Heavy-ion fusion reactions of deformed nuclei
: from the medium-heavy to the superheavy regions

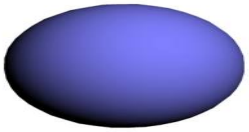
Kouichi Hagino
Tohoku University, Sendai, Japan

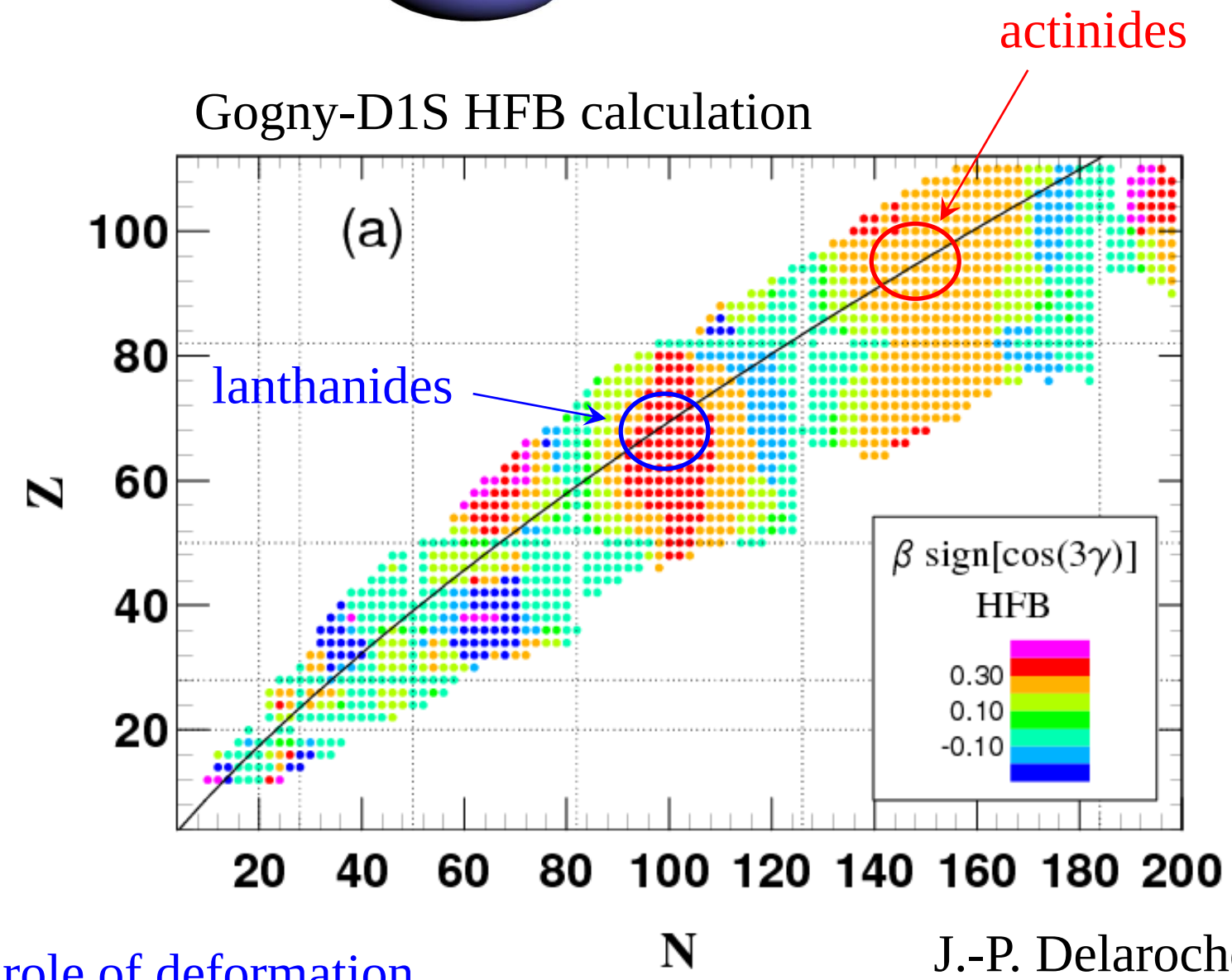
TOHOKU UNIVERSITY

1. Nuclear deformation and barrier distribution
2. Hot fusion reactions for superheavy elements
3. TDHF + Langevin approach
4. Summary

Sakura-2019 “Nuclear Fission and Structure of Exotic Nuclei”, March 25-27, 2019, JAEA

Nuclear Deformation





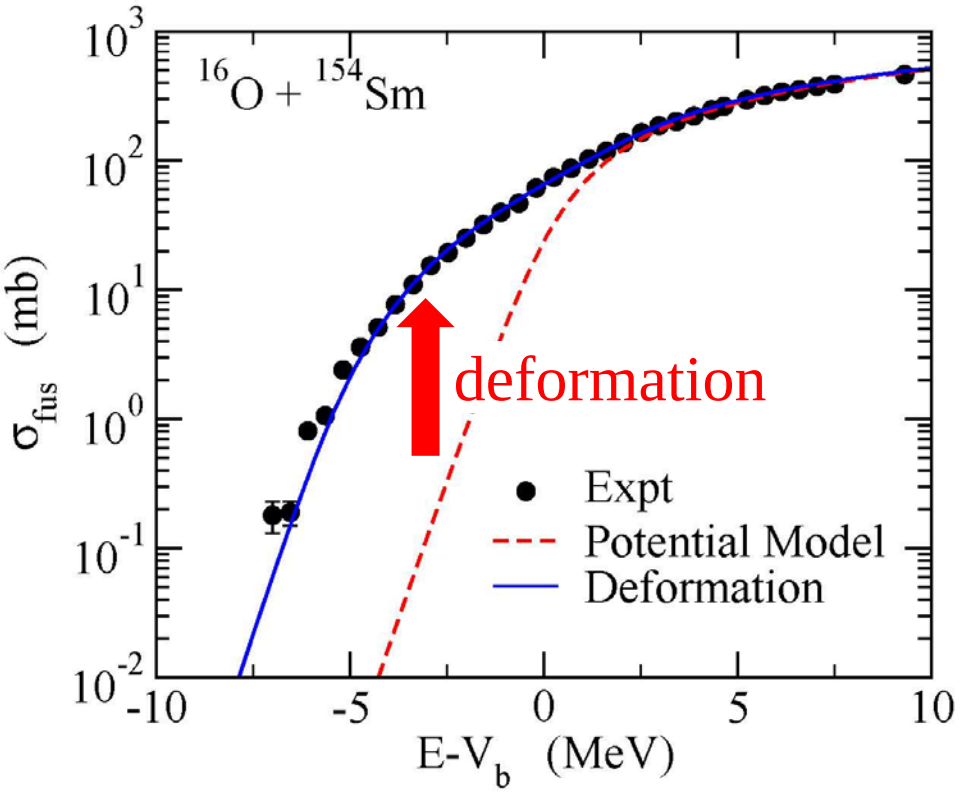
the role of deformation
in heavy-ion reactions?

