Holography near Tc

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Holographically emulating deconfinement as disappearance of hadron states

R. Zollner, BK, Phys. Rev. C (2016), CPOD (2016) procs.

Holographic view on the phase diagram

R. Yaresko, J. Knaute, BK, EPJC (2015), PLB (2015)

Partner von DRESDEN concept exzellenz-dresden.de

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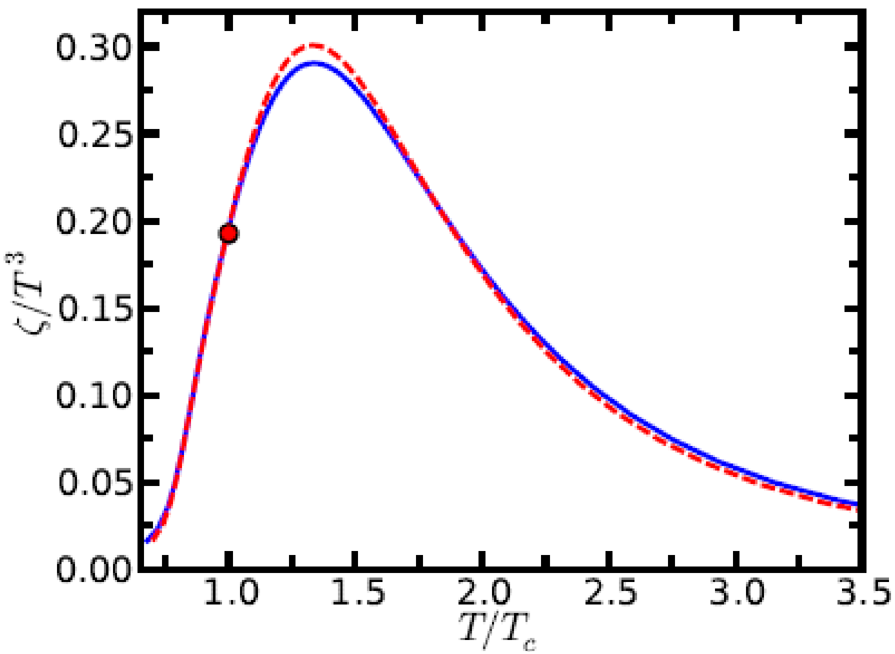
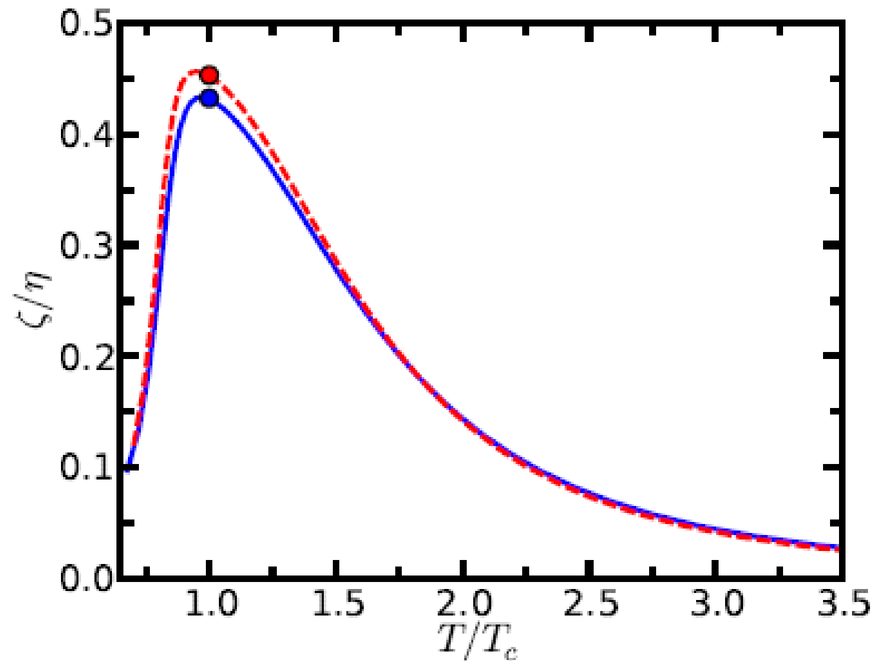
Holographic Viscosities for NeD





$$S = \frac{1}{2\kappa_5^2} \int d^5x \sqrt{-g} \left[R - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right]$$

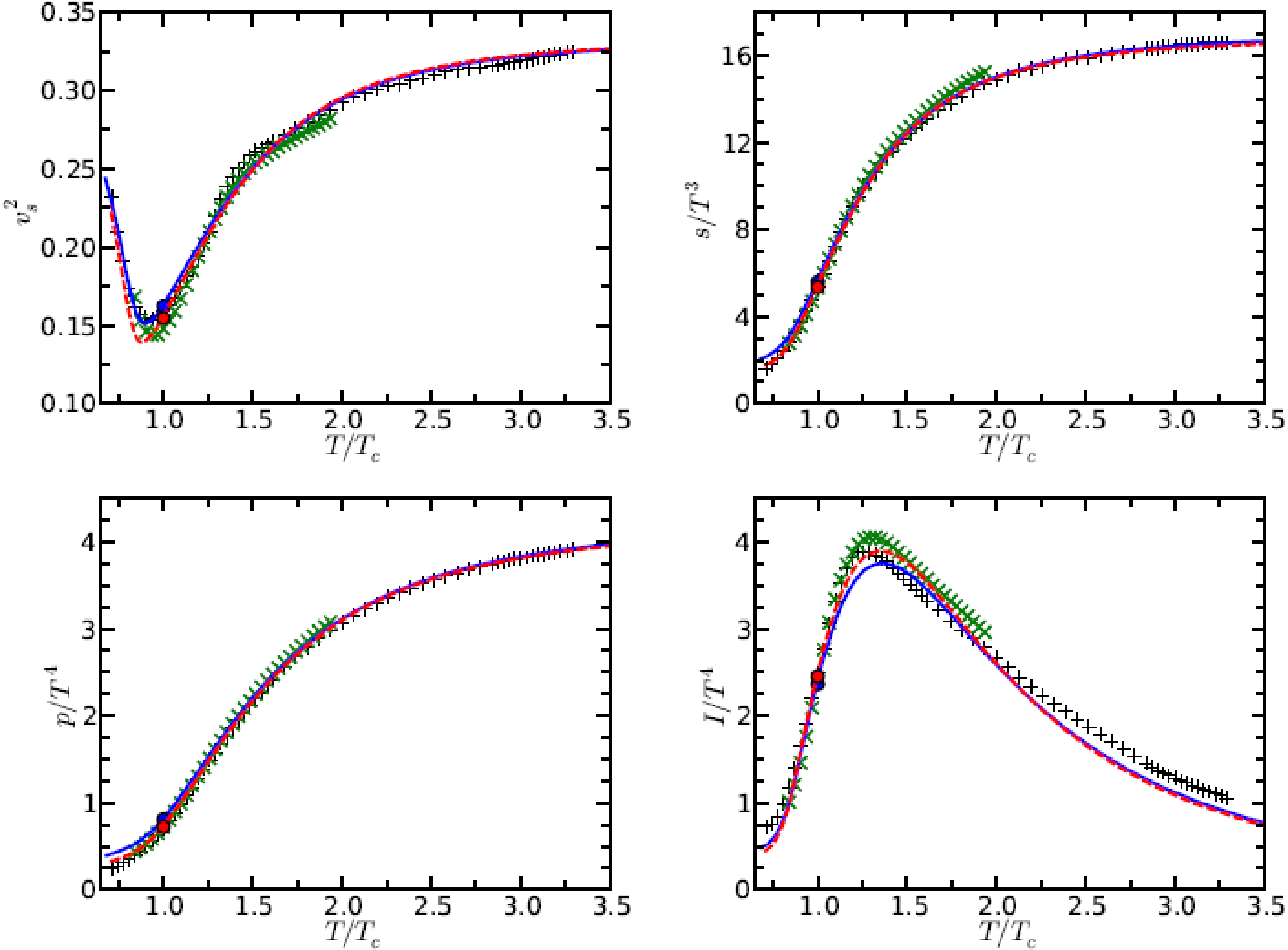
adjusted to QCD

Eling-Oz formula [18]

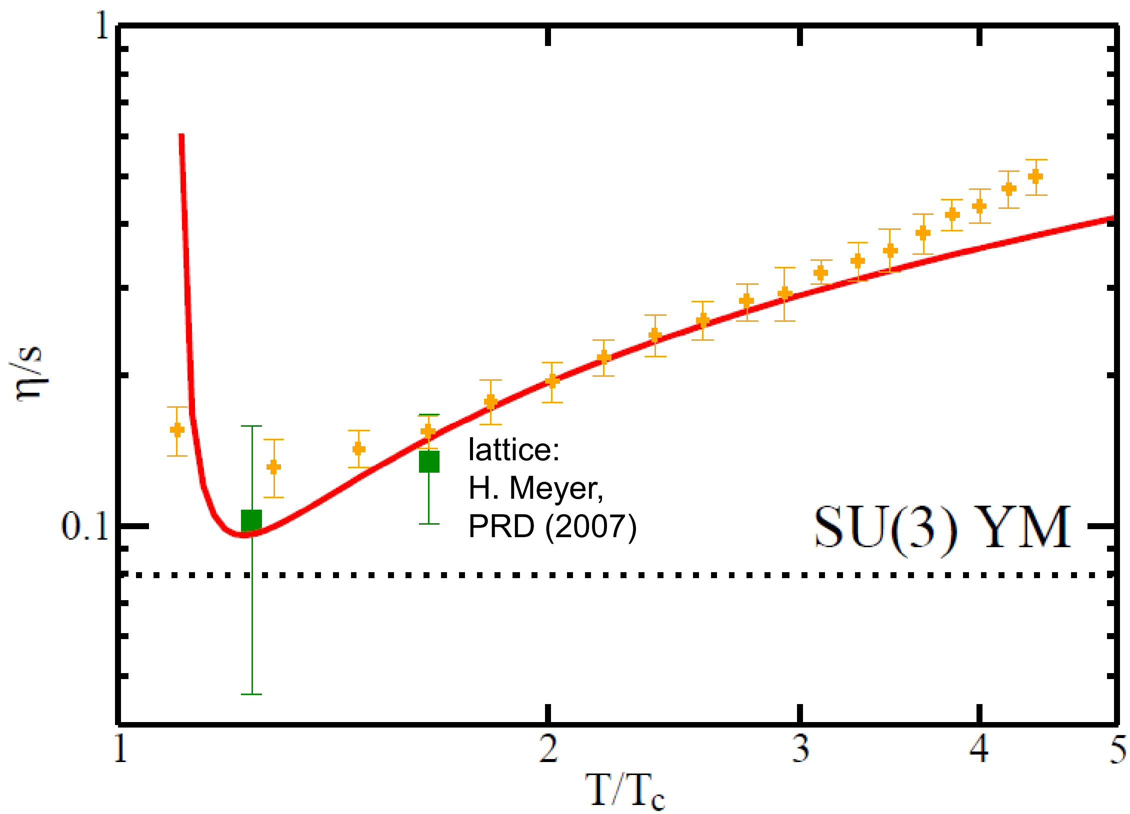
$$\frac{\zeta}{\eta}\bigg|_{\phi_H} = \left(\frac{d \log s}{d\phi_H} \right)^{-2} = \left(\frac{1}{v_s^2} \frac{d \log T}{d\phi_H} \right)^{-2},$$

