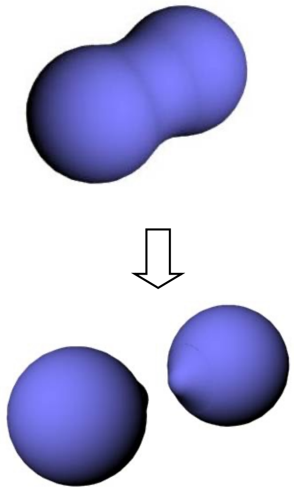
An application of shell model to low-energy induced nuclear fission



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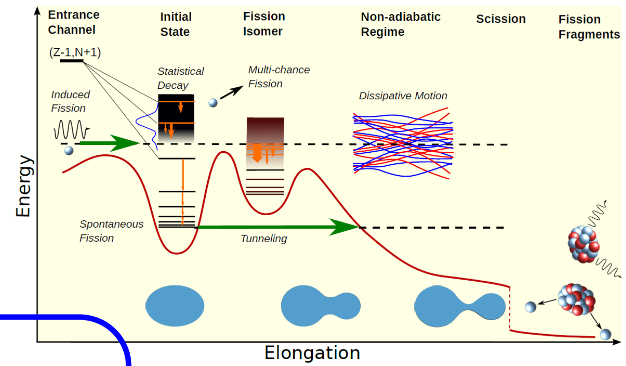
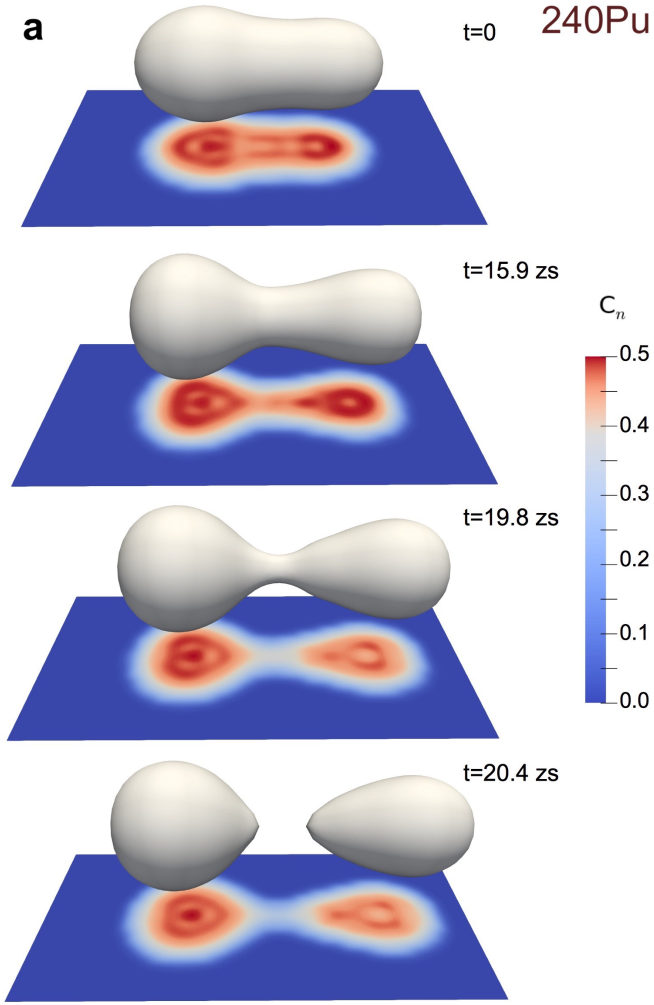


