KISS/KISS-1.5 to explore the origin of heavy elements synthesized by r-process from their nuclear spectroscopy

KEK Isotope Separation System (KISS)
to study nuclear properties from astrophysical interest
Multi-nucleon transfer reactions to produce neutron-rich nuclei

Yoshikazu HIRAYAMA
(Wako Nuclear Science Center, IPNS, KEK)

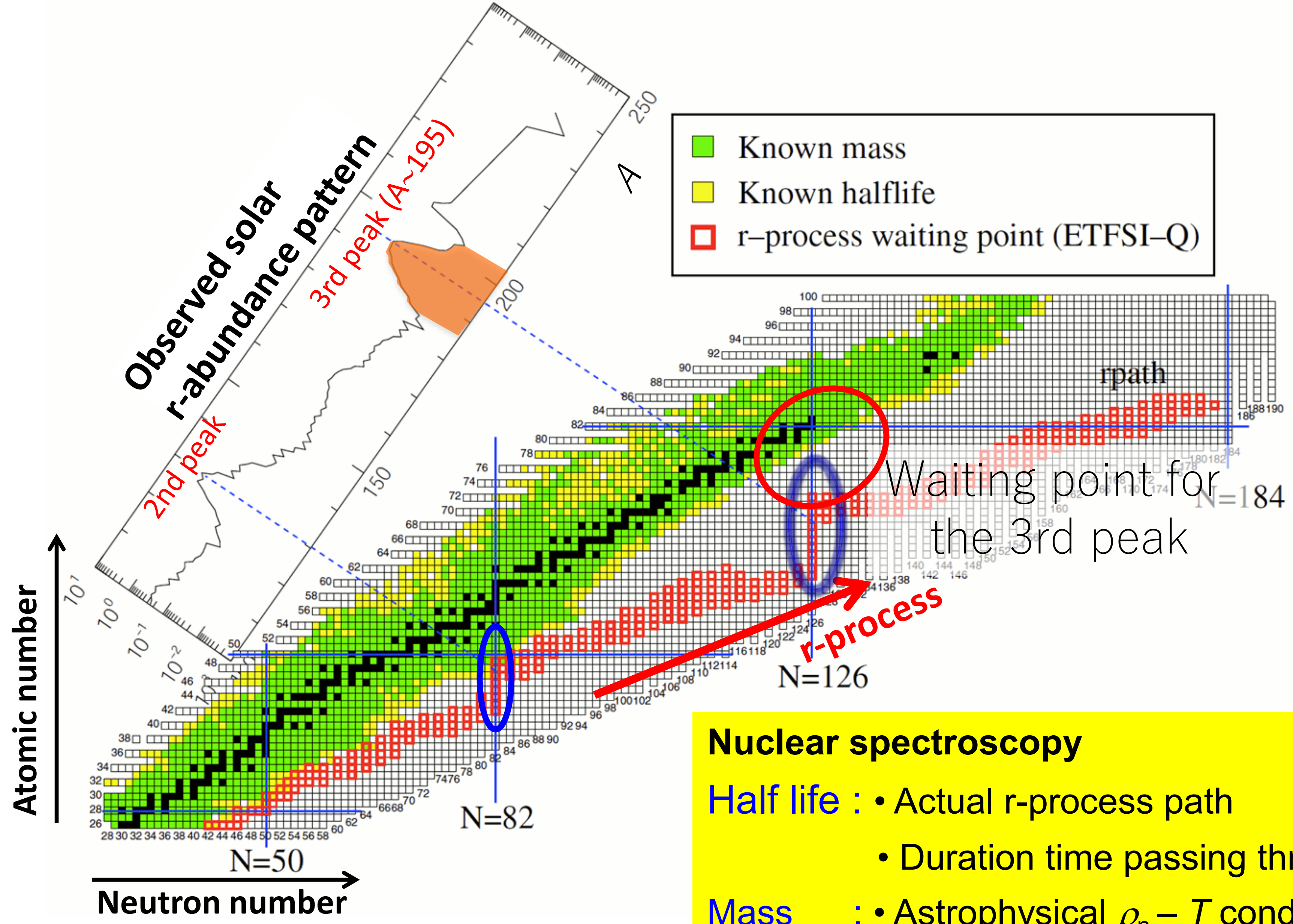
Outline :

