**Introduction: The Story of \( O \)**

We focus on the lightest vector glueball \( O \) supposedly made up of 3 constituent gluons. It should mix less with \( q\bar{q} \) mesons hence is cleaner than 2\( g \) glueballs.

We are motivated by some recent developments:

1. The \( 0^{++} \) glueball candidate \( f_0(1500) \);
2. Continued absence of \( \psi' \rightarrow \rho\pi, K^*\bar{K} \), with similar situation emerging for \( VT \) modes;
3. Absence of distortion in the energy scan of \( J/\psi \rightarrow \rho\pi \) indicates that \( \Gamma_O \gg \Gamma_{J/\psi} \).

\( O \) may also play a role in the OZI violating \( \bar{p}p \rightarrow \phi\gamma, \phi\pi \) production puzzle.

In 1982, we were working on 3\( g \) glueballs in a potential model similar to the naive quark model. Taking the constituent gluon mass to be \( m_g \approx 0.5 \text{ GeV} \), we estimated that \( m_O \approx 4.8m_{\psi} \approx 2.4 \text{ GeV} \). To account for the prediction of FN, we relaxed their SU(4) assumption by allowing for QCD motivated \( q^2 \) dependence, viz. \( f_{\phi} : f_{O\phi} = (\sqrt{2} : -1 : 1) f(q^2) \). At that time MARK II had just reported for the first time the "\( \rho\pi, K^*\bar{K} \) anomaly". That is, although \( J/\psi \rightarrow \rho\pi, K^*\bar{K} \) decays are quite sizable (~1%), \( \psi' \rightarrow \rho\pi, K^*\bar{K} \) decays were anomalously absent, in contrast to the "15% rule", \( R_{\psi'\psi} \approx BR(\psi' \rightarrow X)/BR(J/\psi \rightarrow X) \approx 0.15 \), satisfied by most modes. To explain this anomaly, we conveniently invoked \( O \) pole dominance. Due to the proximity of \( O \) to \( J/\psi \) and its preference to decay via \( \rho\pi \), it dominates over 3\( g \) continuum for this mode, but for most other modes the continuum is dominant. \( \psi' \), however, lies too far away from \( O \) to be affected. Thus, resonance enhancement of \( J/\psi \) leads to the suppression

\[
\frac{\Gamma(\psi' \rightarrow \rho\pi)}{\Gamma(J/\psi \rightarrow \rho\pi)} \approx \left( \frac{m^2_{\psi'} - m^2_O}{m^2_{\psi'} - m^2_{\phi}} \right)^2 \frac{f^2_{O\phi}}{f^2_{\phi}}.
\]

With \( m_O \approx 2.4 \text{ GeV} \), the propagator ratio gives rise to a factor of 4 suppression.
As the $\rho\pi$ anomaly deepened, implying that $O$ must be rather close in mass to $J/\psi$, BLT added the width factor and proposed that

$$|m_O - m_\psi| < 80 \text{ MeV}, \quad \Gamma_O < 160 \text{ MeV},$$

(2)

was necessary to explain the anomaly. Since $O$ is a $3g$ state while $J/\psi$ a $c\bar{c}$ state, this “accidental degeneracy” may seem somewhat fortuitous.

2 Crystal Barrel: 0$^+$ Glueball Candidate and Its Impact

An excess of 0$^+$ states between 1350 – 1750 GeV is observed by the Crystal Barrel experiment and others at LEAR. If we take $G \equiv f_0(1500)$ as mainly a 0$^+$ glueball, we find that $m_G \approx 1.4 - 1.5$ GeV, which agrees well with lattice results. Using potential model estimate $m_G \approx 2.3m_g$, we infer the reasonable value $m_g \approx 600 - 650$ MeV $\approx 2m_{\pi}$, implying that $m_O \approx 4.8m_g \approx 2.9 - 3.1$ GeV, right in the ballpark of Eq. 2! The properties of $O$ have to be rechecked.

Since $m_G + m_O > m'_\psi$, the decay $J/\psi, \psi' \to G + O \to \pi\pi + \rho\pi$ are forbidden. But clearly $J/\psi \to \gamma G$ and $\psi' \to \pi\pi + O$ search should continue.

