NEW SIGNATURES OF NUCLEAR VISCOSITY FROM RELATIVISTIC HEAVY-ION COLLISIONS STUDIED AT GSI

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Introduction

- What is the viscosity?
  Quantified by β, reduced dissipation coefficient

$$E_{col} = E_{col}^{eq}\left[1-\exp(-\beta t)\right]$$

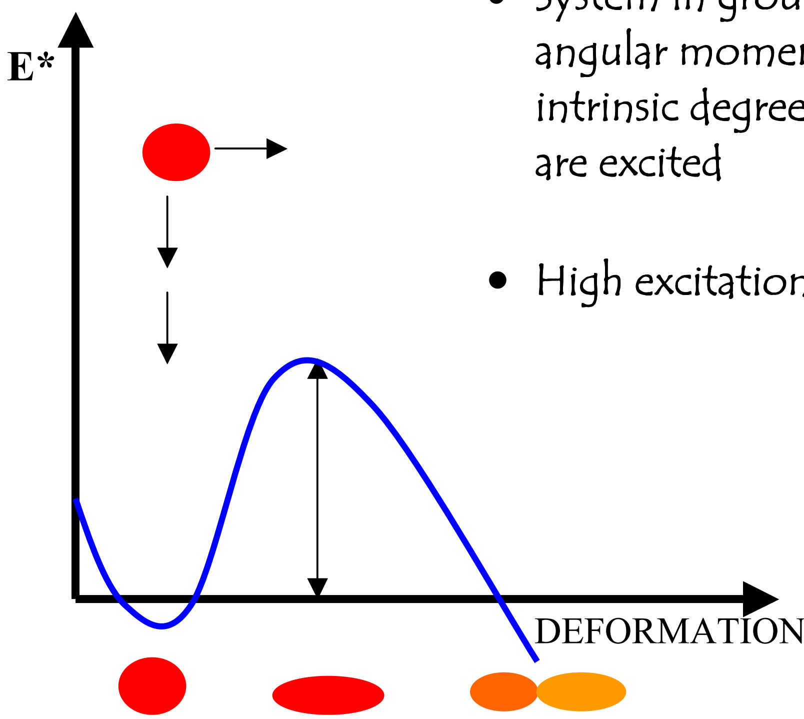
  Time is needed to reach thermal equilibrium.
  Contrast with respect to Statistical Model (SM)

- Fission is an appropriate tool for investigating viscosity

- Current experimental knowledge on β:
  Deformation dependence
  Temperature dependence

- New method
  Not too many side effects
  Sensitive to dissipation at small deformation

Ideal scenario

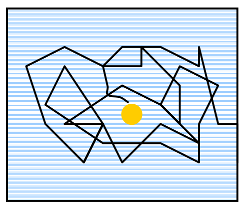


- System in ground state, no angular momentum. Only intrinsic degrees of freedom are excited
- High excitation energies

Due to viscosity, fission is inhibited at high E* and the number of fission events decreases respect to the SM

Model of Grangé & Weidenmüller (1980)
(Kramers 1940)

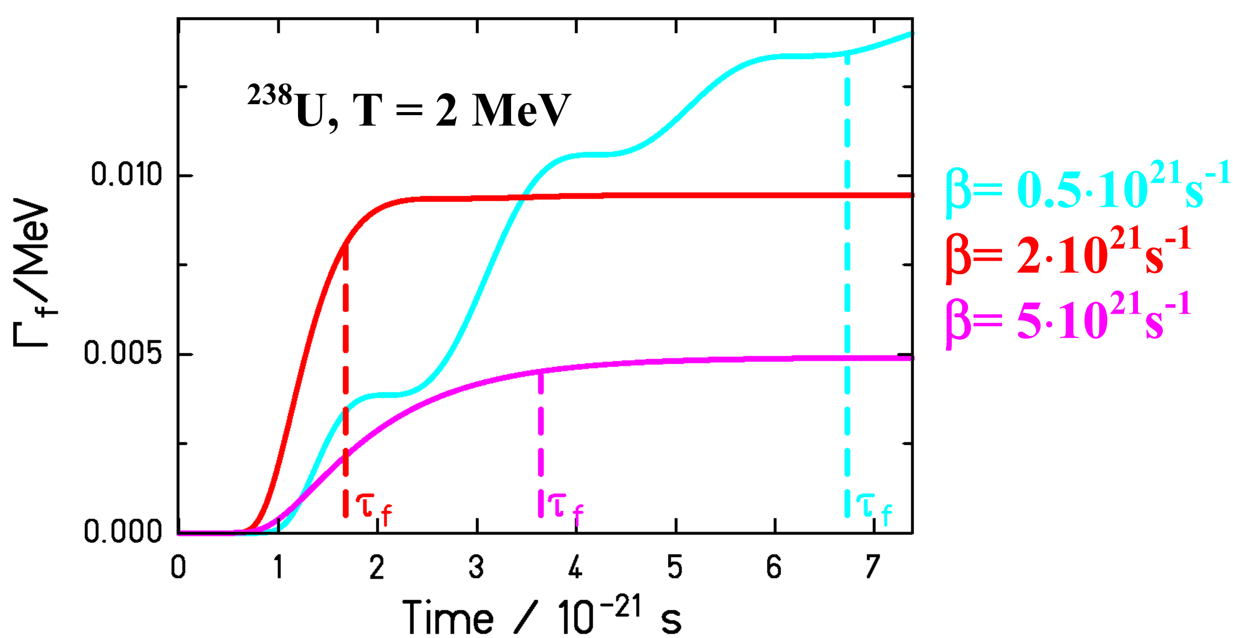
Fission process is considered as the evolution of the fission collective degree of freedom (e.g. elongation) in the heat bath formed by the individual nucleons.
Fokker-Planck equation (FPE), β is a parameter.



Brownian Motion

Numerical solution of the FPE under the conditions of the ideal scenario

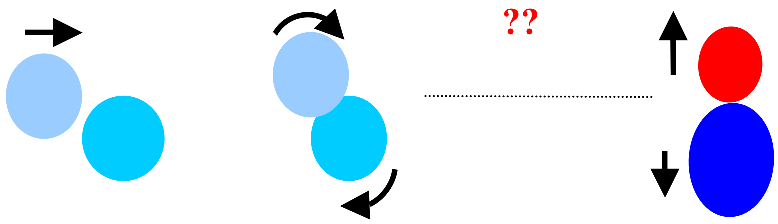
$\Gamma_f(t)$



Can we achieve experimentally the ideal scenario?

