Symbiotic mass measurement with ZD-MRTOF

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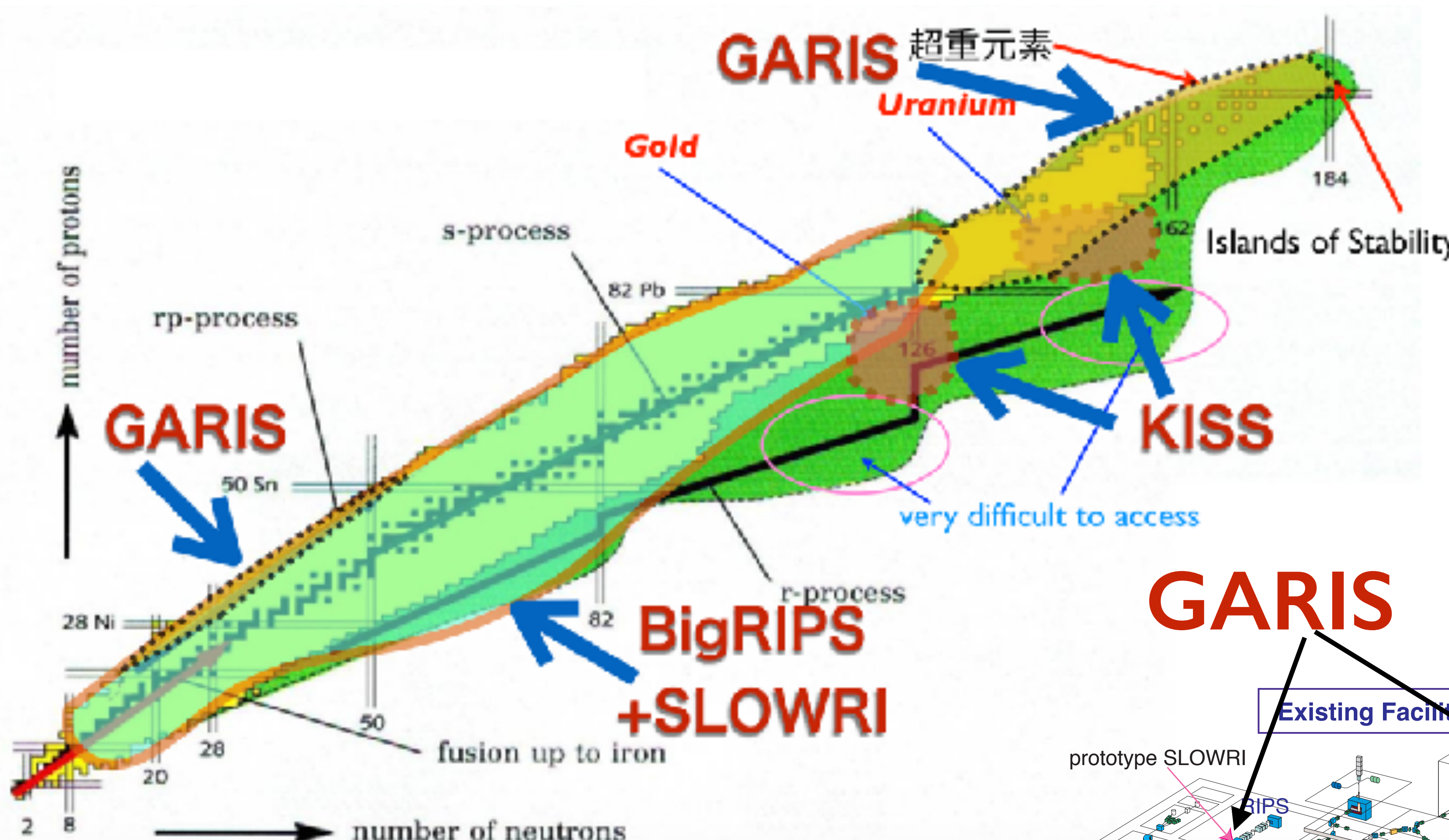
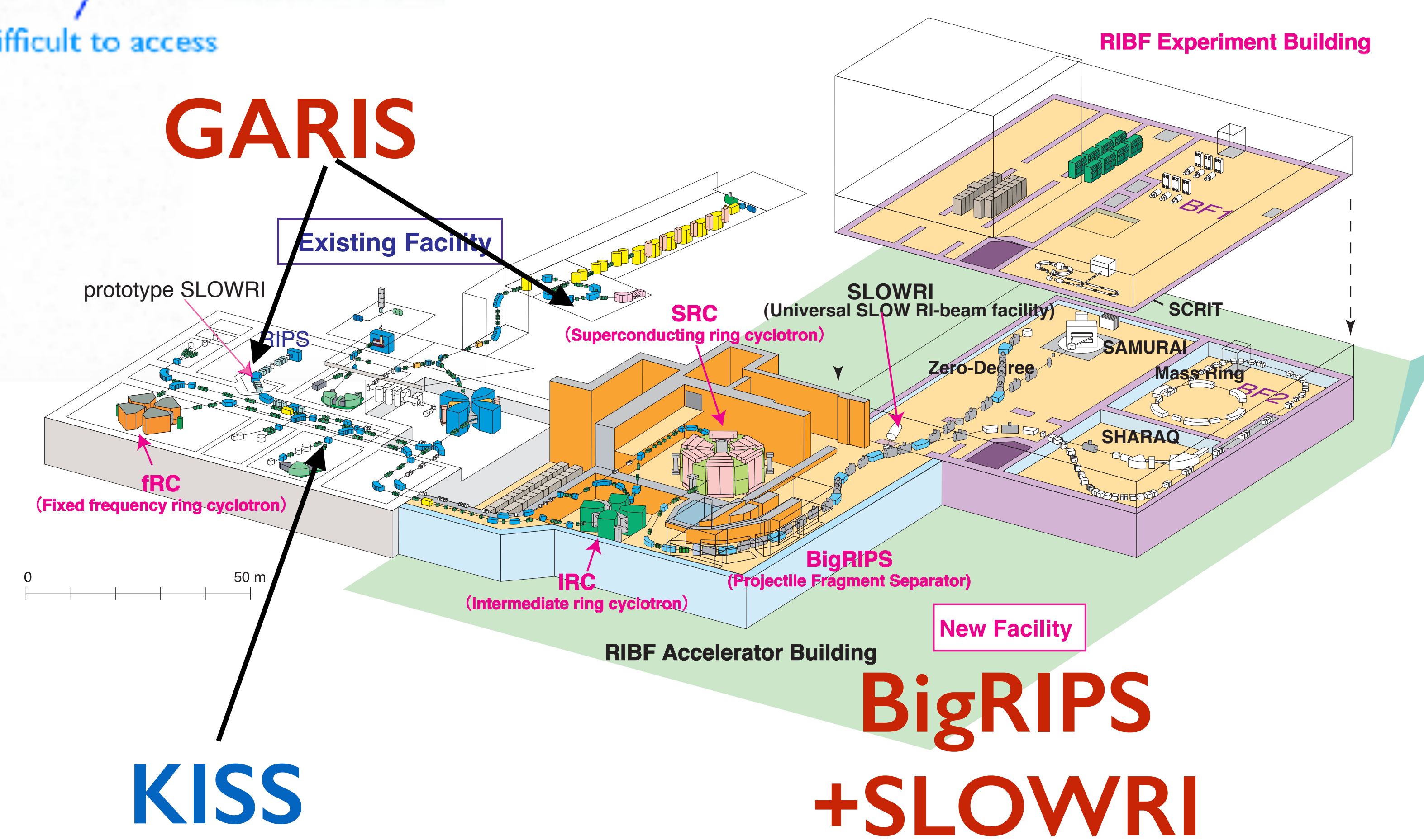




we plan to measure all available nuclides at RIBF, using multiple MRTOF mass spectrographs cf. AME2016

