In-gas-cell laser ionization spectroscopy of heavy refractory nuclei produced at KISS (KEK Isotope Separation System : KISS)

Study of nuclear properties through nuclear spectroscopy
(laser spectroscopy) from astrophysical interest
to investigate heavy elements synthesis in the universe

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Laser spectroscopy of unstable nuclei

HFS measurements

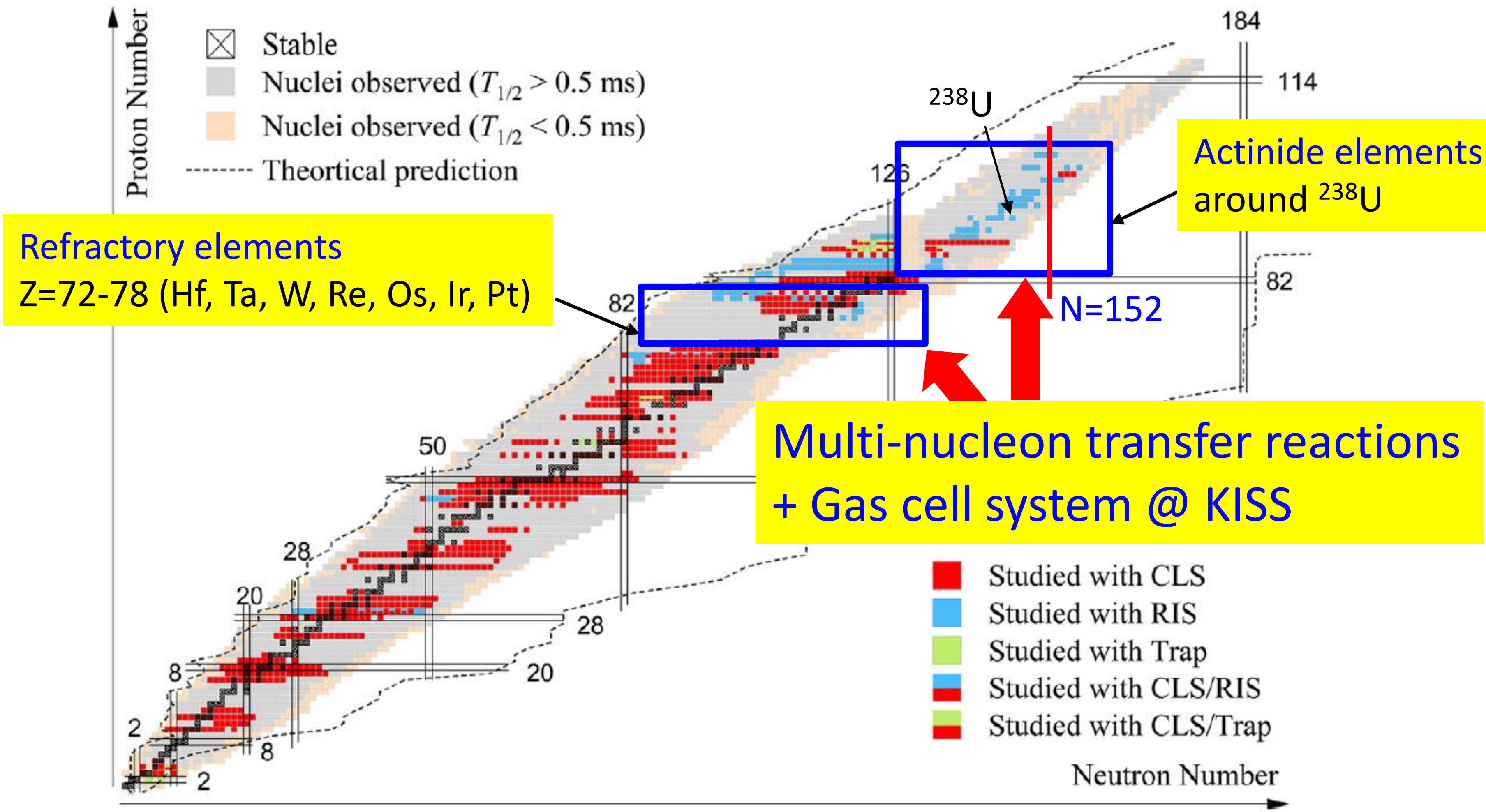
Nuclear electro-magnetic moments : μ_I, Q

→ Nuclear structure (wave function, deformation)

Isotope shift : $\delta\nu$

→ $\delta\langle r^2\rangle$

→ nuclear deformation parameter $|\beta_2^2|^{1/2}$ for the nuclei with I = 0, 1/2

