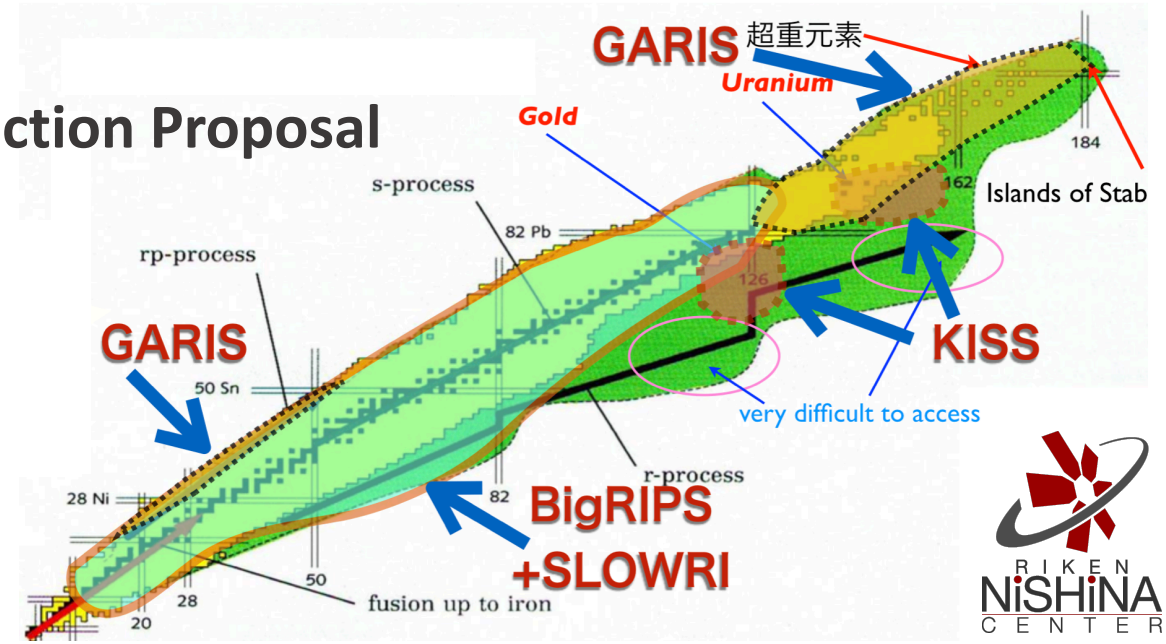
Status and Future Plans for MRTOF Mass Measurements at RIKEN-RIBF

Marco Rosenbusch for the SHE-Mass Collaboration
RIKEN Nishina Center for Accelerator-Based Science
2-1 Hirosawa, Wako, Saitama 351-0198, Japan

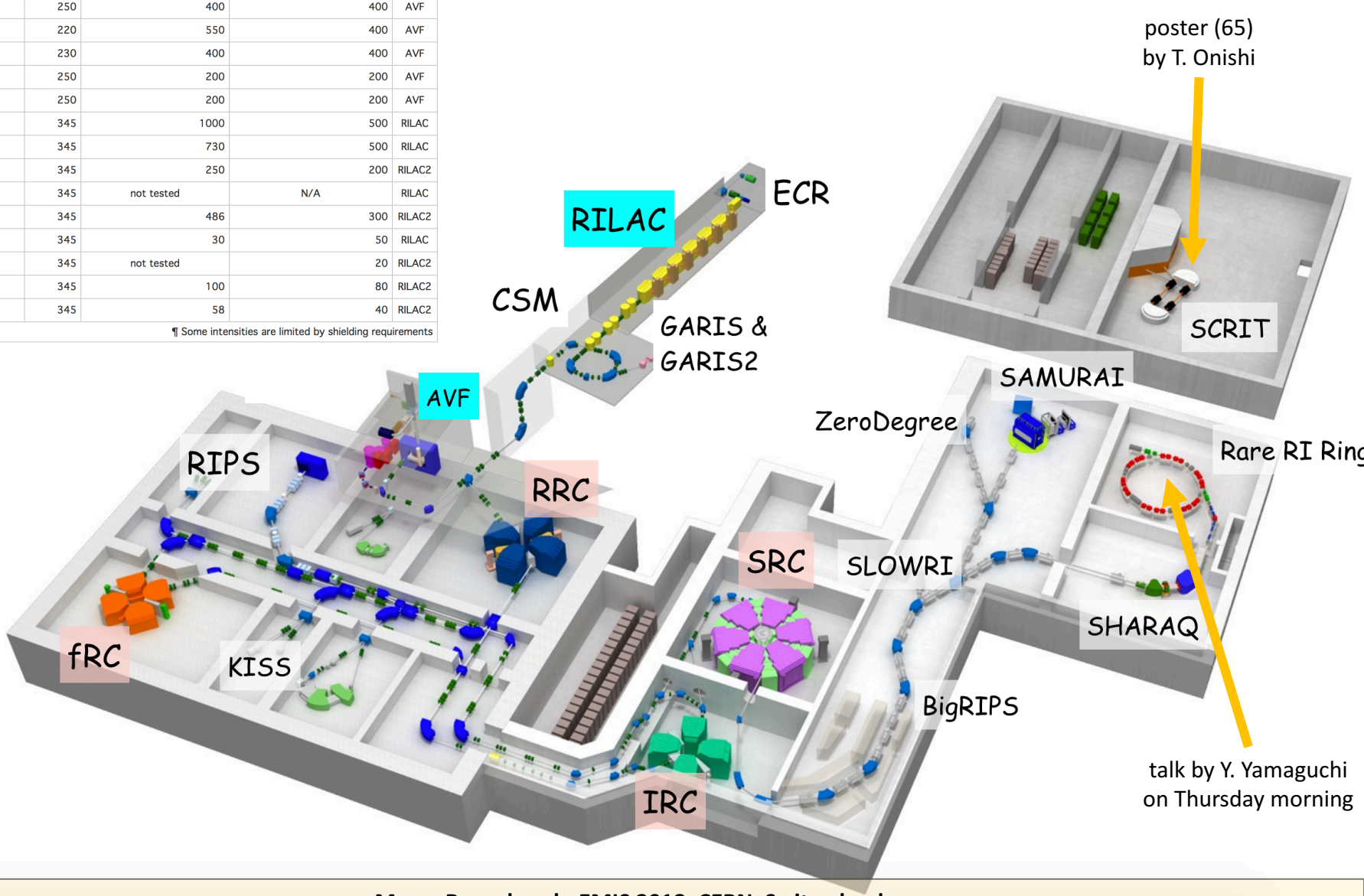
- Motivation for MRTOF Mass Measurements at RIKEN-RIBF
- Achievements in the Past at GARIS-II
- Setups in Preparation
- Approved (Big) Construction Proposal
- Future Experiments



RIKEN's RIBF facility

Beam particle	E/A(MeV)	Beam current (pnA)		Injector
		Maximum (instantaneous) achieved so far	Expected ¶ (for exp. planning in your proposal)	
d	250	1000	200	AVF
d(pol.)	250	120	30	AVF
^{4}He	320	1000	1000	RILAC
^{14}N	250	400	400	AVF
^{18}O	220	550	400	AVF
^{18}O	230	400	400	AVF
^{16}O	250	200	200	AVF
^{18}O	250	200	200	AVF
^{18}O	345	1000	500	RILAC
^{48}Ca	345	730	500	RILAC
^{70}Zn	345	250	200	RILAC2
^{76}Ge	345	not tested	N/A	RILAC
^{78}Kr	345	486	300	RILAC2
^{86}Kr	345	30	50	RILAC
^{136}Xe	345	not tested	20	RILAC2
^{124}Xe	345	100	80	RILAC2
^{238}U	345	58	40	RILAC2