Masses to be measured

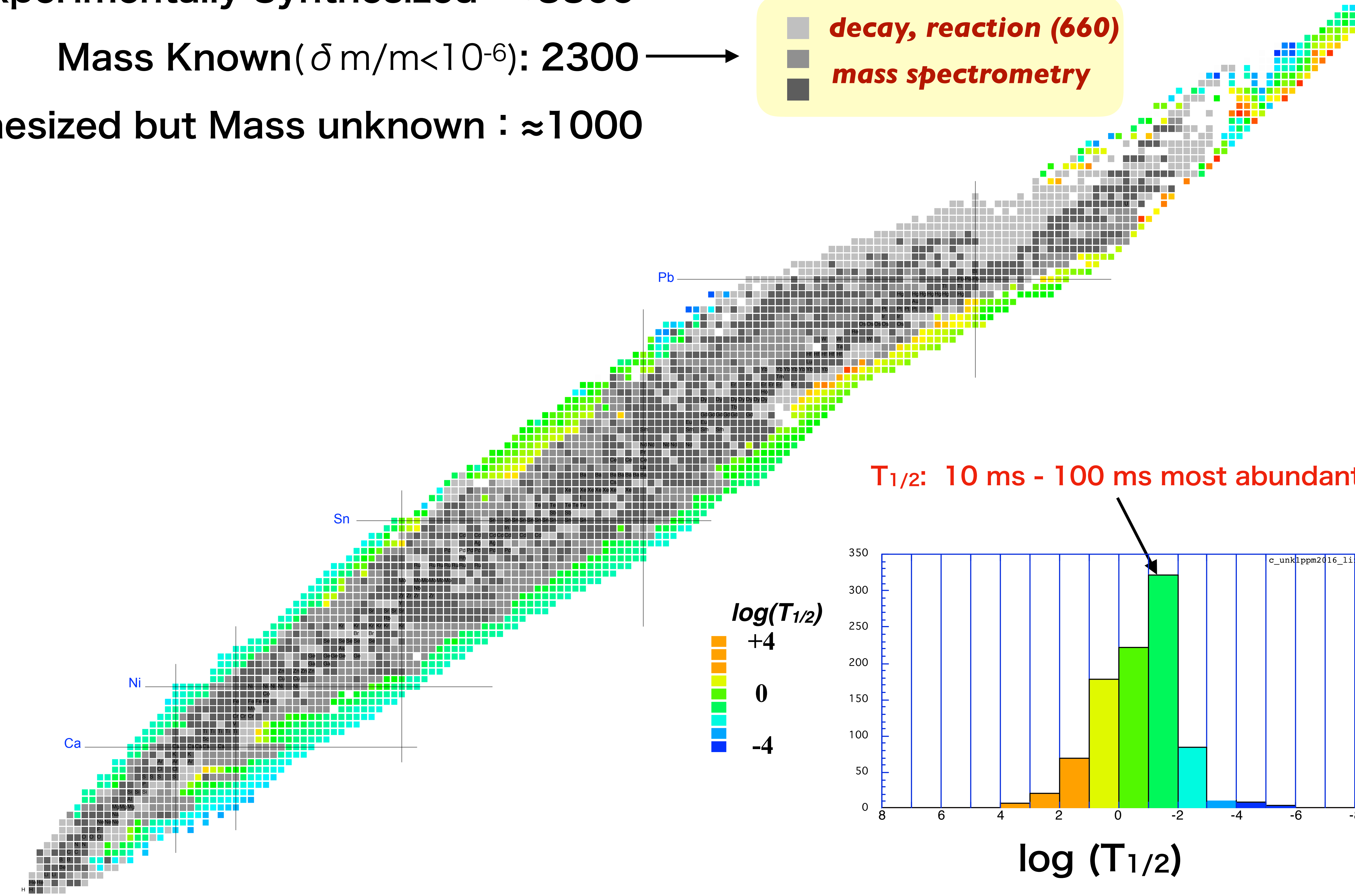
note: many known masses were measured indirectly

Experimentally Synthesized : ≈3300

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

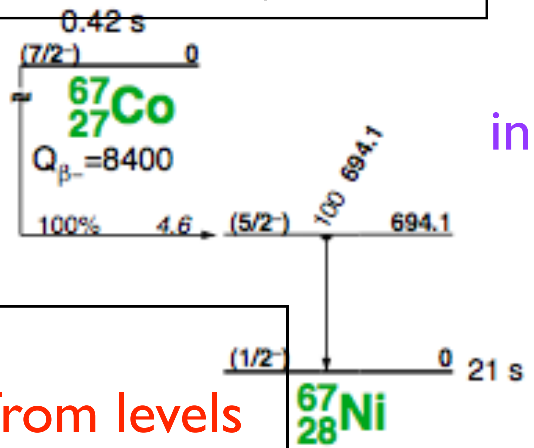
- ***decay, reaction (660)***
- ***mass spectrometry***

Synthesized but Mass unknown : ≈1000



Mass Measurements of Short-lived Nuclei

Q-value (decay or reaction)

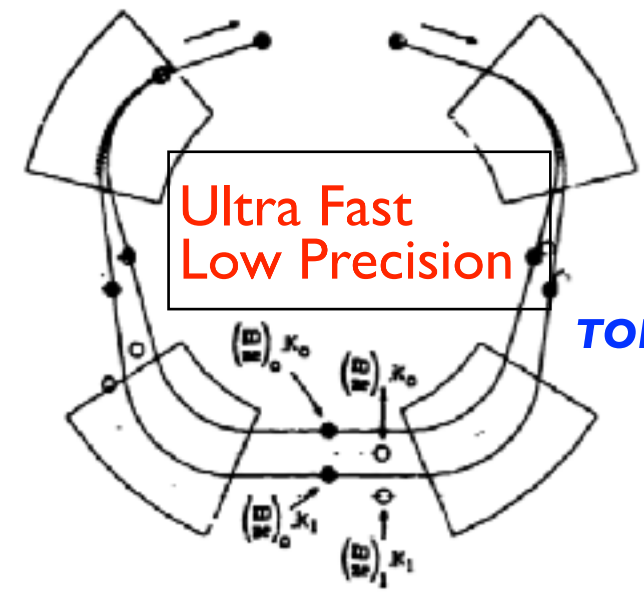


Universal
Ambiguity from levels

indirect

direct

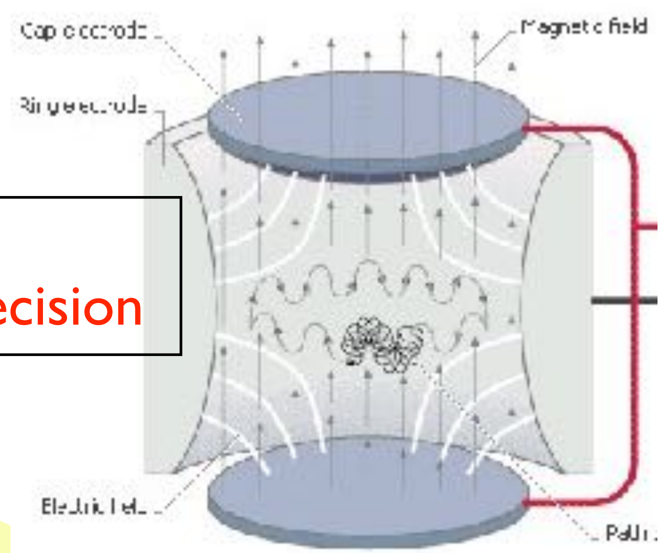
In-flight spectrometer



Ultra Fast
Low Precision

TOFI, SPEG ..

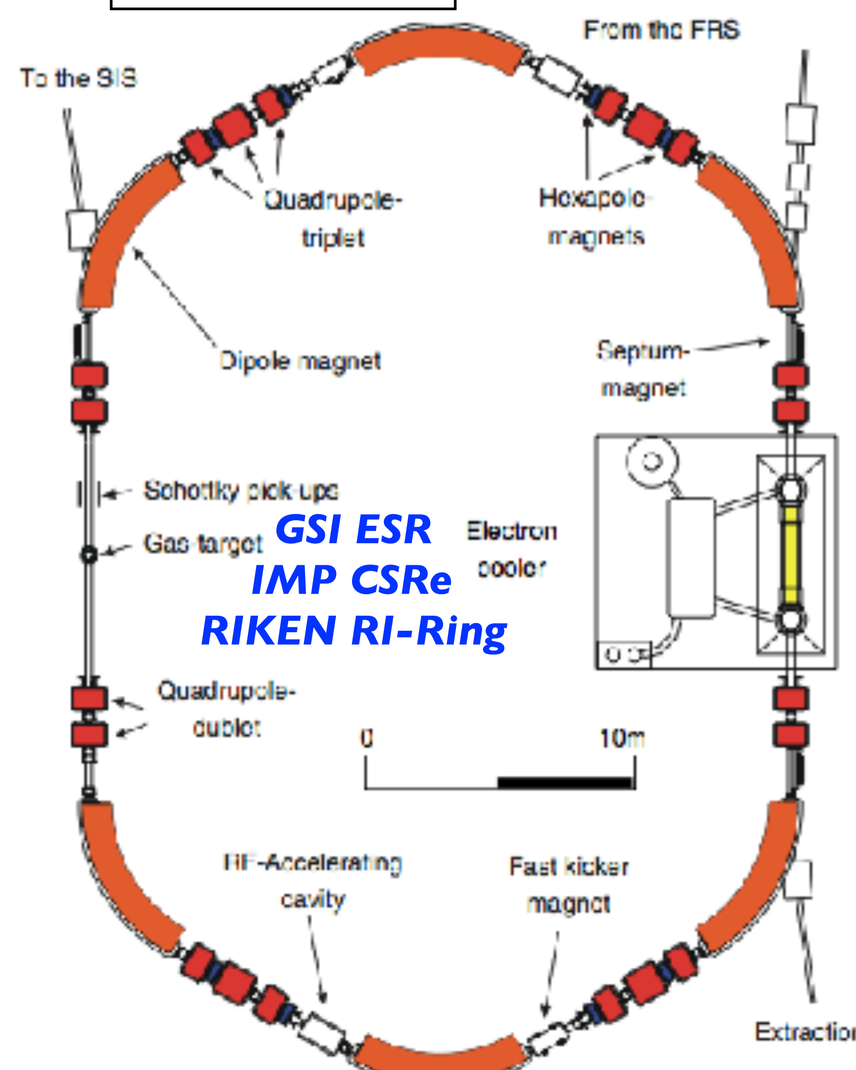
Penning Trap



Slow
Ultra precision

ISOLDE, JYFL...

