Exotic mesons: some progress?

CERN, August 2, 2007

Luciano Maiani

Universita' di Roma "La Sapienza"

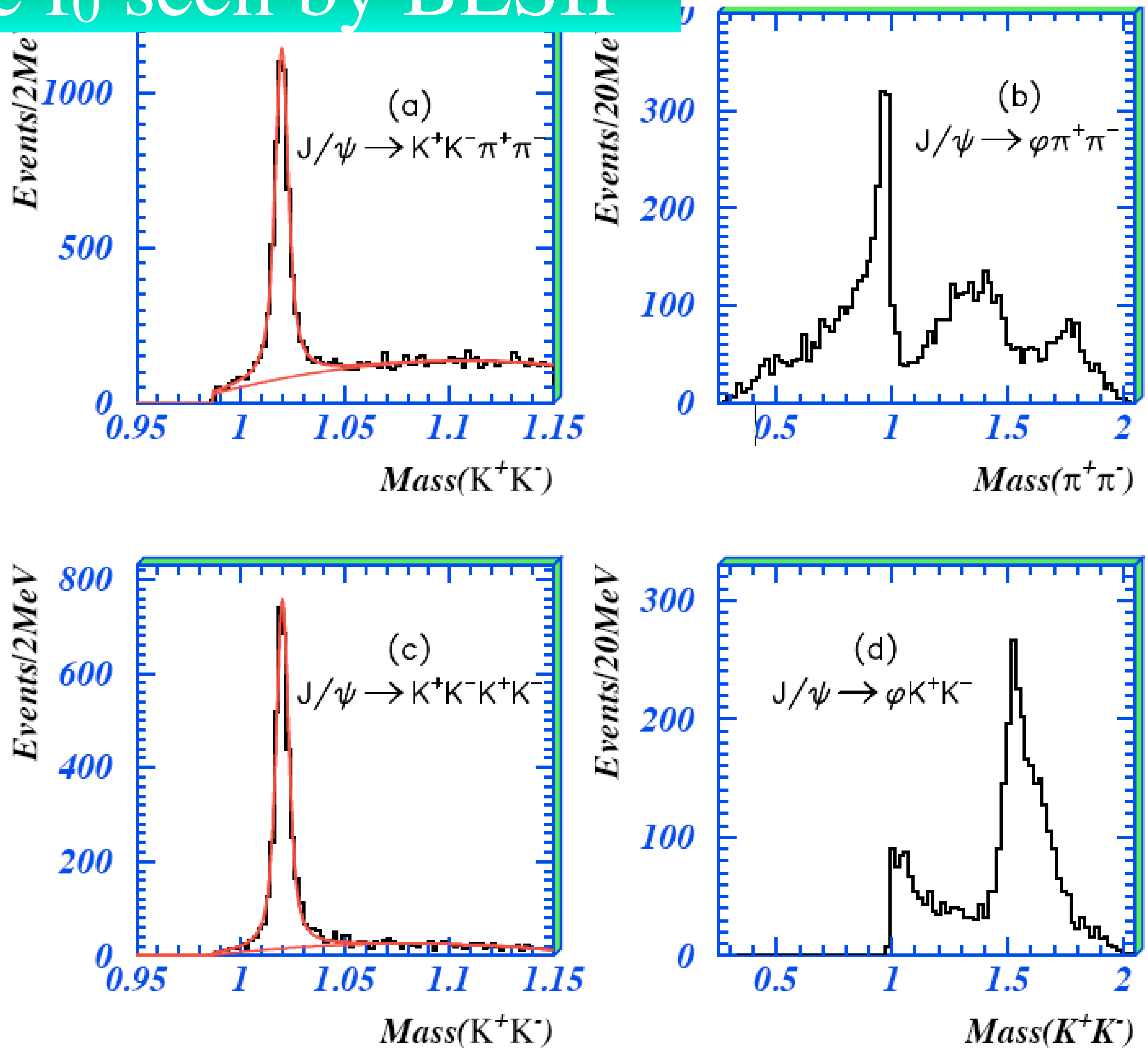
1. The $f_0(980)/a_0(980)$ puzzle

- Old and new puzzles in meson spectroscopy point to few anomalous cases
- the case of light $J^{PC}=0^{++}$ mesons is well-known:
  - $f_0(980)$, I=0, $a_0(980)$, I=1, almost degenerate
  - q-qbar in P-wave ?
  - a_0 should be:

$$a_0 = (u\bar{d},\ \frac{u\bar{u} - d\bar{d}}{\sqrt{2}},\ d\bar{u})$$

  - if same quarks, $f_0 = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}}$
  - but f_0 shows strong affinity with K-Kbar channel
  - $f_0 = s\bar{s}$? why degenerate with a_0??

the f_0 seen by BESII



f_0 affinity for Kaons

$$BW_{f_0(980)} = \frac{1}{m_{\pi\pi}^2 - m_0^2 + i m_0 (\Gamma_\pi + \Gamma_K)} \ , \tag{4}$$

with

$$\Gamma_\pi = g_\pi \sqrt{m_{\pi\pi}^2/4 - m_\pi^2} \tag{5}$$

and

$$\Gamma_K = \frac{g_K}{2} \left(\sqrt{m_{\pi\pi}^2/4 - m_{K^+}^2} + \sqrt{m_{\pi\pi}^2/4 - m_{K^0}^2} \right) \ . \tag{6}$$

	m_{f_0} [MeV]	$g_{\pi\pi}$	$g_{K\bar{K}}$
WA76 (1991) ππ & KK seen	979±4	0.28±0.04	0.56±0.18
BES (2004) $\psi \longrightarrow \phi$ ππ, ϕ KK	965±8±6	0.34±0.04	1.4±0.11

