Strong interaction stable doubly heavy tetraquarks

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OUTLINE

- *"Good light diquark" configurations and the heavy baryon spectrum*

- *Qualitative implications for doubly heavy tetraquark channels*

- *Lattice results for candidate strong-interaction-stable tetraquark channels*

Heavy baryons: "good" vs. "bad" light diquarks in a heavy 3_c field

- "Good" ($I = J = 0$, $C = \bar{3}$) vs. "bad" ($I = J = 1$, $C = \bar{3}$) ud diquarks
  - $\Sigma_b - \Lambda_b$: 194 Mev
  - $\Sigma_c - \Lambda_c$: 167 Mev

- "Good" ($F = \bar{3}$, $J = 0$, $C = \bar{3}$) vs. "bad" ($F = 6$, $J = 1$, $C = \bar{3}$) us diquarks
  - $\Xi_b' - \Xi_b$: 142 Mev
  - $\Xi_c' - \Xi_c$: 109 Mev

- Key observations
  - $\Sigma_b - \Lambda_b$ splitting (maximally suppressed heavy-quark spin interactions) $\Rightarrow \sim 145$ MeV "good" ud attraction c.f. spin average
  - $\Xi_b' - \Xi_b$ splitting $\Rightarrow \sim 106$ MeV "good" us diquark attraction c.f. spin average
  - $\Rightarrow$ increased spin-dependent "good diquark" attraction with *decreasing* light quark mass
  - Reduced splittings in charm sector $\Rightarrow$ less suppressed residual spin-dependent charm-light interactions eat into "good diquark" binding

- In doubly heavy tetraquark channels $\bar{Q}\bar{Q}'\ell\ell'$
  - * $F = \bar{3},\ J_\ell = 0,\ C_\ell = \bar{3},\ J_h = 1,\ C_h = 3,\ J^P = 1^+$ channel allows "good light diquark" configuration, no heavy quark spatial excitation
  - * Heavy quark mass suppression of spin-dependent interactions $\Rightarrow$ spin-dependent attraction for asymptotic $B^*B,\ B^*D,\ D^*D\ J^P = 1^+$ states small c.f. "good diquark" attraction available to tetraquark
  - * Additional (smaller) tetraquark attraction from $\bar{Q}\bar{Q}'$ $C_h = 3$ color Coulomb
- $\Rightarrow$ expect doubly heavy tetraquark bound wrt 2-meson threshold, for $\overline{b}\overline{b}\ell\ell'$ case at least

