Glueball Searches: Experiment

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Outline:

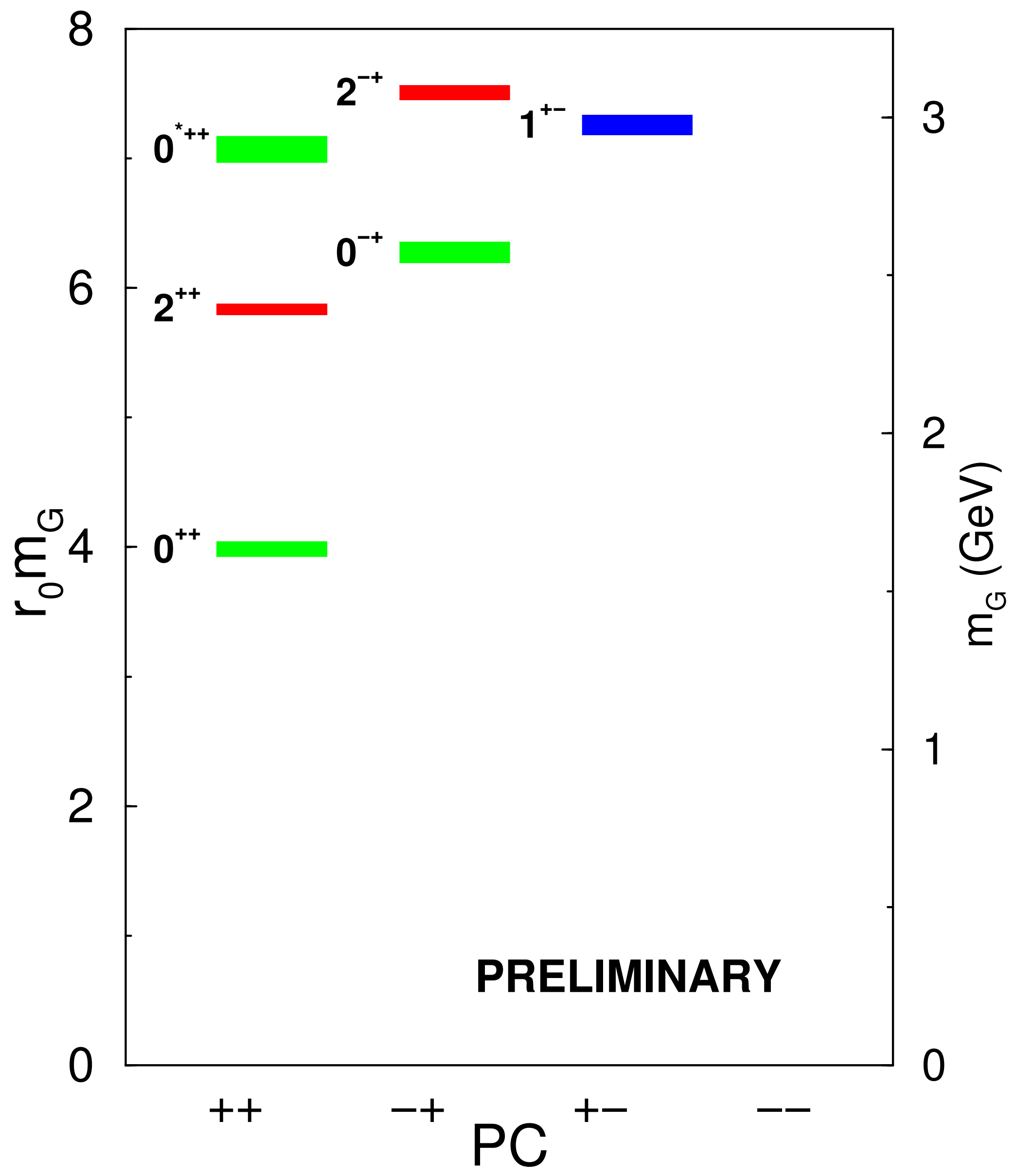
- Looking for glue: Where and How
- History and puzzles
    - The scalars $f_0(1710)$, $f_0(1370)$, and $f_0(1500)$
    - The pseudoscalars $\eta(1418)$ and $\eta(1475)$
- Resolving the puzzles
    - High statistics $J/\psi \rightarrow \gamma X$ using partial waves
    - $J/\psi \rightarrow \gamma X$ followed by $X \rightarrow \gamma Y$
- $M_X \geq 2$ GeV$/c^2$: Tensor glueballs and $J = 4$ mesons

CLEO-c/BESIII Joint Workshop, Beijing, 13-15 Jan 2004

Looking for glue: *Where?*

Morningstar & Peardon

arXiv:nucl-th/0309068



Key Point: Masses and quantum numbers look like ordinary $q\bar{q}$ mesons

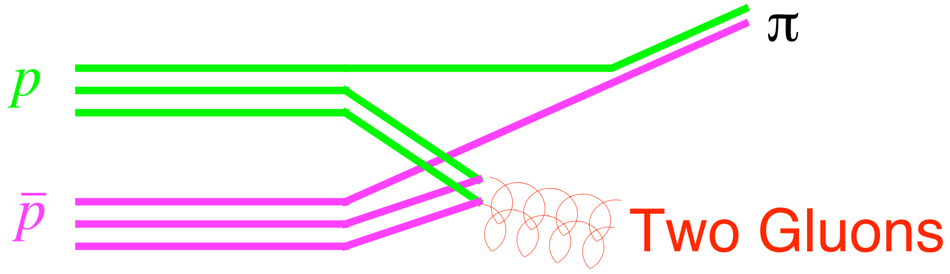
⇒ You need to consider the *dynamics* of production and decay.

So, how do we create "glue rich" situations?

