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$1^{\pm +}$ Resonances in $\gamma\gamma$ Collisions*

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ABSTRACT

We show that $1^{\pm +}$ resonances can be observed at an appreciable rate in tagged e^+e^- experiments at low q^2. We discuss the $(q\bar{q})$, $(qq\bar{q}\bar{q})$, $(q\bar{q}g)$, (gg) and (ggg) spectroscopy and compute the corresponding $\gamma\gamma^*$ partial widths.

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1. Introduction

Because of several experimental progress[1] resonance production in $\gamma\gamma$ collisions has become again a very active field. Recent calculations[2] have been done for the various kinds of states of the $C = +1$ spectroscopy (0^{-+}, 0^{++}, 2^{++}, 2^{-+}) that can appear in real $\gamma\gamma$ collisions. These channels dominate hadron production in untagged $e^+e^- \to e^+e^- +$ hadrons processes. $1^{\pm+}$ states cannot couple to two real photons because of spin and statistics. However as soon as one (or both) photons become slightly virtual (i.e., with $|q^2| \simeq m_V^2$) we expect to have the same $\gamma\gamma^*$ partial width as for other states allowed to couple to two real photons. On another hand tagged experiments are now in progress. Already the $f \to \gamma\gamma^*$ width has been measured in the range $0 \le |q^2| \le 1$ GeV[3]. It well agrees with the VDM prediction (q^2 fall-off given by ρ form factors) if one assumes that the process still dominantly goes through total helicity $\lambda = 2$.

So we found interesting to point out theoretical expectations for $1^{\pm+}$ states. 1^{++} states appear in $(q\,\bar{q})$, $(qq\,\bar{q}\,\bar{q})$, $(q\,\bar{q}\,g)$ and (ggg) spectroscopy. Exotic states 1^{-+} can appear as $(q\,\bar{q}\,g)$, (gg) and (ggg) bound states. Both of them are either badly or not at all experimentally known. $\gamma\gamma$ collisions can be fruitful for shedding some light on these $1^{\pm+}$ unusual states. The paper is organized as follows. In sect. 2 we develop the basic kinematical properties of $1^{\pm+} \to \gamma\gamma^*$ processes (invariant forms, helicity amplitudes, symmetrization properties, q^2-dependences and VDM structure). Sects. 3 to 6 are respectively devoted to the study of $(q\,\bar{q})$, $(qq\,\bar{q}\,\bar{q})$, $(q\,\bar{q}\,g)$ and glueball states. In sect. 7 we summarize the results and discuss the observability of such states in $\gamma\gamma$ collisions.

2. Kinematical Properties

2.1 1^{++} Resonances

Due to spin and parity conservation the decays of 1^{++} resonances into two vector mesons depend upon three independent amplitudes. They correspond to vector meson helicity states $(\pm,\pm)$, $(0,\pm)$, $(\pm,0)$. States $(0,0)$ and $(\pm,\mp)$ are forbidden. If these vector mesons are virtual photons one can develop the amplitude on the basis of three gauge-invariant forms[4]:

$$
\begin{aligned}
I_1 =& i\epsilon \cdot Q\epsilon^{\mu\nu\rho\sigma} e_\mu e'_\nu P_\rho Q_\sigma \\
I_2 =& i\Big[P \cdot pe \cdot Q - Q \cdot pe \cdot P\Big]\epsilon^{\nu\rho\sigma\tau} e'_\nu P_\rho Q_\sigma \epsilon_\tau \\
I_3 =& i\Big[P \cdot qe' \cdot Q - Q \cdot qe' \cdot P\Big]\epsilon^{\mu\rho\sigma\tau} e_\mu P_\rho Q_\sigma \epsilon_\tau
\end{aligned}
$$

where (e, p), (e', q) are the polarization and momentum 4-vectors of the photons, ϵ is the polarization 4-vector of the 1^{++} resonance and $P = p + q$, $Q = \frac{1}{2}(q - p)$. In the case of $1^{++} \to \gamma\gamma^*$ where (e, p) represent the real photon, only I_1 and I_3 remain and correspond to $(\pm, \pm)$ and $(\pm, 0)$ helicity states:

$$
\begin{aligned}
I_1(\pm\pm) &= \mp \frac{(W^2 - q^2)^2}{4W} \quad , \\
I_3(\pm, 0) &= \pm \frac{(W^2 - q^2)^2}{4} \sqrt{-q^2} \quad .
\end{aligned}
$$

