Scalar Mesons and the Fragmented Glueball

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Scalar mesons and the fragmented glueball

1. The scalar glueballs is expected to have a mass in the range 1700 to 2000 MeV (see Matteo Rinaldi).
2. Radiative J/ψ decays seem to be prime reaction to search for glueballs (see Shunangshi Fang and Arkaitz Rodas).
3. The partial wave analysis of a large body of data reveals 10 isoscalar scalar resonances (see Andrey Sarantsev).
4. None of them sticks out as evident scalar glueball.
5. Thus we ask: Where is the scalar glueball ?

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Coupled channel analysis

A. V. Sarantsev, I. Denisenko, U. Thoma and E. Klempt,
"Scalar isoscalar mesons and the scalar glueball from radiative J/ψ decays,"
Phys. Lett. B 816, 136227 (2021).

J/ψ	$\rightarrow$	$\gamma\pi^0\pi^0$	$\gamma K_S K_S$	$\gamma\eta\eta'$	$\gamma\omega\phi$	BESIII
χ^2/N; N		1.28; 167	1.21, 121	0.8; 21	0.2; 17	
$\bar{p}p$	$\rightarrow$	$3\pi^0$	$\pi^0\pi^+\pi^-$	$2\pi^0\eta$	$\pi^0\eta\eta$	CB (liq. H_2)
χ^2/N, N		1.40; 7110	1.24, 1334	1.23; 3475	1.28; 3595	
$\bar{p}p$	$\rightarrow$	$3\pi^0$		$2\pi^0\eta$	$\pi^0\eta\eta$	CB (gas. H_2)
χ^2/N, N		1.38; 4891		1.24; 3631	1.32; 1182	
$\bar{p}p$	$\rightarrow$	$K_L K_L \pi^0$	$K^+K^-\pi^0$	$K_S K^\pm \pi^\mp$	$K_L K^\pm \pi^\mp$	CB (liq. H_2)
χ^2/N, N		1.08; 394	0.97; 521	2.13; 771	0.76; 737	
$\bar{p}n$	$\rightarrow$	$\pi^+\pi^-\pi^-$	$\pi^0\pi^0\pi^-$	$K_S K^-\pi^0$	$K_s K_S \pi^-$	CB (liq. D_2)
χ^2/N, N		1.39; 823	1.57; 825	1.33; 378	1.62; 396	
$\pi^+\pi^-$	$\rightarrow$	$\pi^+\pi^-$	$\pi^0\pi^0$	$\eta\eta$	$\eta\eta'$	K^+K^-
χ^2/N, N		1.32; 845	0.89; 110	0.67; 15	0.23; 9	1.06; 35
		CERN-Munich		GAMS		BNL

Results and interpretation

Pole masses and widths (in MeV) of scalar mesons. The RPP values are listed as small numbers for comparison.

Name	$f_0(500)$	$f_0(1370)$	$f_0(1710)$	$f_0(2020)$	$f_0(2200)$
M	410 ± 20 $400\to550$	1370 ± 40 $1200\to1500$	1700 ± 18 1704 ± 12	1925 ± 25 1992 ± 16	2200 ± 25 2187 ± 14
Γ	480 ± 30 $400\to700$	390 ± 40 $100\to500$	255 ± 25 123 ± 18	320 ± 35 442 ± 60	150 ± 30 ~ 200
Name	$f_0(980)$	$f_0(1500)$	$f_0(1770)$	$f_0(2100)$	$f_0(2330)$
M	1014 ± 8 990 ± 20	1483 ± 15 1506 ± 6	1765 ± 15	2075 ± 20 2086^{+20}_{-24}	2340 ± 20 ~2330
Γ	71 ± 10 $10\to100$	116 ± 12 112 ± 9	180 ± 20	260 ± 25 284^{+60}_{-32}	165 ± 25 250 ± 20