Crypto-exotic mesons

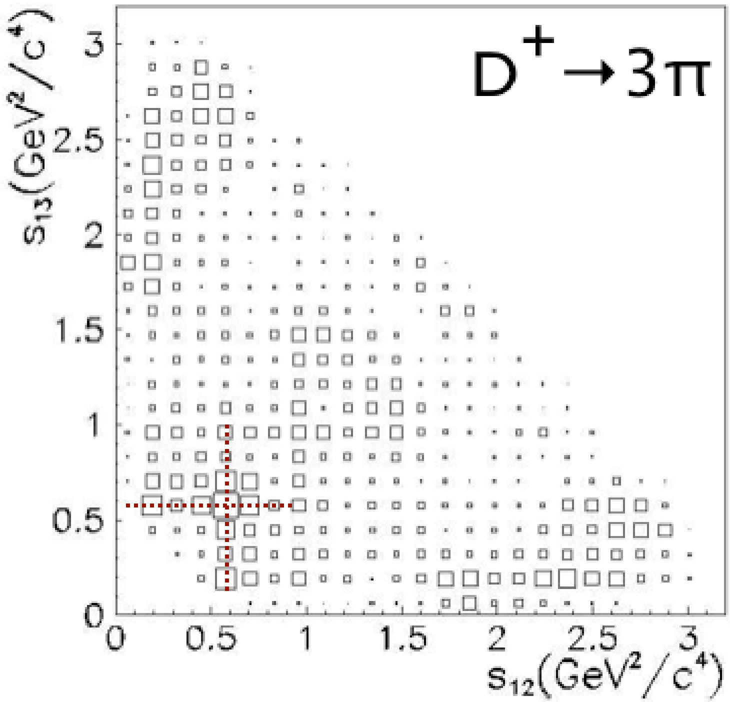
- f_0 and a_0 are candidate for a new class of mesons:

$$f_0/(a_0)^0 = \frac{[su][\bar{s}\bar{u}] \pm [sd][\bar{s}\bar{d}]}{\sqrt{2}}$$

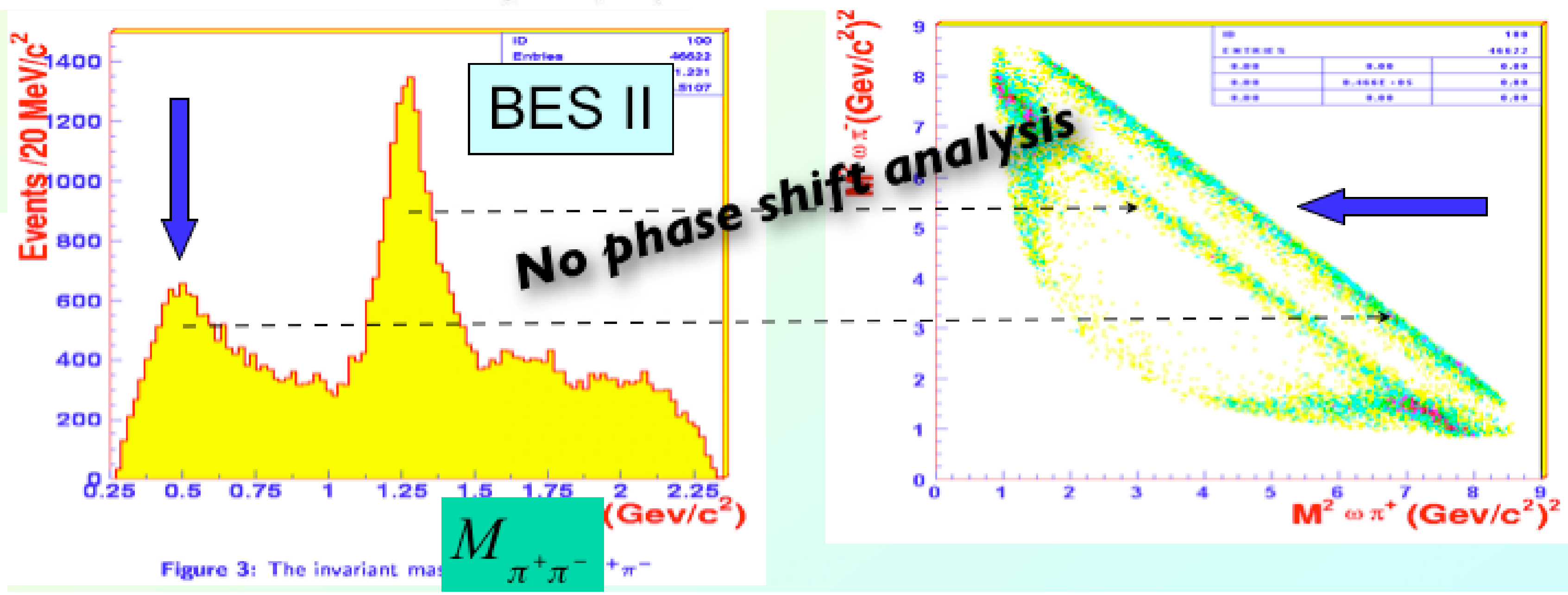
- earlier proposal by Jaffe and Jaffe &Wilczeck, more recent reconsidered by our group (L.M., F. Piccinini, A. Polosa, V. Riquer, Phys.Rev.Lett. **93**:212002,2004; hep-ph/0407017)
- evidence for lighter states (to complete a full nonet) accumulated recently from D non leptonic decays (E791, BES, more recently BeBar)

$$\kappa = [su][\bar{u}\bar{d}],\ [sd][\bar{u}\bar{d}]$$
$$\sigma = [ud][\bar{u}\bar{d}]$$

