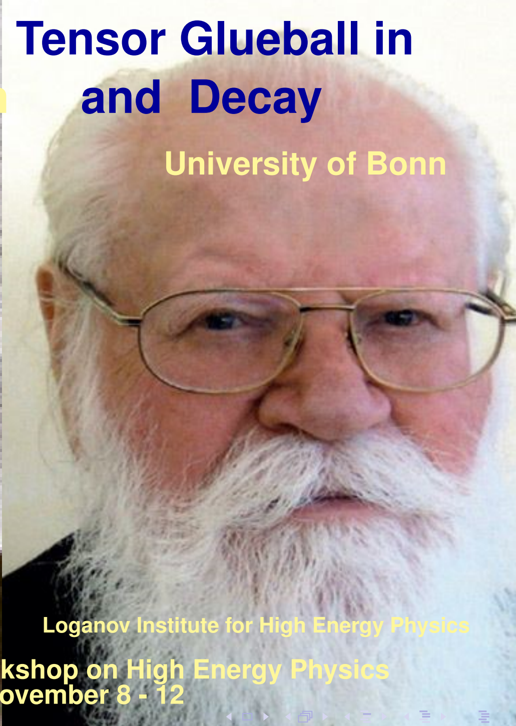
The Scalar and Tensor Glueball in Production and Decay

Eberhard Klempt
University of Bonn



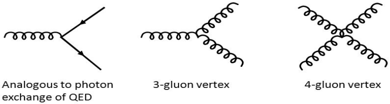
National Research Center Kurchatov Loganov Institute for High Energy Physics

XXXIII International Workshop on High Energy Physics
2021, November 8 - 12

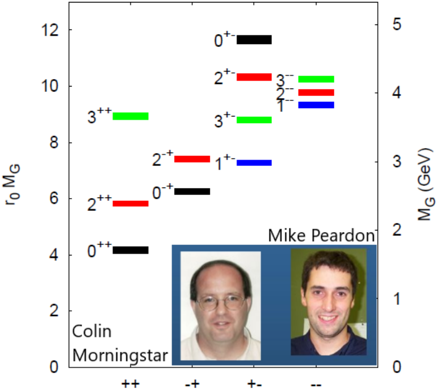
The Scalar and Tensor Glueball in Production and Decay

1. **Glueballs**
2. **Data and oupled channel analysis**
3. **The scalar glueball in production**
4. **The decays of the scalar glueball**
5. **Discussion**
6. **The hidden tensor glueball**
7. **Summary**

1. Glueballs: Masses



The self-interaction between gluons leads to the prediction of glueballs[1]



[1] H. Fritzsch and M. Gell-Mann, "Current algebra: Quarks and what else?," eConf C720906V2, 135 (1972).

0^{++}	$1710 \pm 50 \pm 80$ MeV
2^{++}	$2390 \pm 30 \pm 120$ MeV
0^{-+}	$2560 \pm 35 \pm 120$ MeV

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

0^{++}	1980 MeV	1920 MeV
2^{++}	2420 MeV	2371 MeV
0^{-+}	2220 MeV	

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," [arXiv:2101.02616 [hep-ph]].

0^{++}	1850 ± 130 MeV
0^{-+}	2580 ± 180 MeV

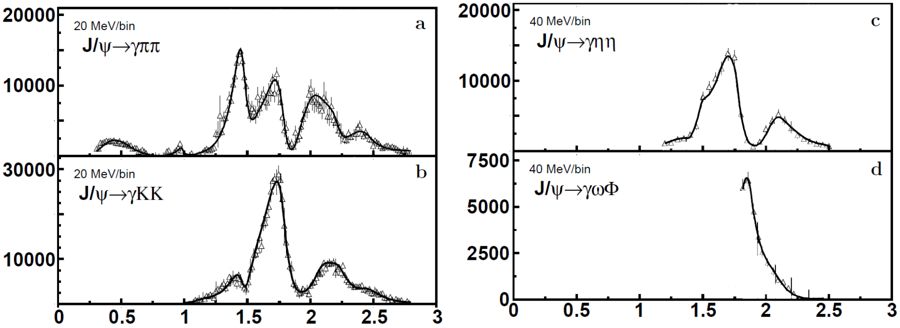
M. Q. Huber, C. S. Fischer and H. Sanchis-Alepuz, "Spectrum of scalar and pseudoscalar glueballs from functional methods," Eur. Phys. J. C 80, no.11, 1077 (2020).

