Nuclear orientation in fusion and synthesis of heavy element at sub-barrier energy

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Contents

(1) Effects of nuclear orientation on fusion and quasifission.

In-beam Fission Fragment measurement

- ^{30}Si, ^{31}P, ^{34}S, ^{36}S, ^{40}Ar, ^{40}Ca, ^{48}Ca + ^{238}U

Evaporation Residue measurement

- ^{30}Si + ^{238}U (^{263,264}Sg), ^{34}S + ^{238}U (^{267,268}Hs)

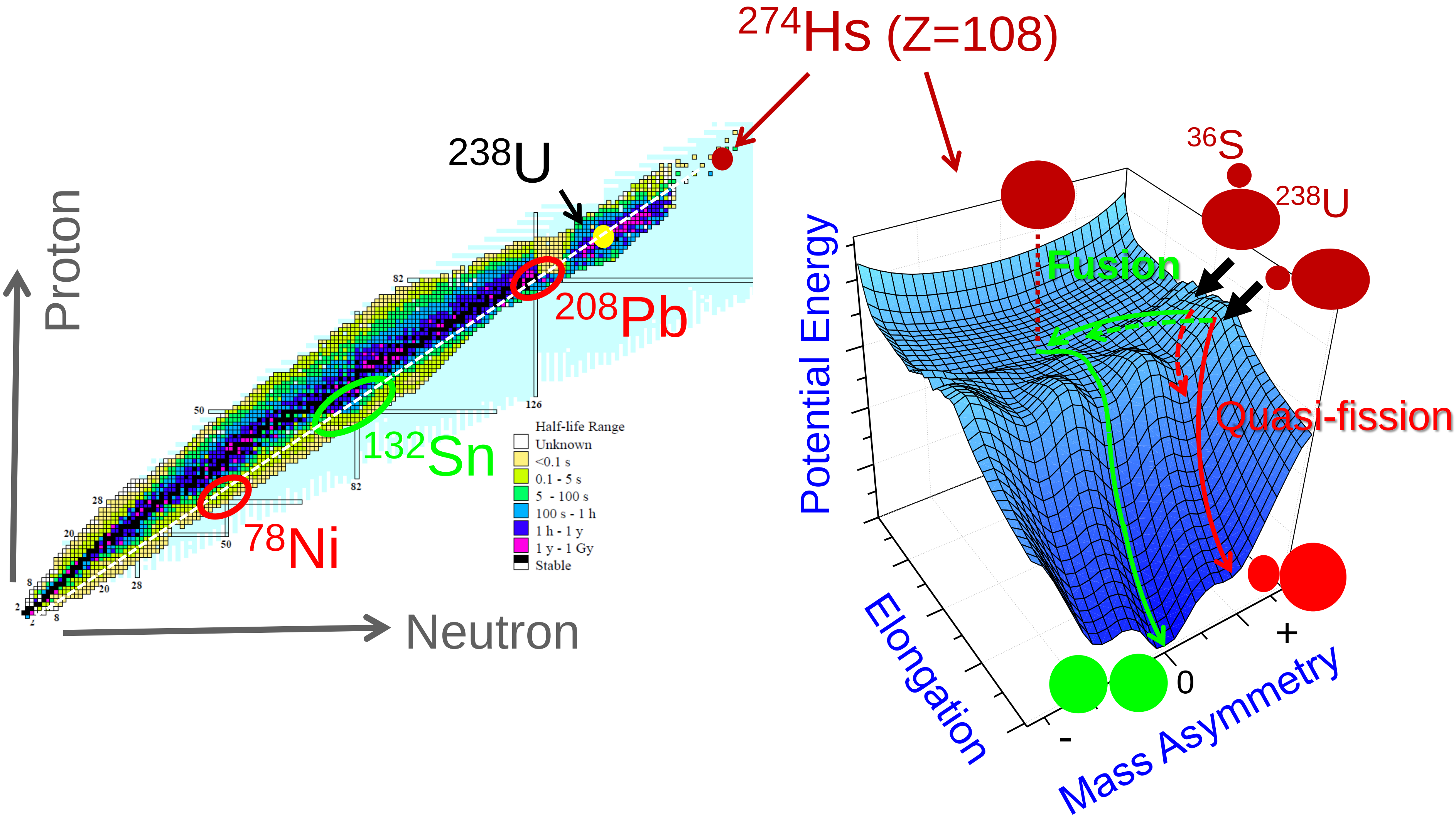
(2) Existence of Deep-quasifission

(3) Influence of Q-value on Fusion

In-beam Fission Measurement → JAEA Tandem Facility

Evapo. Resid. Measurement → UNILAC at GSI

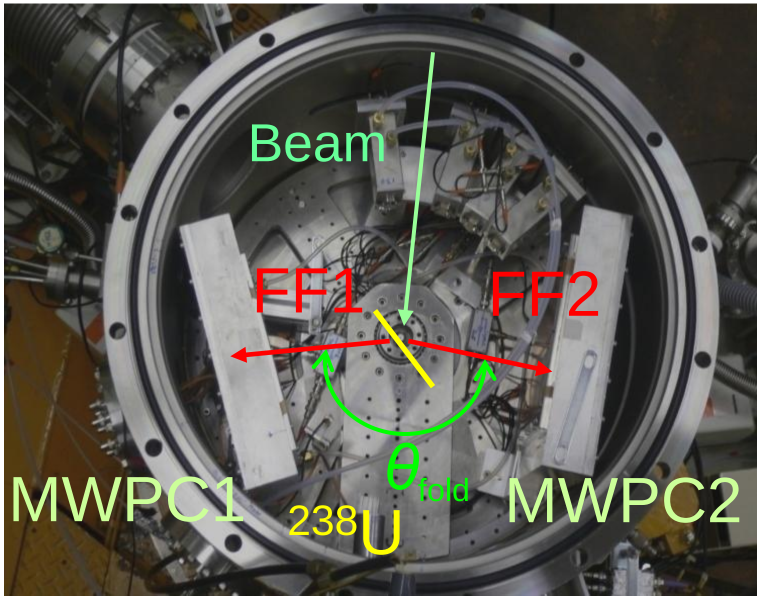
Fusion-fission and Quasi-fission



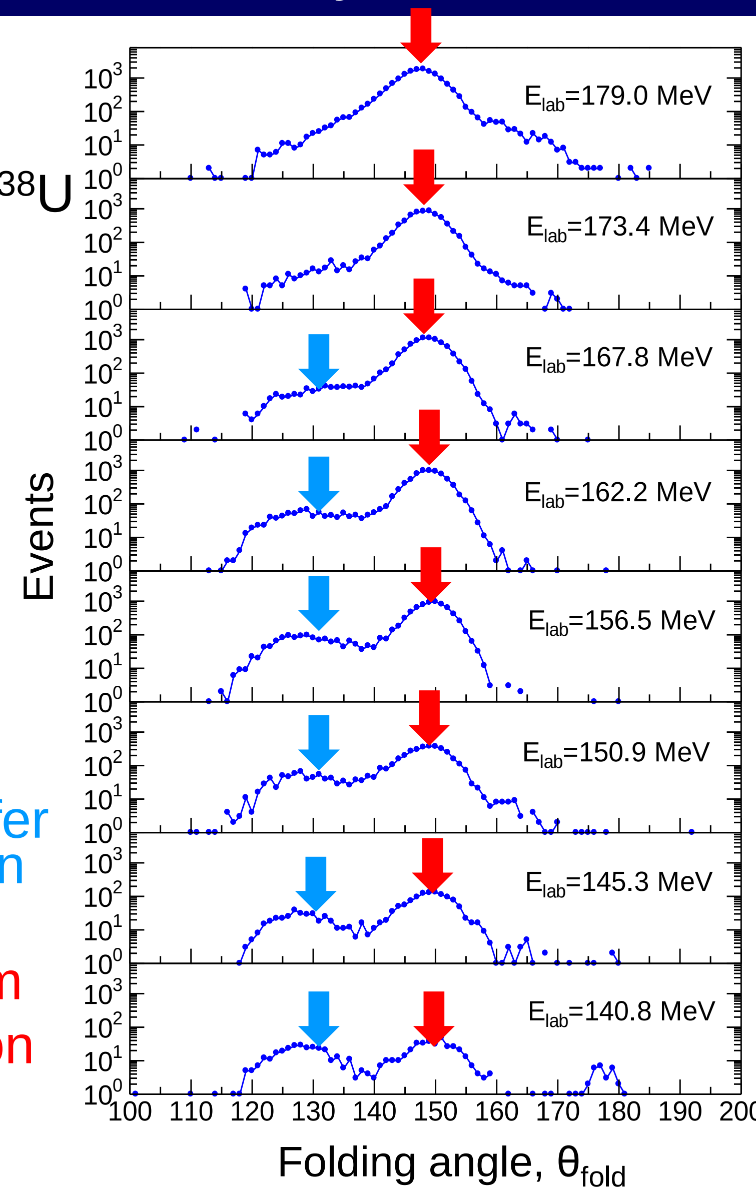
Calculated by Y.Aritomo

Fission fragment measurement at the JAEA tandem-booster facility

^{30}Si, ^{31}P, $^{36,34}S$, ^{40}Ar, $^{40,48}Ca$ Beams



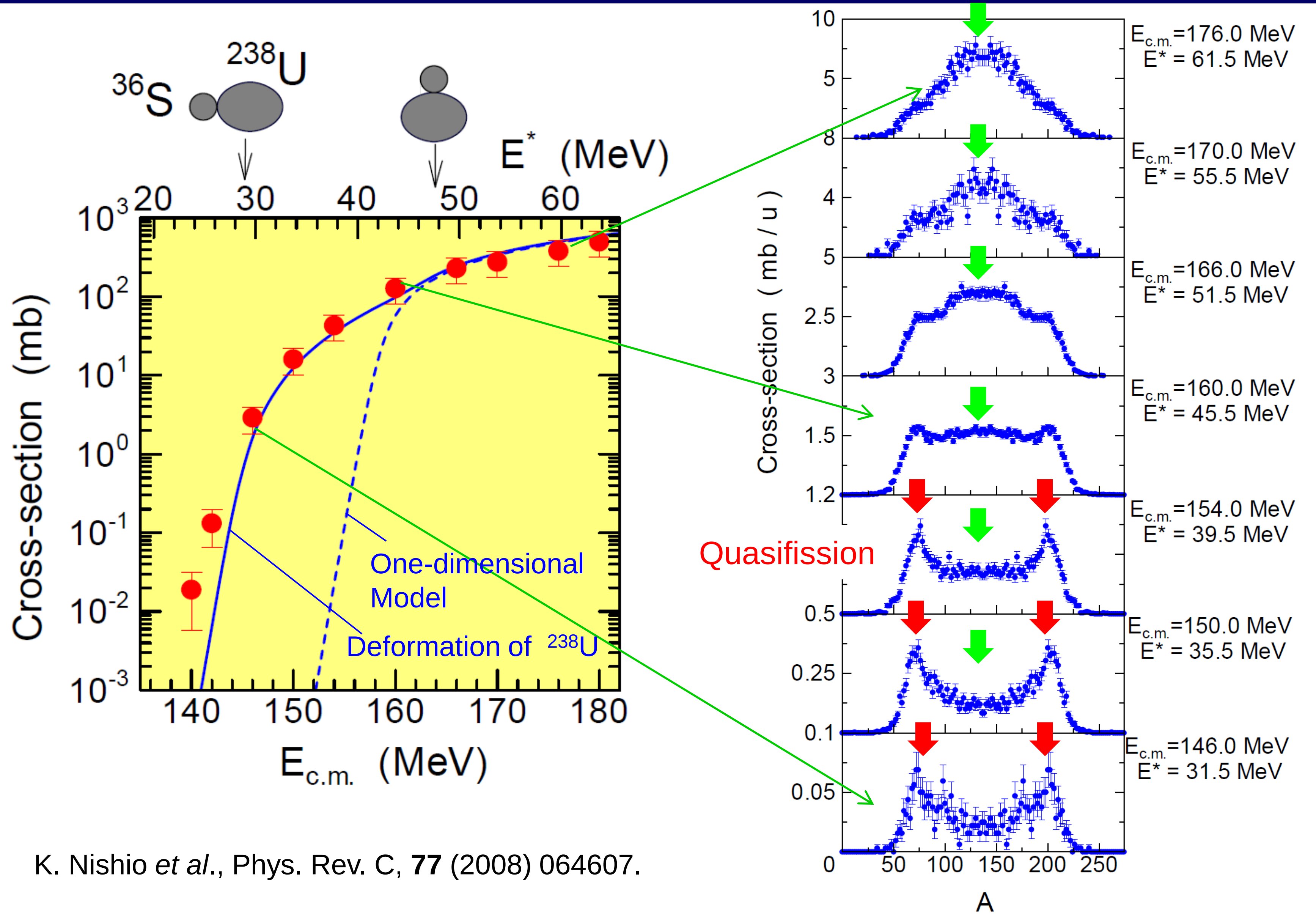
^{30}Si + ^{238}U



Nucleon-transfer induced Fission

