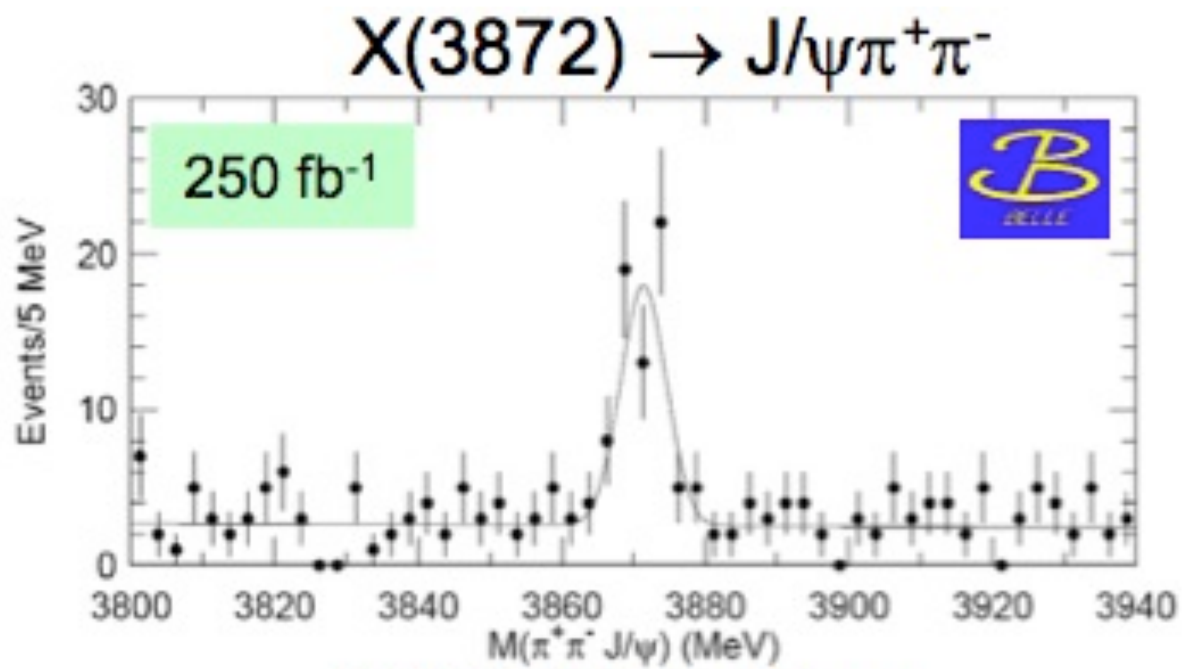
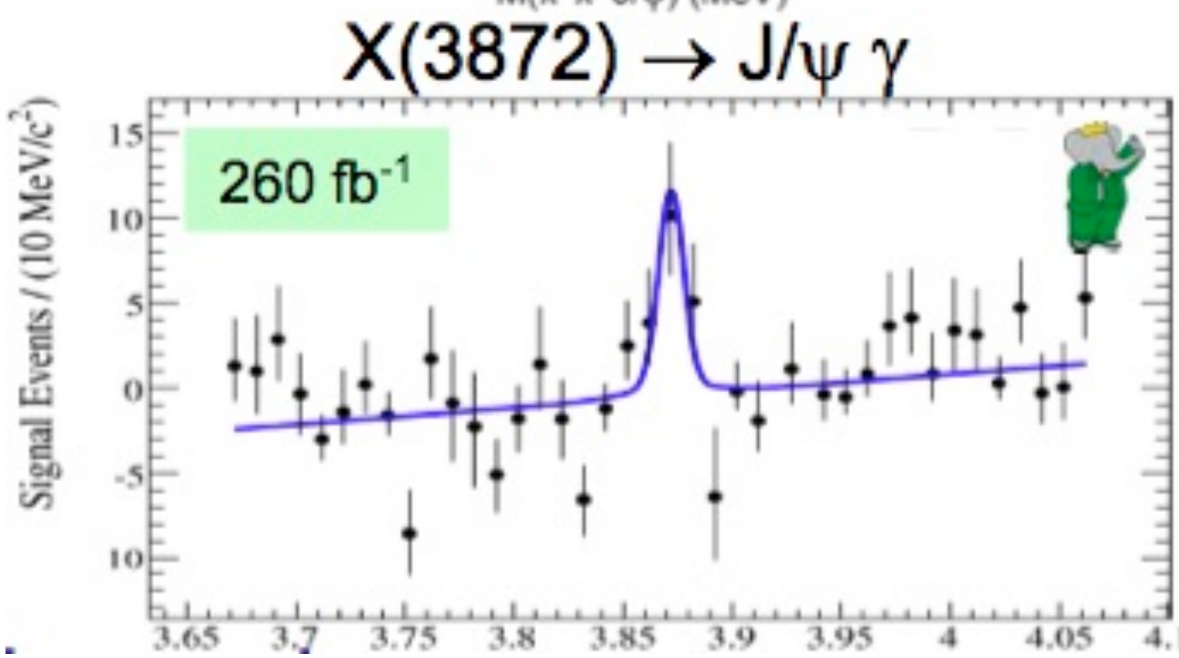
X(3872), molecules and diquarks

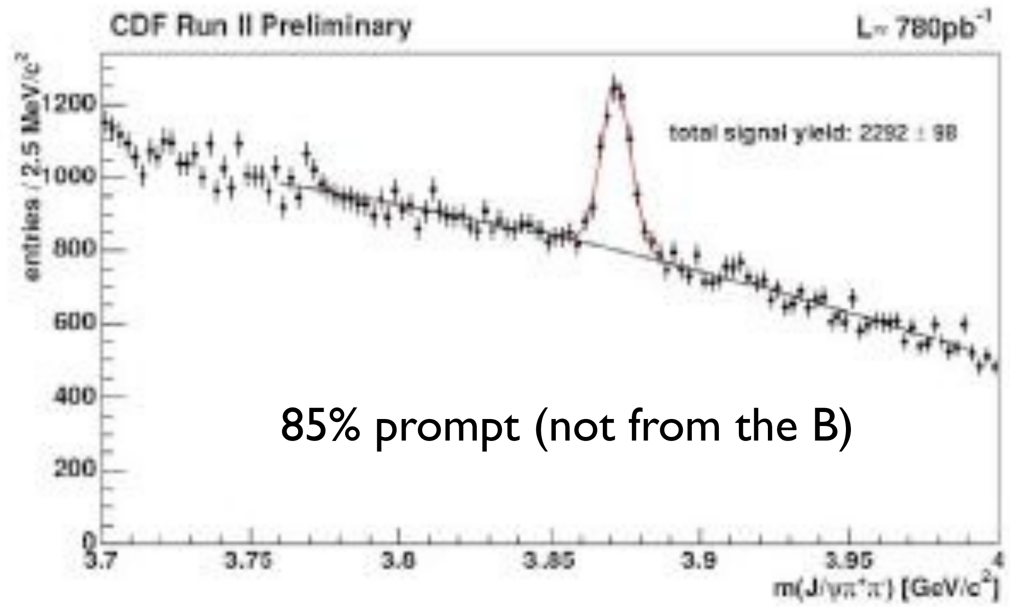
AD Polosa (INFN Roma I)

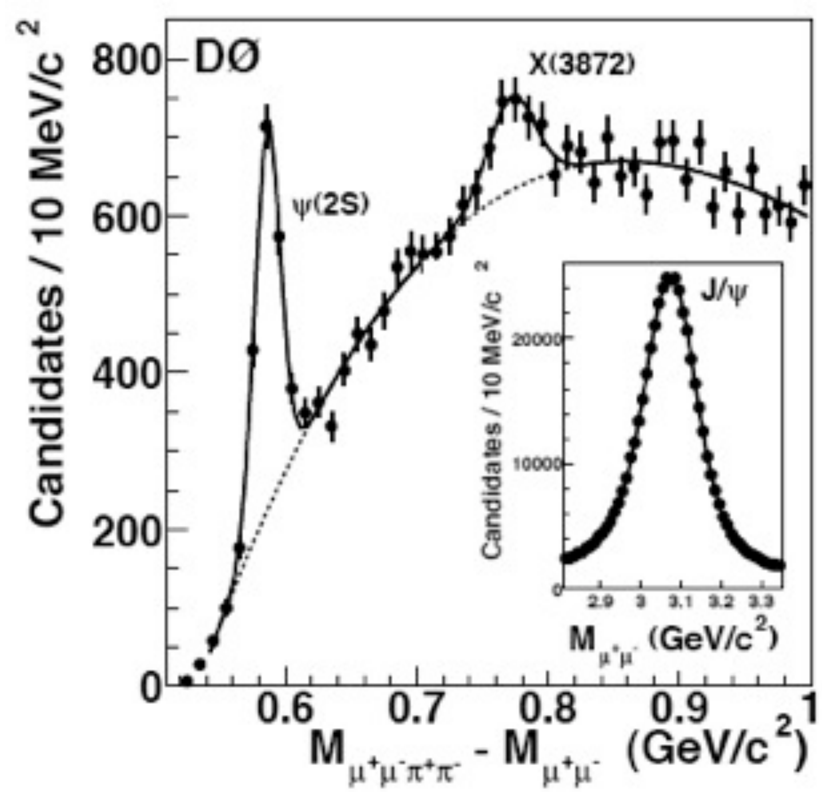
$$B^{\pm} \to K^{\pm} \underbrace{\pi^+\pi^- J/\psi}_{X \to \rho J/\psi}$$

