

MRTOF development & Status

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comprehensive precision spectroscopy of short-lived nuclides for the origin of elements

KISS: multi-nucleon transfer reactions for n-rich nuclides

@ GARIS: fusion reactions for superheavy elements

BigRIPS-SLOWRI: in-flight fragmentations/fissions

by

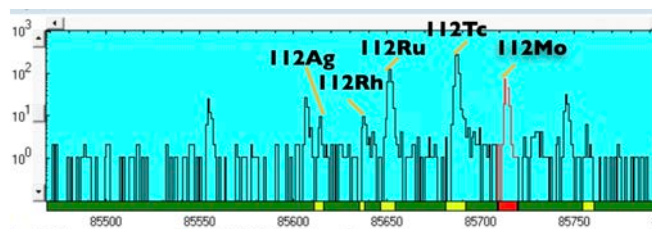
Decay $\beta\gamma$: T1/2, level scheme..

Laser: radii, moments

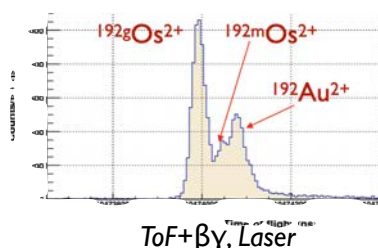
Mass: binding & separation energies

with Gas Catchers (Ar, He) & MRTOF Mass spectrographs

MRTOF spectrum of A=112 isobar



MRTOF spectrum@KISS



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

P. Schury et al, PRC95(2017)011305R **M**

T. Niwase et al, submitting to PRC **M D**

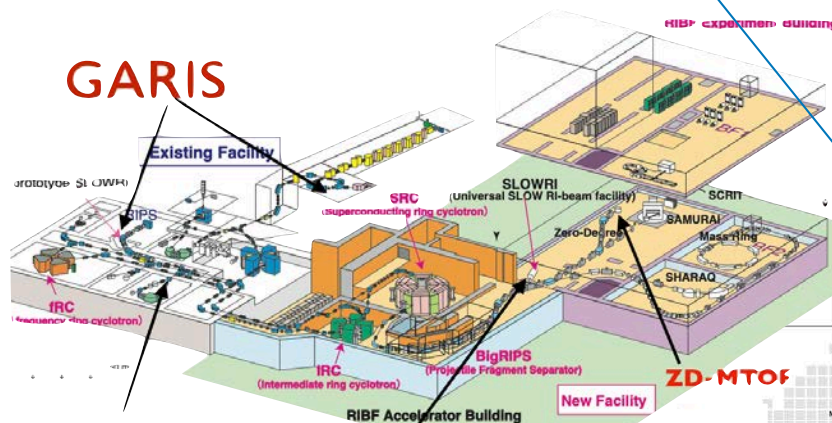
P. Schury et al, submitted to PRL **M**

Y. Ito to PRL 120, 102501 (2018) **M**

P. Schury et al, in preparation **M**

Y. Ito et al, in preparation **M**

GARIS



KISS **BigRIPS+SLOWRI**

(KEK Isotope Separator System)

