Recent progress in charmonium physics:
Role of (Heavy) Meson Loops

THIS IS NOT A REVIEW TALK

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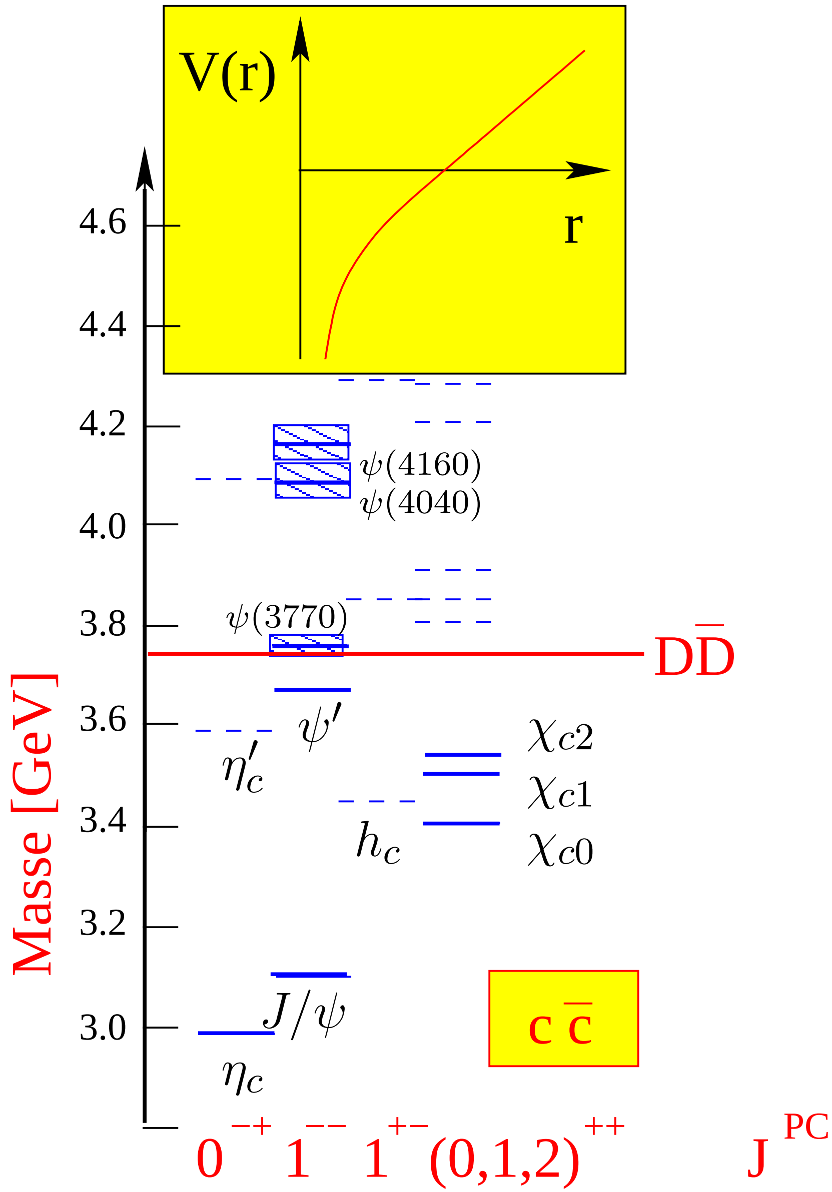
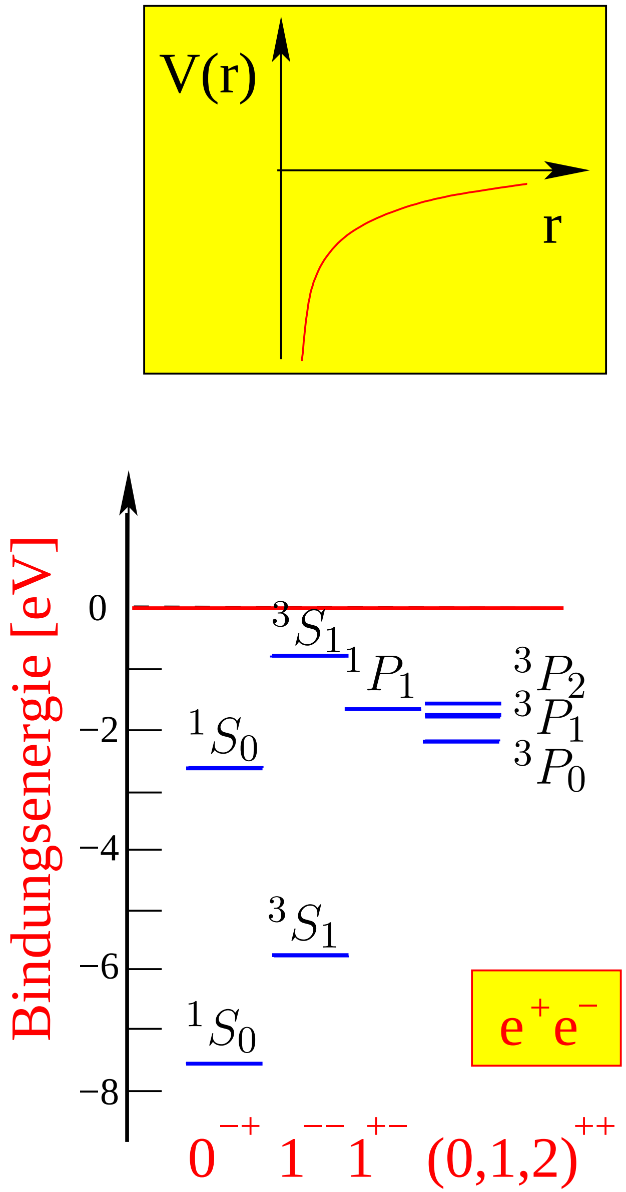
Charmonium before 2002