$$pp \to X \to \underbrace{\pi^+\pi^- J/\psi}_{X \to \rho J/\psi}$$



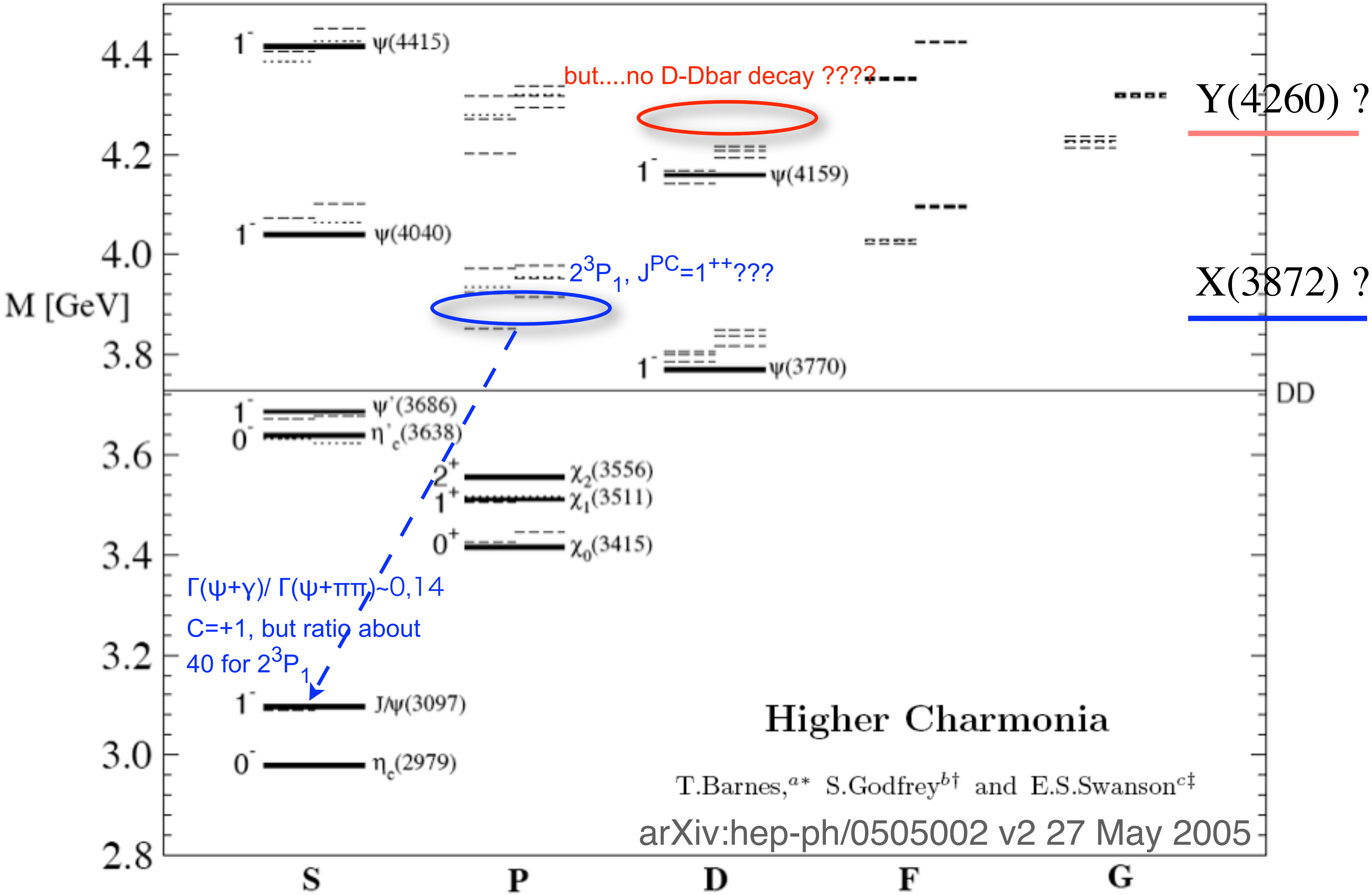






$$X \to \gamma J/\psi \mapsto C = +1 \quad \text{and} \quad X \to \rho^0 J/\psi \to (\pi^+\pi^-)_S J/\psi \mapsto P = 1$$

X(3872) and Y(4260) are not charmonium states



More strange thinghs about X(3872)

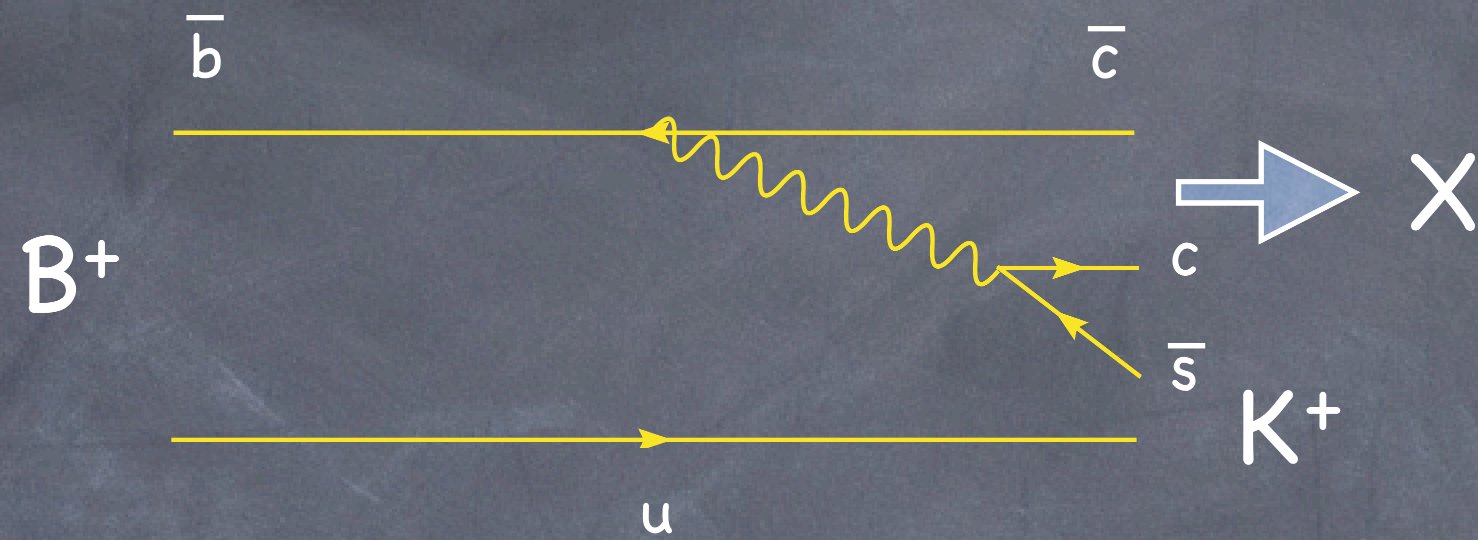
-Its mass happens to be extremely close to DD* threshold

-Large isospin violations

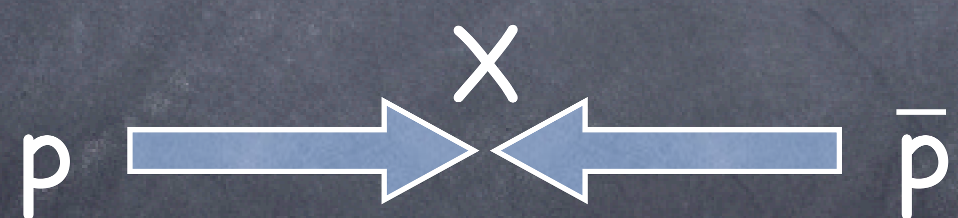
$$\frac{\mathcal{B}(X \to J/\psi\pi^+\pi^-\pi^0)}{\mathcal{B}(X \to J/\psi\pi^+\pi^-)} = 1 \pm 0.5 \text{ Belle}$$

Is that a molecule of D & D*?

$$\Gamma(D^{*0}\bar{D}^0) = 3.4^{+1.6}_{-1.0} \text{ MeV}$$



production from B decay



prompt production at CDF and D0

From CDF data we can estimate a minimum xsect

$$\sigma(p\bar{p} \to X(3872) + \mathrm{All})^{\mathrm{min}} \simeq 3.2 \pm 0.7 \text{ nb}$$

from CDF II we know that

$$\frac{\sigma(p\bar{p} \to X(3872) + \mathrm{All})_{\mathrm{prompt}} \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-))}{\sigma(p\bar{p} \to \psi(2S) + \mathrm{All})} = 4.7 \pm 0.8\%$$

with the acceptance cuts

$$p_\perp > 5 \text{ GeV} \quad \text{and} \quad |y| < 1$$

using reccently published CDF data we also have

$$\sigma(p\bar{p} \to \psi(2S) + \mathrm{All}) = 67 \pm 9 \text{ nb}$$
$$\text{for} \quad p_\perp(\psi(2S)) > 5 \text{ GeV}, \quad |y(\psi(2S))| < 0.6$$

[and assume that X and ψ(2S) have the same rapidity distribution for y<1]

On the other hand we can also estimate an upper bound for the theoretical xsect

$$\sigma(p\bar{p} \to X(3872)) \sim \left| \int d^3\mathbf{k} \langle X | D\bar{D}^*(\mathbf{k}) \rangle \langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle \right|^2 \simeq \left| \int_{\mathcal{R}} d^3\mathbf{k} \langle X | D\bar{D}^*(\mathbf{k}) \rangle \langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle \right|^2$$

$$\leq \int_{\mathcal{R}} d^3\mathbf{k} |\psi(\mathbf{k})|^2 \int_{\mathcal{R}} d^3\mathbf{k} |\langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle|^2 \leq \int_{\mathcal{R}} d^3\mathbf{k} |\langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle|^2 \sim \sigma(p\bar{p} \to X(3872))^{\max}$$

Pythia/Herwig

Require MC tools to generate 2→2 QCD processes with loose partonic cuts (pT > 2 GeV :: |y| < 6).

[Configurations with one gluon recoiling from a charm pair, are those configuration expected to produce two collinear charm quarks and in turn collinear open charm mesons. The parton shower algorithms in Herwig and Pythia treat properly these configurations at low pT (enhanced by collinear logarithms) whereas they are expected to be less important at higher pT. This has been verified using ALPGEN with pT(gluon)>5 and f.f. set to 1]

What is the region R?

$$\mathcal{E}_0 \sim M_X - M_D - M_{D^*} = -0.25 \pm 0.40 \text{ MeV}$$

$$r_0 \sim 8 \text{ fm} \quad (8.6 \pm 1.1 \text{ fm})$$

$$\Delta p \sim 12 \text{ MeV}$$

[One can check that changing the value of $g^2/4\pi$ ~ O(10) has a small effect on the size of R].