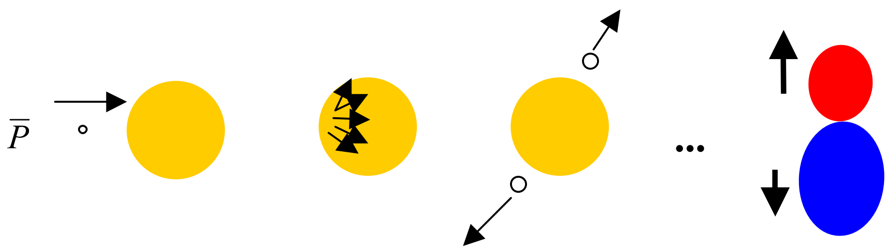
Fusion-Fission and Quasifission reactions

$E_{projectile} \approx$ 5-10 A MeV



Dynamical models needed to describe these reactions

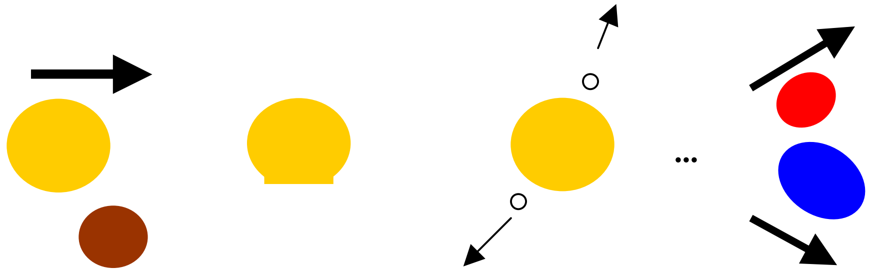
Antiproton annihilation



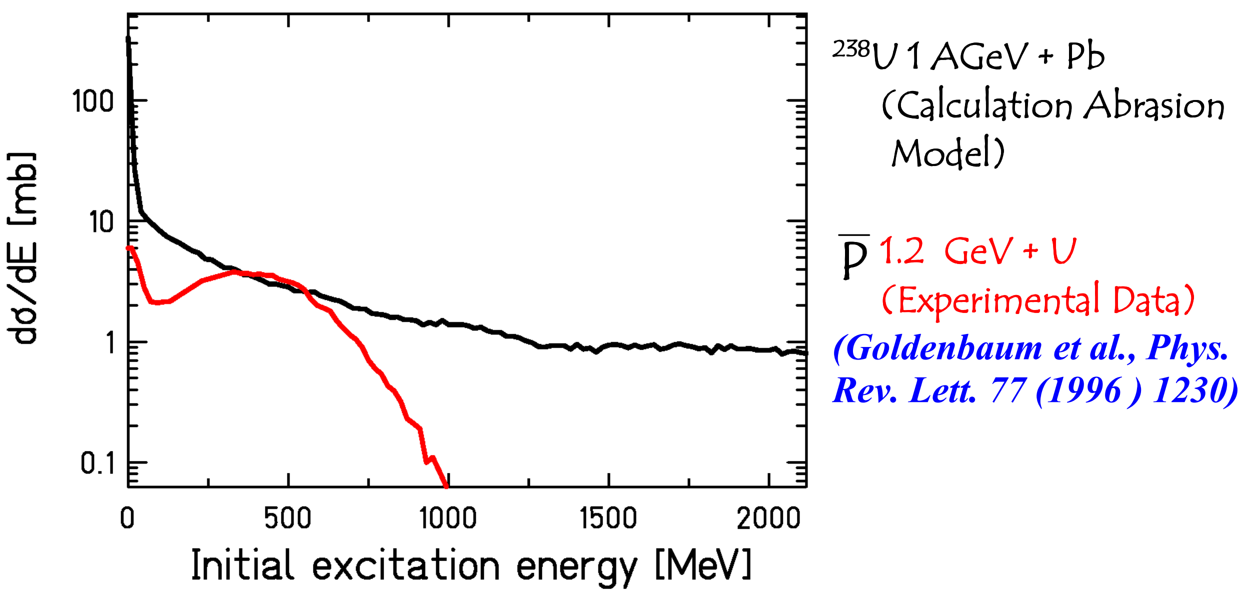
The same initial conditions as the model of Grangé and Weidenmüller

