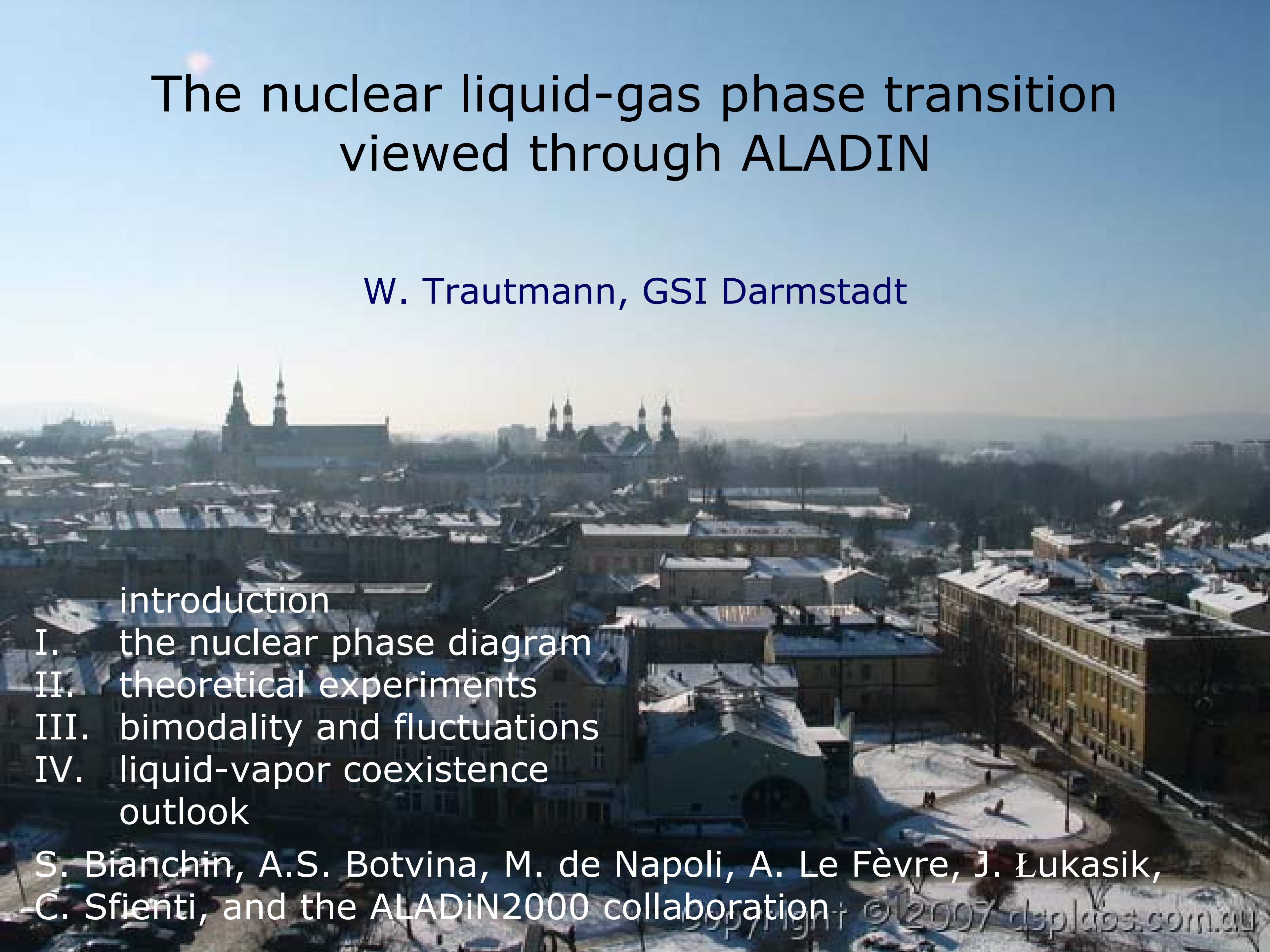
The nuclear liquid-gas phase transition viewed through ALADIN

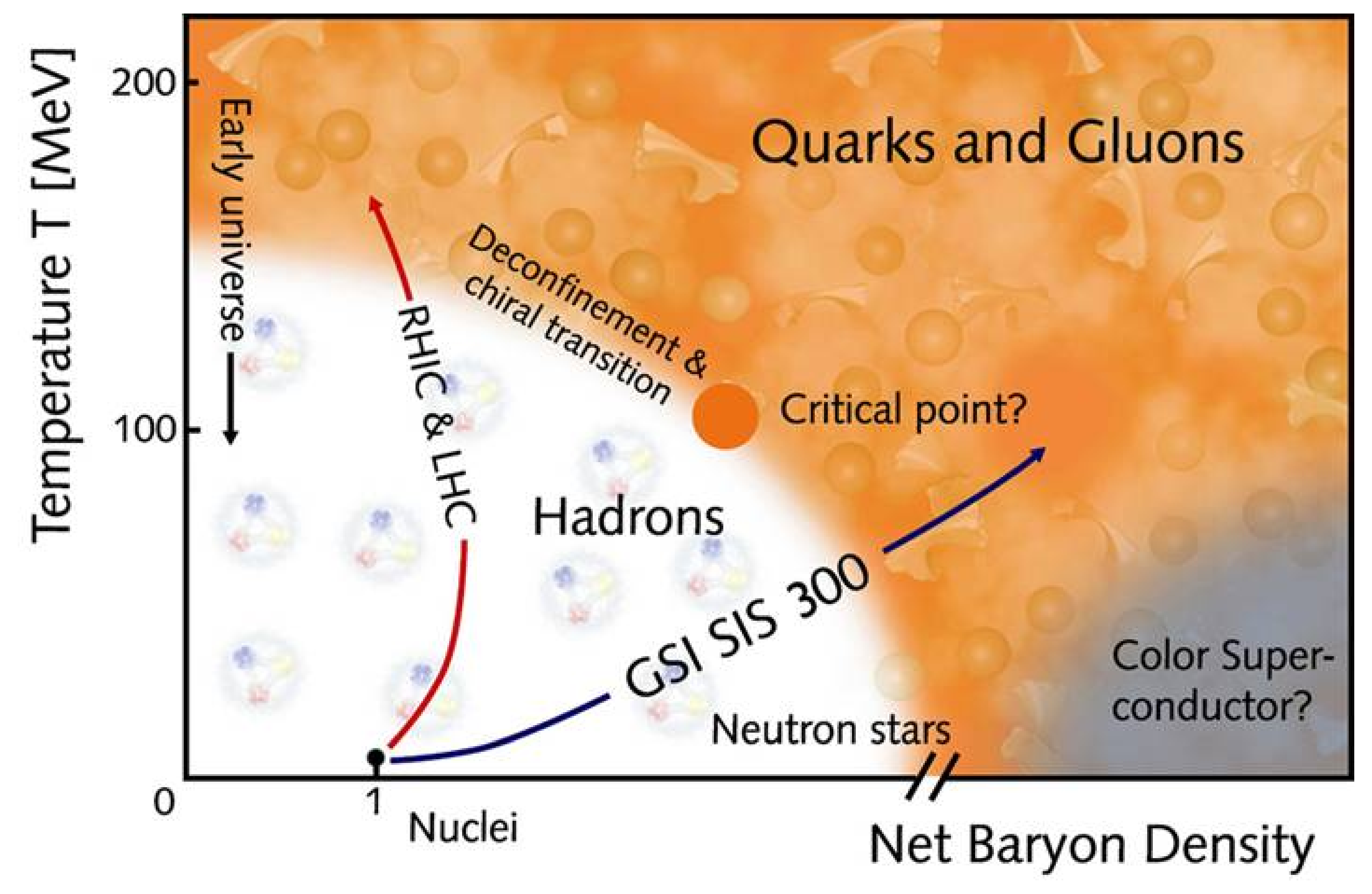
W. Trautmann, GSI Darmstadt



introduction
I. the nuclear phase diagram
II. theoretical experiments
III. bimodality and fluctuations
IV. liquid-vapor coexistence
outlook

S. Bianchin, A.S. Botvina, M. de Napoli, A. Le Fèvre, J. Łukasik, C. Sfienti, and the ALADiN2000 collaboration

the phase diagram of strongly interacting matter

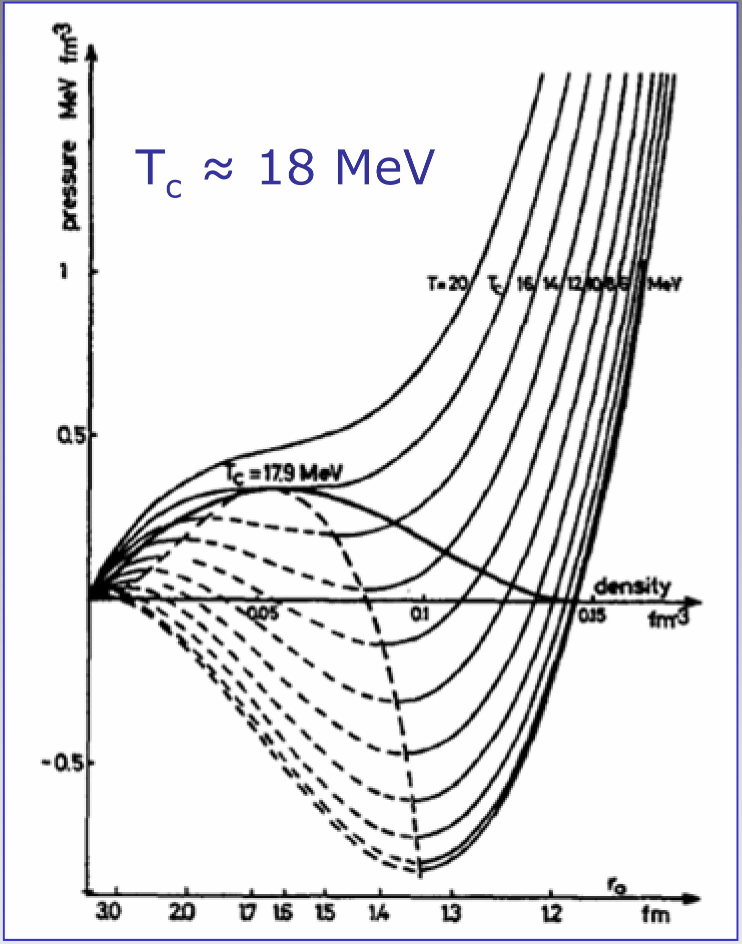


the nuclear phase diagram

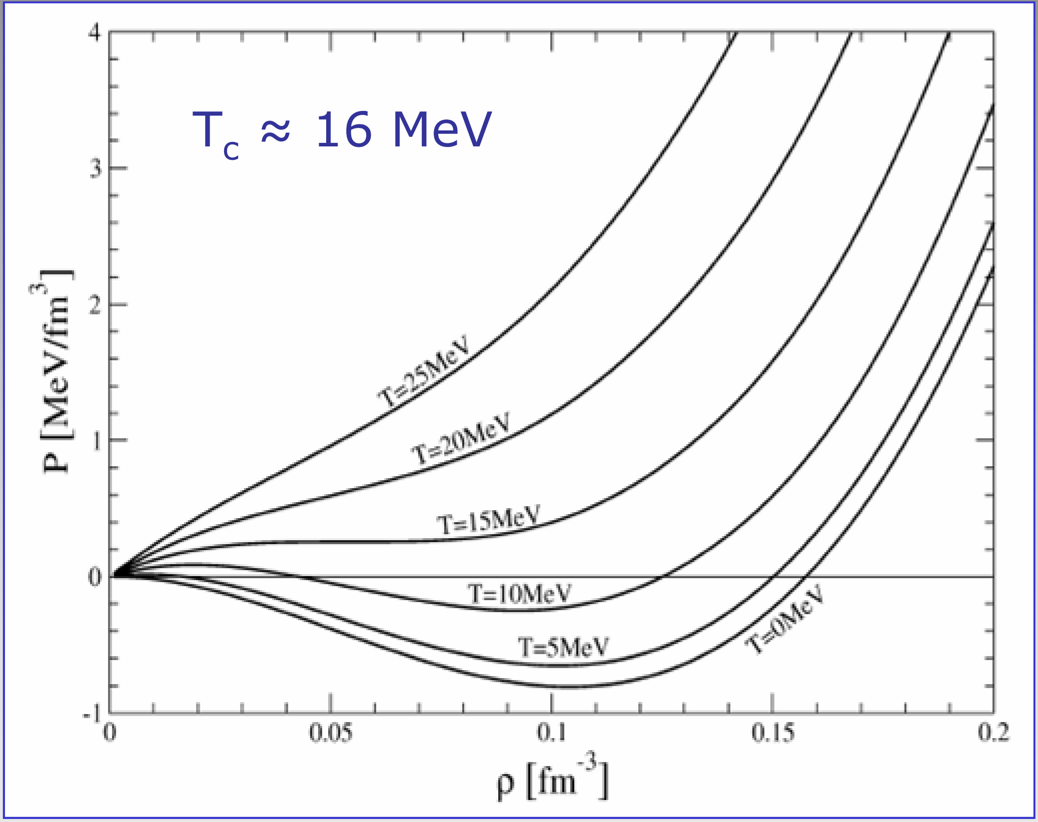
temperature dependent
Hartree-Fock theory

1976 - today

chiral effective
field theory



$T_c \approx 18$ MeV



$T_c \approx 16$ MeV

from Sauer, Chandra, Mosel
Nucl. Phys. A 264, 221 (1976)

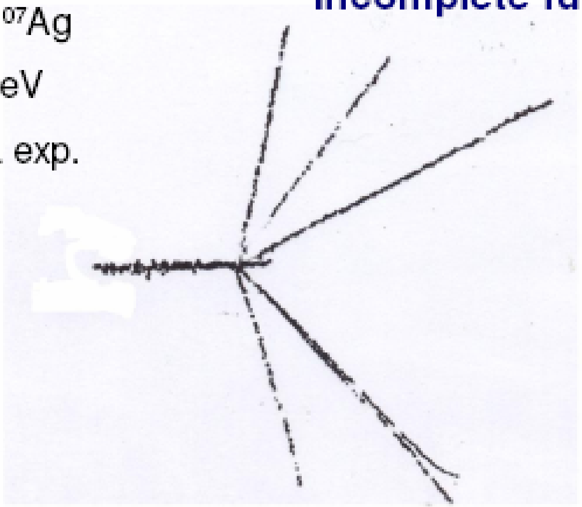
from Fritsch, Kaiser, Weise
Nucl. Phys. A 750, 259 (2005)

Incomplete fusion

^{16}O + ^{107}Ag

30A MeV

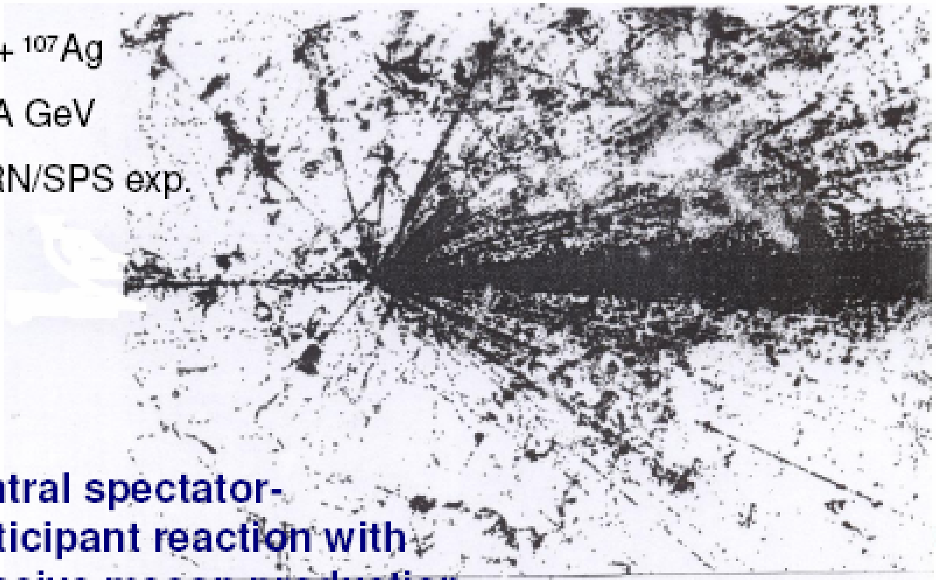
GANIL exp.



^{16}O + ^{107}Ag

200A GeV

CERN/SPS exp.



