Heavy-ion Fusion and Fission Study at JAEA

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A. Andreyev, D. Jenkins

S. Hofmann, D. Ackermann, F.P. Heßberger, S. Heinz, J. Khuyagbaatar, B. Kindler, V.F.Comas J.A. Heredia, I. Kojouharov, B. Lommel, R. Mann, B. Sulignano, Ch.E. Düllmann, M.Schädel

S. Chiba

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Y. Aritomo

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Tokai Campus, JAEA
Tokyo
J-PARC
Tandem facility

Experimental Nuclear Physics Program at JAEA

Tandem Facility

- Fusion-Fission Study for Heavy-element Synthesis
- Multi-nucleon transfer-induced Fission and Surrogate Reaction
- Structure study for nuclei around ^{100}Sn using JAEA Recoil Mass Separator

J-PARC

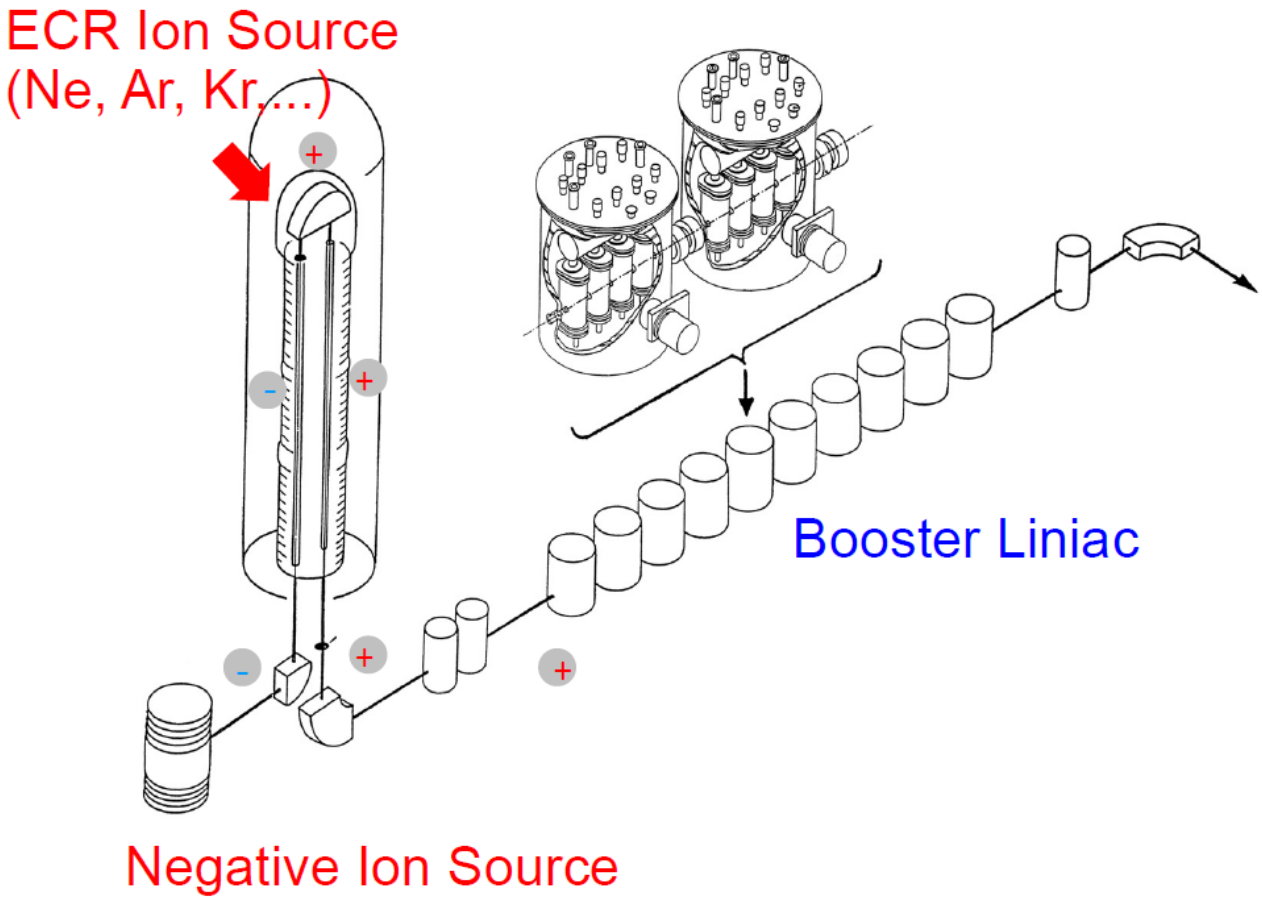
- Neutron TOF measurement for fission and neutron-capture study

Contribution to Fukushima Issues

- New surveillance detector for criticality of melted fuel at Fukushima power plant.

JAEA Tandem facility

20 MV Tandem accelerator (20UR)
Super-conducting Booster Liniac
ECR Ion Source on the terminal



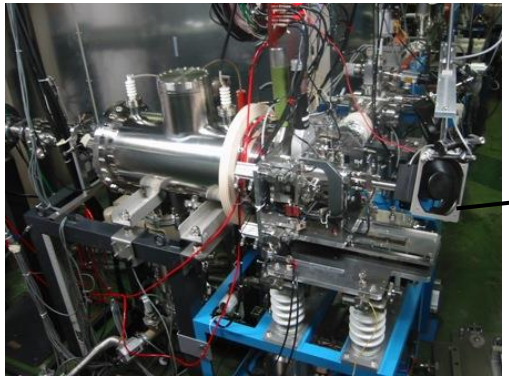
Magnetic Spectrometer

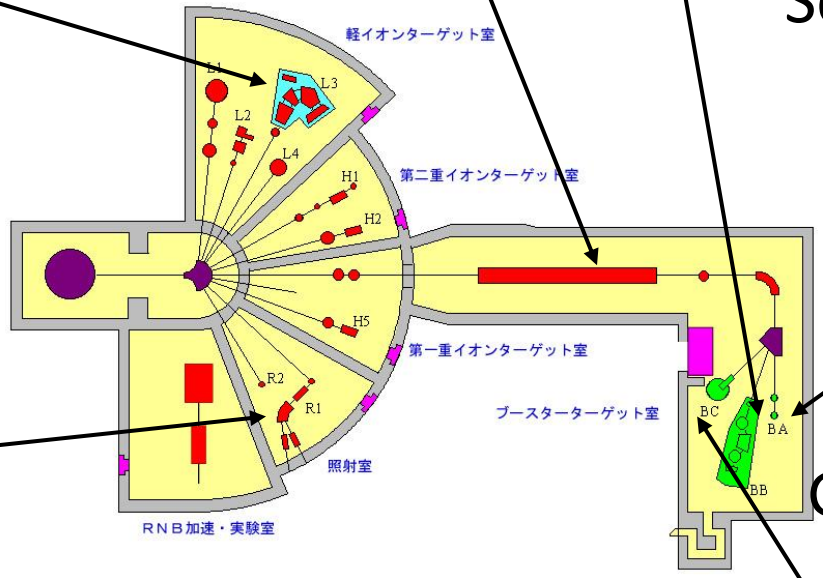
Booster Liniac

Recoil Mass Separator

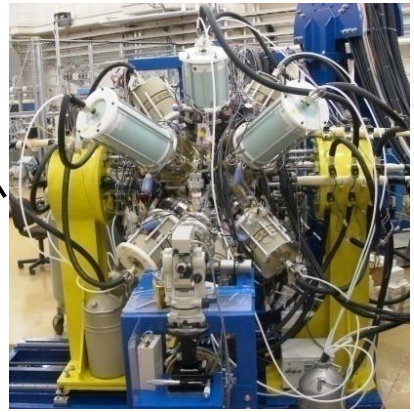
Scattering Chamber

ISOL (p + ^{238}U)