1. Motivation
2. KISS
3. KISS-1.5
4. Summary

INPC2025
26-30th May, Daejeon, Koria

Physics motivation

Identification of astrophysical site for r-process



Nuclear spectroscopy

Half life : • Actual r-process path

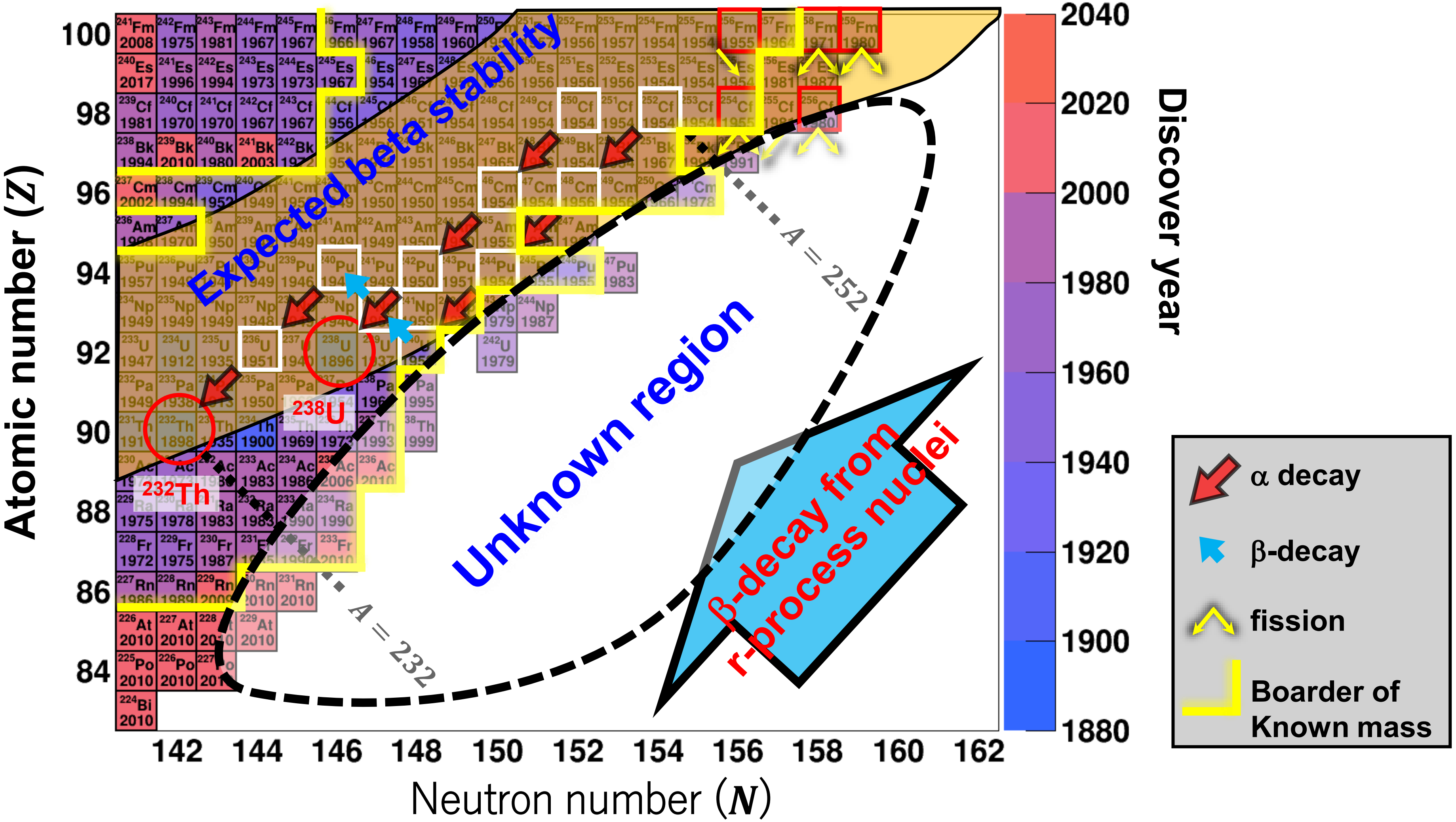
• Duration time passing through waiting point

Mass : • Astrophysical $\rho_n - T$ condition

β–γ spectroscopy, laser spectroscopy : precise predictions

H. Grawe et al., Rep. Prog. Phys. 70 (2007), 1525-1582.

Explore the origin of uranium and thorium
~ Nuclear spectroscopy of actinide elements ~



- The origin of U and Th would be r-process nuclei with *A* = 232-252.
- No experimental data for neutron rich nuclei
- MNT reactions can produce these neutron-rich actinide nuclei

KISS
KEK Isotope Separation System
in RIKEN RIBF

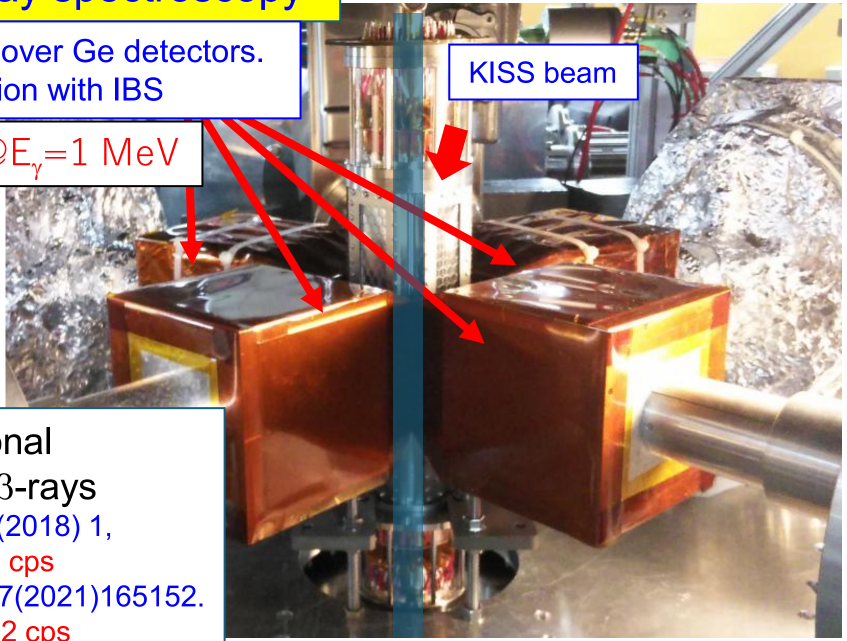
Production (MNT reactions)
Separation (KISS)
of the nuclei around $N = 126$

