KPII seminar
February 2003

Determination of the freeze-out temperature in the fragmentation of relativistic ^{238}U projectiles by means of the isospin thermometer

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GSI

Karl-Heinz Schmidt, M. Valentina Ricciardi, Alexandre Botvina, Timo Enqvist, Nuclear Physics A 710 (2002) 157–179

GLOSSARY

Isospin

Just an expression for N/Z

Freeze-out temperature

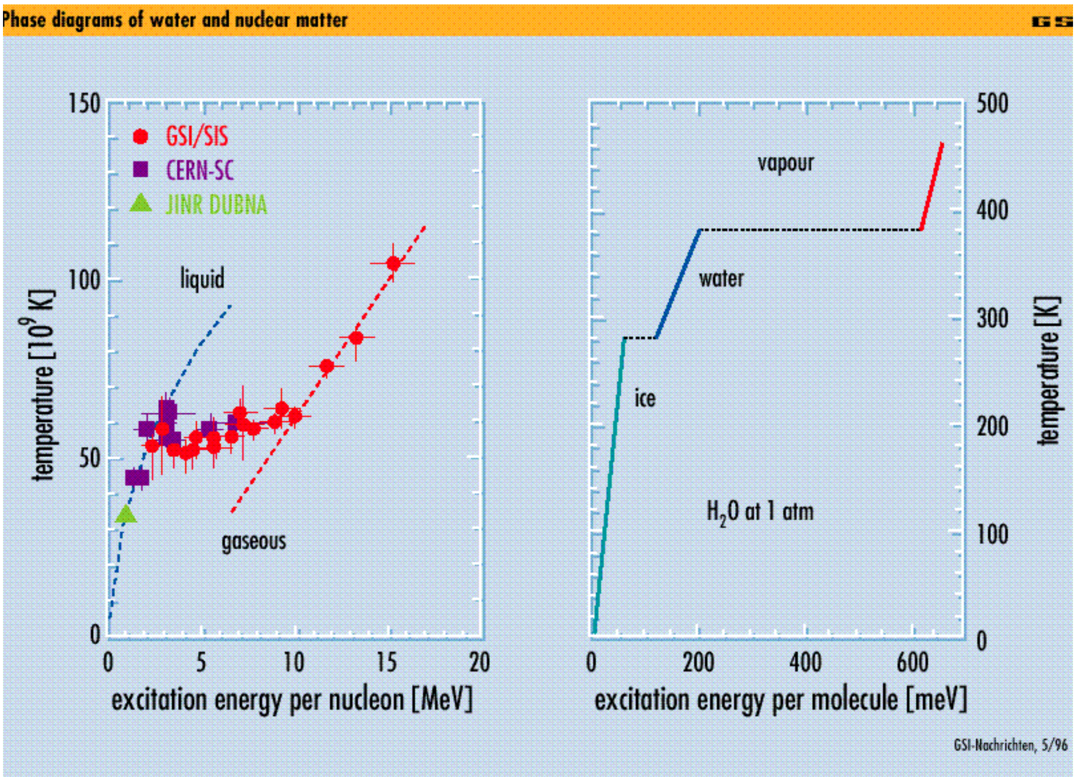
When "something" decouples from the hot source in the cooling process

Isospin thermometer

A specific thermometer based on the measurement of the N/Z

The liquid-gas phase transition in a nucleus

Exploring the nuclear-matter phase-diagram and identifying the different phases of nuclear matter is one of the main challenges of modern nuclear physics.



Up to now: Information gained with the observation of light (A<20) fragments

Temperature → isotopic ratio

High-resolution magnetic spectrometer
--> Mass identification is achievable for all residues

OUTLINE

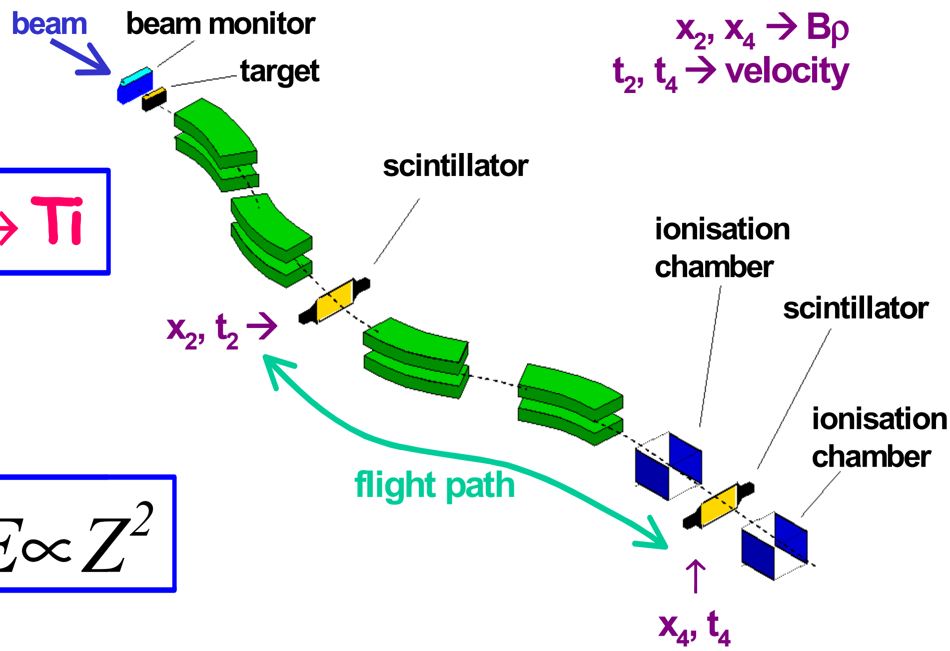
1 Experiments: $^{238}U \rightarrow Pb$ at 1 A·GeV at FRS
$^{238}U \rightarrow Ti$ at 1 A·GeV at FRS