Looking for glue: *How?*

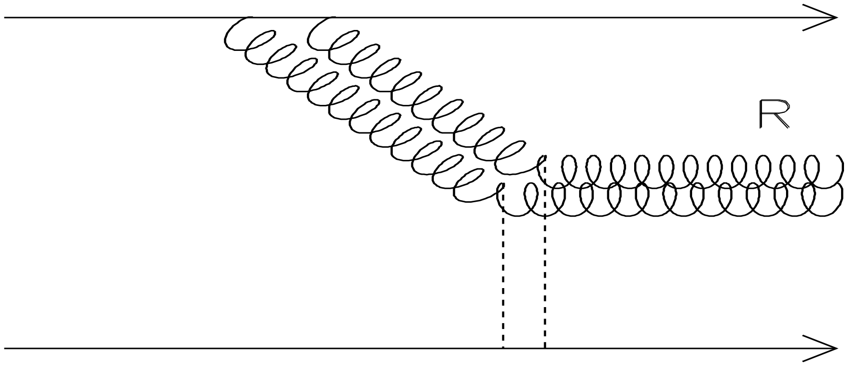
$\bar{p}p$ Annihilation

**C. Amsler,
Rev.Mod.Phys.
70(1998)1293**



pp Central Collisions

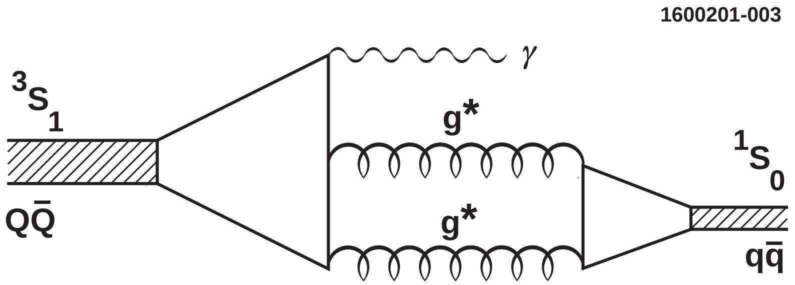
**F. Close & A. Kirk,
Phys.Lett.B 397(1997)333**



J/ψ Radiative Decay

**F. Close, G. Farrar & Z. p.Li,
Phys.Rev.D55(1997)5749**

Main focus of this talk!



History and Puzzles

More states found than are predicted by the quark model.
$\Rightarrow$ Could the extra states be glueballs?

- The scalars $f_0(1710)$, $f_0(1370)$, and $f_0(1500)$

Quark Model predicts only two.
(These are the isoscalar $u\bar{u} + d\bar{d} \equiv n\bar{n}$ and $s\bar{s}$.)
Prime suspect for the lightest glueball.

- The pseudoscalars $\eta(1418)$ and $\eta(1475)$

Quark Model predicts only one.
(This is the $\eta'(958)$ radial excitation).
Mass disagrees with lattice QCD.

$J/\psi \to \gamma X$ *is a key dynamical ingredient!*

The Scalars $f_0(1710)$, $f_0(1370)$, and $f_0(1500)$

Prime tool is $J/\psi \to \gamma X$ with $X \to YY$ and spin-zero Y

$f_0(1710)$

Early glueball excitement @ SPEAR: The $\theta(1700)$

Xtal Ball ($J/\psi \to \gamma\eta\eta$) and Mark-III ($J/\psi \to \gamma K^+K^-$)

Spin/Parity assignments using Partial Wave Analysis

Mark-III (W. Dunwoodie) in SLAC-PUB-7163 (1997)

BES: J. Z. Bai *et al.* Phys. Rev. D 68, 052003 (2003)

$f_0(1370)$

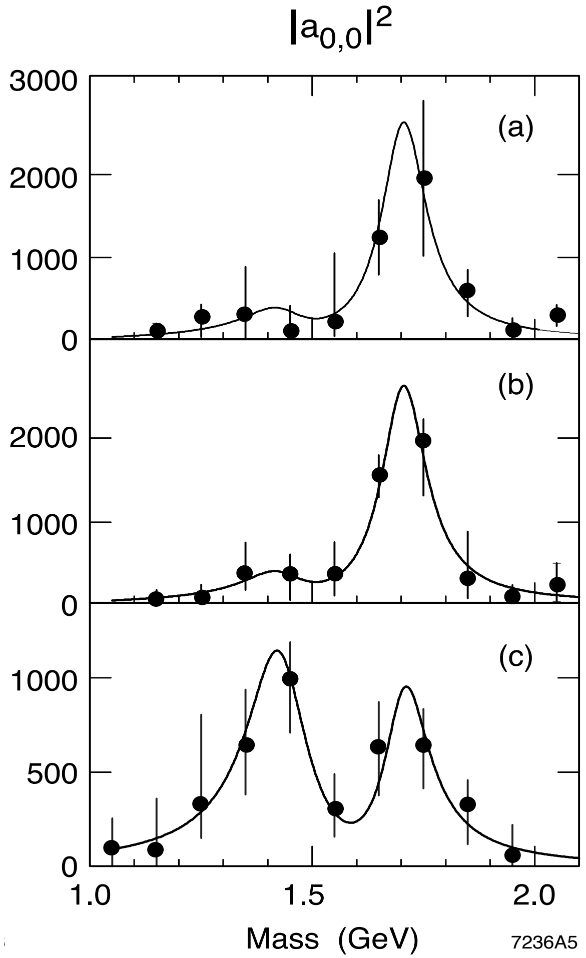
Broad S-wave enhancement known since 1970's.
It seems to be clear in $J/\psi \to \gamma\pi^+\pi^-$.

$f_0(1500)$

Excitement in 1990's: Narrow $\pi^0\pi^0$ state in $\bar{p}p \to 3\pi^0$.
Little or no evidence in $J/\psi \to \gamma X$!