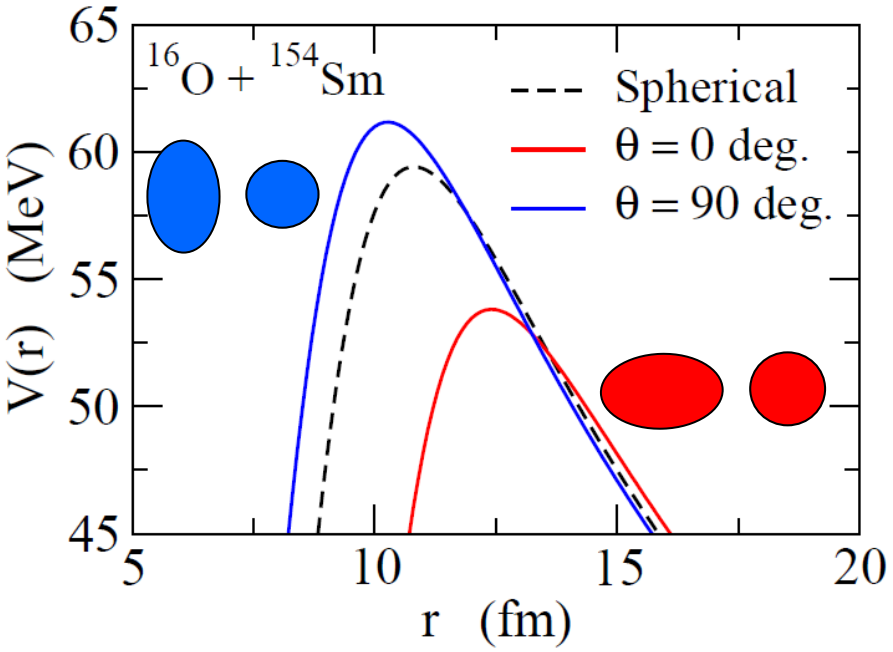
J.-P. Delaroche et al.,
PRC81 (‘10) 014303

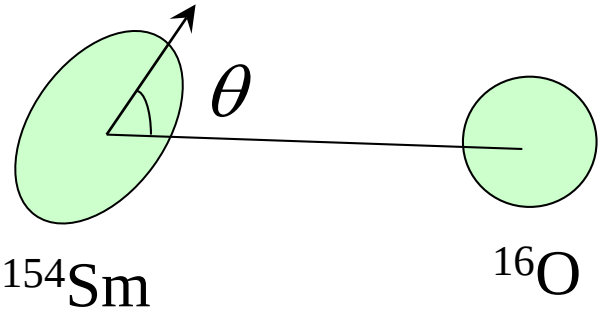
Nuclear deformation and barrier distribution

Nuclear deformation → a large sub-barrier enhancement of fusion cross sections

$^{16}O+^{154}Sm$



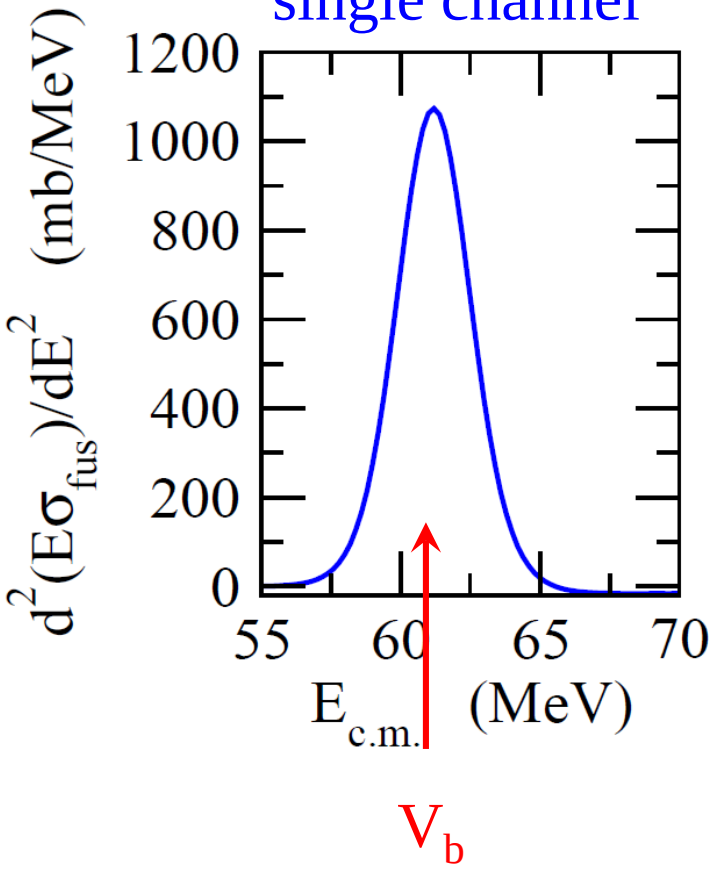


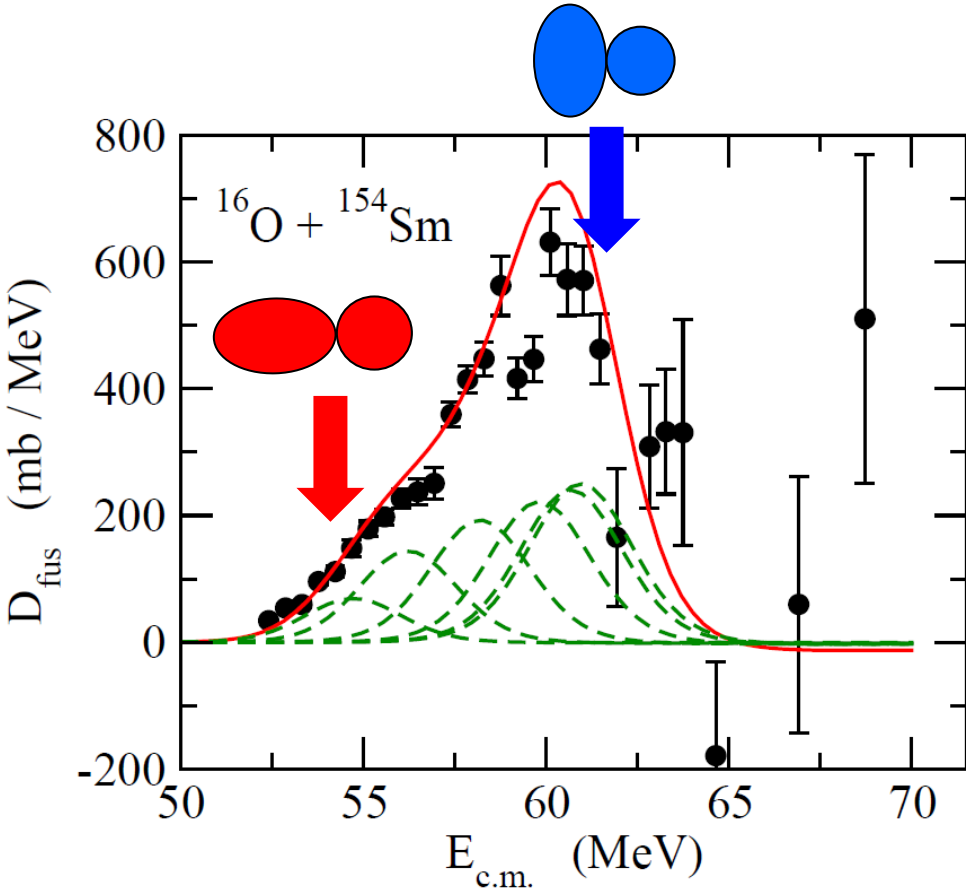


Fusion barrier distribution [Rowley, Satchler, Stelson, PLB254('91)]

