Reaction dynamics for hot fusion reactions with a deformed nucleus

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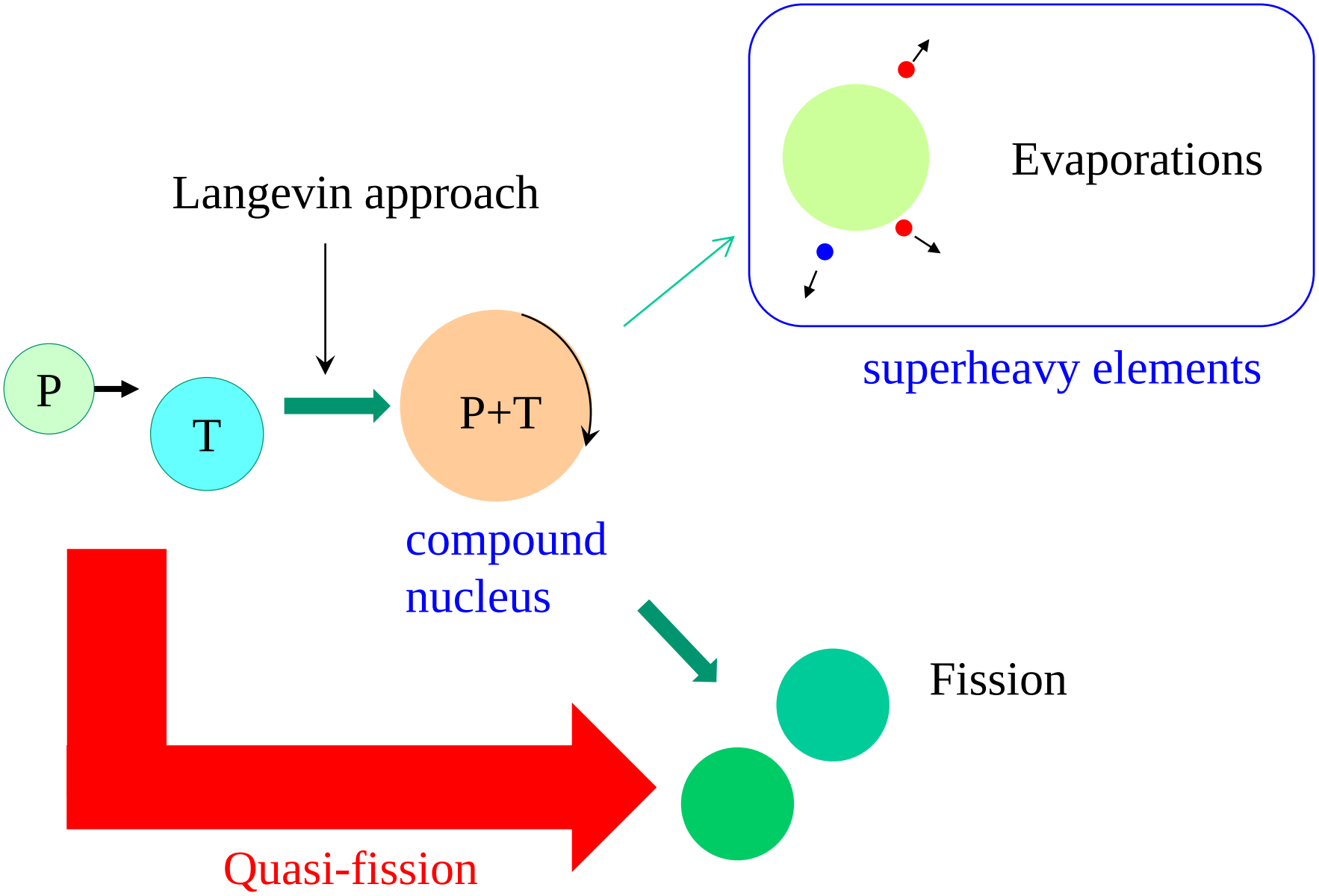
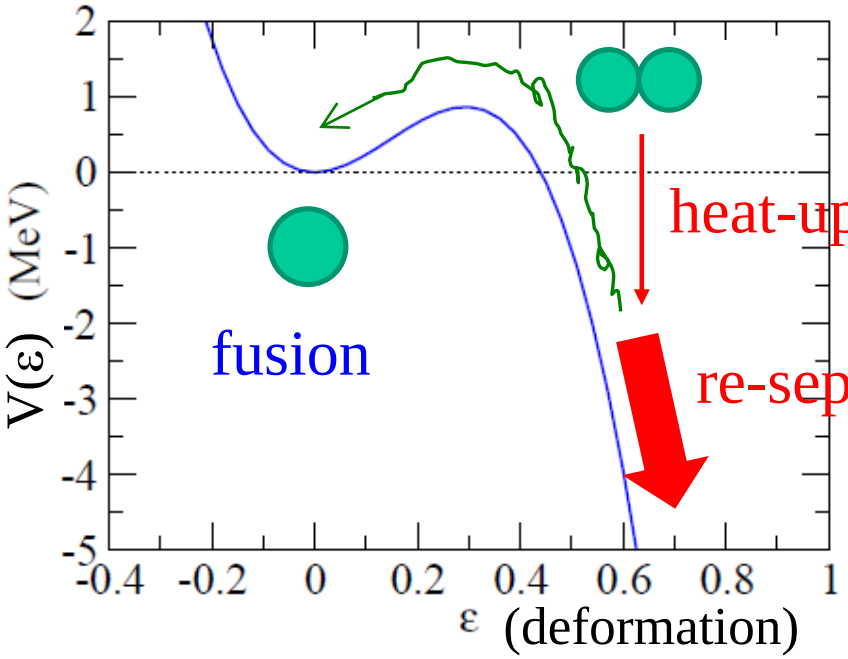
1. Diffusion over the saddle: Langevin approach
2. TDHF + Langevin approach for hot fusion
3. Odd-mass target: role of spin alignment
4. Summary

