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C. A. Dominguez and M. Greco: CHARM, EVDM AND NARROW
RESONANCES IN e^+e^- ANNIHILATION.

Charm, EVDM and Narrow Resonances in e^+e^- Annihilation.

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Recent experiments at BNL ⁽¹⁾, SLAC ⁽²⁾ and Frascati ⁽³⁾ have shown the existence of very narrow resonances (ψ) which couple to $\mu^+\mu^-$, e^+e^- and hadrons. So far two such states have been detected with masses of 3.1 GeV and 3.7 GeV. The partial and total widths of the first resonance $\psi(3105)$ are approximately the following:

$$(1) \quad \begin{cases} \Gamma_{\psi}^{\mu\bar{\mu}} \sim \Gamma[(\psi, \rho, \omega) \rightarrow e^+e^-], \\ \Gamma_{\psi}^{\text{had}} \sim 20\Gamma^{\mu\bar{\mu}}. \end{cases}$$

⁽¹⁾ J. J. AUBERT, U. BECKER, P. J. BIGGS, J. BURGER, M. COHEN, G. EVERHART, P. GOLDHAGEN, J. LEONG, T. MCCORRISTON, T. G. RHOADES, M. RHODE, S. C. C. TING, S. L. WU and Y. Y. LEE: *Phys. Rev. Lett.*, **33**, 1404 (1974).

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⁽³⁾ C. BACCI, R. BALDINI CELIO, M. BERNARDINI, G. CAPON, R. DEL FABBRO, M. GRILLI, E. IAROCCHI, L. JONES, M. LOCCI, C. MENCUCCHINI, G. P. MURTAS, G. PENSO, G. SALVINI, M. SPANO, M. SPINETTI, B. STELLA, V. VALENTE, B. BARTOLI, D. BISELLO, B. ESPOSITO, F. FELICETTI, P. MONACELLI, M. NIGRO, L. PAOLUZI, I. PERUZZI, G. PIANO MORTARI, M. PICCOLO, F. RONGA, F. SEBASTIANI, L. TRASATTI, F. VANOLI, G. BARBARINO, G. BARBIELLINI, C. BEMPORAD, R. BIANCASTELLI, M. CALVETTI, M. CASTELLANO, F. CEVENINI, F. COSTANTINI, P. LARICCIA, S. PATRICELLI, P. PARASCANDALO, E. SASSI, C. SPENCER, L. TORTORA, U. TROTA and S. VITALE: *Phys. Rev. Lett.*, **33**, 1408 (1974).

It has been shown⁽⁴⁾ that the previous data on $e^+e^- \rightarrow \text{hadrons}$ ⁽⁵⁾ are consistent with a two-component model. The first component giving rise to scaling, in agreement with EVMD predictions both for R ⁽⁶⁾ ($R \approx 2.5$) and for single inclusive distributions⁽⁷⁾. The second component being responsible for the observed rising of R and for the break-down of scaling in single inclusive distributions at low x .

However, in view of the new experimental results it seems possible that the first two narrow resonances discovered so far can account (after inclusion of radiative tails) for the difference between experimental cross-sections (SPEAR I) and a constant R ⁽⁸⁾. Adding the possibility that there might be more ψ -states, so far undetected, one would have a way of explaining the rise of R . Combining this with the magnitudes of the widths, eq. (1), one is naturally led to think of the new narrow resonances as charm-anticharm vector mesons⁽⁹⁾. The properties of such states have been discussed by CARLSON and FREUND⁽¹⁰⁾ who have suggested that they should be searched for in photoproduction and hadron formation experiments. A charm-anticharm vector meson is expected to decay into lepton pairs with a rate comparable to that of the normal vector mesons. However, due to the absence of low-mass charmed hadrons, the decay into normal hadrons would proceed via weak interactions. This leads therefore to very narrow widths in agreement with what has been observed so far for the ψ -states.

In this letter we shall make the following two assumptions:

i) in analogy with the normal vector mesons, the masses of the new narrow resonances obey a Veneziano-like spectrum, *i.e.*

$$(2) \quad m_n^2 = m_0^2(1 + bn);$$

ii) scaling will be reached at sufficiently high energies.

