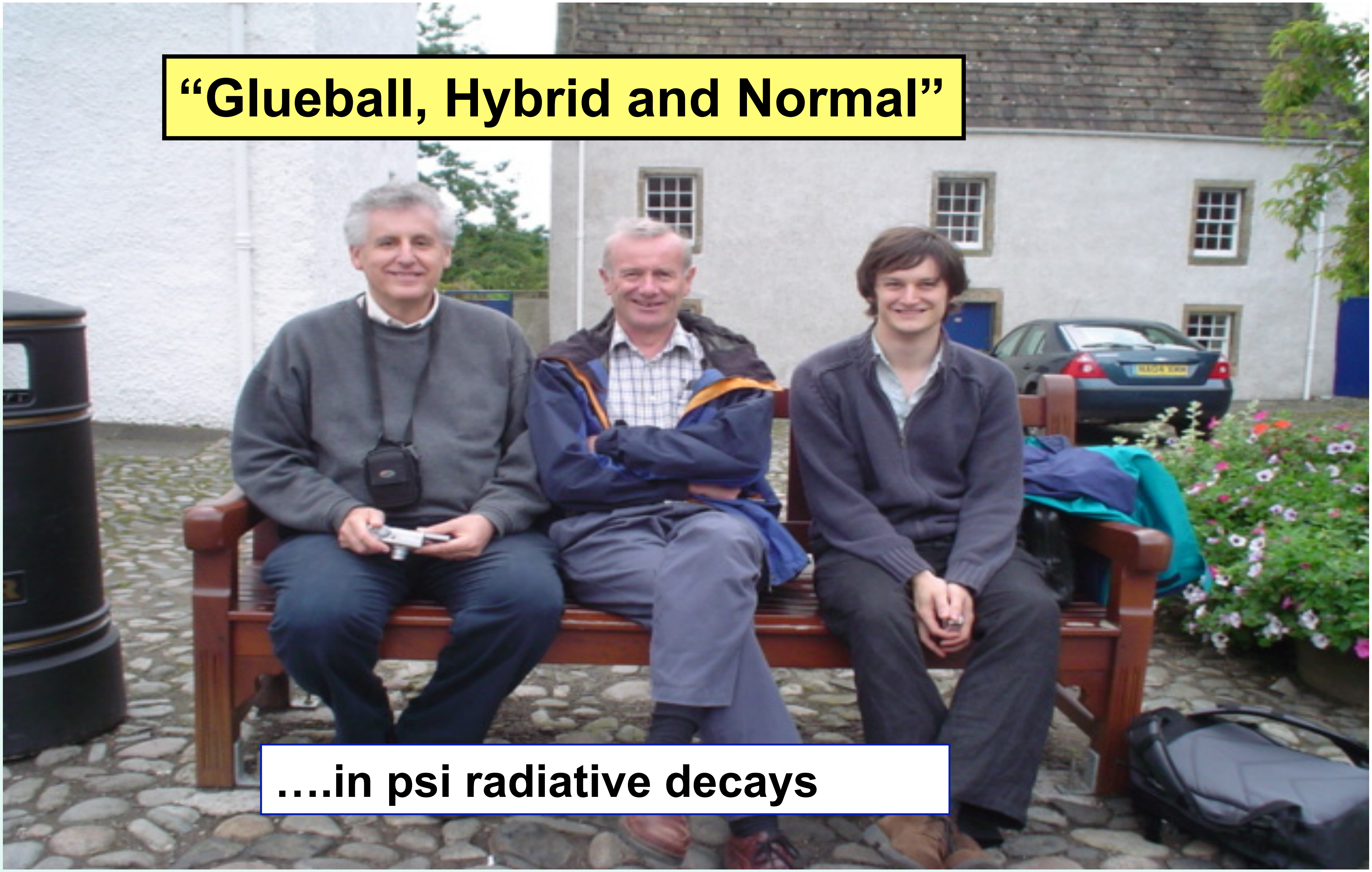
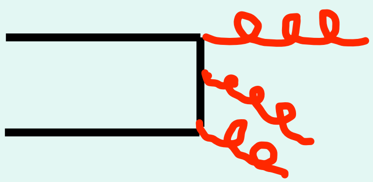
“Glueball, Hybrid and Normal”

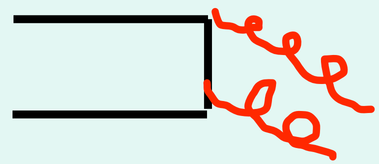


….in psi radiative decays

Frank Close
SURA05

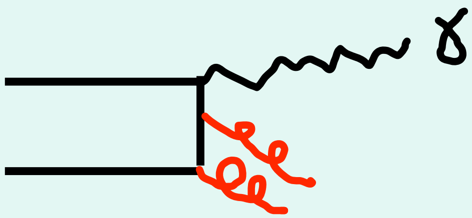
pQCD Folklore





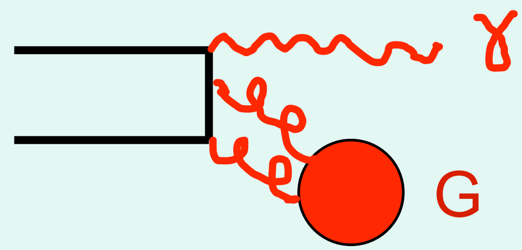
Psi hadronic and chi_1 widths…..

….Smaller than chi_0 and chi_2 widths



$$\frac{\Gamma_B(\psi(3.1)\to\gamma+2\text{ gluons}\to\text{hadrons})}{\Gamma_{tot}(\psi(3.1)\to 3\text{ gluons}\to\text{hadrons})} = \frac{16}{5}\frac{\alpha}{\alpha_s}\left(1-2.6\frac{\alpha_s}{\pi}\right)$$

Expt ~ 8% …..