Facilities in RIKEN RIBF

Ni

Ca

Fe

Si

Al

Mg

Na

Ne

F

GARIS-II

KISS

BigRIPS-SLOWRI

D Decay spectroscopy

L Laser spectroscopy

M Mass spectrometry

A. Takamine et al, in preparation **M**

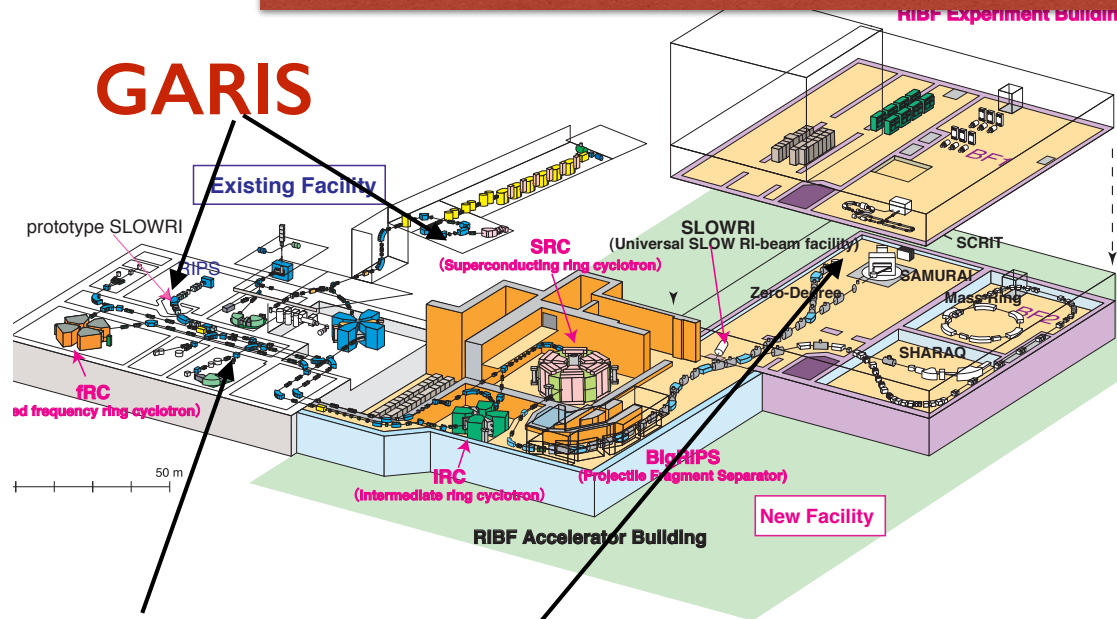
S. Chen et al, in preparation **M**

S. Kimura et al, IJMS 430, 134-142 (2018) **M**

M. Rosenbusch et al, in preparation **M**

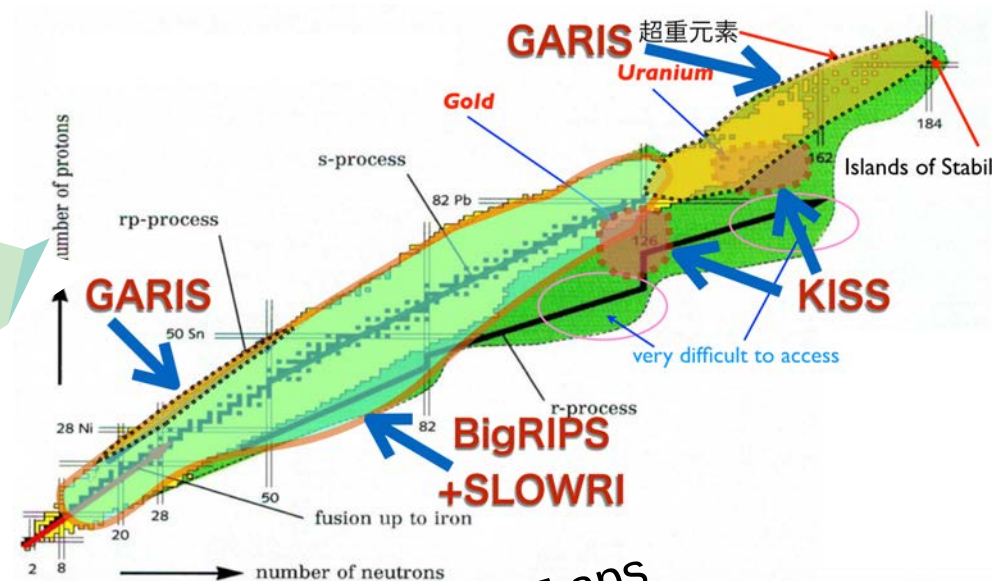
Nuclides studied at WNSC 2017~

Parallel Measurements @ 3 facilities of RIKEN RIBF



KISS

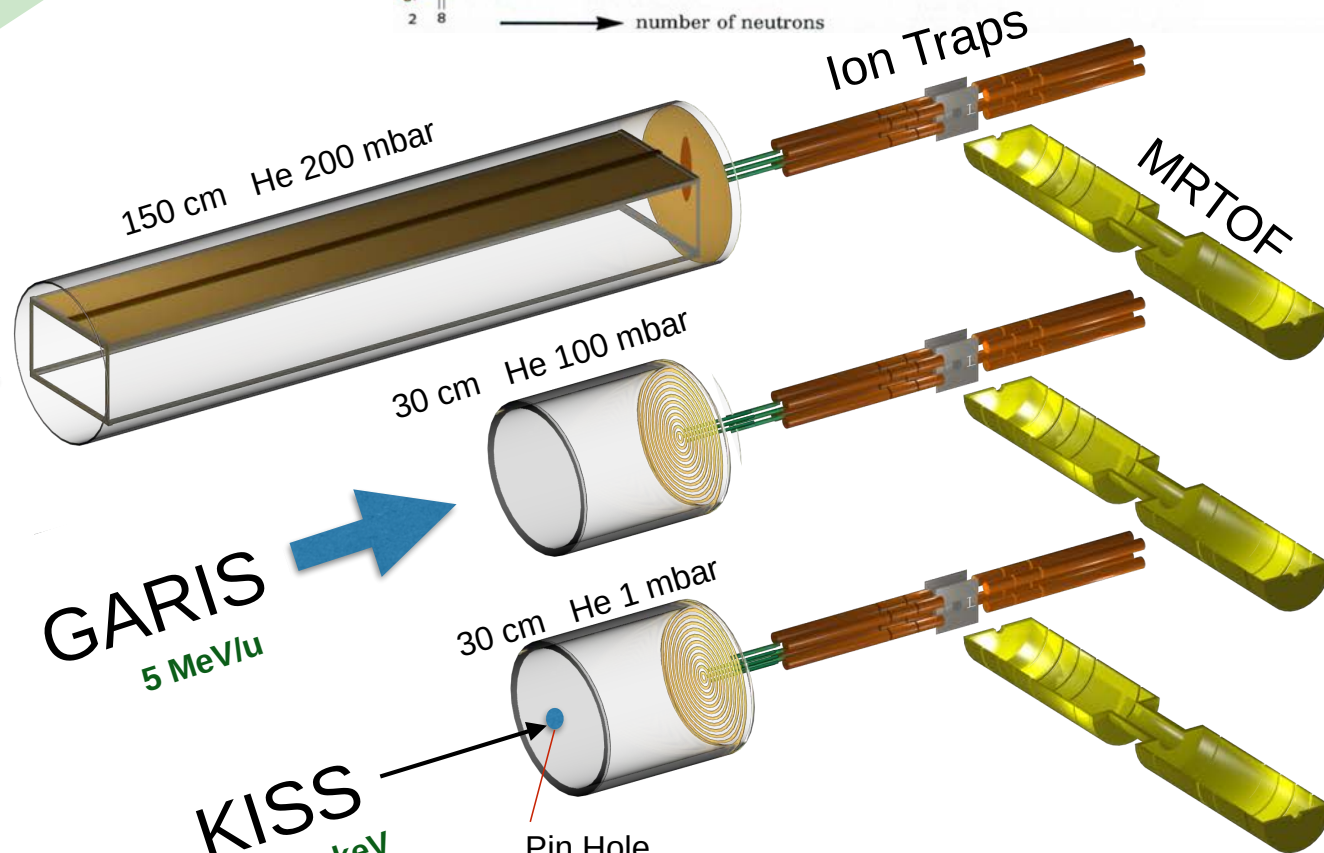
**BigRIPS
+SLOWRI**



BigRIPS
200 MeV/u

GARIS
5 MeV/u

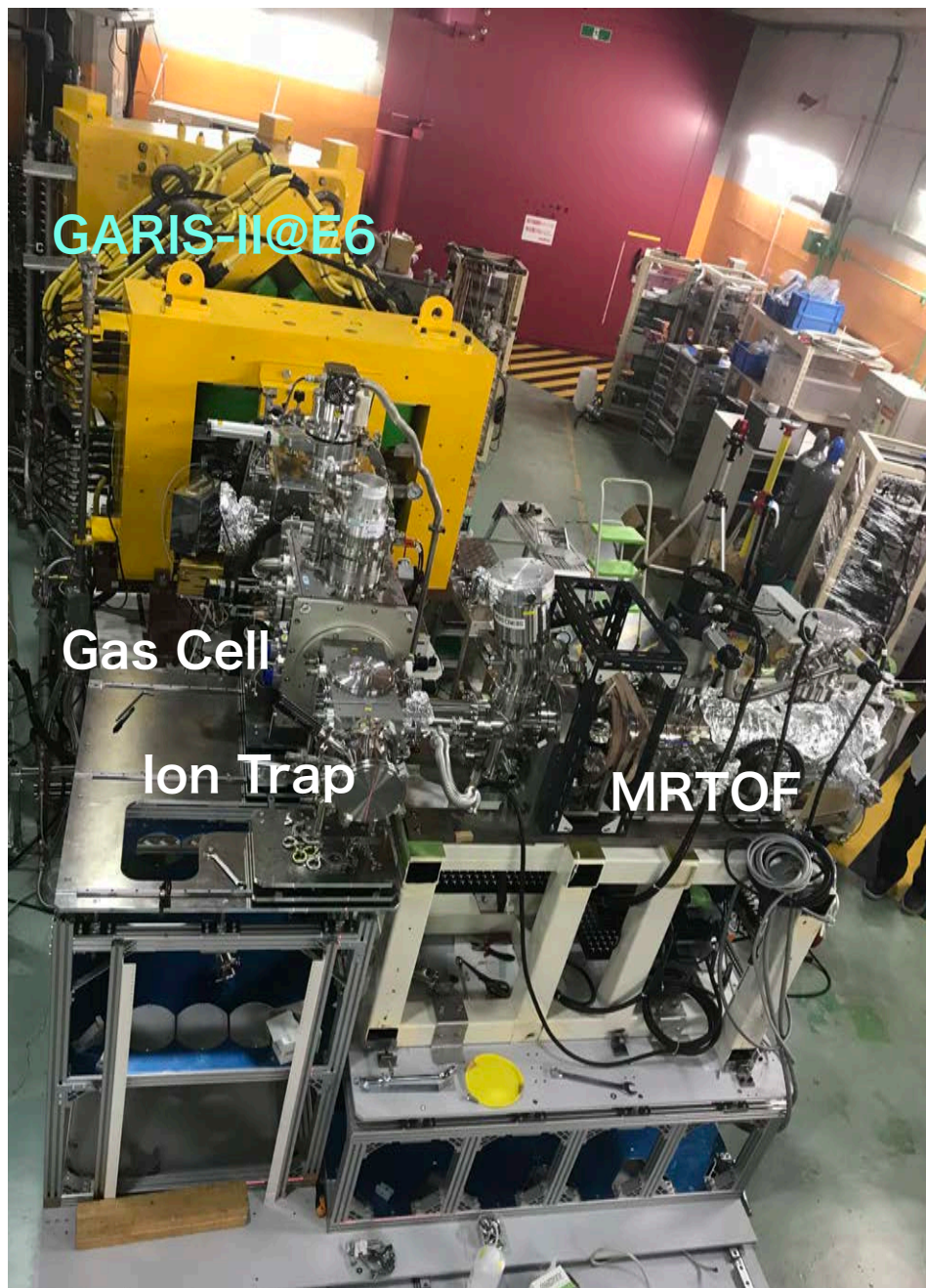
KISS
30 keV



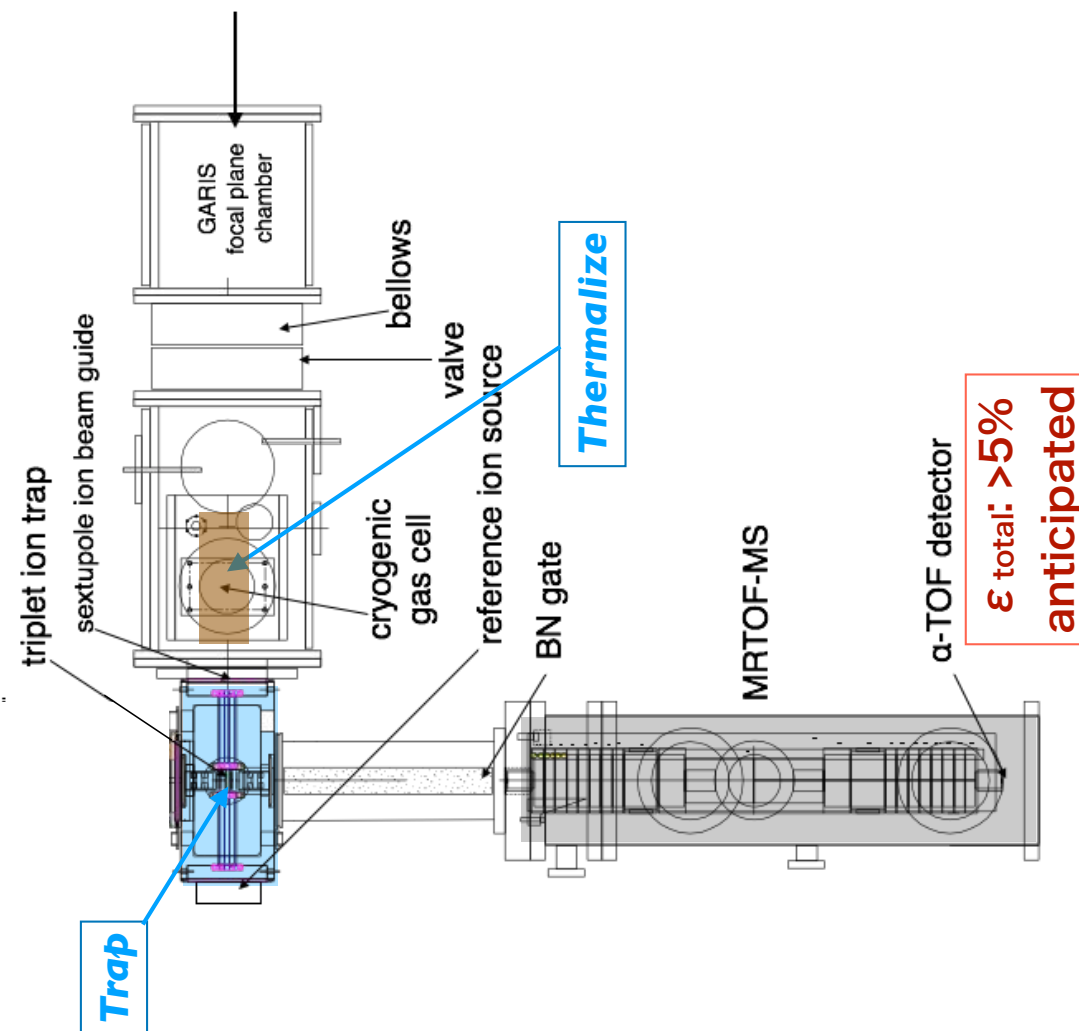
GARIS

GARIS-II'

GasCell+Trap+MRTOF all in one



SHE-Mass-II @E6 RIBF

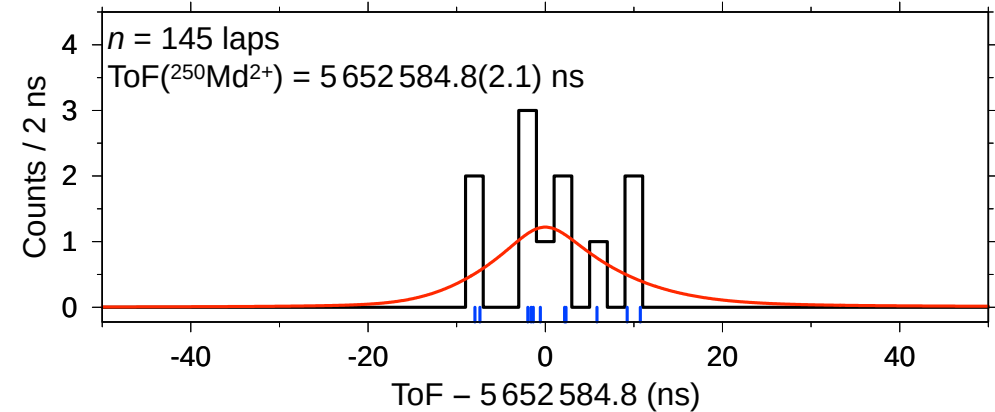
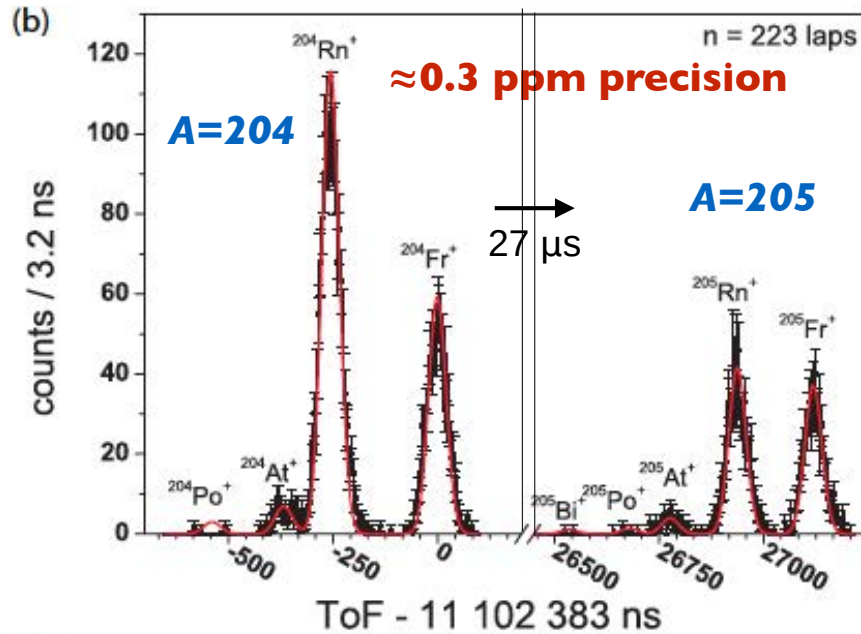


