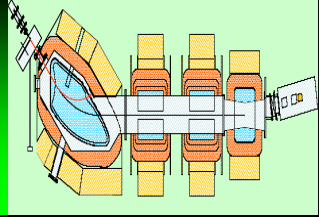
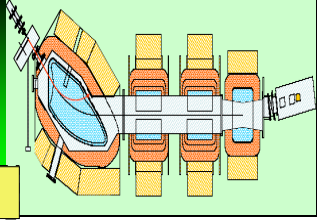
Present status of the heaviest elements' study using GARIS at RIKEN

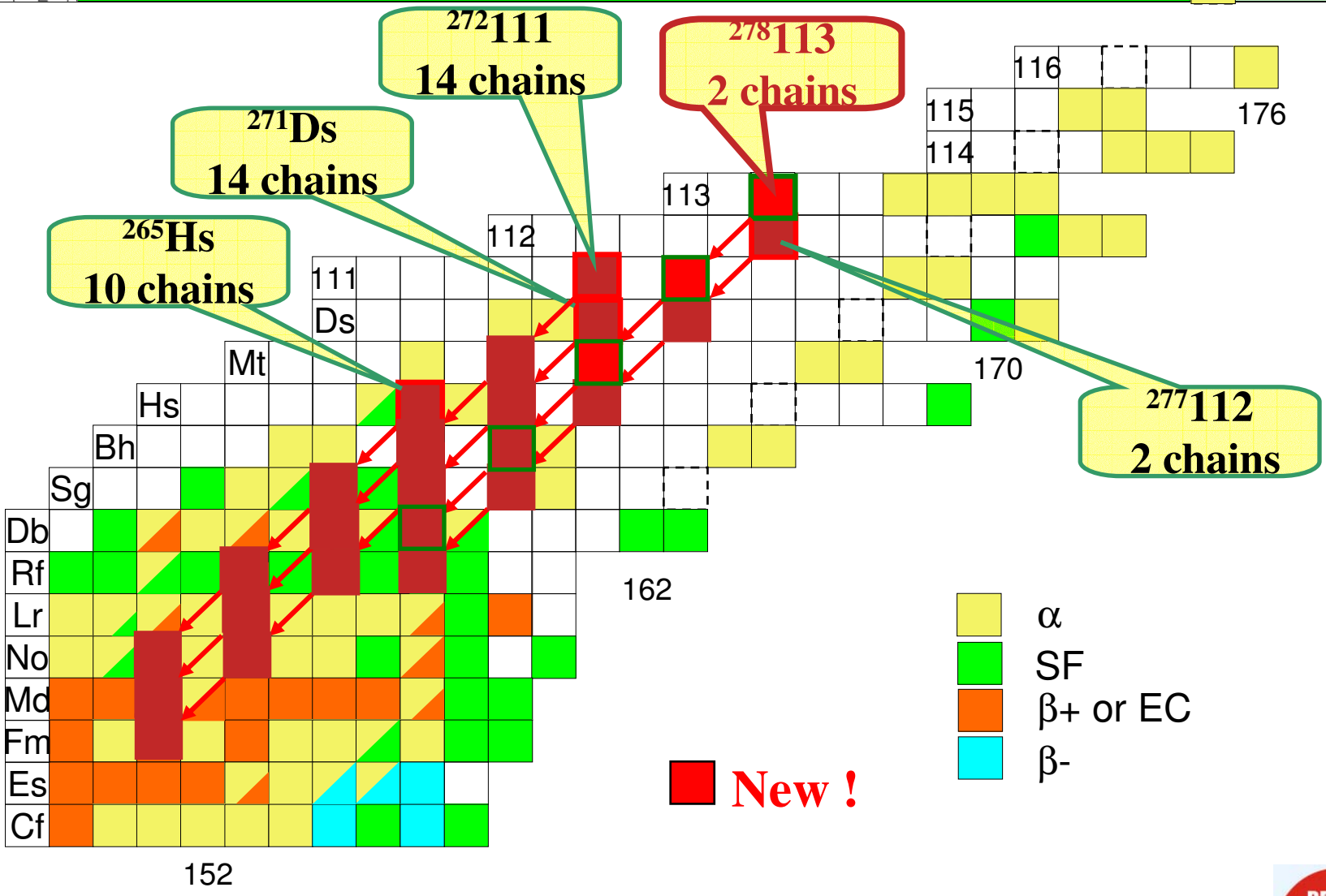


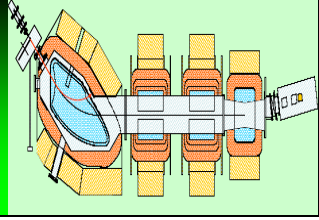
Kosuke Morita

Superheavy Element Laboratory
RIKEN Nishina Center for Accelerator Based Science

Reactions studied at GARIS







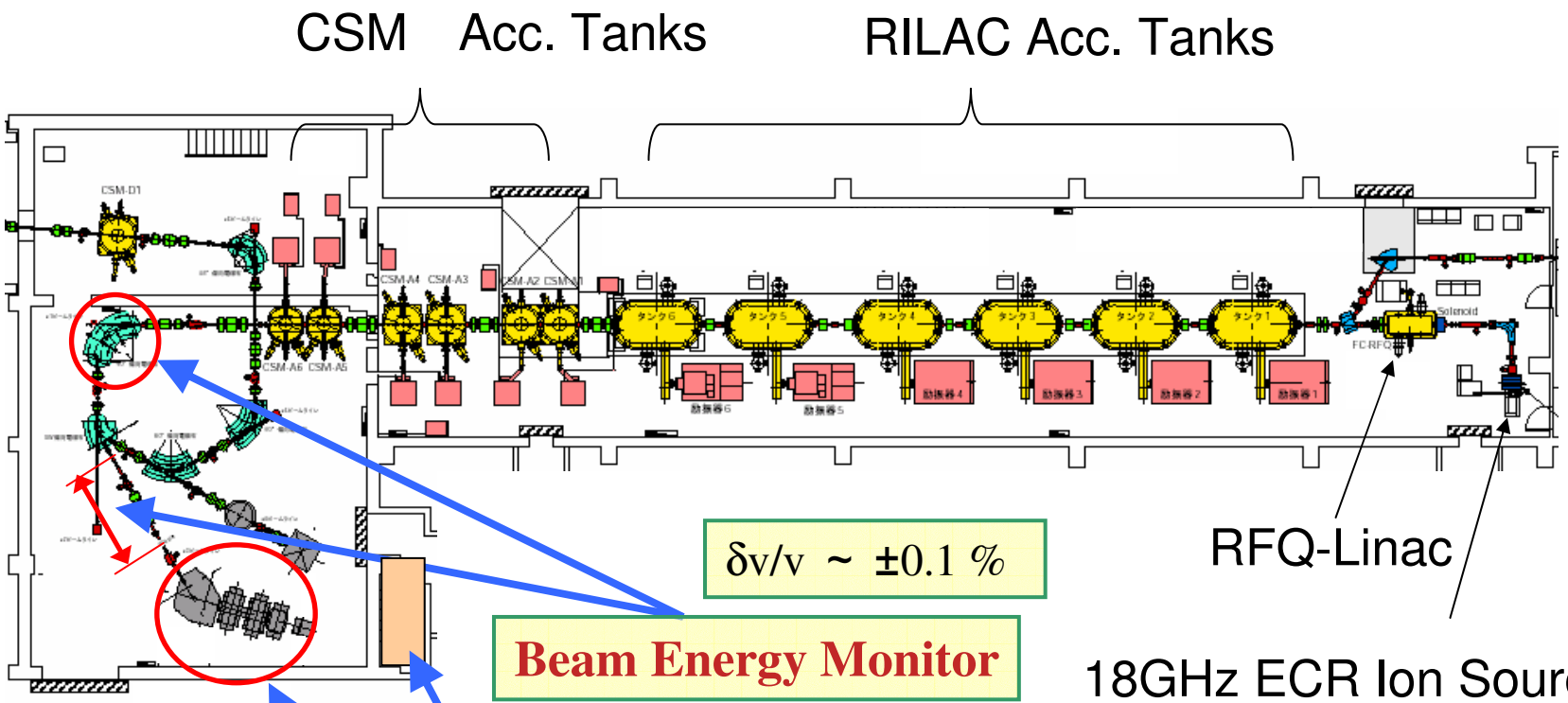
Yield – Cross section (sensitivity)

