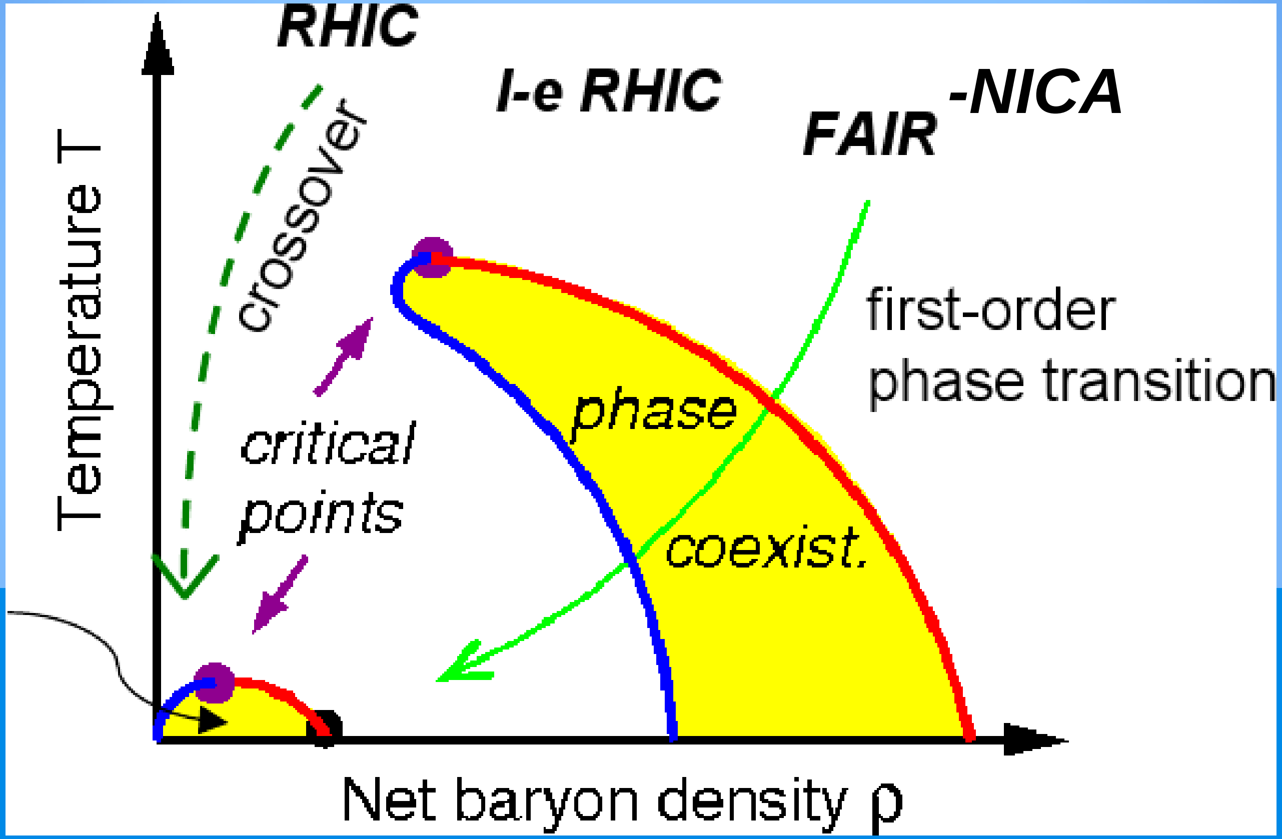
Lecture 5: Some examples of experimental data analysis

I. Mishustin
Frankfurt Institute for Advanced Studies

Expected phase diagram of strongly-interacting matter



Such a phase diagram is still a beautiful dream! We hope that future FAIR-NICA experiments will help to establish what is the reality.

