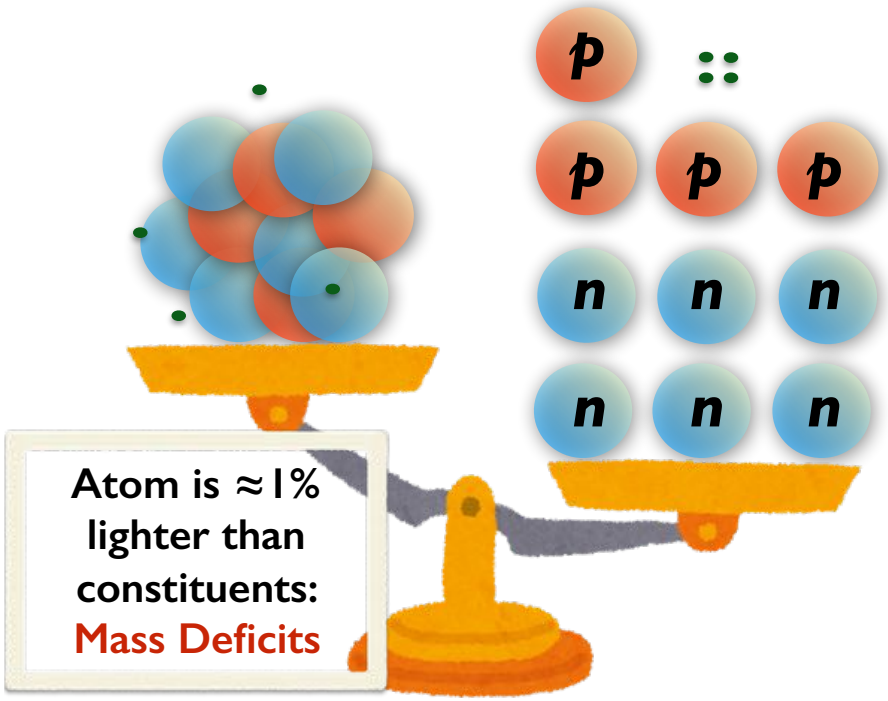
Mass Measurements with MRTOF at RIKEN RIBF

Michiharu Wada for the SHE-Mass Collaboration
KEK, Wako Nuclear Science Center

- Mass measurement of short-lived nuclei
- Summary of measurement @GARIS-II
- Mc and Nh measurement preparation
- Plan at the end of ZeroDegree

Why Atomic Mass?



Atom is ≈1% lighter than constituents: Mass Deficits

Mass Deficit = Binding Energy ***B***

$$B_{Z,N} = M_p Z + M_n N - M_{Z,N} + M_e Z$$

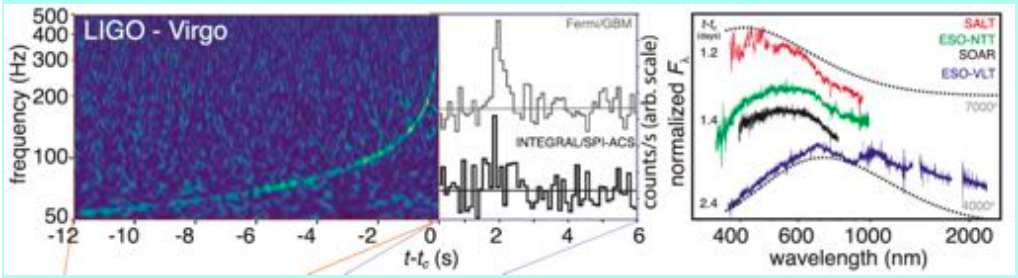
Σ constituents **Atomic mass**

- Most fundamental nuclear property
  - Defines Stability, Decay mode, Structure
- Finger Print: Unique value for a nucleus
- Key values for NucleoSynthesis
  - *Derivation of mass : Sn (n-separation energy)*

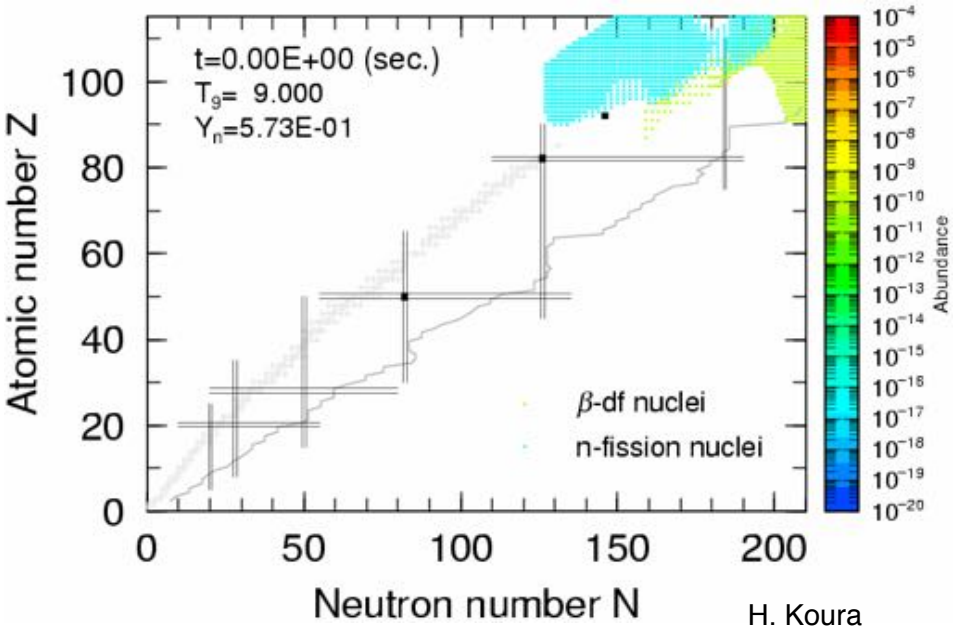
Astro Physicist:

"We saw the moment of Au Pt synthesis in n-star merger!"

r-process nova?



G-Wave **γ-flash** **optical**



H. Koura

ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 2017 October 20

cf. AME2016

Masses to be measured

note: many known masses were measured indirectly

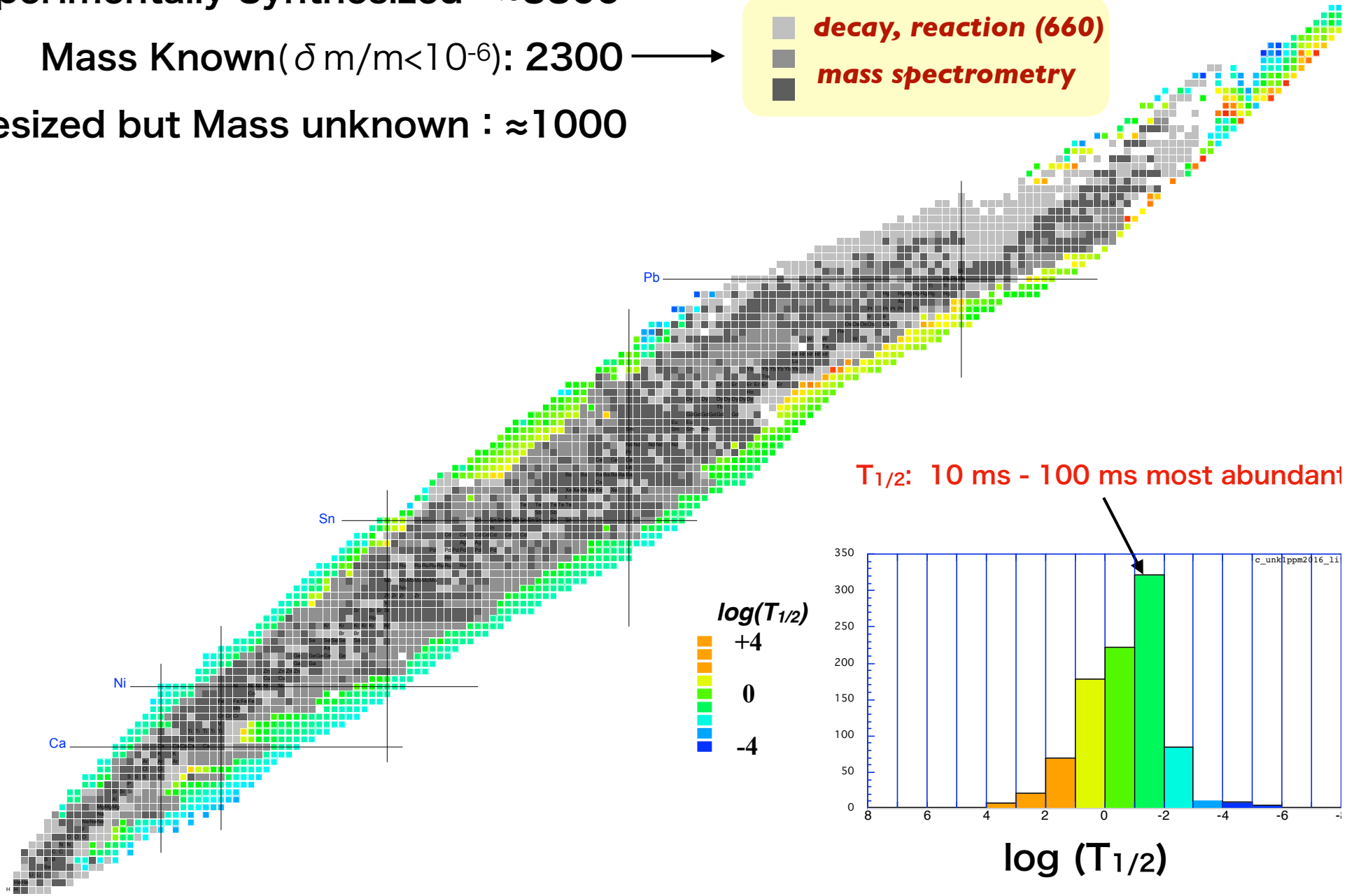
Experimentally Synthesized : ≈3300

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

Synthesized but Mass unknown : ≈1000

decay, reaction (660)

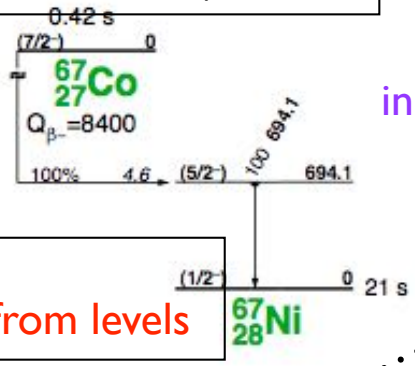
mass spectrometry



$T_{1/2}$: 10 ms - 100 ms most abundant

Mass Measurements of Short-lived Nuclei

Q-value (decay or reaction)

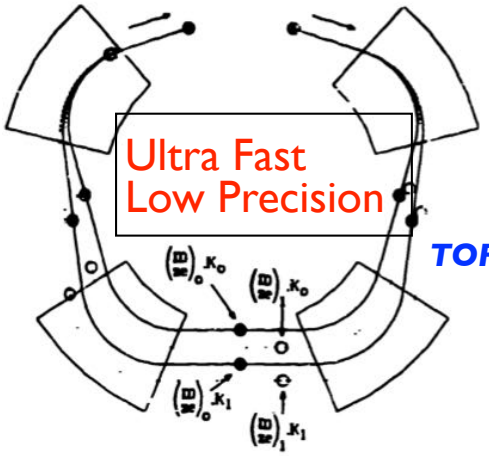


Universal
Ambiguity from levels

indirect

direct

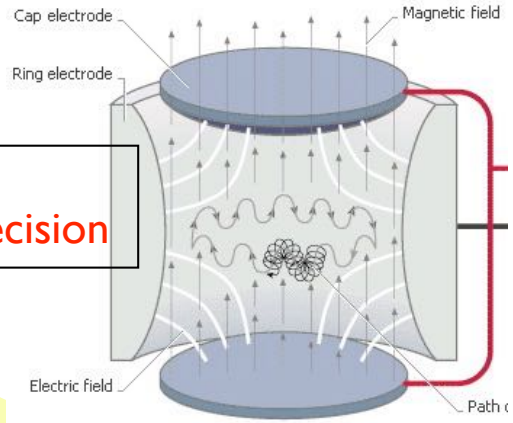
In-flight spectrometer



Ultra Fast
Low Precision

TOFI, SPEG ..