1. Introduction
2. Shell Model for induced fission
3. Summary

The 6th Joing meeting of APS/JPS meeting, Hawaii, 2023.11.26-12.1

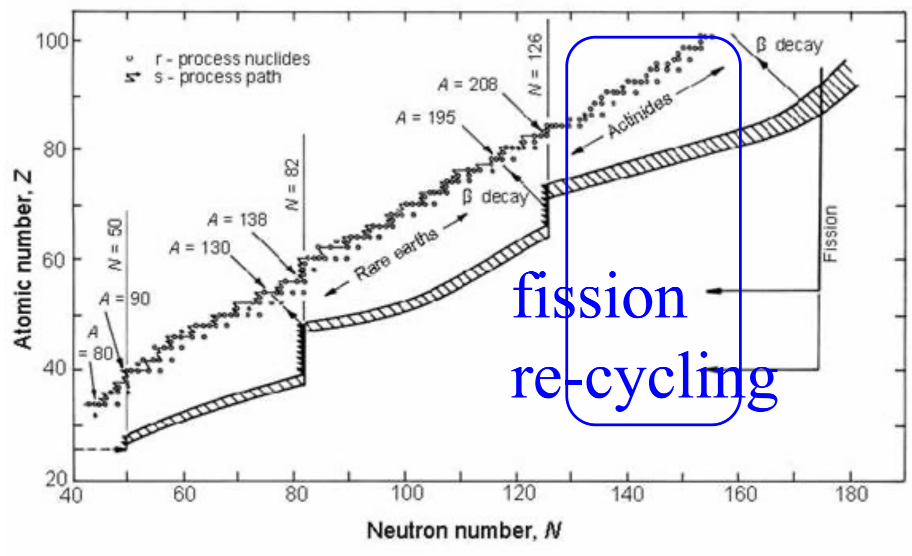
Nuclear Fission



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

✓ Superheavy elements

✓ r-process nucleosynthesis

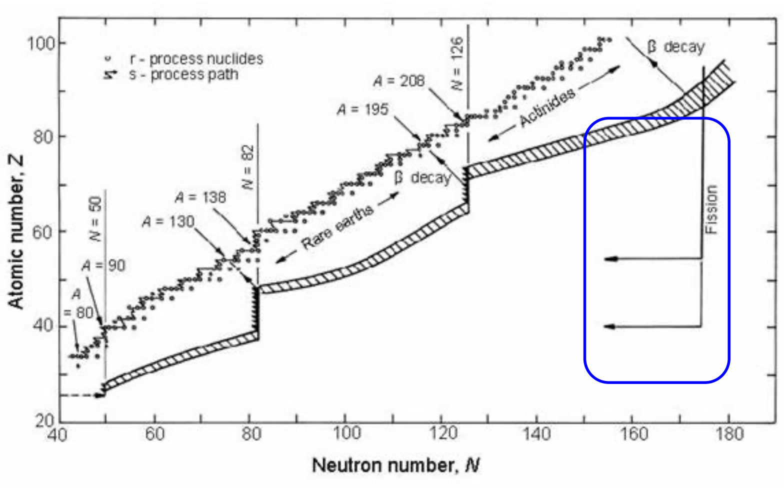


a large change of nuclear shape
(a large amplitude motion)
→ microscopic description
: far from complete

an ultimate goal of nuclear physics

Importance of a microscopic approach

➢ r-process nucleosynthesis



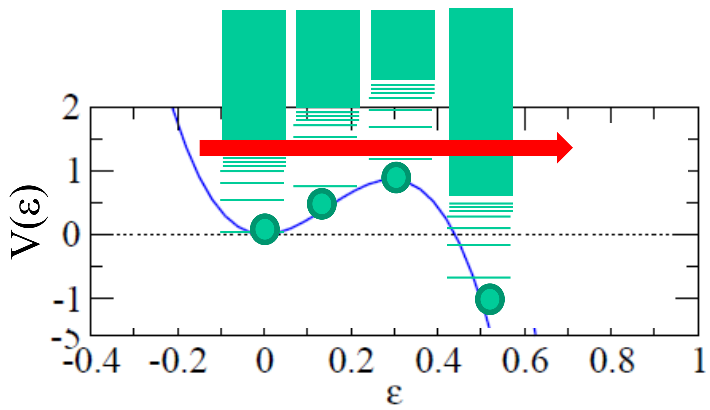
(neutron induced) fission of neutron-rich nuclei

→ low E^* and low $\rho(E^*)$

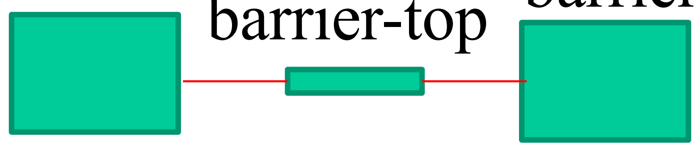
✓Validity of statistical models?

✓Validity of the Langevin approach?

