Charm Tetraquarks

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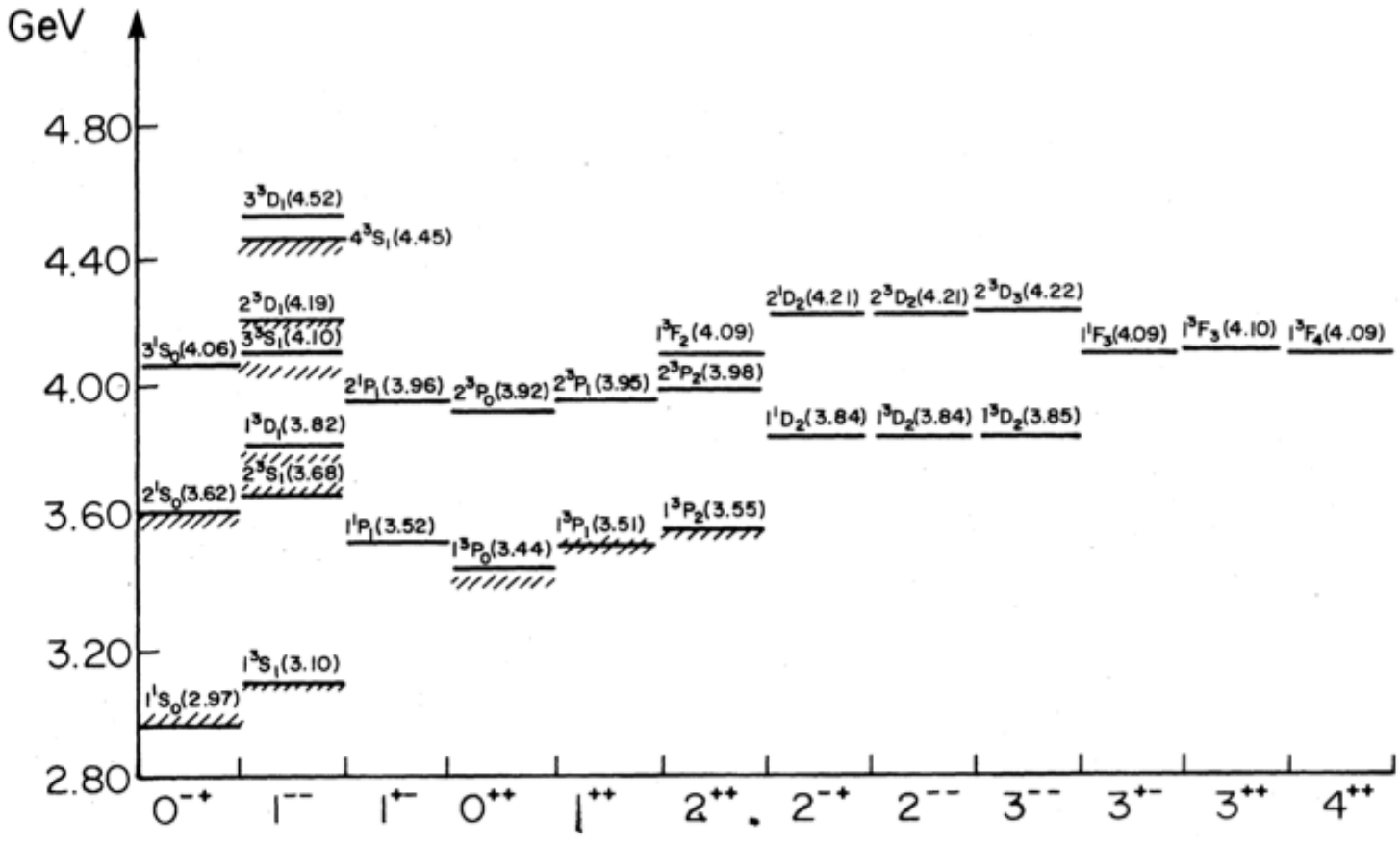
[GC, Thomas, Dudek, Edwards, JHEP 1711 (2017) 033]

