Fusion barrier distributions for superheavy elements

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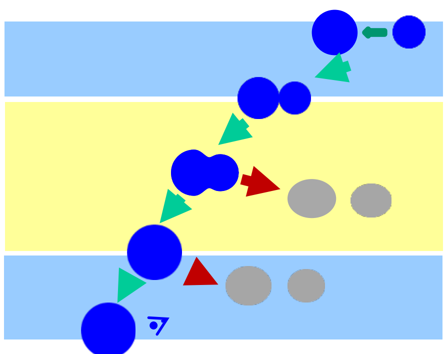
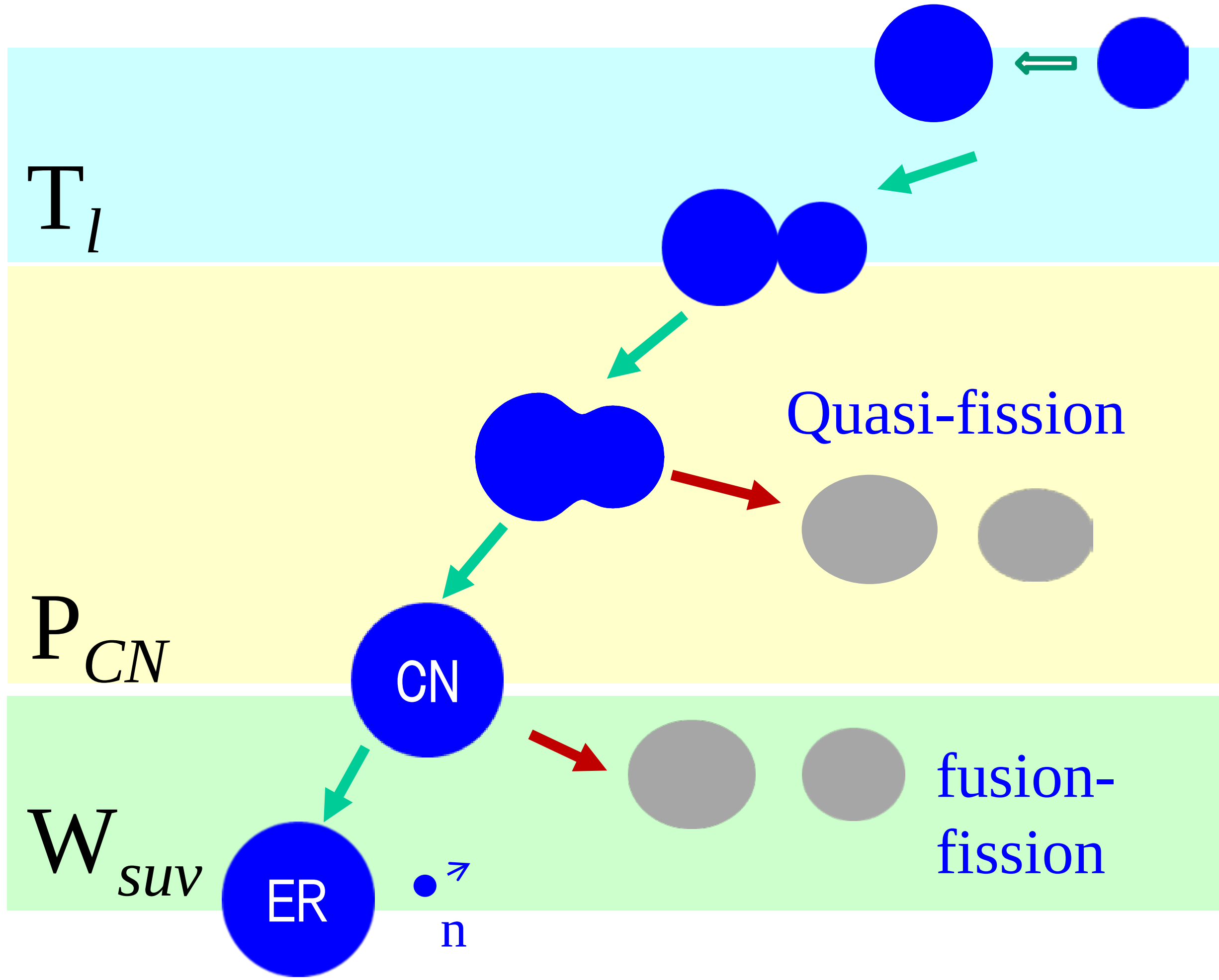


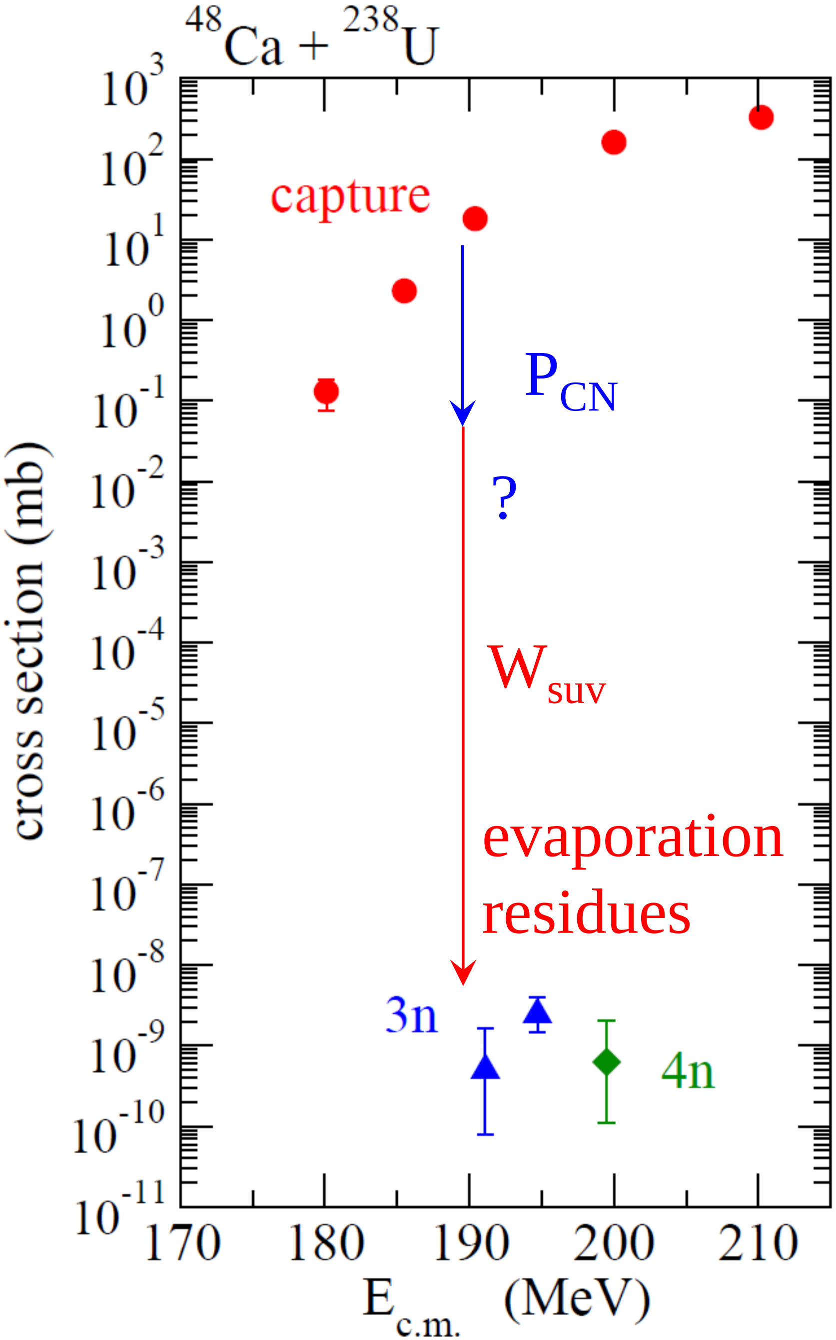
1. Introduction: Fusion reactions for SHE
2. Approaching phase: role of deformation
3. Fusion barrier distribution
4. Application to SHE
5. Summary

