Meson spectra at non-zero temperatures

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Envisaged scenario

- $T = 0$: Regge trajectory for vector mesons (relevant for dilepton spectroscopy)
- $T = T_c$: disappearance of hadrons (= deconfinement; hadronization: hadrons appear upon cooling at T_c)
- $T \approx T_c$: QCD thermodynamics, adjusted at lattice results
- stage 1: toy model - combine suitable holographic elements
- stage 2: bottom-up holography - solving Einstein equations
- goal: address non-zero chemical potential, e.g. holographic critical point in phase diagram

AdS/CFT correspondence

developed: [J. M. Maldacena, Adv. Theor. Math. Phys. 2, 231 (1998)]

[E. Witten, Adv. Theor. Math. Phys. 2, 505 (1998)]

[S. Gubser et al., Phys. Lett. B 428, 105 (1998)]

duality between:

QFT		gravitational theory
• d-dimensional • strongly coupled • Minkowski-spacetime	$\leftrightarrow$	• $(d+1)$-dimensional • classical • AdS-spacetime

one important result: $\frac{\eta}{s} = \frac{1}{4\pi}$

ρ-meson in the probe limit

- action

$$S = \frac{1}{k} \int e^{-\Phi} F^2 \sqrt{g} \, \mathrm{d}x^4 \, \mathrm{d}z \tag{1}$$

- 5D-metric with determinant g and line element

$$\mathrm{d}s^2 = e^A (f \mathrm{d}t^2 - \mathrm{d}\vec{x}^2 - \mathrm{d}z^2/f) \tag{2}$$

- Hawking temperature

$$T(z_H) = -\frac{1}{4\pi} f'(z) \mid_{z=z_H} \tag{3}$$

- $T = 0 \Leftrightarrow f = 1 \Leftrightarrow z_H = \infty$
- Bekenstein entropy density $s \propto e^{\frac{3}{2}A(z_H)}$
- scalar dilaton field $\Phi(z)$ as symmetry breaker
- field strength tensor F of $U(1)$ vector field V with $F_{MN} = \partial_M V_N - \partial_N V_M$

Equation of motion

eom becomes Schrödinger equation

$$(\partial^2 - (U_T - m_n^2))\psi = 0 \tag{4}$$

with potential

$$U_T(z) = U_0 f^2 + \frac{1}{2} s' f' f \tag{5}$$

$$U_0(z) = \frac{1}{2} S'' + \frac{1}{4} S'^2 \tag{6}$$

$$S = \frac{1}{2} A - \Phi \tag{7}$$

Soft Wall Model

[A. Karch, E. Katz, D. T. Son, M. A. Stephanov, Phys. Rev. D 74, 015005 (2006).]

- ansätze at $T = 0$: $A(z) = -2\ln\frac{z}{L}$, $\Phi(z) = \frac{z^2}{L^2}$
- Schrödinger equivalent potential

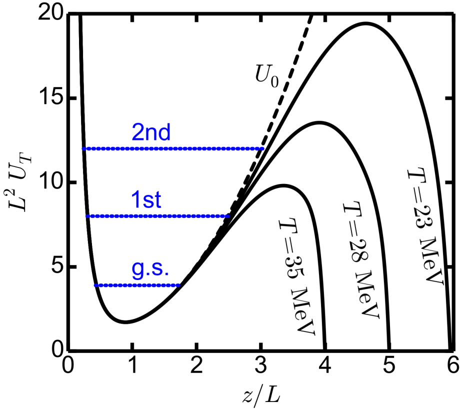
$$U_0(z) = \frac{3}{4z^2} + \frac{z^2}{L^4} \tag{8}$$

- Regge spectrum $m_n^2 = 4(n+1)/L^2$ with $n = 0, 1, \ldots$
- AdS-BF $f(z) = 1 - \frac{z^4}{z_H^4}$
  $\Rightarrow T = \frac{1}{\pi z_H}$
  $\Rightarrow$ sequential dissociation of the states at $T \leq 55$ MeV

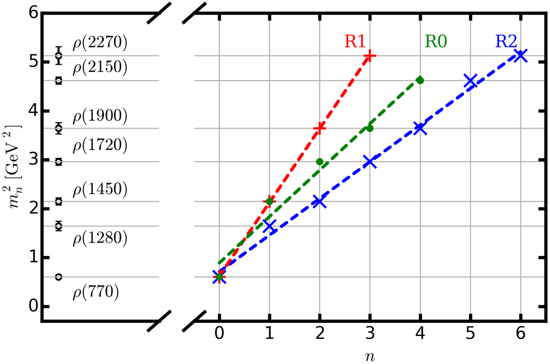
  [P. Colangelo, F. Giannuzzi, S. Nicotri, Phys. Rev. D 80, 094019 (2009).]

