Excited & exotic heavy-light meson spectroscopy

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hadspec

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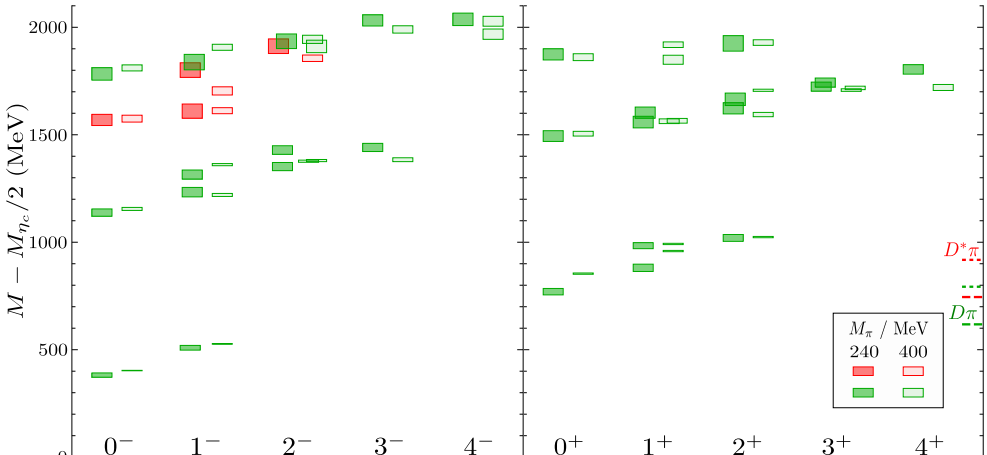
OUTLINE

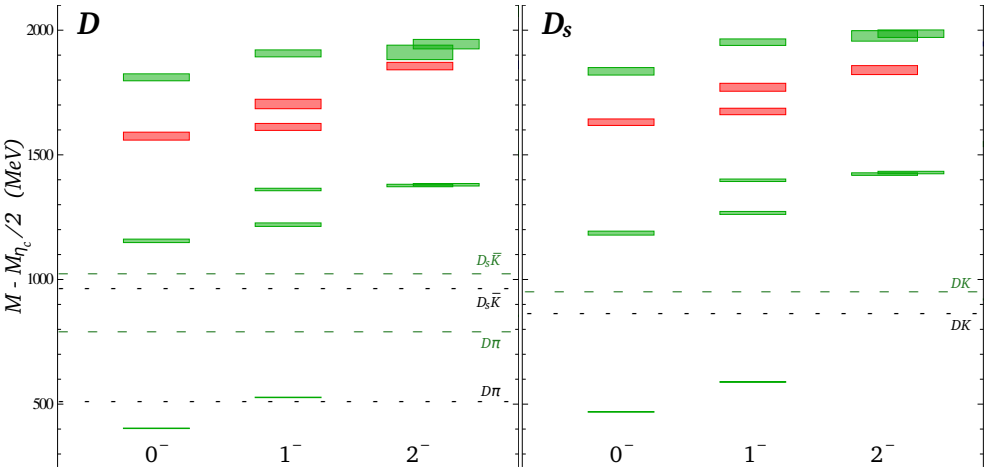
- Motivation and some lattice details [most as in JHEP02 (2021) 213].
- Anisotropy and dispersion relations in the heavy quark sector: quarkonium and heavy-light mesons.
- Brief details of the analysis.
- Preliminary results
  - The spectra of excited and exotic states up to J=4: B, B_s, B_c.
  - Focus on hybrids in B_c - a lightest supermultiplet identified.
- Conclusions & ongoing work.

EXTENDING SIMILAR WORK - OPEN CHARM FOR $J \leq 4$



JHEP12 (2016) 089

IS THERE A HEAVY-LIGHT HYBRID SUPERMULTIPLET AS IN D?



