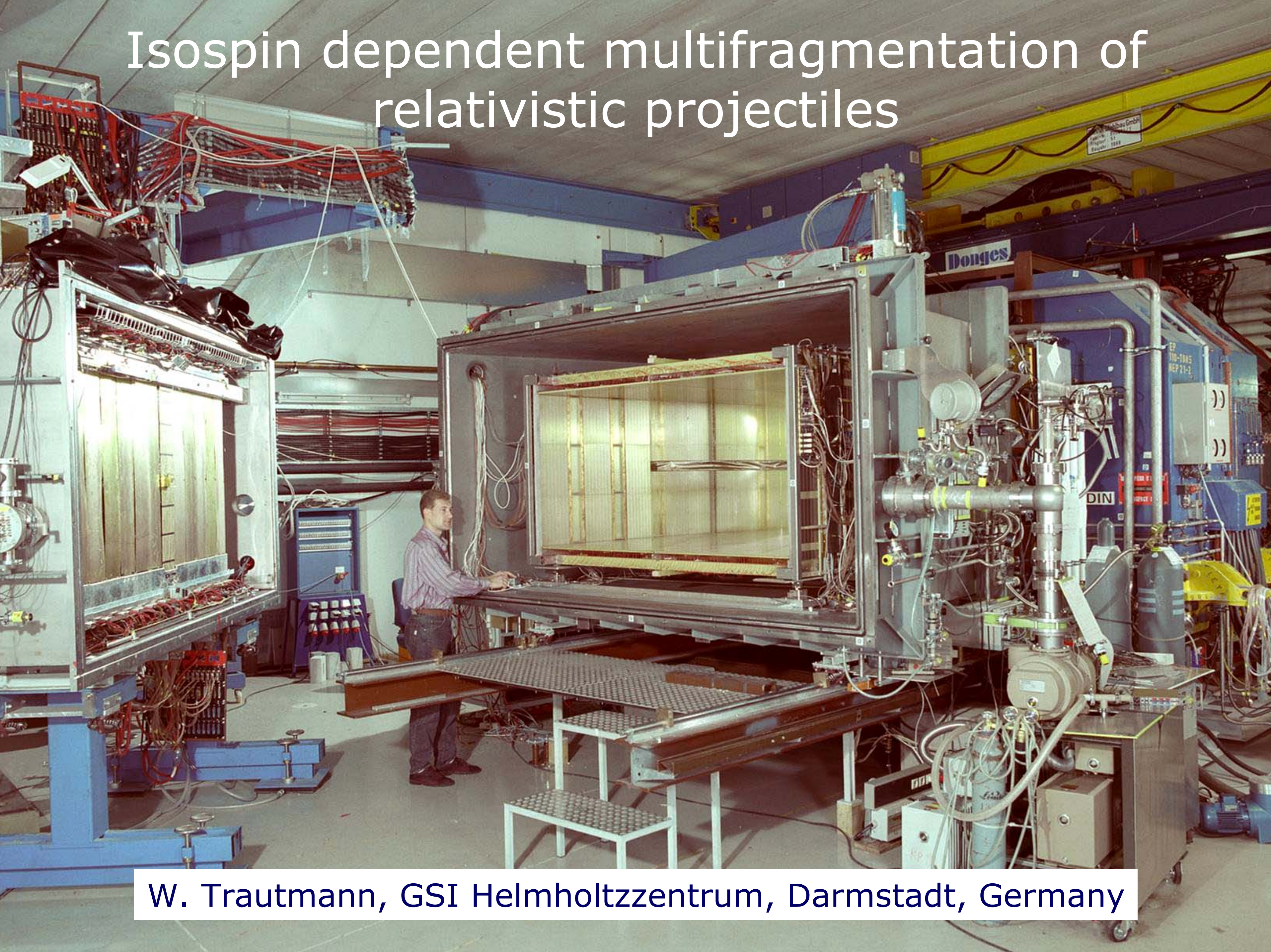
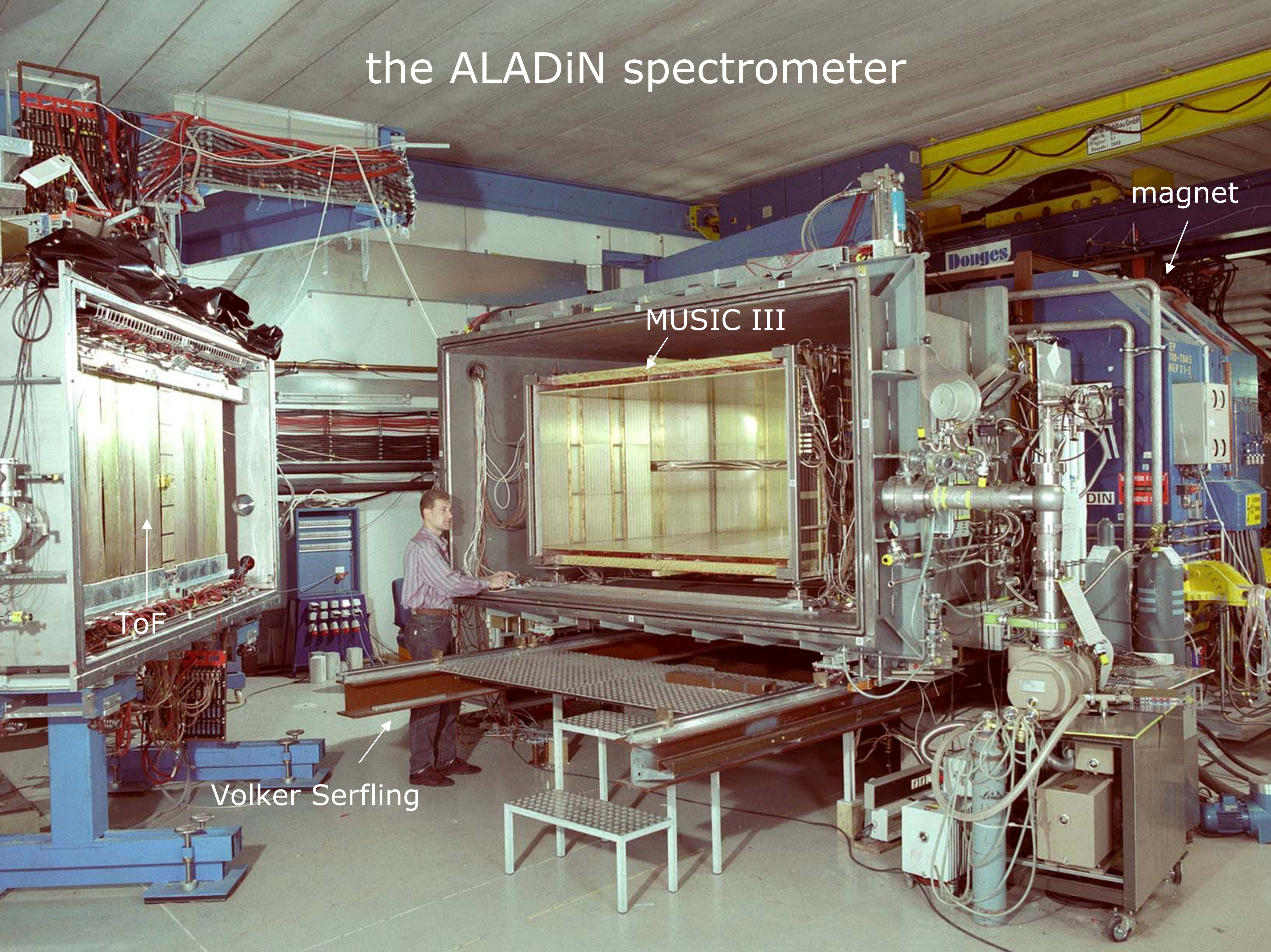
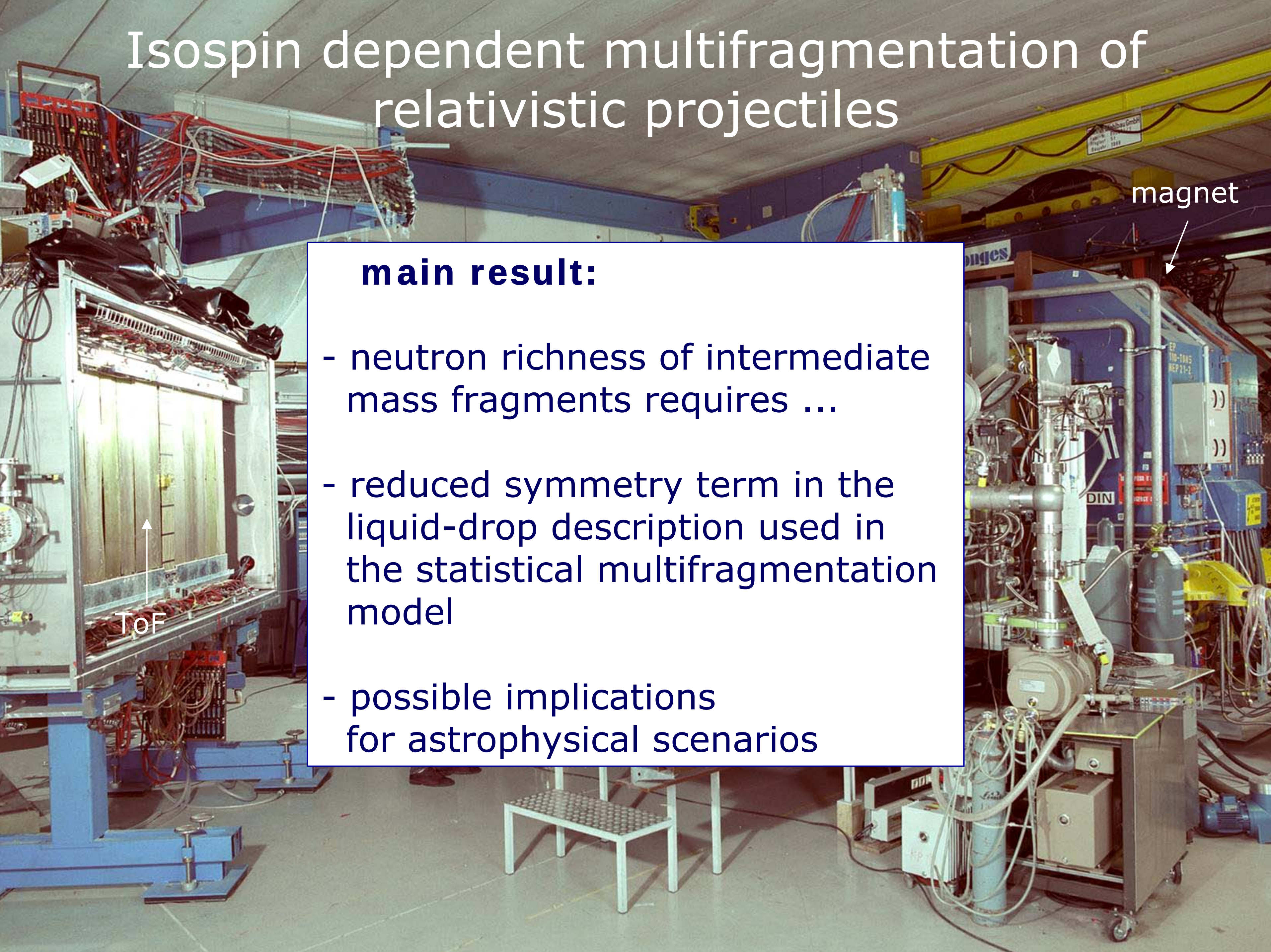
Isospin dependent multifragmentation of relativistic projectiles

W. Trautmann, GSI Helmholtzzentrum, Darmstadt, Germany




the ALADiN spectrometer
magnet
Donges
MUSIC III
ToF
Volker Serfling

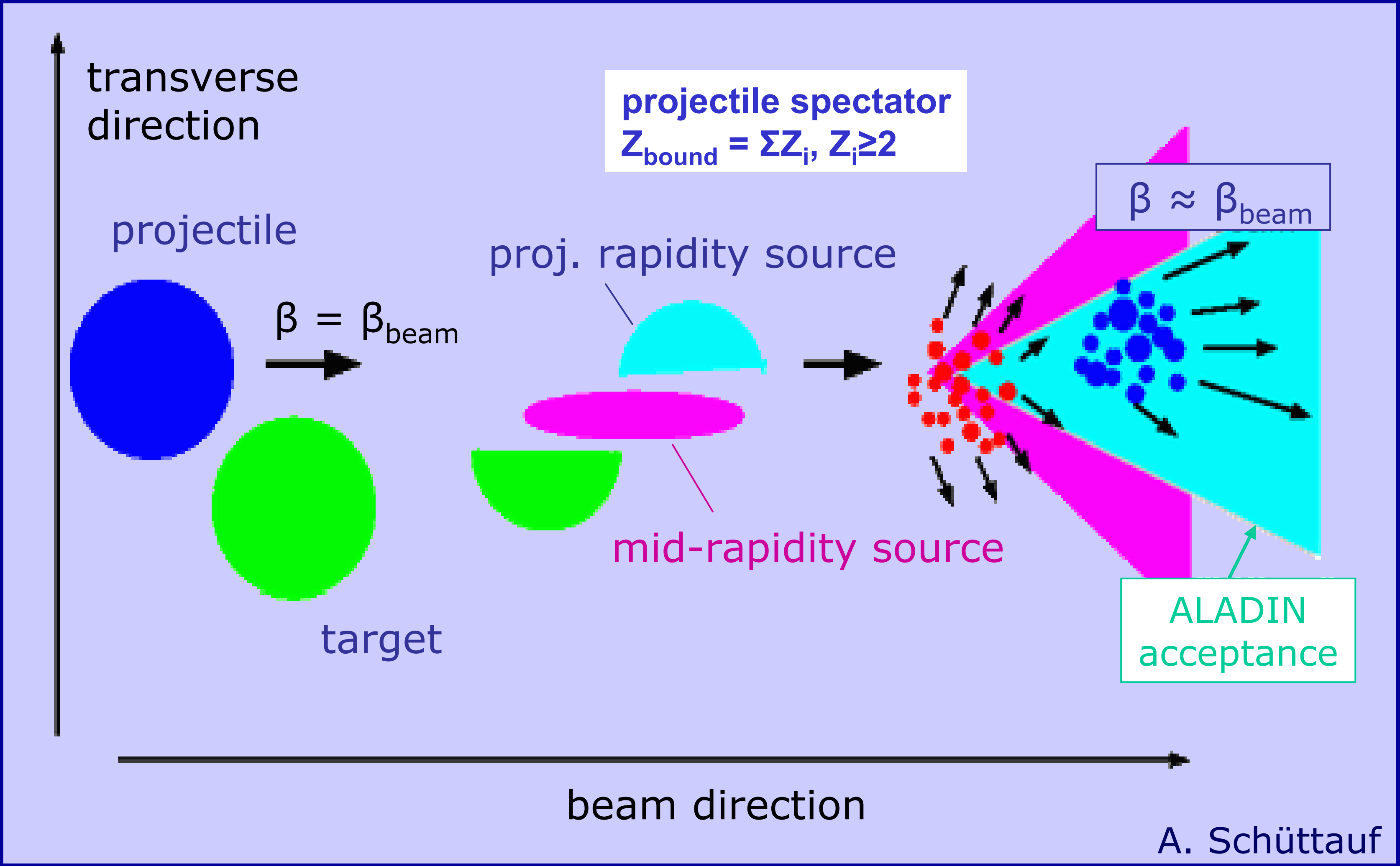
Isospin dependent multifragmentation of relativistic projectiles



main result:

- neutron richness of intermediate mass fragments requires ...
- reduced symmetry term in the liquid-drop description used in the statistical multifragmentation model
- possible implications for astrophysical scenarios

introduction: projectile fragmentation

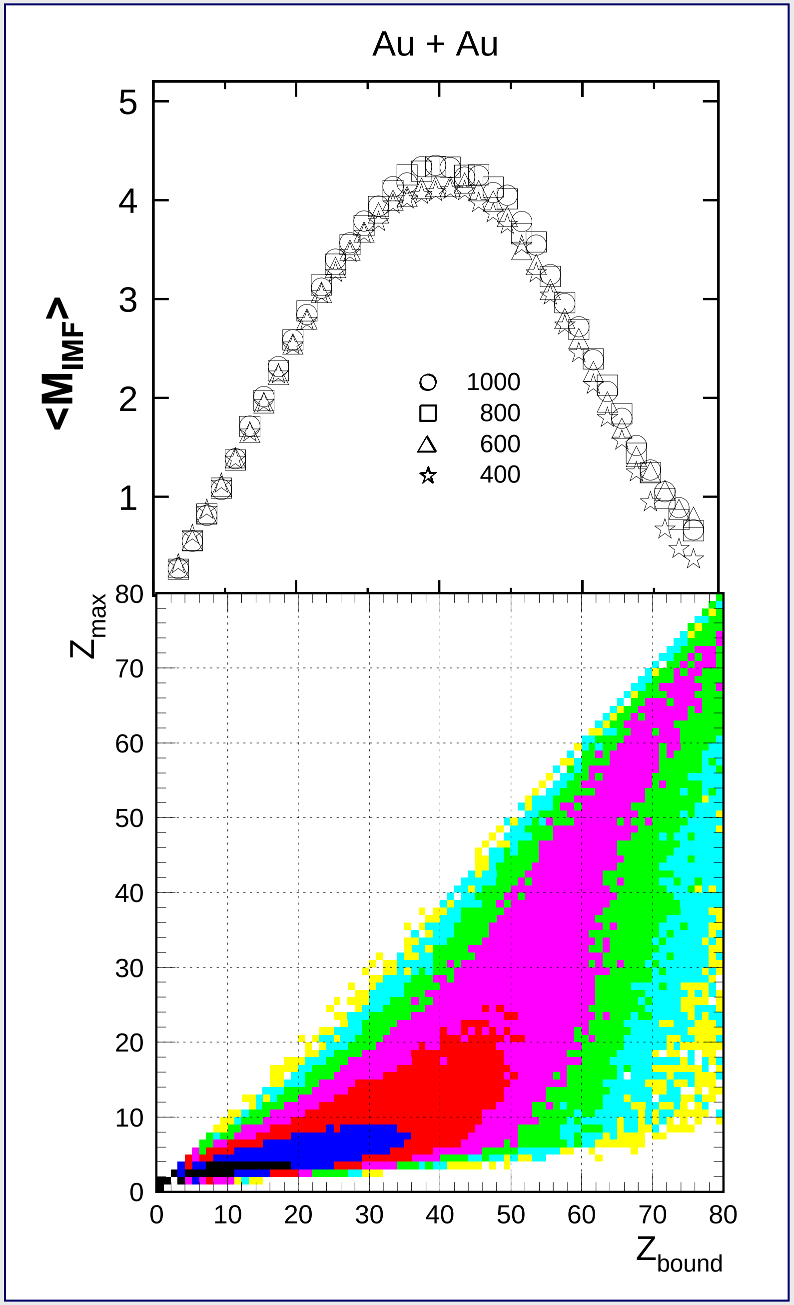


the rise and fall of multiframentation

invariance with target
or incident energy
as indicator of equilibrium

equilibrium conditions
T≈5-6 MeV and $\rho \approx \rho_0/3$
experimentally determined

large fluctuations in the
transition region
between heavy-residue
formation and
multifragmentation

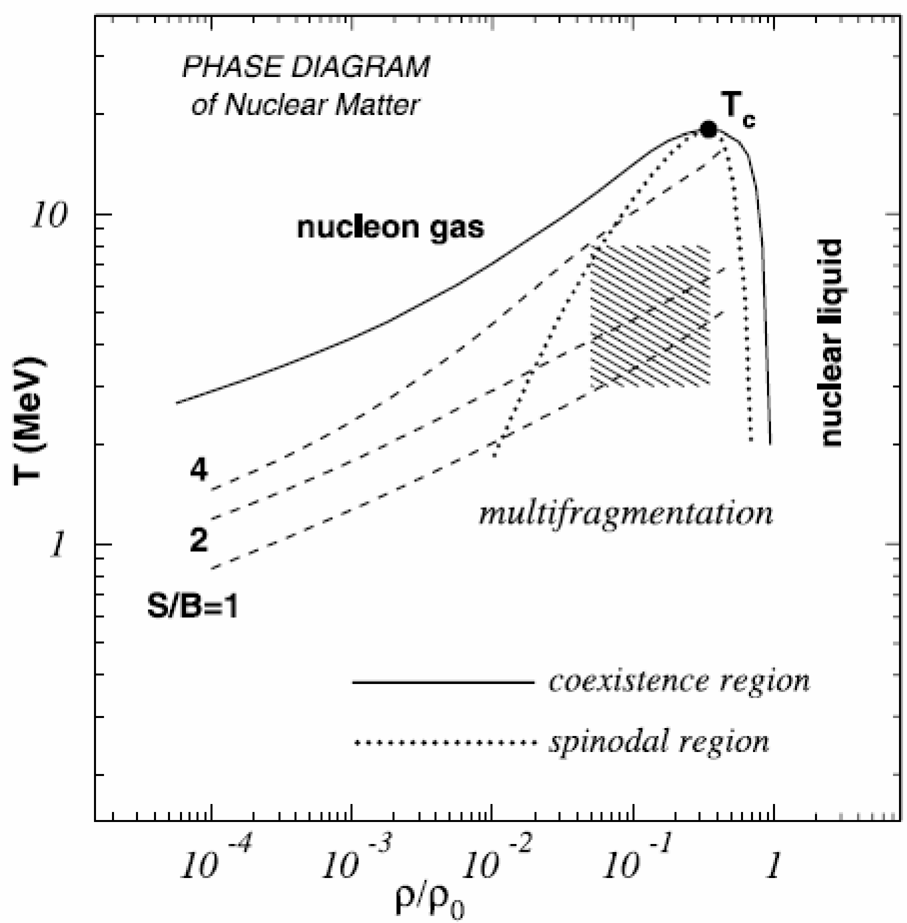


A. Schüttauf et al., NPA 607 (1996) "Universality of spectator fragmentation ..."

astrophysical motivation

dashed:
adiabatic evolution, e.g., collapse along constant entropy per baryon S/B

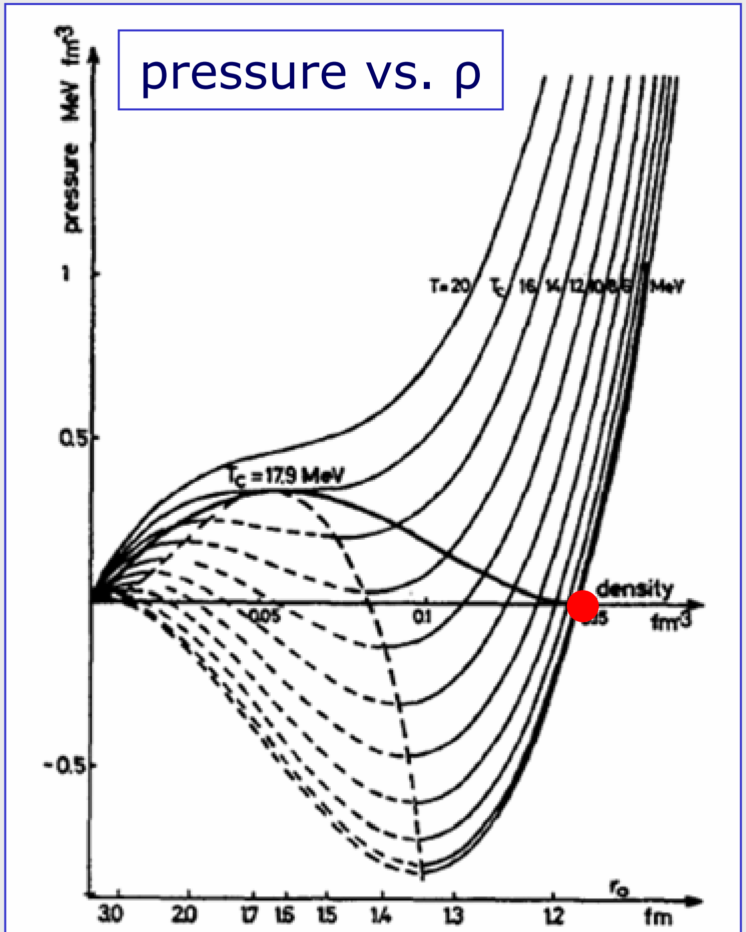
A.S. Botvina, I.N. Mishustin / Nuclear Physics A 843 (2010) 98–132

