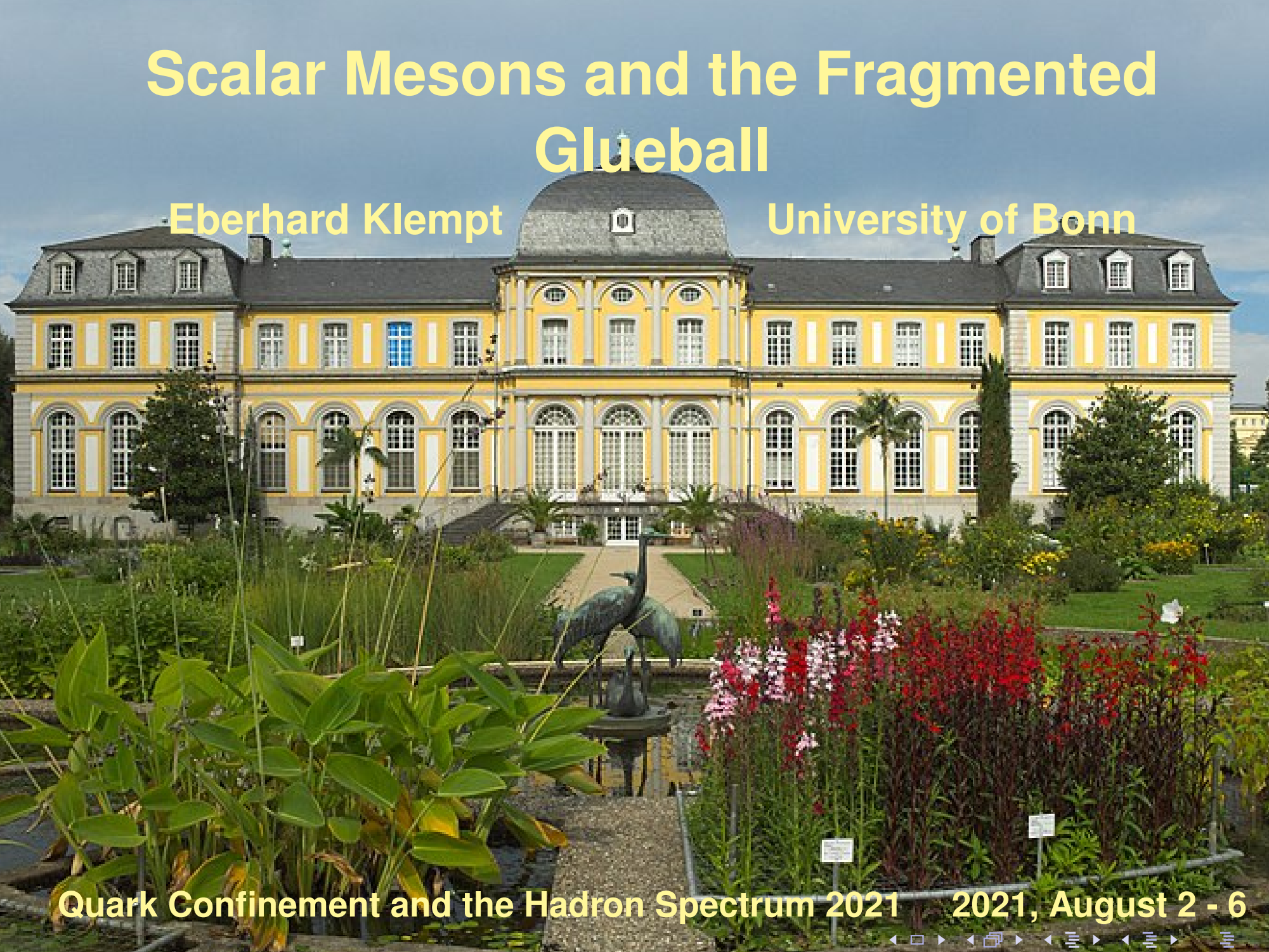
Scalar Mesons and the Fragmented Glueball

Eberhard Klempt University of Bonn

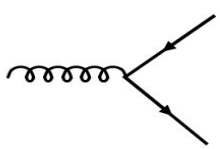


Quark Confinement and the Hadron Spectrum 2021 2021, August 2 - 6

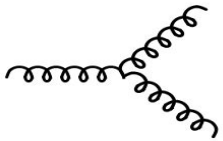
Scalar mesons and the fragmented glueball

1. **Glueballs**
2. **Coupled channel analysis**
3. **Results and interpretation**
4. **Summary**

