NEW EVIDENCE OF 4q STRUCTURE IN THE X SYSTEM

AD POLOSA
INFN ROMA I - LA SAPIENZA

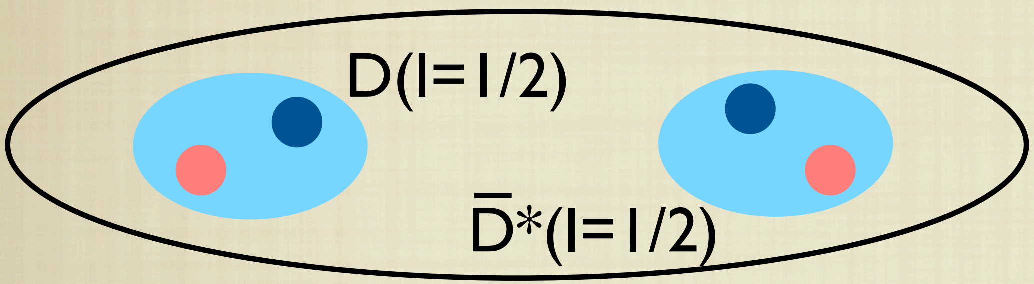
ISOSPIN VIOLATION AND TWO X'S

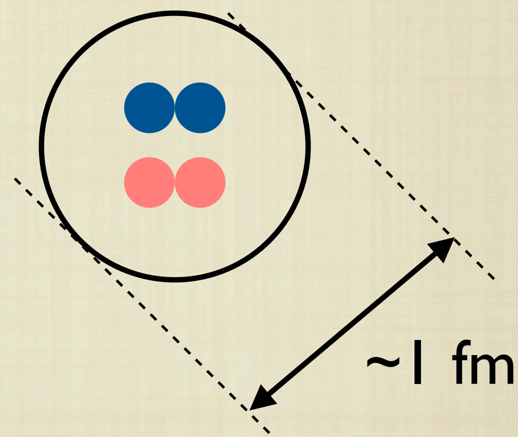
$$\frac{\mathcal{B}(X \to \pi^+\pi^-\pi^0 J/\psi)}{\mathcal{B}(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$$