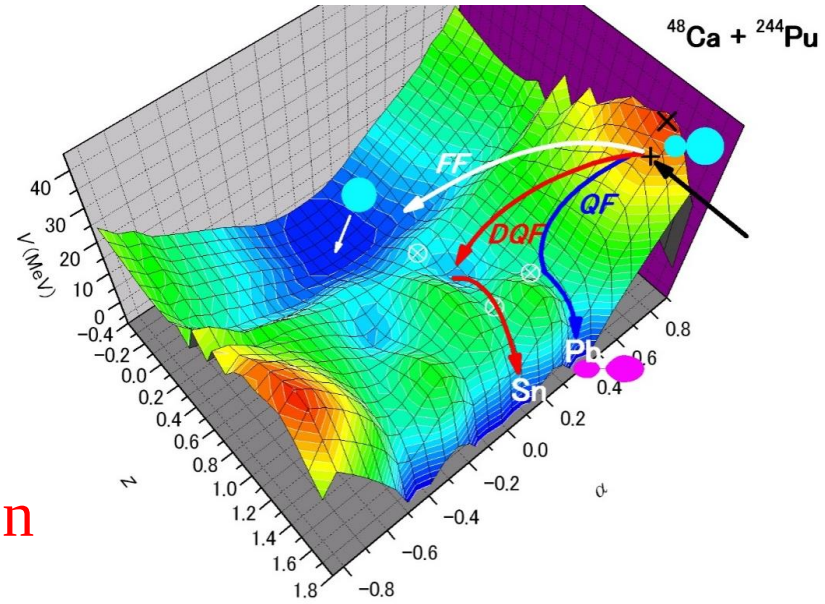
The 4th International Symposium on Superheavy Elements (SHE2019), Dec. 1-5, 2019, Hakone

