Fission Studies of using Multi-nucleon Transfer Reactions

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Tsukuba-CCS workshop on “microscopic theories of nuclear structure and dynamics”

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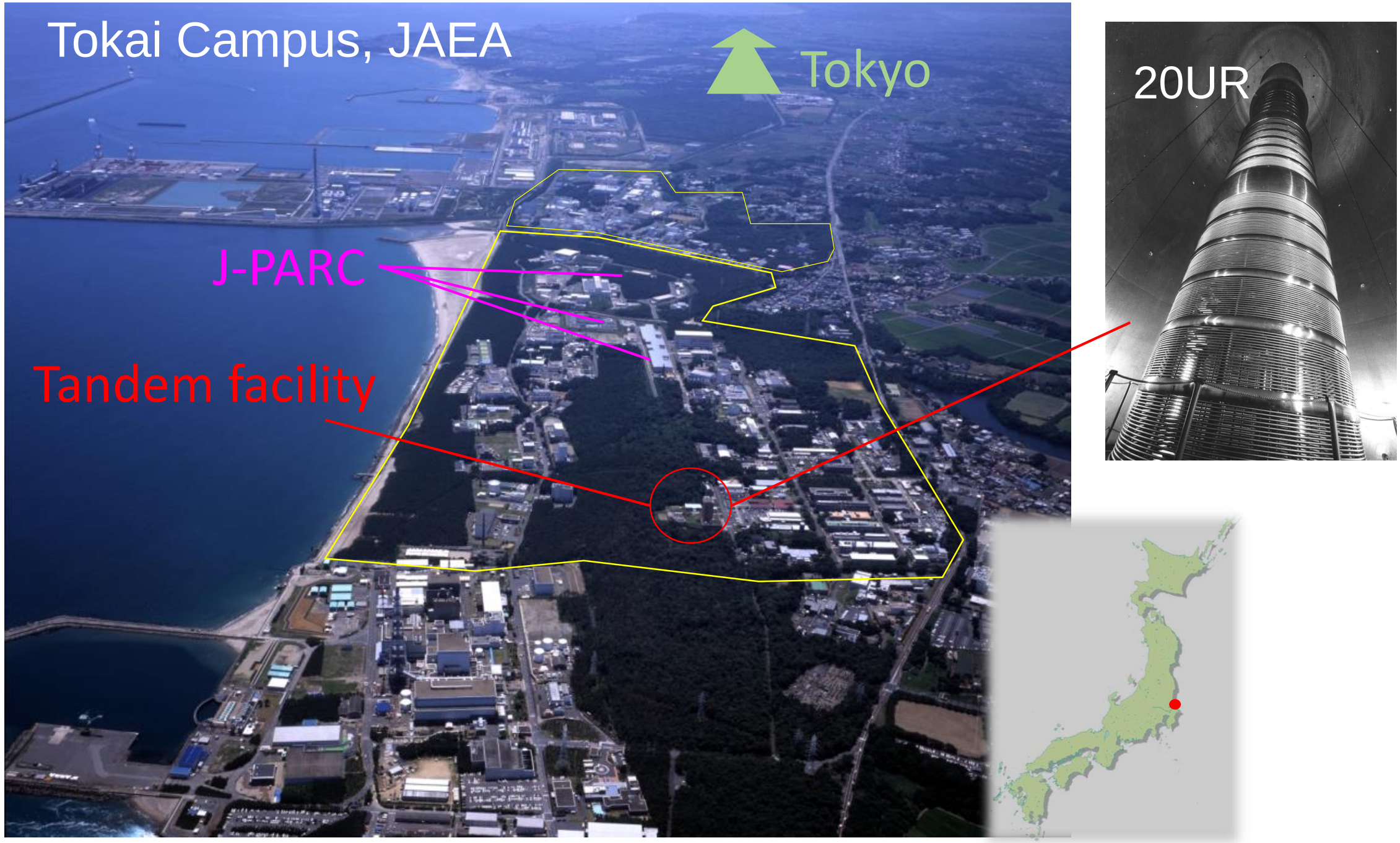
Tokai Campus, JAEA
Tokyo
J-PARC
Tandem facility
20UR

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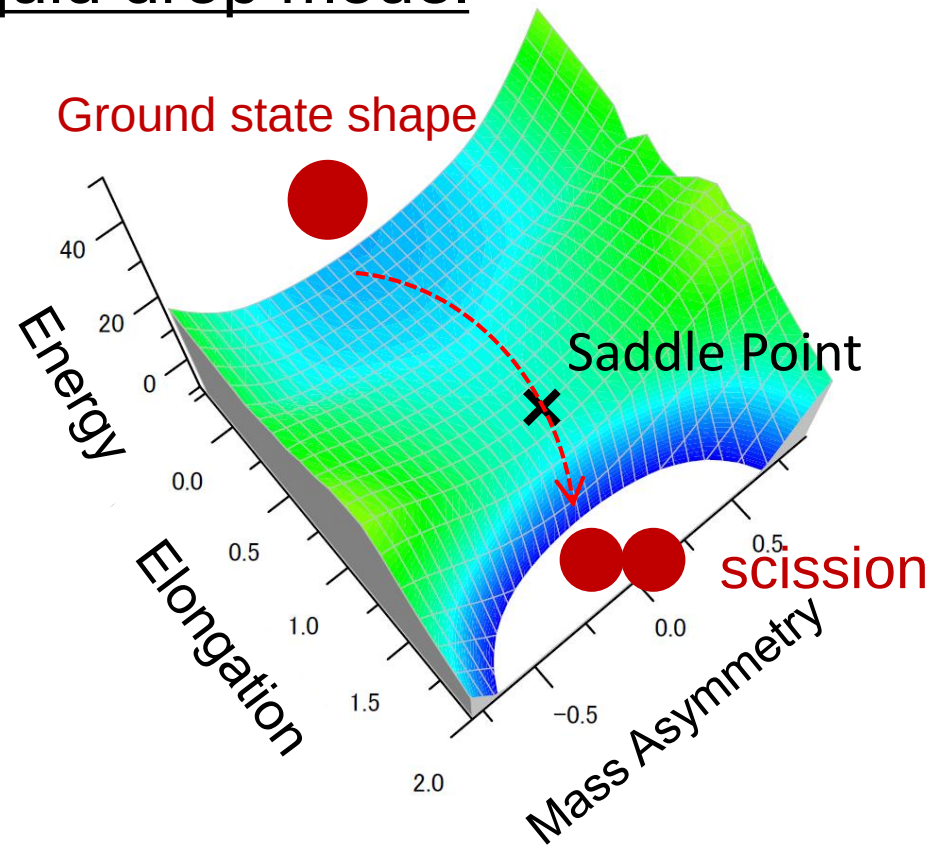
- ☑ Multi-nucleon transfer (MNT) reactions and fission
- ☑ Experimental setup
- ☑ Experimental results and discussions
- ☑ Fission experiments using ^{254}Es target (element 99)
- ☑ Summary

