Strongly intensive measures for chemical fluctuations in A+A and p+p collisions: statistical and transport models

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The chemical fluctuations may indicate a presence and determine the position of the critical point on a phase diagram of the QCD matter. This inspired energy and system size scan program of NA61 collaboration at the SPS CERN and low energy scan program of STAR collaboration at the RHIC BNL. However, many other effects – fluctuations of the number of nucleon participants in A+A collisions, effects of global conservation laws, and the change in the detector acceptance with energy – may hide or produce the fluctuation signals.

The basic variables that describe fluctuations are the moments $\langle \mathrm{N}^{\mathrm{k}} \rangle \equiv \sum \mathrm{N} \cdot \mathrm{P}(\mathrm{N})$ of particle distribution $\mathrm{P}(\mathrm{N})$. They are proportional to the volume $\langle \mathrm{N}^{\mathrm{k}} \rangle \sim \mathrm{V}^{\mathrm{k}}$ in statistical model or to the number of participants in the model of independent sources.

In order to compare pp and AA collisions, as well as collisions at different energies, one needs the variable independent of volume (intensive measure). One can construct scaled variance which corresponds to the width of the particle distribution and the correlation coefficient between particle species A and B .

$$\omega_{\mathrm{A}} \equiv \frac{\langle \mathrm{A}^2 \rangle - \langle \mathrm{A} \rangle^2}{\langle \mathrm{A} \rangle}$$

$$\rho_{\mathrm{AB}} \equiv \frac{\langle \mathrm{AB} \rangle - \langle \mathrm{A} \rangle \langle \mathrm{B} \rangle}{\sqrt{(\langle \mathrm{A}^2 \rangle - \langle \mathrm{A} \rangle^2)(\langle \mathrm{B}^2 \rangle - \langle \mathrm{B} \rangle^2)}}$$

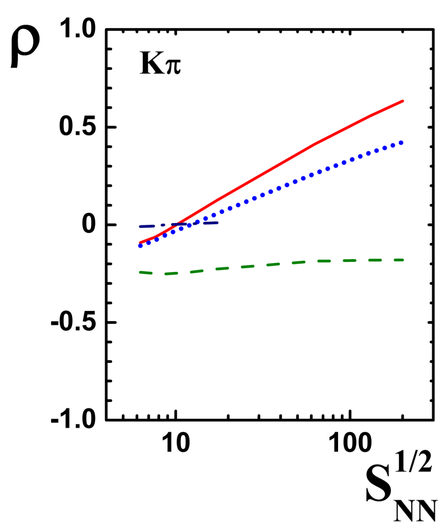

Fig. 2: Correlation coefficient for pions and Kaons in HSD transport model for AA and pp collisions, also within NA61 (NA49) acceptance, and in microcanonical ensemble with full charge and energy conservation, quantum statistic and resonance decays.

However, scaled variance depends on volume fluctuations, while we need the strongly intensive measure (independent of volume and volume fluctuations) for the search of critical point. Recently, such measures were proposed by M. Gorenstein and M. Gazdzicki (arXiv:1101.4865):

Volume and volume fluctuations cancel for these measures in statistical and independent source models.

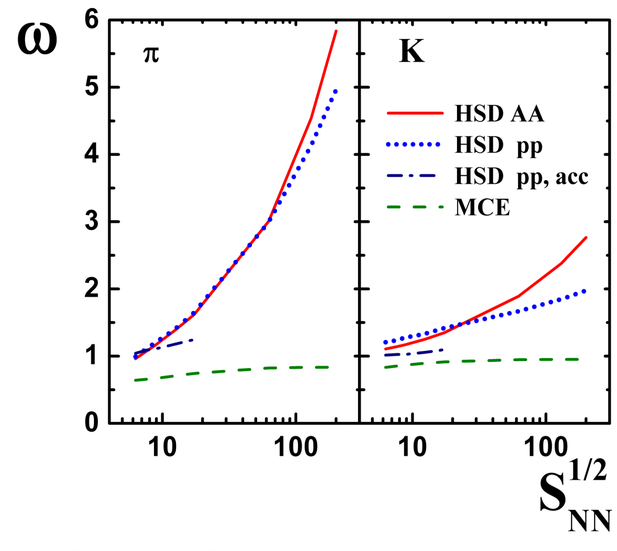

Fig. 1: Scaled variance for pions (pi+ + pi-) and Kaons (K+ + K-) in HSD transport model for AA and pp collisions, also within NA61 (NA49) acceptance, and in microcanonical ensemble with full charge and energy conservation, quantum statistic and resonance decays.

$$\Delta^{\mathrm{AB}} = \frac{\langle \mathrm{B} \rangle \omega_{\mathrm{A}} - \langle \mathrm{A} \rangle \omega_{\mathrm{B}}}{\langle \mathrm{A} \rangle + \langle \mathrm{B} \rangle}$$

$$\Sigma^{\mathrm{AB}} = \frac{\langle \mathrm{B} \rangle \omega_{\mathrm{A}} + \langle \mathrm{A} \rangle \omega_{\mathrm{B}} - 2\rho_{\mathrm{AB}} \sqrt{\langle \mathrm{A} \rangle \langle \mathrm{B} \rangle \omega_{\mathrm{A}} \omega_{\mathrm{B}}}}{\langle \mathrm{A} \rangle + \langle \mathrm{B} \rangle}$$

