International Workshop XXXI
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The Isospin Thermometer - A New Method to Determine the Freeze-out Temperature in Fragmentation Reactions

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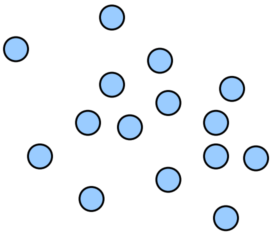
GSI

INTRODUCTION

Hunting for signatures of the liquid-gas phase transition



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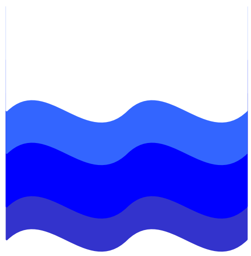


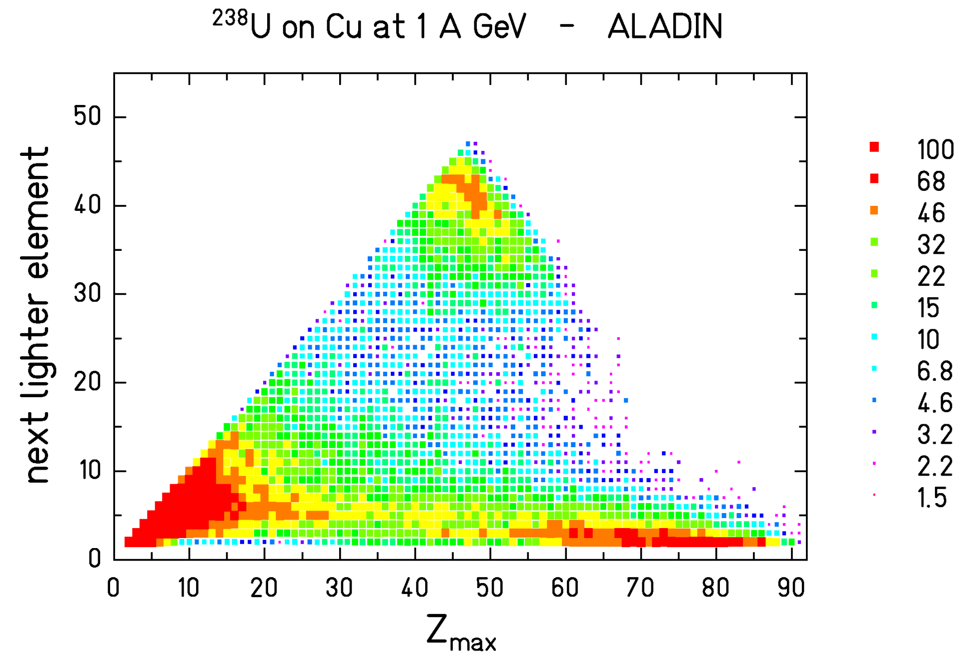
investigation of light clusters (multifragmentation)	**investigation of heavy clusters (fragmentation)**

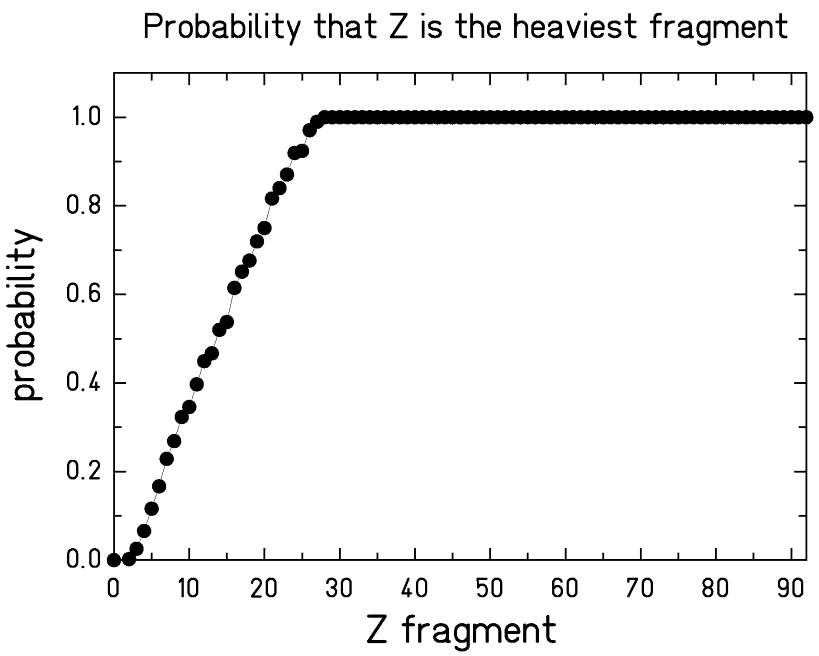
★ The formation of light clusters (multi-fragmentation) has widely been exploited to search for thermal instabilities of excited nuclei

★ Light clusters might be emitted by liquid and gaseous phase. - Heavy residues are clearly associated to the liquid phase.

★ The identification of heavy residues needs specific experimental tools.

What can we learn from ALADIN data?





- **Separation between multifragmentation and "spallation".**
- **Z>20 is the heaviest fragment in the reaction.**

(List-mode data provided by the ALADIN group)