- other alternative: K-Kbar *molecules* ?
- existence of sigma is crucial to tell the difference



D+ → 3π
s13(GeV²/c⁴)
s12(GeV²/c⁴)



BES II
Events /20 MeV/c2
No phase shift analysis
(Gev/c2)
Figure 3: The invariant mas
M π+π−
M2 ωπ+ (Gev/c2)2

Theoretical evidence for sigma

arXiv:hep-ph/0512364v2 7 Apr 2006

Mass and width of the lowest resonance in QCD

I. Caprini
National Institute of Physics and Nuclear Engineering, Bucharest, R-077125 Romania

G. Colangelo and H. Leutwyler
Institute for Theoretical Physics, University of Bern, Sidlerstr. 5, CH-3012 Bern, Switzerland

Dispersion equation analysis of π π scattering in S-wave indicate a broad resonance around 500 MeV, σ, and a narrow one around 980, f_0.

$$m_0 = (441 \pm 4) - i\,(272 \pm 6)\ \text{MeV}$$

The values of the S-matrix element

$$S_0^0(s) = 1 - 2\sqrt{4\,M_\pi^2/s - 1}\;t_0^0(s) \qquad (6)$$

on the second sheet can be calculated from those on the first sheet: unitarity implies the relation [15]

$$S_0^0(s)^{II} = 1/S_0^0(s)^I \quad . \qquad (7)$$

The Roy equation thus automatically also specifies the function $S_0^0(s)$ on the second sheet, in the same domain of the s-plane [16]. In particular, the amplitude contains a pole on the second sheet if and only if $S_0^0(s)$ has a zero

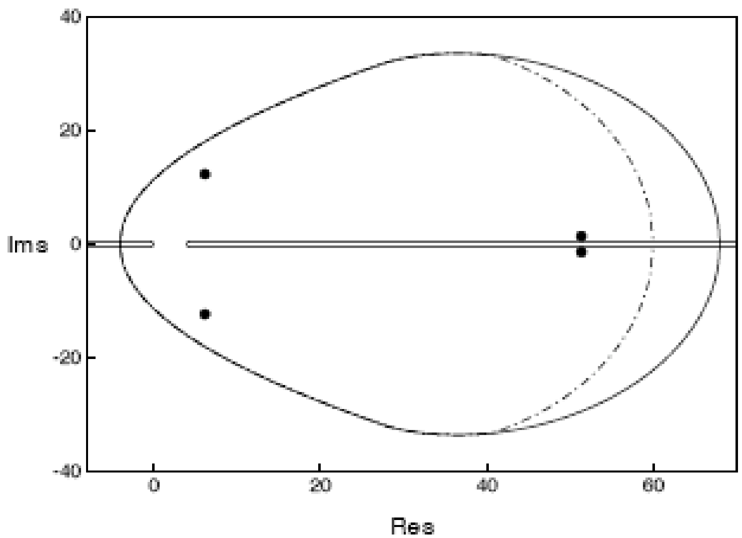
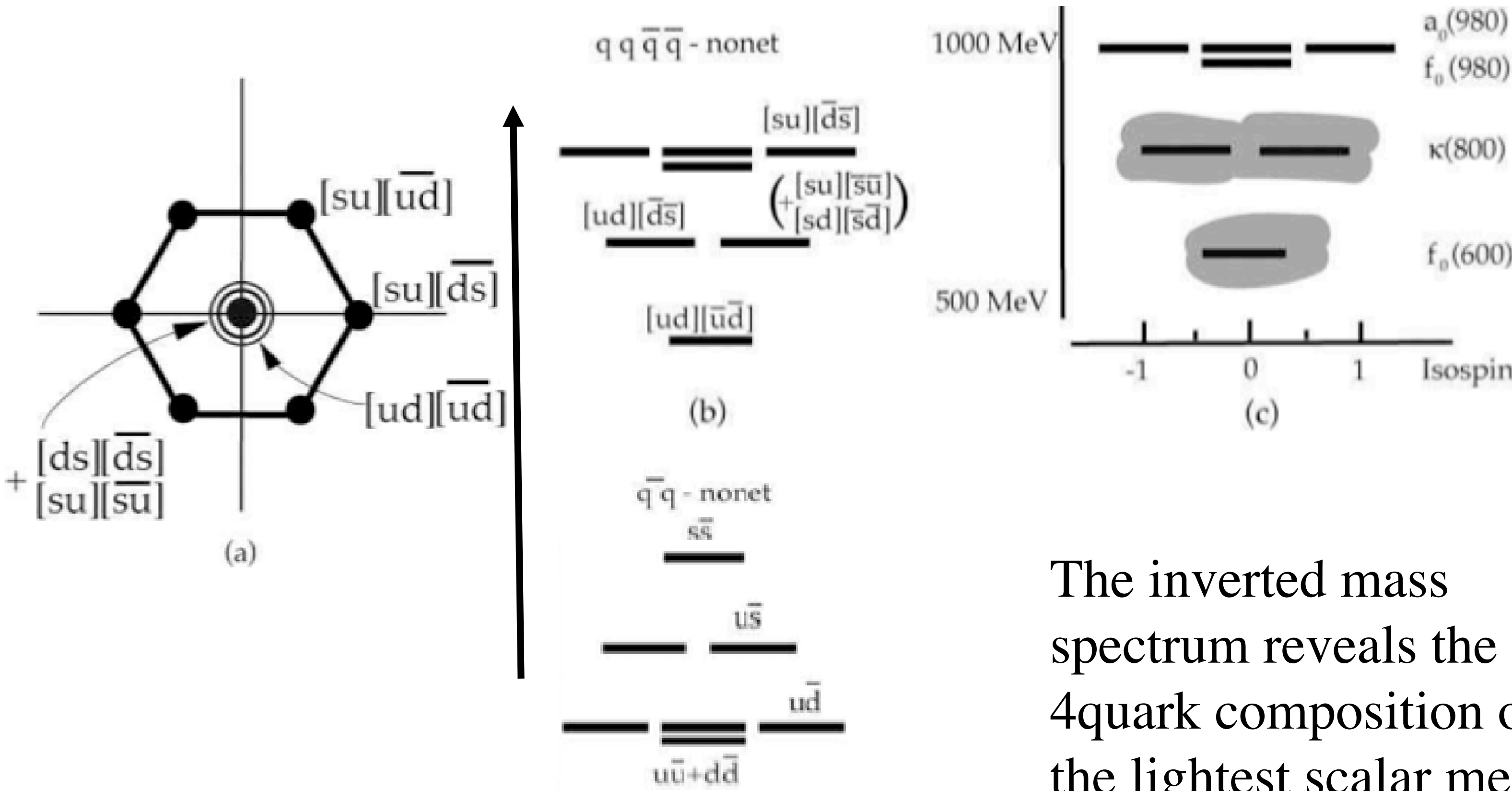


