EVIDENCE FOR NON-QUARK-MODEL MESONS

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Abstract

I review and update a previous analysis of non-quark-model mesons. I find that there are several interesting states that cannot be accounted for by the quark model. These including the $f_0(1590)$, most likely a glueball; the $\eta(1460)$, $f_1(1420)$ and $f_2(1720)$ which are all prominent in J/ψ radiative decays, but which have not been classified; and the exotic $M(1406)$, which, with the $\rho(1480)$, may be a P-wave 4-quark state.

INTRODUCTION

Examination of the spectrum of mesons has traditionally been a fertile field for the study of the strong interactions. The early success of the quark model (QM) in explaining the spectrum helped establish the existence of quarks and the QCD theory of quark and gluons. The absence of any state that could not be described as a quark-antiquark bound state was important in that context. It is ironic that now we do not understand why the quark model is so successful, and we expect to find states that are indeed not $q\bar{q}$ bound states! In fact, there are compelling reasons to expect states of two or three gluons (gg, ggg), hybrid quark-antiquark-gluon ($q\bar{q}g$), and four quarks ($q\bar{q}q\bar{q}$). Predictions do not include reliable mass estimates, however, nor are the effects of mixing with nearby states, or the effects of decay channels taken into account.

This talk is based on, and updates the review of Burnett and Sharpe (BS) [1], which reviewed the theoretical reasons, and examined some of the experimental evidence for such states. Following BS, I examine the scalar, pseudoscalar, axial vector, tensor, and exotic $J^P = 1^{+-}$ sectors.

SCALAR SECTOR

There is no new information on the $f_0(1590)$, which remains a convincing glueball candidate, due to its dominant $\eta\eta'$ decay. It has been seen by only one group, and still needs confirmation.

As emphasized by BS, it is important that the QM states in each sector be identified. There is a new analysis by Morgan and Pennington[2] affecting interpretation of the $S^*/f_0(970)$. BS had favored the $K\bar{K}$ molecule interpretation of Isgur and Weinstein[4] over the analysis of Au, Morgan and Pennington[3]. The new analysis uses a model-independent parametrization to examine the effects of one *vs.* two poles in the region of the $K\bar{K}$ threshold region. A single pole corresponds to a molecule, two to a quark and/or gluon bound state. They find that the data are better described by two poles, but do not claim that the molecule hypothesis is definitely ruled out. However, I find the evidence from the reaction $J/\psi \to \phi\pi\pi$ and $J/\psi \to \phi K\bar{K}$ to be very convincing. In Figure 1 I

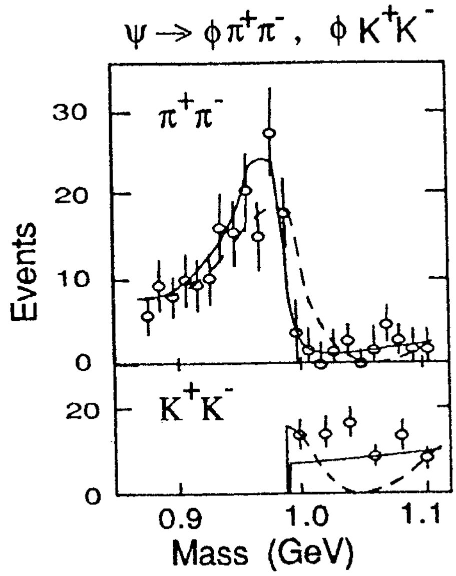

Figure 1: Comparison of the distributions of $m_{\pi\pi}$ or m_{KK} for the reactions $J/\psi \to \phi\pi\pi$ and $J/\psi \to \phi K\bar{K}$ with the one-pole (dashed) or two-pole (solid) parametrizations of Morgan and Pennington.

have plotted the DM2[5] data with curves for the two hypotheses: dashed for one pole, solid for two. Note that the former appears to have a zero in the amplitude at 1.05 GeV. This completely disagrees with the data, especially for the K^+K^- case. The statistical weight of a null prediction, if one uses Poison statistics, is very high. If the prediction of the zero is correct, and there is no unknown background source for the data, the molecular interpretation is certainly ruled out. Obviously, both caveats should be checked.