Quark-Model: Eichten et al. (1978)

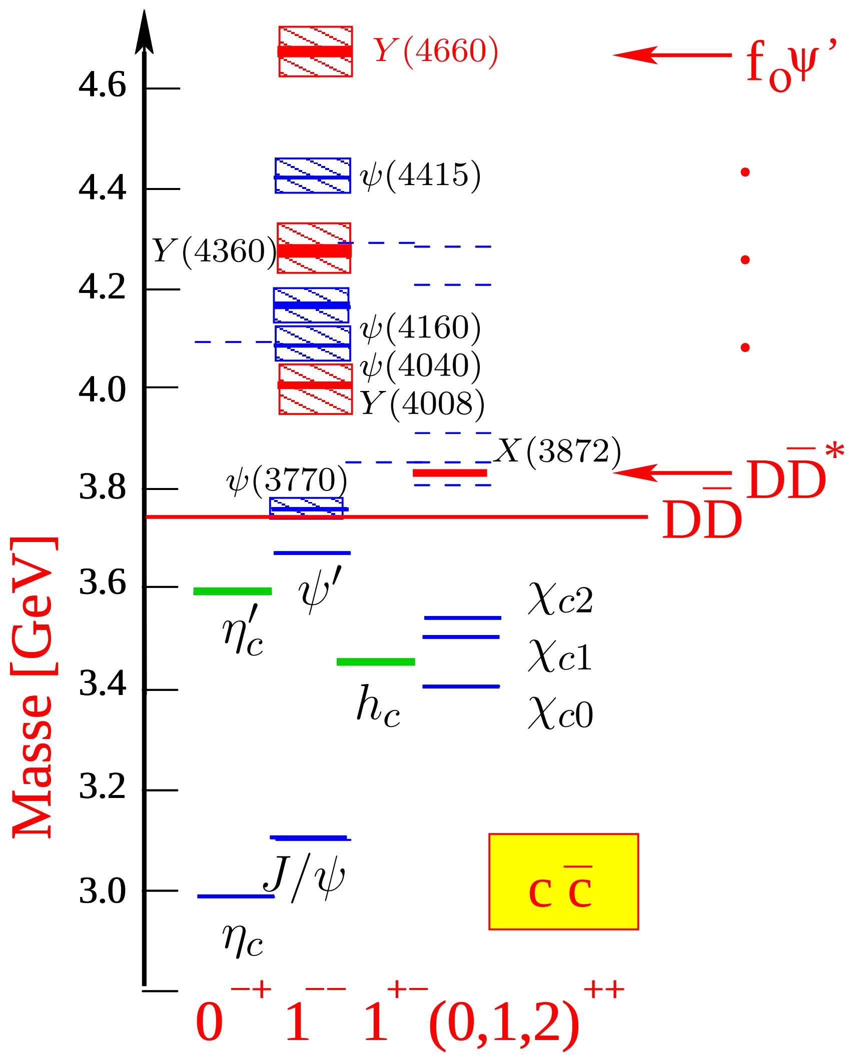




Charmonium after 2002

Quark-Model: Eichten et al. (1978)

A new particle Zoo!



→ missing low lying states found

→ Above the $\bar{D}D$ threshold:

- ▷ Many new states
- ▷ incompatible with quark model in mass and properties

What are they?

