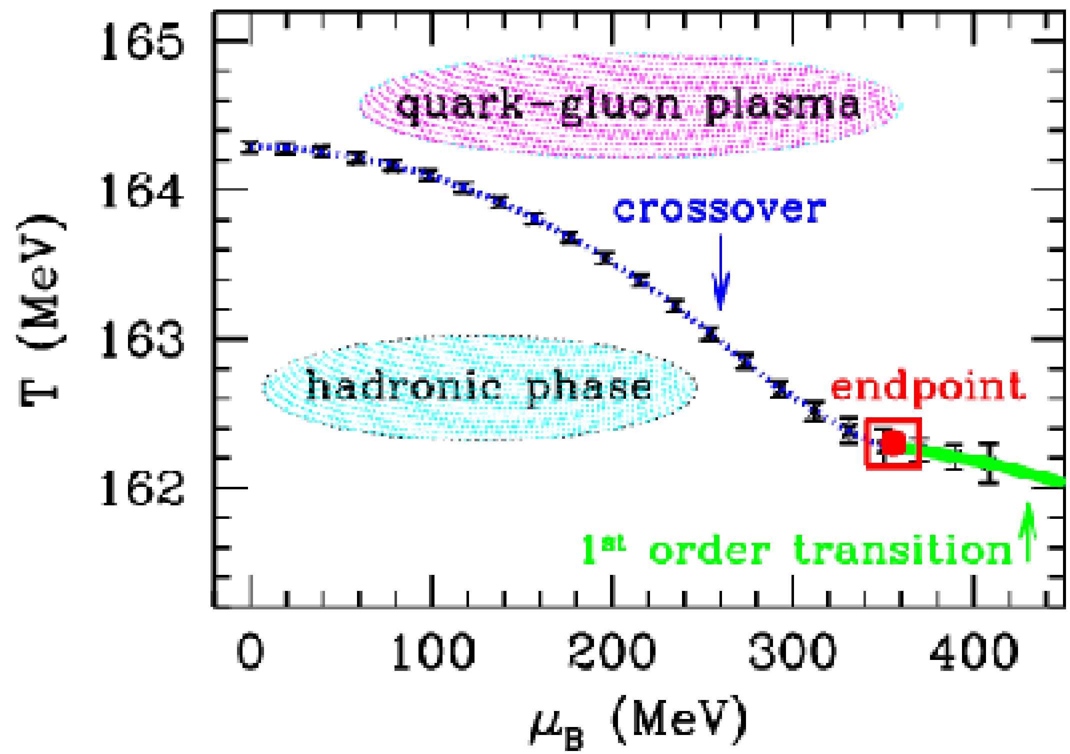
Chiral Hydrodynamics

Adrian Dumitru, Goethe Univ., Frankfurt

in collab. with Kerstin Paech

- Critical Fluct. at endpoint ?
- Change in bulk dynamics left/right of endpoint ?



Fodor, Katz, JHEP '04

Large N: $SU(N) \to U(N)$

$$V_{gl}(\ell) \sim m^2 \ell\ell^* + \ldots$$

$$V_{qk}(\ell) \sim h(e^{\mu}\ell + e^{-\mu}\ell^*)$$

$\ell = (1/N)\,\mathrm{tr}\, L$: Polyakov loop

$$Z = \int dL \exp[-V_{gl}(\ell) - V_{qk}(\ell,\mu)]$$

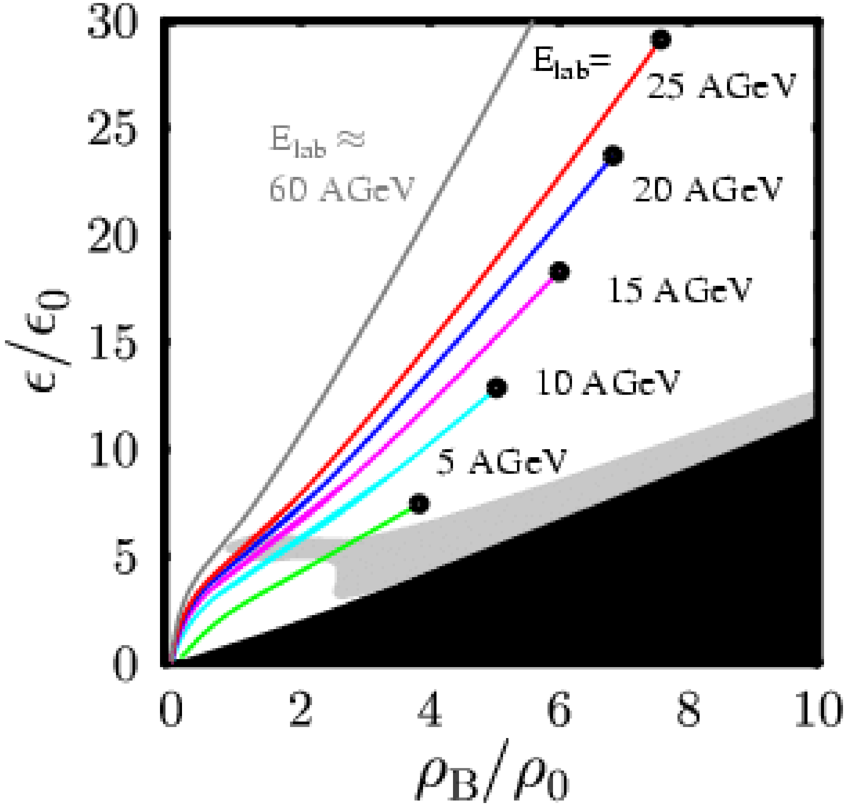
$$\to \int dL \exp[-V_{gl}(\ell) - V_{qk}(\ell,\mu=0)]$$

