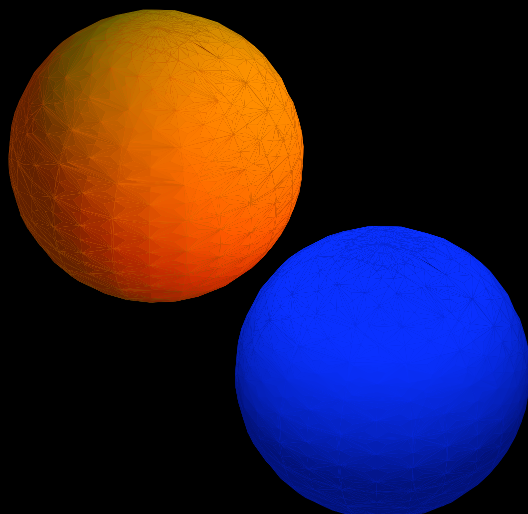
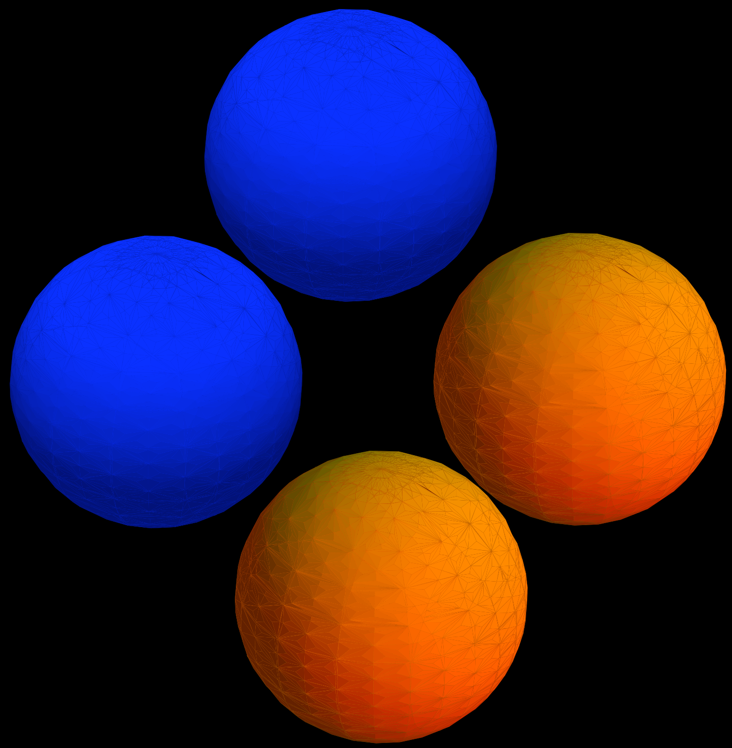


Hints of a 4-quark Spectroscopy

AD Polosa, INFN Roma



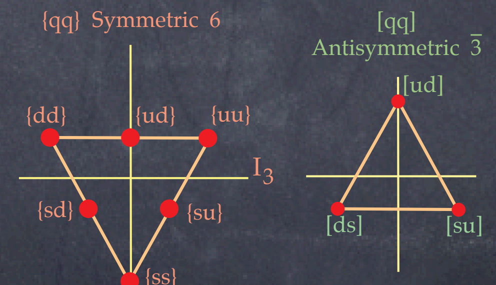
Hints of a 4-quark Spectroscopy

AD Polosa, INFN Roma

Why diquarks?

- diquarks are bound states in color anti-triplet channel: 3* (lattice, group-theory arguments and x->1 DIS)
- a diquark-anti-diquark (dq-adq) state is bound by color forces
- spin 0 (the `good` ones) diquarks are $3_{f.}$ The spin 1 are less bound (Sakharov Λ-Σ puzzle) :: $6_{f.}$
- the exotic spectrum is reduced because 3x3* < 3x3x3*x3* :: crypto-exotic light scalar hadrons

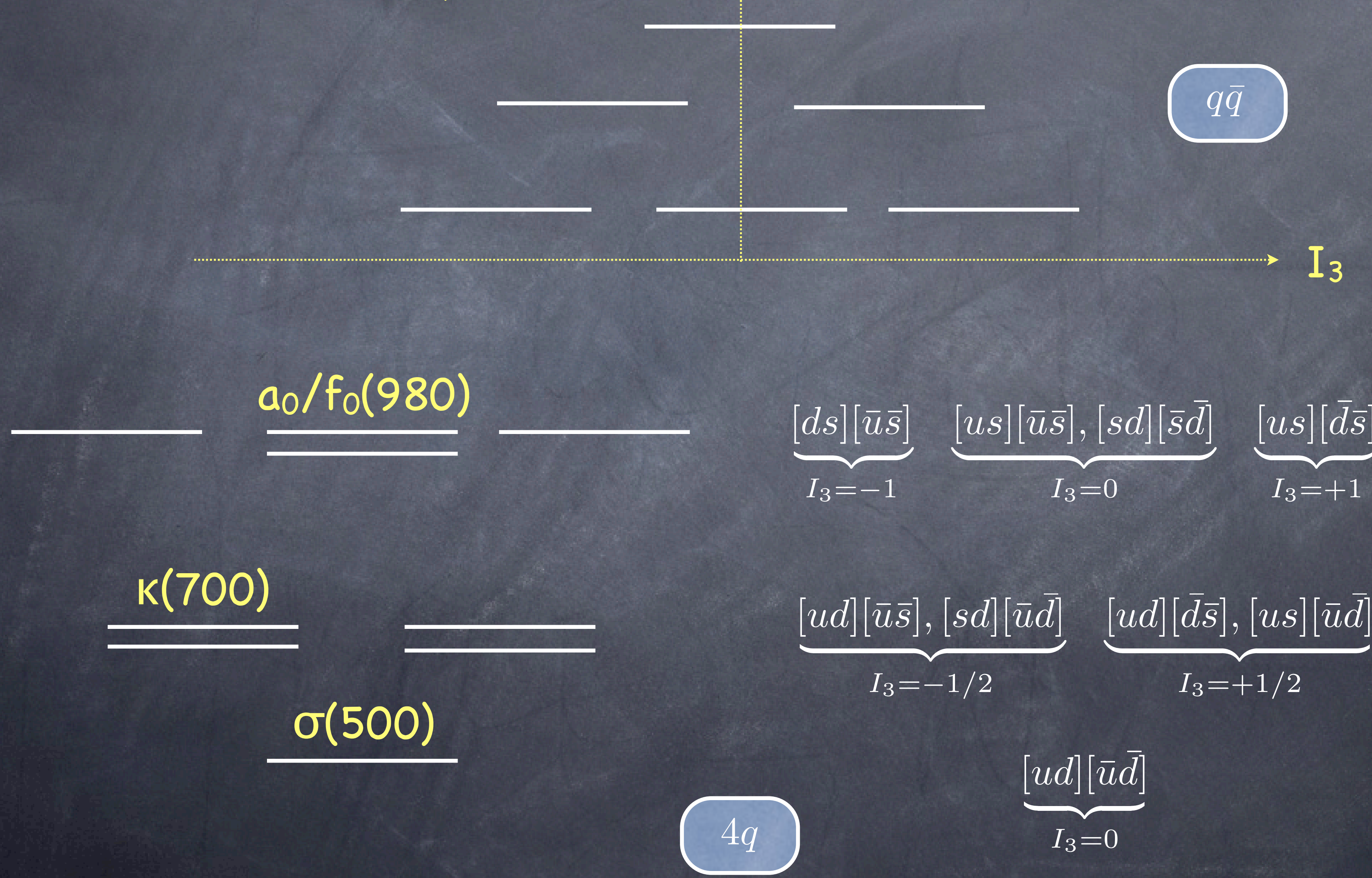
$$[qq]^{\text{good}}_{ia} = \epsilon^{(\text{col})}_{ijk}\,\epsilon^{(\text{flav})}_{abc}(-i\sigma_2)_{rt}\,q^{jb}_r\,q^{kc}_t$$

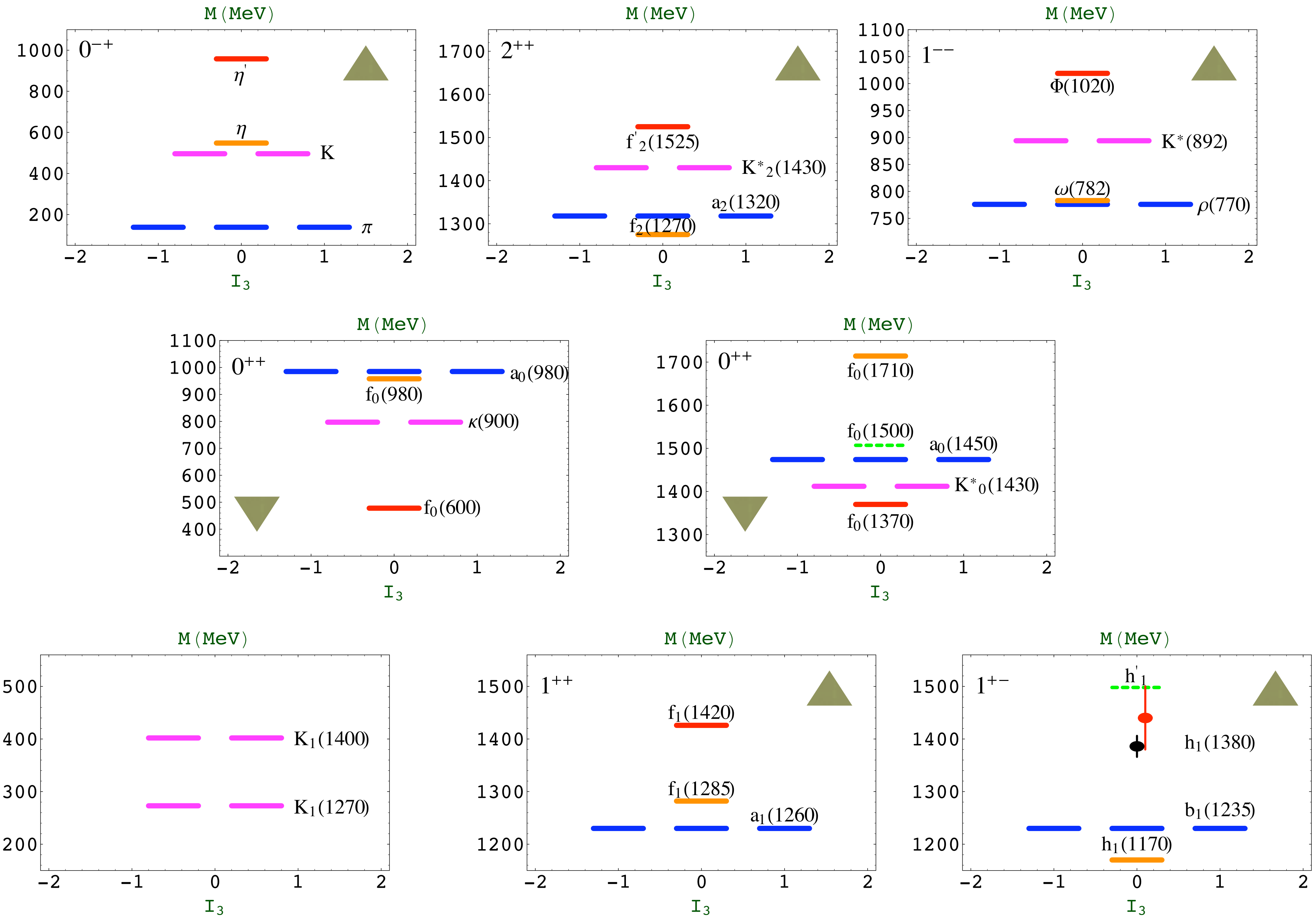


The inverted mass spectrum

Jaffe, '70 (see recent reviews)

Maiani, Piccinini, Polosa, Riquer PRL 2004





M (MeV)
0−+
η'
η
K
π
I3
M (MeV)
2++
f'2(1525)
K*2(1430)
a2(1320)
f2(1270)
I3
M (MeV)
1−−
Φ(1020)
K*(892)
ω(782)
ρ(770)
I3
M (MeV)
0++
a0(980)
f0(980)
κ(900)
f0(600)
I3
M (MeV)
0++
f0(1710)
f0(1500)
a0(1450)
K*0(1430)
f0(1370)
I3
M (MeV)
K1(1400)
K1(1270)
I3
M (MeV)
1++
f1(1420)
f1(1285)
a1(1260)
I3
M (MeV)
1+−
h'1
h1(1380)
b1(1235)
h1(1170)
I3

