Diquark-antidiquark Mesons : a new spectroscopy?

Report on work done with F. Piccinini, A. Polosa, V. Riquer

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Tetraquark Mesons

An idea which got momentum in the 70s (R. Jaffe, H. Lipkin...);

QCD encourages the speculation that such states are indeed possible;

As we shall see, the light scalar mesons a(980), f(980) really look like

$$[qq]_{col=\bar{3}}[\bar{q}\bar{q}]_{col=3}$$

In alternative: a(980), f(980) could be K-Kbar "molecules", bound by one-π exchange, i.e. in the configuration:

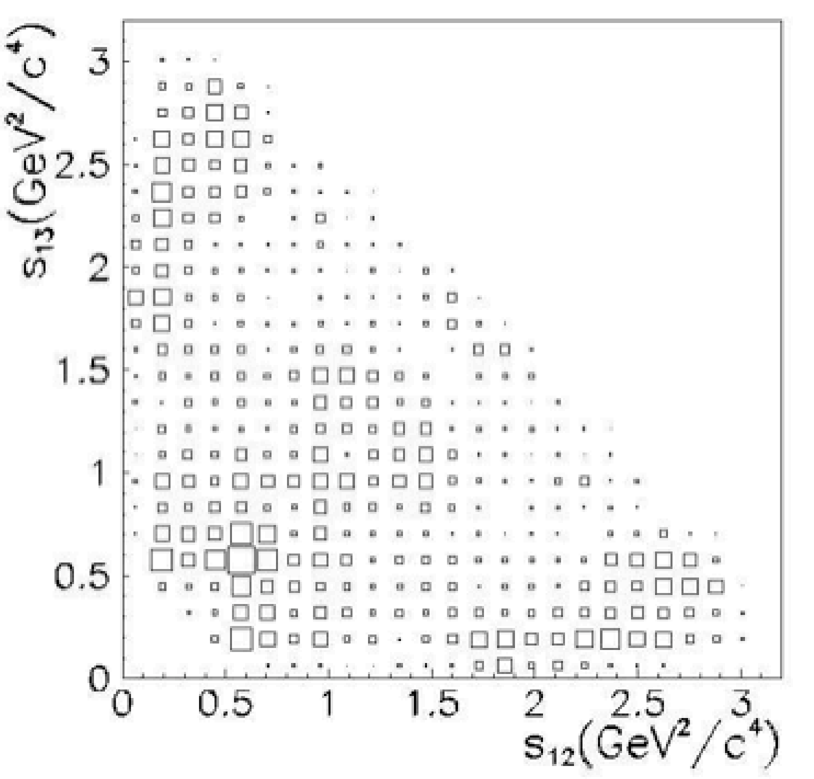
$$(q\bar{q})_{col=1}(q\bar{q})_{col=1}$$

The existence of lighter partners, σ and κ is crucial;

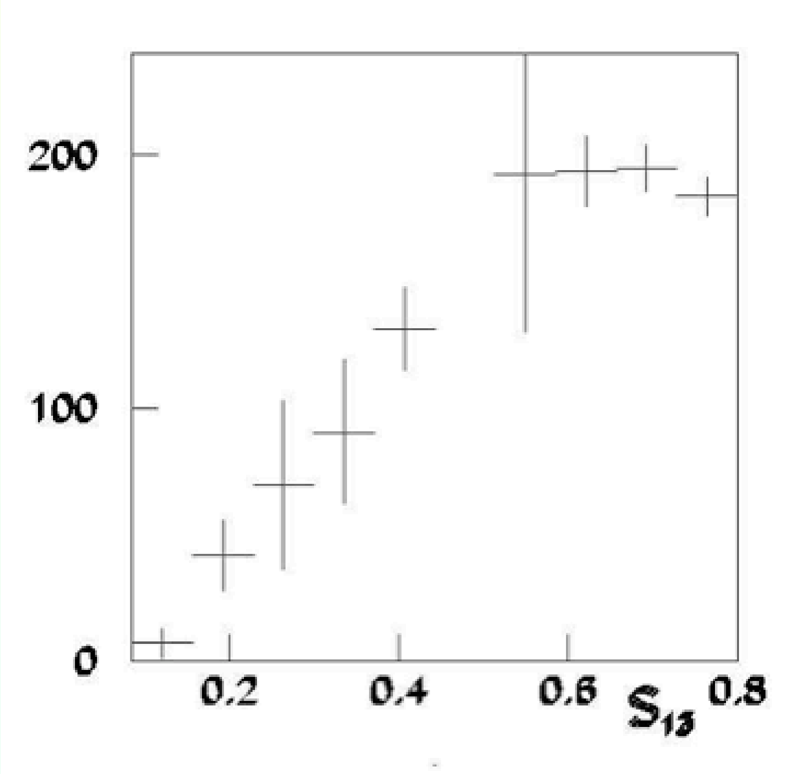
Recent expts, at FNAL(E791), Frascati (KLOE) and BES, have seen again σ and κ : this would be against "molecules";

…and there are states with hidden/open charm that do not look like charmonium states: X(3872), X(3940), (Belle, Babar in B decays), X(2632) (SELEX).

$\sigma(600)$ ad E791



PRL 86, 770 (2001)



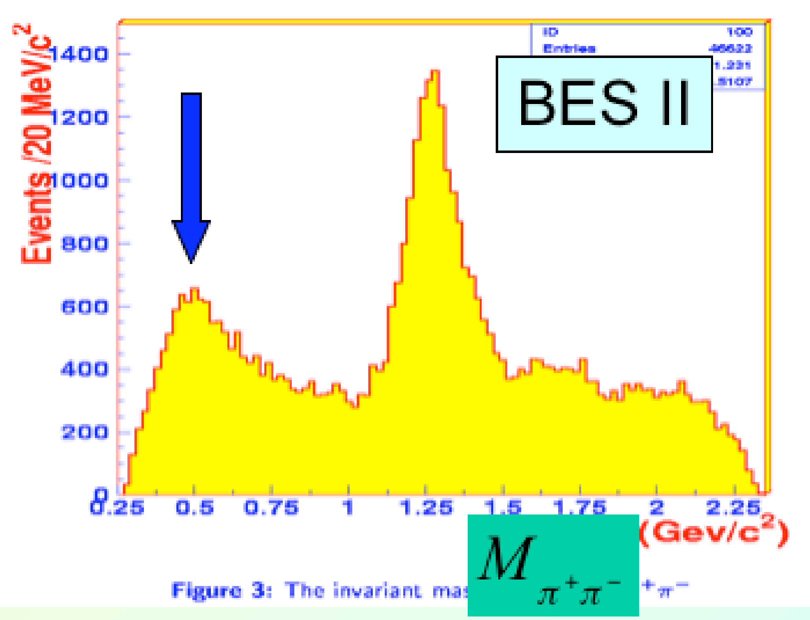
hep-ex/0307008 (2003)

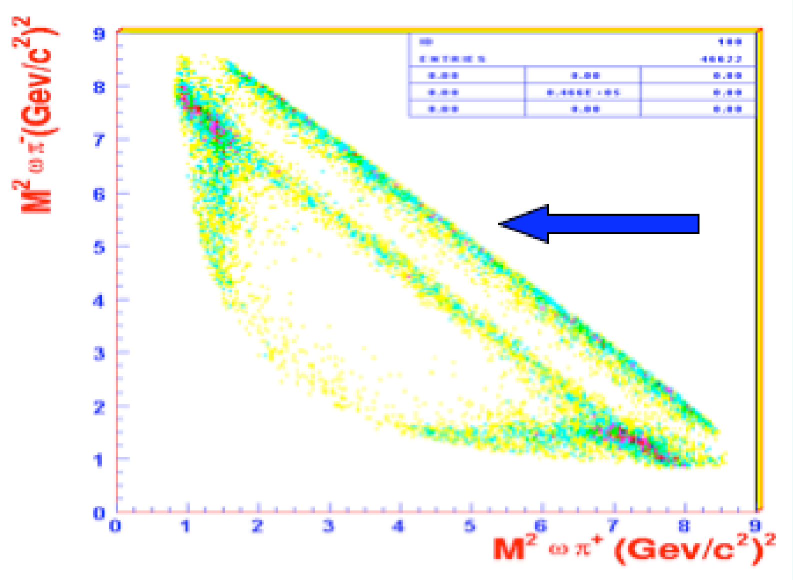
$M = 478 \pm 23 \pm 17$ MeV

$\Gamma = 324 \pm 40 \pm 21$ MeV

$\sigma(600)$ @ BES II

- **BES II: σ in $J/\psi \to \omega\pi^+\pi^-$.**



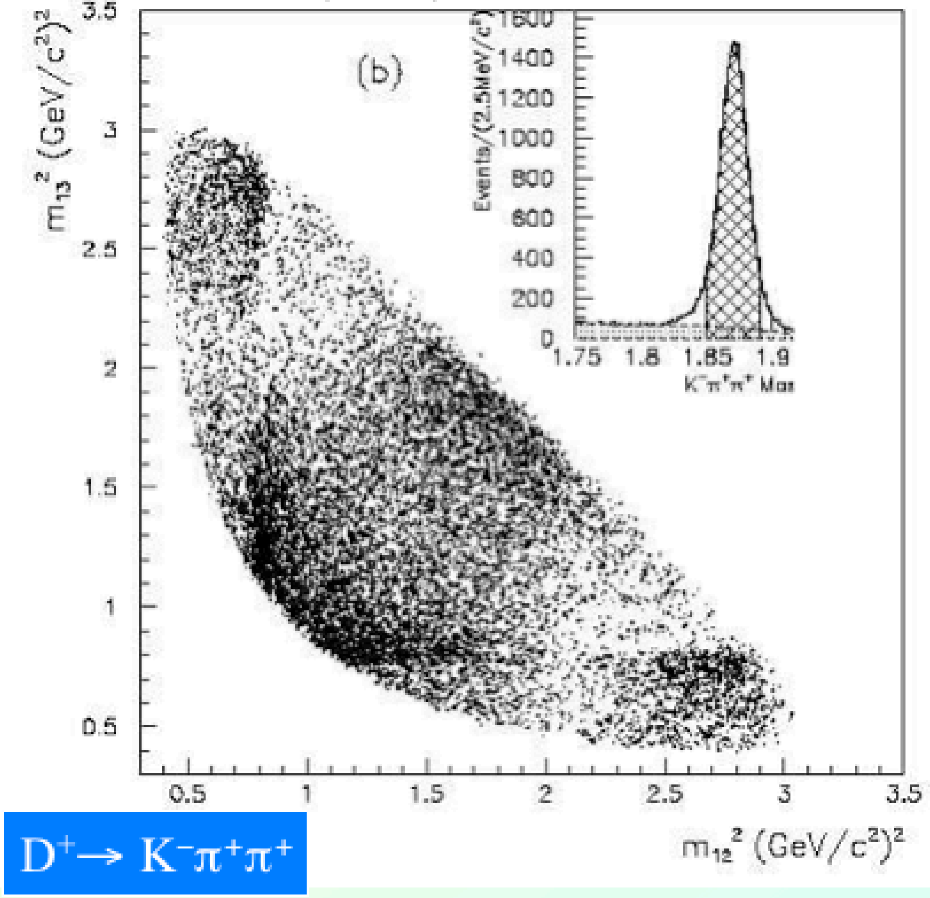


- **Partial wave analysis: pole position**

$$(541 \pm 39) - i(252 \pm 42) \quad MeV$$

κ(800) @ E791

PRL 89, 12801 (2002)