Storage Ring



GSI ESR
IMP CSRe
RIKEN RI-Ring

Electron Cooling

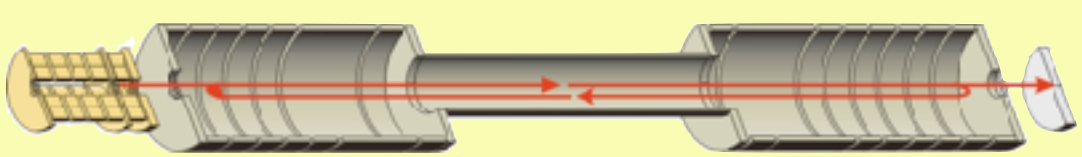
Very Slow
High Precision

Isochronous

Fast
Low Precision

New method

MRTOF (multi-reflection TOF)

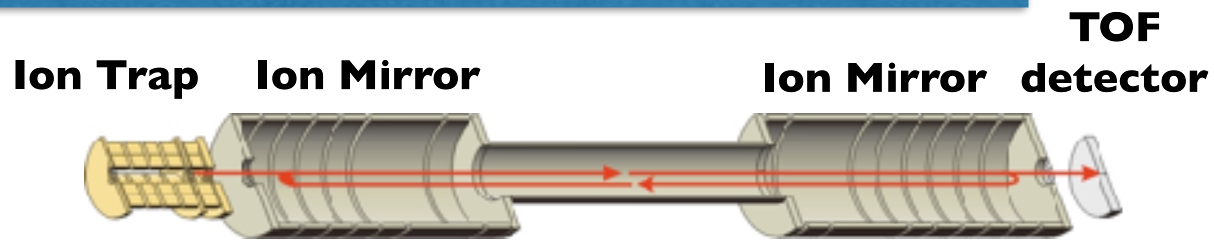


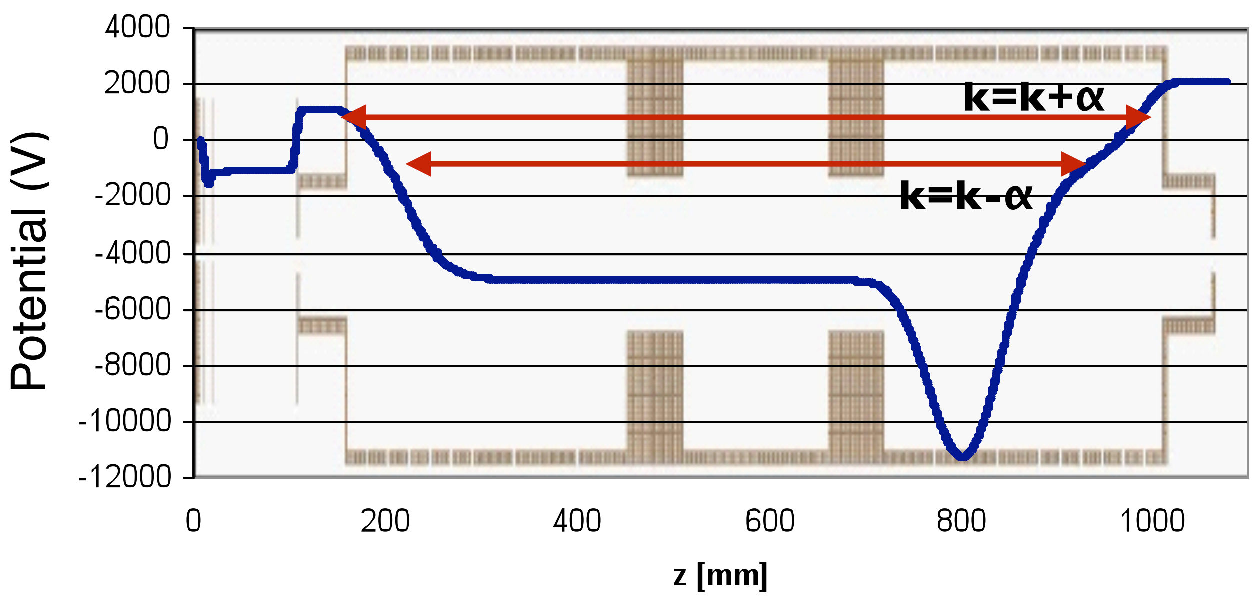
RIKEN, Giessen, ISOLDE ..

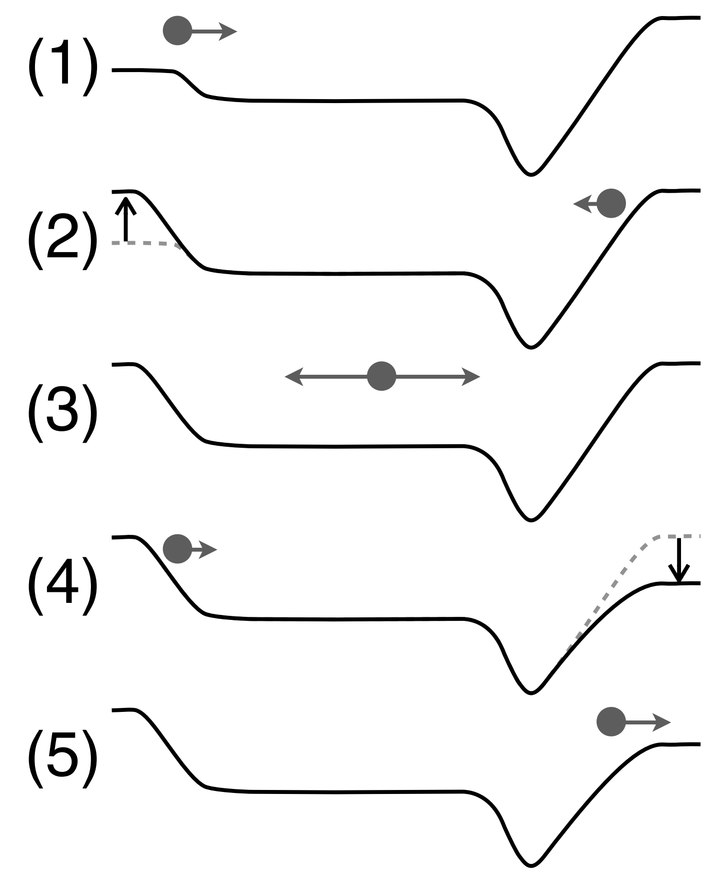
Fast
High Precision

MRTOF Mass Spectrograph

(Multi Reflection Time of Flight…)