The $f_0(500) - f_0(980)$ mixing angle

$$g(f_0(500)\to\pi\pi) = -\frac{\sqrt{3}}{4}\cos\theta g_1 - \sqrt{\frac{3}{10}}\sin\theta g_8\,,$$
$$g(f_0(500)\to K\bar{K}) = -\frac{1}{2}\cos\theta g_1 + \frac{1}{\sqrt{10}}\sin\theta g_8\,,$$
$$g(f_0(500)\to \eta_8\eta_8) = \frac{1}{4}\cos\theta g_1 - \frac{1}{\sqrt{10}}\sin\theta g_8\,,$$
$$g(f_0(980)\to\pi\pi) = \frac{\sqrt{3}}{4}\sin\theta g_1 - \sqrt{\frac{3}{10}}\cos\theta g_8\,,$$
$$g(f_0(980)\to K\bar{K}) = \frac{1}{2}\sin\theta g_1 + \frac{1}{\sqrt{10}}\cos\theta g_8\,,$$
$$g(f_0(980)\to \eta_8\eta_8) = -\frac{1}{4}\sin\theta g_1 - \frac{1}{\sqrt{10}}\cos\theta g_8\,.$$

$\theta = (19\pm 5)^\circ$

J. A. Oller, "The Mixing angle of the lightest scalar nonet," Nucl. Phys. A 727, 353-369 (2003).

$f_0(500) \approx$ singlet;

$f_0(980) \approx$ octet

$(19\pm5)^\circ$	$(39\pm6)^\circ$	$(17\pm3)^\circ$	$(1^{+15}_{-9})^\circ$	$(12\pm4)^\circ$	$(32\pm3)^\circ$
[1]	[2]	[3]	[4]	[5]	[6]

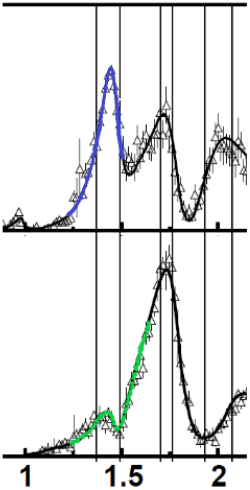
$\approx 10^\circ$	$(3\pm8)^\circ$	$(12\pm3)^\circ$	$(0\pm5)^\circ$	$(8\pm2)^\circ$
[7]	[8]	$D^+\to\pi^+\pi^+\pi^-$	$D^0\to\pi^0\pi^+\pi^-$	$J/\psi\to\gamma\pi\pi$

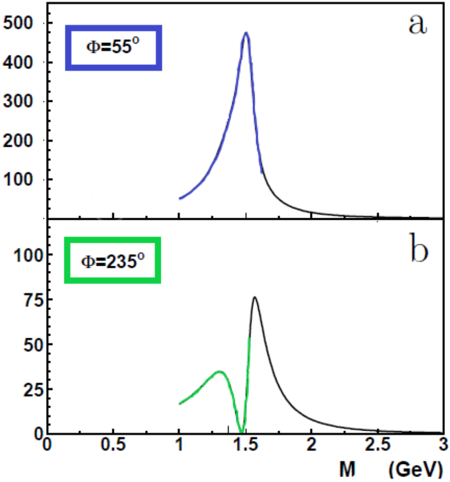
$\theta = (14\pm4)^\circ$

E. K., "Scalar mesons and the fragmented glueball", Phys. Lett. B820 (2021) 136512.

[1] J. A. Oller, Nucl. Phys. A 727, 353 (2003). [2] A. V. Anisovich *et al.*, Eur. Phys. J. A 12, 103 (2001). [3] W. Ochs, J. Phys. G 40, 043001 (2013). [4] J. W. Li *et al.*, Eur. Phys. J. C 72, 2229 (2012). [5] R. Aaij *et al.* [LHCb], Phys. Rev. D 92, 032002 (2015). [6] R. Aaij *et al.* [LHCb], Phys. Rev. D 89, 092006 (2014). [7] X. Liu, Z. T. Zou, Y. Li and Z. J. Xiao, Phys. Rev. D 100, 013006 (2019). [8] N. R. Son *et al.*, Phys. Rev. D 102, 016013 (2020).

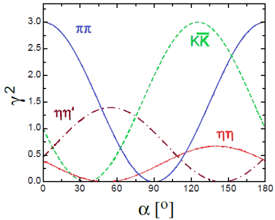
The $f_0(1370) - f_0(1500)$ mixing angle





Phase difference between $\pi\pi$ and $K\bar{K}$ decay mode is 180°: $n\bar{n} - s\bar{s}$ and $n\bar{n} + s\bar{s}$!

$f_0(1370)$ and $f_0(1500)$ are SU(3) singlet and SU(3) octet-like and not $n\bar{n}$ and $s\bar{s}$!



SU(3) fit to branching fractions of $f_0(1500)$ and $f_0(1370)$.