OUTLOOK

1 Experiments at FRS of GSI

2 Results

3 Sequential decay or
simultaneous break-up?

4 Idea behind the isospin thermometer

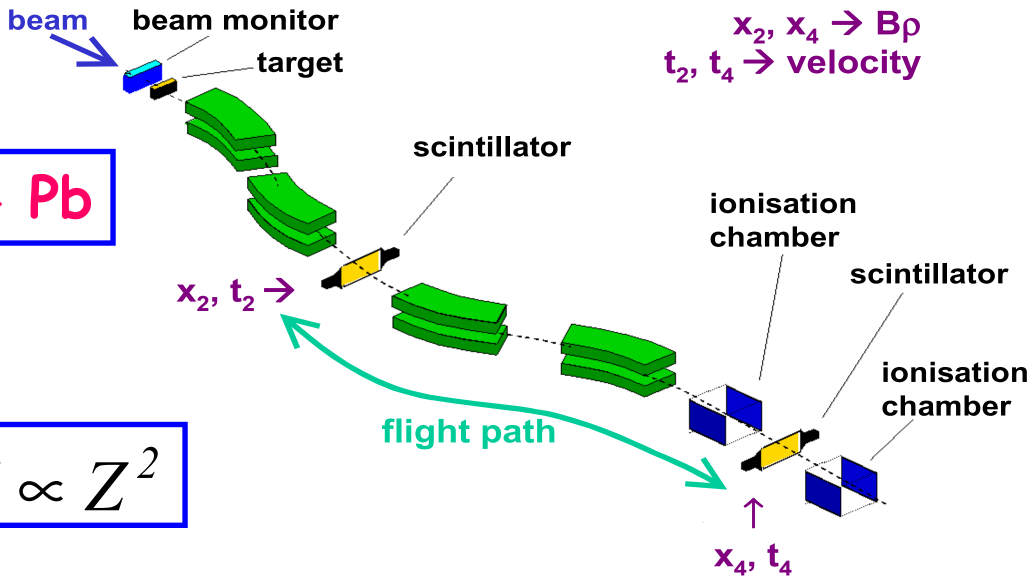
5 Comparison with a three-stage model

6 Comparison with SMM calculations

7 Possible scenario of mid-peripheral high-
energy nucleus-nucleus collisions

8 Conclusions

THE EXPERIMENT AT THE FRS AT GSI

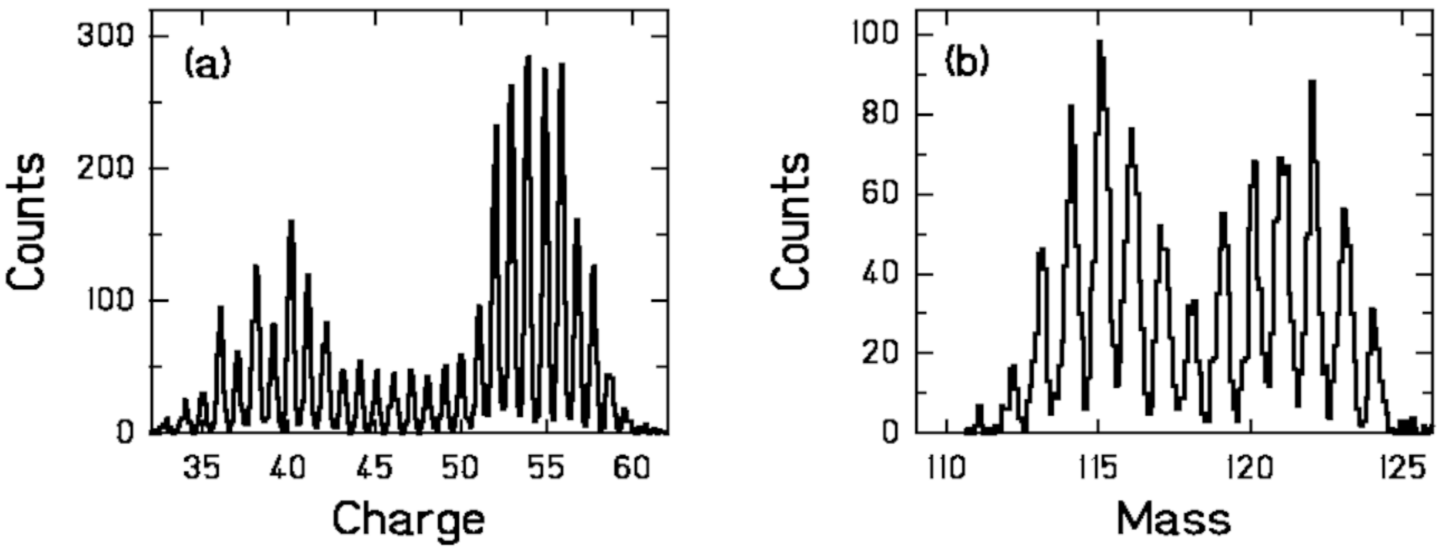


1 A·GeV $^{238}U \rightarrow Pb$

Z from IC: $\Delta E \propto Z^2$

A/Z from time and position: $\frac{A}{Z} = \frac{e}{m_0} \frac{B\rho}{c\beta\gamma}$

T. Enqvist et al. / Nuclear Physics A 658 (1999) 47–66

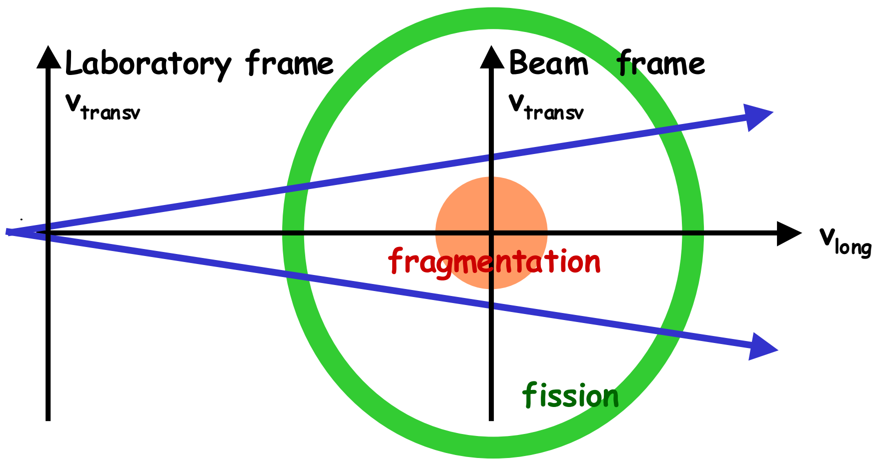


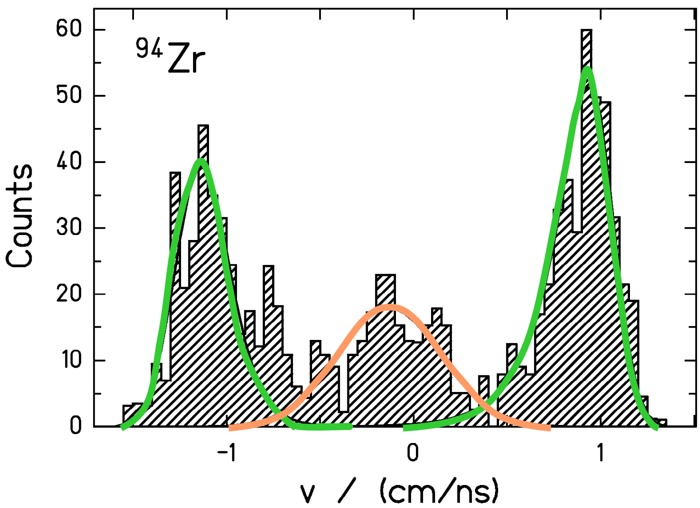
velocity is calculated from Bρ:

$$\gamma v = B\rho \frac{Z \cdot e}{A \cdot m_0}$$

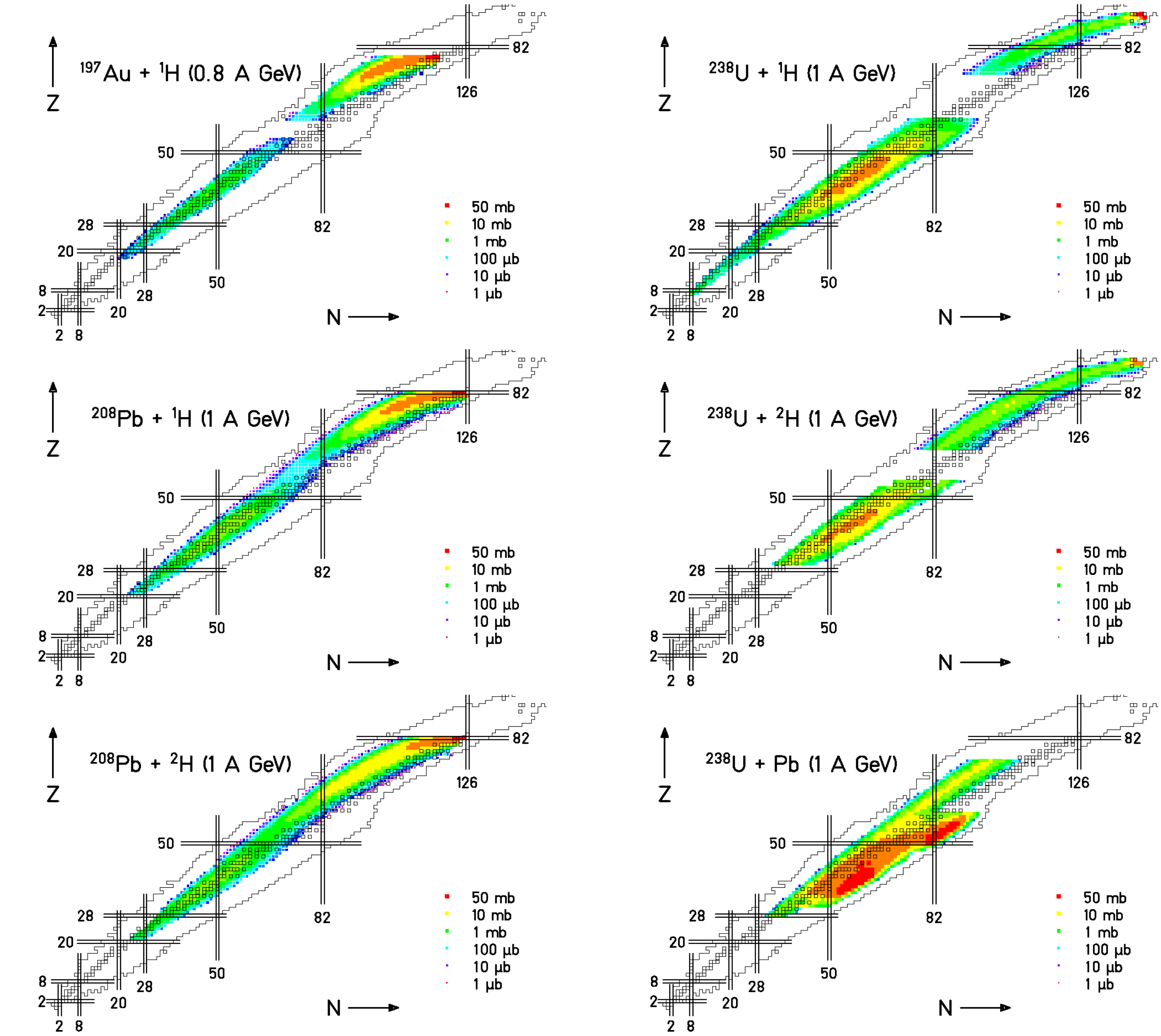
very precise evaluation!