Difficulty to reach very high energies with large cross sections

Peripheral Heavy-Ion collisions at relativistic energies

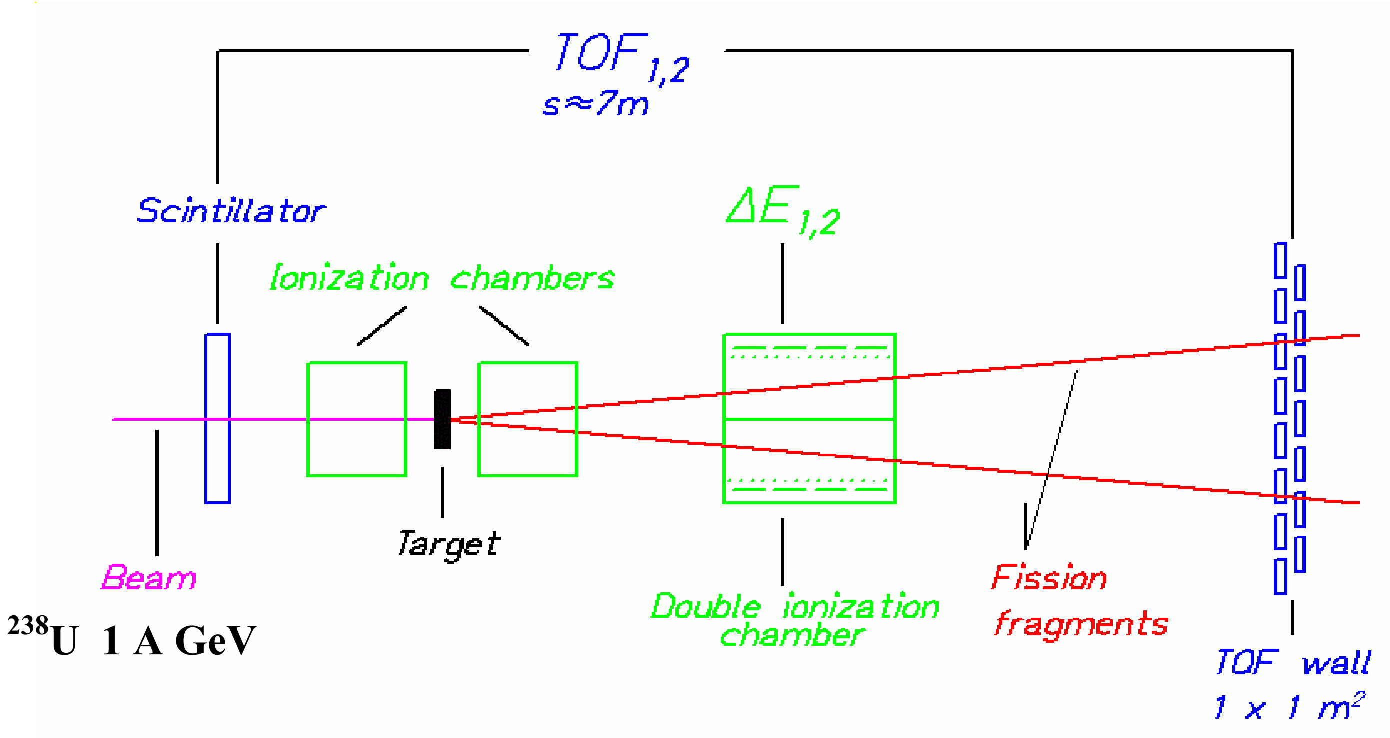


- Small shape distortion
- Low angular momentum
- High intrinsic excitation energies $E^* \sim \Delta A$

