Quark Matter 2005

18th International Conference on Nucleus-Nucleus Collisions

August 4-9, Budapest, Hungary

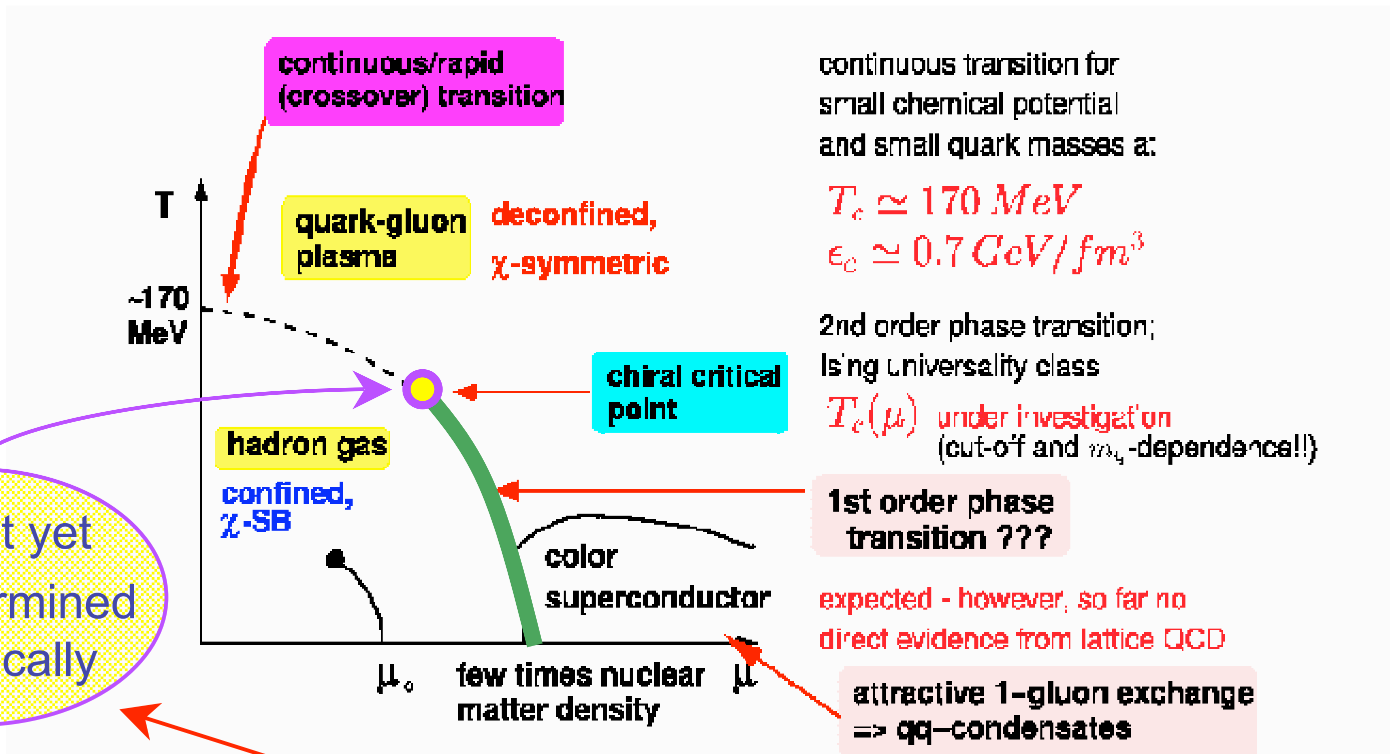
Strangeness trapping

Jørgen Randrup, Volker Koch, and Abhijit Majumder

Lawrence Berkeley National Laboratory

Phase diagram of strongly interacting matter

Expectations from lattice gauge calculations:

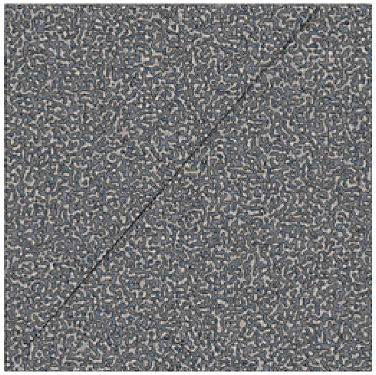


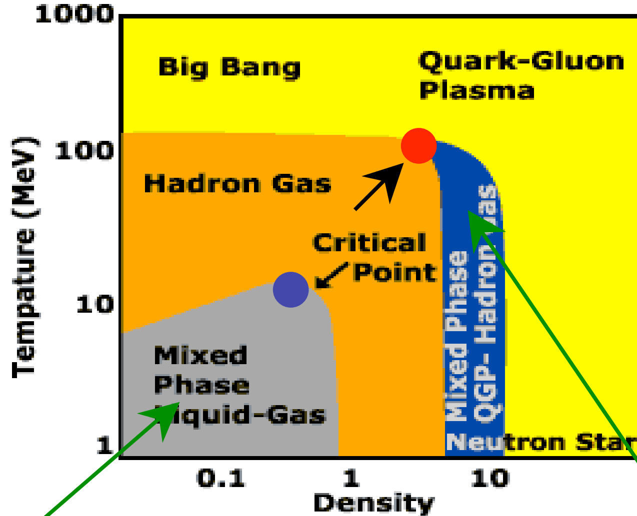
[Karsch: QM'04]