➢ barrier-top fission



CN — barrier-top — post barrier



high ρ(E) — low ρ(E) — high ρ(E)

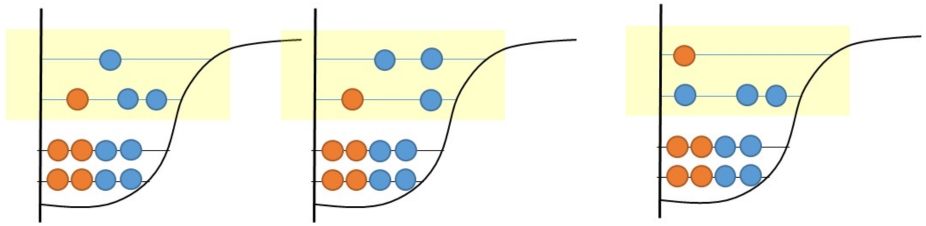
↓

discrete levels

How to connect to a many-body Hamiltonian?

Shell model approach?

Shell model



$|\Psi\rangle = \quad v_1|m_1\rangle \quad + \quad v_2|m_2\rangle \quad + \quad v_3|m_3\rangle \quad + \cdots$

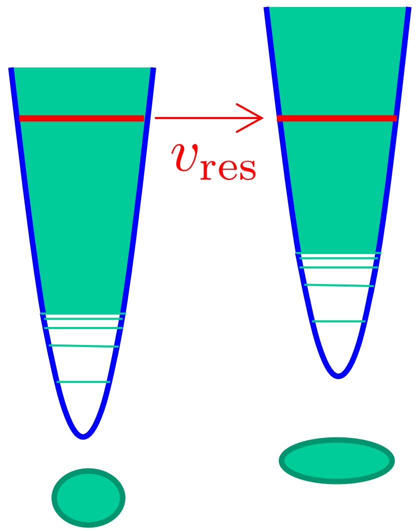
Figure: Noritaka Shimizu (Tsukuba)

many-particle many-hole config.
in a mean-field potential
→mixing by <u>residual interactions</u>

$$|\Psi\rangle = \sum_Q \sum_i \nu_i(Q)|m_i(Q)\rangle$$

GCM with excited states

A similar approach for nuclear fission?