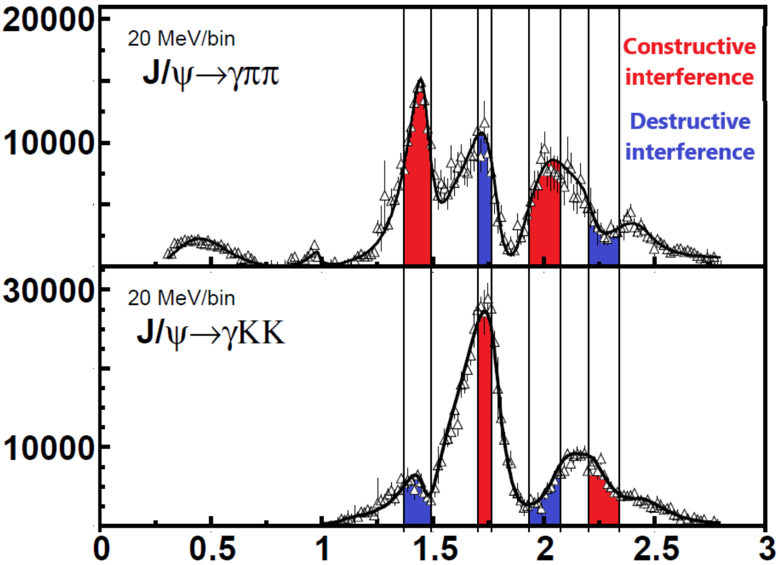
$$BR_\alpha = c\,(\gamma_{SU3})^2\,\rho_\alpha\,/\,M\Gamma\,,$$

$$<\rho_\alpha> = \int_{\mathrm{threshold}}^{\infty} \frac{ds}{\pi}\,\frac{\rho_\alpha(s)}{(M^2-s)^2+M^2\Gamma^2}$$

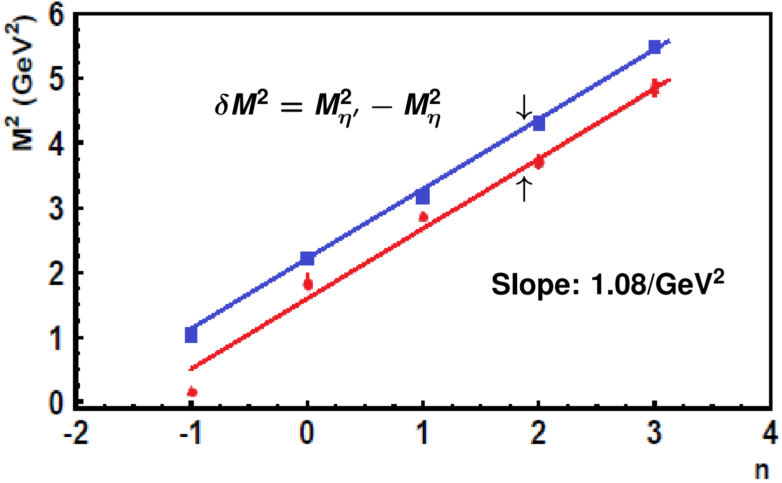
$$\gamma_{SU3}(f\to\pi\pi) = \sqrt{3}\cos\varphi^s$$

$f_0(1500) \to$	$<\rho_\alpha>$	$\lvert\gamma_{SU3}\rvert^2$	R_{exp} AS	R_{fit}	$\vartheta_s = (3\pm7)^\circ$ (Octet: 0°)
$\pi\pi$	0.957	0.882	0.191±0.051	0.230	
$K\bar{K}$	0.710	0.470	0.060±0.025	0.038	
$\eta\eta$	0.635	0.089	0.020±0.010	0.031	
$\eta\eta'$	0.123	1.350	0.024±0.012	0.060	
$f_0(1370) \to$					$\vartheta_s = (114\pm15)^\circ$ (Singlet: 90°)
$\pi\pi$	0.872	2.878	0.368±0.120	0.284	
$K\bar{K}$	0.579	1.424	0.125±0.042	0.093	
$\eta\eta$	0.499	0.377	0.037±0.013	0.022	
$\eta\eta'$	0.160	0.255	0.007±0.003	0.005	

