

Systematic study of spallation reactions in inverse kinematics at the FRS at GSI

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Nuclear physics at GSI for the design of Accelerator Driven Systems

① Experiments on residue productions

Study of proton induced reactions at 100 - 1500 A MeV for few representative systems (Fe, Xe, Au, Pb, U).

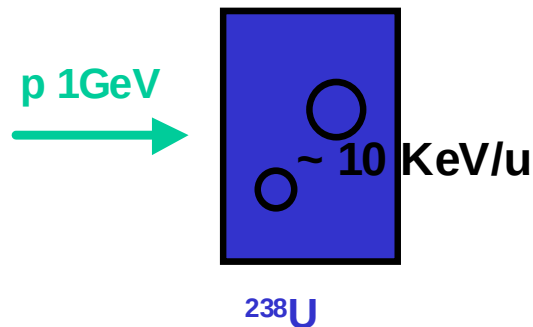
② Model development

The experimental data put important constraints on the models to be improved or developed.

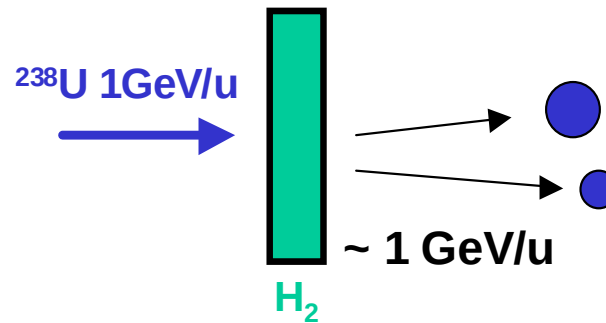
Important also for: design of radioactive-beam facilities, astrophysics, space technology, neutron sources.

The inverse kinematics at relativistic energies

direct kinematics



inverse kinematics



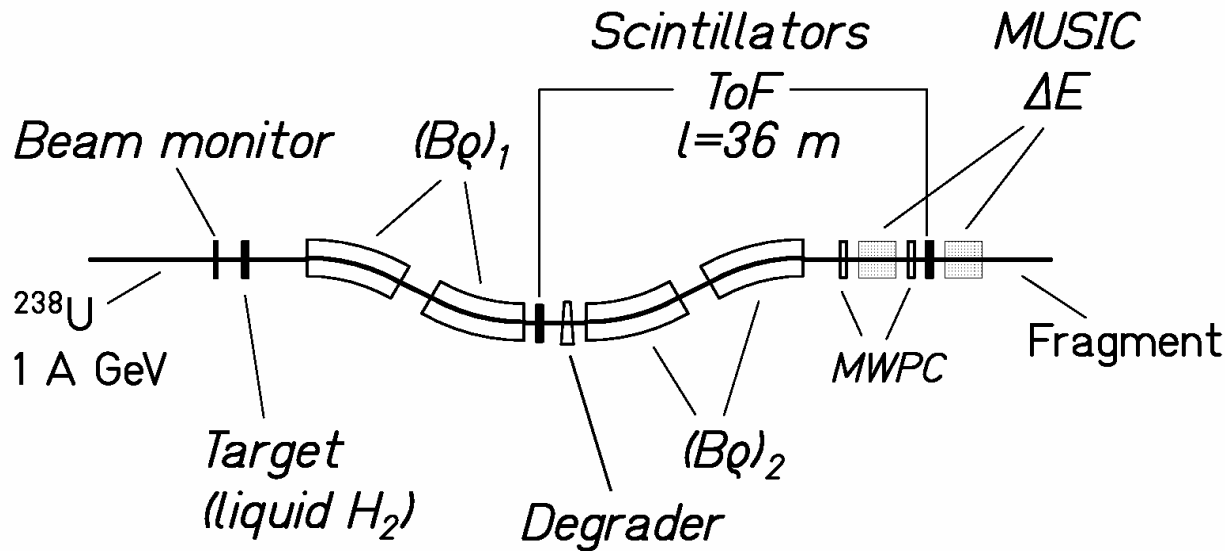
Identification off-line with chemistry or γ spectroscopy:

- only cumulative yields of long-lived isotopes
- no knowledge on the kinematics of the reaction