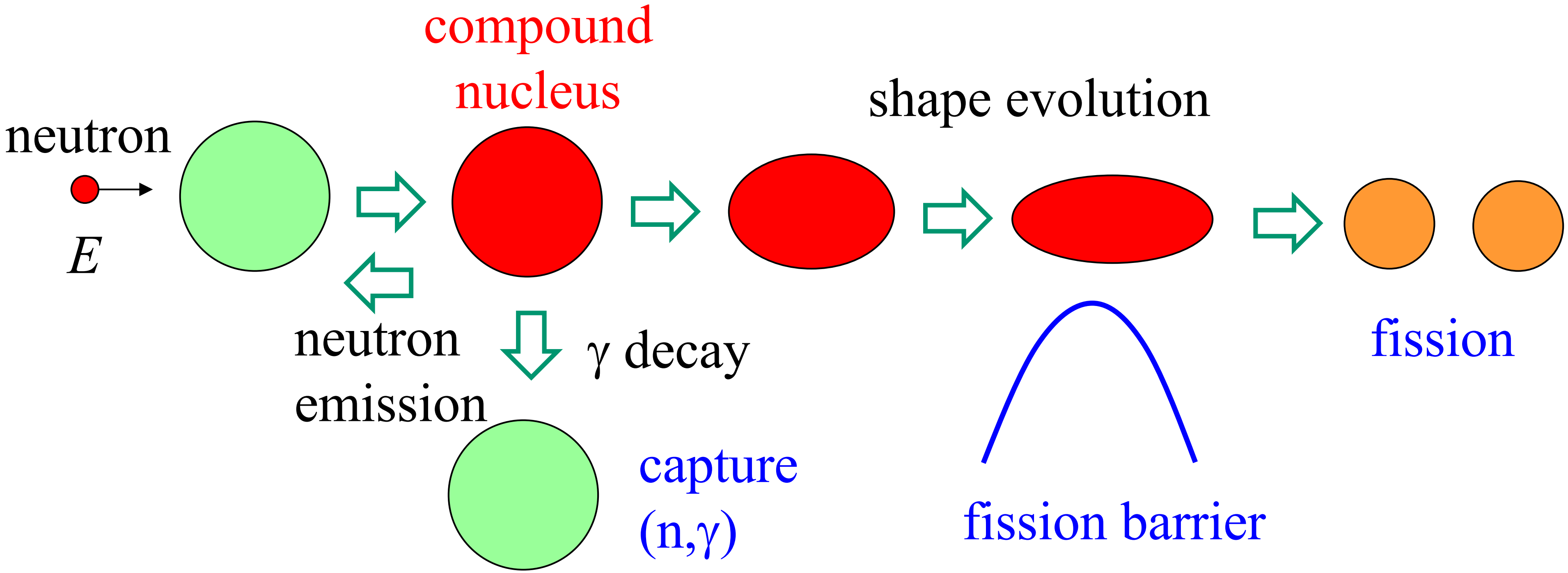


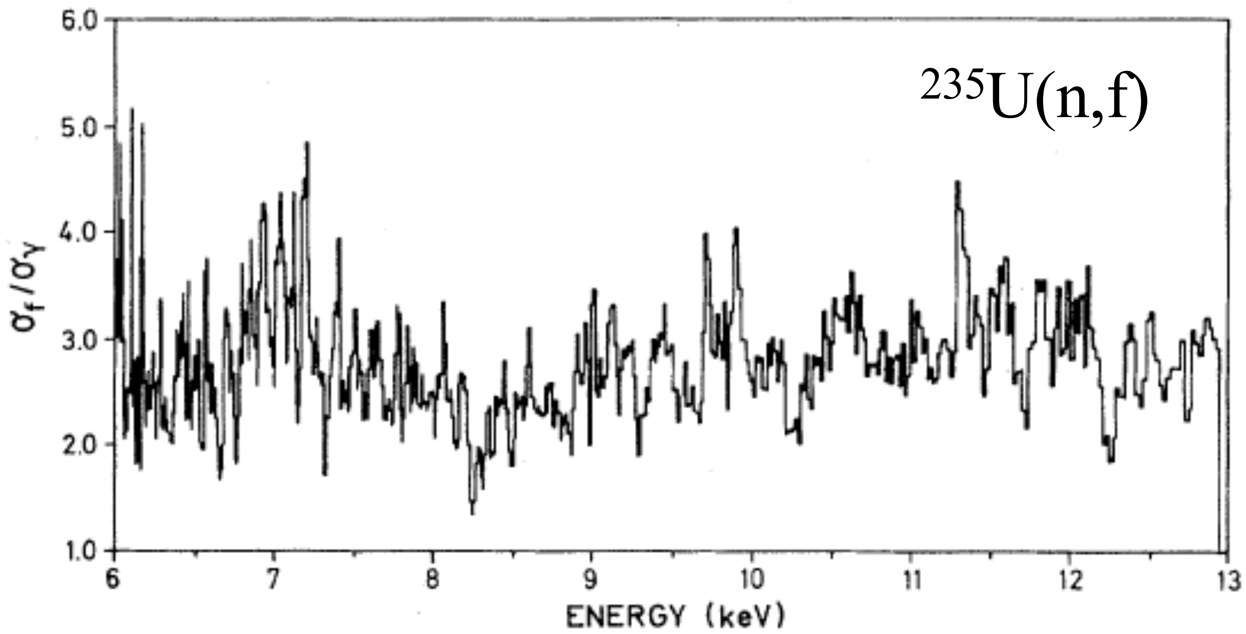
- Many-body configurations in a MF pot. for each shape
- hopping due to res. int.