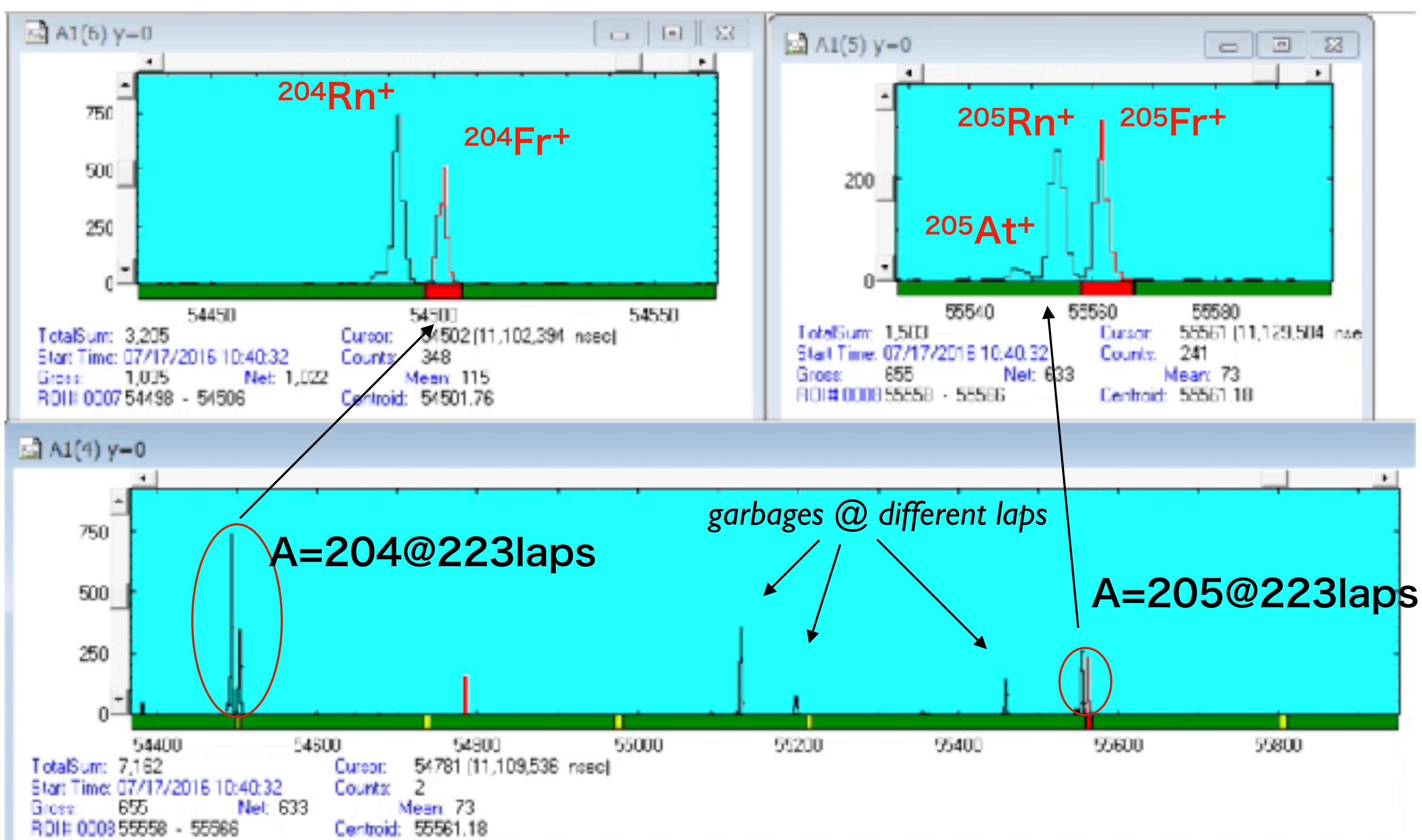
Open entrance to inject

Close entrance before coming back

go back and forth for ≈200 times

Open exit at pre-defined timing

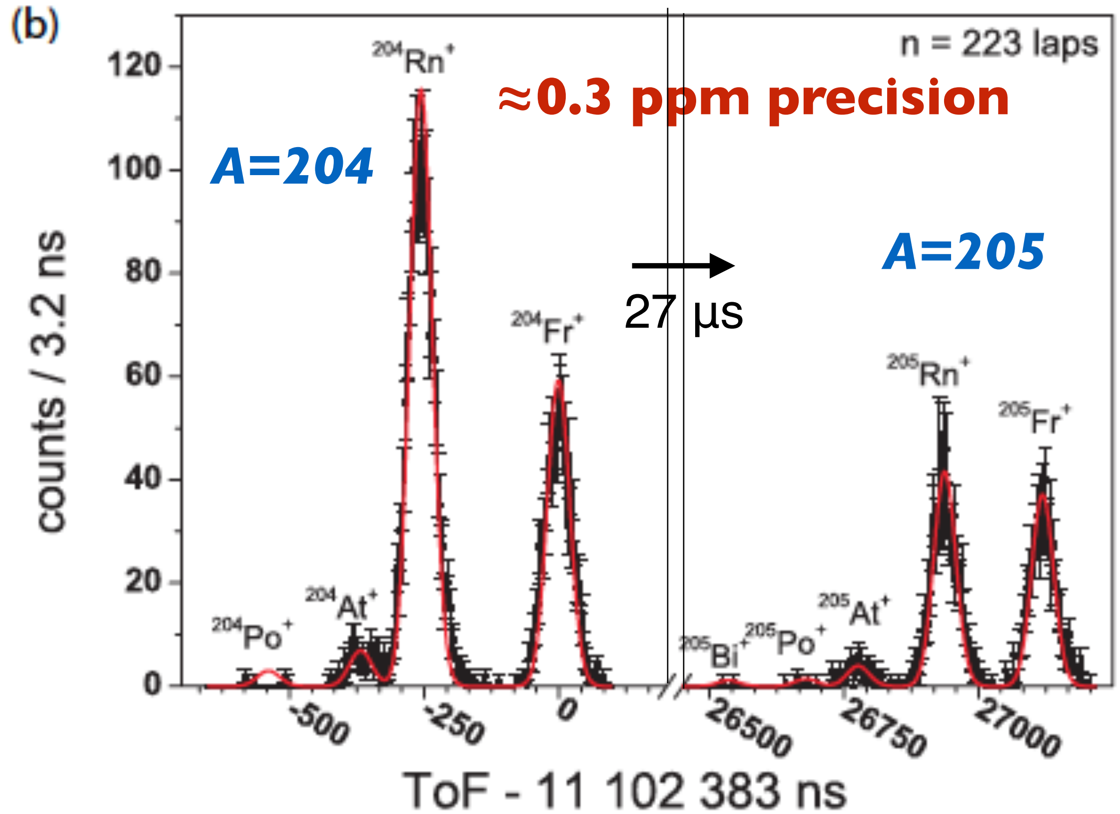
Detect ions'ToF

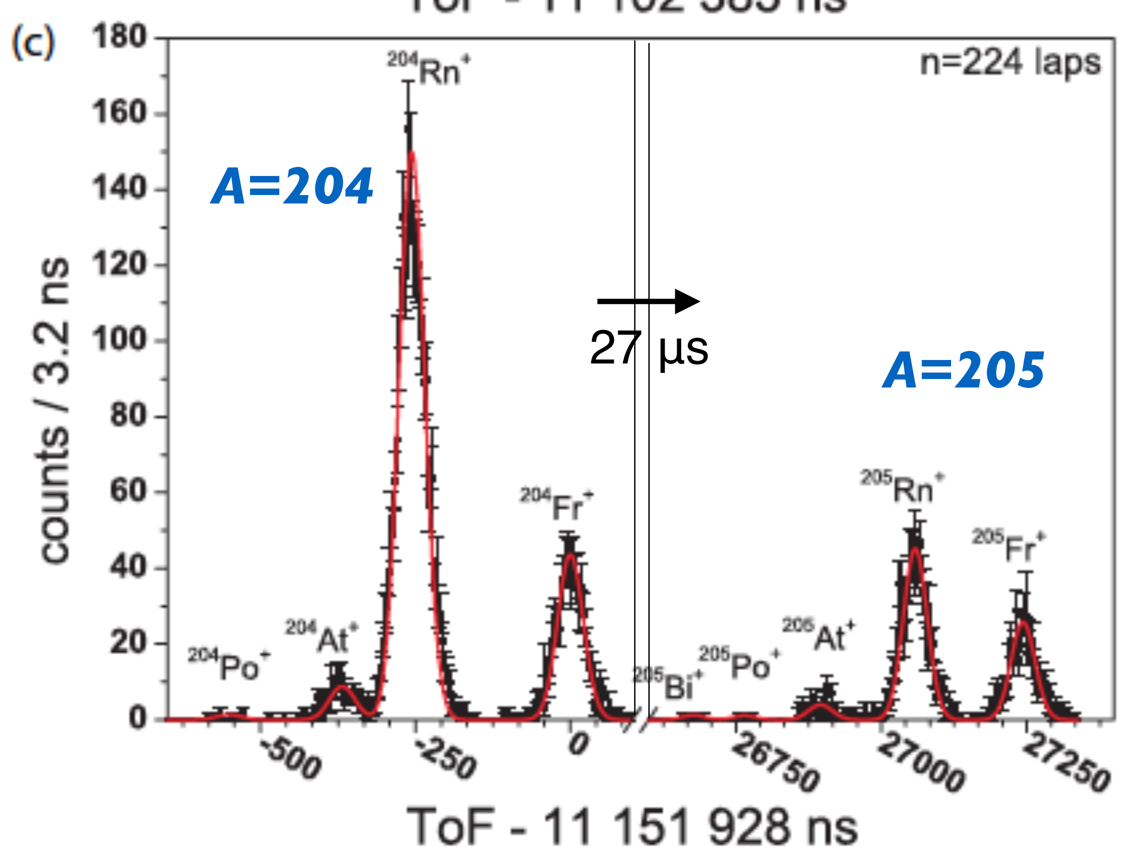


$$m_x = \left(\frac{ToF_x}{ToF_r}\right)^2 m_r$$

garbage ions can be discriminated by different number of laps