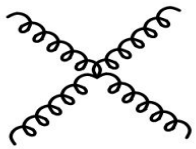
1. Glueballs: Masses



Analogous to photon exchange of QED

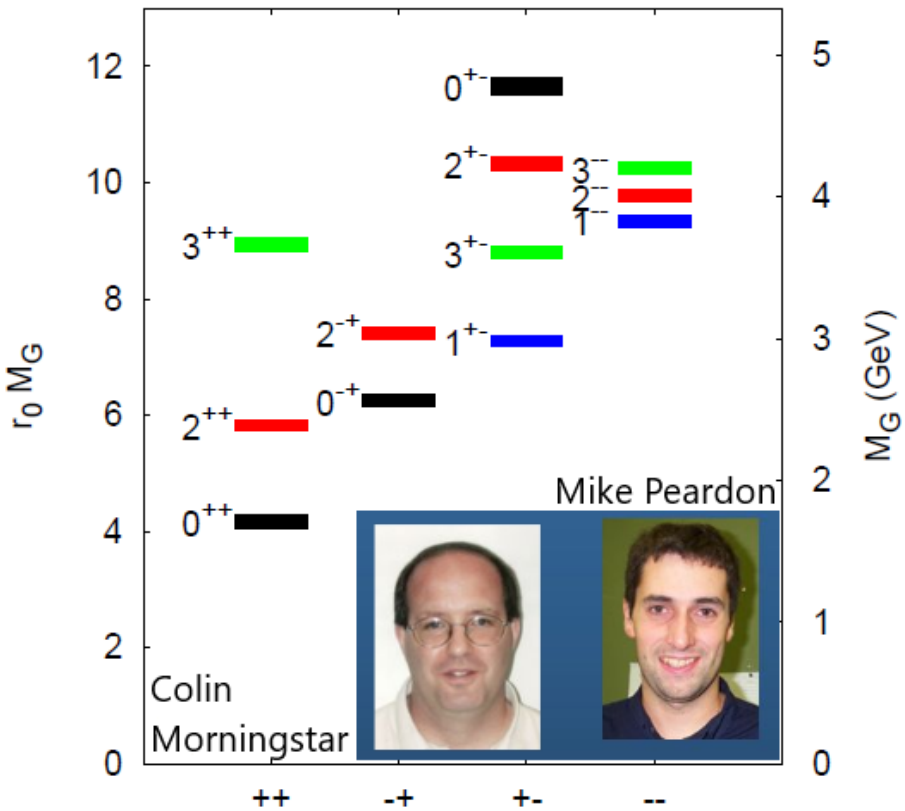


3-gluon vertex



4-gluon vertex

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

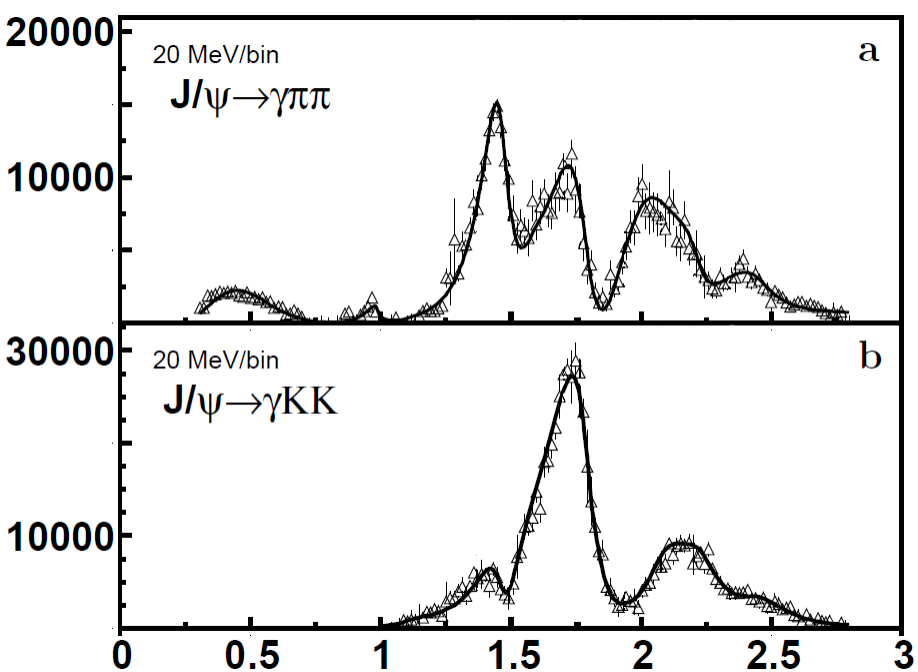
M. Q. Huber, C. S. Fischer and H. Sanchis-Alepuz, "Spectrum of scalar and pseudoscalar glueballs from functional methods," Eur. Phys. J. C 80, no.11, 1077 (2020).