JHEP05 (2013) 021

LATTICE DETAILS

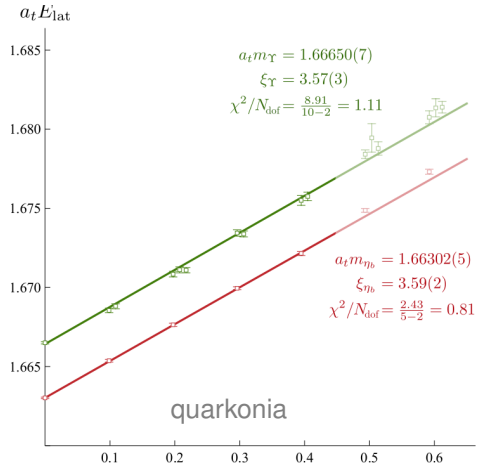
- Symanzik-improved anisotropic gauge action with tree-level tadpole-improved coefficients and $N_f = 2 + 1$.
  Anisotropic clover fermion action with stout-smeared spatial links.
- $\xi = a_s/a_t = 3.5$; $a_s \approx 0.12\,\mathrm{fm}$, $a_t^{-1}(m_\Omega) = 5.67(4)\,\mathrm{GeV}$.
- $20^3 \times 128$ volume; $m_\pi \sim 400\,\mathrm{MeV}$
- Distillation for quark propagation.
- Operators of definite momenta constructed with up to 3 derivatives in each channel. In general, a large bases for GEVP (up to 26 operators in e.g. T_1).

Related work:

- Charmonium: JHEP1207 (2012) 126, JHEP 1612 (2016) 089.
- Open charm: JHEP 05 (2013) 021 & JHEP12 (2016) 089.
- Bottomonium: JHEP02 (2021) 213.

THE LATTICE DISPERSION RELATION

- Fermion action has 2 parameters to tune: m_q and ξ.
- Tuned such that $M_{\eta_b}^{latt} = M_{\eta_b}^{expt}$ *and* a relativistic dispersion relation recovered.



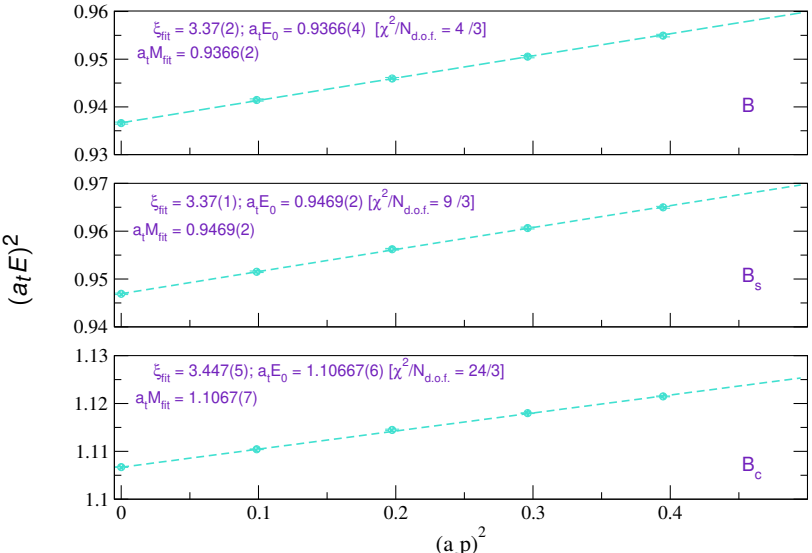
$$(a_t E)^2 = (a_t M)^2 + \left(\frac{2\pi}{\xi L/a_s}\right)^2 n^2.$$

- Momenta to $(2, 0, 0)$ in fits; no significant $(a_s p)^4$ term.
- Rest, kinetic masses consistent.
- Compare to heavy-light dispersion relations using these tuned parameters.

JHEP02 (2021) 214

DISPERSION RELATIONS OF HEAVY-LIGHT MESONS

- Parameters tuned at η_b. Fits within 2(B_c) - 4(B)% of target anisotropy
- Showing pseudoscalar dispersion relations. Vector similar.



