Scalar meson and glueball in B-decays

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4/2002

New observation of scalars ($J^{PC} = 0^{++}$) in charmless B-decays with strangeness

- $B \to K f_0(980)$ $\quad Br \sim 14 \times 10^{-6}$ $\quad (\pi\pi)$
- $B \to K$ "$f_x(1500)$" $\quad Br \sim 55 \times 10^{-6}$ $\quad (K\bar{K})$

$\uparrow$ $\Gamma \sim 700$ MeV

Belle 02, Babar prel.

also

- $f_0(980)$ as leading component in gluon jet

Delphi prel.

1. Low mass scalar spectroscopy

   $f_0(980) \Leftrightarrow \eta'$

2. Simple model for 2 body decays

   $B \to PP$, VP with K or K^*

   $\to$ $B \to PS$, VS no charm ($b \to s X_\not{c}$)

3. Glueball interpretation of "$f_x(1500)$"

4. Gluonic decay rate compared with

   $Br(b \to sg) \sim 2..5 \times 10^{-3}$

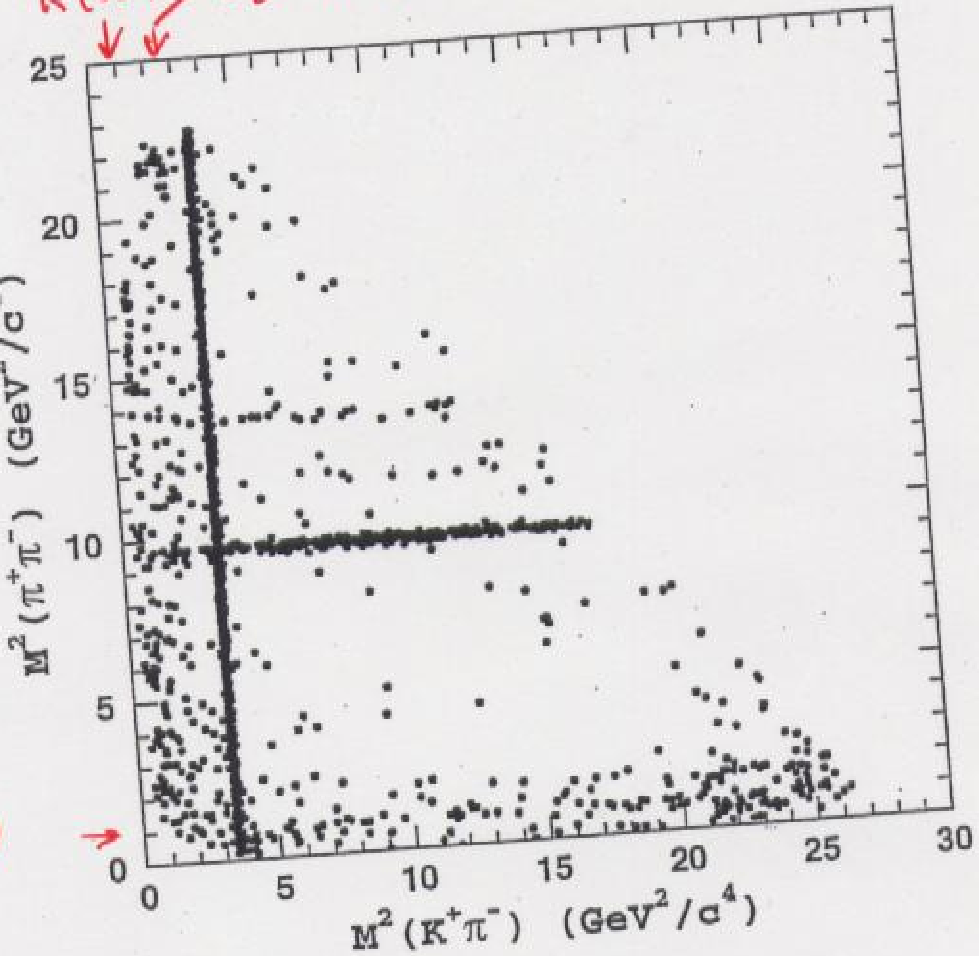
   how is this process saturated by hadrons?

