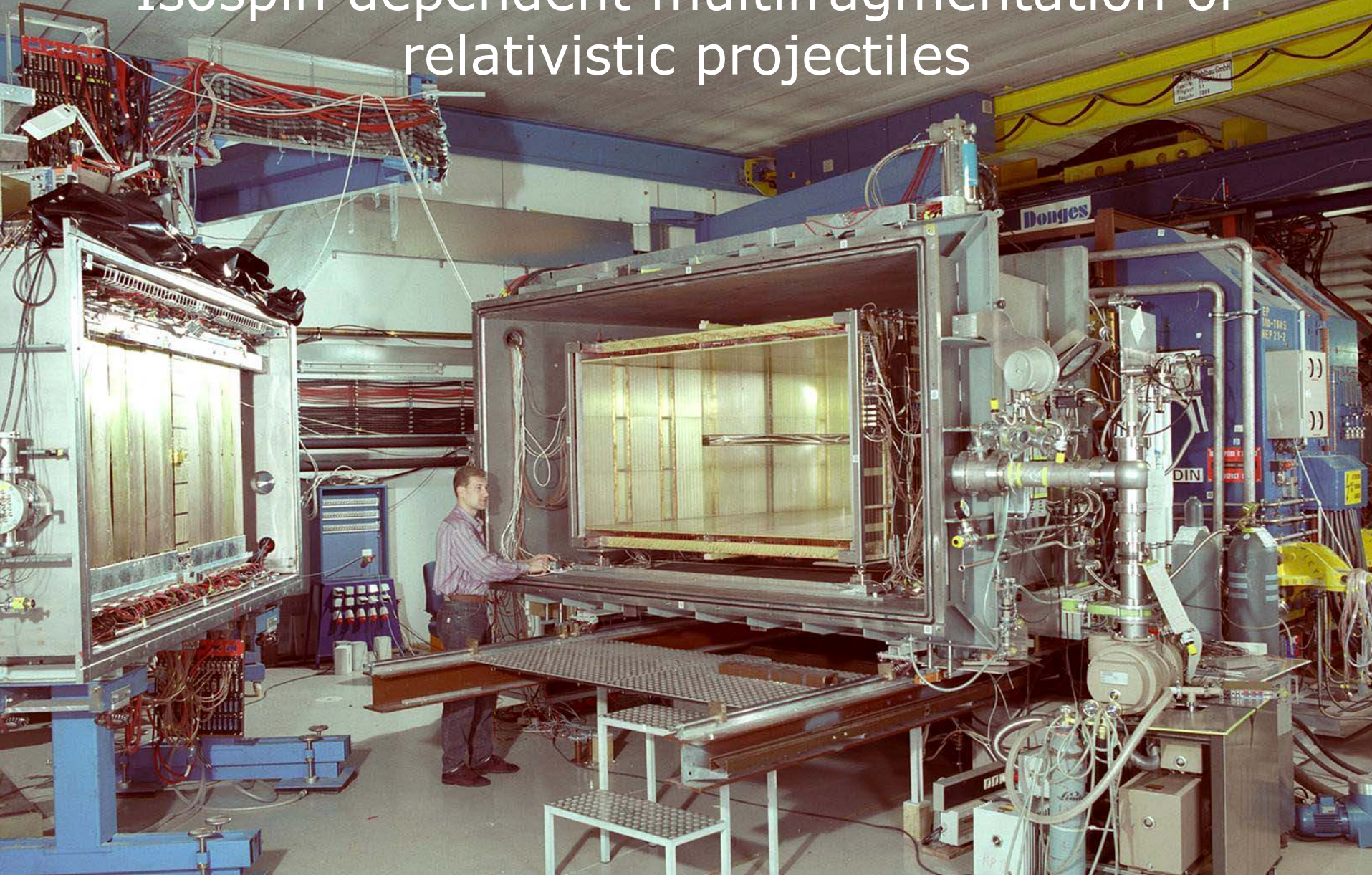
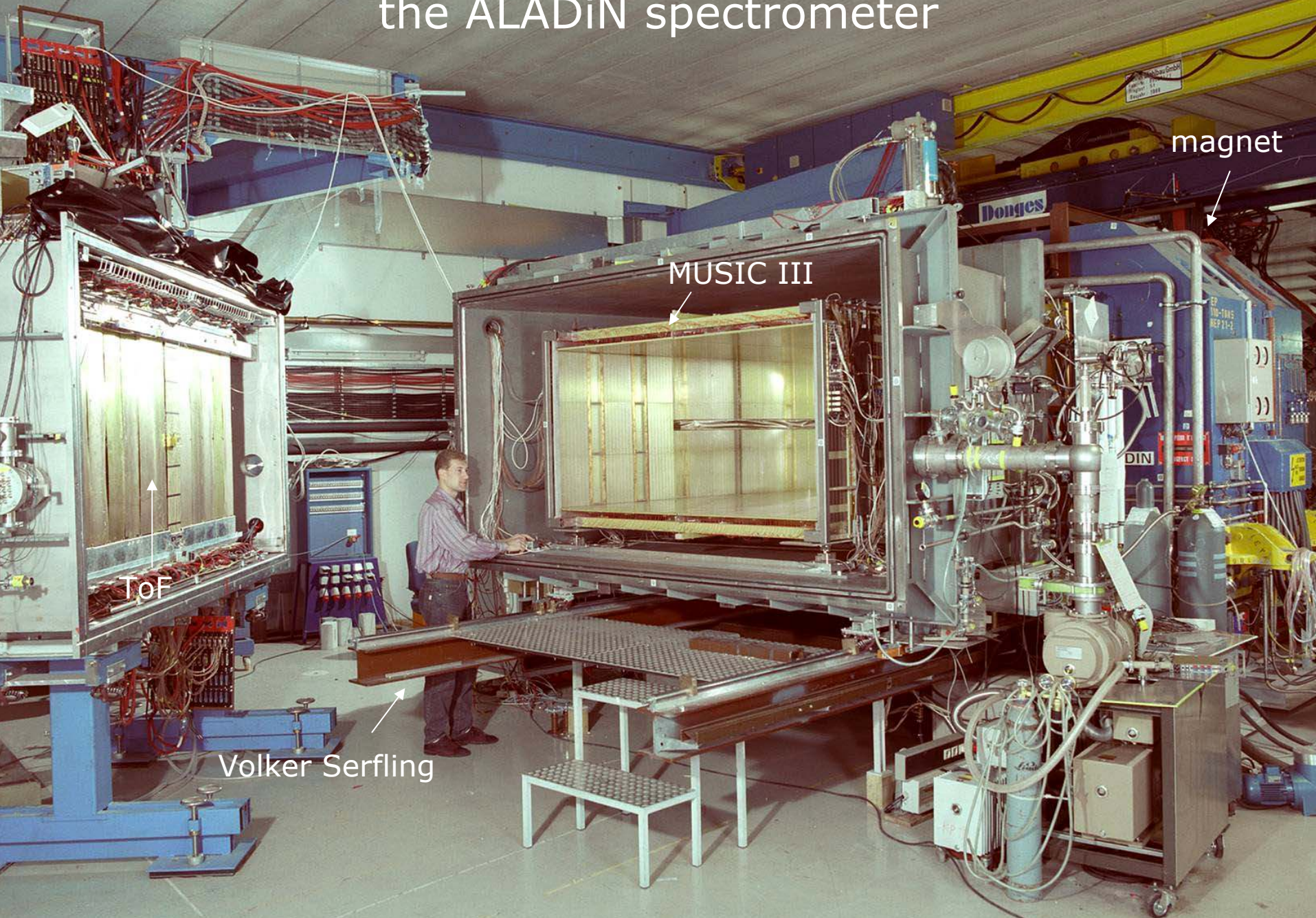


Isospin dependent multifragmentation of relativistic projectiles



W. Trautmann, GSI Helmholtzzentrum, Darmstadt, Germany

the ALADiN spectrometer



magnet

MUSIC III

ToF

Volker Serfling

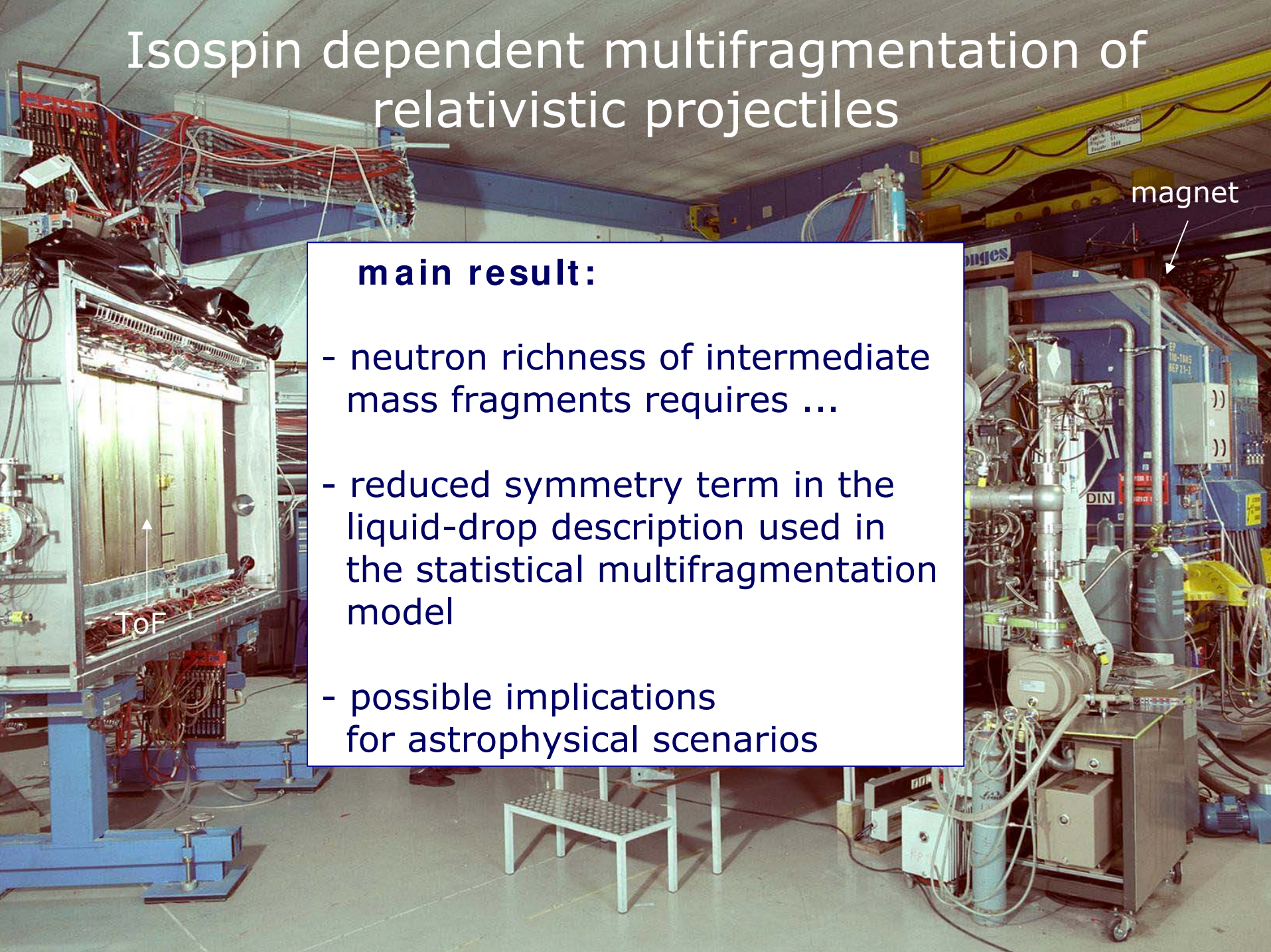
Isospin dependent multifragmentation of relativistic projectiles

main result:

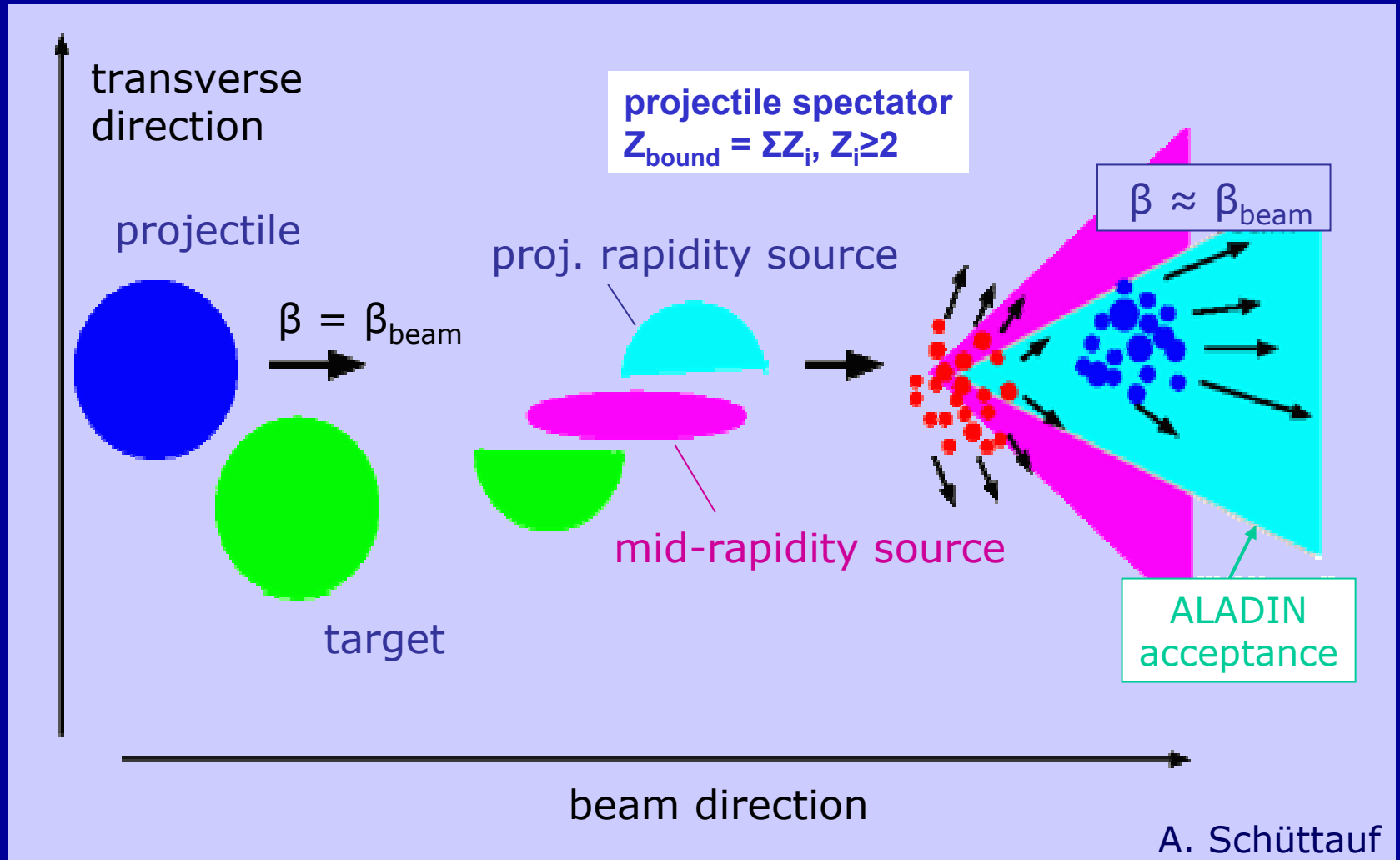
- neutron richness of intermediate mass fragments requires ...
- reduced symmetry term in the liquid-drop description used in the statistical multifragmentation model
- possible implications for astrophysical scenarios

magnet

ToF



introduction: projectile fragmentation

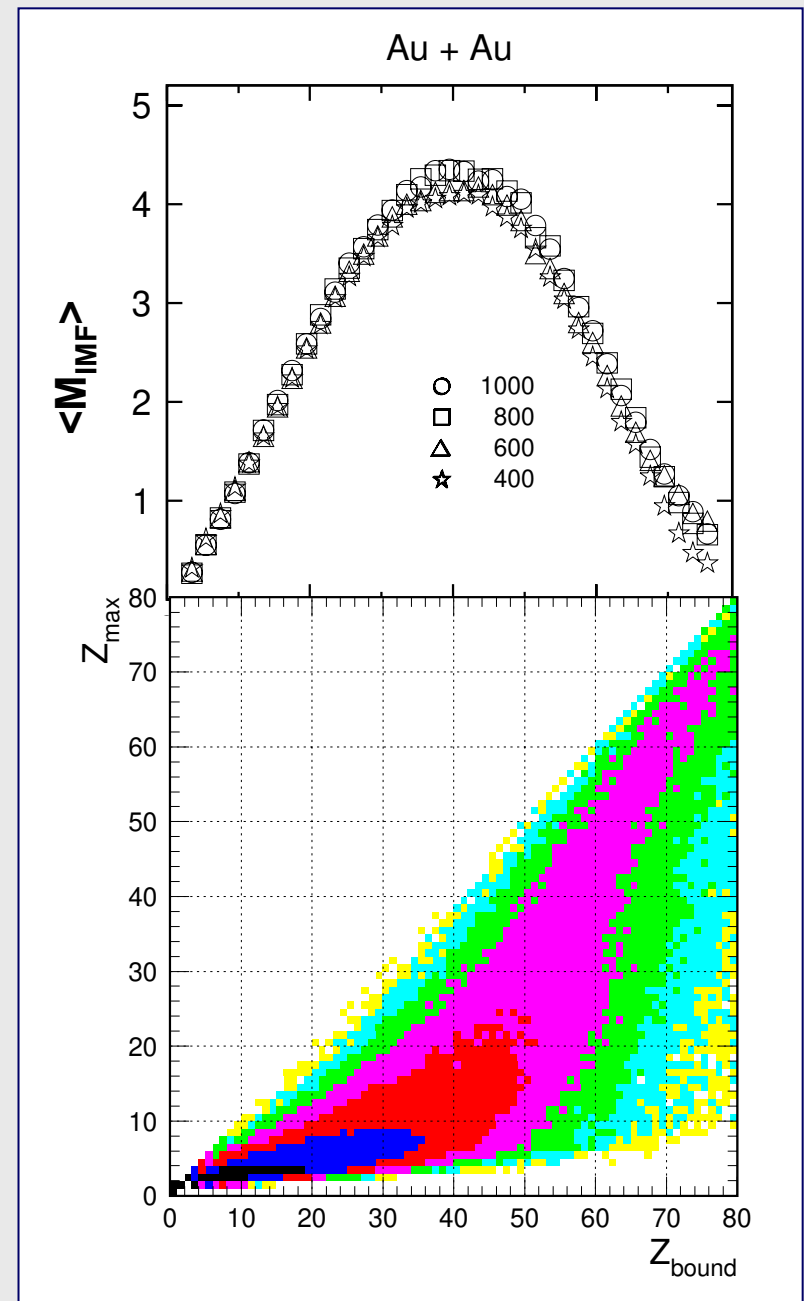


the rise and fall of multifragmentation

invariance with target
or incident energy
as indicator of **equilibrium**

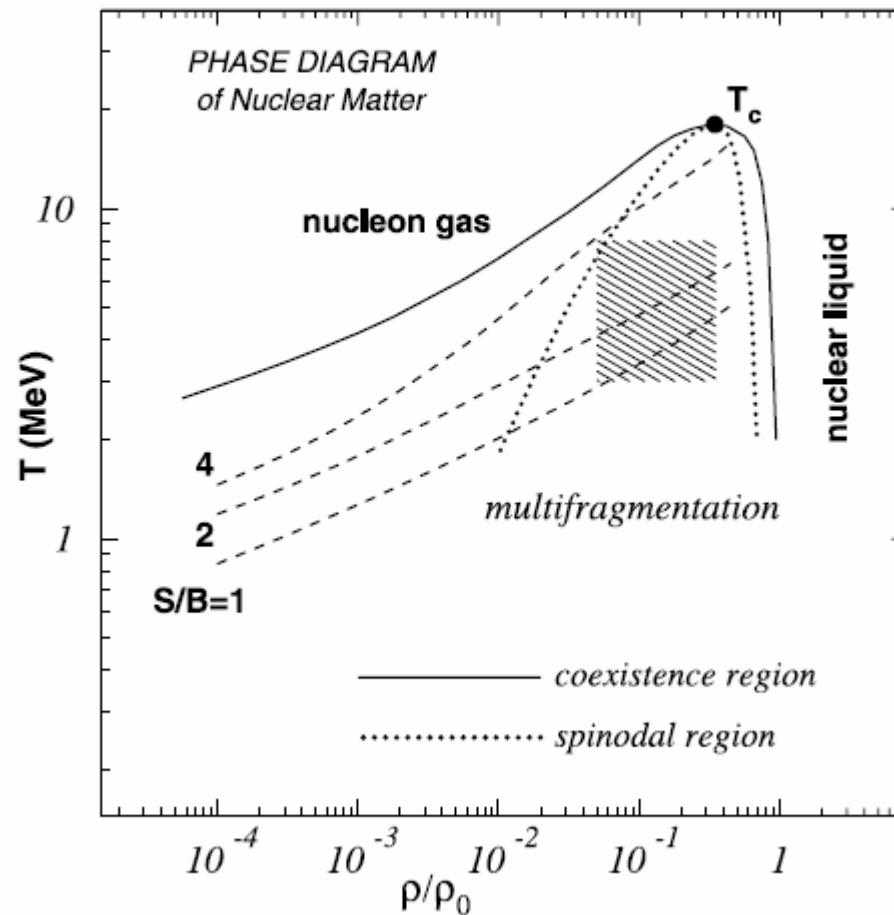
equilibrium conditions
 $T \approx 5-6$ MeV and $\rho \approx \rho_0/3$
experimentally determined

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



astrophysical motivation

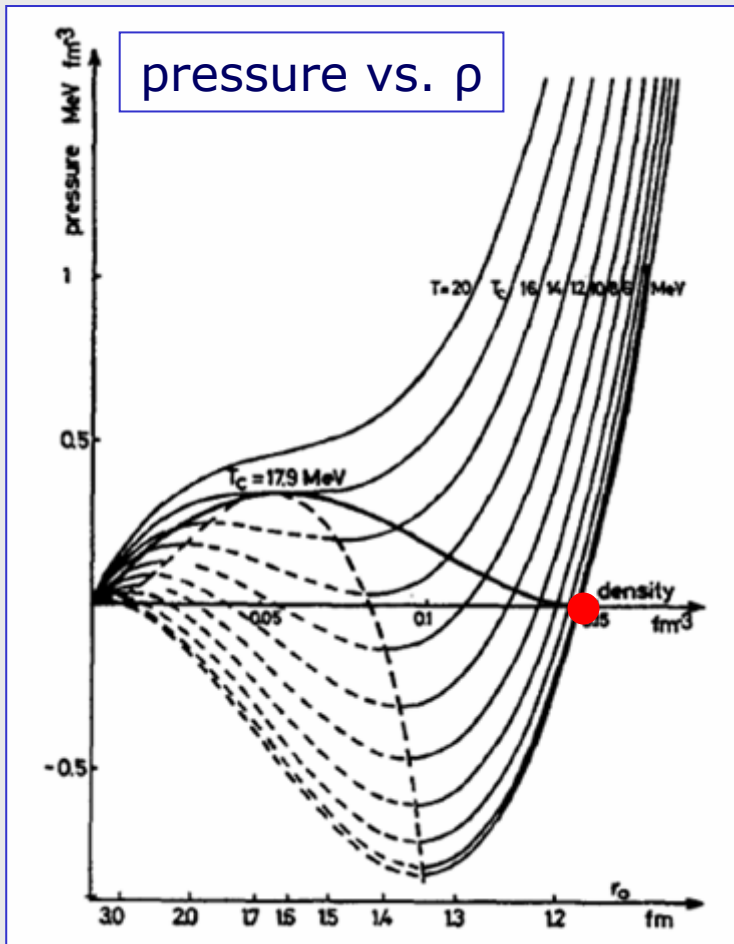
A.S. Botvina, I.N. Mishustin / Nuclear Physics A 843 (2010) 98–132



