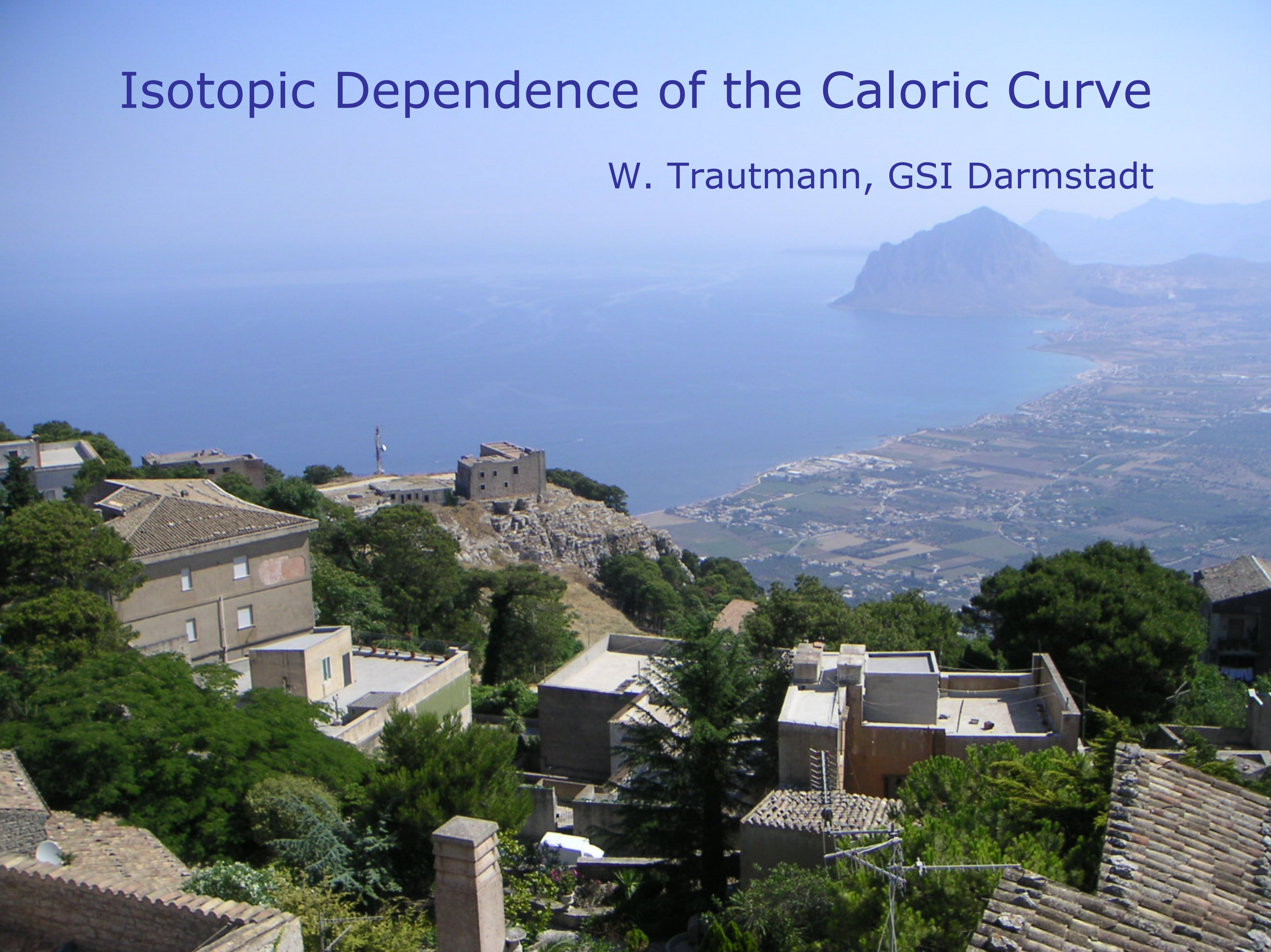
Isotopic Dependence of the Caloric Curve

W. Trautmann, GSI Darmstadt



Isotopic Independence of the Caloric Curve

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	introduction
I.	motivation: limiting temperatures
II.	ALADIN experiment S254
III.	results and consequences
IV.	isoscaling and the symmetry energy
	outlook

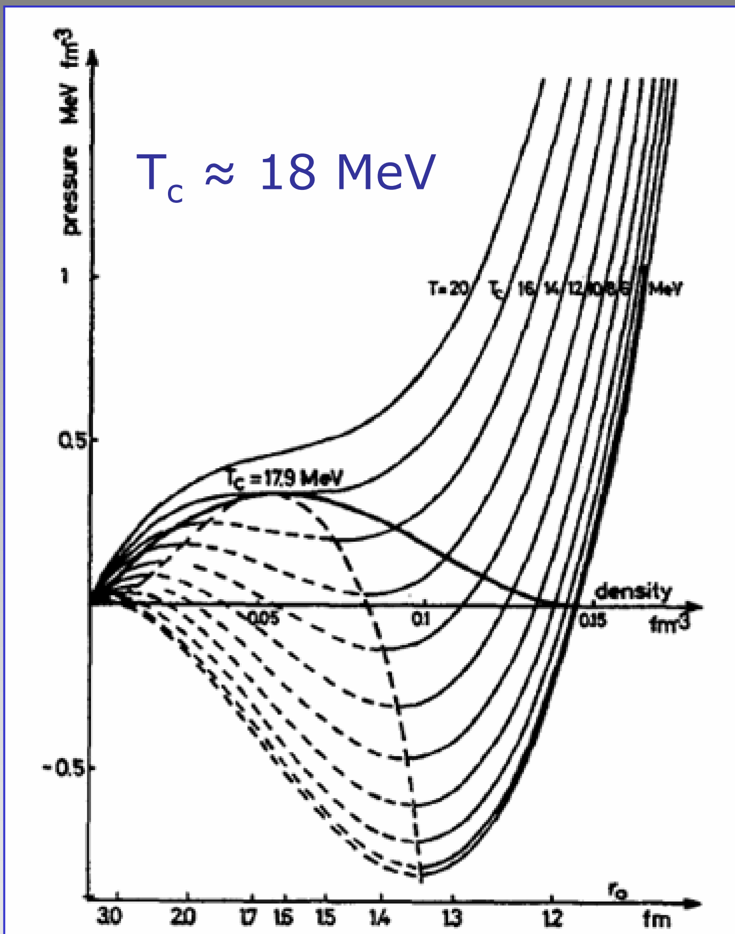
S. Bianchin, A.S. Botvina, M. de Napoli, A. Le Fèvre, J. Łukasik,
A. Mykulyak, C. Sfienti, and the ALADiN2000 collaboration

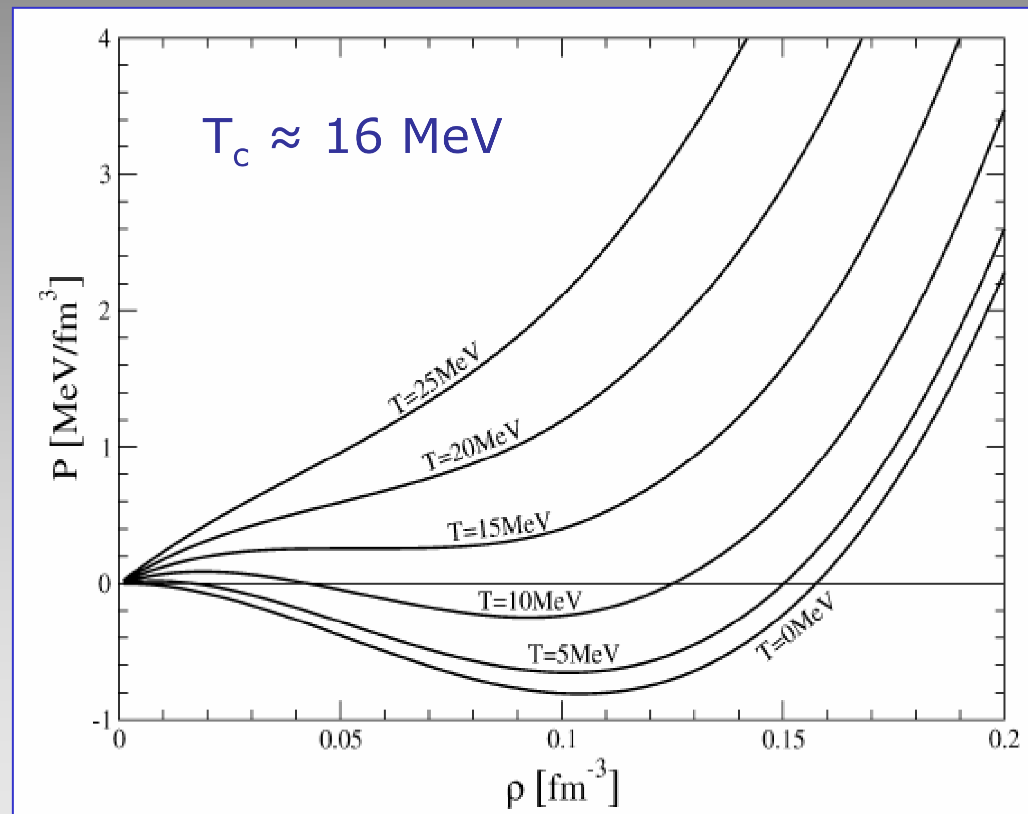
the nuclear phase diagram

temperature dependent
Hartree-Fock theory

1976 - today

chiral effective
field theory



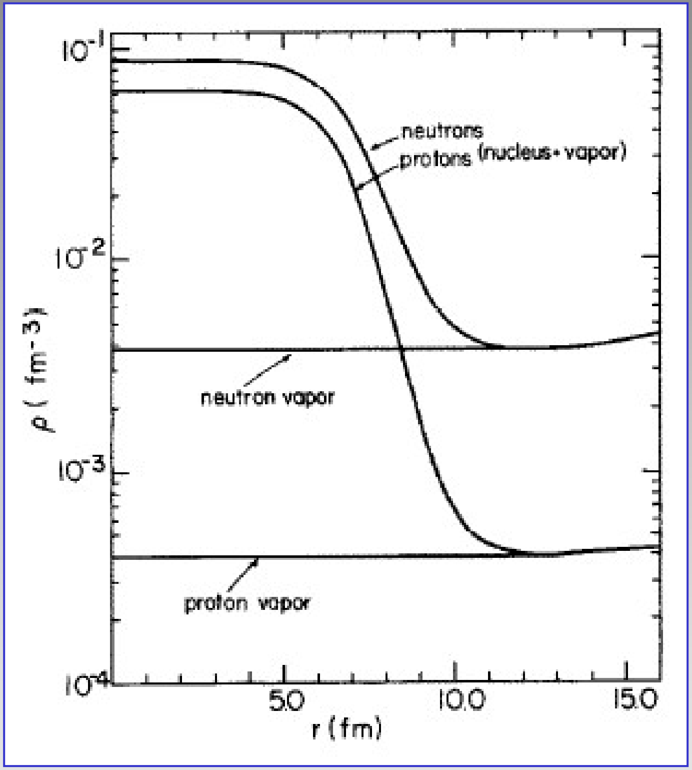


from Sauer, Chandra, Mosel
Nucl. Phys. A 264, 221 (1976)

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

I. motivation: limiting temperatures

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



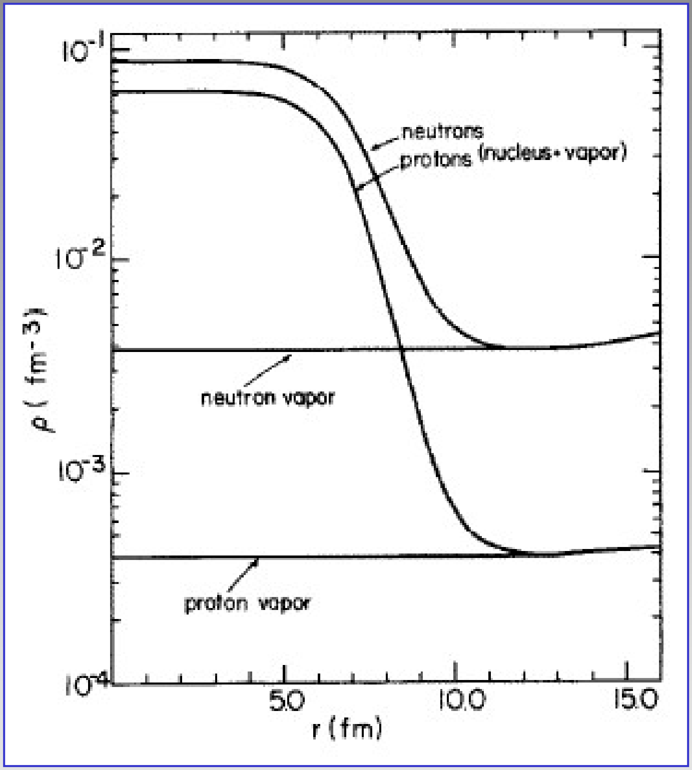
question:
what is the limiting temperature up to which a compound nucleus can be excited

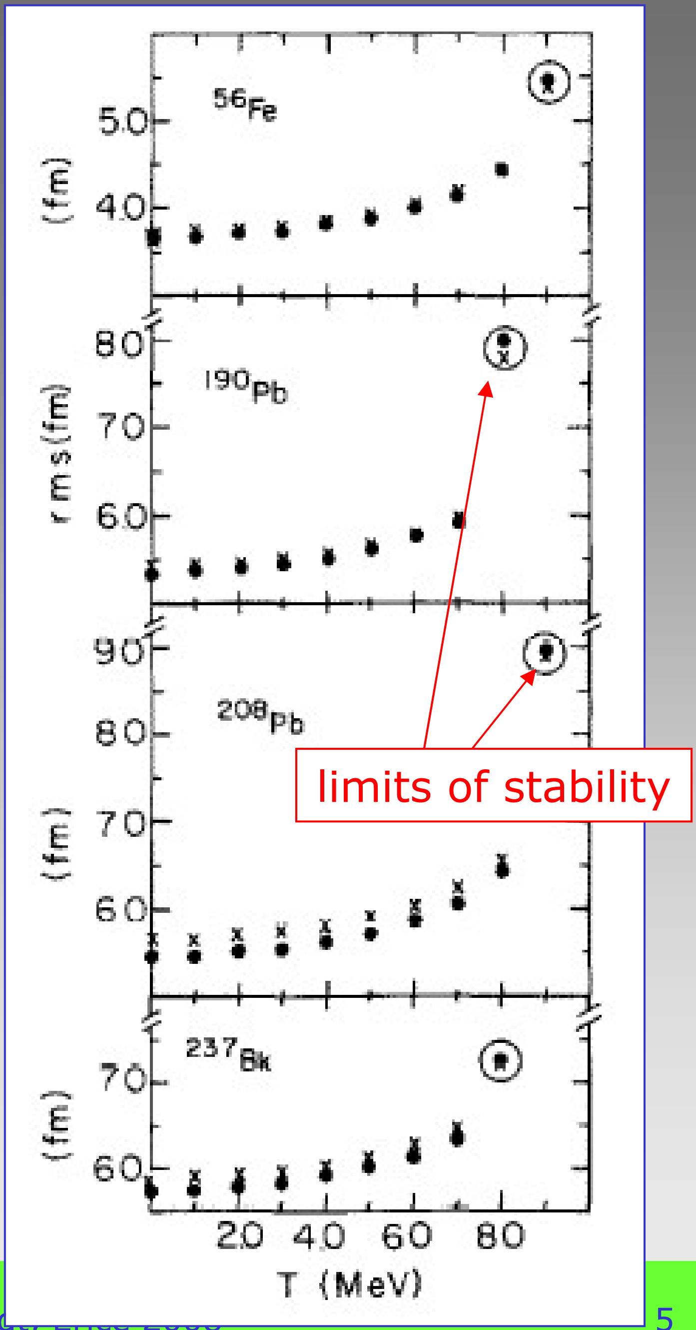
answered with temperature-dependent Hartree-Fock calculations

