

Heavy quark spin symmetry and heavy meson hadronic molecules

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Based on:

F.K.G., C. Hanhart, U.-G. Meißner, Phys.Lett.B665(2008)26; Phys.Rev.Lett.102(2009)242004;
F.K.G., J. Haidenbauer, C. Hanhart, U.-G. Meißner, arXiv:1005.2055 [hep-ph].

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.,

$$M_D + M_K - M_{D_{s0}^*(2317)} \approx M_{D^*} + M_K - M_{D_{s1}(2460)}$$

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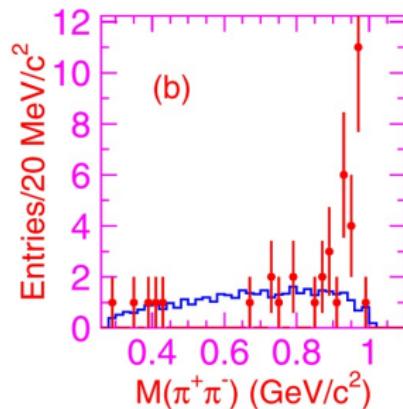
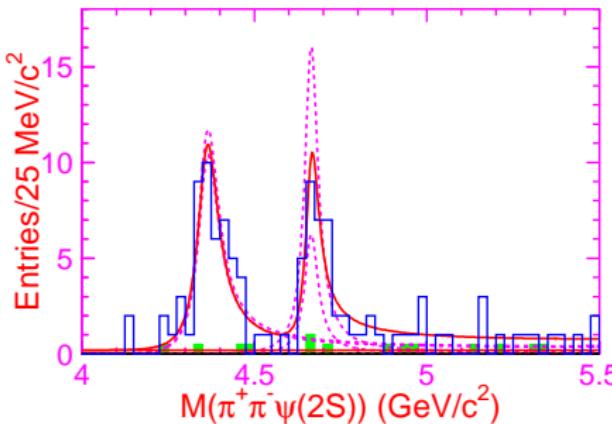
- General theorem for S-wave loosely bound states:

$$\frac{g^2}{4\pi} = 4(m_1 + m_2)^2 \sqrt{\frac{2\epsilon}{\mu}} \left[1 + \mathcal{O}\left(\frac{r}{a}\right) \right]$$

g : coupling cons., ϵ : binding energy, μ : reduced mass, r : force range
scattering length $a = -1/\sqrt{2\mu\epsilon}$ at LO

S. Weinberg, PR130(1963)776; 131(1963)440; 137(1965)B672. V. Baru, *et al.*, PLB586(2004)53.

Experimental facts of the $\Upsilon(4660)$



X.L. Wang, et al. [Belle Collaboration], PRL99(2007)142002.

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

$Y(4660)$ —a loosely $\psi' f_0(980)$ bound state

F.K.G., Hanhart, Meißner, PLB665(2008)26

- Proximity of the mass to the threshold
 $M(\psi') + M(f_0) = 4666 \pm 10$ MeV.

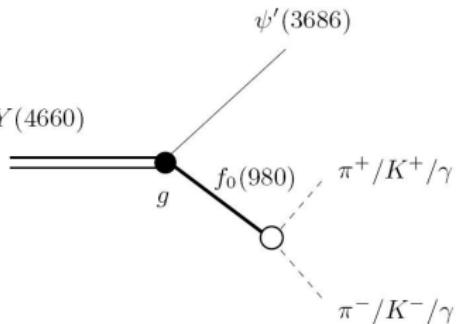
$\psi(4660)$ —a loosely $\psi' f_0(980)$ bound state

F.K.G., Hanhart, Meißner, PLB665(2008)26

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



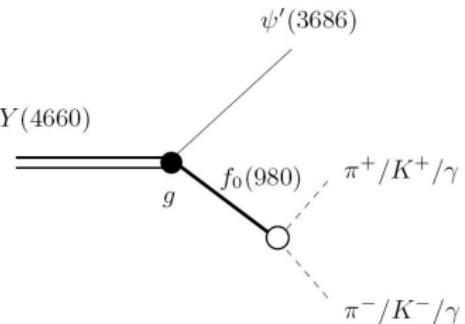
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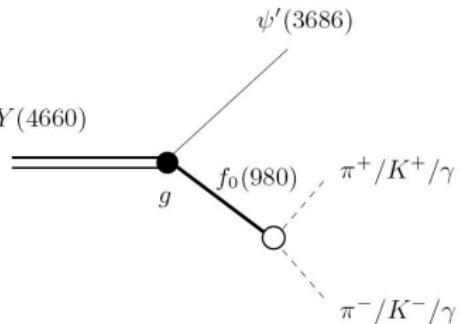
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- Explain naturally the single peak in the $\pi\pi$ mass distribution.
- QCD van der Waals interaction is attractive.