….. dominated by glueballs

?

$\Gamma(\psi)$ =91keV. (12 $\pm$2 via $\gamma^* =$ e.m.)

$\Gamma(\eta_c) = 17.3 \pm 2.7$ MeV

Consistent with 3g versus 2g

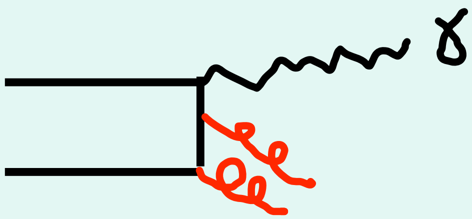
$\Gamma(\chi_0) = 10 MeV; \chi_1 = 0.9 MeV; \chi_2 = 2.1 MeV$

Consistent with axial decoupled from 2g

$\frac{\Gamma(\chi_0 \to \gamma\gamma)}{\Gamma(\chi_2 \to \gamma\gamma)} \sim 6 > \frac{15}{4}$ Approx consistent with 2g ?

(data vary widely; need precision)

pQCD Folklore



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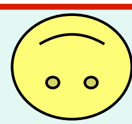
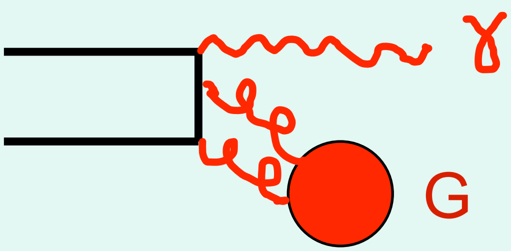


Qualitatively expect this order of magnitude anyway?

(What is actual precision b.r.?)

Need x (M_hadron) dependence pQCD; + expt precision not just integrated rate.



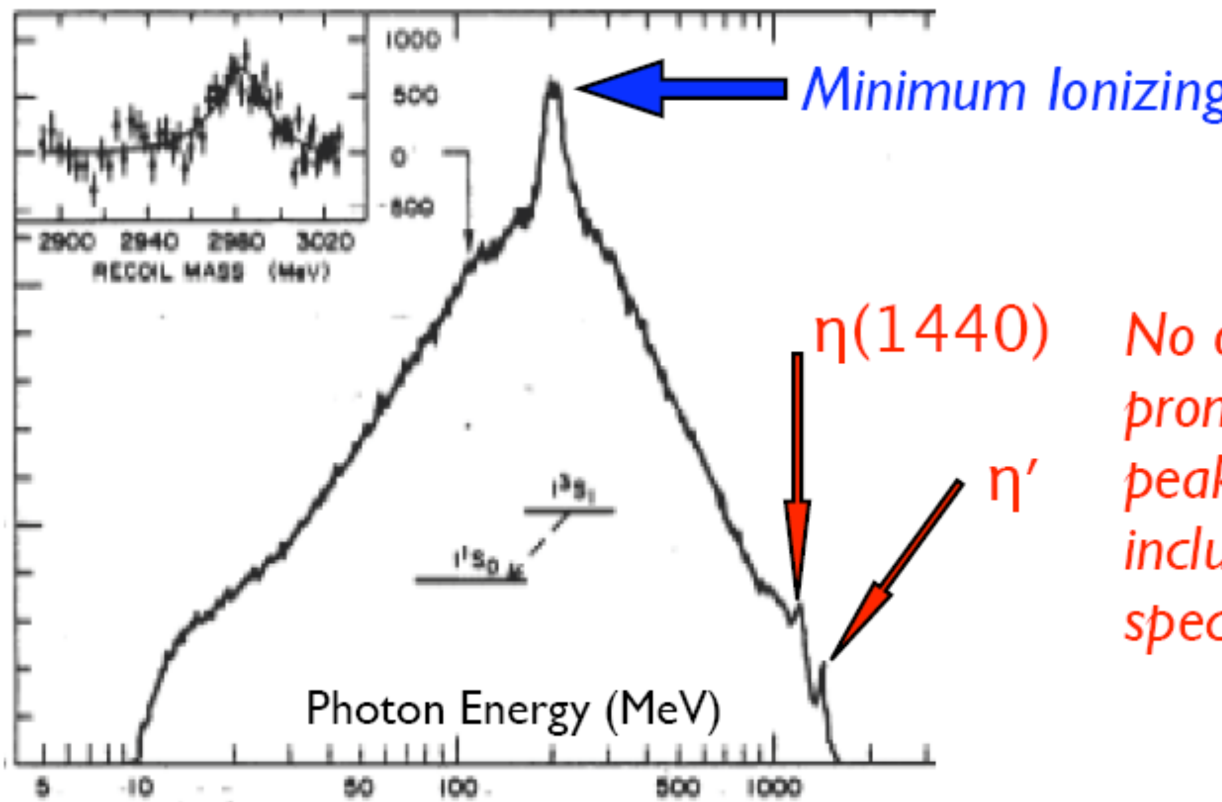
….. dominated by glueballs

?

next

psi to gamma X (see Jim Napolitano talk)

Bloom & Peck (Crystal Ball) Ann.Rev.Nuc.Part.Sci. 33(1983)143



No other prominent peaks in the inclusive spectrum.

Some prominent radiative b.r.'s (10^{-4})

total psi -> gamma X ~ 800 (10^{-4})

0-+: **eta 8; eta' 43**; eta(1405/1475) > 30

2++: **f2(1270) 14; f2(1525) 5**; f2(1950) >7

1++: **f1(1285) 6; f1(1420) 8**; f1(1510) 4?

----> Prominent qq* 2++ which are not glueballs
and prominent 1++ which pQCD naively thought to be zero

Some prominent radiative b.r.'s (10^{-4})

total psi -> gamma X ~ 800 (10^{-4})

0-+: **eta 8; eta' 43**; eta(1405/1475) > 30

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1++: **f1(1285) 6; f1(1420) 8**; f1(1510) 4?

