Multiplicity fluctuations with respect to QGP phase transition in Monte-Carlo simulations of heavy ion collisions

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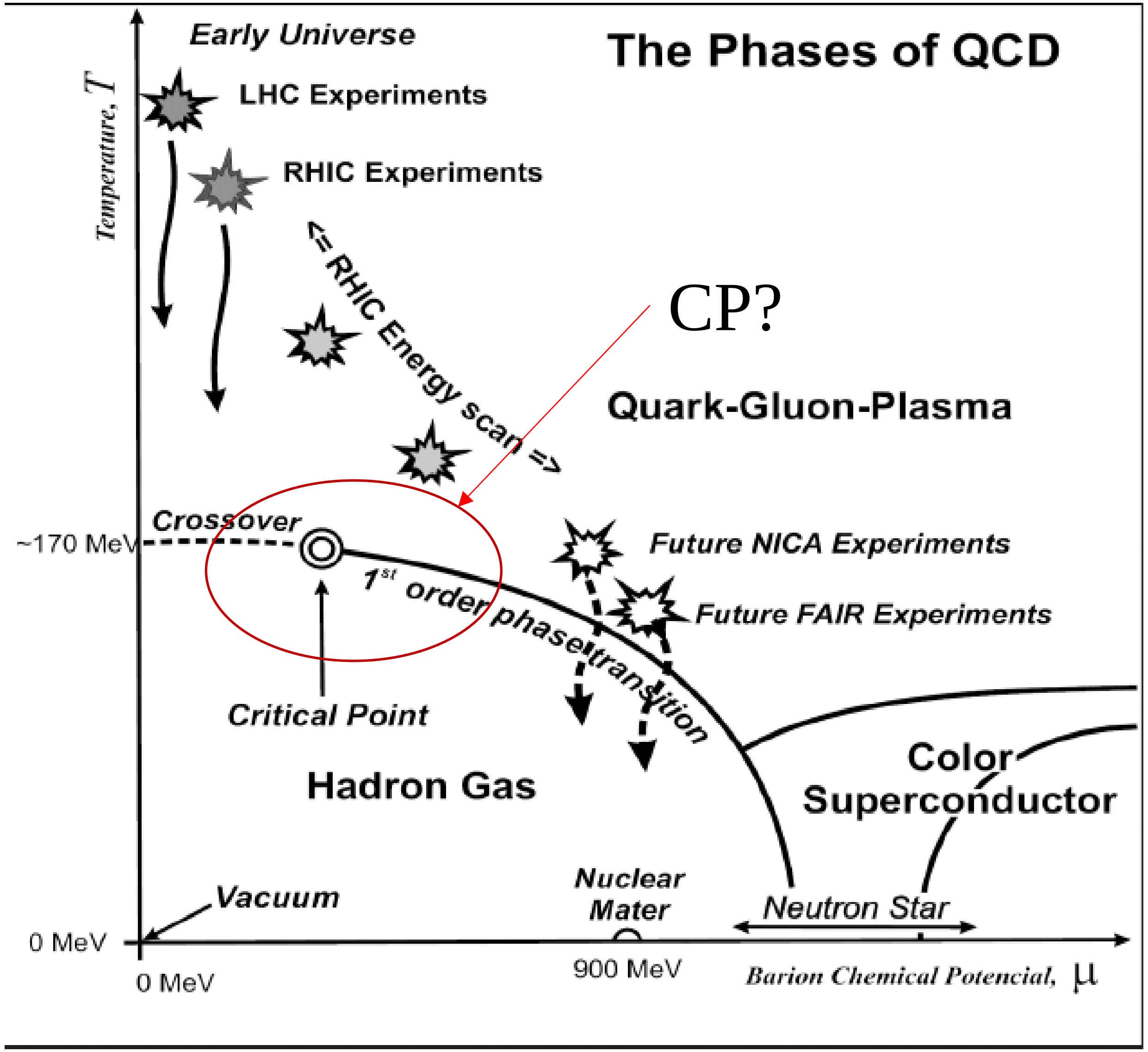


QCD phase diagram

Changing collision energy and centrality, we can “scan” the diagram in search of the phase transition. The most interes-ting areas are 1st order phase transition line and critical point.