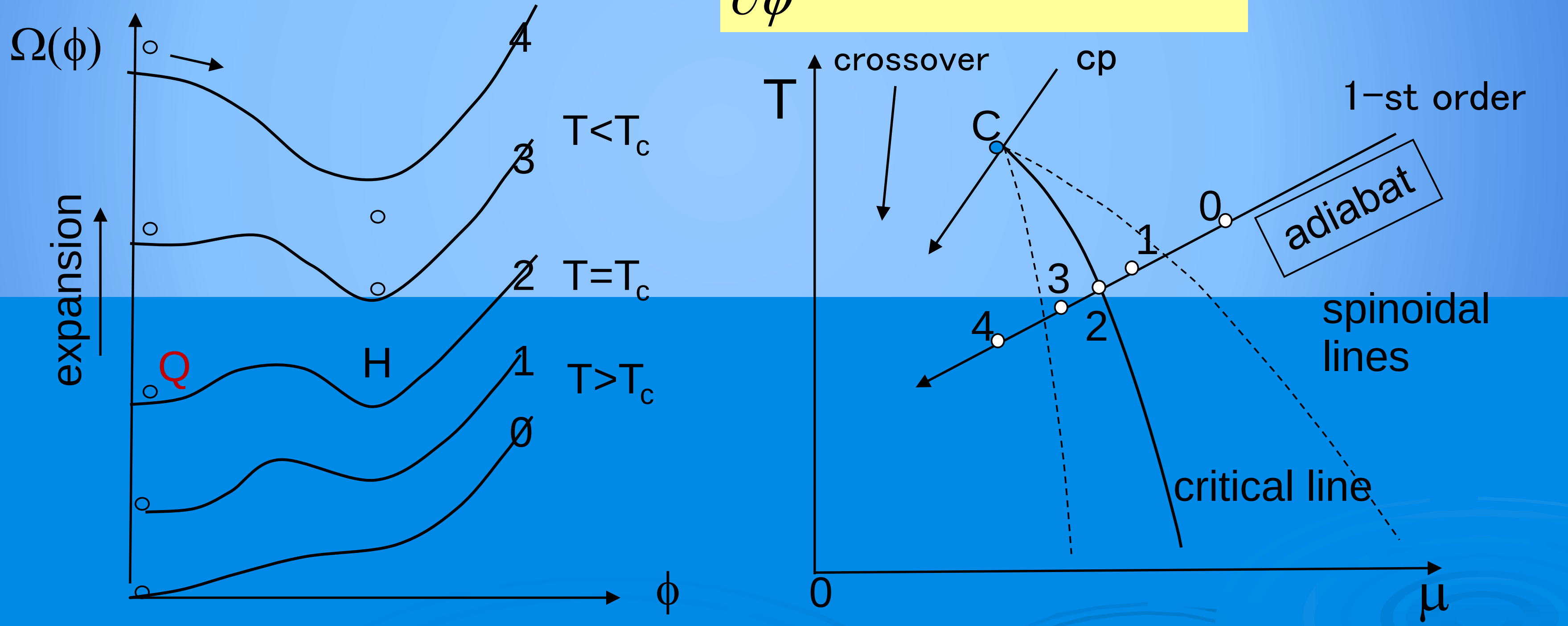
Effects of fast dynamics

Effective thermodynamic potential for a 1st order transition

$$\Omega(\phi;T,\mu) = \Omega_0(T,\mu) + \frac{a}{2}\phi^2 + \frac{b}{4}\phi^4 + \frac{c}{6}\phi^6$$

