Fission fragment mass distribution of Fm isotopes

- Fluctuation-Dissipation Dynamics of Fission -

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Contents

- Observed quantities in fission
- What is fluctuation-dissipation dynamics?
- Langevin equation in fission
  - Fragment distribution (mass & TKE)
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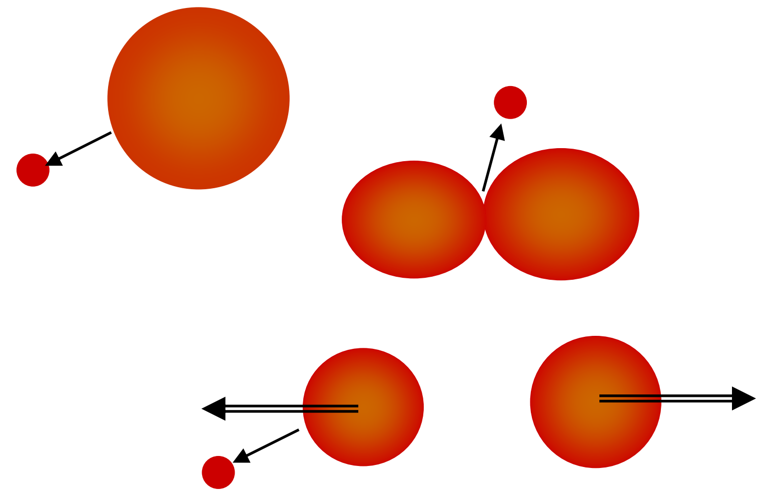
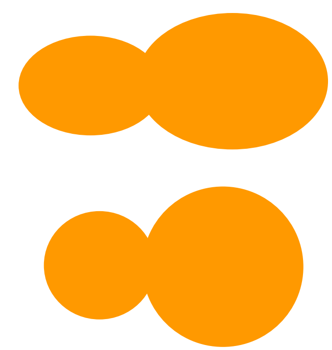
Key quantities in fission

- Fission rate
  - Height of fission barrier
- Particle emission
  - Pre-scission
  - At Scission
  - Post-scission
- Fission fragments
  - Mass distribution
    - Shell correction
  - Total kinetic energy distribution
    - Scission configuration



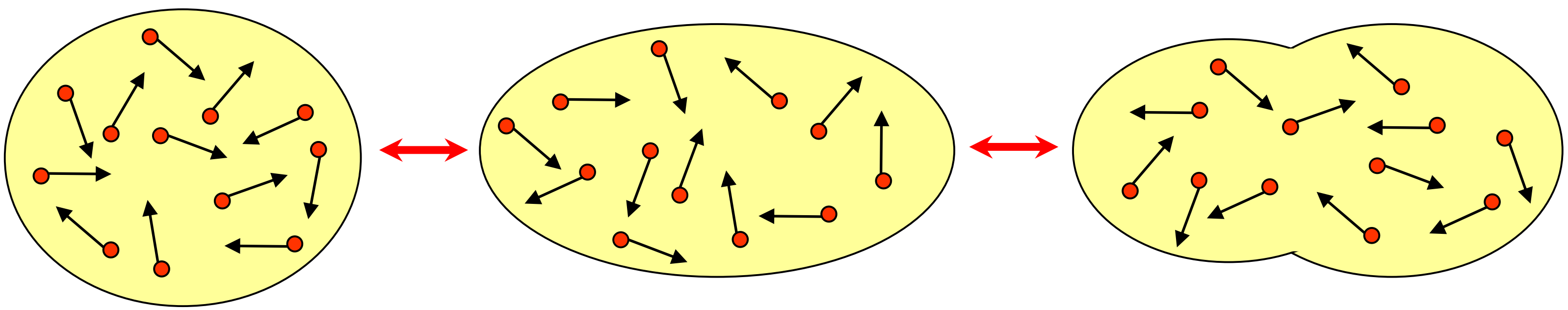


Fluctuation-dissipation dynamics

- Brownian motion picture
  - Macroscopic degree(s) of freedom interacting with microscopic degrees of freedom in thermal motion

    Dissipation (collective → nucleonic) ⇐ Friction

    Fluctuation (nucleonic → collective) ⇐ Random force



- Macroscopic degrees of freedom

  = Nuclear shape

  (elongation, deformation, neck, mass asymmetry etc.)

Two approaches

Langevin equation

$$\frac{dq}{dt}=\frac{p}{m} \qquad \frac{dp}{dt}=-\frac{\partial U}{\partial q}-\frac{\gamma}{m}p+\sqrt{\gamma T}R(t)$$