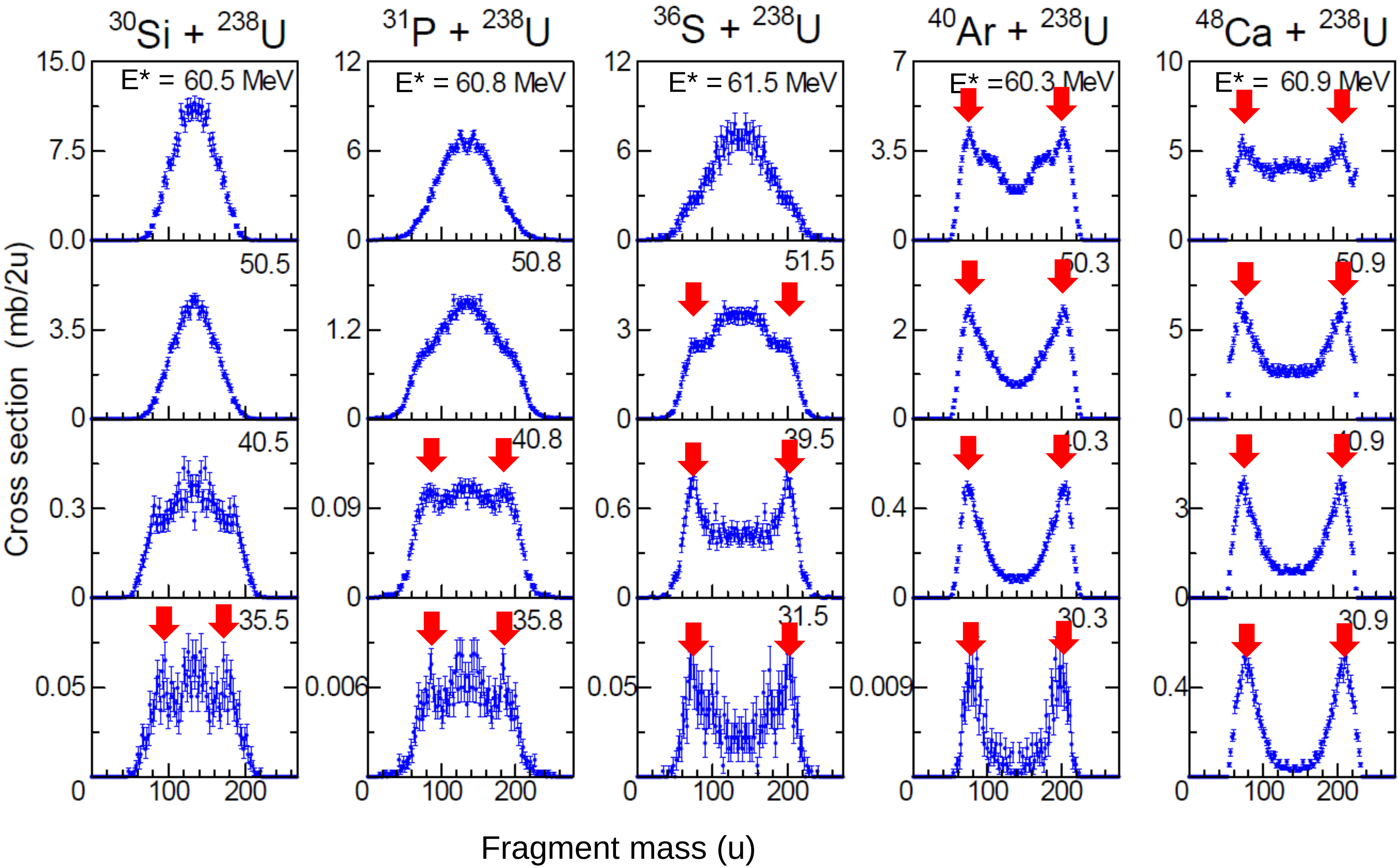
Full Momentum Transfer Fission

Orientation effects on fragment mass distributions for $^{36}S + ^{238}U$



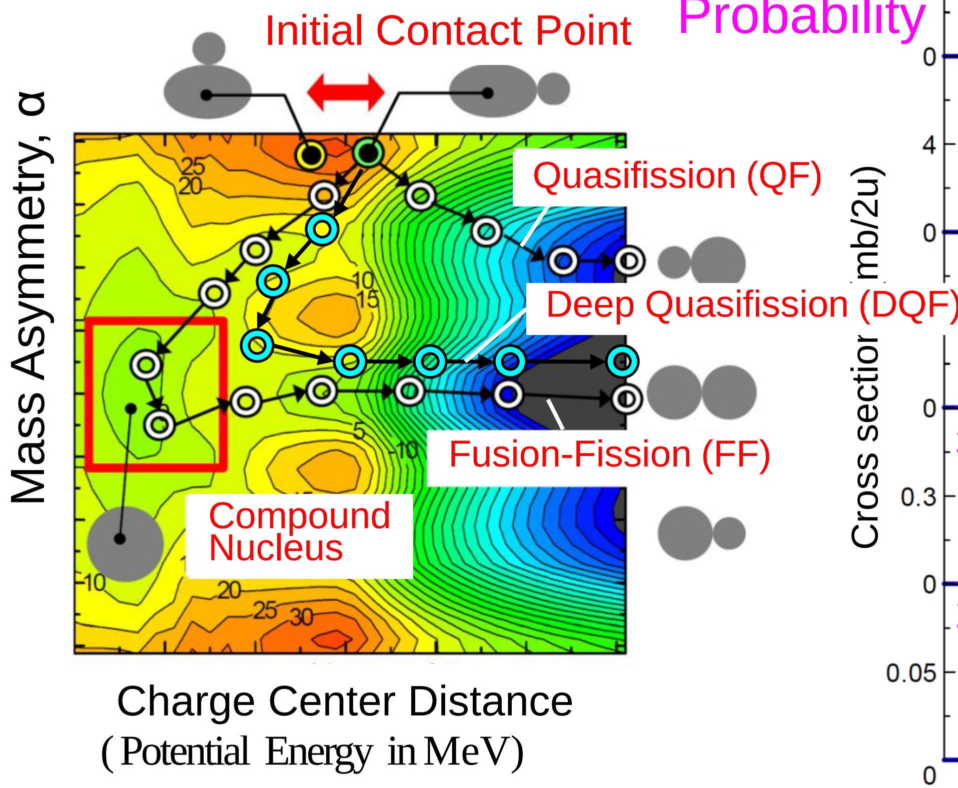
K. Nishio *et al*., Phys. Rev. C, **77** (2008) 064607.

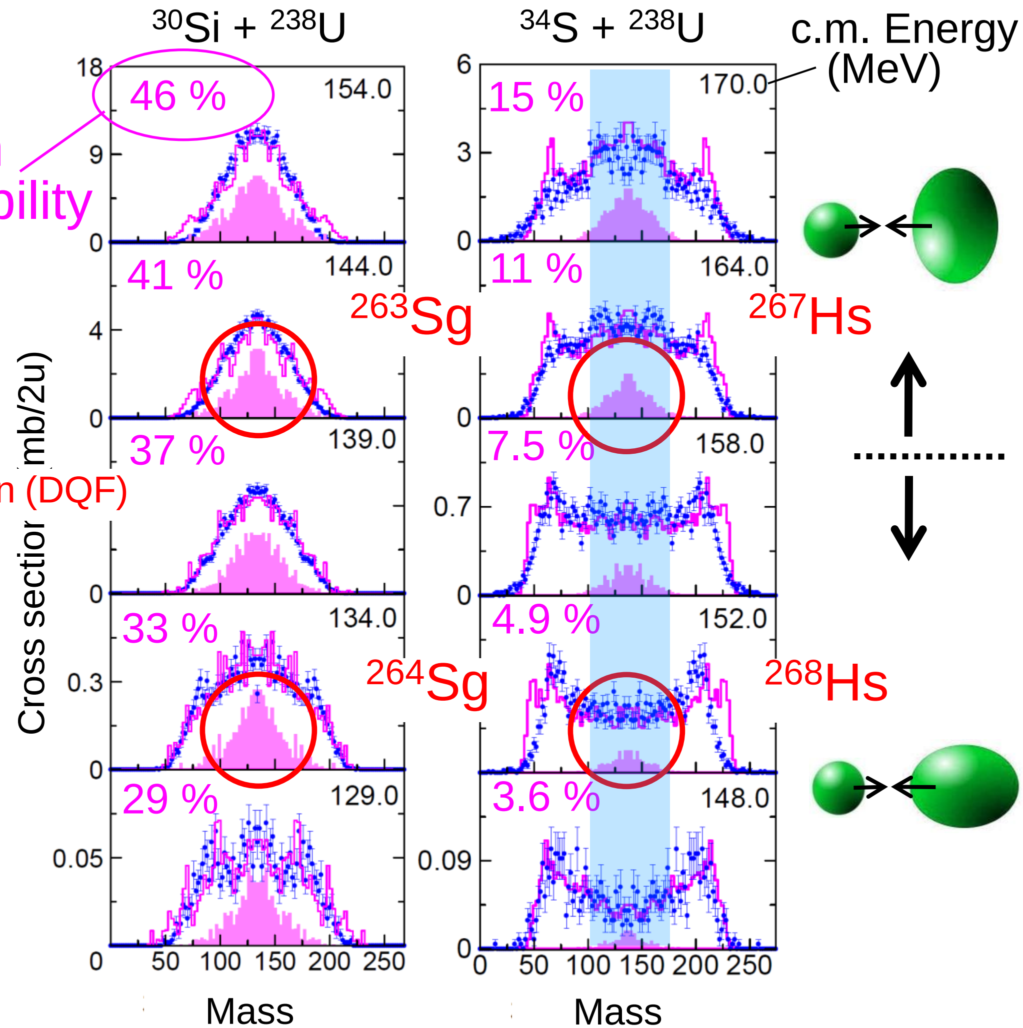
Fragment mass distributions



Fusion probability

Fluctuation-Dissipation Model
(Langevin Equation)





Histogram	All Fission Fragments
Filled Area	Fusion-Fission
●	Experimental Data

V. Zagreabev, J. Phys. G, **31,** 825 (2005).
Y. Aritomo et al., Nucl.Phys. **A753**, 152 (2005).
Y. Aritomo, Phys.Rev.C, **80**, 064604 (2009).

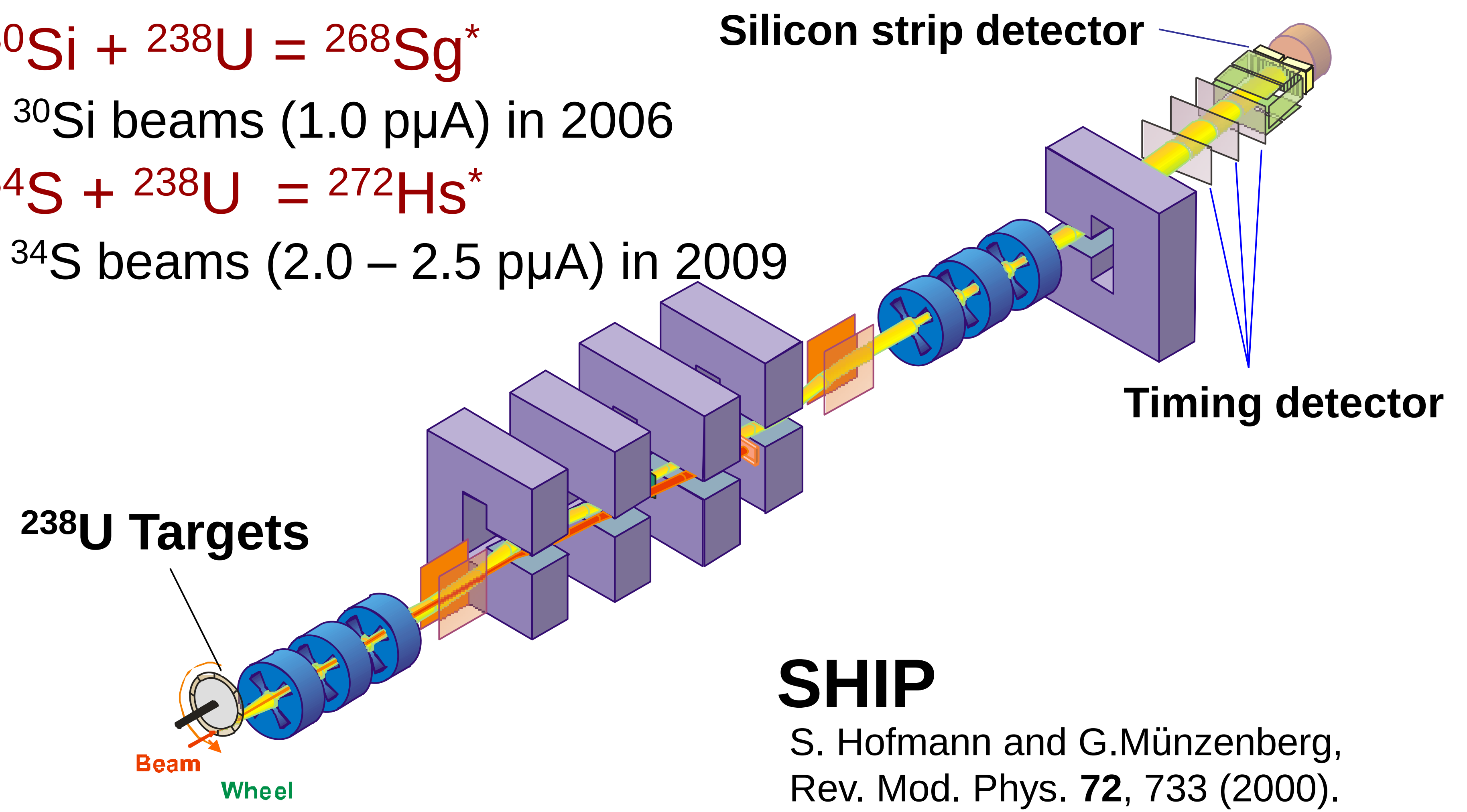
Measurement of evaporation residue (ER) cross sections at GSI

$^{30}Si + ^{238}U = ^{268}Sg^{*}$

^{30}Si beams (1.0 pμA) in 2006

$^{34}S + ^{238}U = ^{272}Hs^{*}$

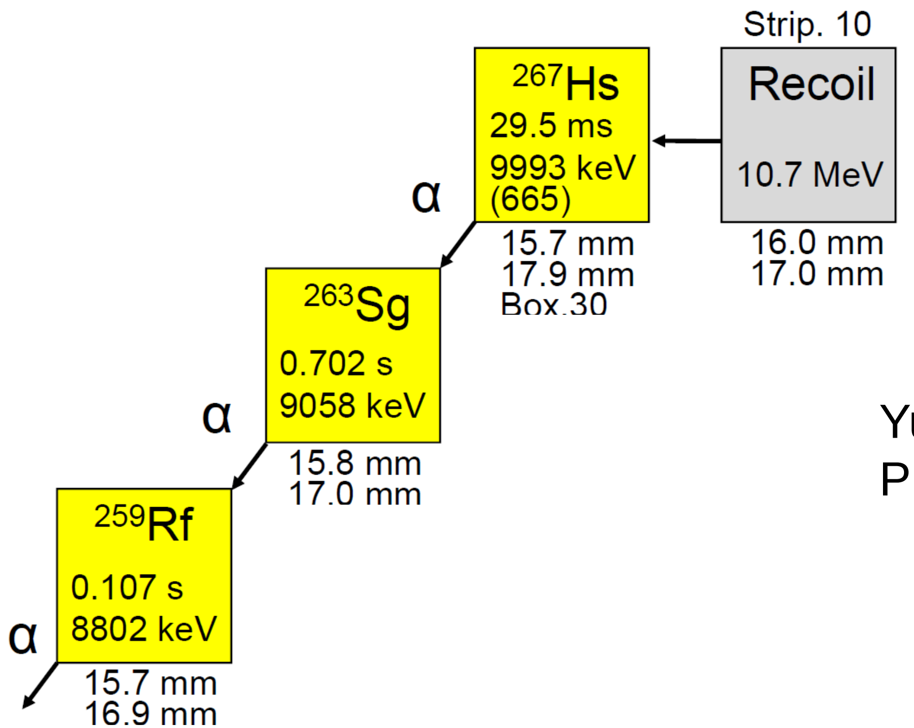
^{34}S beams (2.0 – 2.5 pμA) in 2009



SHIP

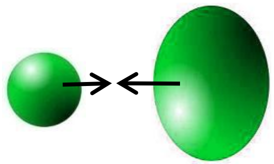
S. Hofmann and G.Münzenberg,
Rev. Mod. Phys. **72**, 733 (2000).