2 Comparison of the experimental data with the EPAX prediction -> N/Z is sensitive to the temperature

3 Exploiting the new information: the isospin thermometer

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

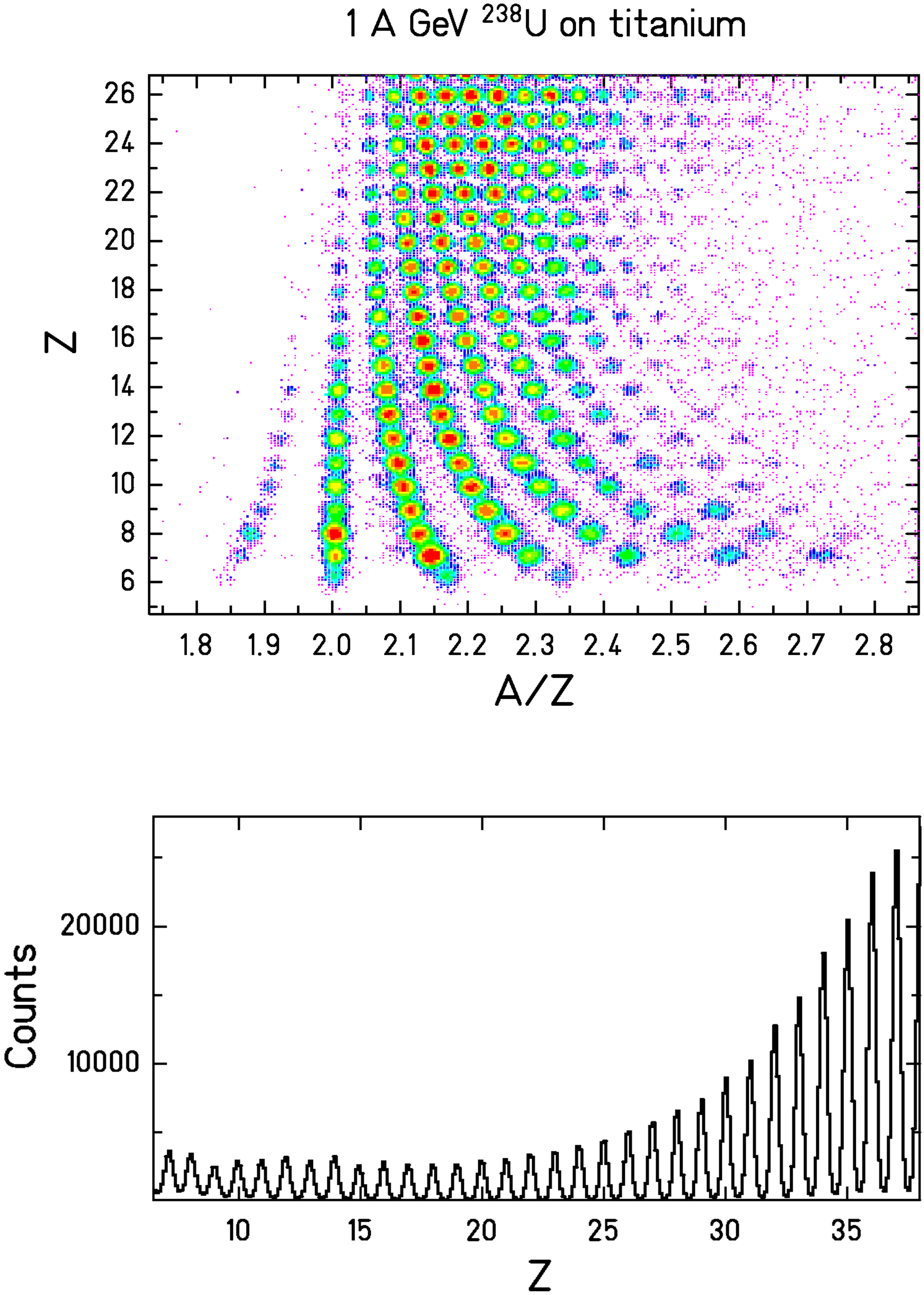
THE EXPERIMENT AT THE FRS AT GSI



1 A·GeV $^{238}U \rightarrow Ti$

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

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

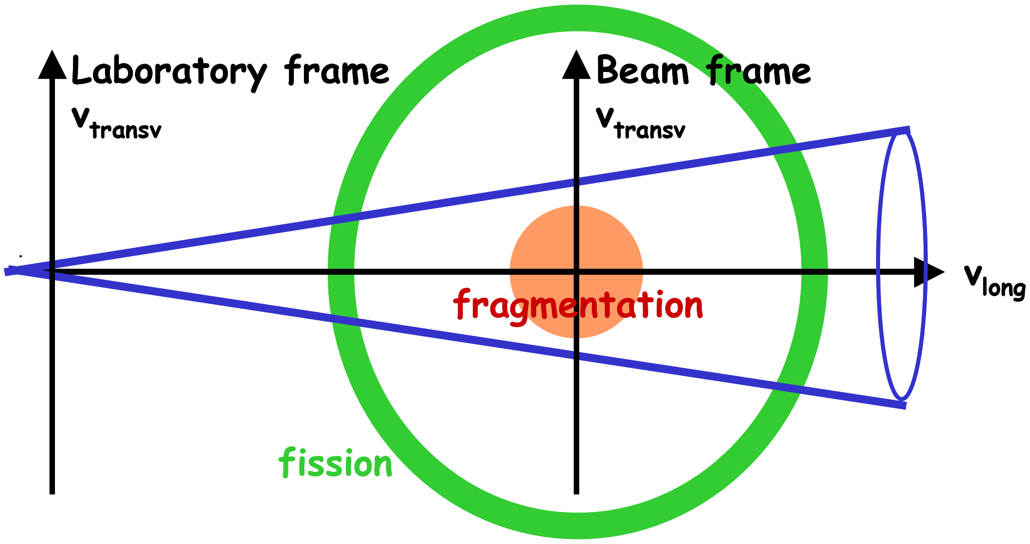

1 A GeV ^{238}U on titanium
Z
A/Z
Counts
Z

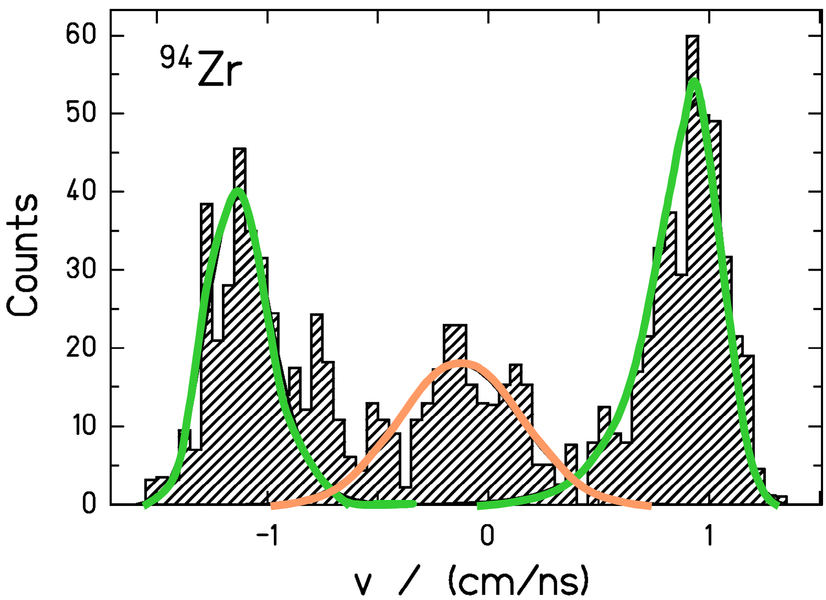
velocity is calculated from Bρ:

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

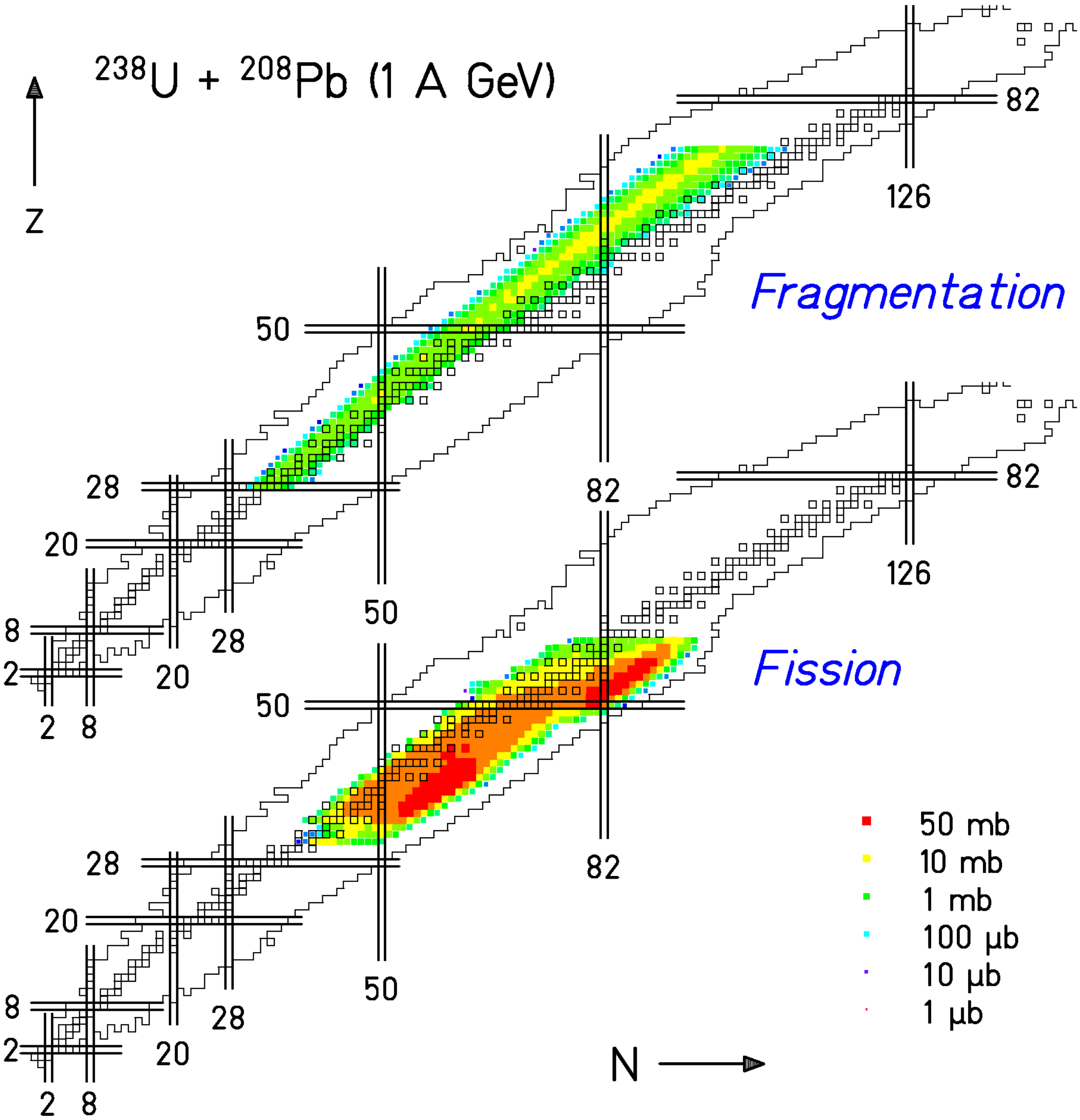
very precise evaluation!

DISCRIMINATION OF FISSION EVENTS





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

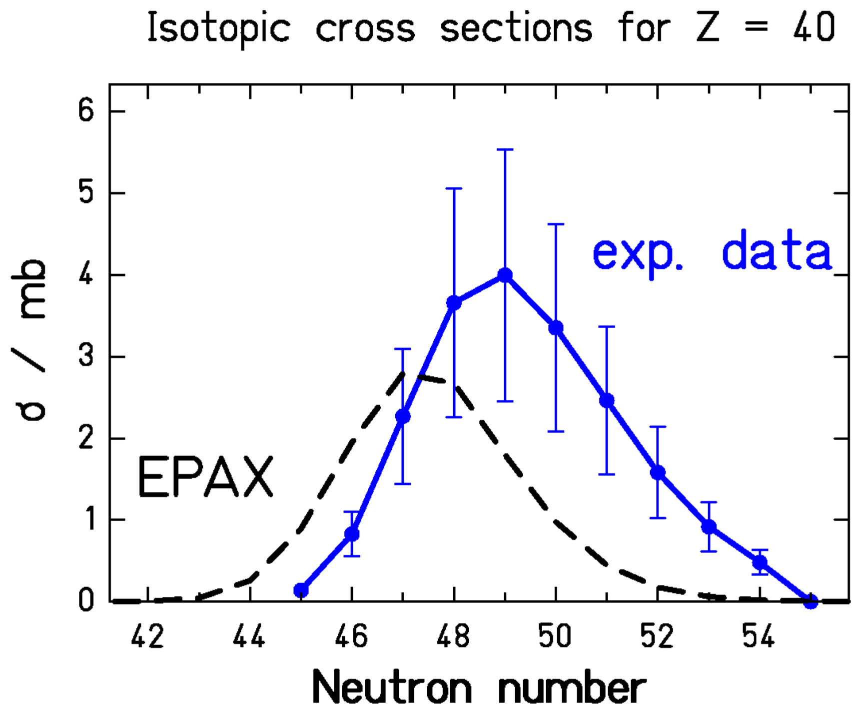


- **Fission from low and high excitation energies**
- **Fragmentation in high-energy nuclear collisions**

Neutron excess reflects excitation energy induced.

Evaporation leaves traces which can be exploited!

EXPERIMENTAL RESULTS
(fission discharged)

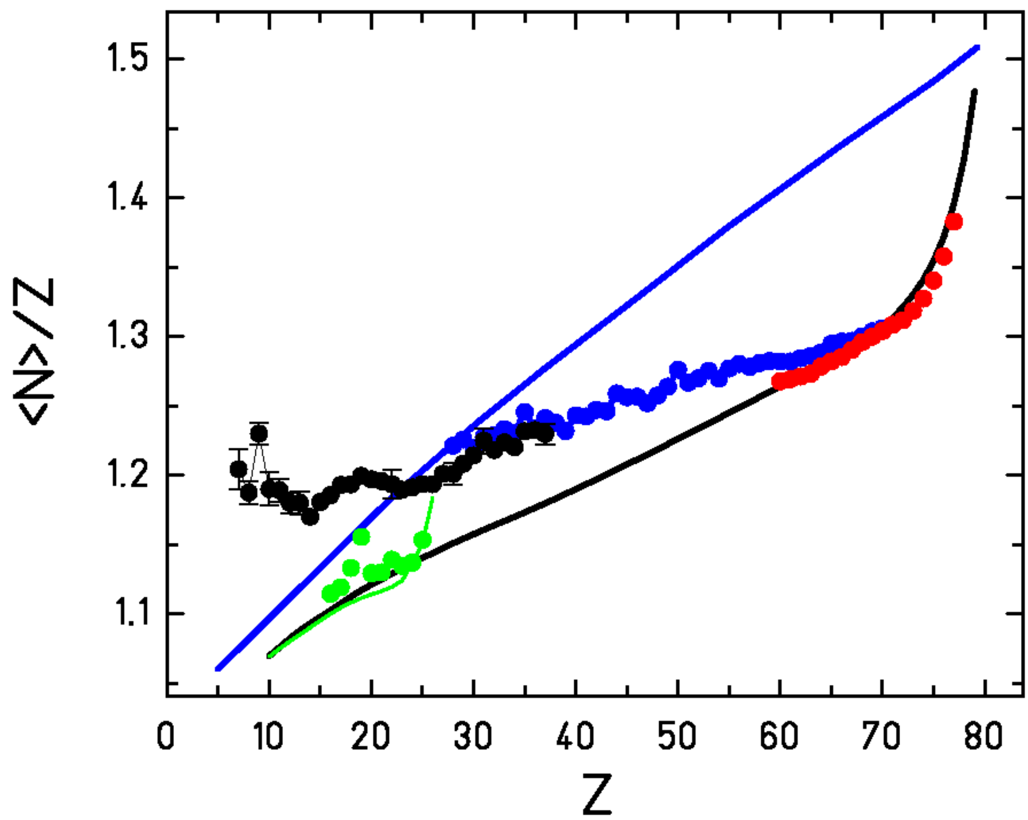


EPAX: a *systematics* of isotopic cross sections in projectile fragmentation

(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)