as for the central value we can take

$$k \simeq \sqrt{2}\mu(-0.25 + 0.40) \simeq 17 \text{ MeV}$$

$$k = \sqrt{\lambda(m_X^2, m_D^2, m_D^{*2})}/2m_X \simeq 27 \text{ MeV}$$

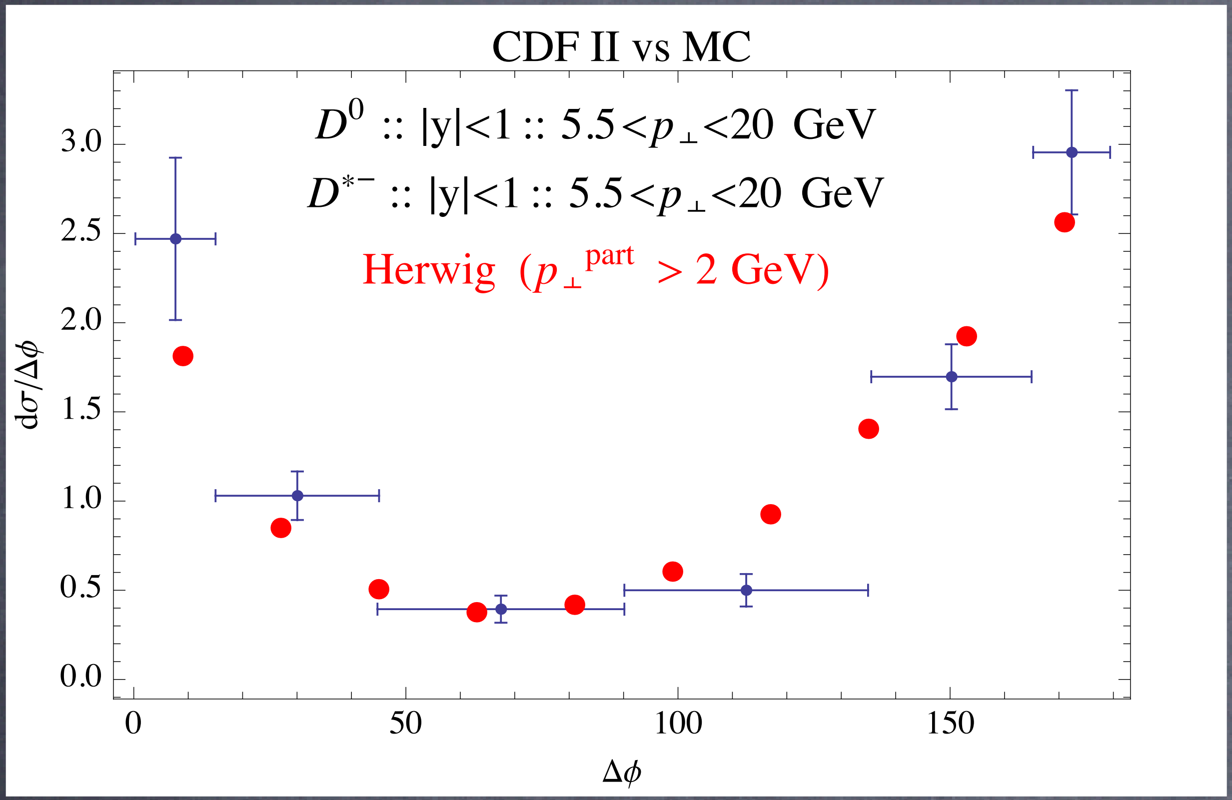
we set

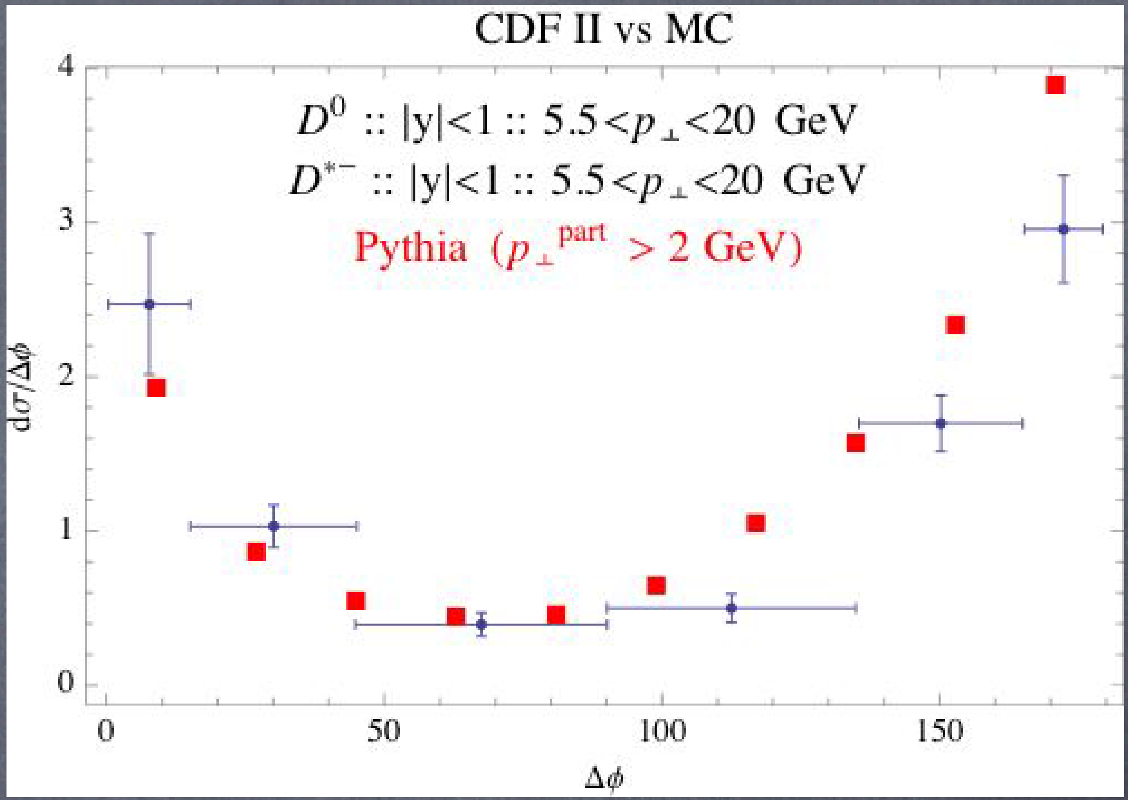
$$\mathcal{R} \simeq [0, 35] \text{ MeV}$$

[With such values of k in the COM only S-waves are possible L~k/m_π]

Tuning the MC

work in collab w/
C Bignamini (Karlsruhe), B Grinstein (UCSD), F Piccinini (Pavia),
and C Sabelli (Roma)



