Bottomonium screening masses in $2+1$ flavor QCD

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based on the work
P. Petreczky, SS, J. H. Weber, Phys. Rev. D 104, 054511 (2021) [hep-lat/2107.11368].
Heavy Flavor Production in Heavy-Ion and Elementary Collisions, INT-22-3

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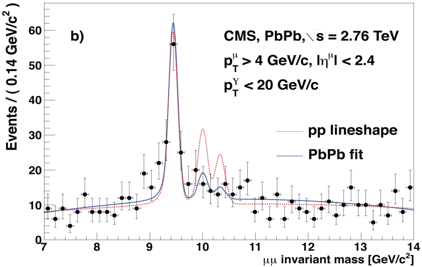
- At finite temperature, the quarkonium states are expected to be suppressed due to screening → Signal of quark-gluon plasma [Matsui & Satz, 86]. Hints from experiments! [CMS collaboration, 16].



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- The temporal extent N_τ of the lattice becomes smaller at higher temperature as $T = \frac{1}{N_\tau a}$ $\rightarrow$ the number of data points for the Euclidean temporal correlator limited. Hence extraction of the spectral function from it is an ill-defined problem.

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- Since the kinetic energy of the heavy quarks is less than its rest mass, it is possible to integrate out d.o.f at the scale $\sim m_b$ to obtain non-Relativistic QCD (NRQCD) effective theory.
- Within the NRQCD, it is now known from lattice studies that ground state $\eta_b(1s)$ melt at $T > 400$ MeV whereas the fate of 1P-bottomonia states is not yet completely settled.

[G. Aarts et. al. 10, 14, S. Kim et. al., 14, 18, R. Larsen et. al., 18, 19.]

Screening mass: definition

- Alternatively we look at the spatial correlators. Screening masses for the meson operator $J = \bar{\psi}\Gamma\psi$ are defined as [De Tar & Kogut, 87],

$$C(z) = \int_0^{\beta} d\tau \int dxdy \; \langle J(\mathrm{x}) J(0) \rangle \sim \mathrm{e}^{-\mathrm{M_{scr} z}} + ..$$

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- When there are well-defined bound state peaks in the spectral function the M_{scr} is simply the pole mass of the corresponding meson channel. At high T at LO, the $M_{scr} = 2\sqrt{m_q^2 + (\pi T)^2}$.

Set-up

- We use $2+1$ flavor QCD ensembles @HotQCD in the temperature range 350-1000 MeV.
- We have for 3 lattice spacings at most temperatures which correspond to $N_\tau = 8, 10, 12$. Since $T = \frac{1}{N_\tau a}$ so we are in this way approaching the continuum limit .
- Furthermore the spatial sites $N_\sigma = 4N_\tau \rightarrow$. large enough for thermodynamic limit.
- At each temperature $am_b \lesssim 1$ to control mass-dependent cut-off effects.

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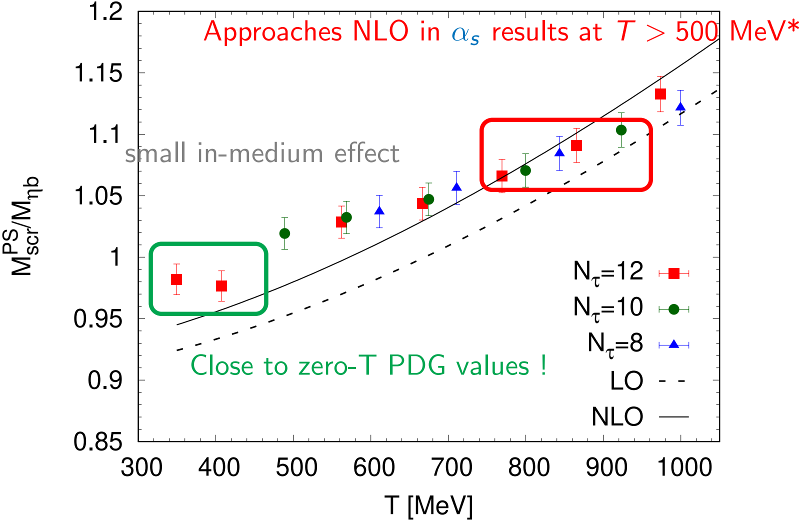
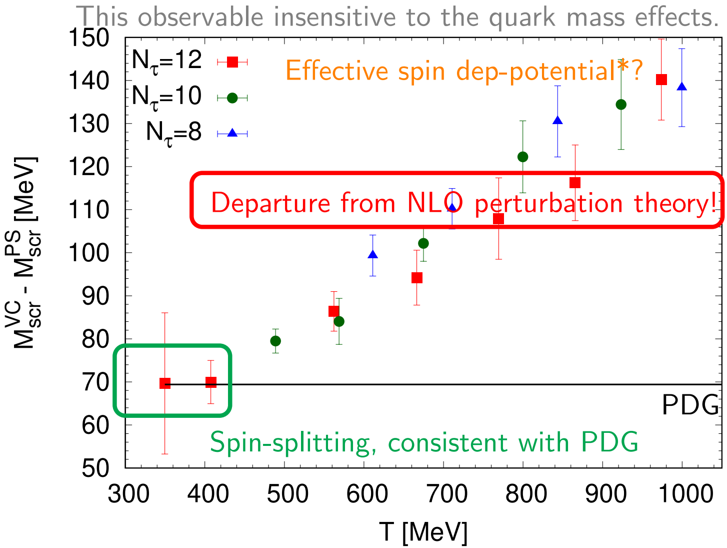
- Systematic uncertainty of $\sim 1\%$ in extracting bottomonium mass at zero-T through interpolation from earlier data of η_b vs m_b at all β values [Petreczky & Weber, 19]. Cut-off effects are much smaller than these systematic +scale setting+stat. errors!

