NEW SIGNATURES ON DISSIPATION FROM THE STUDY OF RELATIVISTIC HEAVY-ION COLLISIONS

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Contents

- Introduction and motivation
- New experimental approach to investigate dissipation
- Experimental set-up
- Experimental observables sensitive to dissipation
- Results
- Conclusions

Introduction

Deexcitation process of the nucleus:

- Statistical model
- Dynamical model

    Transport theories

Two types of degrees of freedom

Collective ⇄ ***intrinsic***

Dissipation:

$$\beta = dE_{coll}/dt\ [1/(E^{eq}_{coll} - E_{coll})]$$

β **rules the relaxation of the coll. degrees of freedom**

$$\beta\ (T,\ q)$$

Fission is an appropriate tool for investigating dissipation

Current knowledge on dissipation

Theory:

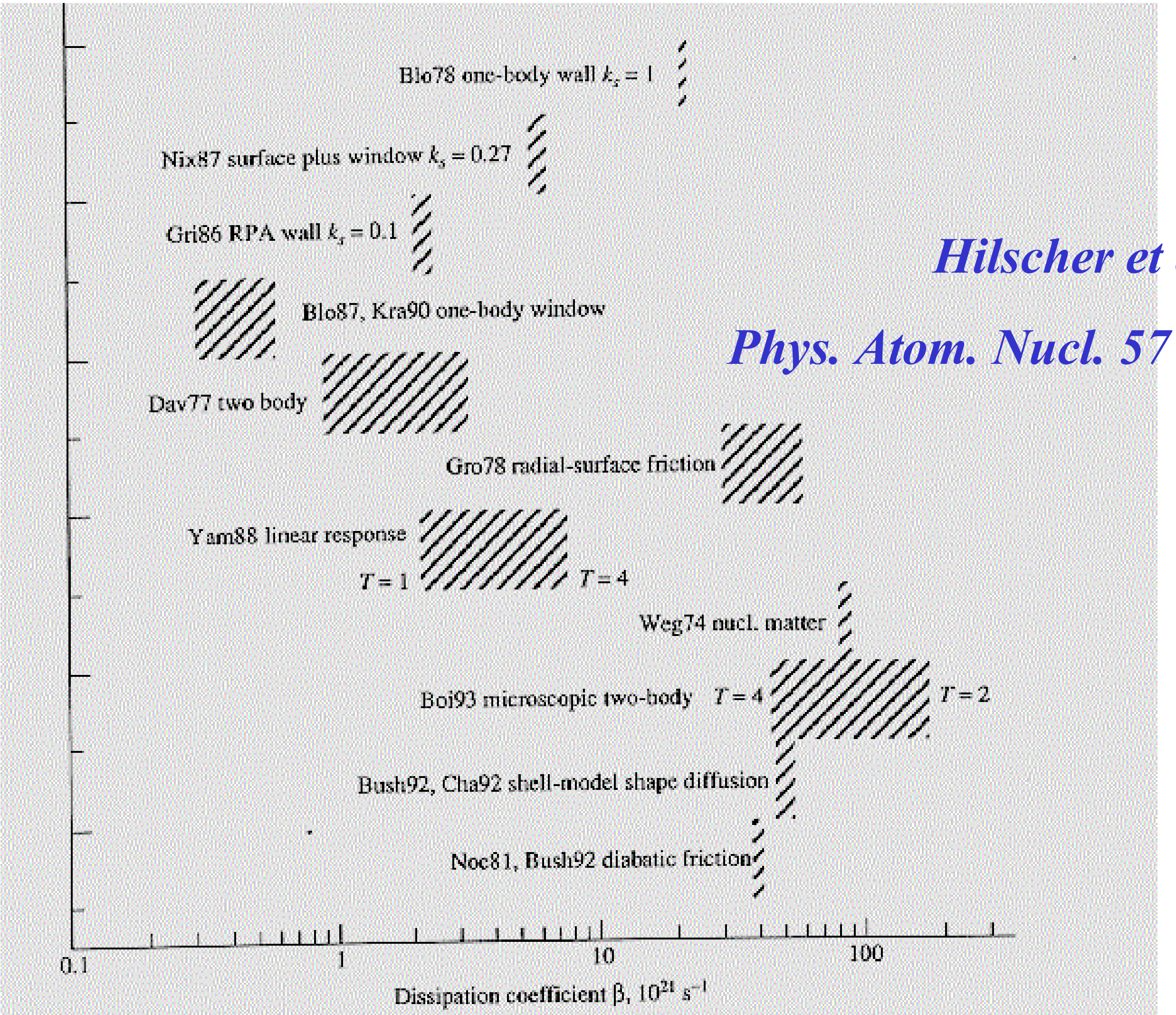


Fig. 13. Theoretical expectations for the dissipation coefficient β deduced from various theoretical models. The references for these models are Blo78 [44], Nix87 [3], Gri86 [45], Kra90 [46], Dav77 [47], Gro78 [48], Yam88 [49], Weg74 [50], Boi93 [51], Bush92 [52], Cha92 [36], and Nör81[53].

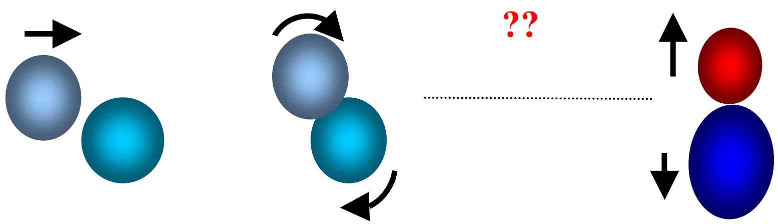
Hilscher et al.

Phys. Atom. Nucl. 57 (1994) 1187

Experiment:

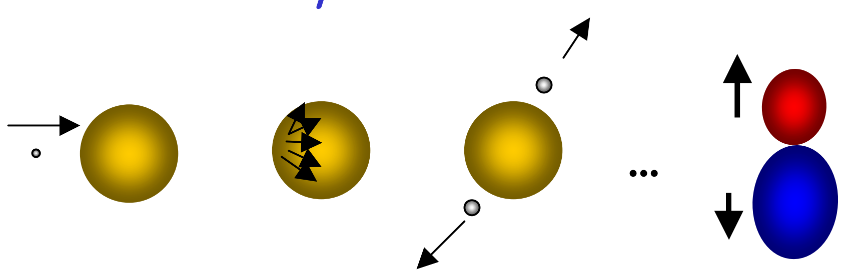
Standard reaction mechanisms to induce fission

Heavy-ion collisions at $E_{projectile} \approx$ 5-10 A MeV
(Fusion-Fission, Fast fission, Quasifission)



Dynamical models needed to describe these reactions

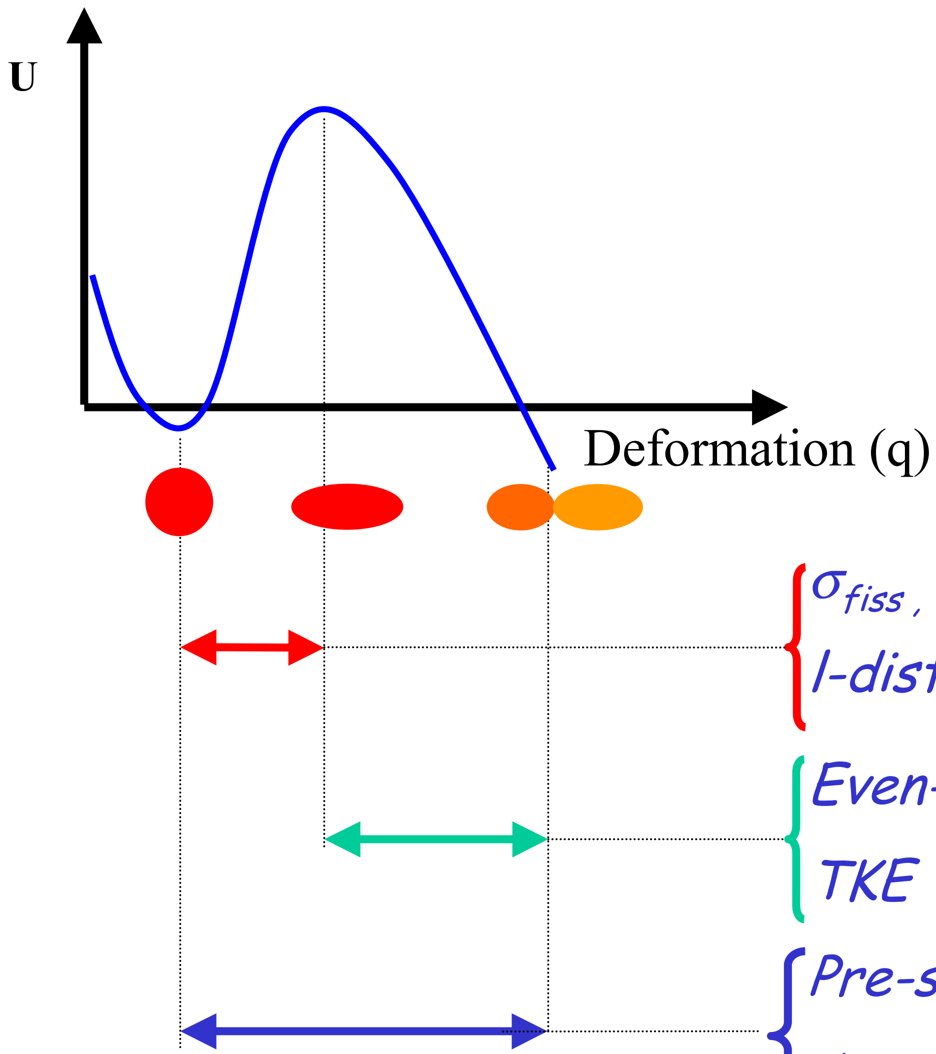
Antiproton annihilation and spallation reactions



