Shape evolution of atomic nucleus and clustering

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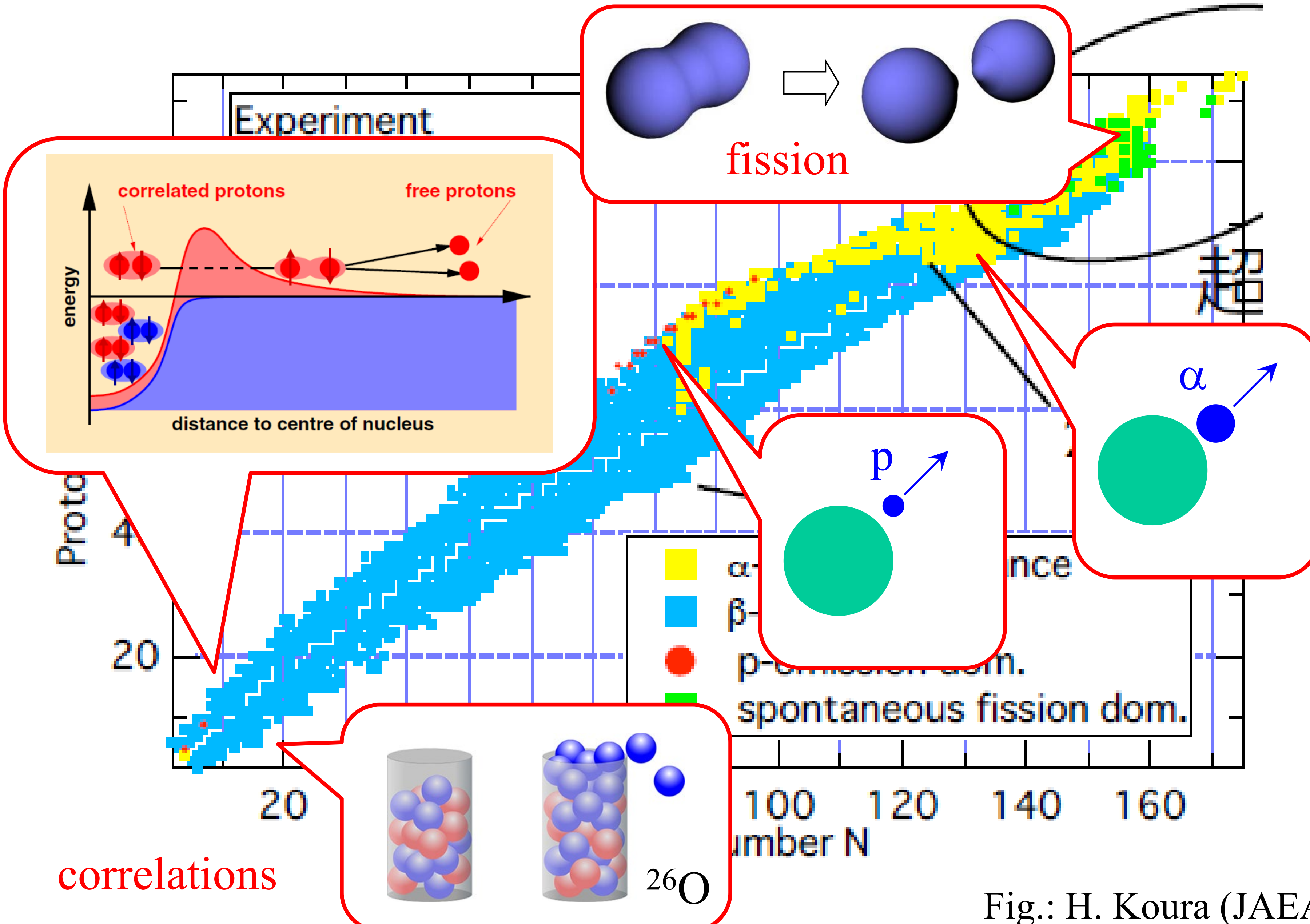
1. Introduction
2. CI model for cluster decays
3. Extension to induced fission
4. Summary

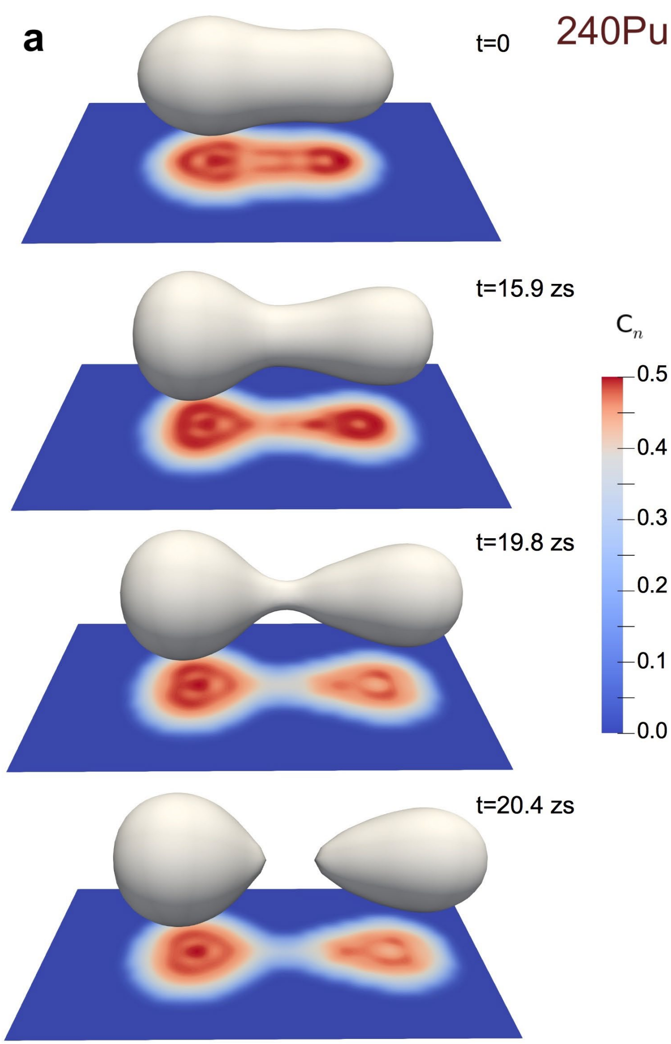
Introduction: particle emission decays of unstable nuclei