¶ Some intensities are limited by shielding requirements



cf. AME2016

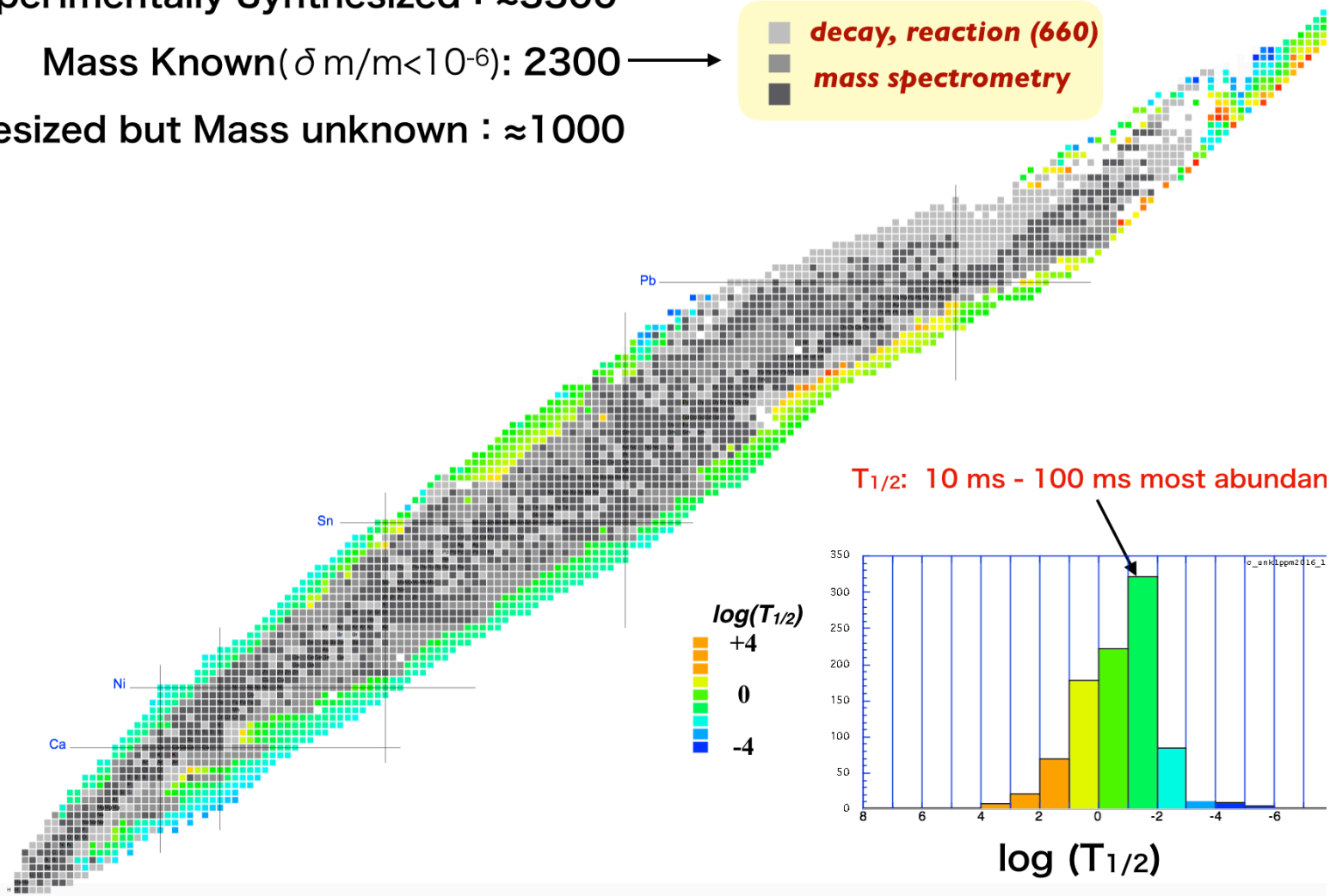
Masses to be measured

note: many known masses were measured indirectly

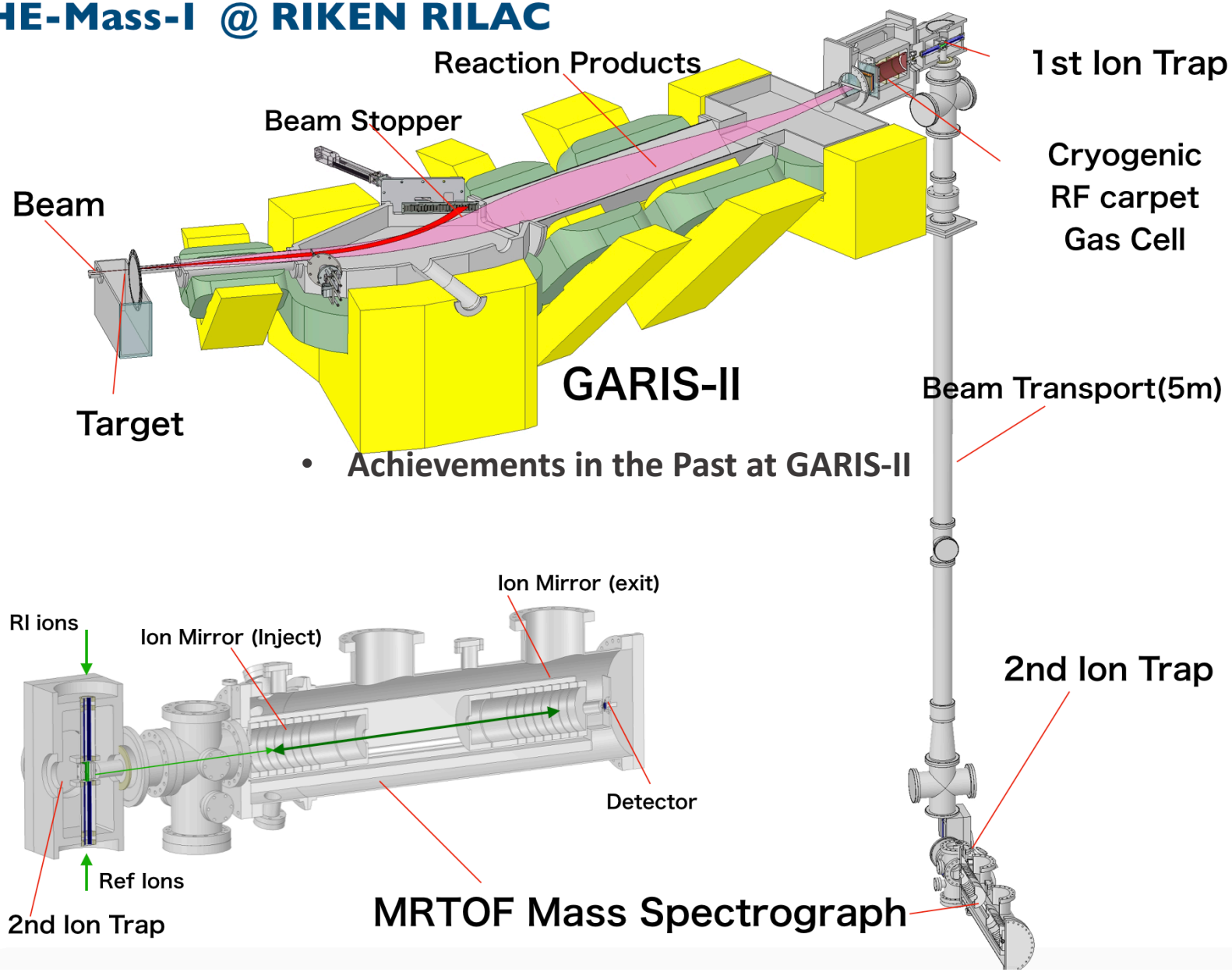
Experimentally Synthesized : ≈3300

Mass Known($\delta m/m<10^{-6}$): 2300 →

Synthesized but Mass unknown : ≈1000



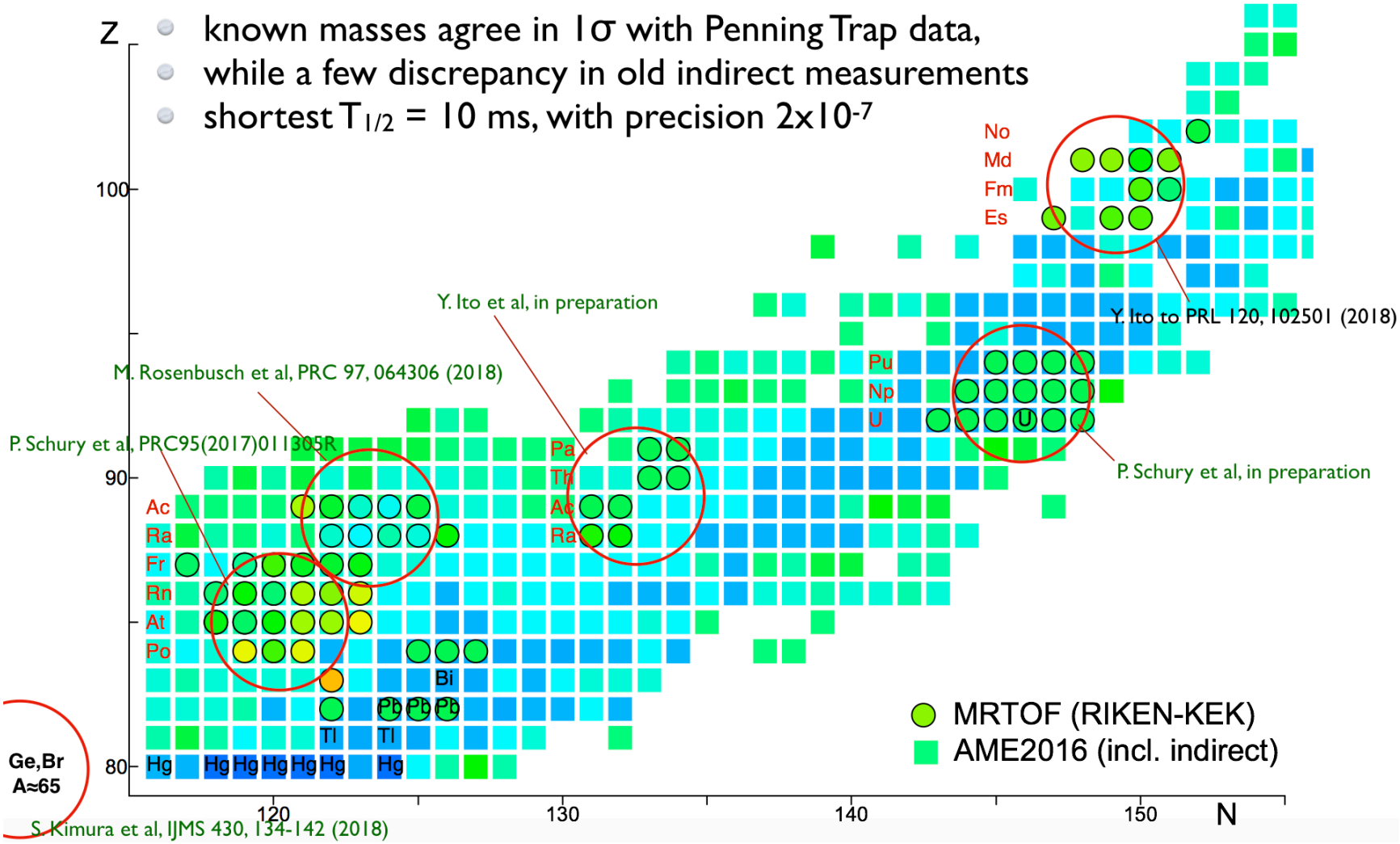
SHE-Mass-I @ RIKEN RILAC



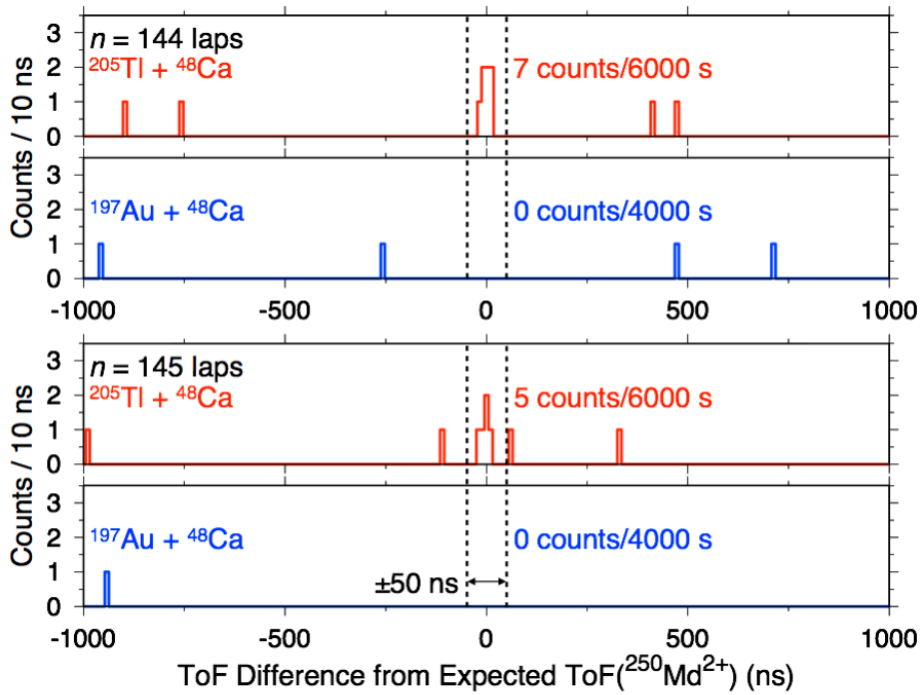
- Achievements in the Past at GARIS-II

Masses Measured in 2016 summer - 2017 spring

- > 80 masses were measured in total 4 weeks beam time
- 6 first masses in trans-uranium elements (Es, Md isotopes)
- > 30 first direct mass measurements
- known masses agree in 1σ with Penning Trap data,
- while a few discrepancy in old indirect measurements
- shortest $T_{1/2}$ = 10 ms, with precision 2×10^{-7}



$^{250}Md^{++}$ Time of Flight Spectra



≈ 1 event /1000 s

Mass determined with $\delta m/m = 6\times10^{-7}$

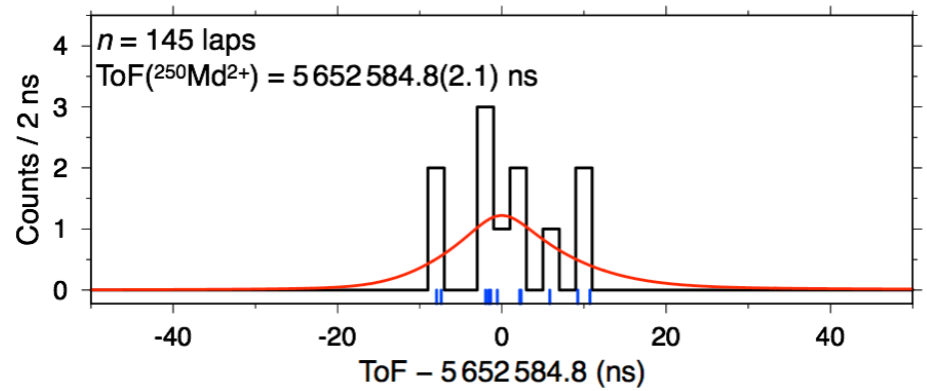


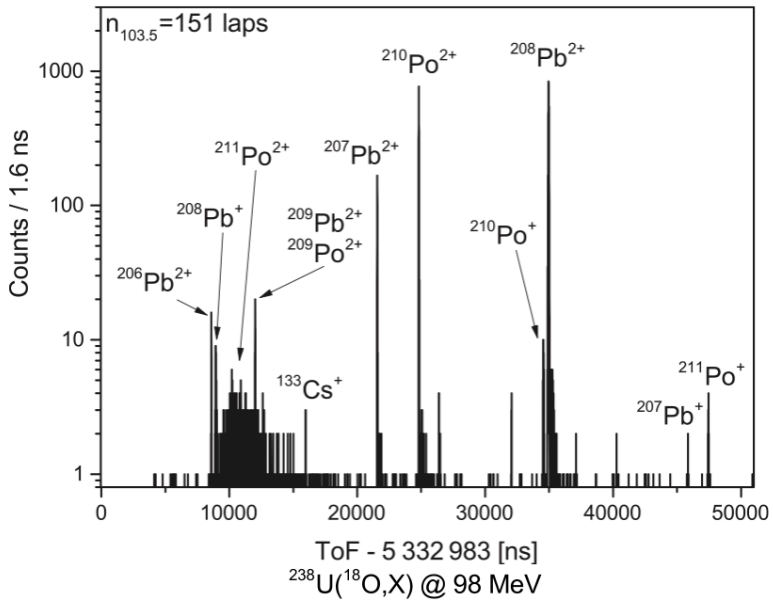
TABLE I. Measured isotopes, reactions, reaction energies at target center i
squared time-of-flight ratio to reference ion of $^{133}Cs^{+}$ (ρ^2), mass excess (M
work. Mass excesses from the atomic mass evaluation 2016 (AME16) [27]

