Research on Superheavy Elements at RIKEN

New Result in Production and Decay of an Isotope, $^{278}113$, of the 113^{th} Element

Kosuke Morita

Superheavy Element Laboratory
RIKEN Nishina Center for Accelerator-Based Science, RIKEN

New Result in Production and Decay of an Isotope, $^{278}113$, of the 113th Element

Kosuke Morita

Superheavy Element Laboratory
RIKEN Nishina Center for Accelerator-Based Science, RIKEN

Journal of the Physical Society of Japan **81** (2012) 103201 LETTERS
http://dx.doi.org/10.1143/JPSJ.81.103201

New Result in the Production and Decay of an Isotope, $^{278}113$, of the 113th Element

Kosuke MORITA[1*], Kouji MORIMOTO[1], Daiya KAJI[1], Hiromitsu HABA[1], Kazutaka OZEKI[1], Yuki KUDOU[1], Takayuki SUMITA[2,1], Yasuo WAKABAYASHI[1], Akira YONEDA[1], Kengo TANAKA[2,1], Sayaka YAMAKI[3,1], Ryutaro SAKAI[4,1], Takahiro AKIYAMA[3,1], Shin-ichi GOTO[5], Hiroo HASEBE[1], Minghui HUANG[1], Tianheng HUANG[6], Eiji IDEGUCHI[7†], Yoshitaka KASAMATSU[1‡], Kenji KATORI[1], Yoshiki KARIYA[5], Hidetoshi KIKUNAGA[8], Hiroyuki KOURA[9], Hisaaki KUDO[5], Akihiro MASHIKO[10], Keita MAYAMA[10], Shin-ichi MITSUOKA[9], Toru MORIYA[10], Masashi MURAKAMI[5], Hirohumi MURAYAMA[5], Saori NAMAI[10], Akira OZAWA[11], Nozomi SATO[9], Keisuke SUEKI[11], Mirei TAKEYAMA[10], Fuyuki TOKANAI[10], Takayuki YAMAGUCHI[3], and Atsushi YOSHIDA[1]

(Received August 29, 2012; accepted September 10, 2012; published online September 27, 2012)

An isotope of the 113th element, i.e., $^{278}113$, was produced in a nuclear reaction with a ^{70}Zn beam on a ^{209}Bi target. We observed six consecutive α-decays following the implantation of a heavy particle in nearly the same position in the semiconductor detector under an extremely low background condition. The fifth and sixth decays are fully consistent with the sequential decays of ^{262}Db and ^{258}Lr in both decay energies and decay times. This indicates that the present decay chain consisted of $^{278}113$, ^{274}Rg ($Z = 111$), ^{270}Mt ($Z = 109$), ^{266}Bh ($Z = 107$), ^{262}Db ($Z = 105$), and ^{258}Lr ($Z = 103$) with firm connections. This result, together with previously reported results from 2004 and 2007, conclusively leads to the unambiguous production and identification of the isotope $^{278}113$ of the 113th element.

KEYWORDS: new element 113, gas-filled recoil ion separator, α-decay chain

Periodic table of the elements (2012)

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

Superheavy elements (SHEs)

Pure Appl. Chem., ASAP Article
doi:10.1351/PAC-REP-10-05-01

Discovery of the elements with atomic numbers greater than or equal to 113 (IUPAC Technical Report)*

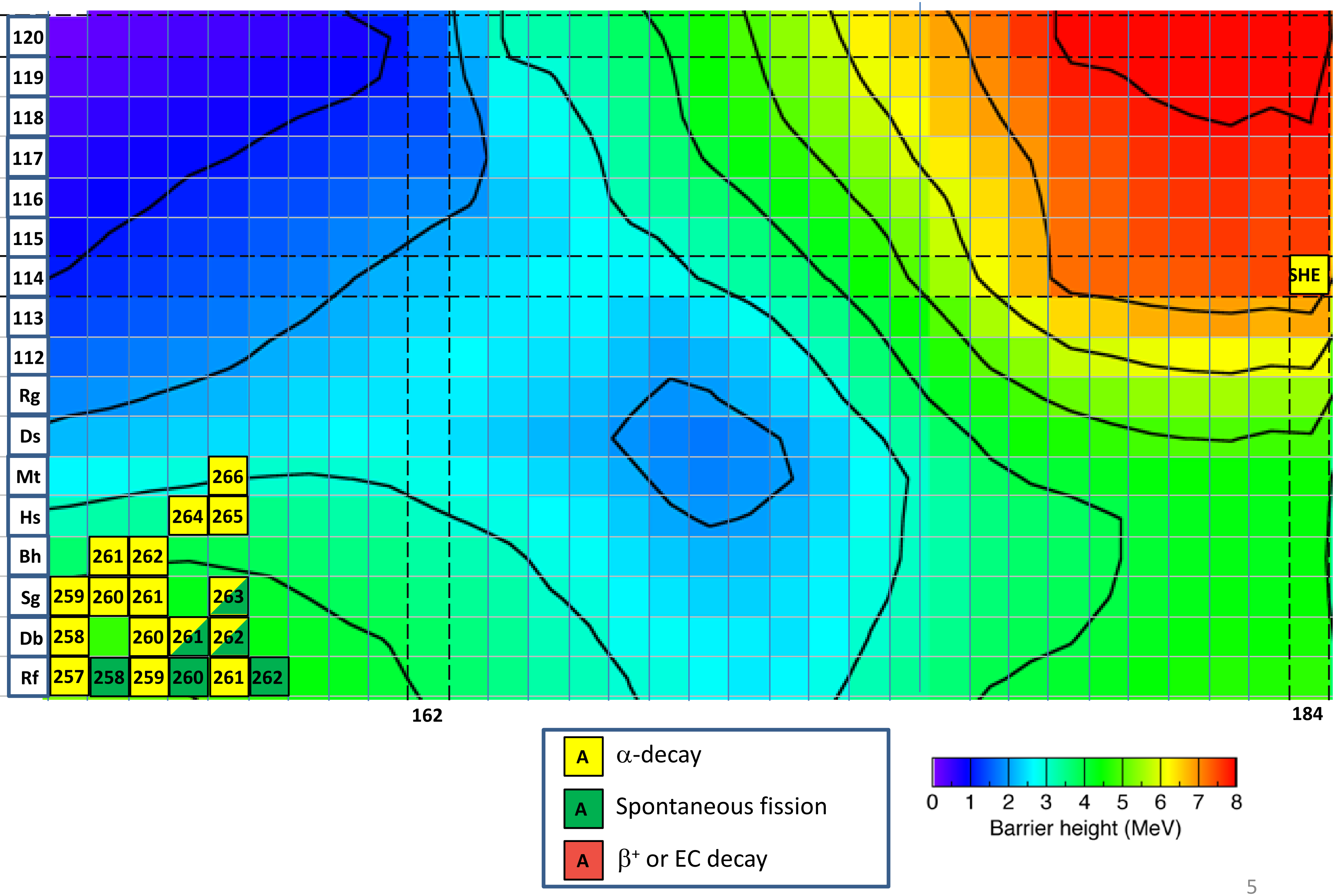
Robert C. Barber[1], Paul J. Karol[2,‡,§], Hiromichi Nakahara[3], Emanuele Vardaci[4], and Erich W. Vogt[5]

[1]Department of Physics and Astronomy, University of Manitoba, Manitoba, R3T 2N2, Canada; [2]Department of Chemistry, Carnegie Mellon University, Pittsburgh, PA 15213, USA; [3]Chemistry Department, Tokyo Metropolitan University, Tokyo 192-03, Japan; [4]University of Naples "Federico II" and Istituto Nazionale di Fisica Nucleare, Napoli, Italy; [5]TRIUMF, Vancouver, BC, V6T 1W5, Canada

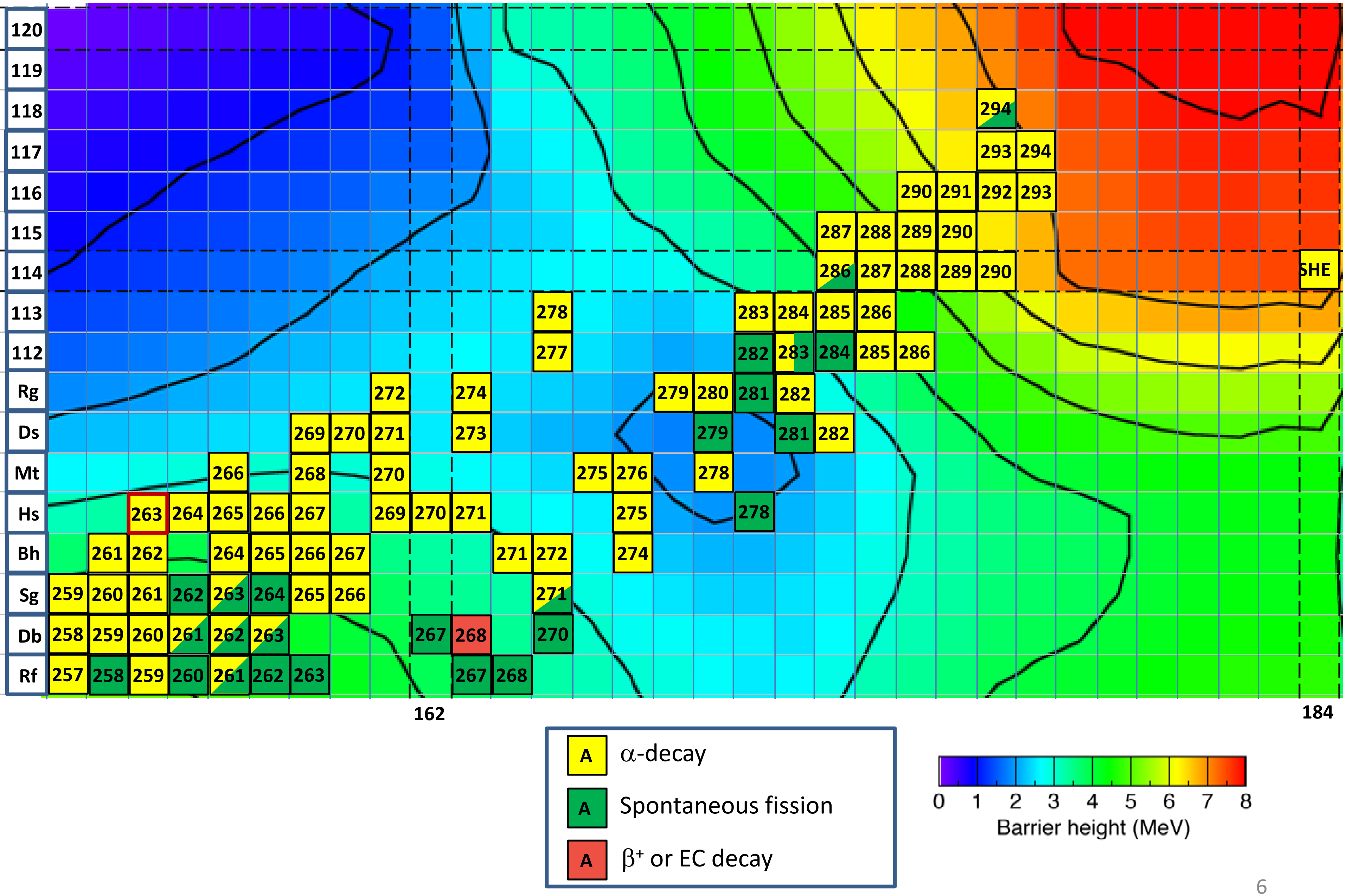
Abstract: The IUPAC/IUPAP Joint Working Party (JWP) on the priority of claims to the dis-
covery of new elements 113–116 and 118 has revi
several claims. In accordance with the criteria for th
lished by the 1992 IUPAC/IUPAP Transfermium W
subsequent IUPAC/IUPAP JWP discussions, it wa
collaborations share in the fulfillment of those crite
synopsis of experiments and related efforts is prese