$$Y = \sigma \times T \times B \times \varepsilon$$

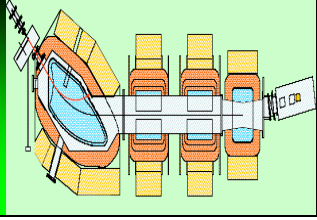
			typical value	
Y	event rate	/s		
σ	cross section	cm^2	10^{-36}	1 p-barn
T	target thickness	$/cm^2$	1.3×10^{18}	450 mg/cm^2
B	beam intensity	/s	4×10^{12}	0.65 particle mA
ε	efficiency		0.8	

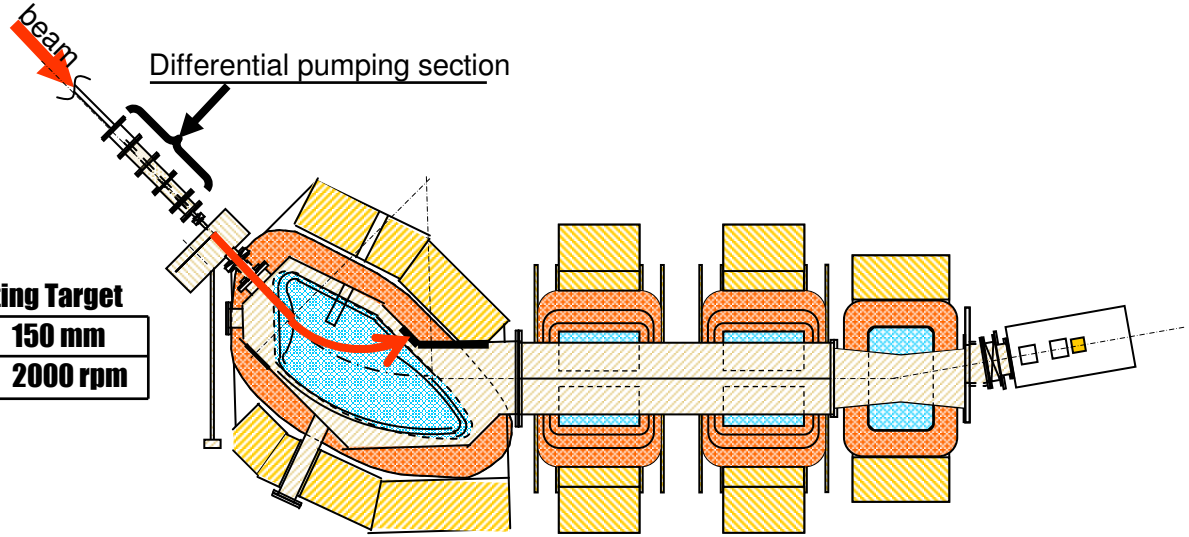
$Y = 4\times10^{-6}$ /s → 1 event/3days/p-barn

RILAC Facility



RIKEN Gas-filled Recoil Separator GARIS





Rotating Target

r	150 mm
ω	2000 rpm

D1

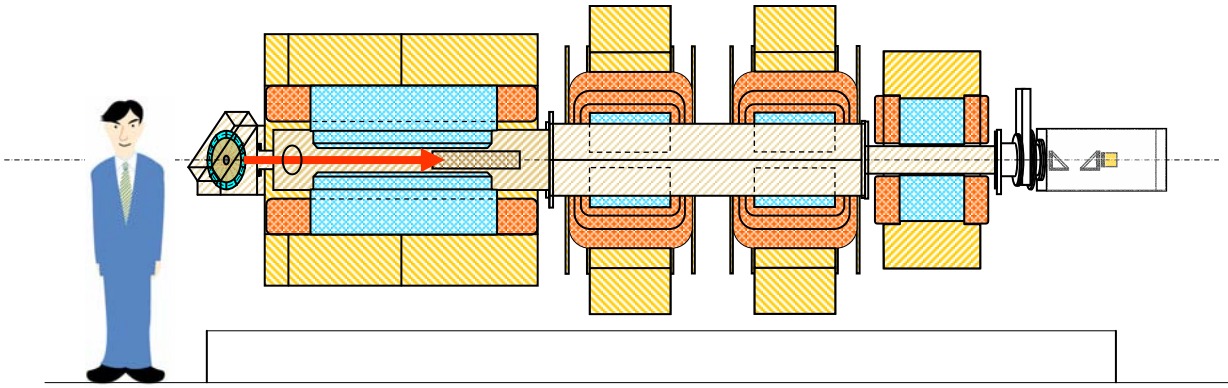
Bending angle	45 degree
Pole gap	150 mm
Radius of central ray	1200 mm
Maximum field	1.54 T