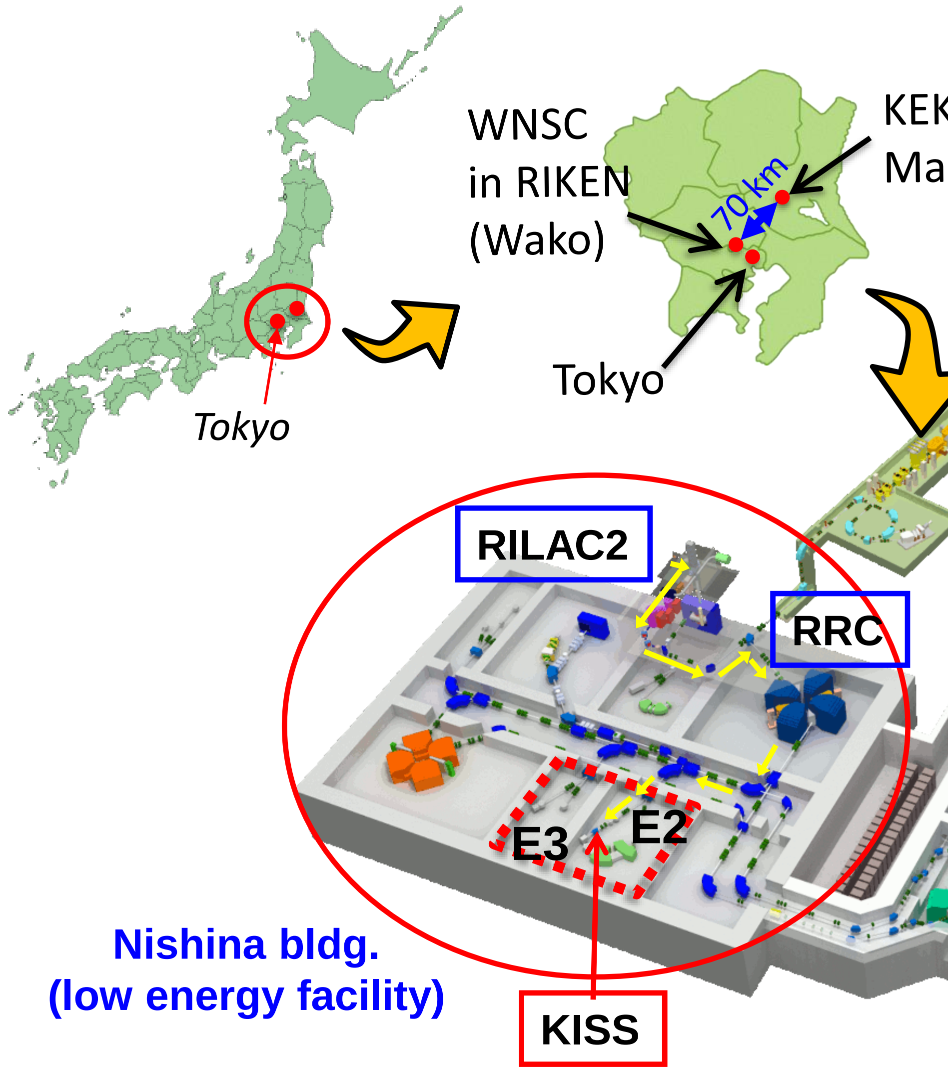


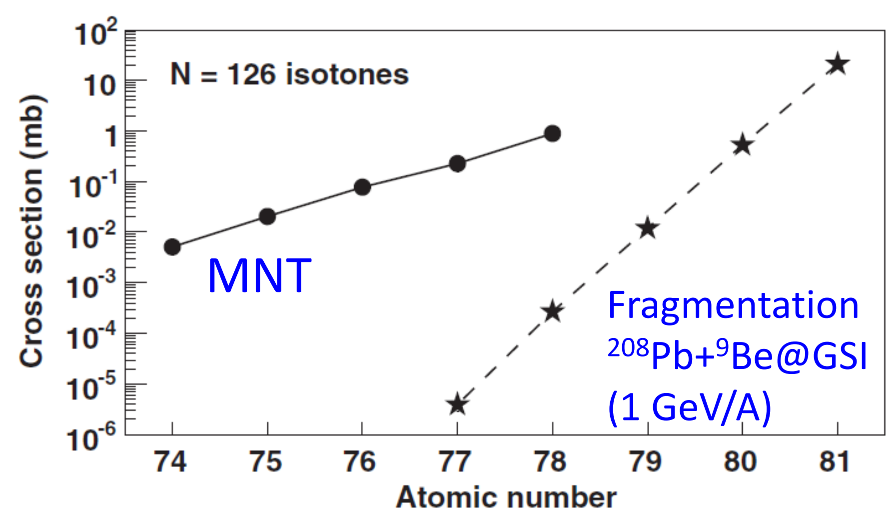
X.F. Yang et al., Prog. Part. Nucl.Phys. 129 (2023) 104005.

KISS facility

- Multi-nucleon transfer reactions
- Ar gas-cell based laser ion source
- Mass separator

Wako Nuclear Science Center and KISS in RIKEN





Y.X. Watanabe et al., PRL 115 (2015) 172503.