The Periodic Table has been evolving!

one end of nuclear chart '84—'94

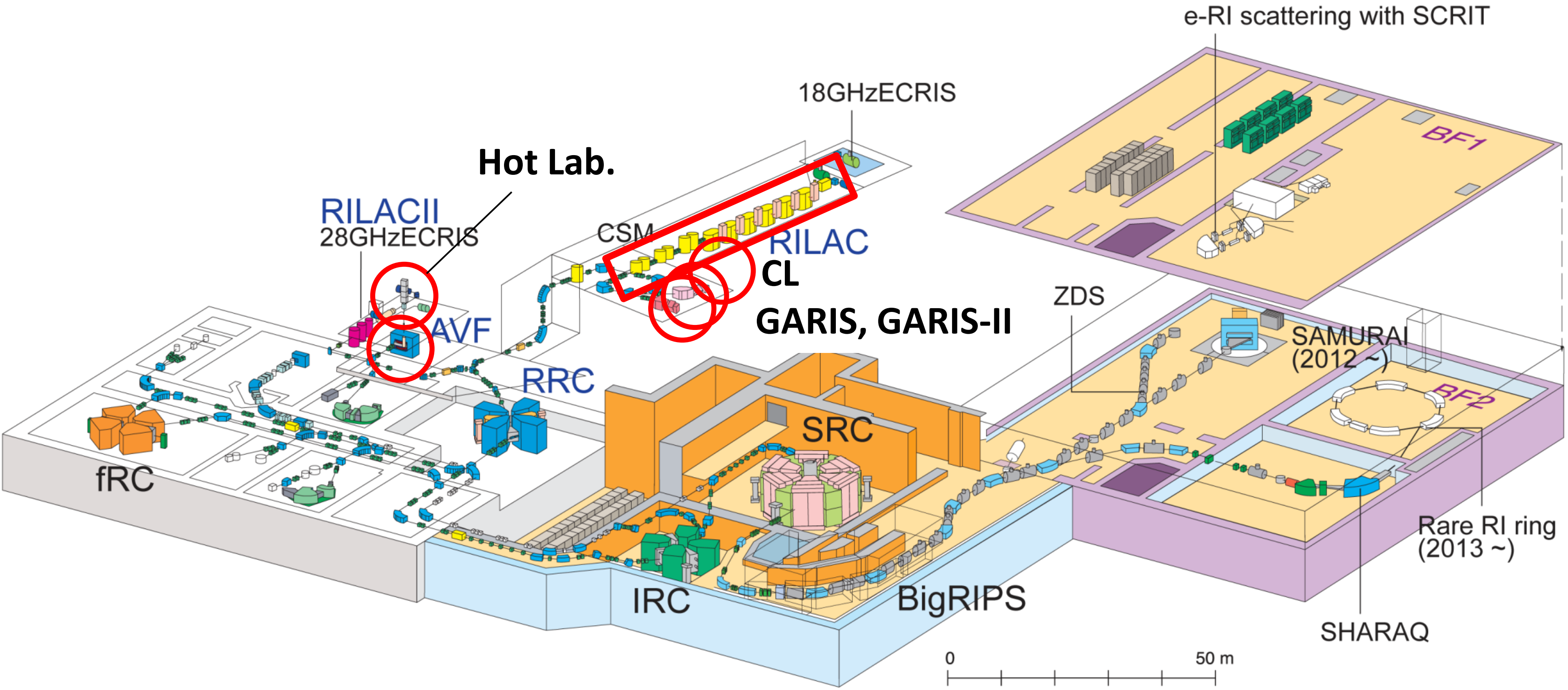


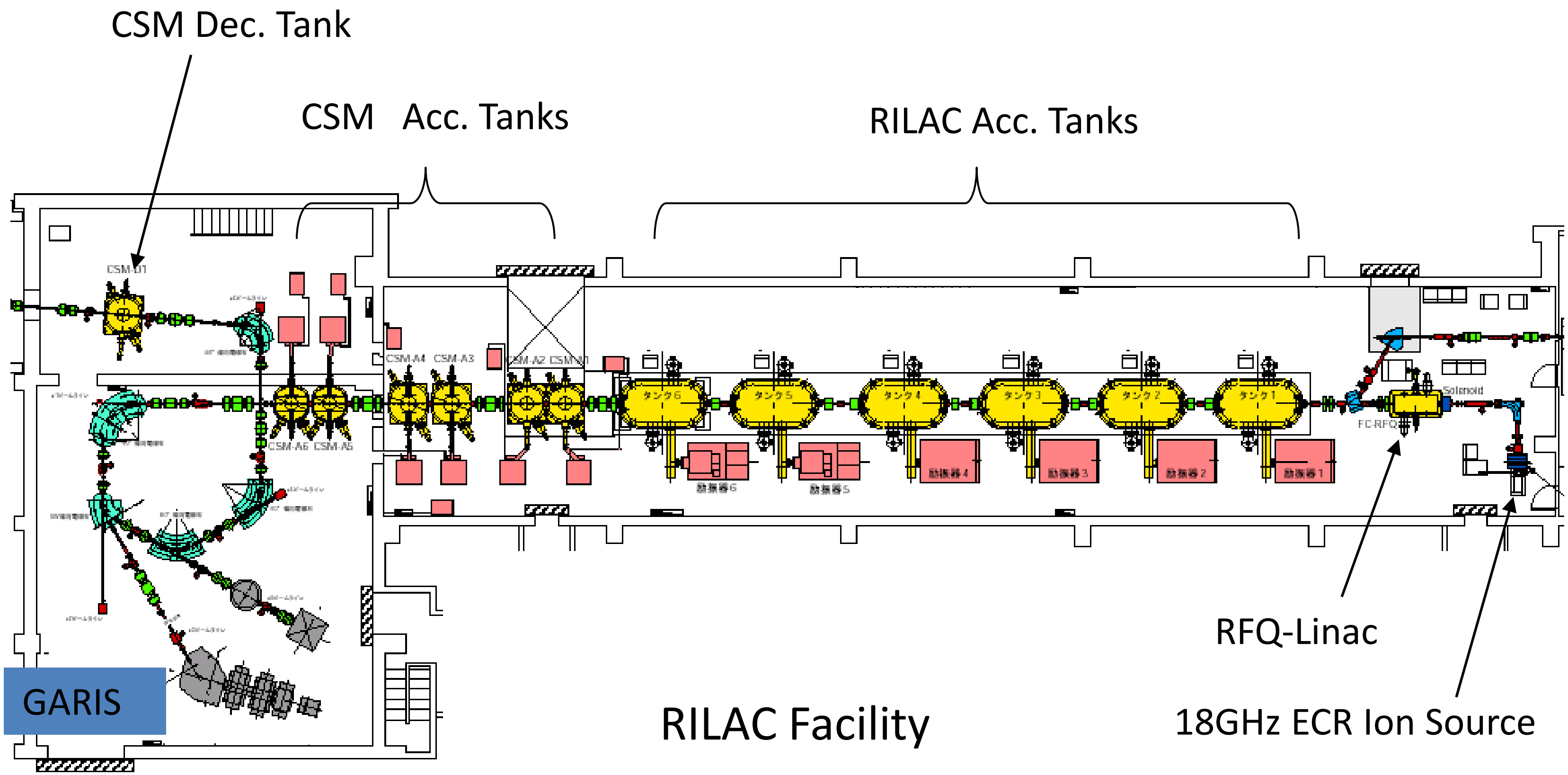
one end of nuclear chart 2010



Superheavy Element Study at RIKEN RIBF

Experimental setups

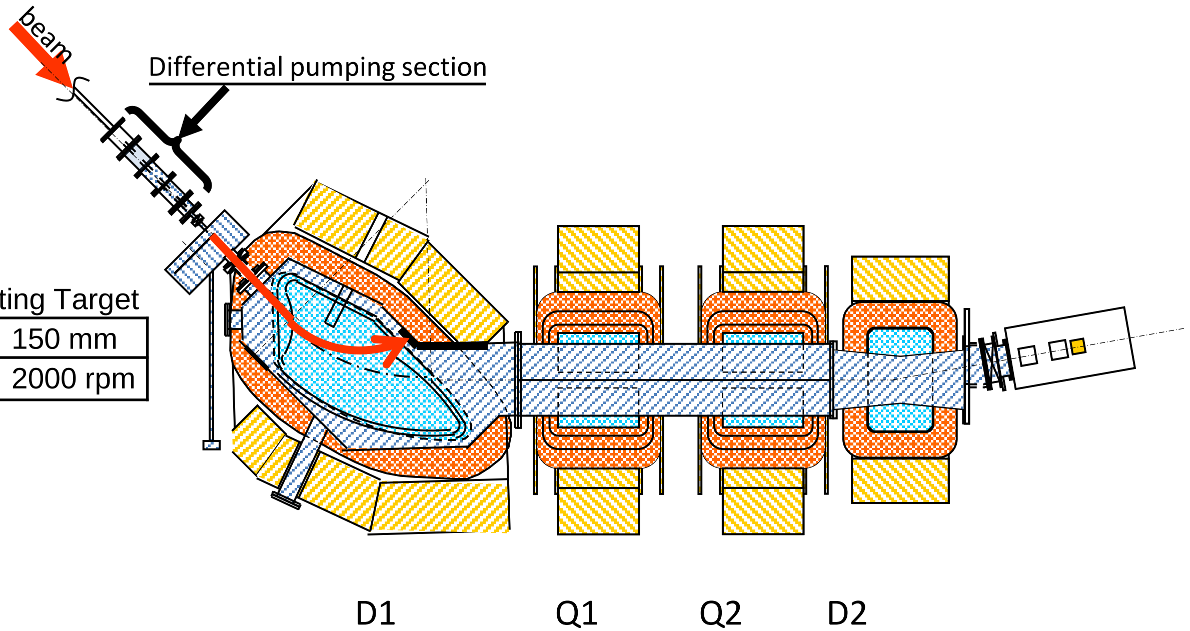




RILAC Facility

Standard method for heavy element physics: recoil separator + position sensitive FPD