15 May 2018

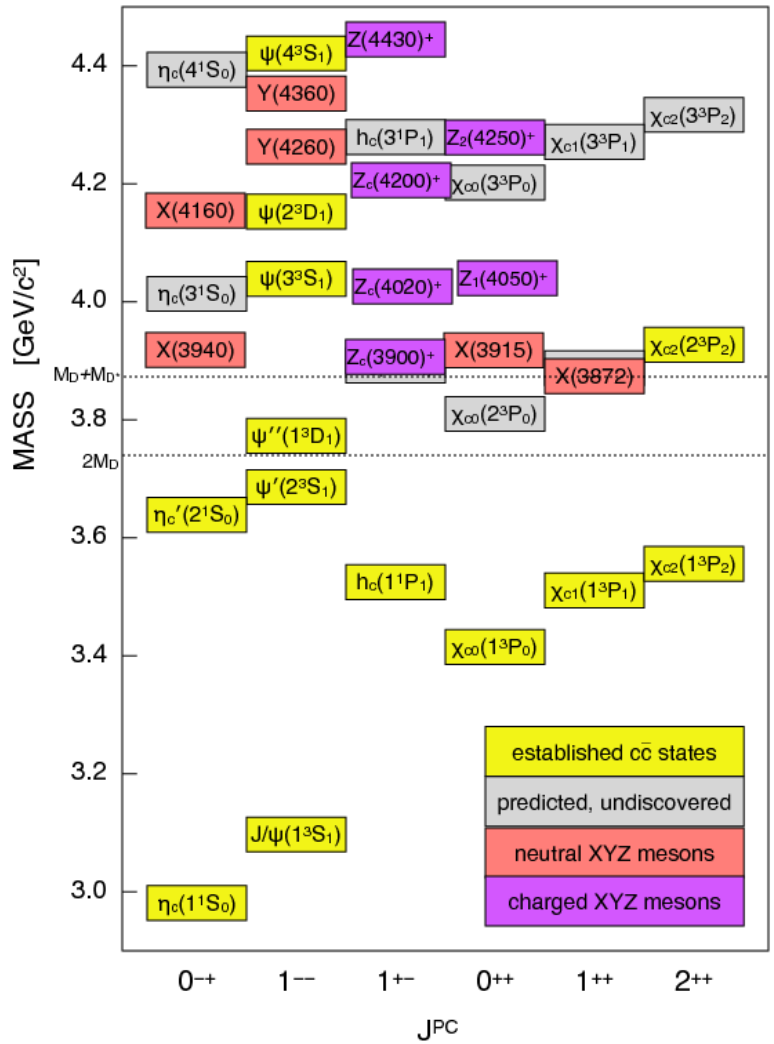
Quark Model and the $c\bar{c}$ Spectrum



S. Godfrey, N. Isgur, Phys. Rev. D 32, 189 (1985)

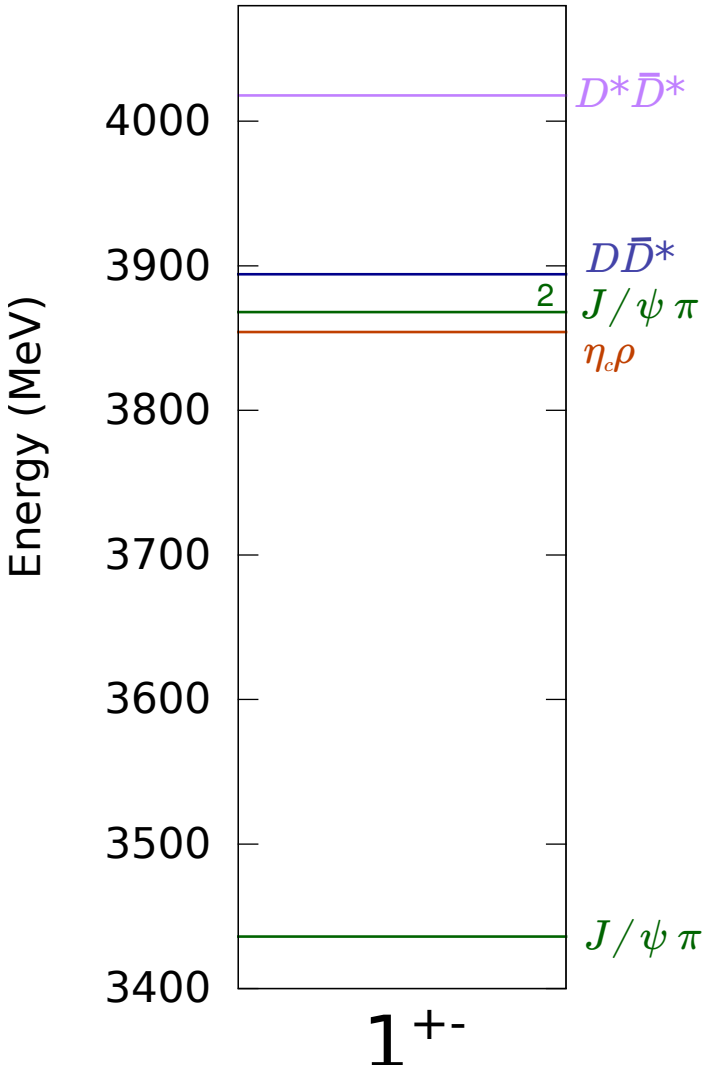
Charmonium Spectrum Today

- Large number of X, Y, Z states have been seen above threshold.
- Charged Z states suggest $c\bar{c}q\bar{q}$ structure. Molecules? Compact tetraquarks?
- Do QCD calculations predict these states?



