Alpha-decay Spectroscopy of Transfermium Nuclei at JAEA

Advanced Science Research Center, Japan Atomic Energy Agency

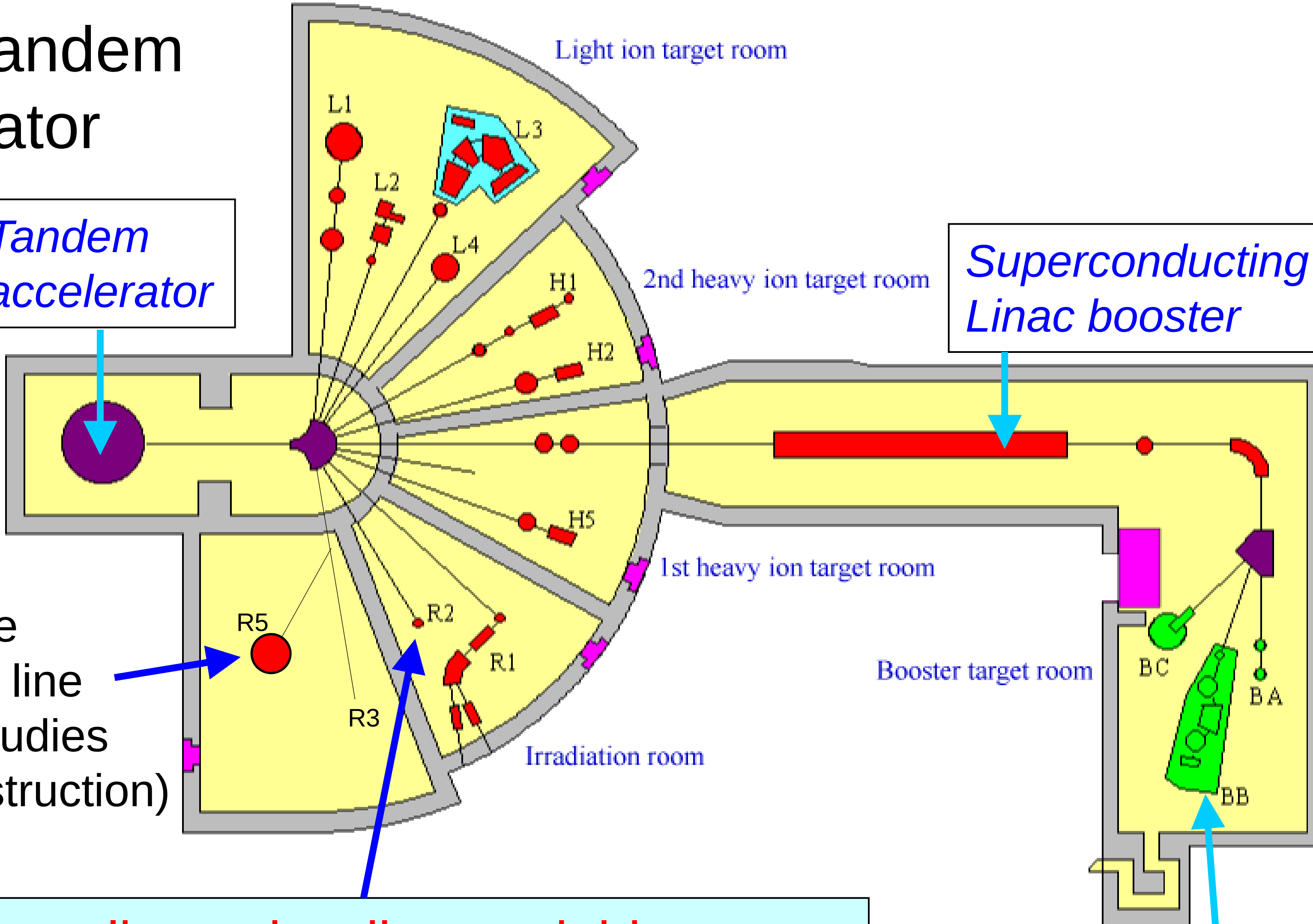
Masato Asai

JAEA Tandem accelerator

JAEA Tandem accelerator

Tandem accelerator

Superconducting Linac booster



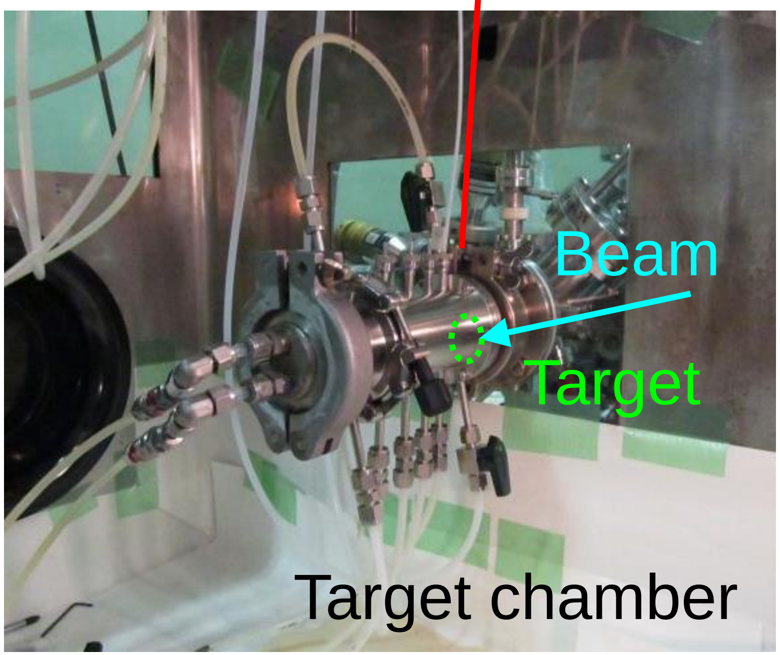
New actinide target beam line for fission studies (Under construction)

Recoil mass separator (RMS)

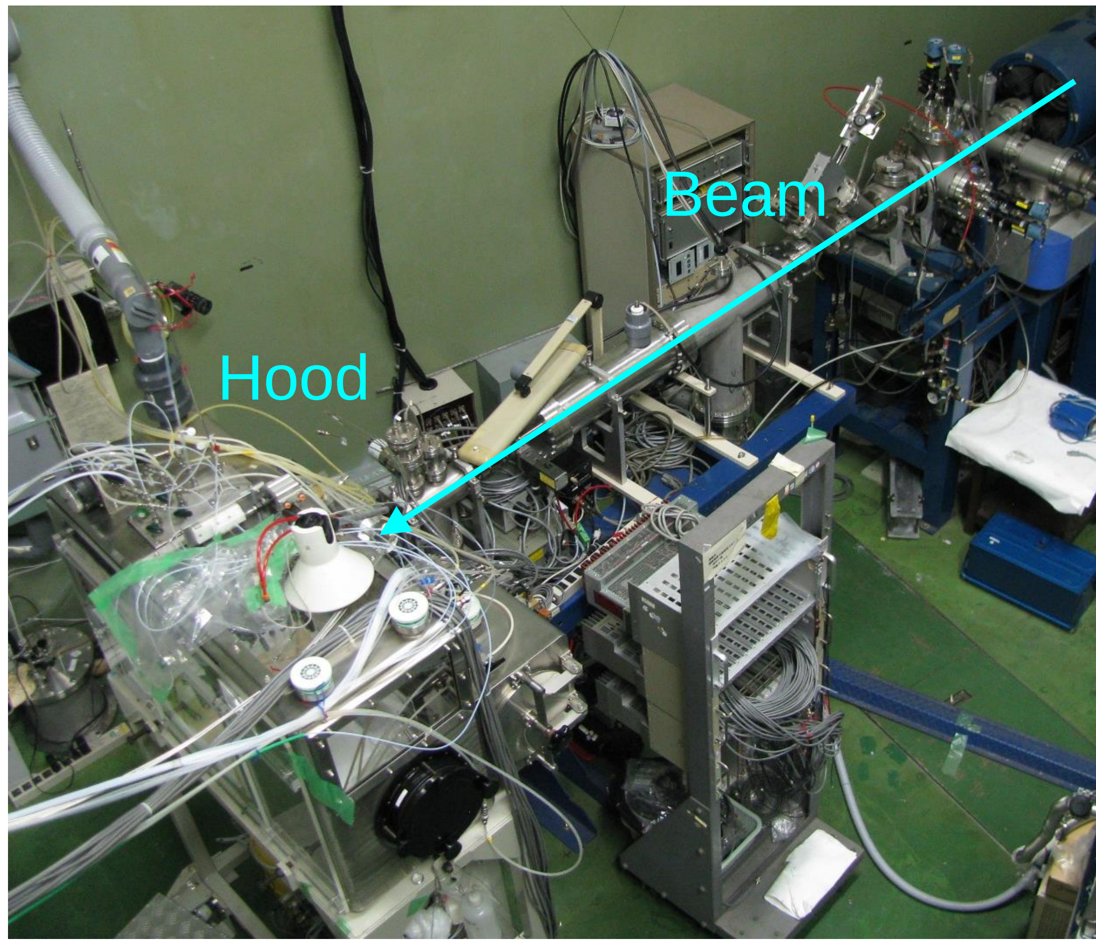
- Beam line to irradiate actinide target
- Gas-jet transport system
- On-line isotope separator (ISOL)

Actinide targets available at JAEA tandem

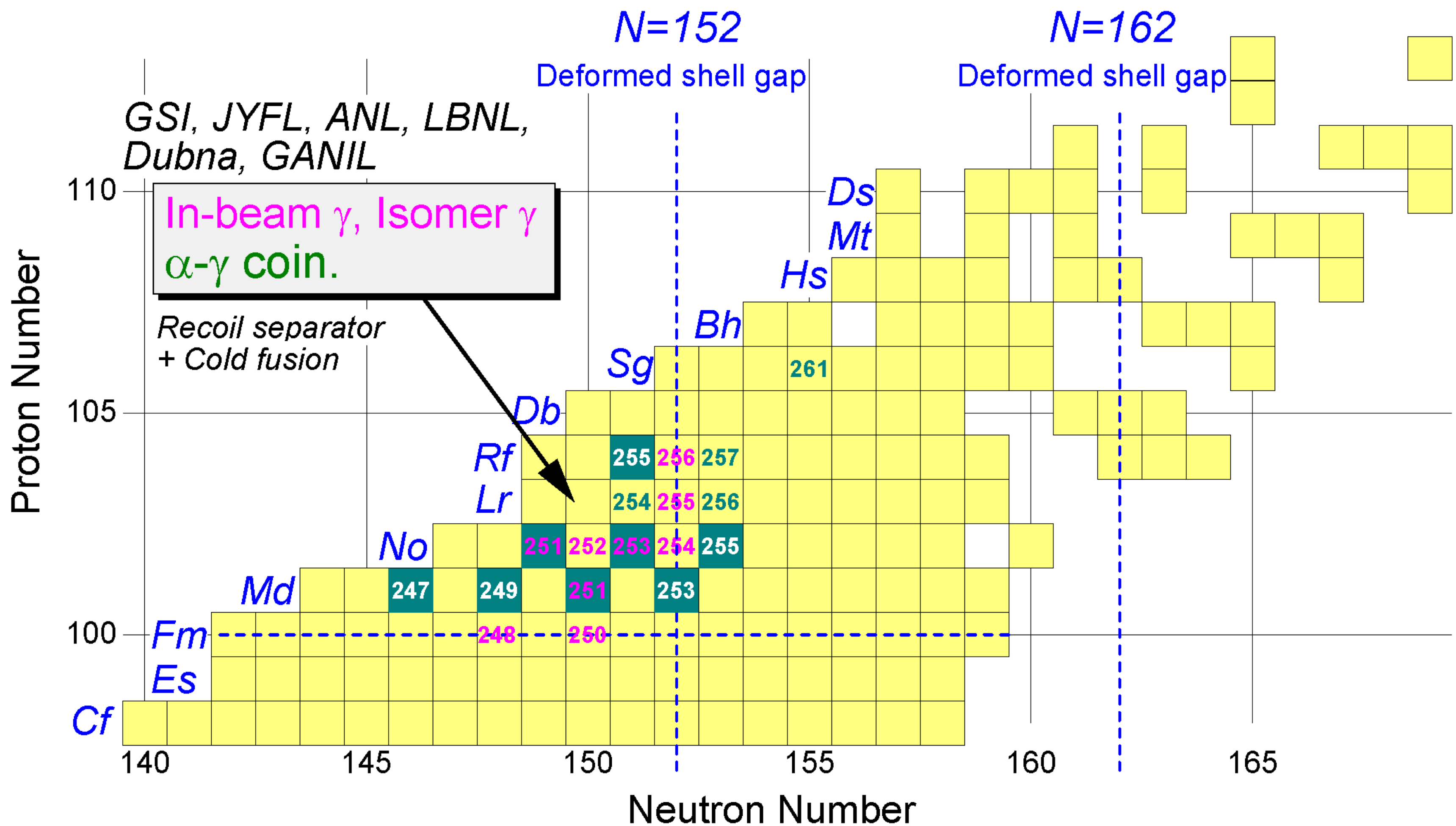
^{232}Th	^{241,243}Am
^{231}Pa	^{248}Cm
^{232}U, ^{233}U, ^{235}U, ^{238}U	^{249,251}Cf
^{237}Np	
^{239}Pu, ^{244}Pu	