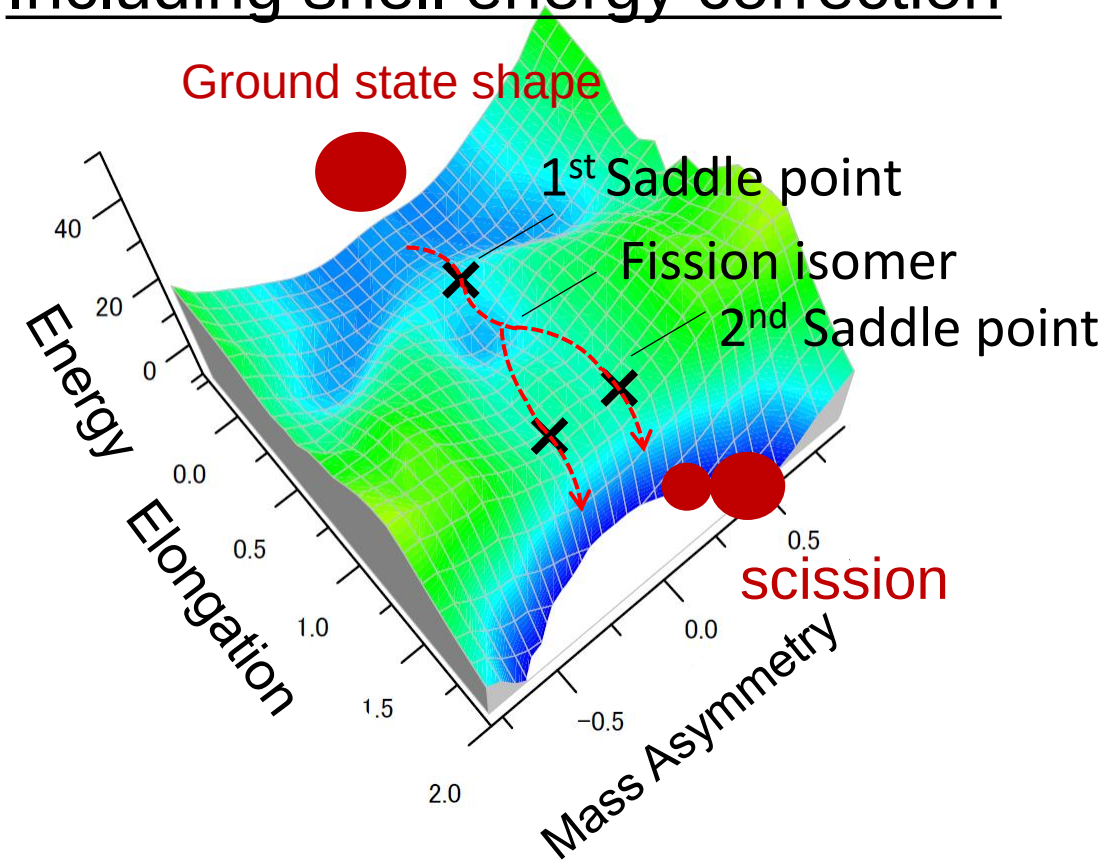
Nuclear Structure and Fission

Liquid drop model

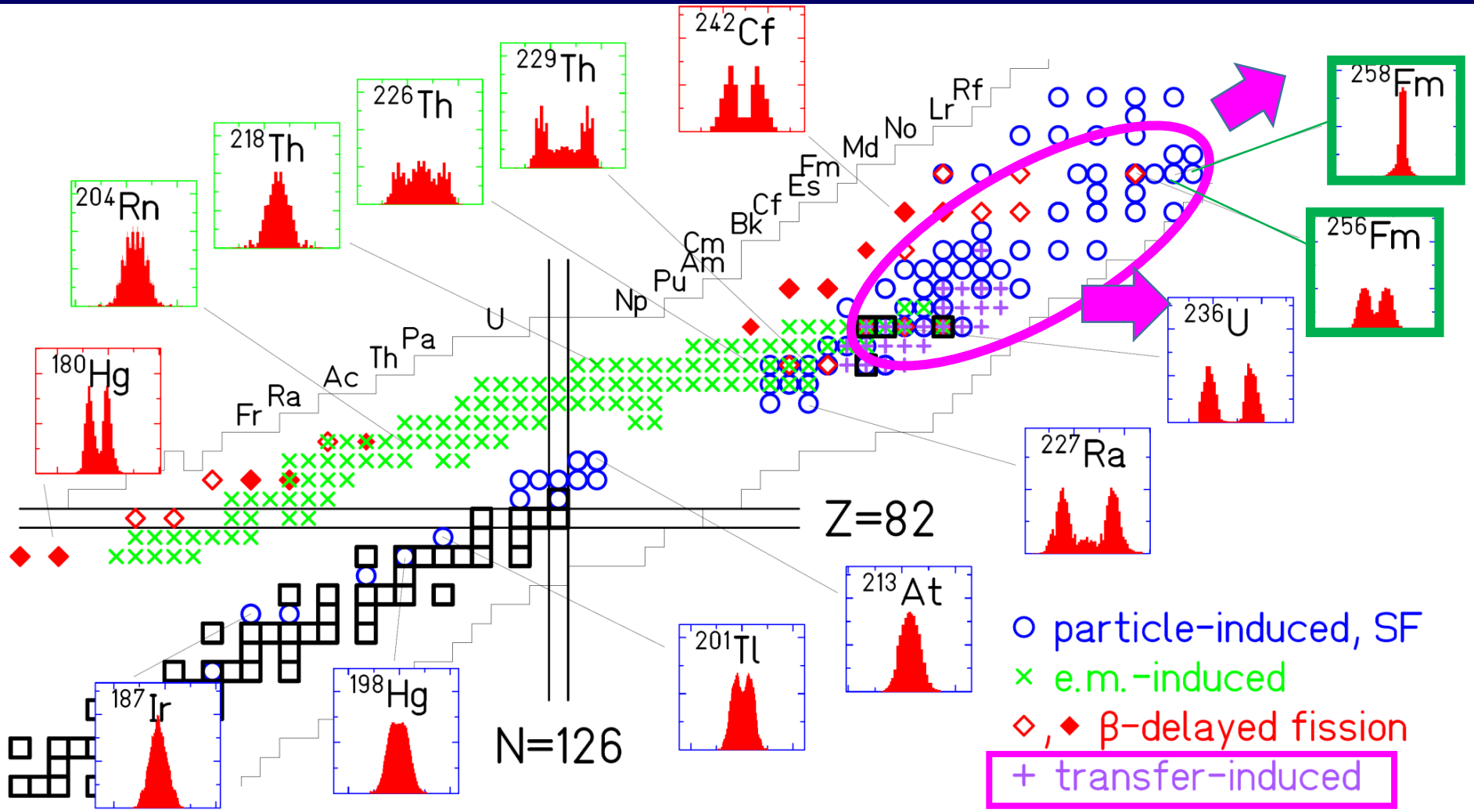
^{240}U



Including shell energy correction



Measured Fission-Fragment Mass/Charge Yields ~2017



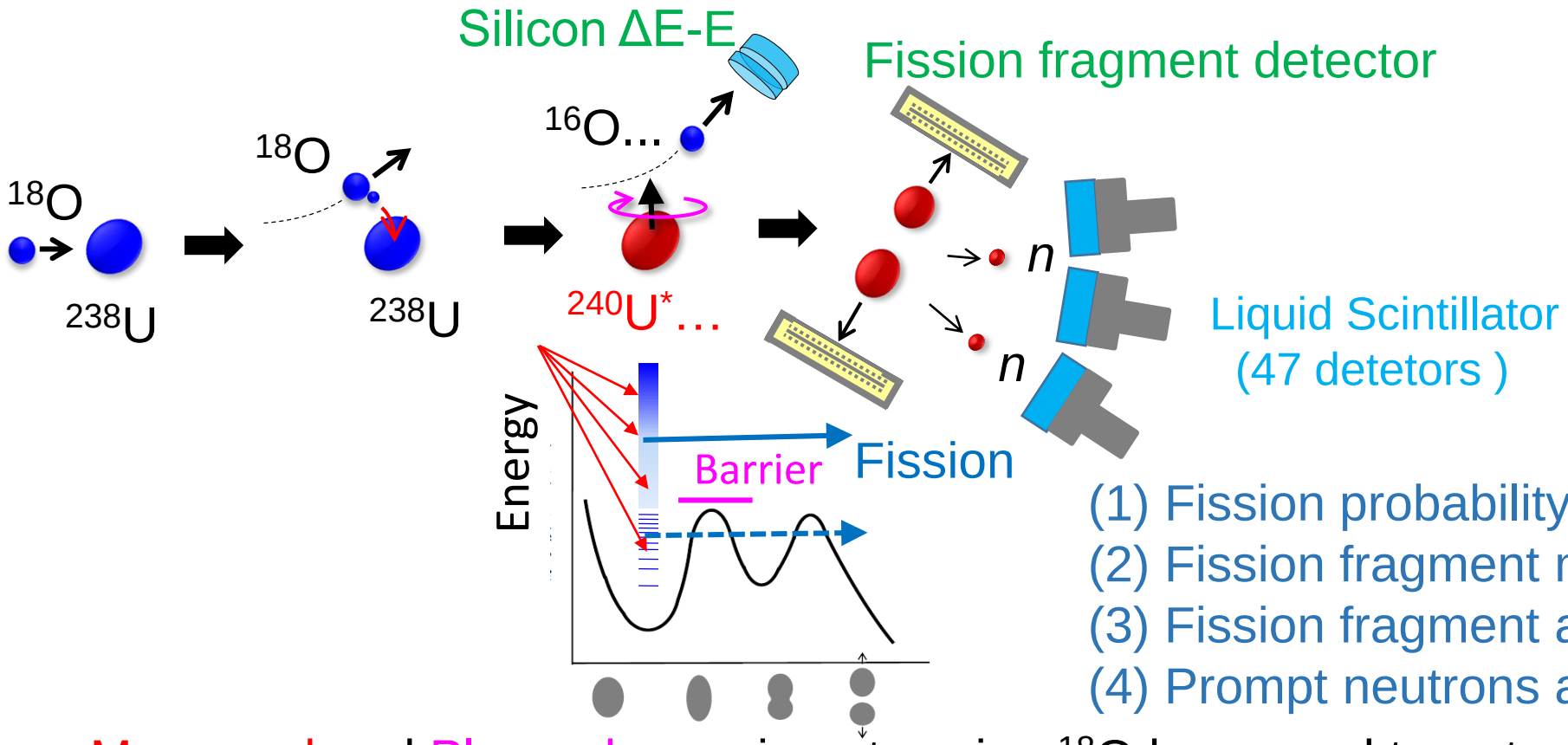
R. Léguillon *et al.*, Phys. Lett. B **761**, 125 (2016)

K. Hirose et al. Phys. Rev. Letters, **119**, 222501 (2017)

A.N. Andreyev, K. Nishio, K.-H. Schmidt, Reports on Progress in Physics, **81**, 016301(2018)

Multi-nucleon transfer reactions and fission

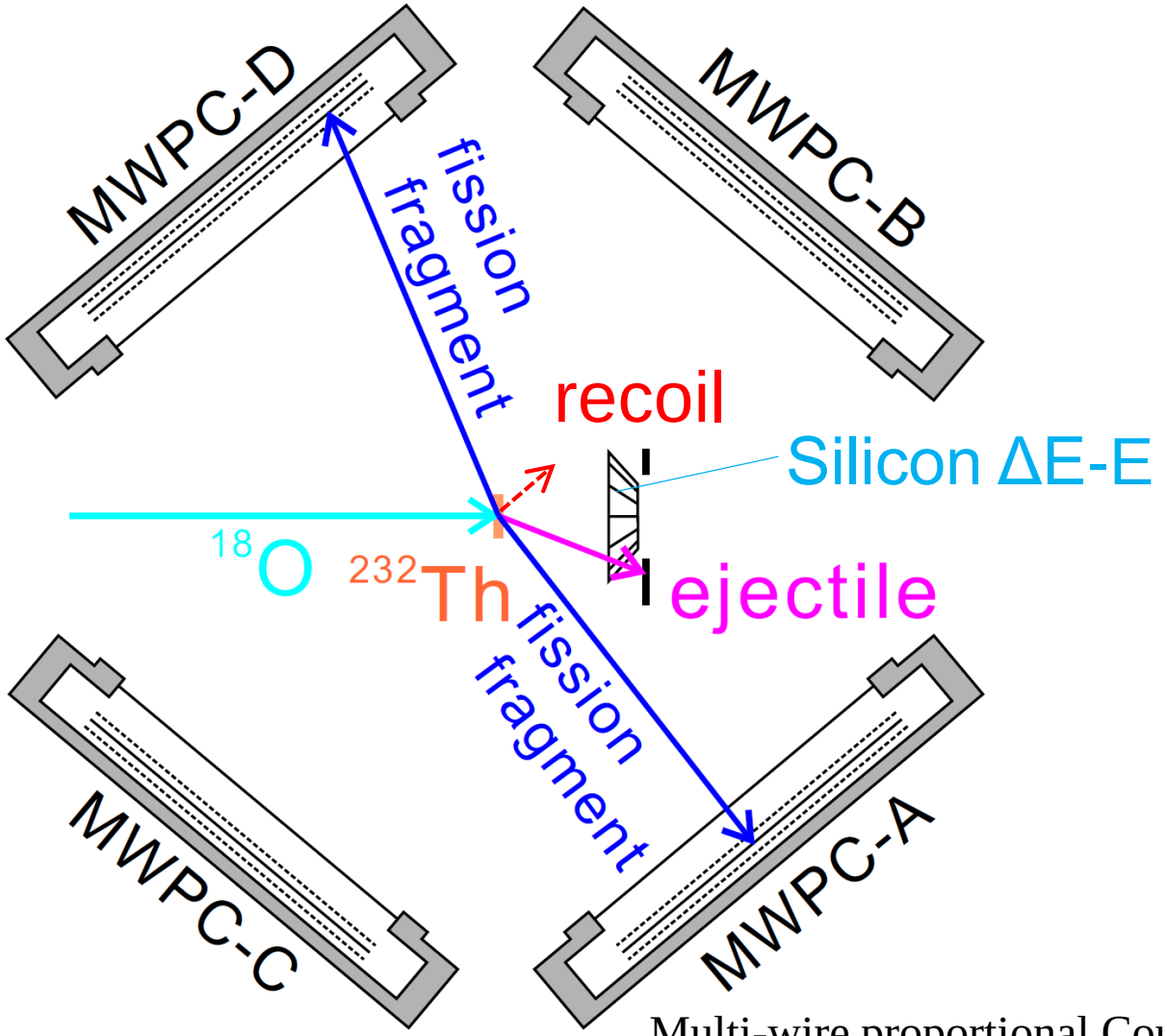
In the multi-nucleon transfer (MNT) reactions:
(1) We can generate many nuclei depending on transfer channels.
(2) Excitation energy of compound nucleus distributes widely.

