Scalar Meson Spectroscopy in Hadronic J/ψ Decays at a τ-charm Factory

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1. Introduction

To unambiguously identify a state as a scalar glueball requires a detailed understanding of scalars in quark spectroscopy. However, despite years of study, the spectroscopy of 0^{++} $q\bar{q}$ mesons remains unsettled. Due to their narrow observed widths[1] and substantially lower masses, the two well-established 0^{++} states, the $f_0(975)$ and $a_0(980)$, do not seem to fit into the same nonet as the broader and heavier states, the $f_0(1400)$ and $K_0^*(1430)$.[2] As an alternative, it has been suggested that, due to their proximity to $K\overline{K}$ threshold, the $f_0(975)$ and $a_0(980)$ might be weakly bound $K\overline{K}$ molecules.[10] Others have suggested that the $f_0(975)$ and $a_0(980)$ are four-quark states[3,4] or composite quark and glue structures.[5] To study the $f_0(975)$ and other isoscalar 0^{++} states in a controlled environment,[7] decays of the J/ψ into two pseudoscalar ($P\overline{P}$) final states recoiling against a vector (V) meson are examined. The charged channels include

$$
\begin{aligned}
J/\psi &\to \phi\pi^+\pi^- , && (1.1)\\
&\to \phi K^+K^- , && (1.2)\\
&\to \omega\pi^+\pi^- , && (1.3)\\
&\to \omega K^+K^- , && (1.4)
\end{aligned}
$$

where the ideally-mixed ω $(u\overline{u} + d\overline{d})/\sqrt{2}$ and ϕ $(s\overline{s})$ are expected to project out respectively, the non-strange and strange quark-based states in the recoil system. Both scalar (S) and tensor (T) states may be produced against the vector.

The low-multiplicity vector-$P\overline{P}$ final states are inherently straightforward to analyze and are nearly background-free. Excellent π-K-p separation can be achieved using current-technology time-of-flight and dE/dX systems, together with kinematic fitting, due to the relatively low momenta involved (0.3-1.0 GeV/c). The particle identification requirements are even less severe here than in the corresponding radiative decays, because the vector mesons are massive. In most regions of $P\overline{P}$ mass, present analyses are handicapped by limited statistics and incomplete tracking, calorimetric and particle identification solid-angle coverage. I review the present knowledge of nonradiative 0^{++} isoscalar production into the $P\overline{P}$ final state, and indicate how a τ – Charm Factory experiment will help to solve some of the outstanding experimental questions. The radiative decays are presented by T. Bolton at this conference.[6]

2. Selected Results from Current Data Samples

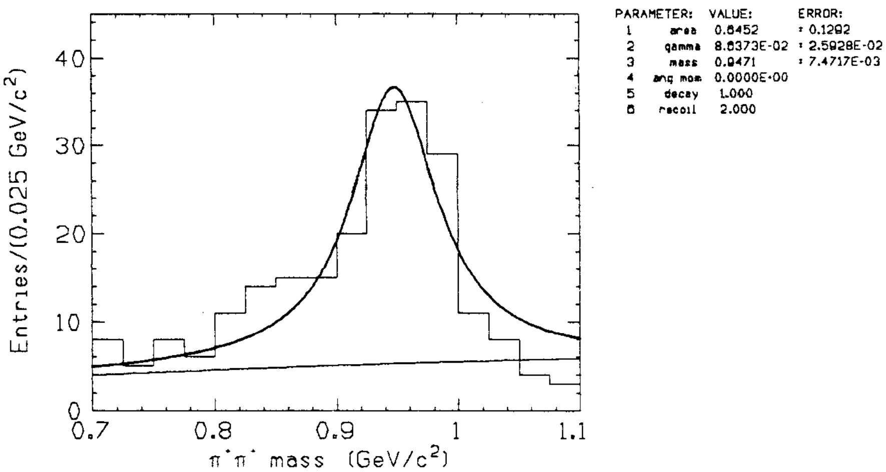

Fig. 1. Relativistic Breit-Wigner fit to the $f_0(975) \to \pi^+\pi^-$ line shape.