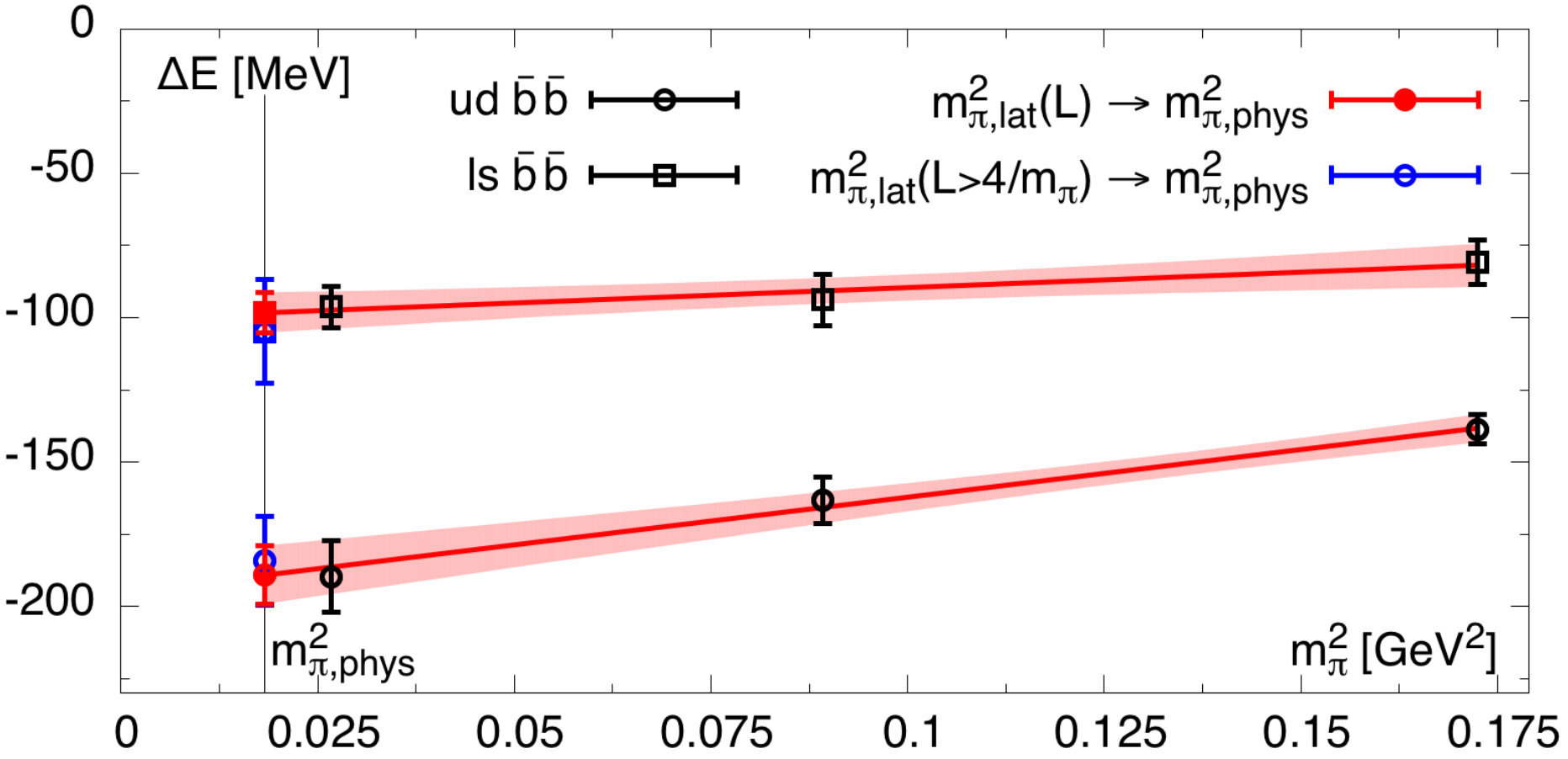
LATTICE INPUT

- light quarks: PACS-CS n_f=2+1 ensembles [PRD79 (2009) 034503]

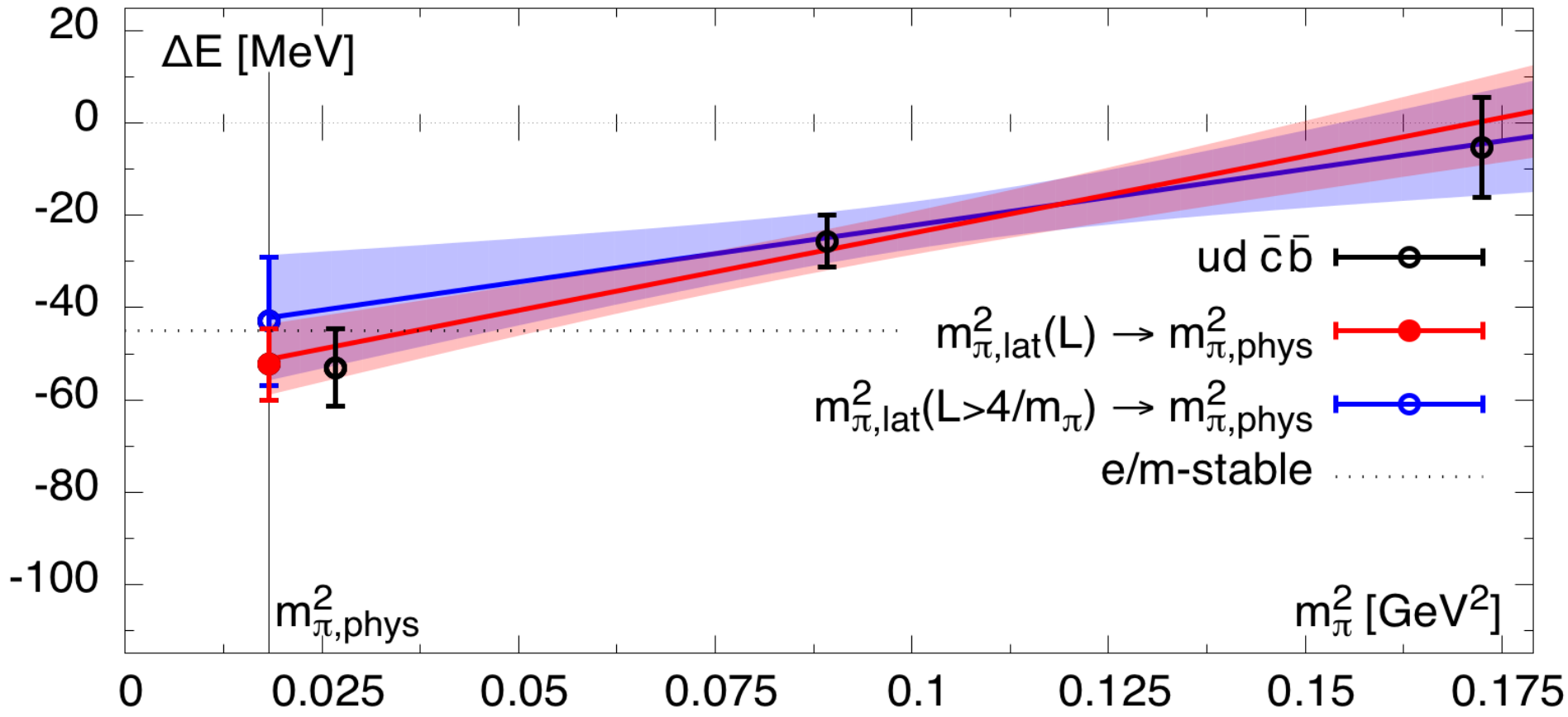
Size	32^3x64	32^3x64	32^3x64
1/a [GeV]	2.194	2.194	2.194
m_π [MeV]	415	299	164
m_π L	6.1	4.4	2.2
m_Υ [GeV]	9.528(79)	9.488(71)	9.443(76)
Configurations	400	800	165
Measurements	800	800	3078