Scalars from Theory

(1) Caprini, Colangelo, Leutwyler PRL 2005 -- the sigma

(2) Descotes-Genon, Moussallam EPJC 2006 -- the kappa

Partial wave S-matrix elements are real-analytic

$$S^*(s) = S(s^*)$$

and from unitarity

$$S(s) = 1/S(s^*)$$

zeroes from the first sheet -> poles on the second

Dispersion equation analysis of $\pi\pi$ scattering in S-wave indicate a broad resonance around 500 MeV

(1)

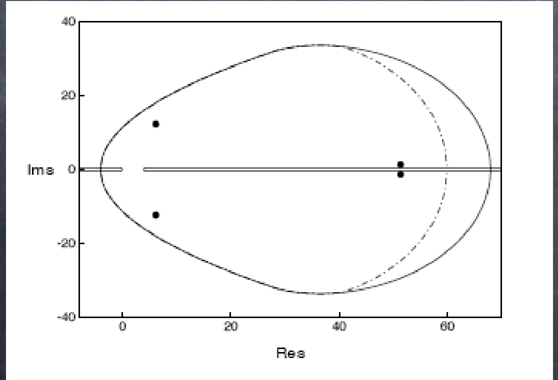
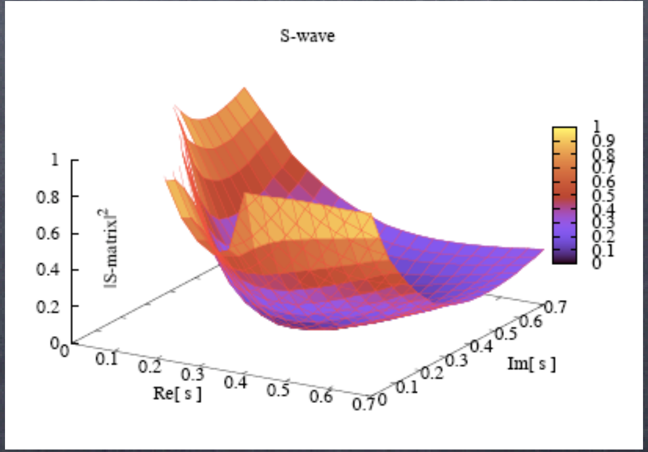


FIG. 2: Domain of validity of the Roy equations.

(2)



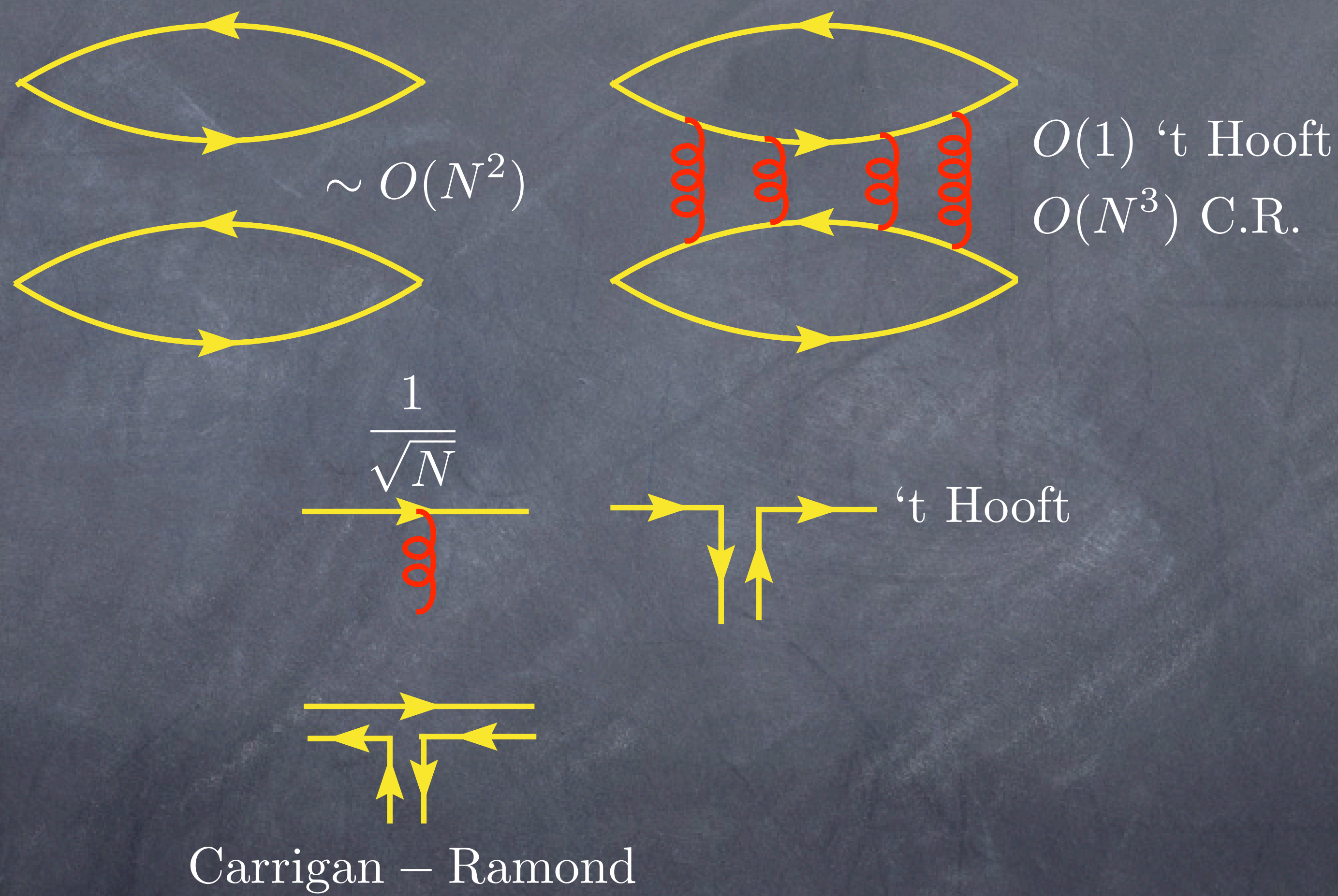
Can dq-adq hadrons exist?

In the `t Hooft large N limit they do not exist since the leading term in the 1/N expansion of any two-point correlation function of a 4-q operator is a disconnected graph

But:

1. N=3
2. other large N limits exist (Carrigan-Ramond) where the quark is in the 3*

in diagrams...



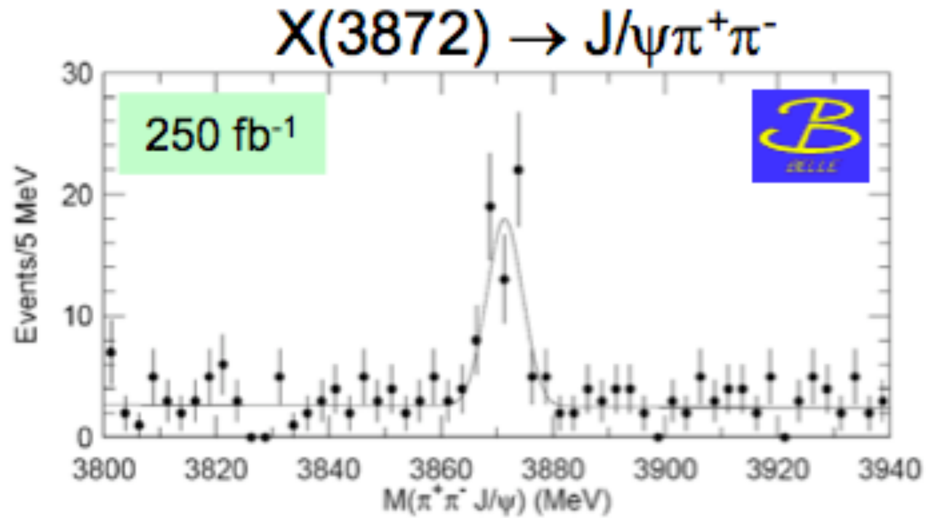
Stems from the fact that there are no color singlets made up of 3 fermions (baryons) for N>3. C-G introduce quarks and \`larks\` trasforming as N and 1/2 N(N-1) of SU(N) respectively. In SU(3), a lark=antiquark. In SU(N) a baryon is a qqL*.

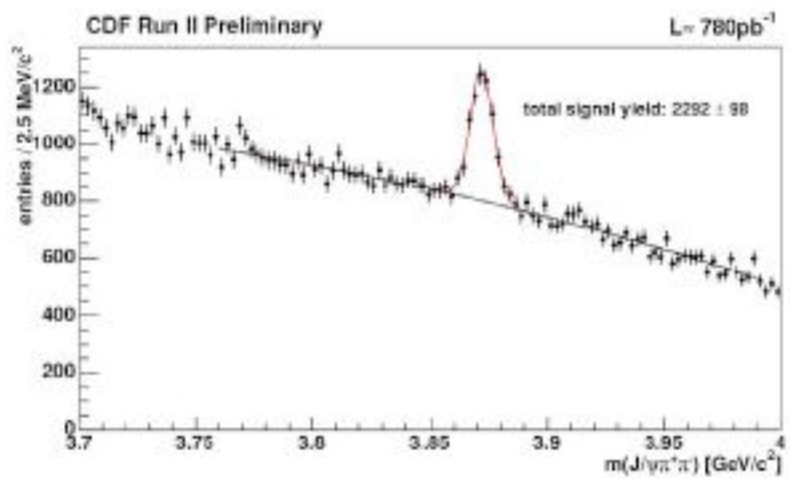
dq-adq :: where else?

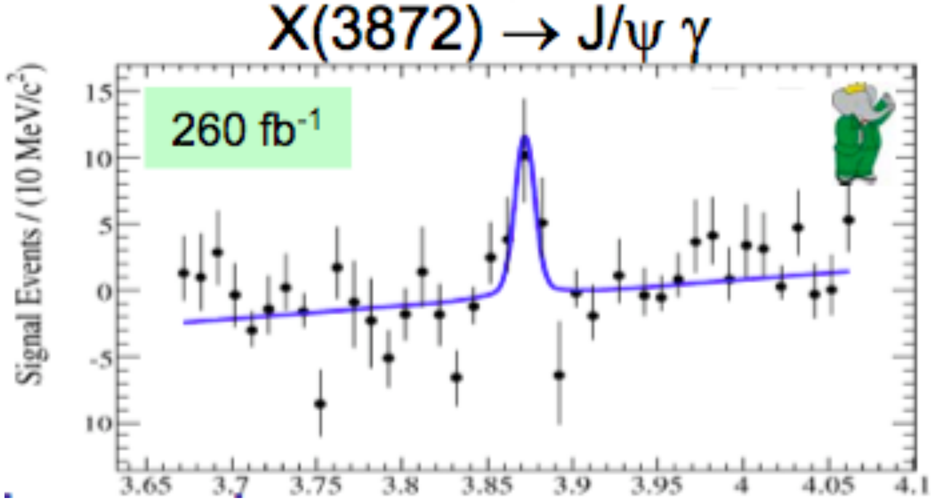
- For some time they played a role to understand the so colled pentaquark baryons (Wilczek & Jaffe)
- The newly discovered X,Y,Z partilces [Belle & BaBar].

