Basic Research for the Transmutation of Nuclear Waste

A. Kelić[1], K.-H. Schmidt[1], P. Armbruster[1], L. Audouin[2], J. Benlliure[3], M. Bernas[2], A.Boudard[4], E. Casarejos[3], S. Czajkowski[5], L. Donadille[4], T. Enqvist[1], B. Fernandez[4], K.Helariutta[1], V.Henzl[1], D.Henzlova[1], B. Jurado[1], R. Legrain[4], S. Leray[4], B. Mustapha[2], P.Napolitani[1,2], J.Pereira[3], M. Pravikoff[5], F. Rejmund[2], M. V. Ricciardi[1], C. Stéphan[2], J.Taïeb[2], L.Tassan-Got[2], C. Villagrasa[4], F. Vives[1], C. Volant[4], W. Wlazło[4], O. Yordanov[1]

[1] GSI Darmstadt, Germany

[2] IPN Orsay, France

[3] University Santiago de Compostela, Spain

[4] DAPNIA/SPhN CEA/Saclay, France

[5] CENBG Gradingan, France

Glossary

- Few words about nuclear waste.
- **Fragment separator:**

  Resolution and acceptance
- **Experimental results – general view:**

  Velocity distributions.

  Nuclide distributions.
- **Experimental results – specific:**

  Dissipation in fission.

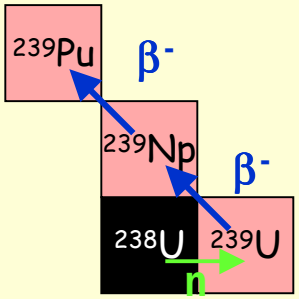
  Thermal instabilities in nuclei.

  Response of the spectator to the participant blast.
- Outlook.

Motivation – Radioactive waste

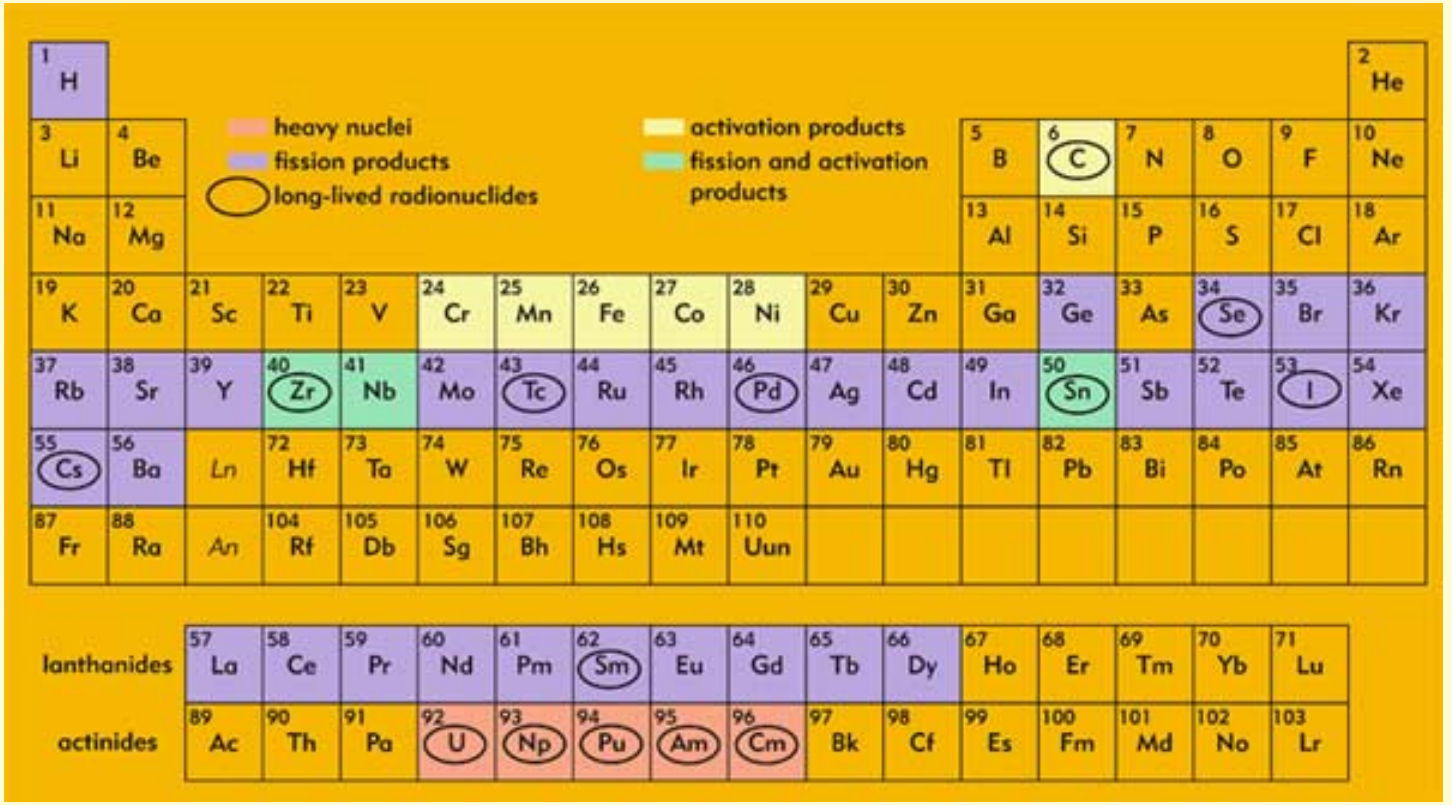
Fission products:

^{129}I ($15.7 \cdot 10^6$ y),
^{107}Pd ($6.5 \cdot 10^6$ y),
^{135}Cs ($2 \cdot 10^6$ y),
^{93}Zr ($1.5 \cdot 10^6$ y) ...

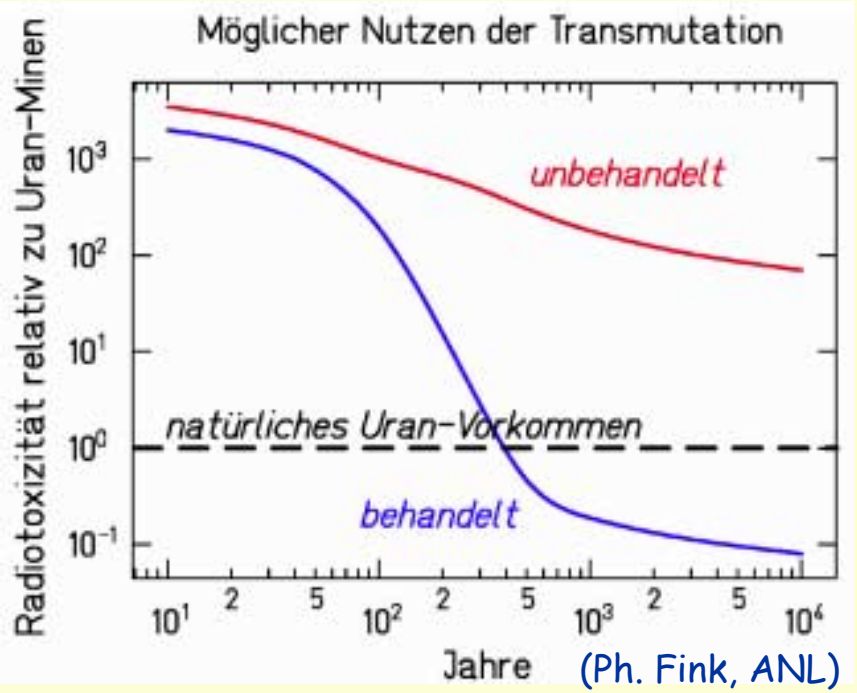


Heavy nuclei:

^{239}Pu ($2.4 \cdot 10^4$ y),
^{237}Np ($2.1 \cdot 10^6$ y),
^{241}Am (432.6 y),
^{242}Am (141 y) ...