RIKEN Gas-filled Recoil Separator GARIS



Rotating Target

r	150 mm
ω	2000 rpm

D1

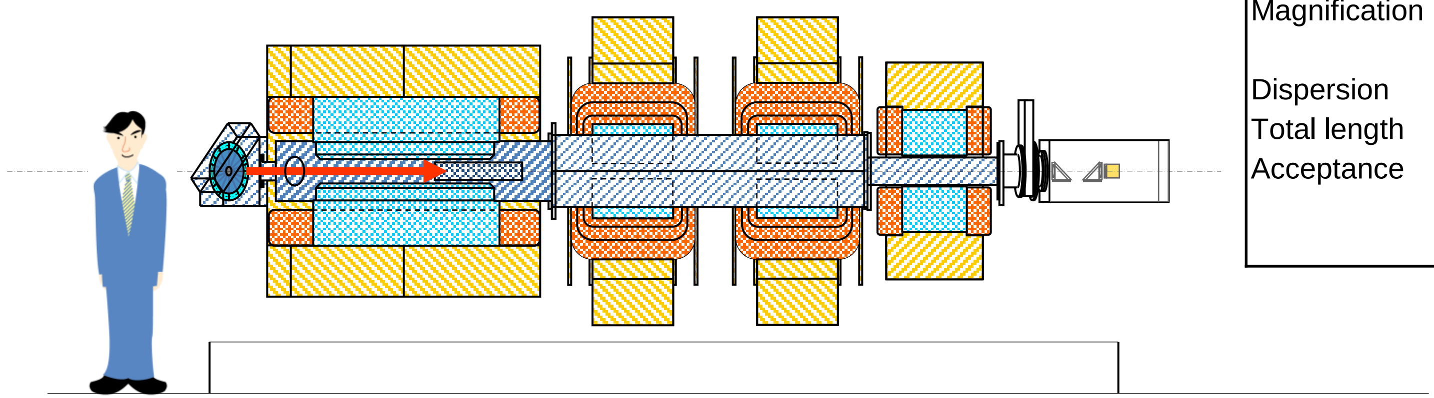
Bending angle	45 degree
Pole gap	150 mm
Radius of central ray	1200 mm
Maximum field	1.54 T

Q1, Q2

Pole length	500 mm
Bore radius	150 mm
Maximum field gradient	5.2 T/m

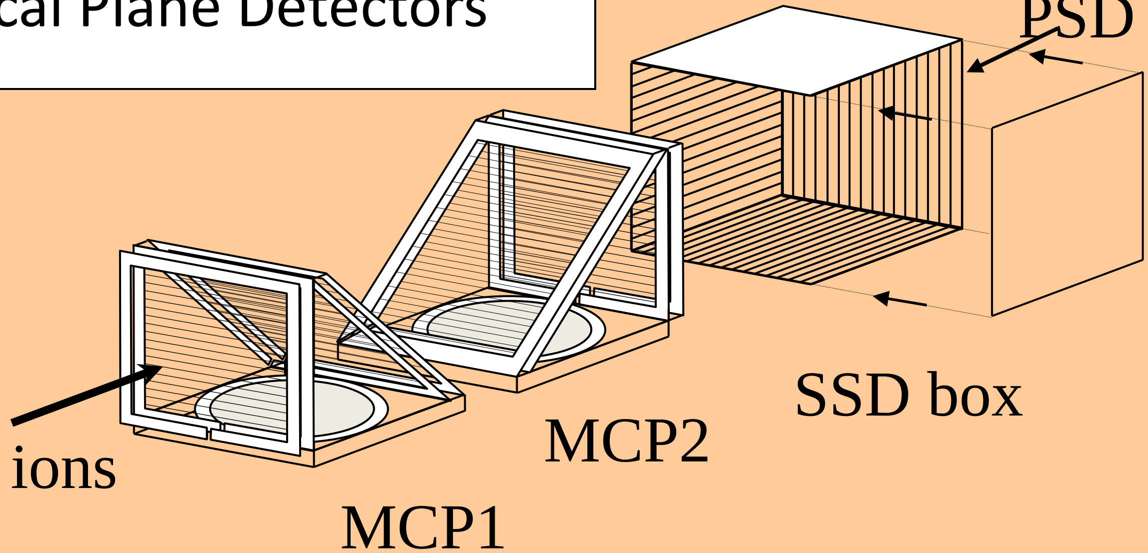
D2

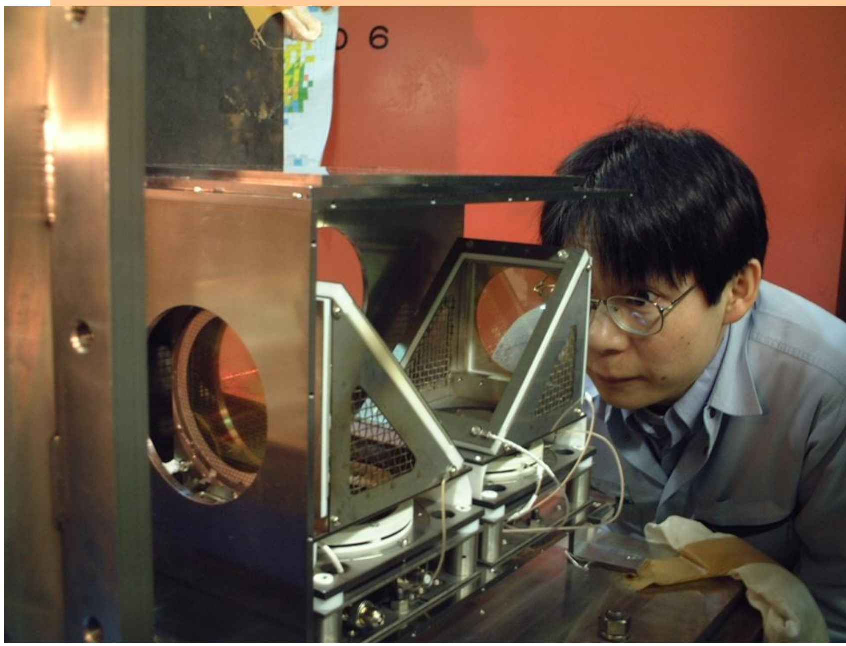
Bending angle	10 degree
Pole gap	160 mm
Pole length	400 mm
Maximum Field	1.04 T

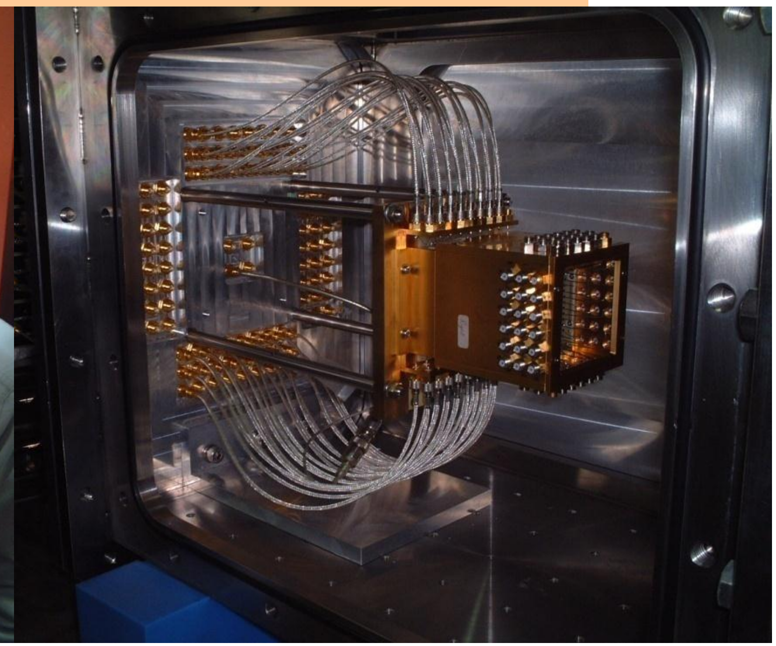


Magnification	X	-0.76
	Y	-1.99
Dispersion		0.97 cm/%
Total length		5760 mm
Acceptance	Δθ	±68 mrad
	Δϕ	±57 mrad
	ΔΩ	12.2 msr