work with Peter Minkowski (Uni Bern)
hep-ph/0304144

$B^+ \to K^+\pi^+\pi^-$

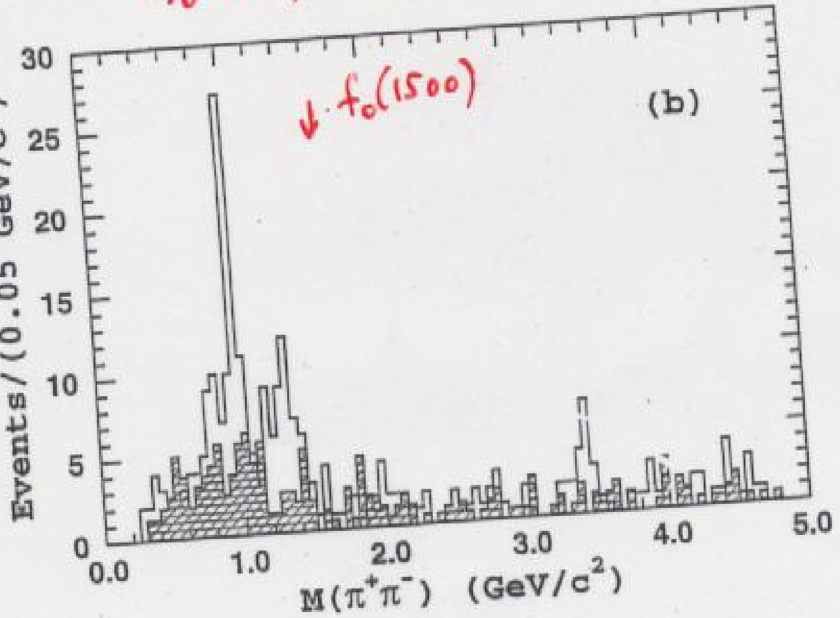
Belle

$K^*(890)$ $K_0^*(1430)$?



$f_0(980)$

$f_0(980)$



$f_0(1500)$

no $f_0(1500)$

Low mass scalar spectroscopy

Problems

- $q\bar{q}$ nonet of lowest mass
  (parity partners of pseudoscalars)
- glueball 0^{++} believed the lightest

Lattice (quenched)	$M \sim 1600$ MeV
QCD sum rules	$M \sim 1000$ MeV Narison

- special states
  - σ, κ do they exist?
  - $f_0(980)$ $q\bar{q}$, $K\bar{K}$ molecule, $4q$?

possible answer

Minkowsk, W.O. '99

- $\pi, K, \eta, \eta' \leftrightarrow a_0(980), K_0^*(1430), f_0(1500), f_0(980)$

mixing

~ singlet $f_0(980) \sim \eta' \sim (u\bar{u}+d\bar{d}+2s\bar{s})/\sqrt{6}$

~ octet $f_0(1500) \sim \eta \sim (u\bar{u}+d\bar{d}-s\bar{s})/\sqrt{3}$

- glueball : $f_0(400-1200)$ ("σ") & $f_0(1370) \rightarrow gb(1000)$
  broad object $\Gamma \sim 500 \cdots 1000$ MeV
  seen in $\pi\pi$ elastic, $\pi\pi \rightarrow K\bar{K}, \eta\eta$ ...