KEK Isotope Separation System

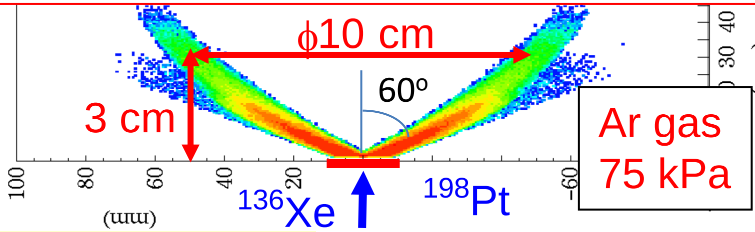
^{136}Xe and ^{238}U beams @ E = 10.75 MeV/A

Multi-nucleon transfer reactions :

promising production method of neutron-rich nuclei with higher cross-sections

Laser resonant ionization spectroscopy @KEK Isotope Separation System (KISS)

Stopping distribution of MNT products

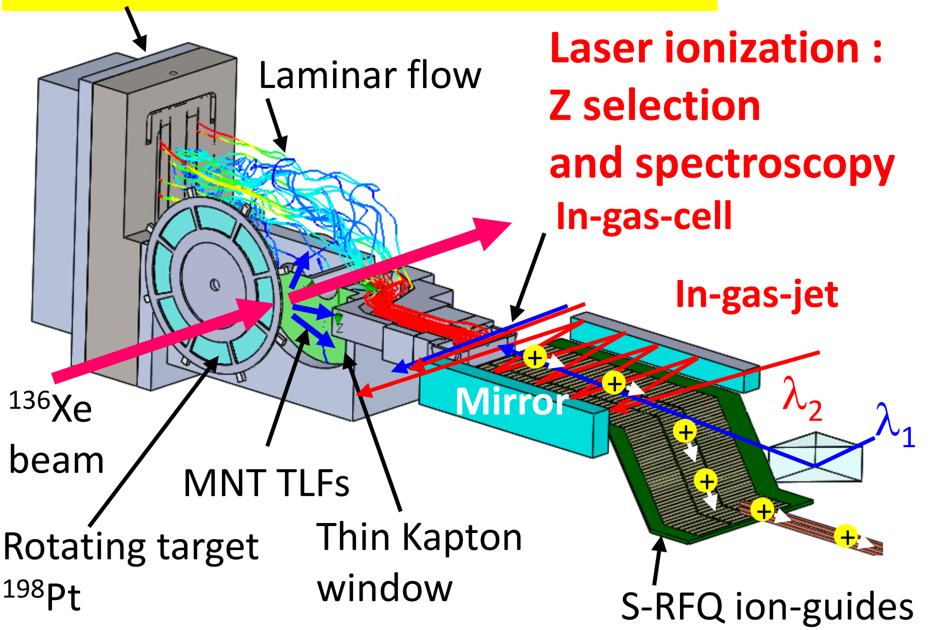


Angles ~ 60°
Energy : 0-1 MeV/A

Refractory elements (Z = 73-78)
By ^{136}Xe beam + ^{198}Pt target

Y.X. Watanabe et al. PRL 115 (2015) 172503.