FIG. 2: Domain of validity of the Roy equations.

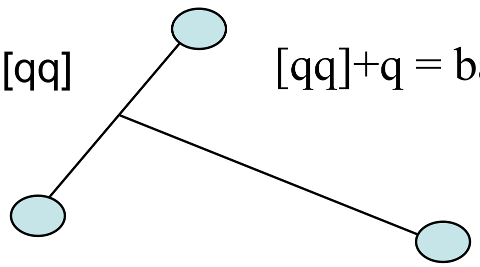
Quantum numbers and mass spectrum



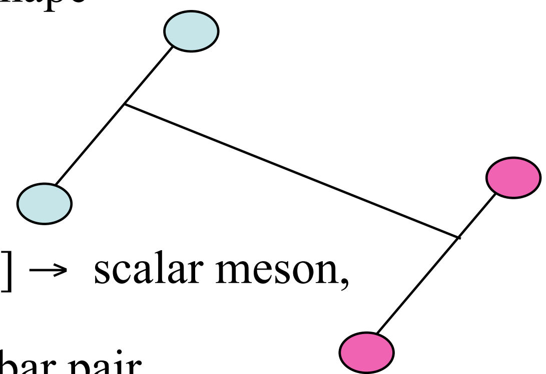
The inverted mass spectrum reveals the 4quark composition of the lightest scalar mesons

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

A diquark needs to combine with other colored objects

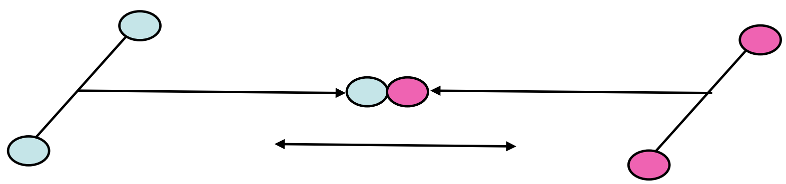


[qq]+q = baryon (e.g. Λ), Y-shape



[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?

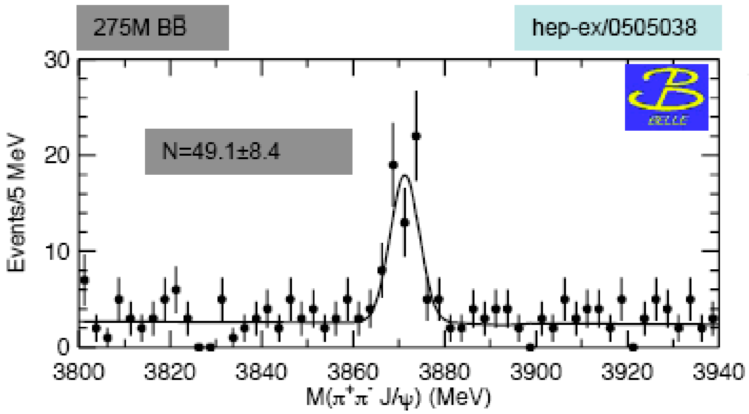
2. Hidden charm mesons are being found by BELLE and BaBar, which do not fit the Charmonium picture

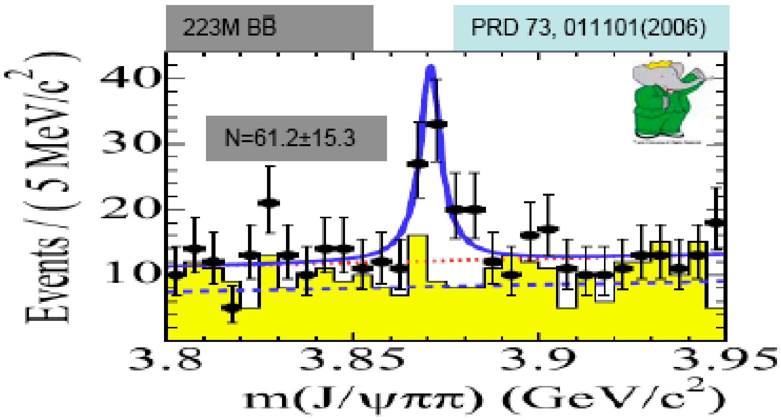
X(3872) State

First observation by BELLE in B decays: $B^{\pm} \to X(3872)K^{\pm}$ with $X(3872) \to J/\psi\pi^+\pi^-$ PRL 91, 262001(2003)