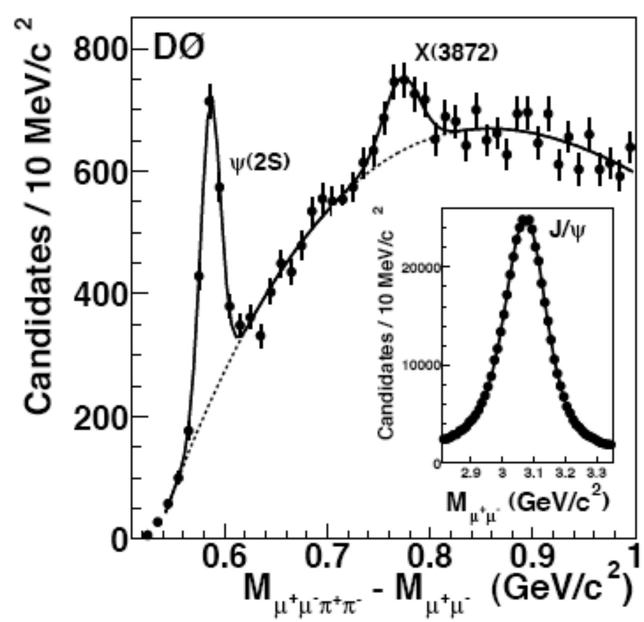
$$B^{\pm} \to K^{\pm} \underbrace{\pi^+\pi^- J/\psi}_{X \to \rho J/\psi}$$

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









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

X(3872) is a 1^{++} state

Is this compatible with a good dq-adq structure?

NO!

We need bad, spin 1 diquarks

But bad diquarks are less bound (lattice)...

Anyway X must contain charm quarks!

$$\text{spin} - \text{spin interactions} \sim \frac{1}{m_Q}$$

Building the states (L=0)

J^{PC}	wave functs.
0^{++}	$[cq]_0[\bar{c}\bar{q}]_0 \ \vee \ ([cq]_1[\bar{c}\bar{q}]_1)_0$
1^{++}	$\frac{[cq]_1[\bar{c}\bar{q}]_0 + [cq]_0[\bar{c}\bar{q}]_1}{\sqrt{2}}$
1^{+-}	$\frac{[cq]_1[\bar{c}\bar{q}]_0 - [cq]_0[\bar{c}\bar{q}]_1}{\sqrt{2}} \ \vee \ ([cq]_1[\bar{c}\bar{q}]_1)_1$
2^{++}	$([cq]_1[\bar{c}\bar{q}]_1)_2$

$$([\ ]_s[\ ]_s)_J$$

Isospin & 2 * X(387_) states

We set in the flavor basis X_u, X_d

$$M = \begin{pmatrix} 2m_u & 0 \\ 0 & 2m_d \end{pmatrix} + \delta \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

where the mixing matrix has a diagonal structure in the Isospin $I = 0, 1$ basis, its eigenvectors being

$$\frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix} \quad \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

At the charmonium scale we expect the annihilations to be small and quark mass to dominate :: *observed* X -> ω/ρ isospin breaking

$$\frac{\mathcal{B}(X \to \pi^+\pi^-\pi^0 J/\psi)}{\mathcal{B}(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$$

G.C. Rossi, G. Veneziano; L. Maiani, F. Piccinini, ADP, V.Riquer PRD 2005

FIND THESE TWO X'S IN DATA
(MPPR `05)

A MASS DIFFERENCE X_u-X_d OF ABOUT ~ 5 MEV WAS PREDICTED :: THEY COULD APPEAR IN B^+ AND B^0 SEPARATELY

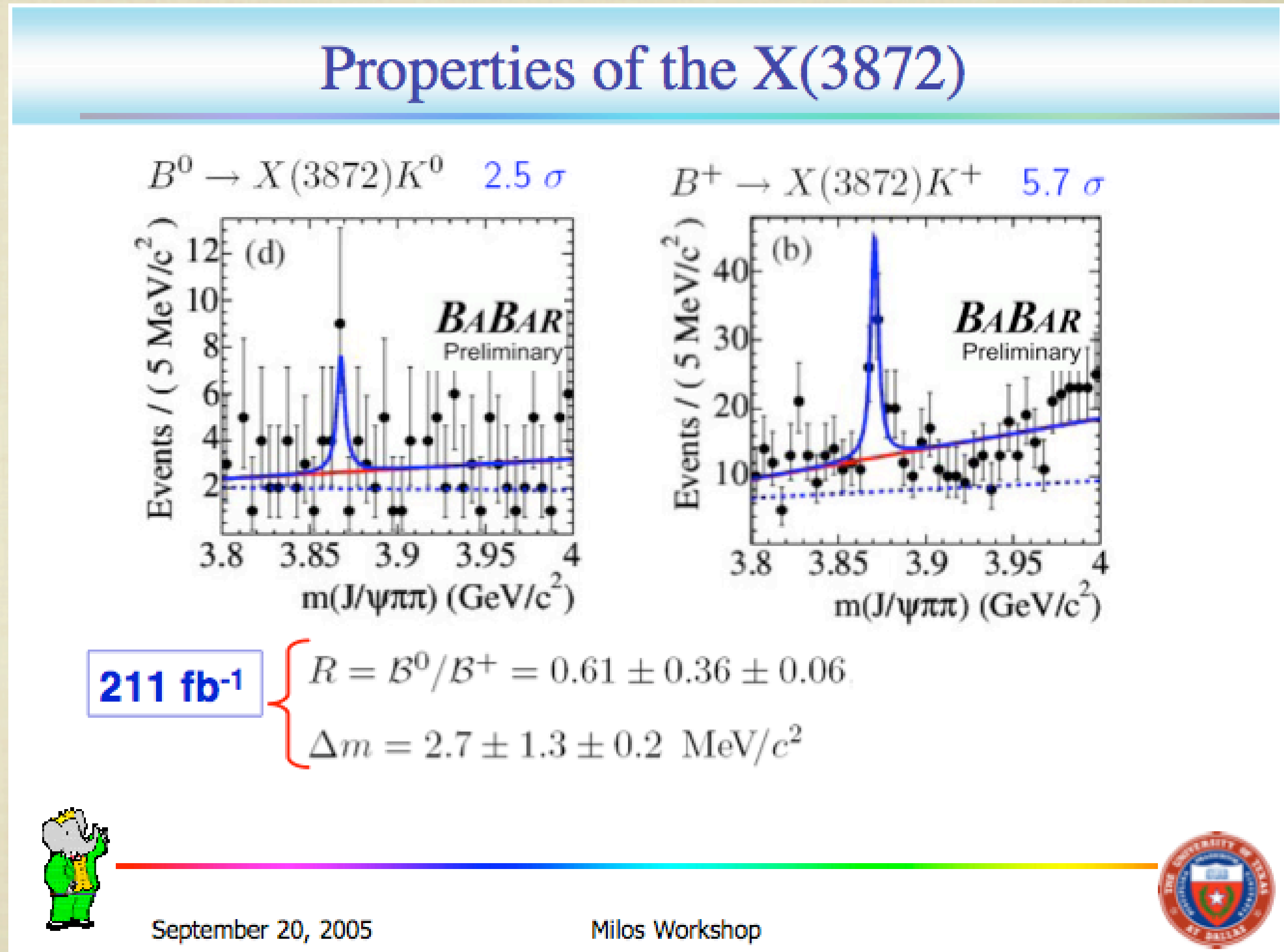
$B^+ \to K^+ X_u$ with rate Γ_1

$B^+ \to K^+ X_d$ with rate Γ_2

suppose $\Gamma_1 \gg \Gamma_2$ ► $\Gamma_4 \gg \Gamma_3$

$B^0 \to K^0 X_u$ with rate Γ_3

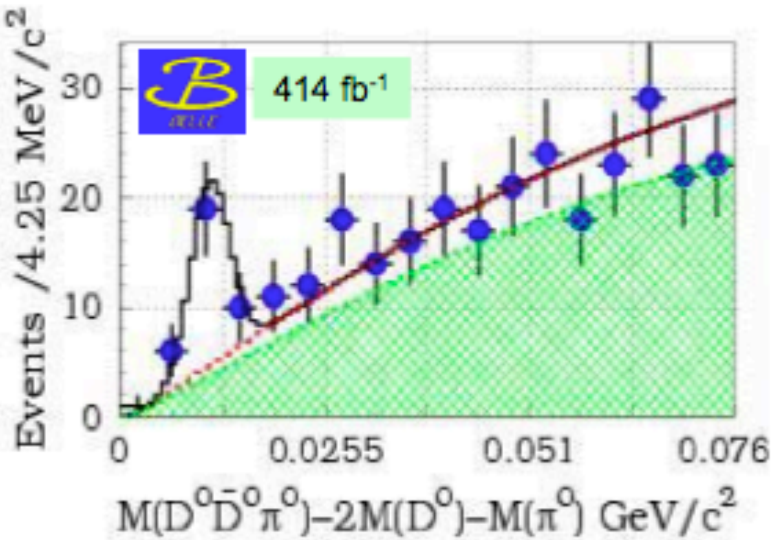
$B^0 \to K^0 X_d$ with rate Γ_4



DIFFERENCE IN MASS FROM DATA NOT SIGNIFICATIVE!

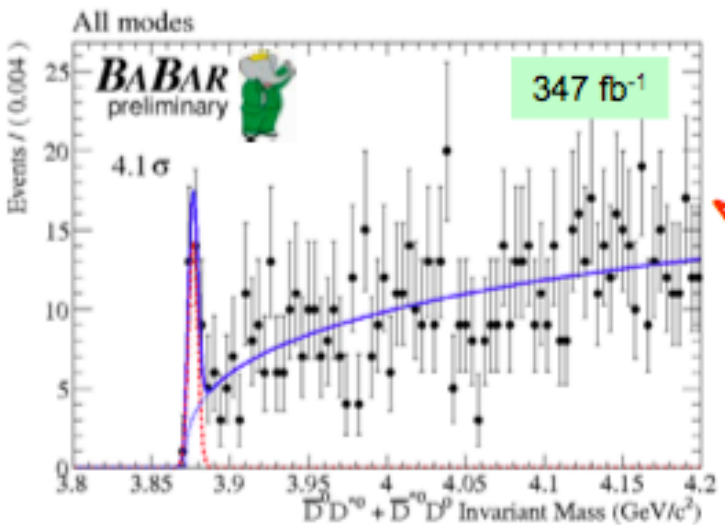
X(3872): STILL SOME SURPRISES

- Belle: looking at $B \to \bar{D}^0 D^0 \pi^0 K$



- Excess in the $\bar{D}^0 D^0 \pi^0$ invariant mass
  - $M = 3875.4 \pm 0.7\ ^{+1.2}_{-2.0}$ MeV/c^2

- BaBar: looking at $B \to \bar{D}^0 D^{*0} K$ ($D^{*0} \to D^0\pi^0/\gamma$)



New result preliminary

- Excess in the $\bar{D}^0 D^{*0}$ invariant mass
  - $M = 3875.6 \pm 0.7\ ^{+1.4}_{-1.5}$ MeV/c^2

- Masses between **Belle** and **BaBar** in good agreement
- 2.5σ away from the X(3872) world average!
- If X(3872), $J^P = 2^+$ disfavored

$M(J/\psi\pi^+\pi^-) = 3871.2 \pm 0.5$ MeV (World Average)

hep-ex/0606055

Belle: Phys. Rev. Lett. 97 (2006) 162002
BaBar: preliminary

ARE THERE TWO DIFFERENT X PARTICLES?

(MAIANI, POLOSA, RIQUER PRL `07)

:: OUR **NEW** HYPOTHESIS: TWO X, GENERICALLY PRODUCED IN $B^{+,0}$ ::

$$X_u \equiv \text{X state decaying into } D^0\bar{D}^0\pi^0 \;=\; X(3876)$$
$$X_d \equiv \text{X state decaying into } J/\psi\pi^+\pi^- \;=\; X(3872)$$

:: THE TWO NEUTRAL STATES IN THE 4Q-COMPLEX ::

$$X^+ = [cu][\bar{c}\bar{d}] \quad X^- = [cd][\bar{c}\bar{u}]$$
$$X_u = [cu][\bar{c}\bar{u}] \quad X_d = [cd][\bar{c}\bar{d}]$$

IT IS TRICKY THAT X_D TURNS OUT TO BE LIGHTER THAN X_U

(MAYBE ELECTROSTATICS IS RESPONSIBLE FOR THIS)

HOW FAR IS THIS PICTURE CONSISTENT WITH A FOUR QUARK MODEL?

HOWEVER, THE ASSUMPTION, THAT XU AND XD WOULD DECAY IN J WITH SIMILAR BRANCHING RATIOS WAS NOT JUSTIFIED AND THE EARLIER SCHEME IS SUPERSEDED BY THE ONE PRESENTED HERE.

