S-Wave Bottomonium Decay Matrix Element in non-zero Temperature

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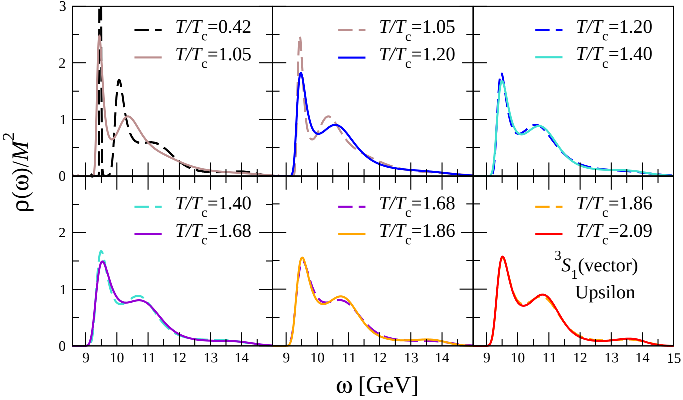
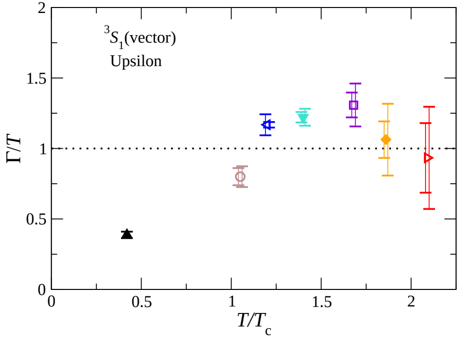
Outline

Temperature dependence of lattice NRQCD spectral function



Temperature dependence of lattice NRQCD spectral function

- width of $\Upsilon(1S)$ peak



- EFT prediction (Brambilla et al, JHEP **1009** (2010) 038)

$$\frac{\Gamma}{T} = \frac{1156}{81}\alpha_s^3 \simeq 14.27\alpha_s^3 \quad (1)$$

(lattice result: $\alpha_s \sim 0.4$)

Quarkonium decay matrix element in zero temperature

• heavy quark (Q)–heavy anti-quark ($\overline{Q}$) annihilation is point-like four-fermion interaction (size $\sim \frac{1}{M}$) in NRQCD

• imaginary parts of $Q\overline{Q} \to Q\overline{Q}$ scattering amplitudes are related to $Q\overline{Q}$ annihilation rates by optical theorem

$$\delta\mathcal{L}_{4-\text{fermion}} = \sum_n \frac{f_n(\Lambda)}{M^{d_n-4}} \mathcal{O}_n(\Lambda) \tag{2}$$

• For example, dimension-6 operators are:

$$\mathcal{O}_1({}^1S_0) = \psi^\dagger\chi\chi^\dagger\psi \tag{3}$$
$$\mathcal{O}_1({}^3S_1) = \psi^\dagger\vec{\sigma}\chi\cdot\chi^\dagger\vec{\sigma}\psi \tag{4}$$
$$\mathcal{O}_8({}^1S_0) = \psi^\dagger T^a\chi\chi^\dagger\psi \tag{5}$$
$$\mathcal{O}_8({}^3S_1) = \psi^\dagger\vec{\sigma}T^a\chi\cdot\chi^\dagger\vec{\sigma}T^a\psi \tag{6}$$

(cf. Bodwin, Braaten, Lepage, PRD51 (1995) 1125)

Quarkonium decay matrix element in zero temperature

- for electromagnetic annhiliation, e.g, $\Upsilon \rightarrow \mu^+\mu^-$

$$\Gamma(\Upsilon \rightarrow \mu^+\mu^-) = \frac{4|R(0)|^2}{9M^2}\alpha_{em}^2\sqrt{1-4(\frac{M_{\mu\mu}}{M_\Upsilon})^2}\left[1+2(\frac{M_{\mu\mu}}{M_\Upsilon})^2\right]+\cdots \quad (2)$$

