Bottomonium at finite temperature from Lattice QCD

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Outline

- Background
  - Follows from Charmonium at finite temperature on dynamical ($N_f = 2$) lattices. [arXiv:0705.2198]
  - NRQCD and relativistic bottomonium on dynamical lattices
  - Zero temperature spectroscopy
    - the value of extended operators for $b\bar{b}$ excitations
- Results
  - preliminary results from NRQCD and relativistic simulations
- Some conclusions and outlook

Why bottomonium?

- Many b quarks will be produced at ALICE
- Melting of S and P waves?
- $T_d^{\Upsilon} \sim 5T_c$, difficult to do on a lattice
- Use two approaches and compare results: NRQCD and relativistic.

Dynamical anisotropic lattices

- A large number of points in the time direction required
- To reach $T = 2T_c$, $\mathcal{O}(10)$ points $\Rightarrow a_t \sim 0.025\mathrm{fm}$.
- Far too expensive with an isotropic ($a_s = a_t$) lattice $\Rightarrow$ anisotropic, $a_t \ll a_s$.
- Gives an independent handle on temperature

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- Introduces 2 additional parameters to the action
- Non-trivial but now understood tuning problem [PRD 74 014505 (2006)]

Simulation parameters

arXiv:07075.2198

Light quarks	m_π/m_ρ	0.54	
Anisotropy	ξ	6	
Lattice spacing	a_t	0.025fm	
	a_s	0.17fm	
Lattice volume	N_s^3	8^3	$\rightarrow 12^3$
Critical temp.	T_c	$1/33.5a_t$	210MeV
1/Temperature	N_t	16	$T \sim 2.1\,T_c$
		24	$T \sim 1.4\,T_c$
		32	$T \sim 1.05\,T_c$
		80	$T \sim 0$

Use all-to-all propagators and extended operators for better overlap with states.

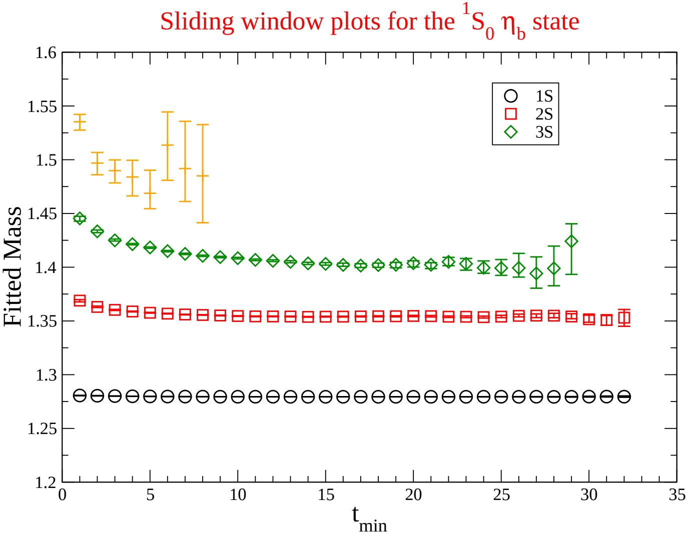
b-quark methods on the lattice

Need $am_b < 1$ which becomes increasingly difficult for heavy quarks

- Fermilab: mass-dependent renormalisation of the action and operators. Expensive to improve beyond $\mathcal{O}(a)$.
- NRQCD: Good for b quarks, not c and no continuum limit.
  Use an action good to lowest order in v^2.
- Anisotropic relativistic: keeps $a_t m_b < 1$. Continuum limit possible.
  Use an action improved to $\mathcal{O}(a_s^3, a_t^2, \alpha_s a_s^2)$.