S. Olsen, arxiv:1511.01589

Finite-volume Spectrum ($c\bar{c}q\bar{q}$)

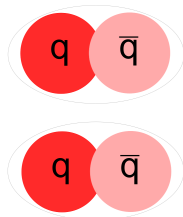


- Compute finite-volume spectrum and determine scattering amplitudes from them.
- Non-interacting meson-meson levels used as a guide as to what operators to reliably calculate finite-volume spectrum.
- Degenerate levels due to partial wave mixing. Will need a suitable number of diverse operators to correctly extract them.

Meson-meson Operators

- Meson-meson operators (M)

$$\mathcal{O}^{\Lambda}(\vec{p}=0,t) \sim \sum_{\vec{x}} e^{i\vec{p}\cdot\vec{x}} M_1^{\Lambda_1}(\vec{x},t) \sum_{\vec{y}} e^{-i\vec{p}\cdot\vec{y}} M_2^{\Lambda_2}(\vec{y},t).$$

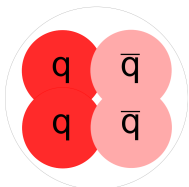


- In infinite-volume, suppose $M_1 = J/\psi$ and $M_2 = \pi$. There are two ways to couple the operator to obtain two linearly independent operators corresponding to S and D-wave. Similar manifestation to obtain $\Lambda = T_1^+$ operator on lattice. A reliable extraction of the spectrum will require all these relevant operators.

Tetraquark Operators

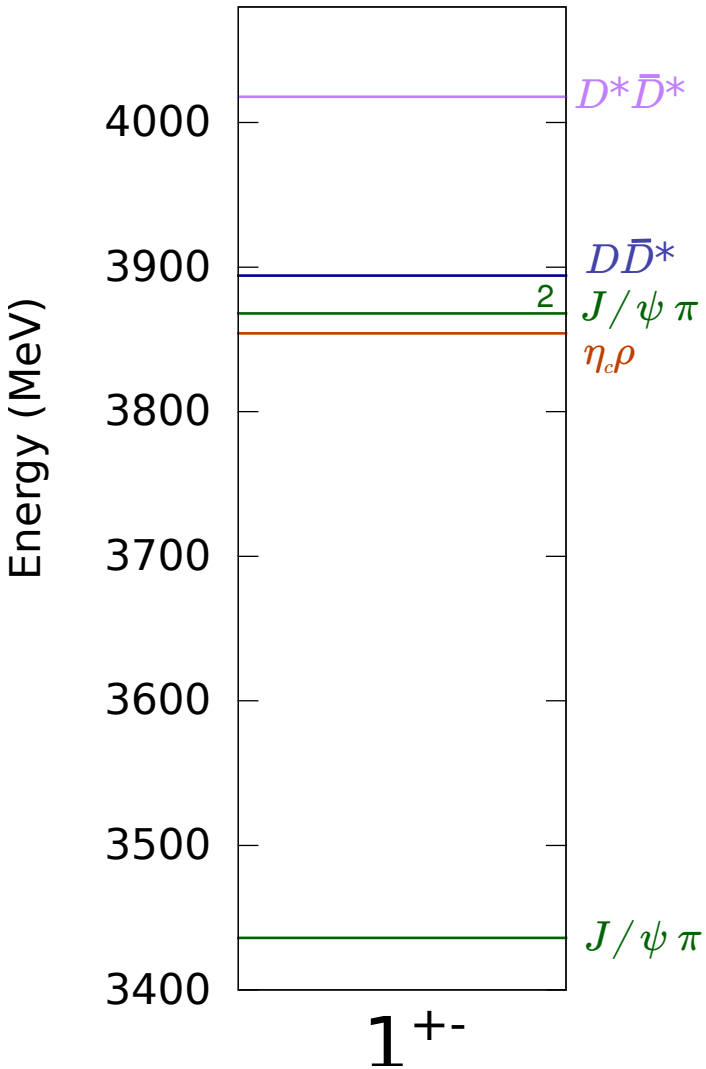
- Tetraquark operators (T)

$$\mathcal{O}^{\Lambda}(\vec{p}=0,t) \sim \sum_{\vec{x}} G_{ad} \underbrace{\left(g_{abc}\, c_{b\vec{x}} (C\Gamma_1) q^T_{c\vec{x}}\right)}_{\text{Diquark}} \underbrace{\left(g_{def}\, \bar{c}^T_{e\vec{x}} (\Gamma_2 C) \bar{q}_{f\vec{x}}\right)}_{\text{Anti-diquark}}.$$



- We construct these operators to transform irreducibly under lattice symmetries, have a range of colour-flavour-spin structures and respect other relevant symmetries.