Mark-III Spin Parity Assignments

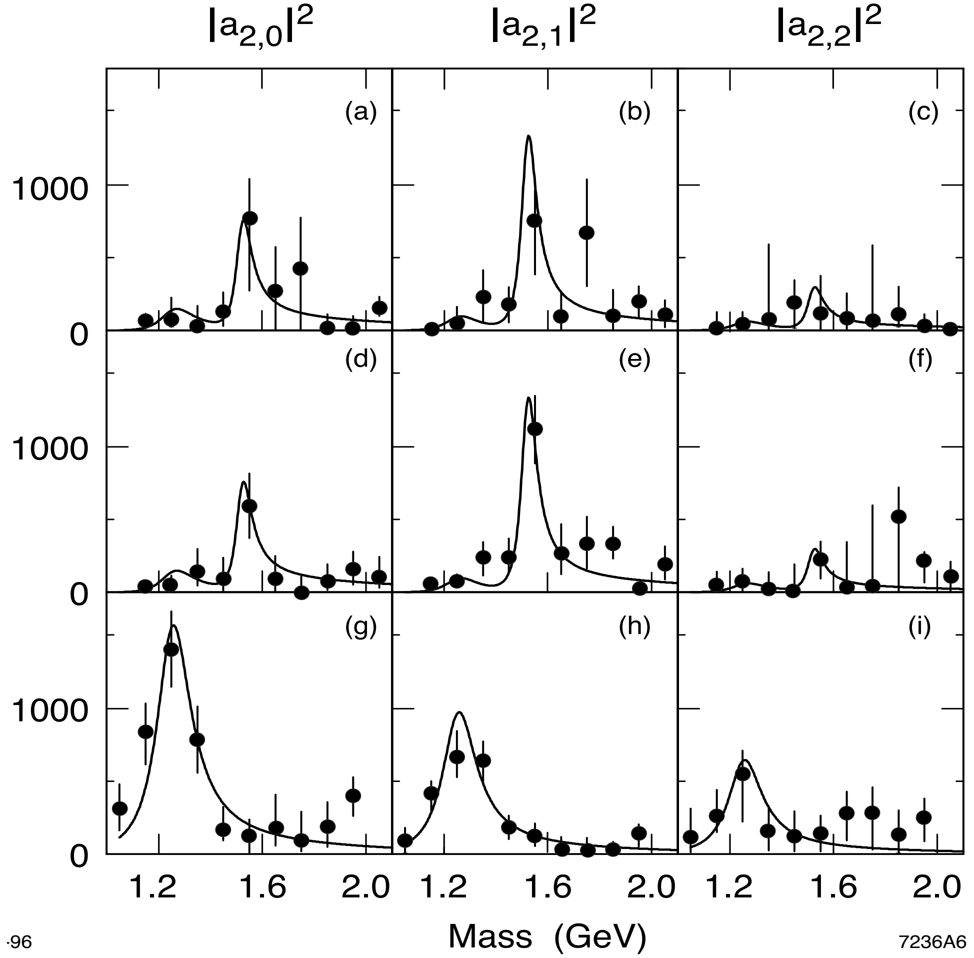
Recall $J/\psi \rightarrow \gamma X$, where $X \rightarrow \ldots$