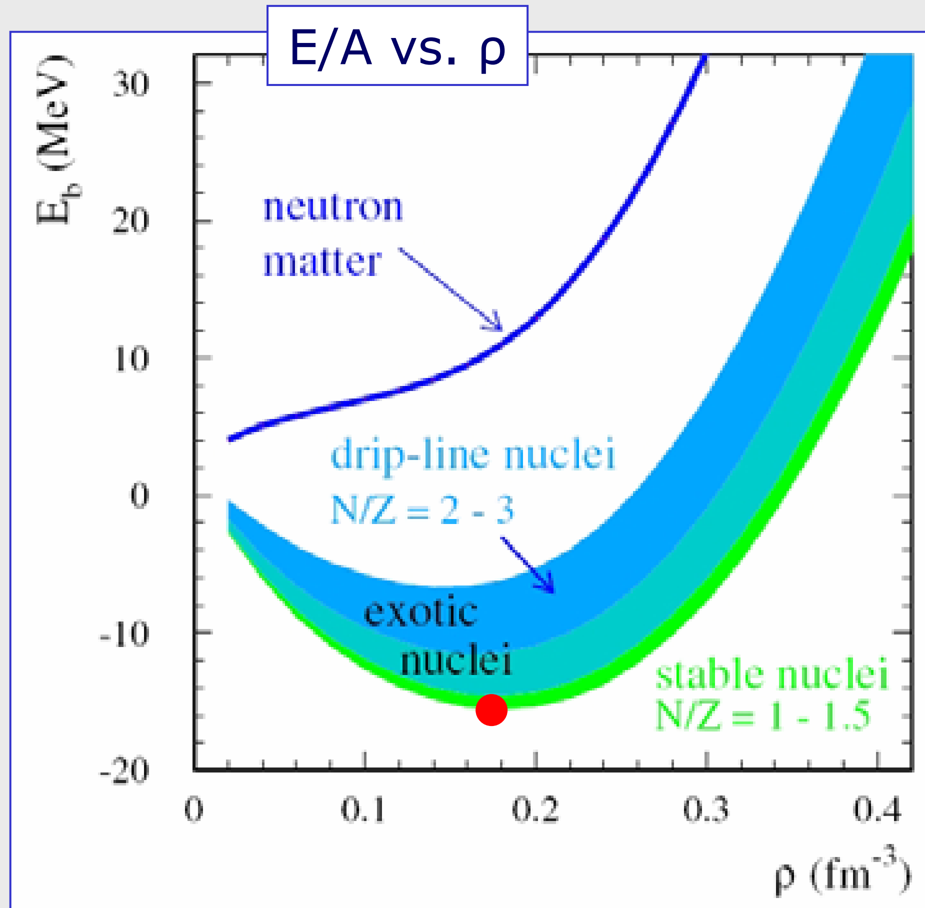


the nuclear equation-of-state

temperature dependent
Hartree-Fock theory

relativistic
Brueckner-Hartree-Fock theory

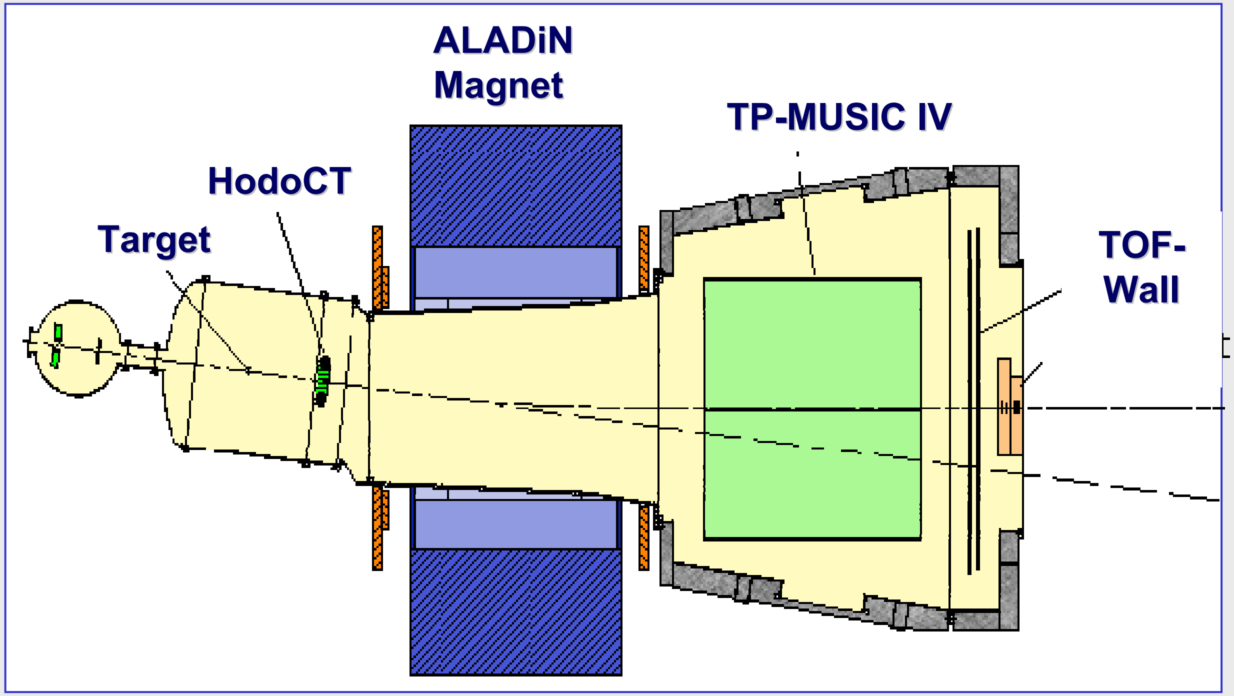


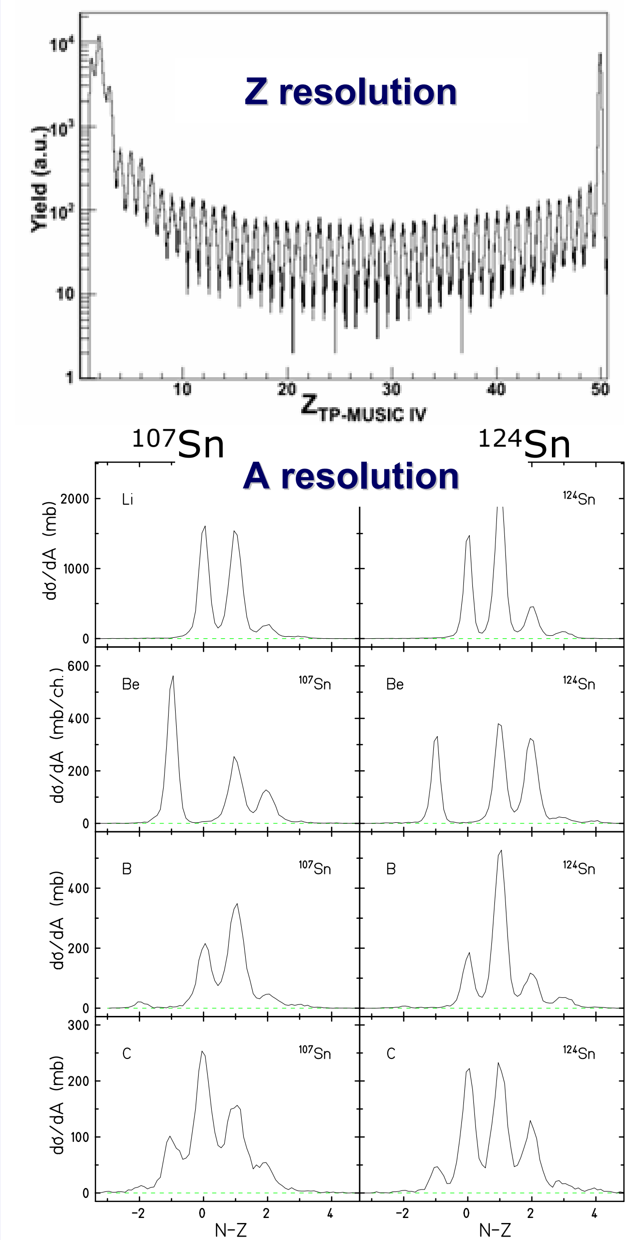


from Sauer, Chandra, Mosel
Nucl. Phys. A 264, 221 (1976)

from de Jong and Lenske
Phys. Rev. C 57, 3099 (1998)

experiment: isospin dependence of multifragmentation of relativistic projectiles





S254: ^{107}Sn, ^{124}La, ^{124}Sn at 600 A MeV

neutron poor secondary beams from FRS

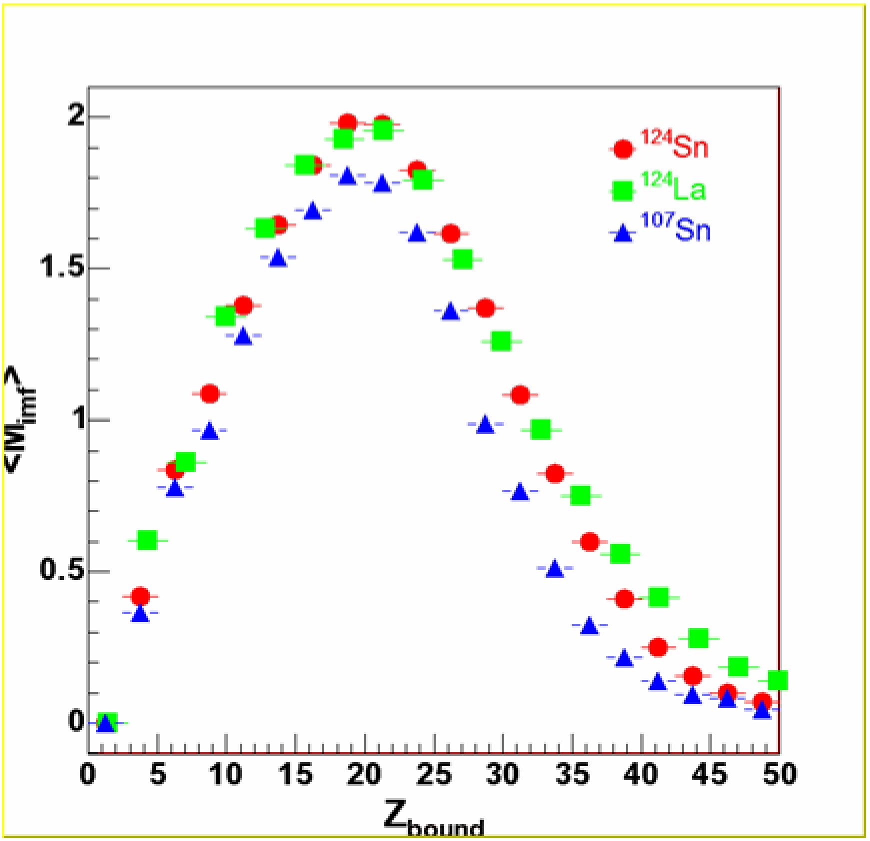
C. Sfienti et al., PRL 102 (2009), R. Ogul et al., arXiv:1006.3723 (2010)

The Aladdin 2000 Collaboration

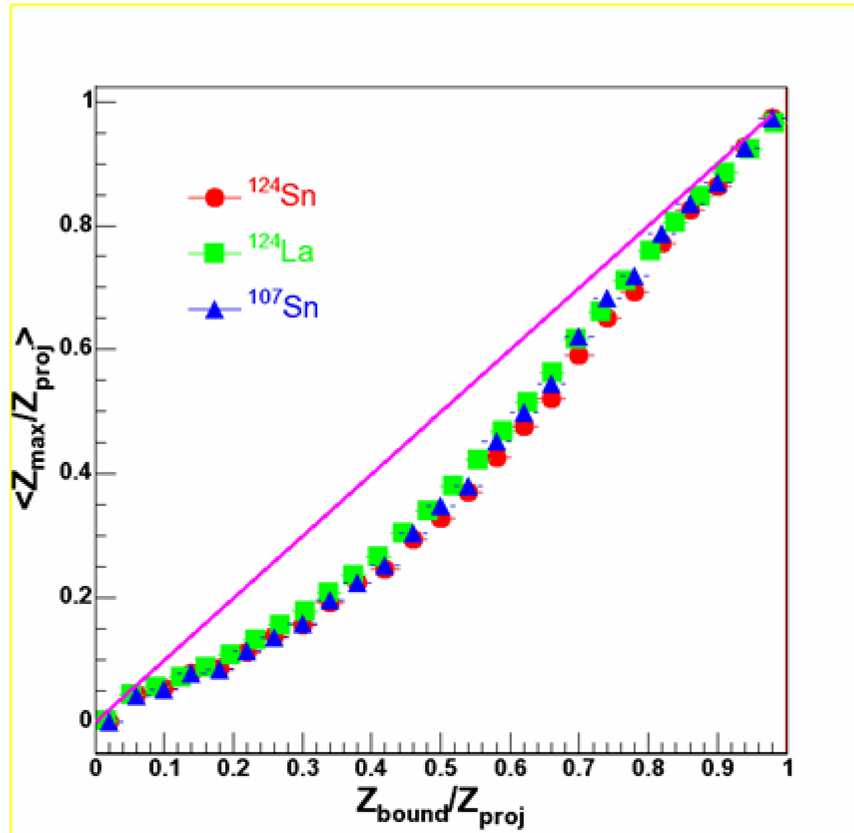
S. Bianchin, K. Kezzar, A. Le Fèvre, J. Lühning, J. Lukasik, U. Lynen, W.F.J. Müller, H. Orth, A.N. Otte, H. Sann, C.Schwarz, C. Sfienti, W. Trautmann, J. Wiechula, M.Hellström, D. Henzlova, K. Sümmerer, H. Weick, P.Adrich, T. Aumann, H. Emling, H. Johansson, Y. Leifels, R. Palit, H. Simon, M. De Napoli,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