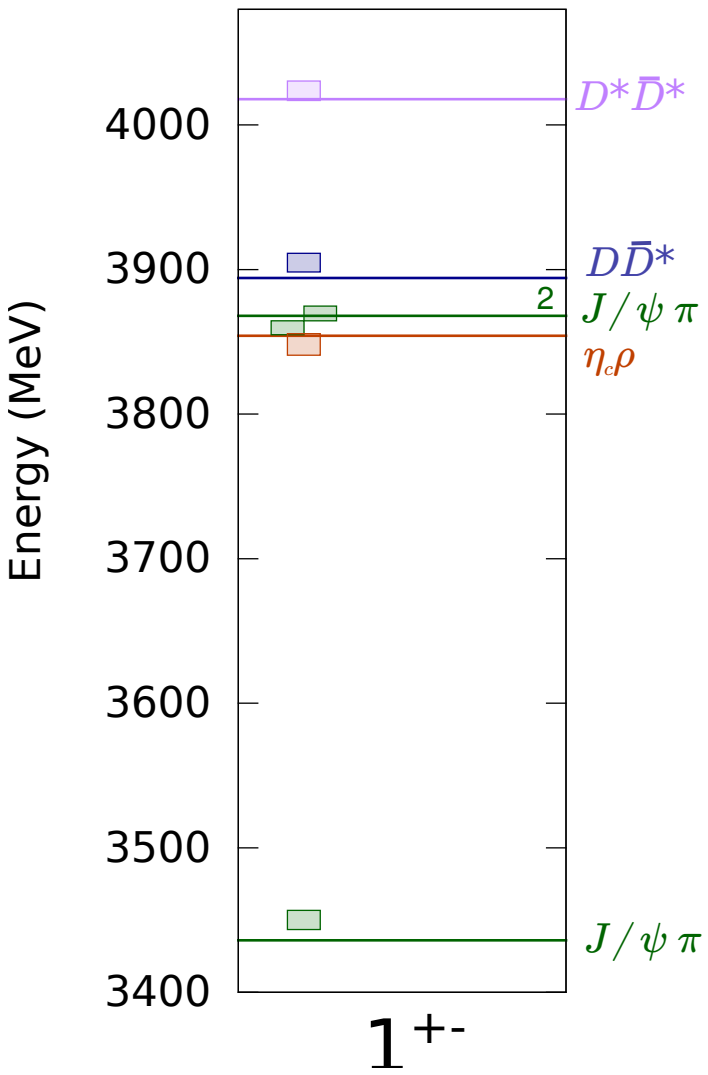
Finite-volume Spectrum ($c\bar{c}q\bar{q}$)



- In the non-interacting limit, we know how many meson-meson levels are in this channel. Will we see an 'extra' energy level of tetraquark origin?
- Will there be large shifts from the non-interacting levels suggesting a strong interaction? Hints of bound states or narrow resonances?

