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Experimental Review of Light Quark Spectroscopy From e^+e^- Production and $\gamma\gamma$ Collisions*

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Abstract

This is an experimental review of light quark spectroscopy from e^+e^- production and $\gamma\gamma$ collision results presented at the 2nd International Conference on Hadron Spectroscopy at KEK, Japan. The recent results in $\gamma\gamma$ production have evidence for the $J^{PC} = 1^{++}$, $E/f_1(1420)$ and $D/f_1(1285)$, mesons from the TPC and Mark II collaborations and upper limits for pseudoscalar resonances from the Crystal Ball collaboration. The results in J/ψ reactions include $D/f_1(1285)$ meson production in radiative decays and a complete measurement of the hadronic decays into pseudoscalar-vector pairs from the DM2 collaboration and evidence for $\phi\phi$ production in radiative decays and a study of the ι line shape from the Mark III collaboration. A short review of simple theoretical ideas is presented.

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1. Introduction

The study of light quark spectroscopy in e^+e^- production and $\gamma\gamma$ collisions has produced many new and surprising results in the last few years.[1] In radiative J/ψ decays new states, the iota ($\iota(1440)$) and theta ($\theta(1720)$), are prime glueball candidates. Recent studies of hadronic J/ψ decays provide tests of the quark content of these new states as well as conventional $q\bar{q}$ mesons. In $\gamma\gamma$ collisions the resonance production of mesons has unambiguously proved that there is a spin one $E/f_1(1420)$ meson. In conjunction with searches for gluonium candidates seen in radiative J/ψ decays, the upper limits set in $\gamma\gamma$ collisions provide very strong evidence that these candidates contain little quark content, supporting the gluonium hypothesis.

In this paper, the recent results from the TPC, Crystal Ball and Mark II groups in $\gamma\gamma$ collisions and the J/ψ results from the DM2 and Mark III groups presented at this conference are reviewed. This section begins with a short summary of the theoretical guidelines to provide a general interpretation of the experimental results.

1.1 $\gamma\gamma$ Production of Resonances

The study of resonance production in $\gamma\gamma$ collisions provides a method to measure the quark content and, more recently, a means to determine the spin-parity of resonances. In $\gamma\gamma$ production the partial width, $\Gamma_{\gamma\gamma}$, couples to the 4th power of the quark charges, $\Gamma_{\gamma\gamma} \propto \langle e_q^2 \rangle^2$. This predicts a large difference in the production rate of strange and non-strange states,

$$\left| \frac{u\bar{u} + d\bar{d}}{\sqrt{2}} \right\rangle : | s\bar{s} \rangle \cong \frac{25}{2} : 1$$

and enables a determination of the mixing angle between the octet and singlet parts of the isoscalar members of a given nonet such as the η, η' and f, f'. An important general feature of states produced in $\gamma\gamma$ production is the coupling to gluonium states should be small since they contain no charge.

Resonances produced in $\gamma\gamma$ production can be spin-parity analyzed depending on their production rate in experiments with small angle triggers (SAT) that detect the scattered $e^\pm$ track near the e^+e^- beam axis. In the case where neither the e^- nor the e^+ is observed in the SAT's, both photons are quasi-real ($Q^2 \cong 0$) and, as is well known from Yang's theorem, they produce resonances that must have even spin. If a resonance is produced where one of the leptons is detected in the SAT, then one of the photons is now virtual, γ^* ($Q^2 \neq 0$), and the resonance can have even or odd spin. Consequently, observing a resonance in the data sample with a SAT tag and *not* in the untagged data sample proves that the spin will be odd. This can be further checked by measuring the Q^2 dependence of the cross section which for odd spin will go to zero as Q^2 goes to zero. In this case, the partial width is measured at $Q^2 = 0$ and the useful width for comparison to theory and experiment ,as $Q^2 \to 0$, is $\frac{m^2}{Q^2}\,\Gamma_{\gamma\gamma^*}$.[2]