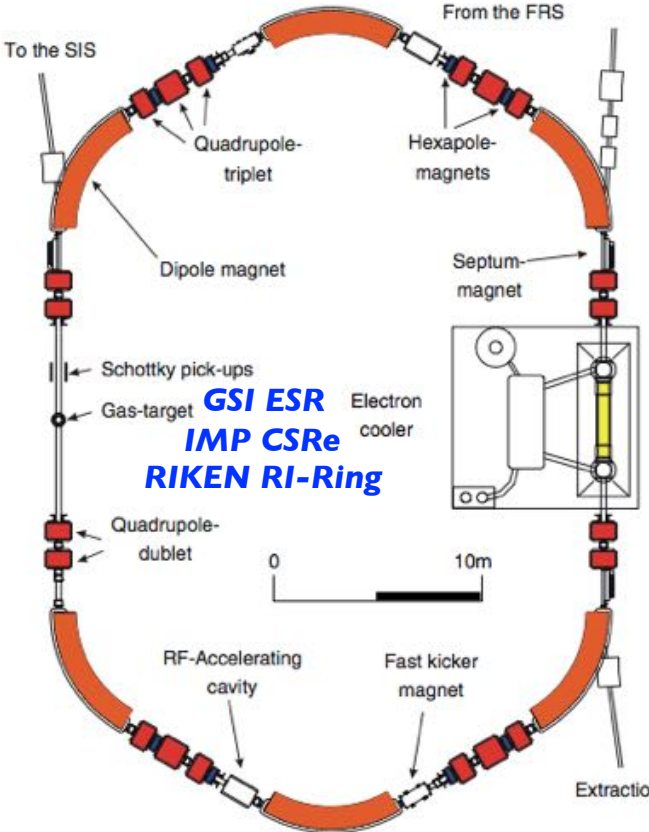
Penning Trap



Slow
Ultra precision

ISOLDE, JYFL...

Storage Ring



GSI ESR
IMP CSRe
RIKEN RI-Ring

Electron Cooling

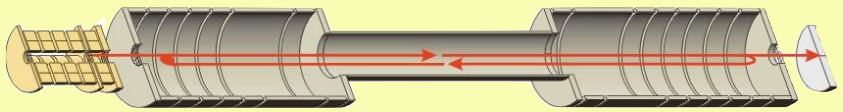
Very Slow
High Precision

Isochronous

Fast
Low Precision

New method

MRTOF (multi-reflection TOF)

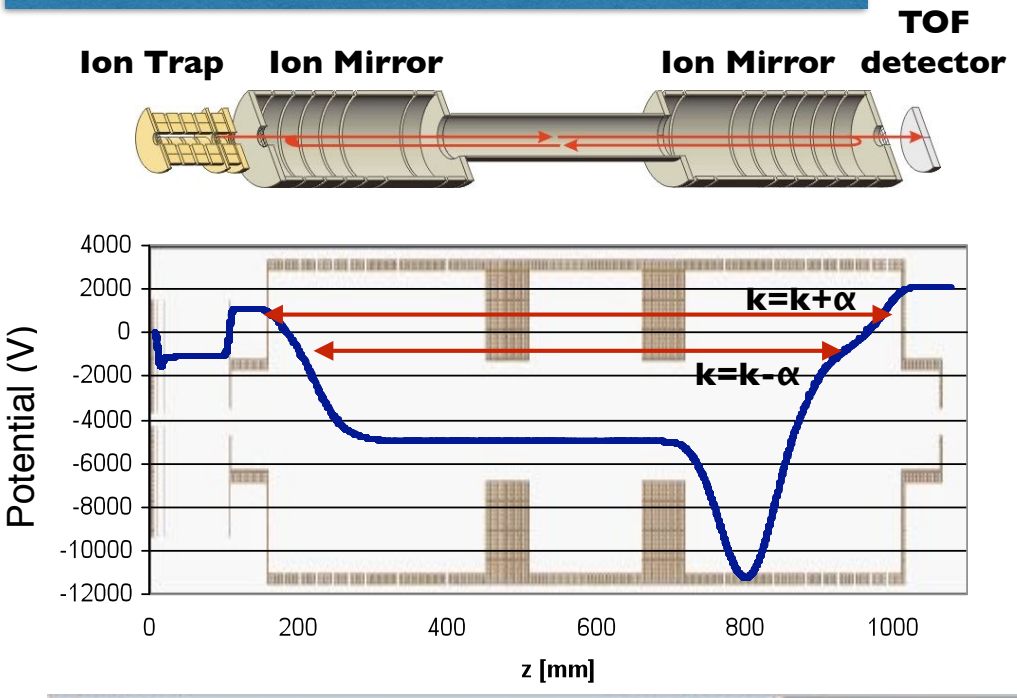


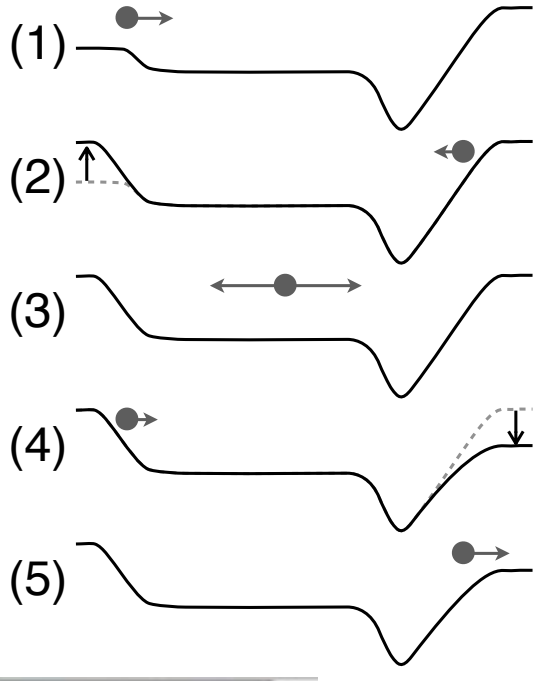
RIKEN, Giessen, ISOLDE ..

Fast
High Precision

MRTOF Mass Spectrograph

(Multi Reflection Time of Flight…)