Doughnut-shaped argon gas cell

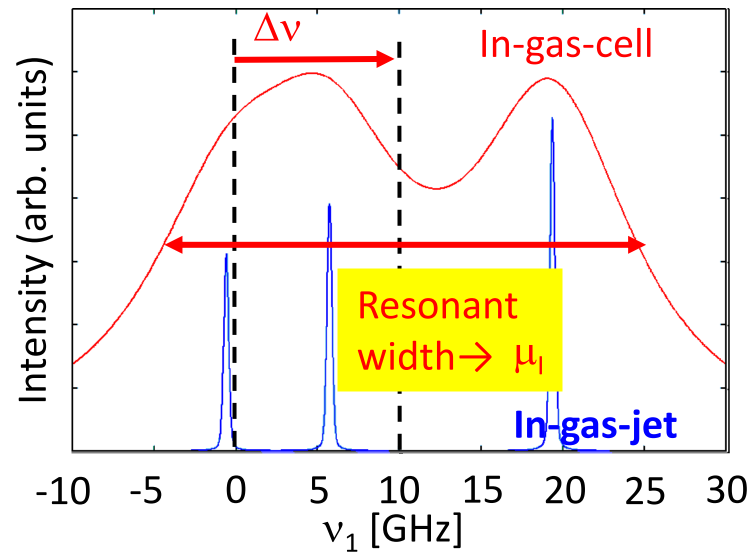


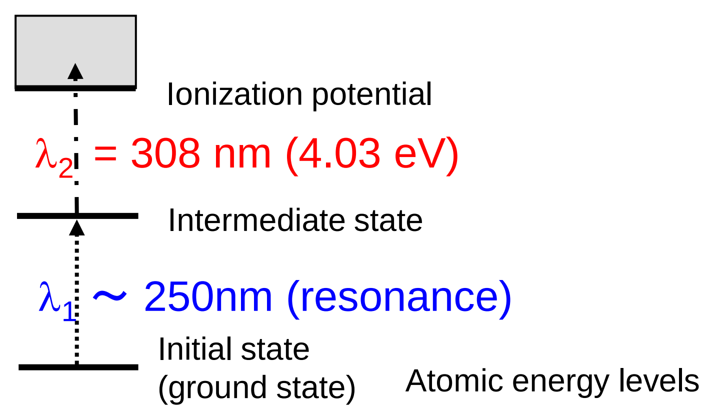
Y.Hirayama *et al.* NIMB412(2017)11, NIMB463(2020)425

In-gas-cell : Argon gas pressure ~ 80 kPa
→ Pressure broadening (~10 GHz)

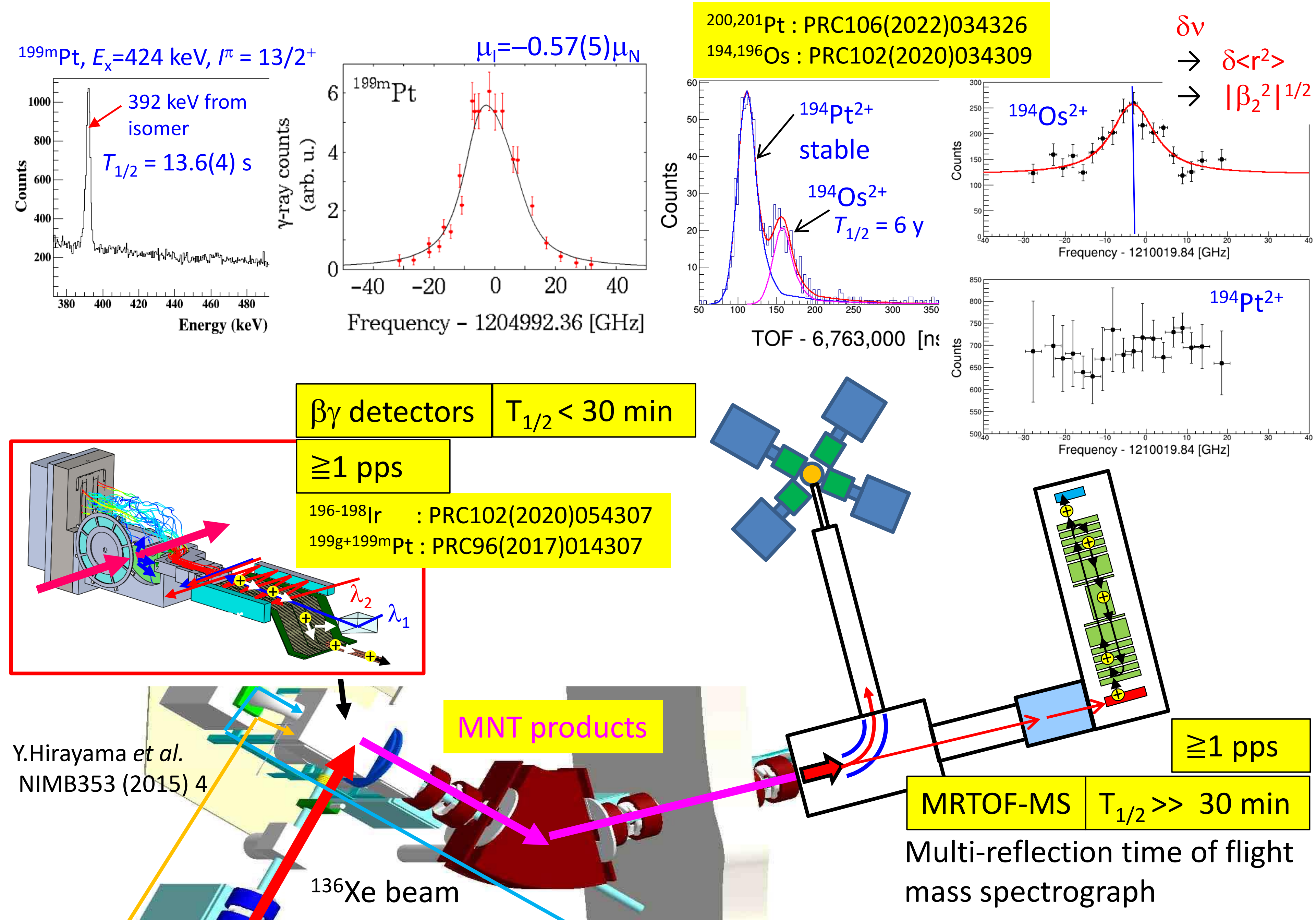
ΔE_{HFS} distribution : Scan excitation laser λ_1