Identification on-line with recoil separator:

- identification of every reaction product in-flight prior to β decay
- velocity spectrum for every produced isotope

The Fragment Separator at GSI



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

Resolution:

- $\Delta(\beta\gamma)/\beta\gamma \approx 5 \cdot 10^{-4}$

- $\Delta Z / Z \approx 5 \cdot 10^{-3}$

- $\Delta A / A \approx 2.5 \cdot 10^{-3}$

- Precise velocity measurement for every nuclide
- Disentangling different reaction mechanisms

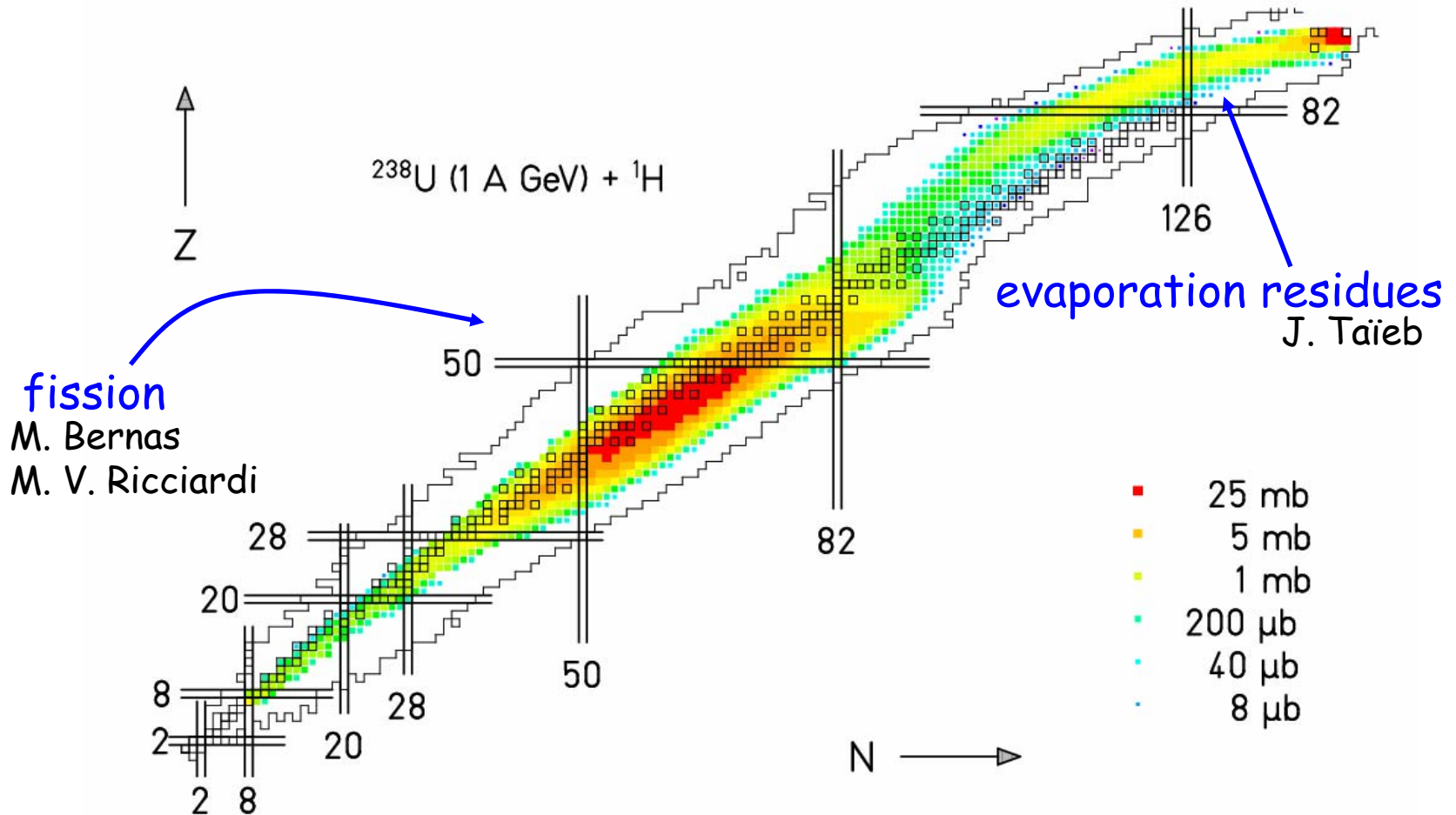
Full identification of every product

Experimental data for the following systems:

Projectile	Target	Energy [<i>A</i> GeV]
^{56}Fe	^1H	0.3, 0.5, 0.75, 1, 1.5
$^{136,124}\text{Xe}$	$^{1,2}\text{H}$, Ti, Pb	0.2, 0.5, 1
^{197}Au	^1H	0.8
^{208}Pb	$^{1,2}\text{H}$, Ti	0.5, 1
^{238}U	$^{1,2}\text{H}$, Ti, Pb	1

- ✓ Production cross sections (fission, evaporation)
- ✓ Velocity spectra for every produced nuclide

Example: production cross sections for 1 A GeV ^{238}U on p

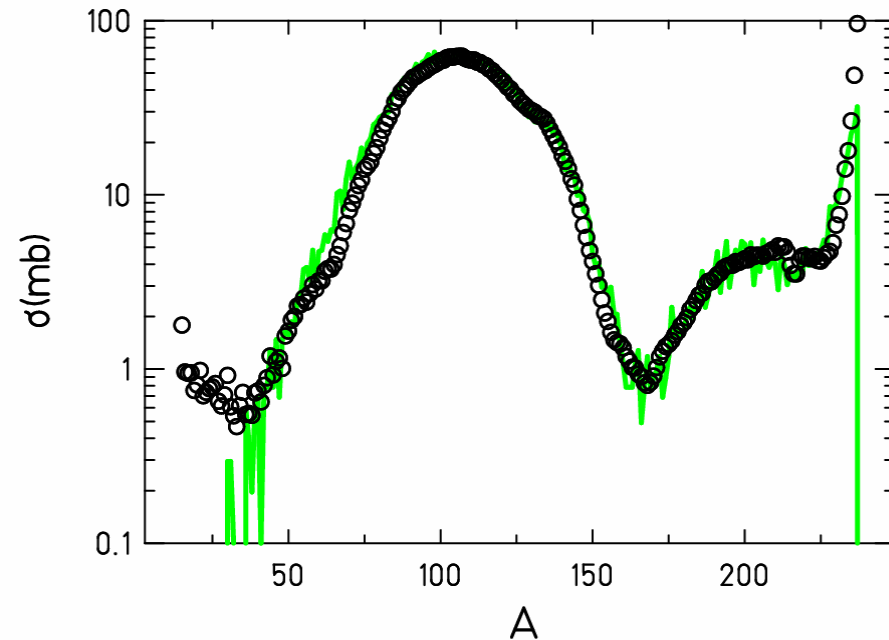


Data available at: <http://www-w2k.gsi.de/charms/data.htm>

Role of dissipation in fission

$^{238}\text{U} + \text{p}$ at 1 A GeV; Experiment vs. ABRABLA calculations

Dynamical model



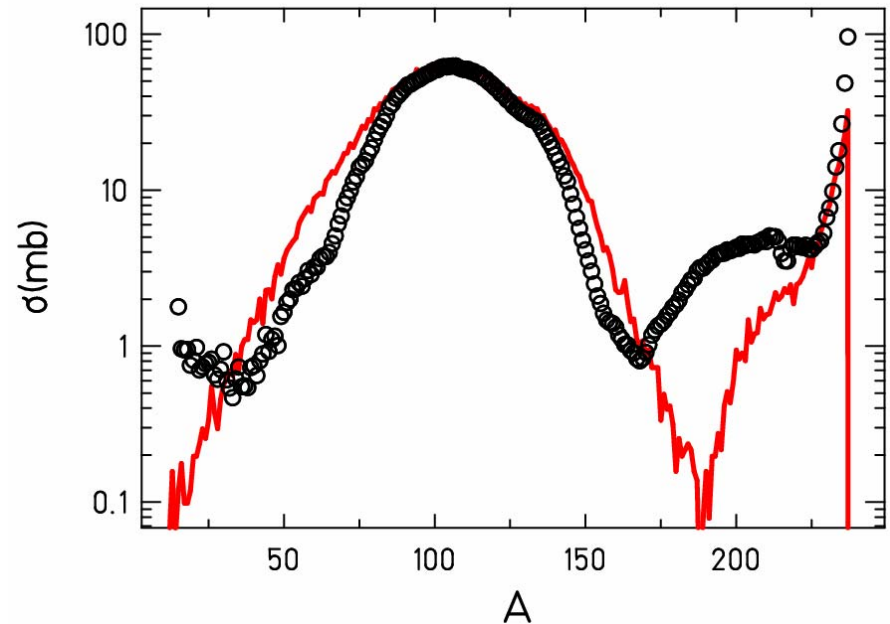
Exp. data:

J. Taïeb et al., NPA 724 (2003) 413

M. Bernas et al., NPA 725 (2003) 213

M.V. Ricciardi, PhD thesis

Transition-state model



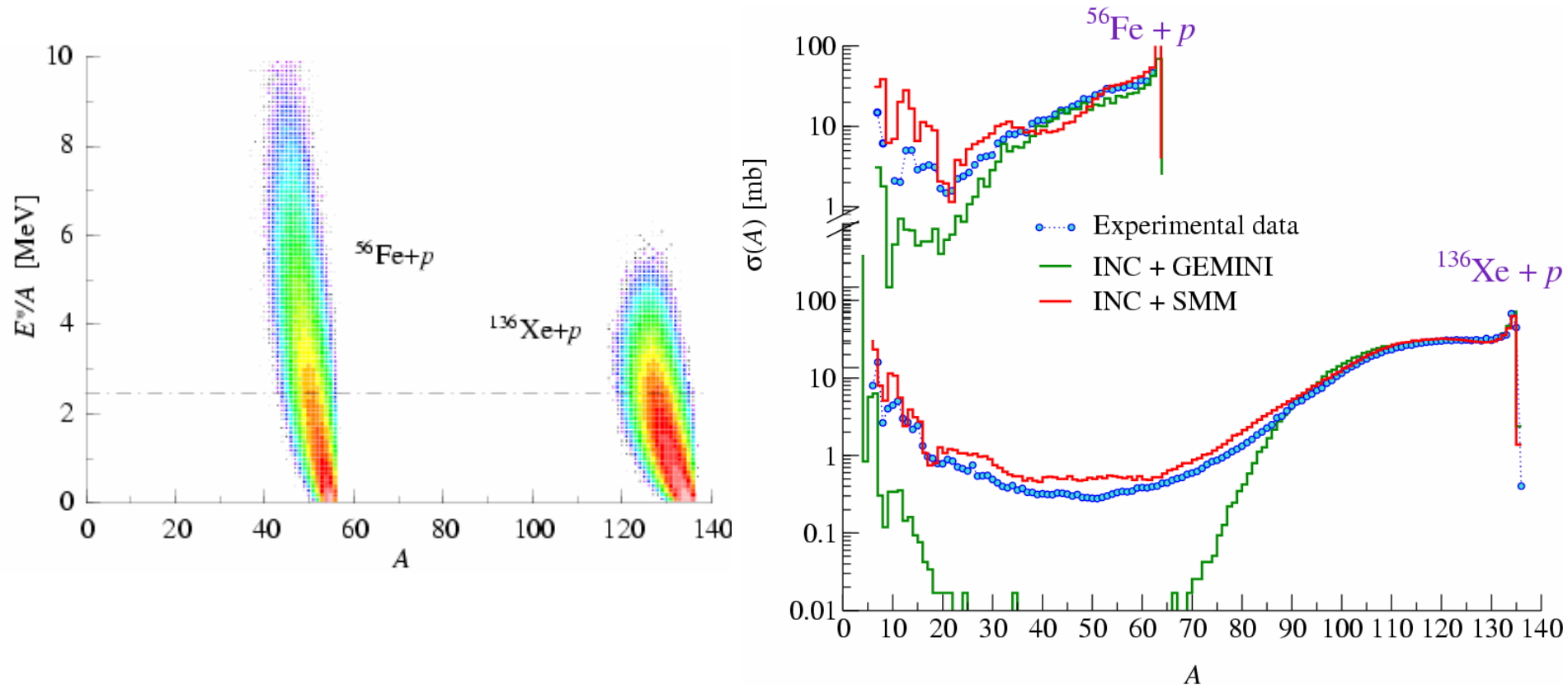
EXP: $\sigma_{\text{fiss}} = 1.53 \pm 0.2 \text{ b}$