a,b,c are functions of T and μ

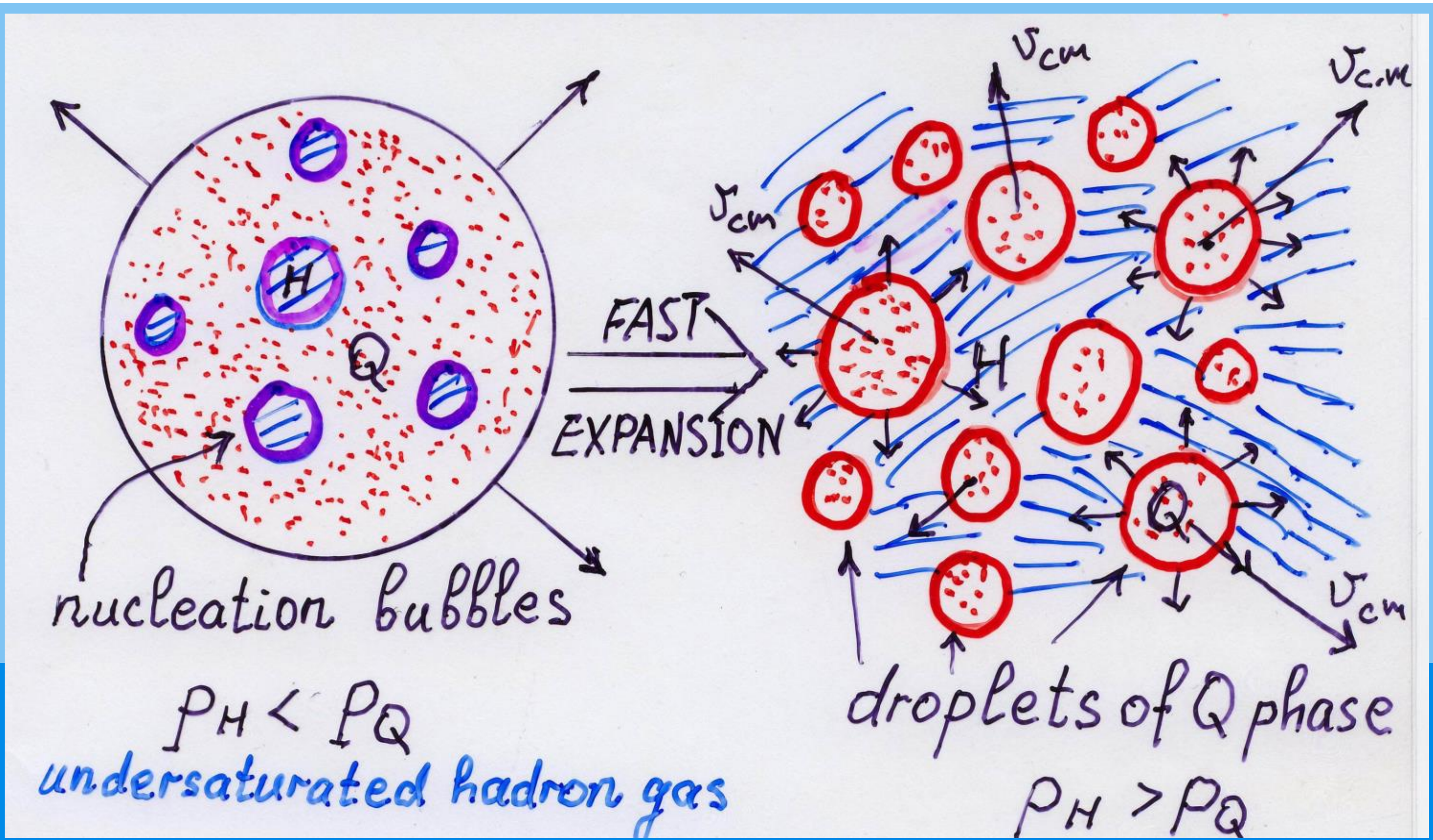
Equilibrium ϕ is determined by $\frac{\partial \Omega}{\partial \phi} = 0 \Rightarrow P = -\Omega(\phi_{eq})$



In rapidly expanding system 1-st order transition is delayed until the barrier between two competing phases disappears - spinodal decomposition

