STUDY OF EVENT-BY-EVENT FLUCTUATIONS IN HEAVY ION COLLISIONS

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ABSTRACT. We propose Kolmogorov-Smirnov test as a means for recognising event-by-event fluctuations of rapidity distributions in relativistic heavy ion collisions. Such fluctuations may be induced by the spinodal decomposition of the rapidly expanding system during the 1st order quark-hadron phase transition.

1 INTRODUCTION

In heavy ion collisions matter in state with deconfined quarks (quark-gluon plasma) may be produced depending on the collision energy. The deconfined matter expands and cools down very quickly, possibly reaching the line of the 1st order phase transition between the quark phase and the hadronic phase. During this transition the system supercools and if the expansion rate is fast enough it may go through the so-called spinodal decomposition - the fragmentation of quark-gluon plasma into pieces of characteristic size [3, 1, 2]. These fragments will eventually hadronize, emitting particles with a unique rapidity spectrum which reflects a unique nature of fragmentation of a given event. Rapidity spectra thus fluctuate non-statistically on event-by-event basis.

We propose a method for the study of these fluctuations based on Kolmogorov-Smirnov (KS) test. KS test addresses the question if two empirical distributions $F_{n_1}(X), F_{n_2}(X)$ are generated from *the same* underlying probability distribution. The maximum difference D between $F_{n_1}(X), F_{n_2}(X)$ is distributed according to

$$H = \lim_{n_1,n_2\to\infty} P(\sqrt{n}D < t) = \sum_{k=-\infty}^{k=\infty} (-1)^k \exp\left(-2k^2t^2\right) \tag{1}$$

with $n = n_1 n_2/(n_1 + n_2)$.

2 RESULTS

Below we calculate quantity $Q = 1 - H$ for rapidity spectra (empirical distributions $F_{n_1}(X), F_{n_2}(X)$) of random pairs of simulated events where rapidities were first generated according to test (Gaussian) distributions and then for pairs of events generated with our Monte Carlo droplet generator which simulates particle emission from the fragments emerging from spinodal decomposition. If rapidity spectrum for each event is generated from the same underlying distribution, we expect an equal number of event pairs at any Q - a uniform, constant line histogram (we expect this in the case when no fragments are present). For events drawn from different underlying distributions the pairs group at low Q values, indicating non-statistical fluctuations.

This point is illustrated in Fig. 1 where we show results of KS test on data randomly generated from two different Gaussian distributions: **a)** half of 10^5 events was generated according to the distribution $(\mu, \sigma) = (1, 0.1)$, half according to $(\mu, \sigma) = (2, 0.1)$, **b)** half according to $(\mu, \sigma) = (1.99, 0.1)$, half according to $(\mu, \sigma) = (2, 0.1)$. Multiplicities ranged in both cases from 8 to 535. The Q value was calculated for 10^5 random pairs of these events and the histogram of the number of pairs as a function of the corresponding Q value was plotted.

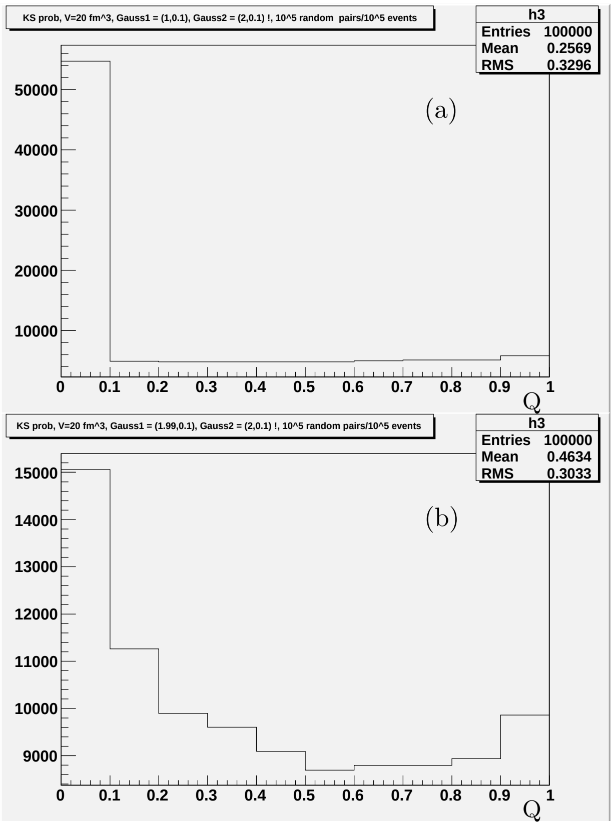

Fig. 1. KS test for data from two different Gaussian distributions: **a)** $(\mu, \sigma) = (1, 0.1)$ and $(\mu, \sigma) = (2, 0.1)$, **b)** $(\mu, \sigma) = (1.99, 0.1)$ and $(\mu, \sigma) = (2, 0.1)$.

We can see in Fig. 1a that half of pairs is distributed uniformly (5000 pairs in each bin) and half (50 000) is concentrated in the first bin. The first half consists of events generated from the same distribution (like events) which form a constant line, the second half consists of events from opposite distributions (unlike events) which group at small Q values. Note that the statistical fluctuation is $\pm\sqrt{N}$. The deviation from the constant line at $N = 10000$ above $\sqrt{N} = 100$ represents non-statistical fluctuation.