$$D_{\rm fus}(E) = \frac{d^2(E\sigma_{\rm fus})}{dE^2} \propto \frac{dP_{l=0}}{dE}$$

single channel





can be used to identify the side/tip collisions

K.H., N. Takigawa, PTP128 ('12) 1061

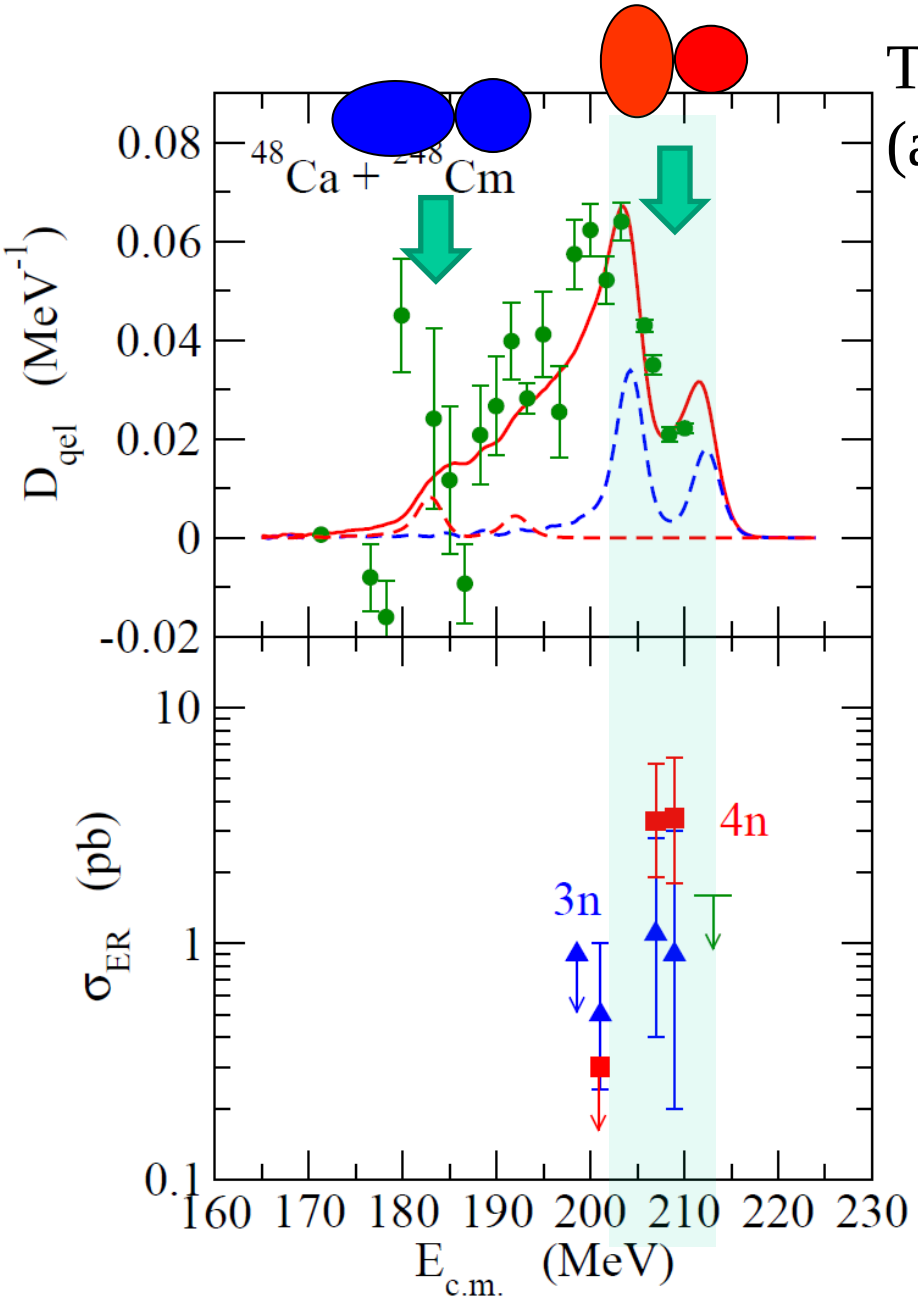
Application to hot fusion reactions

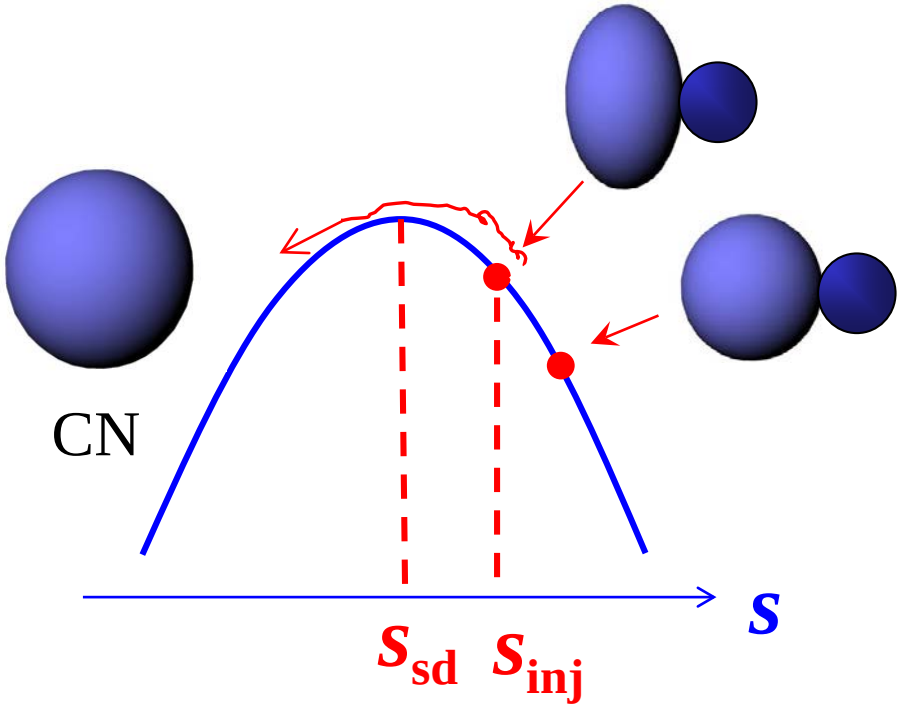
$^{48}Ca + {}^{248}Cm \rightarrow {}^{296}_{116}Lv^{*}$