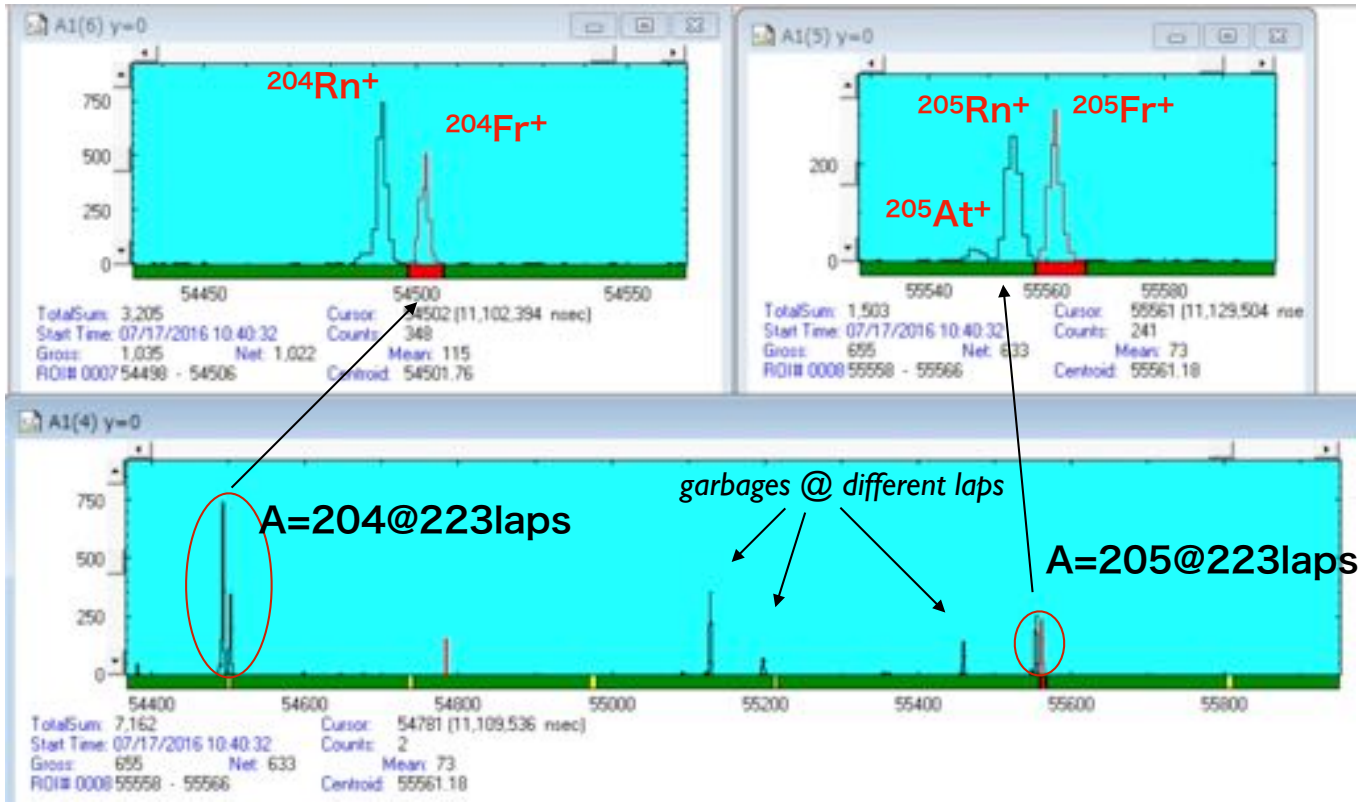
Open entrance to inject

Close entrance before coming back

go back and forth for ≈200 times

Open exit at pre-defined timing

Detect ions'ToF



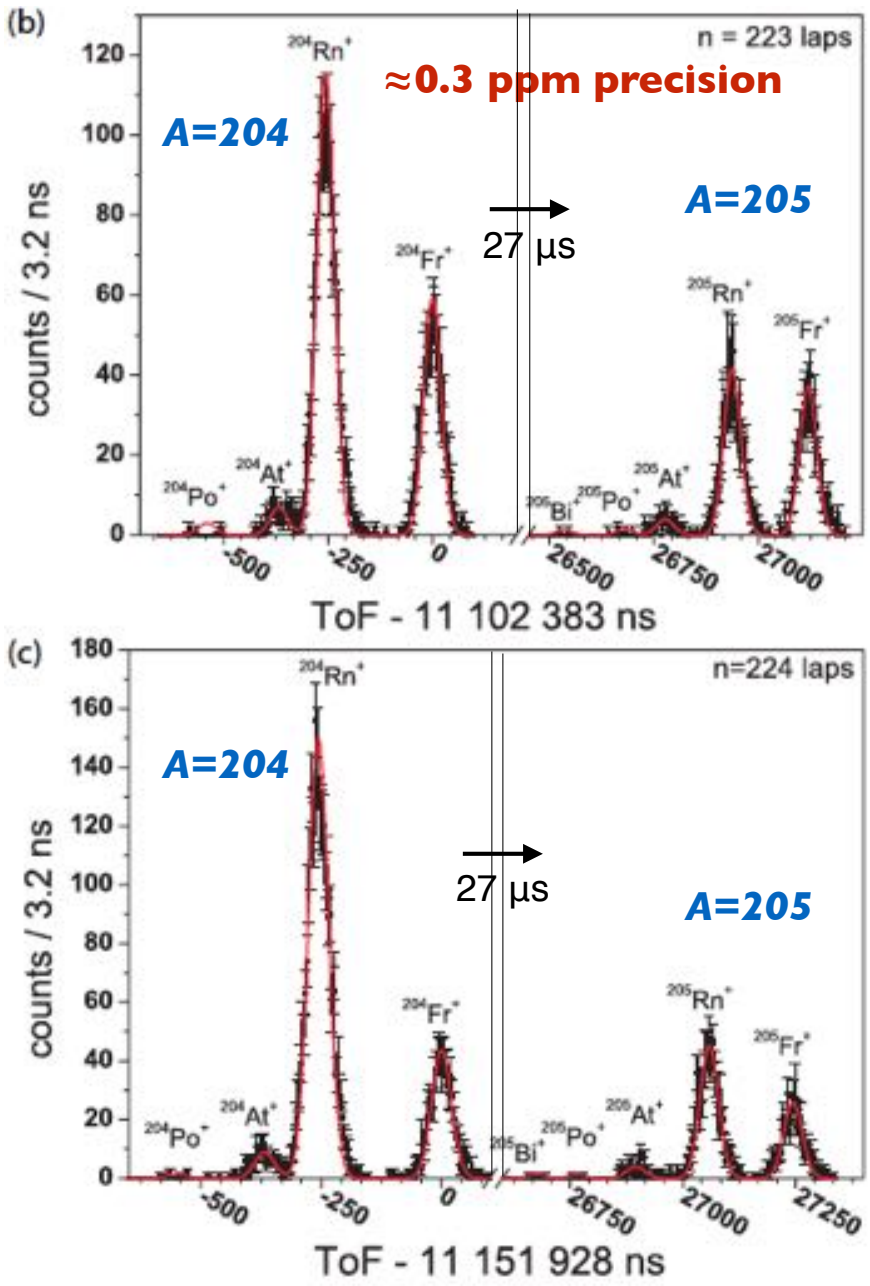
100,000 cycles in 3000s

total 7000 events

>90% are no ions

garbage ions can be discriminated by different number of laps

Typical Mass Measurement Results

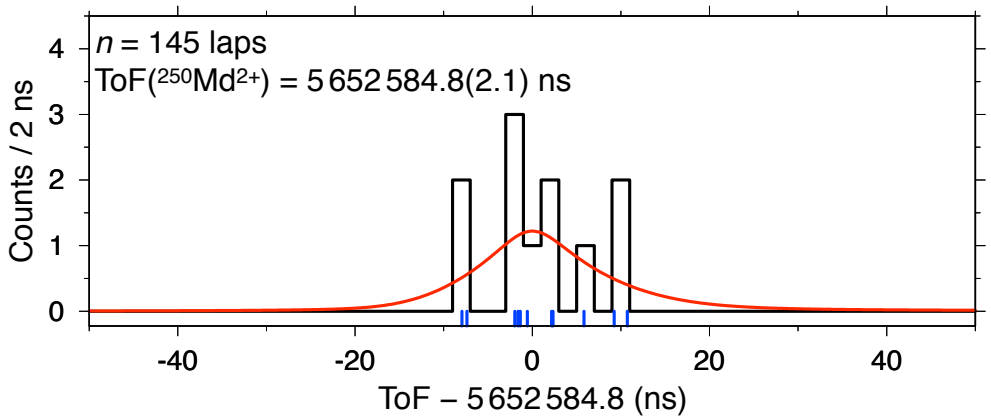


P. Schury et al, PRC 95(2017)011305(R)

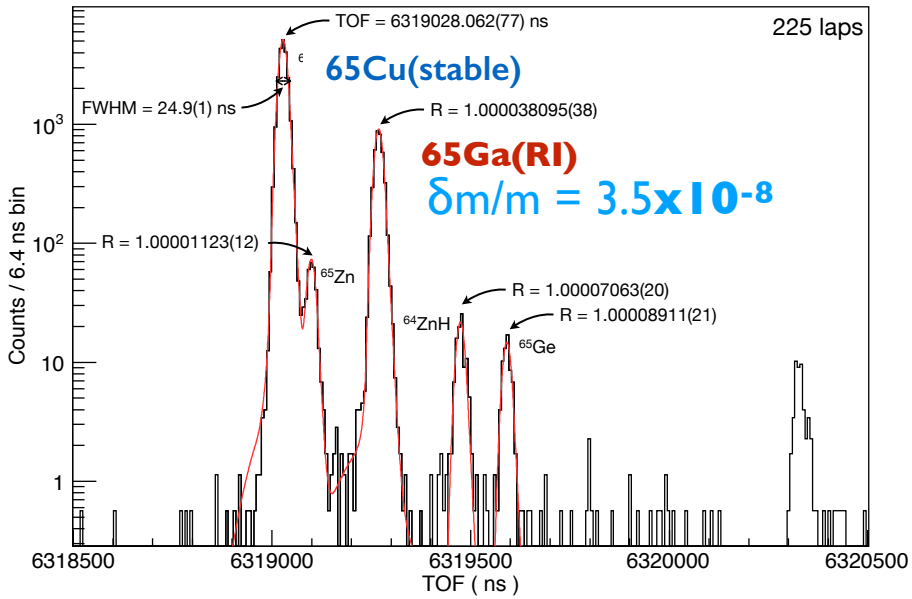
$^{250}Md^{++}$ measurement

≈ 1 event /1000 s

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



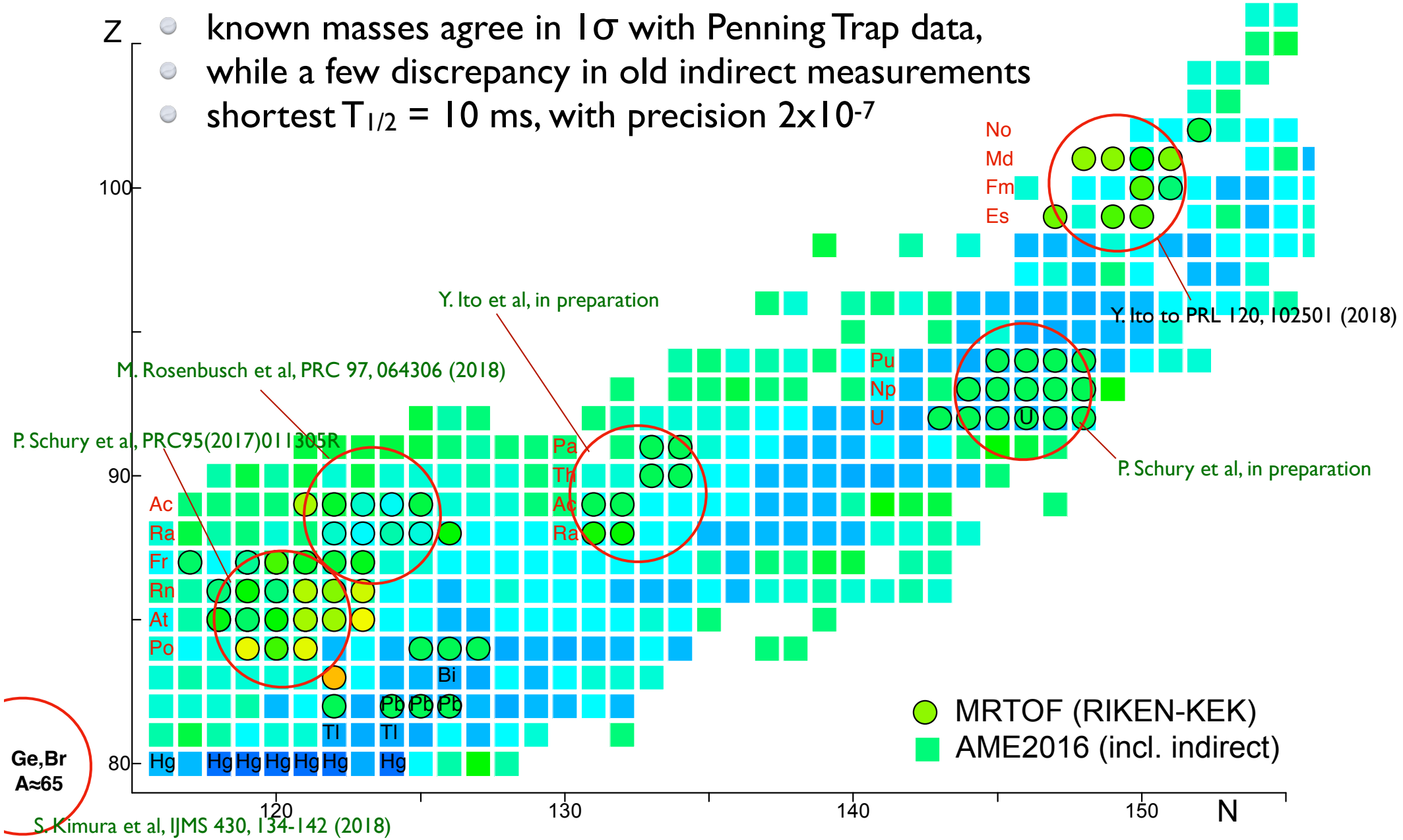
Y. Ito et al, PRL 120 (2018)0102501



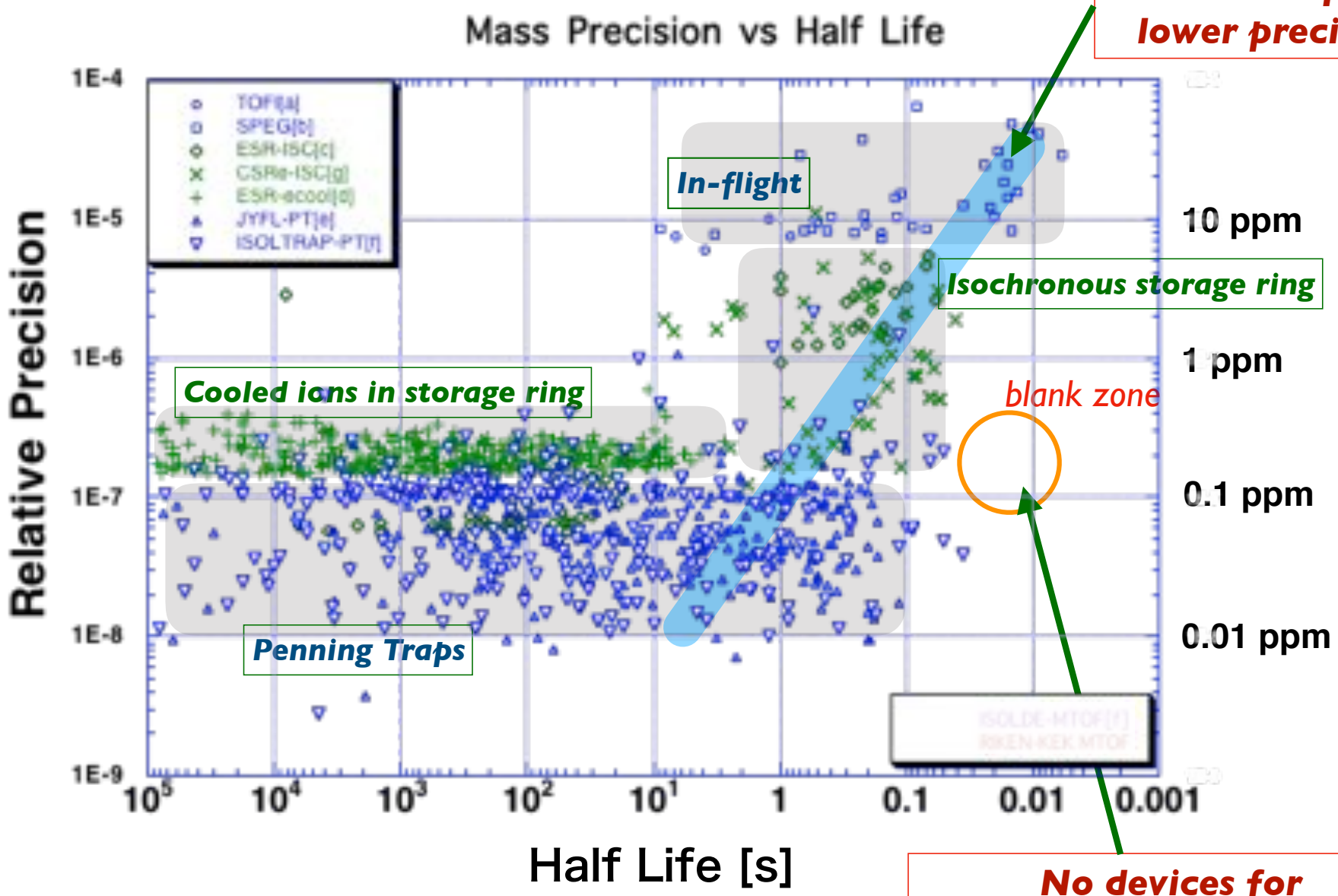
S. Kimura et al, IJMS 430, 134-142 (2018)