$D^+ \to K^-\pi^+\pi^+$

M = 797± 19± 43 MeV

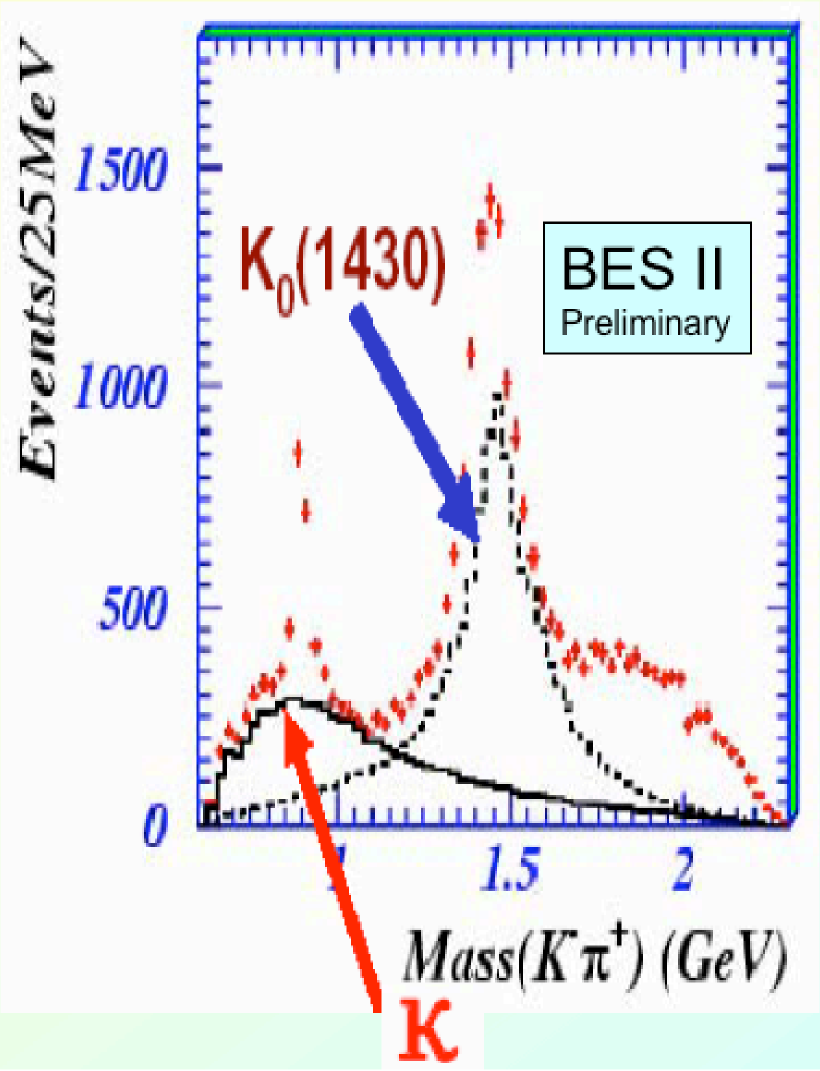
Γ = 410 ±43± 87 MeV

Non Res. Bkg. :90% (no k)→13% (k)

No k needed in Dalitz plot fit of $D^0 \to K^-\pi^+\pi^0$ e $D^0 \to K_S\, \pi^+\pi^-$ (CLEO)

No k needed in Dalitz plot fit of $D^0 \to K^0\, K^-\pi^+$ e $D^0 \to K\, K^+\pi^-$ (BABAR)

$\kappa(800)$ @ BES II



- BES II: **κ** in $J/\psi \to K^* K\pi \to K\pi K\pi$.

$$(760 \sim 840) - i(310 \sim 420) MeV$$

The present work (1)

Recent evidence for σ at low energy led us to reconsider the case of sub-GeV scalar mesons.
Many previous investigations (Joffe, Close&Tornqvist, Schecter and coll...).

We propose:

- ***all scalars below 1 GeV are diquark-antidiquark bound states (1 nonet),***
- ***the q-qbar scalar nonet (L=1, S=1, J=0) has to be above.***

Results:

- Low energy states show inverted mass spectrum, consistent with "perfect mixing";
- Strong decays are reasonably accounted for;
- Relations with ealier proposal by Rossi&Veneziano suggests connection to baryon-antibaryon, rather than meson-meson states (or molecule)

PRL **93**, 212002 (2004), hep-ph/0407017

The present work (2)

PR D70 054009 (2004), hep-ph/0407028;
hep-ph/0412098 (PR D71, 014028, 2005)

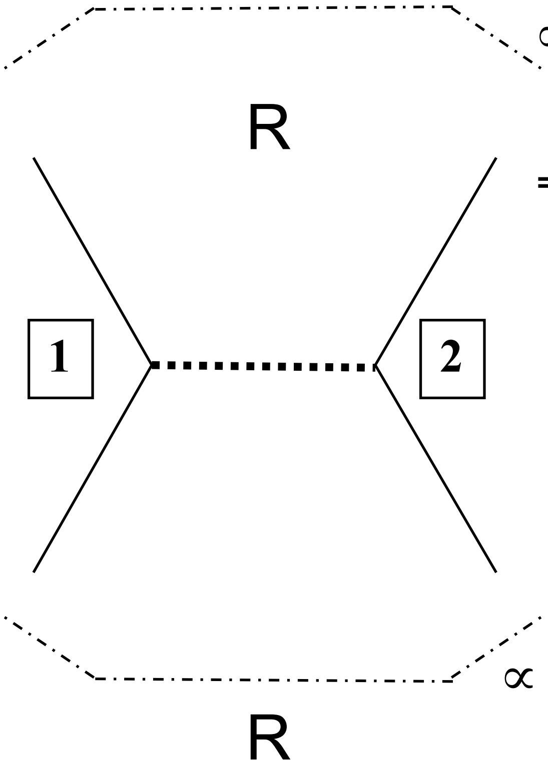
- Heavy quark interactions are spin independent: new spin states?
  - We propose that X(3872) observed by Belle and by Babar ***is a diquark-antidiquark bound state and estimate the spectrum of states of the spin multiplet with the same flavors:***
  - X(3872)=(J=1^{++})= $(cq)_{col=\bar{3},S=1}(\bar{c}\bar{q})_{col=3,S=1}$
  - with the same parameters, we can accommodate the X(2632) observed by SELEX:
  - X(2632)=(J=2^{++}) =$(cq)_{col=\bar{3},S=1}(\bar{s}\bar{q})_{col=3,S=1}$
- ***we predict X(3872) is made by two states with Δm = (5-8) MeV ≈ 2 (m_d - m_u)***
- ***if one state only in the decay: $B^+ \rightarrow K^+ X(3872)$, the other must appear in $B^0 \rightarrow K_S X(3872)$***
- ***a charged partners must exist:*** $X^+ = (cu)_{col=\bar{3},S=1}(\bar{s}\bar{d})_{col=3,S=1}$
- ***bounds to the production of X^+ are close but not in contradiction with BaBar.***

Summary

-
- Attractive and repulsive channels in QCD
- String structures: the “baryonium” model (Rossi & Veneziano, 1977)
- The light scalar mesons;
- Two-meson decays;
- Surprising charmonium states seen by Belle, Babar and Selex;
- S-wave Tetraquarks, the X(3872) and spectrum of related states;
- Selex particle, X(2632), and associated spectrum;
- Alignment to quark masses, isospin breaking;
- Conclusions

Attractive & repulsive channels in QCD

Interaction of two colored objects:



$$\propto g^2 <\vec{T}_1\cdot\vec{T}_2>_R = \frac{g^2}{2}[<(\vec{T}_1+\vec{T}_2)^2>_R - <\vec{T}^2>_1 - <\vec{T}^2>_2] =$$

$$= \frac{g^2}{2}[C^{(2)}(R)-C^{(2)}(1)-C^{(2)}(1)]$$

$$q\bar{q} = \begin{cases} \text{octet} = +1/3 & \text{repulsion} \\ \text{singlet} = -8/3 & \text{attraction} \end{cases}$$

$$qq = \begin{cases} \text{“3bar”} = -4/3 & \text{attraction} \\ \text{“6 “} = +2/3 & \text{repulsion} \end{cases}$$

Spin-spin interaction

$$\propto -g^2 <\sigma_1\vec{T}_1\cdot\sigma_2\vec{T}_2>_R \propto -g^2[C^{(2)}{}_{eff}(R)][J(J+1)-3/2]$$

$$<q\bar{q}>_1 \; and \; <qq>_{\bar{3}} = \begin{cases} \text{spin } 1 = +1/2 & \text{repulsion} \\ \text{spin } 0 = -3/2 & \text{attraction} \end{cases}$$

Baryons in the octet:

Λ=([ud]$_{J=0}$ s); Σ^0 =({ud}$_{J=1}$s)→ Λ is lighter than Σ

With antisymmetry in color and spin and a common spatial configuration, Fermi statist$\bar{\mathbf{3}}_{\mathbf{f}}$cs
$\Rightarrow$

Good diquarks: $[qq]_{\bar{\mathbf{3}}_{\mathbf{c}},\mathbf{1}_{\mathbf{s}},\bar{\mathbf{3}}_{\mathbf{f}}}$
Bad diquarks: $(qq)_{\bar{\mathbf{3}}_{\mathbf{c}},\mathbf{3}_{\mathbf{s}},\mathbf{6}_{\mathbf{f}}}$

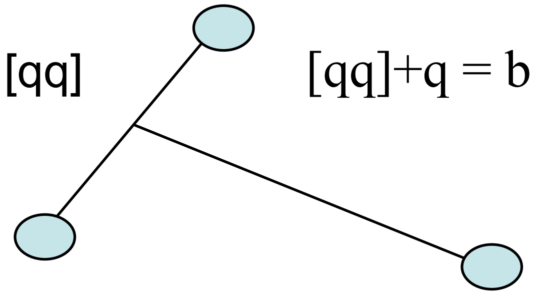
Since spin interaction is a relativistic effect we might expect stronger for the lightest quarks....

