

SHE Research at RIKEN/GARIS



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元素周期表 Periodic Table of Elements (Reported)

族	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
周期	1 H 1																	He 2
2	Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
3	Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
4	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
5	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
6	Cs 55	Ba 56	* ●	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
7	Fr 87	Ra 88	† ●	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112	113 113	Fl 114	115 115	Lv 116	117 117	118 118
			→ 超アクチノイド元素															
*ランタノイド			↓															
†アクチノイド			→															
			La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71	
			Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103	

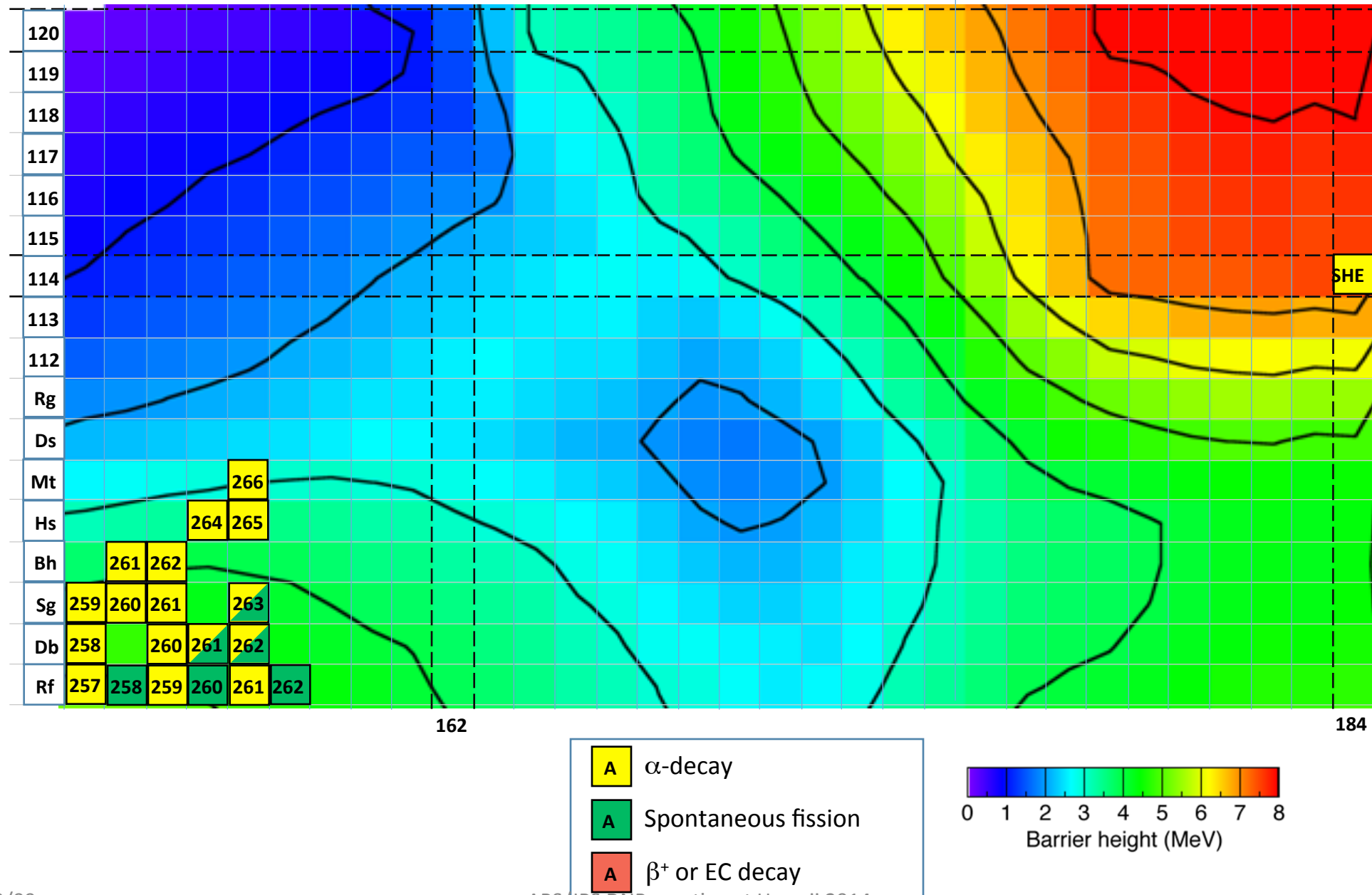


自然界で発見された元素

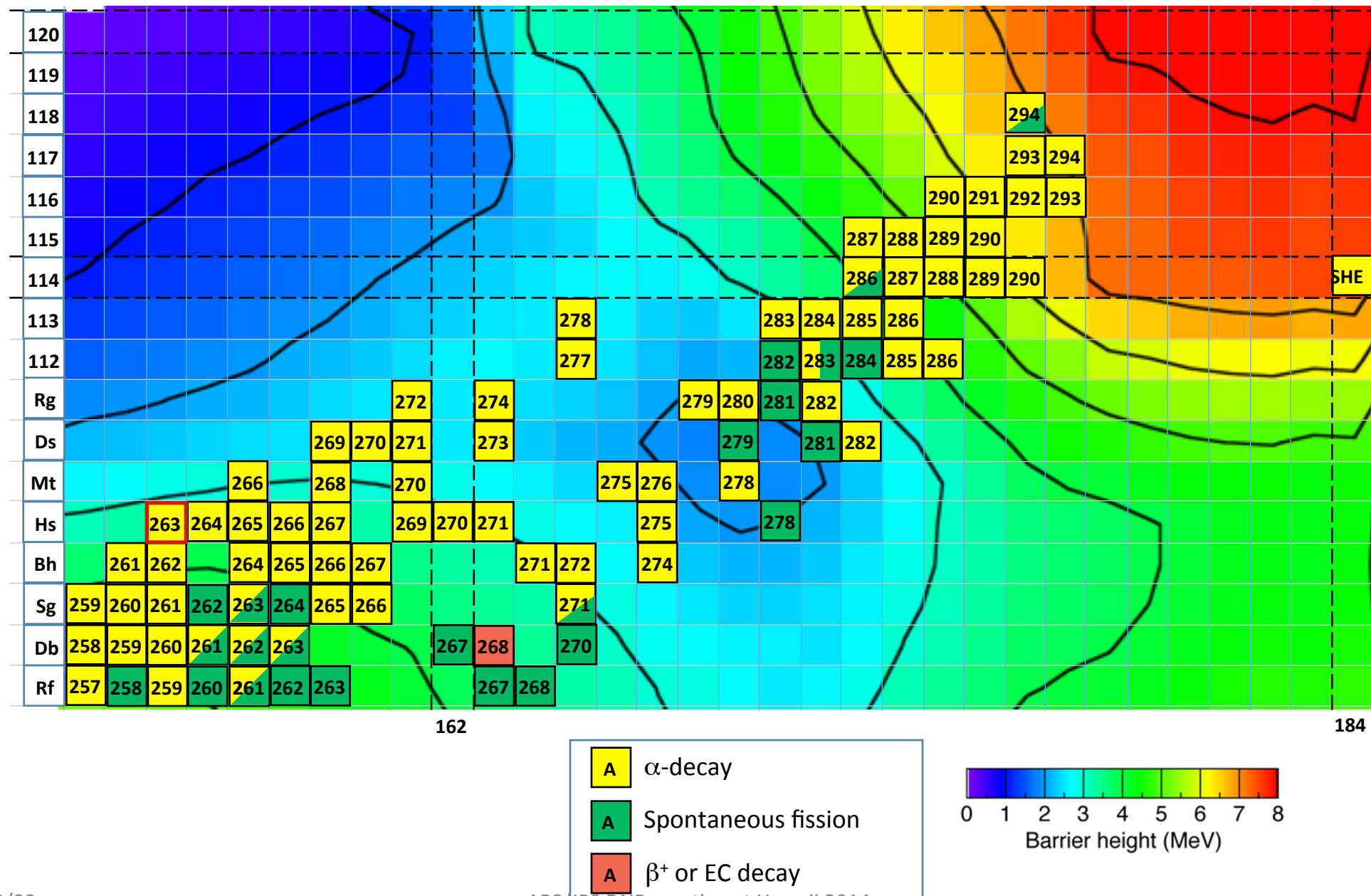


人工合成により発見された元素

科学を語る会@九大西新プラザ



one end of nuclear chart 2010



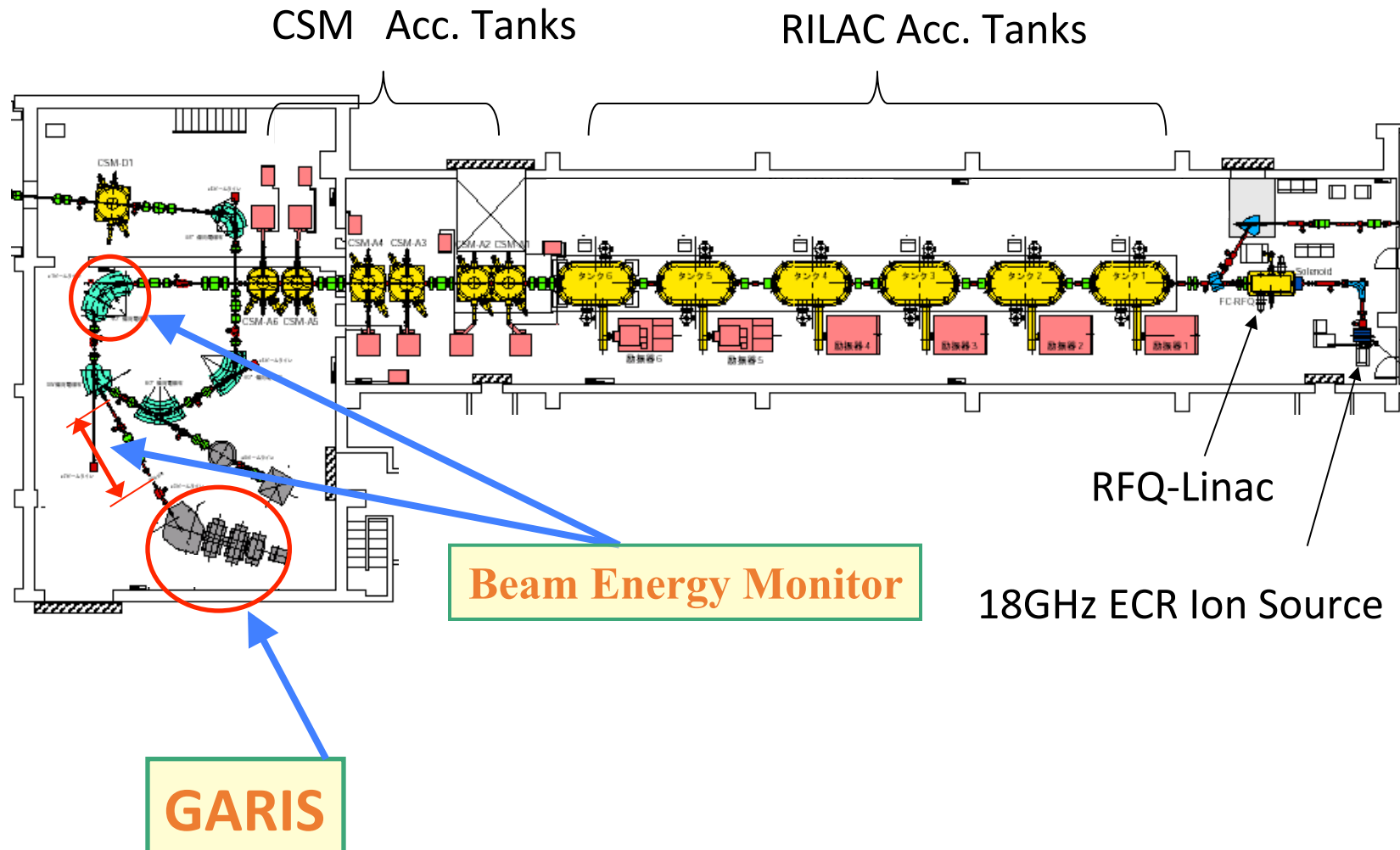
Main Limitations of Various Approaches to SHE

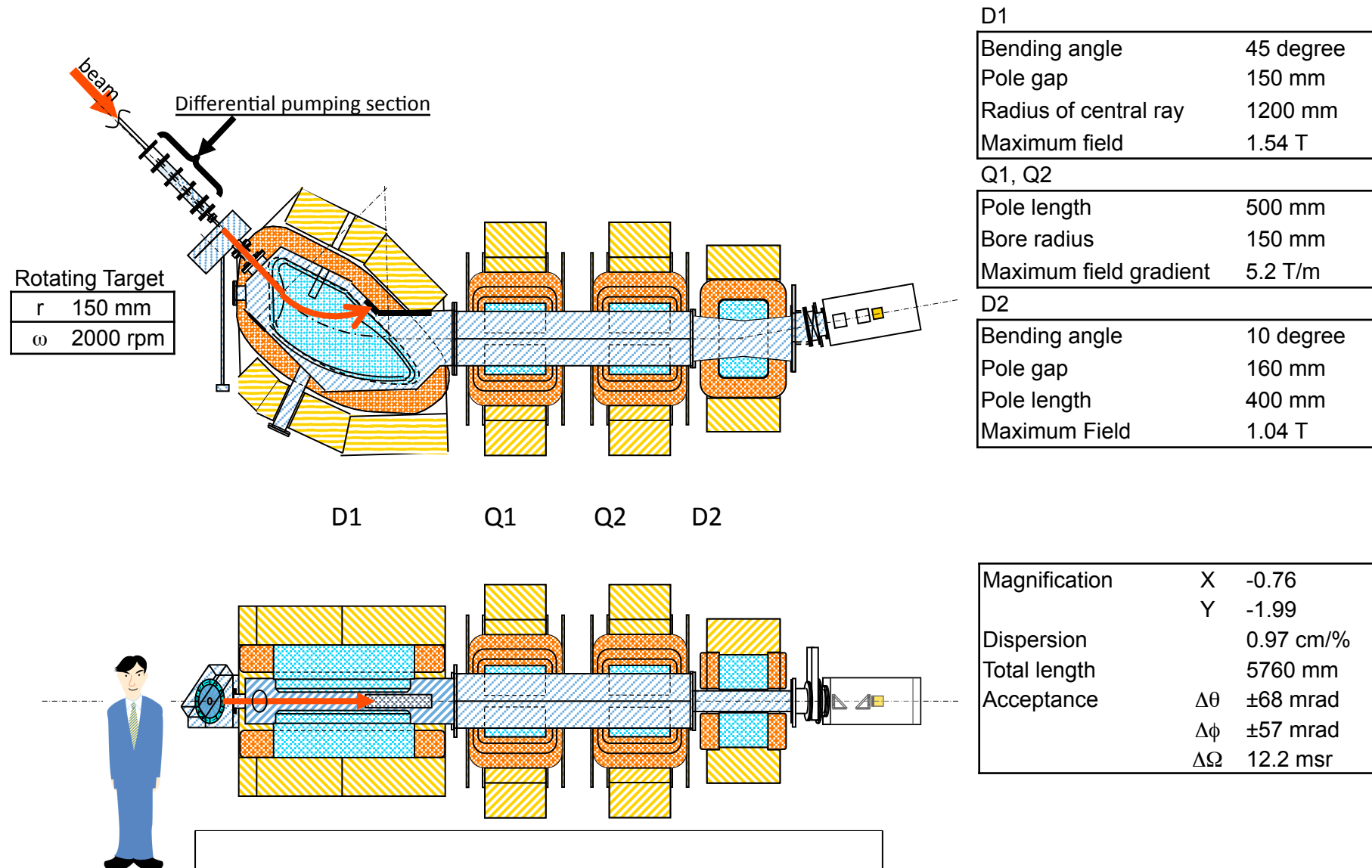
Reaction Mode	Proj. (Aproj)	Limitation	Heaviest Nuclide		comment
			(Z)	(N)	
multiple n-capture	n	SF* of Fm isotopes	100	157	maybe possible in nature (r-process)
hot fusion (HI,xn);x=3-6 Ucn≥40 MeV	≤34 &48	small survival prob. (Γ_n/Γ_f very small)	118	177	N-rich beam often improves. (cf. ^{48}Ca ;warm fusion)
cold fusion (HI,xn);x=1,2 Ucn ≤20 MeV	50-70	small fusion prob. (dynamical hindrance of fusion?)	113	165	
transfer reaction	≤22	lack of target heavier than $^{254}\text{Es}^{**}$	103	159	