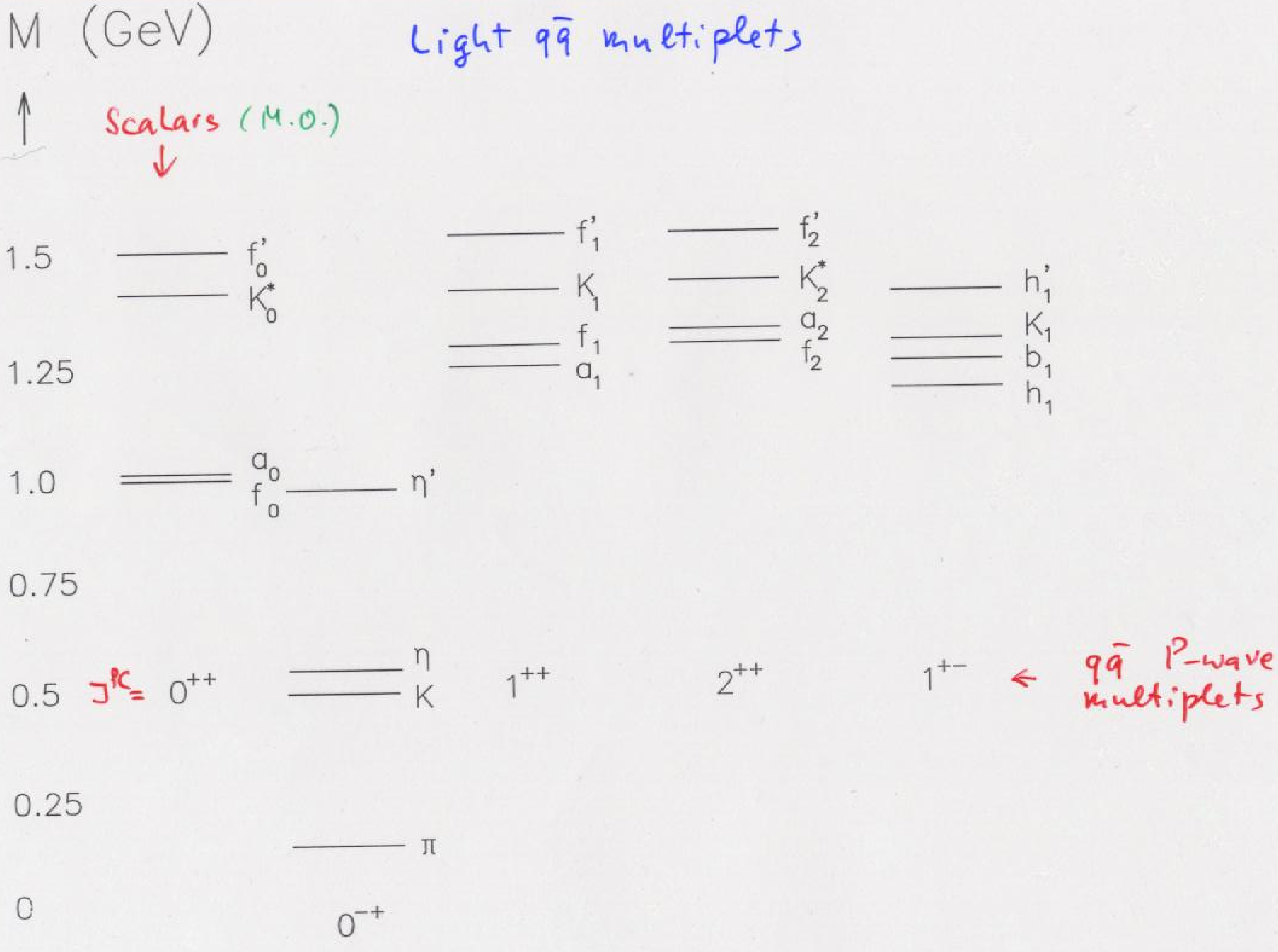
other options for nonet & glueball

broad glueball & f_0's , $f_0(980) \rightarrow$ octet
Anisovich et al.

similar nonet, but $a_0(980) \rightarrow a_0(1450)$ Klempt, Metsch et al.

$f_0(980) - \sigma$ strongly mixed from
$gb(1000)$ & $S = (u\bar{u}+d\bar{d})/\sqrt{2}$ Narison

Light $q\bar{q}$ multiplets



charm less B-decays with strangeness
$B \to PP$, VP

Large rate for

$B^+ \to \eta' K^+$ $(75 \pm 7)\times 10^{-6}$

Cleo '98
Babar
Belle

gluonic production

- Atwood & Soni
- Fritzsch
- He, Hou, Huang
- Dighe, Gronau Rosner '96

systematic QCD results

- perturbative calculations
  $b \to q\bar q s$ & QCD anomaly not sufficient

  Ali, Chay, Greub, Ko '98

- including radiative corrections
  consistent but large uncertainties

  Beneke Neubert '03

Phenomenological approach

$B \to h_A h_B$ symmetry relations for A, B multiplets

Dighe
Gronau
Rosner

amplitudes for
penguin $b \to u\bar u s, d\bar d s, s\bar s s$ ⊕ CKM suppressed tree diagrams ⊕ flavour singlet amplitude

further simplification

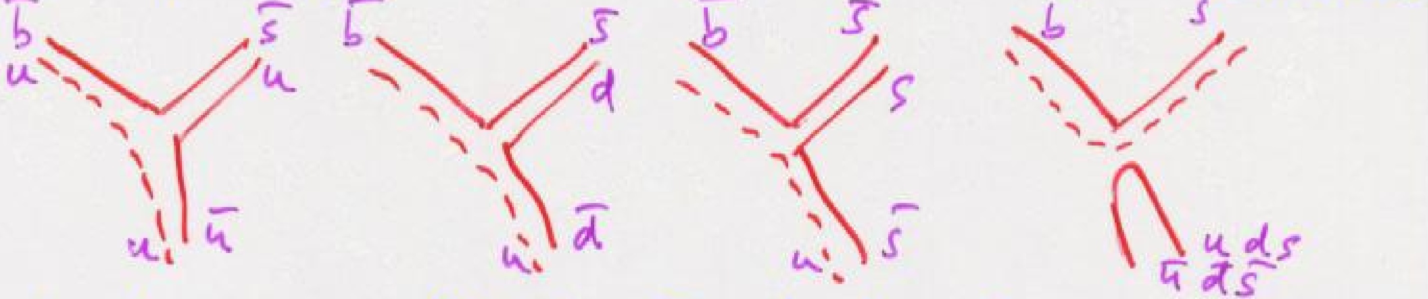
- CKM suppressed decays small compared to penguin (±20%)
- also found in phenomenological determination