→ shape evolution

a good connection to nuclear reaction theory

a process which we would like to dicscuss





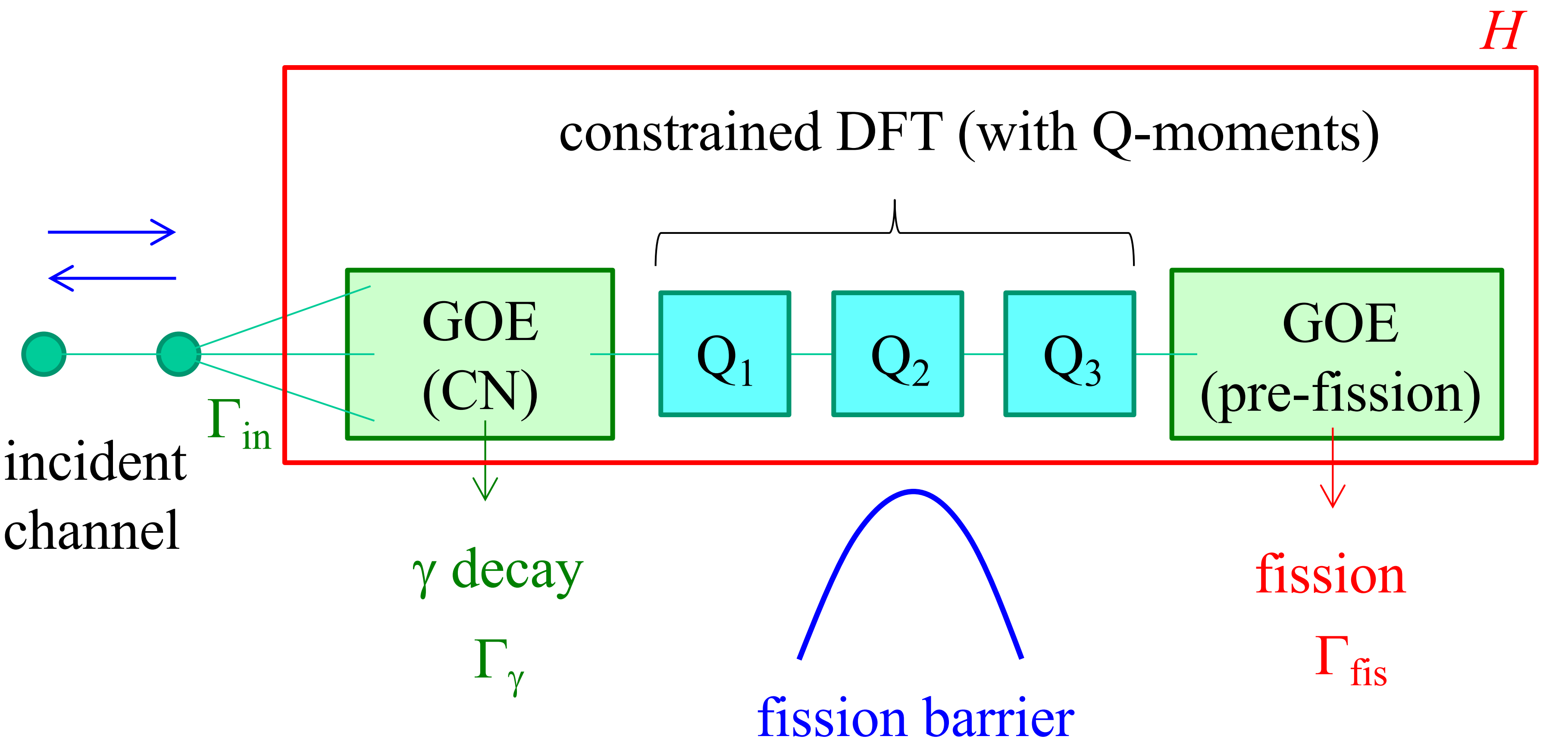
branching ratio

$$\alpha^{-1} = \frac{\sigma_f}{\sigma_\gamma}$$

sensitive to intermediate structure

M.S. Moore et al., PRC30 ('84) 214

a process which we would like to dicscuss



Reaction theory (absorption probability):

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

$$T_{\mathrm{cap}} = Tr[\Gamma_{\mathrm{in}} G(E) \Gamma_{\gamma} G^{\dagger}(E)]$$

"Datta formula"

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

Calculations based on Skyrme Hartree-Fock method

G.F. Bertsch and K.H., Phys. Rev. C107, 044615 (2023).

Simplifications:

- ✓ ^{236}U : only neutron configurations, up to 4 MeV
- ✓ Dynamics of the first barrier: axial symmetry
- ✓ seniority-zero config. only: occupation of (K, -K)
- ✓ a scaled fission barrier with $B_f = 4$ MeV

$$\langle \Psi_\mu(Q) | \Psi_\mu(Q') \rangle \sim e^{-1}$$

dim.							
=100	42	97	153	125	65	32	100
GOE	18b	22b	26b	29b	33b	37b	GOE
↓ Γ_{cap}	many-body config. based on UNEDF1 (HF basis, E* < 4 MeV)						↓ Γ_{fis}