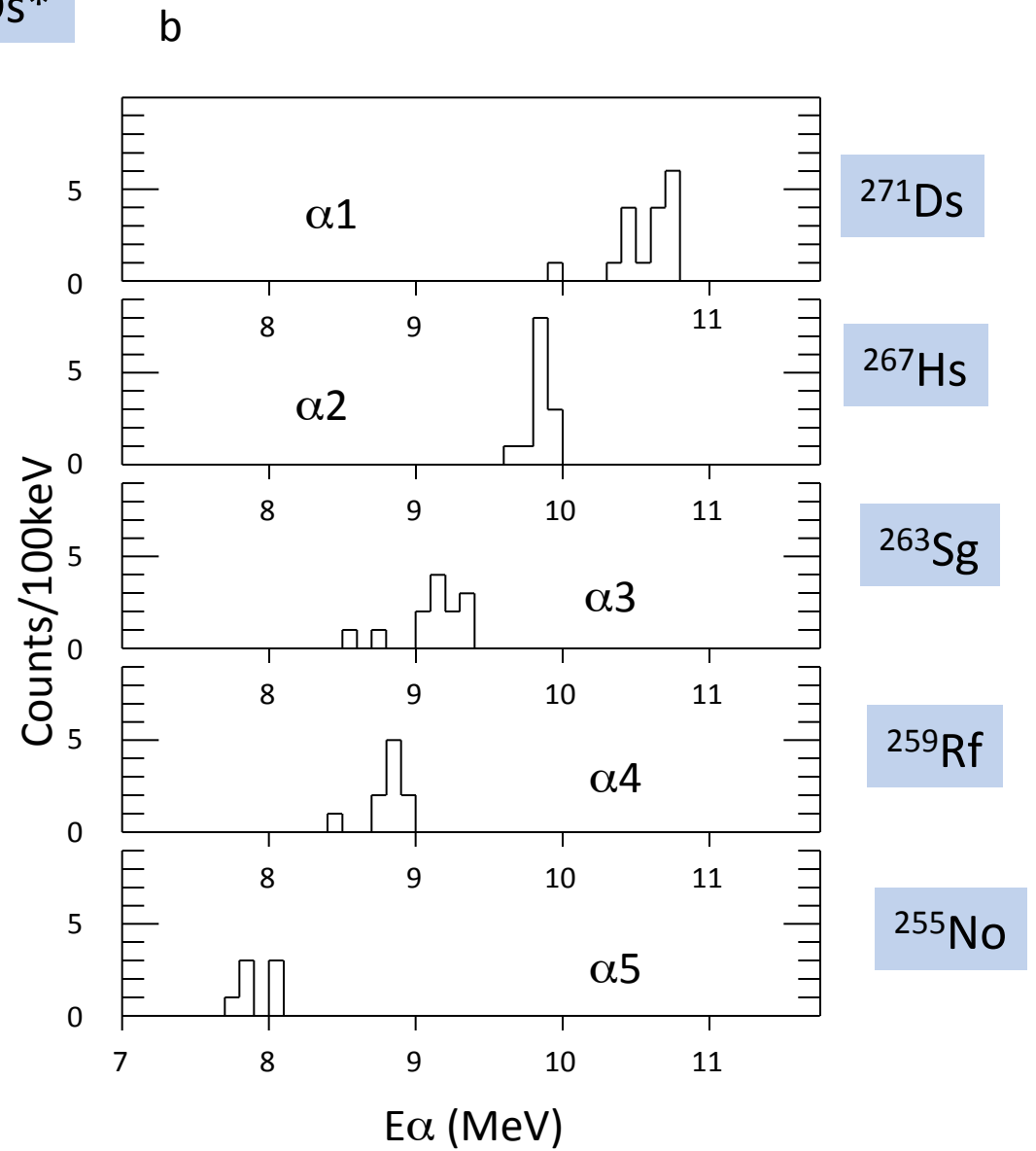
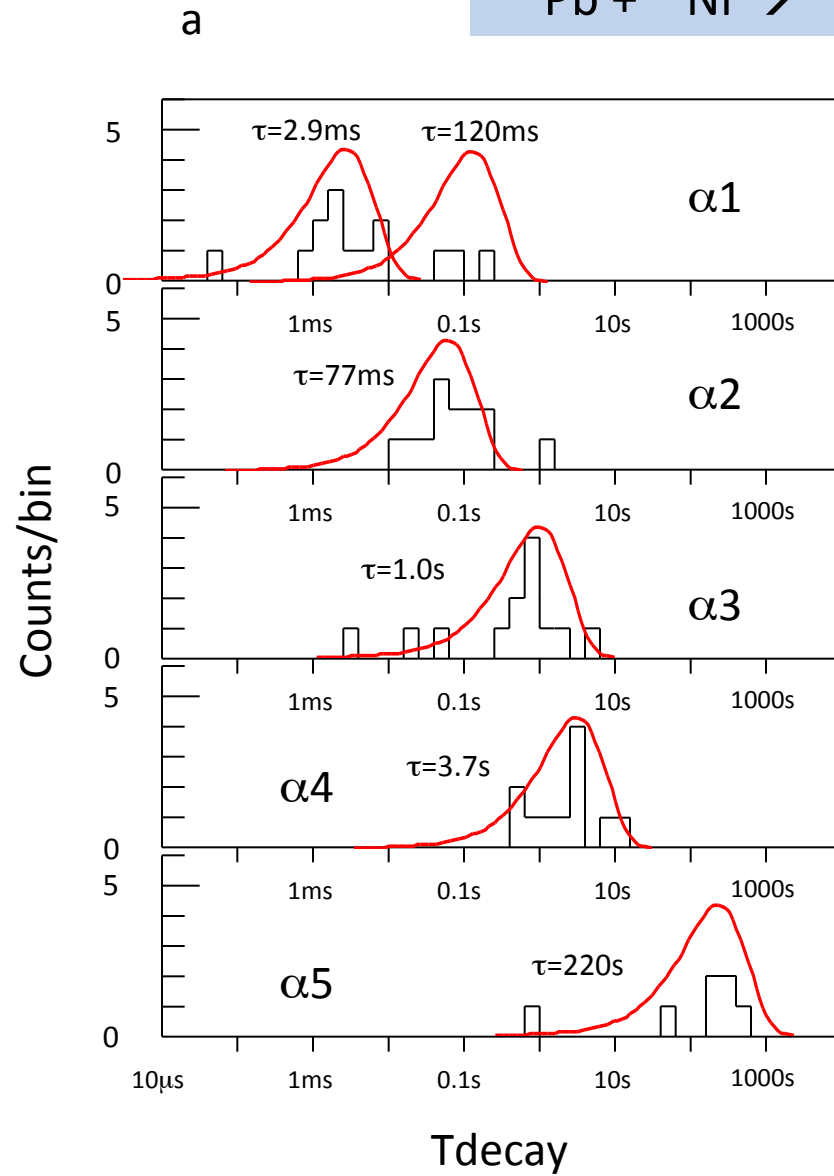
*SF: spontaneous fission. cf. $T_{1/2}$ of $^{258}\text{Fm}_{158} \approx 400 \mu\text{s}$.

** $^{254}\text{Es}(Z=99)$: $T_{1/2} \approx 276 \text{ day}$

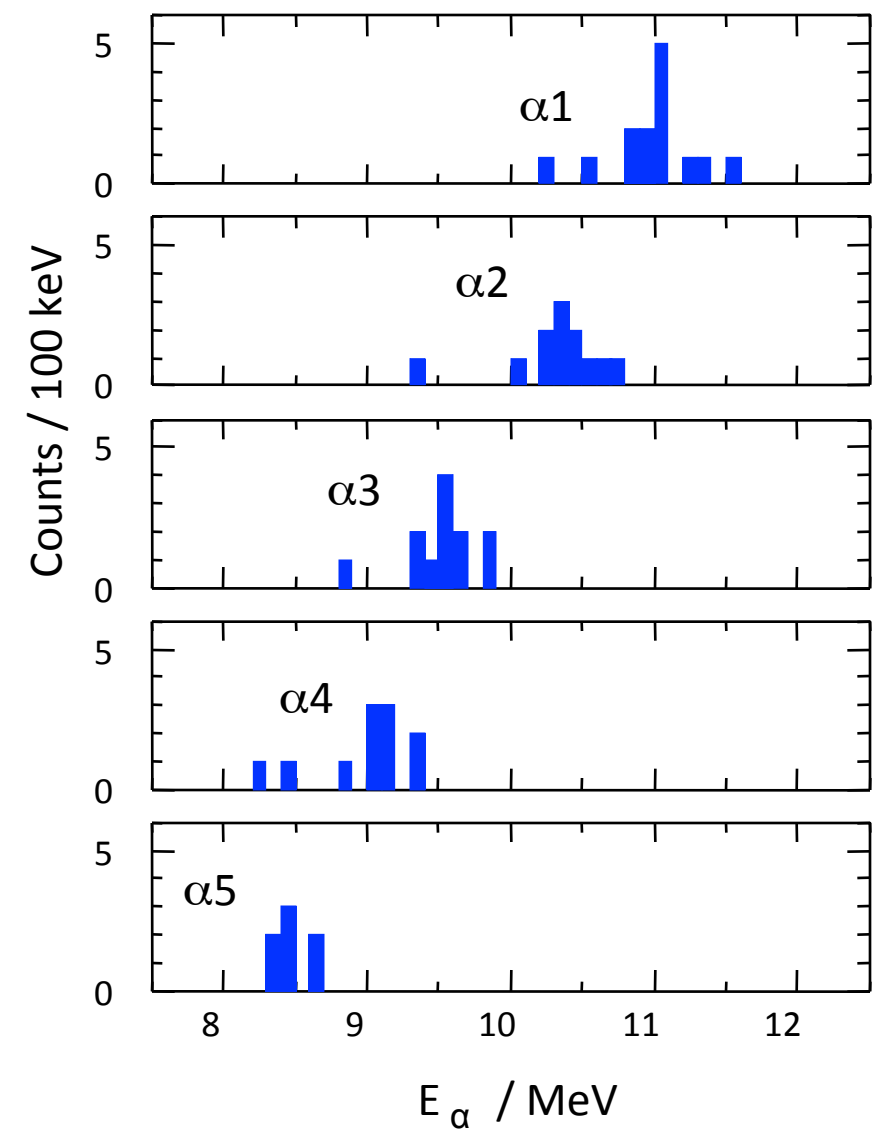
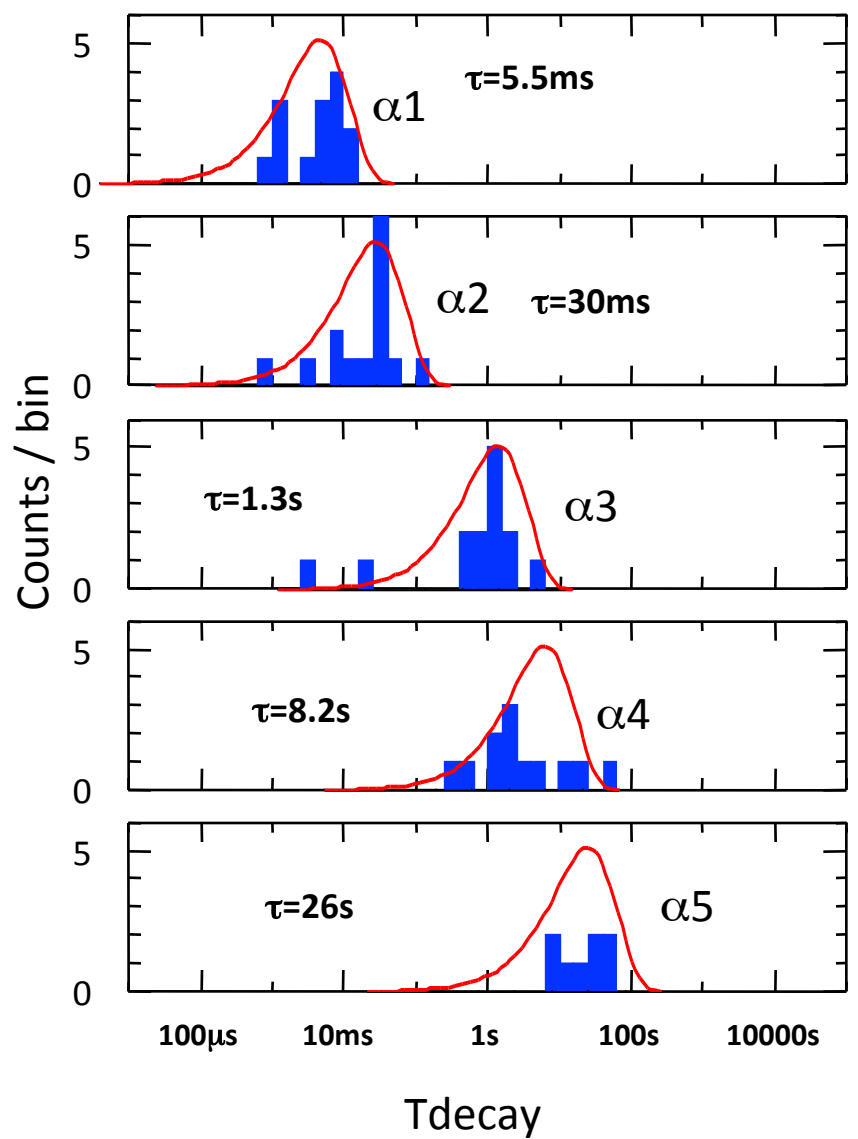
Linear Accelerator Facility