T. Tanaka et al., JPSJ 87 (‘18) 014201
(also, Tanaka’s talk this afternoon)

capture barrier distribution

cf. notion of compactness:
D.J. Hinde et al.,
PRL74 (‘95) 1295





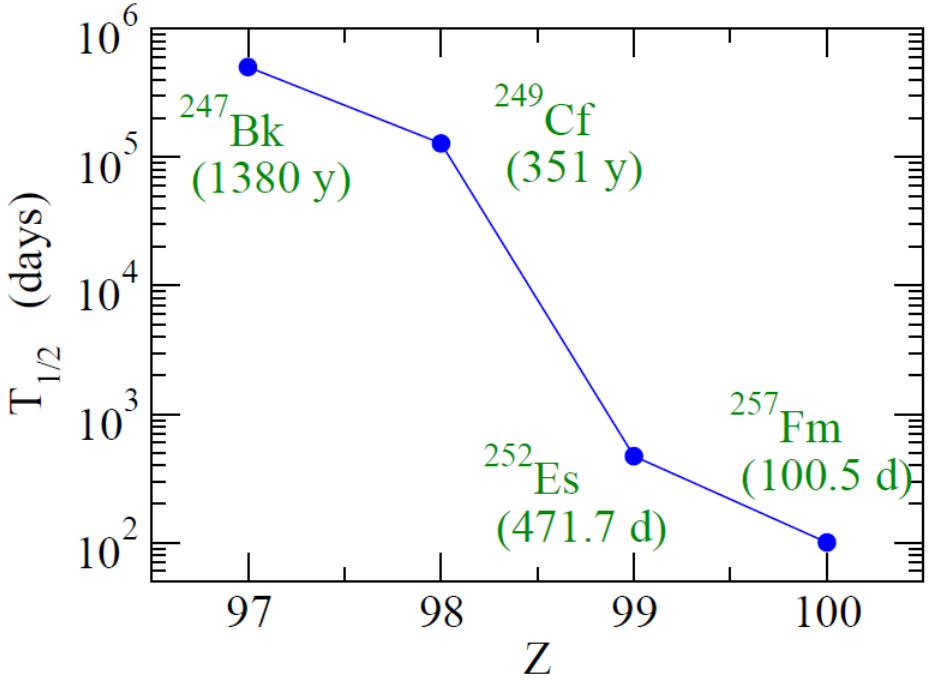
Hot fusion towards Z=119 and 120 nuclei

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

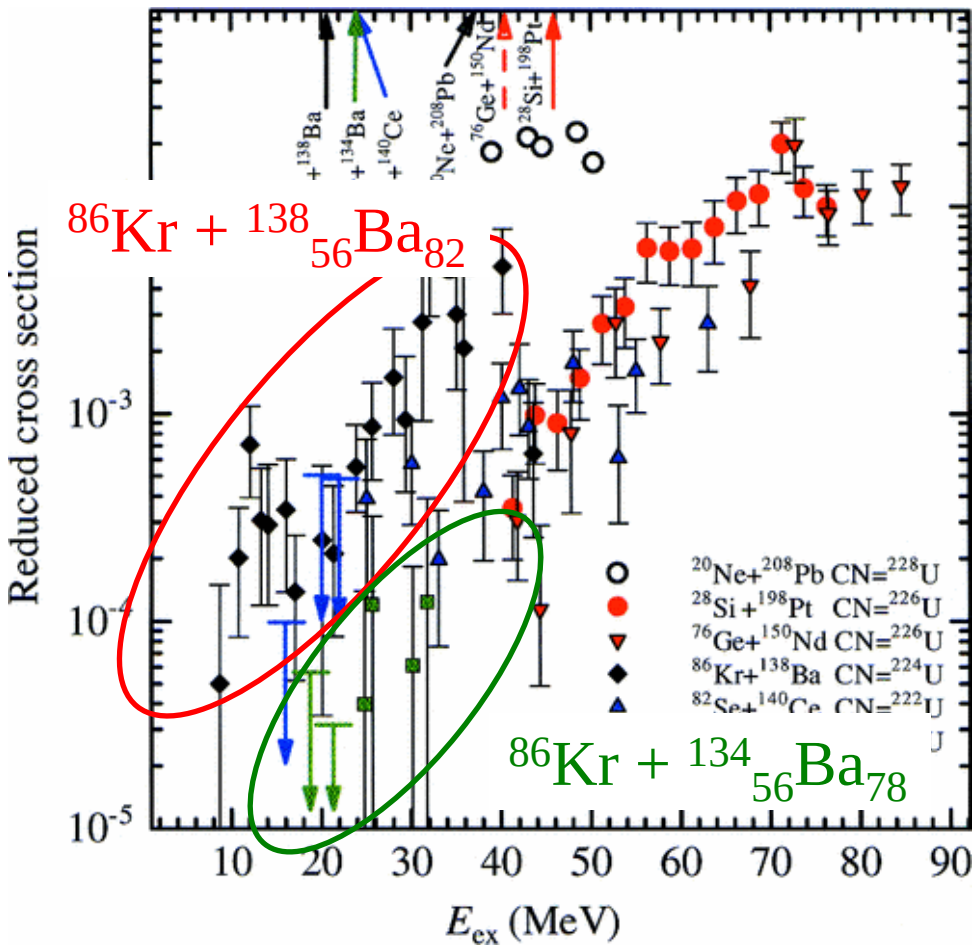


^{48}Ca → $^{50}_{22}$Ti, $^{51}_{23}$V, $^{54}_{24}$Cr projectiles

how much will cross sections be affected?

