Dynamical study of fluctuations in relativistic nuclear collisions

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- Introduction
- Fluctuations in the number of participants
- Multiplicity fluctuations
- Baryon number and electric charge fluctuations
- Energy dependence of multiplicity fluctuations
- Fluctuations at RHIC

In collaboration with Elena Bratkovskaya (Frankfurt) and Mark Gorenstein (Kiev)
Study of fluctuations within transport models

HSD – Hadron-String-Dynamics transport approach
UrQMD – Ultra-relativistic-Quantum-Molecular-Dynamics

Transport models allow to study:

- statistical and dynamical fluctuations
- event-by-event analysis similar to the experiment
- the influence of the experimental acceptance on the final results on fluctuations
- the centrality dependence
- the energy dependence of fluctuations
Fluctuations in the number of participants in HSD & UrQMD

\[ \langle N^\text{targ}_P \rangle = N^\text{proj}_P \]

\[ N^\text{proj}_P = A - N^\text{proj}_S \] – projectile participants

\[ N^\text{targ}_P = A - N^\text{targ}_S \] – target participants
Fluctuations in the number of participants in HSD & UrQMD

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The scaled variance of “X”:

\[ \omega_X = \frac{\langle X^2 \rangle - \langle X \rangle^2}{\langle X \rangle} \]

\(\omega_{N_p}^{\text{targ}}\) is the scaled variance of the number of target participants \(N_p^{\text{targ}}\)

in each sample with \(N_p^{\text{proj}} = \text{const}\) the number of target participants \(N_p^{\text{targ}}\) fluctuates considerably: \(\omega_{N_p}^{\text{targ}} \sim 3\) at \(N_p^{\text{proj}} \sim 25\)

V. Konchakovski, GSI Darmstadt 2007
Baryon number fluctuations (HSD)

Baryon number is a conserved quantity:

the net baryon number in the full phase space \( B \) is equal to the total number of participants \( N_p = N_{p^{\text{proj}}} + N_{p^{\text{targ}}} \)

at fixed \( N_{p^{\text{proj}}} \) the \( N_p \) number fluctuates due to the fluctuations of \( N_{p^{\text{targ}}} \) in the full phase space

\[
\omega_B \equiv \frac{1}{2} \omega_p^{\text{targ}}
\]

\( O_B \sim \frac{1}{2} \omega_p^{\text{targ}} \)

\( O_B \sim \frac{1}{2} \omega_p^{\text{proj}} \)

\( \omega_B^{\text{targ}} > \omega_B^{\text{proj}} \)

\( \omega_B^{\text{targ}} \sim \omega_B^{\text{proj}} \)

PRC 74 (2006) 064911
Multiplicity fluctuations in projectile and target hemispheres

- **HSD and UrQMD** show strong multiplicity fluctuations of dynamical origin;

- **HSD and UrQMD** show strong multiplicity fluctuations in 4\pi 'full' acceptance, however, the observed (by NA49) non-trivial system size dependence of multiplicity fluctuations is not reproduced by HSD and UrQMD.

- \( \phi - p_T \) acceptance cuts strongly decrease fluctuations!

- Fluctuations in target hemisphere are larger than in projectile hemisphere.

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V. Konchakovski, GSI Darmstadt 2007
Net-electric charge fluctuations

sensitive to the EoS at the early stage of the collision and to its changes in the deconfinement phase transition region

\[ \Phi_x = \sqrt{\frac{Z^2}{N}} - \sqrt{z^2}, \quad z_i = x_i - \bar{x}, \quad Z = \sum_{i=1}^{N} (x_i - \bar{x}) \]

\[ \Delta \Phi_q = \Phi_q - \Phi_{q,GCC} \]

\[ \Phi_{q,GCC} = \sqrt{1-P-1}, \quad P = \frac{\langle N_{ch} \rangle}{\langle N_{ch} \rangle_{tot}} \]

\[ \Delta \Phi_q = 0, \quad \text{if particles are correlated by global charge conservation only!} \]

**Definition of \( \Phi \)-measure of fluctuations:**

Gazdzicki, Mrowczynski, Z. Phys. C 54 (1992) 127:

Jeon, Koch, PRL85 (2000) 2076

Asakawa, Heinz, Muller PRL85 (2000) 2072

net-charge fluctuations are smaller in QGP than in a hadron gas

\[ X - \text{single-particles variable} \]

\[ N - \text{number of particles in 1 event} \]

\[ \langle ..., \rangle - \text{averaging single-particle distribution over events} \]

V. Konchakovski, GSI Darmstadt 2007
The decay of resonances strongly modifies the initial QGP fluctuations!
Energy Dependence of Multiplicity Fluctuations in N+N and central A+A

PLB, in press [nucl-th/0703052]

- HSD gives good description of experimental data for charged hadron multiplicities in A+A.
- Fluctuations in p+p and A+A are very close within HSD.
- Fluctuations of the number of participants do not explain excess over p+p fluctuations
  \[ \omega_i = \omega_i - n_i \omega_P \] (6)
- Statistical model shows very small and energy independent fluctuations and contradicts to the transport calculations where \( \omega \) reaches significant values for the large energies.