0++: **f0(1370) 4pi >80; f0(1500) >6 ; f0(1700) >9**

0++: f0(980) = ??

Some prominent radiative b.r.'s (10^{-4})

total psi -> gamma X ~ 800 (10^{-4})

0-+: eta 8; eta' 43; eta(1405/1475) > 30

eta pi pi > **60**

VV in 0- > **40**?

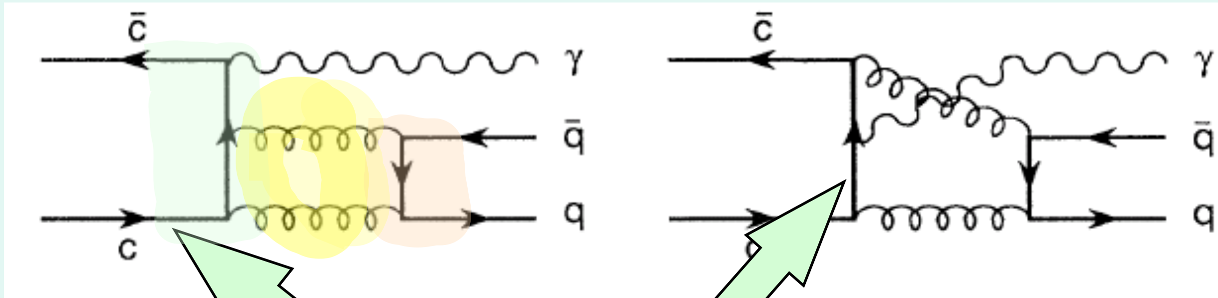
0++: f0(1370) 4pi >80; f0(1500) >6 ; f0(1700) >9

4pi > **120**

JPC need measuring

Isolating 0++ a challenge anyway. Also look for exotic 1-+

The JPC dependence of psi radiative in pQCD



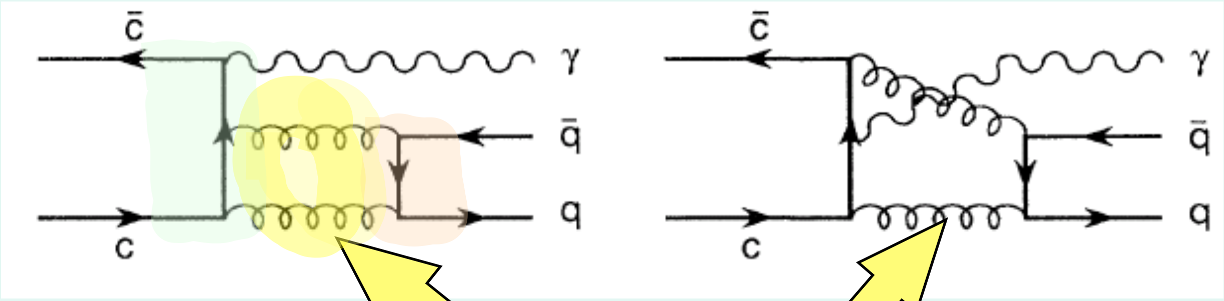
Psi decay piece

$$b_{\mathrm{rad}}(Q\overline{Q}_V \to \gamma + R_J) = \frac{c_R x \left|H_J(x)\right|^2}{8\pi(\pi^2-9)} \frac{m_R}{M_V^2} \Gamma(R_J \to gg)$$

qq* to gamma gamma
+ pQCD =
qq* to gg

Close Farrar Li

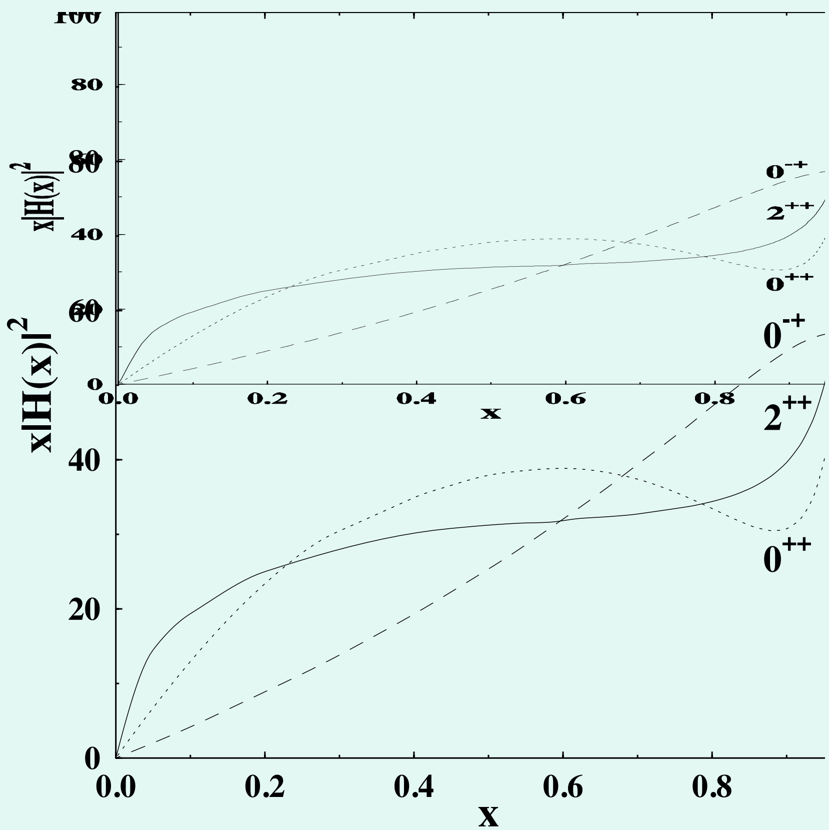
The JPC dependence of psi radiative in pQCD