$$\text{Splitting}: \ (ud)-[ud] > (us)-[us] > \underline{(uc)-[uc] \approx 0}$$

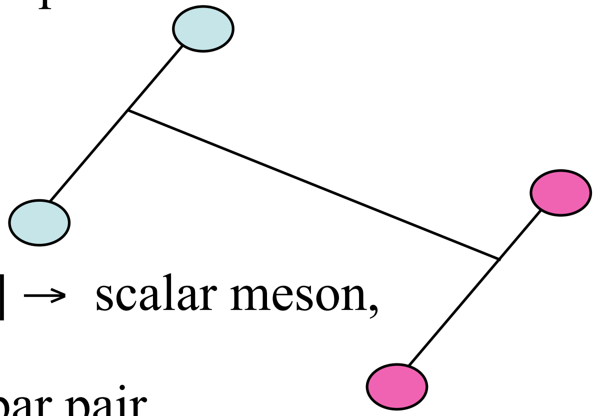
HQ Spin Symmetry

Diquark: [qq] in color = 3bar, spin=0, SU3 flavour = 3bar makes a simple unit to form color singlets (Jaffe..more recently Jaffe&Wilcezck, Karliner & Lipkin for penta-quark)

Diquark needs to combine with other colored objects

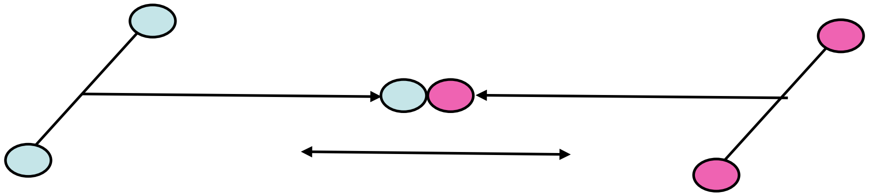


[qq]+q = baryon (e.g. Λ), Y-shape



[qq]+ [qbar qbar] → scalar meson,

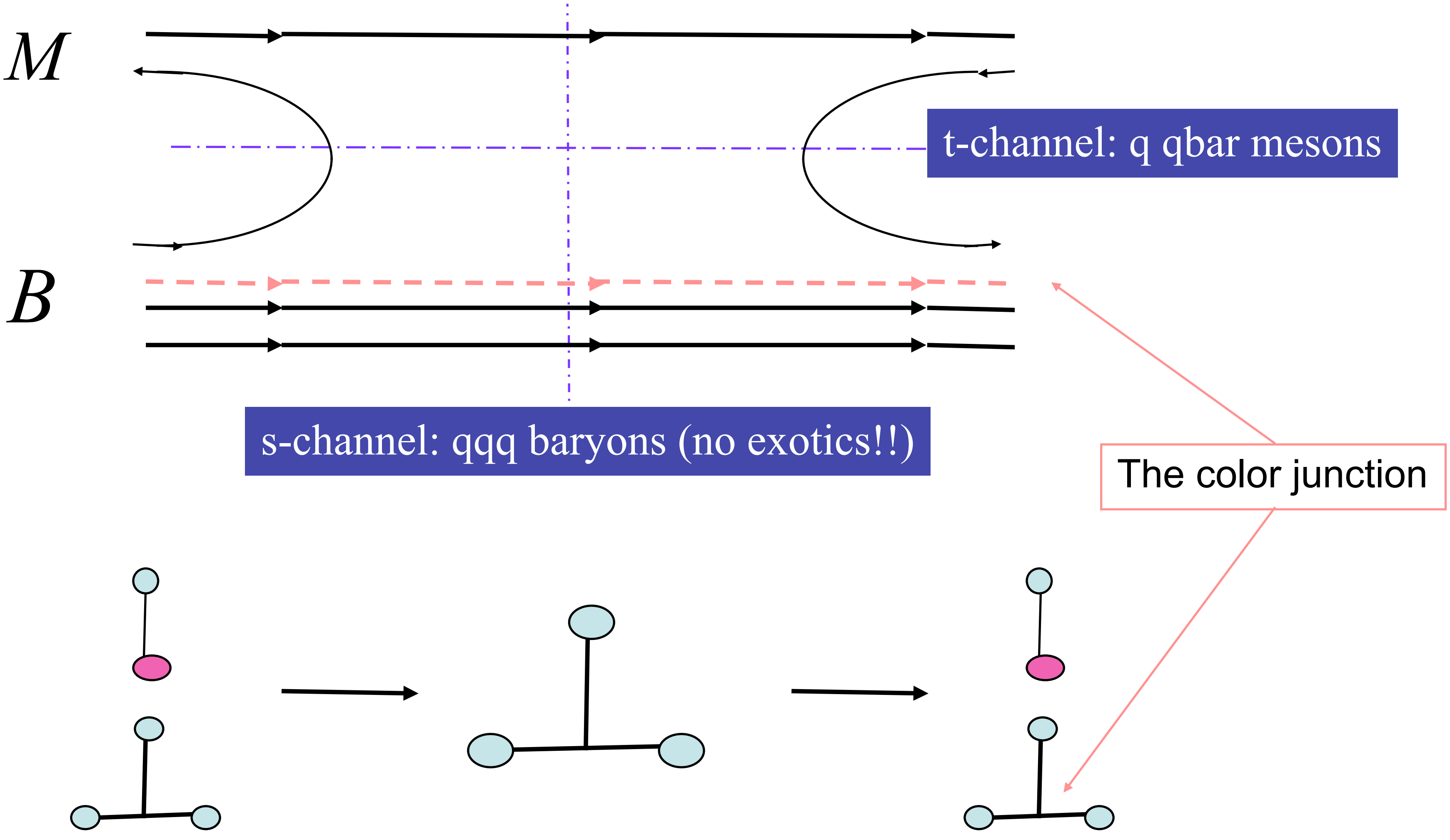
if you stretch the string, [qq][qbar qbar]→ B Bbar pair
a new topology, related to B-B bar.



meson-meson molecules are in different color configuration.
But: do “residual” forces bind?

Duality in Meson-Baryon scattering

G.C. Rossi and G. Veneziano, Nucl. Phys. **B123** (1977) 507

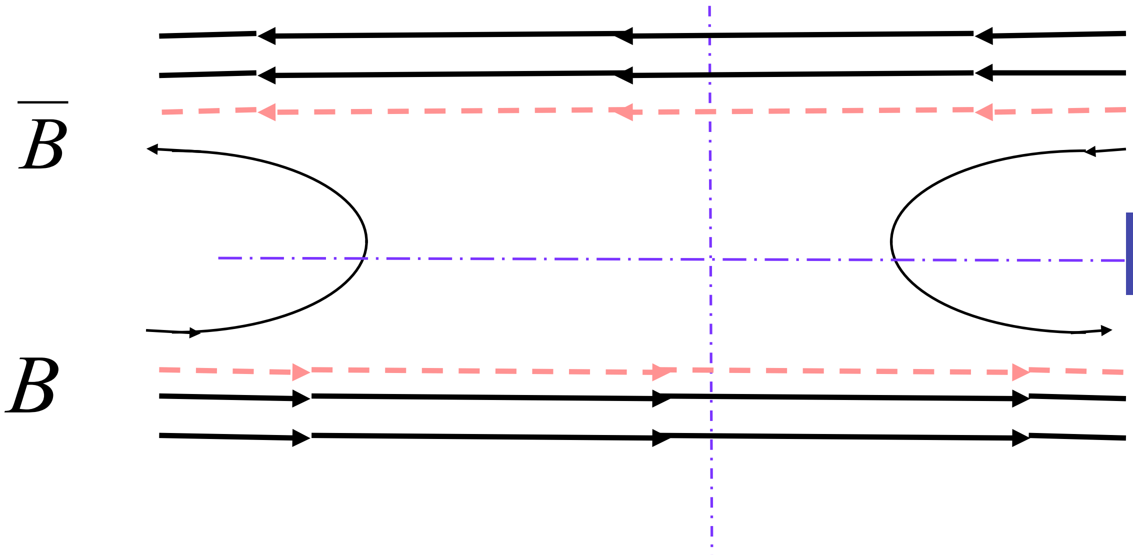


t-channel: q qbar mesons

s-channel: qqq baryons (no exotics!!)

The color junction

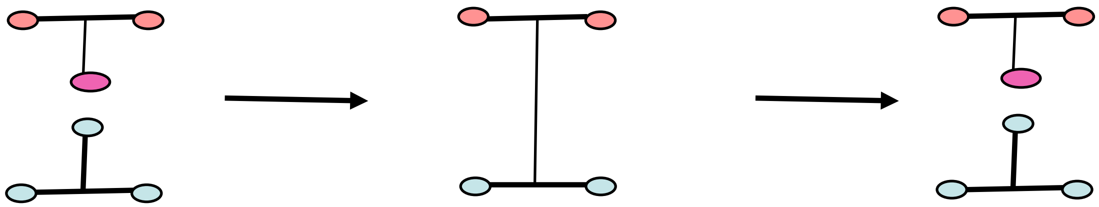
What about Baryon-Antibaryon scattering ?



t-channel: q qbar mesons

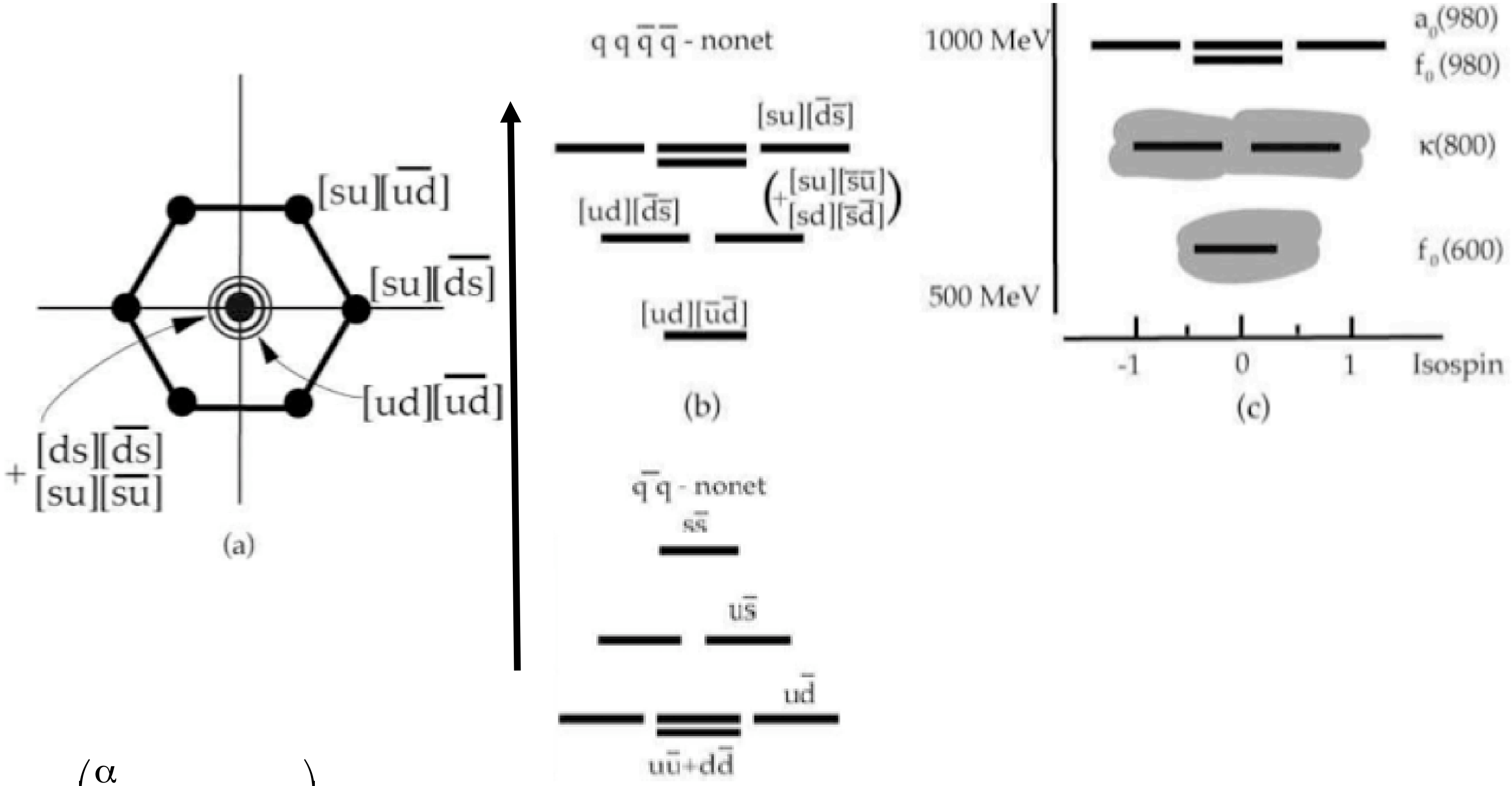
s-channel: [qq][qbar qbar] (Baryonium)