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

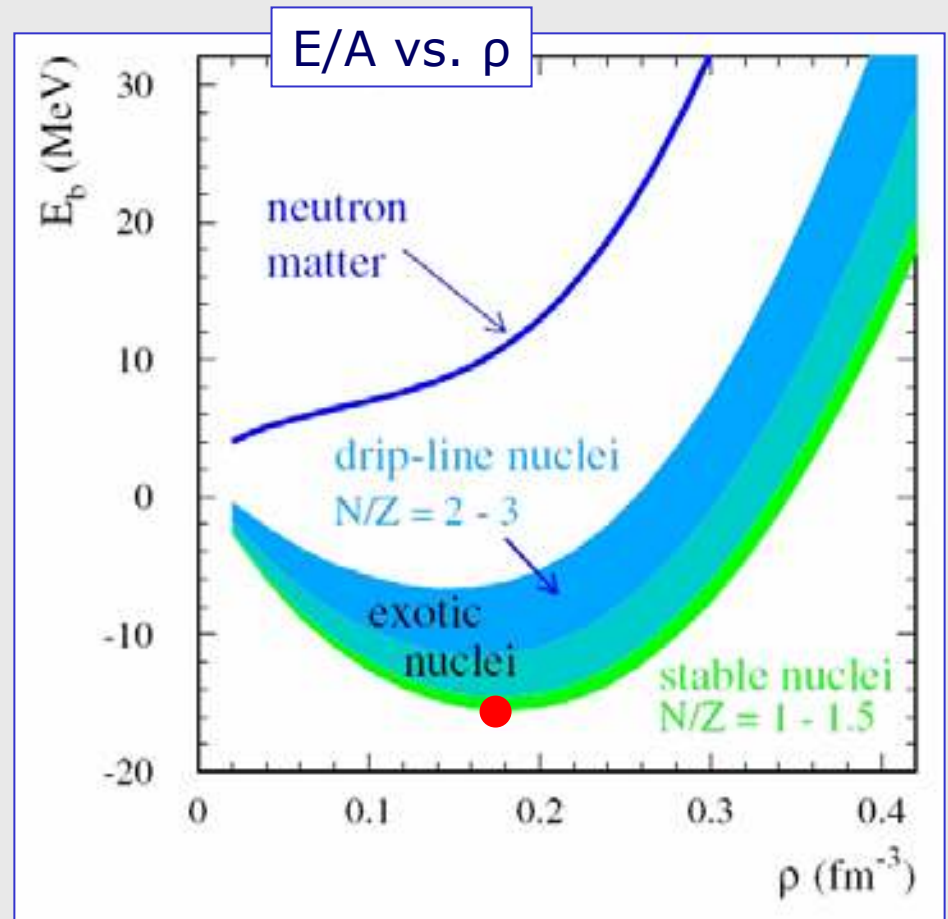
the nuclear equation-of-state

temperature dependent
Hartree-Fock theory



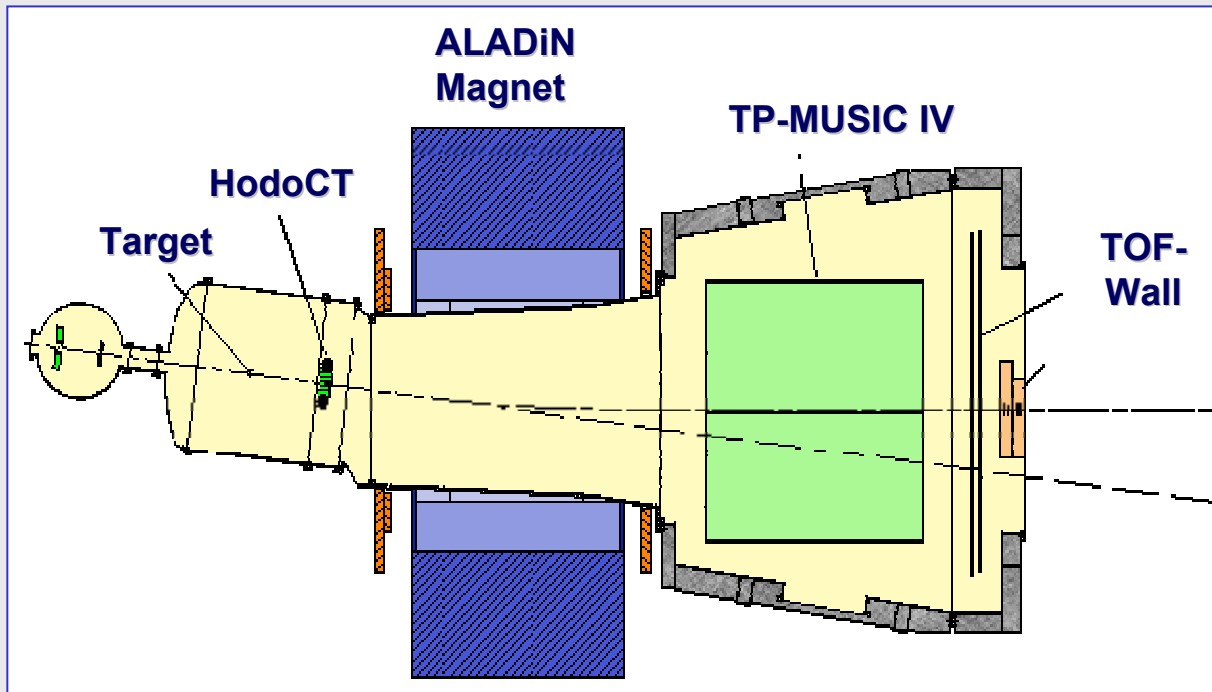
from Sauer, Chandra, Mosel
Nucl. Phys. A 264, 221 (1976)

relativistic
Brueckner-Hartree-Fock theory



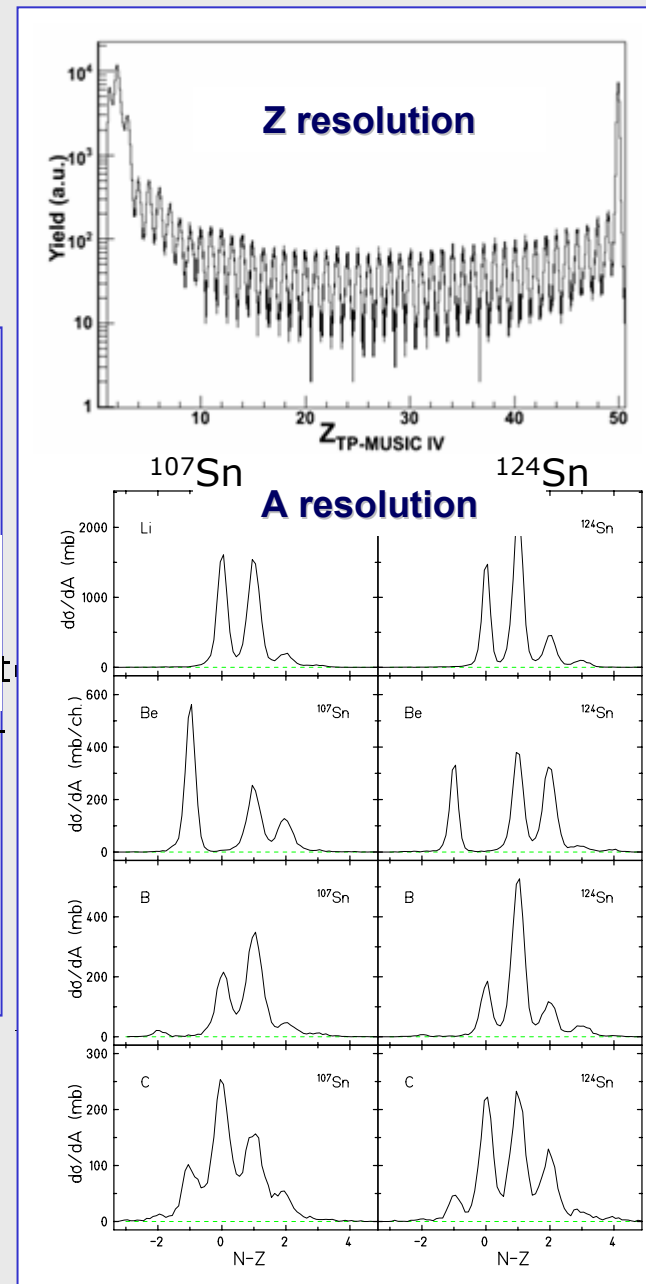
from de Jong and Lenske
Phys. Rev. C 57, 3099 (1998)

experiment: isospin dependence of multifragmentation of relativistic projectiles



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

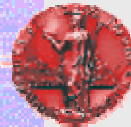
neutron poor secondary beams from FRS



The Aladdin 2000 Collaboration

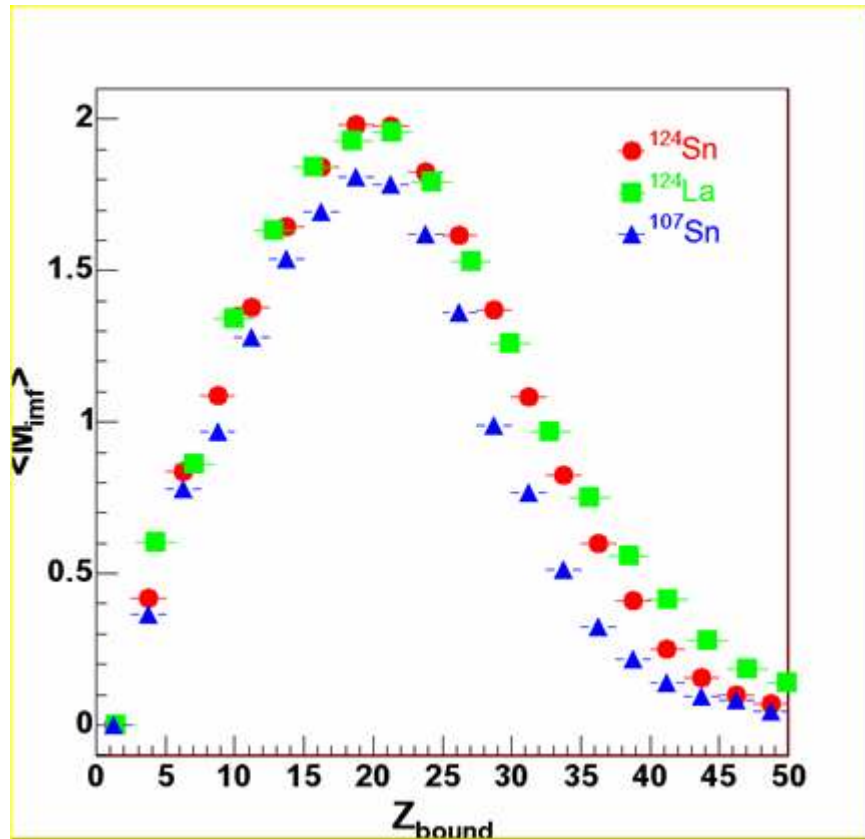


S. Bianchin, K. Kezzar, A. Le Fèvre, J. Lühning, J. Lukasik, U. Lynen, W.F.J. Müller, H. Orth, A.N. Otte, H. Sann, C.Schwarz, C. Sfienti, W. Trautmann, J. Wiechula, M.Hellström, D. Henzlova, **K. Sümmerer**, H. Weick, P. Adrich, T. Aumann, H. Emling, H. Johansson, Y. Leifels, R. Palit, H. Simon, M. De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



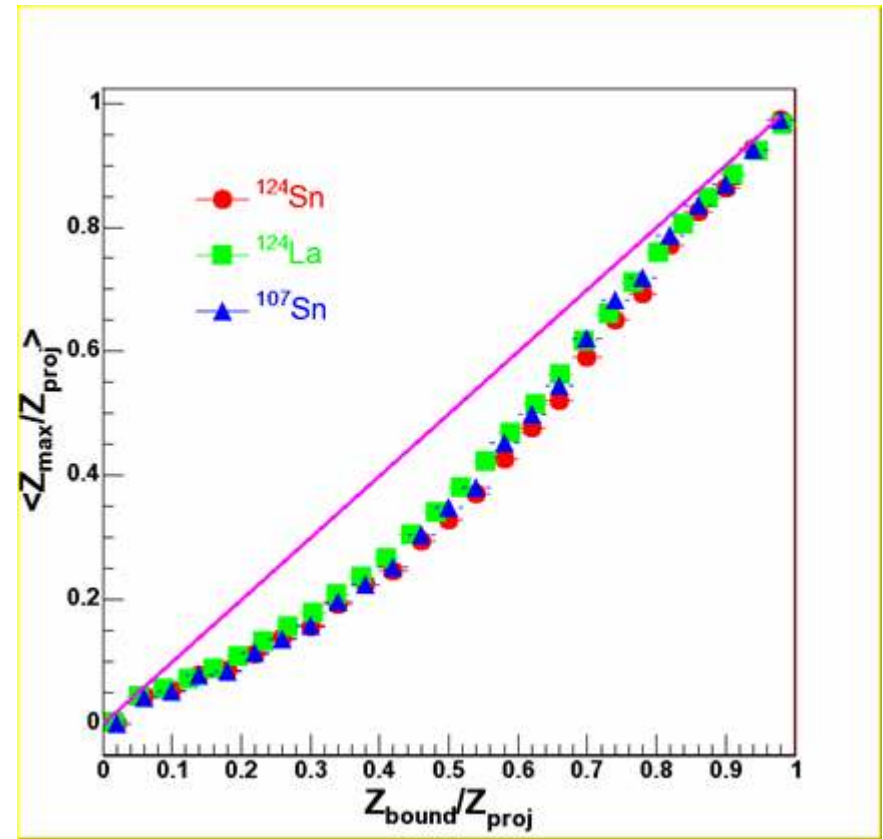
global observables: isotopic effects are small

