Study on Some Candidates of Glueball or Mixed State at BES

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Outline

1. **Introduction**
2. 0^{++} **glueball candidates** $f_0(1500)$ **and** $f_0(1710)$
3. $\xi(2230)$
4. **Summary**

1. Introduction

- **The glueballs are predicated by QCD**

  They are bosons, SU(3) singlets

- **Criteria of glueballs**

  a) For a given m, Γ, J^{PC}(same as $q\bar{q}$) and I^G, if it is out of $q\bar{q}$ nonet, it may be a glueball candidate.

  b) Produced in "gluon-rich process", for example, J/ψ radiative decay, central production with π, K and p beam and $\bar{p}p$ annihilation

1. Introduction

c) Width is narrower than a typical $q\bar{q}$.

d) decay flavour symmetric (or flavour blind), since gluons do not know one flavour from another.

e) suppressed to decay into two photon, because gluon don't carry electric charge.

f) combine b) and e) Chanowitz created, "stickiness" to measure gluon content

$$S = \frac{\Gamma(J/\psi \to \gamma X)}{\Gamma(\gamma\gamma \to X)} \times \frac{PS(\gamma\gamma \to X)}{PS(J/\psi \to \gamma X)}$$

PS denotes phase space
Large S $\to$ more gluon content
F.Close G.Farrar and Z.Li developed the idea of stickiness

1. Introduction

g) For J/ψ decays

$$R_v(X) = \frac{\Gamma(J/\psi \to \omega X)}{\Gamma(J/\psi \to \phi X)} = \begin{cases} 2 & \mathrm{SU(3)singlet} \\ \frac{1}{2} & \mathrm{SU(3)octet} \end{cases}$$

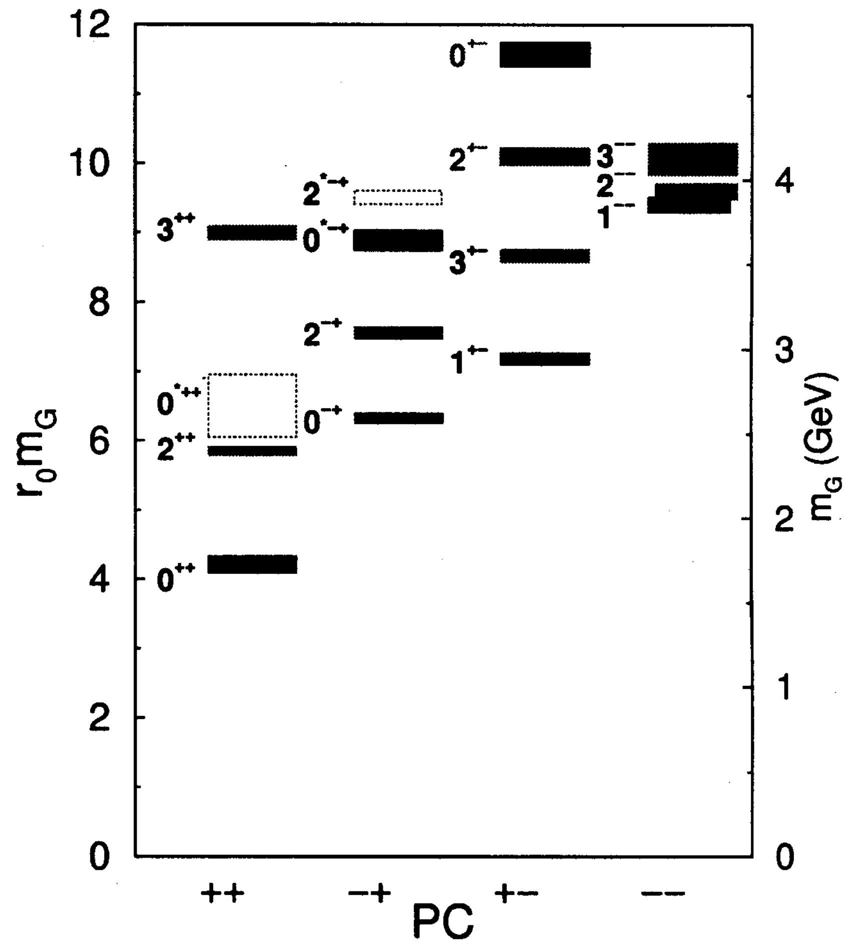
h)