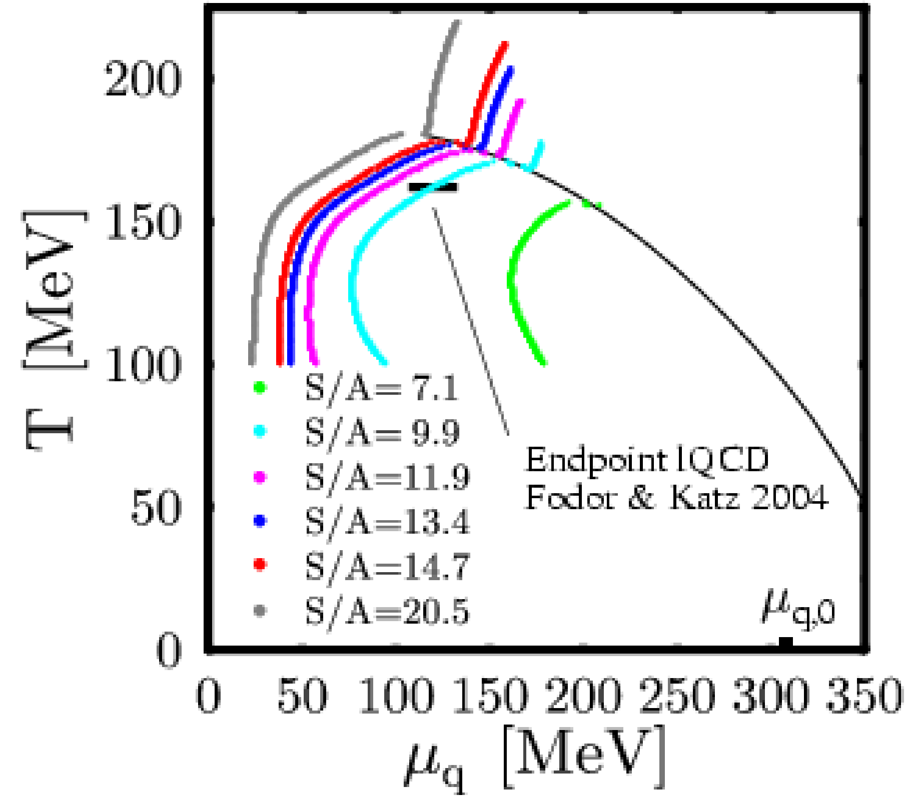
μ-effects are $O(1/N)$:

T_c depends weakly on μ

Zschiesche, Pisarski, A.D.
hep-ph/0505256

Zeeb, Zschiesche, Schramm '05

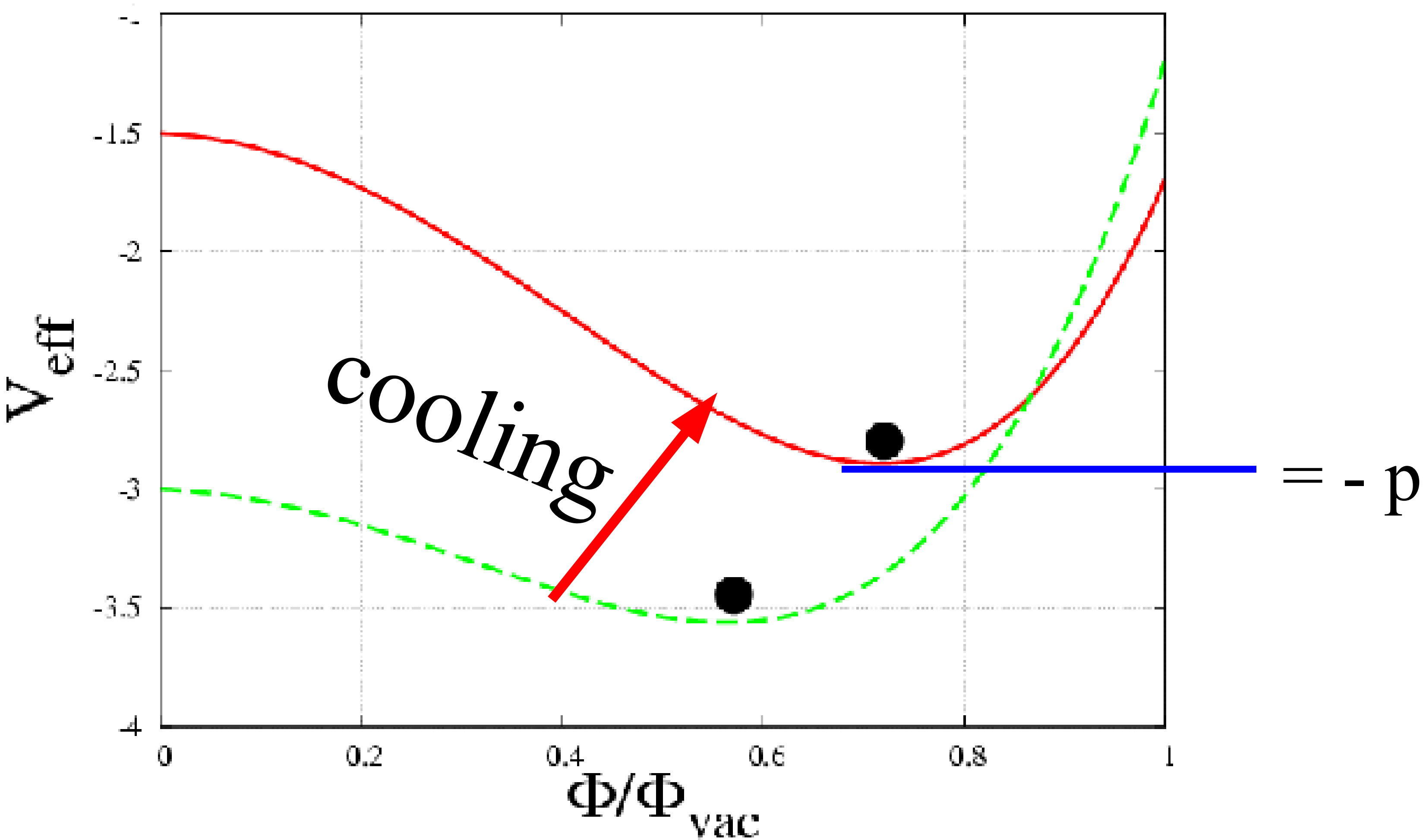




★ How does the transition to the broken state happen ?