$^{254}\text{Md} \leftarrow ^{256}\text{Lr} \leftarrow ^{260}\text{Db} \leftarrow ^{264}\text{Bh} \leftarrow ^{268}\text{Mt} \leftarrow ^{272}\text{Rg}$



Cn

	GSI		RIKEN			FLNR	
ref.	1	2	3	4	present	5	6
²⁷⁷ Cn	11.45	11.17	11.09±.07	11.32±.04	11.07±.07		
	0.28 ms	1.41 ms	1.10 ms	1.22 ms	0.37 ms		
²⁷³ Ds	11.08	11.20	11.14±.04	11.15±.07	11.03±.07	11.35	
	0.11 ms	0.31 ms	0.52 ms	0.04 ms	0.373 ms	0.39 ms	
²⁶⁹ Hs	9.23	9.18	9.17 _c	9.25±.07	9.14±.04		
	19.7 s	22.0 s	14.2 s	0.27 s	36.01 s		
²⁶⁵ Sg	4.60	0.20	8.71±.04	8.70±.04	8.66±.07	8.63	
	7.40 s	18.8 s	23.0 s	79.9 s	13.84 s	158 s	
²⁶¹ Rf	8.52	153	197	156	176		8.30±0.06
	4.70 s	14.5 s	2.97 s	8.30 s	3.73 s		54 ⁺⁸ ₋₄ s
²⁵⁷ No	8.34					8.22	8.24, 8.34
	15.0 s					384 s	17 s

ref.

1 Hofmann S. et al., Z. Phys. A354, 229 (1996)

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

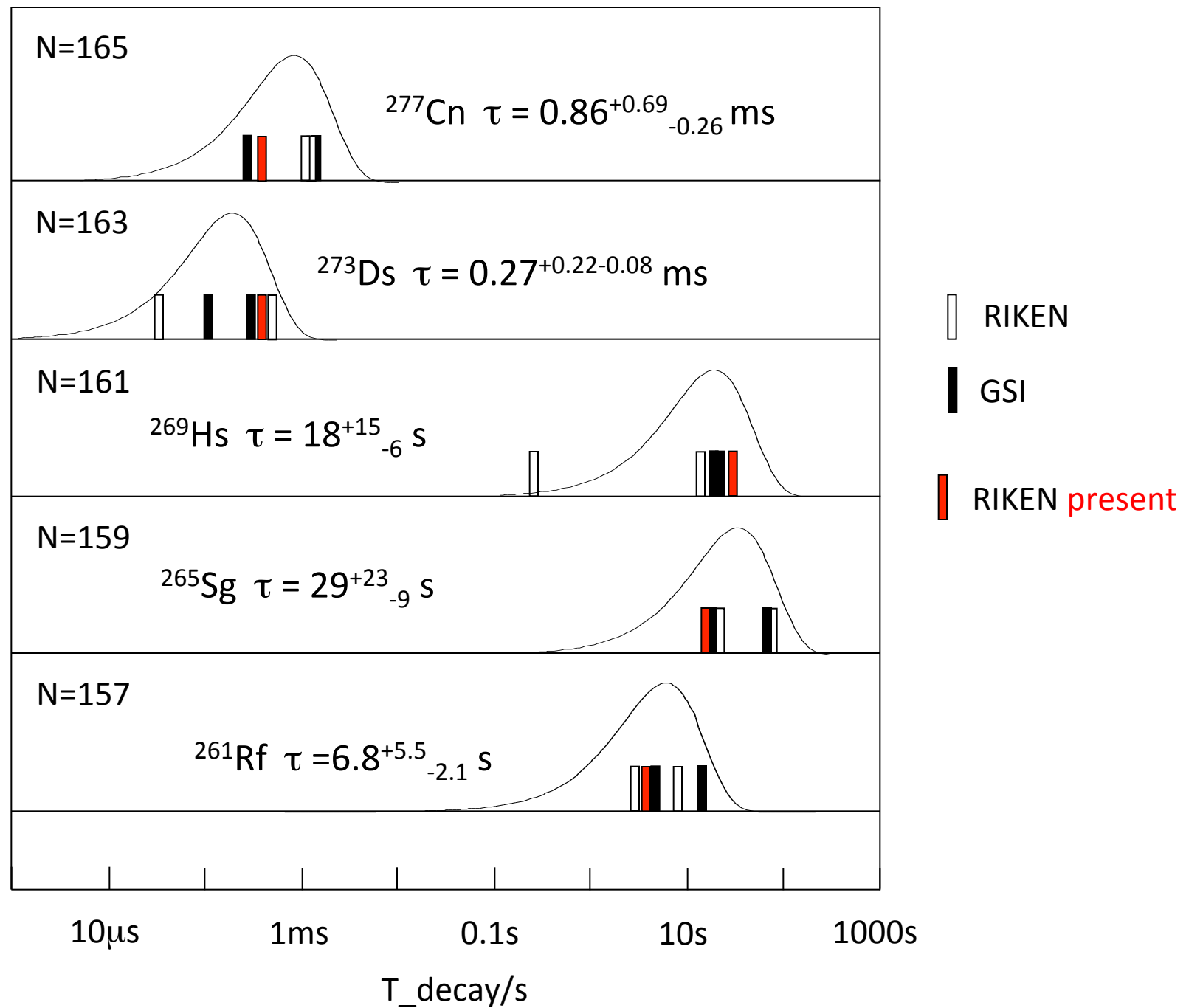
3,4 J. Phys. Soc. Jpn., Vol. 76, No. 4, p.043201(2007)

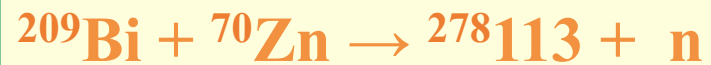
present

5 Lazarev Yu. A. et al., Phys. Rev. C54, 620 (1996)

6 Lazarev Yu. A. et al., Phys. Rev. C62, 064307(2000)

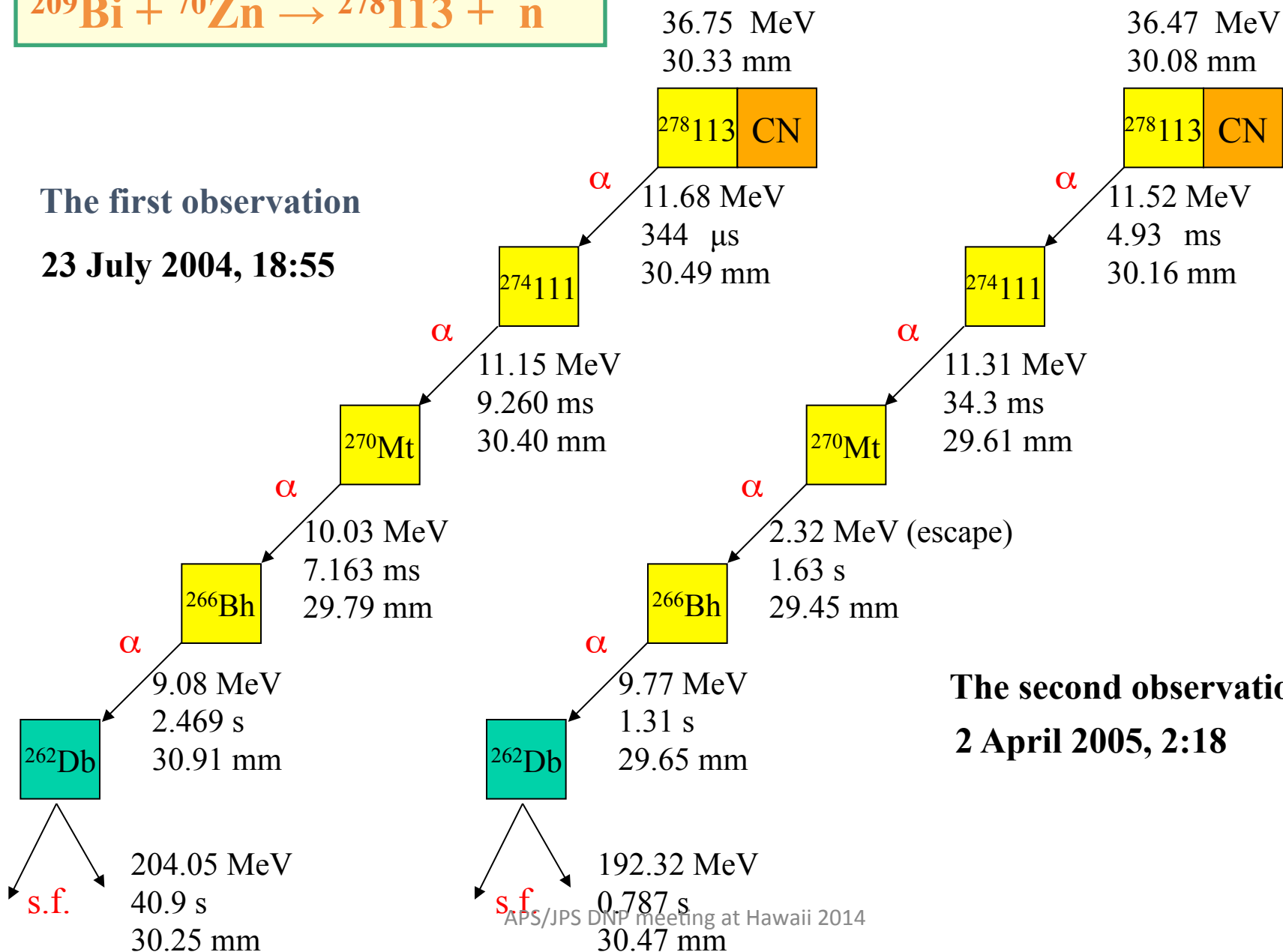
 $^{208}\text{Pb} + ^{70}\text{Zn} \rightarrow ^{277}\text{Cn} + n$ $^{208}\text{Pb} + ^{70}\text{Zn} \rightarrow ^{277}\text{Cn} + n$ $^{208}\text{Pb} + ^{70}\text{Zn} \rightarrow ^{277}\text{Cn} + n$ $^{208}\text{Pb} + ^{70}\text{Zn} \rightarrow ^{277}\text{Cn} + n$ $^{244}\text{Pu} + ^{34}\text{S} \rightarrow ^{273}\text{Ds} + 5n$ $^{244}\text{Pu} + ^{22}\text{Ne} \rightarrow ^{261}\text{Rf} + 5n$





