Pub-81/66

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

ANL-HEP-PR-81-23
June, 1981

THE E IS NOT A GLUE BALL--BUT FLAVOR SYMMETRY SHOWS HOW TO FIND THEM*

Harry J. Lipkin‡

Fermi National Accelerator Laboratory
Batavia, Illinois 60519

and

Argonne National Laboratory
Argonne, IL 60439

ABSTRACT

Unitary singlet character of glue ball gives useful signature for decay in $\eta\pi\pi/K\bar{K}\pi$ branching ratio and in $V\gamma$ decays. Success of SU(3) predictions for unitary singlet charmonium decays via gluons support validity of similar SU(3) predictions for glue balls. Absence of strong $\eta\pi\pi$ signal relative to $K\bar{K}\pi$ in E decay rules out $\delta\pi$ dominance of $K\bar{K}$ and unitary singlet classification for E. Enhancement of low mass $K\bar{K}$ s-wave shown to follow from G parity without presence of δ. Data consistent with normal 1^+ nonet and broken nonets of quarkonium pseudoscalars with nearest neighbor radial mixing.

---

*Work performed under the auspices of the United States Department of Energy.

‡On leave from the Department of Physics, Weizmann Institute of Science Rehovot, Israel

suggest that the photon is isoscalar and is emitted from the charmonium system before the annihilation.[7] Thus M is even under G.

The crucial point is that the $\eta\pi\pi$ decay (1b) is related to the $K\bar{K}\pi$ decay (1a) by SU(3) and has a larger phase space. Thus the comparative absence of the $\eta\pi\pi$ decay when there is a strong $K\bar{K}\pi$ signal places important constraints on the quantum numbers of M. If M is a unitary singlet glue ball, the $\eta\pi\pi$ signal must be at least as strong as the $K\bar{K}\pi$ signal. If the decay is dominated by the $\delta\pi$ final state the $\eta\pi\pi$ signal must be very much stronger than $K\bar{K}\pi$. There are natural mechanisms for obtaining a strong $K\bar{K}\pi$ signal and a weak $\eta\pi\pi$ signal from quarkonium states which are not unitary singlets. But these mechanisms do not apply to a unitary singlet.

We now discuss a number of relevant symmetry properties.

1. The $K^*\bar{K}$ decay mode is forbidden by SU(3) for a unitary singlet meson M_1 which is even under C,

$$\Gamma(M_1 \rightarrow K^*\bar{K}) = 0 \ . \tag{2}$$

This prediction is stable against SU(3) symmetry breaking. Thus if M decays into $K^*\bar{K}$ it cannot be a unitary singlet and cannot be a glueball.

A unitary octet meson M_8 can decay into $K^*\bar{K}$. However, this is the only vector-pseudoscalar channel allowed by charge conjugation and isospin invariance. Thus decays into the $\eta\pi\pi$ mode via a VP intermediate state is forbidden for all states M be neglected because of the centrifugal barrier, the kaon pair will be in an s-wave if M is even under G and in a p-wave if M is odd. Thus in an even-G decay, like the reaction (1), the s wave dominance at low mass can appear to be the tail of a δ, even if no δ is present. This could explain the tendency to find δ signals in $K\bar{K}\pi$ decays of the E meson. Even in the case where all the $K\bar{K}\pi$ signal comes from the $K^*\bar{K}$ mode this enhancement of the s wave in the $K\bar{K}$ system still occurs, and results from the interference between the $K^*\bar{K}$ and $K\bar{K}^*$ amplitudes.[5] In hadronic experiments, where both even and odd G final states are present, a low-mass "δ-cut" on the $K\bar{K}$ effective mass separates the s-wave even-G signal from p-wave odd-G background whether or not a δ is present. Evidence for the δ in such states obtained only from the $K\bar{K}$ mass distribution is therefore unconvincing.

3. The $\eta\pi$ and $K\bar{K}$ decay modes of the δ are related by SU(3). The ratio of the two transition matrix elements is given by SU(3) Clebsches of order unity in all models, although specific details depend upon η-η' mixing and the possible classification of the δ as a four quark state. There is no suppression of the $\eta\pi$ matrix element relative to $K\bar{K}$. Thus, since the δ is below the $K\bar{K}$ threshold and has ample phase space for $\eta\pi$ decays, the $\eta\pi$ mode is expected to dominate. This has been verified by experimental analysis of δ production and decay[8,9] showing that the $K\bar{K}$ decays are less than 1/5 of $\eta\pi$. The coupled channel analysis of the data uses the SU(3) ratio of coupling constants from unmixed octets

$$g^2_{\delta K\bar{K}}/g^2_{\delta\eta\pi} = 3/2 \ . \tag{4a}$$

experiments which claim to see the δ may well be seeing the s-wave enhancement resulting from G invariance mentioned above.

4. The $\delta\pi$ decay mode of a unitary singlet M is related by SU(3) symmetry to other decays; e.g. $\epsilon\eta$ and $\kappa\bar{K}$. Although these factors are uncertain, they can only lead to further reduction of the $M \to \delta\pi \to K\bar{K}\pi$ branching ratio and of the contribution of the $\gamma\delta\pi$ state to the reaction (1a).

5. In the $\pi^+\pi^-\eta$ decay mode of an even C state the two pions are required by C invariance to be in an even parity state. The same is true for the two kaons in the $K^-K^+\pi^\circ$ decay mode. This special case of the G-parity condition above follows from the weaker assumption of C invariance.