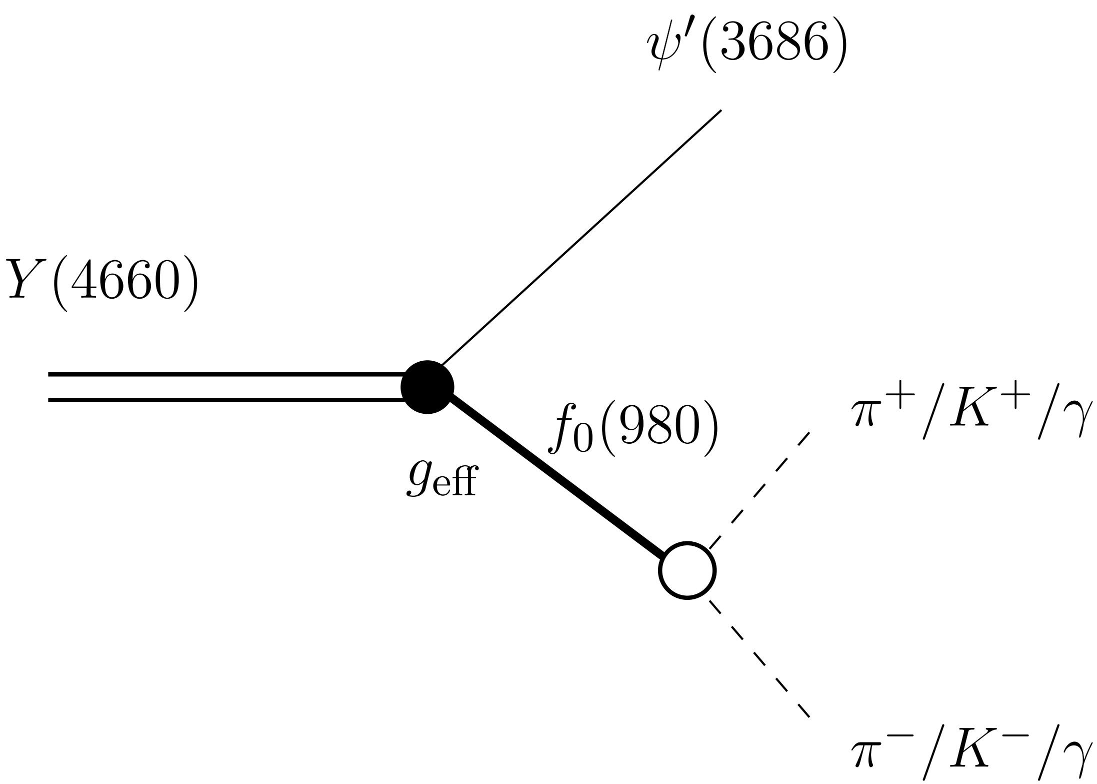
$Y(4660)$ a hadronic molecule?

Properties:

$\rightarrow$ Close to $f_0\psi'$ threshold ($m_{f_0} + M_{\psi'} = 4666$ MeV)

$\rightarrow$ Seen only in $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-\psi' \rightarrow J^{CP} = 1^{--}$

$\rightarrow$ Not seen in $e^+e^- \rightarrow \bar{D}^{(*)}\bar{D}^{(*)}$ and $e^+e^- \rightarrow \bar{J}/\psi D^{(*)}\bar{D}^{(*)}$



we use

Landau (1960)

Weinberg (1963); Baru et al. (2004)

