A scheme for studying the heavy pentaquark spectrum in lattice QCD

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Outline

- Why heavy pentaquarks?
- Case of pentaquarks with two heavy quarks
- Possible *fall-apart* modes
- Spectroscopy and m_Q dependence
- Testing for molecular vs tightly bound one-body state
- Outlook

Why heavy pentaquarks?

- (Almost) all work presented here are on tetraquarks
- (Almost) all work presented here are on near-threshold states
- Such states are molecular - two mesons with a pionic bond
- Hence the great effort on three-body states in a finite volume
- What is really more interesting are tightly bound states, more like a proton or a pion or kaon
- We still have chance of beating experiments to a prediction of such a state
- Most of what I discuss here is relevant to heavy tetraquarks as well

States with heavy quarks

- States with one, two, three, four and five heavy quarks
- Hidden heavy vs open heavy
- States claimed so far are hidden-charm
- We will consider the case of two heavy quarks

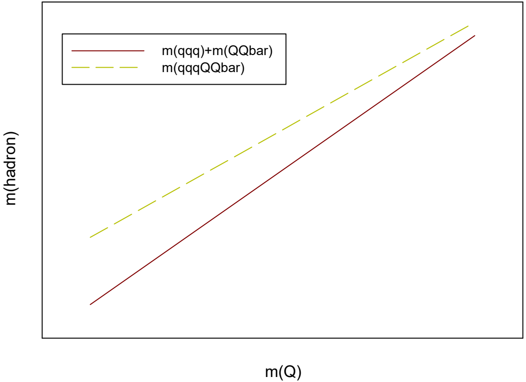
States with two heavy quarks

- Heavy antiquark $qqqQ\bar{Q}$
  - Hidden heavy quark $qqqQ_1\bar{Q}_1$
  - Open heavy quark $qqqQ_1\bar{Q}_2$
- Light antiquark $QQqq\bar{q}$

Possible *fall-apart* modes

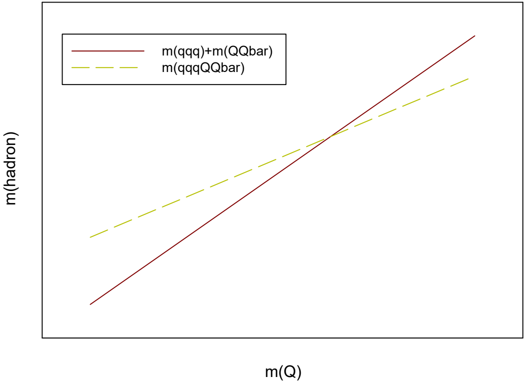
- Open heavy quark $qqqQ_1\bar{Q}_2$
  - $qqq+Q_1\bar{Q}_2$, $Q_1qq+q\bar{Q}_2$
  - Look at mass relations like
    $\Lambda(uds) + B_c(c\bar{b}) < \Lambda_c(udc) + B(s\bar{b})$
    to identify the lowest mass combination
  - A stable pentaquark state will have to be (well) below this strong-decay threshold
    - If it is *just below* threshold, it will be *molecular*, *loosely bound*
    - Any state *well below* threshold may be *tightly bound* and *one-body*

Spectroscopy and m_Q dependence



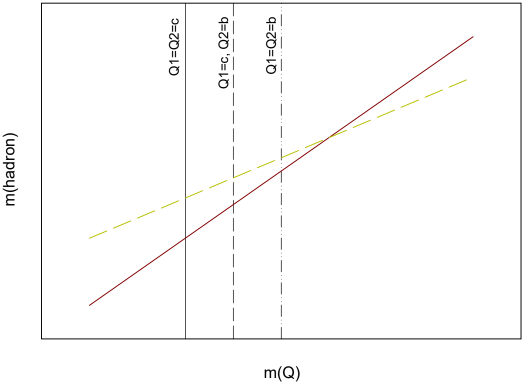
Not interesting

Spectroscopy and m_Q dependence



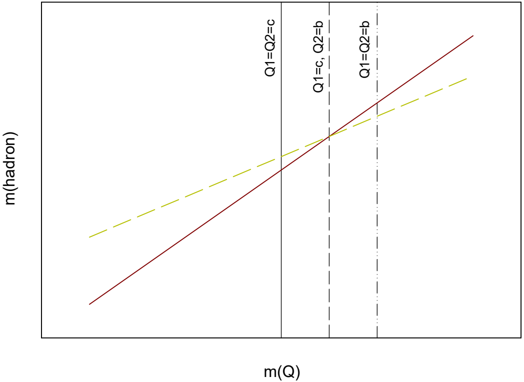
Interesting! But, we need to check for the position of m_Q.

