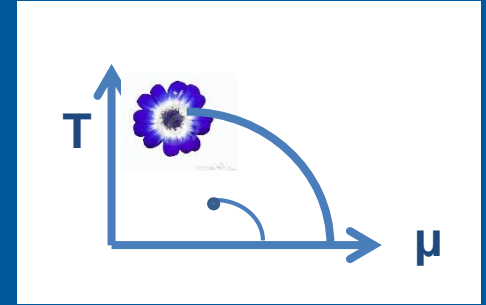


# Holographic qcd phase diagram

**B. Kämpfer**

**Helmholtz-Zentrum Dresden-Rossendorf  
& Technische Universität Dresden**



Holographically emulating deconfinement as disappearance

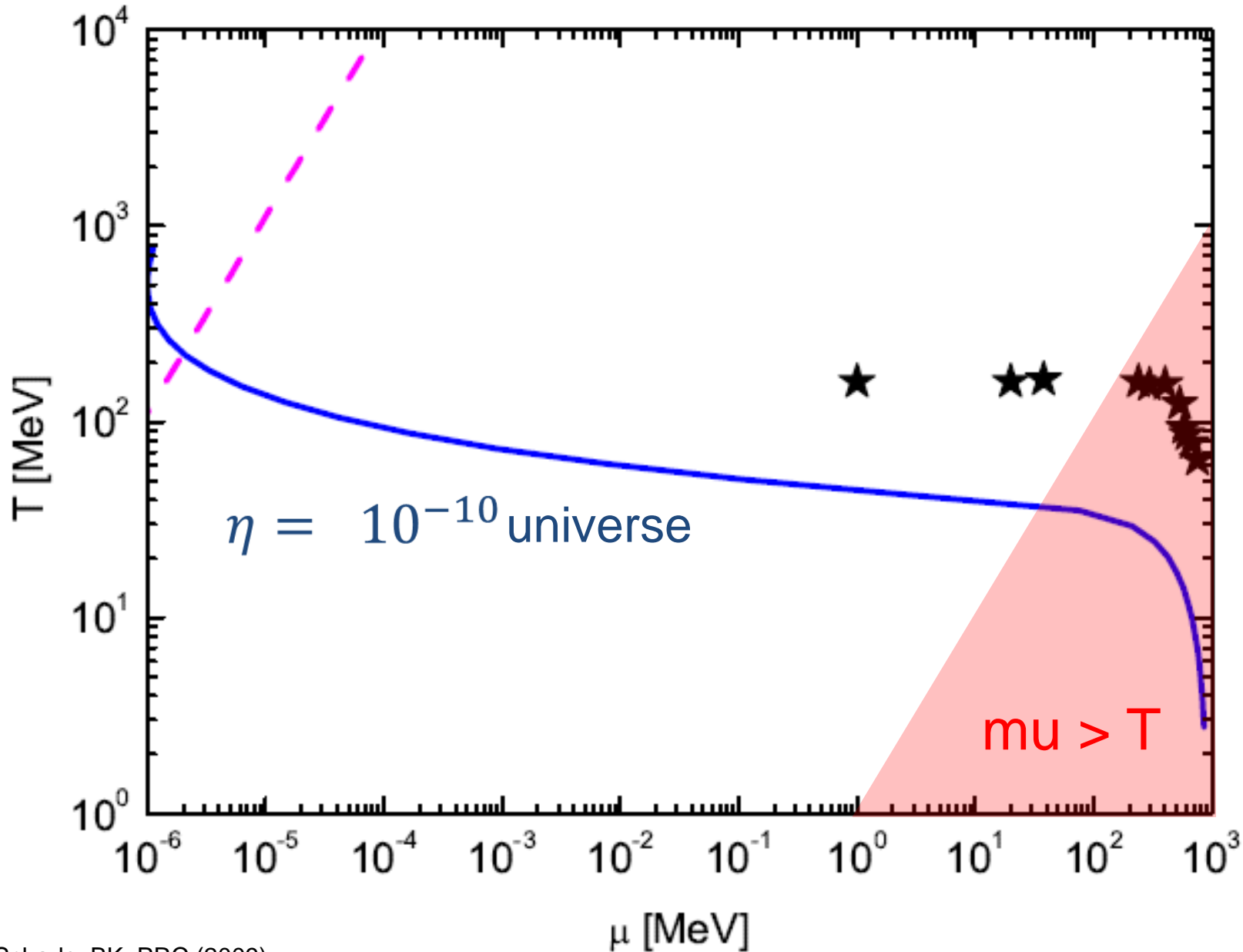
R. Zollner

Holographic view on the phase diagram

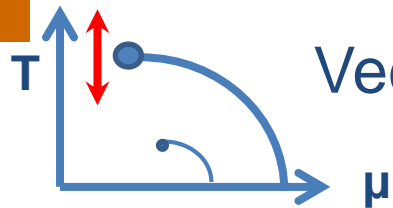
R. Yaresko, J. Knaute



# Cosmic Swing: from estimates to precision



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



