Scalar isoscalar mesons and the scalar glueball from radiative J/ψ decays

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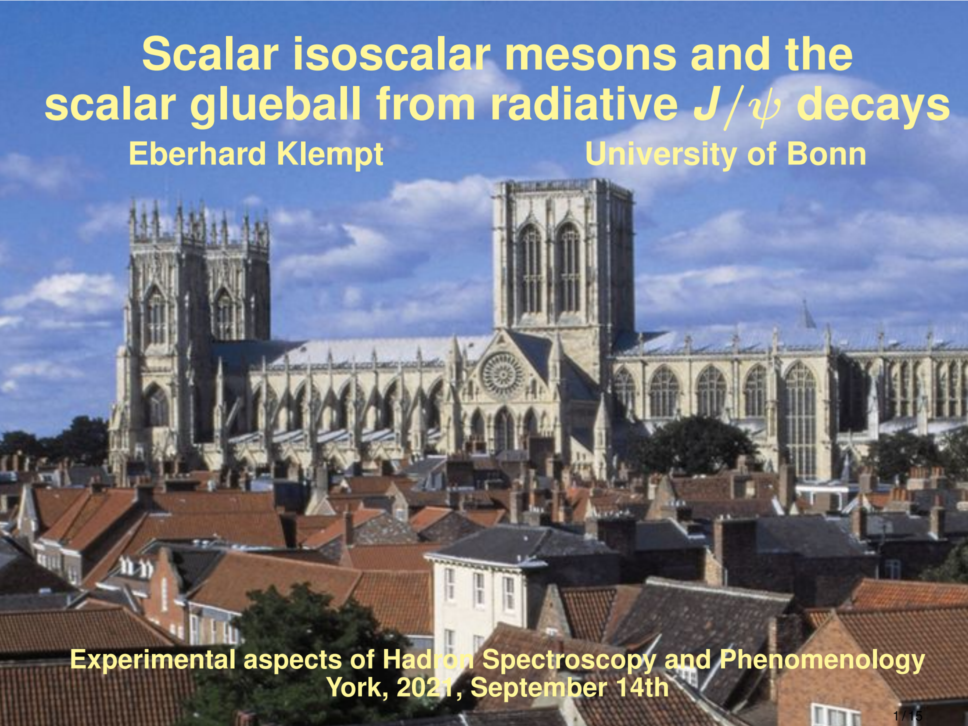
Experimental aspects of Hadron Spectroscopy and Phenomenology
York, 2021, September 14th



Scalar isoscalar mesons and the scalar glueball from radiative J/ψ decays

1. **Glueballs and how to search for them**
2. **Coupled channel analysis**
3. **Results and interpretation**
4. **Summary**

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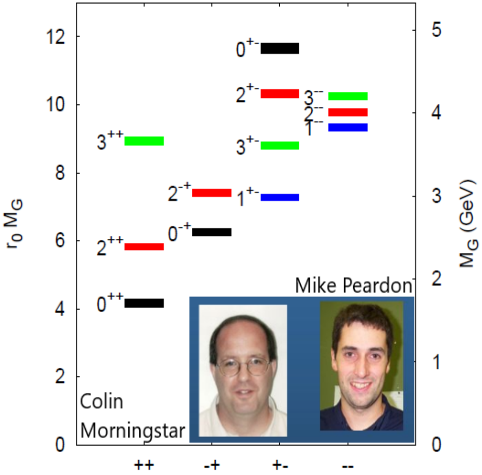
1. Glueballs and how to search for them

Glueballs masses



Y. Chen *et al.* "Glueball spectrum and matrix elements on anisotropic lattices," Phys. Rev. D 73, 014516 (2006).

A. P. Szczepaniak and E. S. Swanson, "The Low lying glueball spectrum," Phys. Lett. B 577, 61-66 (2003).

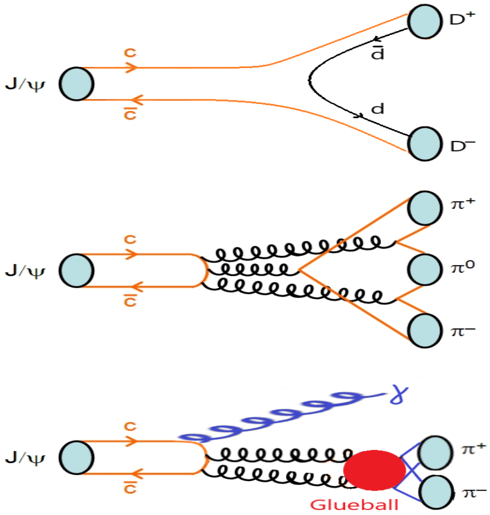
M. Rinaldi and V. Vento, "Meson and glueball spectroscopy within the graviton soft wall model, Phys. Rev. D," 104 no.3, 034016 (2021).

