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SLAC 3/9/99
τ-c workshop

Radiative J/ψ decay and the search for glueballs

While there has been progress,

- improved lattice simulations
- data from BES, LEAR, BNL, KEK...

today's glueball search bears uncomfortable similarity to 1990:

- interesting candidates, none elected
- election requires consistent, definitive results from theory & experiment
- lattice still can't cope w $\bar{q}q$ mixing

  (Devil's advocate: even pure Y-M results aren't rigorously proven, could have presently unknown systematic errors)
- experimental situation still far from clear
  - greatest single need is to surpass current ψ data samples

    $$\text{BES} \sim \text{MkIII} \sim \text{DM2} \sim \text{MkII} \approx 8 \cdot 10^6\,\psi$$

    in order to resolve many remaining issues in $\psi \to \gamma$ + hadrons.

Other processes might be gluon-enhanced
- $\bar{p}p$ annihilation, $\pi p, pp$ central production, g-jet fragmentation ...

but none as gluon-pure & clean as

$$\psi \to \gamma X \sim \psi \to \gamma g g$$

$$\frac{\Gamma(\psi \to \gamma g g)}{\Gamma(\psi \to g g g)} = \frac{16}{5} \frac{\alpha}{\alpha_s} + \cdots$$

Semiquantitative
Spectrum v. diff. than lowest order QCD

$$\Rightarrow \quad B(\psi \to \gamma X) \sim 0.06 \pm 0.02$$

(Consistent w Mk II inclusive γ-)

$\Rightarrow$ copious source of color singlet gg's pairs, perfectly matched to $1-2\frac{1}{2}$ GeV region,

e.g., $$\frac{\psi \to \gamma X_{1\text{-}2\,\mathrm{GeV}}}{\Upsilon \to \gamma X_{1\text{-}2\,\mathrm{GeV}}} \sim \frac{\sigma_\psi}{\sigma_\Upsilon} \left(\frac{e_c}{e_b}\right)^2 \frac{\left(\dfrac{\psi \to \gamma X_{1\text{-}2\,\mathrm{GeV}}}{\psi \to \gamma X}\right)}{\left(\dfrac{\Upsilon \to \gamma X_{1\text{-}2}}{\Upsilon \to \gamma X}\right)}$$

$$\sim 10^2 \cdot 4 \cdot 10 \sim 4000$$

$\Rightarrow$ Clearly God gave us radiative ψ decay to find & study glueballs.

- Dominant gg partial waves in $\psi \to \gamma g g$ are 0^{++}, 0^{-+}, 2^{++}, precisely the quantum nos. of the ground-state glueballs expected at $\sim 1\frac{1}{2} - 2\frac{1}{2}$ GeV.
- Relative to prominent meson signals,

$$B(\psi \to \gamma \eta'_{958}) \sim 0.4\%$$

$$B(\psi \to \gamma f_2(1270)) \sim 0.14\%$$

we expect $\gtrsim$ signals for leading glueballs (corrected for phase space).

[Expect $>$ for $J=2$, $\gtrsim$ for 0^{-+} since η' rate is enhanced by anomaly]

- Goal: statistics in $\psi \to \gamma X$ comparable to LASS for $\bar{s}s$, $\bar{s}n$

$$\Longrightarrow \quad O(10^8 \ \psi\text{'s})$$

(will settle for ~ 30M in short run)

The current crop of candidates

$f_J(2230)$	ξ
$f_J\ (1710)$	θ?
$f_0\ (1500)$	G
"$\eta\,(1440)$ – region"	2/E

$\xi = f_J(2230)$

BES confirms Mk III

	$B(\psi \to \gamma\xi_{\hookrightarrow X})\ (10^{-5})$	$\sim$ # events
$\pi^+\pi^-$	$5.6\,^{+1.8}_{-1.6} \pm 2$	30
$\pi^0\pi^0$	$4.5 \pm 2.6 \pm 1.3$	15
K^+K^-	$3.3\,^{+1.6}_{-1.3} \pm 1.2$	30
$K_s K_s$	$2.7\,^{+1.1}_{-0.9} \pm 0.8$	15
$\bar{p}p$	$1.5\,^{+0.6}_{-0.5} \pm 0.5$	15

- Insufficient data to measure J
- LASS $f_4(2220)$ could be different, need J measured in $\psi \to \gamma\xi$
- Even if $J_\xi = 0$ or 2, above facts alone do not strongly suggest $\xi = G$. Possibility that $\xi = G$ rests on two failures to observe ξ.