Color junctions



[qq][qbar qbar] mesons are dual to q qbar mesons in B-Bbar scattering. The relation to B-Bar persists in decays!!

Quantum numbers and mass formula



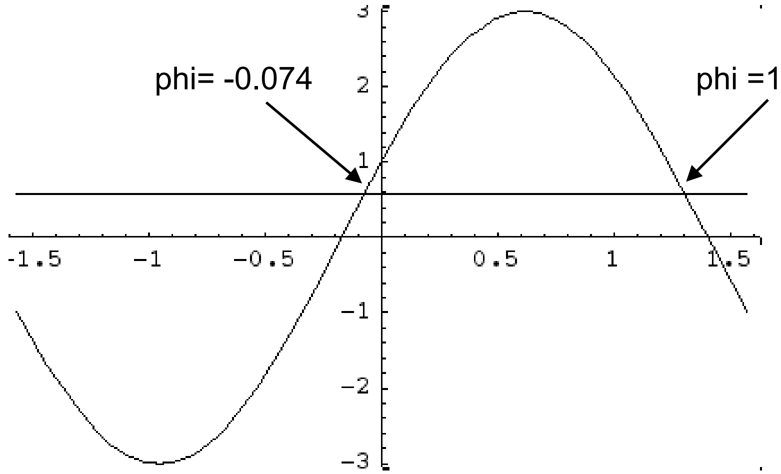
$$m = \begin{pmatrix} \alpha & & \\ & \alpha & \\ & & \beta \end{pmatrix} = \text{diquark masses}$$

4 parameters, 4 masses+1 mixing, one overall relation:

$$\boxed{\cos 2\phi + 2\sqrt{2}\sin 2\phi = 1 \ +4\frac{a+\sigma-2\kappa}{a-\sigma}}$$

$$f_\circ(I=0) \ = \ \frac{1}{\sqrt{2}}\left([su][\bar{s}\bar{u}] + [sd][\bar{s}\bar{d}]\right)$$
$$\sigma_\circ(I=0) \ = \ [ud][\bar{u}\bar{d}]$$

$$|f\rangle \ = \ \cos\phi|f_\circ\rangle + \sin\phi|\sigma_\circ\rangle$$
$$|\sigma\rangle \ = \ -\sin\phi|f_\circ\rangle + \cos\phi|\sigma_\circ\rangle.$$



-Two solutions (see also Schecter et al.):

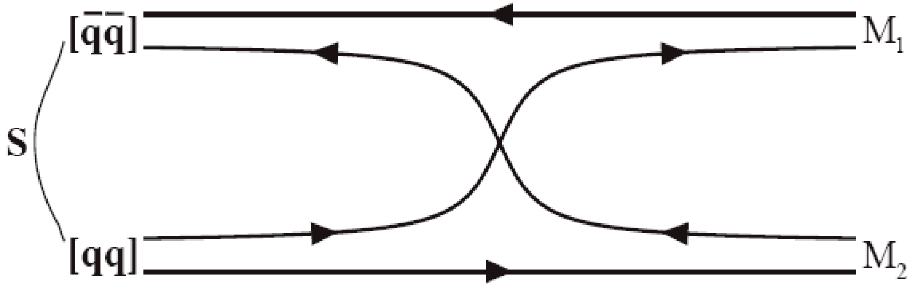
First: almost "ideal mixing"

Second: σ~u-ubar + d-dbar.

But: how to explain mass pattern in q-model? unfavoured by decays

- Linear mass formula gives very similar results
- With Linear m.f., parameters related to diquark masses: α=480 MeV, β = 250 MeV
- Note: α–β=230 MeV vs m_s=150 MeV.

Strong Decays



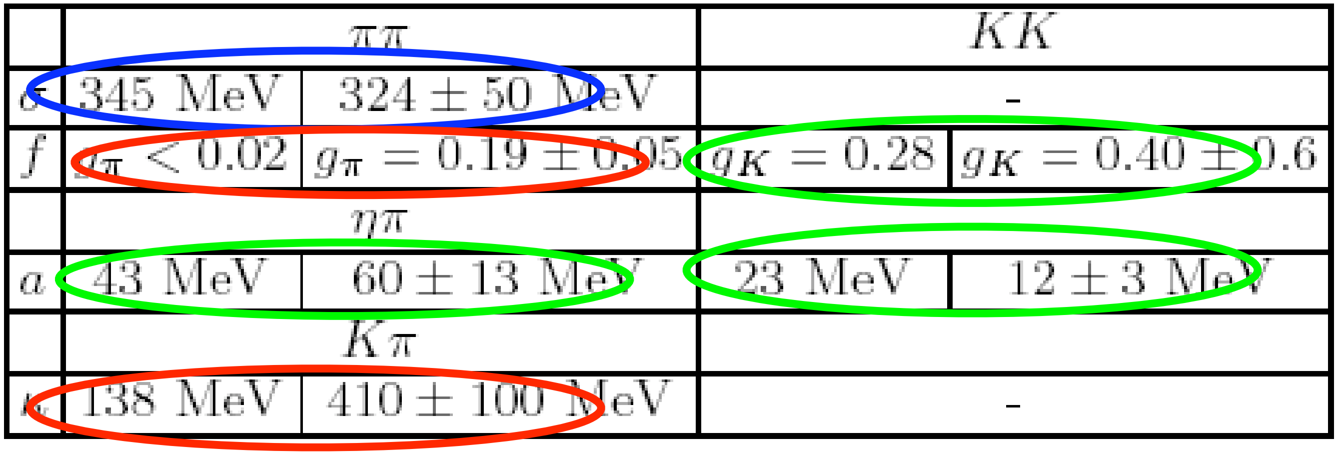
$$L_1 = A(S_i^j \varepsilon_{jlm} \varepsilon^{ikn})M_k^l M_n^m$$

No derivative coupling!

FIG. 1: The decay of a scalar meson S made up of a diquark-antidiquark pair in two mesons $M_1 M_2$ made up of standard $(q\bar{q})$ pairs.

$$\Gamma(S \to i) = \frac{A^2}{8\pi} \frac{p}{M_s^2} x_{s\to i}, \qquad (13)$$

where p is the decay momentum, M the mass of the scalar meson and $x_{s\to i}$ a factor which includes numerical coefficients in the individual amplitudes and isospin multiplicities.



	Theory	Experiment	Theory	Experiment
	$\pi\pi$		KK	
σ	345 MeV	324 ± 50 MeV	-	
f	$g_\pi < 0.02$	$g_\pi = 0.19 \pm 0.05$	$g_K = 0.28$	$g_K = 0.40 \pm 0.6$
	$\eta\pi$			
a	43 MeV	60 ± 13 MeV	23 MeV	12 ± 3 MeV
	$K\pi$			
κ	138 MeV	410 ± 100 MeV	-	

Input

Good

Bad

TABLE II: Fit with a single parameter $A = 2.6$ GeV. For g_π we have reported the upper limit to the decay rate obtained from the $f - \sigma$ mixing considered previously, see text.

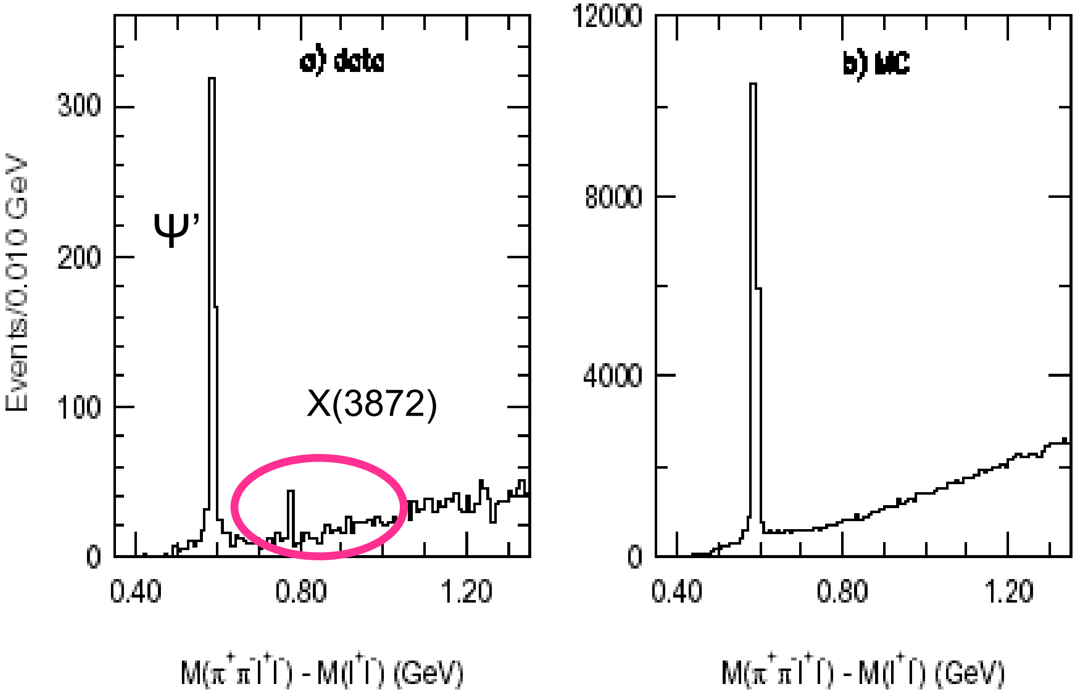
Maybe f ππ comes from “one-loop”: $f \to K\bar{K} \to \pi\pi$,