→ real-time dynamics of order parameter

Cross over

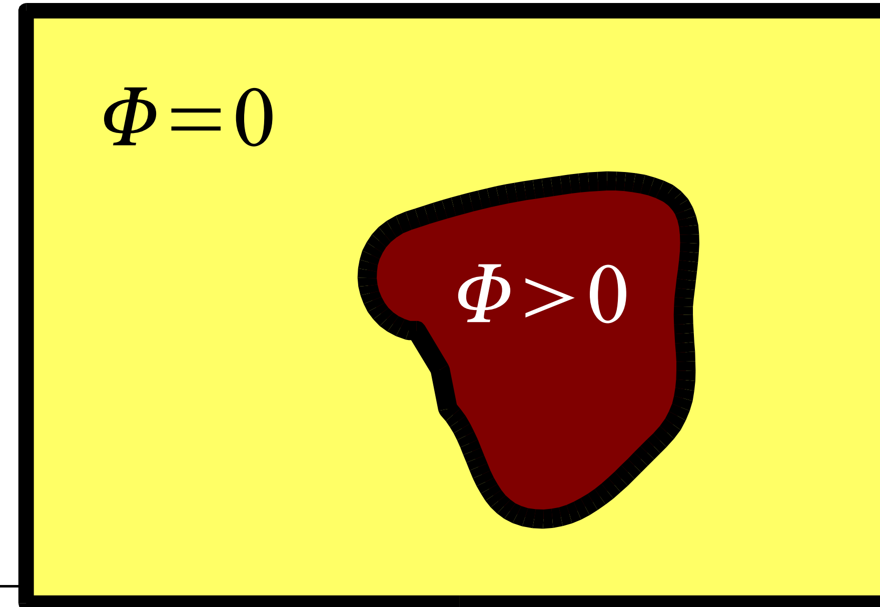


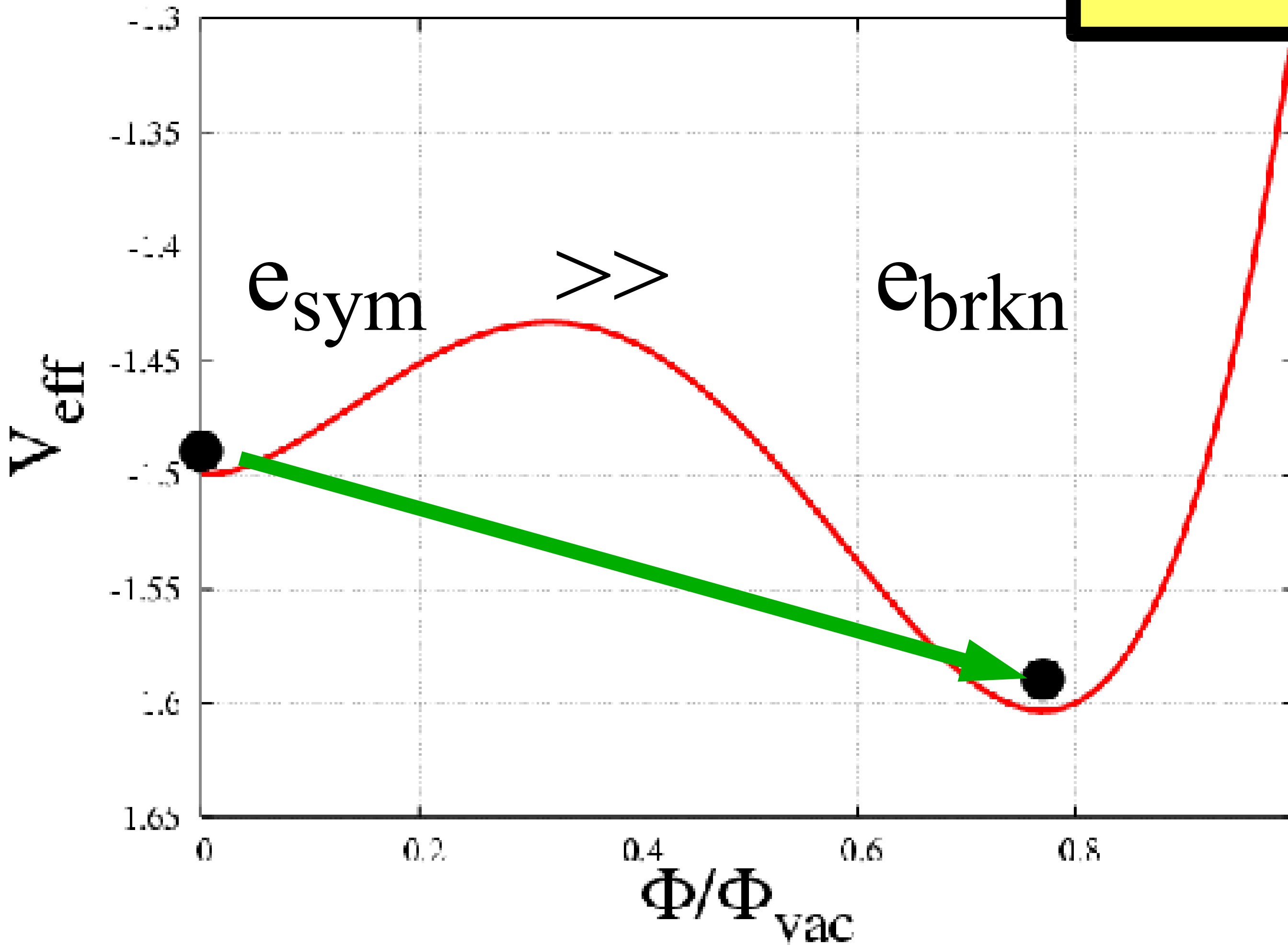
- e varies smoothly with Φ

→ expect relatively homogeneous system

Thermal 1st-O transition

→ produce inhomogeneities !





Gell-Mann Levy Model

$$L=\bar{\Psi}\left[i\partial_\mu\gamma^\mu-g(\sigma+i\gamma_5\vec{\tau}\vec{\pi})\right]\Psi+\frac{1}{2}(\partial_\mu\Phi)^2-U(\Phi)$$

$$U(\Phi)=\frac{\lambda}{4}(\Phi^2-v^2)^2-h\Phi_0$$

tilted “Mexican hat” vacuum potential

$\Phi^a=(\sigma,\vec{\pi})$ O(4) chiral vector

T, μ >0 : q's constitute thermalized fluid: integrate out the quarks (1 loop)

$$V_{eff}=U(\Phi)+V_T(\Phi)$$

$$V_T(\Phi)=T\nu_q\int\frac{d^3p}{(2\pi)^3}\;\log\left(1+e^{-\frac{E+\mu}{T}}\right)+\log\left(1+e^{-\frac{E-\mu}{T}}\right)$$

EoM: $$\partial_\mu \partial^\mu \Phi^a + \frac{\delta V_{eff}}{\delta \Phi^a} = 0$$

$$\partial_\mu (T^{\mu\nu}_{fl} + T^{\mu\nu}_{\Phi}) = 0 \quad , \quad \partial_\mu (\rho u^\mu) = 0$$