Simplified theoretical description

Difficulty to reach very high E* with large cross sections

Standard experimental observables



$\sigma_{fiss}\,,\ \sigma_{evap}$

l-distrib. of evap. residues

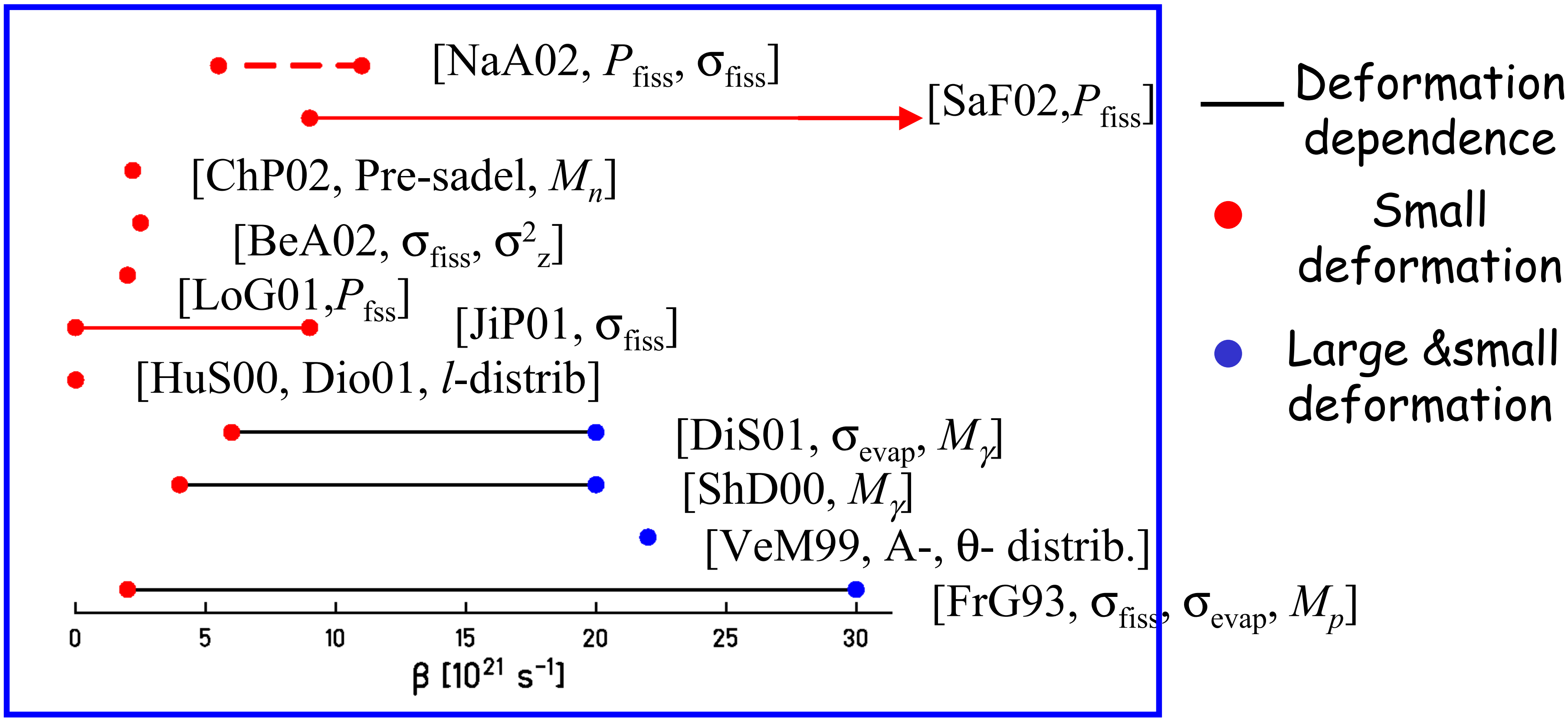
Even-odd effect

TKE

Pre-scission part. and γ-multiplicities

Ang., mass and charge distrib.

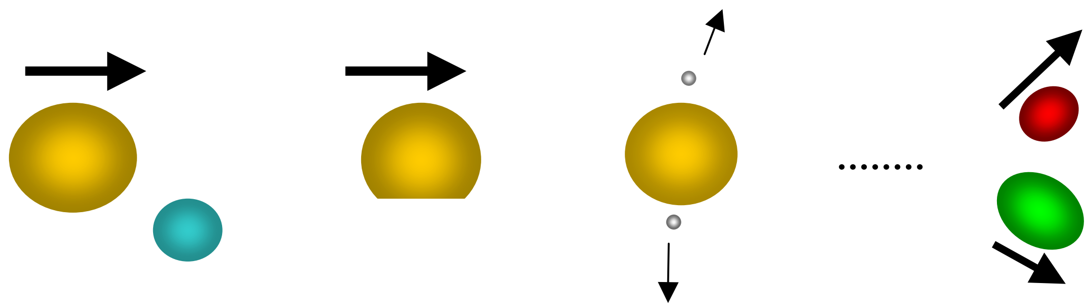
Latest experimental results



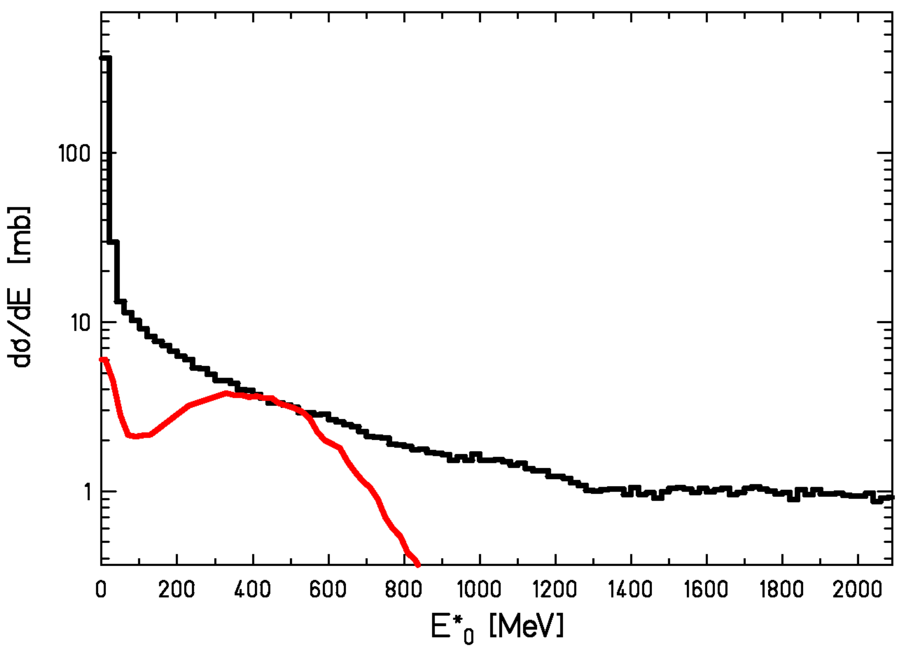
Temperature dependence ??

Fissility dependence ??

Peripheral heavy-ion collisions at relativistic energies



- Small shape distortion
- Low angular momentum
- High intrinsic excitation energies E* ~ ΔA



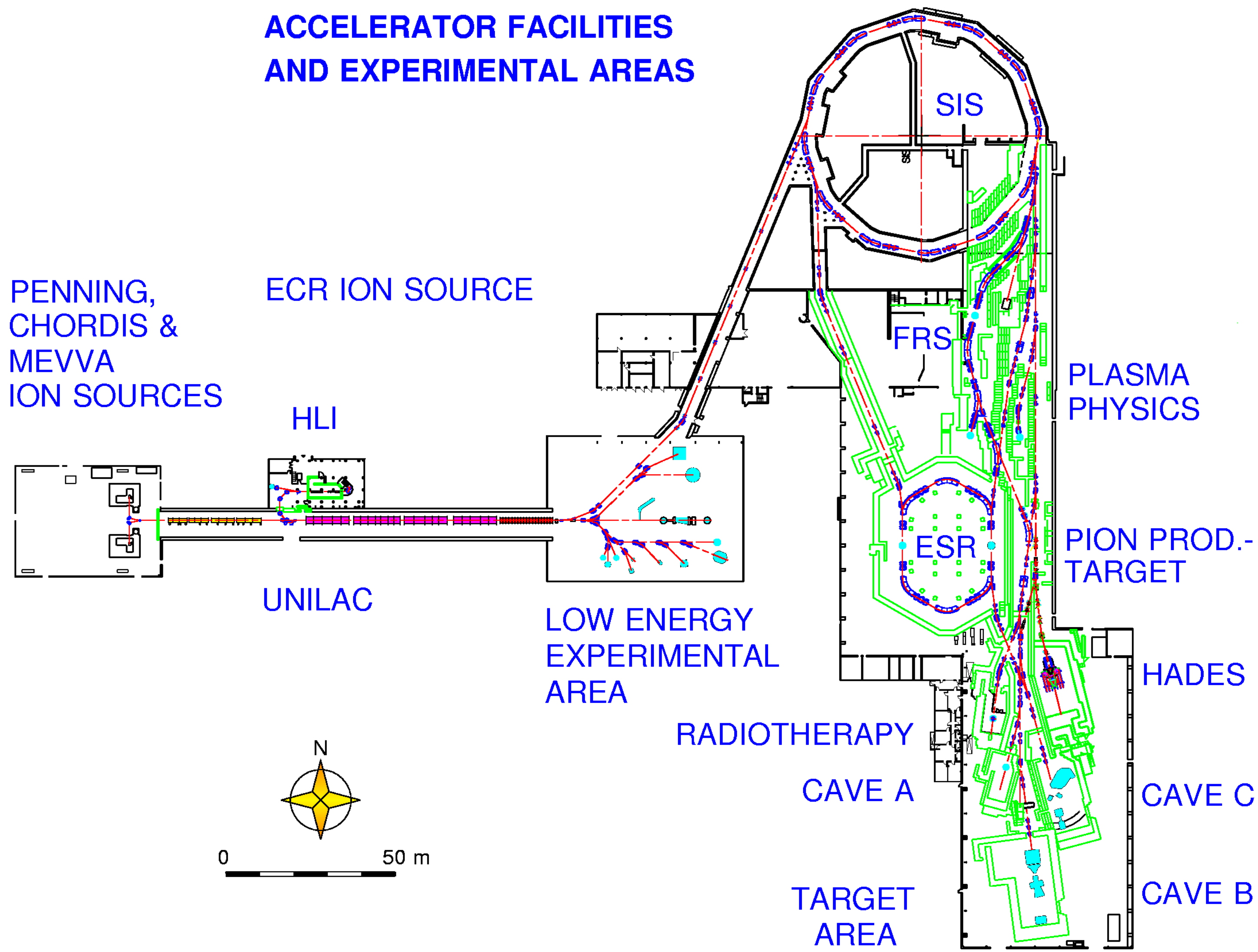
^{238}U (1 AGeV) + Pb
(Calculation Abrasion Model)