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

MOLECULES

4-QUARKS





NO PROBLEM WITH ISOSPIN VIOLATION :: <u>1 STATE</u> :: <u>SMALL</u> DECAY RATE TO DDπ

NEED <u>TWO STATES</u>, AND MAKE ISOSPIN VIOLATION POSSIBLE

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

FIND THESE TWO X'S IN DATA

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

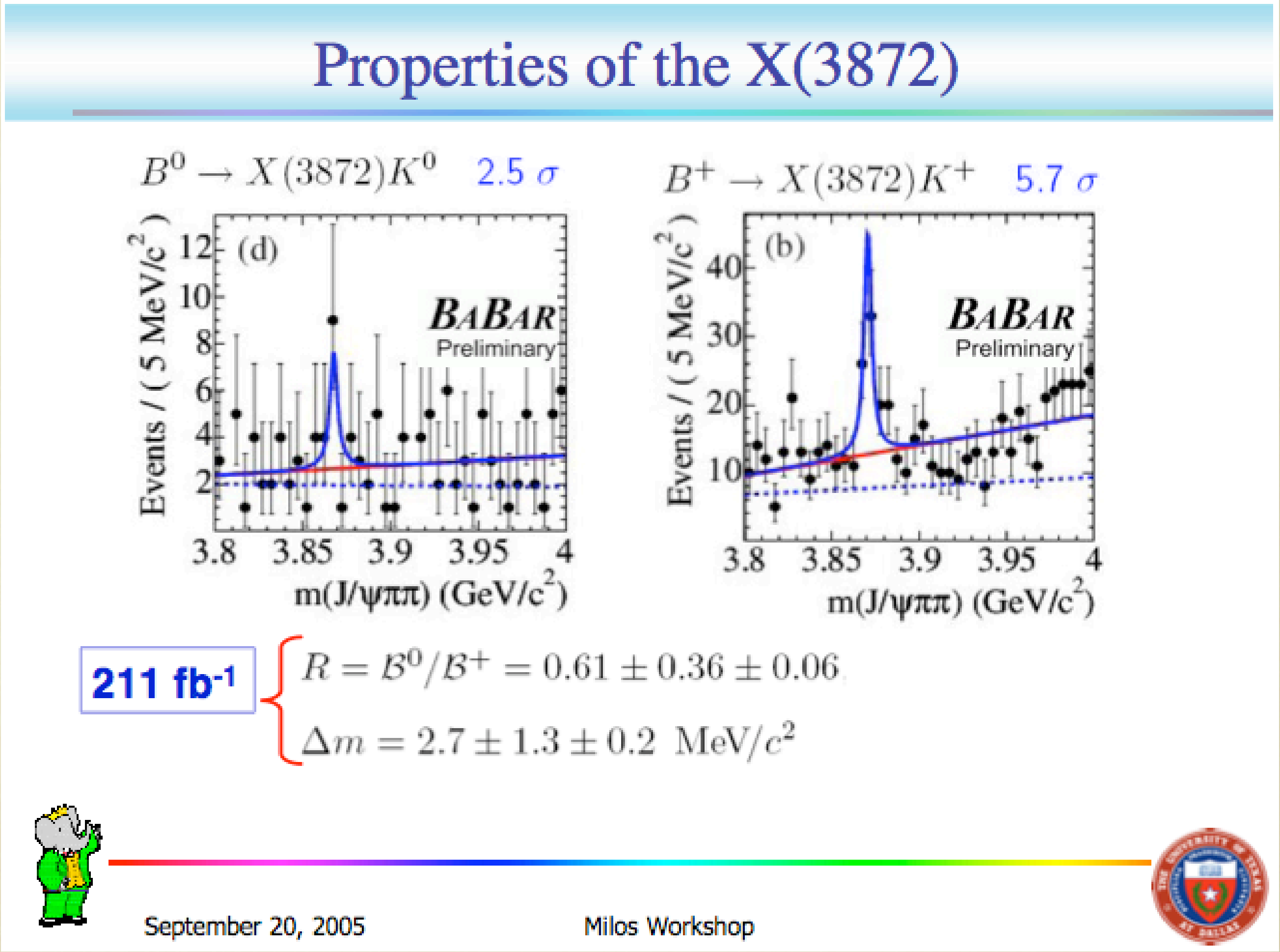
$B^+ \to K^+ X_u$ with rate Γ_1

$B^+ \to K^+ X_d$ 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

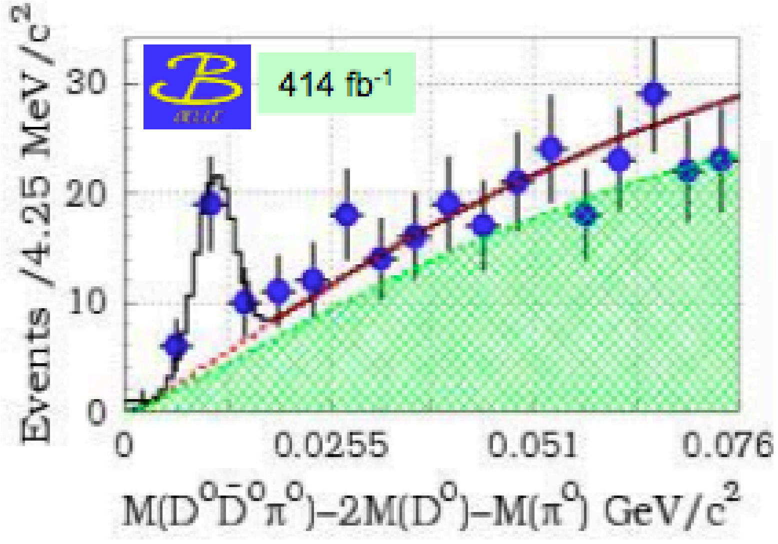
$B^0 \to K^0 X_d$ with rate Γ_4



DIFFERENCE IN MASS FROM DATA NOT SIGNIFICATIVE

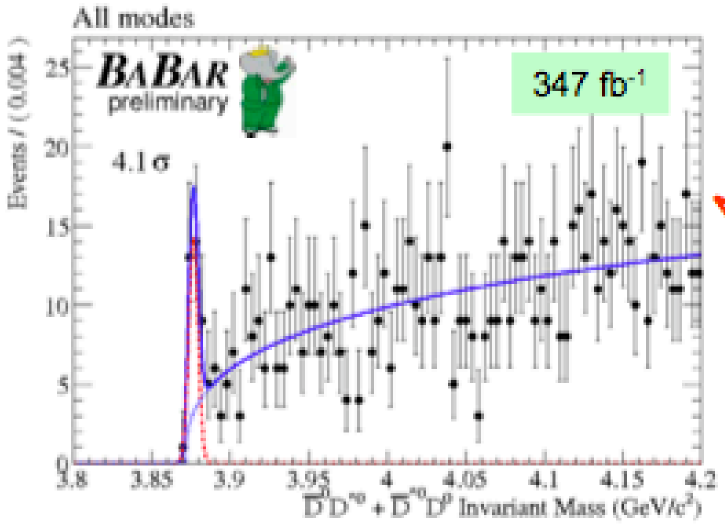
X(3872): STILL SOME SURPRISES

- 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?

:: OUR 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

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

(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