the nucleus in equilibrium with its surrounding vapor

limiting temperatures

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





limiting temperatures

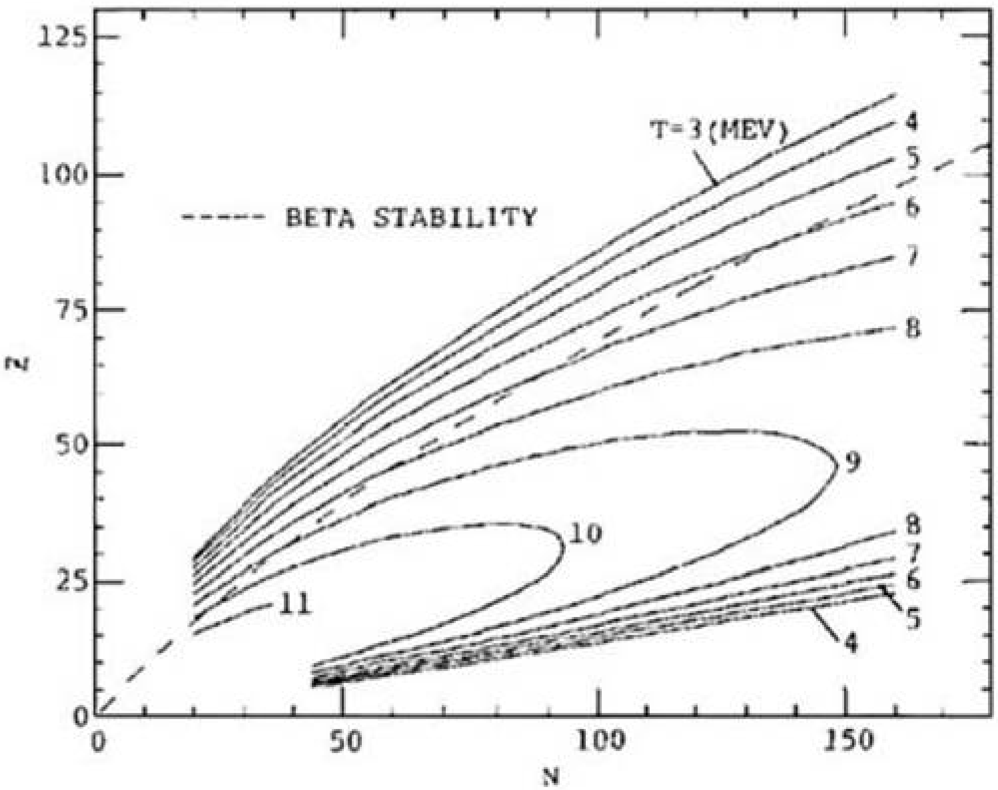


Fig. 1. Limiting temperatures predicted by Besprosvany and Levit [86]. Phys. Lett. B 217, 1 (1989)

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

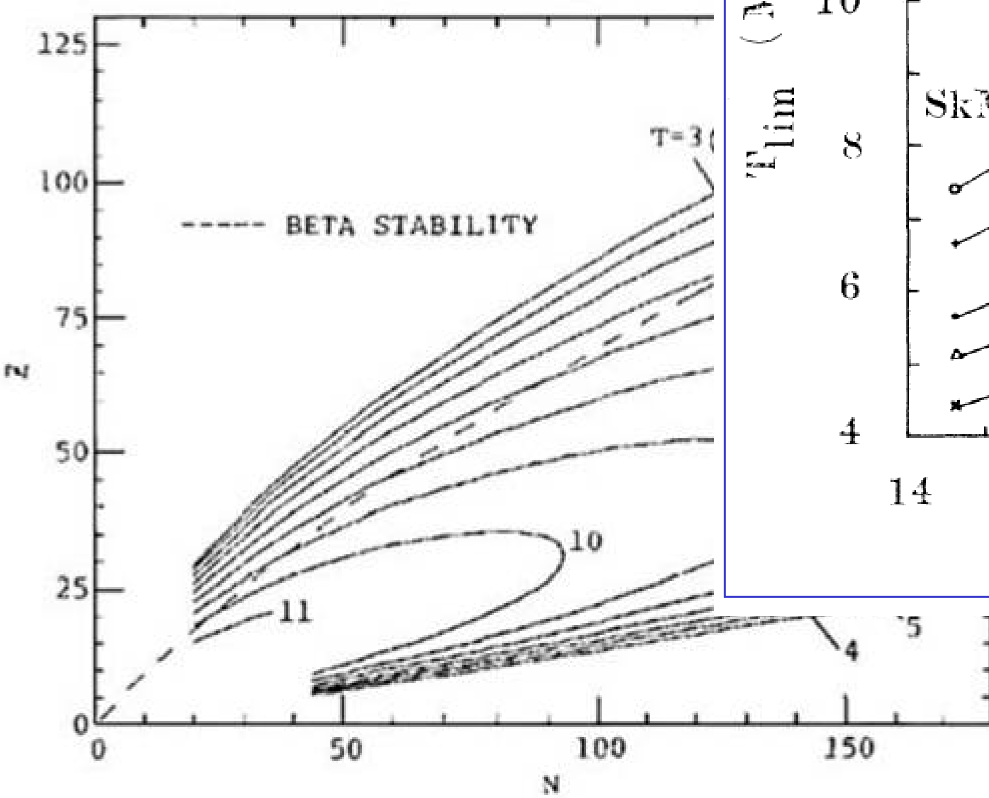
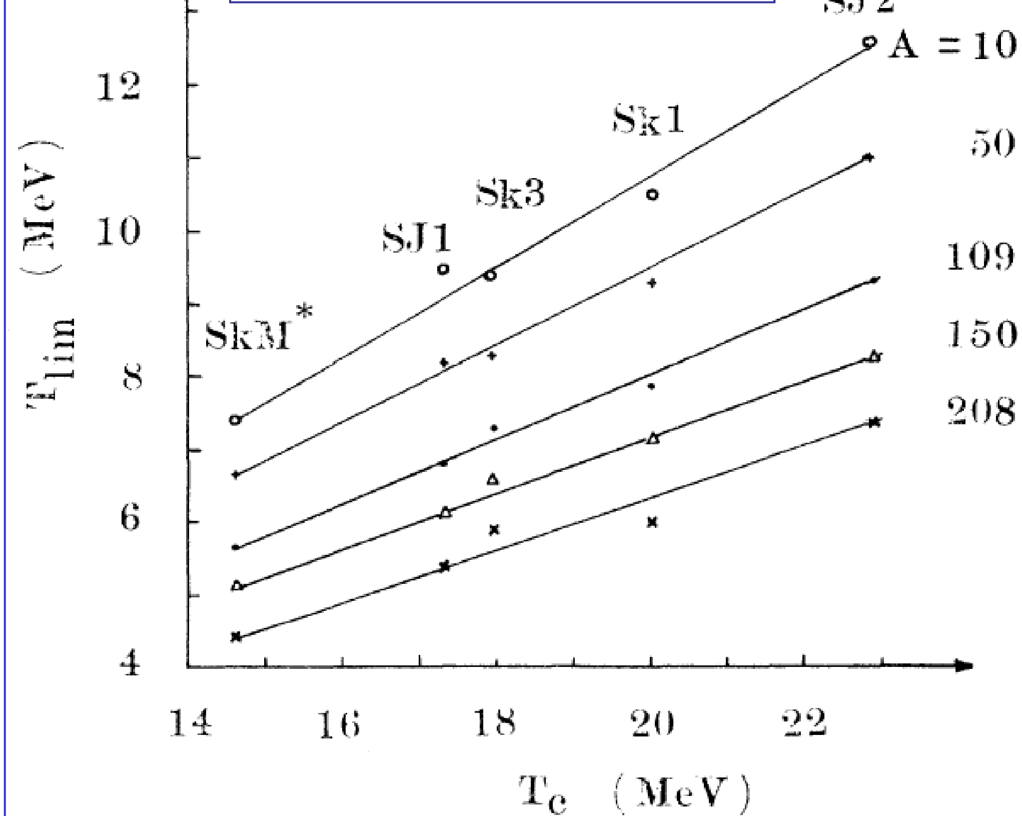


Fig. 1. Limiting temperatures predicted by Besprosvany and Levit [86]. Phys. Lett. B 217, 1 (1989)

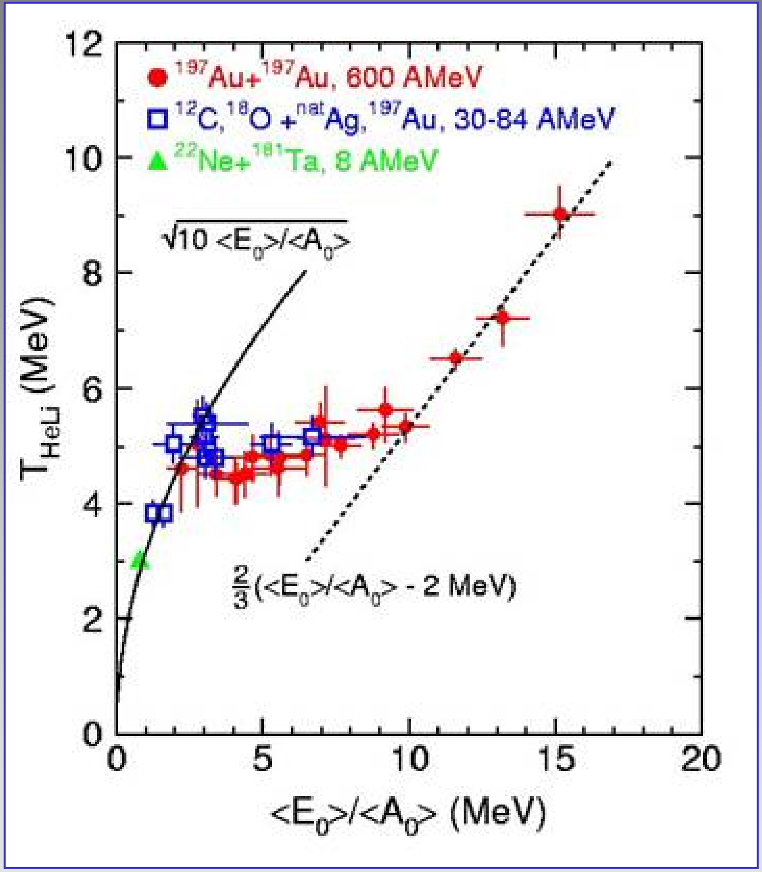
Song & Su, PRC 44 (1991)



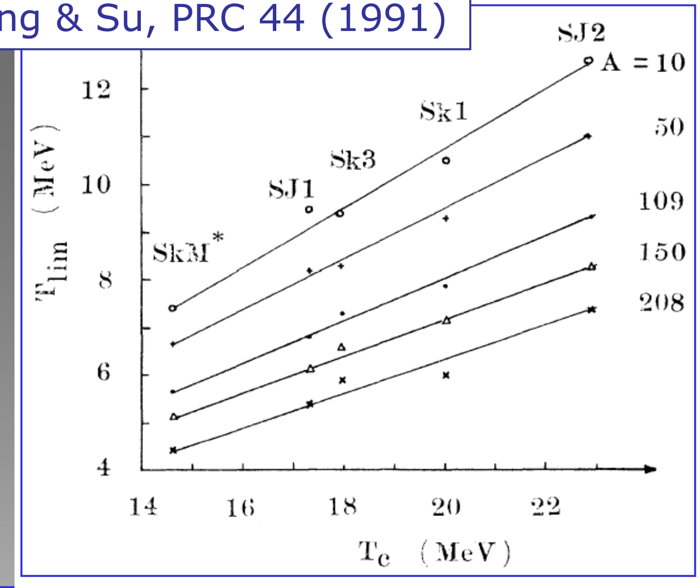
the limiting temperature is sensitive to the equation of state and to the temperature dependence of the surface tension

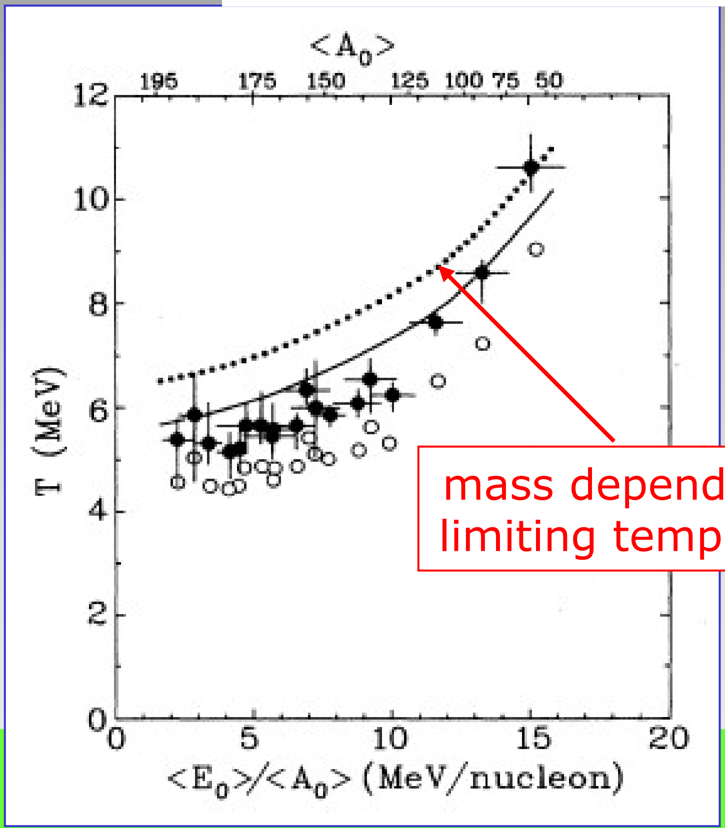
the nuclear caloric curve

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



Song & Su, PRC 44 (1991)