RECIPE FOR (MESON) SPECTROSCOPY

- Construct a basis of local and non-local operators $\bar{\Psi}(x)\Gamma D_i D_j \ldots \Psi(x)$ from *distilled* fields [PRD80 (2009) 054506].
- Build a correlation matrix of two-point functions

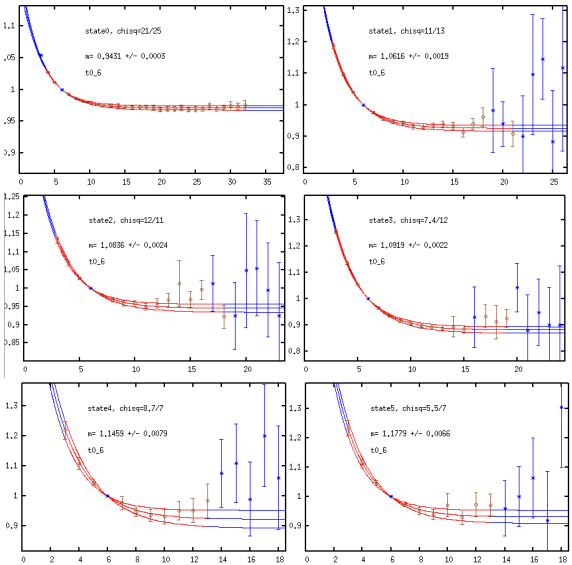
$$C_{ij} = \langle 0|\mathcal{O}_i \mathcal{O}_j^\dagger|0\rangle = \sum_n \frac{Z_i^n Z_j^{n\dagger}}{2E_n} e^{-E_n t}$$

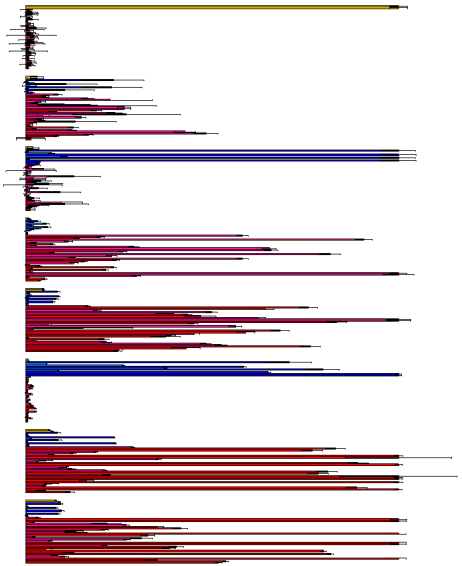
- Ground state mass from fits to $e^{-E_n t}$
- Beyond ground state: Solve generalised eigenvalue problem $C_{ij}(t) v_j^{(n)} = \lambda^{(n)}(t) C_{ij}(t_0) v_j^{(n)}$

- eigenvalues: $\lambda^{(n)}(t) \sim e^{-E_n t}\left[1 + O(e^{-\Delta E t})\right]$ - principal correlator
- eigenvectors: related to overlaps $Z_i^{(n)} = \sqrt{2E_n} e^{E_n t_0/2} v_j^{(n)\dagger} C_{ji}(t_0)$

PRINCIPAL CORRELATORS (B MESON)

Example: T_1^-, operators subduced from continuum Spin 1, Spin 3, Spin 4 operators.

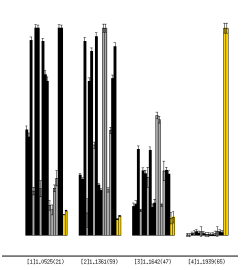




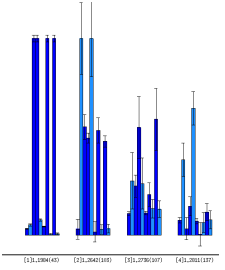
- operators of definite J^{PC} subduced into relevant irrep
- subduced irrep has “memory” of continuum spin J from which it was subduced - **overlaps** predominantly with states of this J.

J	0	1	2	3	4
A_1	✓	0	0	0	✓
A_2	0	0	0	✓	0
E	0	0	✓	0	✓
T_1	0	✓	0	✓	✓
T_2	0	0	✓	✓	✓

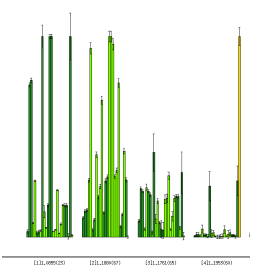
- Using $Z = \langle 0|\Phi|k\rangle$, helps to identify continuum spins
- Find agreement across irreps of subduced continuum spin states