Typical Mass Measurement Results



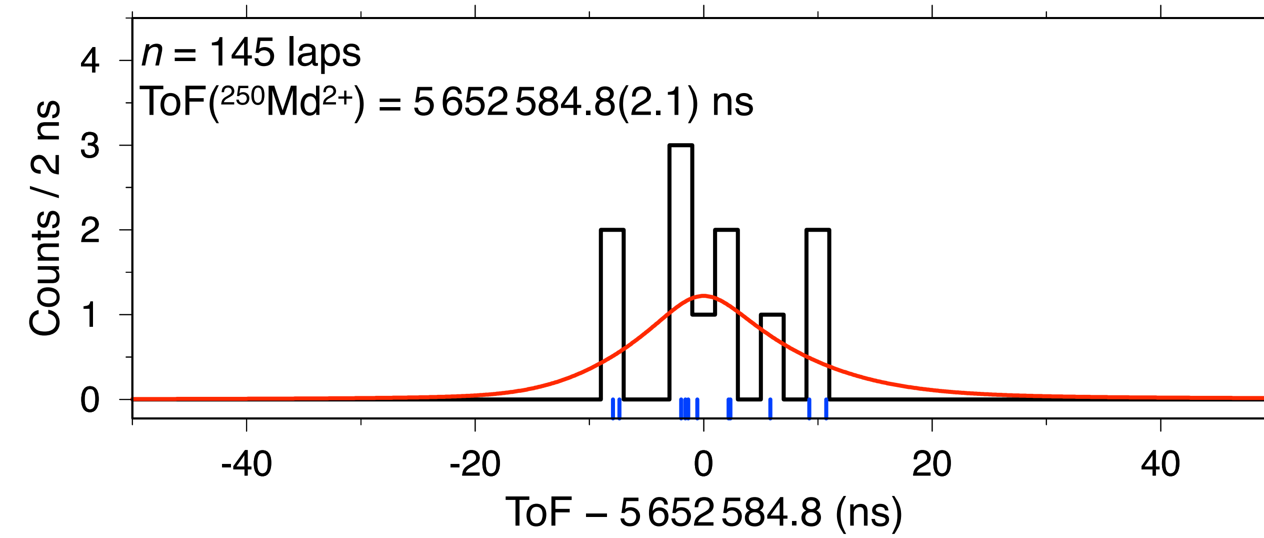


P. Schury et al, PRC 95(2017)011305(R)

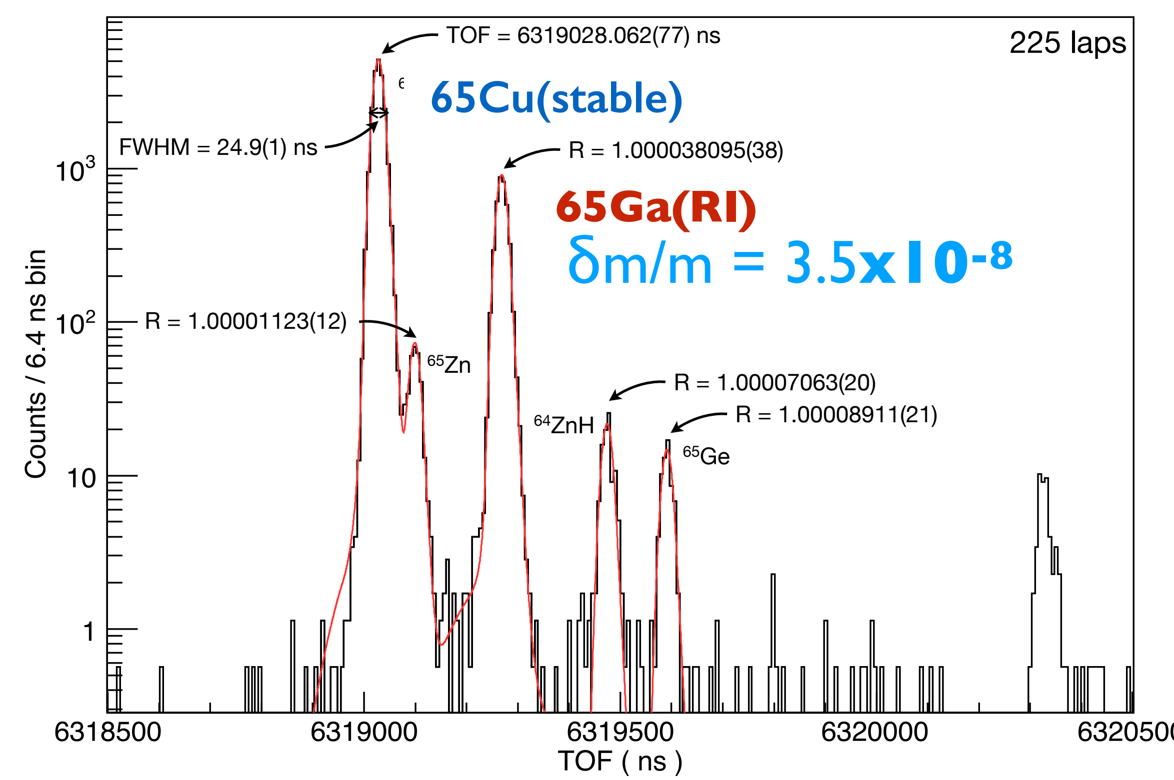
^{250}Md^{++} measurement

≈ 1 event /1000 s

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

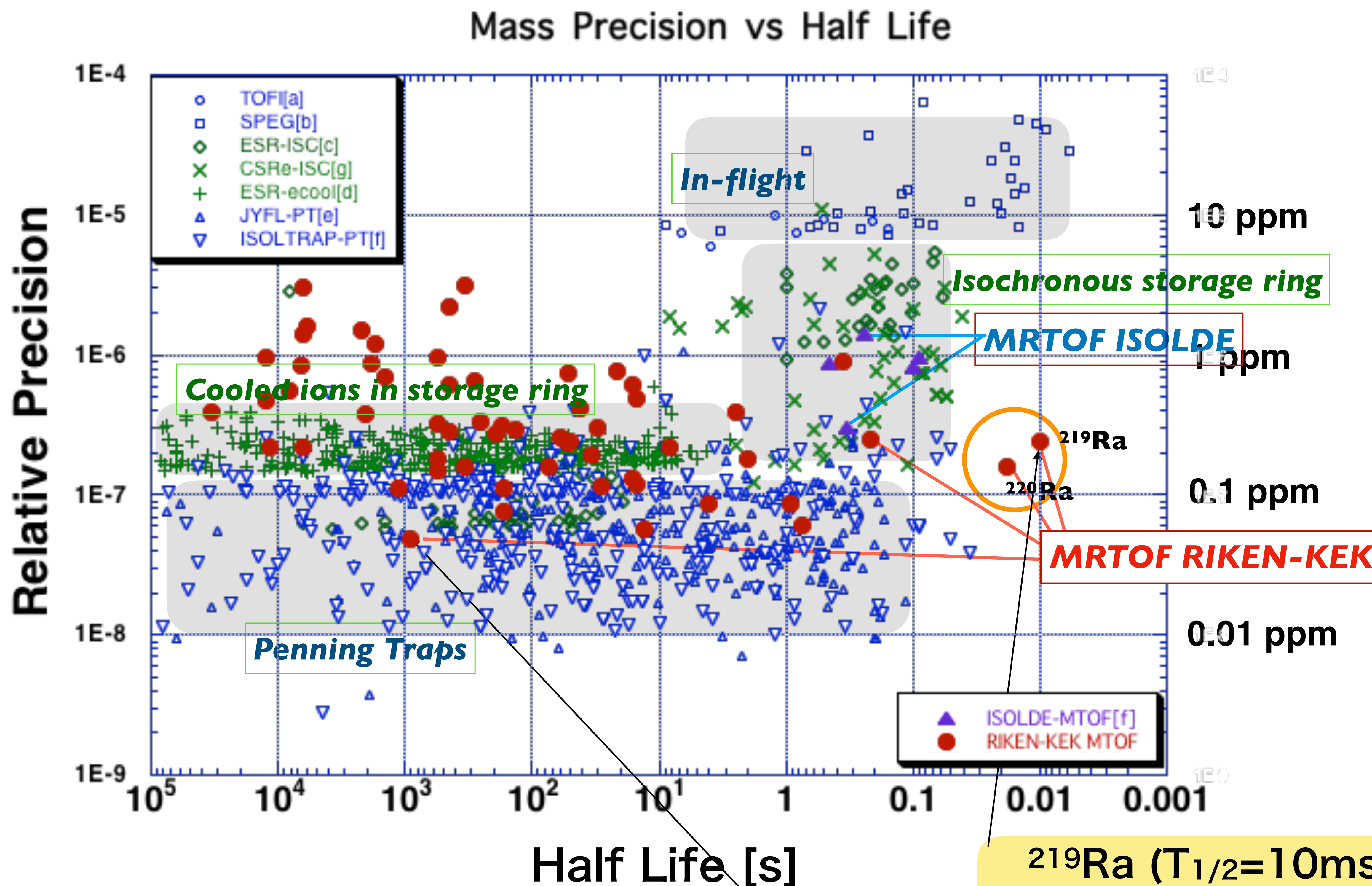


Y. Ito et al, PRL 120 (2018)0102501