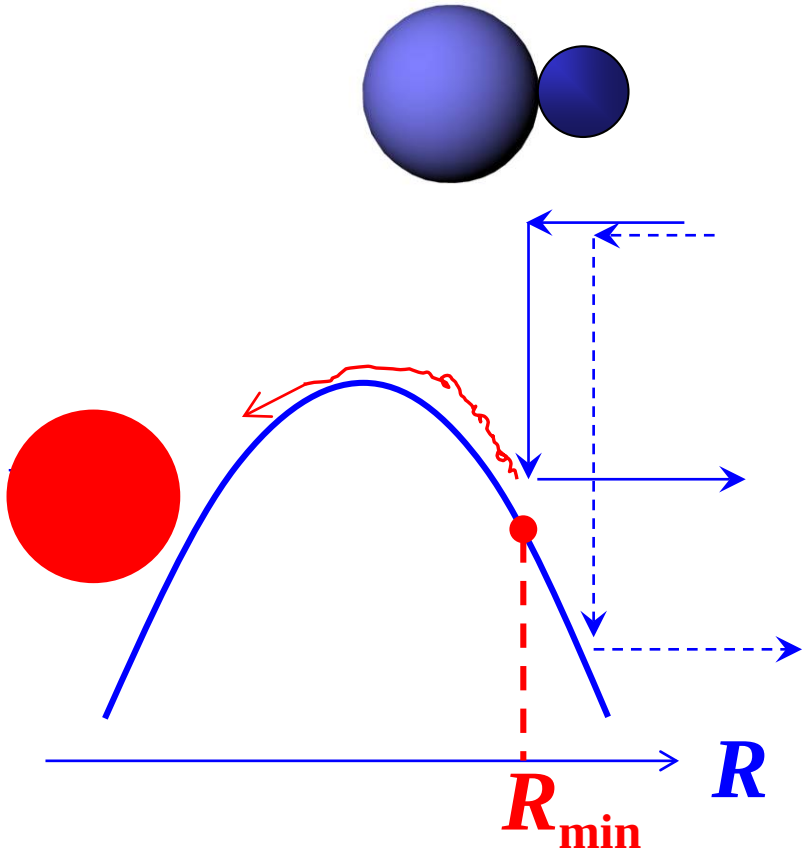
closed shell → open shells

Role of magicity



K. Satou, H. Ikezoe et al.,
PRC73 (‘06) 034609

can proceed deeper
with less friction

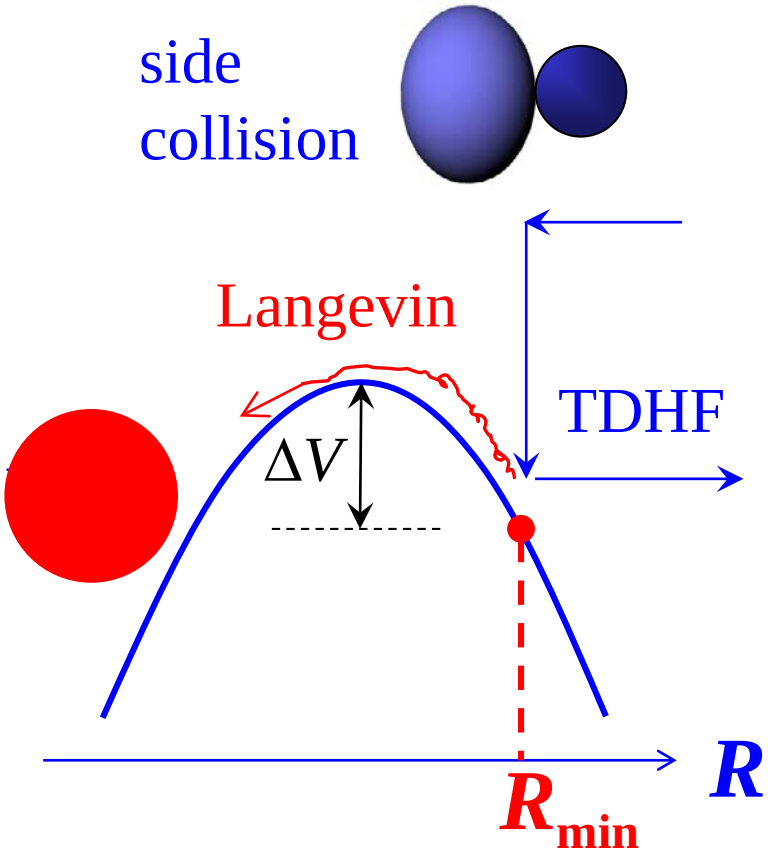


cf. P. Moller et al.,
Z. Phys. A359 (‘97) 251.

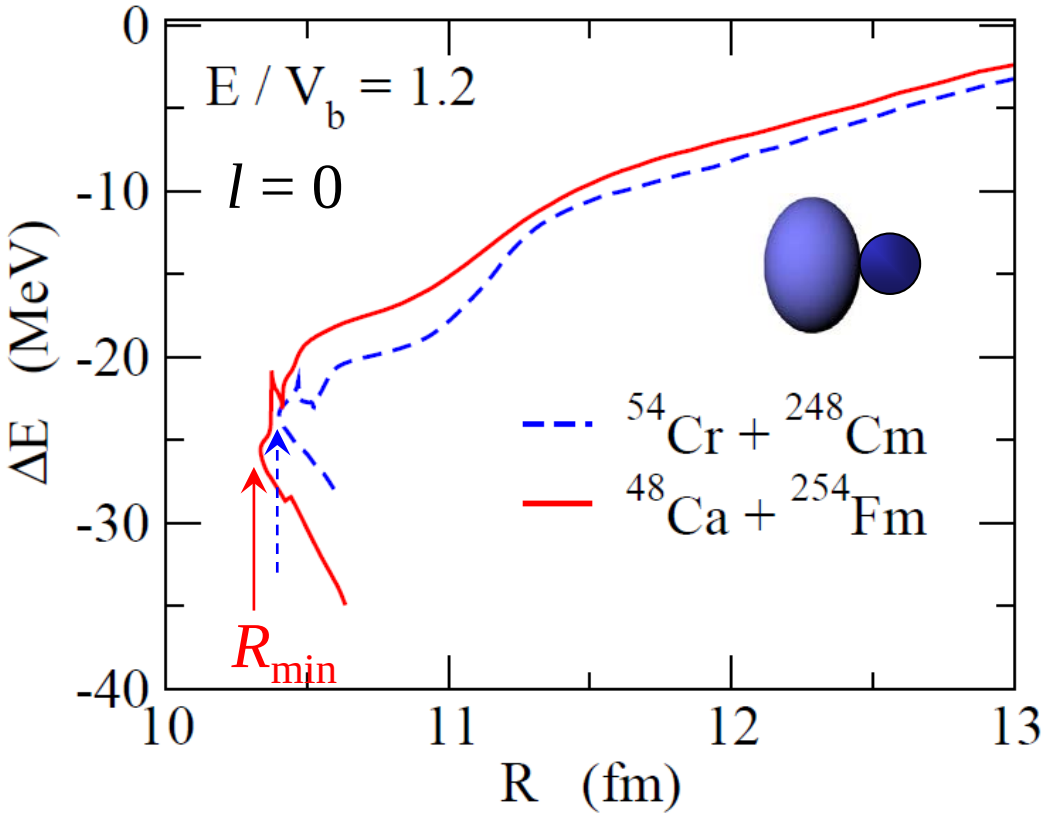
similar effect for ^{48}Ca?