Actinide target beam line



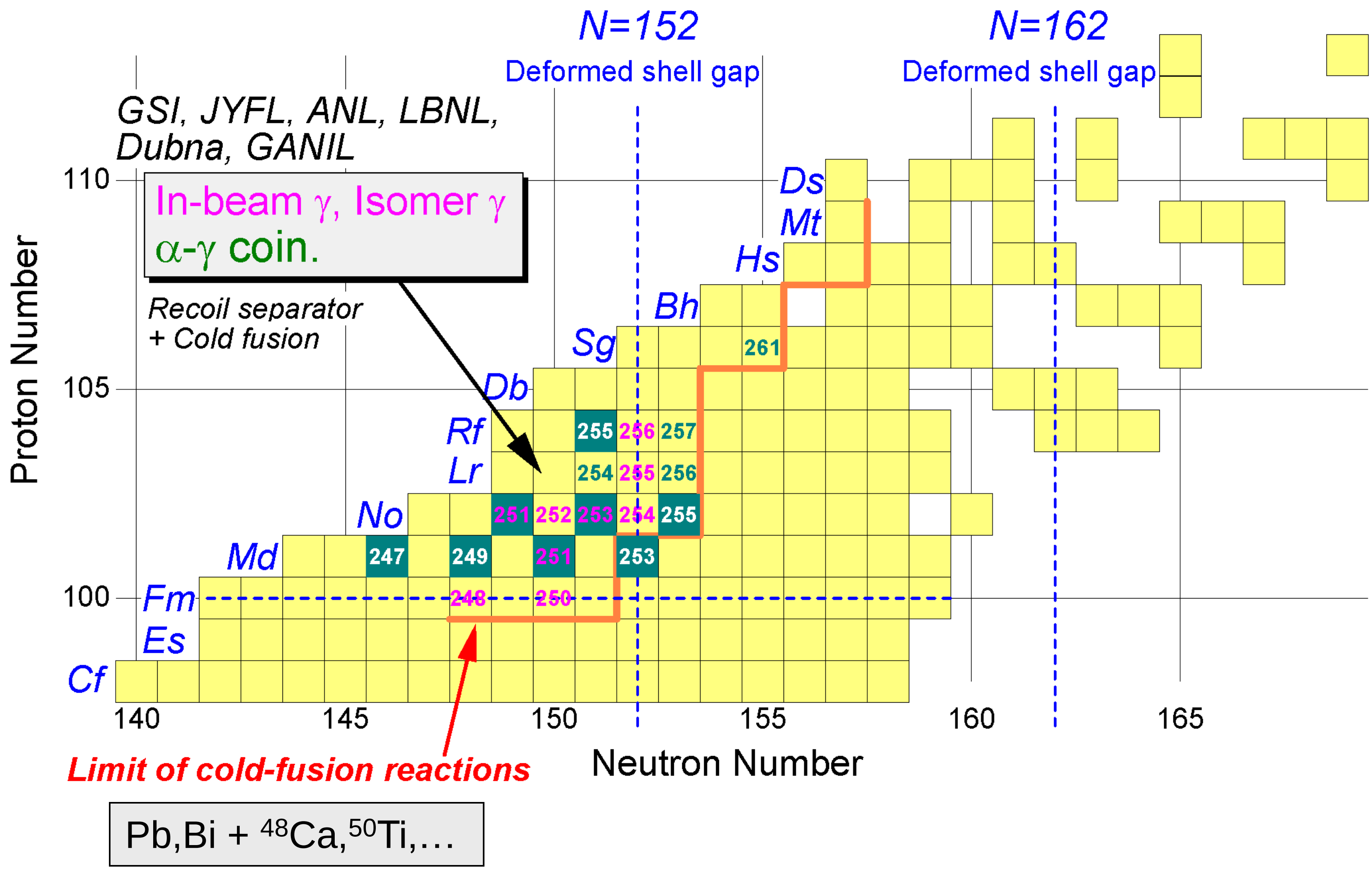
Current status of spectroscopic studies for superheavy nuclei



Pb,Bi + ^{48}Ca,^{50}Ti,…

Spin-parity and configuration assignments are very scarce !
especially in the region of $Z > 101$ and $N > 153$

Current status of spectroscopic studies for superheavy nuclei



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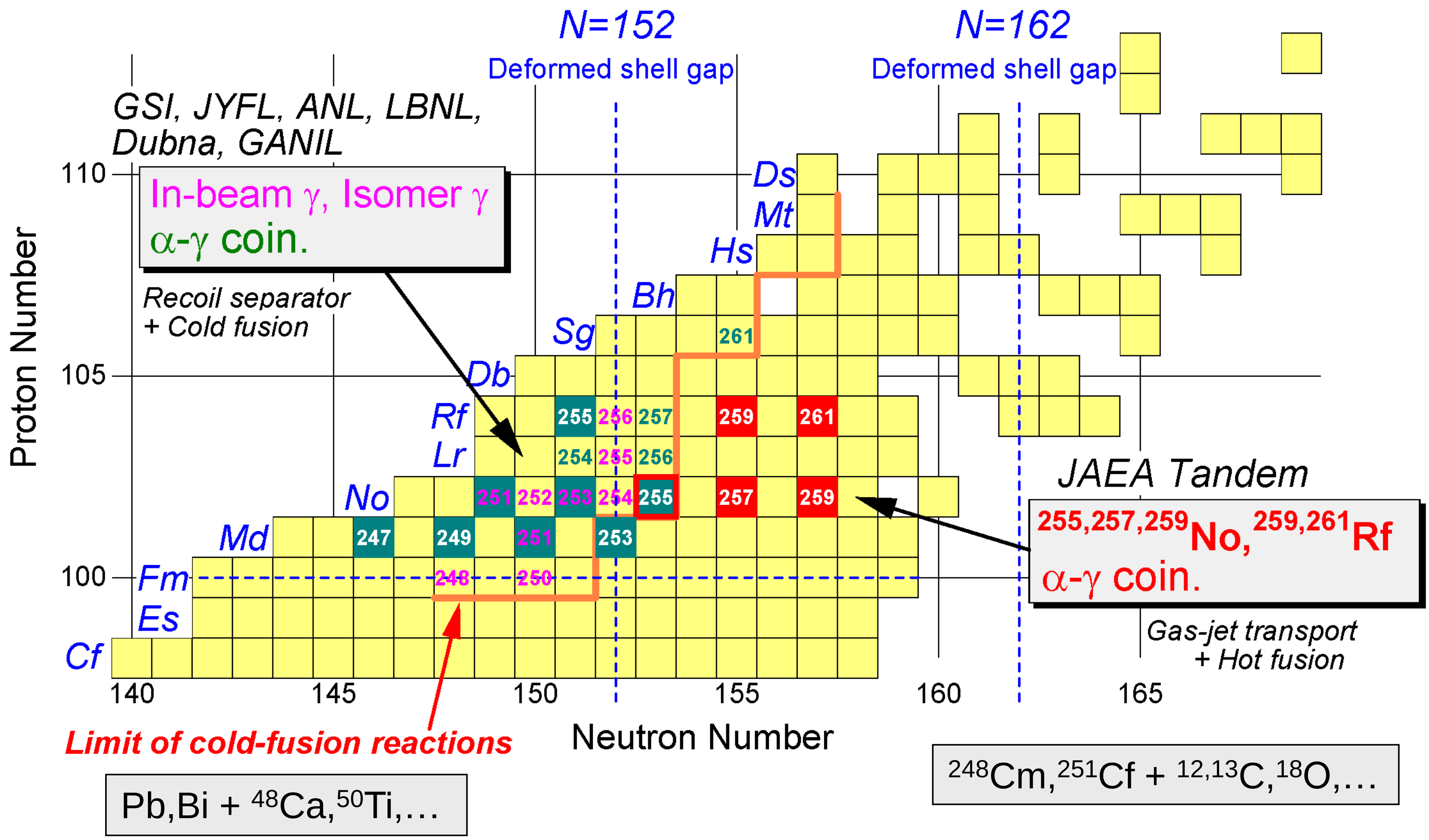
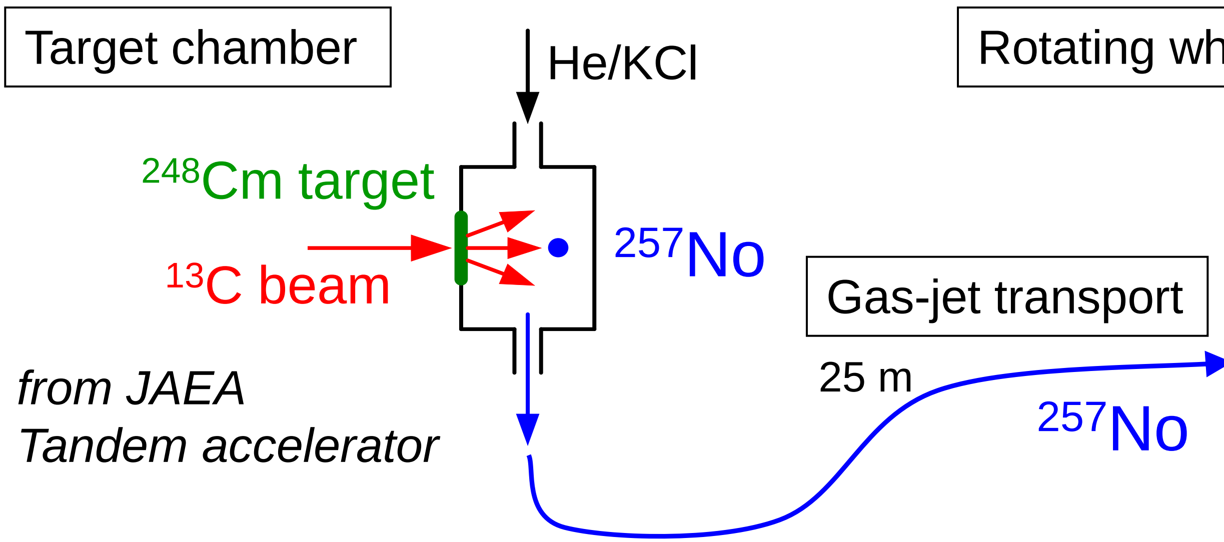
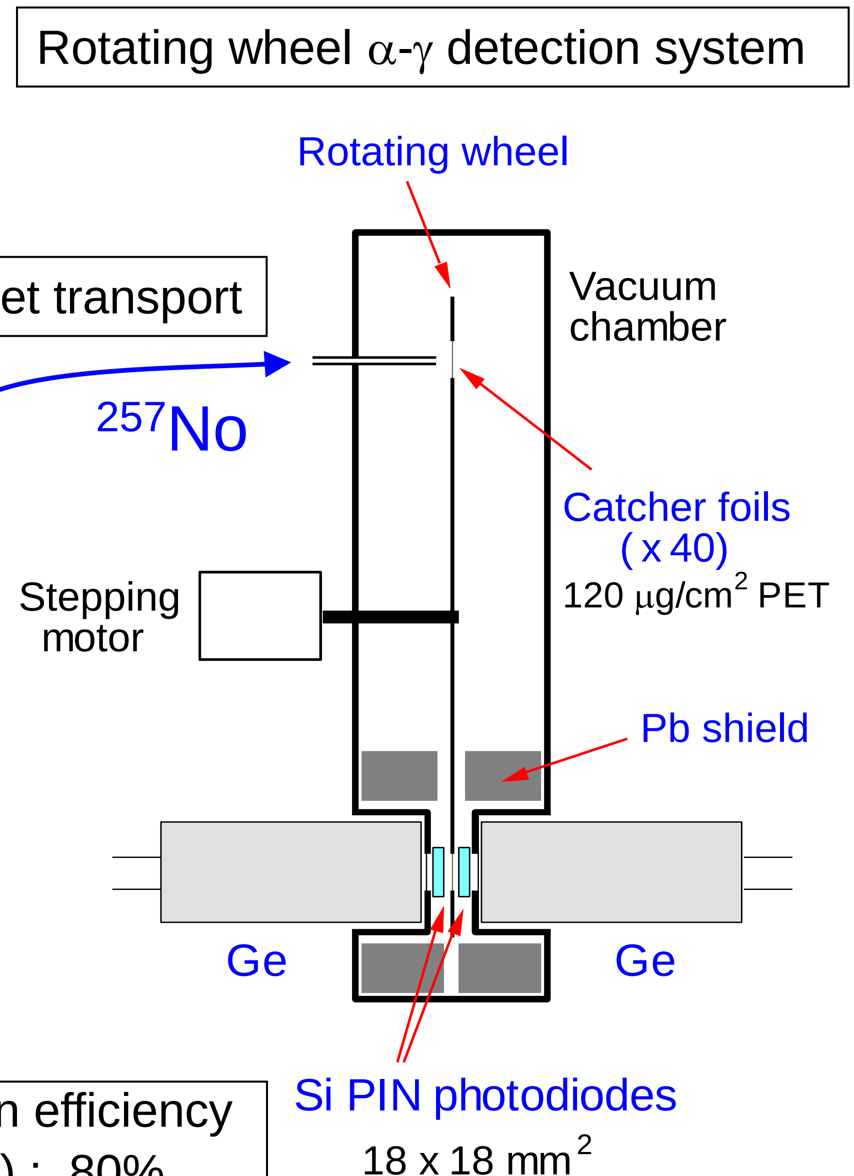
Current status of spectroscopic studies for superheavy nuclei

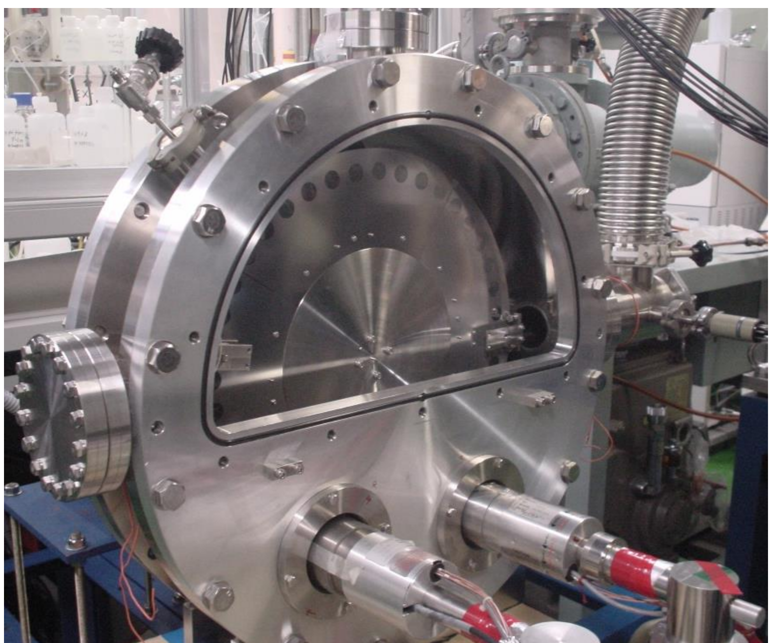


Spin-parity and configuration assignments are very scarce !
especially in the region of Z > 101 and N > 153