DISCRIMINATION OF FISSION EVENTS





Systematic survey on residual nuclide production

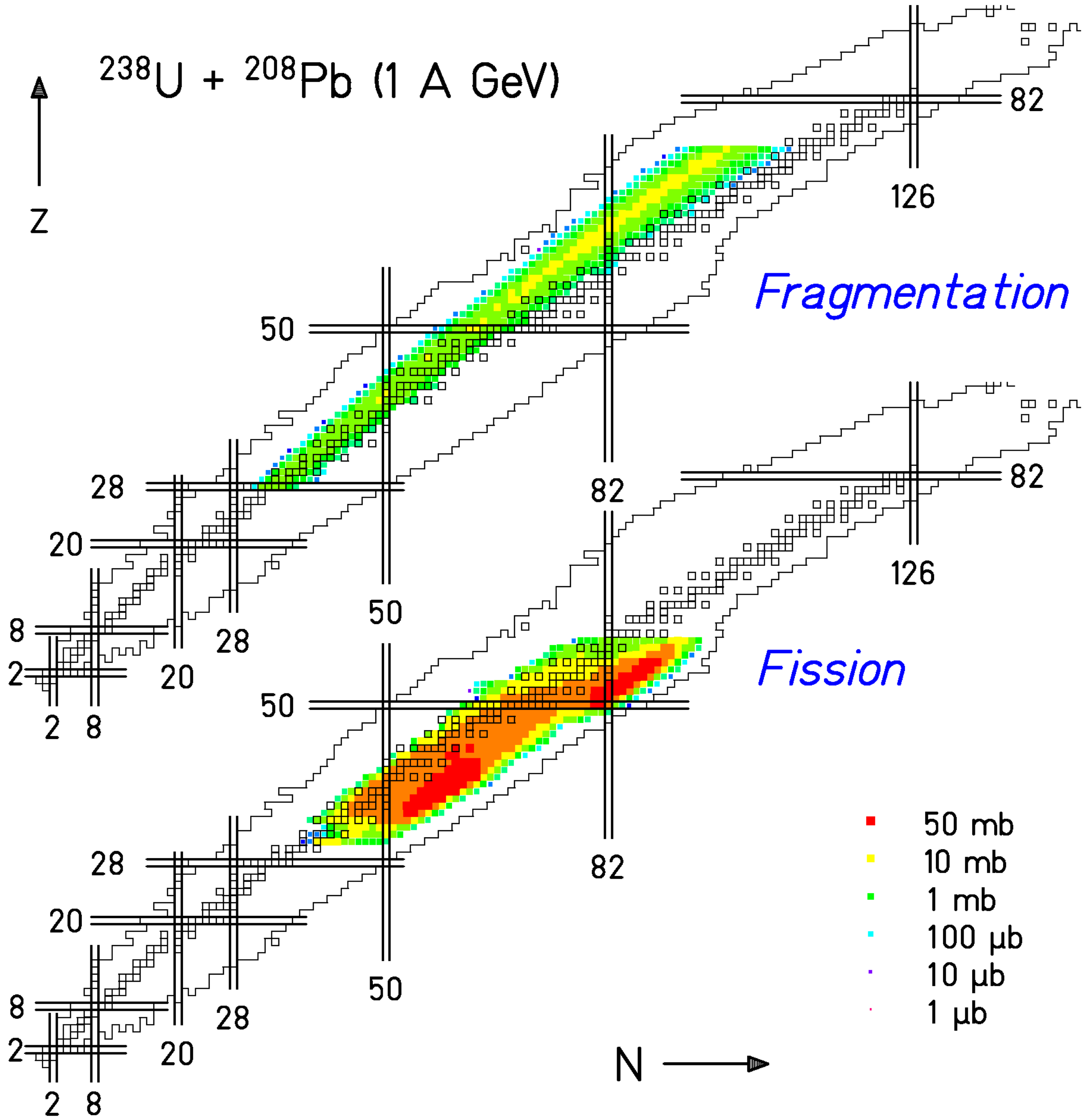


6000 individual data points!

Basic data for

- EURISOL and GSI project
    - Intensities of secondary beams
- HINDAS
    - Nuclear data for incineration of nuclear waste

From electromagnetic-induced fission to fragmentation of ^{238}U

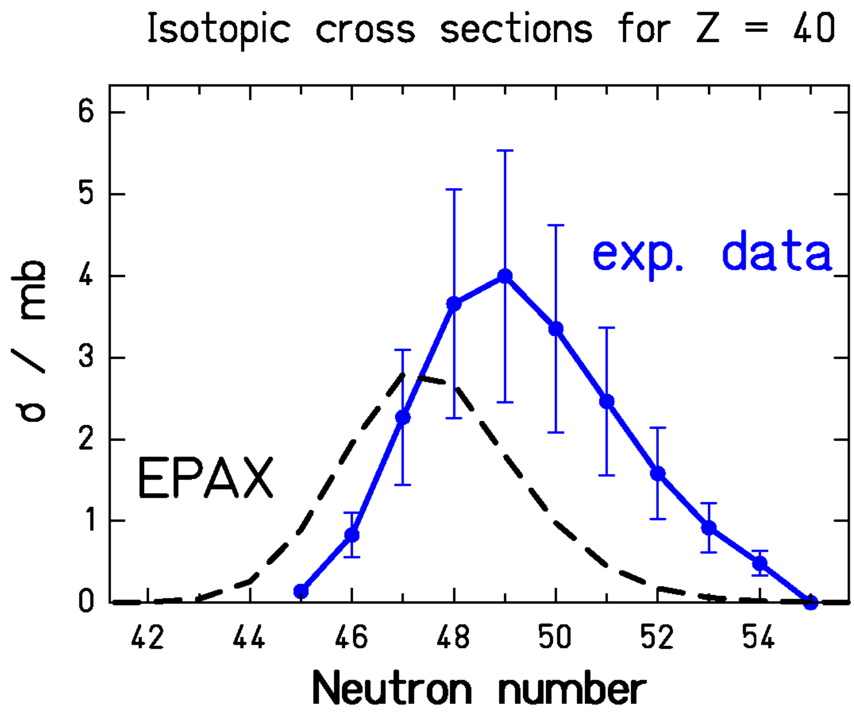


- **Fission from low and high excitation energies**
- **Fragmentation in high-energy nuclear collisions**