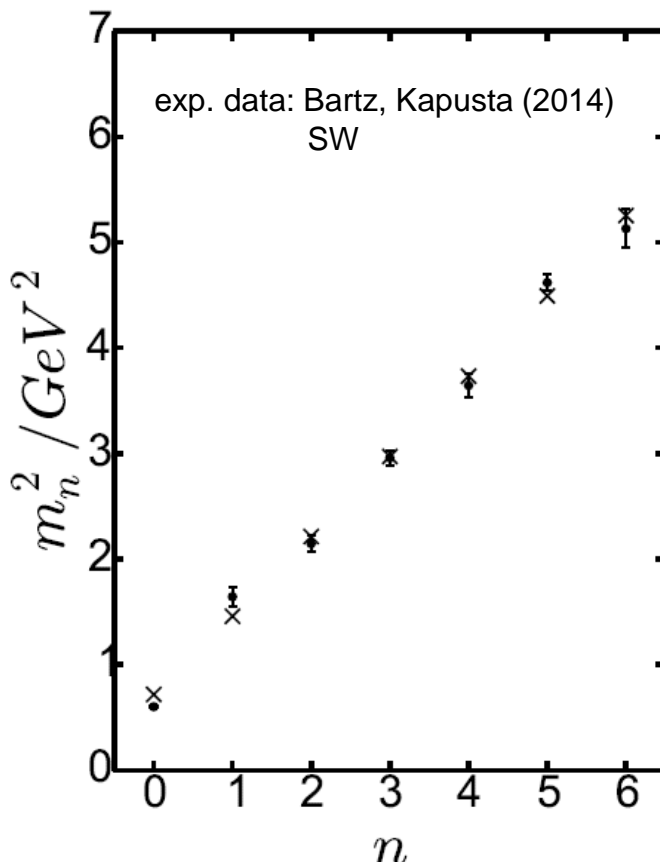
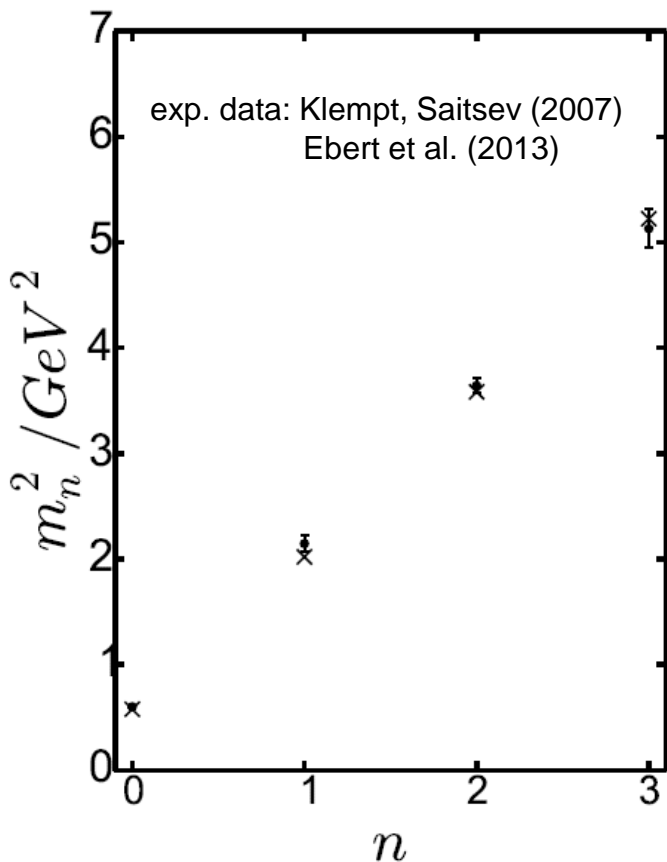
# Vector mesons in AdS/CFT – extended soft wall model

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

$$S_V = F(\text{warp factor, blackening function, } \text{dilaton}, V \text{ wave function})$$

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

EoM of  $V \rightarrow$  Schrödinger eq. in tortoise coordinate,  $T = 0 \rightarrow$  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