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}



Typical Mass Measurements before MRTOF

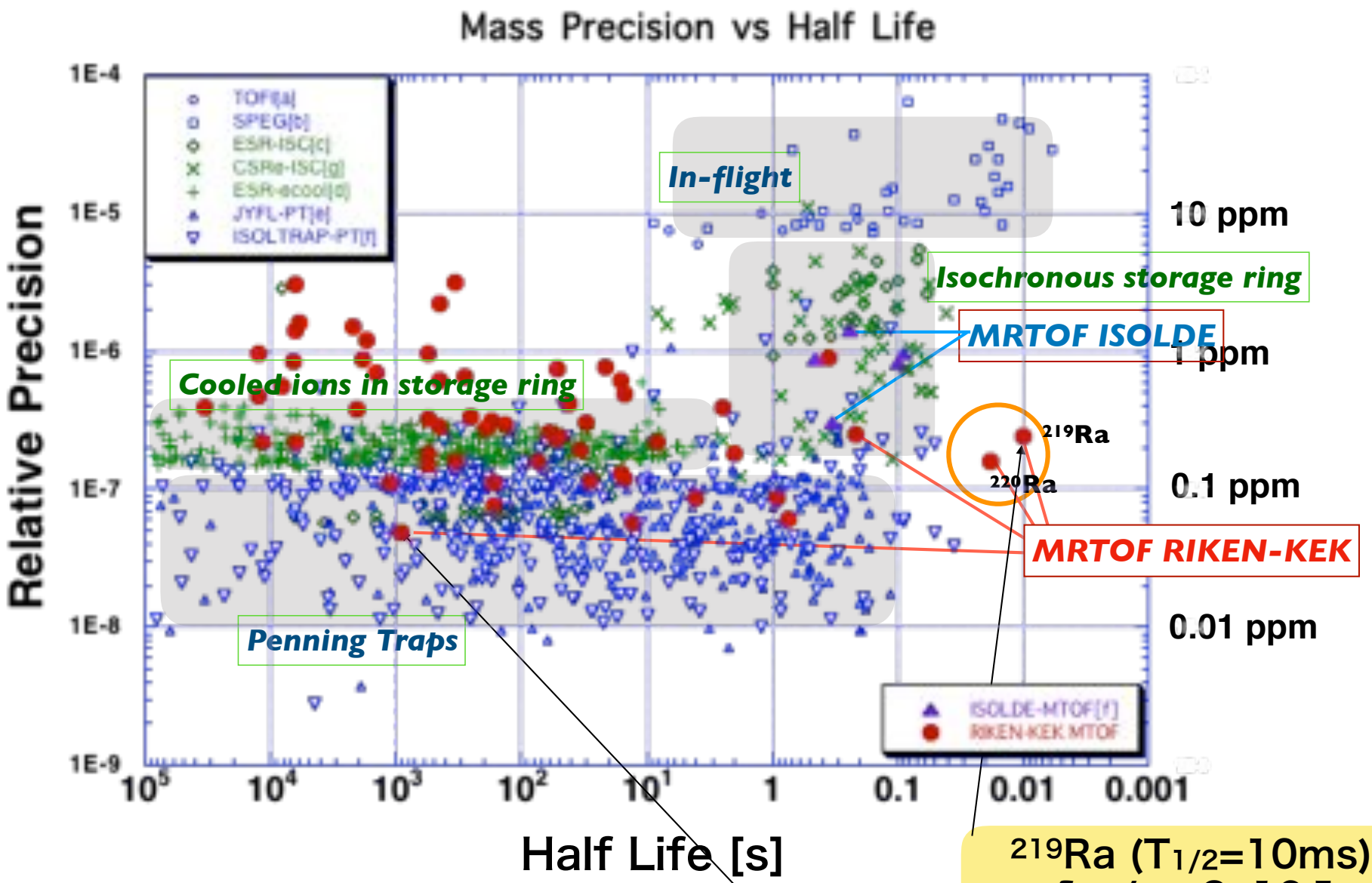


Shorter half-life, lower precision

No devices for $T_{1/2} \approx 10$ ms, $\delta m/m \approx 0.1$ ppm

[a] Y. Bai et al., AIP Conf. Proc. 455 (1998)90.
[b] F. Sarazin et al., Phys. Rev. Lett. 84 (2000)5062.
[c] R. Knöbel et al., EP. J.A. 52 (2016)138, Chen et al, NPA882(2012)71
[d] Yu.A. Litvinov et al., Nucl. Phys. A756(2005)3.
[e] http://research.jyu.fi/igisol/JYFLTRAP_masses/
[f] https://isoltrap.web.cern.ch/isoltrap/database/isodb.asp
[g] H.S. Xu et al IJMS349(2013)162 and others

MRTOF plays a role in Mass Measurements



^{219}Ra ($T_{1/2}$=10ms)
$\delta m/m=3\times10^{-7}$

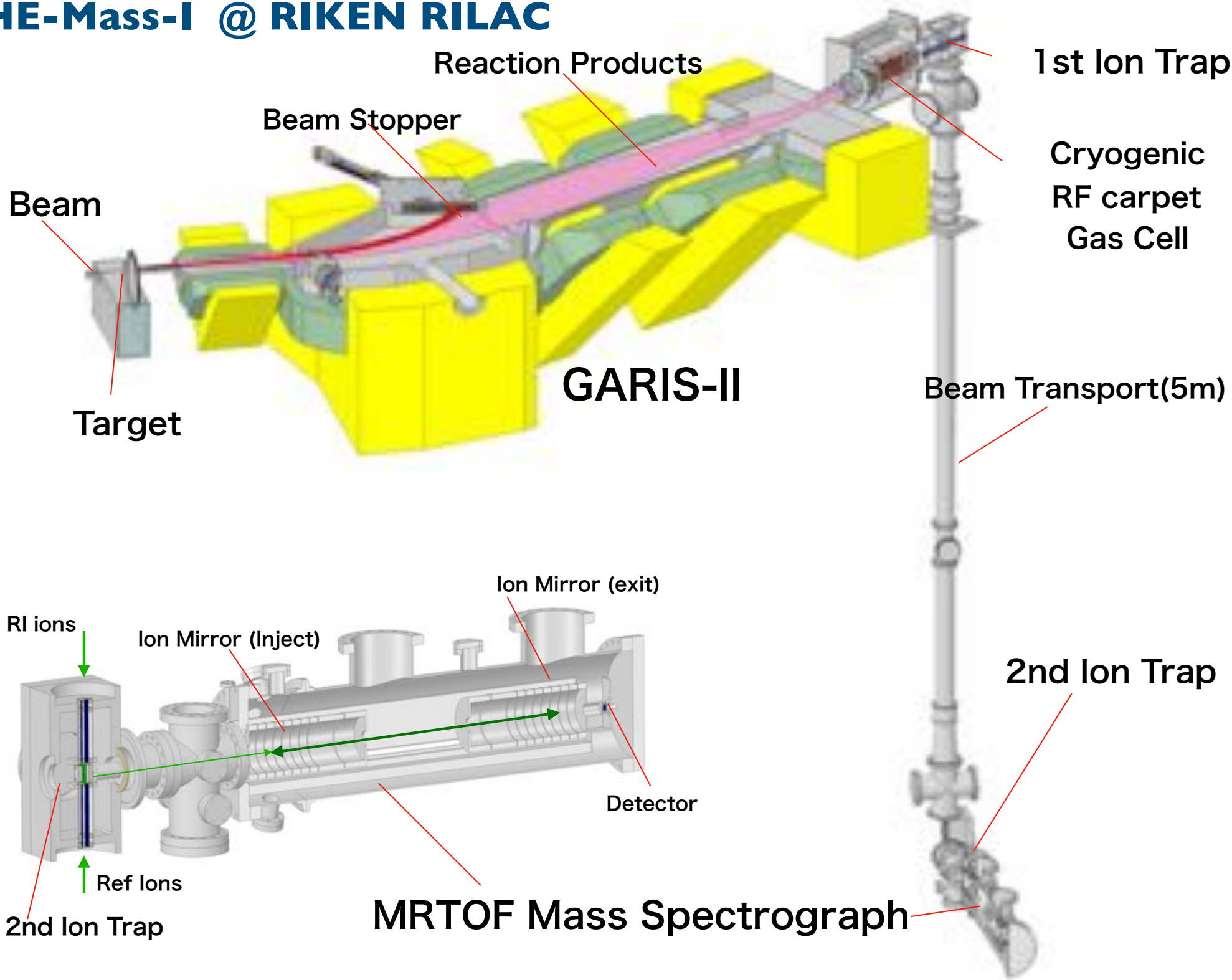
Y. Ito et al.,to be submitted

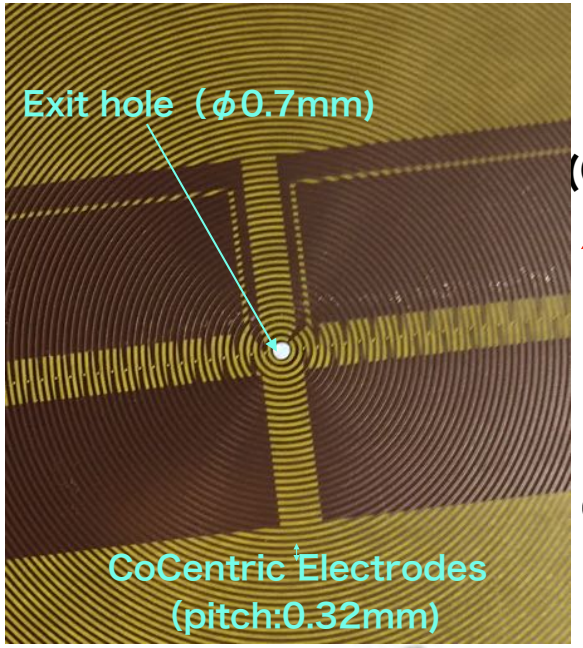
^{65}Ga: $\delta m/m=3.5\times10^{-8}$
still agree with Penning trap

Kimura et al.,IJMS 430 (2018) 134

[a] Y. Bai et al., AIP Conf. Proc. 455 (1998)90.
[b] F. Sarazin et al., Phys. Rev. Lett. 84 (2000)5062.
[c] R. Knöbel et al., EP. J.A. 52 (2016)138, Chen et al, NPA882(2012)71
[d] Yu.A. Litvinov et al., Nucl. Phys. A756(2005)3.
[e] http://research.jyu.fi/igisol/JYFLTRAP_masses/
[f] https://isoltrap.web.cern.ch/isoltrap/database/isodb.asp
[g] H.S. Xu et al IJMS349(2013)162 and others

SHE-Mass-I @ RIKEN RILAC





RF-Carpet(traveling wave)

(Central part)

1st Ion Trap Setup

Linear RFQ ion trap

RF Six-pole beam guide

DC cylinder

Flat RFQ ion trap

Cryogenic gas cell

Window(0.5μm)

