NRQCD at $T > 0$ with extended correlators

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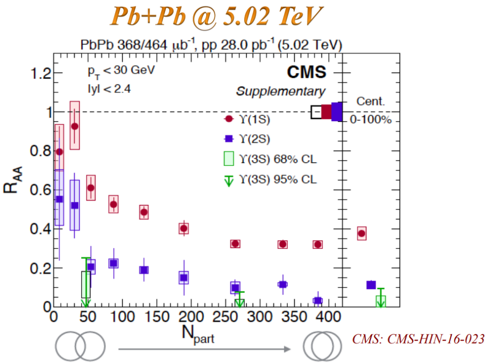
Motivation

- 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

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

Observables

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

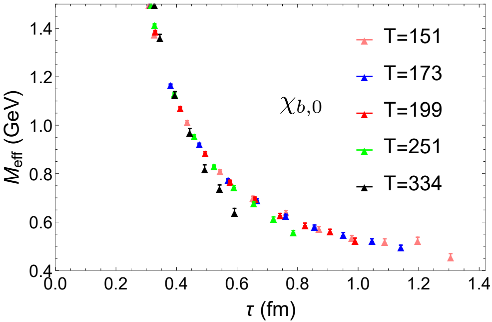
$$\int d^3x < O(\tau, x)O(0,0) > \;=\; C(\tau) \;=\; \int_0^\infty \rho(\omega)\exp(-\omega\tau)d\omega \qquad (1)$$

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

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

Present Status

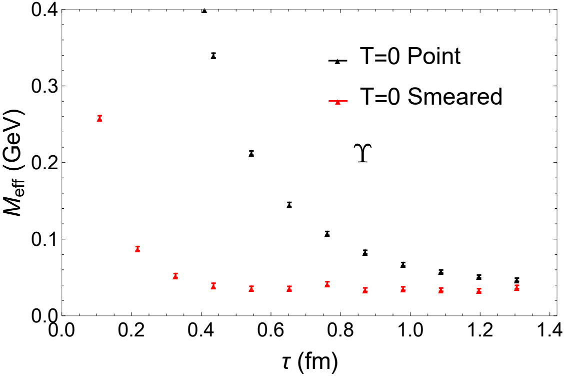
- Finite temperature correlators for $\chi_{b,0}$ with point sources used
- Time direction $L_\tau = \frac{1}{T}$ $->$ No plateau ever reached



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

Improved Sources

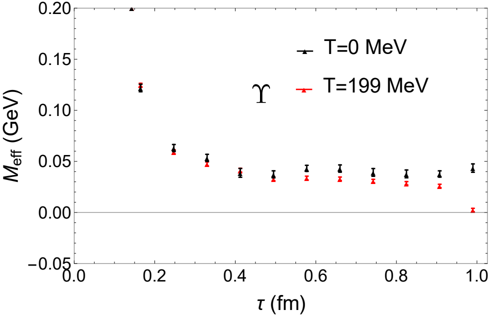
- We smear the source and sink in the correlator

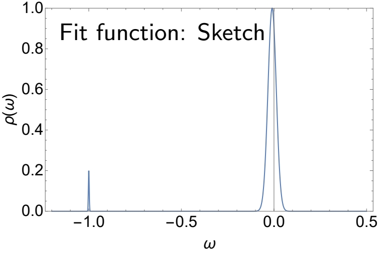


- 0 Corresponds to energy of η_b at $T = 0MeV$.
- Smearing corresponding to Gaussian width of $0.2fm$ was found to produce best results

Fitting formula

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



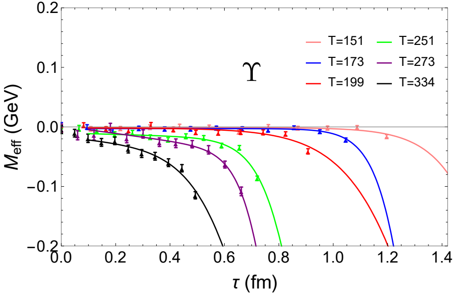


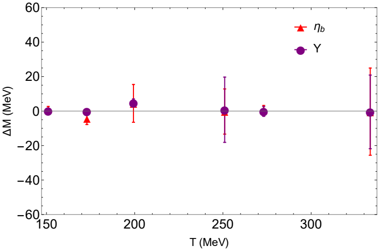
- Effective mass $M_{eff} \sim \log[C(t)/C(t+1)]$

