Excited and exotic Charmonium, D_s and D meson spectra for two light quark masses

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Southampton, 28^{th} July, 2016

Outline of talk

- Why charmed mesons?
- Method and Lattice Details
- Results from $M_\pi \sim \ 240 MeV$
- Comparison with $M_\pi \sim \ 400 MeV$

Why mesons with charm quarks?

- Open-charm mesons and Charmonium contain a number of experimentally well-established states.
- However, there are a plethora of unexpected charmonium-like states discovered (X, Y, Z's) and they are subject to many theoretical interpretations.
- Possibilities: hybrid states, tetra-quarks, molecular mesons, hadro-quarkonium.

  - Measured masses and widths of the low-lying $D_{s0}^{*}(2317)^{\pm}$ and $D_{s1}(2460)^{\pm}$ states are significantly lighter and narrower than expected from phenomenological models. [arXiv:hep-ph/0505206v2]
  - Complete understanding of these states can in principle be achieved using lattice QCD.

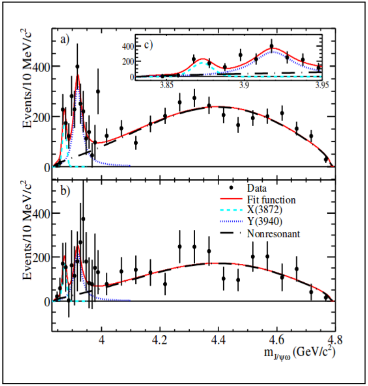


Figure: BaBar $B^+ \to J/\psi\omega K$, $B^0 J/\psi\omega K_S^0$ decays [arXiv:1012.0074]

Lattice details and Method

- Goal: Determine spectrum of open and hidden charmed meson states, including excitations and any states with an intrinsic gluonic component at pion mass $M_\pi \sim 240 MeV$. Compare with previous study with $M_\pi \sim 400 MeV$. [arXiv:1301.7670]

- We use the setup of the Hadron Spectrum Collaboration; dynamical 2+1 anisotropic lattices [arXiv:1004.4930v1]

- We use distillation to compute correlation functions for a large basis of interpolating operators
- Employing this we solve a GEVP:

$$C_{ij}(t)v_j^n = \lambda(t,t_0)^n C_{ij}(t_0)v_j^n \qquad (1)$$

- $\lambda \propto e^{-E_n(t-t_0)}$, v_j^n related to $Z_i^n = \langle n| O_i^\dagger |0\rangle$

Lattice Volume	M_π (MeV)	$N_{\rm cfgs}$	$N_{\rm tsrcs}$ for $c\bar{c}$, $c\bar{s}$, $c\bar{l}$	$N_{\rm vecs}$
$24^3 \times 128$	391	553	32, 16, 16	162
$32^3 \times 256$	236	484	1, 1, 2	384

Operator Overlaps

$M_\pi \sim 240 MeV$

$M_\pi \sim 400 MeV$

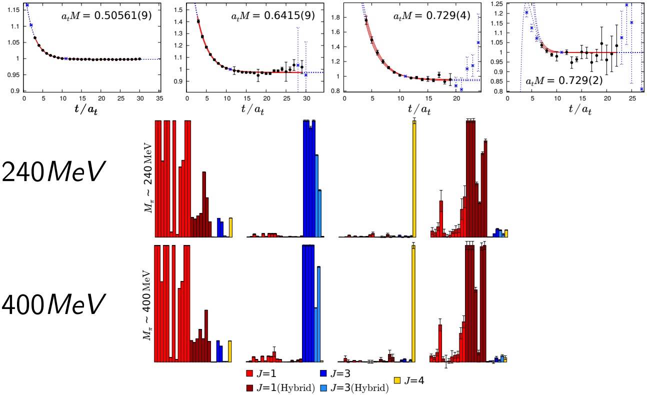


Figure: **Top row**: principal correlators for a selection of low-lying charmonium states in the T_1^{--} irrep. **Middle row**: the operator-state overlaps, Z, for the state above. **Bottom row**: overlaps for the corresponding state on the $M_\pi \sim 400$ MeV ensemble.