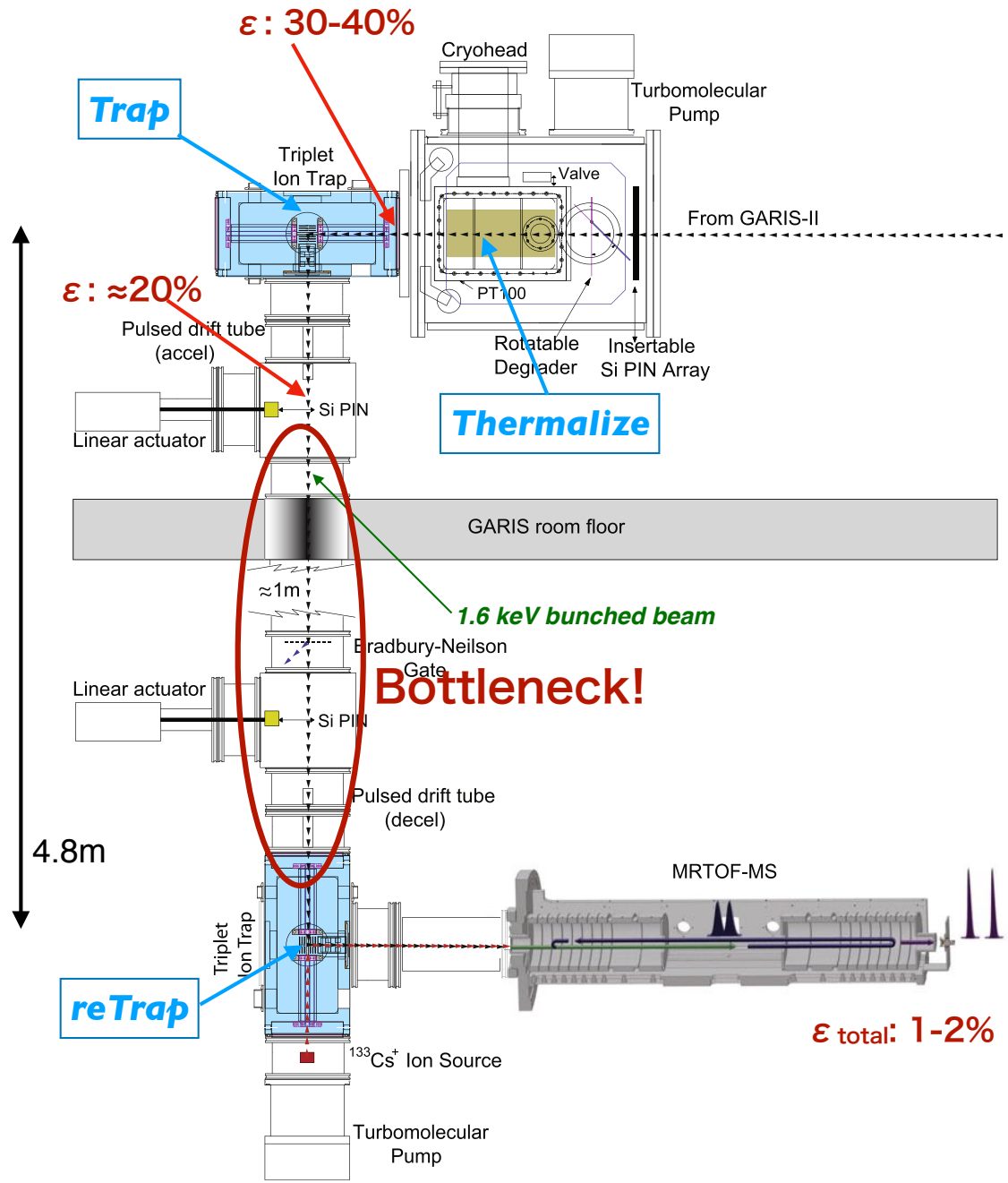
Md, Es…

Recoil Ions

Bunched Ion Beam

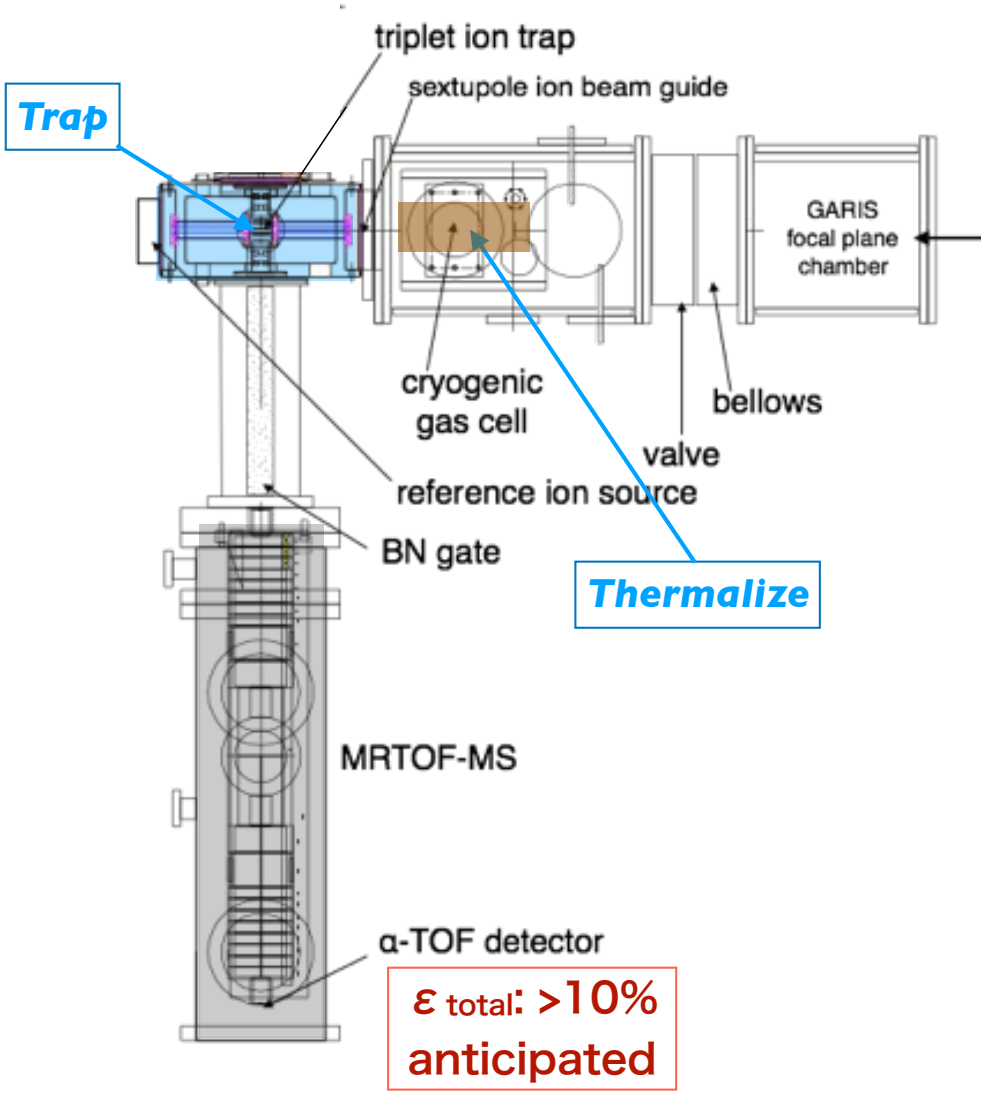
α-β Detector (retractable)