KISS : detectors and MRTOF-MS

β–γ decay spectroscopy

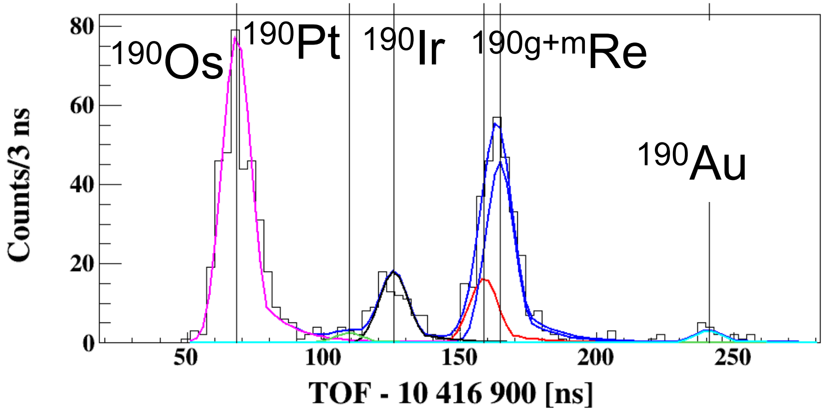
4 Super Clover Ge detectors.
Collaboration with IBS

ε_{γ}=10%@E_{γ}=1 MeV



Multi-Segmented proportional gas counter (MSPGC) for β-rays

2DT : M. Mukai *et al.*, NIM A884 (2018) 1,
ε_{β}=40%@Q_{β}=1MeV, BG rate : 0.1 cps
3DT : Y Hirayama *et al.*, NIM A997(2021)165152.
ε_{β}=20%@Q_{β}=1MeV, BG rate : 0.02 cps



MRTOF-MS : R_m> 500,000, ε= 8%

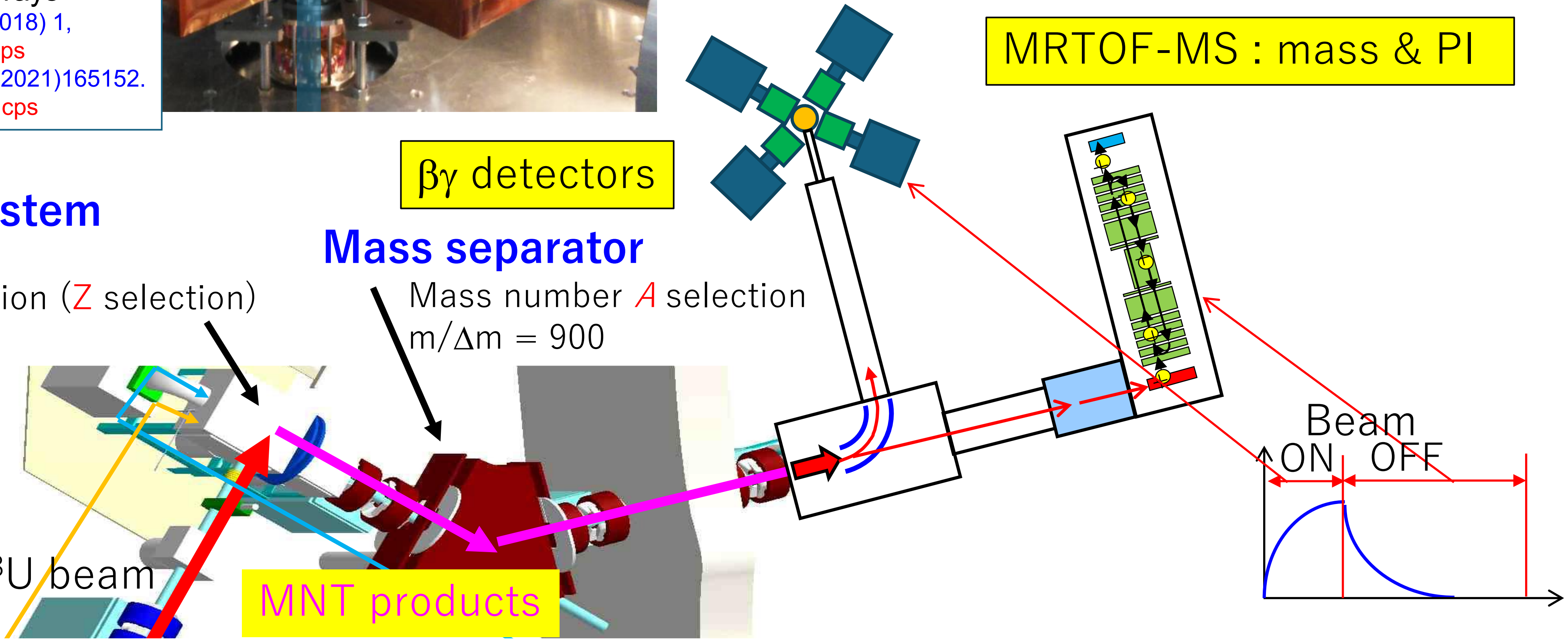
MRTOF-MS : mass & PI

Gas cell system

Argon gas cell
+ laser ionization (Z selection)

