DO MULTIQUARK STATES EXIST AMONG THE 0^{++} MESONS?

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Abstract:

It has been proposed that, in addition to the conventional P wave $q\bar{q}$ nonet of 0^{++} mesons, there should be a second 0^{++} nonet composed of $qq\bar{q}\bar{q}$ states nearby in mass. This nonet contains the lightest multiquark states and is therefore particularly suitable for experimental investigation. We review the status of 0^{++} mesons in the light of this proposal.

Précis :

Il a été proposé que, par surcroît au P wave $q\bar{q}$ nonet normal des 0^{++} mesons, il y a besoin d'un deuxième 0^{++} nonet composé des $qq\bar{q}\bar{q}$ états proche en masse. Ce nonet contient les états multi-quark les plus légers et donc c'est particulièrement convenable pour l'investigation expérimentale. Nous passons en revue l'état des 0^{++} mesons du point de vue de cette proposition.

The $J^{PC} = 0^{++}$ mesons are of unusual importance in meson spectroscopy. However, they continue to be a centre of controversy, both theoretically and phenomenologically. The reasons are clear. On the theoretical side we may expect, in the quark-gluon approach to strong interactions, a rich spectrum of 0^{++} states below about 1.4 GeV. First we have the conventional P wave $q\bar{q}$ nonet of 0^{++} mesons. In addition, there is also the possibility of $qq\bar{q}\bar{q}$ states. The apparent spectroscopic absence of such multiquark hadrons could be because the mass of the hadron increases roughly linearly with the number of quarks. Jaffe[1) has studied the S wave $qq\bar{q}\bar{q}$ states and, with the magnetic gluon interaction for the mass splitting[2)], finds the lowest lying multiquark states belong to a 0^{++} nonet. Interestingly, an explicit quark-bag model calculation[1)] estimates the mass of such states to be about 1 GeV or less. So if multiquark states exist, we expect two 0^{++} nonets below about 1.4 GeV. A third possibility for 0^{++} mesons are states built entirely from gluons (glueballs). The expectations here are hard to quantify and we will not consider this further. However, it should be borne in mind that an (I=0) 0^{++} two-gluon state could exist as low as 1 GeV[3)].

On the phenomenological side the identification of 0^{++} mesons has been far from easy. This is true despite their strong coupling to the readily accessible 0^-0^- channels, such as $\pi\pi$, πK, $K\bar{K}$. The resonances either appear very broad, or near the $K\bar{K}$ threshold, or hidden under the leading peripheral 2^{++} states. In each case they are prone to ambiguity.

To establish notation for the members of a 0^{++} nonet, we denote the isotriplet by δ, the isodoublets by κ and $\bar{\kappa}$, the isosinglets by ε and S. If the nonet satisfies magic mixing we take S to contain an $s\bar{s}$ pair, and ε to be built entirely of non-strange quarks. Suppose that the S and ε mix magically in the conventional $q\bar{q}$ nonet, then ε and δ will be degenerate in mass with the S state at higher mass. On the other hand, if the S and ε states are magically mixed in the $qq\bar{q}\bar{q}$ nonet, then the quark content is as shown in Fig. 1. That is, the S and δ are degenerate in mass and the ε lies at lower mass. The resulting mass spectrum for the two nonets is sketched in Fig. 2. It was the approximate degeneracy of the observed S*(990) and δ(970) which prompted Jaffe to assign these states to the $qq\bar{q}\bar{q}$ nonet, together with broad $\varepsilon(\pi\pi)$ and $\kappa(K\pi)$ states. Indeed, the only obvious problem with this identification is the observed width of the $\delta\to\pi\eta$ decay; since $qq\bar{q}\bar{q} \to q\bar{q} + q\bar{q}$ are "fall apart" decays, it should be

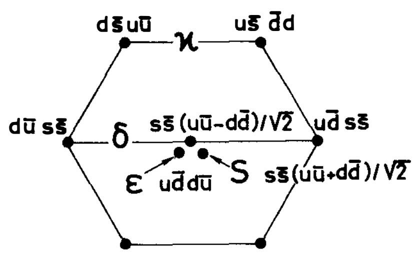

Fig.1

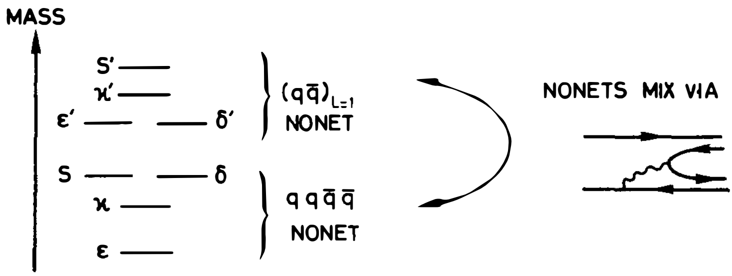

Fig.2

much broader. Of course this approach raises the problem of observing another nearby 0^{++} nonet (ε',δ', κ', S' of Fig. 2).