- in NRQCD

$$\Gamma(\Upsilon \rightarrow \mu^+\mu^-) = \frac{2\mathrm{Im}\, f_{\mu\mu}(^3S_1)}{M^2}|\langle 0|\chi^\dagger\vec{\sigma}\psi|\Upsilon\rangle|^2+\cdots \quad (3)$$

- $\Upsilon \rightarrow \mathrm{LH}$

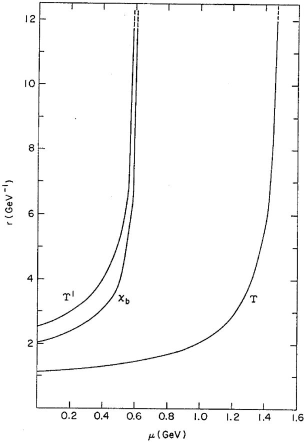
$$\Gamma(\Upsilon \rightarrow LH) = \frac{2\mathrm{Im}\, f_1(^3S_1)}{M^2}\langle\Upsilon|\mathcal{O}_1(^3S_1)|\Upsilon\rangle+\cdots \quad (4)$$

Quarkonium decay in non-zero temperature

- $\int d^3x|\phi|^2 = 1 \rightarrow |R(0)|^2 \sim \frac{1}{a^3}$
- color screening $\rightarrow$ looser bound state, reduced $|R(0)|$
- reduced leptonic decay width
- what about hadronic width?

Quarkonium decay in non-zero temperature

- F. Karsch, M.T. Mehr, and H. Satz, Z.Phys.C37 (1988) 617.



Lattice

- two point functions

$$\langle 0|\chi^\dagger \psi(T)\psi^\dagger \chi(0)|0\rangle \quad (5)$$

for $^1S_0$ and

$$\langle 0|\chi^\dagger \sigma_i \psi(T)\psi^\dagger \sigma_i \chi(0)|0\rangle \quad (6)$$

for $^3S_1$

- for large T, $|\langle 0|\psi^\dagger \chi|^1S_0\rangle|^2 e^{-E_{^1S_0}T}$ (if the ground state dominates)

Lattice

- three point function

$$\langle 0|\chi^\dagger\psi(T)\psi^\dagger\chi\chi^\dagger\psi(0)\psi^\dagger\chi(T')|0\rangle \tag{5}$$

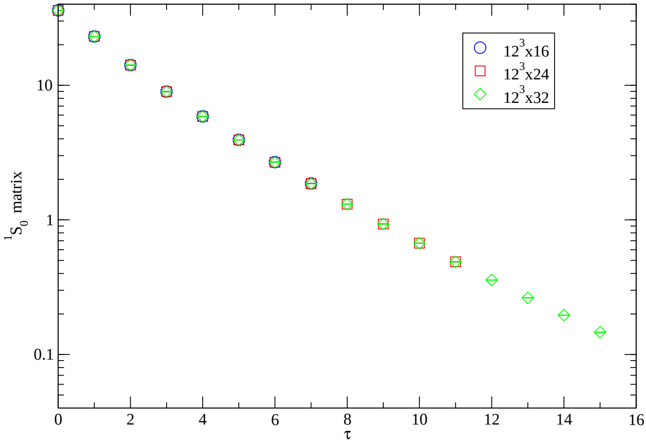
for $^1S_0$

$$\langle 0|\chi^\dagger\sigma_i\psi(T)\psi^\dagger\sigma_i\chi\chi^\dagger\sigma_i\psi(0)\psi^\dagger\sigma_i\chi(T')|0\rangle \tag{6}$$