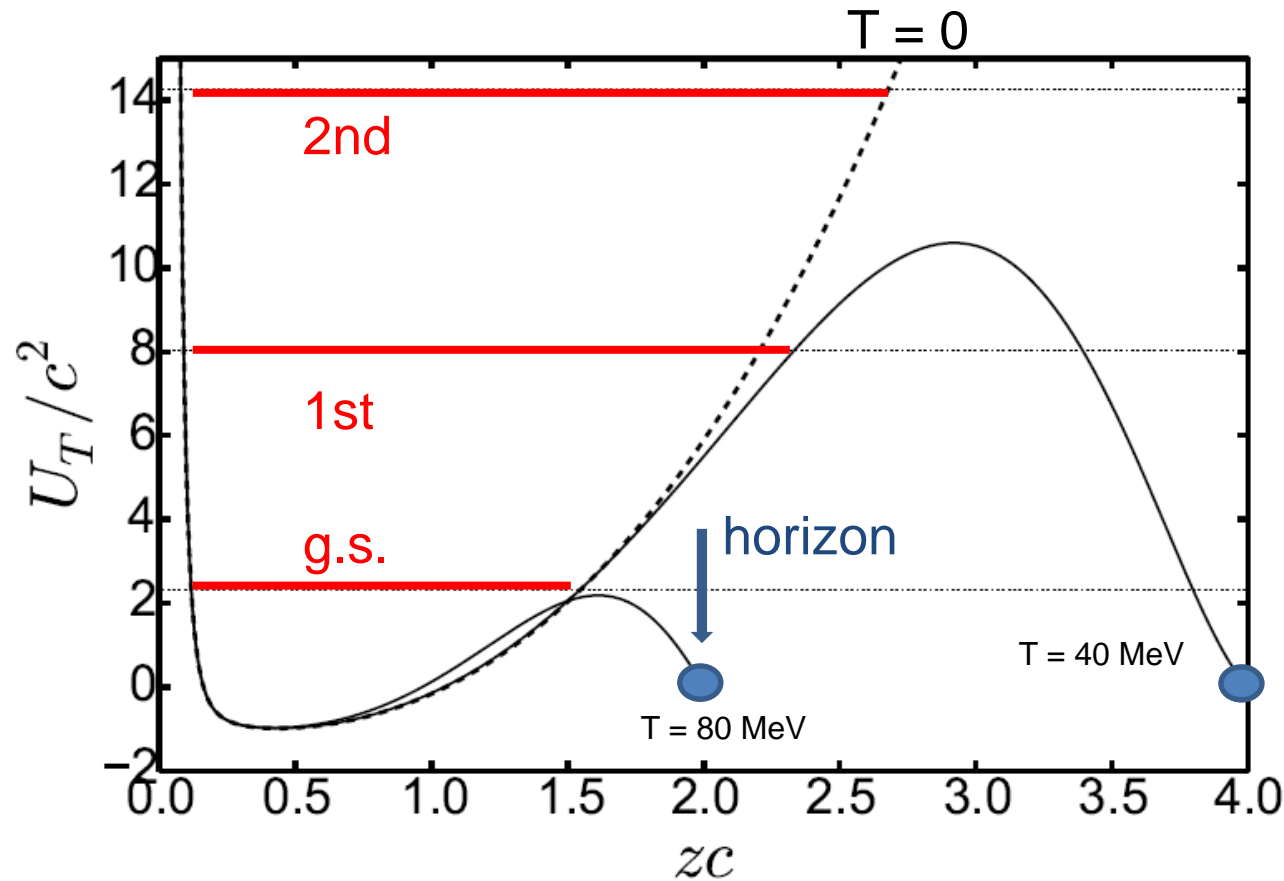


AdS/CFT dictionary:  $T(zH)$  as Hawking temperature of boundary theory

warning: Hawking-Page transition at  $T < T_c$

# Schrödinger equivalent potential

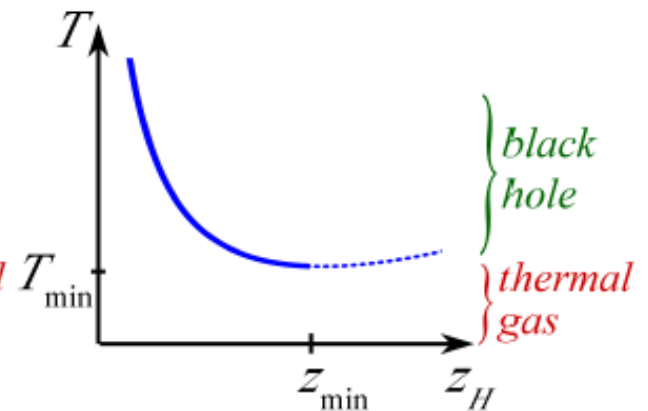
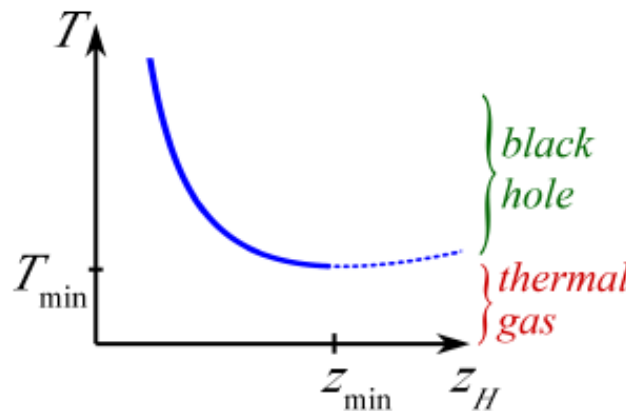
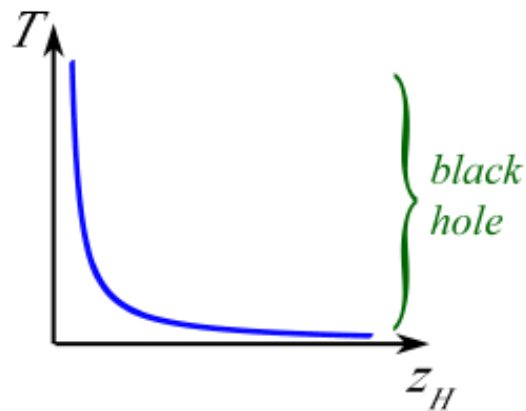
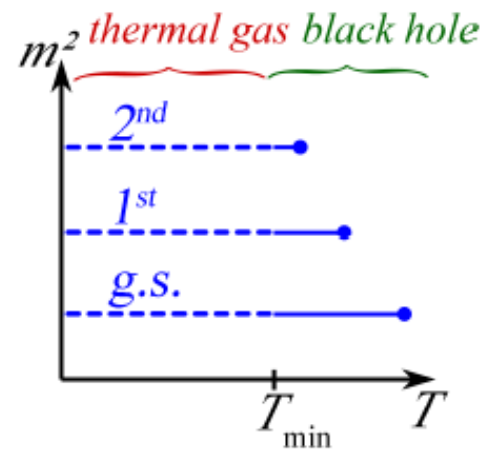
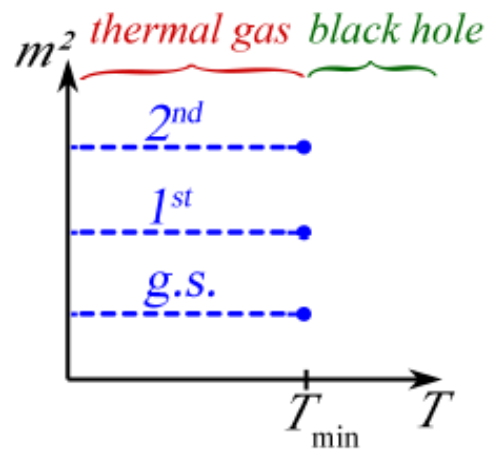
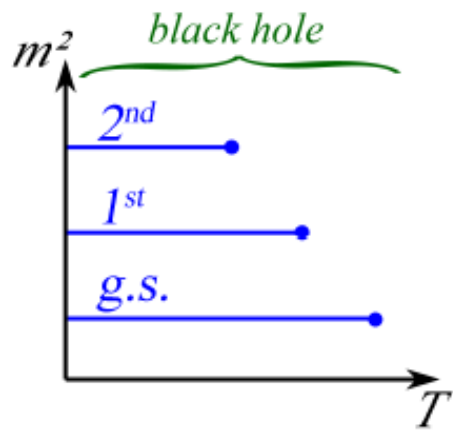
for modes in Klein-Kaluza decomposition of  $V$  in axial gauge