The spectrum described above represents an idealized situation. There will be complications. First the members of the two nonets can mix by gluon exchange, as shown in Fig. 2. Second we expect some violation of magic mixing. For example, in a $qq\bar{q}\bar{q}$ state one $q\bar{q}$ pair spends a fraction of the time in a colour octet state[1)] or in a 0^- state. In either case this will lead to violations of magic mixing.

Now let us review the observed spectrum so that we may compare it with the above expectations. The δ(970) is clearly established in the πη channel. The S*(990) is seen both in the ππ and $K\bar{K}$ channels, though with some flexibility in the couplings. The 0^{++} partial waves extracted in ππ and Kπ phase shift analyses

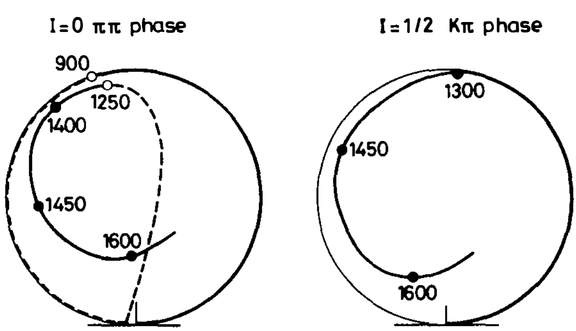

Fig.3

are shown in Fig. 3. These represent the general trend of almost all solutions, though the solutions differ in detail. In both cases the phases rise slowly to 90^o and then rotate rapidly anticlockwise in the region of 1.45 GeV. It is conceivable that this behaviour can accommodate the broad† ε, κ and the ε', κ' states, though clearly without definitive identification.

So far the situation is much as Morgan[5)] studied in 1974. He found the observed decays $\varepsilon, S^* \to \pi\pi, K\bar{K}$; $\delta \to \pi\eta, K\bar{K}$; $\kappa \to K\pi$ could be made compatible with a $q\bar{q}$ non-magically mixed nonet (mixing angle about 70^o), provided the states were taken to be $S^*(980)$, δ(970), κ(1200), ε(1300). Also the ε(1300) was an elastic ππ resonance.

Recent developments have occurred in the $K\bar{K}$ channels. The processes studied are of the type $\pi N \to K\bar{K}N$. Here $K\bar{K}$ production in the I=0 S wave state (ε,S) proceeds dominantly via π exchange, whereas I=1 S wave production (δ) proceeds via B or Z exchange. Z is used to denote a possible 2^{--} exchange trajectory which couples to helicity non-flip at the nucleon vertex, whereas both π and B exchange couple to helicity flip.

The S wave $K\bar{K}$ mass spectrum obtained from $K^o_s K^o_s$ and K^+K^- production data[6,7)] show a significant bump near 1.3 GeV. This structure was originally attributed[6)] to a state in the I=1 $K\bar{K}$ channel, but a more recent analysis[8)] favours an I=0 assignment. To help unravel the I=0 and I=1 $K\bar{K}$ effects the ANL group[7,8)] studied both $\pi^- p \to K^- K^+ n$ and $\pi^+ n \to K^- K^+ p$. In Fig. 4 we plot the S wave contribution

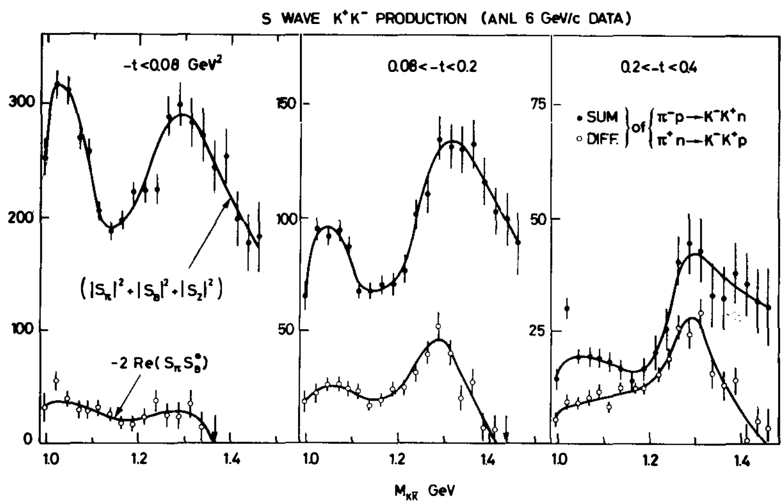

Fig.4

isolated from the sum and from the difference of these data for three different t intervals. For the sum we use the moments $\langle Y_4^{0,2} \rangle$, $\langle Y_2^2 \rangle$ and $\langle Y_0^0 \rangle$ to isolate

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†See ref.4 for a model for the phase behaviour of these states.

$|S|^2 = |S_\pi|^2 + |S_B|^2 + |S_Z|^2$. For the difference we simply plot $-\langle Y_0^0\rangle$, since the higher moments indicate that this is essentially S wave, namely $-2\mathrm{Re}(S_\pi S_B^*)$; S_Z does not contribute to this I=0,1 interference if we assume A_1 quantum number exchange is negligible compared to π exchange. The effect of the S*(990) is clearly visible in the sum, $|S|^2$, with a t dependence characteristic of π exchange. On the other hand the structure at 1.3 GeV does not have π exchange t dependence which is expected for I=0 $K\bar{K}$ production.