Confirmed by BABAR, CDF, D0

Branching fraction and mass measurement:





$B(B \to XK) \times B(X \to J/\psi\pi\pi) = (10.5 \pm 1.8)10^{-6}$

$m = (3871.2 \pm 0.5)$ MeV/c^2

$\Gamma < 2.3$MeV at 90% CL

Search for a charged partner:

If X has isospin=1: $B(B \to X^+K) \approx 2B(B \to X^0K)$

$B(B^0 \to X^-K^+) \times B(X \to J/\psi\pi^-\pi^0) < 5.4\ 10^{-6}$
$B(B^- \to X^-K^0) \times B(X \to J/\psi\pi^-\pi^0) < 22\ 10^{-6}$ @90%CL

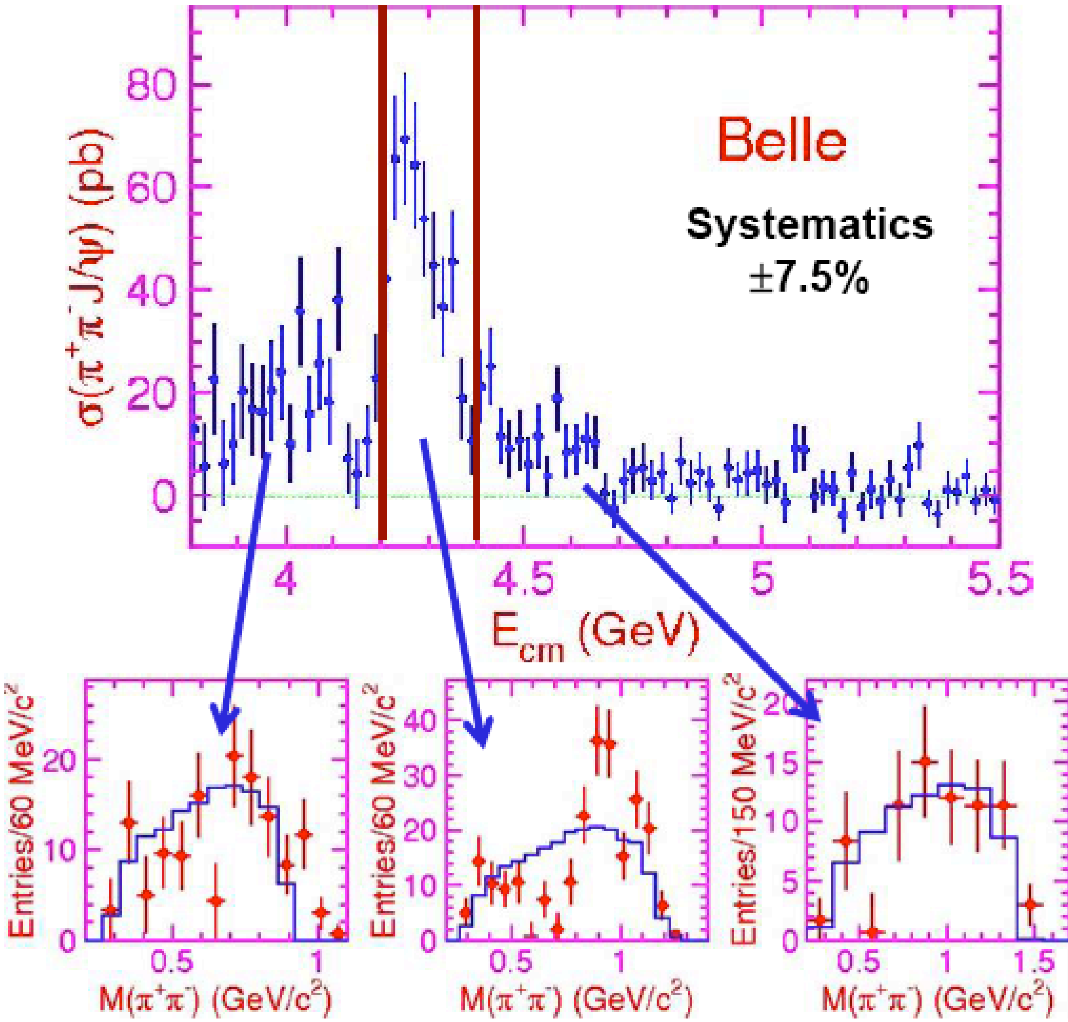
No Signal PRD 71, 031051(2006)

Moriond QCD 2007 Grenier Philippe

X seen to decay in $\psi 2\pi$ and $\psi 3\pi$
isospin violation of O(1)!

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

ee→J/ψππ cross-section



Bg subtracted M(J/ψππ) 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 √s regions:

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

..and a new one seen by BELLE..