^{195}Pt $I^{\pi} = 1/2^{-}$ 1 GHz ≈ 0.2 pm





Laser resonant ionization spectroscopy @KISS



Experimental results

Laser spectroscopy : $^{191,192}Re$

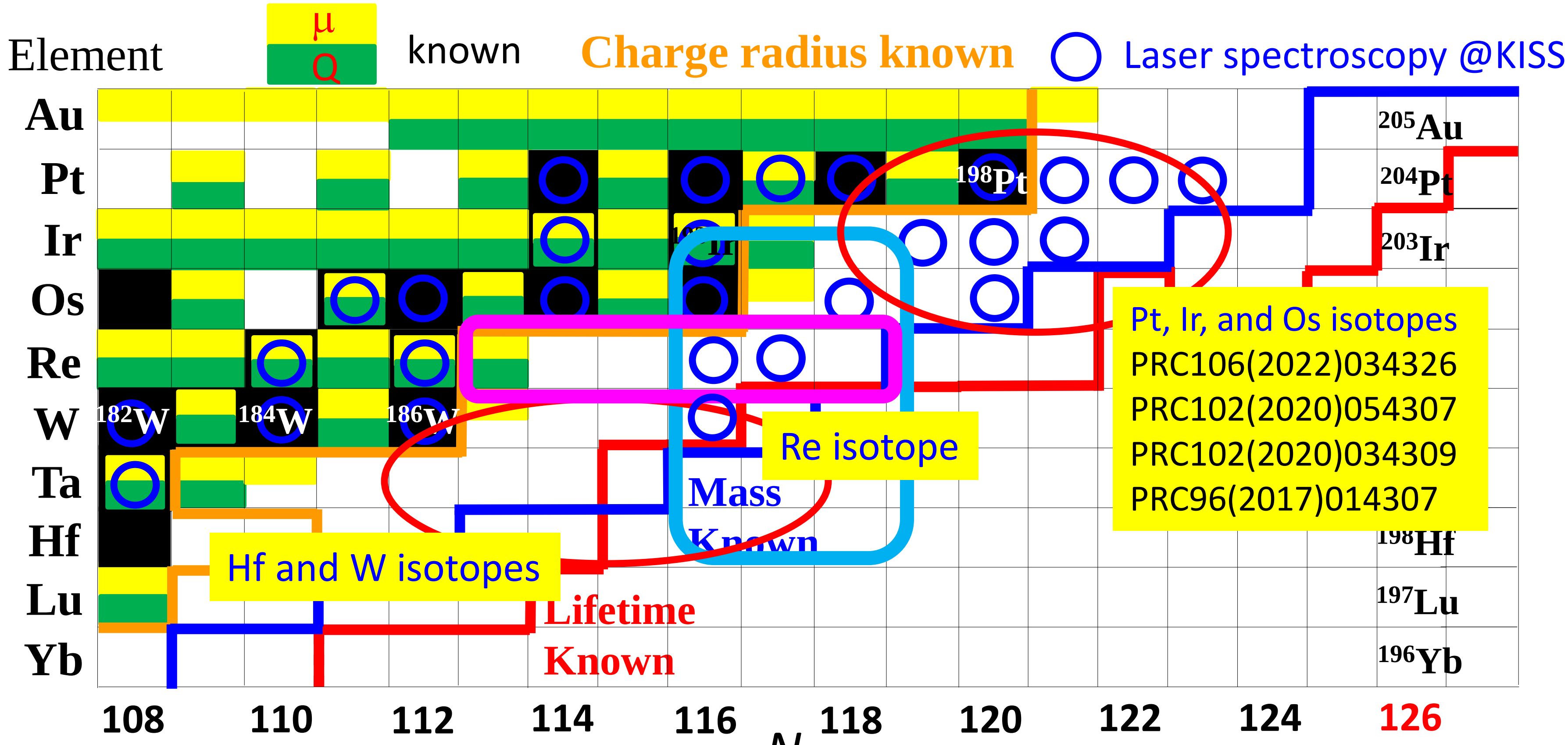
Physics motivation in the vicinity of N = 126

Predominance of prolate shape in the deformed ground states remains as global issue.
→ Exact mapping of prolate and oblate shapes in the nuclear chart is indispensable.

Naoki Tajima and Norifumi Suzuki, Phys. Rev. C 64, 037301 (2001).
Satoshi Takahara et al., Phys. Lett. B 702, 429 (2011). M. Sugawara, Phys. Rev. C 106, 024301 (2022).