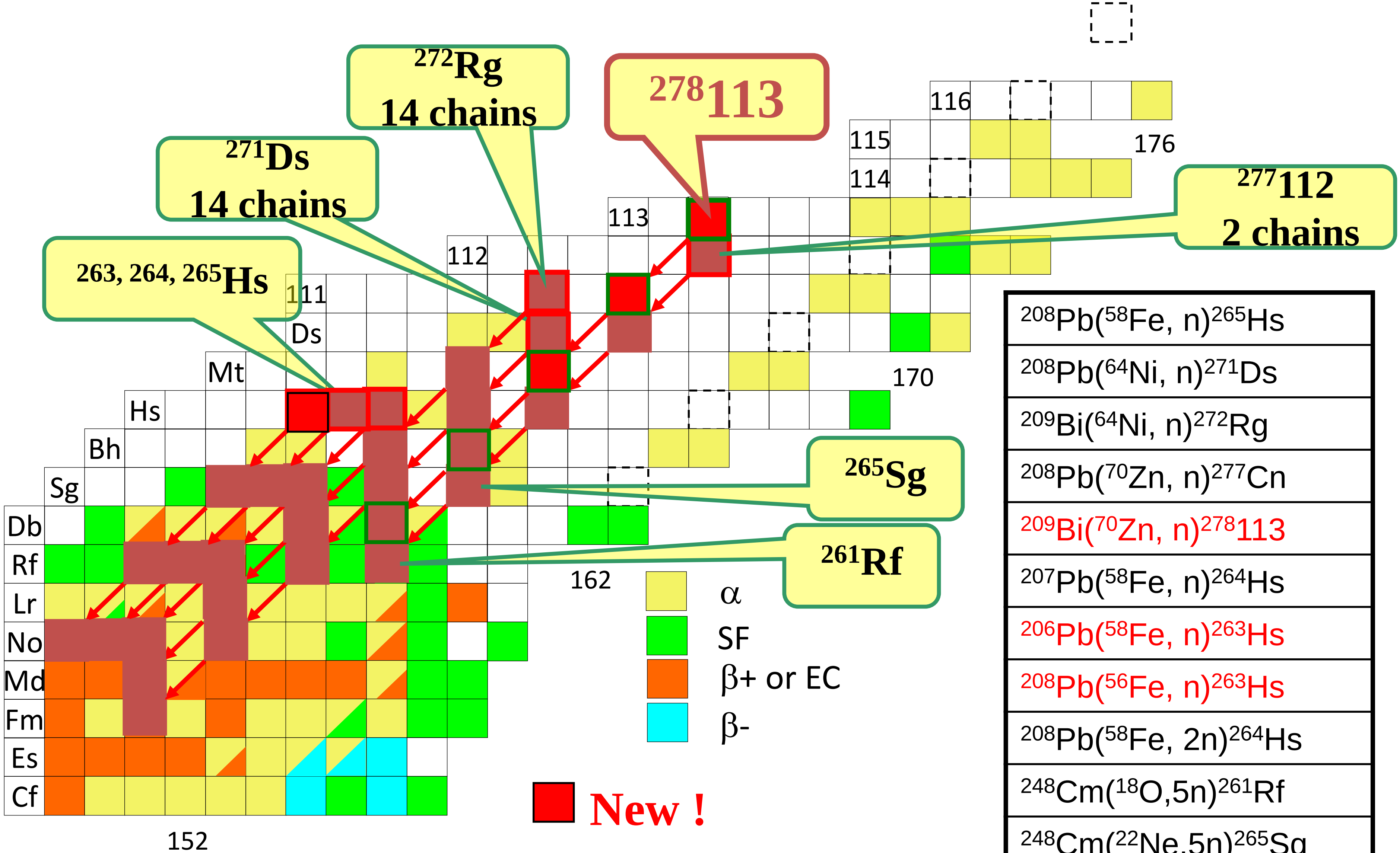
Focal Plane Detectors



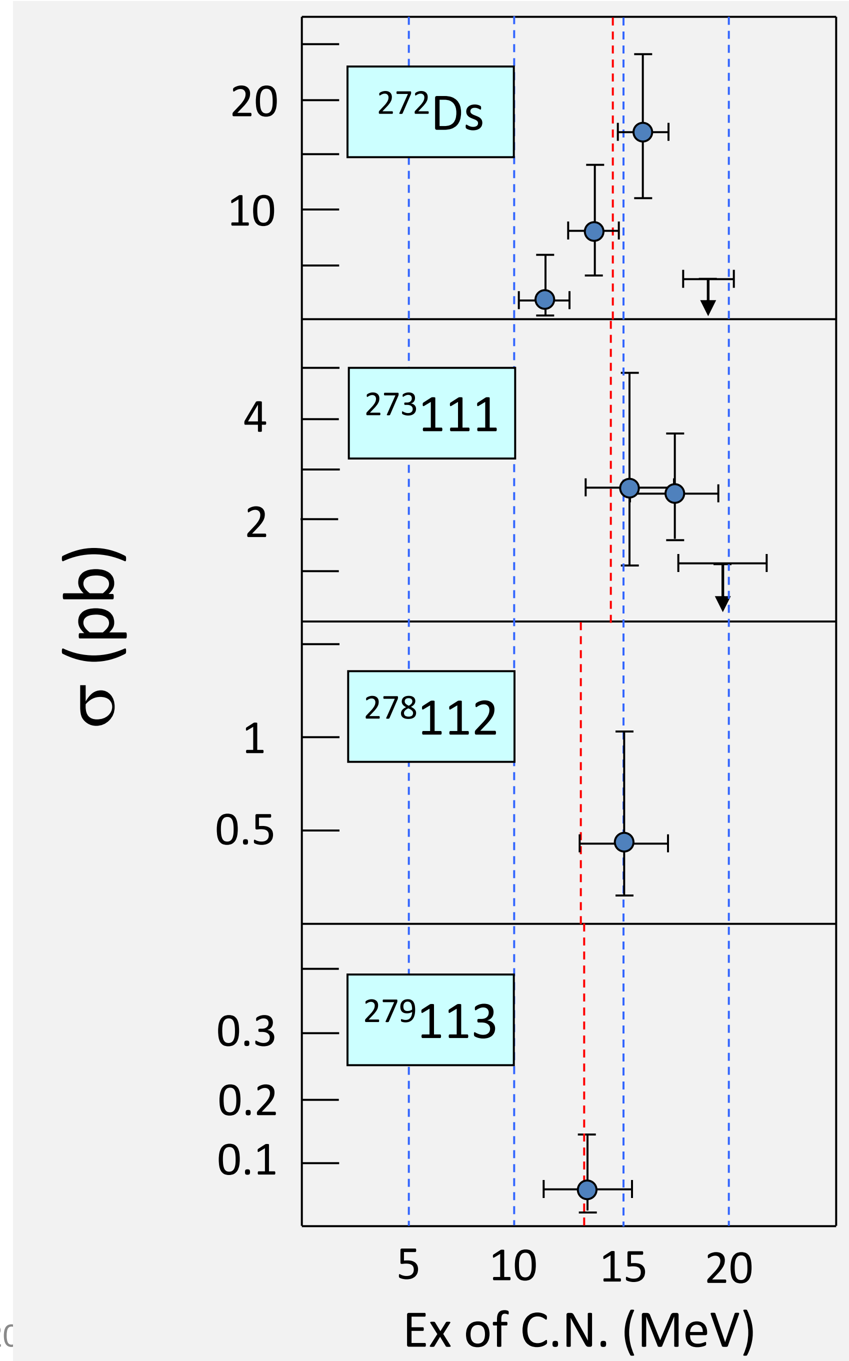




Reactions studied at RIKEN-GARIS



^{208}Pb(^{58}Fe, n)^{265}Hs
^{208}Pb(^{64}Ni, n)^{271}Ds
^{209}Bi(^{64}Ni, n)^{272}Rg
^{208}Pb(^{70}Zn, n)^{277}Cn
^{209}Bi(^{70}Zn, n)^{278}113
^{207}Pb(^{58}Fe, n)^{264}Hs
^{206}Pb(^{58}Fe, n)^{263}Hs
^{208}Pb(^{56}Fe, n)^{263}Hs
^{208}Pb(^{58}Fe, 2n)^{264}Hs
^{248}Cm(^{18}O,5n)^{261}Rf
^{248}Cm(^{22}Ne,5n)^{265}Sg
^{248}Cm(^{23}Na,5n)^{266}Bh



Calculated threshold of fission
after 1n emission

Masses of Beams & Targets
Audi & Wapstra, Nucl. Phys A565, 1 (1993)

Masses of Compound Nuclei
Myers & Swiatecki, Nucl. Phys. A601, 141 (1996)

Summary of ^{209}Bi + ^{70}Zn experiment

period	2003/9/5 ～ 2012/8/18	
Beam Energy	5.03 AMeV	
	348 MeV at target half depth	
Total Dose	$1.35\text{x}10^{20}$	
Target Thickness	$1.3\text{x}10^{18}$ /cm^2	(0.45 mg/cm^2)
ε_GARIS	0.8	
σ(2-ev.)	$2.2\text{x}10^{-38}$ cm^2	
	$22\ ^{+20}_{-13}$ fb	
Irradiation time	13274 Hours	(553 Days)
Beam Intensity	$2.8\text{x}10^{12}$ /s	(0.47 p-μA)

J. Phys. Soc. Jpn., Vol. **73** (2004) 2593

J. Phys. Soc. Jpn., Vol. **76** (2007) 045001

J. Phys. Soc. Jpn., Vol. **81** (2012) 103201

Table I. Summary of beamtime used.

beamtime		irradiation time	beam dose/sum	number of observed events
year	month/day	[days]	[$\times 10^{19}$]	
2003	9/5 - 12/29	57.9	1.24/1.24	0
2004	7/8 - 8/2	21.9	0.51/1.75	1
2005	1/20 - 1/23	3.0	0.07/1.82	0
2005	3/20 - 4/22	27.1	0.71/2.53	1
2005	5/19 - 5/21	2.0	0.05/2.58	0
2005	8/7 - 8/25	16.1	0.45/3.03	0
2005	9/7 - 10/20	39.0	1.17/4.20	0
2005	11/25 - 12/15	19.5	0.63/4.83	0
2006	3/14 - 5/15	54.2	1.37/6.20	0
2008	1/9 - 3/31	70.9	2.28/8.48	0
2010	9/7 - 10/18	30.9	0.52/9.00	0
2011	1/22 - 5/22	89.8	2.01/11.01	0
2011	12/2 - 12/19	14.4	0.33/11.34	0
2012	1/15 - 2/9	25.0	0.56/11.90	0
2012	3/13 - 4/17	33.7	0.79/12.69	0
2012	6/12 - 7/2	15.7	0.25/12.94	0
2012	7/14 - 8/18	32.0	0.57/13.51	1
Total		553	13.51	3