Ge-detector array

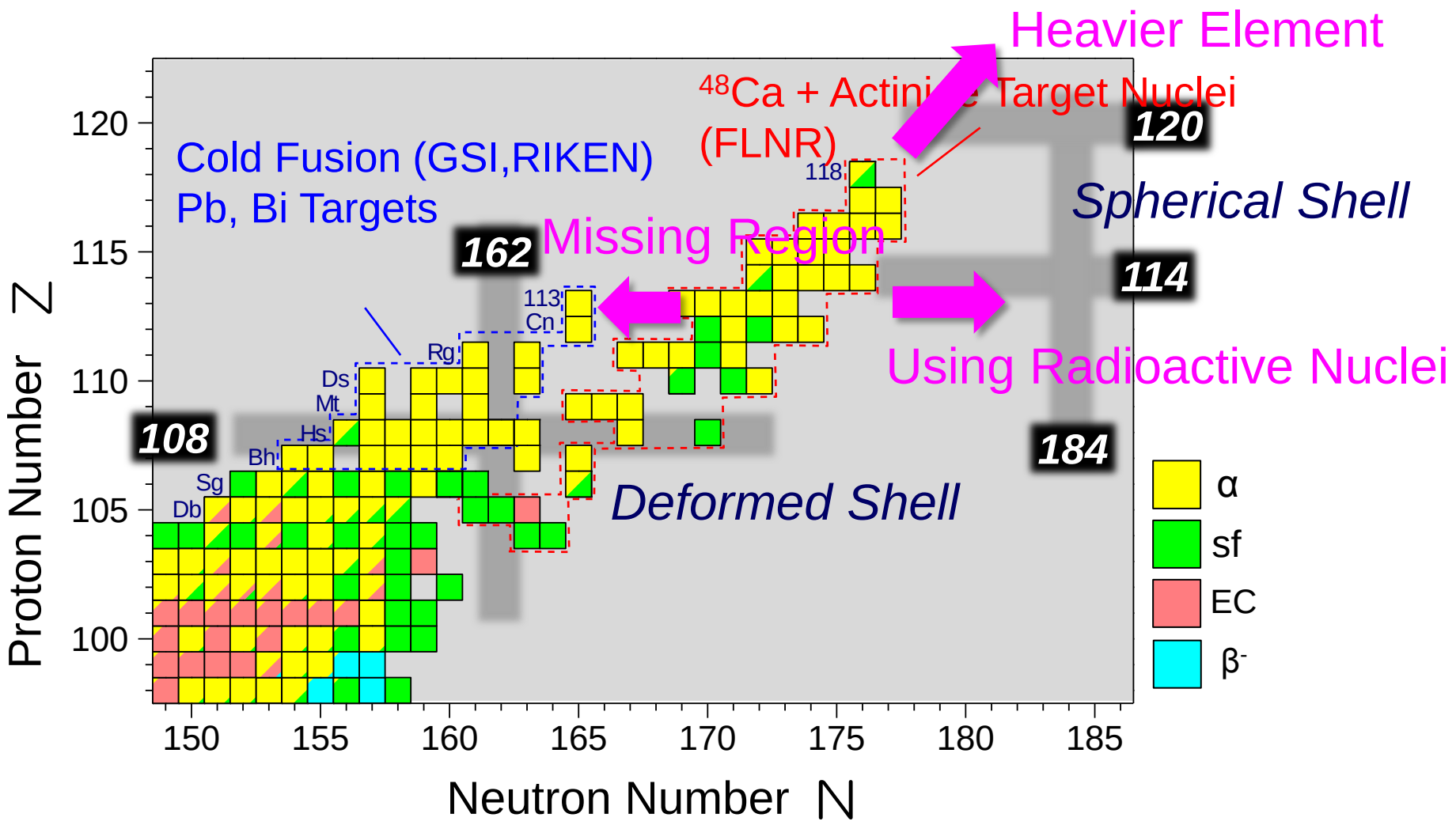


Radioactive target materials can be used

Th, U, Np, Pu, Np, Am, Cm, Cf

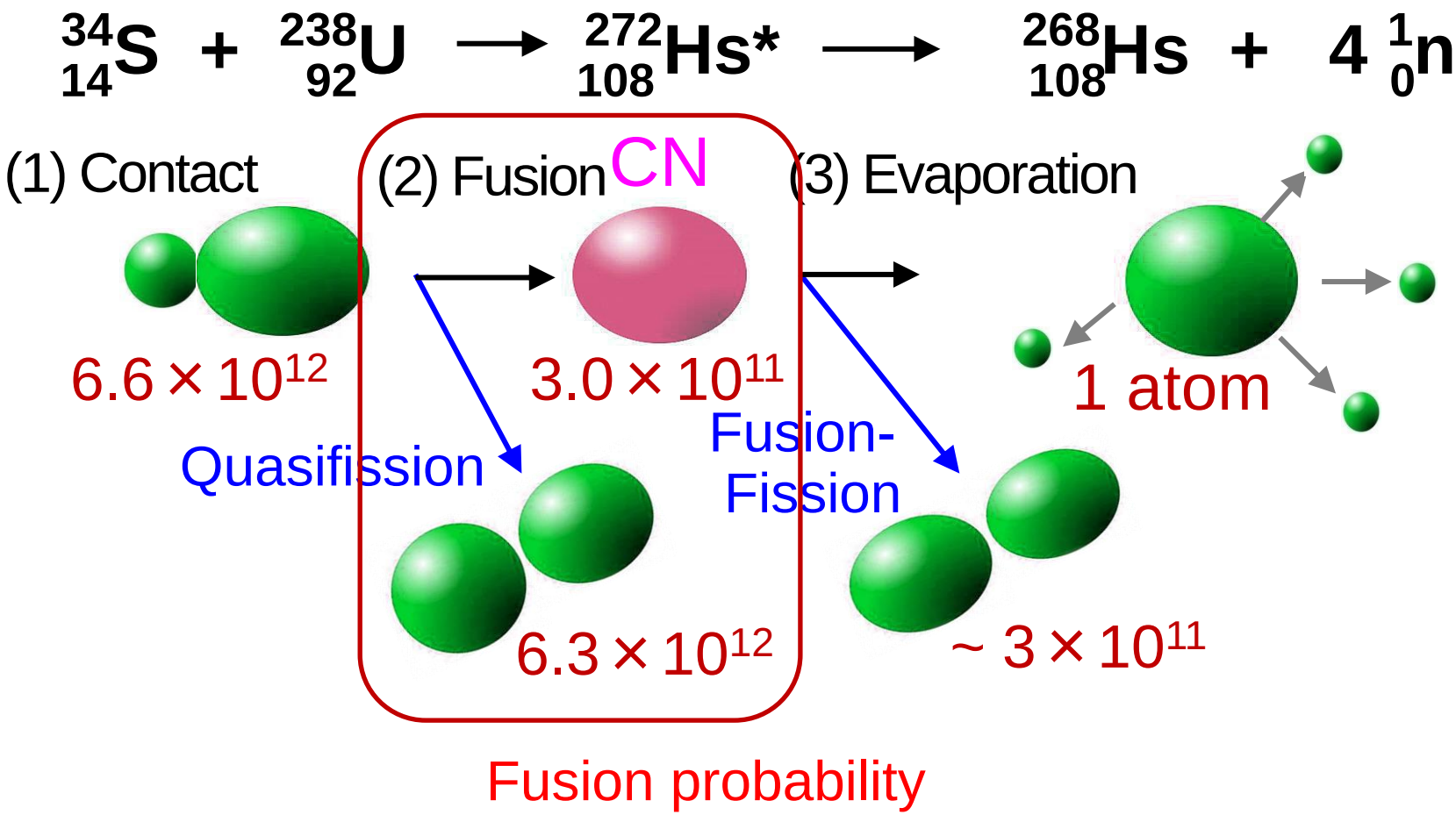
Fusion-Fission Study for Heavy Element Synthesis

Super-heavy Nuclei



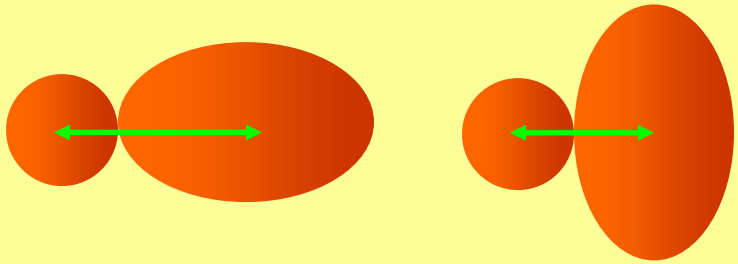
Understanding for fusion using actinide target nuclei are important to explore SHN

Three steps for heavy-element synthesis



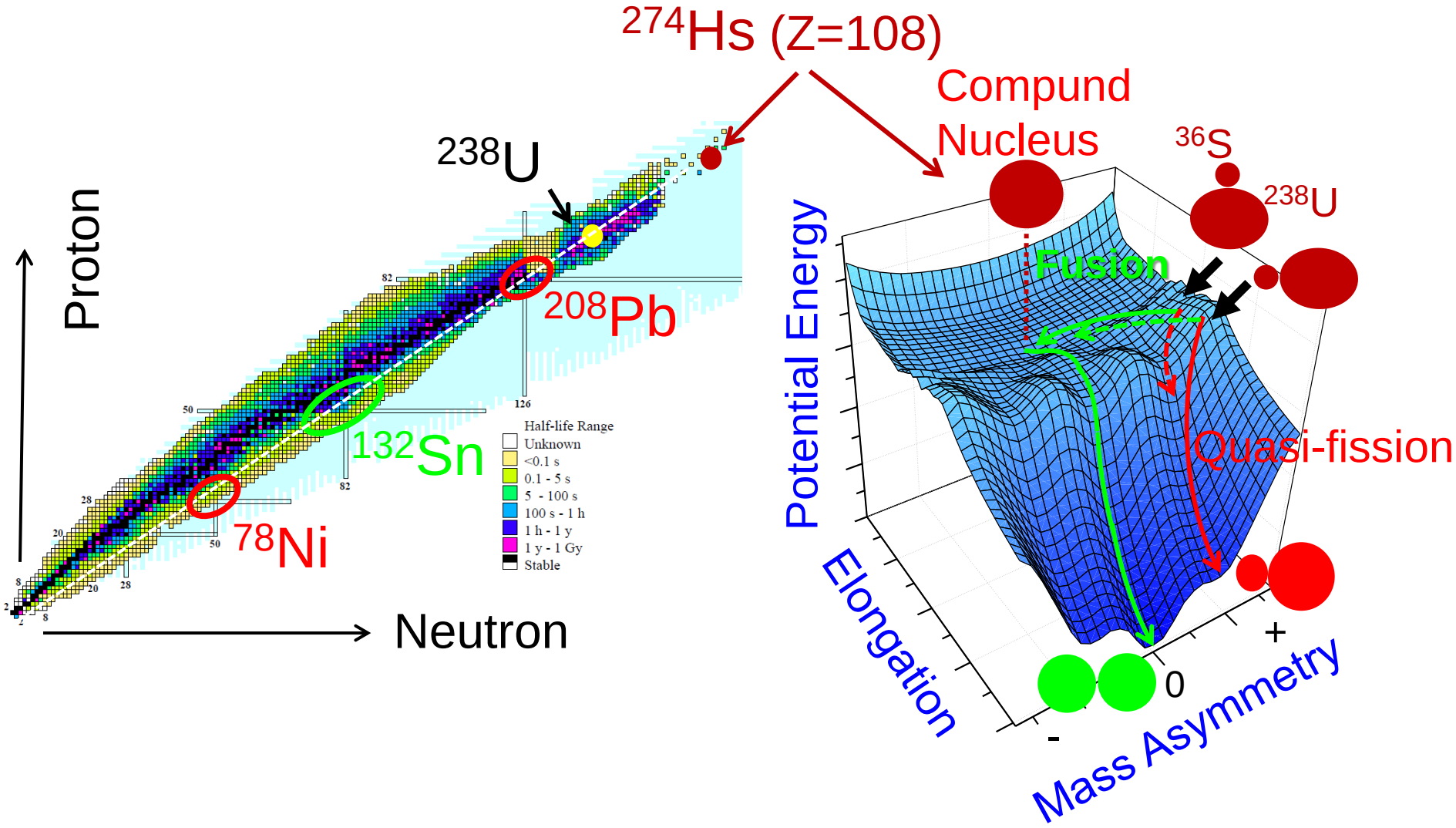
Effects of Nuclear Deformation on Fusion

Orientation effects of target nucleus



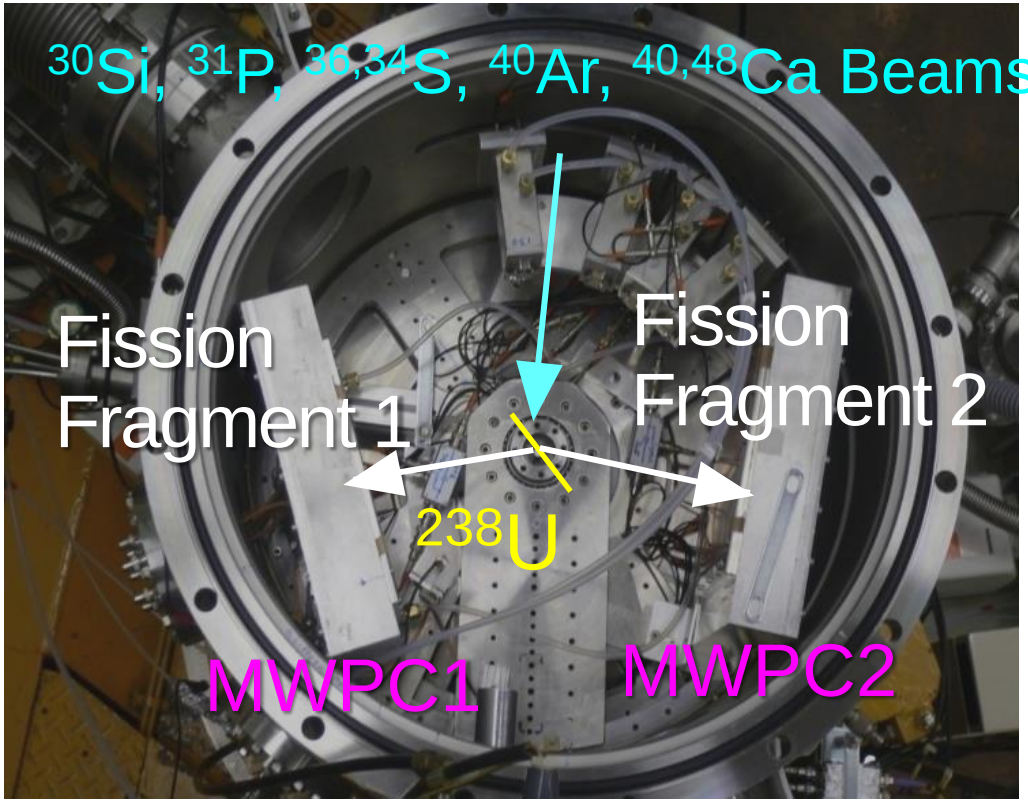
Polar	Equatorial
Low energy	High energy
(sub-barrier)	(above barrier)