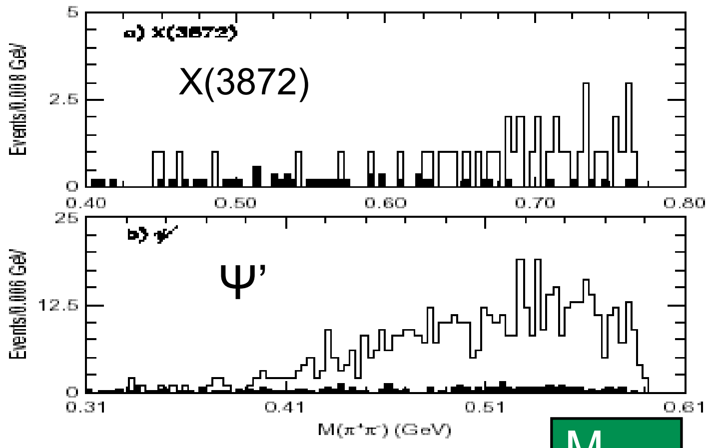
or perhaps (!!) $f \to B\bar{B} \to \pi\pi$ (Baryonium ?, see later)

All in all we get quite a consistent picture, reconciles the large σ width with narrow a and f widths and reinforces [qq][qbar qbar] assignement

Observation of a narrow charmonium-like state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays

BELLE Collaboration



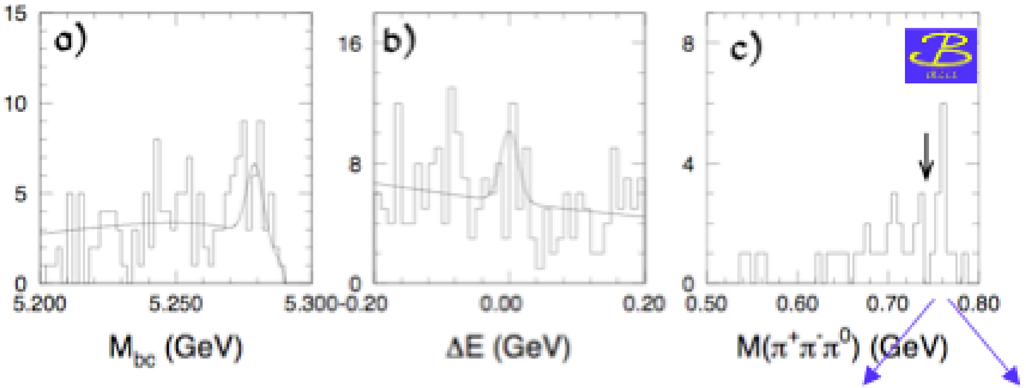


$M_{\pi\pi}$

No D-Dbar decay seen

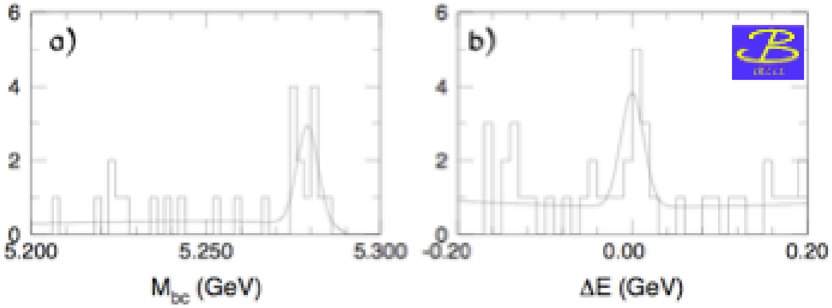
By the way…

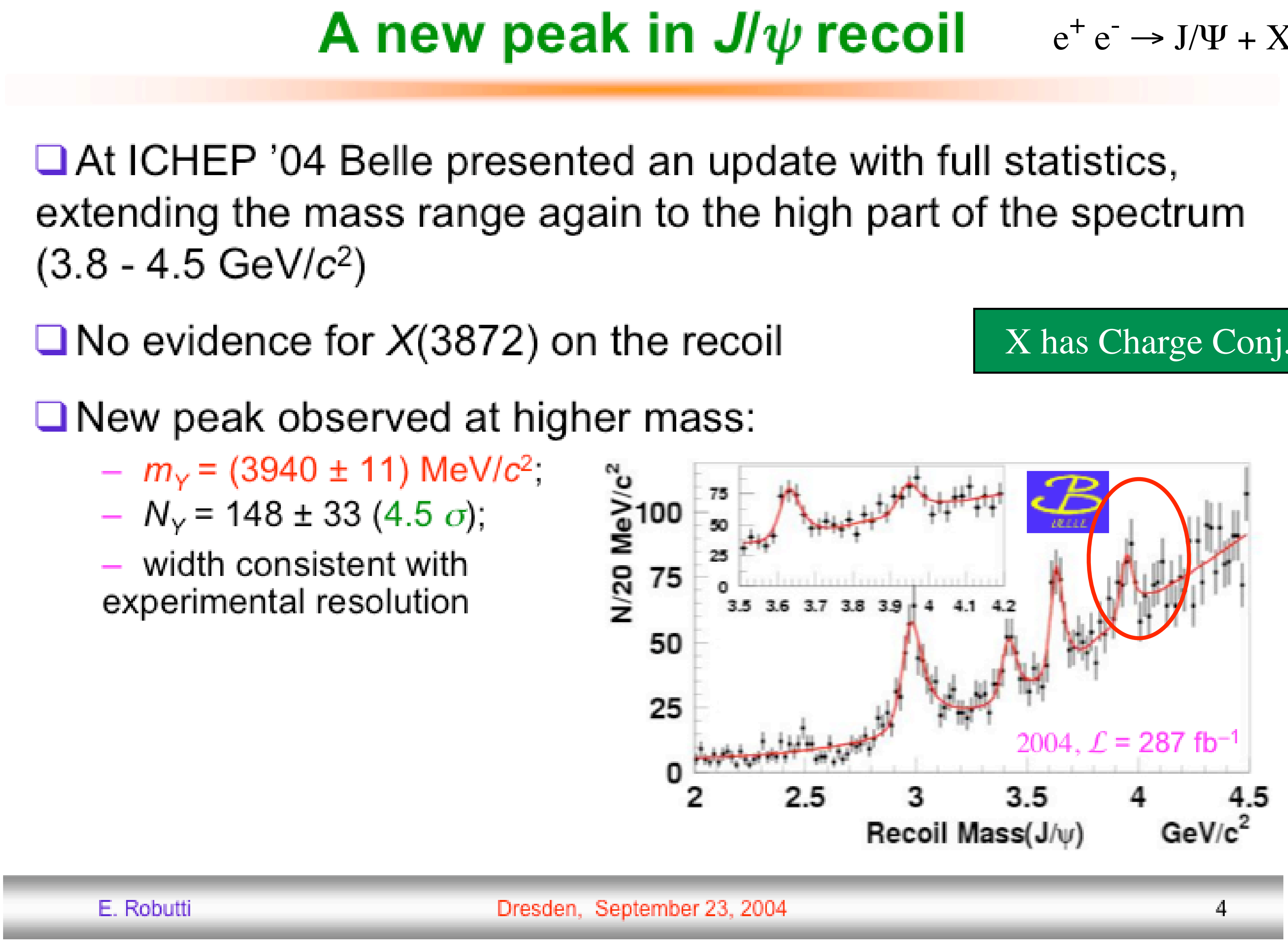
- Events selected within 2σ (12 MeV/c^2) of 3872 MeV/c^2 show hints of a *B* signal.
  - After cutting at $m(\pi^+\pi^-\pi^0) > 750$ MeV/c^2, a cleaner signal is present over a low background. Fit yields 10.0 ± 3.6 events (5.8 σ)



- Assuming all signal is ω (and *X*(3872)!):

$$\frac{\Gamma(X \to J/\psi\,\omega)}{\Gamma(X \to J/\psi\,\pi^+\pi^-)} = 0.8 \pm 0.3 \pm 0.1$$





A new peak in J/ψ recoil

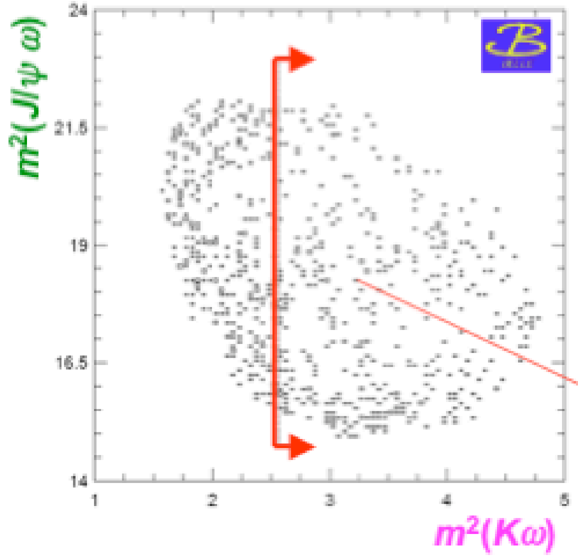
$e^+ e^- \to J/\Psi + X$

- ❑ At ICHEP '04 Belle presented an update with full statistics, extending the mass range again to the high part of the spectrum (3.8 - 4.5 GeV/c^2)
- ❑ No evidence for $X(3872)$ on the recoil

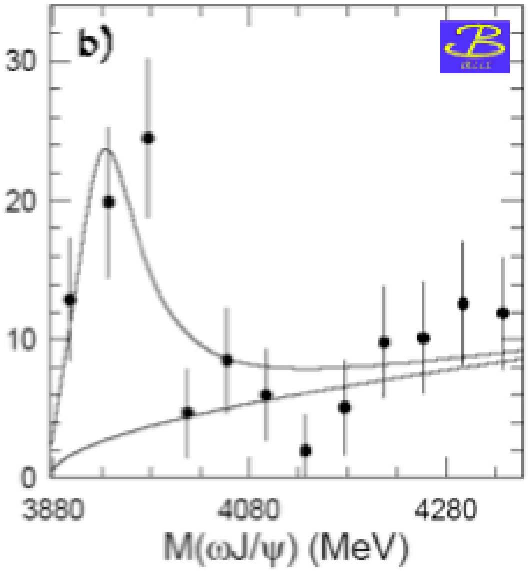
X has Charge Conj. =+

- ❑ New peak observed at higher mass:
  - $m_Y = (3940 \pm 11)$ MeV/c^2;
  - $N_Y = 148 \pm 33$ ($4.5\ \sigma$);
  - width consistent with experimental resolution

New status decaying to $J/\psi\ \omega$?