In Fig. 1, a prominent $f_0(975)$ signal is seen in the mass spectrum of the $\pi\pi$ system opposite the ϕ in the MARK-III data sample. Similar structure is seen in the DM2 J/ψ sample.[8] together with a box-like structure at higher mass. Of the decays considered here, the $\phi\pi\pi$ channel is the only one in which the $s\overline{s}$ quarks appearing in the vector are not present in the $P\overline{P}$ final state. In the case of the $f_0(975)$, the state itself couples strongly to $s\overline{s}$, but then decays through the only kinematically accessible channel, $\pi\pi$. A fit to the invariant mass distribution using a relativistic Breit-Wigner over a phase space background is shown in Figure 1. The fit does not describe the asymmetric distribution of events around the peak. The mass and width from this fit are $M = (947 \pm 7)$ MeV/c^2 and $\Gamma = (86 \pm 26)$ MeV, respectively. These quantities do not agree particularly well with the particle data book values for the mass and width of 976 and 34 MeV, respectively.[1] Correcting for detector efficiency, the ϕ branching ratio to K^+K^-, and the $f_0(975) \rightarrow \pi^0\pi^0$ decay mode yields a product branching ratio of $B(J/\psi \rightarrow \phi f_0(975)) \times B(f_0(975) \rightarrow \pi\pi) = (3.4 \pm 0.7 \pm 0.3) \times 10^{-4}$, where the first error is statistical and the second error is the estimated uncertainty on the number of produced J/ψ.

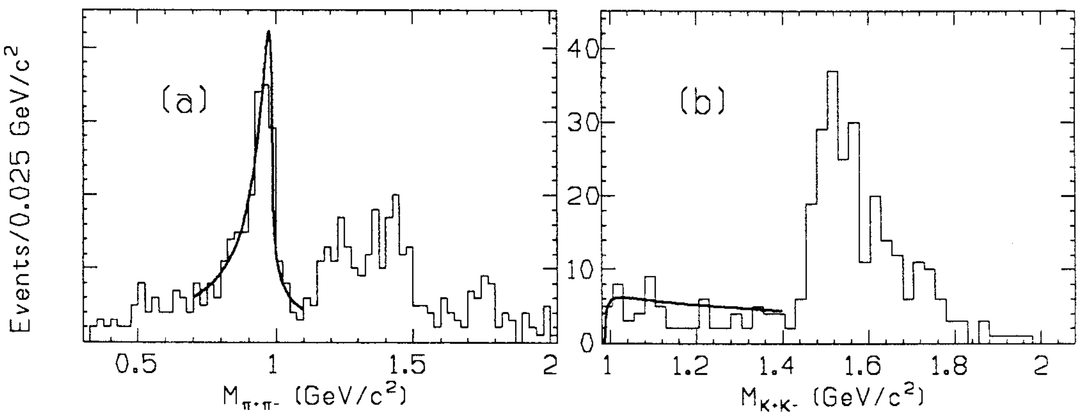

Fig. 2. (a) Coupled channel Breit-Wigner fit to the $f_0(975) \rightarrow \pi^+\pi^-$ lineshape. (b) $K\overline{K}$ prediction from fit in (a).

Fitting the lineshape to a coupled channel Breit-Wigner[9] modulated by a mass-dependent scalar amplitude determined from a fit to the production and decay angular distributions produces a better fit, as shown in Fig. 2(a). The resulting $f_0(975)$ mass is (976 ± 6) MeV/c^2. The lineshape of the resonance is distorted by the opening of the $K\overline{K}$ channel. Taking this distortion into account, the fit yields a true width of about 500 MeV, similar to the other nearby scalar states, the $f_0(1400)$ and $K_0^*(1430)$. This contrasts to the predicted $f_0(975)$ width of ~ 15 MeV, assuming the $f_0(975)$ is a $K\overline{K}$-molecule.[10] The ratio of the squares of the KK to $\pi\pi$ couplings is determined to be (4.5 ± 0.6), indicating that the $f_0(975)$ is comprised mainly of strange quarks. In addition to the $f_0(975)$, the higher-mass structure in Fig. 2(a) may contain the $f_0(1400)$ and $f_2(1270)$. The angular distribution of the π in the 1.1 to 1.5 GeV/c^2 $\pi\pi$ mass region indicates that a spin-two object is present. However, a bin-by-bin wave analysis in this region appears to be intractable given the present limited statistics and acceptance. The curve in Fig. 2(b) is the $K\overline{K}$ rate predicted from the coupled channel fit to the spectrum in 2(a).

In Fig. 2(b), the invariant mass distribution of the $K\overline{K}$ system against the ϕ is dominated by the $f_2(1525)$. There is also a shoulder on the high side of the $f_2(1525)$ which may be due to the $f_2(1730)$; an analysis[13] to determine the line shapes and helicity structures of the combined $f_2(1525)$ and "$f_2(1730)$" structure has met with limited success, due to the complexity of the angular distribution, limited acceptance and statistics, and also because there is most probably more than two states in this region. To fully understand the structure in this region, a wave analysis in small ($\sim$ 20 MeV/c^2) $K\overline{K}$ mass bins is needed. Such an analysis is beyond the scope of present experiments.

