PHYSICAL REVIEW D VOLUME 48, NUMBER 11 1 DECEMBER 1993

Decay $J/\psi \to \phi(MM)$ demands the $f_0(S^*)$ be narrow

D. Morgan
Particle Physics Department, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon. OX11 0QX, United Kingdom

M. R. Pennington
Centre for Particle Theory, University of Durham, Durham DH1 3LE, United Kingdom

(Received 5 August 1993)

The nature of $f_0(S^*)$ is revealed by its pole structure in the complex energy plane. Data on $\pi\pi \to \pi\pi$, $\pi\pi \to K\bar{K}$, and $pp \to pp\pi\pi(K\bar{K})$ in the neighborhood of the $K\bar{K}$ threshold are described by unitary amplitudes with at least one nearby pole, which sits on sheet II. However, we reiterate that results on $J/\psi \to \phi\pi\pi(K\bar{K})$ decay require an additional nearby pole on sheet III, forcing the $f_0(S^*)$ to be narrow, in contradistinction to the very recent claims of Zou and Bugg.

PACS number(s): 14.40.Cs, 11.80.Gw, 13.75.Lb

The nature of the $f_0(S^*)$ has been an issue ever since its discovery as an enhancement in $K\bar{K}$ production [1] and as a sharp fall in the $\pi\pi$ production cross section in high energy $\pi^+ p \to \pi^+\pi^-\Delta^{++}$ [2] close to $K\bar{K}$ threshold. The questions are [3] the following: (a) Is this isoscalar scalar state made of $q\bar{q}$ [4,5] or $qq\bar{q}\bar{q}$ [6] or is it a $K\bar{K}$ molecule [7]? (b) Despite the observed signal being narrow ~ 50 MeV, what is the width of the underlying dynamical object? Could it be wide [6]? It is clear that these issues can only be resolved by high precision data on dimeson final states in the neighborhood of $K\bar{K}$ threshold with f_0 quantum numbers. These questions were the motivation for a recent analysis [8] using all high statistics data with $\pi\pi$ and $K\bar{K}$ final states in the mass range of 870 to 1100 MeV (a region in which $\pi\pi$ and $K\bar{K}$ are the only channels that have to be considered). We investigated the distinction between a *quark model* state and a *molecular* object by studying the nearby poles in the complex energy plane demanded by these data. A *molecular* state has only one nearby pole, on what is conventionally called sheet II, while a *quark model* state also has a pole on sheet III as explained in detail in Ref. [8], where this analysis in terms of Jost functions is described. We found that while data on $\pi\pi \to \pi\pi$ [9], $\pi\pi \to K\bar{K}$ [10] and central dimeson production in pp collisions [11] are basically described equally well by one pole or two pole amplitudes, the new results from DM2 [12] and Mark III [13] on J/ψ decay to $\phi\pi\pi$ and $\phi K\bar{K}$ in 10 MeV bins require nearby poles on *both* sheets II and III at $E = (988 - i24)$ and $(978 - i28)$ MeV, respectively, with an error of ± 10 MeV on the real part and ± 6 MeV on the imaginary part of the position of the sheet II pole [8]. These correspond to a rather narrow $f_0(S^*)$, 52 MeV wide.

In recent weeks these results have been called into question by the work of Zou and Bugg [14]. They claim to show the $f_0(S^*)$ to be wide having one nearby pole on sheet II at $(988 - i23)$ MeV, while that on sheet III is at $(797 - i185)$ MeV. Zou and Bugg arrive at this conclusion fitting $\pi\pi \to \pi\pi$ [9] and central dimeson production results [11] from 280 to 1700 MeV, ignoring all constraints from the conflicting $\pi\pi \to K\bar{K}$ results [10]. They use what they profess to be a more general parametrization than that of our earlier Au-Morgan-Pennington (AMP) analysis [15], revealing a clearer separation of "background" and resonance efforts. This claimed greater generality comes from their inclusion of pole terms along the left-hand cut for their "background" contribution, rather than the polynomials of AMP. While one form or another may be more economical in disposition of parameters, pole terms like $c/(s + s_0)$ (with $s_0 > 0$) can, of course, be reexpressed as a polynomial for $s \geq 4m_\pi^2$. Moreover, despite the claim of greater generality, Zou and Bugg use as their main parametrization a very *specific* form of Dalitz and Tuan [16]. In this problem this formulation allows no "background" to the $f_0(S^*)$ in other than the $\pi\pi \to \pi\pi$ channel. This is particularly worrying given the claims of various scalar states above 1 GeV coupling to channels other than $\pi\pi$, to $K\bar{K}$, $\eta\eta$, and $\eta\eta'$, as, for example, with the $f_0(1590)$ signal of [17]. What is more, despite the suggestion of Zou and Bugg [14] to the contrary, there is no model-independent way of separating resonances from "background" using only real values of the energy. Only by continuing the amplitude to the resonance pole position in the complex energy plane can either of these be unambiguously defined, as frequently stressed in the literature [18].