fragment multiplicity



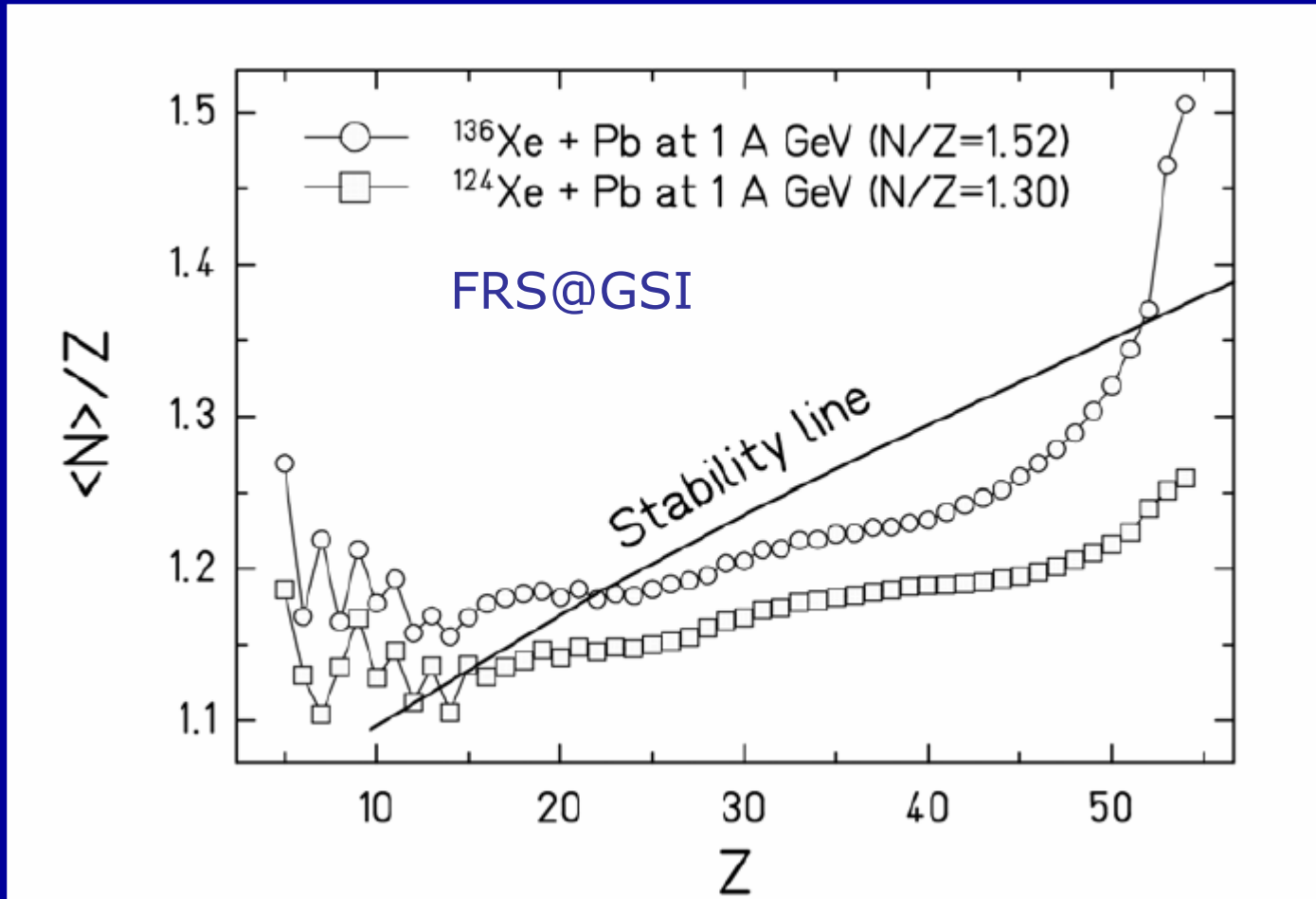
$$Z_{\text{bound}} = \sum Z_i (Z_i \geq 2)$$

largest fragment

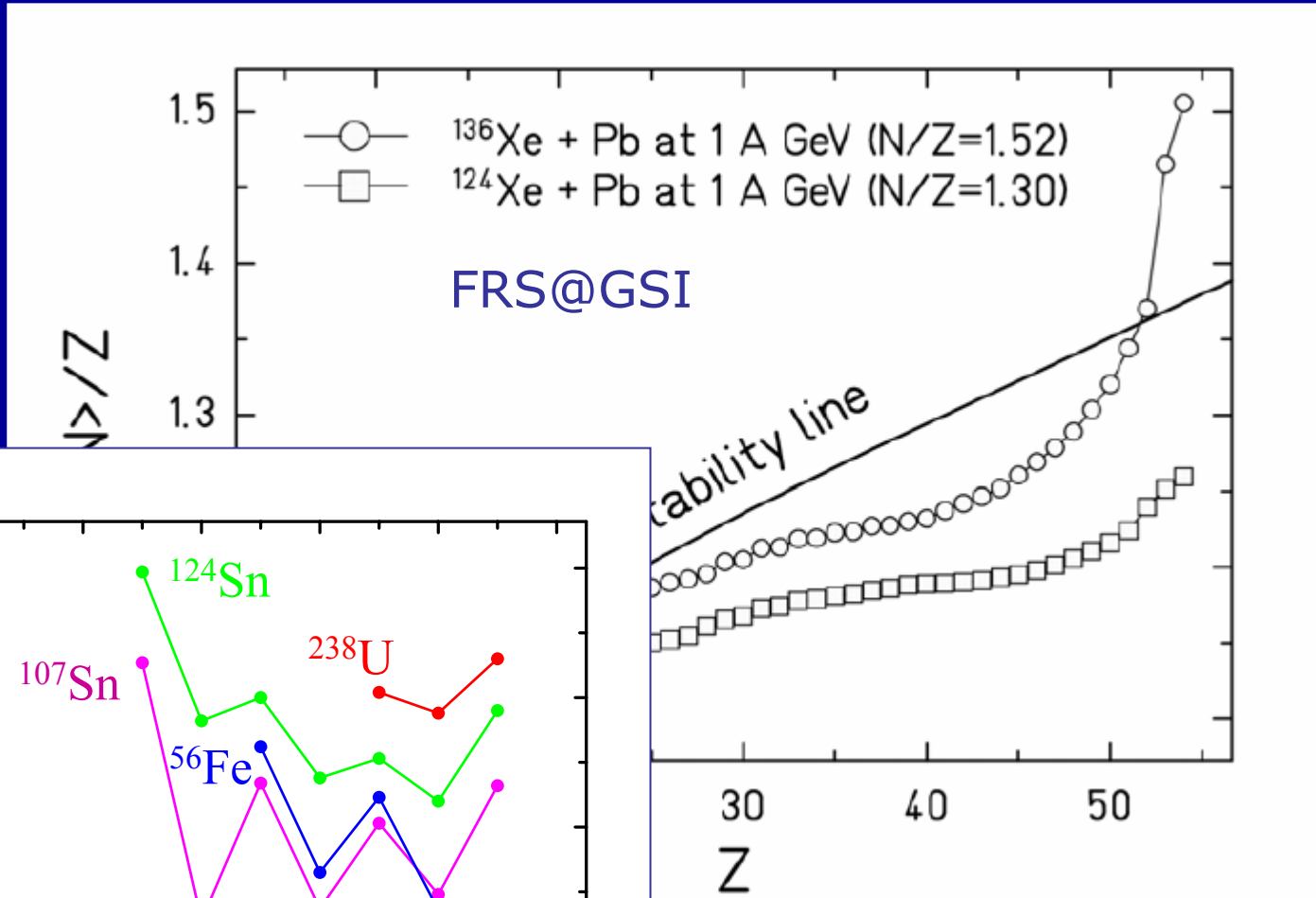


C. Sfienti et al., PRL 102, 152701 (2009)

isotopes: nuclear structure and memory effects



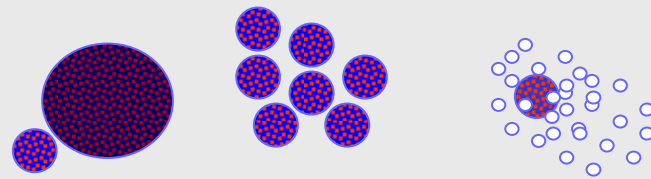
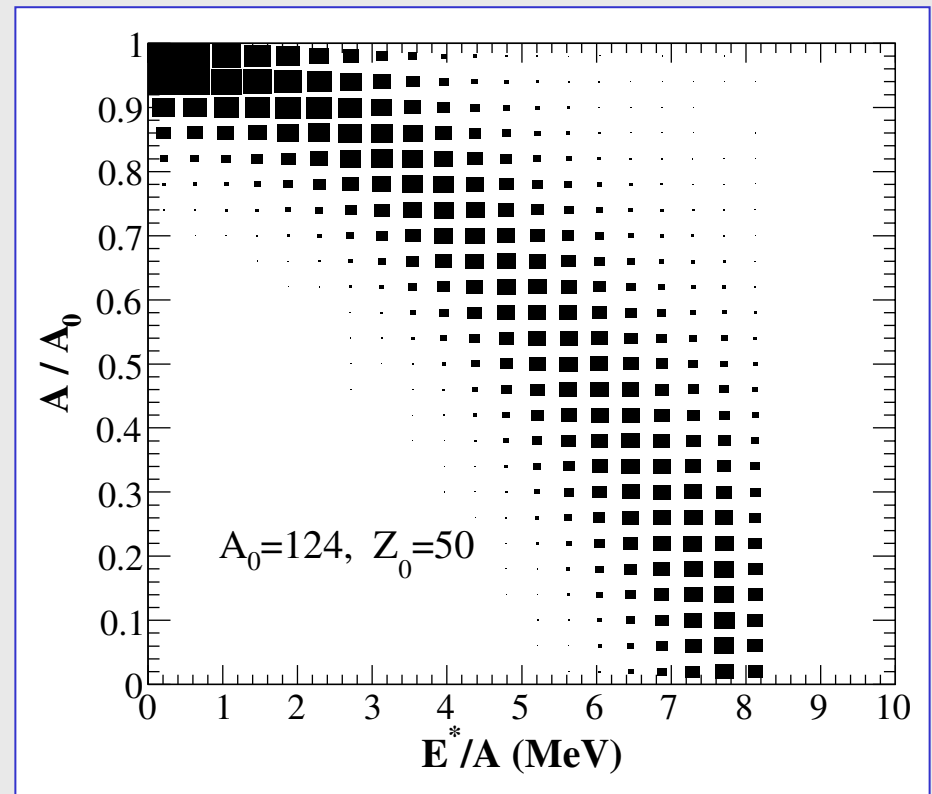
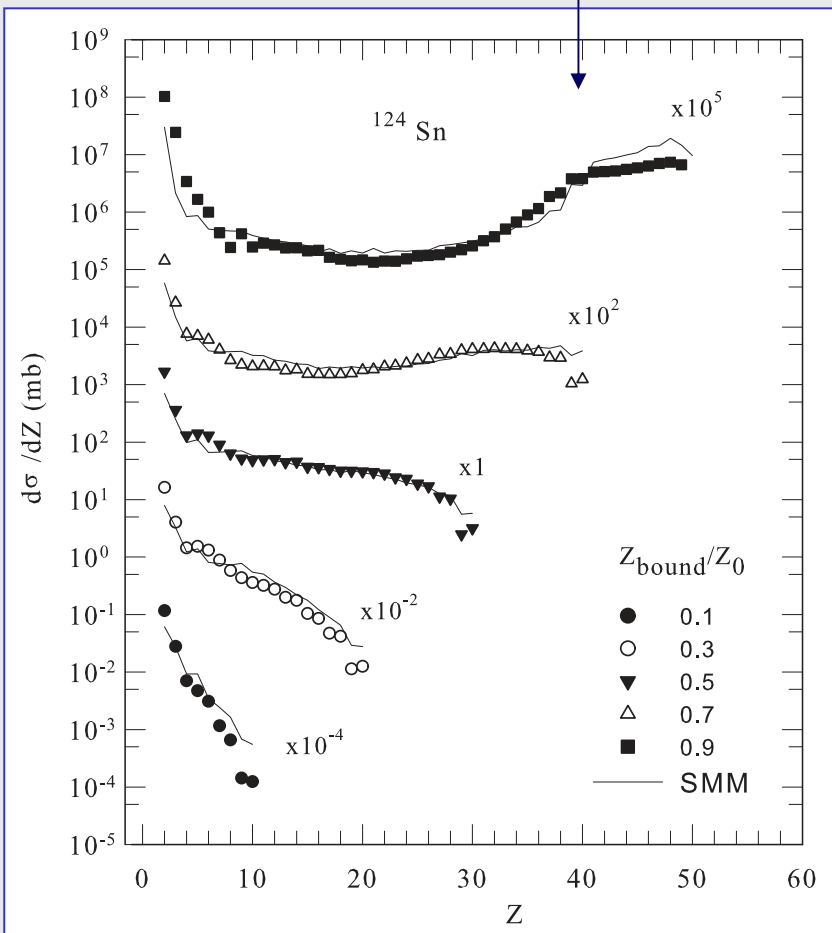
isotopes: nuclear structure and memory effects



SMM ensemble calculations used for analysis

(SMM: Statistical Multifragmentation Model)