NLO:
- Lenz, Nierste Ostermair
- Greub, Liniger

Chiang
Rosner '02

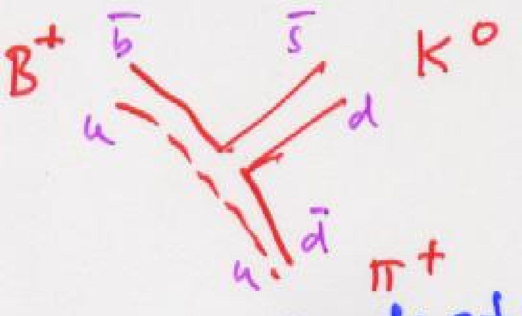
Simple Model for $B \to PP$ and $B \to VP$

only penguin & flavour singlet amplitudes



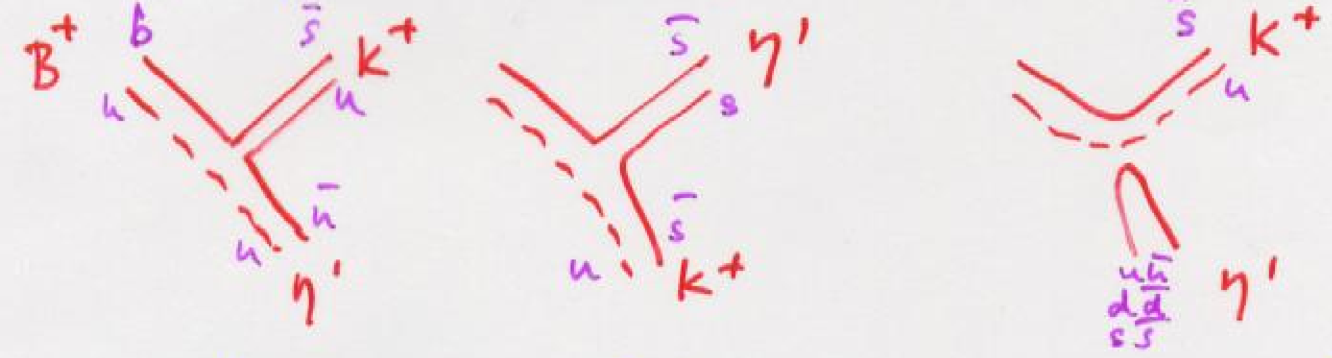
hadronic amplitude $B \to h_A h_B : P_{AB}$ singlet $\gamma_{AB} P_{AB}$

Decay $B \to PP$



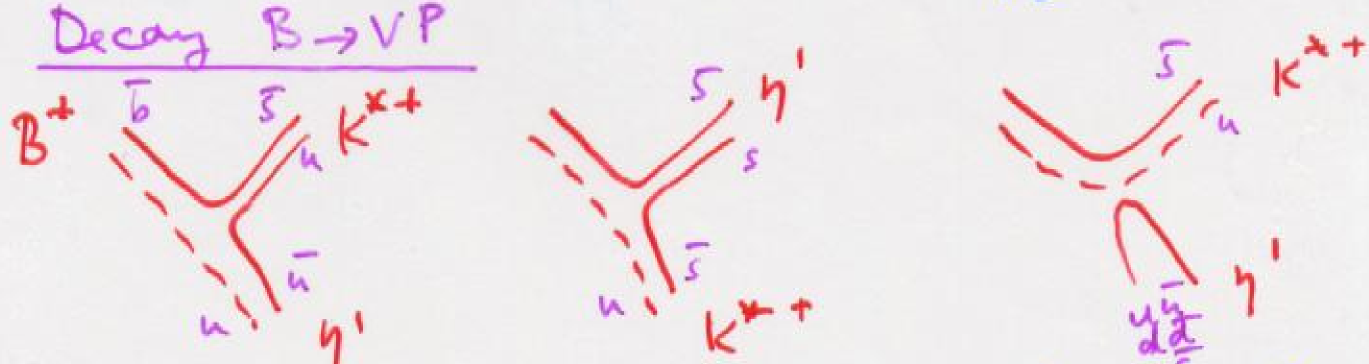
amplitude $F = P_{PP}$

production of $\eta' = (u\bar{u} + d\bar{d} + 2s\bar{s})/\sqrt{6}$



$$F = \frac{1}{\sqrt{6}} P_{PP} + \frac{2}{\sqrt{6}} P_{PP} + \frac{4\gamma}{\sqrt{6}} P_{PP} = \frac{3+4\gamma}{\sqrt{6}} P_{PP}$$

Decay $B \to VP$



$$F = \frac{1}{\sqrt{6}} P_{VP} + \frac{2}{\sqrt{6}} \beta' P_{VP} + \frac{4\gamma'}{\sqrt{6}} P_{VP} = \frac{4\gamma' - 1}{\sqrt{6}} P_{VP}$$

$\beta' = (-1)^L \beta$

Lipkin

try $\gamma' = \gamma$, $\beta = 1$, P_{AB} real

Table 1: Branching ratios for B^+ and B^0 decays into pseudoscalar (P) and vector (V) particles (col. 4-6) in terms of amplitudes T_q (col. 2) for decays $b \to s\bar{q}q$, γ, γ' and β for gluonic and interchange processes, col. 3: p_{AB} set to 1, col. 5: $\alpha = 0.67$, $\gamma = 0.53$ (always $\beta = -\beta' = 1$, $\gamma = \gamma'$), see also text.