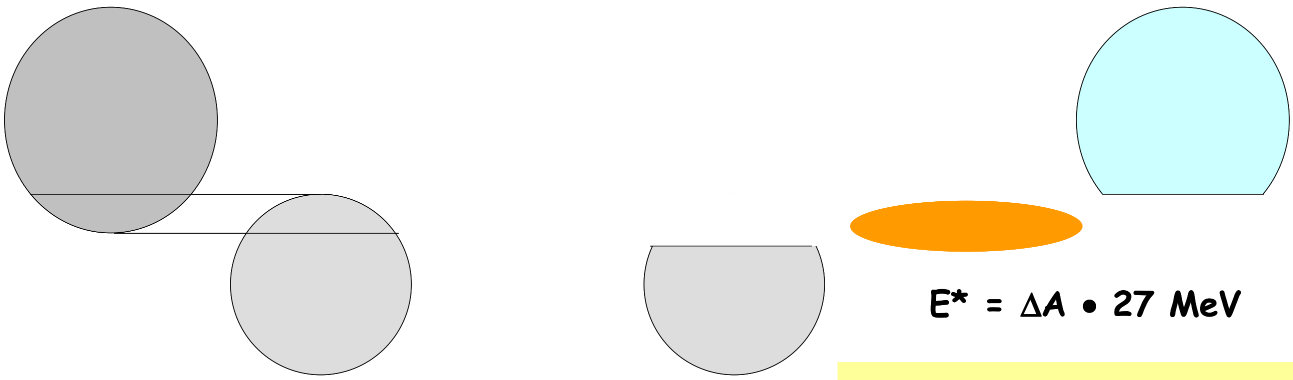
● 414 A·MeV Fe + p - W.R.Webber AJ 508 (1998)

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

● 1000 A·MeV U + Ti – this work

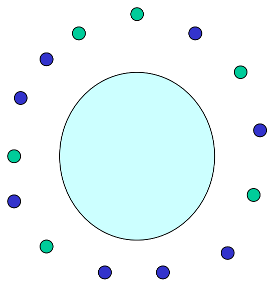
Why do some data agree with EPAX and some deviate?