Independent information on S wave $K\bar{K}$ production has recently been obtained from an analysis of University of Geneva 10 GeV/c $\pi^- p \to K^- \bar{K}^0 p$ data[9]. The relevant results[9a], Fig. 5, show evidence for an S wave structure just below

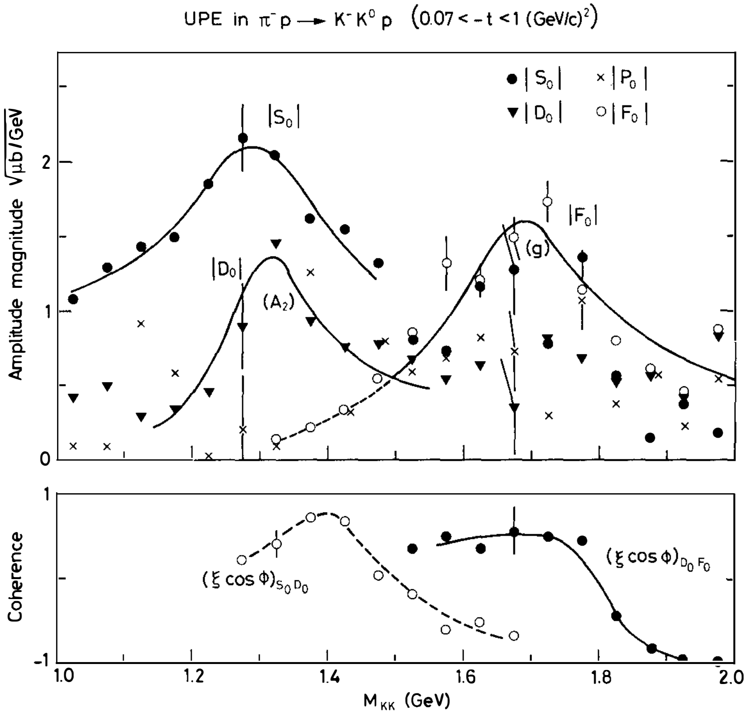

Fig.5

1.3 GeV. Here it must be I=1, that is $|S_0|^2 = |S_B|^2 + |S_Z|^2$. Moreover, the t dependence[9b] of the S wave indicates that Z exchange dominates for $-t \lesssim 0.15\ \mathrm{GeV}^2$. This correlates nicely with the behaviour of $\mathrm{Re}(S_\pi S_B^*)$ of Fig. 4, which suggests S_B becomes relatively more important at larger $|t|$.

If the resonance identification, δ'(1270), of this I=1 structure is confirmed, this will be clear evidence for the existence of the two 0^{++} nonets

Moreover, this structure cannot account for the entire S wave bump in the K^+K^- data; there is a residual I=0 S wave effect, perhaps arising from the ε'. However, for the moment we must conclude the existence of multiquark states remains an open question. On the other hand, we have seen the low mass 0^{++} states offer a good testing ground. Investigation of $\pi\pi$, $K\bar{K}$ channels in other charge configurations, or of the $\eta\eta$ channel, would be invaluable in this respect. This, together with a quantitative analysis of the observed couplings, should settle the issue.

Acknowledgements

I thank Robert Jaffe, David Morgan, Emin Ozmutlu, Euan Squires and the members of the Geneva collaboration for useful discussions.

References

1. R. L. Jaffe, Phys. Rev. D15, 267 (1977)
2. A. De Rújula, H. Georgi and S. L. Glashow, Phys. Rev. D12, 147 (1975)
3. R. L. Jaffe and K. Johnson, Phys. Lett. 60B, 201 (1975)
   D. Robson, Nucl. Phys. B130, 328 (1977)
4. R. L. Jaffe and F. E. Low; see R. L. Jaffe, these proceedings
5. D. Morgan, Phys. Lett. 51B, 71 (1974)
6. N. M. Cason, V. A. Polychronakos, J. M. Bishop, N. N. Biswas, V. P. Kenny, D. S. Rhines, W. D. Shephard and J. M. Watson, Phys. Rev. Lett 36, 1485 (1976)
7. A. J. Pawlicki, D. S. Ayres, D. Cohen, R. Diebold, S. L. Kramer and A. B. Wicklund, Phys. Rev. D15, 3196 (1977)
8. D. Cohen, Proc. 5th Experimental Meson Spectroscopy Conf., Boston (1977)
9. A. D. Martin, E. N. Ozmutlu, R. Baldi, T. Böhringer, P. A. Dorsaz, V. Hungerbühler, M. N. Kienzle-Focacci, M. Martin, A. Mermoud, C. Nef and P. Siegrist; a) Phys. Letts. (1978); b) Submitted to Nucl. Phys. (1978)