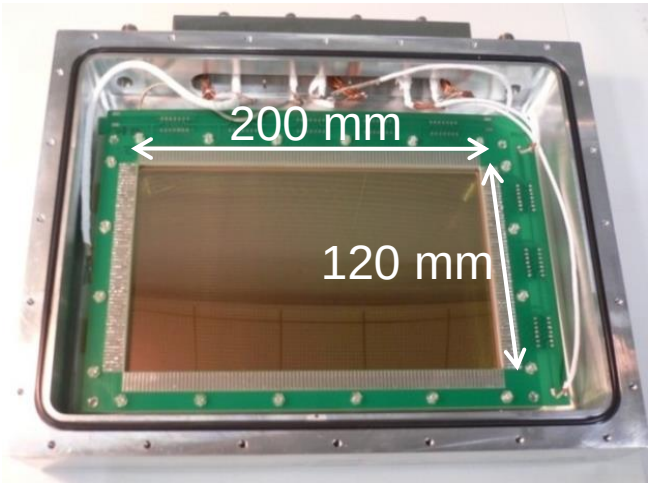
Fusion-fission and Quasi-fission



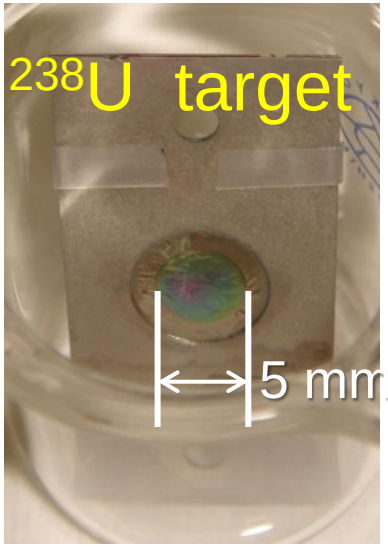
Potential by Y. Aritomo

In-Beam Fission Measurement



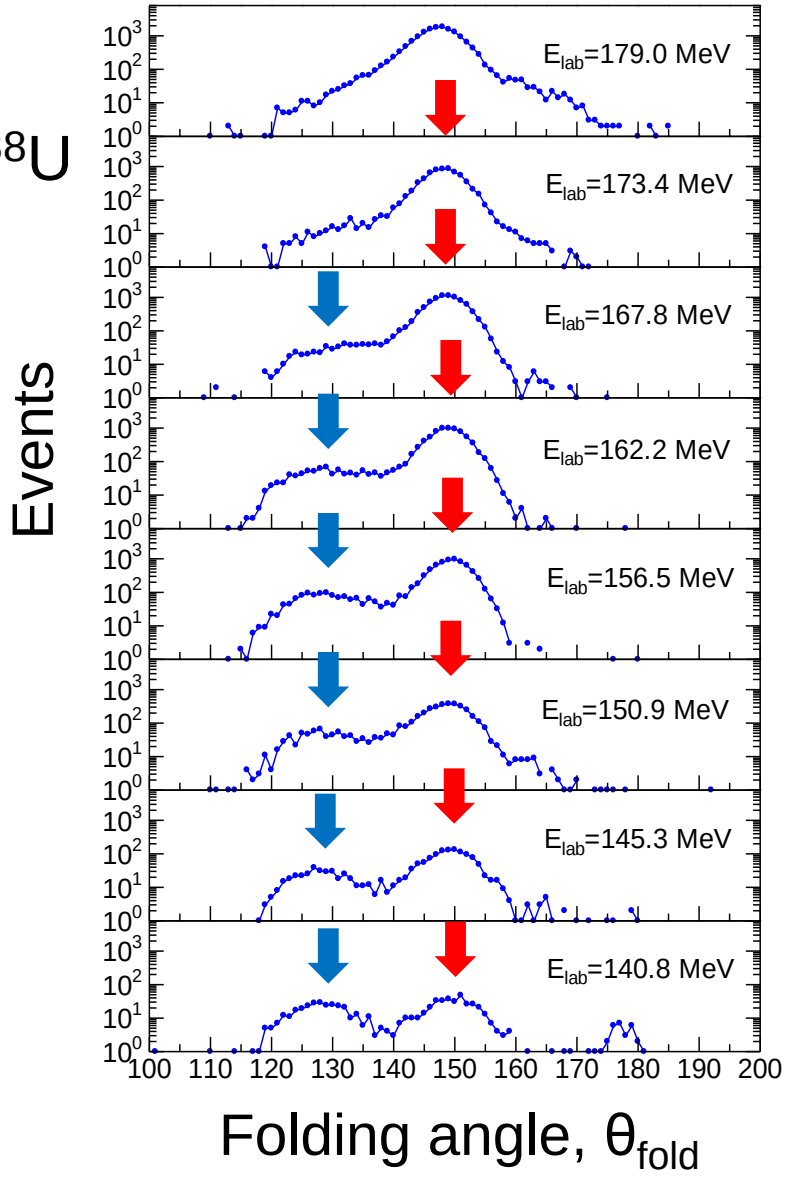


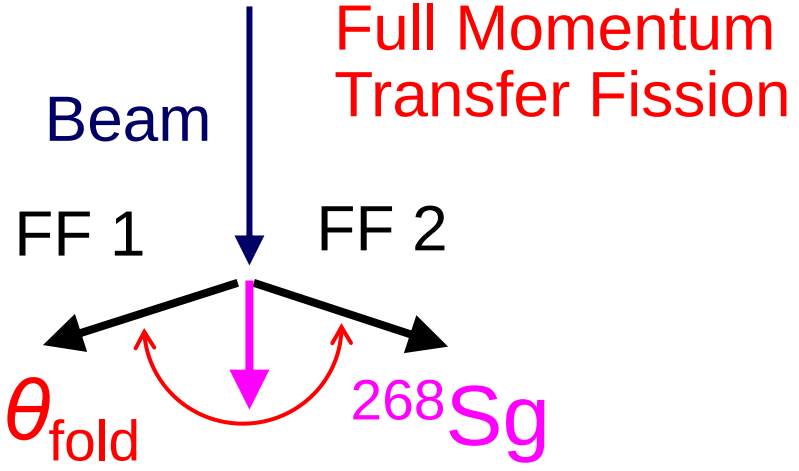
Multi-Wire Proportional Counter

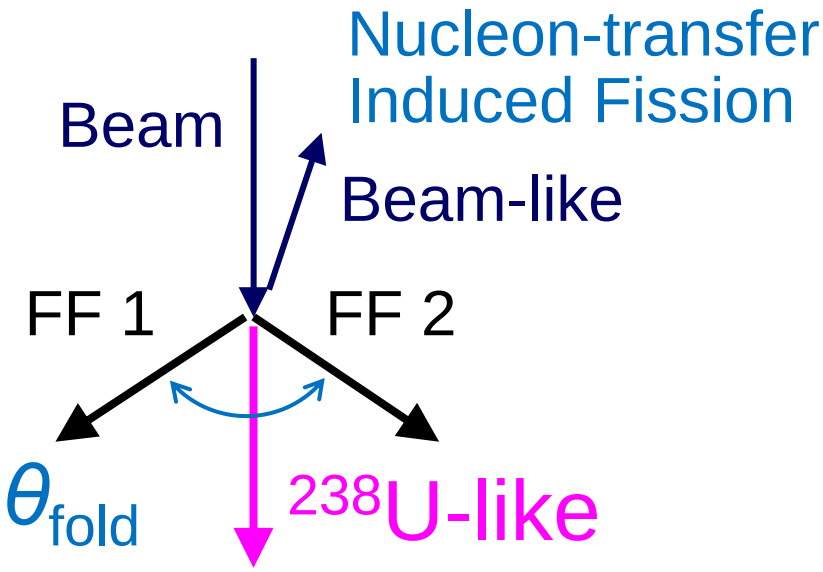


Folding Angle Distribution

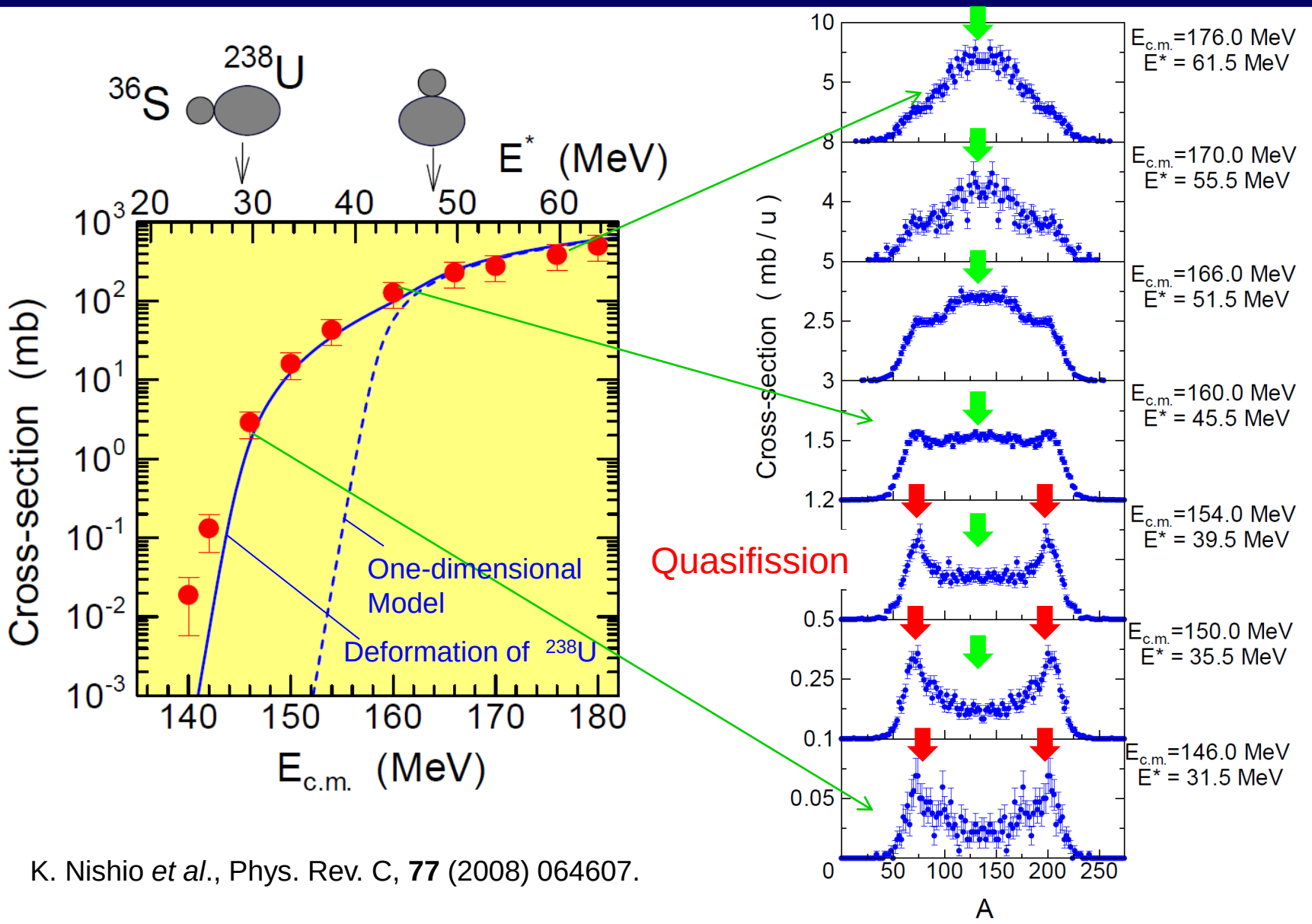
$^{30}Si + ^{238}U$





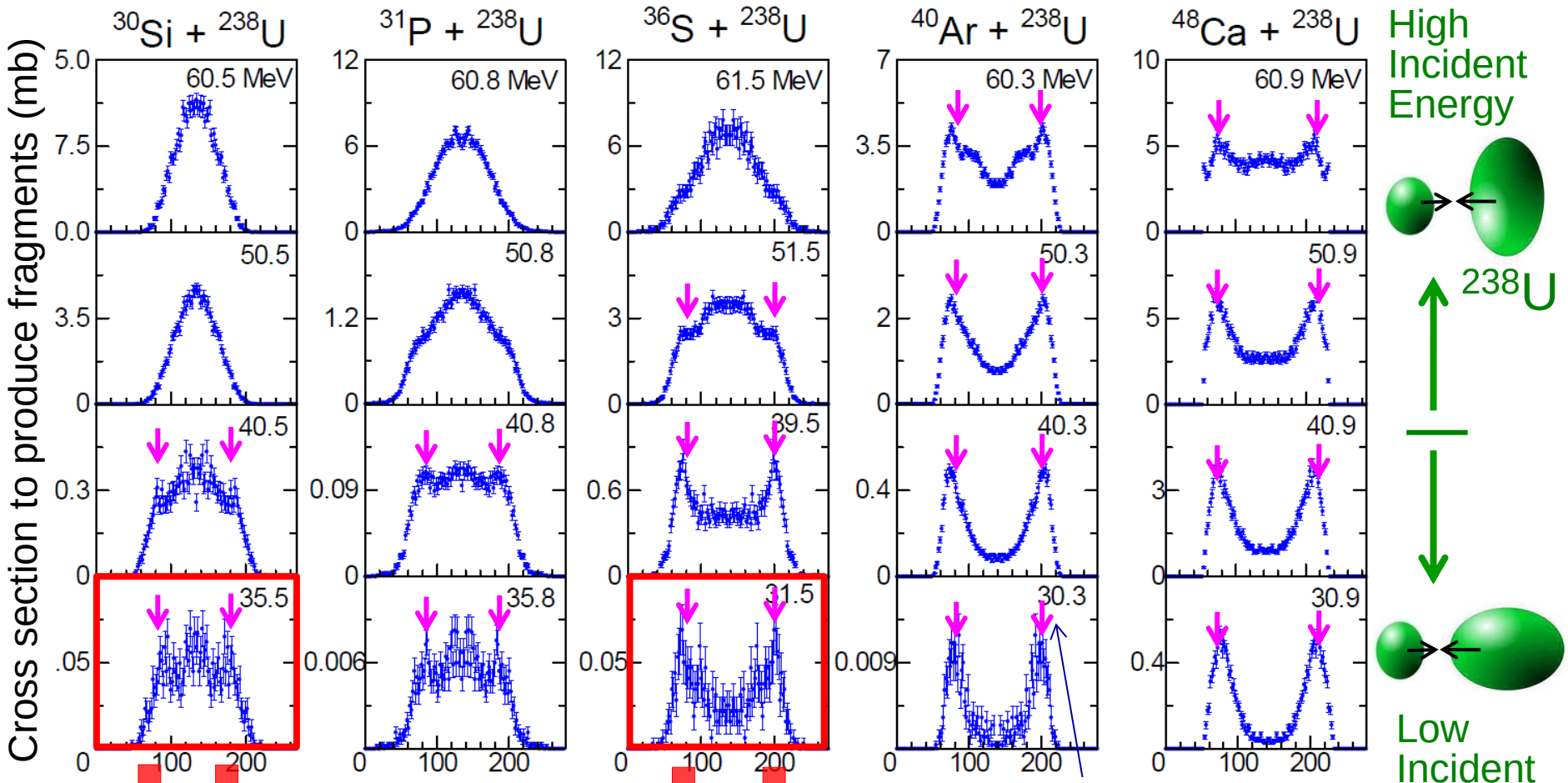


Orientation effects on fragment mass distributions in $^{36}S + ^{238}U$



