Title
RADIATIVE WIDTHS OF RESONANCES (EXPERIMENTS)

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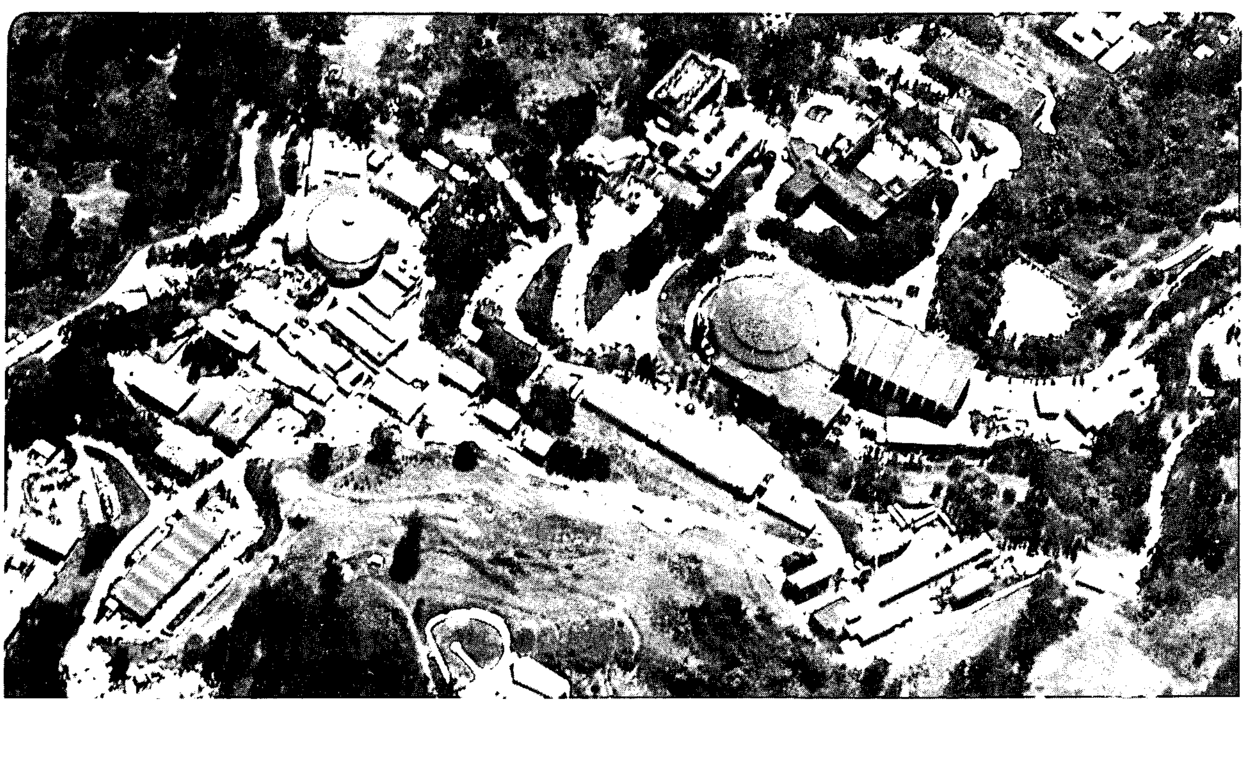

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Radiative Widths of Resonances (Experiments)*

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After a hiatus of several years, this conference brings us considerable new data on resonance production in photon photon interactions. I will first discuss the contributions concerning the tensor, pseudoscalar and scalar mesons, then review the current status of the ($c\bar{c}\,\eta_c$) and finally summarize the exciting new results concerning the spin 1 mesons.

The radiative widths of the meson resonances have traditionally been considered the most direct measure of their quark content. In a model where the photons couple directly to quarks with charge eq, the matrix element $<q\bar{q}/\gamma\gamma> \sim e_q^2\psi(0)$ in the s-wave and $<q\bar{q}/\gamma\gamma> \sim e_q^2\psi'(0)$ in the p-wave, so the radiative width $\Gamma_{\gamma\gamma} \sim (\sum_q c_q e_q^2)^2$. For example, for the pseudoscalar and tensor nonets

π^0 (A_2)	$\sqrt{\frac{1}{2}}(d\bar{d} - u\bar{u})$	$<e_q^2> = \frac{-1}{3\sqrt{2}}$
$\eta_8(f_8)$	$\frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2\,s\bar{s})$	$\frac{1}{3\sqrt{6}}$
$\eta_1(f_1)$	$\frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$	$\frac{2}{3\sqrt{3}}$

where $\eta = \cos\theta\,\eta_8 - \sin\theta\eta_1$

$\eta' = \sin\theta\,\eta_8 - \cos\theta\,\eta_1$ (same for f,f')

In the case of ideal mixing ($\theta = 35.3°$), the η and f are pure ($u\bar{u} + d\bar{d}$), while the η' and f' are pure $s\bar{s}$. Thus the radiative width of the $s\bar{s}$ member of a nonet is extremely sensitive to small admixtures of $u\bar{u}$ and $d\bar{d}$ components, i.e., to a small deviation from ideal mixing.

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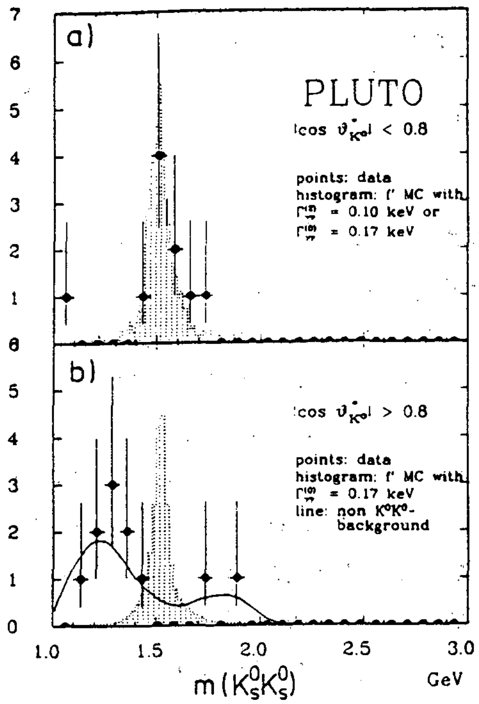


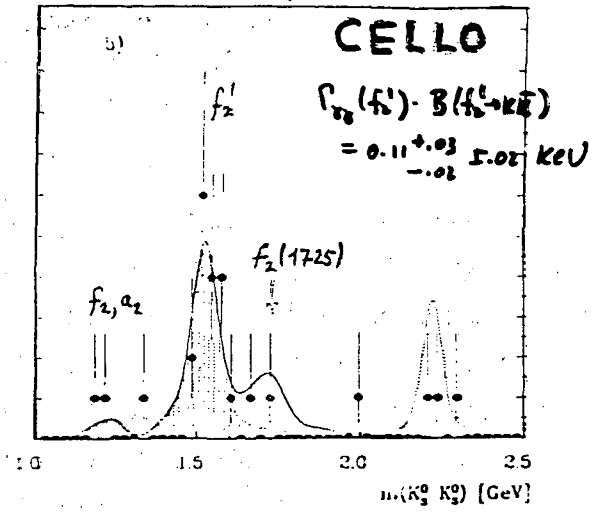


Figure 1

Table I

Meson	Mode	$\Gamma_{\gamma\gamma}$ [keV]	Experiment	Ref
$f_2(1270)$	$\pi\pi$	$2.3 \pm 0.5 \pm 0.35$	PLUTO	[65]
	$\pi\pi$	$3.6 \pm 0.3 \pm 0.5$	MARK II/SPEAR	[66]
	$\pi\pi$	$3.2 \pm 0.2 \pm 0.6$	TASSO	[67]
	$\pi\pi$	$2.7 \pm 0.2 \pm 0.6$	Crystal Ball/SPEAR	[68]
	$\pi\pi$	$2.5 \pm 0.1 \pm 0.5$	CELLO	[69]
	$\pi\pi$	$2.70 \pm 0.05 \pm 0.2$	DELCO	[70]
	$\pi\pi$	$2.52 \pm 0.13 \pm 0.38$	Mark II	[71]
	$\pi\pi$	$2.85 \pm 0.25 \pm 0.5$	PLUTO	[72]
	$\pi\pi$	$3.2 \pm 0.1 \pm 0.4$	TPC/$\gamma\gamma$	[73]
$f_2(1270)$		2.78 ± 0.14	average	
$a_2(1320)$	$\eta\pi$	$0.77 \pm 0.18 \pm 0.27$	Crystal Ball (SPEAR)	[77]
	$\rho\pi$	$0.81 \pm 0.19^{+0.42}_{-0.11}$	CELLO	[46]
	$\rho\pi$	$1.06 \pm 0.18 \pm 0.19$	PLUTO	[78]
	$\eta\pi$	$1.14 \pm 0.20 \pm 0.26$	Crystal Ball (DORIS)	[79]
	$\rho\pi$	$0.90 \pm 0.27 \pm 0.16$	TASSO	[80]
$a_2(1320)$		0.95 ± 0.14	average	
$f_2'(1525)$ $\times$ Br($f_2' \to K\bar{K}$)	KK	$(0.11 \pm 0.02 \pm 0.04)$	TASSO	[81]
	KK	$(0.12 \pm 0.07 \pm 0.04)$	TPC/$\gamma\gamma$	[73]
	KK	$(0.07 \pm 0.015 \pm 0.035)$	DELCO	[83]
	KK	(0.10 ± 0.04)	Mark II (prelim.)	[84]
$f_2'(1525)$ $\times$ Br($f_2' \to K\bar{K}$)	KK	(0.094 ± 0.023)	average	

$0.10^{+.04}_{-.03}{}^{+.03}_{-.02}$ PLUTO

$0.11^{+.03}_{-.02} \pm .02$ CELLO

$0.092 \pm .020 \pm .023$ ARGUS

The PLUTO[1], CELLO[2], and ARGUS[3] groups have submitted new measurements of the predominantly $s\bar{s}$ $f'_2(1510)$ radiative width, nearly doubling the available measurements. It is particularly noteworthy that the PLUTO spectrometer is sensitive in the forward direction, so that no assumption regarding the helicity structure of the $f'_2(1510)$ is required to extract $\Gamma_{f'_2\gamma\gamma}$. Some of the measurements are shown in Figure 1 and the resultant widths given in Table I, added to a recent compilation of Kolanowski and Zerwas[4]. The new world average is then $\Gamma_{f'_2\gamma\gamma}$ $B(f'_2 \rightarrow K\bar{K}) = 0.097 \pm 0.016$.