ER cross-sections for ^{267,268}Hs in the ^{34}S + ^{238}U reaction



$E_{c.m.}$ = 163 MeV

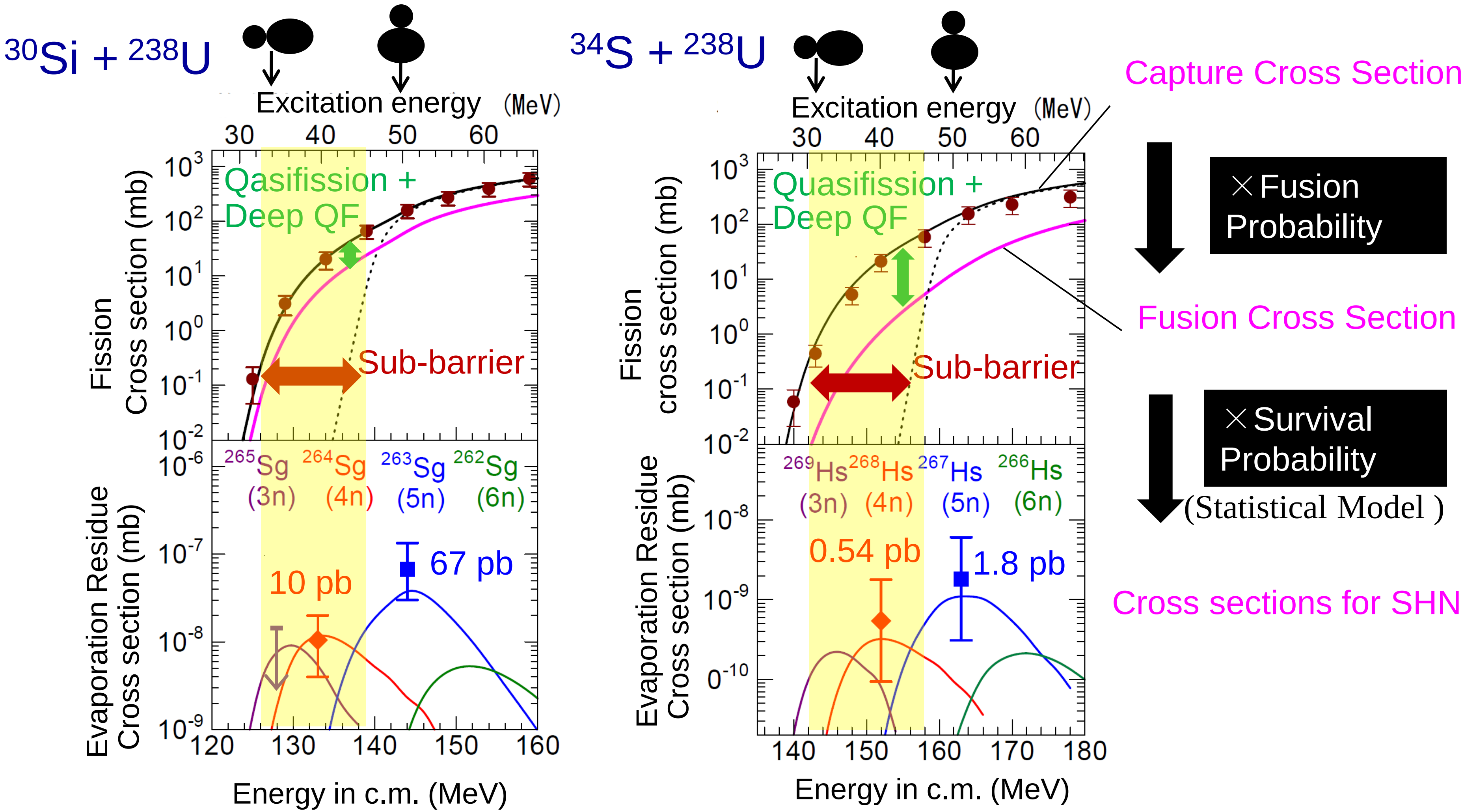
E* = 51 MeV



$1.8^{+4.2}_{-1.5}$ pb

Yu.A Lazarev *et al*., ^{267}Hs (**2.5 pb**), PRL75(1995) 1903.

Fusion and ER cross sections



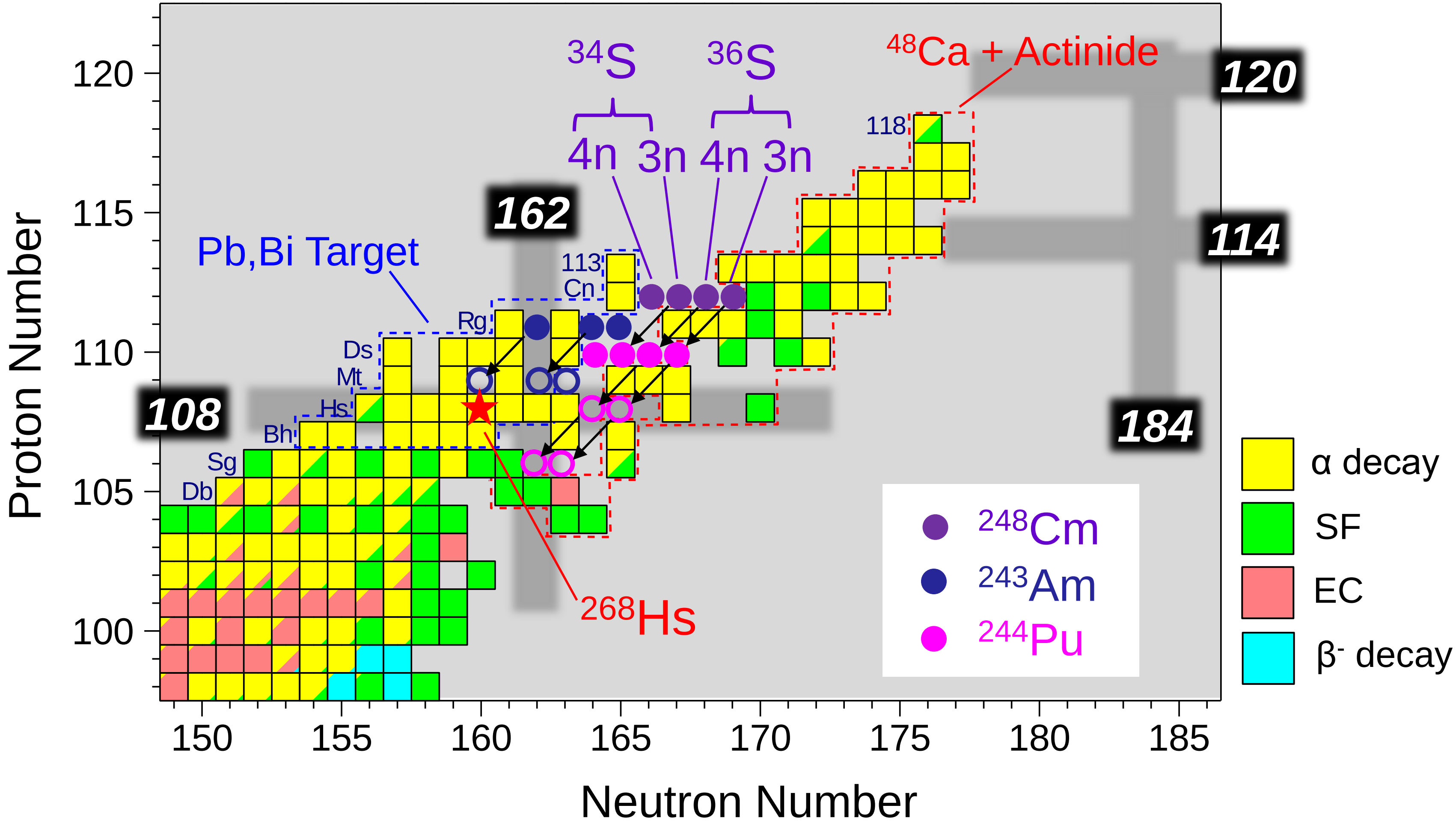
K. Nishio *et al.*, PRC **82**, 044604 (2010).

K. Nishio *et al.*, PRC **82**, 024611 (2010).

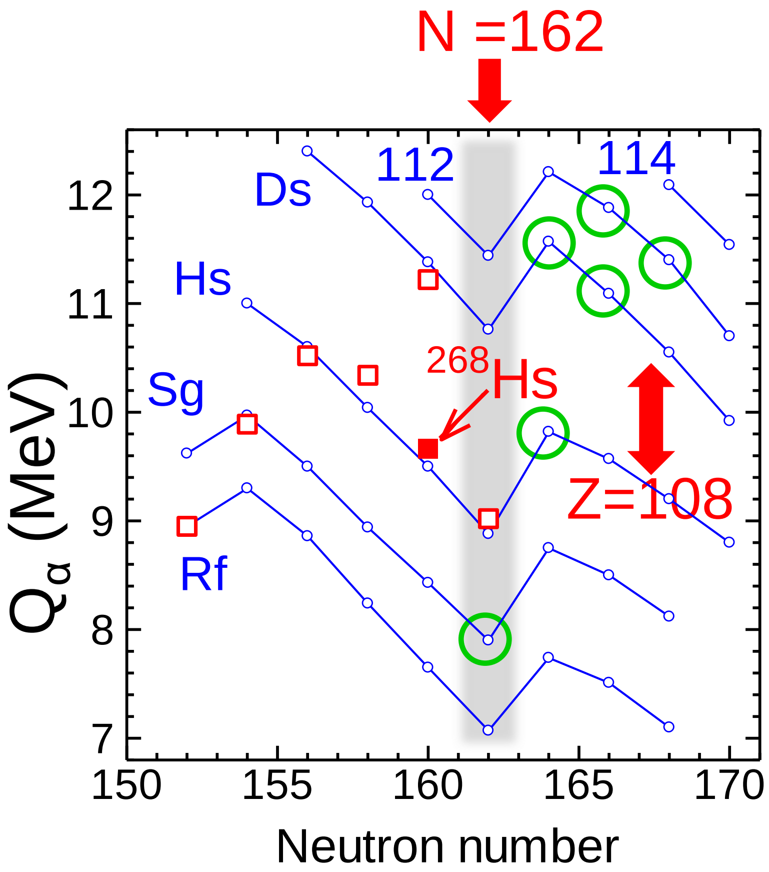
→ SHN can be produced at the sub-barrier energies (4*n* and 3*n*)

Production on New Isotopes

$^{34,36}S$ + actinide reactions would produce new isotopes in the missing region of chart of nucleus (18 nuclei).



Deformed shells at N=162, Z=108



New Isotopes located in the Missing Region of Chart of nucleus

Theory : I. Muntian, Acta.Phys.Pol. B**34** (2003).

Mass and $\overline{TKE}$ Distribution for fission of $^{40,48}Ca + ^{238}U$

$^{48}Ca + ^{238}U = ^{286}Cn$

Q = -159.1 MeV

$E_{c.m.}$, E^*

(240.0, 80.9)

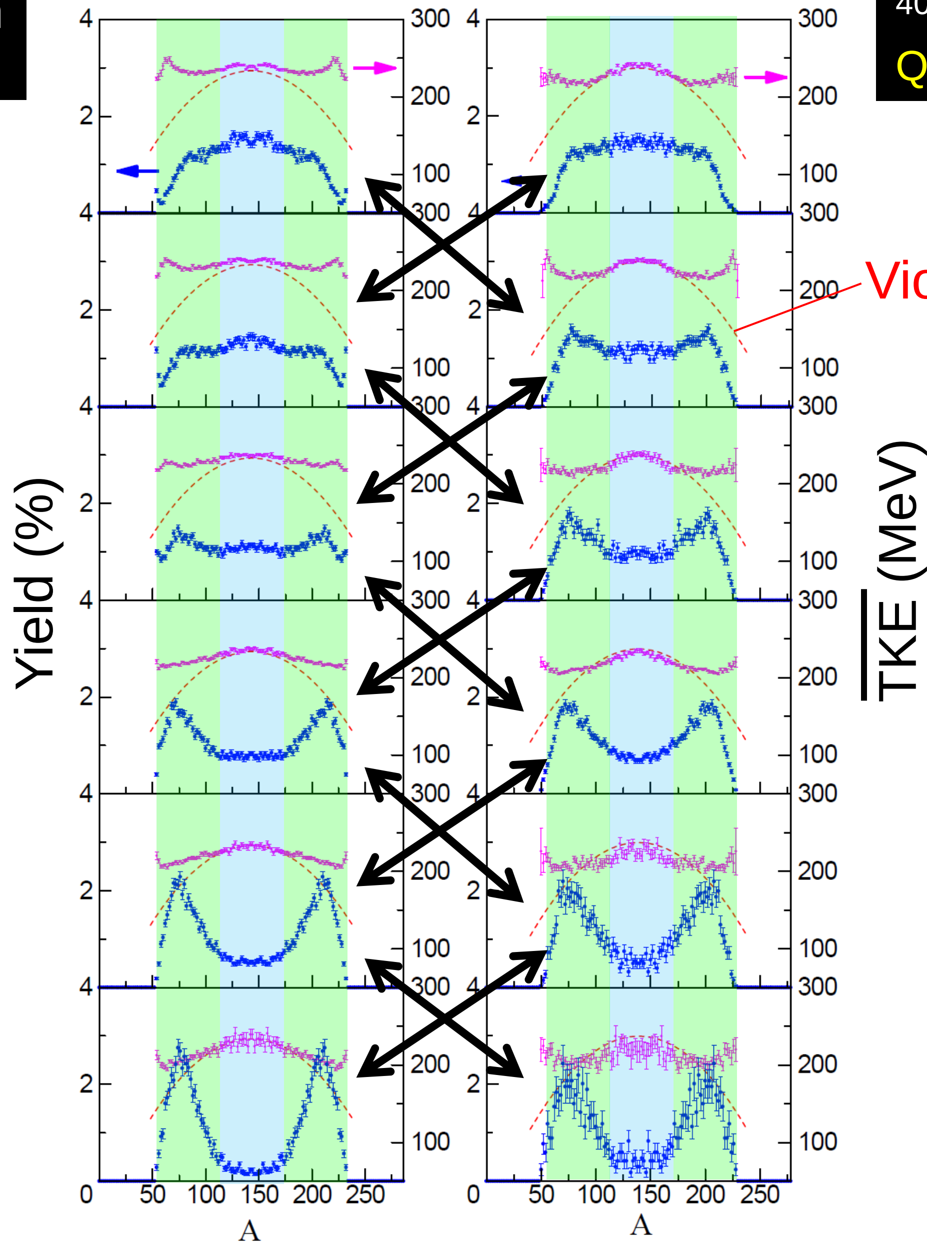
(230.0, 70.9)

