Y(4660) as a $\psi' f_0(980)$ state
Prediction: an $\eta_c' f_0(980)$ bound state
$X(4630)$ and $Y(4660)$

Summary

Heavy quark spin symmetry and heavy meson hadronic molecules

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Based on:
Towards identifying heavy hadronic molecules

- Spin dependent int. suppressed by $1/m_Q \Rightarrow$ heavy quark spin symmetry
  $\Rightarrow$ leading heavy–light hadron interaction preserves spin symmetry $\Rightarrow$
  spin multiplet of heavy hadronic molecules with almost the same mass splitting with the heavy hadrons

E.g., $M_D + M_K - M_{D_0}^{*}(2317) \approx M_{D^*} + M_K - M_{D_{s1}}(2460)$

Towards identifying heavy hadronic molecules

- Spin dependent int. suppressed by $1/m_Q \Rightarrow$ heavy quark spin symmetry
  - leading heavy–light hadron interaction preserves spin symmetry $\Rightarrow$
    spin multiplet of heavy hadronic molecules with almost the same mass splitting
    with the heavy hadrons
  - E.g., $M_D + M_K - M_{D_s^*}(2317) \approx M_{D^*} + M_K - M_{D_{s1}(2460)}$

- General theorem for $S$-wave loosely bound states:
  \[
  \frac{g^2}{4\pi} = 4(m_1 + m_2)^2 \sqrt{\frac{2\epsilon}{\mu}} \left[ 1 + O\left(\frac{r}{a}\right) \right]
  \]
  $g$: coupling cons., $\epsilon$: binding energy, $\mu$: reduced mass, $r$: force range
  scattering length $a = -1/\sqrt{2\mu\epsilon}$ at LO

Experimental facts of the $Y(4660)$

- Observed in the $\pi^+\pi^-\psi'$ invariant mass distribution in $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-\psi'$
  
  \[ M_Y = 4664 \pm 11 \pm 5 \text{ MeV}, \quad \Gamma_Y = 48 \pm 15 \pm 3 \text{ MeV}, \quad J^{PC} = 1^{--} \]

- Not observed in:
  
  \[ e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^- J/\psi, \ D\bar{D}, \ D\bar{D}^*, \ D^*\bar{D}^*, \ D\bar{D}_{\pi}, \ J/\psi D^{(*)}\bar{D}^{(*)}. \]

- Single peak in the $\pi\pi$ mass distribution at the high end.

**WHY?**

**Experiment**

$X. L. \text{ Wang, et al. [Belle Collaboration], PRL99(2007)142002.}$

- Guo
- Heavy meson hadronic molecules
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Y(4660)—a loosely $\psi' f_0(980)$ bound state

- Proximity of the mass to the threshold
  \[ M(\psi') + M(f_0) = 4666 \pm 10 \text{ MeV}. \]


Guo

Heavy meson hadronic molecules
Proximity of the mass to the threshold
\[ M(\psi') + M(f_0) = 4666 \pm 10 \text{ MeV}. \]

Explain naturally why observed in the \( \pi^+\pi^-\psi' \) final state.
Proximity of the mass to the threshold \( M(\psi') + M(f_0) = 4666 \pm 10 \text{ MeV} \).

Explain naturally why observed in the \( \pi^+ \pi^- \psi' \) final state.

Explain naturally the single peak in the \( \pi\pi \) mass distribution.
Y(4660)—a loosely $\psi' f_0(980)$ bound state

- Proximity of the mass to the threshold $M(\psi') + M(f_0) = 4666 \pm 10$ MeV.
- Explain naturally why observed in the $\pi^+ \pi^- \psi'$ final state.
- Explain naturally the single peak in the $\pi \pi$ mass distribution.
- QCD van der Waals interaction is attractive.

May be strong enough to form bound states (Hadro-charmonia).


Brodsky, Miller, PLB412(1997)125

Y(4660) as a $\psi' f_0(980)$ state
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**Summary**

Fit to the data

We use

$$\frac{g^2}{4\pi} = 4(m_1 + m_2)^2 \sqrt{\frac{2\epsilon}{\mu}}.$$ 

Two parameters fit to the $\psi' \pi^+ \pi^-$ invariant mass distribution (solid)

$$N = 10 \pm 2 \text{ GeV}^2, \quad M_Y = 4665^{+3}_{-5} \text{ MeV}.$$ 

$\Rightarrow g = 11 \sim 14 \text{ GeV}.$

If we loosen the b.s. constraint of $g$ (dashed)

$$M_Y = 4672 \pm 9 \text{ MeV}, \quad g = 13 \pm 2 \text{ GeV}.$$
Predicted $\pi^+\pi^-$ and $K^+K^-$ invariant mass spectra

Predictions:

- Solid curves: from the best fit with two parameters ($N$, $M_Y$).
- Dashed curves: from the best fit with three parameters ($N$, $M_Y$, $g$).
Spin partner: $Y_\eta$—an $\eta'_c f_0(980)$ bound state

If the $Y(4660)$ is a $\psi' f_0(980)$ bound state, there should be an $\eta'_c f_0(980)$ bound state, $Y_\eta$, since spin-dep. int. suppressed by $1/m_Q^2$!

$$M_{Y_\eta} = M_Y - (M_{\psi'} - M_{\eta'_c}) = 4616^{+5}_{-6} \text{ MeV}, \quad \Gamma(Y_\eta \to \eta'_c \pi\pi) = 60\pm30 \text{ MeV}.$$
Y(4660) as a $\psi' f_0(980)$ state
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Summary
Suggested searching channels