Charmonium Spectrum $M_\pi \sim 240 MeV$

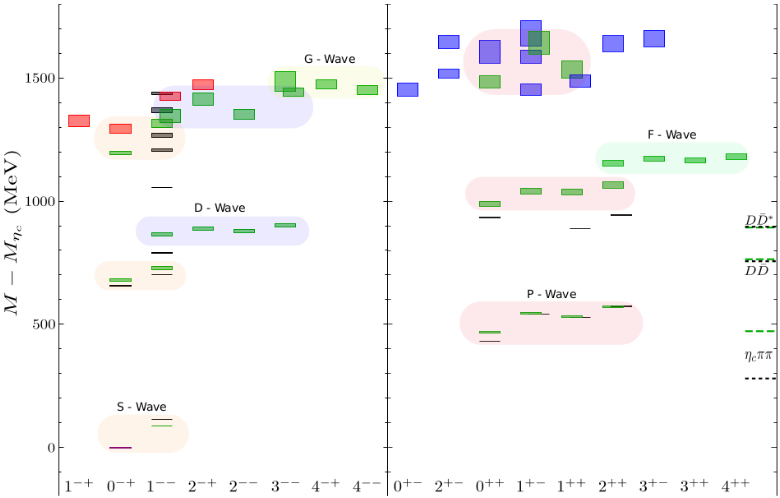
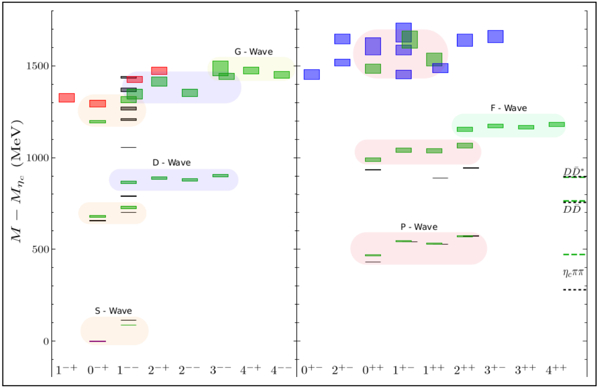


Figure: Charmonium spectrum up to around 4.5 GeV.

Charmonium Spectrum $M_\pi \sim 240 MeV$

- States labeled by J^{PC}
- Masses presented with M_{η_c} subtracted
- Most states follow $n^{2S+1}L_J$ pattern, grouped into S,P,D,F,G wave multiplets using Z_i
- Red + Blue 'hybrids', some states with exotic quantum numbers 1^{-+},0^{+-},2^{+-}



  - Group hybrids into multiplets, pattern consistent with $q\bar{q}$ coupled to 1^{+-} gluonic excitation

D_s spectrum $M_\pi \sim 240 MeV$

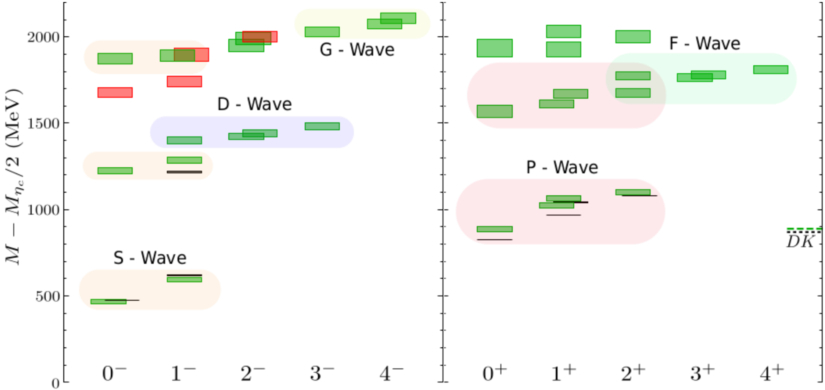
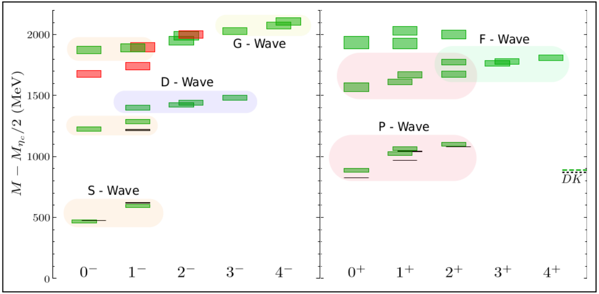


Figure: D_s meson spectrum.