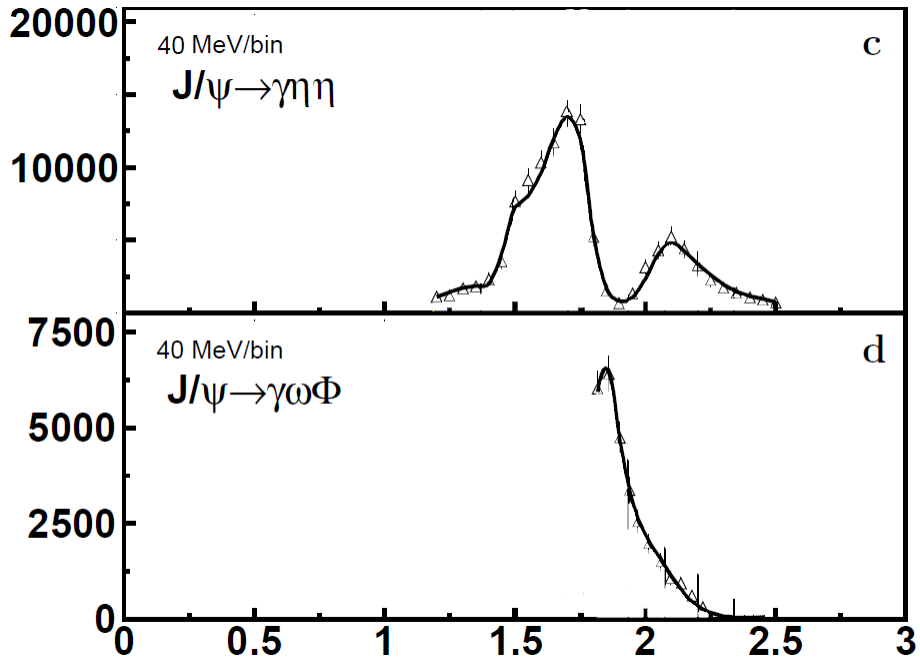
The scalar glueball is expected in the 1700 to 2000 MeV mass range

2. 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,"

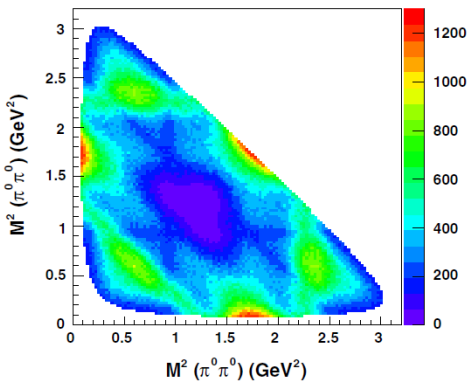
BESIII: $J/\psi \to \gamma\pi^0\pi^0$ and K_SK_S $\eta\eta$ and $\omega\phi$

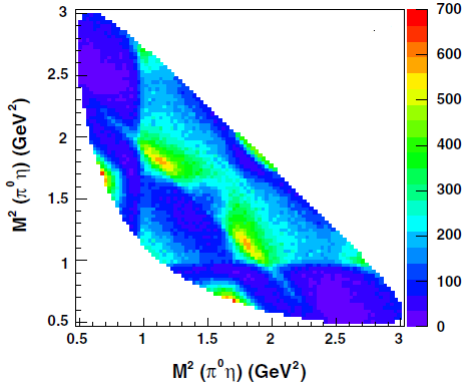


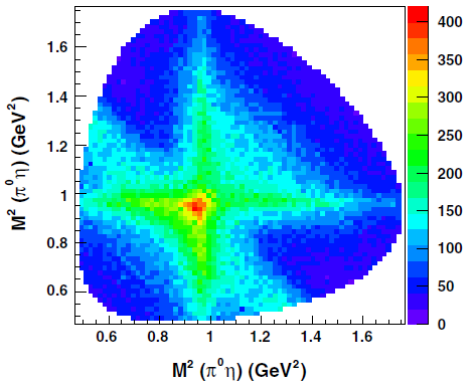


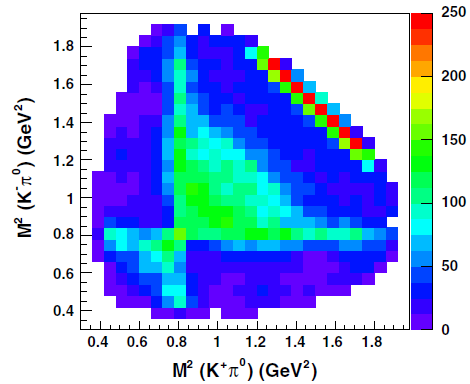
M. Ablikim *et al.* [BESIII Collaboration], "Amplitude analysis of the $\pi^0\pi^0$ system produced in radiative J/ψ decays," Phys. Rev. D 92 no.5, 052003 (2015).
M. Ablikim *et al.* [BESIII Collaboration], "Amplitude analysis of the K_SK_S system produced in radiative J/ψ decays," Phys. Rev. D 98 no.7, 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).