The scalar glueball is expected in the 1700 to 2000 MeV mass range

2. Data and coupled channel analysis

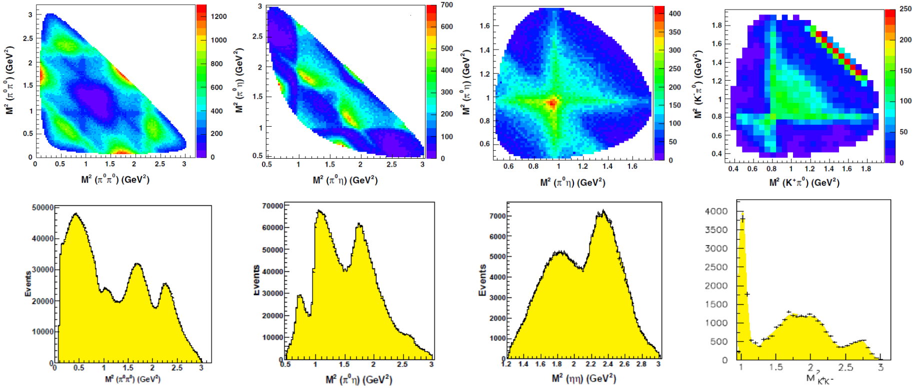
A. V. Sarantsev, I. Denisenko, U. Thoma and E. Klempt, Phys. Lett. B 816, 136227 (2021).
"Scalar isoscalar mesons and the scalar glueball from radiative J/ψ decays,"

BESIII: $J/\psi \to \gamma\pi^0\pi^0$ and $K_S K_S$ $\eta\eta$ and $\omega\phi$



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 $K_S K_S$ 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).

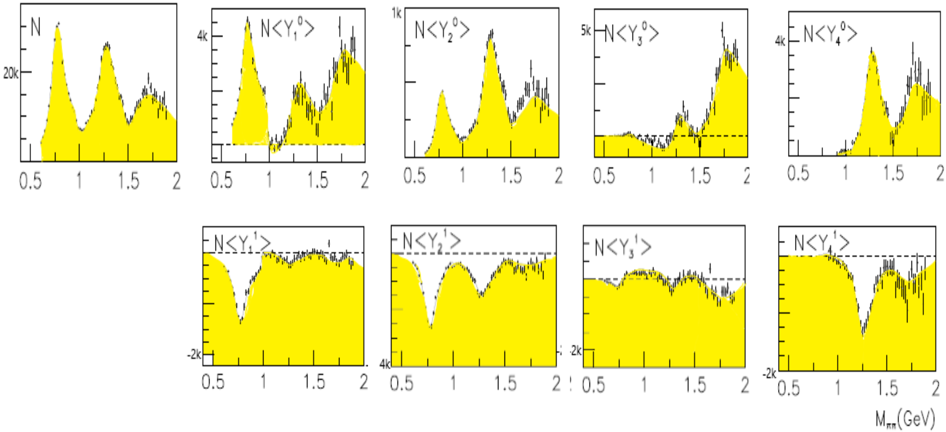
The Crystal Barrel data



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

$\cdots$ **and 11 further Dalitz plots.**

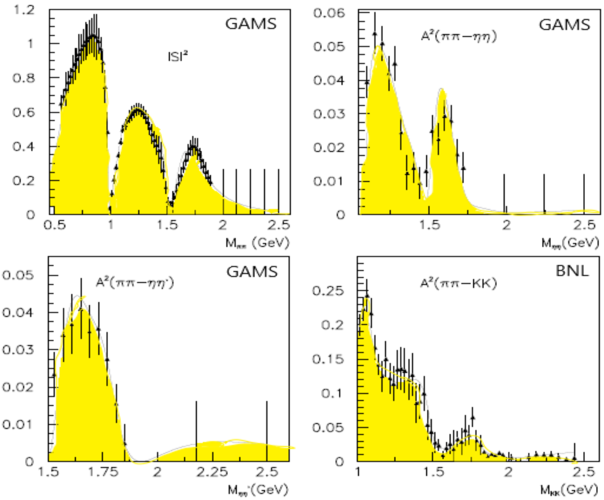
The CERN-Munich data on $\pi\pi \to \pi\pi$ elastic scattering



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).

Low-mass $\pi\pi$ interactions from $K^\pm \to \pi\pi e^\pm \nu$ decay (NA48/2)

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).