$$\langle R(t)\rangle = 0,\ \langle R(t_1)R(t_2)\rangle = 2\delta(t_1-t_2)$$

Eq. of motion of a Brownian particle

Focker-Planck (Kramers) equation

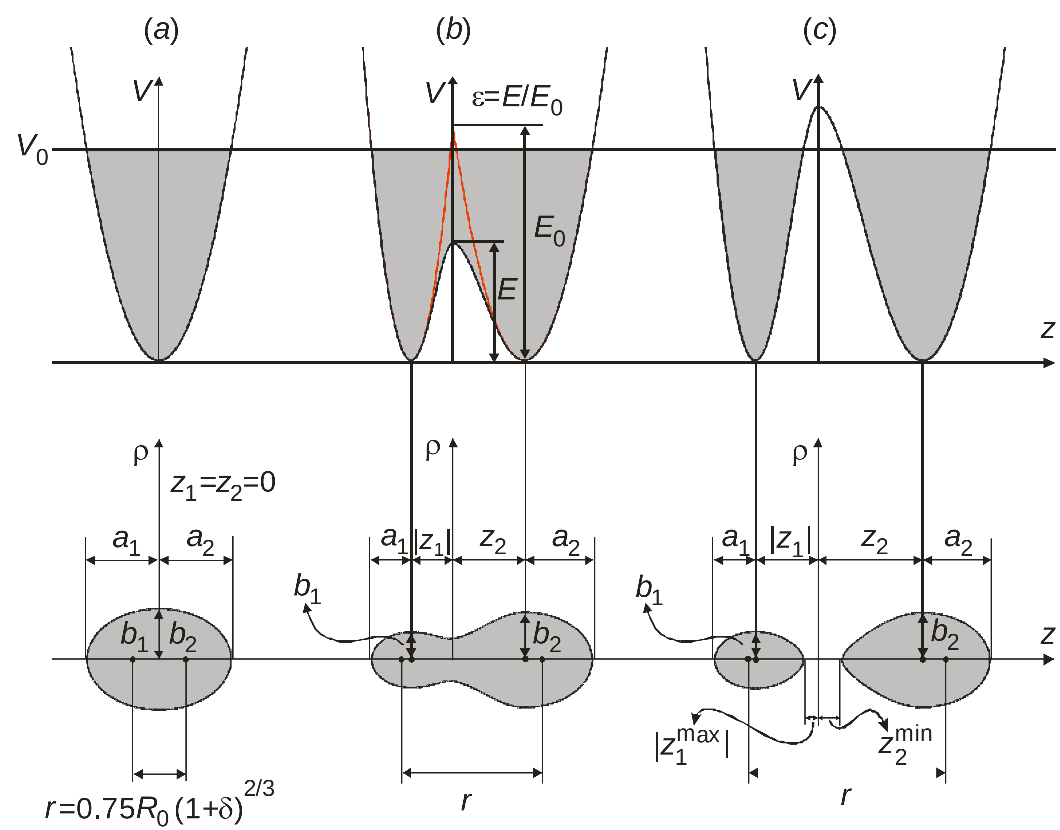
$$\frac{\partial f}{\partial t}=-\frac{p}{m}\frac{\partial f}{\partial q}+\frac{\partial U}{\partial q}\frac{\partial f}{\partial p}+\frac{\gamma}{m}\frac{\partial}{\partial p}(pf)+\gamma T\frac{\partial^2 f}{\partial p^2}$$

Distribution of the Brownian particles

Two-center shell model parameterization

$$\rho_S{}^2 = \begin{cases} b_i{}^2 - (b_i / a_i)^2 (z - z_i)^2 \\ \qquad , \quad z_1 - a_1 \le z \le z_1 \text{ or } z_2 \le z \le z_2 + a_2 \\ \left\{ b_i{}^2 - (b_i / a_i)^2 \left[1 + p_i (z - z_i) + q_i (z - z_i)^2 \right] (z - z_i)^2 \right\} / \left[1 + g_i (z - z_i)^2 \right] \\ \qquad , \quad z_1 \le z \le z_2 \end{cases}$$

elongation (Z_0)
neck parameter (ε)
deformation (δ_1, δ_2)
mass asymmetry (α)



J. Maruhn and W. Greiner, Z. Phys, 1972

TKE systematics

- Viola systematics
  (1985, V. E. Viola)

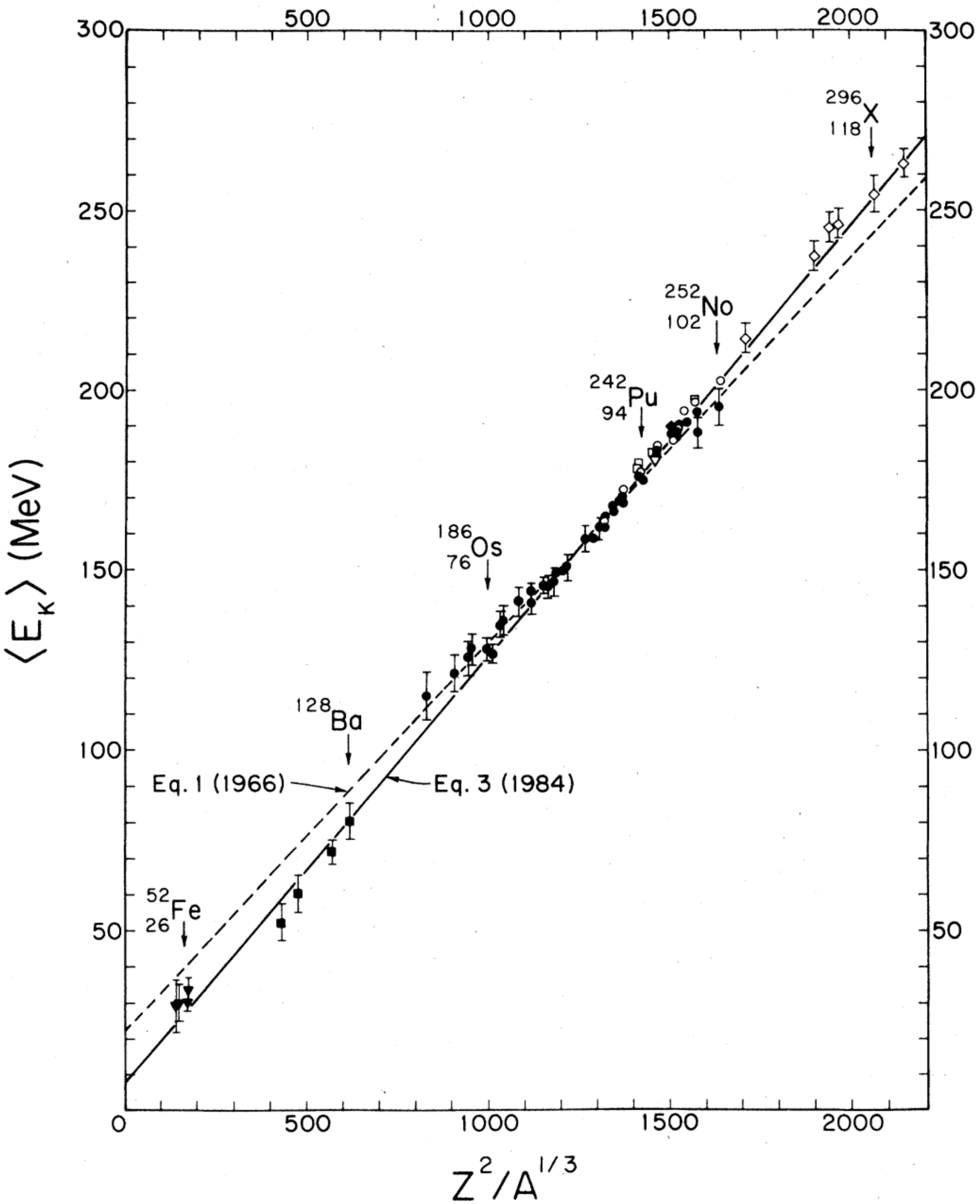
$$\langle E_K \rangle = 0.1071 Z^2/A^{1/3} + 22.2 \text{ MeV}$$