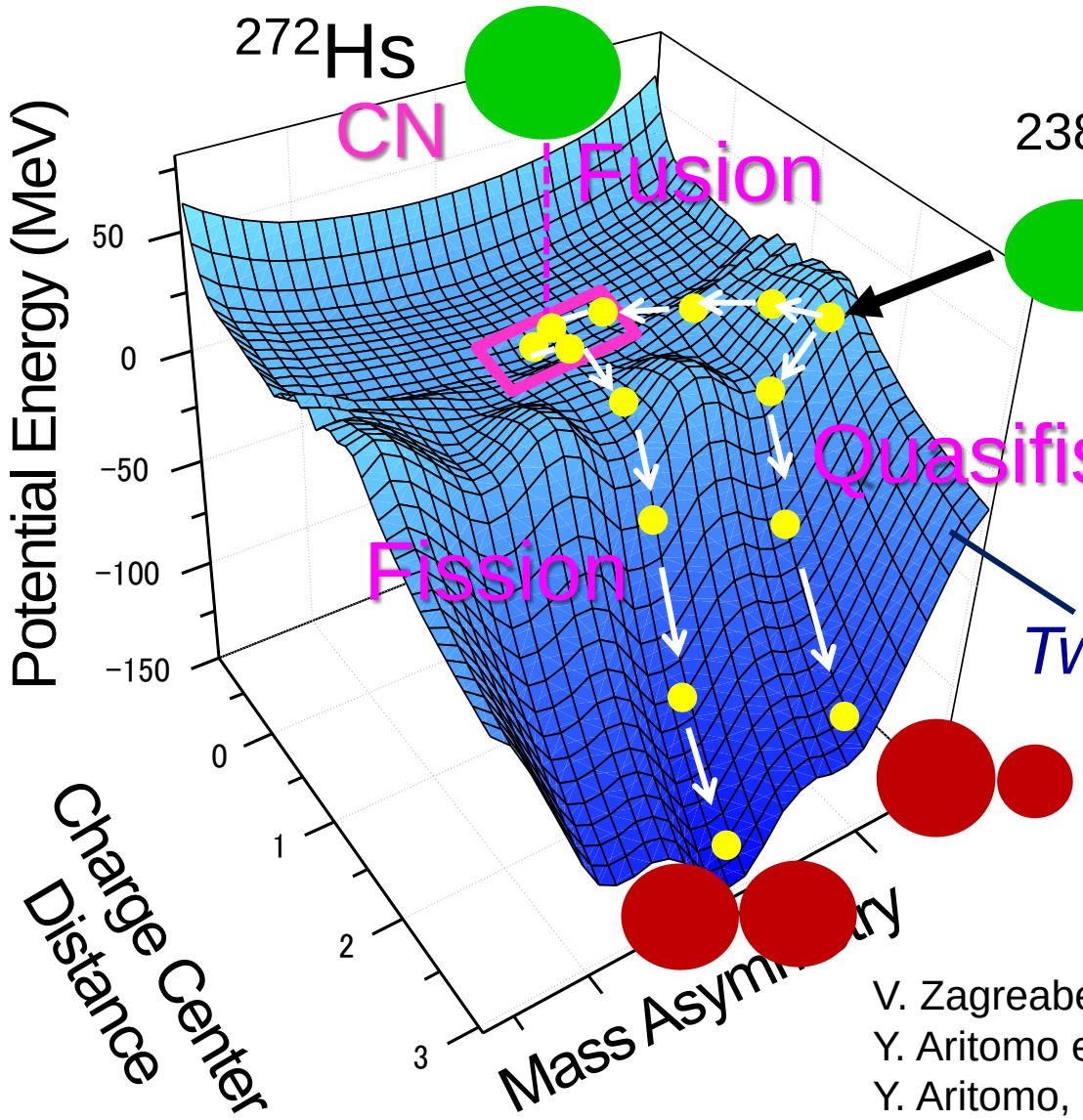
K. Nishio *et al.*, Phys. Rev. C, **77** (2008) 064607.

Fission Fragment Mass Distributions



K. Nishio et al., Phys. Rev. C, **77**, 064607 (2008).
K. Nishio et al., Phys. Rev. C, **82**, 044604 (2010).

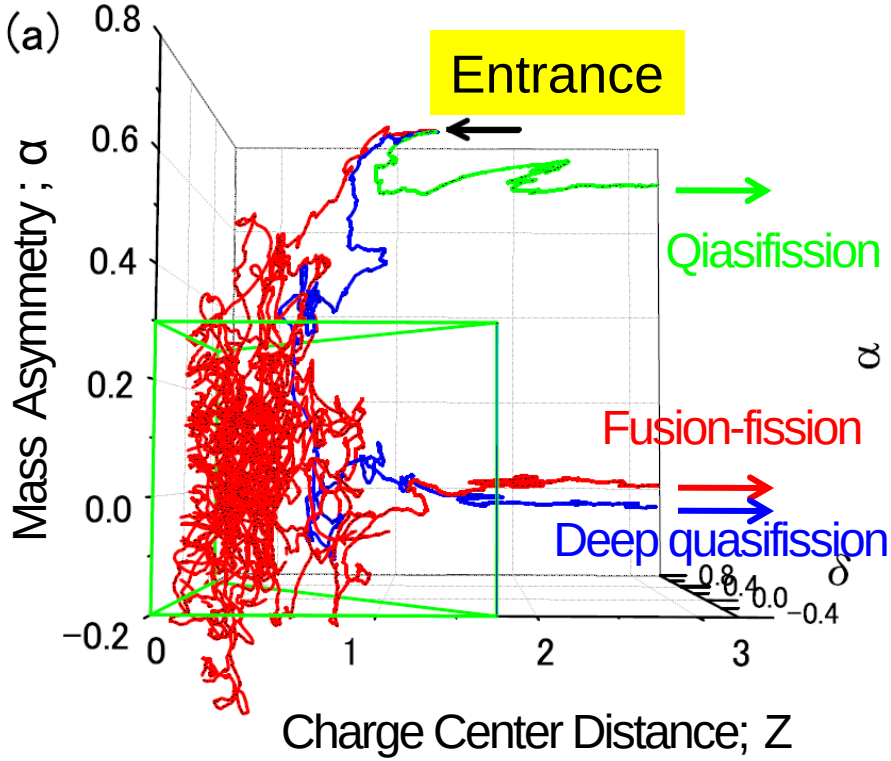
Dynamical calculation of nuclear shape
– Fluctuation dissipation model –

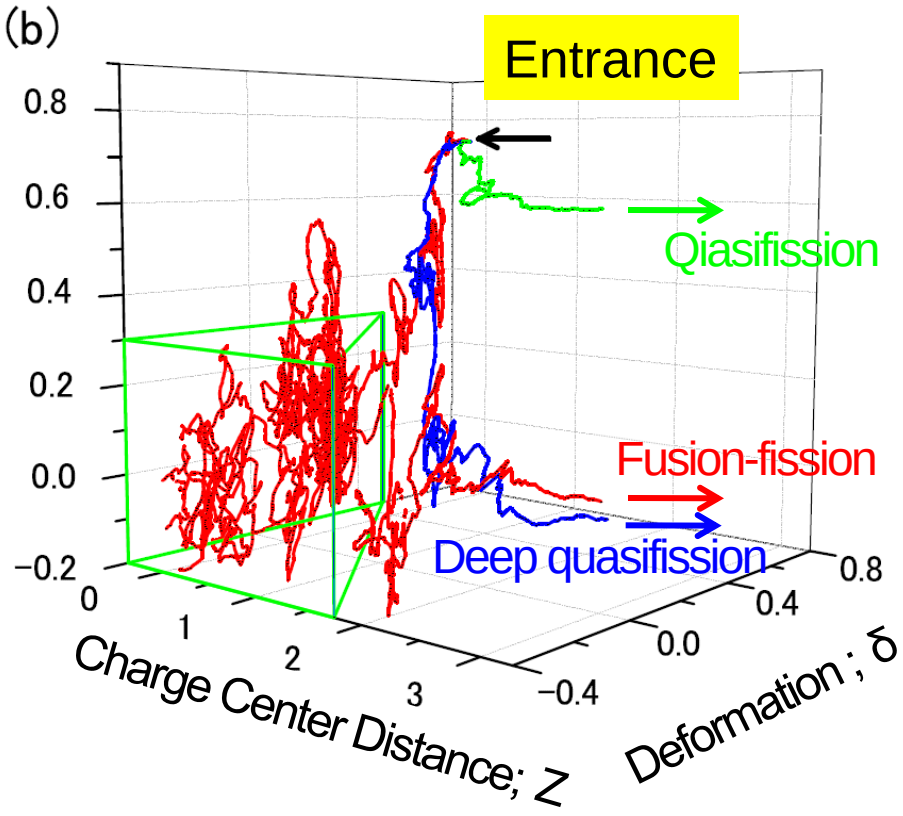


Two center shell model
(3 dimension)

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).