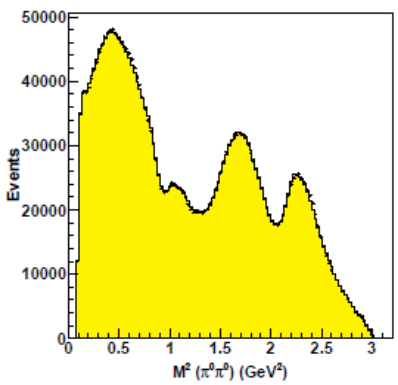
The Crystal Barrel data



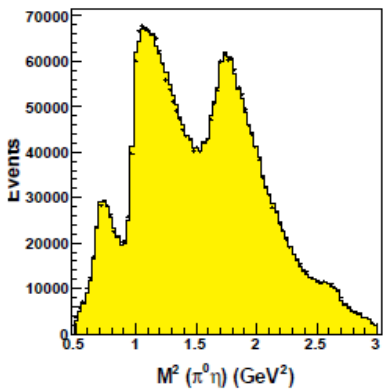




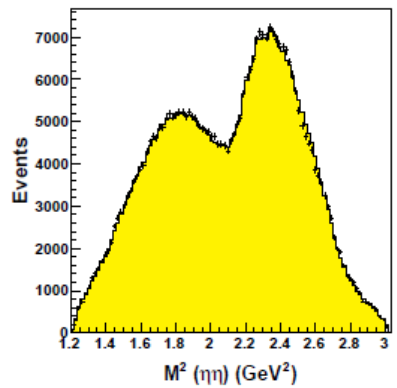




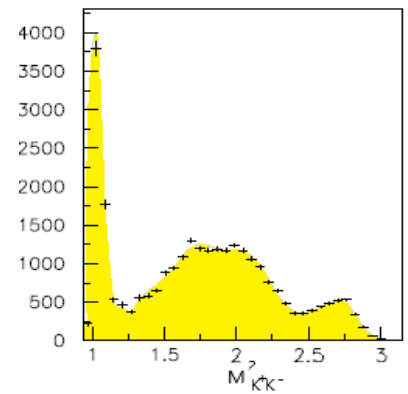
$\pi^0\pi^0\pi^0$



$\pi^0\pi^0\eta$



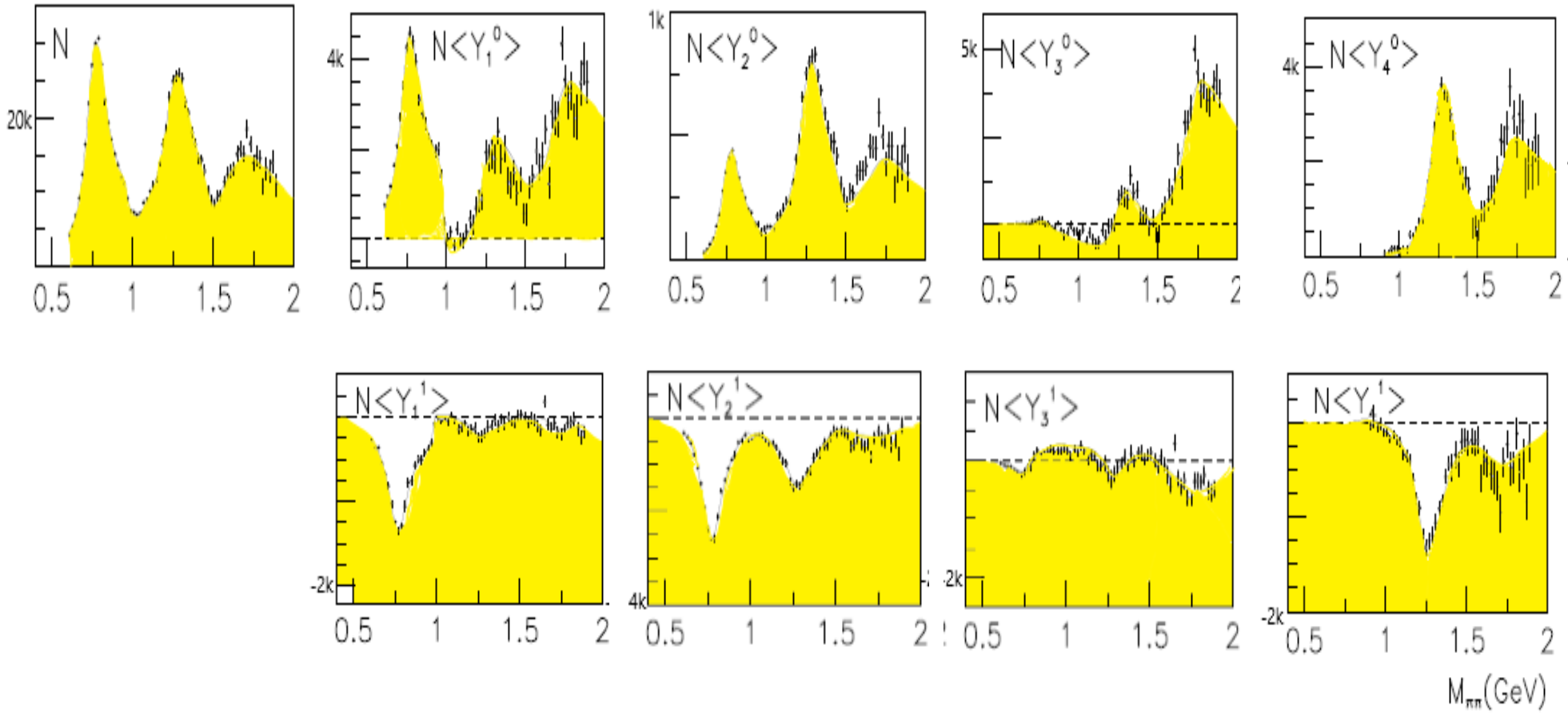
$\pi^0\eta\eta$



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

· · · and 11 further Dalitz plots.