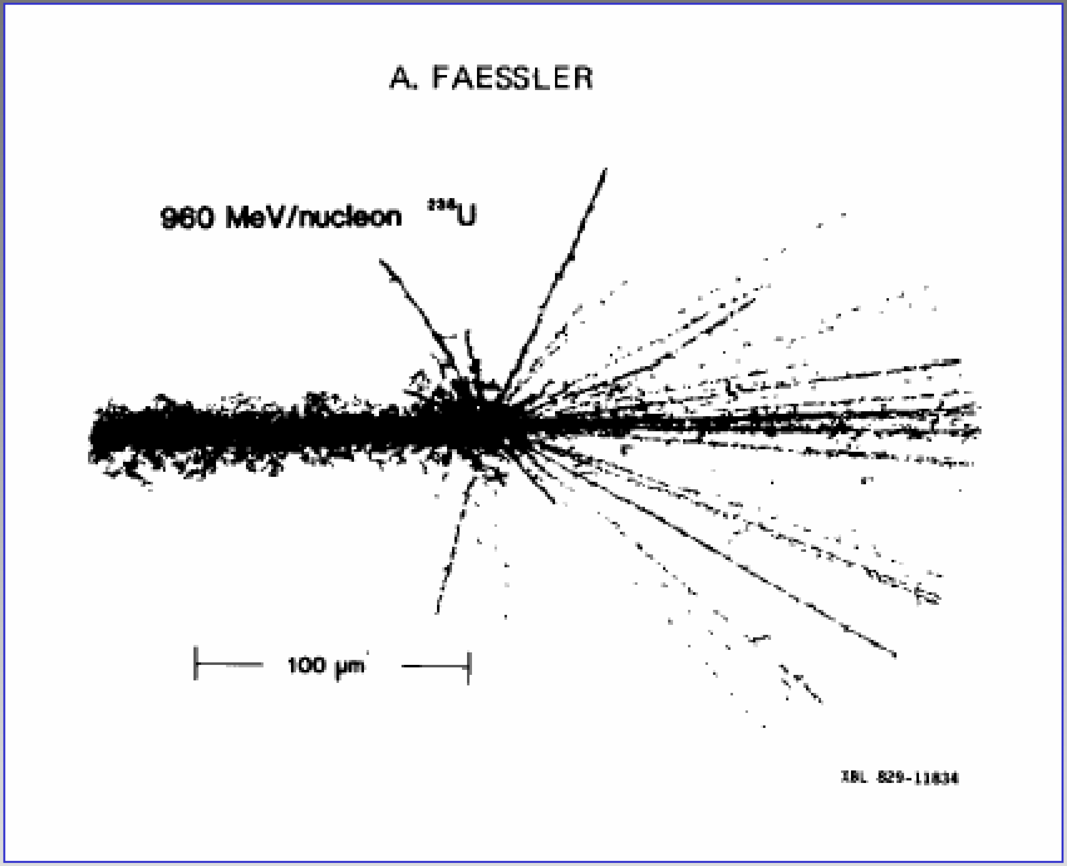




mass dependence of limiting temperatures

J.B. Natowitz et al.,
Phys. Rev. C 52 (1995)

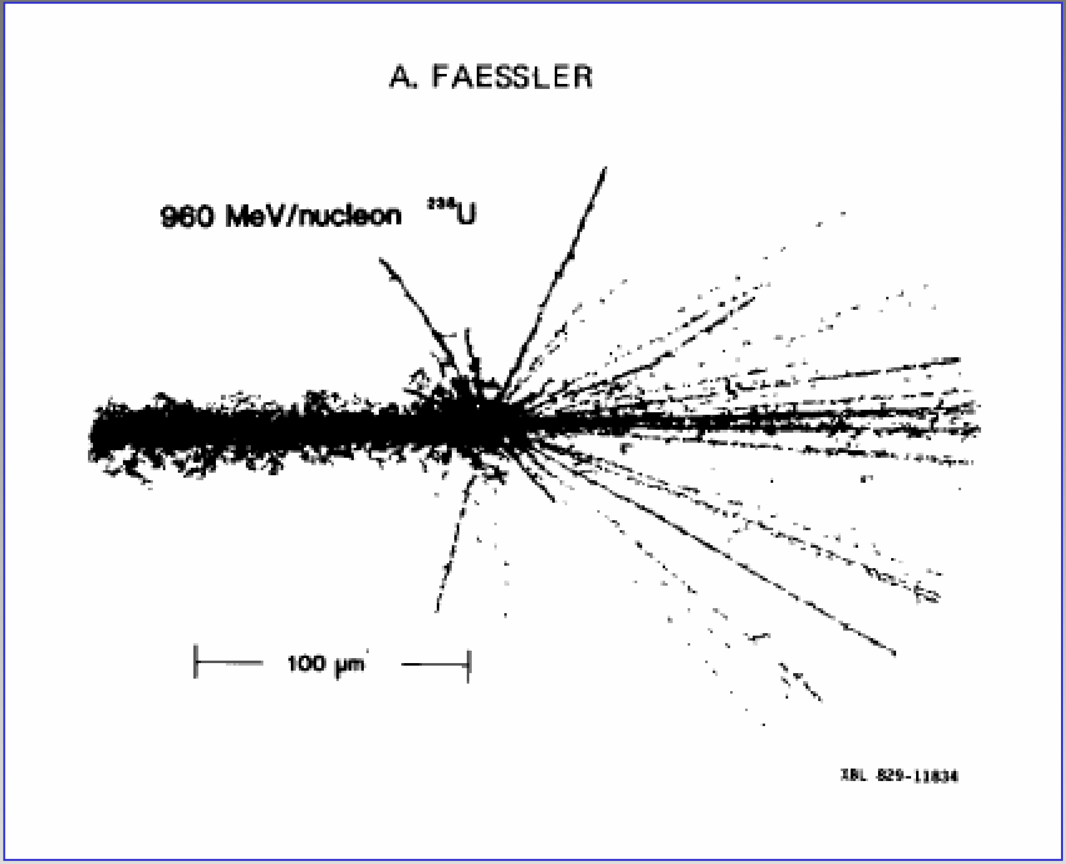
II. experiment: projectile fragmentation

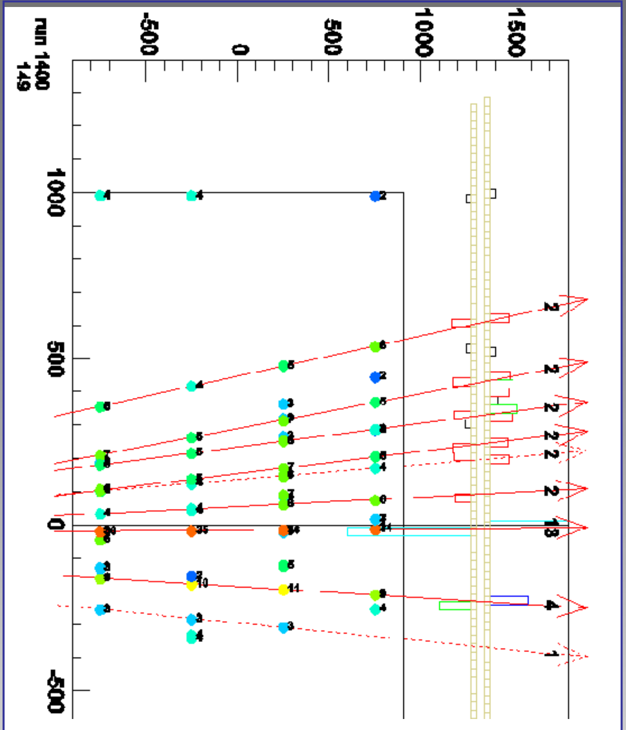


"... the future has already started
and we have to go back to work not to miss it."

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)

projectile fragmentation with ALADIN





tracking and ToF
multi-hit recognition

"... the future has already started
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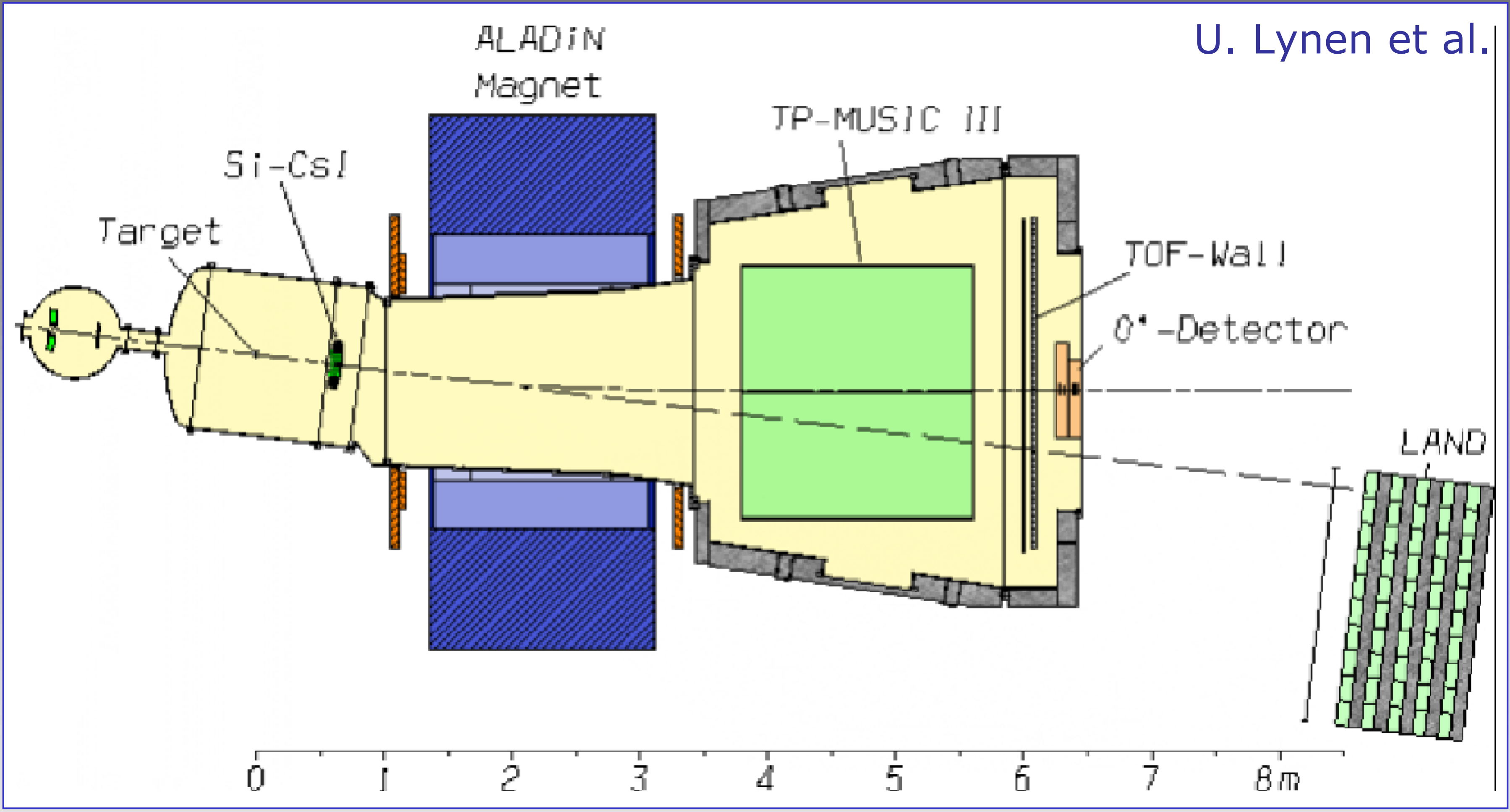
Nucl. Phys. A 400 (1983) 565; H.H. Heckman et al., Phys. Rev. C 27 (1983)

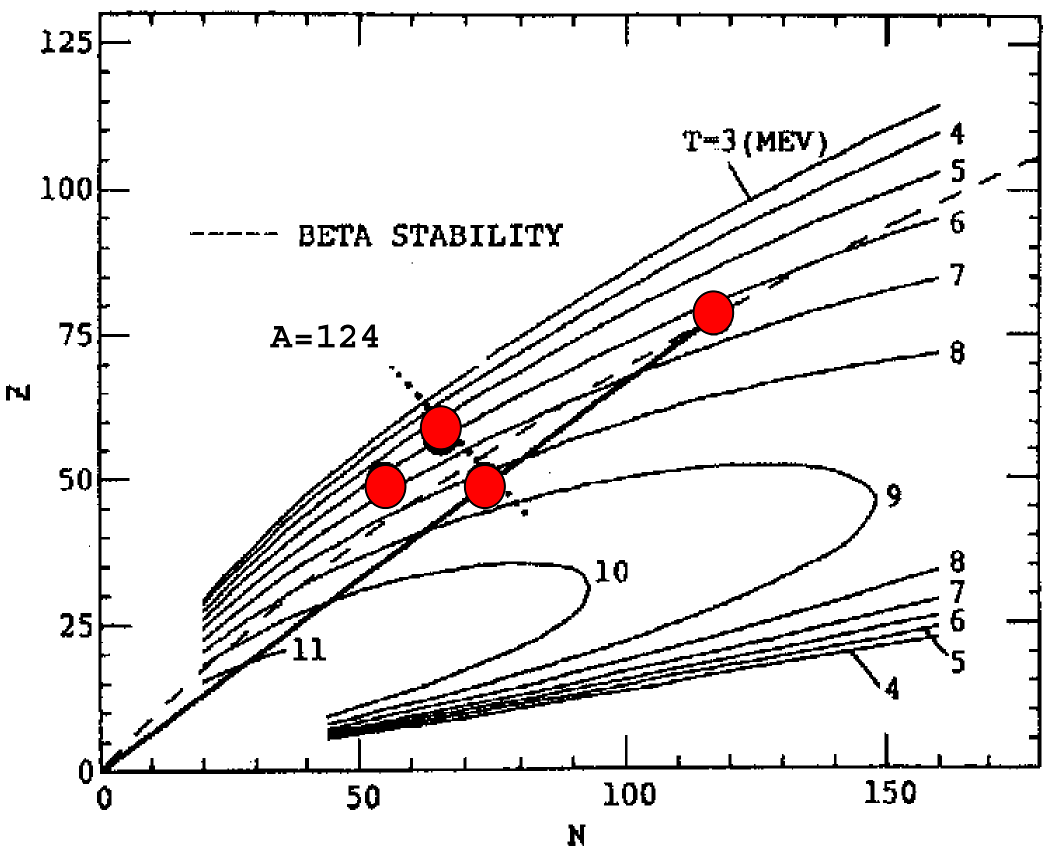
the ALADiN spectrometer



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

ALADIN experiment S254

"Mass and isospin effects in multifragmentation"