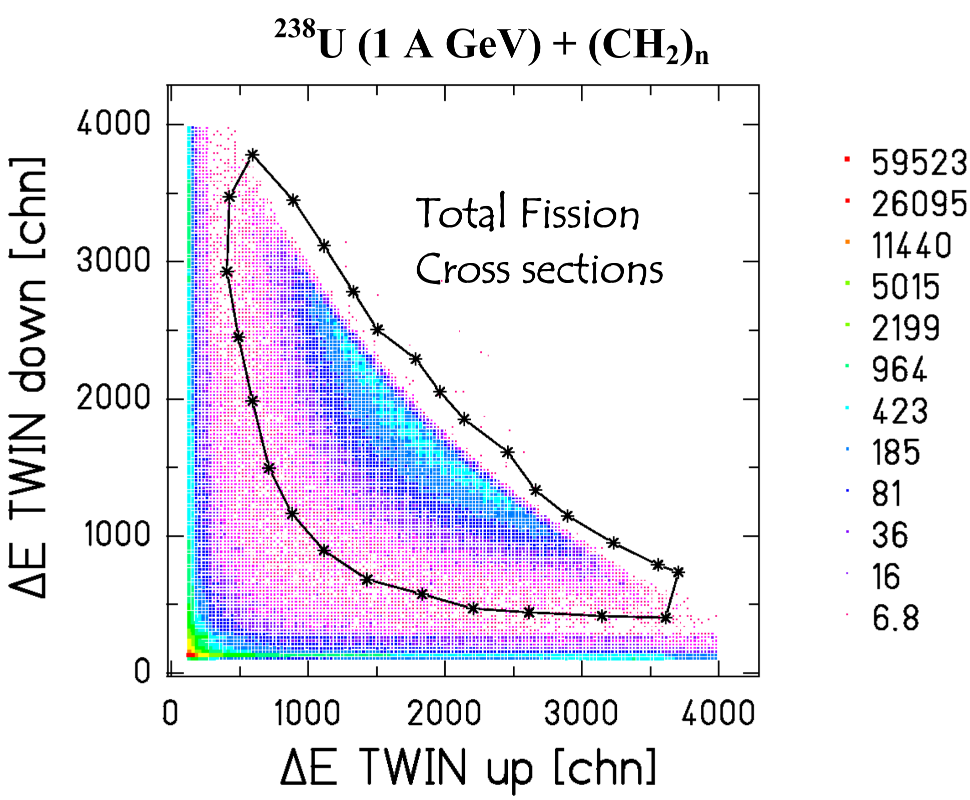


- Inverse kinematics

Experimental set-up for fission studies in inverse kinematics

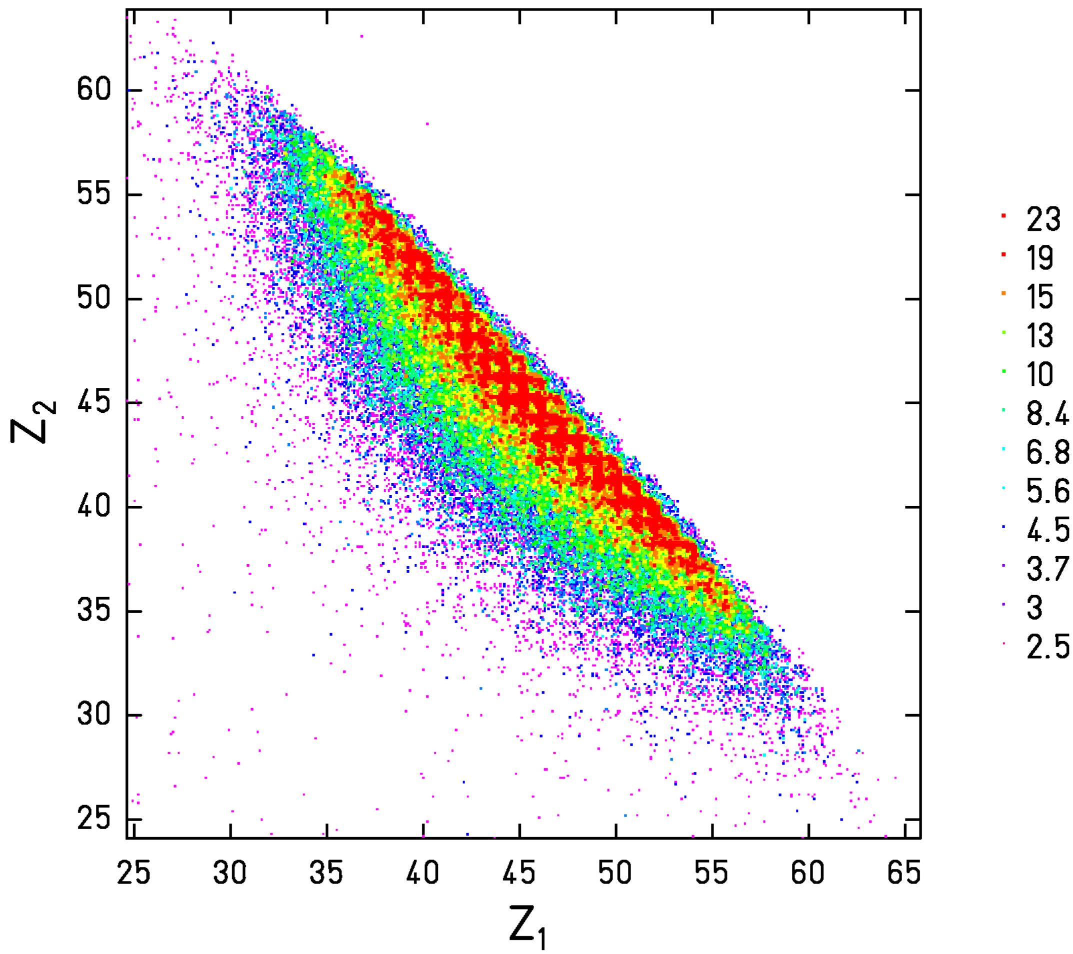


95% of detection efficiency



New observables !!!