correlations

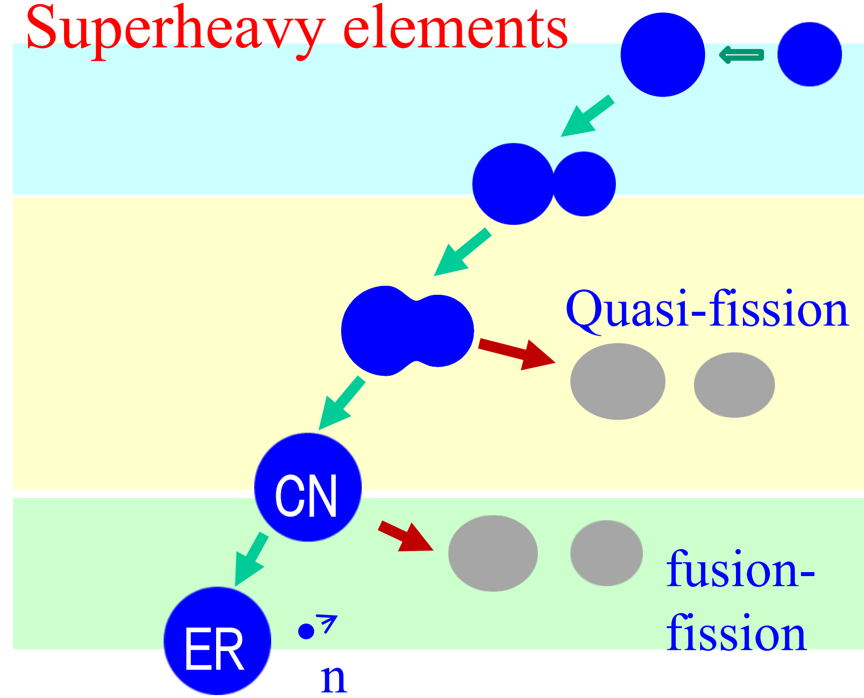
Fig.: H. Koura (JAEA)