QCD input: Nf = 2+1, phys. q masses

Bazazov et al (2014), Borzanyi et al (2014), Tc = 150 MeV



Einstein-Hilbert action → $\frac{\eta}{s} = 1/4\pi$



funct. methods:
Christiansen, Pawlowski, Strodthoff, PRL (2015)

QPM:
M. Bluhm et al., PRC (2011), PLB (2012)

holography:
Kovtun, Starinets, Son, PRL (2015)

adding Gauss-Bonnet terms → T dependence

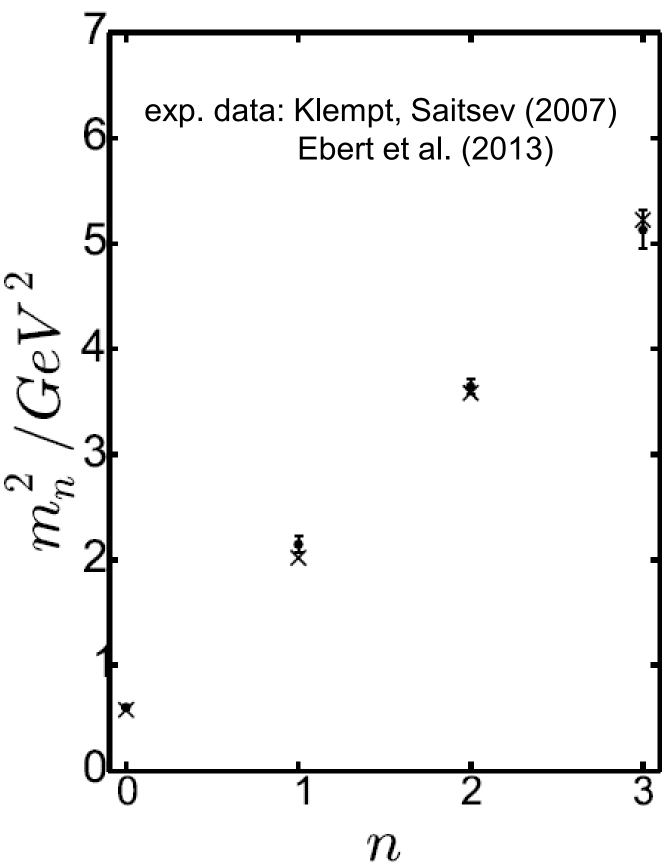
Vector mesons in AdS/CFT – extended soft wall model

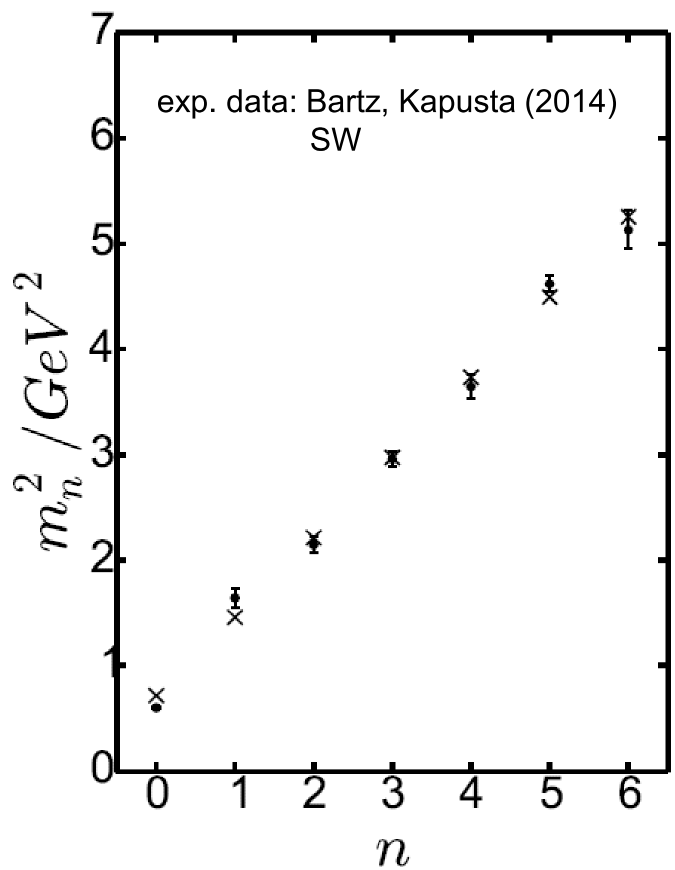
5D gravity | conf. symmetry breaker | sourced by $\bar{q}\gamma^\mu q$

S_V = F(warp factor, blackening function, dilaton, V wave function)

soft wall (probe limit): $A(z) = \ln (L/z)^2$ $\quad f(z) = 1 - (\frac{z}{H})^4$ $\quad \Phi(z) = (cz)^2$

EoM of V→Schrödinger eq. in tortoise coordinate, T = 0 → Regge type spectrum





rho trajectory from mod. SW: $\tilde{A}, \tilde{f}, \tilde{\phi}$

SW & theor. reasoning: Karch, Katz, Son, Stephanov PRD (2006)

A black brane in AdS

(analog to Schwarzschild Black Hole in Friedmann universe)

a patch of the AdS:

AdS with black brane

AdS/CFT dictionary: T(zH) as Hawking temperature of boundary theory
s(zH) as Bekenstein-Hawking entropy

warning: Hawking-Page transition at T < Tc action:

$$S_V = -\frac{1}{4k_V}\int \mathrm{d}z\,\mathrm{d}^4x\,\sqrt{g}e^{-\Phi(z)}F^2$$

rad. & Lorenz gauge

$$V_\mu = \epsilon_\mu \varphi(z)\exp\{ip_\nu x^\nu\}$$

ansatz:

$$ds^2 = e^{A(z)}\left(f(z)dt^2 - d\vec{x}^{\,2} - \frac{1}{f(z)}dz^2\right)$$

EoM:

$$\left(\partial_\xi^2 - (U_T - m_n^2)\right)\psi = 0,$$

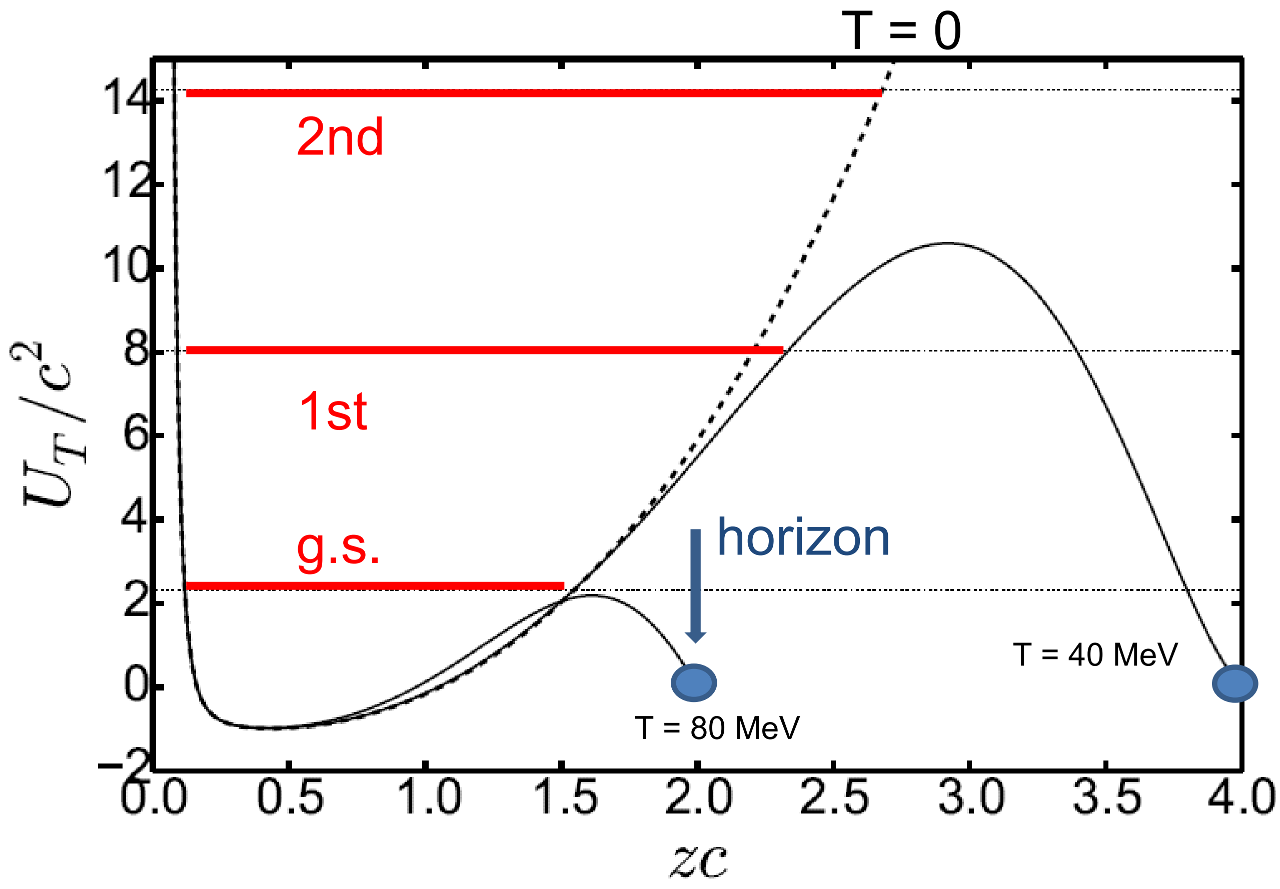
$$U_T = \left(\frac{1}{2}(\frac{1}{2}\partial_z^2 A - \partial_z^2\Phi) + \frac{1}{4}(\frac{1}{2}\partial_z A - \partial_z\Phi)^2\right)f^2 + \frac{1}{4}(\frac{1}{2}\partial_z A - \partial_z\Phi)\partial_z f^2.$$