Typical Mass Measurement Results @GARIS-II @RILAC

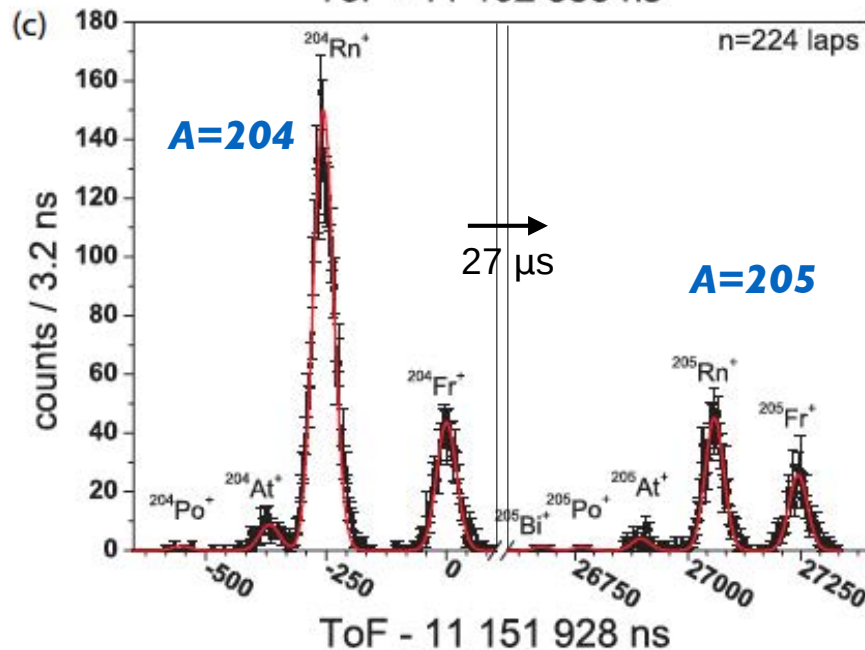
$^{250}\text{Md}^{++}$ measurement

≈ 1 event /1000 s

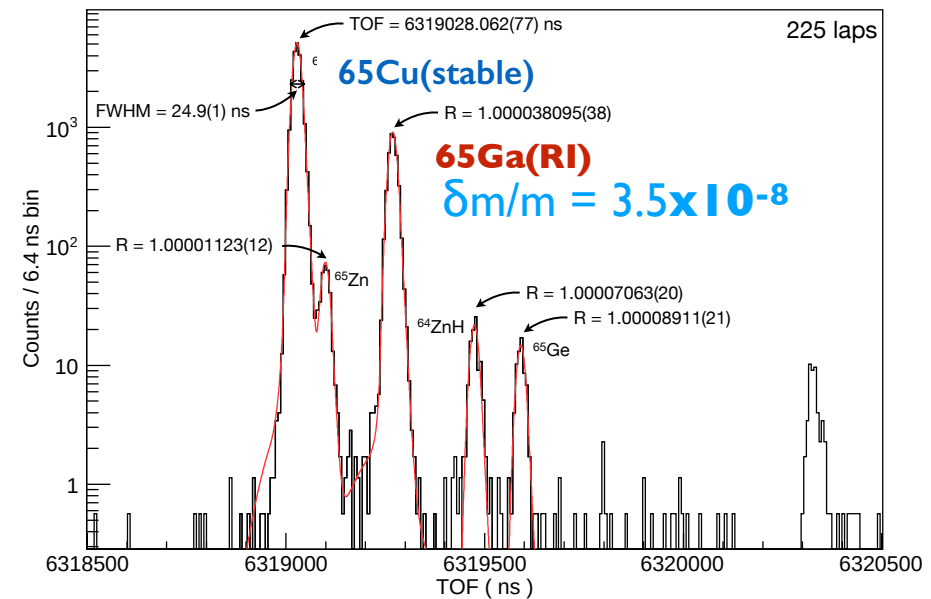
Mass determined with $\delta m/m = 6 \times 10^{-7}$



Y. Ito et al, PRL 120 (2018)0102501

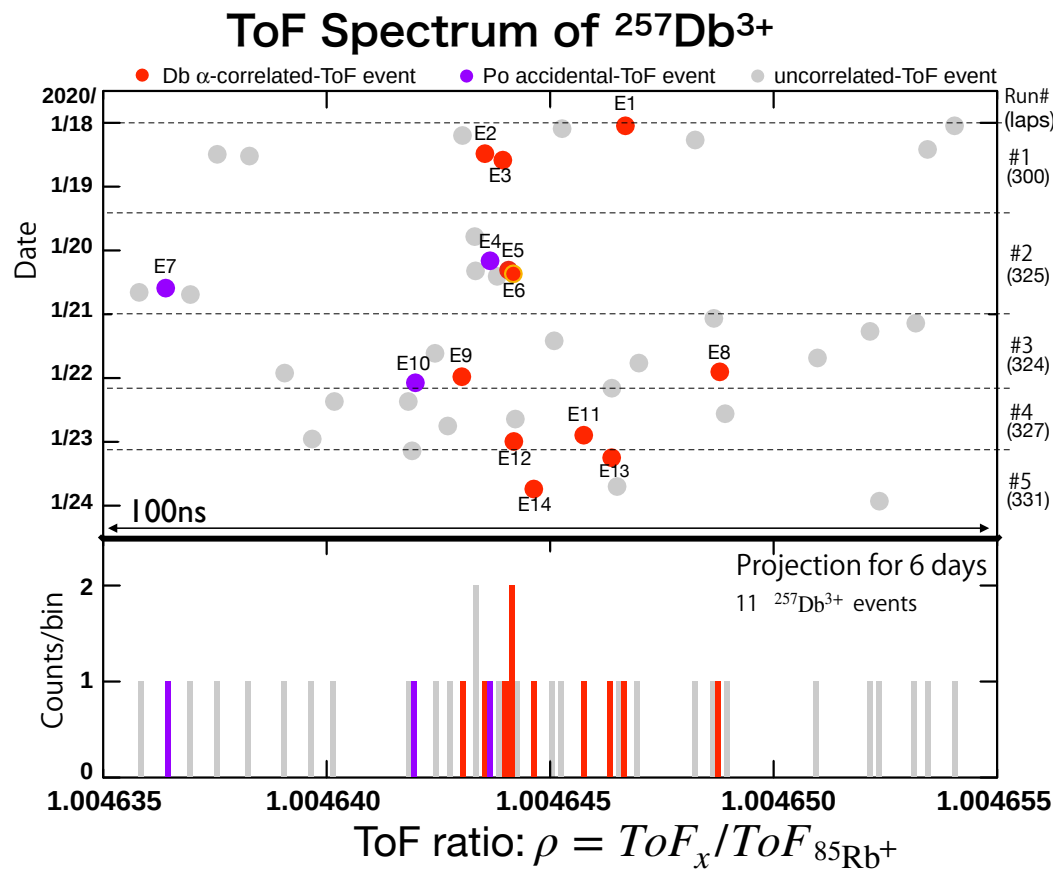


P. Schury et al, PRC 95(2017)011305(R)



S. Kimura et al, IJMS 430, 134-142 (2018)

First SHN direct mass measurement: ^{257}Db @GARIS-II'

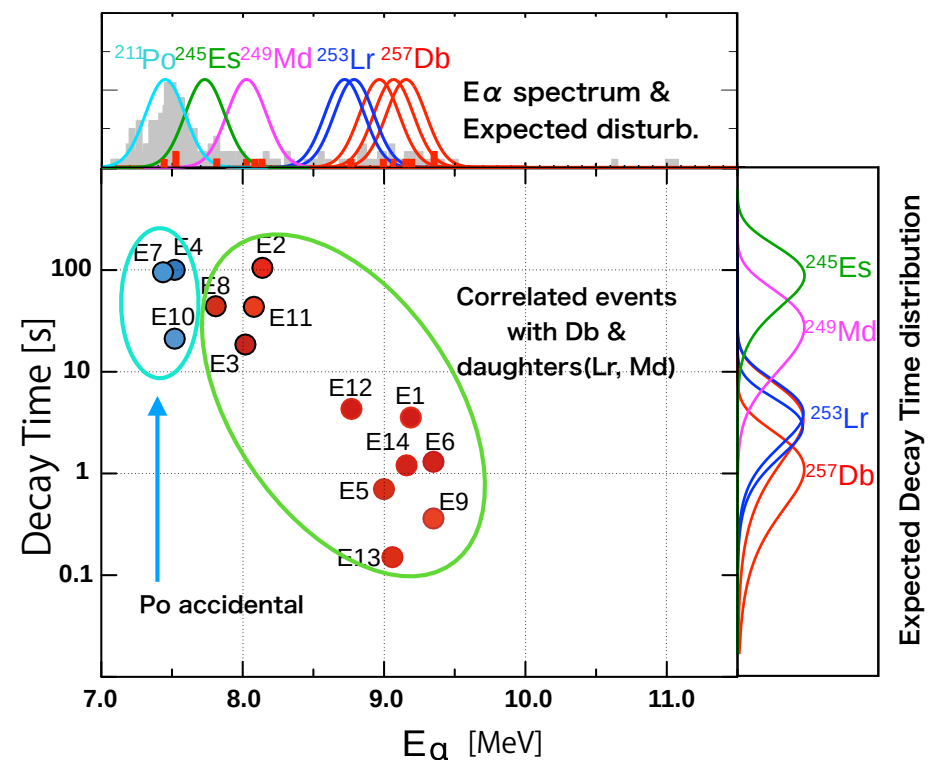
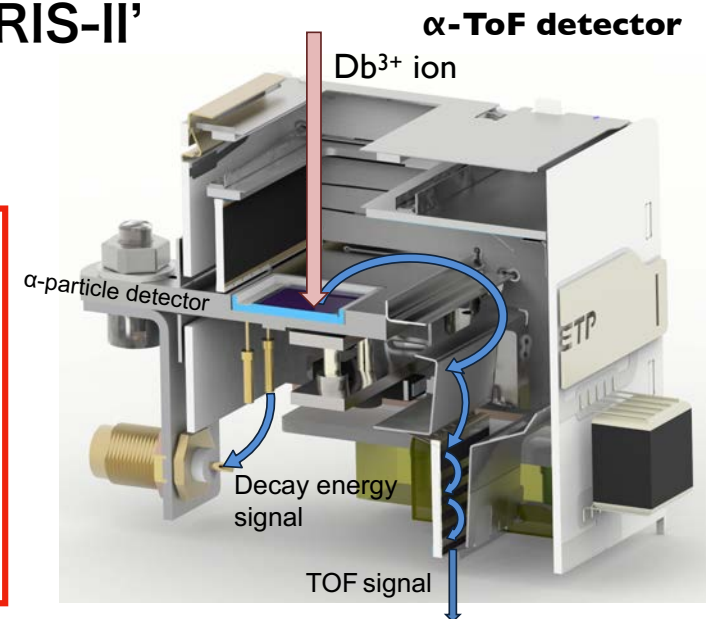