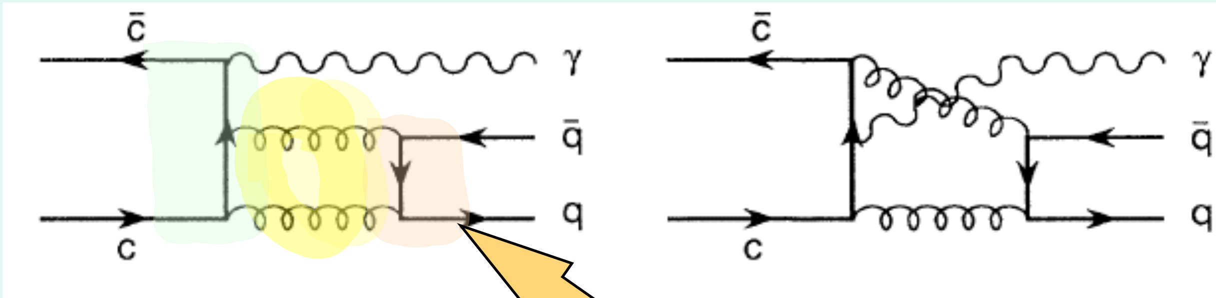
H_J(x) Loop integral

$$b_{\rm rad}(Q\overline{Q}_V \to \gamma + R_J) = \frac{c_R x |H_J(x)|^2}{8\pi(\pi^2-9)} \frac{m_R}{M_V^2} \Gamma(R_J \to gg)$$

What HJ(x) look like for 0-,0+,2+



The JPC dependence of psi radiative in pQCD

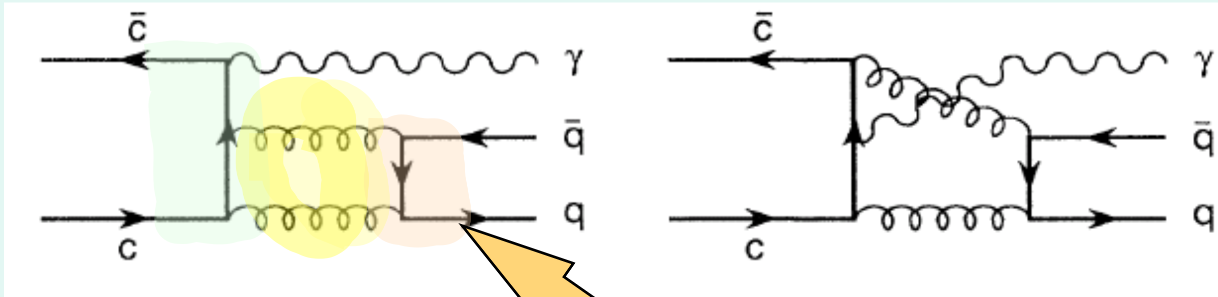


using data as input…..

…quantify this gg measure

$$b_{\rm rad}(\overline{Q\bar{Q}}_V \rightarrow \gamma + R_J) = \frac{c_R x |H_J(x)|^2}{8\pi(\pi^2-9)} \frac{m_R}{M_V^2} \Gamma(R_J \rightarrow gg)$$

The JPC dependence of psi radiative in pQCD



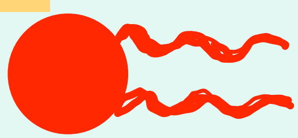
using data as input…..

…quantify this gg measure

$$b_{\rm rad}(Q\overline{Q}_V \to \gamma + R_J) = \frac{c_R x |H_J(x)|^2}{8\pi(\pi^2-9)} \frac{m_R}{M_V^2} \Gamma(R_J \to gg)$$

b.r($R \longrightarrow gg$)

G

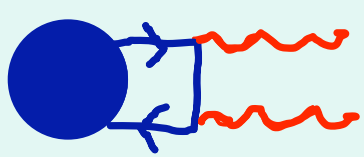


O (1)

Cakir Farrar

qq* in gamma gamma convert to gg

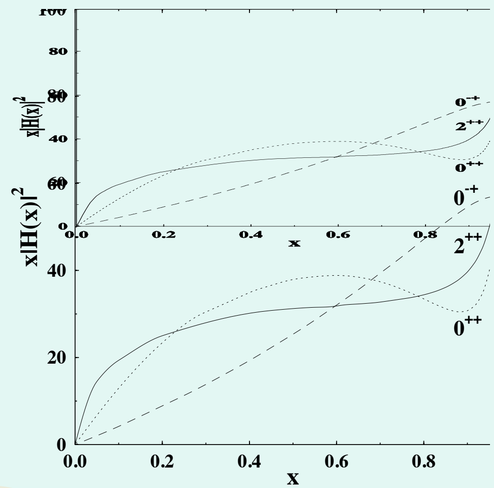
nn*



O(α^2) ~ 0.1-0.2

Close Farrar Li

Rewrite the b.r. in a more user friendly way…………



$$10^3 br(J/\psi \to \gamma 2^{++}) = \left(\frac{m}{1.5\ \mathrm{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{26\ \mathrm{MeV}}\right)\frac{x|H_S(x)|^2}{35}$$

$$10^3 br(J/\psi \to \gamma 0^{++}) = \left(\frac{m}{1.5\ \mathrm{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{96\ \mathrm{MeV}}\right)\frac{x|H_S(x)|^2}{35}$$

$$10^3 br(J/\psi \to \gamma 0^{-+}) = \left(\frac{m}{1.5\ \mathrm{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{50\ \mathrm{MeV}}\right)\frac{x|H_S(x)|^2}{45}$$

O(1) O(1)

