DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 75/21
July 1975

Heavy Vector Meson Dominance

by

T. F. Walsh

2 HAMBURG 52 · NOTKESTIEG 1

Heavy Vector Meson Dominance

by

T.F. Walsh

Deutsches Elektronen-Synchrotron DESY, Hamburg

Abstract

We suggest that current amplitudes involving known (light) hadrons are dominated solely by light vector mesons ρ, ω, ϕ, ρ', ... and that current amplitudes where one or more new heavy particles are present are dominated solely by new heavy vector mesons J/ψ, ψ', ... We discuss the consequences of this for radiative decays of the new heavy mesons and for photo and lepto-production of new particles.

Vector meson dominance (VMD) is a proven concept, relating processes with vector mesons to those with currents (1). It's natural to extend this to the recently discovered heavy mesons /1/. There has already been some work in this direction (3).

The main assumption is the approximate constancy of vector-meson-hadron amplitudes for $0 \leq Q^2 \leq M^2$ or, in dispersion theory language, the absence of significant continuum (non-pole) contributions in the current channel. Empirically, this works for the light vector mesons. The question is open so far as the new mesons are concerned. We will make the same smoothness or pole dominance assumption for the new heavy mesons. (i) This assumption is testable: it means that the total cross section $\sigma_{\psi N}$ from VMD and $\gamma N \to \psi N$ must agree with that extracted from coherent nuclear photoproduction independent of VMD. We will detail other tests. (ii) The small width of $J/\psi(3.1)$ and $\psi(3.7) = \psi'$ to light hadrons suggests that the ψ's have suppressed couplings to these light hadrons, but normal strong couplings to other new heavies (which must then be present in decays of the broad $\psi(4.1) = \psi''$). If this is so, then the typical hadronic scale for the new mesons is $\sim M_\psi^2$, not M_ρ^2, and there is no evident reason why VMD should be worse for the heavy mesons than for the light ones.

We expand on this. The relative contribution of J/ψ to a light hadron form factor at $Q^2 = 0$ is in order of magnitude $\sim [\Gamma(\psi \to h\bar{h}) / \hat{\Gamma}]^{1/2}$ where $\hat{\Gamma}$ is a normal hadronic width, $\hat{\Gamma} \sim .1 - .5$ GeV. This holds if the $\psi - \gamma$ coupling is "normal" - i.e. $f_\psi \sim f_\rho$ or f_ω, f_ϕ. The contribution to a deep inelastic amplitude involving only light hadrons is of order $\sim [\Gamma(\psi)/\hat{\Gamma}]^{1/2}$. Both numbers are small. We can also estimate the $\psi-\psi'$ contribution to the $\eta \to \gamma\gamma$ amplitude to be of relative order $\sim 10^{-3}$ from $\psi' \to \psi\eta$ (see our later discussion and ref. (4)).

The contribution of light vector mesons to radiative ψ decay will also turn out to be small. To summarize: the new heavy mesons do not contribute to the current amplitudes of light mesons and vice versa. Thus we split VMD into a light LVMD and a heavy HVMD.

Now we establish the last remark about radiative decays of ψ's. Using LVMD with the ρ^0 , the known branching ratio $B(\psi \to \rho\pi) = 1.3\%$[2] and $\Gamma(\psi) = 69 \pm 15$ keV we find $\Gamma(\psi \to \pi^0\gamma) = 1$ eV. If the $\psi \to 1\gamma \to \omega\pi^0$ rate is as small as in (model dependent) estimates [5], it can be ignored here. We go further and bound $\Gamma(\psi \to \pi^0\gamma)_{LVMD}$ by using the $\rho'(1600) \to \rho\epsilon \to 4\pi$ contribution, $B(\psi \to 4\pi^c 1\pi^0) \approx 4\%$, $f_\rho / f_{\rho'} \approx 1/2$ and by assuming complete coherence of ρ and ρ' . Namely,

$$\Gamma(\psi \to \pi^0\gamma)_{LVMD} \leq \Big[\Big| \frac{e}{f_\rho} \frac{1}{3} \Gamma(\psi \to \rho\pi) \Big|^{1/2} + \Big| \frac{e}{f_{\rho'}} \frac{3}{2} \Gamma(\psi \to 4\pi^c 1\pi^0) \Big|^{1/2} \Big]^2 \qquad (1)$$

$$\approx 7.4 \text{ eV}$$

The same can be done for $A_2^0\gamma$ using $\psi \to 3\pi\rho^0$ and for $\pi^+\pi^-\gamma$ using $\psi \to \pi^+\pi^-\omega$. The result is always $\Gamma(\psi \to \gamma + m)_{LVMD} \sim 10^0$ eV.