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

AS A CONSEQUENCE WE HAVE

$$\left(\frac{B^0}{B^+}\right)_{J/\psi} = \frac{\mathcal{B}(B^0 \rightarrow K^0 X_d)\mathcal{B}(X_d \rightarrow J/\psi\pi^+\pi^-)}{\mathcal{B}(B^+ \rightarrow K^+ X_d)\mathcal{B}(X_d \rightarrow J/\psi\pi^+\pi^-)} = \frac{\mathcal{B}(B^0 \rightarrow K^0 X_d)}{\mathcal{B}(B^+ \rightarrow K^+ X_d)} =$$

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

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

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

DECAYS

>=3 for spin parity 1+

POSSIBLE DECAY MODES:

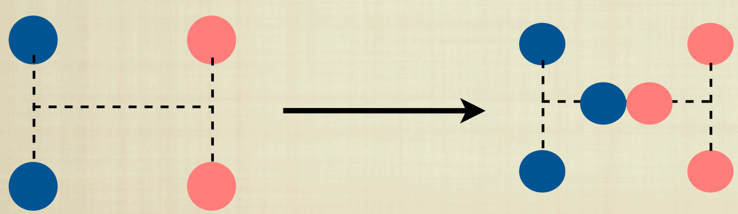
1 :: ANNIHILATION INTO GLUONS (> 2) GIVING A MULTIHADRON UNCHARMED FINAL STATE

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

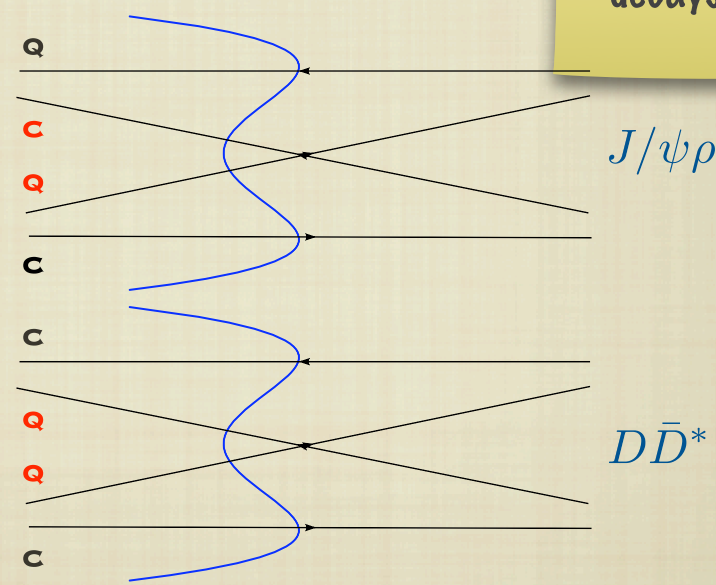
2 :: ANNIHILATION $X \to gg + q\bar{q}$ BUT CCB ARE J=1 (VOLOSHIN), SO ↛ TO TWO GLUONS