Failure #1 CLEO (Assume $J=2$)

$$\Gamma(\xi \to \gamma\gamma) \cdot B(\pi^+\pi^-) < 2.5 \text{ eV}$$

$$\text{"} \cdot B(K_S K_S) < 1.3 \text{ eV}$$

95%

$\Rightarrow$ lower bound on stickiness

$$S_X = C \cdot \frac{\Gamma(\psi \to \gamma X)}{\Gamma(X \to \gamma\gamma)} \cdot \frac{LIPS(X \to \gamma\gamma)}{LIPS(\psi \to \gamma X)}$$

Normalize C so that $S_{f_2(1270)} = 1$

For $f_2 - f_2'$ ideal mixing, expect naively that

$$S_{f_2'(1525)} = \frac{1}{2} \cdot \frac{\left(\frac{1}{\sqrt{2}}\left(\frac{2^2}{3} + \frac{1^2}{3}\right)\right)^2}{\left(\frac{1}{3}\right)^4} = 6\frac{1}{4}$$

cf $\quad S_{f_2'(1525)} = 11.1 \pm 3.4$

CLEO combined bound from $\pi^+\pi^- + K_S K_S$ is

$$S_\xi > 102 \qquad 95\% \text{ CL}$$

Failure #2 LEAR: PS185 + JETSET

Assume $J = 2$ $\Gamma_\xi > 5$ GeV

JETSET analysis of combined data: (more conservative than PS185 analysis)

$$B(\xi \to \bar{p}p) \cdot B(\xi \to K_s K_s) < 7.5 \cdot 10^{-5} \quad 95\%$$

Crudely, combining all errors in quadrature,

$$B^2(\psi \to \gamma\xi)\, B(\xi \to \bar{p}p)\, B(\xi \to K_s K_s) = 4.1 \pm 2.8 \cdot 10^{-10}$$

$$\Rightarrow \quad B(\psi \to \gamma\xi) > 2.3^{+0.7}_{-1.3} \cdot 10^{-3}$$

i.e., suggests $B(\psi \to \gamma\xi) \sim O(10^{-3})$

$\Rightarrow$ $B(\psi \to \gamma\xi)$ might be in plausible range for glueball.

(Stronger lower bounds on $B\,\psi \to \gamma\xi$ are claimed in literature)

With more statistics we could

- measure J_ξ
- increase precision for
  $B^2(\psi \to \gamma\xi \to \bar{K}K, \bar{p}p)$
  to obtain a robust lower bound.
- find missing multibody decays

$f_J(1710)$

- Long, confusing history, perhaps dating to Crystal Ball $\psi \to \gamma\, \Theta(1640) \to \eta\eta$
- BES moment analysis $\psi \to \gamma K^+K^-$

$$\Rightarrow \quad J=2 \qquad m=1696 \qquad \Gamma=103$$

$$B(\psi \to \gamma f_J)\, B(\bar{K}K) = 8.5^{+1.2}_{-0.9} \cdot 10^{-4} \qquad \text{PDG}$$

- BES $\quad B(\psi \to \gamma f_J)\, B(\pi^0\pi^0) = 8.3 \pm 5.3 \pm 2.8 \cdot 10^{-5}$

$$\Rightarrow \quad B(\bar{K}K) > B(\pi\pi)$$

- CELLO

Most conservative CELLO bound $\quad \Gamma(f_2^{1710} \to \gamma\gamma)\, B(\bar{K}K) < 0.2 \text{ keV} \qquad 95\%$

$$\Rightarrow \quad S(f_2^{1710}) / S(f_2^{1270}) > 12$$

$$\text{Cf} \qquad S(f_2'^{\,1525}) \sim 11$$

$\Rightarrow$ interpretation unclear

f_0 (1500)

Crystal Barrel & Obelix

$f_0 \to \eta\eta, \eta\eta', 4\pi, \pi\pi, \bar{K}K$

$m = 1500 \pm 10 \qquad \Gamma = 112 \pm 10 \qquad$ PDG

Could be $I=0$ partner of $f_0(1370)$

(PDG: $m \sim 1200-1500$, $\Gamma \sim 200-500$)

but $\dfrac{B(\bar{K}K)}{B(\pi\pi)} \cdot \dfrac{q_{\pi\pi}}{q_{\bar{K}K}} = 0.24 \pm 0.9$