Tensor 2++

$$10^3 b(J/\psi \to \gamma 2^{++}) = \left(\frac{m}{1.5\ \text{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{26\ \text{MeV}}\right)\frac{x|H_T(x)|^2}{34}$$

f2(**1270**)

1.4 +- 0.14 → 41 +- 7 MeV

Total width = 185 +- 20MeV → b.r = 0.22 ~

O(α_s^2) ~ 0.1-0.2

Tensor 2++

$$10^3 b(J/\psi \to \gamma 2^{++}) = \left(\frac{m}{1.5\ \text{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{26\ \text{MeV}}\right)\frac{x|H_T(x)|^2}{34}$$

f2(**1270**)

1.4 +- 0.14 → 41 +- 7 MeV

Total width = 185 +- 20MeV → b.r = 0.22 ~

$O(\alpha_s^2)$ ~ 0.1-0.2

f2(**1520**)

0.45 +- 0.07 → 12 +- 2 MeV

Total width = 76 +- 10MeV → b.r = 0.15 ~

$O(\alpha_s^2)$ ~ 0.1-0.2

Axial 1++

$$10^3 b(J/\psi \to \gamma 1^{++}) = \left(\frac{m}{1.45\ \text{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{12\ \text{MeV}}\right)\frac{x|H_1(x)|^2}{30}$$

f1(**1285**)

0.65 +- 0.1 → ~ 8 MeV

Total width = 24 +- 3MeV → b.r ~ 0.3

$O(\alpha_s^2) \sim 0.1\text{-}0.2$

f1(**1420**) → also → b.r ~ 0.3

Scalar 0++

$$10^3 b(J/\psi \to \gamma 0^{++}) = \left(\frac{m}{1.5\ \text{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{96\ \text{MeV}}\right)\frac{x|H_S(x)|^2}{35}$$

f0(**1710**)

0.85 +- 0.1

$$\Gamma(f_0(1710)\to gg) = \frac{(78\pm 10)\text{MeV}}{b(f_0(1710)\to K\bar{K})}$$

Total width ~ 140 MeV

$$b(f_0(1710)\to gg) \geq 0.52 \pm 0.07$$

Scalar 0++

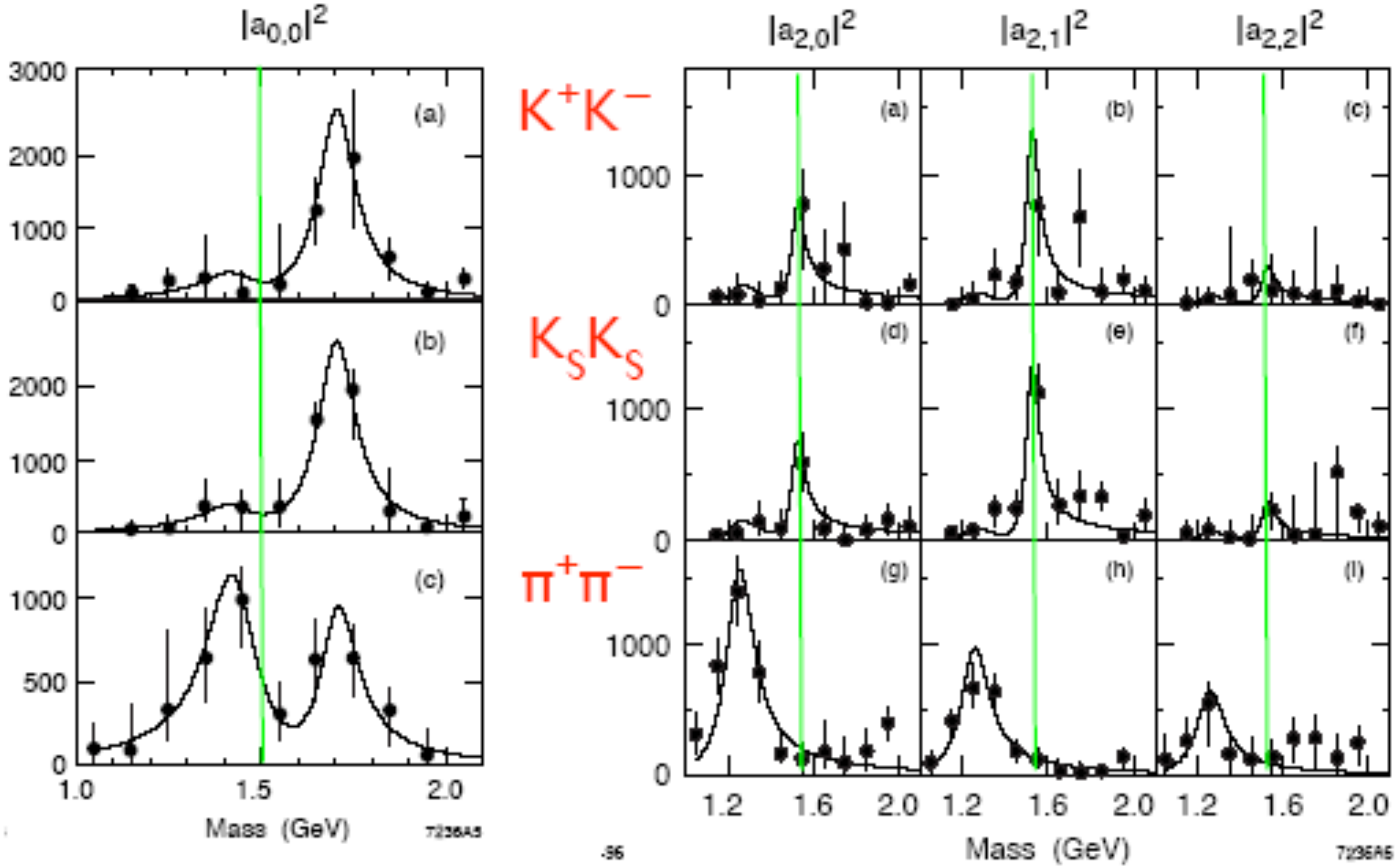
$$10^3 b(J/\psi \to \gamma 0^{++}) = \left(\frac{m}{1.5\ \text{GeV}}\right)\left(\frac{\Gamma_{R\to gg}}{96\ \text{MeV}}\right)\frac{x|H_S(x)|^2}{35}$$

f0**(1500)**

$$(0.57 \pm 0.08)\times 10^{-3} \leqslant b(J/\psi \to \gamma f_0(1500)) \leqslant (1.15 \pm 0.15)\times 10^{-3},$$

