Lattice QCD results on bottomonia at high temperatures

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1: Introduction

We explore the S- and P-states for bottomonia at high temperatures, above the critical temperature Tc, using non-relativistic QCD (NRQCD). We extract the spectrum as a function of temperature using smeared source correlators. We push to the limit of NRQCD for $N_\tau = 12$ which allows us to find the bottomonium spectrum up to a temperature of 334MeV.

The main purpose of this work has been to understand the changes to color screening at finite temperatures. This has been done by looking at the existence of bottomonia states at finite temperature, since the large mass probes smaller distances in the confining interaction. We look for the bottomonia states by calculating the correlation function (1) which can be inverted to give us the spectral function $\rho(\omega)$. At finite temperature the available range is small $\frac{1}{T}$ so in order to see the lowest states, we smear the correlators, which give us better overlap with the states of interest (see block 4). In order to extract the bottomonia states we make an ansatz in block 5, which allows us to extract the change in the energy ΔM and the width σ as are shown in block 6 for η_b and Υ and in block 7 for the χ_b states.

2: Approach

- Bottom mass $\sim 4GeV$ and inverse lattice spacing $a^{-1} \sim 3GeV$ similar in size: Bottom mass too large for lattice QCD. Solution: Use Non Relativistic QCD (NRQCD), NRQCD work on rough lattices with mass times lattice spacing > 1
- Setup:
  - HotQCD configurations from temperature $T = 151MeV$ to $T = 334MeV$
  - Pion mass $160MeV$, Physical Kaon mass, $N_s = 48$, $N_\tau = 12$
  - Explore Υ, η_b, $\chi_{b,0}$ and $\chi_{b,1}$
- Will explore the states of Bottomonia by calculating the Correlation function $C(\tau)$

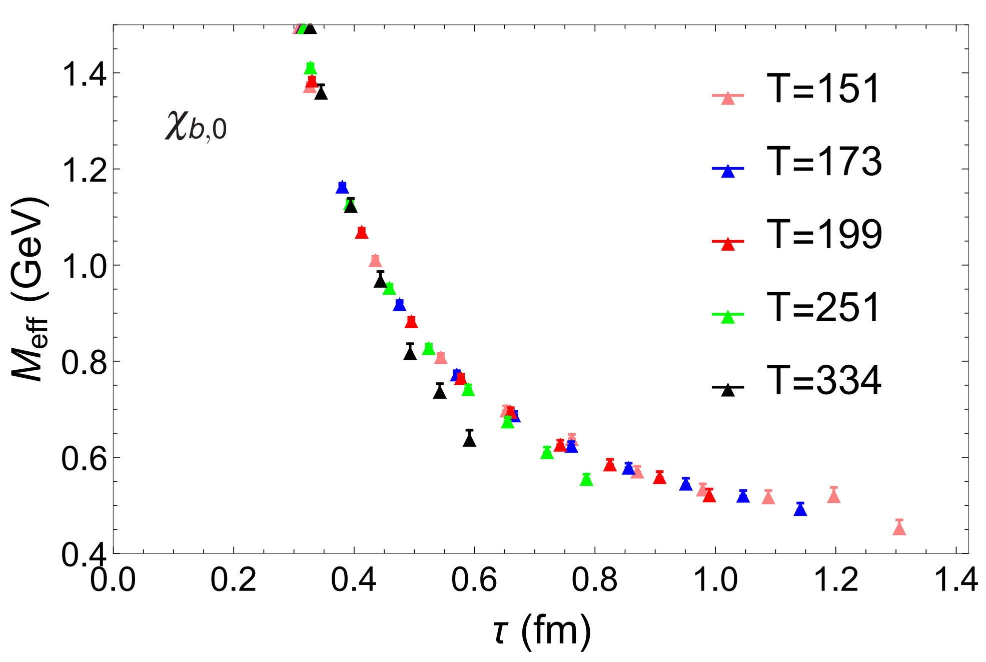
$$\int d^3x < \hat{O}(\tau, x)\hat{O}(0,0) > = C(\tau) = \int_0^\infty \rho(\omega)\exp(-\omega\tau)d\omega \qquad (1)$$