We shall then work out the consequences of these assumptions in complete analogy with standard EVDM, which so far has given predictions in very good agreement with experiment both in the space and timelike regions^(4,6).

The total cross-section can then be written as

$$(3) \quad \sigma_{\text{had}} \equiv \sigma(e^+e^- \rightarrow \psi_n \rightarrow \text{hadrons}) = 12\pi \sum_n \frac{\Gamma_n^{\text{ll}} \Gamma_n}{(s - m_n^2)^2 + m_n^2 \Gamma_n^2},$$

where

$$(4) \quad \Gamma_n^{\text{ll}} = \frac{m_n g_n^2}{12\pi}$$

and $g_n^2/4\pi$ are the coupling constants of the ψ_n -states to lepton pairs. It is worth mentioning that the data on the $\psi(3105)$ gives $g \simeq 0.6 \cdot 10^{-2} \simeq \alpha$. Equation (3) can be

⁽⁴⁾ M. GRECO: Lectures given at the *International School of Subnuclear Physics, Erice, 1974*.

⁽⁵⁾ B. RICHTER: Rapporteur's talk, *XVII International Conference on High-Energy Physics (London, 1974)*.

⁽⁶⁾ A. BRAMON, E. ETIM and M. GRECO: *Phys. Lett.*, **41** B, 609 (1972); M. GRECO: *Nucl. Phys.*, **63** B, 398 (1973).

⁽⁷⁾ M. GRECO and Y. N. SRIVASTAVA: Frascati preprint LNF-74/52 (1974).

⁽⁸⁾ T. GOLDMAN: private communication.

⁽⁹⁾ For the meaning of «charm» see: S. L. GLASHOW, J. ILIPOULOS and L. MAJANI: *Phys. Rev. D*, **2**, 1285 (1970).

⁽¹⁰⁾ C. CARLSON and P. G. O. FREUND: *Phys. Lett.*, **39** B, 349 (1972).

rewritten as

$$(5) \quad \sigma_{\text{had}} = 12\pi^2 \sum_n \frac{\Gamma_n^{\bar{l}l}}{m_n} \delta(s - m_n^2).$$

In order to have scaling the partial widths must behave as

$$(6) \quad \Gamma_n^{\bar{l}l} \sim \frac{1}{m_n},$$

in which case one has, with the aid of eq. (2), that

$$(7) \quad \sigma_{\text{had}} = \frac{12\pi^2}{s} \frac{\Gamma_0^{\bar{l}l} m_0}{b m_0^2} = \frac{12\pi^2}{s} \frac{\Gamma_\psi^{\bar{l}l} m_\psi}{b m_0^2},$$

while the contribution to the μ pair cross-section is given by

$$(8) \quad \sigma_{\mu\bar{\mu}} = \sigma(e^+e^- \rightarrow \psi_n \rightarrow \mu^+\mu^-) = \sigma_{\text{had}} \left(\frac{\Gamma^{\bar{l}l}}{\Gamma} \right).$$

Assuming

$$(9) \quad \begin{cases} b m_0^2 = 4.1 (\text{GeV})^2, \\ \Gamma_\psi^{\bar{l}l} = 3 \text{ keV}, \\ \frac{\Gamma^{\bar{l}l}}{\Gamma} = \text{const} = 0.05, \end{cases}$$

as indicated by the trend of the present data ⁽²⁾, one obtains

$$(10) \quad \sigma_{\text{had}} = 2.7 \cdot 10^{-4} \frac{1}{s} = 104.7 \frac{1}{s(\text{GeV}^2)} \text{ nb},$$

$$(11) \quad R = \frac{\sigma(e^+e^- \rightarrow \gamma \rightarrow \text{hadrons}) + \sigma(e^+e^- \rightarrow \psi_n \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \gamma \rightarrow \mu^+\mu^-) + \sigma(e^+e^- \rightarrow \psi_n \rightarrow \mu^+\mu^-)} \simeq \\ \simeq \frac{\sigma(e^+e^- \rightarrow \gamma \rightarrow \text{hadrons}) + \sigma(e^+e^- \rightarrow \psi_n \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \gamma \rightarrow \mu^+\mu^-)} \equiv R_{\text{normal}} + R_{\text{charm}} \simeq 2.5 + 1.2 = 3.7.$$

The ψ_n contribution to R , R_{charm} is in agreement with the prediction of the enlarged quark model, as is also the case for the normal contribution.