Shape transition from prolate to oblate around *N* = 116 – 118 for refractory elements

K. Nomura et al., Phys. Rev. C 97, 064314 (2018), X.Q. Yang et al., Phys. Rev. C 103, 054321 (2021).

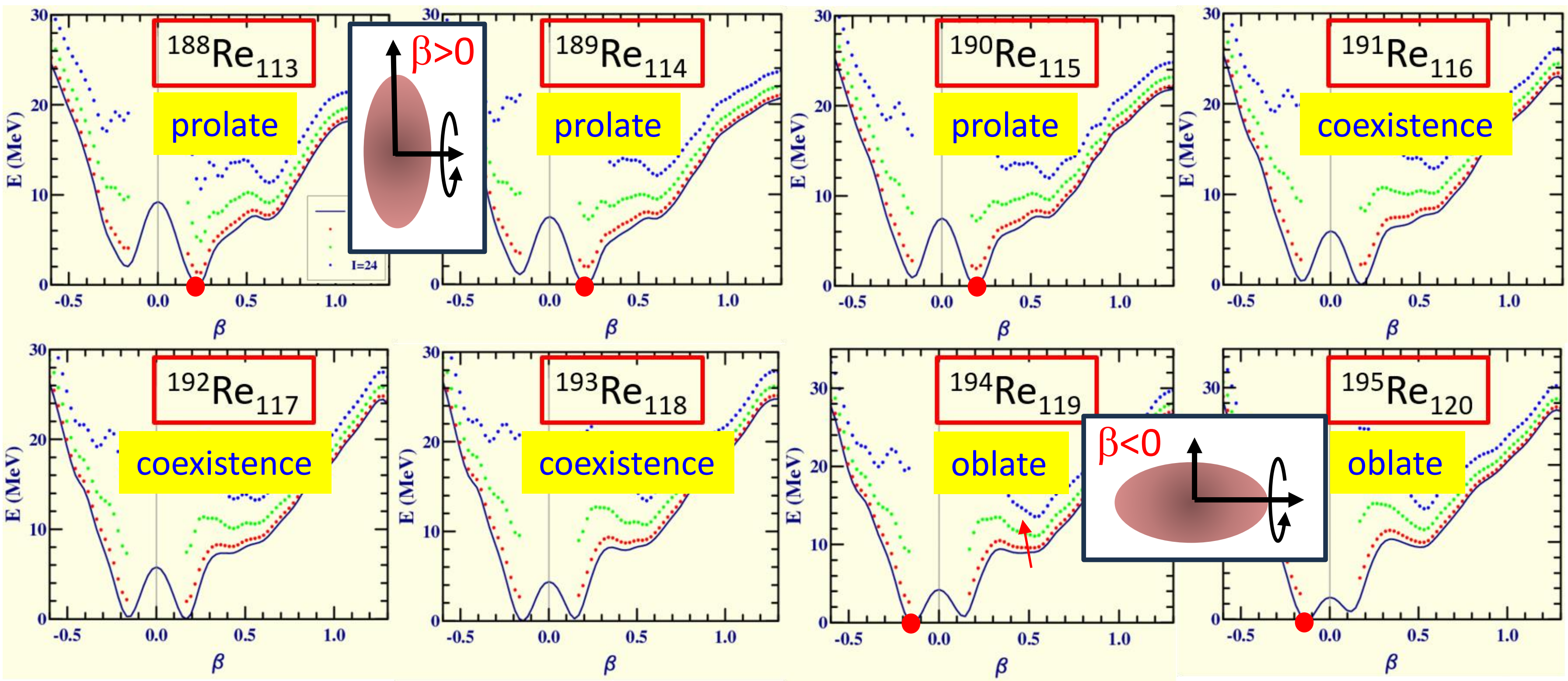


Lifetime : http://wwwndc.jaea.go.jp/CN14/index.html(2014)
Charge radii : Atomic Data and Nucl. Data Tables 99 (2013) 69
EM moments : Atomic Data and Nucl. Data Tables 90 (2005) 75

Re laser spectroscopy : physic motivation

- PES calculated by CHFB+5DCH, shape transition at N = 118

J.-P. Delaroche et al., Phys. Rev. C 81, 014303 (2010).



- Change of the proton orbit from [402]5/2$^+$ to [411]1/2$^+$ at N = 116
  from the β-decay study of ^{192}Re at KISS

H. Watanabe et al., Phys. Lett. B 814, 136088 (2021).

➡ Suggested I^{π} = 1/2$^+$ for ^{191}Re, 0$^-$ for ^{192}Re, and 1/2$^+$ for ^{193}Re

