{f_0\to4\pi}(m)$ intermediate between these limiting cases. For the function $m\Gamma_{f_0\to4\pi}(m)$, we use the expression

$$\begin{aligned} m\Gamma_{f_0\to4\pi}(m)&=\frac{G^2}{16\pi}R(m)\\ &=\frac{G^2}{16\pi}\int_{4m_\pi^2}^{(m-2m_\pi)^2}dm_1^2\int_{4m_\pi^2}^{(m-m_1)^2}dm_2^2\\ &\quad\times F(m_1)F(m_2)\rho(m,m_1,m_2), \end{aligned}\tag{7}$$

where $\rho(m,m_1,m_2)=(\{1-[(m_1-m_2)/m]^2\}\{1-[(m_1+m_2)/m]^2\})^{1/2}$, and the functions $F(m_1)$ and $F(m_2)$ describe the $(2\pi)_1$ and $(2\pi)_2$ mass spectra in the $f_0\to(2\pi)_1(2\pi)_2$ decay, respectively. In case I,

[2]A full account of the indistinguishability of identical pions in the final state leads, generally speaking, to very complicated formulas for the differential distributions (see, for example, Ref. [8]). In addition, to obtain one-dimensional distributions it is necessary to carry out a Monte Carlo integration over a large number of independent variables. However, the indistinguishability of identical pions does not play a crucial role in the point in question.

[3]The very important role of the $\rho\rho$ intermediate state in the $f_0(1370)\to4\pi$ decay has been stressed, for example, by the last Crystal Barrel experiment [10].

$$G=g_{f_0\rho\rho},\quad F(m_i)=\frac{1}{\pi}\,\frac{m_i\Gamma_\rho(m_i)}{(m_\rho^2-m_i^2)^2+[m_i\Gamma_\rho(m_i)]^2},\tag{8}$$

$$\Gamma_\rho(m_i)=\Gamma_\rho(m_\rho)\,\frac{m_\rho}{m_i}\left(\frac{q(m_i)}{q(m_\rho)}\right)^3\frac{2q^2(m_\rho)}{q^2(m_\rho)+q^2(m_i)},$$

$$q(m_i)=\frac{1}{2}\sqrt{m_i^2-4m_\pi^2},\tag{9}$$

$i=1,2$. In case II,

$$G=\tilde{g}_{f_04\pi},\quad F(m_i)=\sqrt{\pi^3/8}\sqrt{1-4m_\pi^2/m_i^2}.\tag{10}$$

For the mass spectrum $dN_{4\pi}/dm$, we shall analyze the expression[4]

$$\frac{dN_{4\pi}}{dm}=C\rho(\sqrt{s},m,m_\pi)\,\frac{2m}{\pi}\left(\frac{m\Gamma_{f_0\to4\pi}(m)}{(m_{f_0}^2-m^2)^2+[m\Gamma_{f_0}^{\rm tot}(m)]^2}\right)\tag{11}$$

with $m\Gamma_{f_0}^{\rm tot}(m)$ determined by Eq. (6).

There is an essential distinction between Eqs. (5) and (11). In the case where there is a strong increase of $m\Gamma_{f_0}^{\rm tot}(m)$, an additional suppression of the right wing of the Breit-Wigner distribution arises in Eq. (11). Thus, Eq. (11) cannot provide a peak near 1500 MeV if $m_{f_0}\approx1370$, in contrast to Eq. (5) with a constant total width $\Gamma_{f_0}^{\rm tot}$. However, a shift of the $f_0$ mass in Eq. (11) above 1500 MeV allows one to obtain an enhancement in $dN_{4\pi}/dm$ concentrated in the interval 1200–1740 MeV and peaked around 1500 MeV. The results of our calculations, using Eqs. (5)–(11), are shown in Figs. 1–4.