These points are however of little concern to the main issue of the nature and parameters of the $f_0(S^*)$. For this, data at 300 or 1700 MeV are quite irrevelant. Focusing on the $K\bar{K}$ threshold region discussed in our Jost function analysis, the poles of the Zou-Bugg amplitudes are at first sight much more like our one pole amplitude, JOST1, rather than our favored JOST2 with its two nearby poles [8], since their sheet III pole is far from $K\bar{K}$ threshold in the complex plane. As already stated, it is the recent precision results on $J/\psi \to \phi\pi\pi$, $K\bar{K}$ that are the crucial discriminant. We have therefore fitted these data from DM2 [12] and Mark III [13] with the Zou-Bugg amplitudes. They give two specific parametrizations [14] for the hadronic amplitudes for

$$T_{11} \equiv T(\pi\pi \to \pi\pi)\ , \quad T_{22} \equiv T(K\bar{K} \to K\bar{K})\ ,$$
$$T_{12} \equiv T_{21} \equiv T(\pi\pi \to K\bar{K})\ , \tag{1}$$

one using the Dalitz-Tuan form [16], the other a more conventional K-matrix model. From these the amplitudes for J/ψ decay are given by

$$F_1 \equiv F(\psi \to \phi\pi^+\pi^-) = \sqrt{\tfrac{2}{3}}[\alpha_1(s)T_{11}+\alpha_2(s)T_{21}] \,,$$
$$F_2 \equiv F(\psi \to \phi K^+K^-) = \sqrt{\tfrac{1}{2}}[\alpha_1(s)T_{12}+\alpha_2(s)T_{22}] \,, \tag{2}$$

where $\sqrt{\frac{2}{3}}$ and $\sqrt{\frac{1}{2}}$ are the appropriate $I=0$ Clebsch-Gordan coefficients. The coupling functions $\alpha_1(s)$, $\alpha_2(s)$ [15] are required by unitarity to be real functions above $\pi\pi$ threshold and having only left-hand cut structures are expected to be smooth for $s \geq 4m_\pi^2$. These functions we parametrize as Zou and Bugg do [14] (except that the on-shell appearance of the Adler zero is irrelevant for the $K\bar{K}$ threshold region) by

$$\alpha_i(s)=\frac{\beta_{i1}}{s+s_{i1}}+\gamma_{i0}+\gamma_{i1}s \,. \tag{3}$$

The S-wave dimeson mass spectrum for $J/\psi \to \phi(MM)$ is then formed from the modulus squared of the appropriate amplitude F_i of Eq. (2) multiplied by the well-known phase-space for these decays. With the hadronic amplitudes T_{ij} fixed by Zou and Bugg [14], the coupling functions $\alpha_i(s)$ are all that are at our disposal in fitting the data. We find that the two Zou-Bugg hadronic parametrizations (Dalitz-Tuan or K matrix) give almost identical fits to the J/ψ decay data—consequently we show only one in Fig. 1. Since the fits choose $s_{i1} \gg 1$ GeV^2, the two left-hand poles, in fact, play no role for $s \simeq 1$ GeV^2. Looking at Fig. 1, we see the *best* fits are not good, having a χ^2 of 133 for 67 degrees of freedom. These are very similar to the fits using the JOST1 amplitude of Ref. [8]. These are to be compared with a χ^2 of just 62 for JOST2 with its two nearby poles [8]—see Fig. 2 for how well a