^{238}U (1 A GeV) + $(CH_2)_n$

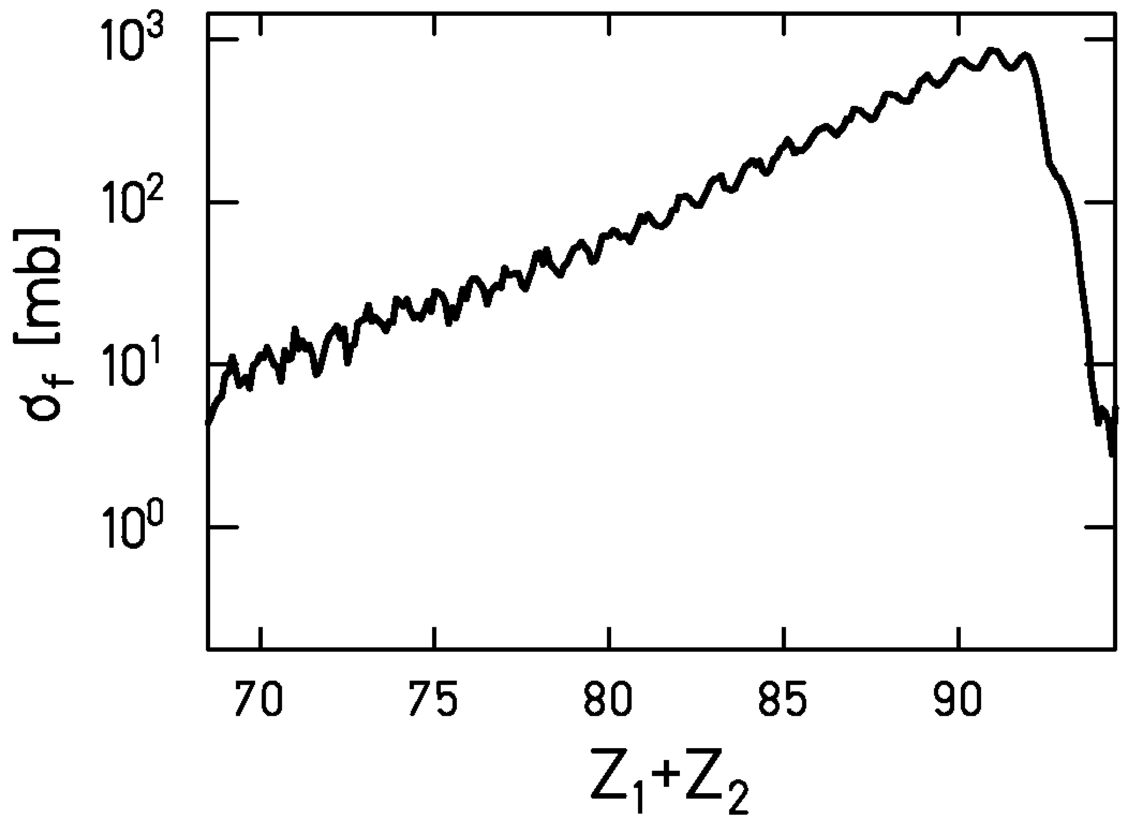


Partial fission cross sections $\sigma_{fiss}(Z_1 + Z_2)$

Width of the charge distributions of the fission fragments

Partial fission cross sections

^{238}U (1 A GeV) + $(CH_2)_n$

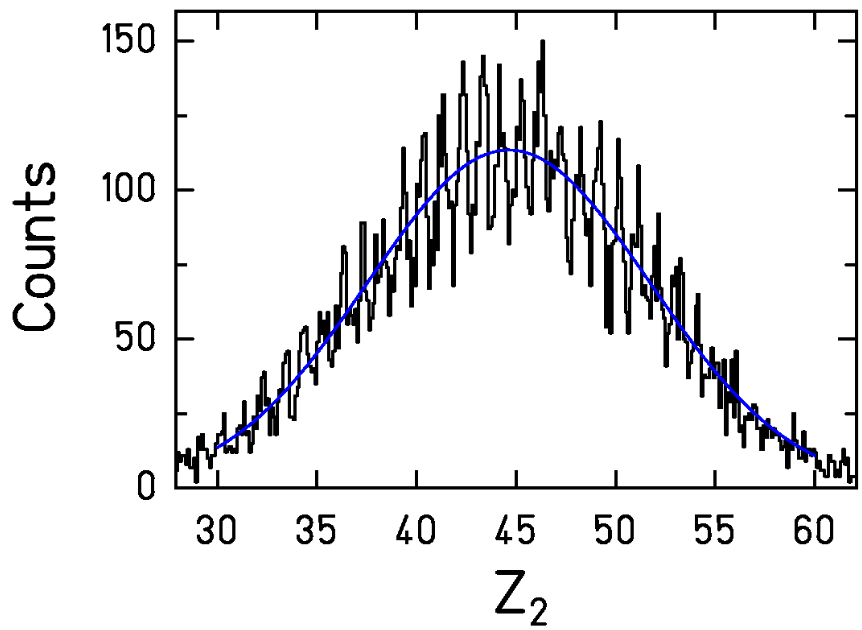


B_f

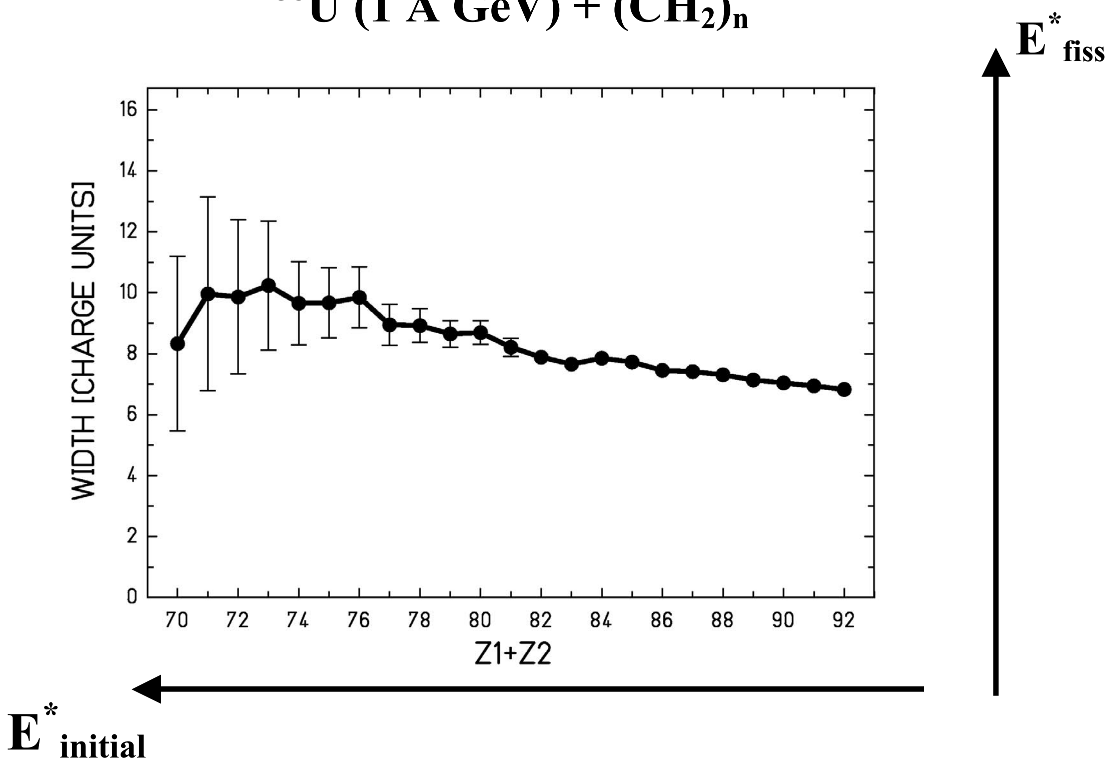
$E^*_{initial}$

Widths of the charge distributions of the fission fragments

$Z_1 + Z_2 = 89$

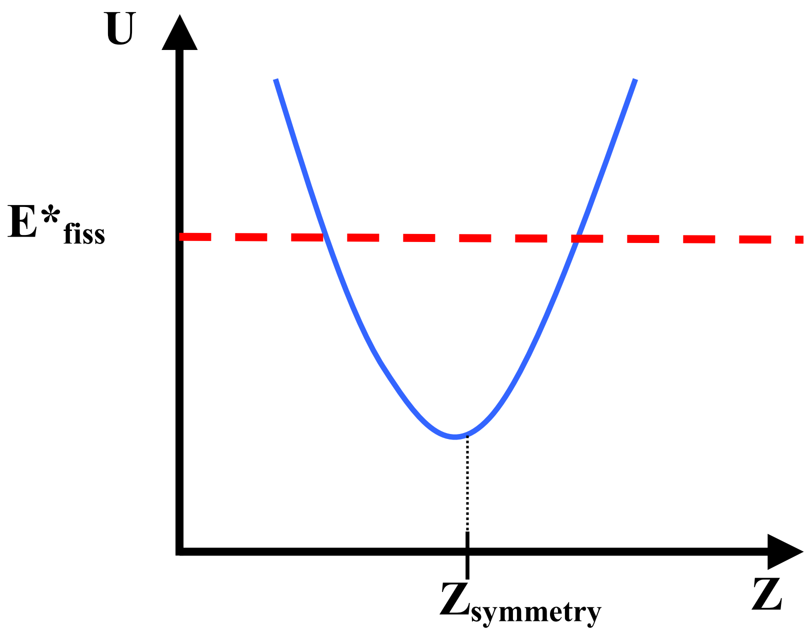