Data before 1966

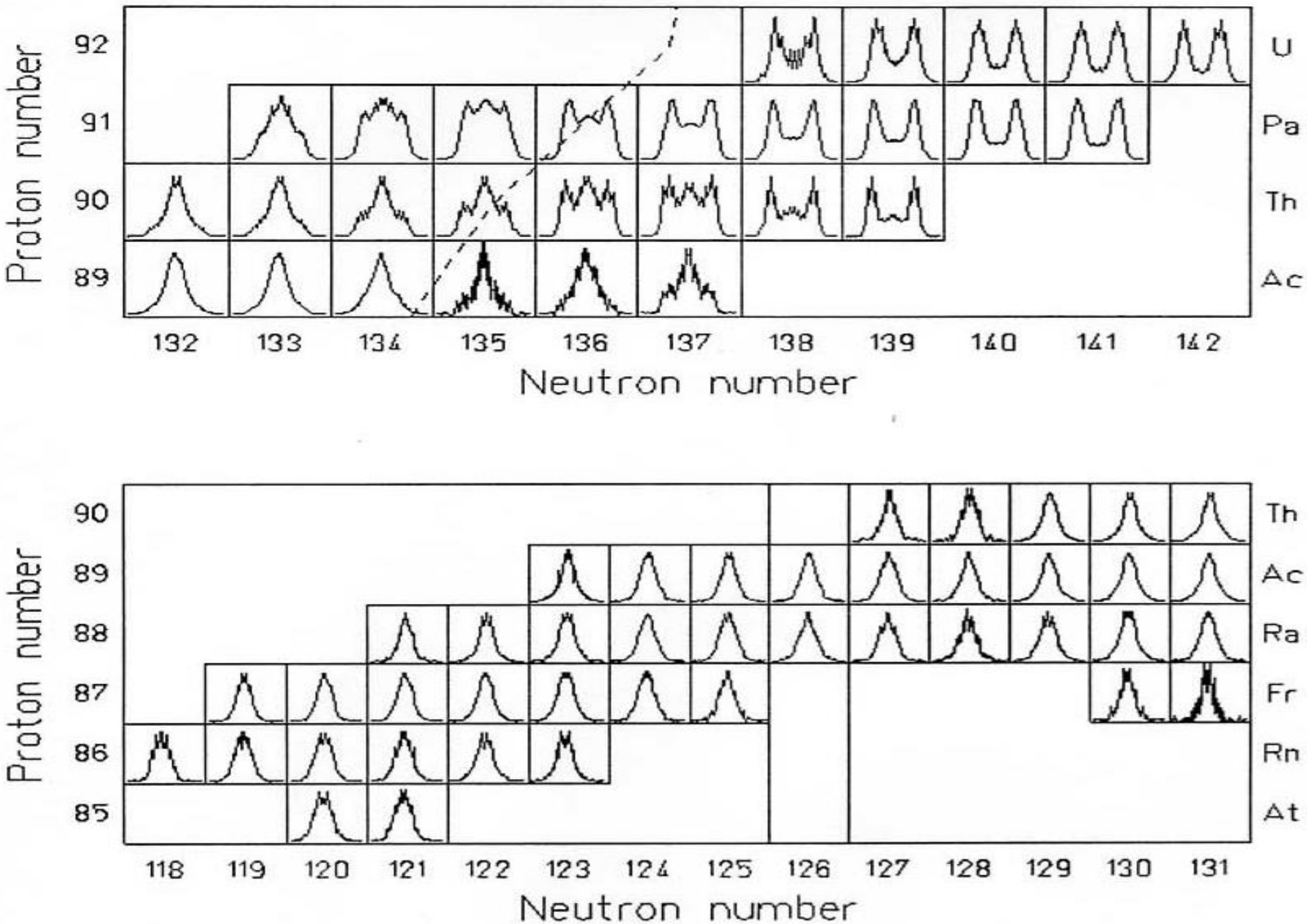
$$\langle E_K \rangle = 0.1189 Z^2/A^{1/3} + 7.3 \text{ MeV}$$

Data up to 1984

  - Main contribution to TKE comes from Coulomb repulsion
  - Measure of the fragment deformation



Fission modes



K. –H. Schmidt et al.

Extension to multi-dimension

Multi-dimensional Langevin equation

$$\frac{dq_i}{dt} = \left(m^{-1}\right)_{ij} p_j \qquad i, j, k = 1, \ldots, N$$

$$\frac{dp_i}{dt} = -\frac{\partial V}{\partial q_i} - \frac{1}{2}\frac{\partial}{\partial q_i}\left(m^{-1}\right)_{jk} p_j p_k - \gamma_{ij}\left(m^{-1}\right)_{jk} p_k + g_{ij} R_j(t)$$

$$\left\langle R_i(t) \right\rangle = 0, \ \left\langle R_i(t_1) R_j(t_2) \right\rangle = 2\delta_{ij}\delta(t_1 - t_2) \qquad \sum_k g_{ik} g_{jk} = T\gamma_{ij}$$