The f(1270) radiative width has been measured many times, but again this conference has brought new insight with $\pi^+\pi^-$ measurements from CELLO[2] and Mark II[5], and new $\pi^0\pi^0$ measurements from both Crystal Ball[6] and JADE[7]. In Figure 2 we show the $\pi^0\pi^0$ spectrum obtained by JADE and Crystal Ball, and the $\pi^+\pi^-$ spectrum obtained by Mark II. The dominant feature is the f(1270). The $\pi^+\pi^-$ data is fit with a background of consisting of the Born amplitude for each helicity state and scalar resonances at the high and low end. Mennessier[8] and more recently, Morgan and Pennington[9] have pointed out the necessity of taking final state interactions into account in such fits, and in particular the importance of requiring consistency between the fitted $\pi\pi$ phase shifts and those independently measured in peripheral πN interactions. As in the case of all the 2^{++} nonet members, the value of $\Gamma_{f_2\gamma\gamma}$ is sensitive to the assumed helicity structure. Although most experiments do not sample the entire $\cos\theta$ interval, the most precise measurements are able to get limits on the helicity 0 contribution from the shape of the angular distribution. An example is the JADE measurement for the $f_2(1270)$ in Figure 2. The resulting widths are given in Table II and are all somewhat higher than the previous world average (Table I).

The $a_2(1230)$ is usually identified by its $\rho\pi$ decay but a rather clear signal has now been observed by both the Crystal Ball[10] and JADE[7] groups in the $\pi^0\eta$ decay mode as shown in Figure 3 and Table II.

With helicity 2 dominance, the radiative widths of the 2^{++} mesons can be used to evaluate the mixing angle and coupling ratio $R = F_8/F_1$ with the

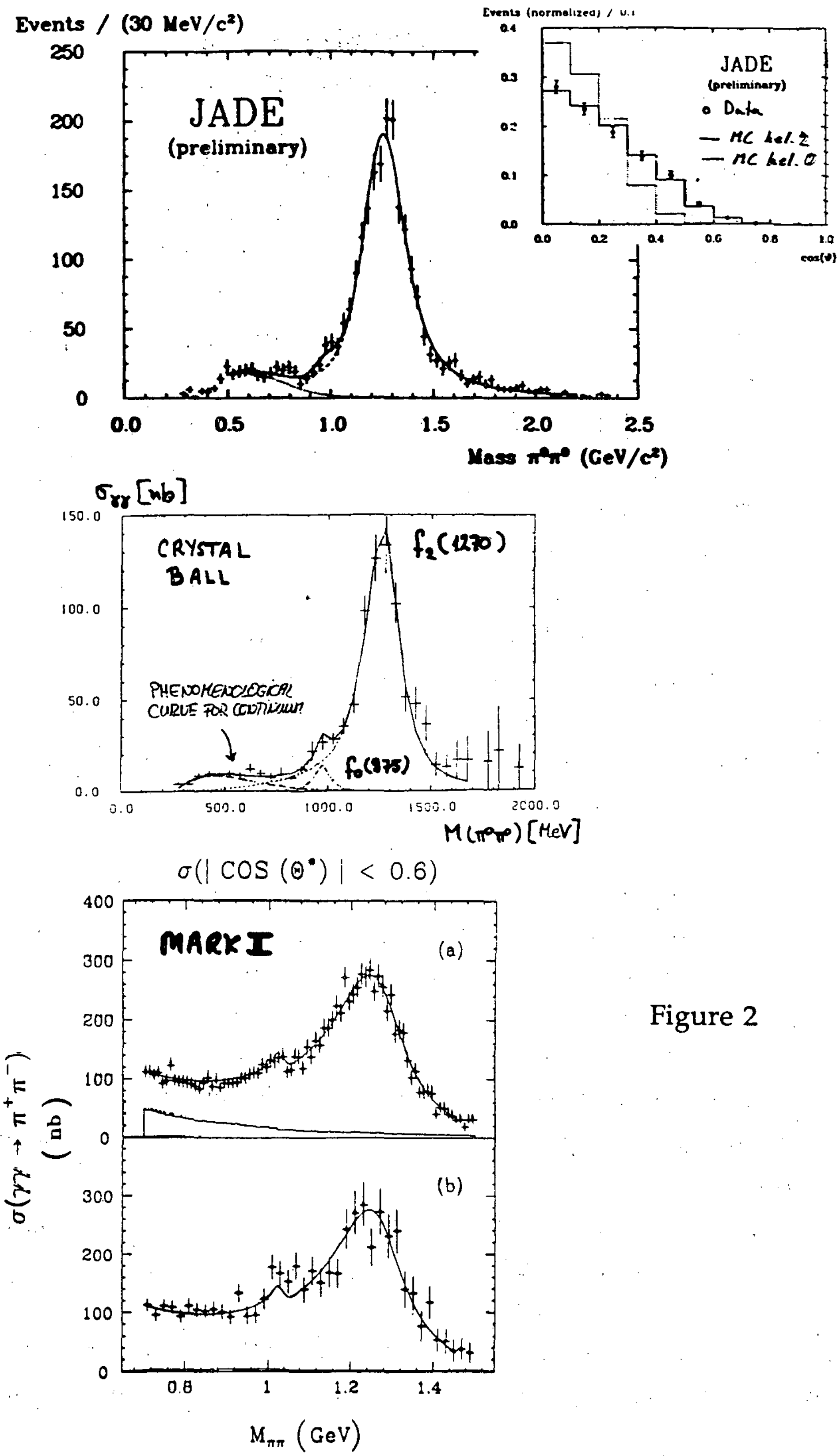

Events / (30 MeV/c²)
JADE
(preliminary)
Mass π⁰π⁰ (GeV/c²)
Events (normalized)
JADE
(preliminary)
o Data
— MC hel. 2
— MC hel. 0
cos(θ)
σγγ [nb]
CRYSTAL BALL
f₂(1270)
PHENOMENOLOGICAL CURVE FOR CONTINUUM
f₀(975)
M(π⁰π⁰) [MeV]
σ(| COS (Θ*) | < 0.6)
MARK II
(a)
(b)
σ(γγ → π⁺π⁻) (nb)
Mππ (GeV)

Figure 2

relations:

$$\frac{\Gamma(f_2' \rightarrow \gamma\gamma)}{\Gamma(a_2 \rightarrow \gamma\gamma)} = \frac{1}{3}\left(\frac{m_{f_2'}}{m_{a_2}}\right)^3 (\cos\theta - 2\sqrt{2}\, R \sin\theta)^2$$

$$\frac{\Gamma(f_2 \rightarrow \gamma\gamma)}{\Gamma(a_2 \rightarrow \gamma\gamma)} = \frac{1}{3}\left(\frac{m_{f_2}}{m_{a_2}}\right)^3 (\sin\theta - 2\sqrt{2}\, R \cos\theta)^2$$

The resulting values remain consistent with nonet symmetry ($R \simeq 1$) and with the mixing angle given by the Gell-Mann-Okubo mass formula ($\theta \simeq 28°$).

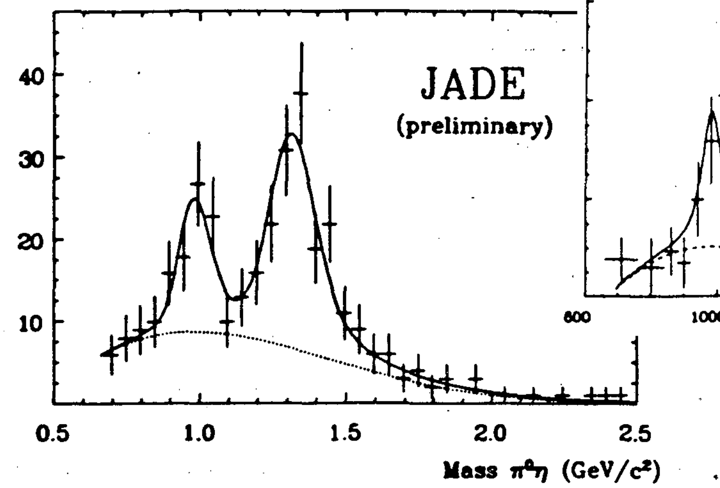
Table II

	$\Gamma_{\gamma\gamma} f_2(1270)$	$\Gamma_{\gamma\gamma} a_2(1320)$
Crystal Ball $\pi^0\pi^0$	$3.26\ ^{+0.16}_{-0.15} \pm 0.46$ KeV	$1.14 \pm 0.20 \pm 0.26$ KeV
JADE $\pi^0\pi^0$	$3.09 \pm 0.10 \pm 0.38$ ($\lambda_0 < 0.15$)	$1.09 \pm 0.14 \pm 0.25$
CELLO $\pi^+\pi^-$	$2.99 \pm 0.10 \pm$	--
Mark II $\pi^+\pi^-$	$3.21 \pm 0.09 \pm 0.40$ ($\lambda_0 < 0.15$)	--