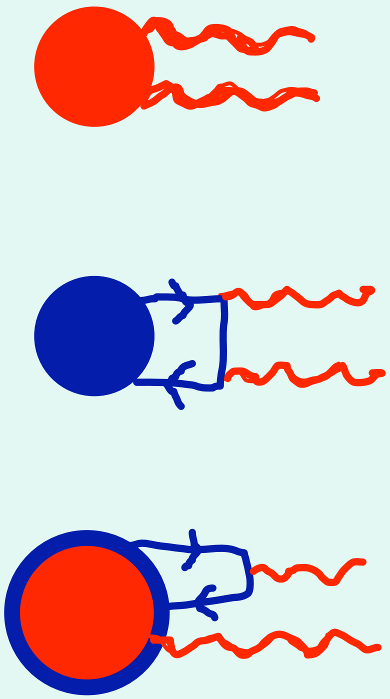
$$0.5 \pm 0.1 \leqslant b(f_0(1500) \to gg) \leqslant 0.9 \pm 0.2.$$

“Partial Wave Analysis” *SLAC Mark-III (Dunwoodie, et al.)*



b.r(R ⟶ gg)

HYBRID MESONS TOO?



G — 1

nn* — $O(\alpha^2) \sim 0.1\text{-}0.2$

Gnn* — α

should be significant

Needs calculation of HJ(x) for 1-+

apply to I=0 partners of pi1(1600)

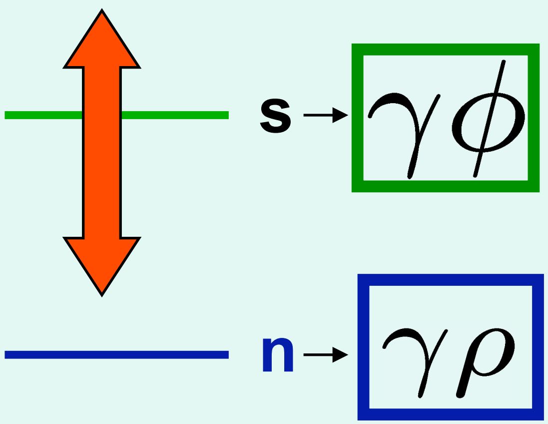
Or 0-+, 2-+ hybrid components…
….eta(1440)???

More on Glue in C=+ Mesons

- How psi radiatives can sort out the PDG

Scalar Glueball and Mixing

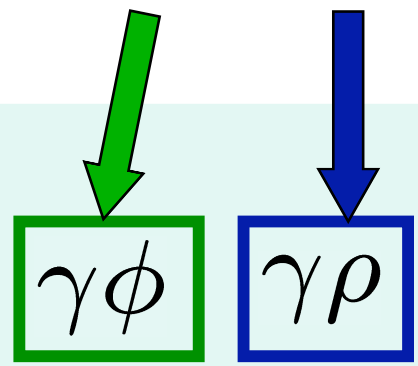
a simple example for expt to rule out



Meson	G	ss*	nn*
1710	0.39	0.91	0.15
1500	- 0.65	0.33	- 0.70
1370	- 0.69	0.15	0.70