$$\frac{g_{\rm eff}^2}{4\pi} = 4(m_1 + m_2)^2 \sqrt{\frac{2\epsilon}{\mu}}$$

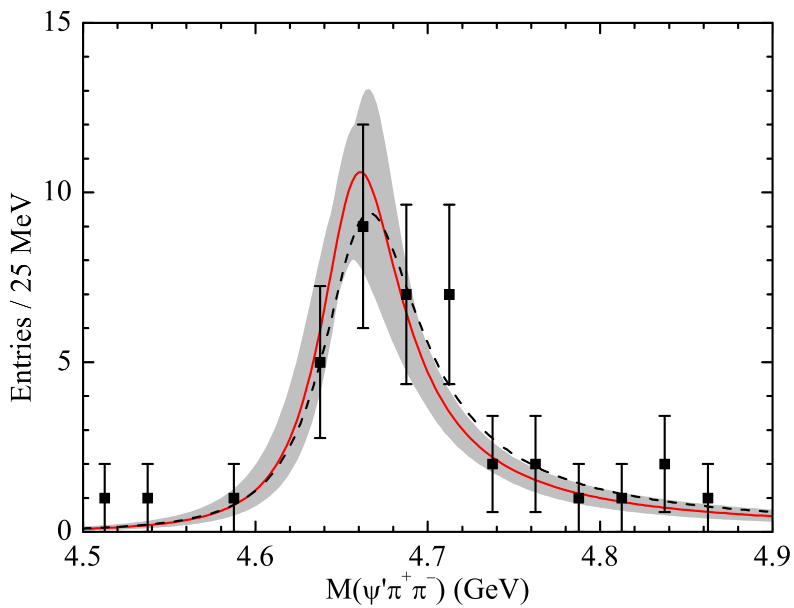
Free parameters

$\rightarrow$ M_Y

$\rightarrow$ normalization

Fit to data

Comparison with data



← this fitted, which yields

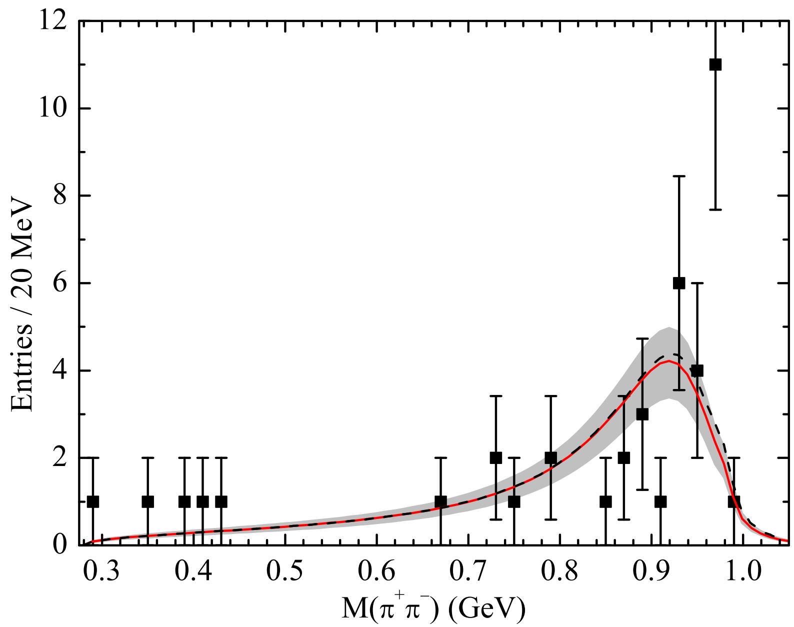
$$M_Y = \left(4665^{+3}_{-5}\right) \text{ MeV}$$

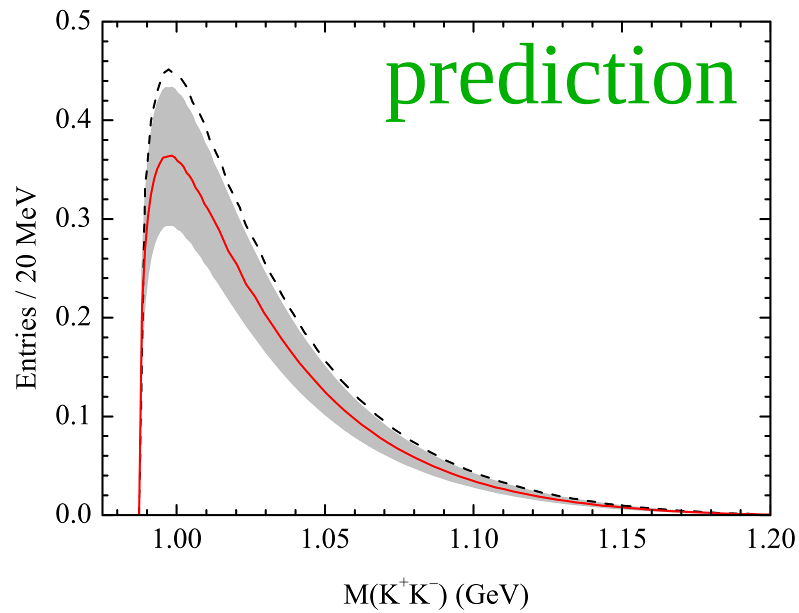
and thus $g_{\text{eff}} = 11..14$ GeV.