714x714 Hamiltonian matrix

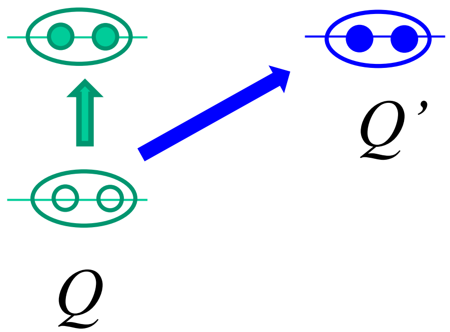
Calculations based on Skyrme Hartree-Fock method

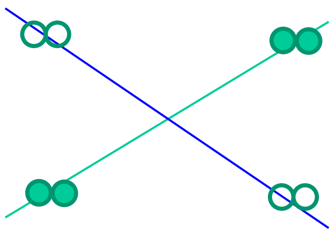
G.F. Bertsch and K.H., Phys. Rev. C107, 044615 (2023).

GOE → Γ_{cap} | 18b | 22b | 26b | 29b | 33b | 37b | GOE → Γ_{fis}

many-body config. based on UNEDF1 (18b – 37b)

- ✓ overlap: $\langle \Psi_\mu(Q) | \Psi_\mu(Q') \rangle \sim e^{-1}$
- ✓ pairing: $v_{\text{pair}} = -GP^\dagger P$
- ✓ diabatic:

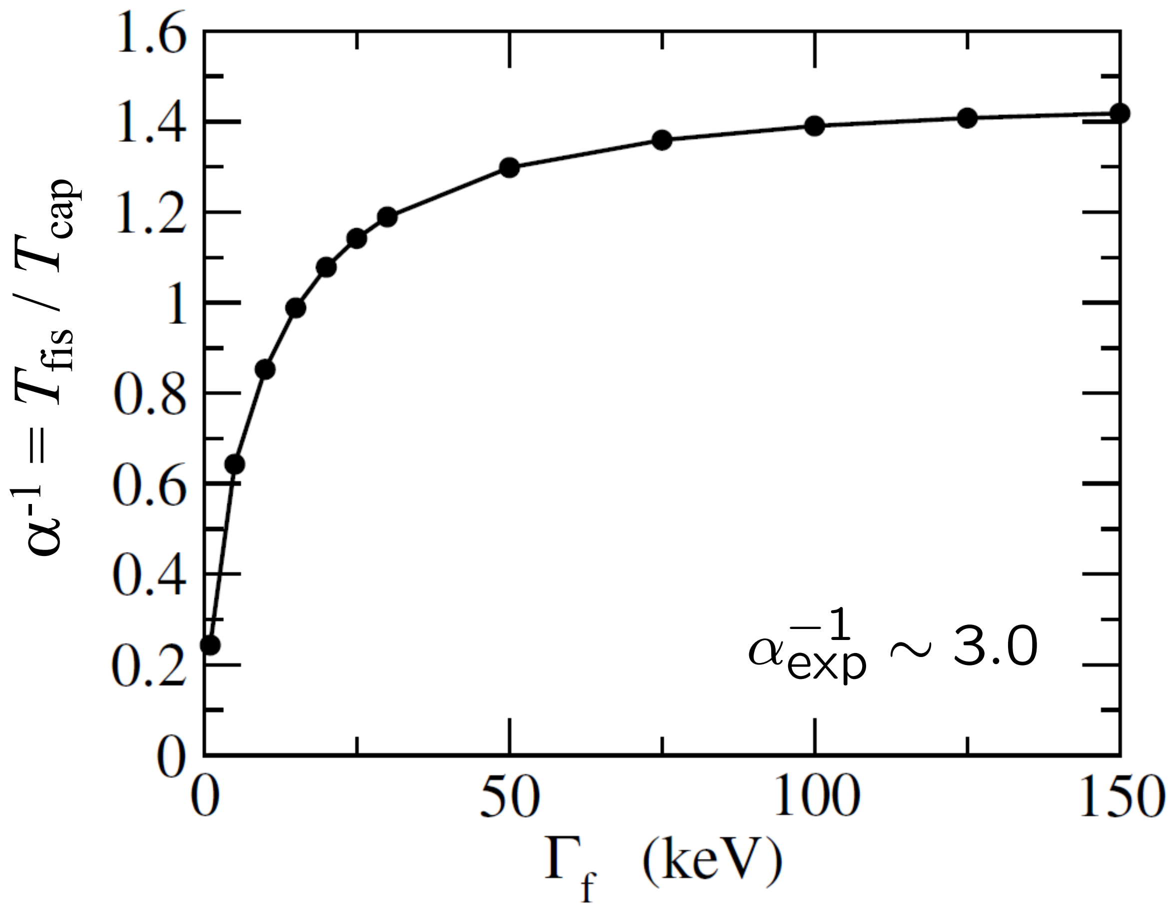




$$\frac{\langle \Psi_\mu(Q) | H | \Psi_\mu(Q') \rangle}{\langle \Psi_\mu(Q) | \Psi_\mu(Q') \rangle} \sim E_\mu(\bar{Q}) - h_2(\Delta Q)^2$$

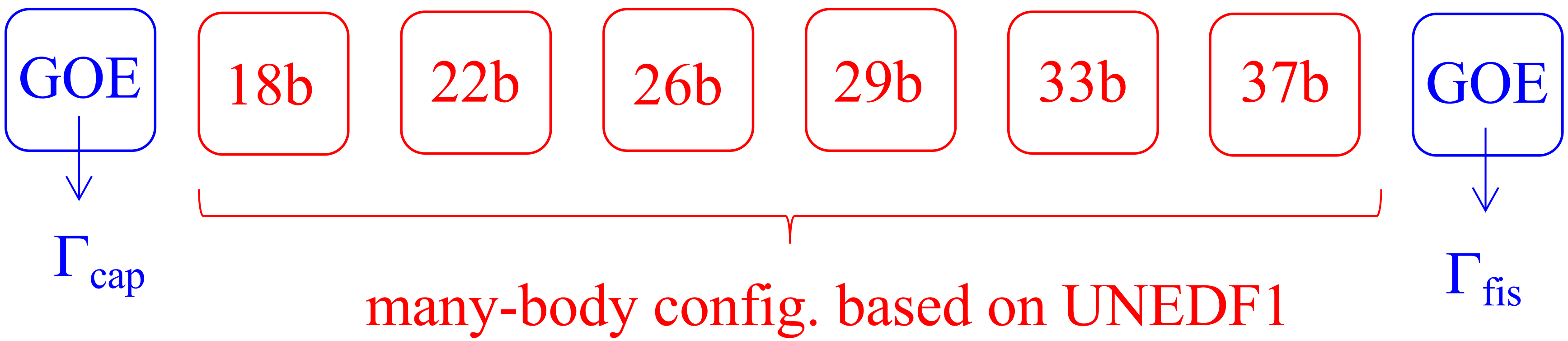
- ✓ Γ_{cap}: exp. data (scaled according to N_{GOE}), Γ_{fis}: insensitivity