P (1.2 GeV) + U
(Experimental Data)

(Goldenbaum et al., Phys. Rev. Lett. 77 (1996) 1230)

- Inverse kinematics

ACCELERATOR FACILITIES AND EXPERIMENTAL AREAS



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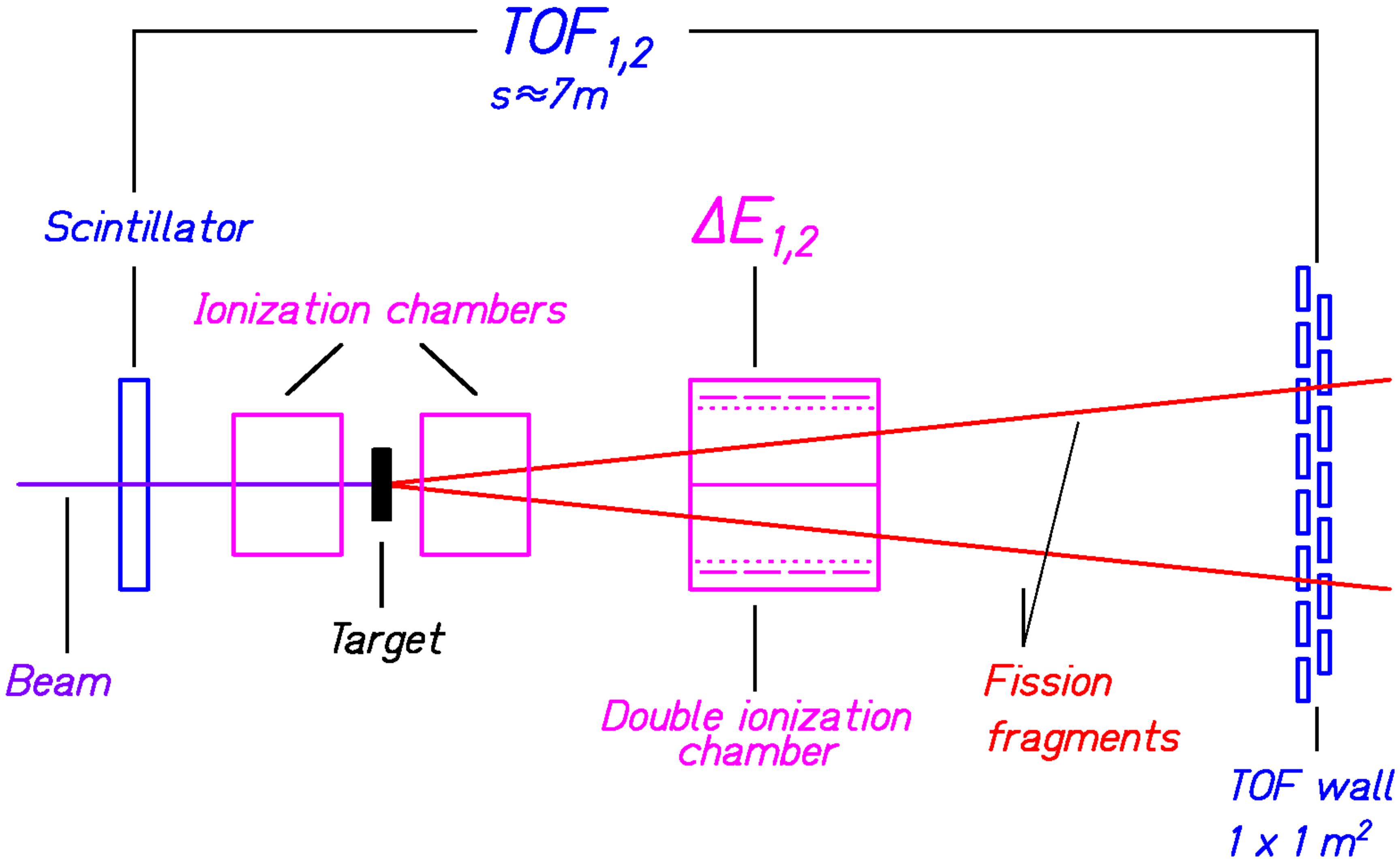
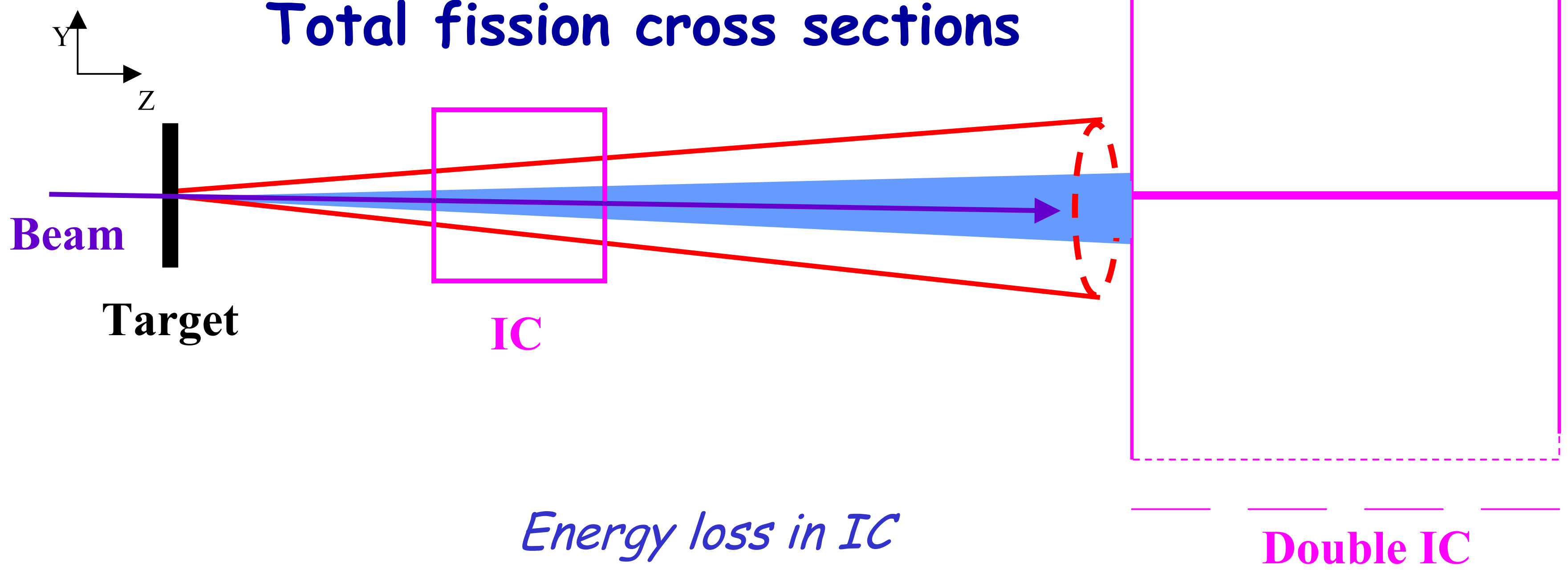
Experimental set-up for fission studies in inverse kinematics