dashed line: g also fitted

$\rightarrow\ g = (13 \pm 2)$ GeV,

$M_Y = (4672 \pm 9)$ MeV





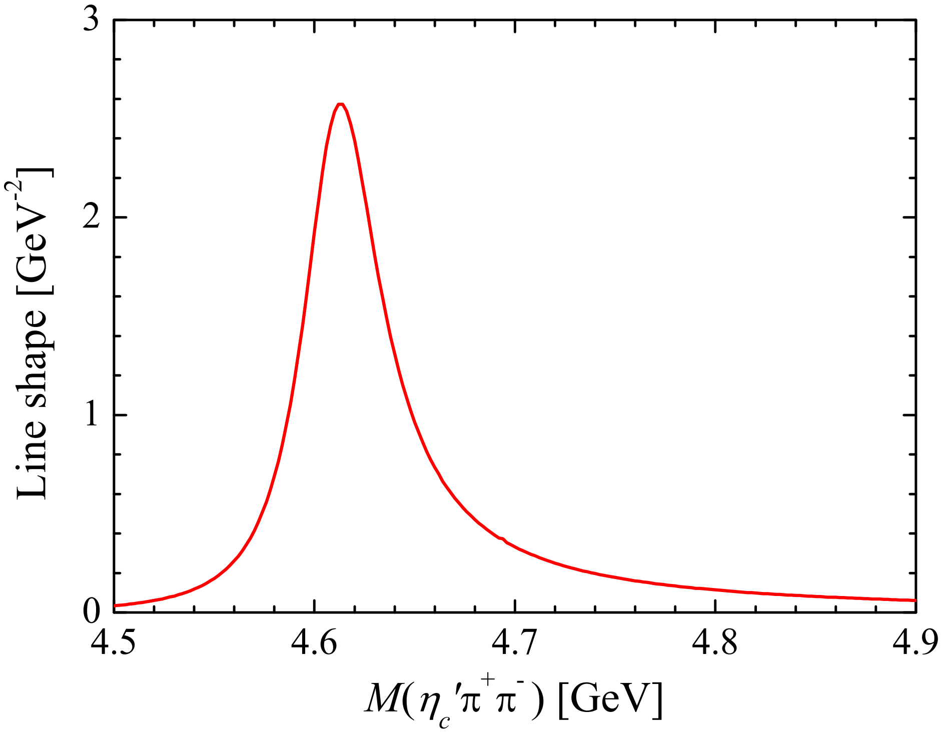
Data: Belle (2007); F.-K. Guo, C.H., U.-G. Meißner (2008)

Heavy Quark Symmetry

If the $Y(4660)$ is a $f_0\psi'$ molecule, heavy quark symmetry allows us to predict

the $J^{PC} = 0^{-+}$ state $Y_\eta(4616)$ as a $\eta_c' f_0$ molecule

Guo, C.H., Meißner (2009)



$$M_{Y_\eta} = M_Y - (M_{\psi'} - M_{\eta_c'}) + \mathcal{O}\left(\left(\Lambda_{QCD}/m_c\right)^2 \right)$$

$$\frac{g_{\rm eff}^2}{4\pi} = 4(m_1 + m_2)^2 \sqrt{\frac{2\epsilon}{\mu}}$$

$$\Gamma(\eta_c'\pi\pi) = (60 \pm 30) \text{ MeV}$$

Proposed discovery channel: $B^\pm \to \eta_c' K^\pm \pi^+\pi^-$

VALUE OF M_{Y_η} SPECIFIC FOR MOLECULAR PICTURE!!!

Origin of $X(4630)$?