The scalar mesons remain a puzzle, although some new results have been reported to this conference. JADE[7] has now confirmed the previous observation of the $a_0(980)$ by the Crystal Ball[10] group in the $\pi^0\eta$ channel. Both $\pi^0\eta$ mass spectra are shown in Figure 3 and give radiative widths,

	$\Gamma_{\gamma\gamma}(a_0(980)) \cdot B(a_0 \rightarrow \pi^0\eta)$
JADE	$0.29 \pm 0.05 \pm 0.14$ KeV
Crystal Ball	$0.19 \pm 0.07 \pm\ ^{+0.10}_{-0.07}$ KeV

Both the Mark II[5] and Crystal Ball[6] require an $f_0(975)$ to fit a shoulder in their respective $\pi^+\pi^-$ and $\pi^0\pi^0$ spectra, although the fitted mass and width are somewhat different. A simple Breit Wigner fit results in values of the radiative width



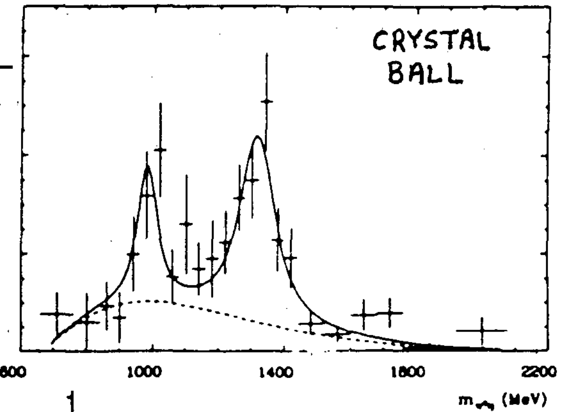


Figure 3

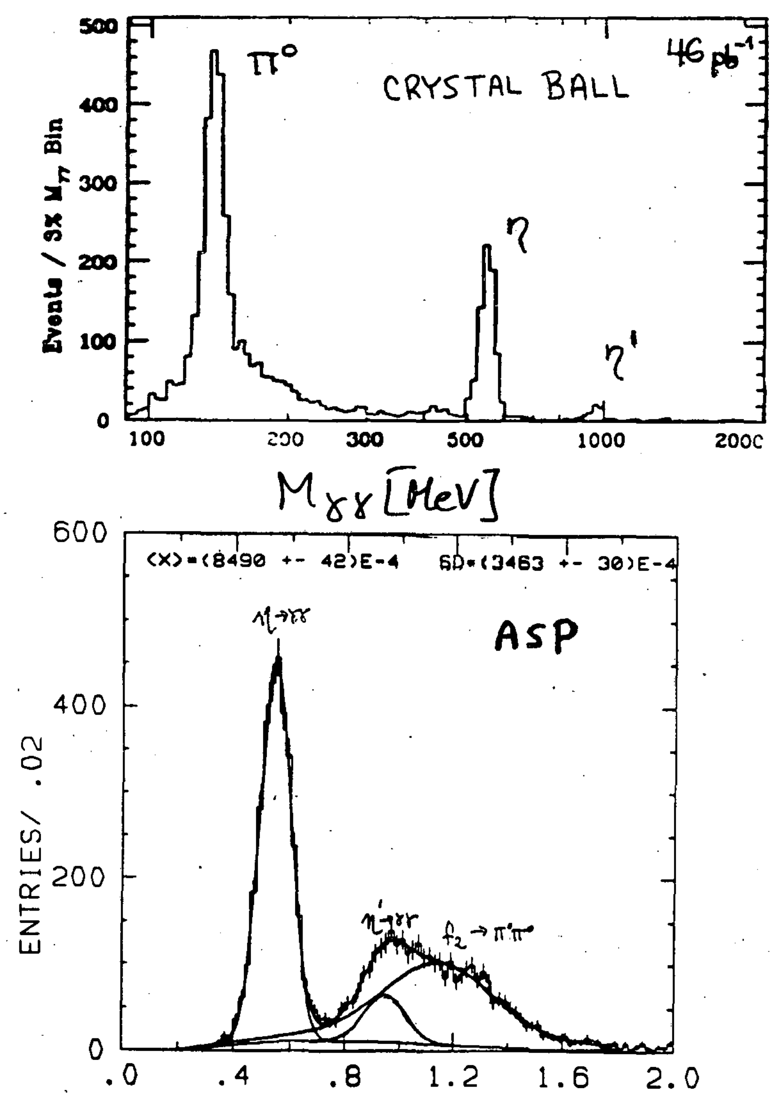


Figure 4

	$\Gamma_{\gamma\gamma}(f_0(975))$
Mark II	$0.24 \pm 0.06 \pm 0.15$ KeV
Crystal Ball	$0.31 \pm 0.14 \pm 0.11$ KeV
	(or <0.55 KeV at 90% C.L.)

although such a simple parametrization is certainly inadequate. Most $(q\bar{q})$ models predict $\Gamma_{\gamma\gamma f_0} \sim$ 2-5 KeV and $\Gamma_{\gamma\gamma f_0}/\Gamma_{\gamma\gamma a_0} \simeq \frac{25}{9}$ while $q\bar{q}q\bar{q}$ and $(K\bar{K})$ molecule models[11] predict $\Gamma_{\gamma\gamma f_0} \sim$ 0.3 - 0.6 KeV and $\Gamma_{\gamma\gamma f_0}/\Gamma_{\gamma\gamma a_0} \simeq 1$. We should then ask why the other 0^{++} mesons have not yet been observed in $\gamma\gamma$ interactions? (See following talk by Chanowitz)

We have heard reports on the ultimate two photon reaction, $\gamma\gamma \rightarrow \gamma\gamma$ from both the Crystal Ball[12] and ASP[13] groups (Figure 4). As was already clear from earlier results, the reaction is totally dominated by the pseudoscalars - π^0, η and η'. The same is true of the $\pi^0\pi^0\pi^0$, $\eta\pi^+\pi^-$ and $\eta\pi^+\pi^-$ final states and JADE[14], Crystal Ball[15], and CELLO[2] reported their data in these channels (Figure 5). The non resonant background is extremely small in all these channels and there is no evidence that this is continuum $\eta\pi\pi$ production rather than background. The Crystal Ball group has actually translated this absence of signal into an upper limit on $\Gamma_{x\gamma\gamma} \cdot B(x \rightarrow \eta\pi\pi)$ for the whole available range of masses (Figure 6).

Tables III and IV then display these new results and the compilation of previous data from Kolanowski and Zerwas[4]. It is interesting that the two new measurements, as most previous measurements of the η' width, have a spread beyond the statistical error, but are consistent within the systematic errors indicating the difficulty in obtaining measurements more accurate than 10-20%.

Table III

	$\gamma\gamma \rightarrow \gamma\gamma$		$\gamma\gamma \rightarrow \eta\pi\pi, 3\pi^0$	
(KeV)	**Crystal Ball**	**ASP**	**JADE**	**CELLO**
$\Gamma_{\gamma\gamma}(\pi^0)$	$7.7 \pm 0.5 \pm 0.5$	--	--	--
$\Gamma_{\gamma\gamma}(\eta)$	$0.51 \pm 0.02 \pm 0.04$	0.498 ± 0.009	$0.53 \pm 0.05 \pm 0.10$	--
$\Gamma_{\gamma\gamma}(\eta')$	$4.7 \pm 0.5 \pm 0.5$	--	$3.8 \pm 0.13 \pm 0.50$	$4.7 \pm 0.2 \pm 1.0$

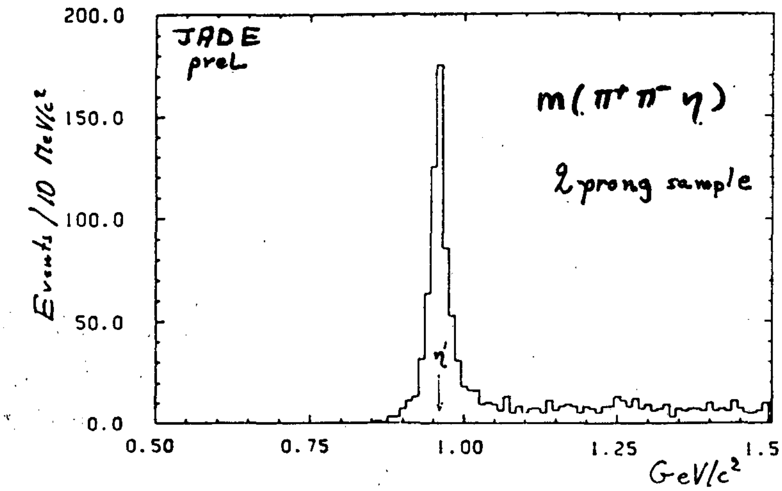
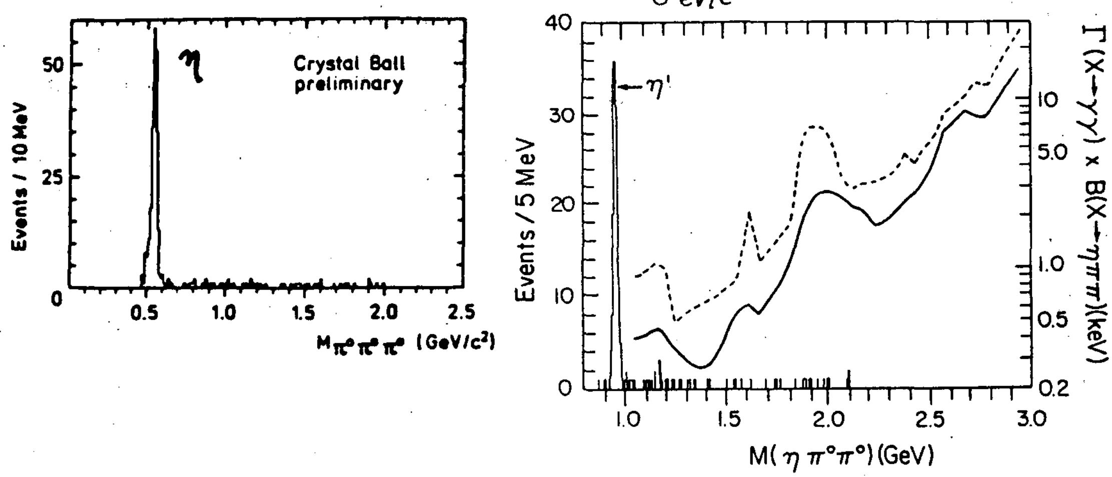