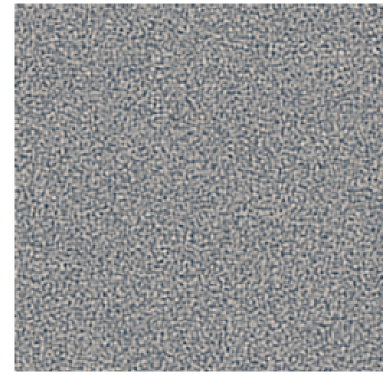
μ_c is not yet well determined theoretically

… an *experimental* question!

First-order phase transitions

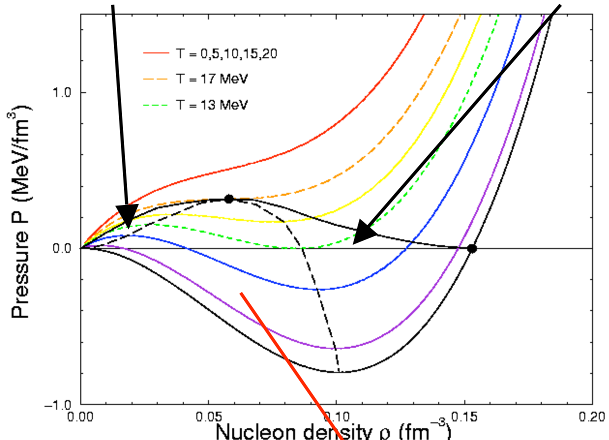






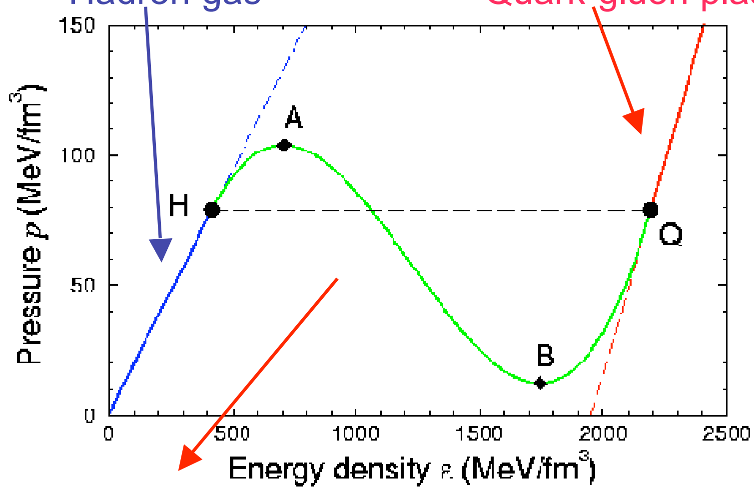
Nucleon gas

Nuclear liquid



Hadron gas

Quark-gluon plasma



Spinodal decomposition!

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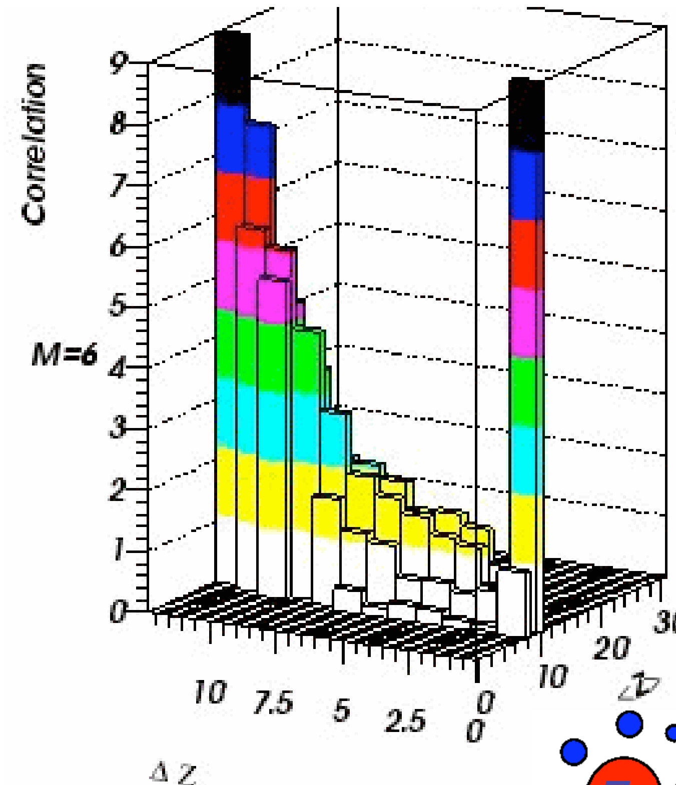
Ph. Chomaz, M. Colonna, J. Randrup
Physics Reports 389 (2004) 263