Interference in $\pi\pi$ and $K\bar{K}$

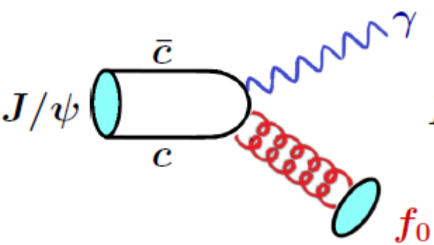


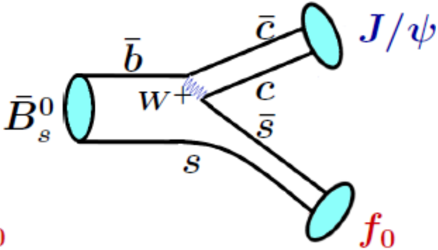
(M^2, n) trajectories of scalar mesons

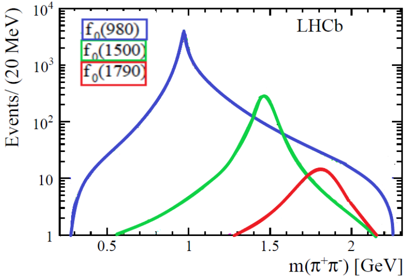


··· and where is the scalar glueball ?

Comparison with B_s decays

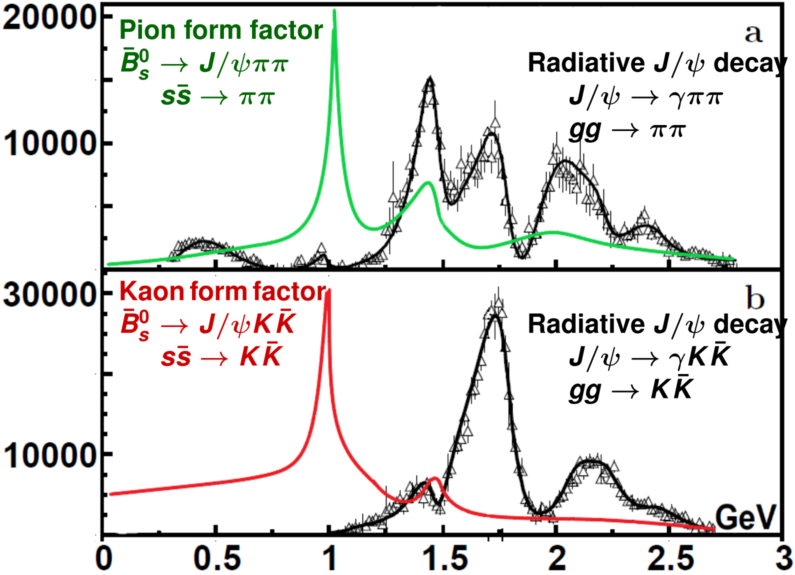






R. Aaij *et al.* [LHCb], R. Aaij *et al.* [LHCb], "Measurement of resonant and CP components in $\bar{B}^0_s \to J/\psi\pi^+\pi^-$ decays," Phys. Rev. D 89, no.9, 092006 (2014). R. Aaij *et al.* [LHCb], "Resonances and *CP* violation in B^0_s and $\overline{B}^0_s \to J/\psi K^+K^-$ decays in the mass region above the $\phi(1020)$," JHEP 08, 037 (2017).

Evidence for strong glue-glue interactions

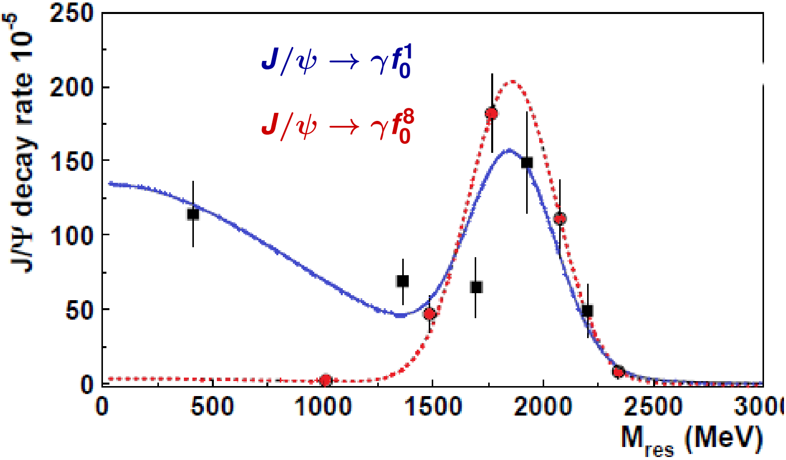


S. Ropertz, C. Hanhart and B. Kubis, "A new parametrization for the scalar pion form factors," Eur. Phys. J. C 78, no.12, 1000 (2018).