Q1, Q2

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

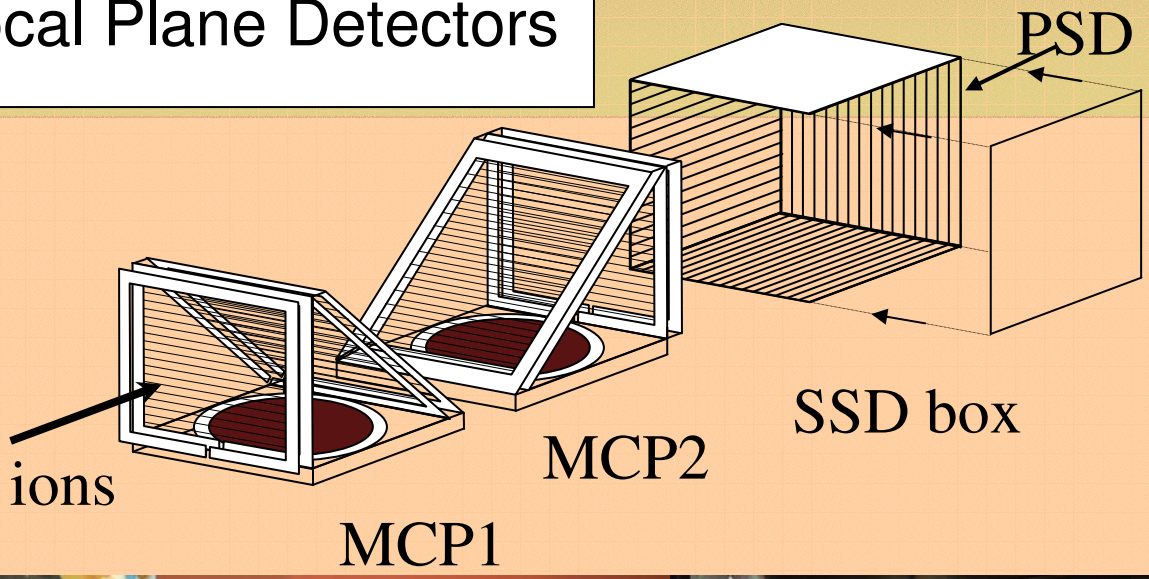
D2

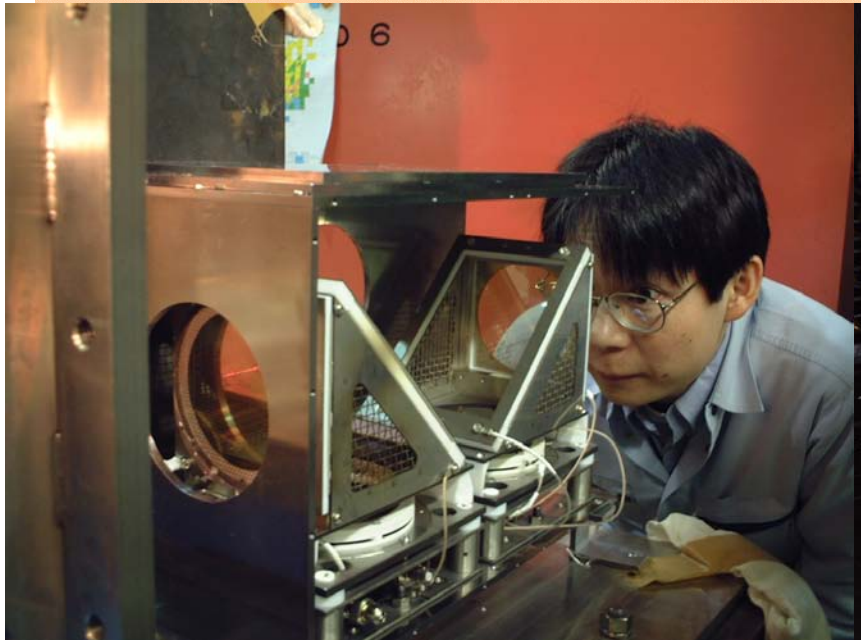
Bending angle	10 degree
Pole gap	160 mm
Pole length	400 mm
Maximum Field	1.04 T

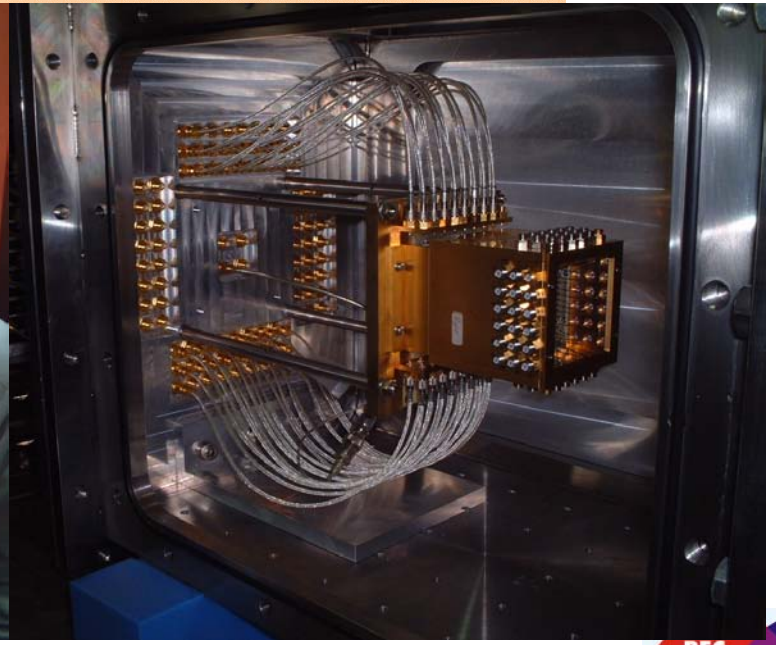


Magnification	X	-0.76
	Y	-1.99
Dispersion		0.97 cm/%
Total length		5760 mm
Acceptance	Δθ	±68 mrad
	Δϕ	±57 mrad
	ΔΩ	12.2 msr