The Int. Sympo. on Physics of Unstable Nuclei 2017 (ISPUN2017), Halong Bay, Vietnam, Sep. 25-30, 2017

Introduction: Fusion reactions for SHE



$$\sigma_{\mathrm{ER}}(E) = \frac{\pi}{k^2} \sum_l (2l+1) T_l(E)\, P_{\mathrm{CN}}(E,l)\, W_{\mathrm{suv}}(E^*,l)$$



ER formation
: a very rare process

→ large uncertainties

a big challenge:
to reduce theoretical uncertainties
and make reliable predictions

this talk: capture process

$$\sigma_{cap}(E) = \frac{\pi}{k^2}\sum_l (2l+1)T_l(E)$$

a question:
how to extract T_l from σ_{cap}?

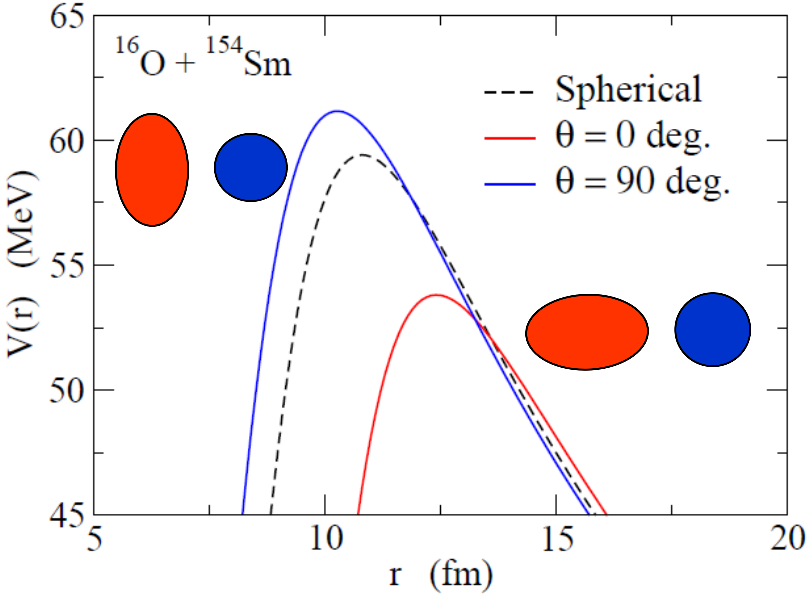
a standard tool:
coupled-channels method
with collective excitations

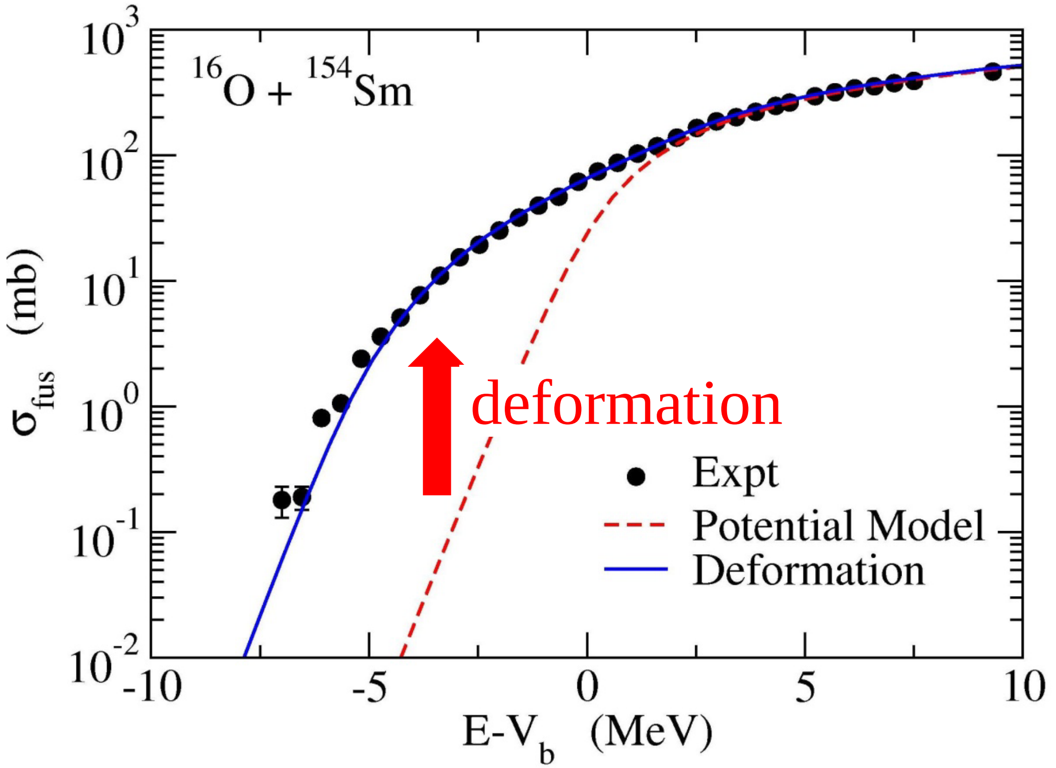
Capture process: coupled-channels method