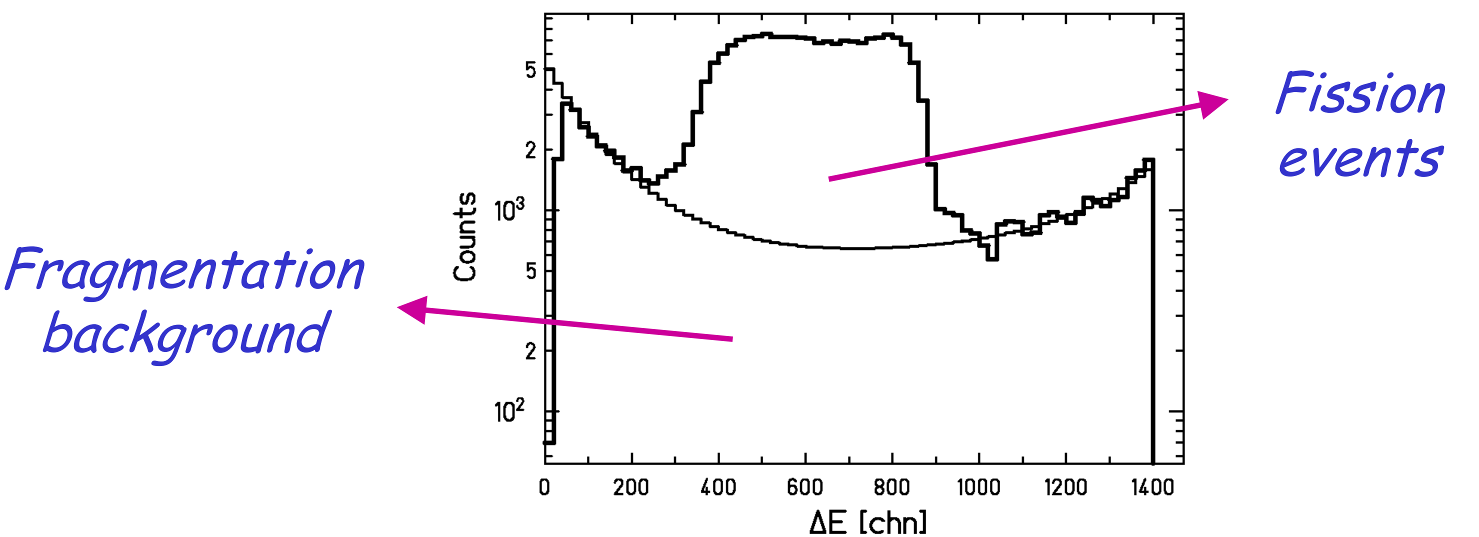


Observables

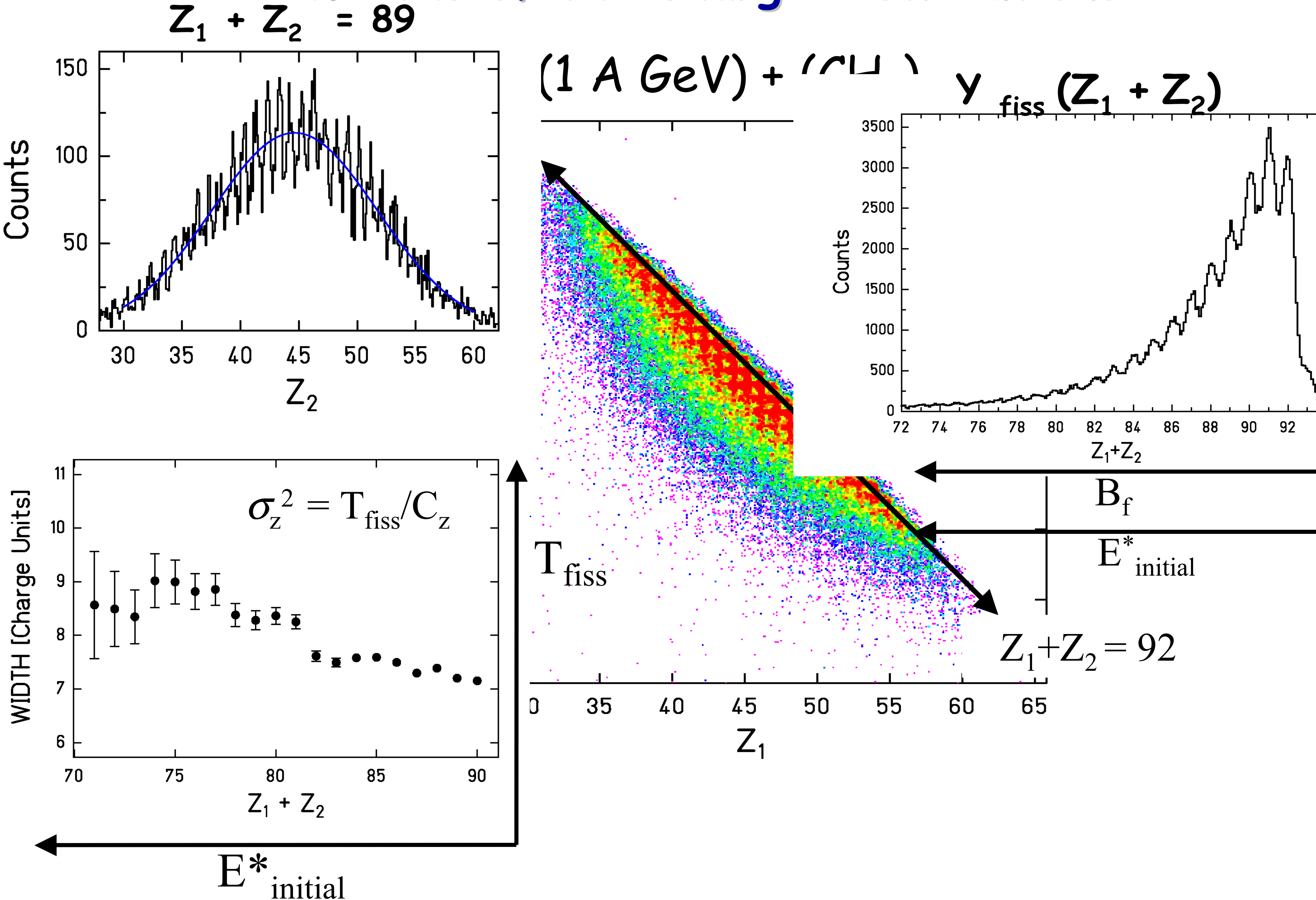
Total fission cross sections



Energy loss in IC

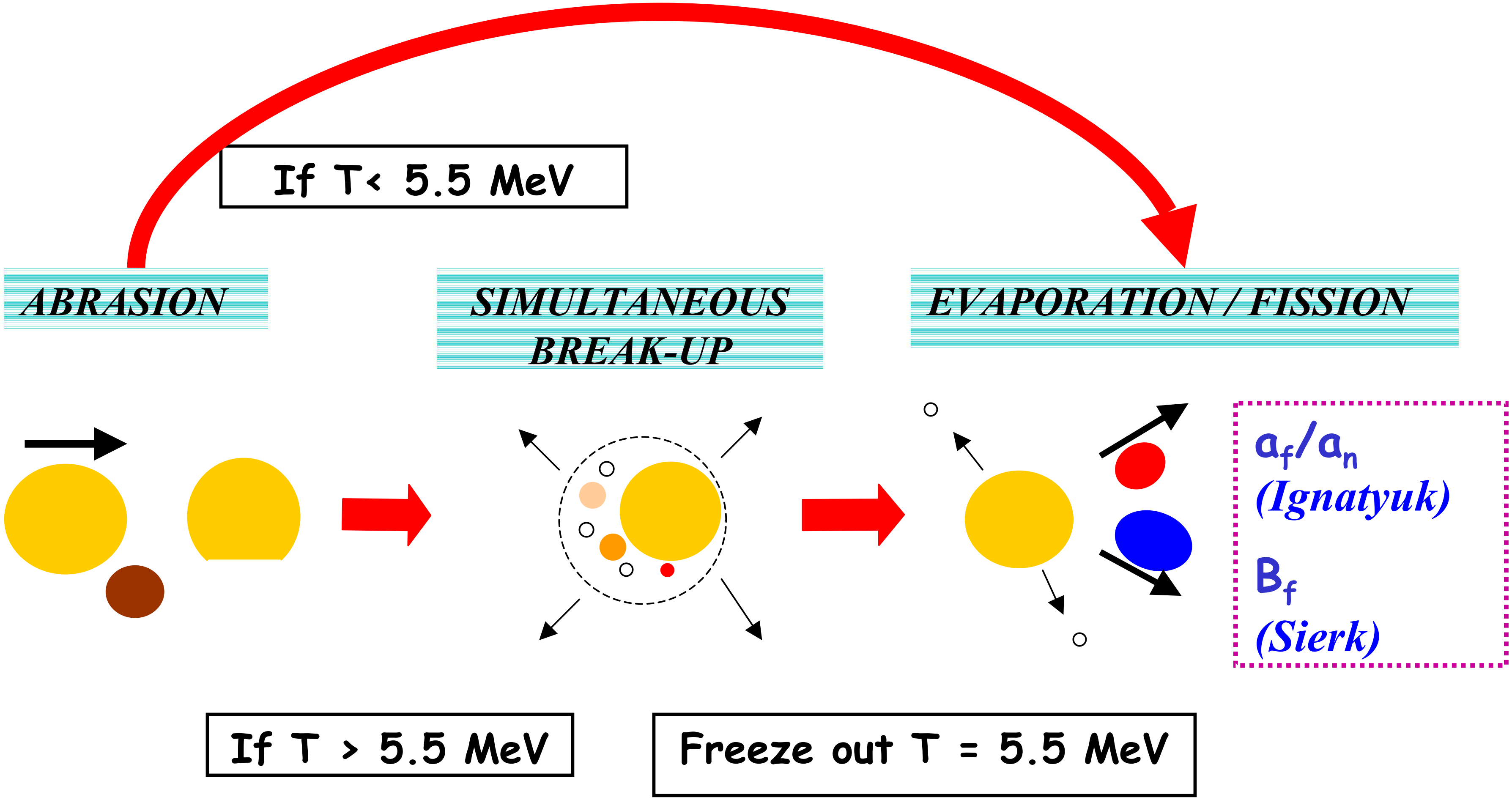


New observables: Partial fission cross sections & Widths of the charge distributions



The model

Updated version of GSI code ABRABLA:



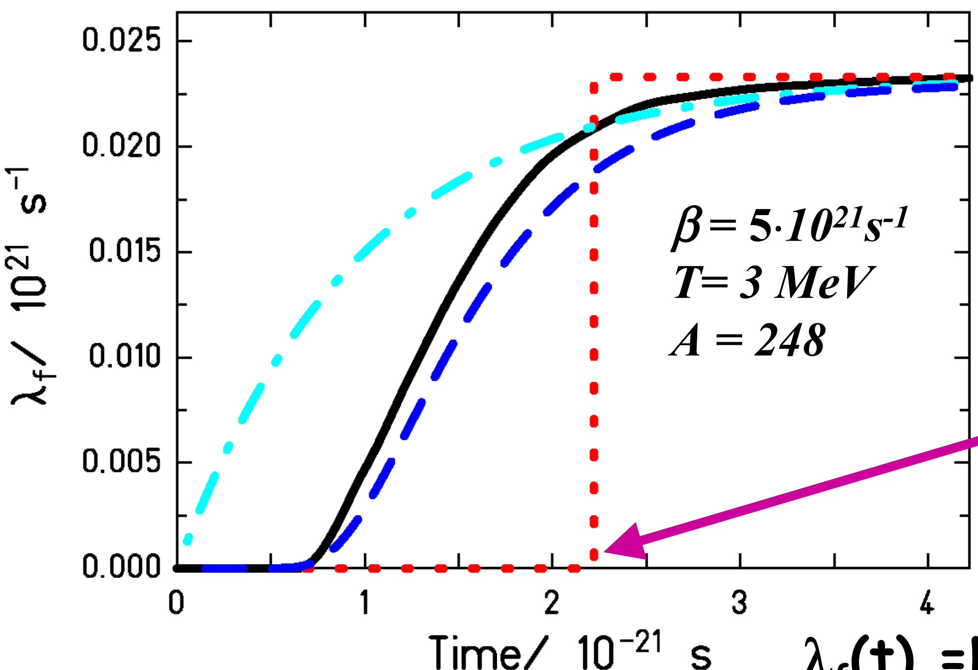
M.V. Ricciardi PhD. Thesis

Model of Grangé & Weidenmüller (1980)

Kramers (1940)

Numerical solution of the FPE under specific initial conditions

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



Transient time τ_f

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

(K.-H. Bhatt, et al., Phys. Rev. C 33 (1986) 954)

$\lambda_f(t)$ = Step Function

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

$\lambda_f(t)$ = Analytical approximation

Dependence of β on $\Gamma_{fiss}(t)$

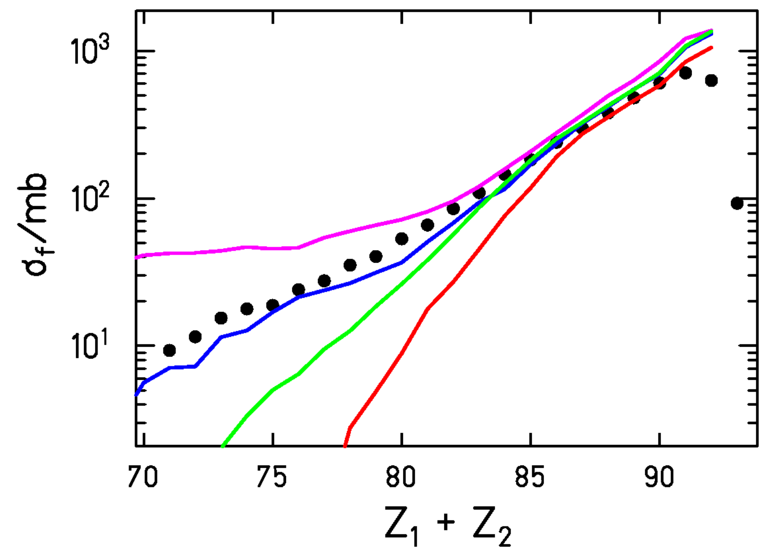
σ_f^{nucl} $^{238}U(1\ A\ GeV) + Pb$

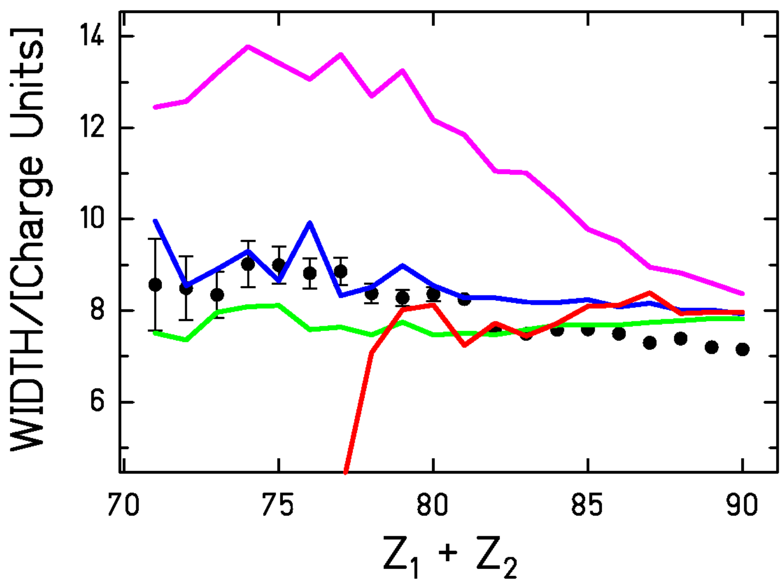
Experiment	**2.16±0.14 b**
Transition-state model	**3.33 b**
$\Gamma_f(t)$ **step** $\beta = 2 \cdot 10^{21}\ s^{-1}$	**2.00 b**
$\Gamma_f(t) \sim 1-\exp(-t/\tau)$ $\beta = 4 \cdot 10^{21}\ s^{-1}$	**2.04 b**
$\Gamma_f(t)$ **FPE** $\beta = 2 \cdot 10^{21}\ s^{-1}$	**2.09 b**

The value of β depends on the description for $\Gamma_f(t)$

Influence of β on $\sigma_f(Z_1+Z_2)$ and Z-Width(Z_1+Z_2)

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





● Experimental data

Transition-state model

$\beta = 2 \cdot 10^{21} s^{-1}$

$\beta = 0.5 \cdot 10^{21} s^{-1}$

$\beta = 5 \cdot 10^{21} s^{-1}$

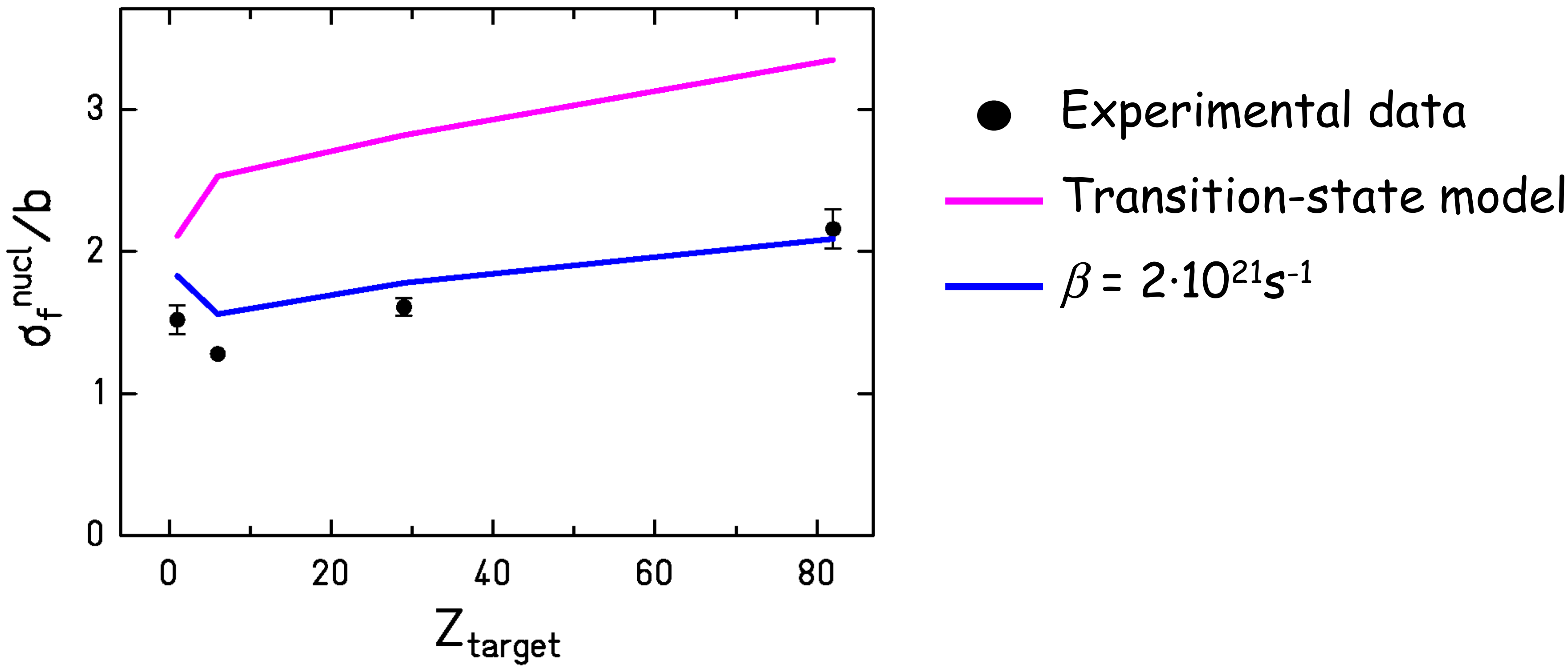
$\beta = 2 \cdot 10^{21} s^{-1}$

⬇

$\tau_f \approx (1.7 \pm 0.4) \cdot 10^{-21}\, s$

Target dependence of σ_f^{tot}

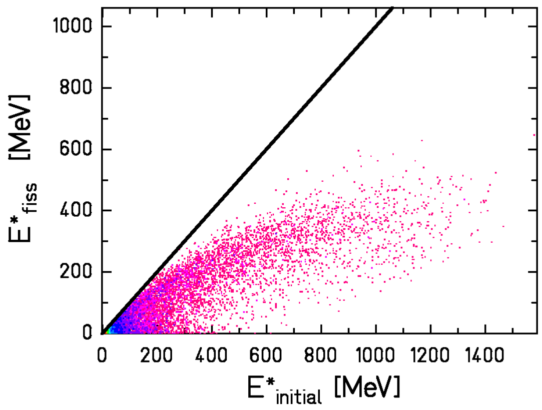
^{238}U (1 A GeV)



