

# A Tale of Two Glueballs

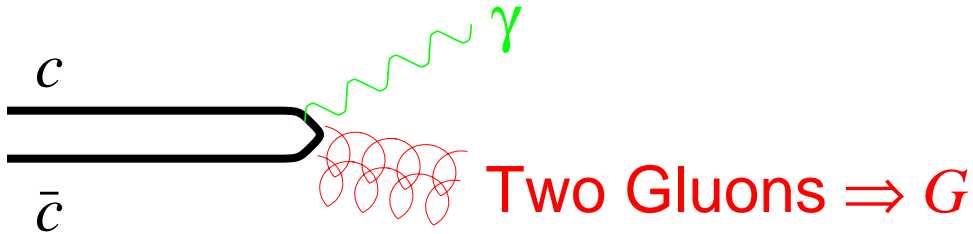
or

*What I Did on my Summer Vacation*

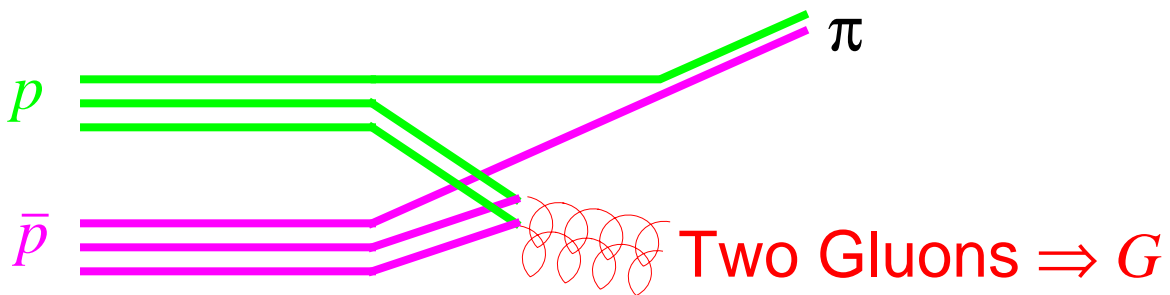
- **Quarks, Gluons, and QCD**
- **Lattice QCD**
- **Glueballs:** Solutions with no quarks  
*Agreement on the lightest glueball*
- **Hunting for Glueballs**  
*Good ways to make them*  
*Good ways to not make them*  
 *$q\bar{q}$ , or glueballs, or both?*
- **☞ The Two (Experimental) Glueballs**  
*The  $f_0(1500)$*   
The glueball from Crystal Barrel  
*The  $f_J(1710)$*   
The “old” glueball from SLAC
- **Other Glueballs**
- **Where Do We Go from Here?**

# Good Ways to Make Glueballs

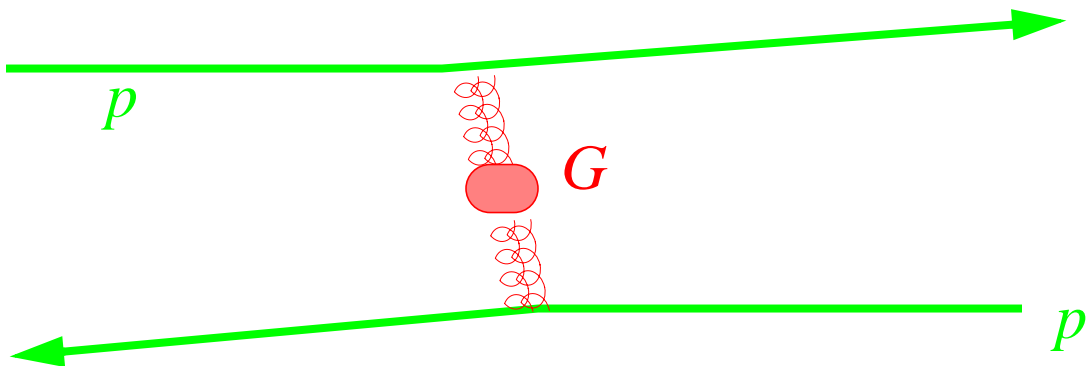
**$J/\psi$  Radiative Decay:**  $J/\psi \rightarrow \gamma G$