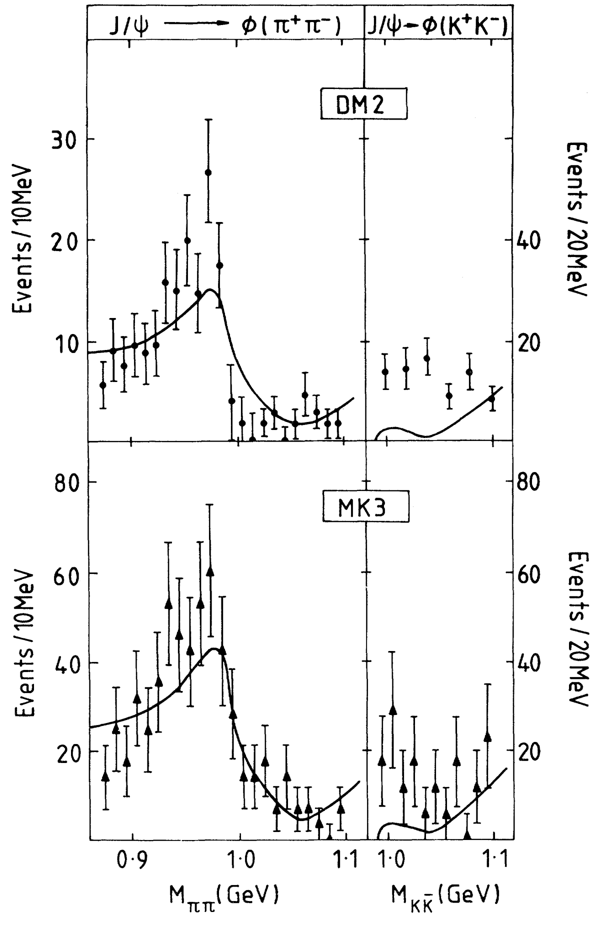

FIG. 1. Fit to data on $J/\psi \to \phi\pi\pi(K\bar{K})$ production [assuming the final $\pi\pi$ ($K\bar{K}$) system is all $I=0$ S wave] using the amplitudes of Zou and Bugg [14]: ●, data from Ref. [12]; ▲, data from Ref. [13]. Whether the Dalitz-Tuan or K-matrix form of the amplitudes of Ref. [14] are used the fits are almost identical. For the Dalitz-Tuan form, the fits find the coupling functions, Eq. (3), $\alpha_1(s) \simeq -3.52+3.79s$, $\alpha_2(s) \simeq 28.08-25.69s$, with s in GeV^2, since the left-hand pole terms are irrelevant here, e.g., $\beta_{11}=22.20$, $\beta_{21}=1.14$ with $s_{11}=4421$, $s_{21}=18$ GeV^2. For the K-matrix amplitude $\alpha_1(s) \simeq -10.78+8.71s$, $\alpha_2(s) \simeq 30.29 -28.07s$ again with $s_{i1} \gg 1$ GeV^2.

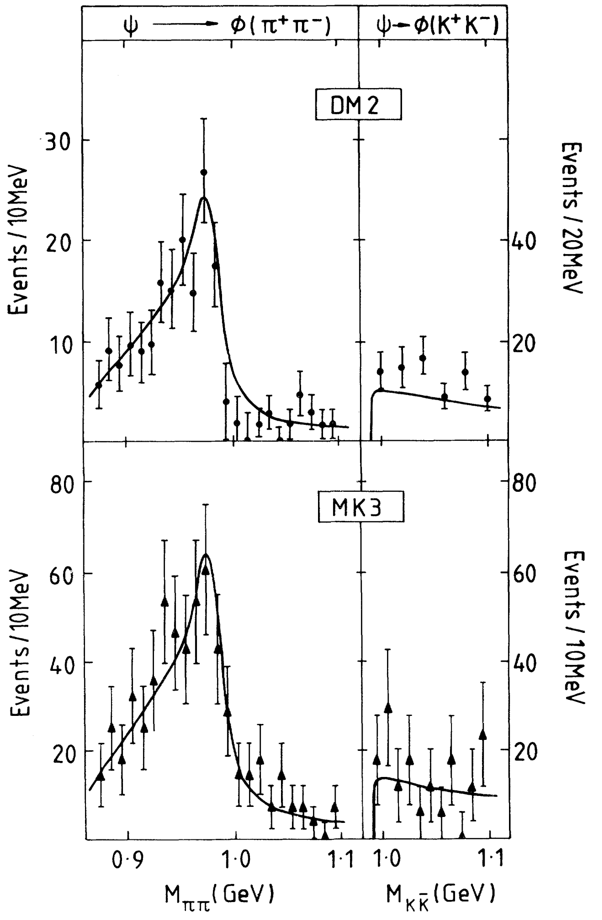

FIG. 2. Fit to the same $J/\psi \to \phi\pi\pi(K\bar{K})$ data as in Fig. 1 using a typical amplitude with nearby poles on both sheets II and III [8]. The solution favored by all sectors of data is shown as JOST2 in Ref. [8].

typical JOST2 amplitude fits these data with just a two-parameter form for the $\alpha_i(s)$'s linear in s. We see that to obtain fits with the Zou-Bugg amplitudes, it is the greater number of data points with the $\pi\pi$ final state that fix the $\alpha_i(s)$'s in this case. Consequently, most of the χ^2 in Fig. 1 comes from the $K\bar{K}$ channel. Nevertheless, the shape of the $\pi\pi$ distribution is not convincingly described.

Thus we see that the results of Zou and Bugg highlight the conclusion of our Jost-function analysis [8] that the precision data on $J/\psi \to \phi(MM)$ decay demand a narrow $f_0(S^*)$, the wide Zou-Bugg version faring worse by some 6 standard deviations. Let us end by reiterating Ref. [8], that precise results on almost any $I=0$ S-wave $K\bar{K}$ channel would be invaluable in confirming this conclusion.