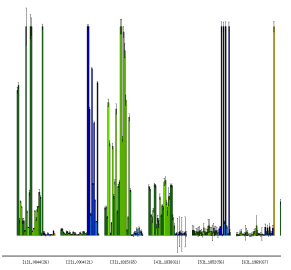
A_1^-



A_2^-



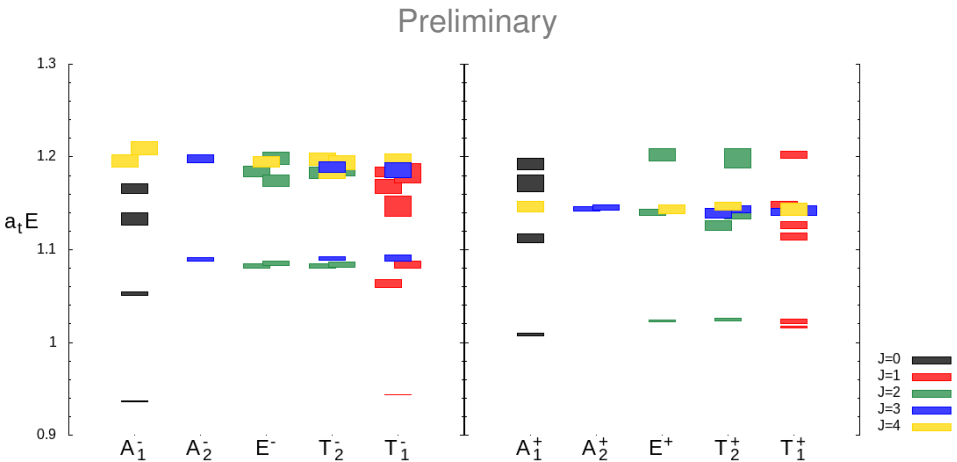
E^-



T_2^-

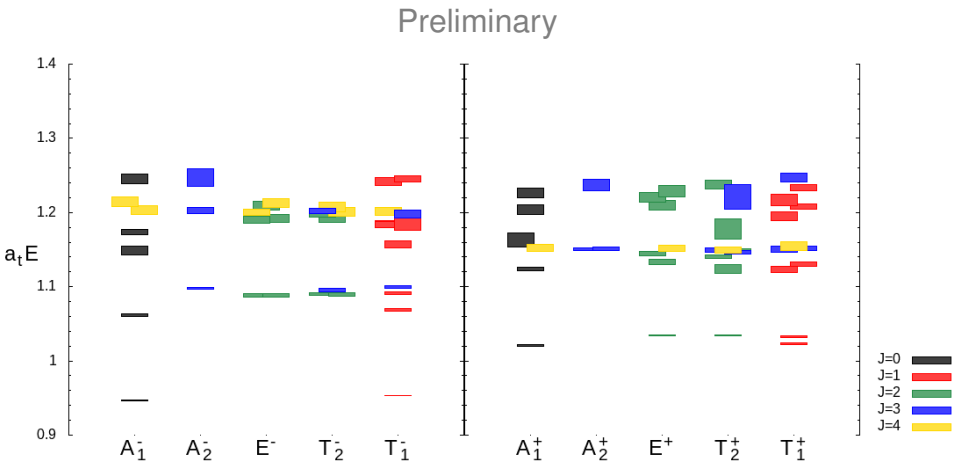
- All polarisations of the spin-4 state are seen.
  Spin labelling: **Spin 2**, **Spin 3** and **Spin 4**.