No obvious signal for $\psi \to \gamma f_0(1500)$, but indicated by isobar model of $\psi \to \gamma \pi^+\pi^-\pi^+\pi^-$

Bugg et al. $\quad B(\psi \to \gamma f_0 \to \sigma\sigma \to 4\pi) = 5.7 \pm 0.8 \cdot 10^{-4}$

Important to verify $\psi \to \gamma f_0(1500)$ in 4π & other decay channels

Crystal Barrel:

$$B(f_0^{1500} \longrightarrow \pi\pi) = 29 \pm 7.5 \ \%$$

$$B(f_0^{1500} \rightarrow 4\pi) = 62 \pm 10 \ \%$$

$\Longrightarrow$ Bugg et al. fit

$$B(\psi \rightarrow \gamma f_0^{1500} \hookrightarrow \pi\pi) \sim 3 \cdot 10^{-4}$$

$$B(\psi \rightarrow \gamma f_0^{1500} \hookrightarrow \pi^0\pi^0) \sim 1 \cdot 10^{-4}$$

Cf BES:

$$B(\psi \rightarrow \gamma f_J^{1710} \hookrightarrow \pi^0\pi^0) = 8.3 \pm 5.3 \pm 2.8 \cdot 10^{-5}$$

FIGURE

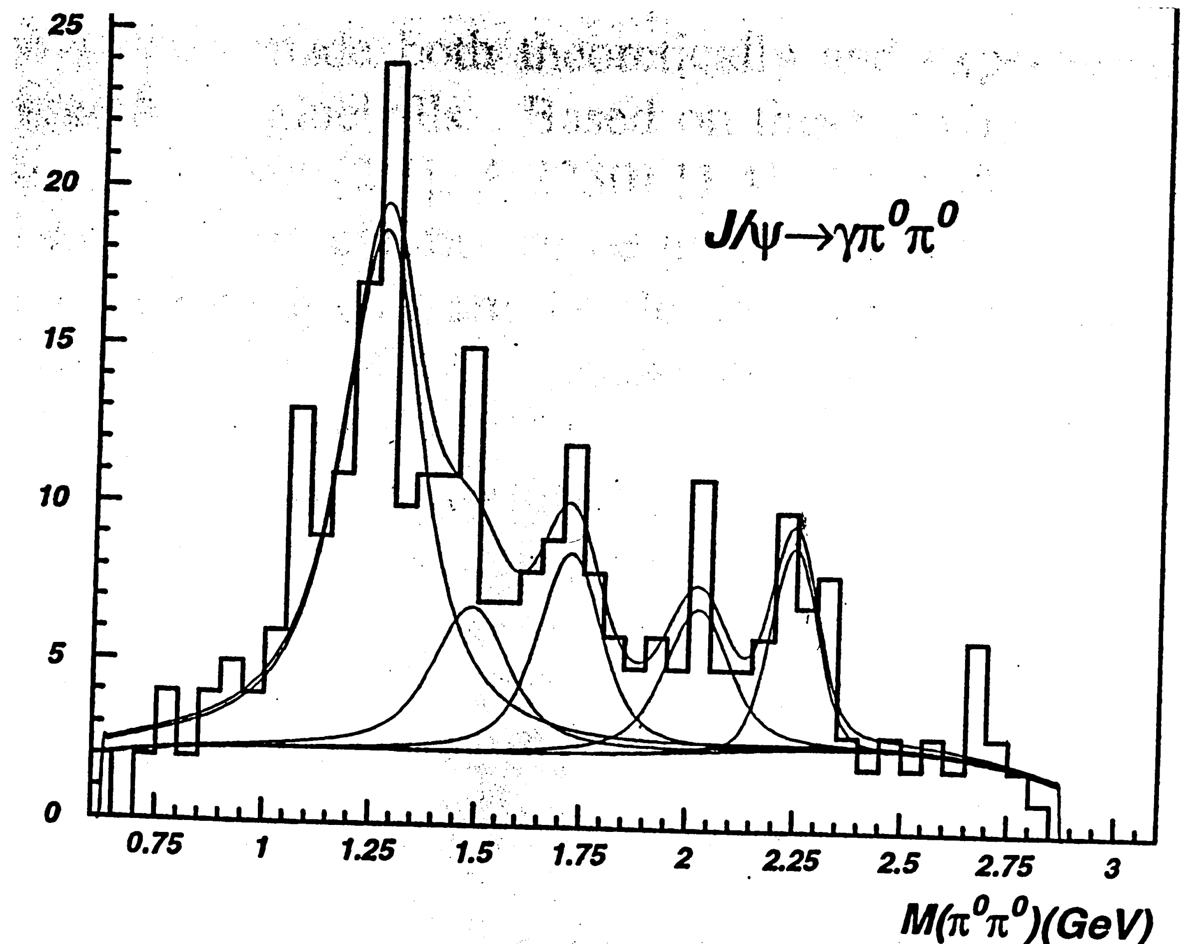

FIG. 2. Fitted invariant mass spectrum of $\pi^0\pi^0$

$E/\iota/\eta_{1440}$ region

- Very interesting & very unclear
- $\psi \to \gamma K K \pi$: BES, MkIII, DM2, MkII
  - no two experiments agree

	0^{-+} m,Γ		0^{-+} BR (10^{-3})		1^{++} m,Γ		1^{++} BR (10^{-3})
MkII	1440, ~50	$a_0\pi$	~4				
DM2	1460, 75	$a_0\pi$	1.8	POOR FITS	1460, 130	K^*K	0.8
	1420, 63	K^*K	0.8				
OR (interfering amps)							
DM2	1410, 40	$a_0\pi$	3.6				
	1410, 34	K^*K	1.9				
MkIII	1416, 54	$a_0\pi$	0.7		1440, 70	K^*K	0.9
	1490, 90	K^*K	1.0				
BES (unpublished)	1470, 90		1.9	3-body analysis	1435, 60		0.8
					1497, 44		0.5

$\Longrightarrow$ need higher statistics pwa to unravel.