1.2 RADIATIVE J/ψ DECAYS

In radiative J/ψ decays the major focus has been the search for gluonium states (gg) and hybrid states ($q\bar{q}g$). The gluonium resonances are expected in the lowest order Feynman diagram,

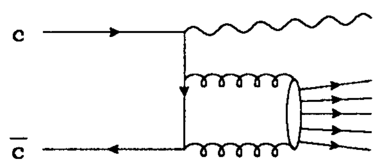

Fig. 1. Radiative J/ψ Decays

and should be charge conjugation even, G-parity even and an SU(3) singlet which causes it to decay equally into strange and non-strange $q\bar{q}$ states. The bag models, a rough guide for the mass spectrum, predict scalar, pseudoscalar and tensor glueball states in the 1-2 GeV/c^2 mass region. The main candidates are the pseudoscalar $\iota(1440)$, which is now called the $\eta(1440)$, and the tensor $\theta(1720)$, now called the $f_2(1720)$. These two states have large radiative branching ratios and they are not seen in $\gamma\gamma$ production.

Conventional mesons, the η, η', f and f', are also observed in radiative J/ψ decays. Their relative radiative rates are in approximate agreement with a pure $SU(3)$ singlet coupling and the mixing angle as determined from the two photon partial widths.[3] The spin one states, isovector states and odd G-parity states are suppressed as expected for resonances produced from 2 gluons. In addition there are no conventional scalar states, S^* or δ, nor new scalar states observed in J/ψ radiative decays.

A qualitative comparison between states seen or not seen in radiative J/ψ decays and $\gamma\gamma$ collisions can be made from, $S_X = \frac{\Gamma(J/\psi\to\gamma X)/PS(J/\psi\to\gamma X)}{\Gamma(X\to\gamma\gamma)/PS(X\to\gamma\gamma)}$, the ratio of the radiative branching ratio to the $\gamma\gamma$ partial width normalized by phase space.[4] In the later sections, this ratio called stickiness will be found to be very large for gluonium candidates relative to conventional mesons.

1.3 HADRONIC J/ψ DECAYS

The study of hadronic two body J/ψ decays has been used to understand quark flavor correlations of $q\bar{q}$ resonances and gluonium candidates with mesons of known $q\bar{q}$ content such as the ϕ and ω. In hadronic decays the dominant diagram procedes via three gluons,

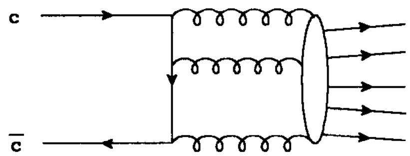

Fig. 2. Hadronic J/ψ Decays

and the two body diagram should have the form

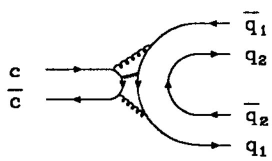

Fig. 3. Hadronic two body J/ψ Decays

which couples the quark flavors between pairs of mesons. The general idea is that if a resonance is produced with a ϕ it should have a large $s\bar{s}$ content and conversely if a resonance is produced with an ω it should have a large $u\bar{u} + d\bar{d}$ content. The main amplitude, shown in Fig. 3, will produce pairs of mesons that are SU(3) singlets. There are corrections from the isospin violating electromagnetic diagram and the double OZI violating diagram,

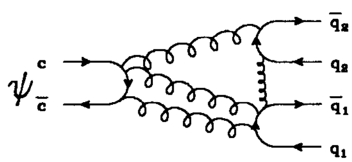

Fig. 4. Double OZI violating J/ψ Decays

If the double OZI diagram (DOZI) is negligible the flavor coupling is not mixed. Simple models[5] have been developed to explain the branching ratios in the J/ψ decays into two bodies for the vector-pseudoscalar case and reasonable results have been obtained. A model[6] including the DOZI contributions obtains the $\eta - \eta'$ mixing angle that agrees with the two photon width and the η' appears not to contain non-$q\bar{q}$ content.