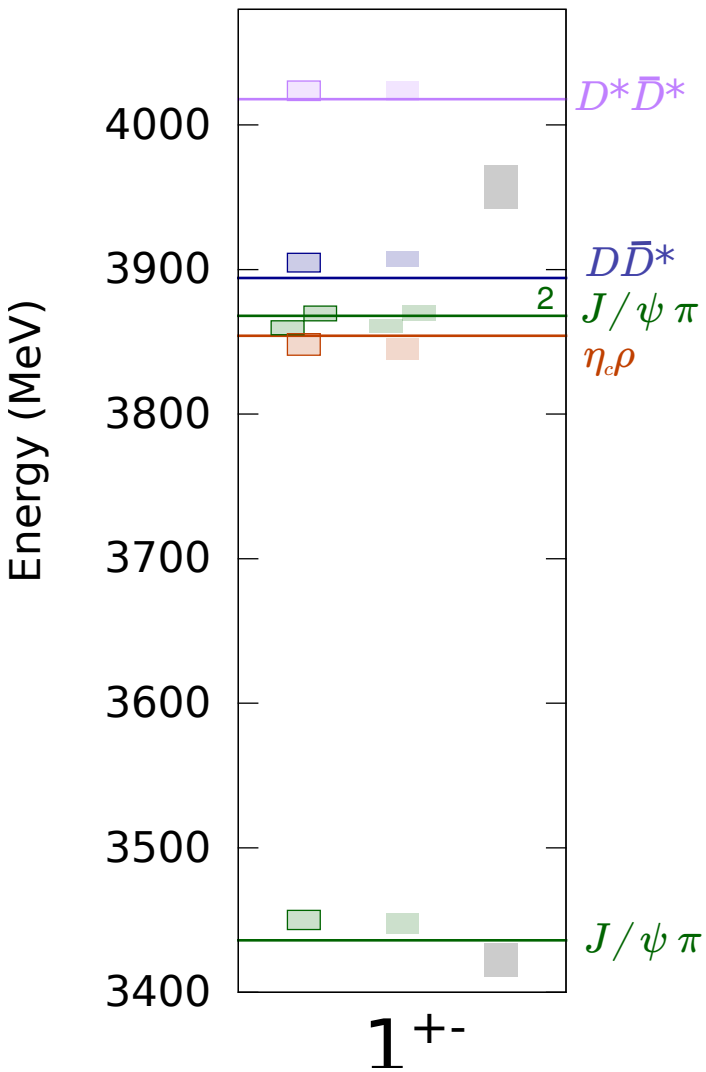
Results

Isospin-1 $c\bar{c}q\bar{q}$ Spectrum at $m_\pi \sim 400$ MeV



- The number of energy levels we find is equal to the number of expected non-interacting meson-mesons due to the sufficient number of operators.
- Finite-volume spectrum lies close to non-interacting meson-meson levels suggesting there are weak meson-meson interactions.
- There is no strong indication for a bound state or narrow resonance in this channel. $Z_C(3900)$?
- Tetraquark operators do not have a significant effect on calculating the spectrum.