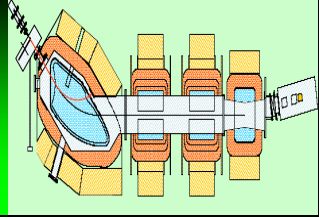
Focal Plane Detectors



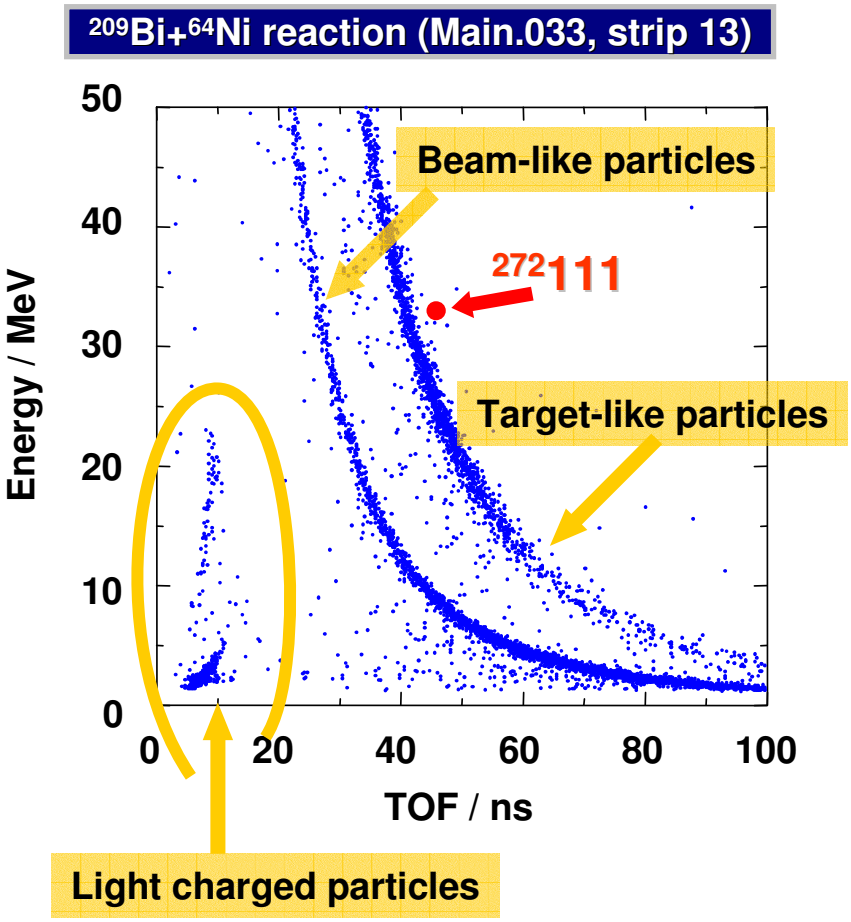




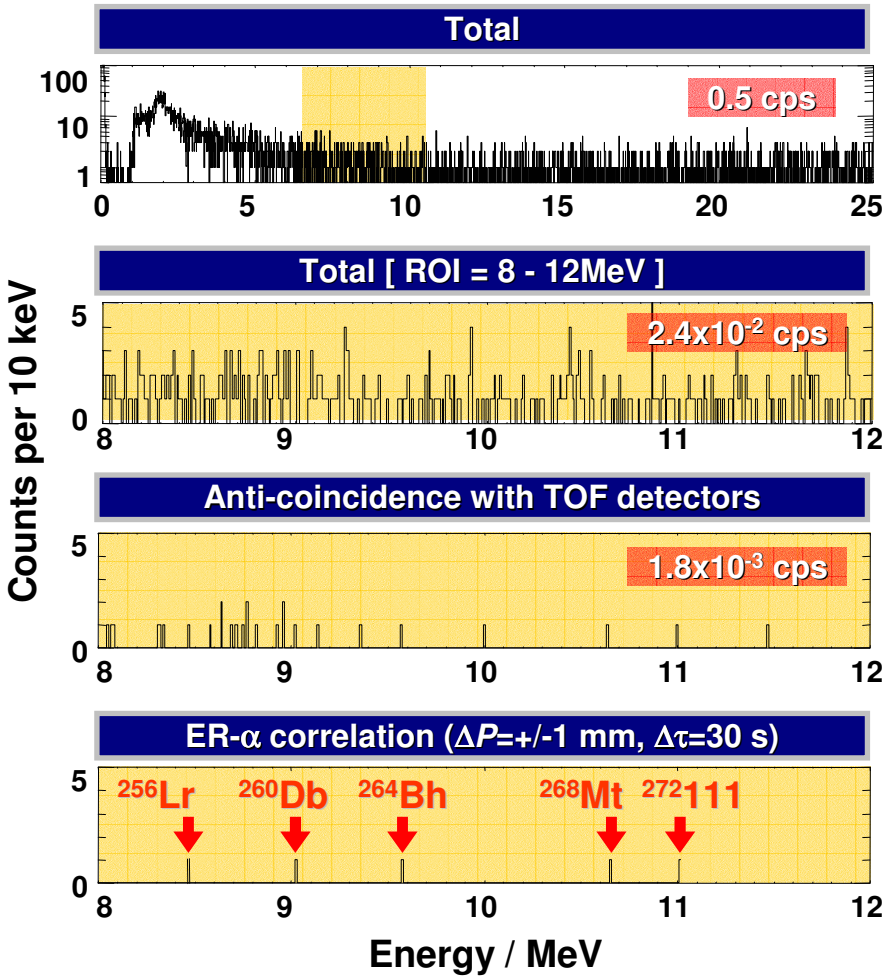
Performance of detection system



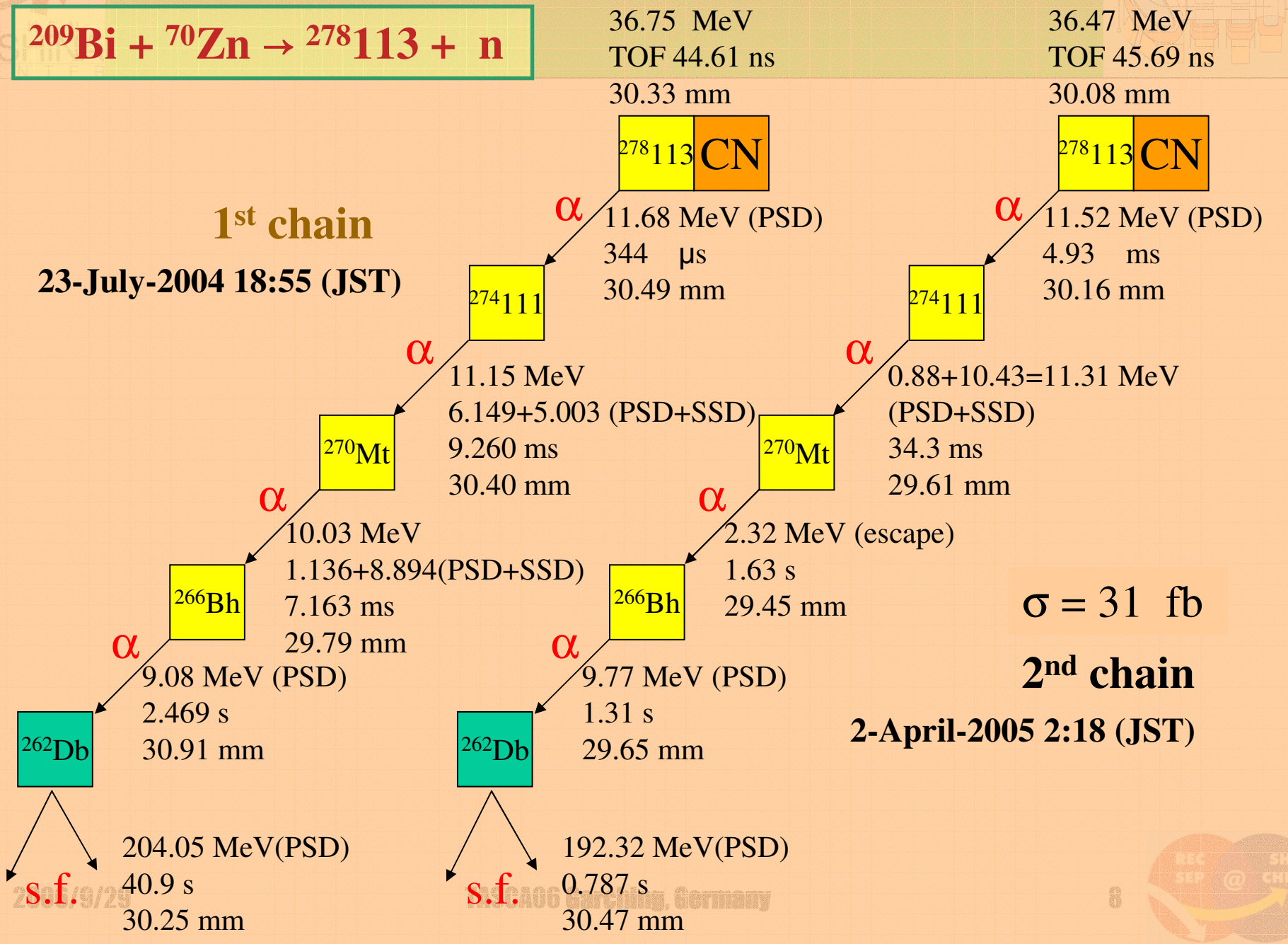
TOF-energy spectrum



ER-α correlation analysis



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



Observed events at RIKEN in $^{208}Pb + {}^{70}Zn$ reaction

16-April-2004
E (^{70}Zn) = 349.5 MeV

Strip #8

34.42 MeV
23.33 mm

$^{277}112$ CN

11.09 ± 0.07 MeV
1.10 ms
23.57 mm

^{273}Ds

11.14 ± 0.04 MeV
0.52 ms
23.45 mm

^{269}Hs

9.17 ± 0.04 MeV
14.19 s
23.34 mm

^{265}Sg

8.71 ± 0.04 MeV
23.02 s
23.45 mm

^{261}Rf

197.3 MeV
2.97 s
23.41 mm

Strip #11

35.13 MeV
18.45 mm

$^{277}112$ CN

11.32 ± 0.04 MeV
1.22 ms
18.31 mm

^{273}Ds

11.15±0.07MeV (2^{nd} trig. PSD+SSD)
39.9 μs
20.18 mm

^{269}Hs

9.25 ± 0.07 MeV(PSD+SSD)
0.270 s
19.03 mm

^{265}Sg

8.70 ± 0.04 MeV
79.9 s
18.05 mm

^{261}Rf

156.3 MeV
8.3 s
18.50 mm

22-May-2004
E (^{70}Zn) = 349.5 MeV

	GSI		RIKEN		FLNR	
ref.	1	2	3	4	5	6
^{277}112	11.45	11.17	11.09±.07	11.32±.04		
	0.28 ms	1.41 ms	1.10 ms	1.22 ms		
^{273}Ds	11.08	11.20	11.14±.04	11.15±.07	11.35	
	0.11 ms	0.31 ms	0.52 ms	0.04 ms	0.39 ms	