SHE-Mass-I @ RILAC



Side View

SHE-Mass-II @E6

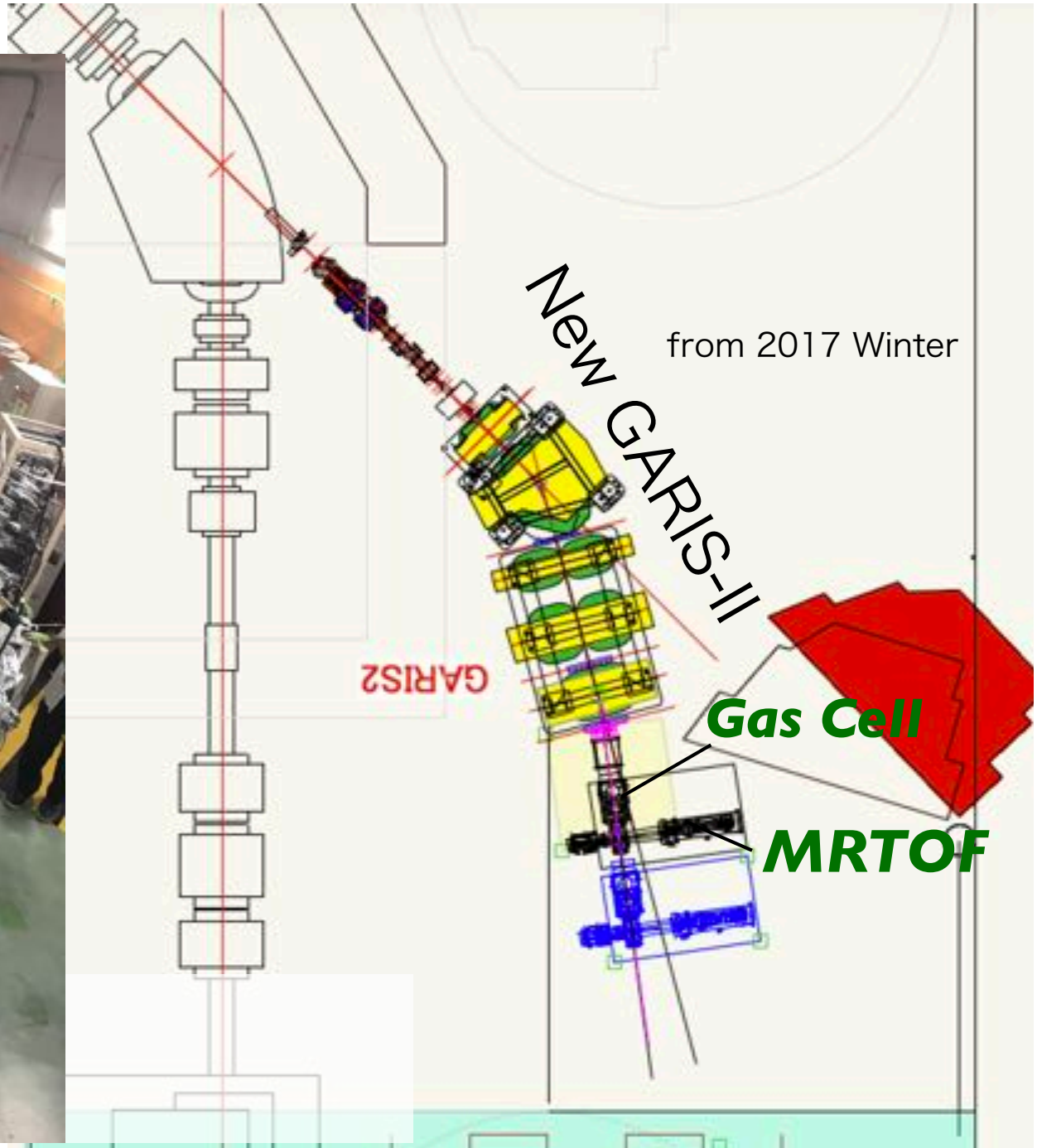


Top View

Large free area

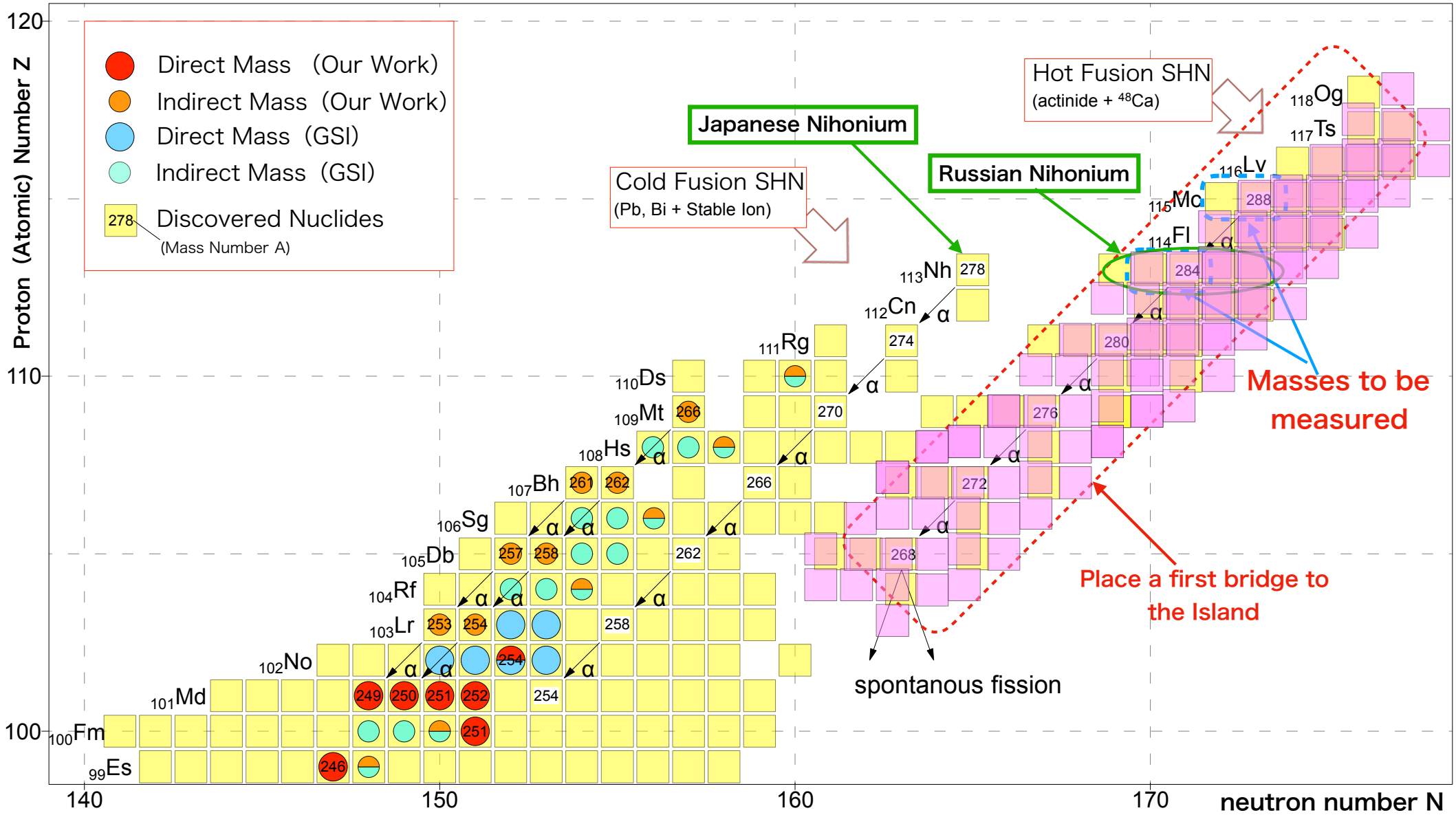
GasCell+Trap+MRTOF all in one

SHE-Mass-II @E6 RIBF



Masses of Super Heavy Nuclides

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



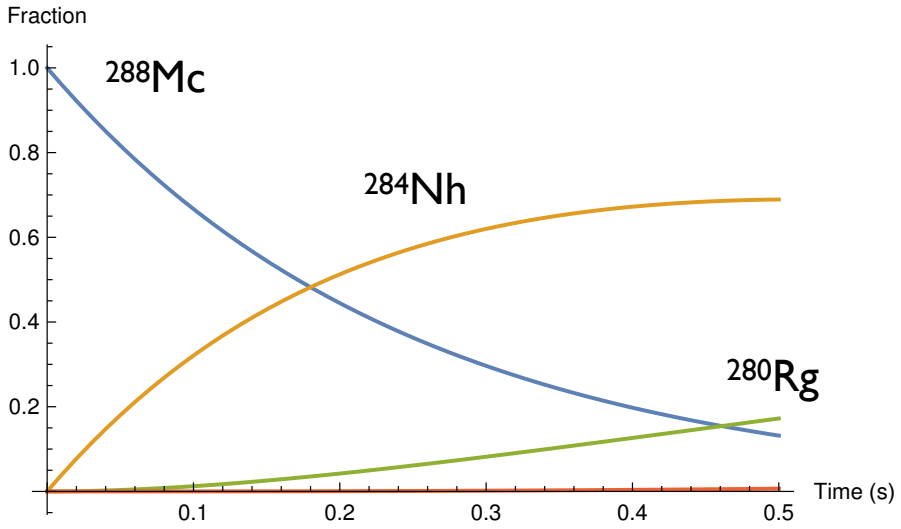
Candidates in first Hot Fusion SHE Mass Measurement

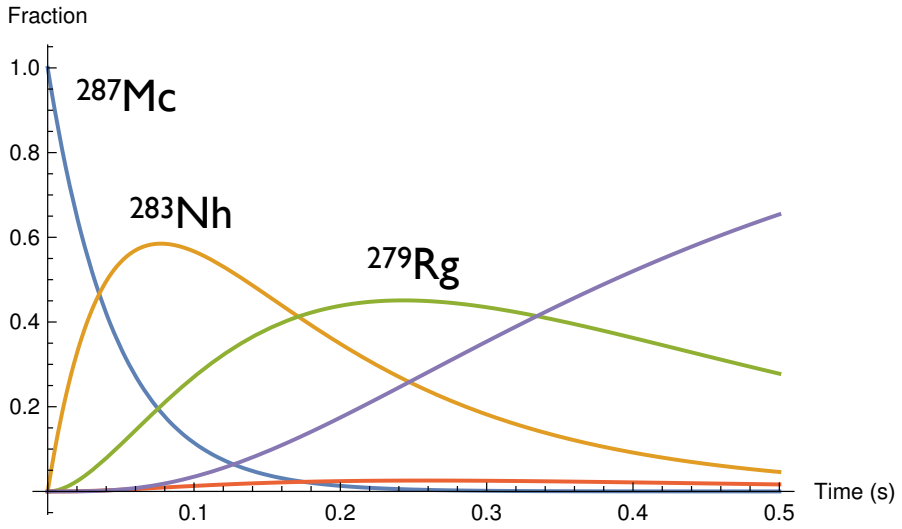
$^{243}Am(^{48}Ca, 3n)^{288}Mc \rightarrow ^{284}Nh \rightarrow ^{280}Rg$

0.5 mg/cm^2 2 pμA 8.5 pb 4 /day@GARIS

ε_{total}= 10%
10 events/month !

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



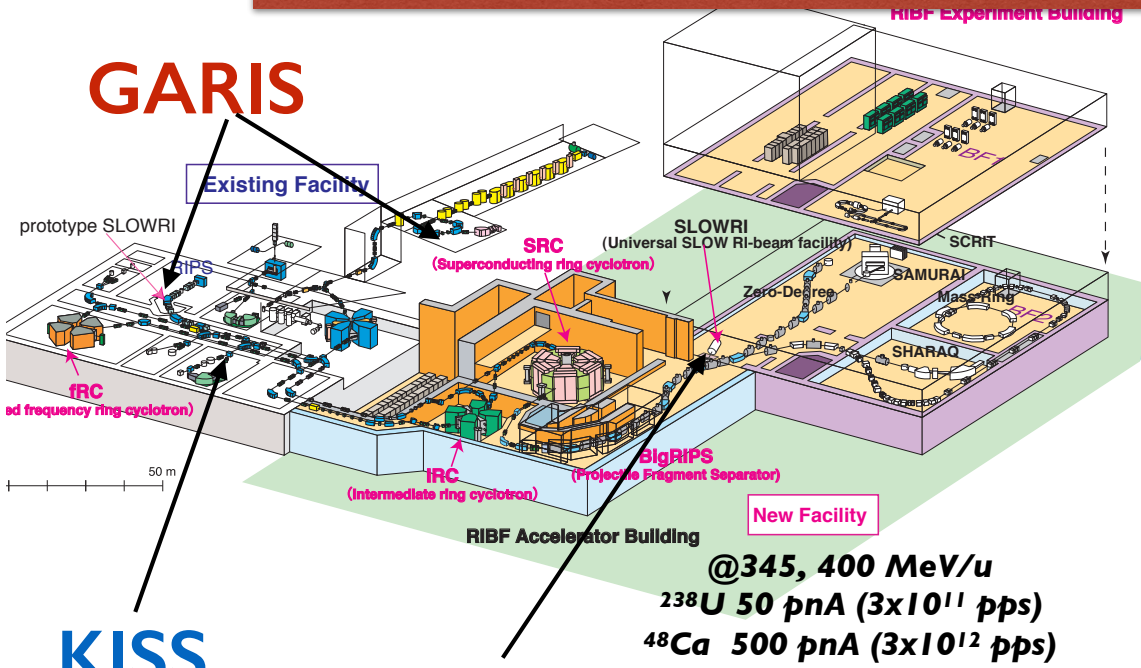


other interesting mass measurements

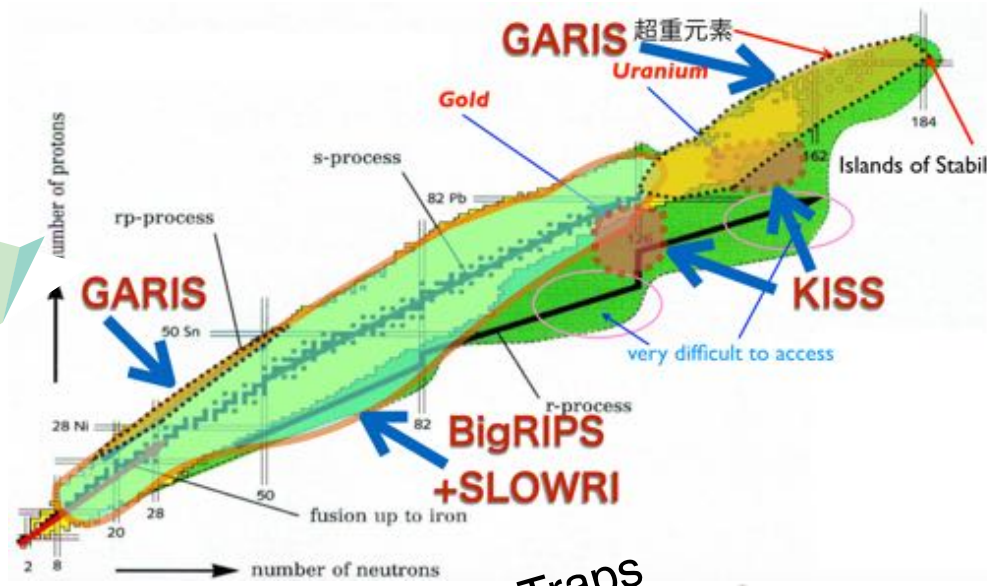
$^{248}Cm(^{14}N, 4n)^{258}Lr$ ***mass anchor for 278Nh***

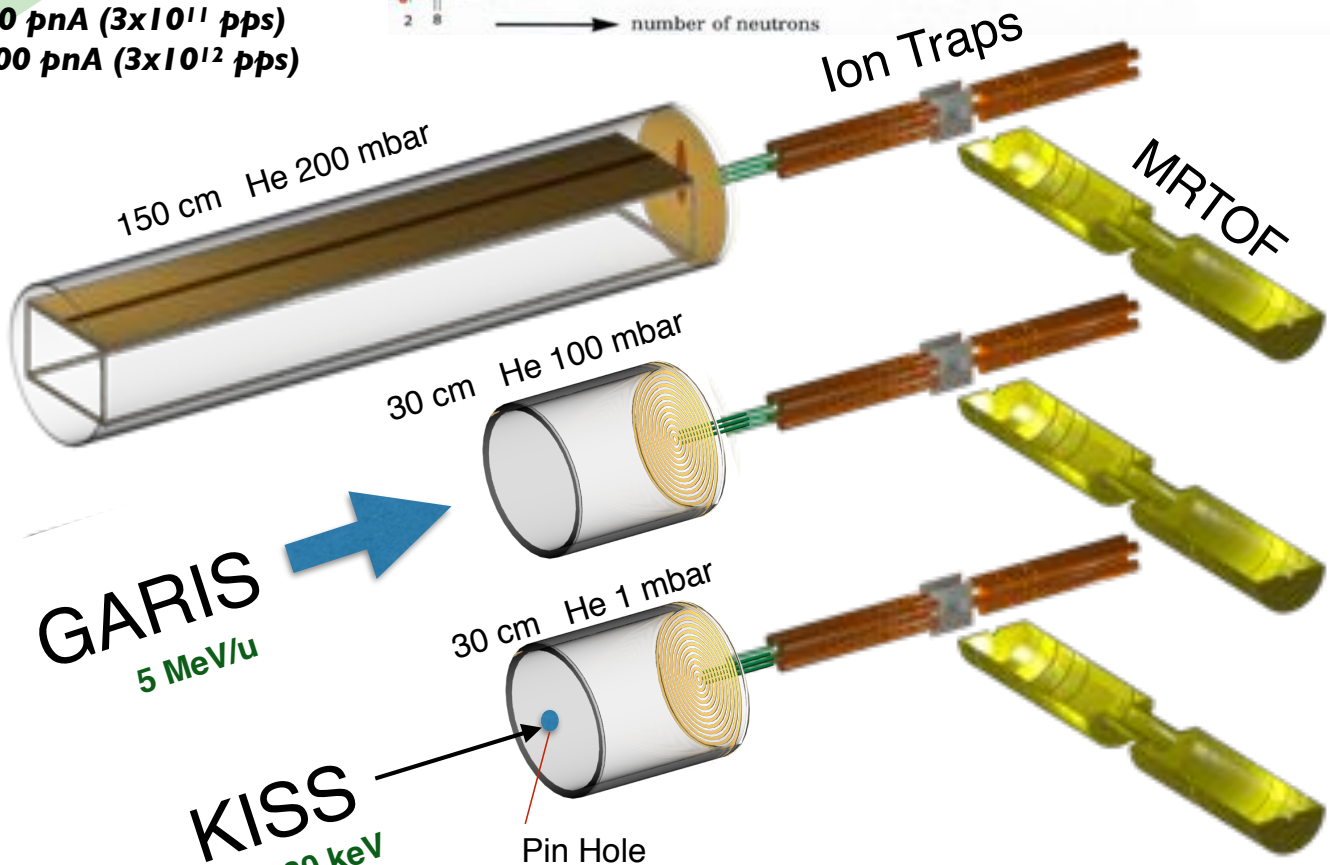
$^{244}Pu(^{48}Ca, xn)^{292-x}Fl \rightarrow ^{288-x}Cn$ ***anchor for even hot fusion SHE***