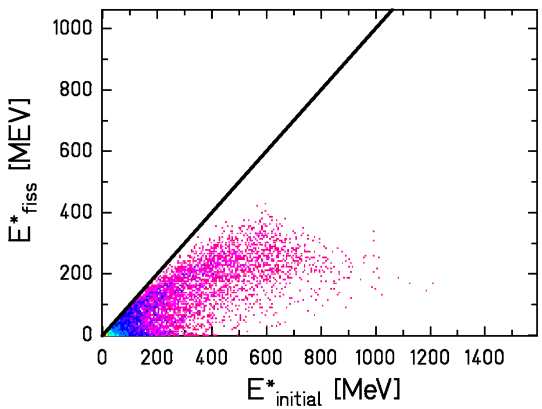
The minimum at Z_{target} = 6 can only be reproduced if dissipation is included

Calculations:

For fission events produced $^{238}U(1\cdot A\ GeV)+Pb$



NO BREAK-UP

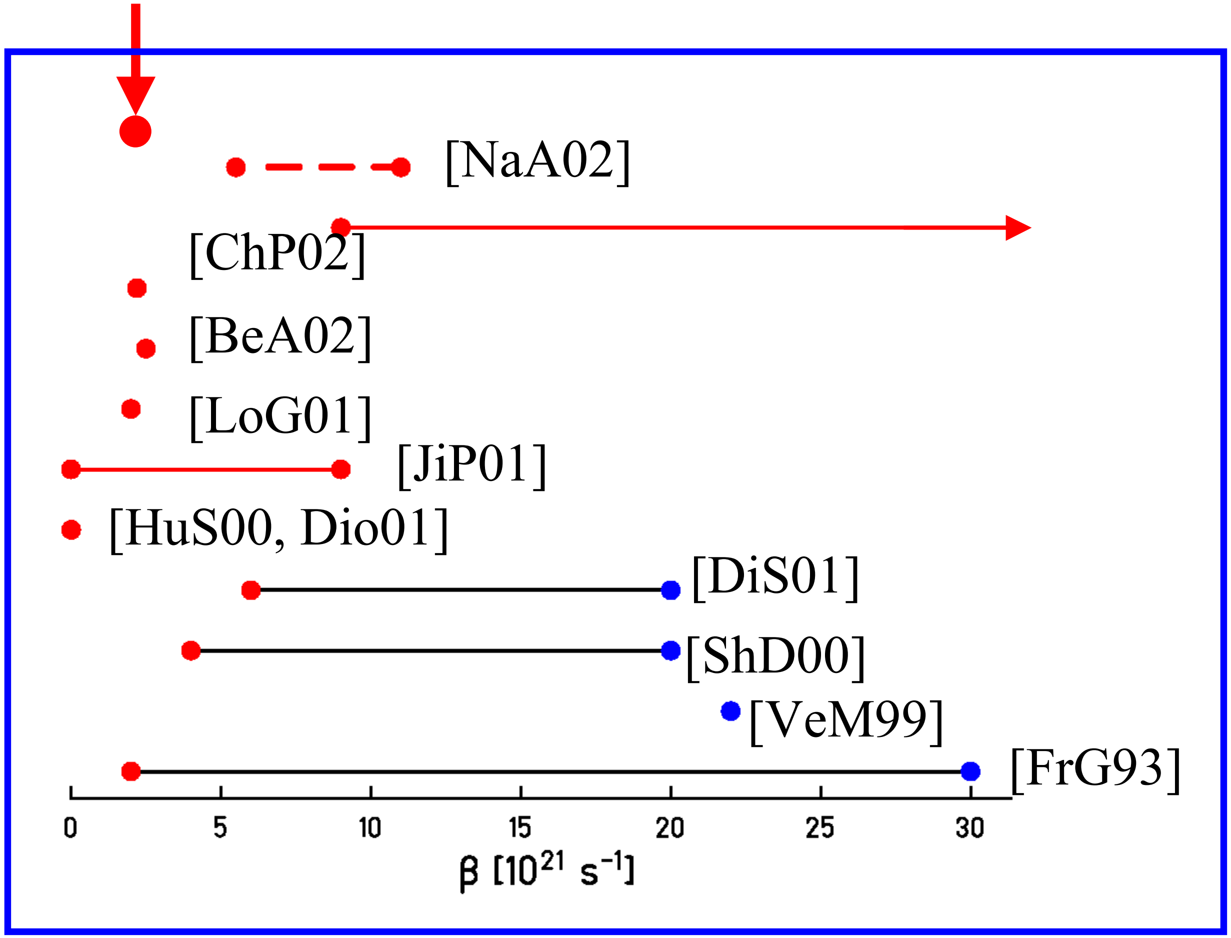


BREAK-UP

*Fission is mainly suppressed by dissipation at high E**

Fission completely suppressed at $E^* \geq 350$ MeV

Our result!



Deformation dependence

Small deformation

Large & small deformation

Conclusions

- *Fission induced by peripheral heavy-ion collisions at relativistic energies, ideal conditions for the investigation of dissipation at small deformations*

- *Determination of new observables*

- Total nuclear fission cross sections for different targets
-Partial fission cross sections
-Partial widths of the charge distributions of fission fragments

- *Realistic description for* $\Gamma_f(t)$

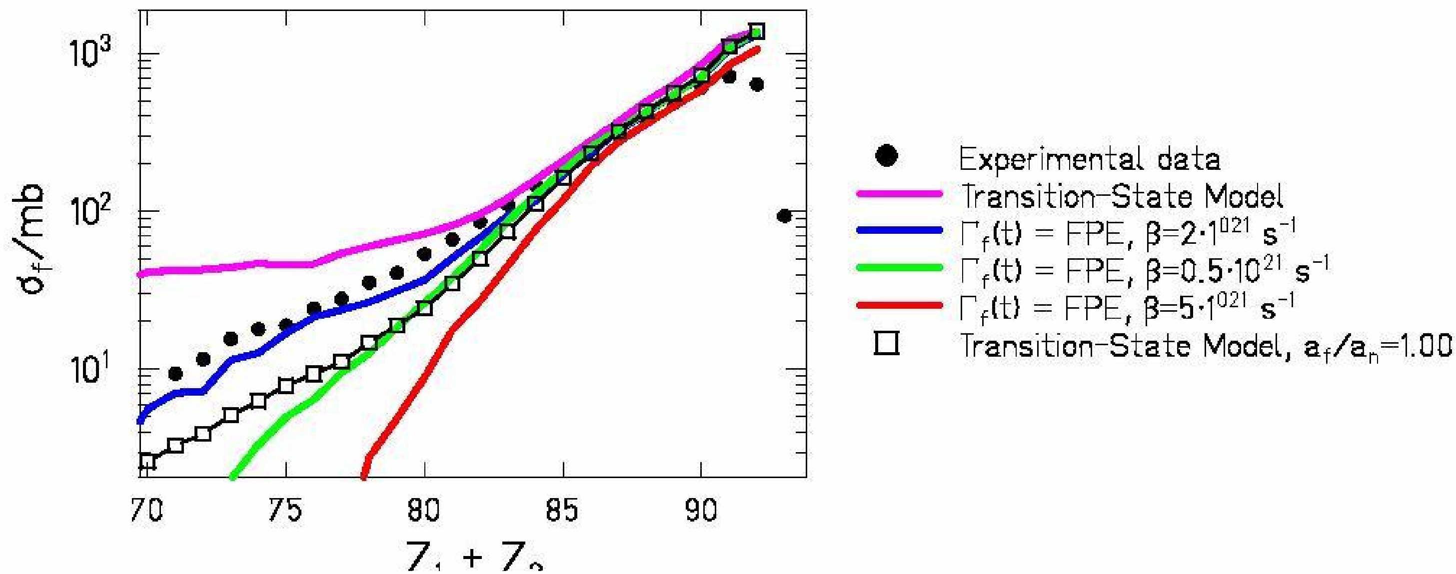
- *All observables described by a constant value of*

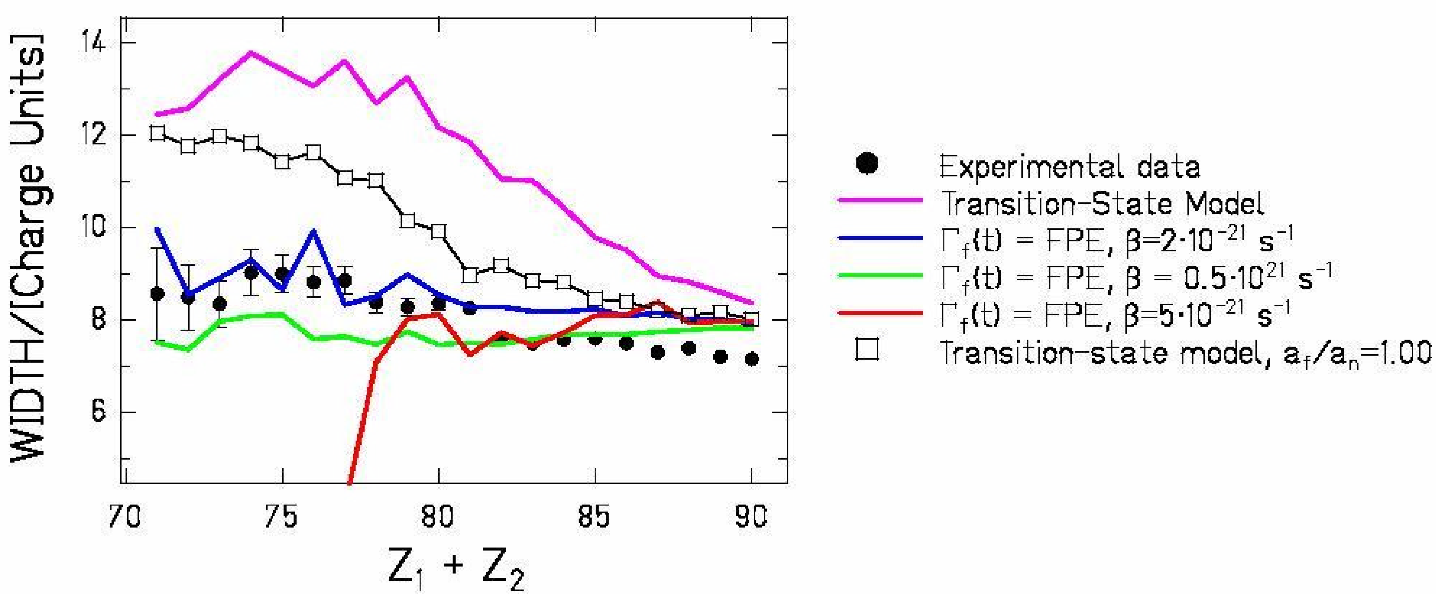
$$\beta = 2 \cdot 10^{21} s^{-1} \Longrightarrow \tau_f \approx (1.7 \pm 0.4) \cdot 10^{-21}\, s$$