They are combinations of E_1 and M_2 multipole amplitudes. Notice that the $I_1(\pm\pm)$ form is antisymmetric with respect to the exchange of the two vector mesons (or photons). It will not contribute to the case of identical particles (for example two real photons).

2.2 1^{-+} Resonances

Because of the change of Parity with respect to the previous case we have now four independent amplitudes which correspond to the helicity states $(\pm, \pm)$, $(0, \pm)$, $(\pm, 0)$, $(0, 0)$. States $(\pm, \mp)$ are still forbidden for a spin one resonance. The four gauge-invariant forms can be chosen as:

$$
\begin{aligned}
I'_1 =& \epsilon \cdot p(e \cdot e'p \cdot q - e \cdot qe' \cdot p) \\
I'_2 =& (e \cdot \epsilon p \cdot q - e \cdot q\epsilon \cdot p)(q^2 e' \cdot p - e' \cdot qp \cdot q) \\
I'_3 =& (e' \cdot \epsilon p \cdot q - e' \cdot p\epsilon \cdot q)(p^2 e \cdot q - e \cdot pp \cdot q) \\
I'_4 =& \epsilon \cdot p(q^2 e' \cdot p - e' \cdot qp \cdot q)(p^2 e \cdot q - e \cdot pp \cdot q) \quad .
\end{aligned}
$$

Only two of them (I'_1, I'_2) remain in the case of one real (e, p) photon, again corresponding to $(\pm, \pm)$ and $(\pm, 0)$ helicity states:

$$I'_1(\pm\pm) = -\frac{(W^2 - q^2)^2}{4W} \qquad\qquad I'_2(\pm 0) = \frac{(W^2 - q^2)^2}{4} \sqrt{-q^2}$$

which are now combinations of M_1 and E_2 multipole amplitudes. Forms $I'_1(\pm\pm)$ and $I'_4(0,0)$ are antisymmetric with respect to the exchange of the vector mesons.

2.3 VDM Relations for Two Photon Decays

We suppose that the hadronic decay amplitudes $1^{\pm +} \to VV'$ are known for on-shell vector mesons V and V'. In order to use them for evaluating two (real or virtual) photon decays an extrapolation is needed from $(m_V^2, m_{V'}^2)$ to the actual photon masses. There is always an ambiguity in choosing gauge invariant forms which coincide with the hadronic amplitudes for on-shell vector mesons. The VDM hypothesis consists in taking the weakest p^2 and q^2 dependences in the amplitudes. Using the invariant forms given above we write

$$R(VV') = \sum_i I_i g_{i,VV'}$$

and

$$R(\gamma^*\gamma^*) = \sum_{V,V'} \frac{e^2 g_{V\gamma} g_{V'\gamma}}{(m_V^2 - p^2)(m_{V'}^2 - q^2)} \sum_i I_i g_{i,VV'}$$

where $g_{i,VV'}$ are constant hadronic couplings.