- NRQCD for b quark [PRD46 (1992) 4052, PRD79 (2009) 014502]
- Tsukuba tuned RHQ c quark action [PRD84 (2011) 074505]

Binding energies, doubly bottom channels

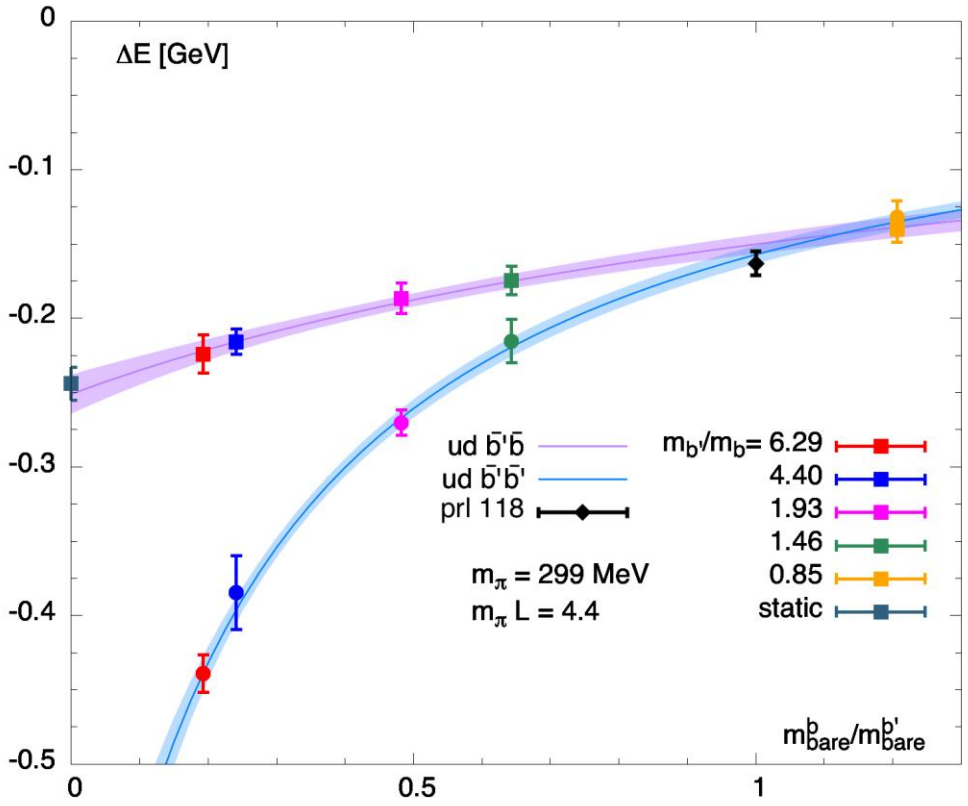


Binding energies, I=0 bottom-charm channel

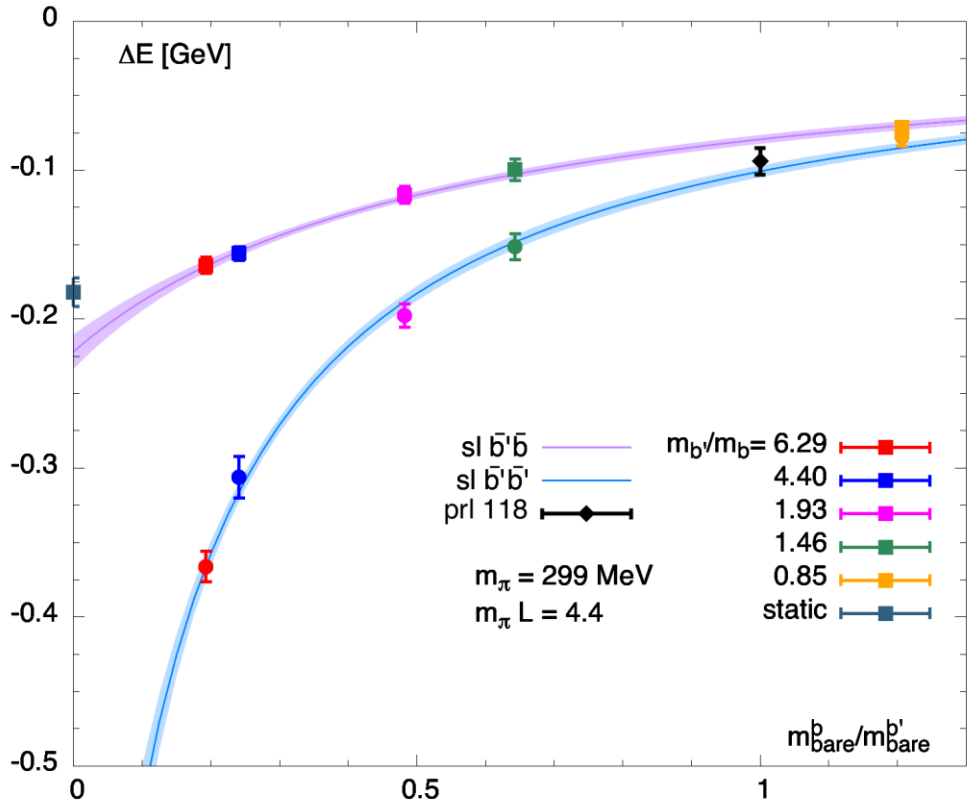


NRQCD variable m_Q interpolation/extrapolation

I=0

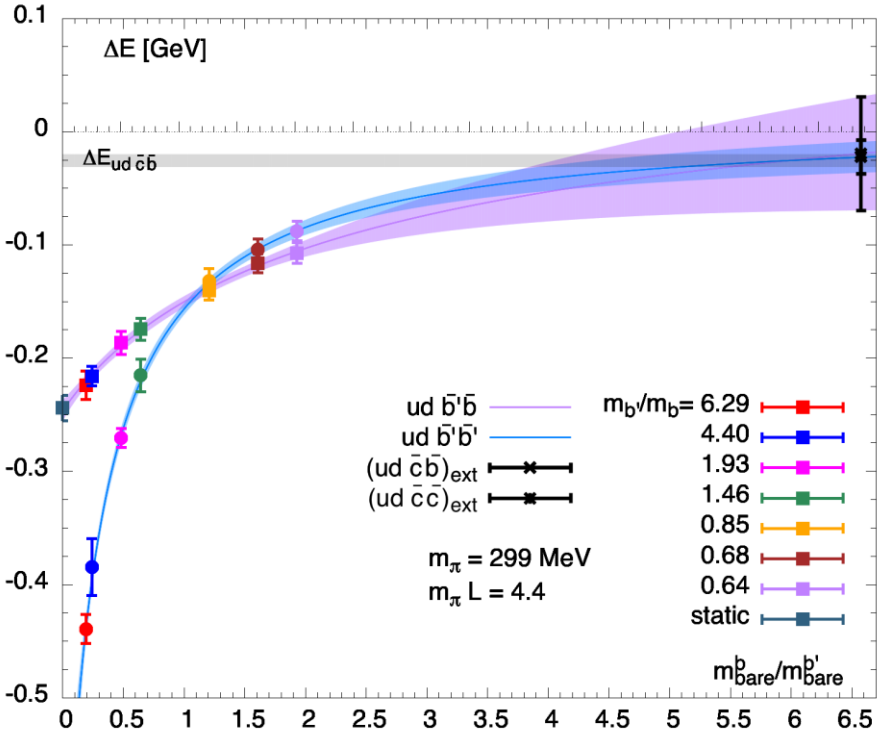


I=1/2

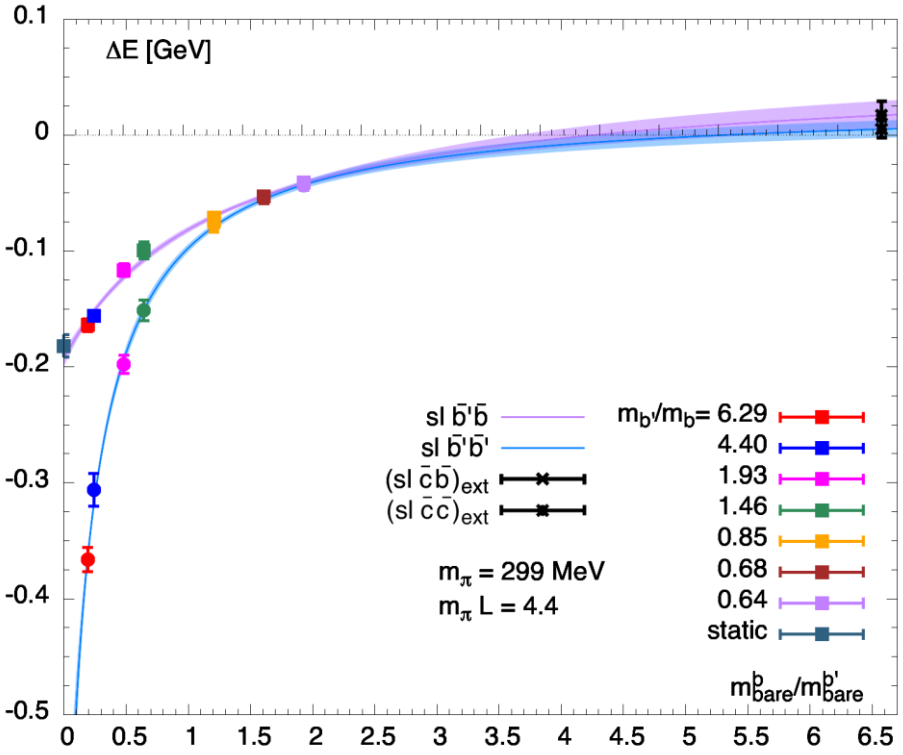


Extending the NRQCD, variable m_Q extrapolation all the way to charm

I=0



I=1/2



CONCLUSIONS

- Clear evidence for deeply bound strong-interaction-stable $J^P = 1^+$ $I = 0$ $ud\overline{b}\overline{b}$ and $I = 1/2$ $\ell s\overline{b}\overline{b}$ tetraquark states

- Binding for doubly bottom states such that only weak decays possible (displaced vertices, searchable at LHCb)

- Evidence for strong-interaction-stable $J^P = 1^+$ $I = 0$ $ud\overline{c}\overline{b}$, but EM decay threshold in BE error band, so decays may or may not have displaced vertex