Sub-barrier enhancement of capture cross sections

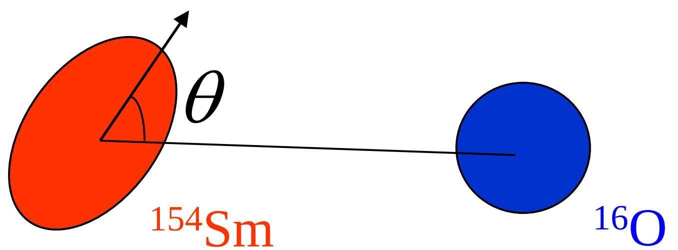
⟵ channel coupling effects

role of deformation





$$\sigma_{\text{cap}}(E) = \int_0^1 d(\cos\theta)\sigma_{\text{cap}}(E;\theta)$$

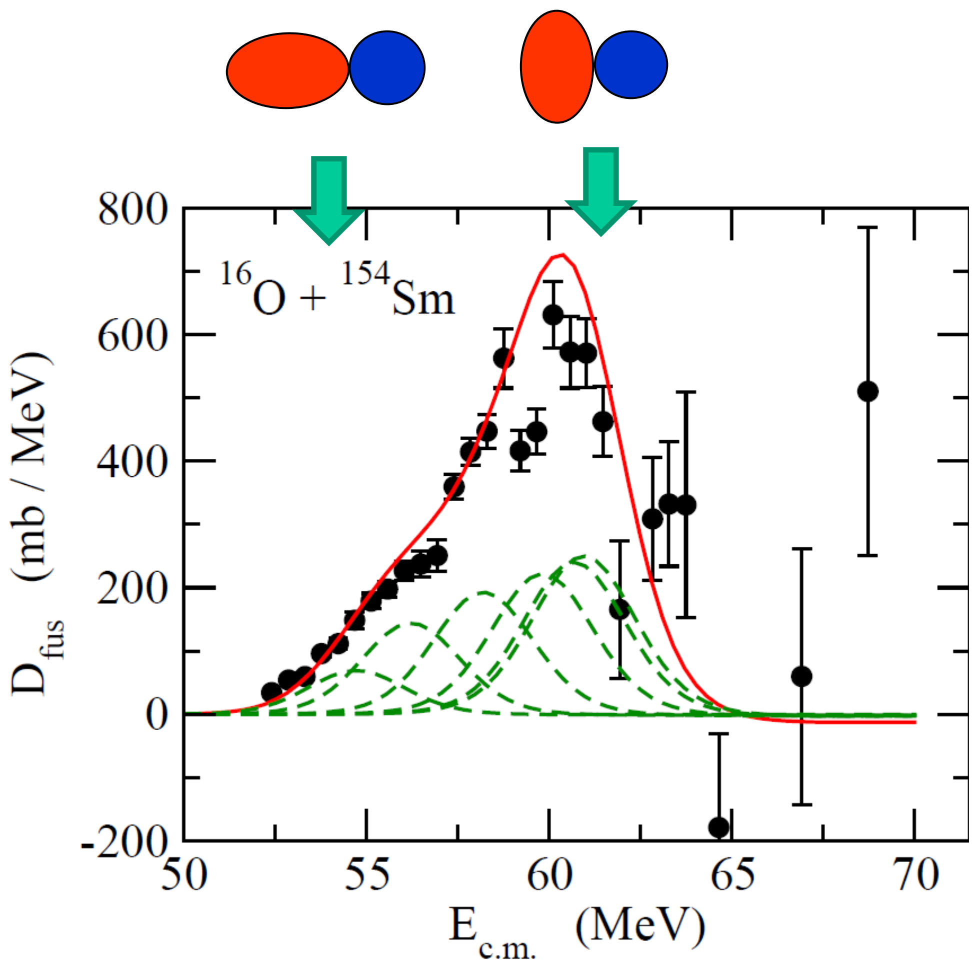


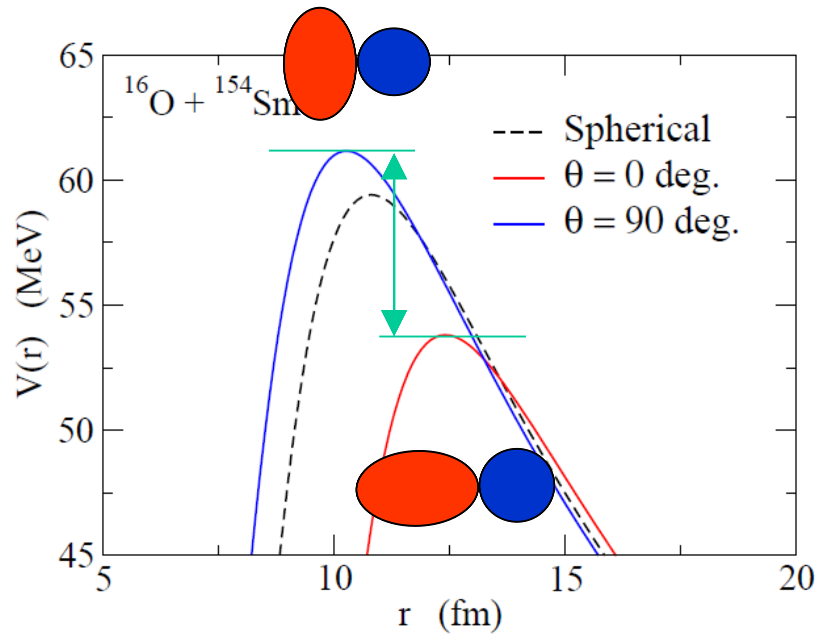
K.H., N. Takigawa, PTP128 ('12) 1061

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

$$D_{\text{fus}}(E) = \frac{d^2(E\sigma_{\text{fus}})}{dE^2}$$

"B-plot"





a nice tool to understand the reaction dynamics

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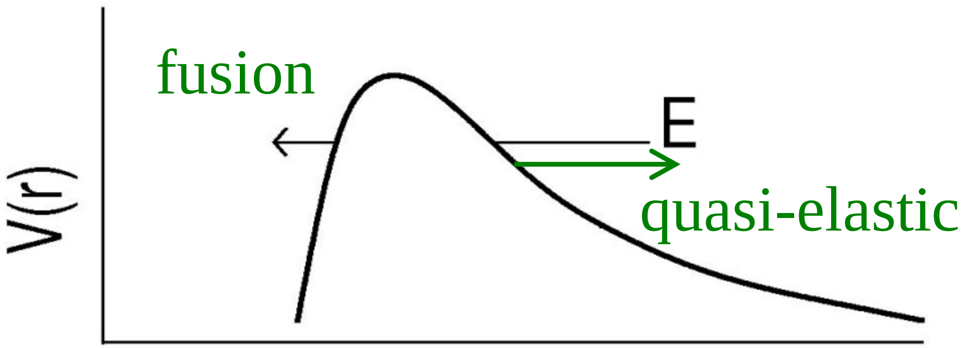
Recent application to SHE : Quasi-elastic B.D.

hot fusion reactions

^{48}Ca + actinide nucleus → SHE

= deformation ⇒ reaction dynamics with barrier distributions?