Some other known fluctuation measures that include first and second moments depend on volume and therefore can not be used for pp and AA comparison

$$\sigma^2_{\mathrm{dyn}} = \nu^{\mathrm{AB}}_{\mathrm{dyn}} = \frac{\langle \mathrm{A} + \mathrm{B} \rangle}{\langle \mathrm{A} \rangle \langle \mathrm{B} \rangle} \left[\Sigma^{\mathrm{AB}} - 1 \right] \sim \frac{1}{\mathrm{V}}$$

or they are an analog of sigma and delta, as phi measure:

$$\Phi = \frac{\sqrt{\langle \mathrm{A} \rangle \langle \mathrm{B} \rangle}}{\langle \mathrm{A} + \mathrm{B} \rangle} \left[\Sigma^{\mathrm{AB}} - 1 \right]$$

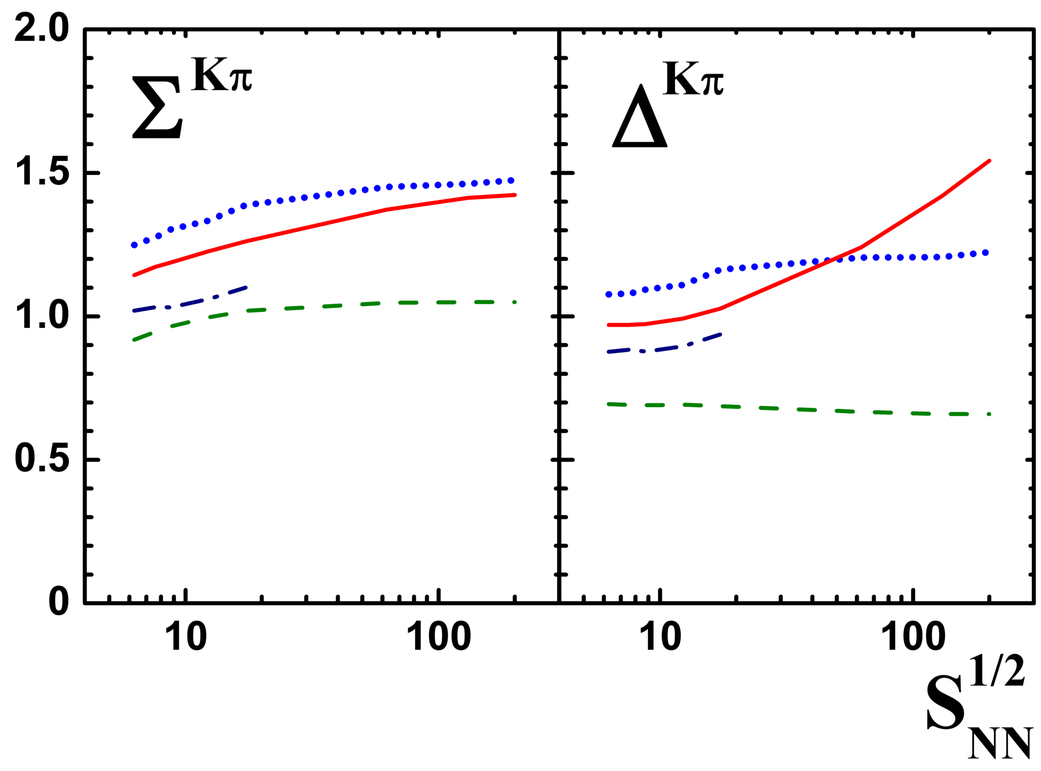

Fig. 3: Strongly intensive fluctuation measures for pions (pi+ + pi-) and Kaons (K+ + K-) in HSD transport model for AA and pp collisions, also within NA61 (NA49) acceptance, and in microcanonical ensemble with full charge and energy conservation, quantum statistic ans resonance decays.

One can see in Fig. 1 the suppression of fluctuations (omega is lower than for Poisson distribution $\omega_{\mathrm{Poisson}} = 1$) in microcanonical ensemble (MCE) and anti-correlation of pions and Kaons in Fig. 2, because of energy conservation in MCE.

HSD gives much larger fluctuations and positive correlations in pp and AA collisions at high energies because of HSD strings that decay into multi-particle states. Finite acceptance (15-20%) lower the signal.

HSD as well as statistical model do not contain any sources for the appearance of critical point. Therefore they can be the background on top of which one can look for the critical point. However, they give different results for scaled variances, see Fig. 1.

The strongly intensive measures in Fig. 3 remain close to each other for HSD and statistical model, and therefore make better background with higher resistance to finite acceptance effects.