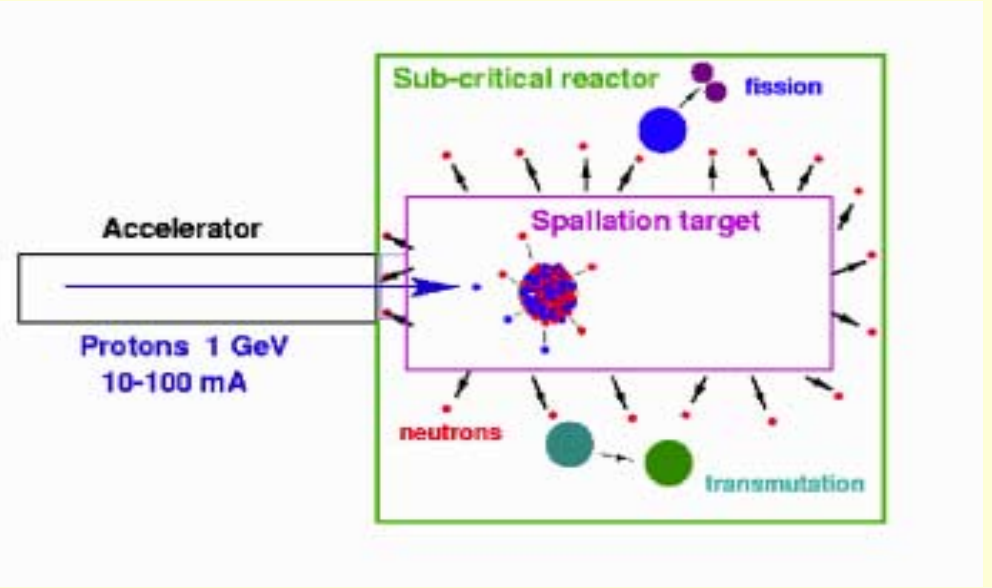


Motivation - Hybrid System (ADS)



(Ph. Fink, ANL)

Possible solution:



HINDAS, nTOF, MUSE...

Hybrid System (ADS) - Problems

- Accelerator:

  High intensity (>10 mA) and stability of 0.8-1.5 GeV proton beams...

- Window:

  Heating, pressure and temperature gradient, damages due to irradiation...

- Spallation source:

  Yields of spallation neutrons, production of radioactive nuclei...

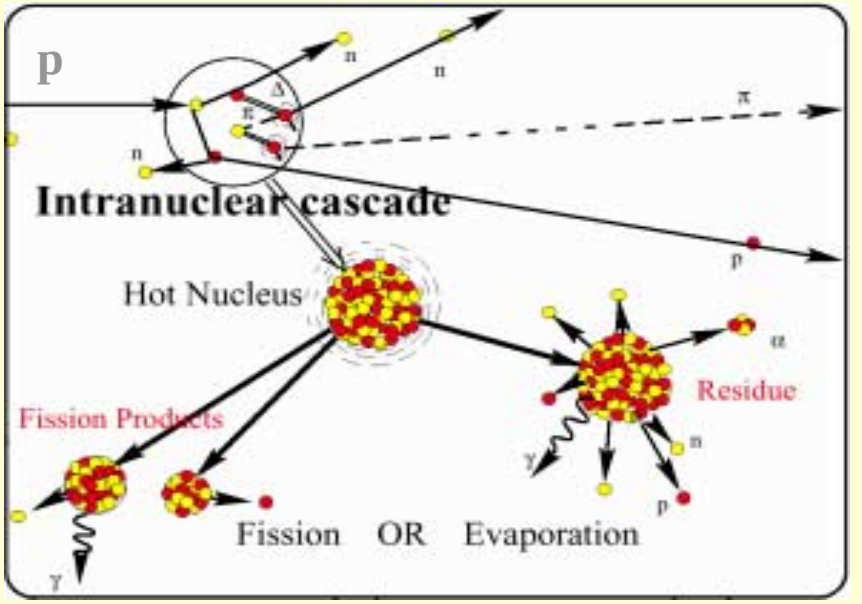
- Coolant:

  Design, corrosion ...

Nuclear physics at GSI for ADS design

Aim:

- Complete understanding and modelling of spallation reactions at 0.2 – 2 A GeV.



⇨ Energy deposition in spallation.
⇨ Decay of hot nucleus.
⇨ Kinematics of final products ...

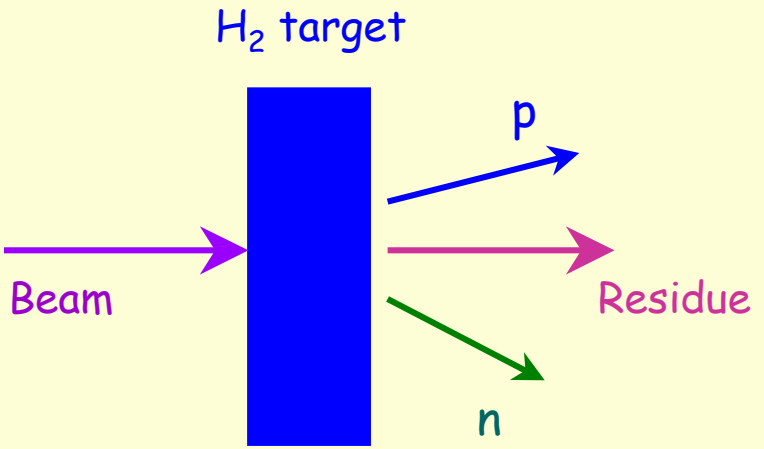
Nuclear physics at GSI for ADS design

How-to:

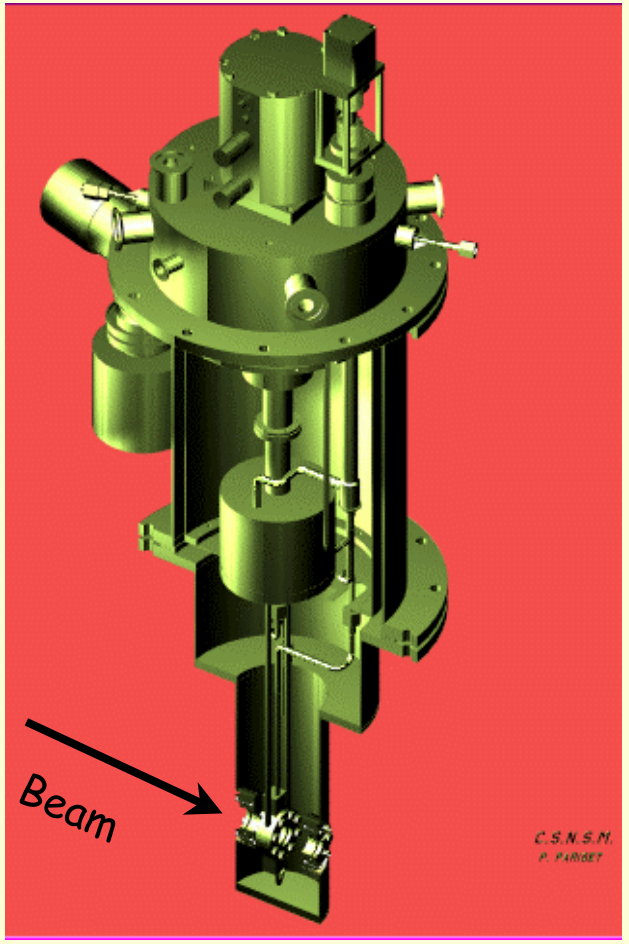
- The data on systematic investigation of a few representative systems (Fe, Xe, Au, Pb, U) put important constraints on the models to be improved or developed.