$$P + R = 1$$

Quasi-elastic scattering
: reflected flux at the barrier

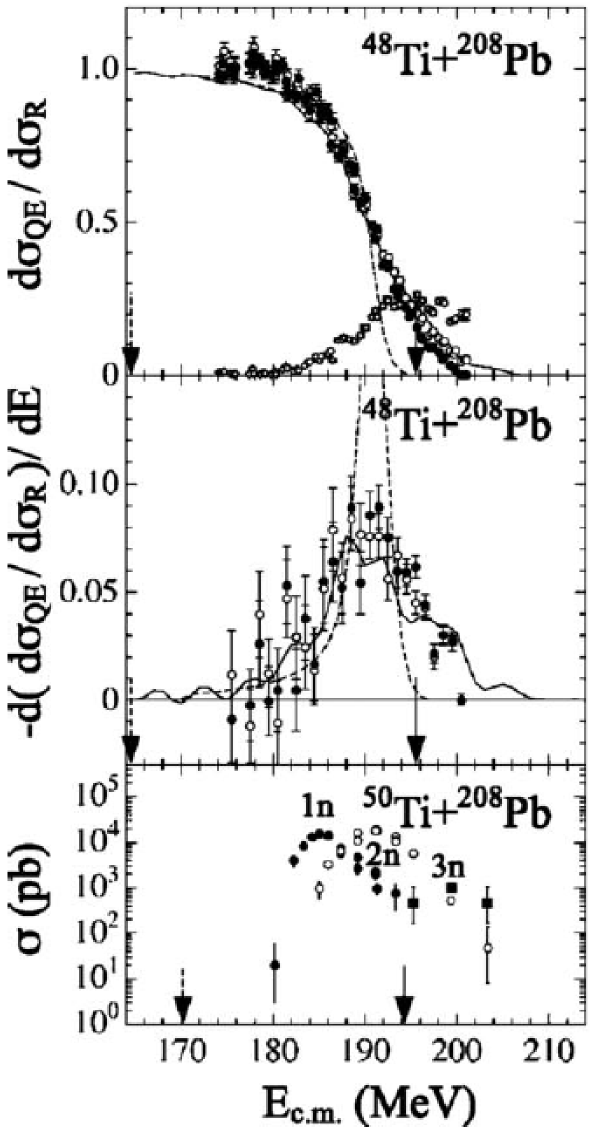
- a sum of elastic, inelastic, and transfer
- easier to measure than capture

Quasi-elastic barrier distribution

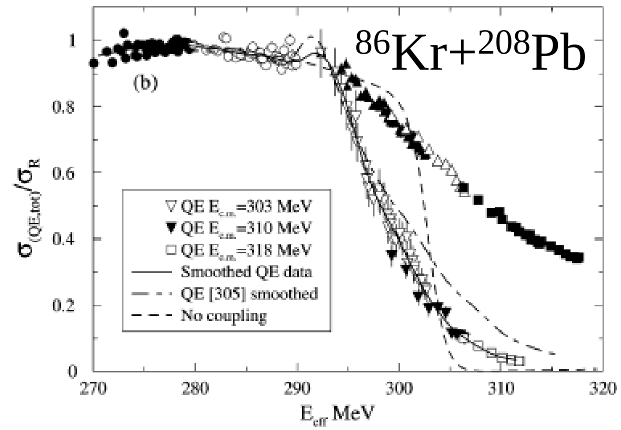
$$D_{\rm qel}(E) = -\frac{d}{dE}\left(\frac{\sigma_{\rm qel}(E,\pi)}{\sigma_R(E,\pi)}\right)$$