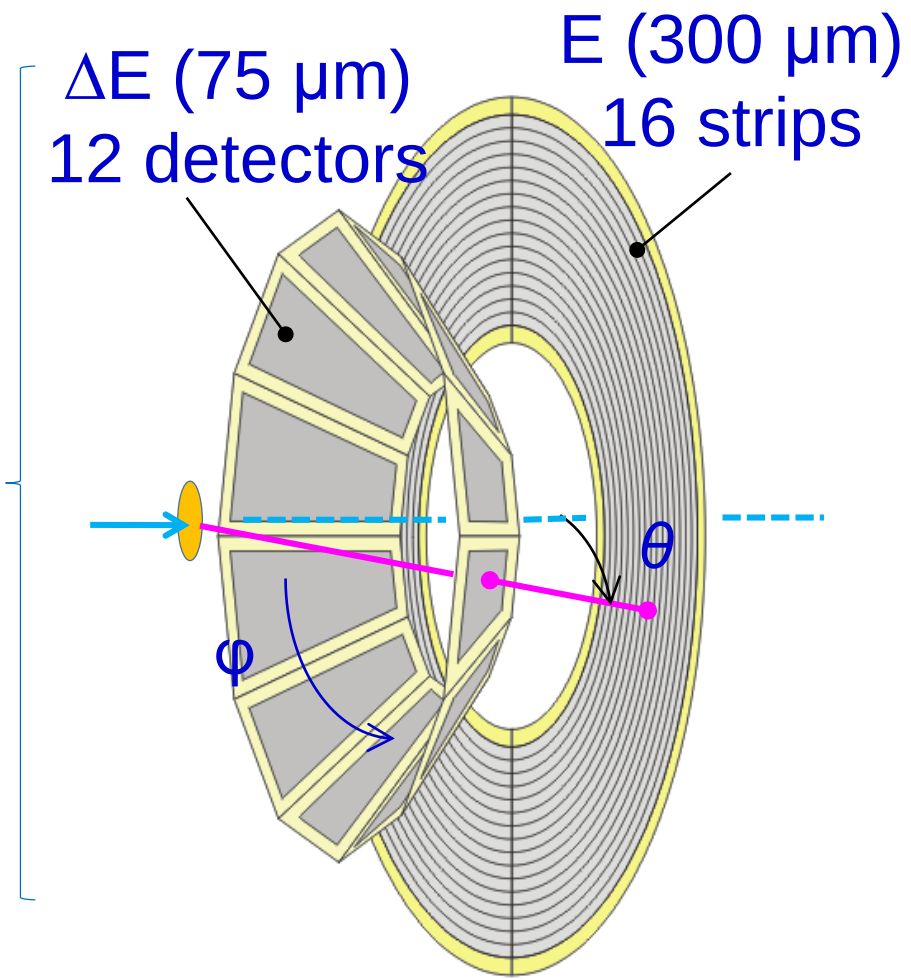


(1) Fission probability and Fission barrier height.
(2) Fission fragment mass distributions.
(3) Fission fragment angular distributions.
(4) Prompt neutrons accompanied by fission.

Measured and Planned experiments using ^{18}O beam and targets of
^{232}Th, ^{238}U, ^{248}Cm, ^{237}Np, ^{249}Cf, ^{243}Am, ^{249}Bk, ^{254}Es

Experimental Setup

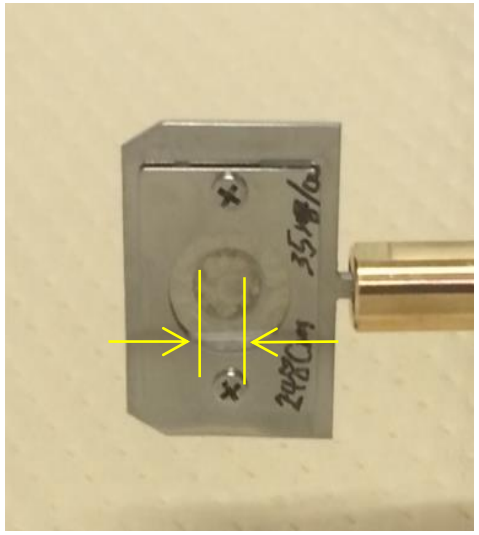




Multi-wire proportional Counter

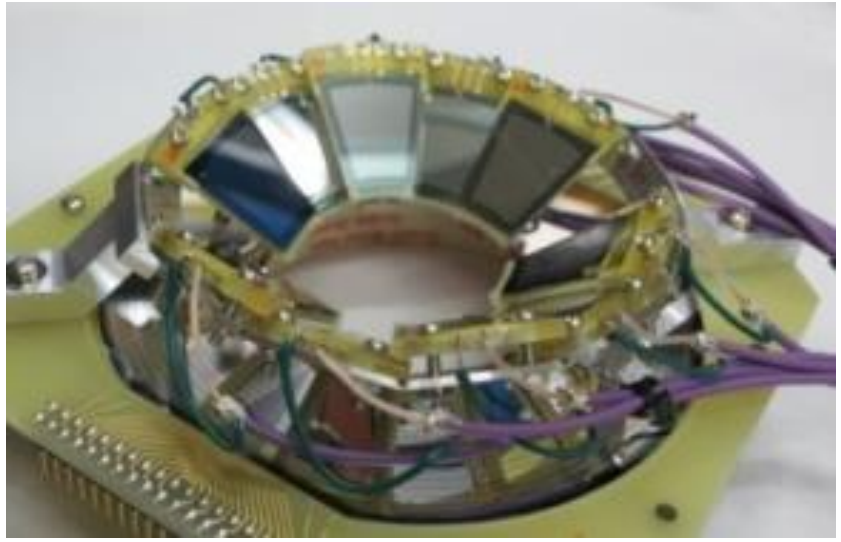
Targets and Detectors

Target (^{248}Cm)



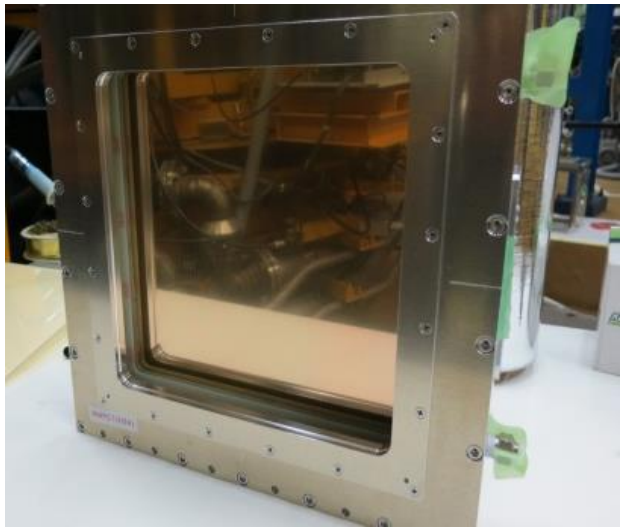
~ 30 - 60 μg/cm^2
~ ø2.0 mm

Silicon ΔE-E detector



ΔE = 75 μm
Thickness fluctuation < 1 μm.

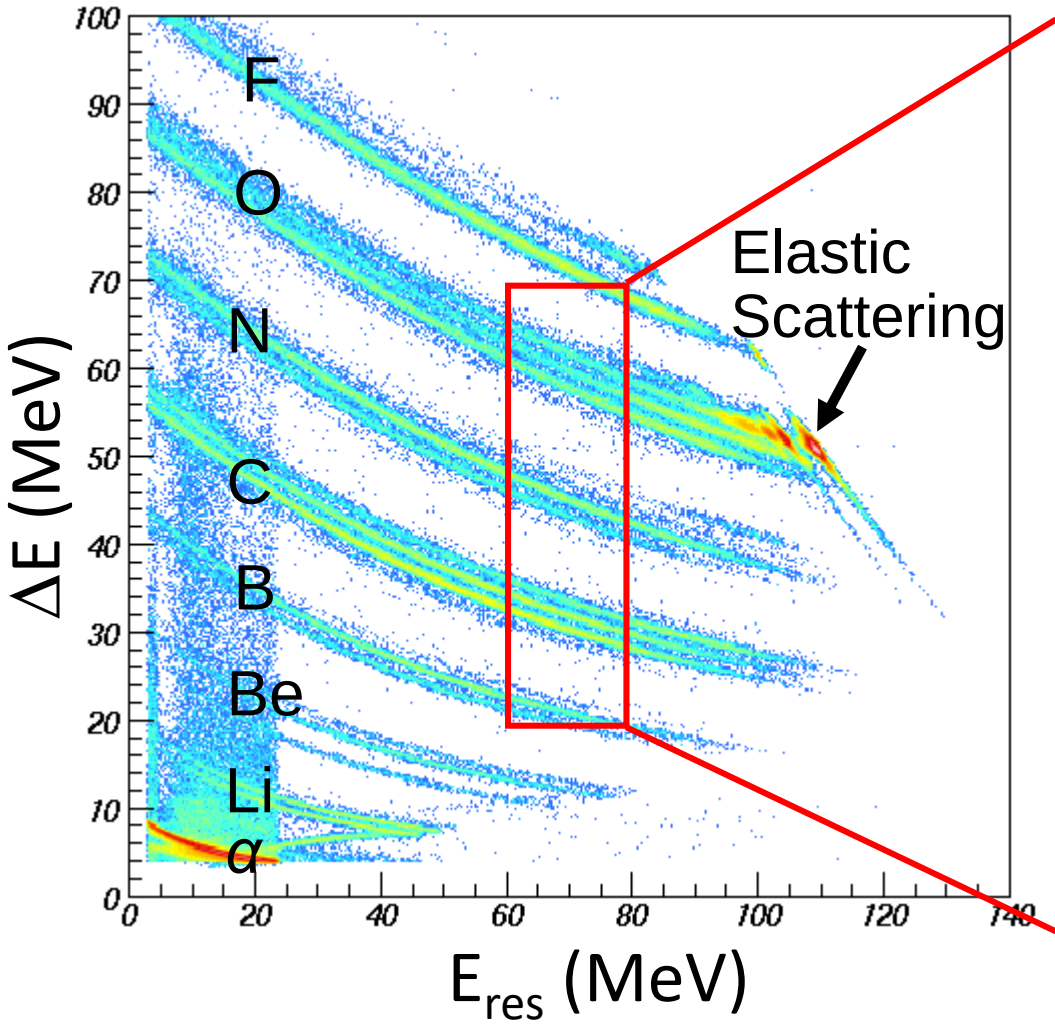
MWPC

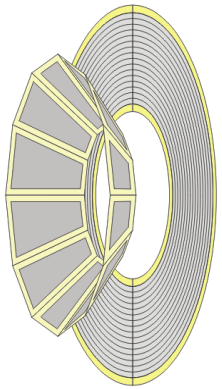


Position Sensitive
200 x 200 mm^2

Particle Identification using ΔE–E Telescope

$^{18}O + {}^{248}Cm$ (E_{beam}= 162MeV)