$m_{ij}(q)$ Hydrodynamical inertial mass

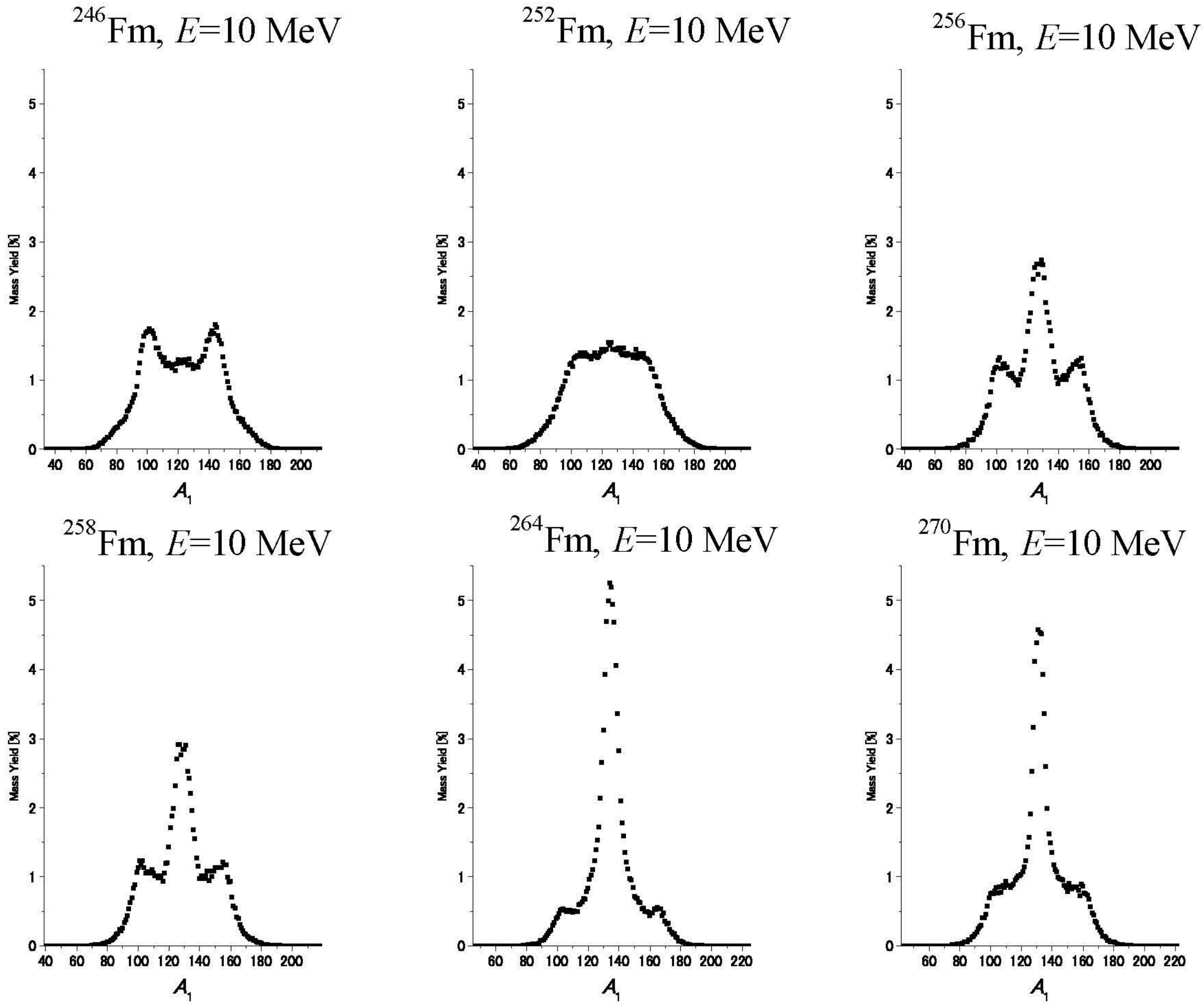
$\gamma_{ij}(q)$ Wall-and-Window (one-body) friction

$V(q)$ Macro-microscopic potential

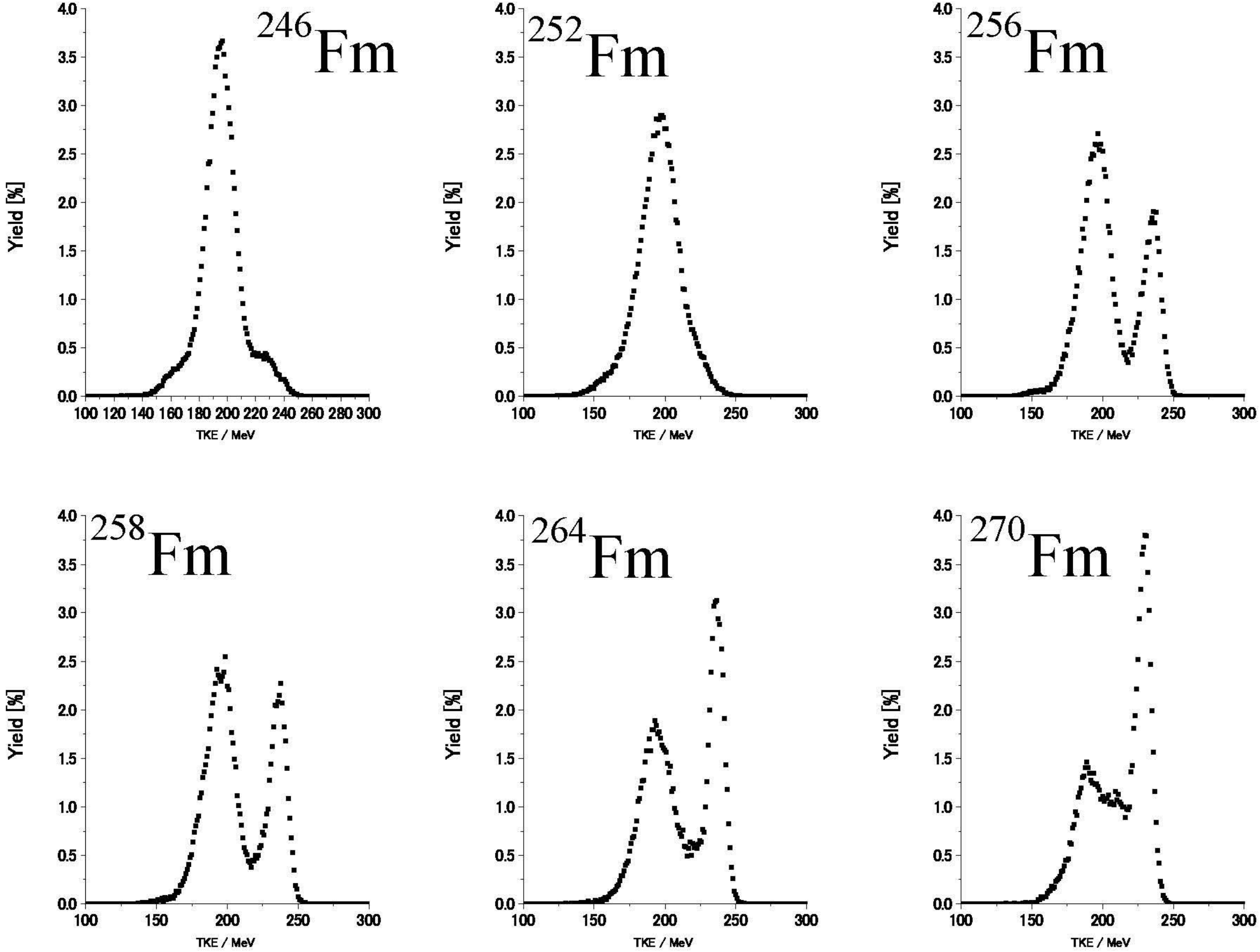
$$V\left(q, E_x\right) = V_{\mathrm{LD}}(q) + \Delta E_{\mathrm{shell}}\left(q, E_x = 0\right) \exp\left(-\frac{E_x}{E_d}\right)$$