ABRASION
+
EVAPORATION



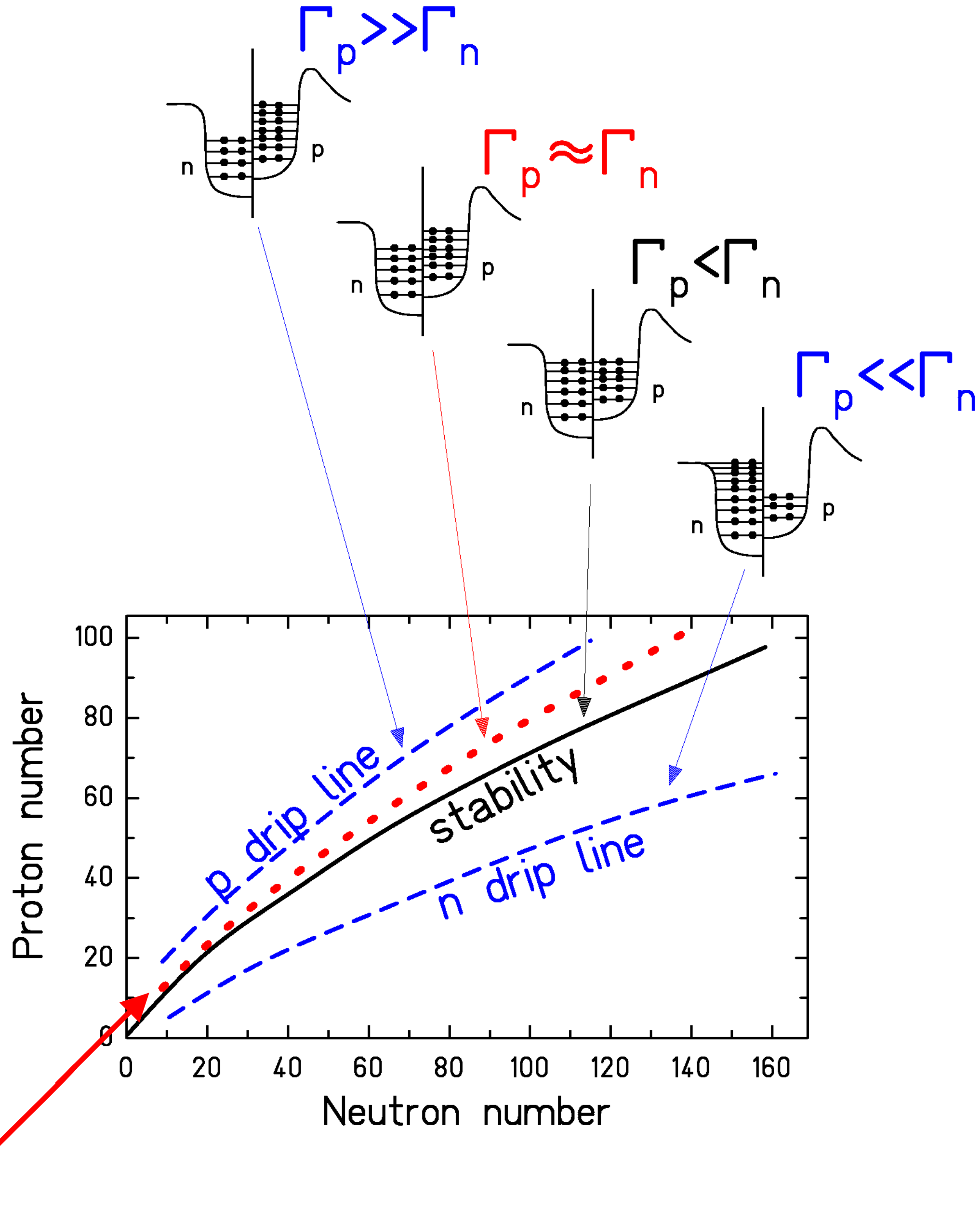
$\langle N \rangle / Z$ = constant

$E^* \propto$ abraded mass



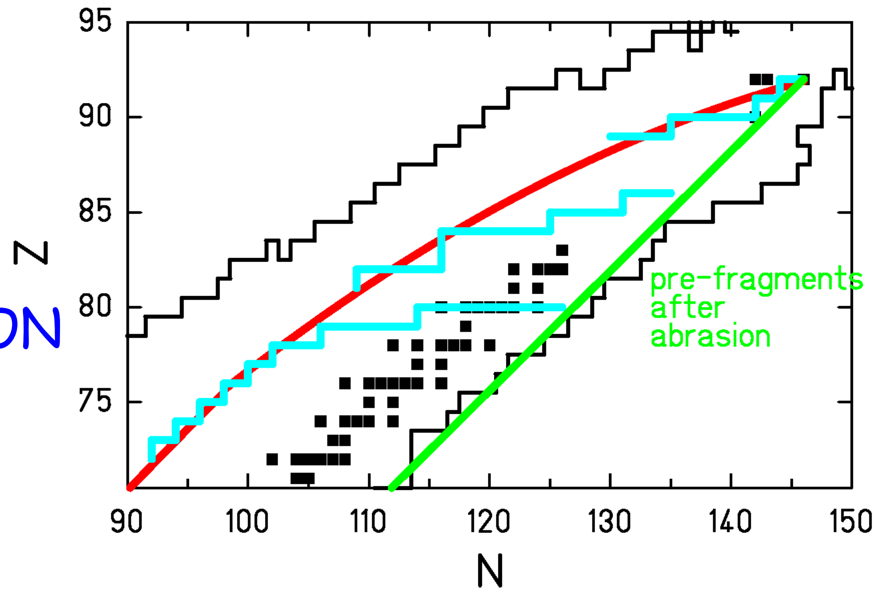
evaporation cascade

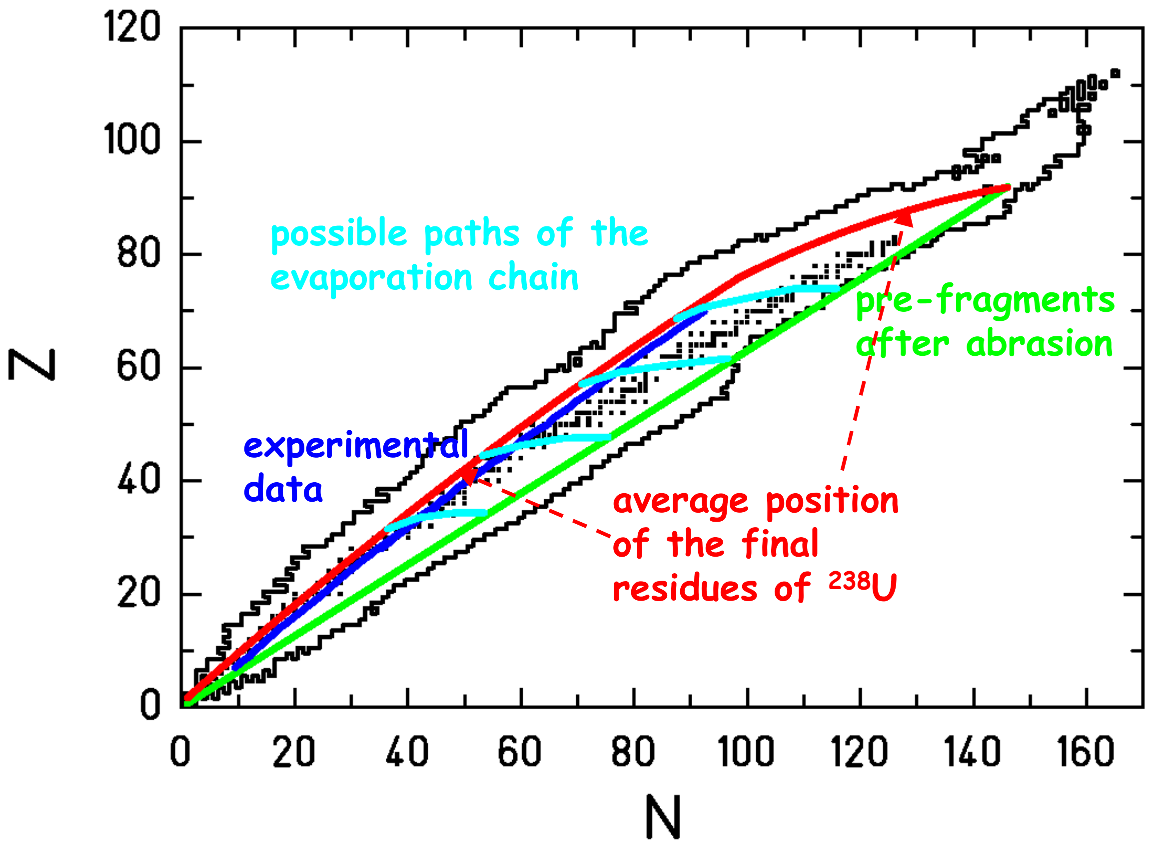
SEQUENTIAL DECAY
(EVAPORATION)



"evaporation corridor"
or
"attractor line"

IDEA BEHIND LIMITING FRAGMENTATION



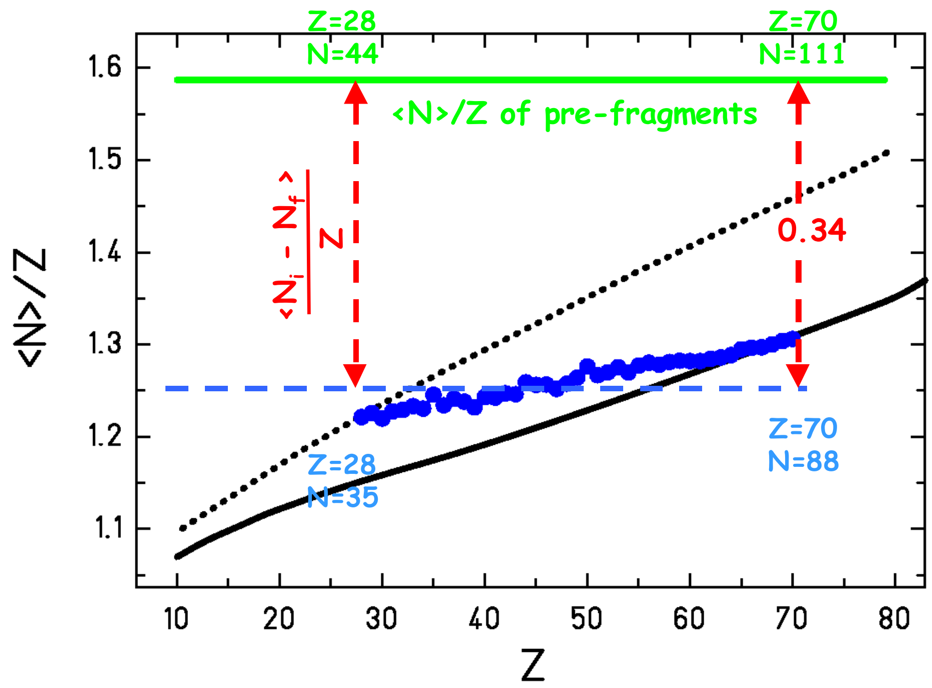


In more violent collisions the evaporation strats at lower excitation energies!

