

Recent lattice QCD results on bottomonia at high temperatures

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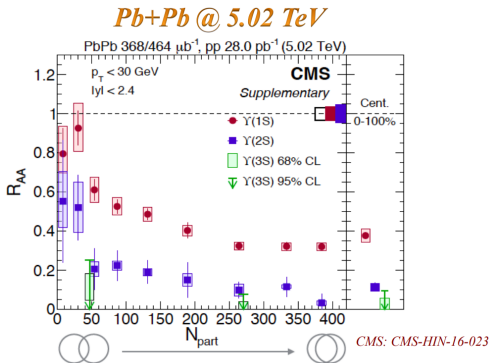
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April 12. 2019

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Motivation

- Motivation:
 - Use the existence of Bottomonium states as probe for change in color screening
 - Experimental results show suppression of Bottomonium states at finite temperature



- Objective
 - Look for Bottomonium states at Finite Temperature
 - Explore Υ , η_b , $\chi_{b,0}$ and $\chi_{b,1}$

- Approach
 - Bottom mass $\sim 4\text{GeV}$
 - Lattice spacing $a^{-1} \sim 3\text{GeV}$
 - Bottom mass too large for lattice QCD \rightarrow Non Relativistic QCD (NRQCD)
 - NRQCD work on rough lattices with mass times lattice spacing > 1
- Setup:
 - HotQCD configurations from $T = 151\text{MeV}$ to $T = 334\text{MeV}$
 - $N_s = 48$, $N_\tau = 12$
 - Pion mass 160MeV , Physical Kaon mass
 - Explore Υ , η_b , $\chi_{b,0}$ and $\chi_{b,1}$

- Main observable: Correlation function $C(\tau)$

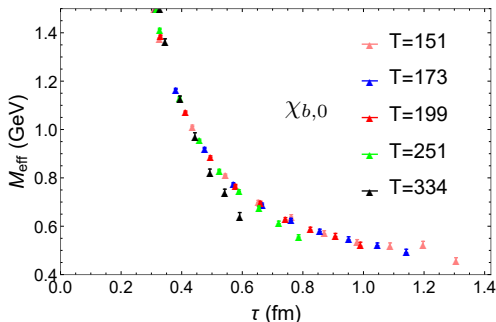
$$\int d^3x \langle O(\tau, x)O(0, 0) \rangle = C(\tau) = \int_0^\infty \rho(\omega) \exp(-\omega\tau) d\omega \quad (1)$$

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

$$M_{eff} = -\partial_\tau \log(C(\tau)) \quad (2)$$

Present Status

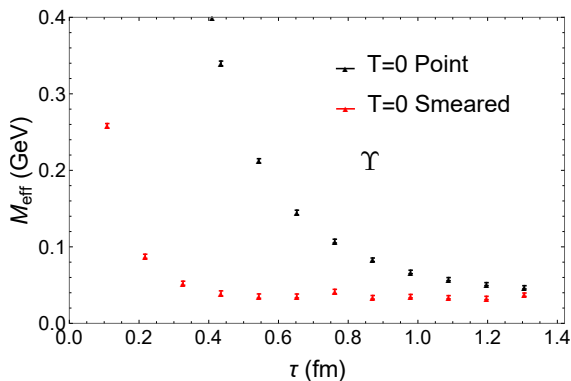
- Finite temperature correlators for $\chi_{b,0}$ with point sources used
- Time direction $L_\tau = \frac{1}{T}$ \rightarrow No plateau ever reached



- Effective mass $M_{\text{eff}} \sim \log[C(t)/C(t+1)]$
- Our improvements:
 - Use Smeared Source and Sink \rightarrow Better projection on states