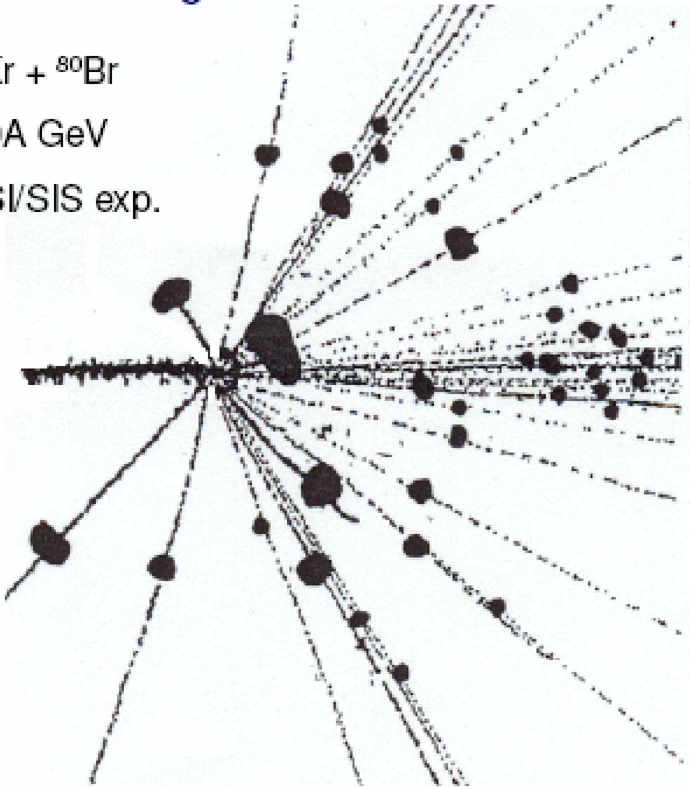
Central spectator-participant reaction with massive meson production

Multifragmentation

^{86}Kr + ^{80}Br

1.0A GeV

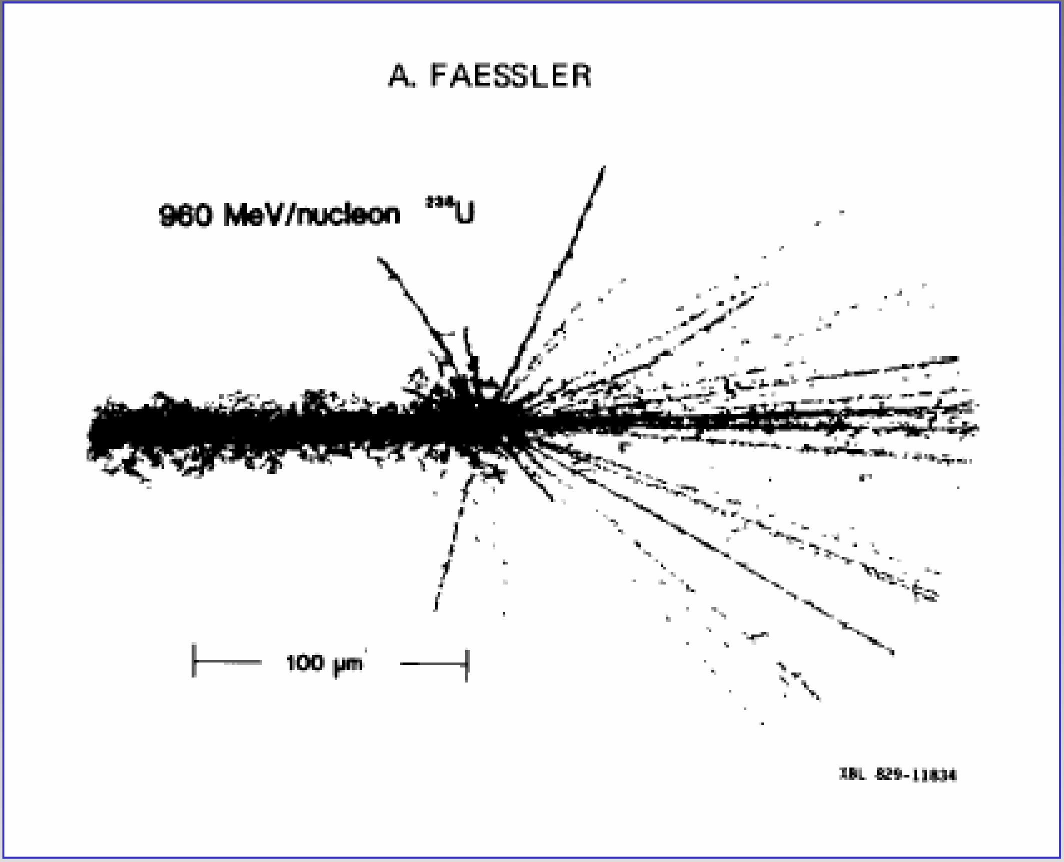
GSI/SIS exp.

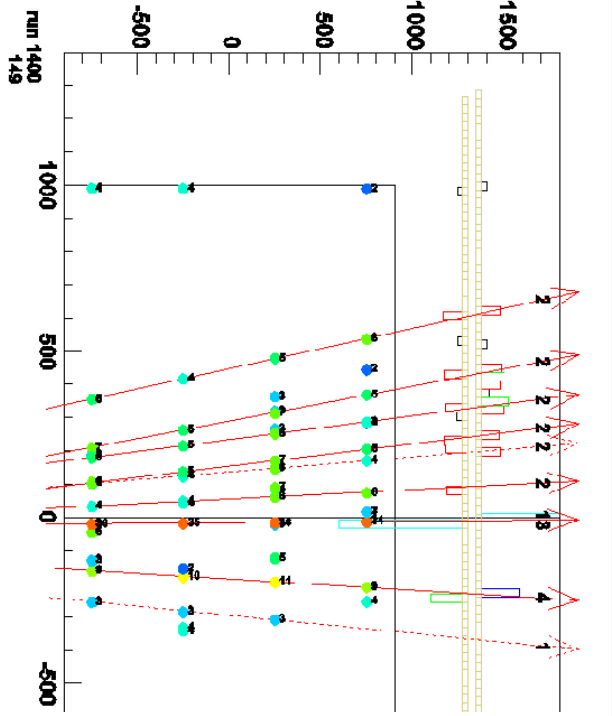


emulsion data

taken from talk by Bo Jakobsson at NUFRA2007 in Kemer/Antalya
see http://fias.uni-frankfurt.de/nufra2007/

projectile fragmentation with ALADIN



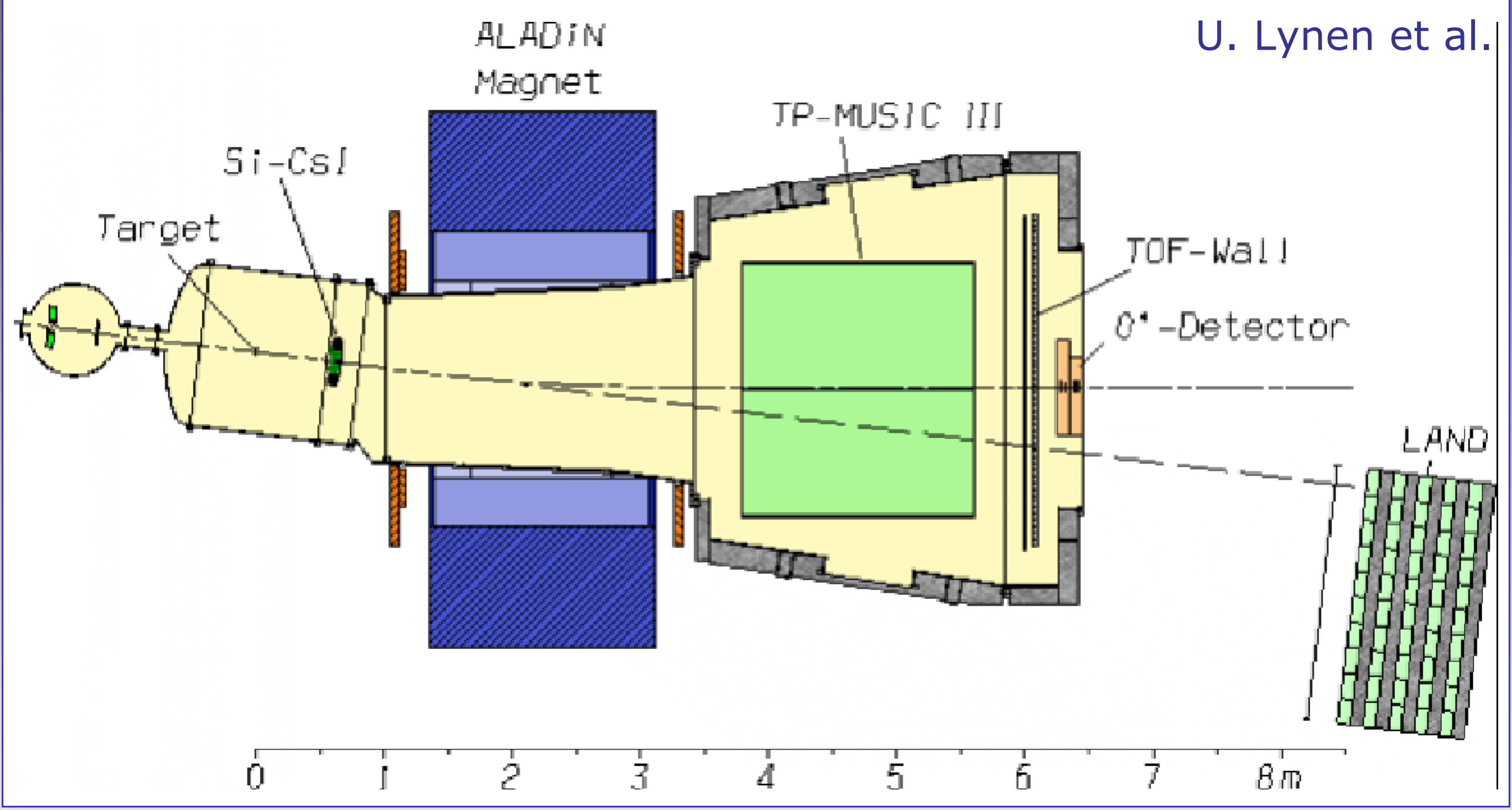


Z, tracking and ToF
multi-hit recognition

"... the future has already started
and we have to go back to work not to miss it."

taken from summary talk by A. Faessler at Int. Conf. on Nucleus-Nucleus Collisions, MSU, East Lansing, Michigan, Sept/Oct 1982
Nucl. Phys. A 400 (1983) 565; H.H. Heckman et al., Phys. Rev. C 27 (1983)

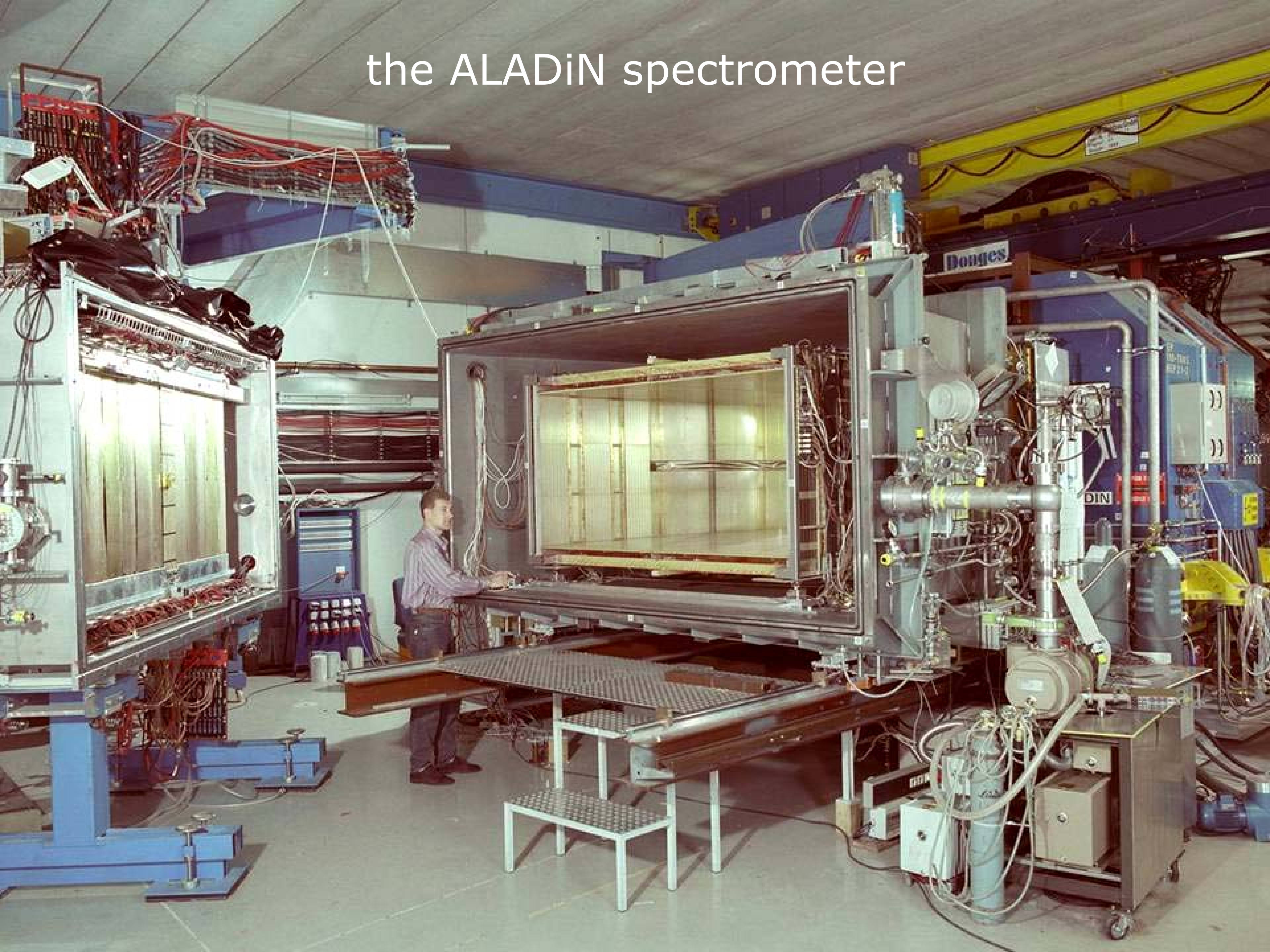
the ALADiN spectrometer



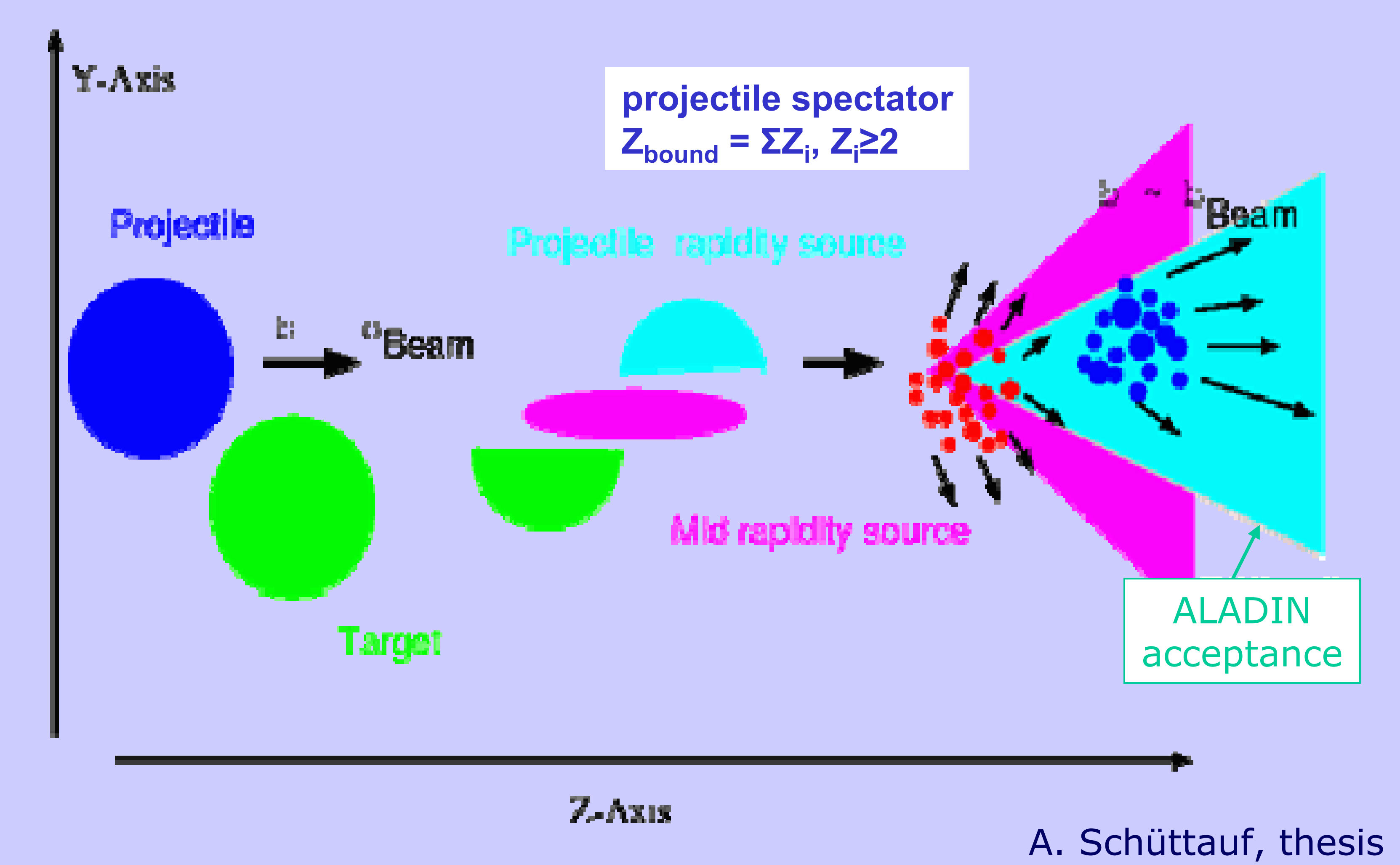
U. Lynen et al.

