Bimodality and Scaling-Signs of phase transition in Nuclear Multifragmentation ?

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Multifragmentation is phenomenon in which nuclear system decays to a final configuration that contains multiple intermediate mass fragments (IMF's) of charge $3 \leq Z \leq 30$

- Discovered in cosmic rays
- Later observed in accelerator experiments
- The name 'multifragmentation' introduced in 1976 (J.P. Bondrof)

These findings stimulated many theoretical models to put forward the attractive idea that copious production of IMF's may be related to a liquid-gas phase transition in nuclear matter.

Today there are two experimental approaches to prepare the hot nuclear system for multifragmentation examination:

- **Nearly symmetric A+A reactions in the Fermi-energy regime** (E/A~20-100 MeV) (introduces compression, angular momentum, neck region)

- **Very asymmetric h(He, π-meson)+ A reactions at several GeV** (small compression, small angular momenta, single hot source => suitable to study the thermal component of the multifragmentation)

- **“Desperately seeking signs of a phase transition in nuclear matter”**

Liquid-Gas Phase transition signals:

Critical behaviors: Power law, critical exponents

Charge correlations: Spinodal decomposition

Abnormal fluctuations: Negative capacities

Caloric curves: E^*-T relationship

Universal scalings: Fisher, Δ-scaling

Bimodality:….!

Recently, the most attention was paid to the bimodality signal and Δ-scaling observed in heavy ion collisions around the Fermi energy

Bimodality means that the probability distribution of an order parameter of the considered system at phase transition exhibits two peaks separated by a minimum. Bimodality is a property of finite systems undergoing a first-order phase transition.

As relevant **order** parameters for multifragmentation process the charge ($\mathbf{Z_{max}}$) of the largest fragment in one event and the charge asymmetry (**varsym**=$(Z_{max1}-Z_{max2})/(Z_{max1}+Z_{max2})$) between the two largest fragments in events were proposed.

Δ-scaling behavior is expected on the basis of model-independent theory of the universal fluctuations. According to this theory experimental observables related to an order parameter can be identified through their Δ–scaling behavior. Theory was tested on the INDRA collaboration data and it was claimed that $\mathbf{Z_{max}}$ plays the role of an **order** parameter defining two different regimes according to the scaling properties of its fluctuations.

It was concluded that both bimodality and Δ-scaling are a very promising signatures of phase transition but some open questions need to be answered in order to firmly asses the validity of these signals.

One of the proposed directions of further investigations is the examination of the **asymmetrical** reactions i.e. **the collisions of light ions (or nucleons/pions) with heavy targets.**

Our experiment:

14.6 GeV ^{4}He + Au

Our experiment

- Studied interactions: 14.6 ^{4}He+Au

-Detector used: CR-39

Advantages of our method:

-low detection threshold for examined fragments

-angular, charge and energy distributions can be precisely determined

-allows the study of the internal correlations in one event

-enables one model independent determination of parameters important for understanding of the interaction

Experiment:

-Detection: CR-39 plastic track detector in sandwich technique

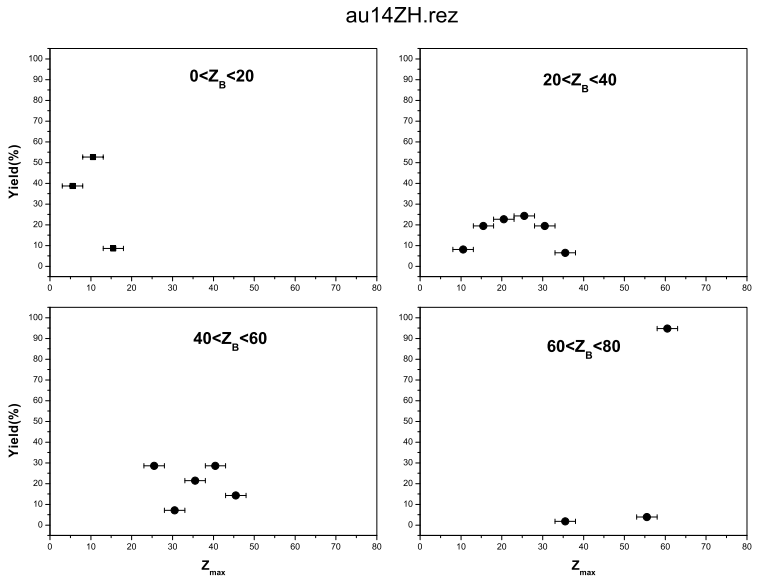
-Irradiation: 14.6 GeV ^{4}He at synchrophasotron in Dubna

-Track etching: 6.25 N NaOH at 70^{o}C for 3h

-Fragment identification: from the measured parameters of the finished tracks

-Analysis: event by event analysis in 4π geometry

-Relevant fragments: intermediate mass fragments (IMF's,$3 \leq Z \leq 30$)



