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PHYSICS LETTERS B

Physics Letters B 621 (2005) 269–275

www.elsevier.com/locate/physletb

Tensor glueball photoproduction and decay

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Received 28 May 2005; accepted 20 June 2005

Available online 1 July 2005

Editor: H. Georgi

Abstract

Using vector meson dominance (VMD), tensor glueball photoproduction cross sections, asymmetries and widths are calculated. The predicted hadronic VV' decays are comparable for different vector meson ($V = \rho, \omega$ and ϕ) channels with the $\omega\phi$ width the largest but the radiative $\omega\gamma$ and $\phi\gamma$ decays are suppressed relative to $\rho\gamma$ by over a factor of 2. This decay profile is distinct from typical meson branching rates and may be a useful glueball detection signature. Results are compared to a previous VMD scalar glueball study.

PACS: 12.39.Mk; 12.40.Nn; 12.40.Vv; 25.20.Lj

Keywords: Glueball widths; Glueball photoproduction; Vector and tensor meson dominance

Documenting hadron states with predominantly gluonic degrees of freedom, i.e., glueballs, has been a challenging and somewhat elusive pursuit. Even though such states are consistent with quantum chromodynamics (QCD) and predicted by both lattice simulations [1–4] and gluonic models [5,6], clear experimental evidence is lacking. The purpose of this Letter is to motivate additional experimental investigations by providing estimates, based upon VMD, of tensor glueball photoproduction observables and also to detail a possible decay signature for hadronic states with a significant gluonic component. The latter entails comparable VV' hadronic widths, with the largest branch to $\omega\phi$ that promptly goes to $3\pi K\bar{K}$, and somewhat suppressed $\omega\gamma$ and $\phi\gamma$ radiative decays relative to $\rho\gamma$. As discussed below, this decay signature is not expected for hadrons with a predominantly quark structure. These results are essentially model-independent since they follow directly from the general principles of VMD, which has been found to agree with more fundamental QCD based meson ra-

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0370-2693/$ – see front matter
doi:10.1016/j.physletb.2005.06.069

diative calculations [7], and the flavor independence of quark-gluonic couplings.

Consider the radiative decay $f_2 \to V(k')\gamma(k)$ of a neutral tensor hadron with arbitrary quark, gluon structure and mass M_f. Here k, k' are the momenta of the photon and vector meson with mass M_V ($k'^2 = M_V^2$). The most general, gauge invariant $f_2 V\gamma$ vertex is [8,9]

$$\langle\gamma(k)V(k')|f_2\rangle = \epsilon^{\kappa}\epsilon'^{\lambda} f^{\mu\nu} A_{\kappa\lambda\mu\nu}(k,k'), \tag{1}$$

$$A_{\kappa\lambda\mu\nu}(k,k') = 4\frac{g_1}{M_f^4}B_{\kappa\lambda\mu\nu} + 2\frac{g_2}{M_f^2}C_{\kappa\lambda\mu\nu}, \tag{2}$$

$$B_{\kappa\lambda\mu\nu}(k,k') = (g_{\kappa\lambda}k\cdot k' - k'_{\kappa}k_{\lambda})k_{\mu}k_{\nu}, \tag{3}$$

$$\begin{aligned} C_{\kappa\lambda\mu\nu}(k,k') = {} & 2g_{\kappa\lambda}k_{\mu}k_{\nu} + g_{\lambda\mu}k'_{\kappa}k_{\nu} + g_{\lambda\nu}k'_{\kappa}k_{\mu} \\ & - g_{\kappa\mu}k_{\lambda}k_{\nu} - g_{\kappa\nu}k_{\lambda}k_{\mu} \\ & - k\cdot k'(g_{\kappa\mu}g_{\lambda\nu} + g_{\kappa\nu}g_{\lambda\mu}), \end{aligned} \tag{4}$$

where ϵ^{κ}, ϵ'^{λ} and $f^{\mu\nu}$ are the photon, vector meson and f_2 polarization vectors and tensor, respectively. Note that there are two possible coupling constants, g_1 and g_2, which in VMD (also tensor meson dominance) are given by [8]

$$g_1 = 0, \qquad g_2 = e g_{f_2 V\gamma} = e\sum_{V'} \frac{g_{f_2 VV'}}{f_{V'}}, \tag{5}$$