Figure 5

Figure 6



The Crystal Ball group has reported[16] the first evidence for the $\gamma\gamma$ production of a radial excitation; the $J^{PC} = 2^{-+}$ $\pi_2(1680)$. It is observed in the reaction $e^+e^- \rightarrow e^+e^- \pi_2(1680)$; $\pi_2(1680) \rightarrow f_2(1270)\, \pi^0$; $f_2(1270) \rightarrow \pi^0\pi^0$ where one π^0 is rather fast and hence both of its decay gammas are "merged" into a single shower. The efficiency corrected $3\pi^0$ spectrum is shown in Figure 7 and a fit gives $\Gamma_{\pi_2\gamma\gamma} = 1.4 \pm 0.3$ KeV. As in the case of the scalars we must then ask -- where are the other radial excitations?

The η_c has been a long sought prize of $\gamma\gamma$ physics. Its high mass and many decay modes have meant that only the highest luminosity experiments would be capable of observing it. Most experiments chose the $K^0_S\, K^\pm\pi^\mp$ decay and PLUTO[17] first reported a measurement

$$\Gamma_{\eta_c\gamma\gamma} \cdot B(\eta_c \rightarrow K^0_S K^\pm\pi^\mp) = 0.5^{+0.2}_{-0.15} \pm 0.1 \text{ KeV}$$

Table IV

Meson	Decay Mode	$\Gamma_{\gamma\gamma}$ [keV]	Experiment
π^0		$(7.85 \pm 0.54) \cdot 10^{-3}$ $(7.25 \pm 0.18 \pm 0.11) \cdot 10^{-3}$ $(7.8 \pm 0.4 \pm 0.9) \cdot 10^{-3}$	PDG (1984) NA30 (lifetime) [35] Crystal Ball (prel.) [34]
π^0		$(7.48 \pm 0.33 \pm 0.31) \cdot 10^{-3}$	average^a
η		1.00 ± 0.22 0.324 ± 0.046	DESY (Primakoff) [38] Cornell (Primakoff) [39]
η		$0.56 \pm 0.12 \pm 0.10$ $0.53 \pm 0.04 \pm 0.04$ $0.64 \pm 0.14 \pm 0.13$ $0.51 \pm 0.02 \pm 0.06$	Crystal Ball (SPEAR) [40] JADE [41] TPC/$\gamma\gamma$ [42] Crystal Ball (DORIS) (prel.) [43]
η		0.53 ± 0.04	average (e^+e^- only)
η'	miss.-mass $\rho\gamma$ $\rho\gamma$ $\rho\gamma$ $\rho\gamma$ $\rho\gamma$ $\rho\gamma$ $\gamma\gamma$ $\rho\gamma$ $\eta\pi\pi(\eta \to \gamma\gamma)$ $\eta\pi\pi(\eta \to 3\pi)$	5.4 ± 2.1 $5.8 \pm 1.1 \pm 1.2$ $6.2 \pm 1.1 \pm 0.8$ $5.0 \pm 0.5 \pm 0.9$ $5.1 \pm 0.4 \pm 0.7$ $3.8 \pm 0.26 \pm 0.43$ $4.5 \pm 0.3 \pm 0.7$ 4.0 ± 0.9 3.8 ± 0.5 4.3 ± 0.8 3.6 ± 1.0	πp scattering [44] Mark II (SPEAR) [45] CELLO [46] JADE [47] TASSO [48] PLUTO [49] TPC/$\gamma\gamma$ [51] JADE [41] Mark II (PEP) (prel.) [50] Mark II (PEP) (prel.) [50] Mark II (PEP) (prel.) [50]
η'		4.3 ± 0.3	average

which, when taken with the average Branching ratio[18] gave $\Gamma_{\eta_c\gamma\gamma} = 28 \pm 15$ KeV. Mark II[19] and CELLO[2] see considerably smaller signals in the same decay mode. A TPC/2γ result[20] using the decay mode $K^+K^+K^-K^-$, and the beautiful R704 experiment[21] at the ISR which utilized the $\bar{p}p$ formation of the η_c and its subsequent decay into $\gamma\gamma$, also gave smaller values. At this conference TASSO has presented[22] the results of a global fit to three decay modes; $K^0K^{\pm}\pi^{\mp}$, $K^+K^-\pi^+\pi^-$, and $\pi^+\pi^+\pi^-\pi^-$, giving $\Gamma_{\eta_c\gamma\gamma} = 19.9 \pm 6.1 \pm 8.6$ KeV.

These results are shown in Figure 8 and summarized in Table V. All are consistent with the range of theoretical predictions. The simplest $^1S_0$ $c\bar{c}$ model predicts 7 KeV, although at this conference Lipkin has indicated[23] corrections that can raise this prediction by about 20%.

Table V

$\Gamma_{\gamma\gamma}\eta_c$	
PLUTO	28 ± 15 KeV
TASSO	19.9 ± 6.1 ± 8.6 KeV
TPC/2γ	$6.4^{+5.0}_{-3.5}$ KeV
	<15.5 KeV
CELLO	<12 KeV
Mark II	8 ± 6 KeV
R704	$4.3^{+3.4}_{-3.7} \pm 2.4$