spirit of soft-wall model: ansatz for A,f, phi

vector mesons = normalizable modes

Schrödinger equivalent potential

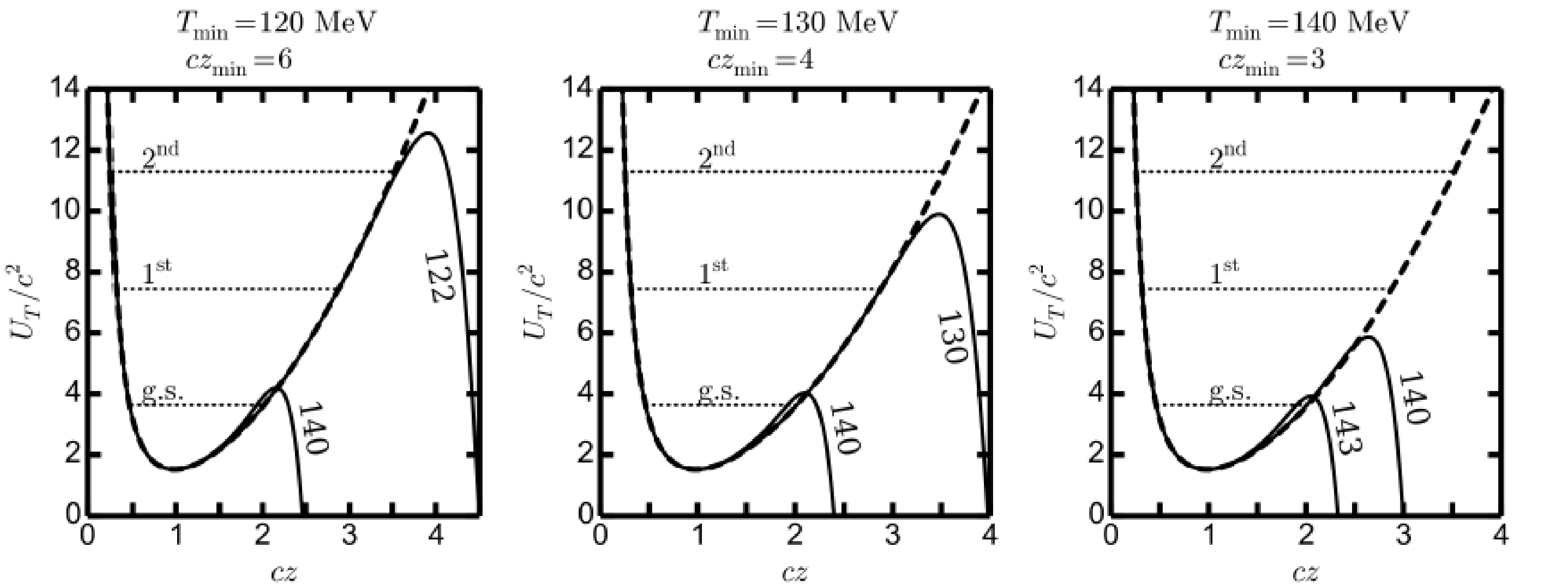
for modes in Klein-Kaluza decomposition of V in axial gauge



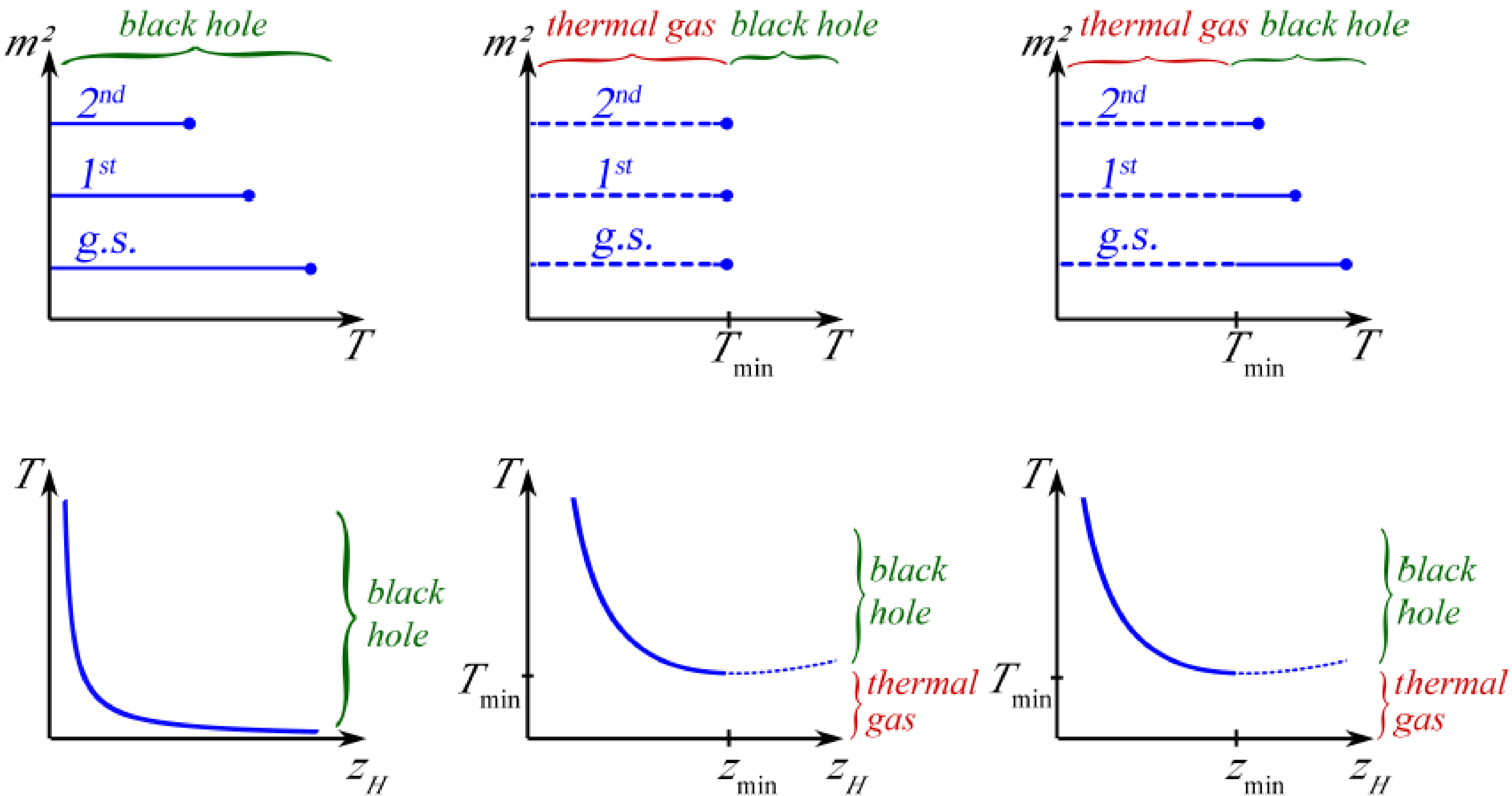
SW(T > 0):
Colangelo, Giannuzzi, Nicotri, JHEP (2012)

H → T(H)
needs
fine tuning

sequential disappearance upon temperature increase



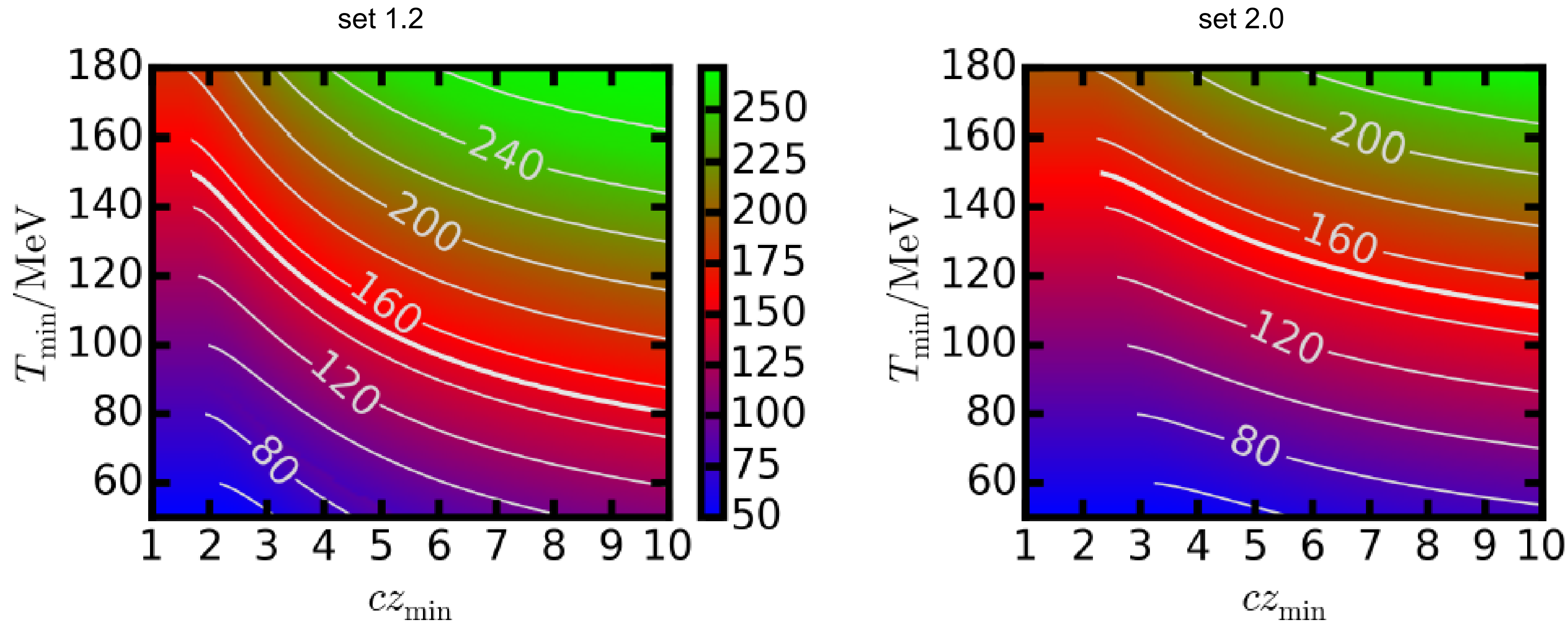
T_{min} = 120 MeV
cz_{min} = 6
T_{min} = 130 MeV
cz_{min} = 4
T_{min} = 140 MeV
cz_{min} = 3
U_T/c^2
cz
2nd
1st
g.s.
122
140
130
143

