Bimodality: a robust signature of the (liquide-gas?) phase transition of nuclear matter

The possible signals:
- caloric curve
- negative heat capacity
- charge correlations
- delta scaling
- Fisher scaling
- bimodality

This talk is devoted to:
- bimodality
- possible interpretation in terms of phase transition
- correlations with other signals: delta scaling and negative heat capacity
Advantages: bimodality is a direct and robust signal

It is still observed if the system is out of equilibrium

Lattice-gas approach
216 particles

Momentum distribution
beam

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Data and analysis

- Symmetrical collisions
  Au + Au and Xe + Sn from 60 to 100 MeV/u

- Set up : INDRA at GSI (Indra + Aladin groups)

Main features of the analysis

● possible separation of QP and QT contributions
● no event rejection (but completeness -80% - on QP side)
● bimodality analysis : on the QP side
● sorting variable : QT side transverse energy of LCP (Etrans)

→ two advantages :
  - no artificial sorting effect
  - Etrans/A ≈ temperature (if thermalization is achieved)
vpar-vper alpha - Au+Au 80MeV/u

8 zones in Etrans for LCP on QT side
The bimodality variables

\[ \text{Varsym} = \frac{Z_{\text{max}} - Z_{\text{max-1}}}{Z_{\text{max}} + Z_{\text{max-1}}} \]

\[ \text{Varsym} \approx 1 \quad \leftrightarrow \quad \text{A big residue + light particles} \]
\[ \text{Varsym} \approx 0 \quad \leftrightarrow \quad \text{only small fragments} \]

Remarks: if fission occurs (it is easily recognized), the nucleus before fission is reconstructed
(\(Z_{\text{max}} = Z_{\text{FF1}} + Z_{\text{FF2}}\))

Varsym can be slightly negative if a smoothing procedure is added on Z (to avoid small integer
number effects)
varsym - Au + Au 80 MeV/u

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Evolution with system mass and incident energy

Proportionnality with the system mass
cohrent with a temperature effect
cohrent with a phase transition behaviour

Proportionnality with the bombarding energy
one may understand this result
if $E_{\text{trans}}$ is polluted by preequilibrium

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The role of midrapidity emission

Mid-rapidity does not explain the qualitative change:
residue $\rightarrow$ multifragment emission
Reducing of dynamical effects

The reduction of entrance channel memory (dynamical effects) leads to

- a stronger bimodality signal
- a smaller $E_{\text{trans}}$ in the bimodality region

This result supports the hypothesis that the deposited energy is the relevant parameter.
Bimodality
the two «solutions» should correspond to different excitation energy

Conclusions:
coherence between data and predictions in the phase transition (lattice gas) picture

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Bimodality
the two «solutions» should correspond to the same temperature

difficulty of finding an adapted thermometer:
- residue-like events: slope of the alpha particle spectra
- multifragment events: isotopic double ratio thermometer

Conclusions:
coherence between data and predictions in the phase transition (lattice gas) picture:

*the two bimodality solutions correspond to different excitation energies but to similar temperatures.*
Coherence between bimodality and negative heat capacity but one has to select compact events.
Crossing of the bimodality and delta scaling signals

\[ \Phi(z_\Delta) = \Phi \left( \frac{Z_{\text{max}} - \langle Z_{\text{max}} \rangle}{\langle Z_{\text{max}} \rangle^\Delta} \right) \]

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Crossing of the bimodality and delta scaling signals

\[ \Phi(z_\Delta) = \Phi \left( \frac{Z_{\text{max}} - \langle Z_{\text{max}} \rangle}{\langle Z_{\text{max}} \rangle^{\Delta}} \right) \]

Coherence between bimodality and delta scaling:

transition from order to disorder

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Conclusions

- Bimodality is a general feature for binary collisions
- Bimodality is better evidenced if dynamical effects are reduced
- The excitation energies associated with both « phases » are different; the temperatures are similar
- Coherence between bimodality and negative heat capacity for compact events (for Au+Au systems).
- Coherence between bimodality and delta scaling
- Dynamical effects (mid rapidity, neck) does not seem to explain the data

All these results are coherent with a phase transition behaviour observed for finite and not fully equilibrated systems

The question of the order of the transition is still open to discussion, but many features are coherent with a first order phase transition.

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