Brodsky, Miller, PLB412(1997)125

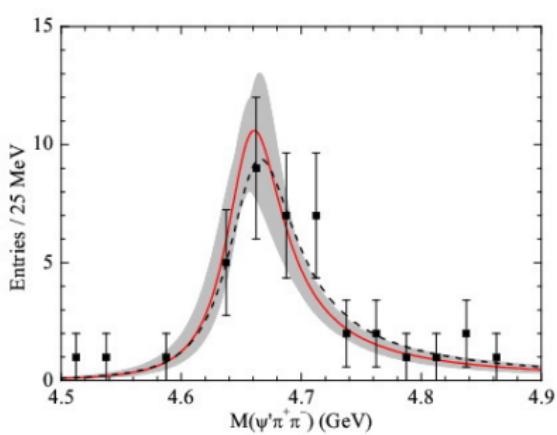
May be strong enough to form bound states (Hadro-charmonia).

Dubynskiy, Voloshin, PLB666(2008)344, Dubynskiy, Gorsky, Voloshin, PLB671(2009)82.

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)

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

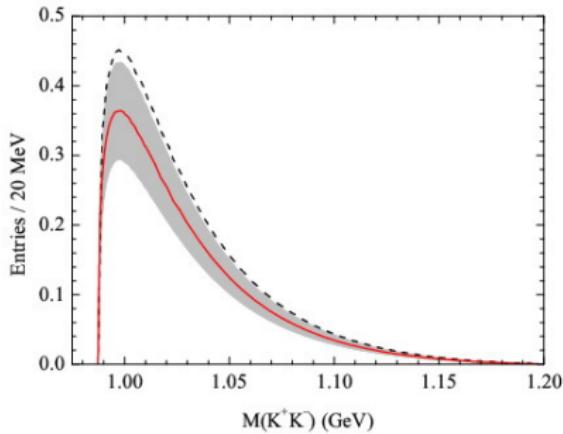
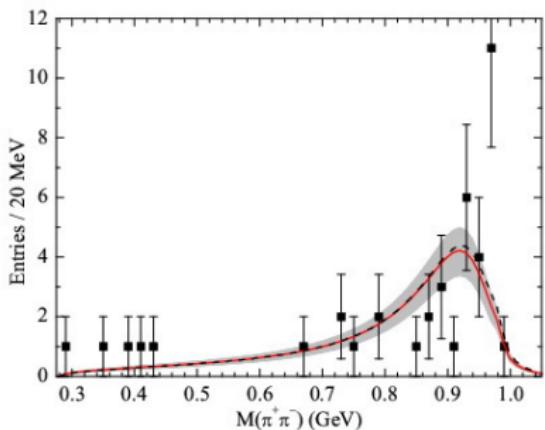
$$\Rightarrow g = 11 \sim 14 \text{ GeV}.$$

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

$$M_Y = 4672 \pm 9 \text{ MeV}, g = 13 \pm 2 \text{ GeV}.$$

Predicted $\pi^+\pi^-$ and K^+K^- invariant mass spectra

Predictions:



Solid curves: from the best fit with two parameters (N, M_Y).

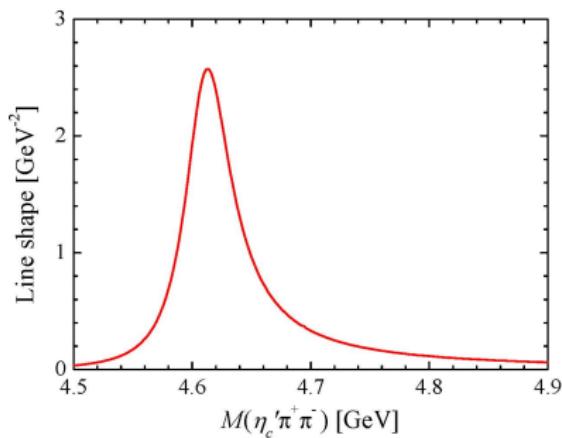
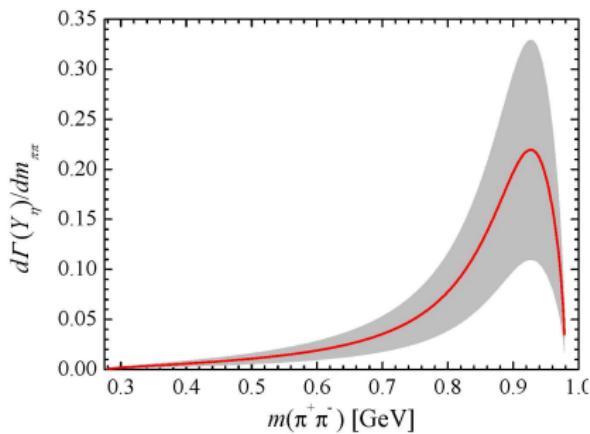
Dashed curves: from the best fit with three parameters (N, M_Y, g).