Fusion for Superheavy elements



Langevin approach

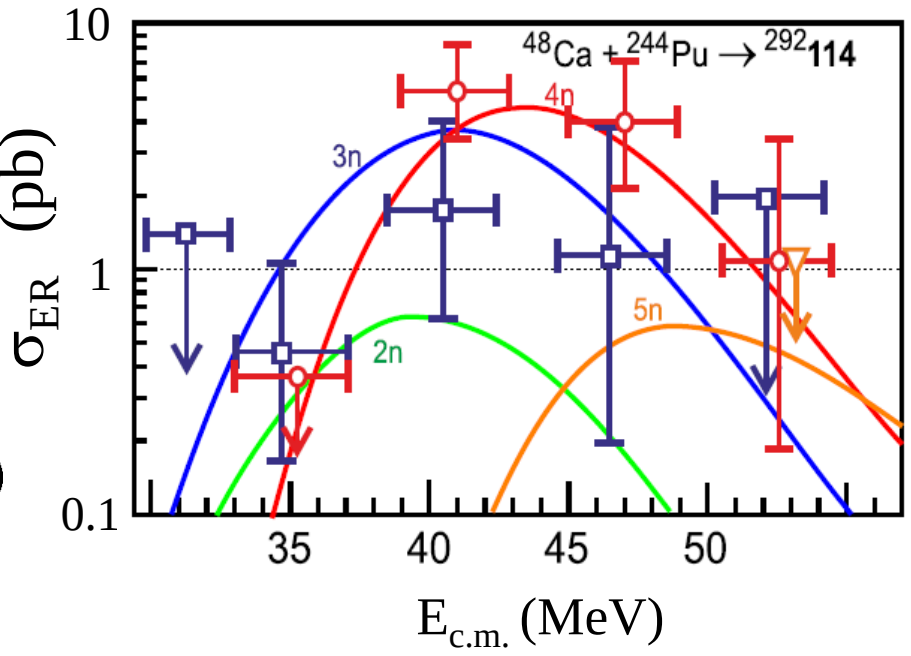




thermal fluctuation

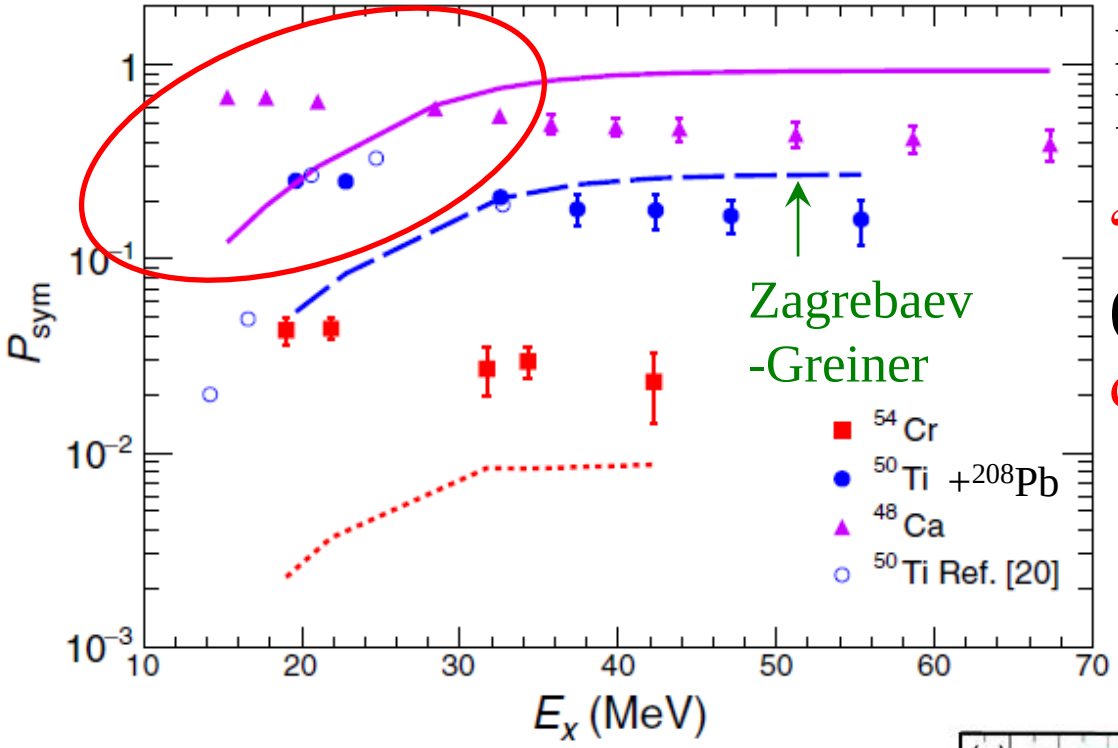
→ Langevin method

$$m\frac{d^2q}{dt^2} = -\frac{dV(q)}{dq} - \gamma\frac{dq}{dt} + R(t)$$



V.I. Zagrebaev and W. Greiner (2015)

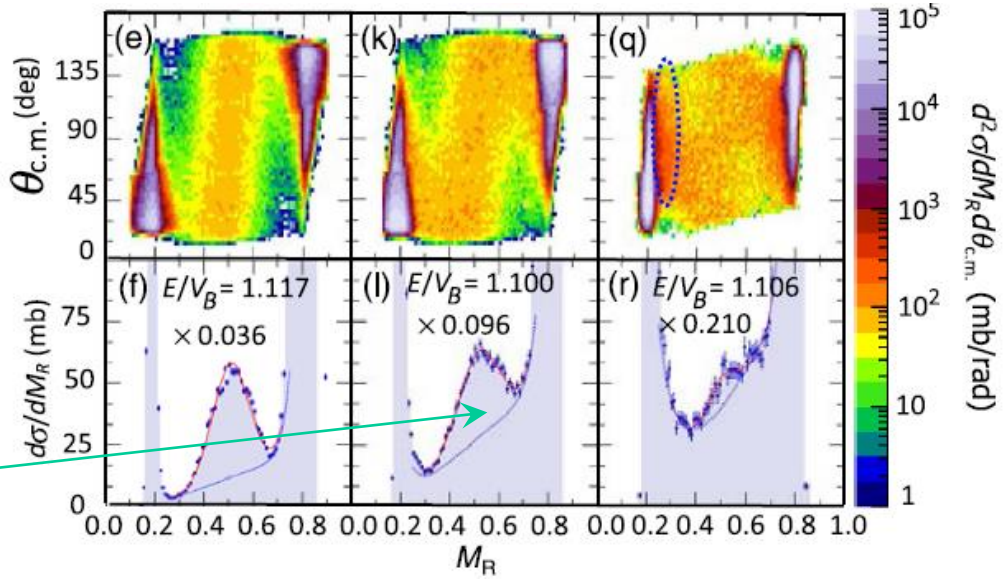
Recent publication by Banerjee et al. (ANU)



K. Banerjee, D.J. Hinde, et al., PRL122, 232503 (2019)

"cold fusion reactions (involving ^{208}Pb) are not driven by a diffusion process"

σ_{ff}



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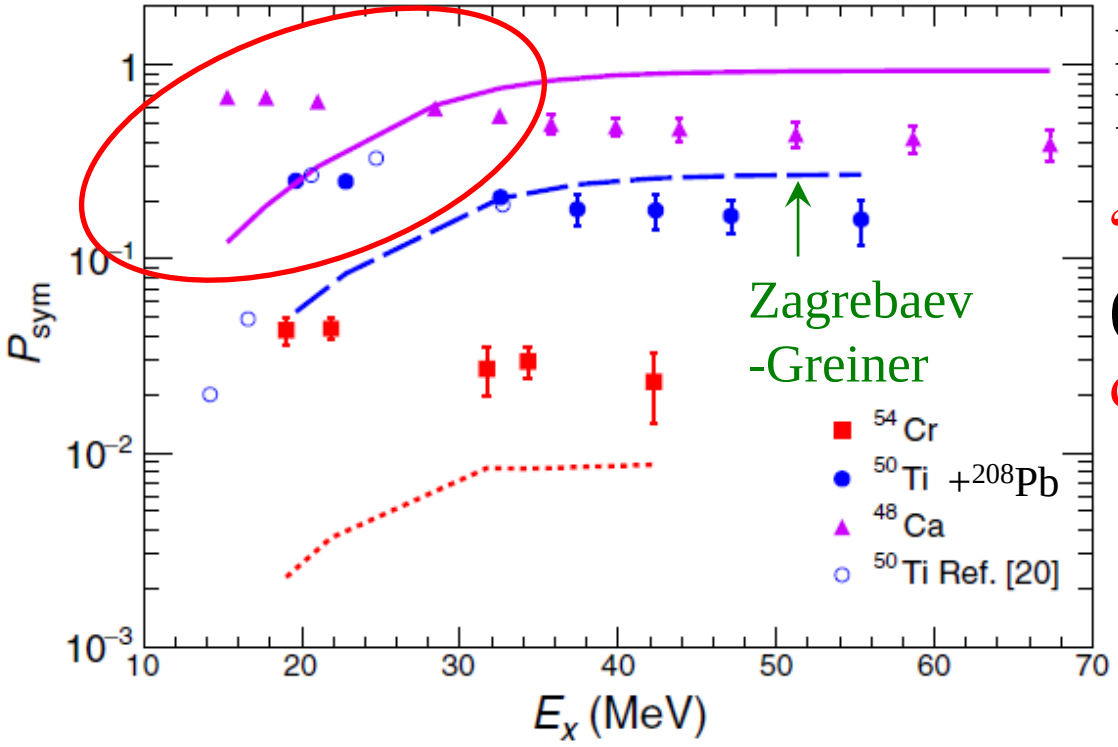