- Invert equation (1) to find spectral density function $\rho(\omega)$
- Plateaus of the effective mass M_{eff} −− > Mass state exists in $\rho(\omega)$

$$C_{sub,T>0} = C_{T>0} - C_{T=0} + A\exp(-m_{T=0}\tau) \qquad (2)$$
$$M_{eff,sub} = -\partial_\tau \log(C_{sub,T>0}(\tau)) \qquad (3)$$

3: Point sources

- Finite temperature correlators for $\chi_{b,0}$ with point sources used

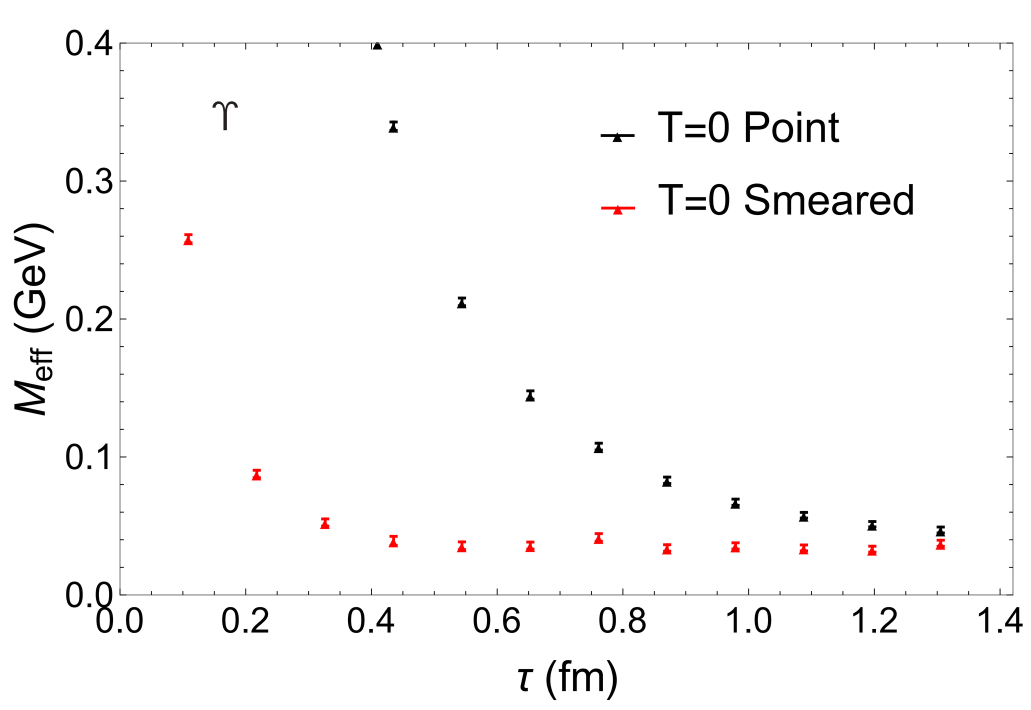


Time direction becomes smaller at higher temperatures $L_\tau = \frac{1}{T}$. Result: No plateau ever reached when looking at the effective mass, which makes it impossible to extract information about the states.

- Our improvements:
  - Use Smeared Source and Sink −− > Better projection on states

4: Smeared vs Point

- We smear the source and sink in the correlator



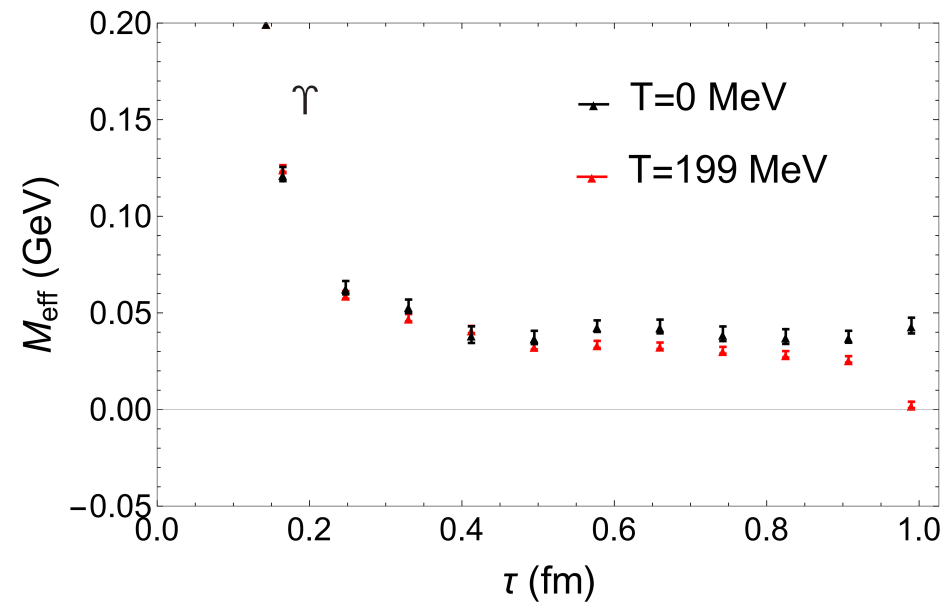
A plateau in the effective mass is reached at much smaller time τ when using smeared sources. This allows us to observe the Bottomonium states at high temperature.