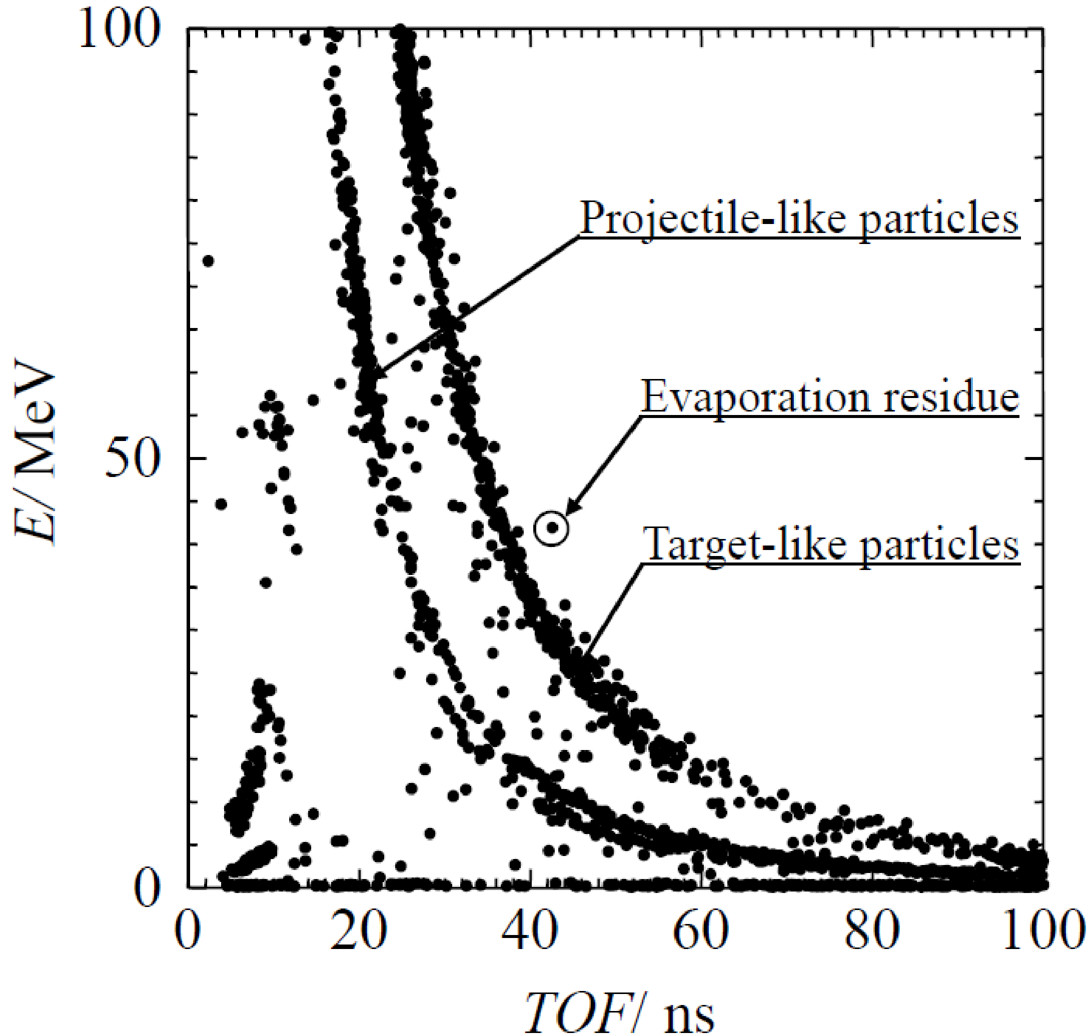
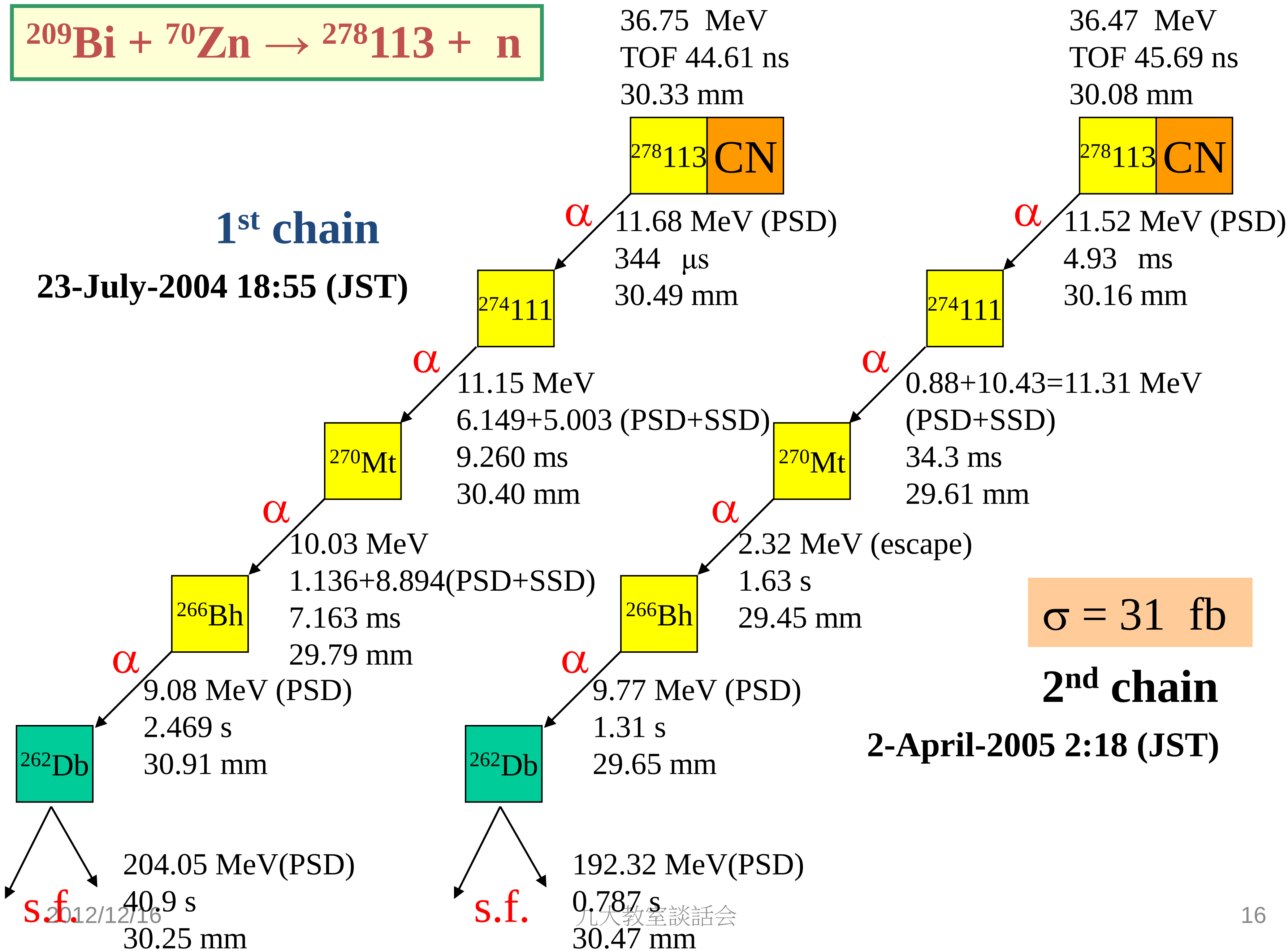
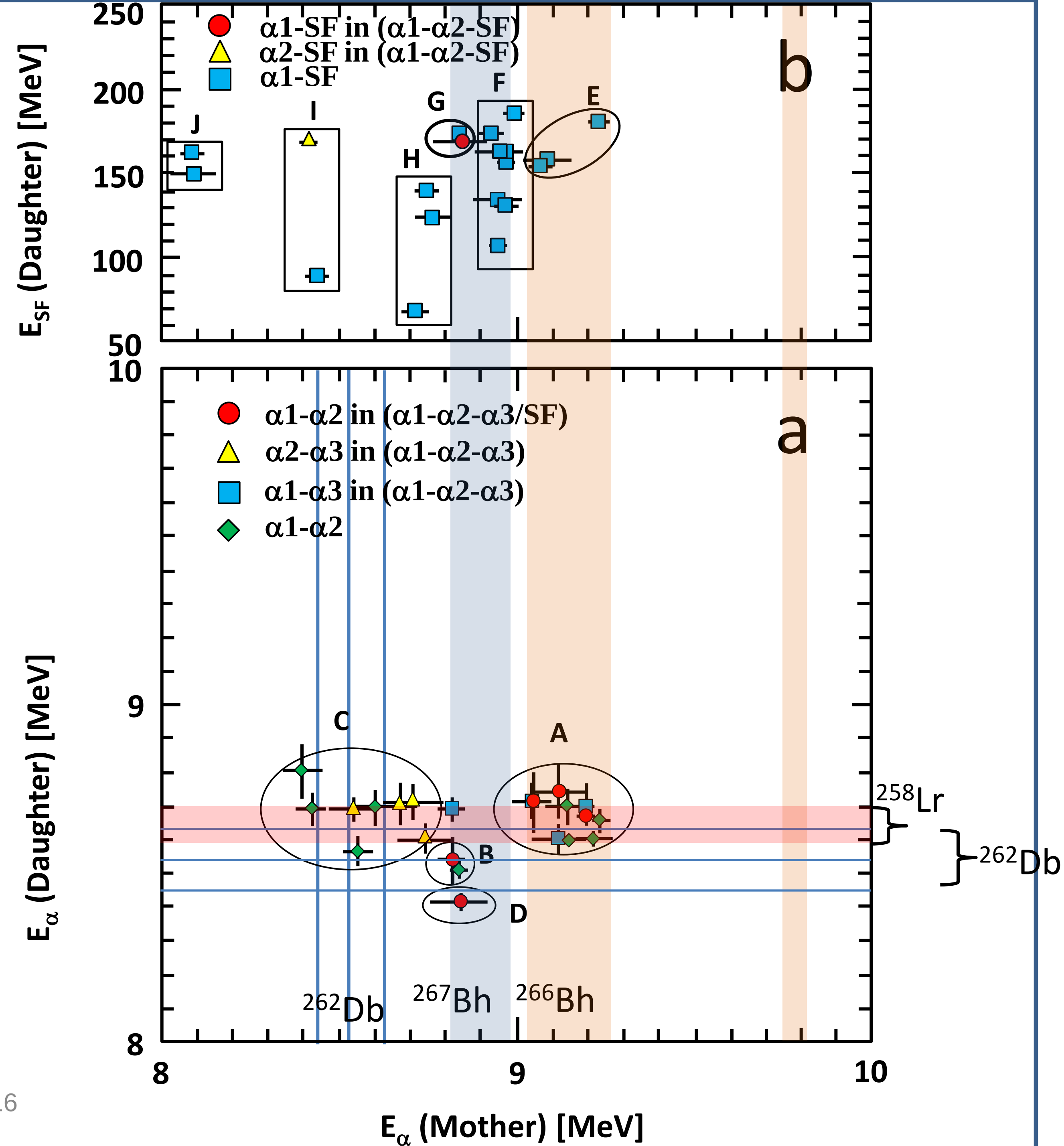


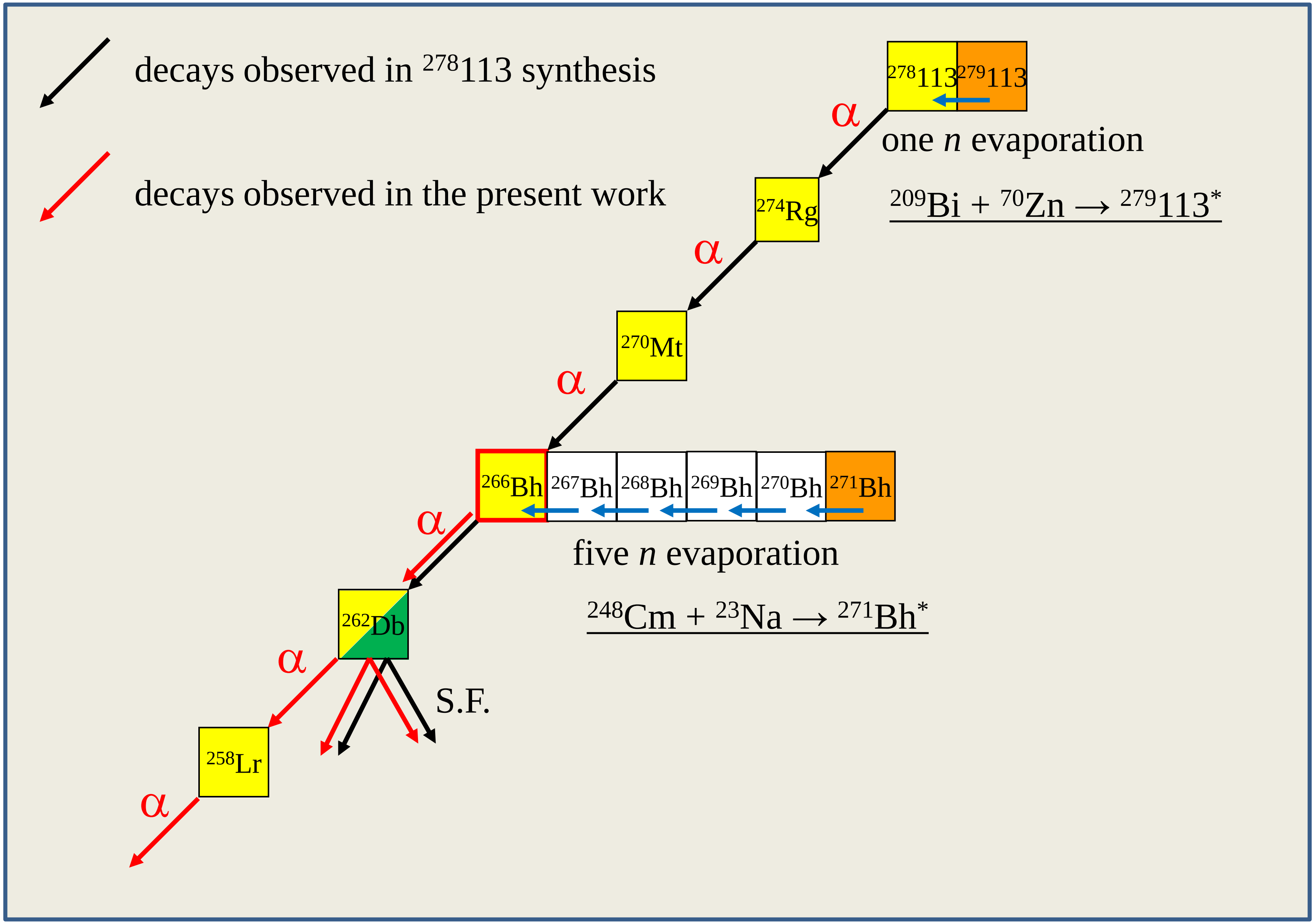
Fig. 1. Two-dimensional plot of energy measured by PSD vs TOF measured using timing counters for the run (time period = 10.8 h), in which the decay chain was observed. Events detected by only strip #7 of PSD are shown. A point corresponding to the implantation event is shown by a circle with an arrow. Loci corresponding to projectile-like particles (A ≈ 70) and target-like particles (A ≈ 209) are also shown.