Isospin-1 $c\bar{c}q\bar{q}$ Spectrum at $m_\pi \sim 400$ MeV



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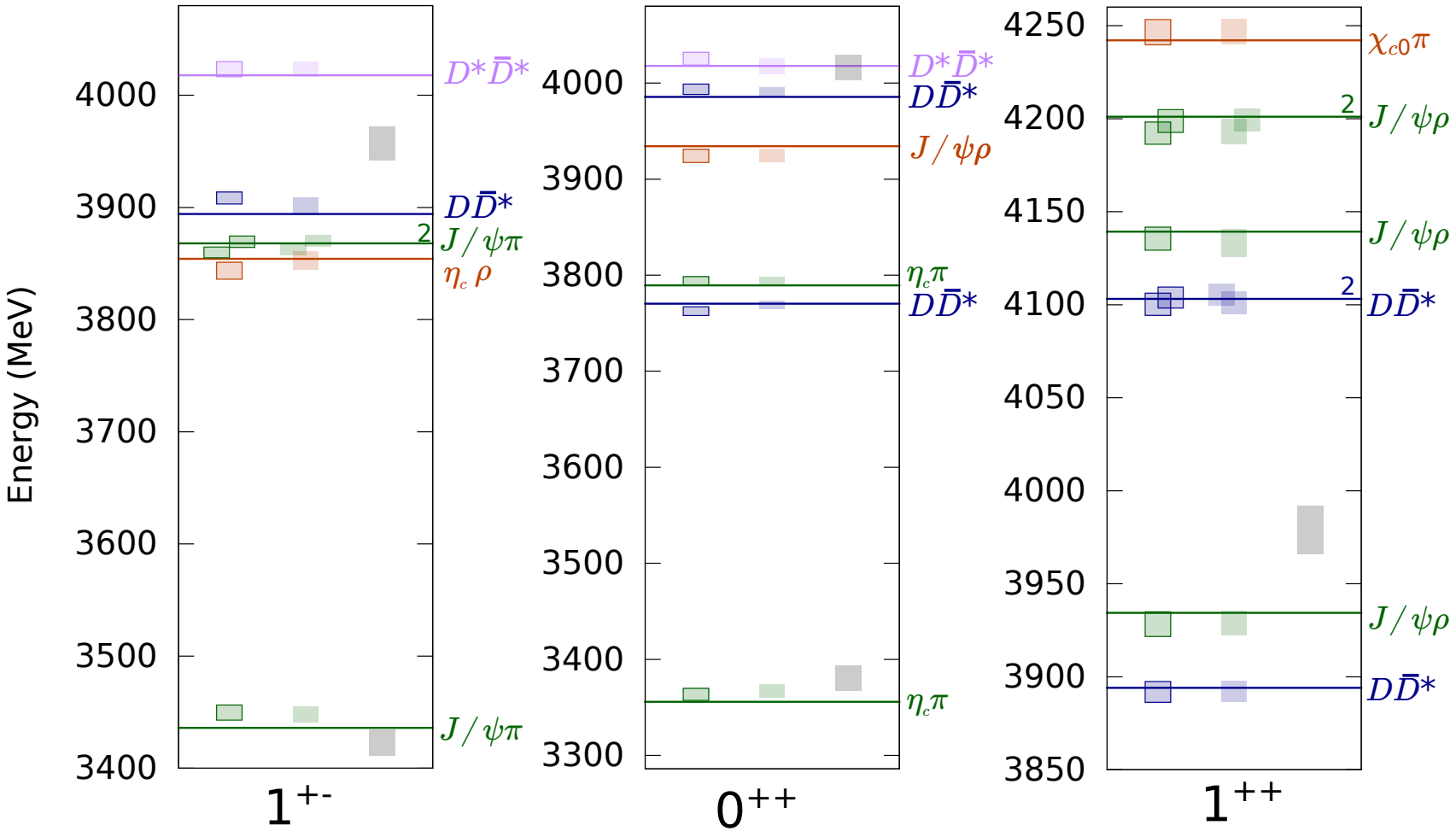
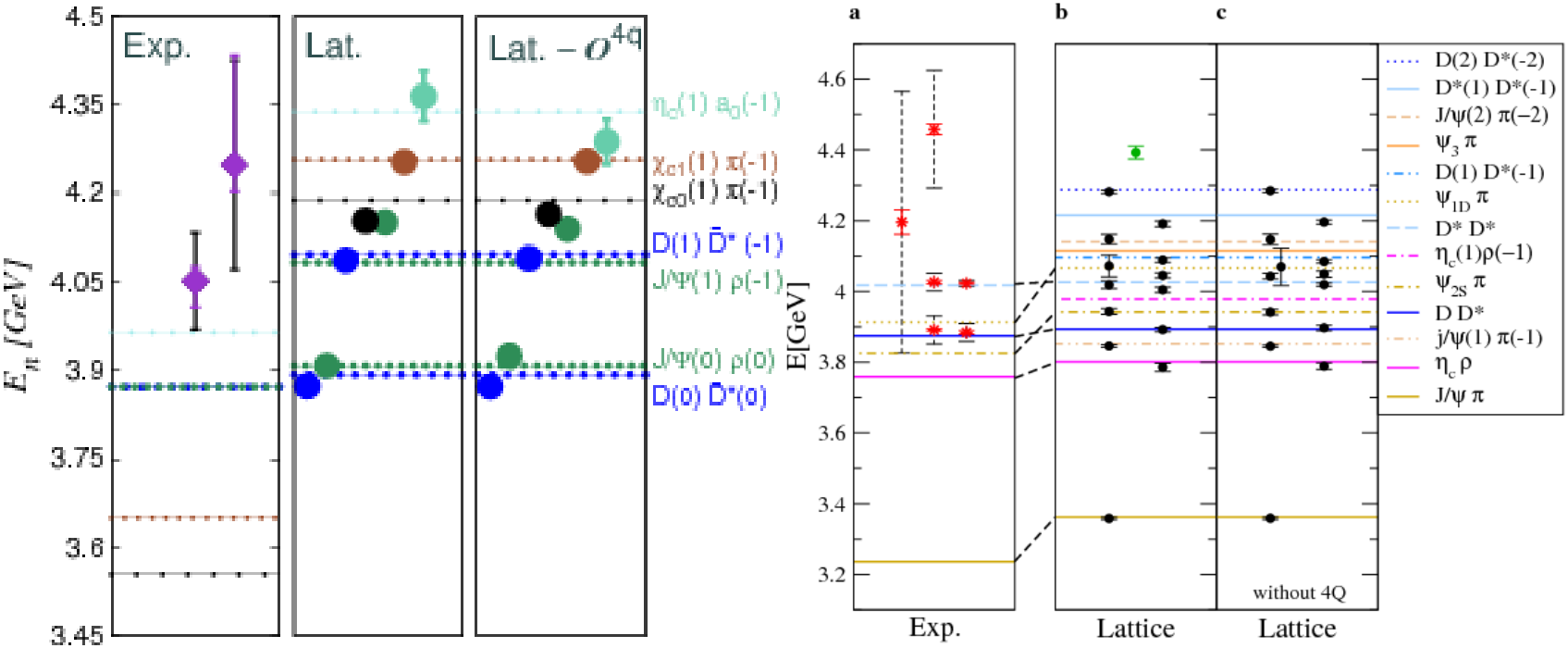