A, Z resolution, large acceptance and dynamic range, no threshold, neutrons

the ALADiN spectrometer



projectile fragmentation

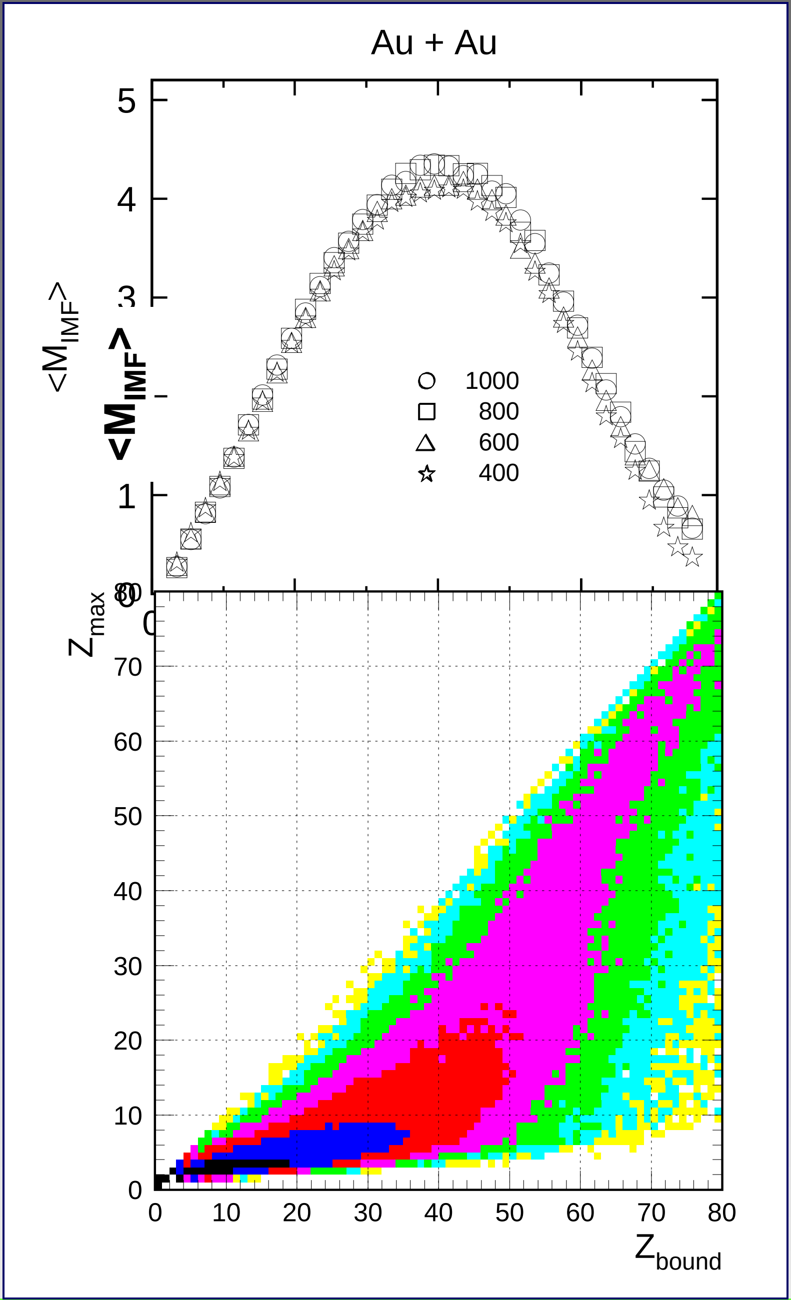


projectile spectator
$Z_{bound} = \Sigma Z_i, Z_i \geq 2$

ALADIN
acceptance

A. Schüttauf, thesis

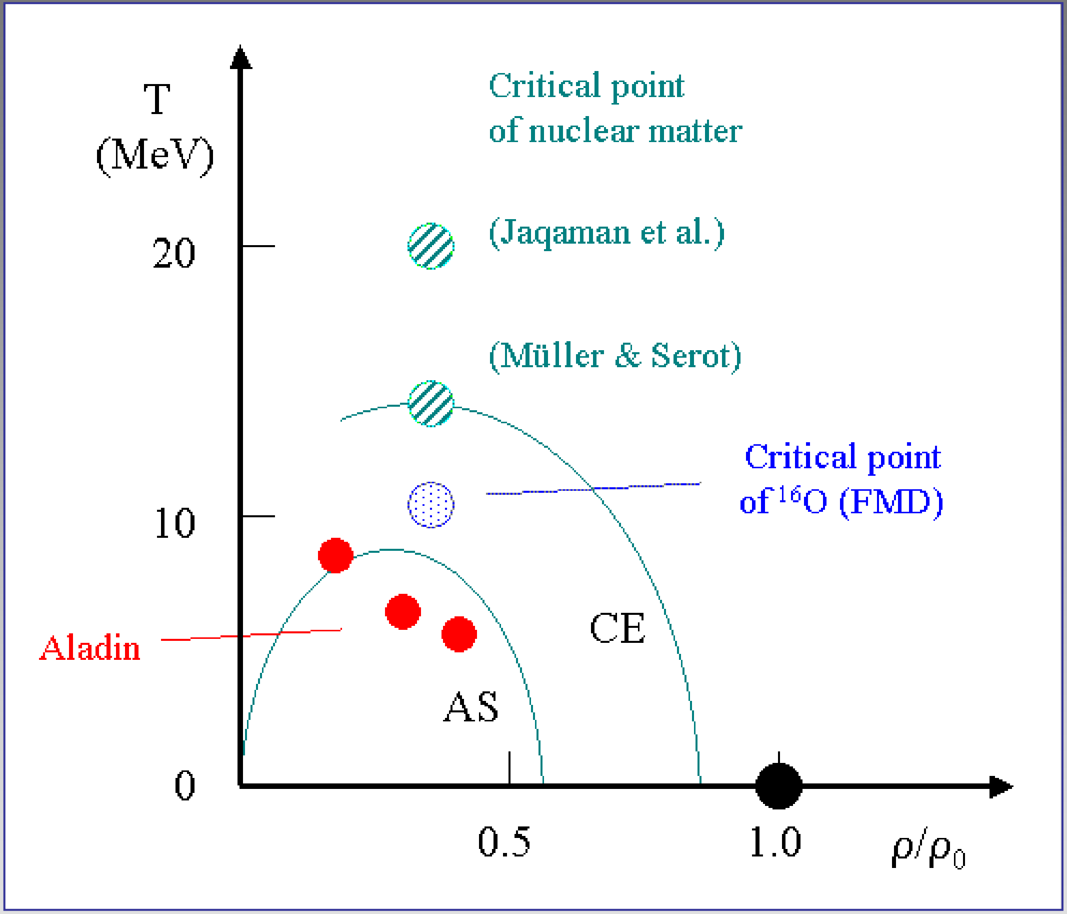
the rise and fall of multiframentation



invariance with target
or incident energy
as indicator of equilibrium

statistical models
of phase space in
coexistence region
quite successful

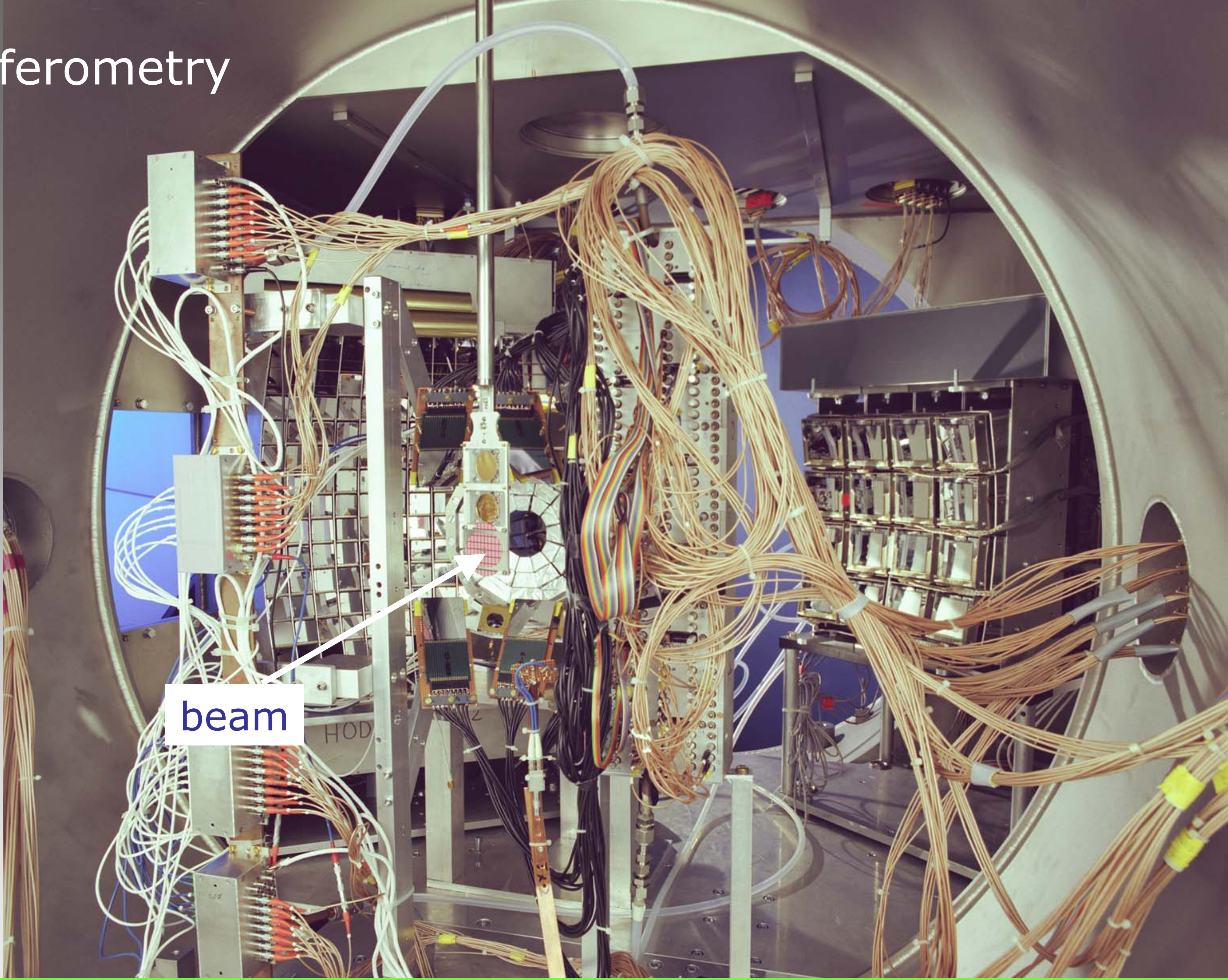
I. the nuclear phase diagram



as we explore it with multifragmentation

W.T., Proceedings of 7th Int. Conference. on Nucleus-Nucleus Collisions, (NN2000, Strasbourg, France), Nucl. Phys. A 685 (2001) 233c