$$\rho = 1.004645162(487)$$

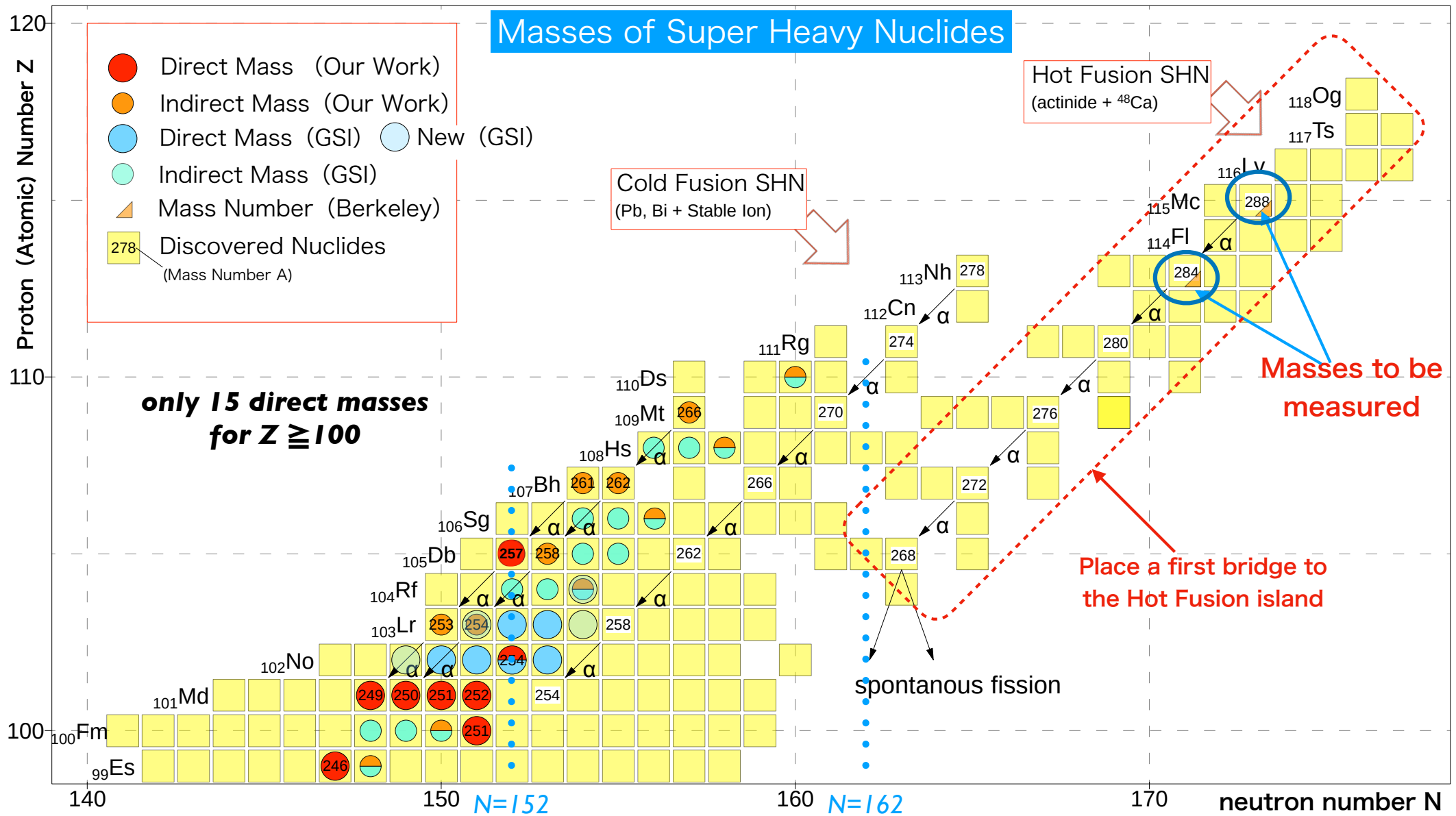
$$m(^{257}\text{Db}) = 257.10742(25) \text{ u} \quad \mathbf{1 \text{ ppm}}$$

$$\text{ME} = 100.06(23) \text{ MeV}/c^2$$

Rare events (2 ev/d), but accurately identify Db events, ToF vs. α -Decay correlation



Flagship exp. @ GARIS: hot-fusion Nh, Mc isotopes



We were ready to run, but no Ca48 available in the market !!

KISS

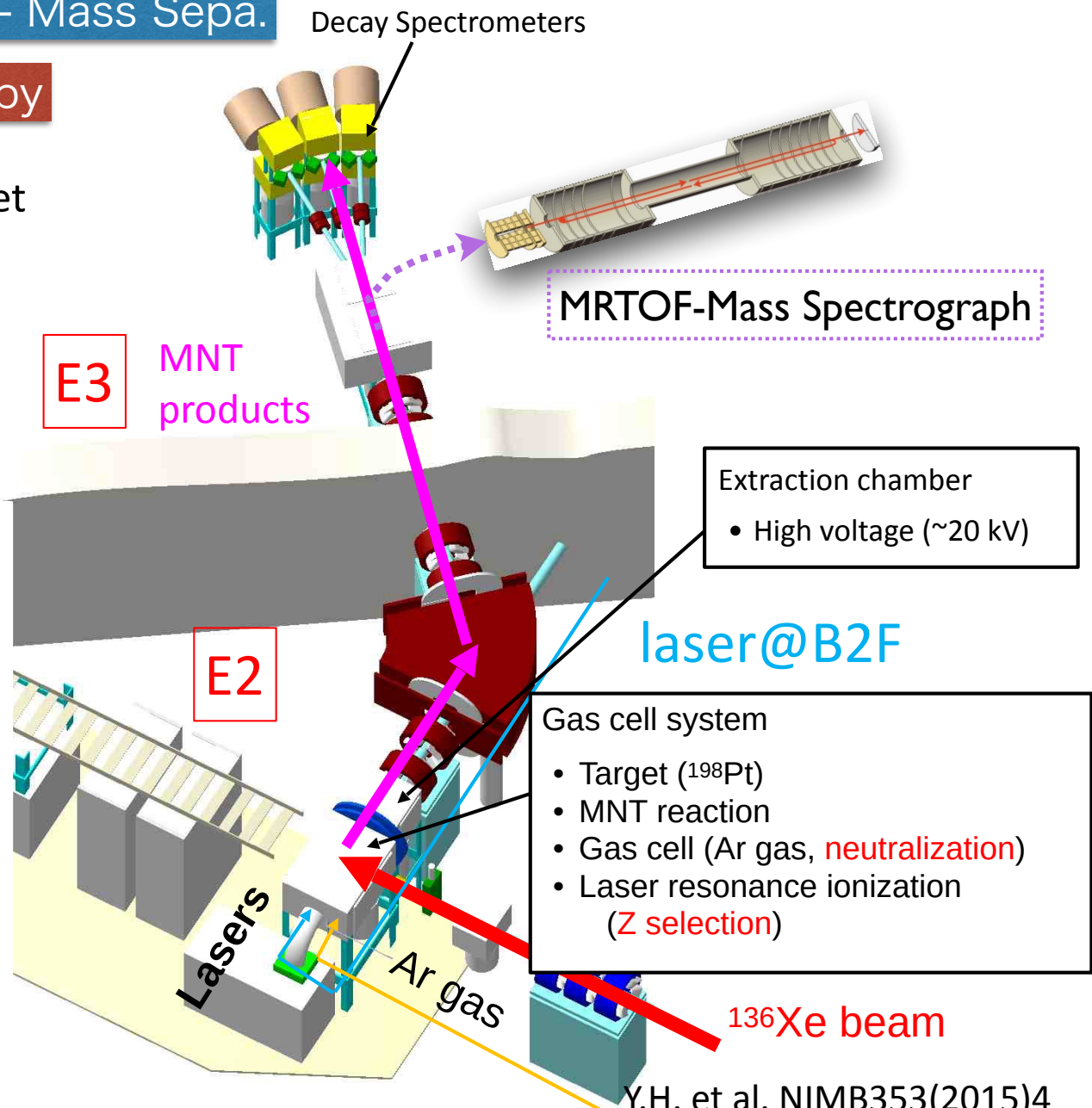
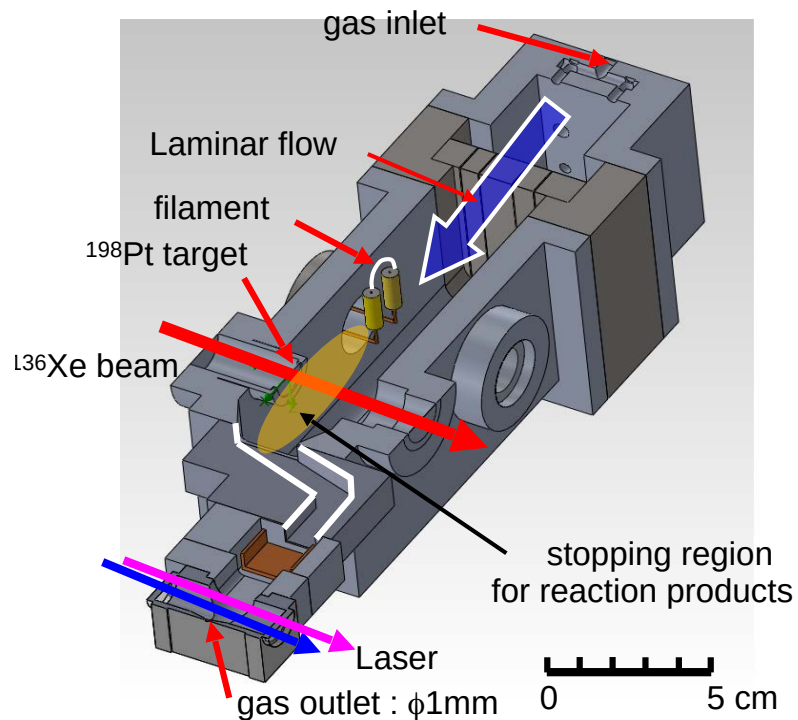
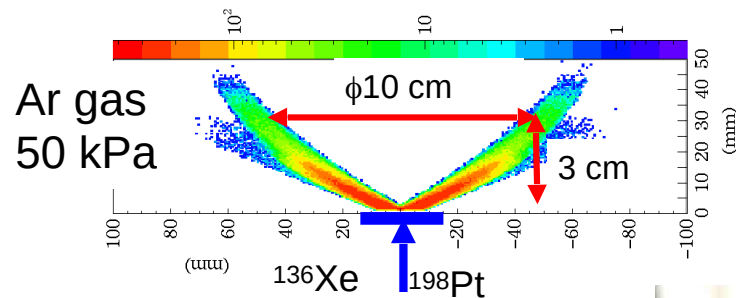
KISS (KEK Isotope Separation System)