Figure 2 shows normalized $(4\pi)^0$ mass spectra, $(dN_{4\pi}/dm)/N_{4\pi}$, in $\bar{N}N\to f_0\pi\to(4\pi)^0\pi$ at rest for the $f_0$ resonance with a mass of 1370 MeV. Here all curves correspond to the first limiting case for the $m$ dependence of $m\Gamma_{f_0\to4\pi}(m)$. Curve 1 corresponds to Eq. (5) with the constant total width $\Gamma_{f_0}^{\rm tot}=300$ MeV. As already noted above, this parametrization gives a quite satisfactory description of the data (see also Fig. 4). Curves 2, 3, and 4 are obtained by using Eq. (11) for $g_{f_0\rho\rho}^2/16\pi=5$, 10, and 20 GeV$^2$, respectively. They differ drastically from curve 1. For $g_{f_0\rho\rho}^2/16\pi<5$ GeV$^2$, a resonance peak becomes still narrower than curve 2 shows, and for $g_{f_0\rho\rho}^2/16\pi>20$ GeV$^2$, it becomes still broader and is shifted even further to lower mass than curve 4 shows. So, for any value of the coupling constant $g_{f_0\rho\rho}^2/16\pi$, a resonance with a mass of 1370 MeV coupled mainly to the $\rho\rho$ channel cannot pretend to describe the data obtained in Refs. [8–10].

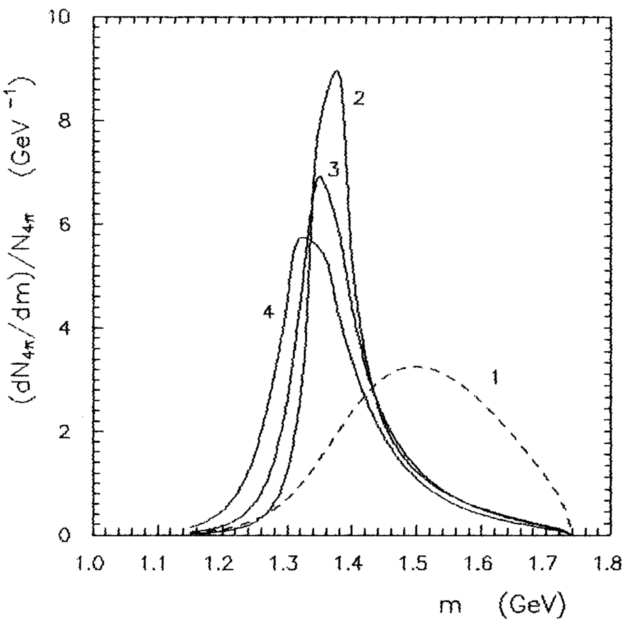


FIG. 2. Normalized $(4\pi)^0$ mass spectra, $(dN_{4\pi}/dm)/N_{4\pi}$, in $\bar{N}N\to f_0(1370)\pi\to(\rho\rho)\pi\to(4\pi)^0\pi$ at rest. Curve 1 corresponds to Eqs. (5) and (7)–(9) with $\Gamma_{f_0}^{\rm tot}=300$ MeV. Curves 2, 3, and 4 correspond to Eqs. (6)–(9) and (11) with $g_{f_0\rho\rho}^2/16\pi=5$, 10, and 20 GeV$^2$ (and $\Gamma_{f_0\to\rm others}\approx12.5$, 21, and 30 MeV), respectively.

Figure 3 shows a similar picture for the second limiting case for the $m$ dependence of $m\Gamma_{f_0\to4\pi}(m)$. As in case I, for no value of the coupling constant $\tilde{g}_{f_04\pi}^2/16\pi$ can a resonance with mass 1370 MeV and a pointlike coupling to the $4\pi$ decay channel describe the data [8–10] (see, in particular, curves 2, 3, and 4). Furthermore, curve 1 in Fig. 3, obtained from Eq. (5) with a constant total width, is inconsistent with the experiment, unlike the corresponding curve in Fig. 2.

Figure 4 shows the Obelix collaboration data for $(dN_{4\pi}/dm)/N_{4\pi}$, which we took from Ref. [9]. Note that they actually studied the reaction $\bar{n}p\to3\pi^+2\pi^-$ and derived an associated $(4\pi)^0$ mass spectrum which in first approximation is free from combinatorial background, i.e., from contributions caused by rearrangements of a recoil $\pi^+$ meson with identical pions from the $(4\pi)^0$ system (see also Refs. [4,8,10,11]). A possible resonance interpretation of this mass spectrum using Eqs. (6)–(11) is illustrated in Fig. 4 by the curves 1 and 2, which correspond respectively to an $f_0$ resonance with $m_{f_0}=1700$ MeV decaying into $4\pi$ through the $\rho\rho$ intermediate state and an $f_0$ resonance with $m_{f_0}=1550$ MeV having a pointlike $4\pi$ decay. Combining the $\rho\rho$ model for the $f_0$ resonance decay with the pointlike $4\pi$ decay model (or with the $\sigma\sigma$ decay model [8–10]) one can obtain a reasonable description of the data at any value of $m_{f_0}$ from 1550 to 1700 MeV.