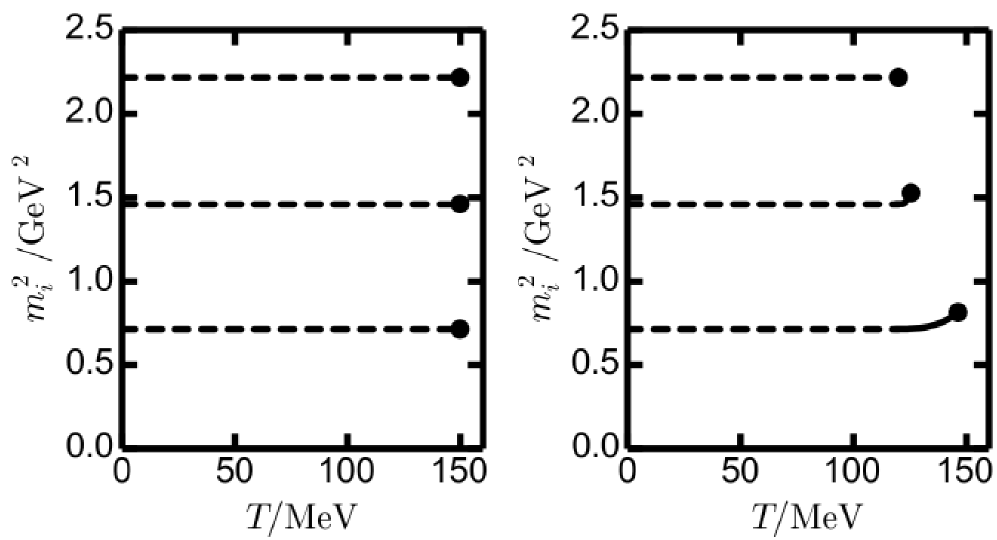


sequential vs. instantan. vs. mixed sequential
disappearance

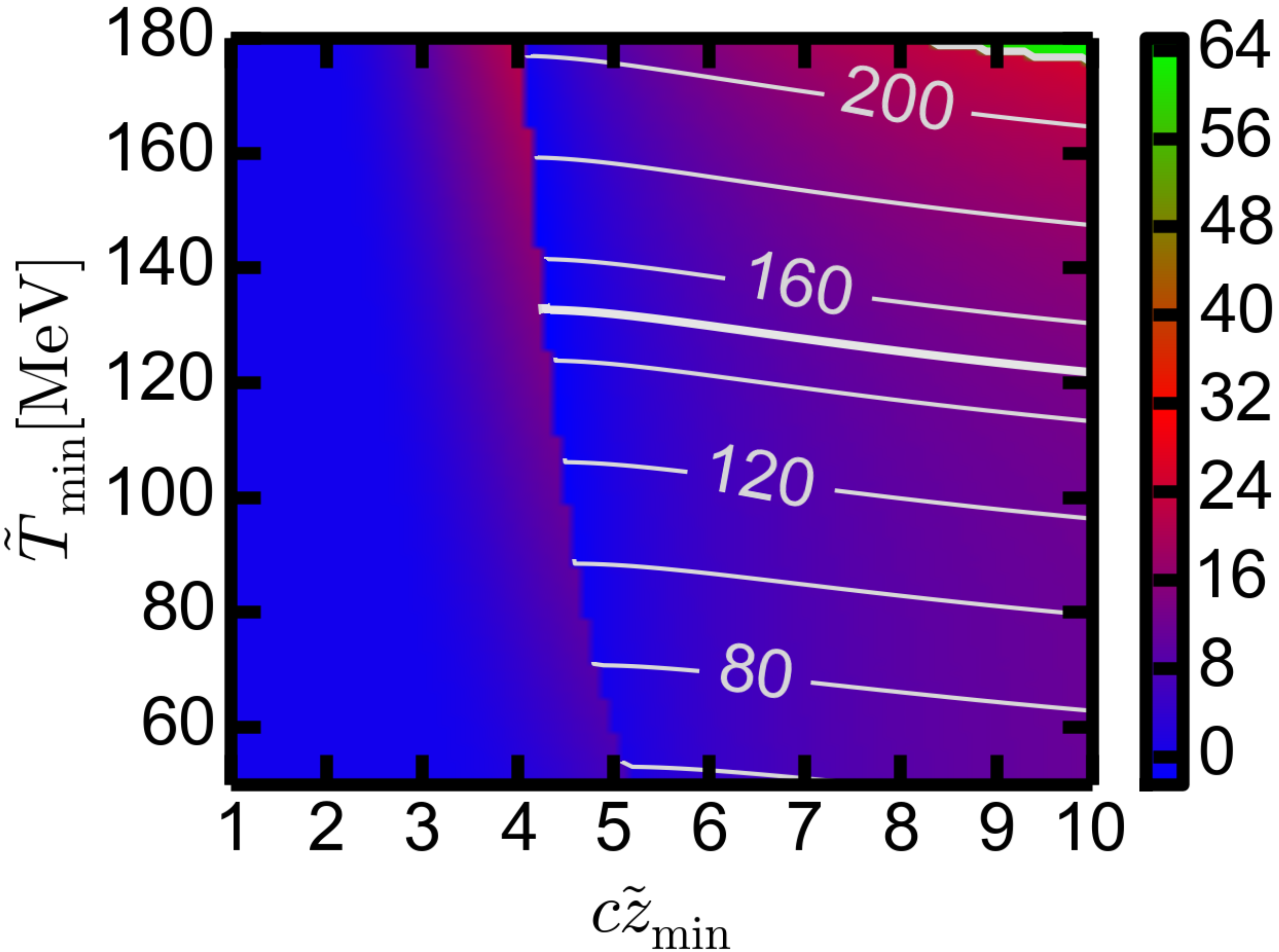
thermodyn. options:
continuous – cross over – 2nd order – 1st order transitions

A two-parameter model for Tdis (Tmin, z_min)





contours: Tdis(2nd), color code: Tdis(2nd) – Tdis(g.s.)



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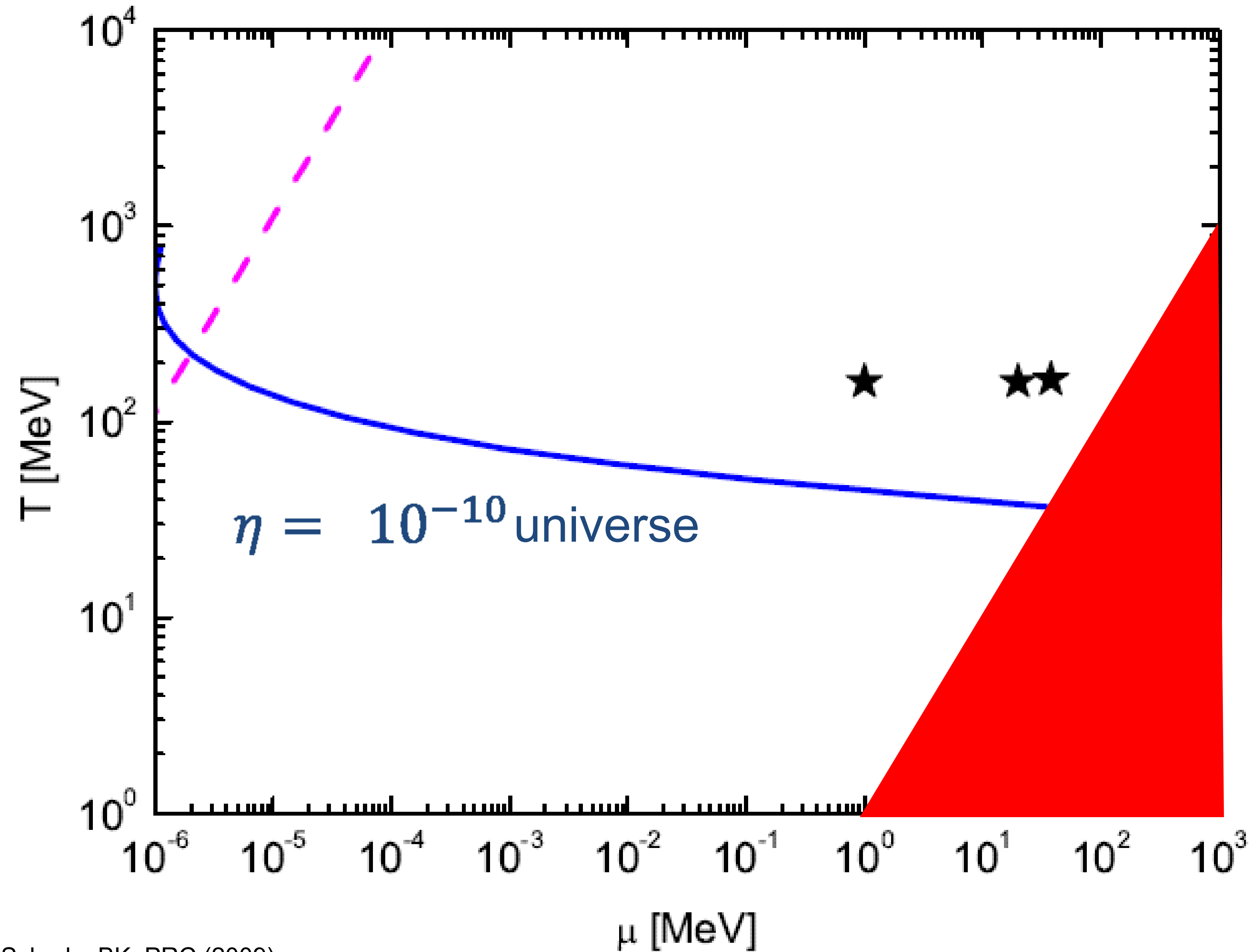
Cosmic Swing: from estimates to precision



stars: chem. freeze-out ABC
(Andronic, Braun-Munzinger, Cleymans et al.)

Schade, BK, PRC (2009)

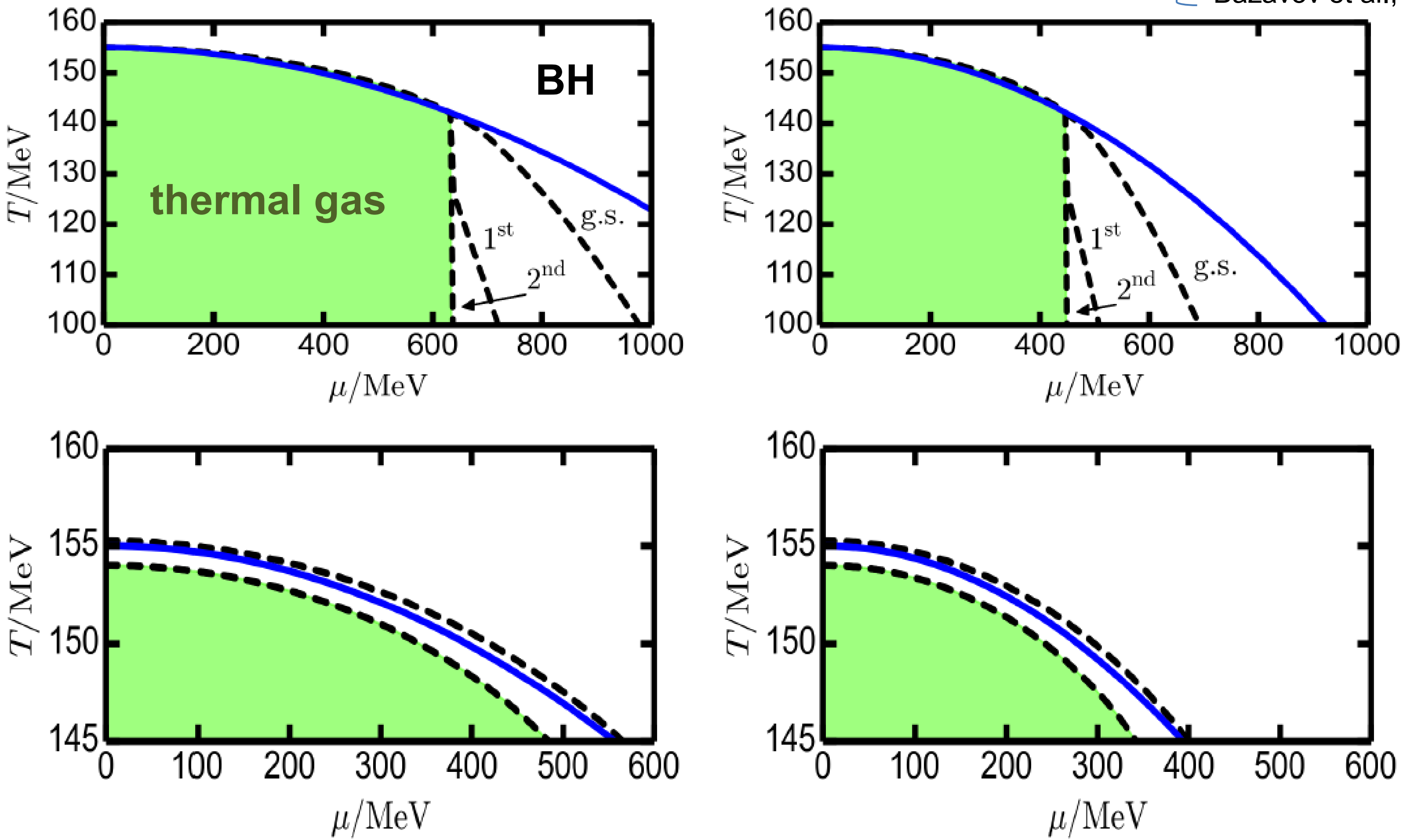
Schwarzschild → Reissner-Nordstrom BH

$$T_{\mathrm{f.o.}}(\mu) \cong T_c(\mu) \cong T_0 \left(1 - \kappa \left(\frac{\mu}{T_0} \right)^2 + \ldots \right)$$