n-rich nuclei via Multi-Nucleon Transfer

Ar gas cell - Resonant Ionization - Mass Sepa.

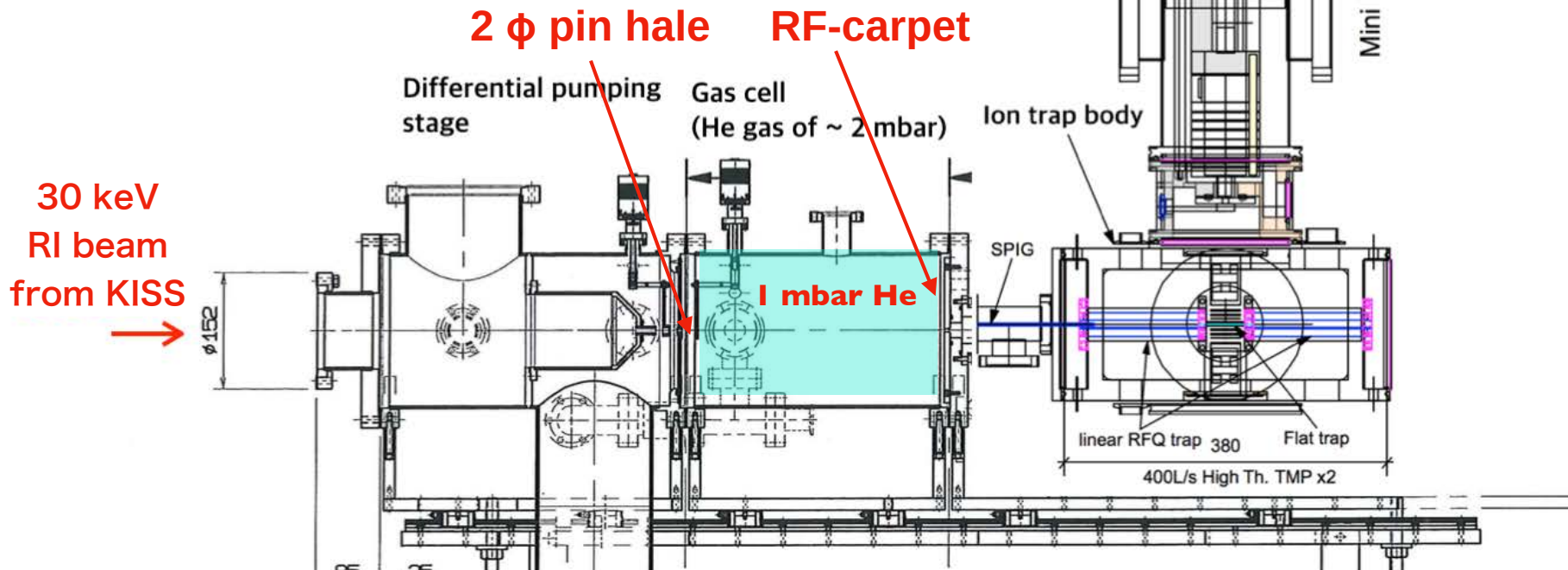
β γ · HFS · Mass Spectroscopy

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



New feature of KISS: GCCB(Gas Cell Cooler Buncher) +MRTOF

- A Novel interface from ISOL beam to Ion Trap
deceleration by 1 mbar He gas cell + extraction by RF-carpet
(cf. conventional system: electrostatic deceleration + RFQ linear trap cooler)
 1. Charge Breeder ($^{194}\text{Os}^+ \rightarrow ^{194}\text{Os}^{++}$)
 2. Molecular Destroyer ($\text{HfO}^+ \rightarrow \text{Hf}^{++}$)
- Successfully coupled to MRTOF & Laser Spectroscopy
 $\epsilon_{\text{total}} \approx 10\%$ (KISS to MTOF detector) @ 1st online
MTOF assisted Laser Spectroscopy



Resonant Laser Ionization Spectroscopy (KISS, PALIS...)

**Detection by Decay is not always efficient
(e.g., long lived isotopes)**

Y. Hirayama et al., PRC96(2017)014307

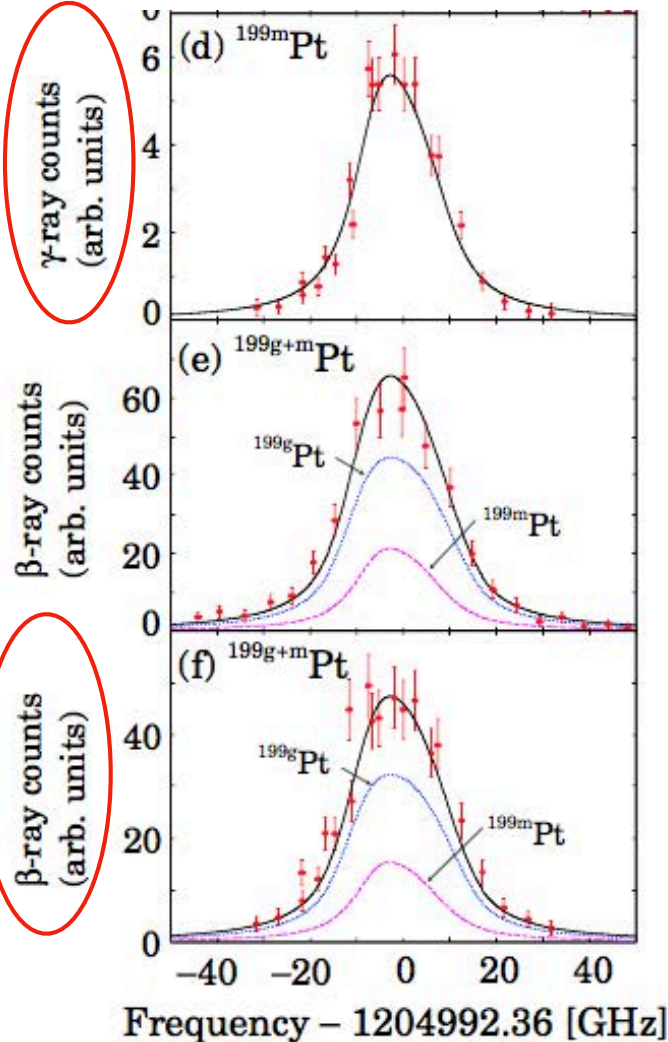
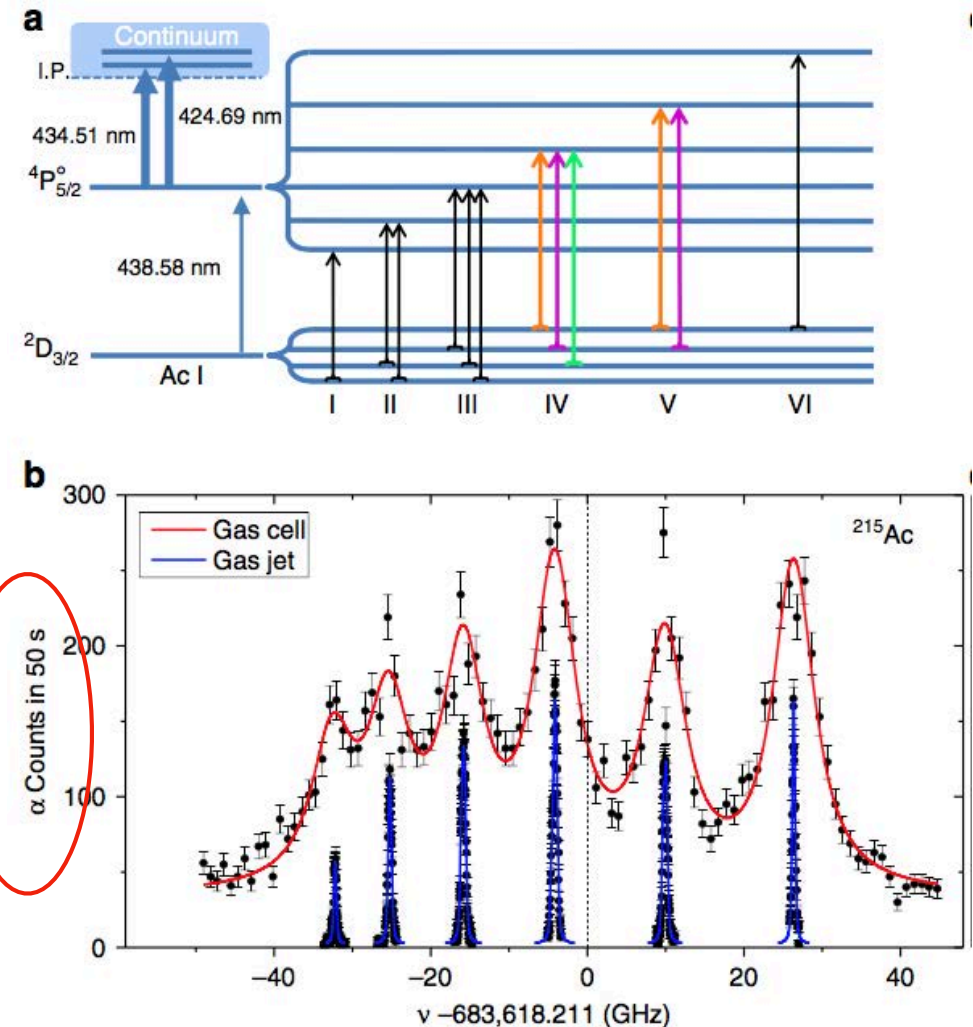
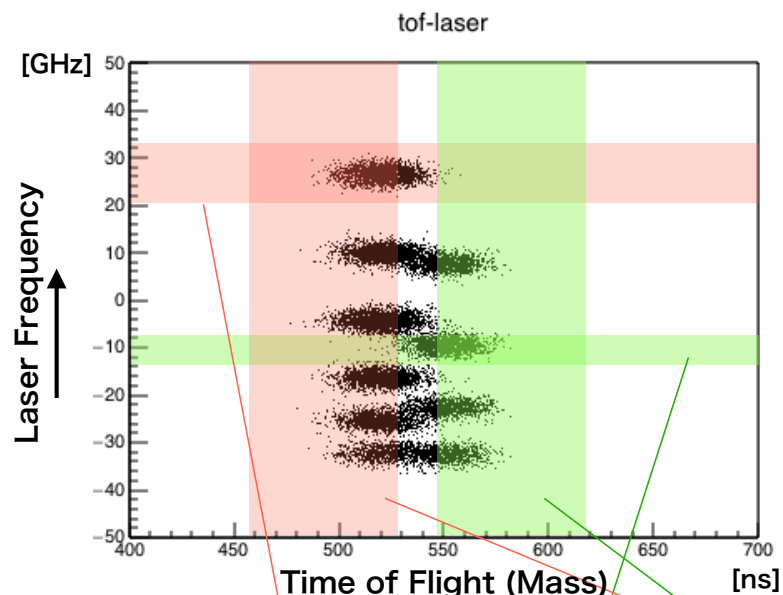