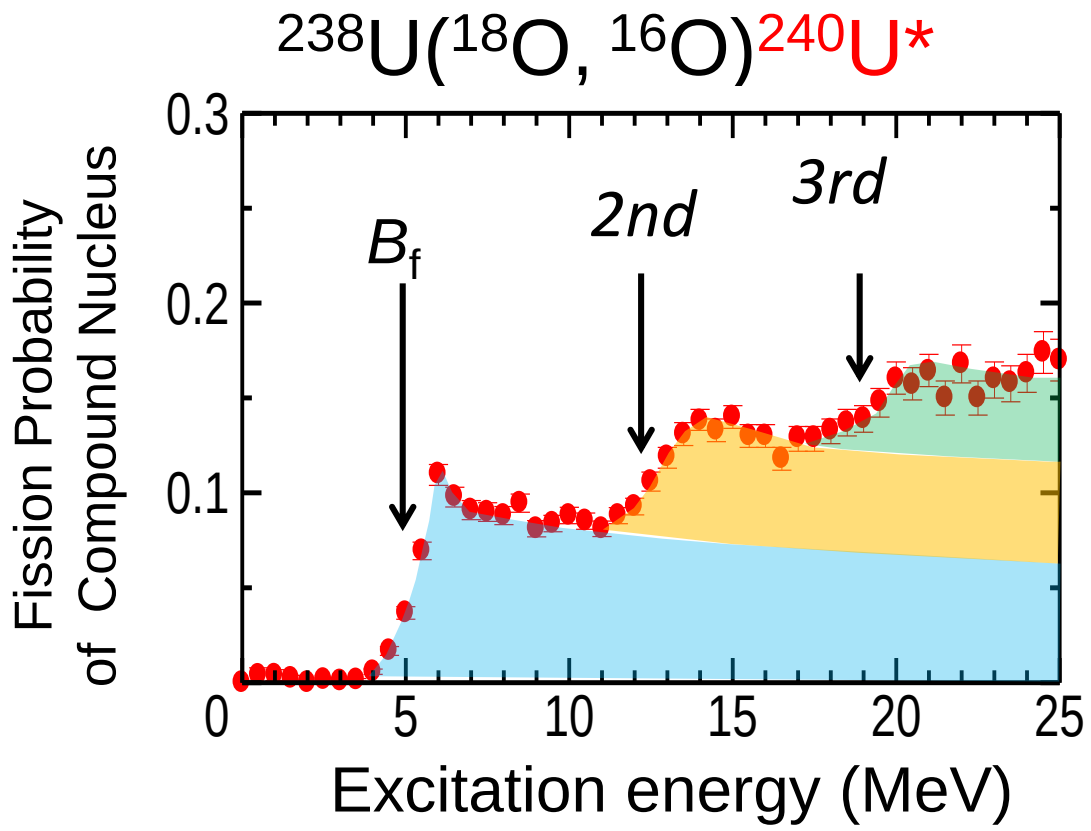


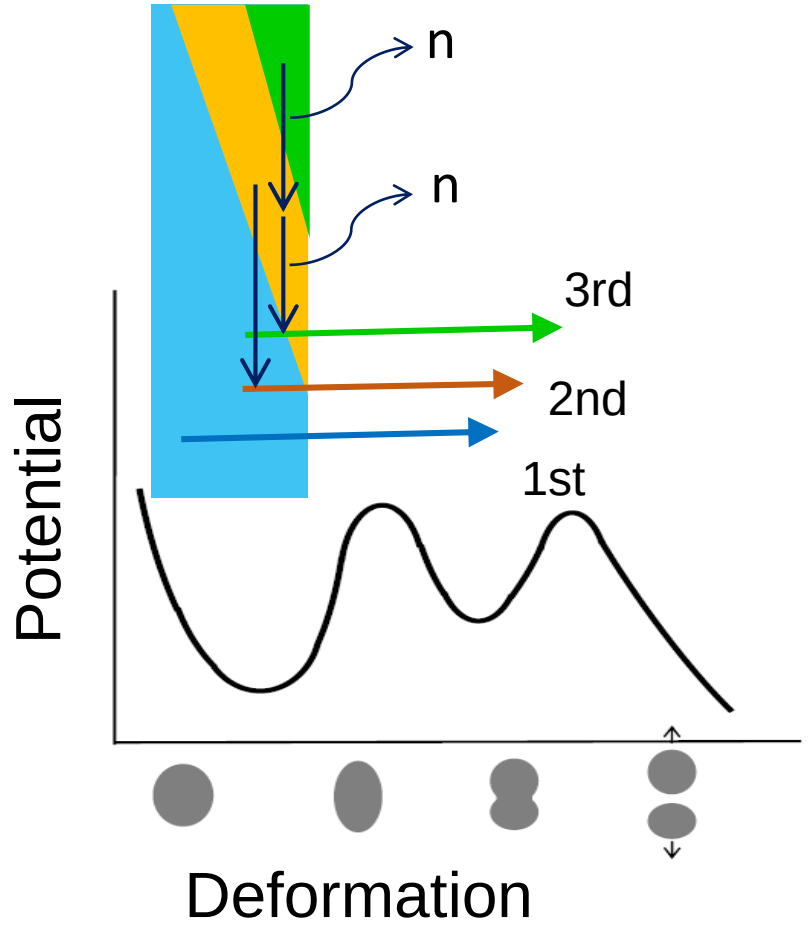
^{18}O (→ $^{248}Cm^*$)
^{17}O (→ $^{249}Cm^*$)
^{16}O (→ $^{250}Cm^*$)

^{15}N (→ $^{251}Bk^*$)
^{14}N (→ $^{252}Bk^*$)

^{14}C (→ $^{252}Cf^*$)
^{13}C (→ $^{253}Cf^*$)
^{12}C (→ $^{254}Cf^*$)

Fission Probability and Fission Barrier Height



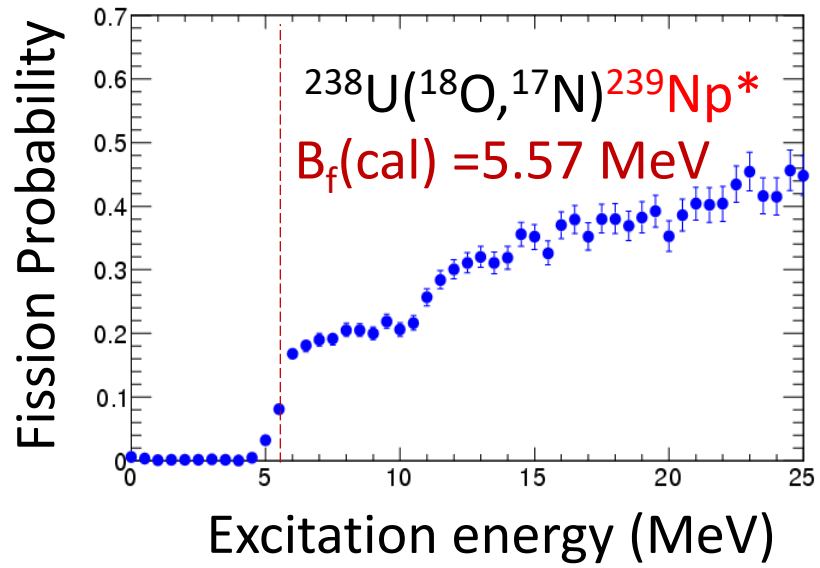


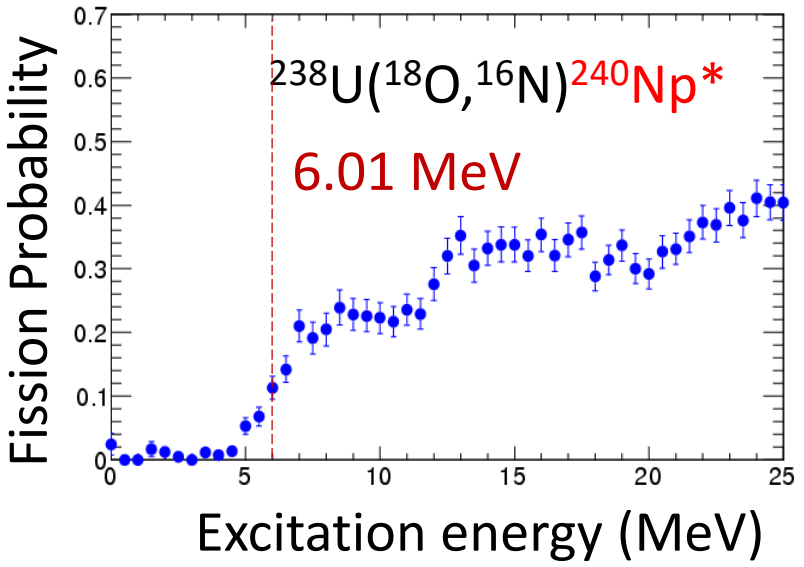
B_f^{exp} = 5.5 MeV

B_f^{cal} = 6.38 MeV (P. Möller)