with $g_{f_2VV'}$ the f_2VV' hadronic coupling constant, $f_{V'}$ the V' leptonic decay constant and the sum is over all vector meson contributions consistent with isospin conservation for the f_2VV' vertex. The radiative decay widths are

$$\Gamma_{f_2\to V\gamma} = \frac{2}{5}\alpha_e g_{f_2V\gamma}^2 M_{f_2}(1-x)^3\left[1 + \frac{x}{2} + \frac{x^2}{6}\right], \tag{6}$$

and $\alpha_e = e^2/4\pi = 1/137.036$, $x = M_V^2/M_{f_2}^2$. Focusing upon isoscalar tensor hadrons ($I_{f_2} = 0$) yields the radiative couplings

$$g_{f_2\rho\gamma} = \frac{g_{f_2\rho\rho}}{f_\rho}, \qquad f_2 \to \rho\gamma, \tag{7}$$

$$g_{f_2\omega\gamma} = \frac{g_{f_2\omega\omega}}{f_\omega} + \frac{g_{f_2\omega\phi}}{f_\phi}, \qquad f_2 \to \omega\gamma, \tag{8}$$

$$g_{f_2\phi\gamma} = \frac{g_{f_2\phi\phi}}{f_\phi} + \frac{g_{f_2\phi\omega}}{f_\omega}, \qquad f_2 \to \phi\gamma. \tag{9}$$

Since the ρ and ω masses are almost equal ($M_{\rho^0} = 775.8$ MeV, $M_\omega = 782.59$ MeV), the ratio of the ω to ρ channel decays is simply

$$R_{\omega/\rho} = \frac{\Gamma_{f_2\to\omega\gamma}}{\Gamma_{f_2\to\rho\gamma}} = \left(\frac{g_{f_2\omega\gamma}}{g_{f_2\rho\gamma}}\right)^2. \tag{10}$$

Application to tensor glueballs, i.e., $f_2 \to G_2$, and assuming flavor independence for the glueball-vector meson couplings, $g_{G_2VV} = g_{G_2V'V''}$, yields

$$R_{\omega/\rho} = \left(\frac{f_\rho}{f_\omega}\right)^2\left(1 + \frac{f_\omega}{f_\phi}\right)^2. \tag{11}$$

Hence the ratio of decay widths is entirely governed by the leptonic decay constants whose magnitudes can be extracted from $V \to e^+e^-$ using

$$\Gamma_{V\to e^+e^-} = \frac{4\pi\alpha_e^2}{3}\frac{M_V}{f_V^2}. \tag{12}$$

The most recent measurements [10] yield $|f_\rho| = 4.965$, $|f_\omega| = 17.06$ and $|f_\phi| = 13.38$ for a relative reduction $R_{\omega/\rho} = 0.44$. The $\phi\gamma$ channel, which is also reduced by this factor, is further suppressed kinematically. As discussed below, suppression of radiative decays to isoscalar vector meson channels is not generally expected for tensor mesons since they will have different $g_{f_2VV'}$ couplings reflecting their various flavor contents. Note also that the relative phase between the ω and ϕ couplings has been assumed to be the same as between their respective decay constants. Depending upon phase convention (i.e., $\phi = \pm s\bar{s}$) the decay constants are often cited with opposite phases in the literature (e.g., the $SU(3)$ relation $f_\rho\sqrt{3} = -f_\omega\sin(\theta) = f_\phi\cos(\theta)$ [11] where $\theta \approx 40^\circ$ is the $\omega\phi$ mixing angle). Consistency requires the same relative sign between the couplings $g_{G_2\omega\omega}$ and $g_{G_2\omega\phi}$ since the latter, like the ϕ decay constant, is linear in the ϕ phase. Because f_ω and f_ϕ are comparable in magnitude, $R_{\omega/\rho}$ is very sensitive to this relative phase and would be dramatically lower, 0.0064, if indeed the net phase was negative. It is therefore important to more rigorously determine the relative phase of the vector meson coupling and decay constants and further study is recommended.

Similarly, the scalar glueball radiative decay widths are [12]

$$\Gamma_{G_0\to V\gamma} = \frac{1}{8}\alpha_e g_{G_0V\gamma}^2\frac{M_{G_0}^3}{M_0^2}(1-x)^3, \tag{13}$$