Importance of fission

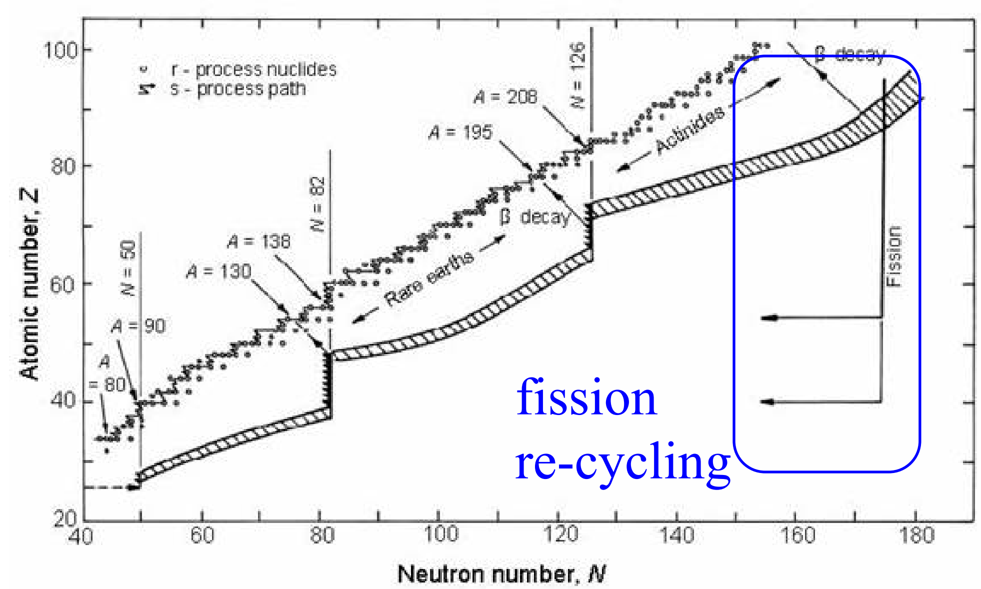


G. Scamps and C. Simenel, Nature 564 (2018) 382

Superheavy elements



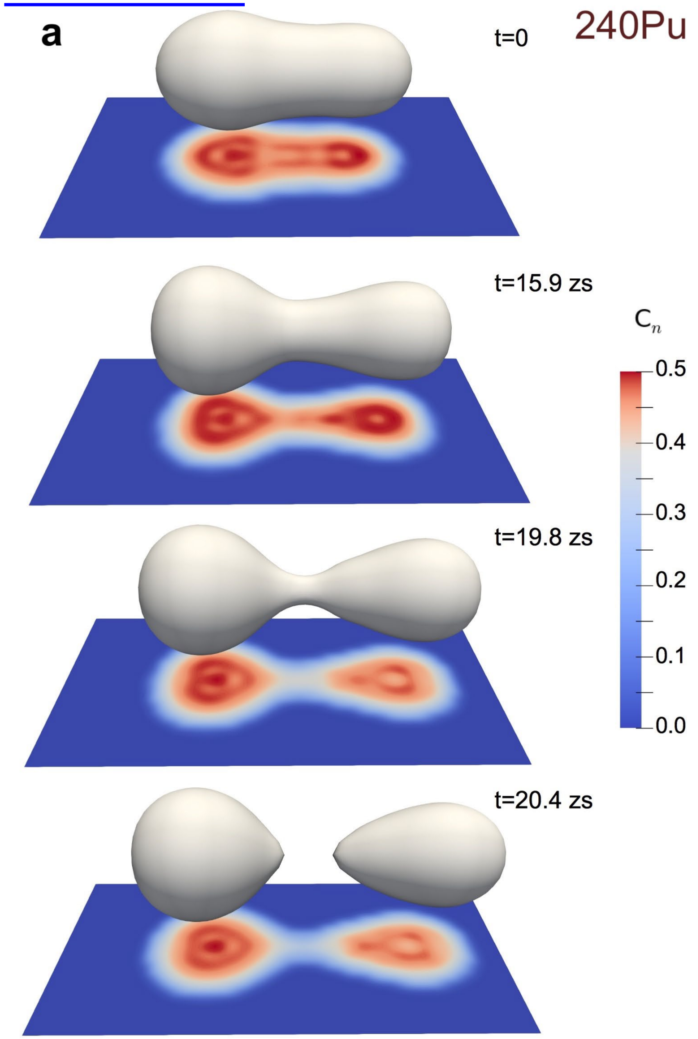
r-process nucleosynthesis



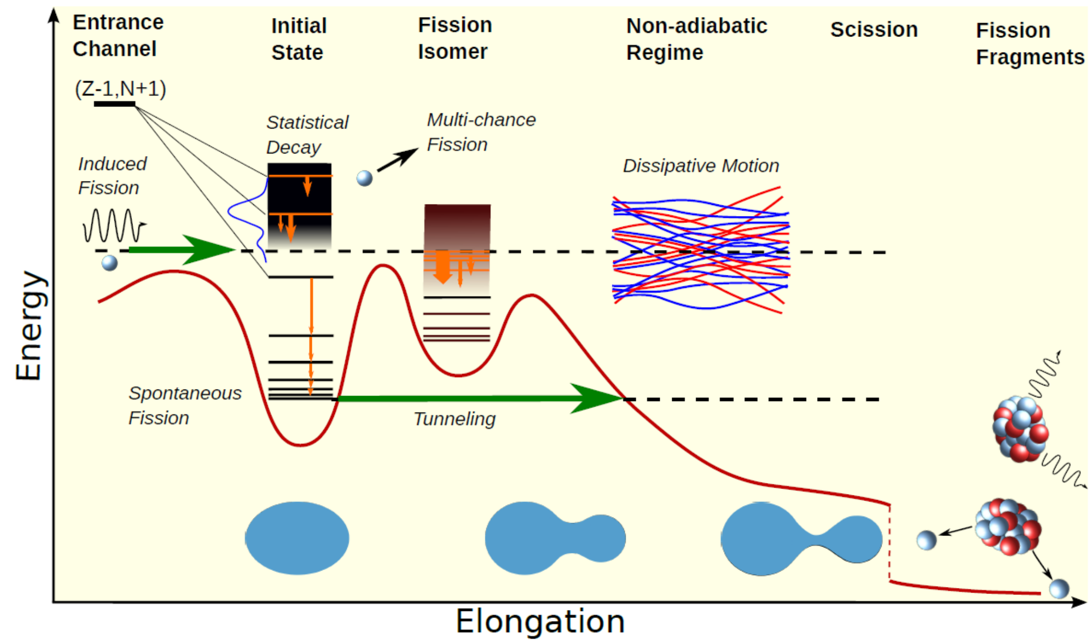
microscopic understanding of fission

large change of nuclear shape
→ microscopic description
: far from complete

an ultimate goal of nuclear physics



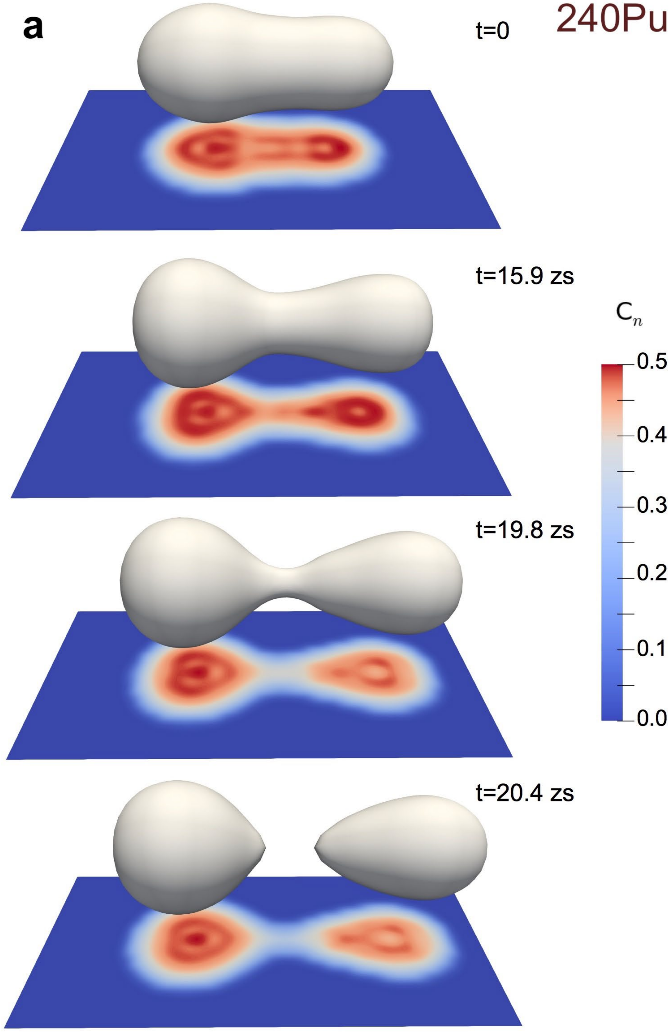
G. Scamps and C. Simenel,
Nature 564 (2018) 382