Results: $\eta_b(1s)$ screening mass



[*M. Laine & M. Vepsalainen, 03]

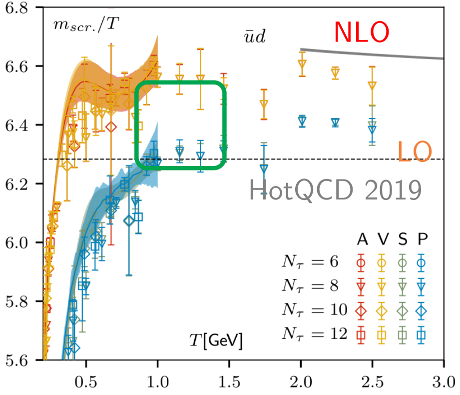
Pseudo-scalar and vector screening masses



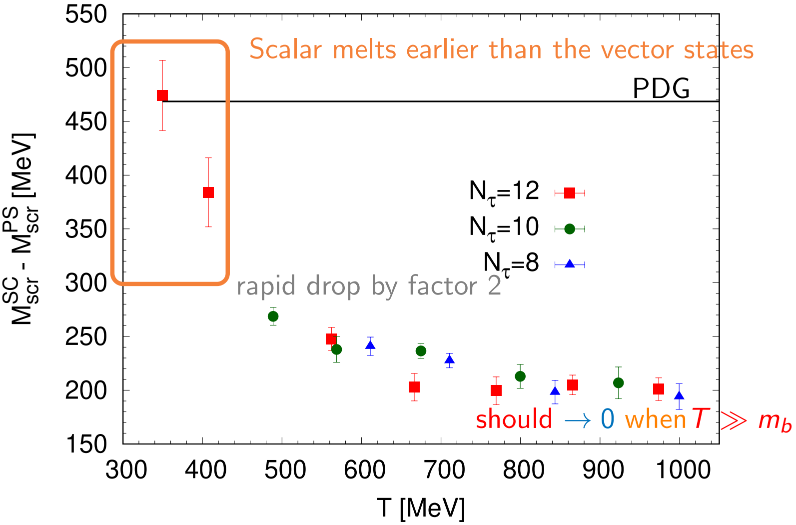
[*V. Koch et. al., 92]

Digression: Screening mass for light hadrons at high T

- Solving effective Schrödinger eq. for heavy quarks of mass πT
  $\left[-\frac{1}{\pi T}\nabla^2_{2D} - \frac{a}{r} + \sigma r\right] = \epsilon\psi$
- Add a spin-splitting term $V(r) = \frac{e^2}{4\pi^2 T^2}\delta^2(r)(S_1.S_2 - \frac{1}{2}S_{1t}.S_{2t})$ [Koch et. al., 91].
- Diff between pseudoscalar and vector screening mass $\sim 0.3\ T$, for $T \gtrsim 1$ GeV [For screening mass at high T see also, 2112.05427]



Scalar and pseudo-scalar M_{scr}



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- We observe that the screening mass corresponding to 1P-bottomonium states show significant thermal modification already at $T > 350$ MeV.
- For vector (Υ) and pseudo-scalar (η_b) screening masses thermal modifications show up at relatively higher temperatures $T \sim 450$ MeV, consistent with earlier lattice results using NRQCD or potential models.

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- We have earlier observed that the linear increase with the temperature for η_c screening mass is seen already at $T > 250$ MeV [A. Bazavov et. al. 14] showing a clear mass-hierarchy in the melting of quarkonia.