^{107}Sn, ^{124}La

^{124}Sn, ^{197}Au

600 A MeV

ur lines represent
ng temperatures

erature dependent
ee-Fock calculations
Skyrme forces

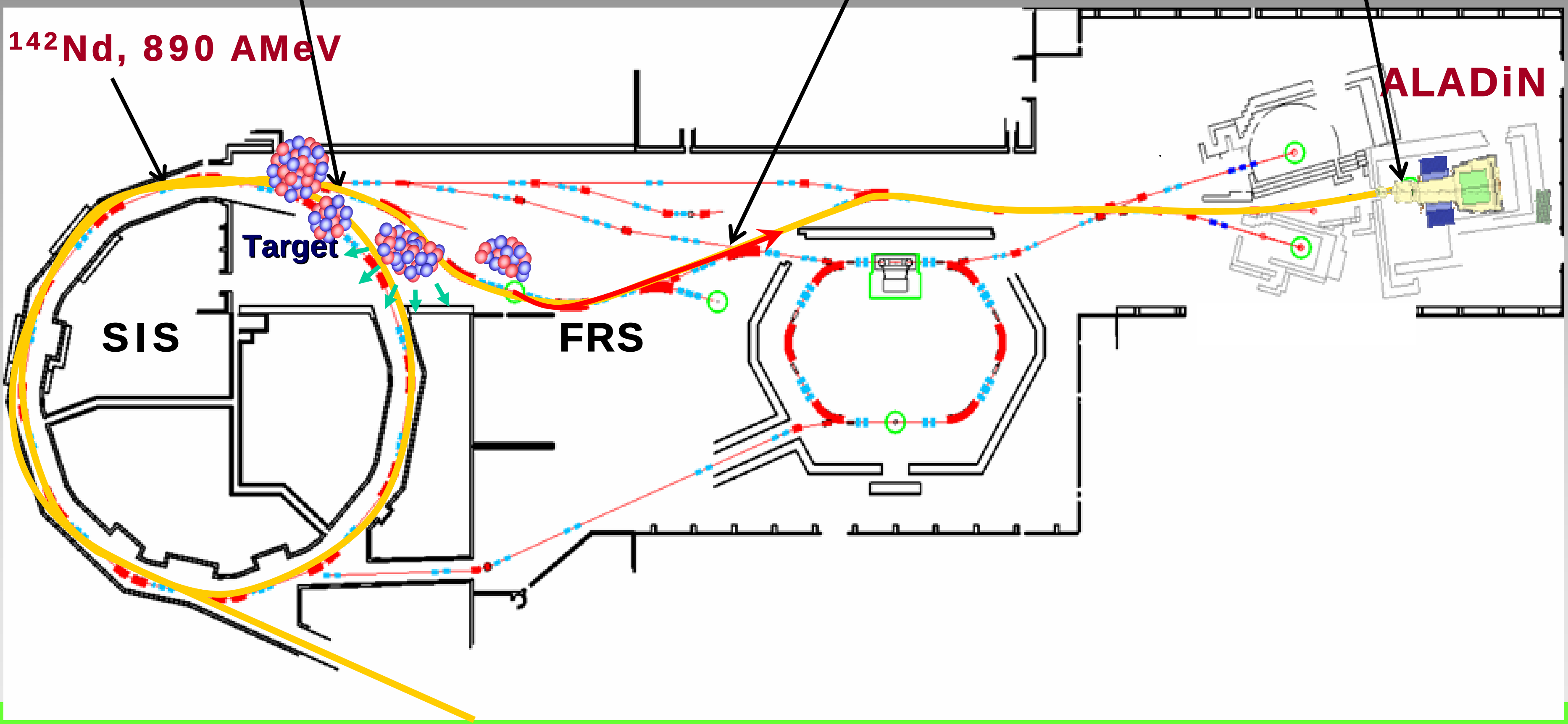
radioactive beam production

^{124}La(^{107}Sn) 600 A MeV

production target

reaction target

^{9}Be, 4009 mg/cm^{2}



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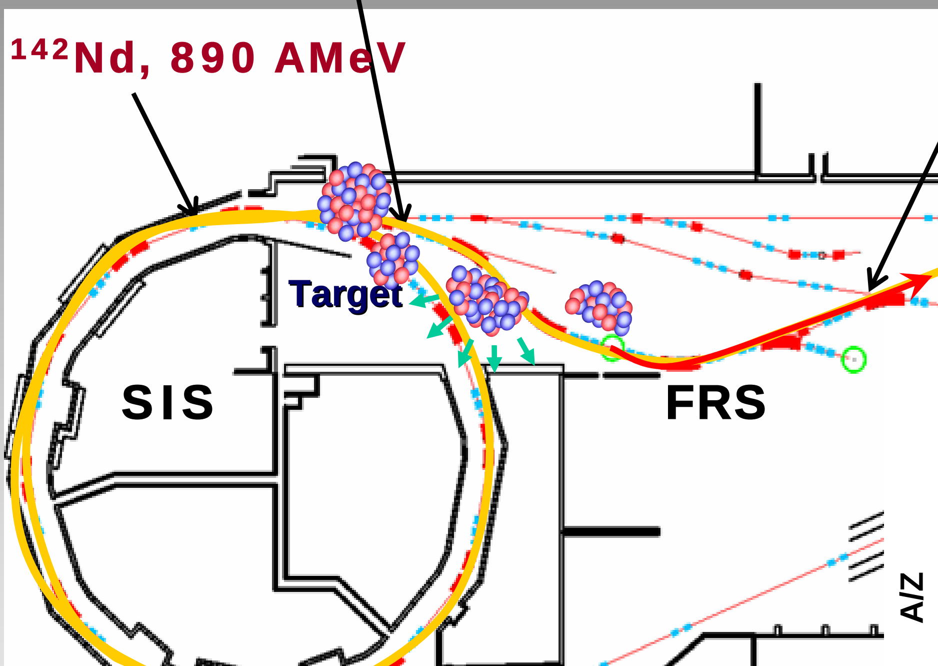
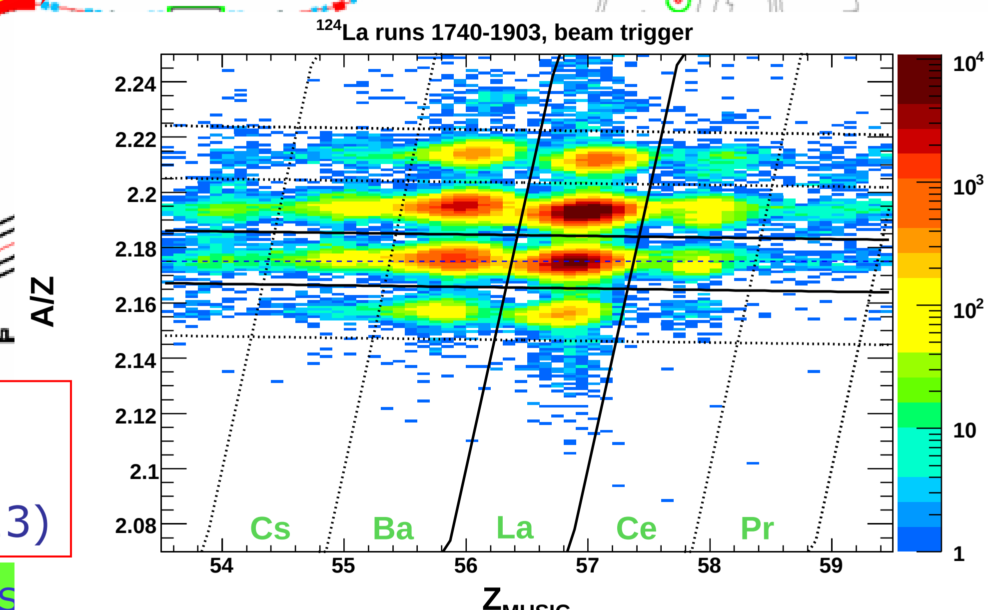




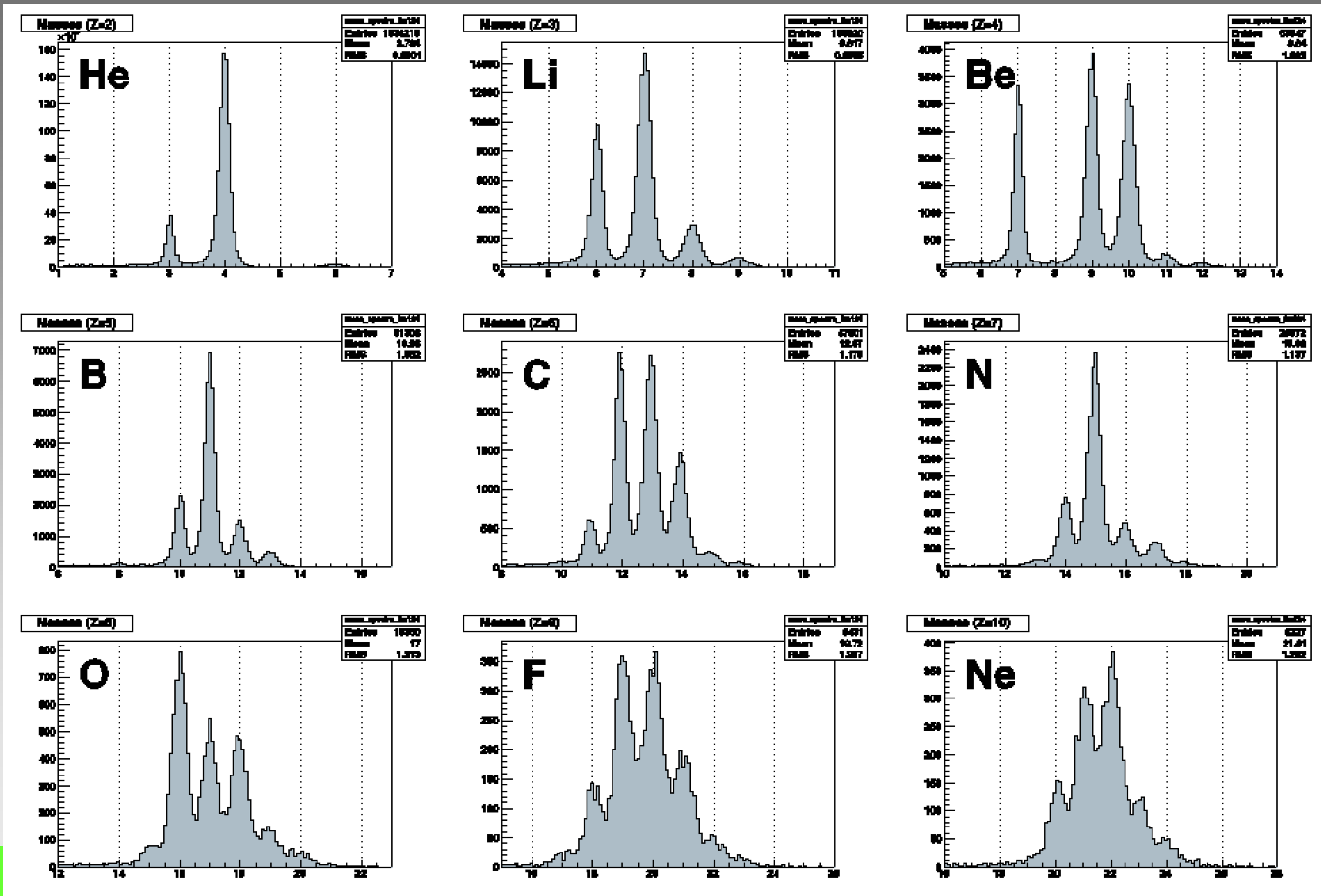
use discriminant analysis
to select pure isotopic beams
(J. Łukasik et al., NIM 587 (2008) 413)

The Aladin 2000 Collaboration

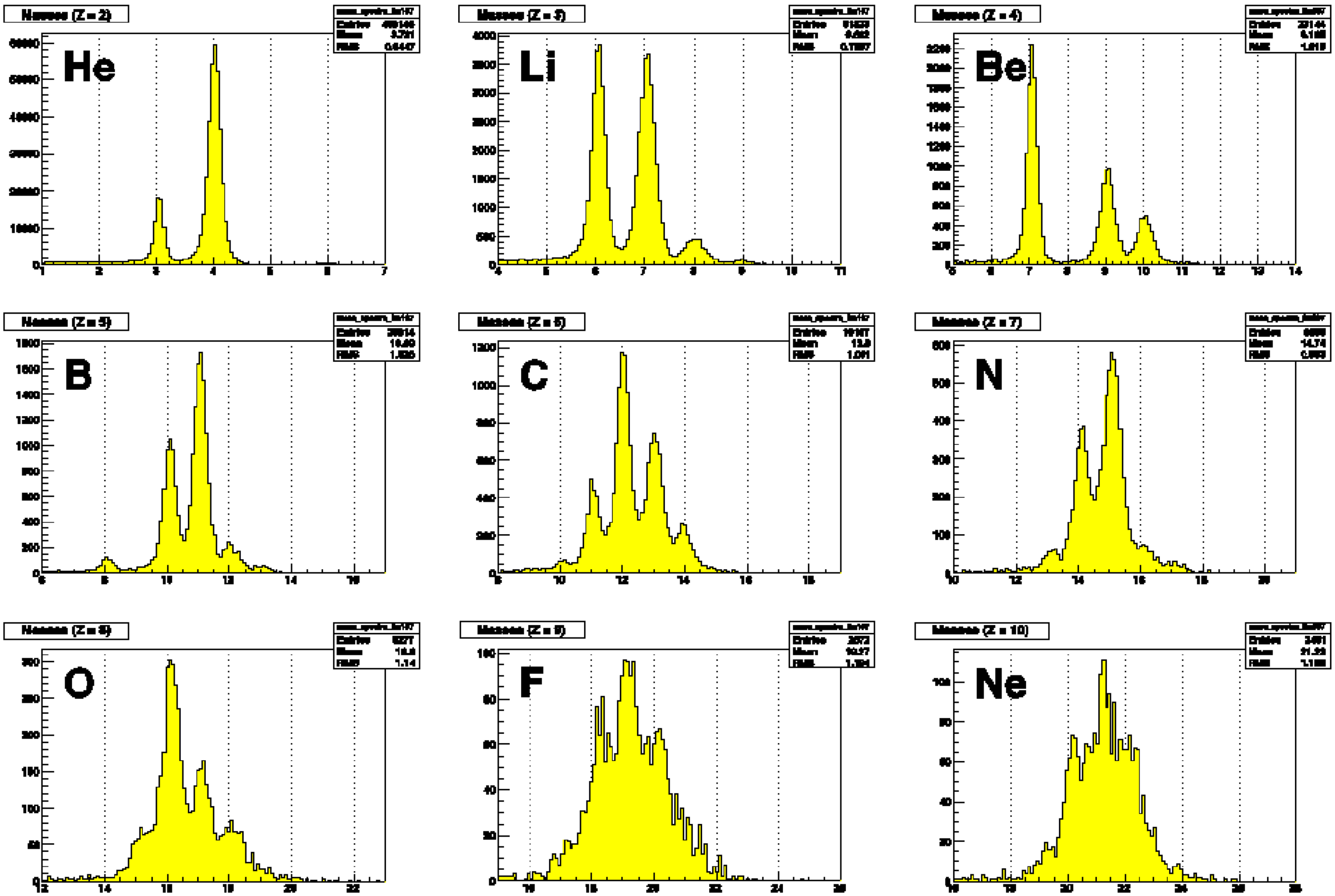
S. Bianchin, K. Kezzar, A. Le Fèvre, J. Lühning, J. Lukasik, U. Lynen, W.F.J. Müller, H. Orth, A.N. Otte, H. Sann, C.Schwarz, C. Sfienti, W. Trautmann, J. Wiechula, M.Hellström, D. Henzlova, K. Sümmerer, H. Weick, P.Adrich, T. Aumann, H. Emling, H. Johansson, Y. Leifels, R. Palit, H. Simon, M. De Napoli, 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

