Static potential at non-zero temperature from the fine lattices

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How interaction between heavy quark and anti-quark are modified at non-zero temperature ?

The potential is expected to be complex

Important for understanding quarkonium production in heavy ion collisions

Wilson loops and potential at $T>0$

Correlation function of static Q and $\bar{Q}$ at distance r ($\tau \times r$ Wilson loop)

$$W(\tau, r, T) = \int_{-\infty}^{\infty} d\omega \sigma_r(\omega, T) e^{-\omega\tau}$$

Rothkopf 2009, Hatsuda, Rothkopf, Hatsuda 2011

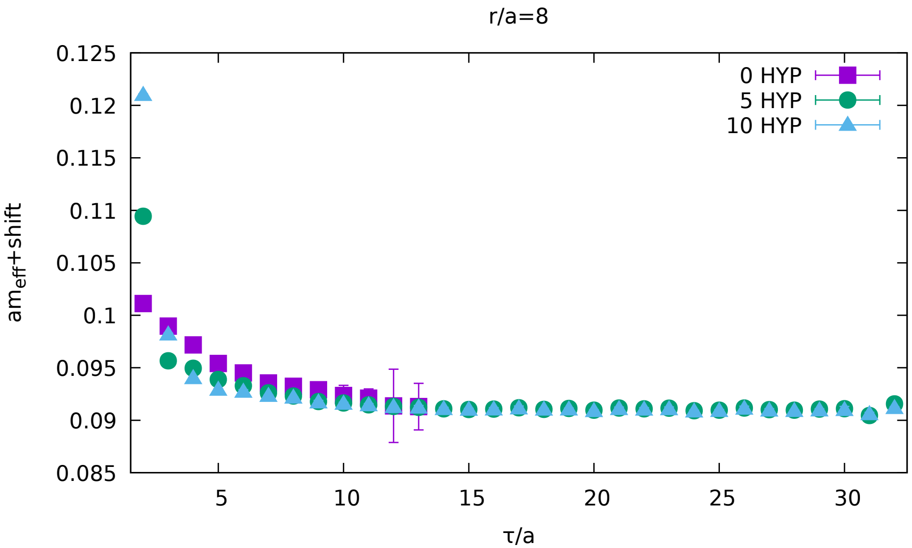
potential at $T > 0$ is related to a peak structure in $\sigma_r(\omega, T)$:
peak position: $\mathrm{Re}V(r, T)$ peak width: $\mathrm{Im}V(r, T)$

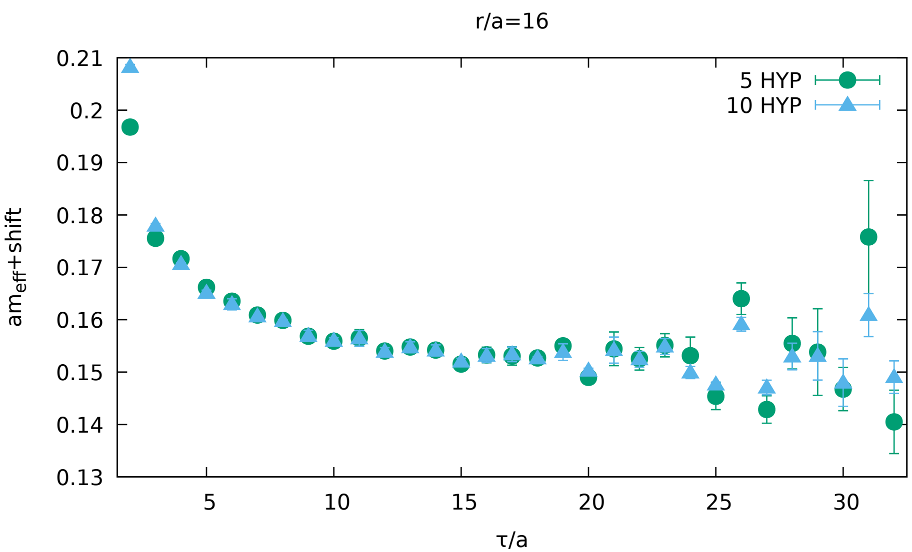
One needs large N_τ to reconstruct $\sigma_r(\omega, T)$ but previous calculations in 2+1 flavor QCD use $N_\tau = 12$

Here: fixed scale approach, $a^{-1} = 7.04$ GeV, $m_\pi \simeq 300$ MeV, $96^3 \times N_\tau$,
$N_\tau = 32$, ($T = 220$ MeV) and $N_\tau = 24$, ($T = 294$ MeV)
Additional $T = 0$ (64^4) lattices for reference