2. Review of $E/f_1(1420)$, $D/f_1(1285)$, $\iota/\eta(1440)$ Results

2.1 $E/f_1(1420)$ Resonance

Recent results from $\gamma\gamma$ resonance production have made important advances in our understanding of the $E/f_1(1420)$ meson. Both TPC[7] and MARK II[8] observe a resonance in the single tag data and not in the untagged data in the $K_S K^{\pm}\pi^{\mp}$ mode. This provides unambiguous evidence for a spin one $E/f_1(1420)$ meson. The Mark II result for $\gamma\gamma^* \rightarrow K\bar{K}\pi$ is shown in figure 5. The mass, width and $\gamma\gamma$ partial width are;

MODE	MASS(MeV)	Γ(MeV)	$\frac{m^2}{Q^2}\Gamma_{\gamma\gamma^*}$(KeV)	GROUP
$K\bar{K}\pi$	1425^{+10}_{-18}	32^{+30}_{-17}	$3.5 \pm 1.0 \pm 0.7$	TPC
$K\bar{K}\pi$	1423 ± 4	narrow	$2.7 \pm 1.2 \pm .5$	MKII

The two photon width as defined and calculated by the TPC group will be factor two larger than the Mark II value. Hence the TPC value is $7 \pm 2 \pm 1.4$ KeV when compared to the Mark II value. The Q^2 dependence of the production cross section in both experiments supports spin 1 and not spin 0. The Dalitz plots are consistent with the quasi-two-body decay, $X(1420) \rightarrow K^*K$. This state is tentatively identified as the $E(1420)$ or $f_1(1420)$. This result is surprising if the $E/f_1(1420)$ is the $s\bar{s}$ isoscalar partner of the $D/f_1(1285)$ because one would expect a small rate if they are ideally mixed, although the rate could be fit with a small mixing angle.[9] However, the Mark III group has evidence for the $E/f_1(1420)$ being produced with an ω and not a ϕ in the J/ψ decays.[10] These results suggest the $E/f_1(1420)$ couples to $u\bar{u} + d\bar{d}$ and not to $s\bar{s}$ even though it decays to $K\bar{K}\pi$. An additional piece of the puzzle is from the LASS group.[11] In the reaction $K^-p \rightarrow K\bar{K}\pi + \Lambda$, $s\bar{s}$ states should be produced. However, they see evidence for the $D'(1530)$[12] and not the $E/f_1(1420)$. If the $D'(1530)$ is the $s\bar{s}$ isoscalar partner of the $D/f_1(1285)$ then one should observe $J/\psi \rightarrow \phi D'(1530)$ and the $E/f_1(1420)$ meson is left out of the 1^{++} nonet and could be something special. A theoretical model by Chanowitz has suggested that this is evidence for a $(u\bar{u} + d\bar{d})g$ hybrid or meikton state.[13]

2.2 $D/f_1(1285)$ Meson

The MARK II Collaboration[14] reports on an observation of the $D/f_1(1285)$, in the single tag sample and not in the untagged sample in the $\eta\pi^+\pi^-$ mode, and TPC[7] has preliminary evidence in the $\pi^+\pi^-\pi^+\pi^-$ channel. The Mark II data is shown in Fig. 6. The results are;

MODE	MASS(MeV)	$\frac{m^2}{Q^2}\Gamma_{\gamma\gamma^*}$(KeV)	GROUP
4π	~ 1285	$4 \pm 1 \pm 3$	TPC
$\eta\pi^+\pi^-$	1286 ± 9	$8.2 \pm 2.2 \pm 1.5$	MKII

As in the previous section, the TPC two photon width should be multiplied by a factor two to compare with the Mark II value. In the MARK II data the dominant quasi-two-body decay is $\delta\pi$. Also there is no evidence for a state near the $E/f_1(1420)$ region.

With these measurements of the $\gamma\gamma$ partial widths the mixing angle can be determined assuming that the $D/f_1(1285)$ and the $E/f_1(1420)$ are the isoscalar members of the 1^{++} nonet. Using the MARK II numbers where we define a state in the ideally mixed combinations, $\cos\theta \mid s\bar{s}\rangle - \sin\theta \mid \frac{u\bar{u}+d\bar{d}}{\sqrt{2}}\rangle$, we obtain $\theta = -14^{\circ+5^\circ}_{-10^\circ}$. As expected the observation of the $E/f_1(1420)$ can be accommodated with a small admixture of non-strange quarks.