⇨ Inverse kinematics

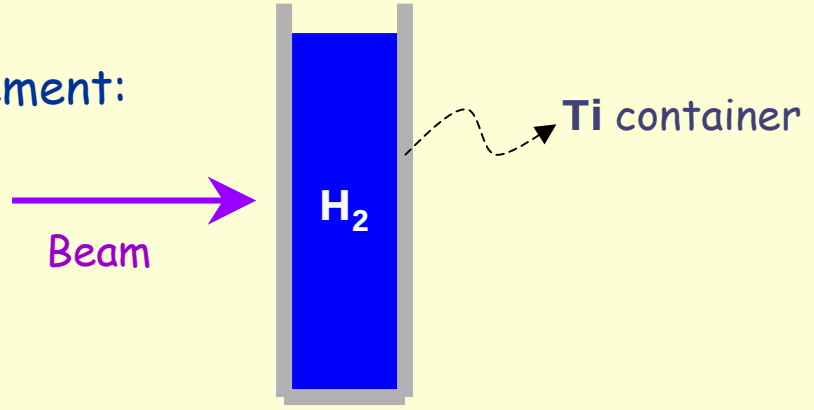
In-flight identifications of heavy reaction products and their kinematical properties.



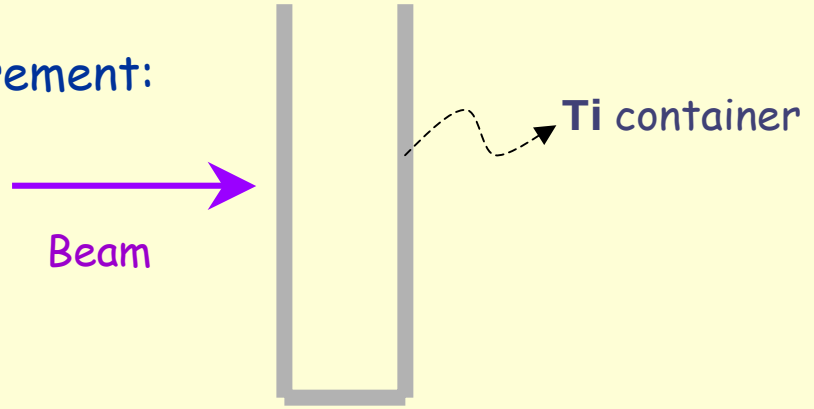
Liquid ^1H (87.3±2.2 mg/cm^2) and ^2H targets (206±6 mg/cm^2)



1st Measurement:

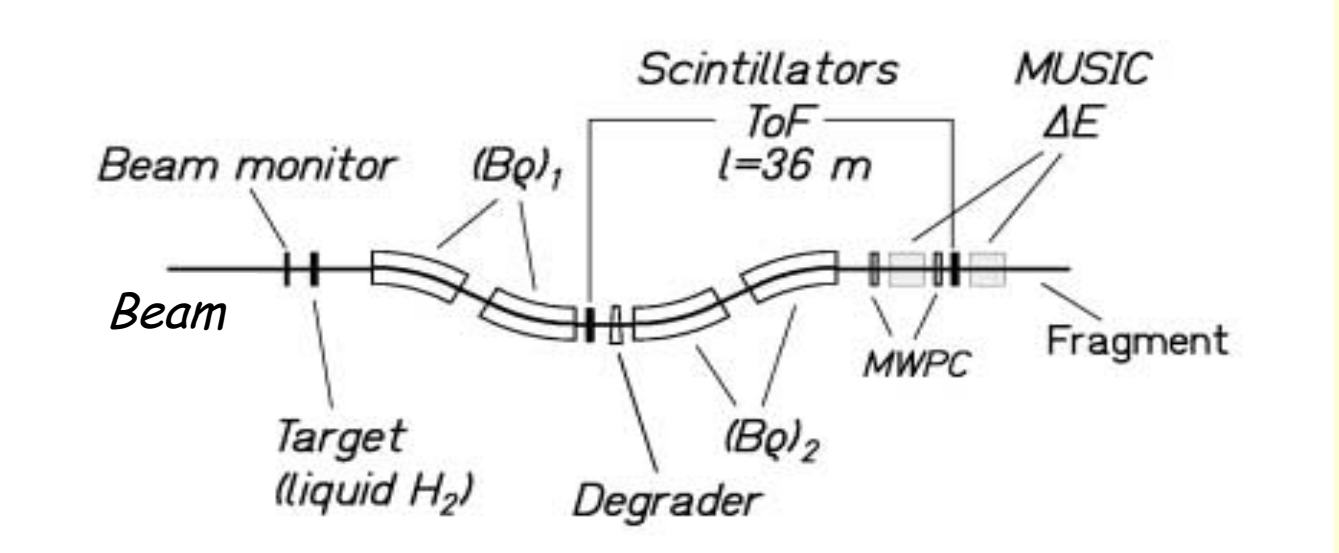


2nd Measurement:



The GSI Fragment Separator

Powerful focusing magnetic spectrometer



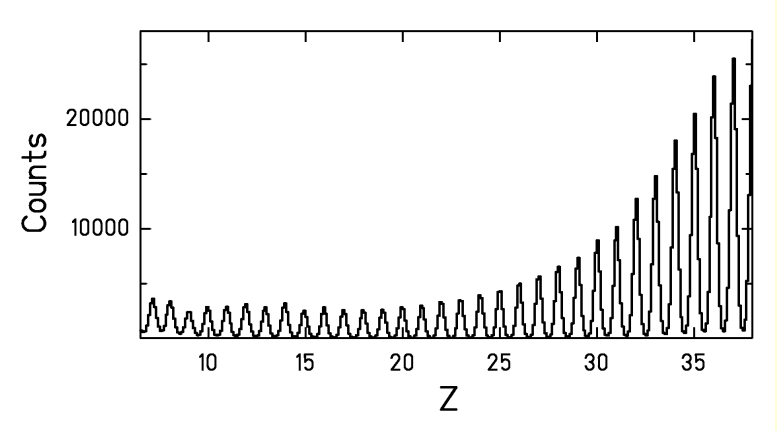
Resolution:

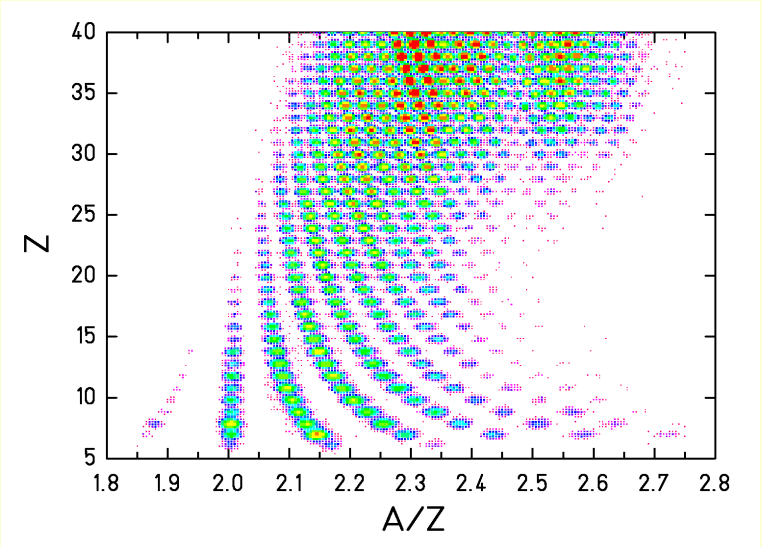
- $\Delta(B\rho)/B\rho \approx 5 \cdot 10^{-4}$.
- $\Delta(\beta\gamma)/\beta\gamma \approx 5 \cdot 10^{-4}$.
- $Z/\Delta Z \approx 200$.
- $A/\Delta A \approx 400$.