K. Banerjee, D.J. Hinde, et al.,
PRL122, 232503 (2019)

"cold fusion reactions (involving ^{208}Pb) are not driven by a diffusion process"

comparisons: to a classical Langevin calculation

→ quantum effect should be crucial at low E_x

K. Washiyama, M. Tokieda, and K. Hagino,
a work in progress

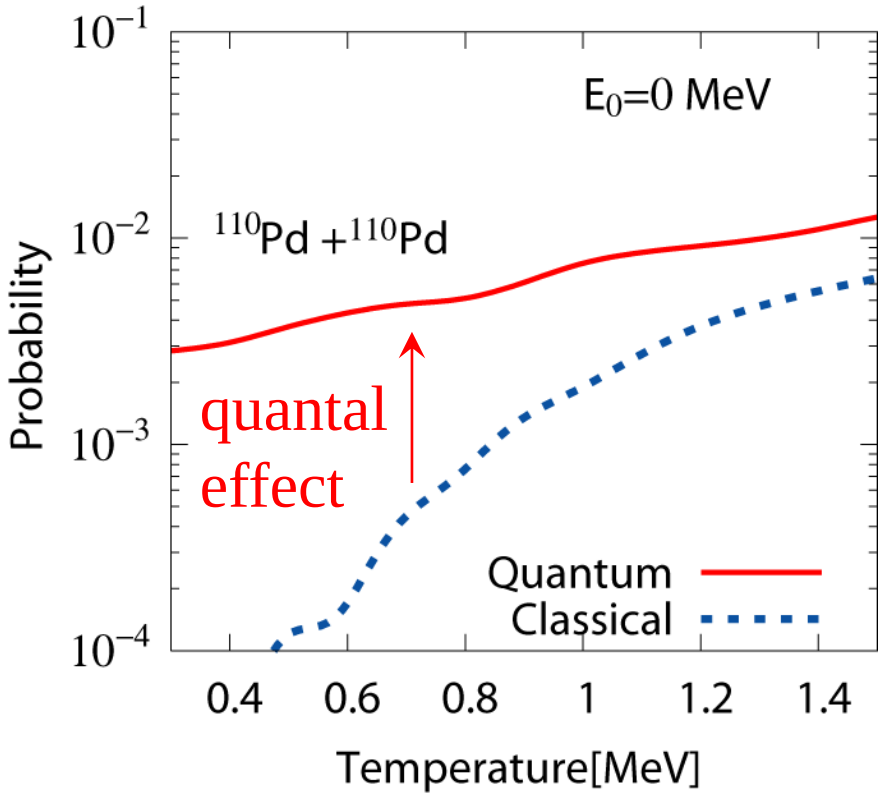
$$m\frac{d^2q}{dt^2} = -\frac{dV(q)}{dq} - \gamma\frac{dq}{dt} + R(t)$$

K. Washiyama, Ph. D. thesis, Tohoku Univ. (March, 2007)

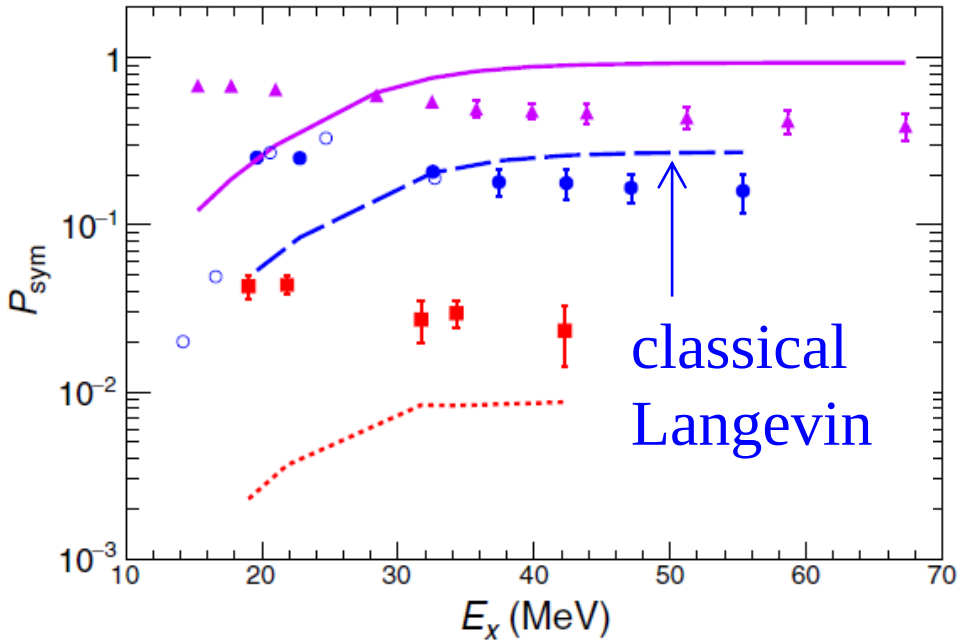
classical: $\langle R(t)R(t')\rangle \propto \delta(t-t')$ (white noise)

quantal:

$$\langle R(t)R(t')\rangle \propto \int_{-\infty}^{\infty}\frac{d\omega}{2\pi}\frac{\hbar\omega}{2T}\coth\frac{\hbar\omega}{2T}\exp\left[-\frac{(\hbar\omega)^2}{2\Delta^2}\right]e^{-i\omega(t-t')}$$