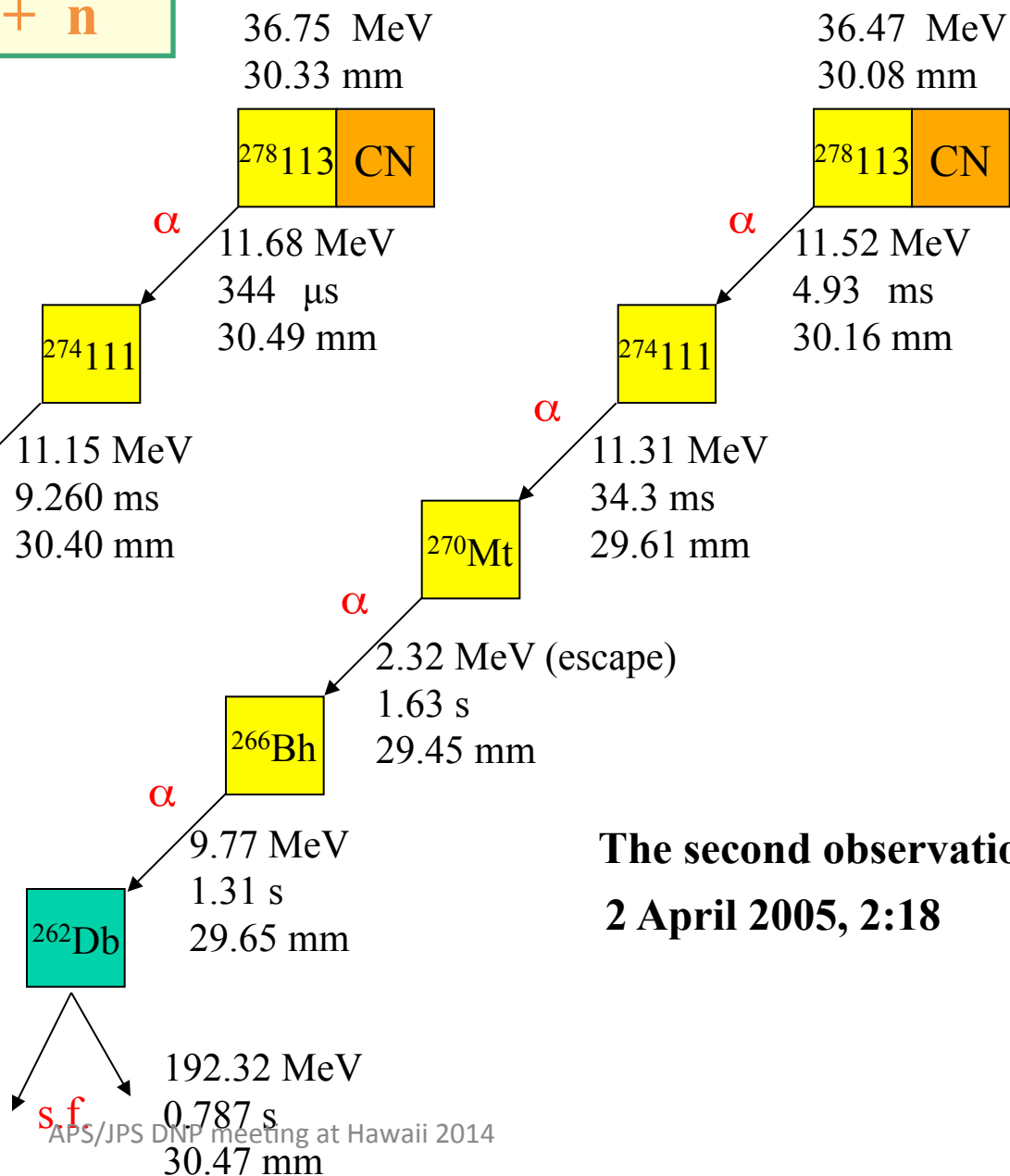
The first observation

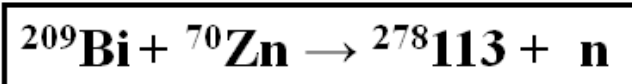
23 July 2004, 18:55



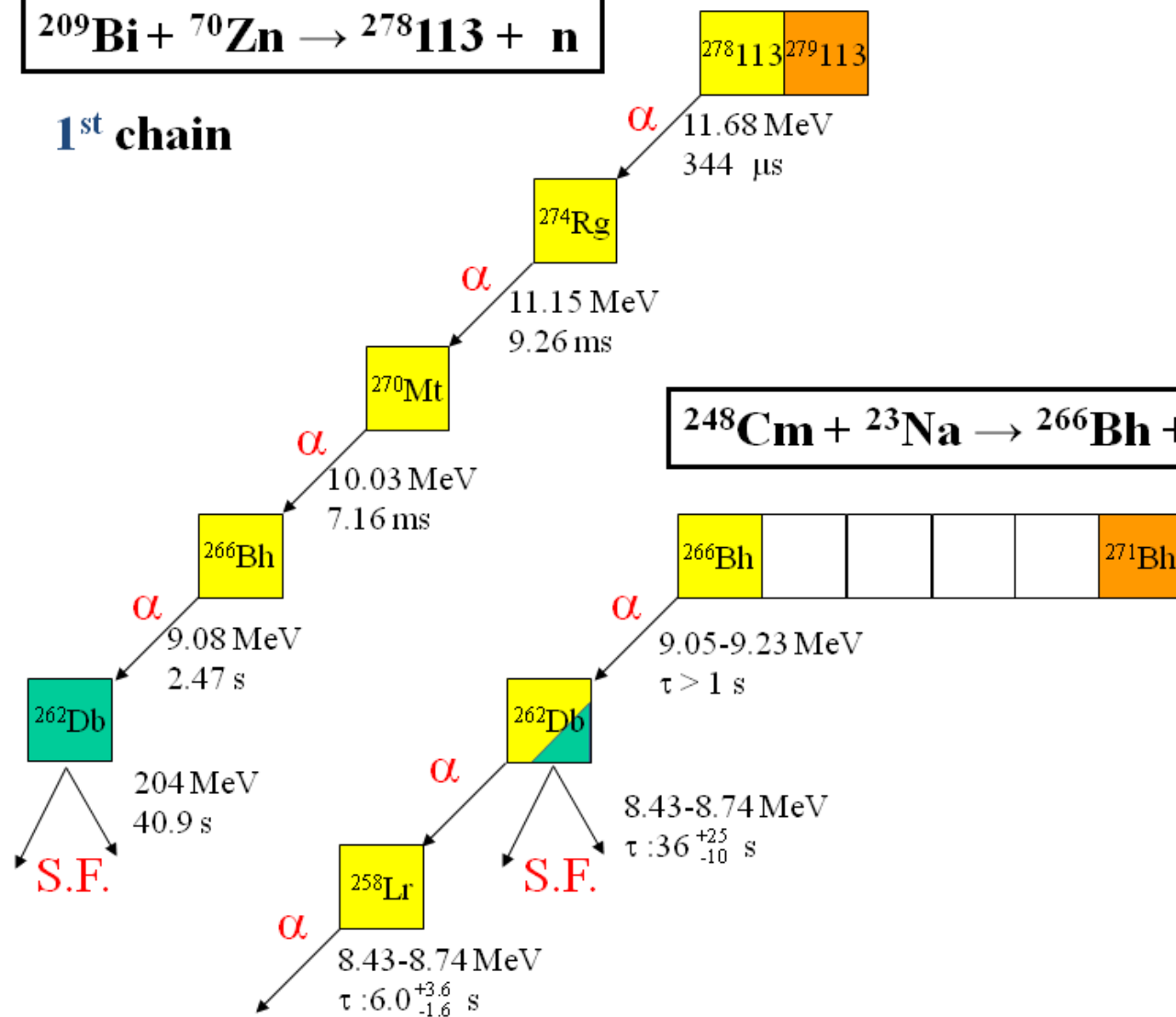
The second observation

2 April 2005, 2:18



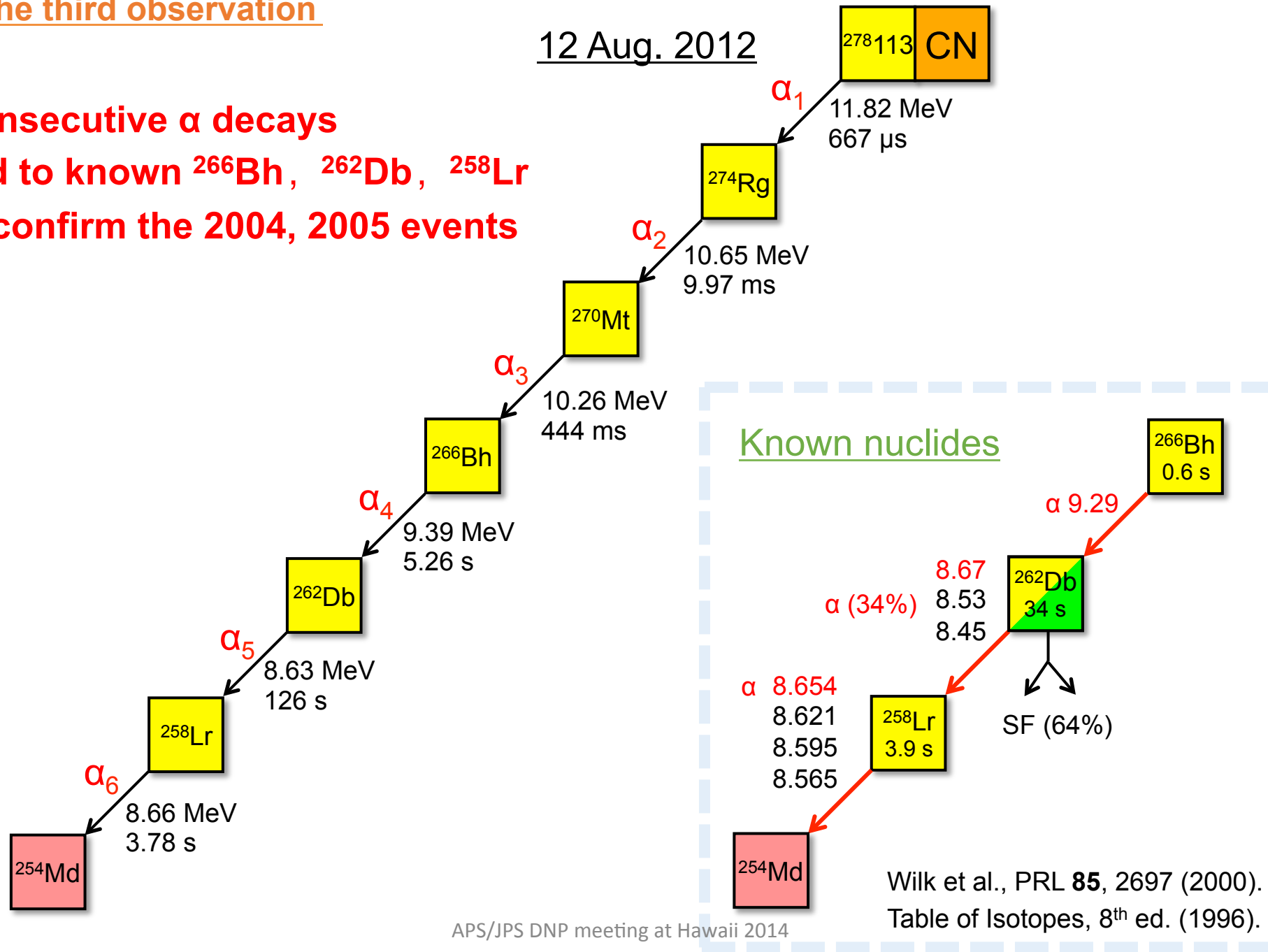


1st chain

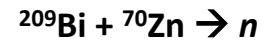


The third observation

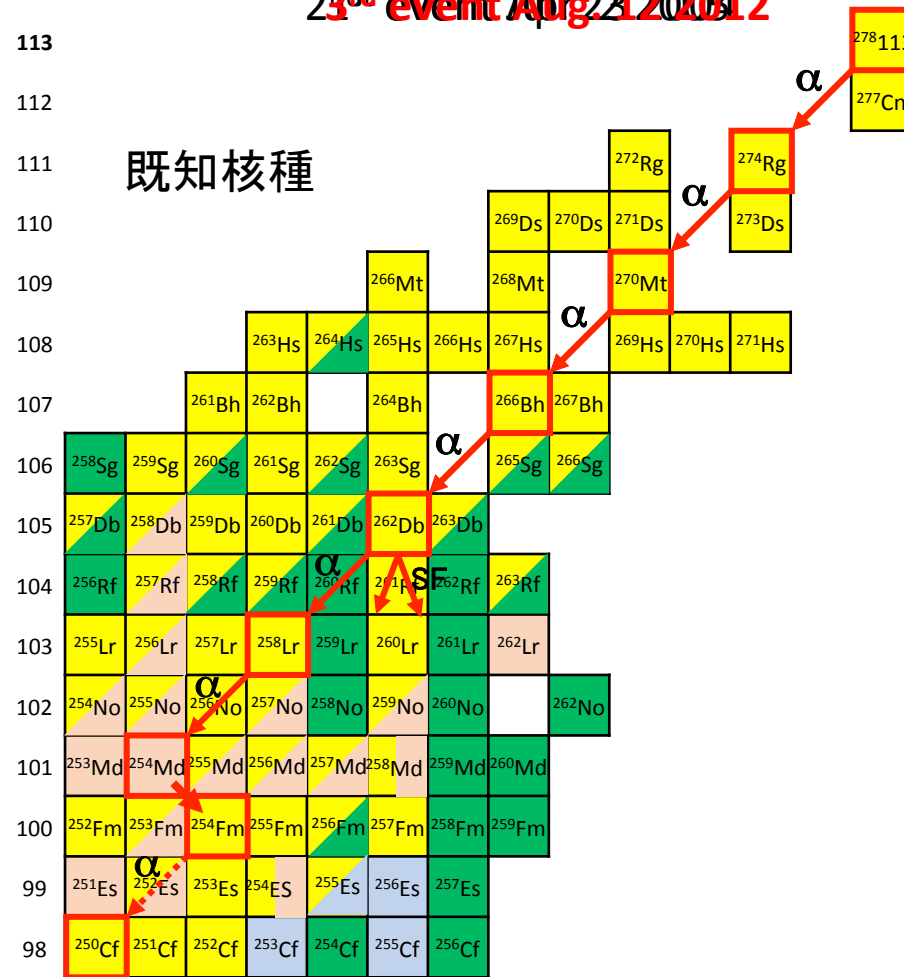
- 6 (7) consecutive α decays
- reached to known ^{266}Bh , ^{262}Db , ^{258}Lr
 $\Rightarrow$ well confirm the 2004, 2005 events



観測された崩壊のまとめ



23rd event Aug 23, 2009





RIKEN

**Tokyo U. of
Physics
Saitama U.
Niigata U.
IMP Lanzhou
U. Tokyo
Tohoku U.
JAEA
Yamagata U.**

**U. Tsukuba
高能物理研究所**

Elm. 113