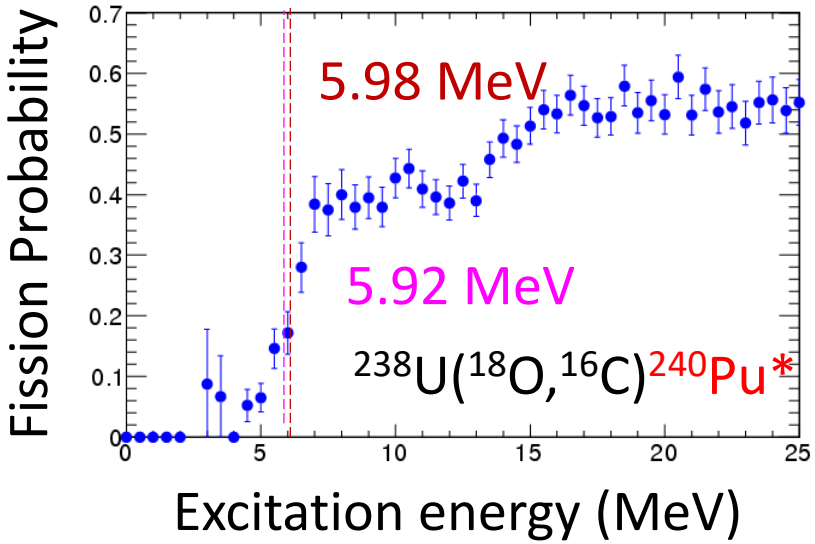
Fission after neutron evaporation is called “Multi-chance fissions”

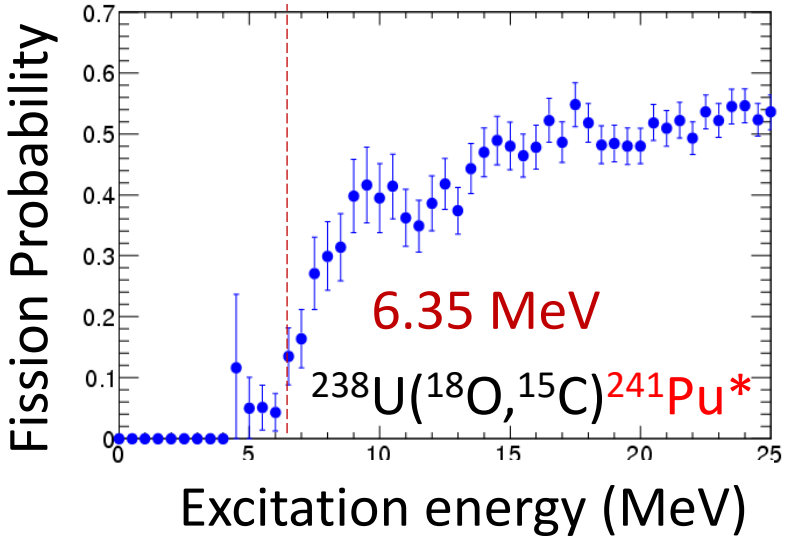
Fission Barrier Height from MNT reactions





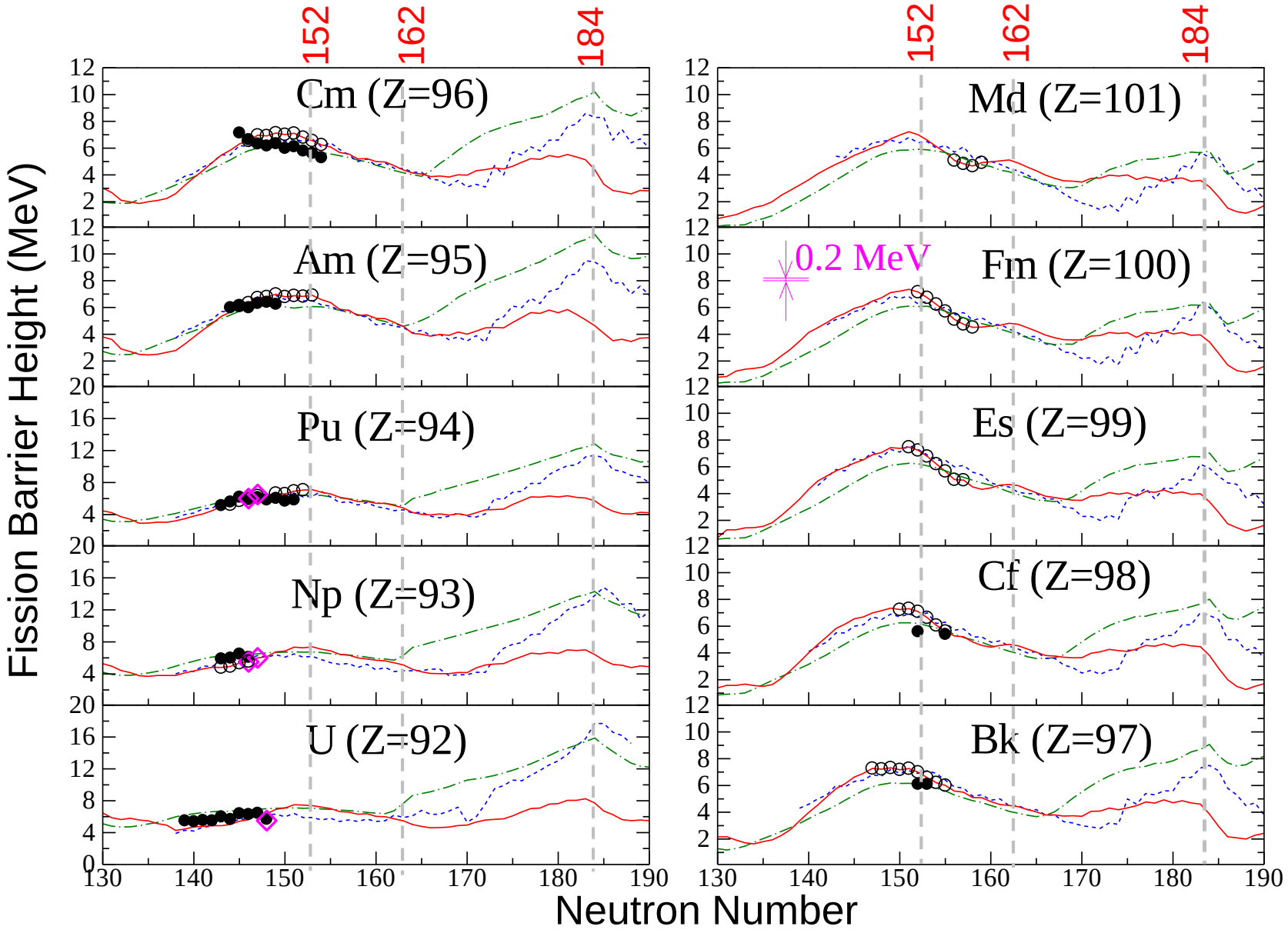
P. Möller et al.,
PRC 79, 064304 (2009)





B.N. Lu et al.,
PRC 89, 014323 (2014)

Extending the Fission Barrier Data using MNT Reactions



Theory (KUYT)

Theory (ETFSI)

Theory (Möller)

● Available Data (33)
RIPL-2, RMP (Bjornholm)

◇ JAEA MNT Setup

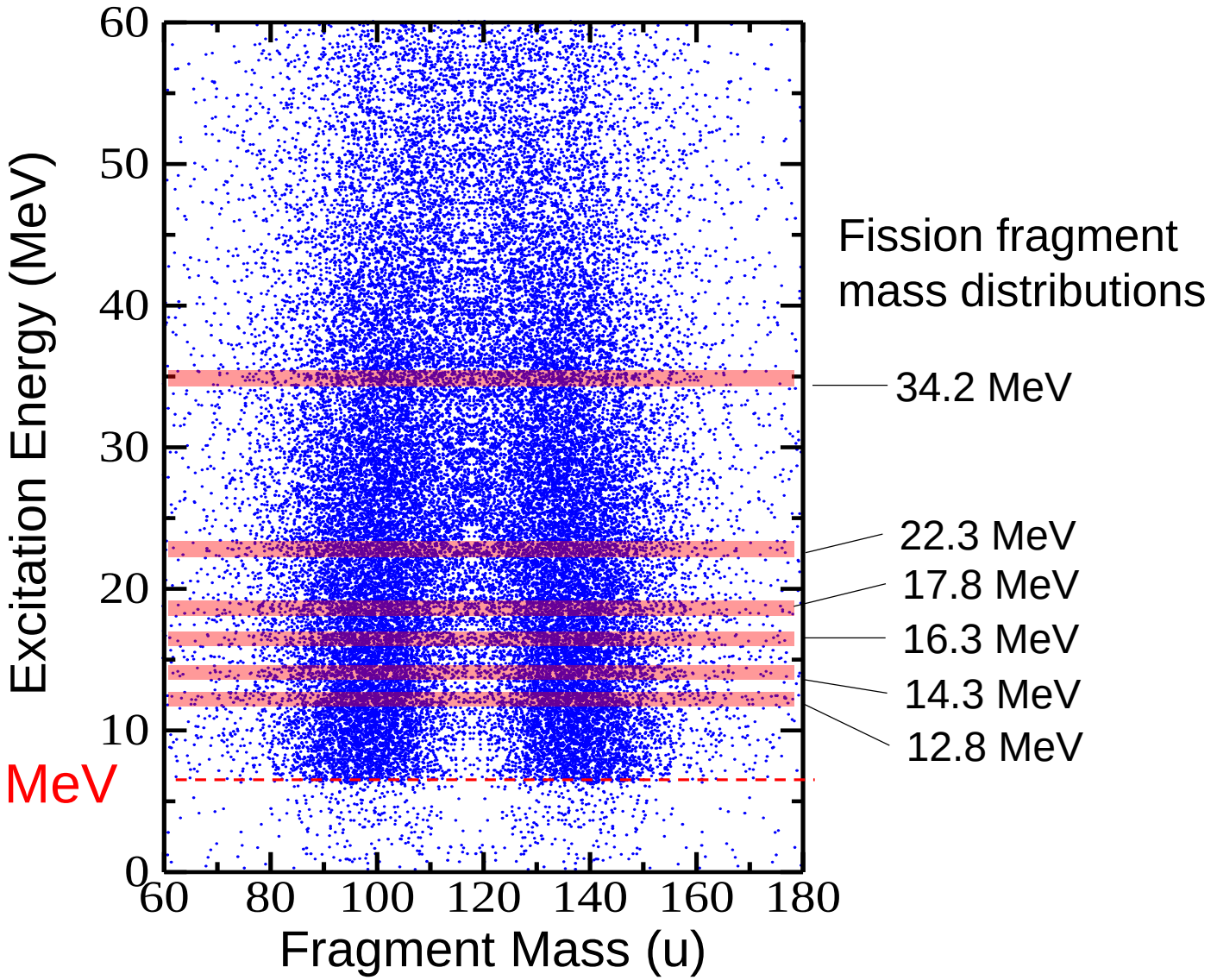
○ **Planned at JAEA**

We plan to obtain 34 new fission barrier data using the reaction of

^{18}O + { ^{237}Np, ^{244}Pu, $^{241,243}Am$, ^{248}Cm, ^{249}Bk, ^{249}Cf, ^{254}Es