D_s spectrum $M_\pi \sim 240 MeV$

- Identify complete S,P,D and F wave multiplets
- Four states highlighted in red that do not fit $n^{2S+1}L_J$ pattern
- Again: Identified as lightest hybrid meson multiplet, consistent with $q\bar{q}$ (in S-wave) coupled to 1^{+-} gluonic excitation
  - Not able to identify first excited hybrid multiplet



D spectrum $M_\pi \sim 240 MeV$

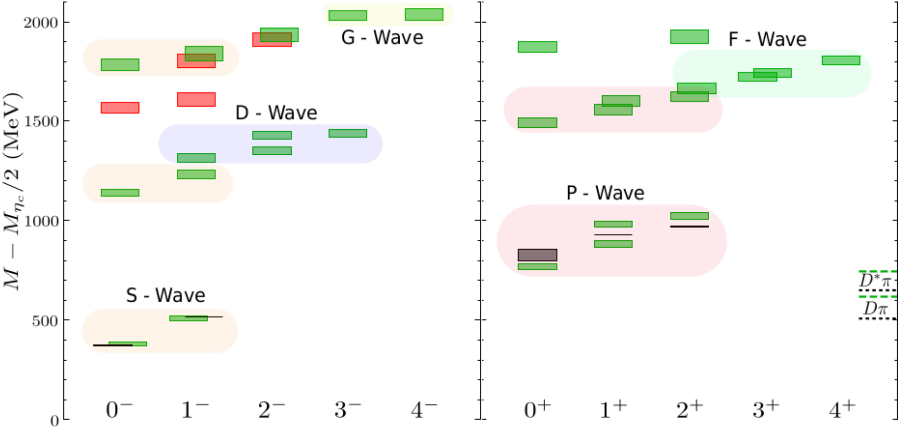


Figure: D meson spectrum.

Charmonium comparison

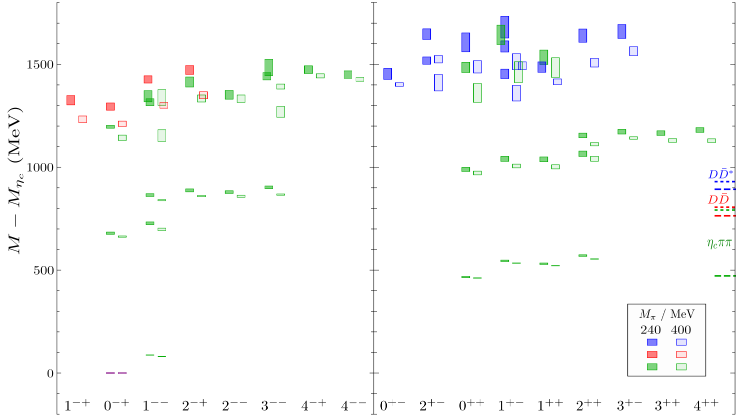
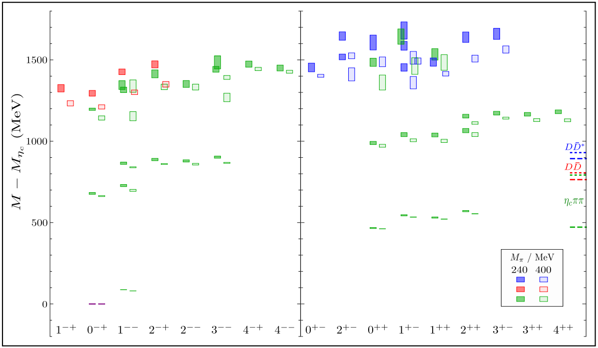


Figure: Charmonium spectrum, with $M_\pi \sim 240$ MeV (left column for each J^{PC}) compared to the spectrum with $M_\pi \sim 400$ MeV (right column for each J^{PC}).

Charmonium comparison

- Light quark dep. enters through sea quarks
- Mild light quark dependence, **no change in overall pattern of states**
- J/ψ: statistically significant increase in mass $\sim 80MeV \rightarrow \sim 87MeV$



- Checked for possible systematic effects arising from scale setting, no effects found!