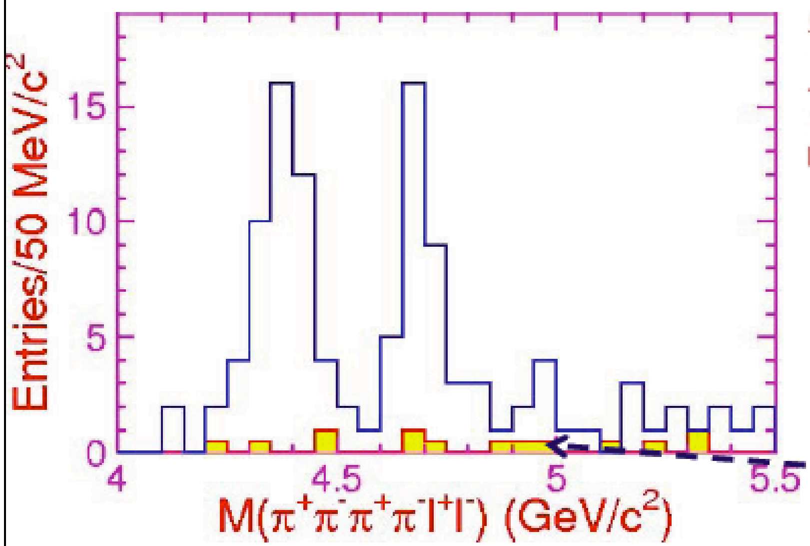
$ee \to \psi'\pi\pi$ at $\sqrt{s}$ ~4-5.5GeV via ISR

670 fb^{-1}

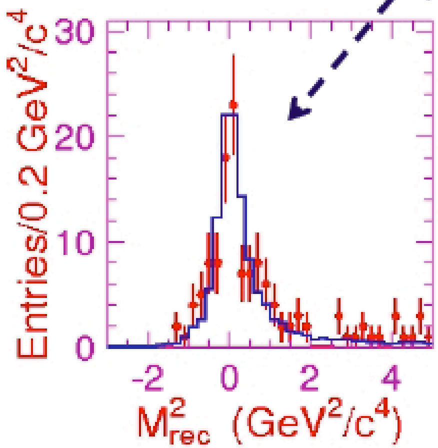
$\psi(\to J/\psi\ \pi\pi)$ + $\pi\pi$ + no extra tracks

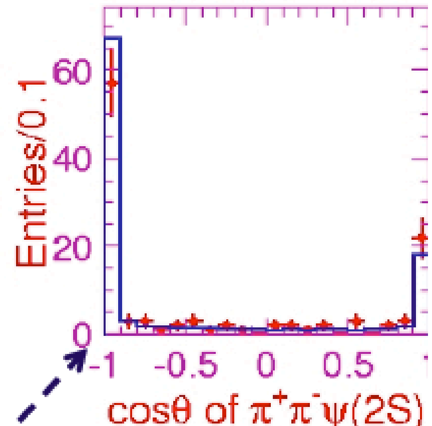
detection of γ_{ISR} is not required

Similar analysis: efficiency is smaller; bgs are almost negligible



- Clear signal of missed massless particle ($M_{rec}^2(\psi'\pi\pi)$~0)