Spectroscopy and m_Q dependence



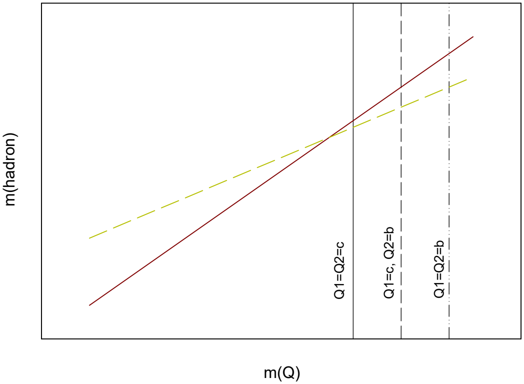
All below threshold. Not interesting.

Spectroscopy and m_Q dependence



One or two just below threshold. Interesting, but probably molecular.

Spectroscopy and m_Q dependence



All below threshold - one or two well below it. Promising as a one-body state.

Testing for molecular vs tightly bound one-body state

- Volume dependence
- Hybrid boundary conditions
- Mass dependence of splitting

Volume dependence

Scattering vs Bound States [Mathur *et al.*(2004), Liu *et al.*(2005)]

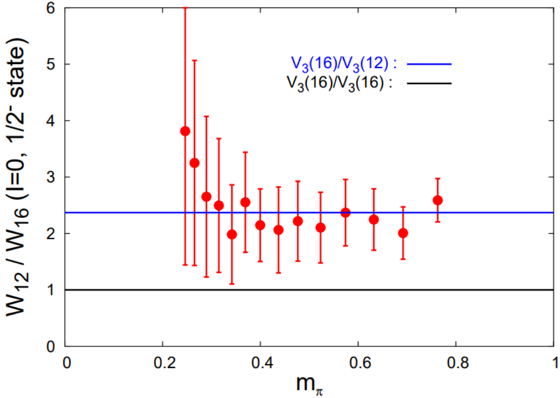
- Single particle states

$$C_2(t) = \sum_{\vec{x}} \langle 0 \mid \mathcal{O}\,(\vec{x},t)\,\mathcal{O}(\vec{0},0) \mid 0 \rangle = \sum_n W_n e^{-E_n t}$$

- Two-particle states

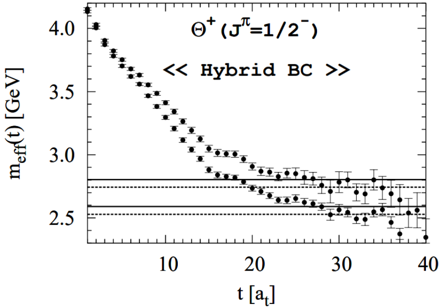
$$C_2(t) = \sum_{\vec{x}} \langle 0 \mid \mathcal{O}_1\,(\vec{x},t)\,\mathcal{O}_2\,(\vec{x},t)\,\mathcal{O}_1(\vec{0},0)\mathcal{O}_2(\vec{0},0) \mid 0 \rangle = \sum_{n_1 n_2} \frac{W_{n_1} W_{n_2}}{V} e^{-(E_{n_1}+E_{n_2})t} \sim \frac{1}{V}$$

Volume dependence



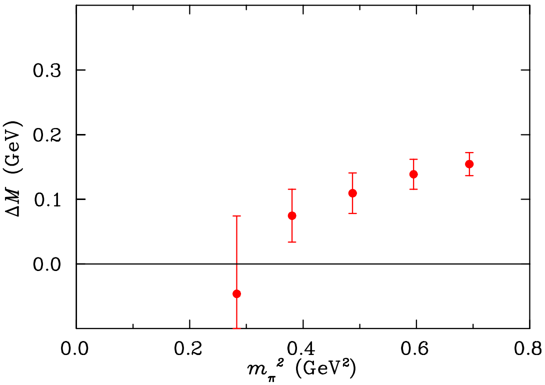
[Mathur *et al.*(2004)]

Hybrid boundary conditions



[Ishii *et al.*(2005)]

Mass dependence of splitting



[Lasscock *et al.*(2005)]

Summary of the scheme

- Look for multiquark states that are still difficult experimentally
- Identify the lowest fall-apart mode
- After a reasonable chiral extrapolation for the light quarks, explore the heavy quark extrapolation across c- and b-quark masses and possible combinations
- Try to identify states that might be tightly bound
- Once promising states are identified, check those for volume dependence, hybrid bc's and mass dependence of splittings
- Hopefully this will lead to predictions of tightly bound one-body multiquark bound states ahead of experiment