^{238}U (1 A GeV) + $(CH_2)_n$



Excitation energy at fission

LQDM + STATISTICAL MODEL

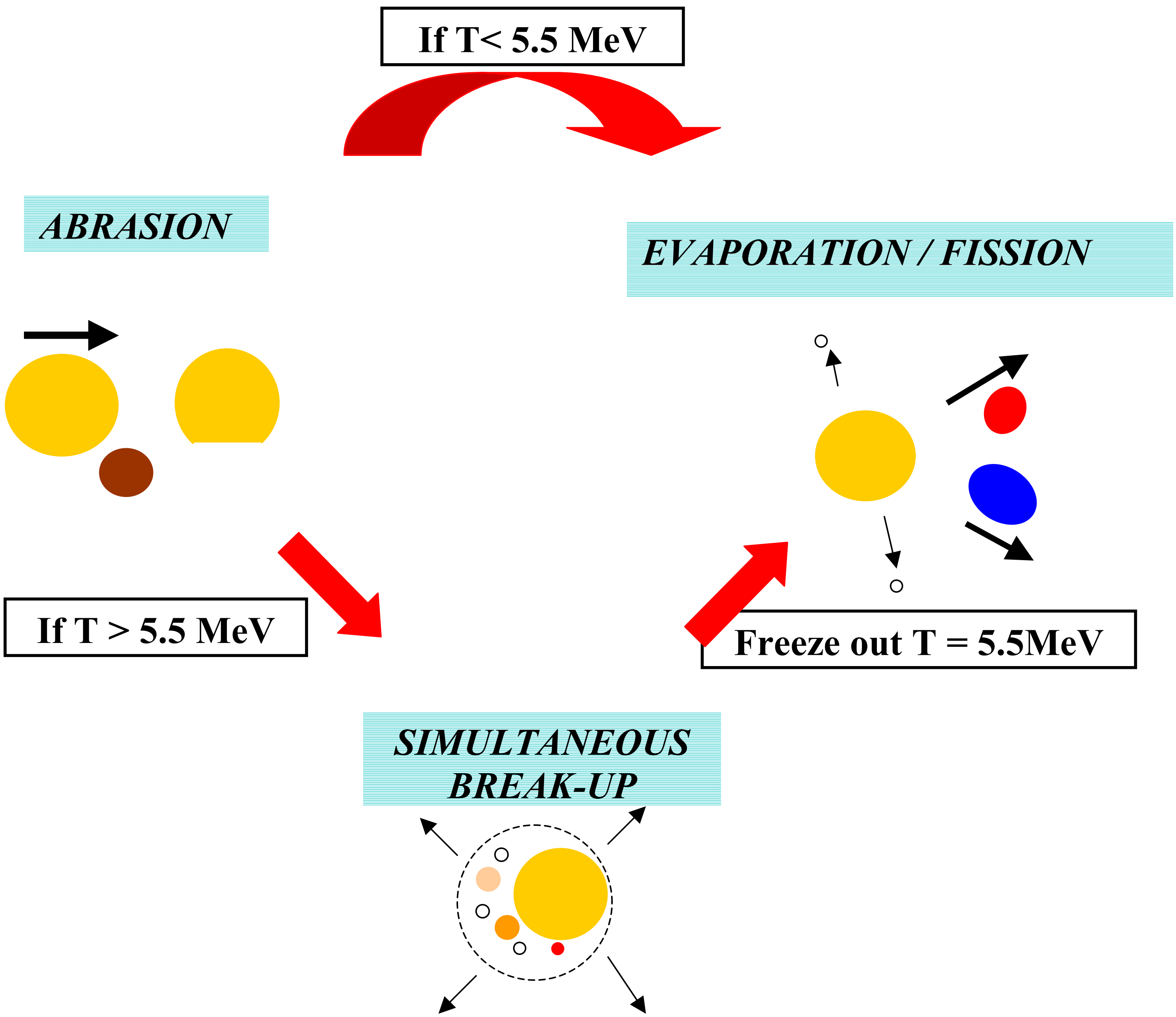


$$2\sigma_z^2 = \frac{1}{\sqrt{a}}\frac{\sqrt{E^*_{fiss}}}{C}$$

C(Z,A) **(S. I. Mulgin et al. Nucl. Phys. A 640 (1998) 375)**

Model to interpret the experimental observables

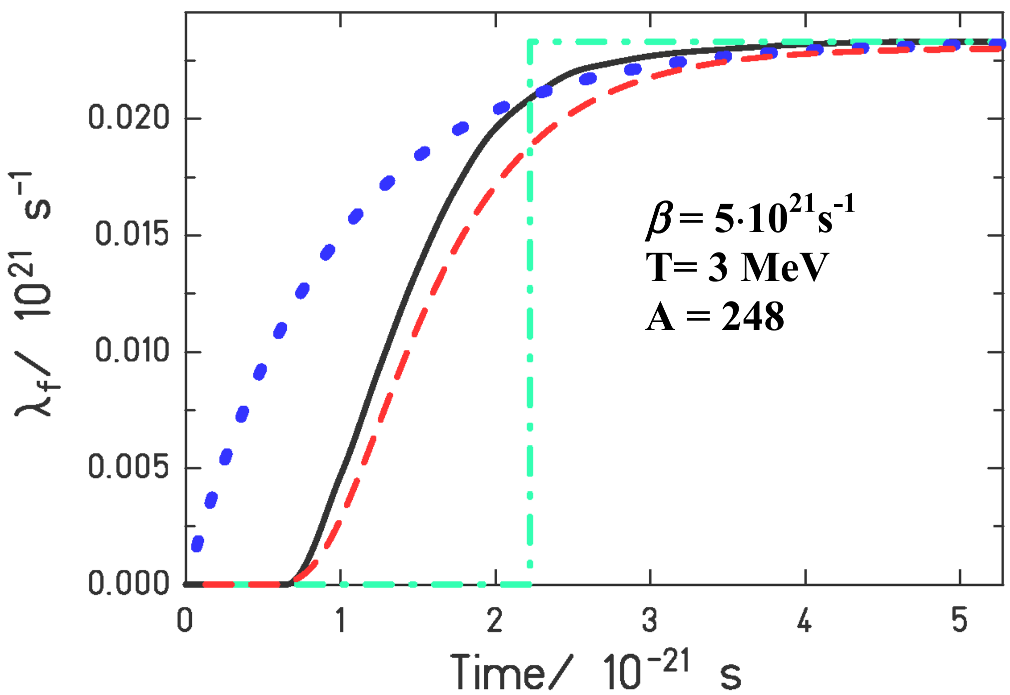
Updated version of GSI code ABRABLA:



(K. H. Schmidt, M. V. Ricciardi, A. Botvina, and T.Enqvist
to be published in Nucl. Phys. A)