Fission Events registered on the Excitation Energy of Compound Nucleus and Fragment Mass

$^{237}Np(^{18}O,^{19}O)^{236}Np^*$



Benchmark of Fission Fragment Mass Distribution (FFMDs)

^{237}Np (^{18}O,^{19}O) $^{236}Np^{*}$

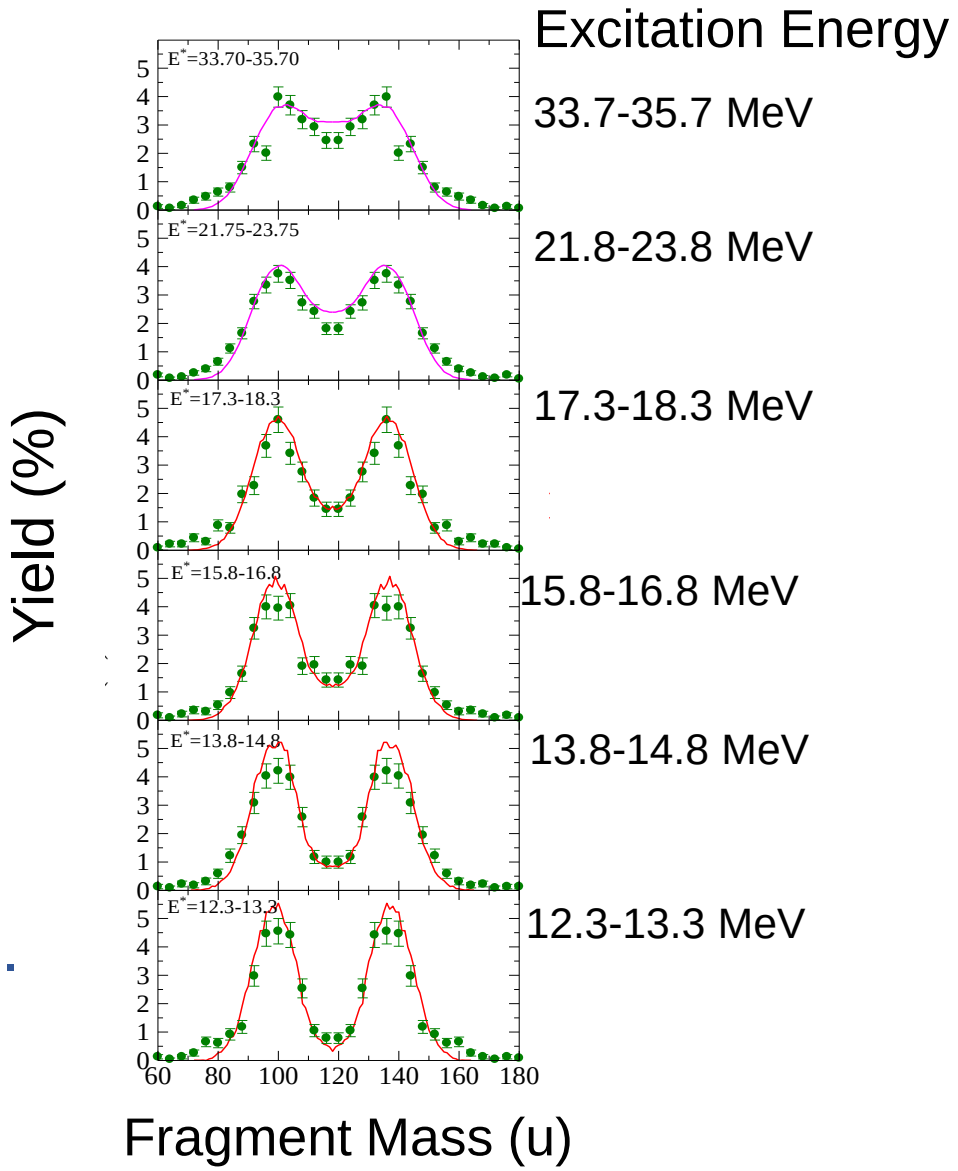
Present Data

$p + {}^{235}U = {}^{236}Np^{*}$

Mulgin (2009)

Ferguson (1973)

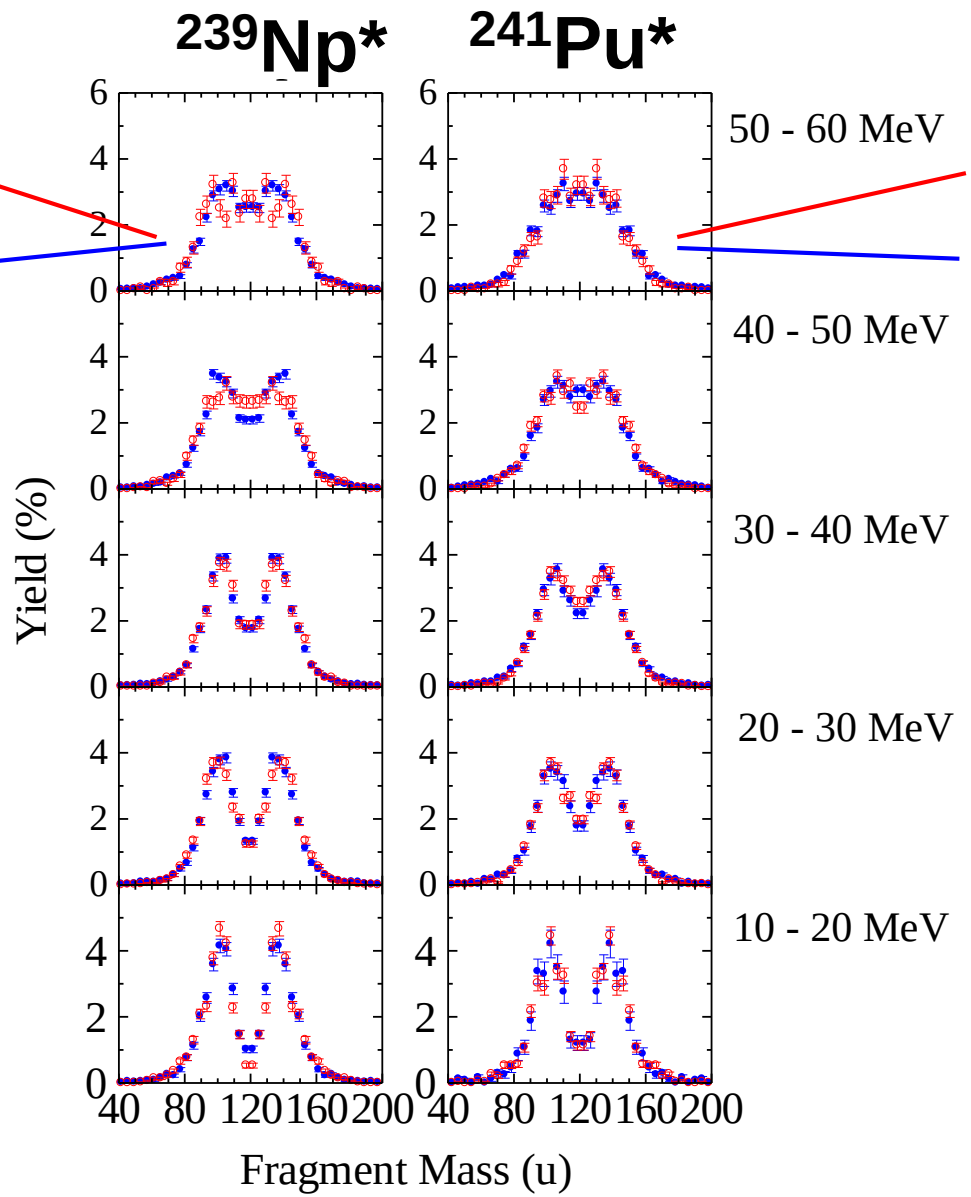
Good agreement with the literature data is found.



FFMDs obtained from different transfer channels

$^{238}U(^{18}O,^{17}N)$ **$^{239}Np^*$**

$^{237}Np(^{18}O,^{16}O)$**$^{239}Np^*$**

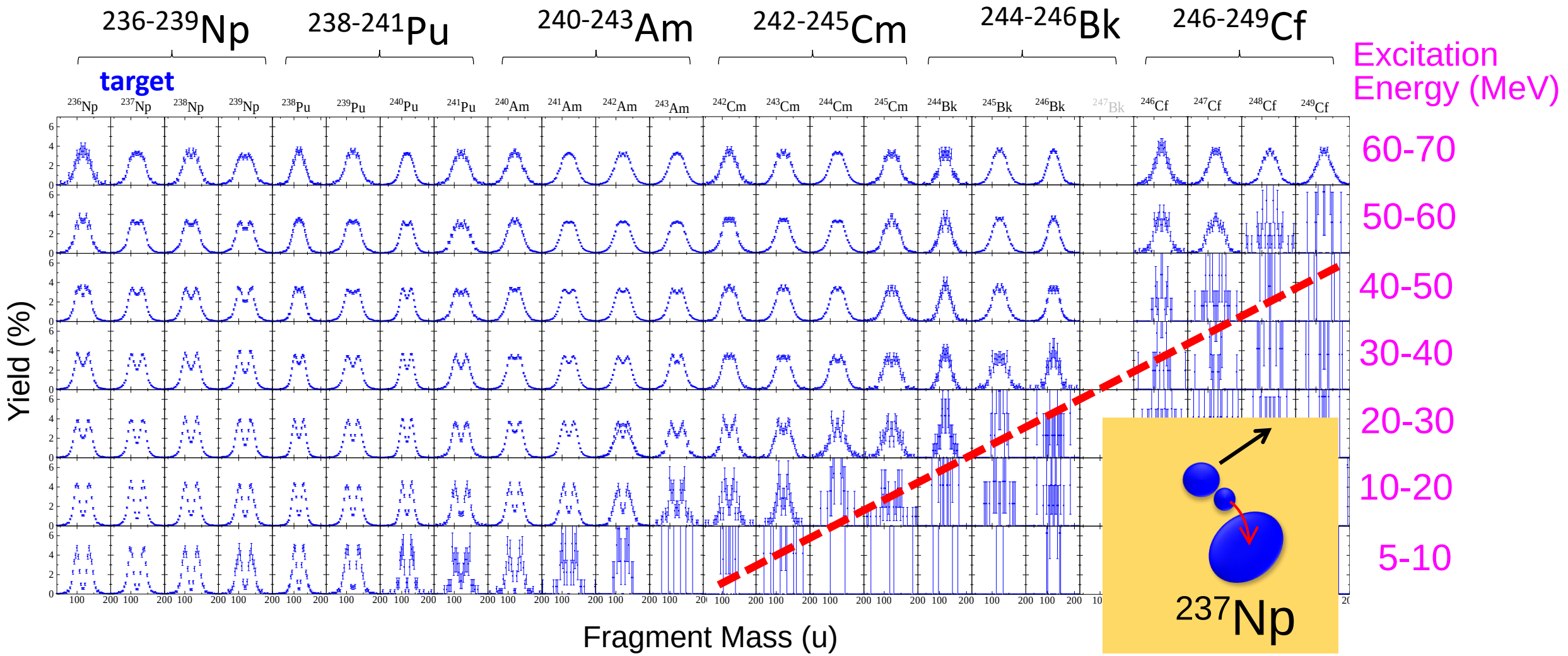


$^{238}U(^{18}O,^{15}C)$ **$^{241}Pu^*$**

$^{237}Np(^{18}O,^{14}N)$**$^{241}Pu^*$**

FFMDs are independent of transfer channels.

