SPECTROSCOPY AND A $\phi$– FACTORY

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Abstract

A $\phi$– factory can provide information about $0^+$ and $0^-$ hadrons which may help our search for gluonic hadrons
The main reason for being interested in mesons today is the search for states "beyond $Q\bar{Q}$". The naive quark model assigns known states to $Q\bar{Q}$ with remarkable success nearly 30 years after the model's conception. Yet the discovery of QCD seemingly implies that states additional to $Q\bar{Q}$ should exist.

The notion of colour itself leads to notions of $QQ\bar{Q}\bar{Q}$ and, as Jaffe has stressed\(^{(1)}\), the lightest states should be $J^{PC} = 0^{++}$. He proposed that the $a_0, f_0$ (which used to be known as $\delta, S^*$) around 980 MeV mass, might be such states. These states can be accessed in $\phi \rightarrow \gamma S(S = 0^{++})$ and one must ask whether a $\phi$ factory can teach us about their constitution. These states are of particular interest because there are conjectures\(^{(2)}\) that they may be $KK$ "molecules" - analogues in the meson world of the baryonic deuteron. On the basis of masses alone one is unlikely to be able to decide among these assignments: $\phi \rightarrow \gamma S$ can help probe the dynamics more cleanly as the $\gamma$ couples to the constituents even at low energies (e.g. magnetic moments of $p$ and $n$ reveal the quark substructure as do the ratios of leptonic widths of $\rho, \omega, \phi$).

QCD implies that glueballs and hybrids may exist. The lightest glueballs are widely predicted to be $0^{++}$ and to help identify this state (expected in the 1 to 2 GeV mass range) it is imperative to understand the known scalars as well as possible. The better we know the present $0^{++}$ states, the more likely it will be that additional "strangers" will be identified.

What do we know so far from $\phi \rightarrow \gamma S$? Very little. The B.R. ($\phi \rightarrow \gamma f_0$) $< 2 \times 10^{-3}$ and that for $\gamma a_0$ is unknown. Even the ratio would be interesting as it measures the ratio of $s\bar{s}$ (or $KK$) content in these states. Thus if $f_0, a_0$ are degenerate $u\bar{u} \pm d\bar{d}$ one expects neither to be produced from $\phi(s\bar{s})$. No one really believes this $q\bar{q}$ assignment because of the strong affinity for $KK$ coupling. Thus if $f_0 = s\bar{s}, a_0 = u\bar{u} - d\bar{d}$ one expects $(\phi \rightarrow \gamma f_0/\gamma a_0) = \infty$. If they are $KK$ molecules one anticipates equality (if $K^+K^-$ is the relevant component that photocouples).

$$f_0(a_0) = \frac{1}{\sqrt{2}} (K^+K^- \pm K^0\bar{K}^0)$$

For a tightly bound $s\bar{s}(u\bar{u} \pm d\bar{d})$ there are two mechanisms

(i) $\phi(s\bar{s}) \rightarrow \gamma(s\bar{s}) \otimes (\text{vac} \rightarrow u\bar{u} + d\bar{d})$.
This produces the $f_0$ but not the $a_0$

(ii) $\phi(K^+K^-) \rightarrow \gamma(K^+K^-) \rightarrow \gamma(f_0, a_0)$.
This produces $f_0, a_0$ equally as in the molecule picture. There may be interesting $I-$spin violation and mixing effects.

The $\phi \rightarrow \gamma(K\bar{K})$ is, in any event, important to measure because it will be a background to CP violating studies of $\phi \rightarrow K\bar{K}$. The study of $\phi \rightarrow \gamma K\bar{K}, \gamma\pi\pi, \gamma\eta\pi$ through the continuum will provide input to phase shift analyses and combined with studies of $\psi \rightarrow \omega\pi\pi, \phi\pi\pi$ etc help to resolve the dynamics of low energy $\pi\pi, \eta\pi, KK$ systems. These questions are discussed elsewhere in these proceedings by Pennington
and Achasov in particular.

The absolute rate for $\phi \rightarrow \gamma f_0, \gamma a_0$ may also be interesting if these states are $KK$ molecules. The $\phi \rightarrow \gamma S$ transition is E1, whose matrix element is proportional to the charge of the constituents and their mean separation. Contrast the tightly bound, $s\bar{s}$ fractional charges with the loose molecule (1-2 fm?) with integer charges for $K^+K^-$. The E1 transition to a molecule could have substantial strength. Isgur and I, in an incomplete and unpublished calculation\(^3\), speculated that the branching ratio to a molecule could be $0(10^{-3})$ which is tantalisingly just below the present limit for $\phi \rightarrow \gamma f_0$. This result is similar to that based on Thomas-Reich-Kuhn sum rule in the first paper in ref 6. More realistic calculations are now needed, including the effects of $KK$ binding, to make serious estimates for the $\phi \rightarrow \gamma S$ branching ratio and tests therewith from the $S$ dynamical origin. Studies of $\phi \rightarrow \gamma S$ have been discussed here by Achasov and in ref 5, together with more recent studies by Nussinov and Truong\(^6\). This latter pair of papers are confusing: in the same volume of the journal two nearly identical papers conclude that the branching ratio for $\phi \rightarrow \gamma K^0\bar{K}^0$ is of order $10^{-5}$ to $10^{-6}$ (first paper), or $10^{-7}$ (second paper). Achasov (ref 5) obtains $10^{-8}$ Lucio and Pestieau (ref 7) criticise ref (6) and conclude that the branching ratio for an on-shell $\phi \rightarrow f_0\gamma$ is $2 \times 10^{-4}$ (consistent with ref 3) but when $f_0$ is off-shell to produce $\phi \rightarrow K^0\bar{K}^0\gamma$ they find a branching ratio

$$\frac{\Gamma(\phi \rightarrow K^0\bar{K}^0\gamma)}{\Gamma(\phi \rightarrow K^0\bar{K}^0)} = 4 \times 10^{-6}$$

However there is also $\phi \rightarrow a_0\gamma$ to be considered which will interfere with the $f_0$ and could change this estimate significantly. The informal discussions at this meeting show that these calculations and their impact on $S, \delta$ dynamics are still controversial; this area will require more study by theorists in the period leading to $\phi$ factory experiments. It is clearly an area ripe for exploration.