<u>Neutron excess reflects excitation energy induced.</u>

<u>Evaporation leaves traces which can be exploited!</u>

EXPERIMENTAL RESULTS



Data: ^{238}U + ^{208}Pb (1 *A* GeV)

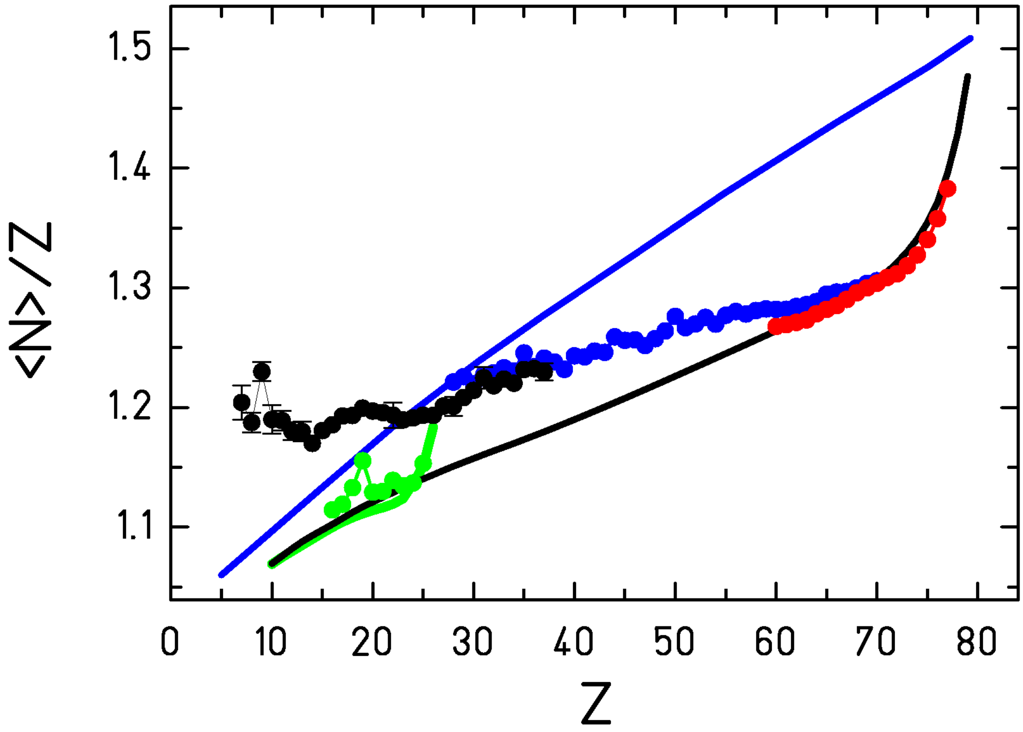
(Only fragmentation, fission discharged)

EPAX: a *systematics* of isotopic cross sections in projectile fragmentation

(K. Sümmerer, B. Blank, Phys. Rev. *C* (2000) 034607)

EPAX is based on the hypothesis of *limiting fragmentation*

Mean N/Z of fragments (fission discharged)



— stability line

— EPAX, projectile = Au

— EPAX, projectile = Fe

● 800 A·MeV Au + p - F.Rejmund NPA 683 (2001)

● 414 A·MeV Fe + p - W.R.Webber AJ 508 (1998)

● 1000 A·MeV U + Pb - T.Enqvist NPA 658 (1999)

● 1000 A·MeV U + Ti - M.V. Ricciardi's thesis (2002)

Some data agree with EPAX and some deviate!

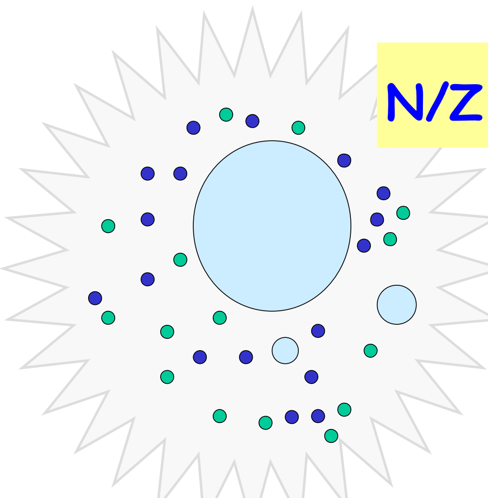
Consolidated knowledge

- Lighter residues originate from more violent collisions
- More violent collisions → larger excitation energy (ABRASION PICTURE)

?

SIMULTANEOUS BREAK-UP | **BOTH** | **SEQUENTIAL DECAY**

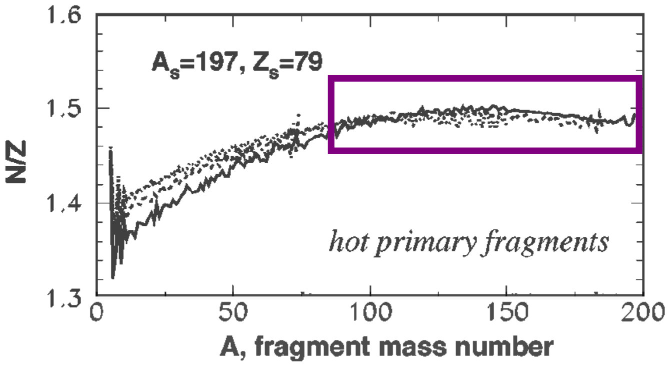
I. SIMULTANEOUS BREAK-UP



N/Z ≅ constant

one process !