$$R_v(X) = \frac{\Gamma(J/\psi \to \gamma X)}{\Gamma(J/\psi \to (\omega, \phi) + X)}$$

$$\gg \mathbf{1}$$

- **Spectrum of glueballs**
  The expected spectrum of glueballs has been calculated in many QCD based models: MIT Bag model (Constituent gluon model),Flux Tube model, QCD Sum Rule calculation and Lattice calculation.

Lattice prediction of glueball masses



(Morningstar 1997)

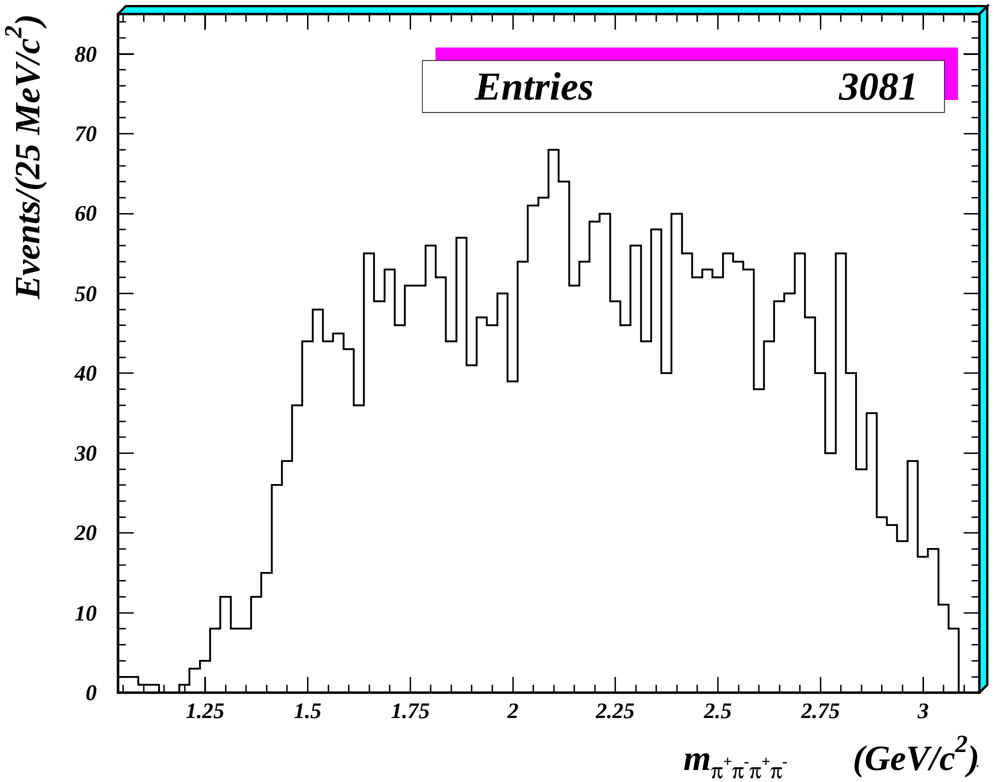
2. 0^{++} glueball candidate

$f_0(1500)$

- Most of the $f_0(1500)$ data are from Crystal Barrel $p\bar{p}$ annihilation at rest experiment. CB measured decay branching ratios of $f_0(1500)$ to $\pi^0\pi^0$, $\eta\eta$, $\eta\eta'$, K_LK_L and $4\pi^0$ final states(94 - 96).
- OBELIX observed $f_0(1500)$ in $\bar{n}p \to \pi^+\pi^+\pi^-$ reaction (98).
- WA91 and WA102 observed $f_0(1500)$ in $pp \to p_f(\pi^+\pi^-)p_s$ and $pp \to p_f(\pi^+\pi^-\pi^+\pi^-)p_s$ (95 - 97).
- Re-analysis of MARKIII $J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$ data by D. Bugg gave the 0^{++} at the mass of 1.5 GeV (95).
- BESI data on $J/\psi \to \gamma 4\pi$ confirmed the 0^{++} at the mass of 1.5 GeV (2000).
- No evidence for $f_0(1500)$ has been reported in $\gamma\gamma$ collisions.