- Doubly charmed $J^P = 1^+$ channels under investigation

- Larger L for lightest m_π desirable (under investigation)

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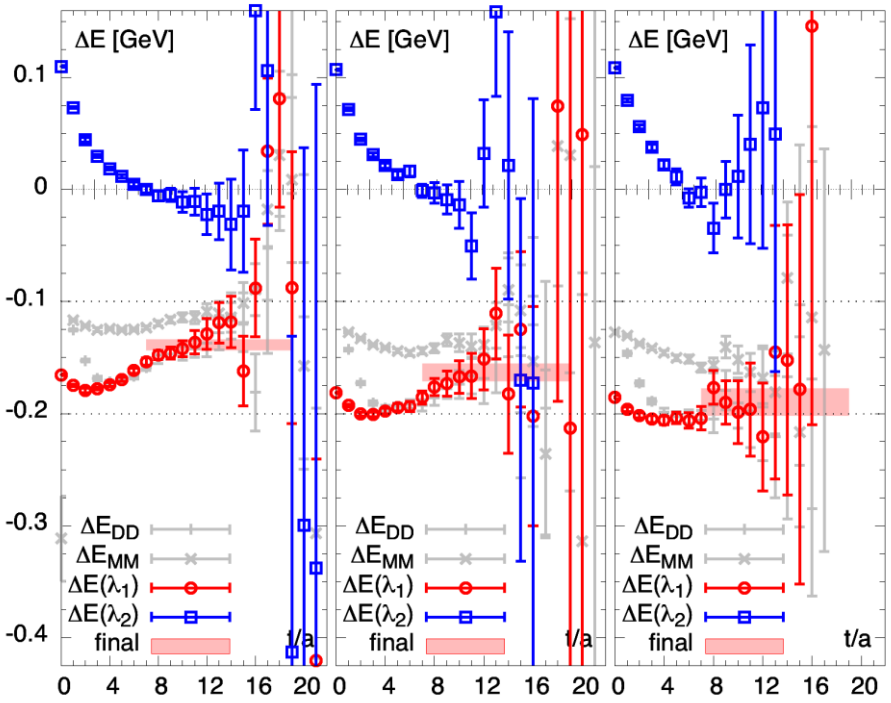
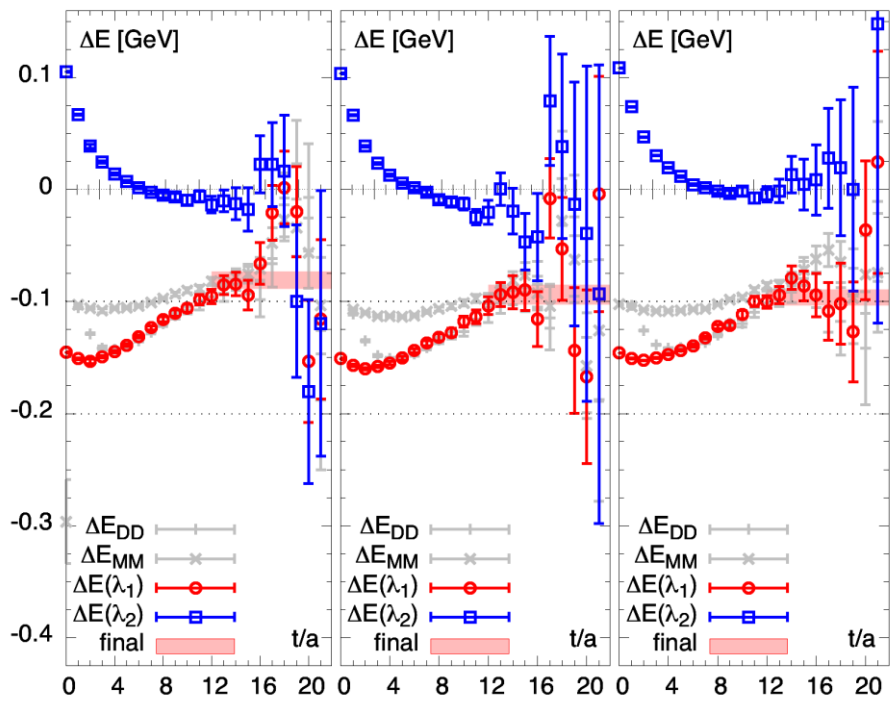
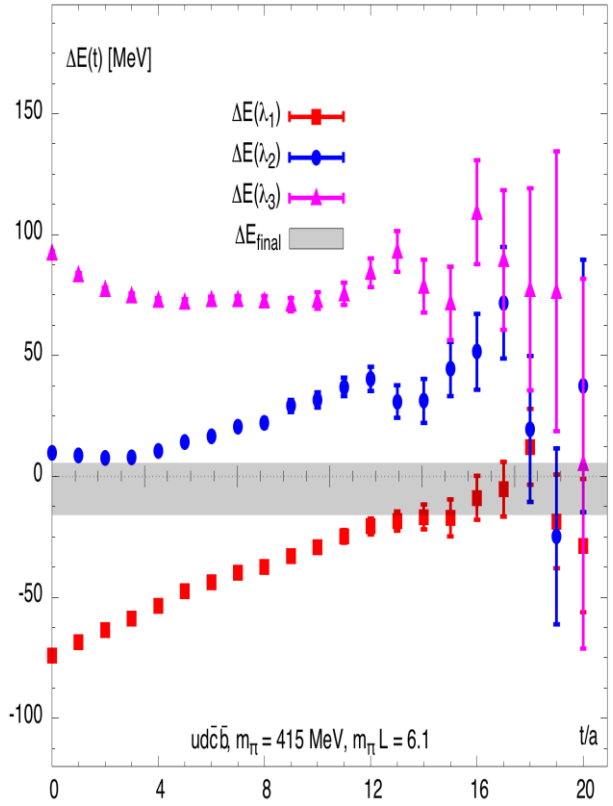
Backup slides