**K. Morita, K. Morimoto, D. Kaji, H. Haba, K. Okeki, Y. Kudo,
Y. Wakabayashi, A. Yoneda, A. Yoshida, T. Onishi, Y. Kasamatsu,
H. Hasebe, M. Huang, T. Ichikawa, R. Kanungo, K. Katori**

T. Sumita, K. Tanaka

T. Yamaguchi, T. Akiyama, R. Sakai, S. Yamaki

H. Kudo, S. Goto, M. Murakami, H. murayama, Y. Kariya

H.-S. Xu , T. Huang

E. Ideguchi

T. Suda, H. Kikunaga

N. Sato, H. Koura, S. Mitsuoka

**F. Tokanai, T. Moriya, K. Mayama, M. Takeyama, S. Namai,
A. Mashiko**

A. Ozawa, K. Sueki

Y.-L. Zhao

Journal of the Physical Society of Japan, 73 (2004) 1593 – 1596.

Journal of the Physical Society of Japan, 76 (2007) 045001.

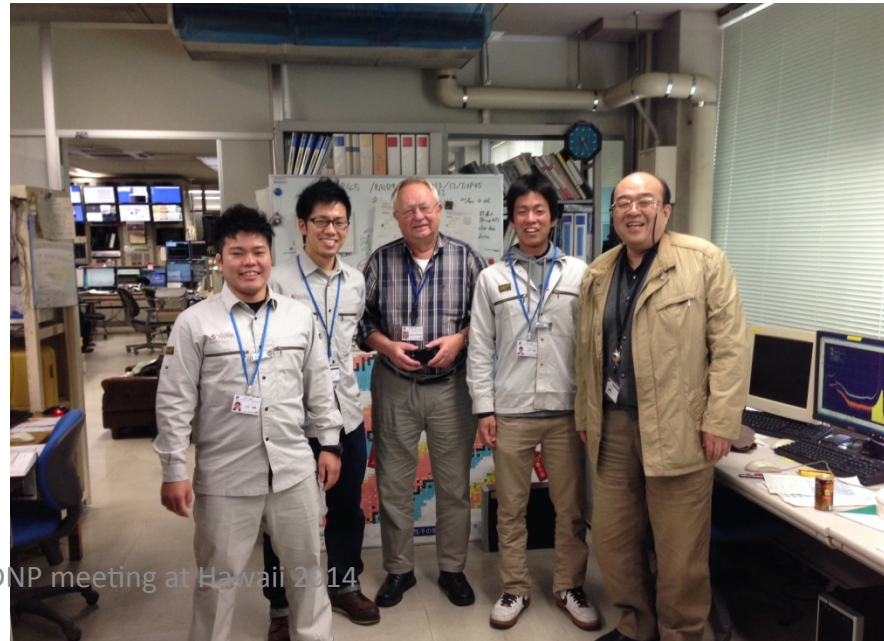
Journal of the Physical Society of Japan, 81 (2012) 103201.