$\{q_i\}$: collective parameters

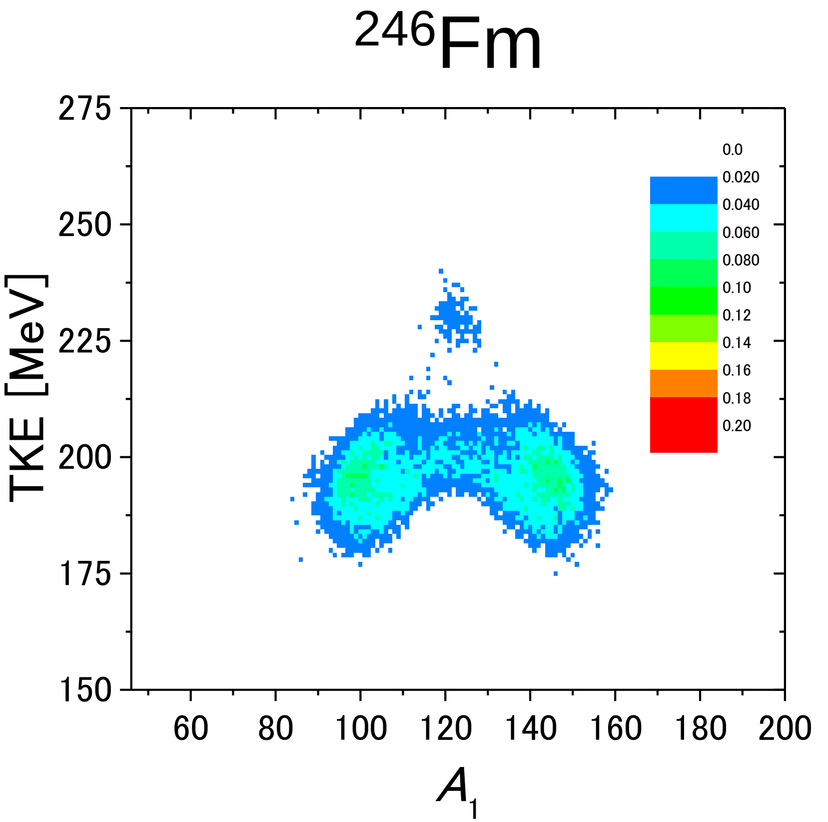
Mass distribution for Fm isotopes

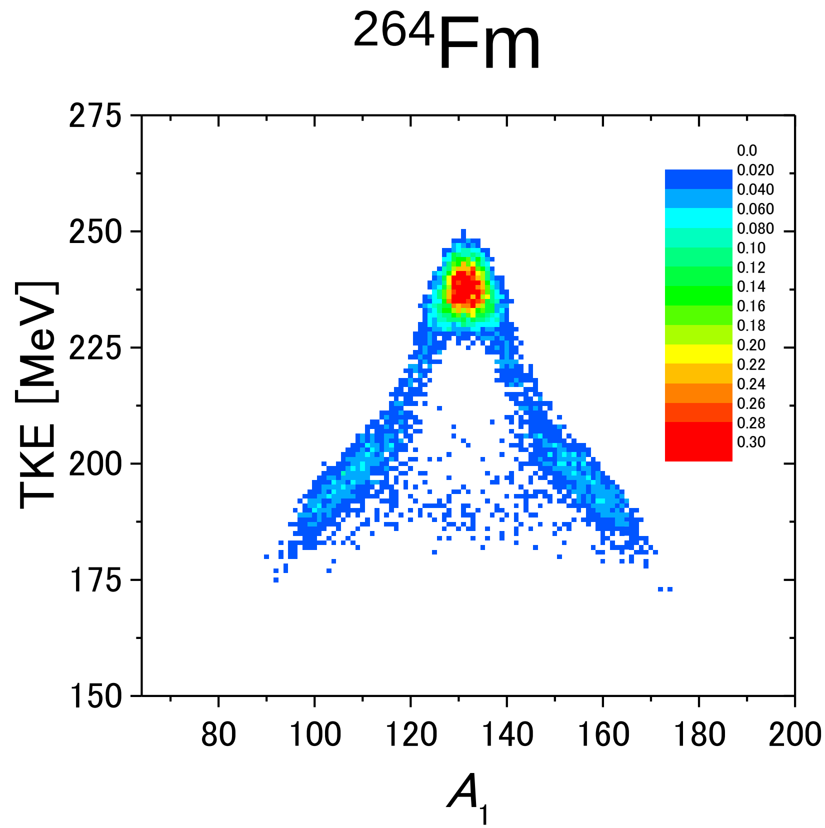


TKE distribution for Fm isotopes