1MeV sets the scale of the background of multihadronic decays

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

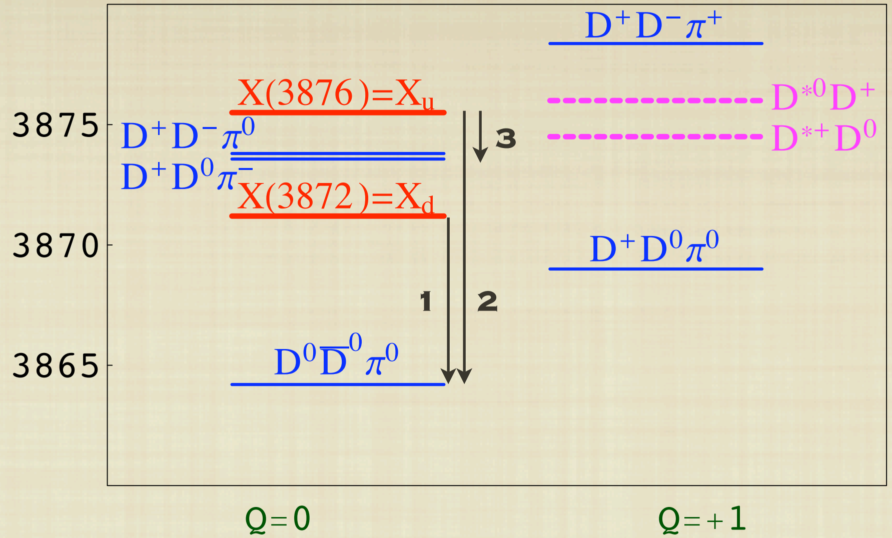


OR



(RED TWISTS)

DECAYS



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

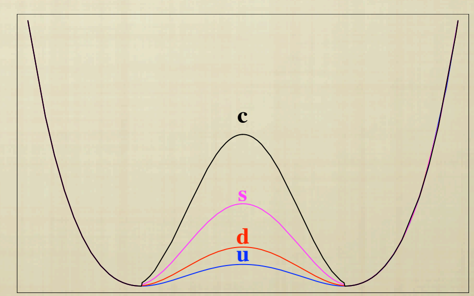
ALTERNATIVE: TWIST C
AND MAKE J/ψ

BY QUARK FLAVOR CONSERVATION X_D SHOULD DECAY IN D^+D^{*-} :: PHASE SPACE FORBIDDEN. D^0D^{*0} 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*

A QUALITATIVE PICTURE
OF THE BARRIERS



THE BARRIER, QUALITATIVELY FROM DATA:

$$\left(\frac{B^0}{B^+}\right)_{D\bar{D}\pi} = \left|\frac{V}{V+S}\right|^2 \simeq 2 \rightarrow \frac{S}{V} \simeq \begin{cases} -0.3 \\ -1.7 \end{cases}$$

AND

$$R = \frac{\mathcal{B}(B^+ \to K^+ X_u)\mathcal{B}(X_u \to D^0 \bar{D}^0 \pi^0)}{\mathcal{B}(B^+ \to K^+ X_d)\mathcal{B}(X_d \to J/\psi \pi^+ \pi^-)} \simeq 10$$

and

$$R = \left|\frac{V+S}{V}\right|^2 \frac{\mathcal{B}(X_u \to D^0 \bar{D}^0 \pi^0)}{\mathcal{B}(X_d \to J/\psi \pi^+ \pi^-)}$$

THEREFORE IT FOLLOWS

$$\mathcal{B}(X_d \to J/\psi \pi^+ \pi^-) \simeq \frac{1}{20} \mathcal{B}(X_u \to D^0 \bar{D}^0 \pi^0)$$

VISIBILITY LIMIT (NO SUSPECT OF TWO INTERFERING STRUCTURES)

$$\mathcal{B}(B^+ \to K^+ X_u)\mathcal{B}(X_u \to \psi\pi\pi) < \frac{1}{3} \times \mathcal{B}(B^+ \to K^+ X_d)\mathcal{B}(X_d \to \psi\pi\pi)$$

$$\Rightarrow \qquad \mathcal{B}(X_u \to \psi\pi\pi) \lesssim \frac{1}{30} \times \mathcal{B}(X_u \to D\bar{D}\pi)$$

we put the X_u here because we trust that it decays in psi

rosso inventato...