TDHF + Langevin approach

K. Sekizawa and K. H.,
arXiv: 1903.06386



^{54}Cr + ^{248}Cm → ^{302}120
^{48}Ca + ^{254}Fm → ^{302}120



→ Langevin caluclation

cf. K. Washiyama and D. Lacroix,
PRC78 (‘08) 024610

→ from TDHF to the dynamics of *R*

TDHF + Langevin approach

K. Sekizawa and K. H.,
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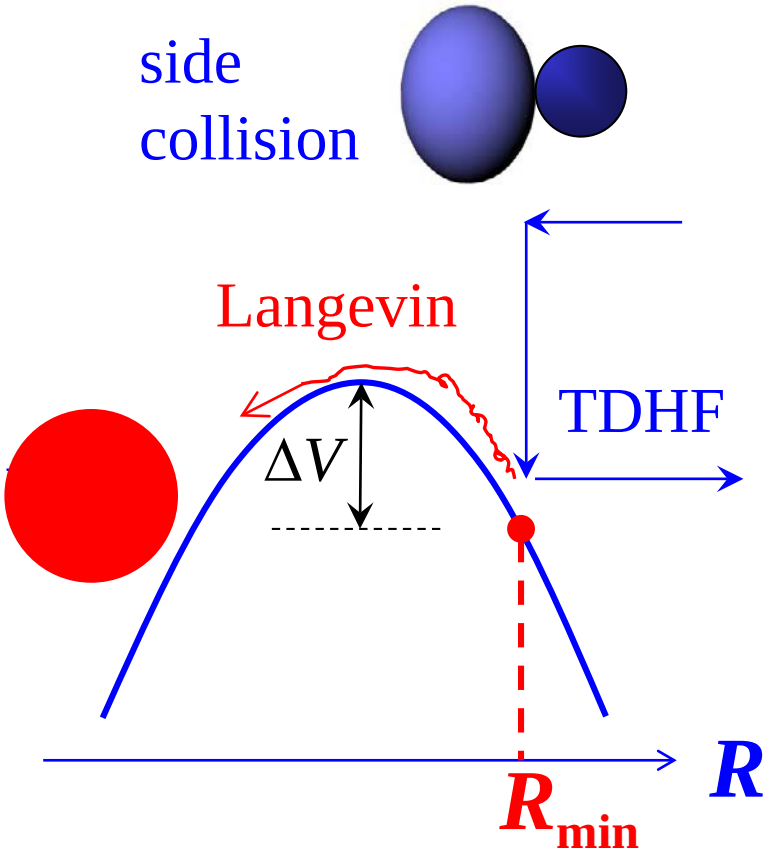