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

Identification pattern

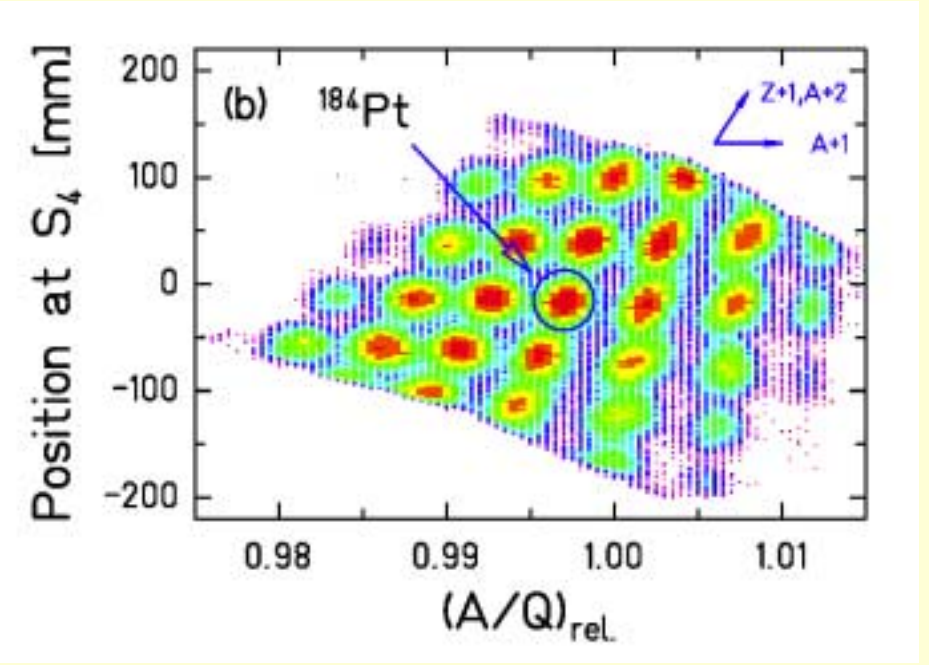
^{238}U+Ti at 1 *A* GeV, Light fragments:





M.V. Ricciardi, PhD thesis

^{208}Pb + ^{1}H, 1 *A* GeV, Heavy fragments:

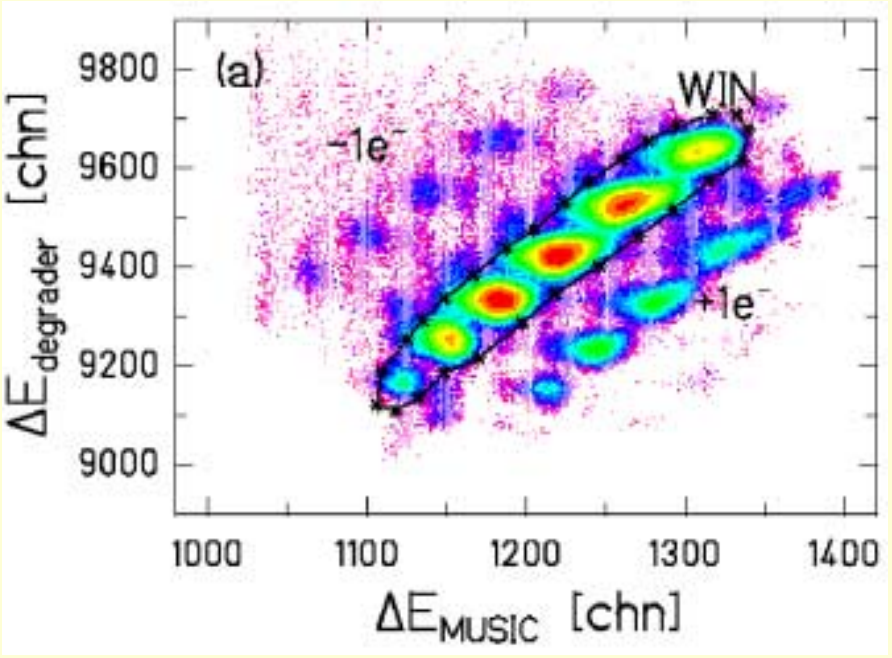


T. Enqvist et al., NPA686 (2001) 481.

Identification pattern

Identification of ionic charge states

$^{208}Pb + {}^{1}H$, 1 *A* GeV.



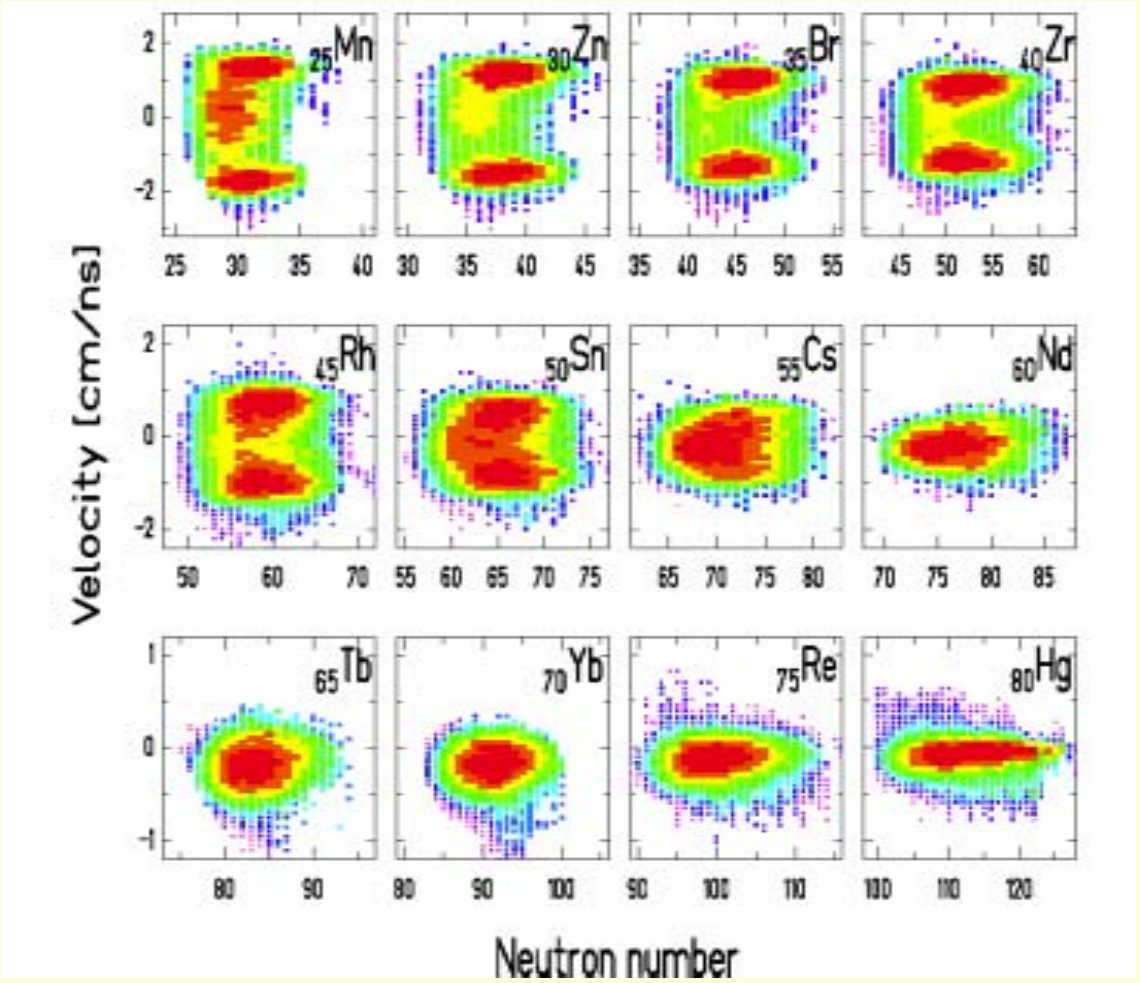
„Nominal energy loss in the degrader":