^{269}Hs	9.23	9.18	9.17±.04	9.25±.07		
	19.7 s	22.0 s	14.2 s	0.27 s		
^{265}Sg	4.60	0.20	8.71±.04	8.70±.04	8.63	
	74.0 s	18.8 s	23.0 s	79.9 s	158 s	
^{261}Rf	8.52	153	197	156		8.30±0.06
	4.70 s	14.5 s	2.97 s	8.30 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) — ^{208}Pb + ^{70}Zn → ^{277}112 + n
2 Hofmann S. and Münzenberg G., Rev. Mod. Phys. 72, 733 (2000) — ^{208}Pb + ^{70}Zn → ^{277}112 + n

3 present — ^{208}Pb + ^{70}Zn → ^{277}112 + n
4 present — ^{208}Pb + ^{70}Zn → ^{277}112 + n
5 Lazarev Yu. A. et al., Phys. Rev. C54, 620 (1996) — ^{244}Pu + ^{34}S → ^{273}Ds + 5n
6 Lazarev Yu. A. et al., Phys. Rev. C62, 064307(2000) — ^{244}Pu + ^{22}Ne → ^{261}Rf + 5n

3.2. Chemistry system coupled to a recoil separator

Haba et al

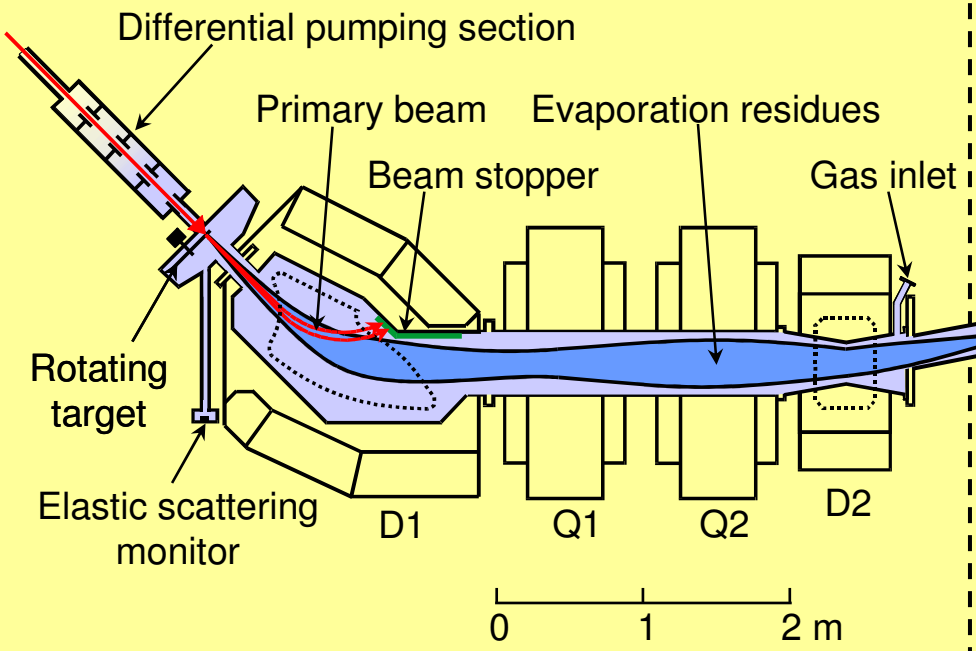
Open new frontiers in SHE chemistry

Chemical experiments under extremely low background conditions
Stable and high gas-jet transport efficiency
Chemical reactions with a large variety of chemical reagents

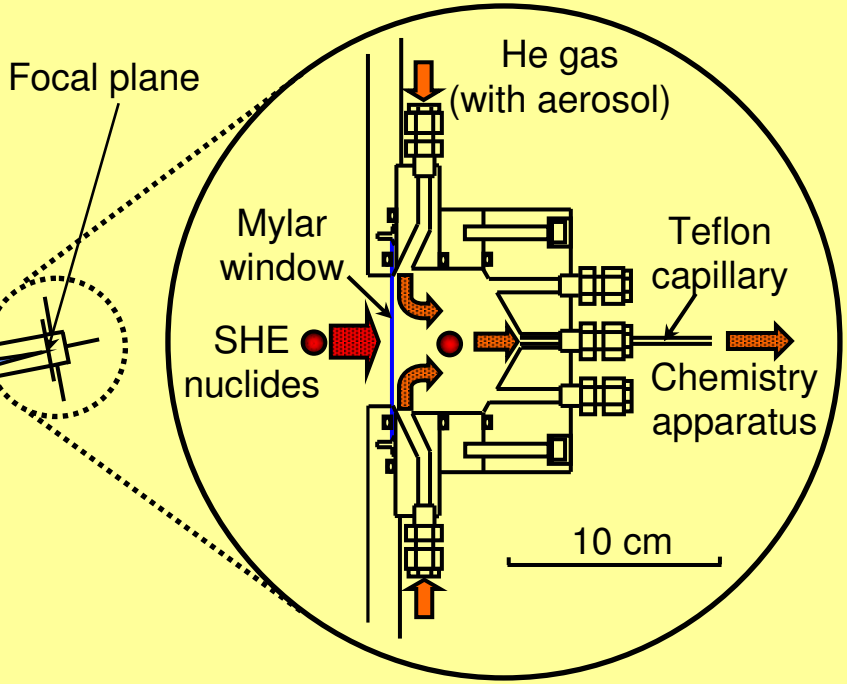
Gas-jet transport system coupled to GARIS

in collaboration with the TASCA community at GSI
(TransActinide Separator and Chemistry Apparatus)