Experimental setup: *Gas-jet transport + Rotating wheel system*





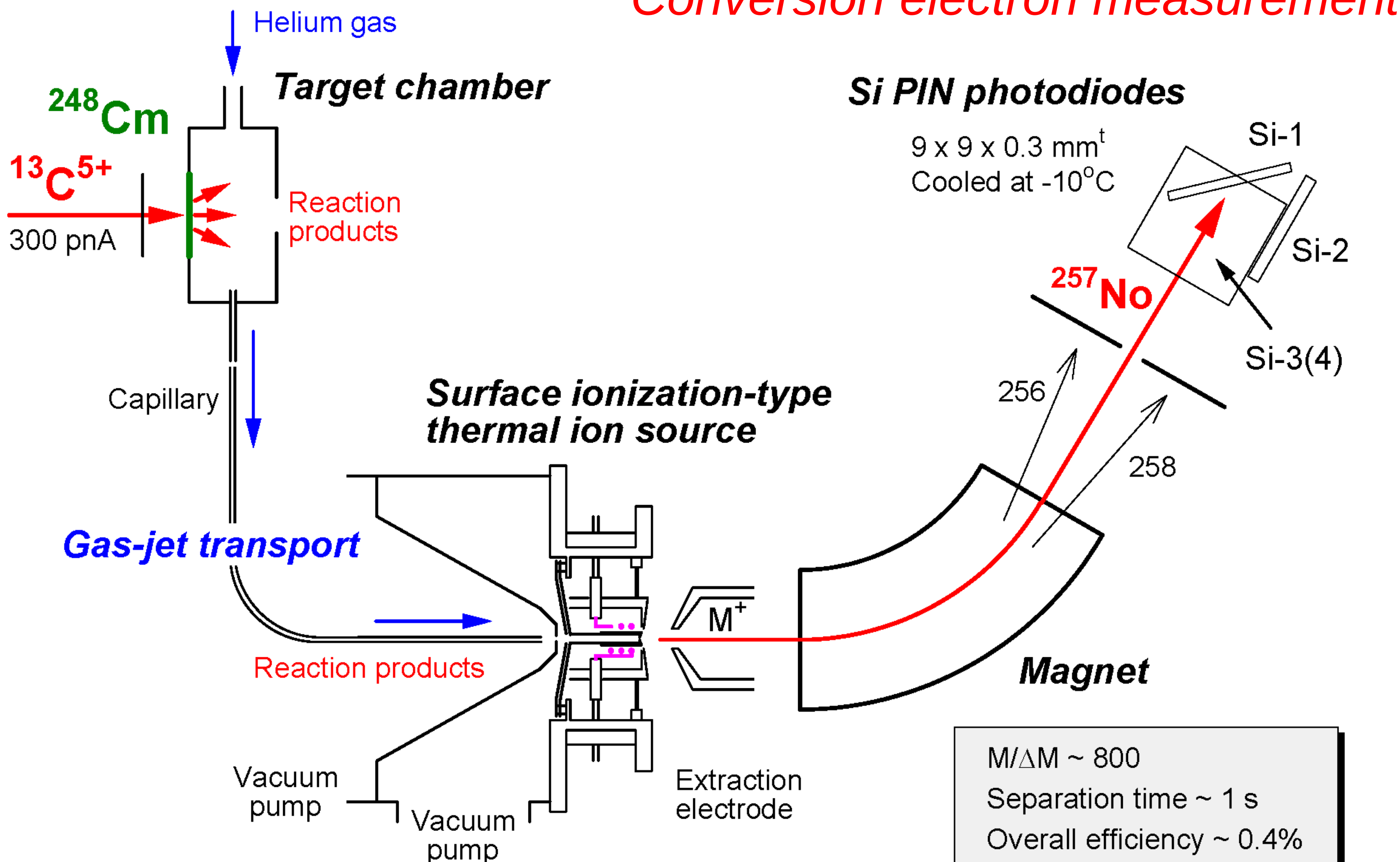


Detection efficiency
Si (α) : 80%
Ge (γ) : 30%

Experimental setup (2):

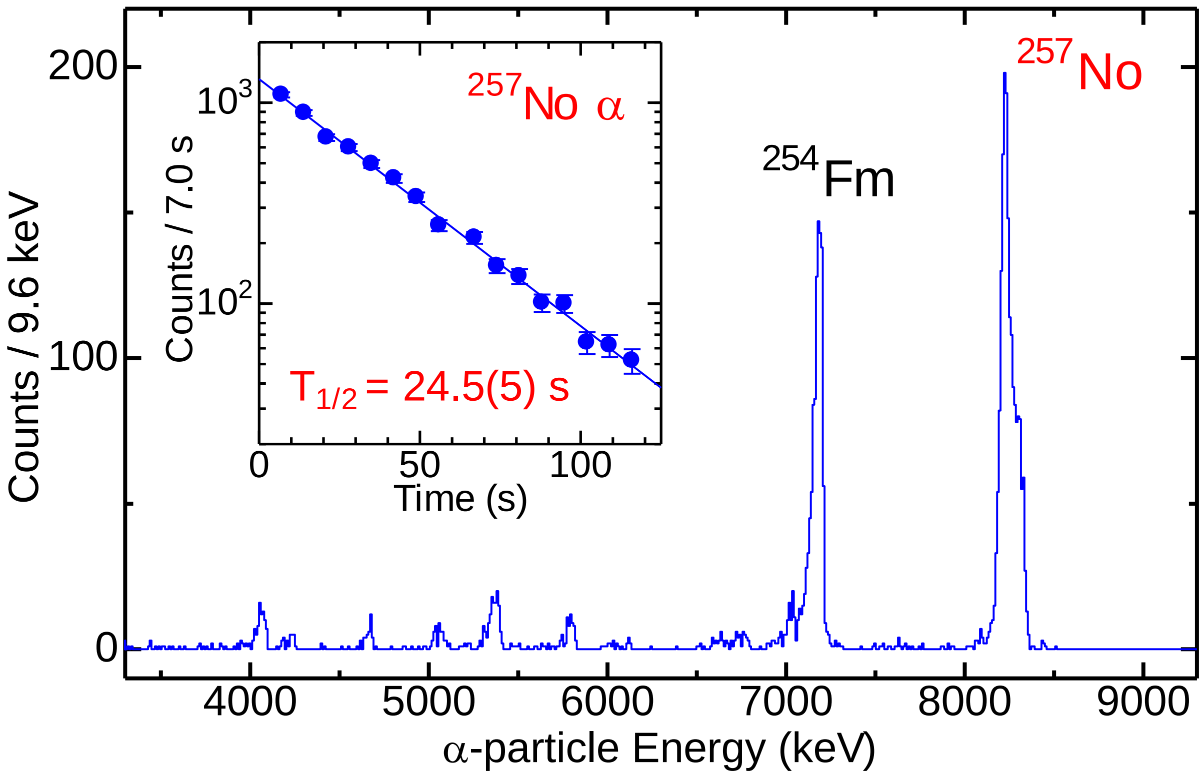
Gas-jet coupled on-line isotope separator (ISOL)

Conversion electron measurement

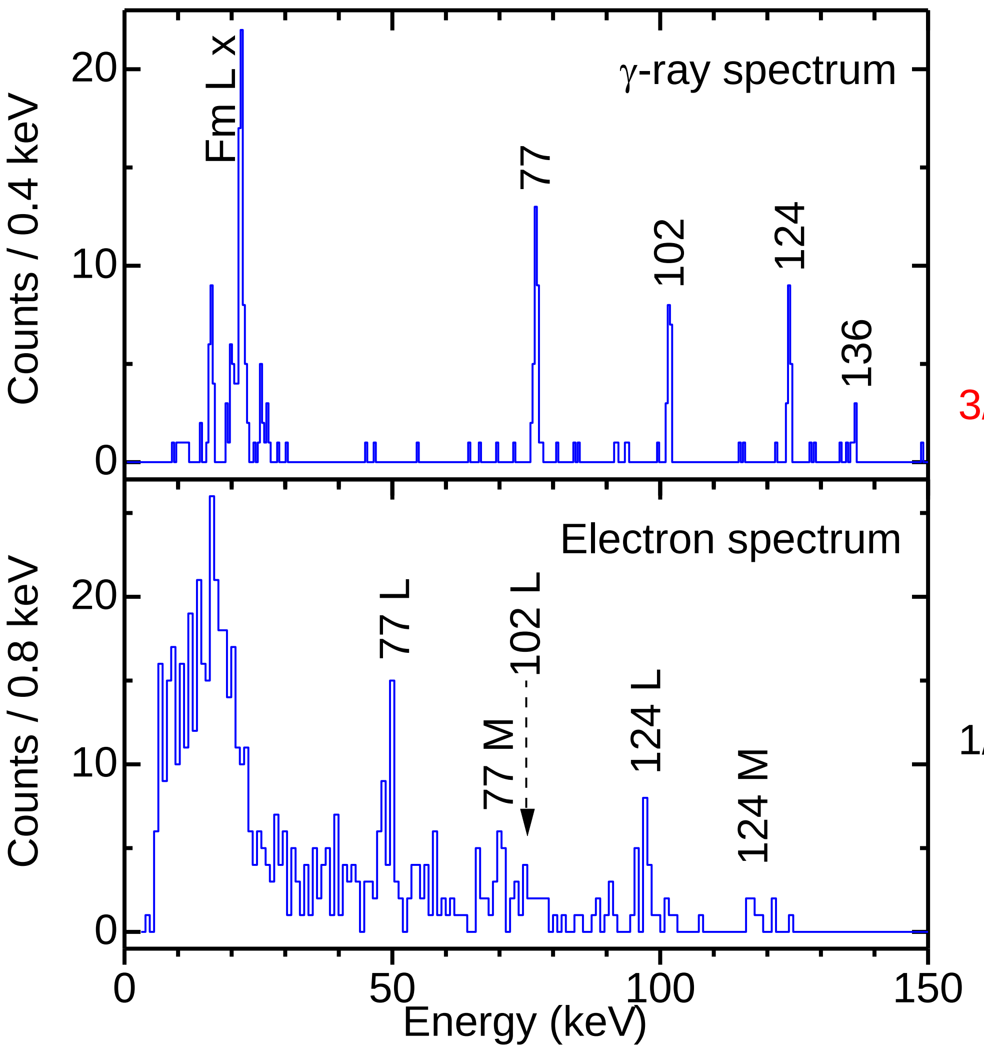


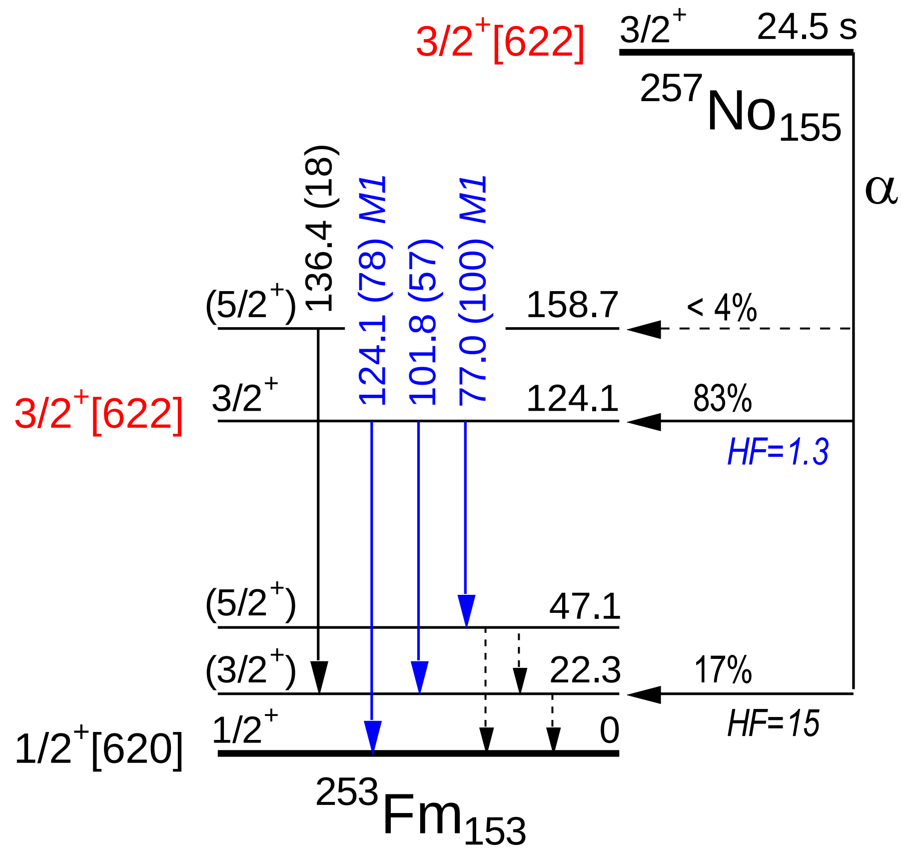
M/ΔM ~ 800
Separation time ~ 1 s
Overall efficiency ~ 0.4%

α-singles spectrum of ^{257}No measured by using gas-jet transport



α-γ(e) coincidence result for ^{257}No





The ground-state configuration of ^{257}No was identified.