Quasifission and Deep-quasifission

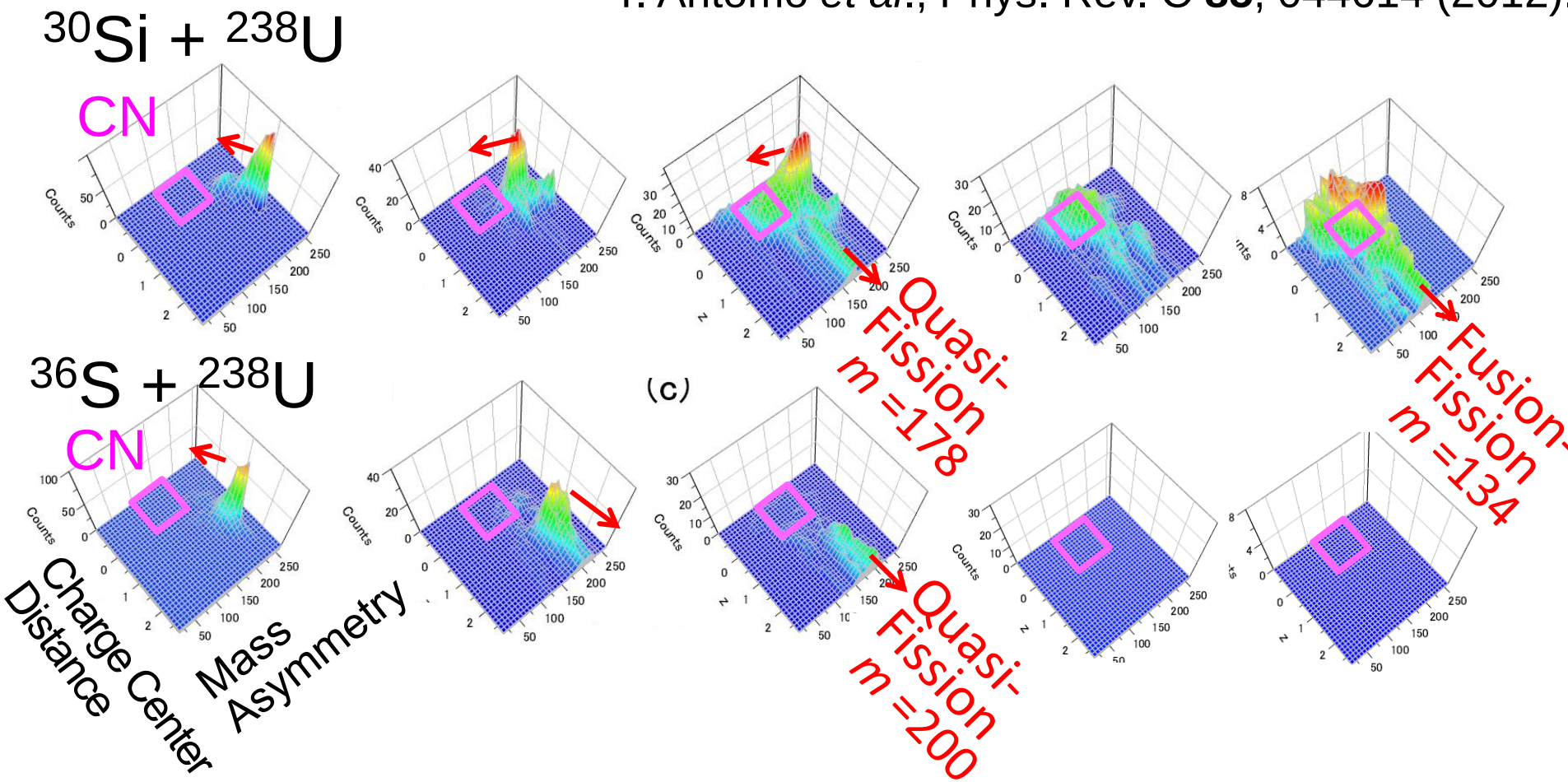




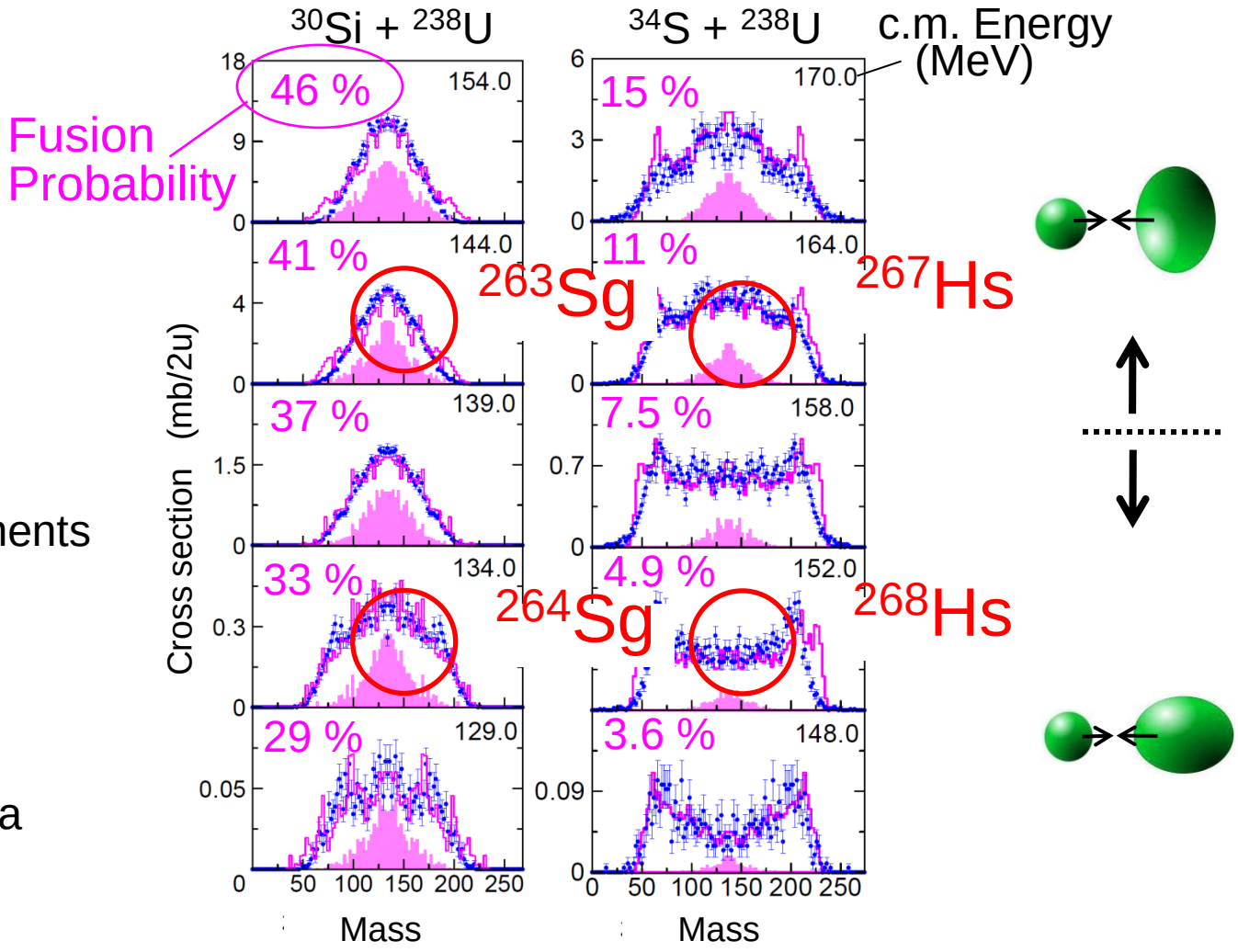
$^{36}S + {}^{238}U \rightarrow {}^{274}Hs$ (E*=35.5 MeV)

Shape evolution (polar collision)

Y. Aritomo *et al*., Phys. Rev. C **85**, 044614 (2012).



Fusion probability



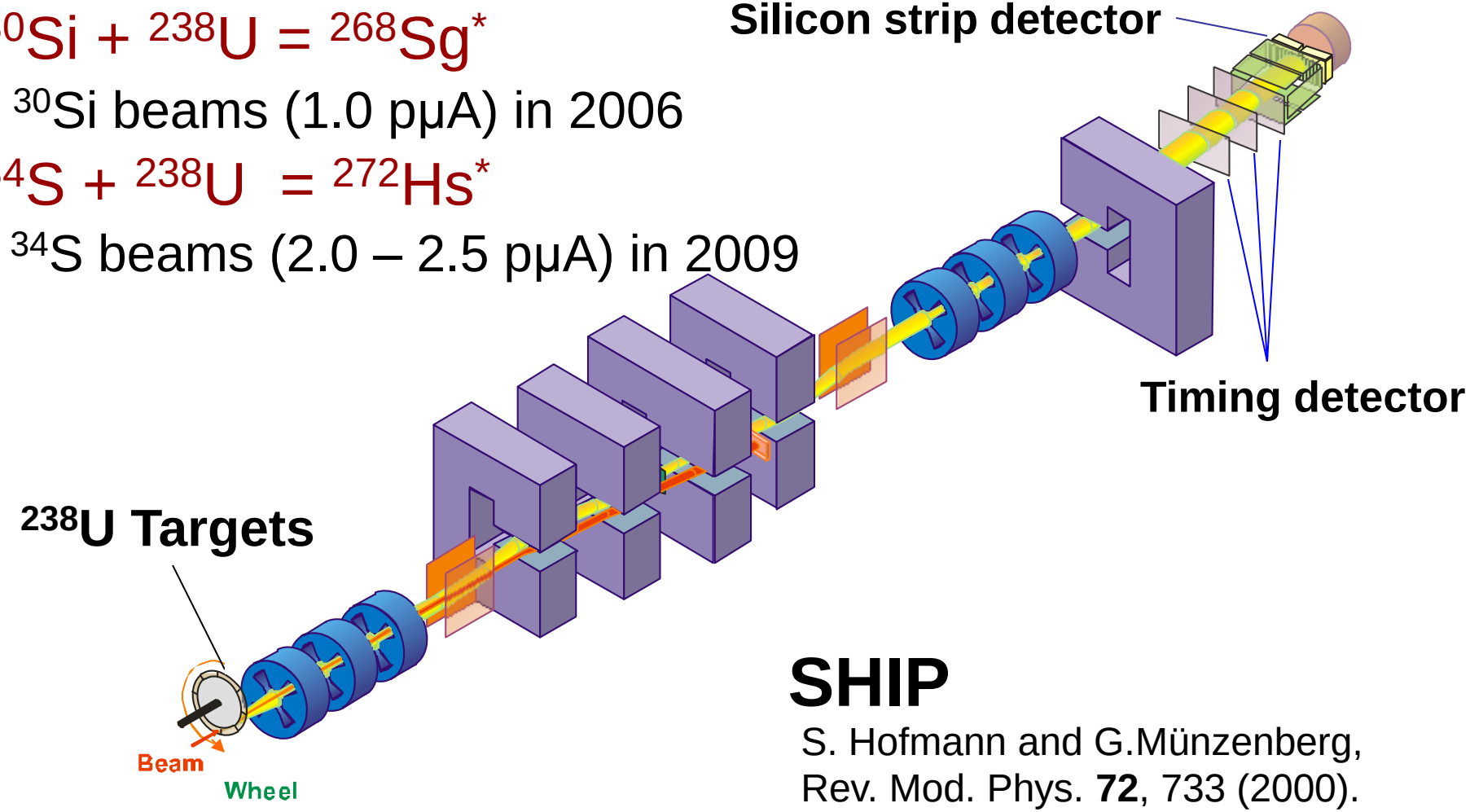
Measurement of evaporation residue (ER) cross sections at GSI