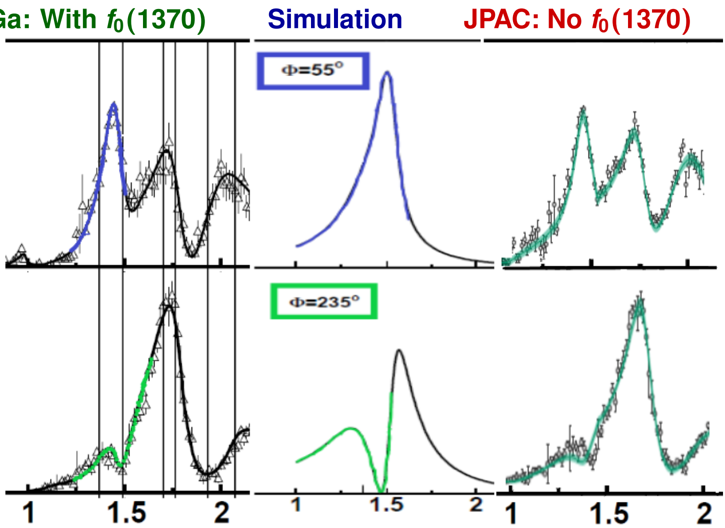
3. The scalar glueball in production

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

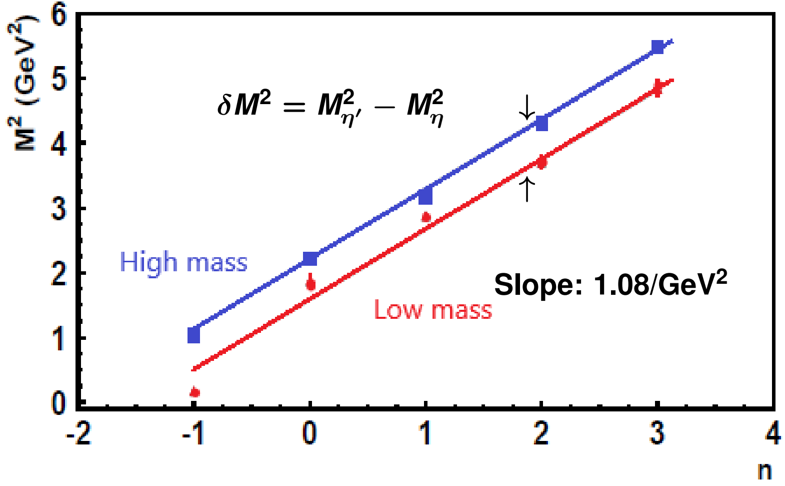
The $f_0(1370) - f_0(1500)$ mixing angle



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

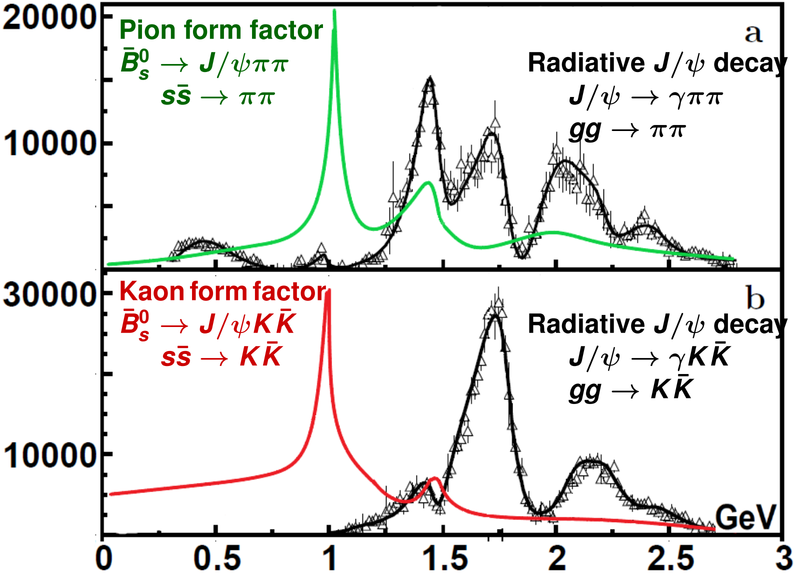
$f_0(1370)$ and $f_0(1500)$ are SU(3) singlet and SU(3) octet-like and not $n\bar{n}$ and $s\bar{s}$!

(M^2, n) trajectories of scalar mesons



$\cdots$ and where is the scalar glueball ?