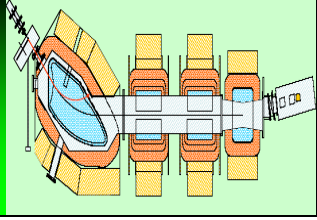
RIKEN GARIS

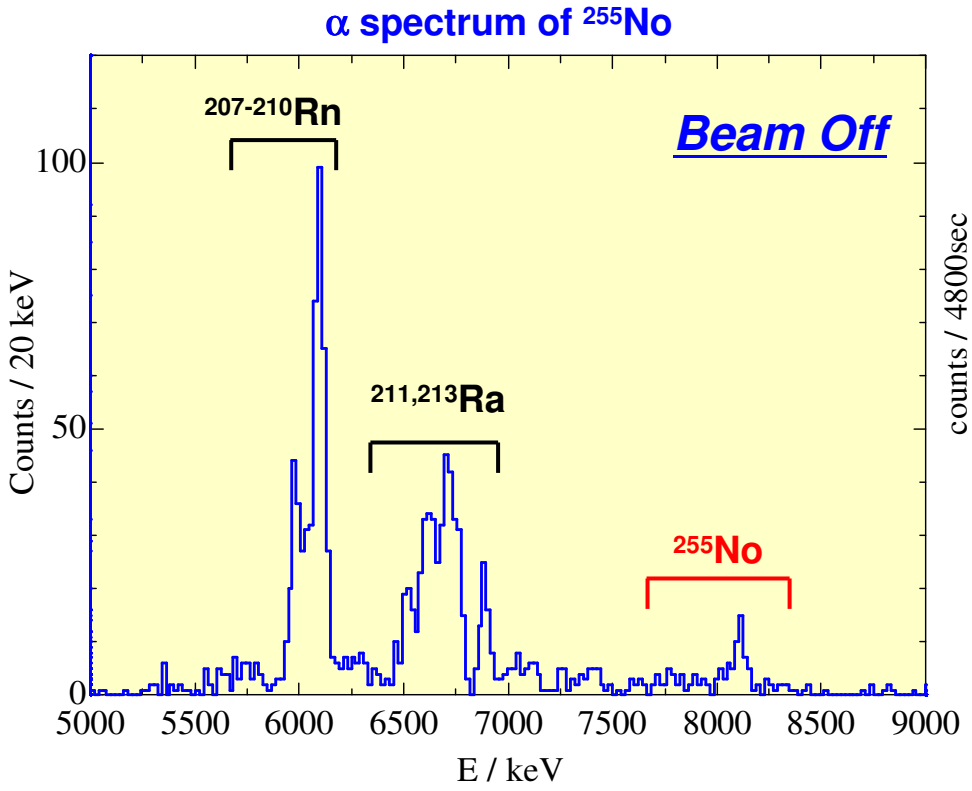


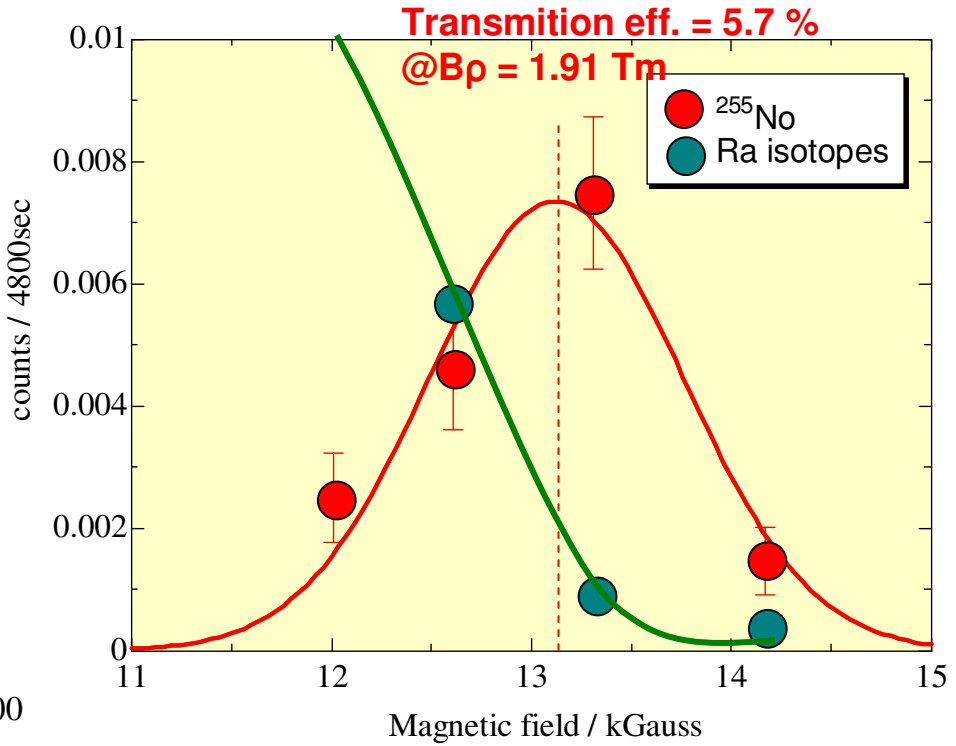
Gas-jet transport system



PSD spectrum







Experimental condition

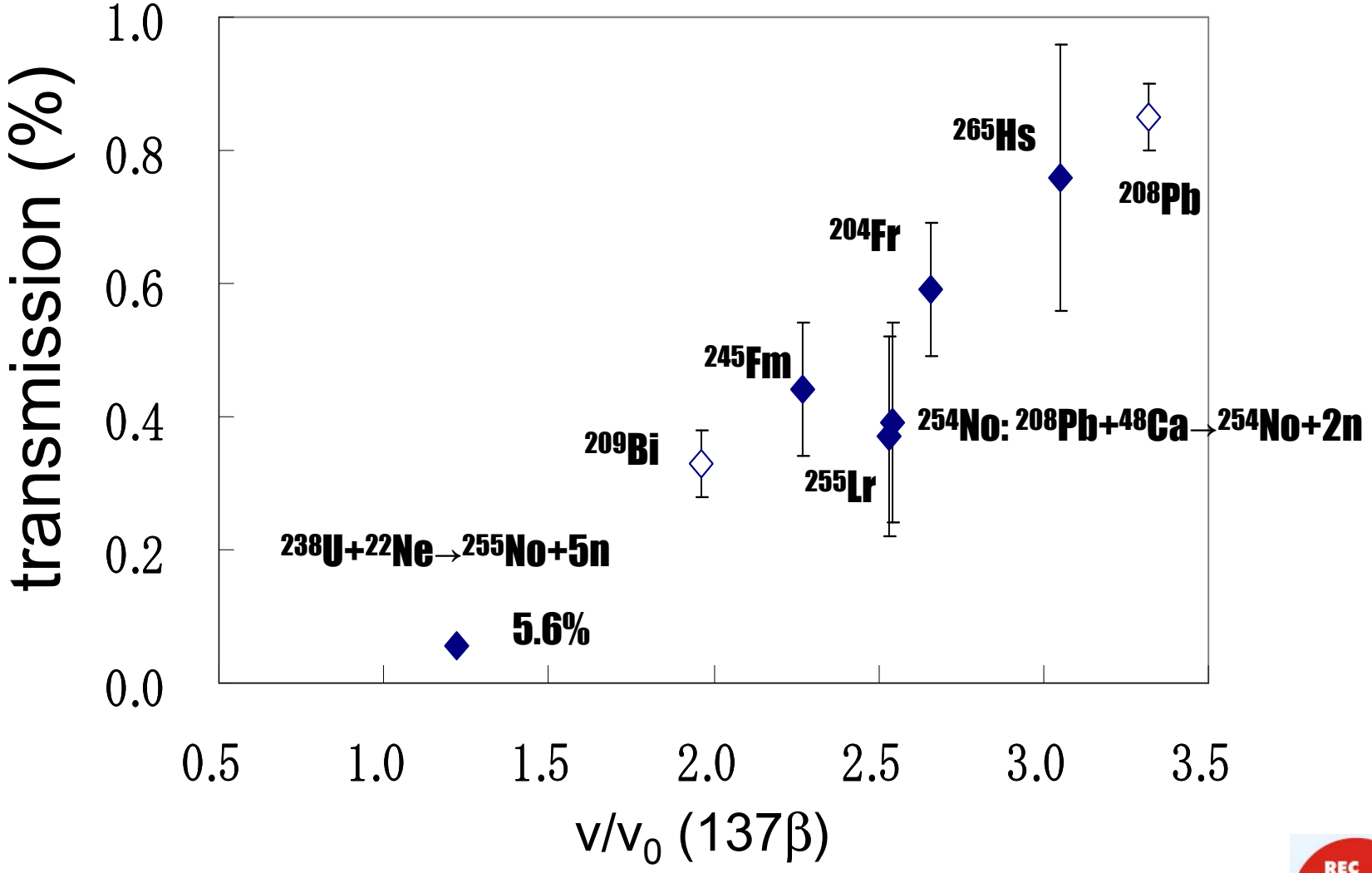
Reaction: $^{238}U(^{22}Ne, 5n)^{255}No$, 90nb
Beam energy: 113.8 MeV
Recoil energy: 9.6 MeV
Beam intensity: 4 pμA
Magnetic rigidity: 1.72-2.04 Tm
He pressure: 38 Pa

