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QCD AND THE HELICITY STRUCTURE OF $\psi \to \gamma 2^{++}$ *

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Abstract

The helicity structure of $\psi \to \gamma f$ disagrees with a QCD model prediction by 4σ. An empirical rule that yields the data precisely is noted in the hope of elucidating the dynamics. The importance of $\psi \to \gamma\theta$ and $\Upsilon \to \gamma f$ helicity measurements is stressed.

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Perturbative QCD predicts the rate for $\psi \to \gamma+(gg \to \text{hadrons})$. When combined with the nonrelativistic charmonium model and the assumption that the gluons are on-shell, it has been used to predict[1] the relative importance of the various helicity amplitudes λ for $\psi \to \gamma(gg)_\lambda \to \gamma 2_\lambda^{++}$. Good data on $\psi \to \gamma f(1270)$ have been published recently which bear directly on this prediction. As seen below, there is a 4σ discrepancy between the QCD model of Ref. 1 and the data (see Fig. 2 of Ref. 2; Fig. 1 of this paper)

	QCD Model[1]	Data[2]	Data[3]
$x \equiv \lambda_1/\lambda_0$	0.76	0.88 ± 0.13	0.81 ± 0.16
$y \equiv \lambda_2/\lambda_0$	0.54	0.04 ± 0.19	0.02 ± 0.15

The most suggestive feature in the data is the possibility that $y \equiv 0$. One can impose a dynamical selection rule that yields this zero. This rule also implies that x is given by the ratio of two Clebsch-Gordan coefficients which turn out to have the value $\sqrt{3}/2$: identical with the datum. If subsequent data reduce the errors and converge on these Clebsch-Gordan coefficient values then we would conclude either that the essential dynamics are not those of the perturbative QCD model with on-shell gluons (Ref. 1) or that its application in this decay is presently incomplete.

To highlight the data and motivate our postulated mechanism, contrast the table above with $\psi' \to \gamma_{soft}+(gg \to \text{hadrons})$ where the hadronic system has the mass of $\chi(2^{++};3550)$. In this case the data are consistent with E1 dominance ($x = \sqrt{3}$; $y = \sqrt{6}$): the transition is from a $^3S_1(c\bar{c};\psi')$ to $^3P_2(\chi)$ and is dominated by flip of the quarks' z-component of orbital angular momentum

$$\psi'(^3S_1;\ L_z=0) \rightarrow \gamma_{soft} + \chi(^3P_2;\ L_z=1) \quad .$$

The helicity amplitudes, λ, for the χ are then related by[4] the orbital and spin coupling of the $c\bar{c}$ to $J = 2$ in the $^3P_2\chi$, hence controlled by the Clebsch-Gordan coefficients $\langle 2\lambda | LL_z;SS_z\rangle$

$$\lambda_2:\lambda_1:\lambda_0 = \langle 22|11;11\rangle : \langle 21|11;10\rangle : \langle 20|11;1-1\rangle$$

$$= \sqrt{6} : \sqrt{3} : 1$$

This well known and successful result was also obtained in the QCD model of Ref. 1 in the soft photon limit.

As the photon energy increases a complicated energy dependence ensues for the helicity amplitudes in Ref. 1 which do not appear to be realized in the data. I know of no published mechanism that would yield the observed x and y values (see Fig. 1).

However there is a dynamical effect that directly yields the data if we are prepared to modify the assumptions of Ref. 1. To see this we first contrast the above soft-photon limit with the extreme $E_\gamma \rightarrow \infty$ ($m_{2^{++}}/m_{1^{--}} \rightarrow 0$). Whereas for γ_{soft} the $Q\bar{Q}$ were produced only with $L_z = 1$, for γ_{hard} the Brodsky-Lepage QCD analyses[5] of exclusive processes imply that the $q\bar{q}$ are produced dominantly with $L_z = 0$: corrections to $L_z = 0$ are suppressed by a factor $(\langle k_\perp\rangle \simeq 300\text{ MeV})/M_c \lesssim 20\%$. If the transition occurs by the intermediary of a quasi-real gg state then $L_z^{gg} = 0$ also. The only way that both of these can be accomodated is if helicity zero is the only non-vanishing amplitude. This result is also found by Krammer's explicit calculations[1] in this limit.

