Accurate survey of transient effects in highly fissile spherical nuclei

CHARMS collaboration, GSI, Darmstadt
http://www-w2k.gsi.de/charms/

Innovative experimental approach :

reaction mechanism : fragmentation induced fission of spherical heavy RIBs
signature : width σ_Z of the fission-fragment nuclear charge distribution

Experimental challenge overcome !
⇒ selective study of transient effects in fission
⇒ insight into previous 'apparent' contradictory results

Collective degrees of freedom
(coordinated motion of nucleons)

Dissipation

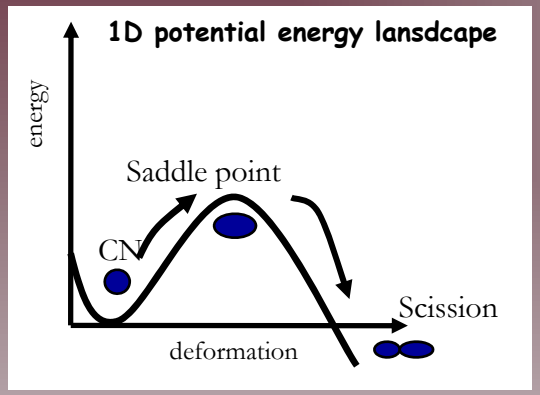
friction →

diffusion ↔

Intrinsic degrees of freedom
(individual nucleon states/heat bath)

⇒ **of importance for the decay of meta-stable states** (mechanics, chemistry, biology, nuclear physics, …)

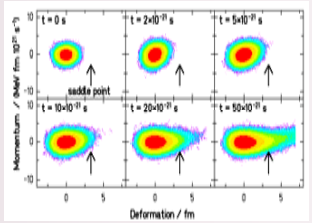
Nuclear Fission : excellent test case for dissipation



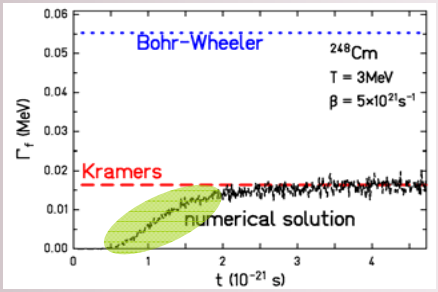
Large-scale collective motion
Escape from a meta-stable potential well

Time evolution:

- **entrance channel → excited compound**
- **adjustement to the phase-space** ($\sim\tau_{trans}$)
- **thermodynamical quasi-equilibrium**
  (population in accordance with phase-space)
- **if escape occurs: sliding down the fission valley**



Time-dependent fission decay-width $\Gamma_f(t)$



Highly **fissile** and **excited spherical** initial compound nuclei:
most suited candidates for isolating early transient effects

- At t=0 : system at the minimum of the potential well
  only fluctuative forces make evolve the distribution probability
- Saddle-to-scission descent: strong driving and friction forces

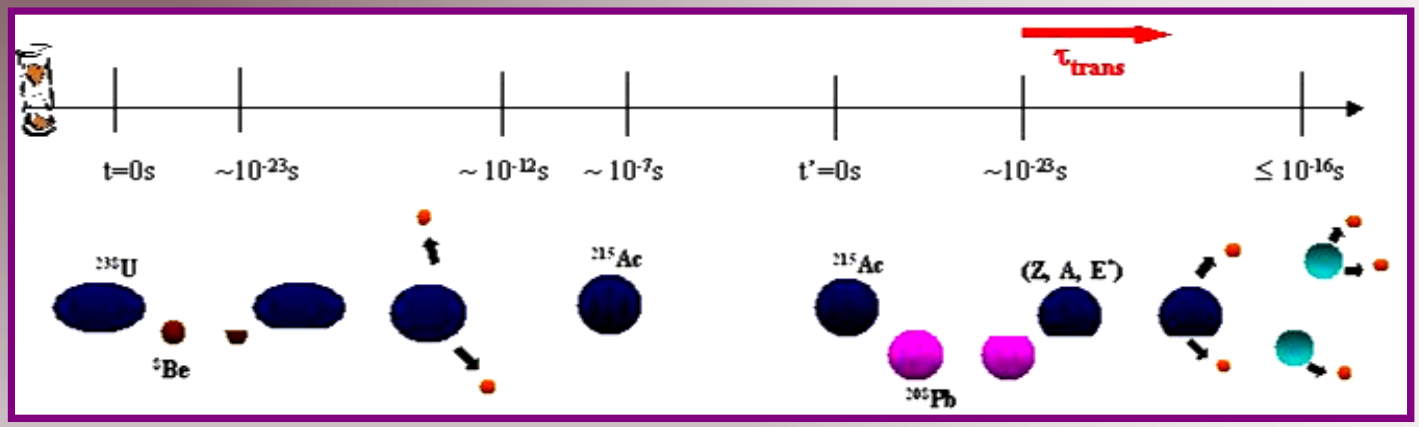
Ideal scenario for discriminating friction and diffusion in nuclei ('theoretical' proposition of Grangé et al.)