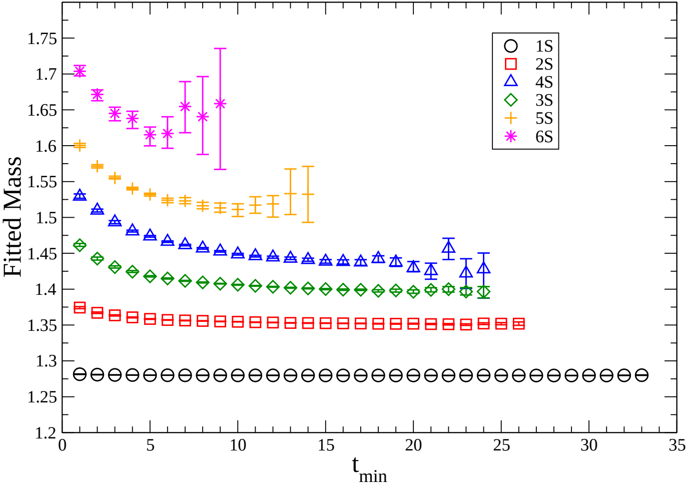
Compare NRQCD and Relativistic anisotropic results on the same dynamical ($N_f = 2$) background configurations.

(Relativistic) zero-temperature spectroscopy: S waves



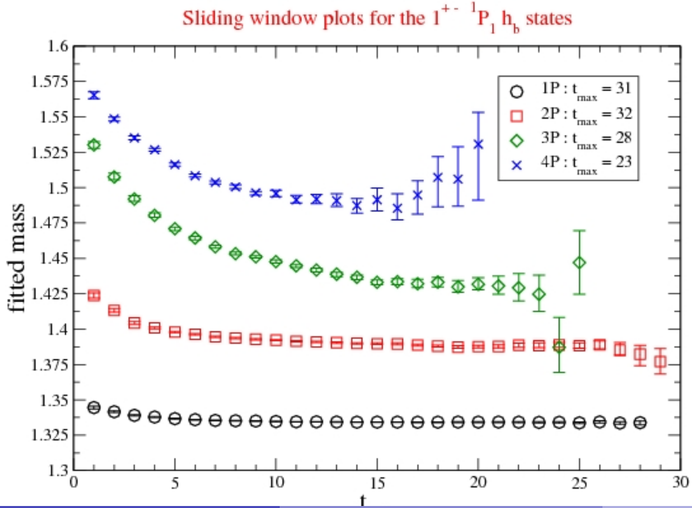
(Relativistic) zero-temperature spectroscopy: S waves

Sliding window plots for the $^3S_1$ 1^{--} Υ state.