See poster of Y. Ito

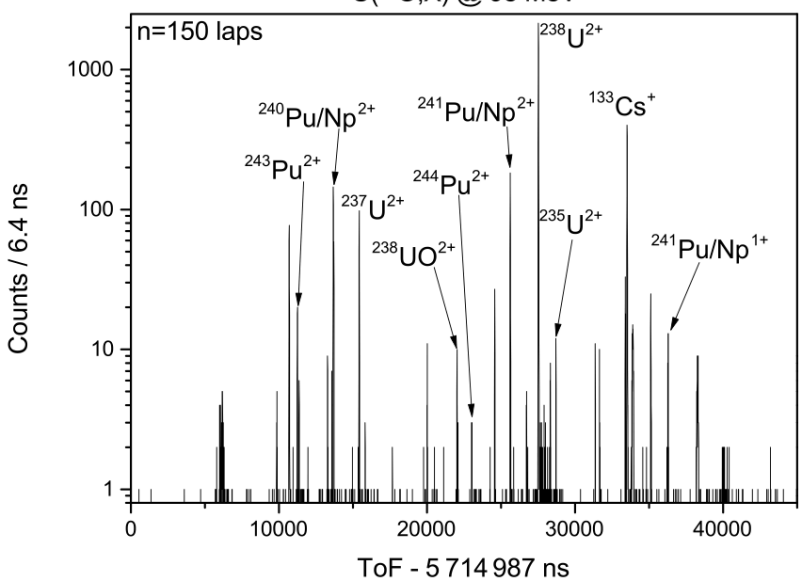
Isotope	Reaction	E_{lab} (MeV)	E_{recoil} (MeV)	σ_{ER} (nb)	ρ^2	ME_{MRTOF} (keV/c^2)	ME_{AME16} (keV/c^2)	Δm (keV/c^2)	N_{ion} (counts)
^{246}Es	^{232}Th(^{19}F, 5n)	99.6, 103	7.5, 7.8	~800 [26]	0.92574351(44)	67812(109)(32)	67900$^{\#}$(224$^{\#}$)	-88(109)(32)	33
^{251}Fm	^{238}U(^{18}O, 5n)	93.9	6.9	4000 [28]	0.94458700(14)	75996(34)(25)	75954(15)	42(34)(25)	397
^{249}Md	^{203}Tl(^{48}Ca, 2n)	215	41.1	~40 [26]	0.93706792(89)	77259(221)(26)	77232$^{\#}$(205$^{\#}$)	27(221)(26)	14
^{250}Md	^{205}Tl(^{48}Ca, 3n)	223	42.3	~200 [26]	0.94083491(56)	78472(138)(25)	78630$^{\#}$(298$^{\#}$)	-158(138)(25)	29
^{251}Md	^{205}Tl(^{48}Ca, 2n)	215	40.8	760 [29]	0.94459923(24)	79025(60)(23)	78967(19)	58(60)(23)	173
^{252}Md	^{238}U(^{19}F, 5n)	98.6	7.3	500 [26]	0.94836715(36)	80467(89)(22)	80511$^{\#}$(130$^{\#}$)	-44(89)(22)	63
^{254g}No	^{208}Pb(^{48}Ca, 2n)	219	41.1	2000 [30]	0.95590832(17)	84675(42)(19)	84723.4(9.3)	-48(42)(19)	398

Y. Ito et al, PRL. 120, 102501 (2018)

Transfer Reaction Products

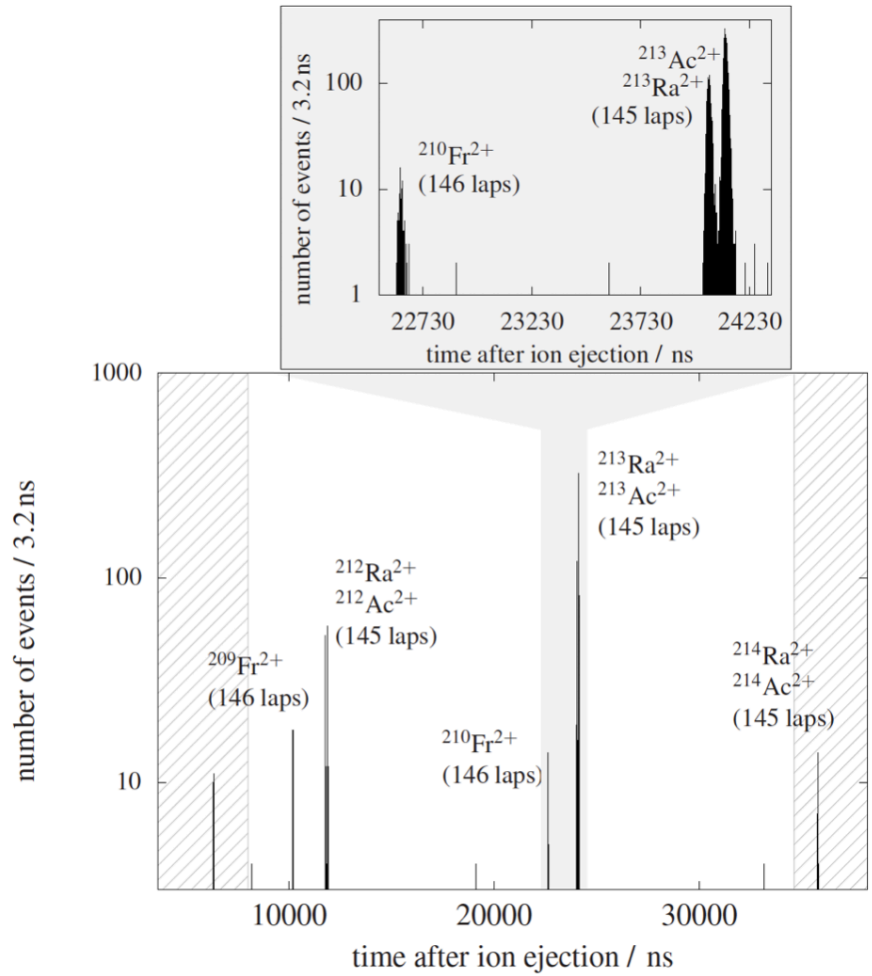


$^{238}U(^{18}O,X)$ @ 98 MeV

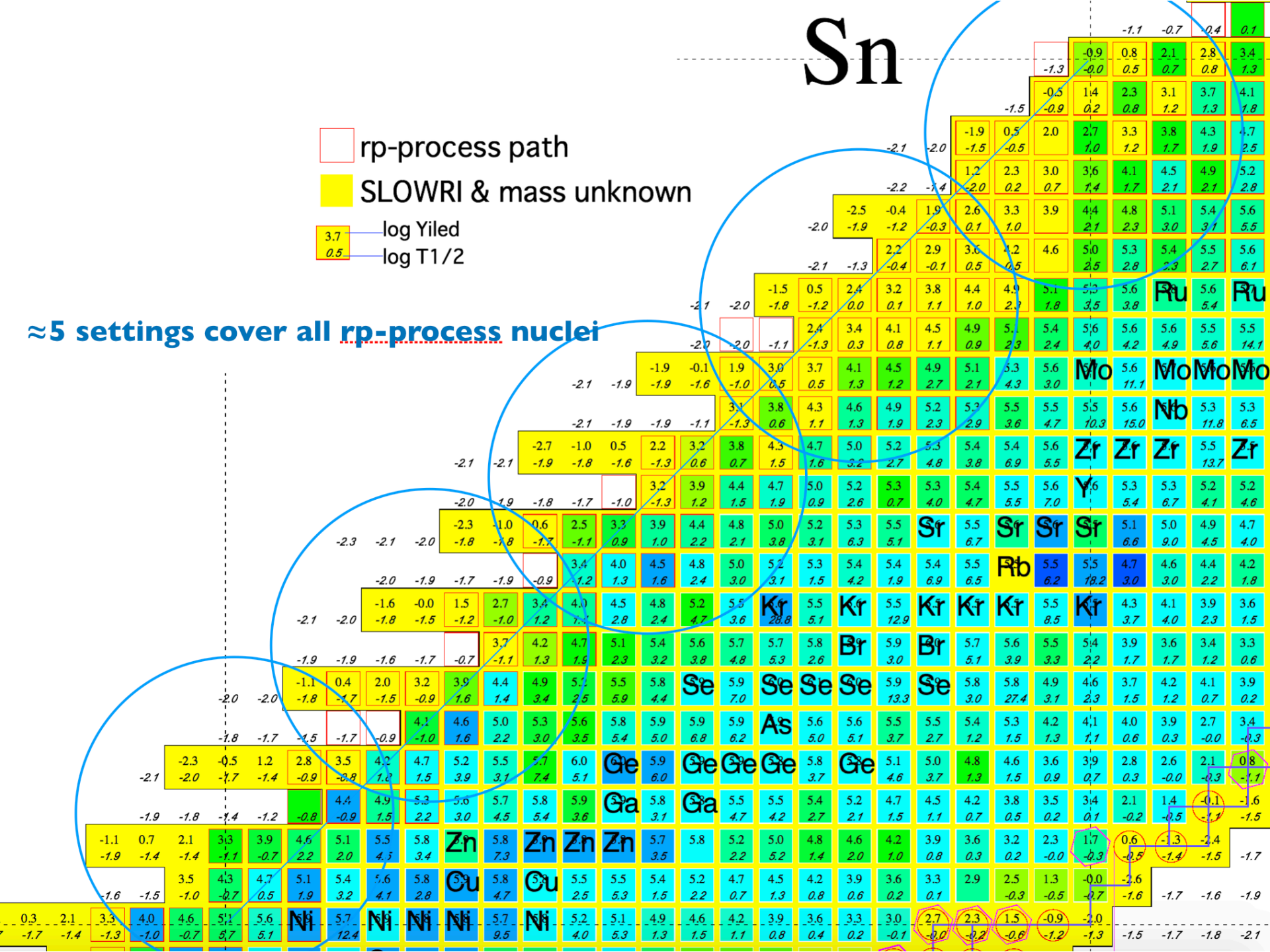


P. Schury et al, to be submitted.

Fusion Evaporation Products

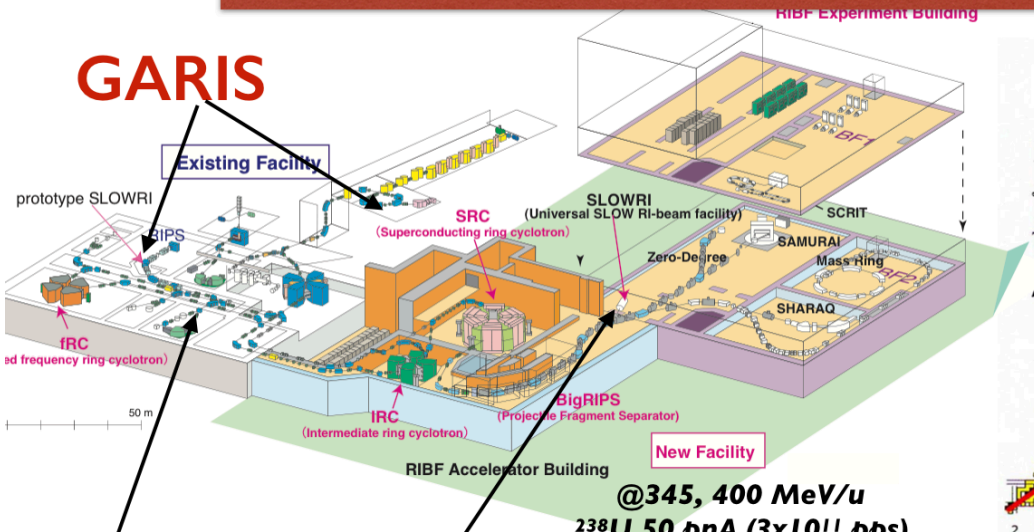


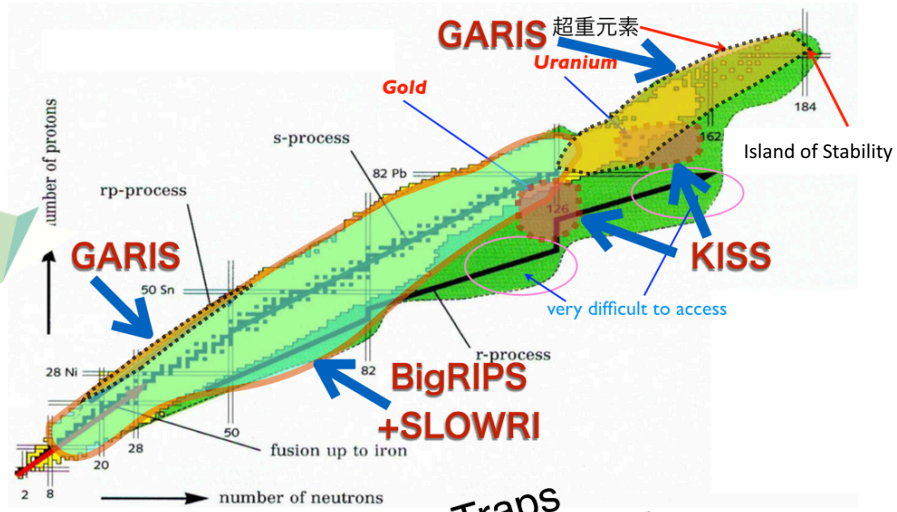
M. Rosenbusch et al, PRC 97, 064306 (2018)