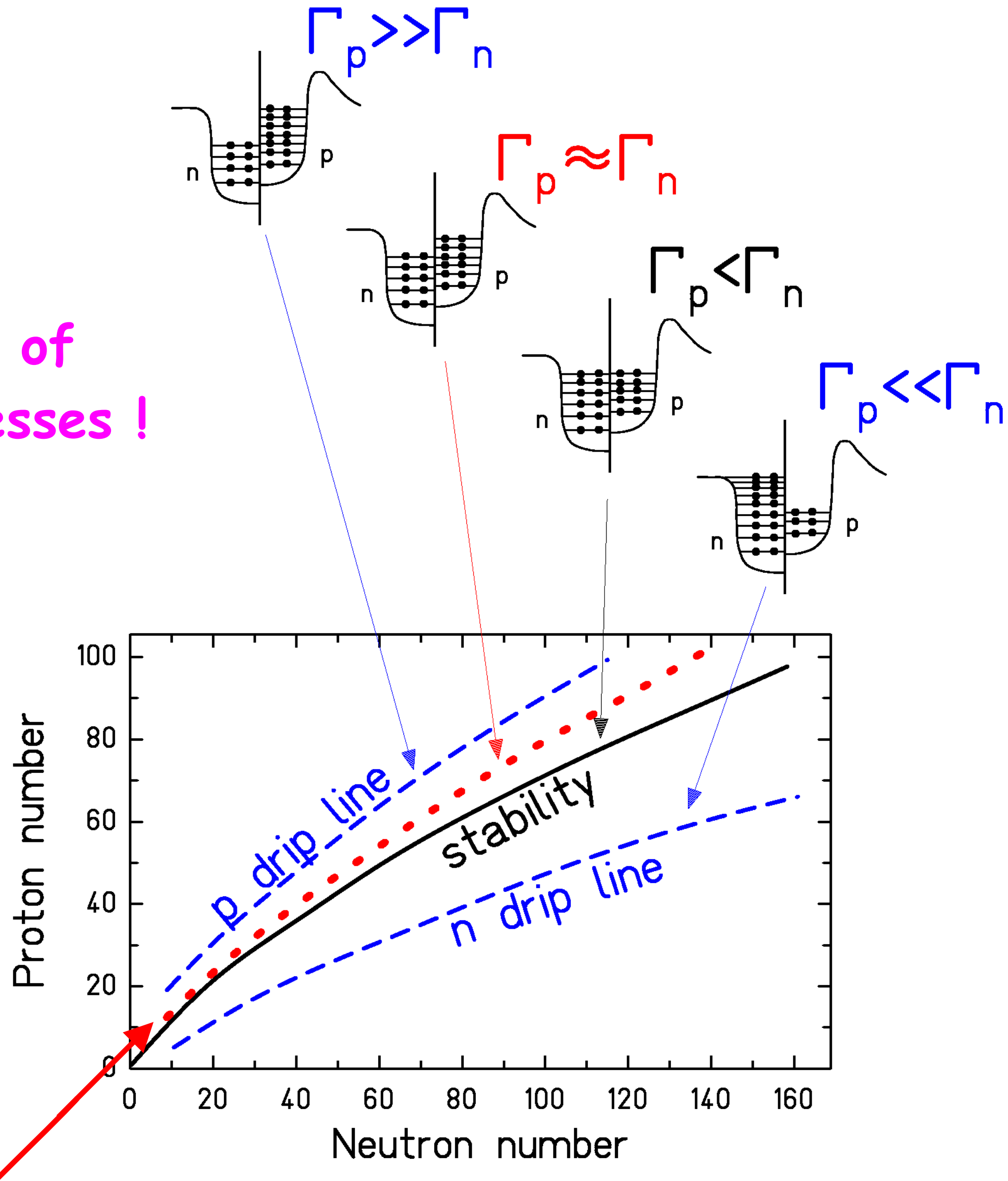
PHYSICAL REVIEW C **63** 061601(R)



different excitation energies

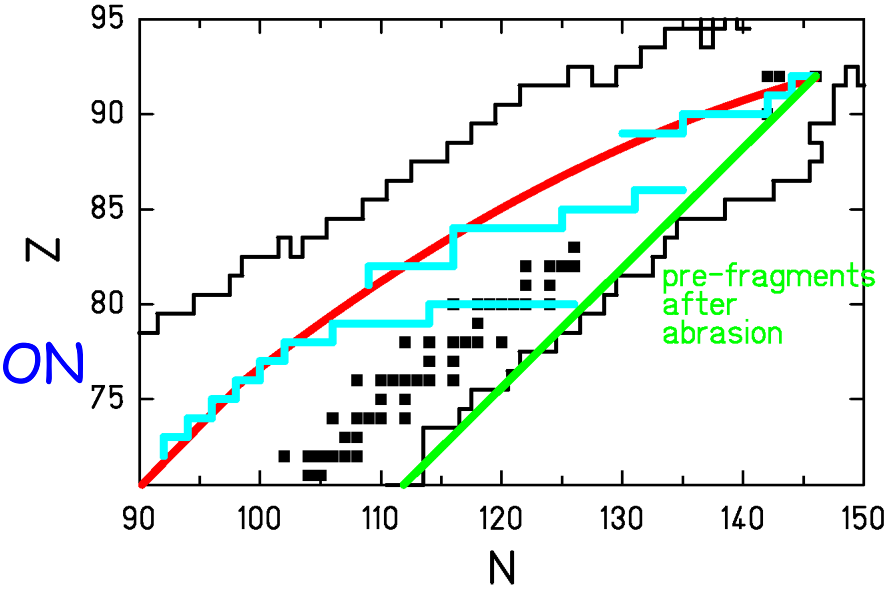
II. SEQUENTIAL DECAY

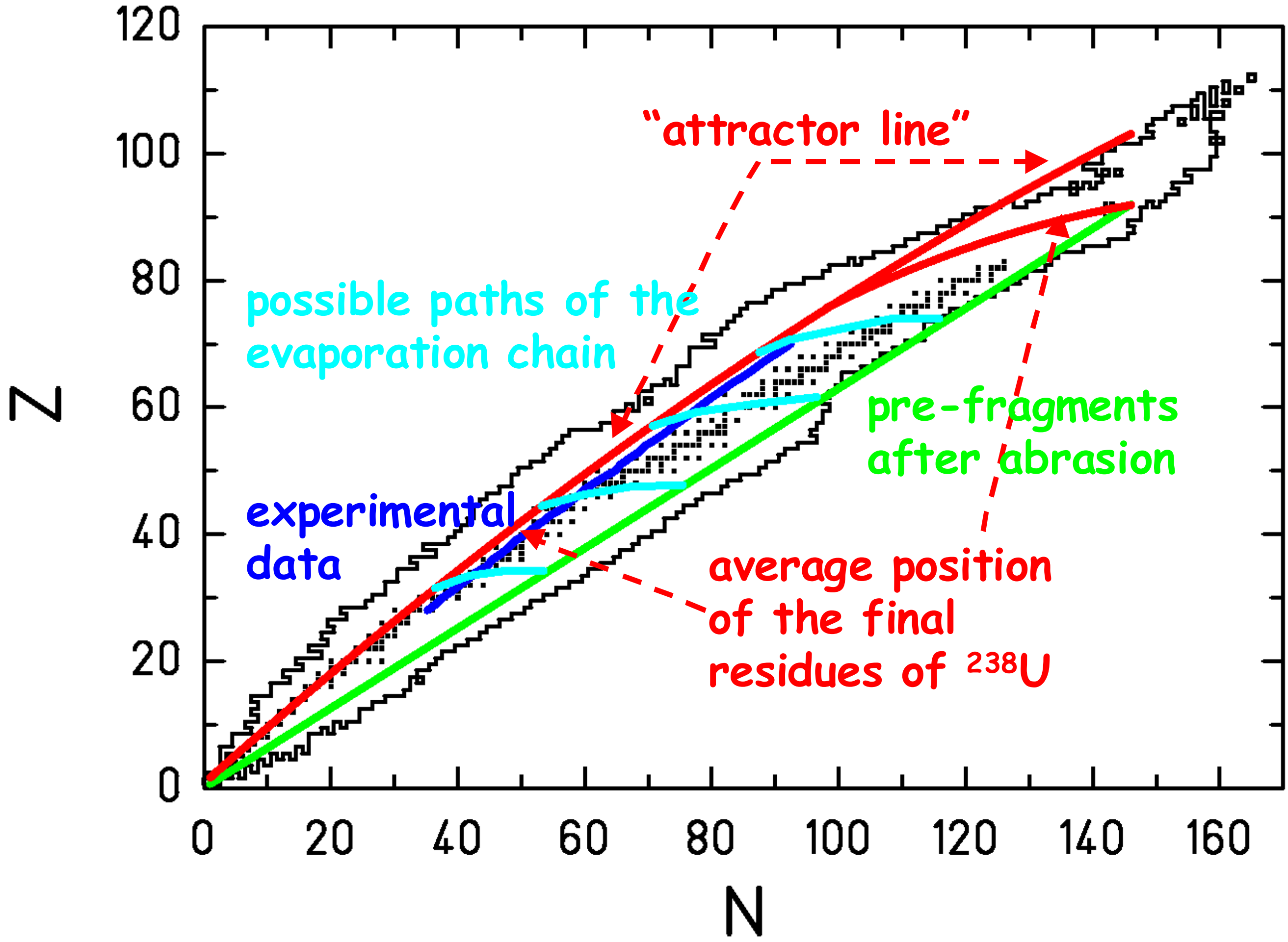
chain of processes !