FIG. 4. Measured hyperfine splittings for $^{198}, ^{195}, ^{199m}, ^{199g+m}\text{Pt}$ nuclei extracted from KISS. Horizontal axis indicates the laser detuning relative to the transition frequency $\nu_0 = 1204992.36$ GHz ($\lambda_1 = 248.792$ nm). The experimental gas pressure and laser power for λ_1 were 88 kPa and 70 $\mu\text{J}/\text{pulse}$, respectively. (a) The analysis of the single resonance peak of ^{198}Pt nuclei provides the line shape measured under the online experimental conditions. (b) In the HFS spectrum of ^{195}Pt nuclei measured at the offline experiment, the lines

R. Ferrer et al., Nature Comm. 8 (2017) 14520

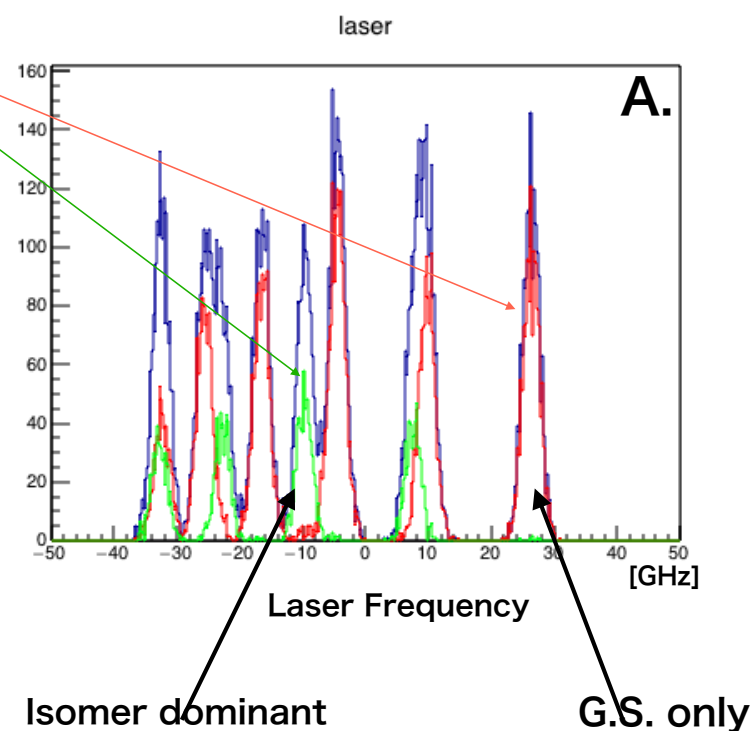
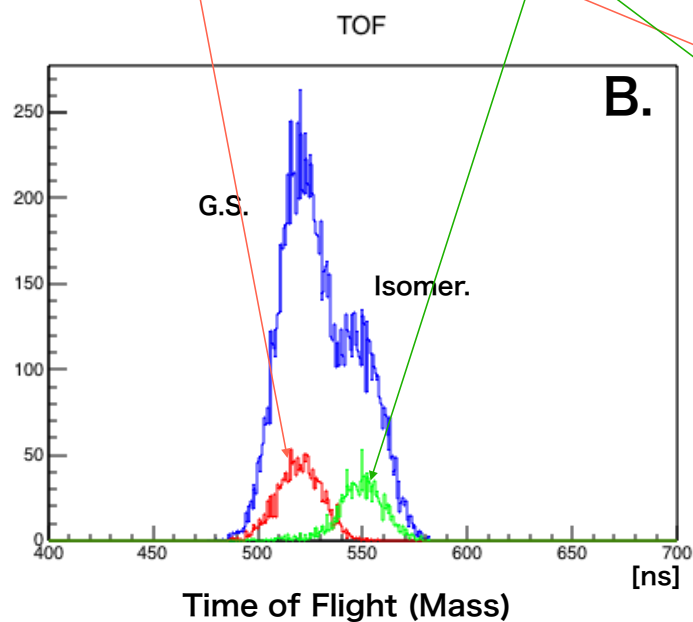


Combination of Resonant Laser Spectroscopy and MRTOF-MS



A. Multiple Isotopes Isomers at once
Very efficient at PALIS

B. Isomer - Ground state identification
by Laser



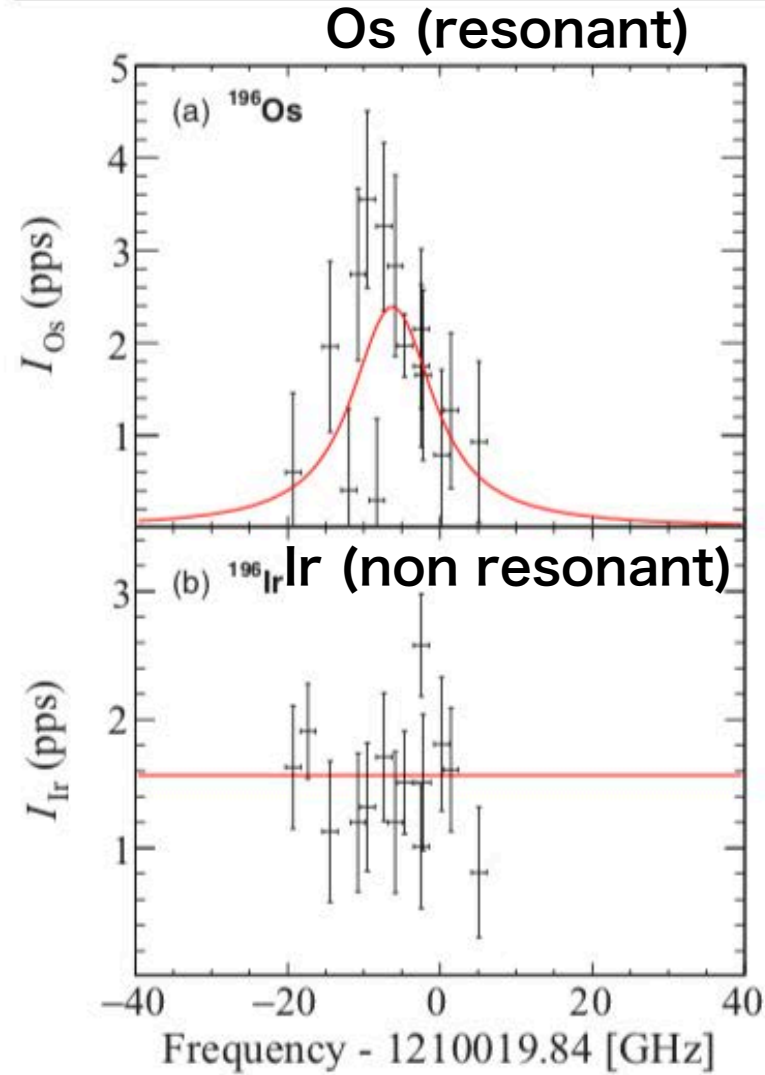
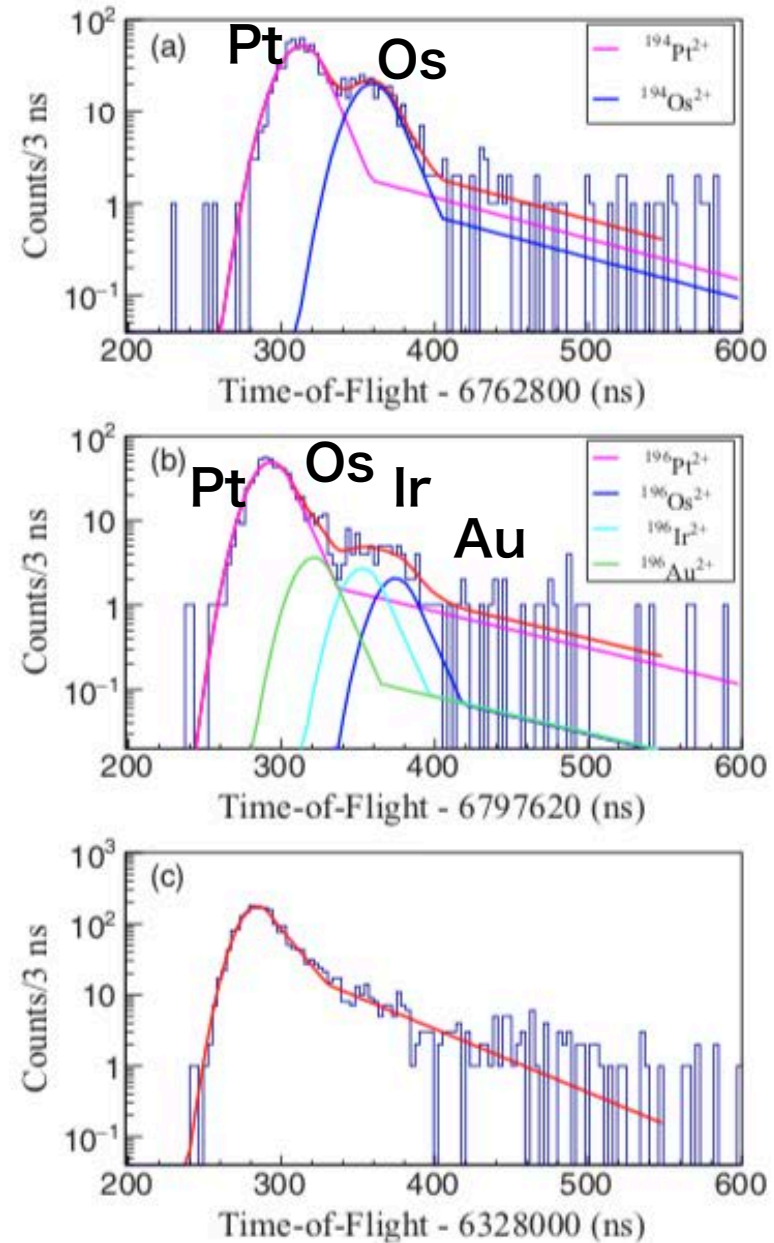