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

$H \rightarrow T(H)$   
needs  
fine tuning

sequential disappearance upon temperature increase



sequential vs. instantan. vs. mixed sequential disappearance

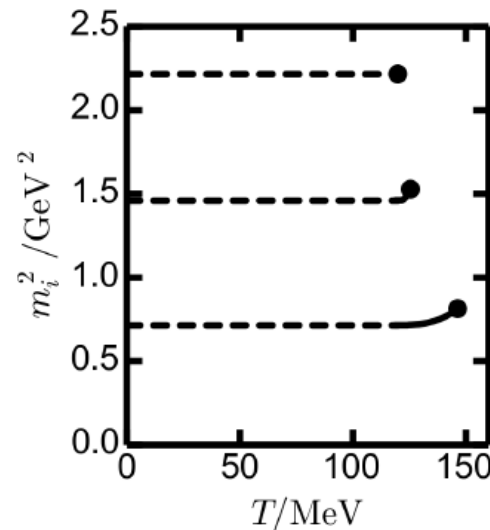
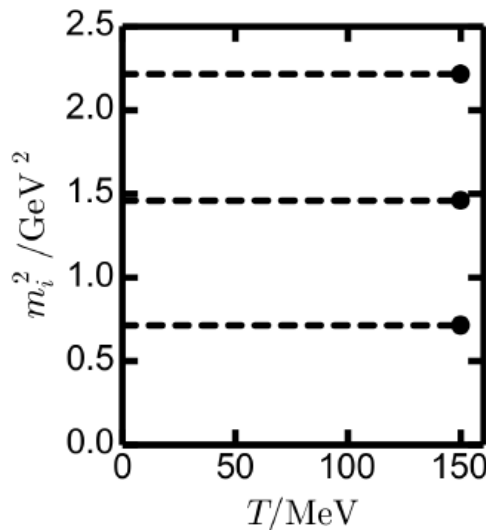
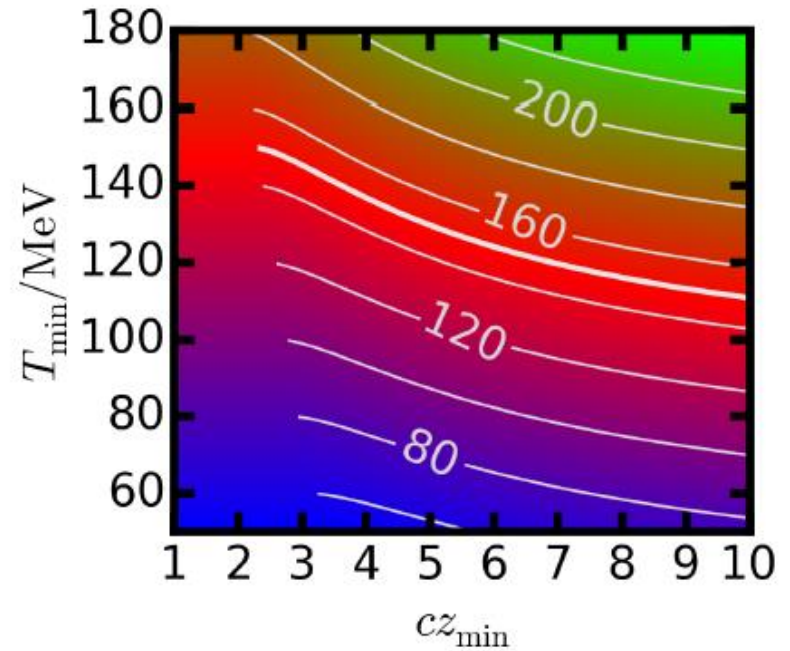
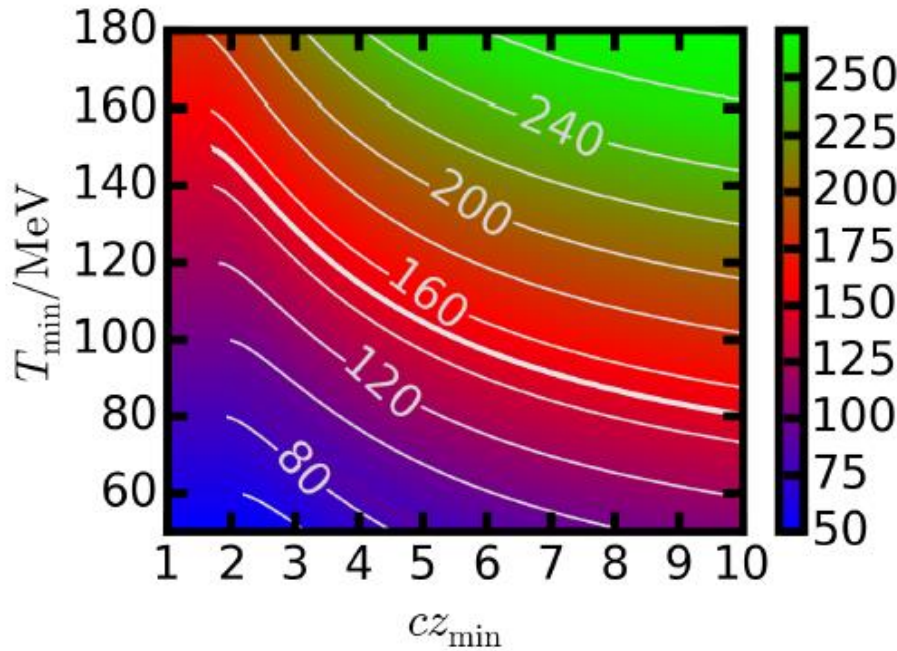
thermodyn. options:

continuous – cross over – 2nd order – 1st order transitions

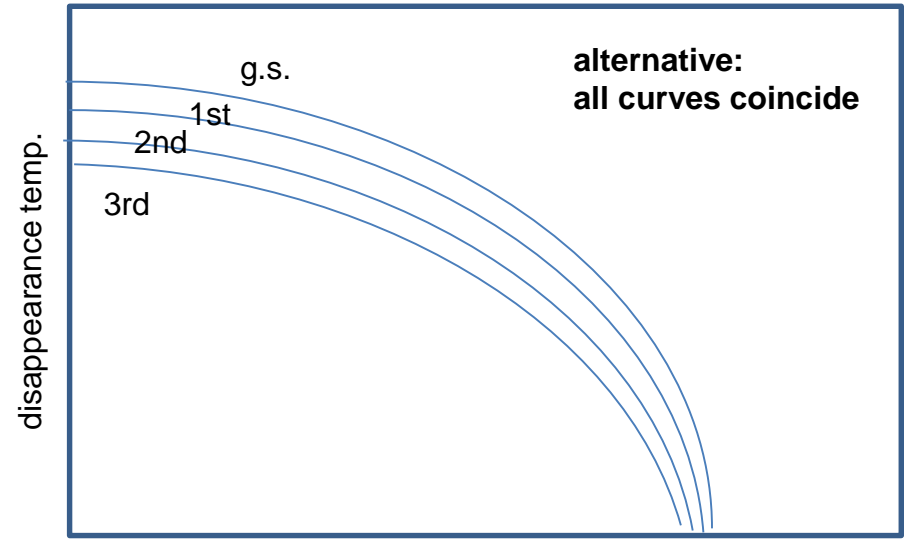
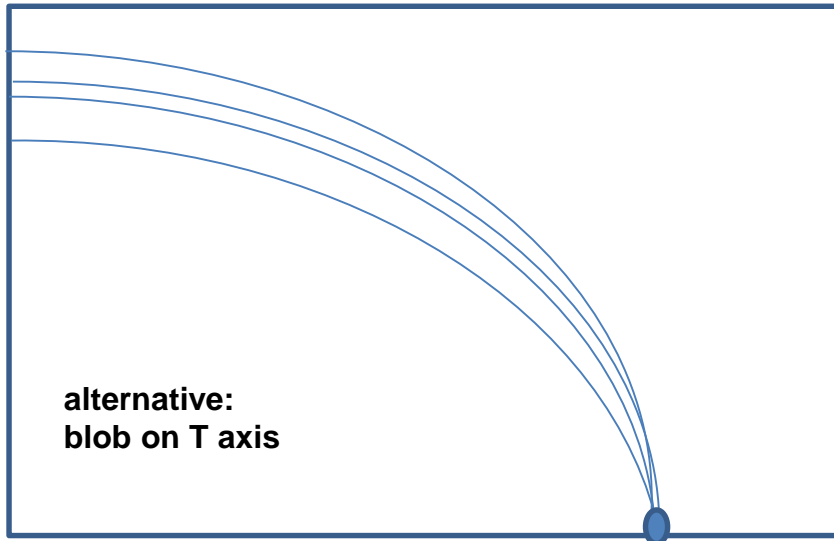


