Unitarity Constraints on Radiative Υ Decays and
Possible Interpretations of $\zeta(8.32)$

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A B S T R A C T

If ζ is a scalar or pseudoscalar meson whose decay rate of less than 80 MeV is given by two gluon decays, the decay $\Upsilon \rightarrow \gamma + \zeta$ with its branching ratio of $\approx 5 \cdot 10^{-3}$ cannot be mediated by gluonic interaction between ζ and the Υ , if perturbative QCD is applicable to this reaction and if absorptive and dispersive parts are of comparable magnitude. Similar, though less stringent arguments apply for tensor mesons and no conflict arises for axial vector states. If ζ is a gluino ball and if $\tilde{b}$ is lighter than expected on theoretical grounds, the predicted rate is compatible with experiment. The experimental limit $\text{Br}(\Upsilon' \rightarrow \gamma + \zeta) / \text{Br}(\Upsilon \rightarrow \gamma + \zeta) < 0.22$ cannot be accommodated within this framework.

There is still no convincing theoretical interpretation for the narrow resonance $\zeta(8.32)$ which has been observed recently in radiative Υ decays [1] with a branching ratio of roughly $5 \cdot 10^{-3}$ and an upper limit on its width of 80 MeV. The comparison with earlier estimates for radiative decays through intermediate gluons into nonrelativistic S- and P-wave bound states of color triplet (like quarkonia [2,3]) or color octet fermions (like gluino balls [4,5,6]) shows that the theoretically expected rate ($\approx 1.2 \cdot 10^{-5}$ for triplet, $\approx 2.5 \cdot 10^{-4}$ for octet S-waves; the results for P-states are even smaller [3,4].) is significantly below the experimental observations.

However, there might be other resonances whose dynamics is quite different from that of nonrelativistic bound states and which might be produced through intermediate gluons in radiative Υ decays (Fig. 1a). Thus the more general question arises whether such a mechanism is able to explain the observed branching ratio, if the experimental limit on the width of ζ is taken into account, or whether a direct coupling of ζ to b quarks is required.

In the following I shall argue that ζ cannot be produced through intermediate gluons, if it is a scalar or pseudoscalar resonance, if perturbative QCD is applicable and if the width of ζ is given by its decay rate into two gluons. A similar though less stringent argument can be made for tensor mesons, whereas the axial vector assignment is still compatible with ζ production through intermediate gluons.

The rate for Υ decay into a photon plus a light pseudoscalar quarkonium has been calculated in the nonrelativistic approximation and is given by [2,3]

$$Br(\Upsilon \rightarrow \gamma + {}^1S_0(q\bar{q})) = \frac{\alpha_s^2}{9\pi^2\alpha} \frac{m(q\bar{q})}{M^2(\Upsilon)} X |\hat{H}^{PS}|^2 \Gamma({}^1S_0(q\bar{q}) \rightarrow gg) Br(\Upsilon \rightarrow e^+e^-)$$

$$X \equiv E_\gamma / M(\Upsilon)$$

$$\hat{H}^{PS} \equiv \frac{4}{X} \left[\mathcal{L}_2(1-2X) - \mathcal{L}_2(1) - \frac{X}{1-2X} \ln 2X - \frac{1-X}{2-X} \left[2\mathcal{L}_2(1-X) - 2\mathcal{L}_2(1) + \frac{1}{2} \ln^2(1-X) \right] \right]$$

$$+ i\pi 4 \frac{1-X}{(2-X)X} \ln(1-X)$$

This result is also applicable, if $(q\bar{q})$ is substituted by a gluino-gluino bound state $(\tilde{g}\tilde{g})$. The difference in the wave function and the color factor enters only in the evaluation of $\Gamma((\tilde{g}\tilde{g}) \rightarrow gg)$. For a pseudoscalar resonance PS of mass 8.32 GeV one finds numerically:

$$\text{Br}(\Upsilon \rightarrow \gamma + \text{PS}) = 0.88 \cdot 10^{-4} (1+r) \Gamma(\text{PS} \rightarrow \text{gg})/80\text{MeV}$$

r denotes the square of the ratio between the real and the imaginary part of $\hat{H}_{\text{PS}}$. In the model calculation and for $m_{\text{PS}}=8.32$ GeV r turns out to be around 0.2. The imaginary part is due to the contribution from gluons with $Q^2=0$ and is thus given directly by $\Gamma(\text{PS} \rightarrow \text{gg})$ independently of internal bound state dynamics. The contributions from off mass shell gluons depend on the unknown Q^2 variation of the pseudoscalar-gluon-gluon vertex function and determine the real part. Thus the result for $\text{Im } \hat{H}_{\text{PS}}$ holds true for any pseudoscalar if perturbative QCD is applicable. Since there is no selection rule to suppress either the absorptive or the dispersive part one expects them to be of comparable magnitude. On the other hand one would need $r>50$ to explain the observed rate, a ratio which looks rather implausible.