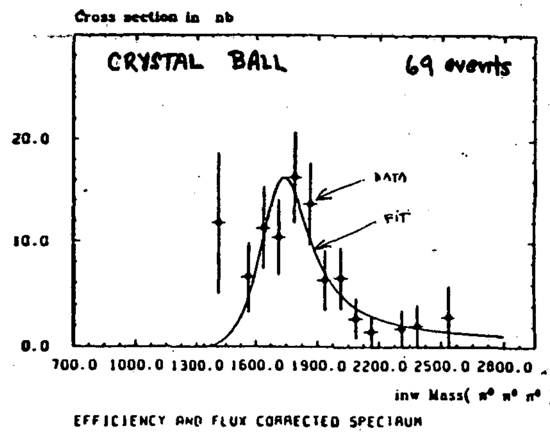


Figure 7

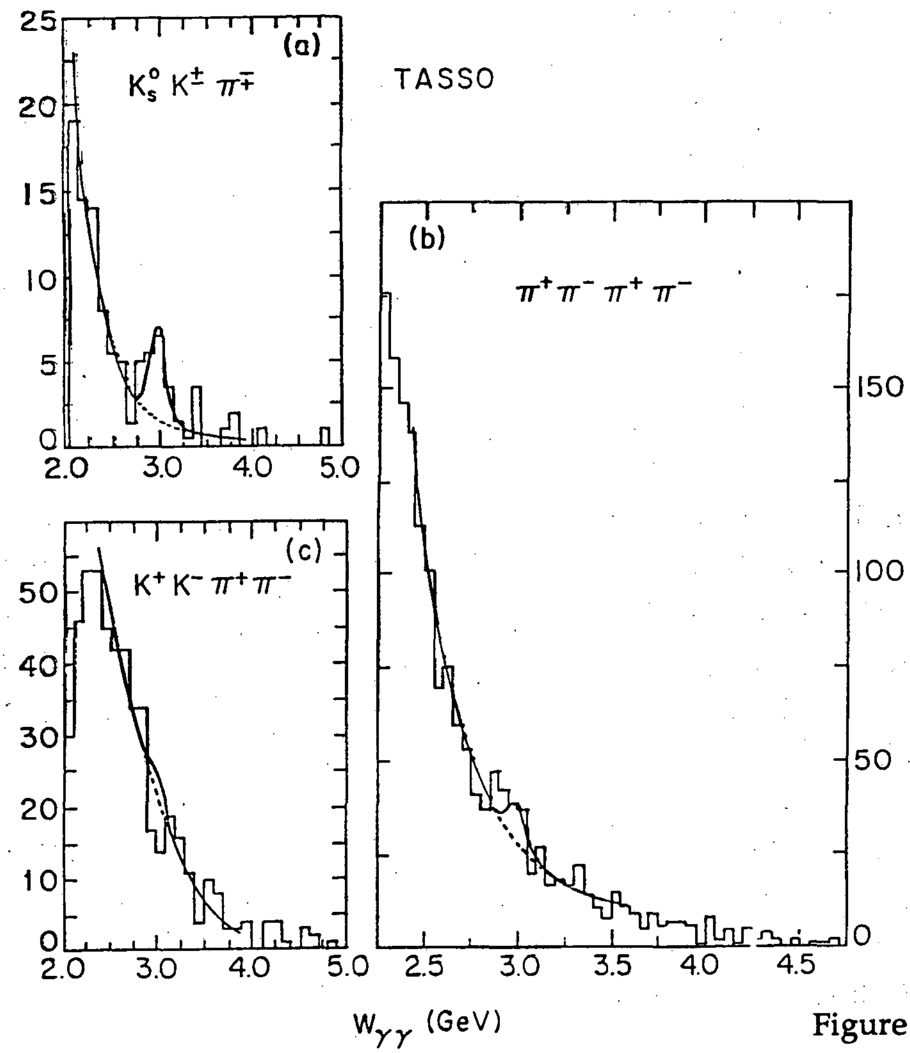
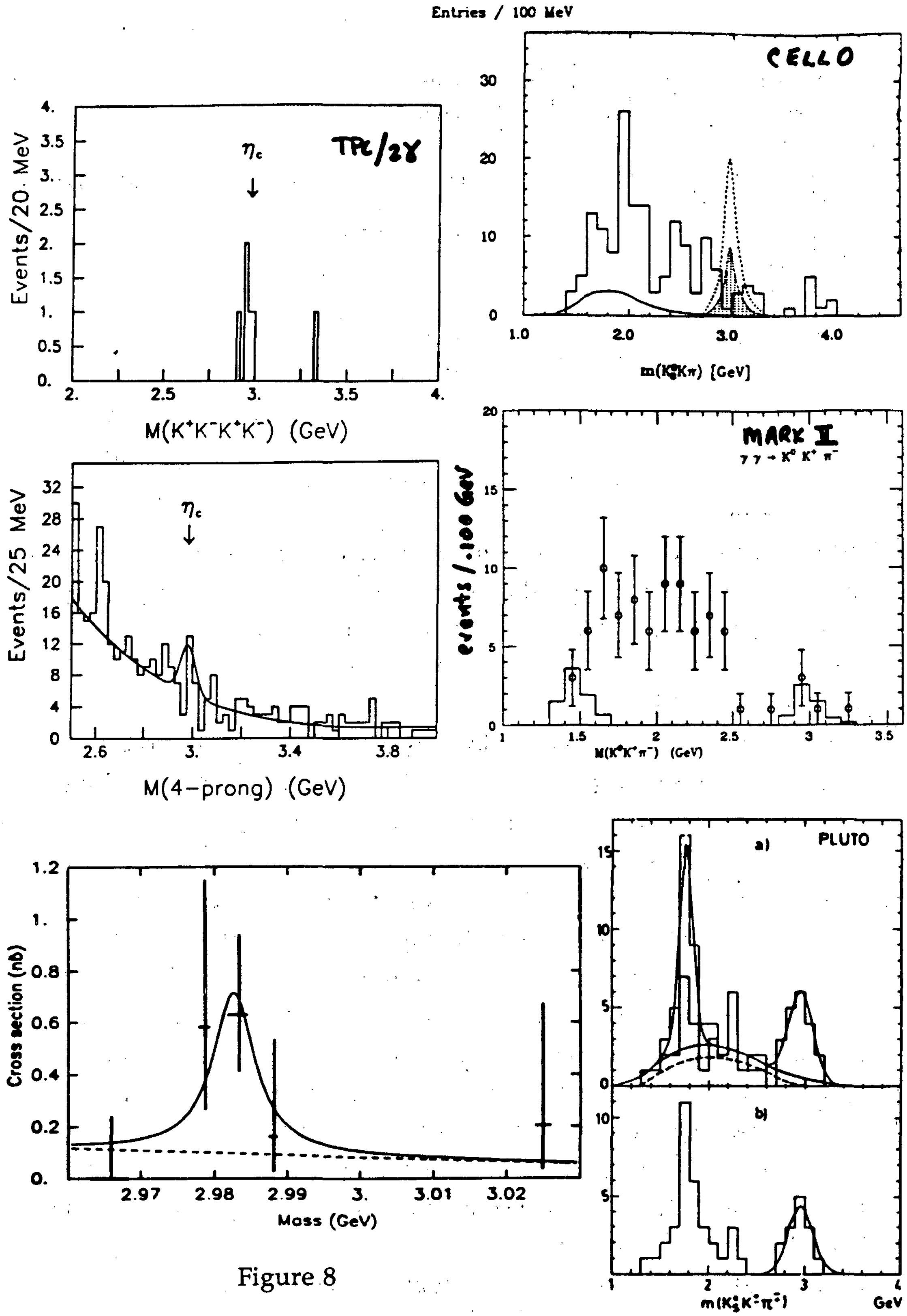


Figure 8



Entries / 100 MeV
CELLO
m(K^0_SKπ) [GeV]
Events/20. MeV
η_c
TPC/2γ
M(K$^+$K$^-$K$^+$K$^-$) (GeV)
MARK II
$\gamma\gamma \to K^0 K^+ \pi^-$
events / .100 GeV
M(K^{0}K$^+\pi^-$) (GeV)
Events/25 MeV
η_c
M(4−prong) (GeV)
Cross section (nb)
Mass (GeV)
a)
PLUTO
b)
m(K^0_SK$^\pm\pi^\mp$)
GeV

Figure 8

Table VI

	Tagging	$<E_b>$	$\int L(pb^{-1})$	Particle ID
JADE	Q^2: 0 - 1.1 43-75 mrad 1/3 32-75 mrad 2/3	18.3	214	$K^{\pm}$ by dE/dx K° by mass
TPC	Q^2: 0 - 5 25-90 mrad 100-180 mrad	14.5	114	$K^{\pm}$ by dE/dx K° by mass
Mark II	Q^2: 0 - 1.2 21-82 mrad	14.5	220	$K^{\pm}$ by TOF K° by VTX and mass
CELLO	Q^2: 0 - 8 50-400 mrad	17.5	86	$K^{\pm}$ by VTX and mass $K^{\pm}$ by best K^*

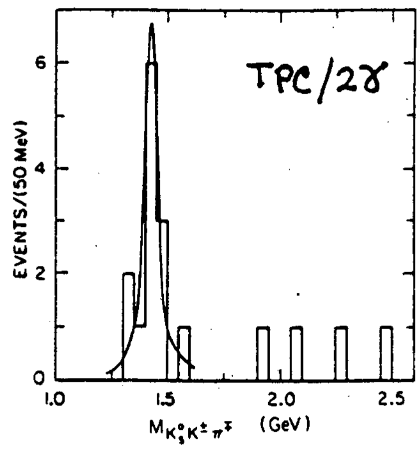


Figure 9

A topic of great interest to this conference is the $\gamma\gamma^*$ production of spin 1 resonances. Although Yang's theorem prohibits the formation of spin 1 mesons by real photons, taking one photon off the mass shell by a relatively small amount, immediately allows their production, as first suggested by Renard.[24]

Dramatic evidence[25] for production of such a spin 1 state at 1425 MeV in the $KK\pi$ channel was presented by the TPC/2γ group at the last Photon Photon Workshop in Paris and their updated result is reproduced in Figure 9. The nonobservation of such a peak in untagged formation confirms the spin 1 nature. This result was subsequently confirmed by Mark II[26], who pointed out the K*K dominance in its decay, and additional confirmation has been presented to this conference by the CELLO[27] and JADE[28] groups. The conditions of the four experiments are given in Table VI. The experimental mass spectra are shown in Figure 10. We take the liberty of combining the data from all four experiments in Figure 11, even though the acceptances and backgrounds are certainly different. If we assume the acceptance to be slowly varying over the resonance region, then the sum indicates that the resonance is rather narrow. Most of the events are in one 50 MeV bin. A simple Gaussian fit gives a mass of 1430 MeV and a σ of 17 MeV, consistent with the typical experimental mass resolution.