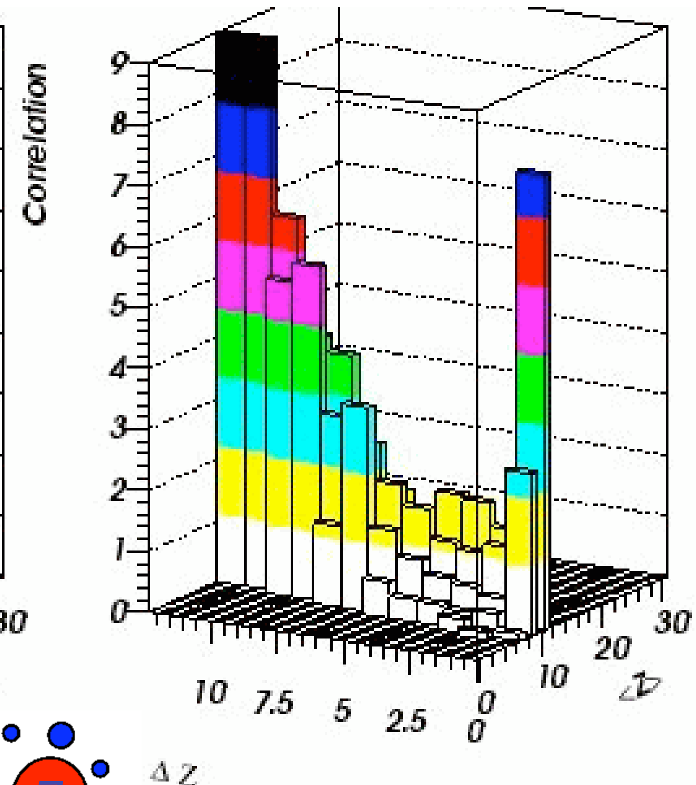
occurs!

Spinodal decomposition in nuclear multifragmentation

Experiment (*INDRA @ GANIL*)



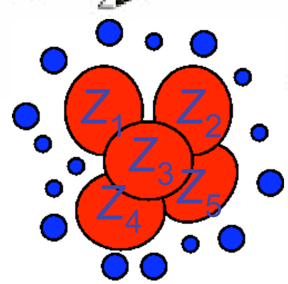
Theory (*BOB ≈ BL*)



32 MeV/A Xe + Sn (b=0)

(events with *M* IMFs)

B. Borderie *et al*, PRL 86 (2001) 3252



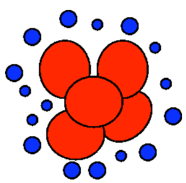
$\langle Z \rangle$: average IMF charge

ΔZ : dispersion in IMF charge

$$(\Delta Z)^2 = \langle Z^2 \rangle - \langle Z \rangle^2$$

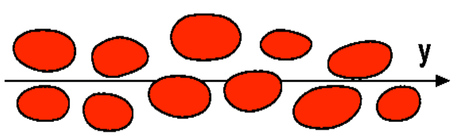
Spinodal decomposition in strongly interacting matter

1) Spinodal decomposition in dilute nuclear matter ✓



Nuclear liquid-gas phase transition

2) Spinodal decomposition in the expanding QGP **?**



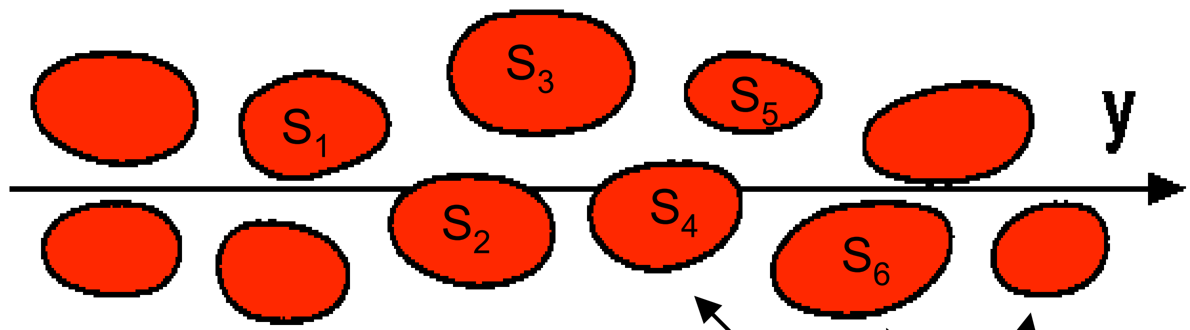
Hadronization phase transition

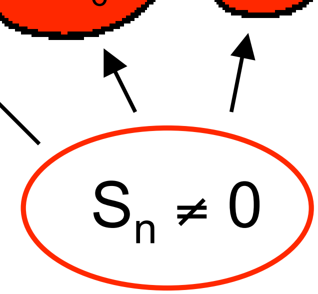
Kinematical correlations: J Heavy Ion Physics 22 (2005) 69