"evaporation corridor"
or
"attractor line"

IDEA BEHIND LIMITING FRAGMENTATION



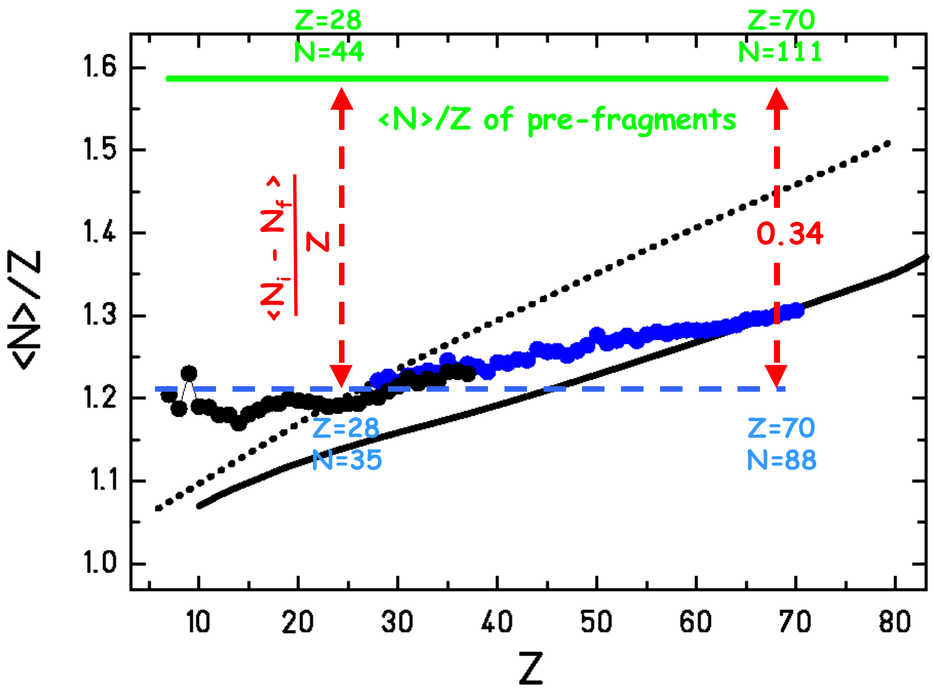


For more violent collisions the evaporation starts at lower excitation energies !!!

PRINCIPLE OF THE ISOSPIN THERMOMETER

Simplifying hypothesises:

- only n-evaporation
- 15 MeV consumed for every evaporated n
- the evaporation stops when $\langle N_{final} \rangle / Z = 1.25$



$$\left.\begin{aligned} E^* &= 15\ \text{MeV} \bullet \langle N_i - N_f \rangle \\ \frac{\langle N_i - N_f \rangle}{Z} &\sim 0.34 \end{aligned}\right\} \quad E^*/Z = \text{constant} \ \text{or} \ E^*/A = \text{constant}$$

$E^* = a\ T^2$

$a \sim A/10$ MeV

$E^*/A = 0.1\ T^2$ $\rightarrow$ $T^2 = \text{constant}$

All pre-fragments start the evaporation cascade at a constant temperature!!!