Spin partner: Y_η —an $\eta'_c f_0(980)$ bound state

F.K.G., Hanhart, Mei&ssner, PRL102(2009)242004

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

$$M_{Y_\eta} = M_Y - (M_{\psi'} - M_{\eta'_c}) = 4616^{+5}_{-6} \text{ MeV}, \quad \Gamma(Y_\eta \rightarrow \eta'_c \pi \pi) = 60 \pm 30 \text{ MeV}.$$



Suggested searching channels

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

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

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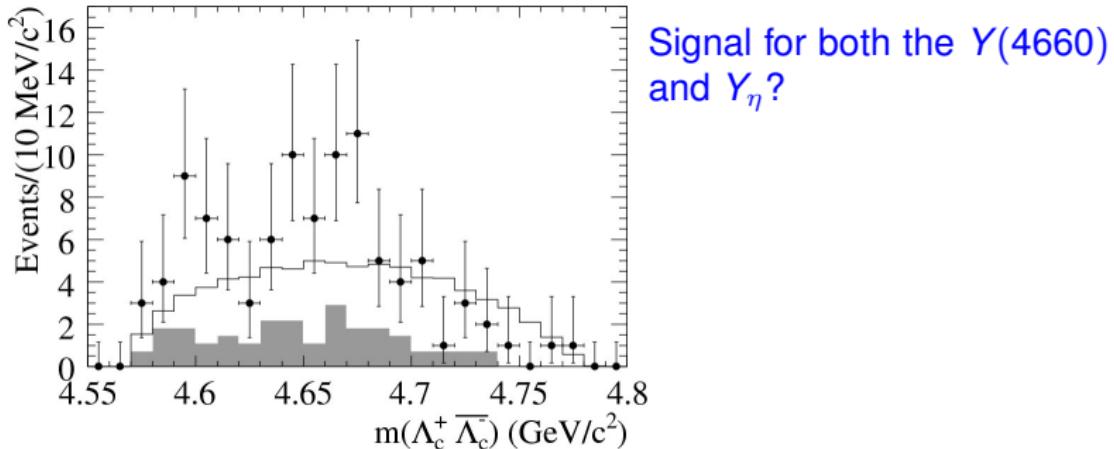
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- $B \rightarrow K \Lambda_c^+ \bar{\Lambda}_c^-$, measured branching fraction (PDG2008)

$$\mathcal{B}(B^+ \rightarrow K^+ \Lambda_c^+ \bar{\Lambda}_c^-) = (8.7 \pm 3.5) \times 10^{-4}$$

BaBar, PRD77(2008)031101



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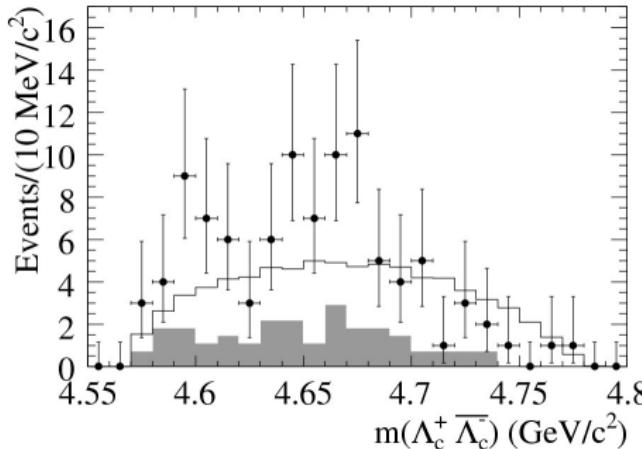
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BaBar, PRD77(2008)031101