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

S-States

- Zero temperature effective mass subtracted

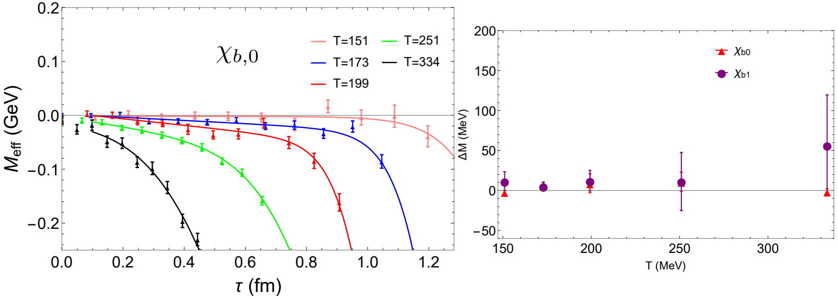




- Mass shift ΔM with respect to zero temperature mass
- Mass shift for Υ and η_b very similar

- Υ Width: 0.0MeV (151), 0.1MeV (173), 28MeV (199), 70MeV (251), 85MeV (273), 94 MeV (334)

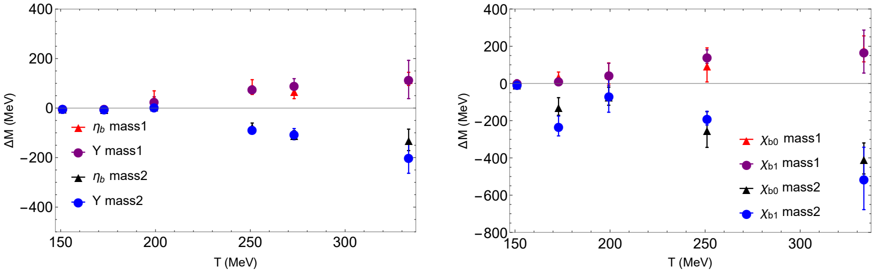
- Zero temperature effective mass subtracted



- 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: 0.0MeV (151), 70MeV (173), 90MeV (199), 122MeV (251) 183MeV (334)

Different Ansatz

- Assume 3 delta functions



- Indicate a finite width around the zero temperature mass

Conclusion

- Calculated correlation functions with smeared sources up to a temperature of 334MeV
- Smeared sources $->$ Highly improved convergence
- No change in mass of S-states
- S-states looked broadened
- P-states harder, but seem to still exist
- P-states broader than the S-states

Point vs Free case

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

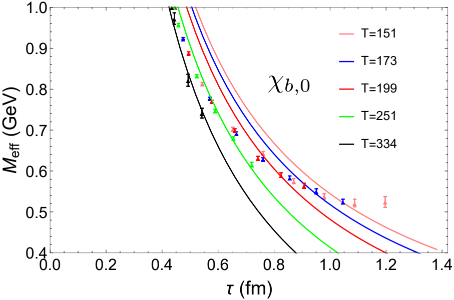


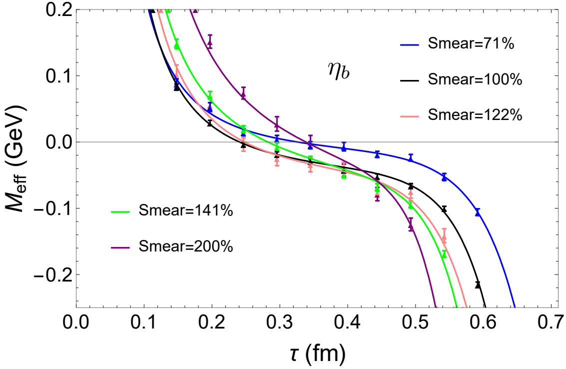
Figure: Effective mass for χ_{b0} for $T = 151.1$(pink), 172.9(blue), 199.3(red), 251.0(green) and 333.5(black). Point correlator.

Smearing

- We smear the source and sink in the correlator

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

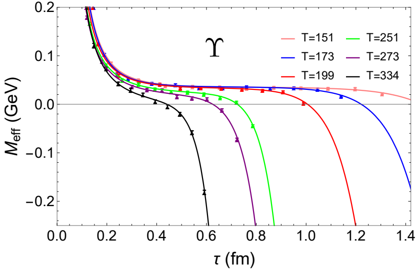
- $\Delta^{(2)}$ is the gauge-covariant 3-dimension Laplace operator

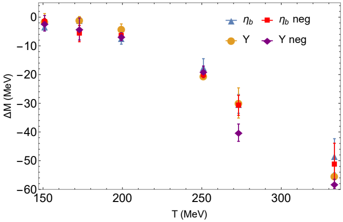


- Smearing corresponding to Gaussian width of $0.2fm$ was found to produce best results

S-States

- Continuum included as a box





P-States

- Continuum included as a box