GSI INFN IN2P3 cea DAPNIA IPN Orsay NSCL GANIL

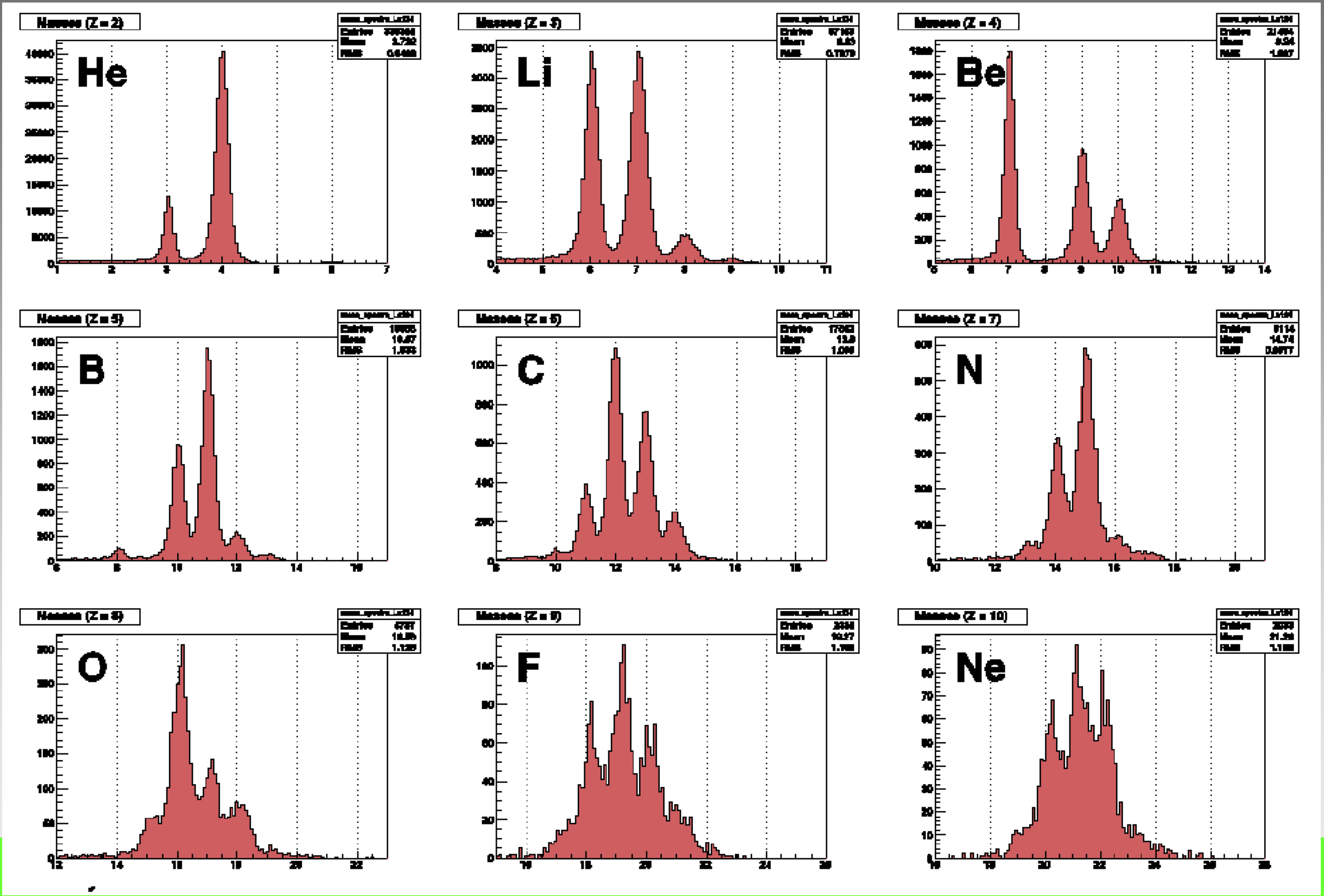
final mass spectra: ^{124}Sn



final mass spectra: ^{107}Sn

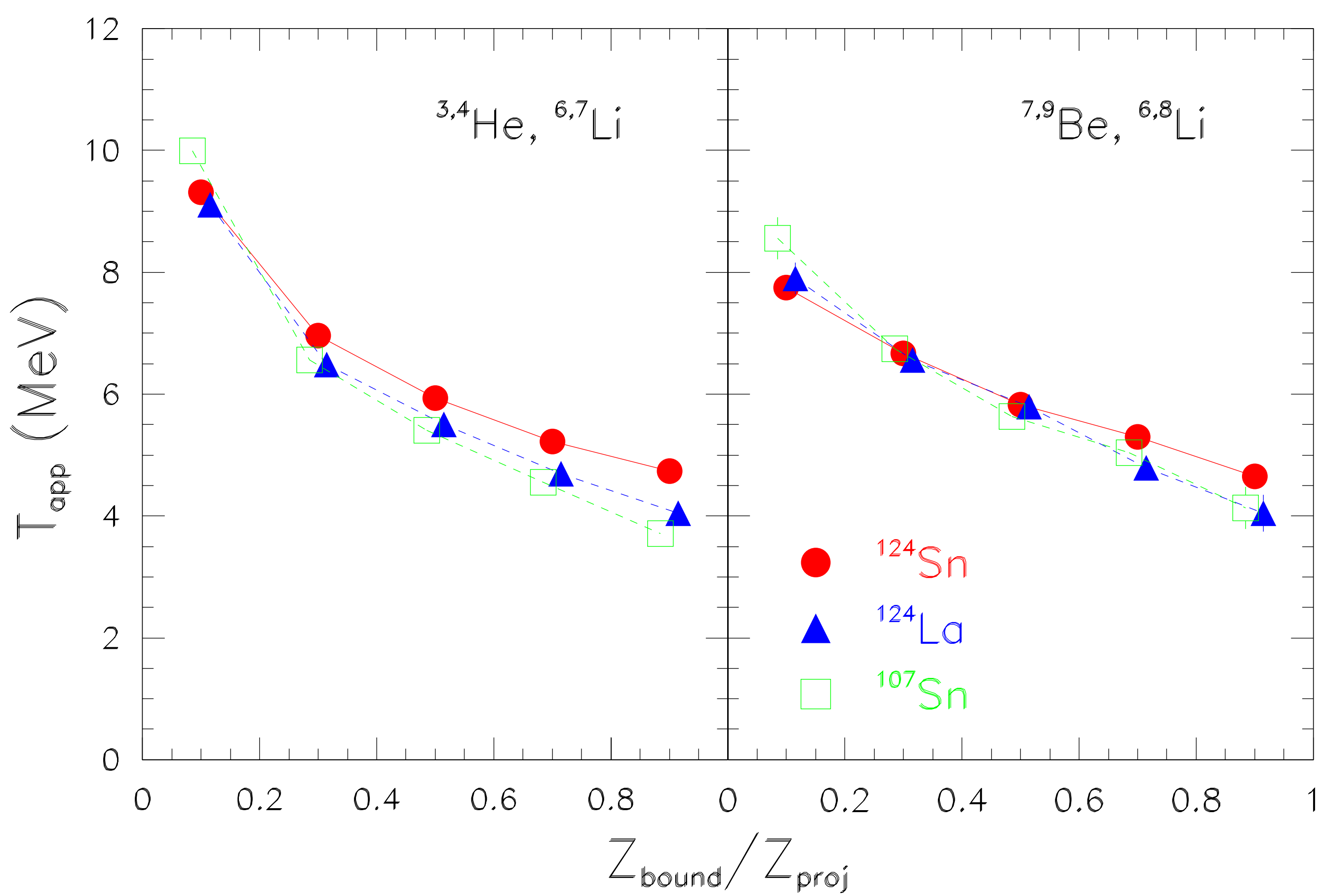


final mass spectra: ^{124}La



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)



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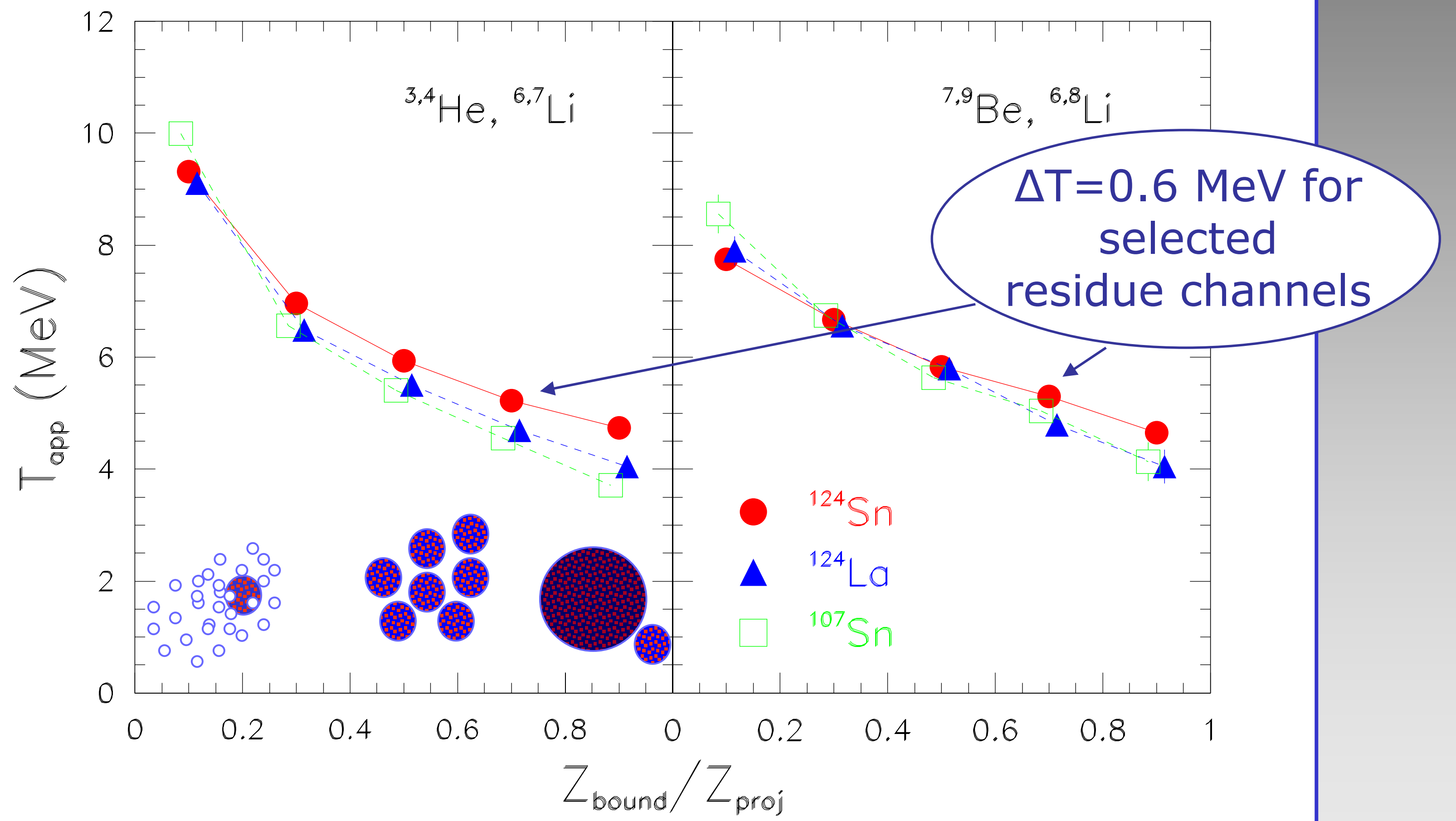
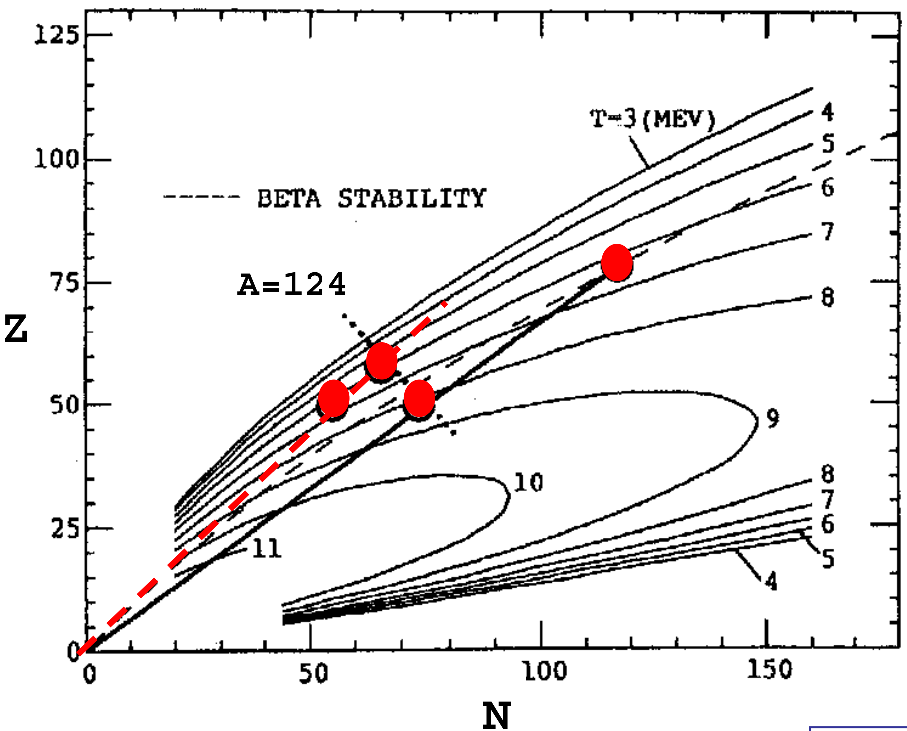
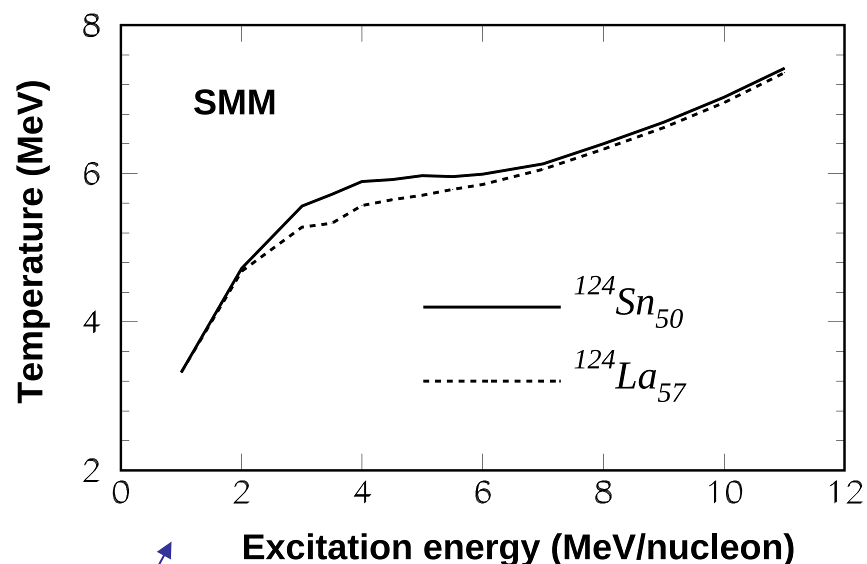


N/Z independence of the nuclear caloric curve



Statistical Multifragmentation Model
Ogul and Botvina, PRC 66 (2002)

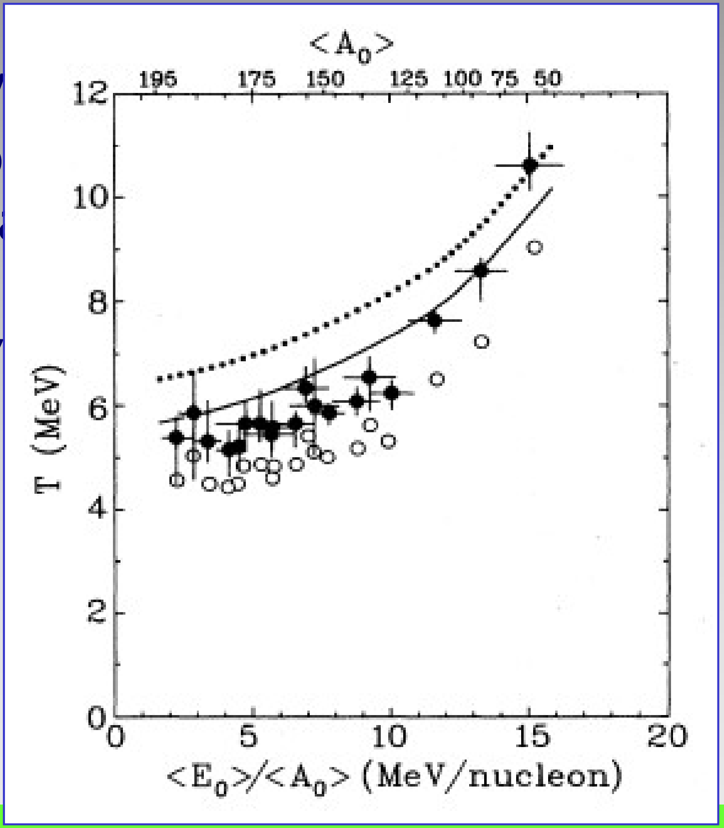


good agreement with the SMM predictions

the predicted isospin dependence is not observed

III. consequences

1. the Z_{bound} dependence is not primarily a mass effect
2. Coulomb effect ΔT=0.6 MeV in
2a. limiting temperature of 6 MeV
2b. the limiting temperature is no
    determined by asymptotic pha
3. multifragmentation: phase-spa
    instead of Coulomb instability