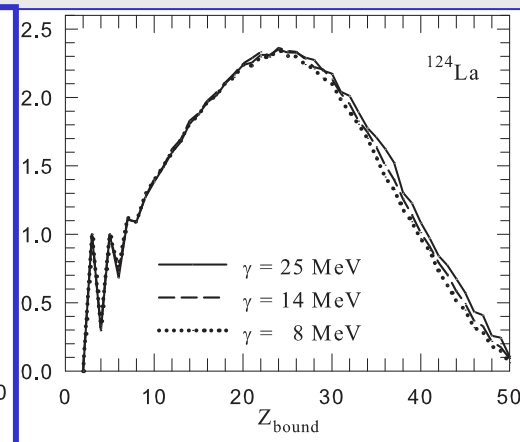
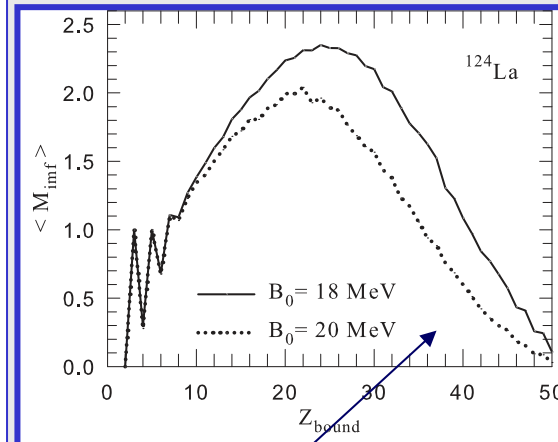
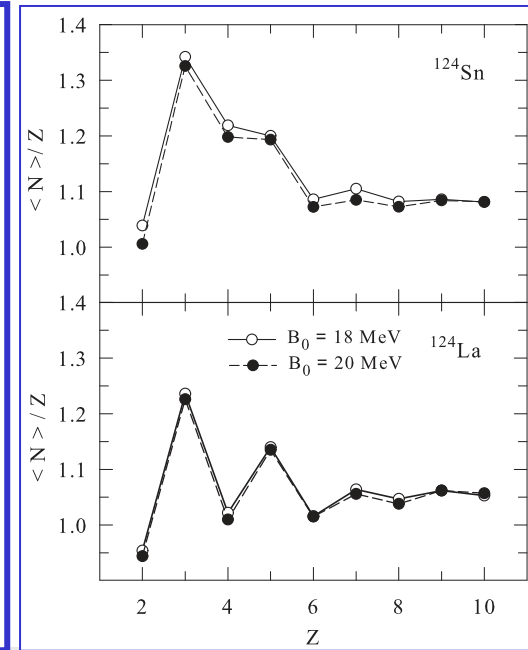
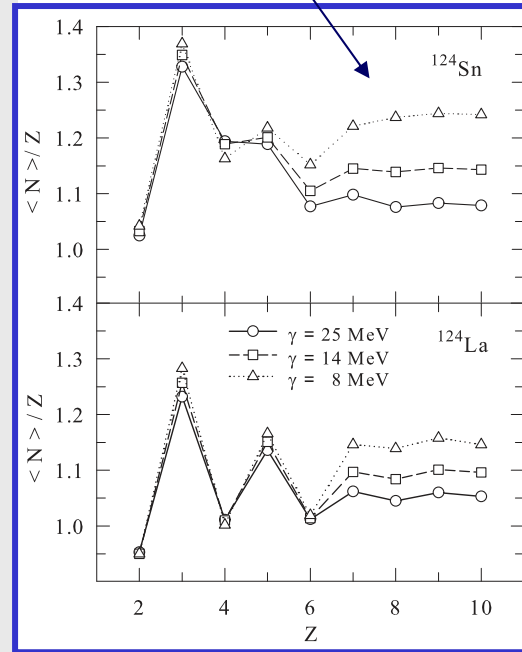
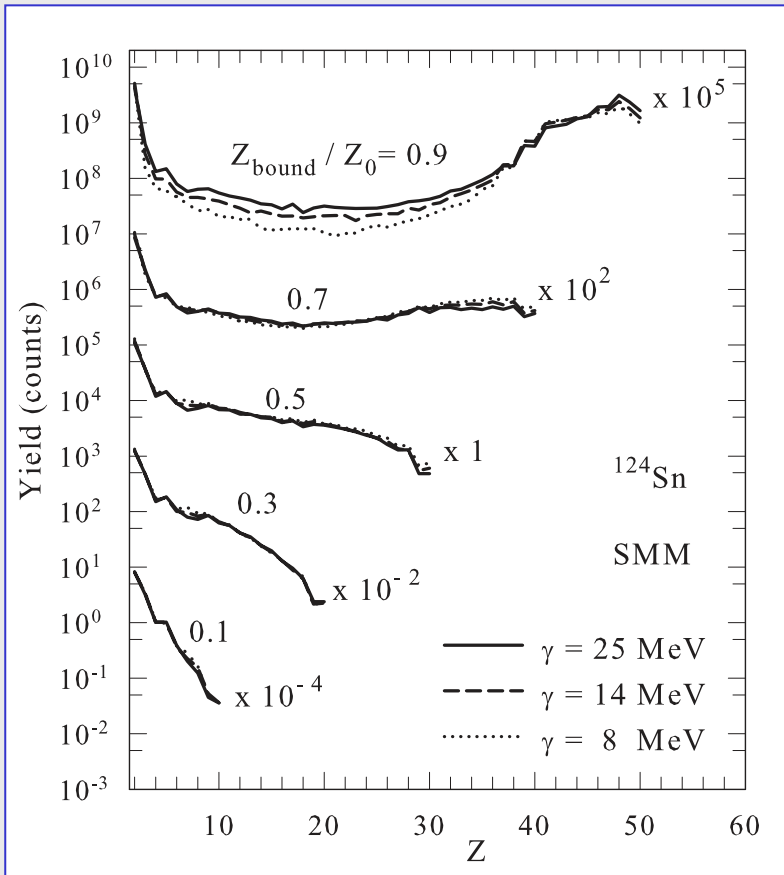
mass variation with excitation →
 energy taken into account;
 fixed to reproduce exclusive yields



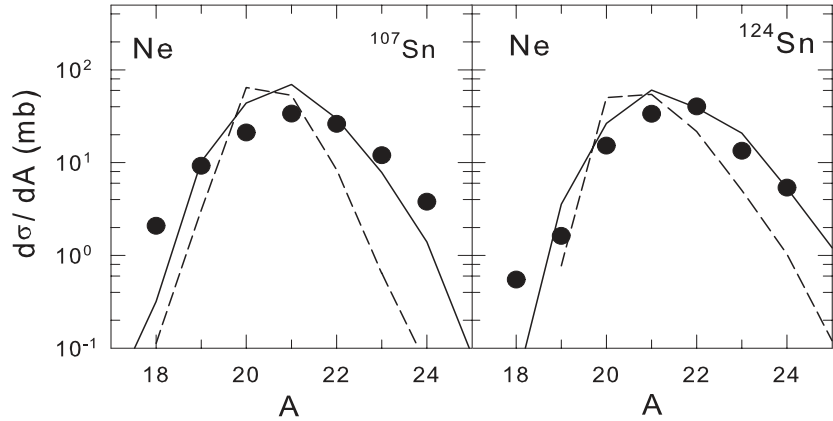
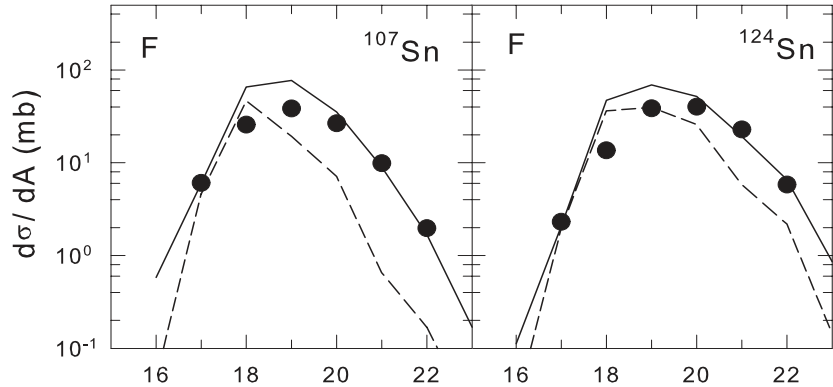
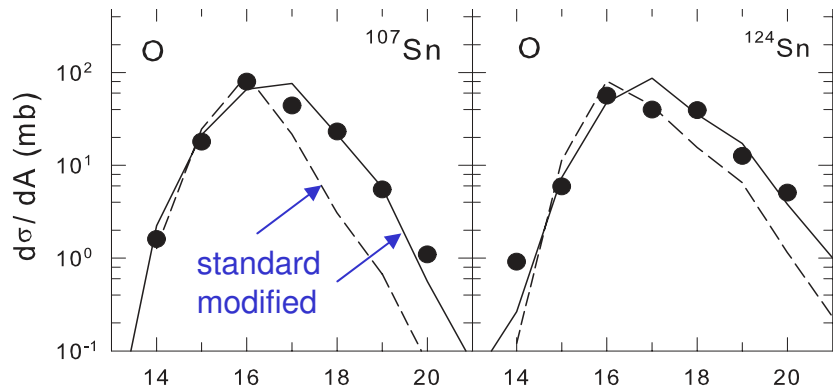
$$Z_{\text{bound}} = \sum Z_i \text{ with } Z_i \geq 2$$