So a resonance interpretation of the $(4\pi)^0$ mass spectra in the reactions $\bar{N}N\to(4\pi)^0\pi$, with the energy dependence of the total width taken into account, leads to the following

[4]We also analyzed a more complicated expression including the dispersive finite width corrections to the real part of the resonance propagator and made sure that in this case the main conclusions based on Eq. (11) remain valid. The consideration of the finite width corrections, probably, will be required for a more sophisticated analysis of the data.

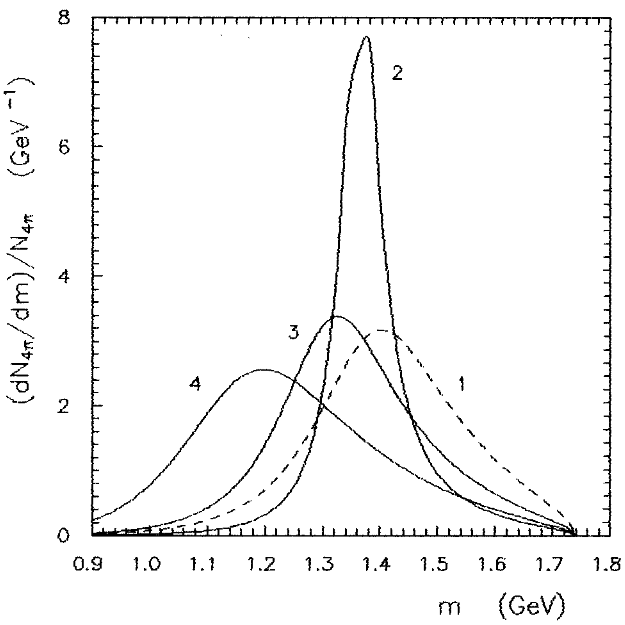


FIG. 3. Normalized $(4\pi)^0$ mass spectra, $(dN_{4\pi}/dm)/N_{4\pi}$, in $\bar{N}N\to f_0(1370)\pi\to(4\pi)^0\pi$ at rest for the case of pointlike $f_0(1370)\to 4\pi$ decay. Curve 1 corresponds to Eqs. (5), (7), and (10) with $\Gamma^{\rm tot}_{f_0}=300$ MeV. Curves 2, 3, and 4 correspond to Eqs. (6), (7), (10), and (11) with $\tilde{g}^2_{f_0 4\pi}/16\pi=0.25$, 1, and 4 GeV$^{-2}$ (and $\Gamma_{f_0\to\rm others}\approx 14.5$, 43, and 90 MeV), respectively.