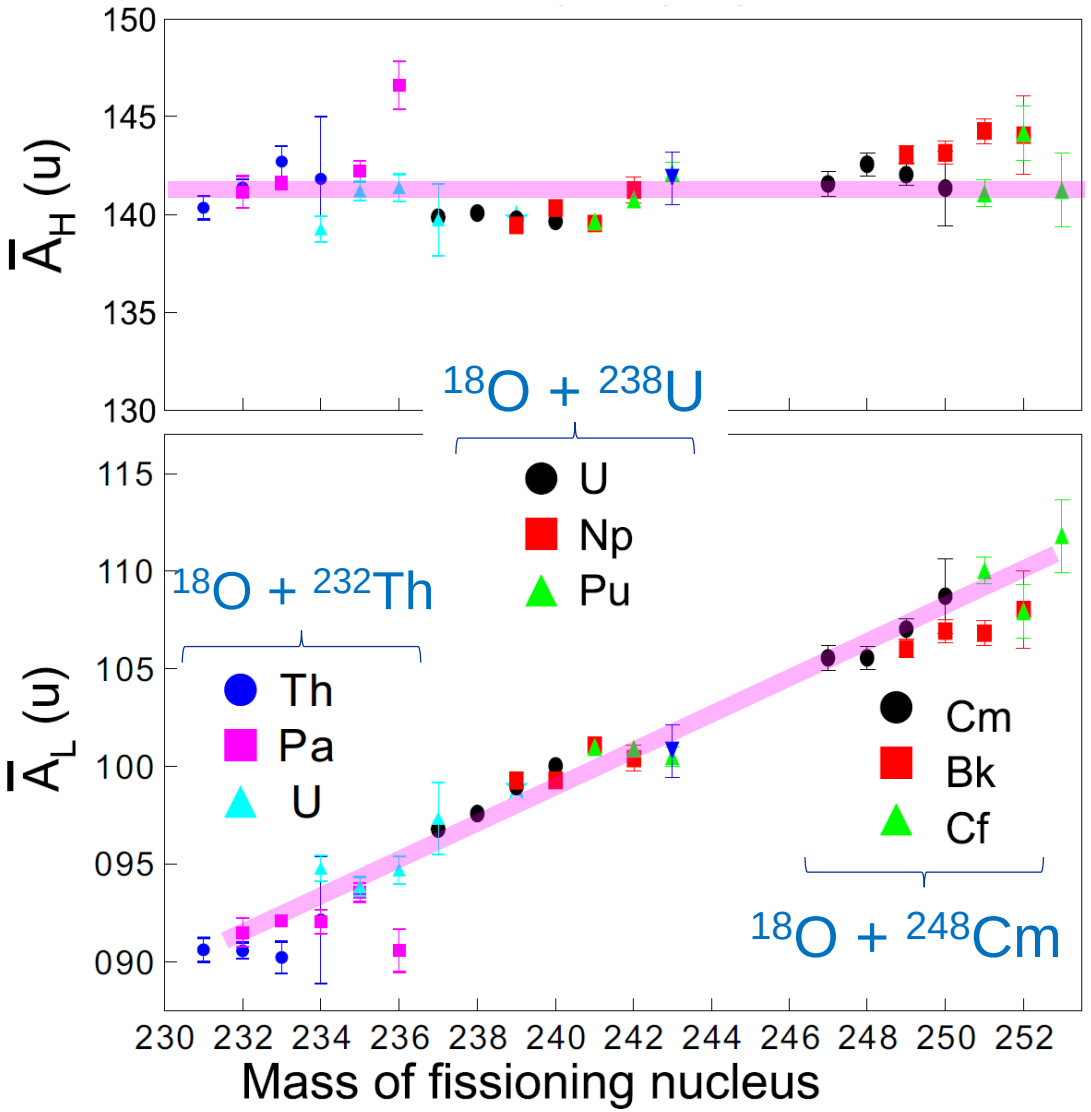
Fission Fragment Mass Distributions (FFMDs) obtained in ^{18}O + ^{237}Np



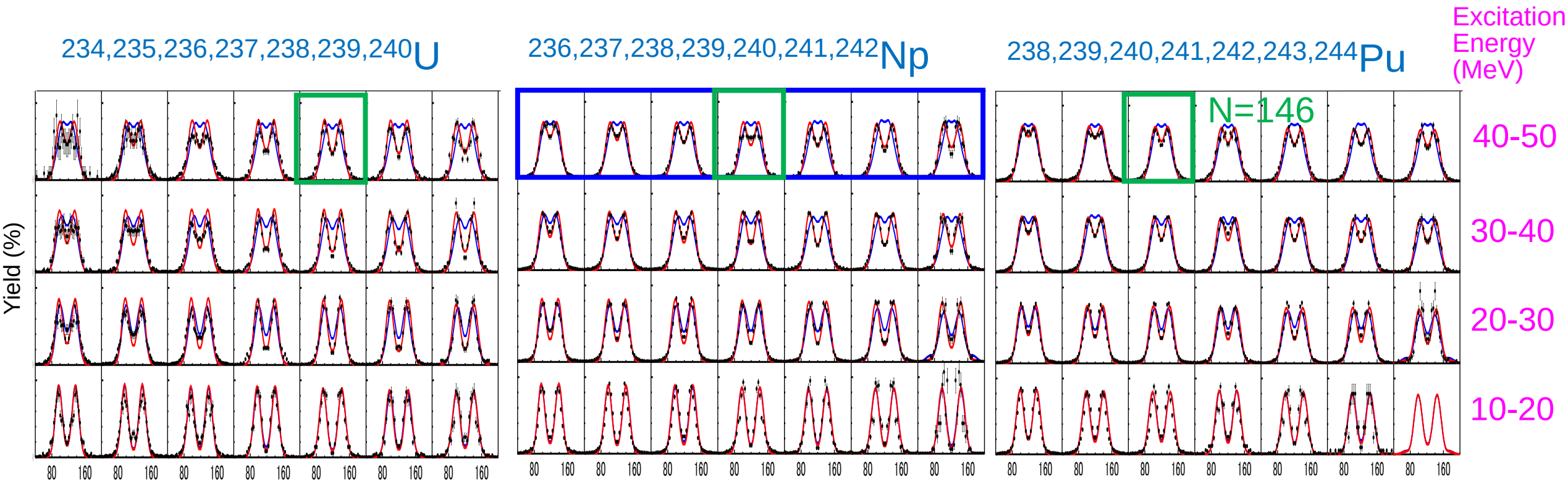
Fission data for 23 nuclides and their excitation energy dependence are obtained in the single experiment.