- Select events in $m(\pi^+\pi^-\pi^0) \sim m_\omega$ region
- Dalitz plot $m^2(J/\psi\ \omega)$ vs. $m^2(K\omega)$:
  - concentration at low $m^2(K\omega)$;
  - select events with $m^2(K\omega)$ to exclude B → $J/\psi\ K^{**}$



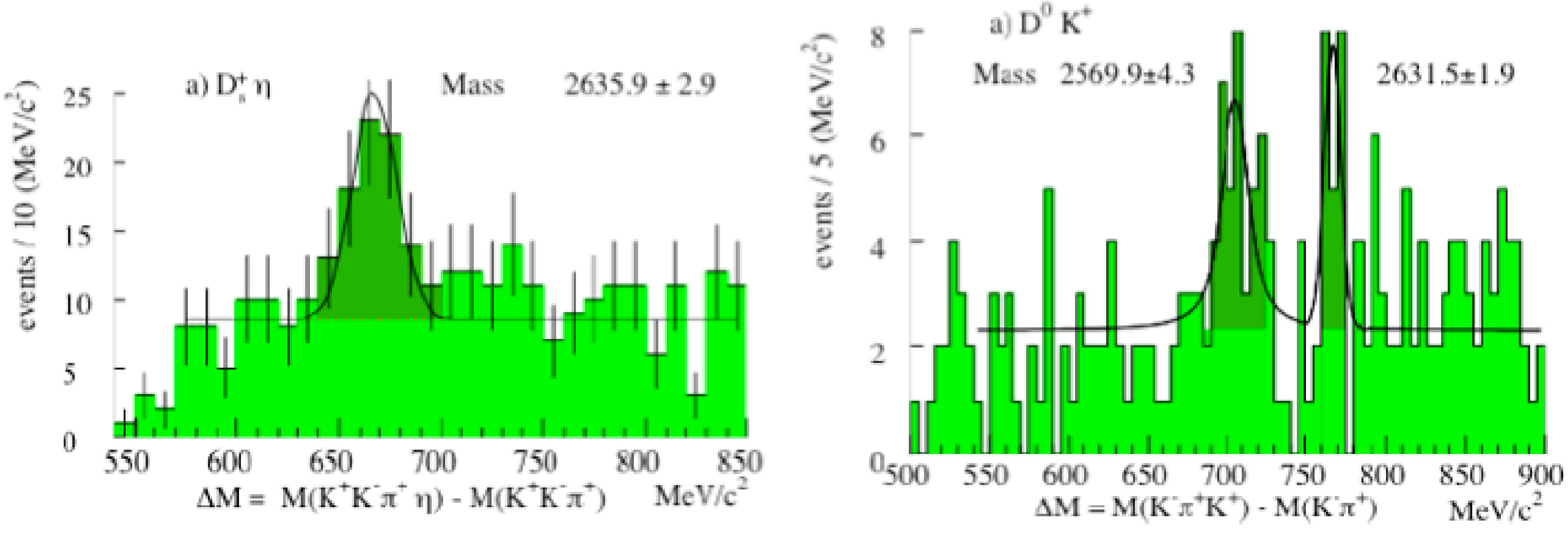
- Plot $m\ (J/\psi\ \omega)$ distribution after combinatorial bkg. subtraction:
  - enhancement just above threshold, not compatible with phase-space B → $J/\psi\ \omega\ K$;
  - Fit to S-wave B-W yields: $N_Y = 61 \pm 11$ ($>8\sigma$); $m_Y = (3491 \pm 11)$ MeV/c^2; $\Gamma_Y = (92 \pm 24)$ MeV

SELEX-Fermilab

hep-ex/0406045

'SELEX reports these peaks as the first observation of yet another high mass Ds state decaying strongly to a ground state charm plus a pseudoscalar meson. The mechanism which keeps this state narrow is unclear[...] The Dsη decay rate dominates the D0K+ by a factor of ~6 despite having half the phase space.'

Dsj(2632) (?)



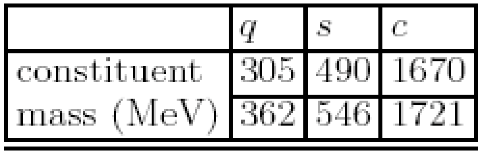
Tetraquarks with open and hidden charm
(Phys.Rev. **D70**, 054009 (2004); hep-ph/0412098)

- The spin-spin interaction between heavy quarks is O(1/M)
  - If S=0 diquarks are bound, S=1 diquarks do
  - All states in the composition $(S=0 \oplus S=1)\otimes(S=0 \oplus S=1)$ must exist
  - not natural spin-parity only!
  - a large multiplet with composition:

    $2\ (J^{PC}=0^{++})+(J=1^{++})+2\ (J=1^{+-})+(J=2^{++})$.
- Mass spectrum determined by:
  - constituent diquark massess
  - spin-spin interactions
  - the latter: from meson and baryon spectrum or from one gluon exchange

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

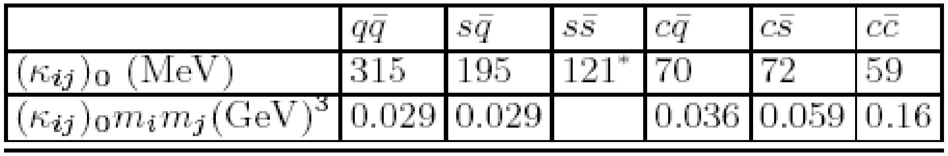
Spin-spin interactions: what do we know?



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

TABLE I: Constituent quark masses derived from the $L = 0$ mesons (first row) or from the $L = 0$ baryons (second row).

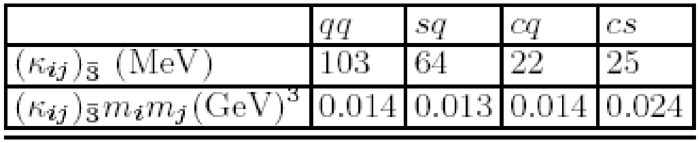
q-qbar Mesons



	$q\bar{q}$	$s\bar{q}$	$s\bar{s}$	$c\bar{q}$	$c\bar{s}$	$c\bar{c}$
$(\kappa_{ij})_0$ (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

TABLE II: Spin-spin couplings for quark-antiquark pairs in color singlet from the hyperfine splittings of $L = 0$ mes (first row). The values in the second row show the app imate scaling of the couplings with inverse masses (ma from meson spectrum). *The $s\bar{s}$ coupling which is not ex imentally accessible, is obtained by rescaling the $s\bar{q}$ one the factor m_q/m_s.

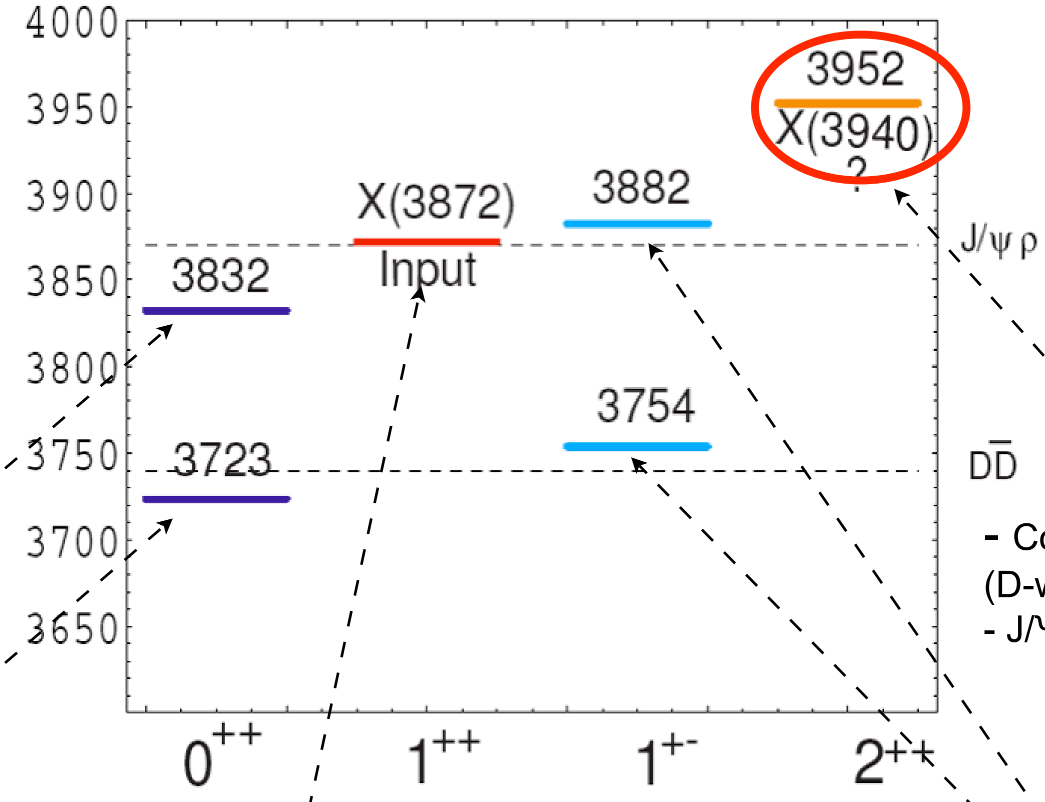
diquarks in Baryons



	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

TABLE III: Spin-spin couplings for quark-quark pairs in color $\bar{3}$ state from $L = 0$ baryons. One gluon exchange implies $(\kappa_{ij})_{\bar{3}} = 1/2(\kappa_{ij})_0$. The values in the second row, show the approximate scaling of the couplings with inverse masses (masses from the baryon spectrum).