Fig. 1b shows the power of the KS test. Although the two Gauss distributions differ by just 0.01 in their mean value ($\sigma = 0.1$), the KS test clearly recognized that the events were not drawn from a single distribution.

After the test of KS test on two Gaussian distributions, we applied the KS test on data generated with the Monte Carlo droplet generator. This generator simulates particle rapidity spectra emerging from the fragments (droplets) originating in the spinodal decomposition. Droplets are generated from a blast-wave source with tunable parameters. In Fig. 2 we show results of KS test on droplets of size a) 50 fm^3 and b) 10 fm^3 at temperature $T = 175$ MeV. As before, we used a sample of 10^5 event pairs randomly chosen out of 10^5 events. All particles come from the droplets. Non-statistical fluctuations are clearly visible in both cases and grow with the droplet size.

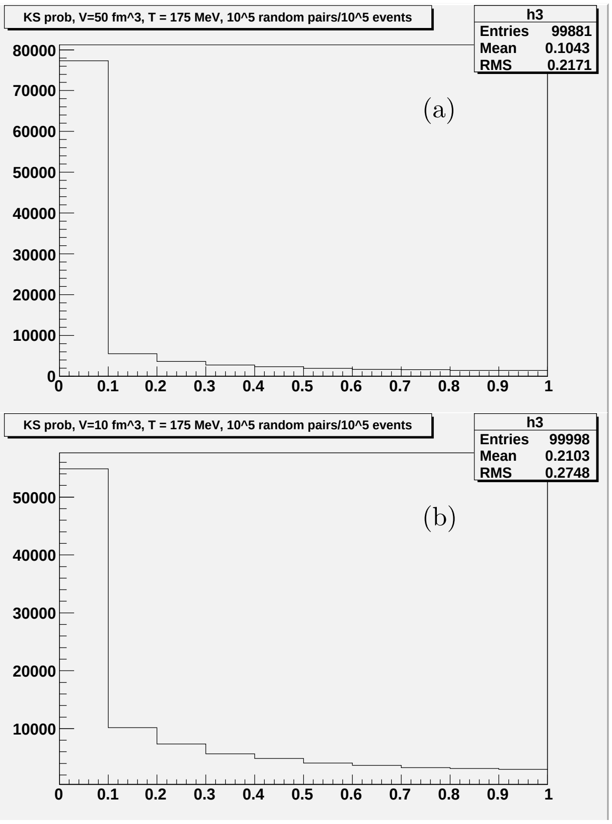

Fig. 2. KS test on droplets of size a) 50 fm^3 and b) 10 fm^3 at temperature $T = 175$ MeV.

Finally, we fix the droplet size at 10 fm^3 ($T = 175$ MeV) and vary the percentage of particles originating in the droplets. In Fig. 3a 20% of particles comes from the droplets as compared with 60% in Fig. 3b. Again the sample was 10^5 event pairs chosen randomly from 10^5 simulated events. The non-statistical fluctuations are present even for the 20% case. They vanish as expected for the 0% case (not shown).

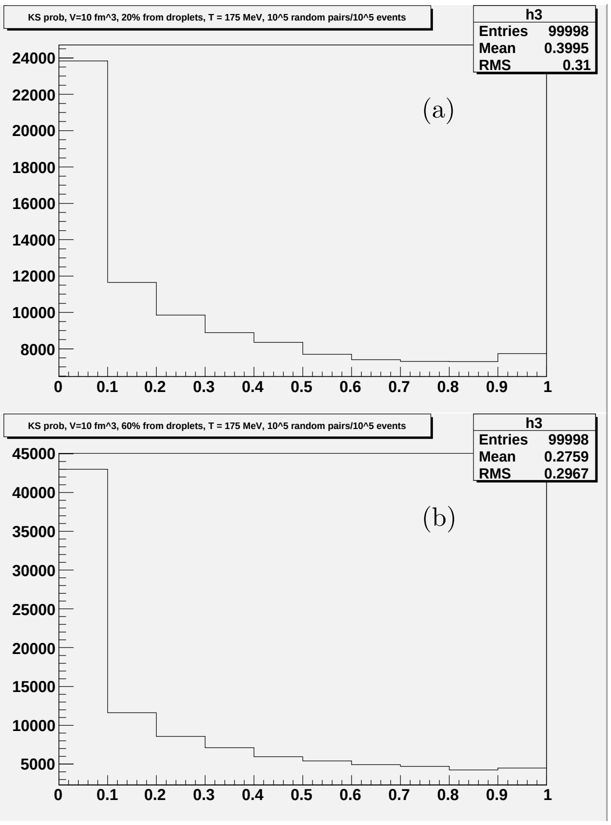

Fig. 3. KS test for the case when only a fraction of particles comes from the droplets: a) 20% and b) 60%.

3 CONCLUSIONS

We studied event-by-event fluctuations of rapidity distributions by means of the KS test. We have shown that the KS test can recognize whether or not the rapidity spectra are drawn from the same underlying distribution. If spinodal decomposition occurs during the 1st order quark-hadron phase transition, the resulting droplets lead to many underlying distributions and thus to event-by-event fluctuations. As a next step, we plan to apply this method on data by NA49 collaboration. Of course, if the fluctuations are indeed there, it does not follow automatically that they are caused by the droplets.

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