Modelling of viscosity effects in fission

$$\lambda_f(t) = \Gamma_f(t) / \hbar$$



$\Gamma_f(t)$ =Num. Sol. FPE

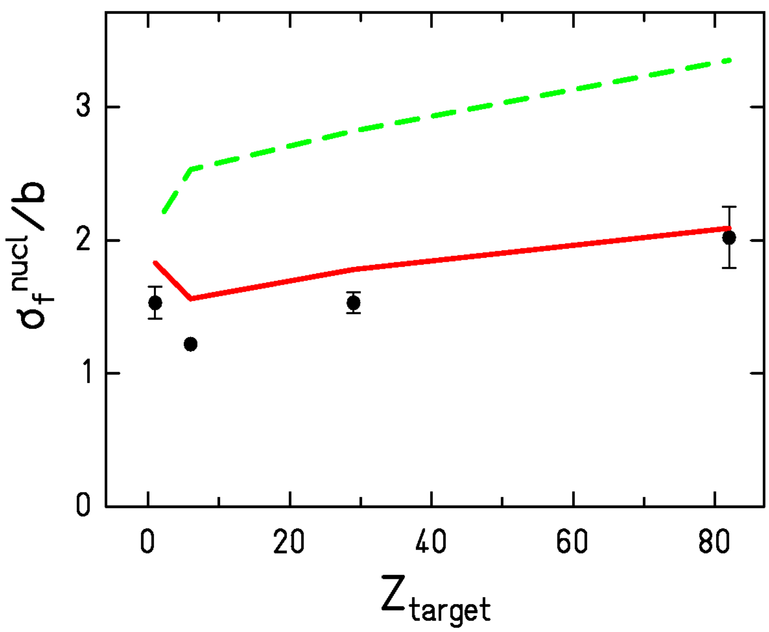
$\Gamma_f(t)$ =Analytical Sol. FPE

$\Gamma_f(t)$ = Step Function

$\Gamma_f(t) \propto (1-\exp(-2.3t/\tau_f))$

Total fission cross sections

^{238}U (1 A GeV) on different targets

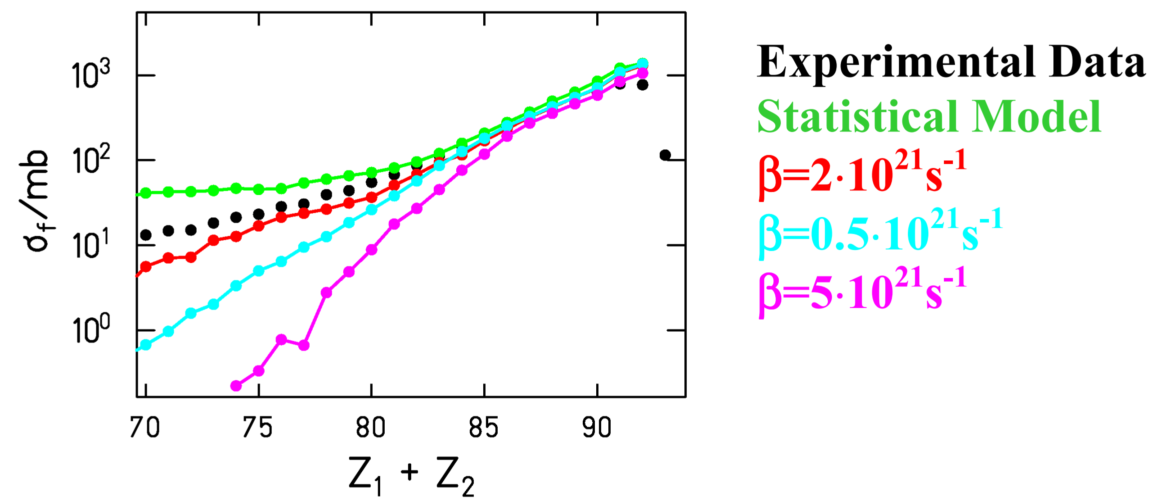


Experimental Data
Statistical Model
$\beta=2\cdot10^{21}s^{-1}$

The right trend of the target dependence is only reproduced when viscosity is considered

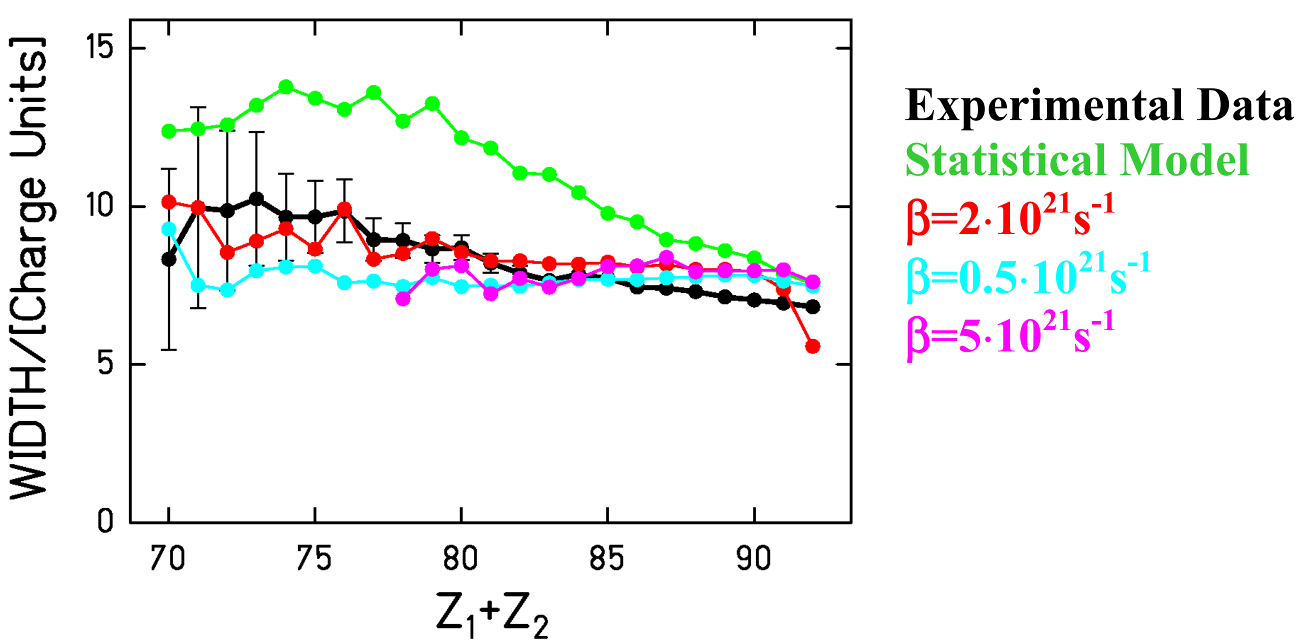
Partial Fission Cross Sections

^{238}U (1 A GeV) + $(CH_2)_n$



Widths of the charge distributions of the fiss. fragments

^{238}U (1 A GeV) + $(CH_2)_n$

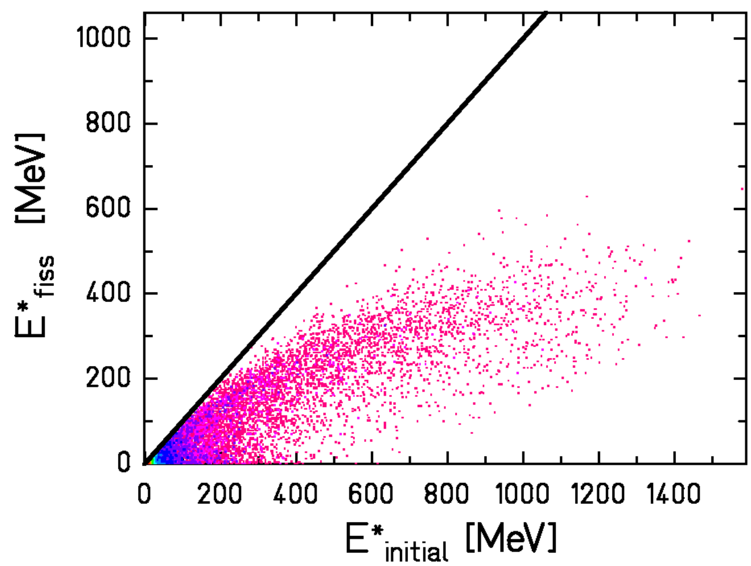


Best description $\beta = 2\cdot10^{21}s^{-1} \rightarrow \tau_f \approx (2.5\pm0.8)\cdot10^{-21}$ s