H. Timmers et al., NPA584('95)190
K.H. and N. Rowley, PRC69('04)054610

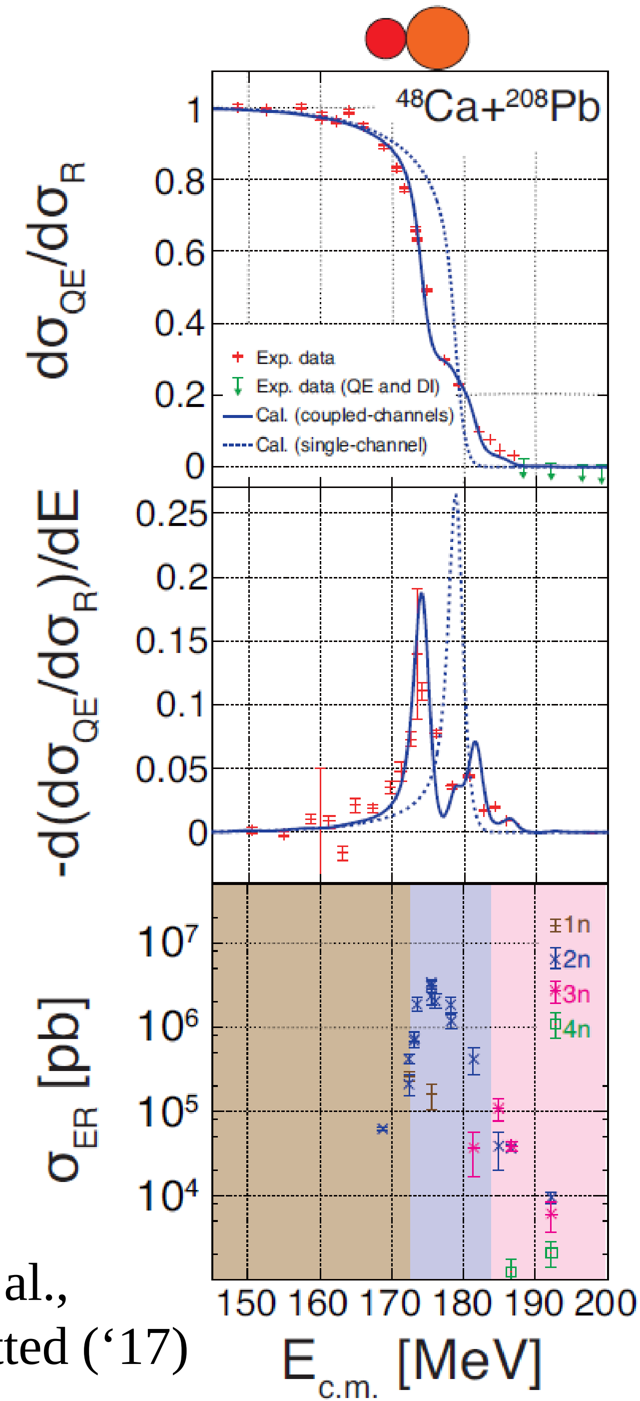
previous attempts



S. Mitsuoka et al., PRL99 (‘07) 182701



S.S. Ntshangase et al., PLB651 (‘07) 27

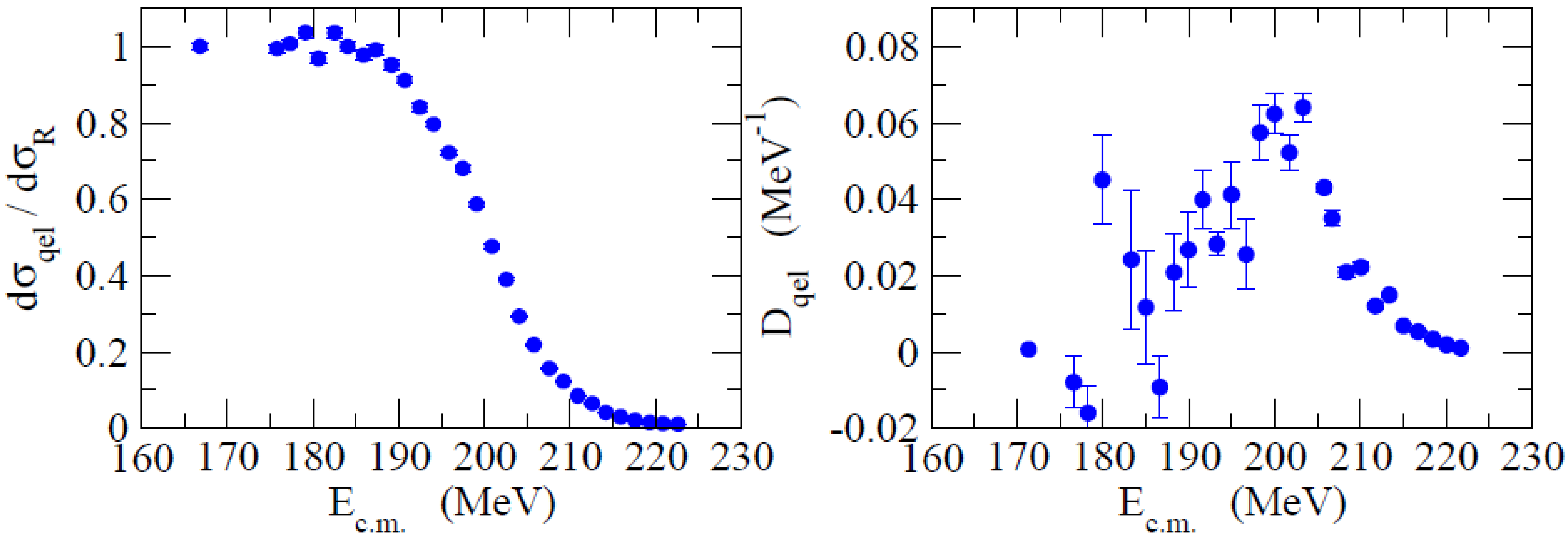


T. Tanaka et al., JPSJ, submitted (‘17)

Analysis for a hot fusion reaction $^{48}Ca + ^{248}Cm$

K.H. and T. Tanaka (2017)

$$^{48}Ca + ^{248}Cm\ (\beta_2 = 0.297,\ \beta_4 = 0.04) \rightarrow {}^{296}_{116}Lv^*$$



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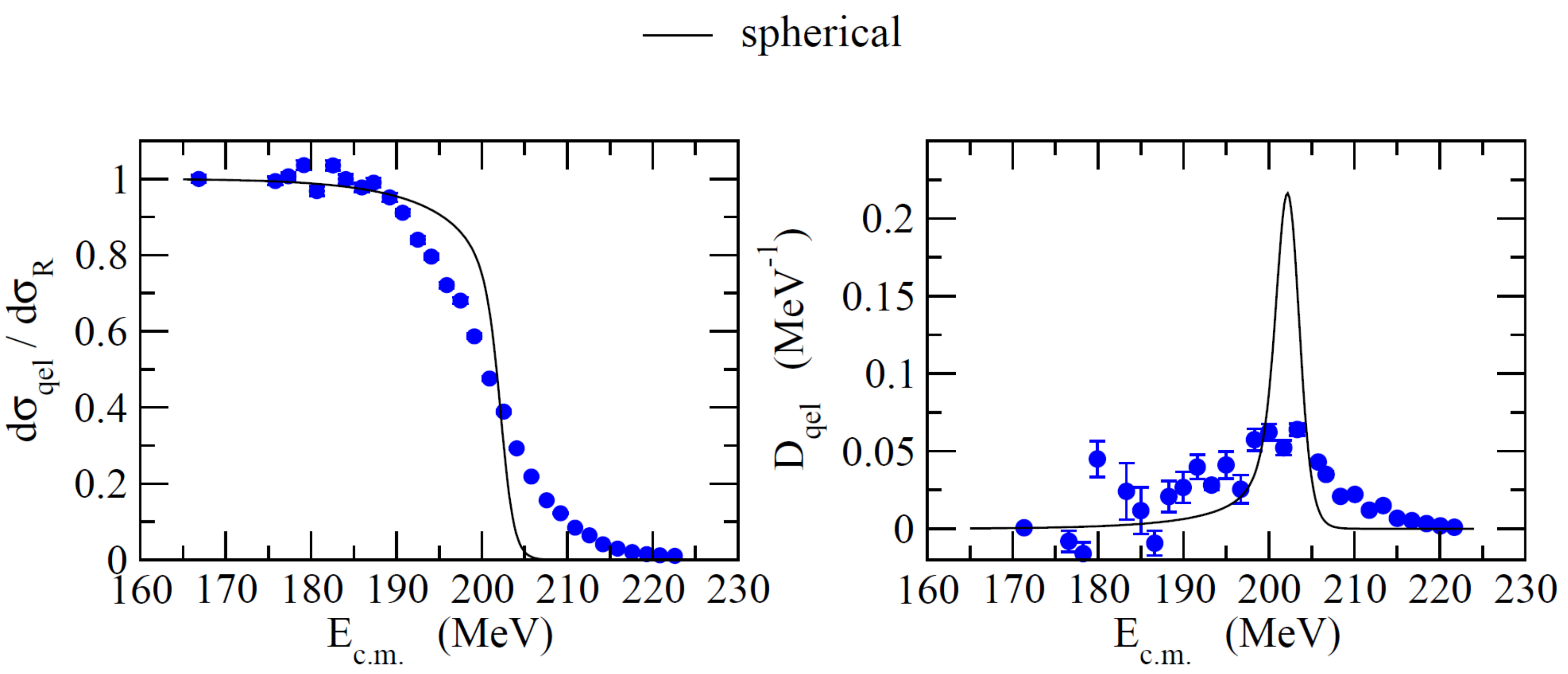