M. Bender et al.,
J. of Phys. G47, 113002 (2020)

"Future of fission theory" White paper

microscopic understanding of fission



G. Scamps and C. Simenel, Nature 564 (2018) 382

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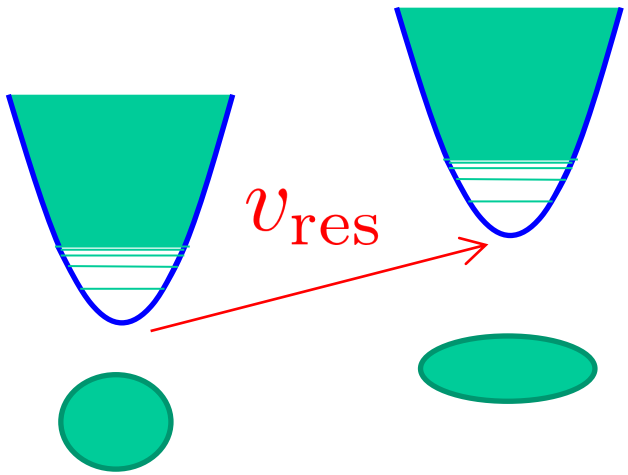
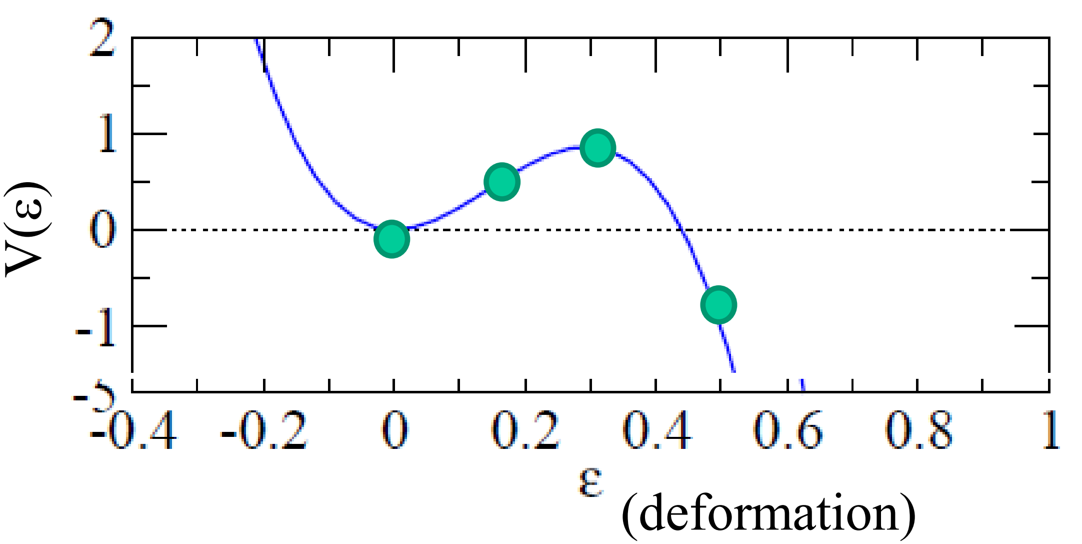
the aim of this work :
to construct a microscopic fission theory based on a many-body Hamiltonian

the method:
configurations based on DFT
→ shell model

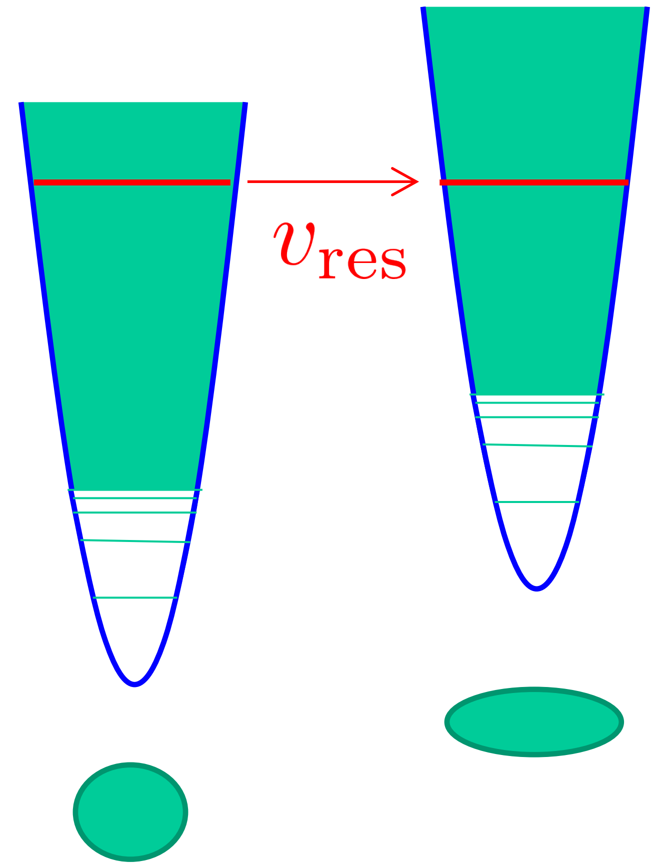
Generator Coordinate Method + CI approach



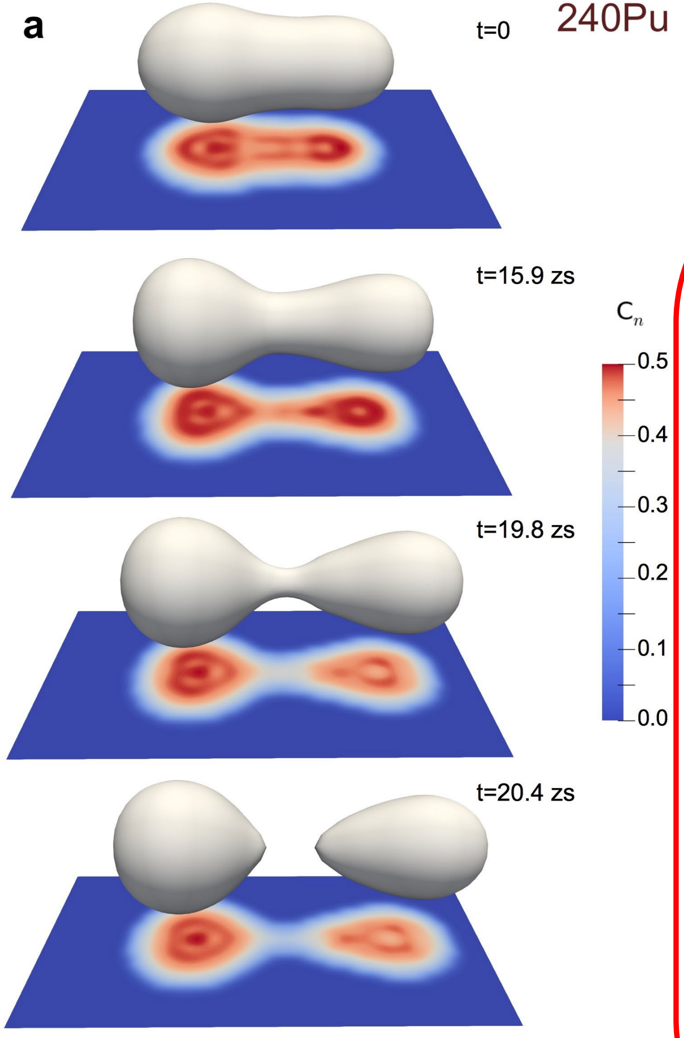
hopping due to residual interactions
→ shape evolution