DM: $\sigma_{\text{fiss}} = 1.52 \text{ b}$

TSM: $\sigma_{\text{fiss}} = 1.73 \text{ b}$

Thermal instabilities

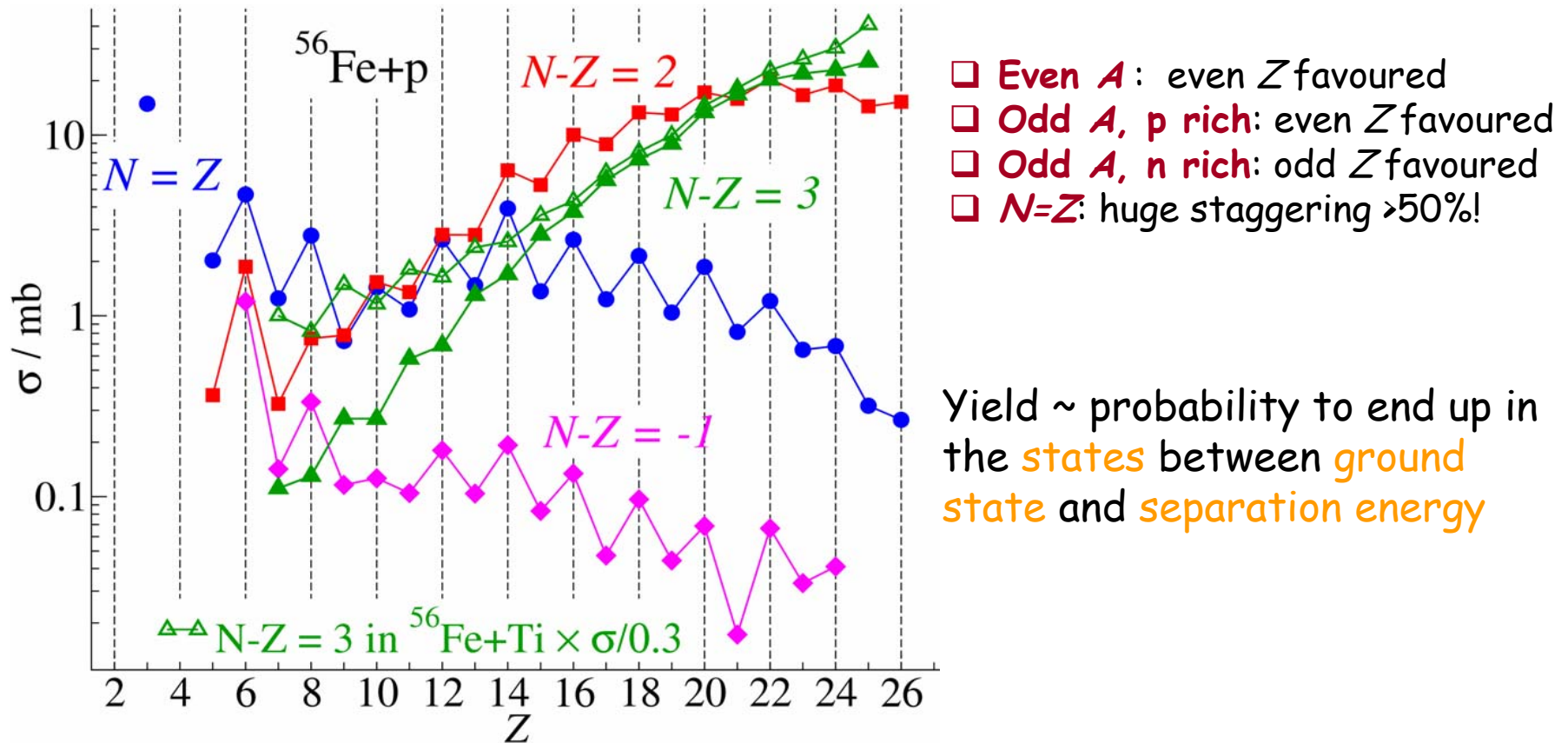
P. Napolitani, Phys. Rev. C 70 (2004) 054607



✓ Have to be considered in order to describe the production of light residues, especially in p-induced reactions on lower-mass targets.