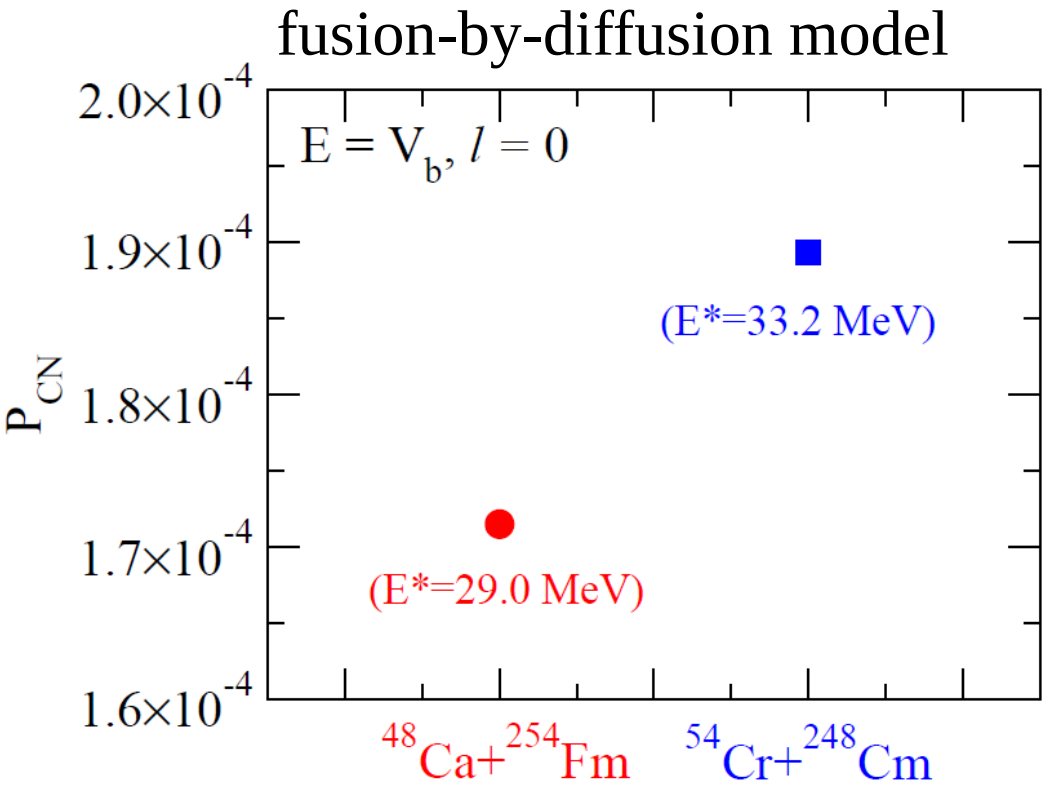

cf. K. Washiyama and D. Lacroix,
PRC78 (‘08) 024610

→ from TDHF to the dynamics of *R*

TDHF + Langevin approach

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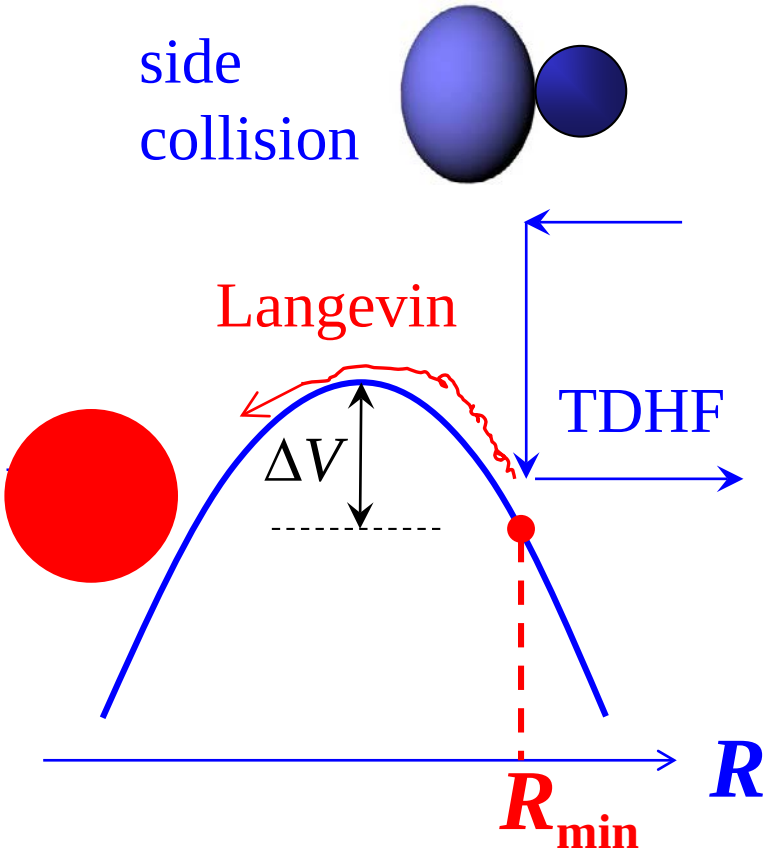
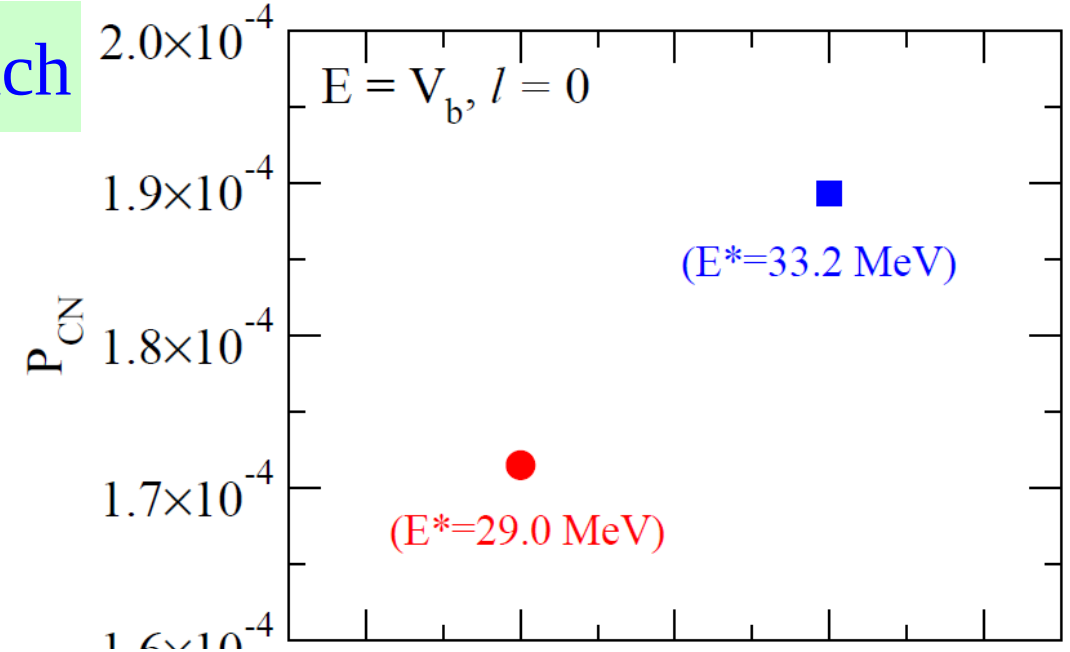
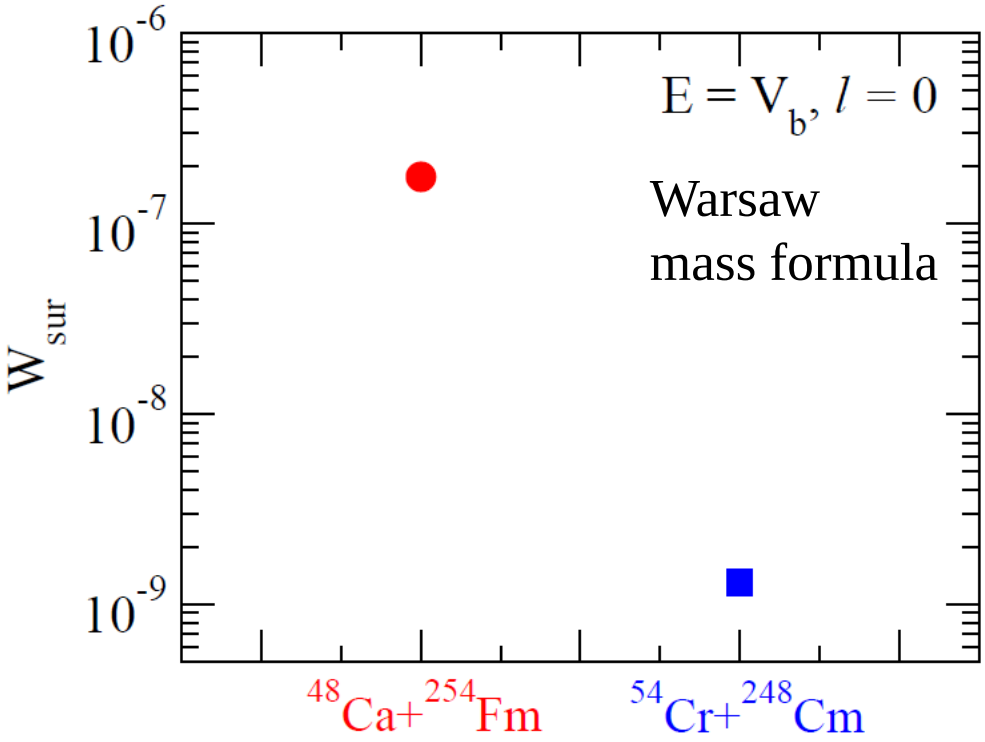
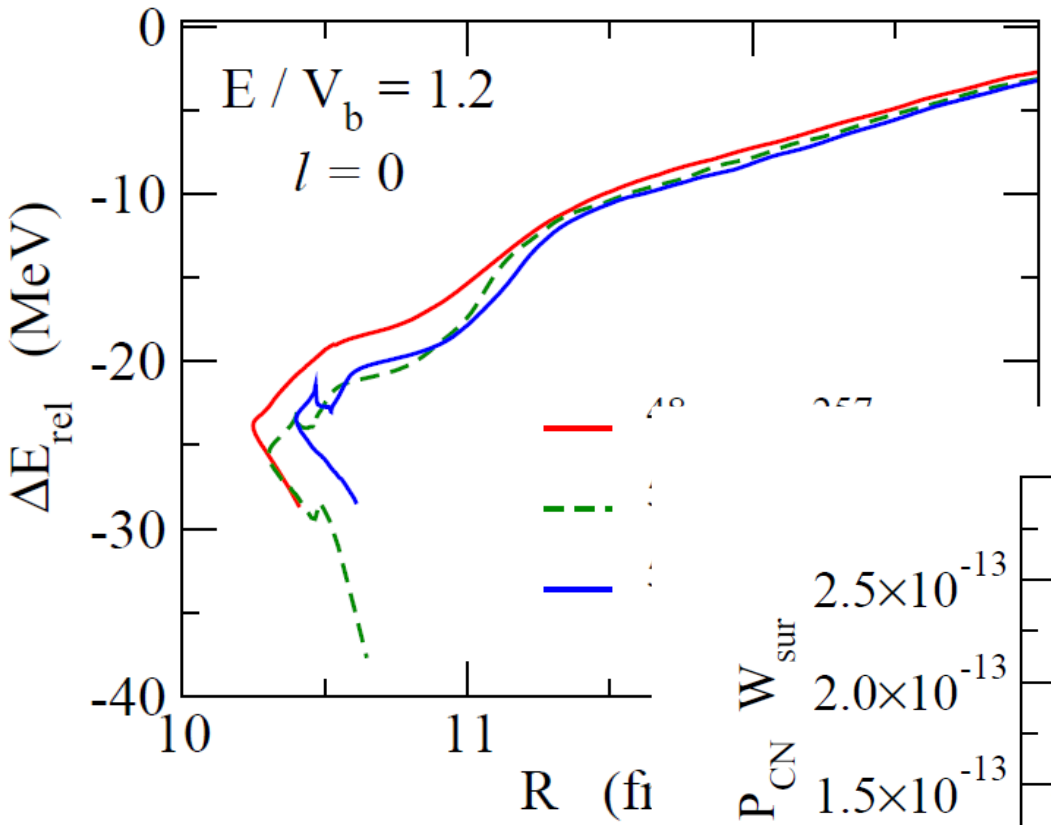