Improved Sources

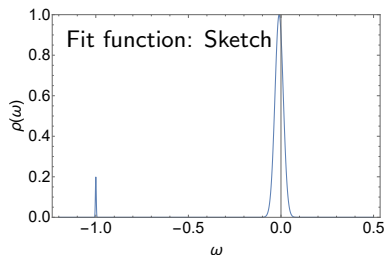
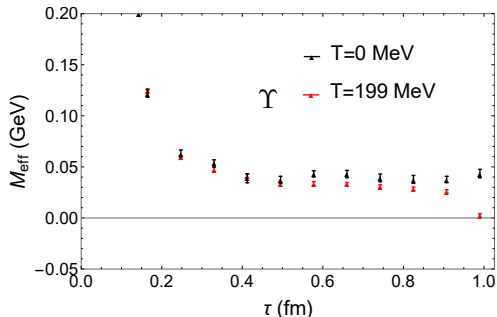
- We smear the source and sink in the correlator



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

Fitting formula

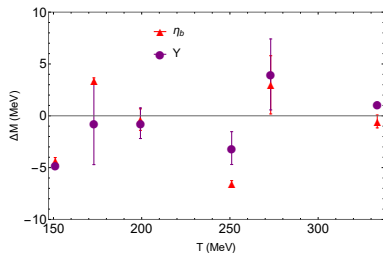
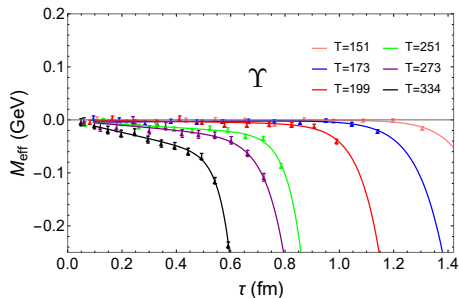
- Finite temperature: Drop in effective mass as $\tau \rightarrow N_\tau$.
- Small τ : 0 and finite temperature almost same



- Effective mass $M_{\text{eff}} \sim \log[C(t)/C(t+1)]$

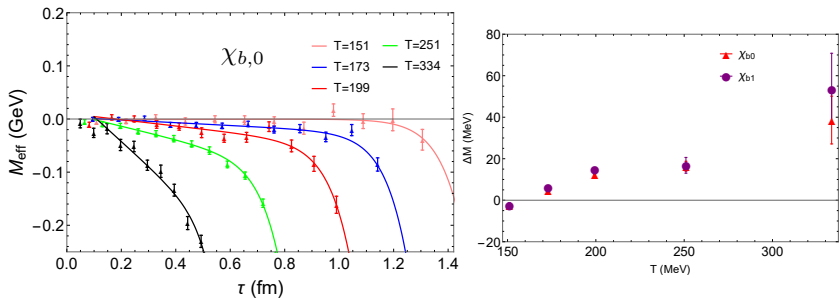
$$\int d^3x \langle O(\tau, x)O(0, 0) \rangle = C(\tau) = \int_0^\infty \rho(\omega) \exp(-\omega\tau) d\omega \quad (3)$$

- Zero temperature effective mass subtracted



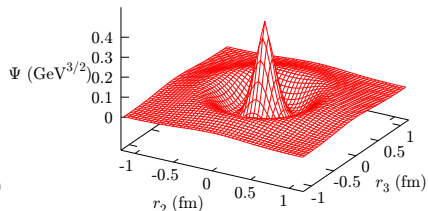
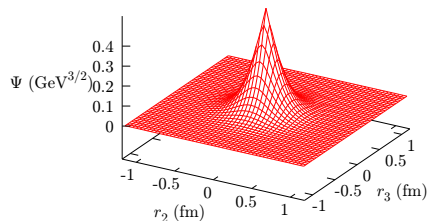
- Mass shift ΔM with respect to zero temperature mass
- Mass shift for Υ and η_b very similar
- Υ Width: 0.8MeV (151), 1.8MeV (173), 1.6MeV (199), 2.8MeV (251), 8.4MeV (273), 20.2 MeV (334)

- Zero temperature effective mass subtracted



- Mass shift ΔM with respect to zero temperature mass
- Mass shift for $\chi_{b,0}$ and $\chi_{b,1}$ very similar
- $\chi_{b,0}$ Width: 0.4MeV (151), 5.0MeV (173), 10.2MeV (199), 26.8MeV (251), 81.8 MeV (334)