Mass separator

Mass number A selection
m/Δm = 900



Experimental results

β-γ spectroscopy

Mass measurement

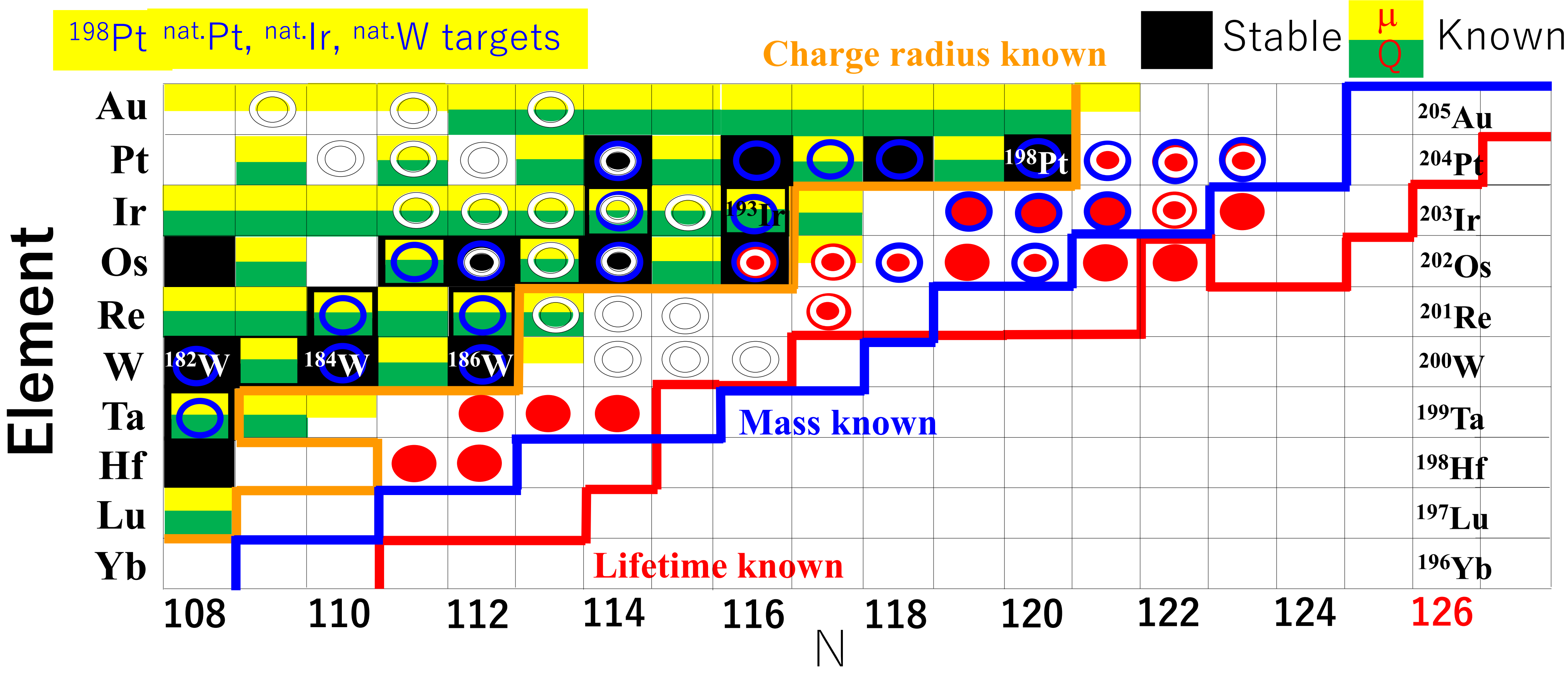
Laser spectroscopy

26th Parallel Session-2, Nuclear Reaction (2)
J.M. Yap

30th Parallel Session-2 -8, Nuclear Structure (1)
J. Chen, M. Mukai

30th Parallel Session-2 -8, Nuclear Structure (3)
T. Niwase, P. Schury

Nuclear spectroscopy around $N = 126$ at KISS



β-γ spectroscopy Mass measurements Laser spectroscopy

^{197,198}Os : Y.H. et al., PRC 98 (2018) 014321

^{195m}Os : Y.X. Watanabe et al., PRC 101 (2020) 041305(R)