PDG2002: $M_{f_0(1500)} = 1507 \pm 5$ MeV$/c^2$, $\Gamma_{f_0(1500)} = 109 \pm 7$ MeV$/c^2$

$J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$ (BES I)

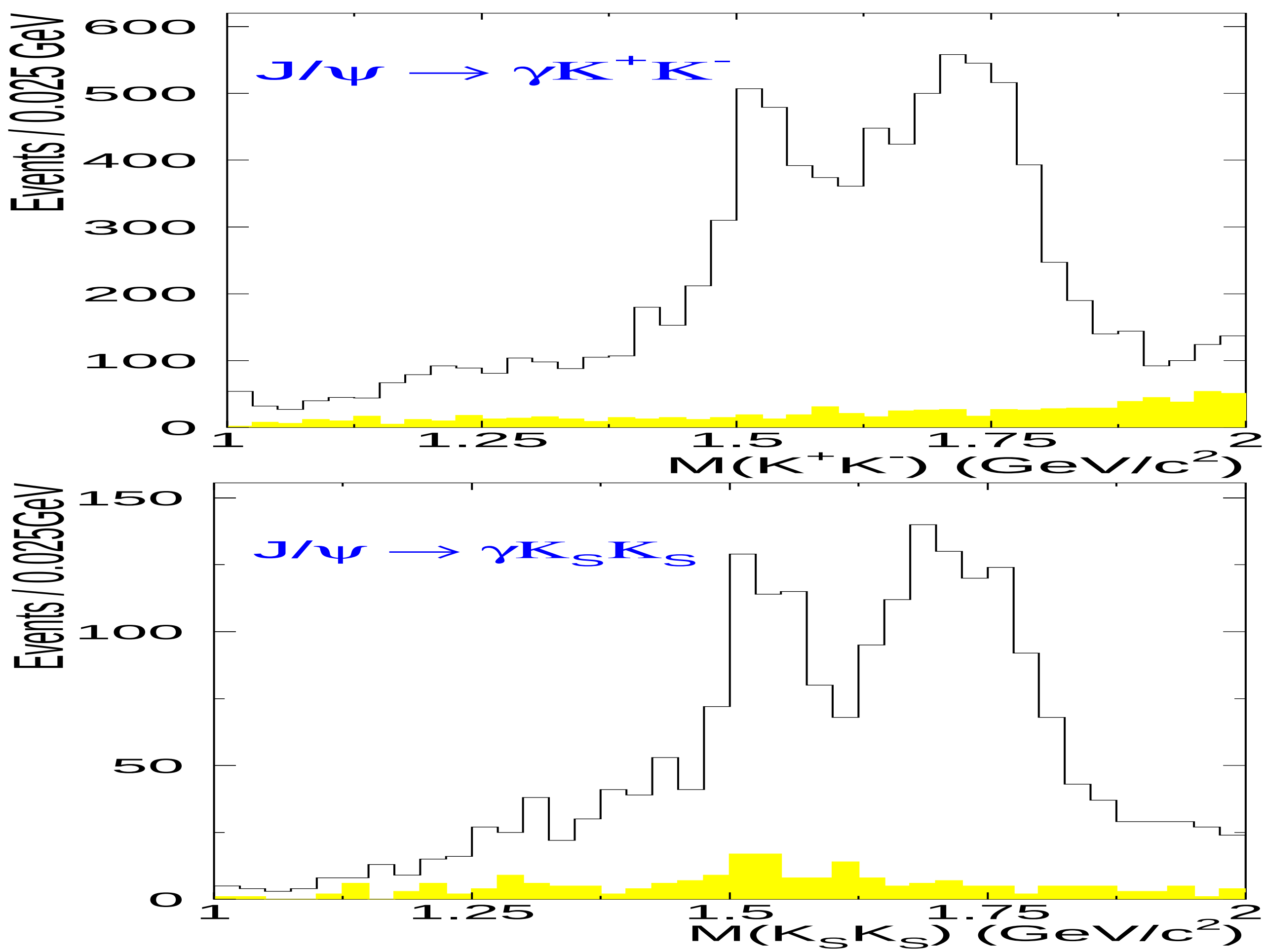


$$M_{f_0(1500)} = 1505 \pm 20\ \mathbf{MeV}/c^2,\ \Gamma_{f_0(1500)} = 125 \pm 30\ \mathbf{MeV}/c^2$$

$f_0(1710)$

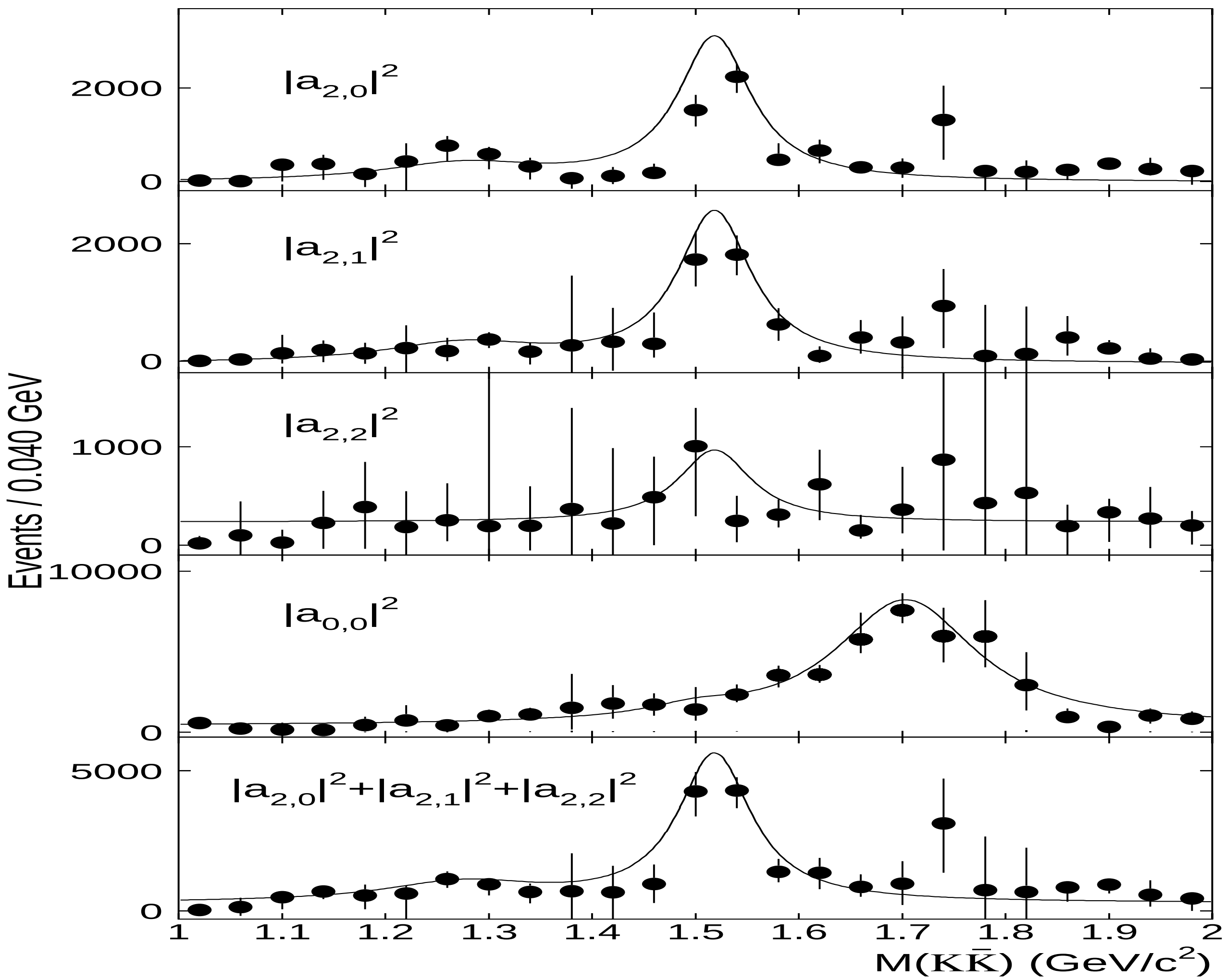
Process	Exp.	M(MeV)	Γ(MeV)	J^{PC}
$J/\psi \to \gamma\eta\eta$	C. B.(82)	1640 ± 50	200^{+100}_{-70}	2^{++}