$^{209}Bi + ^{70}Zn \rightarrow ^{278}113 + n$

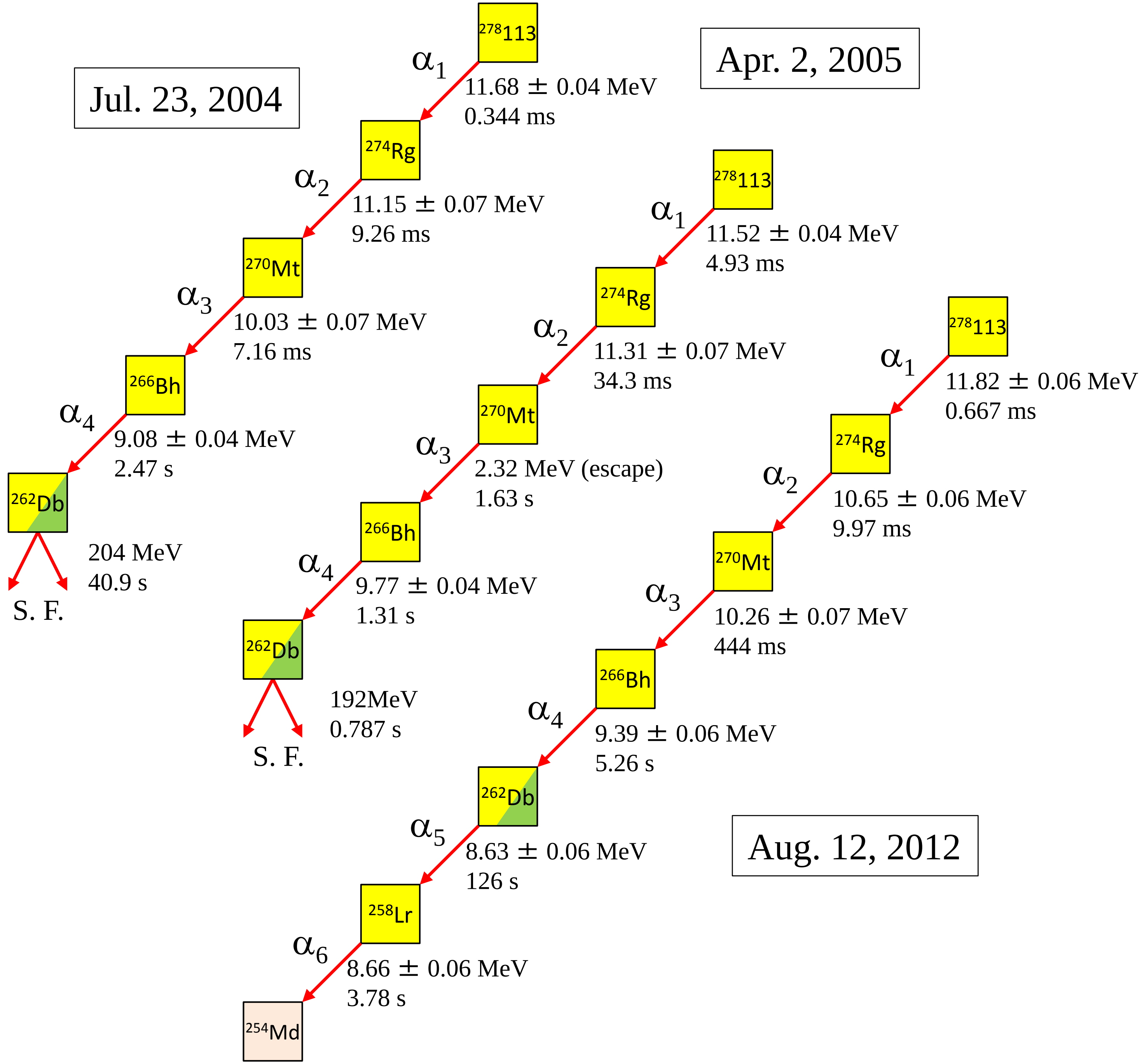




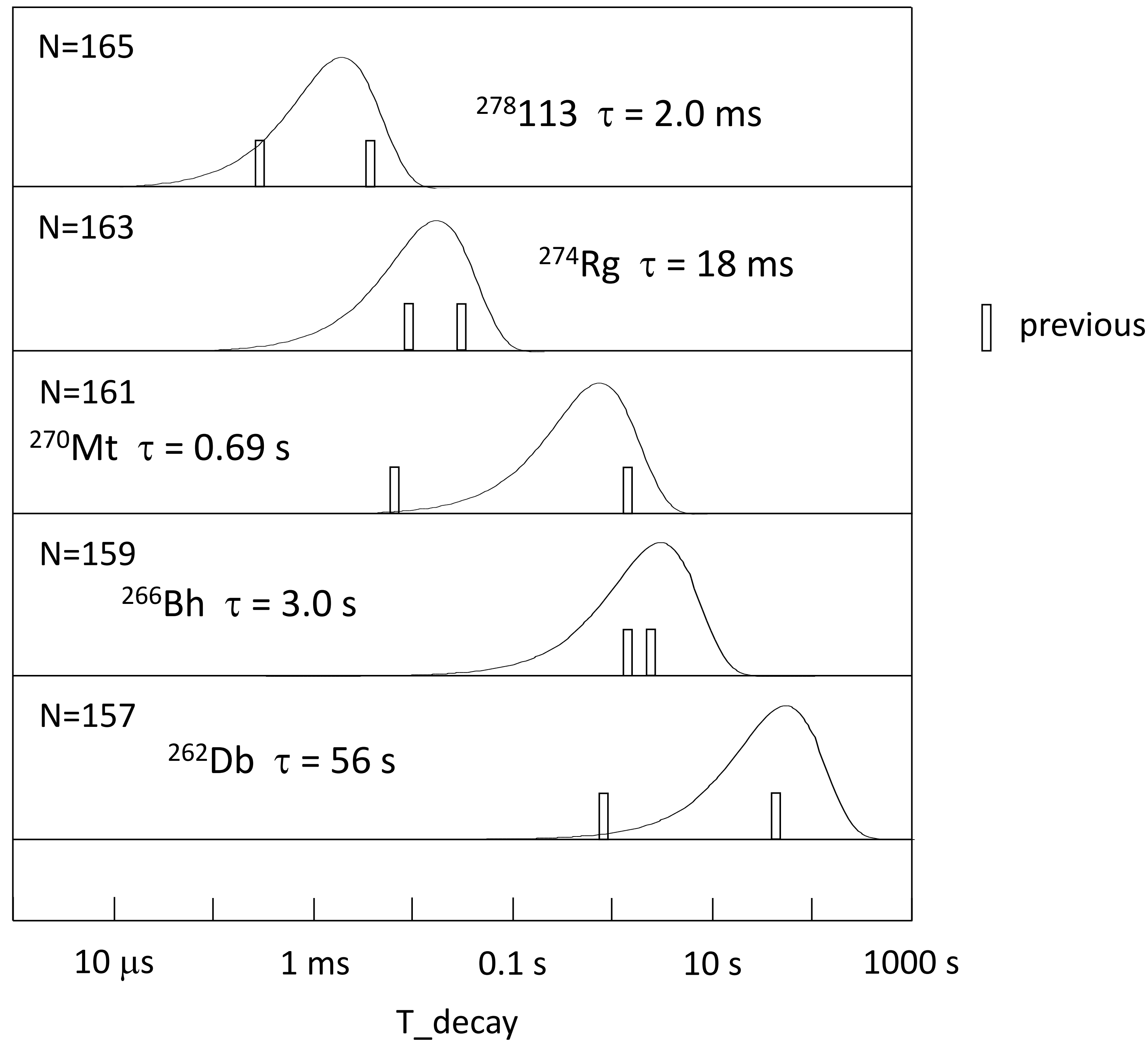
α1-SF in (α1-α2-SF)
α2-SF in (α1-α2-SF)
α1-SF
b
J
I
H
G
F
E
E_{SF} (Daughter) [MeV]
250
200
150
100
50
α1-α2 in (α1-α2-α3/SF)
α2-α3 in (α1-α2-α3)
α1-α3 in (α1-α2-α3)
α1-α2
a
C
A
B
D
^{258}Lr
^{262}Db
^{262}Db
^{267}Bh
^{266}Bh
E_α (Daughter) [MeV]
10
9
8
8
9
10
E_α (Mother) [MeV]