There are useful symmetrization properties to point out. Consider first the contributions with $V = V'$ in the above double summation. Bose statistics for the (VV) state imposes that $g_{i,VV} = 0$ for antisymmetric invariant forms I_1, I'_1 and I'_4. Considering then the $V \neq V'$ contributions, the antisymmetric forms will get the factor $(q^2 + p^2)(m_V^2 - m_{V'}^2)$ which vanish when $m_V = m_{V'}$ (like $m_\rho = m_\omega$), but also vanish when $q^2 = p^2 = 0$. Applying these properties to $1^{\pm +} \to \gamma\gamma^*$ decays we observe that $(\pm\pm)$ amplitudes first vanish like q^2 when q^2 goes to zero but also vanish when only non-strange (ρ, ω) vector mesons occur as intermediate VDM states. The remaining $(\pm, \overline{0})$ amplitudes only vanish like $\sqrt{-q^2}$ when q^2 goes to zero as expected for longitudinal helicity amplitudes.

3. 1^{++} $q\bar{q}$ Bound States

It is now generally believed[5] that the light 1^{++} nonet consists of $\vec{A}_1(1280)$, $Q_A(1340)$, $D(1285)$, and $E(1420)$ and has a nearly ideal structure (i.e., E is almost purely $s\bar{s}$). There is no known VV' decay mode for these states (because of their high threshold) so we cannot make a quantitative VDM prediction for their two photon decays. We can try the quarkonium formalism with $q\bar{q} \to \gamma\gamma$ process. In the non-relativistic and weak binding limit we get:

$$\Gamma_{\gamma\gamma^*} = 64\alpha^2 < e_q^2 >^2 \frac{|q^2|}{M^6} |\phi'(0)|^2 \quad .$$

This result agrees by crossing with the one given by B. Guberina et al.,[6] for the crossed-reaction $Z \to \gamma + (q\bar{q})$. Especially for light quarkonia, can one expect large relativistic corrections.[7] However, ratios among such kind of decays may be less sensitive to these corrections. Taking the results for the other P-wave quarkonia (for example $\Gamma_{S\to\gamma\gamma} = \frac{432\alpha^2 < e_q^2 >^2}{M^4} |\phi'(0)|^2$) we get for small q^2 and neglecting the M dependence:

$$\Gamma_{S\to\gamma\gamma} \left| \frac{M^2}{|q^2|} \Gamma_{A\to\gamma\gamma^*} \right| \Gamma_{T\to\gamma\gamma} = 1 \left| \frac{4}{9} \right| \frac{4}{15}$$

where S, A and T represent 0^{++}, 1^{++}, 2^{++} states with the same quark charge $< e_q^2 >^2$ value. For a given nonet the decay widths of the various members are then given by $< e_q^2 >^2 = \frac{1}{18}, \frac{25}{162}, \frac{1}{81}$ respectively for ideally mixed A_1, D and E states. Notice that these ratios coincide with the ones one would obtain with $SU(3)$ and VDM relations (with $g_{A_1\rho\omega} = g_{D\rho\rho} = g_{D\omega\omega} = -\frac{1}{\sqrt{2}} g_{E\phi\phi}$ and the corresponding $g_{V\gamma}$ couplings). We can now normalize these ratios using $\Gamma_{f\to\gamma\gamma} \simeq 3$ keV.[1] This gives for small q^2:

$$\frac{M_D^2}{|q^2|} \Gamma_{D\to\gamma\gamma^*} \simeq 1.3\,\text{keV}$$

$$\frac{M_{A_1}^2}{|q^2|} \Gamma_{A_1\to\gamma\gamma^*} \simeq 0.5\,\text{keV}$$

$$\frac{M_E^2}{|q^2|} \Gamma_{E\to\gamma\gamma^*} \simeq 0.1\,\text{keV} \quad .$$

The complete q^2 dependence at low q^2 can be estimated by VDM as described in sect. 2.3. With the dominance of $(\pm, 0)$ amplitudes due to the $(\rho\omega)$, $(\rho\rho)$, $(\phi\phi)$ combinations we expect ρ/ω-like poles $(\frac{1}{m_\rho^2-q^2})^2$ in A_1 and D widths and ϕ-like poles $(\frac{1}{m_\phi^2-q^2})^2$ in E widths. At very high q^2 a different behavior is expected. When m_q can be neglected in $q\,\bar{q} \to \gamma\gamma^*$ it is the $(\pm\pm)$ amplitudes which should dominate.[4]