D_s comparison

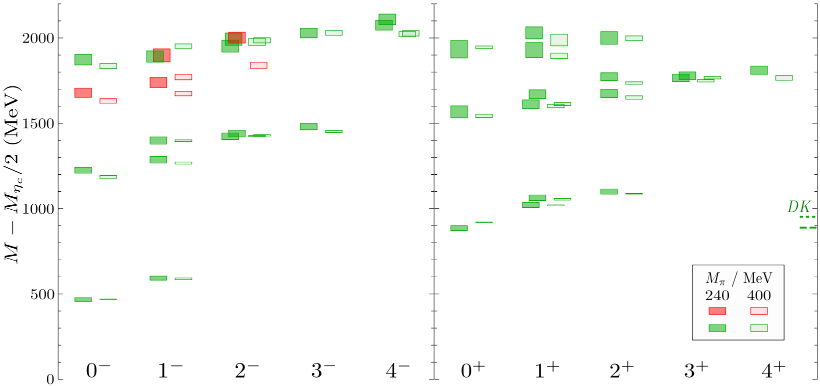
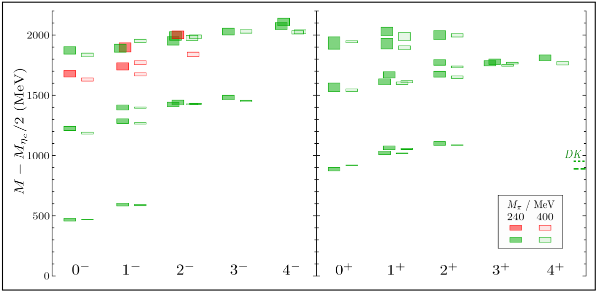


Figure: D_s meson spectrum labelled by J^P.

D_s comparison

- Again, mild light quark dependence, **no change in overall pattern of states**
- Largest change: 0^+ corresponding to $D_{s0}^*(2317)$, expected influence by DK threshold



  - Tendency for hybrids to increase in mass as M_π is reduced (however pattern unchanged)

D comparison

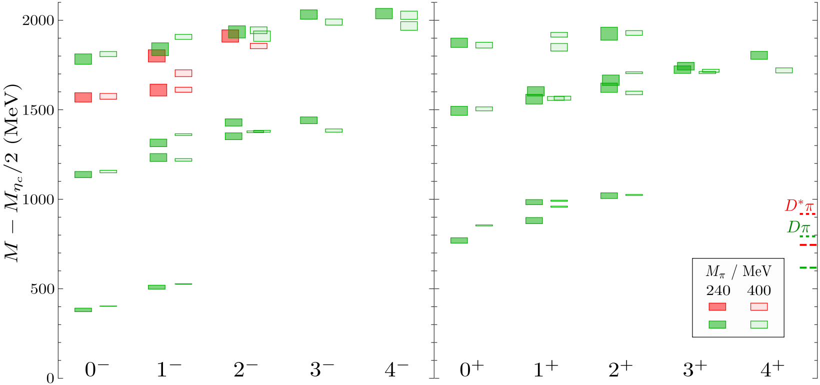
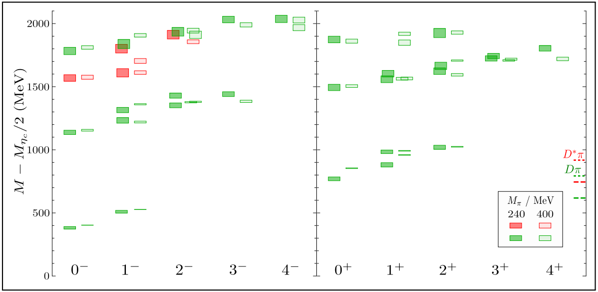


Figure: D meson spectrum labelled by J^P.

D comparison

- D mesons contain light quarks
- Again, we see mild light quark dependence



- Largest change: Lowest 0^+ and 1^+ states, possibly due to coupling to $D\pi$ and $D^*\pi$

Summary

- Distillation and variational method allow us to extract highly excited spectra and robustly identify the continuum $J^{P(C)}$ of states up to $J = 4$
- States with intrinsic gluonic excitations and states with exotic quantum numbers identified
- Many states follow the $n^{2S+1}L_J$ pattern, also find states which we identify as hybrid mesons that fall into hybrid supermultiplets, pattern consistent with a quark-antiquark combination coupled to a 1^{+-} gluonic excitation
- Only mild differences between the spectra calculated on an ensemble where $M_\pi \sim 240$ MeV to our previously determined spectra on an ensemble with $M_\pi \sim 400$ MeV
- Even in the case of the D meson we find only minor quantitative changes
- At least between 240 MeV $\lesssim M_\pi \lesssim$ 400 MeV, the mass of the light quarks play very little role in the overall pattern of structure of our hidden and open-charm spectra

Thank You

- Thank You for listening!