in the case of induced fission



microscopic understanding of fission



G. Scamps and C. Simenel, Nature 564 (2018) 382

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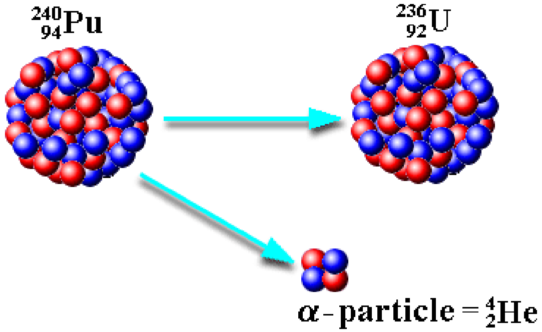
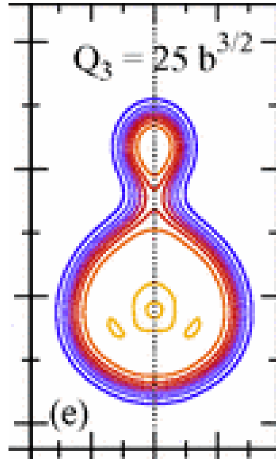
objects:
- cluster decays from the ground state
- induced fission of ^{236}U
- (spontaneous fission of heavy nuclei)

Cluster Radioactivities

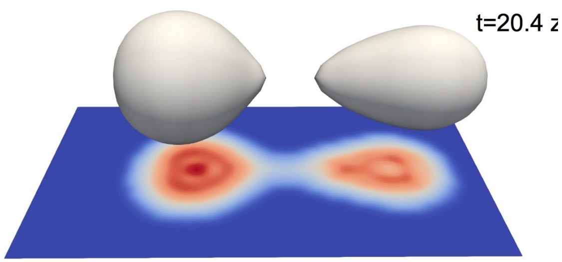
α decays



cluster decays



fission



$^{224}Ra \longrightarrow {}^{14}C + {}^{210}Pb$

M. Warda and L.M. Robledo,
PRC84, 044608 (2011)

- ✓ intermediate between α-decay and fission (very asymmetric fission)
- ✓ first observation in 1984 by Rose and Jones ($^{223}Ra \rightarrow {}^{14}C + {}^{209}Pb$)
- ✓ very small branching to α decays ("rare decay") ^{224}Ra: 4.3 x 10^{-11}
- ✓ may become a dominant decay mode in superheavy nuclei

: $^{294}Og \longrightarrow {}^{86}Kr + {}^{208}Pb$

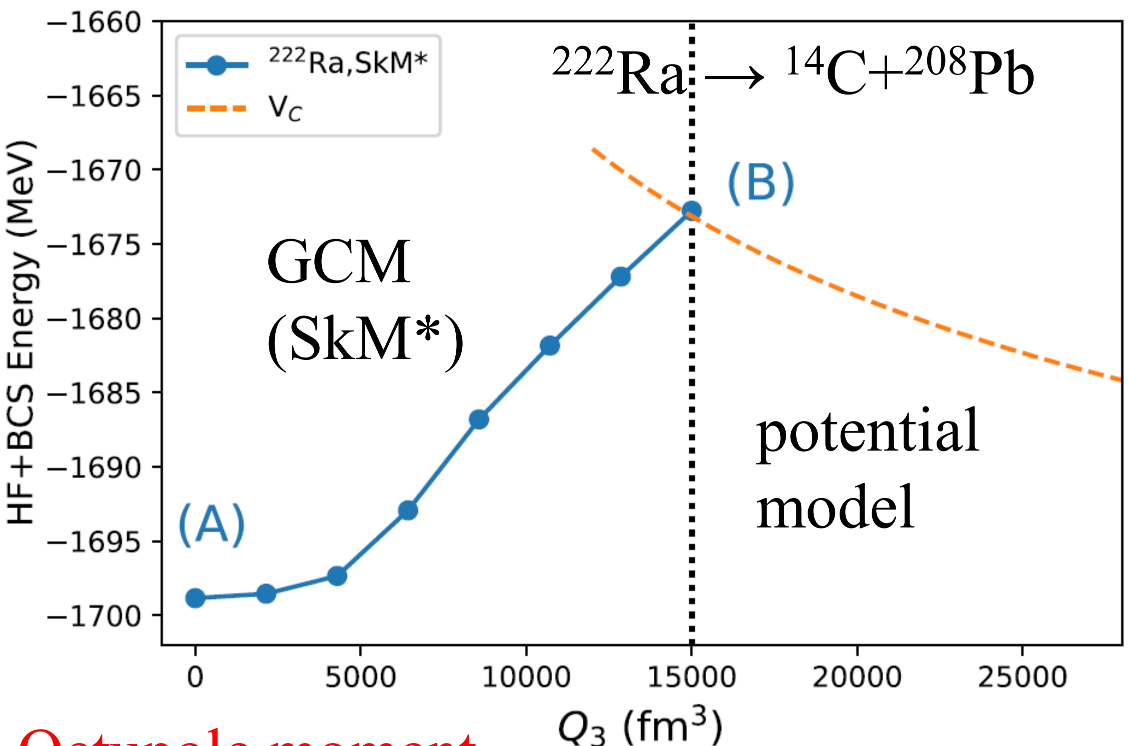
Z. Mateson, Giuliani, Nazarewicz, Sadhukhan, Schunck, PRC99('19) 041304(R)