$\Delta E/q = e[(B\rho)_1/\beta_1 - (B\rho)_2/\beta_2]$

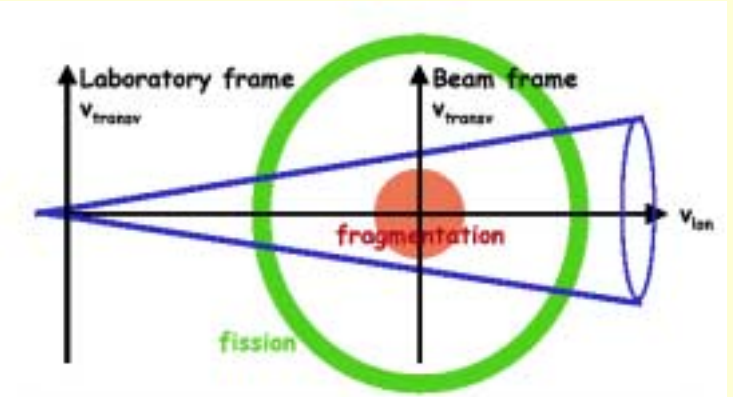
T. Enqvist et al., NPA686 (2001) 481.

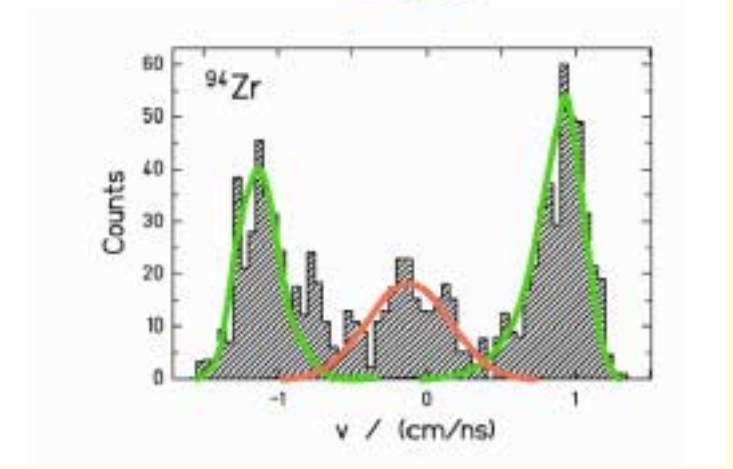
Kinematics

$^{208}Pb + {}^{1}H$, 1 *A GeV*



T. Enqvist et al,
NPA686 (2001), 481.

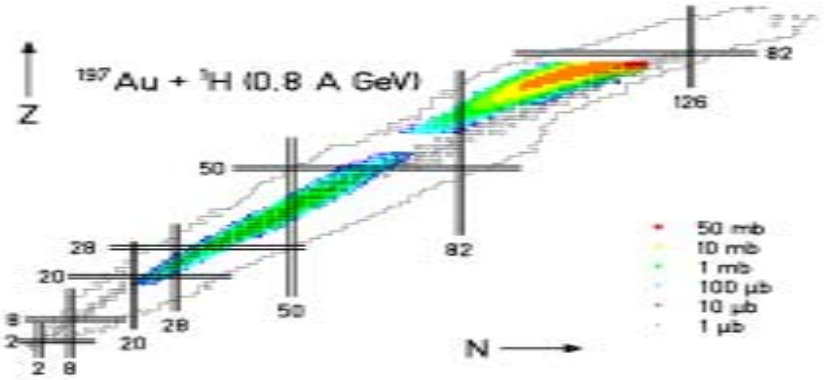


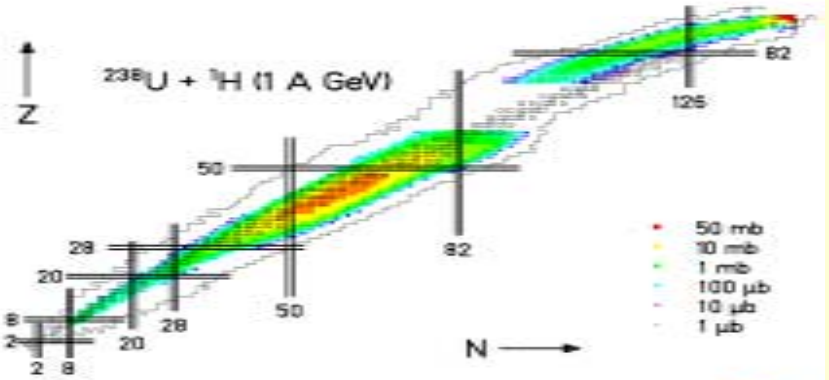


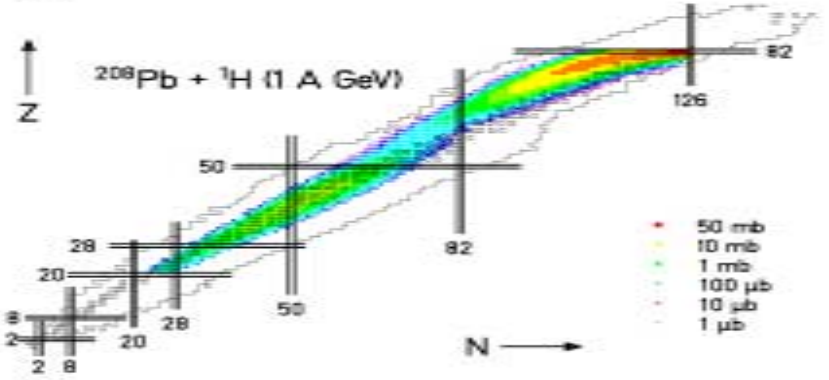
For every nuclide:

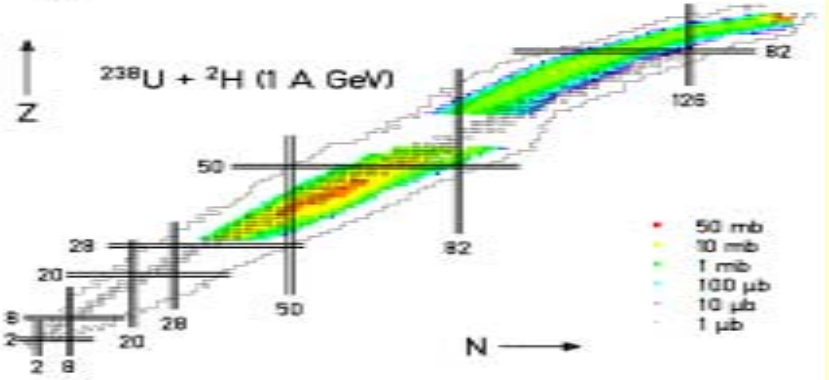
- Recoil energy.
- Production mechanism.