# A two-parameter model for Tdis ( $T_{\min}$ , $z_{\min}$ )

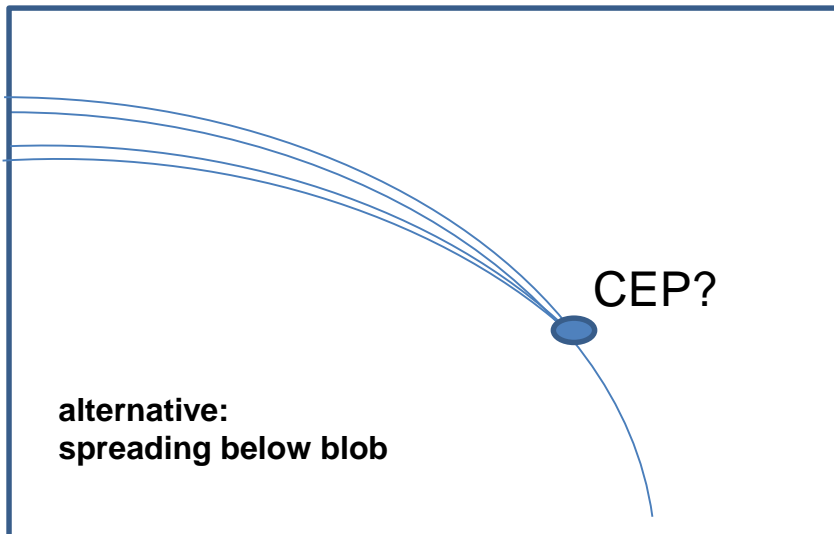
Zoellner, BK, 1607.01512



# Possible holographic designs of „phase diagrams“



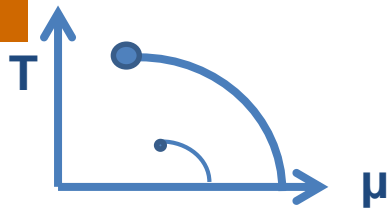
chem. pot.  from RN charge



issues:

- disapp. vs. deconfinement
- chir. restoration
- center symmetry
- consistent thermodyn.





# 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  $\rightarrow V(\phi)$

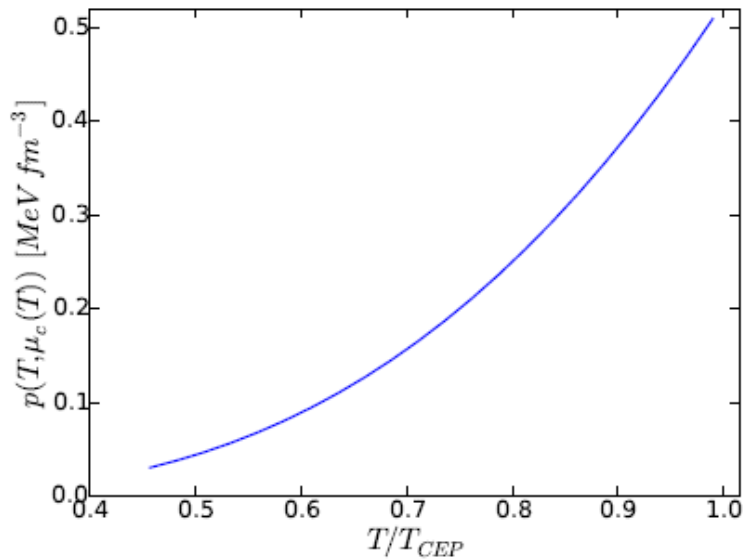
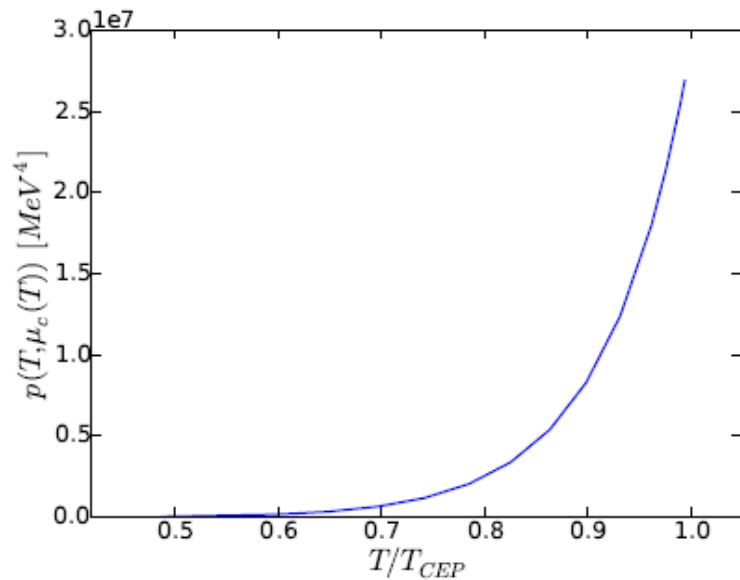
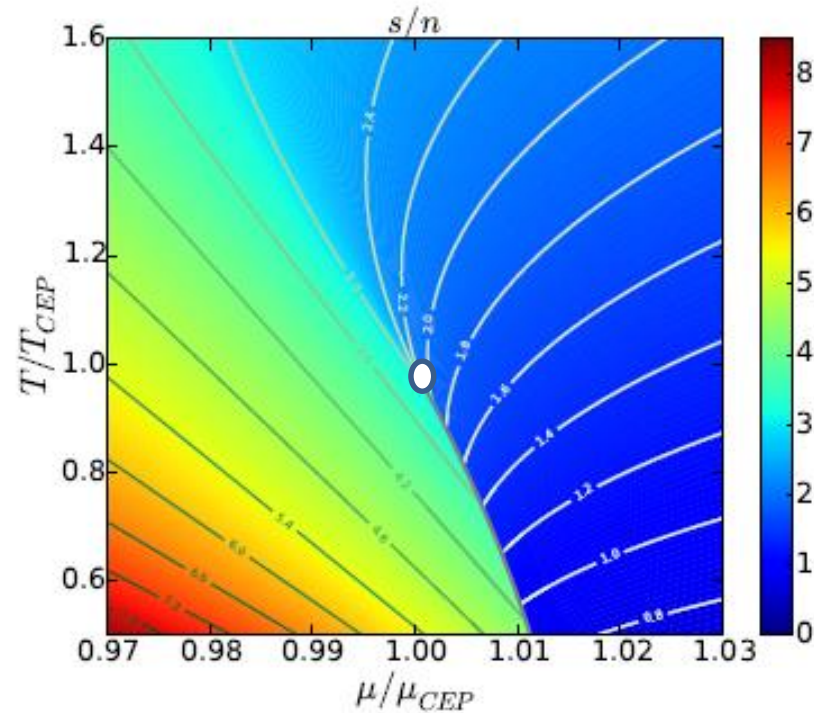
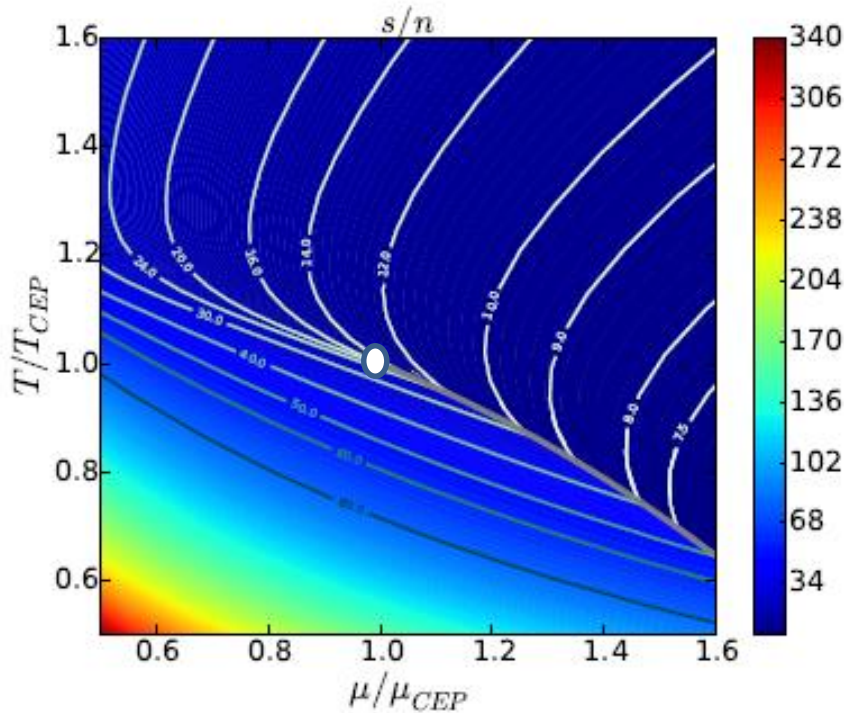
cf. Yaresko, BK, PLB (2015), Yaresko, Knaute, BK, EPJC (2015)