M. Q. Huber, C. S. Fischer and H. Sanchis-Alepuz, "Spectrum of scalar and pseudoscalar glueballs from functional methods," Eur. Phys. J. C 80, no.11, 1077 (2020).

The scalar glueball is expected in the mass range

from 1700 to 2000 MeV

How to search for glueballs



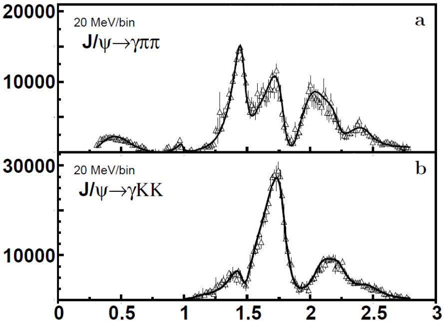
Data from BESIII,
$1.3 \cdot 10^9$ J/ψ decays

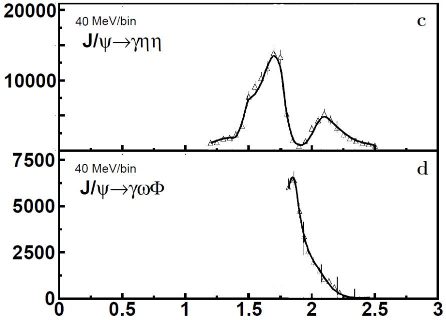
2. Coupled channel analysis

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	$\rightarrow$	$\gamma\pi^0\pi^0$	K_SK_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	
$\bar{p}p$	$\rightarrow$	$K_LK_L\pi^0$	$K^+K^-\pi^0$	$K_SK^\pm\pi^\mp$	$K_LK^\pm\pi^\mp$	CB (liq. H_2)
χ^2/N, N		1.08; 394	0.97; 521	2.13; 771	0.76; 737	
$\bar{p}n$	$\rightarrow$	$\pi^+\pi^-\pi^-$	$\pi^0\pi^0\pi^-$	$K_SK^-\pi^0$	$K_sK_S\pi^-$	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

$J/\psi \to \gamma$ $\pi^0\pi^0$ and K_sK_s $\eta\eta$ and $\omega\phi$



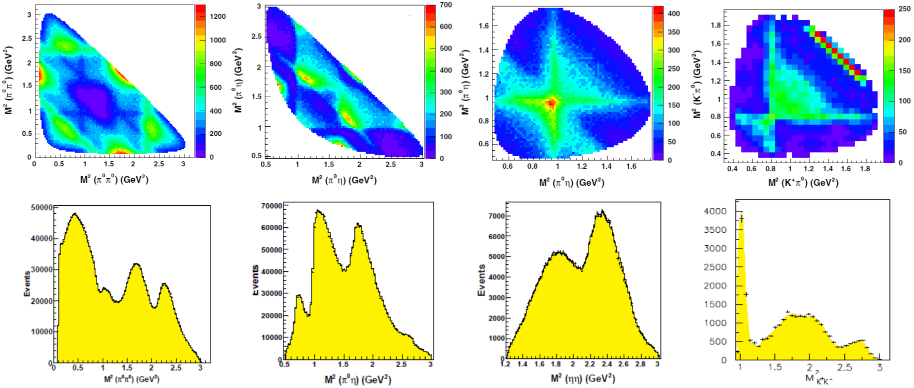


$1.3 \cdot 10^9$ events $0.225 \cdot 10^9$ events

PWA in slices of energy   **Amplitude fit to data**

M. Ablikim *et al.* [BESIII Collaboration], "Amplitude analysis of the $\pi^0\pi^0$ system produced in radiative J/ψ decays," Phys. Rev. D 92 no.5, 052003 (2015).
M. Ablikim *et al.* [BESIII Collaboration], "Amplitude analysis of the K_SK_S system produced in radiative J/ψ decays," Phys. Rev. D 98 no.7, 072003 (2018).
M. Ablikim *et al.* [BESIII Collaboration], "Partial wave analysis of $J/\psi \to \gamma\eta\eta$," Phys. Rev. D 87, no. 9, 092009 (2013).
M. Ablikim *et al.* [[BESIII Collaboration], "Study of the near-threshold $\omega\phi$ mass enhancement in doubly OZI-suppressed' $J/\psi \to \gamma\omega\phi$ decays," Phys. Rev. D 87 no.3, 032008 (2013).