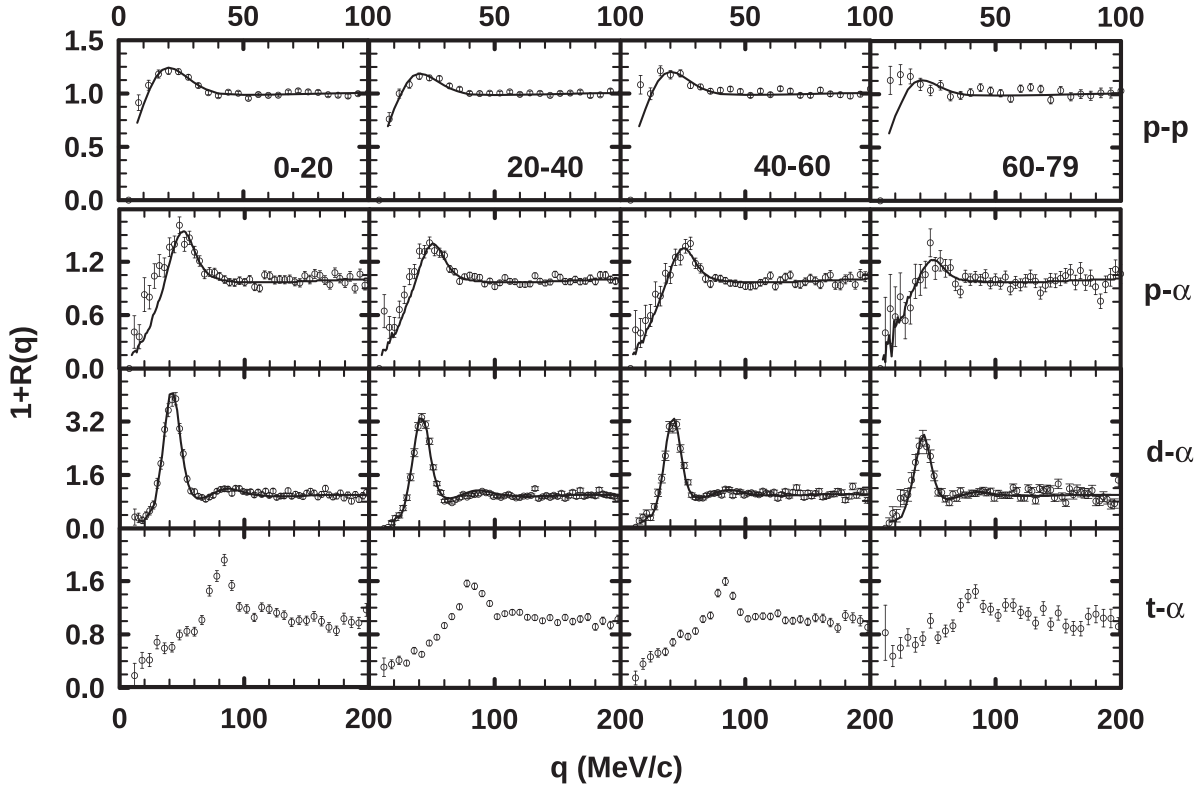
interferometry

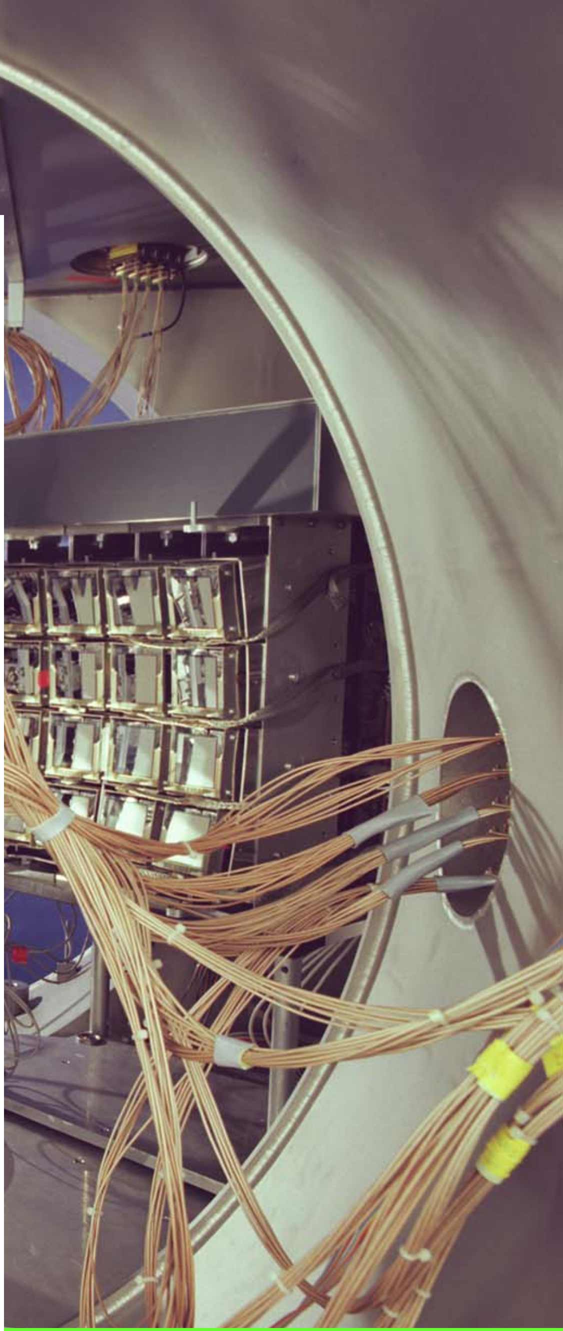


beam

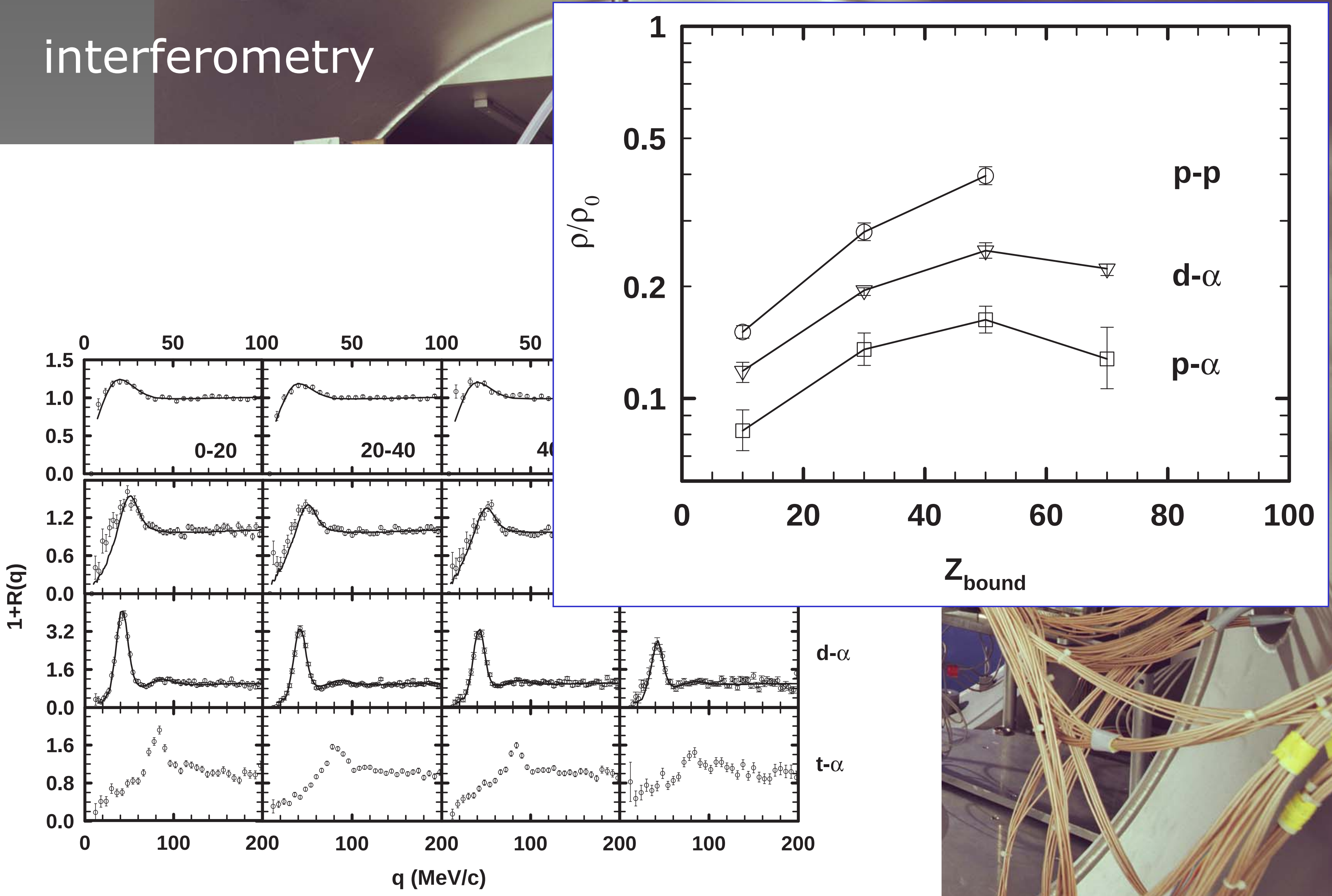
S. Fritz et al., Phys. Lett. B 461 (1999) 315

interferometry



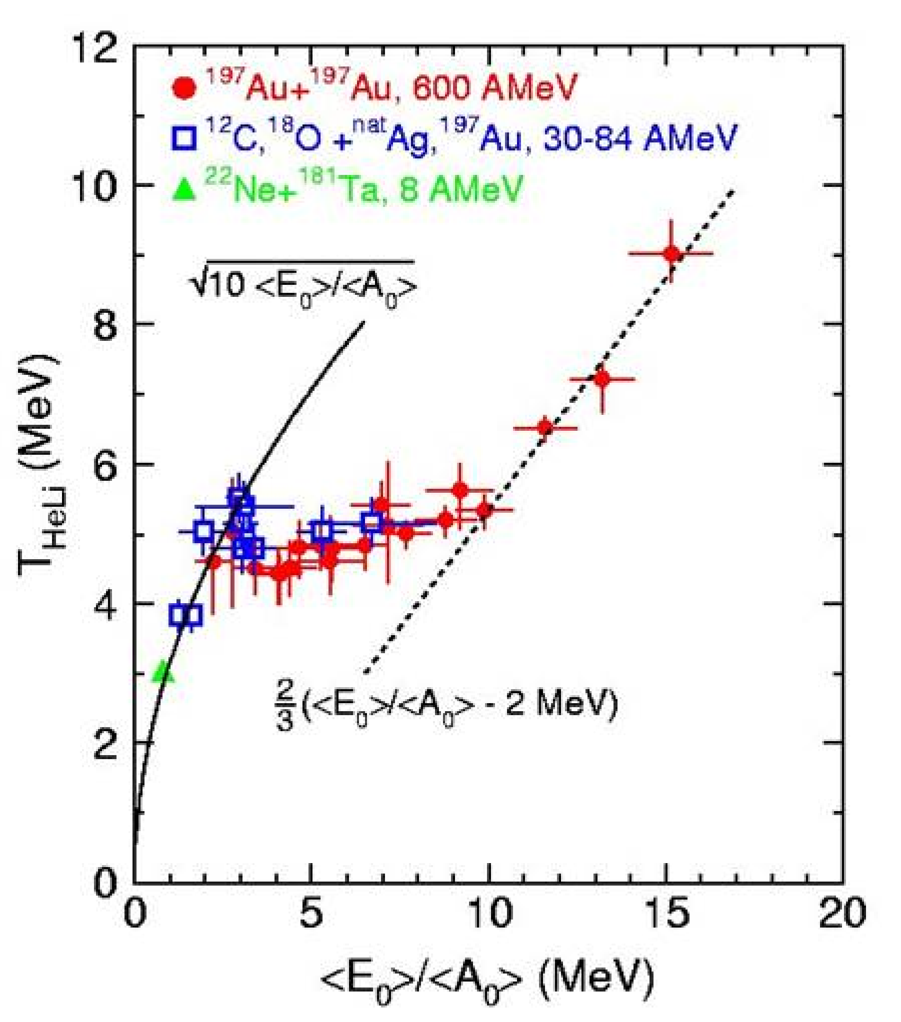


interferometry



315

the caloric curve of nuclei



T_{HeLi} obtained
from ^{3,4}He, ^{6,7}Li
double-isotope
ratios
plus sidefeeding
corrections

excitation energy
from mass balance
including
kinetic energies
and neutrons

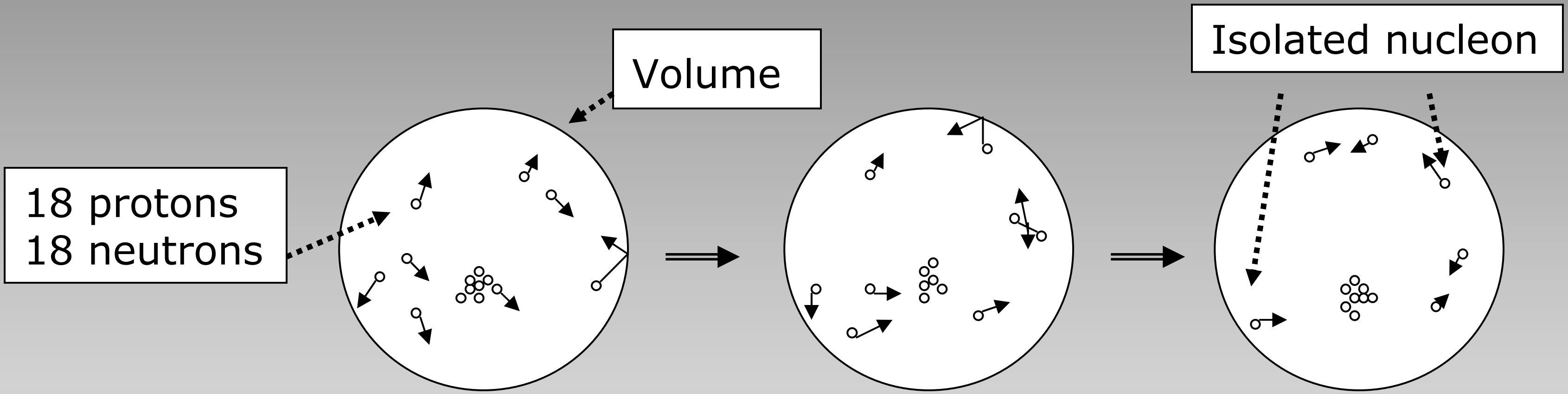
J. Pochodzalla et al., Phys. Rev. Lett. 75, 1040 (1995)