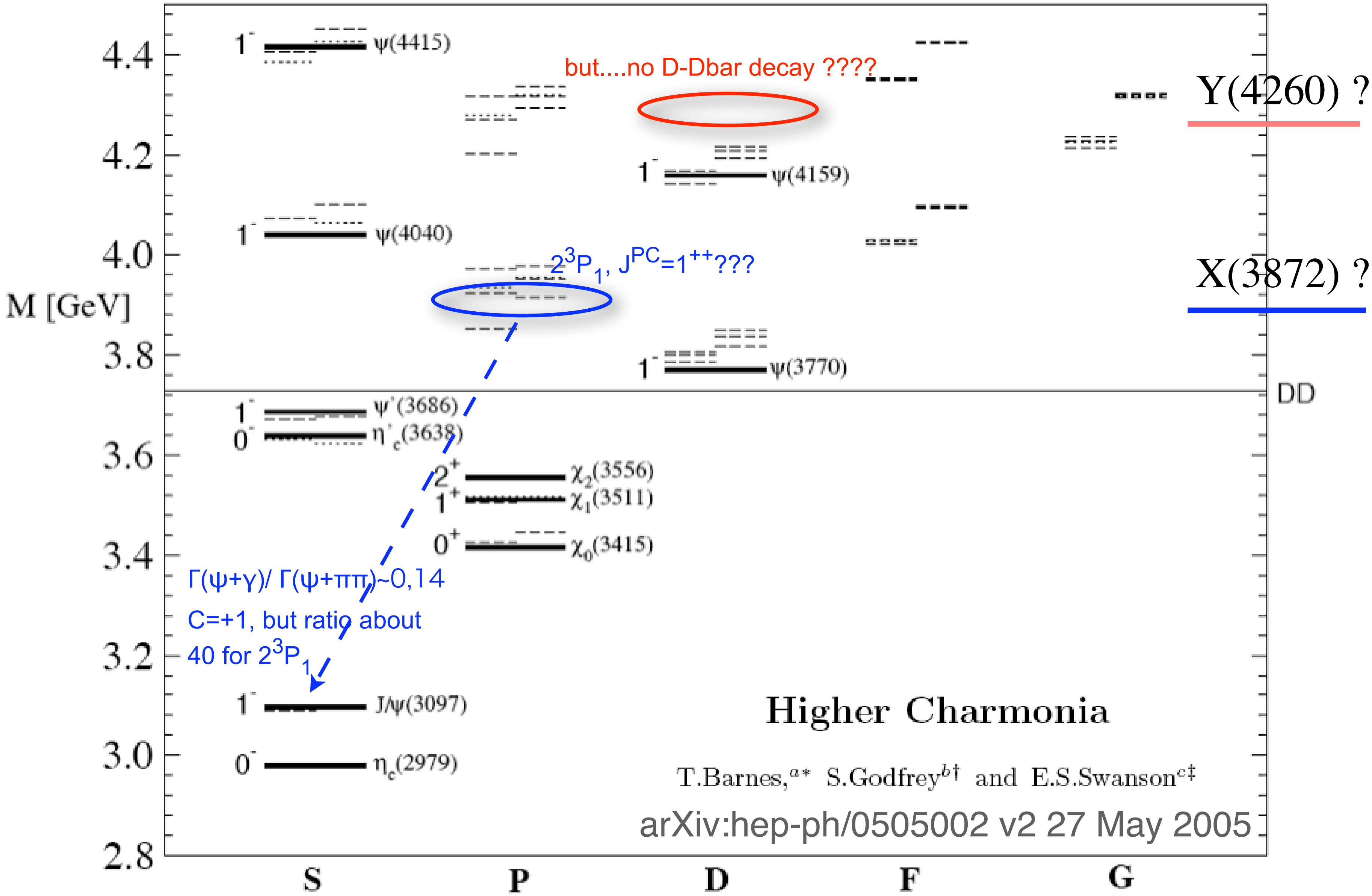




- Polar angle distribution agrees well with ISR expectation
- Combinatorial bg estimated by ψ' sb
- Bgs real $(\psi'\pi\pi)_{non\ ISR}$ or $\psi'\ X_{non\ \pi\pi}$ are negligibly small

Two significant clusters: One is near BaBar reported enhancement
PRL.98:212001,2007 **+ NEW at M~ 4.7 GeV**

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



Proposed interpretations

- X(3872) =

F.E. Close, and P.R. Page (2003);
N.A. Tornqvist (2003), E. Swanson (2004)

  - D-D* molecule: $M(X)-M(D^{*0}D^{0})=0.6\pm1$ MeV
  - diquark-antidiquark bound state:

$$[(cq)\ (\bar{c}\bar{q})]_{S-wave},\ J^{PC}=1^{++};\ \ (q=u,\ d)$$

- Y(4260) =

L. Maiani, F. Piccinini, A. Polosa,
V. Riquer (2004)

  - Hybrid state:
  - diquark-antidiquark bound state:

$$(c\ \bar{c}\ g)$$

F.E. Close, and P.R. Page (2005); E. Kou, O. Pene (2005)

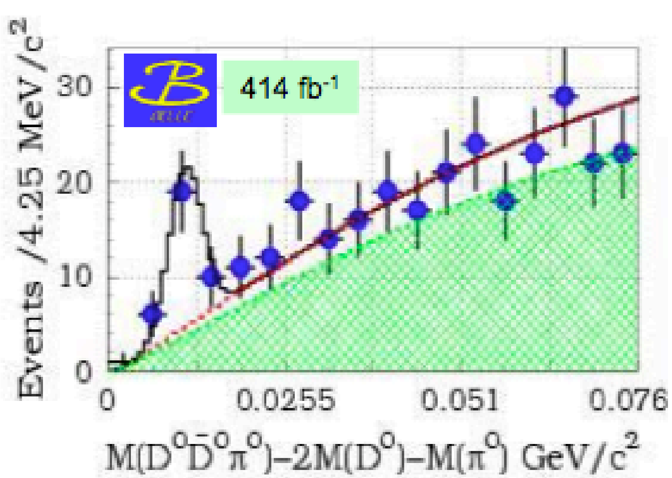
$$[(cs)\ (\bar{c}\bar{s})]_{P-wave},\ J^{PC}=1^{--}.$$

L. Maiani, F. Piccinini, A. Polosa,
V. Riquer (2005)

- hybrid classification for X(3872) excluded by the large isospin violation seen in ψρ and ψω decays;
- Y(4260) is some 33 MeV above D*-D* threshold; parity calls for P-wave: molecule unfavoured ??

X(3872): STILL SOME SURPRISES

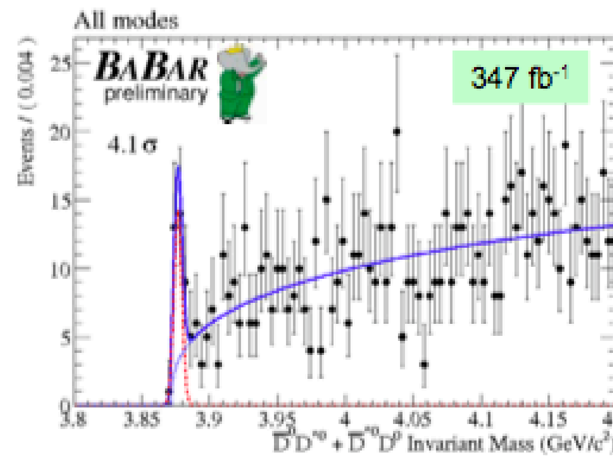
- Belle: looking at $B \to \bar{D}^0 D^0 \pi^0 K$



