On the structure of X(3872) resonance

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The experimental discovery of X(3872)

Belle Collaboration, Phys.Rev.Lett.91:262001,2003.
Observation of a narrow charmonium-like state in the $B^{\pm} \to K^{\pm} X$, $X \to J/\Psi \pi^+ \pi^-$, $M_X = 3872.0 \pm 0.6(\mathrm{stat}) \pm 0.5(\mathrm{syst})$ MeV, very near the $M_D + M_{D^*}$ mass threshold. $\Gamma < 2.3$MeV. $\pi\pi$ produced from ρ decay.

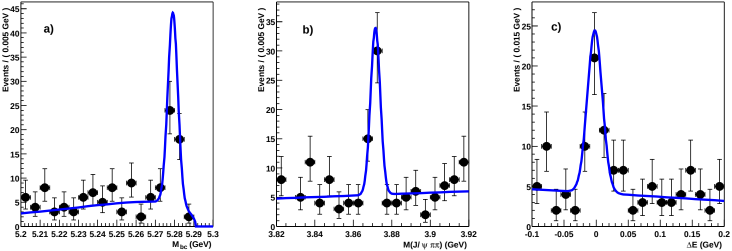


Figure: $M_{J/\Psi\pi^+\pi^-}$ invariant mass spectrum

Confirmed by B. Aubert et al. (BaBar Collaboration), Phys. Rev **D71**(2005)071103; D. Acosta et al. (CDF II Collaboration), Phys. Rev. Lett. **93**(2004)072001; V. M. Abazov et al., (D0 Collaboration), Phys. Rev. Lett.**93**(2004)162002

Newest results from BaBar, arXive: 0803.2838v1:

$$\begin{aligned} Br(B^0 \to XK^0) \times Br(X \to J/\Psi\pi^+\pi^-) &= (3.5 \pm 1.9 \pm 0.4) \times 10^{-6} \\ Br(B^+ \to XK^+) \times Br(X \to J/\Psi\pi^+\pi^-) &= (8.4 \pm 1.5 \pm 0.7) \times 10^{-6} \end{aligned}$$

$$R(X) = \frac{Br(B^0 \to XK^0)}{Br(B^+ \to XK^+)} = 0.41 \pm 0.24 \pm 0.05 \ . \qquad (1)$$

$X(3872) \to J/\Psi\ \pi^+\pi^-\pi^0$ channel

K. Abe et al. (Belle Collaboration), hep-ex/0505037, B. Aubert et al., Phys. Rev. **D74**(2006)071101:
$X(3872) \to J/\Psi\ \pi^+\pi^-\pi^0\ \ (J/\Psi\omega)$
$X(3872) \to J/\Psi\gamma$

$$\begin{aligned} \frac{\mathrm{Br}(X \to \pi^+\pi^-\pi^0 J/\Psi)}{\mathrm{Br}(X \to \pi^+\pi^- J/\Psi)} &= 1.0 \pm 0.4 \pm 0.3\ , \\ \frac{\mathrm{Br}(X \to \gamma J/\Psi)}{\mathrm{Br}(X \to \pi^+\pi^- J/\Psi)} &= 0.14 \pm 0.05\ . \end{aligned}$$

Strong isospin violation effects!

$X \to D^0 \bar{D}^0 \pi^0$ decays

S. K. Choi et al. (Belle Collaboration), Phys. Rev. Lett. 97(2006)162002:

$$\mathrm{Br}(B^+ \to K^+ D^0 \bar{D}^0 \pi^0) = (1.27 \pm .31^{+0.22}_{-0.39}) \times 10^{-4} \ . \qquad (2)$$

$$M_X = 3875.2 \pm 0.7^{+0.3}_{-1.6} \pm 0.8\mathrm{MeV} \qquad (3)$$

Roughly 4 MeV greater than the mass determined from $J/\Psi\pi\pi$ and $J/\Psi\pi\pi\pi$ decays!

A puzzle has to be understood!