$K_S K_S$

$K^+ K^-$

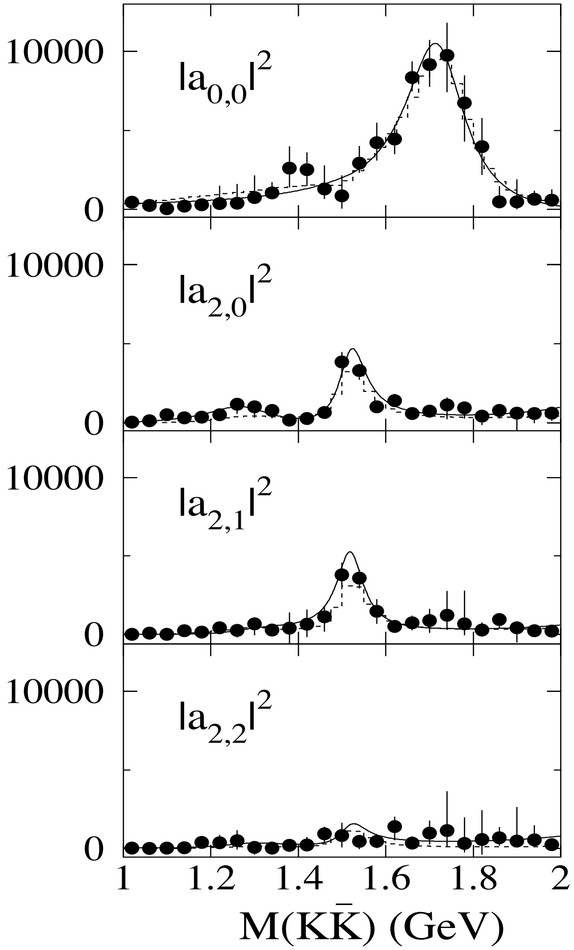
$\pi^+ \pi^-$



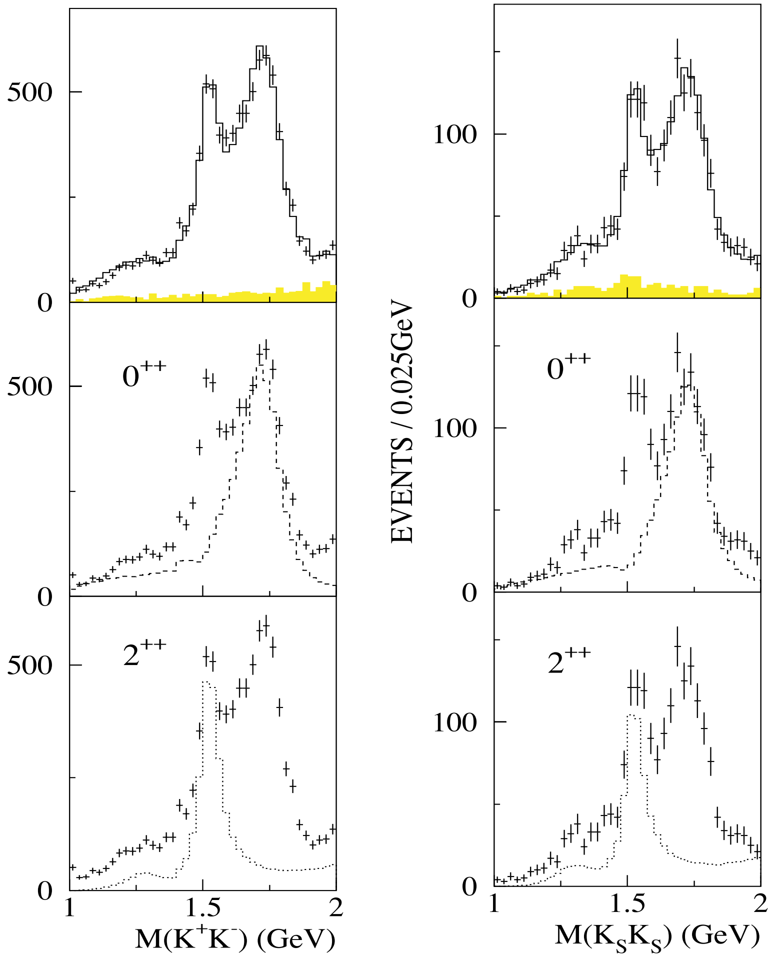
Data Points: A Bin-by-Bin (i.e. Mass Independent) Fit
Solid Lines: A Mass Dependent Fit to the Data Points

Recent BES: $J/\psi \to \gamma K\bar{K}$

Bin-by-Bin Fit



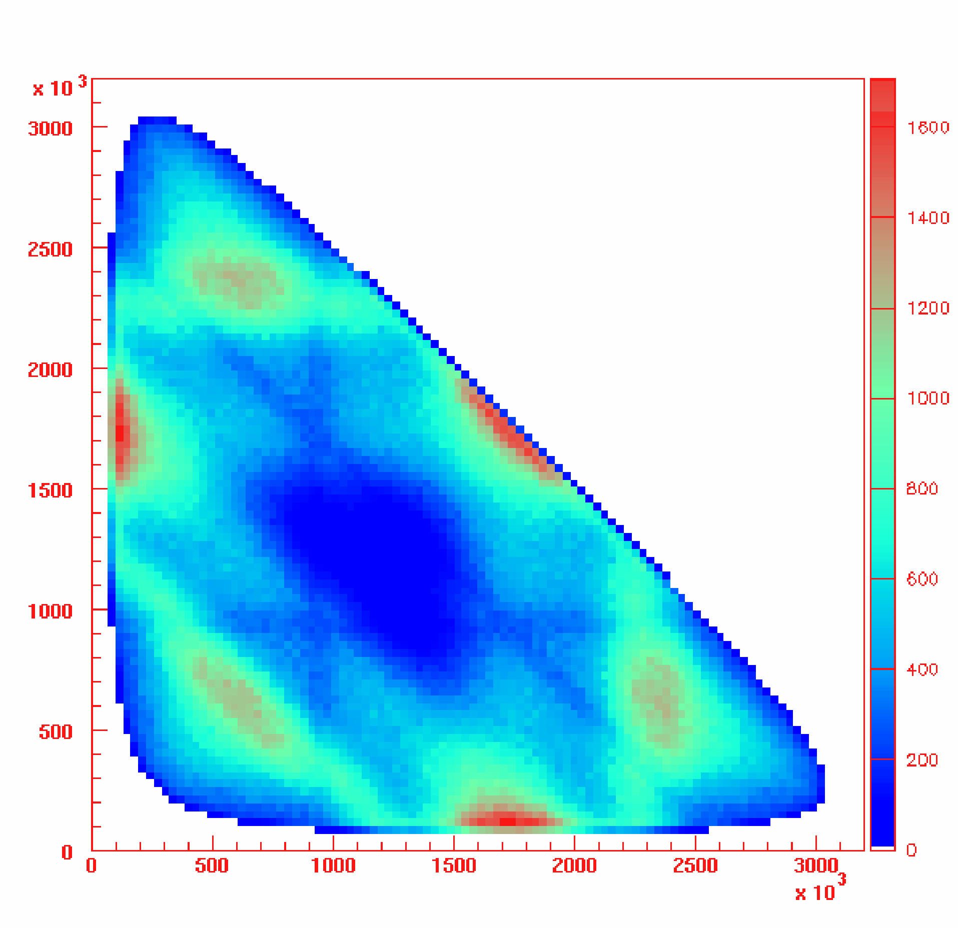
Global Fit



- $J/\psi \to \gamma K\bar{K}$ is dominated by $f_0(1710)$ and $f_2'(1525)$
- $J/\psi \to \gamma\pi^+\pi^-$ is dominated by $f_0(1710)$ and $f_2(1270)$, … and $f_0(1370)$ (See also preliminary BES)