The DM2 group[15] has evidence for the $D/f_1(1285)$ in radiative decays and produced hadronically with a ϕ. They see the modes $D \to \pi^+\pi^-\pi^+\pi^-$ and $\eta\pi^+\pi^-$. The rate observed in the two modes with a ϕ is consistent with the relative rate expected for the $D/f_1(1285)$ into $\eta\pi\pi$ and 4π. The radiative rate via the 4π mode is $BR(J/\psi \to \gamma D/f_1(1285)) = (2.6 \pm 0.6 \pm 0.6) \cdot 10^{-4}$. Although DM2 sees a peak in the radiative $\eta\pi\pi$ spectrum, a branching ratio is not quoted. The Mark III group has also studied the radiative $\eta\pi\pi$ channel and observes a peak at 1285 MeV via $\delta \to \eta\pi$. This is seen in two modes ($\eta \to \gamma\gamma, 3\pi$) and both branching ratios are about a factor two larger than the DM2 result from the 4π mode.

If all of these measurements are correct it could mean that the peak at 1285 MeV is not entirely due to the $D/f_1(1285)$ but could be evidence for the pseudoscalar $\eta(1275)$.[16] [17] The Crystal Ball group searched for pseudoscalar states produced in $\gamma\gamma$ collisions decaying into $\eta\pi\pi$.[18] They have set upper limits for the $\eta(1275)$, $\Gamma_{\gamma\gamma} \cdot B(\eta\pi\pi) < 0.3$ KeV. Naive gluonium models would predict

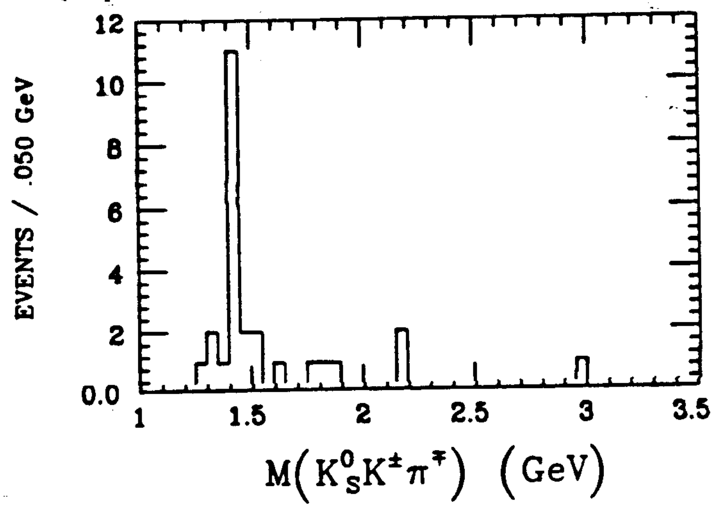

Fig. 5. $K^0_S K^\pm \pi^\mp$ mass distribution from $\gamma\gamma^*$ production from the Mark II collaboration (G. Gidal *et. al.*, SLAC-PUB-4275, April 1987).

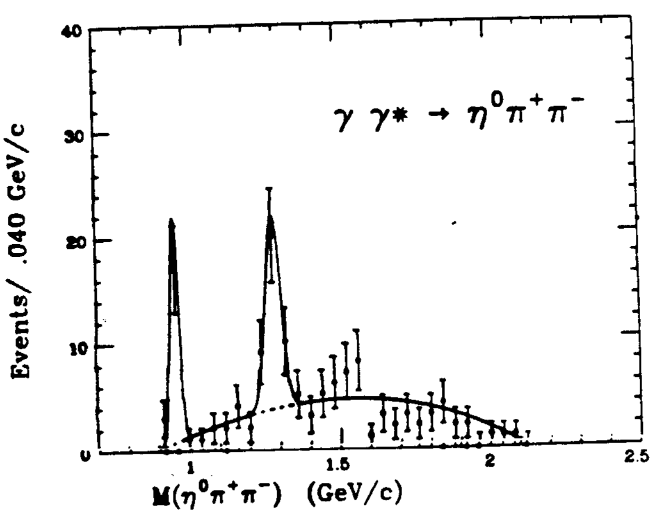

Fig. 6. $\eta\pi^+\pi^-$ mass distribution from $\gamma\gamma^*$ production from the Mark II collaboration (G. Gidal *et. al.*, SLAC-PUB-4274, April 1987).