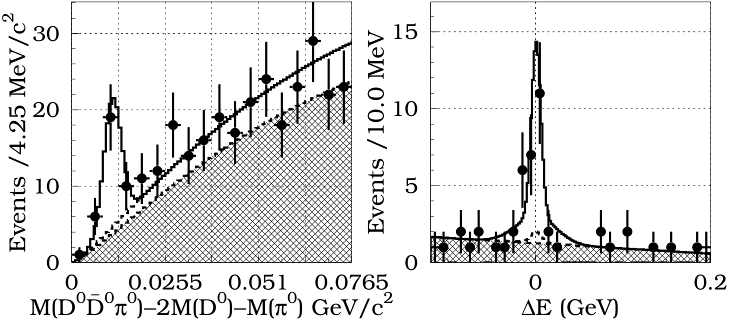
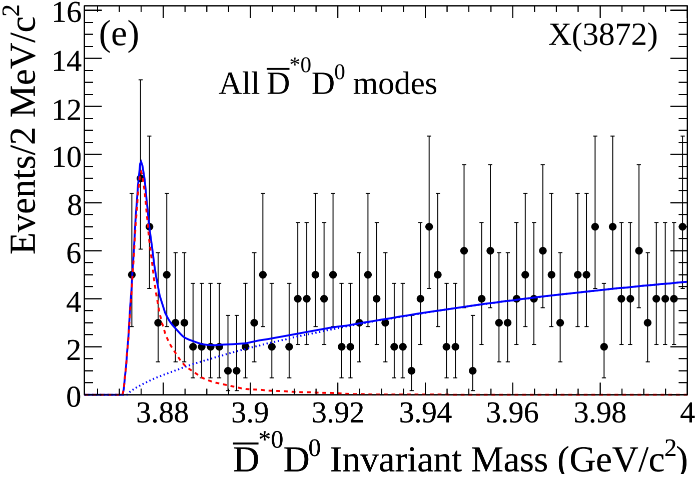


Figure: $M_{D^0\bar{D}^0\pi^0}$ invariant mass spectrum

New measurement on $X \to D^0 \bar{D}^0 \pi^0$

BABAR Collaboration, Phys. Rev. D77: 011102,2008.



Theoretical explanations

1. Normal $c\bar{c}$ state. (C. Meng and K.T. Chao, PRD75, 114002)
2. Tetra quark model predicts two branching ratios equal. See Eq. (1) (L. Maiani et al., Phys. Rev. D71(2005)014028.)
3. Molecule model predicts the neutral mode much smaller than the charged mode. (E. Braaten and M. Kusunoki, Phys. Rev. D71(2005)074005).
4. Dynamical complexity: couple channel effects, cusp, etc. (D.V. Bugg, e-Print: arXiv:0802.0934 [hep-ph])

Complicated cuts and couple channels effects

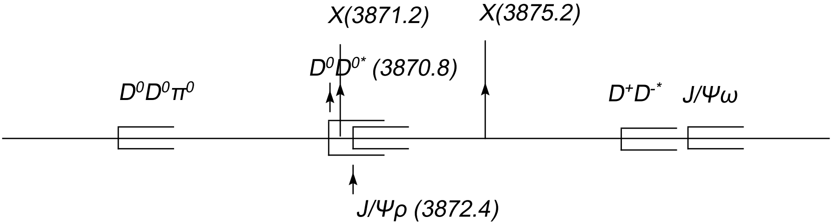
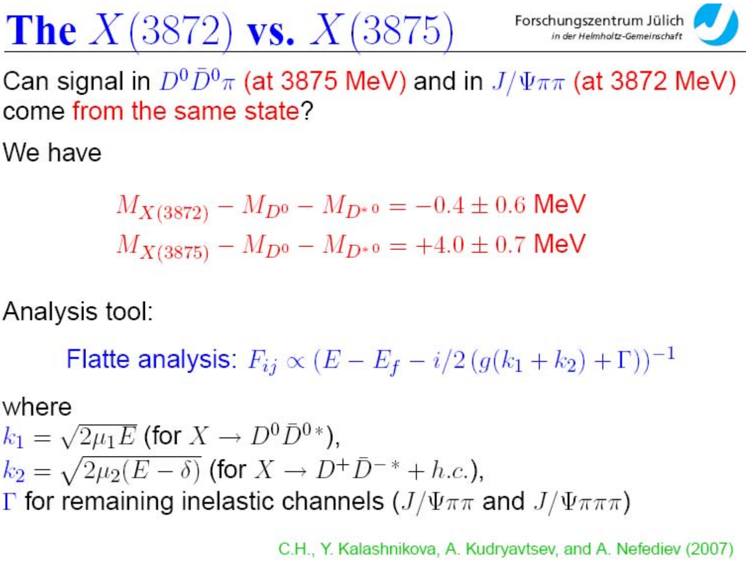


Figure: Cut structure around X(3872)



The $X(3872)$ vs. $X(3875)$

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Can signal in $D^0\bar{D}^0\pi$ (at 3875 MeV) and in $J/\Psi\pi\pi$ (at 3872 MeV) come from the same state?