Quite independent of these estimates we can test the assumption that LVMD works for ψ decay. Assume that ψ is a pure SU_3 singlet and that the LVMD photon is an octet. Then (again we ignore $\psi \to 1\gamma \to m\gamma$):

$$\frac{\Gamma(\psi \to \pi^0\gamma)}{\Gamma(\psi \to \eta\gamma)} \approx 3 \frac{p_\pi^3}{p_\eta^3} \approx 3.3$$

$$\frac{\Gamma(\psi \to \eta'\gamma)}{\Gamma(\psi \to \eta\gamma)} = \frac{p_{\eta'}^3}{p_\eta^3} \tan^2(10^\circ) \approx .025 \tag{2}$$

Radiative widths >> 10 eV and substantial violations of (2) will indicate that the photon has a new SU_3 singlet piece (and perhaps more), and that this is dominated by new heavy mesons. As a possible extreme, suppose that the new piece of the photon is pure SU_3 singlet and that all ψ's are singlet. Then we predict

$$\frac{\Gamma(\psi \to \eta'\gamma)}{\Gamma(\psi \to \eta\gamma)} = \frac{p_{\eta'}^3}{p_\eta^3} \cot^2(10^\circ) \approx 26$$

$$\frac{\Gamma(\psi \to \pi^0\gamma)}{\Gamma(\psi \to \eta\gamma)} << 1 \tag{3}$$

If (3) were wrong it could be due to a strong pseudoscalar mass dependence in the matrix element, to the presence of I = 0 octet ψ's or (in the second case) to I = 1 ψ's . It may be that the ψ's are mixtures of

I = 0 octet and singlet; this can be checked from the $\eta'\gamma/\eta\gamma$ ratio.

Such arguments apply to $\psi \to \epsilon\gamma \to \pi\pi\gamma$; $\psi \to S^*\gamma \to K\bar{K}\gamma$ or $\pi\pi\gamma$; $\psi \to f\gamma$, $f'\gamma$, $A_2^0\gamma$. Little is known about $\epsilon - S^*$ mixing, but it can be studied independently via $\psi \to \epsilon$ or S^* $+\omega$ or ϕ.

These decays will allow one to establish or confirm the SU_3 properties of the ψ's and the new piece of the electromagnetic current.

Consider $\psi \to \pi^0\gamma$; if large, this decay would imply that at least one new heavy has I = 1 (call it $\bar{\psi}$, ψ and ψ' appear to have I = 0). We get [2]

$$\frac{\Gamma(\psi \to \pi^0\gamma)}{\Gamma(\bar{\psi} \to \psi\pi^0)} = \left(\frac{M_{\bar{\psi}}}{M_\psi}\right)^2 \left(\frac{k}{P_\psi}\right)^3 \left(\frac{e}{f_\psi}\right)^2 \qquad (4)$$

provided we ignore other new I = 1 heavies. Similarly for $\psi \to \pi^0_N\gamma$ and $\bar{\psi} \to \pi^0_N\psi$

Notice that decays like $\psi'' \to \pi^0\bar{\psi}$, $\eta\psi$, $\eta'\psi$ and $\psi\pi\pi$ plus $\psi K\bar{K}$ can be used to establish the isospin and SU_3 quantum numbers of this broad state, so long as the decays conserve isospin and (at least approximately) SU_3. This may be useful if ψ'' decays mainly to heavy pairs whose further decays violate I and SU_3.

Now we attempt to estimate the magnitude of these radiative decays for

I = 0 light mesons, $\psi(\psi') \to m\gamma$ /3/. Since ψ and ψ' are I = 0, such estimates are very model dependent. They involve (at least!) $\psi\psi m$, $\psi\psi' m$ and $\psi'\psi' m$ vertices. So we make a drastic assumption, and take the $\psi\psi' m$ vertices to be dominant. We can then predict

$$\frac{\Gamma(\psi' \to m\gamma)}{\Gamma(\psi \to m\gamma)} = \left(f_\psi / f_{\psi'} \right)^2 \tag{5}$$

modulo phase space corrections and mass dependences of the matrix element (see, eq. (4)). If (5) fails, then our following estimates must of necessity be poor, independent of whether HVMD is good or not. To go further would require a model. Let us stick to this assumption. Then we predict

$$\begin{aligned}\Gamma(\psi \to \eta\gamma) &= \left(\frac{M_{\psi'}}{M_\psi}\right)^2 \left(\frac{k}{p_\psi}\right)^3 \left(\frac{e}{f_{\psi'}}\right)^2 \Gamma(\psi' \to \psi\eta) \\ &= (0.16 \pm .02)\ \Gamma(\psi' \to \psi\eta)\end{aligned} \tag{6}$$

For $\Gamma(\psi' \to \psi\eta)$ = 10 keV, $\Gamma(\psi \to \eta\gamma)$ = 1.6 keV. In view of (3), this may be an overestimate /2/.