global observables: isotopic effects are small

fragment multiplicity



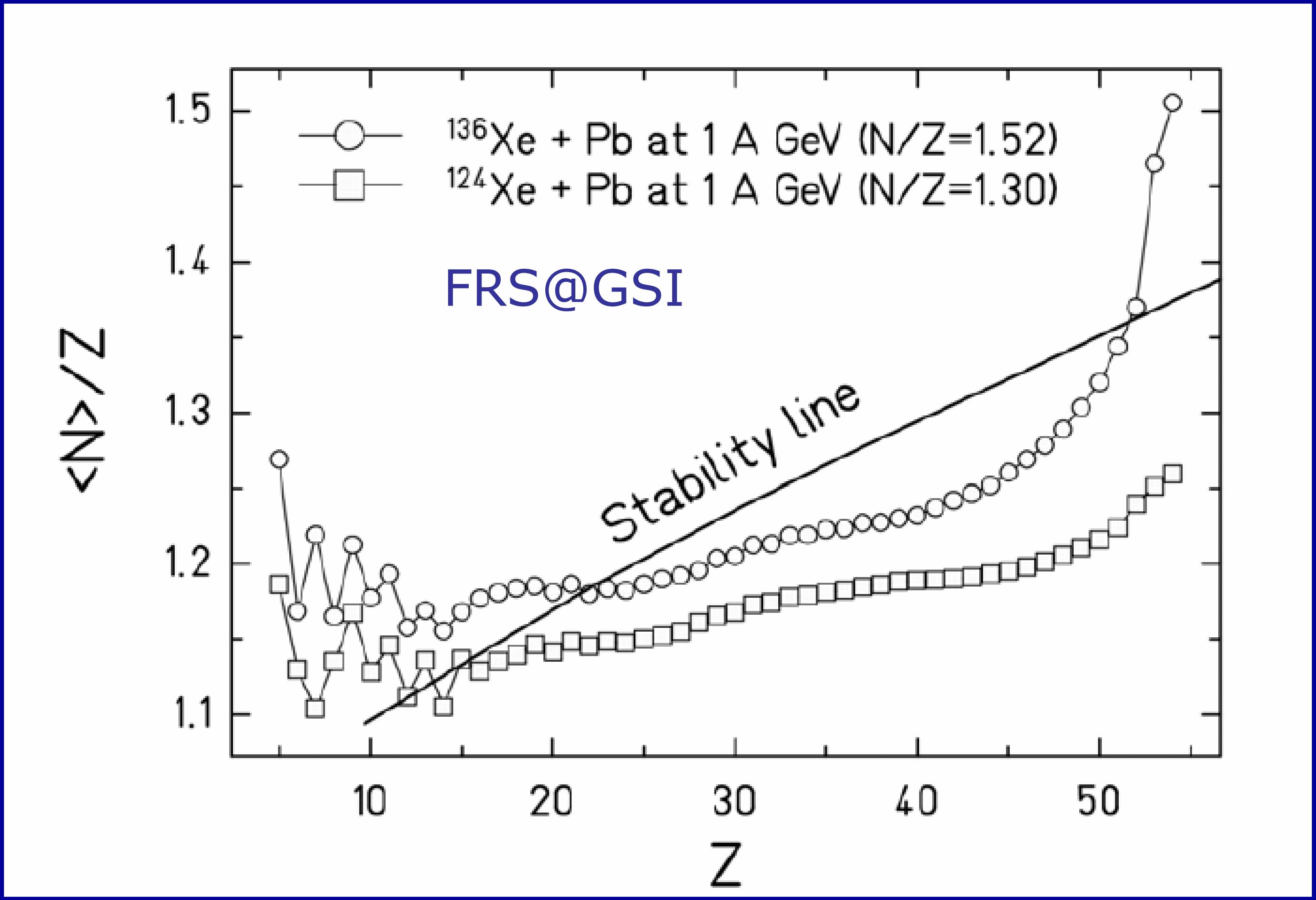
largest fragment



$Z_{bound} = \Sigma Z_i \ (Z_i \geq 2)$

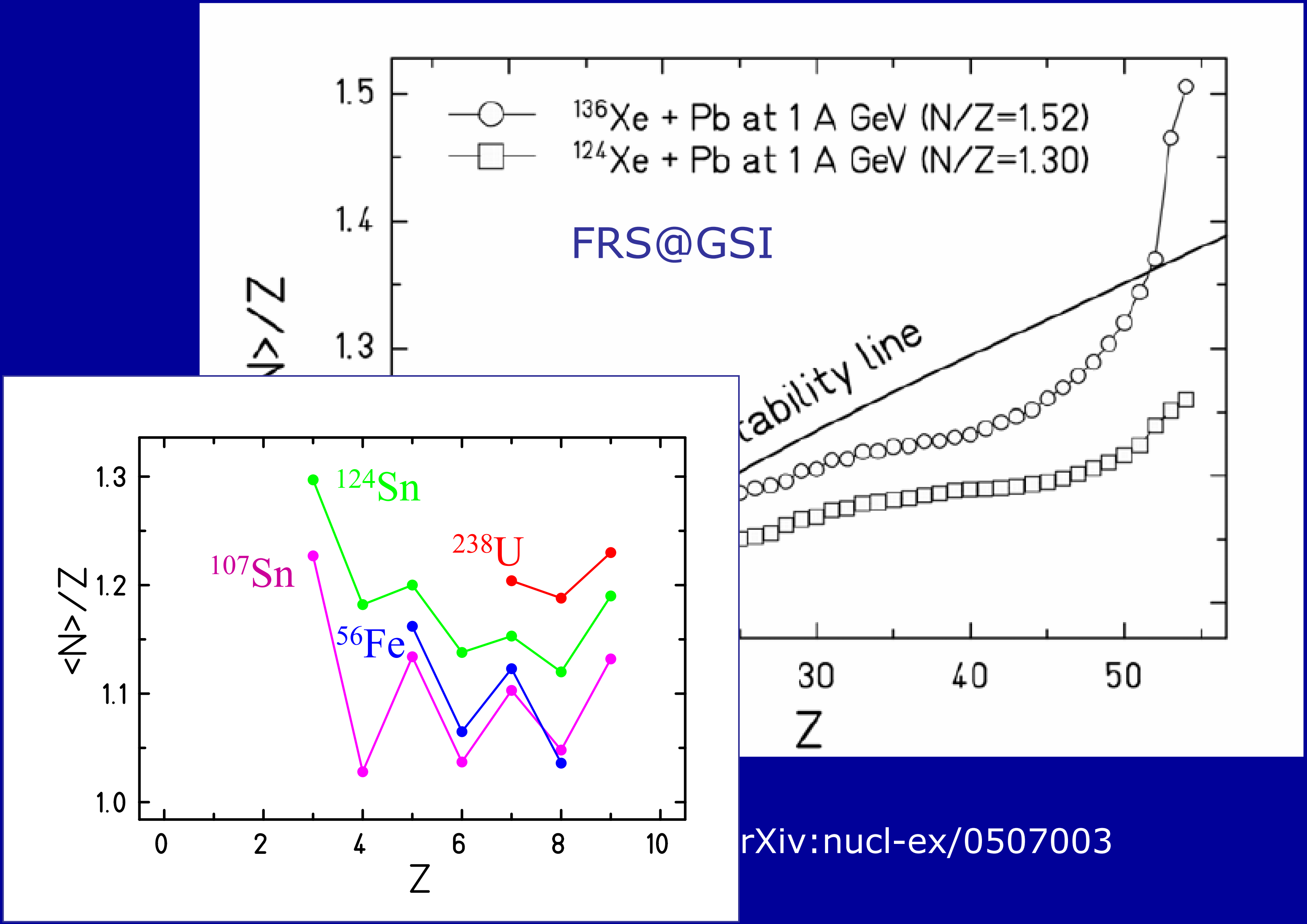
C. Sfienti et al., PRL 102, 152701 (2009)

isotopes: nuclear structure and memory effects



D. Henzlova et al., arXiv:nucl-ex/0507003

isotopes: nuclear structure and memory effects

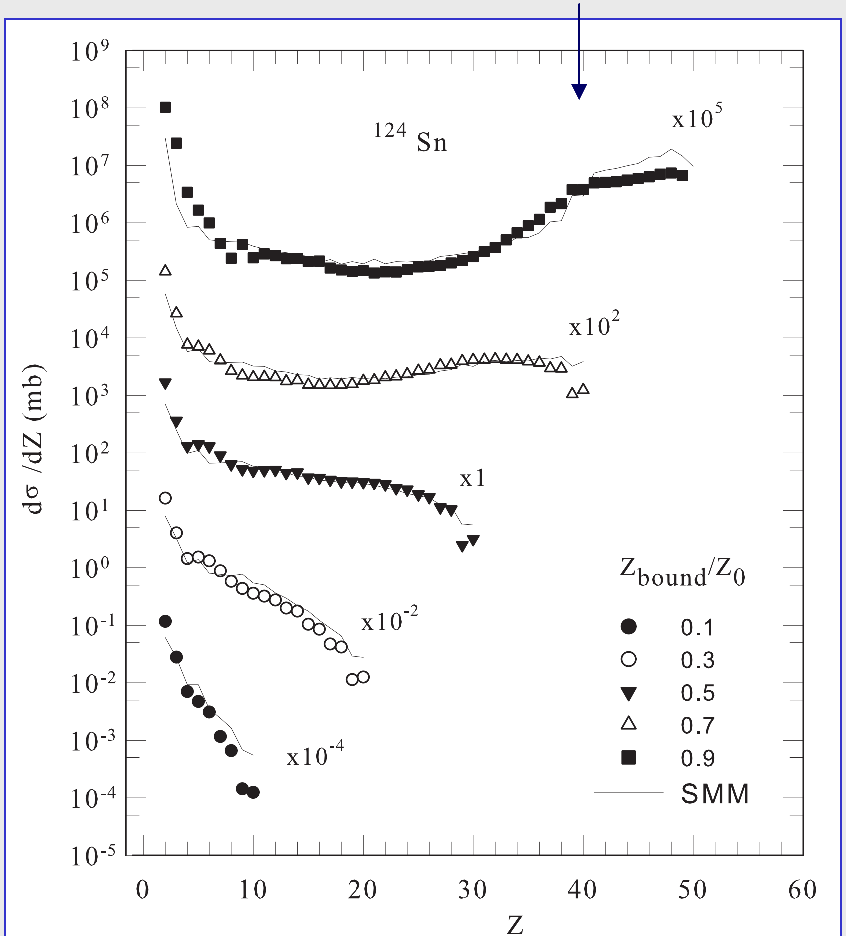


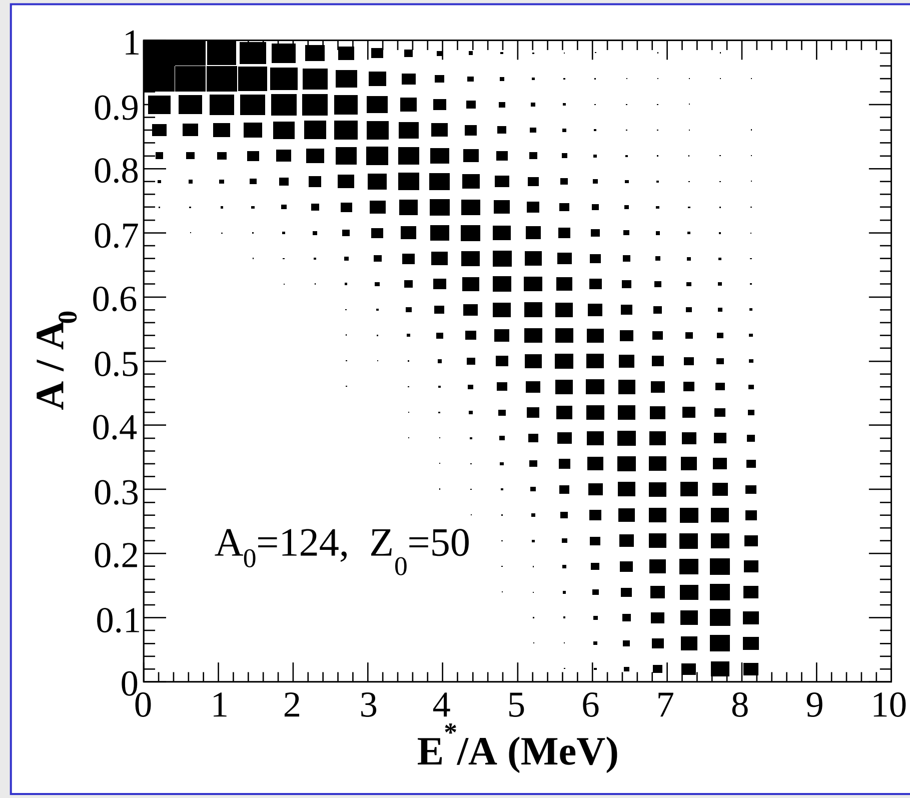
rXiv:nucl-ex/0507003

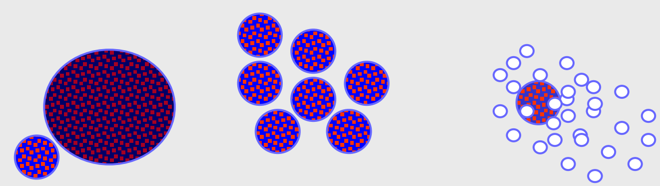
SMM ensemble calculations used for analysis

(SMM: Statistical Multifragmentation Model)

mass variation with excitation energy taken into account; fixed to reproduce exclusive yields





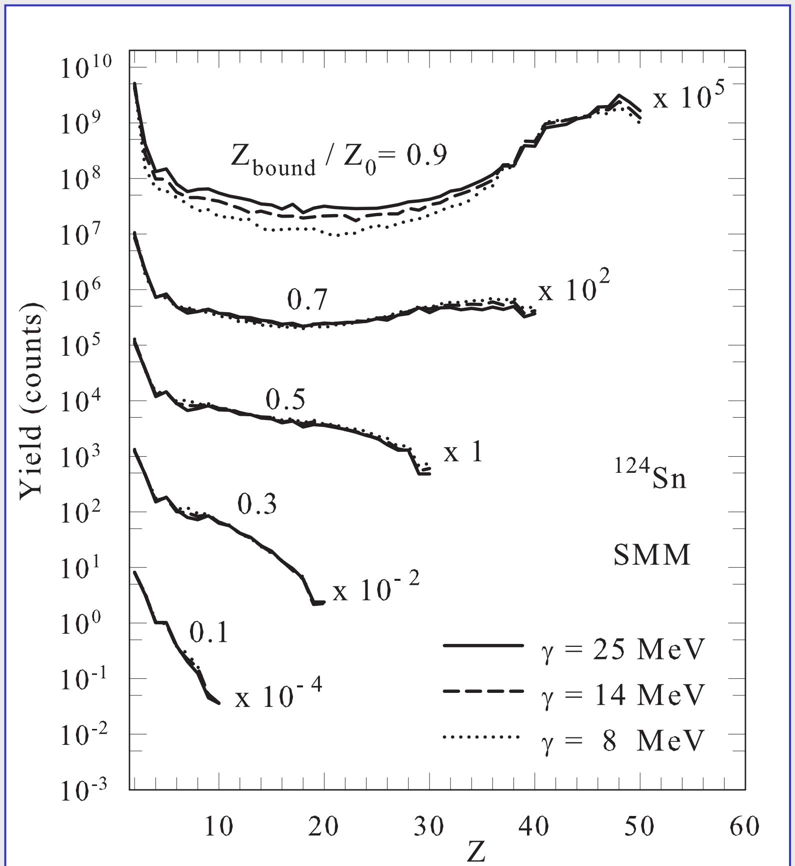


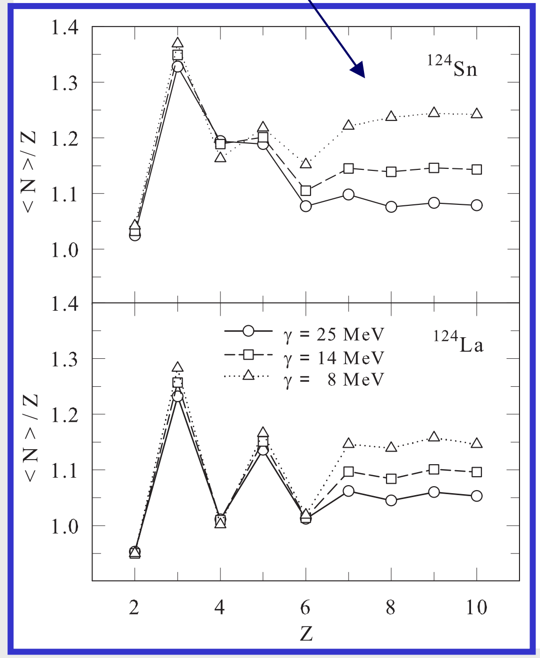
$Z_{bound} = \Sigma Z_i$ with $Z_i \geq 2$

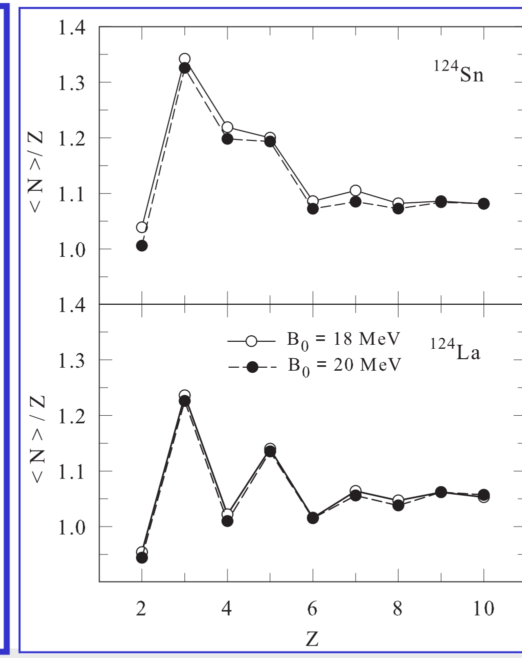
A.S. Botvina, N. Buyukcizmeci, R. Ogul et al.