FIG. 2. (a) and (b) are the resonance spectra of the ^{196}Os and ^{196}Ir , respectively. The horizontal axis indicates the laser detuning relative to the transition frequency $\nu_0 = 1210019.84$ GHz ($\lambda_1 = 247.7583$ nm). The red line in (a) is the best-fit result of simultaneous fitting analysis of the $^{194,196}\text{Os}$ resonance spectra. The implantation rate of ^{196}Ir is independent of the laser frequency, and, therefore, the rate is fitted as a constant indicated by the red line.



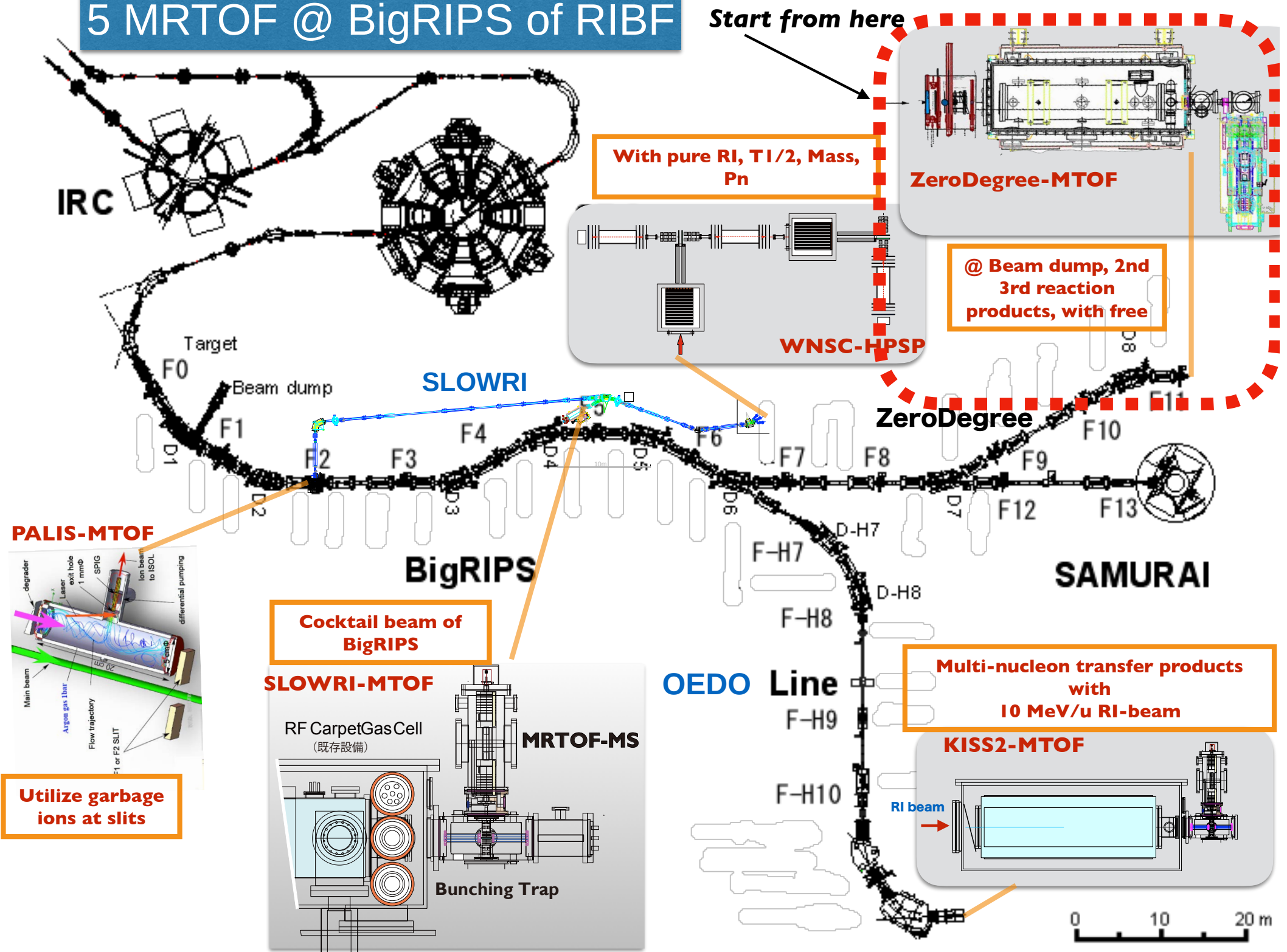
A=194

A=196

FIG. 3. Typical time-of-flight spectra of the ions with the mass-

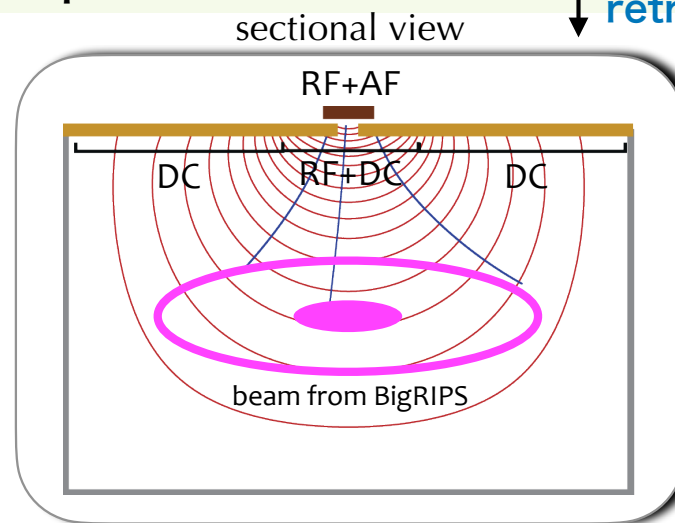
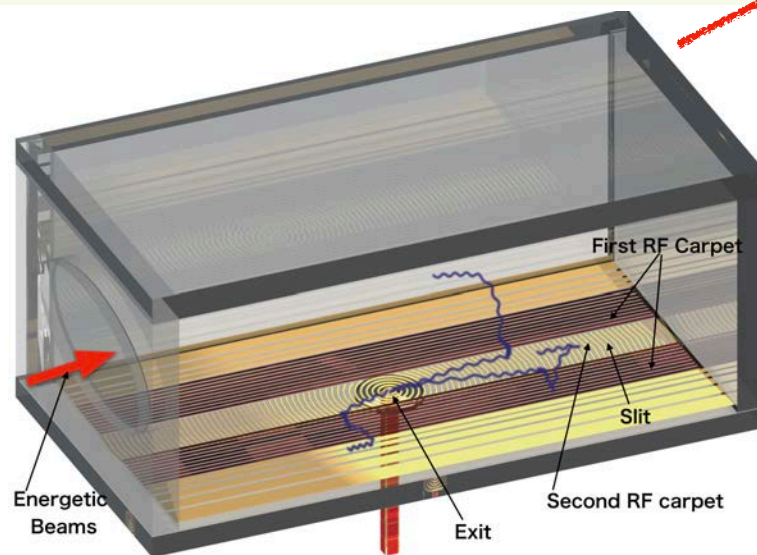
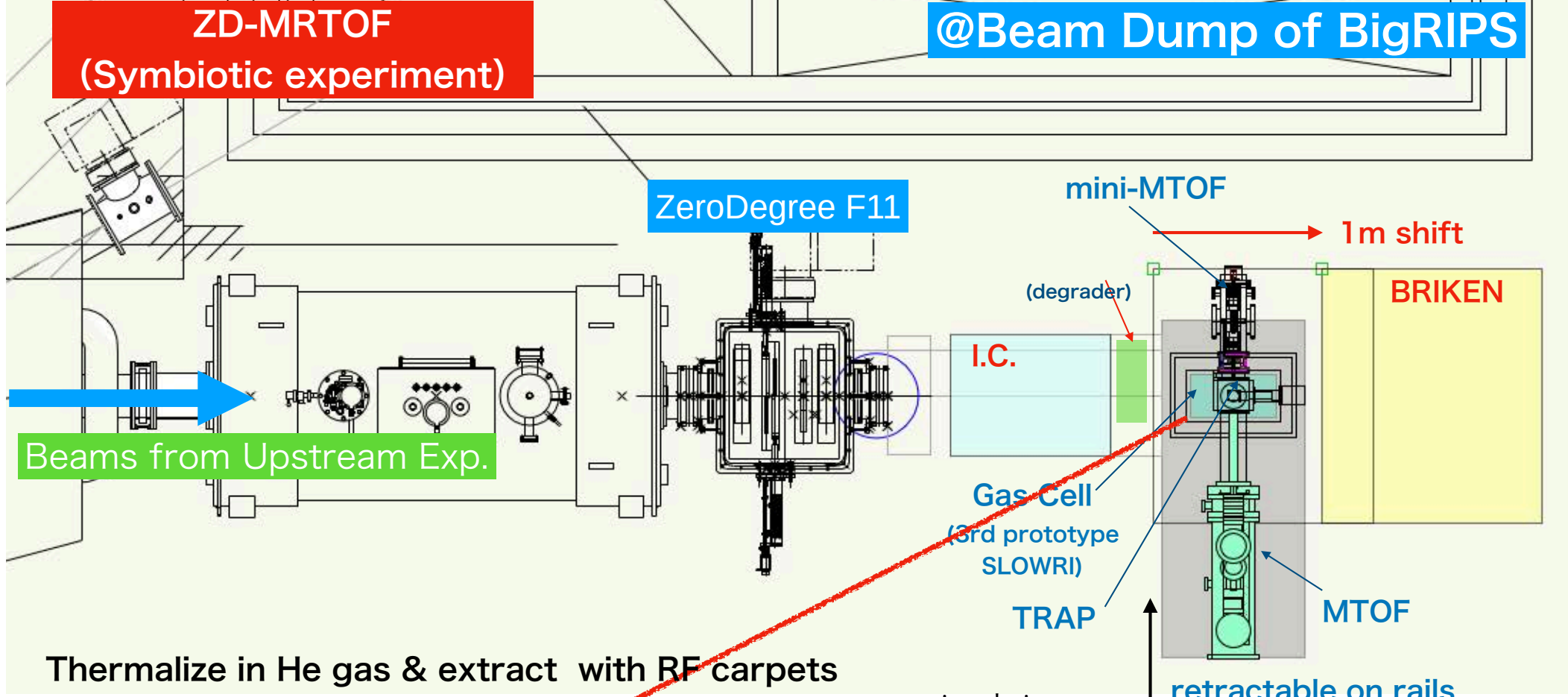
BigRIPS-SLOWRI