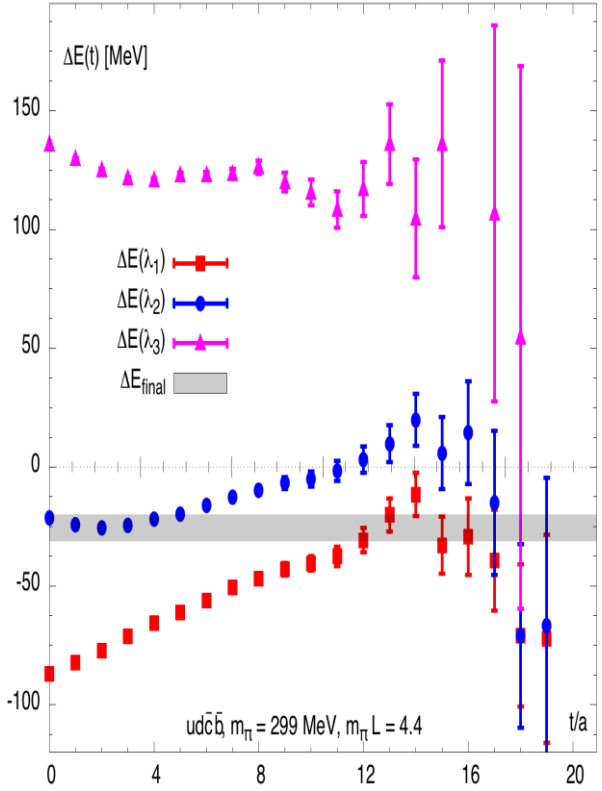
Doubly bottom: left panel: I=0; right panel: I=1/2

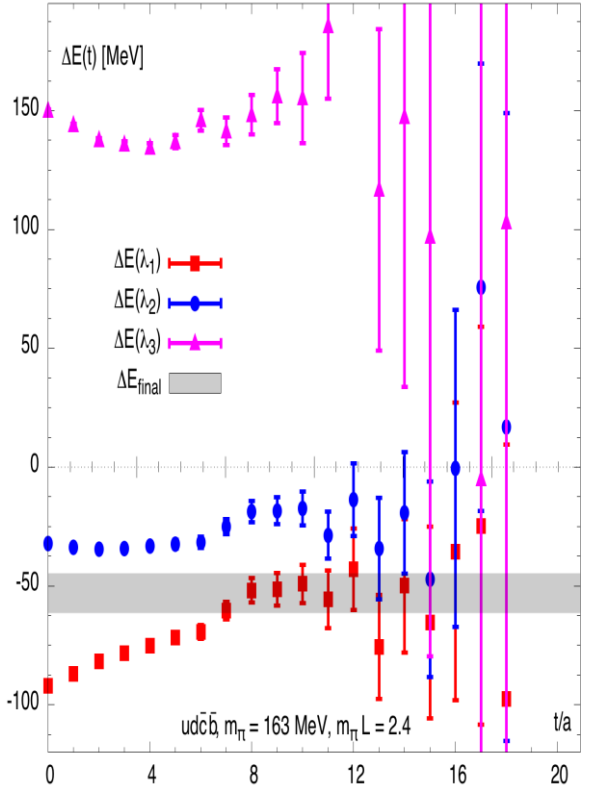




Bottom-charm: left panel: I=0; right panel: I=1/2



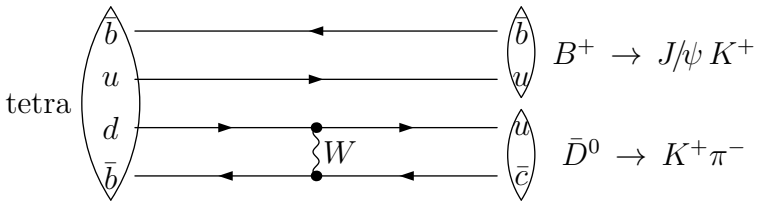




Experimental search for $ud\bar{b}\bar{b}$ tetraquark with $I(J^P) = 0(1^+)$

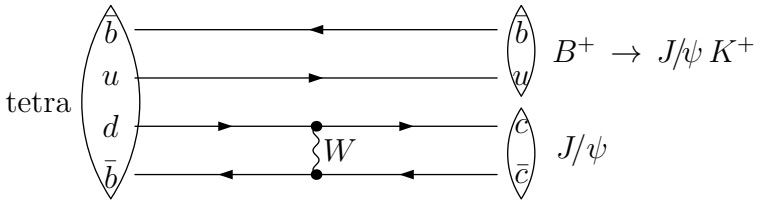
(Our lattice prediction: Francis, Hudspith, Lewis, Maltman, PRL118(2017)142001 = arXiV:1607.05214)