PRINCIPLE OF THE ISOSPIN THERMOMETER

Simplifying hypothesises:

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



$$E^* = 15\ \mathrm{MeV} \cdot \langle N_i - N_f \rangle$$

$$\frac{\langle N_i - N_f \rangle}{Z} \sim 0.34$$

E^*/Z = constant

or

E^*/A = constant

$$E^* = a\,T^2$$

$$a \sim A/10\ \mathrm{MeV}$$

$E^*/A = 0.1\ T^2$

T^2 = constant

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

ABRASION

+

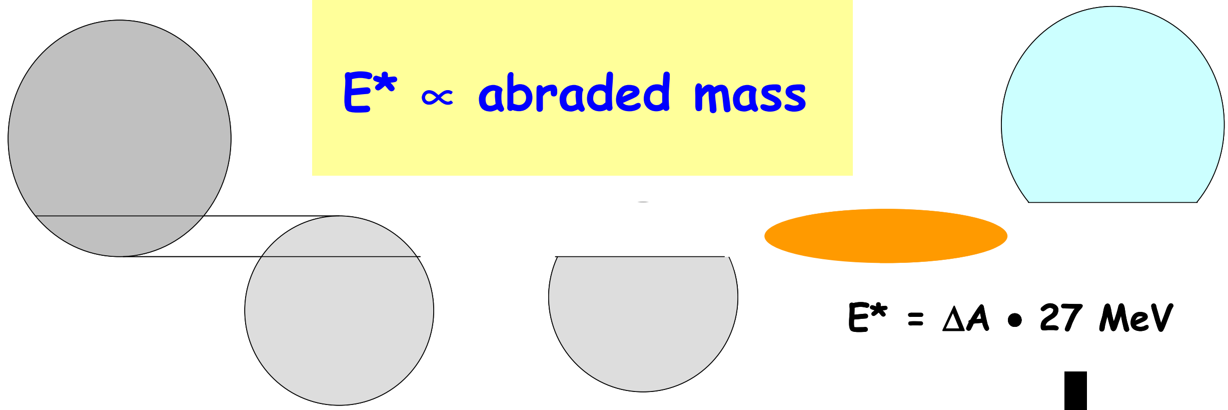
SIMULTANEOUS BREAK-UP

+

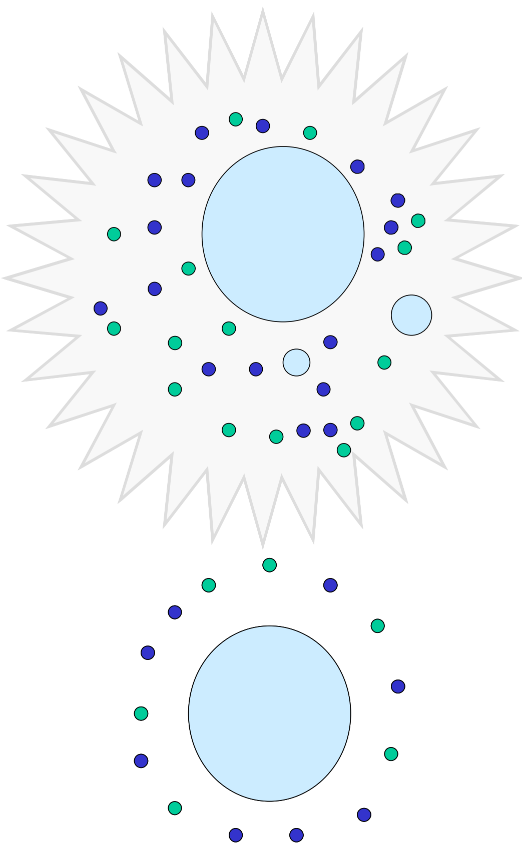