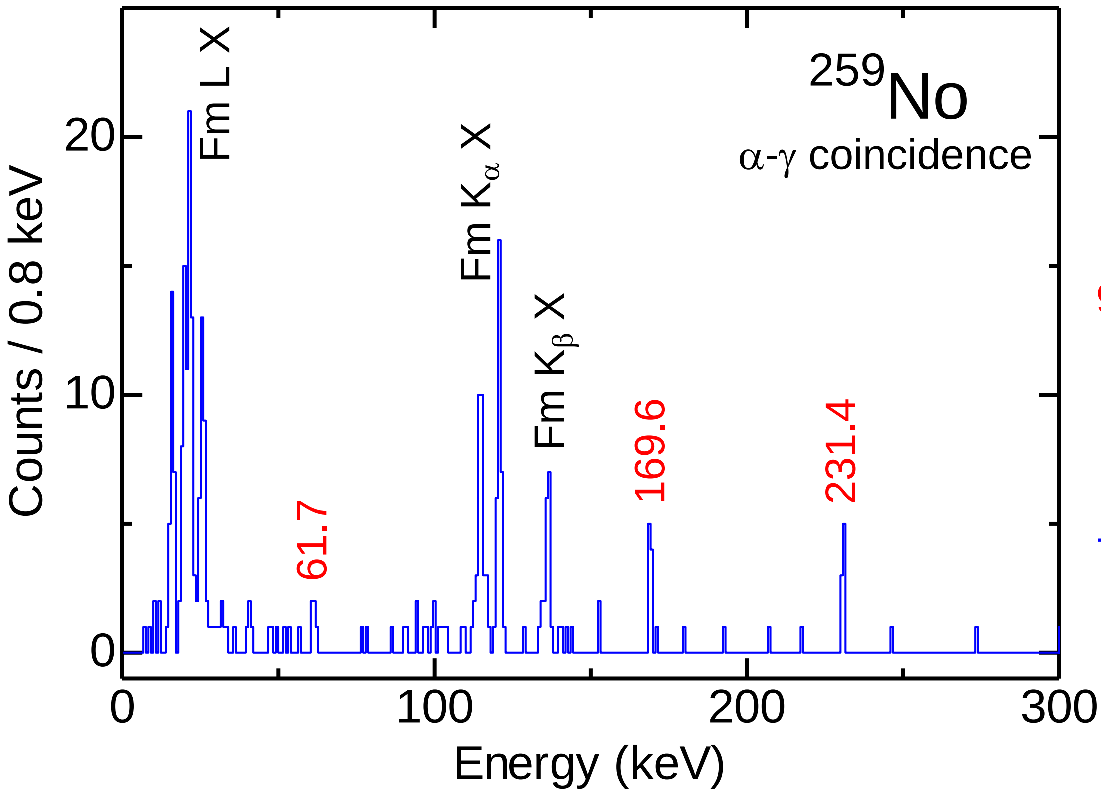
3/2+[622]

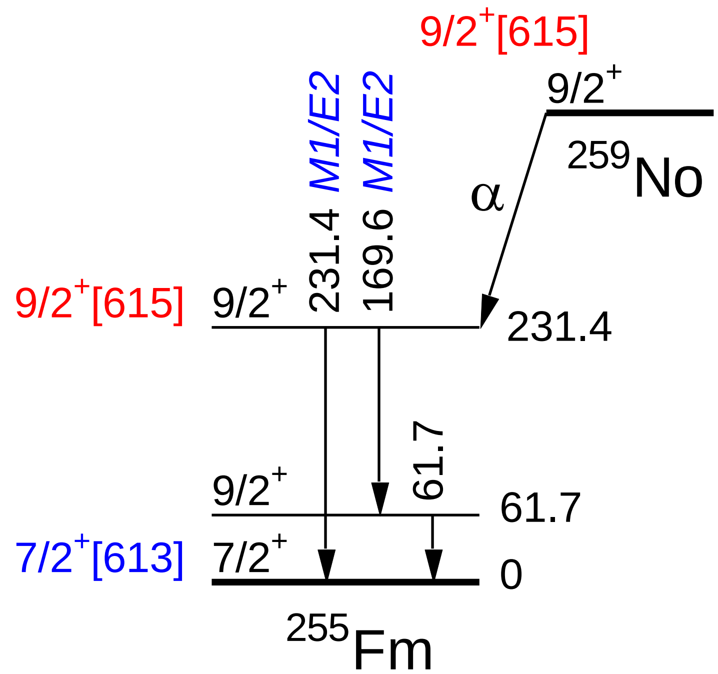
M. Asai *et al.*, PRL 95, 102502 (2005).

α-γ coincidence measurement for ^{259}No

^{248}Cm(^{18}O,α3n)^{259}No: 13 nb

~900 α counts for 9 days





The 169 and 231 keV γ rays were also observed in the EC decay of ^{255}Md (g.s. 7/2$^-$[514]).

Ahmad *et al*., PRC 61 (2000) 044301.

Production of ^{259}Rf

- ^{249}Cf(^{13}C,3n)^{259}Rf ~ 6 nb
- ^{248}Cm(^{16}O,5n)^{259}Rf ~ 5 nb
- ^{251}Cf(^{12}C,4n)^{259}Rf ~ 100 nb (HIVAP calc.)

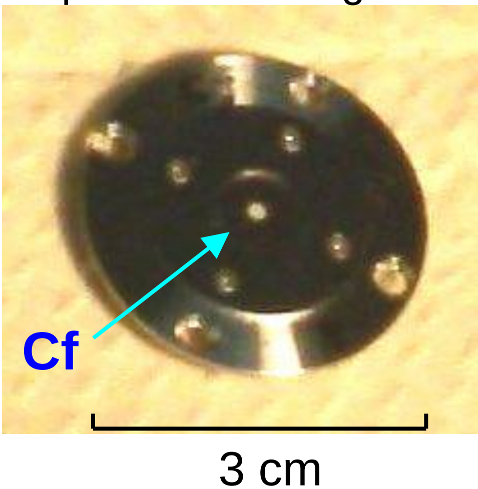
It is almost impossible to obtain a large amount of isotopically enriched ^{251}Cf material !

Mixed Cf target

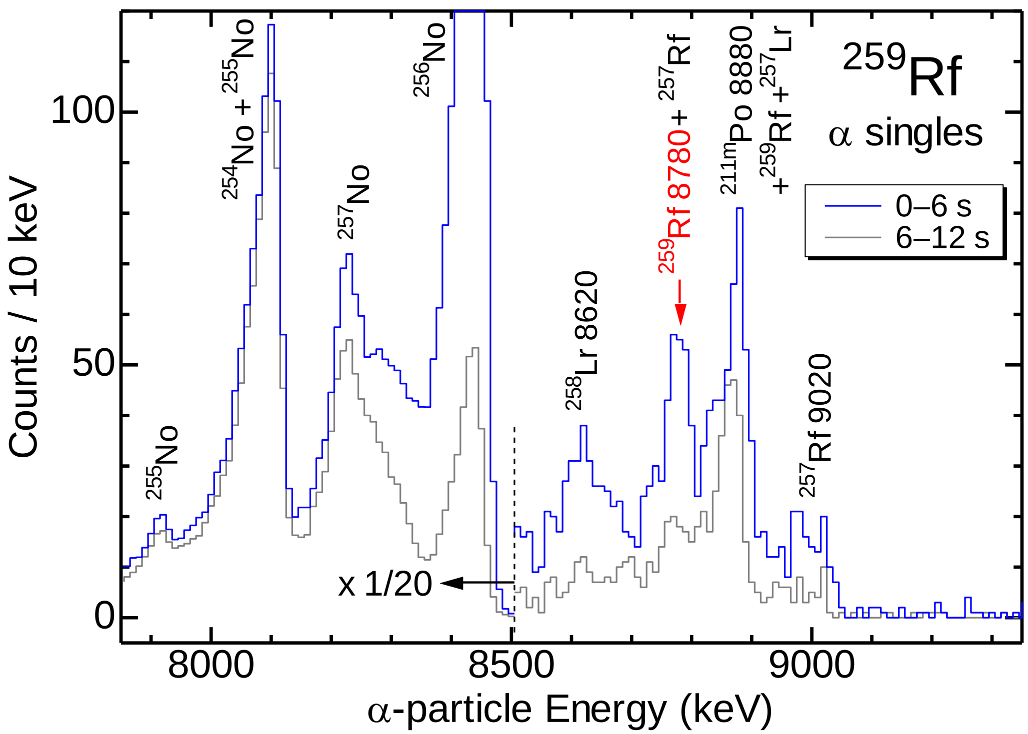
- ^{249}Cf(62%), ^{250}Cf(14%), ^{251}Cf(24%)
- Residue of 40-year-old ^{252}Cf neutron source
- Small-size target : φ1.4 mm x 420 μg/cm^2 = 6.5 μg
- Total radioactivity : 4.1 MBq