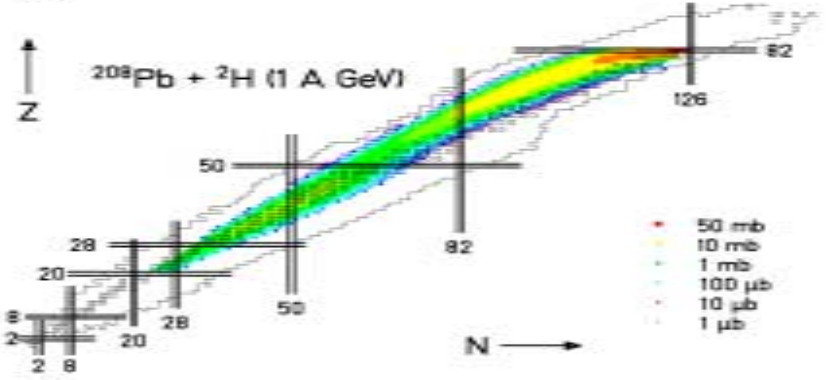
Production cross sections







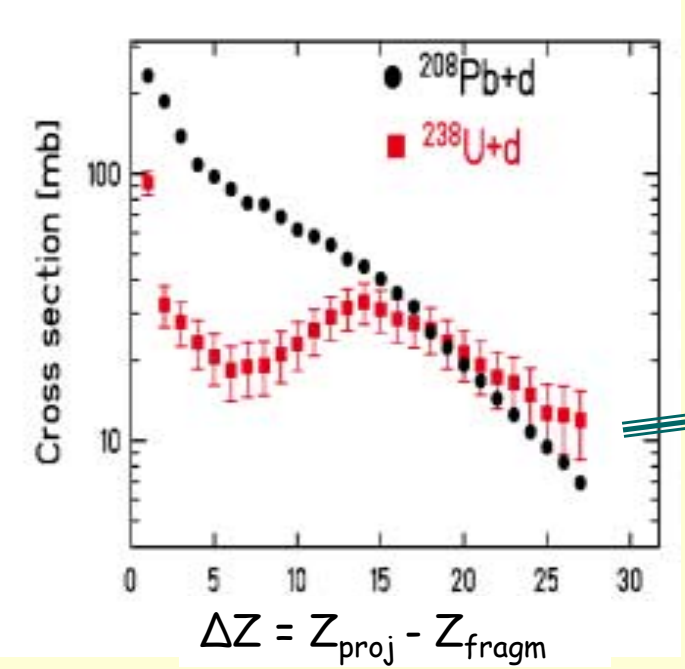




F. Rejmund et al., NPA 683 (2001) 540.
J. Benlliure et al., NPA 683 (2001) 513.
T. Enqvist et al., NPA686 (2001) 481.
T. Enqvist et al., NPA703 (2002) 435.
M. Bernas et al., NPA accepted.
J. Taïeb et al., NPA accepted.
M. Brahim, M.V. Ricciardi, J. Taïeb, J. Pereira, E.Casarejos: PhD Thesis.

Role of dissipation in fission

Partial fragmentation cross sections in **^{208}Pb + d** and **^{238}U + d** at *1 A GeV*.

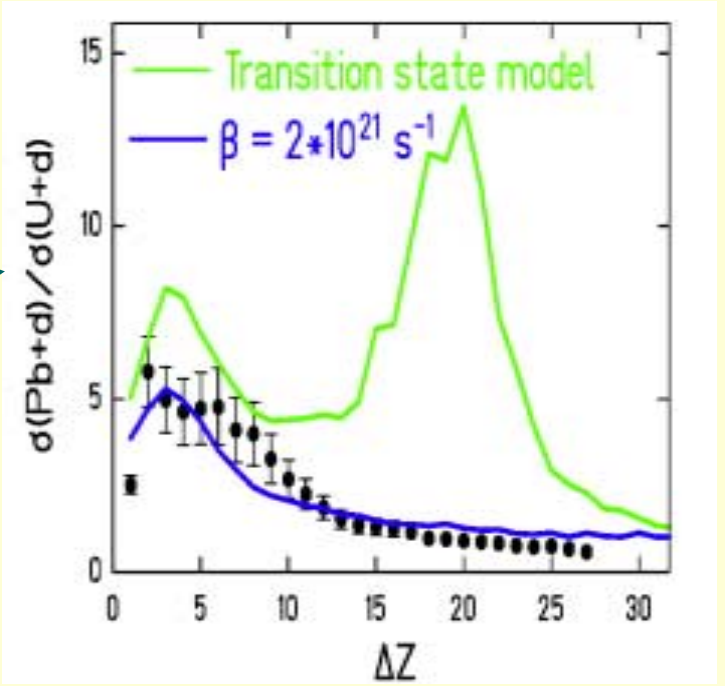


E_{exc}

^{208}Pb+d: Enqvist et al., NPA 703, p. 435.

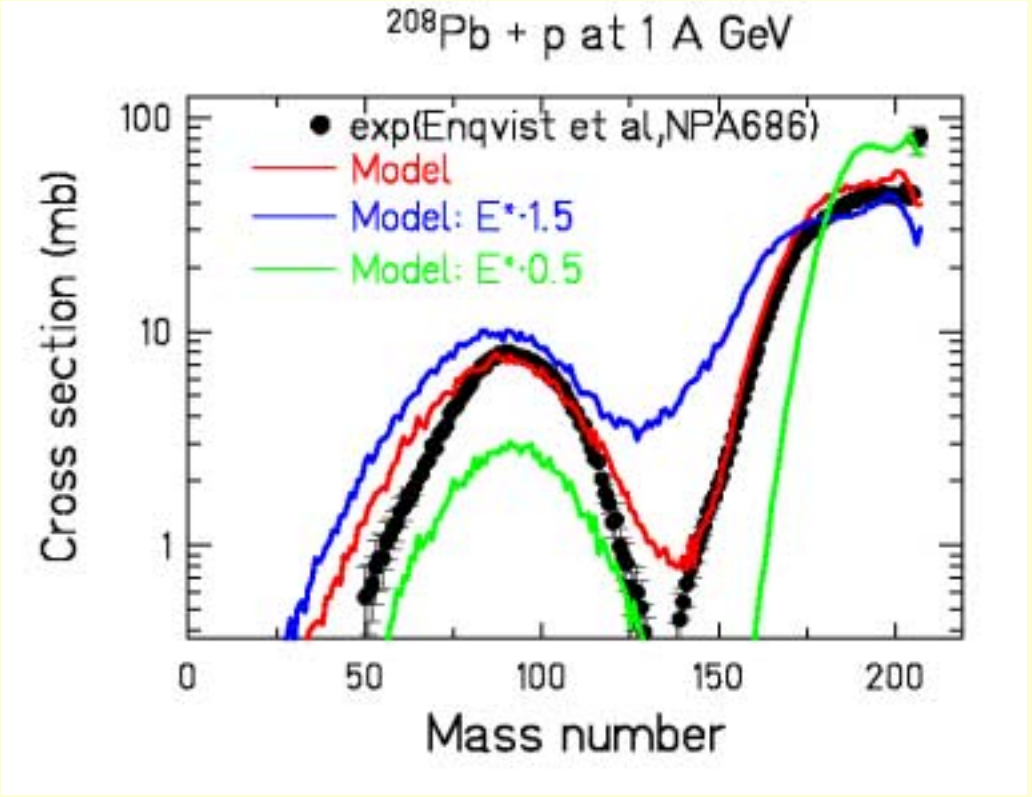
^{238}U+d : E. Casarejos, PhD Thesis.