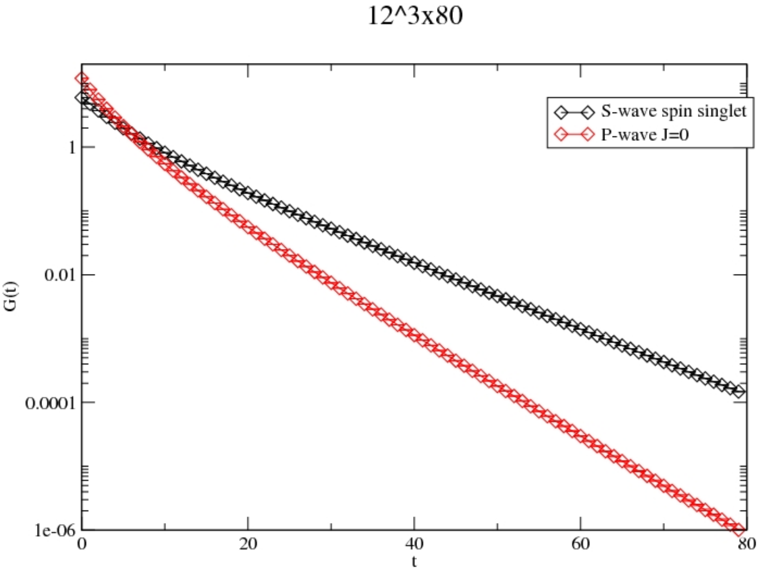


(Relativistic) zero-temperature spectroscopy: P waves

$\rightarrow P - S$ splitting $\approx$ 400MeV. Persists above T_c



NRQCD: S and P waves at $T = 0$, $T > T_c$



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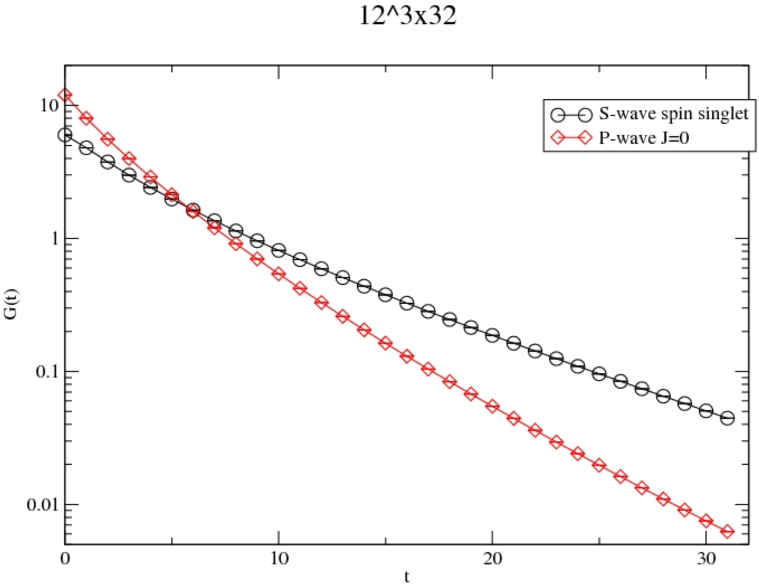


$\rightarrow$ P-S splitting survives at $T > T_c$.

Spectral functions from Maximum Entropy Method

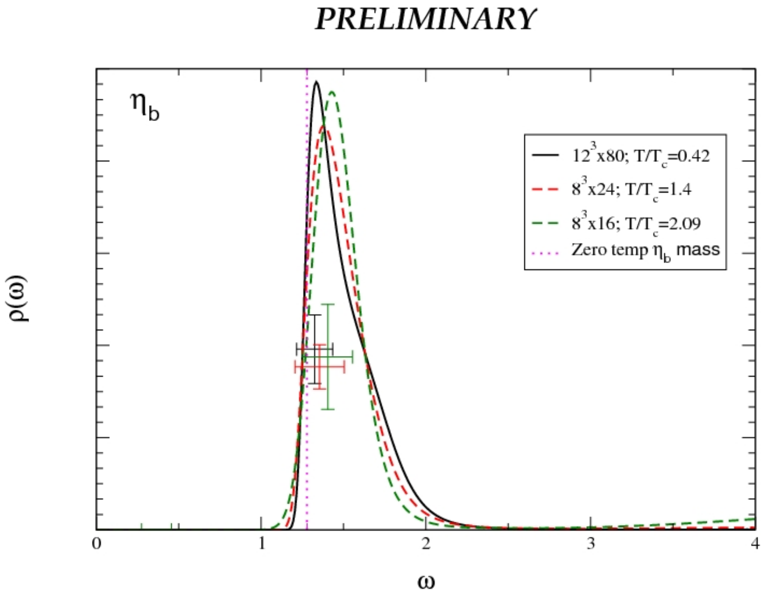
- Spectral functions give information about hadrons in the medium
- Can be used to determine transport coefficients
- $\rho_\Gamma(\omega, \vec{p})$ related to the euclidean correlator $G_\Gamma(t, \vec{p})$ by

$$G_\Gamma(t, \vec{p}) = \int \rho_\Gamma(\omega, \vec{p}) \frac{\cosh[\omega(t - 1/2T)]}{\sinh(\omega/2T)}$$