^{187m}Ta : P. Walker et al., PRL 125 (2020) 192505

^{195g}Os : M. Ahmed et al., PRC 103 (2021) 054312

^{192g}Re : H. Watanabe et al., PLB 814 (2021) 136088

^{186m}Ta : Y.X. Watanabe et al., PRC 104 (2021) 024330

^{187g}Ta : M. Mukai et al, PRC 105 (2022) 034331

^{199g}Pt, ^{199m}Pt : Y.H. et al, PRC 96 (2017) 014307

^{194,196}Os : H. Choi et al, PRC 102 (2020) 034309

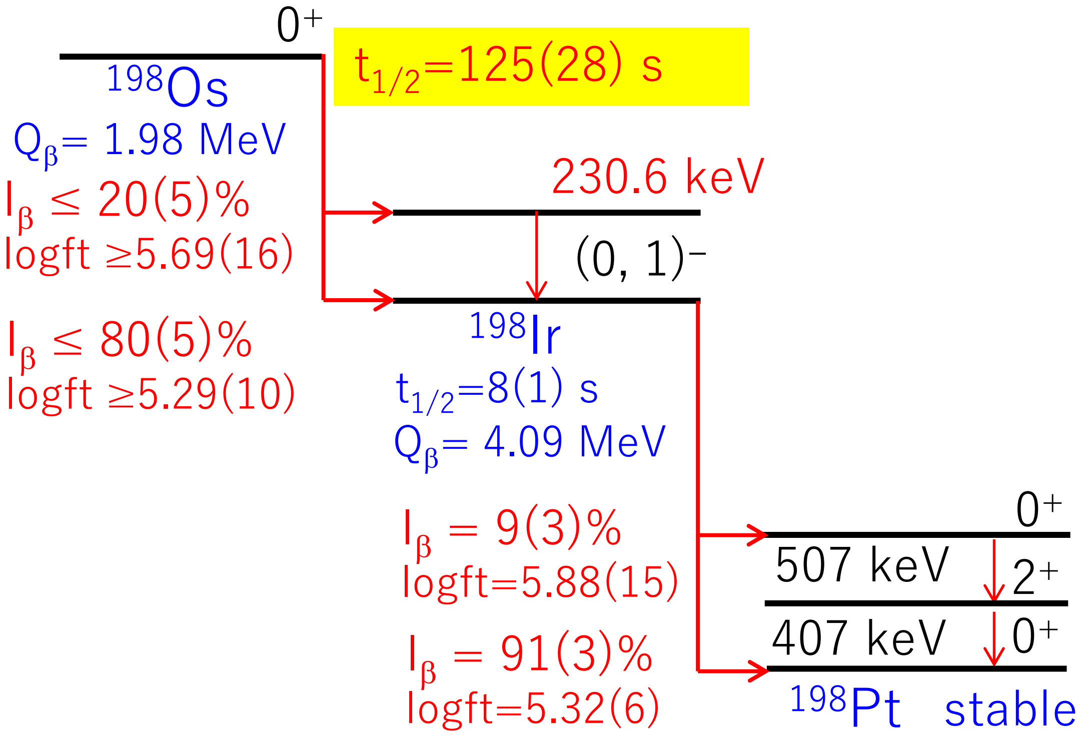
$^{196-198}$Ir : M. Mukai et al, PRC 102 (2020) 054307

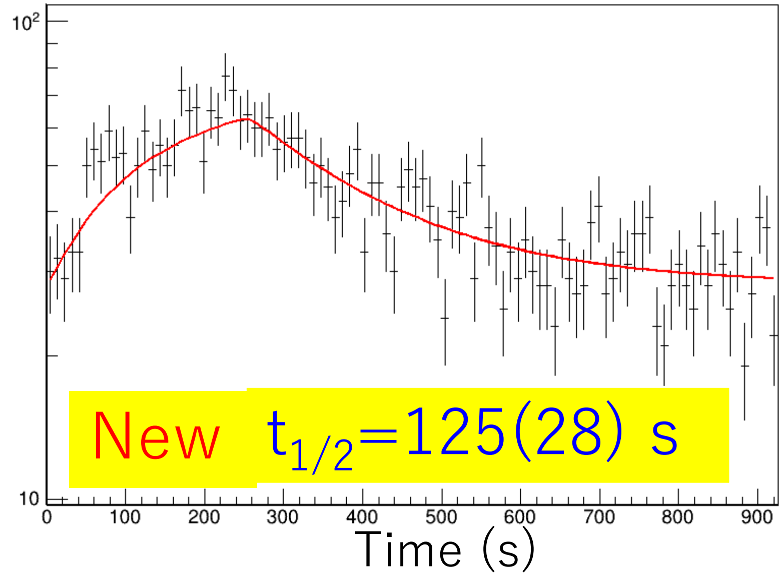
$^{200-201}$Pt: Y.H. et al., PRC 106 (2022) 034326