Suppose $\quad \mathcal{B}(\psi \to \gamma \eta_{1440} \to K K \pi) \gtrsim 2 \cdot 10^{-3}$

CELLO: $\quad \Gamma_{\gamma\gamma} B_{\bar{K} K \pi} < 1.2$ keV $\quad$ 95%

$\Rightarrow S_{1440} : S_{\eta'} : S_{\eta} \sim (>45) : 9 : 1$

- Lattice prefers heavier $G(0^{-+})$
- Extra $0^{-+}, 1^{++}$ could be $\bar{q}qg$
  - X'tal Barrel $(\eta\pi)_{L=1}$ $J^{PC} = 1^{-+}$ $m \sim 1400$
    (+ GAMS, VES, KEK, BNL)
  - $\gamma\gamma^* \to K^*K$ as $(\bar{u}u + \bar{d}d)g$ $J^P = 1^{-+}$
    $\Rightarrow$ predicted $I = 1$ at ~ 1320
  - DM2 $\psi \to \gamma \bar{K} K \pi$ blip in 1^{-+} at 1400
  - Bag model $m_{\bar{q}qg}(0^{-+}) \sim m_{\bar{q}qg}(1^{-+})$
    $\Rightarrow$ might explain extra structure in E/ι.

$\Longrightarrow$ PWA of $\psi \to \gamma \bar{K} K \pi$ should consider possibility of $1^{-+}(K^*K)$

Reprise : 1^{-+} X_{1420} MC : PLB 187 : 409, '87

$$\left.\begin{array}{l}\gamma\gamma \;\not\to \\ \gamma\gamma^* \to\end{array}\right\} K^*K_{1420} \Rightarrow J^C = 1^+$$

Knee jerk reaction 1^{++} $E_{1420} \sim \bar{s}s$

BUT : $f_1(1420)^{\bar{s}s}$ should be suppressed relative to $f_1(1285)^{\bar{n}n}$

Puzzle $\begin{cases} \bullet\ \gamma\gamma^* \to X \Rightarrow \bar{u}u + \bar{d}d \\ \bullet\ K^*K > \eta\pi\pi \Rightarrow \bar{s}s \end{cases}$

Possible solution :

$$J^{PC} = 1^{-+}\,(\bar{u}u + \bar{d}d)g \;\begin{array}{l} \to K^*K \quad \text{p-wave} \\ \to \eta\pi\pi \quad L = 4 \end{array}$$

$\Rightarrow$ $\eta\pi\pi$ kinematically suppressed.