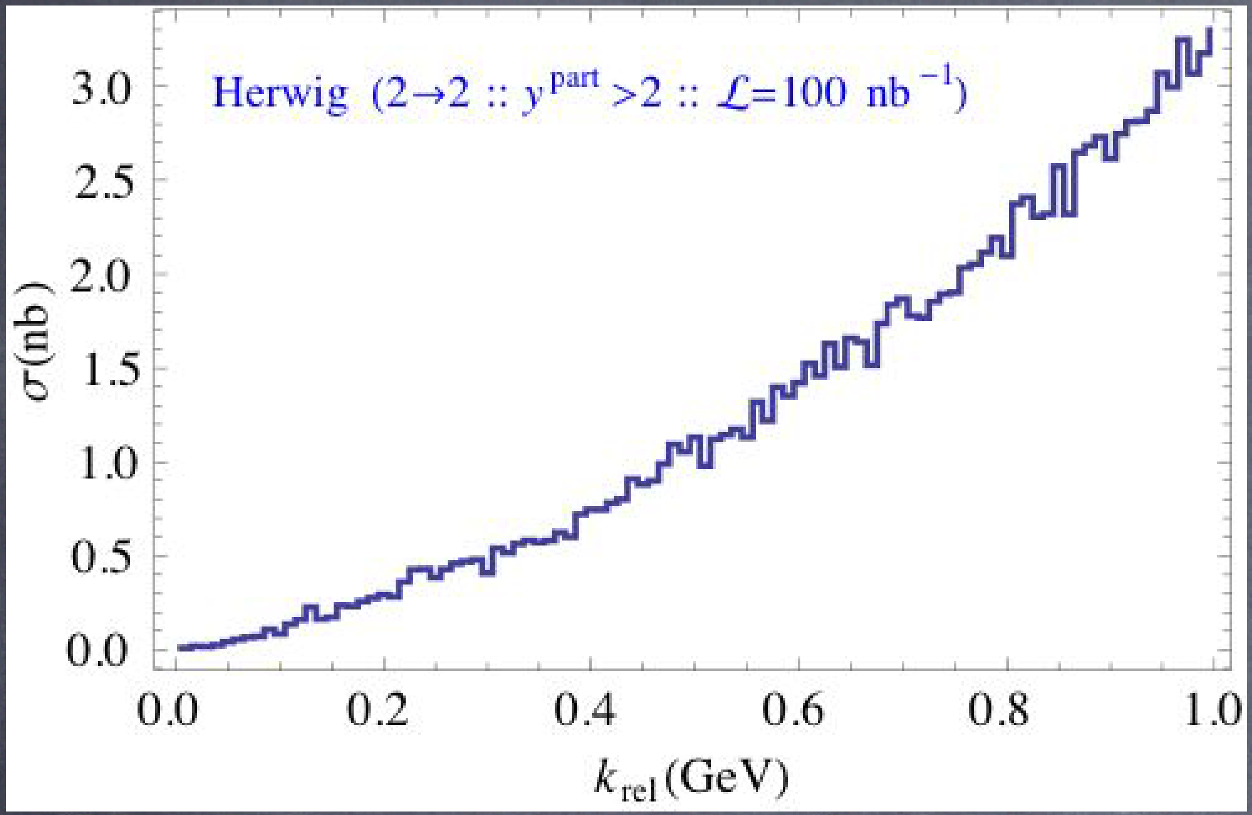


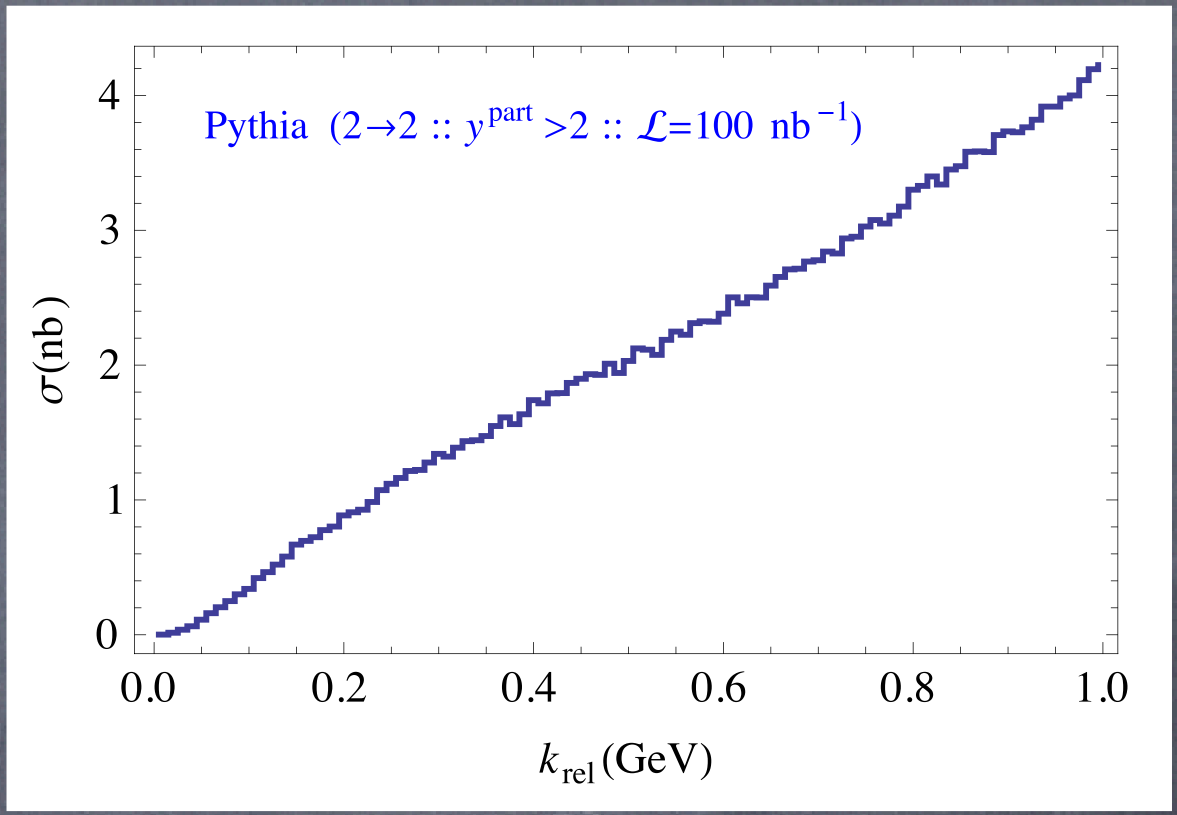
[The D^0 D^{*-} pair cross section as function of Delta phi at CDF Run II.
We find that we have to rescale the Herwig cross section values by a
factor K_{Herwig} = 1.8 to best fit the data on open charm production.
As for Pythia we need K_{Pythia} = 0.74]

Bignamini et al arXiv:0906.0882

Counting pairs (50x10**9 evts generated)

$$D^0\bar{D}^{0*} + \bar{D}^0 D^{0*}$$





Bignamini et al arXiv:0906.0882

$$\sigma \sim 3.1 \pm 0.7 \text{ nb}$$

Herwig $\quad k_{\text{rel}} = 205 \pm 20 \text{ MeV} \quad (0.071 \text{ nb in } \mathcal{R})$

Pythia $\quad k_{\text{rel}} = 130 \pm 15 \text{ MeV} \quad (0.11 \text{ nb in } \mathcal{R})$

We find in the indicated momentum range

$$\frac{\sigma_{\text{exp}}^{\text{min}}}{\sigma_{\text{th.}}^{\text{max}}} \sim 30$$

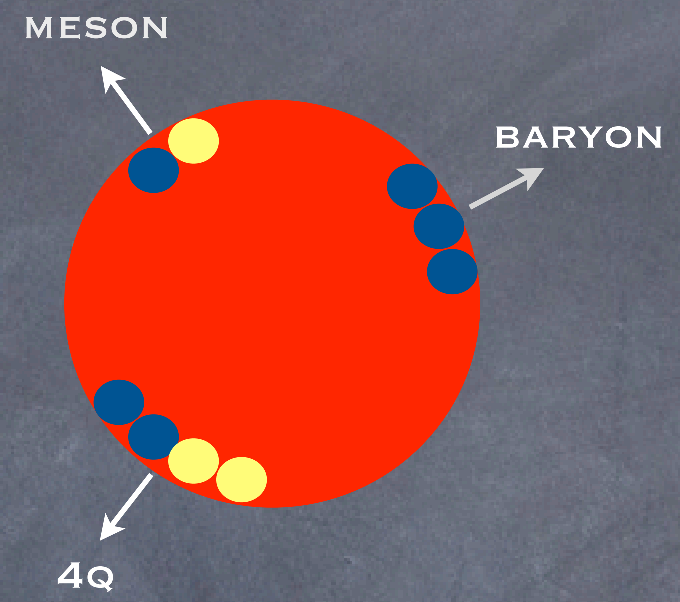
Moreover there are still some, maybe naive, questions as

- Attractive potential do not generate sharp resonances in S-wave (X has a width < 2 MeV).
- In the molecule picture we expect a width of ~70 keV whereas $\Gamma(DD\pi)$ ~ 3.5 MeV

Bignamini et al arXiv:0906.0882

Can Alice say something about X(3872)?

Let's consider the recombination scenario of Muller et al.



The phase space is densely populated by partons. The soft part of the spectrum of produced hadrons is assumed to be formed by the decay of a deconfined state of constituent quarks which `recombine'. The hard part is instead described by pQCD with an implementation of the parton energy loss in medium. This simple picture turns out to be effective at explaining the observation of

$$\frac{\#p}{\#\pi^+} \geq 1 \text{ for } 1.5 \text{ GeV} \leq p_\perp \leq 4 \text{ GeV @ RHIC}$$

this cannot be explained with fragmentation functions where the number of pions expected is much higher than that of protons.

I - The transverse momentum of partons is steeply falling with pT
II - Fragmentation functions favor the situation where the energy of the fragmenting parton is not concentrated in a single hadron but is distributed amid all the radiated partons.

Fragmentation is inefficient at producing high pT hadrons. In particular pions are favored with respect to baryons.

On the other hand, if the phase space is highly populated with partons, then it can simply happen that

$$P_\pi = p_u + p_{\bar{d}}$$
$$P_p = p_u + p_u + p_d$$

Assuming

$$p_u \simeq p_d \simeq p_{\bar{d}} \simeq p$$

and exponentially falling parton spectra we have same yields at the same hadron transverse momenta

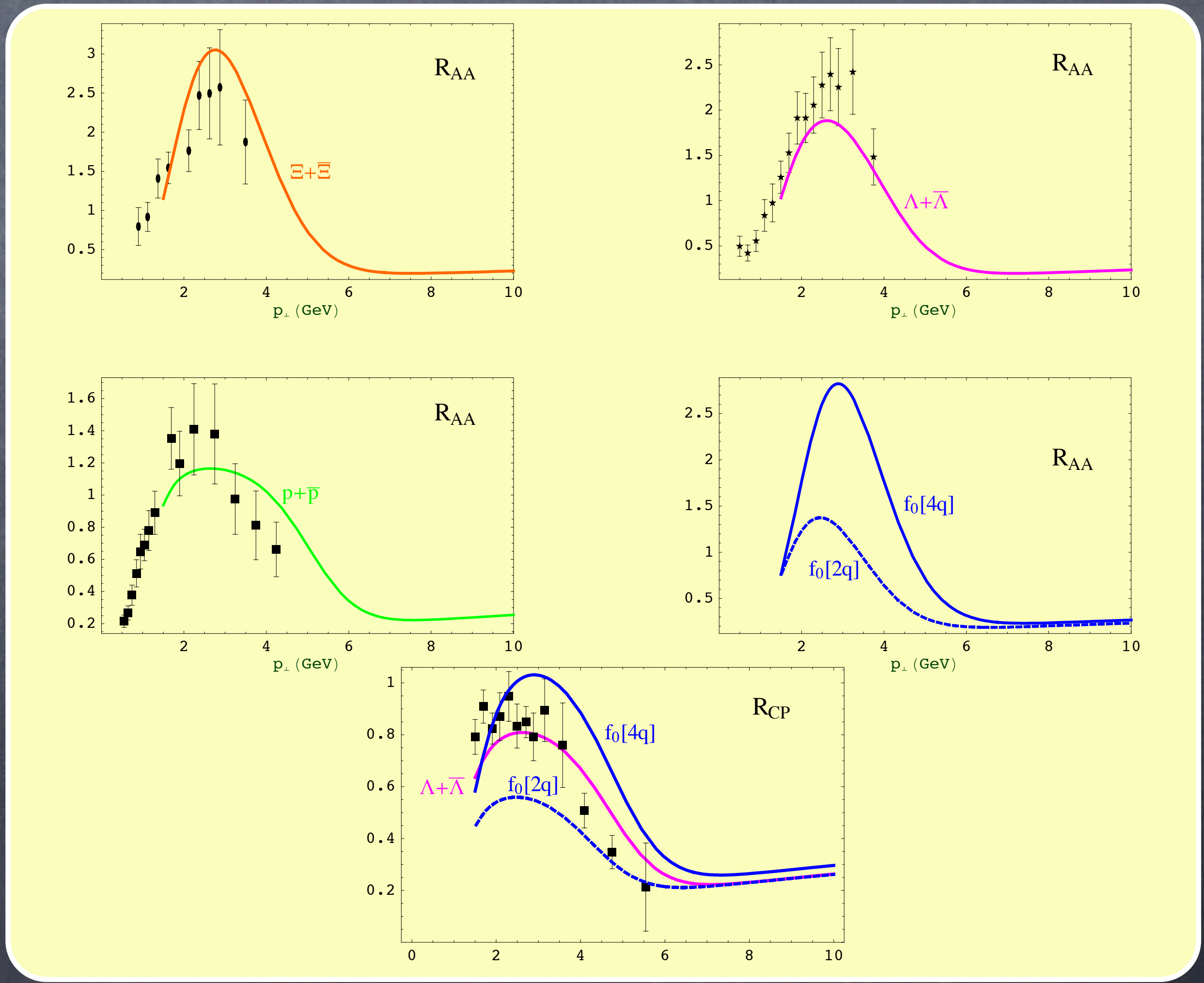
$$\#(\mathrm{protons}) \propto \exp(-3(P_p/3))$$
$$\#(\mathrm{pions}) \propto \exp(-2(P_\pi/2))$$

Similarly, as for recombination, the X should be produced with similar yields as charmonia (either 4q or molecule interpretations are assumed).

$$
\begin{aligned}
&\#(X(3872)_{\rm mol}) \propto \exp(-2(P_D/2))\exp(-2(P_{D^*}/2)) = \exp(-P_X)\\
&\#(X(3872)_{4q}) \propto \exp(-4(P_X/4))\\
&\#(\psi) \propto \exp(-2(P_\psi/2))
\end{aligned}
$$

No phase space suppression for a molecule.

Fragmentation functions should be modified for a tetraquark X whereas the hard part of the spectrum should be left unchanged for the molecule. The fragmentation functions of the tetraquarks are guessed from that of baryons (e.g. Lambdas for f0(980)).