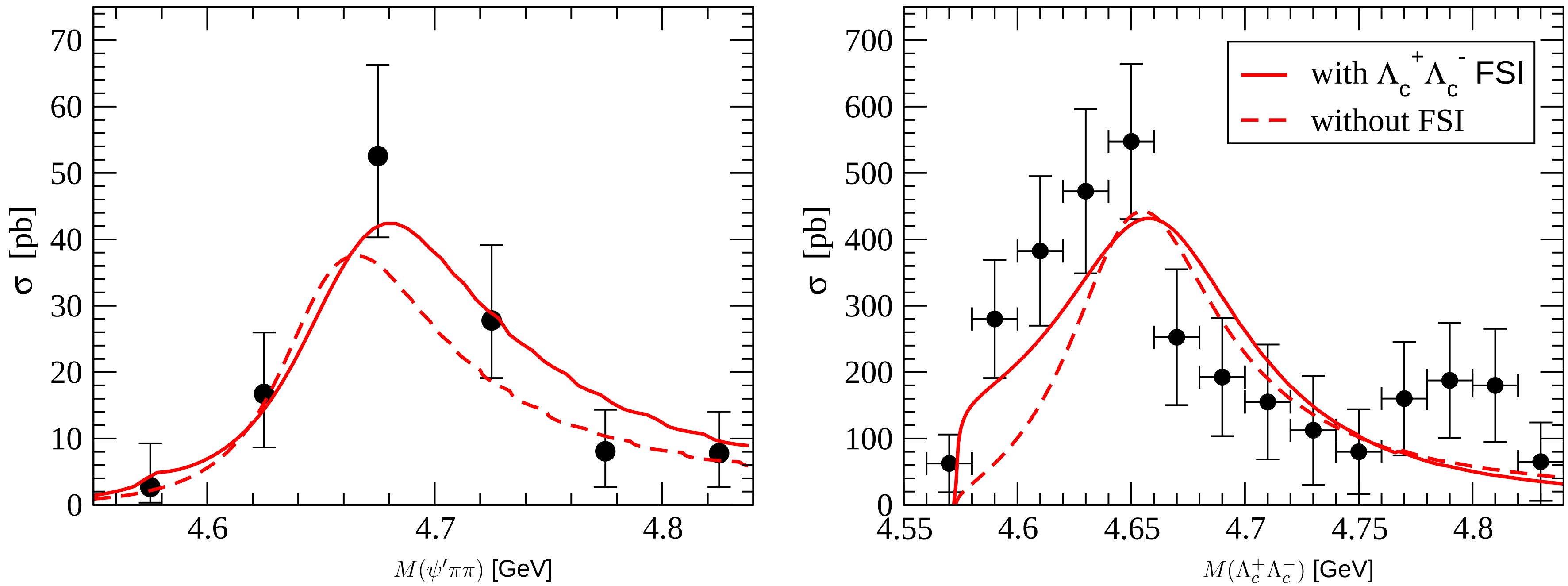
The same state as $Y(4660)$?

Bugg (2008); Cotugno et al. (2010); Guo et al. (2010)

Note:

$$\frac{\mathrm{Br}(Y \to \Lambda_c \bar{\Lambda}_c)}{\mathrm{Br}(Y \to \psi' \pi\pi)} \sim 10 - 20 \ .$$

In conflict with molecular picture? combined fit possible!



But then: $\psi'\pi\pi$ spectrum no longer saturated by $\psi' f_0(980)$ ...

Again: Important to find spin partner

Charmonium decays

Extraction of m_u/m_d from $\psi' \to J/\psi\pi^0/\psi' \to J/\psi\eta$

using QCD Multipole Expansion (QCDME)

$$\frac{\mathcal{B}(\psi' \to J/\psi\pi^0)}{\mathcal{B}(\psi' \to J/\psi\eta)} = 3\left(\frac{m_d - m_u}{m_d + m_u}\right)^2 \frac{F_\pi^2}{F_\eta^2}\frac{M_\pi^4}{M_\eta^4}\left|\frac{\vec{q}_\pi}{\vec{q}_\eta}\right|^3,$$

Joffe, Shifman (1980); Donoghue, Holstein, Wyler (1992)

from this one gets - using data from CLEO (2008)