X-states



Belle

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

DDbar

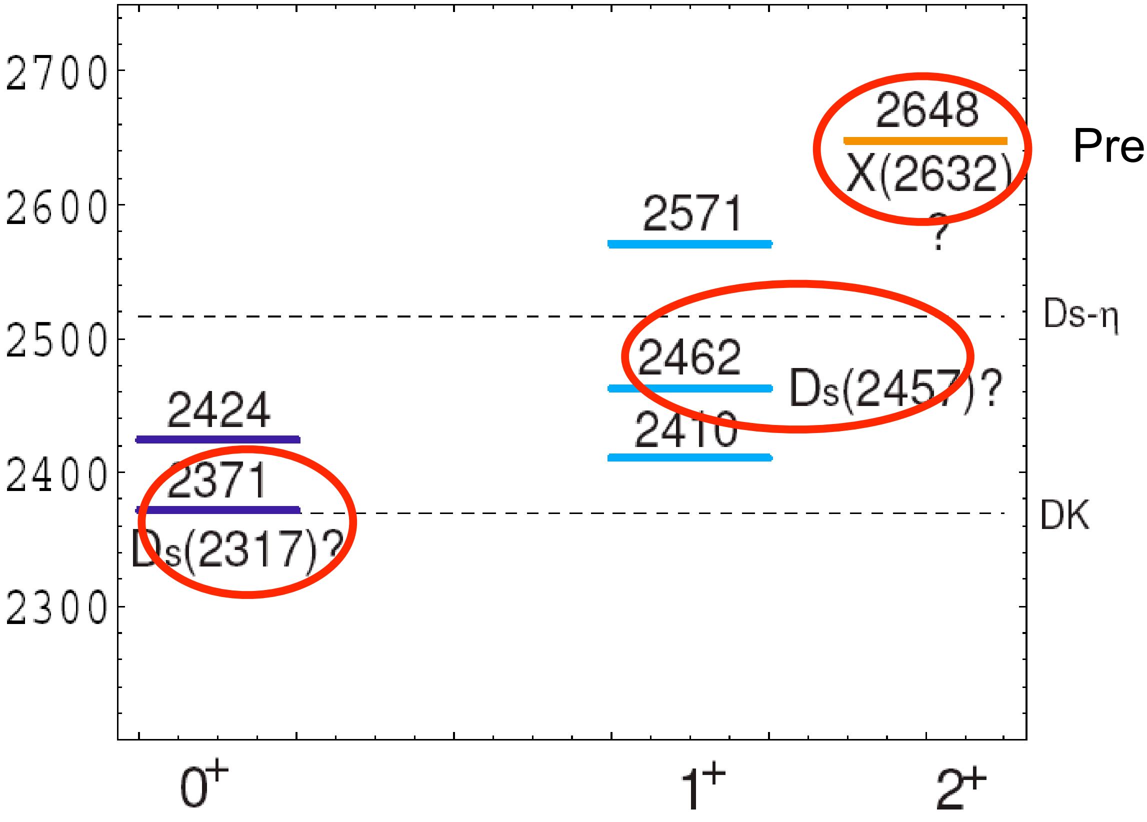
$\eta_c\eta$, $\eta_c\pi$, nH

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

J/Ψ π(η), η_c ρ(ω)

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

The states: $[cu]_{S=0,1}[\bar{s}\bar{u}]_{S=0,1}$



Predict.

- The spectrum is uniquely predicted
- Quantum numbers of Ds(2317) and Ds(2462) fit well
- The assignement of Ds(2327) is more uncertain

Masses

- Two conflicting contributions to the mass of bound states:
  - ***Annihilation***: $d\bar{d} \to u\bar{u}$
  - $u\bar{u} \to d\bar{d}$

  gives a matrix with all equal elements, which is diagonal in the isospin basis;
  - ***Quark Masses***: the eigenvectors are the states with quarks of definite flavor (e.g. ω/ϕ mixing)
- TOTAL:
  - $$\begin{pmatrix} 2m_u+\delta & \delta \\ \delta & 2m_d+\delta \end{pmatrix}$$
  - At charmonium scale, quark mass should dominate (Rossi -Veneziano; Maiani-Piccinini-Polosa-Riquer)
  - and the approximate mass eigenstates should be $X_u = [cu][\bar{c}\bar{u}]$
  - $X_d = [cd][\bar{c}\bar{d}]$

  rather then the I=1,0 states

- Belle sees both: X -> J+ρ, J+ ω with similar B.R.!!!! A new phenomenon !!!!

Isospin breaking

We consider in this section the finer structure of the $X(3872)$. In particular,we consider the neutral states with the composition:

$$X_u = [cu][\bar{u}\bar{c}]; X_d = [cd][\bar{d}\bar{c}] \tag{32}$$

Physical states could be expected to fall in isospin multiplets with $I = 1, 0$:

$$\begin{aligned} a_{c\bar{c}} &= (X_u + X_d)/\sqrt{2}; \\ f_{c\bar{c}} &= (X_u - X_d)/\sqrt{2} \end{aligned} \tag{33}$$

$$\begin{aligned} X_{\rm low} &= \cos\theta X_u + \sin\theta X_d; \\ X_{\rm high} &= -\sin\theta X_u + \cos\theta X_d \end{aligned} \tag{34}$$

we get:

$$\begin{aligned} M(X_d) - M(X_u) &= \frac{2(m_{\rm down} - m_{\rm up})}{\cos(2\theta)} = \\ &= \frac{(6-8)\ \rm MeV}{\cos(2\theta)} \end{aligned} \tag{35}$$

$$\begin{aligned} \frac{\Gamma(3\pi)}{\Gamma(2\pi)})_{X_l} &= \frac{(\cos\theta + \sin\theta)^2}{(\cos\theta - \sin\theta)^2} \cdot \frac{\langle p_\omega \rangle}{\langle p_\rho \rangle} \\ \frac{\Gamma(3\pi)}{\Gamma(2\pi)})_{X_h} &= \frac{(\cos\theta - \sin\theta)^2}{(\cos\theta + \sin\theta)^2} \cdot \frac{\langle p_\omega \rangle}{\langle p_\rho \rangle} \end{aligned} \tag{44}$$

BELLE attributes all events with $\pi^+\pi^-\pi^0$ mass above 750 MeV to ω decay and divides by the total number of observed 2π events. They find:

$$(\frac{\Gamma(3\pi)}{\Gamma(2\pi)})_{BELLE} = 0.8 \pm 0.3_{stat} \pm 0.1_{syst} \tag{45}$$

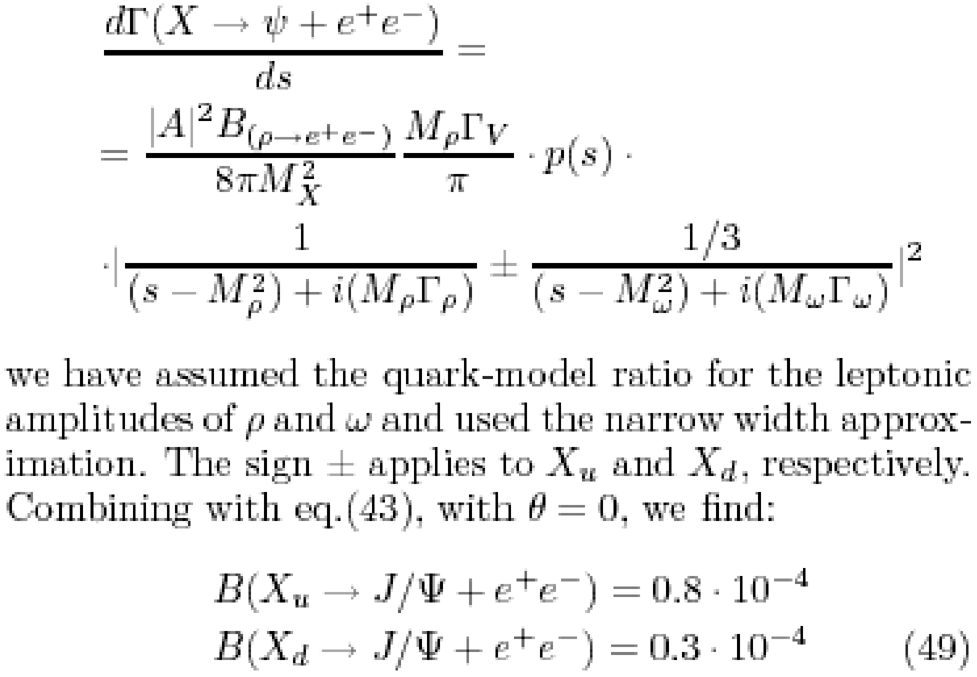
The central value is compatible with eq.(44) for:

$$\theta \simeq \pm 20^0 \tag{46}$$

for X_l or X_h, respectively. Correspondingly, the mass difference of the two states is:

$$M(X_h) - M(X_l) \simeq 7 - 10\ MeV \tag{47}$$

Interference !



$$\frac{d\Gamma(X \to \psi + e^+e^-)}{ds} =$$

$$= \frac{|A|^2 B_{(\rho \to e^+e^-)}}{8\pi M_X^2} \frac{M_\rho \Gamma_V}{\pi} \cdot p(s) \cdot$$

$$\cdot \left| \frac{1}{(s - M_\rho^2) + i(M_\rho \Gamma_\rho)} \pm \frac{1/3}{(s - M_\omega^2) + i(M_\omega \Gamma_\omega)} \right|^2$$

we have assumed the quark-model ratio for the leptonic amplitudes of ρ and ω and used the narrow width approximation. The sign ± applies to X_u and X_d, respectively. Combining with eq.(43), with $\theta = 0$, we find:

$$B(X_u \to J/\Psi + e^+e^-) = 0.8 \cdot 10^{-4}$$
$$B(X_d \to J/\Psi + e^+e^-) = 0.3 \cdot 10^{-4} \qquad (49)$$

Decay widths

- The baryonium picture implies that the two-meson decays go via intermediate baryon-antibaryon states of high mass. This implies basically narrow widths.
- We describe the decay by a single switch amplitude, associated to the process (subscripts indicate color configuration): $[cu][\bar{c}\bar{u}] \longrightarrow (c\bar{c})_{col=1}(u\bar{u})_{col=1}$

$$\begin{aligned} L_{X_u \Psi V} &= g_V\, \epsilon^{\mu\nu\rho\sigma} P_\mu X_\nu \psi_\rho V_\sigma = \\ &= g_V M_X (\mathbf{X} \wedge \psi) \cdot \mathbf{V} \end{aligned} \qquad g_V M_X = \frac{A}{\sqrt{2}}$$