fusion-by-diffusion model



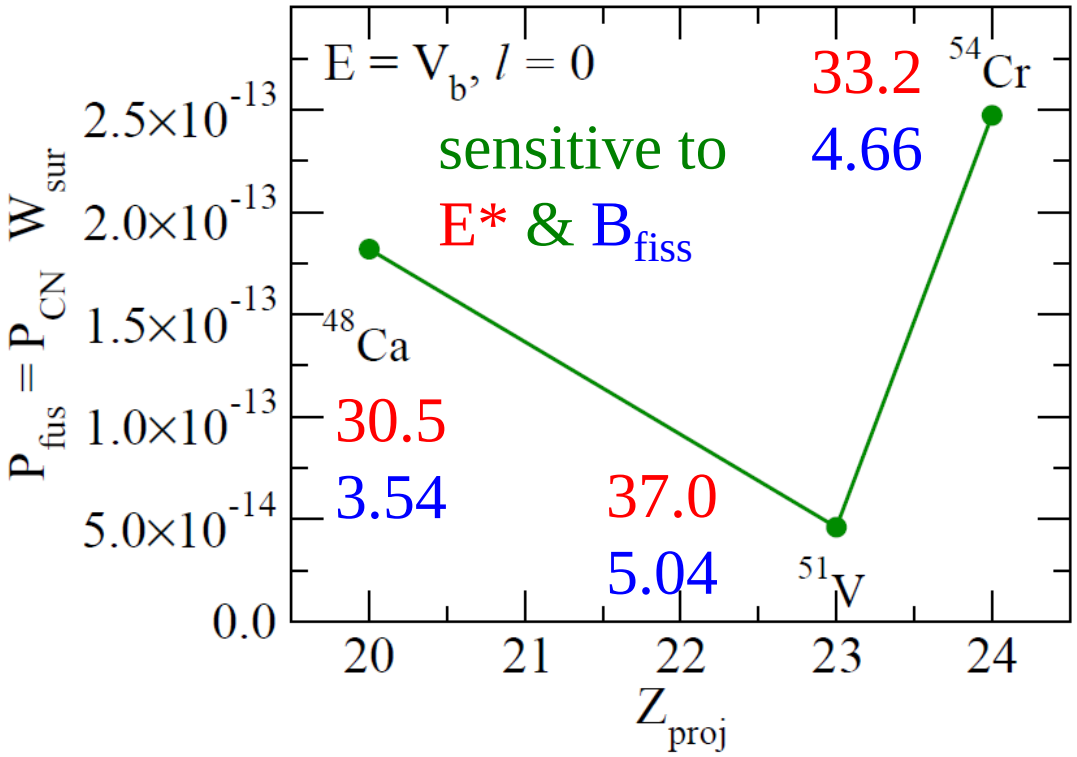


TDHF + Langevin approach

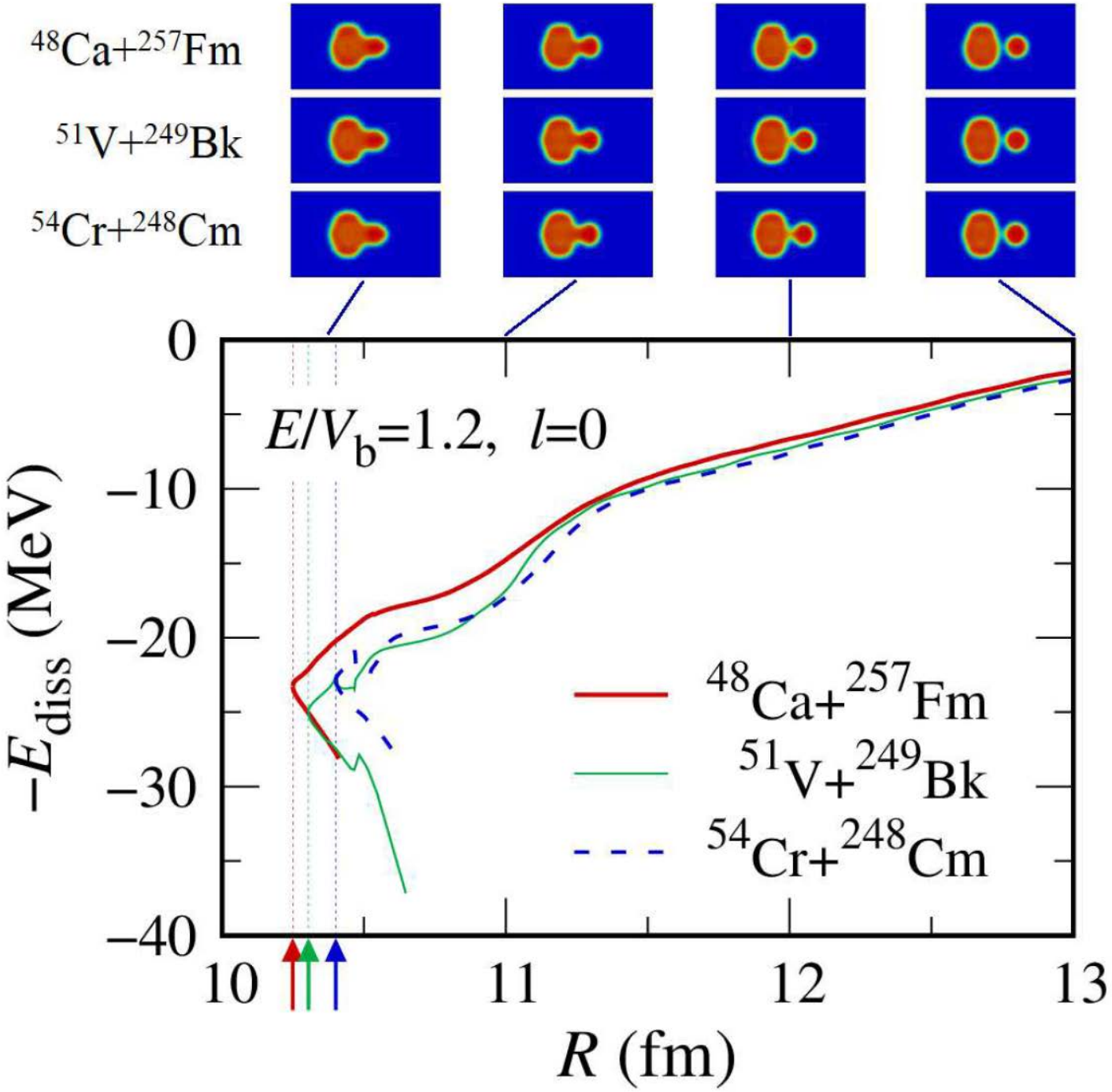


$^{48}Ca + {}^{254}\cancel{Fm} \rightarrow {}^{302}120$

- $^{48}Ca + {}^{257}Fm \rightarrow {}^{305}120$
- $^{51}V + {}^{249}Bk \rightarrow {}^{300}120$
- $^{54}Cr + {}^{248}Cm \rightarrow {}^{302}120$



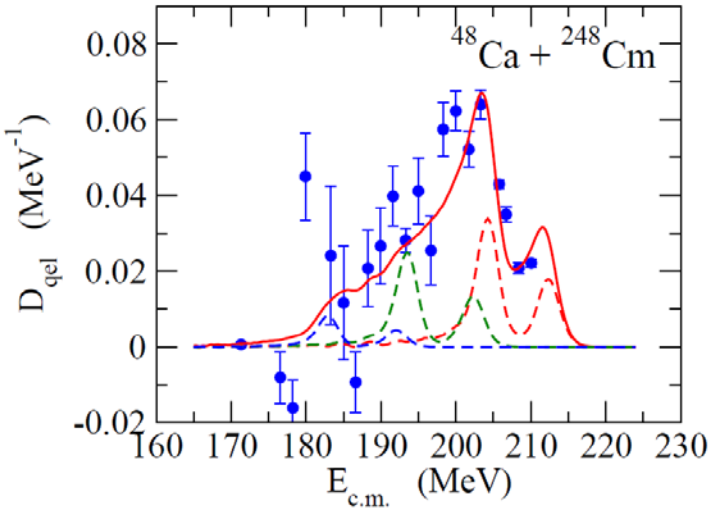
$P_{CN} * W_{sur} \sim 10^{-13}$
for $^{54}Cr + {}^{248}Cm$


^{48}Ca+^{257}Fm
^{51}V+^{249}Bk
^{54}Cr+^{248}Cm
E/V_b=1.2, l=0
$-E_{diss}$ (MeV)
R (fm)
0
−10
−20
−30
−40
10
11
12
13
^{48}Ca+^{257}Fm
^{51}V+^{249}Bk
^{54}Cr+^{248}Cm

Summary

Reaction dynamics for hot fusion reactions to synthesize SHE

- Recent measurements of QEL barrier distributions with GARIS
  - ✓ ^{48}Ca + ^{248}Cm, ^{238}U
  - ✓ notion of compactness: ER formation with side collisions



more data coming soon

cf. the talk by T. Tanaka

- TDHF + Langevin model for hot fusion
  - ✓ not large effect of ^{48}Ca on R_{min}
    → dynamics due to E^* and B_{fiss}

$$\sigma_{ER}(^{48}\mathrm{Ca} + ^{254}\mathrm{Fm} \rightarrow ^{302}120) \sim 100 \cdot \sigma_{ER}(^{54}\mathrm{Cr} + ^{248}\mathrm{Cm} \rightarrow ^{302}120)$$

$$\sigma_{ER}(^{48}\mathrm{Ca} + ^{257}\mathrm{Fm} \rightarrow ^{305}120) \sim \sigma_{ER}(^{54}\mathrm{Cr} + ^{248}\mathrm{Cm} \rightarrow ^{302}120)$$

combination to multi-dim. Langevin calcualtions