Since the model demands that the $J/\psi \to \rho\pi$ width of 1.1 keV is saturated by the $J/\psi \to O \to \omega \to \rho\pi$ process, one gets the relation,

$$f(m_{J/\psi}^2) \approx 0.0247 \sqrt{m_{J/\psi}^2 - m_O^2}. \quad (3)$$

Taking for illustration $m_O \approx 2.9$ GeV, we find the mixing angle

$$\sin \theta_{\psi' - O} \approx f(m_{J/\psi}^2)/(m_{J/\psi}^2 - m_O^2) \approx 0.023,$$ \quad (4)

which is reasonably small. One then finds the widths for $O \to \rho\pi$, $K^*\bar{K}$ to be roughly 2.2 MeV, 1.5 MeV, while $O \to e^+e^-$, $K\bar{K}$, $p\bar{p}$ are 2.7 eV (!), 0.08 MeV and 0.02 MeV, resp. These numbers fit model prerequisites pretty well. Assuming that BR($O \to \rho\pi$) $\sim$ few–10%, we find that $\Gamma_O \approx 30 - 100$ MeV, a slightly narrow but still reasonable hadronic width.

3 BES Results

As reported at this meeting, BES has searched in vain for $\psi' \to \rho\pi$, $K^*\bar{K}$ decay with $3.5 \times 10^6$ $\psi'$. Furthermore, a “VT” anomaly seems to be emerging (e.g. $R_{\psi'\psi}(\omega f_2) < 0.035$). These results seem to strengthen the case for $O$. However, a recently published energy scan for $J/\psi \to \rho\pi$ over a 40 MeV interval sees no distortion from a nearby $O$ state. At first sight this may seem to rule out the BLT range of Eq. 2. We wish to point out, however,
that the null result should probably be expected for $\Gamma_O \gg \Gamma_{J/\psi}$. That is, the two physical states are each admixtures of $c\bar{c}$ and $3g$ wavefunctions: $\left| J/\psi \right\rangle = c_0|c\bar{c}) + s_0|3g)$, $\left| O \right\rangle = -s_0|c\bar{c}) + c_0|3g)$. Hence, the total cross sections for $e^+e^- \rightarrow \rho \pi$ under the $J/\psi$ and $O$ peaks should be equal, and the $J/\psi$ peak stands out only because it is extremely narrow.

In any case we hate to lose BLT hypothesis at this juncture since it is now motivated by mass and width considerations from elsewhere. To give up BLT, one would have to demand that the mixing factor $f_{O\psi}/f_{O\psi}$ be suppressed. This might in fact happen since both $O$ and $J/\psi$ are ground states, while $\psi'$ is a $2S$ state, hence $O$ may overlap less well with $\psi'$.

4 Discussion

We note that $J/\psi \rightarrow VP$ and $VT$ and $\eta_c \rightarrow VV$ modes are quite prominent. In our approach there are two vector states $1^-(0)$ and $1^-(2)$ and one $0^+-(1)$, where number in parenthesis is the spin of an octet $2g$ pair. All three states turn out to be close to degenerate (!), hence, resonance enhancement could occur for both $J/\psi$ and $\eta_c$. The curiosity then is that, as the $3g$ states decay, they seem to “remember” the spin configuration, i.e. as the octet $2g$ state converts to a $q\bar{q}$ pair, it exchanges color and flavor with the other gluon via some octet $q\bar{q}$ system. Crude as it sounds, it may not be completely crazy.

With $m_O > 2.8$ GeV, the $O \rightarrow \rho \pi$ width is no longer huge. In a host of VP and VT decay modes, $\rho \pi$, $\omega f_2$ etc. are the easiest to identify.

We wish to make a final remark on another anomaly coming from LEAR. One normally expects $R_X \equiv \sigma(pp \rightarrow \phi + X)/\sigma(pp \rightarrow \omega + X)$ to be OZI suppressed, which is largely the case except for $R_{\pi}$, $R_{\gamma} \approx 0.1$, 0.24. The former process occurs via a $3S_1$ state, while the latter is from a $1S_0$ state. In these rather controlled processes, $O$ dominance ($O$-\phi and $O$-\omega mixing) would imply the simple ratio $R_X \approx 1/2$. The likely presence of more channels for $\omega + X$ would drive this number down, in accord with observation.

References

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