ideal fluid of quarks: $T^{\mu\nu}_{fl} = (e+p) u^\mu u^\nu - p g^{\mu\nu}$

one-loop $\rightarrow$ ideal gas of massive q's, $m_q = \sqrt{g^2 \Phi^2}$

$p = p(e, \rho, \Phi)$

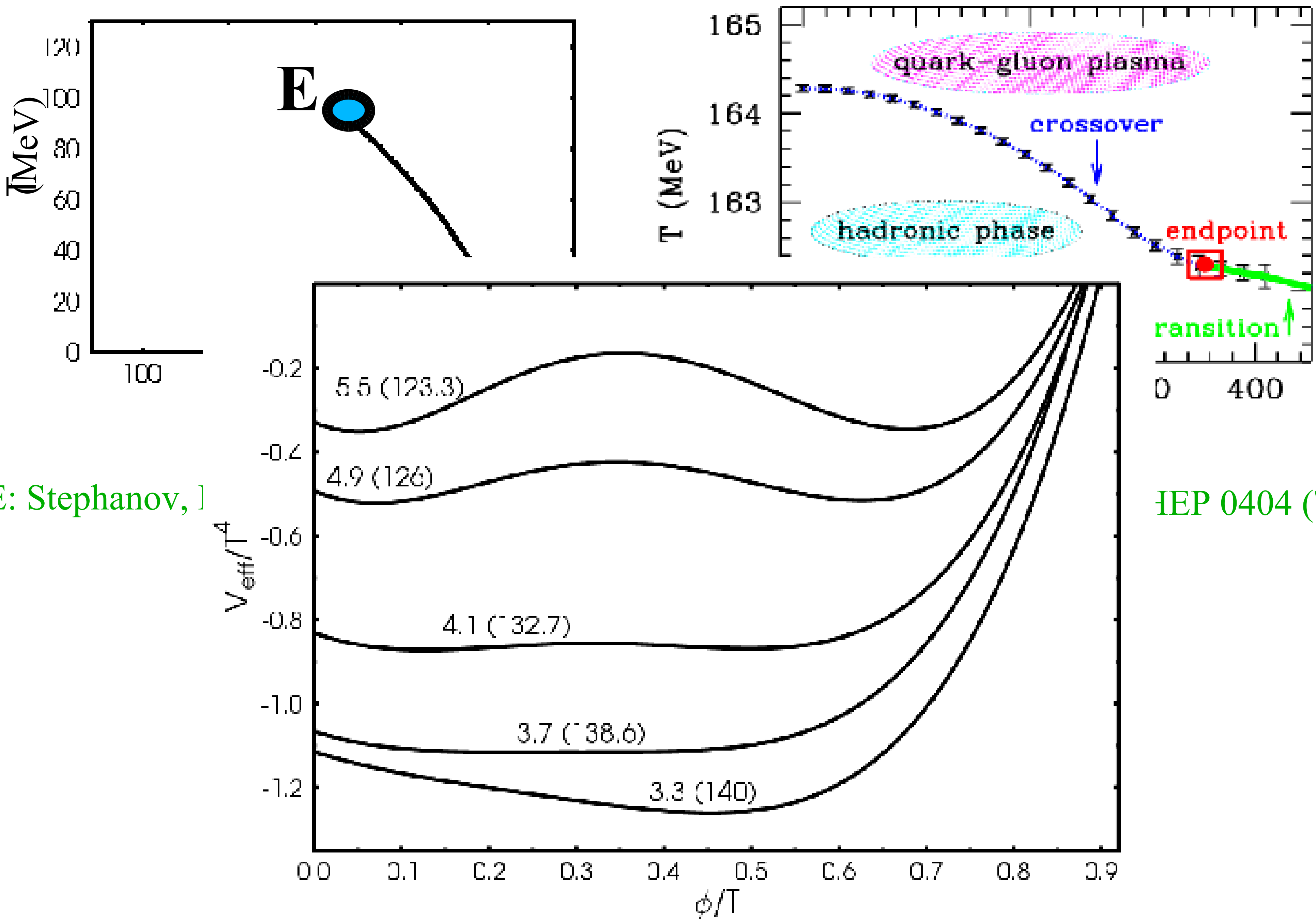
in equilibr. $\Phi = \Phi_0(T,\mu)$ is the minimum of $V_{eff}(T,\mu)$

Scavenius, Mishustin, '97, '98; D.T. Son, '00;

3D solution with classical order parameter fluctuations:

Kerstin Paech, PhD, Frankfurt Univ., '01-'05

The phase diagram for $m_{q,vac} \approx 310$ MeV

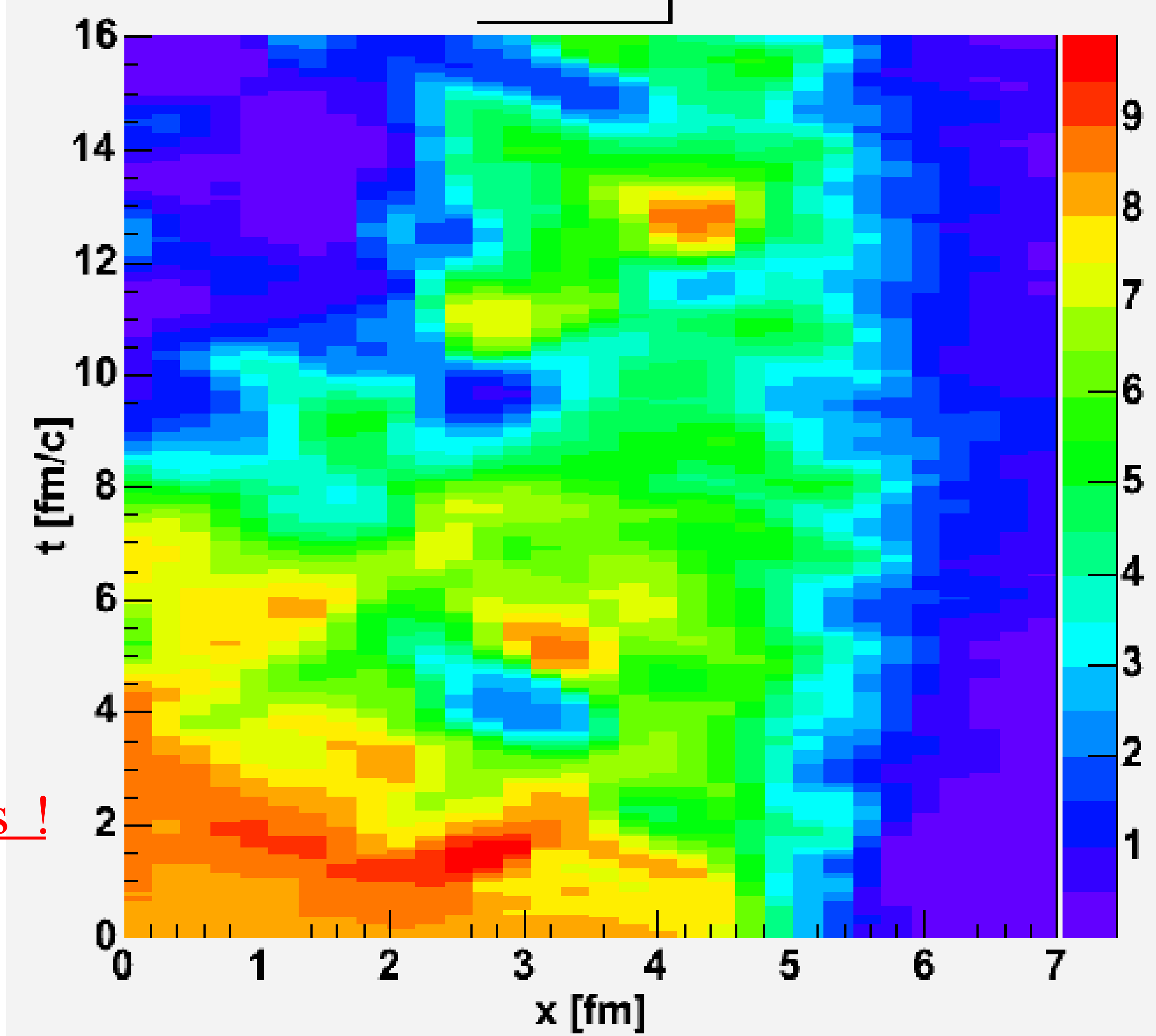


E: Stephanov, I

HEP 0404 ('04)