EVAPORATION

$\langle N \rangle / Z$ = constant

$E^* \propto$ abraded mass



$E^* = \Delta A \bullet 27$ MeV



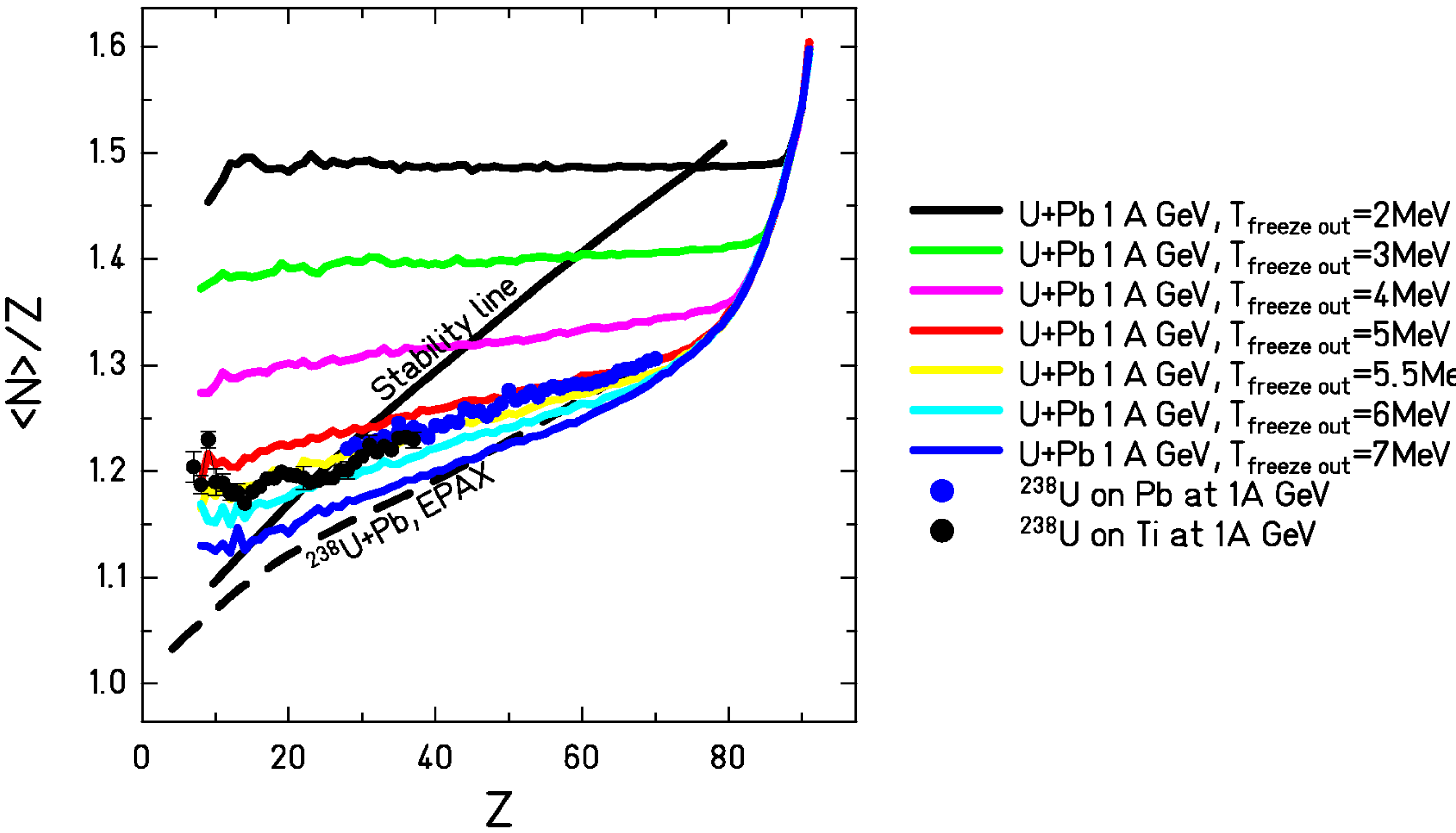
$\langle N \rangle / Z$ = constant

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

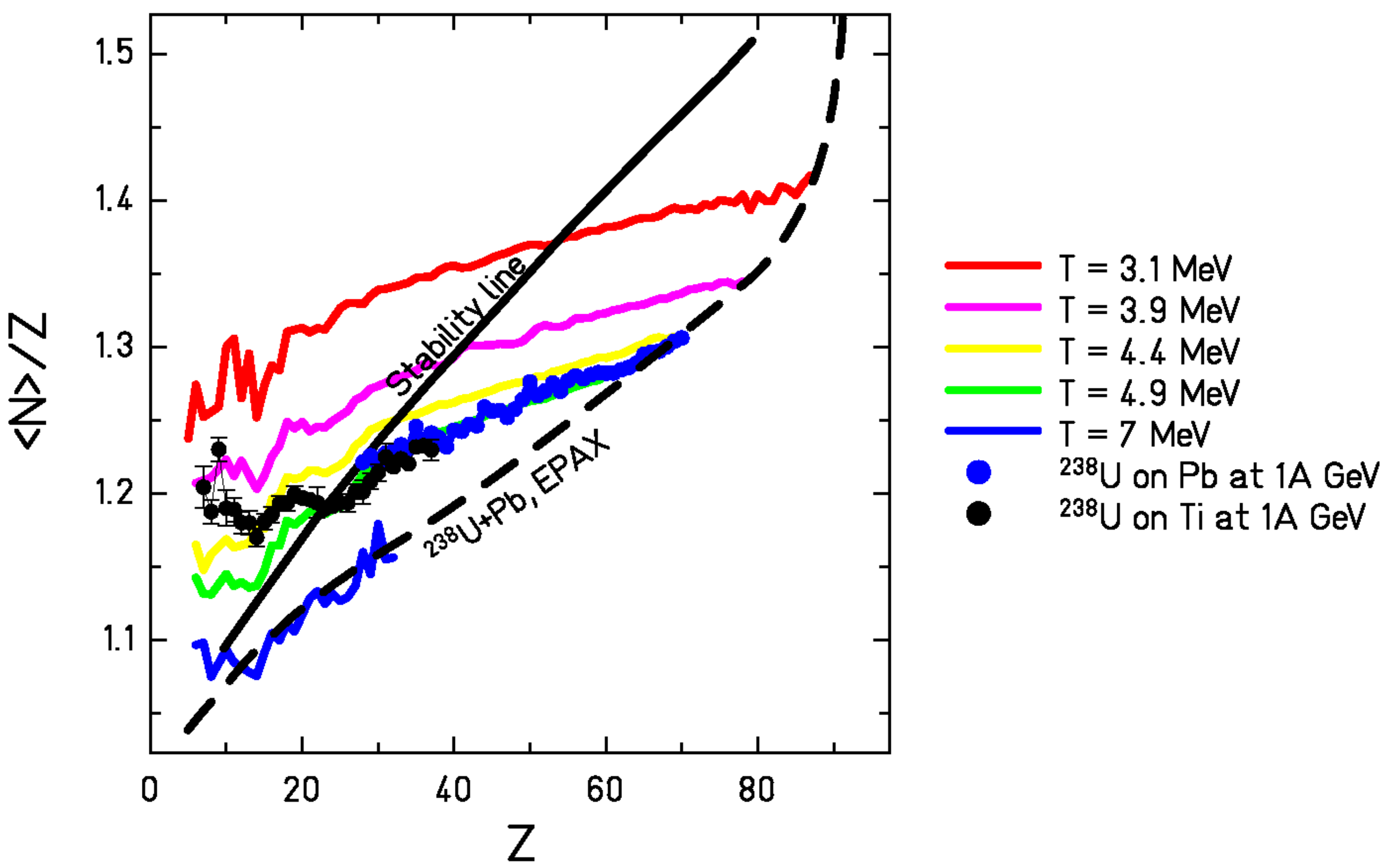
evaporation cascade

COMPARISON WITH A THREE-STAGE MODEL

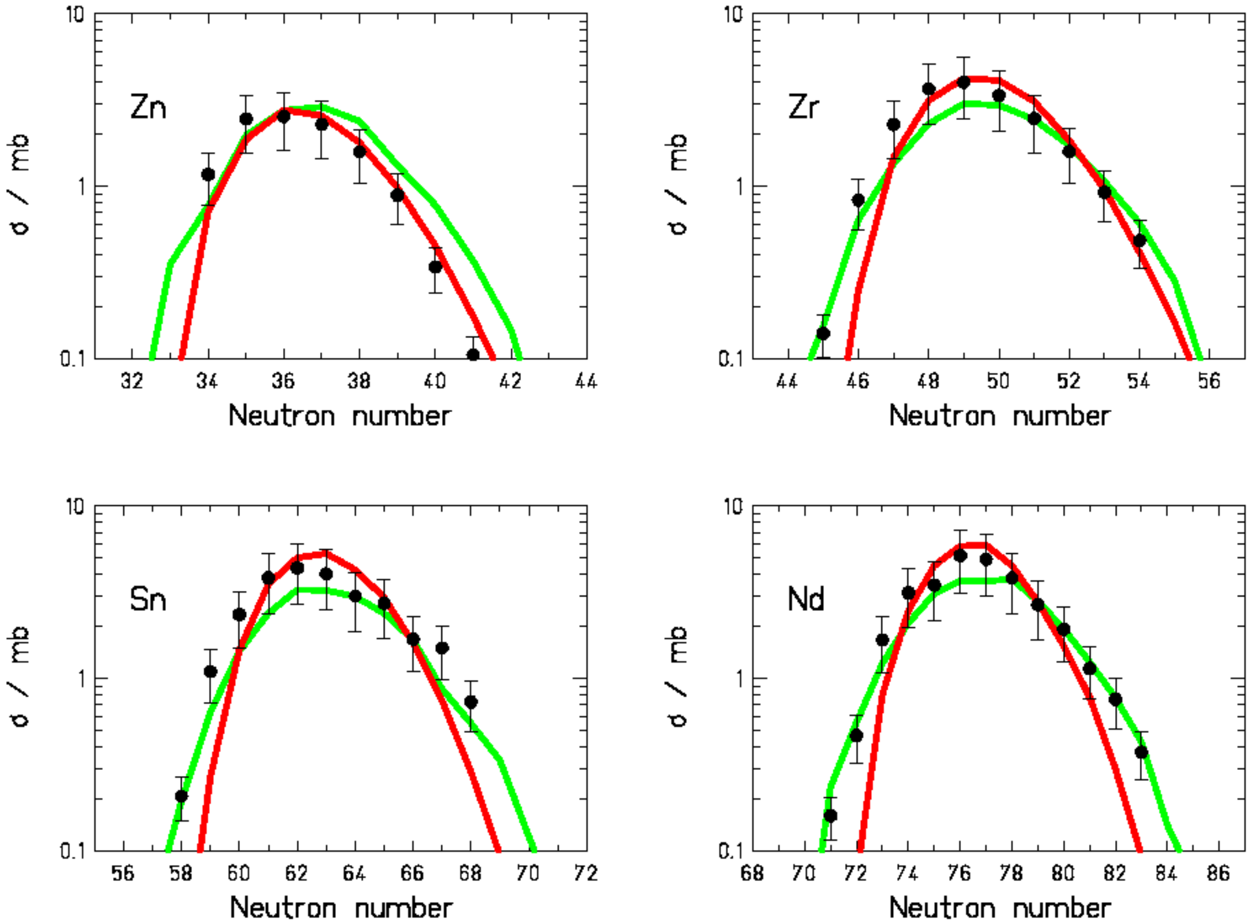
ABRASION / (BREAK-UP) / EVAPORATION



COMPARISON WITH SMM CALCULATIONS



A SHARP CONSTANT TEMPERATURE?