We use temporal Wilson line correlators in Coulomb gauge instead of Wilson loops (better signal)
For large N_τ additional noise reduction is needed $\Rightarrow$ HYP smearing of the temporal Wilson lines

Effective masses at T=0



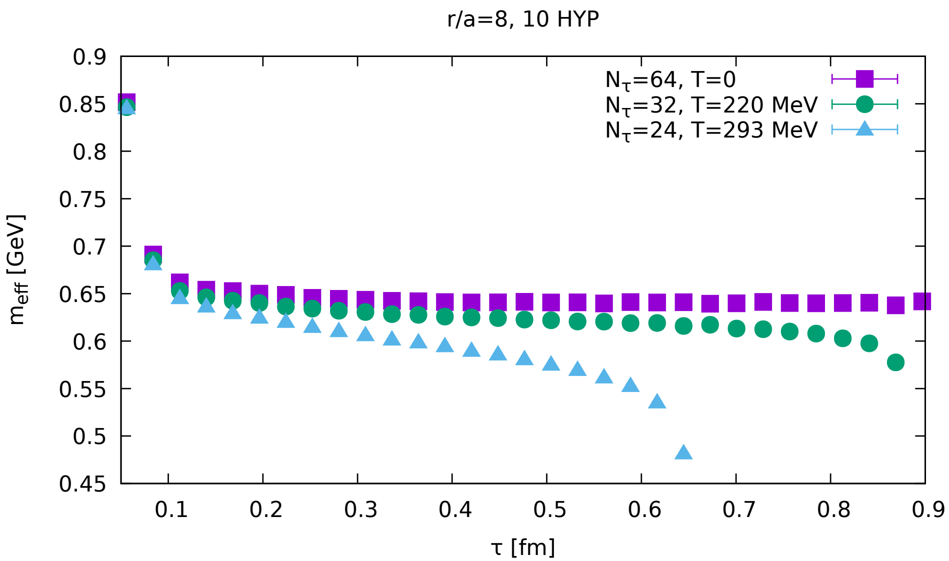


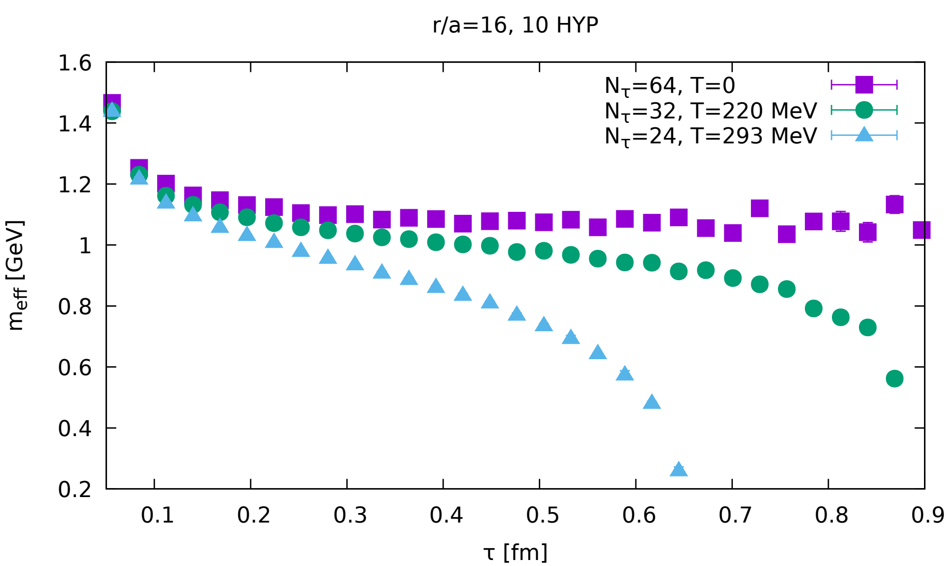
$$m_{\rm eff}(r,\tau,T) = \partial_\tau \ln W(\tau,r,T) = \frac{1}{a} \ln \frac{W(\tau,r,T)}{W(\tau+a,r,T)}$$

HYP smearing is needed to obtain a plateau in $m_{\rm eff}$ already at small r, without smearing the errors are too large for $\tau/a > 10$

For $\tau/a > 10$ HYP smearing only shifts $m_{\rm eff}$ by a constant

Temperature dependence of the effective masses





- Tiny T-dependence at small τ
- The T-dependence increases with increasing r and τ
- No plateau in m_{eff} at $T > 0$, and qualitatively similar to bottomonium effective mass at $T > 0$