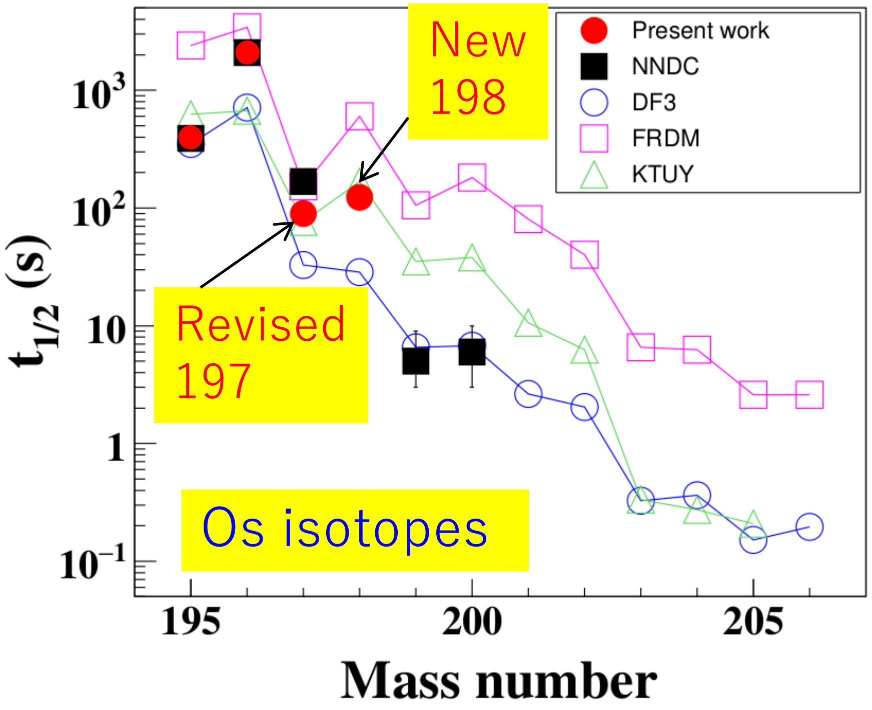
^{189g}W : M. Mukai et al., PRC 111 (2025) 014322

β-γ spectroscopy of ^{198}Os ($t_{1/2}$= unknown)