(220.0, 60.9)

(210.0, 50.9)

(200.0, 40.9)

(190.0, 30.9)



$^{40}Ca + ^{238}U = ^{278}Cn$

Q = -138.6 MeV

$E_{c.m.}$, E^*

(230.0, 91.5)

(219.2, 80.7)

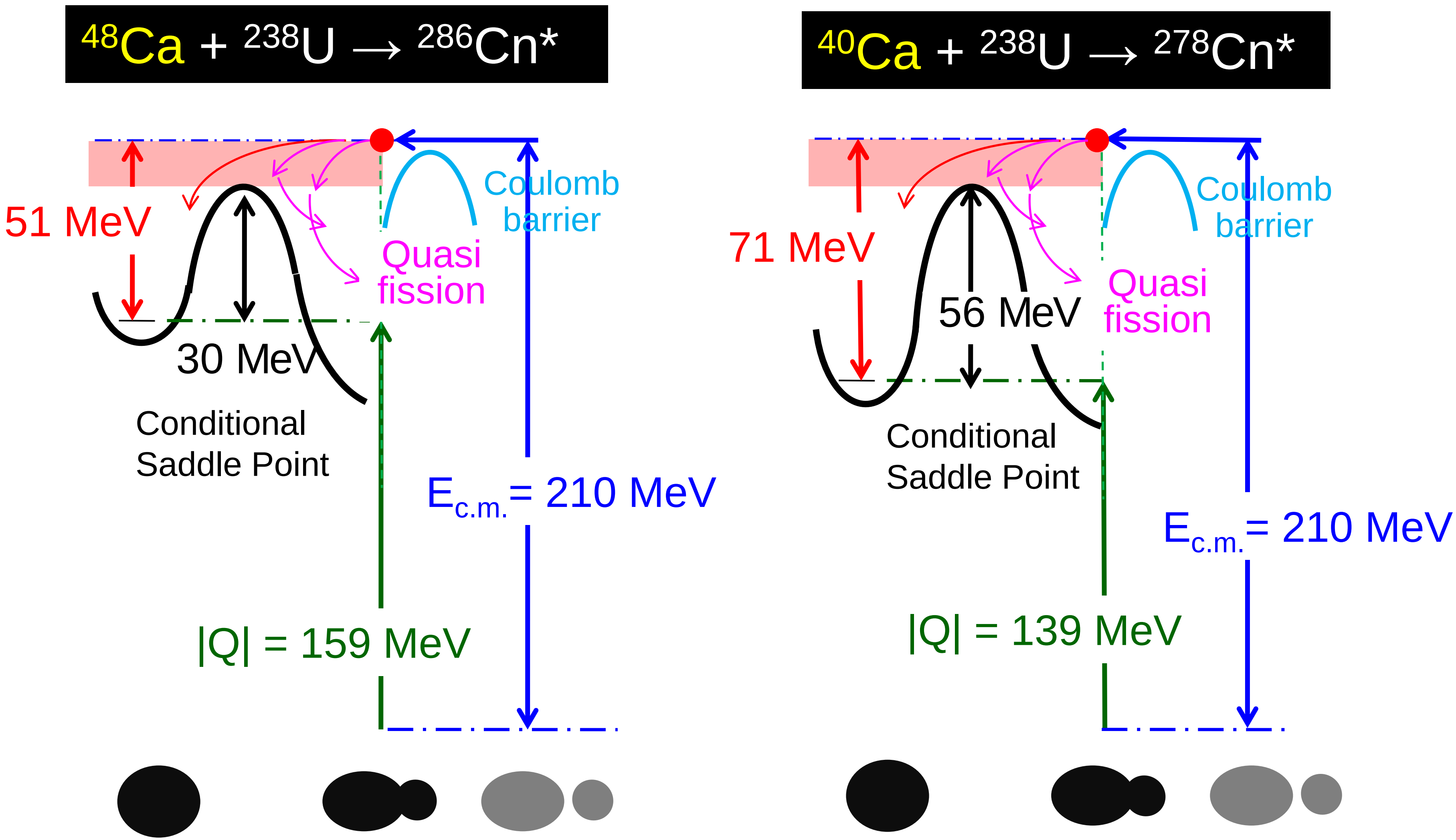
(210.1, 71.6)

(200.0, 61.5)

(190.0, 51.5)

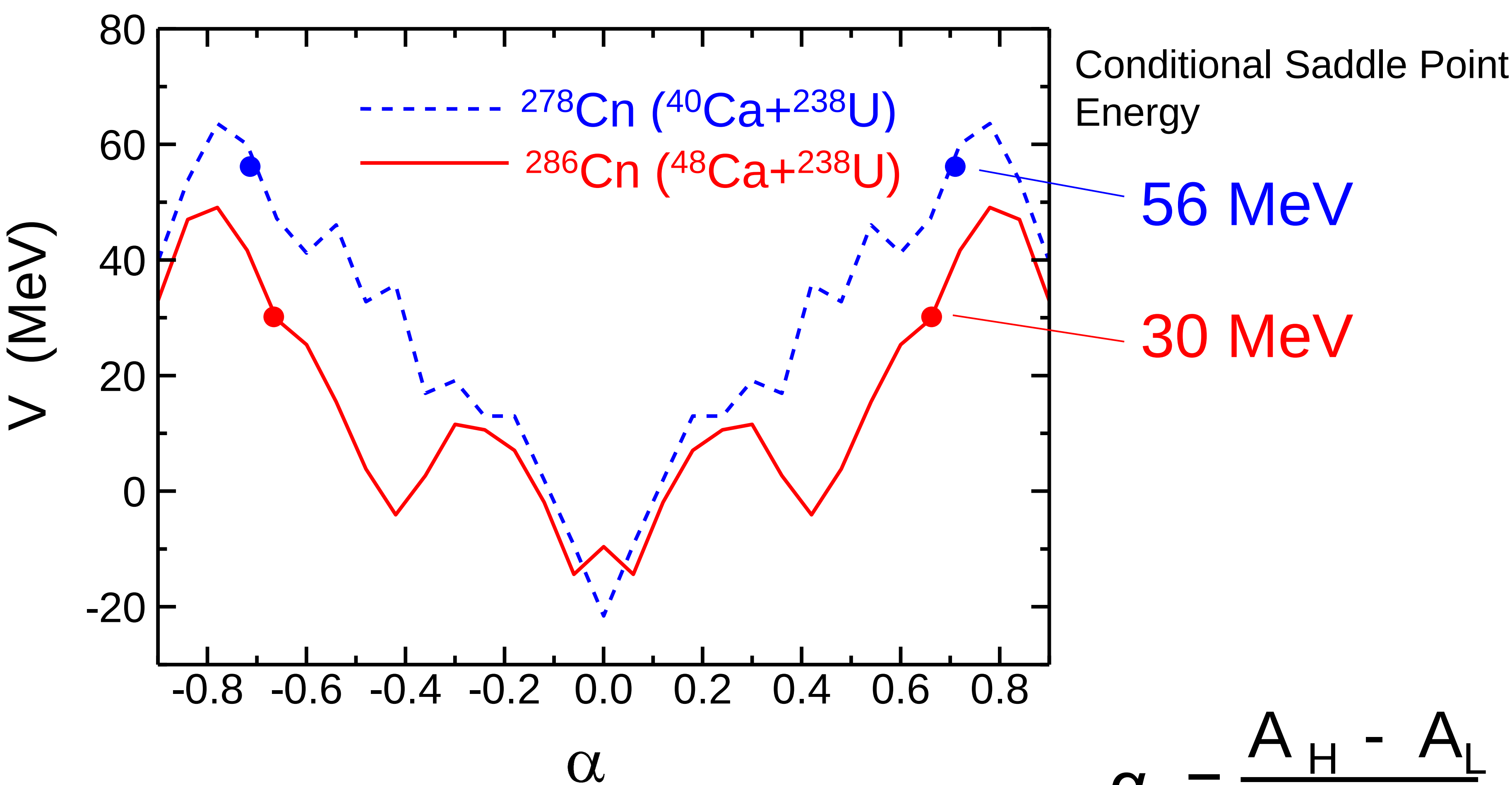
(180.0, 41.5)

Influence of Q-value on Fusion



The mass-asymmetric quasifission probability is determined by the incident energy measured from the conditional saddle point

Conditional Saddle Point Energy



$$\alpha = \frac{A_H - A_L}{A_H + A_L}$$

Conclusions

1. Super-heavy nucleus can be produced at the sub-barrier energy (4*n* and 3*n*).

2. Mass-symmetric fission fragments in the $^{34}S + ^{238}U$ reaction includes deep quasifission.

3. Incident energy measured from the conditional saddle point regulates the mass-asymmetric quasifission probability.

Collaborators

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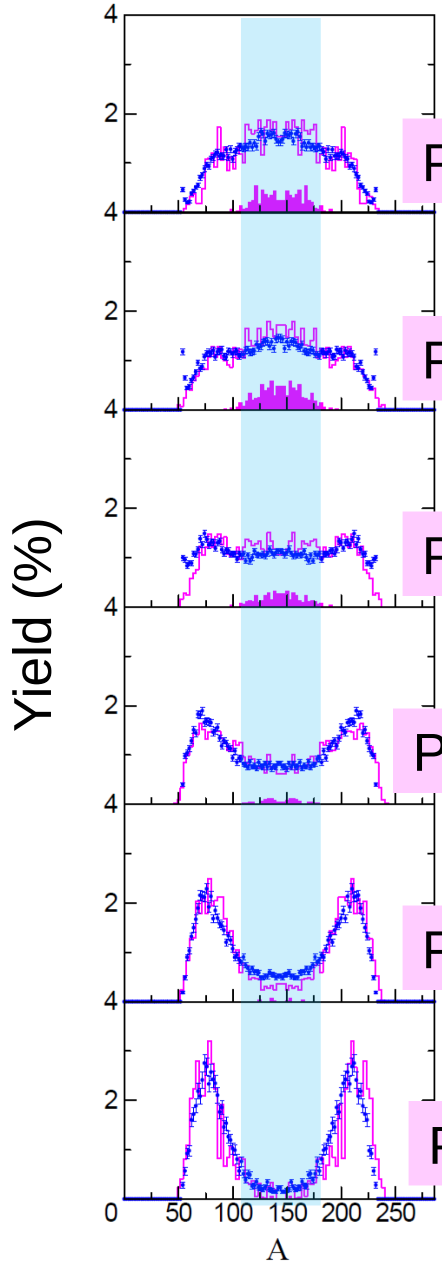
Thank you

Fragment Mass-distribution for $^{48}Ca + ^{238}U$

$E_{c.m.}$, E^*	
(240.0, 80.9)	P_{fus} = 0.11
(230.0, 70.9)	P_{fus} = 0.12
(220.0, 60.9)	P_{fus} = 0.067
(210.0, 50.9)	P_{fus} = 0.022
(200.0, 40.9)	P_{fus} = 0.006
(190.0, 30.9)	P_{fus} = 0.002



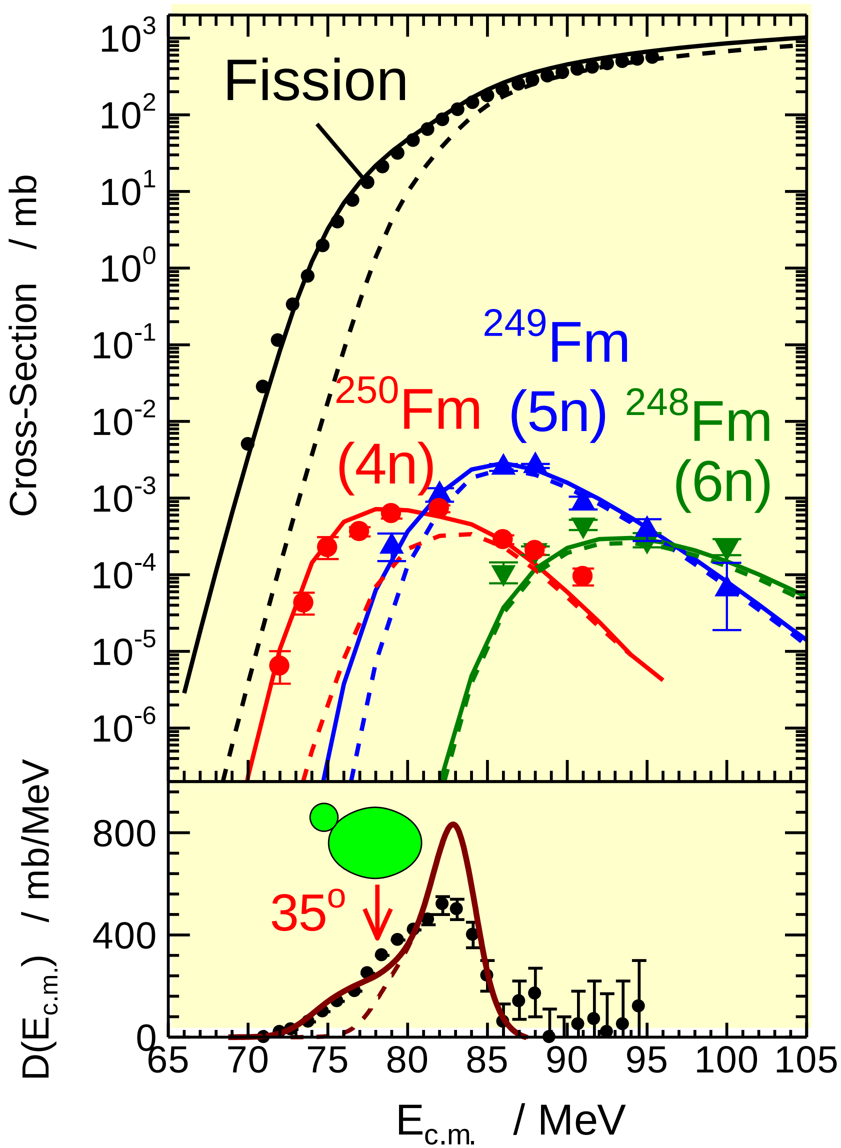
• Experiment

Histogram = All Fission

Filled Area = Fusion-Fission

Calculated by Y.Aritomo

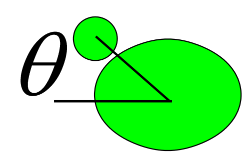
Fusion of ^{16}O + ^{238}U at sub-barrier energies



Complete fusion is the main process in the subbarrier region.