A REMARKABLE FACT

$$\bar{b} + (u) \to \bar{c} + c\bar{s} + (u) + q\bar{q} \quad (\Delta I = 0)$$

(V)alence and (S)ea needed to build the final state Kaons :: observe that the inverted pattern with B0 was already observed in our first paper

$$\mathcal{A}(B^+ \to K^+ X_u) = V + S = \mathcal{A}(B^0 \to K^0 X_d)$$
$$\mathcal{A}(B^+ \to K^+ X_d) = V = \mathcal{A}(B^0 \to K^0 X_u)$$
$$\mathcal{A}(B^+ \to K^0 X^+) = S = \mathcal{A}(B^0 \to K^+ X^-)$$

AS A CONSEQUENCE WE HAVE

$$\left(\frac{B^0}{B^+}\right)_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^0 X_d)\mathcal{B}(X_d \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B^+ \to K^+ X_d)\mathcal{B}(X_d \to J/\psi\pi^+\pi^-)} = \frac{\mathcal{B}(B^0 \to K^0 X_d)}{\mathcal{B}(B^+ \to K^+ X_d)} =$$
$$= \frac{\mathcal{B}(B^+ \to K^+ X_u)}{\mathcal{B}(B^0 \to K^0 X_u)} = \frac{\mathcal{B}(B^+ \to K^+ X_u)\mathcal{B}(X_u \to D\bar{D}\pi)}{\mathcal{B}(B^0 \to K^0 X_u)\mathcal{B}(X_u \to D\bar{D}\pi)} = \left[\left(\frac{B^0}{B^+}\right)_{D\bar{D}\pi}\right]^{-1}$$

WHAT DATA TELL (X(3872) AND X(3876) APPEAR TO BE RELATED BY U⇔D SYMMETRY!)

	$f = J/\psi\pi^+\pi^-$	$f = D^0\bar{D}^0\pi^0$
$\mathcal{B}(B^\pm \to K^\pm X)\mathcal{B}(X \to f)\times 10^5$	1.05 ± 0.18 $1.01 \pm 0.25 \pm 0.10$	$10.7 \pm 3.1^{1.9}_{3.3}$ $- - --$
$\mathcal{B}(B^0 \to K^0 X)\mathcal{B}(X \to f)\times 10^5$	$- - --$ $0.51 \pm 0.28 \pm 0.07$	$17.3 \pm 7.0^{3.1}_{5.3}$ $- - --$
$(B^0/B^+)_f$	$- - --$ $0.50 \pm 0.30 \pm 0.05$	1.62 ± 0.80 $2.23 \pm 0.93 \pm 0.55$

A REMARKABLE FACT

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$$\bar{b} + (u) \to \bar{c} + c\bar{s} + (u) + q\bar{q} \quad (\Delta I = 0)$$

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$$\mathcal{A}(B^+ \to K^0 X^+) = S = \mathcal{A}(B^0 \to K^+ X^-)$$

AS A CONSEQUENCE WE HAVE

$$\left(\frac{B^0}{B^+}\right)_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^0 X_d)\mathcal{B}(X_d \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B^+ \to K^+ X_d)\mathcal{B}(X_d \to J/\psi\pi^+\pi^-)} = \frac{\mathcal{B}(B^0 \to K^0 X_d)}{\mathcal{B}(B^+ \to K^+ X_d)} =$$
$$= \frac{\mathcal{B}(B^+ \to K^+ X_u)}{\mathcal{B}(B^0 \to K^0 X_u)} = \frac{\mathcal{B}(B^+ \to K^+ X_u)\mathcal{B}(X_u \to D\bar{D}\pi)}{\mathcal{B}(B^0 \to K^0 X_u)\mathcal{B}(X_u \to D\bar{D}\pi)} = \left[\left(\frac{B^0}{B^+}\right)_{D\bar{D}\pi}\right]^{-1}$$

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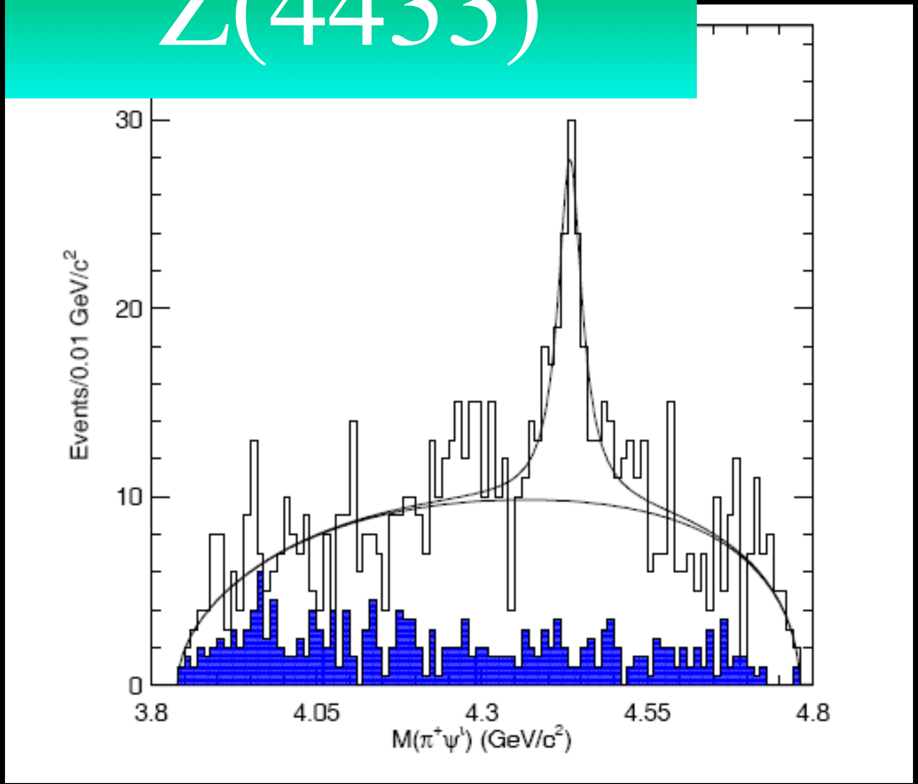
$\mathcal{B}(B^0 \to K^0 X)\mathcal{B}(X \to f)\times 10^5$	$- - --$ $0.51 \pm 0.28 \pm 0.07$	$17.3 \pm 7.0^{3.1}_{5.3}$ $- - --$
$(B^0/B^+)_f$	$- - --$ $0.94 \pm 0.24 \pm 0.10$	1.62 ± 0.80 $1.33 \pm 0.69 \pm 0.52$

Z(4433)

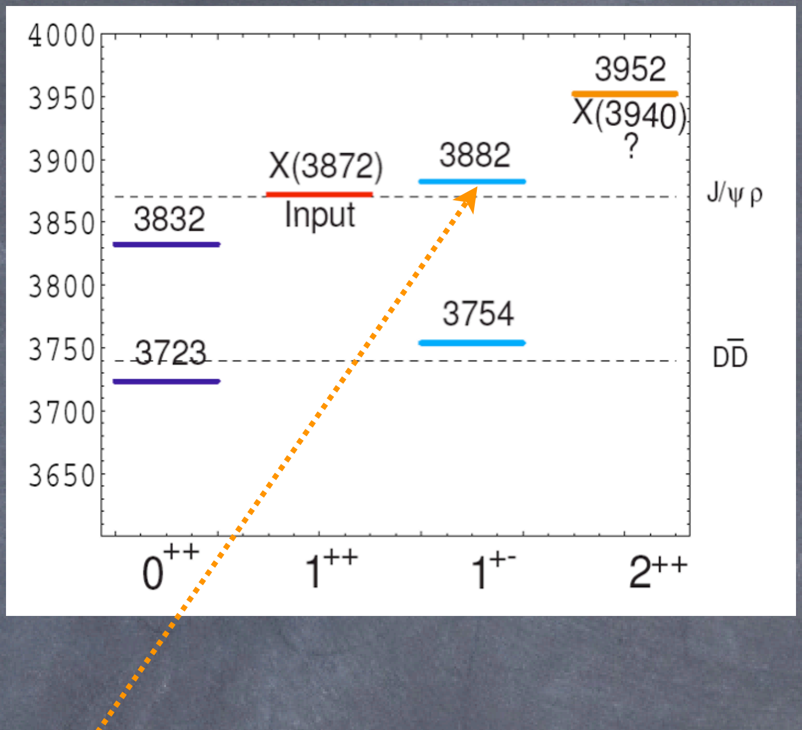


$B^{\pm} \rightarrow Z^{\pm} K_s$; $Z^{\pm} \rightarrow \psi(2S)\pi^{\pm}$

This is the first charged state observed. A 2S state?

$$[cu][\bar{c}\bar{d}]$$

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



J/Ψ π(η),
η_c ρ(ω)
(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 ψ(2S) rather than ψ :: M(ψ(2S))–M(ψ(1S)) ~ 590 MeV

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

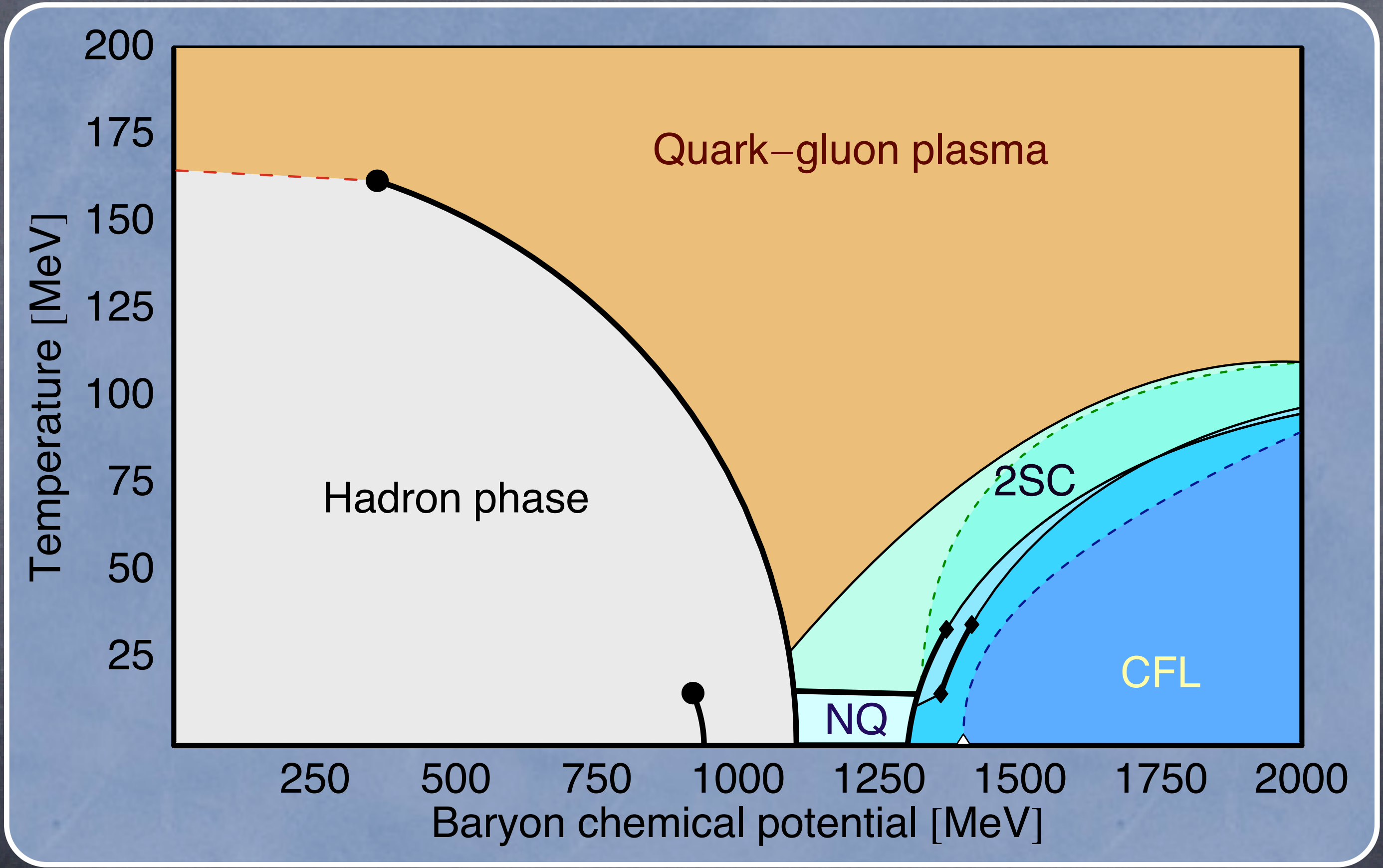
What to look for

- Neutral partners of $Z(4433) \sim X(1^{+-},2S)$ should be close by few MeV and decaying to $\psi(2S)\ \pi/\eta$ or $\eta_c(2S)\ \rho/\omega$
- What about $X(1^{+-},1S)$? Look for any charged state at ≈ 3880 MeV (decaying to $\psi\pi$ or $\eta_c\rho$)
- Similarly one expects $X(1^{++},2S)$ states. Look at $M \sim 4200-4300$: $X(1^{++},2S) \to D^{(*)}D^{(*)}$
- Baryon-anti-baryon thresholds at hand (4572 MeV for $2M_{\Lambda c}$ and 4379 MeV for $M_{\Lambda c}+M_{\Sigma c}$). $X(2^{++},2S)$ might be over bb-threshold.