For $\psi \to \epsilon\gamma \to \pi\pi\gamma$ and $\psi' \to \psi\epsilon \to \psi\pi\pi$ we need a model, and choose a crude one. The $\psi\psi'\epsilon$ vertex is $G_{\psi'\psi\epsilon}\ \psi'_\mu \psi^\mu \epsilon$, m_ϵ = .7 GeV, Γ_ϵ = .45 GeV; for $\Gamma(\psi' \to \psi\pi^+\pi^-)$ = 100 keV we have $G^2_{\psi'\psi\epsilon}/4\pi$ = 1.8 x 10^{-2} GeV^2 and (summing only over transverse photon polarizations)

$$\Gamma(\psi \to \epsilon\gamma) = \frac{1}{3}\left(\frac{e}{f_{\psi'}}\right)^2 \frac{k_\gamma}{M_\psi^2}\,\frac{G^2_{\psi'\psi\epsilon}}{4\pi} \approx 0.22 \text{ keV} \tag{7}$$

This procedure is consistent with the usual assumption that amplitudes with transverse vector mesons extrapolate smoothly in Q^2.

We see that <u>HVMD leads to much larger radiative widths than LVMD does</u>. There is no evidence against this, and some for [2]. The decays $\psi \to \eta'\gamma$ and $\eta\gamma$ are relatively easy to detect because of the presence of a monoenergetic photon (and $\eta\gamma \to 3\gamma$); $\psi \to \pi^+\pi^-\gamma$, $\pi^0\pi^0\gamma$ and $K\bar{K}\gamma$ seem more difficult. Perhaps $\psi \to S^*\gamma$ can be seen using the relatively small S^* width or $S^* \to K^0_S K^0_S$. It will also be interesting to look for $\psi \to f\gamma, f'\gamma$ (and $A_2^0\gamma$), other narrow resonances (e.g. those with $J^{PC} = 1^{++}$), and perhaps multibody states like $\psi \to \pi^+\pi^-\pi^+\pi^-\gamma$. Some of these might be present at the $10^2 - 10^3$ eV level.

A search for $\psi'' \to \psi 4\pi$ and $\psi' \to \psi 4\pi$ may prove rewarding. Unfortunately the latter decay has a microscopic phase space. If present, these decays may be related to $\psi \to 4\pi\gamma$. The presence of many chain decays of I = 0 states would invalidate our estimates, which then must be considered only order of magnitude guesses. We have already remarked that to go further would require a detailed model of $\psi^j - \gamma$ couplings and $\psi^i\psi^j m$ -type vertices, and it is not our aim to construct such a model [4].

These VMD arguments can be applied to photo- and leptoproduction of heavy hadrons. For example, we conclude that dominance of the current channel by heavy mesons is only relevant when new particles are produced (with the possible exception of, e.g., $\gamma N \to \gamma X$ at large p_T). This can be checked. It leads us to predict that for $\gamma_v N \to \psi N$, $\sigma(Q^2) \approx \sigma(0)\,(1 + Q^2/m_\psi^2)^{-2}$. This has the striking consequence that the fraction of deep inelastic final states with a ψ increases with Q^2, roughly proportional to $(\sigma_v^{tot})^{-1} \propto 1 + Q^2/\bar{m}_v^2$ for $Q^2 << m_\psi^2$ [7], where from VMD we expect the mass scale $\bar{m}_v^2 \approx \frac{1}{2} m_\rho^2$ [1].

We can even estimate the total new particle photoproduction cross section σ', using VMD and unitarity. We obtain

$$\frac{\sigma'(0)}{\sigma(\gamma N \to \psi N)} \approx \frac{\sigma_{tot}^{\psi N}}{\sigma_{elastic}^{\psi N}} \approx \frac{16\pi B}{\sigma_{tot}^{\psi N}} \sim 10^2 \qquad (8)$$

for $\sigma_{tot}^{\psi N} \simeq 1\,\text{mb}$ and B = 4 GeV^{-2}. For $\sigma(\gamma N \to \psi N) \approx 15\,\text{nb}$ we expect $\approx 1.5\,\mu\text{b}$ of $\sigma_{tot}^{\gamma N}$ is due to new particle production (not just ψ) at FNAL energies. Extending this to leptoproduction, we note that the small elastic/total cross section ratio (characteristic of an extended, transparent ψ) means that most new particles are produced in inelastic (not diffractive) reactions.