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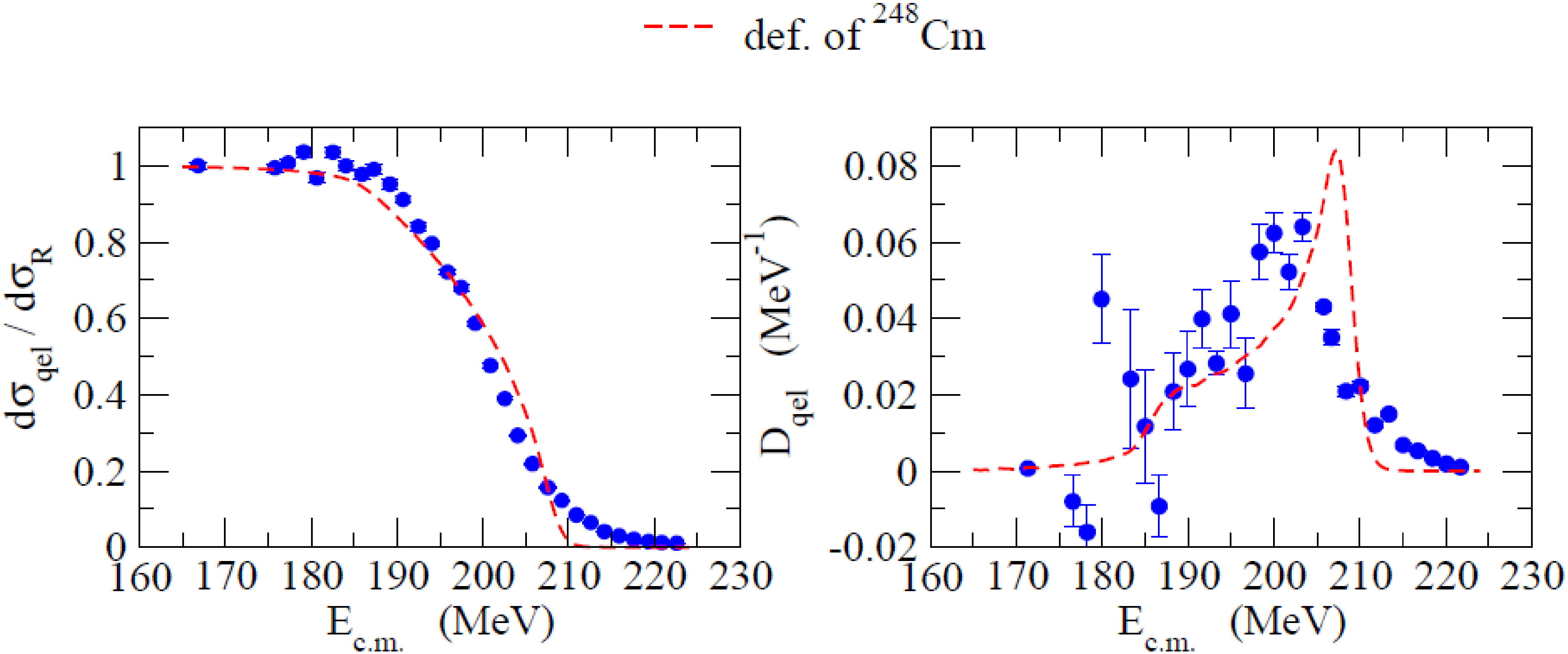

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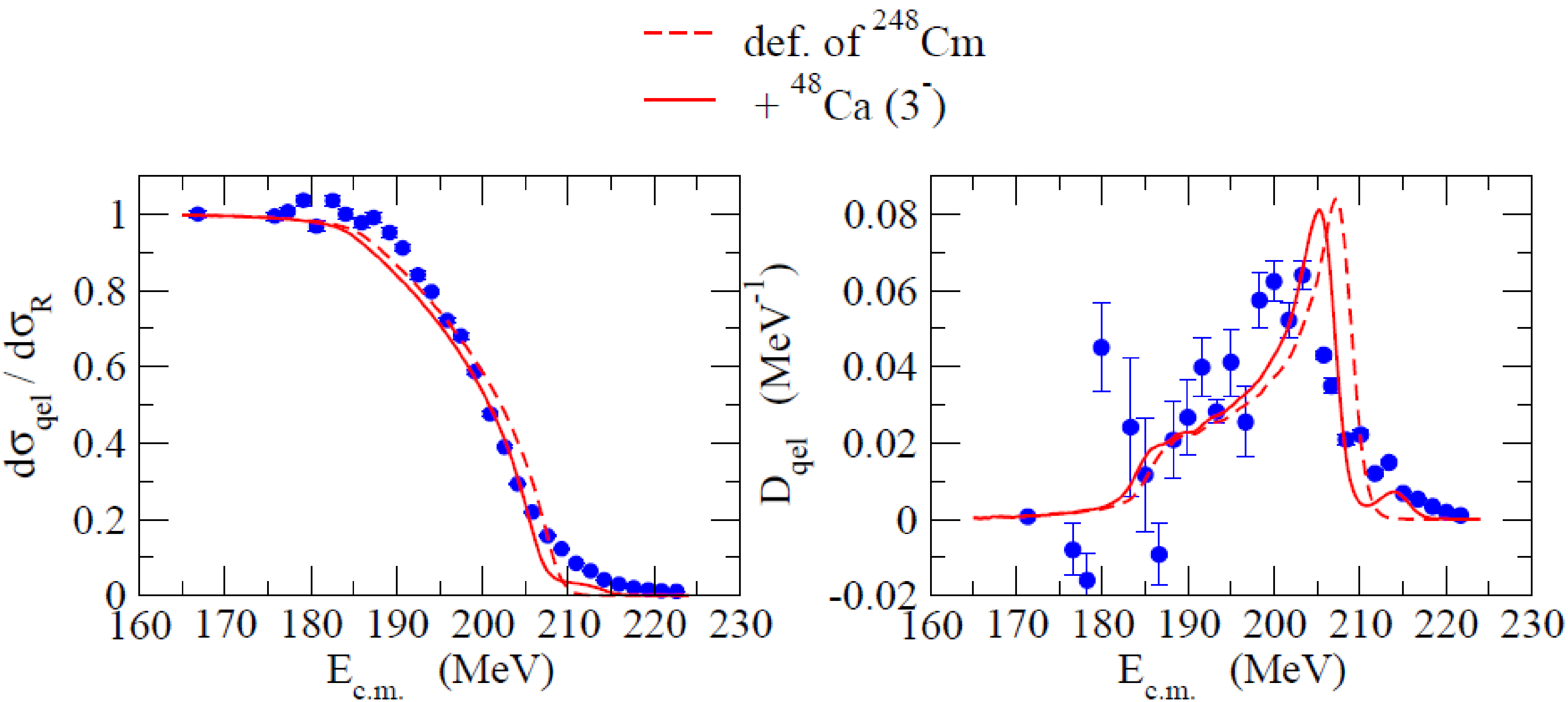