II. theoretical experiments

to observe the nuclear liquid-gas phase transition

put particles in a container

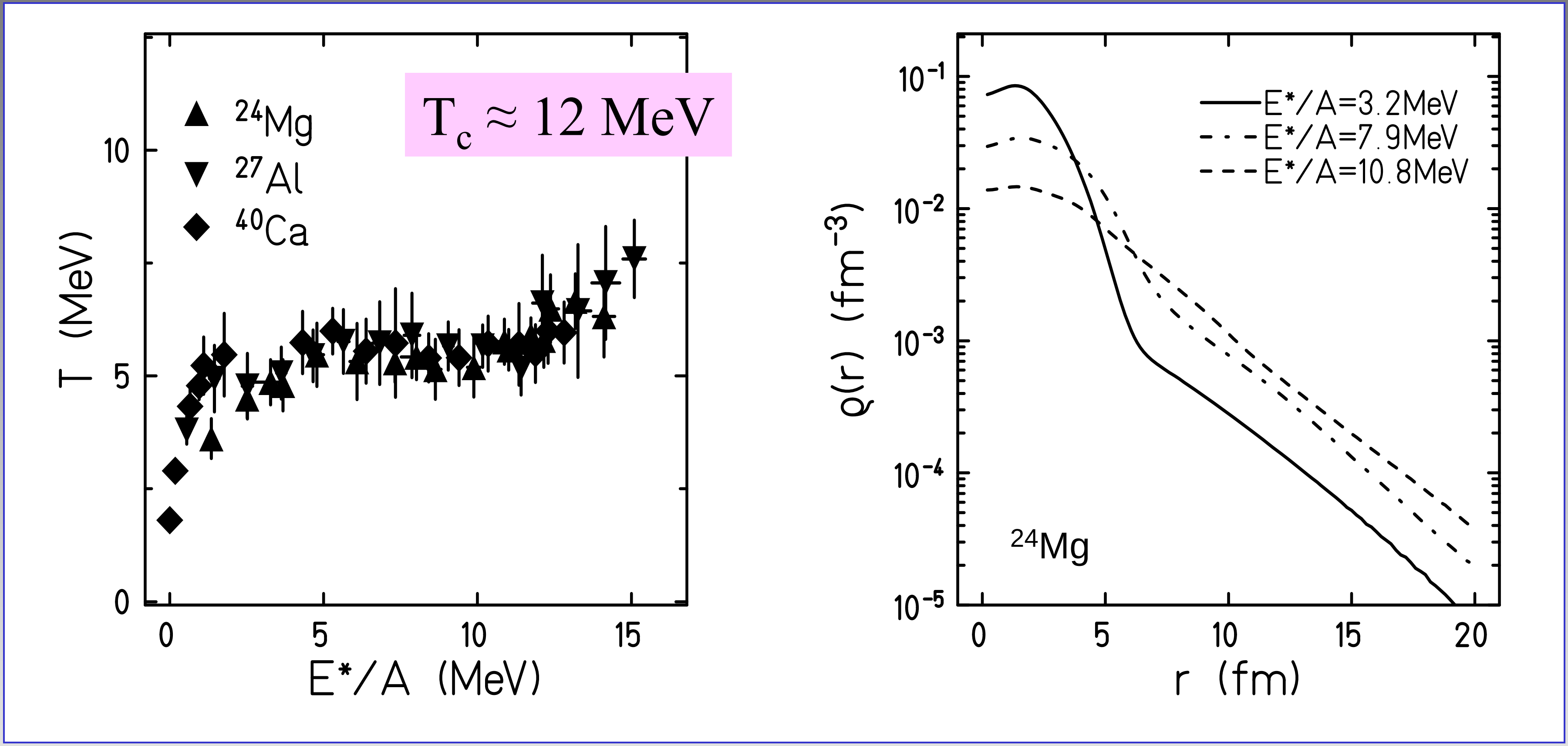
control volume and energy



measure pressure and temperature

and take time averages

Fermionic Molecular Dynamics

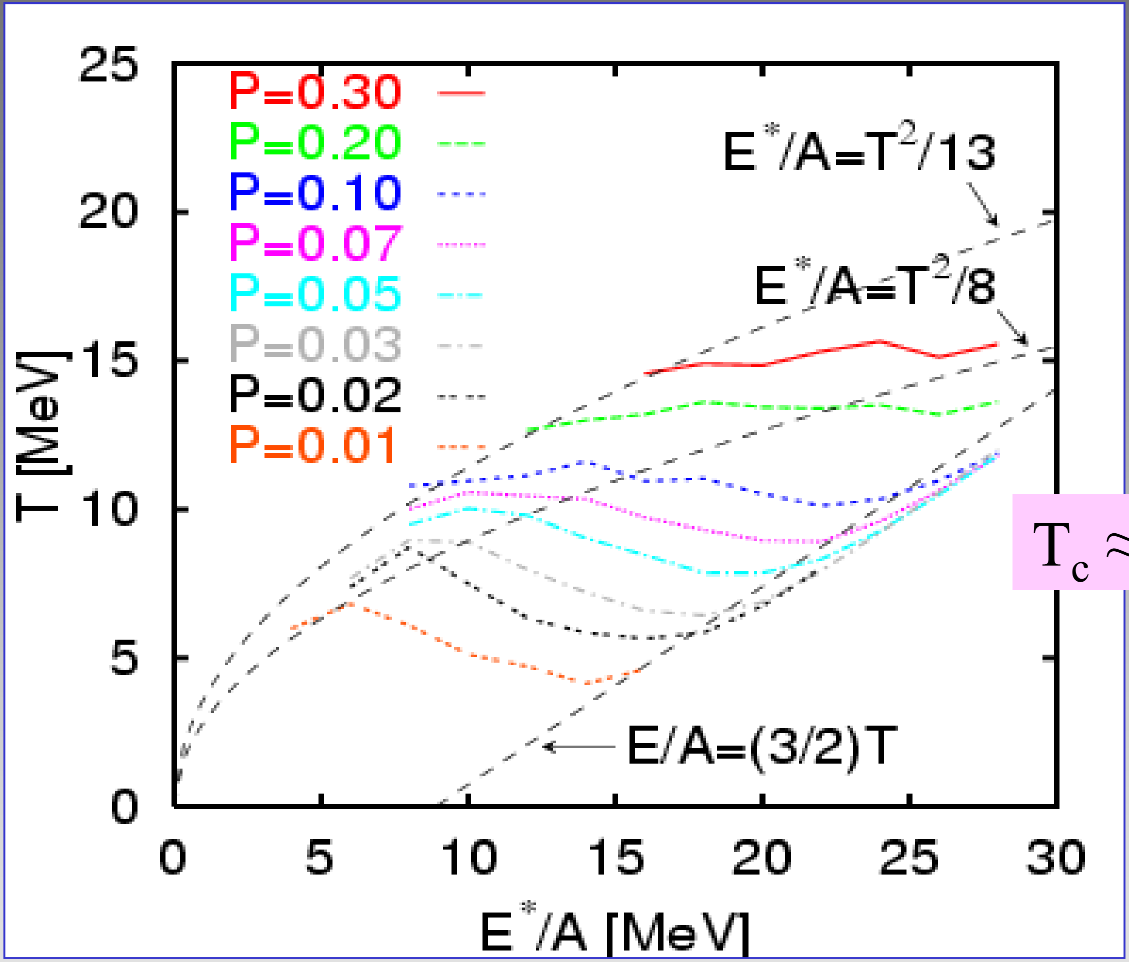


$T_c \approx 12$ MeV

time averages over 10000 fm/c

from J. Schnack and H. Feldmeier,
Phys. Lett. B 409 (1997) 6

Antisymmetrized Molecular Dynamics

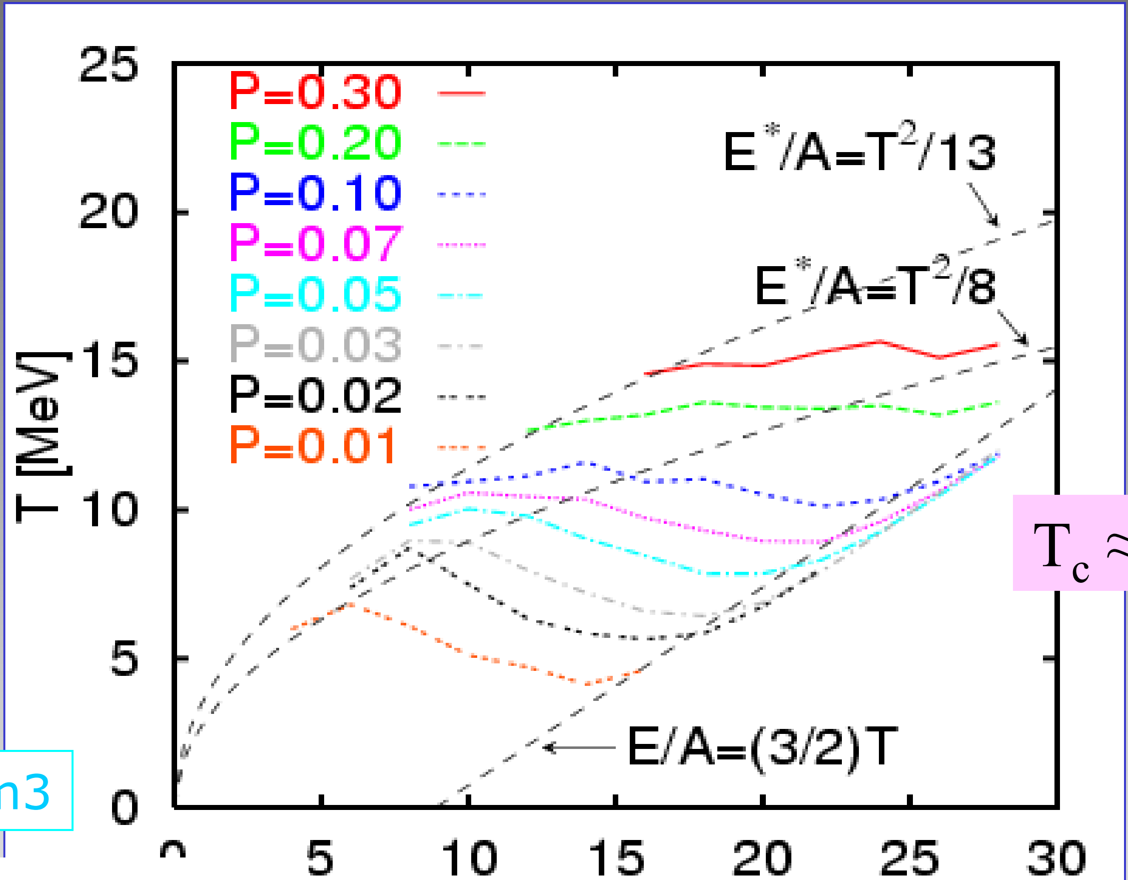


$T_c \approx 12$ MeV

constant pressure caloric curve

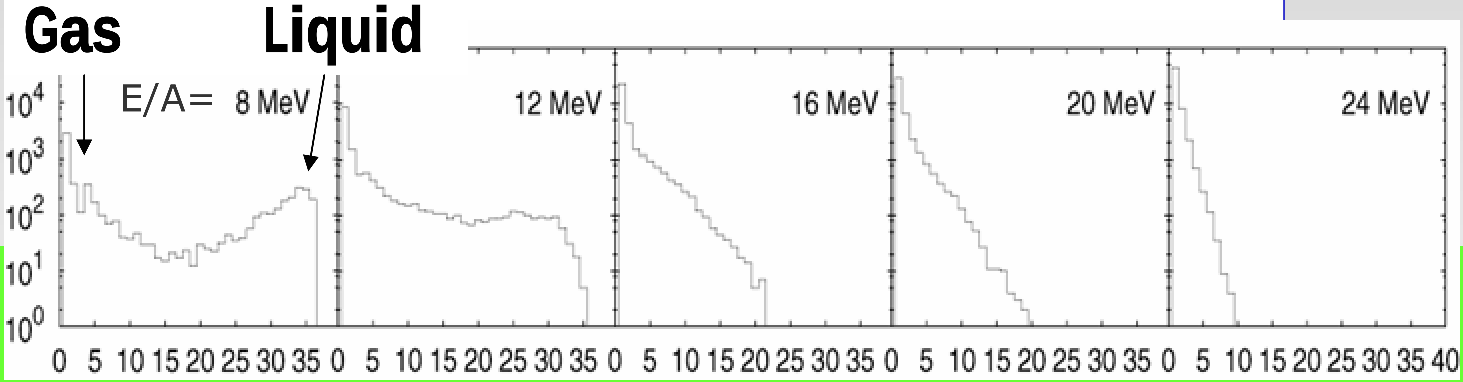
from T. Furuta and A. Ono,
Progr. Theor. Phys. Suppl. 156, 147 (2004); nucl-th/0305050

Antisymmetrized Molecular Dynamics



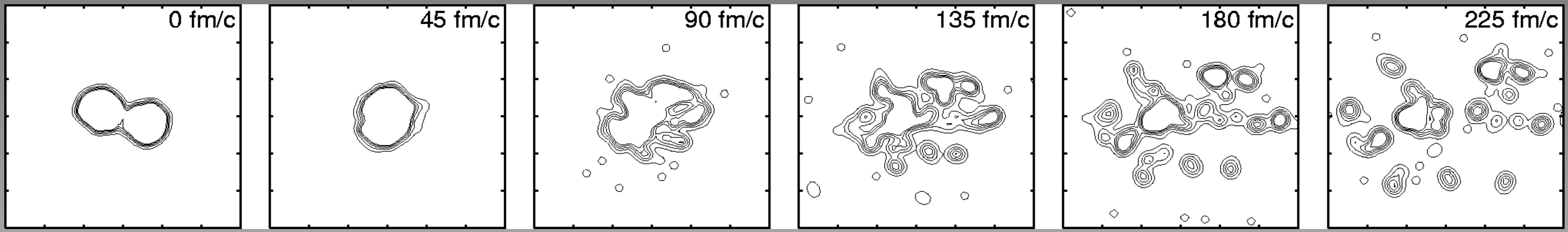
$T_c \approx 12$ MeV

P=0.05MeV/fm3



example of AMD simulation

^{129}Xe + Sn @ 50 A MeV

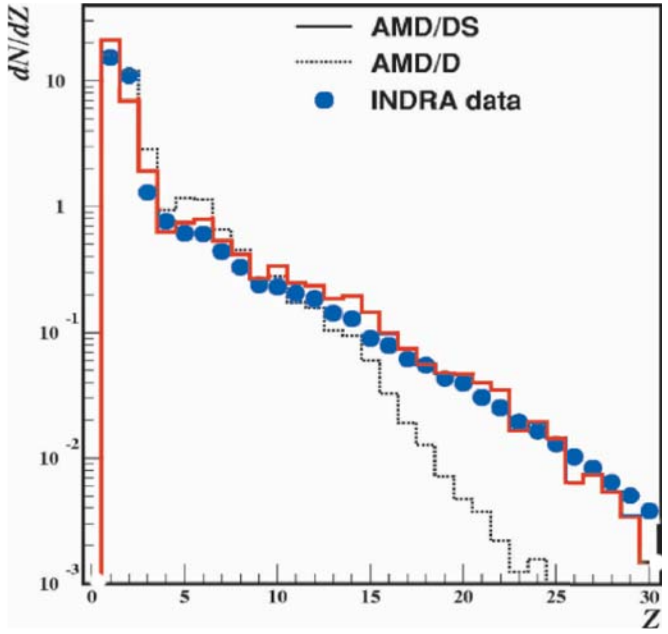


AMD reproduces many aspects of the experimental results very successfully

● Exp.

— AMD

fragment Z distribution

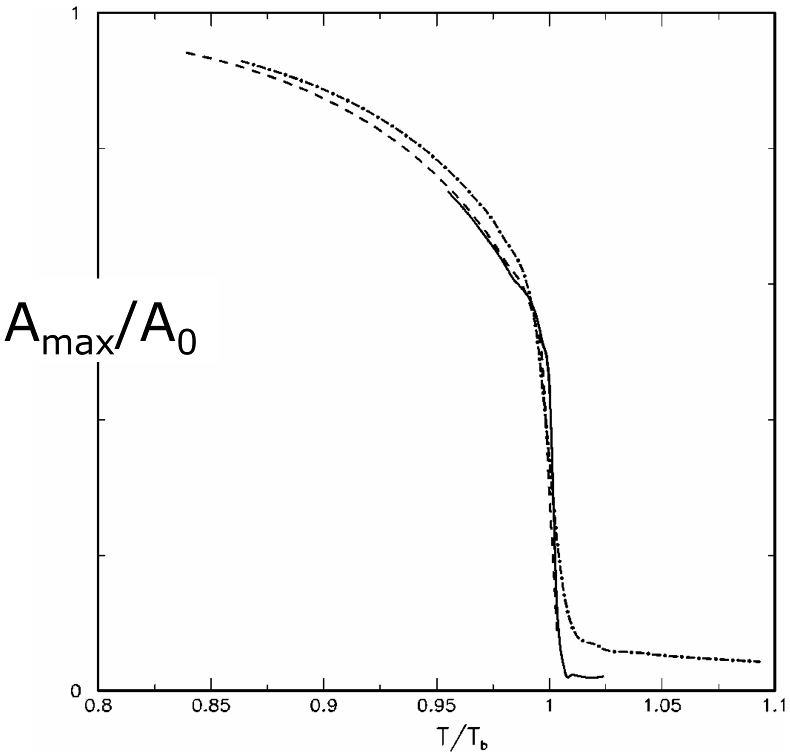


data from INDRA Collaboration
Nucl. Phys. A658, 67 (1999)

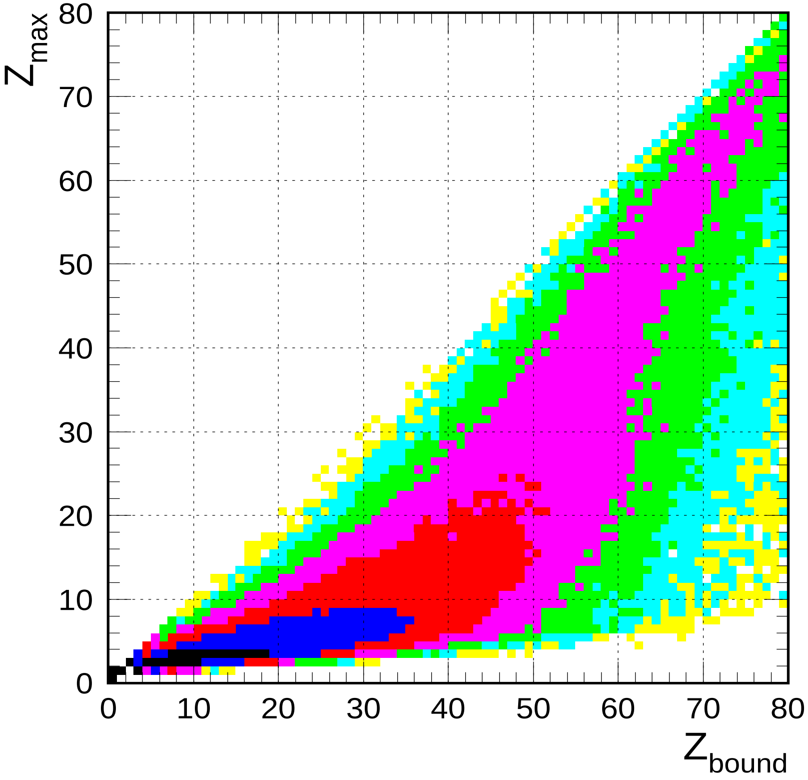
from A.Ono et al., Phys. Rev. C 66, 014603 (2002)

III. largest fragment as order parameter

a simplified statistical model
for nuclear multifragmentation



ALADIN
Au + Au 1000 A MeV

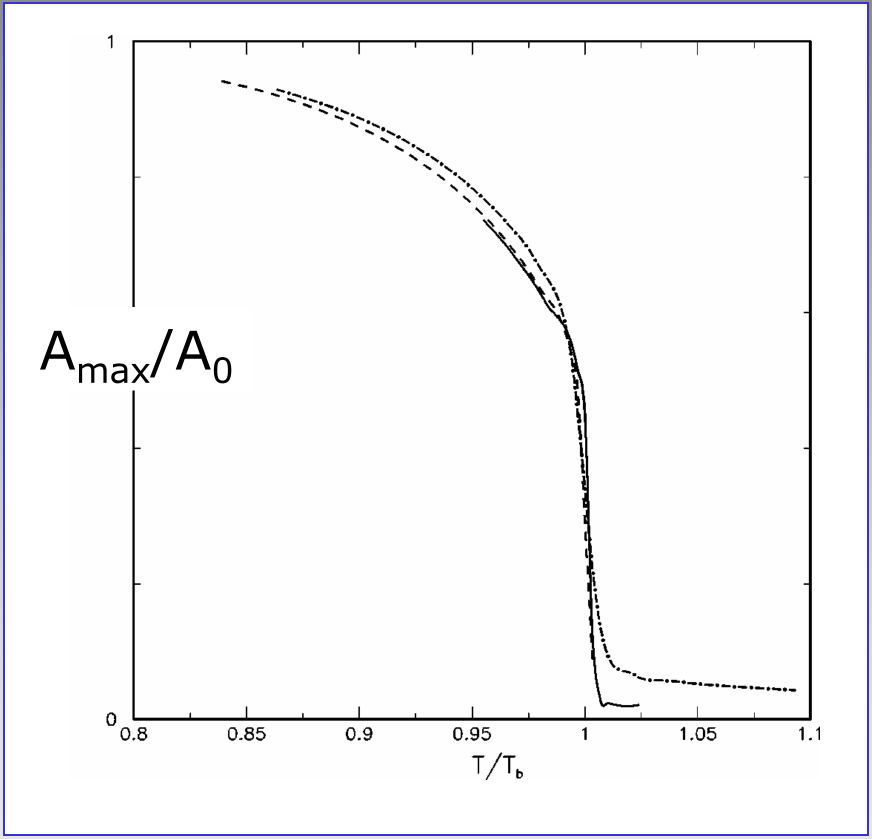


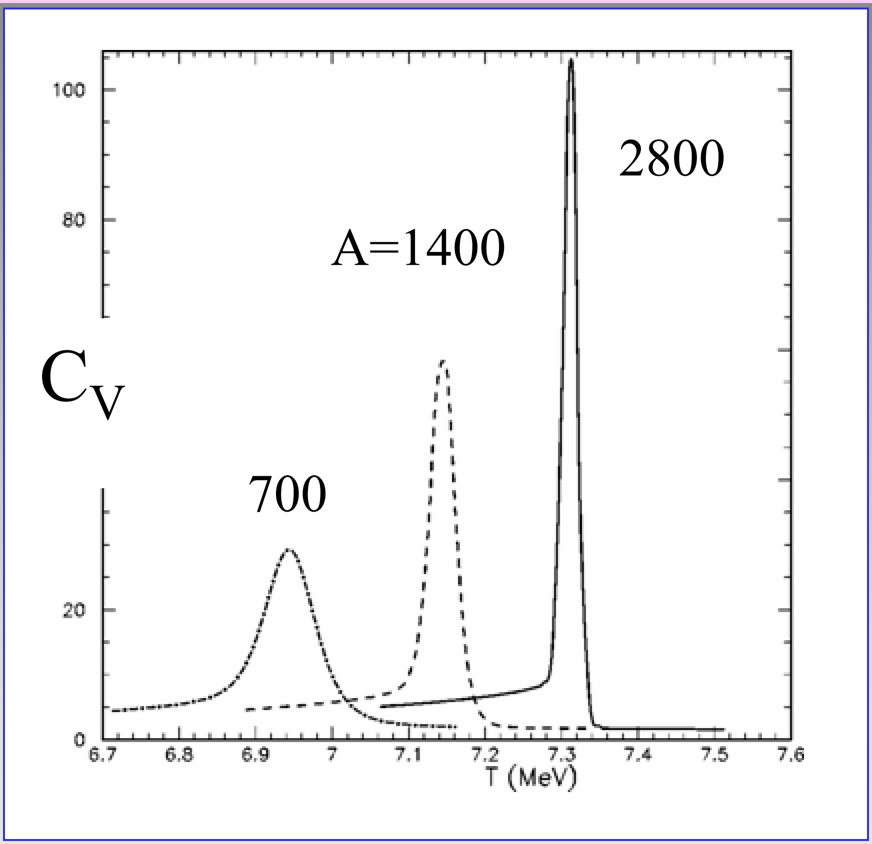
from S. Das Gupta and A.Z. Mekjian,
Phys. Rev. C 57, 1361 (1998)