- 600 pnA ^{12}C beam is focused on this small target

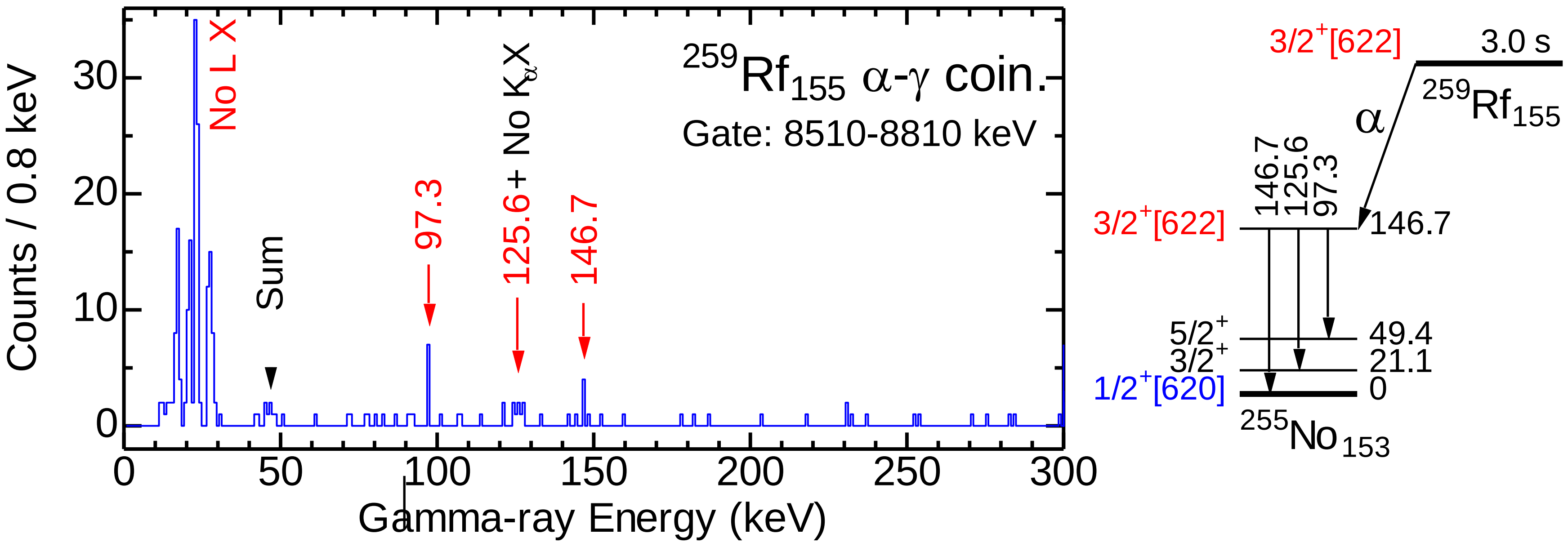
φ1.4-mm Cf target



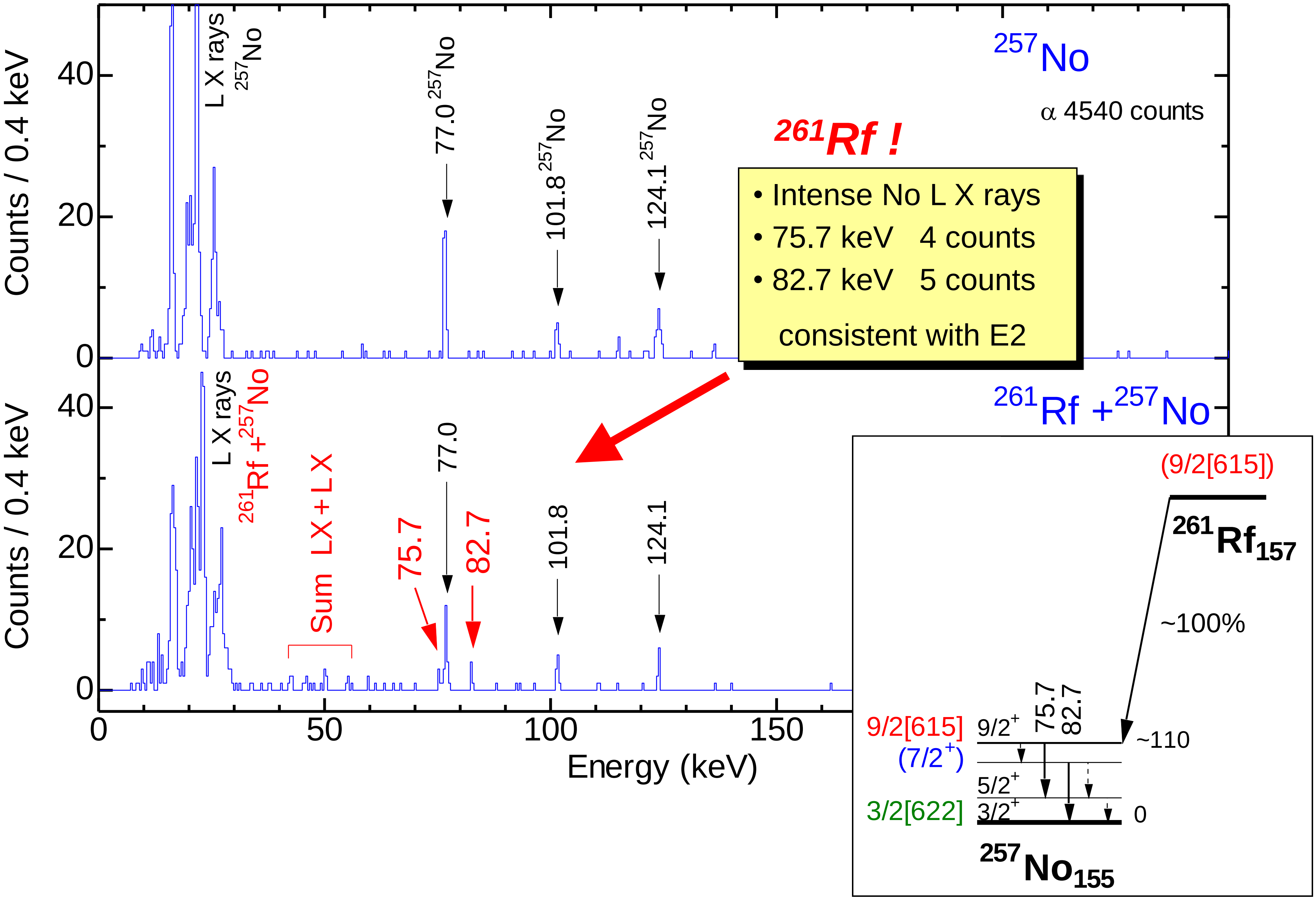
α-singles spectrum



α-γ coincidence spectrum



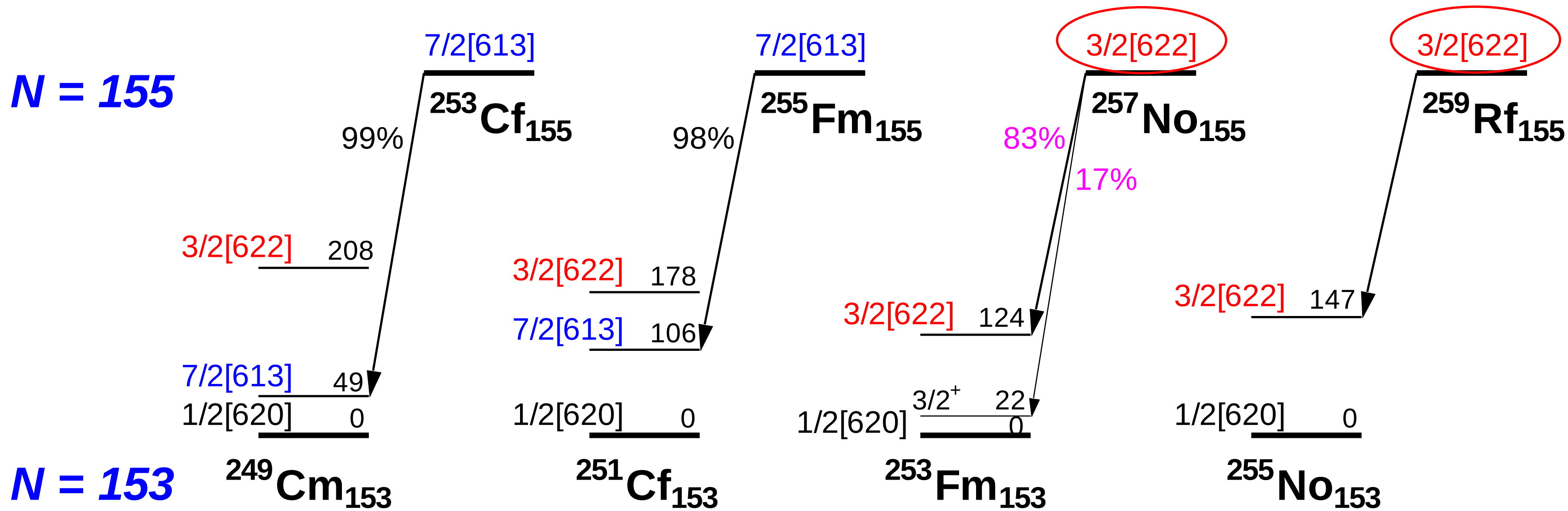
Gamma-ray spectra in coincidence with α particles of ^{261}Rf and ^{257}No

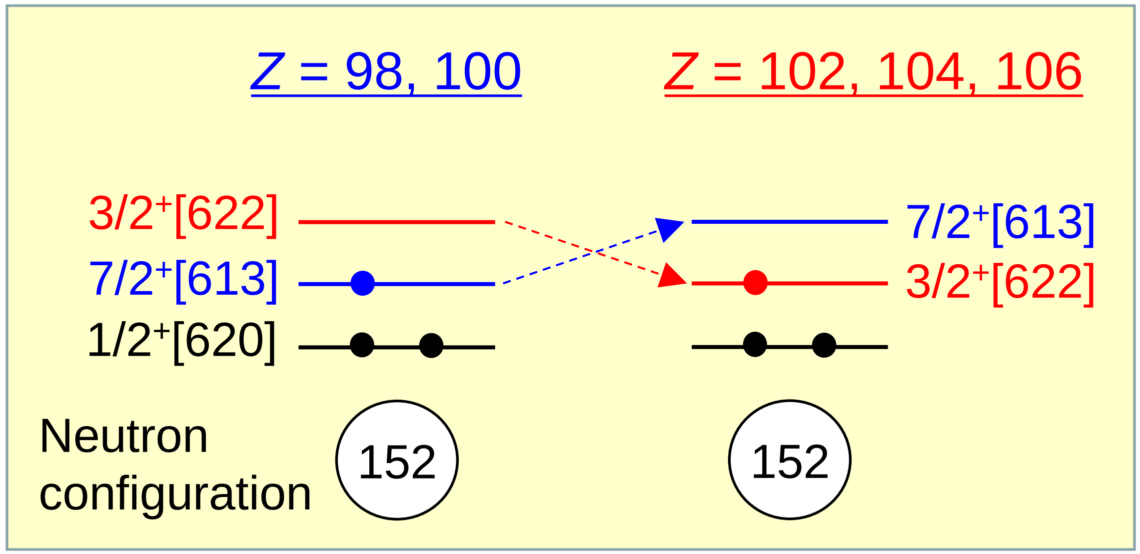


Discussion

- Neutron configurations in N = 155 and 157 isotones
- Neutron configurations in N > 157 nuclei

Ground-state configuration of N = 155 isotones and levels in N = 153 daughters



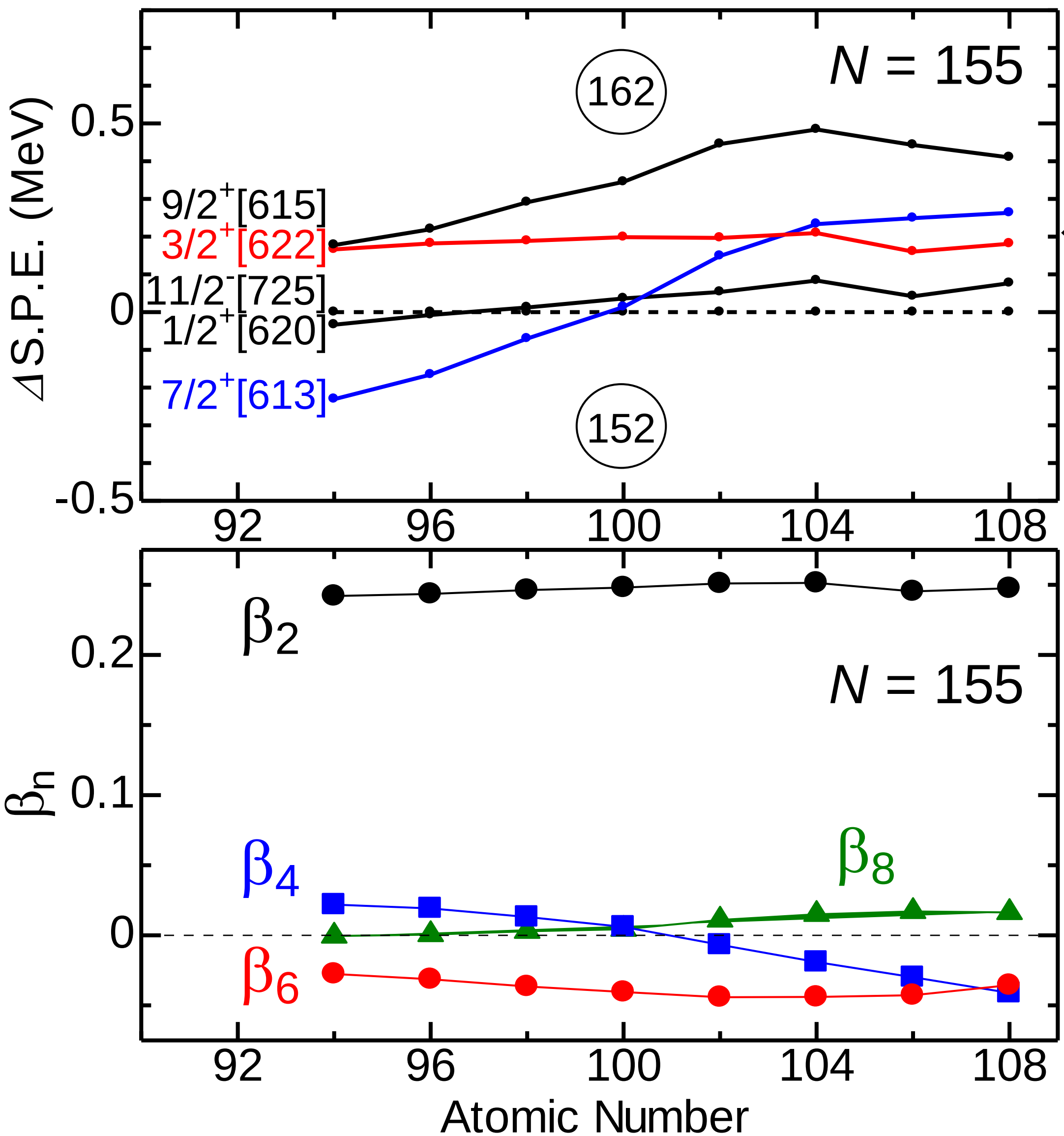


Inverted !

Resulting from deformation change

Inversion of 7/2⁺[613] and 3/2⁺[622] orbitals

Macroscopic-microscopic model calculation by T. Ichikawa



FRLDM + Folded-Yukawa single-particle potential

7/2⁺[613] and 3/2⁺[622] energies are inverted at Z > 102

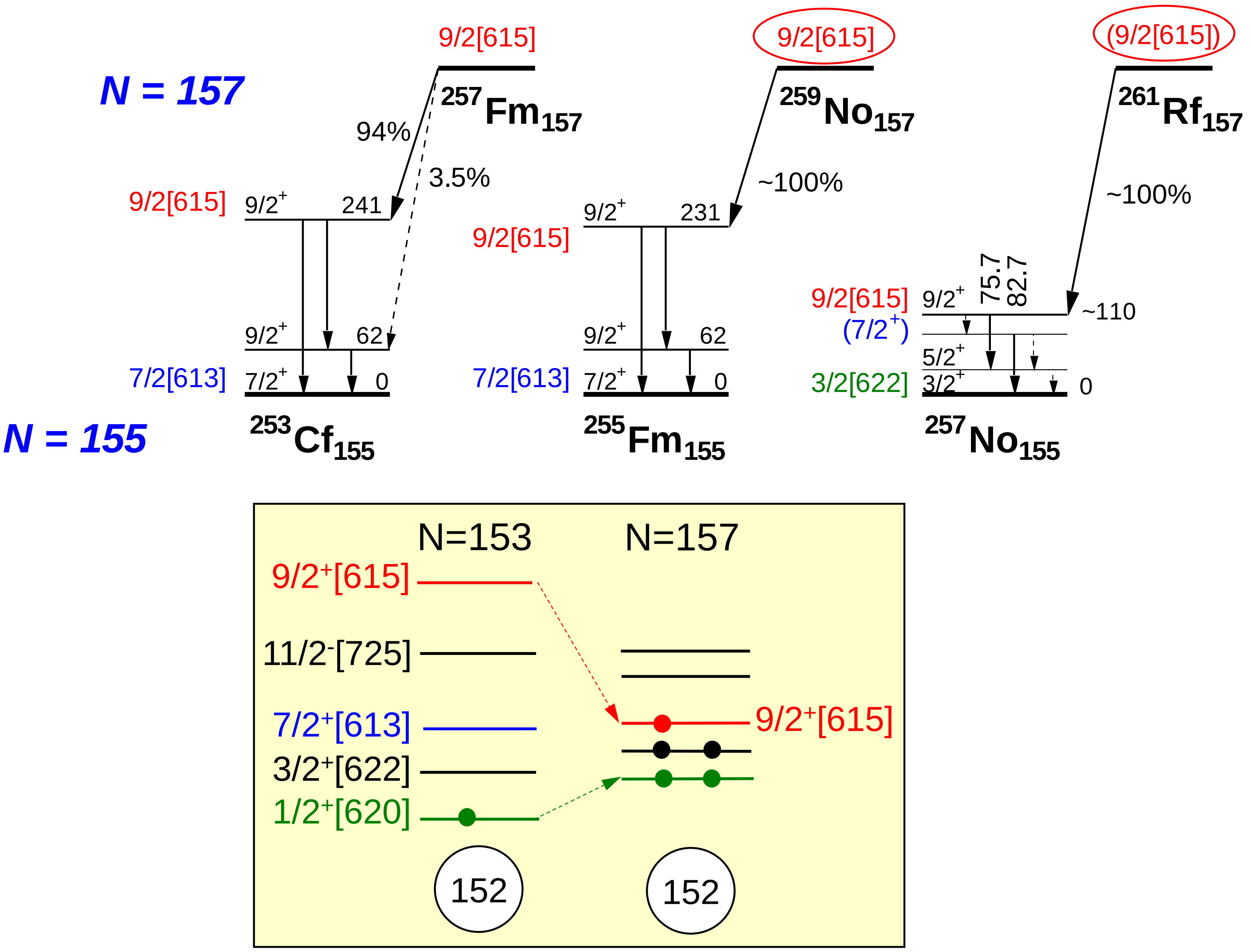
Reproduced well !