The $f_0(1500)$ is Seen Elsewhere

$$\bar{p}p \longrightarrow \pi^0\pi^0\pi^0$$

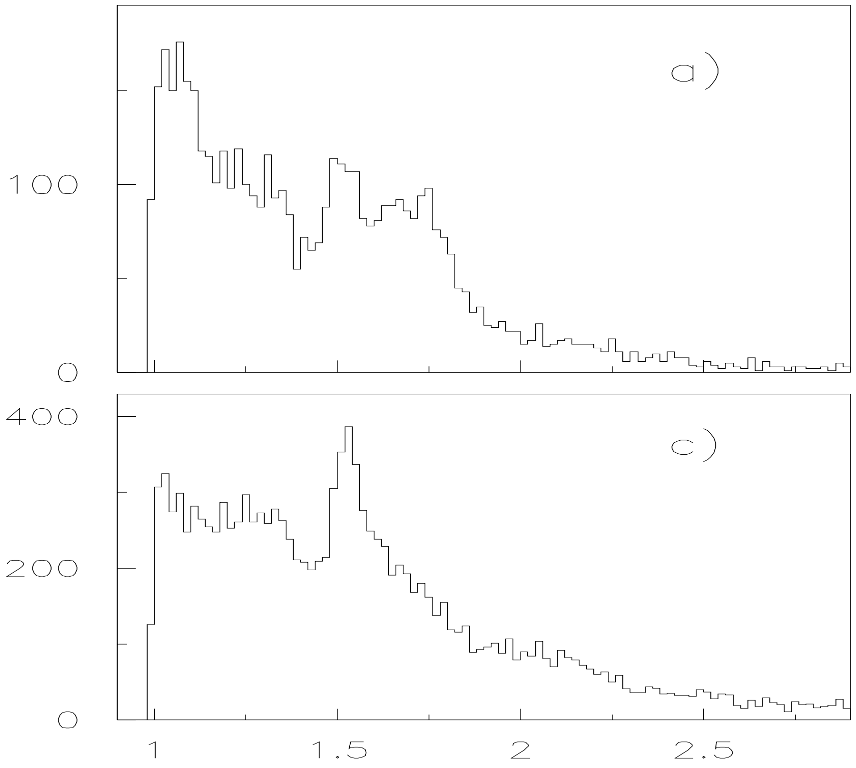


$$M^2(\pi^0\pi^0)$$

Crystal Barrel (1995)

$$pp \longrightarrow p(K^+K^-)p$$

p_t cut $\Rightarrow$ Glueball filter



$$M(K^+K^-)$$

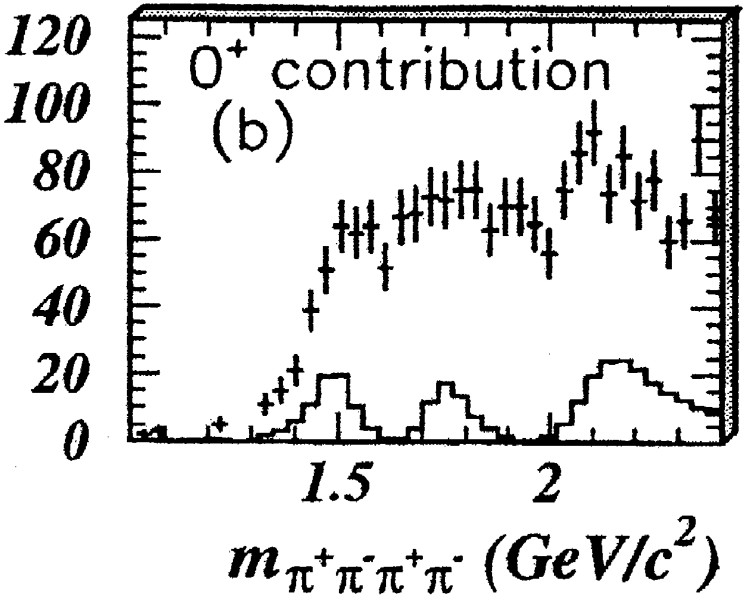
CERN Ω Spect (1999)

Important Goal: Identify $J/\psi \to \gamma f_0(1500)$

Note potential interference with $f_2'(1525)$
$\Rightarrow$ Need careful partial wave analysis

BES Global Fit to $J/\psi \to \gamma K\bar{K}$ shows slight preference for including $f_0(1500)$ in the fit.

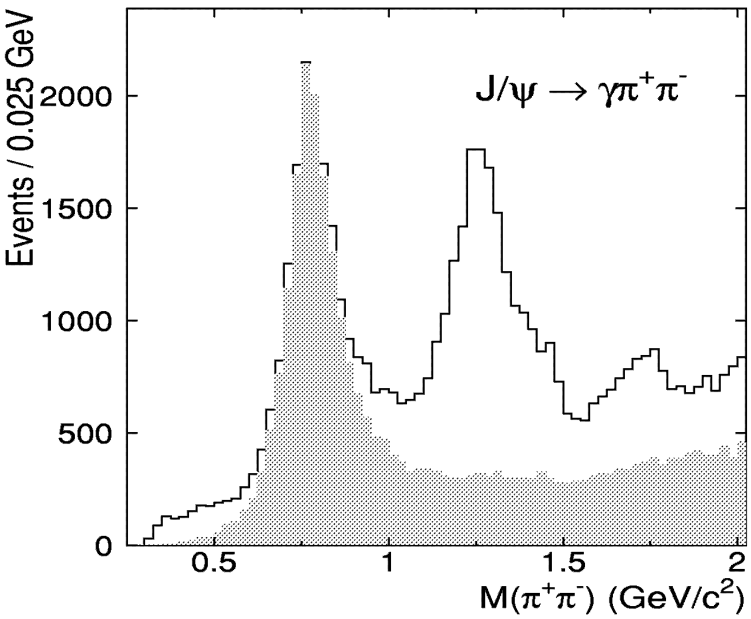
Further evidence from BES in
$J/\psi \to \gamma\sigma\sigma \to \gamma\pi^+\pi^-\pi^+\pi^-$
J. Z. Bai *et al.*,
Phys. Lett. B 472, 207 (2000)