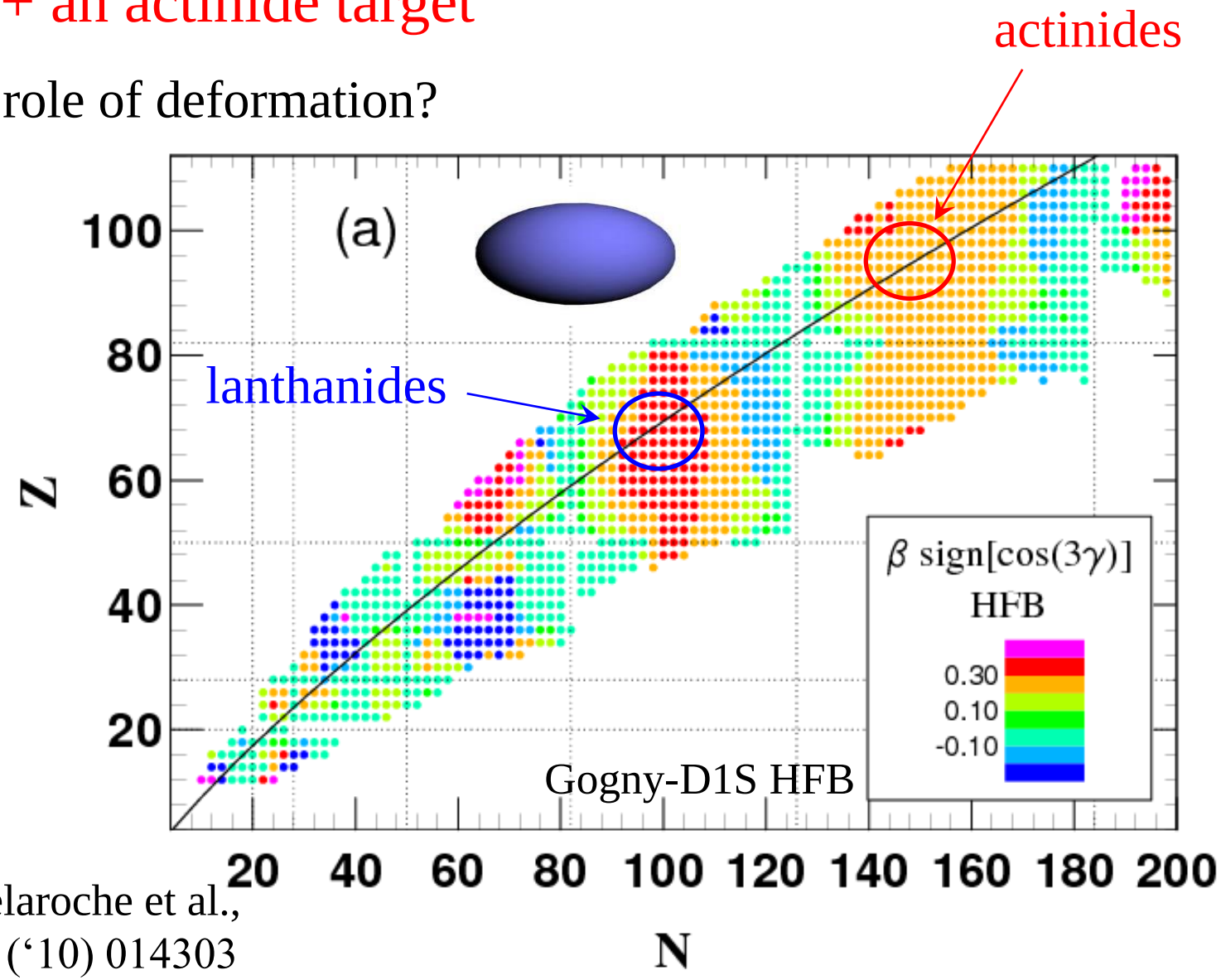
cf. K. Banerjee et al., PRL122('19)



Hot fusion reactions

^{48}Ca + an actinide target

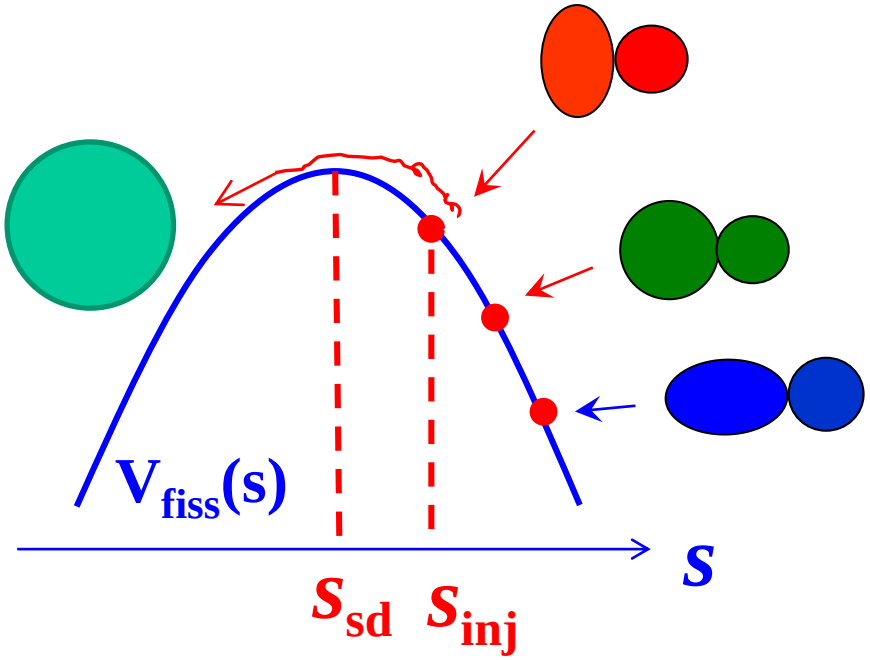
role of deformation?