We have

$$M_{X(3872)} - M_{D^0} - M_{D^{*0}} = -0.4 \pm 0.6 \text{ MeV}$$
$$M_{X(3875)} - M_{D^0} - M_{D^{*0}} = +4.0 \pm 0.7 \text{ MeV}$$

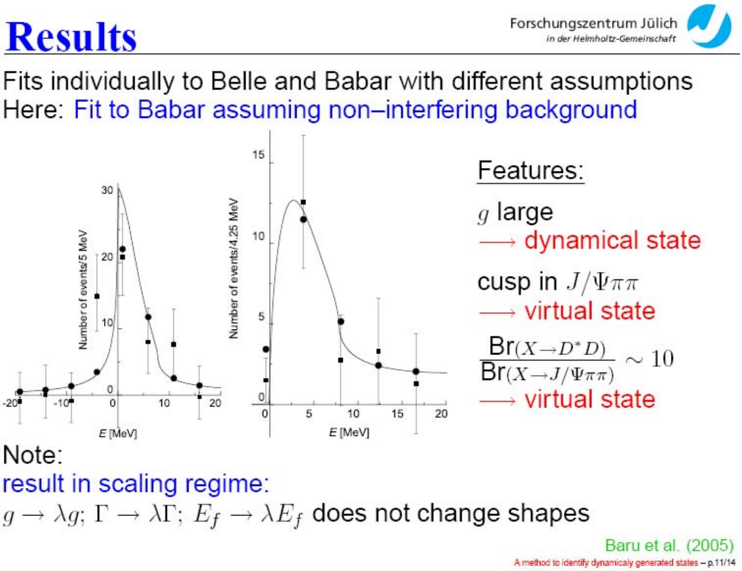
Analysis tool:

Flatte analysis: $F_{ij} \propto (E - E_f - i/2\,(g(k_1 + k_2) + \Gamma))^{-1}$

where
$k_1 = \sqrt{2\mu_1 E}$ (for $X \to D^0\bar{D}^{0*}$),
$k_2 = \sqrt{2\mu_2(E-\delta)}$ (for $X \to D^+\bar{D}^{-*} + h.c.$),
Γ for remaining inelastic channels ($J/\Psi\pi\pi$ and $J/\Psi\pi\pi\pi$)

C.H., Y. Kalashnikova, A. Kudryavtsev, and A. Nefediev (2007)

Figure:



Results

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Fits individually to Belle and Babar with different assumptions
Here: Fit to Babar assuming non–interfering background

Features:

g large
⟶ dynamical state

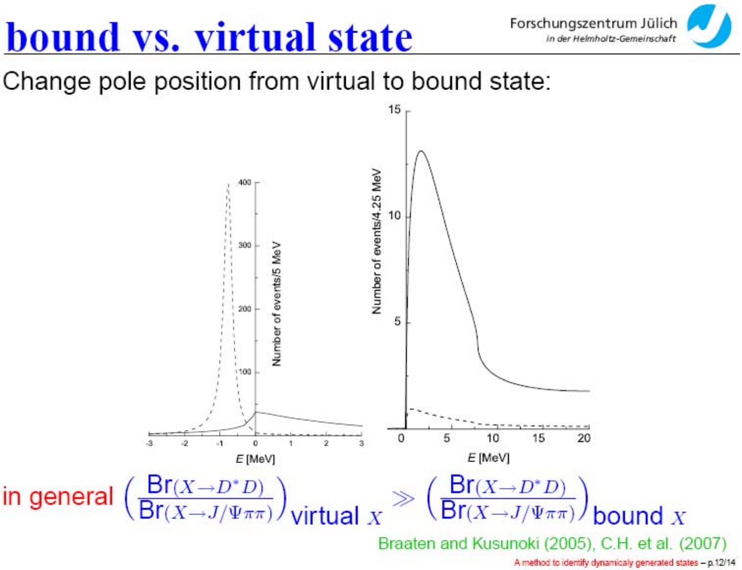
cusp in $J/\Psi\pi\pi$
⟶ virtual state

$\frac{\text{Br}(X\to D^* D)}{\text{Br}(X\to J/\Psi\pi\pi)} \sim 10$
⟶ virtual state

Note:
result in scaling regime:
$g \to \lambda g$; $\Gamma \to \lambda\Gamma$; $E_f \to \lambda E_f$ does not change shapes

Baru et al. (2005)

A method to identify dynamicaly generated states – p.11/14



bound vs. virtual state

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Change pole position from virtual to bound state:

in general $\left(\frac{\mathrm{Br}(X\to D^*D)}{\mathrm{Br}(X\to J/\Psi\pi\pi)}\right)_{\text{virtual } X} \gg \left(\frac{\mathrm{Br}(X\to D^*D)}{\mathrm{Br}(X\to J/\Psi\pi\pi)}\right)_{\text{bound } X}$

Braaten and Kusunoki (2005), C.H. et al. (2007)