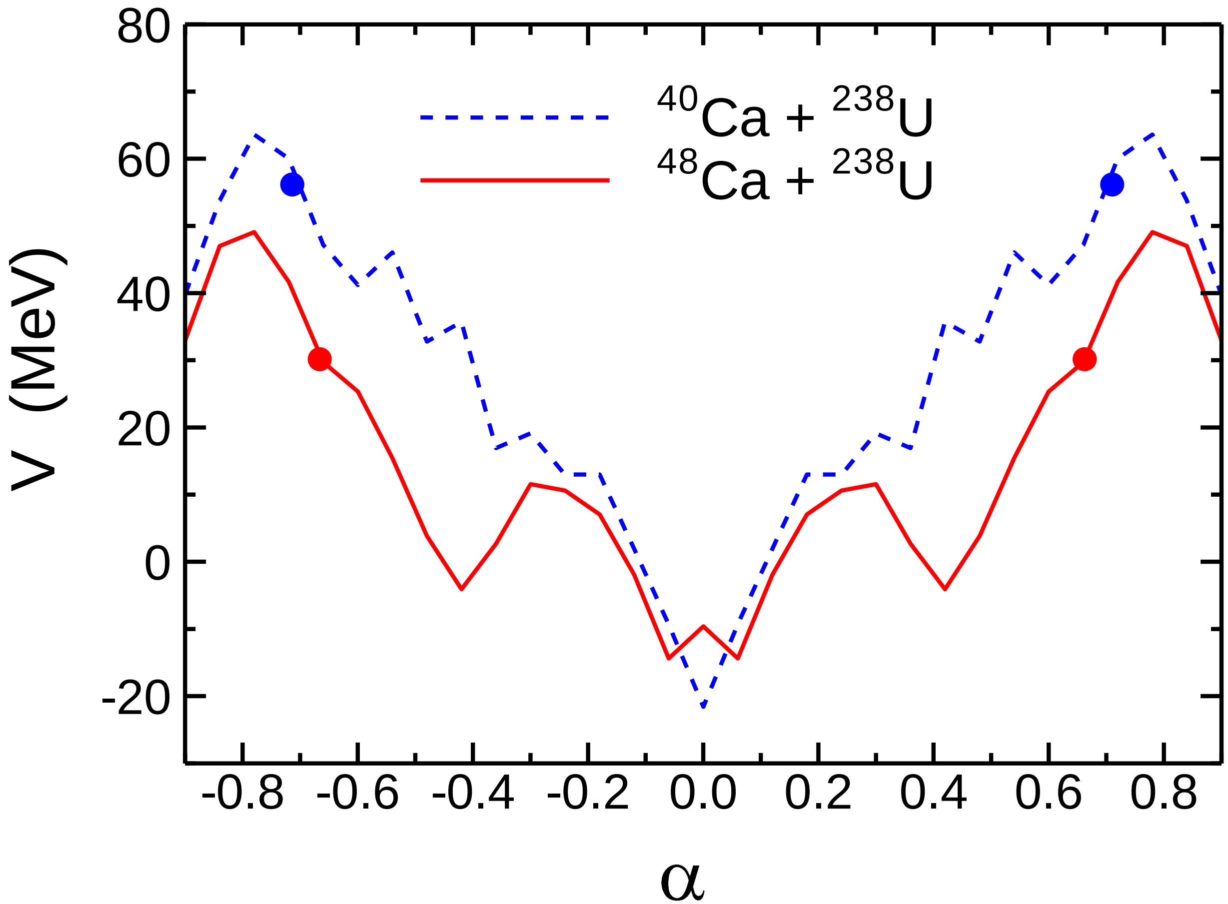
Fusion from every colliding angle

Fusion only for θ > 35°



D.J. Hinde *et al*., PRL **74** (1995)1295.
K. Nishio *et al*., PRL **93** (2004)162701.

Conditional Saddle Point Energy



56 MeV

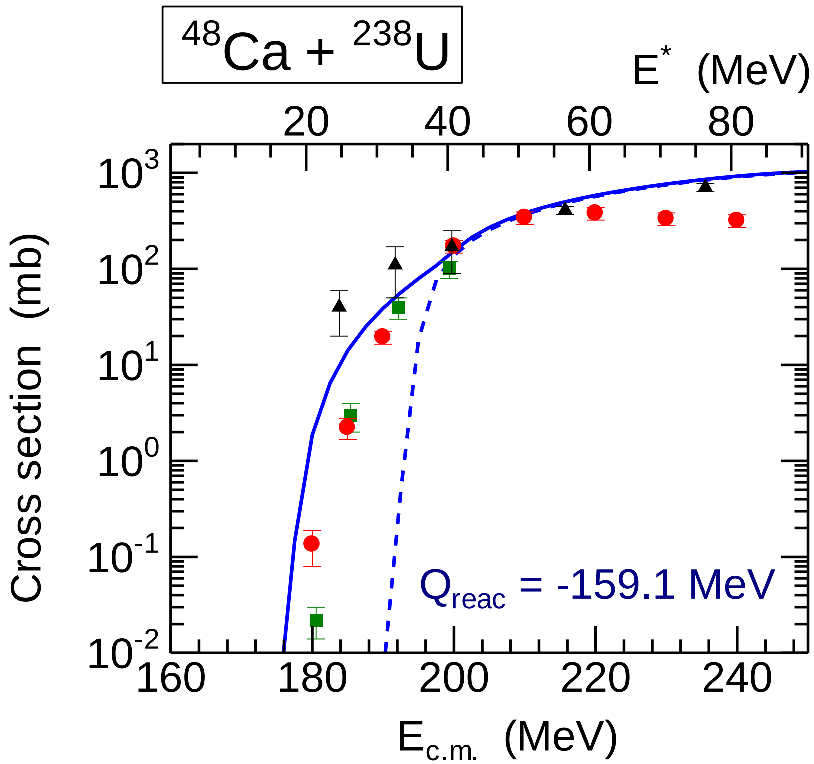
30 MeV

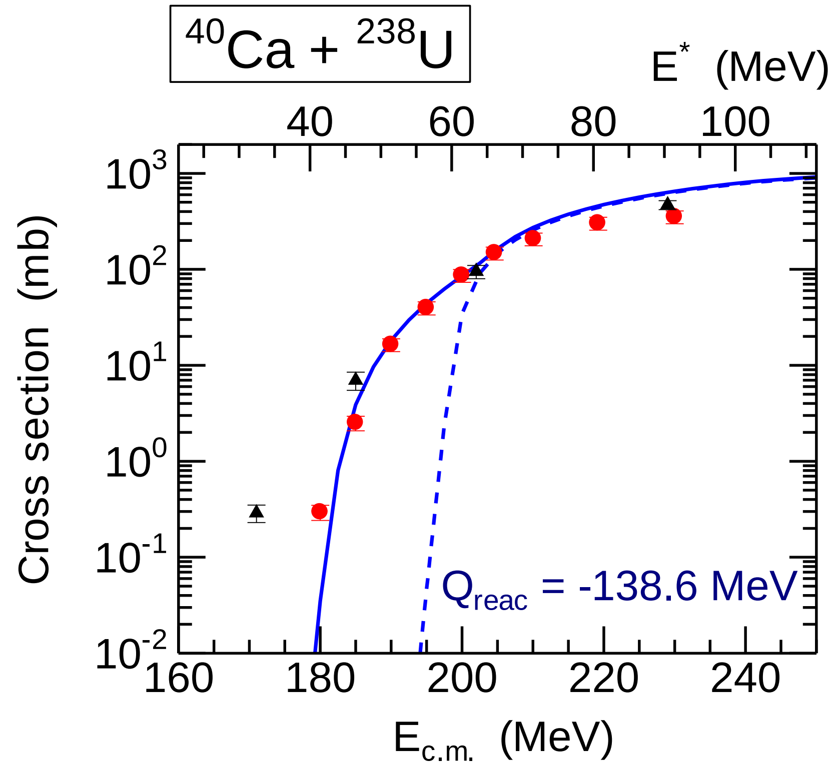
$$\alpha = \frac{A_H - A_L}{A_H + A_L}$$

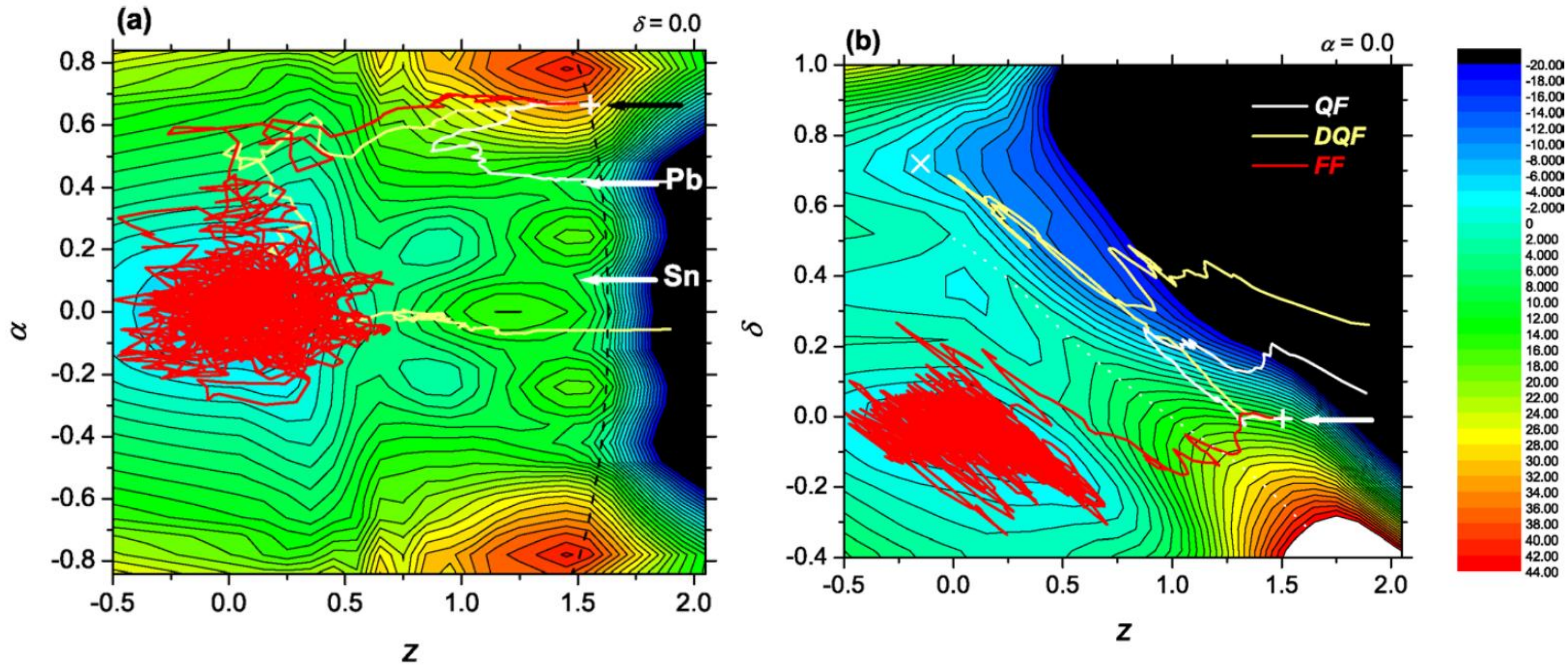
Mass Distribution and TKE for fission of $^{40,48}Ca + ^{238}U$

$^{48}Ca + ^{238}U = ^{286}Cn$

Q = -159.1 MeV

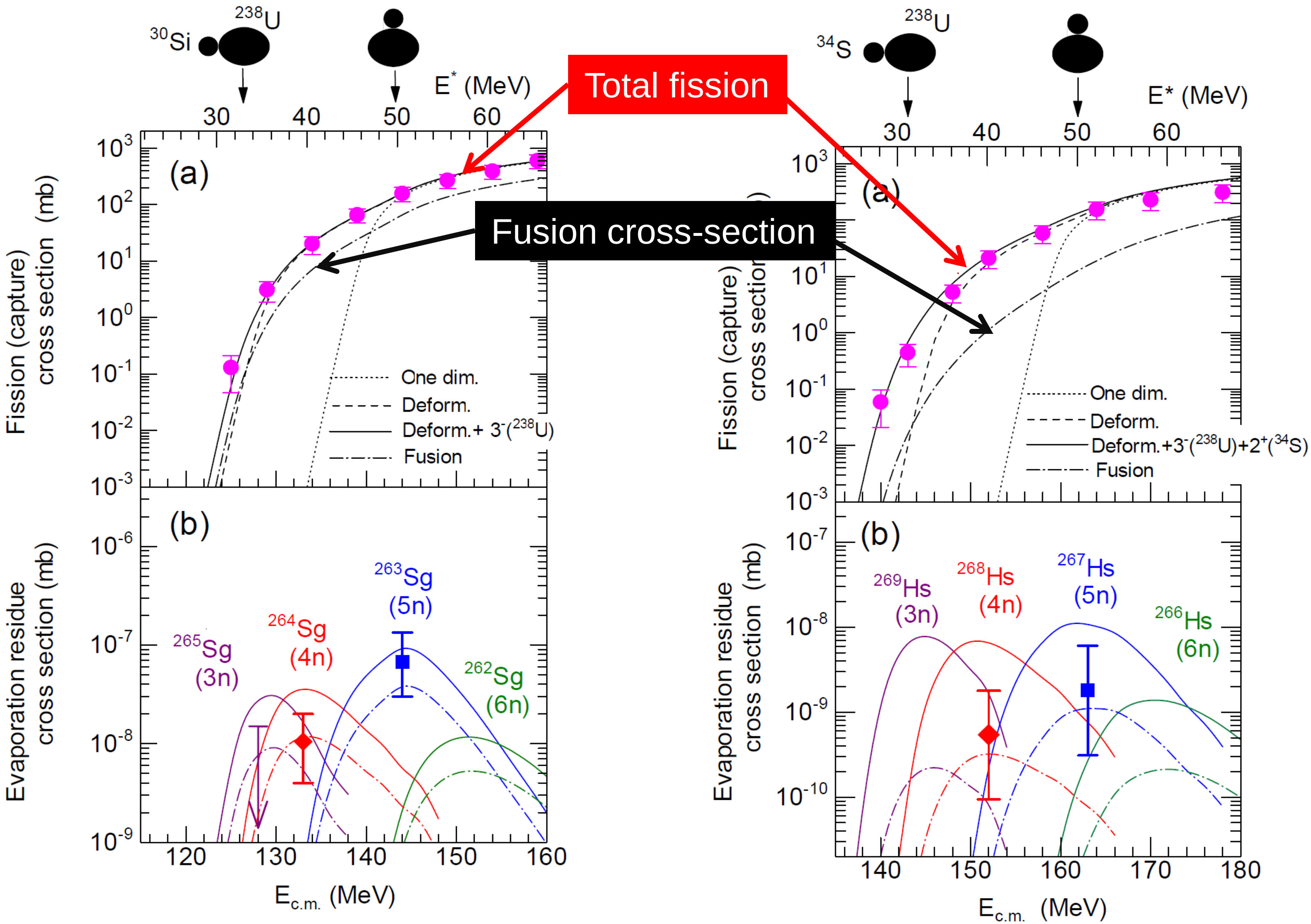






Y. Aritomo et al., Nucl.Phys. **A753**, 152 (2005).

Fusion and ER cross sections



K.Nishio *et al.*, Phys.Rev.C, **82**, 024611 (2010).