$B^\pm \rightarrow K^\pm \eta'_c \pi^+ \pi^-$, not measured

$$B (B^\pm \rightarrow \eta'_c K^\pm \pi^+ \pi^-) \approx B (B^\pm \rightarrow \eta'_c K^\pm) \frac{B (B^\pm \rightarrow \psi' K^\pm \pi^+ \pi^-)}{B (B^\pm \rightarrow \psi' K^\pm)} \sim 1 \times 10^{-3}$$
Suggested searching channels

- \( B^\pm \rightarrow K^\pm \eta_c' \pi^+ \pi^- \), not measured

\[
B(B^\pm \rightarrow \eta_c' K^\pm \pi^+ \pi^-) \approx B(B^\pm \rightarrow \eta_c' K^\pm) \frac{B(B^\pm \rightarrow \psi' K^\pm \pi^+ \pi^-)}{B(B^\pm \rightarrow \psi' K^\pm)} \sim 1 \times 10^{-3}
\]

- \( B \rightarrow K \Lambda_c^+ \Lambda_c^- \), measured branching fraction (PDG2008)

\[
B(B^+ \rightarrow K^+ \Lambda_c^+ \Lambda_c^-) = (8.7 \pm 3.5) \times 10^{-4}
\]

[Signal for both the \( Y(4660) \) and \( Y_\eta \)?]
Prediction: an $\eta_c' f_0(980)$ bound state $X(4630)$ and $Y(4660)$

Summary

Suggested searching channels

- $B^{\pm} \rightarrow K^{\pm} \eta_c' \pi^+ \pi^-$, not measured
  \[ \mathcal{B}(B^{\pm} \rightarrow \eta_c' K^{\pm} \pi^+ \pi^-) \approx \mathcal{B}(B^{\pm} \rightarrow \eta_c' K^{\pm}) \frac{\mathcal{B}(B^{\pm} \rightarrow \psi' K^{\pm} \pi^+ \pi^-)}{\mathcal{B}(B^{\pm} \rightarrow \psi' K^{\pm})} \sim 1 \times 10^{-3} \]

- $B \rightarrow K \Lambda_c^+ \Lambda_c^-$, measured branching fraction (PDG2008)
  \[ \mathcal{B}(B^+ \rightarrow K^+ \Lambda_c^+ \Lambda_c^-) = (8.7 \pm 3.5) \times 10^{-4} \]
  
  BaBar, PRD77(2008)031101

Signal for both the $Y(4660)$ and $Y_{\eta}$?

Could also be the consequence of a $\Xi_c^0(2930)$ with $J^P = \frac{3}{2}^+$ ($\Lambda_c^+ K^-$ in P-wave final state, $J^P = ?$ in PDG).

Or their combined effect.
$X(4630)$ observed in $e^+ e^- \rightarrow \gamma_{\text{ISR}} \Lambda_c^+ \Lambda_c^-$

Belle, PRL101(2008)172001

A new resonance?
The same as $Y(4660)$?


Heavy meson hadronic molecules
Reconciling the $X(4630)$ with the $Y(4660)$

$1^{--}$: $\Lambda_c^+\Lambda_c^-$ in $S$-wave ($^3S_1$), FSI effect should be taken into account!

A combined fit:

$$\frac{\Gamma(Y(4660) \rightarrow \Lambda_c^+\Lambda_c^-)}{\Gamma(Y(4660) \rightarrow \psi'\pi^+\pi^-)} = 11.5,$$

$$\frac{\Gamma(Y_\eta \rightarrow \Lambda_c^+\Lambda_c^-)}{\Gamma(Y_\eta \rightarrow \psi'\pi^+\pi^-)} = 2.7$$

Additional width $\lesssim 30$ MeV other than $\Lambda_c^+\Lambda_c^-$ and $\psi'\pi\pi$ is still allowed.

Heavy quark spin symmetry
⇒ spin *multiplet* of heavy hadronic molecules

*Y(4660) as a $\psi'f_0(980)$ bound state*
  * Data show evidence that the $Y(4660)$ is a $\psi'f_0(980)$ bound state
  * The $X(4630)$ in the $\Lambda_c^+\Lambda_c^-$ spectrum may be the same state
  * Heavy quark spin symmetry ⇒ spin partner, an $\eta'_c f_0(980)$ bound state

Suggested channels for searching for the spin partner
  * $B \to K\eta'_c \pi^+\pi^-$
  * $B \to K\Lambda_c^+\Lambda_c^-$ (A signal already existed in BaBar’s data?)
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$\Lambda_c^+ \Lambda_c^-$ FSI in the $^3S_1$ channel

Haidenbauer, Krein, PLB687(2010)314

$H / (\text{MeV})$
$p / |J|^2$
$1 / |J|^2$

Guo

Heavy meson hadronic molecules
New results including $\Lambda_c^+ \Lambda_c^-$

Three parameters:

\[ N = 237^{+40}_{-36}, \quad M_Y = 4662.5^{+0.1}_{-0.2} \text{ MeV}, \quad g_{Y\Lambda_c\Lambda_c} = 0.7 \pm 0.1 \]

Partial widths:

\[ \Gamma( Y(4660) \rightarrow \psi' \pi^+ \pi^- ) = 8 \text{ MeV}, \quad \Gamma( Y(4660) \rightarrow \Lambda_c^+ \Lambda_c^- ) = 93 \text{ MeV} \]

New predictions for the $Y_\eta$