First-order transition, computed dynamically

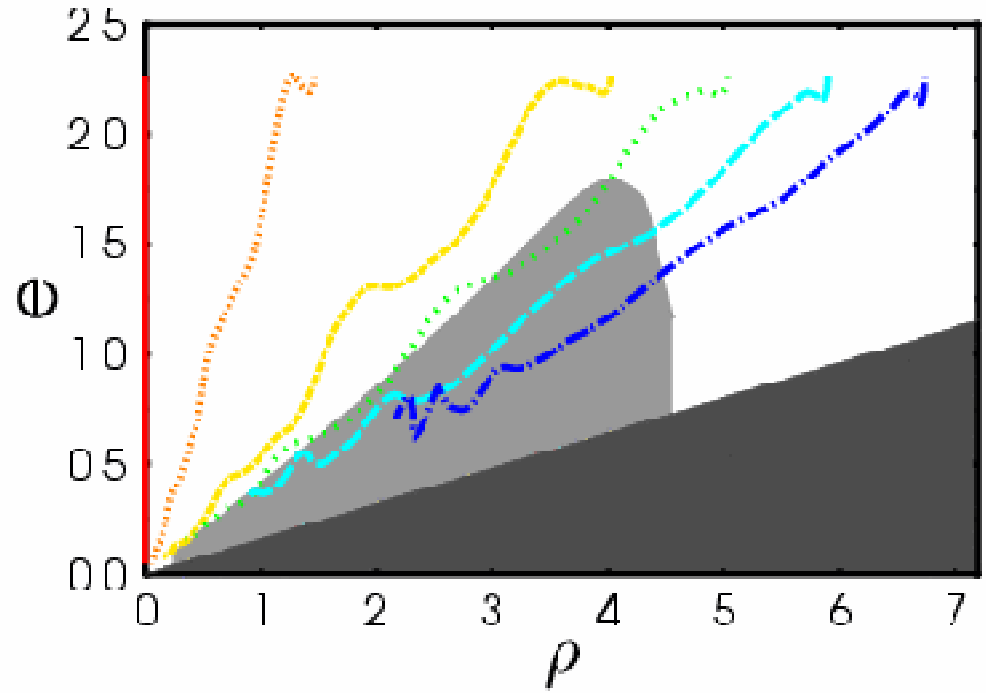
Energy density distribution

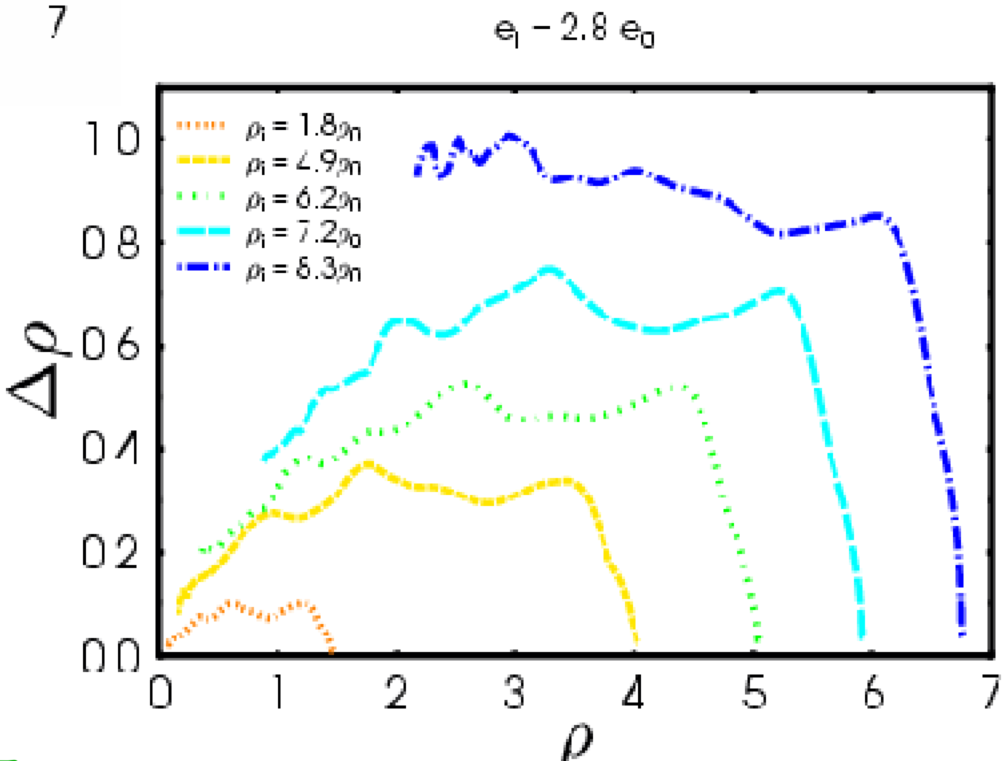


- ⋆ Hot & Dense Spots
- ⋆ Voids ...

→ lst-O transitions lead to inhomogeneities !

K. Paech, H. Stöcker, AD: PRC 68 (2003)



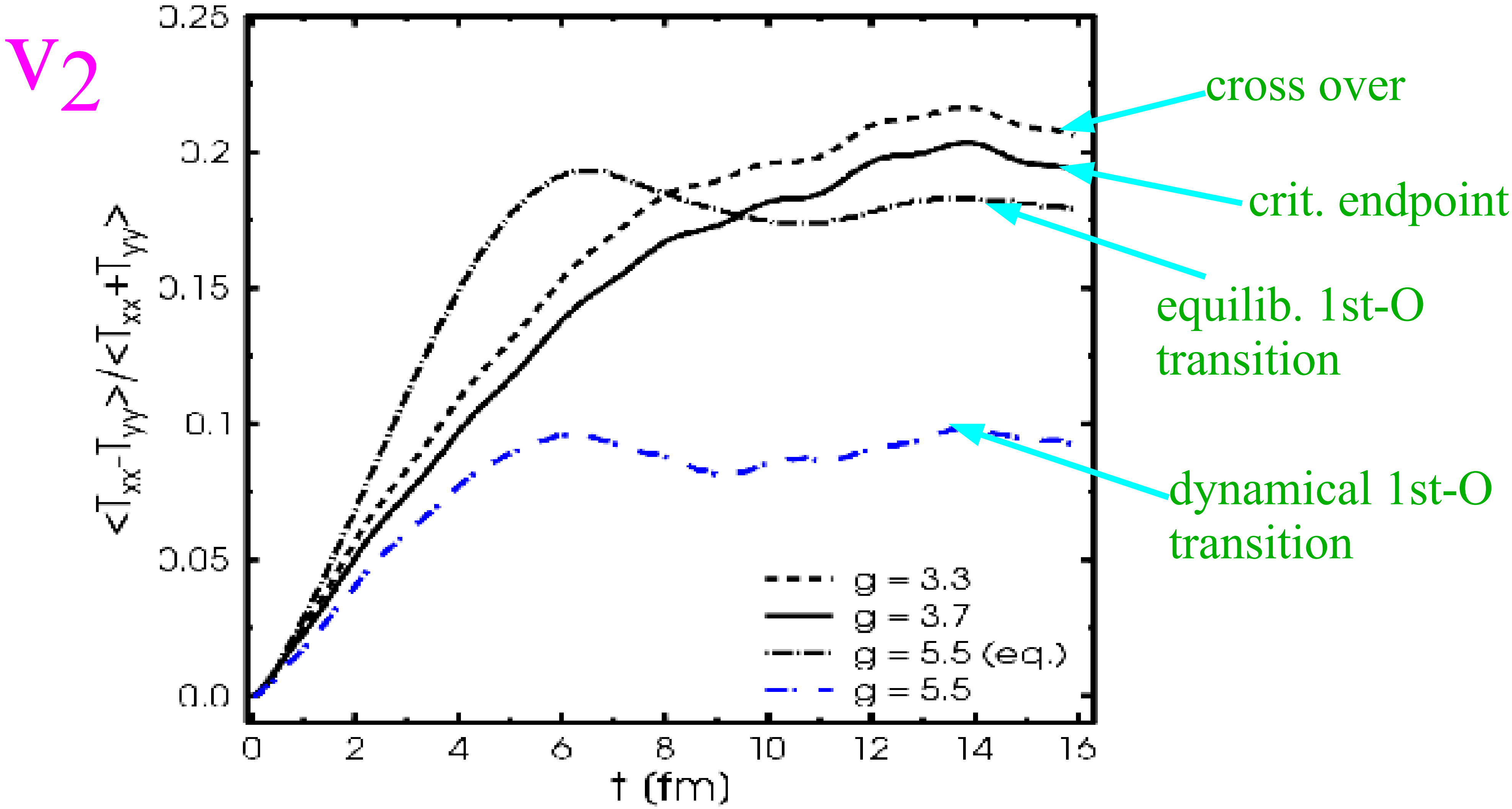


Kerstin Paech, PLB '05

Observables
for CBM @ FAIR ?

