EQUILIBRATION IN HEAVY ION COLLISIONS STUDIED VIA DYNAMICAL FLUCTUATIONS*

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A novel method to study fluctuations in distributions of reaction products has been applied to investigate the process of chemical and thermal equilibration of nuclear matter in Ru+Ru reaction at 1.69 A GeV. The analysed data were obtained with the FOPI detector. Nontrivial fluctuations of the chemical composition and of transverse momenta, and their dependence on centrality were studied. Fluctuations of pion multiplicity were found to decrease with increasing centrality. This kind of dependence is less evident in the case of proton transversal momentum fluctuations.

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Important information on the dynamics of nuclear collisions can be obtained from analyses of correlations and fluctuations. In the present work, a method first proposed to study the equilibration process at high–relativistic energies, has been applied in the range of low–relativistic energies.

In the case of nuclear reactions with high particle multiplicity, two extreme scenarios can be considered: the "superposition" and the "equilibration" scenarios. In the former, a nucleus–nucleus (AA) collision is described as the incoherent sum of the first nucleon–nucleon (NN) interactions. In the latter, one assumes that the colliding system reaches the state of equilibrium due to multiple interactions.

The method, proposed by Gaździcki and Mrówczyński [1], is based on the observation that in NN interactions at high–relativistic energies, averaged values of certain particle observables are correlated with the event multiplicity. This property can be used to probe the dynamics of AA collisions by

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measuring to what degree the correlations present in NN interactions are modified in AA collisions. Those correlations should also be present in nuclear reactions if they are simple superpositions of NN interactions. On the other hand, if nuclear matter reaches the equilibrium state, such correlations would be lost as a result of multiple interactions.

The quantity Φ, proposed [1] as a parameter sensitive to the correlations, is defined as

$$\Phi = \sqrt{\frac{\langle Z^2 \rangle_{\mathrm{ev}}}{\langle N \rangle_{\mathrm{ev}}}} - \sqrt{\overline{z^2}} \quad ,$$

with $Z = \Sigma_{i=1}^{N} z_i$ and $z_i = x_i - \bar{x}$, where x_i is the variable of interest of the i-th particle in an event of multiplicity N, $\bar{x}$ and $\overline{z^2}$ are averages of the inclusive distributions of x and z^2 respectively, and $\langle\,\rangle_{\mathrm{ev}}$ denotes averaging over events.

The parameter Φ has different values for the two mentioned extreme scenarios:

- in the "superposition" scenario, when correlations should be present in the final state, the Φ value would be exactly the same for NN and AA collisions;
- in the "equilibrium" scenario correlations should be lost and so the Φ value would be equal to zero.

The intermediate value of Φ may indicate an intermediate mechanism or possibly suggest the dominating one.

To test the applicability of this method at low–relativistic energies, the data from Ru+Ru at 1.69 A GeV beam energy were analysed. Reaction products were detected by the FOPI multidetector system [2]. The data for this analysis were taken from two subdetectors: the Central Drift Chamber (CDC) and the Outer Plastic Wall of scintillators (PLAWA).

As the mechanism of nuclear reaction may depend on the centrality of collision, it is necessary to select events from specific ranges of the impact parameter. This was done using two selection criteria. One of them is based on the multiplicity of charged particles detected by the PLAWA detector (PM). Assuming monotonic dependence between impact parameter b and multiplicity of particles detected by PLAWA, we divided the sample of events into three categories:

- central collisions ($b \leq 3$ fm, PM ≥ 53);
- semicentral collisions (3 fm $< b \leq 5$ fm, $40 \leq$ PM < 53);
- pheripheral collisions ($b > 5$ fm, PM < 40).

In addition to the PM multiplicity criterion, the criterion based on the transverse-to-longitudinal energy ratio (ERAT) was used to choose more central collisions. For each class of events the value of Φ was calculated.