$^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow ^{296}\text{Lv}^*$ Experiment at RIKEN GARIS Dec. 1 - 12, 2013, Sep. 19 – Oct. 16, 2014

RIKEN	K. Morimoto, D. Kaji, H. Haba, Y. Wakabayashi, M. Huang, J. Kanaya, A. Yoneda, A. Yoshida, K. Katori
Tokyo U. Sci.	K. Tanaka(M2)
Yamagata U.	M. Takeyema(D3) , F. Tokanai, T. Yoshida
Saitama U.	S. Yamaki(D1) , T. Yamaguchi
Niigata U.	M. Murakami(D3)
IMP Lanzhou	Z. Gan, L. Ma
GSI	H. Geissel, S. Hofmann, Y. Maurer, S. Heinz
<u>Kyushu U.</u>	<u>K. Morita, K. Fujita, Y. Narikiyo(M2), T. Tanaka(M1), S. Yamamoto</u>



2014/10/09



APS/JPS DNP meeting at Hawaii 2014

RIKEN/GARIS

Date	Time /days	D(Ti) /mgcm ⁻²	D(Cm) /mgcm ⁻²	E(RILAC) MeV	Elab /MeV (b – c – e)	I _p /pμA	Dose /10 ¹⁸	Ex_ ²⁹⁶ Lv /MeV
2/12 – 12/12 2013	10	0.90	0.265	262.0	251.0 - 250.0 - 249.0	800	4.3	41.5±1.0
19/9 – 16/10 2014	14.2	0.90	0.290	258.0	247.0 - 246.0 - 245.0	680	5.0	37.5±1.1

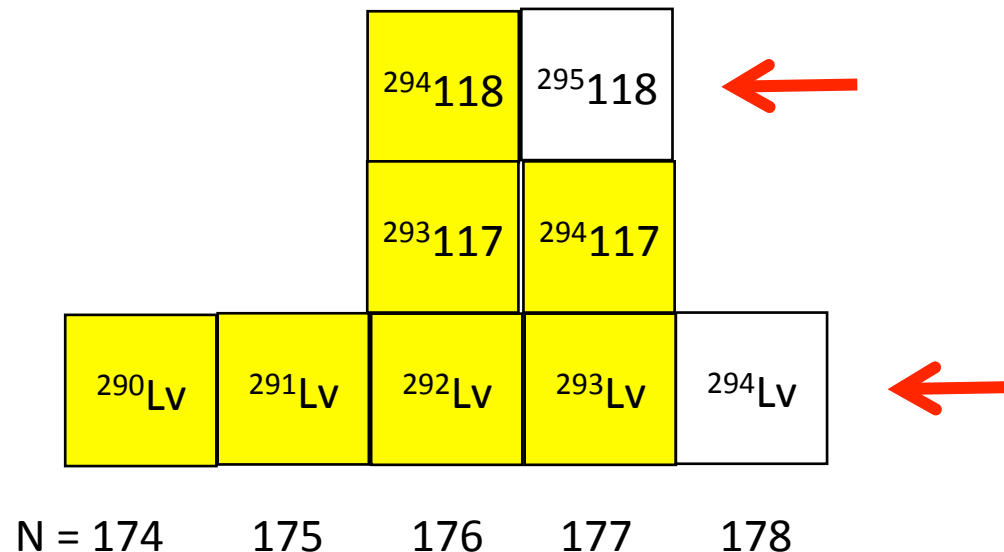
Ex_ ²⁹⁶ Lv /MeV	Correlated events (decay chains)
41.5±1.0	3 (4n), 1 (3n), 1(3n?) tentative
37.5±1.1	1 (3n), 1 (3n?) tentative

Summary

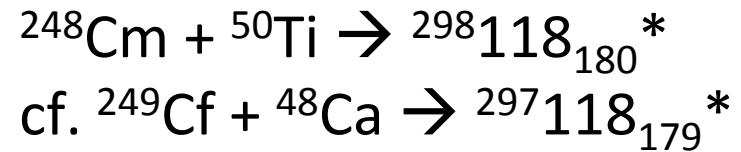
An isotope of the 113th element, $^{278}113$, was produced in the $^{209}\text{Bi} + ^{70}\text{Zn} \rightarrow ^{278}113 + n$ reaction, and unambiguously identified via genetic correlation, connected to the well known nuclides.

^{293}Lv and ^{292}Lv were produced in the $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow ^{296}\text{Lv}^*$ reaction

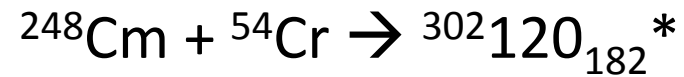
What's Next (New Element Search) ?



Systematic study of the actinide based ^{50}Ti -induced reactions.



Future ?

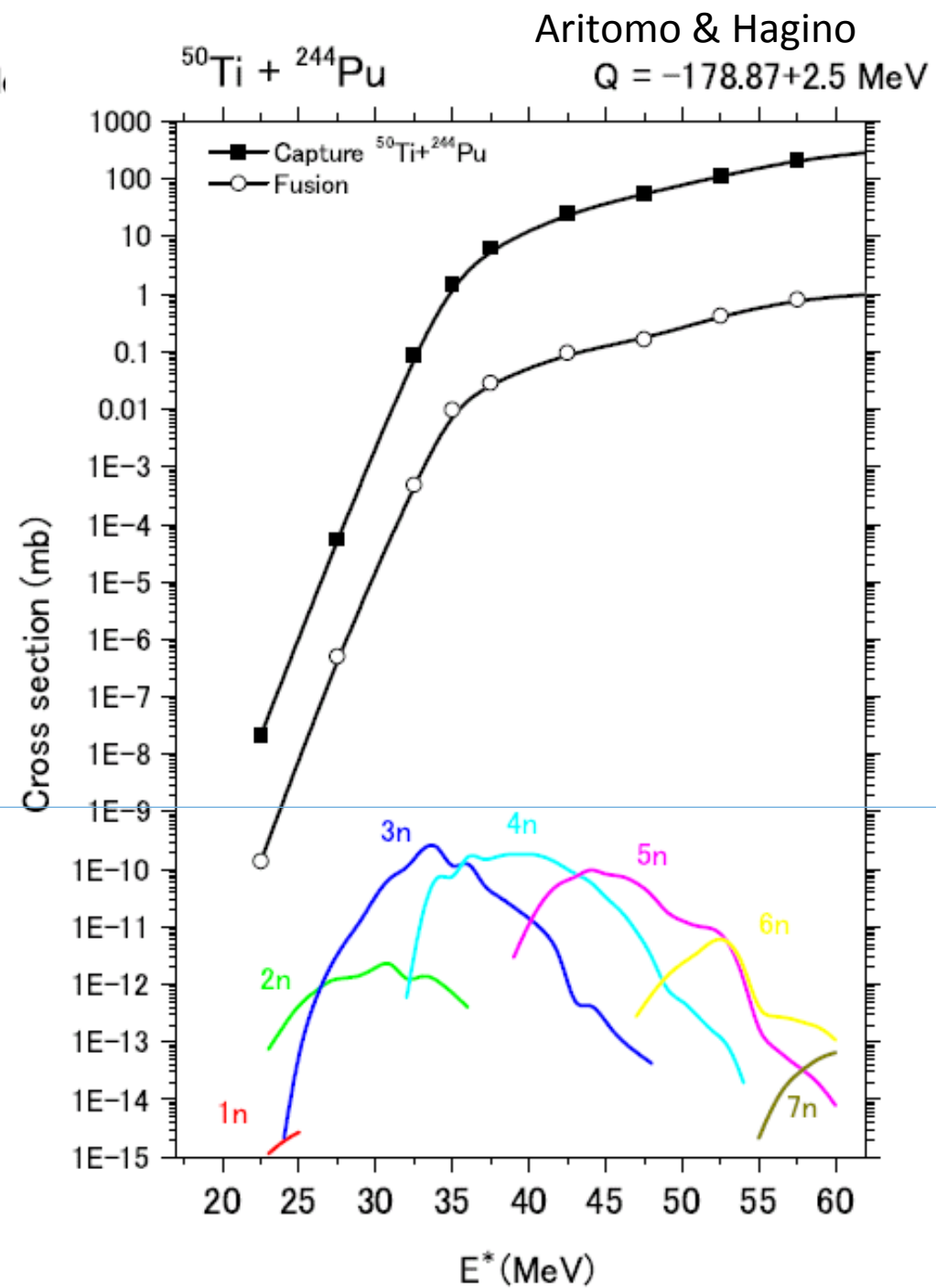
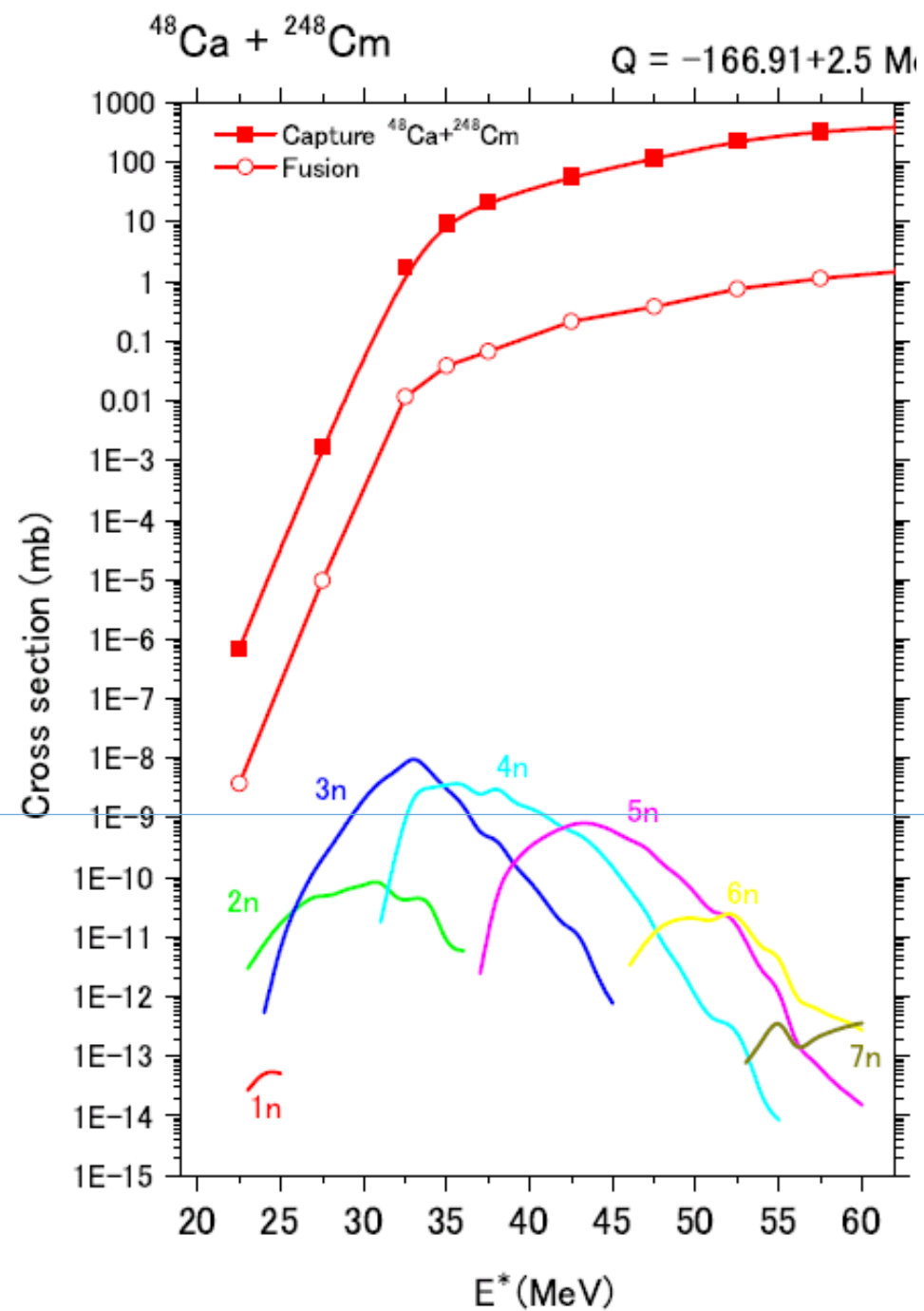