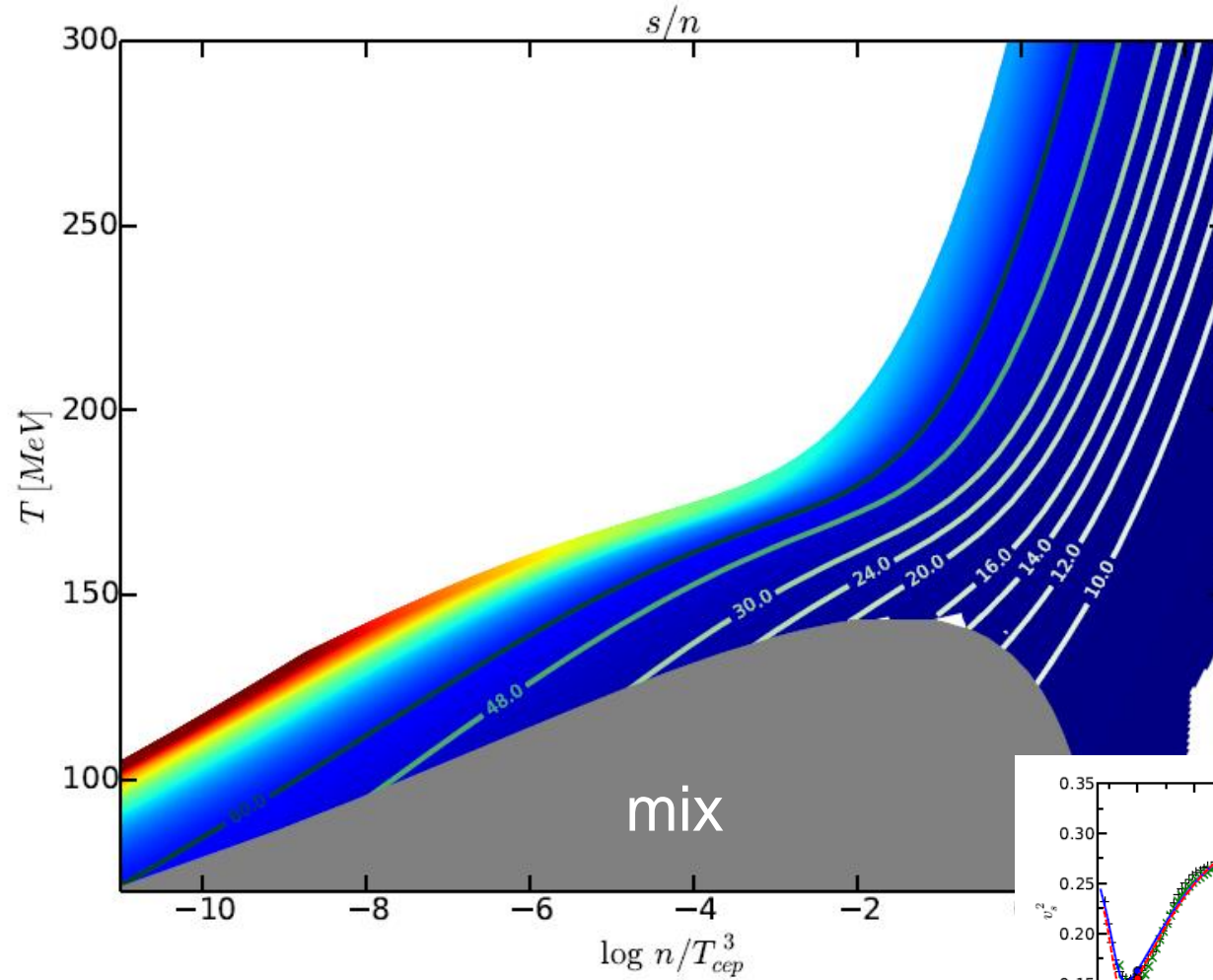
(ii) susceptibilities  $\rightarrow f(\phi)$