$$\frac{m_u}{m_d} = 0.40 \pm 0.01.$$

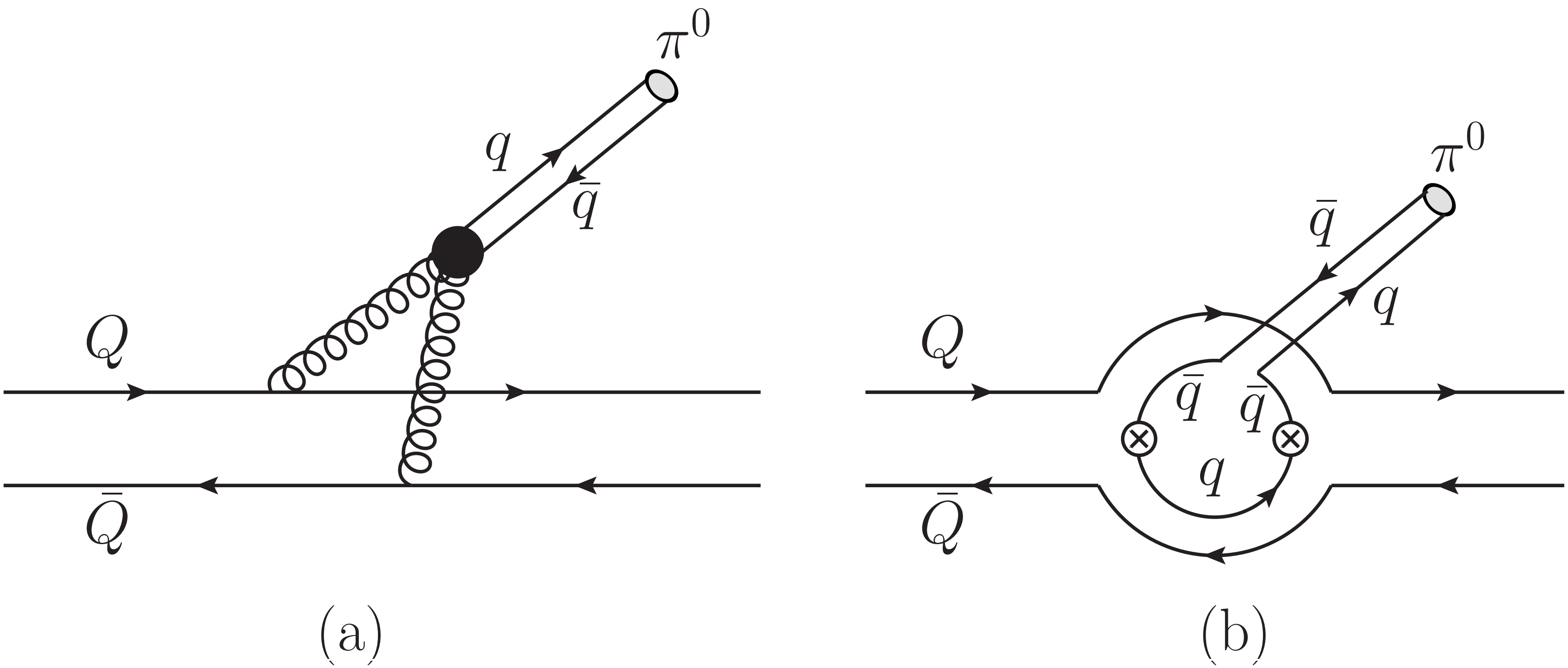
On the other hand

$$\frac{m_u}{m_d} = \frac{M_{K^+}^2 - M_{K^0}^2 + 2M_{\pi^0}^2 - M_{\pi^+}^2}{M_{K^0}^2 - M_{K^+}^2 + M_{\pi^+}^2} = 0.56$$

Weinberg (1977); Gasser, Leutwyler (1982); Leutwyler (1996)

Serious discrepancy!

Beyond QCDME



(a) QCDME:

$\rightarrow$ expansion in (gluon wavelength)/(extension of object)

(b) heavy meson loops:

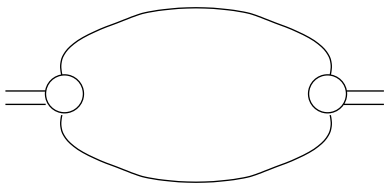
$\rightarrow$ induce (potentially) long ranged effect beyond QCDME

Moxhay (1989); Zhou and Kuang (1991)

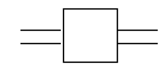
NREFT

Influence of meson loops on properties of $\psi(ns)$

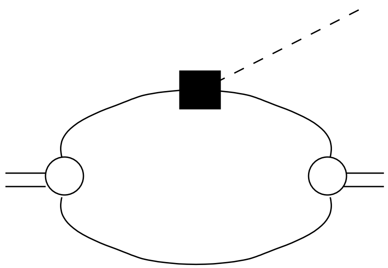
natural expansion parameter: velocity v for $\psi' \to J/\psi\pi^0$: $v \sim 1/2$



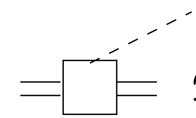
$$\simeq \frac{v^3 v^2}{v^2} = v^3$$



$$\simeq 1$$



$$\simeq \frac{q v^5}{v^4}\left(\frac{\delta}{v^2}\right) = \frac{q\delta}{v}$$



$$\simeq q\delta$$

Thus, in certain decays loops are to be significant!