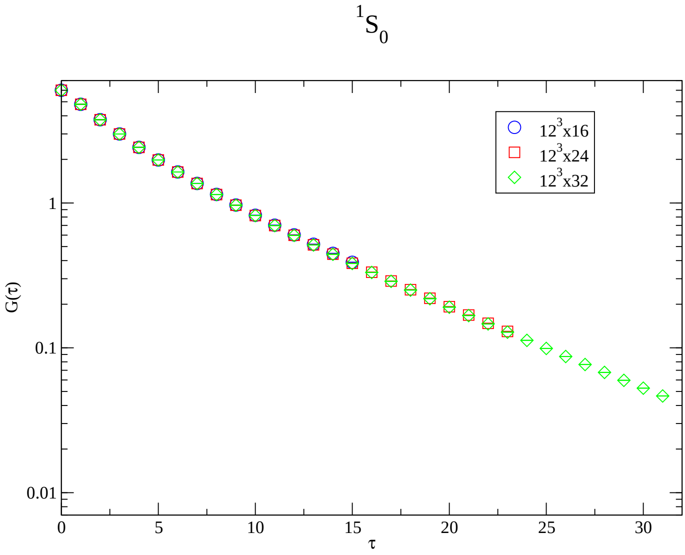
for $^3S_1$

(cf. see e.g., PRD65 (2002) 054504 for zero T case)

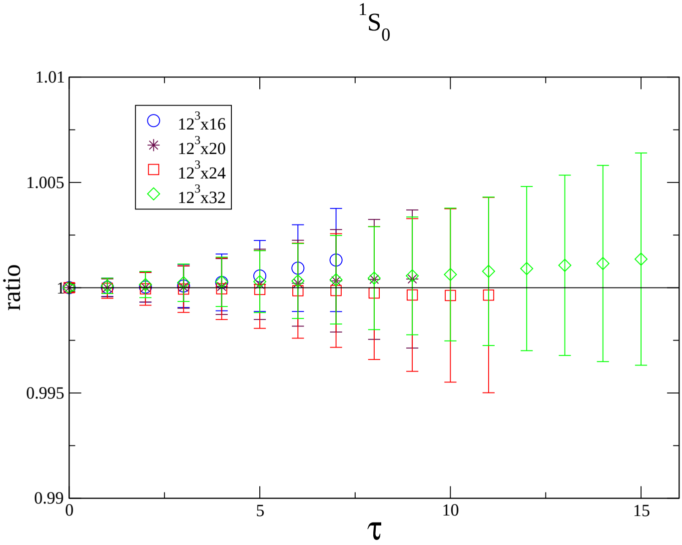
Preliminary result



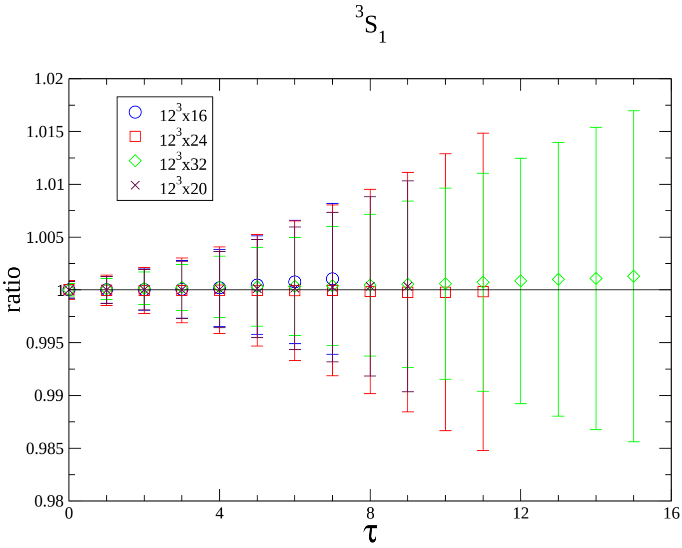
Preliminary result



Preliminary result



Preliminary result



Discussion

- error analysis
- other matrix elements: color octet for S-wave, P-wave, etc
- comparison with potential model?