Simulation models

Hydrodynamical (THESSEUS, Hydro++, HYDJET++ etc.)	Transport (HIJING, QGSM, AMPT, HSD, UrQMD etc.)	Hybrid (Hybrid UrQMD)
EoS (mostly physics) Still has few parameters Phase transitions + Particalization ? Equilibrium!!!!	Boltzmann eq. + phenomenological assumptions (jet quenching, shadowing etc.) Phenomenology => parameters parameters parameters parameters parameters parameters	Transport => Hydro => freeze-out Phase transitions can be implemented with according EoS (manually) Still has QCD.

1st order phase transitions and fluctuations

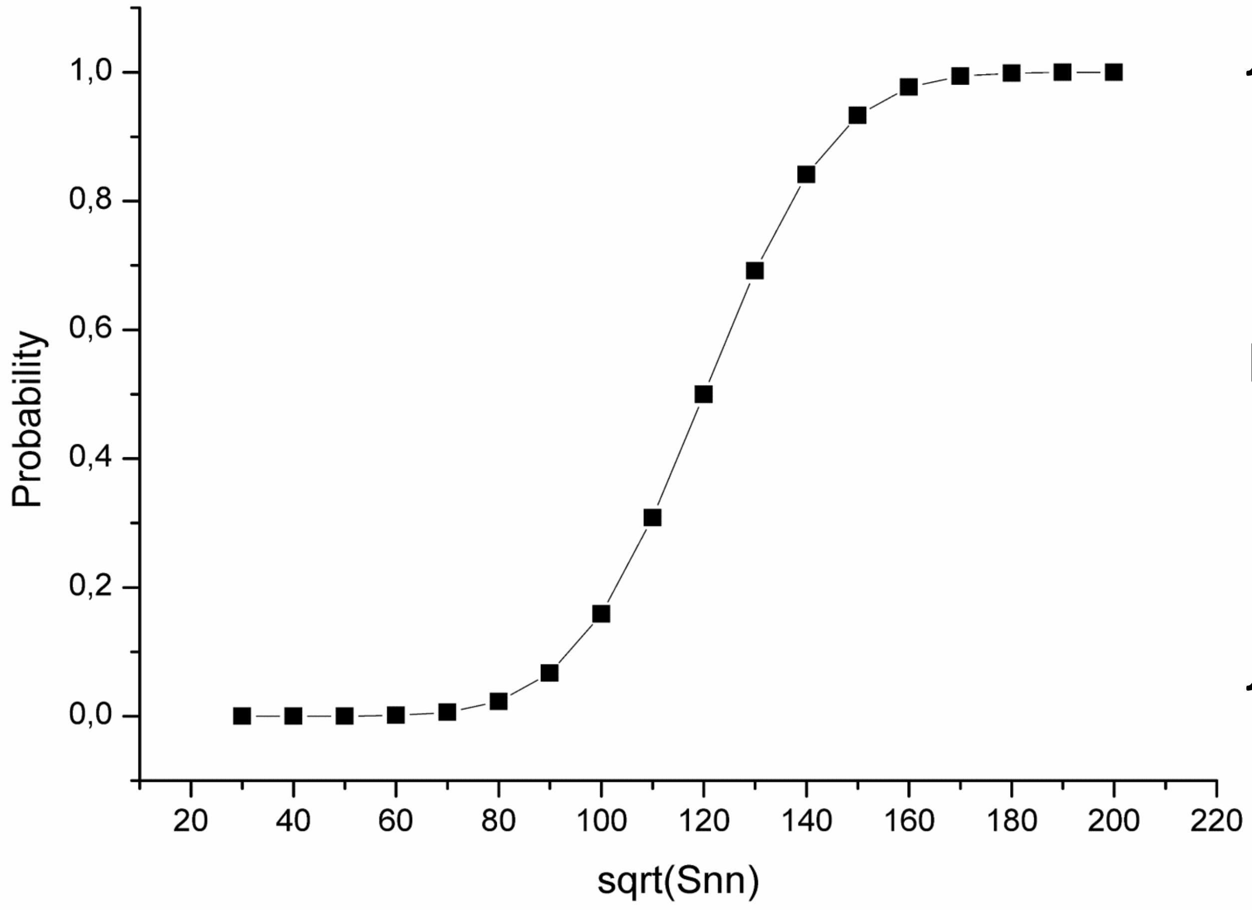
[Pre-transitional effects in rapidly expanding quark-gluon plasmas; A.K. Mohanty, P. Shukla, M. Gleiser]

Assuming the transition to be discontinuous, or first-order, as suggested by some recent lattice QCD simulations [2], the QGP is cooled to a temperature T_1, where a second minimum appears, indicating the presence of a hadronic phase. With further cooling, the two phases become degenerate at the critical temperature T_c, with a free energy barrier which depends on physical parameters characterizing the system, such as the surface tension (σ) and the correlation length (ξ).