sensitive to symmetry term

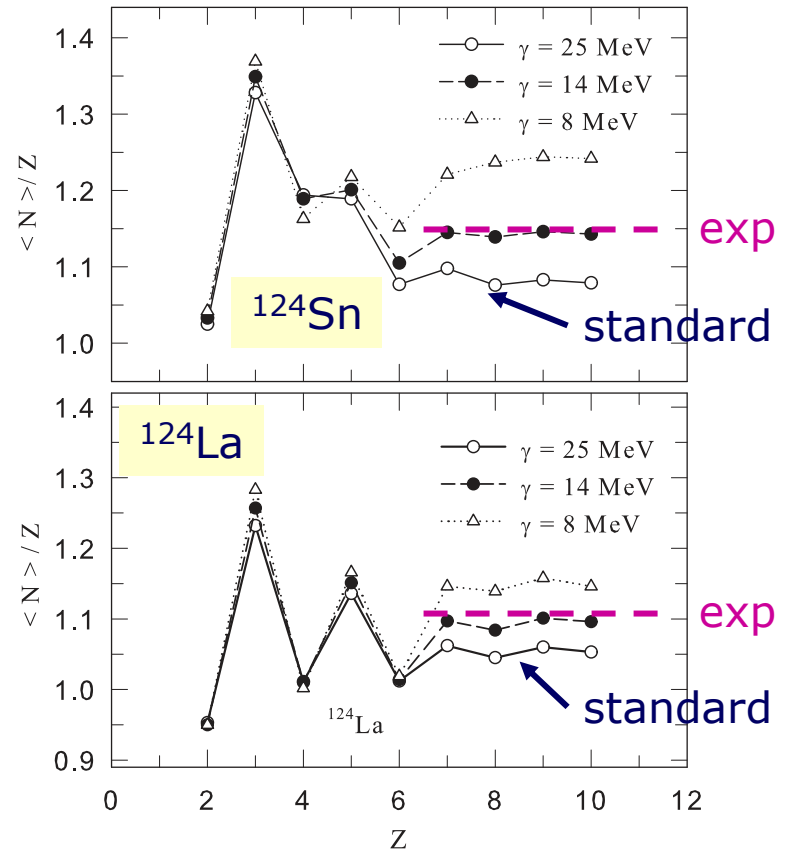
model study of sensitivities



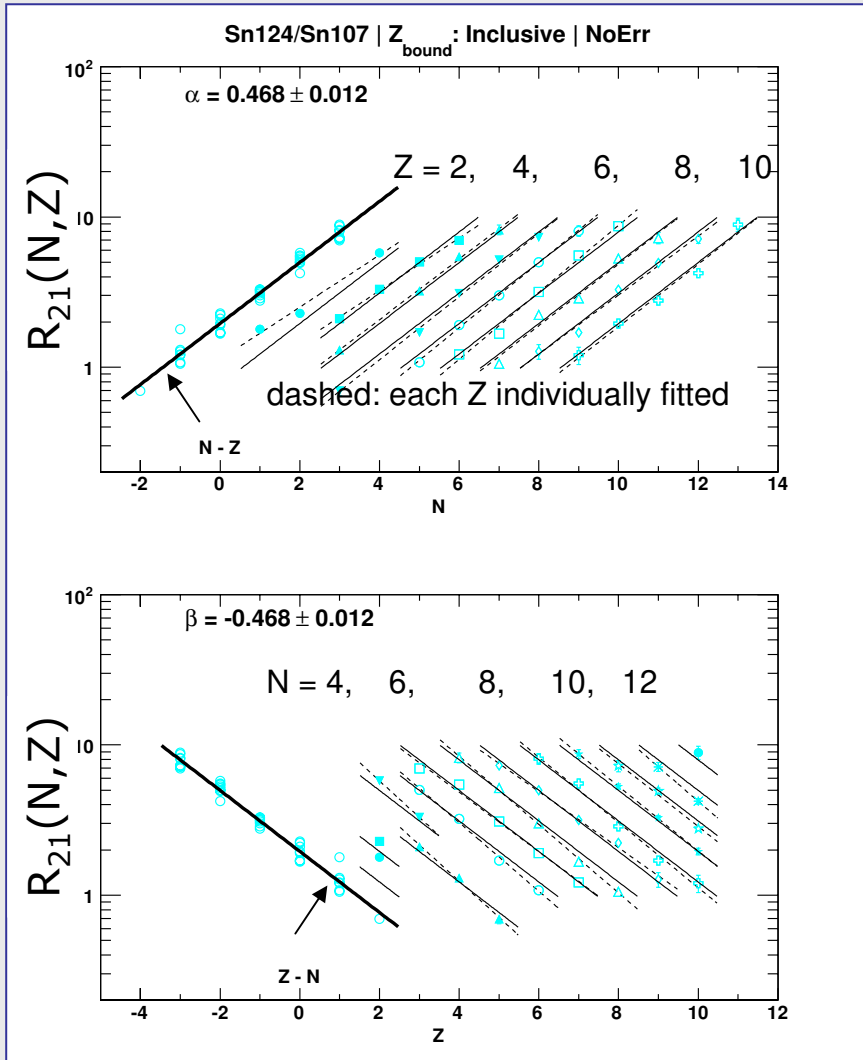
sensitive to surface term



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



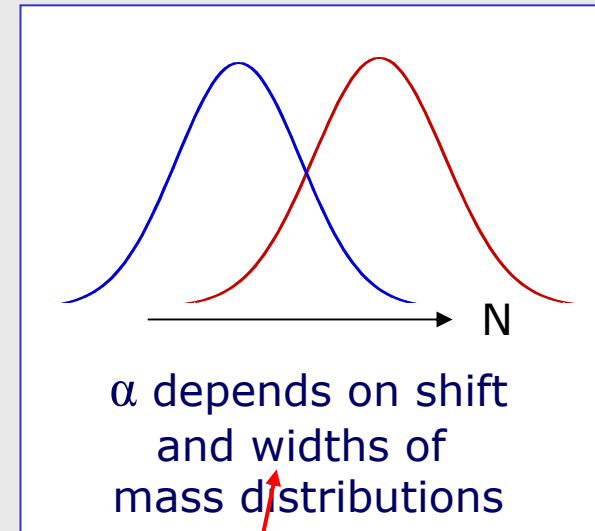
isoscaling fits



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



$$R_{21} = C \exp(\alpha N + \beta Z)$$

$$\alpha = \Delta\mu_n/T$$

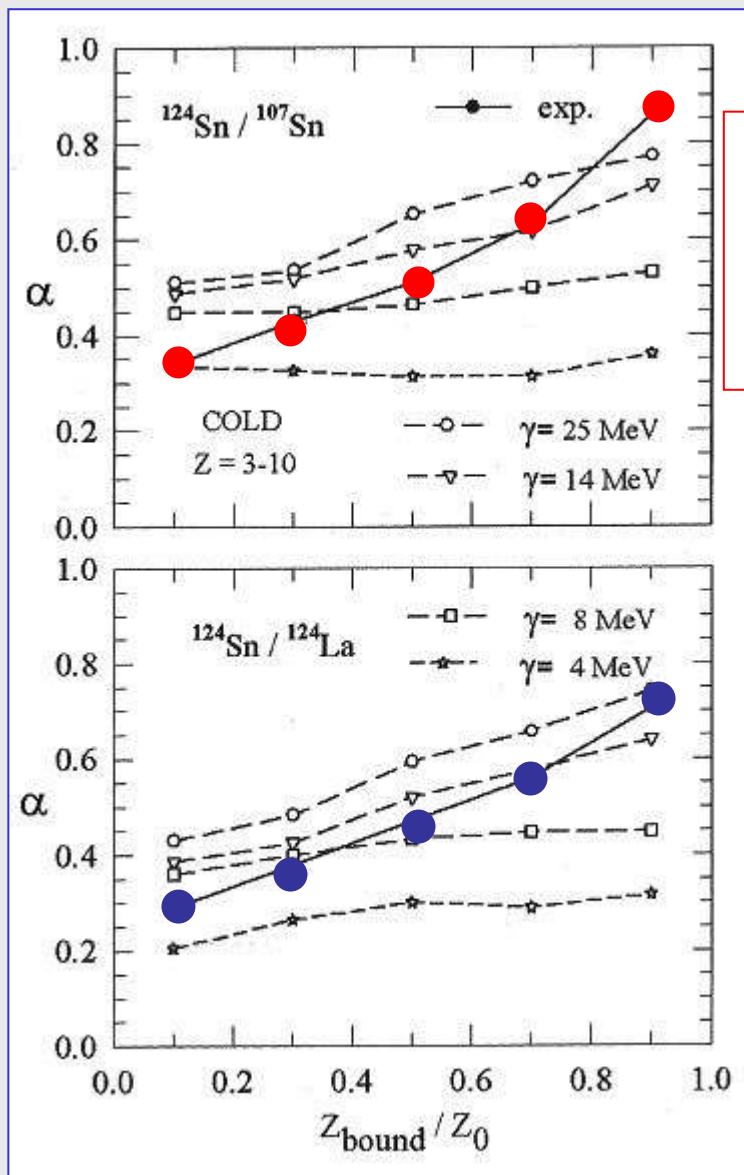
M.B. Tsang et al.,
PRC 64 (2001)

isoscaling analysis

● ● exp. data

similar results with either combination of projectile pairs

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



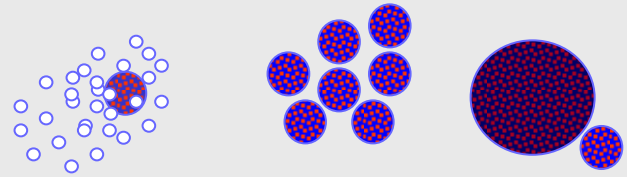
25
14
8
4

open symbols + lines:

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

$\gamma = 25$ (standard),
14, 8, 4 MeV

fragments in the hot environment



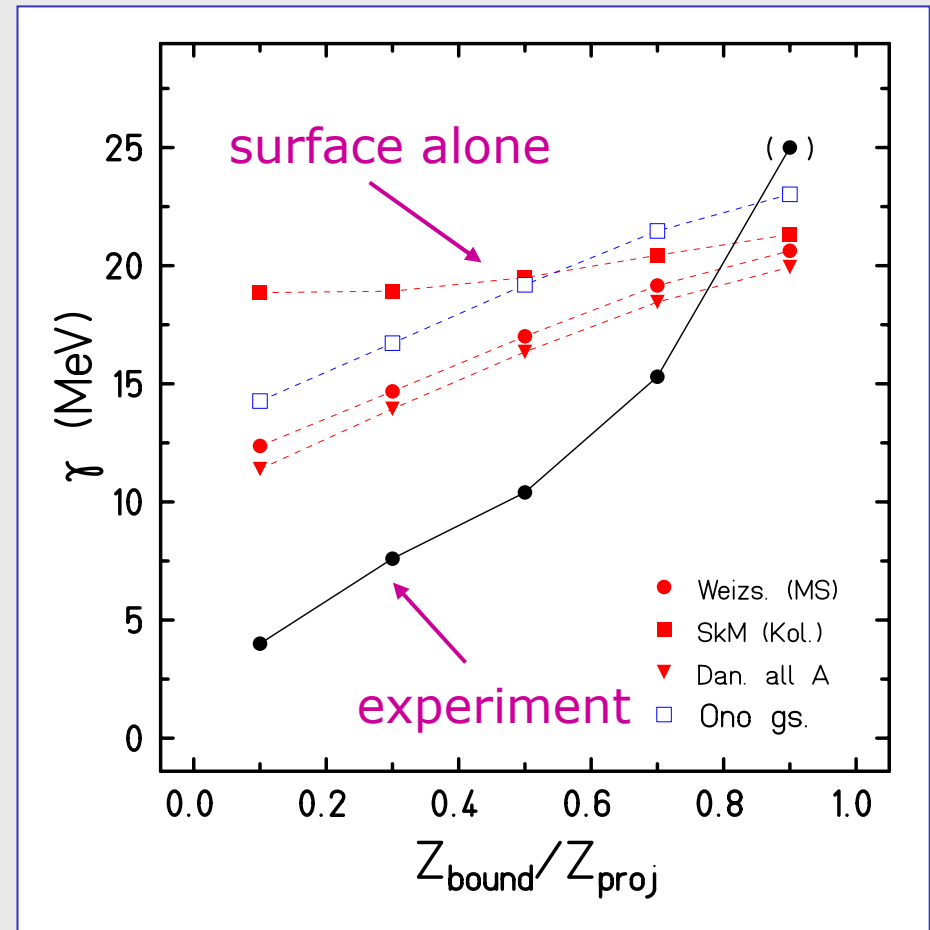
symmetry term reduced
at chemical freeze-out
in multifragmentation reactions

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 ...

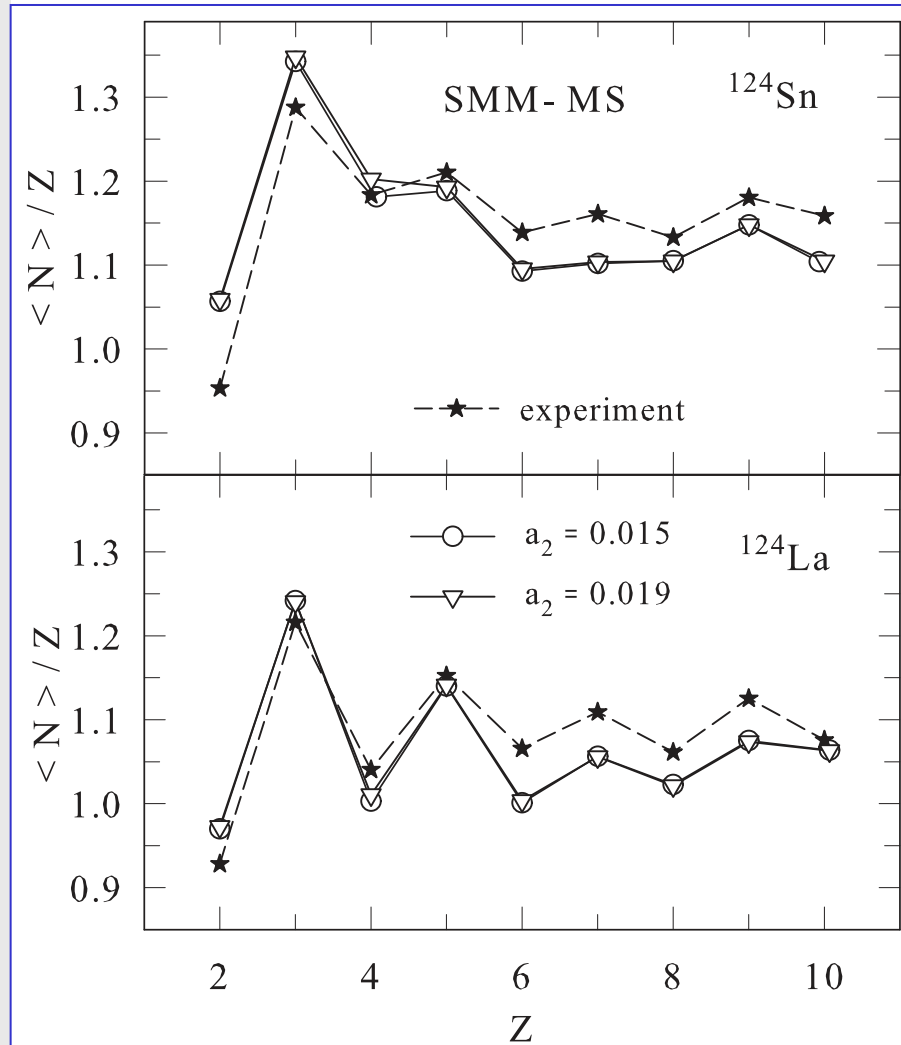
"important for realistic description of
the **nuclear composition** for
understanding stellar dynamics
and nucleosynthesis"



discussion

surface not sufficient

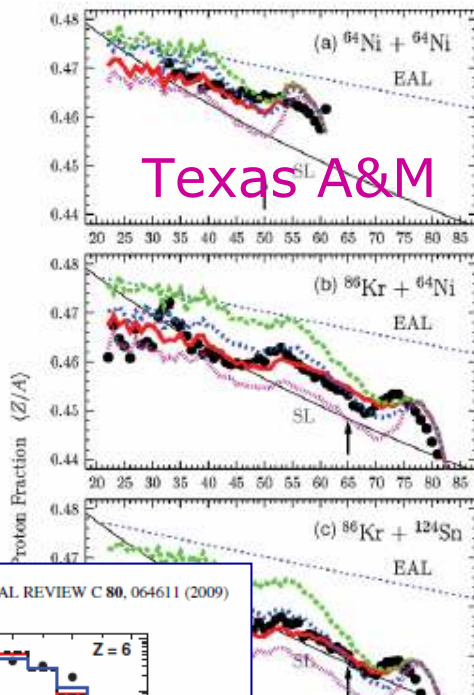
calculation with the
Myers-Swiatecki
parameters for the
volume and surface
symmetry term
coefficients
underestimate
the neutron richness
by $\Delta(\langle N \rangle / Z) \approx 0.05$