Evidence for strong glue-glue interactions

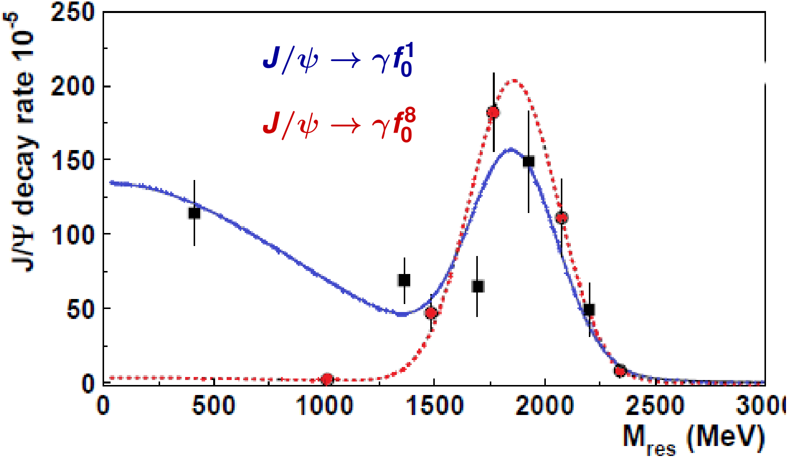


S. Ropertz, C. Hanhart and B. Kubis, "A new parametrization for the scalar pion form factors," Eur. Phys. J. C 78, no.12, 1000 (2018)

The fragmented glueball

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

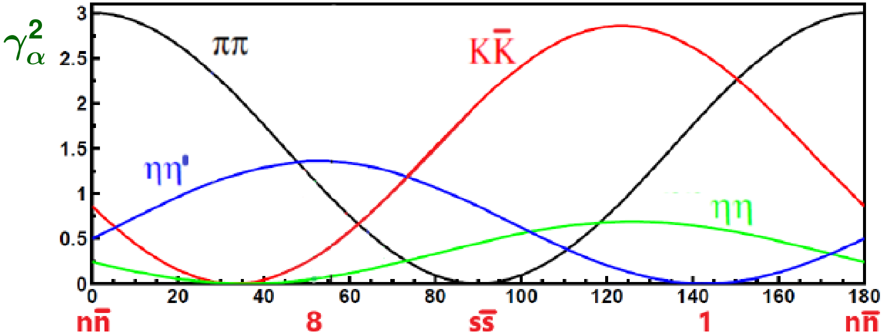
$BR_{J/\psi\to\gamma f_0\to}$	$\gamma\pi\pi$	$\gamma K\bar{K}$	$\gamma\eta\eta$	$\gamma\eta\eta'$	$\gamma\omega\phi$	missing	missing: $\gamma 4\pi$	missing: $\gamma\omega\omega$	total
$f_0(500)$	105±20	5±5	4±3	∼0	∼0	∼0			114±21
$f_0(980)$	1.3±0.2	0.8±0.3	∼0	∼0	∼0	∼0			2.1±0.4
$f_0(1370)$	38±10	13±4	3.5±1	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							



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

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

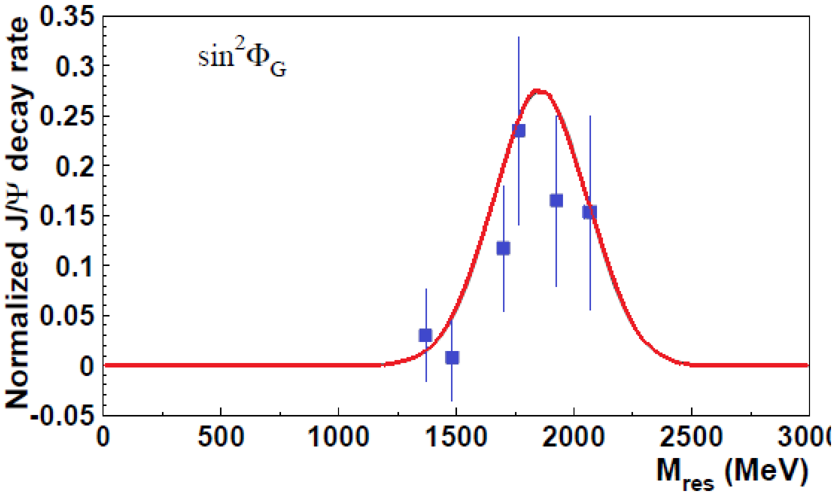
4. The decays of the scalar glueball



$$f_0^{\rm nH}(xxx) = (n\bar{n}\cos\varphi_{\rm n}^{\rm s} - s\bar{s}\sin\varphi_{\rm n}^{\rm s})\cos\phi_{\rm nH}^G + G\sin\phi_{\rm nH}^G$$

$$f_0^{\rm nL}(xxx) = (n\bar{n}\sin\varphi_{\rm n}^{\rm s} + s\bar{s}\cos\varphi_{\rm n}^{\rm s})\cos\phi_{\rm nL}^G + G\sin\phi_{\rm nL}^G$$