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

^{30}Si beams (1.0 pμA) in 2006

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

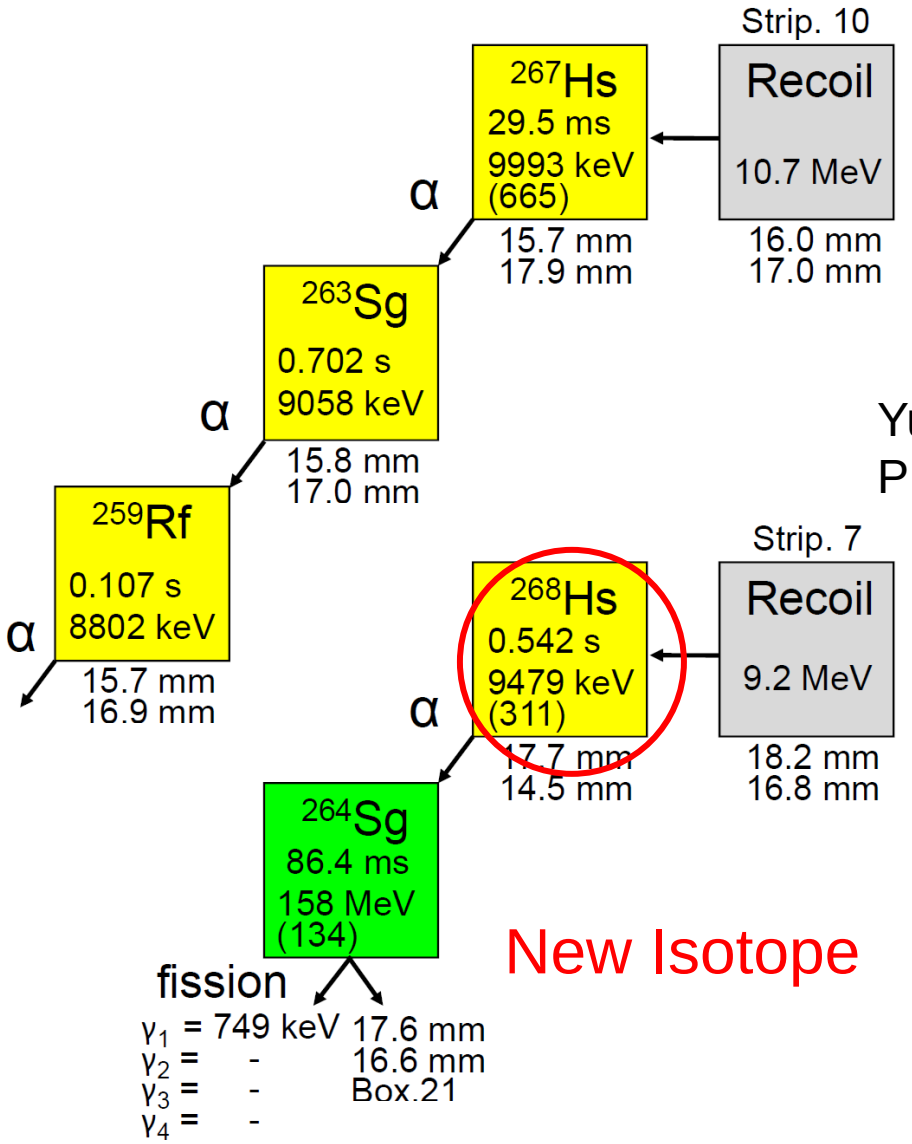
^{34}S beams (2.0 – 2.5 pμA) in 2009



SHIP

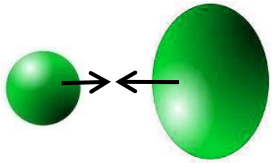
S. Hofmann and G.Münzenberg, Rev. Mod. Phys. **72**, 733 (2000).

Hs isotopes produced in $^{34}S + ^{238}U$



New Isotope

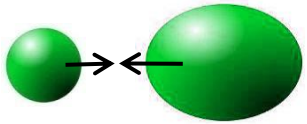
$E_{c.m.}$ = 163 MeV
E* = 51 MeV



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

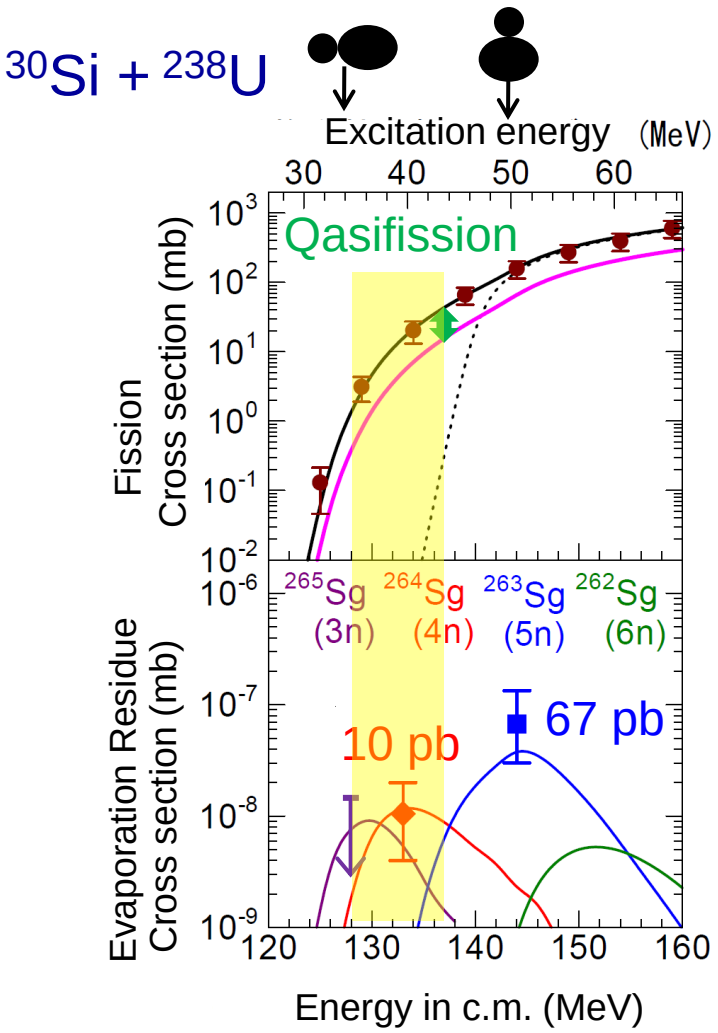
Yu.A Lazarev *et al.*, ^{267}Hs (**2.5 pb**), PRL75(1995) 1903.