⬇

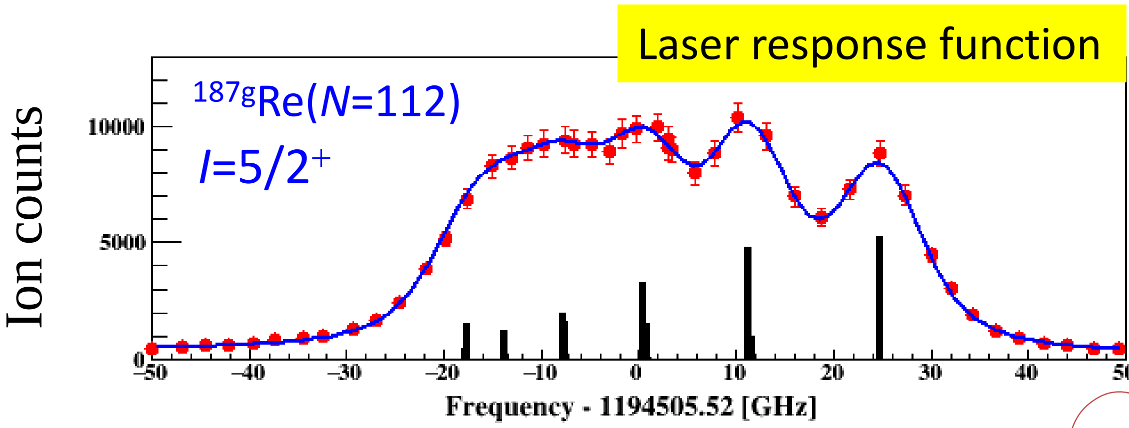
in-gas-cell laser spectroscopy of $^{188\text{-}193}$Re ➡ μ_I sensitive to I^{π}

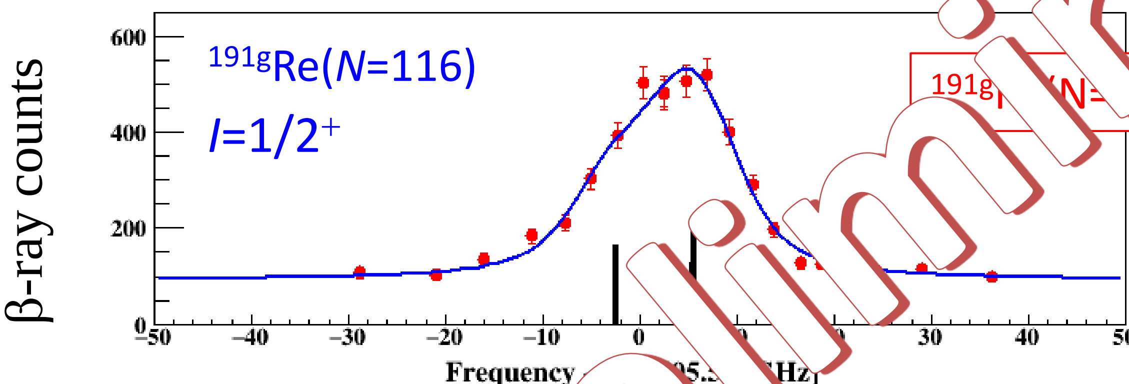
In-gas-cell laser spectroscopy of ^{191,192}Re (Z=75)

A	I^{π}	μ (μ_N)	Q(b)
187	5/2$^+$	+3.2197(3)	+2.07(2)

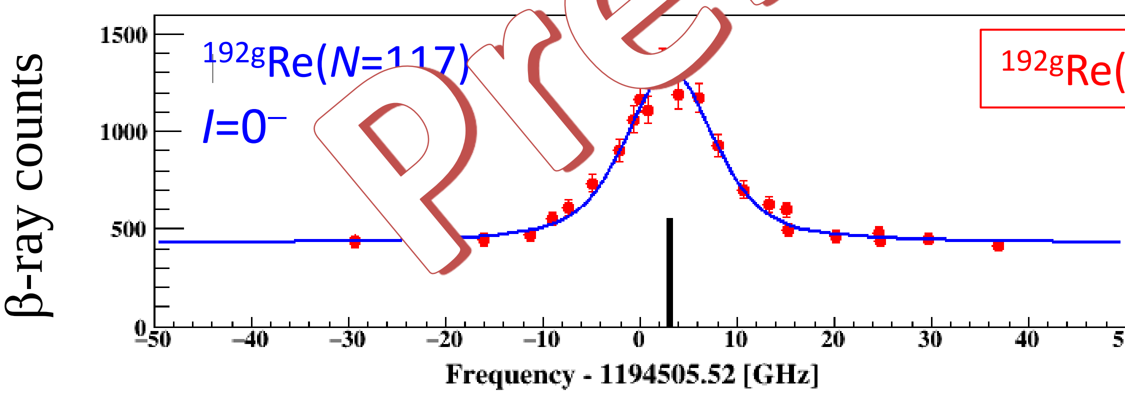
For ^{185}Re
Ag= ... 3994(...) ... Hz
Bg=+0 ... 014(31) ... Hz