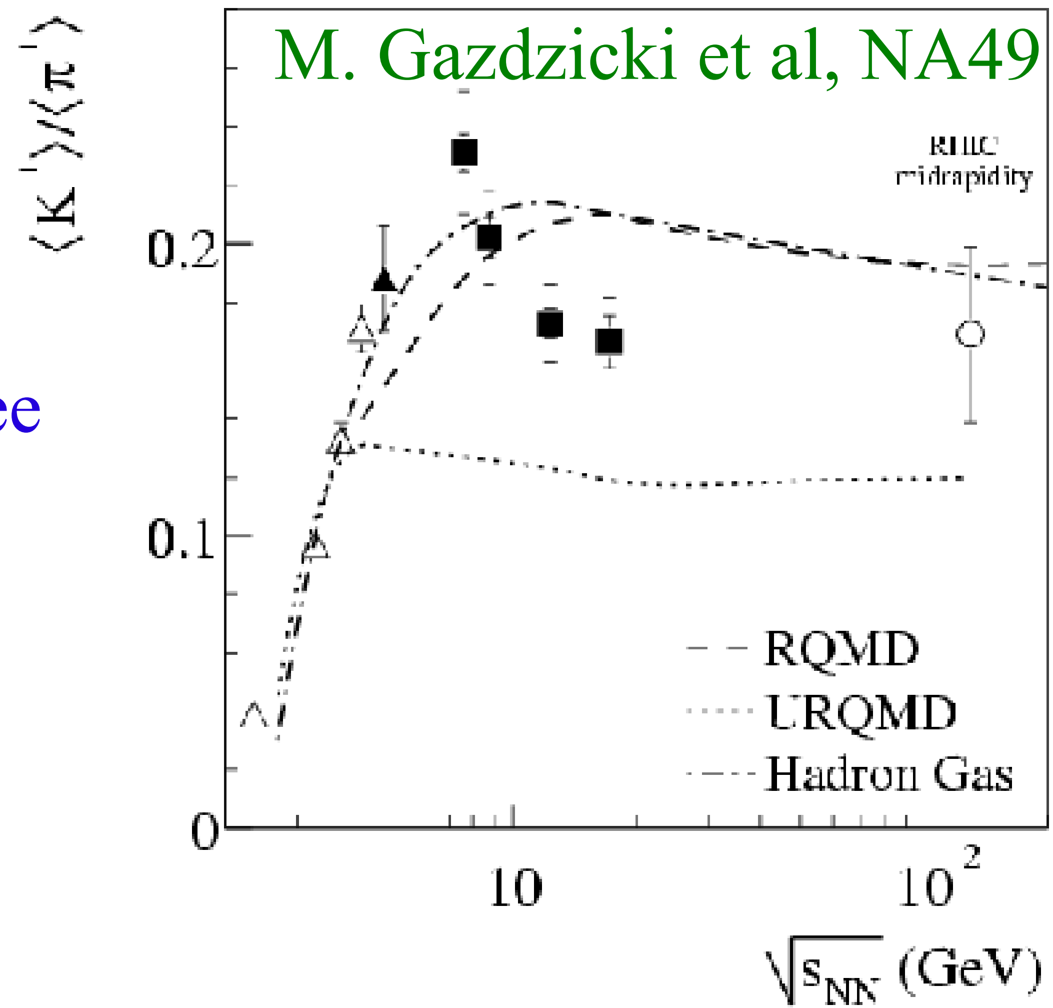
Flow must be affected

Geometry of field fluctuations
uncorrelated to reaction plane



Density Perturbations on the f.o. surface might reflect in hadron "chemistry" !

for example, K+/π+ @ SPS is not reproduced well by homog. hadron gas:



even though T, μ are free fit parameters !

⋆ inhomog. f.o. surface, simple model:

L. Portugal, D. Zschiesche + A.D., '05

take T, μ as Gaussian random variables,

$$P[T] \sim \exp -\frac{(T-\bar{T})^2}{2\,\delta T^2} \qquad P[\mu] \sim \exp -\frac{(\mu-\bar{\mu})^2}{2\,\delta\mu^2}$$

This is the distribution on the f.o. surface in <u>each</u> event!
Do not confuse with EbyE fluctuations !
<u>(If # of "domains" is large, EbyE flucs → 0)</u>

$$N_i = Vol_3 \times \bar{\rho}_i(\bar{T},\bar{\mu},\delta T,\delta\mu)$$

$$\bar{\rho}_i(\bar{T},\bar{\mu},\delta T,\delta\mu) = \int dT\,P[T]\int d\mu\,P[\mu]\;\rho_i(T,\mu)$$

$$\neq \rho_i(\bar{T},\bar{\mu}) \quad \textbf{!}$$

<u>Also check coalescence of nuclei: d, t, α !</u>

Summary

- Real-Time dynamics of 1st-O transition needs to be studied
- Aside from critical fluctuations, changes in bulk evolution may also reflect the crossing of E
- Relatively clean experim. observables
  - Flow
  - Inhomog. predicted for 1st-O, affects flow (v_i), hadron ratios etc

Theory/Modeling permits lots of improvement, examples:

- More realistic EoS/endpoint: include more hadrons
- Quantitative initial conditions from 3-fluid hydro or hadron transport models
- Freeze-out
- Integrate out “hard” field flucs also to 1-loop
- …