insensitivity property

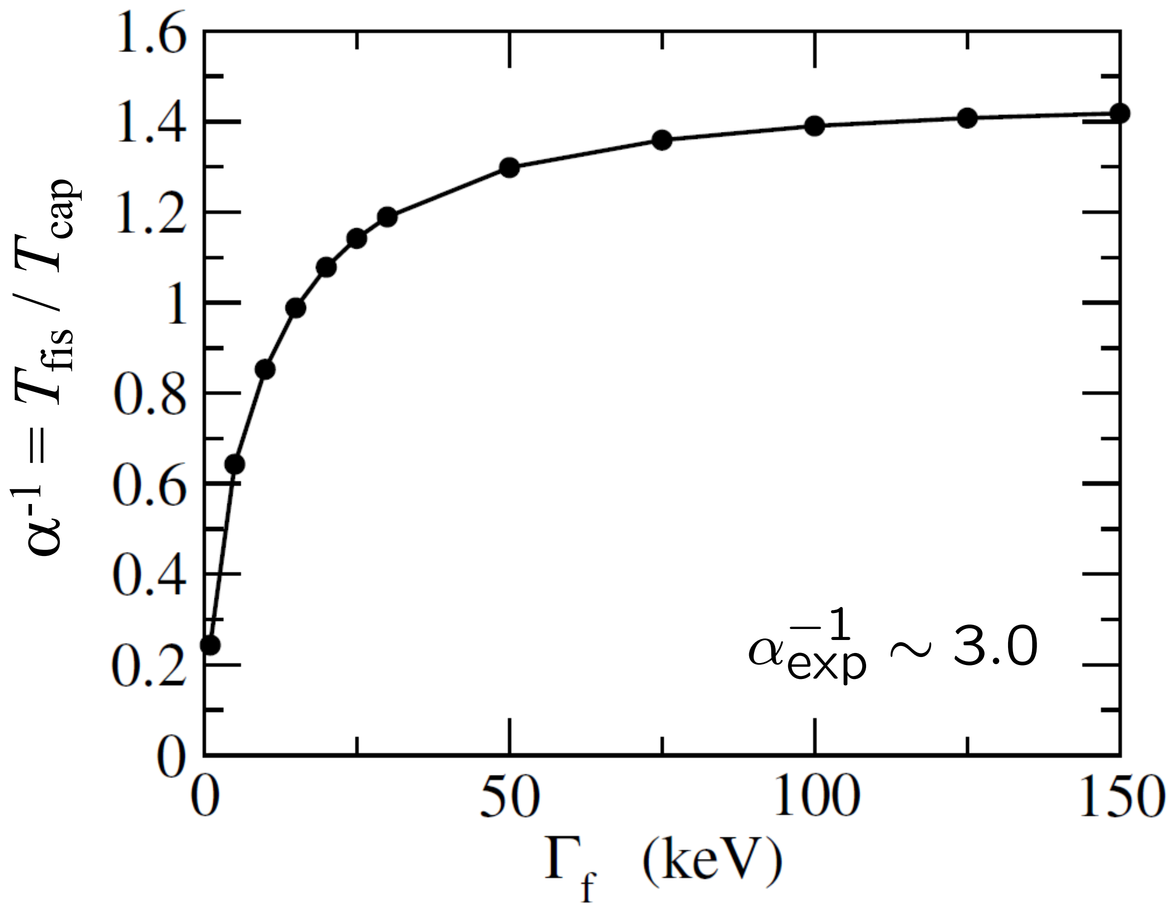


insensitive to Γ_f
(post-barrier dynamics)
→the main assumption of TST

cf. Analytic discussion with a 2GOE+1Q model
K.H. and G.F. Bertsch, arXiv: 2310.09537



[insensitivity property]



base set

G_{pair} = 0.2 MeV

h_2 = 0.15 MeV

$\rightarrow \alpha^{-1} = 0.95$

$G_{pair} \rightarrow G_{pair}/2$

G_{pair} = 0.1 MeV

h_2 = 0.15 MeV

$\rightarrow \alpha^{-1} = 0.37$

sensitive to the pairing, though less than in spontaneous fission

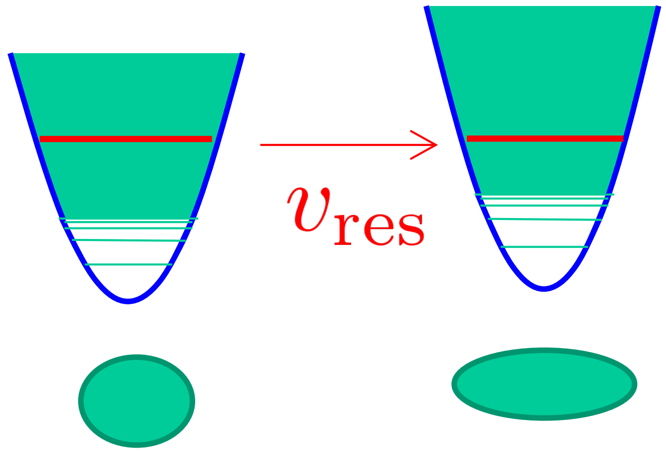
Summary

r-process nucleosynthesis: fission of neutron-rich nuclei

requires a microscopic approach applicable to low E^* and $\rho(E^*)$

also for barrier-top fission

➡ a new approach: shell model + GCM



an application to induced fission of ^{236}U
based on Skyrme EDF

- ✓ neutron configurations only
- ✓ pairing and diabatic interactions
- ✓ truncation at 4 MeV

→an importance of the pairing interaction

Future perspectives: seniority non-zero config. →pn res. interaction

a large scale calculation (~ 10^6 dim.)

the next talk by Uzawa

K. Uzawa and K. Hagino, PRC108, 024319 (2023)