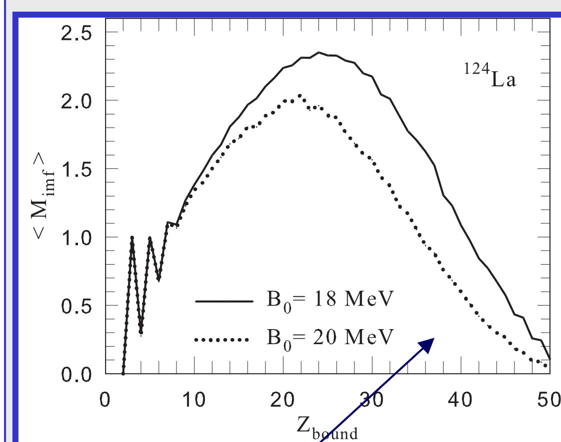
sensitive to symmetry term

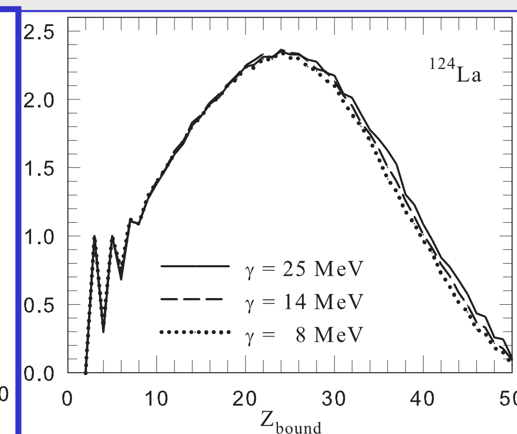
model study of sensitivities



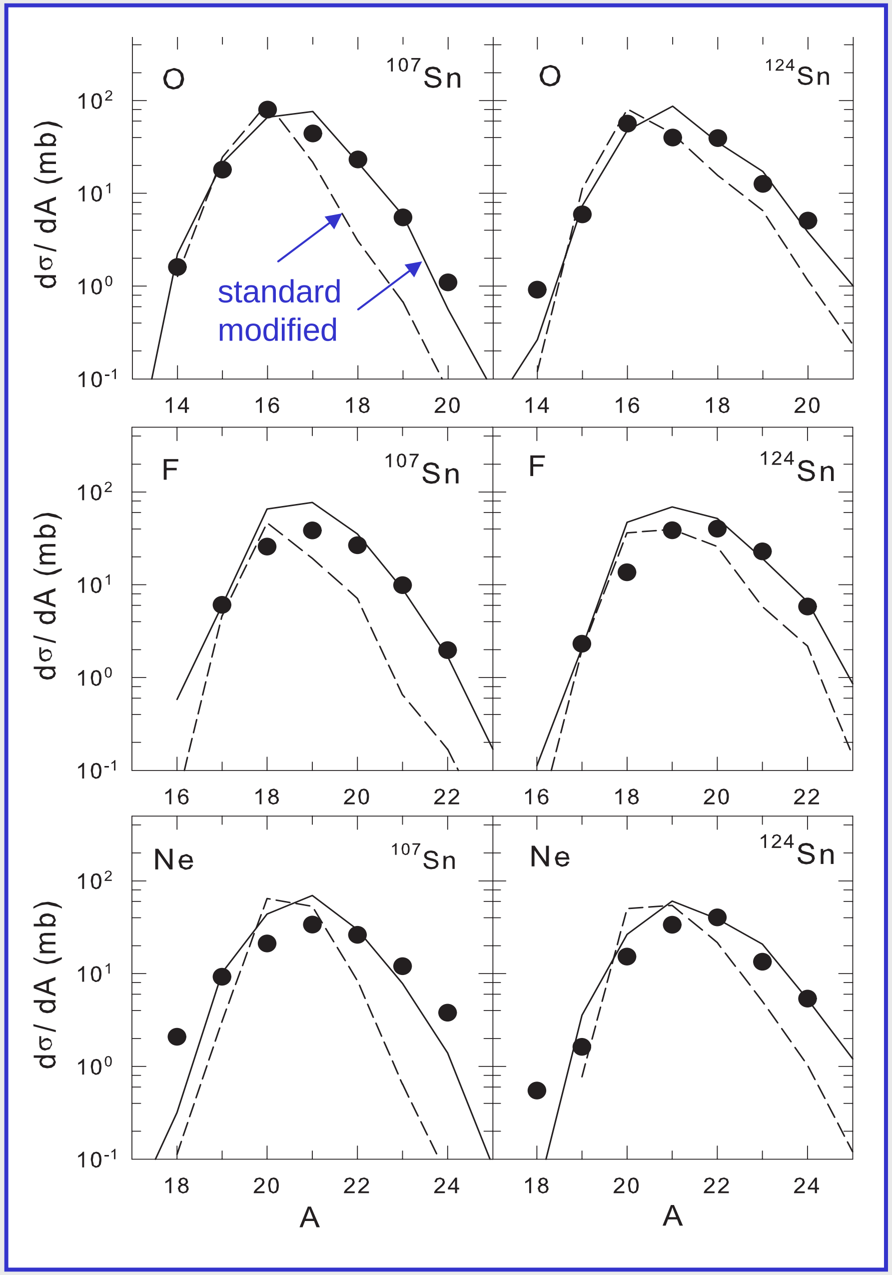




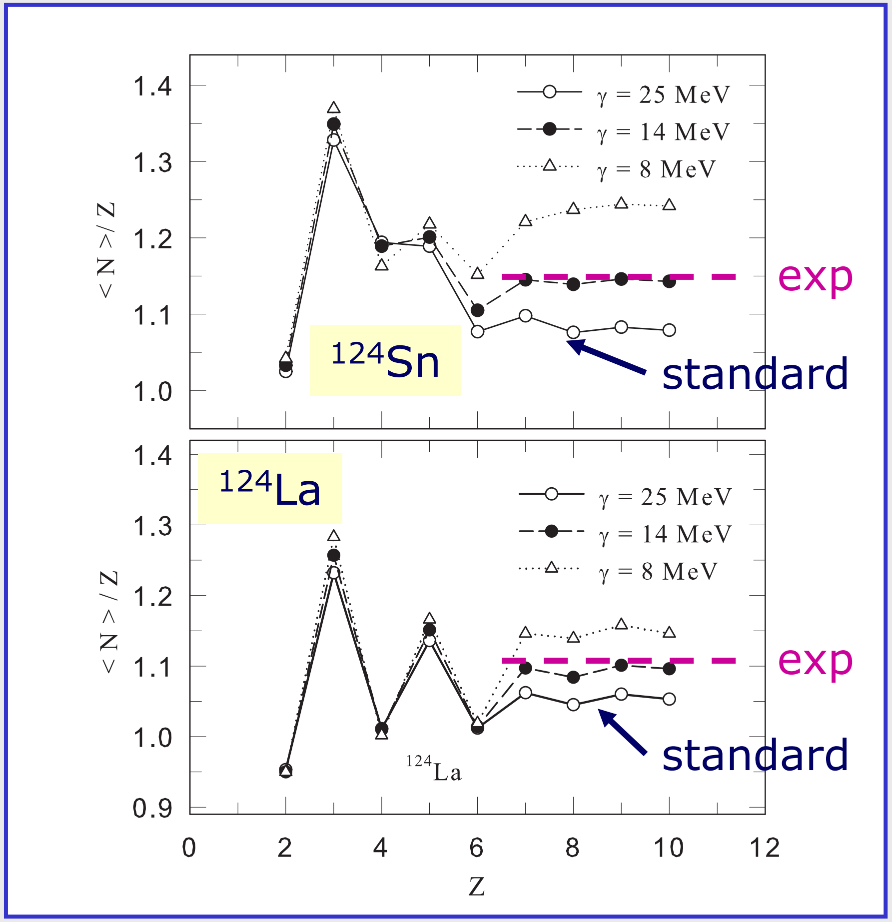




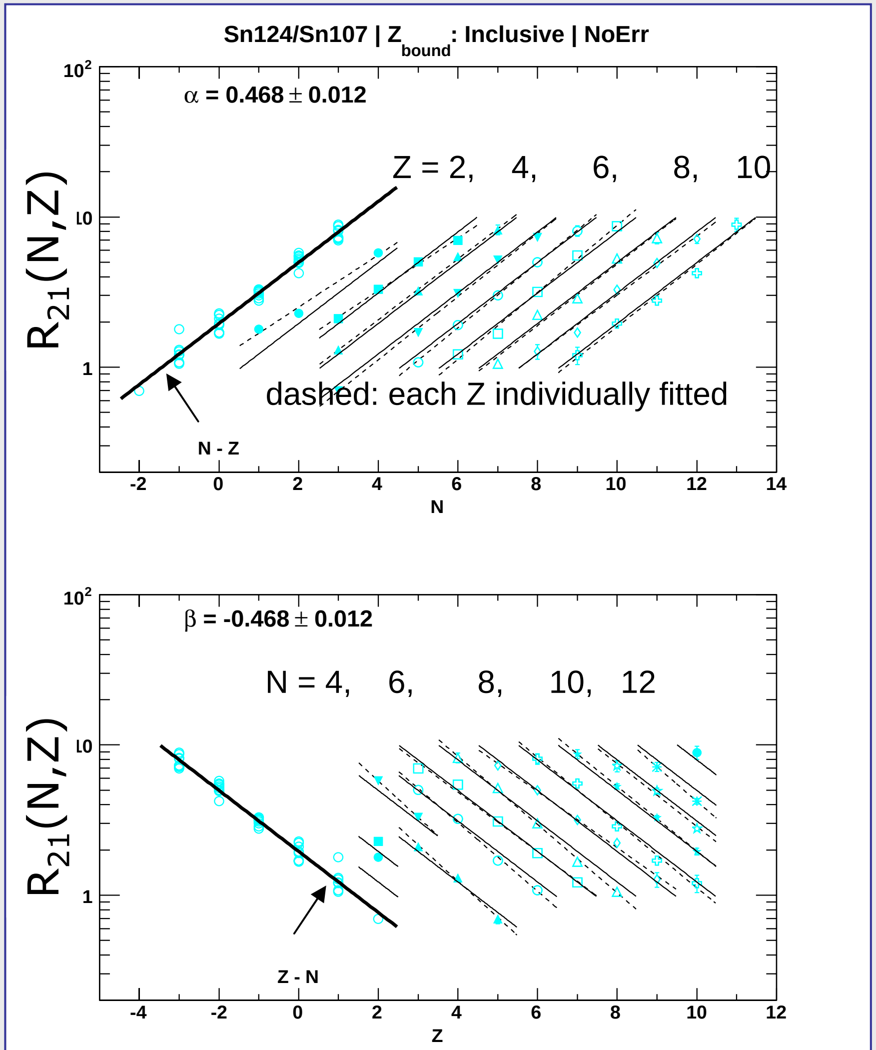
sensitive to surface term



main result:
neutron-rich fragment yields
require low symmetry energy

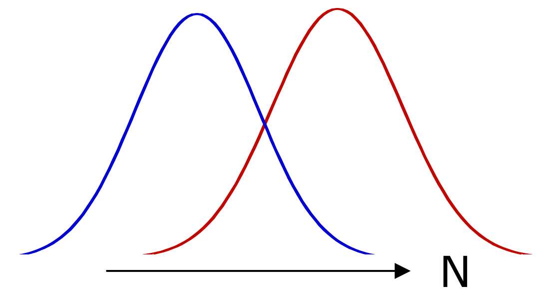


isoscaling fits



S. Bianchin, J. Łukasik

isoscaling:
ratios of fragment yields from two reactions different in N/Z show exponential behavior as functions of neutron or proton numbers