Parallel Measurements @ 3 facilities of RIKEN RIBF



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





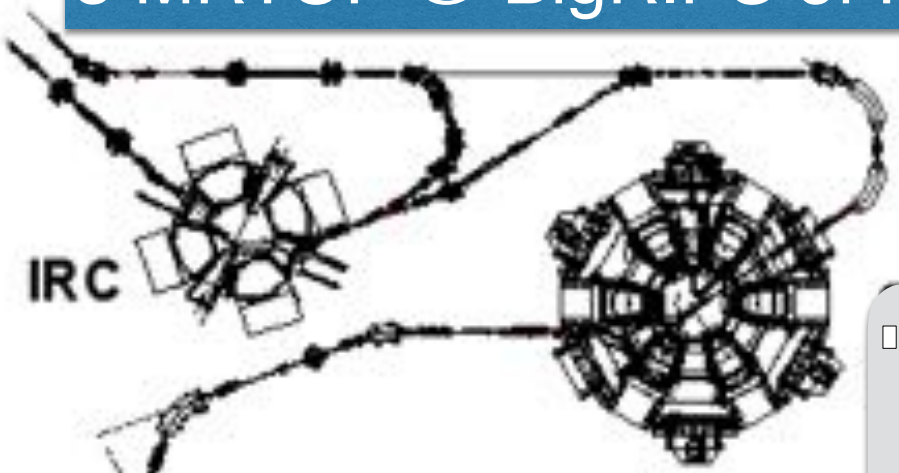
BigRIPS
200 MeV/u

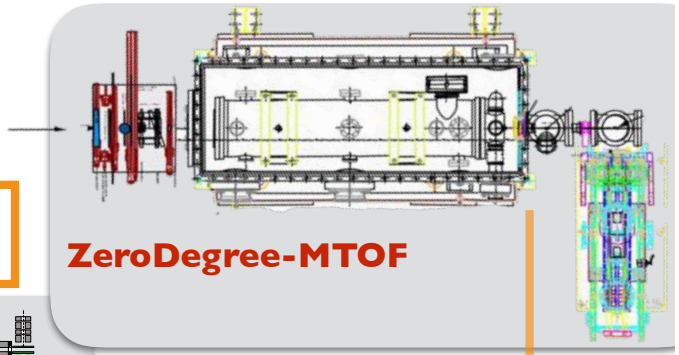
GARIS
5 MeV/u

KISS
30 keV

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

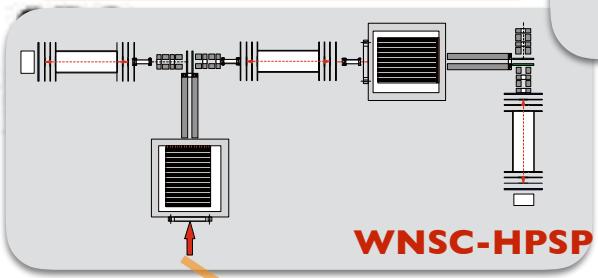
5 MRTOF @ BigRIPS of RIBF





ZeroDegree-MTOF

With pure RI, T1/2, Mass, Pn



WNSC-HPSP

@ Beam dump, 2nd 3rd reaction products, with free

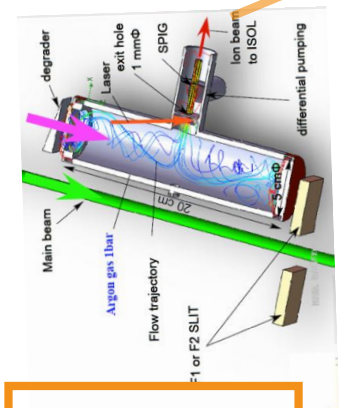
SLOWRI

ZeroDegree

BigRIPS

SAMURAI

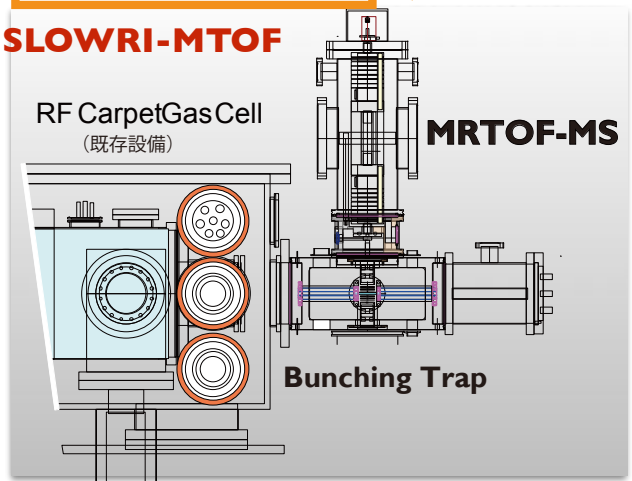
PALIS-MTOF



Utilize garbage ions at slits

Cocktail beam of BigRIPS

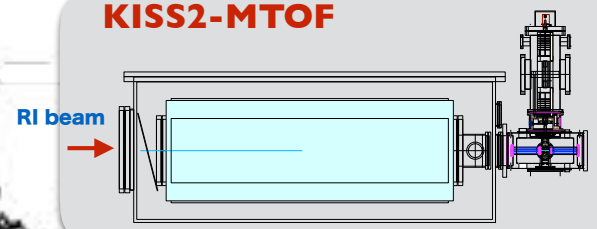
SLOWRI-MTOF



OEDO Line

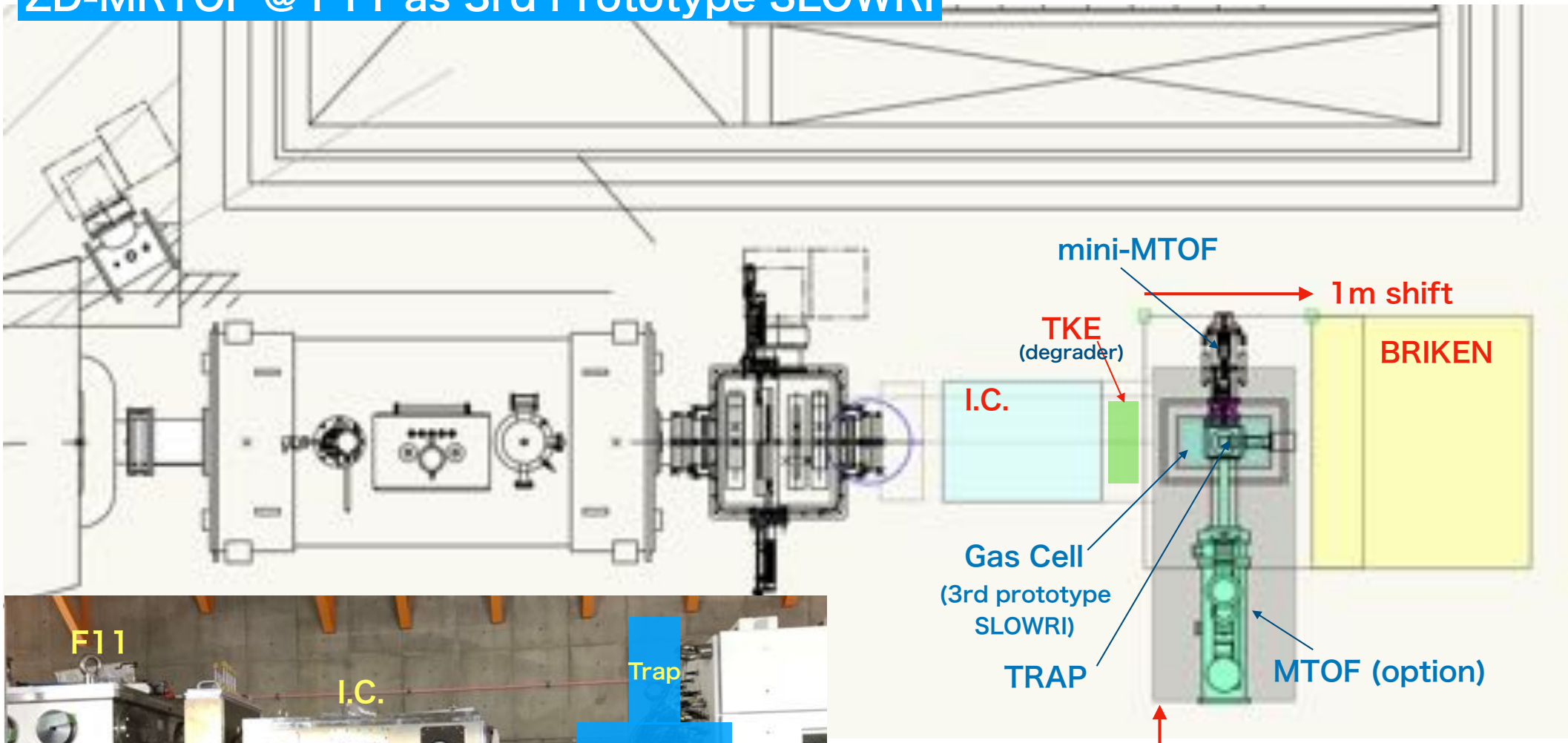
Multi-nucleon transfer products with 10 MeV/u RI-beam

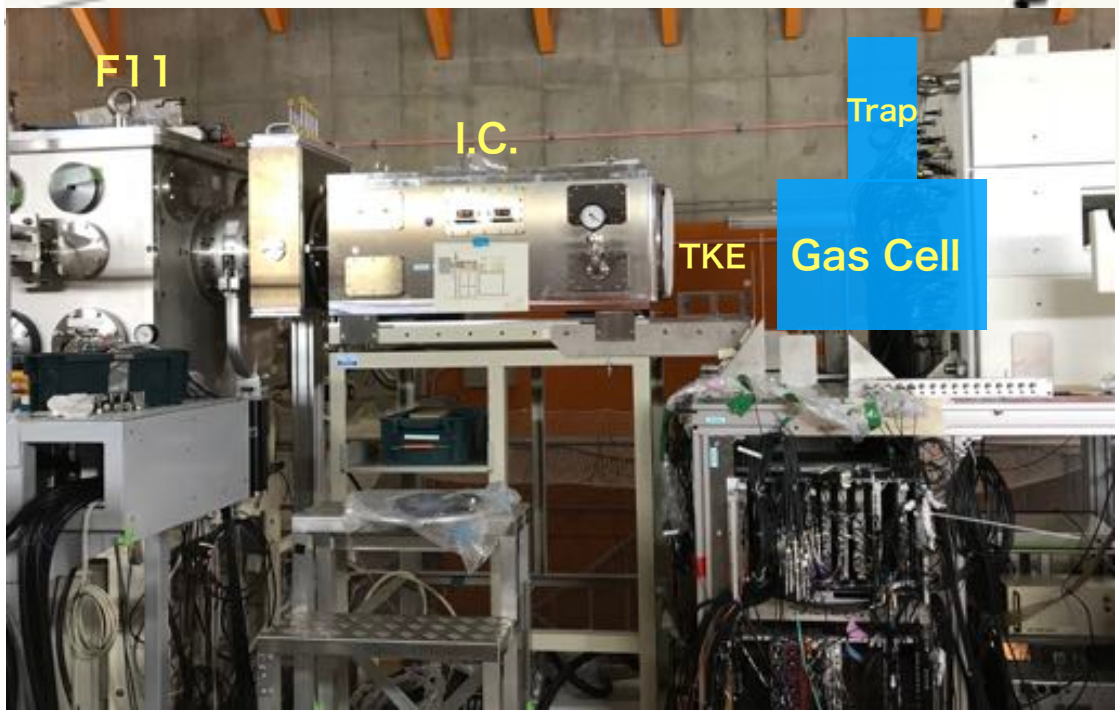
KISS2-MTOF



0 10 20 m

ZD-MRTOF @ F11 as 3rd Prototype SLOWRI





@F11 Symbiotic Experiment will be run

e.g.