A similar argument can be made for a scalar resonance S . In this case one finds

$$\text{Br}(\Upsilon \rightarrow \gamma + S) = 0.86 \cdot 10^{-4} (1+r) \Gamma(S \rightarrow \text{gg})/80\text{MeV}$$

The nonrelativistic model calculation yields $r \approx 0.85$ and again it seems unlikely that r should be larger than ≈ 50 .

For a tensor resonance T two independent helicity amplitudes contribute to the decay rate and hence the relation between $\Gamma(\Upsilon \rightarrow \gamma + T)$ and $\Gamma(T \rightarrow \text{gg})$ is no longer unique. However, if we furthermore assume that the ratio between these amplitudes is the same as in the nonrelativistic case, we find

$$\text{Br}(\Upsilon \rightarrow \gamma + T) = 1.43 \cdot 10^{-4} (1+r) \Gamma(T \rightarrow \text{gg})/80\text{MeV}$$

Based on the nonrelativistic bound state approximation r was found to be ≈ 3.2 and again a value of r of more than 50 seems unlikely.

No such argument can be made for axial vector resonances A since these do not decay into two onshell gluons and the absorptive part of the amplitude for radiative Υ decay vanishes in leading order α_s . Moreover: if the Q^2 dependence of the axial vector coupling to offshell gluons is similar to the one suggested by nonrelativistic bound state calculations, our result

$$\text{Br}(\Upsilon \rightarrow \gamma + A) = 11.0 \cdot 10^{-4} \Gamma(A \rightarrow \text{gg})/80\text{MeV}$$

is not grossly incompatible with the experimental observations.

Another possibility to produce gluino balls in radiative Υ decays is through exchange of the supersymmetric partner of the b quark (fig. 1b). The branching ratio for this contribution [5] is suppressed by $m(\tilde{b})^{-4}$:

$$\begin{aligned} \text{Br}(\Upsilon \rightarrow \Upsilon' + (\tilde{g}\tilde{g})) &= \frac{64}{81} \frac{m(\xi)^2}{\alpha M(\Upsilon)^3} \Gamma(\xi \rightarrow gg) \left(\frac{m(b)}{m(\tilde{b})} \right)^4 \left(1 - \frac{m(\xi)^2}{M(\Upsilon)^2} \right) \\ &= 5 \cdot 10^{-3} (m(b)/m(\tilde{b}))^4 \Gamma(\xi \rightarrow gg) / 80 \text{ MeV} \end{aligned}$$

To explain the experimentally observed rate $m(\tilde{b}) \approx m(b)$ and $\Gamma((\tilde{g}\tilde{g}) \rightarrow gg) \approx 80 \text{ MeV}$ is required. Such a width is quite compatible with earlier estimates [4,5,6]. Although the $\tilde{b}$ and $\tilde{g}$ mass assignments would be contrary to current theoretical expectations^{*)} and are difficult to arrange within an attractive supersymmetric model, they cannot be ruled out as a logical possibility using present experimental information. If the scalar partners of u, d, s and c quarks are sufficiently heavy, light gluinos could be compatible with experiment [7]. Scalar quarks with charge $-1/3$ are only excluded in the mass range between 7.4 GeV and 16.0 GeV [8]. In the decay $\tilde{b} \rightarrow b + \gamma$ the release of missing energy would be reduced and the limits on $m(\tilde{b})$ would be even weaker. If this explanation were to hold true, one would expect to find a comparable branching ratio for $\Upsilon' \rightarrow \zeta + \gamma$ and in addition decays from Υ' to $2S$ and $1P$ ($J=0,1,2$) gluino balls with branching ratios typically smaller by a factor ≈ 10 . Although logically possible, we do not feel that this explanation of the ζ is worthy of strong advocacy.

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FIGURE CAPTIONS

Figure 1a: Production of ζ through intermediate gluons.

Figure 1b: Production of a gluino bound state through exchange
of a scalar b quark.

Fig. 1a

Fig. 1b