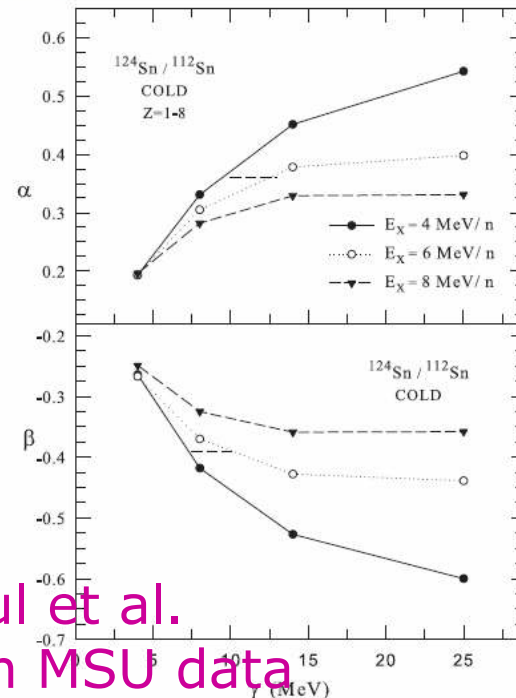
discussion

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

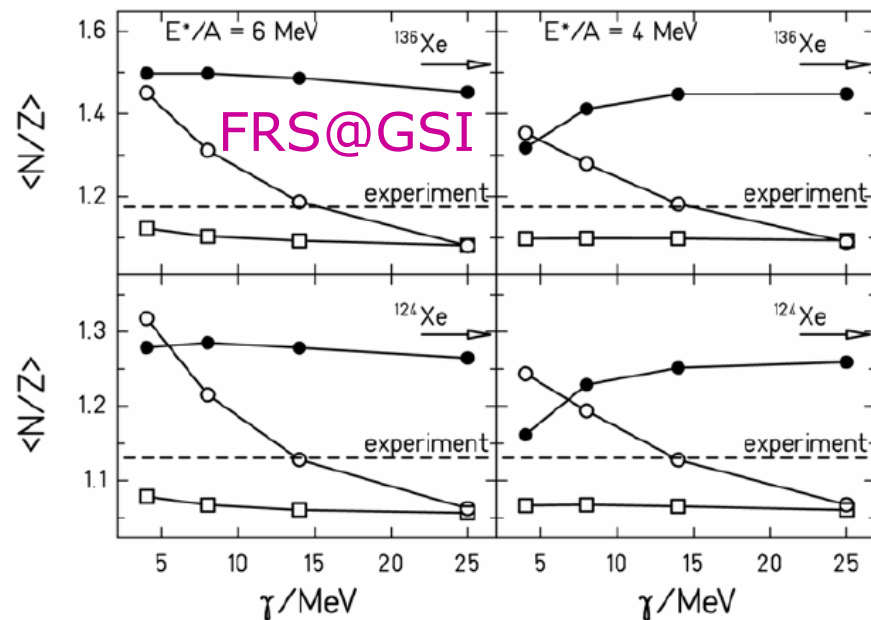
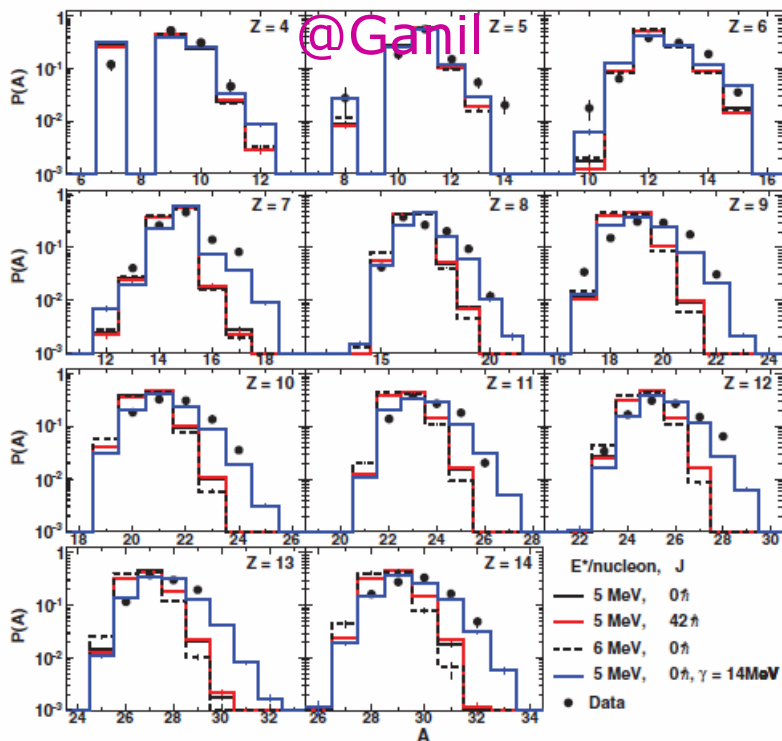


Texas A&M



Ogul et al.
 with MSU data

Indiana
 @Gamil

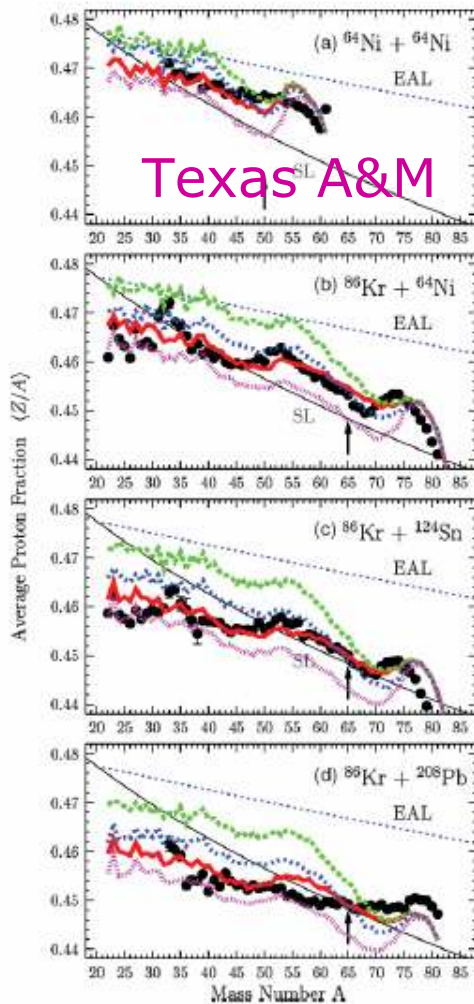


discussion

neutron richness is a general phenomenon

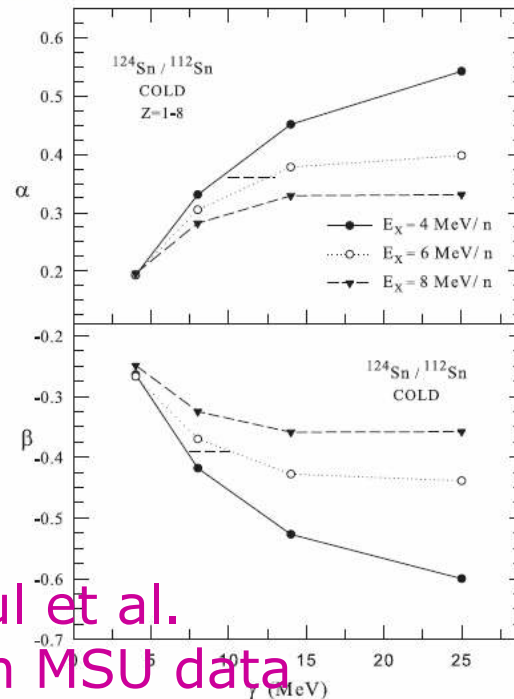
Souliotis et al., PRC 75
 Ogul et al., JPG (2009)
 Hudan et al., PRC 80
 Henzlova et al., arXiv

TRACING THE EVOLUTION OF THE SYMMETRY ENERGY ...



Texas A&M

J. Phys. G: Nucl. Part. Phys. 36 (2009) 115106

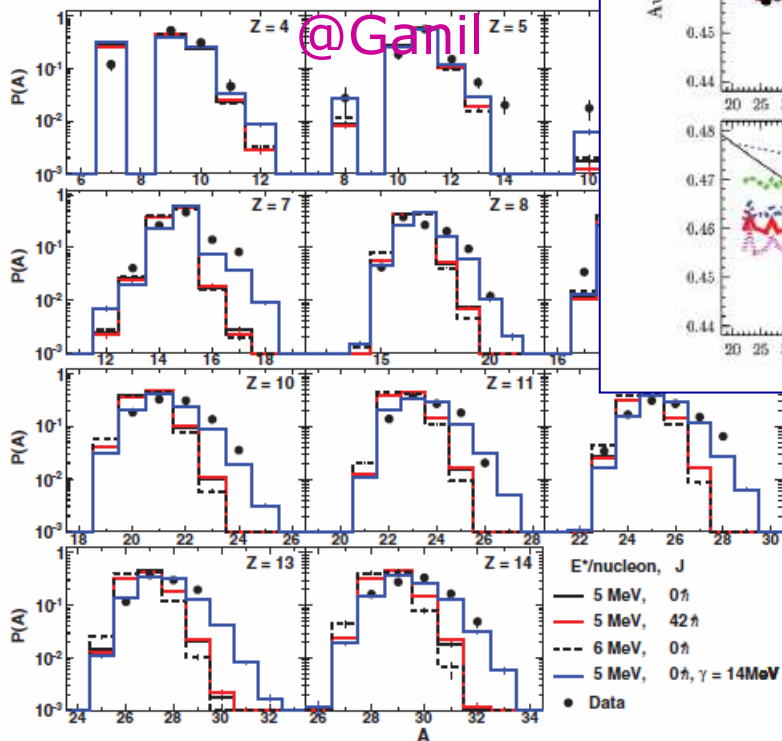


Ogul et al.
 with MSU data

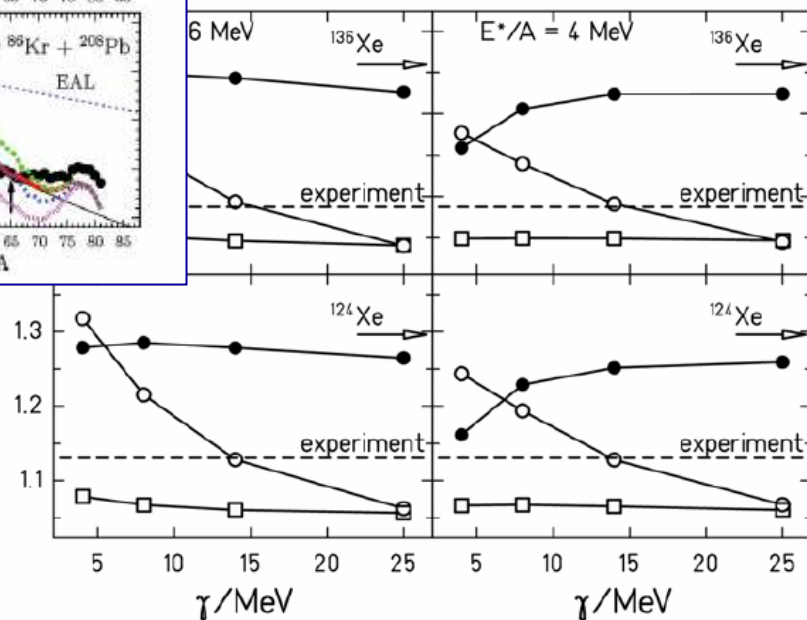
CHARGE CORRELATIONS AND ISOTOPIC ...

Indiana
 @Gamil

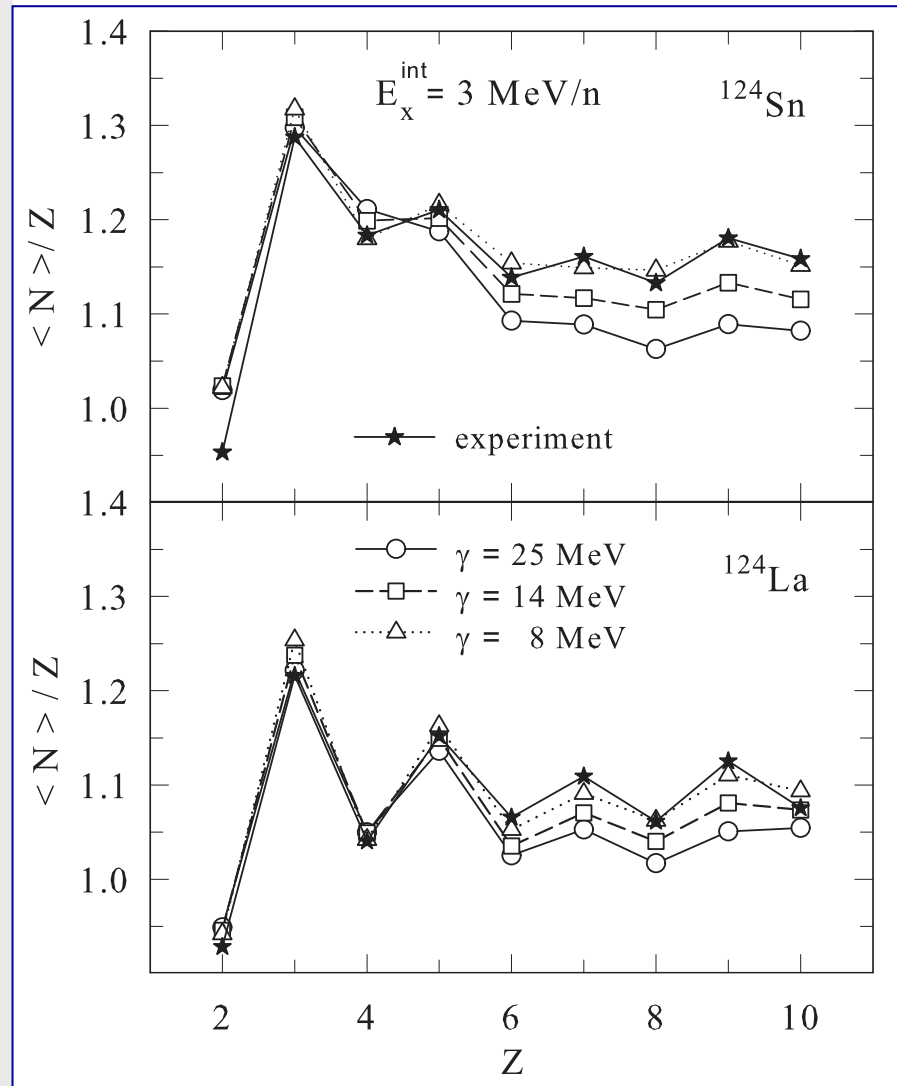
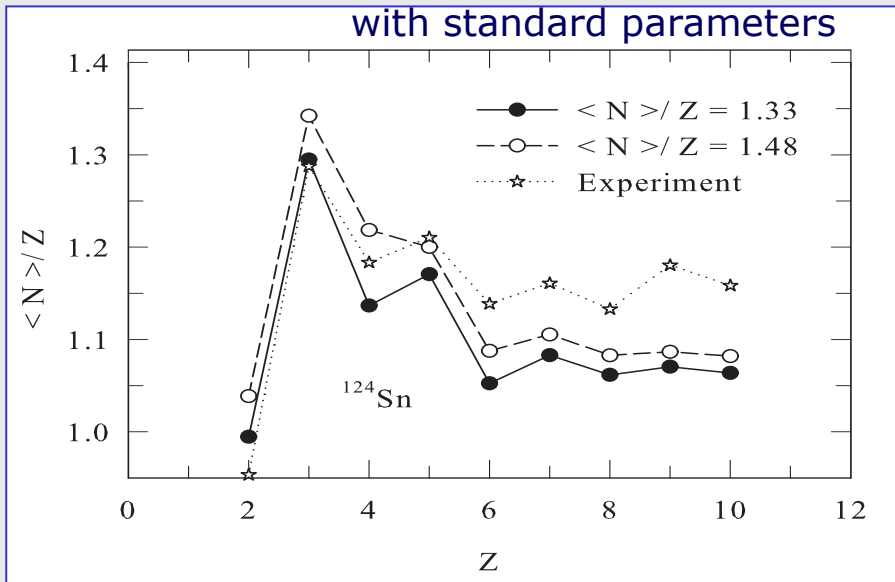
PH