GCM+CI approach to cluster decays

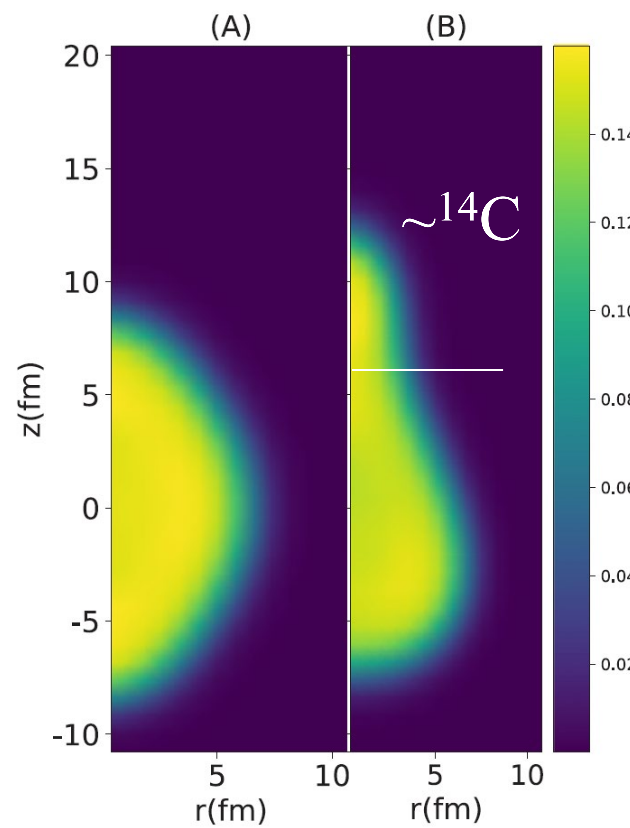
K. Uzawa, K. Hagino, and K. Yoshida, PRC105 (2022) 034326

Gamow theory: $w = S f P_{\text{tunnel}}$

S: Cluster formation prob. → GCM with Q_3
f: attempt frequency
P: tunnel prob.
} →two-body potential model



Octupole moment



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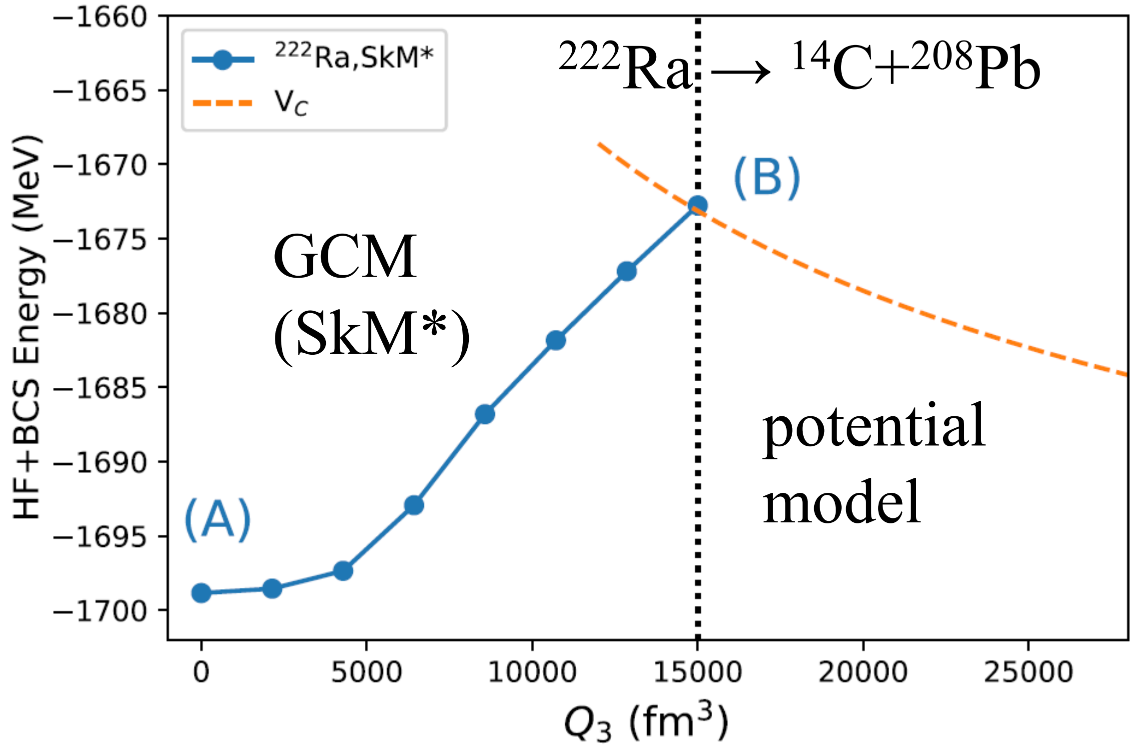