⇨ Chemical correlations: Strangeness trapping

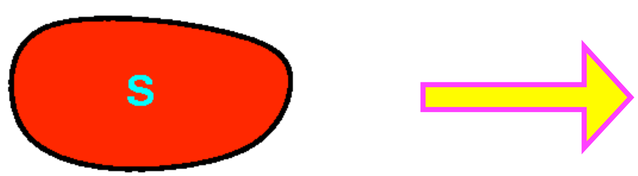
Strangeness trapping

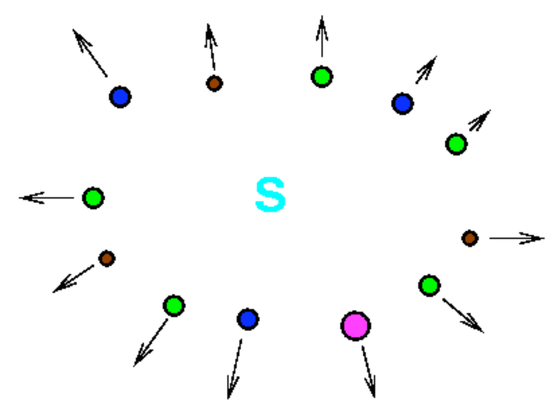
The expanding system decomposes into plasma blobs
that each contain a certain amount of strangeness:





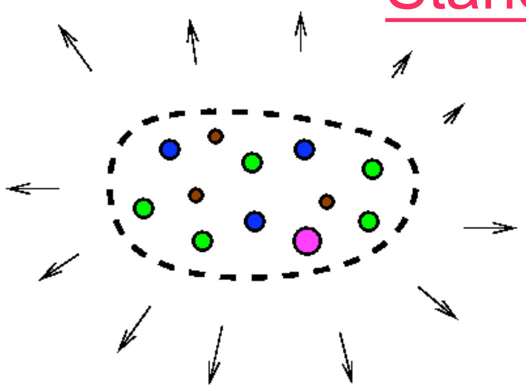
The hadronization of
each isolated blob
conserves strangeness:





- with Volker Koch and Abhijit Majumder

Standard treatment: Grand canonical

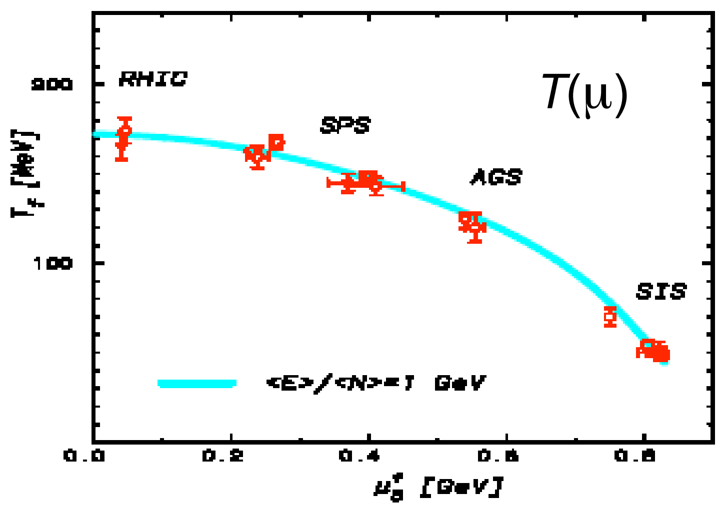


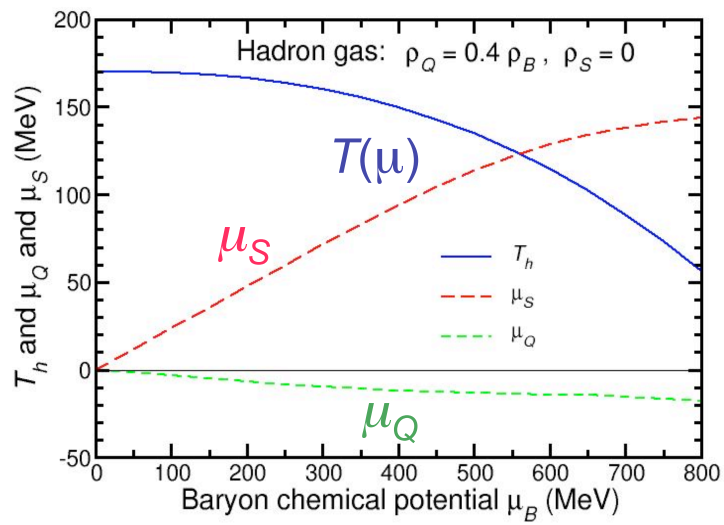
$$\bar{n}_k = \frac{g_k}{2\pi^2} V_h T_h^3 \left(\frac{m_k}{T_h}\right)^2 K_2\left(\frac{m_k}{T_h}\right) \mathrm{e}^{(\mu_B B_k + \mu_Q Q_k + \mu_S S_k)/T_h}$$