$\langle N/Z \rangle$



discussion cont'd: tests of specific assumptions



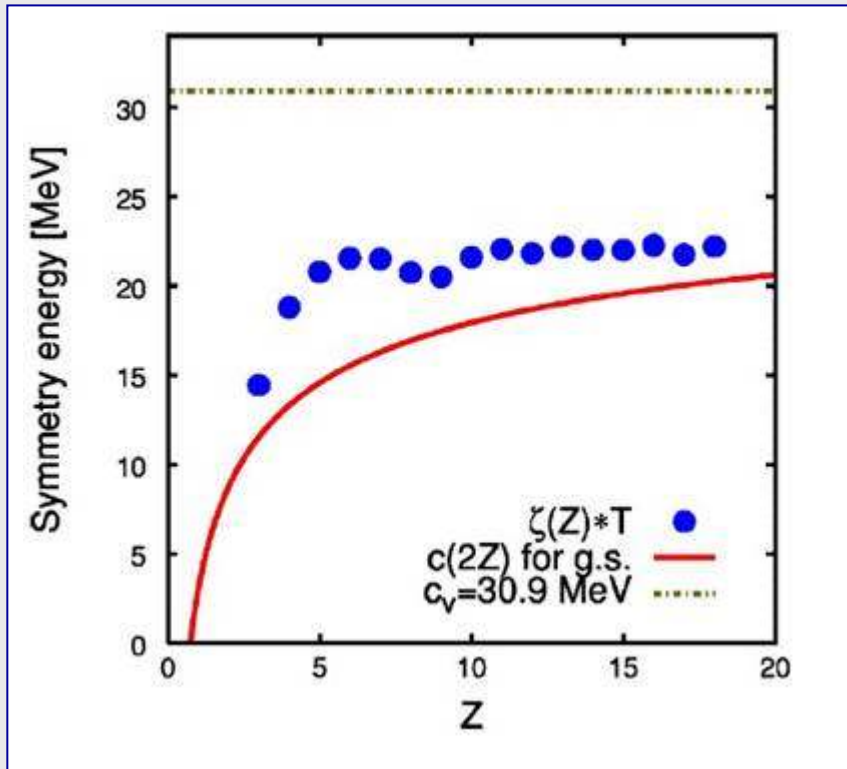
N/ Z of spectator system

N/Z difference reduced =>
 $\langle N \rangle / Z$ moves into wrong direction

restoration interval

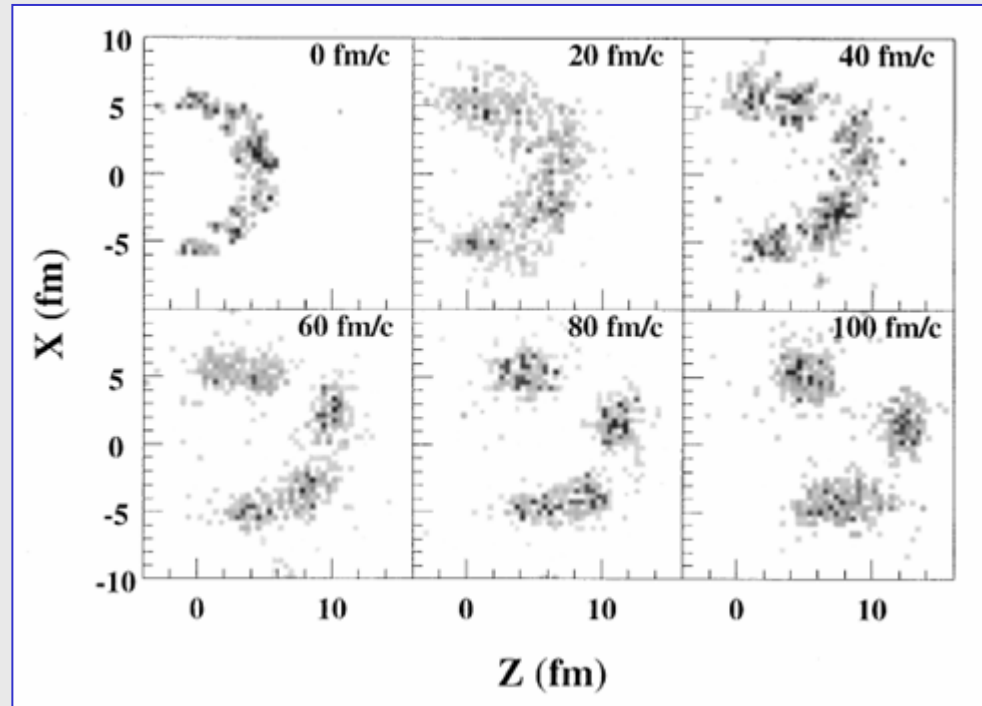
$E_x^{\text{int}} = 3 \text{ MeV}$ corresponds to $T = 5 \text{ MeV}$
requires even smaller γ

explanation:
surface vs. density?



● Symmetry energy of
AMD fragments at breakup

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



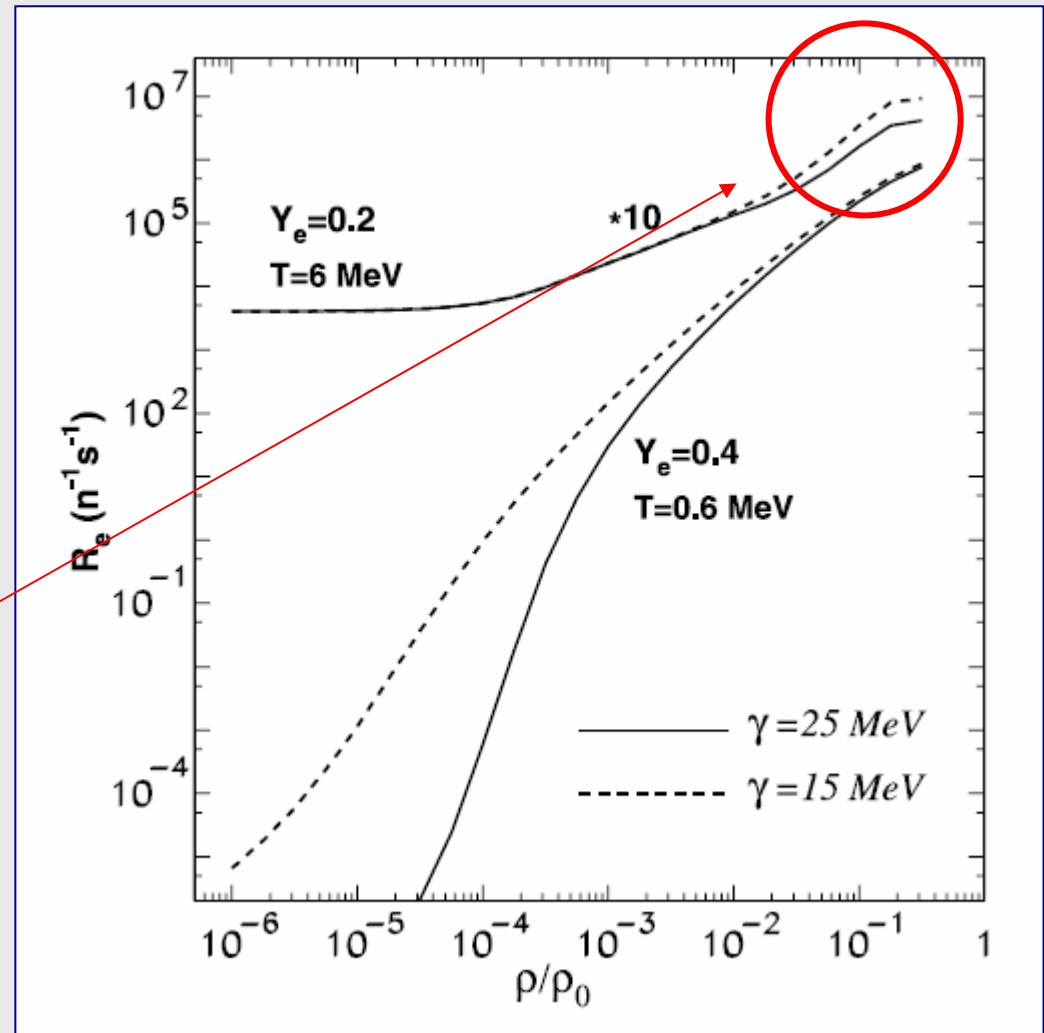
excavated Ag nucleus with 70 nucleons
remaining
M. Colonna, J. Cugnon, and E.C. Pollacco
PRC 55 (1997) 1404

**"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

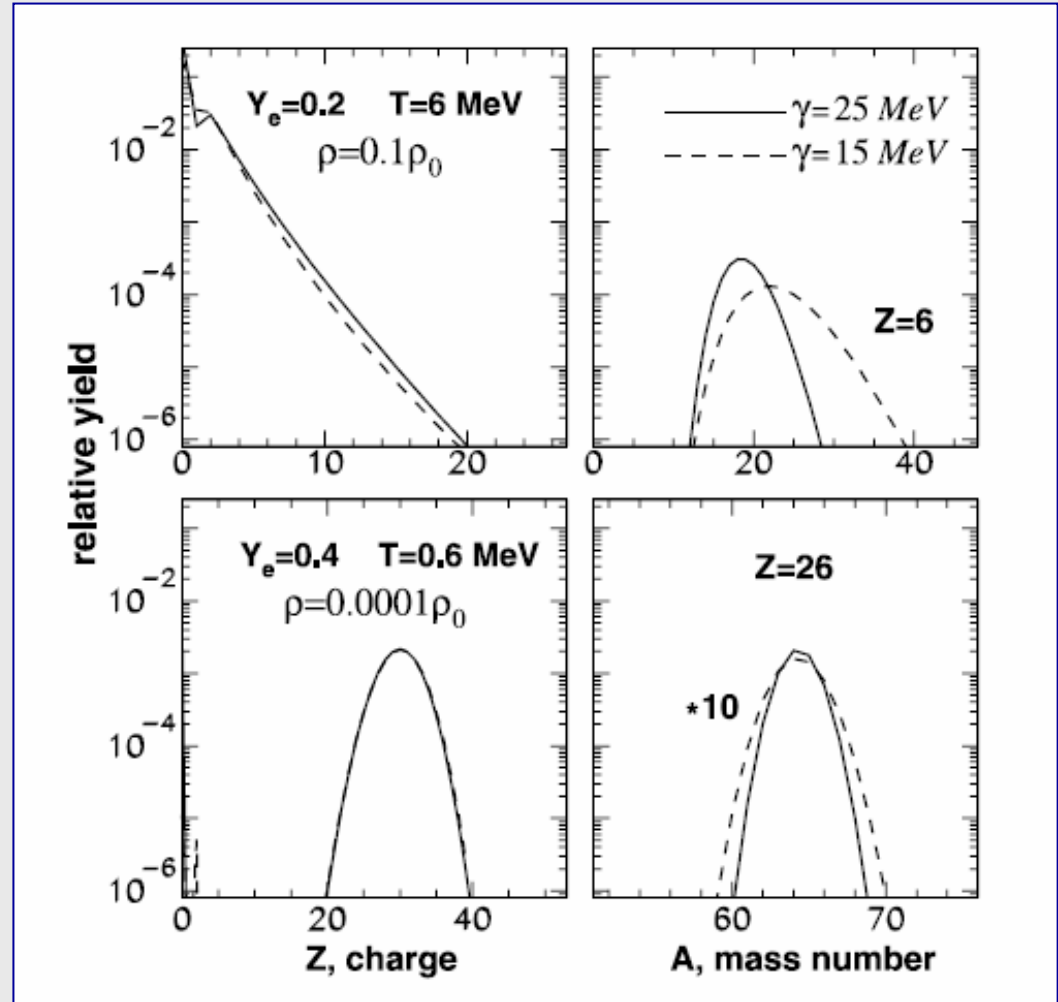


relevance for astrophysics

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



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 .