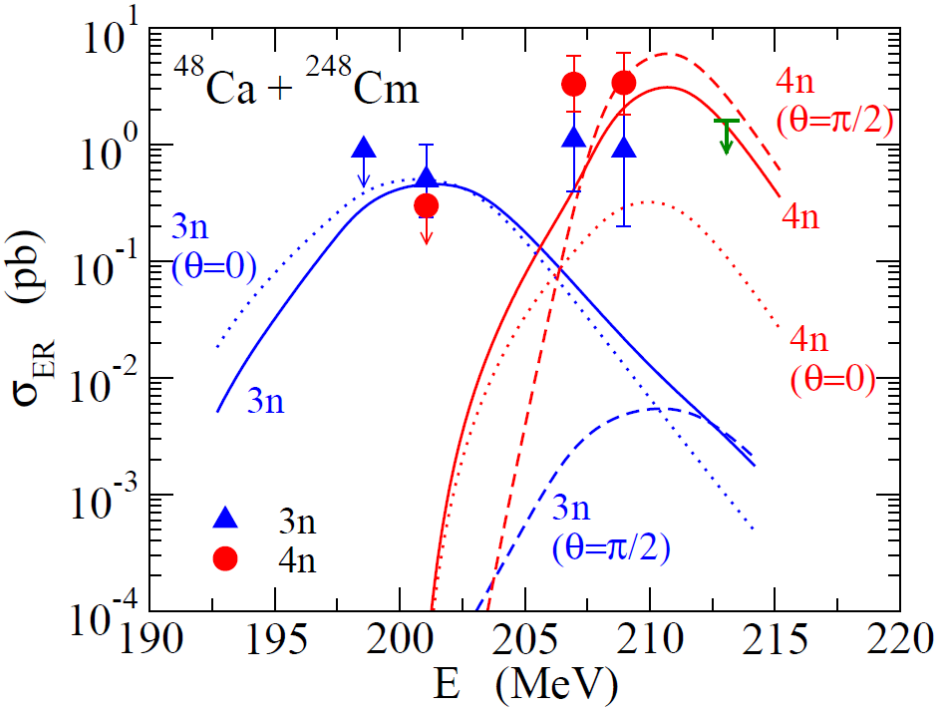


J.-P. Delaroche et al.,
PRC81 (‘10) 014303

Extension of fusion-by diffusion model

K. Hagino, PRC98 (‘18) 014607





cf. barrier distribution measurements by Tanaka et al.

Hot fusion towards Z=119 and 120 nuclei

hot fusion reactions with ^{48}Ca:

$^{48}_{20}Ca + {}_{99}Es \rightarrow 119$

$^{48}_{20}Ca + {}_{100}Fm \rightarrow 120$

short lived →not available with sufficient amounts

$^{48}Ca \rightarrow {}^{50}_{22}Ti, {}^{51}_{23}V, {}^{54}_{24}Cr$ projectiles

how much will cross sections be affected?