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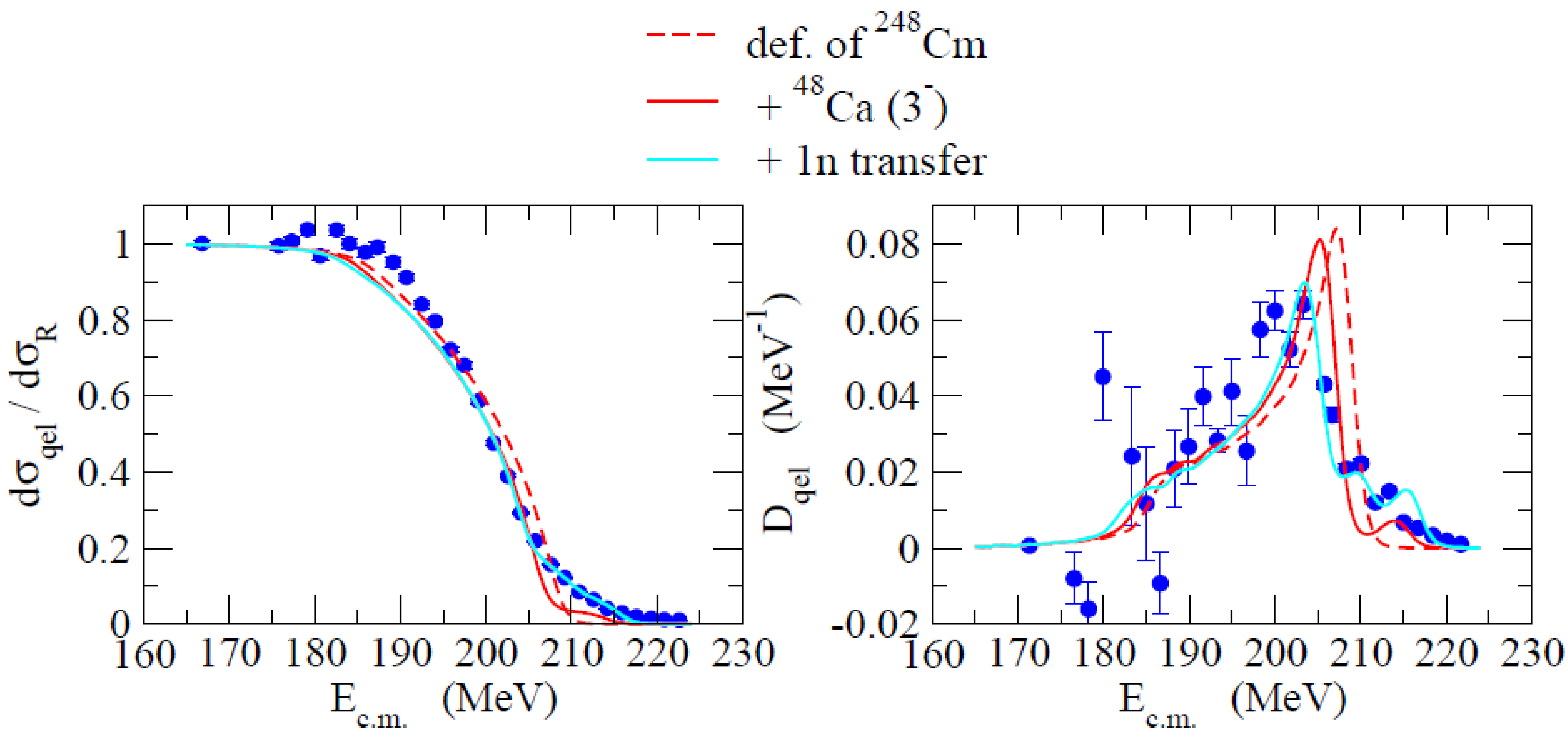
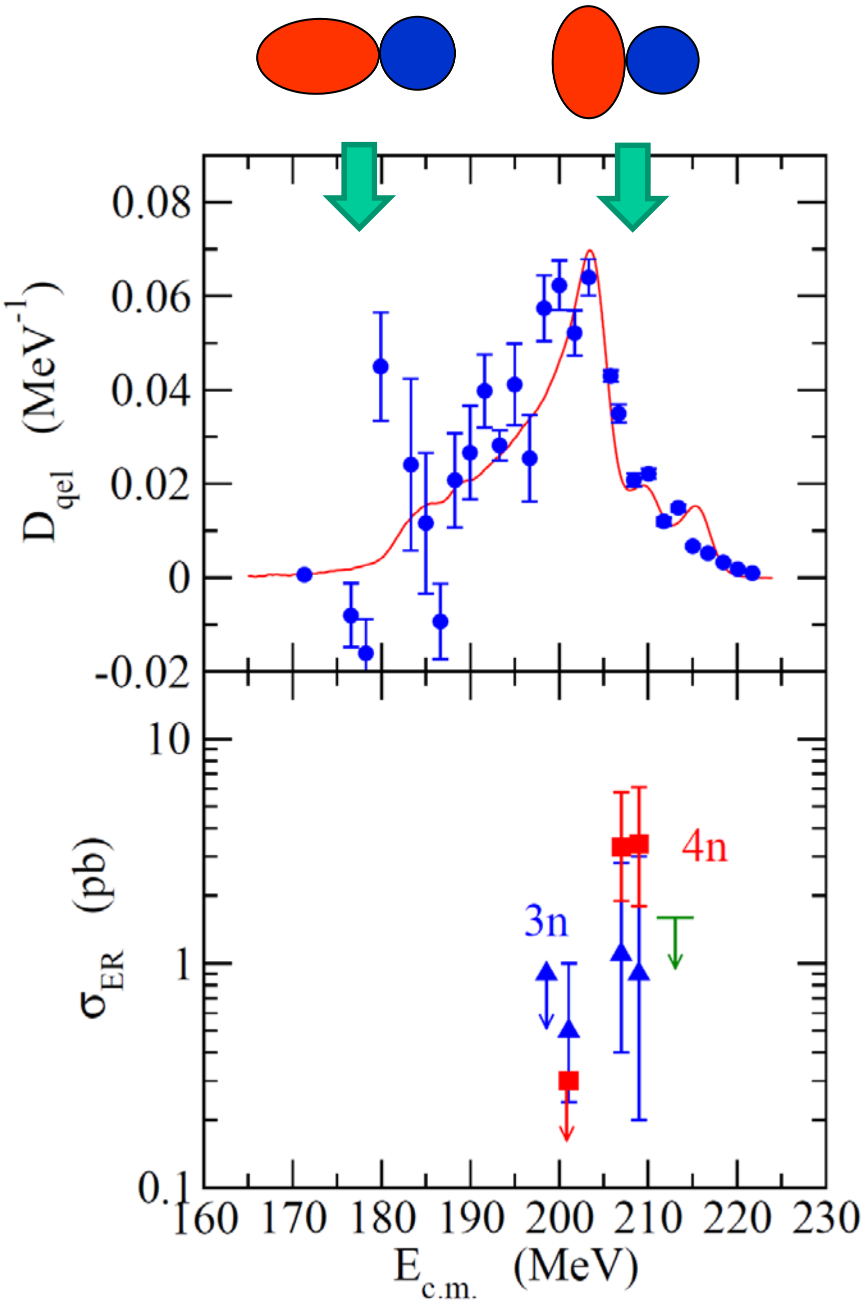
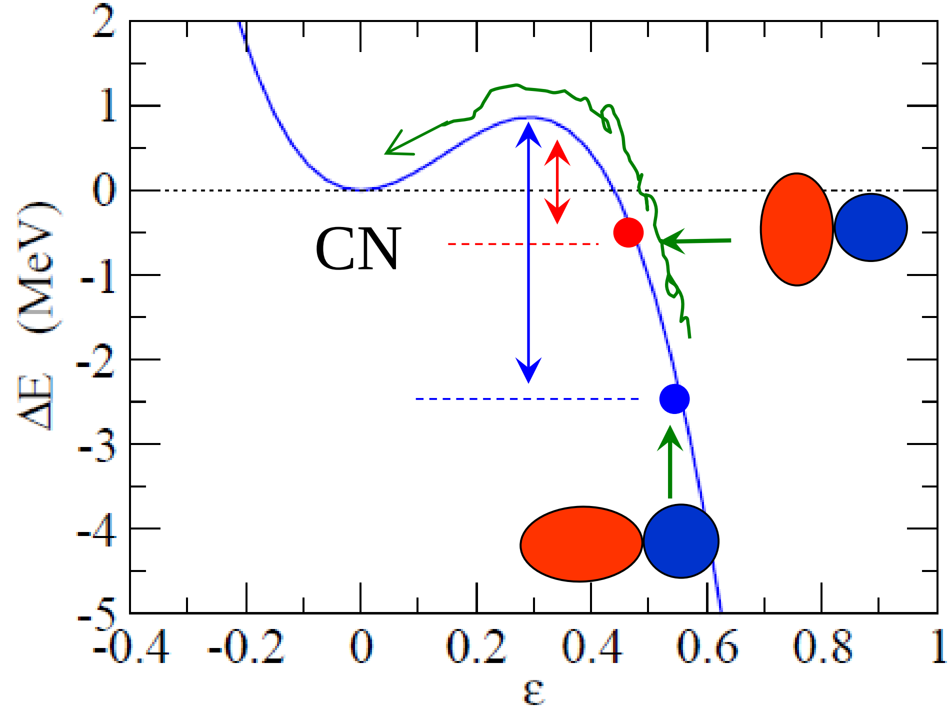
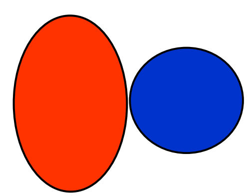