EFFECTIVE DECAY LAGRANGIAN

$$\mathcal{L}_{eff} = \lambda^u_{\psi V} \, \frac{1}{M_\rho} \epsilon^{\mu\nu\rho\sigma} (p_V)_\mu V_\nu \psi_\rho X^{(u)}_\sigma + \lambda^u_{D^* D} \, X^{(u)\mu} (\bar{D}^{*0}_\mu D^0 - \bar{D}^0 D^{*0}_\mu) \simeq$$

$$\simeq \lambda^u_{\psi V} \, \mathbf{X}^{(u)} \cdot (\mathbf{V} \times \psi) + \lambda^u_{D^* D} \, \mathbf{X}^{(u)} \cdot (\mathbf{D}^{*0} D^0 - \mathbf{D}^{*0} \bar{D}^0)$$

how the limit in the latter slide transforms in a value for the couplings?

FROM WHAT DISCUSSED ABOVE WE EXPECT

$$\lambda^u_{\psi V} \ll \lambda^u_{D^* D}$$

LET US COMPUTE THE REDUCED RATES γ OF THE DECAYS ACCORDING TO:

$$\Gamma(X_{u,d} \to f) = |\lambda|^2 \gamma(f)_{u,d}$$

THE REDUCED RATES FOUND FOR THE 3-BODY DECAYS AT HAND ARE

	$f = J/\psi\pi^+\pi^-$	$f = D^0\bar{D}^0\pi^0$	$f = D^+D^-\pi^0$	$f = J/\psi\pi^+\pi^0$	$f = D^+\bar{D}^0\pi^0$
X(3876)=$X_u \to f$	0.59	0.26	$4.5{\cdot}10^{-7}$	—	
X(3872)=$X_d \to f$	0.56	0.0102	0	—	
$X^+(3877) \to f$	—	—	—	1.2	
$X^+(3876) \to f$	—	—	—	1.2	

N.B. THE ρ IS MUCH BROADE[R] THAN D* (FACTOR ~2000)

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

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

COUPLINGS

USING THE RESULT OBTAINED BEFORE

$$\mathcal{B}(X_u \to \psi\pi\pi) \lesssim \frac{1}{30} \times \mathcal{B}(X_u \to D\bar{D}\pi)$$

AND THE RATIO OF REDUCED RATES 0.26/0.59 FROM TABLE, WE GET INDEED

$$\frac{\lambda^u_{\psi V}}{\lambda^u_{D^* D}} \sim 0.13$$

and $\Gamma(X_u \to J/\psi\pi^+\pi^-) \simeq \Gamma(X_d \to J/\psi\pi^+\pi^-) \leq 0.1$ MeV

but we expect X+ just in between of Xu and Xd. u-->d but a repulsion transforms into attraction