The condensed matter physics of QCD

Alford, Rajagopal, Wilczek, '98-'00 and many others

Diquarks play a crucial role



Astrophysical applications (glitches in pulsars...!)

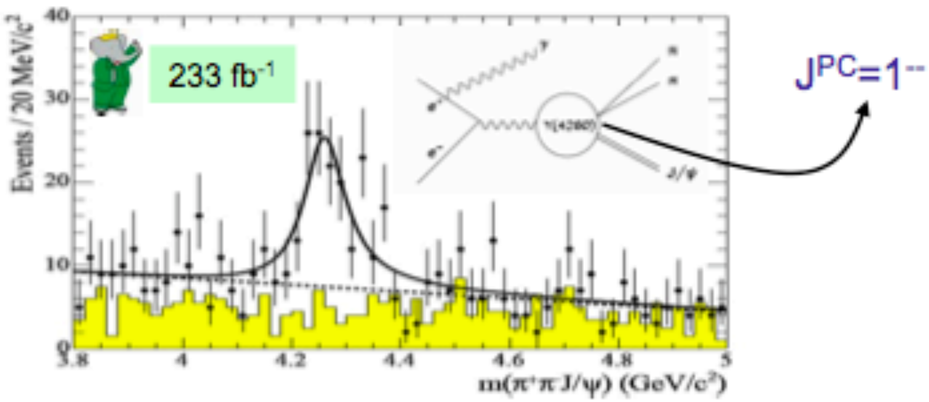
Conclusions

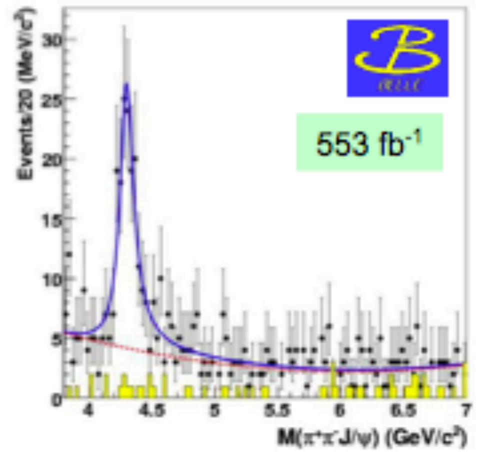
- The 4q-model gives the simplest interpretation of sub-GeV scalar mesons, of the 2-X's observed (prediction), and of the charged state (prediction).
- Still other particles have to be found to firmly assess this interpretation for the heavy-light states.
- If confirmed it has strong implications on various theoretical aspects of QCD.

some back up slides

Y(4260): ANOTHER MYSTERY

- New resonance discovered in $e^+e^- \rightarrow \gamma_{ISR}(J/\psi\pi^+\pi^-)$ by **BaBar**



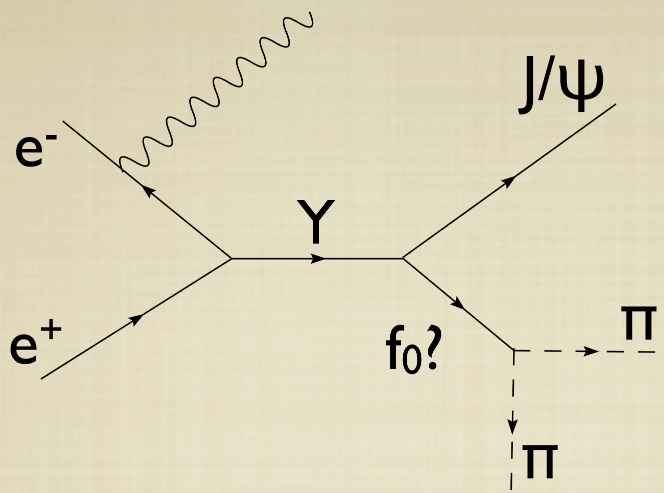


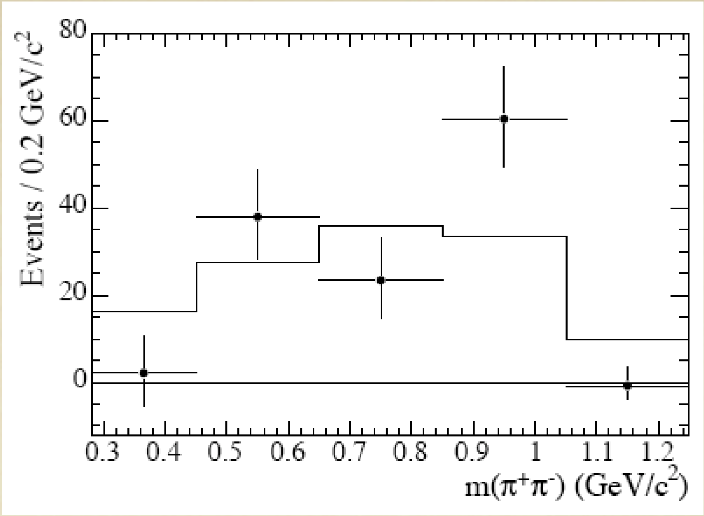
- BaBar measures: $M = (4259 \pm 8)$ MeV/c², $\Gamma = (88 \pm 23)$ MeV
- Belle measures: $M = (4295 \pm 10\ ^{+10}_{-3})$ MeV/c², $\Gamma = (133\ ^{+26}_{-22}\ ^{+13}_{-6})$ MeV
- Confirmed by CLEO: $M = (4283\ ^{+17}_{-16} \pm 4)$ MeV/c²

- No evidence for:
  - $e^+e^- \rightarrow \gamma_{ISR}(D\bar{D})$, $e^+e^- \rightarrow \gamma_{ISR}(\phi\pi^+\pi^-)$, $e^+e^- \rightarrow \gamma_{ISR}(p\bar{p})$, $e^+e^- \rightarrow \gamma_{ISR}(J/\psi\gamma\gamma)$

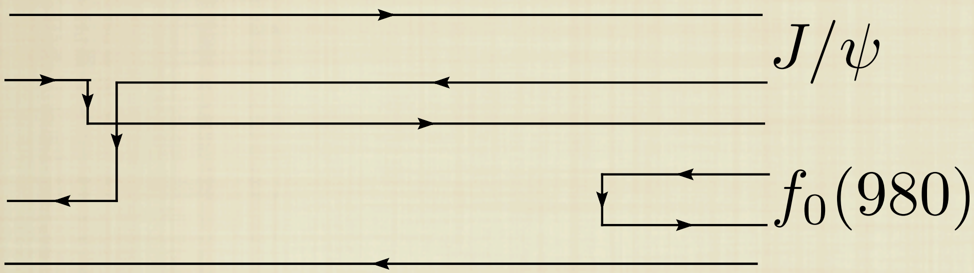
- 3σ enhancement in B decays
  - $B^- \rightarrow YK^-$, $Y \rightarrow J/\psi\pi^+\pi^-$
  - Needs **confirmation**

BaBar: Phys. Rev. Lett. 95 (2005) 142001
Belle: hep-ex/0612006
BaBar: hep-ex/0607083
BaBar: PRD 73, 011101 (2006)



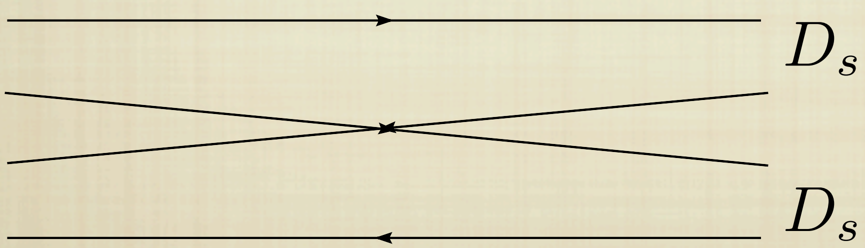


OUR INITIAL BIAS



Negative Parity 1^{--} ► one unit of ℓ

$f_0(980)(\text{as } [sq][\bar{s}\bar{q}]_{S-\text{wave}})$ ► $[sc][\bar{s}\bar{c}]_{P-\text{wave}}$



DIQUARK-ANTIDIQUARK IN A RISING CONFINING POTENTIAL IS EXPECTED TO HAVE A SERIES OF ORBITAL ANGULAR MOMENTUM EXCITATIONS.

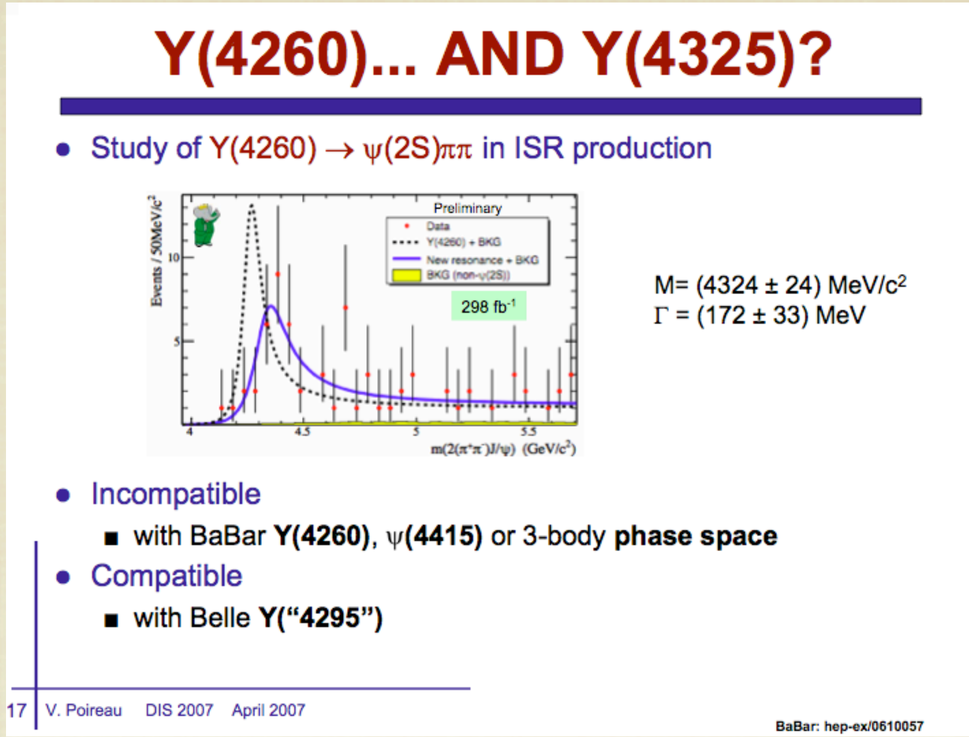
BOUND OBJECTS OF COLOR NEUTRAL STATES SHOULD HAVE A LIMITED SPECTRUM (POSSIBLY S-WAVE ONLY)

RESPONSIBLE OF GOOD PART OF THE WIDTH

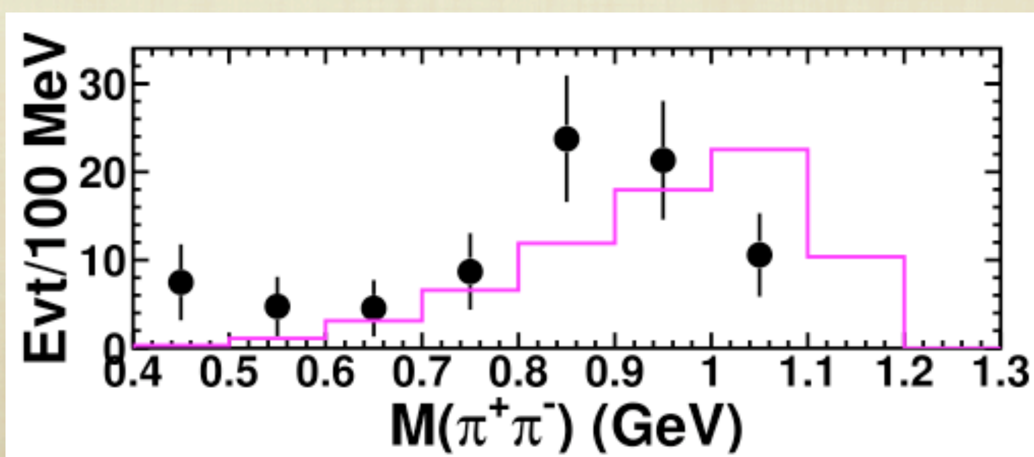
SATELLITES?