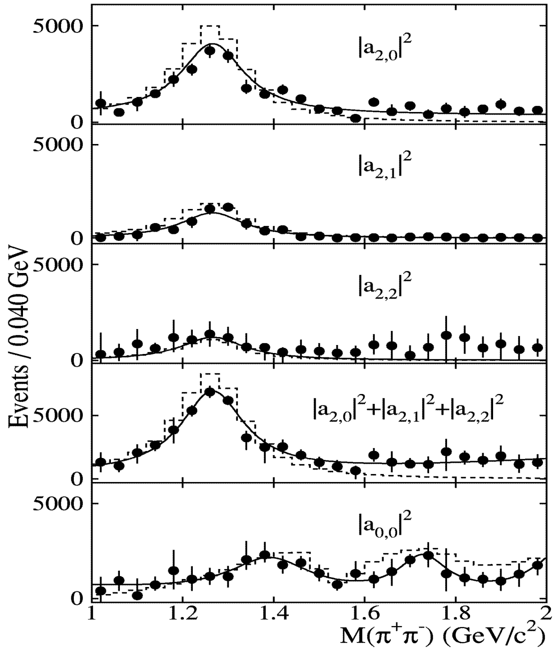


We should be able to observe this in CLEO-c and BESIII and to independently measure branching ratios for various $f_0(1500)$, $f_0(1710)$, and $f_0(1370)$ decays.

The Case for $J/\psi \rightarrow \gamma\pi^0\pi^0 \rightarrow 5\gamma$

$J/\psi \rightarrow \gamma\pi^+\pi^-$ can be done, but it is hard:
X. Y. Shen. Mod. Phys. Lett. A 18, 340 (2003)





Better: Two identical particles (e.g. $\pi^0\pi^0$ or $K_S K_S$)

- Such backgrounds will not be observed.
- Only 0^{++}, 2^{++}, ... are allowed

$J/\psi \rightarrow 5\gamma$ also allows $J/\psi \rightarrow \gamma\eta\eta$

The Pseudoscalars $\eta(1418)$ and $\eta(1475)$

Originally suggested as the "first glueball":
M. S. Chanowitz, Phys. Rev. Lett. 46, 981 (1981)

Observed by Mark-II @ SPEAR in the decay

$$J/\psi \to \gamma K_S K^{\pm}\pi^{\mp}$$

as a peak with $M(K_S K^{\pm}\pi^{\mp}) = 1440$ MeV.

This became the "E/ι Puzzle". We now understand this region as populated by three different resonances:

$f_1(1420) \to \bar{K}K^{\star}$+c.c. Accomodated by Quark Model
$\eta(1418) \to a_0(980)\pi$ Only one of these...
$\eta(1475) \to \bar{K}K^{\star}$+c.c. ...can be accomodated

Could the extra η be a glueball? No experimental evidence against this, but it would disagree with lattice gauge calculations.

Data on $J/\psi \to \gamma K\bar{K}\pi$

Z. Bai *et al.* (MARK-III), Phys. Rev. Lett. 65, 2507 (1990)

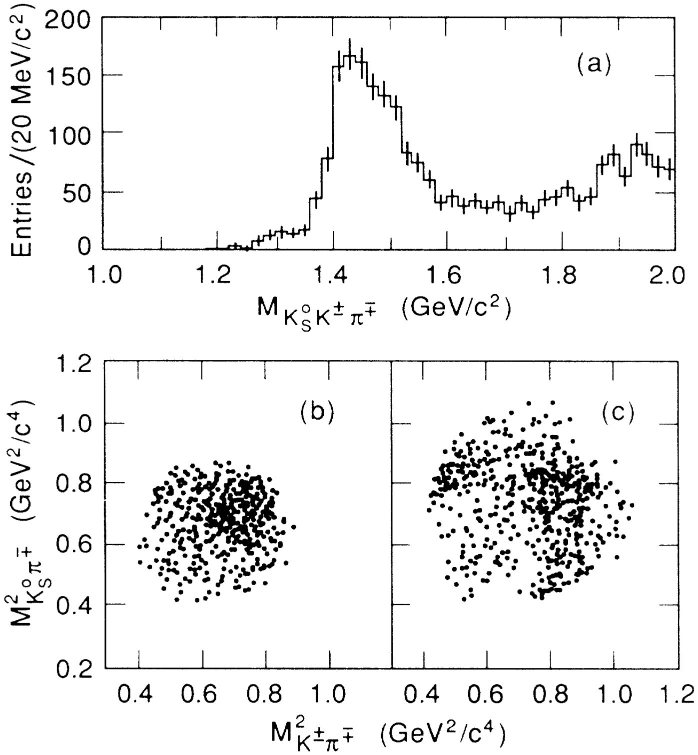
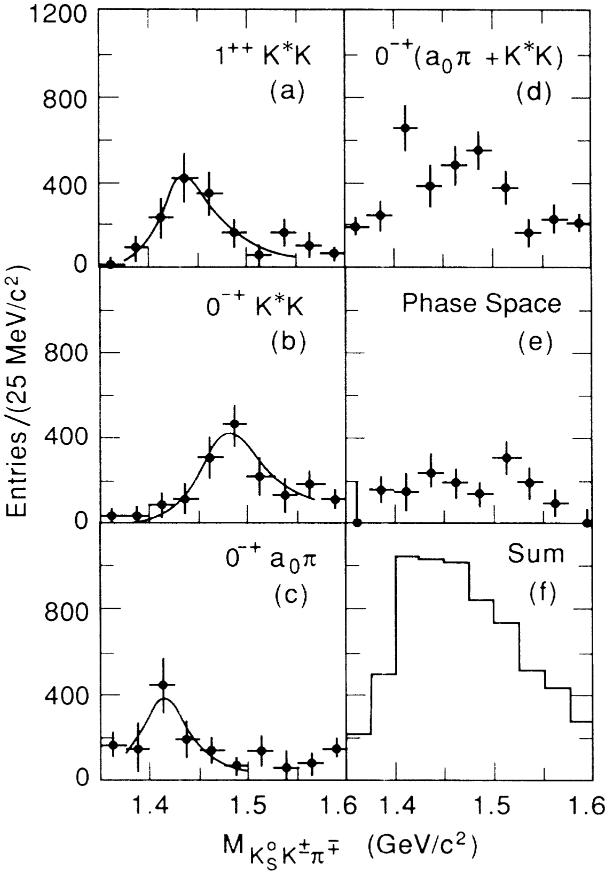