a suppression for spin 1 radiative states since if they are produced from two massless gluons they should be forbidden by Yang's theorem.

2.3 $\iota/\eta(1440)$ Resonance

The $\iota/\eta(1440)$ has the largest radiative J/ψ branching ratio except for the η_c. The results from MARK III[19] and DM2[20] are;

MODE	MASS(MeV)	Γ(MeV)	$BR(10^{-3})$	GROUP
$K\bar{K}\pi$	1457 ± 2	104 ± 5	5.1 ± 1.2	MARK III
$K\bar{K}\pi$	$1460 \pm 3 \pm 8$	$100 \pm 12 \pm 15$	4.1 ± 0.6	DM2

In $\gamma\gamma$ production the $\iota/\eta(1440)$ has not been seen, the upper limit is given as $\Gamma_{\iota/\eta(1440)\to\gamma\gamma} \cdot B(\iota/\eta(1440) \to K\bar{K}\pi) < 1.6$ KeV at 95% C.L.[21] These two aspects provide strong evidence for the $\iota/\eta(1440)$ to be identified as a gluonium state. When stickiness ($S_X = \frac{\Gamma(J/\psi\to\gamma X)/K_\gamma^3}{\Gamma(X\to\gamma\gamma)/m_X^3}$ and is normalized to the η value) is compared between the $\iota/\eta(1440)$, the η' and the η, there is a dramatic increase for the $\iota/\eta(1440)$,

$$S_\eta \ : \ S_{\eta'} \ : \ S_{\iota/\eta(1440)} = 1 \ : \ 4 \ : > 65$$

The spin-parity, over the whole region, has been investigated using the Jacob-Berman analysis which is independent of the quasi-two-body decay of the $K\bar{K}\pi$. The spin-parity assignment from both MARK III and DM2 is $J^{PC} = 0^{-+}$.

The overall shape of the $\iota/\eta(1440)$ is very broad. It does not appear to fit a single Breit-Wigner that decays into a single channel.[22] The $\iota/\eta(1440)$ line shape has been fit with several models and the probability of the χ^2 fits are;

MODEL	PROB (χ^2)
Single B.W.	1.4×10^{-13}
multichannel B.W. fit	47%
2 B.W.'s (non-interfering)	13%
2 B.W.'s (interfering)	58%

The two Breit-Wigner cases had a lower mass near 1420 MeV and the upper mass near 1500 MeV. The multichannel Breit Wigner case used a coupled channel model including K^*K and $\delta\pi$. Clearly the single Breit-Wigner case is excluded.

These results, although not definitive until a full isobar analysis is performed, are somewhat at variance with other results.[9] If the $\iota/\eta(1440)$ really composed of two resonances at 1420 and 1500 and they are both $J^{PC} = 0^{-+}$, then this is evidence for yet another pseudoscalar resonance. The lower one could be identified with the pseudoscalar resonances seen by the MPS[23] and the KEK[17] groups. The upper resonance has no known pseudoscalar in that region. If the multichannel Breit-Wigner case is correct, the $\delta\pi$ mode should appear in the $\eta\pi\pi$ channel, which we turn to next.