Call in Bad Diquarks :: $S = 2 \wedge L = 1$ possible

$S = 2 = 1 \oplus 1$ :: decay preferably to $D_s^* D_s^*$ ► reduction of decay width

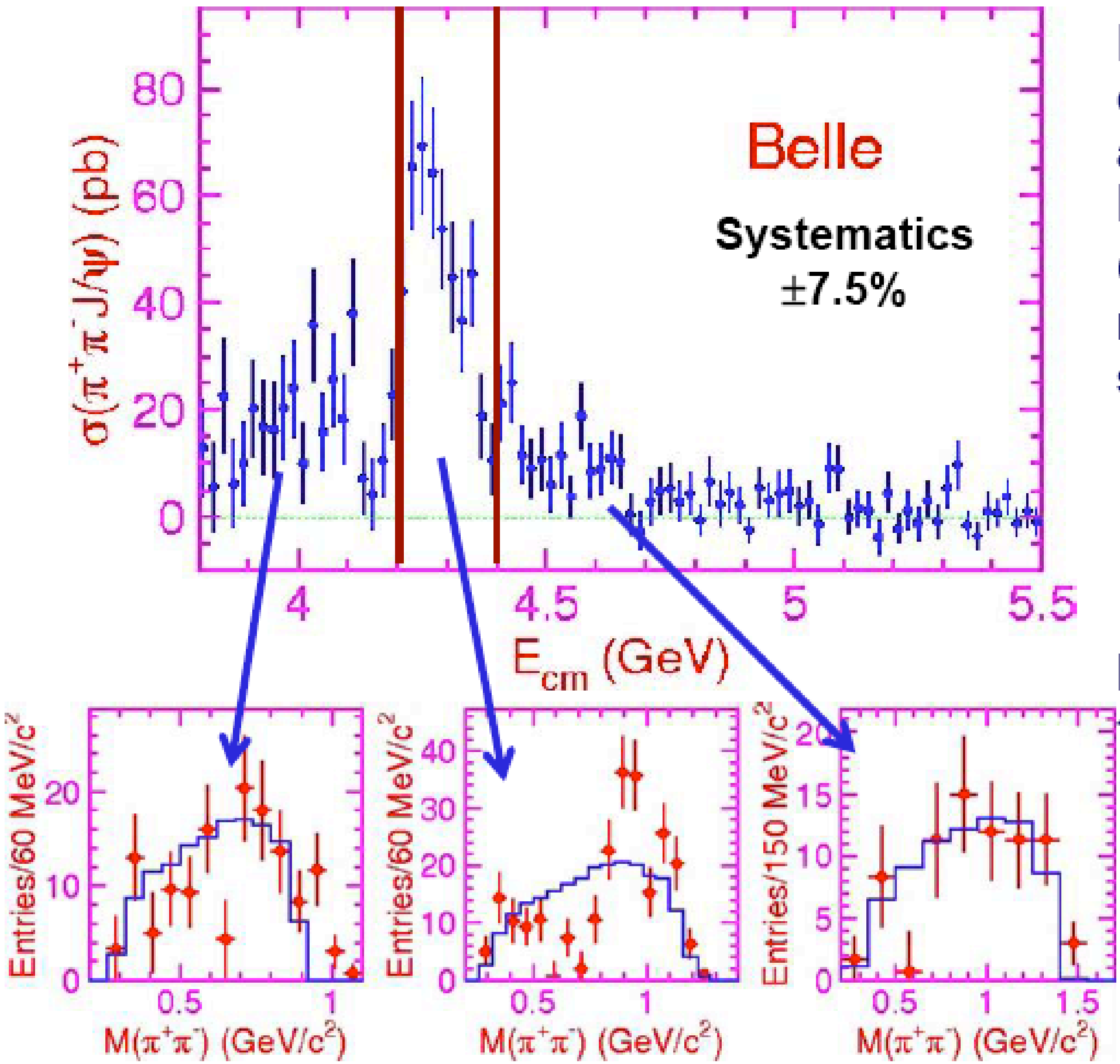


BUT CLEO FINDS NO f_0



Y(4260), discovered by BaBar in 2005, ISR, $J^{PC}=1^{--}$

$ee \to J/\psi\pi\pi$ cross-section



Bg subtracted $M(J/\psi\pi\pi)$ corrected for efficiency and differential luminosity

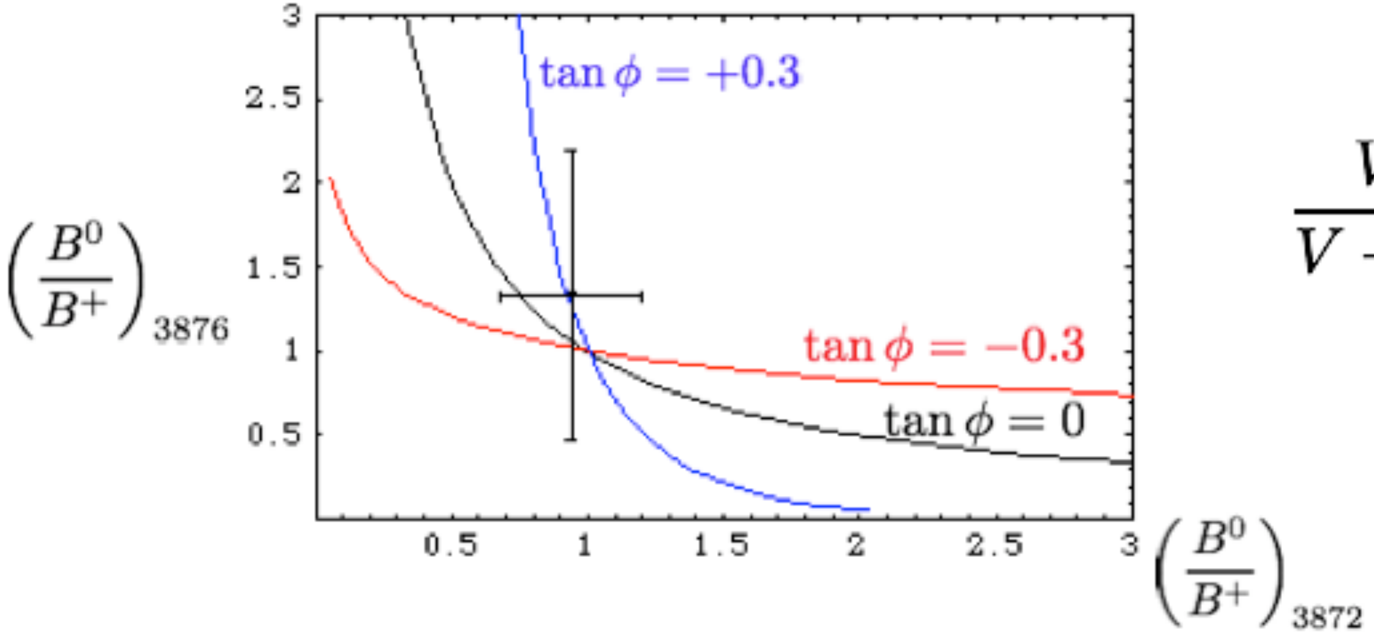
Cross-check: measurement of cross section at ψ' peak:

- $\Gamma_{ee}(\psi')=2.54\pm0.12\pm0.89$
- PDG'06: $\Gamma_{ee}(\psi')=2.43\pm0.05$

$M_{\pi\pi}$ spectra in different $\sqrt{s}$ regions:

- $\sqrt{s}$ 3.8 -4.2 & 4.4-4.6 GeV in agreement with 3-body phase space
- Y(4260) region
  $\sqrt{s}$ 3.8 -4.15 GeV: two clusters at low and high masses

We did not yet consider any mixing between Xu & Xd



$$\frac{V}{V+S} = 1.0 \pm 0.25$$

S very small, not much space to see X⁺ !!

$$\mathcal{A}(B^+ \to K^+ X_u) = V + S = \mathcal{A}(B^0 \to K^0 X_d)$$

$$\mathcal{A}(B^+ \to K^+ X_d) = V = \mathcal{A}(B^0 \to K^0 X_u)$$

$$\mathcal{A}(B^+ \to K^0 X^+) = S = \mathcal{A}(B^0 \to K^+ X^-)$$

DECAYS

>=3 for spin parity 1+

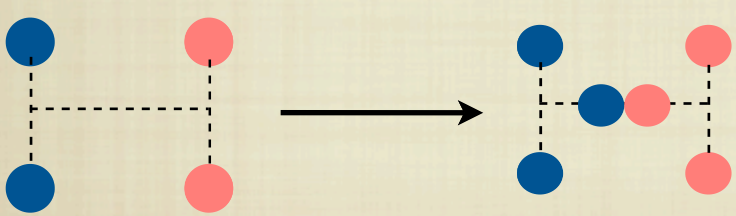
POSSIBLE DECAY MODES:

1 :: ANNIHILATION INTO GLUONS (> 2) GIVING A MULTIHADRON UNCHARMED FINAL STATE

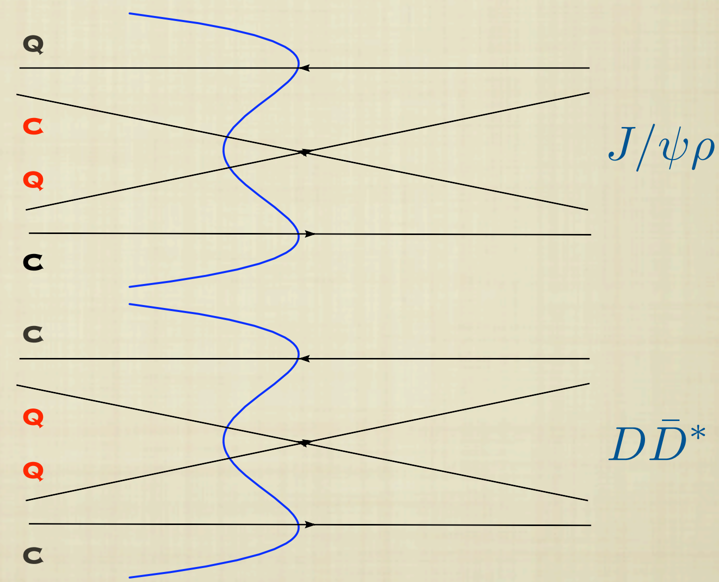
RATE EXPECTED TO BE SIMILAR TO: $\Gamma_{ann}(X) \simeq \Gamma(\chi_{c1}) = 0.96 \text{ MeV}$

2 :: ANNIHILATION $X \to gg + q\bar{q}$ BUT CCB ARE J=1 (VOLOSHIN), SO $\nrightarrow$ TO TWO GLUONS