- 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

hep-ex/0606055

V. Poireau DIS 2007 April 2007

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

3. Are there 2 Xs separated by few MeV?

arXiv:0707.3354v1 [hep-ph] 23 Jul 2007

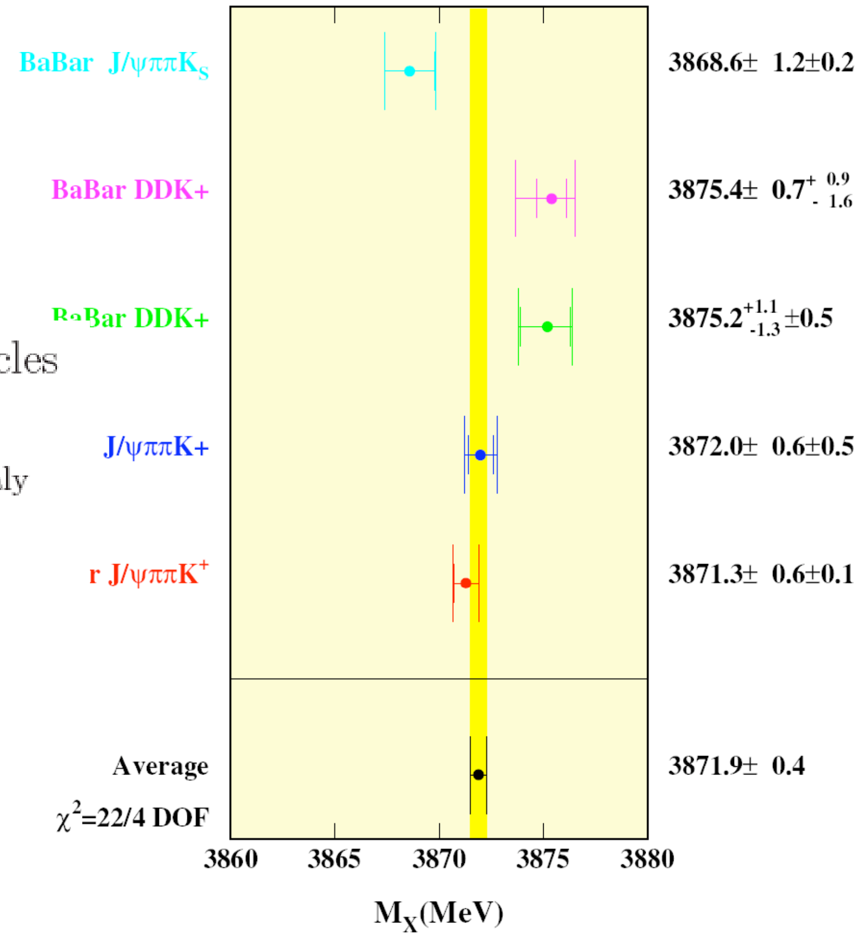
New Evidence for a Four-Quark Structure of X Particles

L. Maiani[a], A.D. Polosa[b], V. Riquer[b],
[a]Dip. Fisica, Università di Roma “La Sapienza” and INFN, Roma, Italy
[b]INFN, Sezione di Roma, Roma, Italy

July 23, 2007

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

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



We assume :

$X_u \equiv$ X state decaying into $D^0\bar{D}^0\pi^0 \;=\; X(3876)$

$X_d \equiv$ X state decaying into $J/\psi\pi^+\pi^- \;=\; X(3872)$

Production rates in B$^{+,0}$ decays

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

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

as a consequence we have

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

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

	$f = J/\psi\pi^+\pi^-$	$f = D^0\bar{D}^0\pi^0$	
$\mathcal{B}(B^\pm \to K^\pm X)\mathcal{B}(X \to f)\times 10^5$	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 $2.23 \pm 0.93 \pm 0.55$	BELLE BaBar

- X(3872) and X(3876) appear to be related by u⇔d symmetry!

4. Decay modes of $X_{u,d}$

- Multigluon annihilation:

$$X = [cq][\bar{c}\bar{q}] \rightarrow \text{n gluons} \quad (\text{n} > 2 \text{ for } 1^{++})$$

$\Gamma(\text{multigl}) \approx \Gamma(\chi_{1c}) \approx 1$ MeV

- quark rearrangement:

$X_u \rightarrow (c\bar{u})_0(\bar{c}u)_0 \rightarrow D^0\bar{D}^{*0}$,

not $D^+\bar{D}^- + D^-\bar{D}^{*+}$

- $X_d \rightarrow (c\bar{d})_0(\bar{c}d)_0 \rightarrow D^+\bar{D}^- + D^-\bar{D}^{*+}$

not $D^0\bar{D}^{*0}$ But no phase space !!

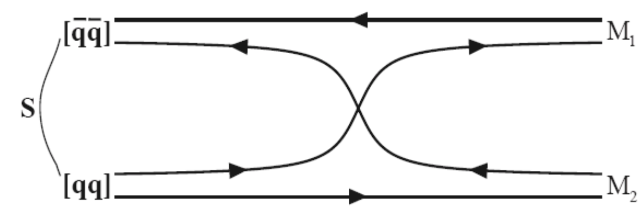


FIG. 1: The decay of a scalar meson S made up of a diquark-antidiquark pair in two mesons M_1M_2 made up of standard $(q\bar{q})$ pairs.

- $X_q \rightarrow (c\bar{c})_0(\bar{q}q)_0 \rightarrow \psi\pi\pi$

- If Xu=X(3876) and ψππ amplitudes are suppressed (tunneling of c vs u/d more difficult?), we can explain why:

i.e. disjoint decay modes

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

the overall picture

- X_u: Γ(multigl)≈1 MeV, $\Gamma(D^0D^0\pi^0)$≈1-3 MeV (B=0.5 to 1); B($\psi\pi\pi$)= negl.
- X_d: Γ(multigl)≈1 MeV, $\Gamma(\psi\pi\pi)$≈0.1 MeV (B=0.05); $\Gamma(DD\pi)$= 0.
- X^+: Γ(multigl)≈0.1-1 MeV, $\Gamma(\psi\pi\pi)$≈0.2 MeV ; $\Gamma(DD\pi)$= strongly mass dependent, may be dominant for M>3876

5. The search for X+

- present 90% confidence limits (BaBar):

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

- translate into:

$$\mathcal{B}(X^+ \to J/\psi\pi^+\pi^0) \leq \left|\frac{V+S}{S}\right|^2 \times \frac{0.54}{0.51} \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) \simeq 0.25$$

- more efforts needed to test conclusively the scheme!