Recent work on the dynamics of weak first-order phase transitions have shown that, in certain cases, it is possible to have nonperturbative, large-amplitude fluctuations before the critical temperature is reached, which promote phase mixing [5].

The dynamics of weakly first-order transitions will be sensitive to the amount of phase mixing at T_c: for large phase mixing, above the so-called percolation threshold, the transition may proceed through percolation of the hadronic phase, while for small amounts of phase mixing, by the nucleation of critical bubbles in the (inhomogeneous) background of isolated hadronic domains, which grow as T drops below T_c.

So, we can implement PT probability function



Лебедев В.В.
«Флуктуационные эффекты
в макрофизике».

В.Г. Бойко
«Термодинамика фазовых переходов
в ядерном веществе».

Ландау.

Implementing “phases” in HIJING

We make different parameters (energy loss) for different types of matter

Hot QCD matter:

$$\left.\frac{dE}{dz}\right|^{total} = \left.\frac{dE}{dz}\right|^{collisional} + \left.\frac{dE}{dz}\right|^{radiative};$$

$$\left.\frac{dE}{dz}\right|^{collisional} [1] = \begin{cases} C_R \pi \alpha_s^2 T^2 \left[\left(A_g + A_q \frac{n_f^{eff}}{6}\right)\ln\frac{ET}{m_D^2} + O(1)\right] & \text{For light partons} \\ \frac{4\pi\alpha_s^2 T^2}{3}\left[\left(A_g + A_q \frac{n_f^{eff}}{6}\right)\ln\frac{ET}{m_D^2} + \frac{2}{9}\ln\frac{ET}{M^2} + c(n_f^{eff})\right] & \text{For heavy quarks} \end{cases}$$

$$\left.\frac{dE}{dz}\right|^{radiative} [2] = \frac{C_R \alpha_S}{8}\frac{\mu^2}{\lambda_g} L \ln\left(\frac{L}{\lambda_g}\right)$$

[1] – Collisional energy loss of a fast parton in QGP, S. Peigne, 2008, arXiv:0806.0242v1 [hep-ph]

[2] – Radiative energy loss of high energy quarks and gluons in a finite volume QGP, R. Baier et.al., 1996, arXiv:hep-ph/9607355v1

Phases in HIJING (cont.)

$$m_g^2 = 4\pi\alpha_s T^2 (A_g + A_q n_f^{eff}/2)/2$$ - Gluon quasiparticle mass

$$\mu^2 = 2m_g^2$$ [3]- Debye screening mass of QGP

$$C_R = \begin{cases} N_c^{eff} & \text{- for gluons} \\ \dfrac{(N_c^{eff}-1)^2}{2N_c^{eff}} & \text{- for quarks} \end{cases}$$

$$A_g = A_q = 1$$ Fugacity factors for gluon and quark, that describe chemical equilibrium (we assume equilibrated system)[4]

$$\lambda_g = \frac{1}{4\pi\alpha_s T}$$ [1, 5] Gluon mean free path

$$L = \frac{3}{4} r_0 A^{1/3}, r_0 = 1.112\, fm$$ Length of QCD medium

$$n_f^{eff} = \left[1 - 2\pi^2 \frac{T^2/Q^2 - T^2/Q_0^2}{\ln\left(\frac{Q^2}{Q_0^2}\right)}\right] n_f, \quad N_c^{eff} = \left[1 + \frac{8\pi^2}{11} \frac{T^2/Q^2 - T^2/Q_0^2}{\ln\left(\frac{Q^2}{Q_0^2}\right)}\right] N_c,$$

$$\alpha_s = \alpha_s(Q,T) = \frac{\alpha_s(Q_0)}{1 + \frac{\alpha_s(Q_0)}{4\pi}\left[\frac{11}{3}N_c^{eff} - \frac{2}{3}n_f^{eff}\right]\ln\left(\frac{Q^2}{Q_0^2}\right)}, \quad N_c = 3, Q_0 = m_Z = 91\,\text{Gev}$$ [6]

[3] – Parton energy loss in an expanding quark-gluon plasma: Radiative vs. collisional, B.G. Zakharov, arXiv:0708.0816v1 [hep-ph]

[4] – Energy loss in perturbative QCD, R. Baier, D. Schiff, B.G. Zakharov, 2000, arXiv:hep-ph/0002198v2

[5] – Quark-gluon plasma and Heavy Ion colliions, F. Gelis, LUTH (Meudon), March 2008.