Ra isotopes and its daughter were observed.

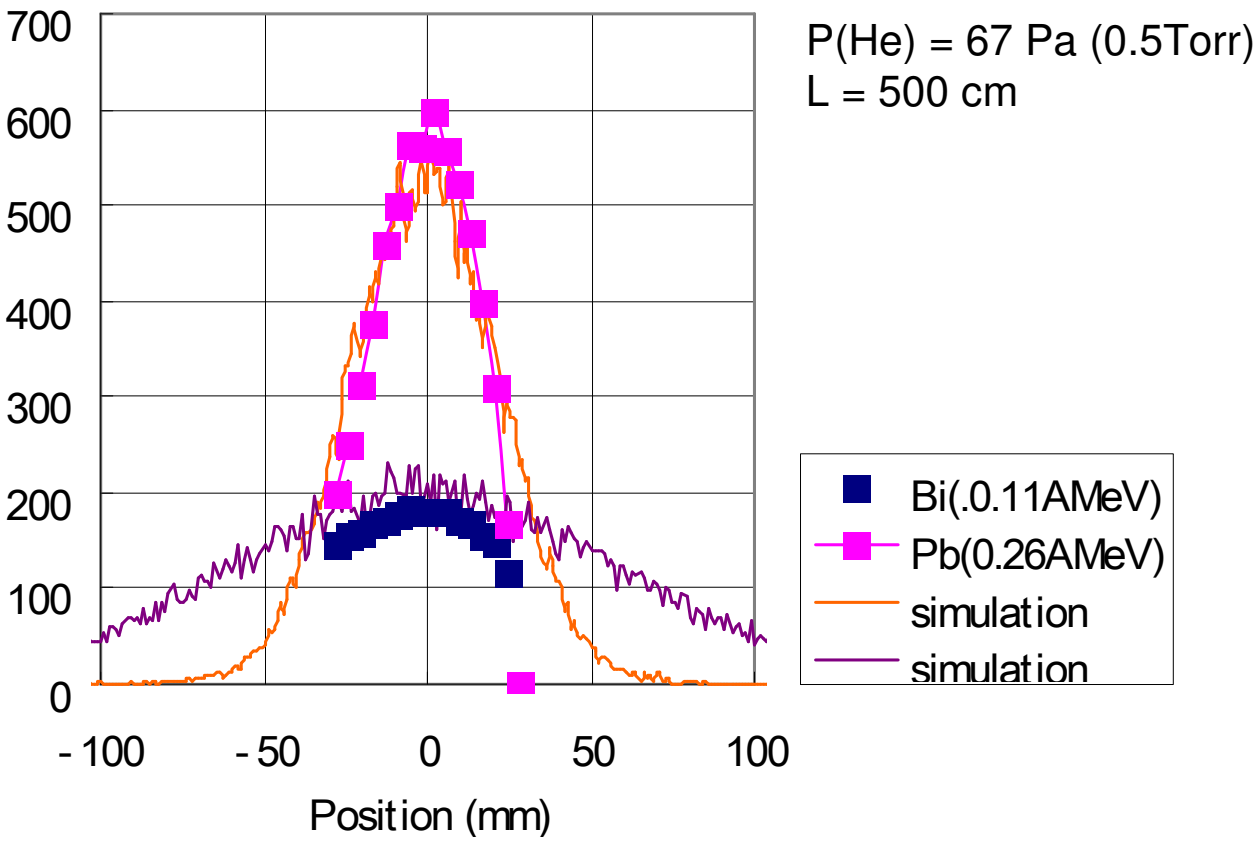
$^{nat}Pt(^{22}Ne, xn)Ra$ reaction

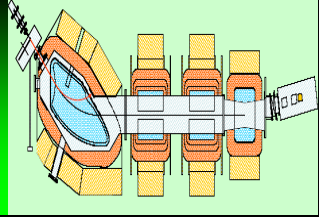
But these isotopes can be separated by GARIS system at **Bρ = 1.91 Tm**

Transmission efficiency of GARIS



Positional Distribution at Focal Plane





$$x_{1/e} = \sqrt{n_{coll}} \times \theta_{av} \times \frac{l}{2} \propto l^{\frac{3}{2}}$$

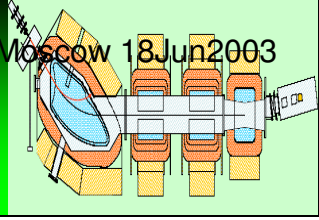
$$n_{coll} = l \times \rho \times \sigma_{eff}$$

$$l : total\_length$$

$$\sigma eff : effective\_cross\_section$$

$$\rho : numver\_decsity\_of\_gas\_atom$$

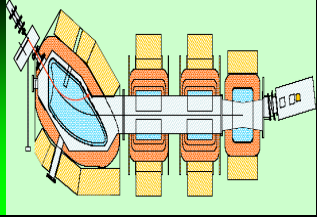
$$\theta_{av} : averaged\_deflection\_angel\_of\_one\_collision$$