In the $\eta\pi\pi$ channel, it is important to identify the δ decay channel. Since the first spin-parity analysis of the $\iota/\eta(1440)$ by the Crystal Ball Group[24] claimed a large $\delta\pi \rightarrow K\bar{K}\pi$ branching ratio, experiments have searched for this mode in $\delta\pi \rightarrow \eta\pi^+\pi^-$. Crystal Ball has recently set upper limits in $\gamma\gamma$ collisions for the $\iota/\eta(1440)$ decaying into $\eta\pi\pi$ of $\Gamma_{\gamma\gamma} \cdot B(\eta\pi\pi) < 0.3$ KeV. In the results from MARK III[25] and DM2[15] there is clear evidence for $J/\psi \rightarrow \gamma\delta\pi$ but there are two peaks, one near the $D/f_1(1285)$ and another below the $E/f_1(1420)$. The higher mass candidate has the following results;

MODE	MASS(MeV)	Γ(MeV)	$BR(10^{-4})$	GROUP
$\eta\pi^+\pi^-, \eta \rightarrow \gamma\gamma$	1391.5	52 ± 9	$4.1 \pm 3 \pm 1$	DM2
$\eta\pi^+\pi^-, \eta \rightarrow \gamma\gamma$	$1382 \pm .6$	69 ± 23	$5.2 \pm 1.8 \pm .5$	MARK III
$\eta\pi^+\pi^-, \eta \rightarrow 3\pi$	1400 ± 7	62 ± 16	$5.2 \pm 1.2 \pm 0.5$	MARK III

All of these results yield a mass that is somewhat low (~ 30 MeV) to be identified as the $E/f_1(1420)$ or the $\iota/\eta(1440)$. The KEK[26] $\eta\pi\pi$ resonance seen in $\pi^- p \rightarrow \eta\pi\pi N$ has a mass and width of 1390 ± 10 MeV and 45 ± 16 MeV. If the state seen in J/ψ radiative decays is identified as $J^{PC} = 0^{-+}$, possibly these may be the same states and not the $\iota/\eta(1440)$ nor the $E/f_1(1420)$.

Another important channel is the mode $J/\psi \rightarrow \gamma\gamma\rho^0$. If the $\iota/\eta(1440)$ has quark content, the state would be expected to have a radiative decay. The search for such a decay has revealed fairly consistent results for a slightly lower mass object. The results from the MARK III ,[19] DM2[27] and Crystal Ball Groups[28] are;

MODE	MASS(MeV)	Γ(MeV)	BR(10^{-4})	GROUP
$\gamma\rho^0$	$1420 \pm 15 \pm 20$	$133 \pm 55 \pm 30$	$1.1 \pm 2.4 \pm 2.5$	MARK III
$\gamma\rho^0$	1401 ± 18	174 ± 44	$0.9 \pm 0.2 \pm .14$	DM2
$\gamma\rho^0$	1390 ± 25	185^{+110}_{-80}	$1.9 \pm .5 \pm .4$	CB

The signal is 1.2 σ low relative to the $E/f_1(1420)$ and $\iota/\eta(1440)$. Because of low statistics, the fits assumed a single Breit-Wigner for the entire mass region. The distributions could not exclude two resonances such as the $D/f_1(1285)$ or $\eta(1275)$ at 1285 MeV and the $E/f_1(1420)$ or $\iota/\eta(1440)$ near 1420 MeV.

3. Review of $\theta/f_2(1720)$ Resonance Results

The $\theta/f_2(1720)$ is a resonance observed in radiative J/ψ decays into $\eta\eta$, K^+K^-, K_SK_S and $\pi^+\pi^-$ modes. The observed rates in J/ψ radiative decay, from the DM2[27] , MARK III[29] and Crystal Ball[28] groups are;

MODE	MASS(MeV)	Γ(MeV)	BR(10^{-4})	GROUP
K^+K^-	1707 ± 10	166 ± 33	$4.6 \pm 0.7 \pm 0.7$	DM2
K^+K^-	1720 ± 7	132 ± 15	$4.8 \pm 0.6 \pm 0.9$	MarkIII
$\eta\eta$	$1655 \pm 33 \pm 5$	219^{+74}_{-54}	$2.6 \pm .8 \pm .7$	CB

In $\gamma\gamma$ production the TPC[30] and TASSO[31] groups searched for this state and set the upper limits of;