PICTURE

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

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

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

I.E., THE LIMIT

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

SUMMARY

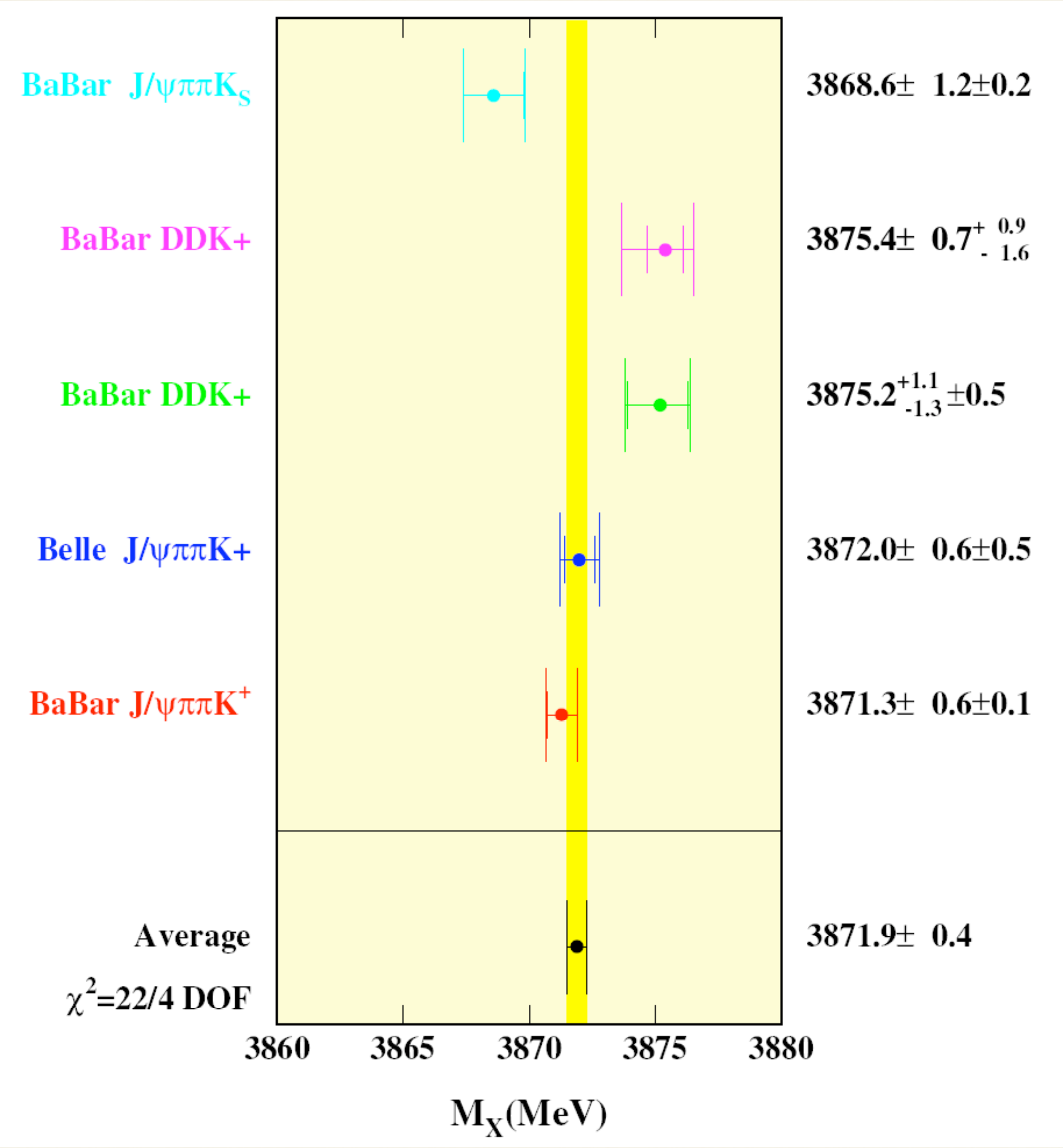
- ARE X(3872) AND X(3876) TWO DIFFERENT PARTICLES? WE GUESS SO AND IDENTIFY THEM AS THE X_d AND X_u OF THE 4Q MODEL

- INDEED THEY CAN EFFECTIVELY BE ACCOMODATED AS THE NEUTRAL COMPONENTS OF A COMPLEX OF FOUR STATES CONTAINING ALSO TWO CHARGED PARTICLES

- MAYBE THE CHARGED PARTNERS HAVE TO BE SEARCHED IN OPEN CHARM FINAL STATES: $X^+ \to D^+ D^- \pi^0$

- SEE MAIANI, POLOSA, RIQUER arXiv:0707.3354

MASSES


BaBar J/ψππK$_S$
3868.6± 1.2±0.2
BaBar DDK+
3875.4± 0.7$^{+0.9}_{-1.6}$
BaBar DDK+
3875.2$^{+1.1}_{-1.3}$±0.5
Belle J/ψππK+
3872.0± 0.6±0.5
BaBar J/ψππK$^+$
3871.3± 0.6±0.1
Average
3871.9± 0.4
χ^2=22/4 DOF
3860
3865
3870
3875
3880
M$_X$(MeV)

BUT...

BELLE AND, VERY RECENTLY, BABAR
REPORT A PEAK IN $DD\pi$ AT A MASS 3875
~2.5 MEV AWAY FROM X(3872)!
TWO STATES?