$B \to PP$	$B \to PP$	amplitudes	$T_q = 1$	$\gamma = 0$	α, γ	$\mathrm{Br}_{\mathrm{exp}}[10^{-6}]$	
B^+	$K^0\pi^+$	T_d	1	input	input	$17.3^{+2.7}_{-2.4}$	
	$K^+\pi^0$	$\frac{1}{\sqrt{2}}T_u$	$\frac{1}{\sqrt{2}}$	8.7	8.7	12.1 ± 1.6	
	$K^+\eta$	$\frac{1}{\sqrt{3}}(T_u - T_s + \gamma T_d)$	$\frac{\gamma}{\sqrt{3}}$	0.0	1.6 !	< 6.9	
	$K^+\eta'$	$\frac{1}{\sqrt{6}}(T_u + 2T_s + 4\gamma T_d)$	$\frac{3+4\gamma}{\sqrt{6}}$	$\boxed{26.0}$	$\boxed{\text{input } \gamma}$	75 ± 7	need $\gamma \neq 0$
B^0	$K^+\pi^-$	T_u	1	15.9	15.9	17.4 ± 1.5	
	$K^0\pi^0$	$\frac{1}{\sqrt{2}}T_d$	$\frac{1}{\sqrt{2}}$	8.0	8.0	$10.7^{+2.7}_{-2.5}$	
	$K^0\eta$	$\frac{1}{\sqrt{3}}(T_d - T_s + \gamma T_d)$	$\frac{\gamma}{\sqrt{3}}$	0.0	1.5	< 9.3	
	$K^0\eta'$	$\frac{1}{\sqrt{6}}(T_d + 2T_s + 4\gamma T_d)$	$\frac{3+4\gamma}{\sqrt{6}}$	$\boxed{23.9}$	69.4	58^{+14}_{-13}	
$B \to VP$	$B \to VP$		$\alpha = 1$				
B^+	$K^{*0}\pi^+$	αT_d	1	17.3	7.9	19^{+6}_{-8}	
	$K^{*+}\pi^0$	$\frac{\alpha}{\sqrt{2}}T_u$	$\frac{1}{\sqrt{2}}$	8.7	3.9	< 31	
	$K^{*+}\eta$	$\frac{\alpha}{\sqrt{3}}(T_u - \beta' T_s + \gamma' T_d)$	$\frac{2+\gamma'}{\sqrt{3}}$	23.1	36.9 !	26^{+10}_{-9}	
	$K^{*+}\eta'$	$\frac{\alpha}{\sqrt{6}}(T_u + 2\beta' T_s + 4\gamma' T_d)$	$\frac{-1+4\gamma'}{\sqrt{6}}$	2.9	3.6 !	< 35	
	ρ^+K^0	$\alpha\beta T_d$	1	17.3	7.9	< 48	
	ρ^0K^+	$\frac{\alpha\beta}{\sqrt{2}}T_u$	$\frac{1}{\sqrt{2}}$	8.7	4.0	< 12	
	ωK^+	$\frac{\alpha\beta}{\sqrt{2}}T_u$	$\frac{1}{\sqrt{2}}$	$\underline{8.7}$	4.0	< 4	
	ϕK^+	$-\alpha T_s$	1	$\underline{17.3}$	$\boxed{\text{input } \alpha}$	$7.9^{+2.0}_{-1.8}$	need $\alpha \neq 0$
B^0	$K^{*+}\pi^-$	αT_u	1	15.9	7.3	< 72	
	$K^{*0}\pi^0$	$\frac{\alpha}{\sqrt{2}}T_d$	$\frac{1}{\sqrt{2}}$	$\underline{8.0}$	3.6	< 3.6	
	$K^{*0}\eta$	$\frac{\alpha}{\sqrt{3}}(T_d - \beta' T_s + \gamma' T_d)$	$\frac{2+\gamma'}{\sqrt{3}}$	21.3	15.7	14^{+6}_{-5}	
	$K^{*0}\eta'$	$\frac{\alpha}{\sqrt{6}}(T_d + 2\beta' T_s + 4\gamma' T_d)$	$\frac{-1+4\gamma'}{\sqrt{6}}$	2.6	1.5	< 24	
	ρ^-K^+	$\alpha\beta T_u$	1	15.9	7.3	< 32	
	ρ^0K^0	$\frac{\alpha\beta}{\sqrt{2}}T_d$	$\frac{1}{\sqrt{2}}$	$\underline{8.0}$	3.6	< 3.9	
	ωK^0	$\frac{\alpha\beta}{\sqrt{2}}T_d$	$\frac{1}{\sqrt{2}}$	8.0	3.6	< 13	
	ϕK^0	$-\alpha T_s$	1	$\underline{15.9}$	7.3	7.6 ± 1.4	
				↑	↑	exp.	
				$\gamma = 0$ $\alpha = 1$ 1Par.	$\gamma = 0.53$ $\alpha = 0.67$ 3Par.		