work in progress

# Holography a la Gubser et al.

# vdW a la Gorenstein et al.

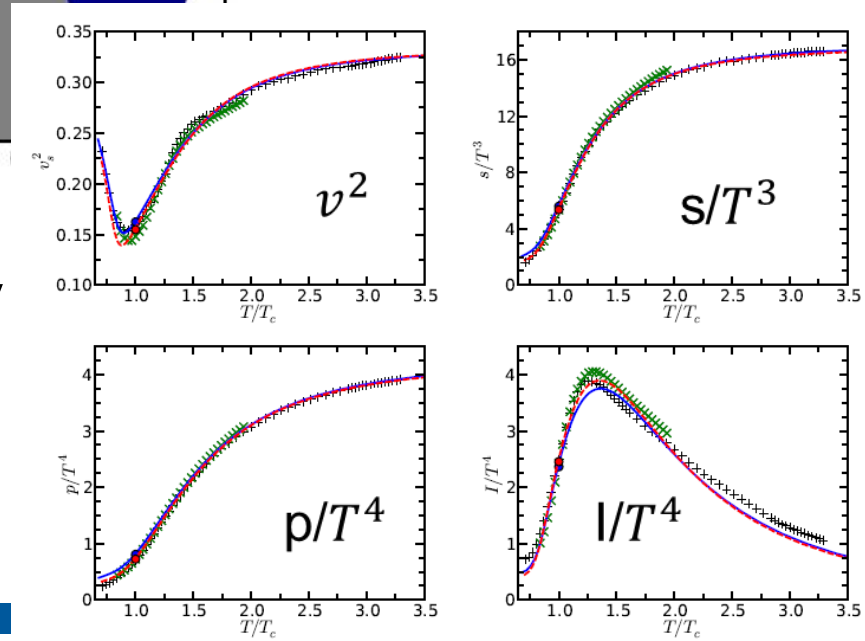




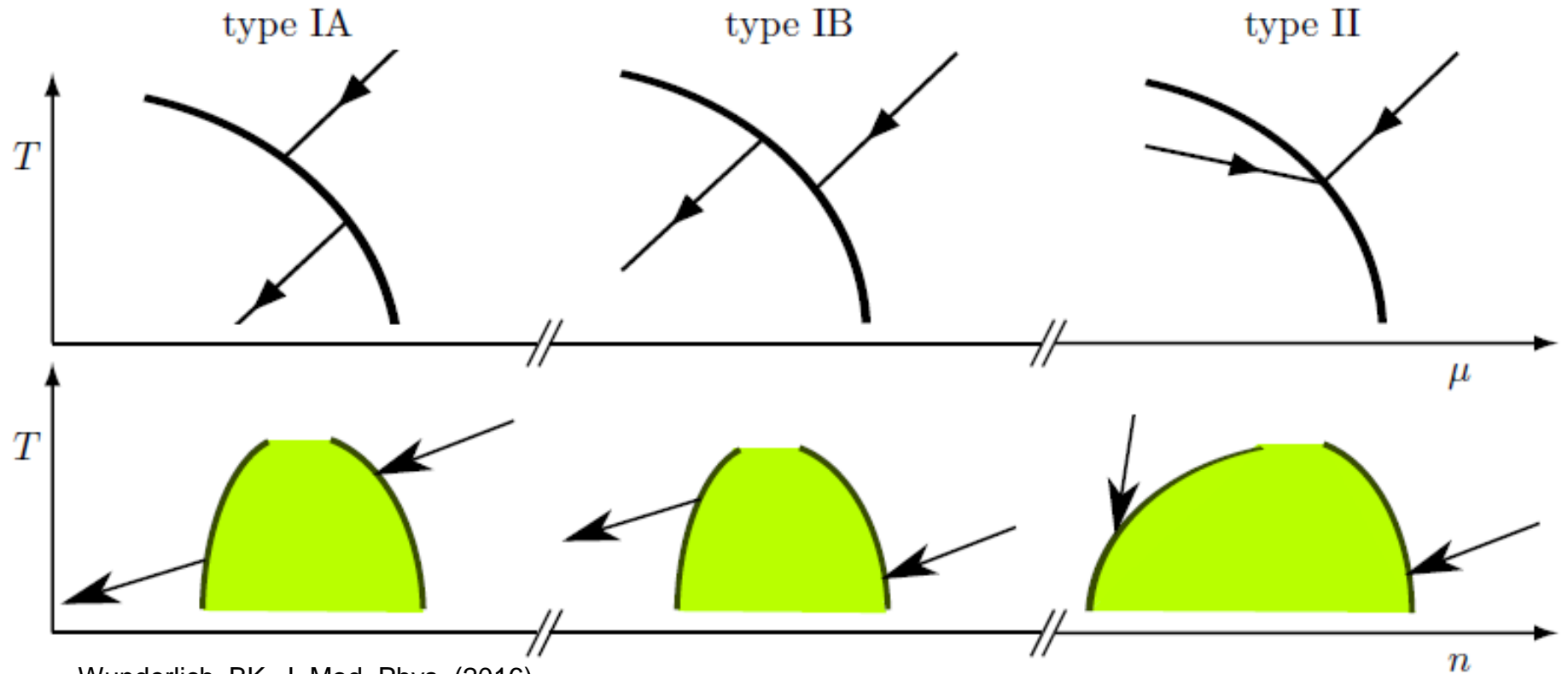
QCD input:  $N_f = 2+1$ , phys. q masses  
 Bazazov et al (2014), Borzanyi et al (2014)

surprize: incoming isentropes only  
 (as in vdW)