$\pi^- p \to K^0_S K^0_S n$	BNL(82)	1771^{+77}_{-53}	200^{+156}_{-9}	0^{++}
$\pi^- N \to K^0_S K^0_S n$	FNAL(84)	1742 ± 15	57 ± 38	—–
$\pi^- p \to \eta\eta N$	GAMS(86)	1755 ± 8	< 50	0^{++}
$J/\psi \to \gamma K^+ K^-$	MARK3(87)	1720 ± 14	130 ± 20	2^{++}
$J/\psi \to \gamma K^+ K^-$	DM2(88)	1707 ± 10	166 ± 33	—–
$pp \to p(K^+ K^-)p$	WA76(89)	1713 ± 10	181 ± 30	2^{++}
$\to p(K^0_S K^0_S)p$		1706 ± 10	104 ± 30	
$J/\psi \to \gamma K\bar{K}$	MARK3(91)	1710 ± 20	186 ± 30	0^{++}
$p\bar{p} \to \pi^0\eta\eta$	E760(93)	1748 ± 10	264 ± 25	$even^{++}$
$J/\psi \to \gamma 4\pi$	MARK3(Bugg(95))	1750 ± 15	160 ± 40	0^{++}
$J/\psi \to \gamma K^+ K^-$	BES(96)	$1696 \pm 5^{+9}_{-34}$	$103 \pm 18^{+30}_{-11}$	2^{++}
		$1781 \pm 8^{+10}_{-31}$	$85 \pm 24^{+22}_{-19}$	0^{++}
$J/\psi \to \gamma K\bar{K}$	MARK3(Dunwoodie)	1704^{+16}_{-23}	124^{+52}_{-44}	0^{++}
$pp \to p(K\bar{K})p$	WA102(99)	1730 ± 15	100 ± 25	0^{++}
$J/\psi \to \gamma 4\pi$	BES(2000)	1740^{+20}_{-25}	135^{+40}_{-25}	0^{++}