Ground states of N=155 isotones

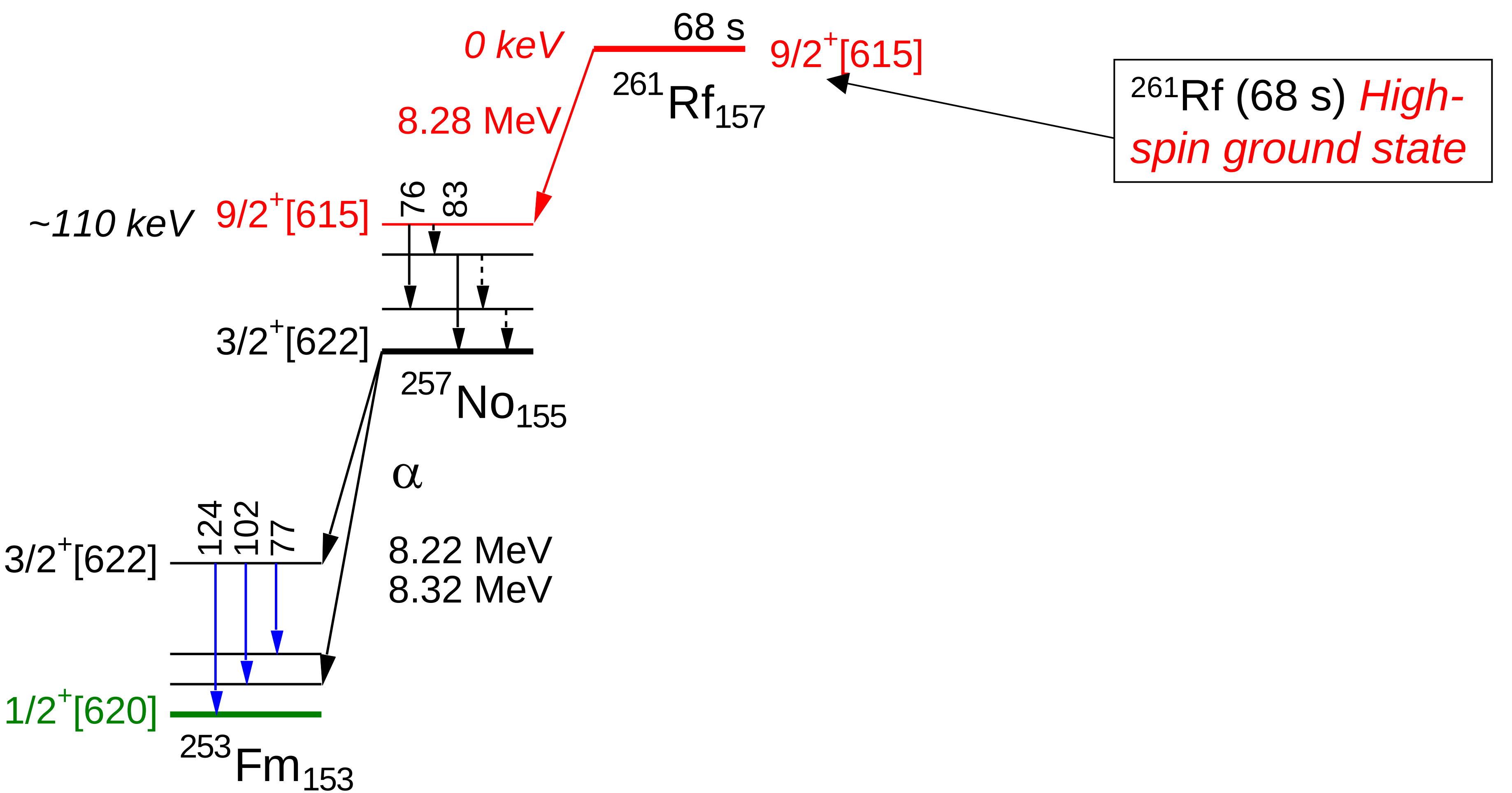
- Z = 98,100 --- 7/2⁺[613]
- Z = 102,104 --- 3/2⁺[622]

Higher-order deformation parameters contribute to the change of these single-particle energies

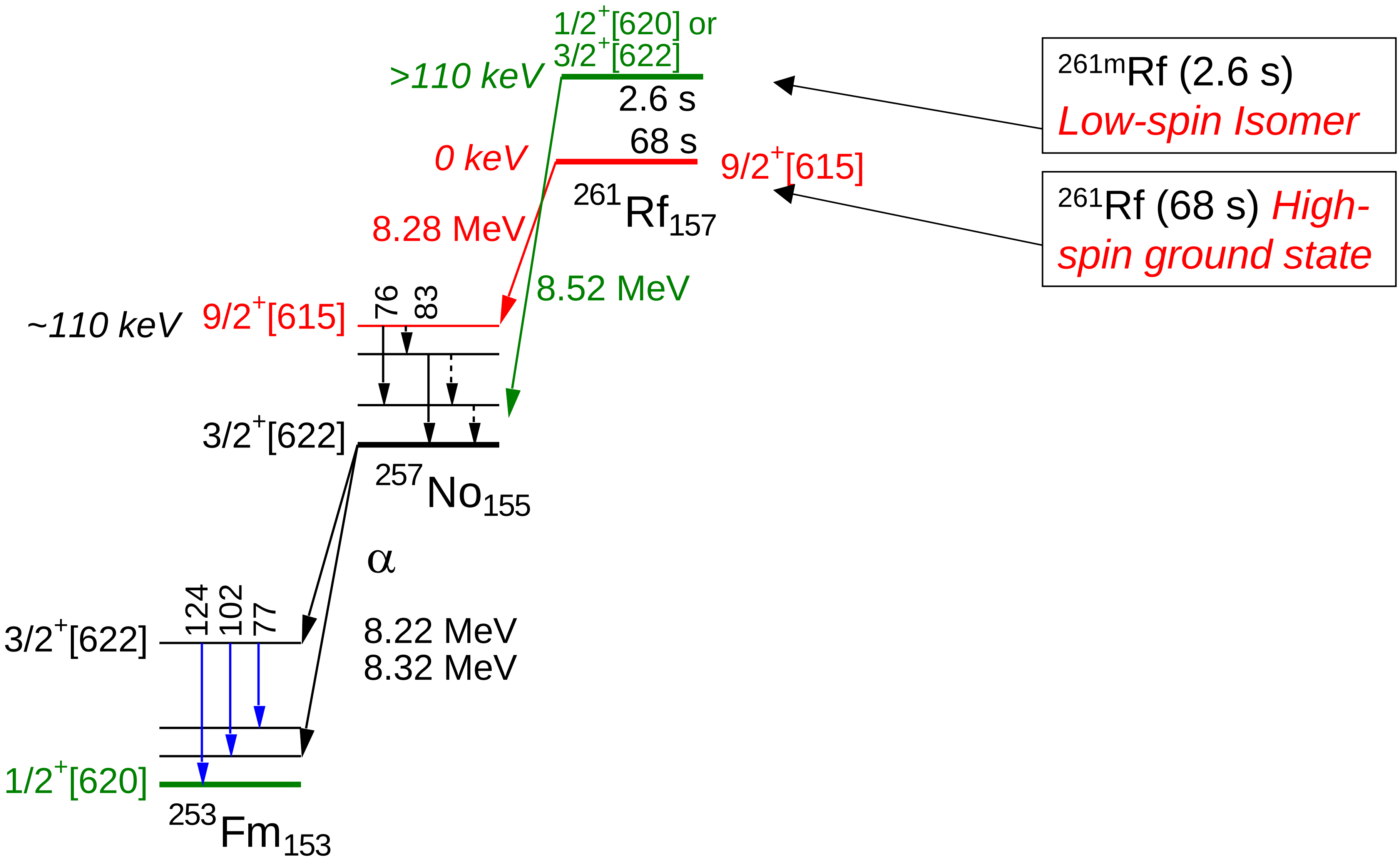
Ground-state configuration of *N=157 isotones*