I. Mishustin, Phys. Rev. Lett. 82 (1999) 4779; Nucl. Phys. A681 (2001) 56

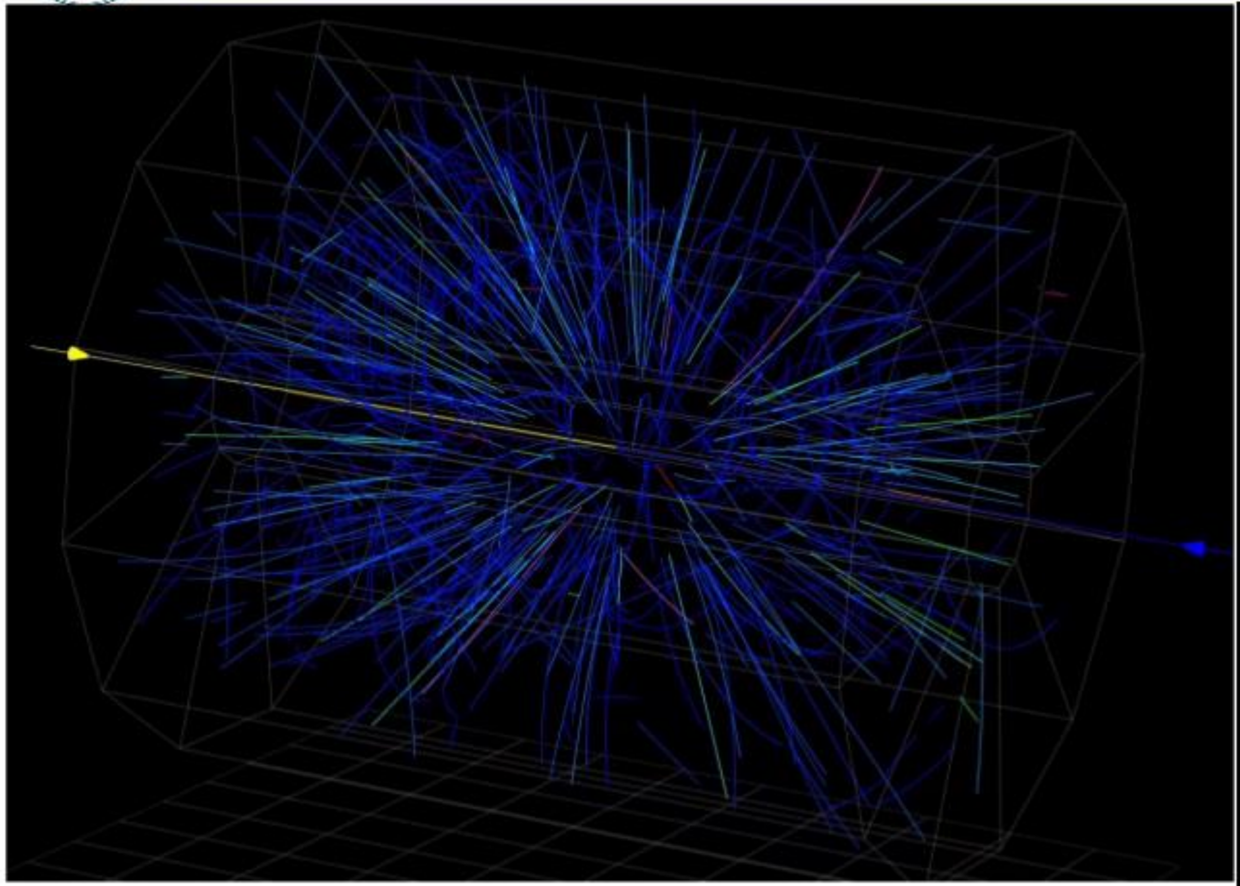
Rapid expansion through a 1st order phase transition