Study of new reaction mechanism (non-complete fusion) to produce SHE such as multi-nucleon transfer, or deep inelastic reaction of $^{248}\text{Cm} + ^{238}\text{U}$?

Breakthrough is needed!

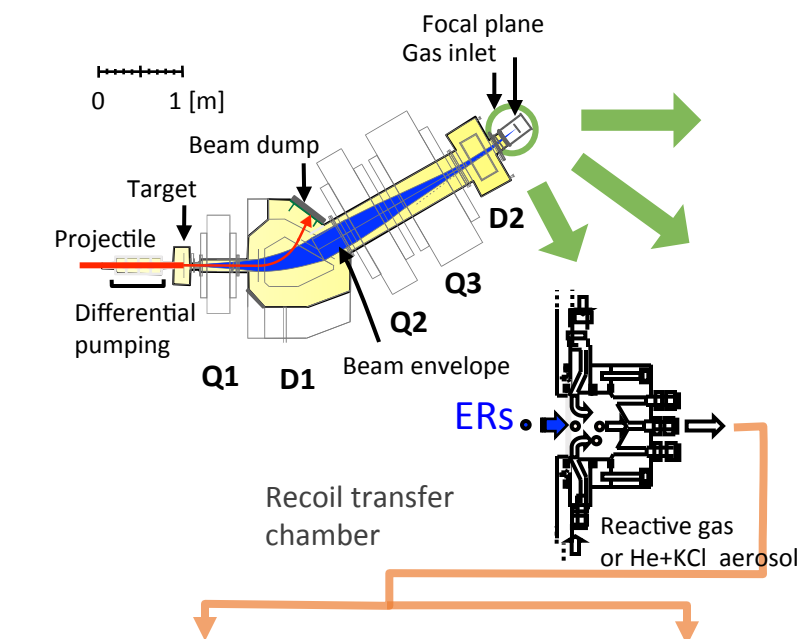
Spectroscopic studies of the isotopes of the heaviest element.
Chemistry of superheavy Element.

Mass measurement of SHE with MR-TOF (Wada-san's group).

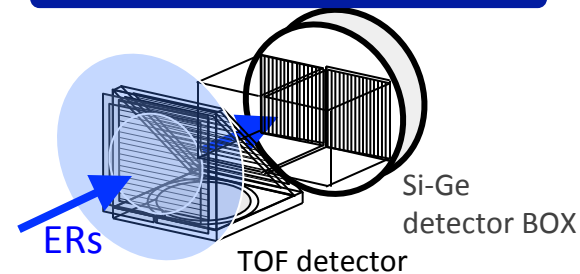


GARIS-II

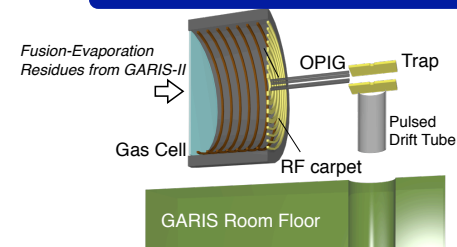
Experimental plans : New SHE search, mass measurement, SHE chemistry, SHE spectroscopy



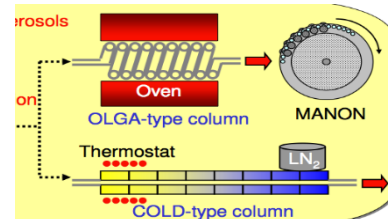
New SHE search



Mass measurement



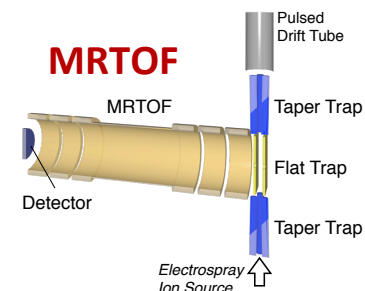
SHE chemistry



SHE spectroscopy

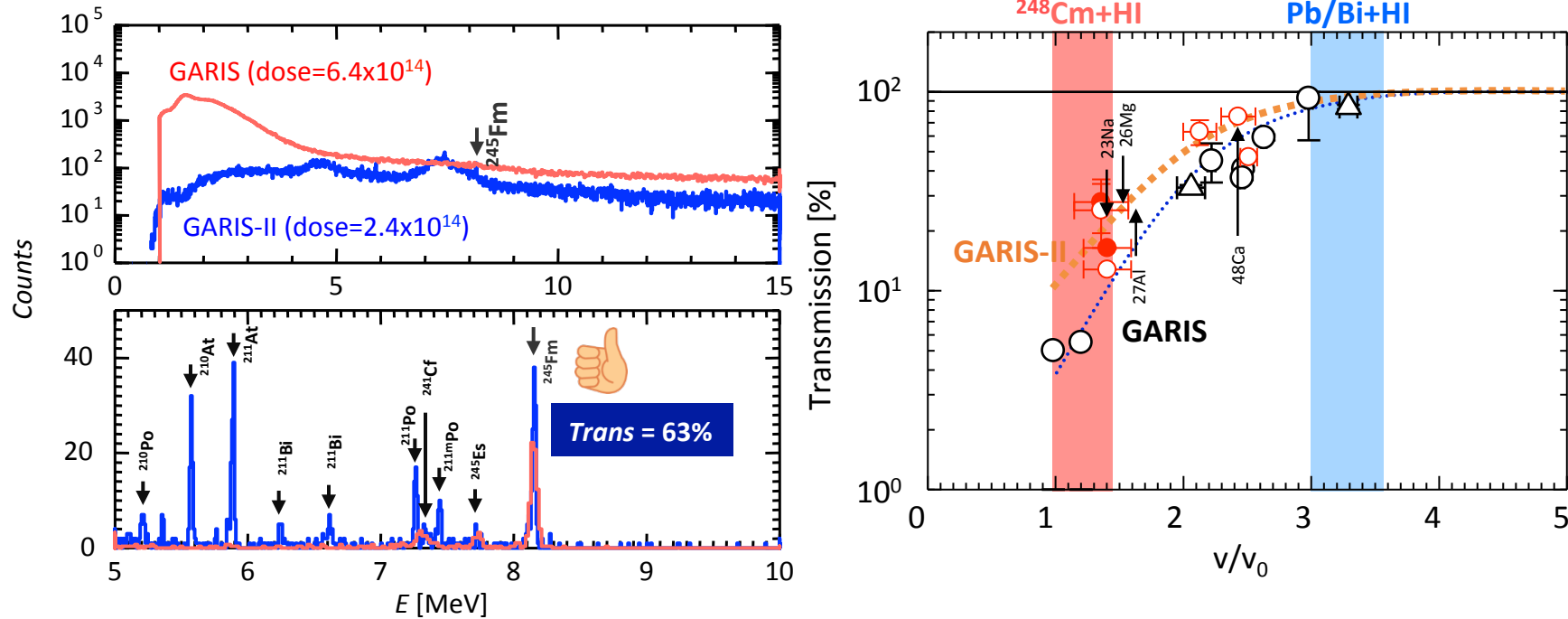


MRTOF



High performance of GARIS-II

High Transmission under Low BG level



Succeeded in the observation of Fm isotope produced by $^{208}\text{Pb}(^{40}\text{Ar}, 3n)^{245}\text{Fm}$.

Observed a-peak due to ^{245}Fm in singles!

→ *BG level* was about 5 times lower than GARIS.

→ *Trans* was 1.5 times higher than GARIS.

5th International Conference on the Chemistry and Physics of the Transactinide Elements May 25 (Mon.) – 29 (Fri.), 2015 Urabandai, Fukushima, Japan



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<http://asrc.jaea.go.jp/conference/TAN15/index.html>

Contact

TAN15@jaea.go.jp

Thank you very much for your kind attention.