MODE	$\Gamma_{\gamma\gamma}$(KeV)	GROUP
K^+K^-	<.28	TASSO
K^+K^-	<.10	TPC

Comparing the stickiness ratio (assuming S wave, $S_X = \frac{\Gamma(J/\psi \to \gamma X)/K_\gamma}{\Gamma(X \to \gamma\gamma)/m_X}$ and is normalized to the f value) a significant increase is observed for the $\theta/f_2(1720)$

relative to the f' and the f.

$$S_f \ : \ S_{f'} \ : \ S_{\theta/f_2(1720)} = 1 \ : \ 7 \ : > 14$$

The $\theta/f_2(1720)$ is not produced in $K^-p \rightarrow K\bar{K}\Lambda$ production where conventional $s\bar{s}$ resonances are produced. A very striking result from the LASS group is the clear evidence for $f'/f_2'(1525)$ production but the complete lack of any $\theta/f_2(1720)$.[11] This is evidence that the $\theta/f_2(1720)$ is not an $s\bar{s}$ state even though it decays into $K\bar{K}$. The $\theta/f_2(1720)$ is seen in several decay modes with a rate approximately,

$$KK \ : \ \eta\eta \ : \ \pi\pi = 3 \ : \ 1 \ : \ 0.8$$

If the $\theta/f_2(1720)$ were a pure SU(3) singlet we expect a rate (with phase space correction),

$$\mathrm{K\bar{K}} \ : \ \eta\eta \ : \ \pi\pi = 3 \ : \ 0.5 \ : \ 6$$

The spin-parity of the $\theta/f_2(1720)$ has been determined to be $J^{PC} = 2^{++}$ and its helicity amplitudes appear in roughly equal amounts. The helicity of the $f'/f_2'(1525)$ is very different having little helicity 2. A search for hadronic production of the $\theta/f_2(1720)$ has provided evidence for a clear peak in the $\mathrm{K\bar{K}}$ mass spectrum recoiling against an ω from both the DM2[32] and MARK III[33] groups. The evidence for the $\theta/f_2(1720)$ produced with a ϕ appears as a shoulder above the $f'/f_2'(1525)$.

All the evidence that the $\theta/f_2(1720)$ is a gluonium state appears more convincing. It is not produced in $s\bar{s}$ channels, it is very suppressed in $\gamma\gamma$ production and it appears to have approximate flavor symmetry.[34] It decays to $\mathrm{K\bar{K}}$, $\eta\eta$ and $\pi\pi$ and it appears to be produced with an ω and a ϕ.

4. Vector-Vector Resonances

The J/ψ radiative decays into 2 vectors (ρ, ω, ϕ) have been extensively measured. The MARK II group[35] originally observed a $\rho^0\rho^0$ resonance near ~1700 MeV. Later the MARK III[36] group observed $\rho^0\rho^0, \rho^+\rho^-$ and $\omega\omega$ resonances produced near threshold and measured that the decay was predominantly $J^{PC} = 0^{-+}$. The DM2[27] group has subsequently confirmed the 0^{-+} resonance in $\rho^0\rho^0$.

This study was extended to $J/\psi \rightarrow \gamma\omega\phi$ and $\gamma\phi\phi$. In the $\omega\phi$ channel, which is an OZI violating decay, the MARK III[33] group observed a small signal. The DM2[37] group has observed a $\phi\phi$ signal near 2.2 GeV/c^2 and the MARK III[22] group has confirmed these results with the $\phi\phi$ signal in two modes, one with both

ϕ's decaying to K^+K^- and the other with one ϕ decaying into K^+K^- and the other into $K_S K_L$. The rates are summarized below;

MODE	MASS(GeV)	$BR(10^{-4})$	GROUP
$\rho^0\rho^0$	<2.0	$47 \pm 3 \pm 9$	MARK III
$\rho^+\rho^-$	<2.0	—	MARK III
$\omega\omega$	<2.0	$12.2 \pm .7 \pm 3.1$	MARK III
$\phi\omega$	1.7 - 3.1	$1.4 \pm 2.5 \pm .28$	MARK III
$\phi\phi$ (K^+K^-)	<2.9	$3.1 \pm .3 \pm .6$	DM2
$\phi\phi$ (K^+K^-)	2.1-2.4	$3.4 \pm .8$	MARK III
$\phi\phi$ $(K_S K_L)$	2.1-2.4	$3.0 \pm .6$	MARK III