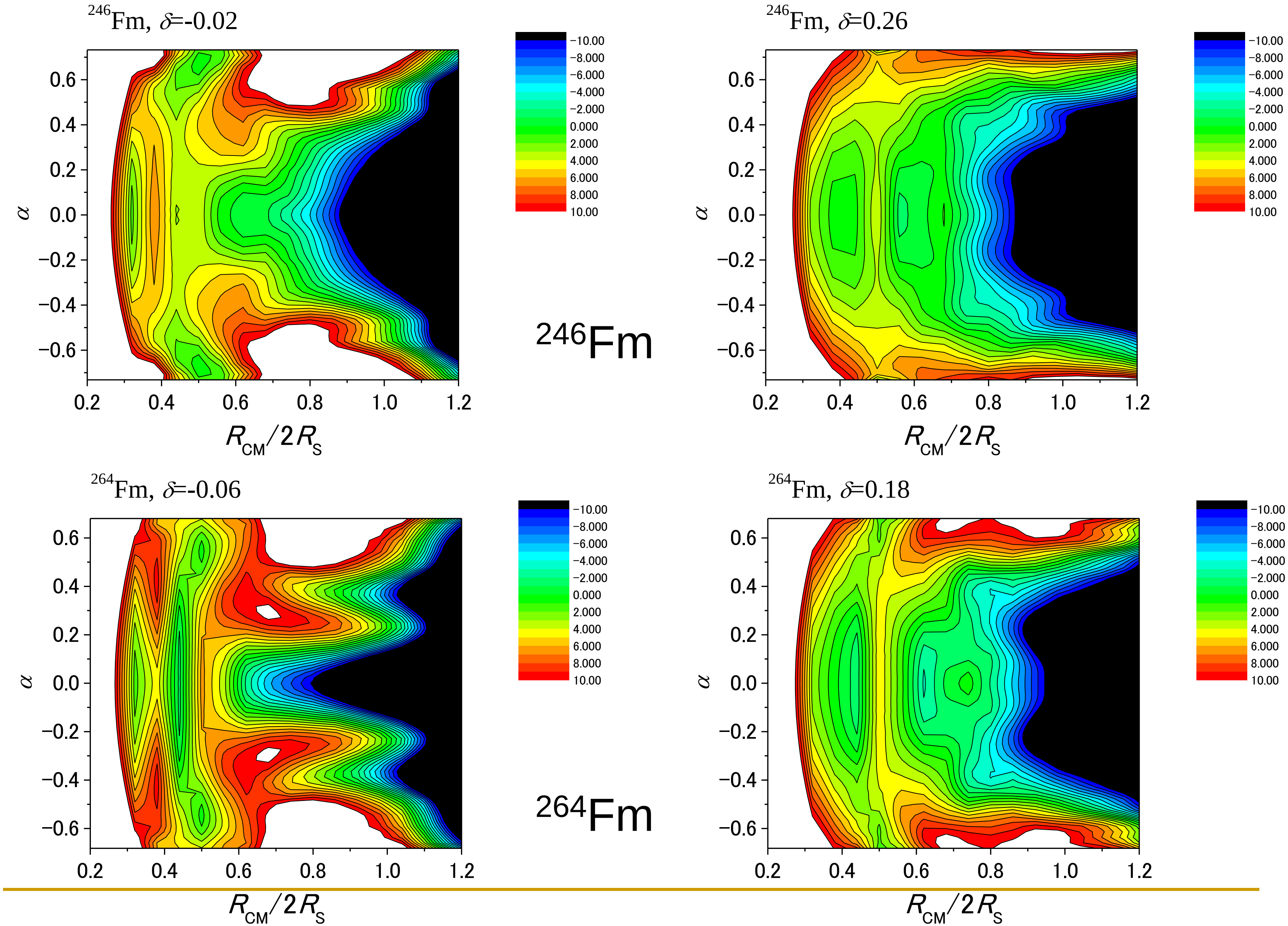


Mass and TKE distribution





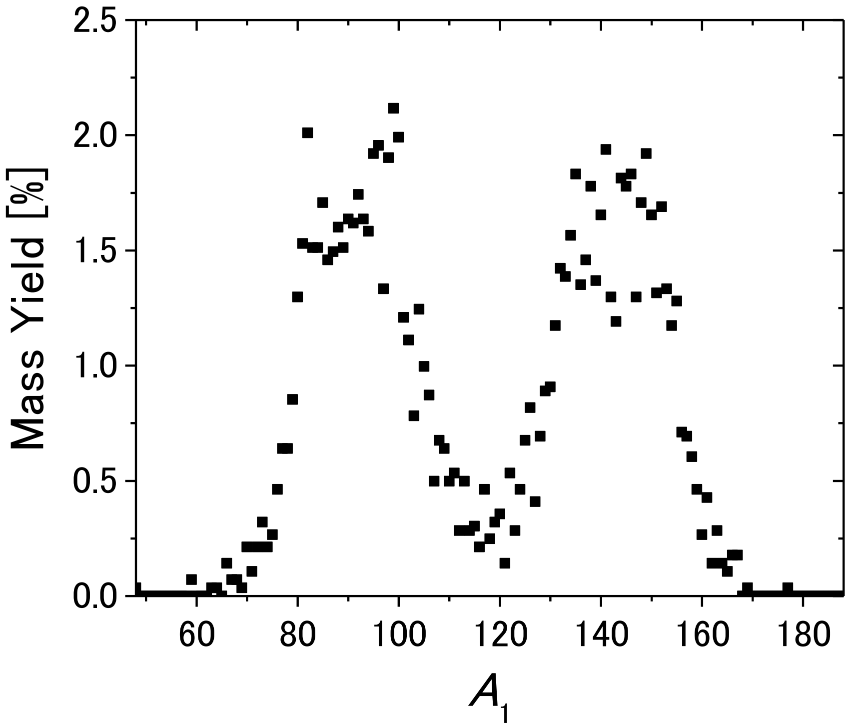
- Strong correlation between mass distribution and TKE distribution