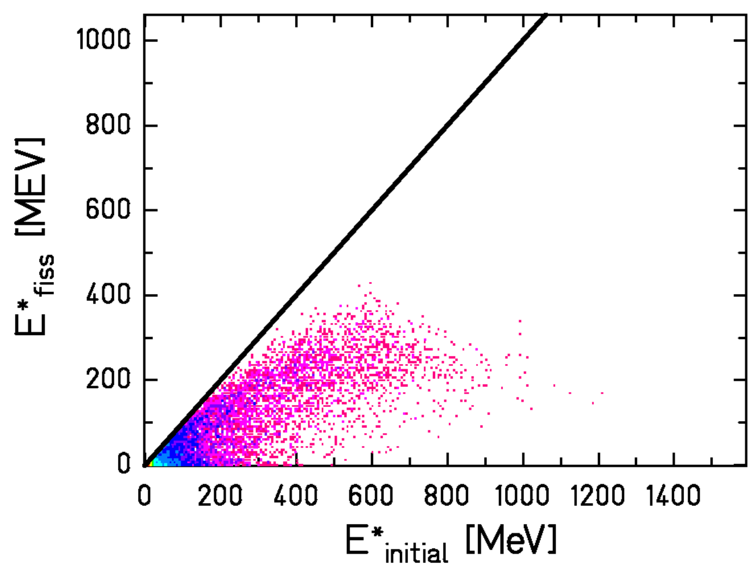
Effect of simultaneous break-up

Calculations for ^{238}U (1 A GeV) + Pb

NO BREAK-UP

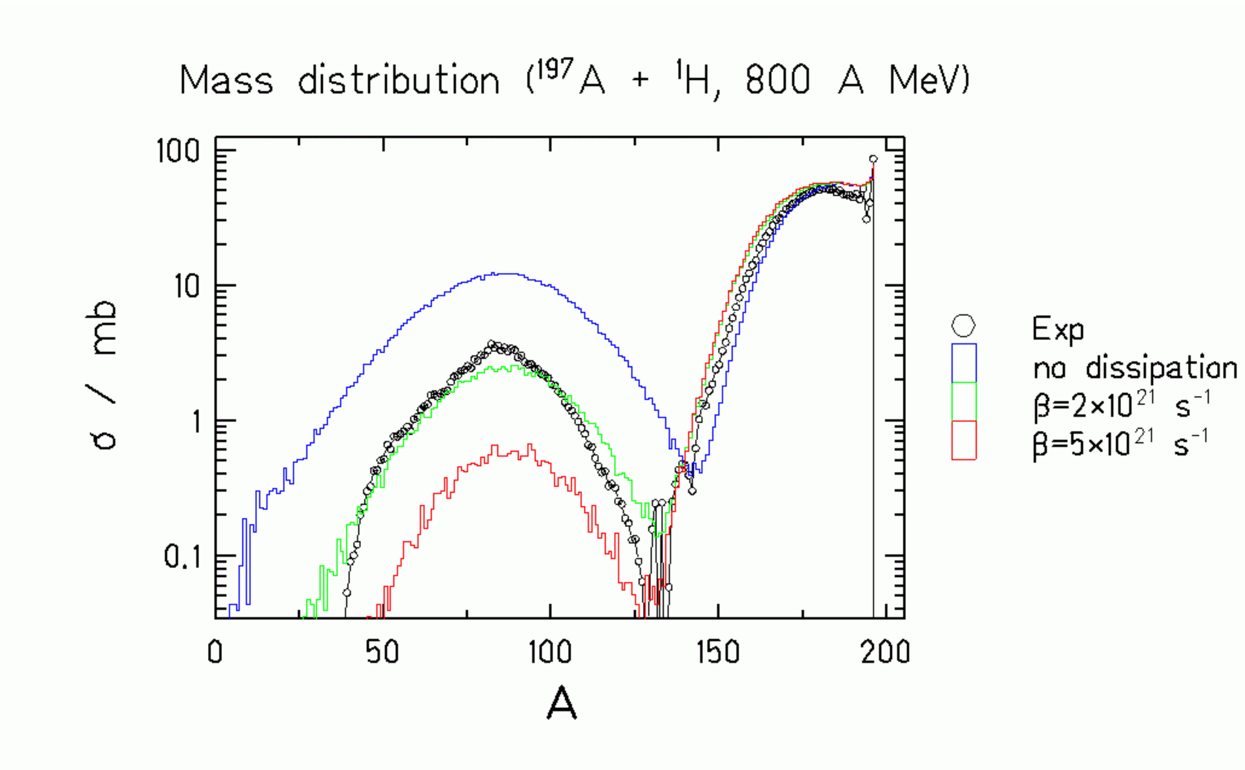


BREAK-UP



- Dissipation inhibits fission at high excitation energies
- The effect of the transient time starts to be remarkable at $E^* \gtrsim 150$ MeV
- The simultaneous break-up has an effect on fission only at $E^* \gtrsim 800$ MeV

Prediction of production cross sections



(J. Benlliure et al., accepted for publication in Nucl. Phys. A)

Conclusions

- Fission induced by peripheral heavy-ion collisions at relativistic energies, ideal conditions for the investigation of viscosity at low deformation

- Analysis of
  - Total nuclear fission cross sections
  - Partial fission cross sections
  - Widths of the charge distributions of fission fragments

- All observables described by $\boldsymbol{\beta = 2 \cdot 10^{21} s^{-1}}$

  - $\boldsymbol{\tau_f \approx (2.5 \pm 0.8) \cdot 10^{-21}}$ **s,**
    In the considered deformation and temperature range, nuclei behave rather like water than honey…

  - Viscosity effects at small deformation remarkable in the E* range

$$150 \text{ MeV} \lesssim E^* \lesssim 450 \text{ MeV}$$