Maiani, Polosa, Riquer, Salgado arXiv:0707.4578 [hep-ph]

Conclusions

The V_2 anisotropies for different hadrons are compatible with a universal value of v_2 in the parton phase i.e. V_2 seems efficient at counting the valence quarks: $V_2 = N_q\ v_2$.

Studying elliptic flow and/or nuclear modification ratios it should be possible to learn something about the quark structue of X(3872) (or Y(4260) and many others).
Are the denominators in RCP small with respect to numerators?

Do they look like charmed baryons ??

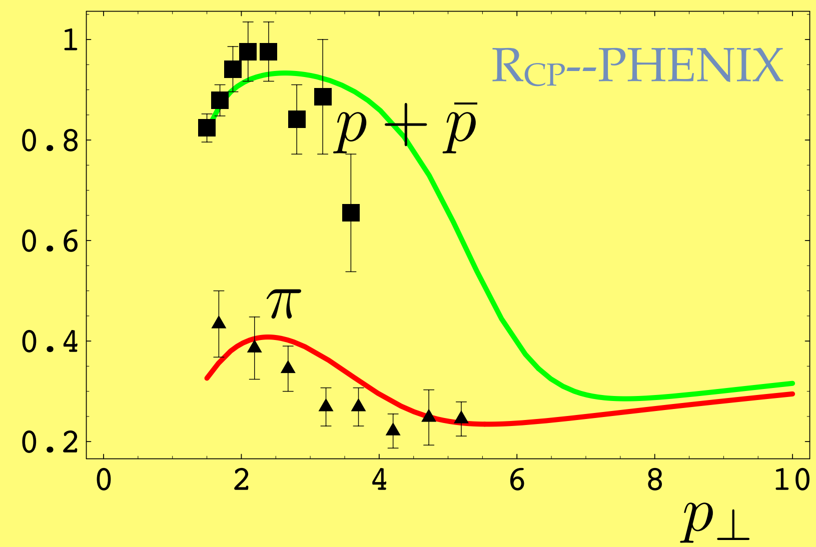
more slides

Nuclear Modification Ratios

$$R_{CP} = \frac{N_{\rm coll}(b)}{N_{\rm coll}(b=0)} \left[\frac{\frac{dN_H(b=0)}{d^2p_\perp}}{\frac{dN_H(b)}{d^2p_\perp}} \right]$$

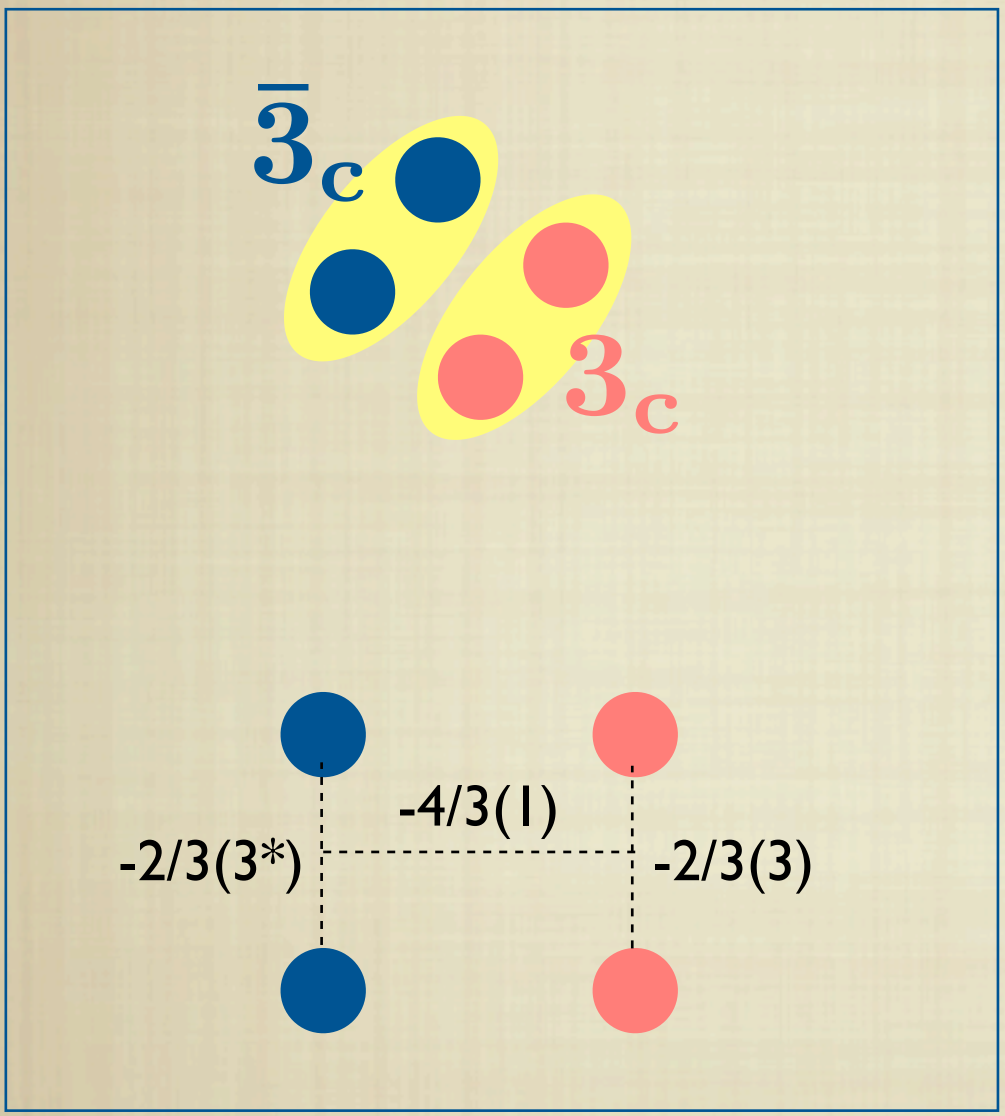
$$R_{AA} = \frac{1}{N_{\rm coll}(b=0)} \left[\frac{\frac{dN_H(b=0)}{d^2p_\perp}}{\frac{dN_H}{d^2p_\perp}\Big|_{pp}} \right]$$

Turn out to be very sensitive to the number of constituents

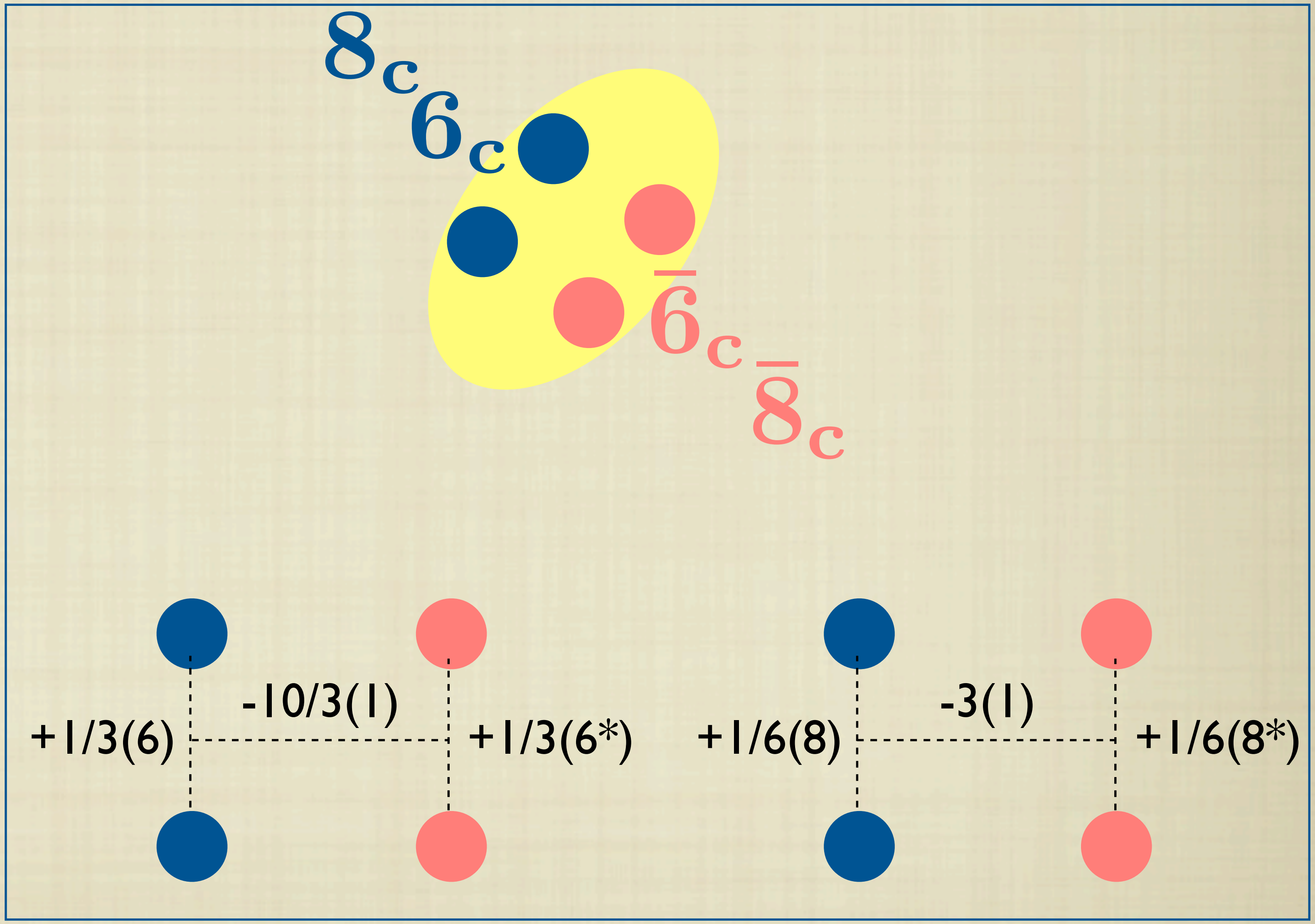


$$\mathcal{I} \propto \sum_a (T^a_{(A)})_{ij} (T^a_{(B)})_{kn} \quad \text{neglecting distance}$$

~Tetraquarks



~Molecules



-2/3-2/3-4/3 = 1/3+1/3-10/3 = 1/6+1/6 -3 = ...