=> $\bar{B} = \sum_k B_k \bar{n}_k \ , \quad \bar{Q} = \sum_k Q_k \bar{n}_k \ , \quad \bar{S} = \sum_k S_k \bar{n}_k$

Use μ_B as the independent variable:

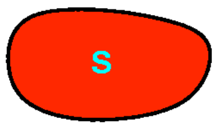
$\bar{Q} = 0.4\bar{B} \ , \ \bar{S} = 0 \ \longrightarrow \ \mu_Q, \mu_S$





Particle production in heavy ion collisions,
P. Braun-Munzinger, K. Redlich, J. Stachel,
in *QGP 3* (Hwa & Wang); nucl-th/0304013

Spinodal model: Plasma blobs form, expand & hadronize



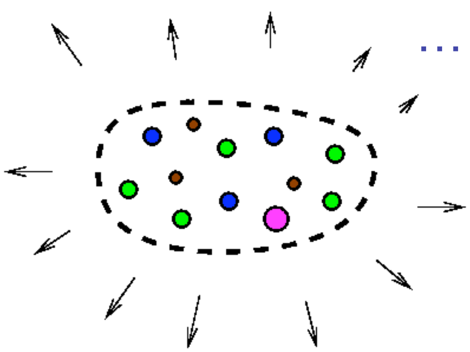
The plasma blob contains strange quarks and antiquarks:

$$\langle\nu\rangle = \langle\bar{\nu}\rangle \approx \zeta_s = \frac{3}{\pi^2} V_q T_q^3 \left(\frac{m_s}{T_q}\right)^2 K_2\left(\frac{m_s}{T_q}\right)$$

Its total strangeness, $S_0 = \nu_{\bar{s}} - \nu_s$, is conserved.

… expands …

$$\left[\begin{array}{l} B_s = +\frac{1}{3} \\ Q_s = -\frac{1}{3} \end{array} \quad \Rightarrow \quad \begin{array}{l} \langle B\rangle_{S_0} = \bar{B} - \frac{1}{3} S_0 \\ \langle Q\rangle_{S_0} = \bar{Q} + \frac{1}{3} S_0 \end{array} \quad \Rightarrow \quad \begin{array}{l} \mu'_B \\ \mu'_Q \end{array}\right]$$



… and hadronizes (at fixed S_0):

Freeze-out volume: $V_h = \chi\, V_q$

Freeze-out temperature: T_h

$$\zeta_k = \frac{g_k}{2\pi^2} V_h T_h^3 \left(\frac{m_k}{T_h}\right)^2 K_2\left(\frac{m_k}{T_h}\right) e^{(\mu'_B B_k + \mu'_Q Q_k)/T_h}$$

$$\mathcal{Z}_{S_0} = \prod_k \left[\sum_{n_k \geq 0} \frac{\zeta_k^{n_k}}{n_k!}\right] \delta\left(\sum_k S_k n_k - S_0\right)$$

Canonical partition function

Schematic scenario: charged kaons only

$$\zeta_K = \frac{g_K}{2\pi^2} V_h T_h^3 \left(\frac{m_K}{T_h}\right)^2 K_2\left(\frac{m_K}{T_h}\right)$$ => $$\langle n_{K^\pm}\rangle_{S_0} = \zeta_K \pm \tfrac{1}{2} S_0 - \tfrac{1}{4} + \frac{4S_0^2 - 1}{32\zeta_K} + \mathcal{O}\left(\frac{1}{\zeta_K^2}\right)$$

Average over distribution of S_0: $\prec S_0 \succ = 0$ & $\sigma^2_{S_0} = 2\zeta_s$

Ensemble average multiplicities:

$$\boxed{\prec n_{K^\pm} \succ = \zeta_K - \tfrac{1}{4} + \frac{8\zeta_s - 1}{32\zeta_K} + \mathcal{O}\left(\frac{1}{\zeta_K^2}\right)}$$

$$\zeta_K = \zeta_s : \left\{ \begin{array}{r} \prec n_{K^\pm} \succ = \sigma^2_{K^\pm} = \zeta_K \\ \sigma_{K^+K^-} = 0 \end{array} \right.$$

Multiplicity (co)variances:

$$\sigma^2_{K^\pm} = \tfrac{1}{2}\zeta_K + \tfrac{1}{2}\zeta_s + \mathcal{O}\left(\frac{1}{\zeta_K}\right)$$

$$\sigma^2_{K^+K^-} = \tfrac{1}{2}\zeta_K - \tfrac{1}{2}\zeta_s + \mathcal{O}\left(\frac{1}{\zeta_K}\right)$$