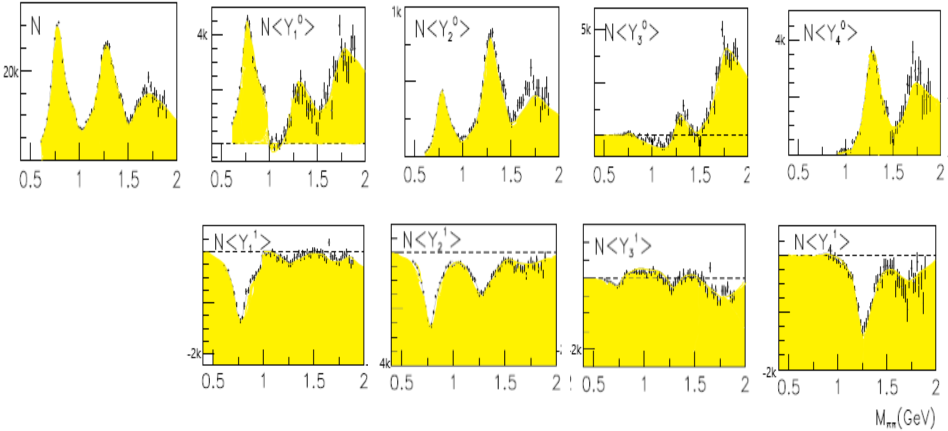
The Crystal Barrel data



$\pi^0\pi^0\pi^0$ $\pi^0\pi^0\eta$ $\pi^0\eta\eta$ $K^+K^-\pi^0$

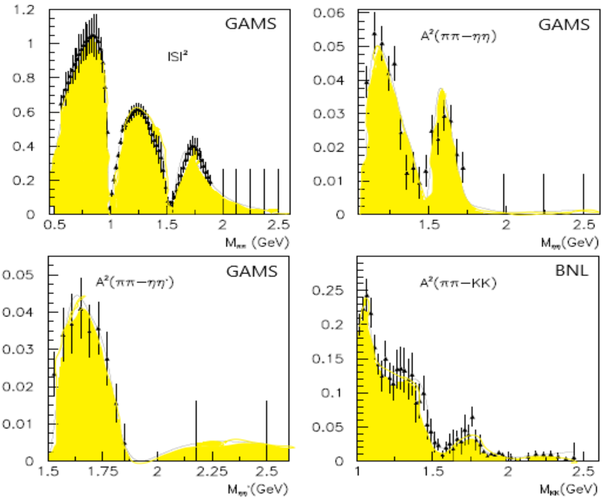
$\cdots$ **and further Dalitz plots.**

The CERN-Munich data on $\pi\pi \to \pi\pi$ elastic scattering



The CERN-Munich data have different PWA solutions. The ambiguity is resolved by the GAMS data on $\pi^- p \to \pi^0\pi^0 n$ (at 200 GeV/c pion momenta).

GAMS and BNL data on pion-induced reactions



GAMS: D. Alde *et al.*, "Study of the $\pi^0\pi^0$ system with the GAMS-4000 spectrometer at 100 GeV/c," Eur. Phys. J. A 3, 361 (1998).
BNL: S. J. Lindenbaum and R. S. Longacre, "Coupled channel analysis of $J^{PC} = 0^{++}$ and 2^{++} isoscalar mesons with masses below 2 GeV," Phys. Lett. B 274, 492 (1992).