≈5 settings cover all rp-process nuclei

Parallel Measurements @ 3 facilities of RIKEN RIBF

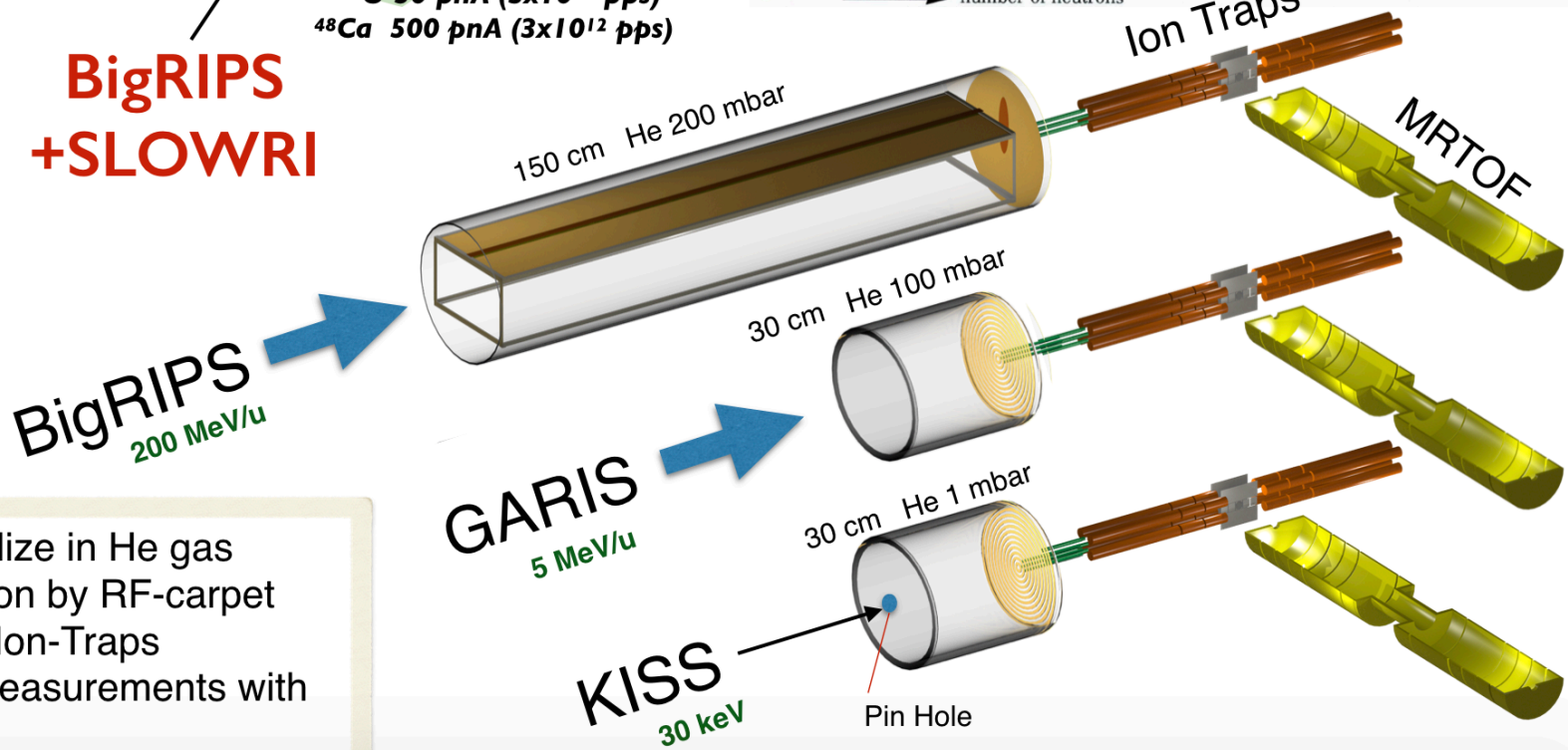




KISS

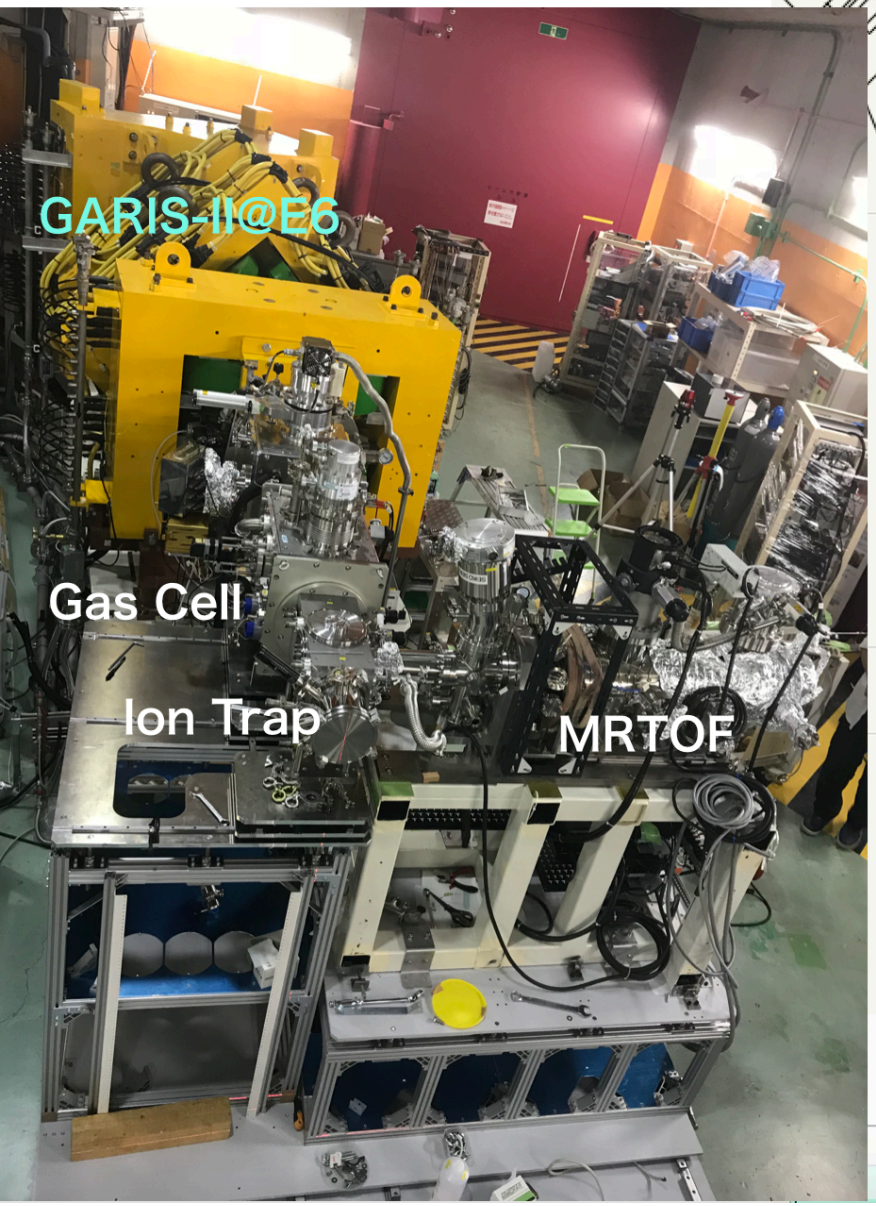
BigRIPS
+SLOWRI

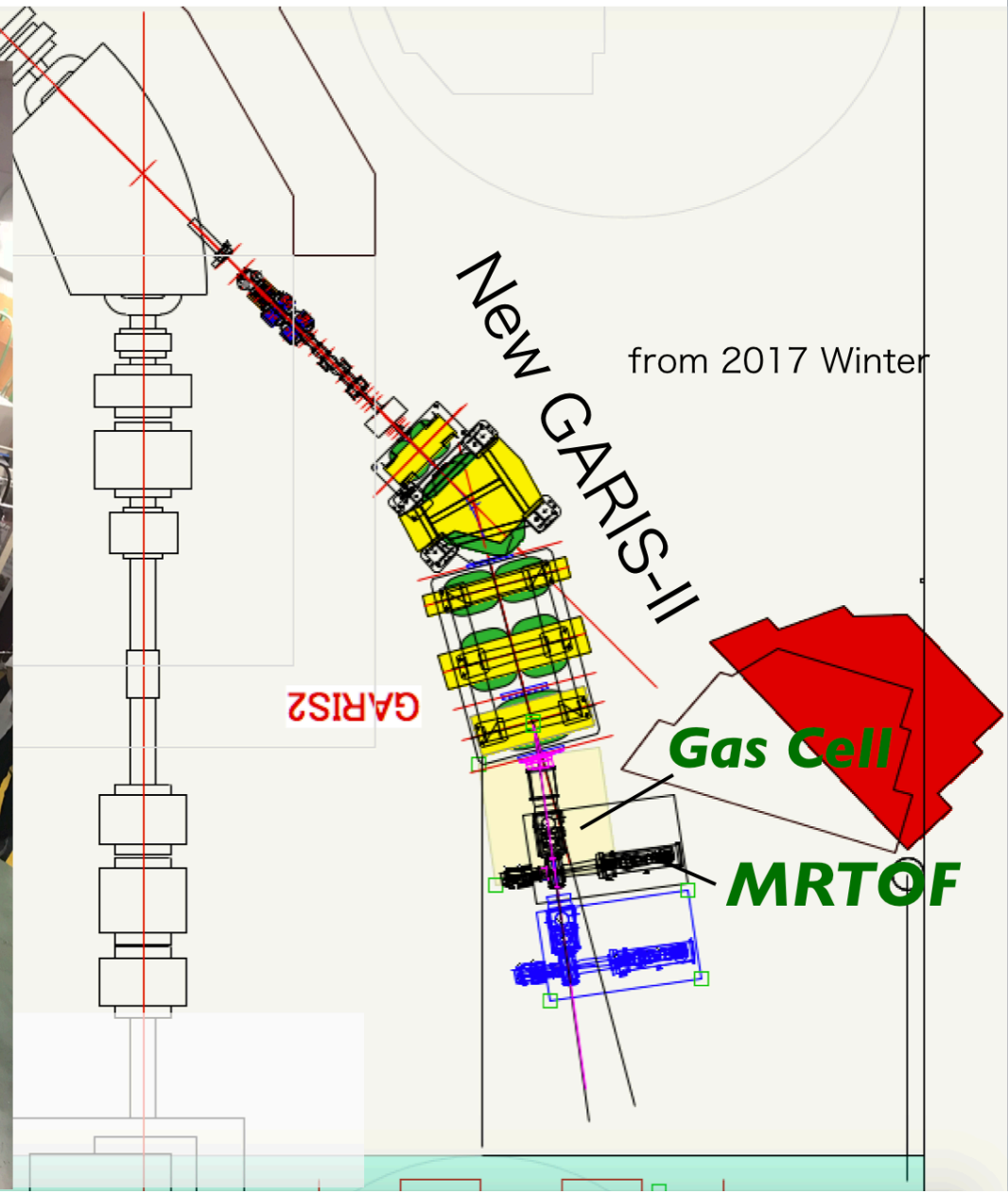
@345, 400 MeV/u
^{238}U 50 pnA (3x10^{11} pps)
^{48}Ca 500 pnA (3x10^{12} pps)