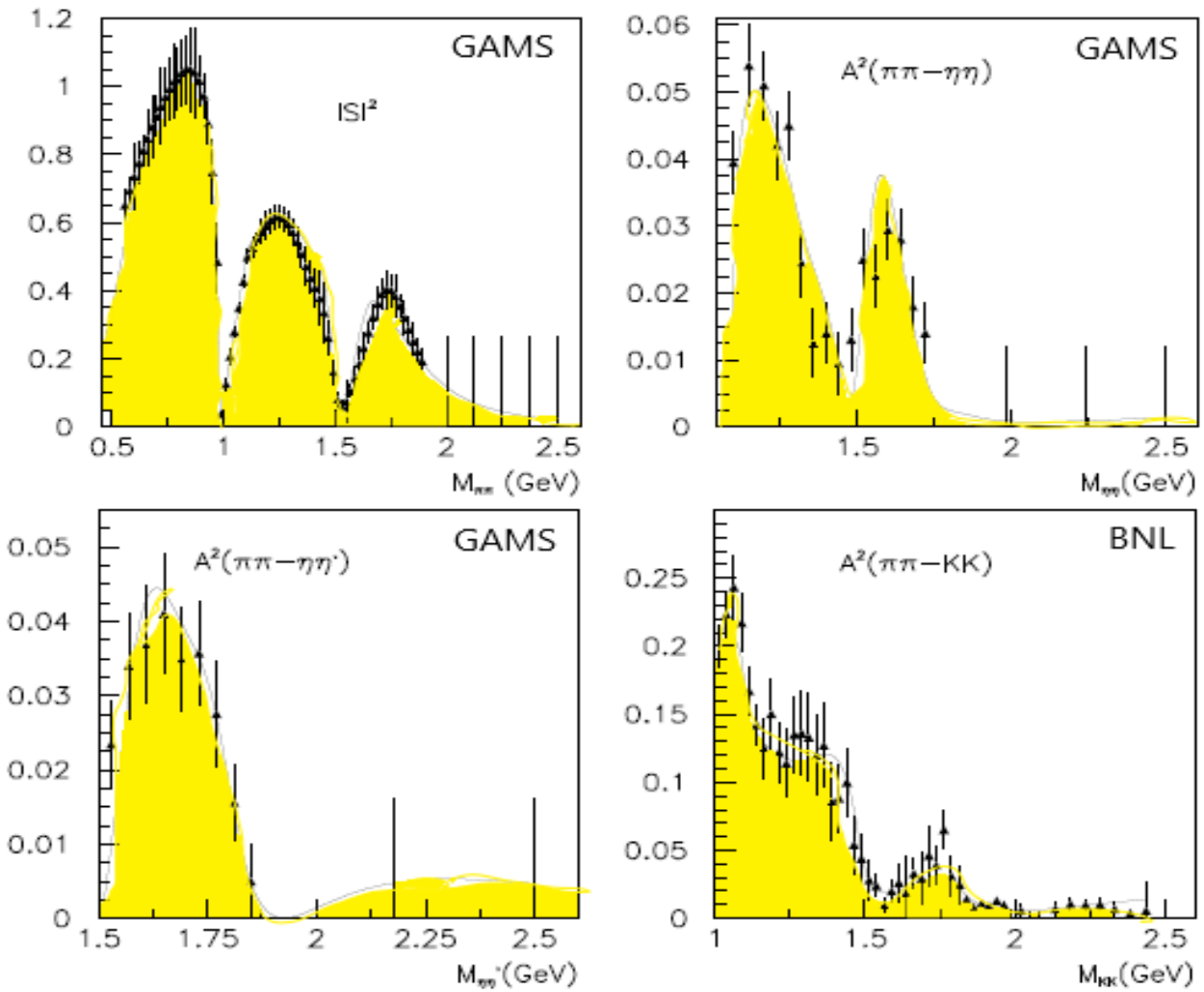
The CERN-Munich data on $\pi\pi \to \pi\pi$ elastic scattering



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).