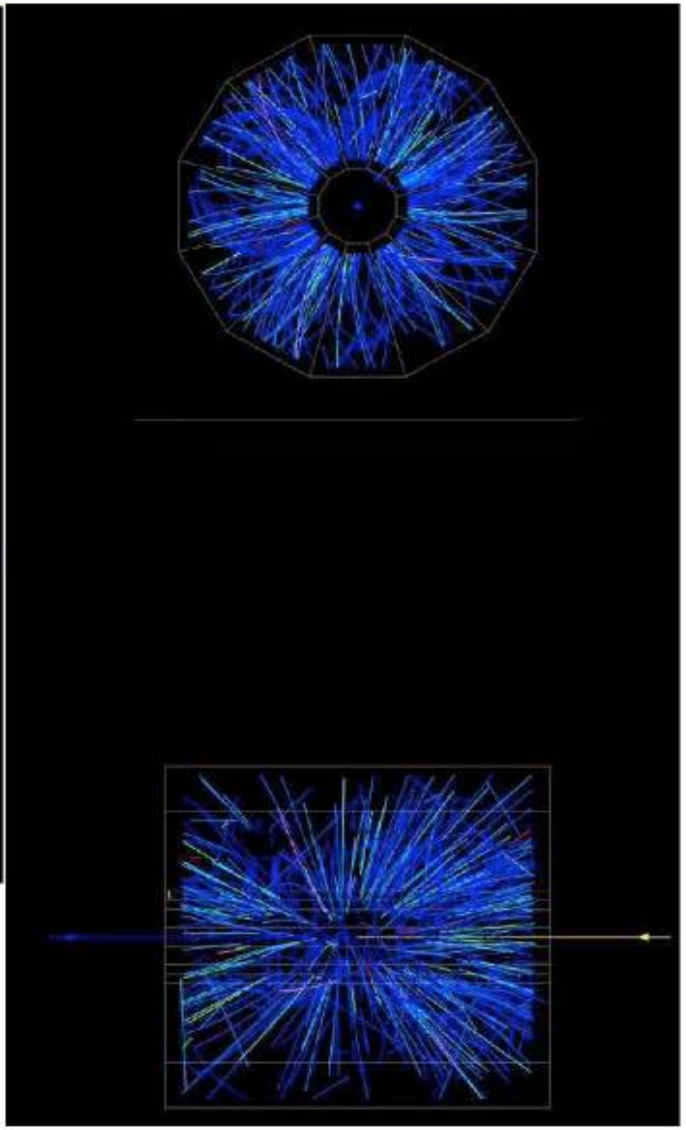


The system is trapped in a metastable state until it enters the spinodal instability region, when Q phase becomes unstable and splits into droplets

Csernai&Mishustin, 1995; Mishustin, 1999; Rafelski et al. 2000; Randrup, 2003; Peach&Stoecker, 2003; Stephanov, 2005, 2009; Steinheimer&Randrup 2013; Nahrgang, Herold, Mishustin, Bleicher, 2013-p.t.; Liang, Li, Song, 2016-p.t.. …