$\boldsymbol{\kappa = 0.005}$

κ=0.01

Becattini et al., 1605.09694
Bazavov et al., PRD (2016)



C12 argument for freezing out at Tc-

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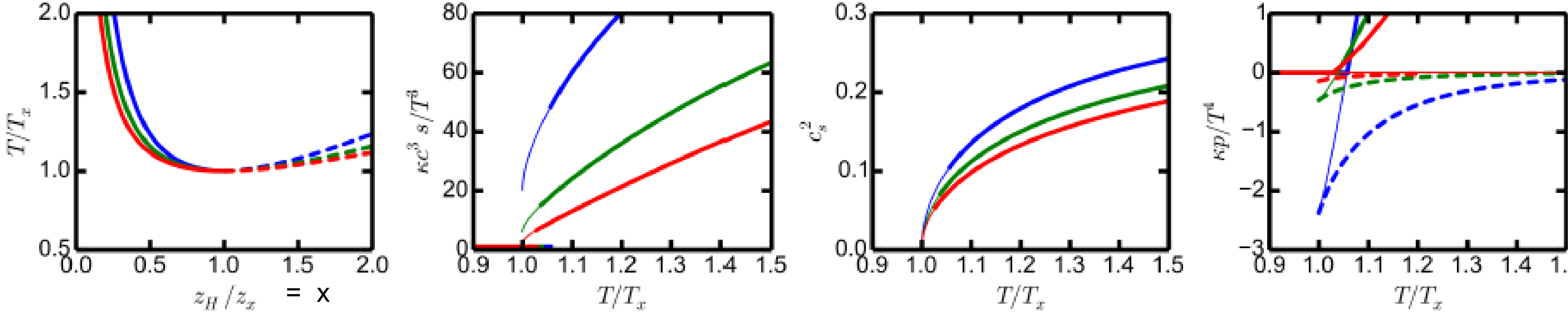
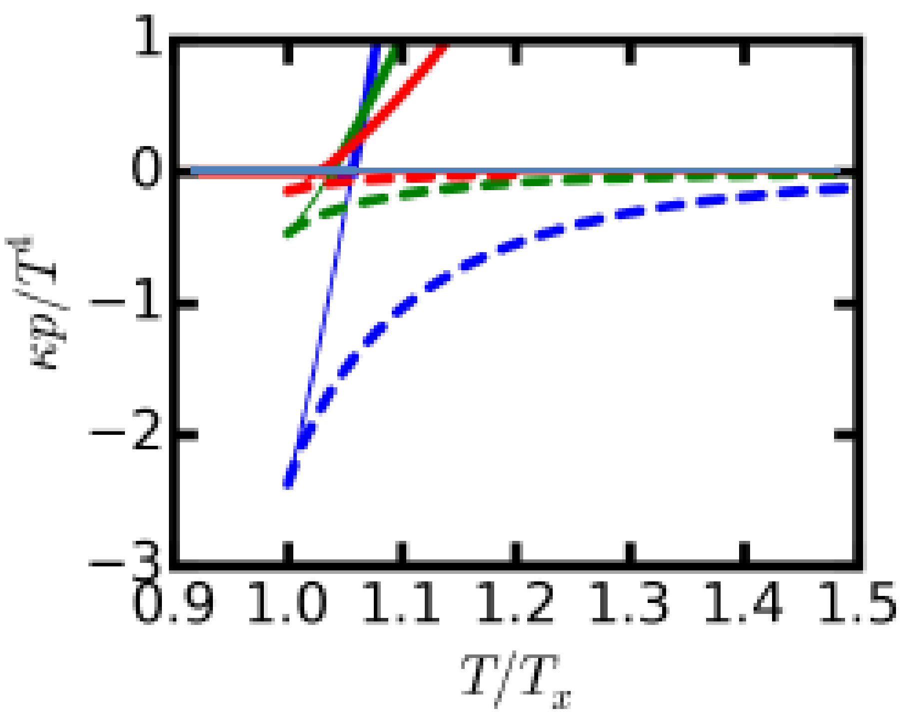
AdS-BH vs. Thermal Gas: FOPT



$$\frac{T}{T_x} = \frac{1}{x\theta} + 1 - \frac{2}{\theta} + \frac{x}{\theta}$$

$\theta = \pi z_x T_x$ = 2/3 (blue), 1 (green), 4/3 (red)



Kiritsis et al. (2008):

p(BH) ~ Nc^2

p(therm.gas) ~ O(Nc^0)

2+1 flavor QCD: phase diagram/Columbia plot

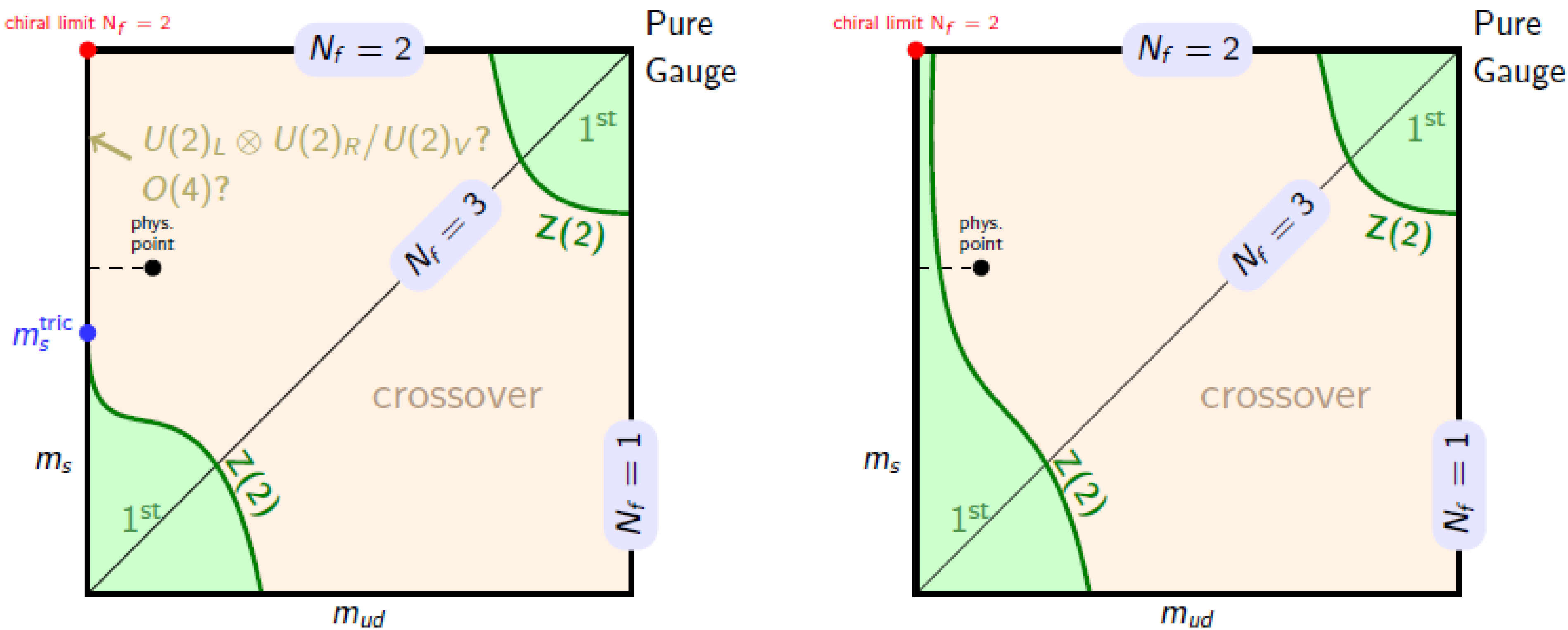
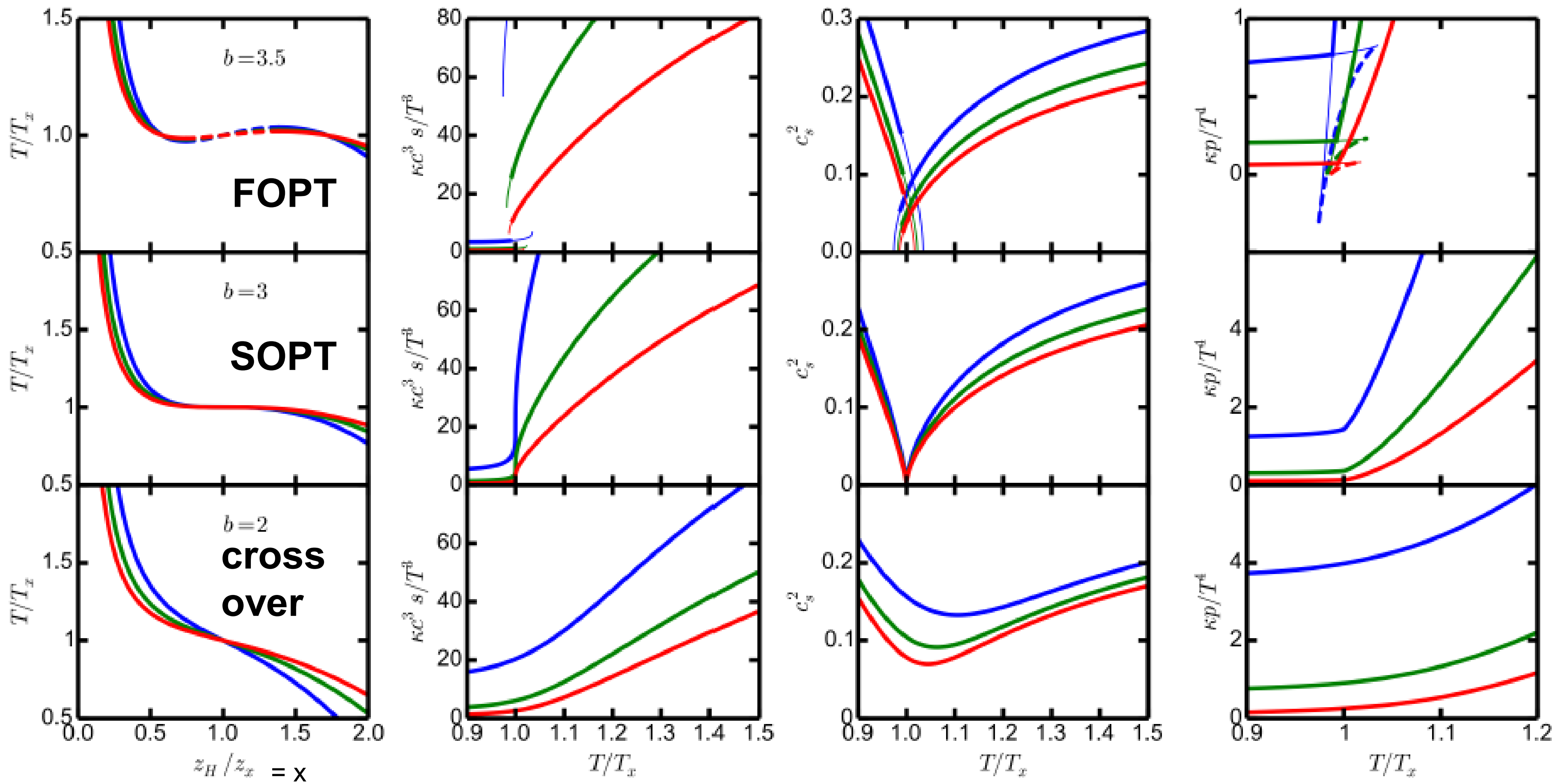


