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Bimodality: A possible experimental signature of the liquid–gas phase transition of nuclear matter

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Abstract

We have observed a bimodal behaviour of the distribution of the asymmetry between the charges of the two heaviest products resulting from the decay of the quasi-projectile released in binary Xe + Sn and Au + Au collisions from 60 to 100 MeV/u. Event sorting has been achieved through the transverse energy of light charged particles emitted on the quasi-target side, thus avoiding artificial correlations between the bimodality signal and the sorting variable. Bimodality is observed for intermediate impact parameters for which the quasi-projectile is identified. A simulation shows that the deexcitation step rather than the geometry of the collision appears responsible for the bimodal behaviour. The influence of mid-rapidity

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emission has been verified. The two bumps of the bimodal distribution correspond to different excitation energies and similar temperatures. It is also shown that it is possible to correlate the bimodality signal with a change in the distribution of the heaviest fragment charge and a peak in potential energy fluctuations. All together, this set of data is coherent with what would be expected in a finite system if the corresponding system in the thermodynamic limit exhibits a first order phase transition.

Keywords: NUCLEAR REACTIONS Sn(Xe, X), Au(Au, X), $E = 60$–100 MeV/nucleon; measured fragments charge distributions, quasi-projectile and quasi-target contributions, transverse energy, correlations; deduced bimodal behavior, possible phase transition features.

1. Introduction

Many experimental features suggestive of the liquid–gas phase transition of nuclear matter have been observed in the Fermi energy regime of nucleus–nucleus collisions. Among these features are: abnormal partial energy fluctuations [1,2], charge correlations [3], a double peaked distribution of an order parameter ("bimodality") [4,5], fluctuation properties of the heaviest fragment size [6,7], Fisher scaling [8], vaporisation [9], flattening of the caloric curve [10,11]. In the present paper, we concentrate on the bimodality signal.

The discontinuity of the order parameter at a first order phase transition is expected to be replaced in a finite system by a bimodal distribution of the order parameter close to the transition point [12]. If the order parameter is one-dimensional [15] and if the transition has a finite latent heat, the bimodality should be observed in the canonical ensemble, the transition temperature being defined as that at which the two peaks have the same height [13]. In the fragmentation transition case, the size of the heaviest cluster produced in each event is an order parameter in many different models [14] including the lattice-gas model of the liquid–gas phase transition [15]. In this picture, when the size of the heaviest fragment is large, the system is mostly on the liquid-like side, whereas if it is small one is mostly dealing with a gas-like behaviour.

An example is given in Fig. 1 obtained in the lattice-gas approach (see for instance Refs. [13, 16]). For temperatures outside of a small range around the transition temperature, the size of the largest fragment exhibits single-humped distributions whereas two peaks of the same height are obtained at the transition temperature value. This result which is obtained for an equilibrated system in the canonical isobar ensemble remains approximately valid even if part of the available energy is not thermalized. This is shown in Fig. 2 in which an aligned momentum has been randomly added for each particle, which simulates the dynamical effects corresponding to the memory of the aligned beam momentum in the entrance channel. Several percentages of aligned momenta have been considered ranging from zero percent (purely thermal situation) to 100 percent (same amount of aligned and thermalized momentum). The bimodality signal is robust in the sense that it is observed even if a sizable amount of the total available momentum is still aligned along the beam direction, with only a slight change of the deduced transition temperature. Only if the aligned momentum is as important as the thermal one (lower right in the figure) the distribution is weakly bimodal and mimics a flat distribution expected for a continuous transition [12, 14].

Guided by these considerations, preliminary evidences of bimodal behaviours in some static observables have been obtained in previous data concerning the systems Ni + Au [18], Ni + Ni [19], and Xe + Sn [20]. In none of these cases, a clear bimodality was observed in the distribution of the heaviest fragment charge. A possible reason is that Refs. [18–20] concern