- a bold guess: A=2.6 GeV

$$\Gamma(X_l \to J/\psi + \pi^+\pi^-) = \frac{2x_{l,\rho}|A|^2}{8\pi M_X^2}\langle p\rangle_\rho =$$

$$= 2x_{l,\rho} \cdot 2.3 \text{ MeV};$$

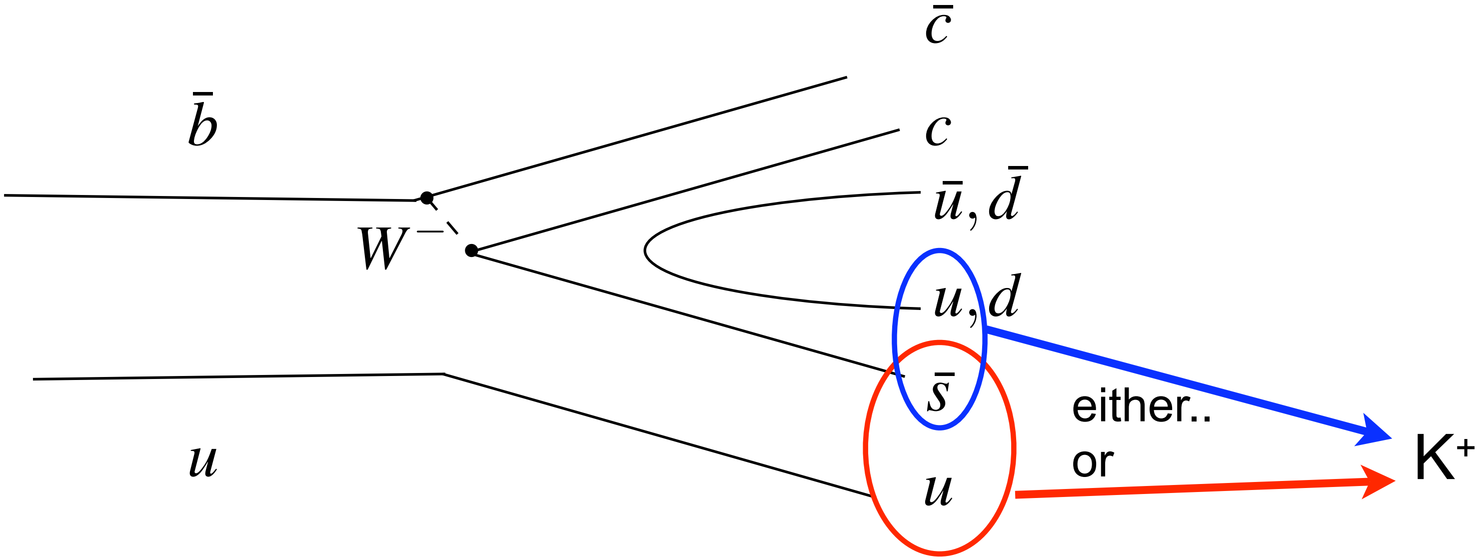
$$\Gamma(X_l \to J/\psi + \pi^+\pi^-\pi^0) = \frac{2x_{l,\omega}|A|^2}{8\pi M_X^2}\langle p\rangle_\omega =$$

$$= 2x_{l,\omega} \cdot 0.4 \text{ MeV}$$

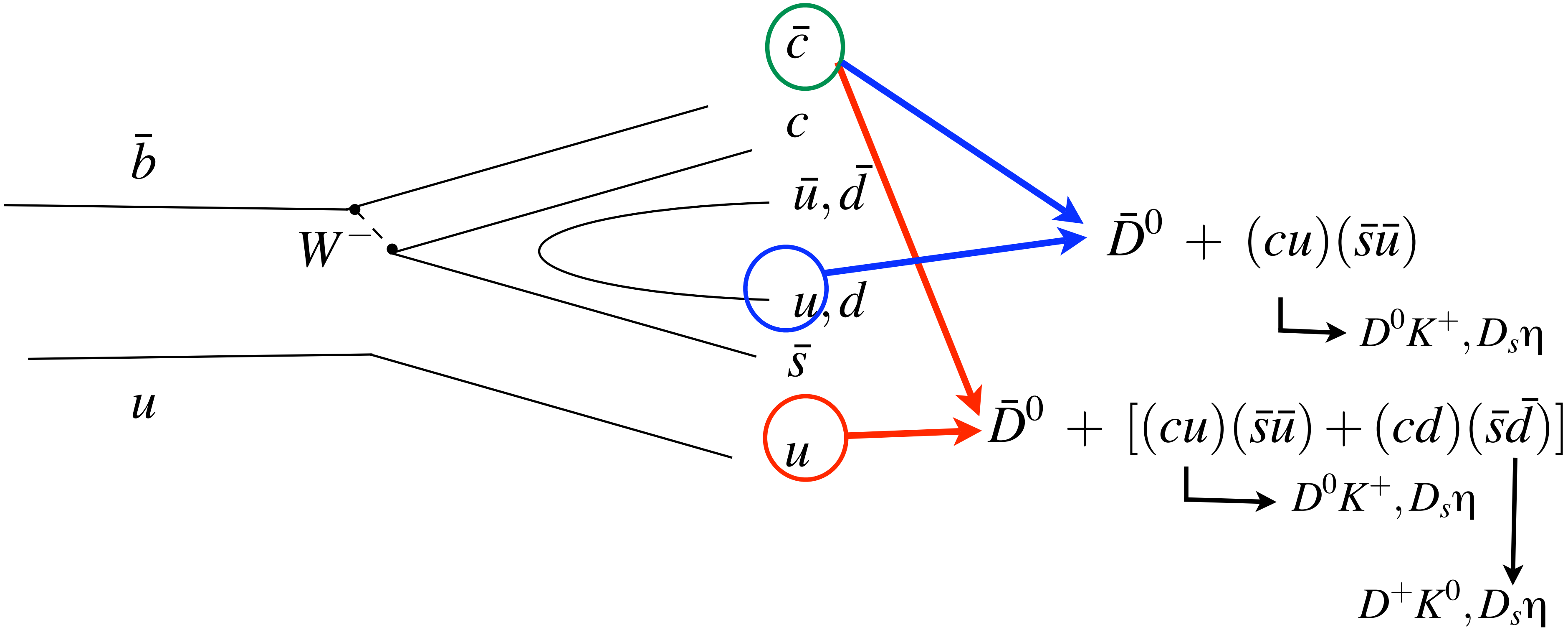
- We anticipate small widths, comparable to the resolution of Belle and Babar

X particles in B decays

There are two amplitudes for B⁺ ⇒ K⁺ X



States (cq)(sbar qbar) in B⁺ decay ?



$\bar{D}^0 + (cu)(\bar{s}\bar{u})$

$\rightarrow D^0K^+, D_s\eta$

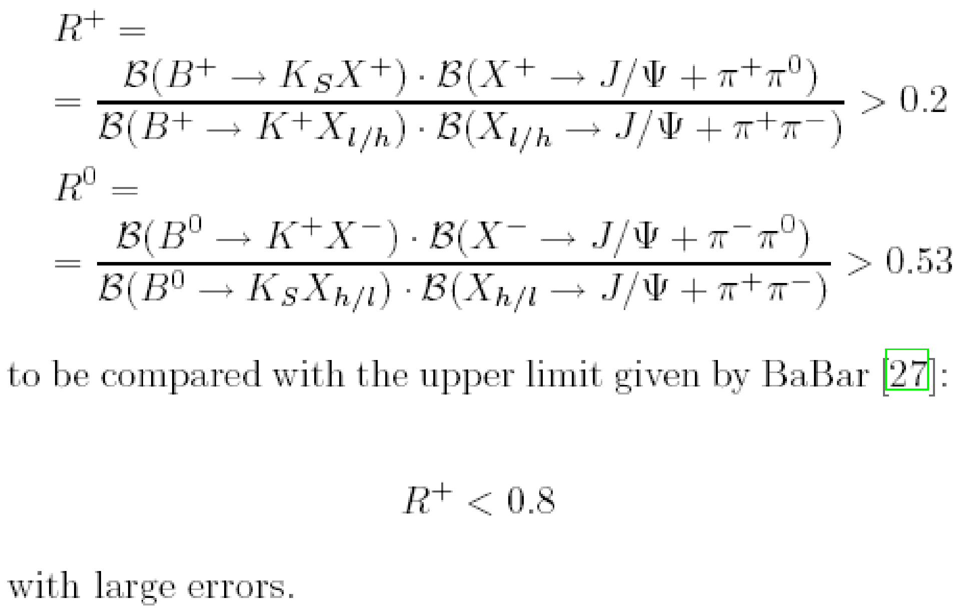
$\bar{D}^0 + [(cu)(\bar{s}\bar{u}) + (cd)(\bar{s}\bar{d})]$

$\rightarrow D^0K^+, D_s\eta$

$\downarrow D^+K^0, D_s\eta$

X particles in B decays

- Two amplitudes: the relative frequence of X_u vs. X_d is not determined
- Taking Belle data at face value, we conclude that only one of the two neutral states is produced appreciably in B^+ decay (too narrow to describe two resonances about 7MeV apart)
- The the other has to appear in B^0 decay:
  - The X particles in B^+ and B^0 decays are not the same, and have a mass difference of 7±2 MeV
- Bounds to the production of X^+:



$$R^+ = \\ = \frac{\mathcal{B}(B^+ \to K_S X^+)\cdot\mathcal{B}(X^+ \to J/\Psi + \pi^+\pi^0)}{\mathcal{B}(B^+ \to K^+ X_{l/h})\cdot\mathcal{B}(X_{l/h} \to J/\Psi + \pi^+\pi^-)} > 0.2$$

$$R^0 = \\ = \frac{\mathcal{B}(B^0 \to K^+ X^-)\cdot\mathcal{B}(X^- \to J/\Psi + \pi^-\pi^0)}{\mathcal{B}(B^0 \to K_S X_{h/l})\cdot\mathcal{B}(X_{h/l} \to J/\Psi + \pi^+\pi^-)} > 0.53$$

to be compared with the upper limit given by BaBar [27]:

$$R^+ < 0.8$$

with large errors.

D-D* molecule

- one state only: D^0-D^{*0}
- ... and very extended:
- $$R = \frac{1}{\sqrt{2M_D E_{bind}}} \sim 4\ fm$$
- most of the time (70-80%), D and D* are too far to exchange a c-quark and form a J/Ψ;
- for a tight state: $BR(\Psi' \to \Psi\pi^+\pi^-) \approx 0.3$, maybe: $BR(X \to \Psi\ \pi^+\pi^-) \approx 0.03$
- the measure of inclusive $B(B^+ \to XK^+)$ determines the X BR from the overall ratio:
- $$R = \frac{B(B^+ \to XK^+)B(X \to J/\Psi\ \pi^+\pi^-)}{B(B \to \Psi' K^+)B(\Psi' \to J/\Psi\ \pi^+\pi^-)} = 0.063 \pm 0.014$$
-
- and give an important clue (G. Wormser, yesterday talk).

The qq-qbar qbar shopping list for X(3872)

Questions

- Do you see X in $B^0 \rightarrow X + K_S$?
- can you see a mass difference between X (B^0) and X (B^+)?
- can you look for the other partner? $X^+ = (cu)(\bar{c}\bar{d})$
-
- Other X-like states:
  - above thresh.: $0^{++}_{high} \rightarrow D + \bar{D}$
  - below thresh.: $0^{++}_{low} \rightarrow \eta_C + \dots$
  - X(3940): seen $X(3940) \rightarrow J/\Psi + \omega$
  - what about ? $X(3940) \rightarrow D + \bar{D}$ (??) (d-wave)
- SELEX-like particles in B decays ???
- how about $D_{sJ}(2317)$, $D_{sJ}(2460)$?

Conclusions

- A convincing picture of light scalars as $[qq][\bar{q}\bar{q}]$ states:
  - Masses
  - Ideal mixing
  - Decays reasonably described (exact SU3!) but for OZI violating (??)
  - Note: Δm(f-a)~10MeV, Δm(up-down) ~5MeV: are f(980) and a(980) pure I-spin eigenstates?
- New phenomena
  - States $[cq][\bar{c}\bar{q}]$ and $[cq][\bar{c}\bar{s}]$ should exist, with both natural and unnatural spin parity;
  - I-spin breaking expected maximal in certain decay: was the SELEX particle just the first case?
  - X(3872) a good candidate, X(3940) predicted

WERE ARE THE EXOTIC STATES??? !