Figure 1: *Possible scenarios for the QCD phase diagram at $\mu = 0$ as function of quark mass.*

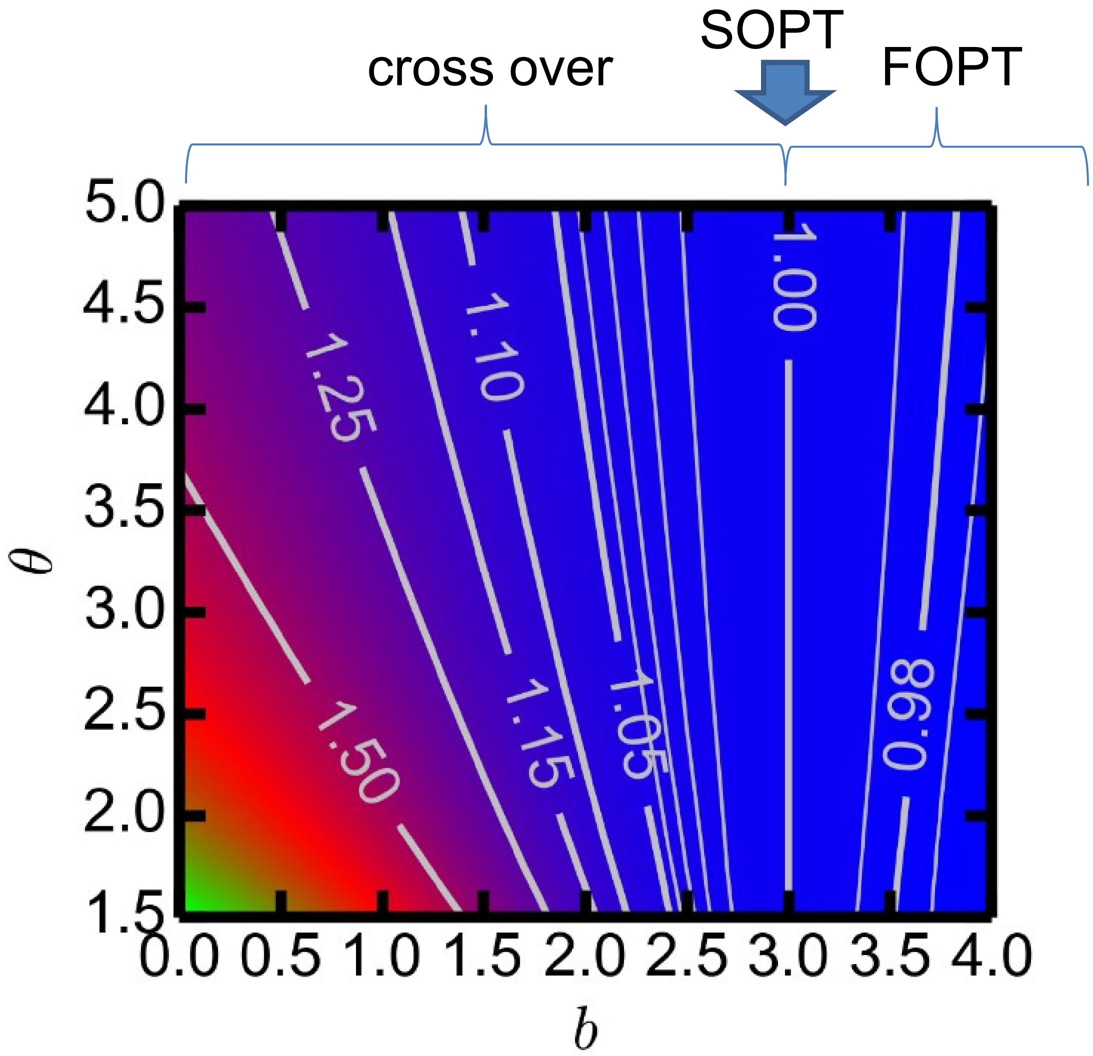
from Pinke & Philipsen, 2015

all the way AdS-BH: thermodynamics



$$\frac{T}{T_x} = \frac{1}{x\theta} + 1 - \frac{b}{\theta} + \frac{bx}{\theta} - \frac{x^2}{\theta}$$

contour plot Tc/Tx vs. Theta - b

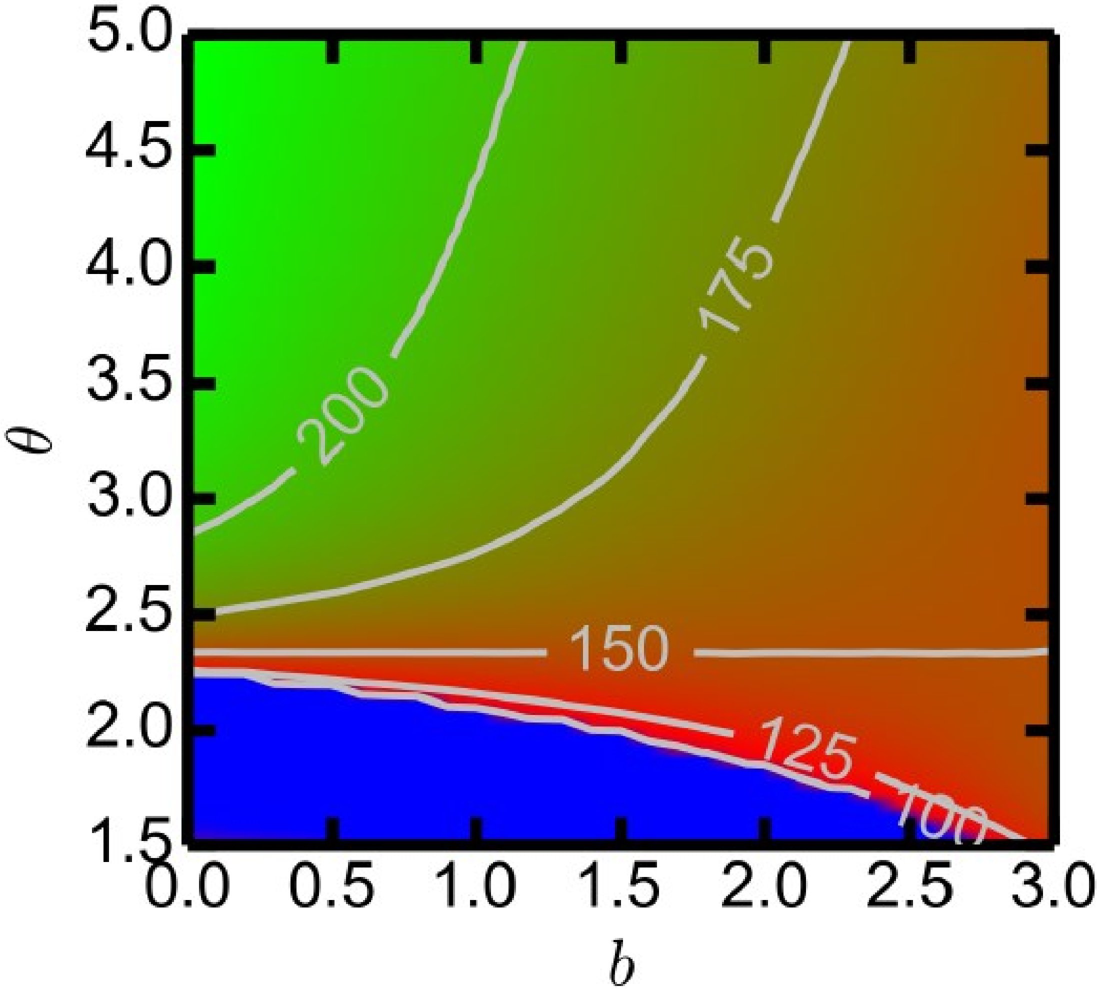


$$\theta = \pi z_x T_x$$

hadron masses → scale setting c in dilaton
thermodynamics → Tx from Tc(QCD)
deconfinement → Tdis = Tc

contour plot Tdis vs. Theta - b at Tx = 150 MeV

for g.s.