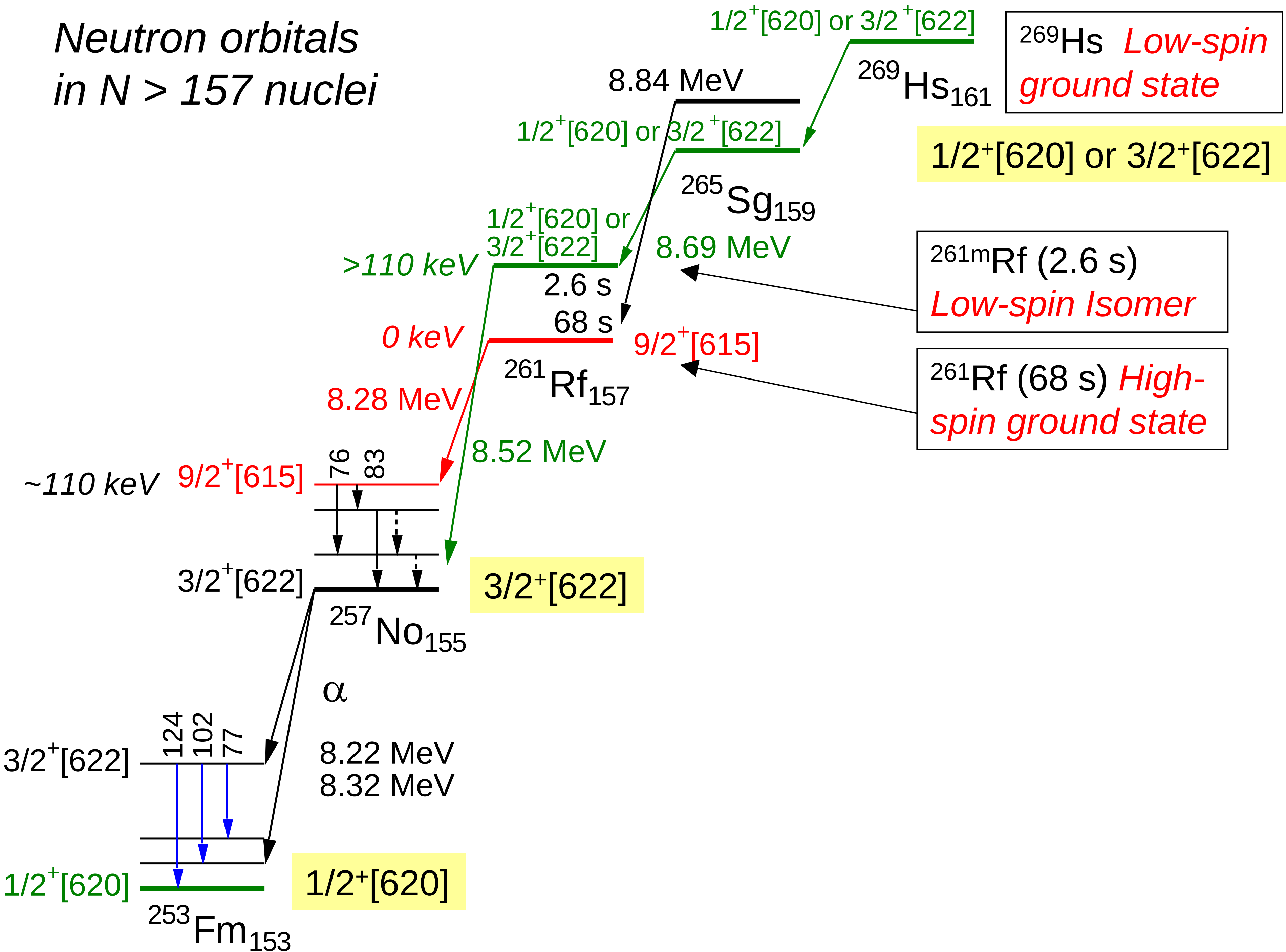


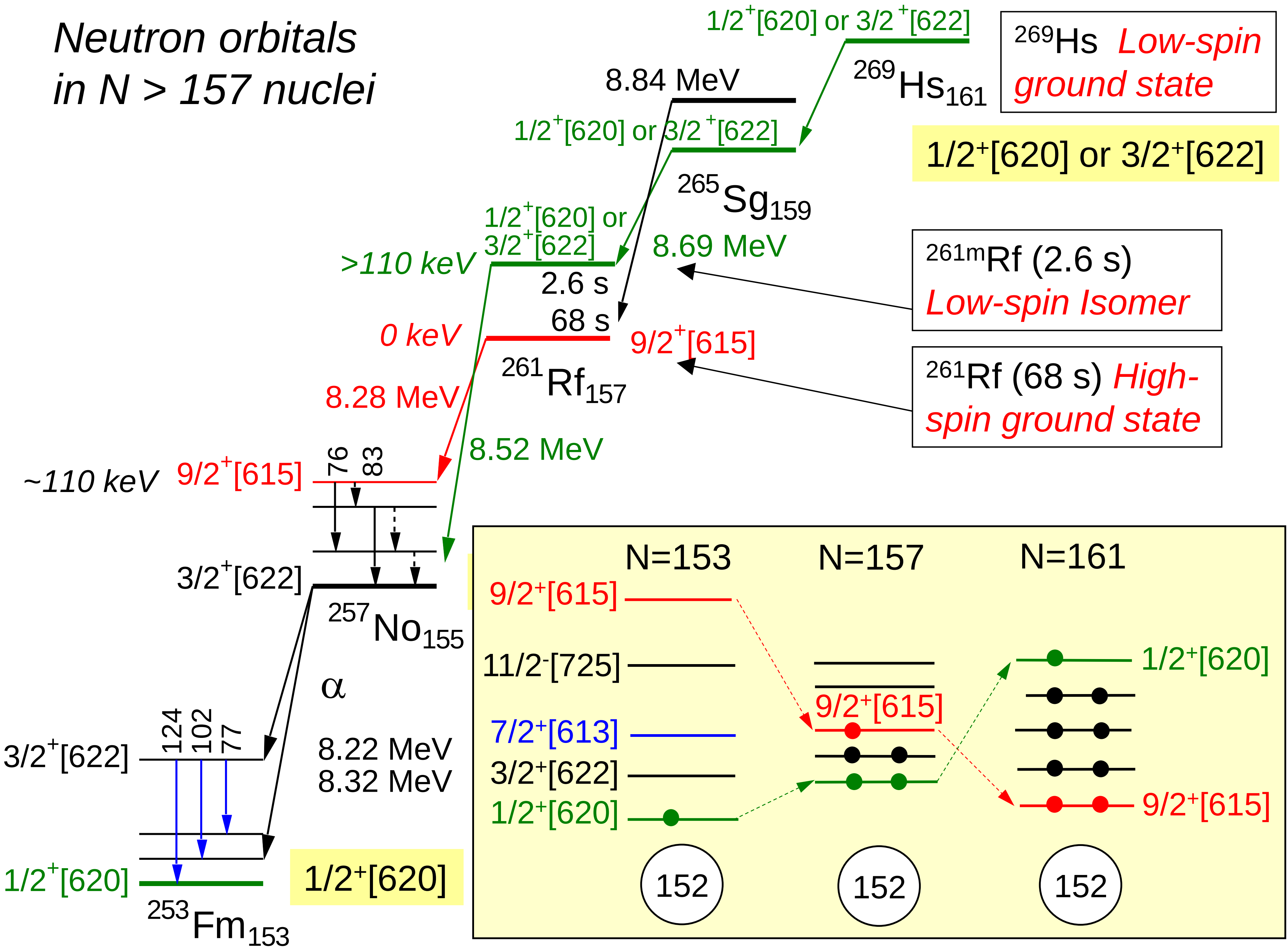
Neutron orbitals
in N > 157 nuclei



Neutron orbitals in N > 157 nuclei




Neutron orbitals
in N > 157 nuclei
1/2+[620] or 3/2+[622]
269Hs161
269Hs Low-spin ground state
8.84 MeV
1/2+[620] or 3/2+[622]
1/2+[620] or 3/2+[622]
265Sg159
1/2+[620] or
3/2+[622]
>110 keV
8.69 MeV
2.6 s
261mRf (2.6 s) Low-spin Isomer
68 s
0 keV
9/2+[615]
261Rf157
261Rf (68 s) High-spin ground state
8.28 MeV
8.52 MeV
76
83
~110 keV
9/2+[615]
3/2+[622]
3/2+[622]
257No155
α
8.22 MeV
8.32 MeV
124
102
77
3/2+[622]
1/2+[620]
1/2+[620]
253Fm153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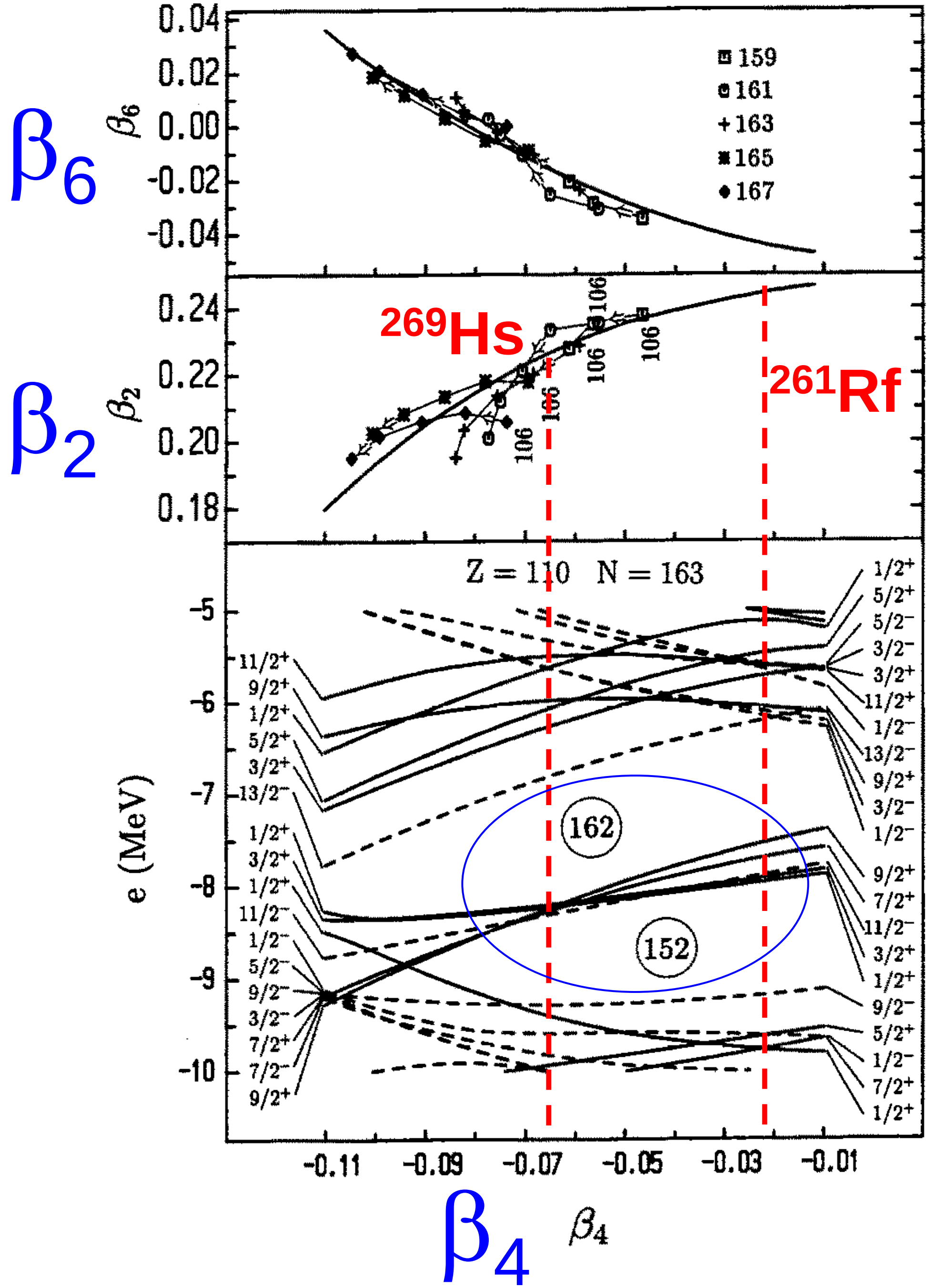
2.6 s
68 s
0 keV
9/2+[615]
261Rf157
8.28 MeV
8.52 MeV
~110 keV
9/2+[615]
76
83
3/2+[622]
257No155
α
8.22 MeV
8.32 MeV
3/2+[622]
124
102
77
1/2+[620]
253Fm153
1/2+[620]
N=153
N=157
N=161
9/2+[615]
11/2-[725]
7/2+[613]
3/2+[622]
1/2+[620]
9/2+[615]
1/2+[620]
9/2+[615]
152
152
152

Calculated neutron orbitals

S. Cwiok *et al*., NPA 573 (1994) 356.

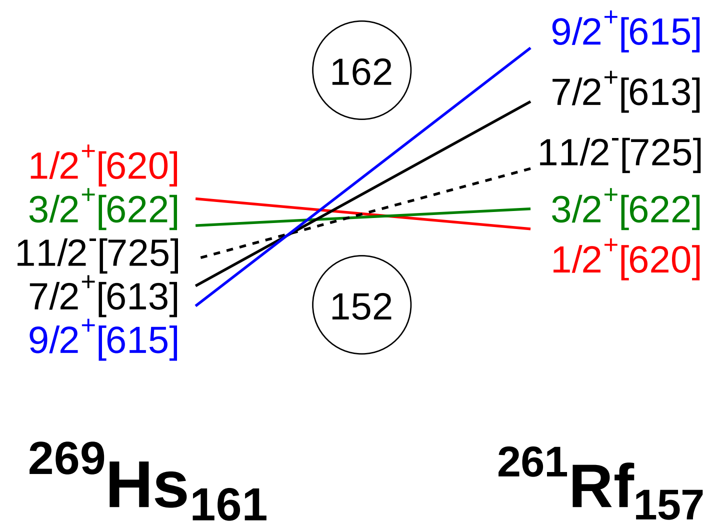
Nilsson-Strutinsky approach with an average Woods-Saxon potential



Small ← β_2

Small ← β_4 / β_6

Large ← β_6



Summary

- Alpha-decay spectroscopy of $^{255,257,259}No$ and $^{259,261}Rf$ was performed at JAEA tandem accelerator using ^{248}Cm and ^{251}Cf targets and gas-jet transport technique

- Order of neutron orbitals was found to be inverted between N=153 and N=161 nuclei, indicating the higher-order deformation change

Ideas of future plan

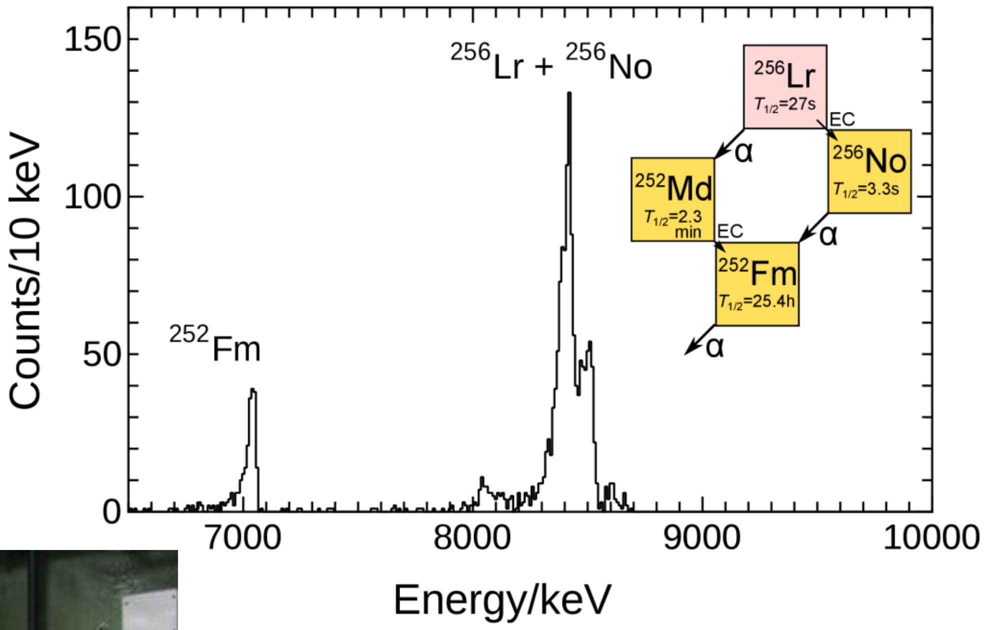
- Mass-separated Lr isotopes are available (T.K. Sato)

Spectroscopy of Lr
Fission studies of Lr
$E(2^+)$ measurement of $^{260}No_{158}$ through EC decay of ^{260}Lr

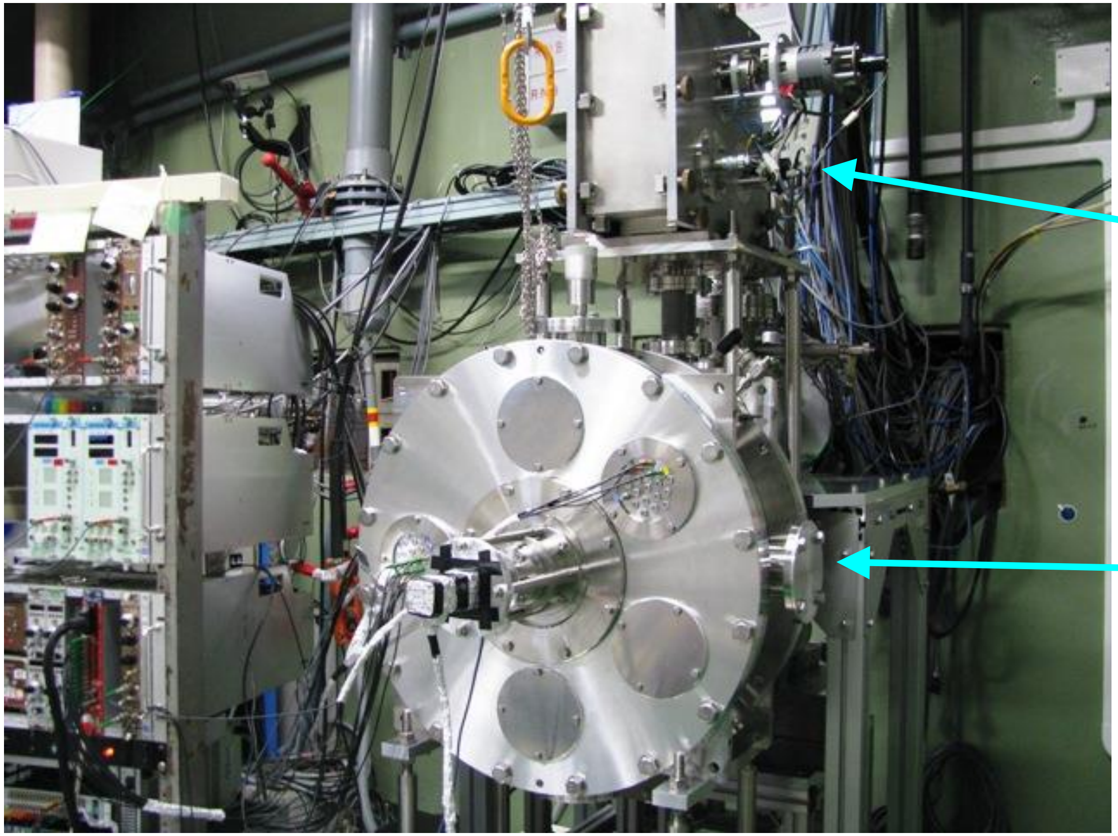
α-energy spectrum of mass-separated ^{256}Lr

Lr ionization efficiency is 40%

(Presentation by T.K. Sato)



Detector station at ISOL beam line



Tape transport system

Rotating-wheel α-detection system

First Circular, February 2014

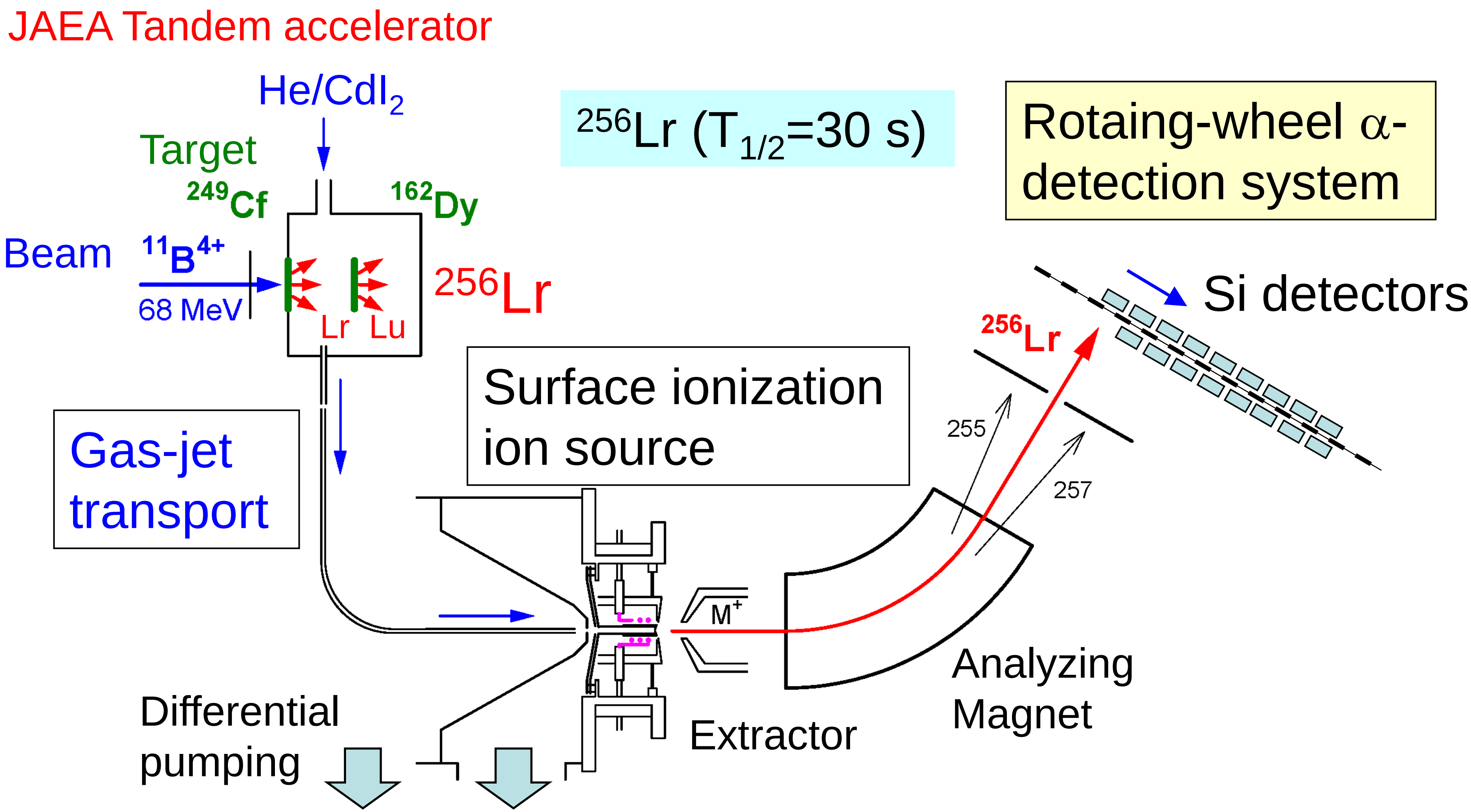
TAN 15
5th International Conference on the Chemistry and Physics of the Transactinide Elements

Urabandai, Fukushima, Japan
May 25 (Monday) – 29 (Friday), 2015

Scope of the conference
This conference is the fifth in a series of conferences dedicated to the recent achievements in chemistry and physics of transactinide elements. The scientific program will cover both theories and experiments of heaviest-element synthesis, nuclear reactions, nuclear structure, chemistry, atomic properties, and other related topics. The previous TAN conferences were held in Seeheim (1999), Napa (2003), Davos (2007), and Sochi (2011).