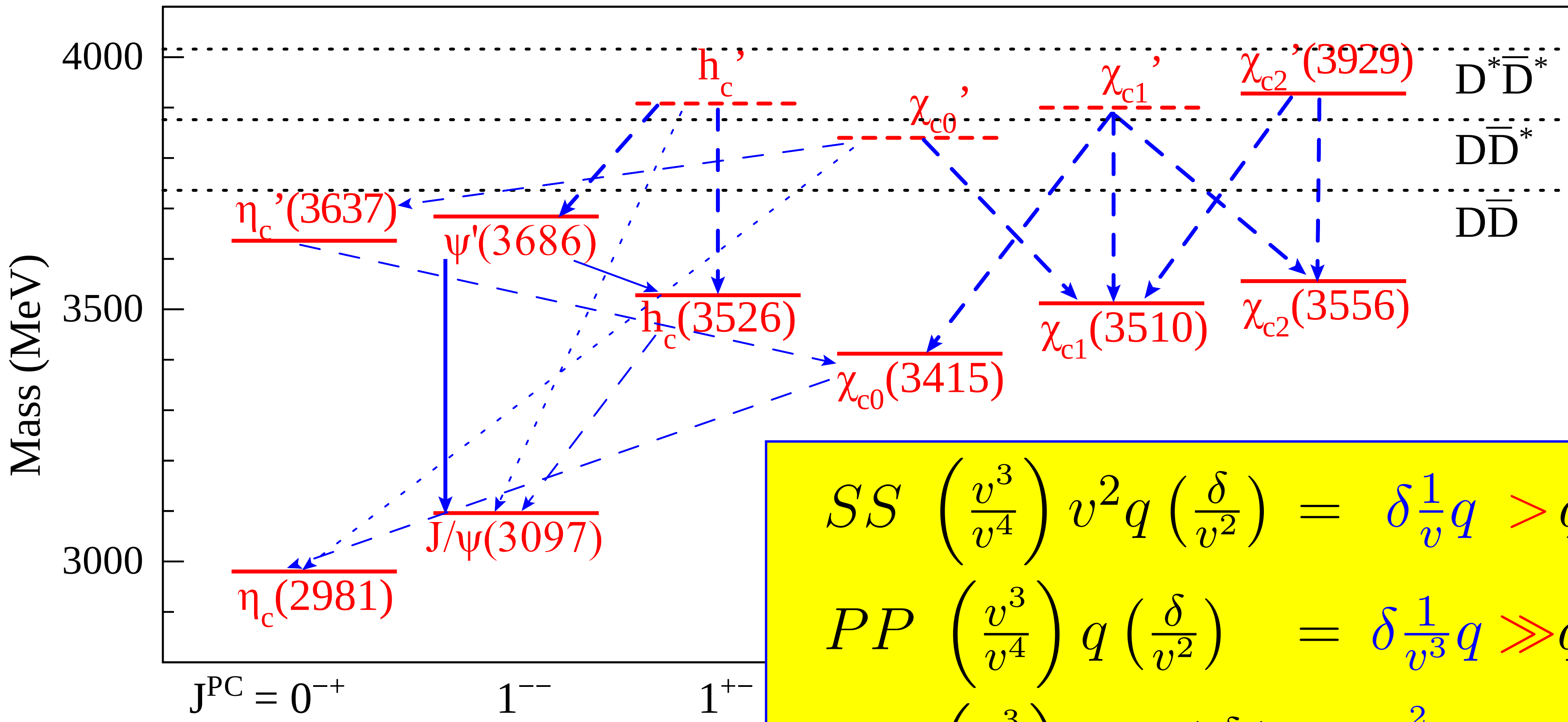
$$\left(\frac{\mathcal{B}(\psi' \to J/\psi\pi^0)}{\mathcal{B}(\psi' \to J/\psi\eta)}\right)_{\rm loops} = 11 \pm 6\ \%\ (\text{Exp: } 4.0 \pm 0.3)\%$$

Guo, C.H., Meißner (2009); see also: Voloshin (2005)

parameter free at leading order (note: sizable uncertainty!)

Whats missing?

Measure analogeous transitions



$$SS \quad \left(\frac{v^3}{v^4}\right) v^2 q \left(\frac{\delta}{v^2}\right) = \delta \frac{1}{v} q > q\delta$$

$$PP \quad \left(\frac{v^3}{v^4}\right) q \left(\frac{\delta}{v^2}\right) = \delta \frac{1}{v^3} q \gg q\delta$$

$$SP \quad \left(\frac{v^3}{v^4}\right) \frac{qq}{M_D^2} \left(\frac{\delta}{v^2}\right) = \frac{q^2}{v^3 M_D^2} \delta < \delta$$

Results double checked with relat. phenomenolog. approach.

Very non–trivial pattern allows for clean test!

Summary

There is strong evidence that (heavy) meson loops play an important role in heavy meson phenomenology in both ways:

$\rightarrow$ non-perturbatively

$\Longrightarrow$ Formation of Hadronic molecules

$\rightarrow$ perturbatively

$\Longrightarrow$ Changing certain charmonium decay rates

To check this we need

$\rightarrow$ From Th. :full exploration of symmetries (spin partners!)

$\rightarrow$ From Exp.:high accuracy data for various channels

Thanks for your attention