Ratio of partial fragmentation cross sections in ^{208}Pb + d and ^{238}U + d at *1 A GeV*.



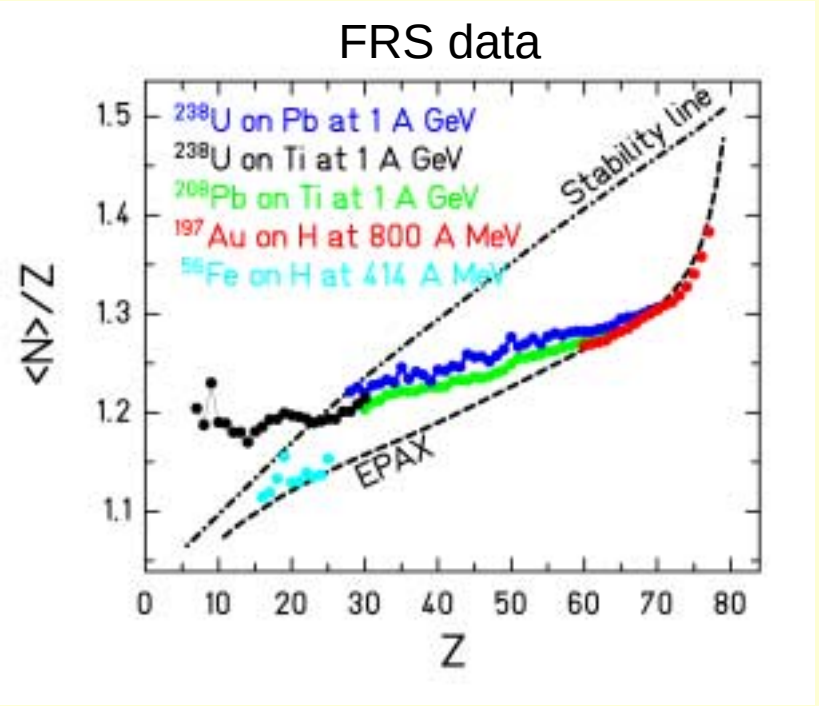
β - reduced dissipation coefficient

Energy deposition in spallation

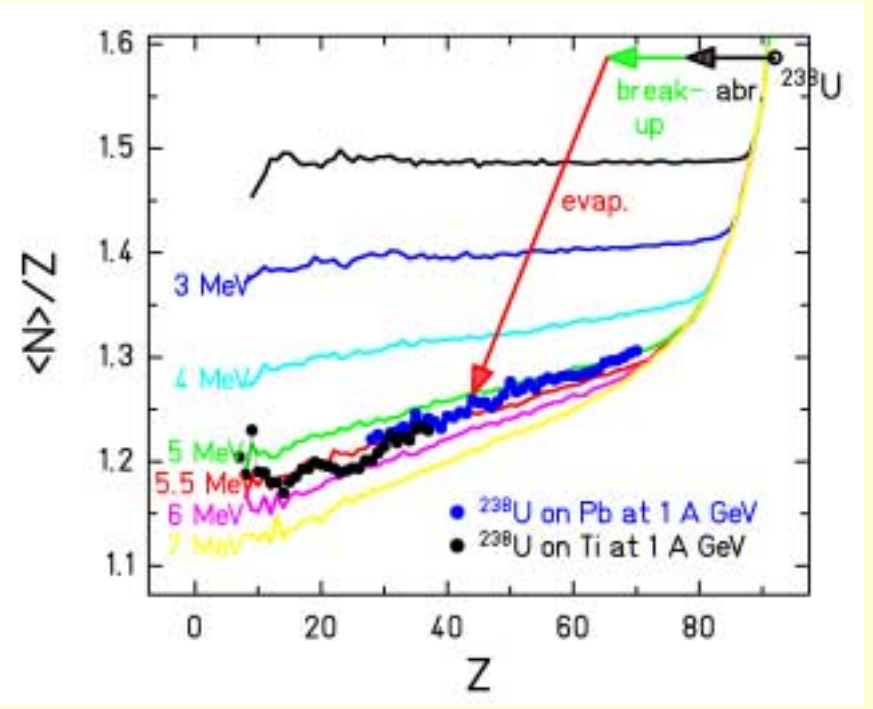


Sensitivity of the measured mass distribution on the excitation energy introduced in the first stage of reaction.

Thermal instabilities



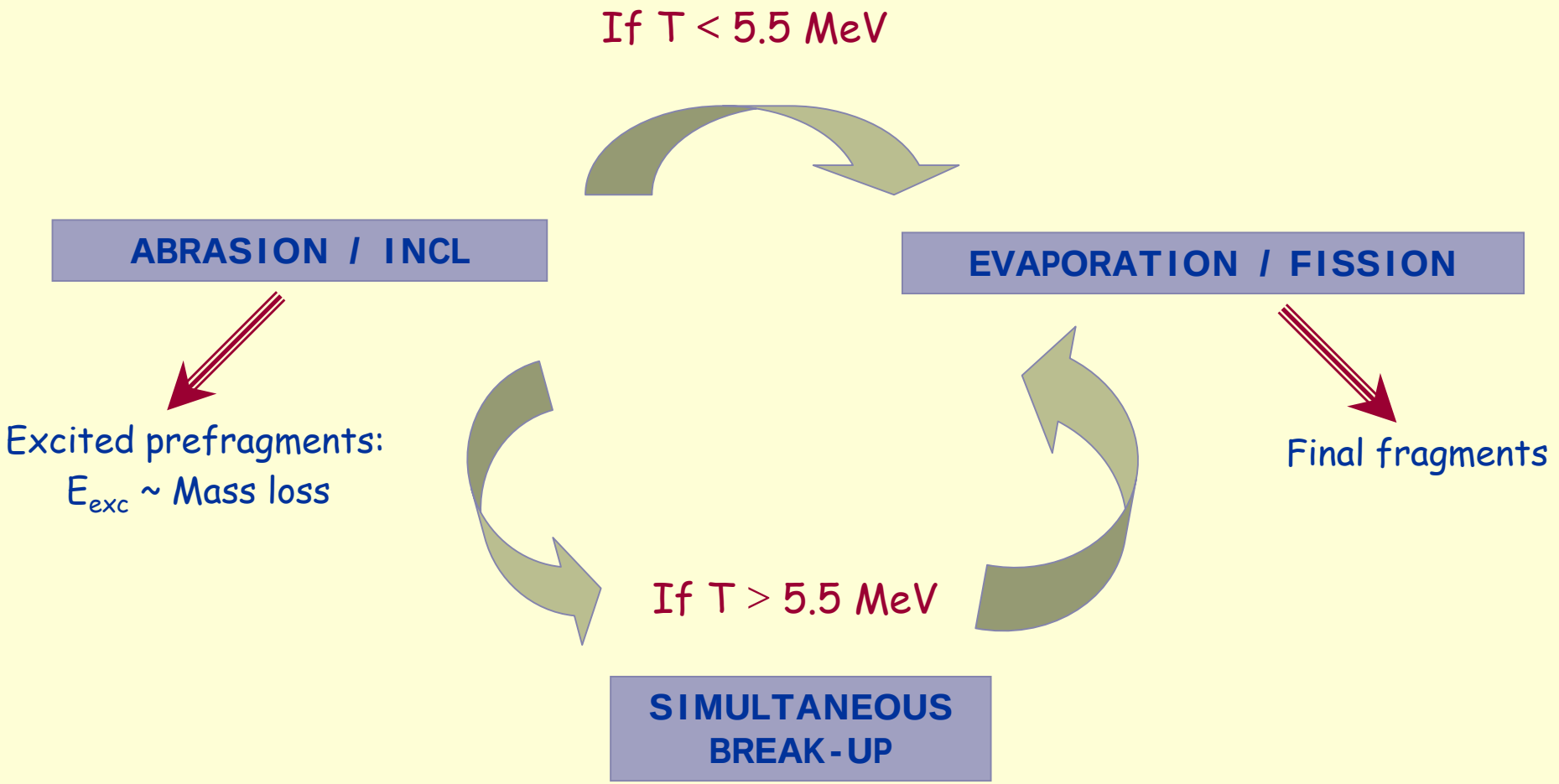
<N>/Z of ^{238}U fragmentation residues compared to EPAX and 3-stage code ABRABLA (with different freeze-out temperatures).