$f_0(1710)$

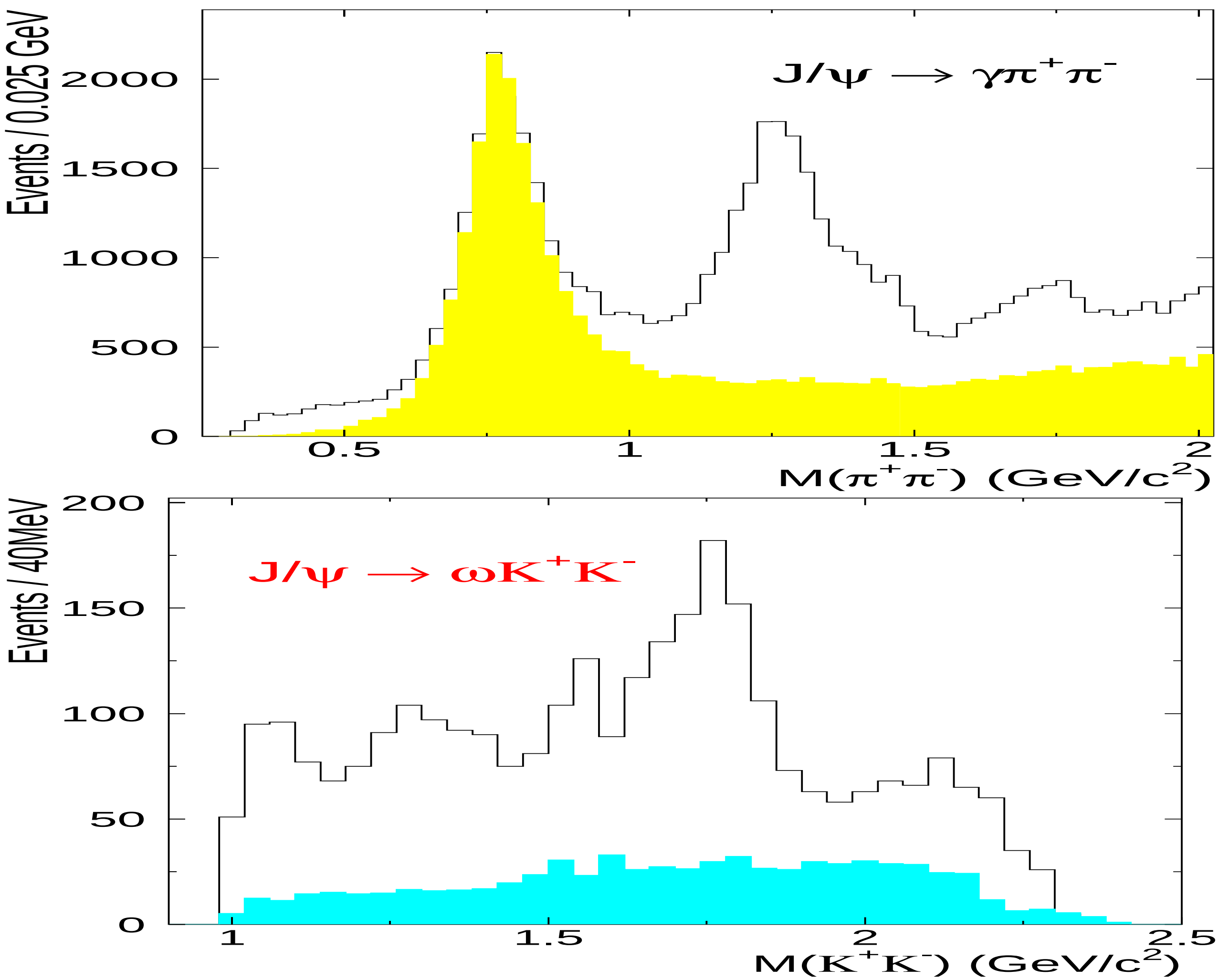


$$M = 1703^{+8}_{-10}\ \mathbf{MeV}/c^2,\ \Gamma = 163^{+27}_{-22}\ \mathbf{MeV}/c^2,\ J^{PC} = 0^{++}$$

$f_0(1710)$



$f_0(1710)$



$J/\psi \longrightarrow \gamma\pi^+\pi^-$
Events / 0.025 GeV
0
500
1000
1500
2000
0.5
1
1.5
2
$M(\pi^+\pi^-)$ (GeV/c^2)
$J/\psi \longrightarrow \omega K^+K^-$
Events / 40MeV
0
50
100
150
200
1
1.5
2
2.5
$M(K^+K^-)$ (GeV/c^2)

2. 0^{++} glueball candidate

Many studies about $f_0(1500)$, $f_0(1710)$. In some aspects they look like glueballs but in some aspects they don't.

Now we believe that both $f_0(1500)$ and $f_0(1710)$ are not pure glueballs but with gluon content.

F.Close and D.Weingarton *et al* suggested that $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ are mixed states of $q\bar{q}$ with glueball, the mass mixing matrix is

$$M = \begin{pmatrix} M_G & f & \sqrt{2}f \\ f & M_s & 0 \\ \sqrt{2}f & 0 & M_N \end{pmatrix}$$

$|G >= |gg >$, $|s > \ |s\bar{s} >$, $|N >= |u\bar{u} + d\bar{d} > /\sqrt{2}$
$f =< G|M|s >=< G|M|N > /\sqrt{2}$

2. 0^{++} glueball candidate

Input the branching ratios decaying to $\pi\pi$, KK, $\eta\eta$ and $\eta\eta'$ measured by WA102:
F. Close assumed $M_S > M_G > M_N$ and get