1. Thermalize in He gas
2. Extraction by RF-carpet
3. Trap in Ion-Traps
4. Mass measurements with MRTOF

Setups in Preparation

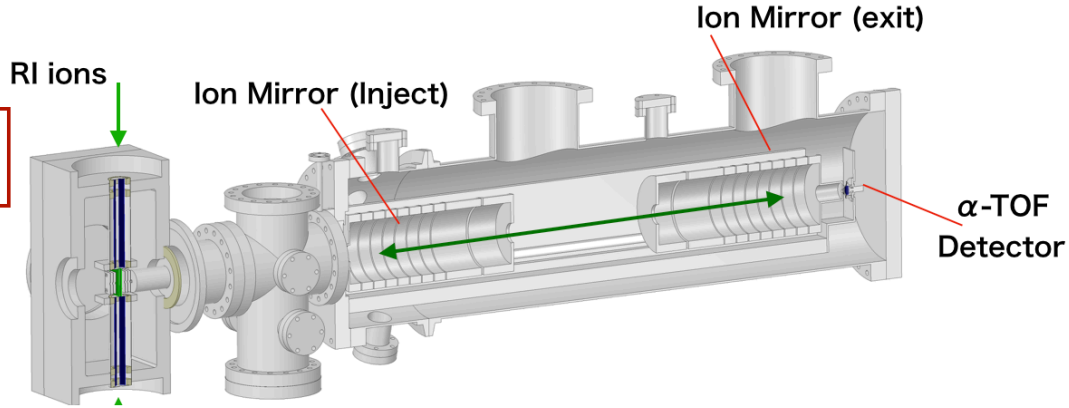


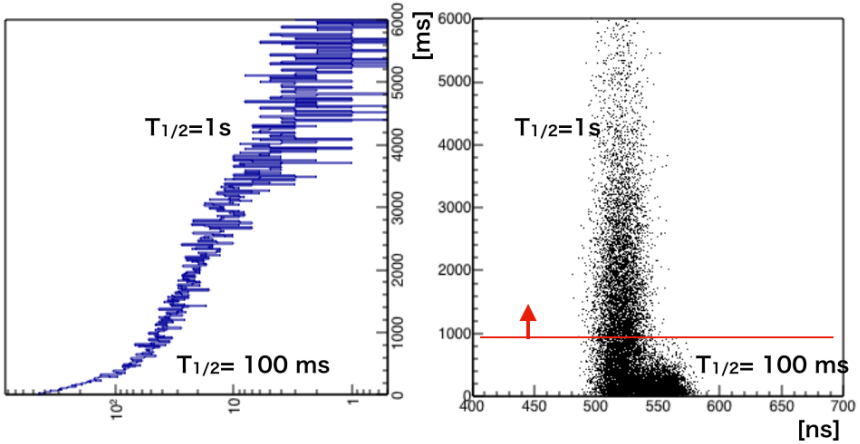


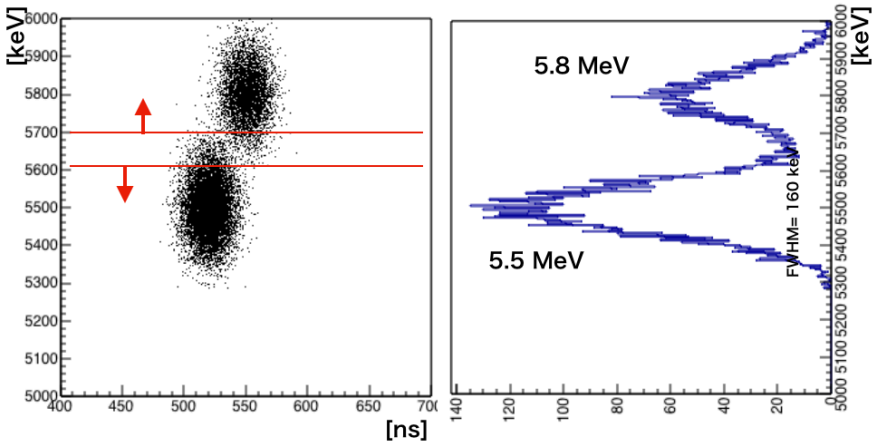
Combination of Decay and Mass

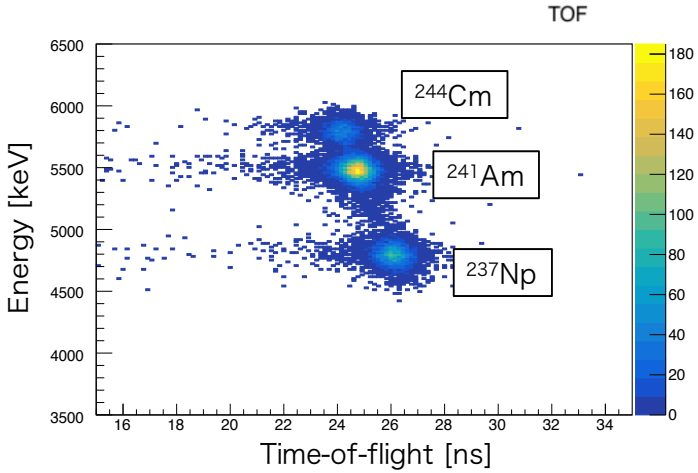
A. Confirm rare TOF events by α-Energy & Decay time

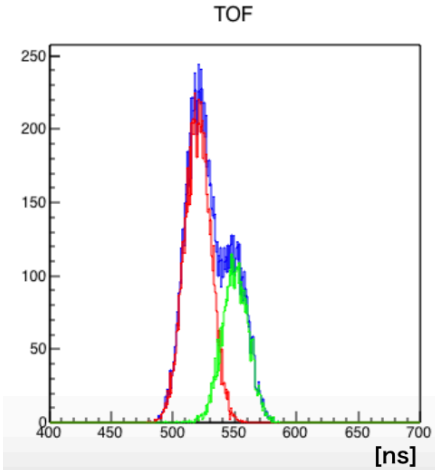
B. Isomer - Ground state identification by α-Energy & Decay time











Energy Gate

KISS (KEK Isotope Separation System)

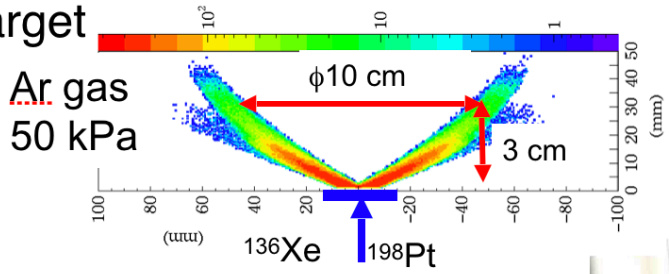
n-rich nuclei via Multi-Nucleon Transfer

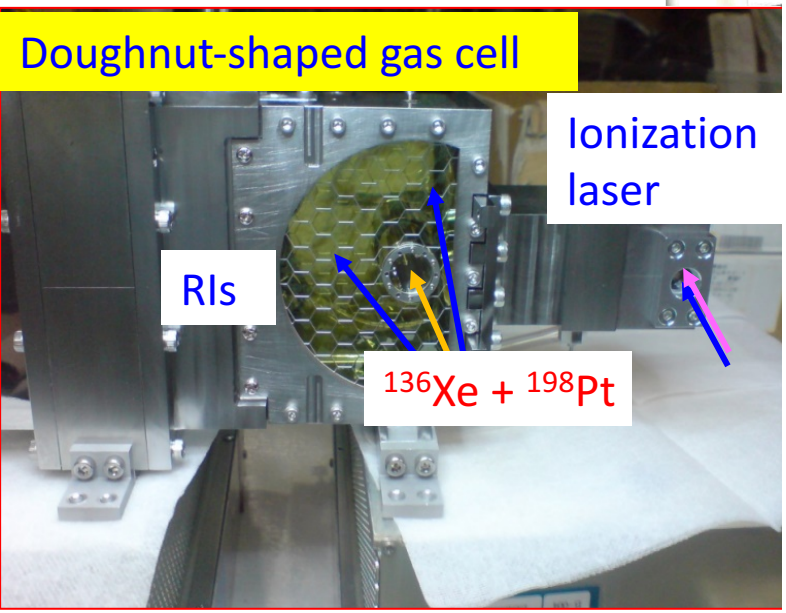
Ar gas cell - Resonant Ionization - Mass Sepa.

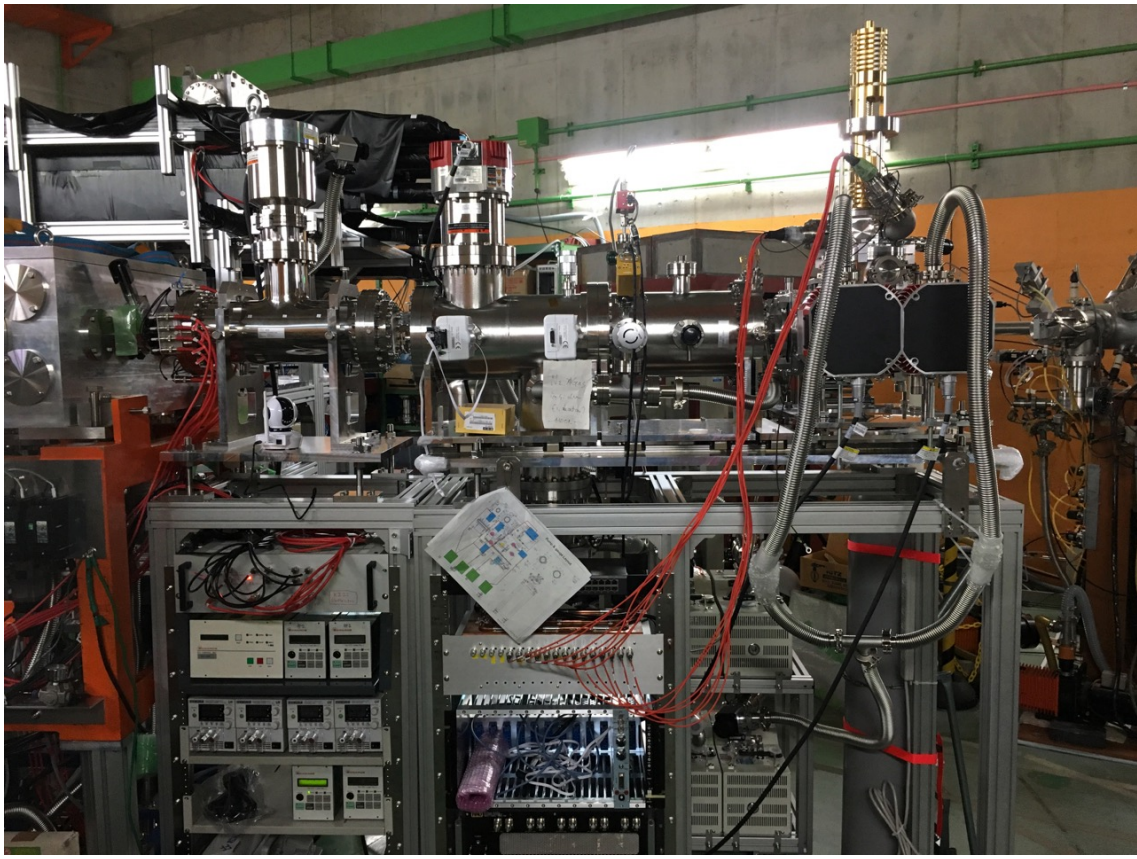
β γ ・HFS ・Mass Spectroscopy

- Deflection of 30kV beam successful
- Ions extracted from low-pressure GC
- ”mini”-MRTOF MS to be tested
- Injection into gas cell to be tested