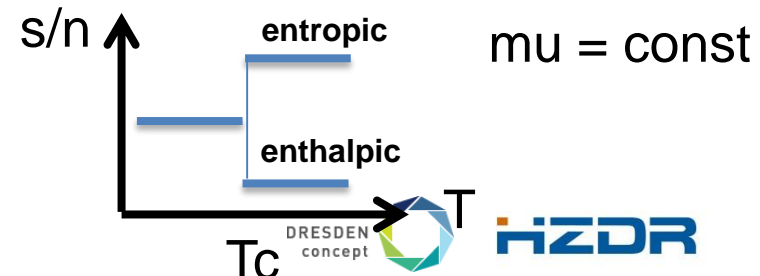
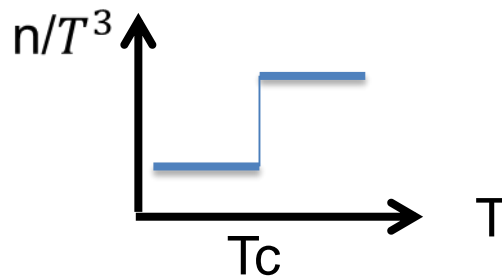
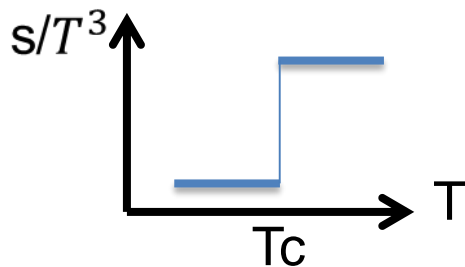
Steinheimer, Randrup, Koch, PRC (2014),  
 Steinheimer, Randrup, PRL (2012),  
 Hempel, Dexheimer, Schramm, Iosilevskiy, PRC (2013)  
 and others claim: deconfinement is accompanied by  
 dropping pressure on critical curve



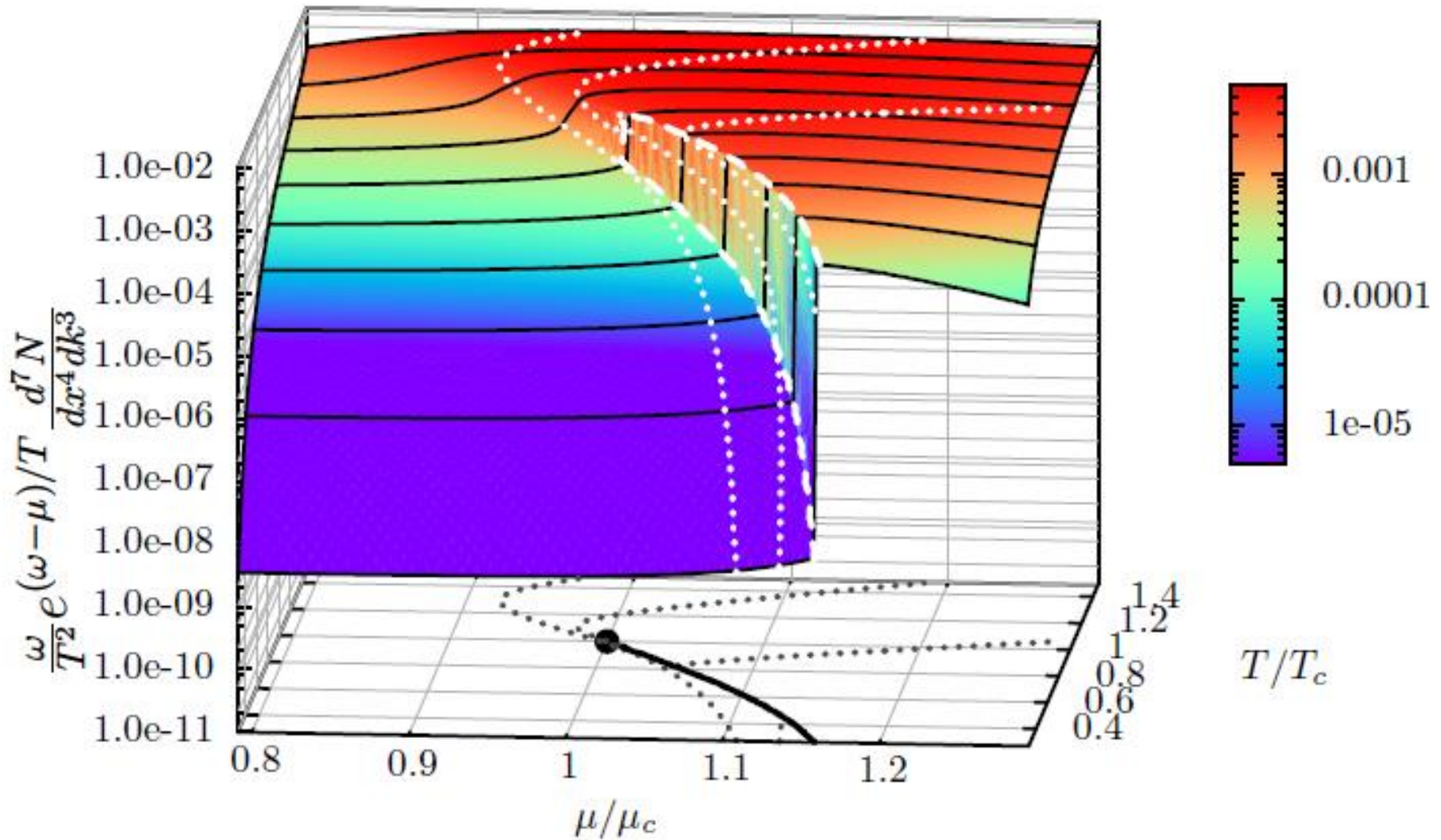
# Crossing the phase border line



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



aside: QM model,  $w = 1000 \text{ MeV}$ ,  $q + \pi \rightarrow q + \gamma$



# Summary

(i) 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  $T(\text{QCD})$
- loose contact to thermodynamics (ambient medium mimicked by dilation via ansatz)
- ? construction of a phase diagram

(ii) holographic phase diagram:

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

perspective: combine (i+) and (ii+)

best wishes to UWH

among friends



Tuscon 1996



den Rücken frei halten

avoid imbalance!





# Toy Models (i) CEP

$$s(T, \mu) = s_{\text{reg}}(T, \mu) + s_{\text{sing}}(T, \mu)$$

Bluhm, BK, PoS (2006)

based on Nonaka, Asakawa, PRC (2005)

based on Giuda, Zinn-Justin, NPB (1997)

3D Ising with proper crit. exps.

special construction

$G(r, h)$ : Gibbs free energy

$M(r, h)$ : magnetization

$h$ : external mag. field

$r = (T - T_c) / T_c$

$$G = h_0 M_0 R^{2-\alpha} g(\theta) - Mh$$

$$r = R(1 - \theta^2),$$

$$h = h_0 R^{\beta\delta} \sum_{i=0}^2 a_{2i+1} \theta^{2i+1},$$

$$\sum_{i=0}^2 a_{2i+1} \theta^{2i+1} (1 - \theta^2 + 2\beta\theta^2) = 2(2 - \alpha)\theta g(\theta) + (1 - \theta^2)g'(\theta)$$