fine tuning of Tx → Tc = Tdis

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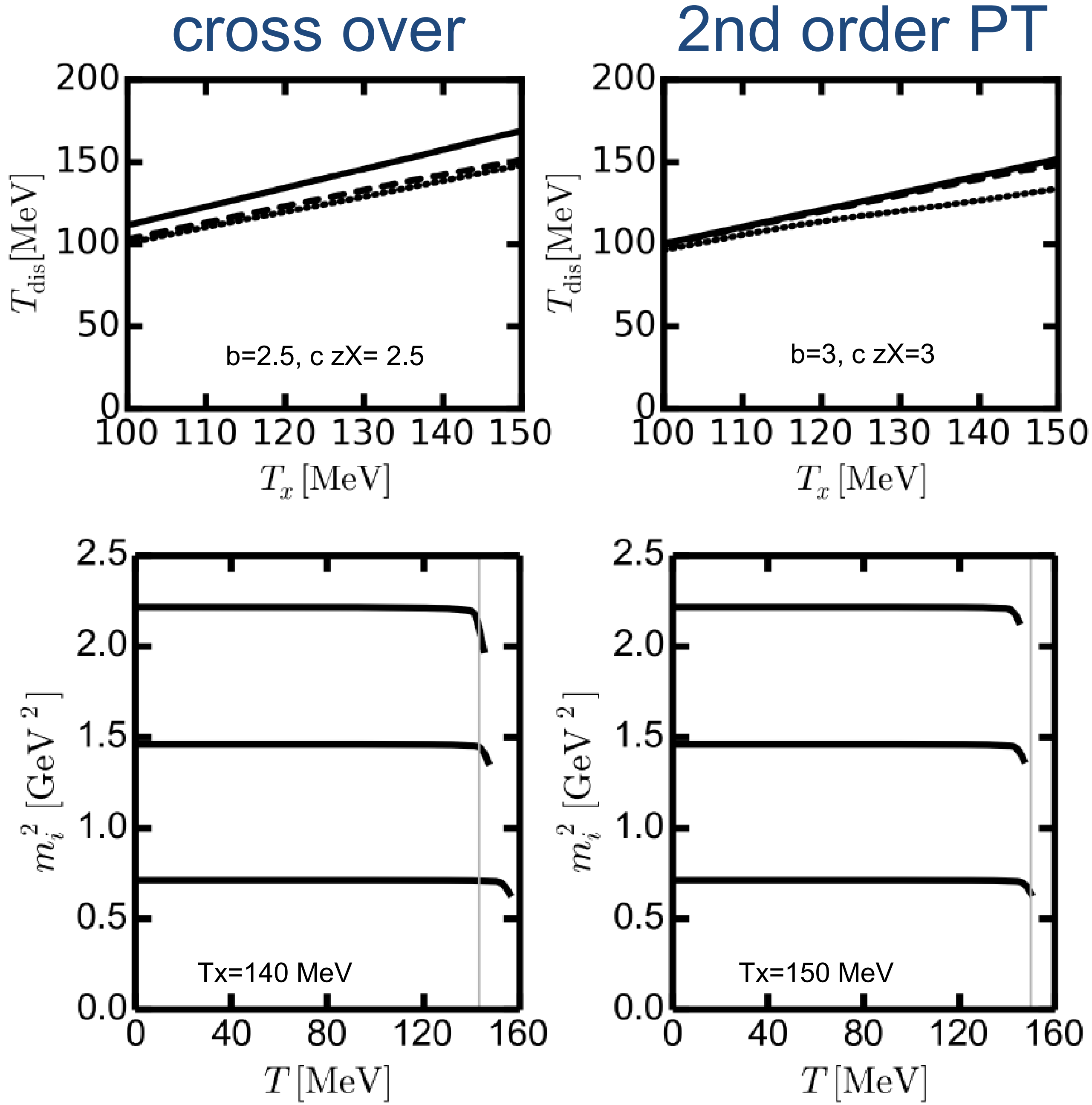
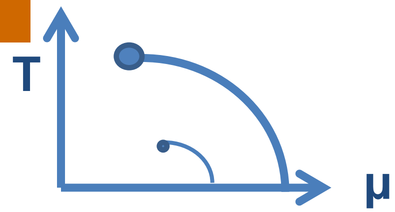
cross over 2nd order PT





A holographic phase diagram: update of the Gubser model

5D Einstein-dilaton-Maxwell model

$$S = \frac{1}{2\kappa_5} \int d^5x \sqrt{-g} \left(R - \frac{1}{2} \partial^\mu \phi \partial_\mu \phi - V(\phi) - \frac{f(\phi)}{4} F_{\mu\nu}^2 \right) + S_{GH}$$

DeWolfe, Gubser, Rosen, PRD (2010, 2011)

solve Einstein eqs. + EoM for dilaton and Maxwell
with proper conds. at boundary and horizon,
get T, s , mu, n (AdS/CFT dictionary),
integrate to get p(T, mu) to be used for susceptibilities

adjustments at mu = 0: (i) lattice QCD thermodynamics → V(phi)

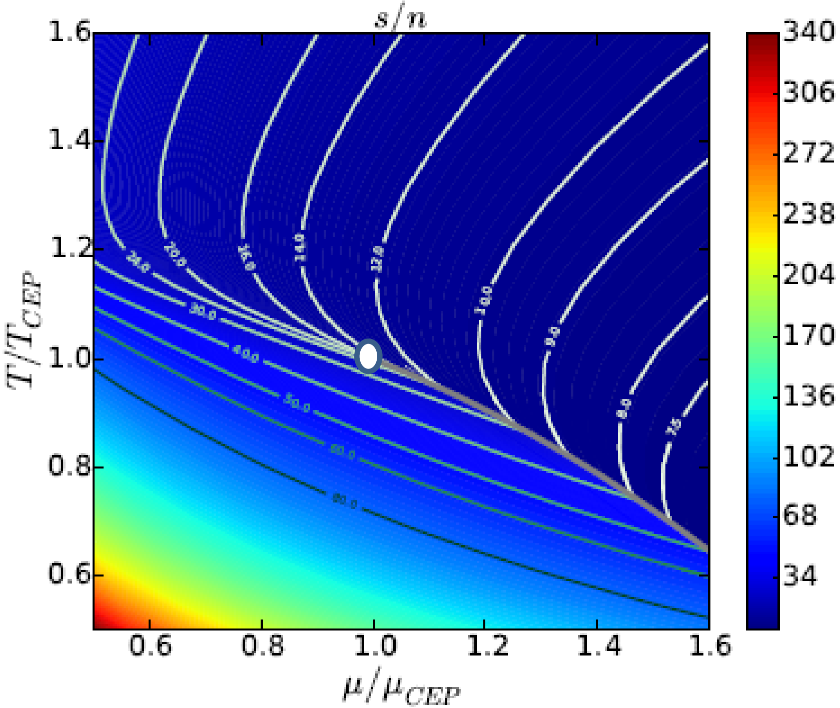
cf. Yaresko, BK, PLB (2015), Yaresko, Knaute, BK, EPJC (2015)

(ii) susceptibilities → f(phi)

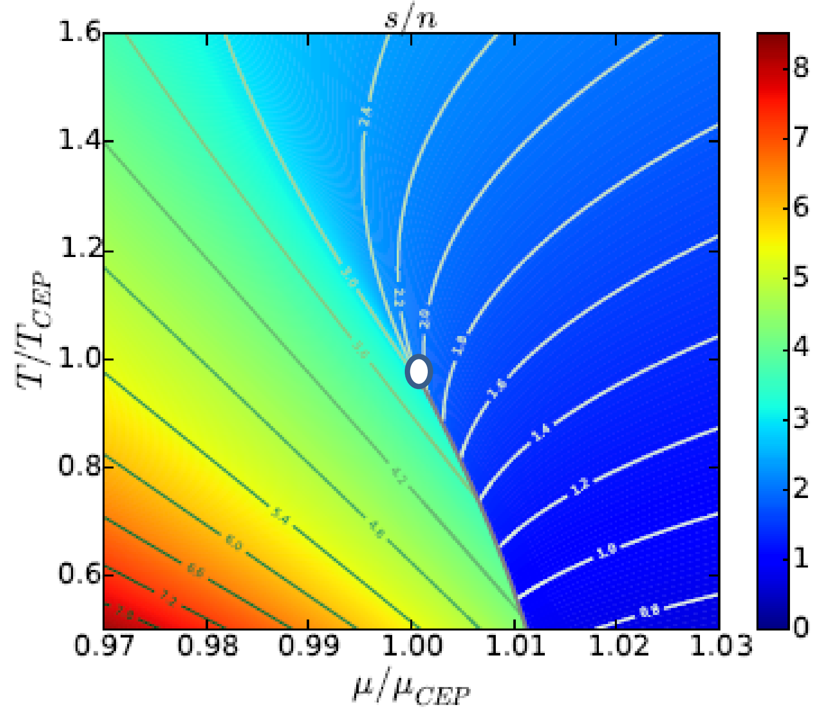
work in progress

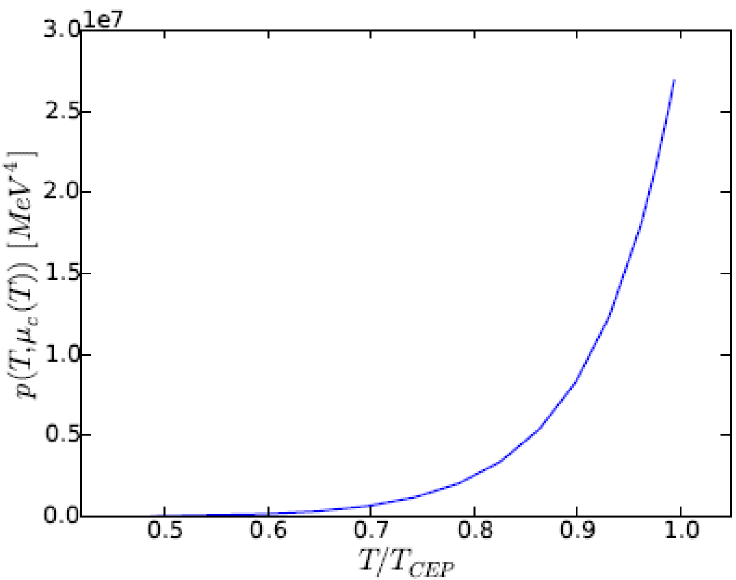
DRESDEN concept HZDR

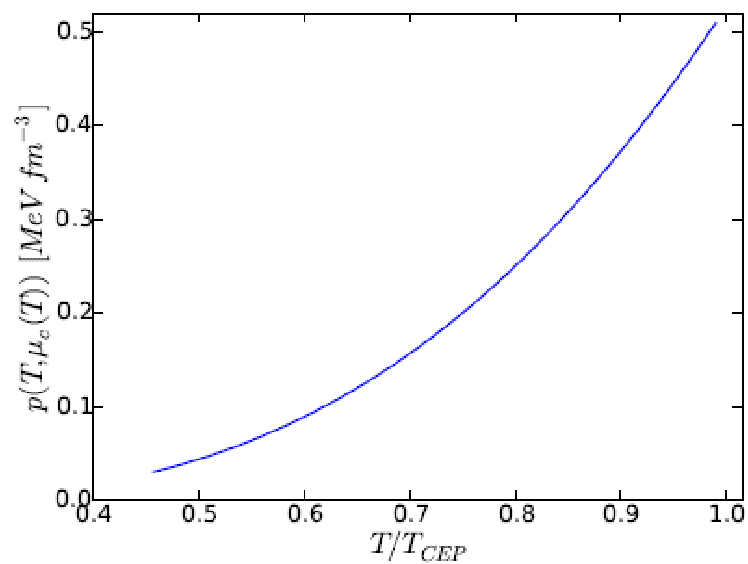
Holography a la Gubser et al.