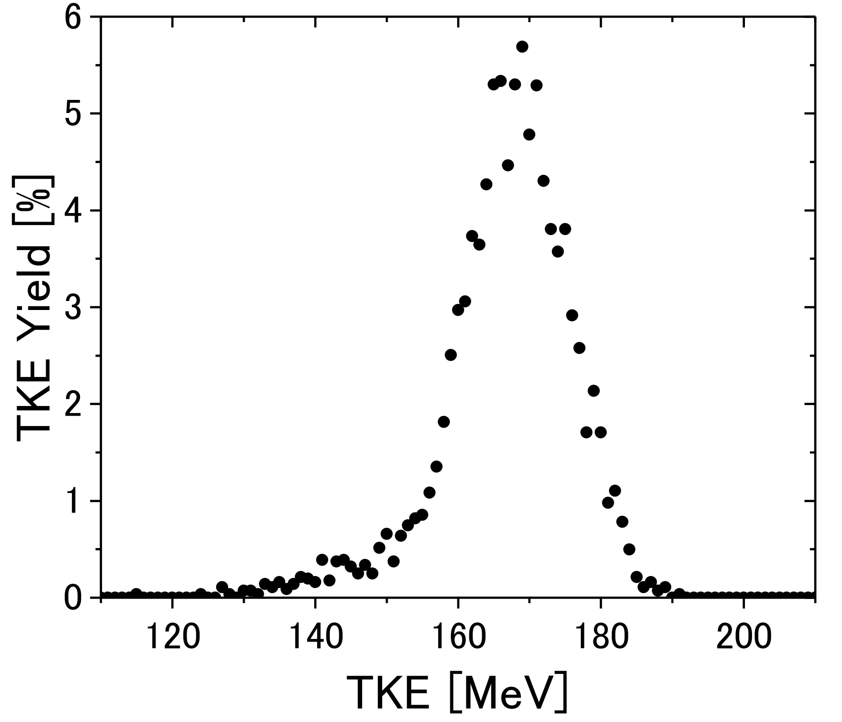


246Fm, δ=-0.02
246Fm, δ=0.26
264Fm, δ=-0.06
264Fm, δ=0.18
246Fm
264Fm
α
R_CM/2R_S
0.2 0.4 0.6 0.8 1.0 1.2
0.6 0.4 0.2 0.0 −0.2 −0.4 −0.6
−10.00 −8.000 −6.000 −4.000 −2.000 0.000 2.000 4.000 6.000 8.000 10.00