We can also use the above ratios in order to predict the decay widths of $1^{++}(^3P_1)$ heavy quarkonia. Taking the recent results by Bergström et al.,[7] for 0^{++} and 2^{++} real photon decays we expect to have

$$\frac{M^2}{|q^2|}\,\Gamma_{\chi_1\to\gamma\gamma^*} \simeq 0.3\,\mathrm{keV} \quad \text{and} \quad 5\,\mathrm{eV}$$

for $c\,\bar{c}$ and $b\,\bar{b}$ states respectively.

4. 1^{++} $(qq\,\bar{q}\,\bar{q})$ States

Four quark states in S wave with $J^P = 1^+$ have been found by Jaffe[8] and classified in $\underline{9}$, $\underline{36}$, $\underline{18}$, $\overline{\underline{18}}$, $\underline{18}^*$, $\overline{\underline{18}}^*$ flavor representations. However states in $\underline{9}$ and $\underline{36}$ have charge conjugation $C = -1$. Charge conjugation $C = +1$ states are found by mixing neutral states in $(\underline{18} + \overline{\underline{18}})$ and $(\underline{18}^* + \overline{\underline{18}}^*)$. They are respectively $C_\pi(1250)$, $C_\pi^s(1650)$, $C^s(1650)$ and $C_\pi^*(1650)$, $C_\pi^{*s}(1950)$, $C^{*s}(1950)$. The first set decays by fall-off into $V+P$ hadrons; the second set decays mainly into $V+V$ but also into $V+P$. The recoupling coefficients are given in Table 1. We first estimate the hadronic widths:

for $(\underline{18} + \overline{\underline{18}})$ states: $\Gamma_{VP} = \frac{pa^2}{18\pi}$

for $(\underline{18}^* + \overline{\underline{18}}^*)$ states: $\Gamma_{VV} = \frac{pa^2}{16\pi}$, $\Gamma_{VP} = \frac{pa^2}{144\pi}$

where p is the final $c.m.$ momentum and a is the fall-off magnitude parameter. In the case of 0^{++} and 2^{++} states. Li and Liu[9] took $a^2 = 45$; see also Achasov et al.[10] With such a value we get the large widths given in Table 2. We can then try to estimate the $\gamma\gamma^*$ decay widths. $(\underline{18} + \overline{\underline{18}})$ states having no VV recoupling cannot receive VDM contributions. This case will be somewhat similar to the $(0^{++}, \underline{9})$ case including $S^*(980)$ and $\delta(980)$ for which a $\gamma\gamma$ decay width of the order of 0.27 keV was estimated in ref. [10] on the basis of direct photon couplings. $(\underline{18}^* + \overline{\underline{18}}^*)$ decay widths can be described by VDM. The S-wave dominance means that the vector mesons are in an antisymmetric spin combination $\vec{\epsilon} \cdot (\vec{\epsilon} \times \vec{\epsilon}')$. From the analysis of sect. 2 we obtain:

$$\frac{M^2}{|q^2|}\,\Gamma_{\gamma\gamma^*} = \frac{e^4 a^2}{192\pi} \cdot \frac{(m_V^2 - m_{V'}^2)(M^2 - q^2)^3}{(m_V^2 - q^2)^2 (m_{V'}^2 - q^2)^2} \cdot \frac{g_{V\gamma}^2}{m_V^4} \cdot \frac{g_{V'\gamma}^2}{m_{V'}^4}$$

with $(V, V') \equiv (\rho, \omega)$, (ρ, ϕ), (ω, ϕ) for C_π, C_π^s and C^s respectively, accordingly to the recoupling coefficients of Table 1. In the case of $C_\pi(1650)$ we get a negligible contribution because $m_\rho \simeq m_\omega$ and again we have to rely on direct photon coupling contributions (of the order of 0.3 keV?). For $C_\pi^s(1950)$ and $C^s(1950)$ we obtain $\frac{M^2}{|q^2|}\,\Gamma_{\gamma\gamma^*} \simeq 2.8$ and 0.3 keV respectively.