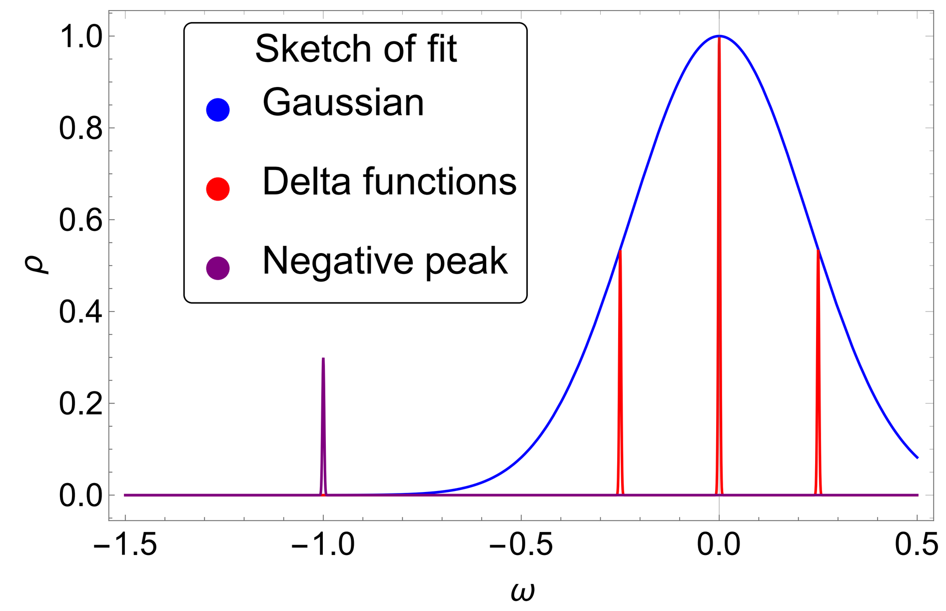
Comments:

- 0 Corresponds to energy of η_b at $T = 0MeV$.
- Smearing that corresponding to a Gaussian width of $0.2fm$ was found to produce best results

5: Modeling the spectral function $\rho(\omega)$

- (left) Finite temperature results very similar to zero temperature. A drop in effective mass at $\tau \to N_\tau$ (right side of plot) is found.
- (left) Small τ: 0 and finite temperature continuum almost same. Will remove zero temperature continuum from finite temperature results using eq. (2)