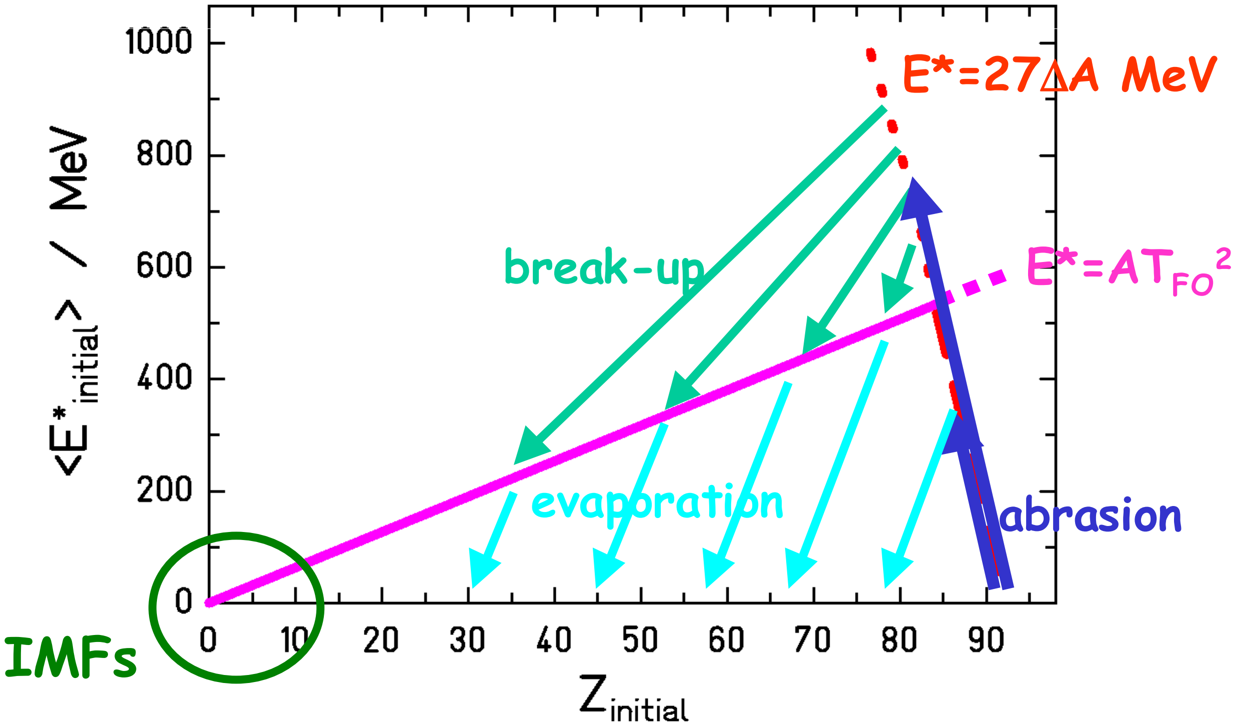
Experimental data

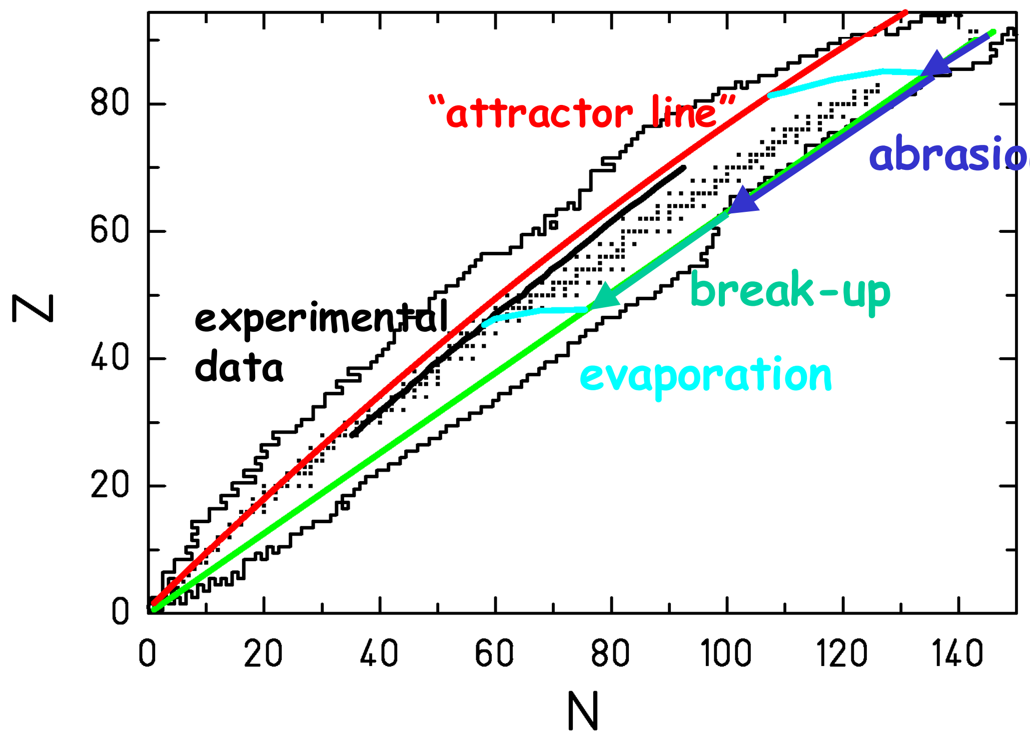
Three-stage model

SMM (arbitray normalised)

- **no indications for important fluctuations in temperature**

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





CONCLUSIONS

★ Heavy residues produced in collisions of ^{238}U with titanium and lead at $1 \cdot A$ GeV are unexpectedly neutron-rich

★ The <N>/Z-ratio is an interesting quantity also for heavy masses produced in fragmentation

★ Isotopic distributions of residual elements from neutron-rich projectile are sensitive to a simultaneous-emission phase

★ The mean *N*/*Z*-ratio of the final elements can be used in combination with statistical-model codes in order to deduce the freeze-out temperature after break up ("isospin thermometer")

★ The average temperature of the break-up configuration at freeze out is $T \approx 5$ MeV

★ consequence: an equilibrated compound nucleus cannot exist above a limiting temperature of 5 MeV (EPAX is valid for $T < 5$MeV)