Yields in radiative J/ψ decays (in units of 10^{-5})

$BR_{J/\psi\to\gamma f_0\to}$	$\gamma\pi\pi$	$\gamma K\bar{K}$	$\gamma\eta\eta$	$\gamma\eta\eta'$	$\gamma\omega\phi$	missing		total
						$\gamma 4\pi$	$\gamma\omega\omega$	
$f_0(500)$	105±20	5±5	4±3	∼0	∼0	∼0		114±21
$f_0(980)$	1.3±0.2	0.8±0.3	∼0	∼0	∼0	∼0		2.1±0.4
$f_0(1370)$	38±10	13±4	3.5±1	0.9±0.3	∼0	14±5		69±12
		42±15				27±9		
$f_0(1500)$	9.0±1.7	3±1	1.1±0.4	1.2±0.5	∼0	33±8		47±9
	10.9±2.4	2.9±1.2	$1.7^{+0.6}_{-1.4}$	$6.4^{+1.0}_{-2.2}$		36±9		
$f_0(1710)$	6±2	23±8	12±4	6.5±2.5	1±1	7±3		56±10
$f_0(1770)$	24±8	60±20	7±1	2.5±1.1	22±4	65±15		181±26
$f_0(1750)$	38±5	99^{+10}_{-6}	24^{+12}_{-7}		25±6	97±18	31±10	
$f_0(2020)$	42±10	55±25	10±10			(38±13)		145±32
$f_0(2100)$	20±8	32±20	18±15			(38±13)		108±25
$f_0(2200)$	5±2	5±5	0.7±0.4			(38±13)		49±17
$f_0(2100)/f_0(2200)$	62±10	109^{+8}_{-19}	$11.0^{+6.5}_{-3.0}$			115±41		
$f_0(2330)$	4±2	2.5±0.5	1.5±0.4					8±3
		20±3						

The fragmented glueball



$$\mathrm{M_{glueball}} = (1865 \pm 25)\,\mathrm{MeV},\ \Gamma_{\mathrm{glueball}} = (370 \pm 50^{+30}_{-20})\,\mathrm{MeV}$$

$$\mathrm{Y}_{J/\psi\to\gamma G_0} = (5.8 \pm 1.0) \cdot 10^{-3}$$

The wave function of scalar mesons

$$
\begin{aligned}
f_0(1500) \quad = \quad & \alpha \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s}) \\
+ \quad & \beta \frac{1}{\sqrt{6}}(u\bar{u}s\bar{s} + d\bar{d}s\bar{s} - 2u\bar{u}d\bar{d}) \\
+ \quad & \gamma \cdot (\text{meson} - \text{meson cloud}) \\
+ \quad & \delta(gg) \\
+ \quad & \epsilon(q\bar{q}g) \\
+ \quad & \cdots \qquad\qquad \text{and some singlet contribution} \\
+ \quad & \{\alpha' \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s}) + \beta' \frac{1}{\sqrt{3}}(u\bar{u}s\bar{s} + d\bar{d}s\bar{s} + u\bar{u}d\bar{d})\}
\end{aligned}
$$

The five Fock states are not realized independently as five mesons !

They are components of the mesonic wave functions.

There is no scalar glueball that intrudes the spectrum of scalar mesons

Summary

- The BESIII collaboration reported data on radiative J/ψ decays with unprecedented statistics
- The data reveal high intensities in the yield of scalar mesons
- The data can be fit with ten scalar isoscalar resonances.
- The scalar resonances can be grouped into a class of mainly-singlet and mainly-octet states
- The two groups fall onto linear (n, M^2)-trajectories
- Octet scalar isoscalar resonances are produced mainly in the 1700 - 2100 MeV mass range
- Singlet scalar resonances are produced over the full mass range. Their intenisty peaks in the 1700 - 2100 MeV mass range
- The enhanced production of scalar mesons in the 1700 - 2100 MeV mass range is due to gluon-gluon in the initial state
- The peak is the scalar glueball of lowest mass.

Thank you for your patience!