5. $1^{\pm +}$ Mixed $q\bar{q}g$ States

Such states have been predicted to exist in bag models or in confining potential models with massive constituent gluons.[11,12] The lowest lying 1^{-+} and 1^{++} states can be respectively obtained by coupling a $^3S_1(q\bar{q})$ state either with a "transverse-electric gluon" or with a "transverse-magnetic gluon." Both will have a nonet flavor structure of the ρ, ω, K^*, ϕ-type. Chanowitz et al.,[12] recently made an evaluation of the gluon self-energy effects on the spectroscopy using as input the $\iota(1440)$ mass (the ι being considered as a 0^{-+} glueball). This gives 1^{-+} ρ, ω-like around 1.61 ± 0.2 GeV and ϕ-like around 1.99 ± 0.2 GeV. 1^{++} states can be expected to lie about 0.25 GeV higher because of the higher transverse-magnetic radiation energy.

Decays can be described with a constituent picture and $g \to q\bar{q}$ fragmentation. In a non-relativistic approximation[13] 1^{++} decays can occur through an S-wave $(q\bar{q}q\bar{q})$ color recombination. The modes PV, PS, PA, PT come with large overlap integrals and lead to expect normal hadronic widths O(100 MeV). On the opposite, 1^{-+} decays need a P-wave recombination. The main decay modes PA, PB will then come with smaller overlap integrals and widths of the order of 10 MeV. However for light quarks relativistic corrections may be important and notably modify these decay patterns. In both 1^{++} and 1^{-+} cases no VV decay is allowed by non-relativistic overlap integrals although kinematically the $1^{++} \to VV$ decay could occur in S-wave. This means that VDM contributions to $1^{\pm +} \to \gamma\gamma^*$ should be small, especially for 1^{-+}. These decays require large relativistic effects or direct photon couplings so we do not expect for them more than 0.3 keV (like for $qq\bar{q}\bar{q}$ states without VV fall-off).

6. $1^{\pm +}$ Glueballs

Glueballs are expected[14] from various formalisms (lattice, bag models, confinement potentials). 1^{-+} states can be found as (gg) bound states of massive gluons (which would correspond to spurious $TE \times TM$ states in the bag model). Recent calculations by Cornwall and Soni[15] predict a mass of the order of 1.45 GeV. Three gluon (ggg) bound states can also be obtained: a 1^{-+} state was expected[16] around 1.8 GeV and a 1^{++} state would have a higher mass.

There is a well-known controversy concerning the magnitude of the glueball widths. The standard claim[14] is that they should be small because of the OZI rule (i.e., small α_s factors from the $gg \to q\bar{q}$ transition) with $\Gamma \simeq$ O(10 MeV) for a 1.5 GeV mass. On another hand the decay $(gg) \to g + g$ is perfectly allowed[15] and the gluons can hadronize non-perturbatively as $\alpha_s(m_g^2)$ with $m_g \simeq 500$ MeV is very large. In this last picture glueballs would have normal hadronic widths. Decay modes should be similar to those of other 1^{++} or 1^{-+} hadronic states (see sects. 3, 4, 5) except that special glueball cascades may be favored. Coyne et al., insist[17] for the modes: $1^{-+} \to \eta\eta'$, $(\pi\pi)_s(\pi\pi)_s$, $\eta i(1440)$ and $1^{++} \to \eta(\pi\pi)_s$, $(\pi\pi)_s i(1440)$.