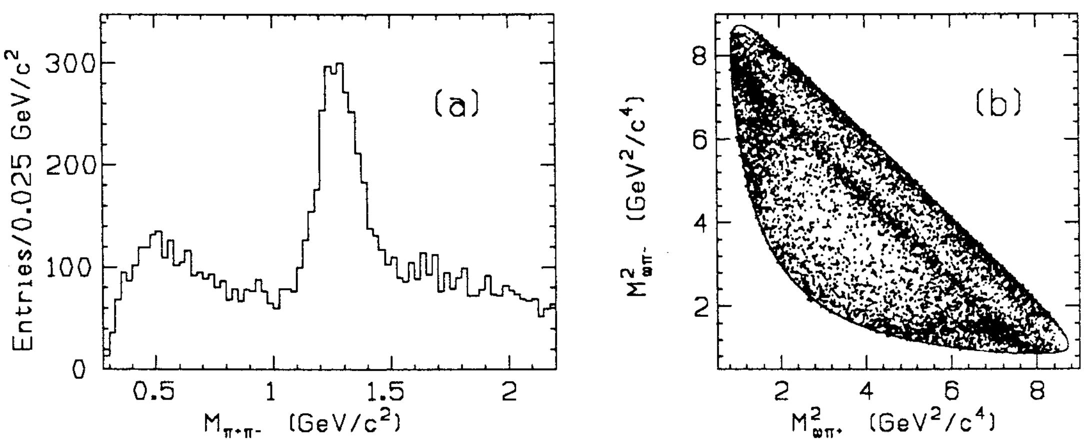

Fig. 3. (a) Mass spectrum of $\pi^+\pi^-$ channel opposite the ω. (b) $\omega\pi^+\pi^-$ Dalitz plot.

Fig. 3(a) displays the observed invariant mass distribution of the $\pi^+\pi^-$ system recoiling against an ω in the MARK-III data sample of 5.8×10^6 produced J/ψ's. Similar structure is seen in the DM2 exposure of 8.6×10^6 J/ψ

events.[11] This spectrum is dominated by a low-mass enhancement and the $f_2(1270)$. The broad, low-mass $\pi\pi$ structure recoiling against the ω does not correspond to any known state. One possible explanation presented at this conference is that this enhancement is a "$\pi\pi$" molecule.[12] In addition, there is a hint of an $f_0(975)$ signal. The DM2 collaboration fits the events in this region to a Breit-Wigner yielding a mass of (959.4 ± 6.5) MeV/c^2 and a branching ratio $B(\mathrm{J}/\psi \to \omega f_0(975)) \cdot B(f_0(975) \to \pi\pi) = (1.10 \pm 0.21 \pm 0.16) \times 10^{-4}$.[11] In the MARK-III data, a fit using the coupled channel Breit-Wigner propagator whose mass, width and coupling parameters have been determined from fitting the invariant mass distributions of $\pi\pi$ and $K\overline{K}$ systems opposite a ϕ yields an upper limit $B(\mathrm{J}/\psi \to \omega f_0(975)) \cdot B(f_0(975) \to \pi\pi) < 1.6 \times 10^{-4}$ at the 90% confidence level.

In Fig. 3(b), the $\omega\pi\pi$ Dalitz plot distribution contains four visible bands. The vertical and horizontal bands are due to $\mathrm{J}/\psi \to b_1(1235)\pi$ decays. The low mass $\pi\pi$ enhancement and $f_2(1270)$ correspond to the diagonal bands near the $\pi\pi$ mass boundary and near the center of the Dalitz plot, respectively. There is no obvious $f_0(975)$ band visible. However, interference with the low mass enhancement, $f_2(1270)$ and $b_1(1235)$ bands may highly distort the $f_0(975)$ decay angular distribution. The events in the $f_0(975)$ region appear to be clustered near the edge of Dalitz plot. A full wave analysis is needed to project out the contributing VS amplitudes.

3. Outlook and Conclusions

An unambiguous assignment of scalar states to the appropriate spectroscopic multiplets has not yet been achieved. However, with the greatly improved sensitivity offered by a $\tau -$ Charm Factory experiment, the identification of vector-scalar and vector-tensor amplitudes will be greatly facilitated (cf. Ref. 6 for a discussion of the spin-determination of the $f_2(1730)$). A systematic study of scalars in hadronic and radiative J/ψ decays will then be possible.

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