[6] – The temperature dependence of running Coupling, F.M. Steffens, Brazilian Journal of Physics, vol. 36, no. 2B, June, 2006

Phases in HIJING (cont.)

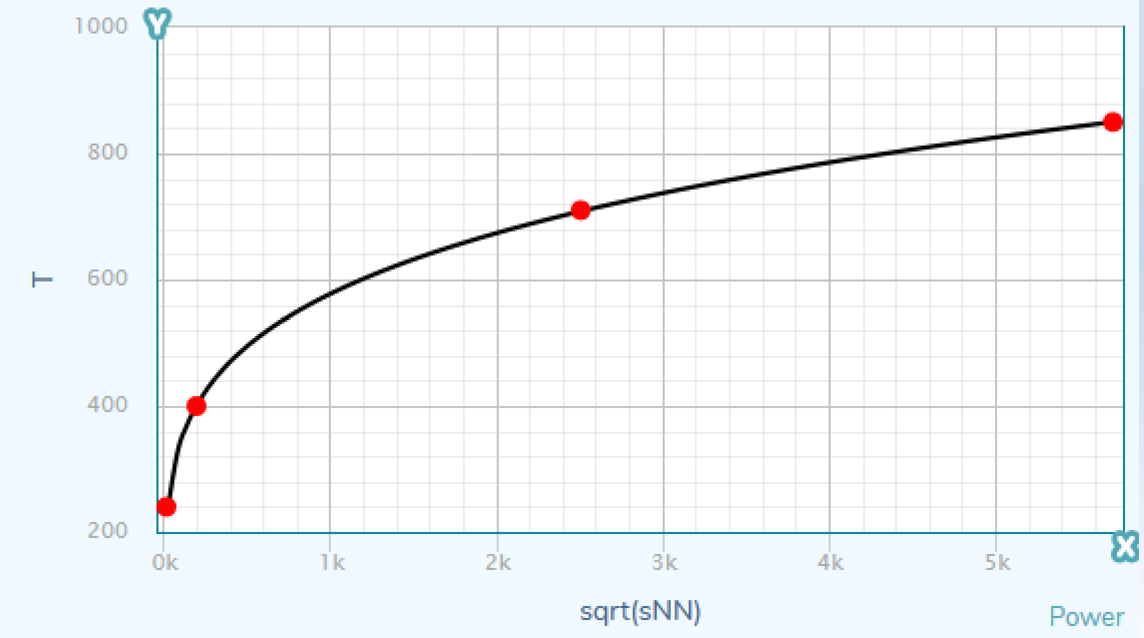
As can be seen, all Hot matter properties depend on the temperature of the medium.
How to get it? HYDRO!!! We use the following results:

I. Vitev, JPG 30 (2004) S791

	$\tau_0[fm]$	$T[MeV]$	$\varepsilon[GeV/fm^3]$	$\tau_{tot}[fm]$	dN^g/dy
SPS	0.8	210-240	1.5-2.5	1.4-2	200-350
RHIC	0.6	380-400	14-20	6-7	800-1200
LHC	0.2	710-850	190-400	18-23	2000-3500

[7] – Hard probes to diagnose the QGP at the LHC, Johanna Stachel, Heavy Ion Physics Perspectives talk, 12-14 September, 2007.

We fit these results => USE WITH CAUTION (but for our purposes they will fit):



Fitted with T(sqrt(sNN)) = a*sqrt(sNN)^b;
a = 123.8294; b = 0.2224218

Phases in HIJING (cont.)

Cold matter:

$$\frac{dE}{dz} = \frac{C_R \alpha_s(Q^2)}{8} \frac{\mu^2}{\lambda} \vartheta L;$$

$$\frac{\mu^2}{\lambda} \vartheta = \frac{2\alpha_s(Q^2)}{3} \pi^2 \rho x G;$$

Estimates for quantities in 2nd equation can be taken, for example, from [8]

[8] – Energy loss and pT broadening of high energy partons in hot and cold QCD matter, A.H. Mueller, Nucl. Phys. A610 (1996), pp. 459 – 469.

How to see a phase transition?