Ideal 'theoretical' scenario … but experimental challenge

Request of highly excited fissile spherical nuclei !

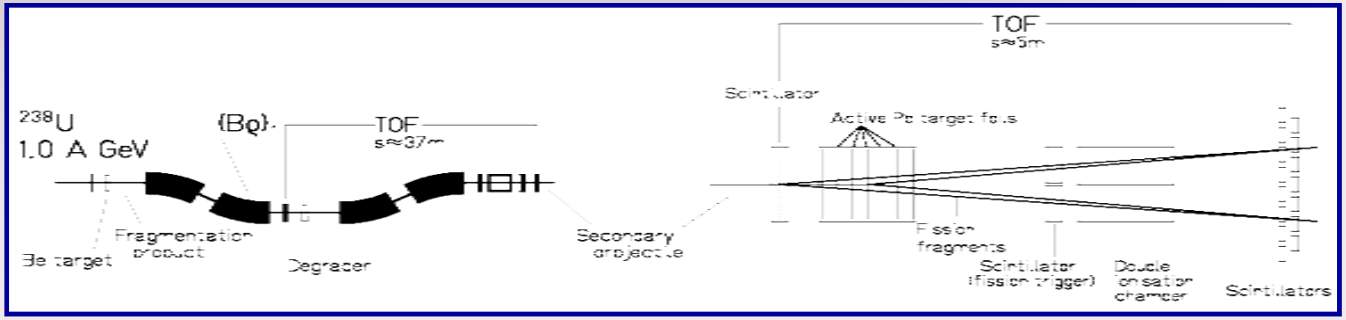
→ Innovative two-step reaction mechanism and set-up (GSI, Darmstadt)

Reaction Mechanism



1. Stable ^{238}U fragmentation -> spherical At-Th isotopes
2. Secondary RIB fragmentation
3. De-excitation of the hot nearly spherical fissile 'pre-fragment'

Set-Up



1. FRS for secondary RIB preparation
2. Secondary target
3. Coincident fission-fragment detection and Z-identification

The FF charge width σ_Z as a thermometer at saddle

Restriction to the pre-saddle region mandatory : for isolating transient effects — particle (n, p, α) and GDR-γ pre-scission multiplicities not well suited

Clock at saddle ? $\tau_{trans} \Rightarrow M^{pre}_{saddle} \Rightarrow E^*_{saddle}$

what allows the translation clock ↔ thermometer $\tau_{saddle} \approx T_{saddle}$

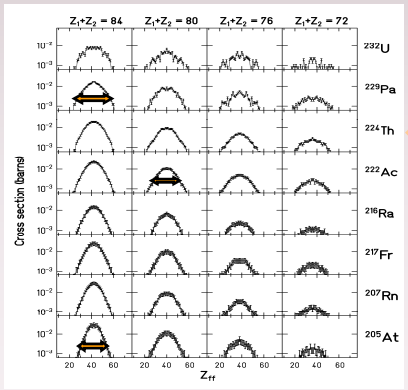
Pre-saddle cooling governed by τ_{trans}

Thermometer at saddle ? $\sigma_Z^2 = \frac{T_{sad}}{C_Z} = \frac{\sqrt{(E^*_{sad}/a)}}{C_Z}$ Width of the fission fragment Z distribution

The Z_1+Z_2 sum as a filter for E^*_{ini} and Z^2/A

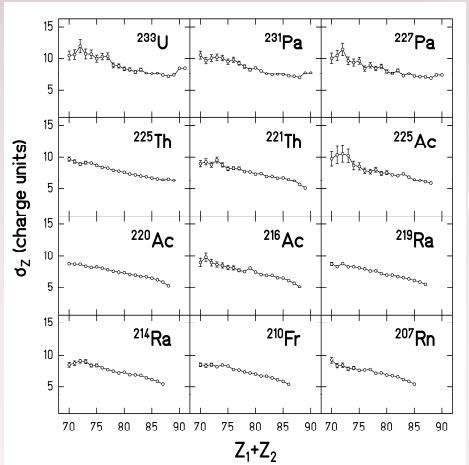
1. $Z_1+Z_2 \approx Z_{fiss} \approx$ pre-fragment Z_{prf}
2. $Z_{prf} \Rightarrow E^*_{ini}$ induced in the system

Pertinent Z_1+Z_2 measurement : classification according to E^*_{ini} and $(Z^2/A)_{fiss}$



fission fragment Z distributions gated by Z_1+Z_2 for various RIBs

σ_Z as function of Z_1+Z_2 for various RIBs



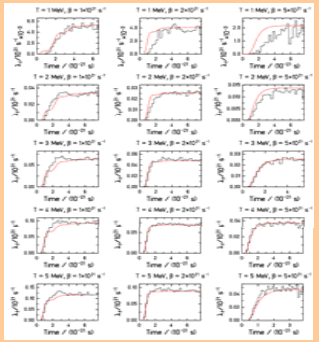
σ_Z increases with increasing E^*_{ini} but $\sigma_Z = f(Z_1+Z_2)$ slope revealing of transients