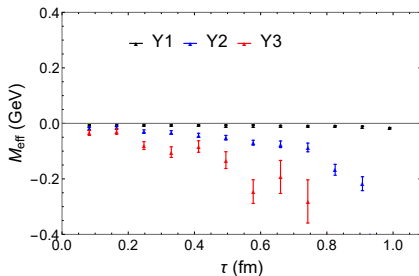
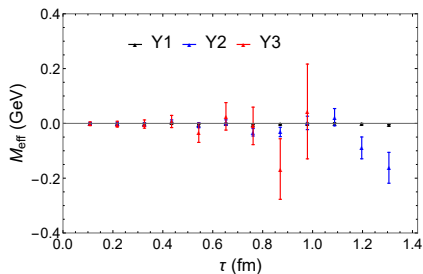
- Gauge fixed wave functions as source and sink
- Left: 1S, Right: 3S



- Possible to see excited states

Preliminary 2

- Upsilon S1, S2 and S3
- Left $T = 151\text{MeV}$, right $T = 199\text{MeV}$
- Zero temperature effective mass subtracted



Conclusion

- Improved sources – \rightarrow Highly improved convergence
- Simple interpretation: No change to S-states
- States looked broadened
- P-states harder, but seem to still exist

- New improved sources allows us to look for excited states at finite temperature
- More to come

Point vs Free case

- Free case expected to go as $m_{eff} = b + 2.5/t$
- No agreement found

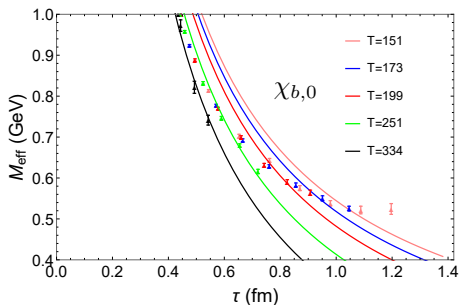


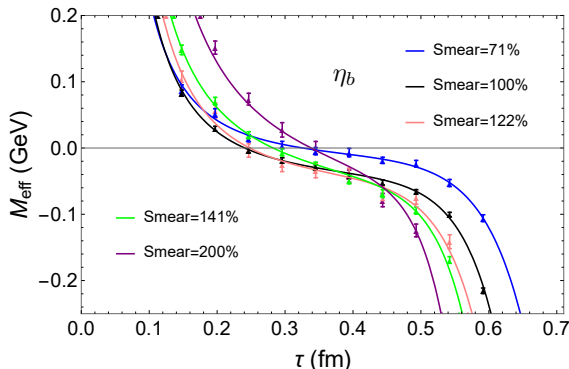
Figure: Effective mass for χ_{b0} for $T = 151.1$ (pink), 172.9 (blue), 199.3 (red), 251.0 (green) and 333.5 (black). Point correlator.

Smearing

- We smear the source and sink in the correlator

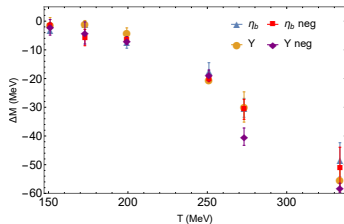
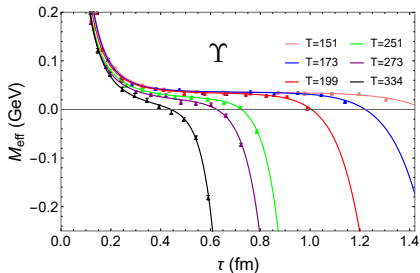
$$q' = \left(1 + \frac{\lambda}{n} \Delta^{(2)}\right)^n q \quad (4)$$

- $\Delta^{(2)}$ is the gauge-covariant 3-dimension Laplace operator



- Smearing corresponding to Gaussian width of $0.2 fm$ was found to produce best results

- Continuum included as a box



- Continuum included as a box