The variable used to study chemical equilibration [3] is defined as

$$x_i = \delta(h^i - h_0) = \begin{cases} 1 \text{ for } h^i = h_0 \\ 0 \text{ for } h^i \neq h_0 \end{cases},$$

where h^i denotes the type of the i-th detected hadron and h_0 — the selected hadron type which is produced in the collision. In our case the amply produced π–mesons were chosen for h_0.

In Fig. 1, values of the Φ parameter related to chemical equilibrium, are shown for various ranges of impact parameter. The vertical bars represent statistical errors, the horizontal ones — equivalent sharp cut off limits of impact parameter.

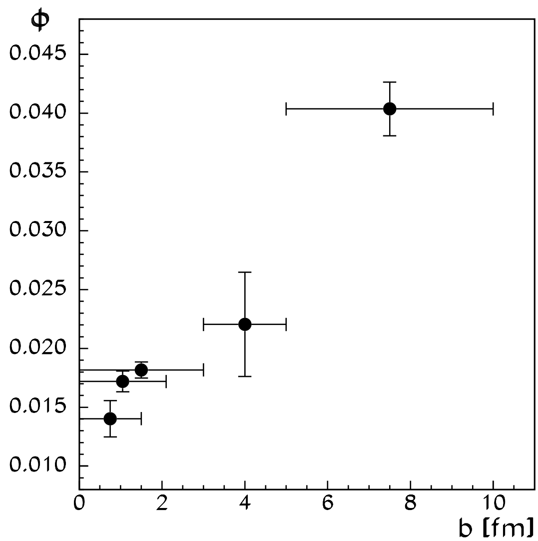

Fig. 1. Values of the Φ parameter related to chemical eqiulibrium for various ranges of the impact parameter. Details are given in the text.

The value of Φ clearly depends on the centrality of the collision. It decreases monotonically upon changing from peripheral to semicentral, central (selected with PM only) and more central (selected by additional cuts ERAT> 0.58 and ERAT>0.72) collisions. This seems to confirm the intuitive expectation that nuclear matter is more chemically equilibrated in central than in non–central collisions.

For studying the fluctuations related to the thermal equilibrium, the choice of transverse momentum $p_\perp$ as a variable is appropriate since it is

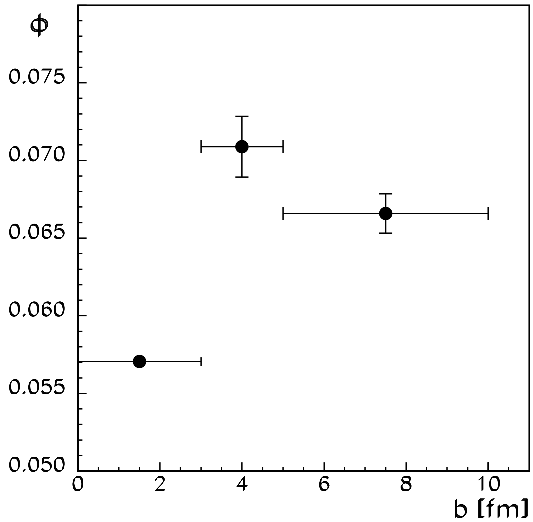

Fig. 2. Values of the Φ parameter related to thermal equilibrium for various ranges of the impact parameter. Details are given in the text.

generated during the collision. In Fig. 2, the Φ values calculated for proton transversal momenta are presented for various ranges of the impact parameter. The ranges of b have been chosen by the PM criterion only, since the use of an ERAT cut could bias the selection of events and therefore the observed fluctuations of $p_\perp$. It seems that the value of Φ is smaller in central than in non–central collisions.

Summarizing, the value of Φ parameter related to chemical composition decreases with decreasing impact parameter. This kind of dependence is less evident when the fluctuations of proton transversal momentum are studied. The observed trends can be interpreted as an indication that central collisions may lead to states which are closer to equilibrium. The agreement with this intuitively expected result can be treated as a test of the new method, which was for the first time applied to experimental data at low–relativistic energies. A more conclusive and quantitative interpretation should be supported by microscopic model simulations.

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