$\Rightarrow$ predict nearly degenerate $I = 1$ partner (Bag : $\Delta m = -100$ MeV)

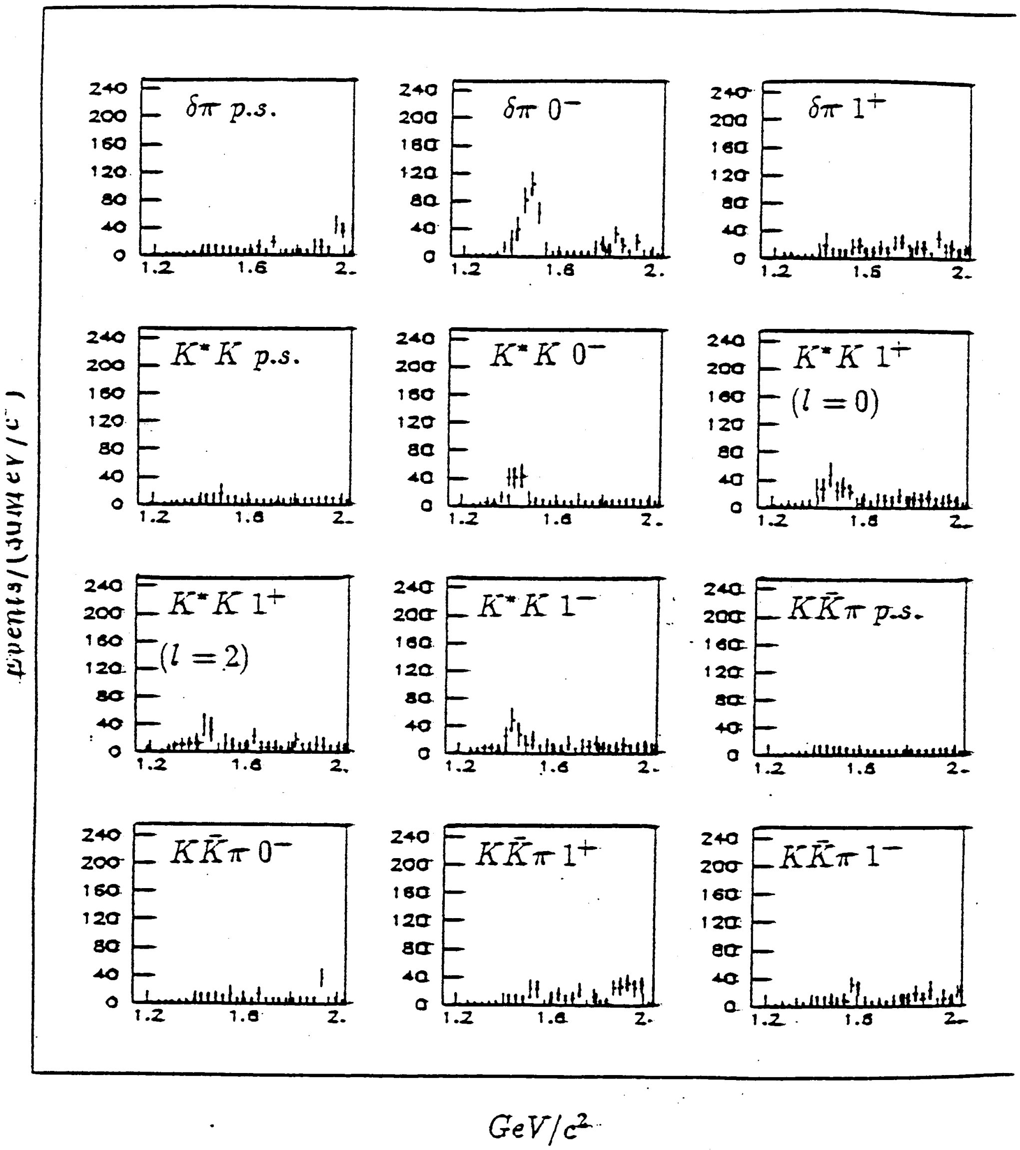

Fig.2 Coupled channel PWA; 12 waves considered.

Conclusion

- In each case —

  ξ, $f_2(1.7)$, $f_0(1.5)$, E-2

  - questions arise that can only be answered by high(er) statistics studies of $\psi \to \gamma X$

- LASS-style analysis with LASS-style statistics is essential