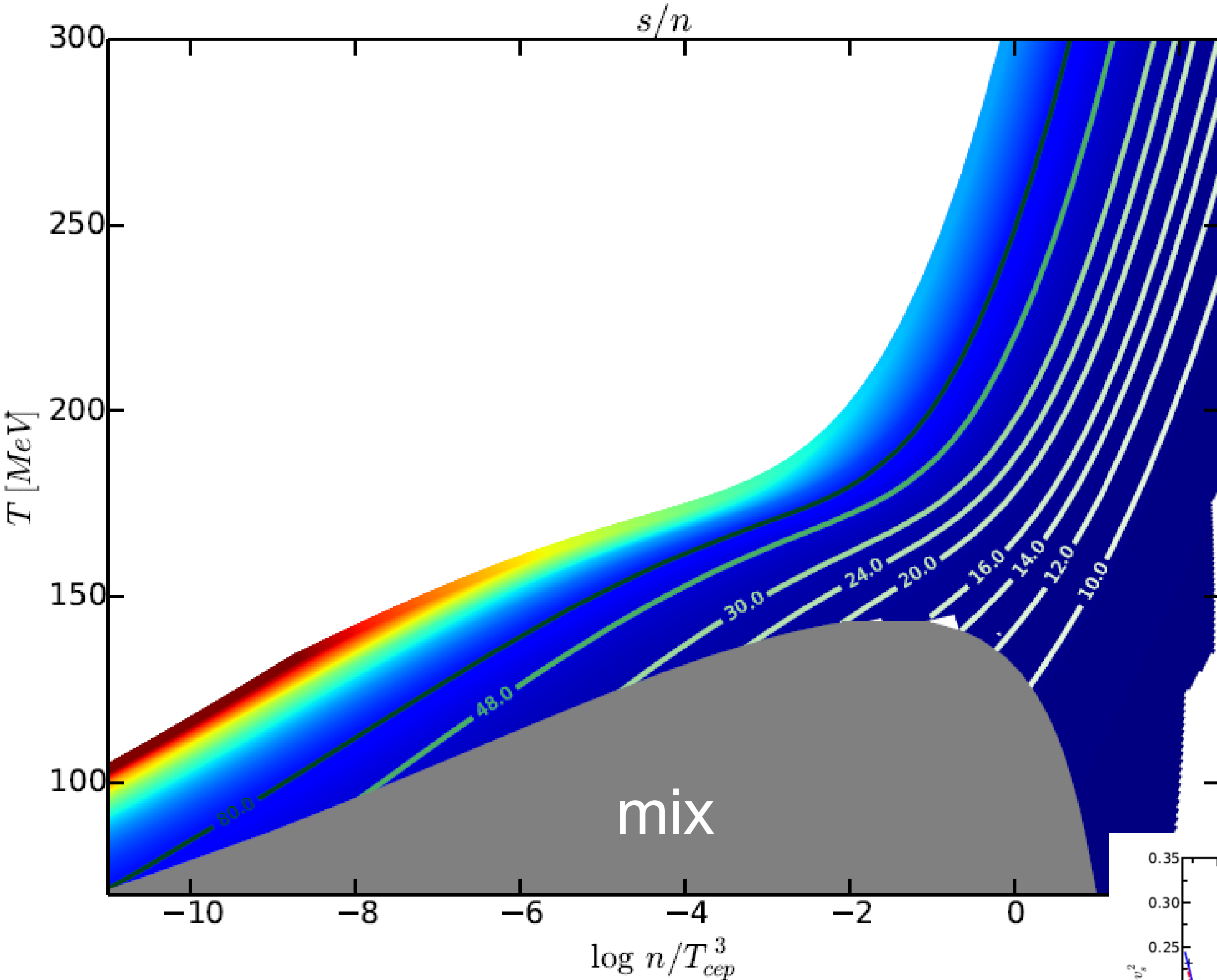


vdW a la Gorenstein et al.

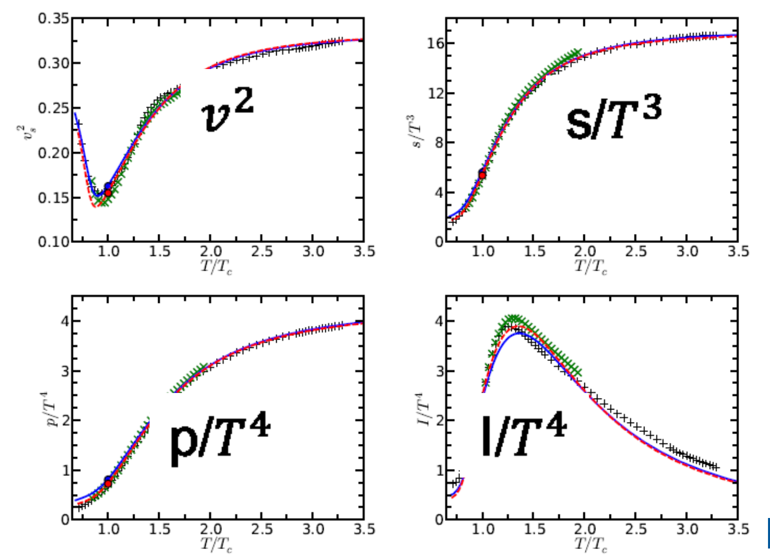








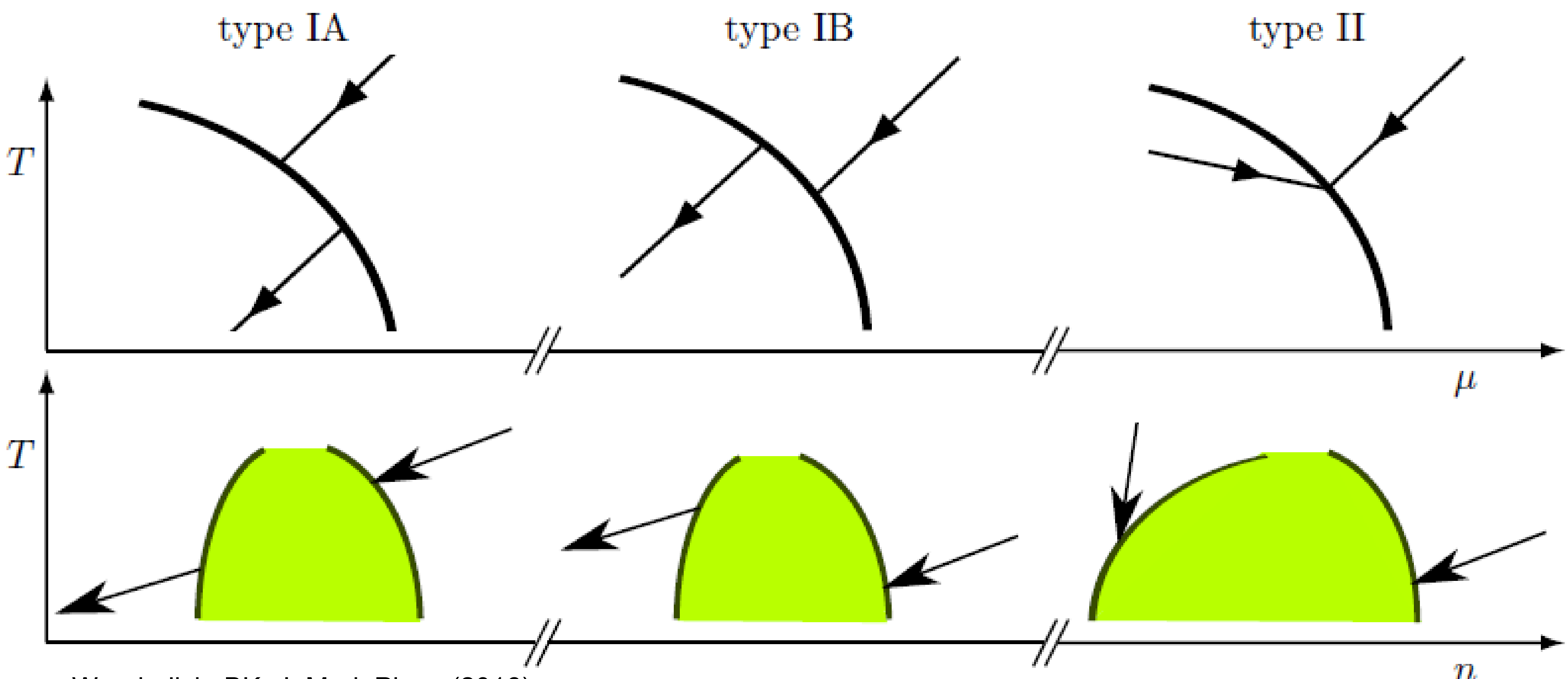
QCD input: Nf = 2+1, phys. q masses
Bazazov et al (2014), Borzanyi et al (2014)



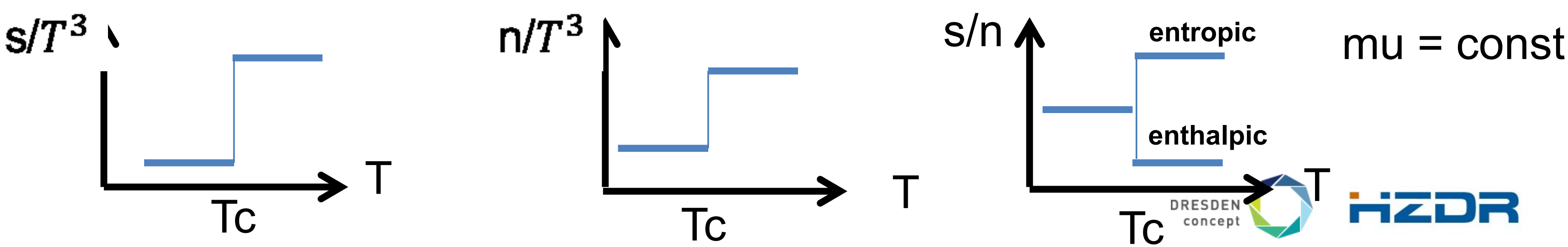
surprize: incoming isentropes only
(as in vdW)

Steinheiner, Randrup, Koch, PRC (2014),
Steinheimer, Randrup, PRL (2012),
Hempel, Dexheimer, Schramm, Iosilevskiy, PRC (2013)
and others claim: deconfinement is accompenied by
droping pressure on critical curve

Crossing the phase border line



Wunderlich, BK, J. Mod. Phys. (2016)



Summary

(i) Bulk viscosity = 0.5 shear viscosity at Tc

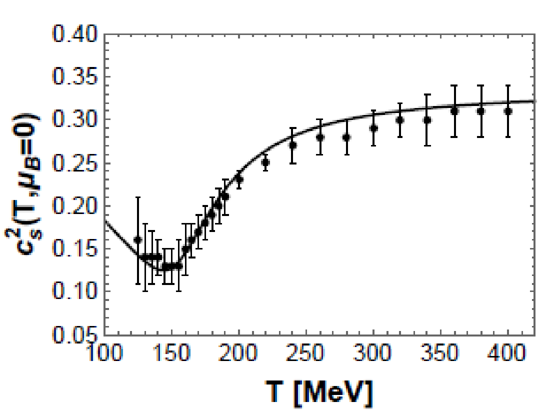
(ii) extended soft wall model for vector mesons:

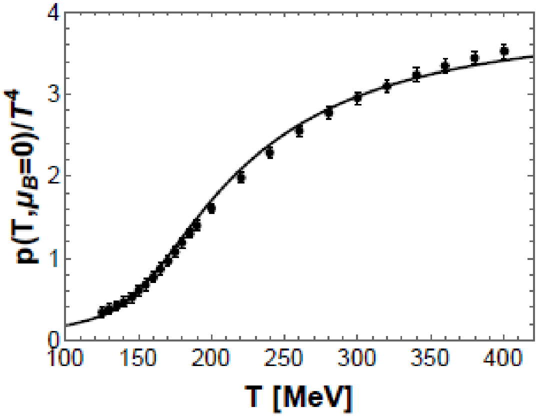
+ T = 0: two options for rho Regge trajectories
+ T > 0: emulating deconfinement as disappearance (instant. vs. sequential) of hadrons at T(QCD)
+ contact to thermodynamics (ambient medium mimicked by dilation via ansatz)
? construction of a phase diagram

(iii) holographic phase diagram:

+ accommodates QCD thermodynamics (medium mimicked by self consist. dilaton)
- no individual hadrons sourcing dilaton below Tc
-- vdW behavior (w/o tuning 4th order susceptibility)

Results of the Sao Paulo Group





Rougemont et al.
JHEP (2015), PRL (2015)