=> $\sigma^2(n_{K^+} - n_{K^-}) = 2\zeta_s = \sigma^2_{S_0}$

$$\zeta_K < \zeta_s = (1+\Delta)\zeta_K : \left\{ \begin{array}{lcl} \prec n_{K^\pm} \succ & \approx & \zeta_K + \tfrac{1}{4}\Delta \\ \sigma^2_{K^\pm} & \approx & \zeta_K + \tfrac{1}{2}\Delta\zeta_K \\ \sigma_{K^+K^-} & \approx & -\tfrac{1}{2}\Delta\zeta_K \end{array} \right.$$

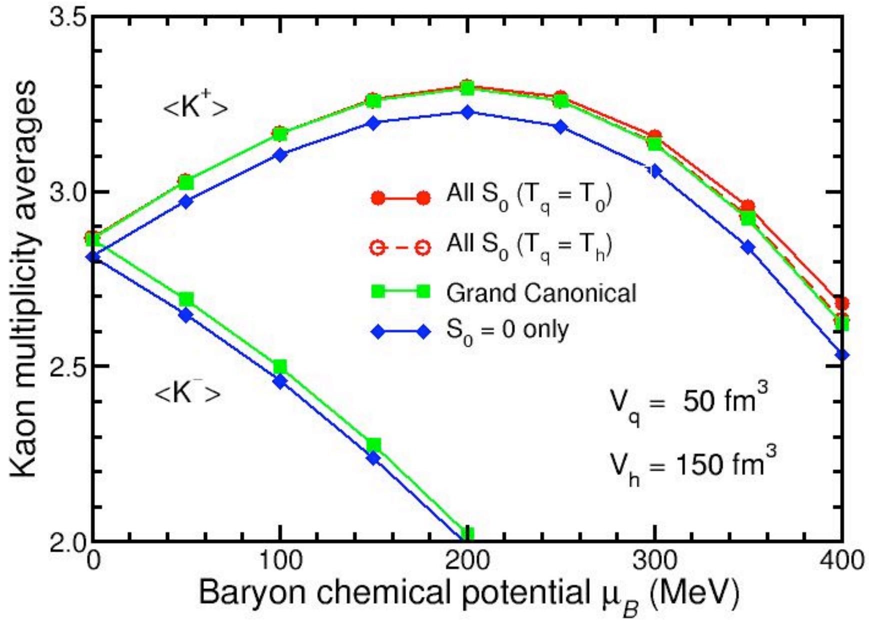
Kaon multiplicity distribution

1) Grand-canonical equilibrium in the hadron blob (V_h = 150 fm^3): $\langle S_0 \rangle = 0$

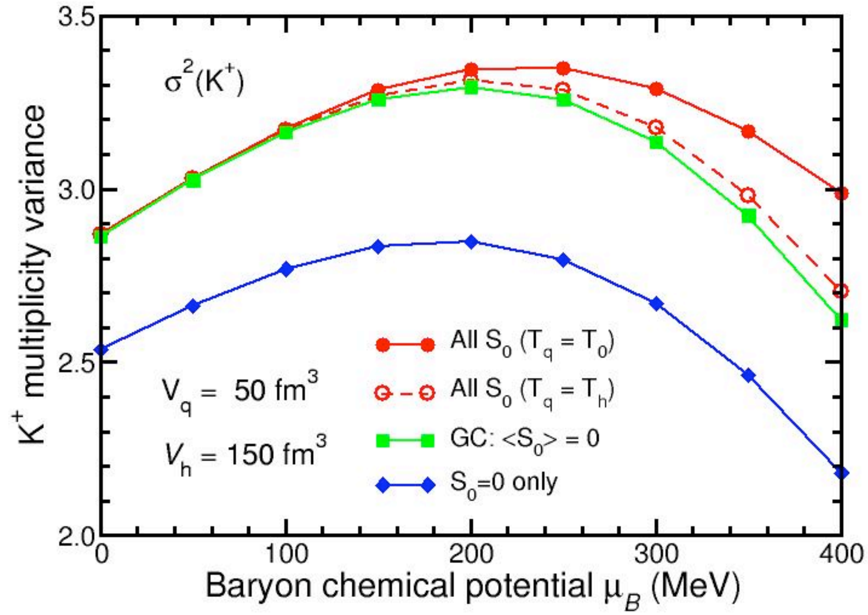
2) Canonical equilibrium in V_h demanding *zero* net strangeness: $S_0 = 0$

3) Canonical equilibrium in V_h with S_0 selected in the plasma (V_q = 50 fm^3)