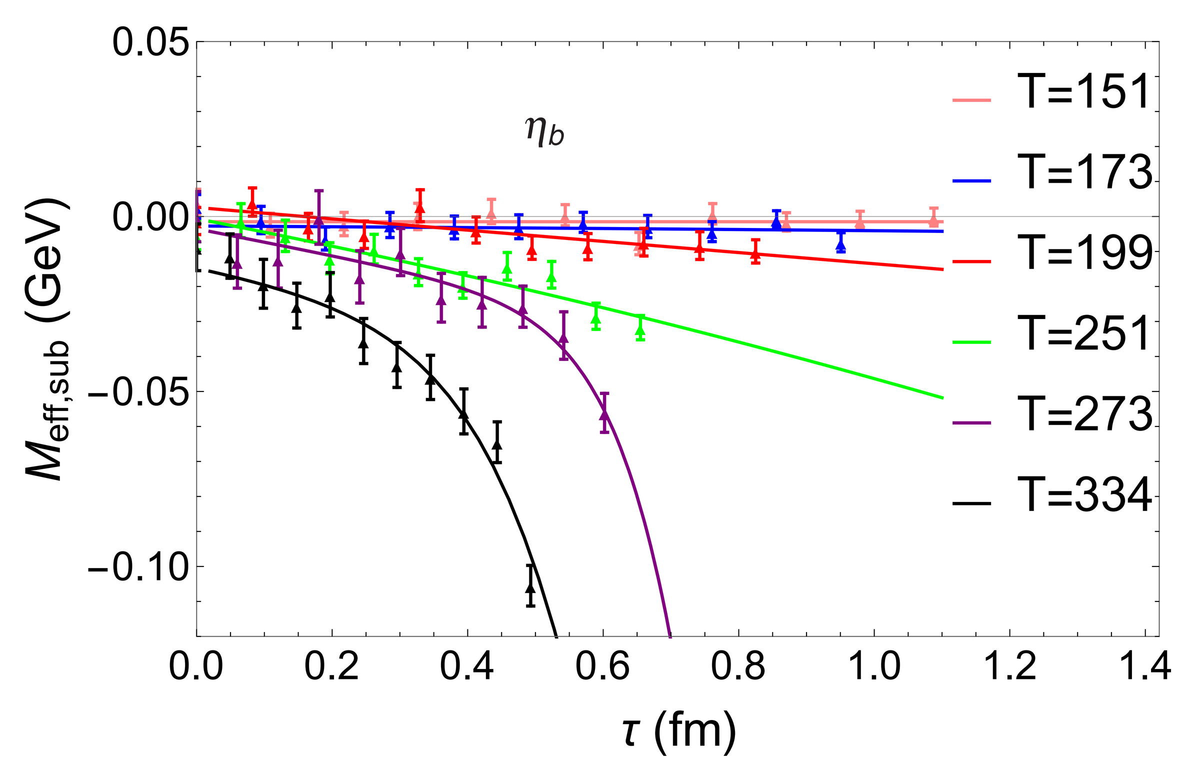


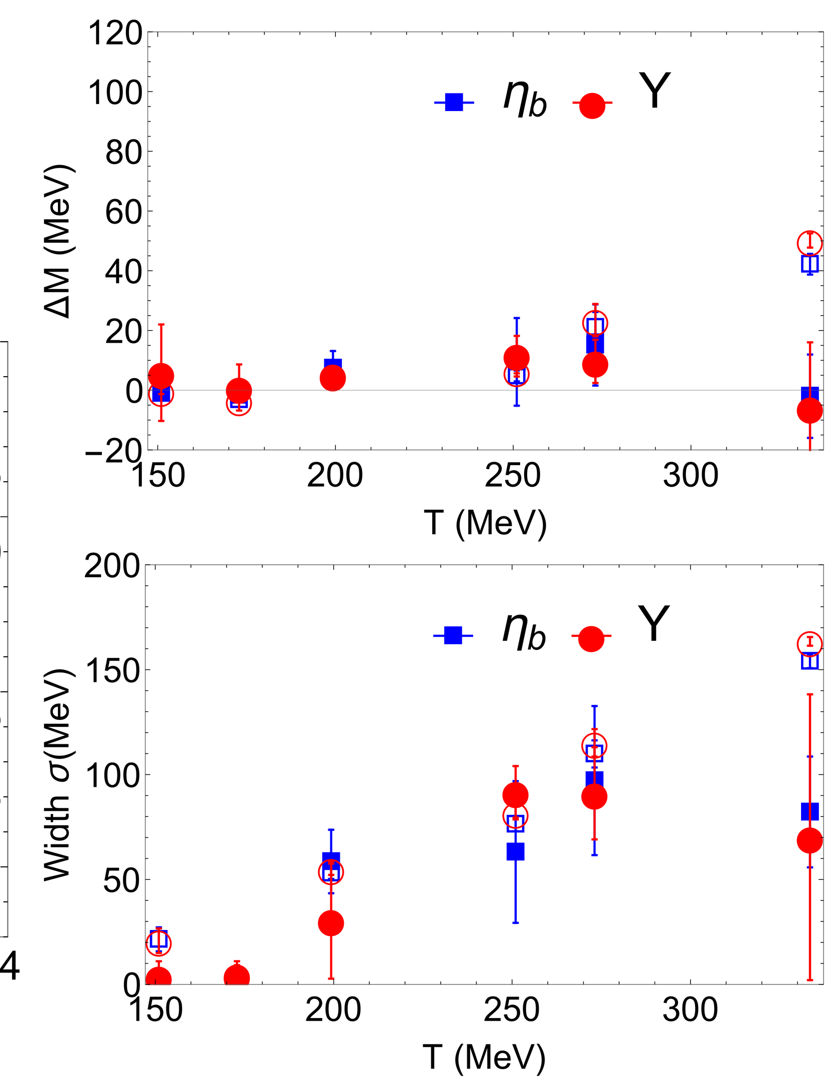


(right) Ansatz for spectral function $\rho(\omega)$ is a gaussian to explain the plateau with a small linear behavior in the effective mass and a Small negative peak included to explain effective mass behavior at $\tau \to N_\tau$ (right side of plot). The gaussian can be seen as an approximation to several delta functions sitting around the zero temperature peak.

6: S-states

- Fitting results for η_b and Υ using ansatz in block 5.
- Fit 1 (Filled symbol): Main peak + small negative peak
- Fit 2 (Empty symbol): Main peak and removed last 2 points
- Fits using fit 1 for η_b shown in left plot
- Results for mass shift ΔM and width σ shown in right plots.