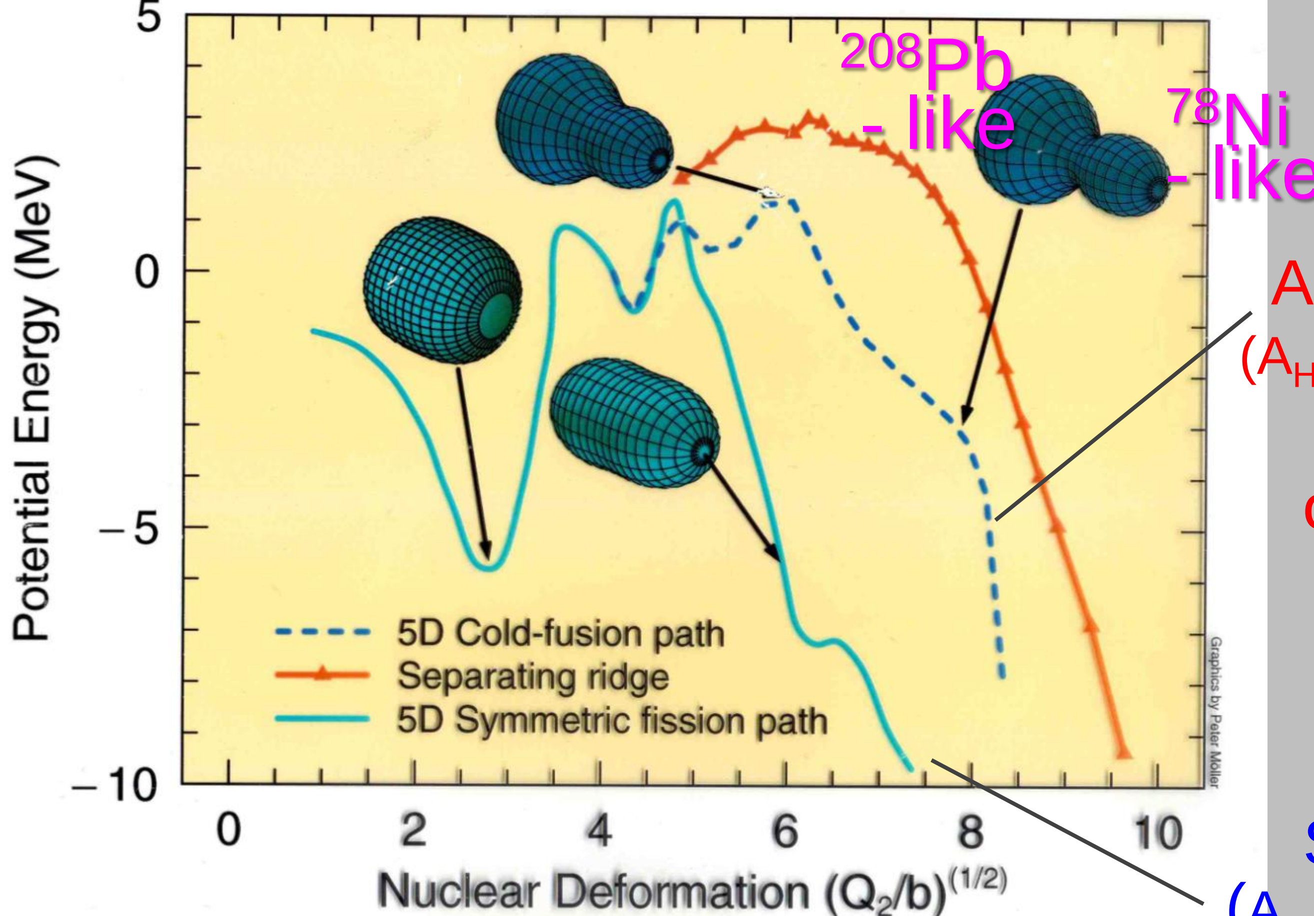
Fusion Probability

Fusion Probability at the *Bass* Barrier Energy calculated by *Langevin* equations

Reaction	P_{fus}
$^{34}S + ^{238}U$	0.096
$^{34}S + ^{244}Pu$	0.079
$^{34}S + ^{248}Cm$	0.057

Potential Energy for ^{274}Hs (^{36}S + ^{238}U)

5-dimensional deformation space



ASymmetric

$(A_H, A_L) = (202, 72)$

$$\alpha = \frac{A_H - A_L}{A_H + A_L}$$

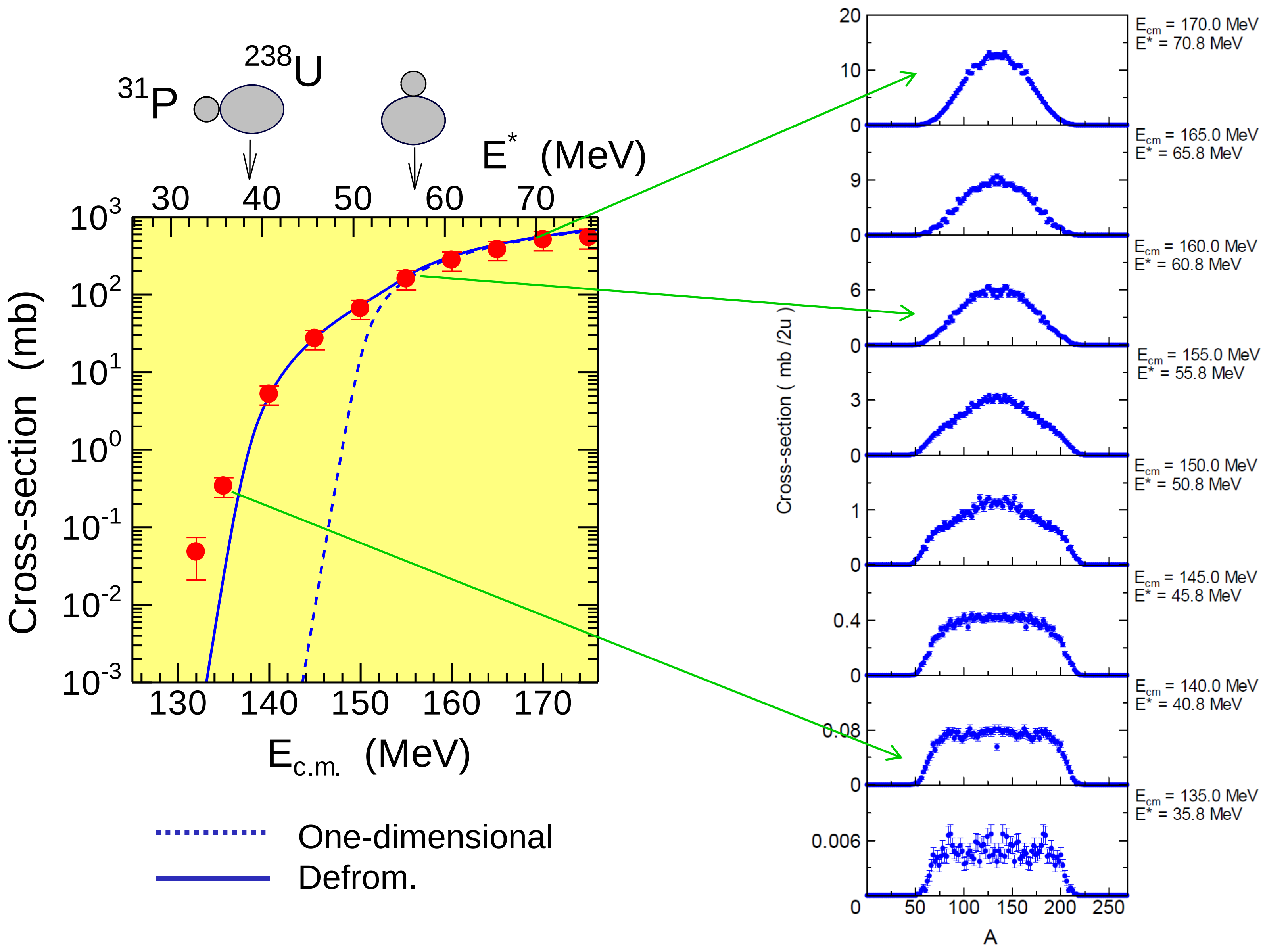
$= 0.47$

Symmetric

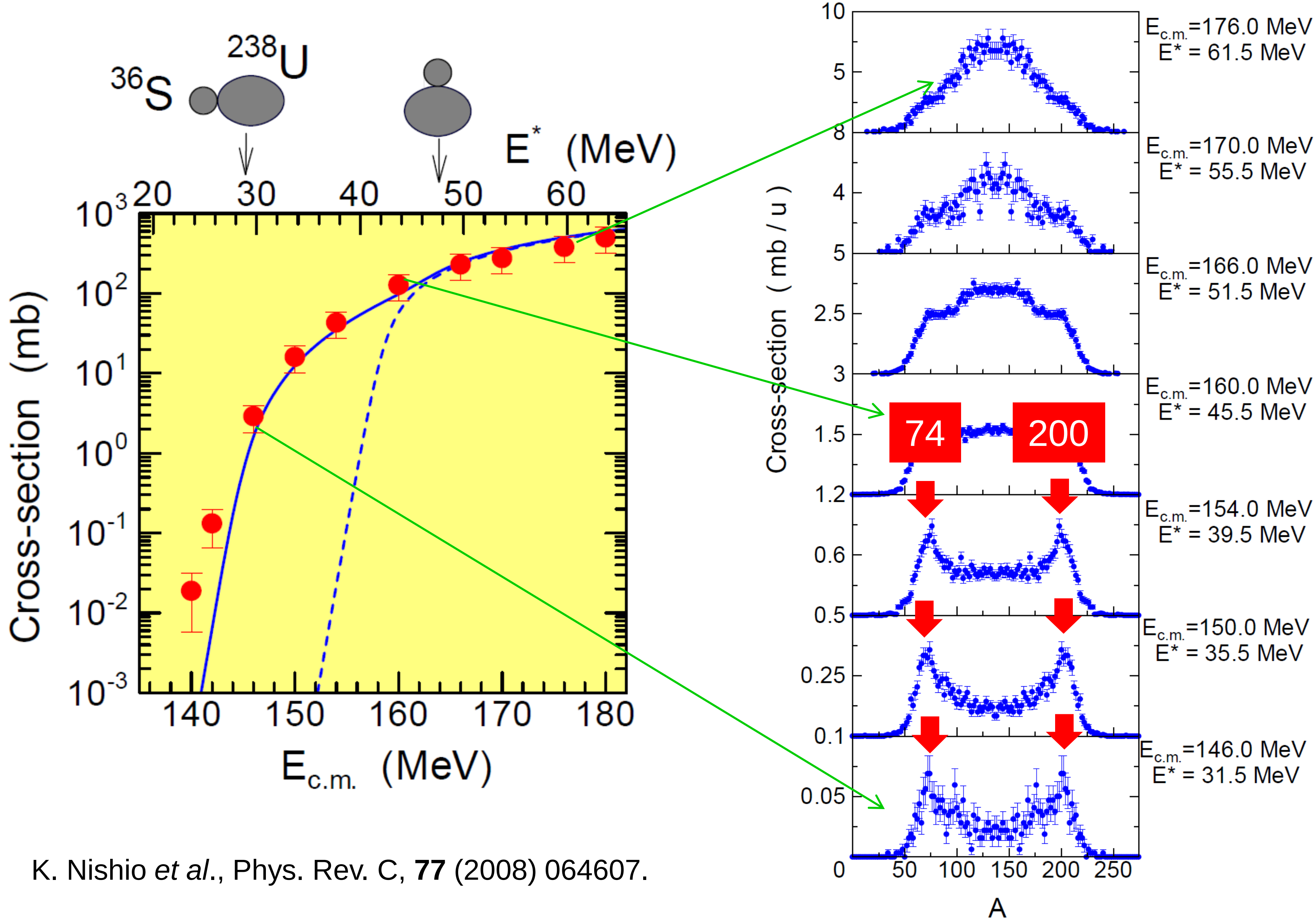
$(A_H, A_L) = (137, 137)$

Calculated by P. Möller of LANL

Fragment mass distributions for $^{31}P + ^{238}U \rightarrow ^{269}Mt$ (Z=107)