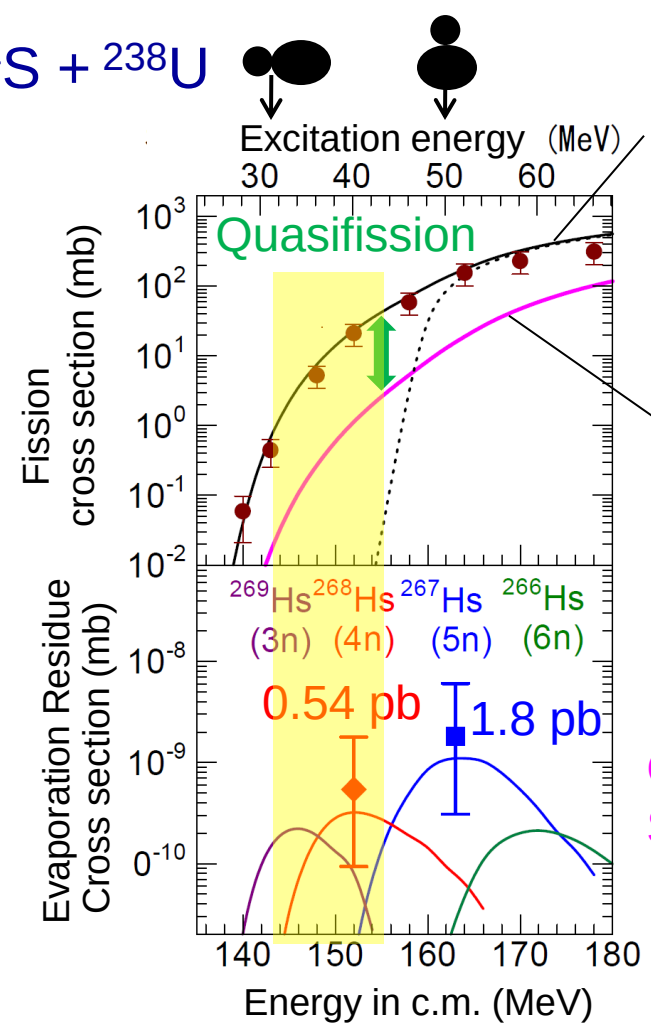
$E_{c.m.}$= 152 MeV
E* = 40 MeV



$0.54^{+1.3}_{-0.45}$ pb

Fusion and ER cross sections





Capture Cross Section

× Fusion Probability

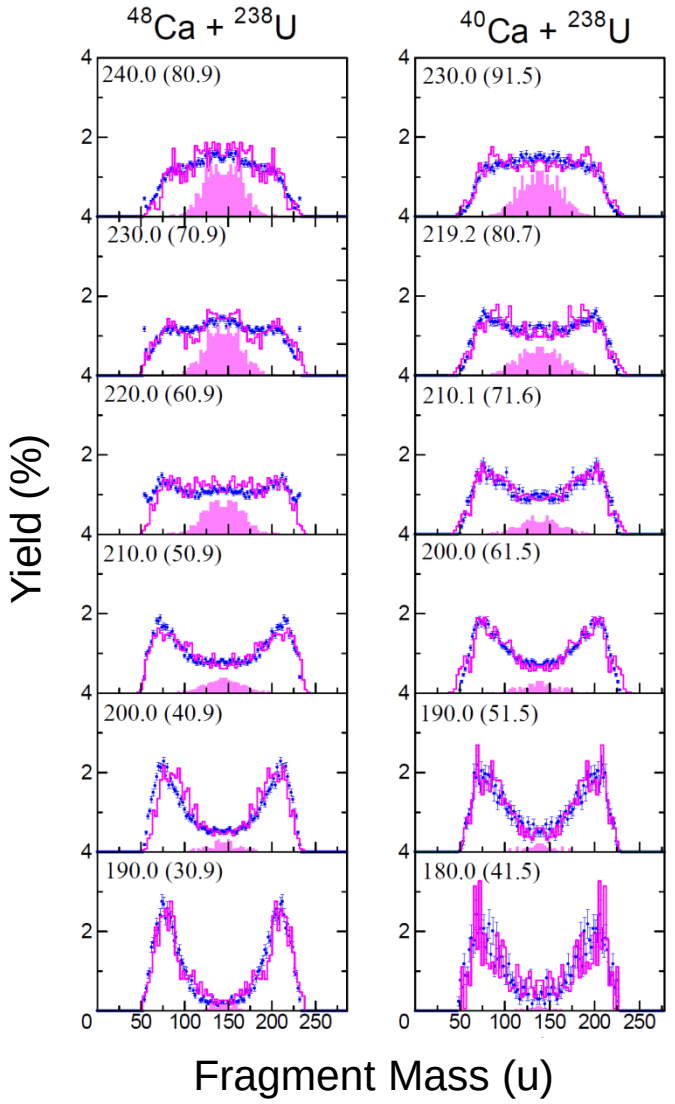
Fusion Cross Section

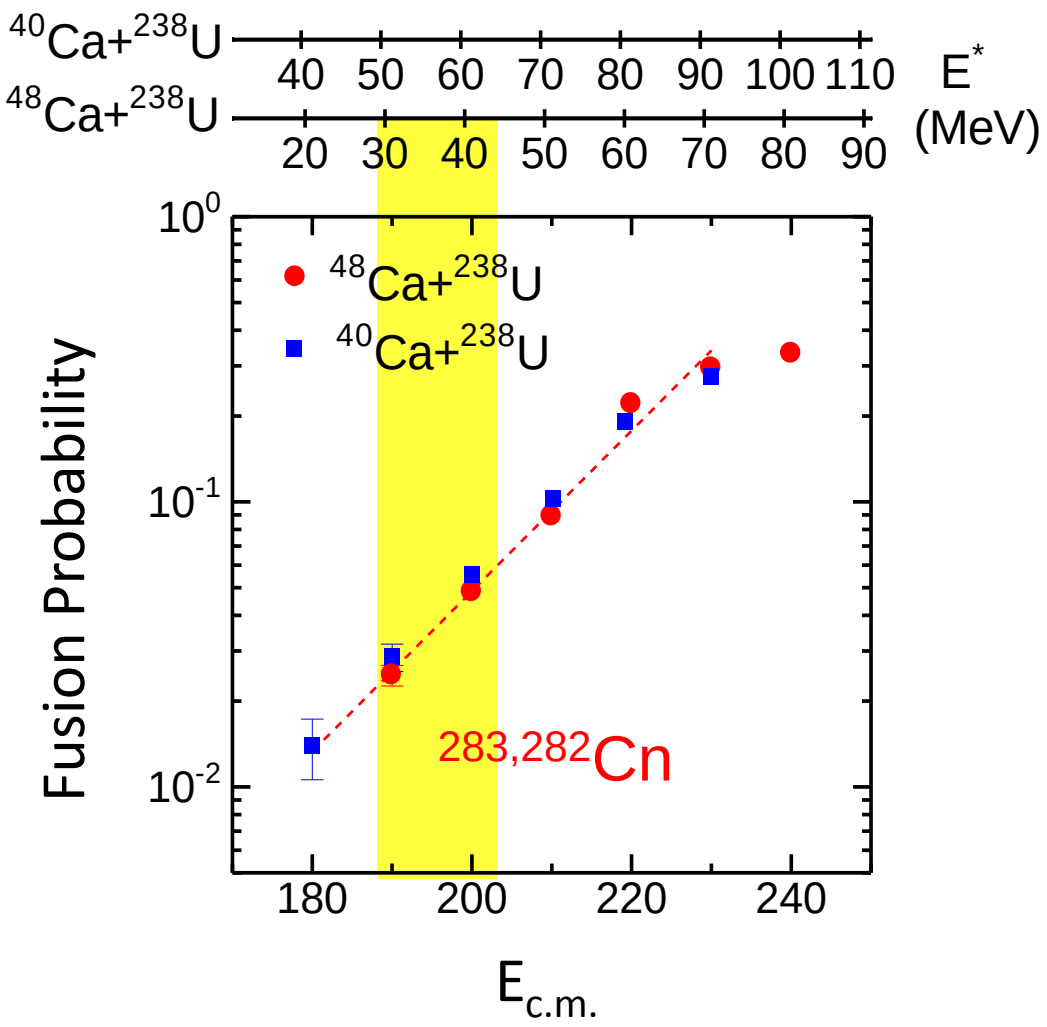
× Survival Probability (Statistical Model)

Cross sections for SHN

K. Nishio *et al*., PRC **82**, 024611 (2010).
K. Nishio *et al*., PRC **82**, 044604 (2010).

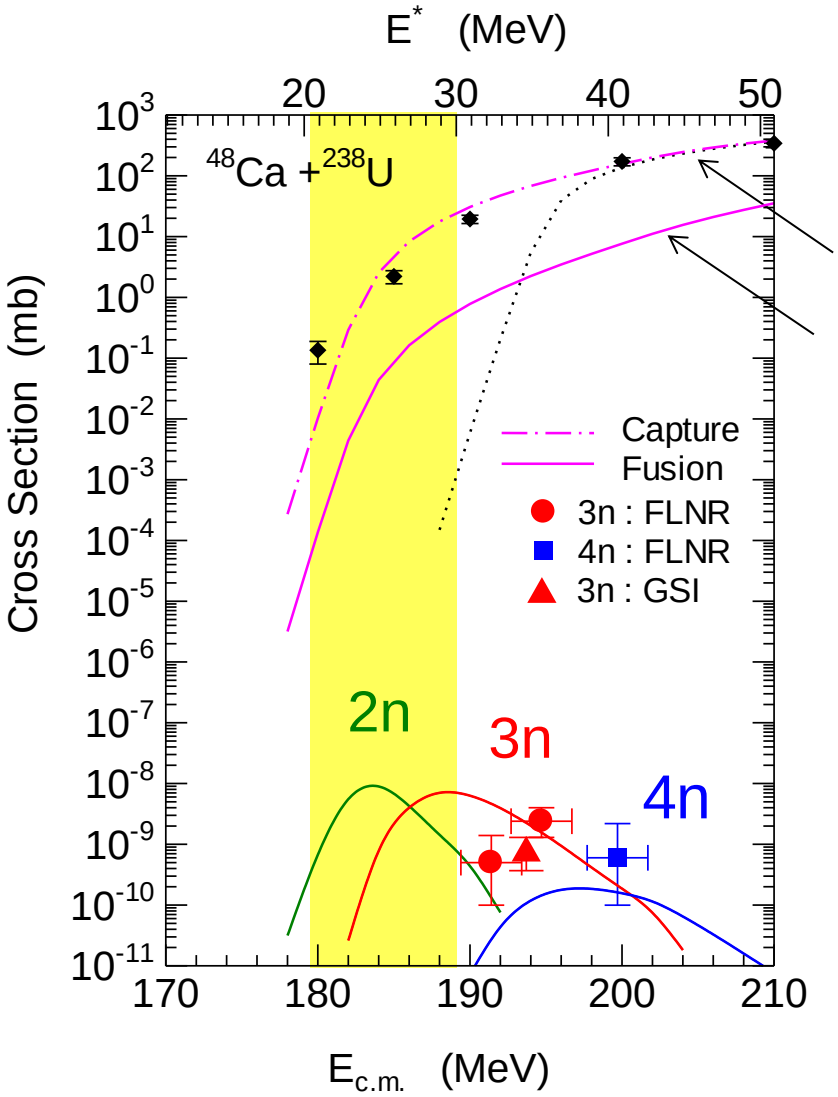
Fusion Probabilities for $^{48}Ca + ^{238}U$ and $^{40}Ca + ^{238}U$





K. Nishio *et al.*, Phys. Rev. C **86**, 034608 (2012).

$^{48}Ca + ^{238}U$



Capture cross section

Fusion Cross section

$^{282,283}Cn$ cross sections from

Yu.Ts. Oganessian, J.Phys.G **34**, R165 (2007).

Yu.Ts. Oganessian *et al.*, Phys.Rev.C **70**, 064609 (2004)

S. Hofmann *et al.*, Eur.Phys.J. A **32**, 251 (2007).

Summary

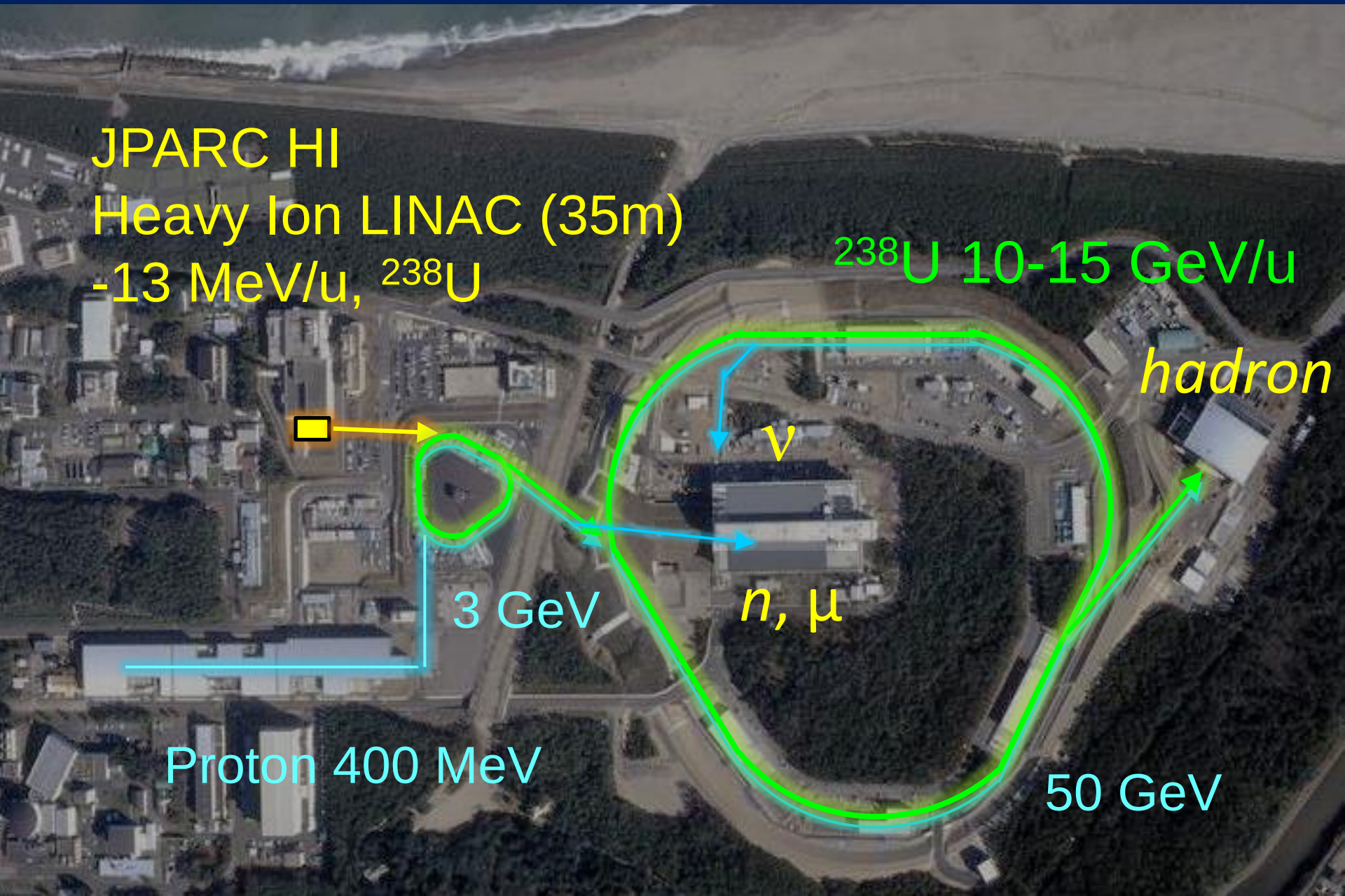
In beam fission experiment can be used to estimate the fusion probability for heavy-element synthesis.

Model calculation in heavy-ion induced fission was shown.

Sub-barrier fusion reaction can be used for heavy-element synthesis.