**$p\bar{p}$  Annihilation:**  $p\bar{p} \rightarrow \pi G$  or  $p\bar{p} \rightarrow \eta G$

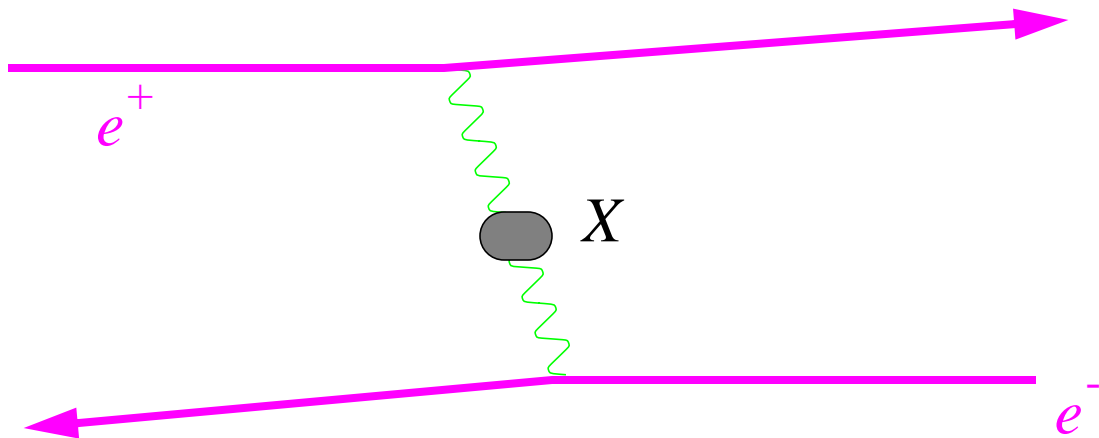


**Central Production:**  $pp \rightarrow p_f(G)p_s$

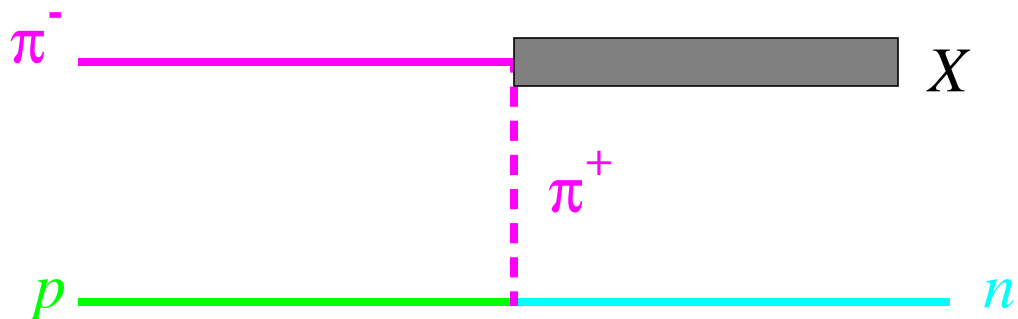


# Good Ways to NOT Make Glueballs

Two-Photon Production:  $\gamma\gamma \rightarrow G$



Peripheral Hadroproduction:  $\pi^- p \rightarrow Gn$  ?



# How Do Glueballs Decay

*Any way they want to!*

Some good choices (based on  $J^{PC}$ ):

Scalar  $J^{PC} = 0^{++}$  and Tensor  $J^{PC} = 2^{++}$

- $G \rightarrow \pi^0 \pi^0, \eta\eta, K_S K_S$   $I = 0$  Only!
- $G \rightarrow \pi^+ \pi^-, K^+ K^-$  OK, not great.
- $G \rightarrow \phi\phi, \omega\omega, \dots$  Hmm....

Pseudoscalar  $J^{PC} = 0^{-+}$

- $G \rightarrow K\bar{K}\pi, \dots$  Some history...

# Scalar Glueball Searches

Look for  $S$ -wave resonances in ...

$$p\bar{p} \rightarrow \pi^0 \pi^0 \pi^0, \eta \pi^0 \pi^0, \pi^0 K_S K_S, \dots$$

or  $J/\psi \rightarrow \gamma \pi^0 \pi^0, \gamma \eta \eta, \gamma K_S K_S, \dots$

or  $pp \rightarrow p_f(\pi\pi, KK, \dots)p_s$

Check that they are *not* observed in ...

$$\gamma\gamma \rightarrow \pi^0 \pi^0, \eta\eta, K_S K_S, \dots$$

You might check to see what's up in ...

$$\pi^- p \rightarrow \pi^0 \pi^0 n, \eta \eta n, K_S K_S n, \dots$$

... as well as the charged versions ( $\pi^+ \pi^-$ , ...)  
of all of these reactions

$\Rightarrow$  Do the production rates and decay patterns support the glueball conjecture?