Magnitude of the dissipation strength β and the transient delay τ_{trans}

Model calculations : ABRABLA reaction code

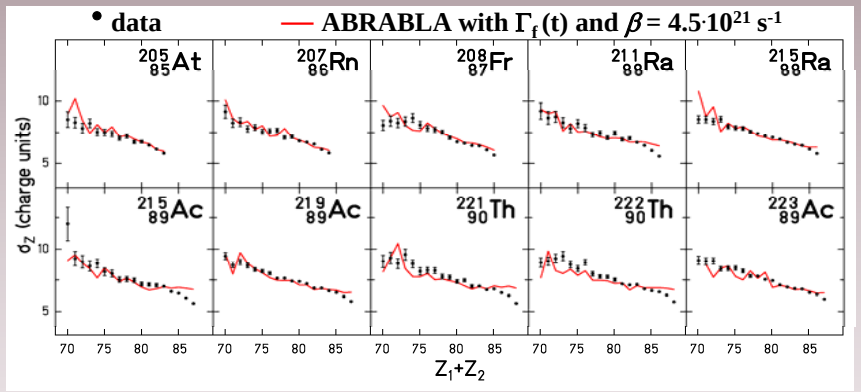
Peripheral Heavy-Ion Collision at Relativistic Energy as a 3 step-process

- **Abrasion** : participant/spectator scheme -> excited prefragment
- Simultaneous **break up** for $T_{prefrgament} > T_{freeze\ out}$
- **Evaporation/fission** competition : dynamical treatment with a realistic time-dependent $\Gamma_f(t)$



Jurado, Schmitt et al., NPA747(2004)14

Conclusive evidence for transient effects



Careful inspection of fragmentation-induced fission for 45 spherical RIBs:

$\beta = (4.5^{\pm 0.5}) \cdot 10^{21} s^{-1}$ and $\tau_{trans} = (3.4^{\pm 0.7}) \cdot 10^{-21} s$

No strong dependence on E^*_{ini} or Z^2/A

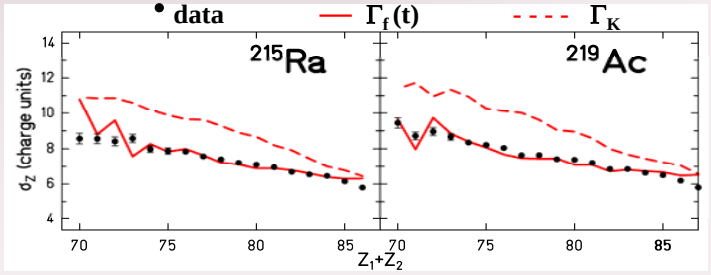
$\Gamma_f(t)$ - versus Γ^K - type calculations :

⇒ undeniable manifestation of transient effects

⇒ σ_Z specifically sensitive to τ_{trans}

To be included in any reliable reaction code

danger of data misinterpretation

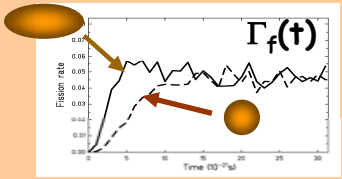


Definite achievement of fragmentation-fission with fissile spherical RIBs

Assets/Uniqueness of the approach:

- unusually **wide excitation energy and fissility** range
- **well-defined initial conditions** matching the ideal theoretical scenario: study of **excited highly fissile spherical** nuclei produced by fragmentation of RIBs
- **sensitive** σ_Z signature of transients

Previous approaches suffered from :



- **strong influence of initial deformation** of the compound nucleus
  - ☛affects τ_{trans} but difficult to model
  - ☛ given by the entrance channel: can be critical in fusion-fission, fragmentation-/spallation-fission with stable fissile projectiles/targets
  - ☛explanation for previous controversy about the magnitude of β and τ_{trans}
- **lack of sensitivity of conventional observables** M^{pre}, σ_{ER}, P_{fiss}, ...
- influence of L, contribution from quasi-, fast-, transfer- induced fission, ...

Conclusion / Perspectives

★ **Intense experimental investment**
➔ 'clean' study of fission transient effects
minimizing complex/uncontrolled side effects

★ **Unusual large set of data**
(fragmentation of 45 RIBs ≈ 400 fusion experiments)

PLANS

@ GSI/FAIR via fragmentation:

- Many species with various E* and Z^2/A simultaneously available
  - Characterisation of the system with large acceptance device

@ Ganil/SPIRAL2 via fusion:

- Long isotopic chains and great energy range available with the beam itself

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