$|f_0(1710)>= 0.39|G> +0.91|s> +0.14|N>$
$|f_0(1500)>= -0.69|G> +0.37|s> -0.62|N>$
$|f_0(1370)>= 0.60|G> -0.13|s> -0.79|N>$

Weingarten assumed $M_G > M_S > M_N$ and get

$|f_0(1710)>= 0.859(54)|g> +0.302(52)|s\bar{s}> +0.413(87)|n\bar{n}>$
$|f_0(1500)>= -0.128(52)|g> +0.908(37)|s\bar{s}> -0.399(113)|n\bar{n}>$
$|f_0(1370)>= -0.495(118)|g> +0.290(91)|s\bar{s}> +0.819(89)|n\bar{n}>$

Gluon content of $f_0(1500)$ and $f_0(1710)$ is quite different from two models. Need more data for $\Gamma_{\pi\pi}$, Γ_{KK}, $\Gamma_{\eta\eta}$ and $\Gamma_{\eta\eta'}$ from experiments and more precise glueball mass spectrum by Lattice QCD.

3. $\xi(2230)$

- **MARKIII(1986) observed $\xi(2230)$ in $J/\psi \to \gamma K\bar{K}$ for the first time.**
- **DM2 didn't find a narrow signal in 2230 MeV mass region.**
- **GAMS(1986) found a rather narrow structure at 2.22 GeV from**

$$\pi^- p \to n\ \eta\eta'.$$

$$\begin{cases} M \approx 2220\text{MeV} \\ \Gamma \leq \text{instr. resol.} \quad (100\text{MeV}) \end{cases}$$

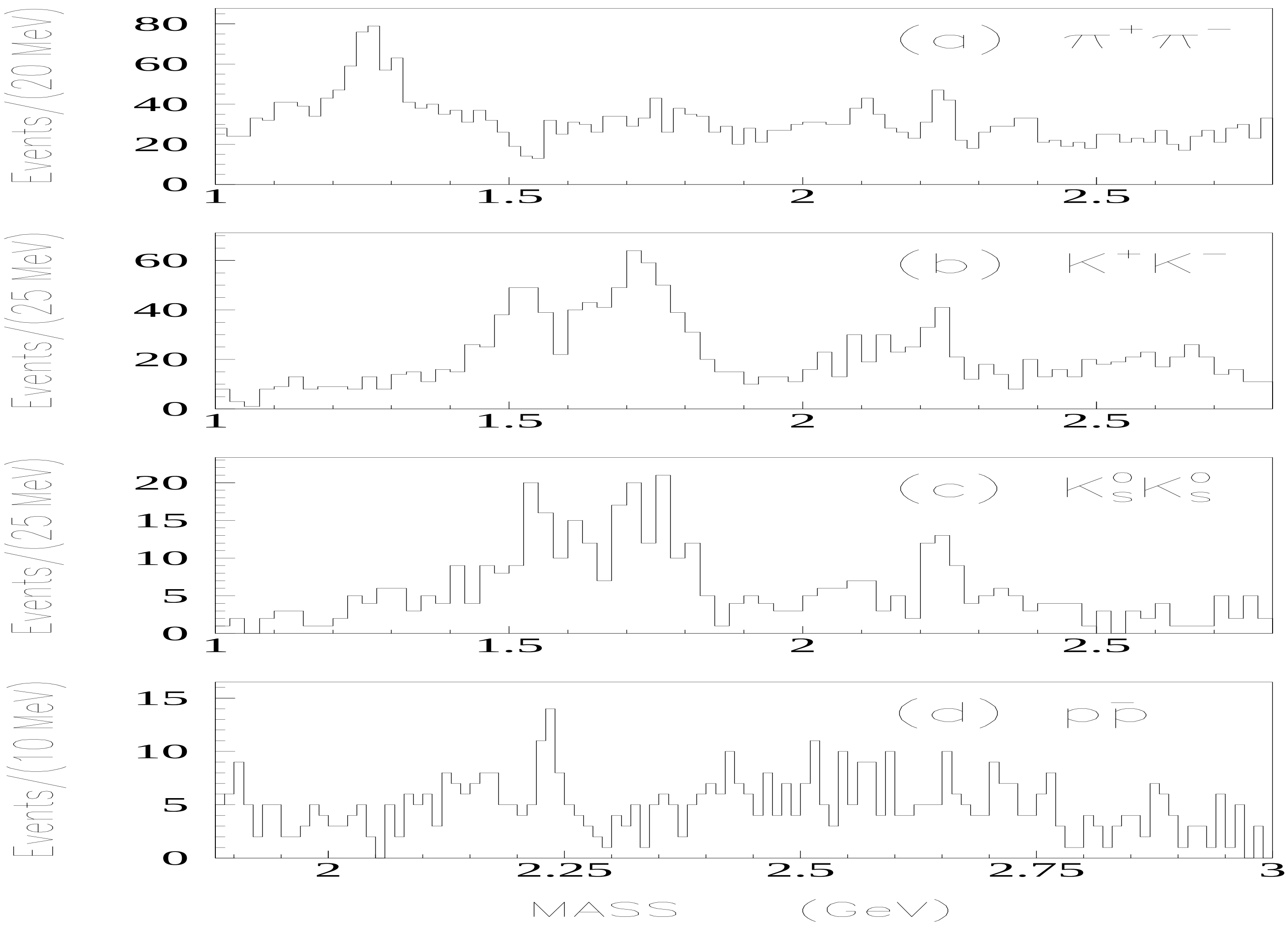
- **E147(1988) found a 2^{++} state at 2230 MeV with the width of 80 MeV from**