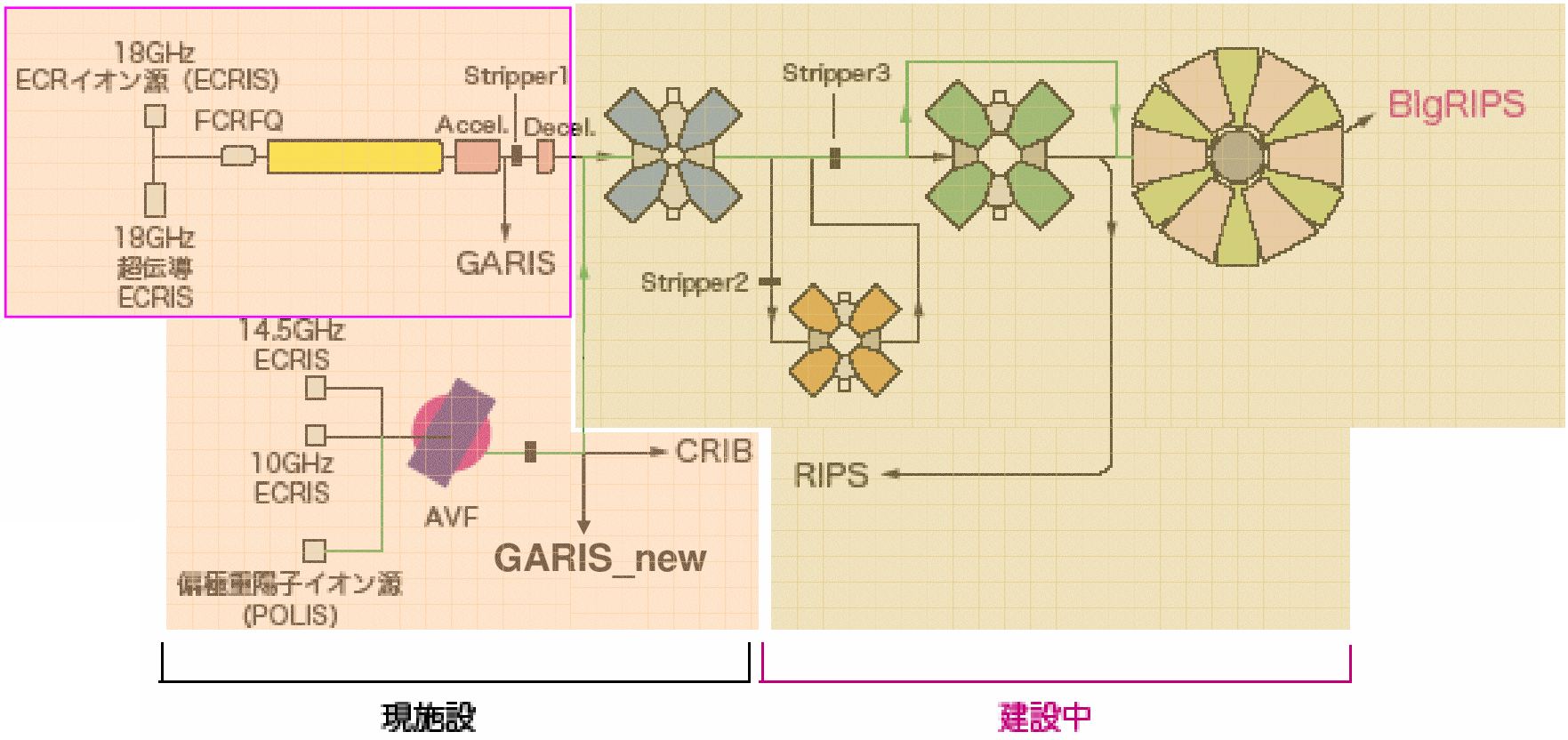


	projectile			target recoil			compound nucleus		
system	E MeV	β	Bρ Tm	E MeV	β	Bρ Tm	E MeV	β	Bρ Tm
$^{208}Pb + ^{58}Fe$	281	0.1020	0.708	191.6	0.0445	1.55	61.27	0.0222	2.05
$^{208}Pb + ^{64}Ni$	309	0.1018	0.724	222.4	0.0479	1.52	72.71	0.0240	2.08
$^{208}Pb + ^{70}Zn$	345	0.1029	0.746	260.0	0.0518	1.49	86.87	0.0259	2.11

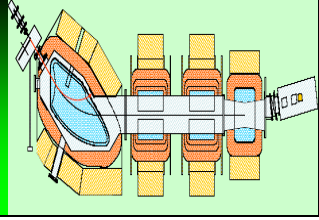
	energy separator		velocity separator		gas-filled separator	
Ep/Ecn	Er/Ecn	βp/βcn	βr/βcn	Bρp/Bρcn	Bρr/Bρcn
4.586	3.128	4.586	2.000	0.346	0.759
4.250	3.059	4.250	2.000	0.348	0.732
3.971	2.993	3.971	2.000	0.354	0.707

RIBF in Future





共同研究者
collaborators



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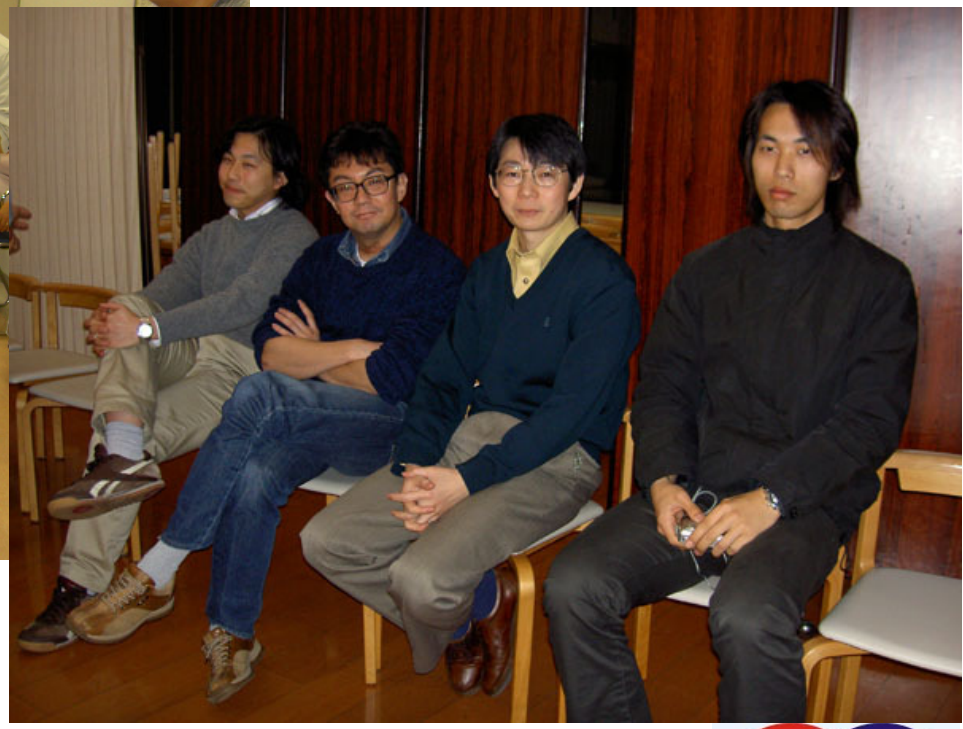
young powers!



Thank you for your attention.

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