FIG. 1. (a) Invariant $K^0_S K^\pm \pi^\mp$ mass distribution; (b) Dalitz plot for $1.35 < M_{K^0_S K^\pm \pi^\mp} < 1.45$ GeV/c^2; (c) Dalitz plot for $1.45 < M_{K^0_S K^\pm \pi^\mp} < 1.55$ GeV/c^2.



However, see also BES results:

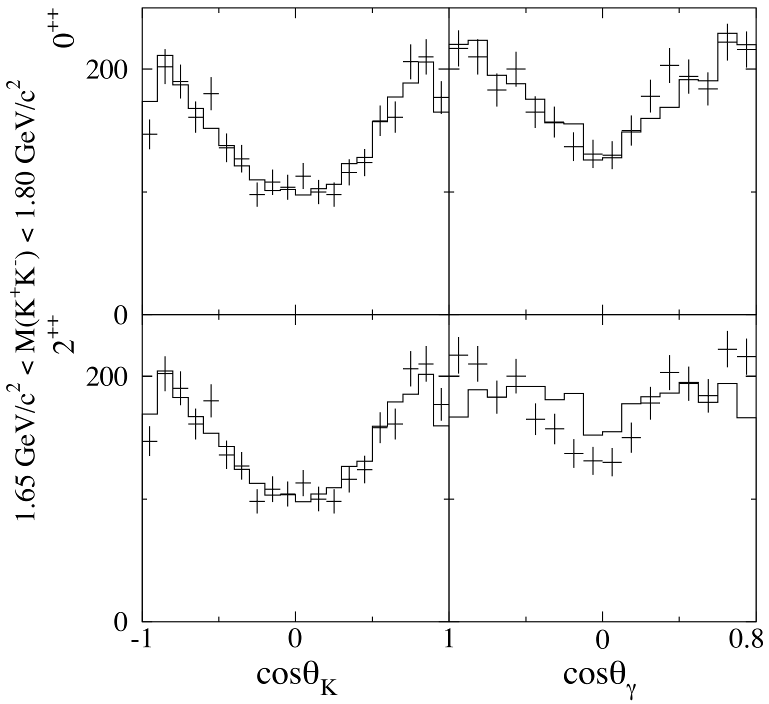
J. Z. Bai *et al.*, Phys. Lett. B 440, 217 (1998)

J. Z. Bai *et al.*, Phys. Lett. B 476, 25 (2000)

Resolving the Puzzles: I

High Statistics $J/\psi \rightarrow \gamma X$

BES: $J/\psi \rightarrow \gamma K^+K^-$



Partial Wave Analysis relies on subtle differences in the various angular distributions.

⇒ Need plenty of statistics not only for quality of fit, but also to test sensitivity of acceptance to various cuts.

Note: Good place to start is with a well understood detector with as flat an acceptance function as possible!

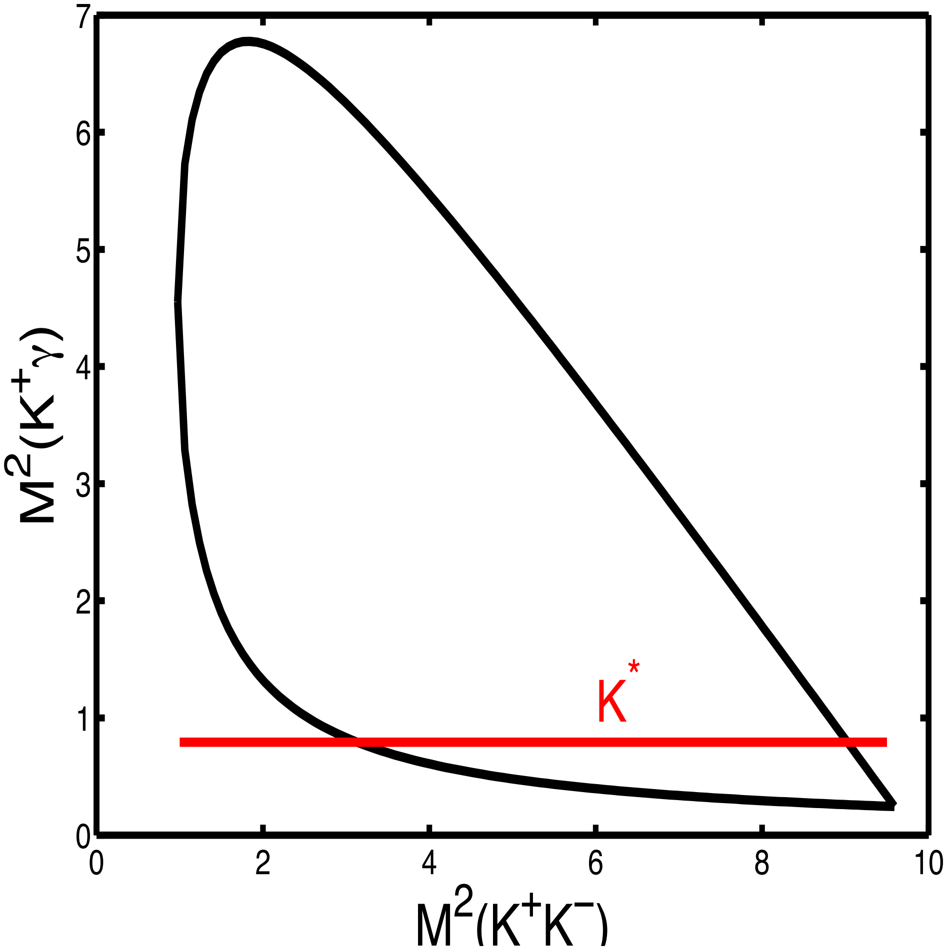
Can one interfere $J/\psi \to \gamma K\bar{K}$ with $J/\psi \to K^\star\bar{K}$?