We now try to use this information for estimating the $\gamma\gamma^*$ decay widths. $1^{-+}(gg)$ and $1^{-+}(ggg)$ can hadronize in VV state only in P-wave. So these widths and the corresponding photon decay widths should be rather small ($\lesssim 0.3$ keV). $1^{++}(ggg)$ can hadronize in S-wave VV state so they could have slightly larger $\gamma\gamma^*$ widths.

From the flavor singlet character of the glueballs we expect the relations $g_{\rho\rho} = g_{\omega\omega} = g_{\phi\phi}$ and only $V = V'$ contributions in the VDM amplitudes. Then only symmetric $(\pm,\ 0)\gamma\gamma^*$ amplitudes should appear behaving like $\sqrt{-q^2}$ for small q^2.

We do not expect much correction to these features coming from mixing with other hadronic states because of the exotic character of the 1^{-+} states (no possible $q\bar{q}$ component) and the high mass expected for 1^{++} states (no nearby low-lying $1^{++}(q\bar{q})$ state).

7. Final Discussion: the $\gamma\gamma^*$ Landscape of $1^{\pm+}$ Resonances

Figure 1 and Table 3 summarize our expectations for the spectrum of $1^{\pm+}$ states and their $\gamma\gamma^*$ decay widths. The non-exotic 1^{++} case seems more favorable especially for the narrow $D(1280)$ strongly coupled to $\gamma\gamma^*$. Four quark 1^{++} states are also strongly coupled to $\gamma\gamma^*$ but they will be more difficult to extract from the non-resonant contributions because of their large total widths. Mixed $(q\,\bar{q}\,g)$ and glueball states are a priori not very favored. 1^{++} states may have normal hadronic widths, however their weak VV mode lead to small $\gamma\gamma^*$ partial widths. Exotic 1^{-+} states are expected to be narrower but simultaneously to have smaller VV and $\gamma\gamma^*$ couplings. We may eventually have some surprise with these new types of states. Typical channels to look for them are $\pi\eta$, $\pi\eta'$ and $\eta\eta'$.

The general behavior of $\Gamma_{\gamma\gamma^*}$ at small q^2 is $\frac{|q^2|}{(m^2-q^2)}$ where m is a vector meson mass. This factor gets its maximum precisely for $|q^2| = m^2$. So this may be a good value for tagging experiments. In fact it is just this range of $|q^2|$ in which $\Gamma_{f\to\gamma\gamma^*}$ has recently been measured. So at least the $D(1280)$ state could be easily identified in its $K\,\bar{K}\,\pi$, $\eta\pi\pi$ or $\rho\pi\pi$ modes.

Globally we found that the $1^{\pm+}$ spectroscopy may non-negligibly contribute to the exclusive limit of the photon structure functions, especially $F_L(W,\ q^2) \propto \sigma(\pm,\ 0)$, (the transverse structure function $F_T(W,\ q^2) \propto \sigma(\pm,\ \pm)$ is expected to be smaller at low q^2 because of symmetrization properties and VDM structure). In particular the broad $qq\,\bar{q}\,\bar{q}$ states may give large contributions. Their VV fall-off can saturate unitarity [2] and in this case we get $\sigma(\gamma\gamma^*) \simeq \frac{24\pi}{W^2} B_{\gamma\gamma^*}$ spread over the total width. $B_{\gamma\gamma^*}$ is given by VDM independently of the strong VV couplings. For $q^2 \simeq m_V^2$ we have $B_{\gamma\gamma^*} \simeq 10^{-5}$ and $\sigma(\gamma\gamma^*) \simeq 75$ nb for $W \simeq 2$ GeV. This just shows that the contribution of the $1^{\pm+}$ channels to $\gamma\gamma^*$ collisions may be as important as other partial waves allowed for two real photons.