We want to stress the fact that no special assumptions have been made regarding the behaviour of the total widths. In case they obey the same law as the partial widths, eq. (6), one would then obtain scaling for $\sigma(e^+e^- \rightarrow \psi_n \rightarrow \mu^+\mu^-)$. However, a behaviour such as that of eq. (6) for the total widths is in contrast with that of the normal vector mesons ($\Gamma_n \sim m_n$). A similar behaviour is expected of course beyond the threshold for

charmed-particle production. In any case our result, eq. (11), is independent of the aforementioned since $(e^+e^- \rightarrow \psi_n \rightarrow \mu^+\mu^-)$ is quite negligible also when $\Gamma_n^{\mu}/\Gamma_n = \text{const.}$

As a final point we shall discuss the possibility that there might be other narrow resonances lying below the $\psi(3105)$. We notice that if SU_4 were an exact symmetry, one would expect an approximate equality between the couplings of the photon to the ρ -meson and to the lowest ψ (which we call ψ_0), *i.e.*

$$(12) \quad f_{\rho\gamma} \simeq f_{\psi_0\gamma}.$$

However, for the $\psi(3105)$ one has instead that

$$(13) \quad \frac{f_{\psi\gamma}^2}{f_{\rho\gamma}^2} \simeq 8.$$

Hence, in the limit of exact SU_4 one is led to conclude that the $\psi(3105)$ is not the lowest-lying state of the family. One can easily estimate the mass of such a state in the following way. Writing R_{charm} as

$$(14) \quad R_{\text{charm}} = \frac{12\pi^2}{b f_{\psi_0\gamma}^2},$$

and knowing that $R_{\text{charm}} \simeq 1.2$, one can use eq. (12) to find that $b \simeq 3$. From eq. (9) one then gets $m_0^2 \simeq 1.4 (\text{GeV})^2$.

The consistency of eq. (12) can be checked by using the following relation, which comes from our scaling assumption:

$$(15) \quad \frac{f_{\psi\gamma}^2}{f_{\psi_0\gamma}^2} \sim \frac{m_{\psi_0}^2}{m_{\psi}^2},$$

where ψ stands, *e.g.*, for the $\psi(3105)$ -state. Then, from eq. (13) and using $m_{\psi_0}^2 \simeq 1.4 (\text{GeV})^2$ it follows

$$\frac{f_{\psi_0\gamma}^2}{f_{\rho\gamma}^2} \simeq 1.1.$$

In conclusion, in the limit of exact SU_4 there should be a narrow resonance with a mass $m_0^2 \simeq 1.4 (\text{GeV})^2$, and the mass spectrum should be given by $m_n^2 = m_0^2(1 + bn)$ with $b \simeq 3$.

The search for new states in e^+e^- annihilation is obviously needed in order to test further the predictions made here.

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Note added in proof.

Evaluation of radiative corrections ⁽¹¹⁾ to $e^+e^- \rightarrow \psi(3.1) \rightarrow \text{hadrons}$ leads to $\Gamma_{\psi}^{\text{th}} \simeq 4.5$ keV. This modifies our predictions for R (eq. (11)) as follows: $R \equiv R_{\text{normal}} + R_{\text{charm}} \simeq 2.5 + 1.8 = 4.3$. Besides, a possible broad resonance in $e^+e^- \rightarrow \text{hadrons}$ in the vicinity of 4.1 GeV has been very recently reported ⁽¹²⁾, with a partial width to electrons comparable to those of the $\psi(3.1)$ and $\psi(3.7)$. This would agree with our predictions (eqs. (2) and (6)).

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