$\mathcal{B}(J/\psi \to \gamma K\bar{K}) \approx 10^{-3}$

$\mathcal{B}(J/\psi \to K^\star\bar{K}) \approx 10^{-2}$

$\mathcal{B}(K^\star \to \gamma K) \approx 10^{-3}$

$\Rightarrow$ $K^\star$ band has $\mathcal{B} \approx 10^{-5}$



$\Rightarrow$ **We might be able to exploit this for higher mass $K\bar{K}$ resonances *if* there are high enough statistics.**

Resolving the Puzzles: II
Radiative Decay as a Flavor Probe

F. E. Close, A. Donnachie and Y. S. Kalashnikova,
"Radiative decays: A new flavor filter,"
Phys. Rev. D 67, 074031 (2003)

Fundamental problem: How do the $n\bar{n}$, $s\bar{s}$, and glueball scalars mix to form the $f_0(1710)$, $f_0(1370)$, and $f_0(1500)$?

Hadronic decays can be used, but glueball is hard to model: F. E. Close and A. Kirk, Eur. Phys. J. C 21, 531 (2001)

Photons only couple to the quarks.
$\Rightarrow$ *Radiative decay width should be very sensitive to the glueball/$q\bar{q}$ admixture.*

Results of Model Calculations

Three Scenarios, based on values of bare masses:

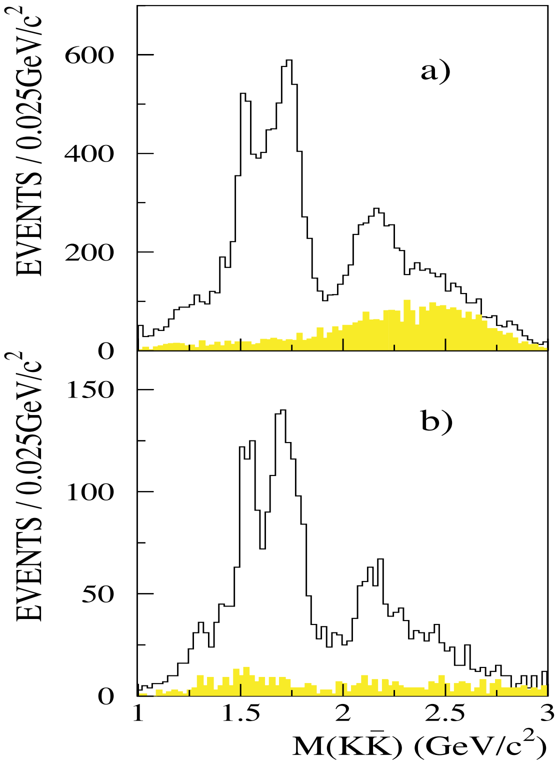
$M(glueball) < M(n\bar{n}) \equiv$ "L"
$M(n\bar{n}) < M(glueball) < M(s\bar{s}) \equiv$ "M"
$M(glueball) > M(s\bar{s}) \equiv$ "H"

Radiative Decay Widths in keV							Γ_{Tot}
	$f_0 \rightarrow \gamma\rho(770)$			$f_0 \rightarrow \gamma\phi(1020)$			MeV
State	L	M	H	L	M	H	
$f_0(1370)$	443	1121	1540	8	9	32	∼300
$f_0(1500)$	2519	1458	476	9	60	454	109
$f_0(1710)$	42	94	705	800	718	78	125

Excellent discrimination!

$\Rightarrow$ Expect $\mathcal{B}(f_0 \rightarrow \gamma V) \approx 10^{-2}$ to 10^{-4}.
For $\mathcal{B}(J/\psi \rightarrow \gamma f_0) \approx 10^{-3}$ we should acquire $10,000$ to 100 events for 10^9 J/ψ.

$M_X \geq 2$ GeV$/c^2$: Tensor glueballs and $J = 4$ mesons



The $J/\psi \rightarrow \gamma X$ mass spectrum shows a lot of structure for $M_X \geq 2$ GeV$/c^2$.

Example (BES):
$J/\psi \rightarrow \gamma K^+K^-$
$J/\psi \rightarrow \gamma K_S K_S$

Quark model predicts many states with $J \leq 4$.
Lattice QCD predicts glueballs with

$$J^{PC} = 2^{++}, 0^{++}, 0^{-+}, 2^{-+}, 1^{+-}.$$

Many interferences will require high statistics and excellent control of systematics to disentangle the states.

Conclusions

Radiative transitions between vector and scalar mesons will provide strong constraints on the presence and structure of glueballs with $1.3 \leq M \leq 2.0$ GeV/c^2.

High statistics $J/\psi \rightarrow \gamma X$, including $X \rightarrow \gamma\{\rho, \phi\}$, may be within reach of CLEO-c and BESIII.

A complete analysis will be limited by data volume.
Will likely need $\geq 10^9$ J/ψ's.

The region with $M_X \geq 2$ GeV/c^2 needs to be carefully explored for narrow and/or broad resonances.
Partial Wave Analysis will be a necessary tool.

High statistics are good, but excellent knowledge of the detector acceptance is also crucial.