[1] W. Beusch, *Experimental Meson Spectroscopy* (Columbia University Press, New York, 1970), p. 185; D. M. Binnie *et al.*, Phys. Rev. Lett. **31**, 1534 (1973).

[2] M. Alston-Garnjost *et al.*, Phys. Lett. **36B**, 152 (1971); S. M. Flatté, *ibid.* **38B**, 232 (1972).

[3] For general reviews, see L. Montanet, Rep. Prog. Phys. **46**, 337 (1983); F. E. Close, *ibid.* **51**, 833 (1988); M. R. Pennington, in *Proceedings of the BNL Workshop on Glueballs, Hybrids and Exotic Mesons,* Upton, New York, 1988, edited by S. U. Chung, AIP Conf. Proc. No. 185 (AIP, New York, 1989), p. 145; N. Isgur, in *Hadron '89,* Proceedings of the 3rd International Conference on Hadron Spectroscopy, Ajaccio, France, 1989, edited by F. Binon *et al.* (Editions Frontières, Gif-sur-Yvette, 1989), p. 709; T. H. Burnett and S. R. Sharpe, Annu. Rev. Nucl. Part. Sci. **40**, 327 (1990).

[4] D. Morgan, Phys. Lett. **51B**, 71 (1974).

[5] N. Törnqvist, Phys. Rev. Lett. **49**, 624 (1982).

[6] R. L. Jaffe, Phys. Rev. D **15**, 267 (1977).

[7] J. Weinstein and N. Isgur, Phys. Rev. Lett. **48**, 659 (1982); Phys. Rev. D **27**, 588 (1983); **41**, 2236 (1990).

[8] D. Morgan and M. R. Pennington, Phys. Rev. D **48**, 1185 (1993).

[9] B. Hyams *et al.*, Nucl. Phys. **B64**, 134 (1973); G. Grayer *et al.*, *ibid.* **B75**, 189 (1974); H. Becker *et al.*, *ibid.* **B151**, 46 (1979).

[10] W. Wetzel *et al.*, Nucl. Phys. **B115**, 208 (1976); V. A. Polychronakos *et al.*, Phys. Rev. D **19**, 1317 (1979); D. Cohen *et al.*, *ibid.* **22**, 2595 (1980); A. Etkin *et al.*, *ibid.* **25**, 1786 (1982); R. S. Longacre *et al.*, Phys. Lett. B **177**, 223 (1986); R. S. Longacre *et al.*, in *Hadron '87,* Proceedings of the 2nd International Conference on Hadron Spectroscopy, Tsukuba, Japan, 1987, edited by Y. Oyanagi *et al.* (KEK Report No. 87-7, Tsukuba, 1988), p. 46; S. J. Lindenbaum and R. S. Longacre, Phys. Lett. B **274**, 492 (1992).

[11] T. Åkesson *et al.*, Nucl. Phys. **B264**, 154 (1986); P. C. Cecil, thesis, Cavendish Laboratory, Cambridge, 1984; Rutherford Appleton Laboratory Report No. RALT-004, 1984 (unpublished).

[12] A. Falvard *et al.*, Phys. Rev. D **38**, 2706 (1988).

[13] U. Malik, in *Strong Interactions and Gauge Theories,* Proceedings of the XXIst Rencontre de Moriond, Les Arcs, France, 1986, edited by J. Tran Thanh Vanh (Editions Frontières, Gif-sur-Yvette, 1986), Vol. 2, p. 431; W. Lockman, in *Hadron '89* [3], p. 109; and (private communication).

[14] B. S. Zou and D. V. Bugg, Phys. Rev. D **48**, R3948 (1993).

[15] K. L. Au, D. Morgan, and M. R. Pennington, Phys. Rev. D **35**, 1633 (1987).

[16] R. H. Dalitz and S. Tuan, Ann. Phys. (N.Y.) **10**, 307 (1960).

[17] F. Binon *et al.*, Nuovo Cimento **78A**, 313 (1983); **80A**, 363 (1984).

[18] R. H. Dalitz, in *Resonances—Models and Phenomena,* Proceedings of the Workshop, Bielefeld, West Germany, 1984, edited by S. Albeverio *et al.*, Lecture Notes in Physics Vol. 21 (Springer, New York, 1984), pp. 1–26; M. R. Pennington, in *Plots, Quarks & Strange Particles,* Proceedings of the Dalitz Conference, Oxford, England, 1990, edited by I. J. R. Aitchison *et al.* (World Scientific, Singapore, 1991), pp. 66–107.