Acknowledgements

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Table 1

Recoupling Coefficients for $(qq\,\bar{q}\,\bar{q})$ 1^{++} States

		VP	VV
	C_π	$\frac{2}{3\sqrt{2}}(\rho^+\pi^- - \rho^-\pi^+)$	0
$(\underline{18}+\underline{\overline{18}})$	C_π^s	$\frac{1}{3}(\overline{K^{*0}}K^0 - K^{*-}K^+ - \overline{K^0}K^{*0} + K^-K^{*+})$	0
	C^s	$\frac{1}{3}(\overline{K^{*0}}K^0 + K^{*-}K^+ - \overline{K^0}K^{*0} - K^-K^{*+})$	0
	C_π^*	$\frac{1}{6}(\rho^+\pi^- - \rho^-\pi^+)$	$\frac{1}{\sqrt{2}}\omega\rho^0$
$(\underline{18^*}+\underline{\overline{18^*}})$	C_π^{*s}	$\frac{1}{6\sqrt{2}}(\overline{K^{*0}}K^0 - K^{*-}K^+ - \overline{K^0}K^{*0} + K^-K^{*+})$	$\frac{1}{\sqrt{2}}\phi\rho^0$
	C^{*s}	$\frac{1}{6\sqrt{2}}(\overline{K^{*0}}K^0 + K^{*-}K^+ - \overline{K^0}K^{*0} - K^-K^{*+})$	$\frac{1}{\sqrt{2}}\phi\omega$

Table 2

Partial Hadronic Widths for $(qq\bar{q}\bar{q})$ 1^{++} States (in GeV)

	VP	VV	Total Width
$C_\pi(1250)$	0.3	–	0.3
$C_\pi^s(1650)$	0.6	–	0.6
$C^s(1650)$	0.6	–	0.6
$C_\pi^*(1650)$	0.1	0.24	0.34
$C_\pi^{*s}(1950)$	0.1	0.4	0.5
$C^{*s}(1950)$	0.1	0.4	0.5