# The Saga of the $\theta/f_J(1710)$

- The “discovery” at SLAC

$J/\psi \rightarrow \gamma\eta\eta$  Crystal Ball, 1982

$J/\psi \rightarrow \gamma\pi^+\pi^-, \gamma K^+K^-$  Mark-III, 1987

“Looks like spin-2”

- Or was it first seen at BNL?

$\pi^- p \rightarrow K_S K_S n$  MPS (L&L), 1982

“Two spin-0 states at ~1500 and ~1710”

- Central production weighs in from CERN

$pp \rightarrow p_f(KK, \pi^+\pi^-)p_s$  WA76, 1989

“Something there, maybe spin-2, or 1?”

- ★ Dunwoodie reanalyzes Mark-III data

“Real PWA shows that  $J=0$ ; No  $f_0(1500)$ ”

- New data from BES on  $J/\psi \rightarrow \gamma K^+K^-$

“They say  $J=0$  and 2, but ...”

# Isoscalar Mesons with J=0

*Is one of them a glueball?*

<u>Meson</u>	<u><math>\Gamma</math> (MeV)</u>	<u><math>\pi\pi</math></u>	<u><math>K\bar{K}</math></u>	<u><math>\eta\eta</math></u>	<u><math>\eta\eta'</math></u>
$f_0(1370)$	$\sim 300$	Most	Tiny	?	0
$f_0(1500)$	$112 \pm 10$	5.1	0.71	$\equiv 1$	1.3
$f_J(1710)$	$133 \pm 14$	$\equiv 1$	$\sim 4$	?	?

Are these a mixture of the three basis states

$$\frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle \equiv |n\bar{n}\rangle \quad [ \approx f_0(1370) ]$$

$|s\bar{s}\rangle$  and  $|G\rangle$  ???

Amsler and Close, 1995 & 1996

Maybe, if J=0, but  $f_0(1500)$  is  $\approx |G\rangle$

Weingarten, Lee, Sexton, Vaccarino, 1995-98

Yes! Obviously, J=0, and  $f_0(1710)$  is  $\approx |G\rangle$

Also, Burakovsky and Page, 1998

# Mixing ala Don Weingarten

D.W., Nucl. Phys. Proc. Suppl. 53(1997)232

$$\text{Ideal } q\bar{q} \text{ mixing} \Rightarrow H = \begin{bmatrix} m_G & z & z\sqrt{2} \\ z & m_{s\bar{s}} & 0 \\ z\sqrt{2} & 0 & m_{u\bar{u} + d\bar{d}} \end{bmatrix}$$

where  $z$  is the amplitude for  $q\bar{q} \rightarrow G$ .

Further assume that

- Unmixed isoscalar mass = 1450 (i.e.  $a_0$ )
- Physical masses = 1390, 1500, 1710

$$\Rightarrow m_G = 1635, m_{s\bar{s}} = 1516, \text{ and } z = 77 \text{ MeV}$$

$$|1710\rangle = +0.87|G\rangle + 0.35|s\bar{s}\rangle + 0.36|u\bar{u} + d\bar{d}\rangle$$

$$|1500\rangle = -0.19|G\rangle + 0.90|s\bar{s}\rangle - 0.40|u\bar{u} + d\bar{d}\rangle$$

$$|1390\rangle = -0.46|G\rangle + 0.28|s\bar{s}\rangle + 0.84|u\bar{u} + d\bar{d}\rangle$$

Destructive interference explains decays??

# Where Do We Go from Here?

Need more experiments

- Lattice QCD looks in good shape
- Theorists can explain any mixing
- Need decay patterns!

Which experiments?

- $J/\psi$  radiative decay is best (?)  
    Problem: Need lots of  $J/\psi$
- Revive the L&L analysis  
    ⇒ **Opportunity for E852!**