Larsen, Meinel, Mukherjee, Petreczky,
PLB 800 (2020) 135119
PRD 100 (2019) 7, 074506

The approximately linear decrease in the effective masses is due to the width

Subtracted effective masses at *T>0*

Tiny T-dependence at small $\tau \Rightarrow \sigma_r(\omega, T) = \sigma_r^{\mathrm{med}}(\omega, T) + \sigma_r^{\mathrm{high}}(\omega)$

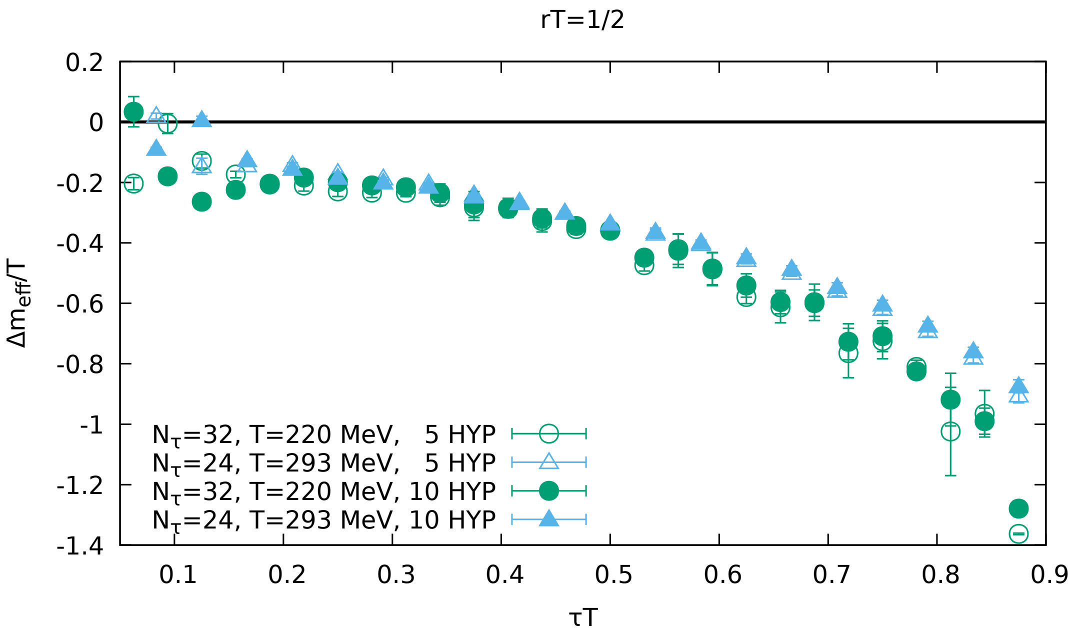
$W(\tau, r, T) = W^{\mathrm{med}}(\tau, r, T) + W^{\mathrm{high}}(\tau, r)$

Excited states

$$\sigma_r(\omega, T=0) = A\delta(\omega - V^{T=0}(r)) + \sigma_r^{\mathrm{high}}(\omega)$$

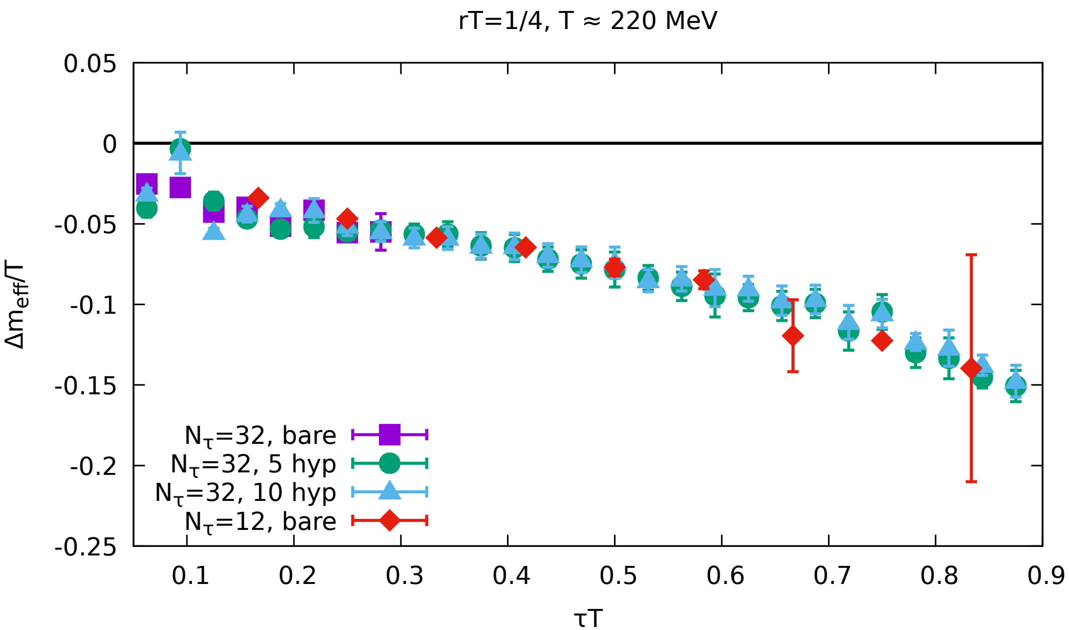
After evaluating the ground state at $T=0$ one can also estimate $W^{\mathrm{high}}(\tau)$