Maximum temperature of ~ 5.5 MeV above which compound system can not survive as an entity.

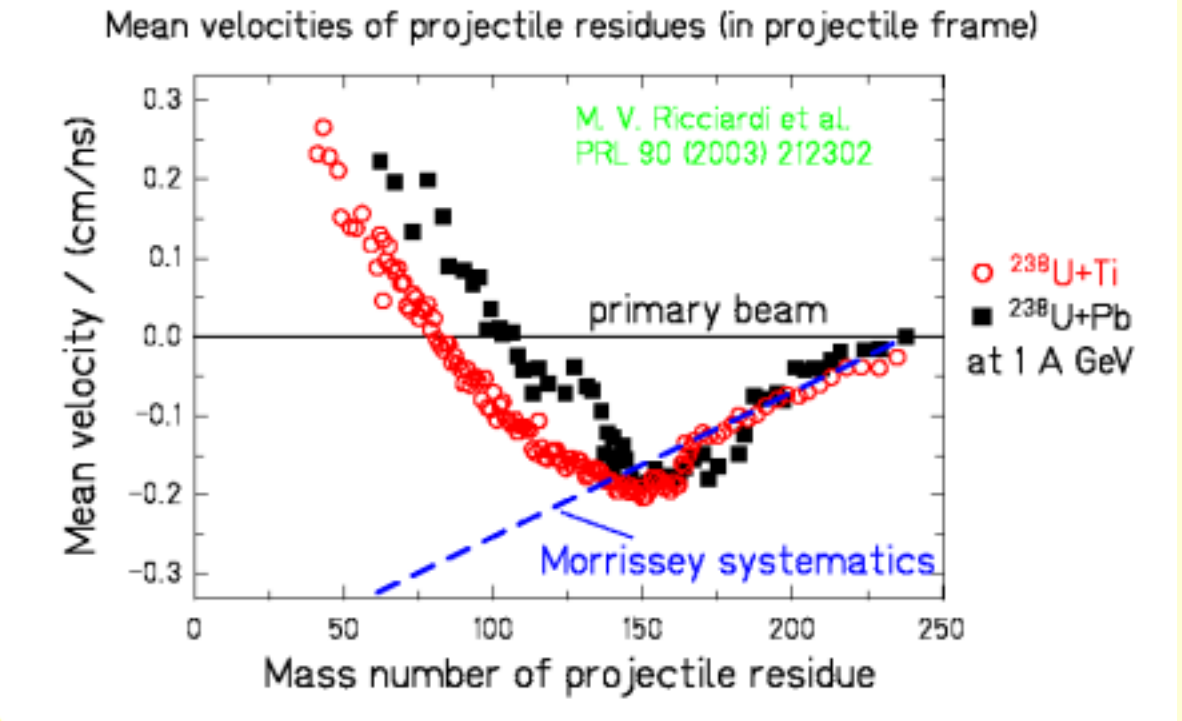
K.-H. Schmidt et al, NPA 710 (2002) 157.

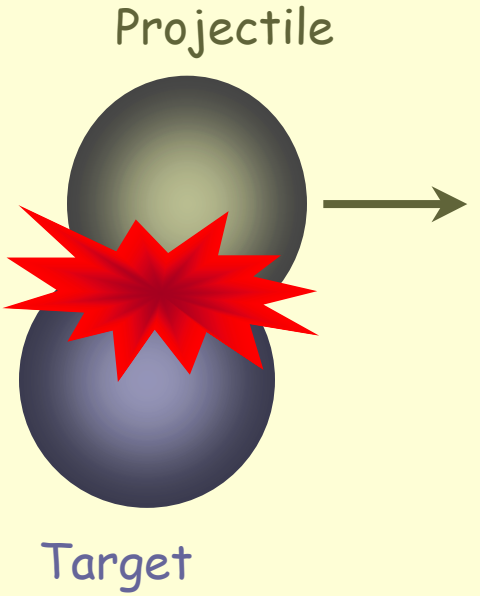
GSI code ABRABLA: Three stage model



Response of the spectator to the participant blast

New FRS results (Fission excluded):





Light projectile residues are faster than the projectiles!

Experimental indication for the response of the spectator to the participant blast*)- a new access to investigate the EOS of nuclear matter.

*) predicted by Shi, Danielewicz, Lacey, PRC 64 (2001) 034601

Outlook

1. Energy dependence of proton-induced spallation of ^{136}Xe (0.2 ... 1 A GeV) at FRS. (Analysis of data in progress).

   Modelling of spallation in a thick target.

2. Coincidence measurement of heavy residues, light charged particles and neutrons with ^{56}Fe and heavier systems at ALADIN. (Experiment in preparation).

   Investigation of the decay of highly excited heavy nuclei.

3. Full identification of both fission fragments, simultaneous measurement of neutrons, light charged particles and gammas with new R3B magnetic spectrometer. (Preparative studies).

   Aiming for a cinematically complete fission experiment.

Summary

Experimental goal:

Full coverage of yields and velocities of:

- Heavy residues, neutrons and light charged particles.

Status:

- Most complete set of relevant data measured
  (~ 1000 isotopes /system, previous: ~ 20).
- 2nd generation experiment in preparation.

New information on critical topics:

- Energy deposition in the INC phase.
- Dissipative hindrance of fission (B. Jurado, PhD Thesis).
- Thermal instabilities of nuclei (K.-H. Schmidt et al., NPA 710 (2002) 157).
- Response of the spectator to the participant blast (M.V. Ricciardi et al., PRL90 (2003) 212302).

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

Collaborations

GSI
P. Armbruster, T. Enqvist, K. Helariutta, V. Henzl, D. Henzlova, B. Jurado, M. V. Ricciardi, K.-H. Schmidt, C. Schmitt, F. Vives, O. Yordanov

IPN-Paris
L. Audouin, M. Bernas, B. Mustapha, P. Napolitani, F. Rejmund, C. Stéphan, J. Taïeb, L. Tassan-Got

CEA-Saclay
A. Boudard, L. Donadille, B. Fernandez, R. Legran, S. Leray, C. Villagrasa, C. Volant, W. Wlazło

University Santiago de Compostela
J. Benlliure, E. Casarejos, J. Pereira

CENBG-Bordeaux
S. Czajkowski, M. Pravikoff

12 PhD