The weak link in this analysis may be the assumption of a quasi-real gluon intermediate state.[6] If we merely insist on the $L_z^{q\bar{q}} = 0$ constraint, then the λ_2 amplitude will still be zero but λ_0 and λ_1 are now both allowed. If we suppose that the remaining dynamics is independent of helicity then we can apply the Wigner-Eckart theorem and the amplitudes will be related by the Clebsch-Gordan coefficients $\langle 2\lambda_i | LL_z; SS_z \rangle$

$$\lambda_2 : \lambda_1 : \lambda_0 \;=\; 0 : \langle 21|10;11\rangle : \langle 20|10;10\rangle$$

$$= 0 : 1/\sqrt{2} : \sqrt{2/3}$$

and so

$$x \equiv \lambda_1/\lambda_0 = \sqrt{3}/2 \equiv 0.87$$

in precise agreement with the data.

The challenge to theory is to justify the assumption that the Wigner-Eckart theorem can be applied in this way. If for example the f(1270) contains an intrinsic $c\bar{c}$ component in its Fock space wave function then $\psi \to \gamma f$ will proceed dominantly through the direct transition ${}^3S_1(c\bar{c}) \to \gamma + {}^3P_2(c\bar{c})$. In this case the Wigner-Eckart theorem would apply but the QCD analysis would only yield $L_z = 0$ dominance if the $c\bar{c}$, when off-shell in f(1270), acted as if they were light $q\bar{q}$.

We have highlighted this empirical rule in the hope that it may inspire further theoretical, and experimental, study of this process. It is important to clarify this further in view of the fact that $\psi \to \gamma\theta$ seems to have a similar helicity structure[2,3] to $\psi \to \gamma f$. (λ_1/λ_0 appears identical; it is possible that there is some λ_2 present in addition.) If the θ is a $2^{++}(q\bar{q})$ state then the above arguments should apply equally to it as to f(1270). If it has a $q\bar{q}q\bar{q}$ or gg component, then its helicity structure could be quite different; in particular there is no reason to suppress λ_2. Further light on the $c\bar{c}$ admixture possibility may be shed if $\Upsilon \to \gamma f(1270)$ or $\gamma\theta$ can be studied. These transitions have $m_{2^{++}}/m_{1^{--}}$ small enough that Refs. 1 and 5 would predict helicity zero dominance. If a self consistent mechanism can be found to underwrite our observation, then it should be used to make a prediction for $\Upsilon \to \gamma f$ to see if it predicts λ_0 dominance or identical behavior to the $\psi \to \gamma f$ data. The $\psi \to \gamma f'$ data should also be studied in this connection.

Other consequences of $L_z = 0$ dominance in hard γ emissions are less amenable to experiment but are not necessarily beyond possible test. Axial meson production is suppressed but should not be entirely absent: $L_z = 0$ dominance has the interesting consequence that this is entirely λ_1 and hence the photon angular distribution relative to the e^+e^- axis will be $\sin^2\theta$. Finally the scalar partner of the tensor should be produced with the relative rate

$$\frac{B(\psi \to \gamma 0^+)}{B(\psi \to \gamma 2^+)} = \frac{2}{7} \quad (L_z = 0) \quad ;$$

though this carries the implicit assumption that the coupling of glue to the 0^+ and 2^+ hadrons is of the same strength. Exotic transitions such as $\Upsilon \to \gamma\chi$ and $T \to \gamma\chi$, for $\chi = 0^+, 2^+$, will also be interesting in this connection.

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REFERENCES

1. M. Krammer, Phys. Lett. 74B, 361 (1978).
2. C. Edwards *et al*., SLAC-PUB-2847 (1982).
3. D. Scharre, Proc. 1981 International Symposium on Lepton and Photon Interactions at High Energies, Bonn (1981).
4. F. J. Gilman and I. Karliner, Phys. Rev. D 10, 2194 (1974); F. E. Close, "Introduction to Quarks and Partons" (Academic Press, 1979), p. 370.
5. S. J. Brodsky and P. Lepage, Phys. Rev. D 4, 2848 (1981).
6. In "bagged-QCD" instantaneous color-Coulomb interactions may play an important role in such transitions. See A. Maciel and S. Monaghan, "On the $(q\bar{q})$-Glueball mixing and the η and η' masses," Oxford University Report 25/82 (1982).