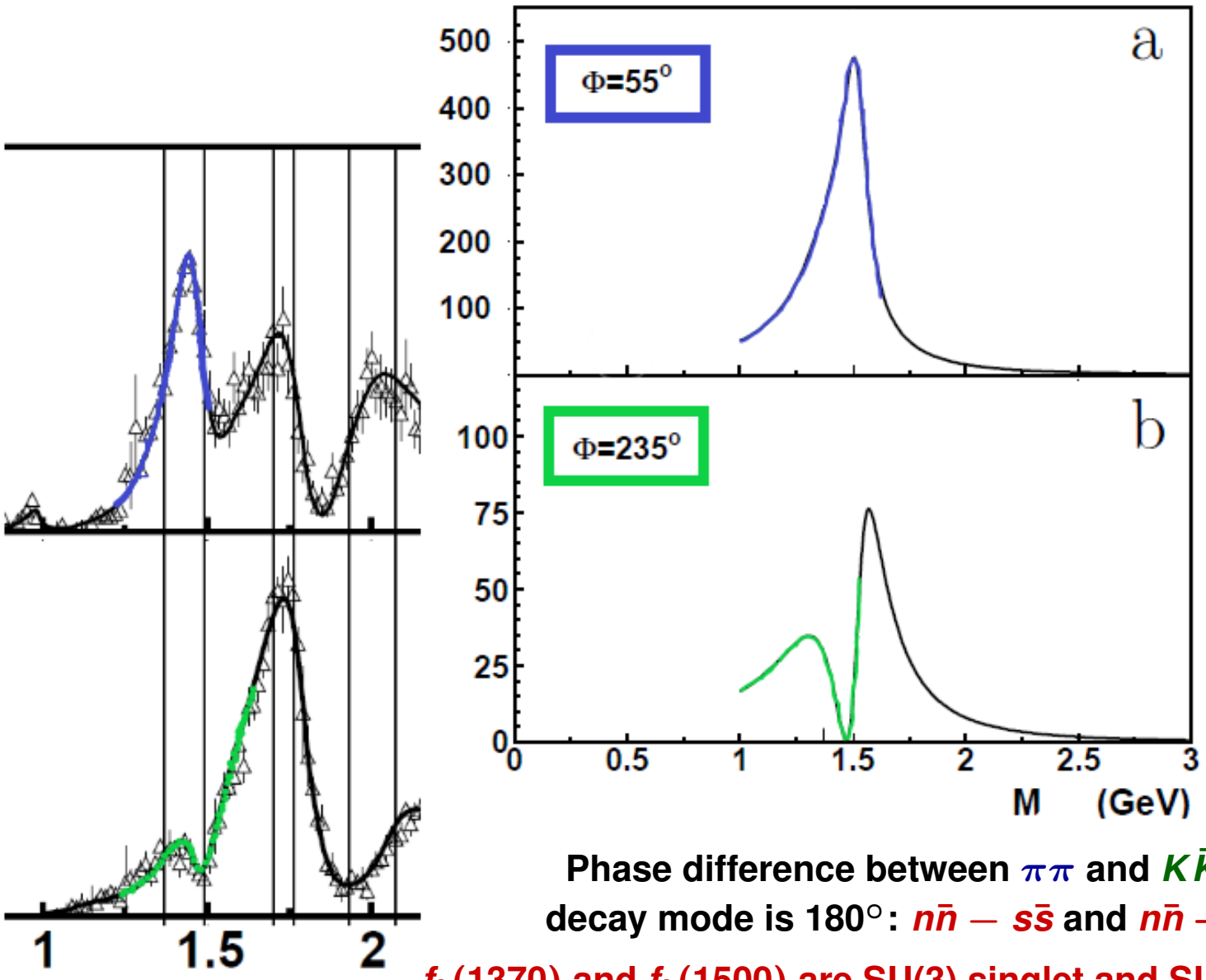
3. Results and interpretation

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 $400 \to 550$	1370 ± 40 $1200 \to 1500$	1700 ± 18 1704 ± 12	1925 ± 25 1992 ± 16	2200 ± 25 2187 ± 14
Γ	480 ± 30 $400 \to 700$	390 ± 40 $100 \to 500$	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 $10 \to 100$	116 ± 12 112 ± 9	180 ± 20	260 ± 25 284^{+60}_{-32}	165 ± 25 250 ± 20

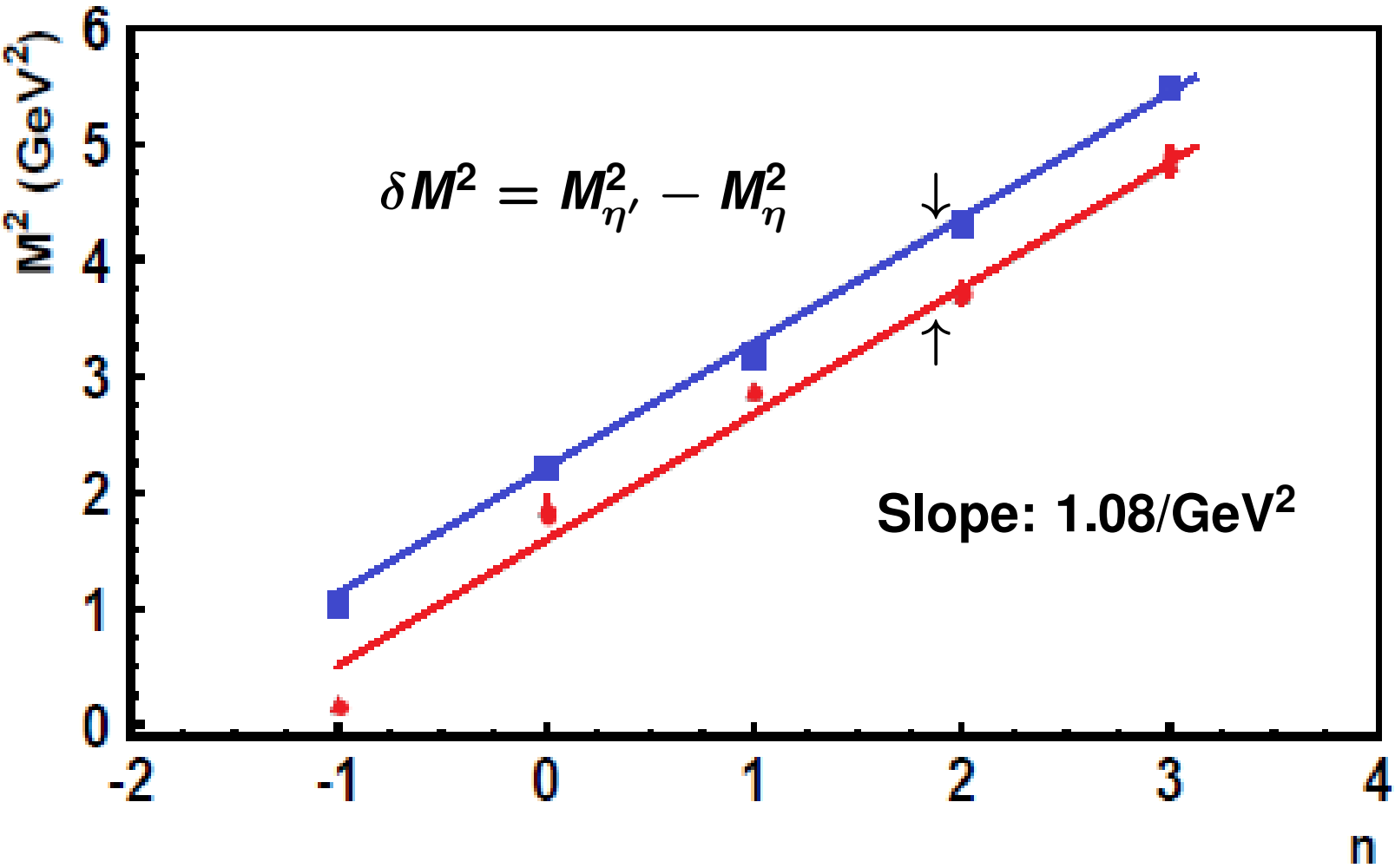
The $f_0(1370) - f_0(1500)$ mixing angle