$$g_\alpha = c_{\rm n}\gamma_\alpha^q + c_G\gamma_\alpha^G$$



3	4	5	6	7	8
$f_0(1370)$	$f_0(1500)$	$f_0(1710)$	$f_0(1770)$	$f_0(2020)$	$f_0(2100)$
$(5\pm4)\%$	$< 5\%$	$(12\pm6)\%$	$(25\pm10)\%$	$(16\pm9)\%$	$(17\pm8)\%$

$$\sum_3^8 \sin^2\phi_G = 0.78 \pm 0.18$$

5. Discussion

$G_0(1865) \cdots$

1. Its mass is compatible with QCD expectations
2. It is abundantly produced in radiative J/ψ decays with two gluons in the initial state
3. The yield in radiative J/ψ decays is compatible with QCD expectation
4. It is not produced under similar kinematic conditions with $s\bar{s}$ in the intitial state
5. The decays of scalar mesons require a glueball contribution
6. The sum of fractional glueball contributions to scalar mesons is compatible with 1

$\cdots$ is the scalar glueball of lowest mass

One caveat: $G_0(1865)$ is not an additional resonance!

Notes on the number of states

$N(1535)1/2^-$ or $N(1535)S_{11}$ can be interpreted in two ways $\cdots$

Quark models:

$N(1535)1/2^-$ is composed of three constituent quarks with 350 MeV effective mass. One quark is orbitally excited with $L = 1$.

Effective field theories:

Meson-baryon $N\bar{K}$, $\Sigma\pi$, $N\eta$ coupled-channel dynamics generate $N(1535)1/2^-$ dynamically.

$\cdots$ but there is only one state!

$X(3872)$ can be interpreted in two ways $\cdots$

Quark models:

$X(3872)$ could be $\chi_{c1}(2P)$, the radial excitation of $\chi_{c1}(1P)$.

Effective field theories:

$X(3872)$ could be a $D^{0*}\bar{D}^0$ + c.c. molecule.

$\cdots$ are there one or two states?

The wave function of scalar mesons

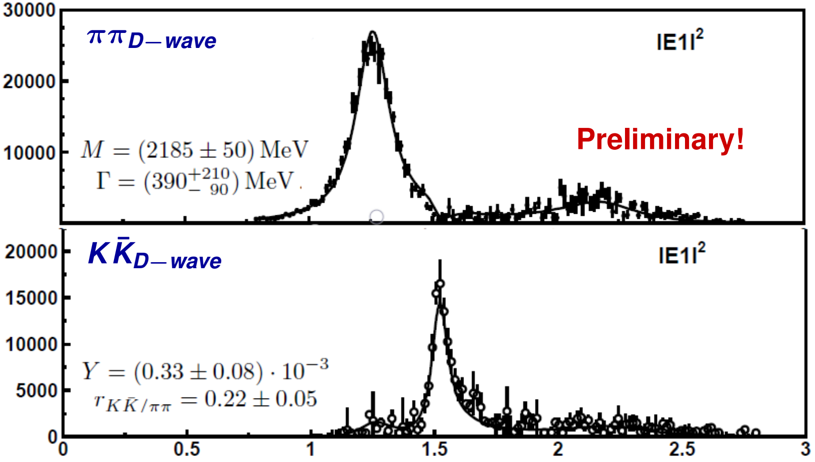
$$
\begin{aligned}
f_0(1500) &= \alpha\frac{1}{\sqrt{6}}(u\bar{u}+d\bar{d}-2s\bar{s}) \\
&+ \beta\frac{1}{\sqrt{6}}(u\bar{u}s\bar{s}+d\bar{d}s\bar{s}-2u\bar{u}d\bar{d}) \\
&+ \gamma\cdot(\text{meson}-\text{meson cloud}) \\
&+ \delta(gg) \\
&+ \epsilon(q\bar{q}g) \\
&+ \cdots \qquad \text{and some singlet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

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

5. The hidden tensor glueball



Too low in mass:	Limited phase space?	Use $\psi(2S)$ radiative decays
Yield too low:	Unseen decays?	Analyse $J/\psi \to \gamma 4\pi, K^*\bar{K}$
Decay modes: $n\bar{n}$	Sum of many f_2 and f_2'?	Higher statistics

6. Summary

- The scalar glueball has been identified in BESIII data on radiative J/ψ decays
- The identification relies on production by two gluons and a decay analysis
- The glueball does not intrude the spectrum of scalar mesons but is part of the wave function of scalar mesons
- The tensor glueball does not exist or hides itself in a large number of $^3P_2$ and $^3F_2$ $n\bar{n}$ and $s\bar{s}$ states that all may carry some glueball component.

Thank you for your patience!