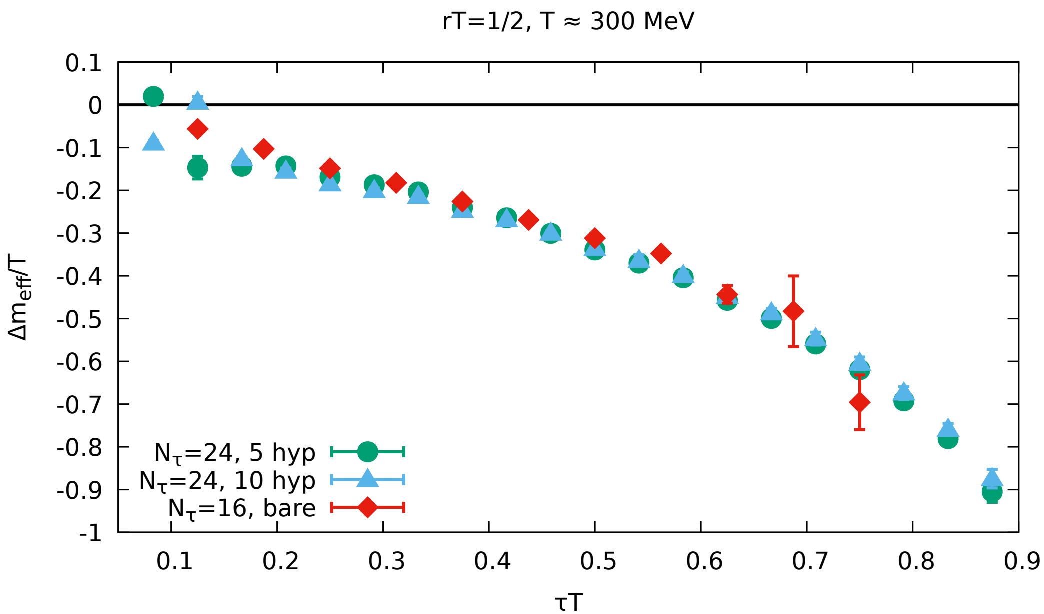
$$W^{\mathrm{sub}}(\tau, r, T) = W(\tau, r, T) - W^{\mathrm{high}}(\tau, r) \qquad \Delta m_{\mathrm{eff}}(\tau, T) = \frac{1}{a} \ln \frac{W^{\mathrm{sub}}(\tau, r, T)}{W^{\mathrm{sub}}(\tau + a, r, T)}$$



- No significant dependence on the number of smearings
- The thermal width $\sim T$

Subtracted effective masses at *T>0* (cont'd)





The subtracted effective masses agree well with the previous calculations on $N_\tau = 12$ and $N_\tau = 16$ lattices for $\tau T > 0.2$ but have smaller errors thanks to HYP smearing

Summary

- We calculated Wilson line correlators on fine lattice with $a^{-1} = 7.04$ GeV and $m_\pi \simeq 300$ MeV at $T = 0$, $T = 220$ MeV and $T = 293$ MeV
- In order to obtain signal at sufficiently large τ HYP smearing has to be used
- The distortion due to HYP smearing can be controlled and are limited to quite small spatial separation and τ
- The temperature and τ dependence of the effective masses is consistent with the non-zero thermal width (imaginary part of the potential), which is roughly proportional to the temperature
- Our results are consistent with previous calculations performed on coarser lattices with $N_\tau = 12$ and 16