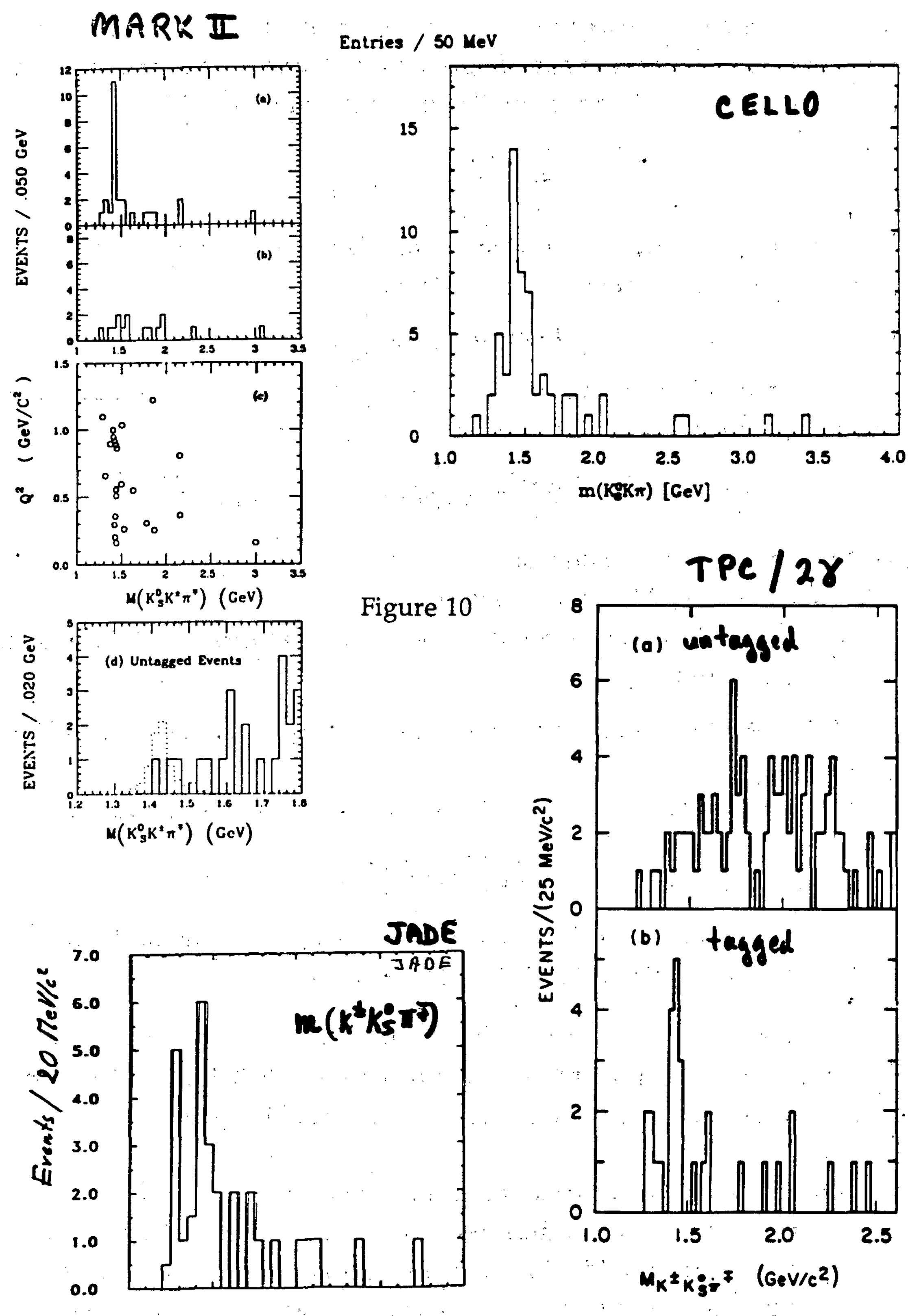

MARK II
EVENTS / .050 GeV
(a)
(b)
(c)
Q^2 (GeV/c^2)
$M(K^0_S K^\pm \pi^\mp)$ (GeV)
(d) Untagged Events
EVENTS / .020 GeV
$M(K^0_S K^\pm \pi^\mp)$ (GeV)
Entries / 50 MeV
CELLO
$m(K^0_S K\pi)$ [GeV]
TPC / 2γ
(a) untagged
(b) tagged
EVENTS/(25 MeV/c^2)
$M_{K^\pm K^0_S \pi^\mp}$ (GeV/c^2)
JADE
Events / 20 MeV/c^2
$m(K^\pm K^0_S \pi^\mp)$

Figure 10

One usually measures $\frac{d\sigma}{dQ^2}$ with the other electron antitagged. Assuming a standard ρ dominance form for $F(Q^2)$ and narrow resonances, and starting from the equations of Budnev et al.[29] or of Bonneau, Gourdin and Martin[30] with

$$\frac{E_1 E_2 d^6\sigma}{dp_1^3 dp_2^3} = \sum L_{ij}\, \sigma_{ij}$$

One retains σ_{TT} and σ_{TL}. It is convenient to define (Renard[24], Cahn[33]) a $\tilde{\Gamma}$, which is nearly independent of Q^2 at small Q^2.

$$\tilde{\Gamma}_{\gamma\gamma^*R} \equiv \Gamma_{\gamma\gamma^*R} \cdot \frac{M^2}{Q^2}$$

Relating σ_{TT} and σ_{TL} in Cahn's nonrelativistic quark model, one then finds a formula analogous to the Low formula (for J = 0,2)

$$\sigma(ee \to eeR) \sim \frac{\tilde{\Gamma}_{R\gamma\gamma^*}}{M^3} \int \frac{dQ^2}{M^2} F^2(Q^2)\ \{1 + a_{model} \cdot \frac{Q^2}{M^2}\}$$

One then compares to the data to deduce $\tilde{\Gamma}$.

Two conventions have now been used:

(1) Cahn[31, 32]: Takes into account non identical nature of T and L photons in relating σ to $\tilde{\Gamma}_{TL}$.

(2) TPC/2γ:[25] Uses same relation between σ and $\tilde{\Gamma}_{TL}$ as between σ and Γ_{TT} for spin 0,2.

The radiative widths extracted from the measured cross sections are related by

$$\tilde{\Gamma}^{Cahn}_{R\gamma\gamma^*} = 2\,\tilde{\Gamma}^{TPC}_{R\gamma\gamma^*}$$

The values obtained in the four experiments are given in Table VII and graphically show in Figure 12. The agreement is excellent.

The rather large radiative width measured for this particle has put into question its association with the predominantly $s\bar{s}$ $f_1(1425)$ or "E" meson. In particular Chanowitz[33] has suggested that it could be an "exotic" 1^{-+} state.

Cahn[31] has pointed out that for small Q^2/M^2, the distribution in the angle between the normal to the decay plane and the incident photon, in the rest frame of the produced resonance, is proportional to $\sin^2\theta$ for a 1^{-+} resonance and to $1 + \cos^2\theta$ for a 1^{++} resonance. Figure 13 shows this

Table VII

$B(K\bar{K}\pi)\cdot\tilde{\Gamma}_{\gamma\gamma^*}(f_1(1425))$		
	TPC/2γ Convention	Cahn Convention
TPC/2γ	$1.3 \pm 0.5 \pm 0.3$ (ρ pole) $0.63 \pm 0.24 \pm 0.15$ (ϕ pole)	$2.6 \pm 1.0 \pm 0.6$ KeV (ρ pole)
Mark II		$3.2 \pm 1.4 \pm 0.6$ KeV ρ pole $2.1 \pm 1.0 \pm 0.4$ (ϕ pole)
JADE	$1.9^{+1.0}_{-0.7} \pm 0.6$ (ρ pole)	$3.8^{+2.0}_{-1.4} \pm 1.2$ KeV (ρ pole)
CELLO	$1.5 \pm 0.4 \pm 0.3$ ρ pole $0.7 \pm 0.2 \pm 0.2$ (ϕ pole)	$3.0 \pm 0.8 \pm 0.6$ KeV (ρ pole)
weighted mean		3.0 ± 0.6 KeV

distribution in cosθ for the several experiments, together with the Monte Carlo expectations for each hypothesis. Clearly, no conclusion is possible at this level of statistics.

Having confirmed the spin 1 particle at 1425, the Mark II group also observed[34] the well known $J^{PC} = 1^{++}$ $f_1(1285)$ in the tagged $\eta\pi^+\pi^-$ events. Again, the tagged events show the η'(958) and the $f_1(1285)$ [Figure 14] while the untagged events show only the η'(958). The Q^2 dependence of the η'(958) is consistent with a ρ-pole Form Factor as was nicely demonstrated by the TPC/2γ group[25] at this Conference (Figure 15), and previously by the PLUTO group.[35] The TPC/2γ[25], CELLO[36], and JADE[37] groups have all now reported observing the $f_1(1285)$ and their contributions to this workshop are shown in Figures 16, 17, and 18. The $f_1(1285)$ actually decays via $a_0(980)\,\pi$ with the $a_0(980) \rightarrow \eta\pi$. This is nicely shown in the JADE $\eta\pi^\pm$ mass plot (Figure 19).