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

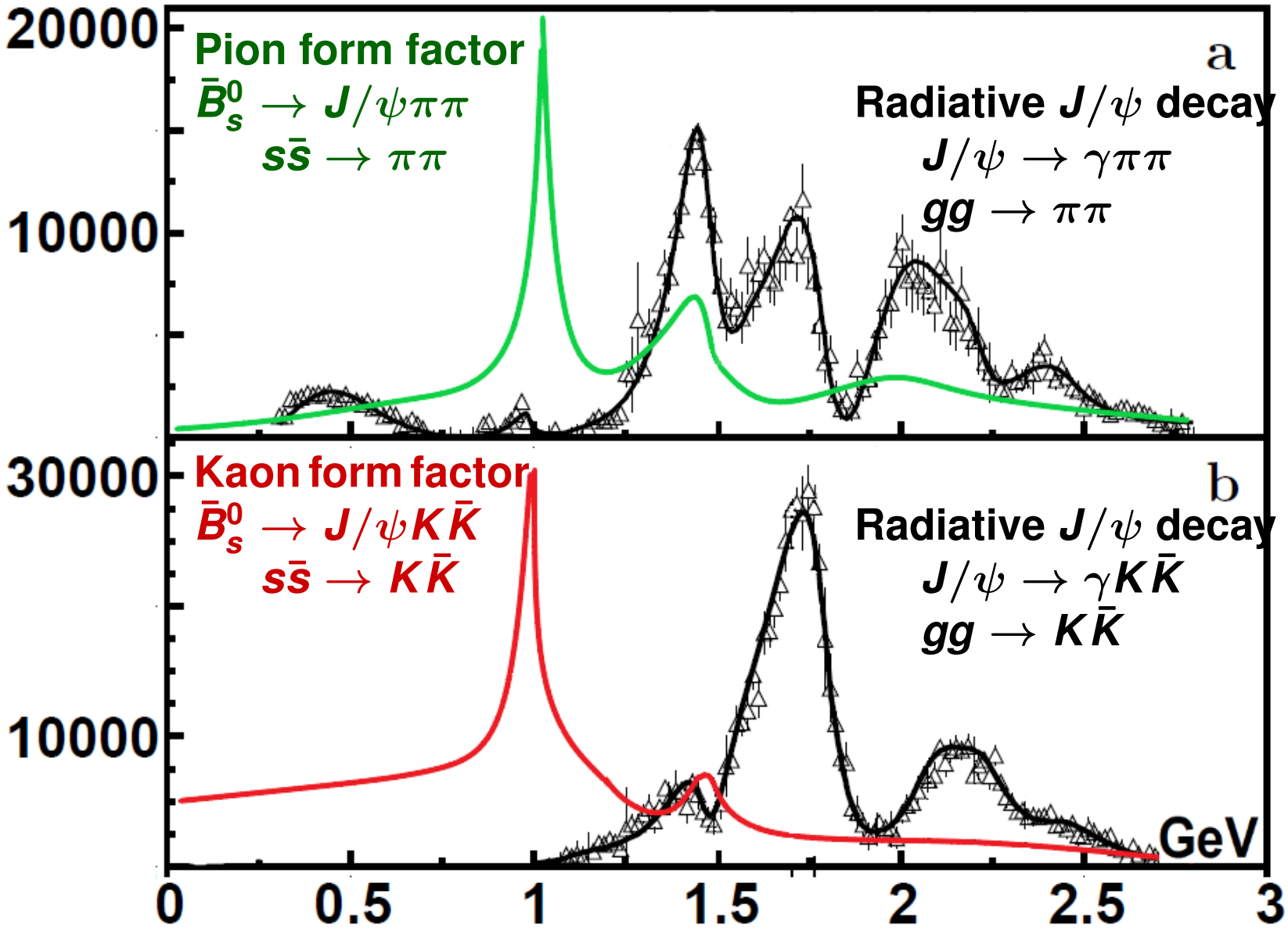
$f_0(1370)$ and $f_0(1500)$ are SU(3) singlet and SU(3) octet-like and not $n\bar{n}$ and $s\bar{s}$!