(critical damping)

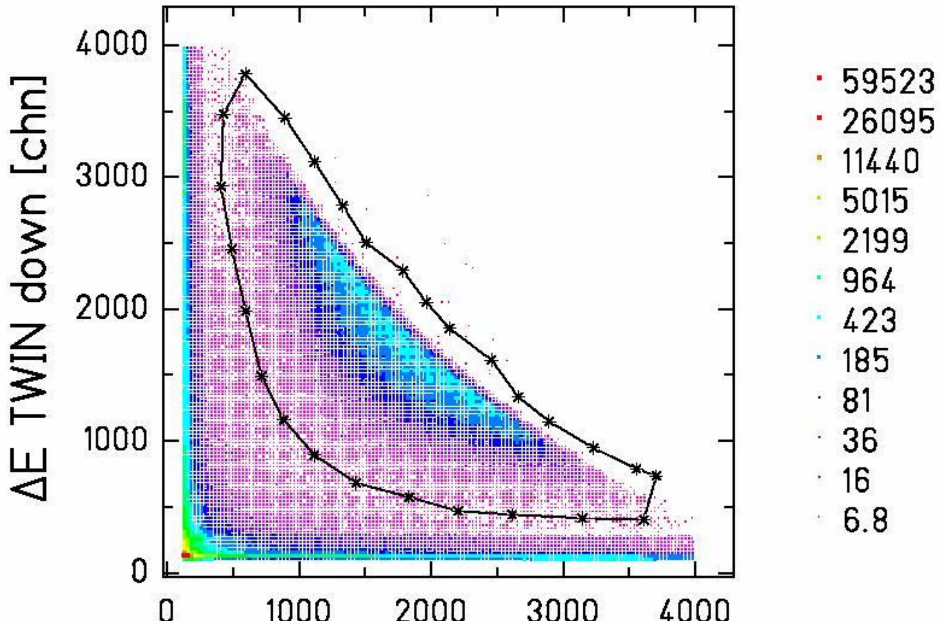
-No indications for dependence on T or Z^2/A
-Evidence for strong increase of β *with deformation*

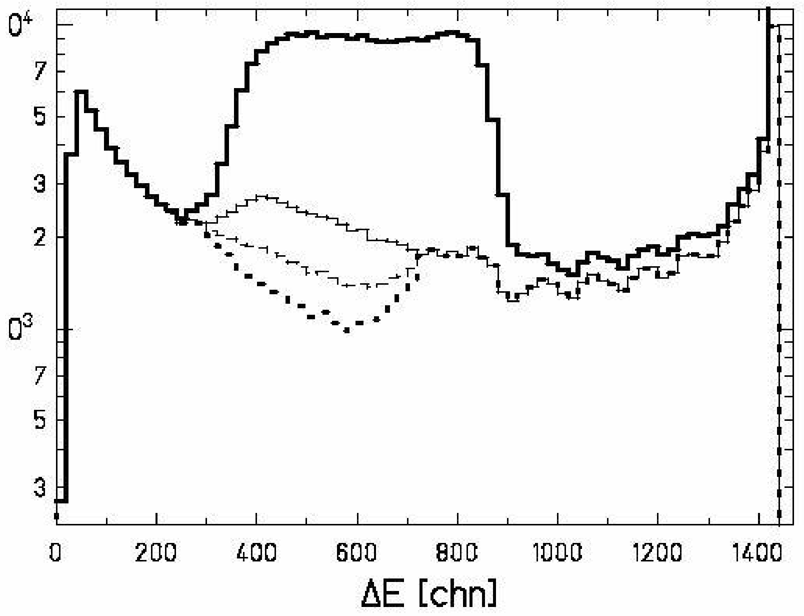
a_f/a_n

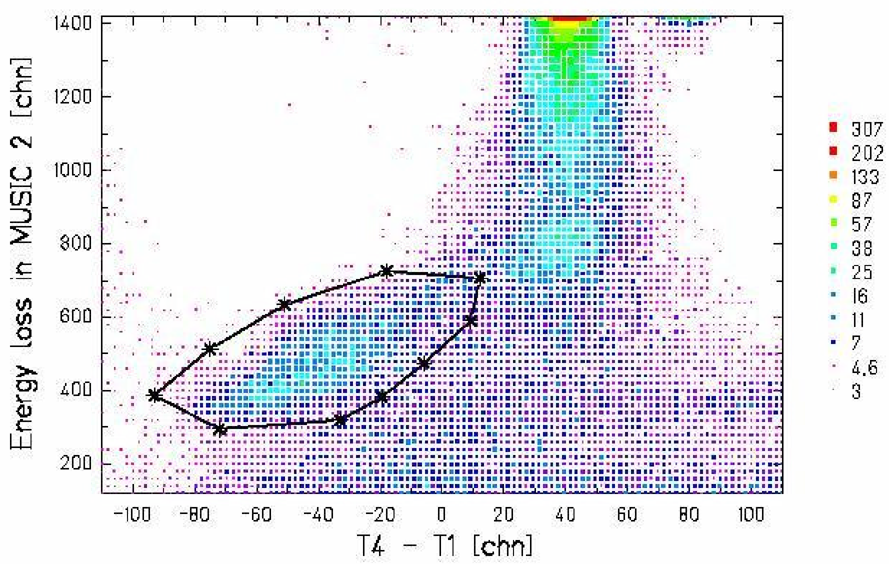

10^3
10^2
10^1
σ_f/mb
70
75
80
85
90
$Z_1 + Z_2$
Experimental data
Transition-State Model
$\Gamma_f(t)$ = FPE, β=2·1021 s^{-1}
$\Gamma_f(t)$ = FPE, β=0.5·10^{21} s^{-1}
$\Gamma_f(t)$ = FPE, β=5·1021 s^{-1}
Transition-State Model, a_f/a_n=1.00


14
12
10
8
6
WIDTH/[Charge Units]
70
75
80
85
90
$Z_1 + Z_2$
Experimental data
Transition-State Model
$\Gamma_f(t)$ = FPE, β=2·10^{-21} s^{-1}
$\Gamma_f(t)$ = FPE, β = 0.5·10^{21} s^{-1}
$\Gamma_f(t)$ = FPE, β=5·10^{-21} s^{-1}
Transition-state model, a_f/a_n=1.00