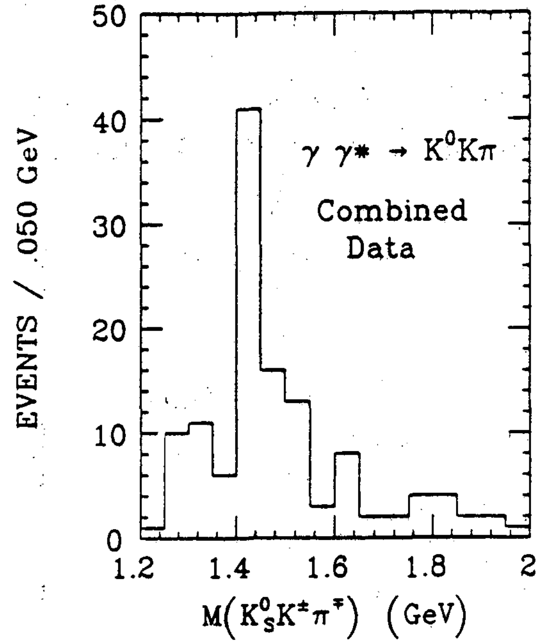


Figure 11

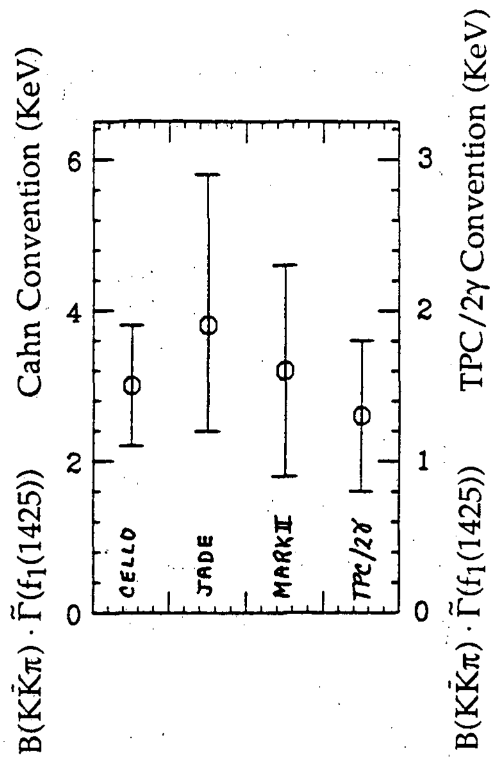
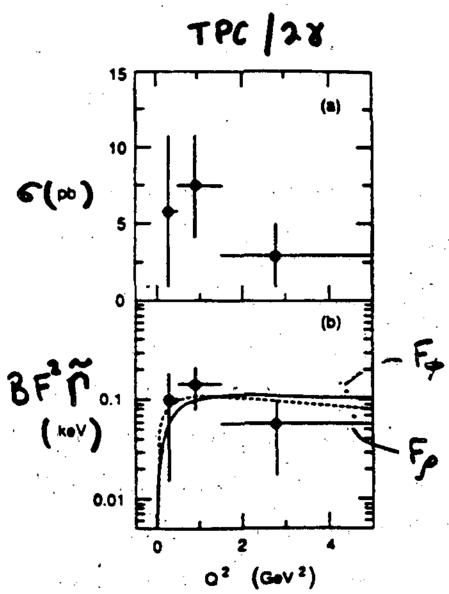
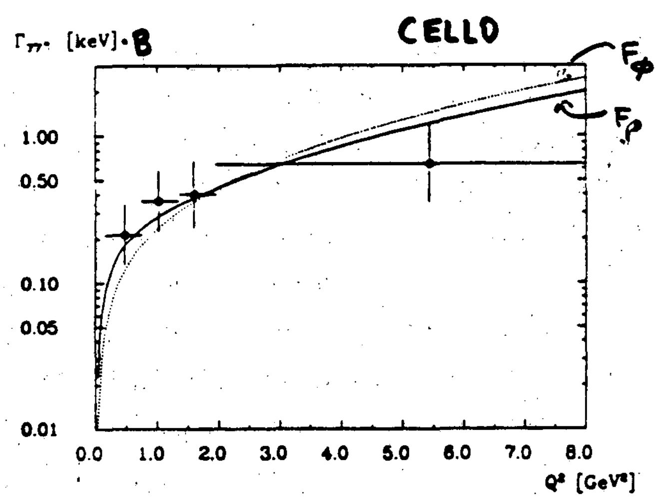
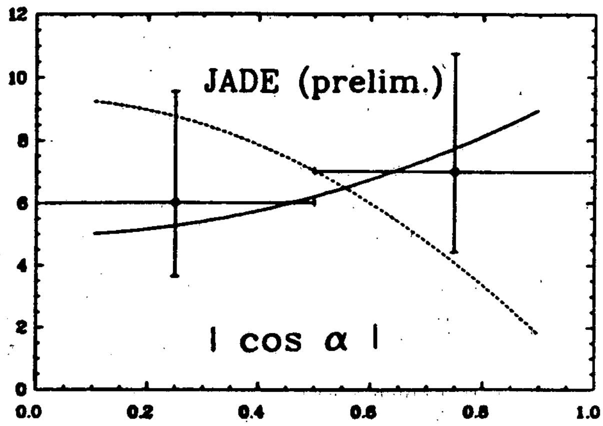


Figure 12







TPC/2γ		
$R = \sigma_{TT}/\sigma_{TL}$		
P = +1,	R = 1,	C.L. = 69%
P = -1,	R = 0	C.L. = 29%
P = -1,	R = 1	C.L. = 1.4%