(M^2, n) trajectories of scalar mesons



· · · and where is the scalar glueball ?

Evidence for strong glue-glue interactions

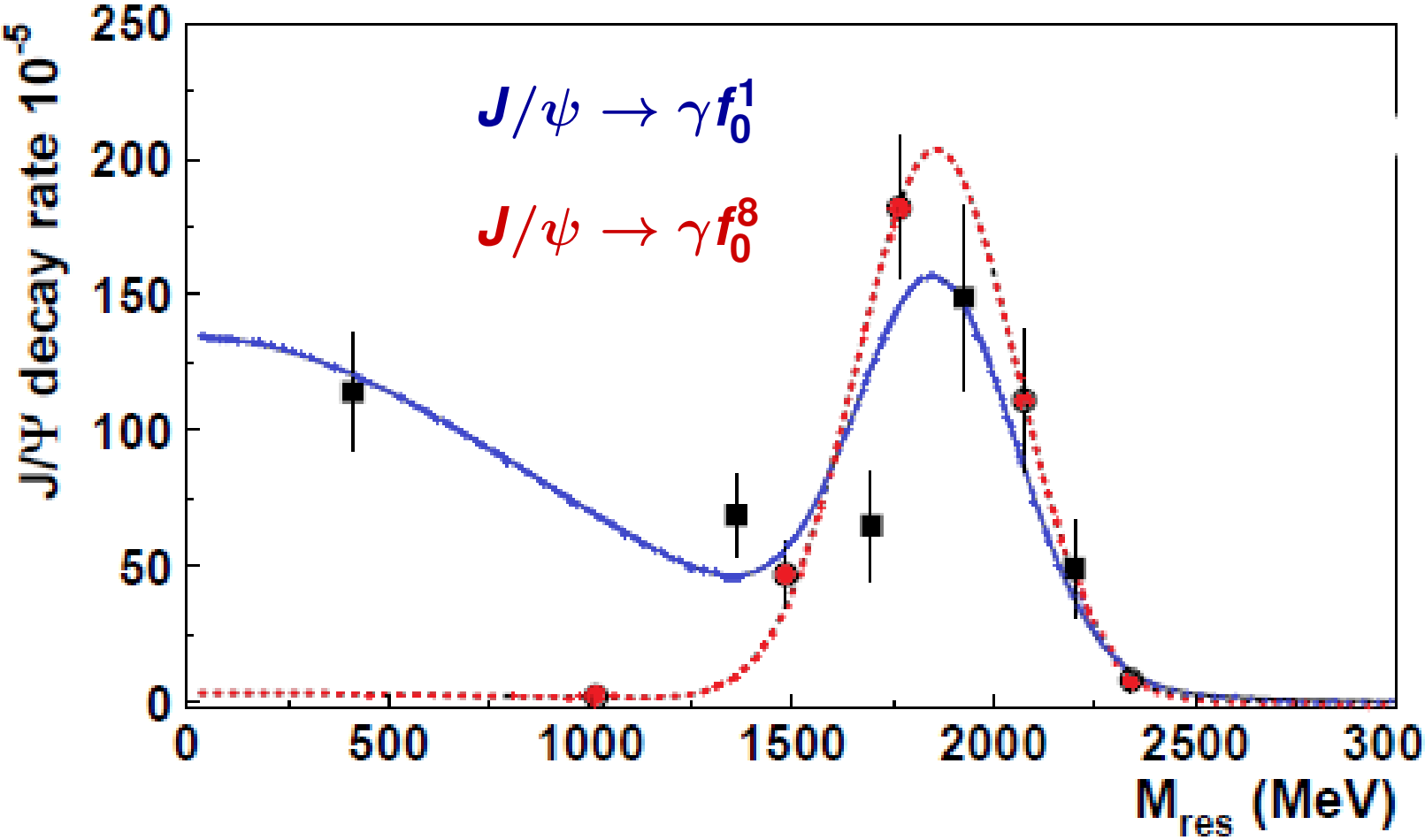


S. Ropertz, C. Hanhart and B. Kubis, "A new parametrization for the scalar pion form factors," Eur. Phys. J. C 78, no.12, 1000 (2018)

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



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

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

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

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 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!