1. Laser ionized Ir
2. Laser ionized Os



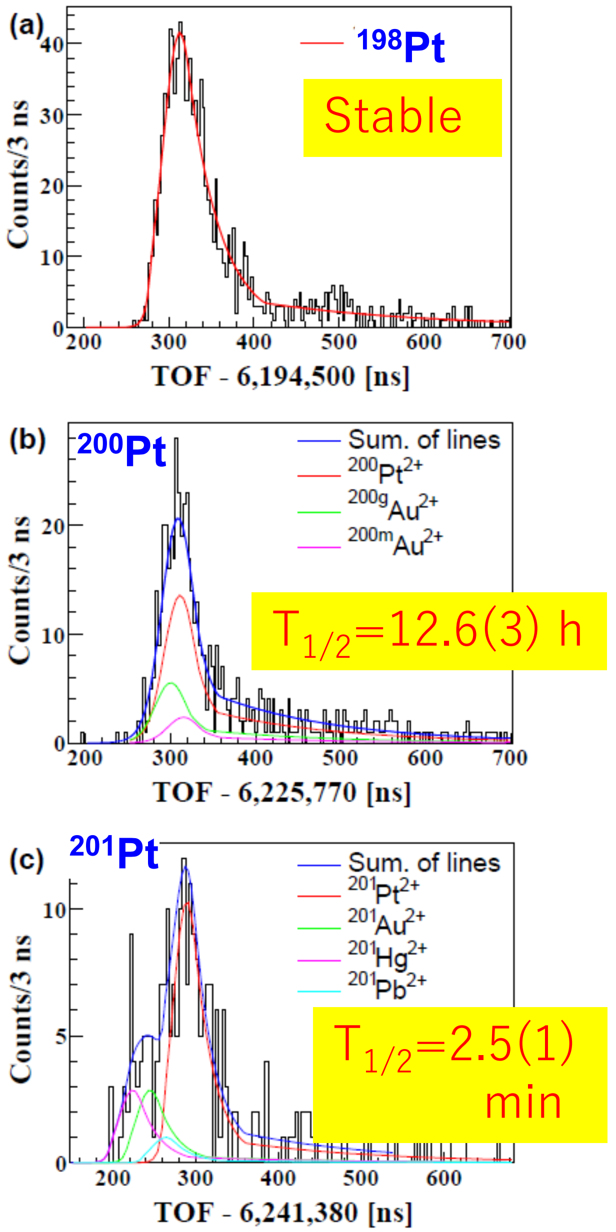




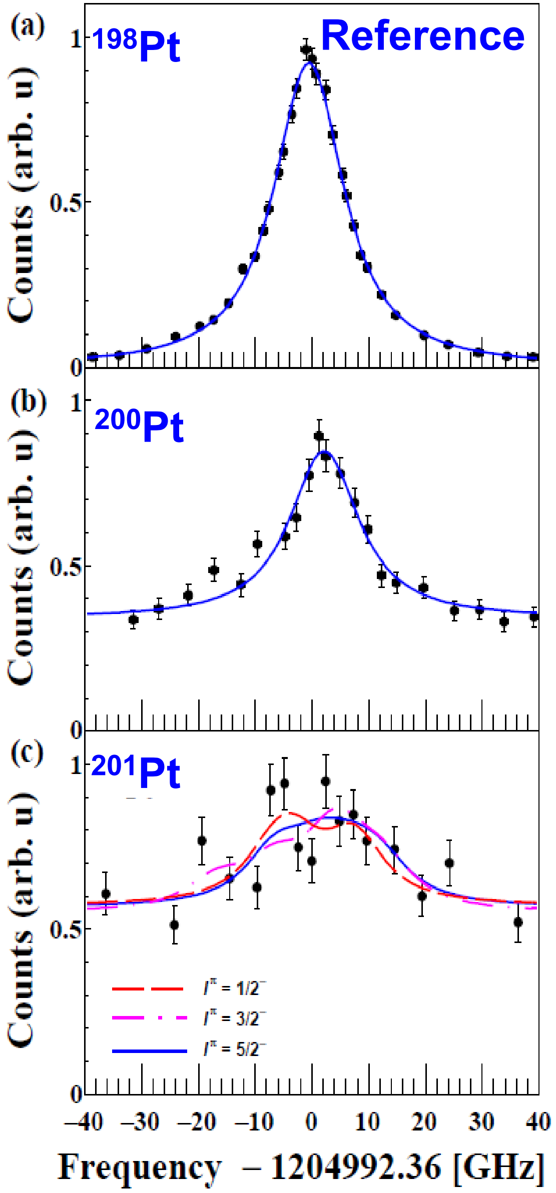
Y.Hirayama et al. PRC98(2018)014321

In-gas-cell laser ionization spectroscopy : ^{200,201}Pt (Z=78)