3 :: QUARK REARRANGEMENT (VIA TUNNELING) GIVING OPEN CHARM OR ψ



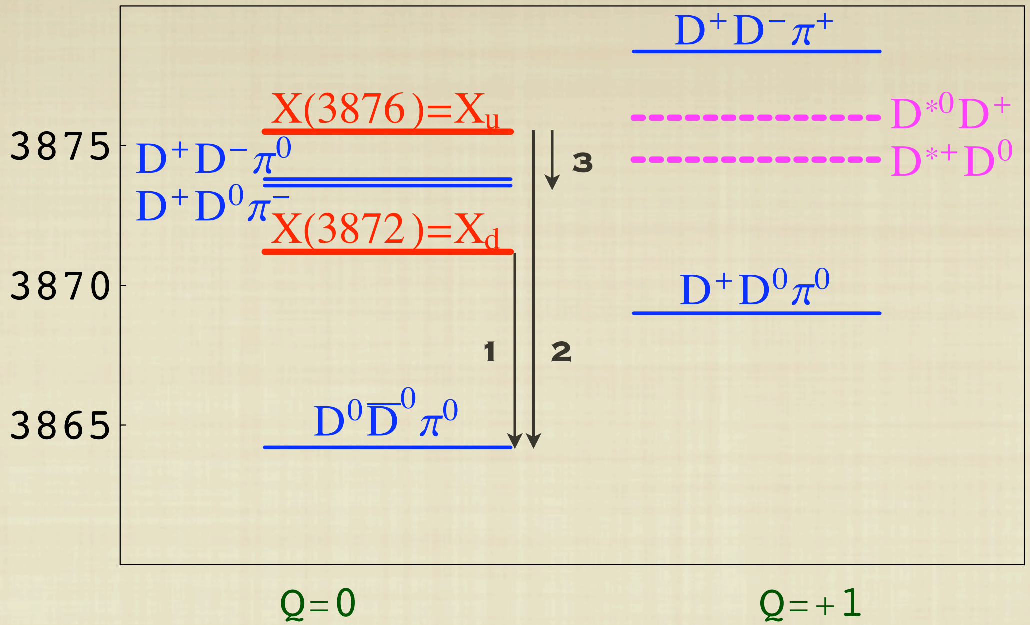
OR



(RED TWISTS)

1MeV sets the scale of the background of multihadronic decays

DECAYS



QUALITATIVELY WE EXPECT THAT :: (1) MUST BE SMALL (FLAVOR) :: (2) IS LARGER THAN (3)

ALTERNATIVE: TWIST C AND MAKE J/ψ

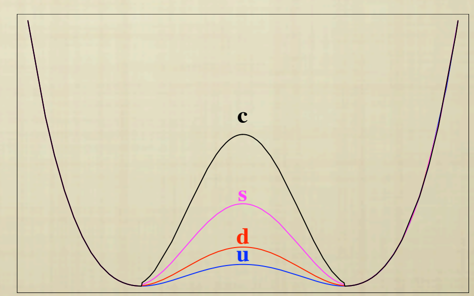
BY QUARK FLAVOR CONSERVATION X_D SHOULD DECAY IN D^+D^{*-} :: PHASE SPACE FORBIDDEN. D^oD^{*o} IS SUPPRESSED TWICE BECAUSE UU ↔ DD

& BECAUSE OF A SMALL `REDUCED RATE`

WE COULD TWIST HERE C AS WELL; BUT THE *CHEAPEST* ALTERNATIVE IS STILL DD*

$$\Gamma(X_u \to D^0\bar{D}^0\pi^0) >> \Gamma(X_u \to J/\psi\pi^+\pi^-) \simeq$$
$$\simeq \Gamma(X_d \to J/\psi\pi^+\pi^-) >> \Gamma(X_d \to D^0\bar{D}^0\pi^0)$$

A QUALITATIVE PICTURE OF THE BARRIERS



THE YET UNOBSERVED X+-

EXPERIMENTAL BOUNDS

$$\mathcal{B}(B^+ \to K^0 X^+)\mathcal{B}(X^+ \to J/\psi \pi^+ \pi^0) \leq 2.2 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K^+ X^-)\mathcal{B}(X^- \to J/\psi \pi^- \pi^0) \leq 0.54 \times 10^{-5}$$

USING PREVIOUS RESULTS WE GET

$$\frac{\mathcal{B}(X^- \to \psi\pi^-\pi^0)}{\mathcal{B}(X_d \to \psi\pi\pi)} \equiv \frac{\mathcal{B}(B^0 \to K^+X^-)\mathcal{B}(X^- \to \psi\pi^-\pi^0)}{\mathcal{B}(B^0 \to K^+X^-)\mathcal{B}(X_d \to \psi\pi\pi)} \leq$$
$$\leq \frac{0.54 \times 10^{-5}}{\mathcal{B}(B^0 \to K^+X^-)\mathcal{B}(X_d \to \psi\pi\pi)} \frac{\mathcal{B}(B^0 \to K^0X_d)}{\mathcal{B}(B^0 \to K^0X_d)} = \frac{0.54}{0.51} \frac{\mathcal{B}(B^0 \to K^0X_d)}{\mathcal{B}(B^0 \to K^+X^-)} \simeq$$
$$\simeq \left|\frac{V+S}{S}\right|^2 \times \frac{0.54}{0.51}$$

I.E., THE LIMIT

$$\mathcal{B}(X^+ \to J/\psi\pi^+\pi^0) \leq \Bigg(\underbrace{\left|\frac{V+S}{S}\right|}_{?}\Bigg)^2 \times \frac{0.54}{0.51} \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)$$

The constituent quark model

$$H = \sum_i m_i + \sum_{i<j} 2\kappa_{ij}(S_i \cdot S_j)$$

De Rujula-Georgi-Glashow

$$H([cq][\bar{c}\bar{q}']) = 2m_{[cq]} + 2\kappa_{cq}\,[S_c \cdot S_q + S_{\bar{c}} \cdot S_{\bar{q}'}] + \\ +2\kappa_{q\bar{q}}\,S_q \cdot S_{\bar{q}'} + 2\kappa_{c\bar{q}}\,[S_c \cdot S_{\bar{q}'} + S_{\bar{c}} \cdot S_q] + 2\kappa_{c\bar{c}}\,S_c \cdot S_{\bar{c}}$$

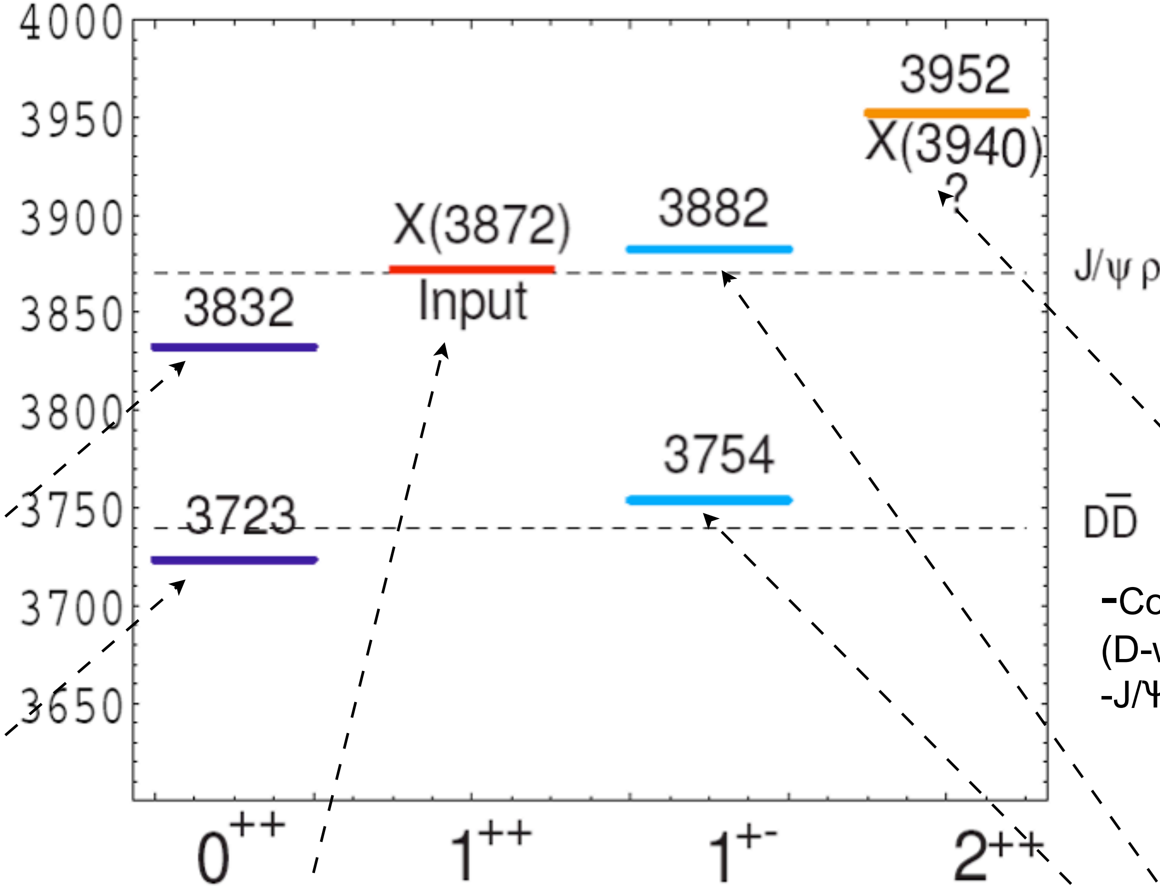
	q	s	c
constituent	305	490	1670
mass (MeV)	362	546	1721

	$q\bar{q}$	$s\bar{q}$	$s\bar{s}$	$c\bar{q}$	$c\bar{s}$	$c\bar{c}$
$(\kappa_{ij})_0$ (MeV)	315	195	121*	70	72	59
$(\kappa_{ij})_0 m_i m_j (\mathrm{GeV})^3$	0.029	0.029		0.036	0.059	0.16

	qq	sq	cq	cs
$(\kappa_{ij})_{\bar{3}}$ (MeV)	103	64	22	25
$(\kappa_{ij})_{\bar{3}} m_i m_j (\mathrm{GeV})^3$	0.014	0.013	0.014	0.024

From data on L=0 mesons and baryons we find relations for the constituent masses and for the couplings.

The X Mass Spectrum



DDbar

$\eta_c\eta$, $\eta_c\pi$, nH

Belle

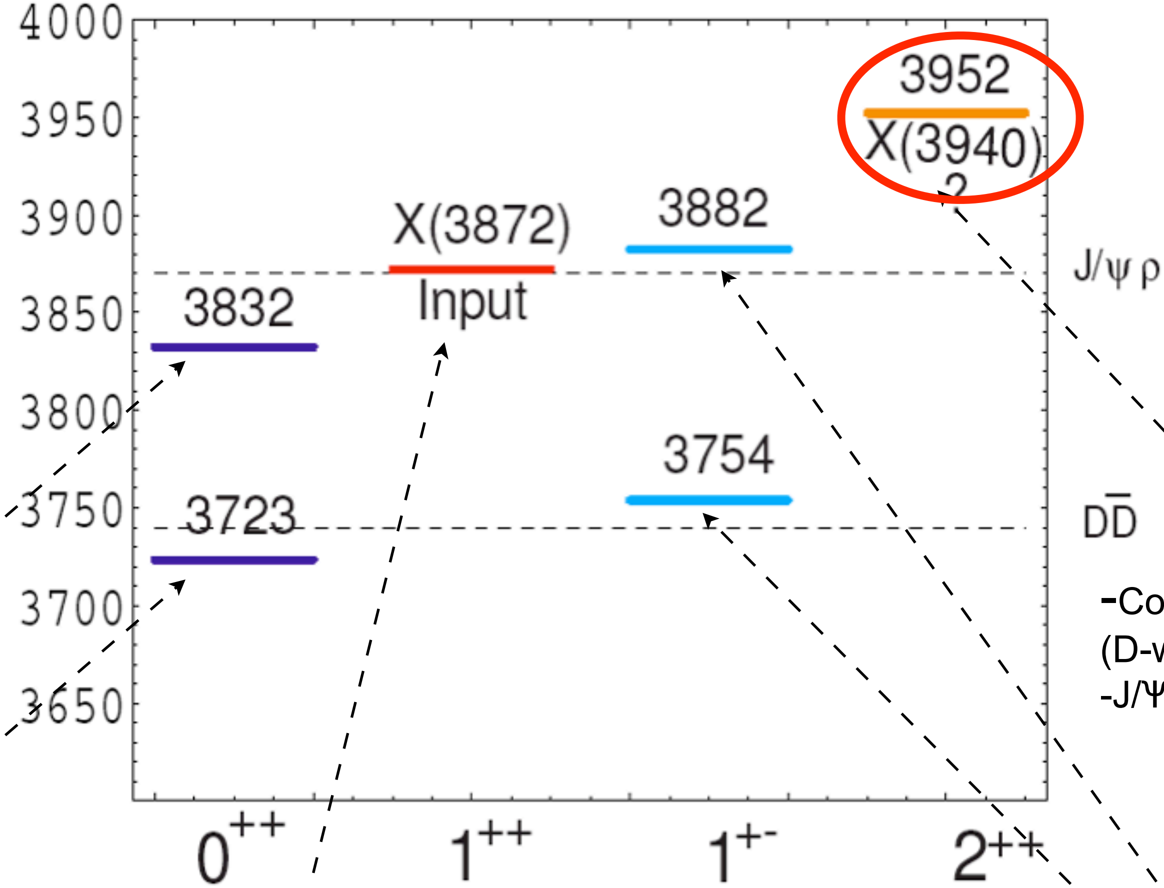
-Could decay DDbar
(D-wave; searched)
-J/Ψ ω seen by BELLE.

$$[cq]_{S=1}(\bar{c}\bar{q})_{S=0} + (cq)_{S=0}[\bar{c}\bar{q}]_{S=1}$$

-Unnatural spin-parity forbids decay in DDbar
Consistent with observed decays in J+ρ/ω.
-It decays both to ρ and ω due to isospin breaking in its wave function.