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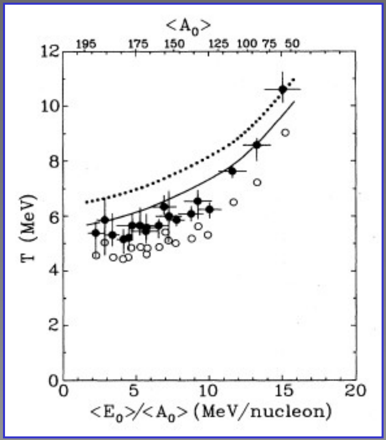


1. the Z_{bound} dependence is not primarily a mass effect
2. Coulomb effect ΔT=0.6 MeV in residue production

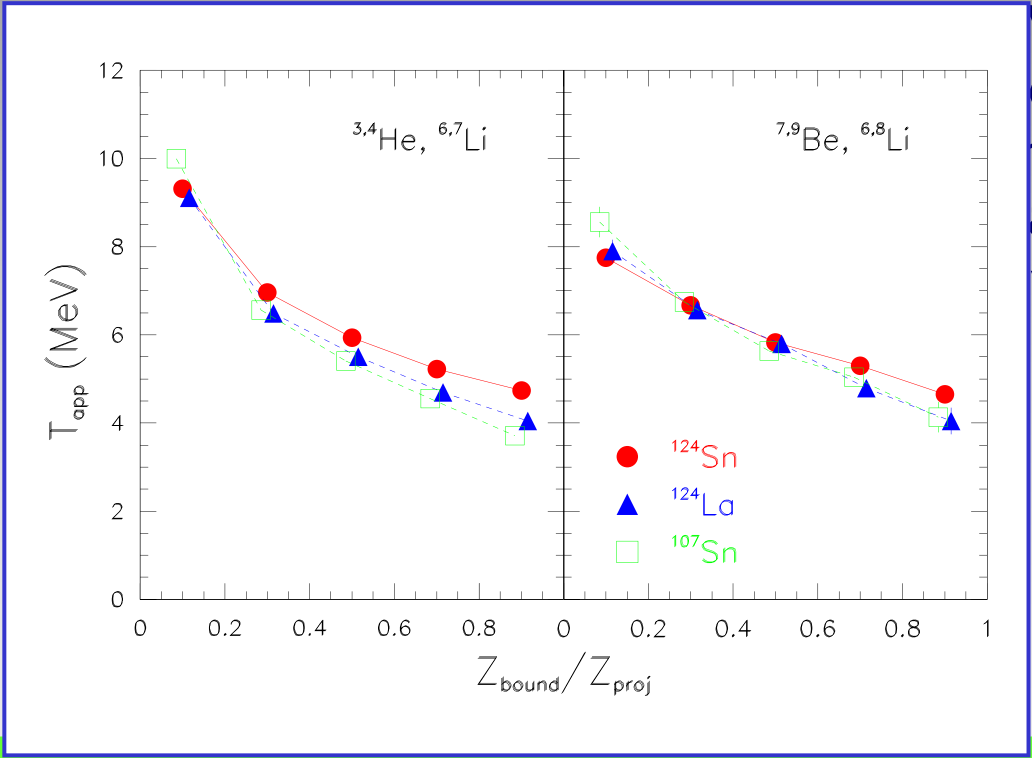
V -> T_c = 15 MeV

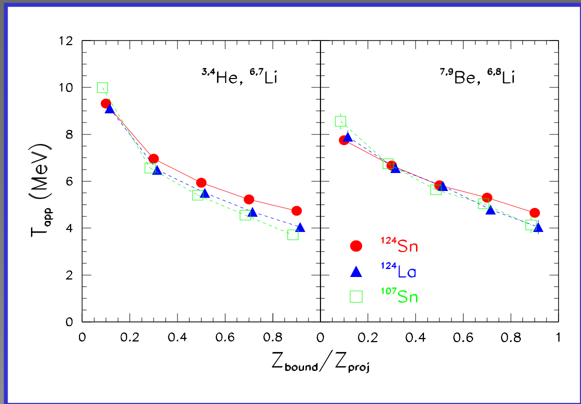
ot tested ->

hase space

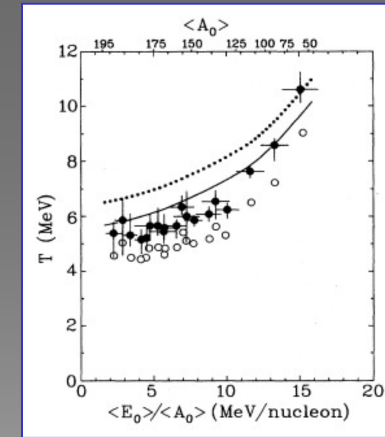
ace driven instability

y

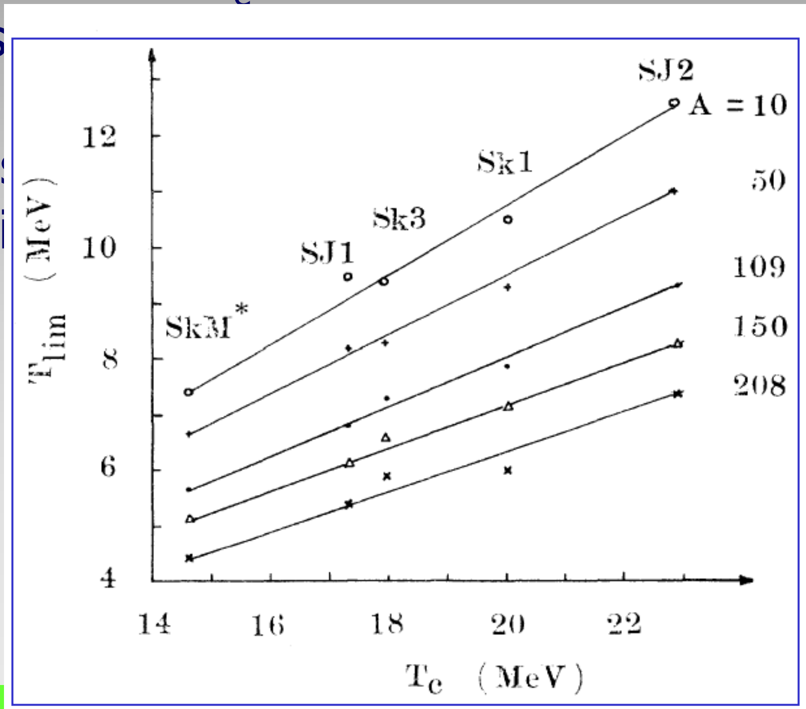


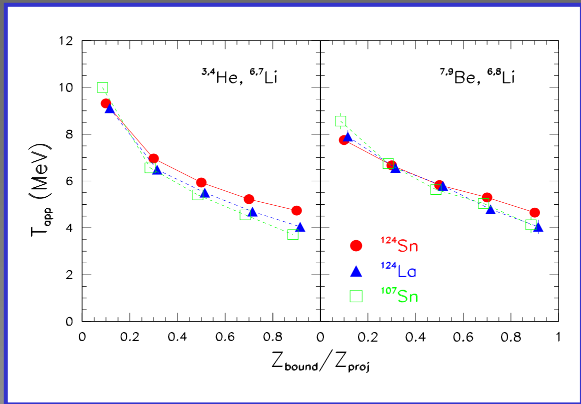


III. consequences

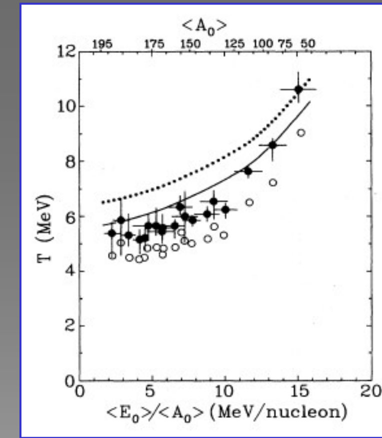


1. the Z_{bound} dependence is not primarily a mass effect
2. Coulomb effect ΔT=0.6 MeV in residue production
2a. limiting temperature of 6 MeV -> T_c = 15 MeV
2b. the limiting temperature is
determined by asymptotic
3. multifragmentation: phase-
instead of Coulomb instabi

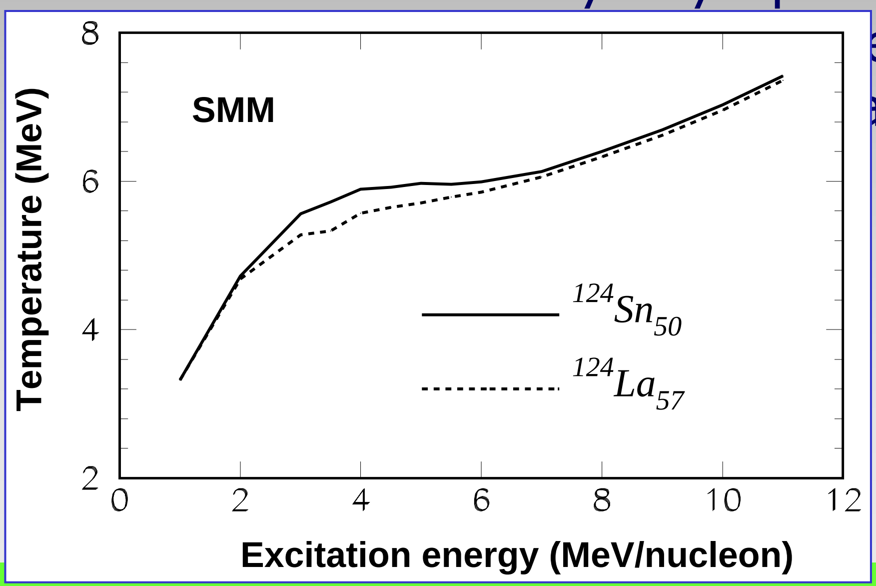


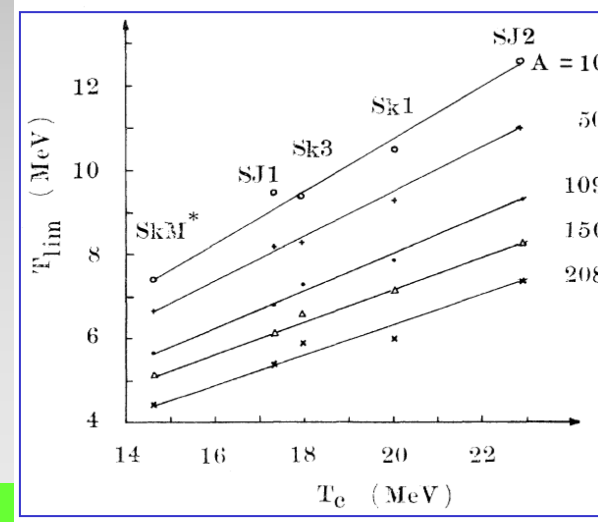


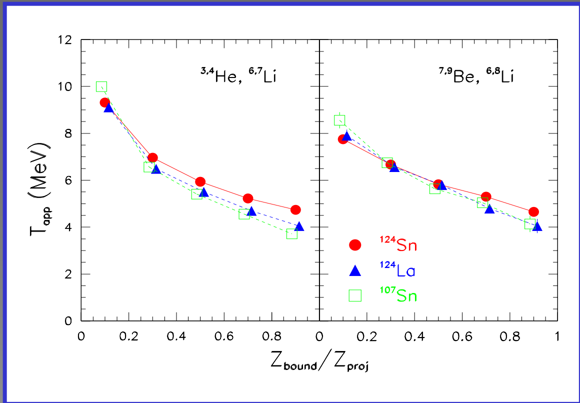
III. consequences



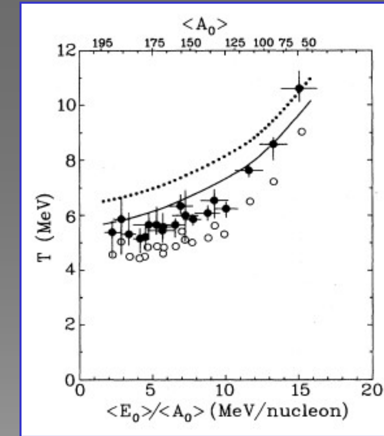
1. the Z_{bound} dependence is not primarily a mass effect
2. Coulomb effect ΔT=0.6 MeV in residue production
2a. limiting temperature of 6 MeV -> T_c = 15 MeV
2b. the limiting temperature is not tested ->
determined by asymptotic phase space
e-space driven instability
ability







III. consequences



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2. Coulomb effect ΔT=0.6 MeV in residue production
2a. limiting temperature of 6 MeV -> T_c = 15 MeV
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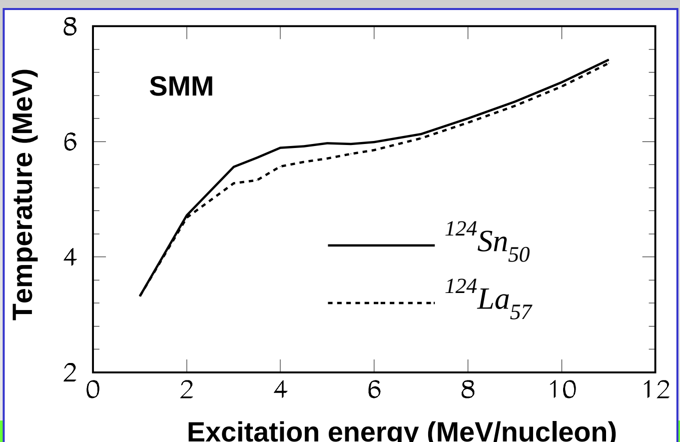
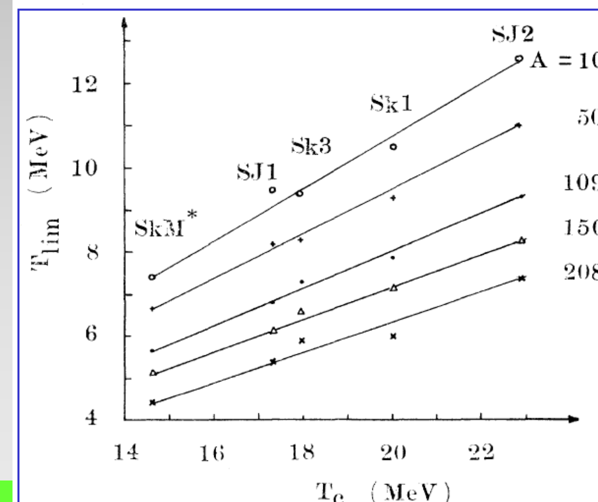
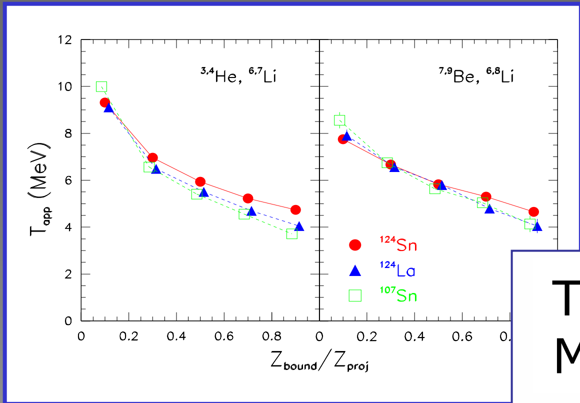
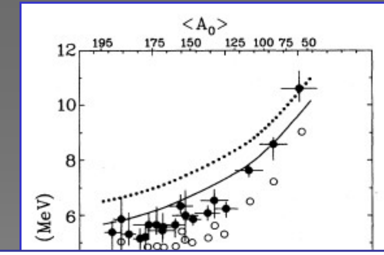
3. multifragmentation: phase-space driven instability
   instead of Coulomb instability



