A New Perspective to Hadronic Excitations above $T_c$

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Strongly Interacting Matter at High Temperature

- QCD in vacuum: broken chiral symmetry, confinement

- At high temperature: heavy-ion collisions, early universe
  - Quark-gluon plasma, “deconfinement”?

- Previous research around chiral symmetry & axial anomaly:
  - Restoration established
  - Crossover, different temperatures (!)
  - Screening spectrum for mesons, baryons
  - Connection between chiral susceptibility and U(1) anomaly? (see talk H.Fukaya, 4-2 A session)
$n_f=2$ Möbius DW fermions ($m_{\text{res}} < 1$ MeV)

Symanzik gauge action @ $\beta=4.30$ ($1/a = 2.6$ GeV)

$N_s = 24, 32, 40, 48$ ($1.8 - 3.6$ fm)

$N_t = 14, 12, 10, 8, 6$ ($T = 190 - 440$ MeV)

$m_{ud} = 0.001 - 0.01$ ($3 - 30$ MeV)

$T_c^{\text{Polyakov}} = 175$ MeV
Thermodynamics and Hadron Melting

Around the chiral transition the hadronic description of strongly interacting matter breaks down!

right: A.Bazavov et al, Phys.Rev.D 95 (2017) 5, 054504
The Screening Mass Spectrum

**Left:** A. Bazavov et al (HotQCD collab) Phys. Rev. D 100 (2019) 9, 094510

**Right:** JLQCD, in preparation

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**Measuring the hadronic spectrum of the quark plasma**

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(Received 6 July 1987)
Looking close at our last years efforts..

\[
Pseudoscalar: \quad C_1(z) = \frac{2\pi}{\beta^3} \frac{e^{-2z\omega_0}/2\omega_0}{2z}\left[1 + \frac{1}{2z\omega_0}\right] + O\left(\frac{e^{-4z\omega_0}/z\omega_0}{z\omega_0}\right)
\]

\[
Vector: \quad C_{\gamma_1}(z) = \frac{2\pi}{\beta^3} \frac{e^{-2z\omega_0}/2\omega_0}{2z}\left[1 + \frac{1}{(2z\omega_0)^2} + \cdots\right] + O\left(\frac{e^{-4z\omega_0}/z\omega_0}{z\omega_0}\right)
\]

\[
Tensor: \quad C_{\gamma_4\gamma_3}(z) = \frac{2\pi}{\beta^3} \frac{e^{-2z\omega_0}/2\omega_0}{2z}\left[1 - \frac{1}{2z\omega_0} + \cdots\right] + O\left(\frac{e^{-6z\omega_0}/z\omega_0}{z\omega_0}\right)
\]

single pole: \[C_\Gamma(z) \sim e^{-mz}\]

not possible!

fit to thermal fermions

cut (two quark state): \[C_\Gamma(z) \sim e^{-\bar{m}z}/z\]

\[\bar{m} = 2\omega_0\]
Fitting $\exp/z$ instead of Single Pole

(local fits on point source correlation functions)
Improved Screening Mass Spectrum

exp/z fits two quarks to lowest Matsubara frequencies

Deviation from $2 \omega_0$ due to interaction!
Introducing $SU(4)$ and Chiral Spin Symmetry

$\Psi \xrightarrow{SU(2)_{CS}} e^{i\vec{\Sigma}_0/2} \Psi$

$\vec{\Sigma}_0 = \{\gamma_0, -i\gamma_5\gamma_0, \gamma_5\}$

Minimal group containing $SU(2)_{CS}$ and chiral symmetry: $SU(2n_f)$

L. Glozman and M. Pak, Phys.Rev. D92 (2015) 1, 016001

free, massless fermions:

$$L = \bar{\Psi}i\gamma^0 D_0 \Psi$$

interacting, massless fermions:

$$L = \bar{\Psi}i\gamma^i D_i \Psi$$

- kinetic term breaks chiral spin
- electric term is invariant
- magnetic term breaks chiral spin

CR et al, Phys.Rev.D 100 (2019) 1, 014502

SU(4) and chiral spin symmetry in meson screening spectrum and spectral functions
**The Nature of QCD Interaction at High-T**

**kinetic** terms factors out through exp/z fit

**electric** term is SU(2)$_{\text{CS}}$ invariant

**magnetic** term breaks SU(2)$_{\text{CS}}$

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Graphs showing:
- **no kinetic**
- **electric & magnetic**
- **purely magnetic**
Conclusion

- High T screening correlators favor two-quark systems over single pole
- Direct comparison to EQCD and dimensionally reduced theories
- Conceptually in agreement with known behavior around $T_c$

*Open problems (so far):*
- Effective degrees of freedom change after $T_c$
- “Strong” strong interaction prevents perturbative description

SU(4), chiral spin symmetry and exp/z unify all phenomena:
- Dominating *color-electric* fields drive split between spin channels
- *Color-magnetic* interaction cause Vector/Tensor mass gap
- Framework to link lattice and perturbative calculations

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