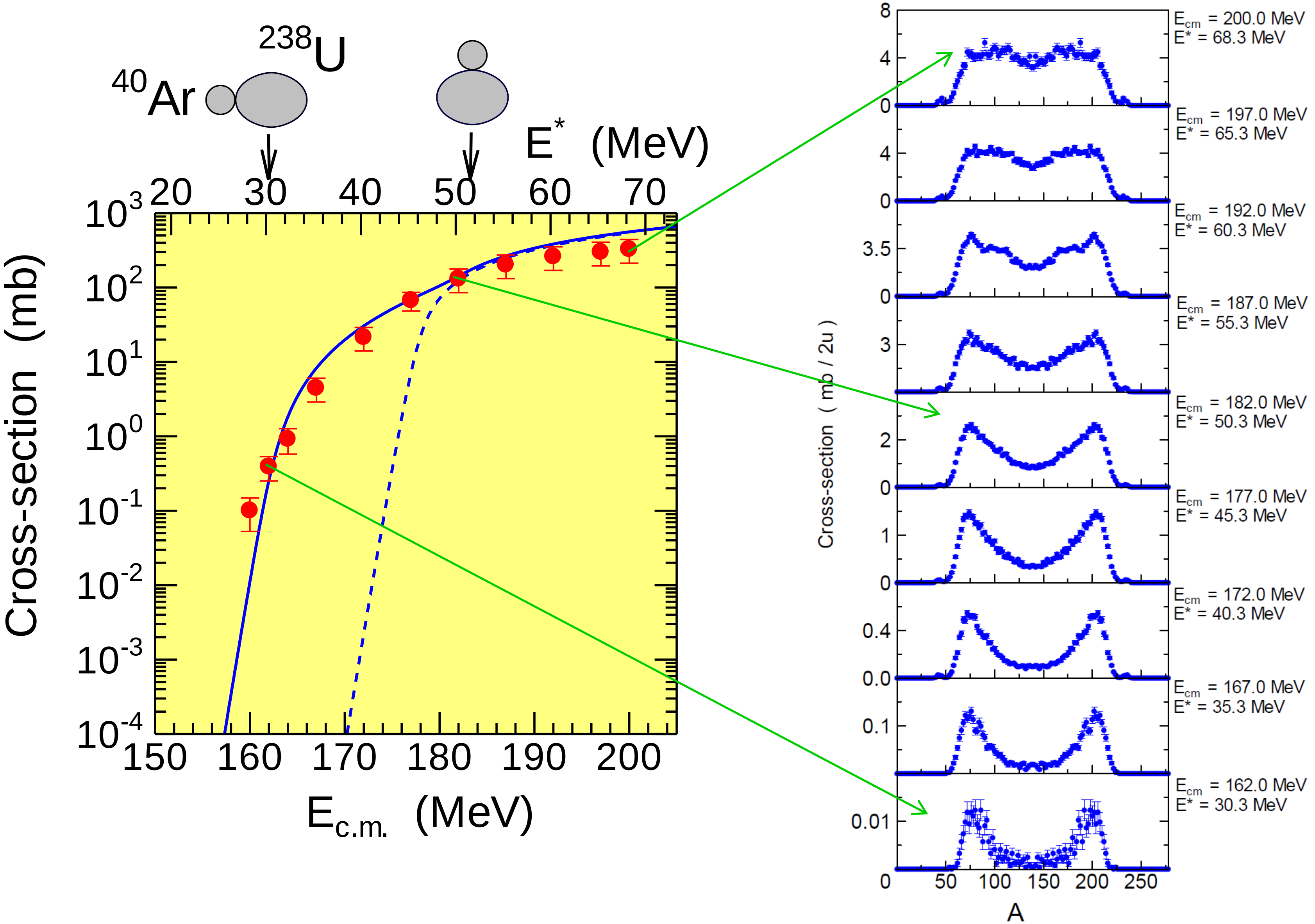


Fragment mass distributions for $^{36}S + ^{238}U \rightarrow ^{274}Hs$ (Z=108)

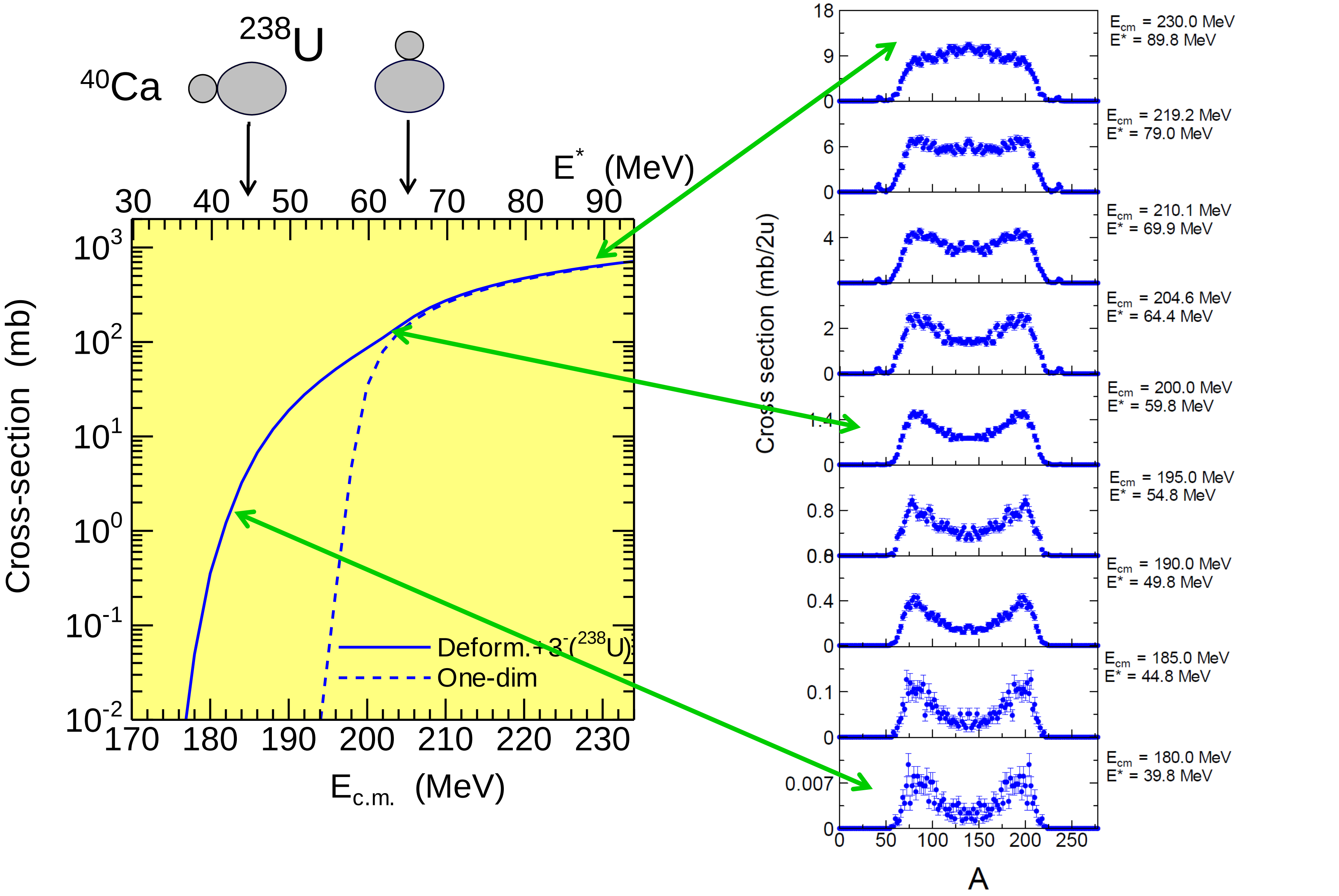


K. Nishio *et al.*, Phys. Rev. C, **77** (2008) 064607.

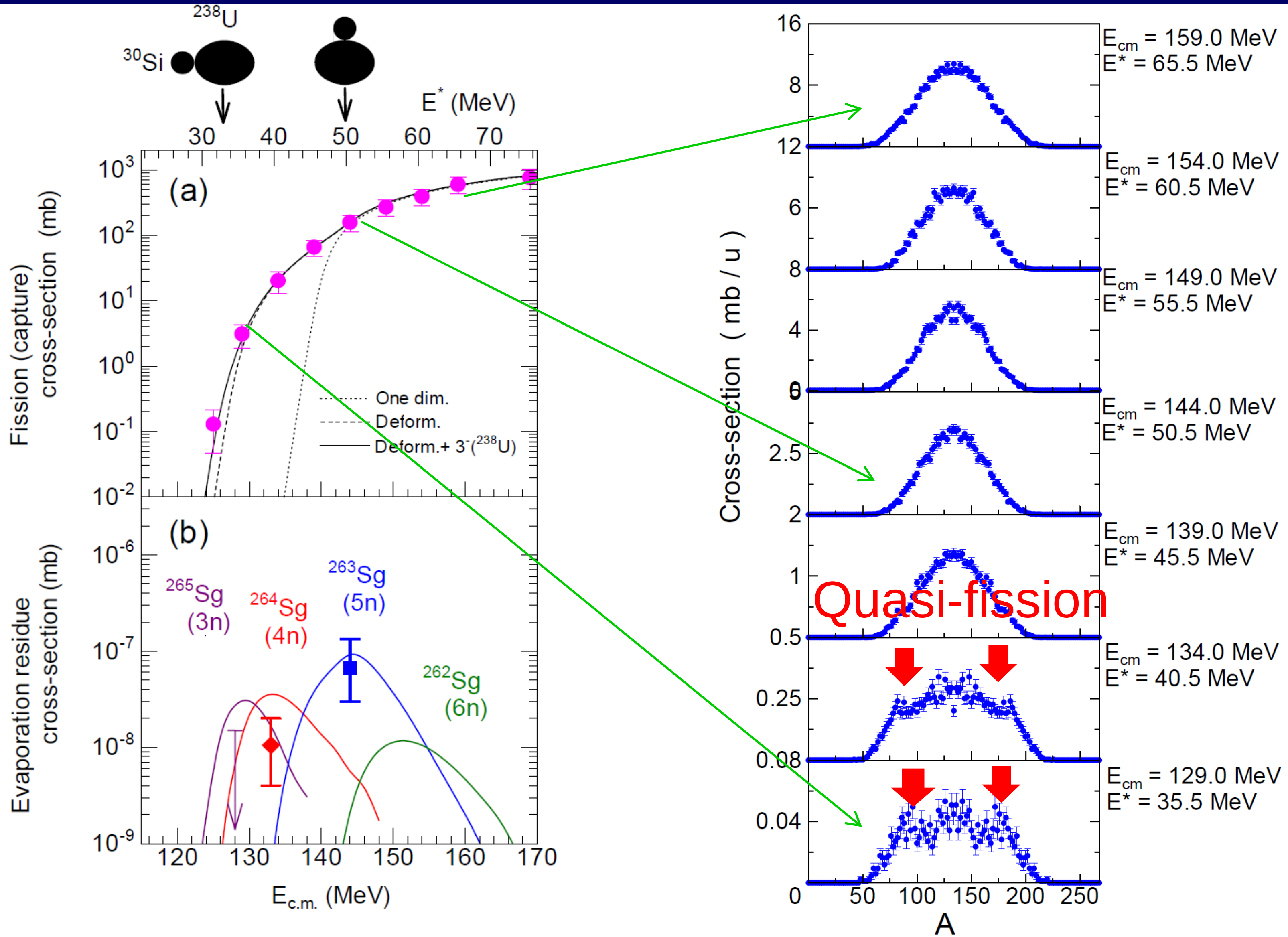
Fragment mass distributions for $^{40}Ar + ^{238}U \rightarrow ^{278}Ds$ (Z=110)



Fragment mass distributions for $^{40}Ca + ^{238}U \rightarrow ^{278}Cn$ (Z=112)



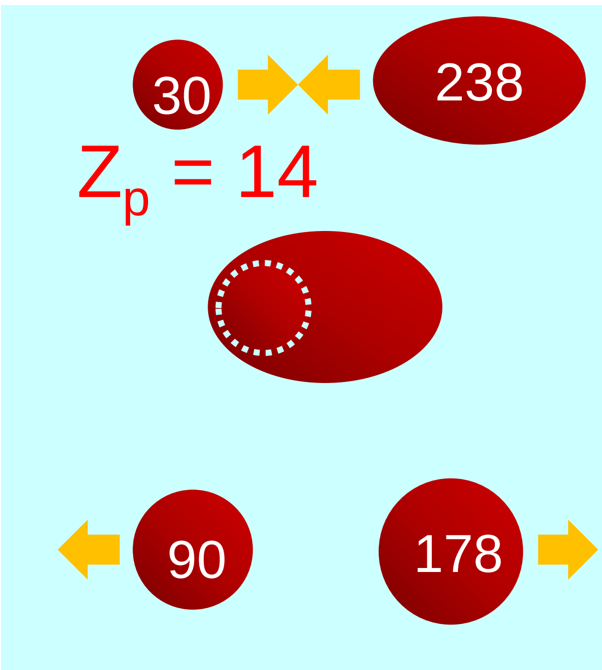
$^{30}Si + ^{238}U \rightarrow ^{268}Sg$ (Z=106)

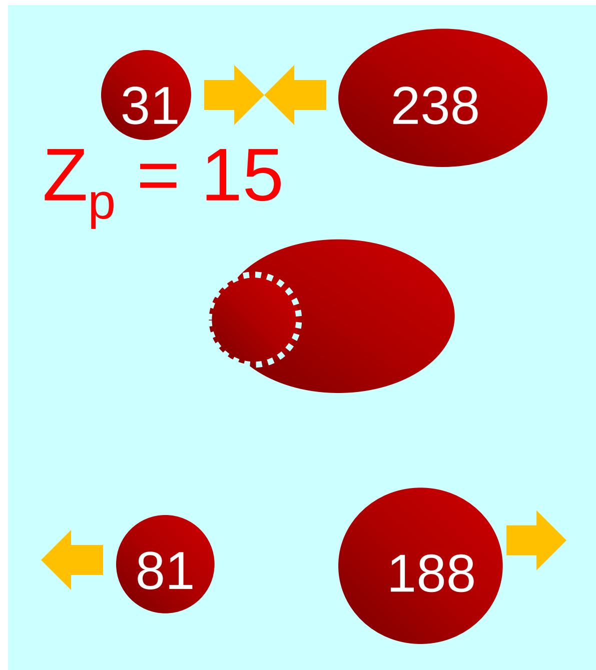


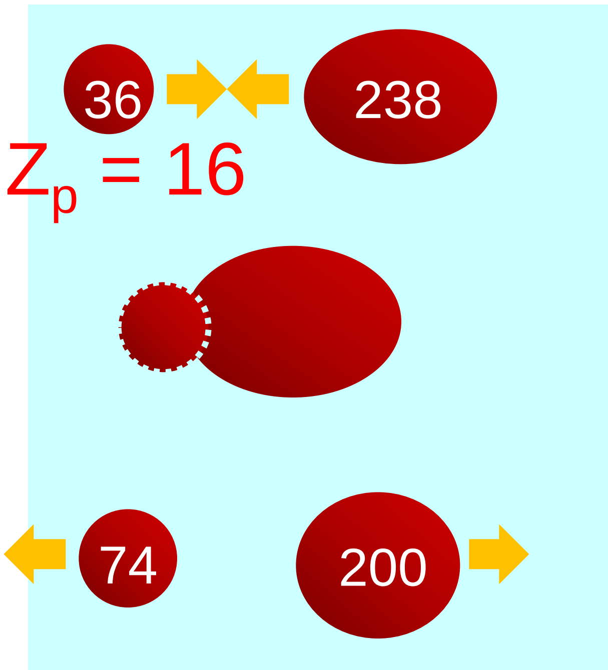
K. Nishio *et al.*, Phys.Rev.C, **82**, 044604 (2010).