MOLECULES? $DD\pi$ IS OBSERVED TO OCCUR
AT A LARGER RATE THAN $J\rho$

By Swanson hep-ph/0311229

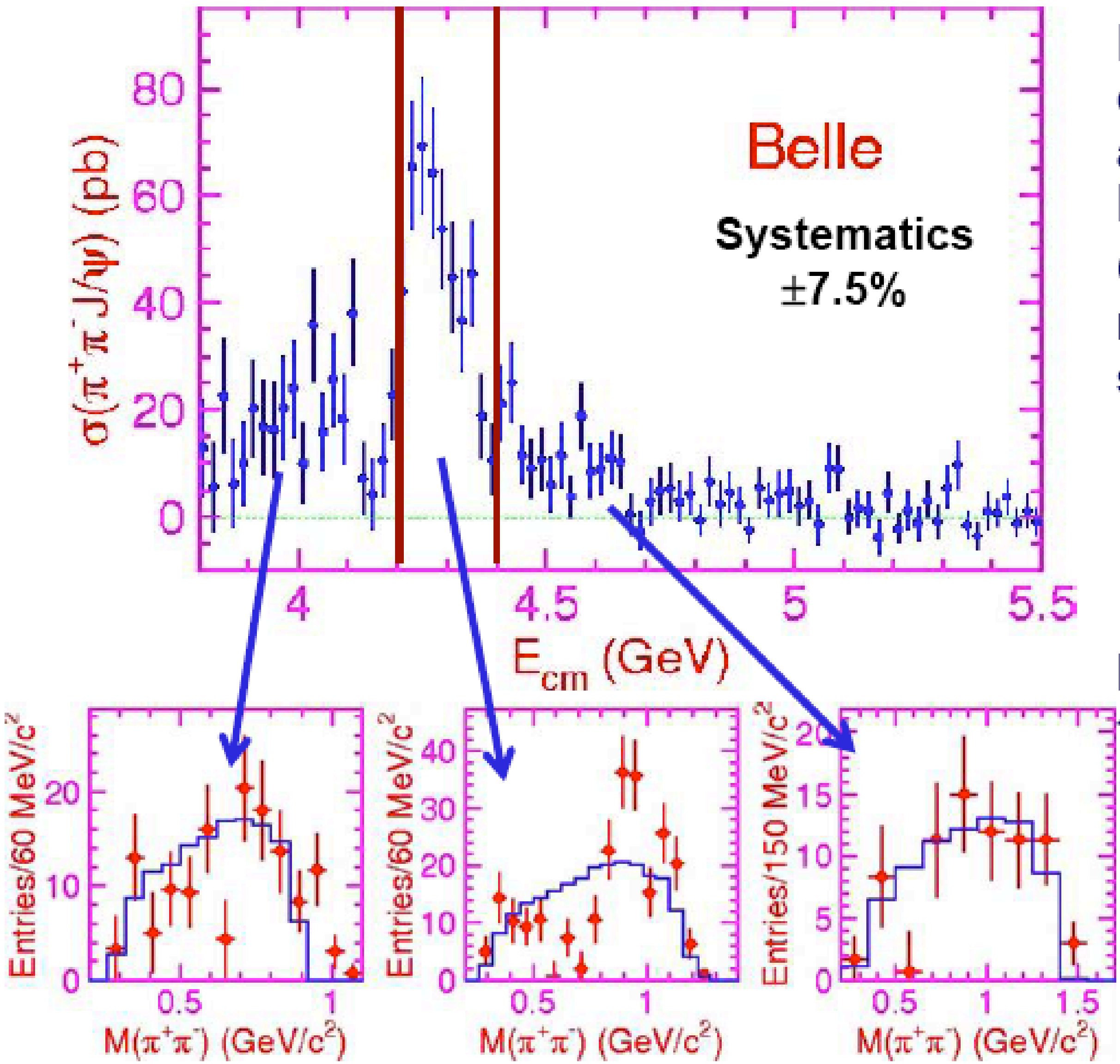
B_E (MeV)	$D^0\bar{D}^0\pi^0$	$\pi^+\pi^- J/\psi$	$\pi^+\pi^-\pi^0 J/\psi$
0.7	67	1290	720
1.0	66	1215	820
2.0	57	975	1040

WHICH AGREES WITH THE SIMPLE EXPECTATION

$$\Gamma(DD\pi) \sim \Gamma(D^{*0}) = 70 \text{ KeV}$$

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 $\sqrt{s}$ 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