Mass and TKE distribution of ^{236}U

E* = 10 MeV

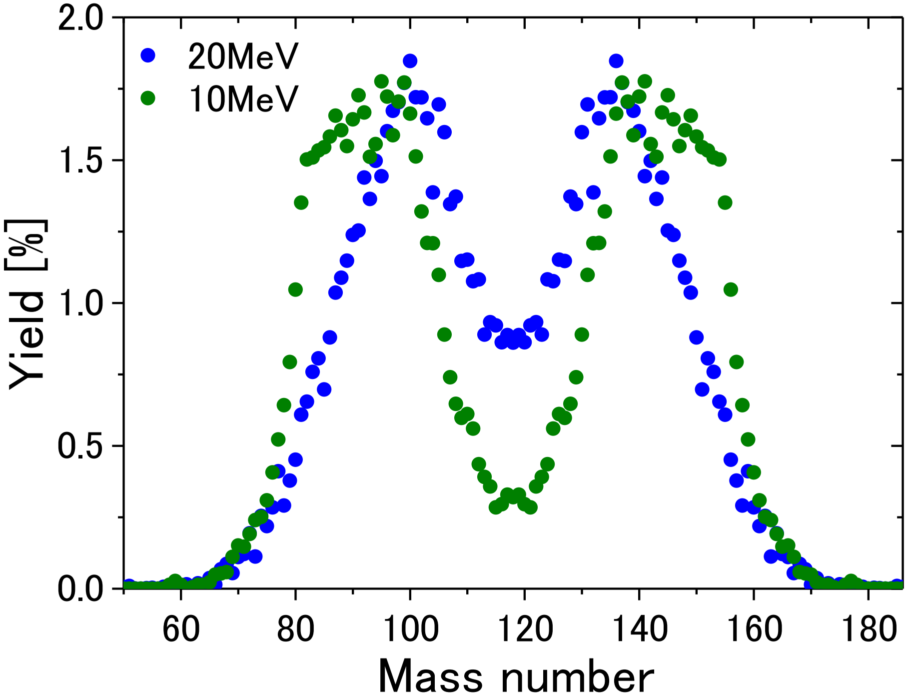




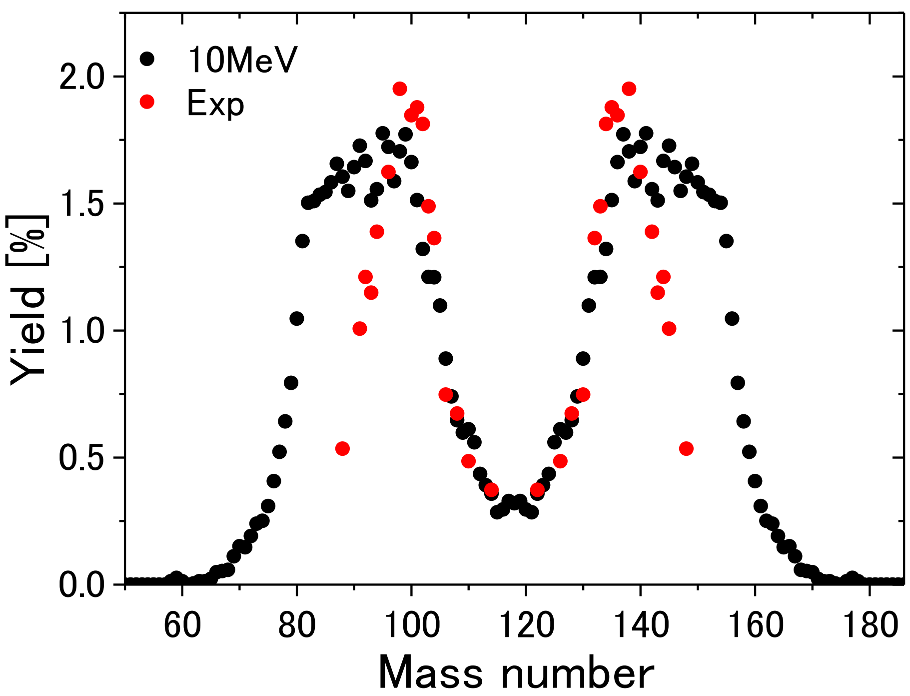
- Statistics is poor
  - High fission barrier and low excitation energy

Mass distribution for ^{236}U

Energy dependence

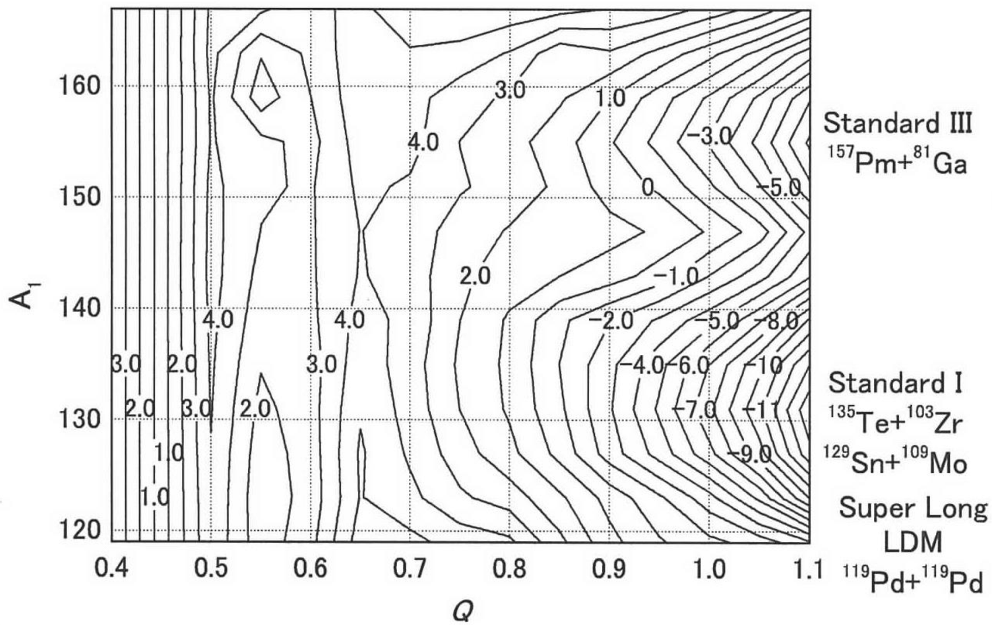


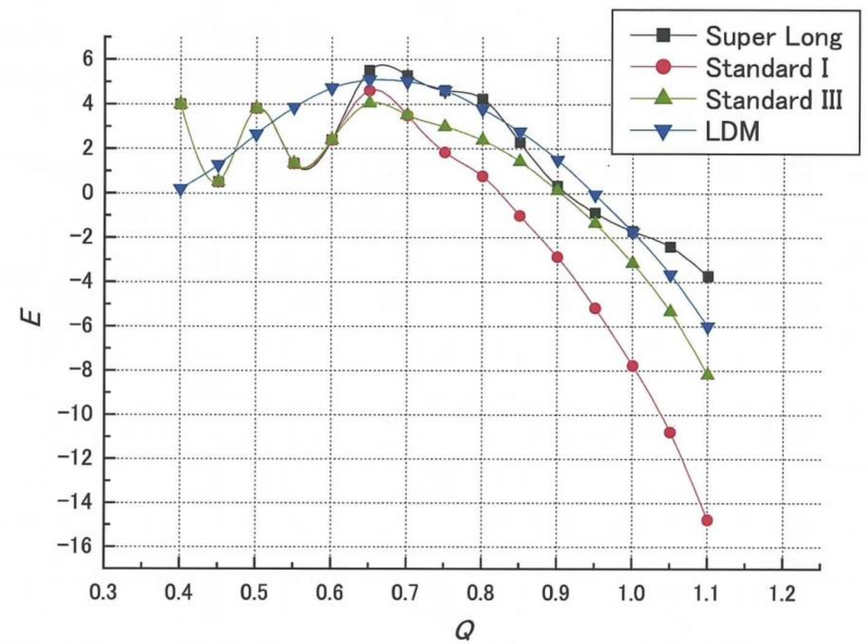
Exp. vs 3D-Langevin



- Symmetric component increases with E*
- Two mass asymmetric components

Fission modes





- Symmetric : super long
- Asymmetric
  - Standard I : Heavy fragment is “magic”
  - Standard III : Heavy fragment is deformed

Summary

- The fluctuation-dissipation dynamics is a general framework to describe the dynamics of a few slow (collective) variables interacting with many fast variables that can be treated as a heat bath.
- Powerful tool to study dynamics of fission
  - Fragment mass and TKE distributions
- Fm isotopes
  - Symmetric vs Asymmetric fission
  - Isotope dependence
- ^{236}U
- More flexible shape parameterization
  - Independent deformation of fragments, Neck