[Search for the QCD critical point with fluctuations of Conserved Quantities in Relativistic Heavy-Ion Collisions at RHIC: An Overview; Xiaofeng Luo, Nu Xu]
ArXiv: 1701.02105v3 [nucl-ex]

Cumulants:

$$M_q = <N_q> = VT^3\chi_1^q, \qquad \sigma_2^q = C_2^q = <(\delta N_q)^2> = VT^3\chi_2^q$$
$$C_3^q = <(\delta N_q)^3> = VT^3\chi_3^q, \quad C_4^q = <(\delta N_q)^4> - 3<(\delta N_q)^2>^2 = VT^3\chi_4^q$$
$$C_5^q = <(\delta N_q)^5> - 10<(\delta N_q)^3><(\delta N_q)^2> = VT^3\chi_5^q$$
$$C_6^q = <(\delta N_q)^6> - 15<(\delta N_q)^4><(\delta N_q)^2> - 10<(\delta N_q)^3>^2 + 30<(\delta N_q)^2>^3 = VT^3\chi_6^q$$

Linear response relations

χ^q- susceptibility of charge q (q = B, Q, S), $\delta N_q \doteq N_q - <N_q>$.

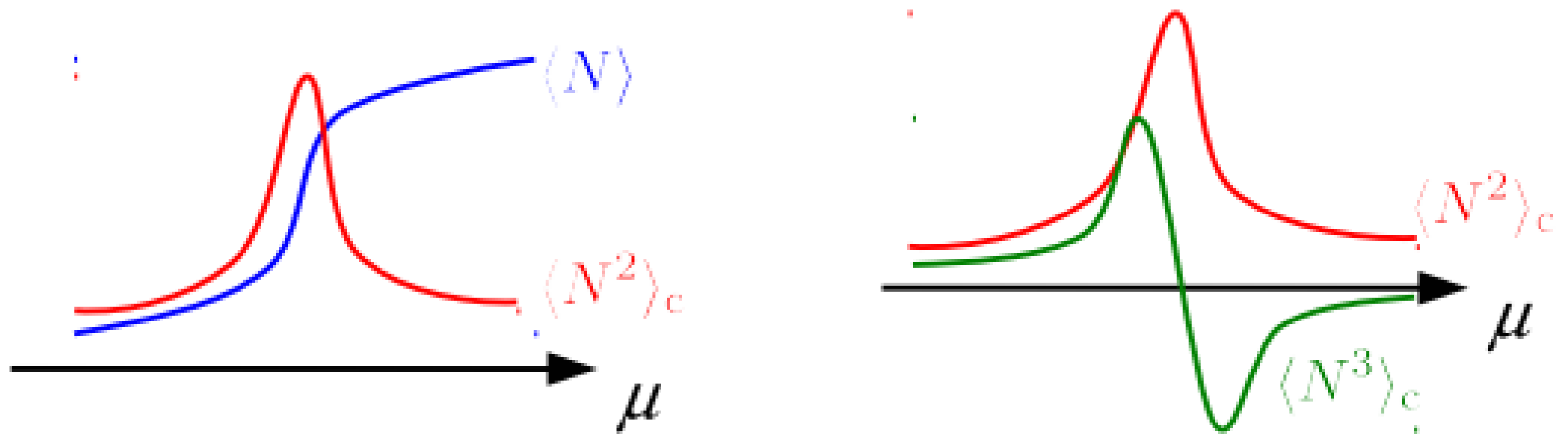
Skewness and Kurtosis:

$$S_q = \frac{<(\delta N_q)^3>}{<(\delta N_q)^2>^{3/2}} = \frac{C_3^q}{(\sigma_2^q)^{3/2}}$$
$$\kappa_q = \frac{<(\delta N_q)^4>}{<(\delta N_q)^2>^2} - 3 = \frac{C_4^q}{(\sigma_2^q)^2}$$

Relations: No V-dependence!

$$\frac{\sigma_q^2}{M_q} = \frac{C_2^q}{M_q} = \frac{\chi_2^q}{\chi_1^q}, \qquad S_q\sigma_q = \frac{C_3^q}{C_2^q} = \frac{\chi_3^q}{\chi_2^q}$$
$$\kappa_q\sigma_q^2 = \frac{C_4^q}{C_2^q} = \frac{\chi_4^q}{\chi_2^q}, \qquad \frac{\kappa_q\sigma_q}{S_q} = \frac{C_4^q}{C_3^q} = \frac{\chi_4^q}{\chi_3^q}$$

Example



Dependences of various cumulants on μ.

So, we expect nonlinear behavior of the cumulants in the phase transition region

In this paper we will overview total charge fluctuations.

Thank you for your attention