6. The extension to SU(3) symmetry of the above C and G constraints require any meson pair in either final state (1) to be in an even parity state if M is a unitary singlet. This also excludes all vector-pseudoscalar decay modes and again gives the selection rule (2), since the two pseudoscalars from vector decay must be in a p-wave.

7. The SU(3) coupling of an even C unitary singlet to three pseudoscalar octet mesons is unique and is totally symmetric. The $K\bar{K}\pi$ and $\eta\pi\pi$ couplings are related by the same Clebsches as in Eq.(4a)

$$g^2_{K\bar{K}\pi} = (3/2)g^2_{\eta\pi\pi} \quad . \tag{6}$$

Since the $\eta\pi\pi$ final state has greater phase space, a unitary singlet meson must have similar branching ratios for the two transitions (1a) and (1b).

state of one configuration and the non-strange quark state of the next radial excitation. This feature has been shown to explain peculiar properties of the η', and similar features should appear in the pseudoscalar state in the E region if the third and fourth states are under the D and E respectively. These mixtures behave very differently from the SU(3) singlet states in the standard nonets.

Production and decay processes for these nearest-neighbor-mixed states can be very different from conventional nonet states. These differences must be taken into account in any attempt to determine the quantum numbers of questionable mesons. There are three characteristic differences:

1. Hadronic peripheral production at low momentum transfer in meson-baryon reactions depends upon form factors dominated by the ground state configuration, which has a large overlap with the initial state. The η and η' should be produced much more strongly than higher states. At higher momentum transfers where radial excitations can be produced the higher states should be more copiously produced. In the model of Ref.6, the two excited pseudoscalar states predicted to be under the D and E, which we denote by P_D and P_E have very different ground state components and P_E is predicted to be produced much more weakly[12] in πp reactions than P_D

$$\sigma(\pi^- p \to P_E n) \ll \sigma(\pi^- p \to P_D n) \ . \tag{7}$$

This is very different from the prediction from standard nonet mixing.[4]

2. Production from gluons and two-photon annihilation is dominated by the wave function at the origin. Here the two dominant contributions from

These are the only two possibilities for obtaining a large $KK\pi$ signal with no related $\eta\pi\pi$ signal. A unitary singlet meson has a significant $\eta\pi\pi$ decay given by the relation (6). An ideally mixed $(u\bar{u} + d\bar{d})$ state gives a strong $\eta\pi\pi$ signal if it does not go via the VP intermediate state. The evidence from charmonium rules out strong SU(3) breaking effects which could enhance strange decay modes.

The large $K\bar{K}\pi$ signal obtained from the E meson suggests that it is either an $s\bar{s}$ state or that it decays to $K^*\bar{K}$ or both. The most probable suggestion is that it is a 1^+ $s\bar{s}$ state[2,5] whose partner is the D meson which is $u\bar{u} + d\bar{d}$. Note however, that exact ideal mixing is not necessary to obtain these properties. The D is below the $K^*\bar{K}$ threshold and the $K\bar{K}\pi$ decay is suppressed by phase space even if it has an $s\bar{s}$ component. If the E is 1^+, any nonstrange component will also naturally prefer the s-wave $K^*\bar{K}$ decay.

The question of possible pseudoscalar states under the D and E then arises, as predicted by the radial mixing model[6] and found experimentally by Stanton _et al._[13] in the $\eta\pi\pi$ mode. It is then necessary to look for small signals in the reactions (1a) and (1b). For this the $\eta\pi\pi$ decay mode is crucial, since the $K\bar{K}\pi$ mode is dominated by the $K^*\bar{K}$ state from the E. Angular distributions and correlations may also be useful in separating axial vector and pseudoscalar states. Four angles have simple physical interpretations:

θ_1. The angle between the photon and the electron beams or the normal to the orbit plane. For polarized electron beams a unique angular distribution is found if M is spin zero; it is ambiguous if M is spin 1.

The $V\gamma$ electromagnetic decays of a unitary singlet will also have a distinctive character since the decay amplitude is proportional to the U spin zero octet component of the vector meson. This gives the well known ratio 9:1:2 for the $V\gamma$ decays,[14]

$$\Gamma(G \rightarrow \rho\gamma)/\Gamma(G \rightarrow \omega\gamma)/\Gamma(G \rightarrow \phi\gamma) = 9/1/2 \ . \tag{7}$$

This is very different from the $V\gamma$ decays of ideally mixed states which either go entirely into $\phi\gamma$ or not into $\phi\gamma$ at all. Nearest neighbor mixing which tends to give approximately equal strange and nonstrange components would tend to increase the ϕ signal relative to the ρ.

The two-photon decays are expected to be down by a factor of α from one photon and probably will not be easily seen in a state which has a hadronic width of 50 MeV. In the η', where the total width is 0.3 MeV, the branching ratio is only 2%. Furthermore, the large difference between the unitary singlet quarkonium and glueball predictions for the two-photon decay[4] may disappear when nearest neighbor mixing is introduced, because the strange and nonstrange components in the quarkonium always interfere destructively, as pointed out above.

Correspondence with Isaac Cohen, in particular with regard to nearest neighbor mixing and Eq.(7) are gratefully acknowledged. Stimulating discussions with E. L. Berger, J. D. Bjorken, S. Meshkov and D. Sivers are also acknowledged.