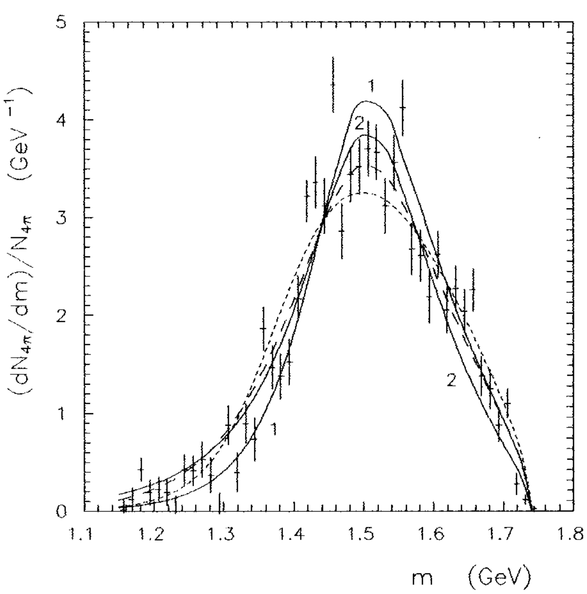


FIG. 4. Normalized $(4\pi)^0$ mass spectra in $\bar{N}N\to(4\pi)^0\pi$ at rest. The data are from Ref. [9] (see a comment in the text). Here the curve depicted by the short dotted line is identical to curve 1 in Fig. 2, which has been described in detail. Curve 1, corresponding to case I, is obtained using Eqs. (6)–(9) and (11) for $m_{f_0}=1700$ MeV, $g^2_{f_0\rho\rho}/16\pi=10$ GeV$^2$, and $\Gamma_{f_0\to\rm others}\approx 60$ MeV. Curve 2, corresponding to case II, is obtained using Eqs. (6), (7), (10), and (11) for $m_{f_0}=1550$ MeV, $\tilde{g}^2_{f_0 4\pi}/16\pi=0.5$ GeV$^{-2}$, and $\Gamma_{f_0\to\rm others}\approx 35$ MeV. The curve depicted by the long dotted line corresponds to a nonresonant description of the data. It is obtained using Eqs. (12) and (7)–(9) for $a=11.1$.

interesting result: $(4\pi)^0$ mass spectra are only weakly sensitive to the resonance mass if this is located above the nominal $\rho\rho$ threshold. This observation combined with the corresponding satisfactory description of the data in terms of a resonance with a large (~300 MeV) constant width (see the curve in Fig. 4 depicted by a short dotted line) suggests that a resonance interpretation of the $(4\pi)^0$ mass spectra is not necessary. Let us consider, for example, the parametrization of the mass spectra by a single channel scattering length approximation:

$$\frac{dN_{4\pi}}{dm}=C\rho(\sqrt{s},m,m_\pi)\,\frac{R(m)}{|1-iaR(m)|^2},\tag{12}$$

where $R(m)$ is the $S$-wave phase space of two unstable $\rho$ mesons [see Eqs. (7)–(9)]. Such a description corresponding to Eq. (12) for $a=11.1$ is depicted by the long dotted line in Fig. 4 and shows that a nonresonant description is indeed viable.

So our analysis indicates that the existence of a scalar resonance with a mass of 1370 MeV in the $4\pi$ channel is doubtful and, at the very least, that a reanalysis of the data is necessary.

## III. A HEAVY $f_0$ RESONANCE IN OTHER DECAY CHANNELS

If the $f_0(1370)$ state is absent in the main $4\pi$ channel then it is hazardous to infer such a resonance state from the enhancements found at 1300–1400 MeV in the $\pi\pi$ and $\eta\eta$ mass spectra in $\bar{N}N\to 3\pi$ and $\bar{N}N\to 2\eta\pi$, respectively.[5]

Let us consider now how a heavy $f_0$ resonance (with a mass $>2m_\rho$ and an energy-dependent total width) occurs in other decay channels. Possible shapes of this resonance in other channels are shown in Fig. 5. The corresponding expression for the mass spectra in the reactions $\bar{N}N\to f_0\pi\to(\text{others})^0\pi$ has the form

$$\frac{dN_{\rm others}}{dm}=C\rho(\sqrt{s},m,m_\pi)\,\frac{2m}{\pi}\times\left(\frac{m_{f_0}\Gamma_{f_0\to\rm others}}{(m^2_{f_0}-m^2)^2+[m\Gamma^{\rm tot}_{f_0}(m)]^2}\right),\tag{13}$$

where $m$ is the invariant mass of the decaying meson system [see also Eqs. (6) and (11)]. This description is somewhat rough because in approximating the width $\Gamma_{f_0\to\rm others}$ by a constant we do not distinguish the $\pi\pi$, $K\bar{K}$, and $\eta\eta$ channels. However, this is not very important if the resonance occurs substantially above the decay thresholds. As is seen from Fig. 5, an $f_0$ resonance with mass between 1550 and

[5]Of course, the $\pi\pi$ and $\eta\eta$ channels are not empty even if the $f_0(1370)$ state is absent. In the range 1300–1400 MeV, there are, at least, large $S$-wave contributions extending from a lower mass region and a contribution of the broad practically elastic $f_0(1300)$ resonance of Ref. [16].