Studied by Maiani, Piccinini, Polosa, Riquer

hep-ph/0412098 :: hep-ph/0507062

Diquark Exoticity

$$\boxed{\begin{array}{c} q \mapsto \bar{\mathfrak{q}} \\ \bar{q} \mapsto \mathfrak{q} \end{array}}$$

Jaffe & Wilczeck PRL 03

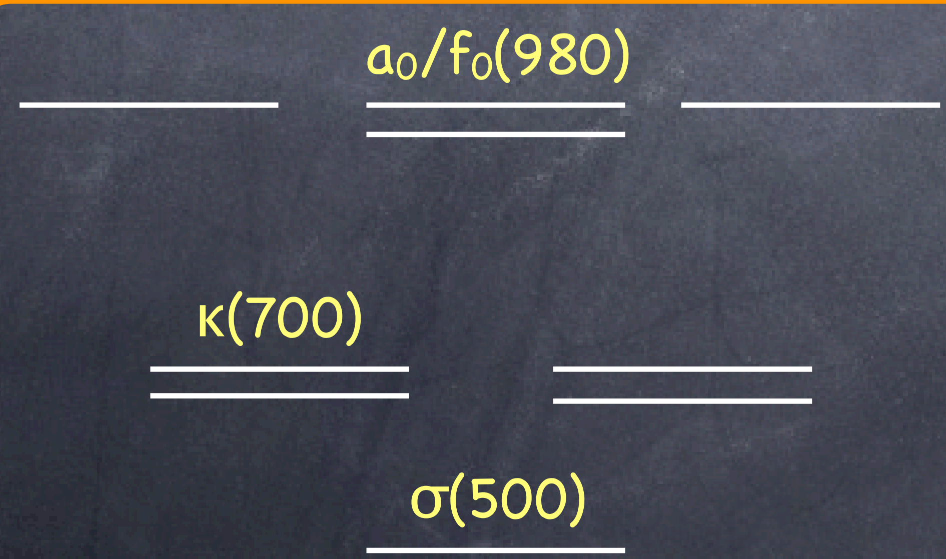
`t Hooft, Isidori, Maiani, Polosa, Riquer PLB 08

$$\mathfrak{q} = [q \uparrow q \downarrow]_{\bar{\mathbf{3}}_{\mathbf{c}}, \bar{\mathbf{3}}_{\mathbf{f}}} \text{ or, more precisely, } \mathfrak{q}_{i\alpha} = \epsilon_{ijk}\epsilon_{\alpha\beta\gamma}\bar{q}_C^{j\beta}\gamma_5 q^{k\gamma}$$

using this notation we have:

$$\begin{aligned}
\sigma &= \mathfrak{q}^3\bar{\mathfrak{q}}^3;\ \text{where } 1,2,3 = u,d,s \\
\kappa &= \mathfrak{q}^2\bar{\mathfrak{q}}^3,\ \mathfrak{q}^1\bar{\mathfrak{q}}^3,\ + \text{conj. doubl.} \\
f_0 &= \frac{\mathfrak{q}^2\bar{\mathfrak{q}}^2 + \mathfrak{q}^1\bar{\mathfrak{q}}^1}{\sqrt{2}} \\
a_0 &= \mathfrak{q}^2\bar{\mathfrak{q}}^1,\ \frac{\mathfrak{q}^2\bar{\mathfrak{q}}^2 - \mathfrak{q}^1\bar{\mathfrak{q}}^1}{\sqrt{2}},\ \mathfrak{q}^1\bar{\mathfrak{q}}^2
\end{aligned}$$

and $$S = \begin{pmatrix} \frac{a^0}{\sqrt{2}} + \frac{f_0^{[0]}}{\sqrt{2}} & a^+ & \kappa^+ \\ a^- & -\frac{a^0}{\sqrt{2}} + \frac{f_0^{[0]}}{\sqrt{2}} & \kappa^0 \\ \kappa^- & \bar{\kappa}^0 & \sigma^{[0]} \end{pmatrix}$$

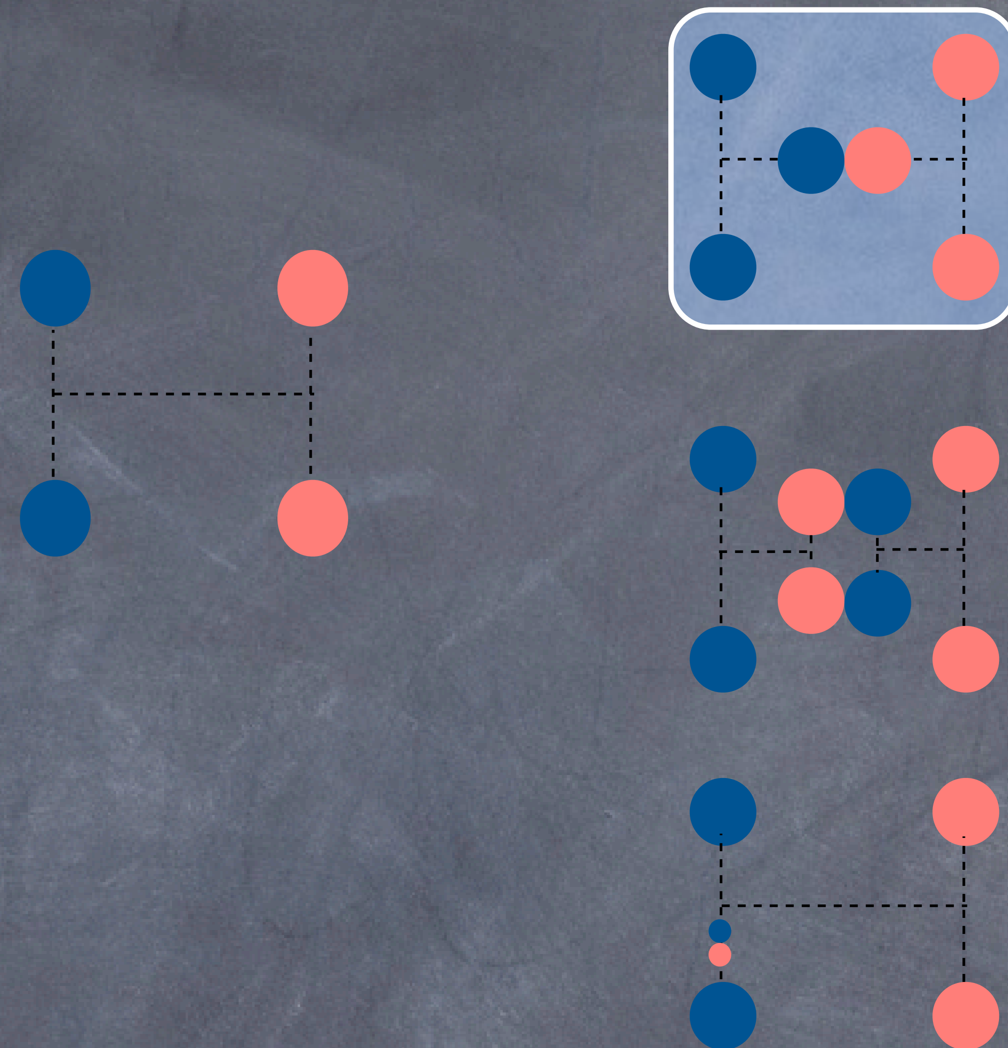


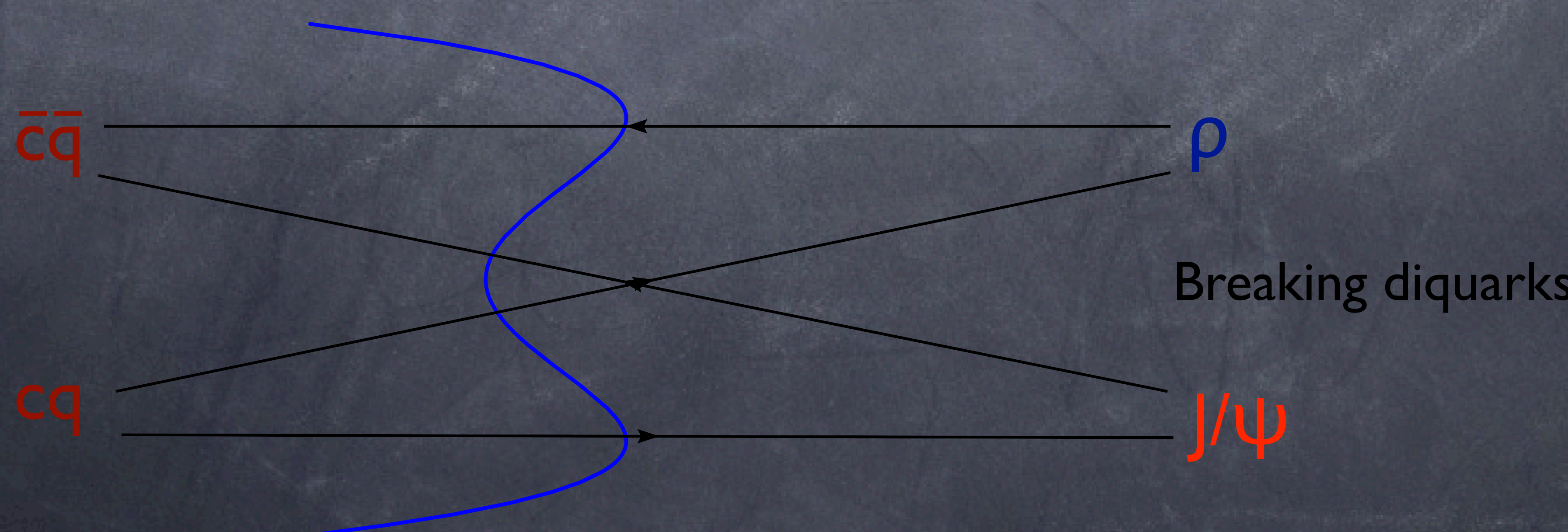
$$\underbrace{[ds][\bar{u}\bar{s}]}_{I_3=-1} \quad \underbrace{[us][\bar{u}\bar{s}],[sd][\bar{s}\bar{d}]}_{I_3=0} \quad \underbrace{[us][\bar{d}\bar{s}]}_{I_3=+1}$$

$$\underbrace{[ud][\bar{u}\bar{s}],[sd][\bar{u}\bar{d}]}_{I_3=-1/2} \quad \underbrace{[ud][\bar{d}\bar{s}],[us][\bar{u}\bar{d}]}_{I_3=+1/2}$$

$$\underbrace{[ud][\bar{u}\bar{d}]}_{I_3=0}$$

Decays of diquark systems





The case of the Y(2175)

