Full $O(a)$-improvement of EQCD

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EQCD as an effective theory for hot QCD

- 3D effective theory for hot QCD ($T > 2T_c$) [1]

$$S_{\text{QCD}} = \int d\tau \int d^3x \left( \mathcal{L}^0 + \mathcal{L}^1 + \mathcal{L}^2 \right)$$

- $S_{\text{QCD}} = \int d^3x \left( \frac{1}{2l_\text{eq}} \text{Tr} \mathcal{L}^1 + \text{Tr} \mathcal{L}^2 \right)$

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- Lattice parameters $y = \frac{n_f}{2l_\text{eq}}$ and $x = \frac{1}{l_\text{eq}}$

- Lattice-continuum matching known to $O(a)$

- Except $\delta y$ (3-loop effect)

$$S_{\text{QCD},x} = \int d^3x \left( \frac{1}{2l_\text{eq}} \text{Tr} \mathcal{L}^1 + \text{Tr} \mathcal{L}^2 \right)$$

- Information about thermodynamics from lattice [2]

- Also correct EFT for $O(a)$-corrections to the jet broadening coefficient $\hat{q}$ and $C(\hat{q})$ [3]

- First lattice study of $\hat{q}$ promising, but lacks continuum limit [4]

Our method

- Measure $O(a)$-dependence of $\delta y$ numerically by fitting to line of constant physics

- Line of constant physics provided by EQCD phase transition

- Phase transition is first order in interesting parameter range [5]

- Multicanonical reweighting ineffective

- New method:
  - prepare configuration in which both phases coexist and are permanently compared to each other
  - tune mass to its critical value $y_{\text{crit}}$

$$y(z) = y_{\text{crit}} + \delta y \cos(2\pi z/L_c)$$

- Prepare configuration with coexisting phases by temporarily introducing a $z$-dependent mass:

- $y(z) = y_{\text{crit}} + \delta y \cos(2\pi z/L_c)$

- Tune $y$ to critical value according to:

$$y_{\text{crit}} = y_{\text{crit}} + \delta y \cos(2\pi z/L_c)$$

- $y_{\text{crit}}$ is $O(a)$-improvement

- Phase discriminator consists of difference of $\text{Tr} \Phi^\dagger \Phi$ operators, i.e. is free of $O(a)$ errors

Results

- Strategy: $y_{\text{crit}}$ at 5 different lattice spacings

- 3. extract slope at $g_3^{2d} = 0$ using constrained curve fitting [7]

- Obtain grand fit

$$\frac{\text{Tr} \Phi^\dagger \Phi}{a} = 0.0151(55)x^3 - 31.8(28)x^2 + 10.8(74)x - 0.86(41)$$

for the mass $O(g_3^{2d})$-improvement as main result

- Find updated (continuum-extrapolated) version of EQCD phase diagram as a corollary

- Further interesting information on the strength of the transition and the $O(g_3^{2d})$-improvement of $\text{Tr} \Phi^\dagger \Phi$ is provided [6]

Conclusion and outlook

- Numerically determined the missing three-loop renormalization coefficient of $y$

- Methodology allows efficient determination of spot of a first-order phase transition on the lattice

- Many byproducts: continuum-extrapolated EQCD phase diagram, study of the transition strength and $\text{Tr} \Phi^\dagger \Phi$ operator renormalization

- Full improvement allows studying EQCD free from $O(a)$-errors, in particular error of $q$ and $C(\hat{q})$ is down to $O(a^2/b_c^2)$

References