The angular distributions of $\phi\phi$ mode have been studied. In the region near 2.2 GeV the $\phi\phi$ signal appears to be $J^{PC} = 0^{-+}$. This suggests that this signal is not connected with the $\phi\phi$ tensors seen in $\pi^- p$ production.[38] A possible interpretation is that this signal is a multichannel Breit-Wigner of an enormous 0^{-+} resonance of the $\iota/\eta(1440)$ which decays into $K^+K^-\pi$, $\rho\rho$, $\omega\omega$ and $\phi\phi$.[39]

5. Pseudoscalar-Vector Hadronic Decays

The DM2 group has presented a complete measurement of $J/\psi \rightarrow$ *vector* + *pseudoscalars*. Their measurements agree with those from the Mark III group.[40] The original Mark III paper included a discussion of a simple model that estimated the quark content of the η' and concluded that the total content was missing 35%. This has been reevaluated in a paper[6] submitted to this conference, which includes a DOZI term, and now the η' appears to be fully made up of quarks. Consequently the relative rates of the vector + pseudoscalar decays appear to be quantitatively understood. The total rate, however, has been a puzzle. When compared to the ψ' decay rates for vector + pseudoscalars the J/ψ rates are much too large. The relative rates should be proportional to the leptonic rates,

$$\frac{B(\psi' \rightarrow hadrons)}{B(J/\psi \rightarrow hadrons)} \sim \frac{B(\psi' \rightarrow e^+e^-)}{B(J/\psi \rightarrow e^+e^-)} = 0.135 \pm 0.023$$

but the $\rho\pi$ and $K^*\bar{K}$ rates are a factor 20 too large for the J/ψ. Several predictions claim that this could be evidence for a vector glueball state that mixes with the J/ψ causing an anomalous rate in certain modes.[41]

6. Summary

The experimental results from e^+e^- production and $\gamma\gamma$ collisions are providing new insights into light quark spectroscopy. When the results from J/ψ, $\gamma\gamma$ and hadronic experiments are combined, the $\iota/\eta(1440)$ and $\theta/f_2(1720)$ appear to be very strong gluonium candidates and now the $E/f_1(1420)$ is suggested to be a hybrid candidate. These states appear to be produced in gluonic and non-strange channels whereas they decay into $s\bar{s}$ channels.

In the radiative decays, the $\iota/\eta(1440)$ and $\theta/f_2(1720)$ have large radiative branching ratios and no observable $\gamma\gamma$ width. The $\iota/\eta(1440)$ appears not to be a single Breit-Wigner decaying into $K\bar{K}\pi$. The $\theta/f_2(1720)$ is not seen in K^-p experiments providing evidence that it is not an $s\bar{s}$ state.

The $E/f_1(1420)$ is very puzzling. This meson appears in $\gamma\gamma$ production and its spin is unambiguously 1. The $\gamma\gamma$ result would indicate a nonzero non-strange quark content. This result is consistent with evidence that the $E/f_1(1420)$ is produced with an ω and not a ϕ if the non-strange content is dominant. Recent LASS results indicate that the $D'(1530)$ is the real $s\bar{s}$ isoscalar partner of the $D/f_1(1285)$. All this evidence leaves the $E/f_1(1420)$ as an extra unexplained axial vector.

In other topics, the relative rates of J/ψ two-body vector+pseudoscalar decays can be explained in simple models including DOZI contributions. The absolute rates, however, do not agree with the rates when compared to the ψ' decays. The radiative decays into $\phi\phi$ have been measured and confirmed. There is an enhancement near 2.2 GeV/c^2 and the preliminary evidence is that it is pseudoscalar, consistent with the other vector-vector resonances produced near threshold.

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