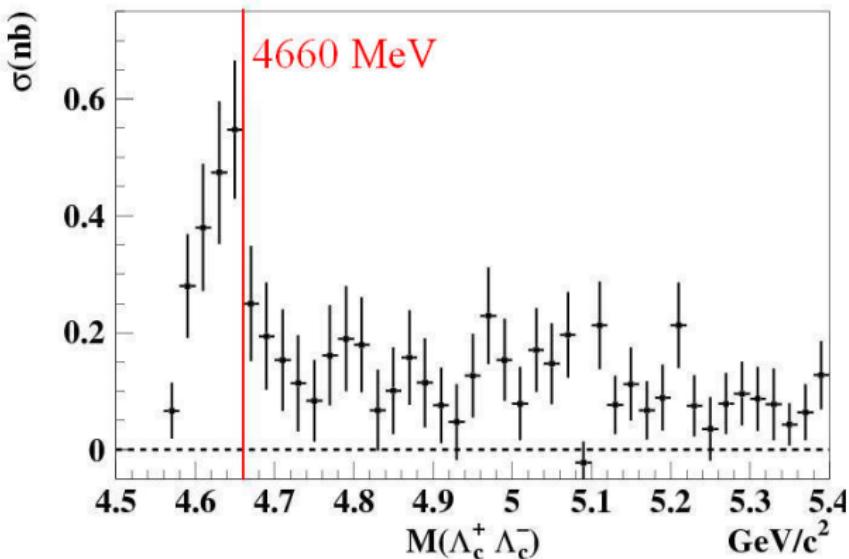
Signal for both the $\Upsilon(4660)$ and Υ_c ?

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 $\Upsilon(4660)$?

Bugg, JPG36(2008)075002; Cotugno et al, PRL104(2010)132005.

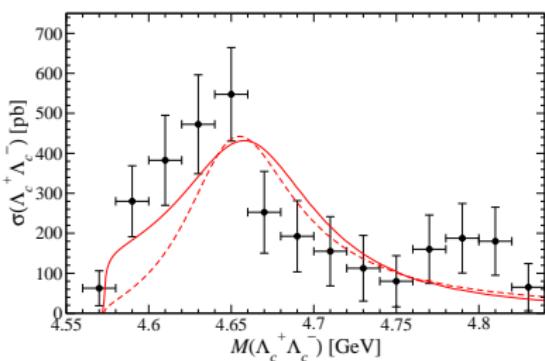
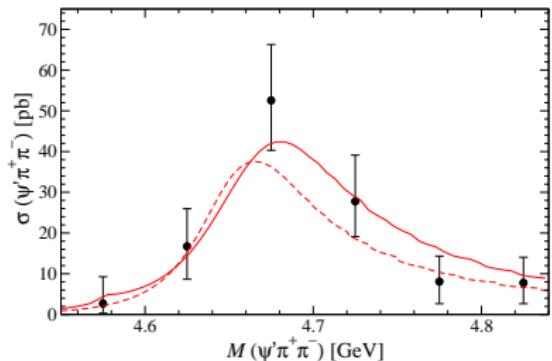
Reconciling the $X(4630)$ with the $Y(4660)$

F.K.G., et al., arXiv:1005.2055 [hep-ph]

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

A combined fit:

FSI: Haidenbauer, Krein, PLB687(2010)314



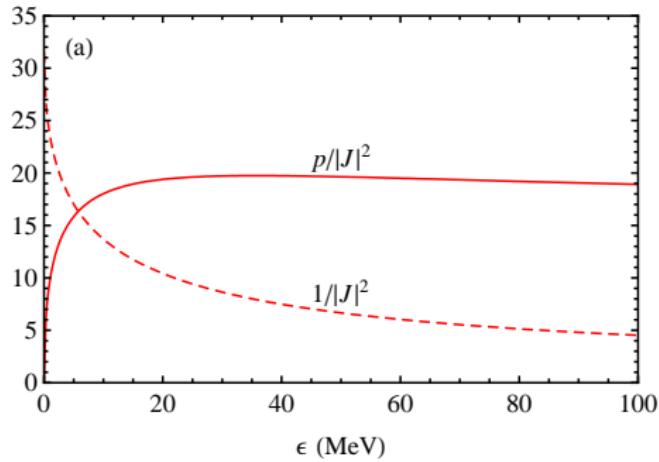
$$\frac{\Gamma(Y(4660) \rightarrow \Lambda_c^+ \Lambda_c^-)}{\Gamma(Y(4660) \rightarrow \psi' \pi^+ \pi^-)} = 11.5, \quad \frac{\Gamma(Y_\eta \rightarrow \Lambda_c^+ \Lambda_c^-)}{\Gamma(Y_\eta \rightarrow \psi' \pi^+ \pi^-)} = 2.7$$

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

Summary

- 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
 - * $B \rightarrow K \eta'_c \pi^+ \pi^-$
 - * $B \rightarrow K \Lambda_c^+ \Lambda_c^-$ (A signal already existed in BaBar's data?)

$\Lambda_c^+ \Lambda_c^-$ FSI in the 3S_1 channel



Haidenbauer, Krein, PLB687(2010)314

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_η