1700 MeV that is strongly coupled to the $4\pi$ channel leads to structures in other channels peaked in the mass range 1425–1480 MeV. It is also necessary to keep in mind that the $f_0$ resonance shape in the $\pi\pi$ and $\eta\eta$ channels can be strongly distorted by interference between the resonance and other contributions (see footnote 5). For example, the peak from a heavy $f_0$ resonance can be shifted to a lower or higher mass region.[6] If, in consequence of such interference, the peak in the $\pi\pi$ and $\eta\eta$ channels is shifted slightly below 1400 MeV the $f_0(1370)$ enhancement in these channels may be, at least in part, attributed to a heavy $f_0$ resonance. Another interesting scenario arises if the peak from a heavy $f_0$ resonance is shifted in the $\pi\pi$ and $\eta\eta$ channels slightly above 1500 MeV. In this case, the $f_0(1520)$ enhancement found in these channels (see the Introduction) may be considered as a direct manifestation of the heavy inelastic $f_0$ resonance. As already noted [see the ratios (3) and (4) and the text immediately following], the $f_0(1520)$ state needs a strong coupling with some unknown decay channel. It would be reasonable to assume that the major inelasticity of the $f_0(1520)$ resonance is due to its coupling with the four-pion decay channel. So the heavy $f_0$ resonance, which dominates the $(4\pi)^0$ mass spectra in the reactions $\bar{N}N \to (4\pi)^0\pi$ and, in this sense, replaces the former $f_0(1370)$ state, can also be responsible for the $f_0(1520)$ phenomenon in the reactions $\bar{N}N \to 3\pi$ and $\bar{N}N \to 2\eta\pi$.

As seen from the above discussion the challenge is to get the visible peak at 1520 MeV in other channels by an interference mechanism or in some other way.

Notice that the $f_0(1590)$ resonance (seen by one group only [16]) cannot explain $4\pi$ data in this energy region. The point is that the ratios of the decays into main channels for the $f_0(1590)$ are $\eta\eta'/4\pi^0/\eta\eta/\pi^0\pi^0 \approx 2.7/0.8/1/<(0.17–0.3)$ [16]. So the $\eta\eta'$, $\eta\eta$, and $\pi^0\pi^0$ decay modes of the $f_0(1590)$ are completely incompatible with those of the $f_0(1520)$ as seen from Eqs. (3) and (4). Moreover, from isotopic symmetry the following ratios should be expected for the $f_0(1590) \to 4\pi$ decay modes: $2\pi^+2\pi^-/\pi^+\pi^-2\pi^0/4\pi^0 = 2/1/0.75$. If the $(4\pi)^0$ spectra in $\bar{N}N \to (4\pi^0)\pi$ were dominated by the $f_0(1590)$ then this state would be seen in the $\bar{N}N \to \eta\eta'\pi$ channel with $B(\bar{n}p \to \eta\eta'\pi^+)/B[\bar{n}p \to (2\pi^+2\pi^-)\pi^+] \approx 1.26$, which drastically contradicts the $\bar{N}N$ data [1–15].

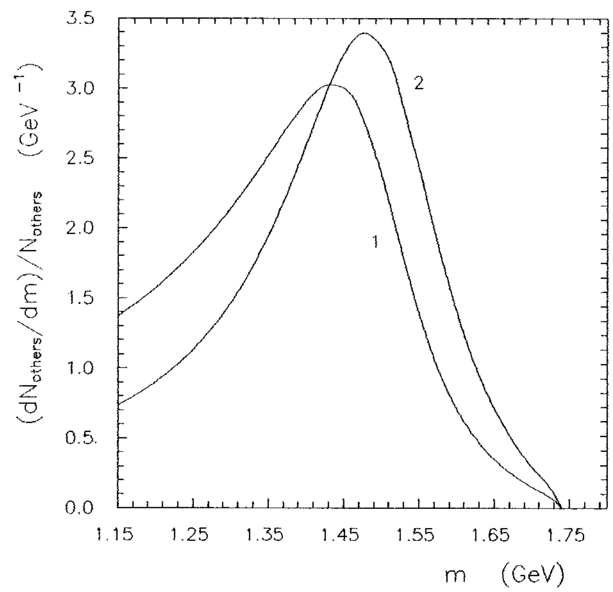


FIG. 5. Heavy $f_0$ resonance shapes in other decay channels in $\bar{N}N \to f_0\pi \to (\text{others})^0\pi$. Curves 1 and 2 are obtained using Eq. (13). In relation to $f_0$ resonance parameters, they correspond to curves 1 and 2 in Fig. 4, respectively (see Fig. 4 caption).

[6] Let us emphasize that these considerations only apply within the framework of the resonance interpretation of the enhancement in the $4\pi$ channel, which, as we showed, is not essential. In principle, the structures in the $\pi\pi$, $\eta\eta$, and $4\pi$ channels can have a different origin and be uncoupled from one another.

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