Mass Asymmetry in Quasifission

$^{30}\mathrm{Si} + {}^{238}\mathrm{U} \rightarrow {}^{268}\mathrm{Sg}$ $^{31}\mathrm{P} + {}^{238}\mathrm{U} \rightarrow {}^{269}\mathrm{Mt}$ $^{36}\mathrm{S} + {}^{238}\mathrm{U} \rightarrow {}^{274}\mathrm{Hs}$





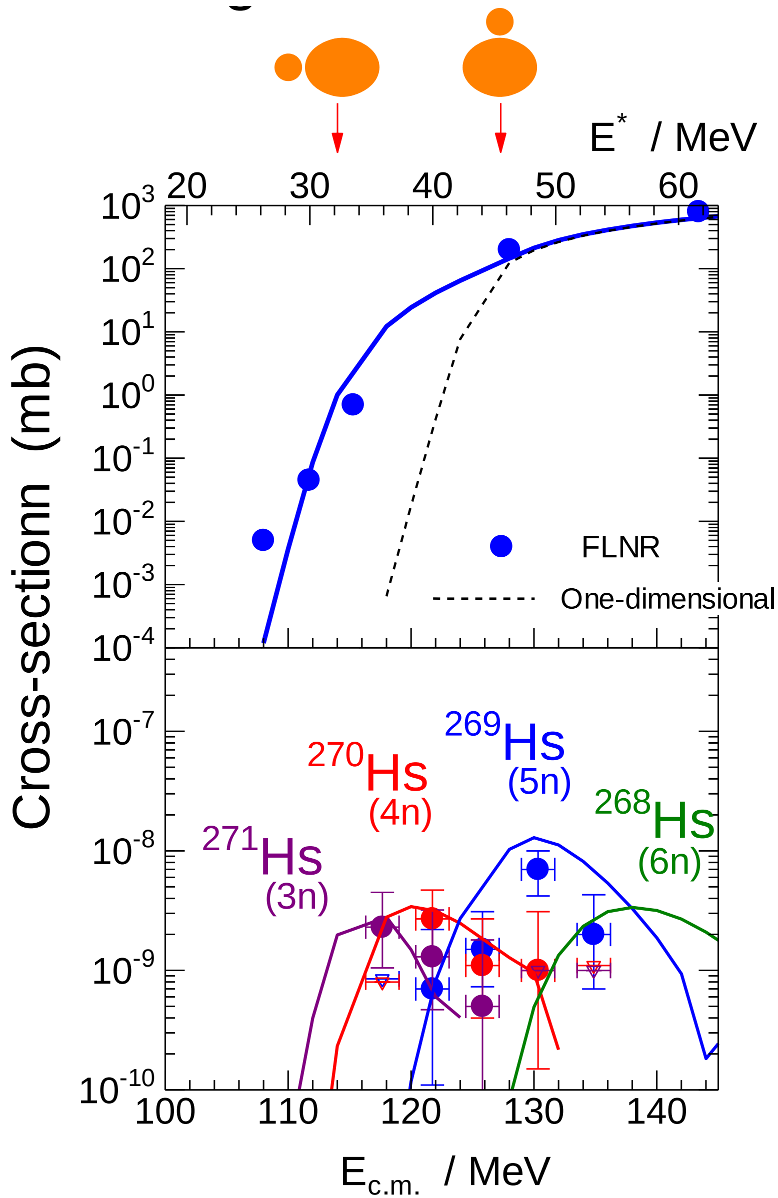


60 nucleons exchanged

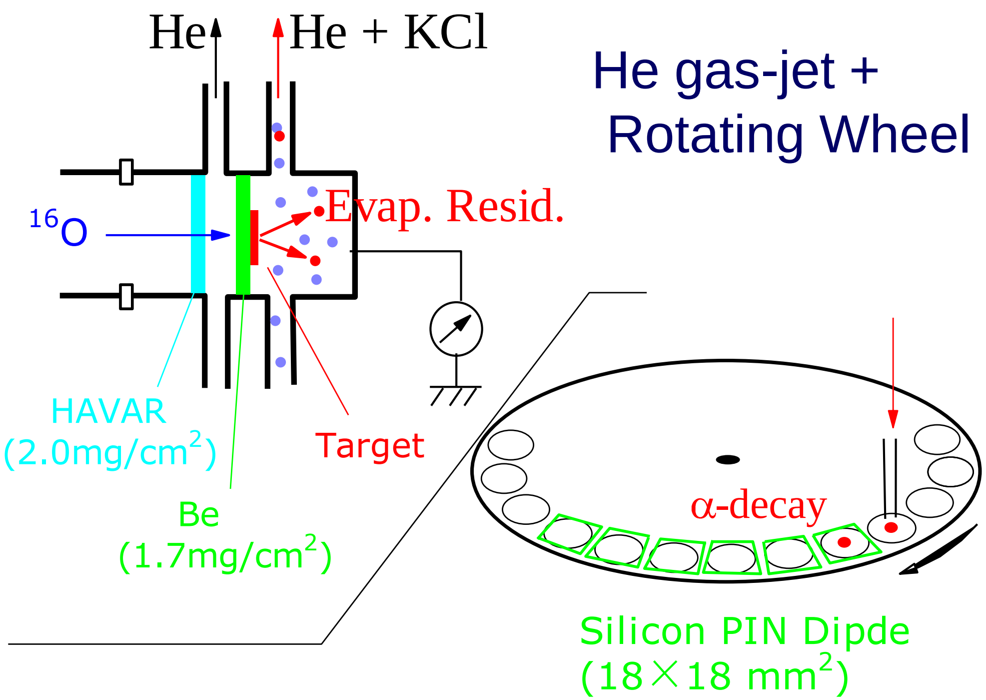
50 nucleons exchanged

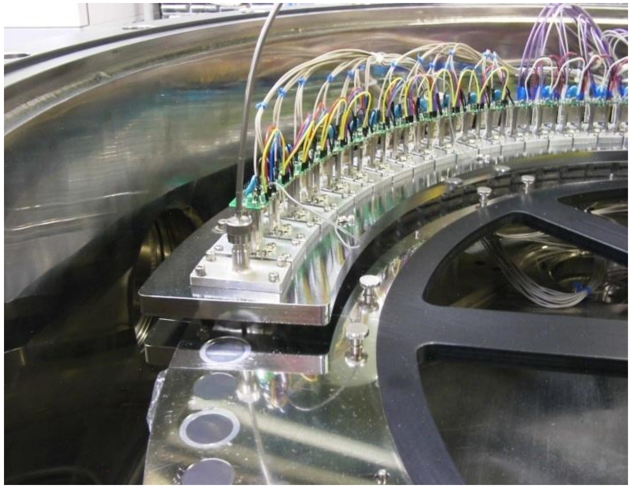
38 nucleons exchanged

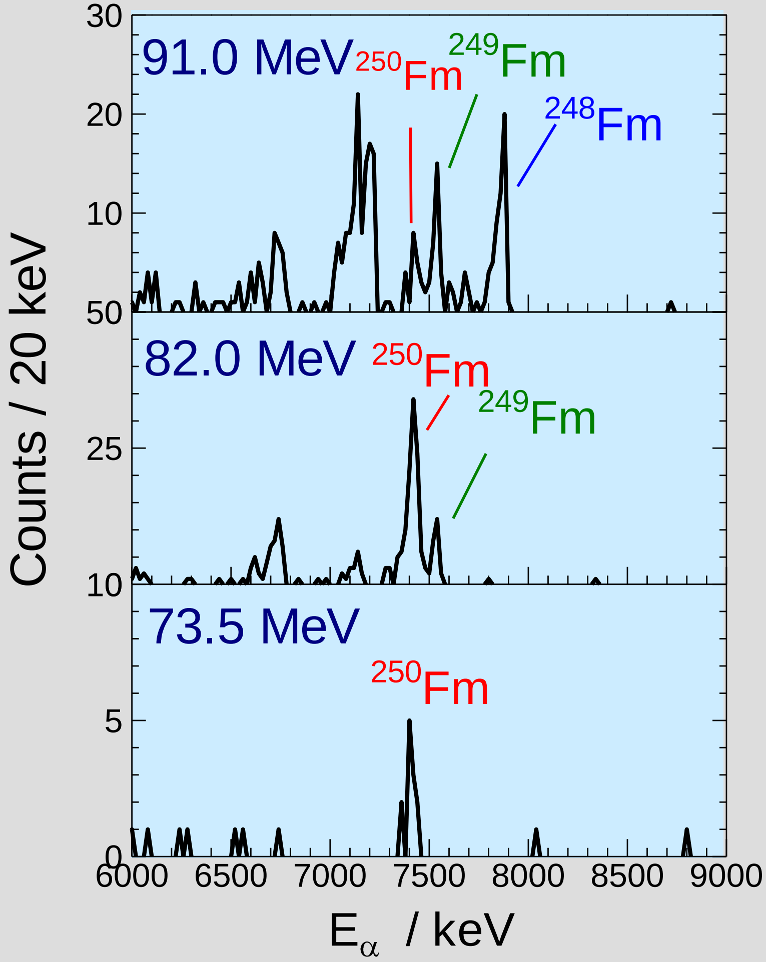
Fission and ER cross-sections for $^{26}Mg + ^{248}Cm$



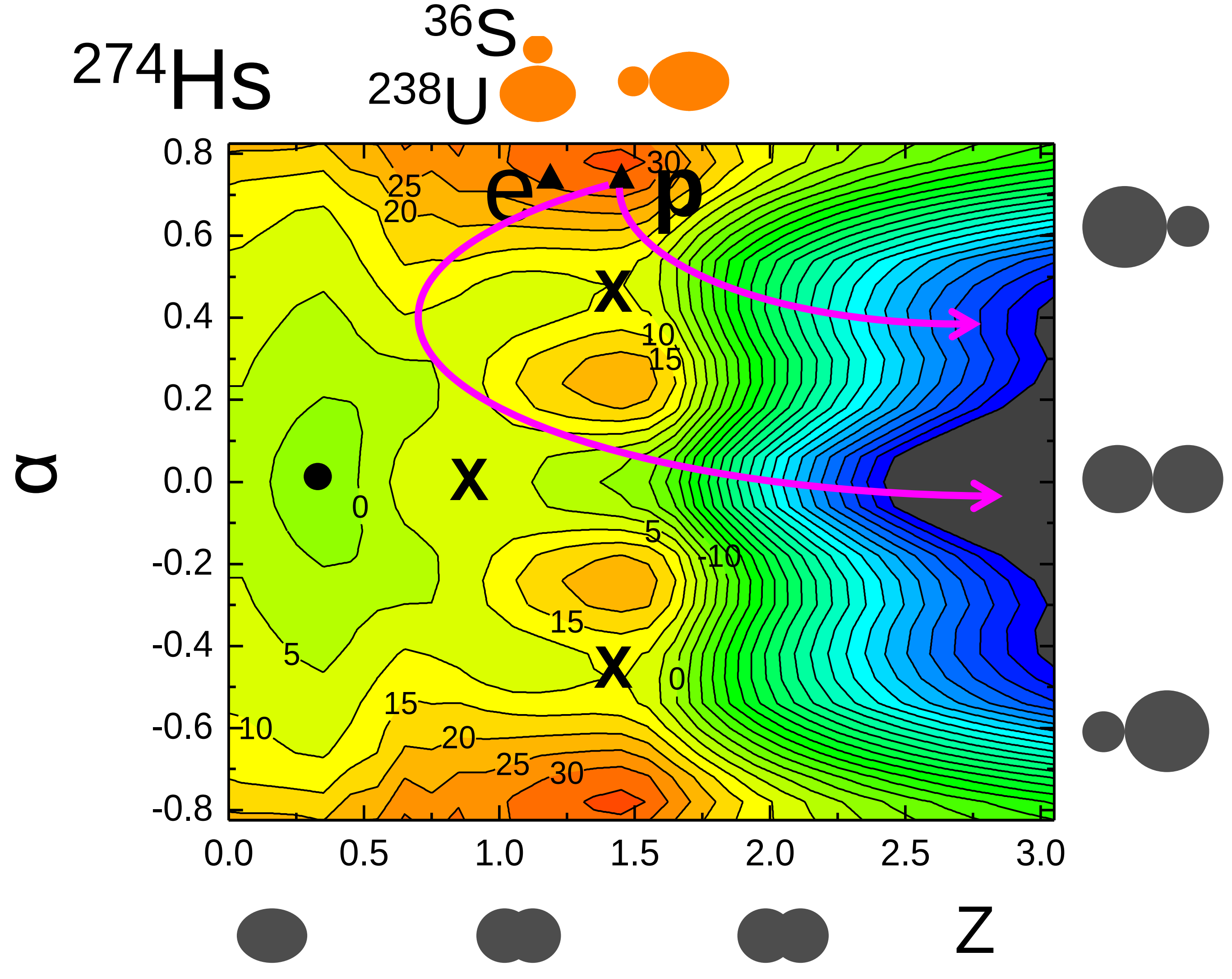
Measurement of ER cross-sections for ^{16}O + ^{238}U at JAEA tandem facility







Trajectory Calculation at sub-barrier energy using Langevin Equation



V.Zagrebaev and W.Greiner, J.Phys.G, **31**, 825 (2005).
Y.Aritomo, Phys.Rev. C, **80**, 064604 (2009).