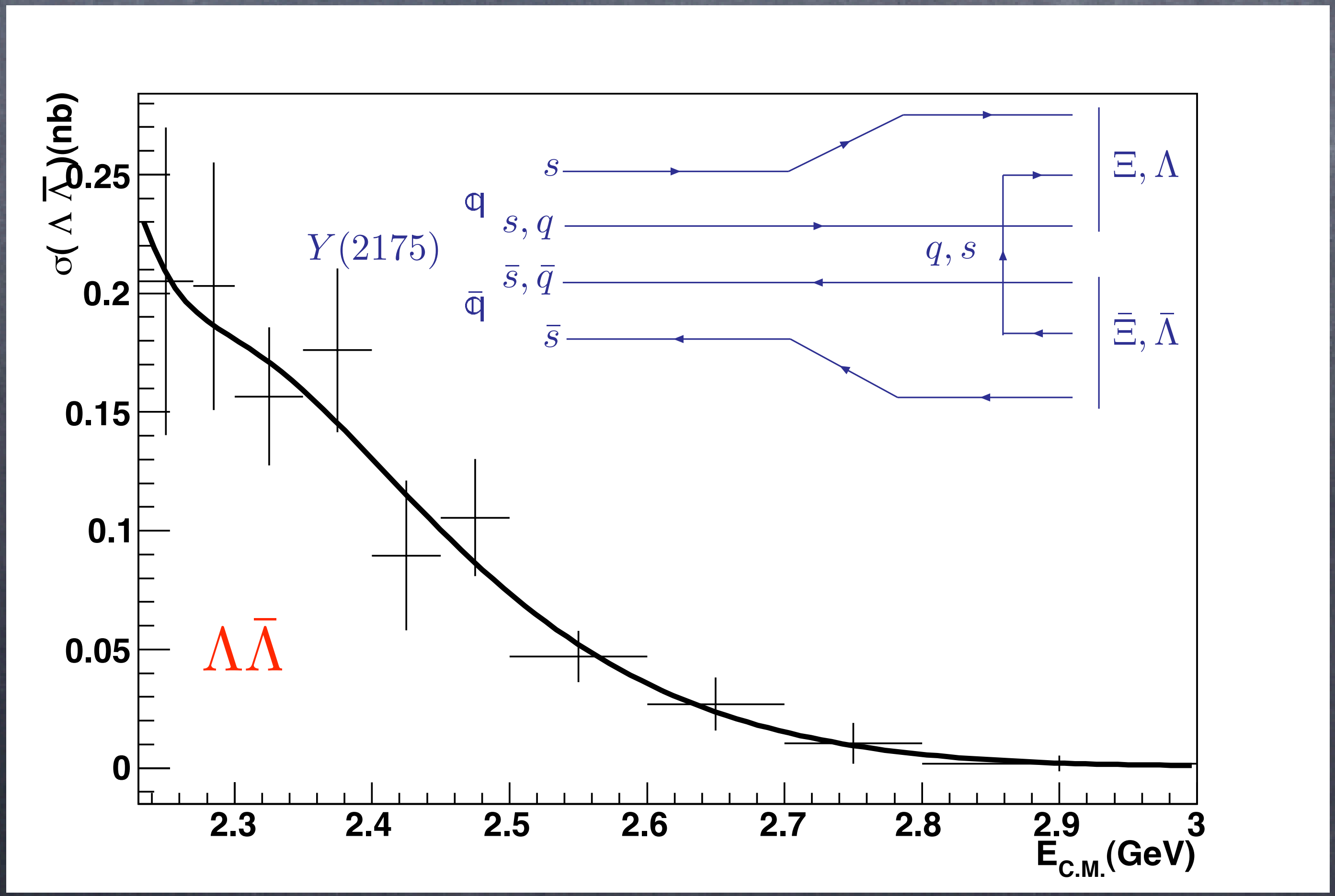
NV Drenska, R Faccini, ADP, PLB08

$$e^+e^- \to \gamma Y(2175)$$
$$Y(2175) \to \phi f_0(980)$$

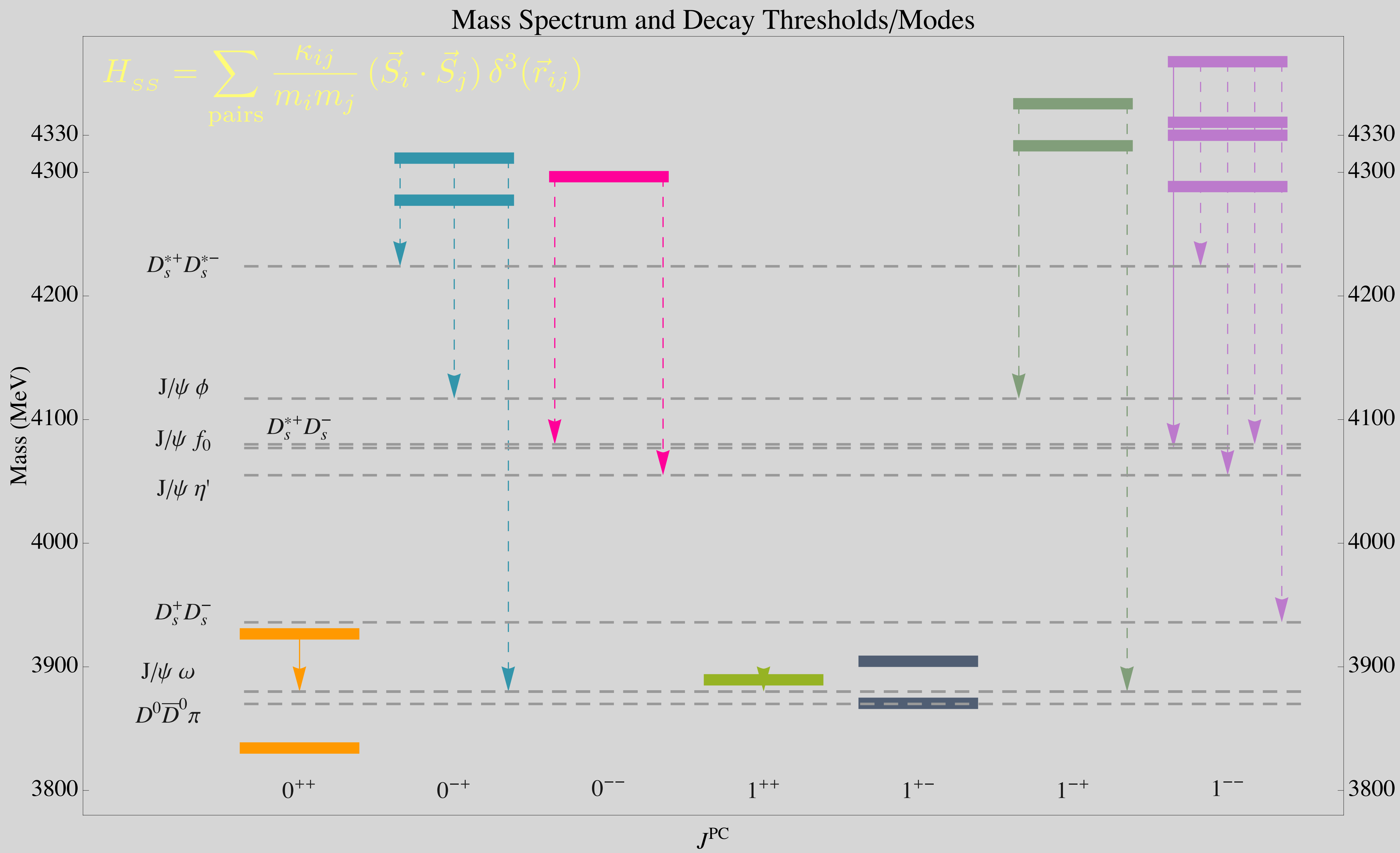
f_0 is expected to be a 4q state ('t Hooft, Isidori, Maiani, ADP, Riquer PLB08). This suggests that Y(2175) could also be a 4q particle: likely an orbital excitation of light quark diquarks. The mass of Y is sufficient to allow:

$$\mathfrak{q} \; q\bar{q} \; \bar{\mathfrak{q}} \to \mathbf{B}\bar{\mathbf{B}}$$

The Y can explain the whole(!) LL mass spectrum.

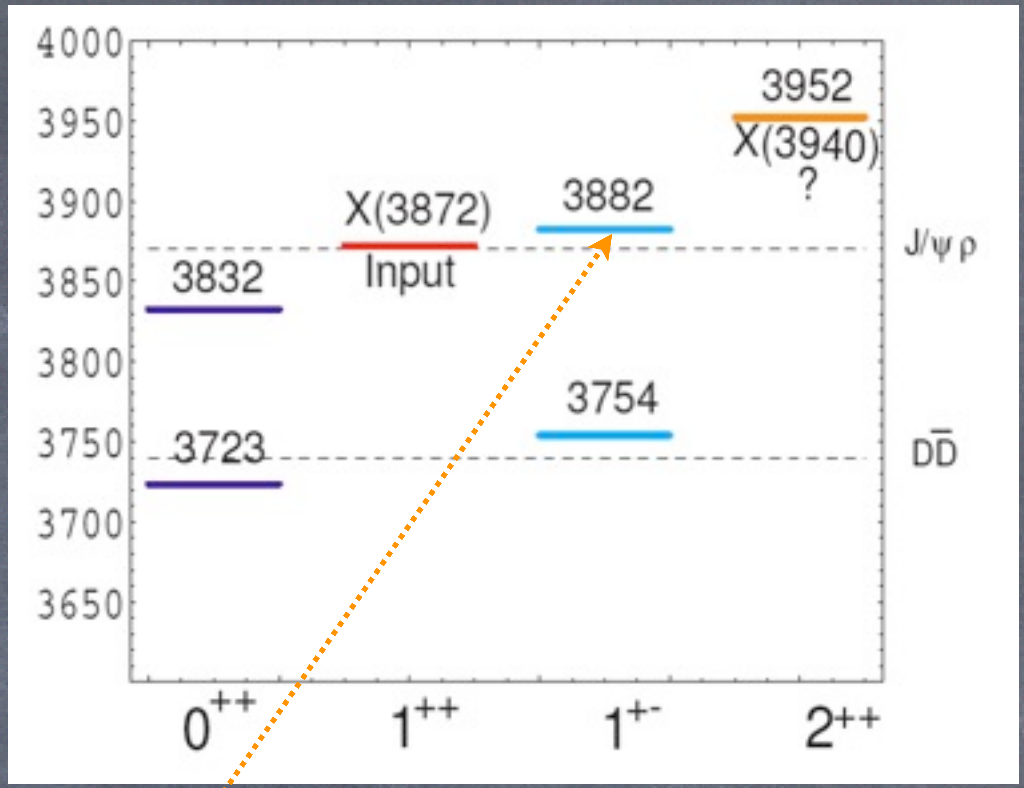


[cs][cb sb] particles?