$$\pi^- p \to K_s^0 K_s^0 n$$

3. $\xi(2230)$

- **No evidence in the inclusive γ spectrum from Crystal Ball's experiment(1989).**
- **BESI results(1996) confirmed the existence of $\xi(2230)$ in $J/\psi \to \gamma K\bar{K}$, based on 7.8×10^6 J/ψ data.**
- **BESI(1996) observed the non-strange decay modes of $\xi(2230)$ to $\pi^+\pi^-$, $\pi^0\pi^0$ and $p\bar{p}$.**
- **L3 (1997) observed a signal consistent with $\xi(2230)$ in the $K_s^0 K_s^0$ channel from 3.6 million of hadronic Z decays.**
- **CLEO (1997) searched for the two-photon production of the glueball candidate $\xi(2230)$ in its decay to $K_s^0 K_s^0$. The limit on the stickiness ($S > 76$) should be considered as strong evidence that $\xi(2230)$ is a glueball.**

BESI $7.8 \times 10^6 J/\psi$ data:



3. $\xi(2230)$

- **No narrow structure exists in $p\bar{p}$ scan at LEAR. The upper limits for a possible narrow $\xi(2230)$ are obtained. PS202 (1997) obtained:** $Br(\xi \to \bar{p}p) \cdot Br(\xi \to K_s K_s) \leq 7.5 \times 10^{-5}$
- **CLEO didn't find the $\xi(2230)$ in $\gamma\gamma \to \pi^+\pi^-$ process (1998).**
- **No signal around 2230 MeV in L3 $\gamma\gamma \to R \to K_s^0 K_s^0$ process (2000).**
- **No clear evidence for $\xi(2230)$ in BES II data.**

5. Summary

- $f_0(1500)$ **is found in BES I from** $J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$

$$M = 1505 \pm 20 MeV/c^2, \quad \Gamma = 125 \pm 30 MeV/c^2$$

- $f_0(1710)$ **is found in BESII from** $J/\psi \to \gamma K^+K^-$ **and** $\gamma\pi^+\pi^-$**, we confirmed it is** $J^{PC} = 0^{++}$

$$M = 1500 \pm 20 MeV/c^2, \quad \Gamma = 110 \pm 20 MeV/c^2$$

- **no clear** $\xi(2230)$ **signal is seen in BESII data**
- **BES and CLEOc are good places to measure precisely the gluon content of** $f_0(1500)$ **and** $f_0(1710)$**.**