FIGURE CAPTION

Fig. 1. Data point from Ref. 2 is denoted ✦. Other points are various theoretical predictions (see Ref. 2) and numbers next to the curves represent units of standard deviations. The $L_z = 0$ model of text gives the result denoted o labeled L. E1 (not shown) is 12 standard deviations from the datum.

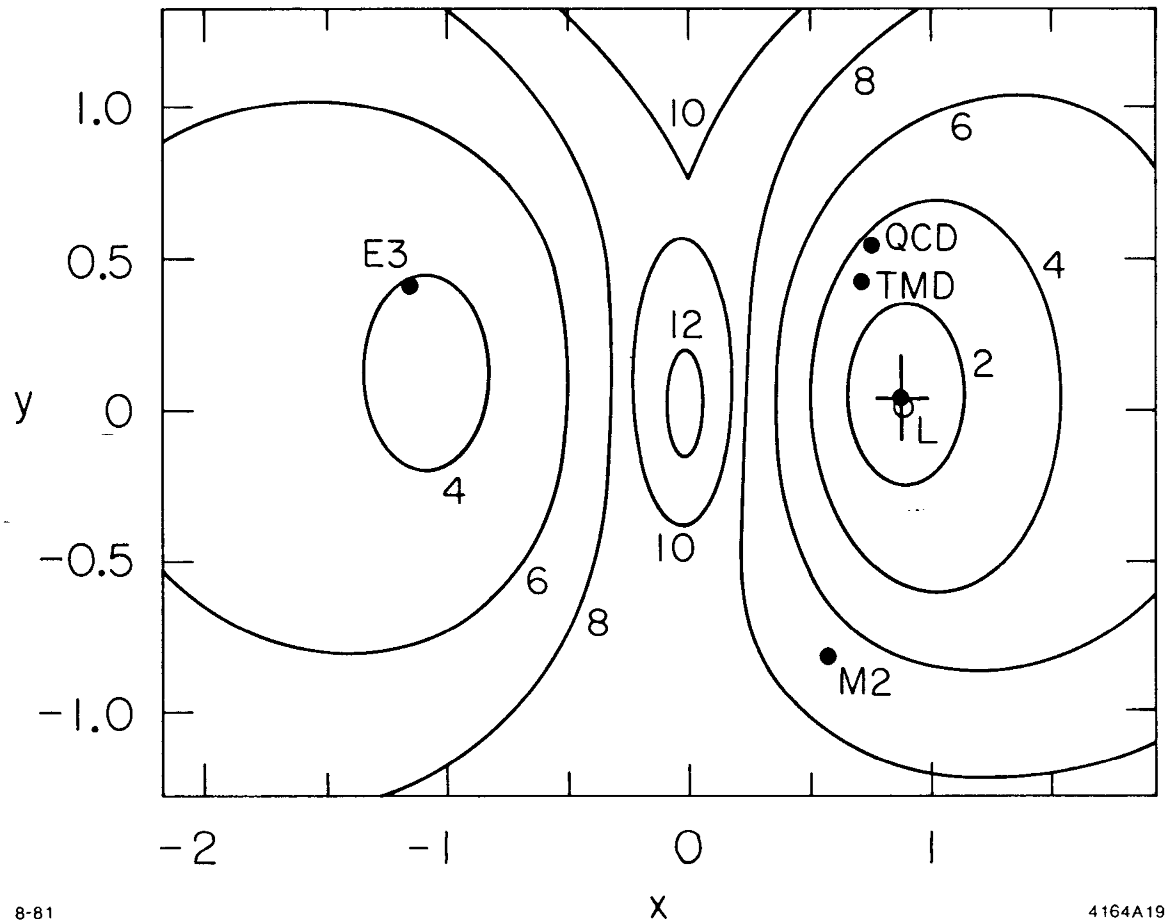

Fig. 1