Drenska, Faccini, Polosa **arXiv:0902.2803** [hep-ph]; PLB09

Z(4433) as a 1^{+-}



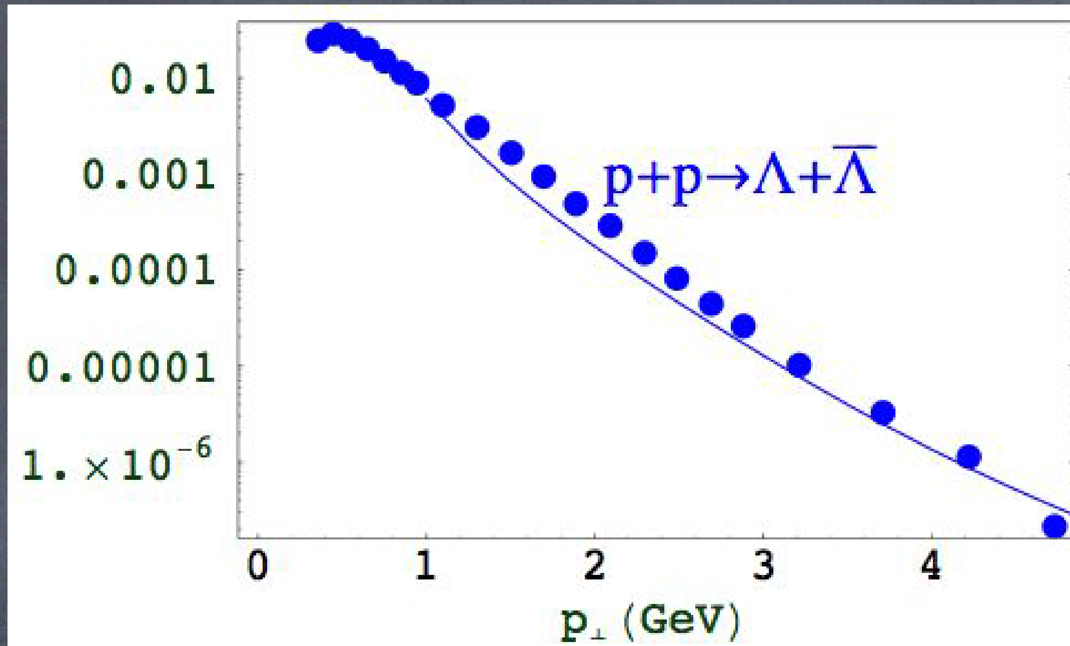
$J/\Psi\ \pi(\eta)$,
$\eta_c\ \rho(\omega)$
(MPPR 05)

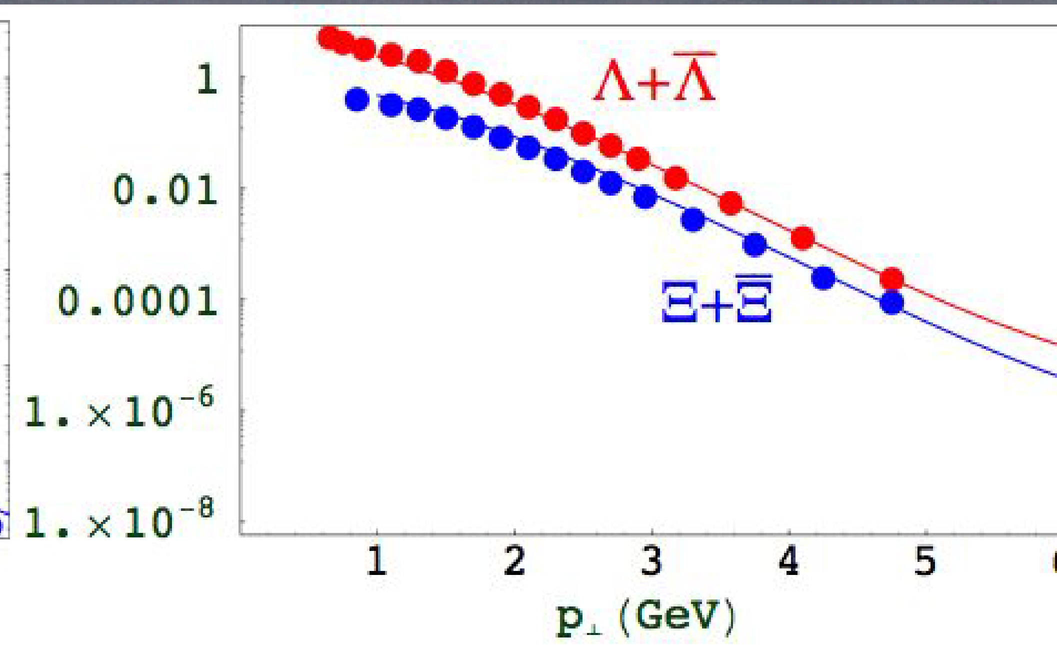
Is the Z(4433) the 2S radial excitation of the 3880?

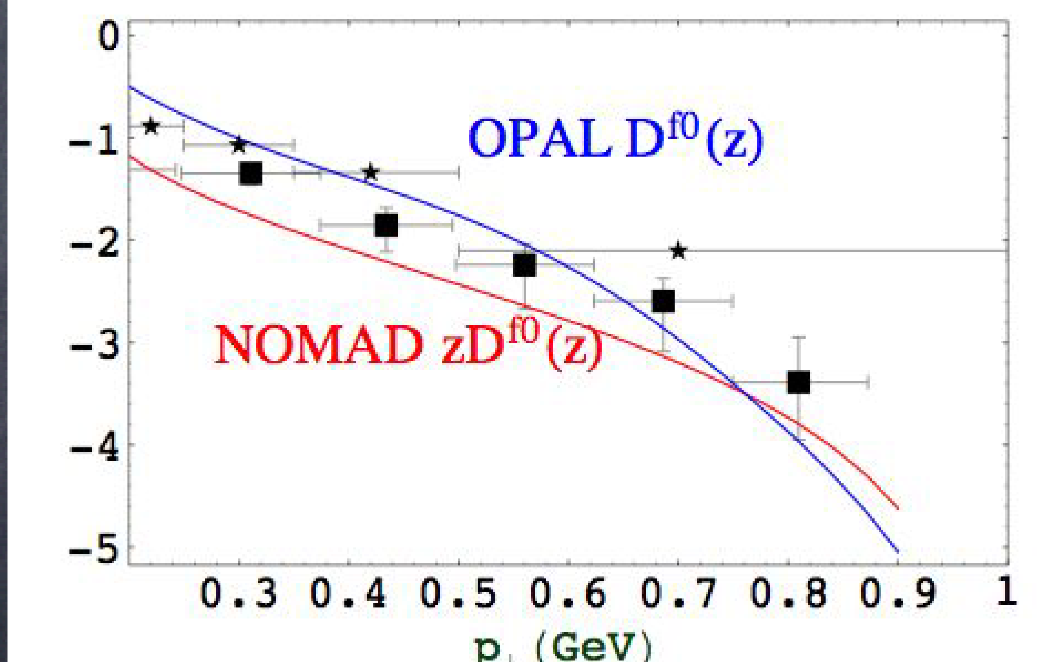
Z is 600 MeV higher than the $X(1^{+-},1S)$ and decays to $\psi(2S)$ rather than ψ :: $M(\psi(2S))-M(\psi(1S)) \sim 590$ MeV

L. Maiani, A. Polosa, V. Riquer,
arXiv:0708.3997v1 [hep-ph] 29 Aug 2007

Fitting







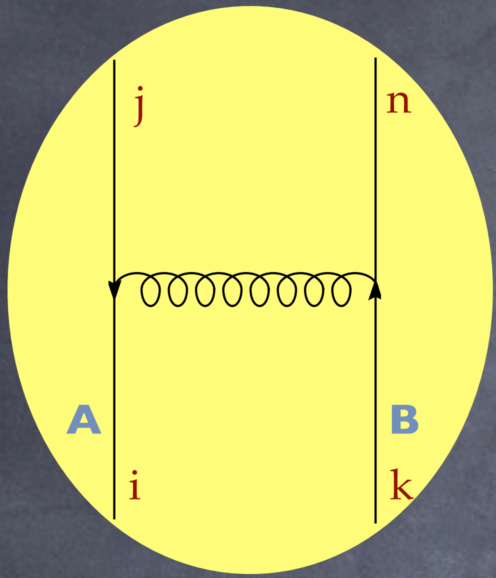
:: Model ::

$$D_q^{f_0(4q)}(z,Q^2) \sim 0.5 \times \left. \frac{D_q^{\Lambda+\bar{\Lambda}}(z,Q^q)}{2} \right|_{\mathrm{AKK}}$$

$$D_g^{f_0(4q)}(z,Q^2) \sim 0$$

arXiv:0707.4578 [hep-ph]

SU3, one-gluon exchange & diquarks



$$\mathcal{I} \propto \sum_a (T^a_{(A)})_{ij} (T^a_{(B)})_{kn} \quad \text{neglecting distance}$$

$$\mathcal{I} = \frac{1}{2}((T^a)^2 - (T^a_A)^2 - (T^a_B)^2)$$

$T^a_{ij,kn} = T^a_{Aij} \otimes \mathbb{1}_{kn} + \mathbb{1}_{ij} \otimes T^a_{Bkn}$ generates the product space $A \otimes B$

$(T^a)^2$ commutes with SU(3) generators $\Rightarrow$ is a number on each IRR

Shur's lemma $\Rightarrow$ $(T^a)^2 \propto \mathbf{1}$ on IRR $\Rightarrow$ $\mathrm{Sp}((T^a)^2) = C(D_{\mathrm{IRR}}) \dim D_{\mathrm{IRR}}$

$$\text{Define } \langle \mathcal{I} \rangle = \frac{1}{2}(C(A \otimes B) - C(A) - C(B))$$

$$A, B = \mathbf{3} \vee \bar{\mathbf{3}} \Rightarrow A \otimes B = \mathbf{1} \oplus \mathbf{8} \vee \bar{\mathbf{3}} \oplus \mathbf{6} \vee \mathbf{3} \oplus \bar{\mathbf{6}}$$

A⊗B	**1**	**3***	**6**	**8**
<I>	-4/3	-2/3	+1/3	+1/6

Use :: $\mathrm{Sp}((T^a_A)^2) = 8k_A$ $\quad$ $\mathrm{Sp}(H_i H_j) = k_A \delta_{ij}$

:: $k_{A\otimes B} = k_B \dim A + k_A \dim B$

:: $k_{A\oplus B} = k_A + k_B$