3D Event Display at STAR

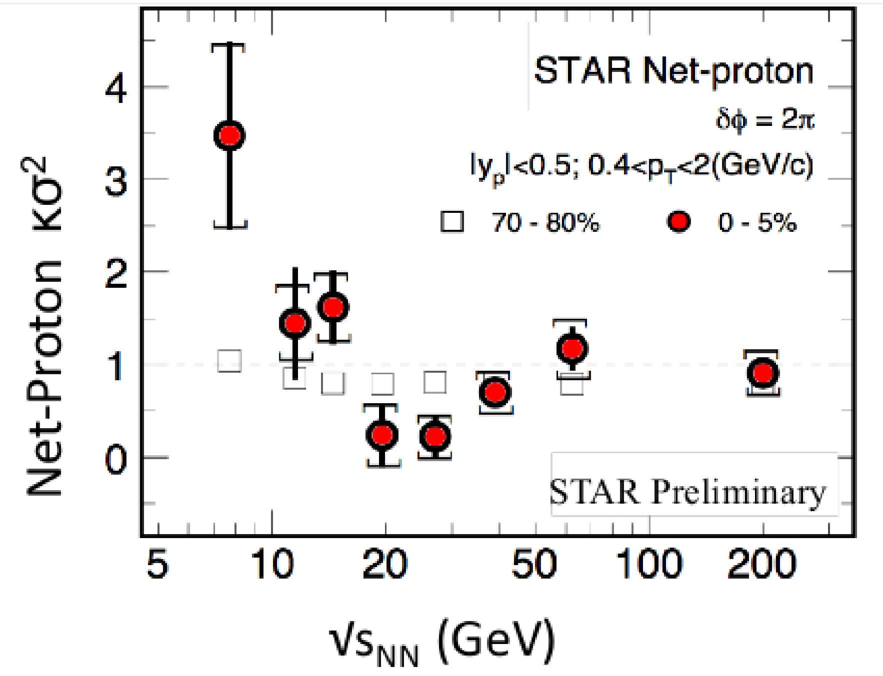




BES-II, Au+Au collisions at 19.6 GeV.

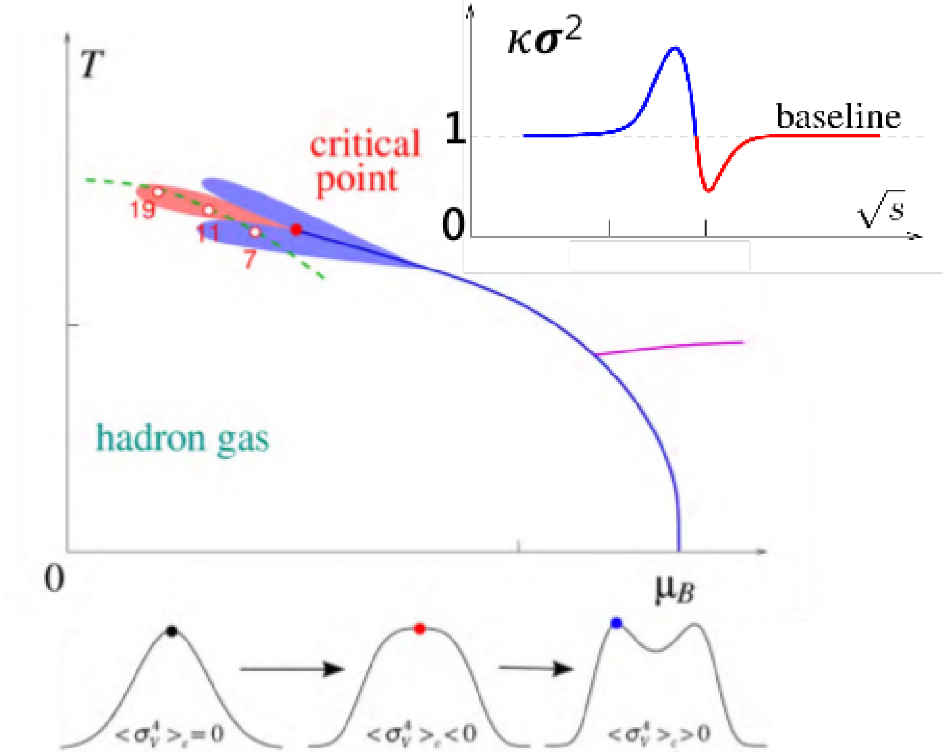
Net-Proton Fluctuations

Experimental Measure



STAR: Phys. Rev. Lett. 105, 022302 (2010).
Phys. Rev. Lett. 112, 032302 (2014).
PoS CPOD2014 (2015) 019.

Theoretical calculations



M. Stephanov, PRL107, 052301(2011)
J. Phys. G: 38, 124147 (2011).

- First observation of the non-monotonic energy dependence of fourth order net-proton fluctuations. Hint of entering Critical Region ?