3. Results and interpretation

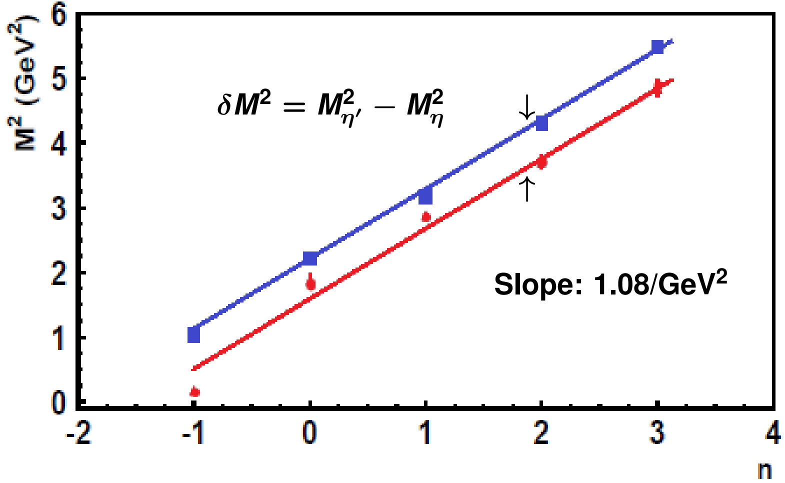
Pole masses and widths (in MeV) of scalar mesons.

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

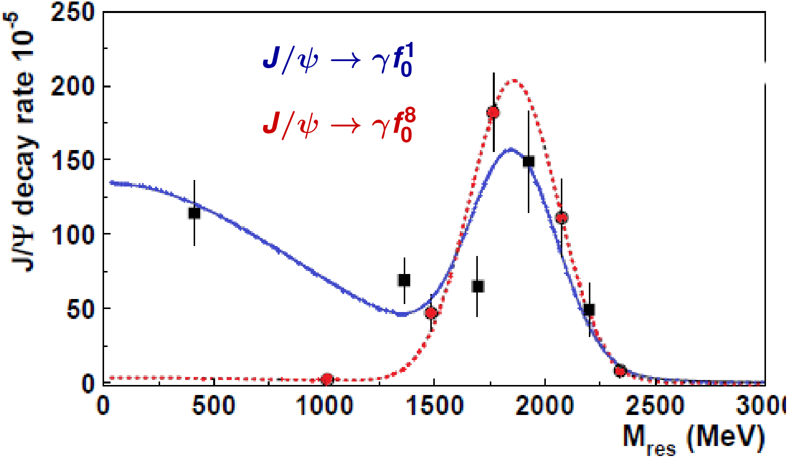
(M^2, n) trajectories of scalar mesons



$\cdots$ and where is the scalar glueball ?

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						

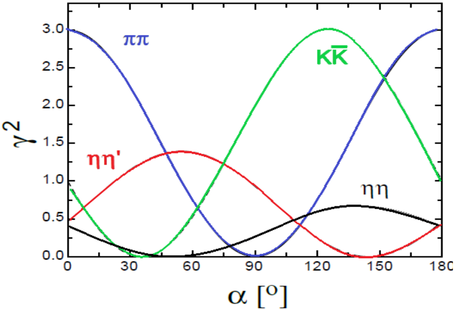


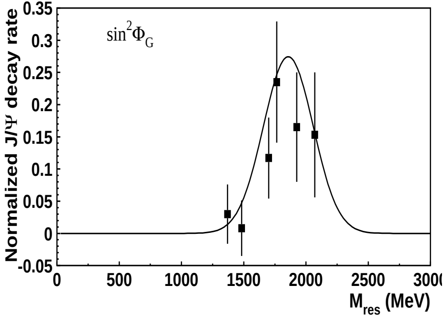
$$\mathrm{M_{glueball}} = (1865 \pm 25)\,\mathrm{MeV},\ \Gamma_{\mathrm{glueball}} = (370 \pm 50^{+30}_{-20})\,\mathrm{MeV}$$

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

Glueball content of scalar mesons

$$|f_0(1770)>= \cos\phi_g(n\bar{n}\cos\alpha - s\bar{s}\sin\alpha)\gamma_{q\bar{q}} + \sin\phi_g\gamma_1$$
$$|f_0(1710)>= \cos\varphi_g(n\bar{n}\sin\alpha + s\bar{s}\cos\alpha)\gamma_{q\bar{q}} + \sin\varphi_g\gamma_1$$





Glueball content from J/ψ radiative production is (nearly) consistent with glueball content from the decays of scalar mesons!

4. Summary

- The BESIII collaboration reported data on radiative J/ψ decays with unprecedented statistics
- The data revelal 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 intensity 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 interactions in the initial state
- The decays of scalar mesons require a significant excess of SU(3) singlet contributions
- The peak is the scalar glueball of lowest mass. It extends over several resonances.

Thank you for your patience!