0- 0-
meson
decays
LEAR/
WA102

FC Kirk



$$\psi \rightarrow \gamma[\gamma V]$$

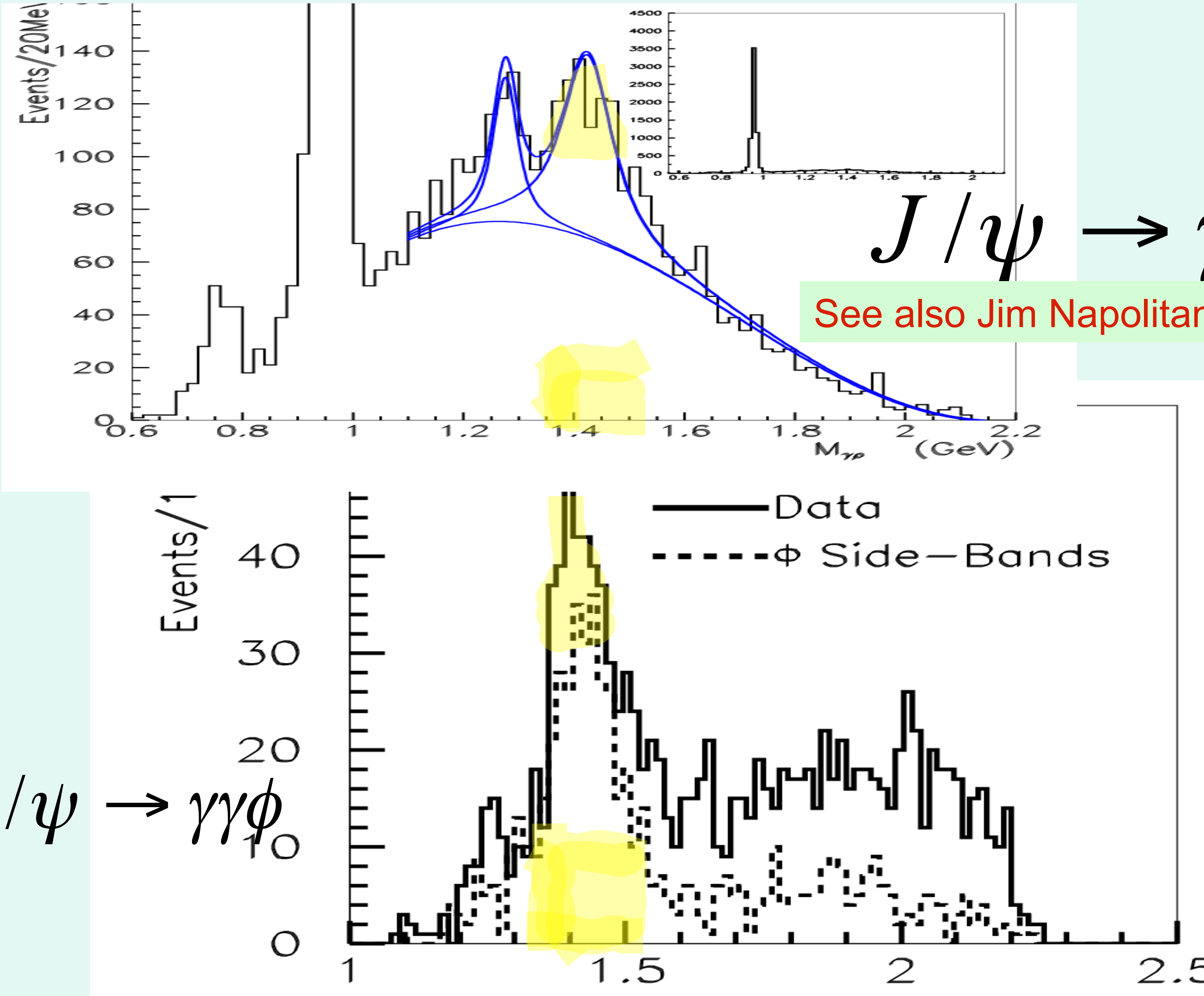
>1 billion

Coming soon from BES and CLEO-c

1000 per meson

A flavour filter for 0++ 0-+ 2++ (and 1++) mesons glueballs et al

Challenge:
Turn Lattice QCD Glueball spectrum into physics



$J/\psi \rightarrow \gamma\gamma\rho$

See also Jim Napolitano talk

$J/\psi \rightarrow \gamma\gamma\phi$

Unusual properties of $f_0(1370)$, $f_0(1500)$ $f_0(1710)$

Scalar Puzzle

$$\psi \to \gamma[\gamma V]$$

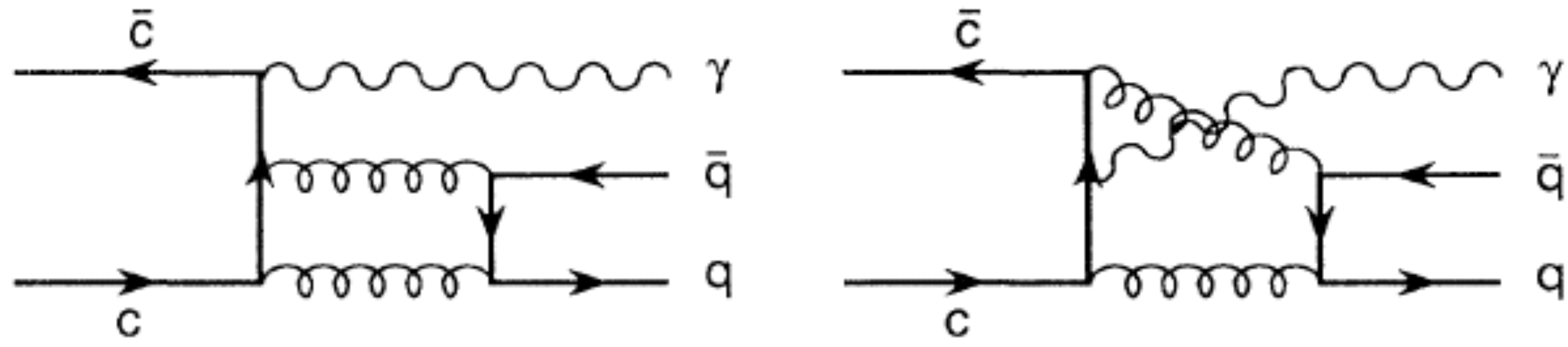
\psi \to 0^{++} V

A consistent pattern in these two experiments can establish role of **Scalar Glueball**

Challenge: quantify the predictions

A further puzzle with Tensors in psi radiative

- 2++ can have helicity 0,1,2
- Ratio of helicity 2:0 = y; 1:0 = x
- What do pQCD and data say?



$$y = 0, \quad x = \frac{\sqrt{3}}{2}\frac{M_T}{M_\psi},$$

Expt: y =0; x=0.9

$$y = \sqrt{6}\frac{1}{(1 - 2k^2/M_T^2)},$$

$$x = \sqrt{3}\frac{M_T}{M_\psi}\frac{M_T E_\psi - k^2}{M_T^2 - 2k^2}$$

$$\psi \to \gamma[\gamma V]$$

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Challenge:
Turn Lattice QCD Glueball spectrum into physics

Lose factor 2 and do psiprime for chi?

qq* in psi rad can quantify if have gamma gamma

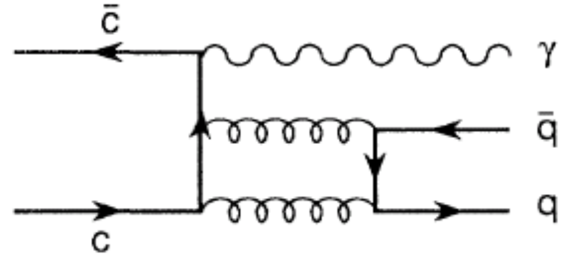
pp to pRp compare signals in psi to gamma R

Psi via gamma* to “forbidden” states

If no big 2++ ~ 2 -2.5gev in psi radiative: why not?