A method to identify dynamicaly generated states – p.12/14

Bound state, virtual state, resonances

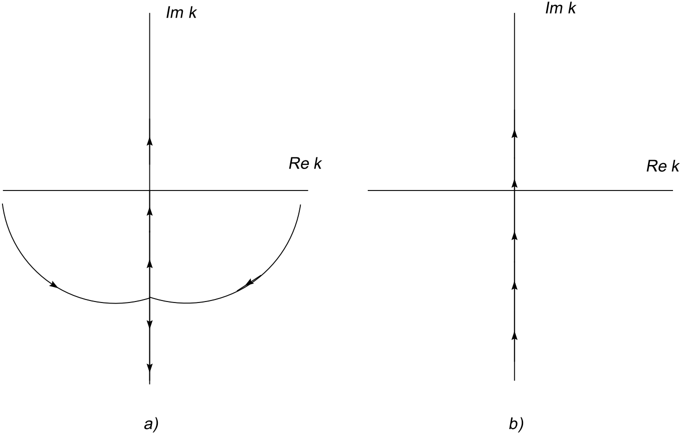


Figure: Typical behavior of pole trajectories w.r.t. coupling strength.

Dispersive part important, provides cusp at threshold!

(D.V. Bugg, e-Print: arXiv:0802.0934 [hep-ph])

$$ik(E) \Rightarrow \frac{1}{\pi}\int_{th.}^{\Lambda} dE' \frac{k(E')}{E' - E - i\epsilon} \tag{4}$$

Rewrite Breit-Wigner propagator; Refit with new data!

New Flatte Parametrization

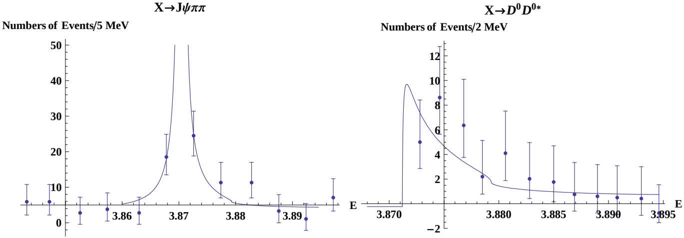
with Dispersive integral,Breit-Wigner propagator:

$$D(E) = E - E_f + \frac{1}{\pi}\int_{th.}^{\Lambda} dE' \frac{gk_1(E') + gk_2(E')}{E' - E - i\epsilon} + \frac{i}{2}\Gamma(E) \qquad (5)$$

Based on Belle and Babar new measurement on X(3872) decay,
$g \simeq 0.11$, $Ef \simeq 3.41$,$f\rho \simeq 0.00079$,$f\omega \simeq 0.0060$
Attention:g, smaller, and cut-dependence to some extent

New Results

Based on Belle and Babar new measurement on X(3872) decay



peak in $J/\Psi\pi^+\pi^-$: higher and narrower

Bound or Virtual State, or Resonances?

Hunting poles on Riemann surface for coupling channels,

1. On the Third Sheet ($J/\Psi\pi^+\pi^-$ and $D^0\bar{D}^{0\star}$ threshold), $a = -17.04 \pm 0.17i$, far below $D^0\bar{D}^{0\star}$ threshold, crazy resonance!
2. On the Second Sheet (for only $J/\Psi\pi^+\pi^-$ threshold), $a = -0.45 \pm 0.04i$, close to threshold

Not virtual state for $D^0\bar{D}^{0\star}$, but typical molecular bound state!

Bound or Virtual State, or Resonances?

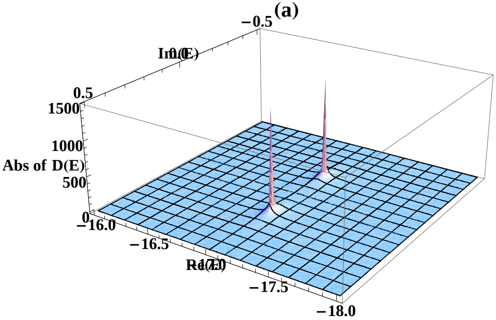


Figure: the Third Sheet of Riemann Surface:(a)for both $J/\Psi\pi^+\pi^-$ and $D^0\bar{D}^{0\star}$ threshold

Bound or Virtual State, or Resonances?

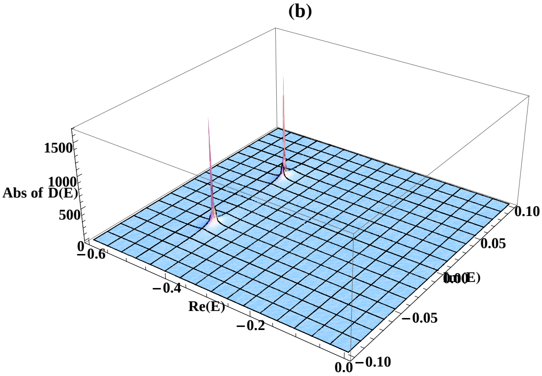


Figure: the Second Sheet of Riemann Surface:(b)for only $J/\Psi\pi^+\pi^-$ threshold

Thank you!