α depends on shift and widths of mass distributions

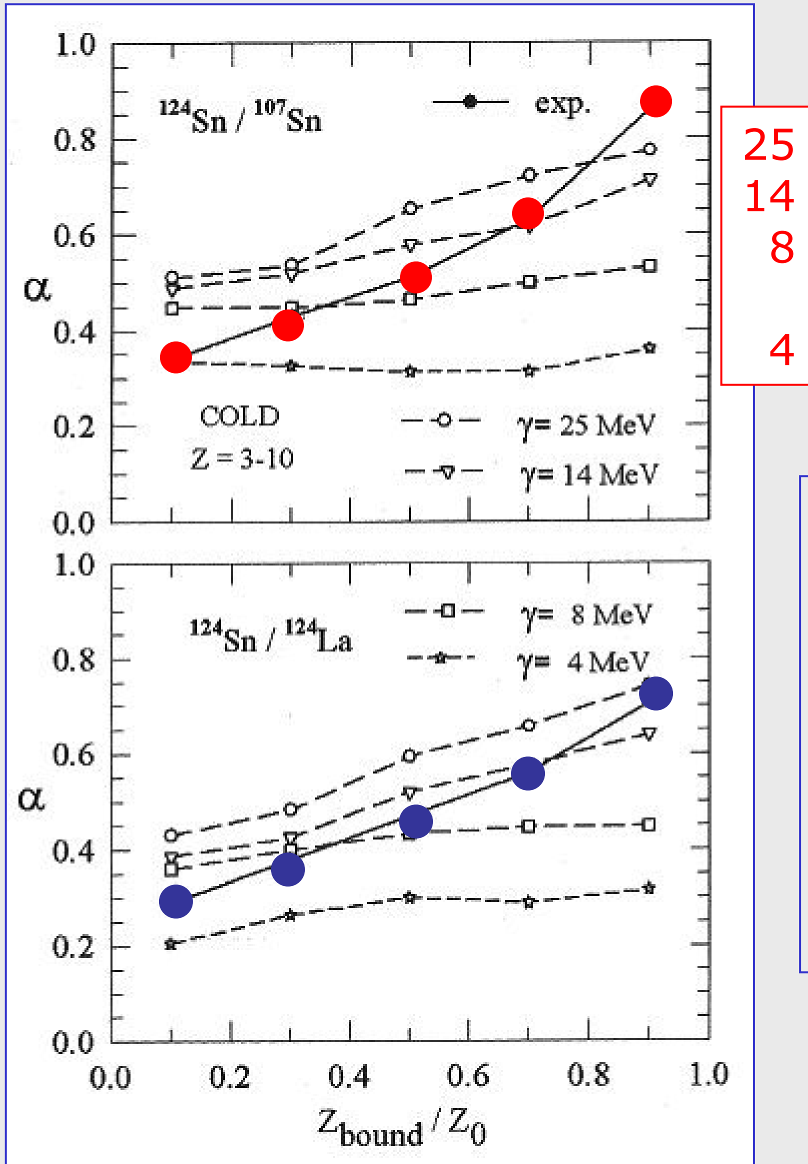
$$R_{21} = C \cdot \exp(\alpha N + \beta Z)$$
$$\alpha = \Delta\mu_n / T$$

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

isoscaling analysis

● ● exp. data

similar results with either combination of projectile pairs



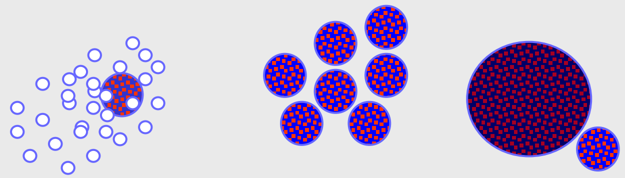
open symbols + lines:

ensemble calculations performed with 4 different values for the symmetry-term coefficient

γ = 25 (standard),
14, 8, 4 MeV

A.S. Botvina,
N. Buyukcizmeci,
R. Ogul et al.

fragments in the hot environment



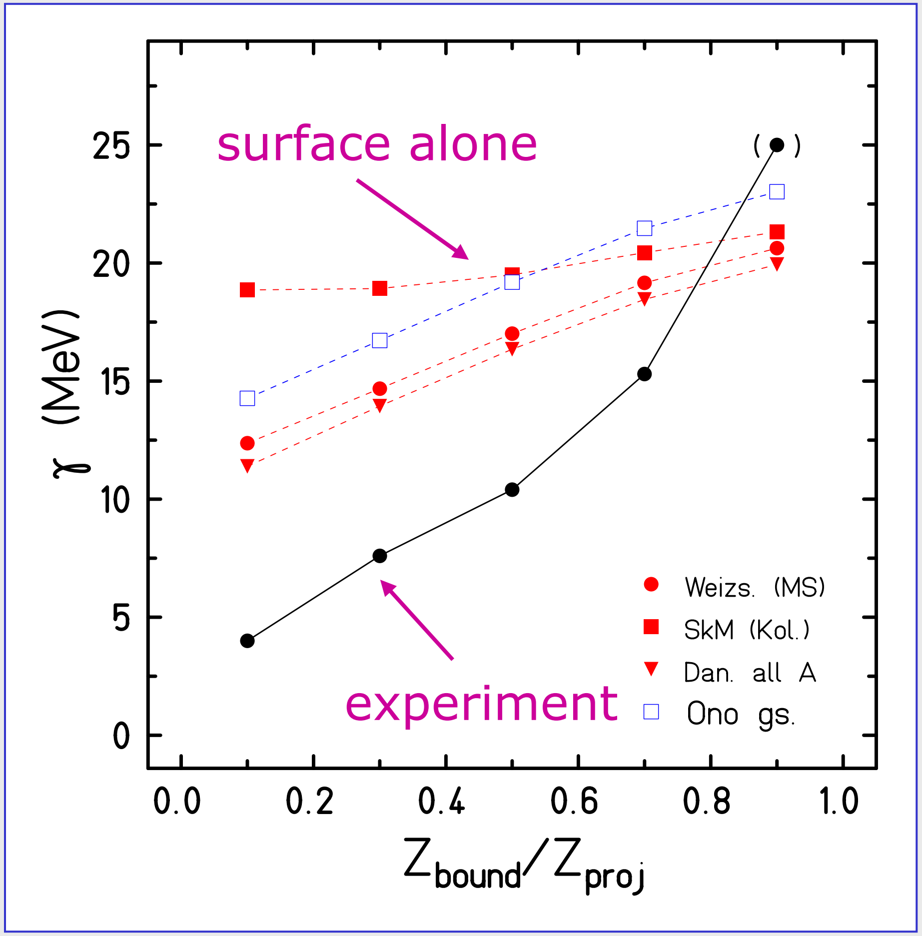
symmetry term reduced
at chemical freeze-out
in multifragmentation reactions

mass distributions become wider as we move from evaporation to vaporization

surface term (and temperature) account for only part of the effect

reported by Le Fèvre et al.,
similar results from Texas A&M,
Indiana@Ganil, FRS@GSI ...

"important for realistic description of the **nuclear composition** for understanding stellar dynamics and nucleosynthesis"

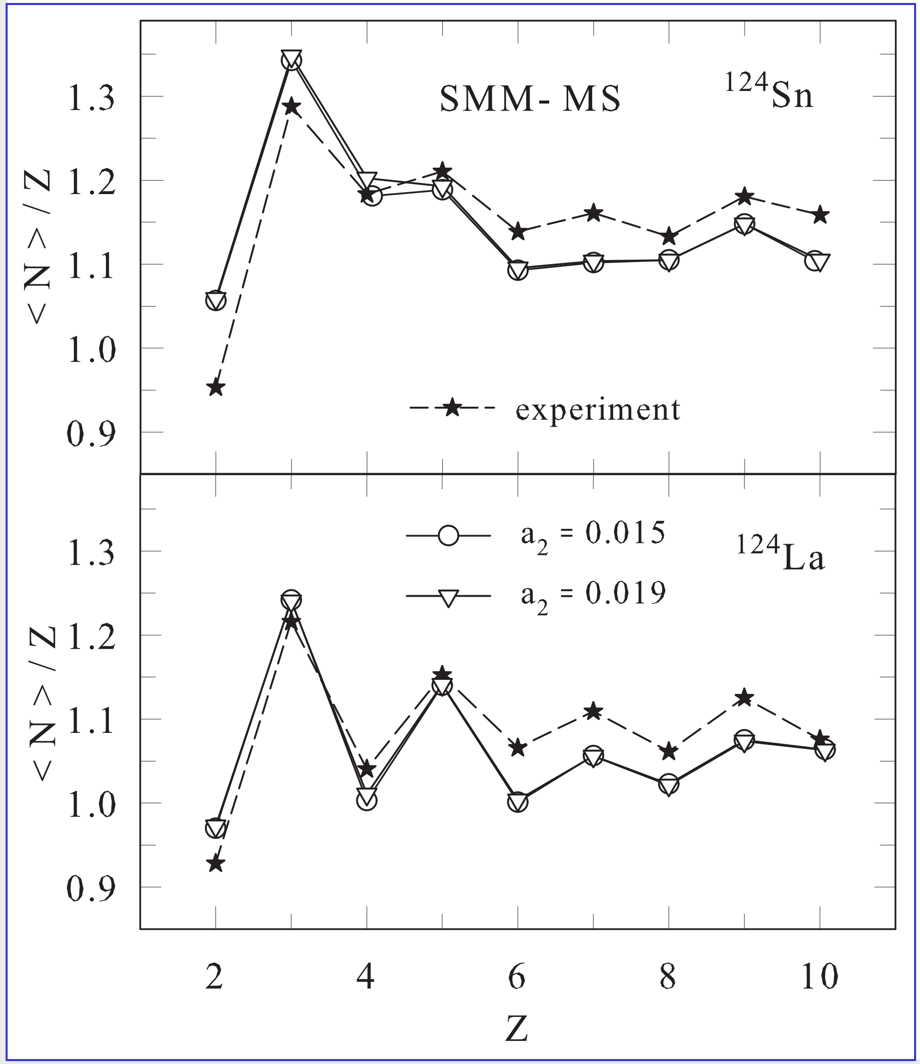


quotation from A.S. Botvina and I.N. Mishustin, NPA 843, 98 (2010)

discussion

surface not sufficient

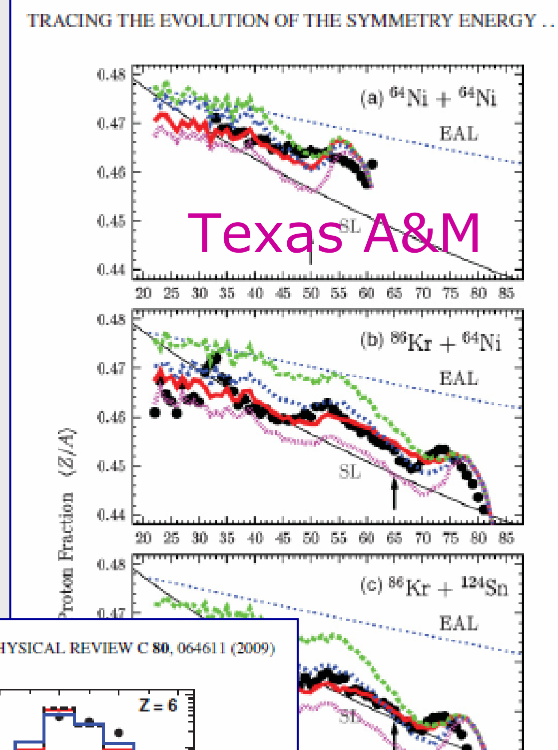
calculation with the Myers-Swiatecki parameters for the volume and surface symmetry term cpefficients underestimate the neutron richness by $\Delta(\langle N\rangle/Z) \approx 0.05$