closed shell → open shells

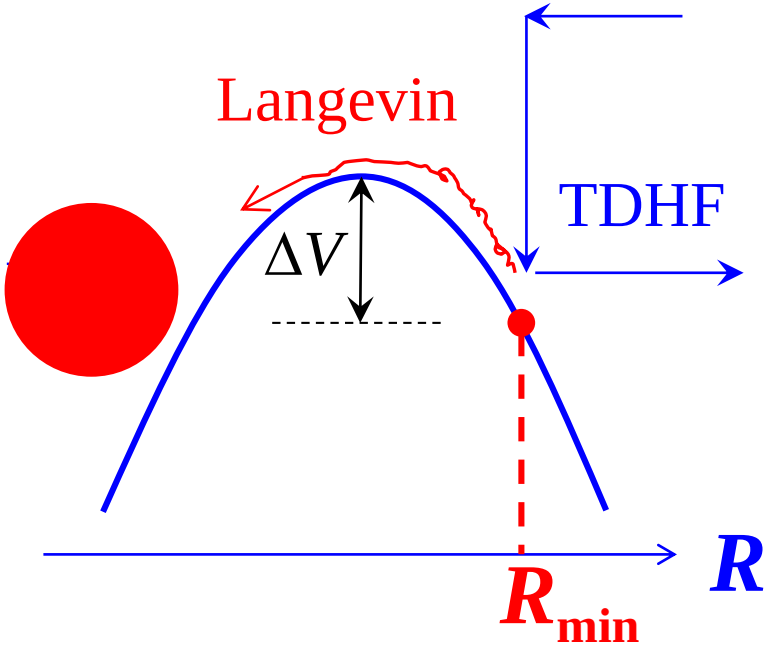
TDHF + Langevin approach

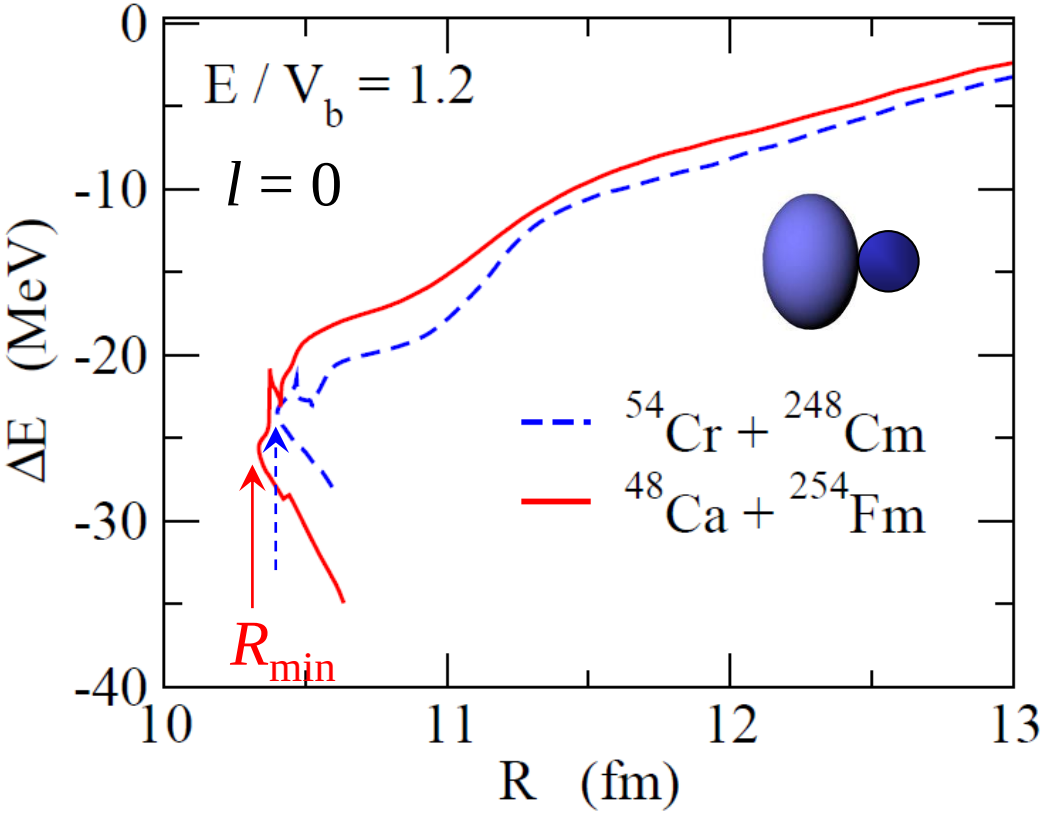
K. Sekizawa and K. H.,
PRC99 (2019) 051602(R)

$^{54}Cr + {}^{248}Cm \rightarrow {}^{302}120$

$^{48}Ca + {}^{254}Fm \rightarrow {}^{302}120$

side
collision





→ Langevin caluclation

New model for fusion for SHE: TDHF + Langevin approach

K. Sekizawa and K.H., PRC99 (2019) 051602(R)

how special is ^{48}Ca ?

System	CN	E^* (MeV)	R_{min} (fm)	P_{CN} ($\times 10^4$)	W_{sur} ($\times 10^9$)	$P_{CN} W_{sur}$ ($\times 10^{13}$)
^{48}Ca + ^{254}Fm	^{302}120	29.0	12.93	1.72	176	302
^{54}Cr + ^{248}Cm	^{302}120	33.2	13.09	1.89	1.31	2.47
^{51}V + ^{249}Bk	^{300}120	37.0	12.94	3.95	0.117	0.461
^{48}Ca + ^{257}Fm	^{305}120	30.5	12.94	2.49	0.729	1.82

similar P_{CN}

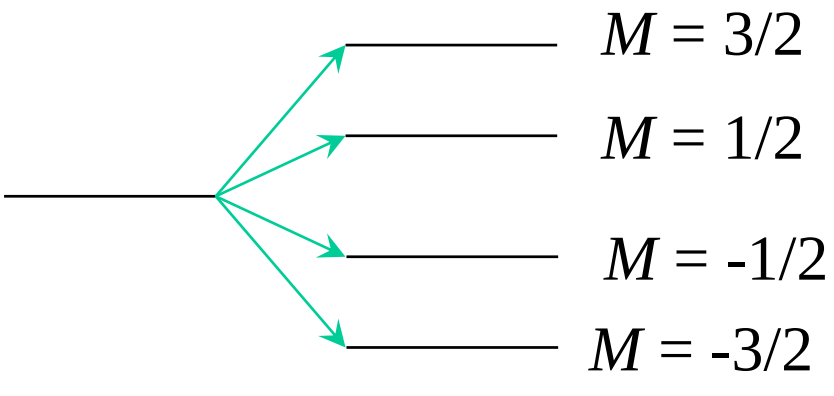
a special role of ^{48}Ca only in W_{sur}