A ... 066(8) GHz
... = ... .66(20) GHz
$\delta\nu^{185,187}$ = −1.65(10) GHz





^{191g} ... (N= ... 6) : $T_{1/2}$ = 9.8 min, β-decay 100%



^{192g}Re(N=118) : $T_{1/2}$ = 15 s, β-decay 100%

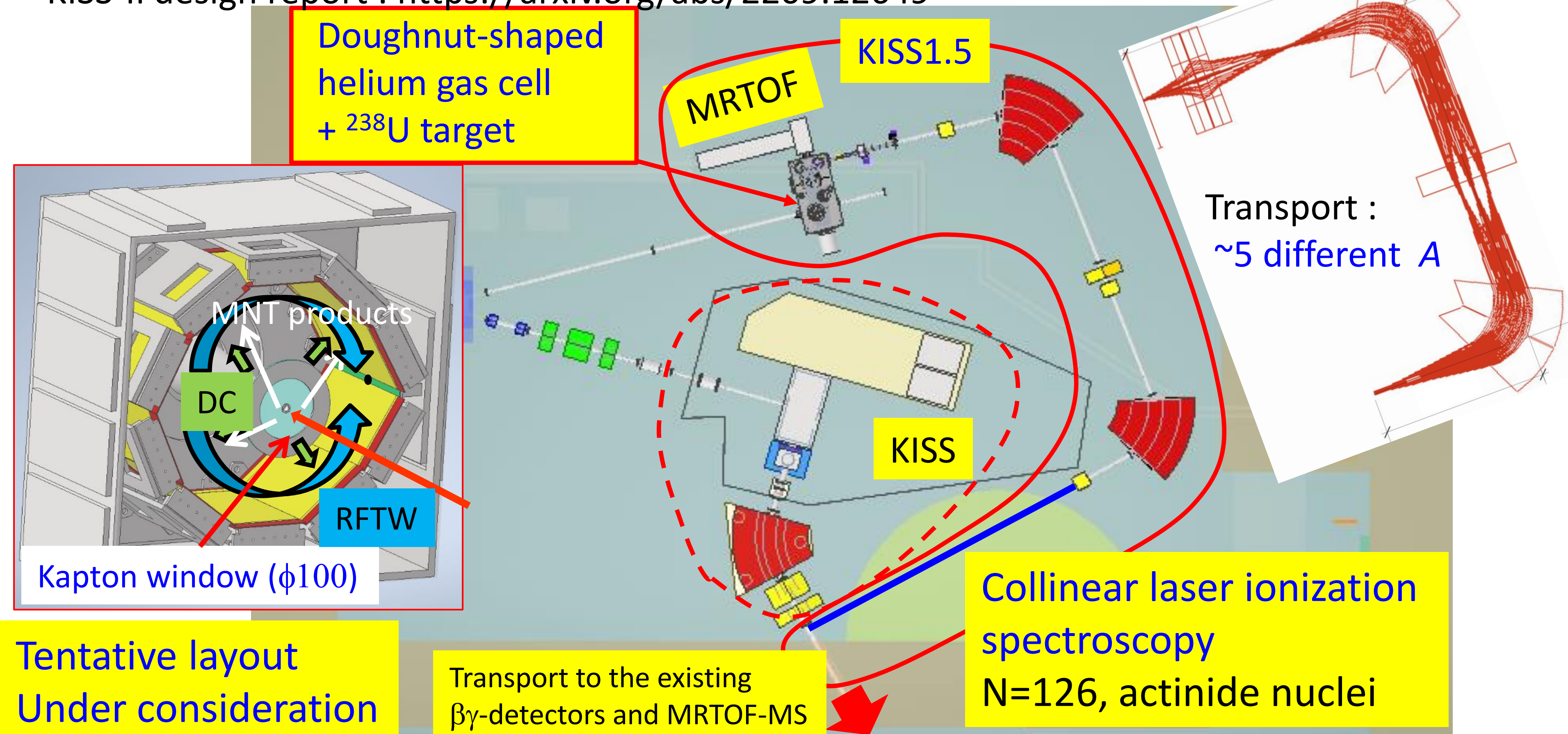
From the β-decay scheme → I=0$^-$,
π1/2$^+$[411](d3/2)⊗ν1/2$^-$ [521] (f5/2)
(PLB814(2021)136088)

Near future plan : KISS−1.5

	Primary beam intensity	Extraction efficiency	Efficacy	Total gain
KISS	10 pnA	<0.1%	1	1
KISS-1.5	50 pnA Doughnut-shaped He GC	>1% RF He gas cell	> 10 MRTOF	> 500
KISS-II	1000 p Solenoid r	[illegible]	[illegible]	> 10 000

KAKENHI approved : 2.8 M € (FY2024-2028)

KISS-II design report : https://arxiv.org/abs/2209.12649



Summary

KISS : MNT reactions + Gas cell system

➡ Access blank spots on the nuclear chart and
Perform laser ionization spectroscopy
for the studies of nuclear structure

- In-gas-cell laser ionization spectroscopy of nuclei in the vicinity of N = 126
  - ➡ Systematic studies of Pt, Ir, Os, and Re isotopes ➡ Atomic and Nuclear theoretical supports
- Precise laser ionization spectroscopy for actinide nuclei
  - ➡ Collinear laser resonant ionization beam line at KISS/KISS-1.5

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Thank you