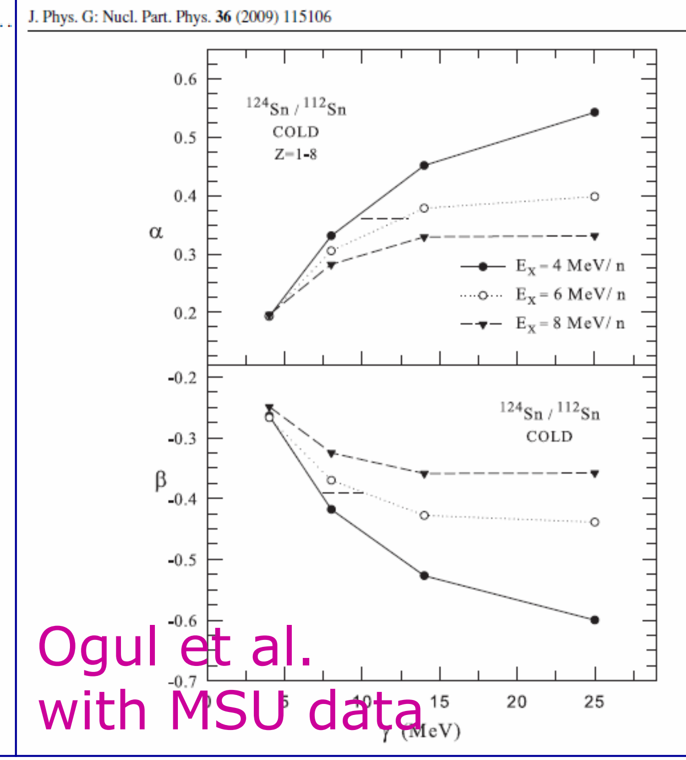


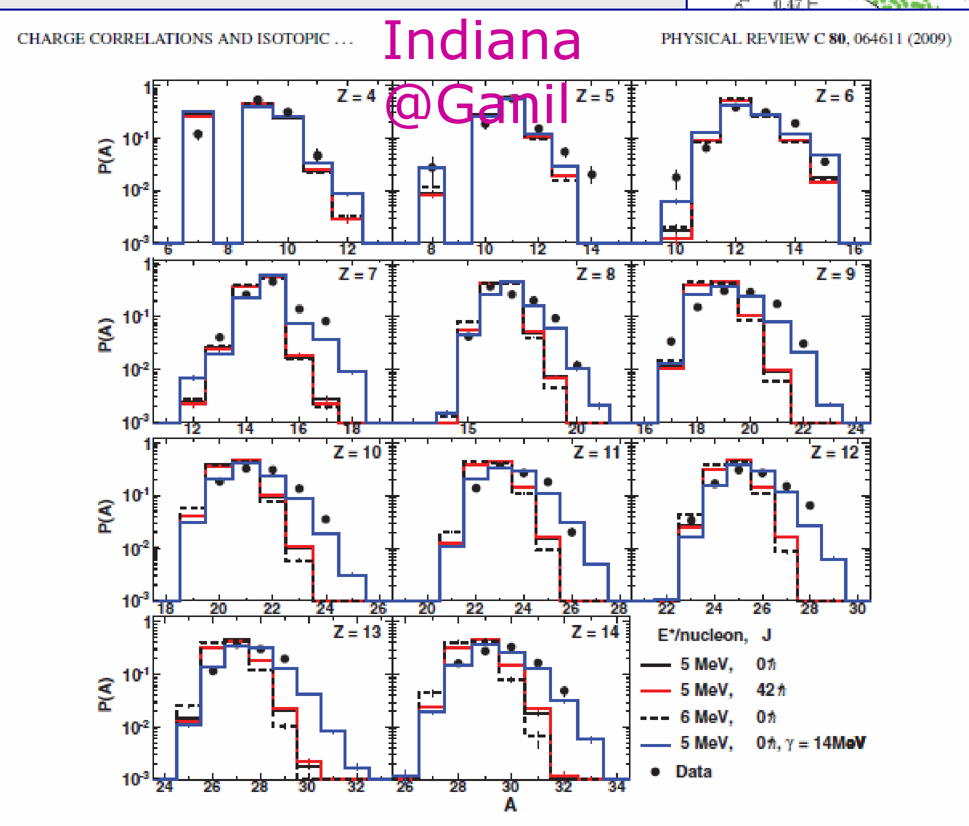
discussion

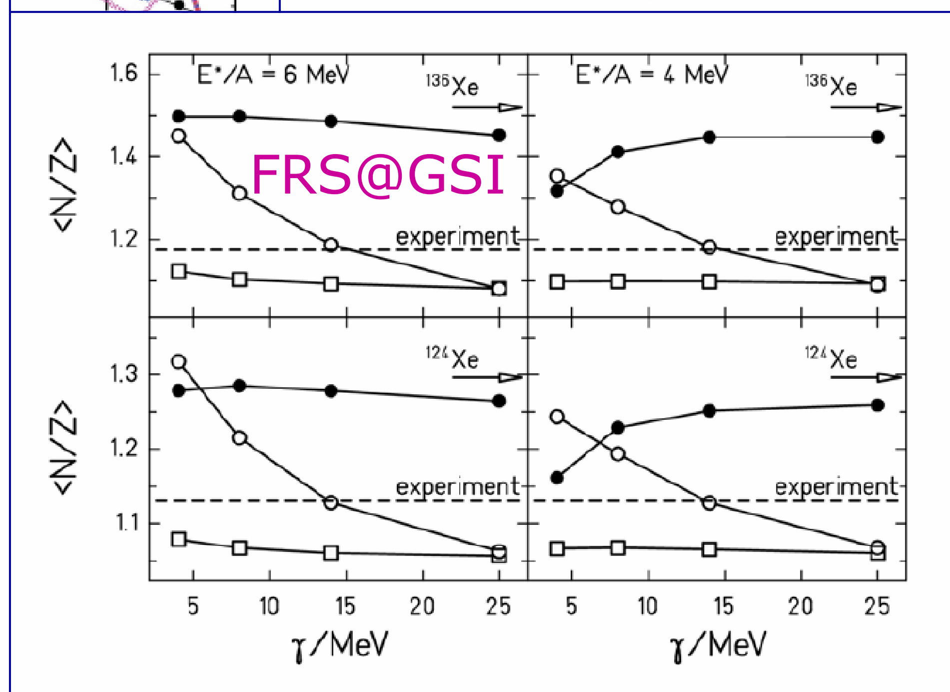
neutron richness is a general phenomenon

Souliotis et al., PRC 75
Ogul et al., JPG (2009)
Hudan et al., PRC 80
Henzlova et al., arXiv





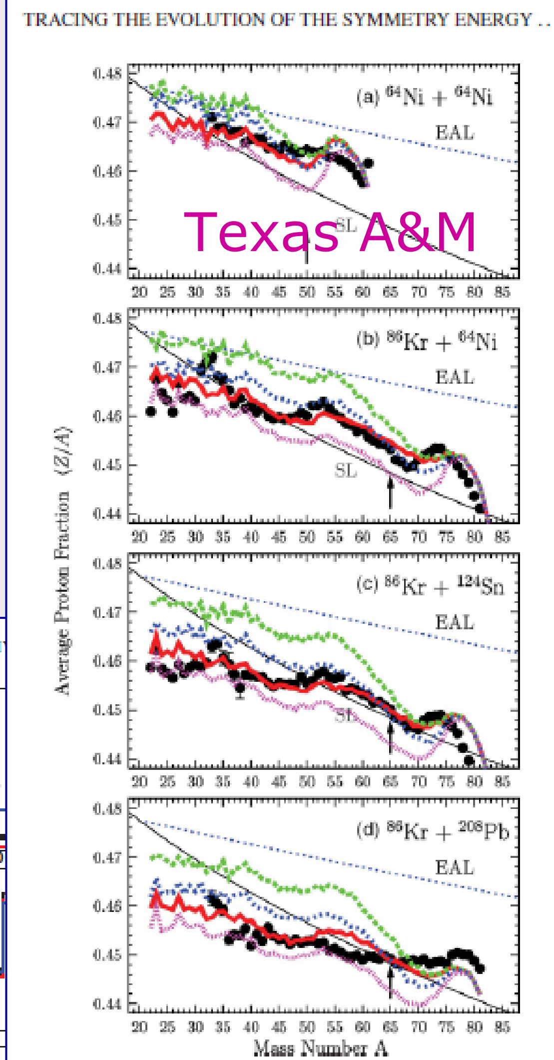




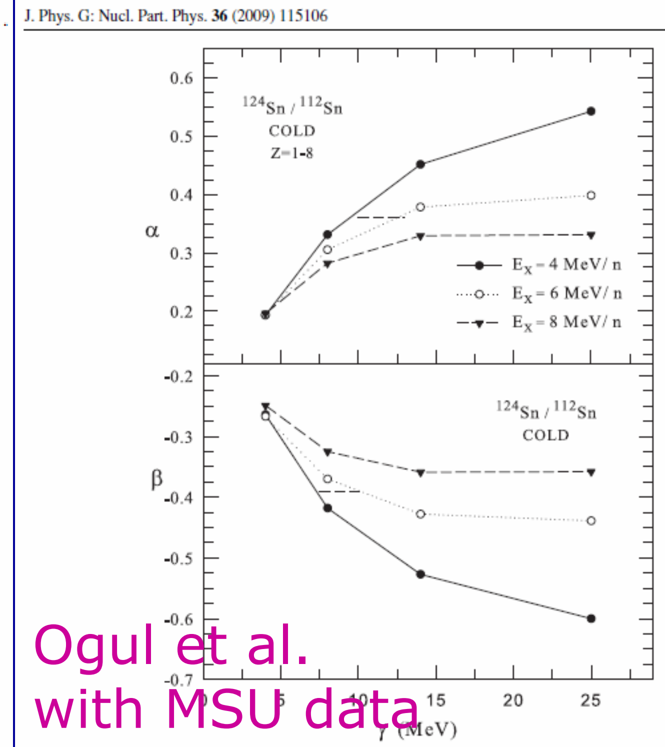
discussion

neutron richness is a general phenomenon

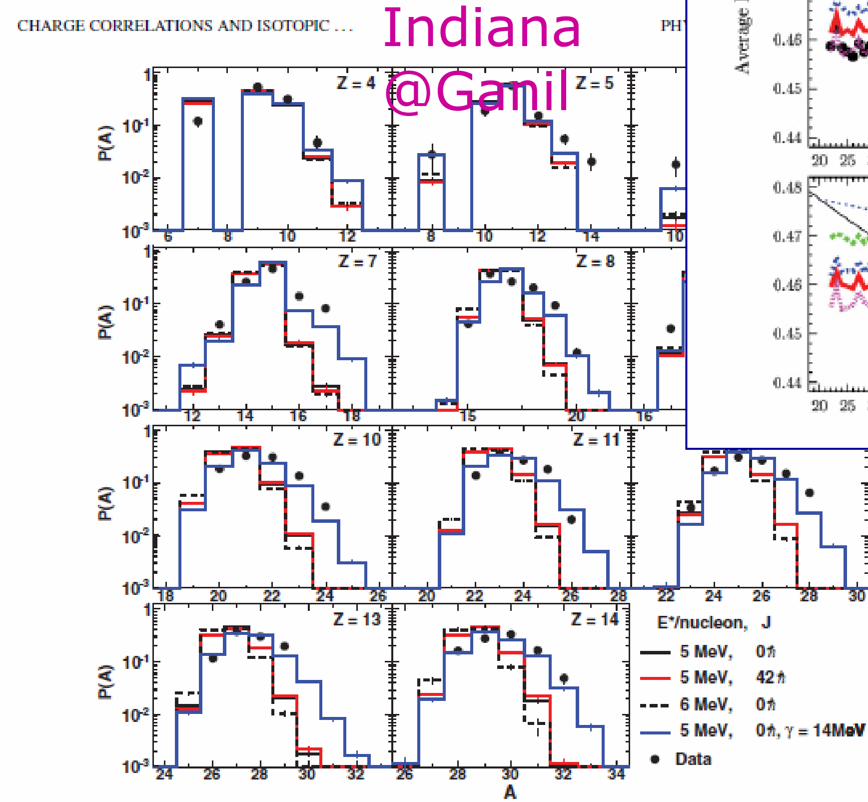
Souliotis et al., PRC 75
Ogul et al., JPG (2009)
Hudan et al., PRC 80
Henzlova et al., arXiv