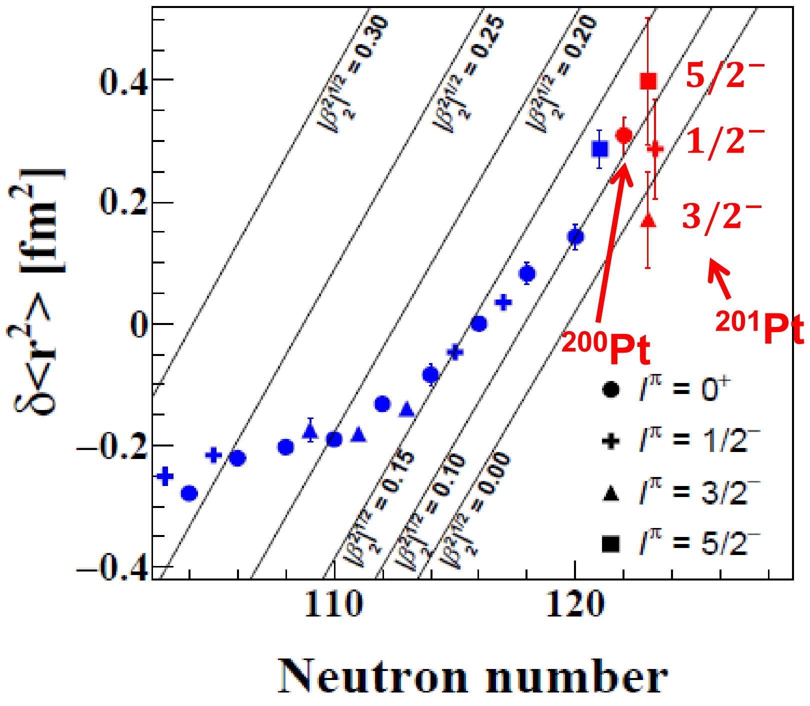
PI by using MRTOF-MS



Laser resonance spectra



Isotope shift : δν → charge radii
→ deformation



Deduce nuclear moment of ^{201}Pt$_{123}$

I^{π}=5/2$^-$, μ = +0.86(21) μ_N → $\nu f_{5/2}$

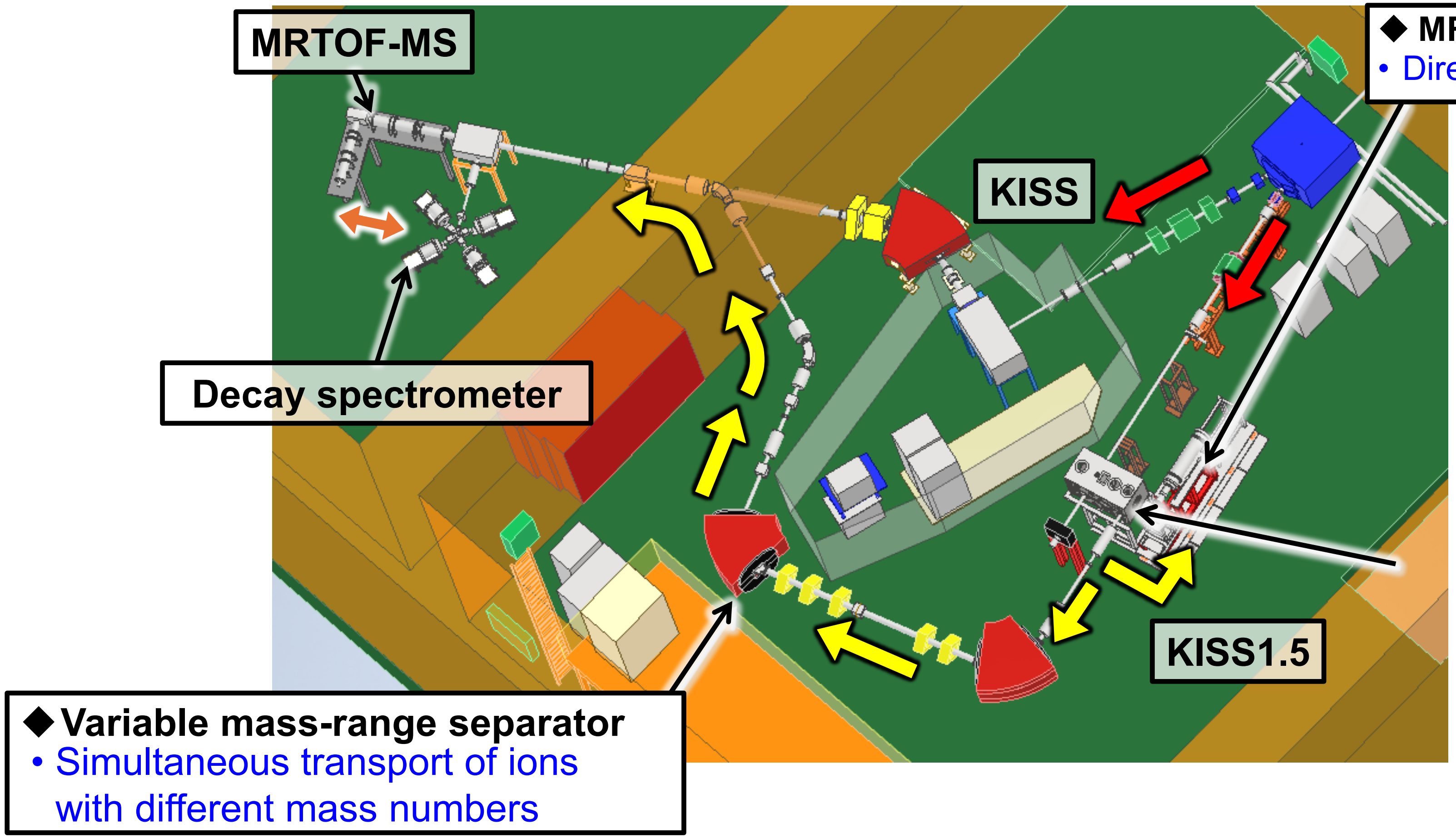
^{203}Hg$_{123}$: I^{π}=5/2$^-$, μ = +0.84895(3) μ_N → $\nu f_{5/2}$

Y. Hirayama et al., Phys. Rev. C 106 (2022) 034326

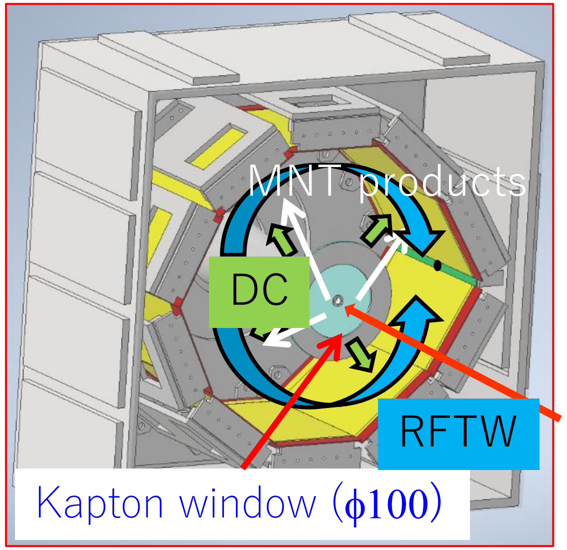
KISS upgrade toward KISS-1.5

Near future plan : KISS-1.5

	Primary beam	Ion extraction efficiency	Simultaneous measured nuclides	Efficacy
KISS	~ 10 pnA	<0.1%	1	1
KISS-1.5	**100 pnA**	**>1%**	**> 10**	**100 ~ 1000**
	◆ Target system ◆ Doughnut-shaped helium gas cell (DSHeGC)	◆ DSHeGC no laser ionization	◆ DSHeGC ◆ MRTOF-MS ◆ Variable mass-range separator	



DSHeGC



Y. Hirayama et. al., NIMA 1058, 168838 (2024).

Y.X. Watanabe et al., Nucl. Phys. A 1061, 123140 (2025).

Summary

To characterize *3^{rd} peak of* abundance pattern and
explore the origin of U and Th from nuclear physics perspective,
nuclear spectroscopy in the vicinity of N=126
and actinide region is essential.

- Installation of KISS was completed.
- Lifetime measurements and β-γ spectroscopy
- Laser spectroscopy for g-factor and charge radius
- Mass measurement by using MRTOF-MS

➡ Proceed further nuclear spectroscopy of nuclei
around N=126 and around ^{238}U (n-rich actinide)

➡ Construction of KISS1.5 will start from the next October

Thank you very much for your attentions!