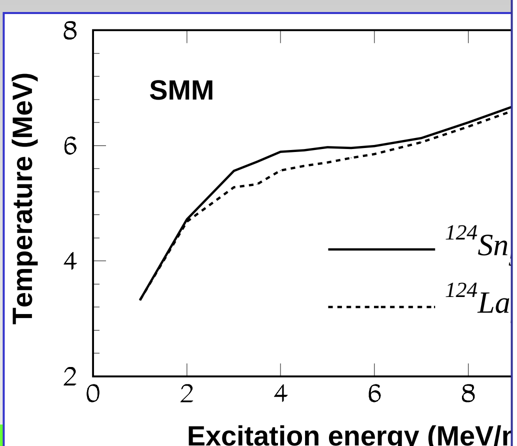






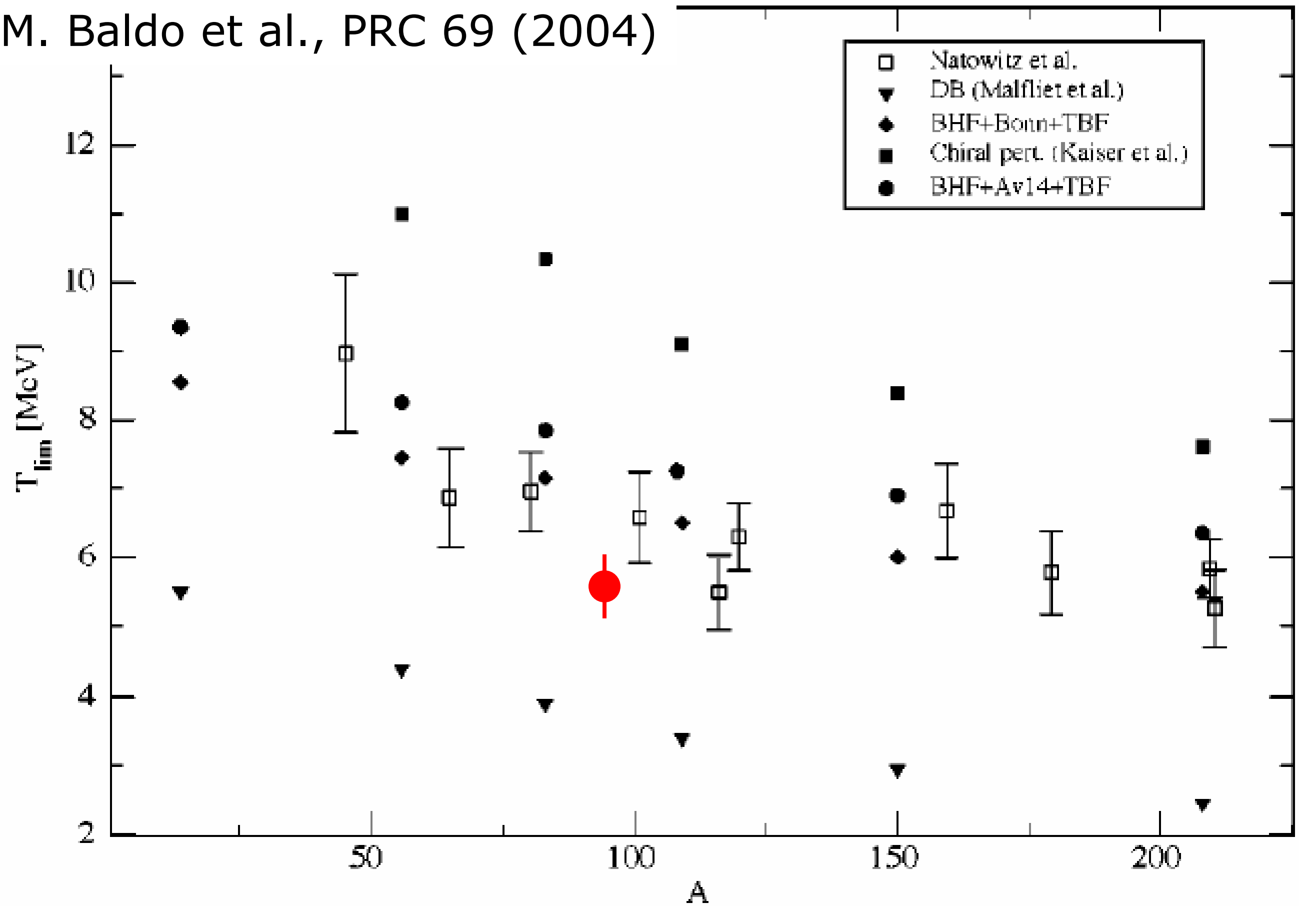
III. consequences

1. the Z_{boun}
2. Coulomb
2a. limiting
2b. the lim
determ
3. multifrag
instead



THE LIMITING TEMPERATURE OF HOT NUCLEI FROM MICROSCOPIC EQUATION OF STATE

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

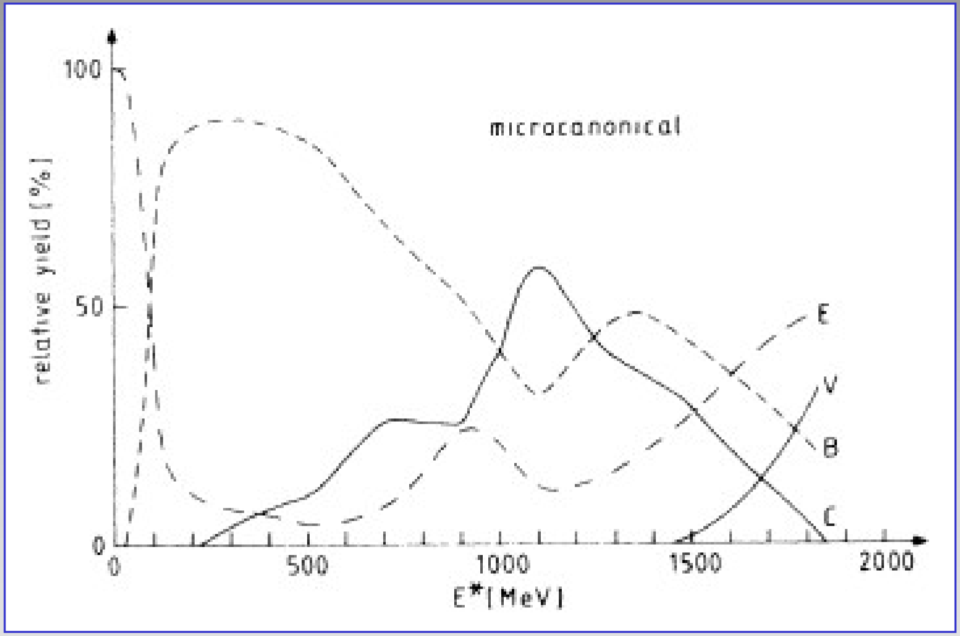


if it is not Coulomb ...
what drives the system to expansion ?

1. the asymptotic phase space
2. early fragment recognition and persistence

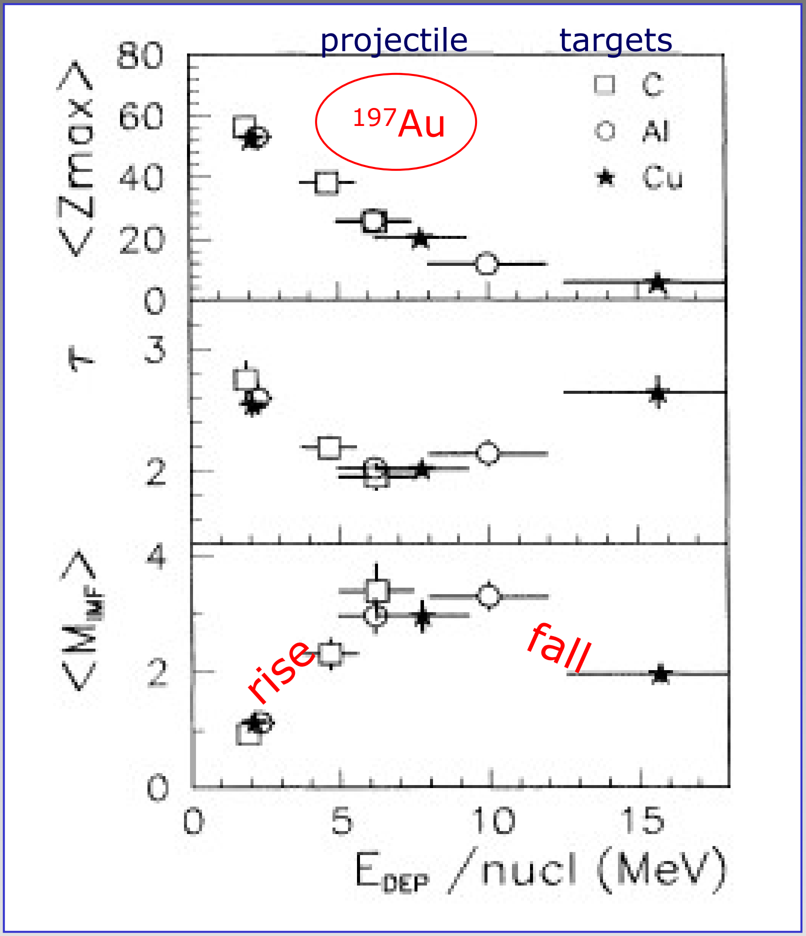
the asymptotic phase space

D.H.E. Gross et al.
PRL 56, 1544 (1986)



decay modes of ^{238}U
c = cracking

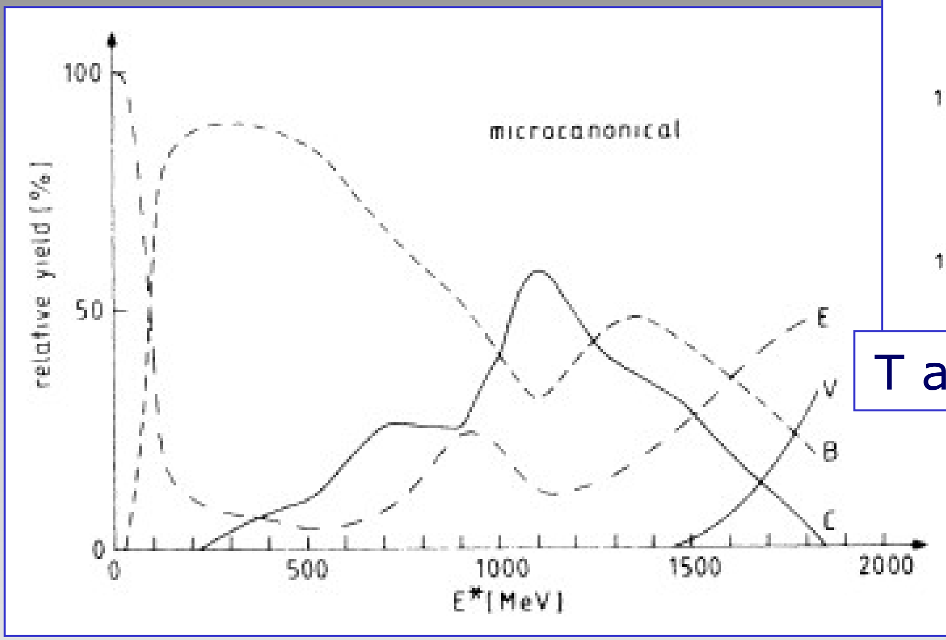
C.A. Ogilvie et al., PRL (1991)



rise and fall of
multi-fragment emission

the asymptotic phase space

D.H.E. Gross et al.
PRL 56, 1544 (1986)



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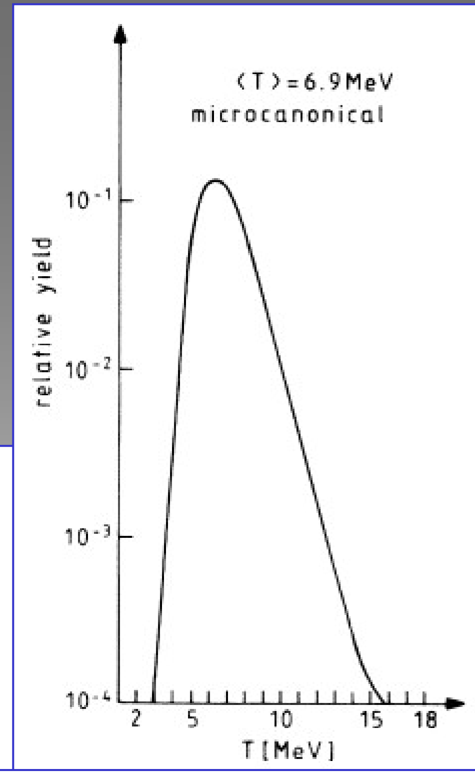
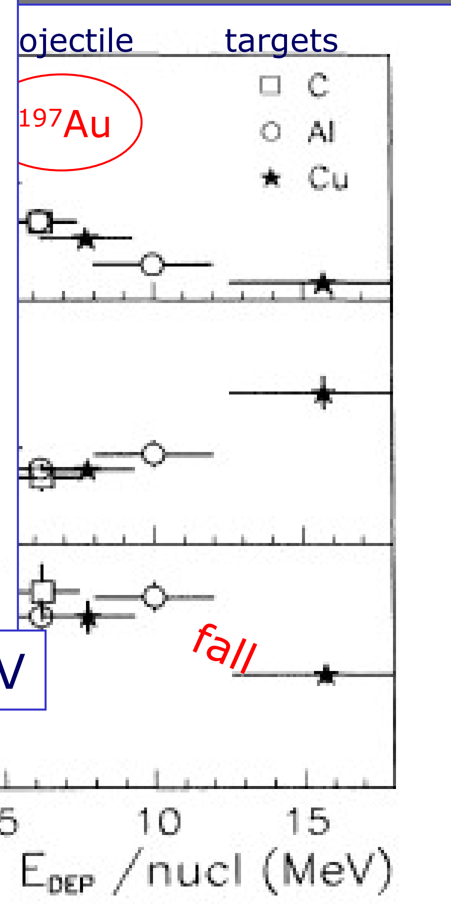