Soft Wall Model

sequential dissociation and Schrödinger potential



scale $1/L = 390$ MeV fixed by mass of ground state linear Regge spectra $m_n^2 = \beta_0 + \beta_1 n + \beta_2 n^2$ with small β_2



R0: [A. Karch, E. Katz, D. T. Son, M. A. Stephanov, Phys. Rev. D 74, 015005 (2006).]

R1: [D. Ebert, R. N. Faustov, V. O. Galkin, Phys. Rev. D 79, 114029 (2009).]

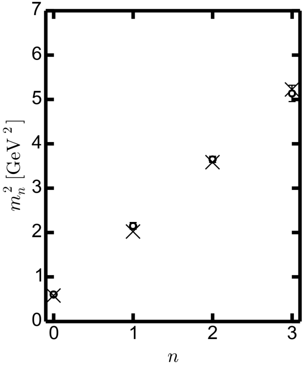
R2: [S. P. Bartz, J. I. Kapusta, Phys. Rev. D 90, 074034 (2014).]

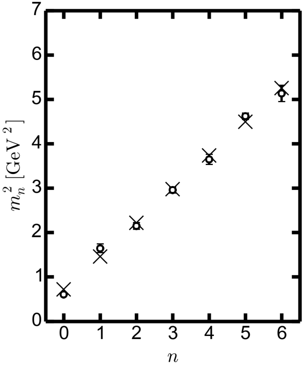
[R. Zöllner, B. Kämpfer, Phys. Rev. C 94, 045205 (2016).]

modified warp factor and dilaton

$$A(z) = \ln(L^2/z^2 + a^2) \qquad \Phi(z) = z^p/L^p \tag{9}$$

$\Rightarrow$ various assignments can be fitted, but do not cure too low $T_{\rm dis}$

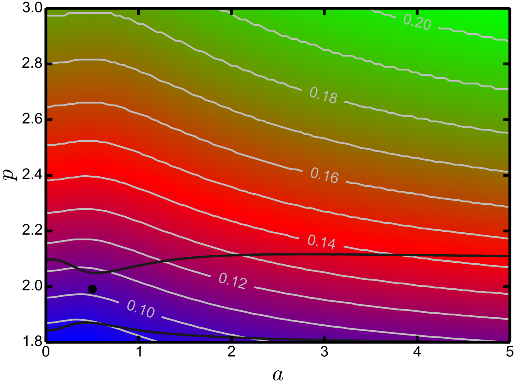




Regge tranjectories R1 (left) and R2 (right)

[R. Zöllner, B. Kämpfer, Phys. Rev. C 94, 045205 (2016).]

LT_{dis} of g.s.



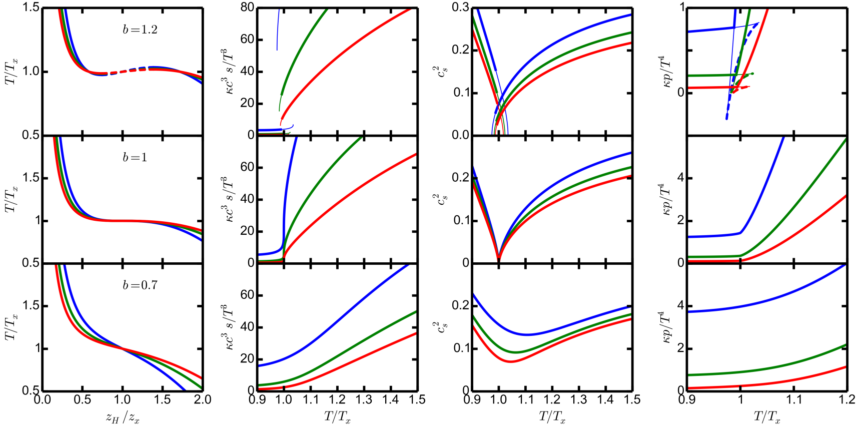
black curve: small β_2, black dot: parameters of R2

[R. Zöllner, B. Kämpfer, Phys. Rev. C 94, 045205 (2016).]

- requirements to $f : [0, z_H] \to [0, 1]$:
  (i) $f(z \to 0) = 1 - \mathcal{O}(z^4)$
  (ii) $f(z_H) = 0$
  (iii) $f'(z_H) = -4\pi T(z_H)$
  (iv) $f' \leq 0$ on $[0, 1]$
- concrete example