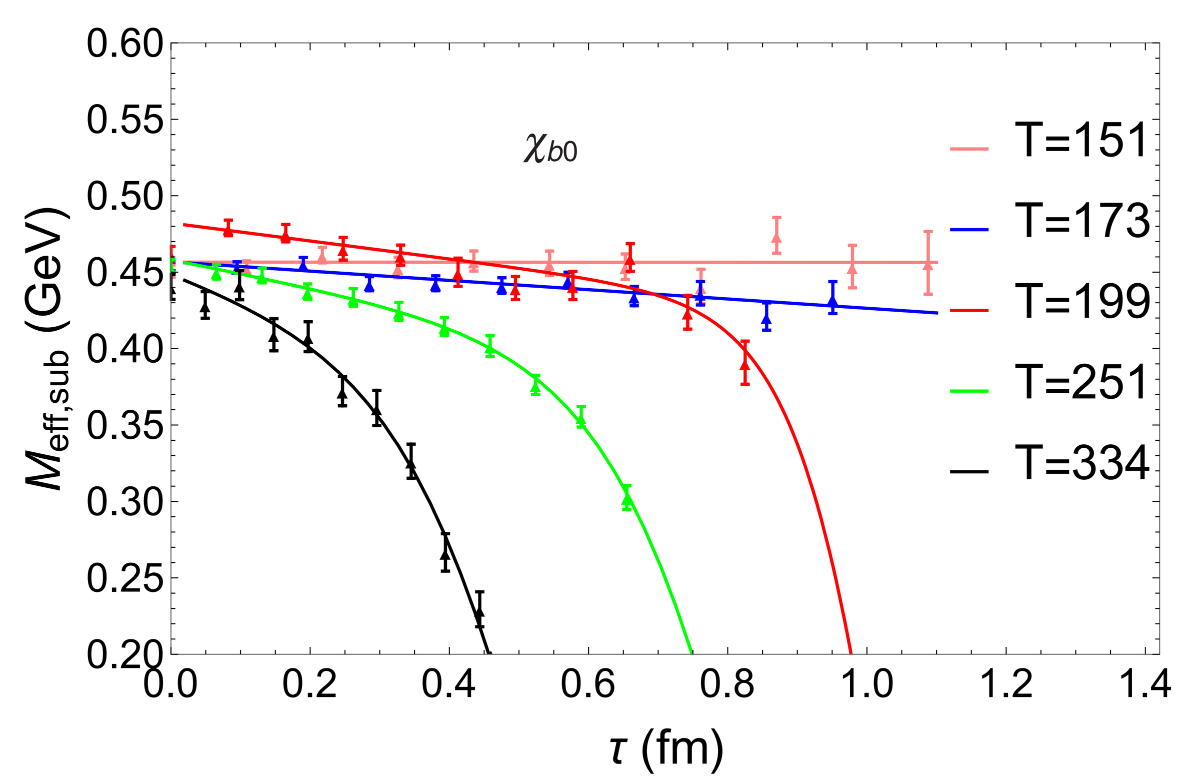


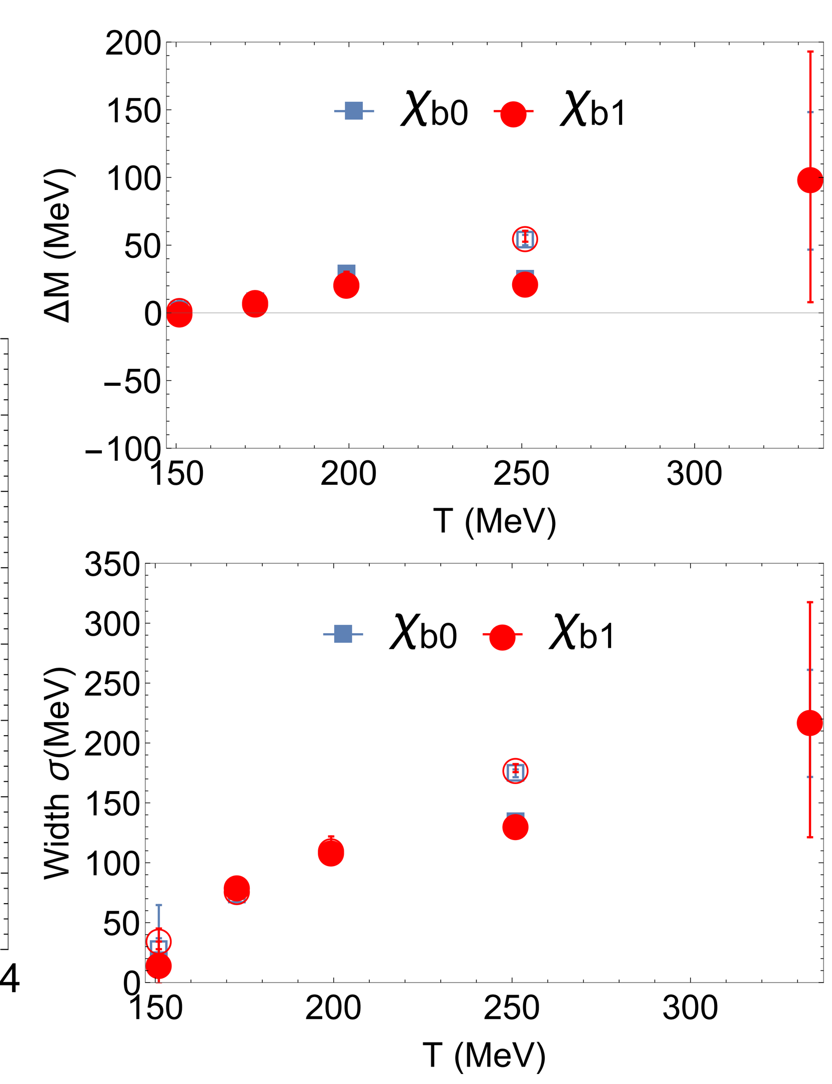


- Mass shift ΔM is consistent with no change compared to zero temperature results
- Υ and η_b behavior very similar

7: P-states

- Fitting results for χ_{b0} and χ_{b1} using ansatz in block 5.
- Fit 1 (Filled symbol): Main peak + small negative peak
- Fit 2 (Empty symbol): Main peak and removed last 2 points
- Fits using fit 1 for χ_{b0} shown in left plot
- Results for mass shift ΔM and width σ shown in right plots.





- Mass shift ΔM is almost consistent with no change compared to zero temperature results. The small change in the mass is smaller than the width observed.
- χ_{b0} and χ_{b1} behavior very similar

8: Summary

We have shown that using smeared sources compared to point sources for Bottomonium states leads to a plateau in the effective mass at much shorter times. This made it possible to observe the states up to a temperature of 334MeV. We find that the mass of the states has essentially not changed, but has become a lot wider of the order of 100MeV. The P-states are wider than the S-states and the effect is seen at lower temperatures.

9: Acknowledgments

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