largest fragment as order parameter

the simplified model permits
the study of large systems

C_V peaks at the boiling temperature:
1st order



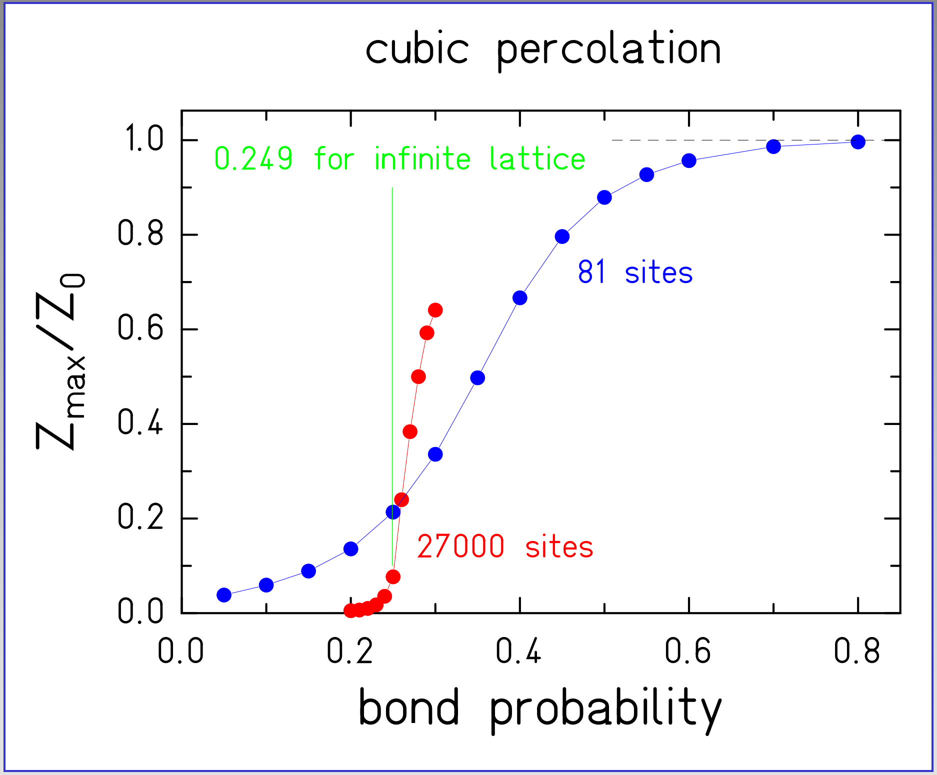


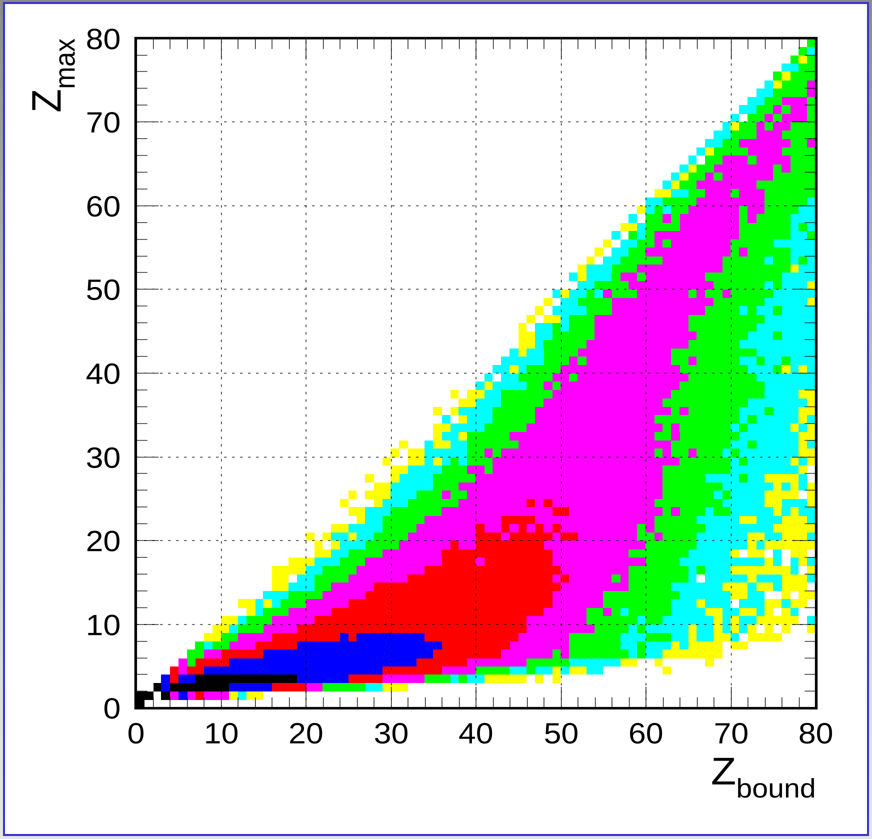
from S. Das Gupta and A.Z. Mekjian,
Phys. Rev. C 57, 1361 (1998)

largest fragment as order parameter

percolation is considered 2nd order

ALADIN
Au + Au 1000 A MeV



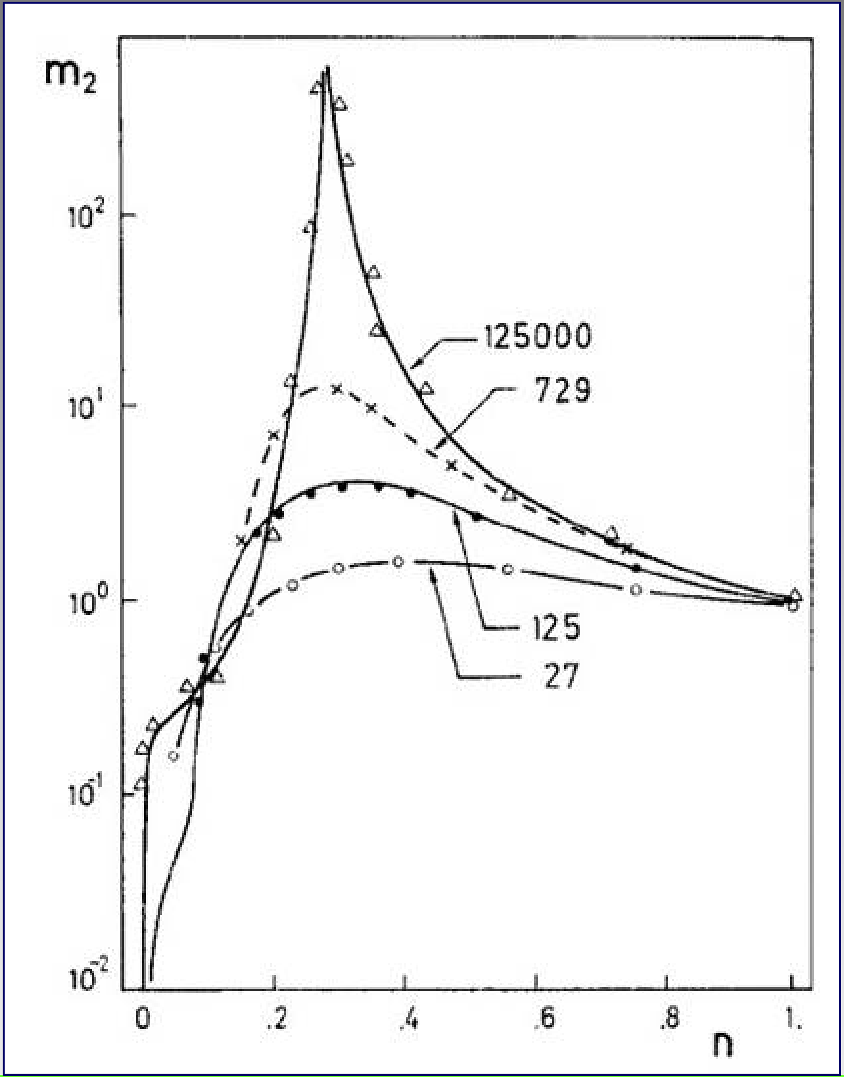


percolation describes the partitions well
see, e.g., P. Kreutz et al., Nucl. Phys. A556 (1993) 672

critical phenomena

cubic percolation:
second moment
of multiplicity distribution
versus multiplicity

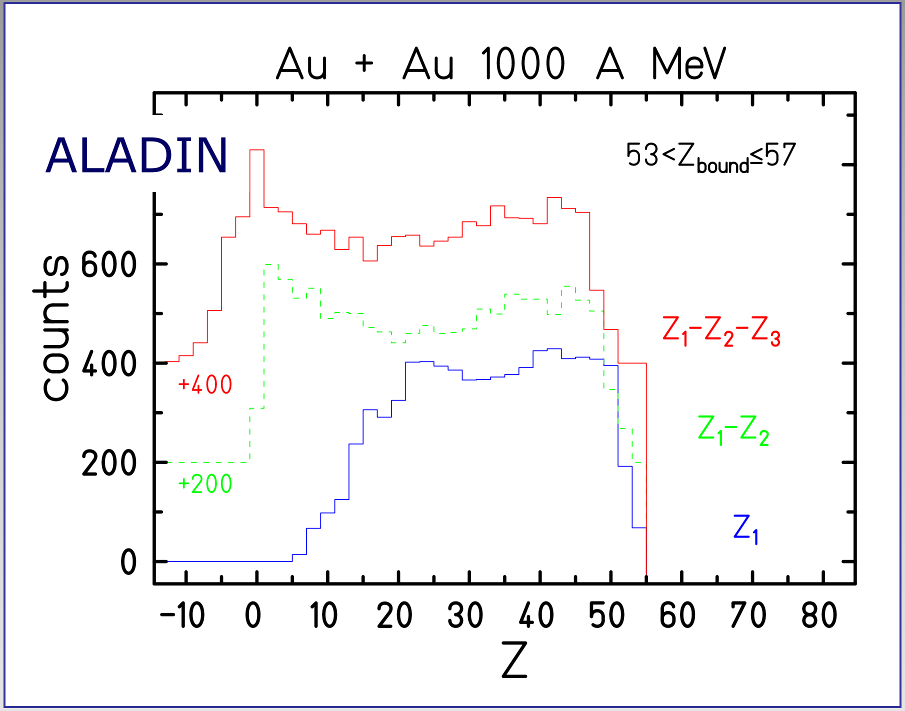
critical phenomena not necessarily associated with the thermodynamical critical point

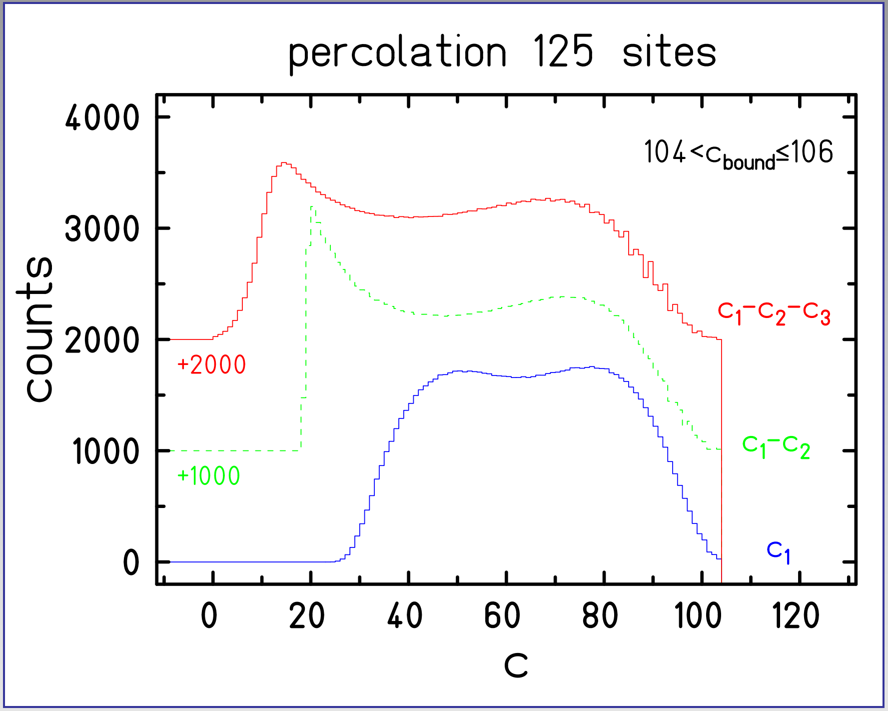


from X. Campi, Phys. Lett. B 208 (1988) 351

data and percolation

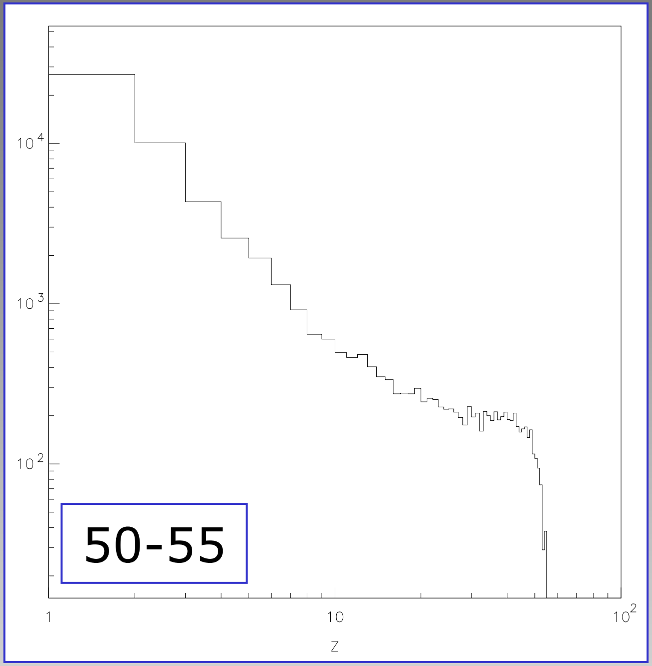
1. two-peak distributions are reminiscent of percolation