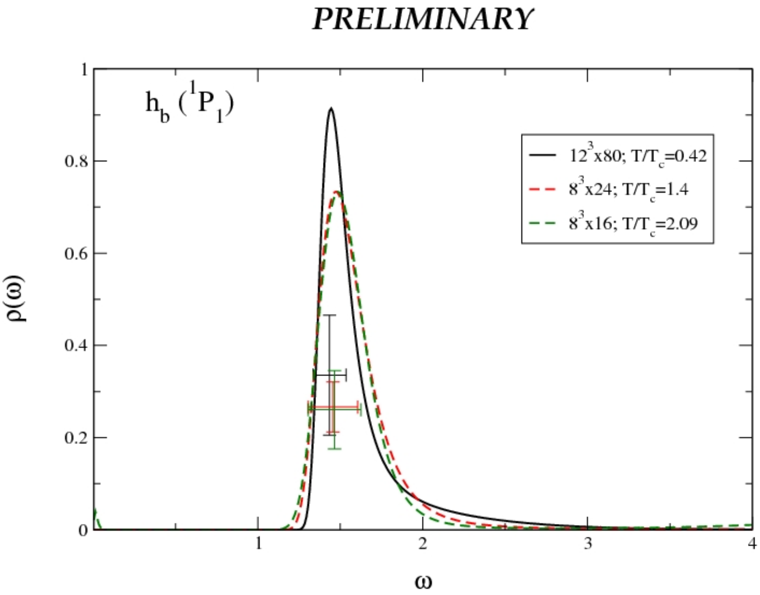
- ill-posed problem - needs a large number of timeslices
- use mem to determine the most likely $\rho(\omega)$.

Preliminary results: no mem systematics included.

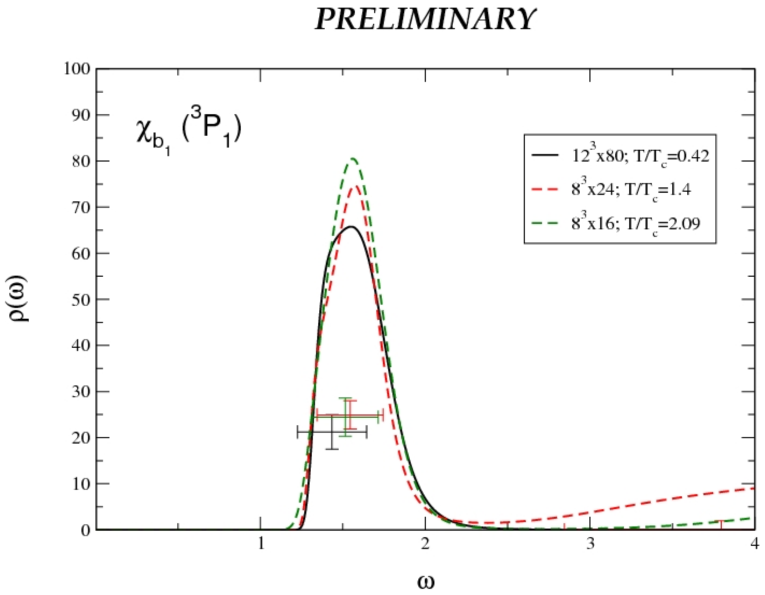
η_b ($^1S_0$) T dependence



h_b $({}^1P_1)$ T dependence



χ_{b_1} $(^3P_1)$ T dependence



Outlook

- Early stages of this work
  - zero temperature spectroscopy and MEM in reasonable agreement
  - little dependence in the MEM of S or P waves on temperature. Up to $T \sim 2T_c$.
  - good signals in NRQCD correlators and observed P-S splitting.
- Discretisation errors
  - finer lattice spacings being generated
- More reliable determination of states
  - Use both extended and point operators (with all-to-all propagators)
  - Better analysis of excitations including particle identification
- Reconstructed correlators
- MEM systematics
  - vary the default model, time ranges etc.
- More in-depth comparison of NRQCD and relativistic results from the same lattices