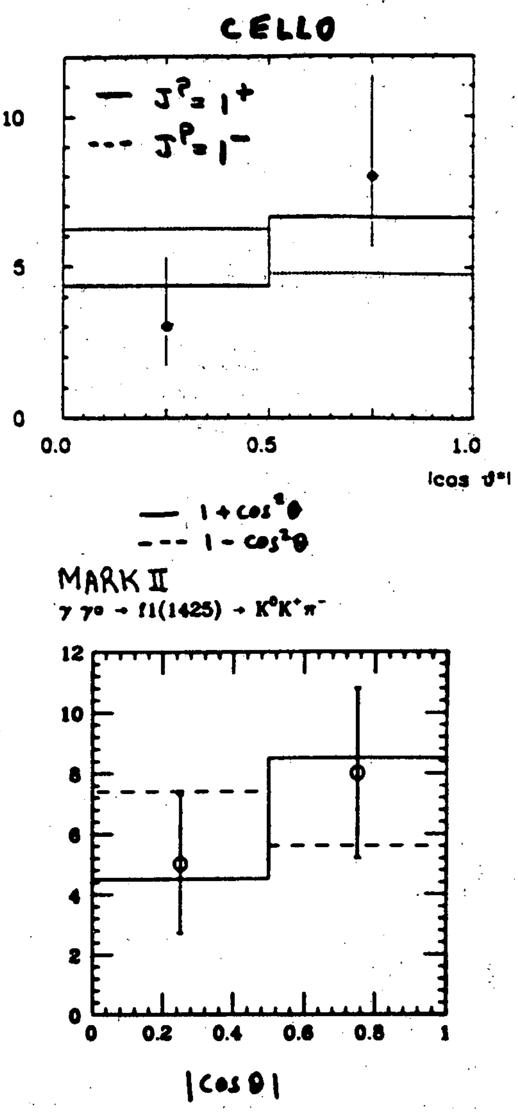


Figure 13

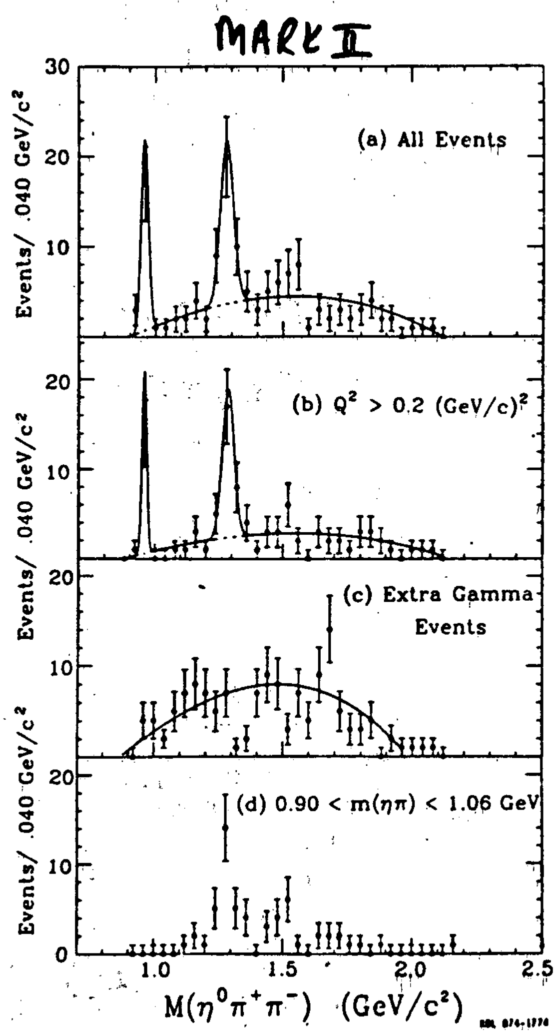


Figure 14

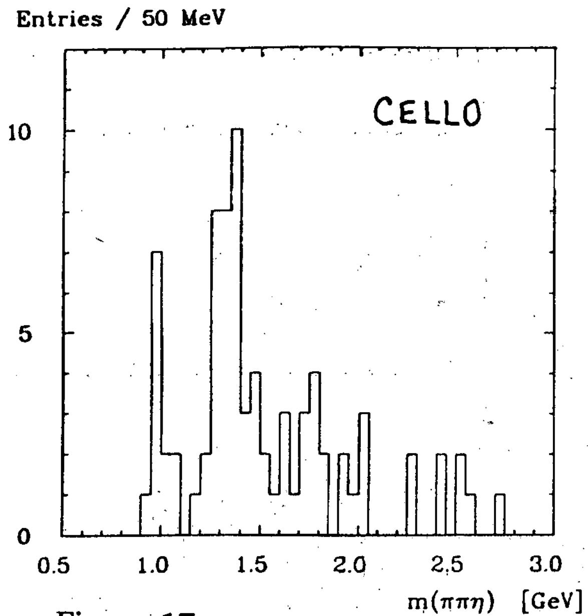


Figure 17

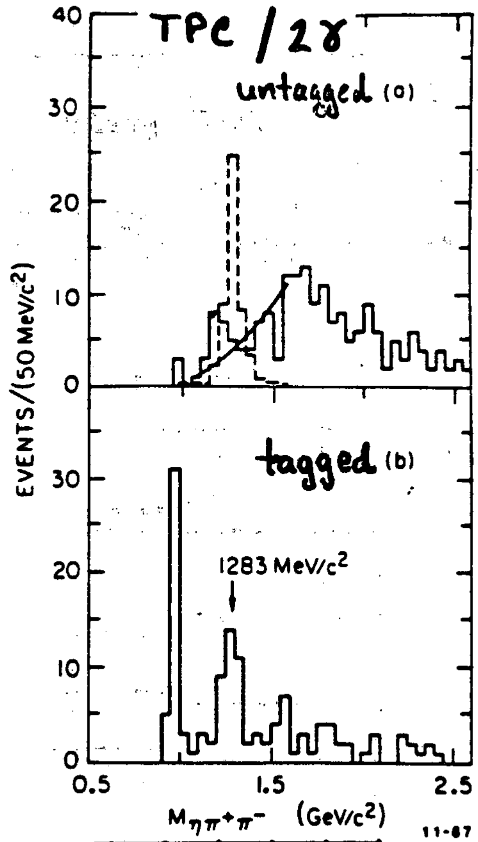


Figure 16

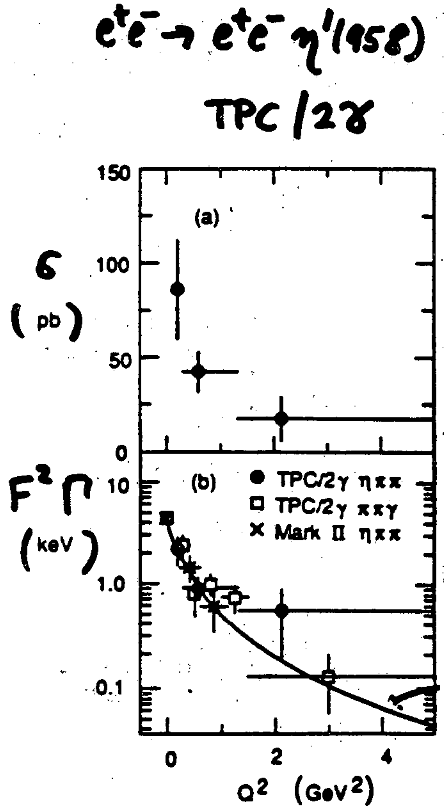
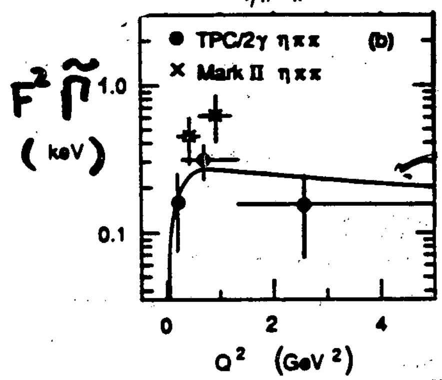


Figure 15



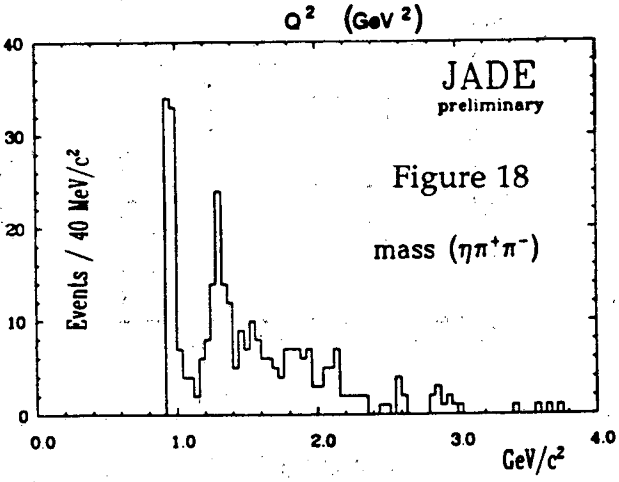


Figure 18

mass $(\eta\pi^+\pi^-)$

In this case the higher statistics and greater acceptance allow a clearer measurement of the parity. Figure 20 shows the Mark II and JADE $\cos\theta$ distribution for the $f_1(1285)$ events and they clearly favor positive parity.

In a non relativistic quark model, the 1^{++} $^3P_1$ $q\bar{q}$ nonet with ideal mixing contains the isoscalars $|A\rangle = s\bar{s}$ and $|B\rangle = (u\bar{u}+d\bar{d})/\sqrt{2}$ with squared charges 1/9 and $5\sqrt{2}/18$ respectively.
For an angle λ deviation form ideal mixing

$$|f_1(1285)\rangle = \cos\lambda\,|A\rangle + \sin\lambda\,|B\rangle$$
$$|f_1(1420)\rangle = \sin\lambda\,|A\rangle + \cos\lambda\,|B\rangle$$

The $\gamma\gamma^*$ matrix element $\langle 0|J_{em}J_{em}|q\bar{q}\rangle$ acting on $|f_1(1285)\rangle \sim \cos\lambda\frac{5}{\sqrt{2}} + \sin\lambda$ and acting on $|f_1(1420)\rangle \sim \sin\lambda\frac{5}{\sqrt{2}} + \cos\lambda$.
Defining

$$R = \frac{\Gamma(f_{1(1285)}\rightarrow\gamma\gamma^*)}{\Gamma(f_{1(1420)}\rightarrow\gamma\gamma^*)} = \frac{\frac{5}{\sqrt{2}}\cos\lambda+\sin\lambda}{-\frac{5}{\sqrt{2}}\sin\lambda+\cos\lambda} = \frac{\sin^2(\lambda+\beta)}{\cos^2(\lambda+\beta)} = \tan^2(\lambda+\beta) \text{ gives}$$
$$\cos\beta \equiv \sqrt{\frac{2}{27}} \text{ and } \sin\beta = \frac{5}{\sqrt{27}}$$

Figure 21 shows this ratio R in terms of λ and the various experimental results. The weighted mean defines a range of λ values between -14° and -25°.

The placement of these spin 1 states in the same 1^{++} nonet is not at all certain. The observation[38] of the $\phi\gamma$ decay of the $f_1(1285)$ insures that it has a sizeable $s\bar{s}$ component, while the recent LASS observation[39] of an $s\bar{s}$ state at 1530 MeV indicates that this state might be the proper partner of the $f_1(1285)$. In fact Caldwell[40] has proposed that the 1425 MeV state observed in $\gamma\gamma^*$ interactions is a four quark state. The resolution of these questions clearly awaits more data.

This summary relied on the contributions of many groups and I thank R. Cahn, H. Mariske, A. Nilsson and J. Olsson for their cooperation in preparing this talk.

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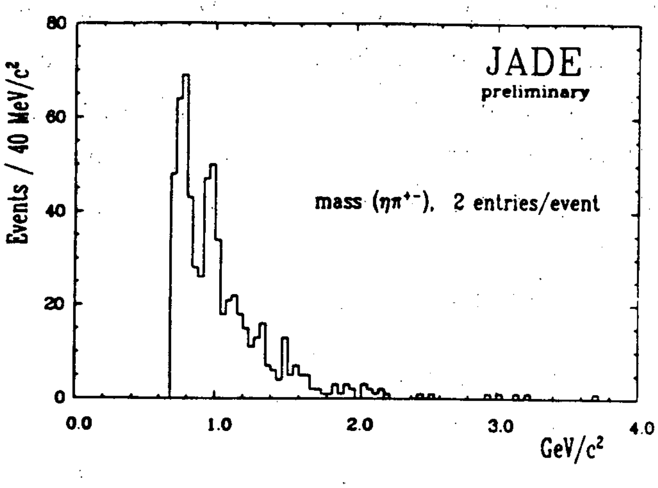


Figure 19

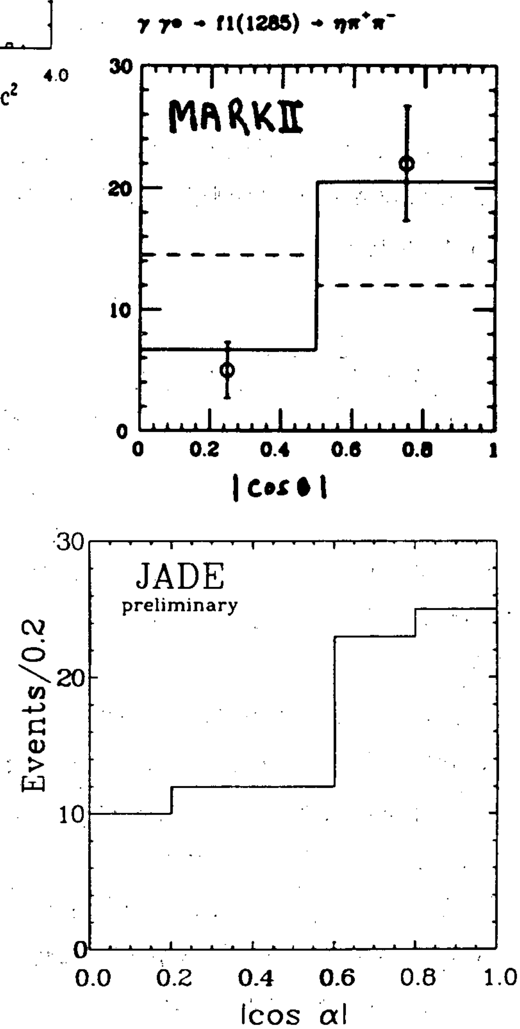
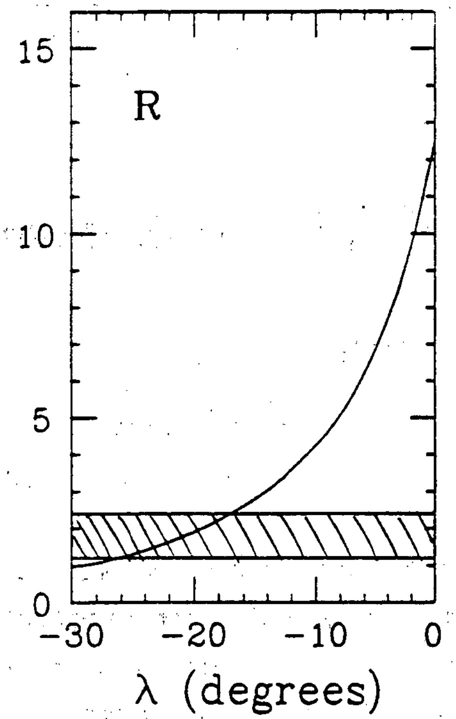


Figure 20



$R\left(\frac{\tilde{\Gamma} f_1(1285)}{\tilde{\Gamma} f_1(1425)}\right)$	
TPC/2γ	1.8 ± 0.8
MARK II	2.9 ± 1.5
JADE	0.95 ± 0.52
CELLO	2.4 ± 1.0
Mean	1.8 ± 0.6

Figure 21

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