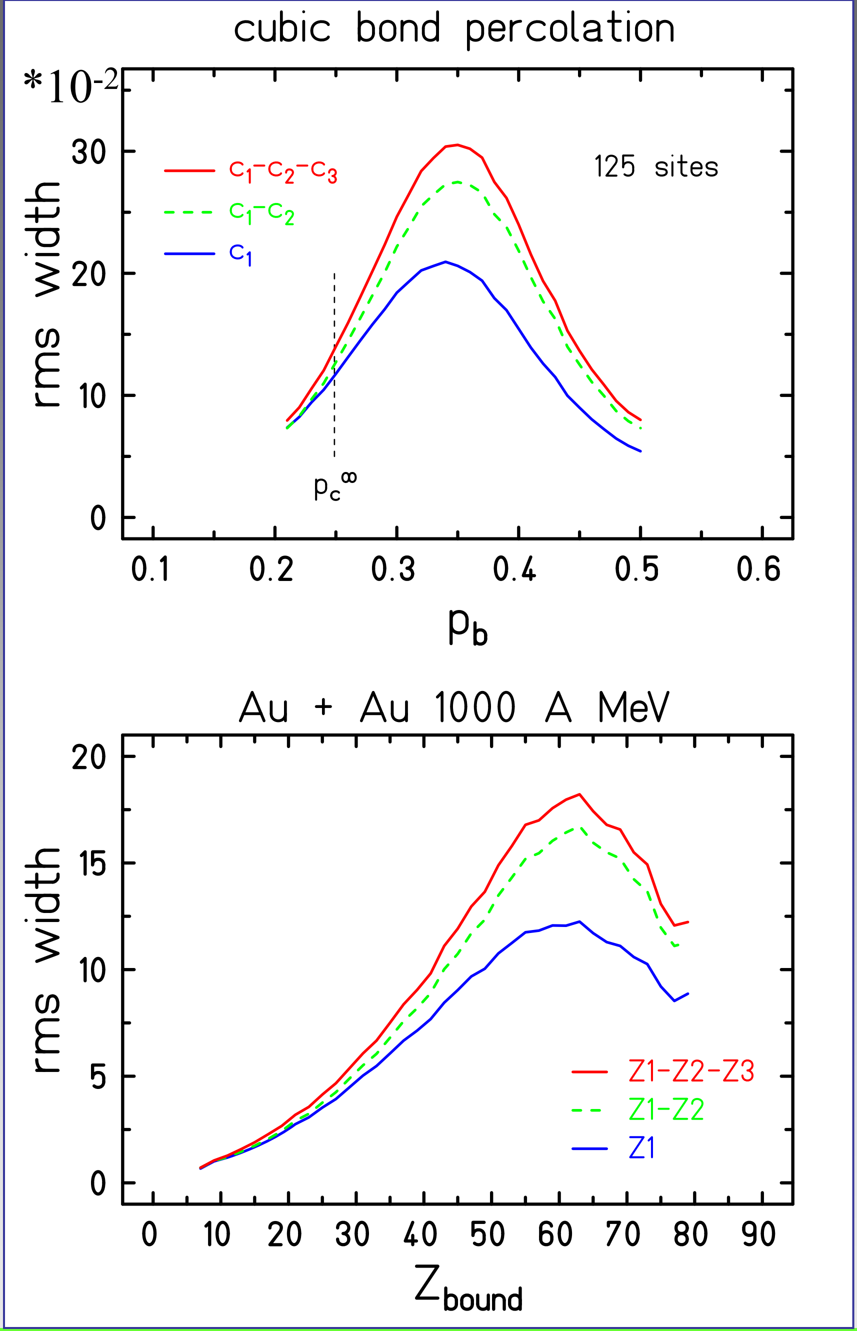




from W. T., Proceedings XLV Winter Meeting, Bormio 2007, p. 207

data and percolation



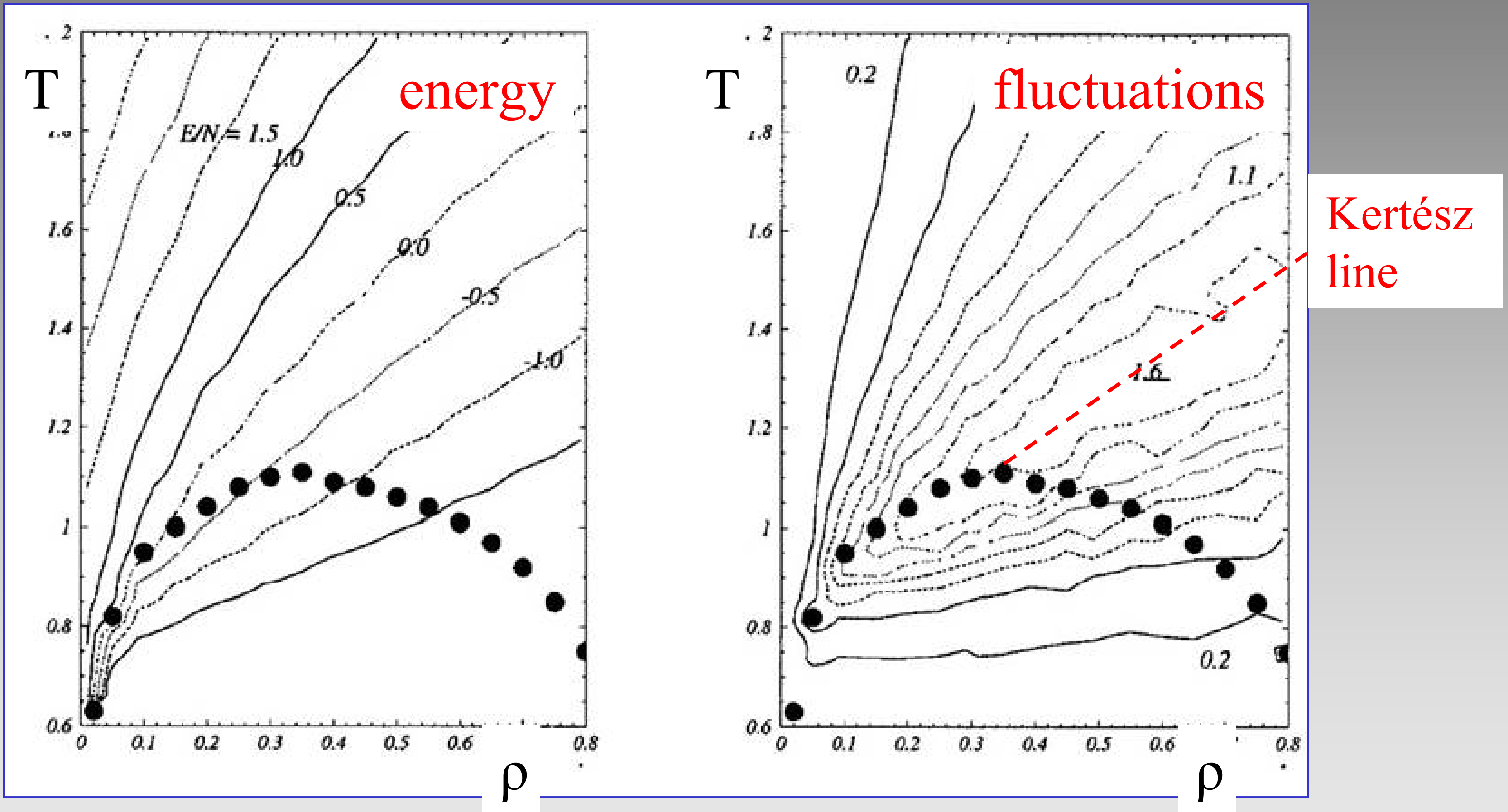


2. fluctuations are maximum near the pseudocritical point and Z spectra follow power law

from W. T., Proceedings XLV Winter Meeting, Bormio 2007, p. 207

classical molecular dynamics

125 particles in a box



energy

fluctuations

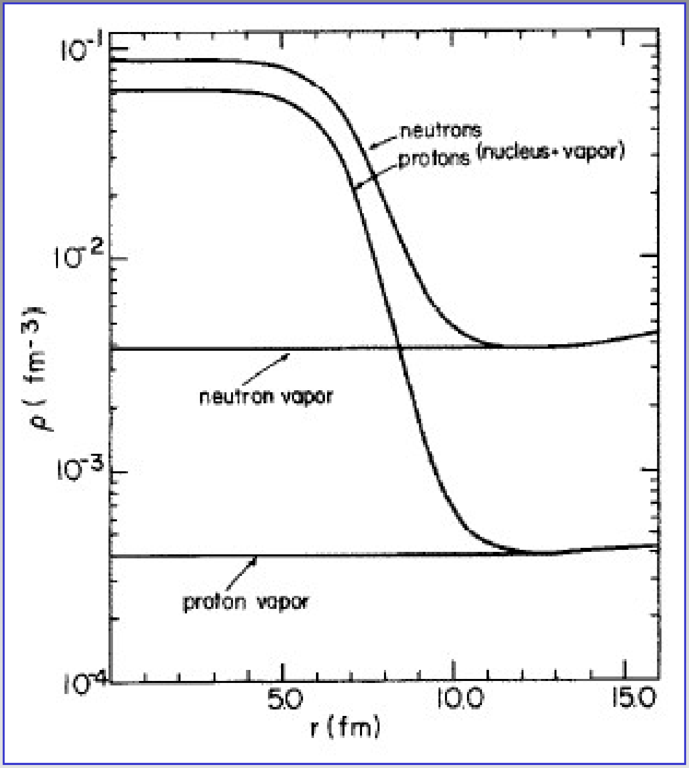
Kertész line

maximum fluctuations expected at the critical percolation line

X. Campi, H. Krivine and N. Sator, Nucl. Phys. A 681 (2001) 458c (CRIS 2000)

IV. limiting temperatures

Bonche, Levit, Vautherin,
NPA 436, 265 (1985)



question:
what is the limiting temperature up to which a compound nucleus can be excited

answered with temperature-dependent Hartree-Fock calculations

the nucleus in equilibrium with its surrounding vapor

limiting temperatures

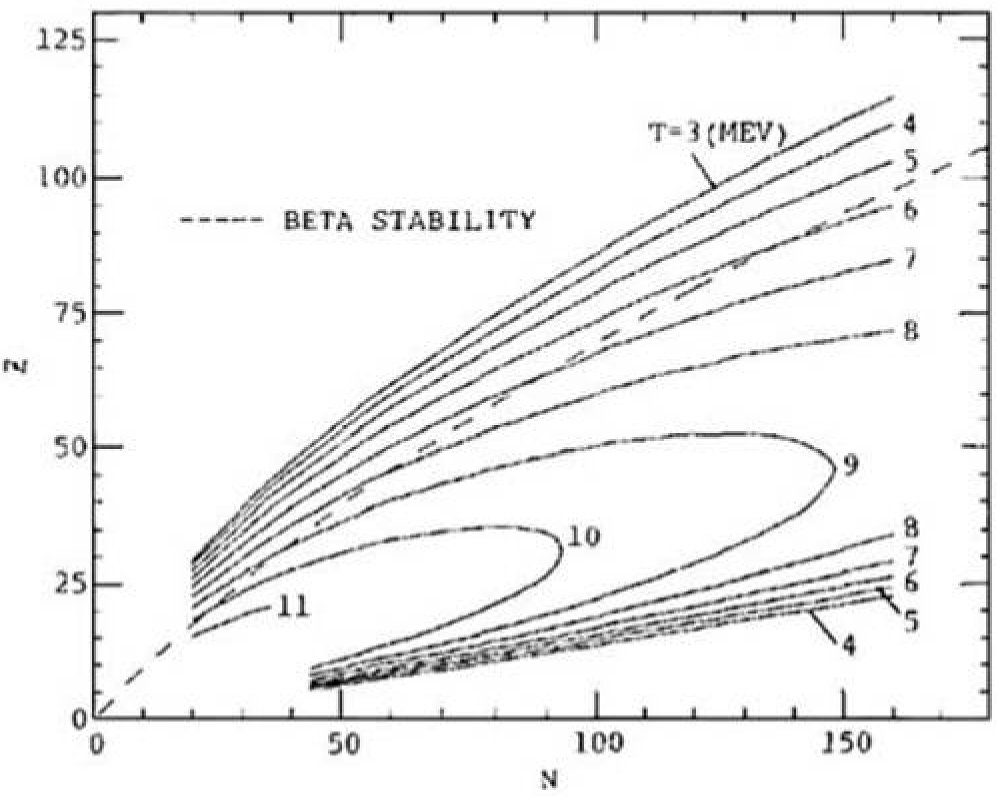


Fig. 1. Limiting temperatures predicted by Besprosvany and Levit [86]. Phys. Lett. B 217, 1 (1989)

liquid-drop model formulated to represent the physics of the finite-temperature Hartree-Fock calculations

the interest:

the limiting temperature is sensitive to the equation of state and to the temperature dependence of the surface tension

limiting temperature

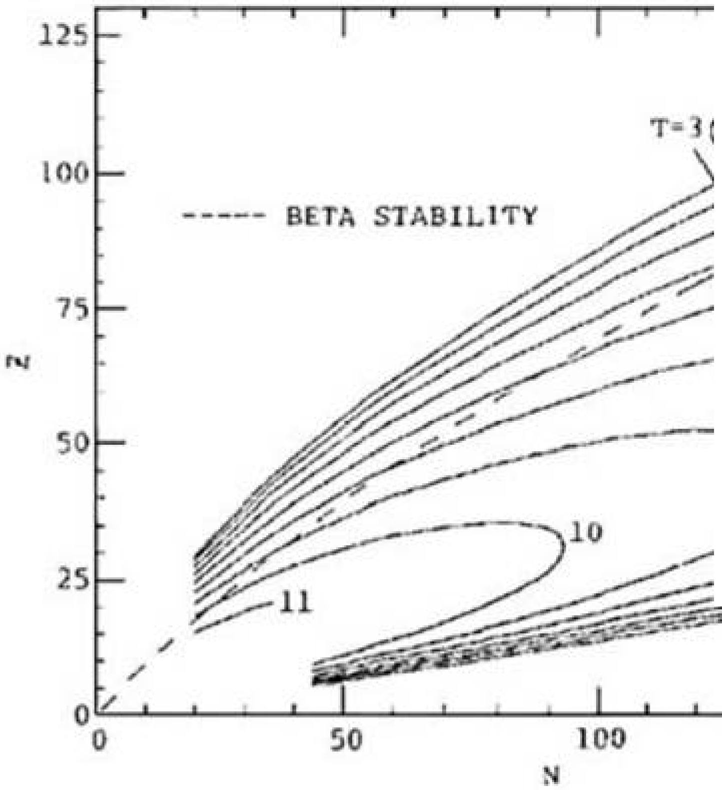
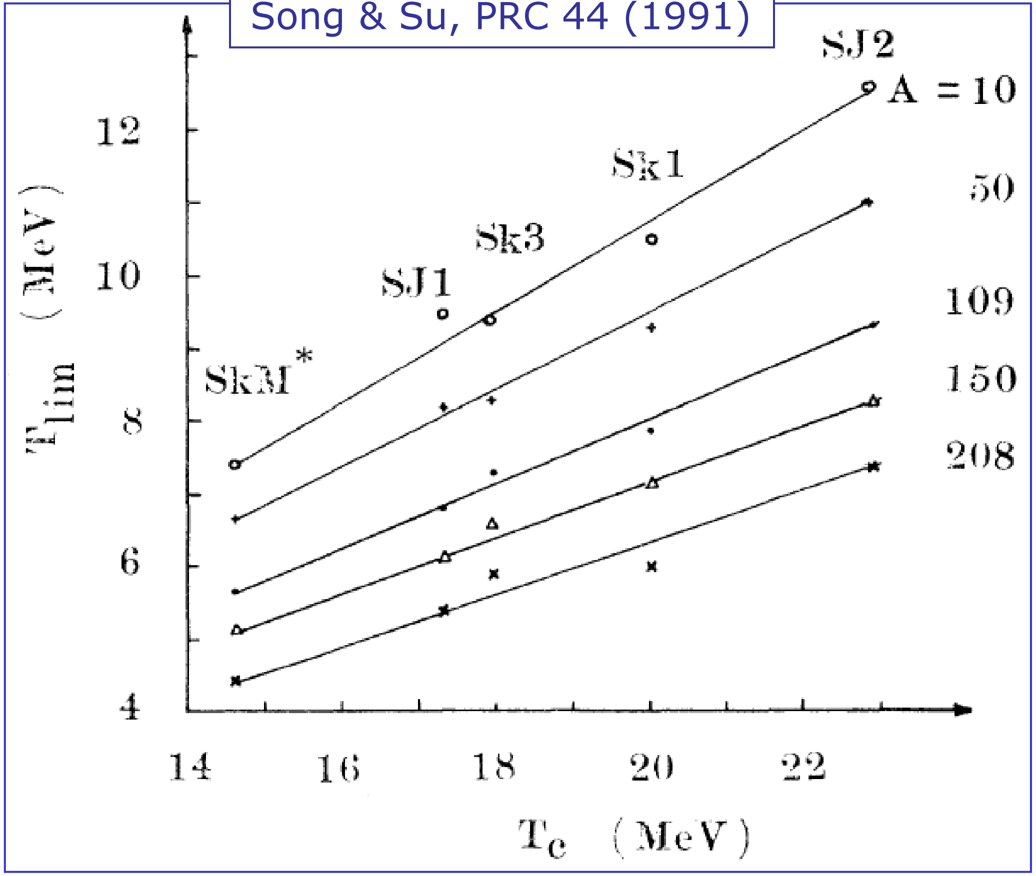


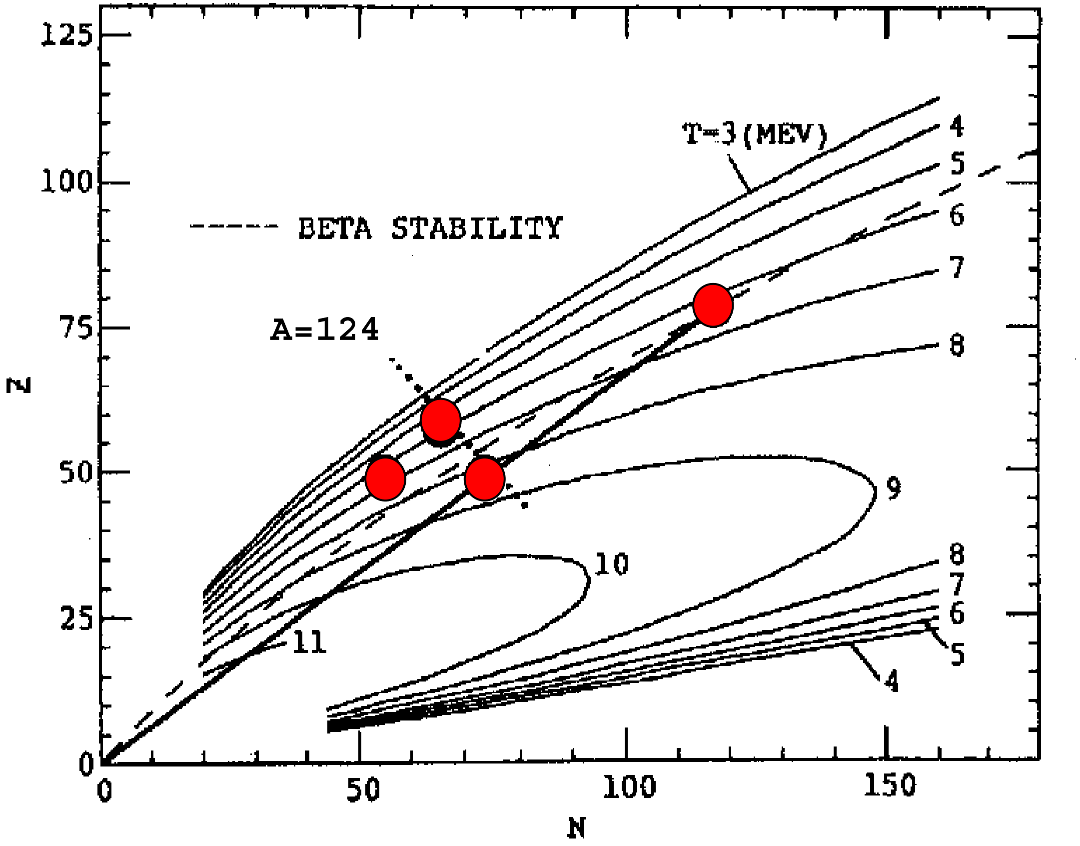
Fig. 1. Limiting temperatures predicted by Besprosvany and Levit [86]. Phys. Lett. B 217, 1 (1989)


Song & Su, PRC 44 (1991)

the limiting temperature is sensitive to the equation of state and to the temperature dependence of the surface tension

ALADIN experiment S254

"Mass and isospin effects in multifragmentation"