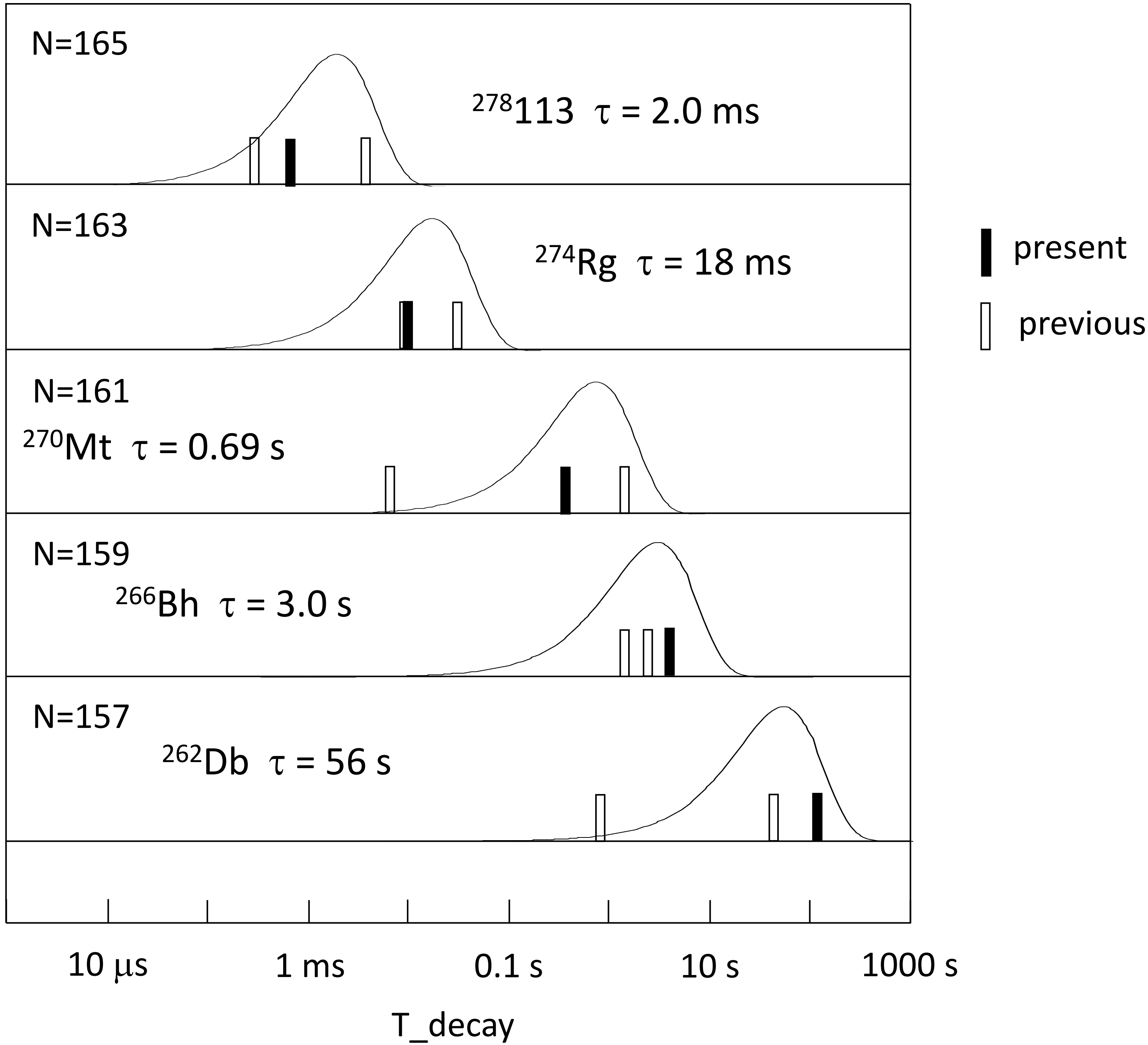
decays observed in 278113 synthesis
decays observed in the present work
278113
279113
α
one n evaporation
274Rg
209Bi + 70Zn → 279113*
α
270Mt
α
266Bh
267Bh
268Bh
269Bh
270Bh
271Bh
α
five n evaporation
262Db
248Cm + 23Na → 271Bh*
α
S.F.
258Lr
α



Jul. 23, 2004
Apr. 2, 2005
Aug. 12, 2012
278113
α1
11.68 ± 0.04 MeV
0.344 ms
274Rg
α2
11.15 ± 0.07 MeV
9.26 ms
270Mt
α3
10.03 ± 0.07 MeV
7.16 ms
266Bh
α4
9.08 ± 0.04 MeV
2.47 s
262Db
204 MeV
40.9 s
S. F.
278113
α1
11.52 ± 0.04 MeV
4.93 ms
274Rg
α2
11.31 ± 0.07 MeV
34.3 ms
270Mt
α3
2.32 MeV (escape)
1.63 s
266Bh
α4
9.77 ± 0.04 MeV
1.31 s
262Db
192MeV
0.787 s
S. F.
278113
α1
11.82 ± 0.06 MeV
0.667 ms
274Rg
α2
10.65 ± 0.06 MeV
9.97 ms
270Mt
α3
10.26 ± 0.07 MeV
444 ms
266Bh
α4
9.39 ± 0.06 MeV
5.26 s
262Db
α5
8.63 ± 0.06 MeV
126 s
258Lr
α6
8.66 ± 0.06 MeV
3.78 s
254Md



N=165
$^{278}113$ τ = 2.0 ms
N=163
^{274}Rg τ = 18 ms
previous
N=161
^{270}Mt τ = 0.69 s
N=159
^{266}Bh τ = 3.0 s
N=157
^{262}Db τ = 56 s
10 μs
1 ms
0.1 s
10 s
1000 s
T_decay


N=165
^{278}113 τ = 2.0 ms
N=163
^{274}Rg τ = 18 ms
N=161
^{270}Mt τ = 0.69 s
N=159
^{266}Bh τ = 3.0 s
N=157
^{262}Db τ = 56 s
present
previous
10 μs
1 ms
0.1 s
10 s
1000 s
T_decay

^{262}Db(Z = 105):
b_α/b_{SF} = 67%/33%.
$T_{1/2}$ = 34 ± 4 s
8.450 ± 0.020 MeV (75%),
8.530 ± 0.020 MeV (16%),
8.670 ± 0.020 MeV (9%)

^{258}Lr(Z = 103):
b_α = 97.5%.
$T_{1/2} = 3.92^{+0.35}_{-0.42}$ s
8.565 ± 0.025 MeV (20%),
8.595 ± 0.010 MeV (46%),
8.621 ± 0.010 MeV (25%),
8.654 ± 0.010 MeV (9%)

^{254}Md/ ^{254m}Md(Z = 101):
b_{EC} = 100%/ 100%,
$T_{1/2}$ = 10 ± 3 / 28 ± 8 min

^{254}Fm(Z = 100):
b_α = 99.94%,
$T_{1/2}$ = 3.240 ± 0.002 h
6.898 ± 0.003 MeV (0.0066%),
7.050 ± 0.002 MeV (0.82%),
7.150 ± 0.002 MeV (14.2%),
7.192 ± 0.002 MeV (84.9%).

α_5

E_α = 8.63 ± 0.06 MeV
τ = 126 s (present)
$\tau = 56^{+77}_{-21}$ s → $T_{1/2} = 39^{+53}_{-14}$ s (three events)

α_6

E_α = 8.66 ± 0.06 MeV
τ = 3.78 s
→ $T_{1/2} = 2.6^{+12}_{-1.1}$ s (one events)

no signal :
E(X-ray of ^{254}Fm)$_{max}$ = 142 keV
Energy threshold of PSD = 800 keV

$\alpha_{7\text{-}1}$
E_α = 7.26 ± 0.07 MeV
τ = 3.96 h P_{acc} = 0.43

$\alpha_{7\text{-}2}$
E_α = 7.18 ± 0.06 MeV
τ = 6.42 h P_{acc} = 0.70

^{250}Cf (Z=98):
b_α = 99.92%
$T_{1/2}$ = 13.08 y

$^{209}Bi + ^{70}Zn \rightarrow ^{278}113 + n$

α_4: ^{266}Bh (Z = 107)

1st	$E_\alpha = 9.08 \pm 0.04$ MeV, $\tau = 2.47$ s
2nd	$E_\alpha = 9.77 \pm 0.04$ MeV, $\tau = 1.31$ s
3rd	$E_\alpha = 9.39 \pm 0.06$ MeV, $\tau = 5.26$ s

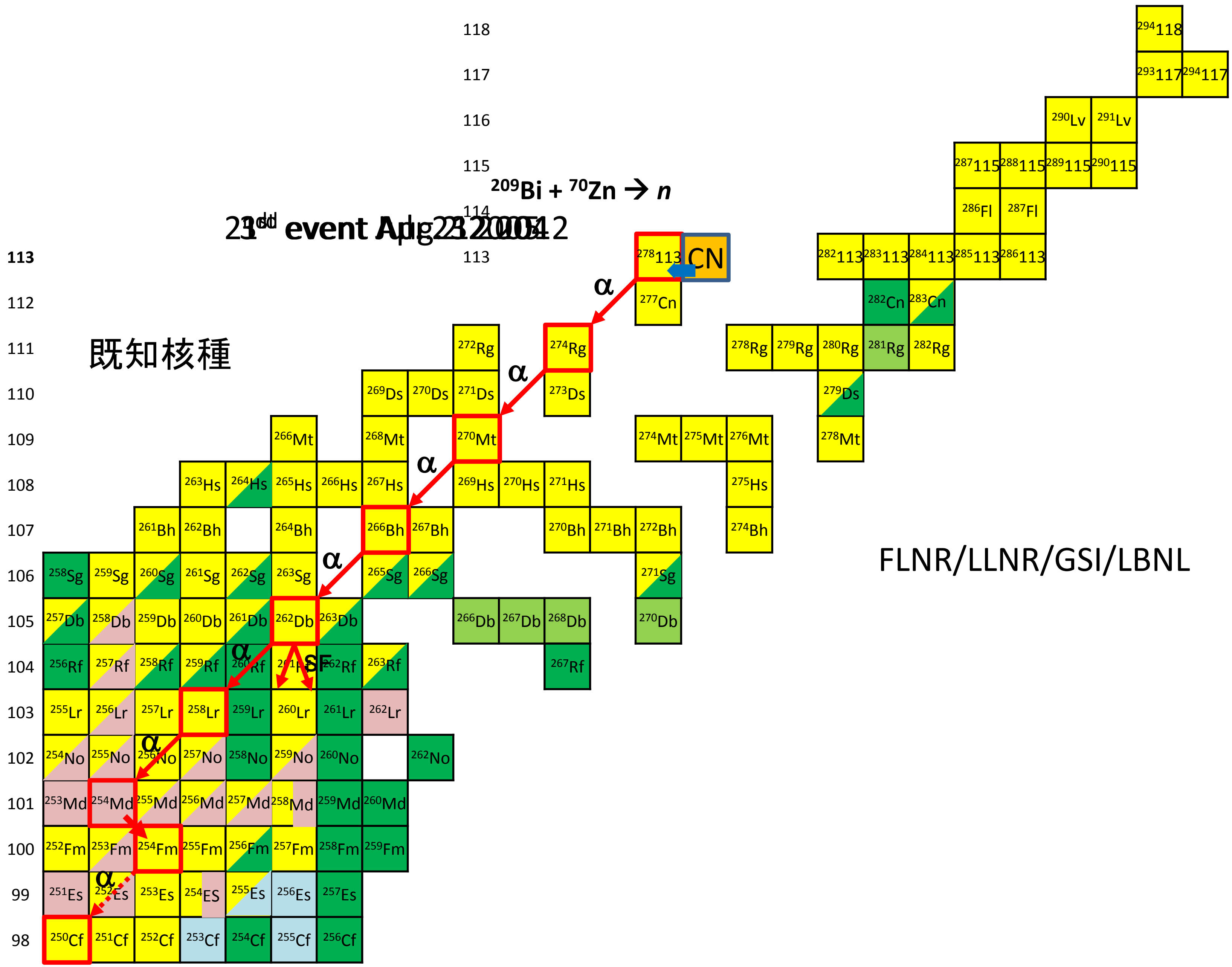
mean-life = $3.0^{+4.2}_{-1.1}$ s $\rightarrow$ $T_{1/2} = 4.3^{+6.1}_{-1.6}$ s

Cf:

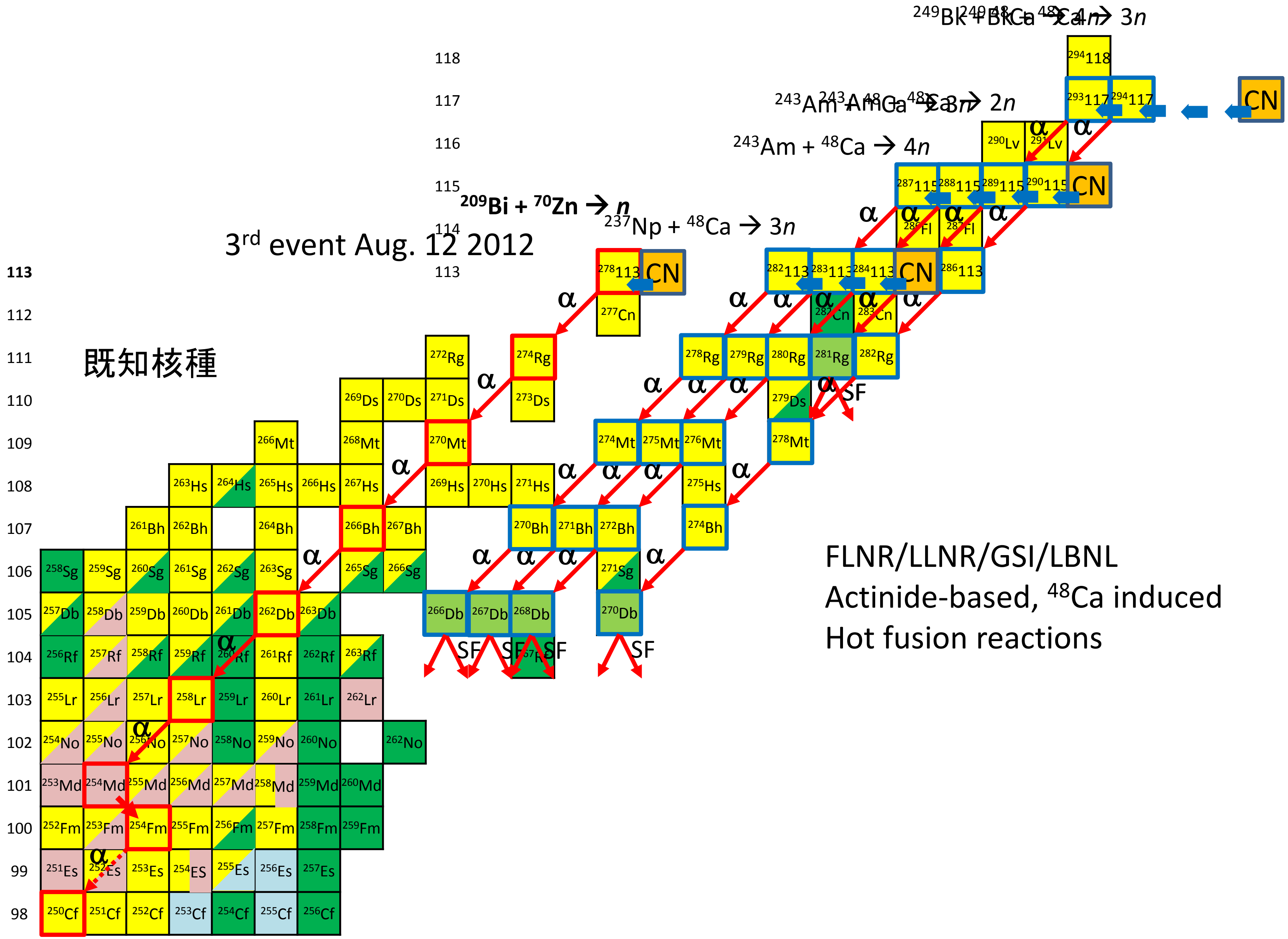
$^{248}Cm + ^{23}Na \rightarrow ^{266}Bh + 5n$

^{266}Bh (Z = 107)

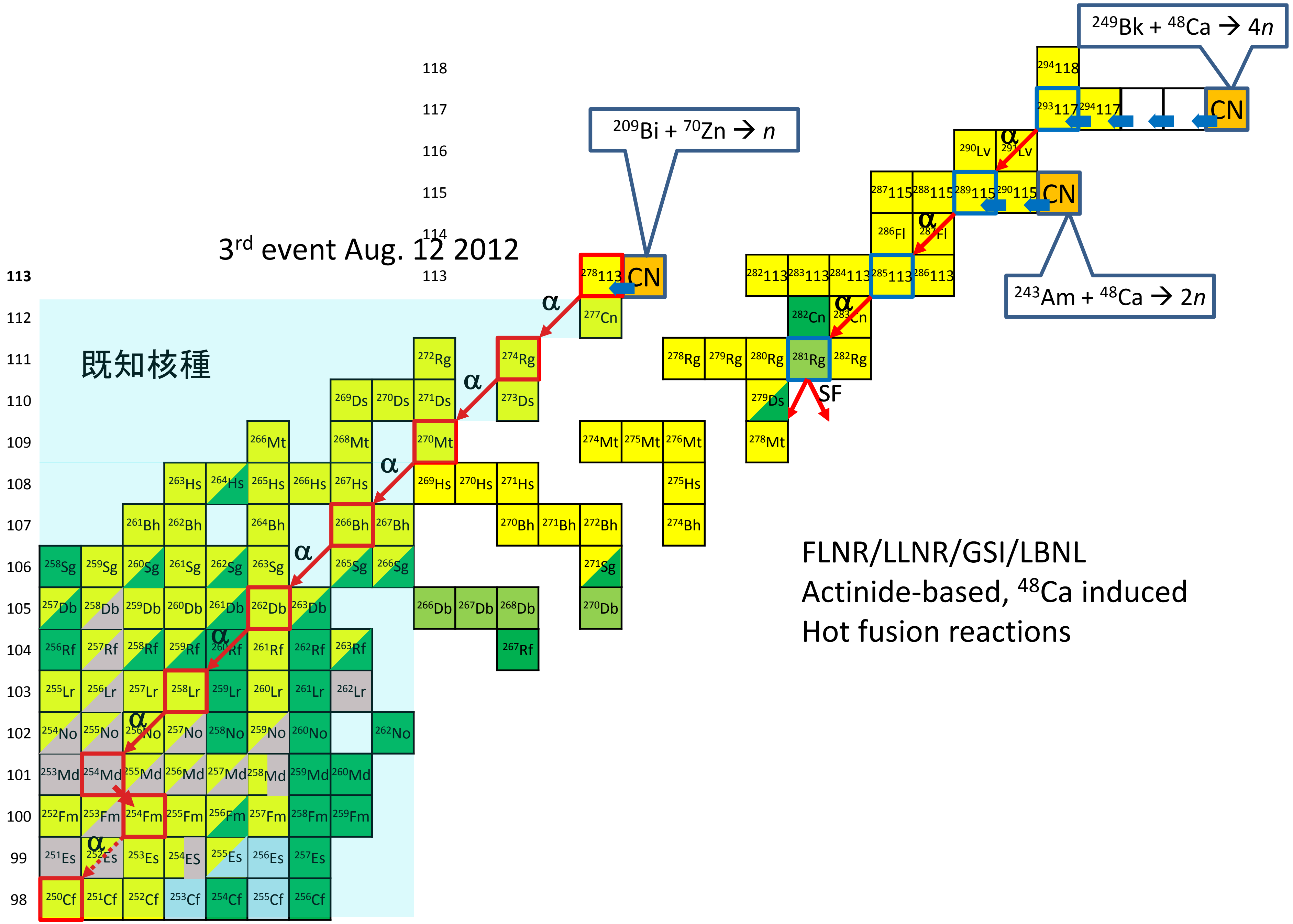
$E_\alpha = 9.05 - 9.23$ MeV, $\tau >$ s



$^{209}Bi + ^{70}Zn \rightarrow n$
3rd event Aug 12 2012
既知核種
FLNR/LLNR/GSI/LBNL
CN
$^{278}113$
α
^{274}Rg
α
^{270}Mt
α
^{266}Bh
α
^{262}Db
α
SF
^{258}Lr
α
^{254}Md
^{254}Fm
α
^{250}Cf



3rd event Aug. 12 2012
既知核種
209Bi + 70Zn → n
237Np + 48Ca → 3n
243Am + 48Ca → 4n
243Am + 48Ca → 3n → 2n
249Bk + 48Ca → 4n → 3n
CN
α
SF
FLNR/LLNR/GSI/LBNL
Actinide-based, 48Ca induced
Hot fusion reactions



^{249}Bk + ^{48}Ca → 4n
^{209}Bi + ^{70}Zn → n
3rd event Aug. 12 2012
^{243}Am + ^{48}Ca → 2n
既知核種
FLNR/LLNR/GSI/LBNL
Actinide-based, ^{48}Ca induced
Hot fusion reactions

Program of SHE search and spectroscopy

$^{209}Bi(^{70}Zn, n)^{278}113$ experiment completed on Oct. 1, 2012.
Study $^{208}Pb(^{76}Ge, n)^{283}114(Fl)$ reaction (under discussion).
Start $^{248}Cm(^{54}Cr, 3n)^{299}120$ experiment (in collaboration with GSI group).
$^{248}Cm(^{48}Ca, 3n)^{293}Lv$
$^{248}Cm(^{50}Ti, 3n)^{295}118$
$^{248}Cm(^{51}V, 3n)^{296}119$

New isotope search of the heaviest nuclei and detailed spectroscopy with cold and hot fusion reactions.

Mass measurement of the heaviest nuclei with m-TOF system coupled to GARIS (Wada-san's group)

Study of heavy ion transfer reaction with GARIS for the study of neutron rich nuclei around N=126 region.

Try to measure X-ray from evaporation residues (in collaboration with W. Henning).

Developing FPD detector system for α-γ-e coincidence experiment

Collaborators (2006 -)

RIKEN Nishina Center
H. Haba, H. Hasebe, D. Kaji, K. Katori, Y. Kudou,
T. Ohnishi, K. Ozeki, K. Morimoto, A. Yoneda, A. Yoshida,

Tokyo University of Science
T. Sumita, K. Tanaka, J. Chiba

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

Tohoku University
T. Suda, H. Kikunaga, T. Shinozuka

JAEA
H. Koura, S. Mitsuoka, K. Ooe, N. Sato, A. Toyoshima,
K. Tsukada, Y. Wakabayashi

Niigata University
S. Goto, M. Murakami, M. Murayama,
Y. Kanaya, H. Kudo,

YITP Kyoto University
T. Ichikawa,

University of Tsukuba
A. Ozawa, K. Sueki

Yamagata University
Y. Fujimori, K. Mayama, T. Mashiko ,S. Namai,
M. Takeyama, F. Tokanai,

Center for Nuclear Science, University of Tokyo
E. Ideguchi

Osaka University
Y. Kasamatsu, Y. Kitamoto, Y. Komori, T. Kuribayashi,
K. Matsuo, D. Saika, A. Shinohara, T. Takabe,
Y. Tashiro, T. Yoshimura

Kanazawa University
T. Nanri, D. Suzuki, I. Yamazaki, A. Yokoyama

Thank you very much for your kind attention!