Distributions of Z_{max} for different bins of Z_B

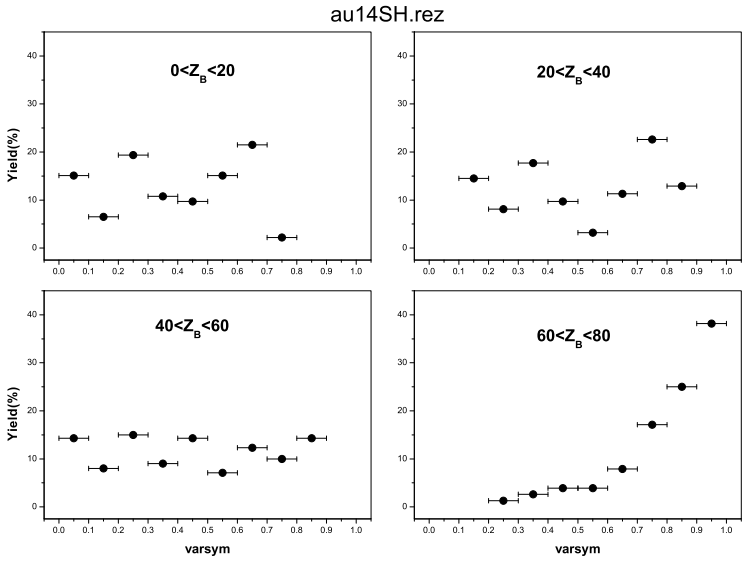
Sorting parameter: $Z_B=\Sigma Z_i$

First

First bin: only multifragmentation events

Forth bin: only events of the residue type

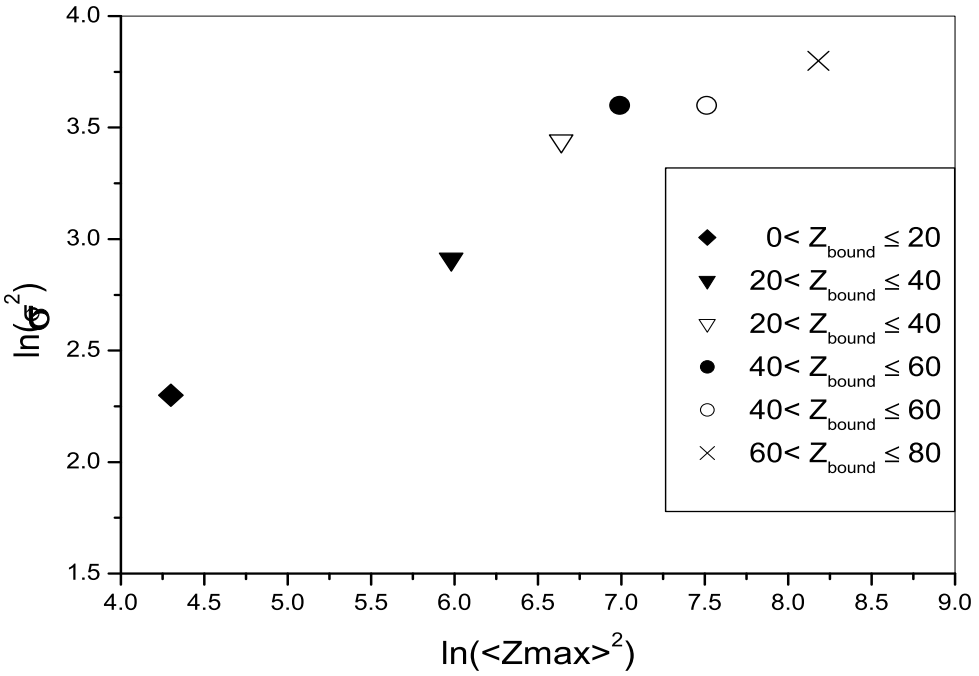
Third bin: **bimodality**



Distributions of varsym for different bins of Z_B

Confusion: for the same set of events Z_B and varsym show different behavior!

The unclear structure in varsym (theoret. expected : Lopez et al., Phys.Rev.Lett .**25,**242701 (2005)



-Selection is made via the bimodality order parameter:

varsym<0.7 and varsym≥0.7

-Transition can be observed in the region where bimodality occurs

-The transition from one class of events to other may indicate transition from an ordered phase to a disordered phase as it is case in phase transition

Δ-scaling for events from 14.6 GeV ^{4}He+Au interaction. Events with small charge asymmetry (full symbols) correspond to Δ~1, and those with large charge asymmetry to Δ~1/2.

Bimodality and Δ–scaling :Z_{max} order parametar in possible PT

Contradiction:

Bimodality: 1st order phase transition

Scaling: 2nd order phase transition

The finite size effects have to be taken into account!

The finite size effects may mimic critical phenomena and therefore many results interpreted in scaling framework are consistent with liquid-gas coexistence (Gulminelli et al.,Phys.Rev. C71, 054607 (2005))

Conclusion:

The **distributions** of the largest fragment charge and the charge asymmetry between the two largest fragment detected in each event have been studied for events from 14.6 GeV ^{4}He+Au interaction. As a sorting parameter we used Z_B.

The **bimodality** is observed for $\mathbf{Z_{maX}}$ distribution while the varsym distributions do not show clear structure.

Δ– **scaling** for $\mathbf{Z_{max}}$ is observed when the events with large charge asymmetry are separated from events with small charge asymmetry. The events with large varsym correspond to Δ~1/2 and the events with small varsym correspond to $\Delta \sim 1$.

Our results indicate that the **charge of the largest fragment** exhibits behavior of a reliable **order parameter** for the first order phase transition in hot nuclei.