J/Ψ π(η),
η_c ρ(ω)

The X Mass Spectrum



DDbar

ηcη, ηcπ, nH

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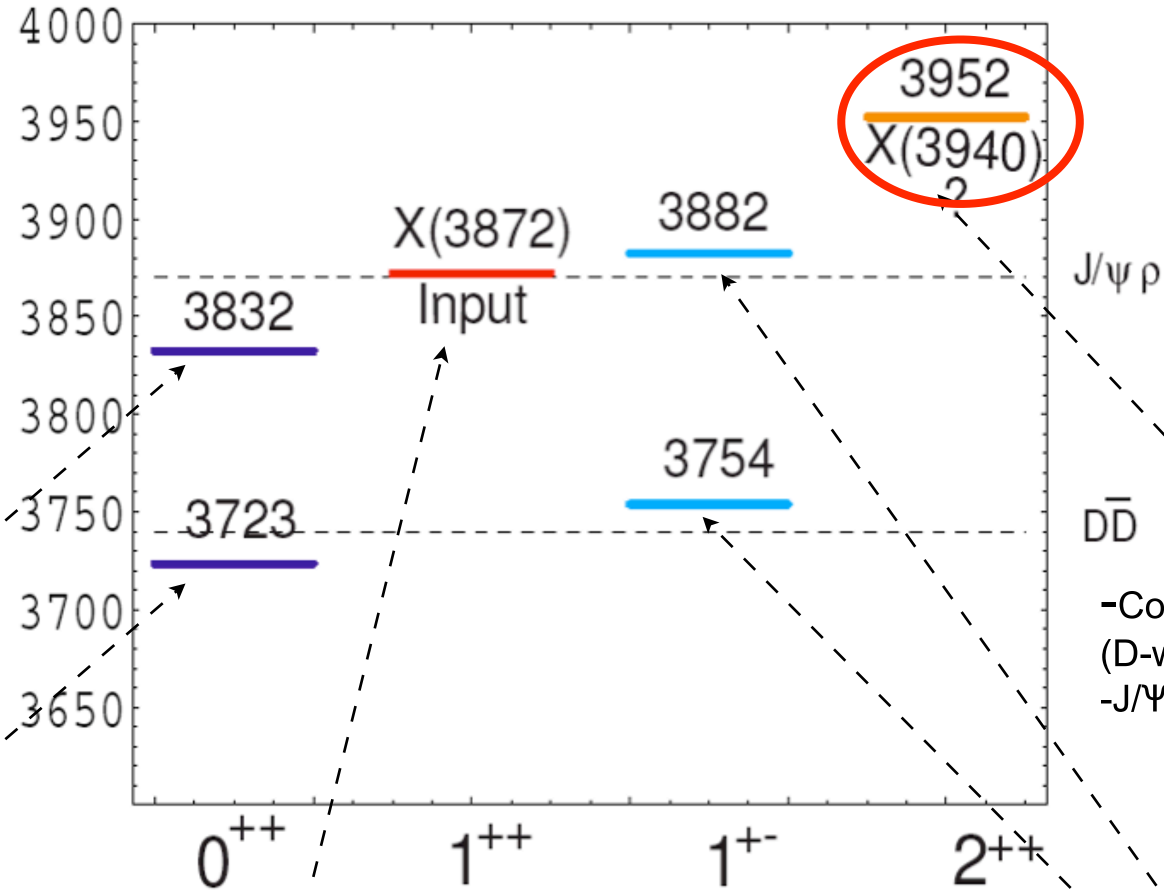
The X Mass Spectrum



DDbar

$\eta_c\eta$, $\eta_c\pi$, nH

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-Could decay DDbar (D-wave; searched)
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J/Ψ π(η), η_c ρ(ω)

$$[cq]_{S=1}(\bar{c}\bar{q})_{S=0} + (cq)_{S=0}[\bar{c}\bar{q}]_{S=1}$$

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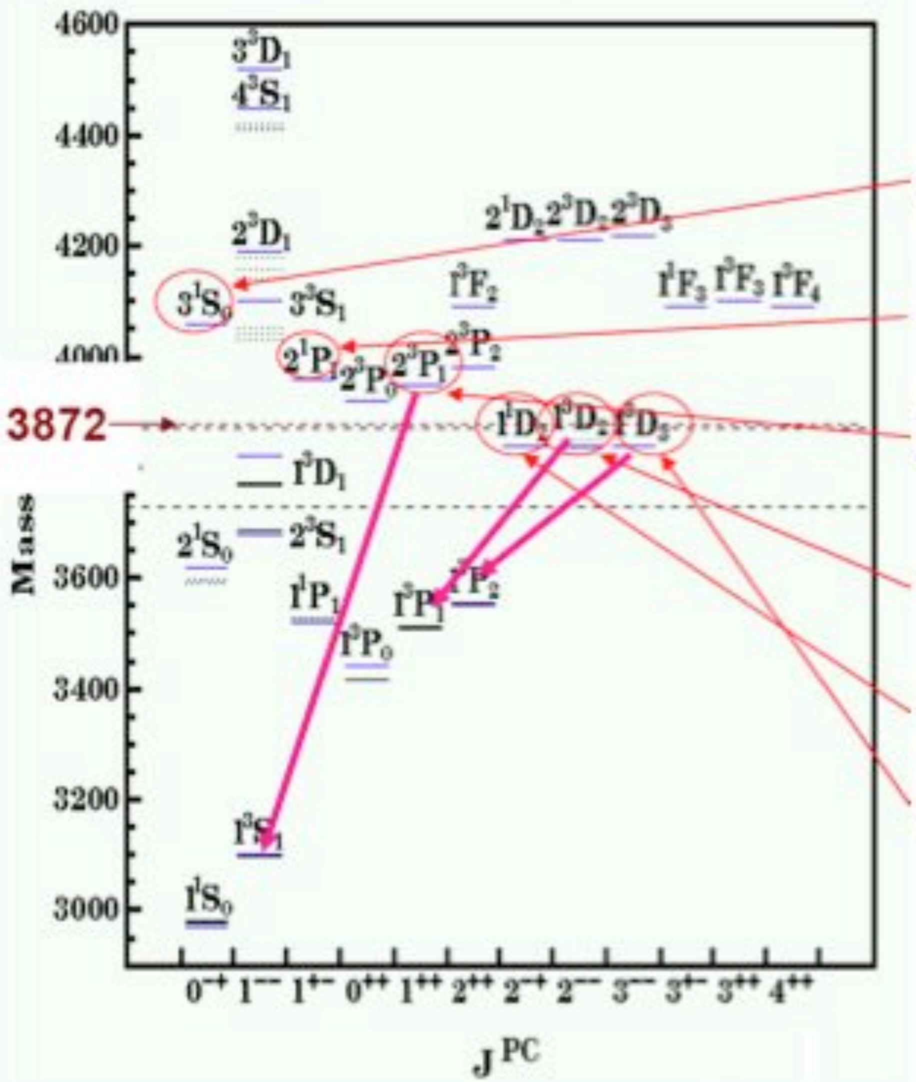
Consistent with observed decays in J+ρ/ω.
-It decays both to ρ and ω due to isospin breaking in its wave function.

$X(3872)$: charmonio?



- $\eta_c(3S)$: massa e larghezza troppo piccole
- $h_c(2P)$: distribuzioni angolari non compatibili con $J^{PC} = 1^{+-}$
- $\chi_{c1}(2P)$: $\mathcal{B}(X \to J/\psi\,\gamma)$ troppo piccolo
- ψ_2: $\mathcal{B}(X \to \chi_{c1}\,\gamma)$ troppo piccolo; $m(\pi^+\pi^-)$ non compatibile
- η_{c2}: dovrebbe dominare $X \to \eta_c\,\pi^+\,\pi^-$
- ψ_3: $\mathcal{B}(X \to \chi_{c2}\,\gamma)$ e $\mathcal{B}(X \to \bar{D}D)$ troppo piccoli

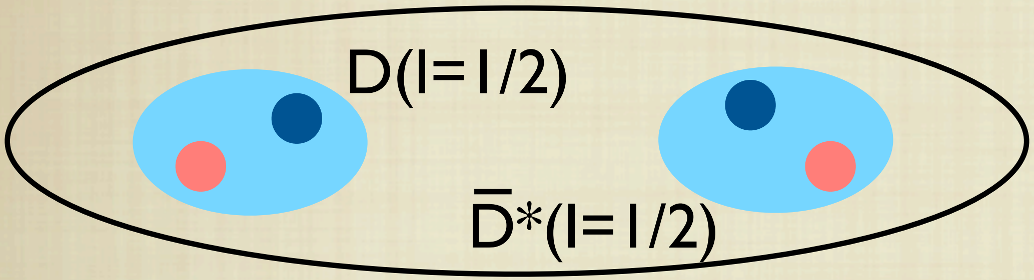
ISOSPIN VIOLATION AND TWO X'S

(MPPR \`05)

$$\frac{\mathcal{B}(X \to \pi^+\pi^-\pi^0 J/\psi)}{\mathcal{B}(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$$

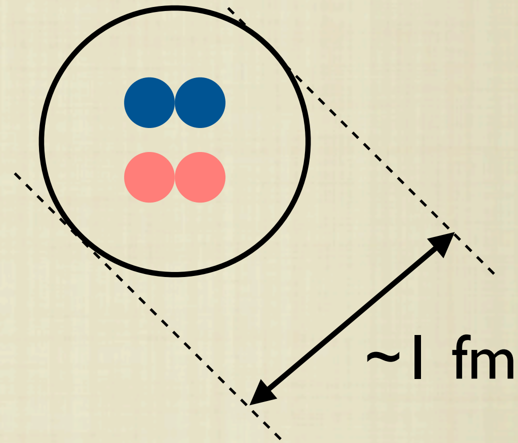
FROM EARLY OBSERVATIONS BY BELLE AND BABAR (\`03-\`04)

MOLECULES



NO PROBLEM WITH ISOSPIN VIOLATION :: 1 STATE :: SMALL DECAY RATE TO DDπ

4-QUARKS



NEED TWO STATES, AND MAKE ISOSPIN VIOLATION POSSIBLE

$$X_u = [cu][\bar{u}\bar{c}]$$
$$X_d = [cd][\bar{d}\bar{c}]$$

THESE TWO INTERPRETATIONS ARE NOT \`COMPLEMENTARY\` OR \`UNRESOLVABLE\`. THEY YIELD DIFFERENT PREDICTIONS.