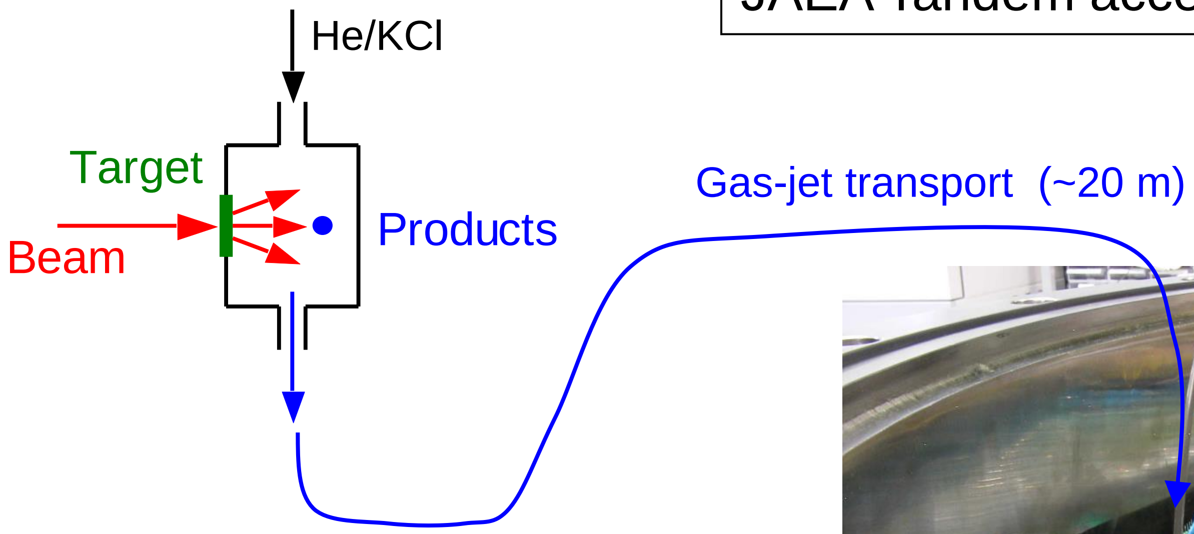
Venue
The TAN 15 conference will be held from May 25–29, 2015,
Urabandai area, the northwest part of Fukushima prefecture, J
area with beautiful nature, ponds, lakes, and volcanoes.

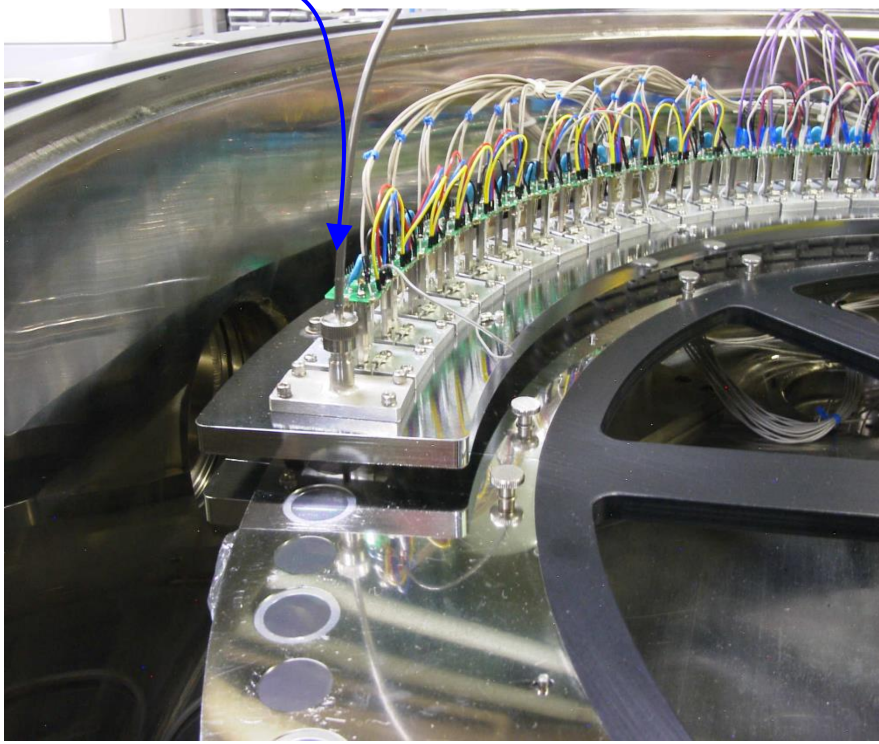
Successful ionization and mass separation of Lr isotope



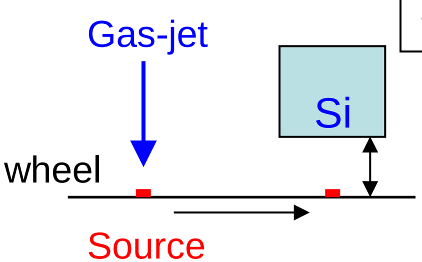
Experimental setup

JAEA Tandem accelerator





Rotating-wheel α-detection system



- Small Si detector (8 mmϕ)

\+

- Source-to-detector distance ~5 mm
- Detection efficiency ~10%

- Thin source

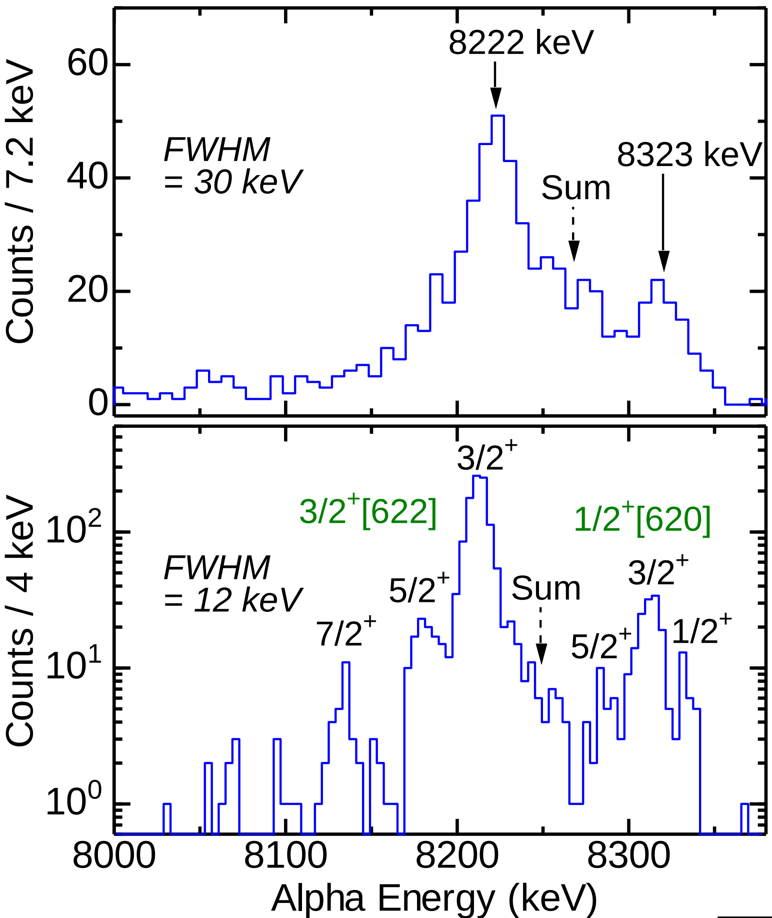
\+

Good α-energy resolution !

FWHM ~ 10 keV

High-resolution α fine-structure spectroscopy

α-particle spectra of ^{257}No



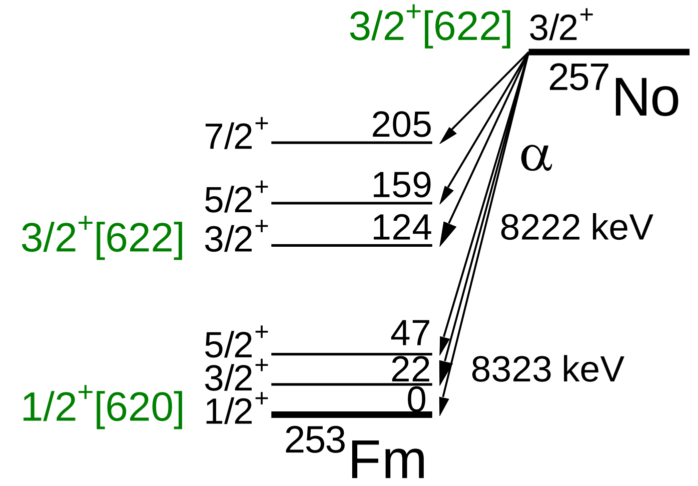
FWHM

30 keV

11 keV

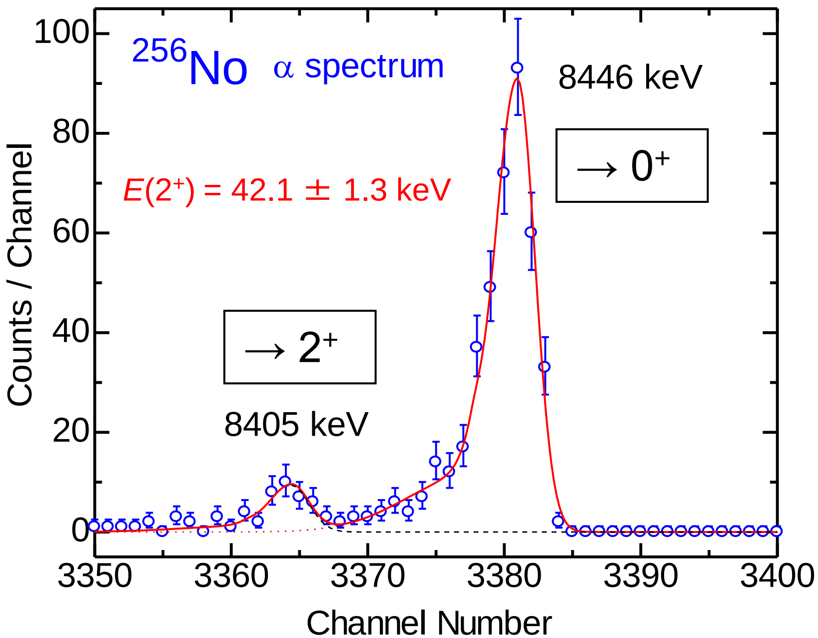
Spin-parities and single-particle configurations can be identified

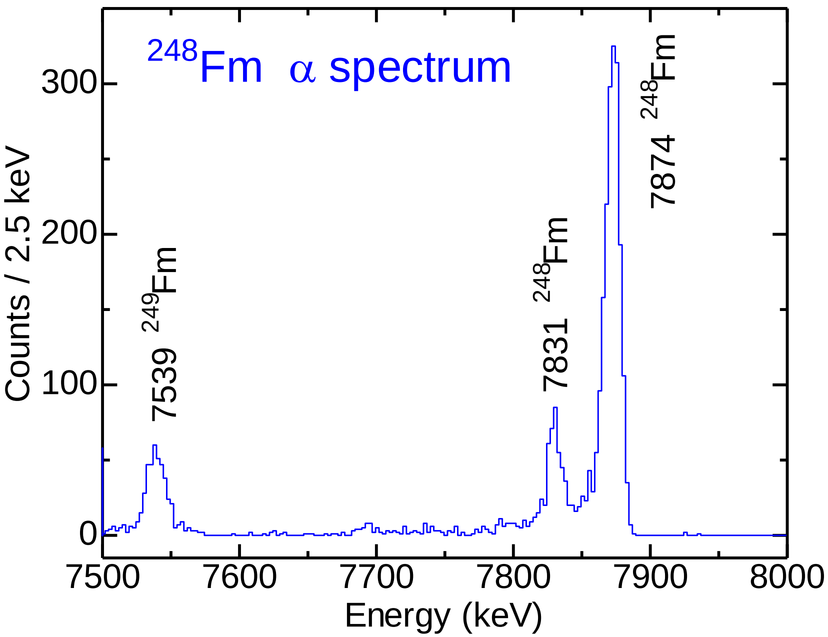
Only through α-energy spectrum



- Rotational-band energies
- Hindrance factors

High-resolution α-energy measurements





^{248}Cm(^{12}C,4n)^{256}No → ^{252}Fm

^{238}U(^{16}O,6n)^{248}Fm → ^{244}Cf

^{238}U(^{12}C,6n)^{244}Cf → ^{240}Cm

^{235}U(^{12}C,5n)^{242}Cf → ^{238}Cm

^{233}U(^{12}C,5n)^{240}Cf → ^{236}Cm → ^{232}Pu