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

MRTOF plays a role in Mass Measurements



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

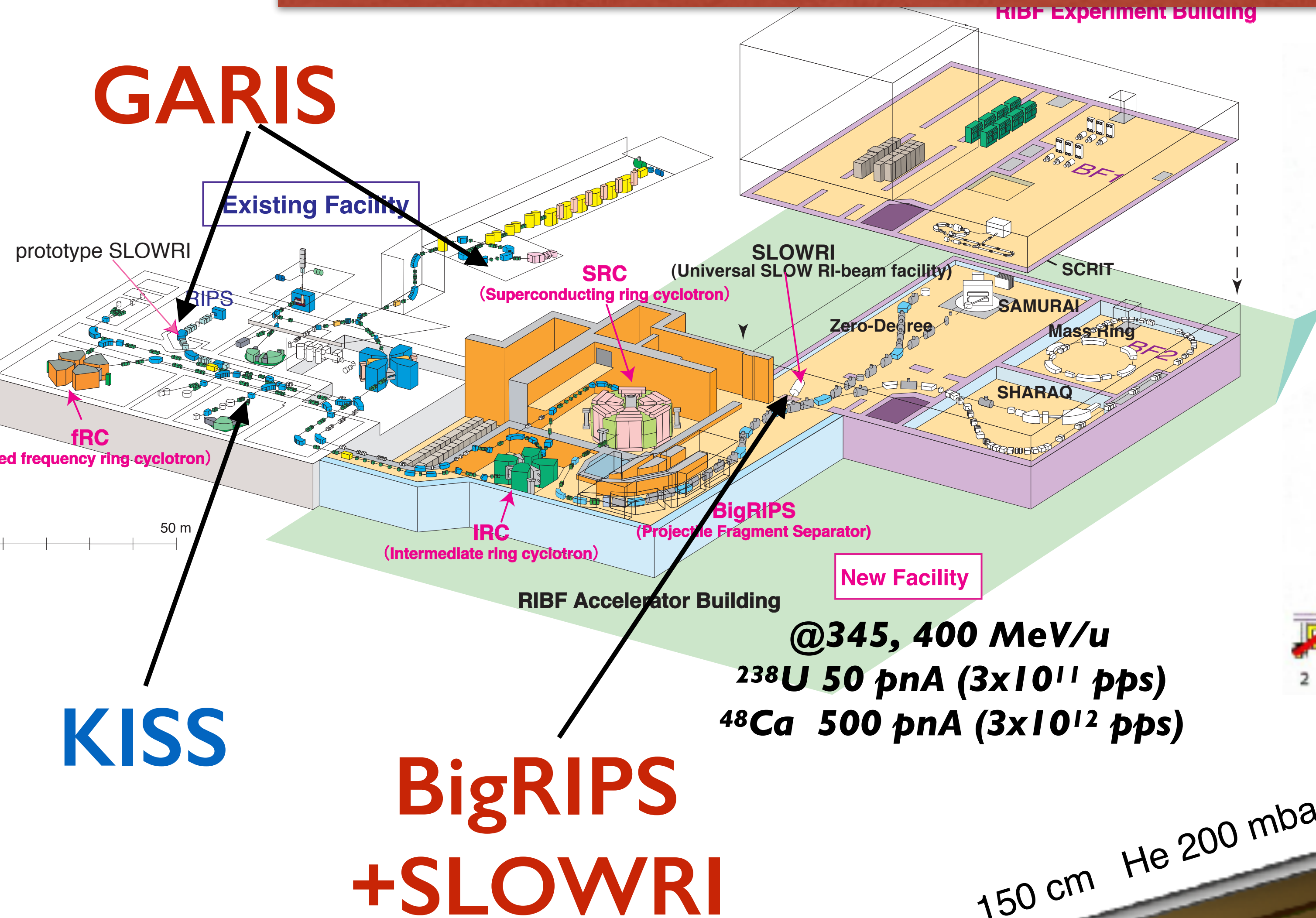
Y. Ito et al.,to be submitted

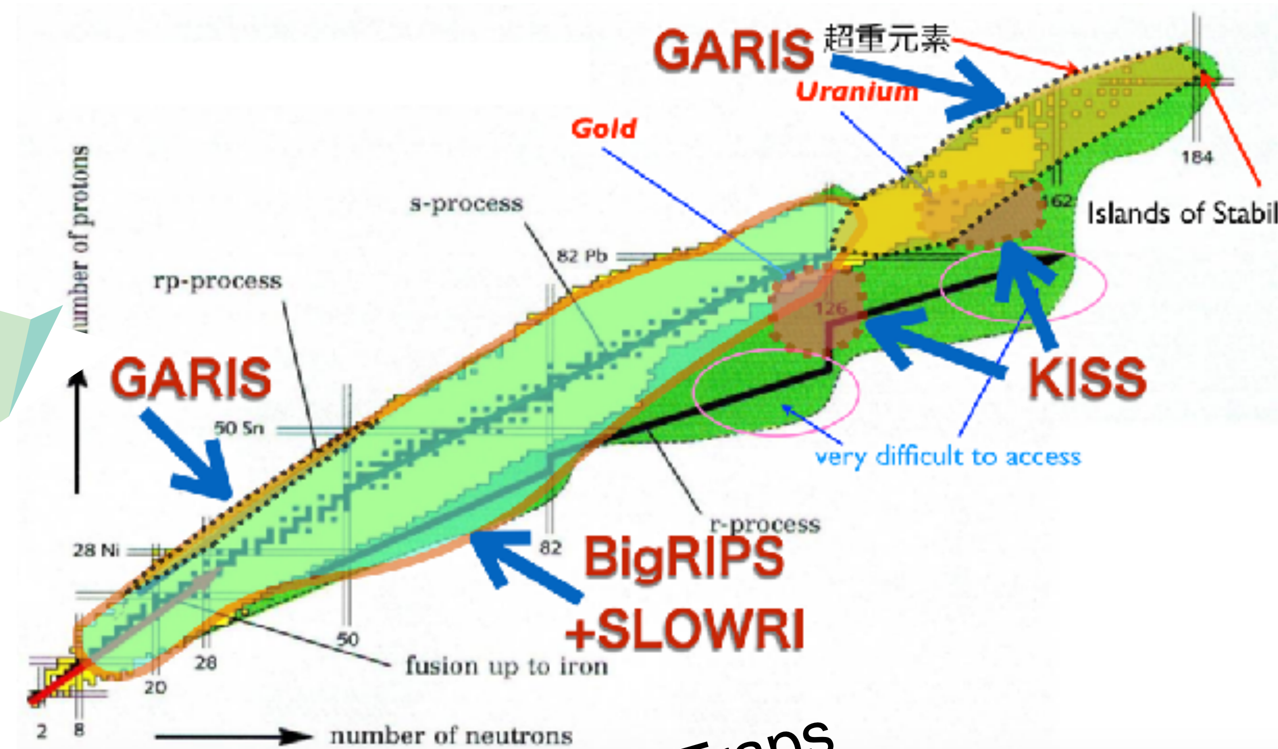
^{65}Ga: $\delta m/m=3.5\times10^{-8}$
still agree with Penning trap