Even-odd staggering in the yields

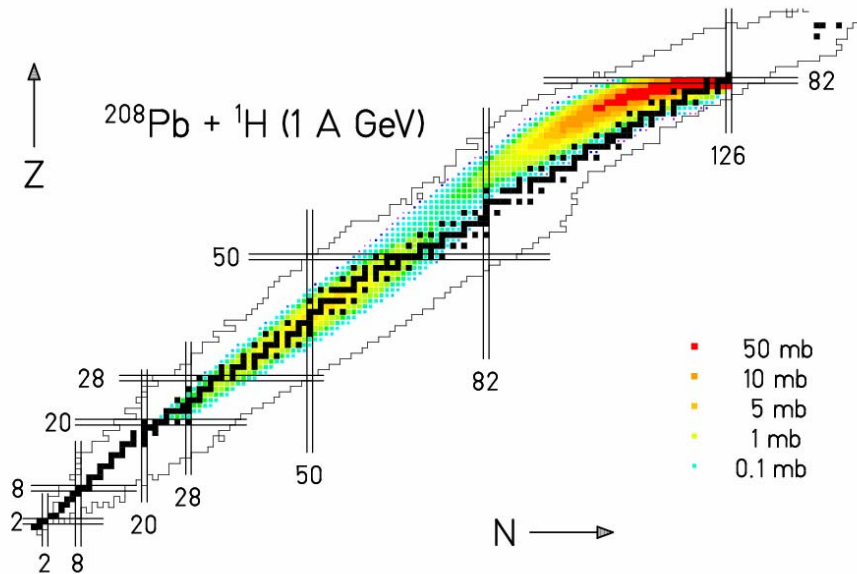
P. Napolitani, PhD Thesis



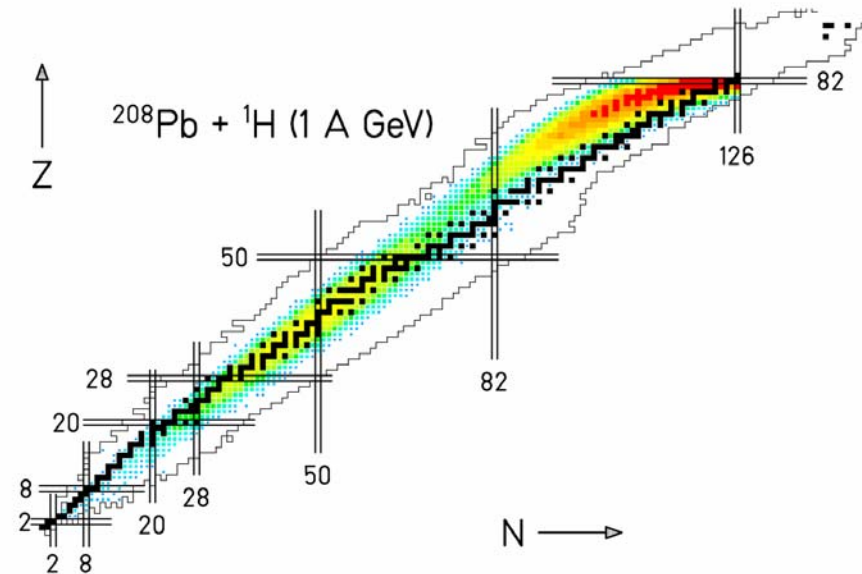
✓ Restoring of the nuclear structure in the last steps of the evaporation

The GSI code ABRABLA

□ Experiment



□ ABRABLA calculations



T. Enqvist et al., NPA686 (01)481

Important new information on some critical topics

Nuclear viscosity, thermal instabilities in nuclei and phase transitions...
(www-w2k.gsi.de/charms/activity.htm)

Summary

The GSI campaign for the investigation of spallation reactions has been extremely successful

- ❑ Experimental results
- ❑ New information on the physics of the reactions
- ❑ Development of a simulation code

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