MNT reaction: ^{136}Xe beam + ^{198}Pt target

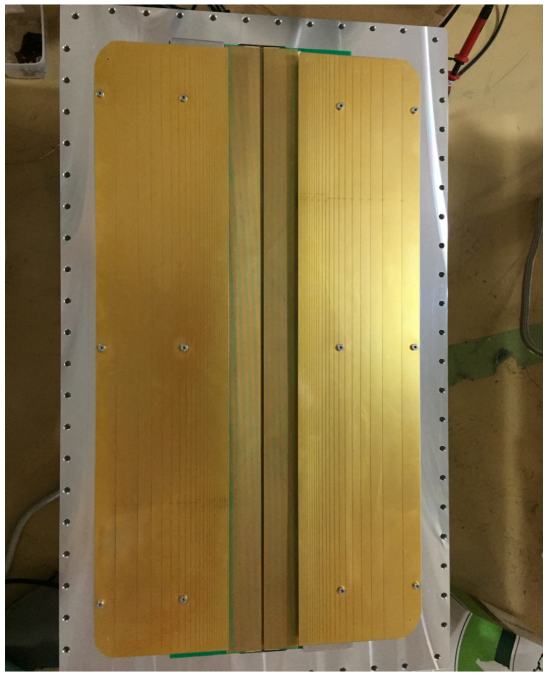


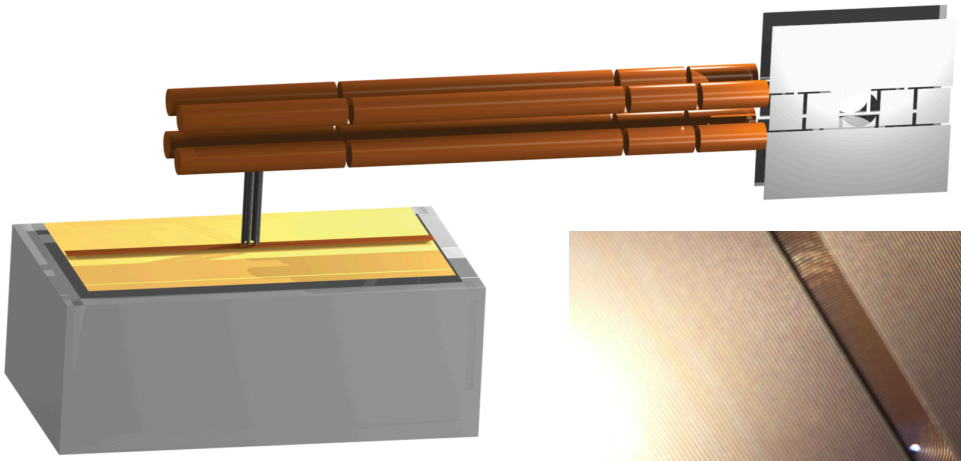


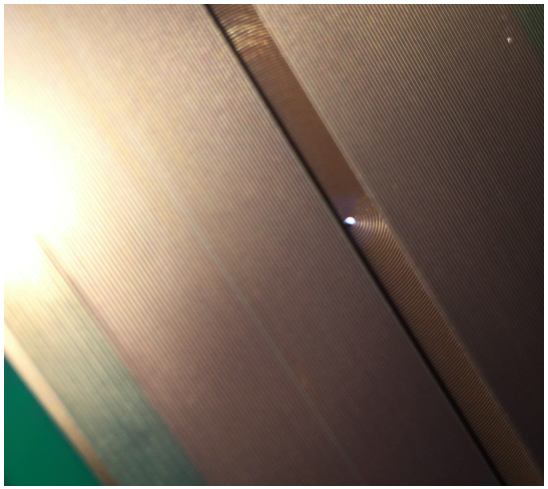


Development of a novel SLOWRI gas-cell

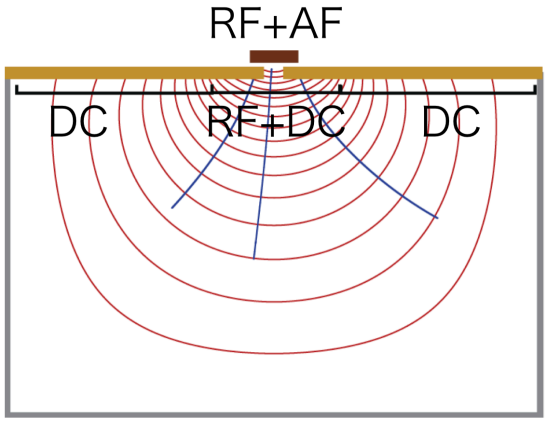
Setups in Preparation

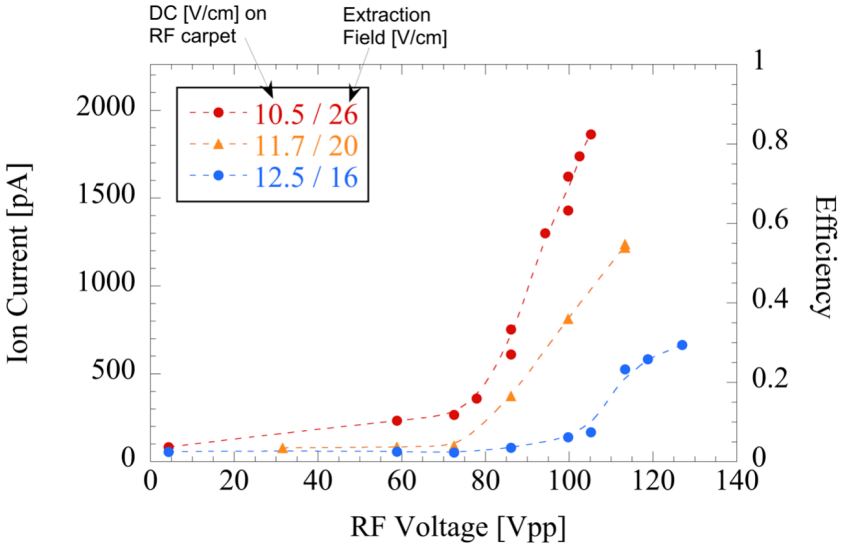


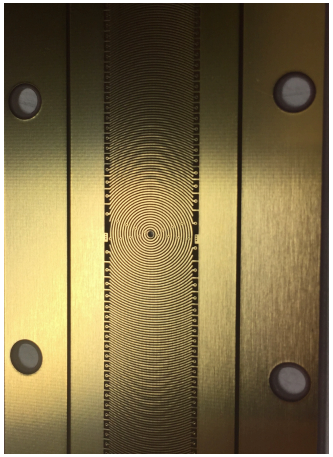




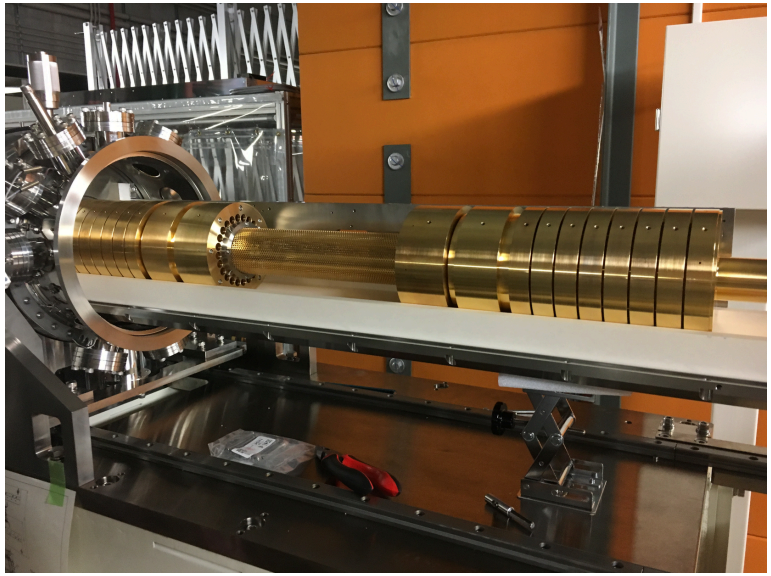
1st RFC test @ 3.7 MHz for ^{133}Cs





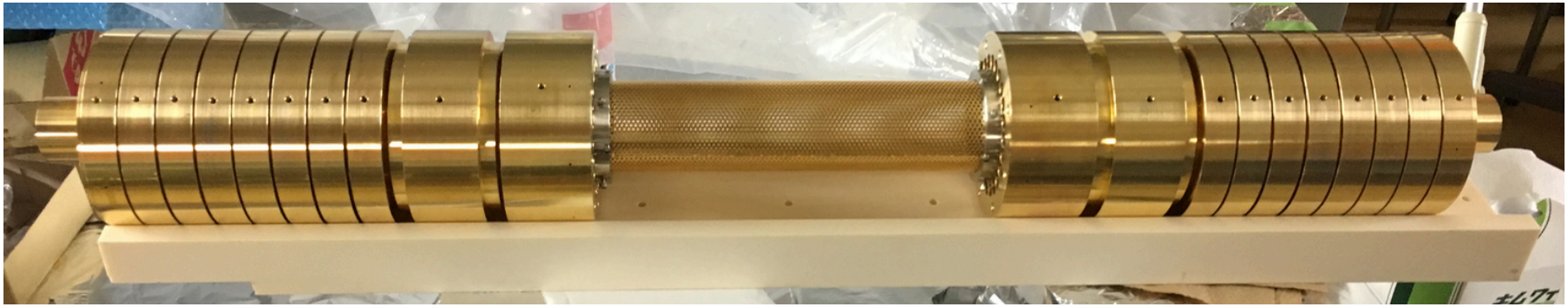


Assembly of a 5 keV MRTOF MS for SLOWRI

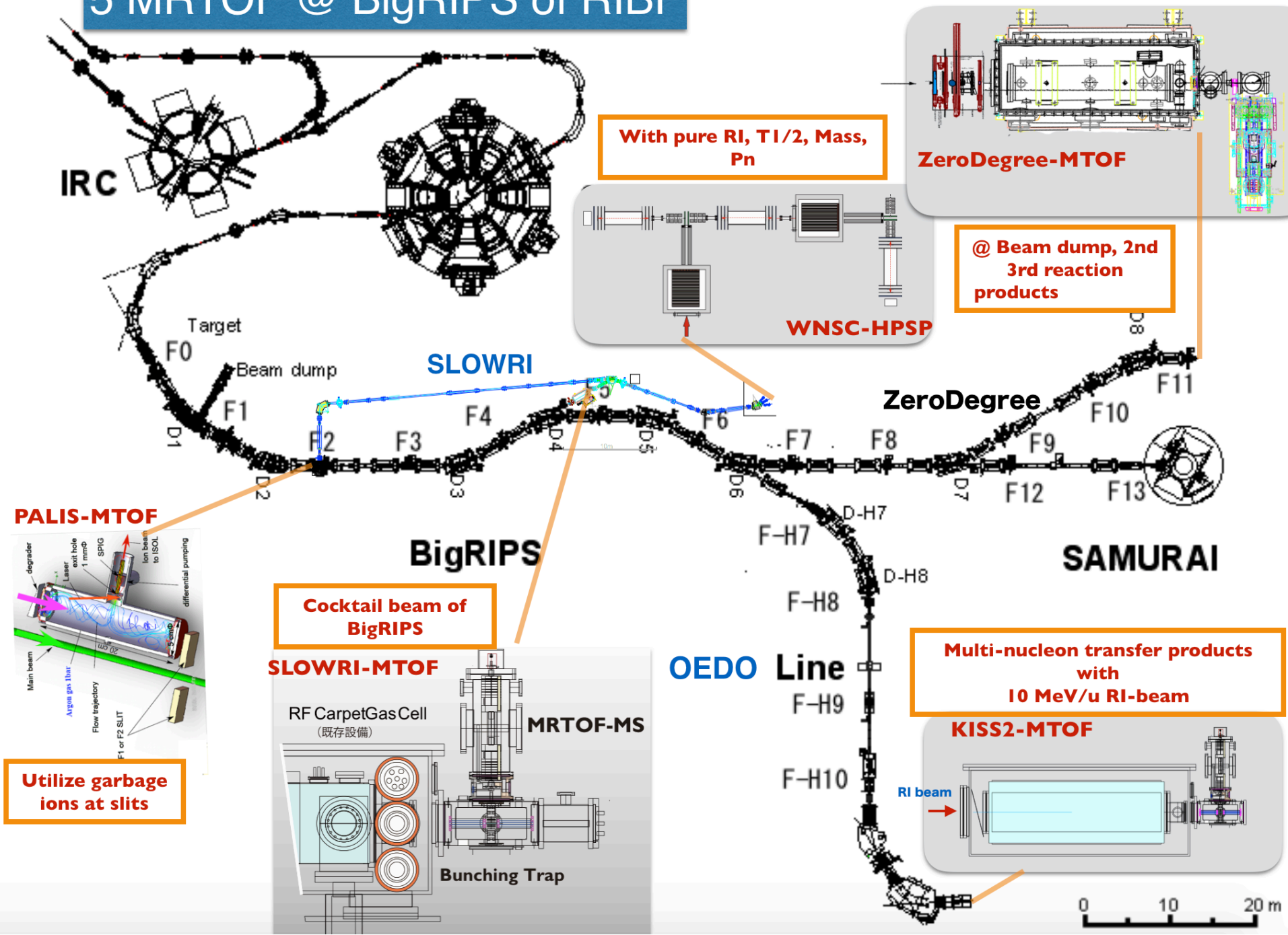


under construction:

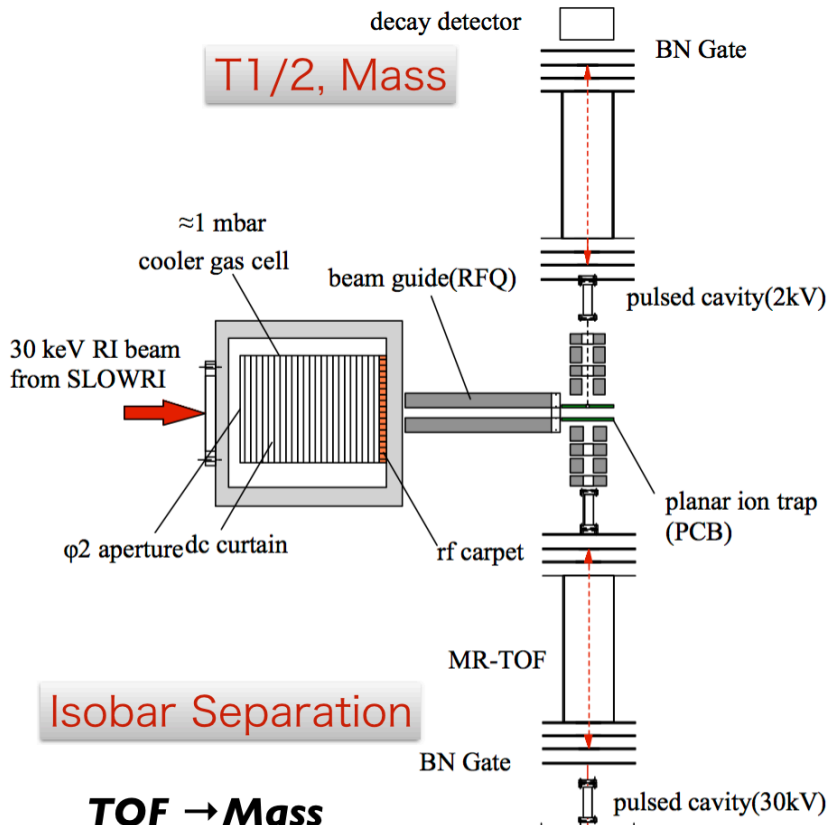
- Installation of electrodes finished
- Now cabling and HV tests (15kV for lens electrodes)
- Soon closing and pumping



5 MRTOF @ BigRIPS of RIBF



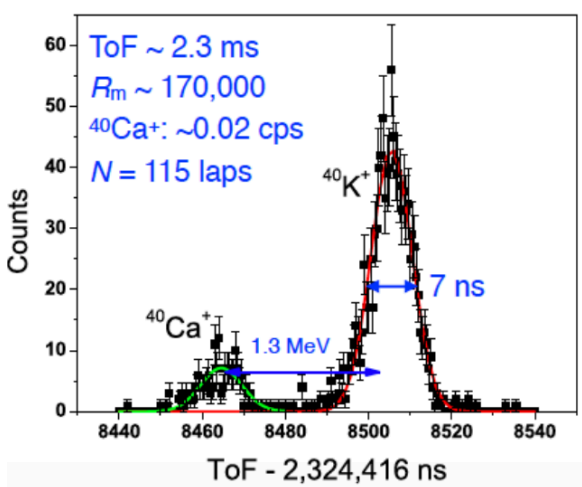
Single & Tandem MRTOF @ SLOWRI

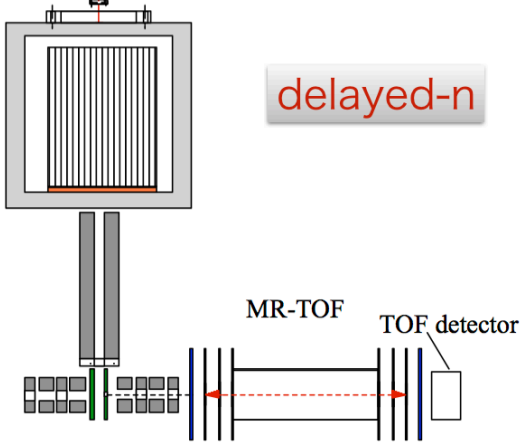


- For neutron rich nuclei and neutron deficient nuclei

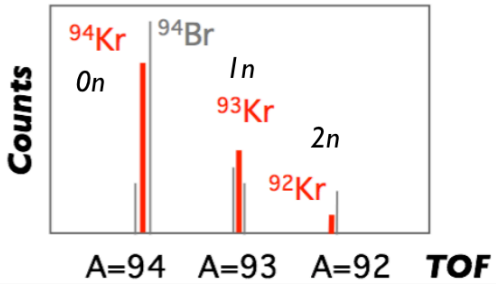
-> impact for nucleosynthesis by measurement of neutron-emission branches

TOF → Mass



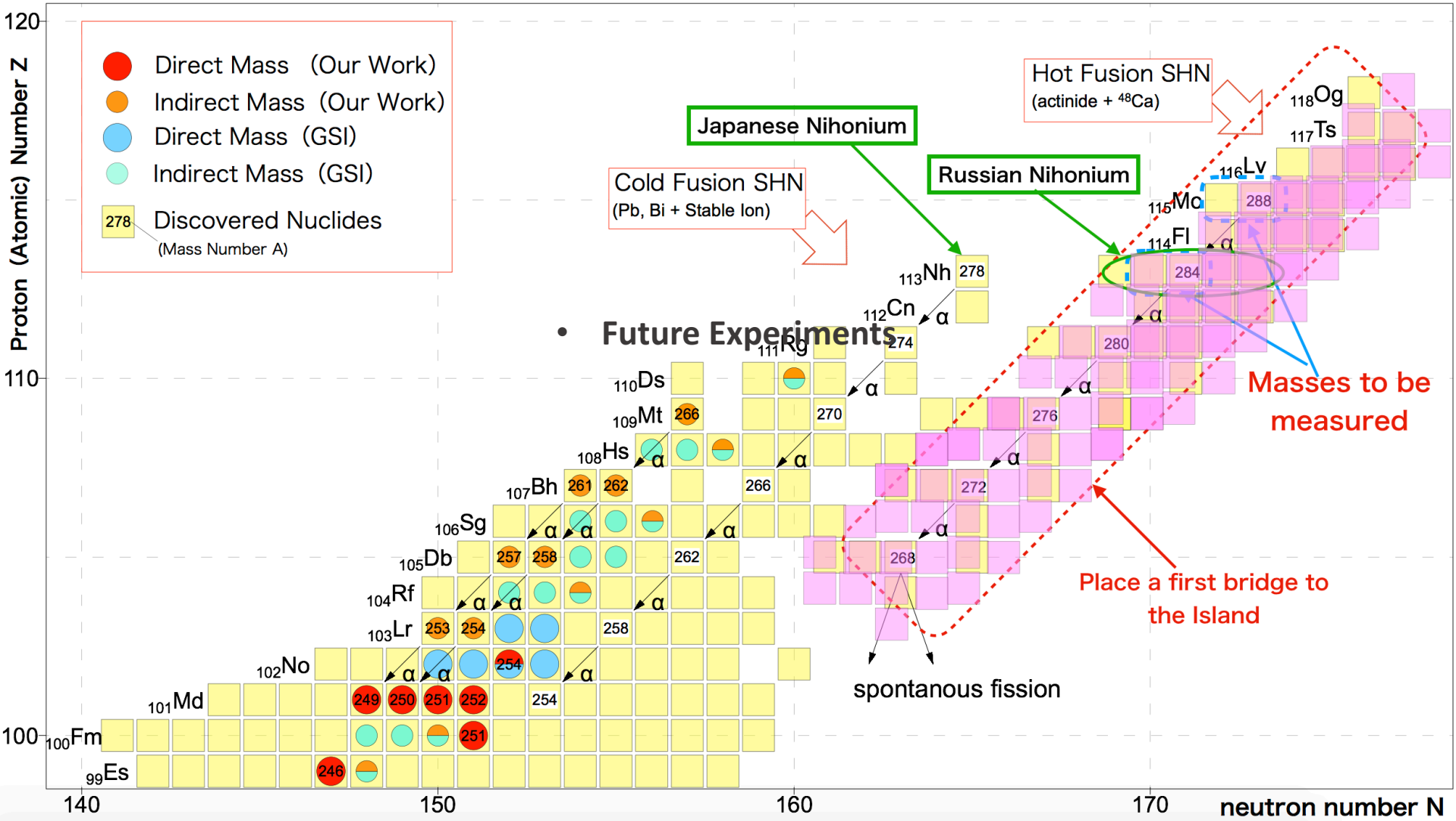


Isotope ratio → Pn



Masses of Super Heavy Nuclides

1. *pin down masses of hot-fusion "island"*
2. *confirm A and Z of hot-fusion SHE*

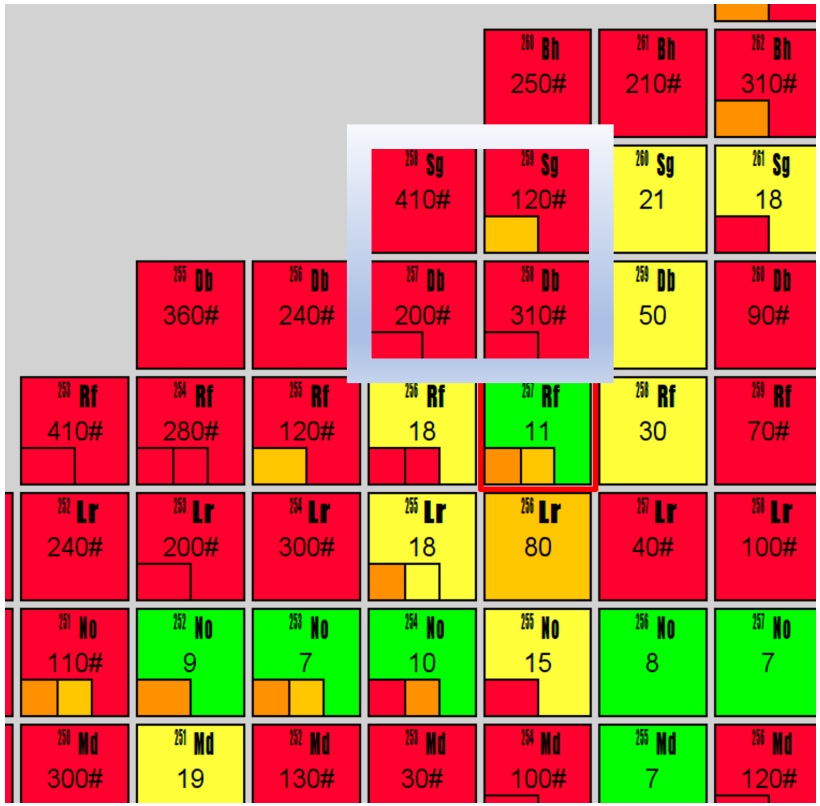


Approved experiments for usage of a vanadium beam:

2puA of ^{51}V available behind the RRC (RIKEN Ring Cyclotron)

Expected:

- 100 cpd for Db
- 10 cpd Sb
- other isotopes of SHE expected

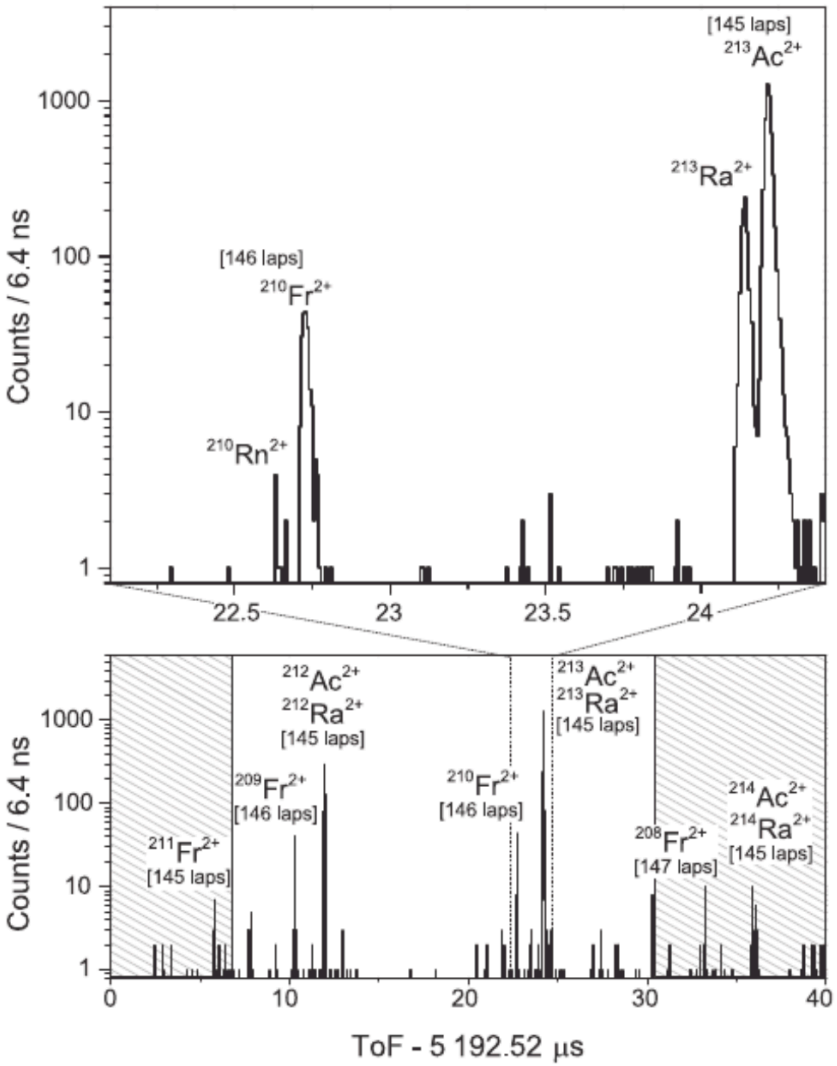


^{208}Pb(^{51}V,1n)^{258}Db	234	2.1	[2]	300	36
^{208}Pb(^{51}V,2n)^{257}Db	239	1.6	[2]	225	36
^{209}Bi(^{51}V,1n)^{259}Sg	234	0.6	[3]	80	48
^{209}Bi(^{51}V,2n)^{258}Sg	239	0.4	[3]	50	48

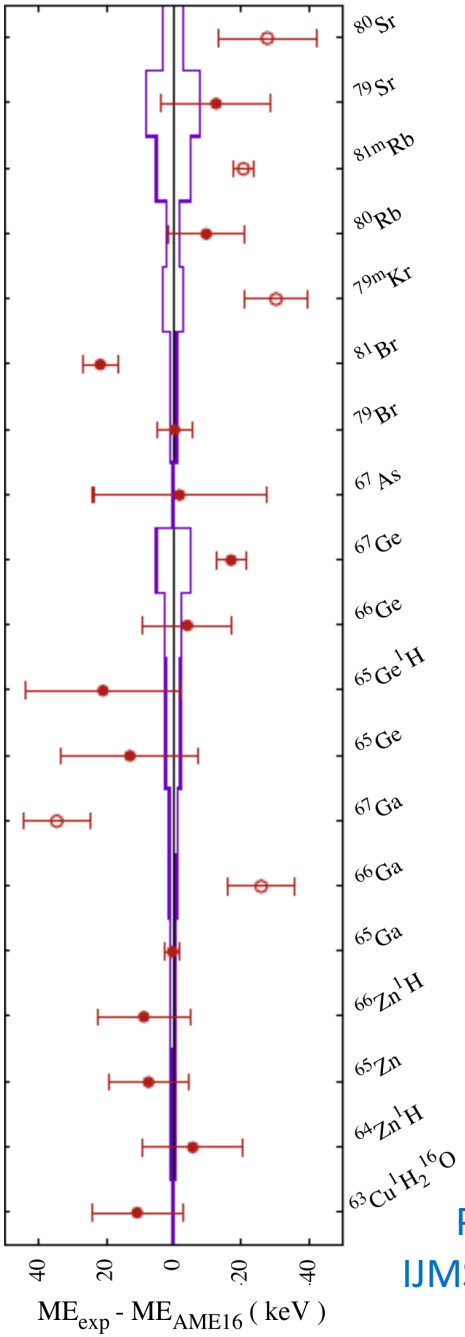
Acknowledgements

Thank you very much,
and many thanks to the RIKEN- and KEK-MRTOF collaboration!

Technical studies: doubly-charged ions



P. Schury et al. NIM B 407, 160 (2017)



Proton-rich isotopes at GARIS II

P. Kimura et al. IJMS 430, 134 (2018)

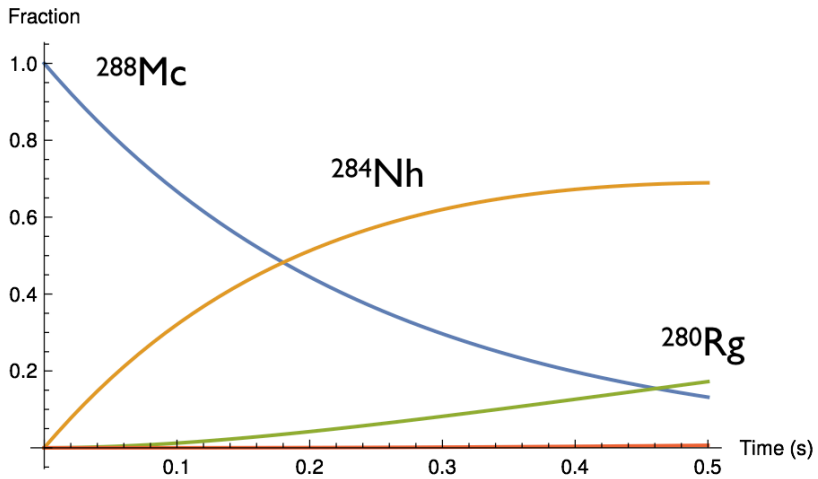
Candidates in first Hot Fusion SHE Mass Measurement

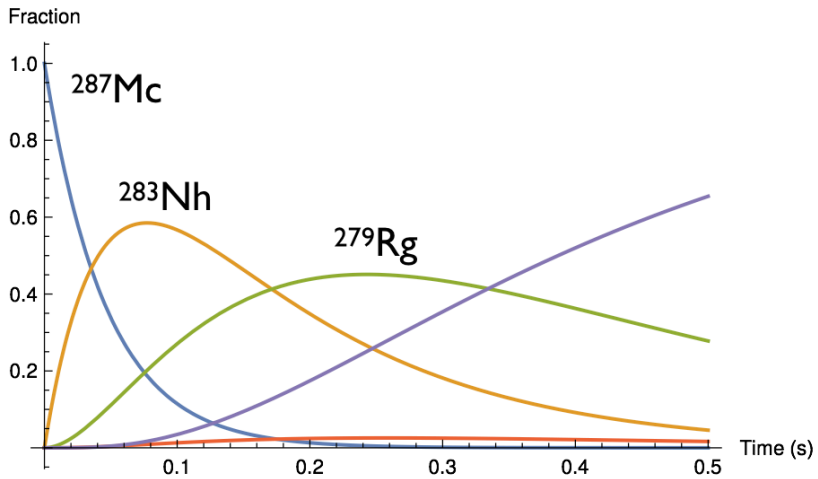
$^{243}Am(^{48}Ca, 3n)^{288}Mc \rightarrow ^{284}Nh \rightarrow ^{280}Rg$

0.5 mg/cm^2 2 pμA 8.5 pb 4 /day@GARIS

ε_{total}= 10%
10 events/month !

$^{243}Am(^{48}Ca, 4n)^{287}Mc \rightarrow ^{283}Nh \rightarrow ^{279}Rg$





other interesting mass measurements

$^{248}Cm(^{14}N, 4n)^{258}Lr$ ***mass anchor for 278Nh***

$^{244}Pu(^{48}Ca, xn)^{292-x}Fl \rightarrow ^{288-x}Cn$ ***anchor for even hot fusion SHE***

physics cases

Feasibility *Impact*

- **Pin down masses of hot-fusion SHE** ***10 events for 0.4 MeV precision***

$$^{288}\mathrm{Mc} - {}^{284}\mathrm{Nh} \xrightarrow{\alpha} {}^{280}\mathrm{Rg} \xrightarrow{\alpha} {}^{276}\mathrm{Mt} \xrightarrow{\alpha} {}^{272}\mathrm{Bh} \xrightarrow{\alpha} {}^{268}\mathrm{Db} \quad \mathrm{sf}$$

$$^{287}\mathrm{Mc} - {}^{283}\mathrm{Nh} \xrightarrow{\alpha} {}^{279}\mathrm{Rg} \xrightarrow{\alpha} {}^{275}\mathrm{Mt} \xrightarrow{\alpha} {}^{271}\mathrm{Bh} \xrightarrow{\alpha} {}^{267}\mathrm{Db} \quad \mathrm{sf}$$

- **First Masses N>162 deformed shell**

Island of Stability prediction depends strongly on N=162 sub shell (cf. H. Koura)

- **A identification** ***2 events is sufficient***

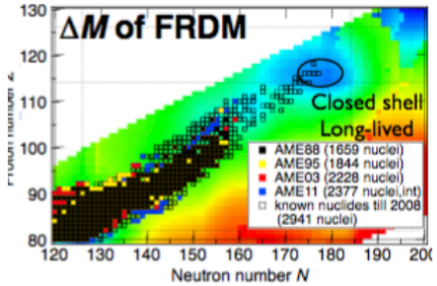
^{243}Am(^{48}Ca, xn)$^{291\text{-}xn}$Mc

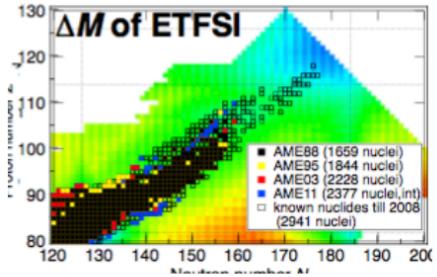
how many n evaporated?

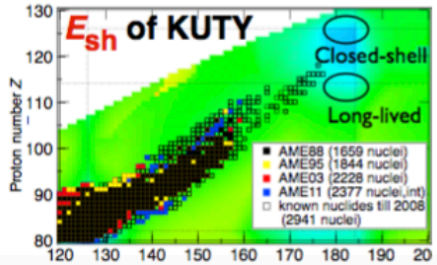
- **Z identification** ***10 events is sufficient if theories are accurate***

^{243}Am(^{48}Ca, 0p0α,xn)$^{291\text{-}xn}$Mc

zero charged particle evaporated?

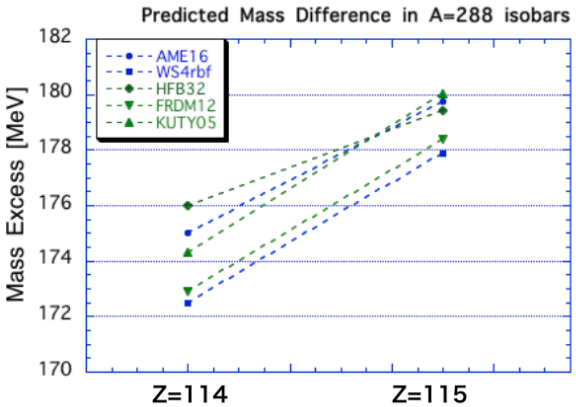






X-ray ?
chemistry ?

not accepted by JWP of IUPAC+IUPAP
but, they ask "Direct Physical Method to identify Z as well as A"



Mass measurement of ^{278}Nh?