$\alpha = \frac{p_{VP}}{p_{PP}}$

B-decays into scalar particles

$B \to PS$, $B \to VS$

Table 2: Dominant contributions for B decays into scalar (S) + pseudoscalar (P) or vector (V) particles: penguin amplitudes p_{AB} (normalized to 1 in each sector), exchange and gluonic amplitudes $\beta \equiv \beta_{PS}, \beta' \equiv \beta_{VS}$ and γ_P, γ_S resp.; also approximate forms for mixing angles $\varphi_S = \varphi_P$ and $\beta = -\beta' = 1$; notations $f_0 \equiv f_0(980)$, $f_0' \equiv f_0(1500)$ and $K^*_{sc} \equiv K^*_0(1430)$.

$B^0 \to$ $P+S$	$B^+ \to$ $P+S$	normalization to p_{PS}	$B^0 \to$ $V+S$	$B^+ \to$ $V+S$	normalization to p_{VS}
K^+a^-	K^0a^+	1	$K^{*+}a^-$	$K^{*0}a^+$	1
K^0a^0	K^+a^0	$\frac{1}{\sqrt{2}}$	$K^{*0}a^0$	$K^{*+}a^0$	$\frac{1}{\sqrt{2}}$
K^0f_0	$\boxed{K^+f_0}$	$\frac{1}{\sqrt{2}}(1+2\gamma_S)\sin\varphi_S$ $+(\beta+\gamma_S)\cos\varphi_S$ $\underline{\approx \frac{1}{\sqrt{6}}(3+4\gamma_S)}$	$K^{*0}f_0$	$K^{*+}f_0$	$\frac{1}{\sqrt{2}}(1+2\gamma_S)\sin\varphi_S$ $+(\beta'+\gamma_S)\cos\varphi_S$ $\underline{\approx \frac{1}{\sqrt{6}}(-1+4\gamma_S)}$
K^0f_0'	K^+f_0'	$\frac{1}{\sqrt{2}}(1+2\gamma_S)\cos\varphi_S$ $-(\beta+\gamma_S)\sin\varphi_S$ $\underline{\approx \frac{1}{\sqrt{3}}\gamma_S}$	$K^{*0}f_0'$	$K^{*+}f_0'$	$\frac{1}{\sqrt{2}}(1+2\gamma_S)\cos\varphi_S$ $-(\beta'+\gamma_S)\sin\varphi_S$ $\underline{\approx \frac{1}{\sqrt{3}}(2+\gamma_S)}$
$\pi^-K^{*+}_{sc}$	$\pi^+K^{*0}_{sc}$	β	$\rho^-K^{*+}_{sc}$	$\rho^+K^{*0}_{sc}$	β
$\pi^0K^{*0}_{sc}$	$\pi^0K^{*+}_{sc}$	$\frac{1}{\sqrt{2}}\beta$	$\rho^0K^{*0}_{sc}$	$\rho^0K^{*+}_{sc}$	$\frac{1}{\sqrt{2}}\beta$
ηK^{*0}_{sc}	ηK^{*+}_{sc}	$\frac{1}{\sqrt{3}}(-1+\beta+\gamma_P)$	ωK^{*0}_{sc}	ωK^{*+}_{sc}	$\frac{1}{\sqrt{2}}\beta$
$\eta' K^{*0}_{sc}$	ηK^{*+}_{sc}	$\frac{1}{\sqrt{6}}(2+\beta+4\gamma_P)$	ϕK^{*0}_{sc}	ϕK^{*+}_{sc}	1

general mixing in scalar sector

$$f_0 \equiv f_0(980) = \frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\sin\varphi_s + s\bar{s}\cos\varphi_s$$

$$f_0' \equiv f_0(1500) = \frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\cos\varphi_s - s\bar{s}\sin\varphi_s$$

$$\varphi_s \approx \varphi_P \,,\ \sin\varphi_s = \frac{1}{\sqrt{3}}$$

Minkowski
w.O.

Scalar particles: remarks

rates

$B^+ \to K^+ f_0(980)$ $\sim 14\times10^{-6}$ Belle Babar

$B \to K^+ f_0(1500)$ $\Gamma \sim 100\,\mathrm{MeV}$

$\hookrightarrow \pi\pi$

$\eta\eta$ $\frac{K\bar{K}}{\pi\pi} \sim 0.2$

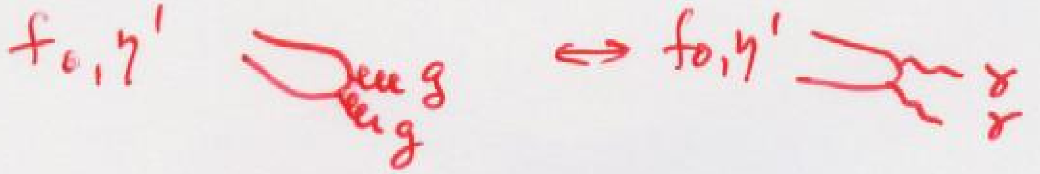
$K\bar{K}$

4π

no signal seen in $\pi\pi$, $K\bar{K}$

- as expected if $f_0(1500) \sim \eta$
- should be reversed for $K^* f_0$, $K^* f_0'$

gluonic coupling



$$R_1 = \frac{B \to f_0 K \,|\, \text{gluon}}{B \to \eta' K \,|\, \text{gluon}} = \frac{\gamma_s P_{PS}}{\gamma_P P_{PP}} \qquad R_2 = \frac{f_0 \to \gamma\gamma}{\eta' \to \gamma\gamma} \sim 0.1$$

parameters for scalars γ_s, P_{PS}
can be determined from $B \to K f_0$ and $R_1 = R_2$