Begun at al, PRC (2006) 044903

Similar results for \( \omega^\pm \) from UrQMD (see talk of M.Bleicher)
Energy Dependence of Multiplicity Fluctuations: NA49 data

Acceptance scaling formulae:
\[ \omega_i^{\text{acc}} = 1 - q_i + q_i \omega_i^{4\pi} \quad (7) \]

NA49 cannot clearly distinguish between statistical and transport models because of small acceptance \( q = 0.04 \ldots 0.16 \) and small differences between the model predictions in this range of energy!

PLB, in press [nucl-th/0703052]

V. Konchakovski, GSI Darmstadt 2007
Fluctuations at RHIC

0704.1831[nucl-th]

Fluctuations of the participant number within different centrality classes in PHENIX for Au+Au @ √s = 200 GeV are significant!

Using the model of independent sources:

\[ \omega_i = \omega_i^* + n_i \omega_P \]

and acceptance scaling formula:

\[ \omega_i^{acc} = 1 - q_i + q_i \omega_i^* \]

we obtain equation:

\[ \omega_i^{acc} = 1 - q_i + q_i \omega_i^* + q_i n_i \omega_P \]

From HSD we took only: \( \omega_p, q_i, n_i \)
Fluctuations at RHIC

0704.1831[nucl-th]

\[ \omega_i^{\text{acc}} = 1 - q_i + q_i \omega_i^* + q_i n_i \omega_P \quad (3) \]

eq.(3) describes exp. data from PHENIX for Au+Au @ \( \sqrt{s} = 200 \text{ GeV} \)

Multiplicity fluctuations represent fluctuations of participants!
Conclusions

- The fluctuations in the number of target participants – for fixed projectile participants - strongly influence all observable fluctuations.

- The measured fluctuations of the electric charge in different acceptance windows are consistent with HSD results.

- Statistical and transport models show different results in central A+A collisions for multiplicity fluctuations versus energy. New measurements at higher energies and with larger acceptance are needed!

- In collider-type experiments the fluctuations of the number of participants are significant. To avoid them one has to consider the most central collisions with more rigid events selection.
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Model of independent sources

Number of independent sources is proportional to number of participants:

\[ \omega_i = \omega_i^* + \frac{1}{2} \omega_p^{\text{targ}} n_i \]

\( \omega_i^* \) is the fluctuation from a single NN source

- \( \omega_-^* = 1.5 \)
- \( \omega_+^* = 1.1 \)
- \( \omega_{\text{ch}}^* = 2.5 \)

HSD: N+N (averaged over pp+nn+pn)

\( n_i \) is the particle number of \( i \)-th type (\( i=+, -, \text{ch} \)) per participant

\[ N_p = N_{p}^{\text{proj}} + N_{p}^{\text{targ}} \]

\[ n_i = \frac{\langle N_i \rangle}{\langle N_p \rangle} \]

\( \omega_p^{\text{targ}} \) is the scaled variance for the fluctuations of the number of target participants \( N_p^{\text{targ}} \)

Gazdzicki, Gorenstein, hep-ph/0511058

V. Konchakovski, GSI Darmstadt 2007
Model of independent sources

\[ \omega_i = \omega_i^* + \frac{1}{2} \alpha_p^{\text{targ}} n_i \]

for \( N_p^{\text{proj}} = N_p^{\text{targ}} \): \( \omega_p^{\text{targ}} = 0 \)

Fluctuations in A+A collisions are dominated by the fluctuations of the particle number in single N+N collisions
Multiplicity fluctuations as a probe of transparency, mixing and reflection of initial flows in HIC

Gazdzicki, Gorenstein, hep-ph/0511058:

- Model of independent sources favors mixing (but not extreme!) scenario
- HSD & UrQMD show smaller mixing as follows from NA49 data, i.e. too transparent
“Nucleon-nucleon” collisions

\[
\langle N_i^{NN} \rangle = \alpha_{pp} \langle N_i^{pp} \rangle + \alpha_{pn} \langle N_i^{pn} \rangle + \alpha_{nn} \langle N_i^{nn} \rangle,
\]

\[
\omega_i^{NN} = \frac{1}{\langle N_i^{NN} \rangle} \left[ \alpha_{pp} \omega_i^{pp} \langle N_i^{pp} \rangle + \alpha_{pn} \omega_i^{pn} \langle N_i^{pn} \rangle + \alpha_{nn} \omega_i^{nn} \langle N_i^{nn} \rangle \right]
\]
N+N & A+A central collisions

\[ \omega_i = \omega_i^\nabla + n_i \omega_P \]

\( \text{Pb} + \text{Pb} \ @ \ 158 \ \text{AGeV}, \ b = 0: \)

\[ \langle N_P \rangle \approx 392 \]

\[ \omega_P \approx 0.055 \]
Fluctuations at RHIC

![Graph showing fluctuations at RHIC](image-url)