Odd-mass target: role of spin alignment

K. Hagino and S. Sakaguchi, arXiv:1911.05890

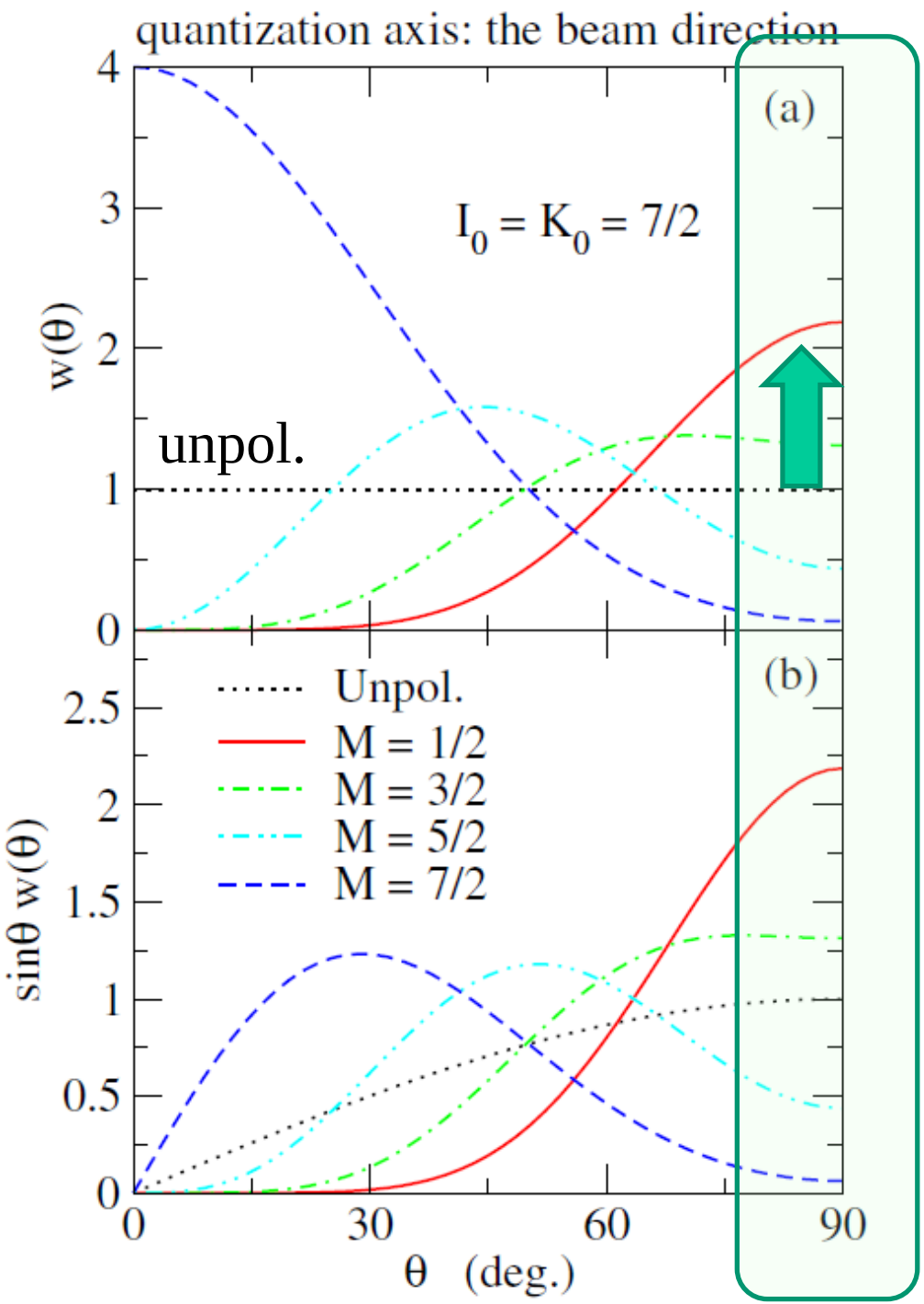
odd-mass: finite spin in the ground state

$$\sigma_{\rm fus}(E) = \int_0^{\pi/2} \sin\theta d\theta\, \sigma_{\rm fus}(\theta)$$

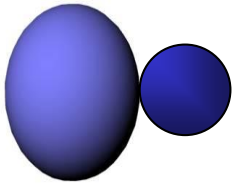


$$\sigma_{\rm fus}^{(M)}(E) = \int_0^{\pi/2} \sin\theta d\theta\, w_M(\theta)\sigma_{\rm fus}(\theta)$$

$$w_M(\theta) = \frac{2I_0+1}{2} \times \left(|d^{I_0}_{MK_0}(\theta)|^2 + |d^{I_0}_{M-K_0}(\theta)|^2\right)$$



side collision



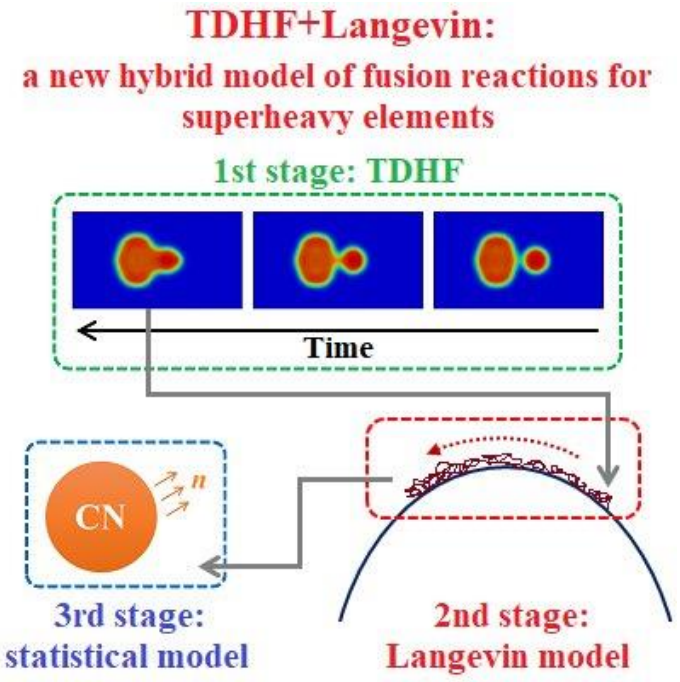
increase of σ_{fus} by a factor of two!

(but with a novel cooling system)

Summary

Reaction dynamics for (hot) fusion reactions to synthesize SHE

- Langevin approach
  - ✓ quantum effects → important in cold fusion
- a new method: TDHF + Langevin approach
  - ✓ ^{48}Ca: no special role in the diffusion stage
- odd-mass target
  - ✓ a spin alignment may increase σ_{fus} by a factor of two



FUSION20

November 15-20, 2020
Shizuoka, Japan

Kouichi Hagino (co-chair) Kyoto University
Katsuhisa Nishio (co-chair) JAEA

Scientific secretaries
K. Hirose, Y. Ito, F. Minato, F. Suzaki (JAEA)