Average

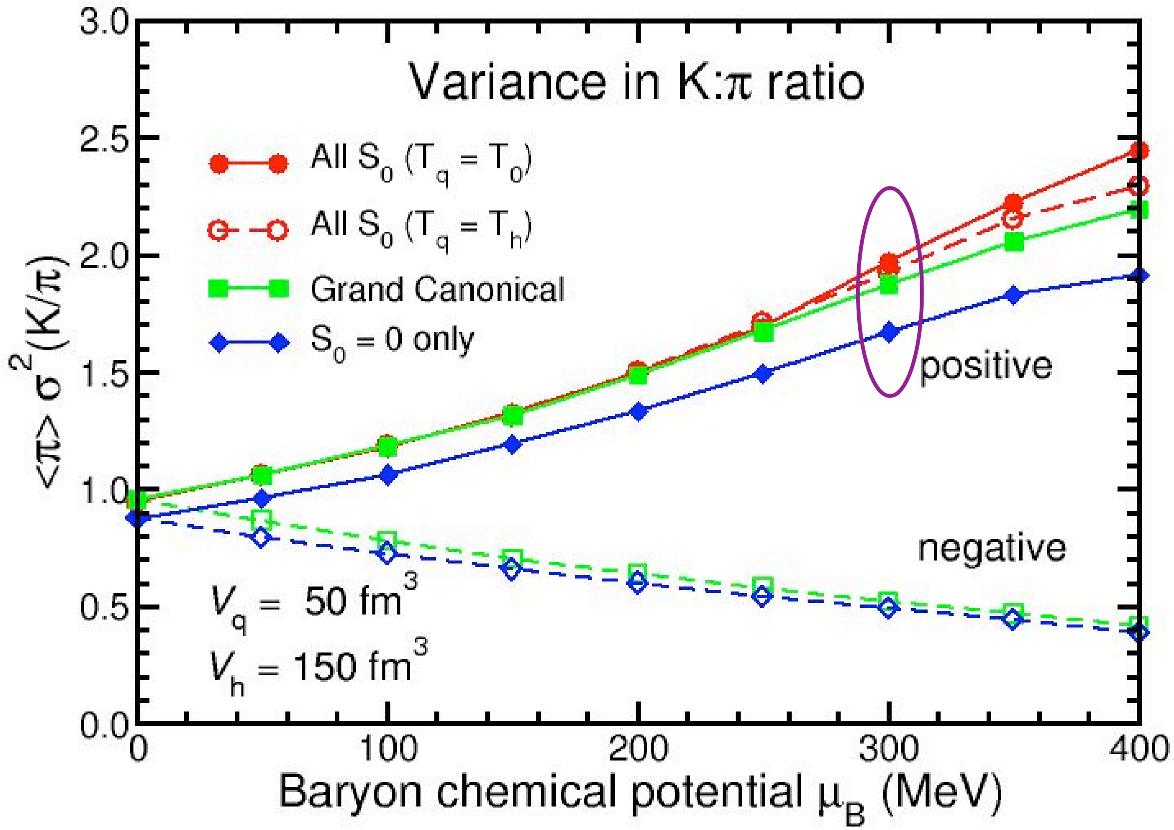


Variance

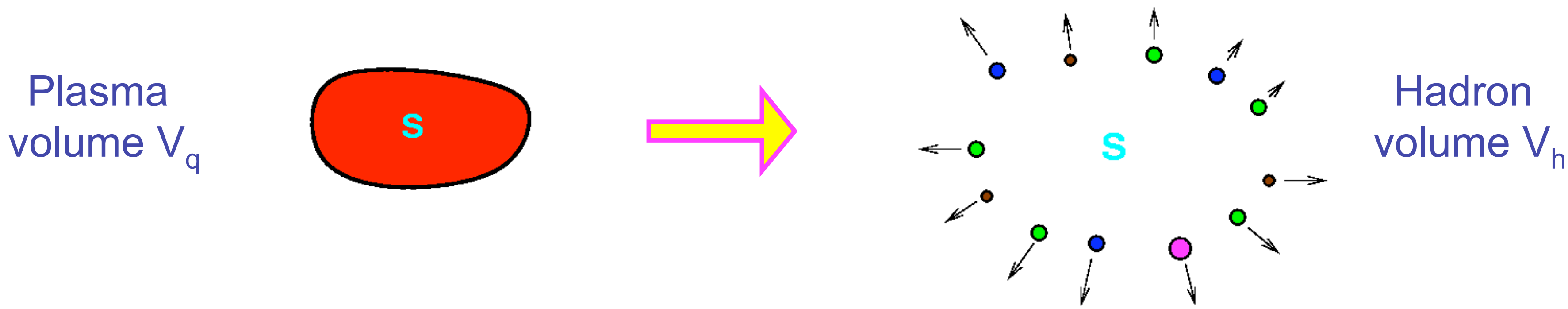


Distribution of the K-to-π ratio

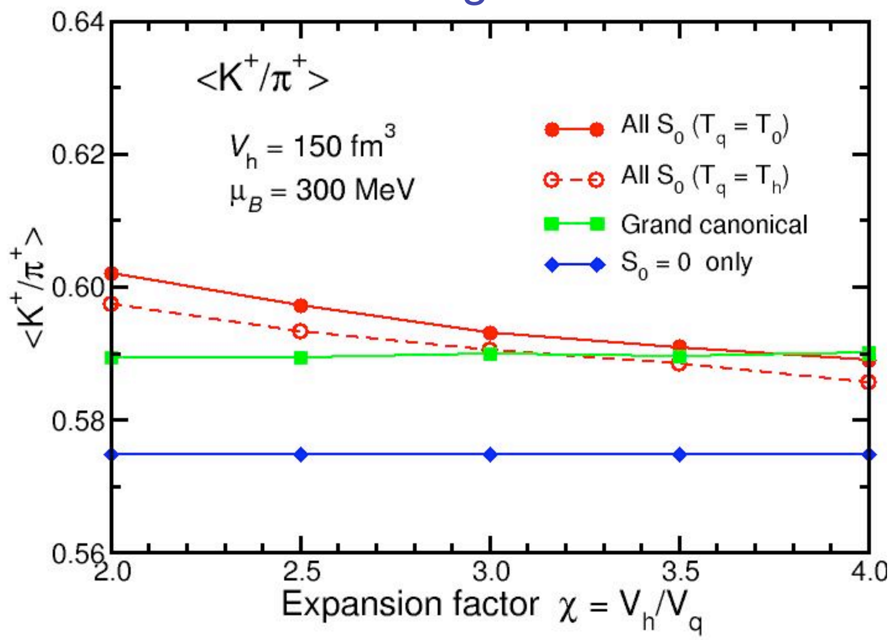
Variance in (N_K / N_π) $\times$ Normalized by the average N_π



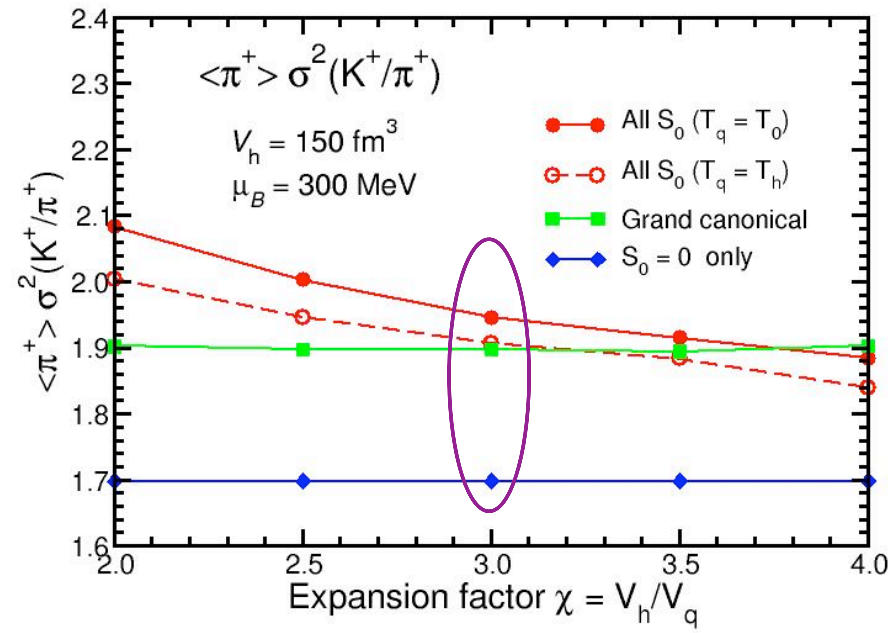
Dependence on the expansion factor χ



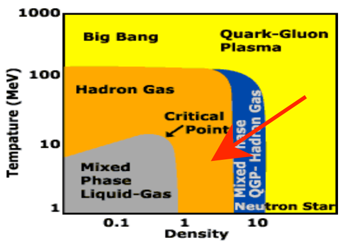
Average of K/π



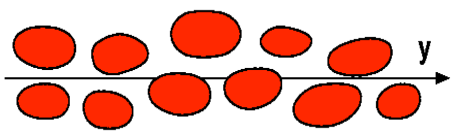
Variance of K/π



Strangeness trapping during hadronization?



If the hadronization phase transition is of first order and
if the bulk matter enters the region of phase coexistence
then spinodal decomposition may occur.

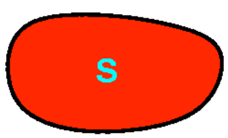


Spatial irregularities will then be amplified and
a characteristic spinodal *clumping may* develop,
prior to the conversion of the plasma into hadrons.

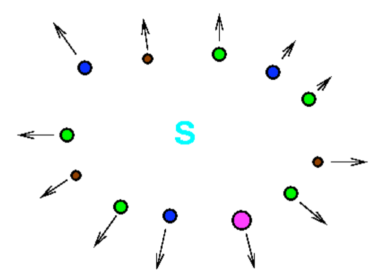
This mechanism *may* produce observable signals:

1) Collective motion => *N*-baryon kinematic correlations

2) *Strangeness trapping* => enhanced K/π fluctuations



Each blob conserves its strangeness
through expansion and hadronization



Has this effect already been seen by NA49 @ CERN?

Can this effect be utilized by CBM @ FAIR?