① $\gamma_s = -0.17$
$P_{PS}^2 = 15\times10^{-6}$
↑ preferred

② $\gamma_s = 0.3$
$P_{PS}^2 = 5\times10^{-6}$

→ predict all rates for scalars!
need more measurements for scalars
K^{*0}_{sc}, a^0, $a^\pm$, f_0, f_0' with K, K^*

Glueball interpretation of "$f_X(1500)$"

- elastic $\pi\pi$ scattering

→ $f_0(980)$, $f_0(1500)$ interferes with broad "background"

→ resonance $M \sim 1000$ $\Gamma \sim 500-1000$ MeV

- inelastic scattering

$\pi\pi \rightarrow K\bar{K}$ $B - f_0(1500)$
$\pi\pi \rightarrow \eta\eta$ $B + f_0(1500)$
B = background

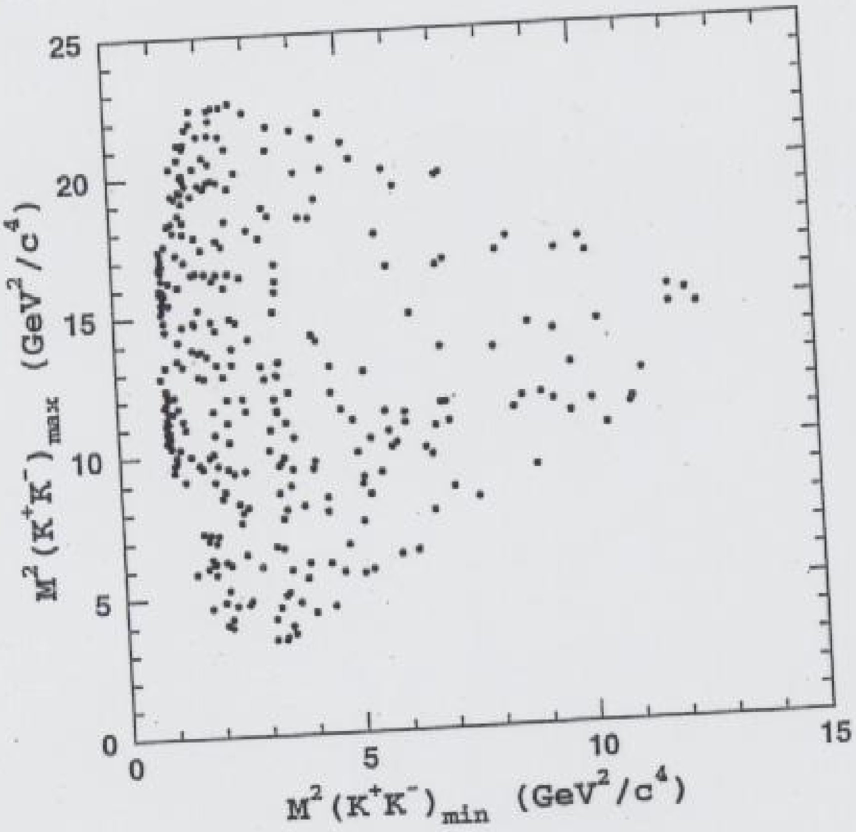
- broad peak in $B \rightarrow K\bar{K}K$