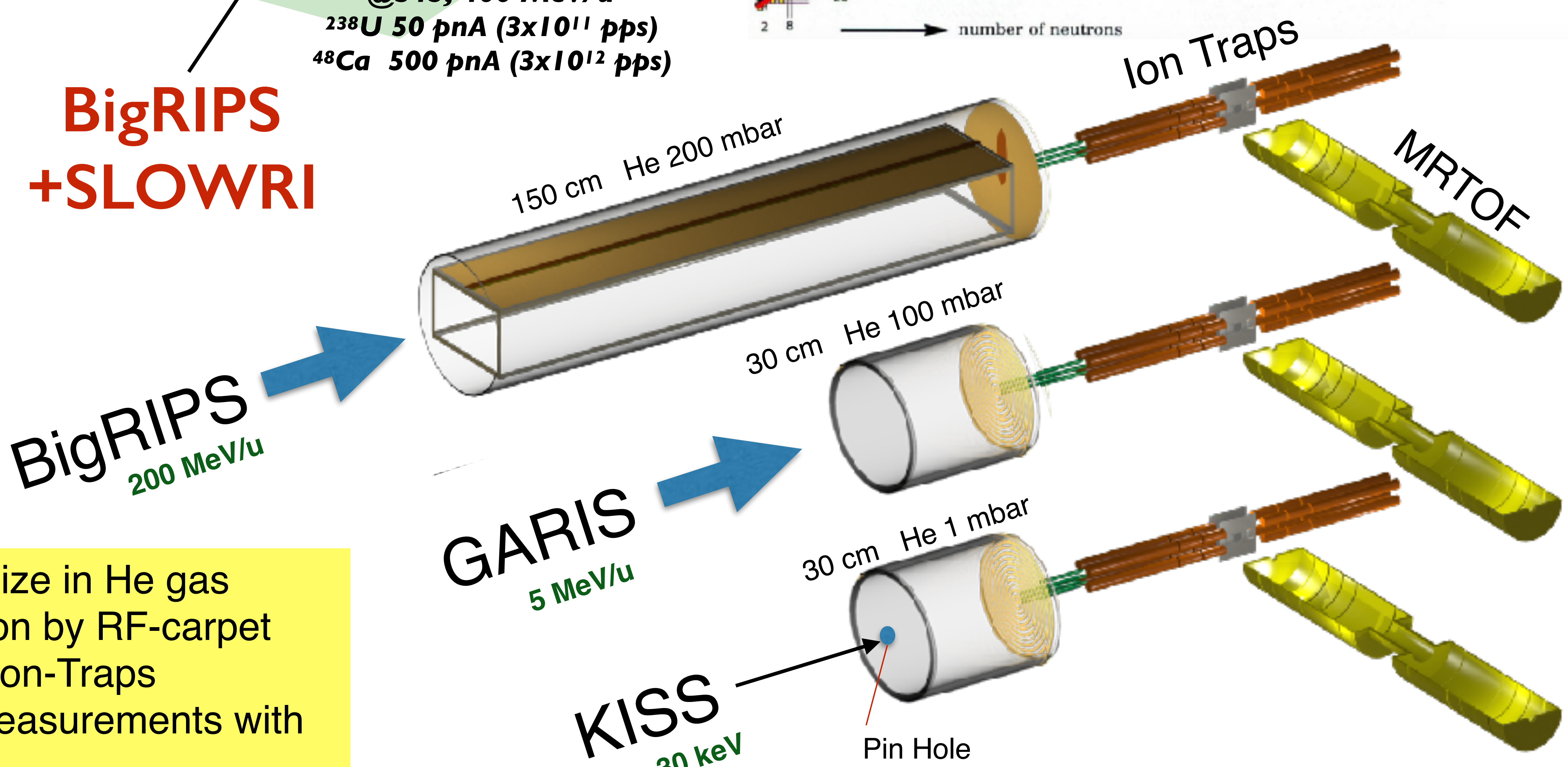
Kimura et al.,IJMS 430 (2018) 134

[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

Parallel Measurements @ 3 facilities of RIKEN RIBF

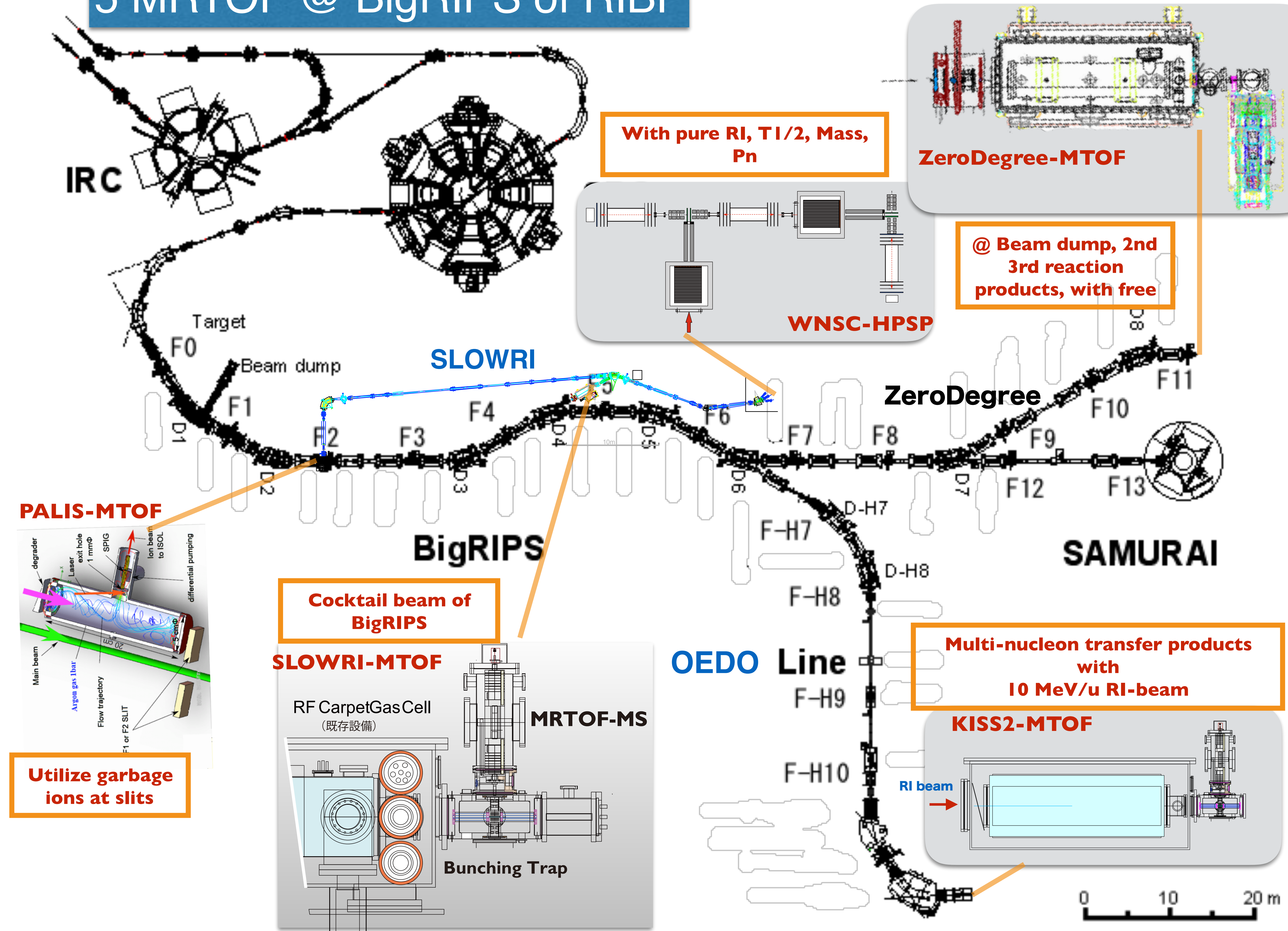




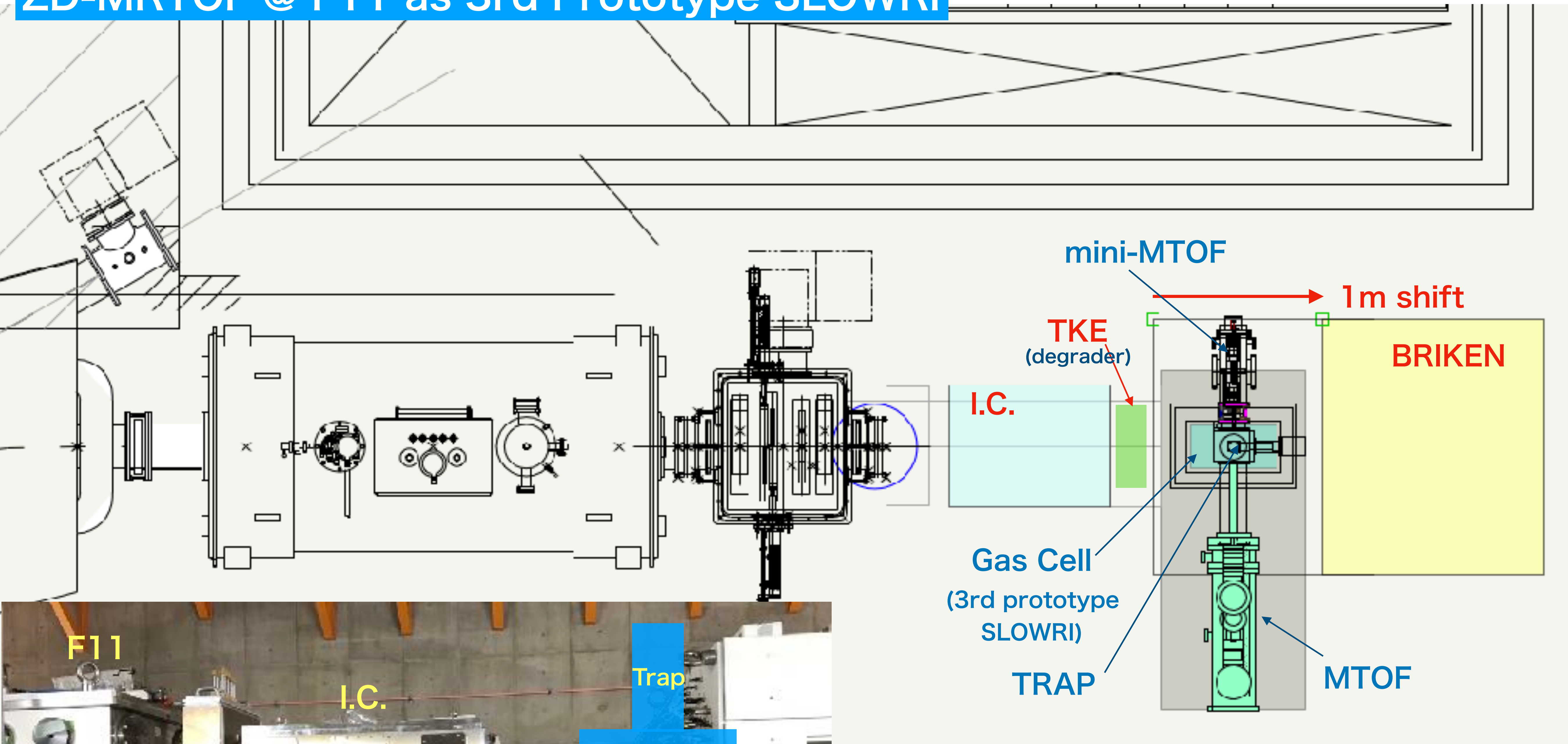


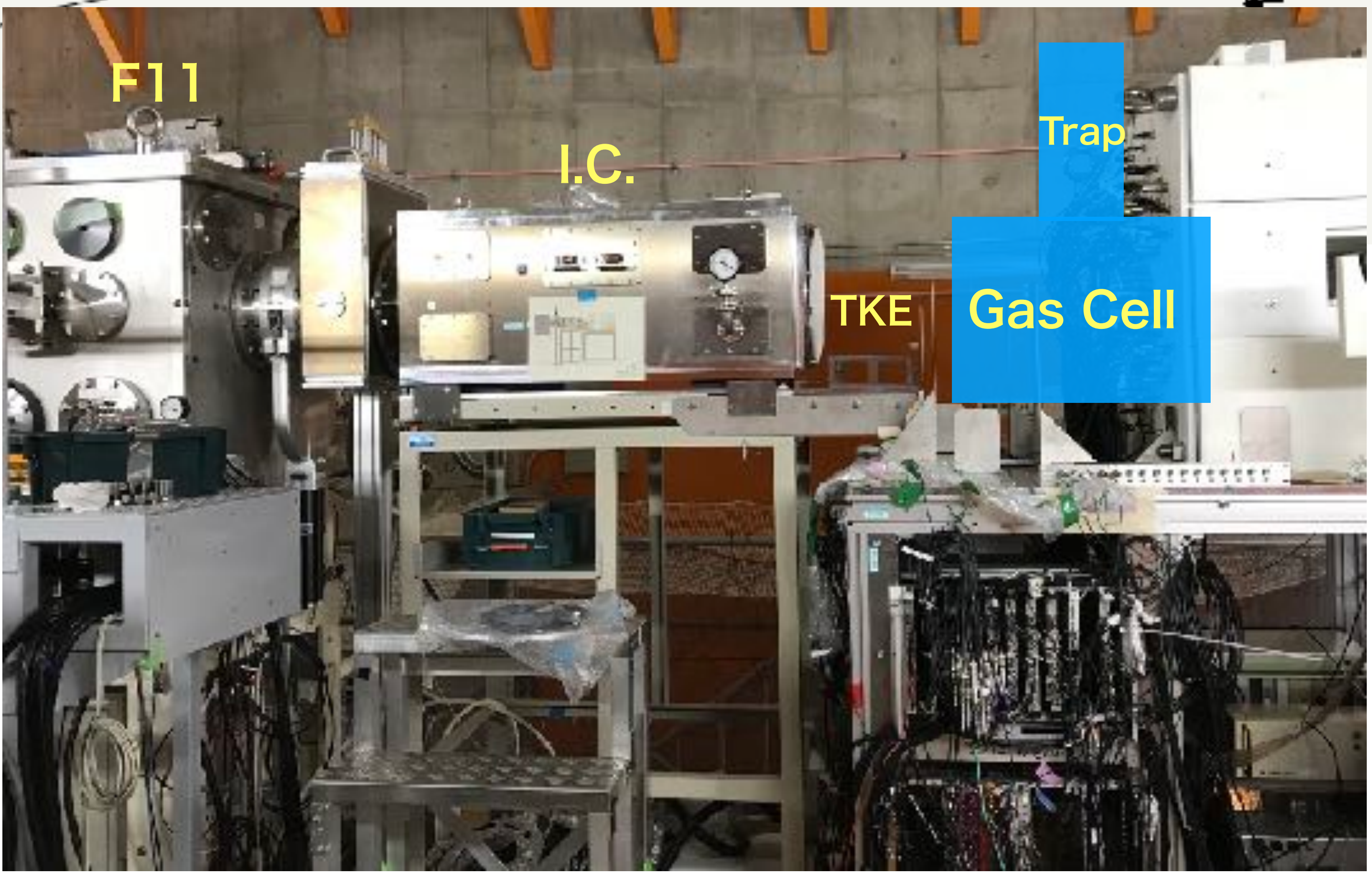
1. Thermalize in He gas
2. Extraction by RF-carpet
3. Trap in Ion-Traps
4. Mass measurements with MRTOF

5 MRTOF @ BigRIPS of RIBF



ZD-MRTOF @ F11 as 3rd Prototype SLOWRI





retractable
on rails

He: 0.2 atm 50 cm (1.8 mg/cm^2)

Stopping: ⊿E(100Mo) ≈ 0.7 MeV/u

Non dispersive - no Wedge degrader

Limited stopping @ Prototype

(cf: 3.7 MeV/u @ 1.5m cell)