Average Masses of Heavy（H）and Light（L）Fragments

Excitation Energy Range
= 10 - 20 MeV



Experimental Data in Comparison with Langevin Calculation



Data from $^{18}O+^{232}Th$ and $^{18}O + ^{238}U$

Without multi-chance fission

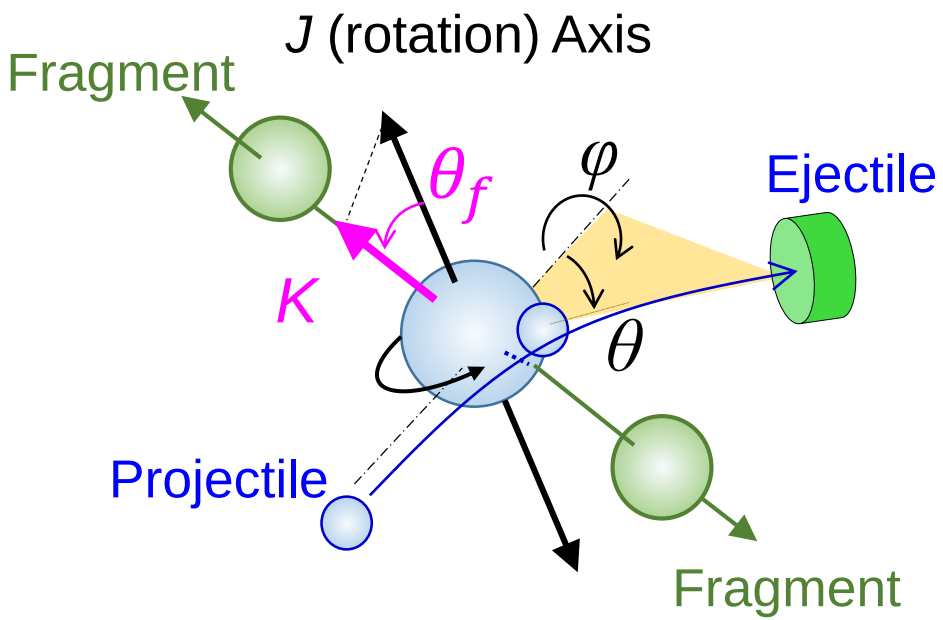
With multi-chance fission

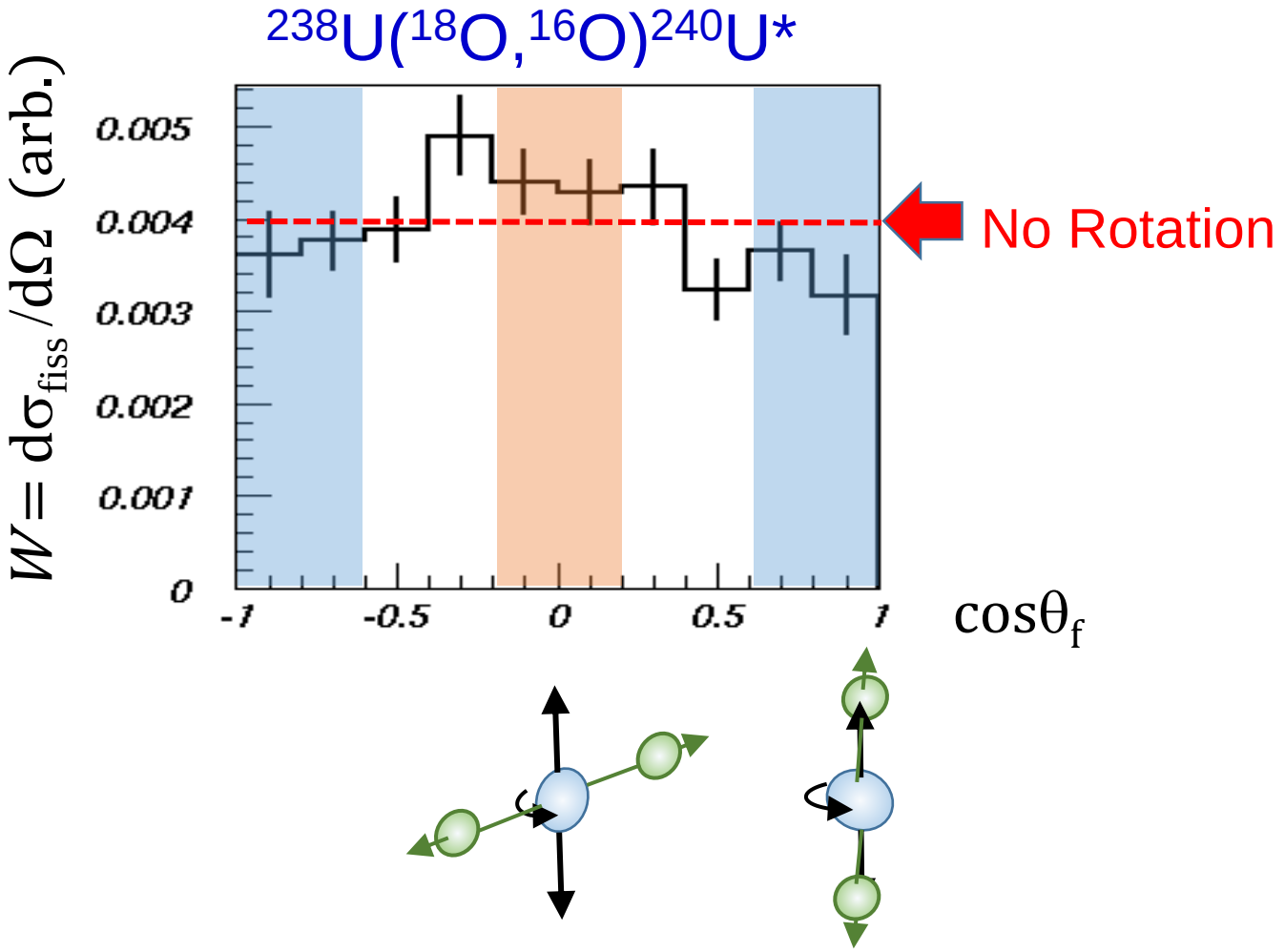
Experimental data

Langevin calculation by S. Tanaka, Kindai Univ.
Y. Aritomo and S. Chiba, Phys. Rev. C **88**, 044614 (2013).

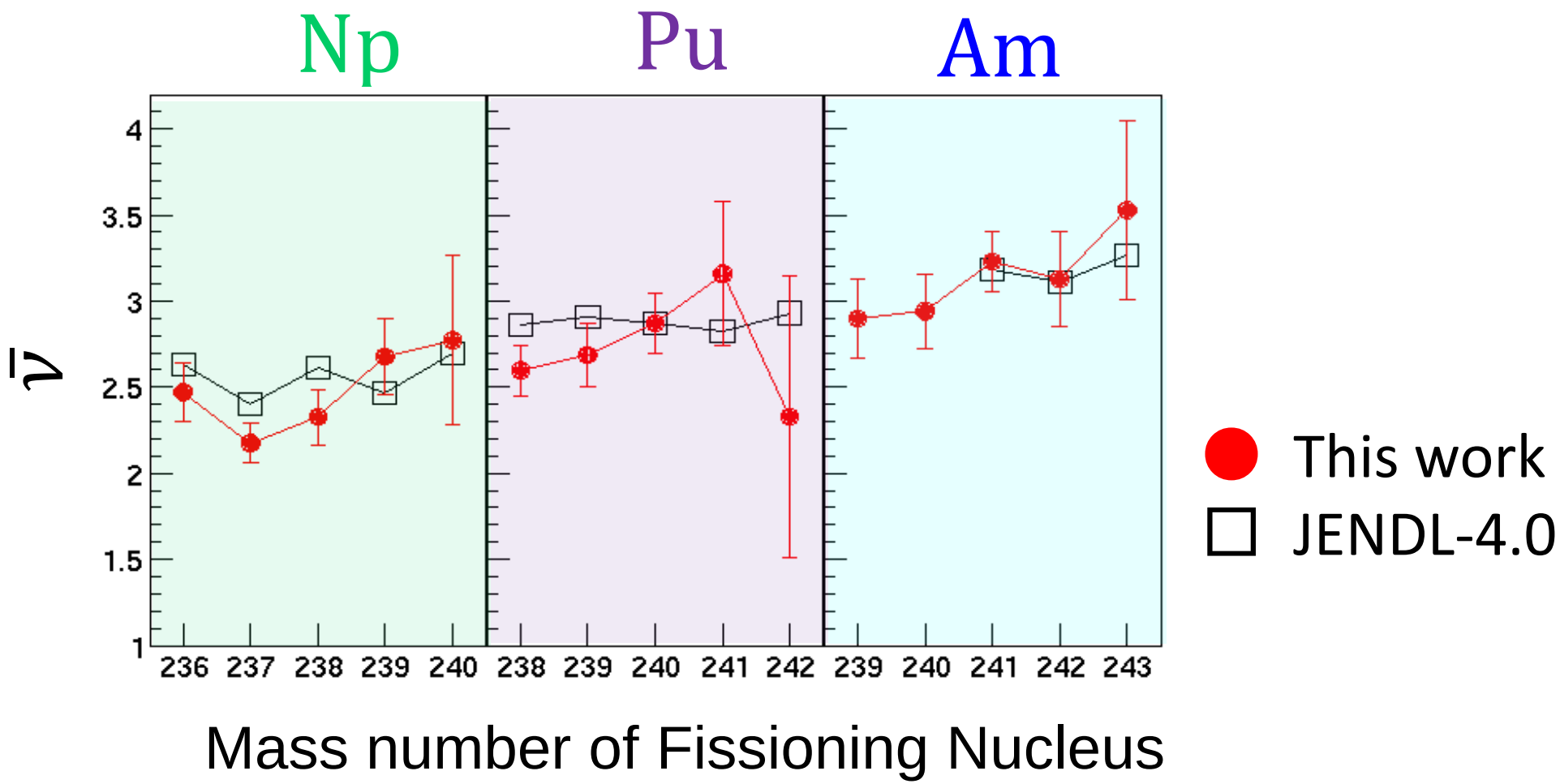
Fission Fragment Angular Distribution

Fission fragment angular distribution has Information on spins of compound nucleus.



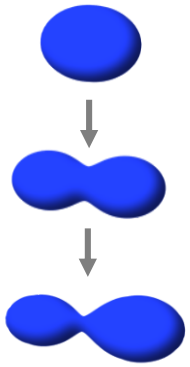


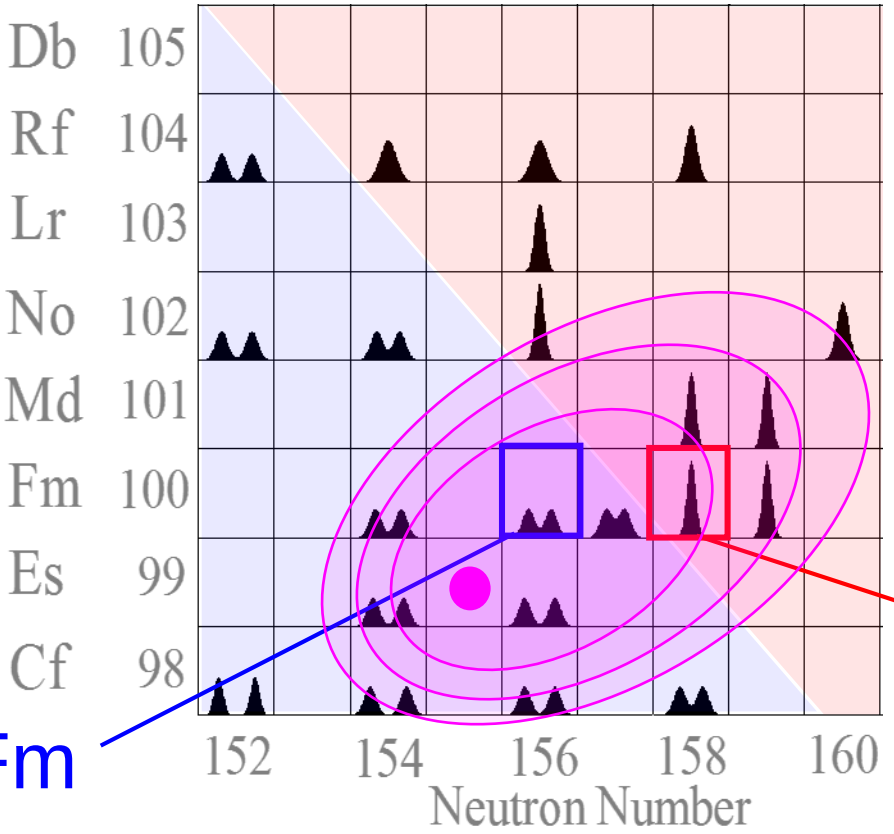
Neutron Multiplicity at the Excitation Energy corresponding to Thermal Neutron-induced Fissions



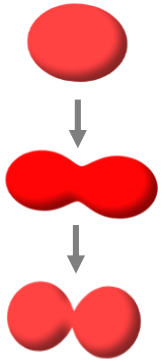
Fissions of Fermium and Heavier-element Isotopes

Asymmetric





Sharp Symmetric



Literature data for Spontaneous fission

$^{254}_{99}Es$ ($T_{1/2}$=276 days)

From Oak Ridge National Laboratory

Summary

- ☑ Multi-nucleon transfer reaction is a powerful tool to study fission and to take fission data.
- ☑ We plan to measure the fission barrier data up to mendelevium (Md), the element 101.
- ☑ We started to obtain fission data for fermium region using ^{254}Es, for the strong benchmark of fission modesl.