The preceeding photoproduction estimate can be extended to include electroproduction. We expect the production of new particles to have the Q^2 dependence $\sigma'(Q^2) = \sigma'(0)\,(1 + Q^2/\bar{m}_\psi^2)^{-1}$, where we have taken over the Q^2 dependence from Generalized Vector

Dominance, with the mass scale $\bar{m}_\psi^2 \sim m_\psi^2$. We now put $\bar{m}_\psi^2/\bar{m}_V^2 \simeq m_\psi^2/m_\rho^2$ and estimate the increase in νW_2 due to production of new particles to be

$$\frac{\delta(\nu W_2)}{\nu W_2} \simeq \frac{\sigma'(0)}{\sigma_{tot}^{\gamma N}(0)} \cdot \frac{m_\psi^2}{m_\rho^2} \simeq 25\%$$

This estimate holds at large values of $\omega' = 1 + W^2/Q^2$. The behavior elsewhere in the $\nu - Q^2$ plane is model dependent. For example, if the photon excited new heavy s-channel baryon resonances, our arguments imply transition form factors decreasing slowly with Q^2. If we can apply this even at some fixed W^2 where no narrow resonances are evident, it would imply that νW_2 rises at fixed W^2 (i.e. for all ω') to some new value at large Q^2. But this option, if married to familiar duality arguments implies that $\gamma N \to \psi N$ resembles $\gamma N \to \rho^0 N$ and approaches its asymptotic limit from above. The data (2) seem to imply an approach from below, as for $\gamma N \to \phi N$ where no s-channel resonances are excited. The dependence of the new particle threshold is probably given by curves of constant t_{min} and u_{min}. Asymptotically, these are tangent to lines of constant (large) ω', and νW_2 rises above the new particle threshold, but only for large ω'.

Arguments of the sort we have presented here can be extended further, but our aim was only to illustrate how one can draw largely model-independent conclusions about the new particles (including those not yet found), based on known concepts and the assumption that all the heavy particles are genuinely new hadrons unrelated to known light hadrons except by some very much suppressed strong interaction mixing. The final decision whether all this is useful or not will rest with experiment.

Acknowledgements

I want to thank R. Devenish, M. Krammer and B. Wiik for comments.

Footnotes

/1/ See reference (2) for an account of the experimental situation.

/2/ For $\bar{\psi} \to \psi \pi^{0}$ the matrix element is proportional to $\epsilon_{\mu\nu\lambda\sigma} e^{\mu}(\bar{\psi}) P^{\lambda}_{\bar{\psi}}\, p^{\sigma}_{\psi}$. It may be that VMD is poor for such P-wave processes when the CM momentum becomes large. This could be due to barrier penetration or form factor effects. The simplest "improvement" is to replace $p^{3} \to p^{3}(1 + R^{2}p^{2})^{-1}$ where R is a hadronic radius. For $\psi \to \eta \gamma$ this gives a reduction factor .22 for $R = m_{\rho}^{-1}$ and .81 for $R = m_{\psi}^{-1}$.

/3/ Such estimates have been made independently by many people (ref. (6)).

/4/ One type of relation not treated in the text: for a $J^{PC} = 0^{-+}$ heavy χ we can relate $\psi' \to \chi \gamma$ to $\chi \to \gamma\gamma$ <u>if</u> we assume that only the $\psi' \chi \gamma$ vertex is nonzero. We have

$$\frac{\Gamma(\psi' \to \chi \gamma)}{\Gamma(\chi \to \gamma\gamma)} = \frac{2}{3} \left(\frac{p_{\chi}}{p_{\gamma}} \right)^{3} \left(\frac{f_{\psi'}}{e} \right)^{2}$$

References

(1) D. Schildknecht, DESY preprint 74/50 and XVII Conference on High Energy Physics, London 1974, p. IV-80

(2) La Physique du Neutrino à Haute Energie (Ecole Polytechnique, 18-20 Mars 1975) Editions du Centre Nationale de la Recherche Scientifique, 1975; Ed. A. Rousset et P. Petian

(3) D. Schildknecht and F. Steiner, Phys. Lett. 56B, 36, (1975)

(4) M. Krammer, D. Schildknecht and F. Steiner, DESY preprint 74/64

(5) M. Krammer, DESY internal note, Feb. 1975 (unpublished)

(6) G. Feinberg, Columbia preprint CO-2271-54,
R. Aviv, Y. Goren, D. Horn and S. Nussinov, Tel Aviv preprint TAUP-471-75,
Wu-yang Tsai, L. De Raad, Jr. and K.A. Milton, UCLA preprint TEP/9 (May 1975),
D. Geffen, private communication,
T.F. Walsh, DESY internal notes (Feb. and May 1975, unpublished)

(7) S. Kitakado, S. Orito and T.F. Walsh, Phys. Lett. B56, 88 (1975)