OPTION #1: $\boxed{\text{tetra} \to J/\psi\, K^+ K^+ \pi^-}$

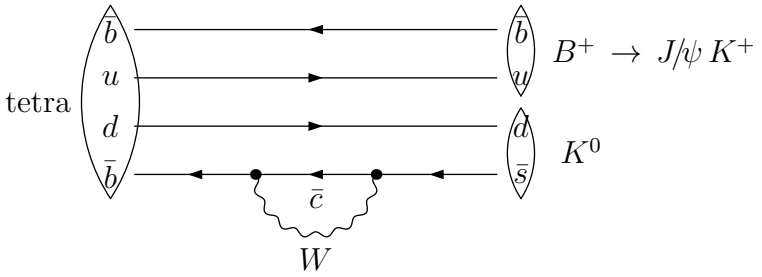


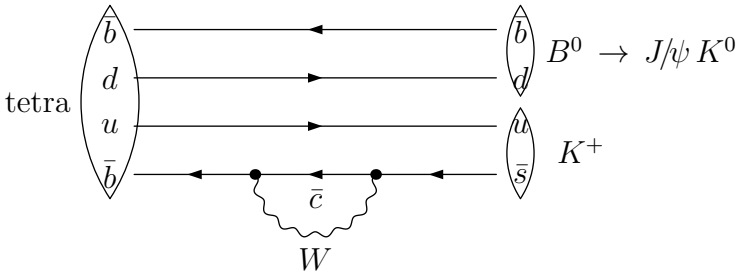
OPTION #2: $\boxed{\text{tetra} \to J/\psi\, J/\psi\, K^+}$

Note: CKM suppression due to V_{cd}.

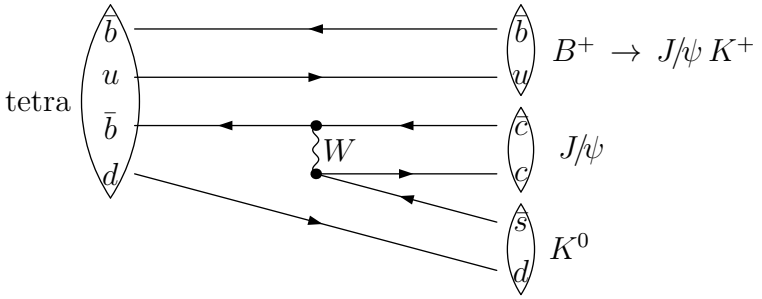


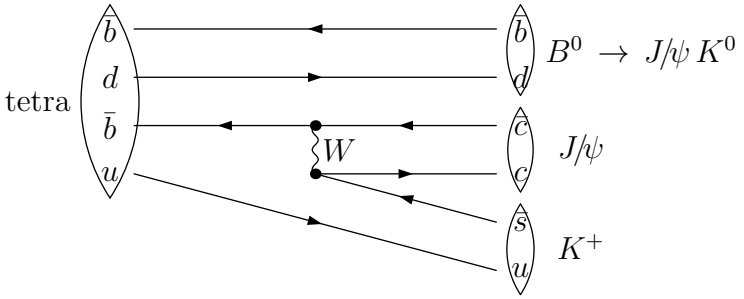
OPTION #3: $\boxed{\text{tetra} \to J/\psi\, K^+ K^0}$



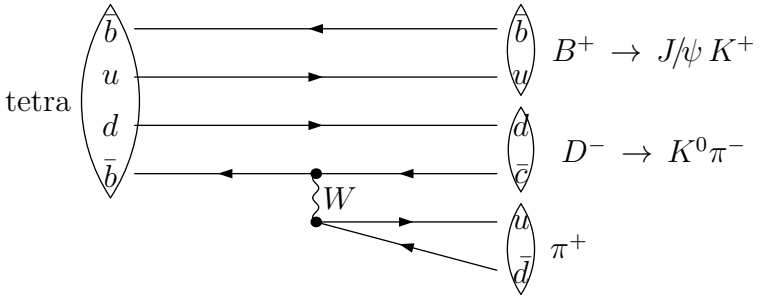


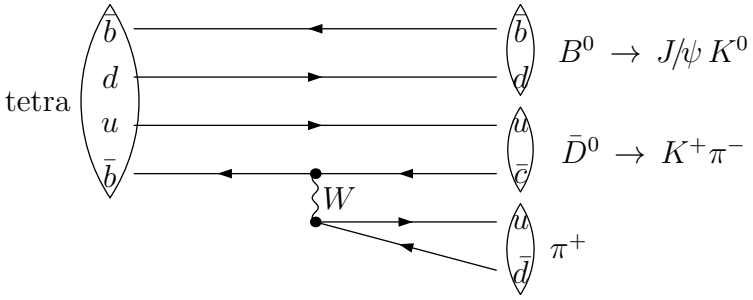
OPTION #4: $\boxed{\text{tetra} \to J/\psi\, J/\psi\, K^+ K^0}$