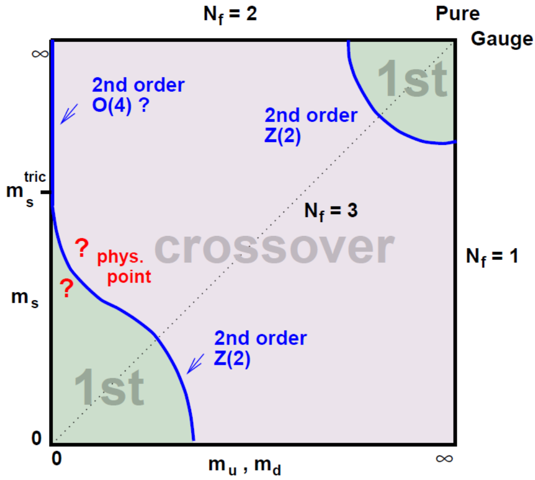
$$f(z) = 1 - \frac{1}{2}\left(\frac{z}{z_H}\right)^4 - \frac{1}{2}\left(\frac{z}{z_H}\right)^{8(\pi z_H T(z_H) - \frac{1}{2})} \tag{10}$$

scenarios of phase transitions



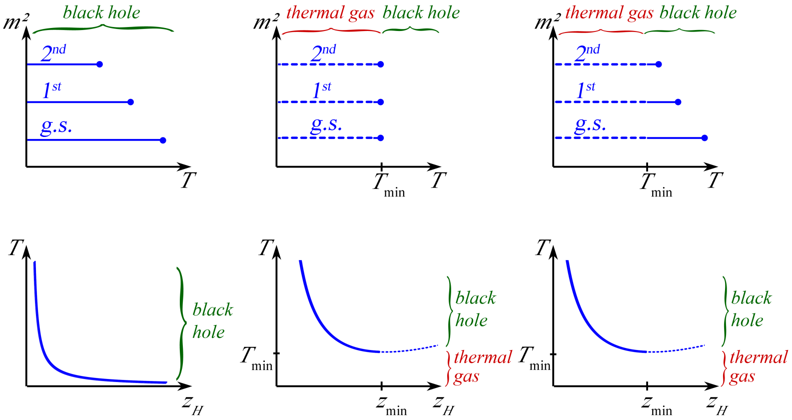
[R. Zöllner, B. Kämpfer, arXiv:1701.01398 [hep-th] (2017).]

scenarios of phase transitions - Columbia plot



[C. Pinke, O. Philipsen, PoS LATTICE2015 (2016) 149.]

adjustment of Regge trajectory and T_{dis} possible

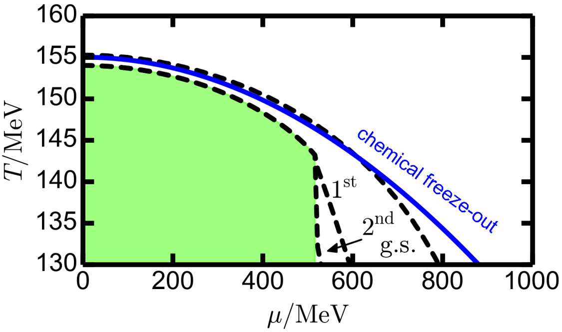


[R. Zöllner, B. Kämpfer, Phys. Rev. C 94, 045205 (2016).]

Further Prospects

[R. Zöllner, F. Wunderlich, B. Kämpfer, arXiv:1611.04124 [hep-th] (2016).]

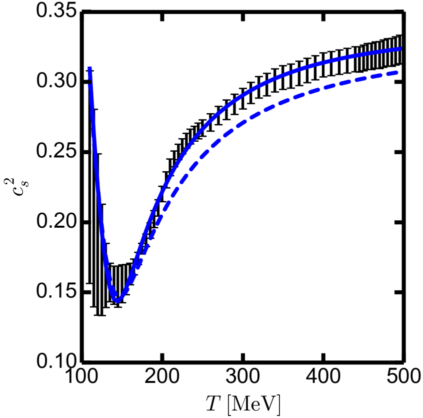
include chemical potential
$\Rightarrow$ RN-compatible extension of blackness function

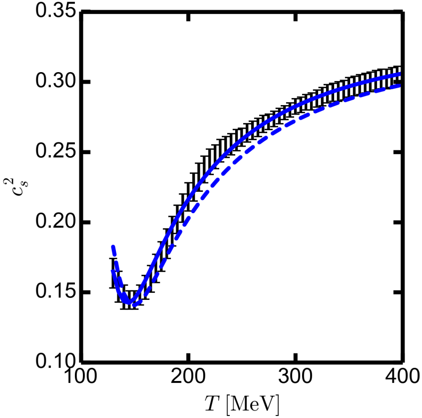


Further Prospects

[R. Zöllner, B. Kämpfer, arXiv:1703.02958 [hep-th] (2017).]

using input provided by QCD-lattice calculations or thermodynamics





left: [S. Borsányi et al., Phys. Lett. B 370, 99 (2014).]

right: [A. Bazavov et al., Phys. Rev. D 90, 094503 (2014).]

recent work

- self-consistent calculation of metric and dilaton via Einstein equations $\Rightarrow$ Einstein-scalar action

$$S_\Phi = \frac{1}{k} \int (R - \frac{1}{2}\partial_M \Phi \partial^M \Phi - V(\Phi))\sqrt{g}\, \mathrm{d}^4 x \, \mathrm{d}z \tag{11}$$

- investigation of possible classes of BF and their physical relevance