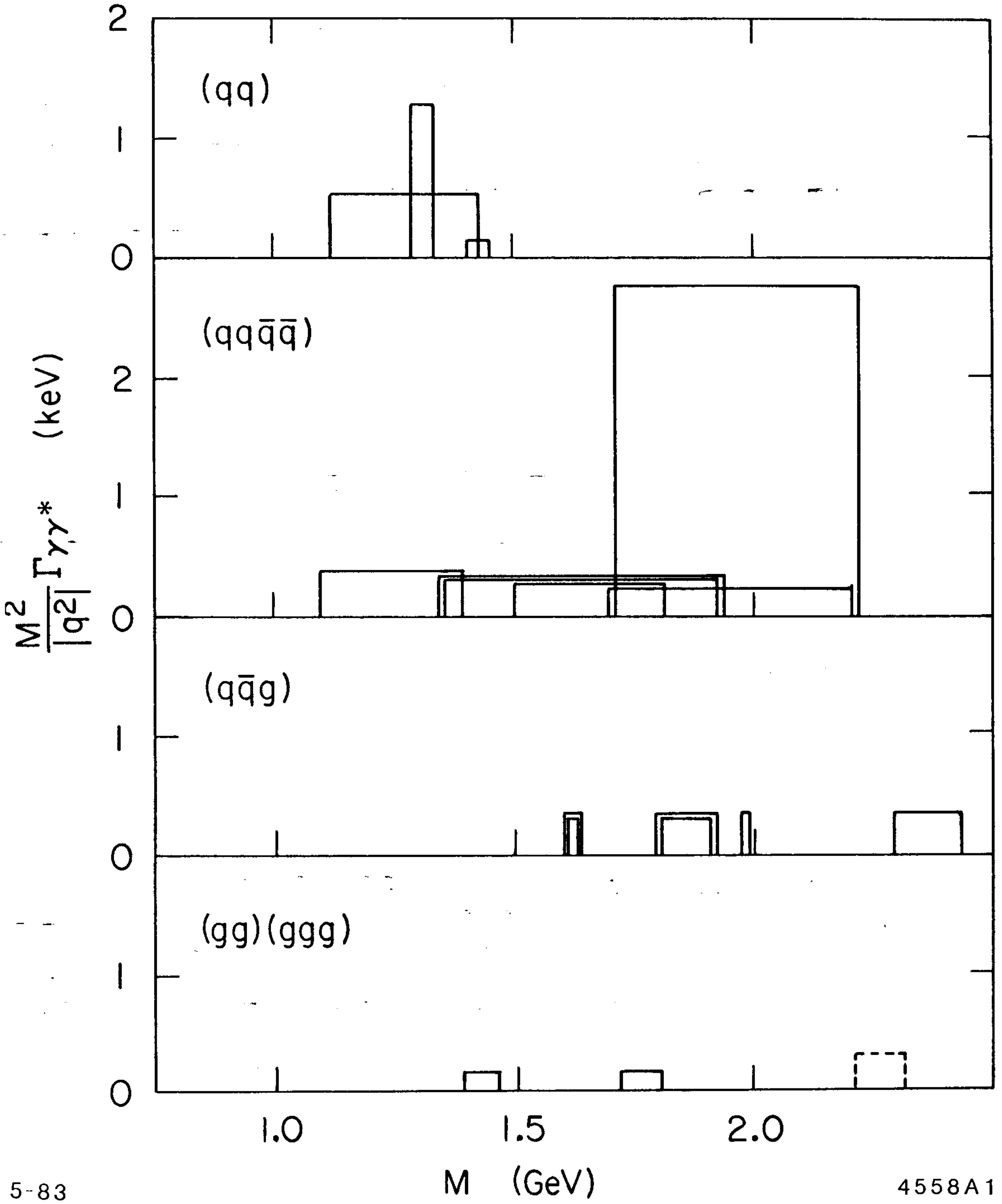
Table 3

Masses, Total Width and Partial $\gamma\gamma^*$ Widths of $1^{\mp +}$ States

		M (MeV)	Γ (MeV)	$\left(\frac{M^2}{\lvert q^2\rvert}\,\Gamma_{\gamma\gamma^*}\right)_{q^2\simeq 0}$ (keV)
$(q\,\bar{q})$	D	1285	26	1.3
	A_1^0	1280	315	0.5
	E	1420	52	0.1
$(qq\,\bar{q}\,\bar{q})$	C_π	1250	300	$\lesssim 0.3$
	C_π^s	1650	600	$\lesssim 0.3$
	C^s	1650	600	$\lesssim 0.3$
	C_π^*	1650	340	$\lesssim 0.3$
	C_π^{s*}	1950	500	2.8
	C^{s*}	1950	500	0.3
$(q\,\bar{q}\,g)$	"ρ"	1610	$\simeq 10$	$\lesssim 0.3$
	"ω"	1610	$\simeq 10$	$\lesssim 0.3$
	"ϕ"	1990	$\simeq 10$	$\lesssim 0.3$
	"A_1"	1860	$\simeq 100$	$\lesssim 0.3$
	"D"	1860	$\simeq 100$	$\lesssim 0.3$
	"E"	2240	$\simeq 100$	$\lesssim 0.3$
(gg)	1^{-+}	1450	10-100	$\lesssim 0.3$
(ggg)	1^{-+}	1800	10-100	$\lesssim 0.3$
	1^{++}	?	100	$\lesssim 0.3$

Figure Captions

1. $\frac{M^2}{|q^2|}\,\Gamma_{\gamma\gamma^*}$ versus masses and widths of $1^{\pm +}$ resonances listed in Table 3.



(qq)
(qqq̄q̄)
(qq̄g)
(gg)(ggg)
0
1
2
$\frac{M^2}{|q^2|}\Gamma_{\gamma\gamma^*}$ (keV)
1.0
1.5
2.0
M (GeV)
5-83
4558A1

Fig. 1