OPTION #5: $\boxed{\text{tetra} \to J/\psi\, K^+ K^0\, \pi^+ \pi^-}$

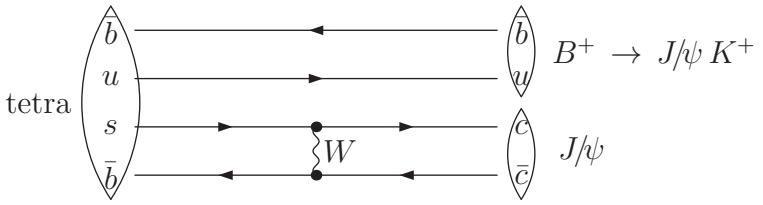




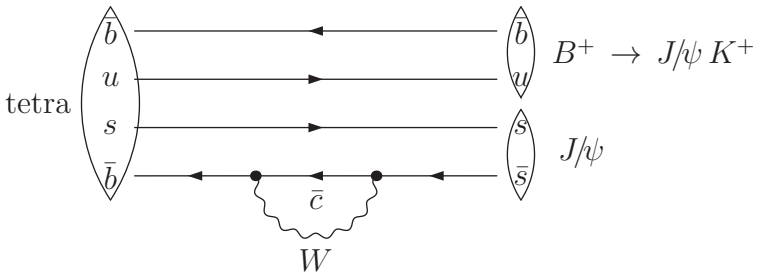
Experimental search for $us\bar{b}\bar{b}$ tetraquark with $J^P = 1^+$

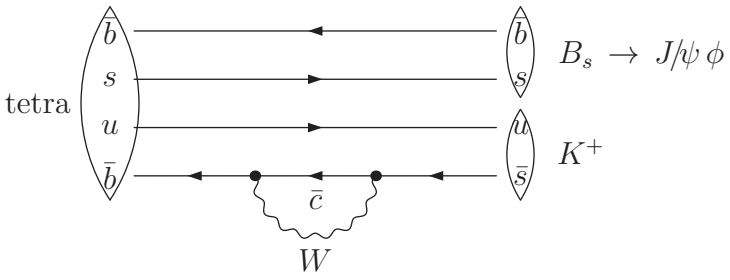
(Our lattice prediction: Francis, Hudspith, Lewis, Maltman, PRL118(2017)142001 = arXiV:1607.05214)

OPTION #1: $\boxed{\text{tetra} \to J/\psi\, J/\psi\, K^+}$

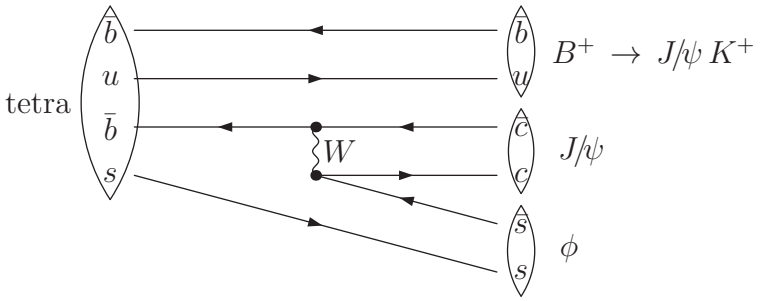


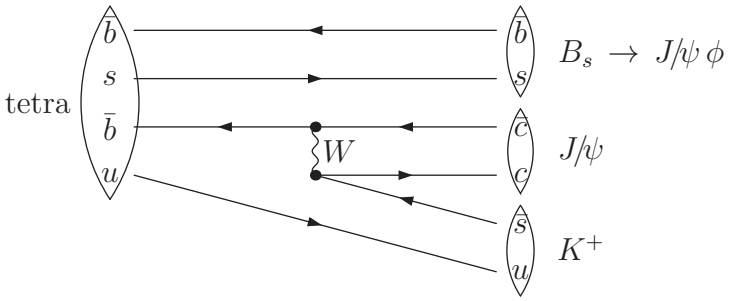
OPTION #2: $\boxed{\text{tetra} \to J/\psi\, \phi\, K^+}$

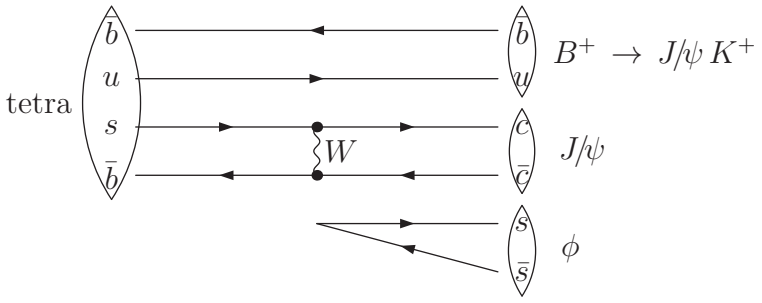




OPTION #3: $\boxed{\text{tetra} \to J/\psi\, J/\psi\, \phi\, K^+}$







OTHER OPTIONS: $\boxed{\text{tetra} \to J/\psi\, \phi\, K\, \pi\, \pi}$, $\boxed{\text{tetra} \to J/\psi\, \phi\, K\, K\, K}$, ...

Note: There is also a $ds\bar{b}\bar{b}$ tetraquark with similar decays (producing K^0 instead of K^+).