Relation to the ER cross sections



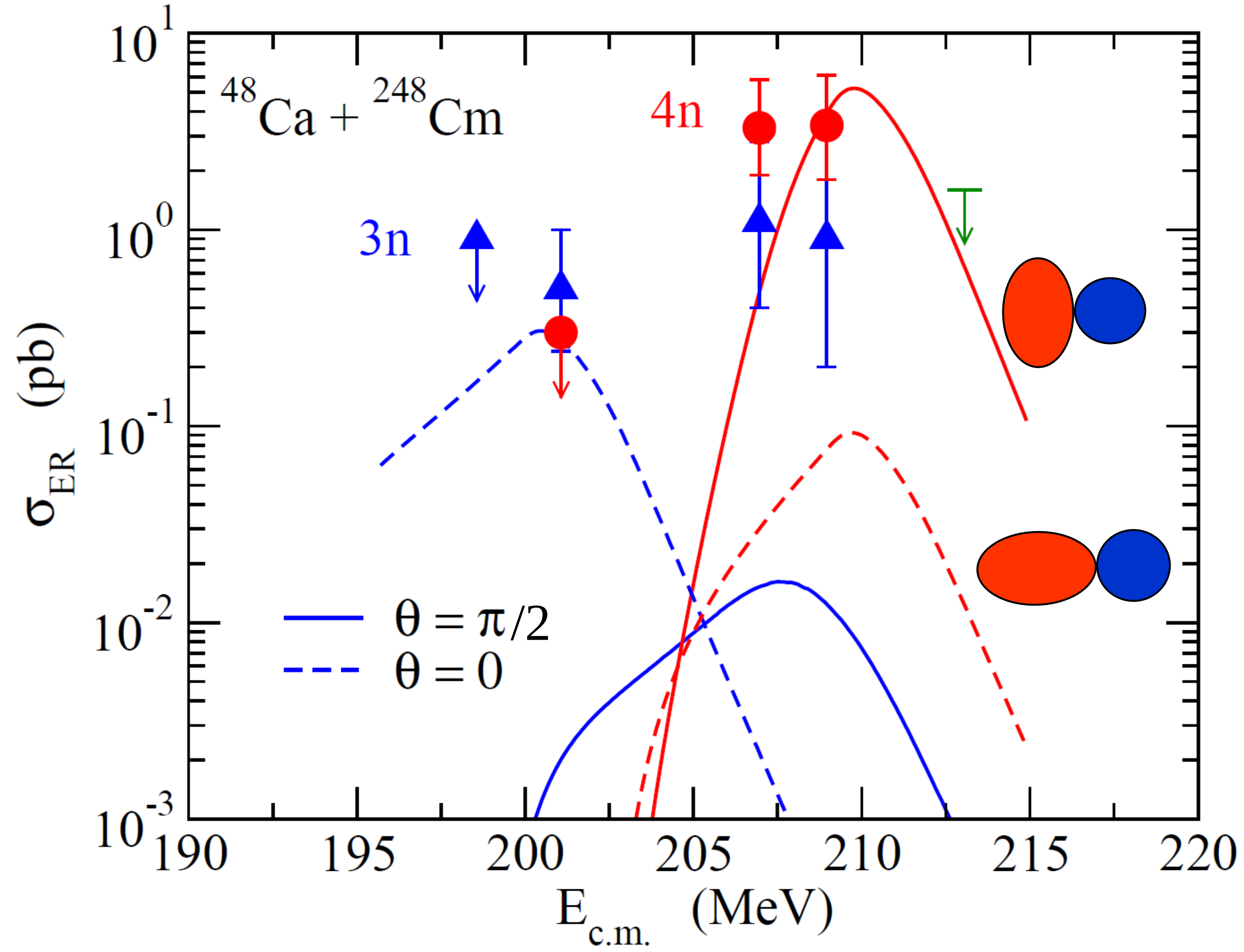
notion of compactness:
D.J. Hinde et al., PRL74 ('95) 1295





= more compact at the touching
→ lower barrier height
→ good for CN formation

role of orientation angle in ER cross sections



Fusion-by-diffusion model (Swiatecki) + deformation

K.H., in preparation

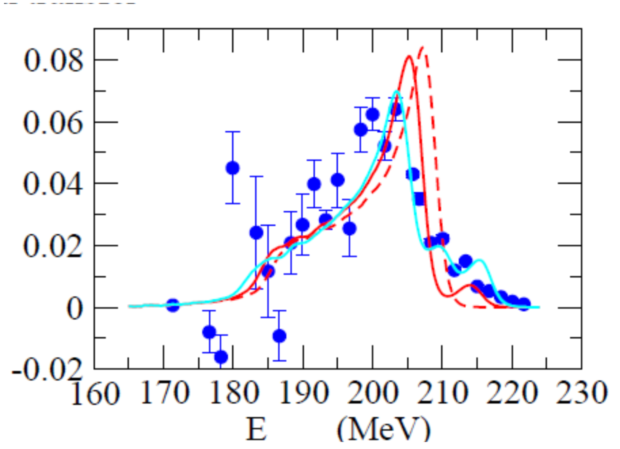
Summary

Heavy-ion fusion reactions for SHE

- ✓ large theoretical uncertainties
- ✓ capture process: relatively well understood
- ✓ coupled-channels effects and barrier distribution

Recent measurement of quasi-elastic barrier distributions with GARIS

- ✓ $^{48}Ca + ^{248}Cm$
- ✓ coupled-channels analysis
- ✓ notion of compactness: ER formation with side collisions



- ➢ more data will come soon for several systems
- ➢ connection to the second (diffusion) and the third (ER) processes