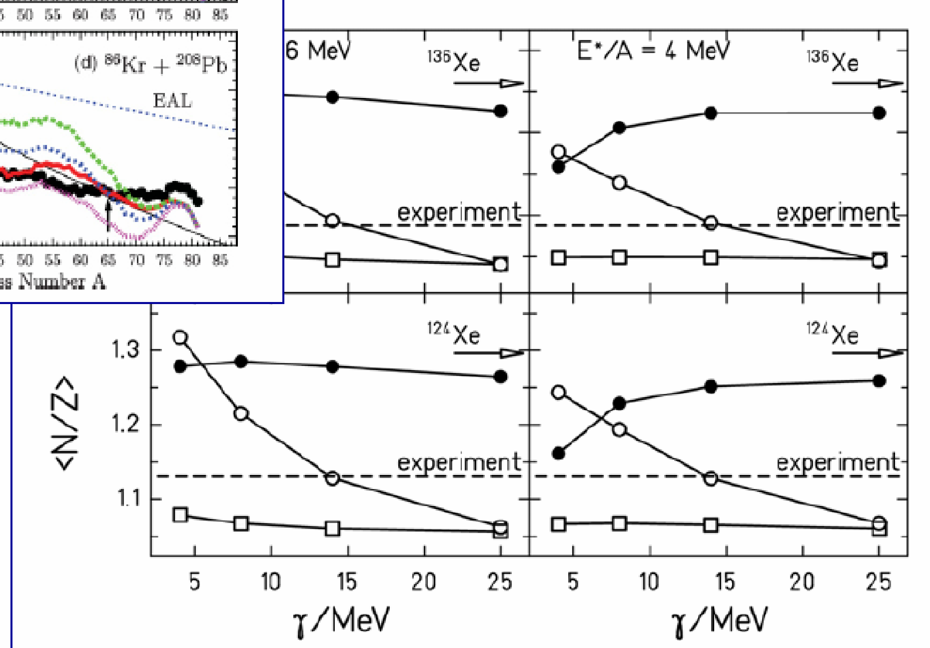
Texas A&M



Ogul et al.
with MSU data

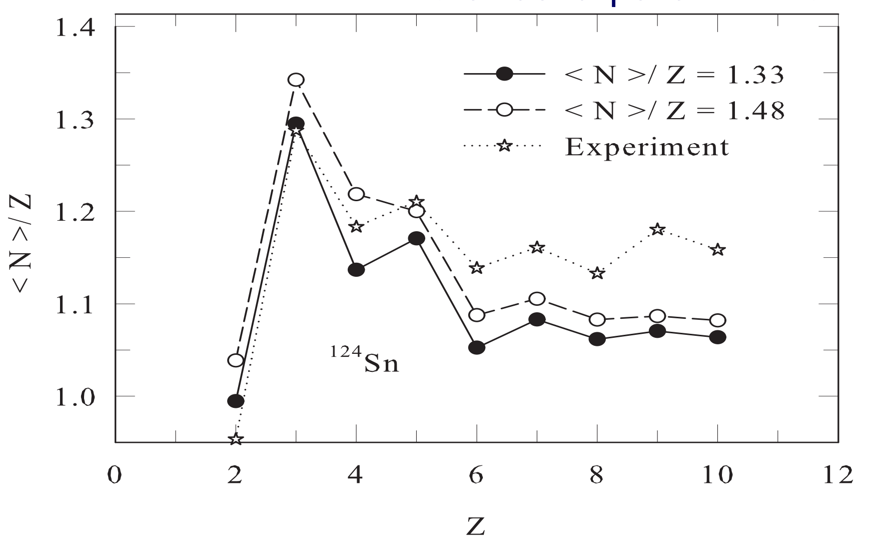


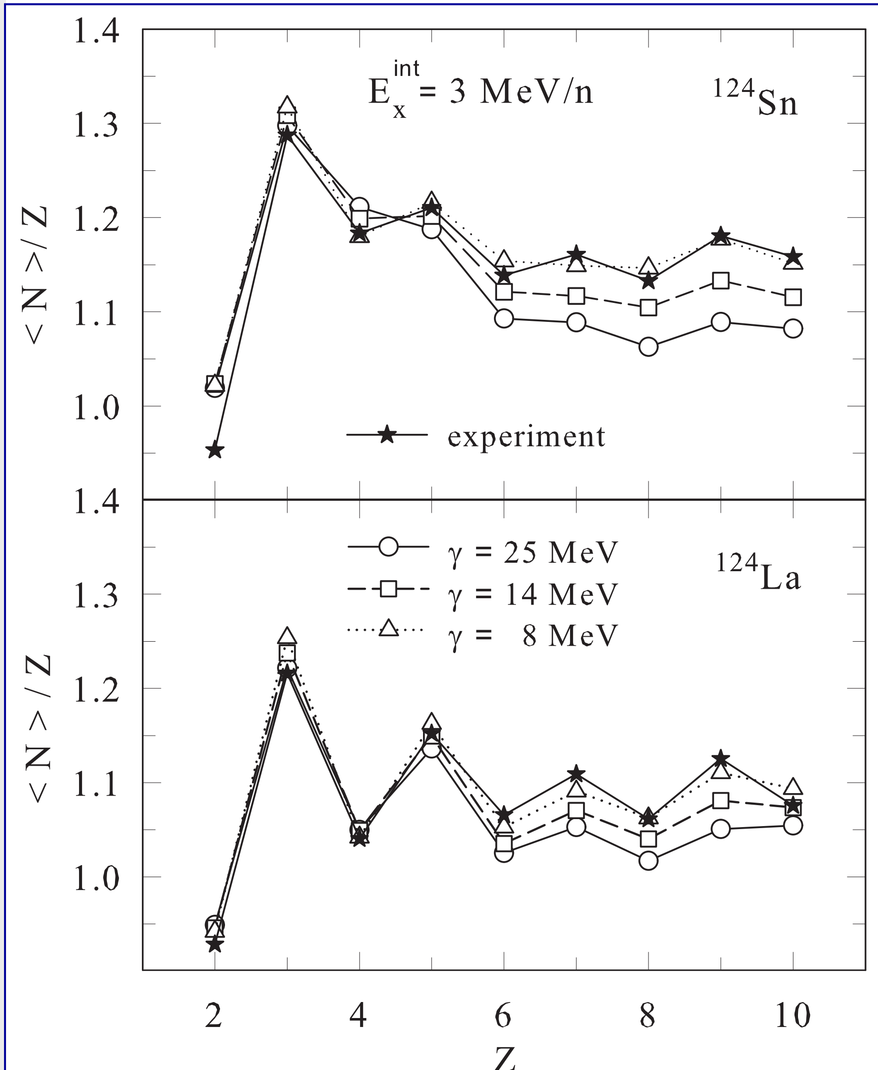
Indiana
@Ganil



discussion cont'd: tests of specific assumptions

with standard parameters





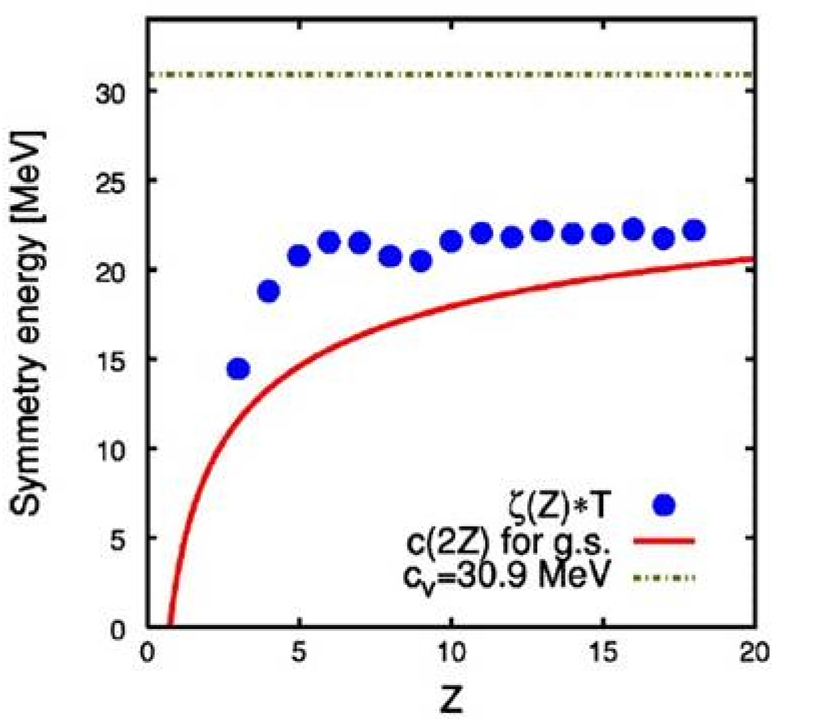
N/Z of spectator system

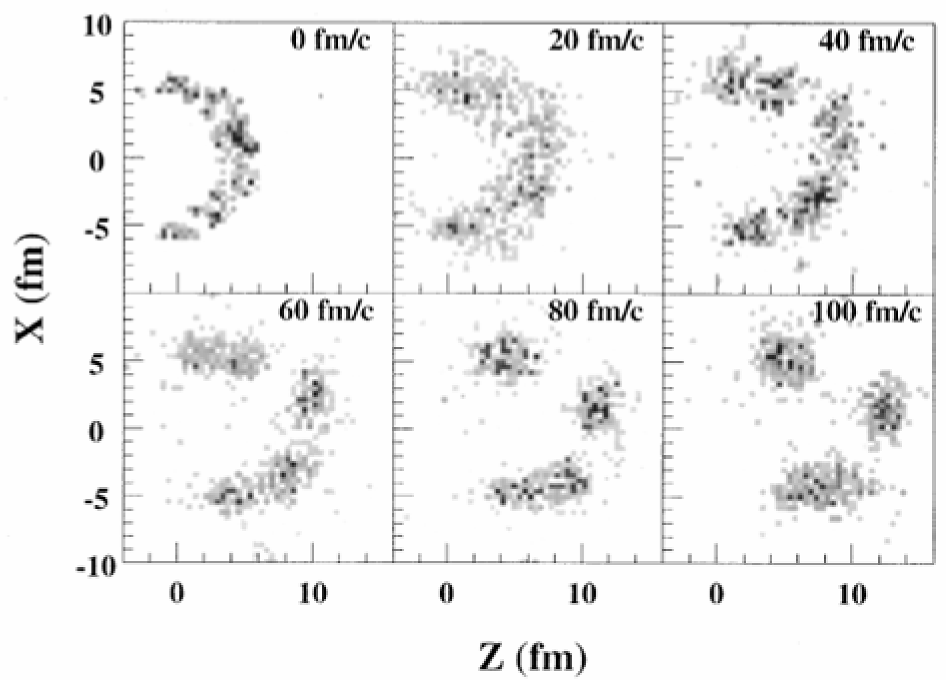
N/Z difference reduced =>
<N>/Z moves into wrong direction

restoration interval

E_x^{int} = 3 MeV corresponds to T=5 MeV requires even smaller γ

explanation:
surface vs. density?





excavated Ag nucleus with 70 nucleons remaining
M. Colonna, J. Cugnon, and E.C. Pollacco
PRC 55 (1997) 1404

● Symmetry energy of AMD fragments at breakup

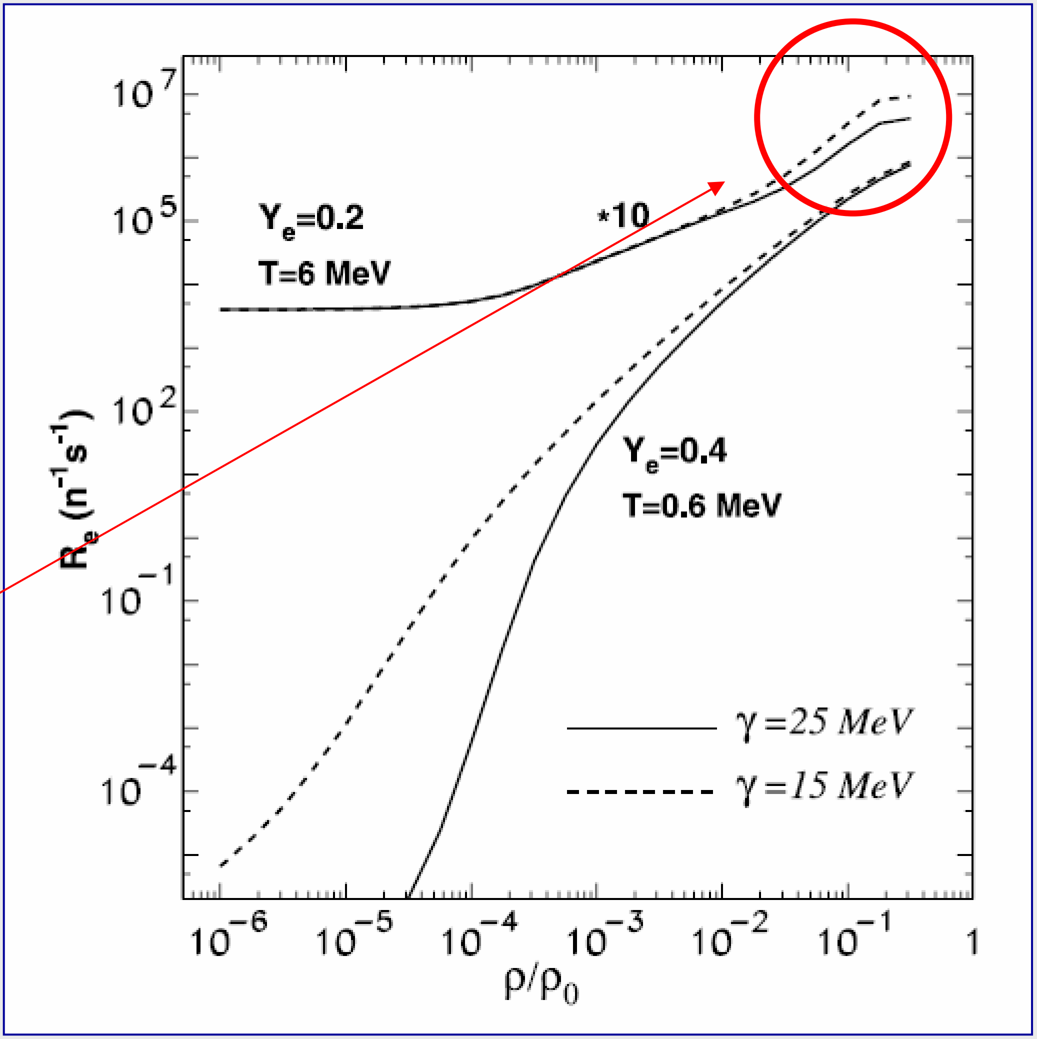
A. Ono et al., PRC 70 (2004)

"Resilience of nuclear matter in light ion induced reactions"

relevance for astrophysics

Density dependence of electron-capture rates R_e on hot nuclei in supernova environment at temperatures T = 6 and 0.6 MeV, and the electron fractions Y_e = 0.2 and 0.4

reduced γ causes factor 2 here



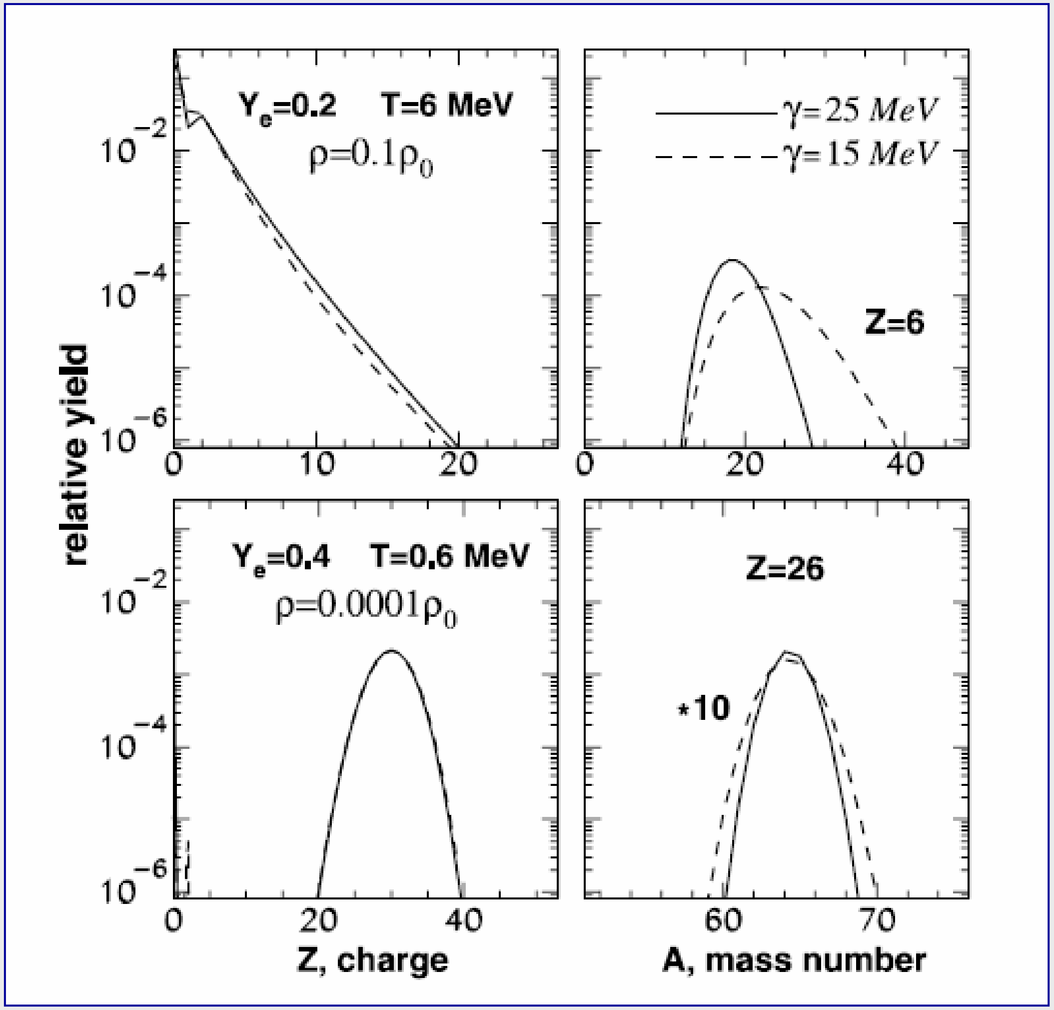
A.S. Botvina and I.N. Mishustin, NPA 843, 98 (2010)

relevance for astrophysics

Z distributions do not depend much on γ (left panels)

mass distributions become wider and more neutron rich (right panels)

examples are for temperatures T = 6 MeV and T = 0.6 MeV and the electron fractions Y_e = 0.2 and 0.4



A.S. Botvina and I.N. Mishustin, NPA 843, 98 (2010)

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. isoscaling obeyed with high accuracy;
   reduced symmetry term for hot fragments

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

6. spectator **neutron source** with T=4 MeV,
   invariant with system N/Z.

C. Sfienti et al., PRL 102 (2009); A.S. Botvina and I.N.Mishustin, NPA 843, 98 (2010);
R. Ogul et al., arXiv:1006.3723 (2010); D. Henzlova et al., arXiv:nucl-ex/0507003