THE B MESON SPECTRUM



$m_\pi = 391\text{MeV}$

THE B_s MESON SPECTRUM



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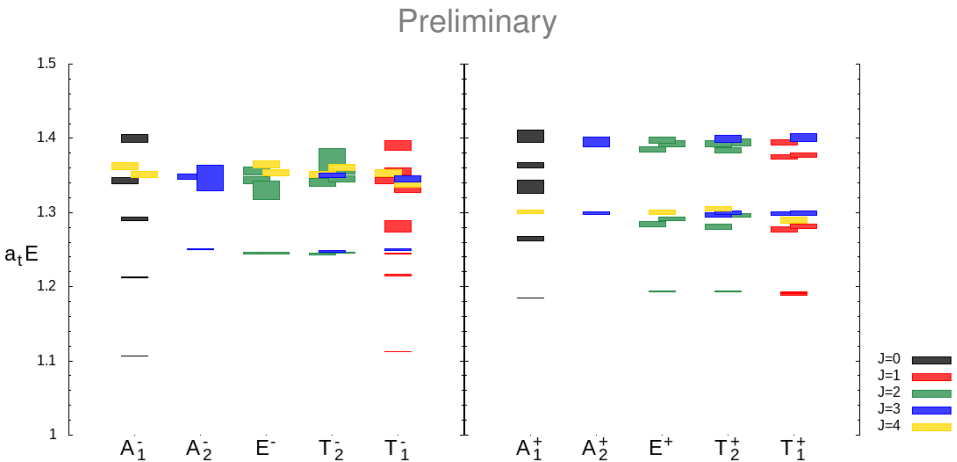
THE B_c SPECTRUM



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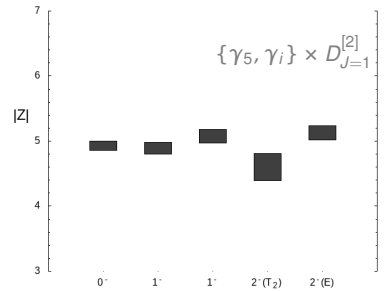
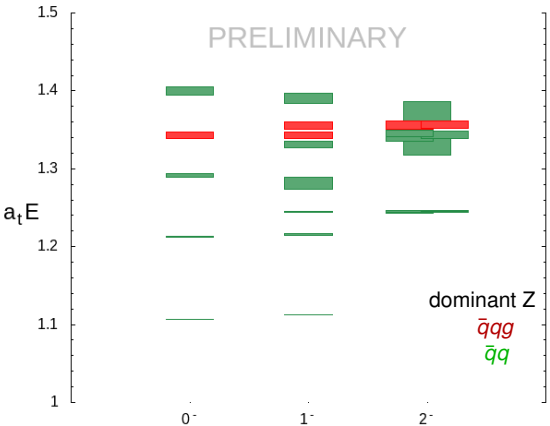
HYBRIDS: A LIGHTEST SUPERMULTIPLET IN B_c

Expect large overlap with $\mathcal{O} \sim F_{\mu\nu}$





- Evidence of a lightest hybrid supermultiplet in B_c. Similar result in B and B_s.
- 1^- hybrids are mixtures of spin-singlet, spin-triplet.

SUMMARY & OUTLOOK

- Exploratory study of heavy meson spectroscopy extended to heavy-light sector.

this work (MeV)		experiment - PDG (MeV)
37(1)	$m_{B^*} - m_B$	45.21 ± 0.21
37.1(6)	$m_{B_s^*} - m_{B_s}$	$48.6^{+1.81}_{-1.5}$
906.1(7)	$m_{B_c} - m_{B_s}$	$907.75 \pm 0.37 \pm 0.27$
602(3)	$m_{B_c}(2S) - m_{B_c}(1S)$	~ 596

preliminary

- Preliminary results for the B, Bs and Bc meson spectra presented:
  - Dispersion relations are consistent between heavy and heavy-light sectors, for parameters tuned once at η_b.
  - Evidence of a hybrid supermultiplet in B, B_s, B_c at energy scale approx 1.3 GeV.
    - similar characteristics in charmonium, open-charm and light mesons.
  - Rotation breaking effects are small, in preliminary analysis at 1 volume.
- The study can be extended to larger volumes and lighter pion masses.
- Paving the way for spectroscopy and decays of heavy mesons.

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Thanks for listening!

B MESON HYBRIDS [PRELIMINARY]

1 Lightest Hybrid Supermultiplet

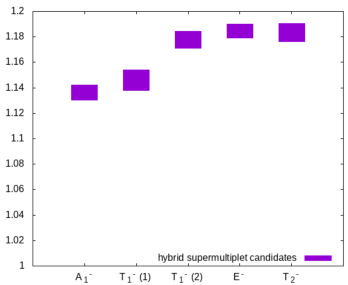

Figure 1: Mass in lattice units of candidate states

- Usual hybrid operators considered: $(\rho \times D^{[2]}_{J=1})^{J=0,1,2}$ and $(\pi \times D^{[2]}_{J=1})^{J=1}$