5 MRTOF @ BigRIPS of RIBF

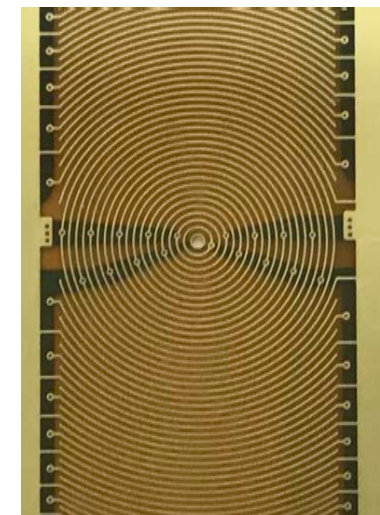


ZD-MRTOF (Symbiotic experiment)

@Beam Dump of BigRIPS



2nd RF carpet (RF+AF)



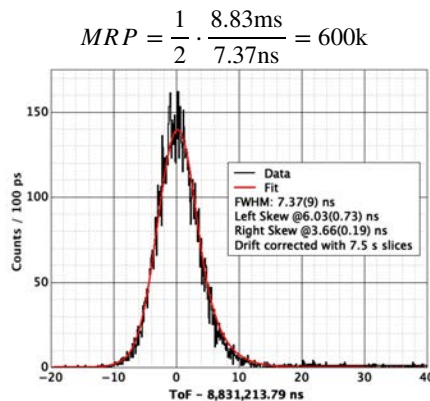
Two stage RFcarpet: "Gutter Structure"

SLOWRI+MRTOF commissioning under symbiotic exp. with HiCARI

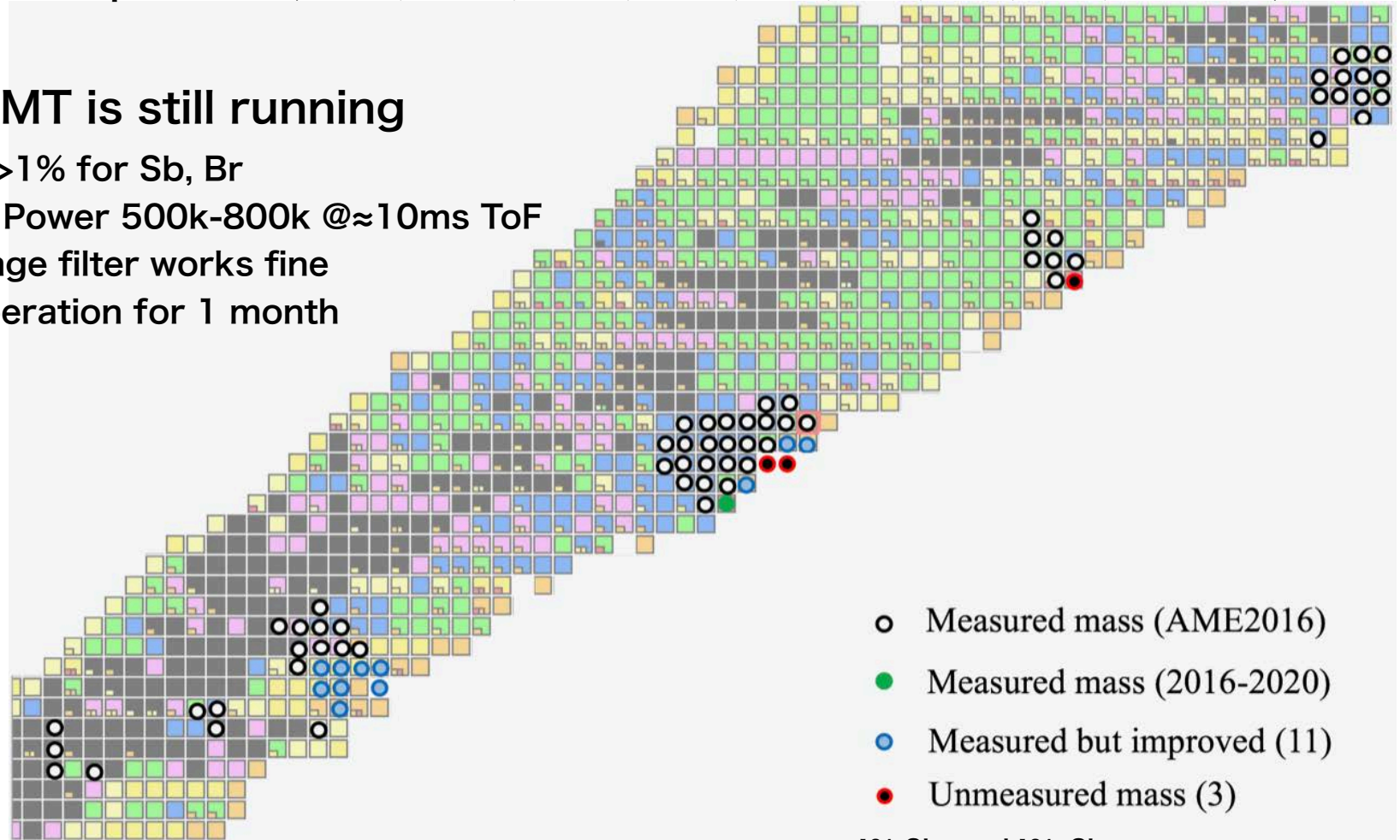
- > 70 more at BigRIPS were measured
- 3 first masses (88As, 89As, 112Mo)
- >10 greatly improved precision (86Ge, 90Se, 91Se, 59Cr, 56V, 57V, 58V, 59V, 56Ti etc)

commissioning MT is still running

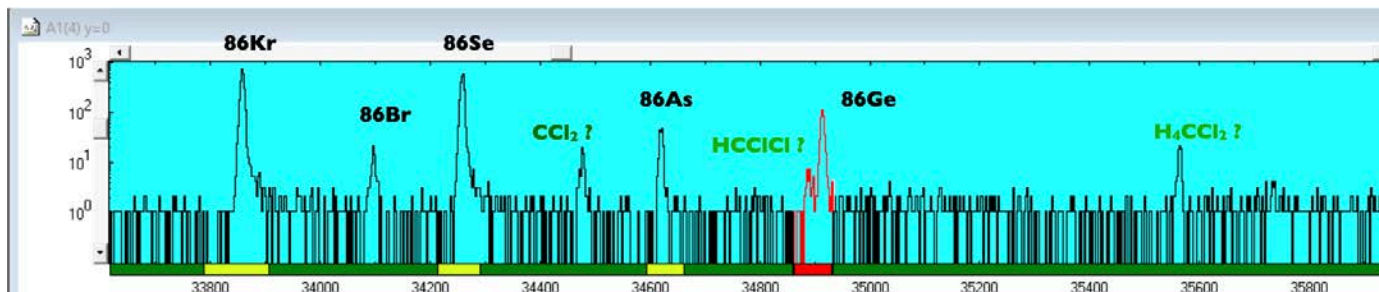
- Total efficiency >1% for Sb, Br
- Mass Resolving Power 500k-800k @ ≈ 10 ms ToF
- Molecular garbage filter works fine
- (Very) stable operation for 1 month



A raw online ToF spectrum

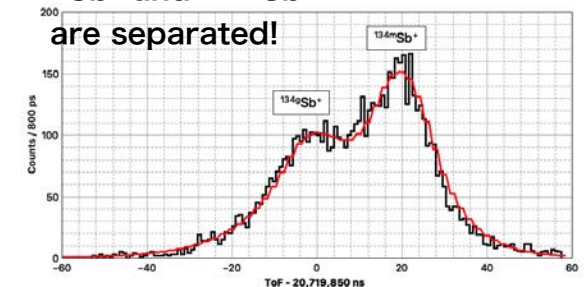


- Measured mass (AME2016)
- Measured mass (2016-2020)
- Measured but improved (11)
- Unmeasured mass (3)



$^{134}\text{gSb}^+$ and $^{134}\text{mSb}^+$

are separated!



Summary

- > 200 more masses were measured
- many physics publications will be published
- some great technical achievements
- many experimental plans are accepted
(Mc, Nh, Db, Sg, Ta-Os, ~Ni78, N~126, N~Z, etc)

present goal:

“measure masses of all available nuclides at RIBF & discovery of new isotopes”

next step:

“Explorer the origin of uranium and discovery of new elements at KISS-2”

Gas catcher + MRTOF will be a game changer!