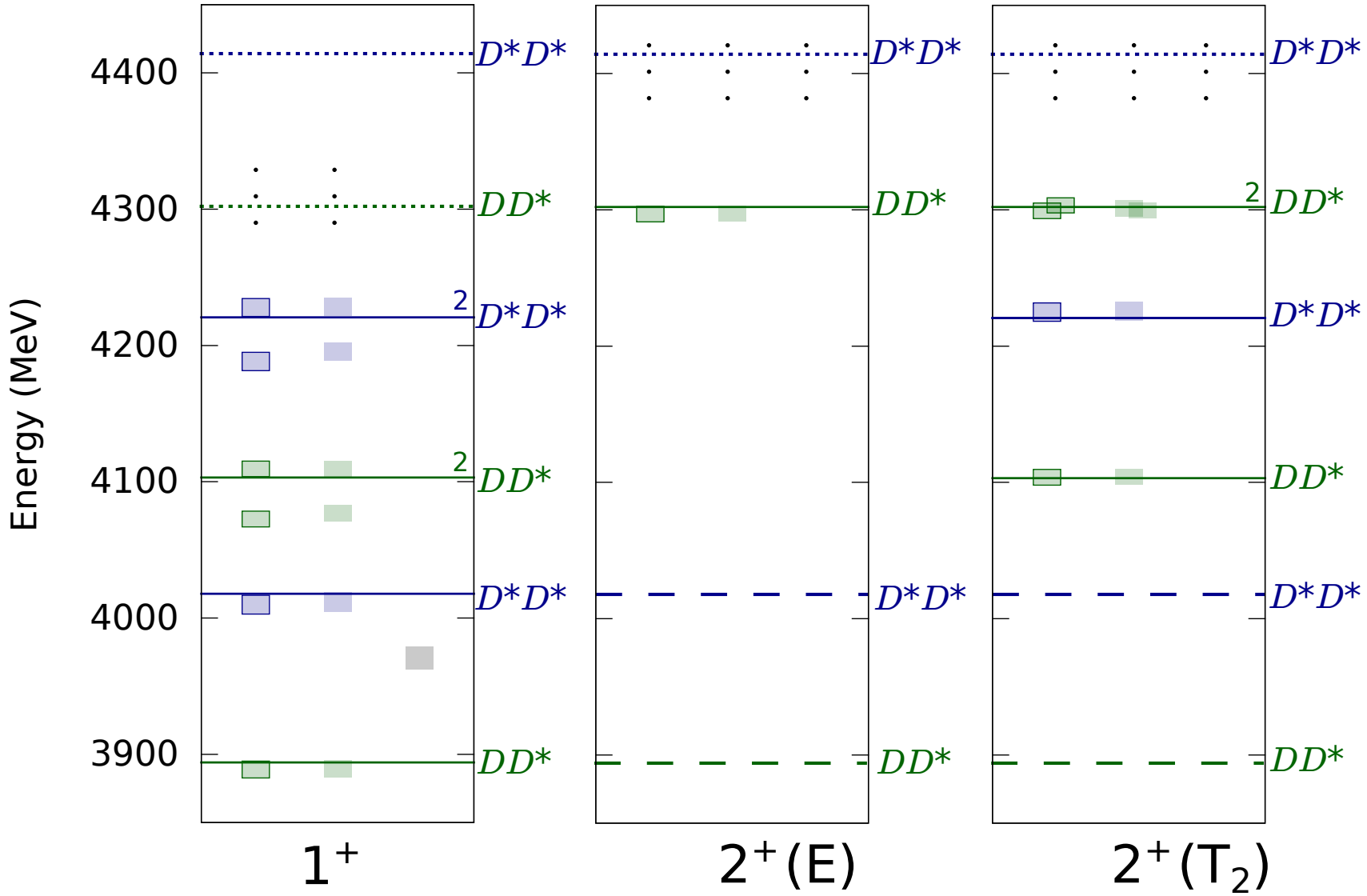
Similar results



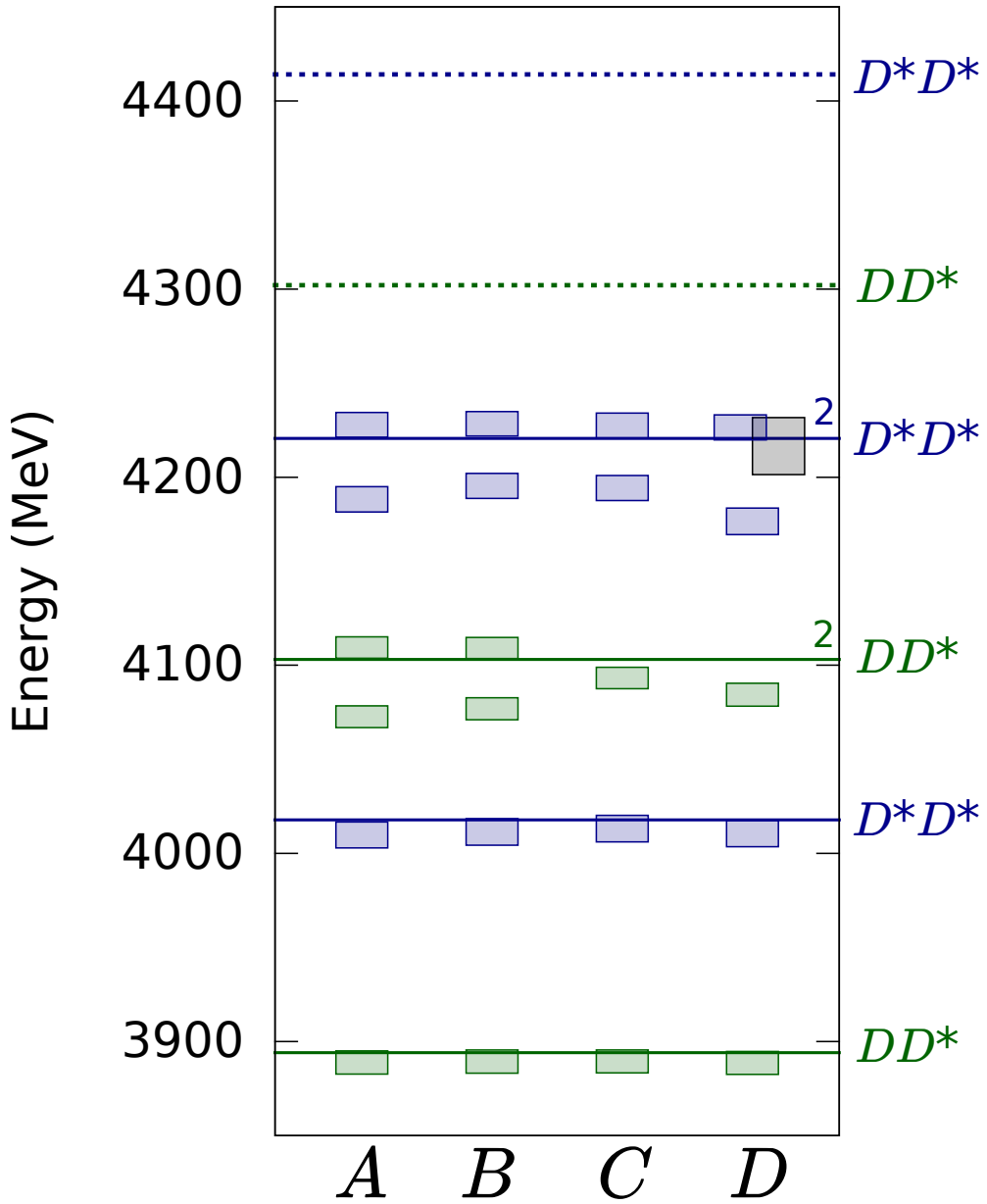
Padmanath, Lang, Prelovsek, Phys.Rev. D92 (2015) no.3, 034501

Prelovsek, Lang, Leskovec, Mohler, Phys.Rev. D91 (2015) no.1, 014504

Isospin-0 doubly charmed spectrum ($cc\bar{q}\bar{q}$)



Varying the operator basis



A - Tetraquark + Meson-meson

B - Meson-meson

C - Meson-meson minus one DD^*

D - Tetraquark + Meson-meson minus one DD^*

Conclusions and outlook

- Important to ensure basis of operators is sufficiently diverse.
- No strong indications for any bound states or narrow resonances in the channels we've studied.
- Addition of a class of tetraquark operators to calculations does not significantly affect the extracted spectrum.
- To rigorously quantify the interaction, next steps are to relate the discrete finite volume spectrum to scattering phenomena using the Lüscher formalism. This would require more spectra in moving frames and different volumes.