Lattice/phenom/principle challenge:

Why is iota(1440) not glueball?

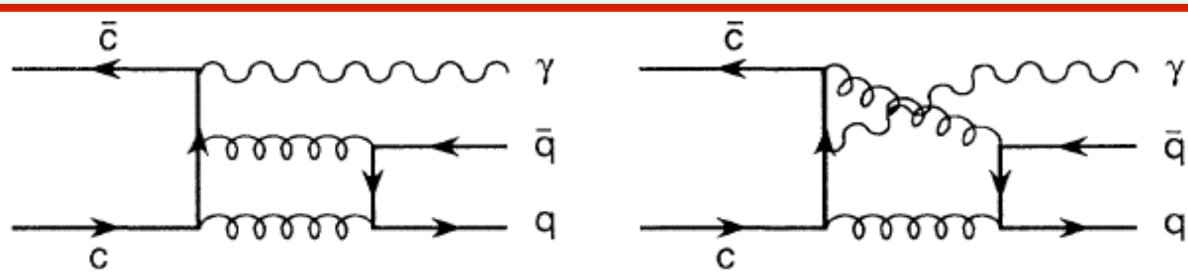


$$A_\lambda \propto \int d\Omega \{A(\psi \to \gamma g_+ g_-)(\theta) d^J_{2\lambda}(\theta) A(g_+ g_- \to M) + A(\psi \to \gamma g_+ g_+)(\theta) d^J_{0\lambda}(\theta) A(g_+ g_+ \to M)\}$$

$$Z \equiv (M_\psi^2 + M_T^2)/(M_\psi^2 - M_T^2)$$

$$I(Z,\lambda) \equiv \int \frac{d\Omega (\sin\theta)^{4-2\lambda}(1-\cos\theta)^{2\lambda}}{Z^2 - \cos^2\theta}$$

	A^C	A^H
A_2	0	$kM_T D(Z,2)$
A_1	$\frac{1}{\sqrt{2}} \frac{E_\psi}{M_\psi} k^2 D(Z,1)$	$\frac{1}{\sqrt{2}} \left[kM_\psi - \frac{k^2 E_\psi}{M_\psi} \right] D(Z,1)$
A_0	$\frac{2}{\sqrt{6}} \frac{E_\psi}{M_T} k^2 D(Z,0)$	$\frac{1}{\sqrt{6}} \frac{M_\psi}{M_T} \left[kM_\psi - \frac{2k^2 E_\psi}{M_\psi} \right] D(Z,0)$



		A^C	A^H
y:	A_2	0	$kM_T D(Z,2)$
x:	A_1	$\frac{1}{\sqrt{2}}\frac{E_\psi}{M_\psi}k^2 D(Z,1)$	$\frac{1}{\sqrt{2}}\left(kM_\psi - \frac{k^2 E_\psi}{M_\psi}\right)D(Z,1)$
1:	A_0	$\frac{2}{\sqrt{6}}\frac{E_\psi}{M_T}k^2 D(Z,0)$	$\frac{1}{\sqrt{6}}\frac{M_\psi}{M_T}\left(kM_\psi - \frac{2k^2 E_\psi}{M_\psi}\right)D(Z,0)$

$$y = 0, \quad x = \frac{\sqrt{3}}{2}\frac{M_T}{M_\psi},$$

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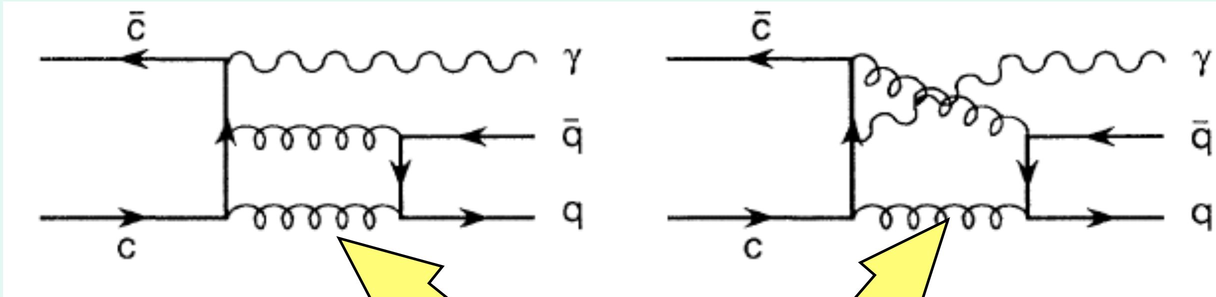
The JPC dependence of psi radiative in pQCD



H_J(x) Loop integral

$$b_{\rm rad}(Q\overline{Q}_V \to \gamma + R_J) = \frac{c_R x |H_J(x)|^2}{8\pi(\pi^2 - 9)} \frac{m_R}{M_V^2} \Gamma(R_J \to gg)$$

Where just to show off:

$$H_{0-+}(x) = \frac{4}{x}\left[L(1-2x) - L(1) - \frac{1-x}{2-x}\left(2L(1-x) - \frac{\pi^2}{3} + \frac{1}{2}\ln^2(1-x)\right) - \frac{x}{1-2x}\ln(2x)\right] + i4\pi\frac{1-x}{(2-x)x}\ln(1-x)$$

where $L(x)$ is a Spence function, defined as

$$L(x) = -\int_0^x \frac{dx}{x}\ln(1-x).$$