$$\Psi = \int dQ_3 f(Q_3) |\Psi_{Q_3}\rangle$$

↑

GCM

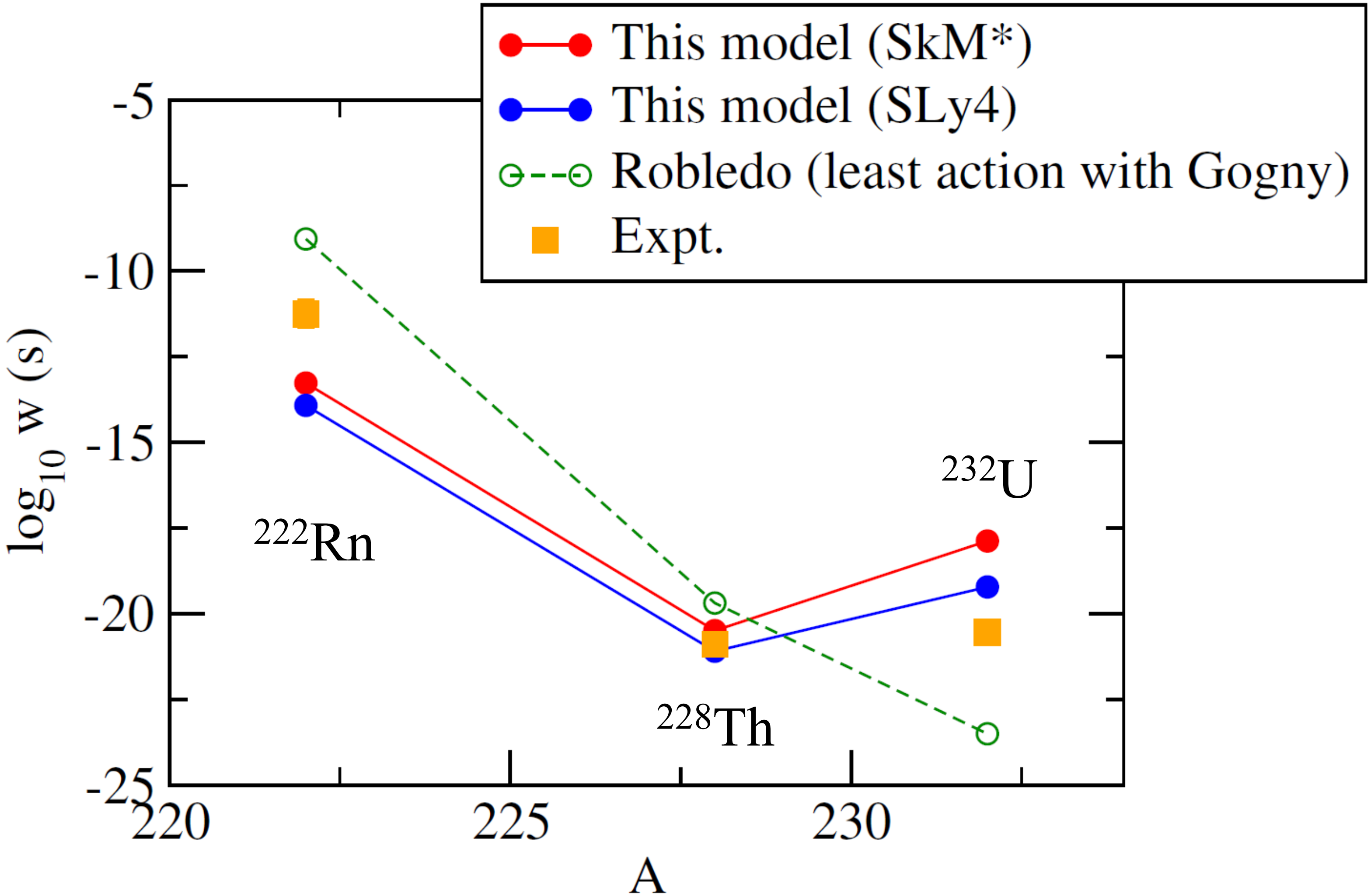
$$S \sim |\sqrt{N} f(Q_{3B})|^2$$

excited configurations at each Q_3 ← shell model aspect

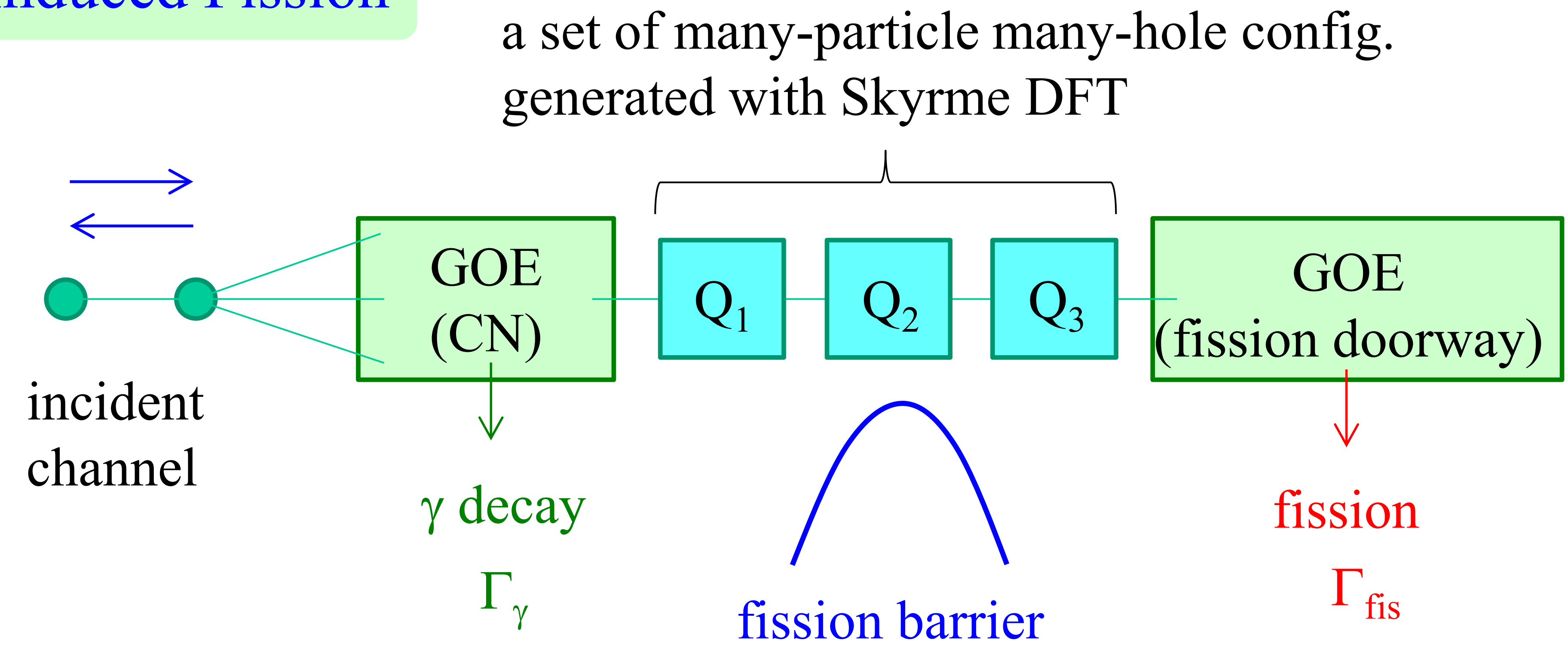
$$|\Psi\rangle = \int dQ_3 \sum_i f_i(Q_3) |\Phi_{Q_3}(i)\rangle$$

GCM+CI approach to cluster decays

K. Uzawa, K. Hagino, and K. Yoshida, PRC105 (2022) 034326



Induced Fission



reaction theory :