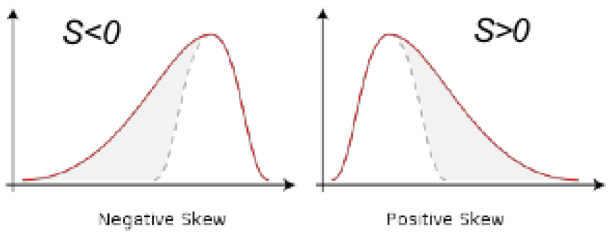
Higher Moments of Conserved Quantities (B, Q, S)

1. Higher order cumulants/moments: describe the shape of distributions and quantify fluctuations. (sensitive to the correlation length (ξ))

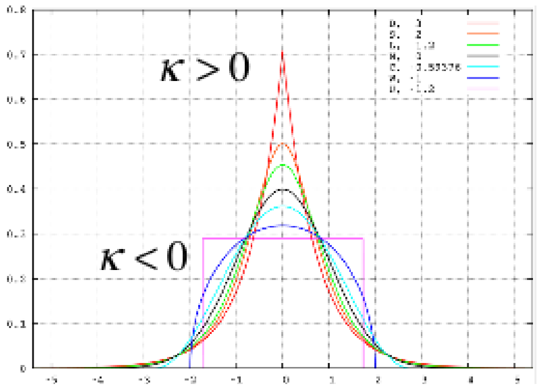
$$< \delta N >= N - < N >$$
$$C_1 = M =< N >$$
$$C_2 = \sigma^2 =< (\delta N)^2 >$$
$$C_3 = S\sigma^3 =< (\delta N)^3 >$$
$$C_4 = \kappa\sigma^4 =< (\delta N)^4 > -3 < (\delta N)^2 >^2$$

$$\left\langle (\delta N)^3 \right\rangle_c \approx \xi^{4.5}, \quad \left\langle (\delta N)^4 \right\rangle_c \approx \xi^7$$

Skewness (S) → asymmetry



Kurtosis (κ) → Sharpness



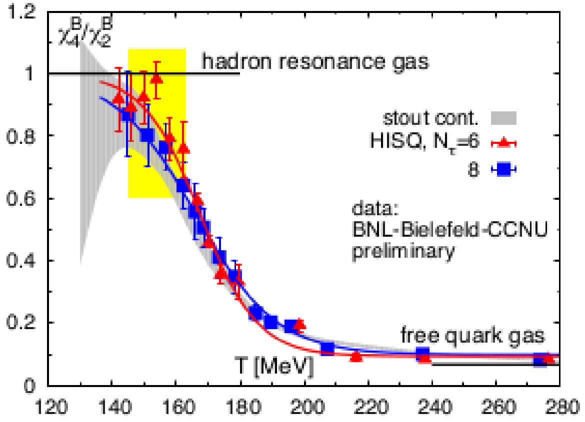
M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009); 107, 052301 (2011).
M.Asakawa, S. Ejiri and M. Kitazawa, Phys. Rev. Lett. 103, 262301 (2009).

2. Direct connect to the susceptibility of the system.

$$\frac{\chi_q^4}{\chi_q^2} = \kappa\sigma^2 = \frac{C_{4,q}}{C_{2,q}} \qquad \frac{\chi_q^3}{\chi_q^2} = S\sigma = \frac{C_{3,q}}{C_{2,q}},$$

$$\chi_q^{(n)} = \frac{1}{VT^3} \times C_{n,q} = \frac{\partial^n (p/T \wedge 4)}{\partial(\mu_q)^n}, q = B,Q,S$$

S. Ejiri et al,Phys.Lett. B 633 (2006) 275. Cheng et al, PRD (2009) 074505. B. Friman et al., EPJC 71 (2011) 1694. F. Karsch and K. Redlich , PLB 695, 136 (2011).S. Gupta, et al., Science, 332, 1525(2012). A. Bazavov et al., PRL109, 192302(12) // S. Borsanyi et al., PRL111, 062005(13)



Conclusions

- Phase transitions in relativistic heavy-ion collisions will most likely proceed out of equilibrium
- 2nd order phase transition (with CEP) is too weak to produce significant observable effects in fast dynamics
- Non-equilibrium effects in a1st order p.t. (spinodal decomposition, dynamical domain formation) may help to identify the chiral/deconfinement phase transition
- If QGP domains (droplets) survive until the freeze-out stage, they will show up by large non-statistical fluctuations of hadron multiplicities in phase space (in single events)
- Exotic objects like strangelets have a better chance to be formed in such a non-equilibrium scenario