^{107}Sn, ^{124}La

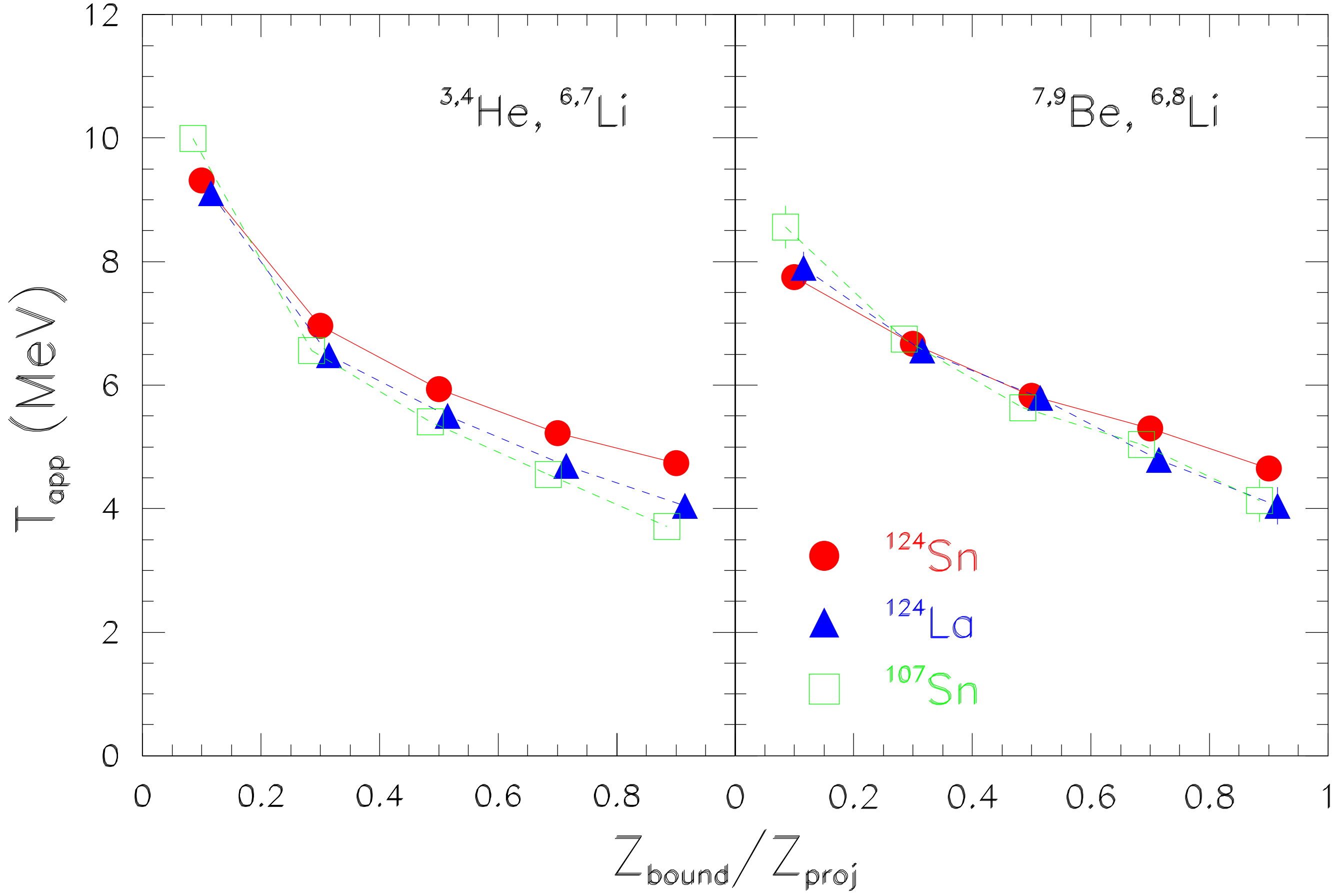
^{124}Sn, ^{197}Au

600 A MeV

contour lines represent limiting temperatures of temperature dependent Hartree-Fock calculations using Skyrme forces

chemical freeze-out temperatures

from double isotope yield ratios: T_{HeLi} (^{3,4}He,^{6,7}Li)
(Albergo's formula) T_{BeLi} (^{7,9}Be,^{6,8}Li)



chemical freeze-out temperatures

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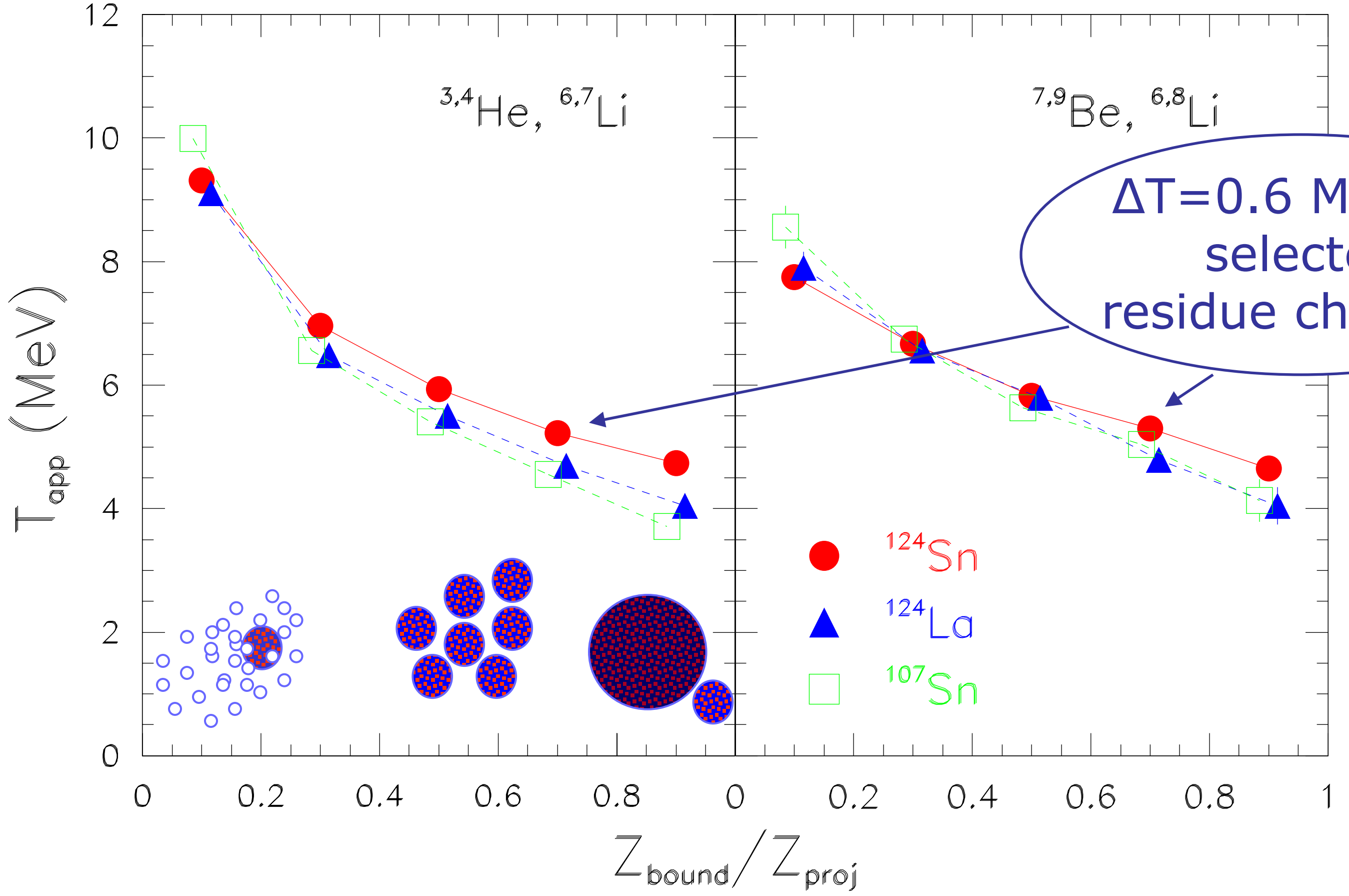
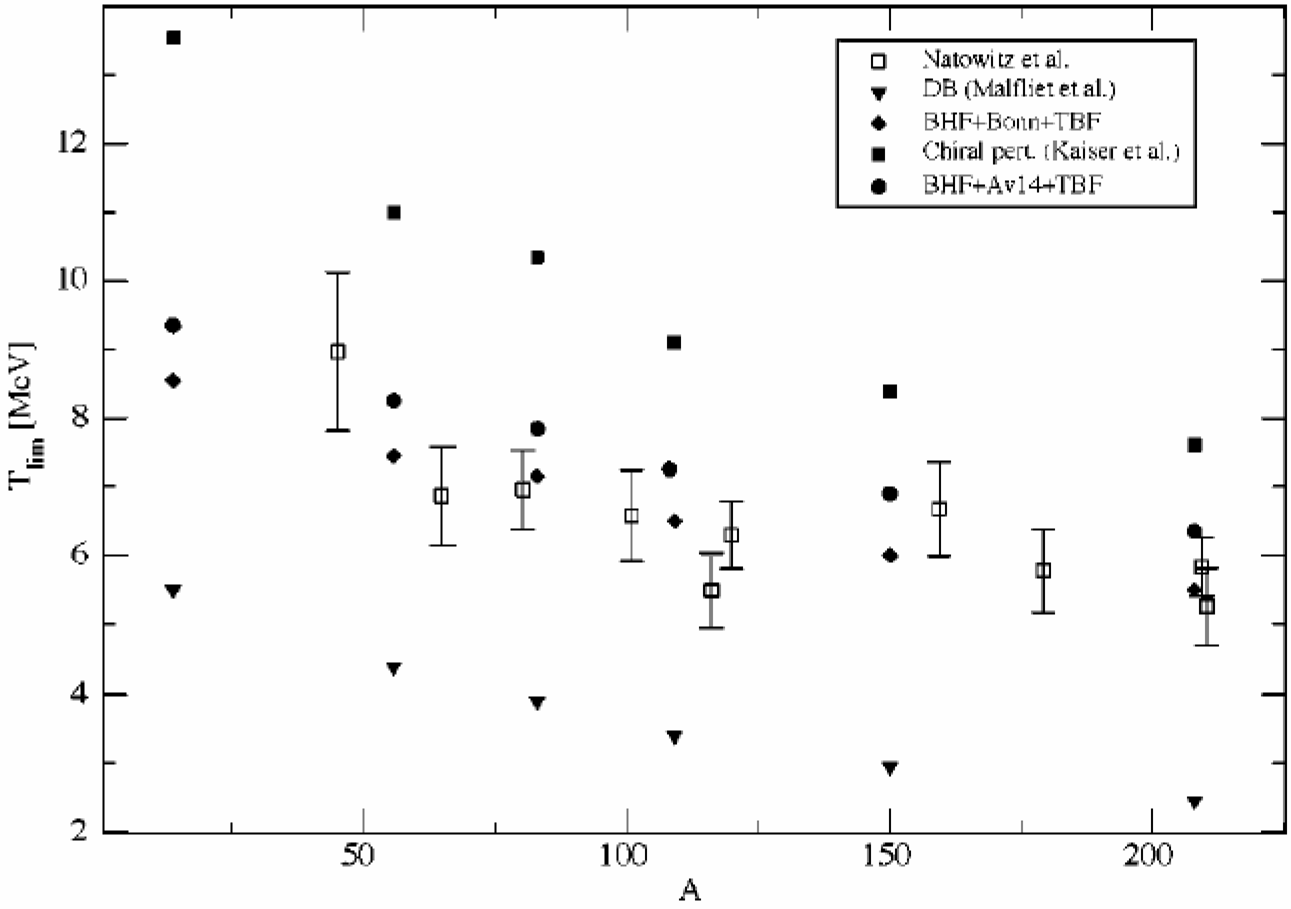


ΔT=0.6 MeV for selected residue channels

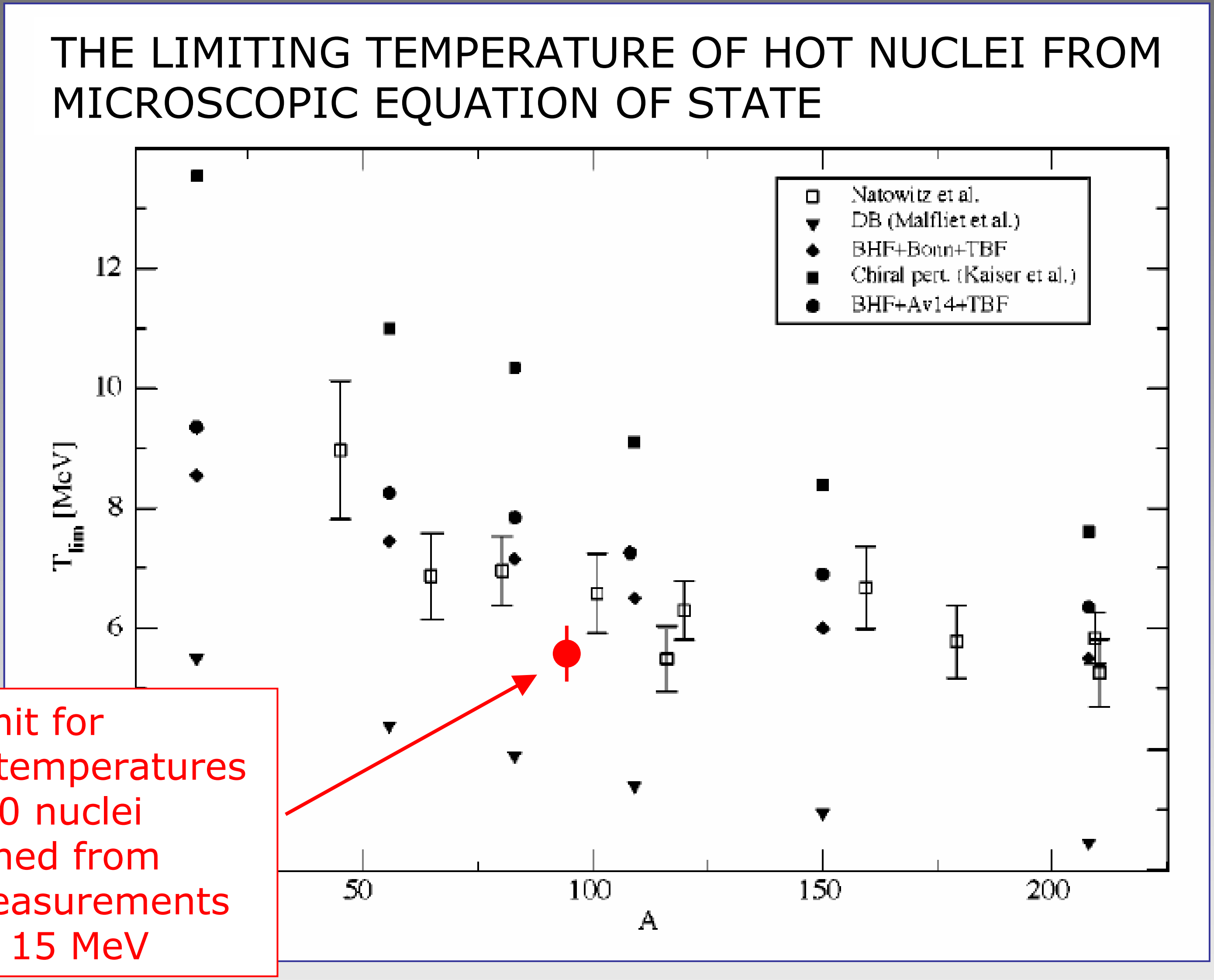
testing microscopic calculations

THE LIMITING TEMPERATURE OF HOT NUCLEI FROM MICROSCOPIC EQUATION OF STATE



M. Baldo et al., PRC 69 (2004)

testing microscopic calculations



THE LIMITING TEMPERATURE OF HOT NUCLEI FROM MICROSCOPIC EQUATION OF STATE

lower limit for
limiting temperatures
of A ≈ 90 nuclei
as obtained from
S254 measurements
=> $T_c \geq 15$ MeV

M. Baldo et al., PRC 69 (2004)

The Aladdin 2000 Collaboration

S. Bianchin, K. Kezzar, A. Le Fèvre, J. Lühning, J. Lukasik, U. Lynen, W.F.J. Müller, H. Orth, A.N. Otte, H. Sann, C.Schwarz, C. Sfienti, W. Trautmann, J. Wiechula, M.Hellström, D. Henzlova, K. Sümmerer, H. Weick, P.Adrich, T. Aumann, H. Emling, H. Johansson, Y. Leifels, R. Palit, H. Simon, M. De Napoli, G. Imme', G.Raciti, E.Rapisarda, R. Bassini, C. Boiano, I. Iori, A. Pullia, W.G.Lynch, M. Mocko, M.B. Tsang, G. Verde, M. Wallace, C.O. Bacri, A. Lafriakh, A. Boudard, J-E. Ducret, E.LeGentil, C. Volant, T. Barczyk, J. Brzychczyk, Z. Majka, A. Wieloch, J. Cibor, B. Czech, P. Pawlowski, A. Mykulyak, B. Zwieglinski, A. Chbihi, J. Frankland and A.S. Botvina

summary

I. freeze-out in the **coexistence region:**
fragments, temperature, density √

2. theoretical experiments demonstrate
phase transition in equilibrium √

3. the largest fragment as order parameter
first or second order ?

4. limiting temperatures and the nucleus in
equilibrium with its vapor ?