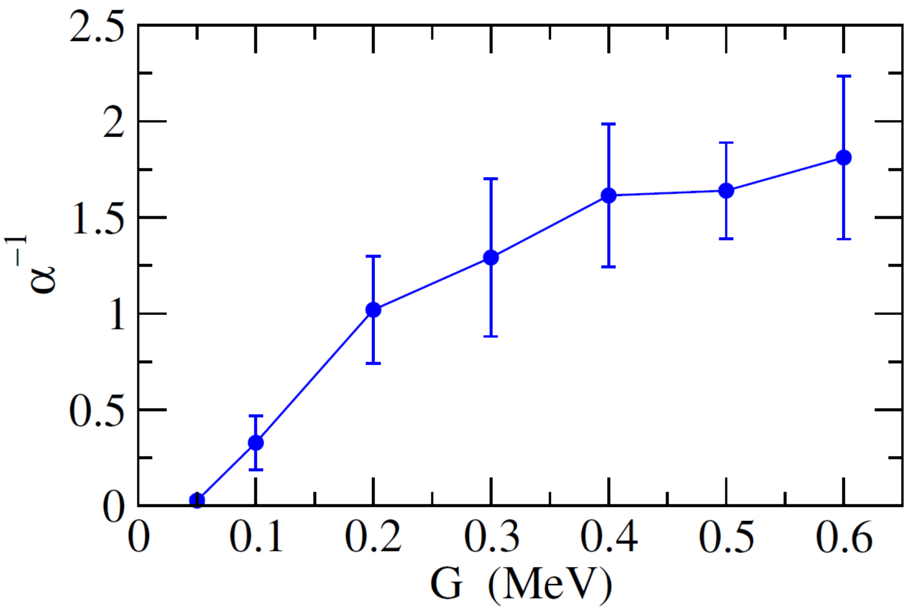
$$T_{\mathsf{fis}} = Tr[\Gamma_{\mathsf{in}} G(E) \Gamma_{\mathsf{fis}} G^\dagger(E)]$$

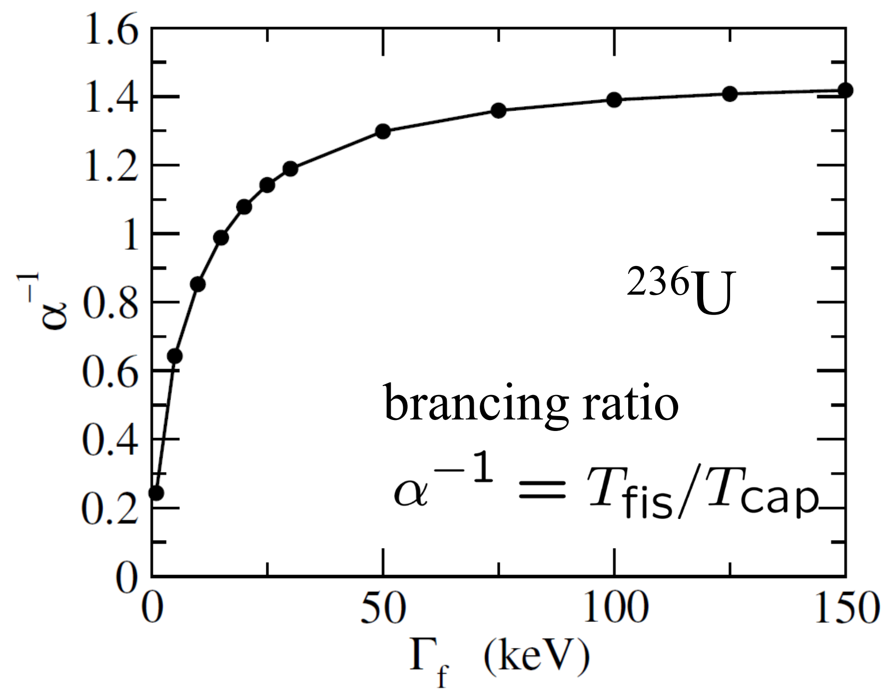
$$G(E) = [H - i\Gamma/2 - EO]^{-1}$$

decay branching ratio : $\alpha^{-1} = T_{\mathsf{fis}}/T_{\mathsf{cap}}$

Induced Fission

G.F. Bertsch and K. Hagino, arXiv: 2302.00572 (2023).
K. Uzawa, K. Hagino, and G.F. Bertsch, in preparation (2023).



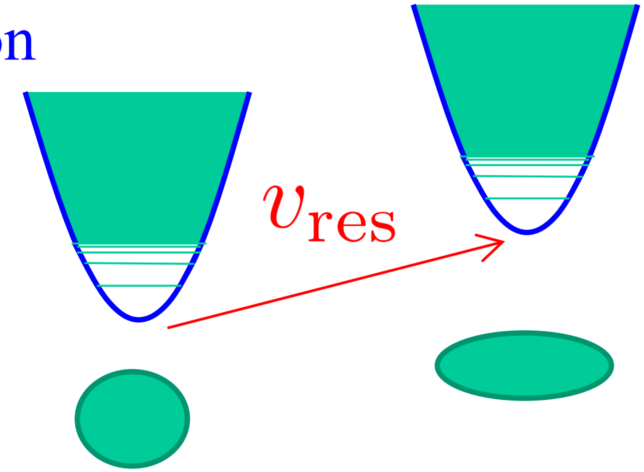


✓ pairing: enhances $T_{\rm fis}$ at energies around the barrier
✓ $T_{\rm fis}$: insensitive to the dynamics after the barrier
  → transition state theory (TST)

Summary

CI approach to nuclear fission

$$|\Psi\rangle = \int dQ \sum_i f_i(Q)|\Phi_Q(i)\rangle$$



- ✓ a microscopic theory based on a many-body Hamiltonian
- ✓ applied to cluster decays and induced fission
- ✓ so far, one degree of freedom

→a challenge: extension to many degrees of freedom

- how clusters are emerged inside a nucleus
- competition between alpha decays and cluster decays

✓ another challenge: realistic calculations for induced fission

- the inversion of a Hamiltonian with a large dimension