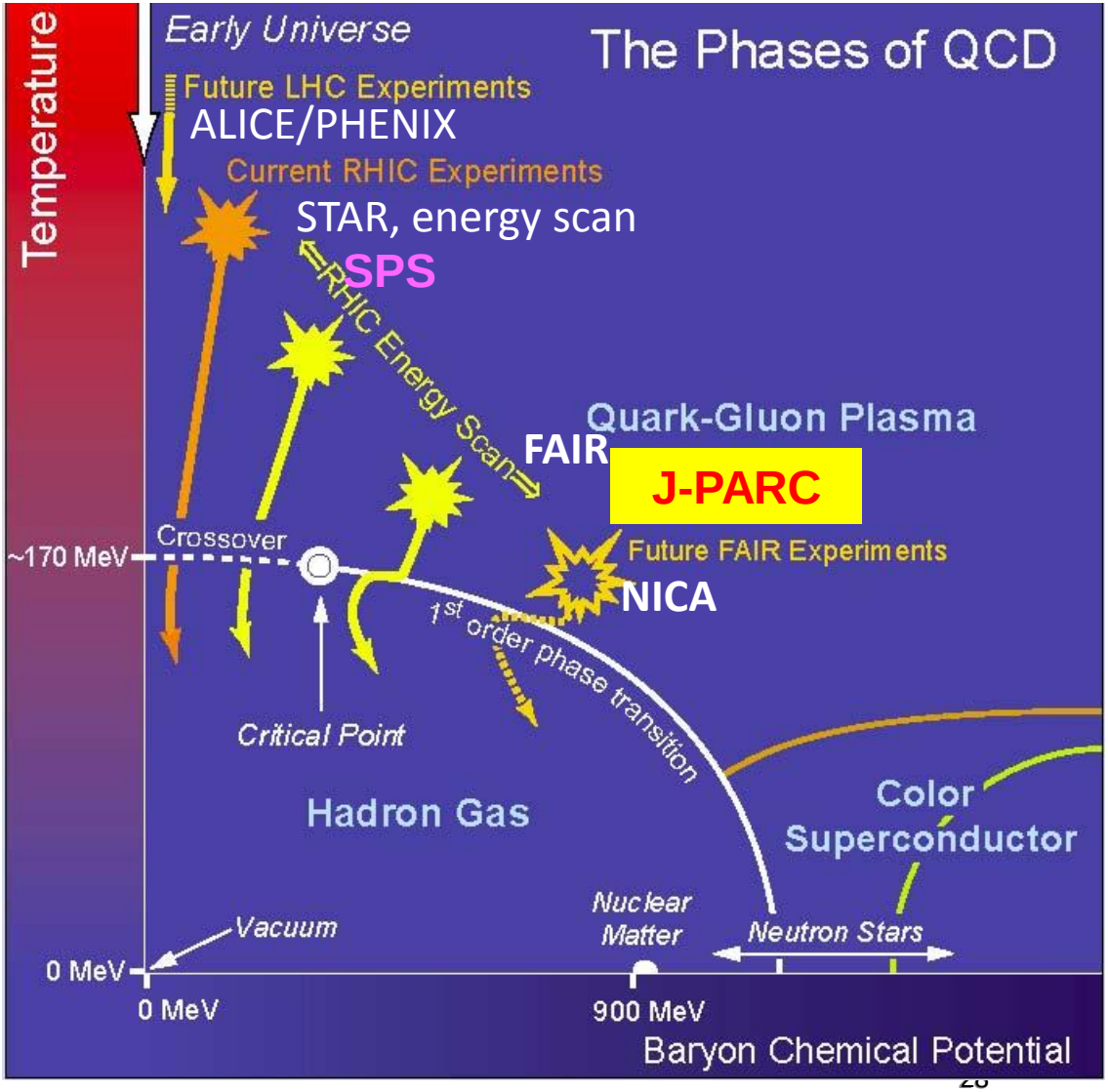
Heavy-Ion Program at J-PARC

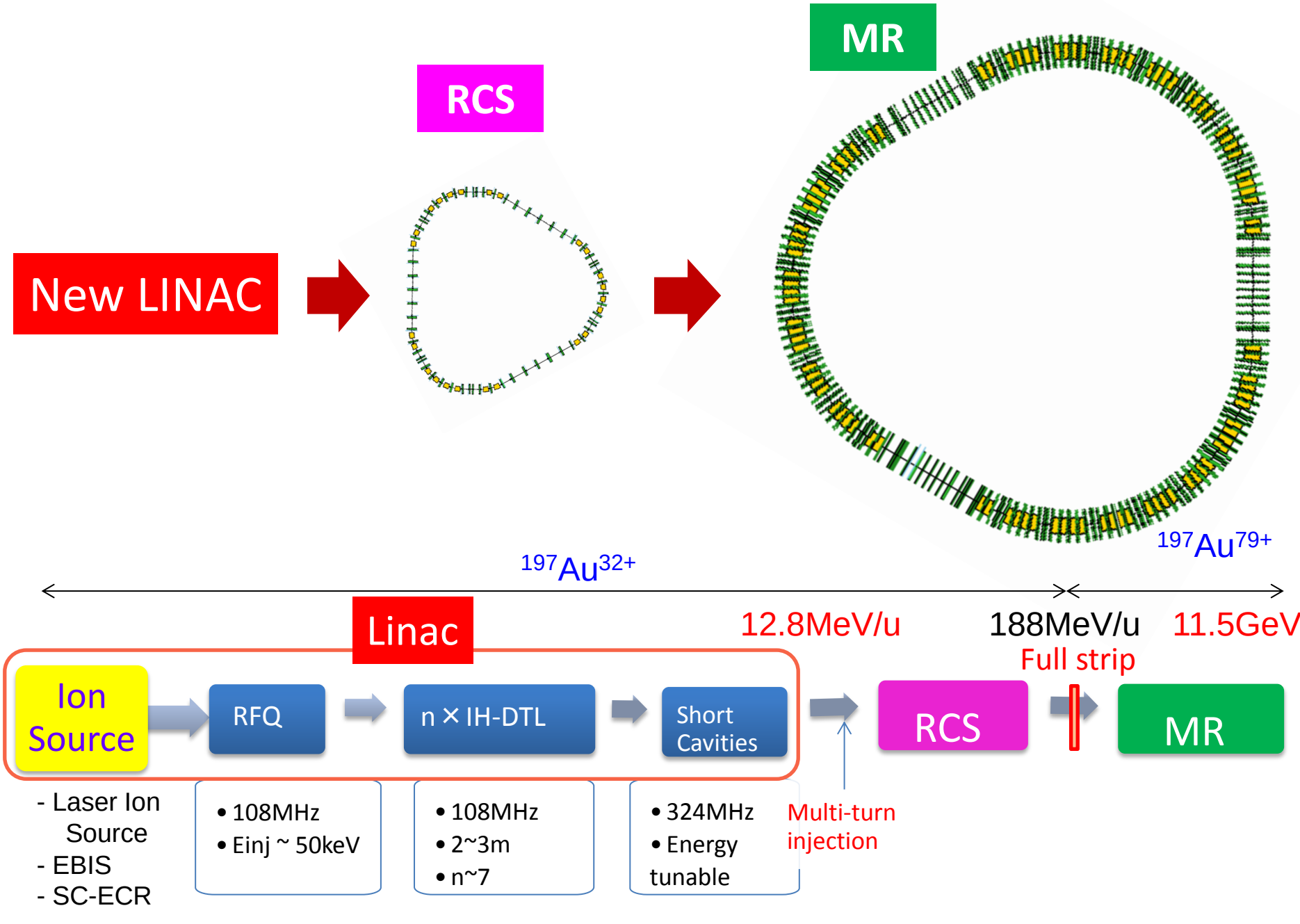
J-PARC HI


JPARC HI
Heavy Ion LINAC (35m)
-13 MeV/u, ^{238}U
^{238}U 10-15 GeV/u
hadron
ν
n, μ
3 GeV
Proton 400 MeV
50 GeV

Heavy-Ion Acceleration at J-PARC

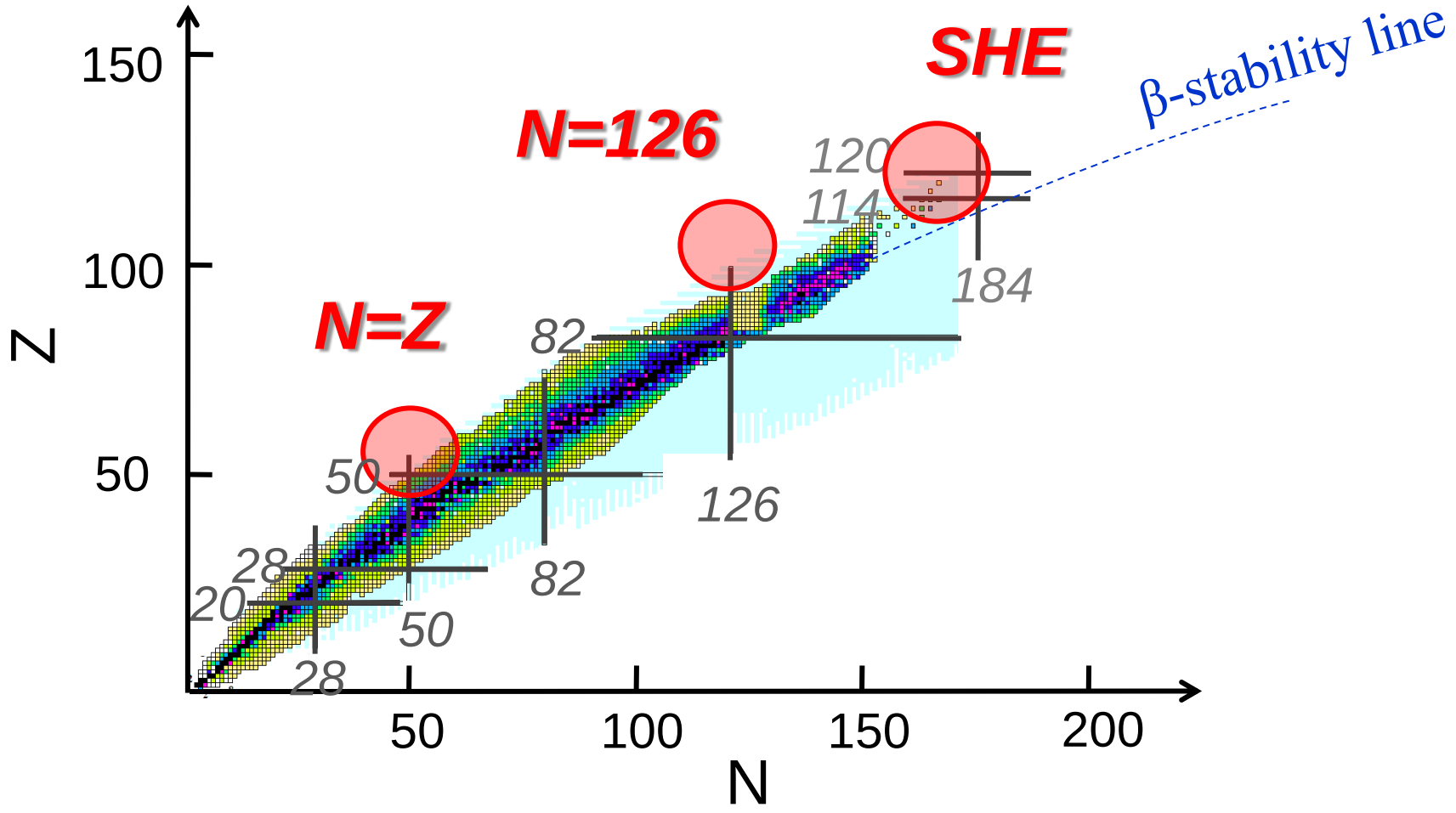
QCD Phase diagram
-search for critical point and phase boundary-




MR
RCS
New LINAC
197Au79+
197Au32+
Linac
12.8MeV/u
188MeV/u
11.5GeV/u
Full strip
Ion Source
RFQ
n × IH-DTL
Short Cavities
RCS
MR
- Laser Ion Source
- EBIS
- SC-ECR
• 108MHz
• Einj ~ 50keV
• 108MHz
• 2~3m
• n~7
• 324MHz
• Energy tunable
Multi-turn injection

Three Extreme Region on Chart of Nuclei

Search for Heaviest N=Z Nuclei
Search for Super-heavy Nuclei
Search for Heaviest N=126 Nuclei



Search for Super-Heavy Nuclei