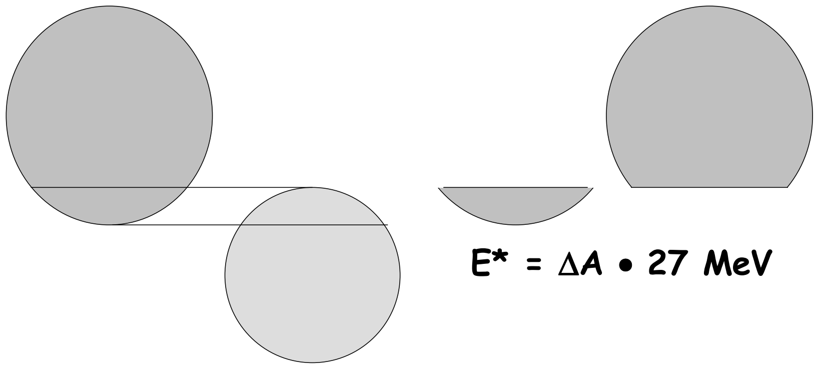
ABRASION

+

SIMULTANEOUS BREAK-UP

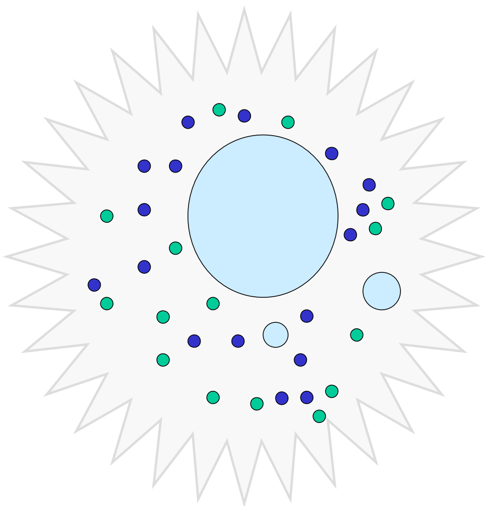
+

SEQUENTIAL DECAY



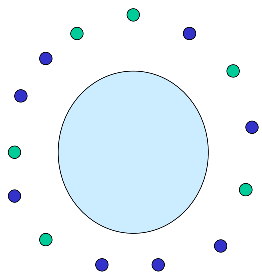
N/Z = constant

$E^* \propto$ abraded mass



N/Z $\cong$ constant

T= constant
$\rightarrow$ E* larger for larger pre-fragments

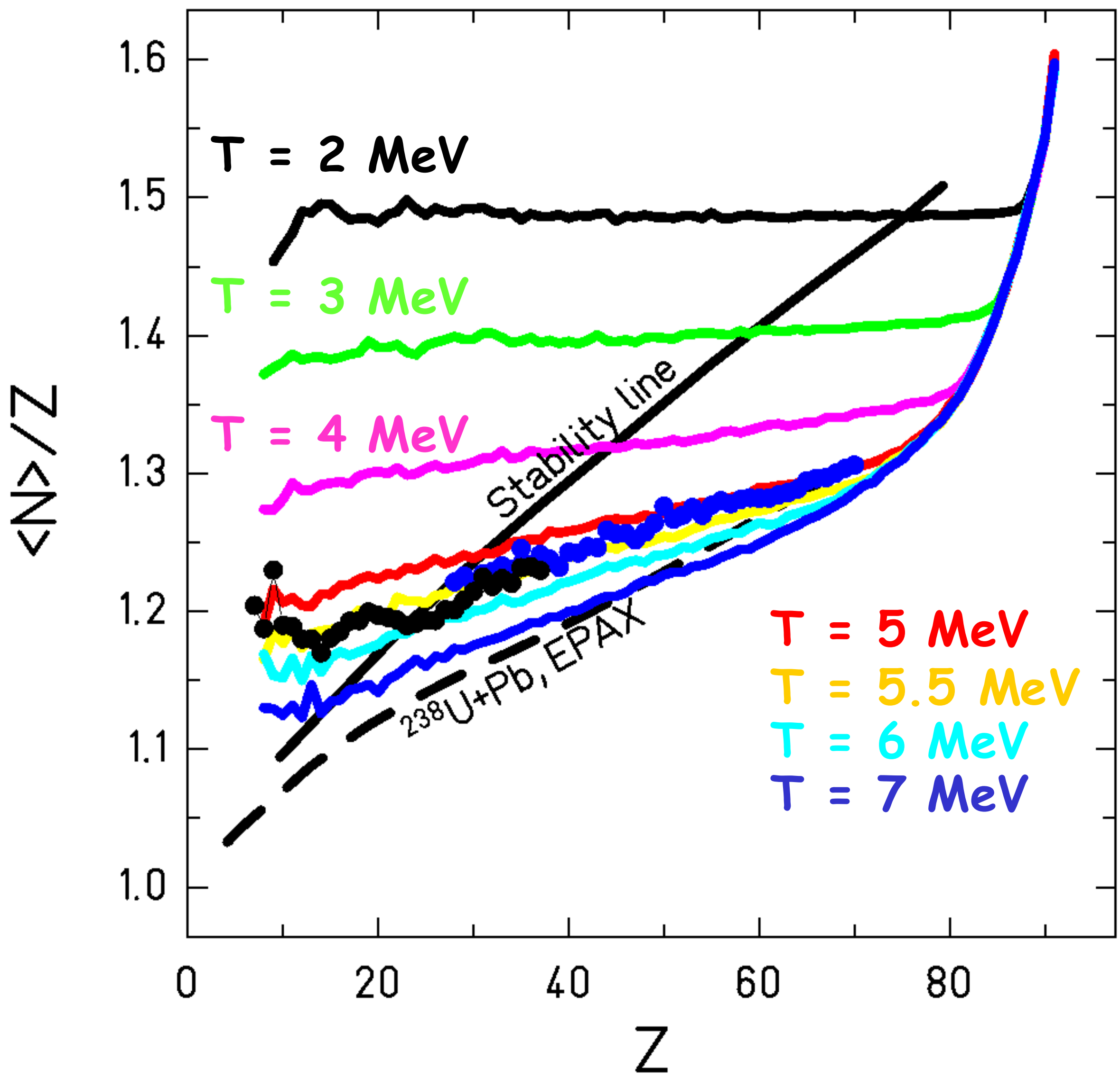


evaporation cascade

COMPARISON WITH A THREE-STAGE MODEL

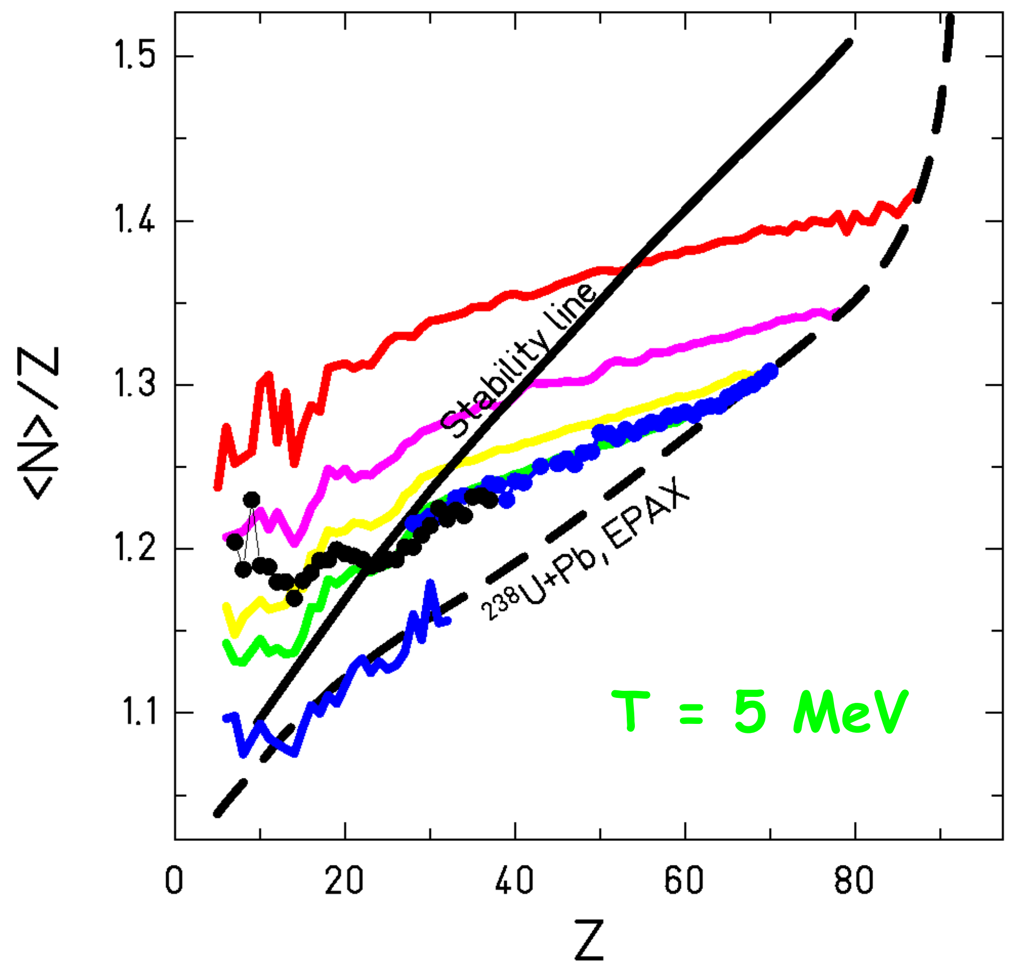
ABRASION / (BREAK-UP) / EVAPORATION

… complete but simplified…



COMPARISON WITH SMM CALCULATIONS

… not complete but more sophisticated…

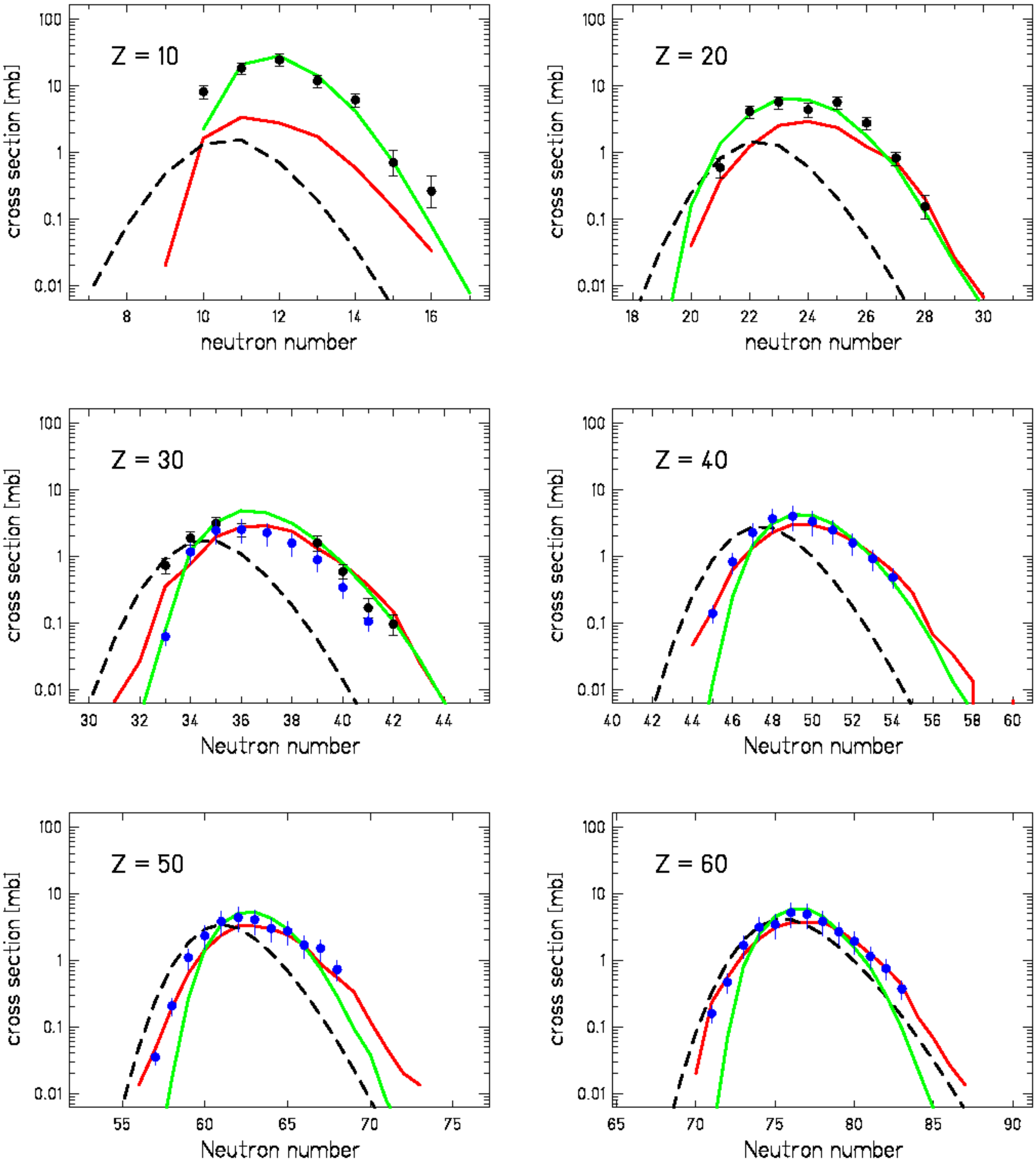


E* = 1 MeV/nucleon
E* = 1.5 MeV/nucleon
E* = 2 MeV/nucleon
E* = 2.5 MeV/nucleon
E* = 8 MeV/nucleon

INITIAL CONDITIONS:
$V=6V_0$
A=238
Z=92

- 1 A GeV ^{238}U on Ti measured at FRS
- 1 A GeV ^{238}U on Pb measured at FRS

A SHARP LIMITING TEMPERATURE?

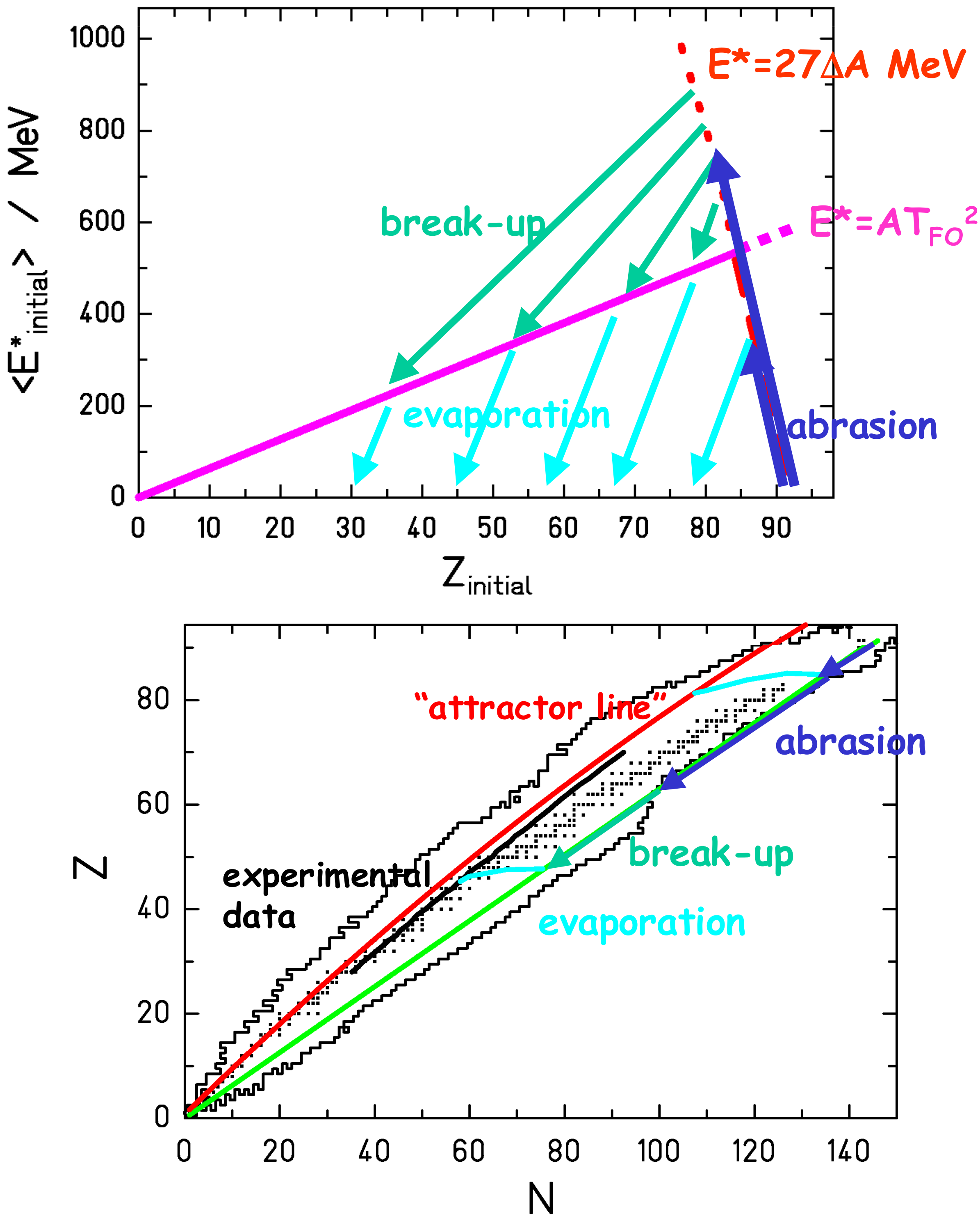


- 1 A GeV ^{238}U on Ti measured at FRS
- 1 A GeV ^{238}U on Pb measured at FRS

Three-stage model

SMM (arbitray normalised)

POSSIBLE SCENARIO OF MID-PERIPHERAL HIGH-ENERGY NUCLEUS-NUCLEUS COLLISIONS



CONCLUSIONS

★ Residues produced in relativistic nucleus-nucleus collisions are more neutron rich than expected from "limiting fragmentation".

★ This neutron excess can be explained by a simultaneous-break-up phase.

★ The break up occurs in most cases, even if a heavy residue is formed.

★ The average freeze-out temperature of the break-up configuration is determined to $T \approx 5$ MeV with the "Isospin-Thermometer" Method.

★ Consequence: The probability for an equilibrated compound nucleus to exist drops strongly above a limiting temperature of 5 MeV.

★ Outlook: Variation of N/Z of projectile to study the isospin dependence of freeze-out temperature.

http://www-wnt.gsi.de/kschmidt/talks.htm