In the glueball hunters' almanac, the $J^P = 0^-$ glueball is predicted to be rather low-lying, though this is less certain than the case of $J^P = 0^+$. The $J^P = 0^-$ channel is interesting because there are clear candidates in the region immediately above 1 GeV [$\eta(1285)$, the iota $\eta(1440)$ which now appears to consist of two states] whose constitution is uncertain.

Although these states will not be directly accessed at a $\phi$ factory, their masses are near enough to the $\eta'(960)$ that it raises the possibility that $\eta(960)$ is not a pure $1S(q\bar{q})$ state but involves mixtures of $2S(q\bar{q})$ and/or gluonic components. This may be investigated by studying $\phi \rightarrow \gamma \eta', \phi \rightarrow \gamma \eta$, which probe the $s\bar{s}$ content of the $\eta-$states; when combined with good data on $\eta' \rightarrow \rho \gamma, \eta' \rightarrow \omega \gamma$ [which probe the $u\bar{u}, d\bar{d}$ content] one can determine whether the $\eta - \eta'$ system is orthonormal in the $1S$ sector or requires further components.
To quantify this write

\[ |\eta> = X_\eta |N> + Y_\eta |S> + Z_\eta |G> \]
\[ |\eta'> = X_{\eta'} |N> + Y_{\eta'} |S> + Z_{\eta'} |G> \]

where the basis states are

\[ |N> = \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}> , |s> + |s\bar{s}> , |G> = |\text{gluonium} > \]

with normalisation \(X^2 + Y^2 + Z^2 = 1\), for the \(\eta\) and \(\eta'\). If \(Z_\eta = Z_{\eta'} = 0\) the \(X\)'s and \(Y\)'s are directly related to the traditional pseudoscalar mixing angle.

Baltrusaitis et al (4) have computed these \(X, Y\) from studies of \(\psi \rightarrow VP\); the idea being that the ideal vector \((V)\) mesons provide flavour filters whereby the flavour content of the pseudoscalars \((P)\) may be weighed. The results of their original global fit to \(\psi \rightarrow VP\) and the \(V \rightarrow P\gamma\) yielded

\[ |X_\eta| = 0.63 \pm 0.06, \quad |Y_\eta| = 0.83 \pm 0.13; \quad X_\eta^2 + Y_\eta^2 = 1.1 \pm 0.2 \]
\[ |X_{\eta'}| = 0.36 \pm 0.05, \quad |Y_{\eta'}| = 0.72 \pm 0.12; \quad X_{\eta'}^2 + Y_{\eta'}^2 = 0.65 \pm 0.18 \]

The results for the \(\eta\) are consistent with the traditional \(10^9\) mixing angle and with the "equal weighting" of \(N\) and \(S\) content. Furthermore, there need be no extra component \(Z, \neq 0\). For the \(\eta'\), however, there may be a more provocative situation; there is a 2\(\sigma\) effect whereby \(Z_{\eta'} \neq 0\). The \(Y_{\eta'}\), within large errors, is consistent with the \(10^9\) mixing and flavour equality, however the \(X_{\eta'}\) seems to be quenched significantly.

Moreover the \(X_{\eta'}\) extracted from \(\psi \rightarrow VP\) seems to disagree with that from \(V \rightarrow P\gamma\) and \(P \rightarrow \gamma\gamma\). It is worth realising that these latter conclusions all depend upon a single number, namely \(\Gamma(\eta' \rightarrow \gamma\gamma)\) and if this were to change by 30\% the results would agree. Hence a copious study of \(\phi \rightarrow \eta'\gamma\) [on which there is no information to date] will provide a direct measure of \(Y_{\eta'}\) with which one can supplement the above analysis. With good statistics one may also accumulate data on \(\eta' \rightarrow \rho\gamma, \omega\gamma\) and even \(\gamma\gamma\) in order to clarify the existing analysis and reduce the errors on the \(\eta'\) mixing angles. Detailed study may then show whether or not the \(\eta'\) is indeed more than simply \(N\) and \(S\) \(q\bar{q}\) states.

One might contemplate \(e^+e^-\) interactions at slightly higher energies so that \(\rho'\) states \((1250?, 1650?)\) are produced. The decays of \(\rho' \rightarrow \gamma + \eta(1285), \eta(1400)\) as well as to \(\eta(960)\) and \(\eta(550)\) may help to explore the \(1S - 2S\) \(q\bar{q}\) mixing in more detail and help to identify the nature of the pseudoscalars above 1 GeV. However that is for a more distant future. What I hope this talk shows is that a \(\phi\) factory, whose primary motivation is CP physics, can provide a probe of scalar and pseudoscalar dynamics that bears on frontline issues in hadron spectroscopy and help in the eventual disentangling of the rôle of gluons in spectroscopy.
References


[3] F. Close and N. Isgur (unpublished);