* Interaction σ exp.
* In-beam γ exp.

after their measurements, all garbage goes to F11

mass measurement can use them without extra charge

Case study:

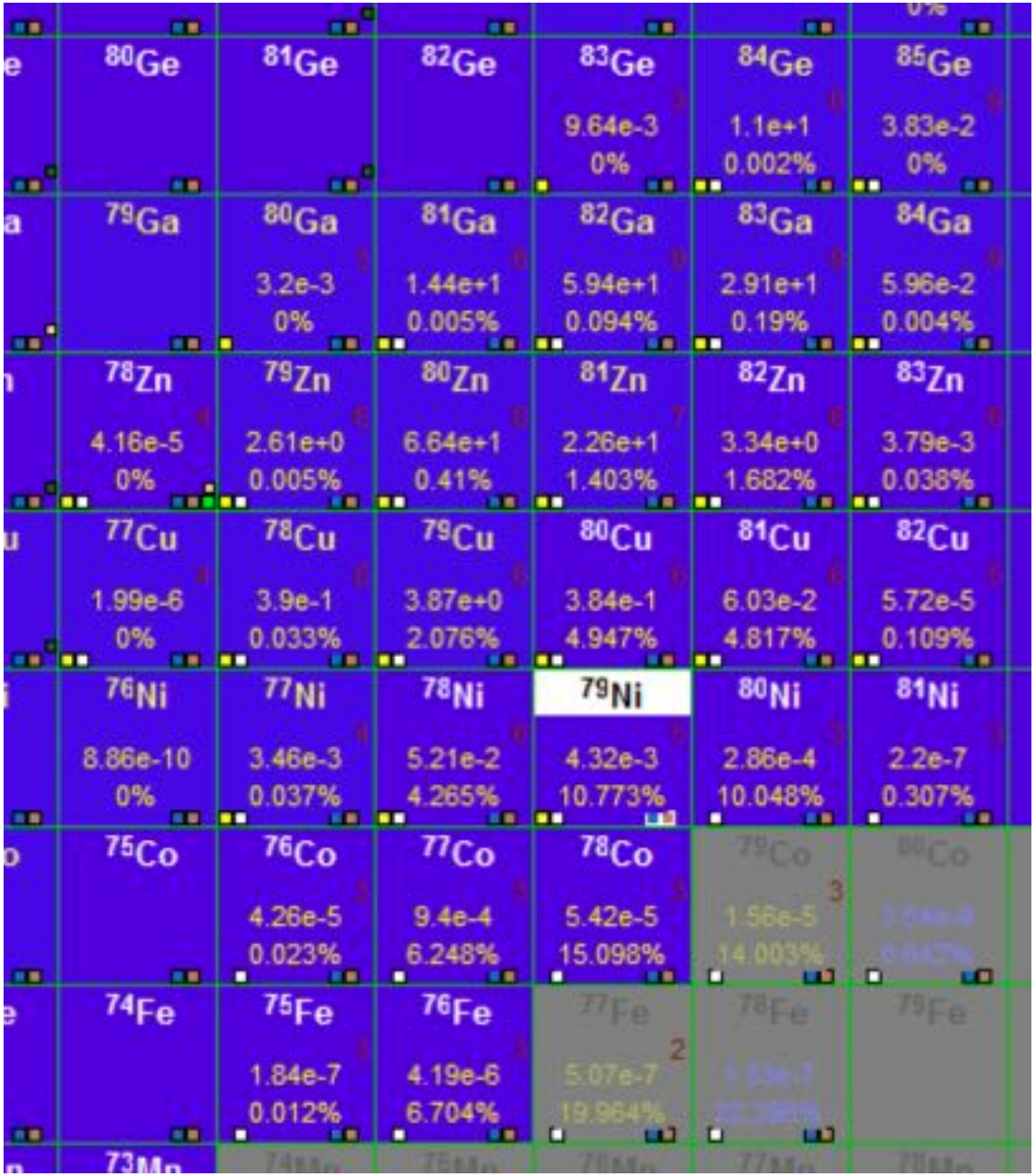
In-beam exp for 79Ni region

40 pnA U beam

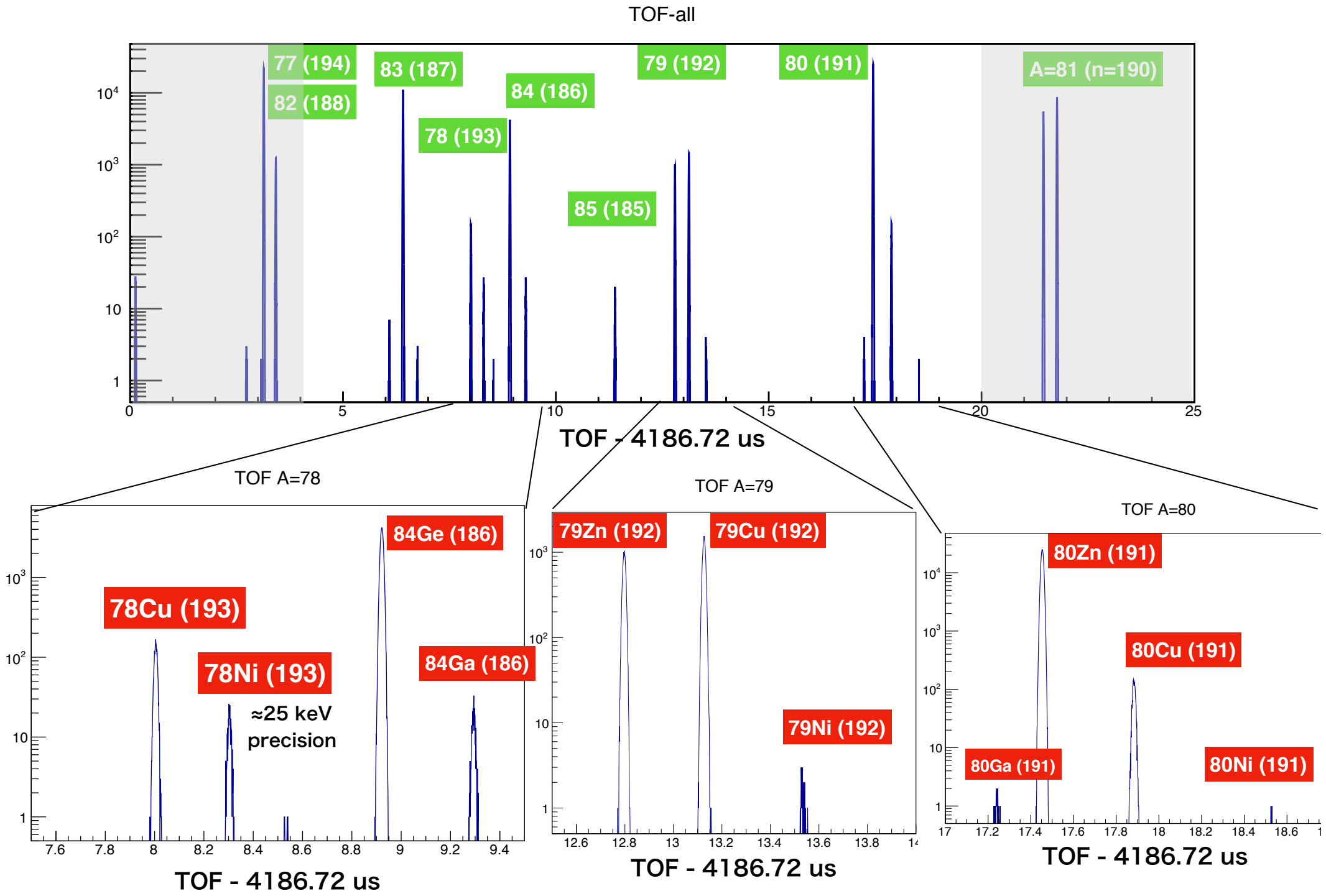
A week of run

1% our total efficiency

What is expected?

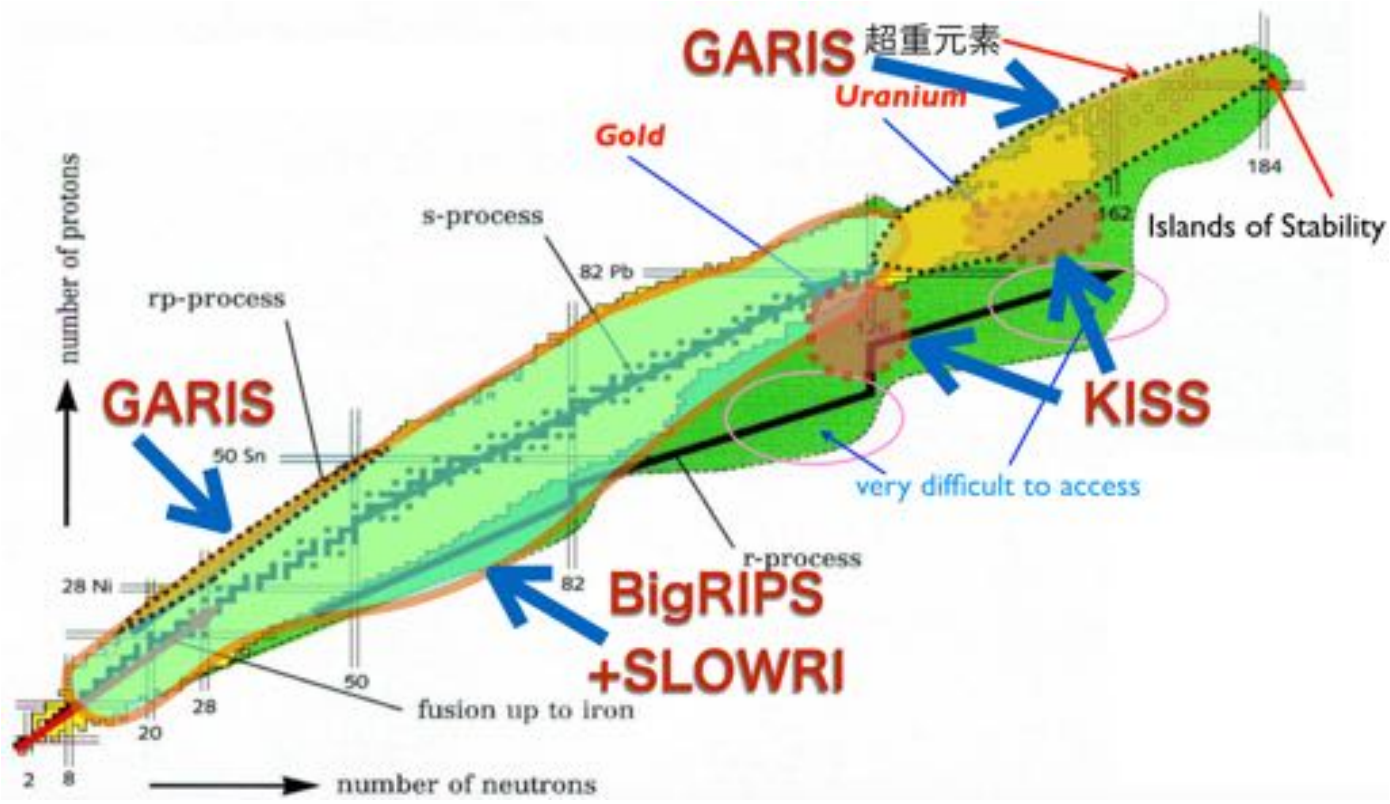


Expected TOF Spectrum (simulation)



Summary

- MRTOF is compatible to short-lived nuclei
- Efficient mass spectrograph (multiple nuclides at once)
- Precise and Accurate (novel referencing method)
- Applicable to Super Heavy Elements
- Compatible also to r-process, rp-process nuclides



Collaborators for the SHE-Mass project

M. Wada, P. Schury, Y.Ito, F. Arai, S. Kimura, D. Kaji, H. Haba, K. Morimoto, M. Rosensuch, I.Murray, J.Y.Moon, T. Niwase, S. Ishizawa, T. Tanaka, A.Takamine, M. Reponen, T. Sonoda, Y. Hirayama, Y.X. Watanabe, H. Miyatake, M. MacCormick, H. Koura, K. Morita, A. Ozawa, H. Wollnik

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New Mexico State University, USA