T at E* = 1100 MeV

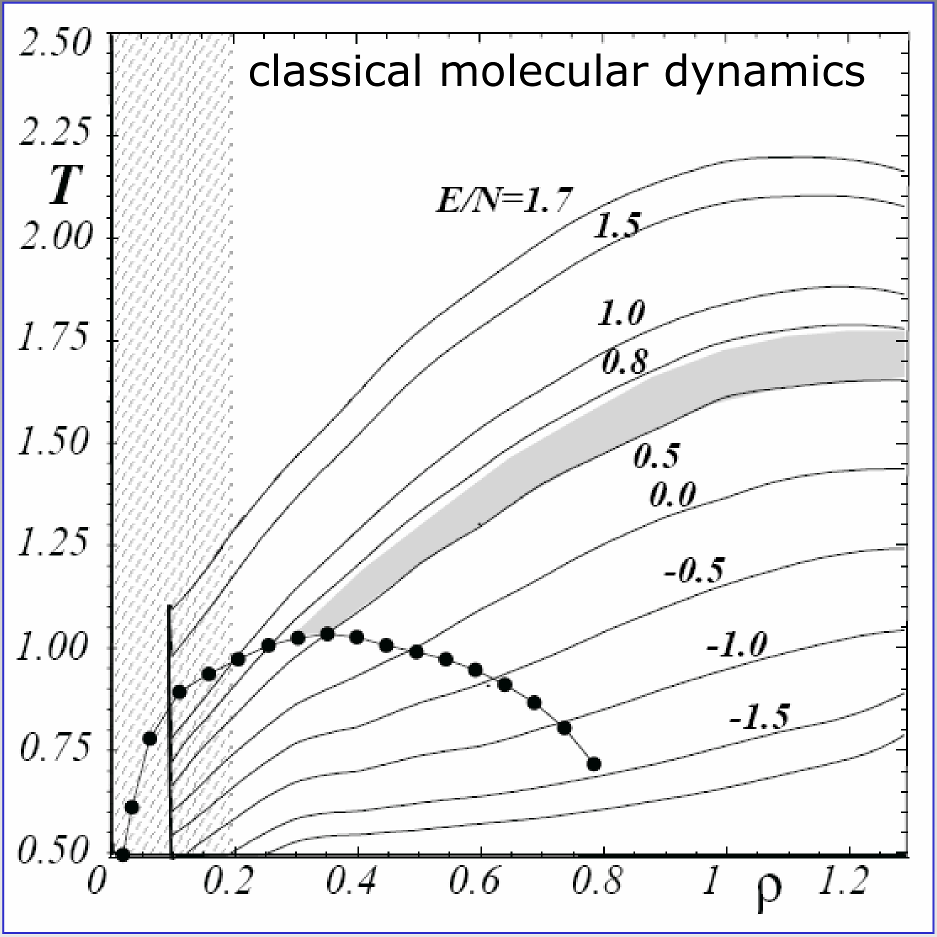
et al., PRL (1991)

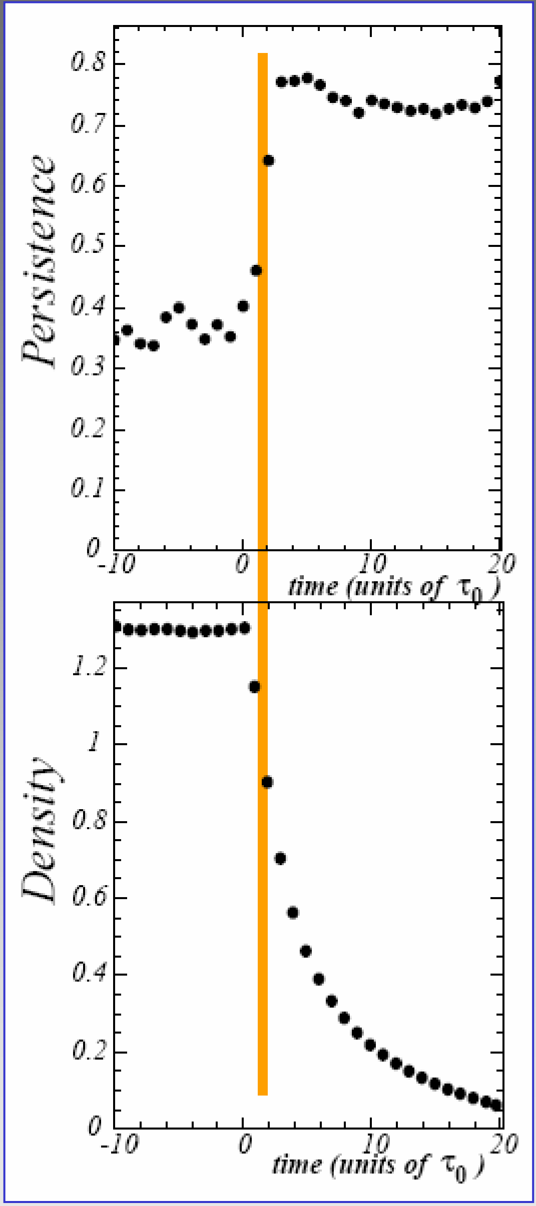


rise and fall of
multi-fragment emission

early fragment recognition and persistence

Campi et al., PRC 67, 044610 (2003)

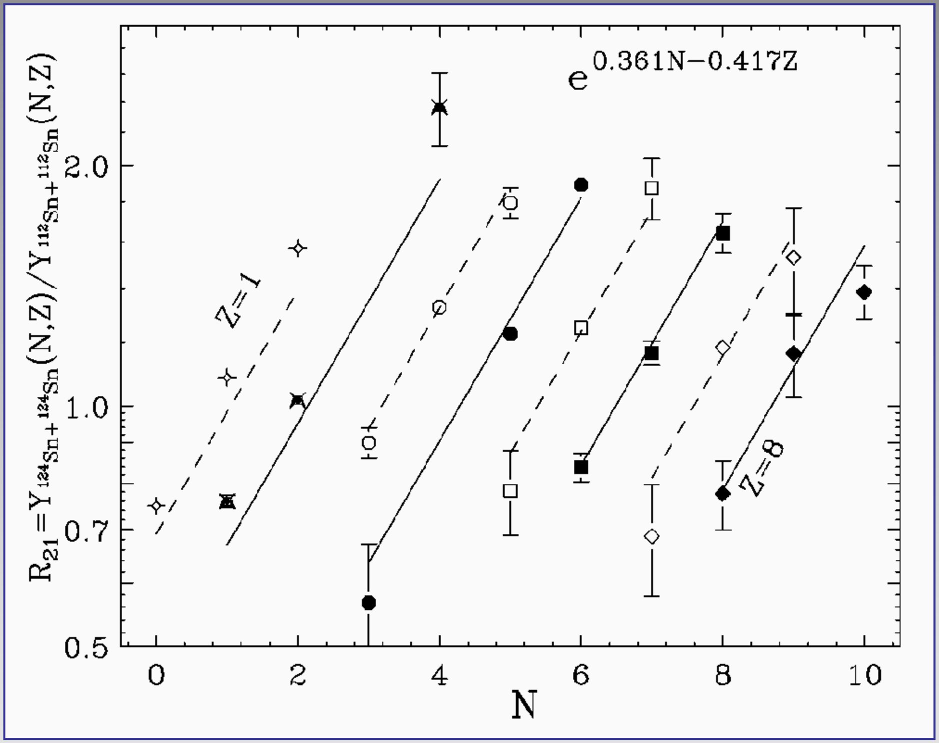




see also: A. Le Fèvre and J. Aichelin, Phys. Rev. Lett. 100, 042701 (2008)

IV. isoscaling

in reactions $^{112}Sn+^{112}Sn$ and $^{124}Sn+^{124}Sn$ at 50 A MeV

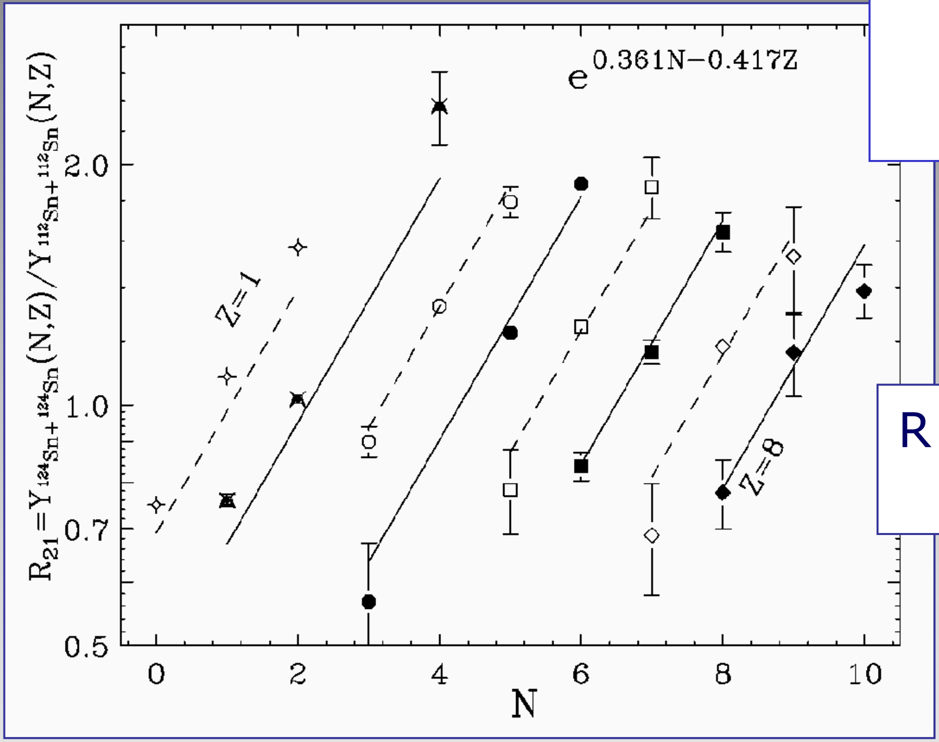


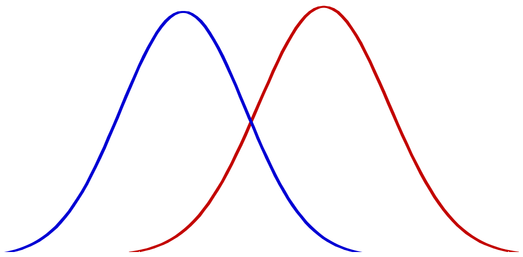
M.B. Tsang et al.,
PRC 64, 054615 (2001)

"systematic behavior of yield ratios following grandcanonical expectations"

IV. isoscaling

in reactions $^{112}Sn+^{112}Sn$ and $^{124}Sn+^{124}$





α depends on shift and widths of mass distributions

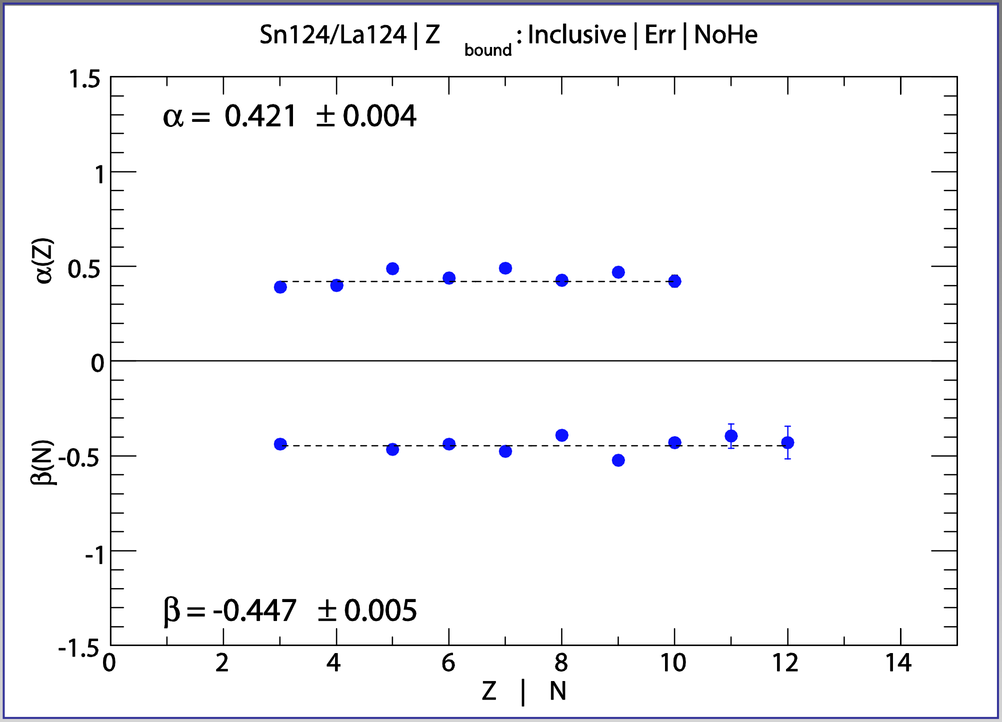
$$R = C \cdot \exp(\alpha N + \beta Z)$$
$$\alpha = \Delta\mu_n / T$$

M.B. Tsang et al., PRC 64, 054615 (2001)

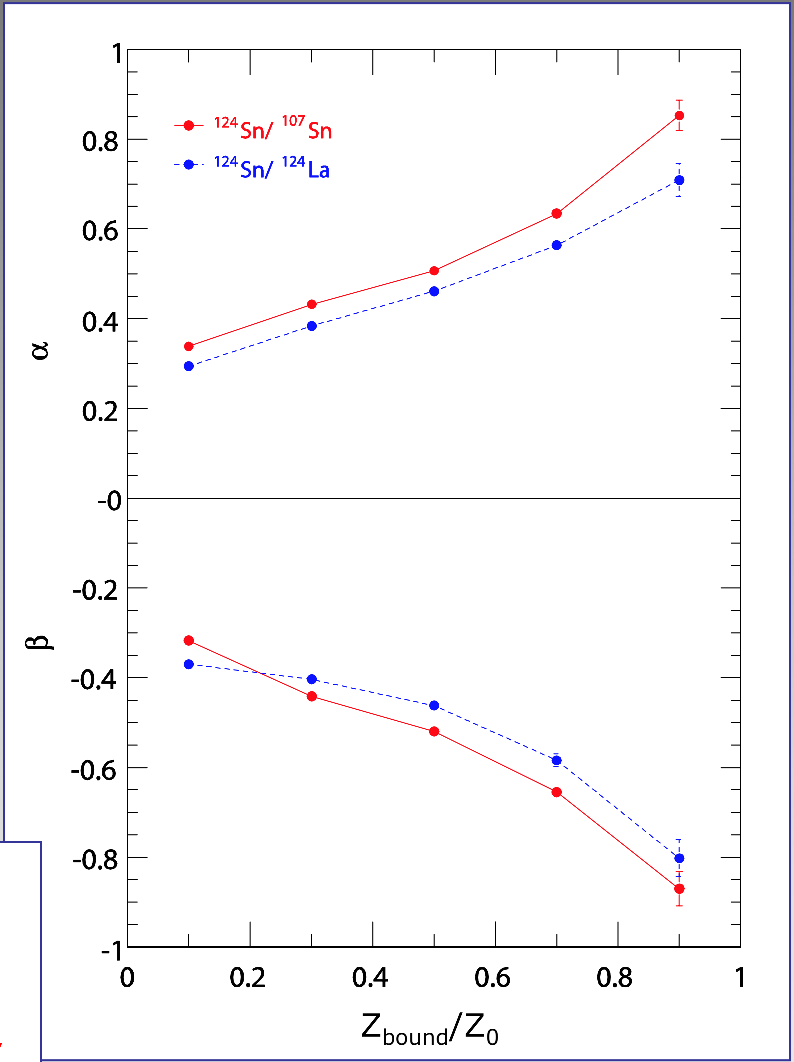
"systematic behavior of yield ratios following grandcanonical expectations"

isoscaling in S254

S. Bianchin, J. Łukasik



p_0 fit of individual-Z (or N) fits



two experimental results:

1) the individual slopes are identical for Z≥3

2) the isoscaling parameters drop with increasing excitation as seen with INDRA@GSI, A. Le Fèvre et al., PRL 94 (2005)

summary of S254

1. **secondary beams essential** to enhance effects

2. **small changes of global observables** with N/Z
   important for isolating isospin effects

3. isotope distributions exhibit
   memory and structure effects

4. N/Z dependence of nuclear caloric curve
   indicates **phase-space driven instability**
   rather than Coulomb instability

5. isoscaling obeyed with high accuracy;
   results of INDRA@GSI confirmed and extended;
   reduced symmetry term for hot fragments