PSEUDOSCALAR AND AXIAL VECTOR SECTOR

BS concluded that there were two nearby pseudoscalar states, $\eta(1420)$ and $\eta(1460)$, with the former the $s\bar{s}$ partner of the $\eta(1295)$, leaving the latter to be clearly a non-QM state, although its composition is not certain. Additionally, and coincidentally at the same mass, the axial vector $f_1(1420)$ is also "extra", in that QM states in this mass region seem to be accounted for. A new Mark III analysis of the spin-parity composition of the large bump in $J/\psi \to \gamma K K\pi$ [6] concludes that both the $f_1(1420)$ and $f_0(1460)$ make substantial contributions to the peak formerly thought to be one state. In addition, the $f_0(1420)$ possibly also contributes. There is not space to expand on the confused situation around 1.4 GeV in $KK\pi$ and $\eta\pi\pi$: clearly there are more states than can be accounted for by the QM, with J/ψ radiative decays trying to tell us something. Hopefully more data will resolve the situation.

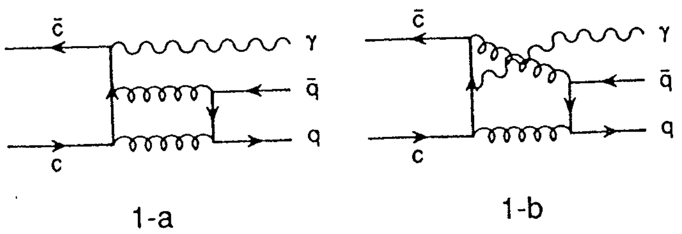

Figure 2: Diagrams for the process $J/\psi \to \gamma gg \to \gamma M$.

TENSOR SECTOR

The $f_2(1720)$, formerly known as the θ, remains an interesting object, distinguished by its prominence in J/ψ radiative decays and the fact that the QM states, the P-wave $f_2(1270)$ and $f_2'(1525)$ are accounted for very well. As emphasized by BS, the pattern of its decays and its suppression in peripheral $K^- p \to \Lambda K^+ K^-$ are not easily accounted for by any model.

A recent analysis of Mark III data[7], using a moment method to measure the components of various spins, has concluded that the events in the θ region are mostly spin zero, contradicting previous analyses[8]. Clearly, resolution of this question is important for analysis of both the tensor and scalar sectors.

Analysis that conclude that the θ is indeed a tensor also measure the production helicity amplitude ratios $x = A_1/A_0$ and $y = A_2/A_0$ for it as well as $f_2(1270)$ and $f_2'(1525)$. These measurements are not consistent with a perturbative QCD calculation, which has been a longstanding puzzle in that the J/ψ decay mechanism, the OZI-suppressed annihilation of the constituent charm-anticharm quark pair into three gluons, or a photon and two gluons, is reasonably well understood. Recently, Close and Li[9] have addressed this question. They note that the calculation in fact requires the sum of the amplitudes corresponding to two diagrams, Figure 2a and 2b. It appears, however, that one gets the "right" answer if only diagram *a* contributed to the QM mesons, while only diagram *b* was responsible for the θ production. A possible explanation is that diagram *b* emphasizes the gluonic component of the J/ψ wavefunction, in turn selected by the θ wavefunction. This explanation clearly needs a firmer basis.

THE EXOTIC 1^{+-}

There is no new information on the interesting $M(1406)$ P-wave $\eta\pi$ state, which is manifestly not a QM meson, given its exotic quantum numbers. I emphasize that it has been seen in only one experiment, and so must be confirmed. If it is real, a nice explanation was given by Close and Lipkin[10], associating it with the (non-exotic) $\rho(1480)$ as P-wave four-quark states.

OUTLOOK

Many of the experimental puzzles I have mentioned will surely be resolved by two next generation experiments:

- E852 at the BNL MPS will collect data in 1995 or so, using the peripheral reaction $\pi^- p \rightarrow nX^0$ with a lead glass detector to reconstruct and trigger on specific all neutral final states. It should verify the many interesting GAMS results, including the $f_0(1580)$ and $M(1406)$. Unlike GAMS, it will also be able to reconstruct the corresponding charged final states, an important check.

- The τ-charm factory in Spain, if approved as expected in 1991, should take data around 1997. It is a low energy (3-5 GeV) high luminosity e^+e^- collider designed to study τ and open charm decays. Nevertheless, with only a few weeks dedicated to the J/ψ, it should easily accumulate 10× the current world data, and with a far superior detector to those that have already given us so much information.

Finally, I note reason for optimism on the theoretical front: lattice gauge calculations can only improve as computing technology grows. collider

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