"$f_X(1500)$" $\Gamma = 700$ MeV

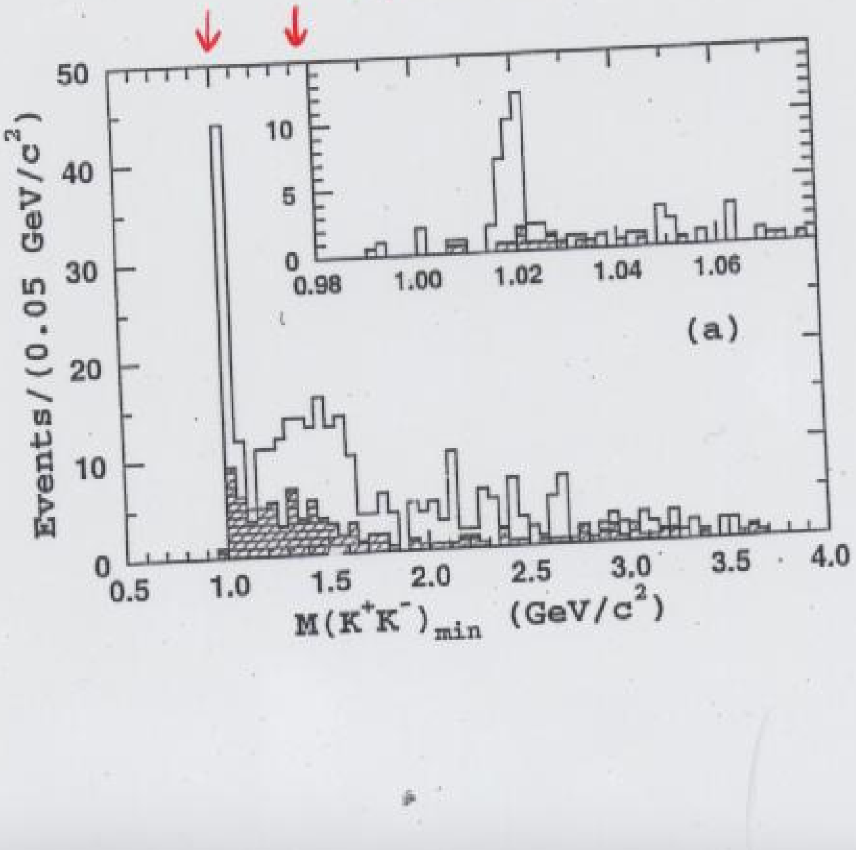
is suggested to be the same broad state

$B^+ \to K^+K^+K^-$

Belle



$\phi(1020)$ "$f_X(1500)$" $\Gamma = 700$ MeV

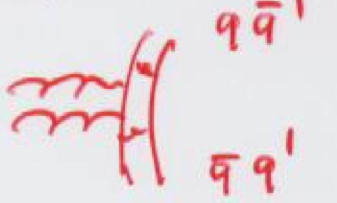


Estimate of rate $B^+ \to K^+ gb(0^{++})$

mass range	Belle br.-ratio [10^{-6}]	corr./exp B
1.0 – 1.7 GeV	K^+K^-: 27.6 ± 4.9	$K\bar{K}$ 55.2 ± 9.8 ($I=0$) $\eta\eta$ 17.3 } singlet "$\pi\pi$" 51.8 } singlet
0.7 – 1.0 GeV	$\pi\pi$: ~8	

all: $\underline{\underline{Br(B \to K^+ gb(0^{++})) \approx 132 \times 10^{-6}}}$

Decay of glue ball



$q\bar{q}'$ saturated by low mass stats

$gb \to$	$\pi^+\pi^-$	$\pi^0\pi^0$	K^+K^-	$K^0\bar{K}^0$	$\eta\eta$	~~$\eta'\eta'$~~
SU(3) symm.	2	1	2	2	1	1
also	$\rho^+\rho^-$	$\rho^0\rho^0$	~~K^*K~~	~~K^*K^*~~		

forbidden terms

Total gluonic decay rates

$b \to sg$ LO : $(2-5) \times 10^{-3}$ Ciuchini et al.

NLO : $(5 \pm 1) \times 10^{-3}$ Greub + Liniger

$B \to \eta', f_0(980) + X$

$$Br(B^+ \to \eta' K^+)|_{gluonic} = \frac{8}{3} |\gamma \beta_{PP}|^2 \sim (15 \ldots 35) \times 10^{-6}$$

$$\frac{\text{inclusive}}{\text{exclusive}} : \frac{B \to \eta' X_s}{B \to \eta' K} \sim 9$$ Cleo

add $f_0(980)$ assuming gluonic part from $R_2 \sim 10\%$

$$Br(B^+ \to \eta', f_0|_{gluonic} + X) \sim 1.5 - 3.5 \times 10^{-4}$$

$B \to$ glueball$(0^{++}) + X$

$$Br(B^+ \to gb(0^{++}) K^+) \sim 132 \times 10^{-6}$$

$$Br(B^+ \to gb(0^{++}) + X_s) \sim 1.2 \times 10^{-3}$$

all observed gluonic mesons

$$Br(B \to gb(0^{++}) + f_0 + \eta' + X_s) \sim (1.5 \pm 0.5) \times 10^{-3}$$

like LO $b \to sg$ or $\frac{1}{3}$ of NLO $b \to sg$

other glue balls

with $B \to gb(0^{-+})X \approx B \to gb(0^{++})X$

and higher spin glueballs

|| the total decay rate $b \to sg$ could be saturated. ||

Conclusions

1) large rate $B \to f_0 K$
and gluon jet $\to f_0(980)\, X$
suggest gluonic affinity like η'
(flavour singlet)

2) Scalar nonet can possibly established
through $B \to KS$, $K^* S$
and gluon jets in colliders

3) glueball hypothesis for $f_x(1500)$
to be tested by missing decay channels
$(\eta\eta, 4\pi)$

4) no strong glueball component in $f_0(980)$

$$\sin^2\varphi_g \approx \frac{\text{rate } f_0}{\text{rate gb}} = \frac{14}{132} \Rightarrow \varphi_g \lesssim 20^\circ$$

5) The decay $b \to sg$ with $Br \sim 5 \times 10^{-3}$
could be saturated by
gluonic mesons