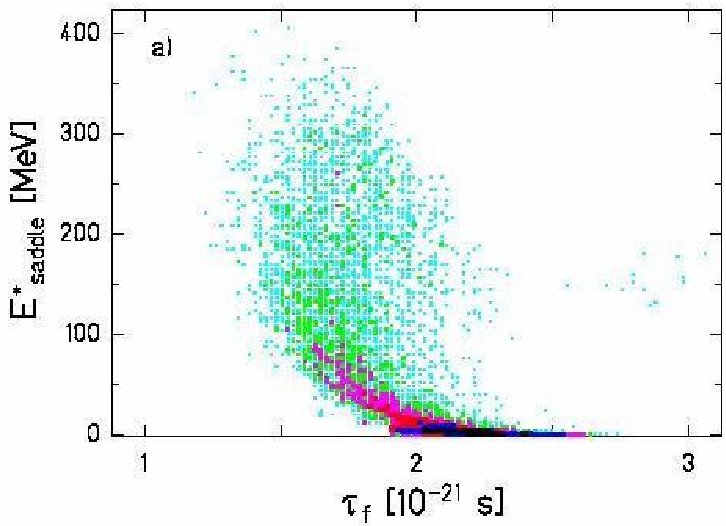
Fragmentation background

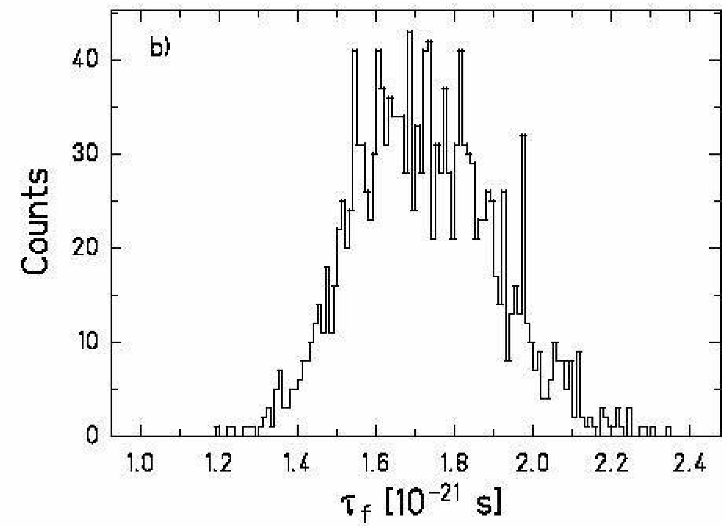


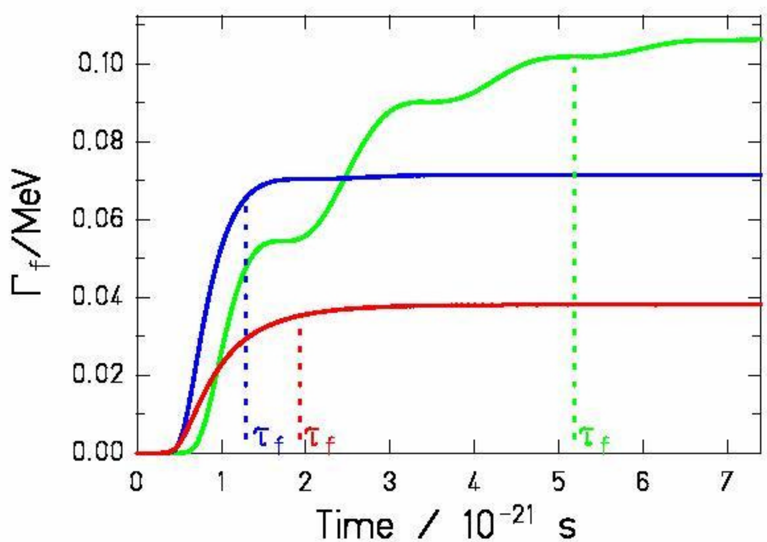


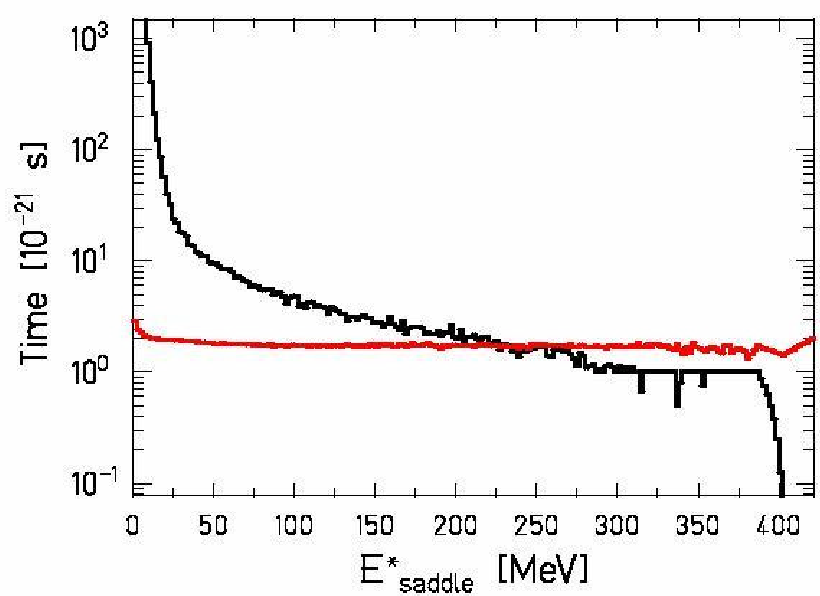


Transient time

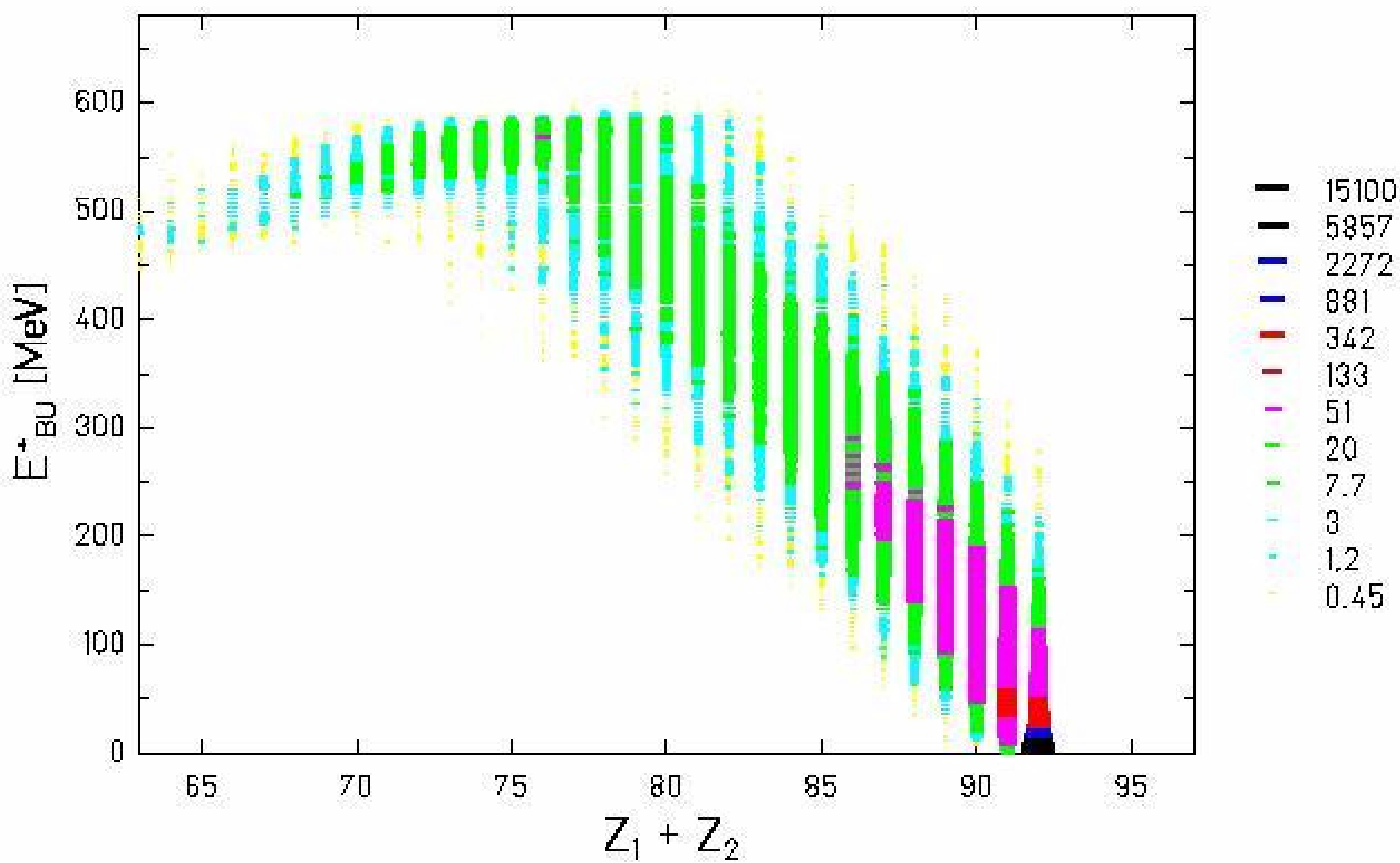




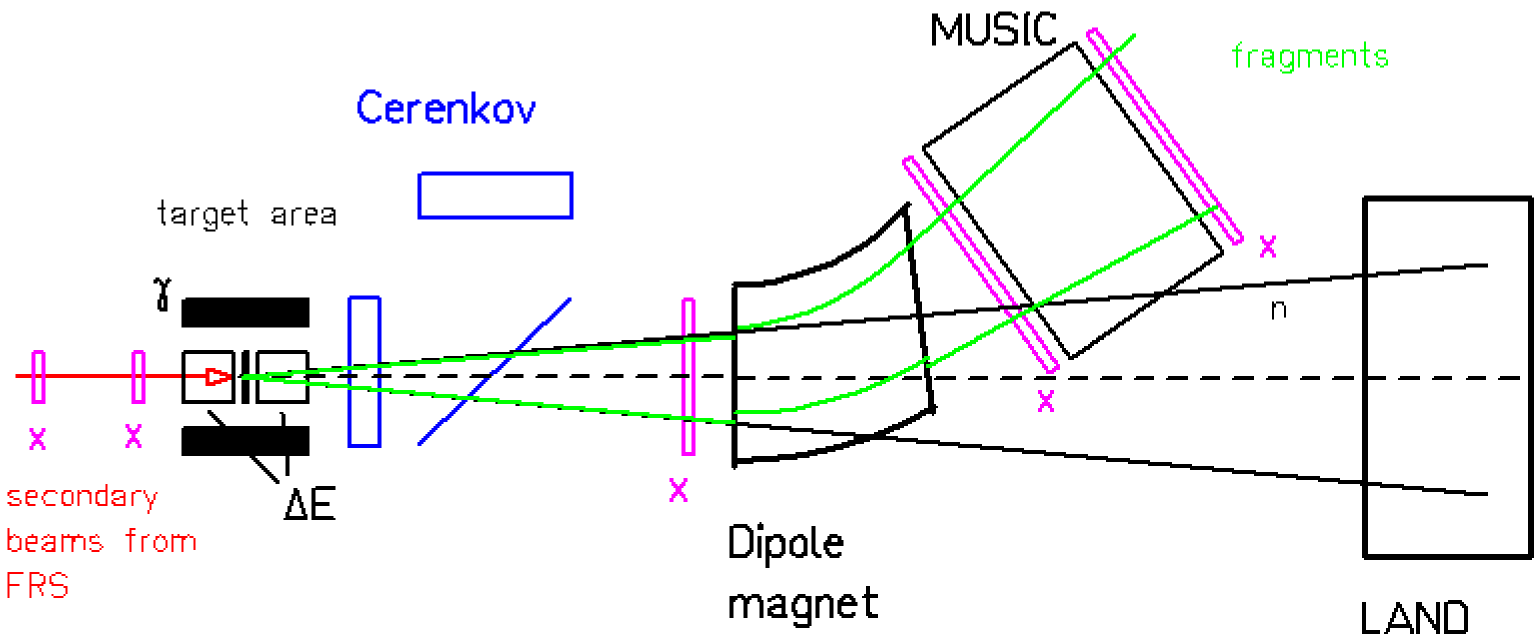




Excitation energy vs. Z



Outlook



MUSIC
fragments
Cerenkov
target area
γ
x
n
x
x
x
x
secondary
beams from
FRS
ΔE
Dipole
magnet
LAND