SLOWRI prototype ver 1 @RIPS

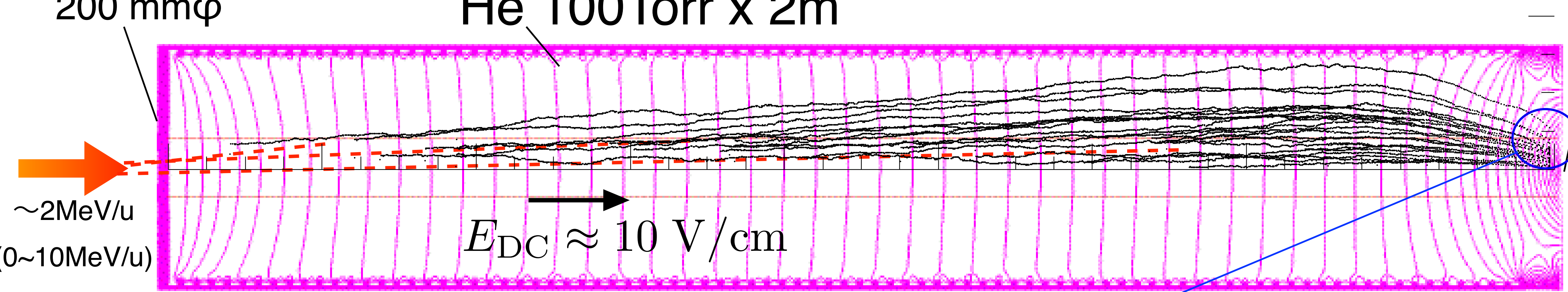
* Be-11,7 laser microwave spectroscopy

A.Takamine et al, PRL112(2014)162502.

K.Okada et al, PRL101(2008)212502.

* Li-8 MRTOF exp

Y.Ito et al, PRC88(2013)011306(R).



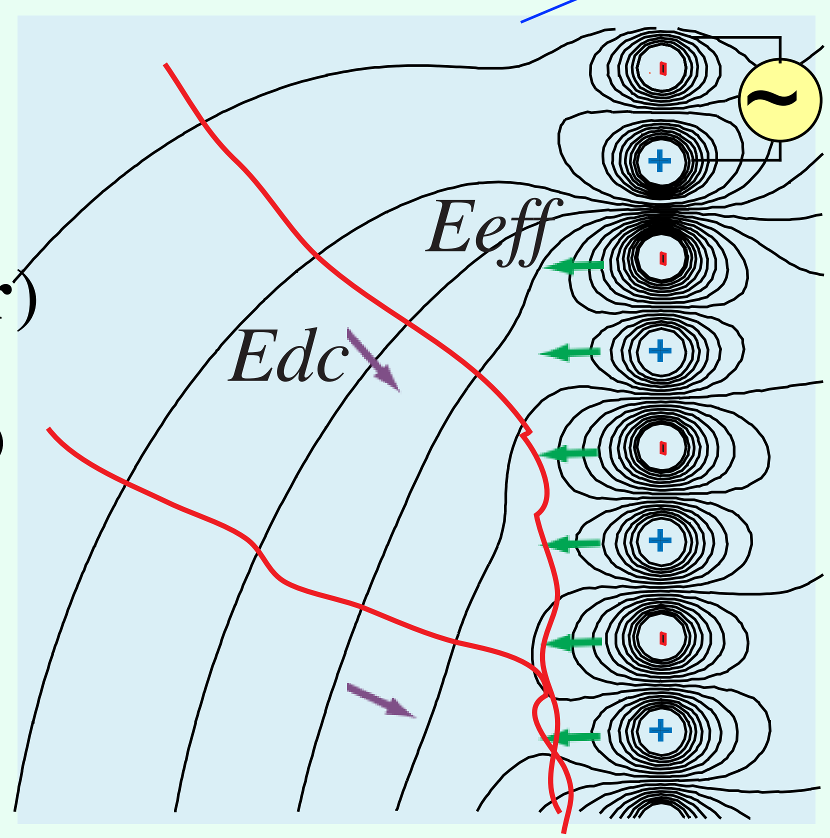
RF gradient Field: Barrier

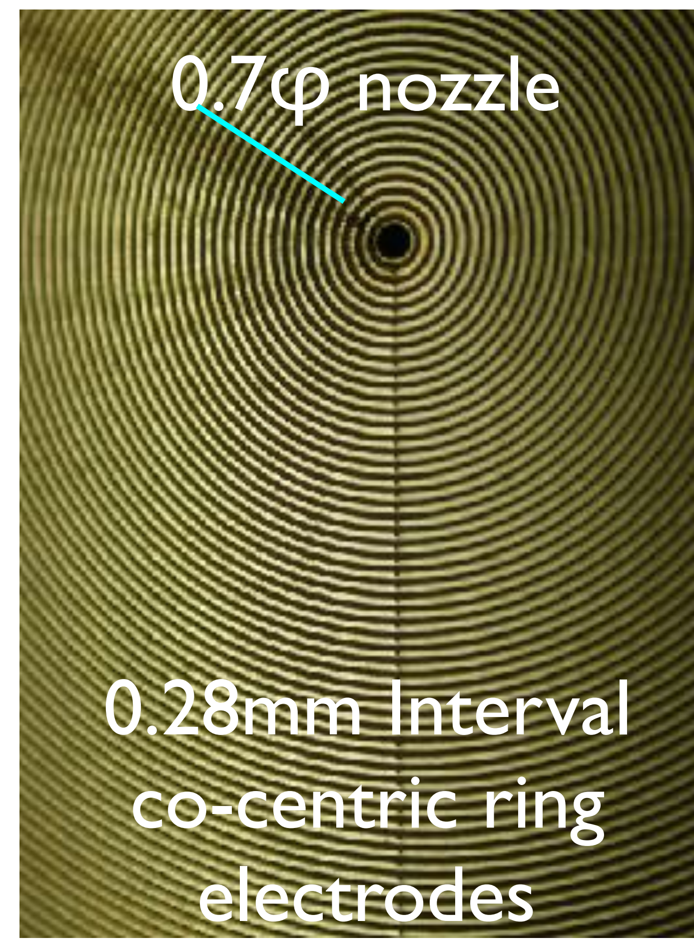
$$\bar{F} = -\frac{e^2}{4m}\frac{1}{(\Omega^2 + 1/\tau_v^2)}\nabla \mathbf{E}_{rf}^2(\mathbf{r})$$

$(\mathbf{E}(\mathbf{r},t) = \mathbf{E}_{rf}(\mathbf{r})\cos(\Omega t),\ \ \tau_v$: relax time$)$

$$E_{\text{eff in gas}}^{\max} = \frac{m\mu^2 V_{rf}^2}{e r_0^3}$$

$2r_0 \approx$ electrode distance



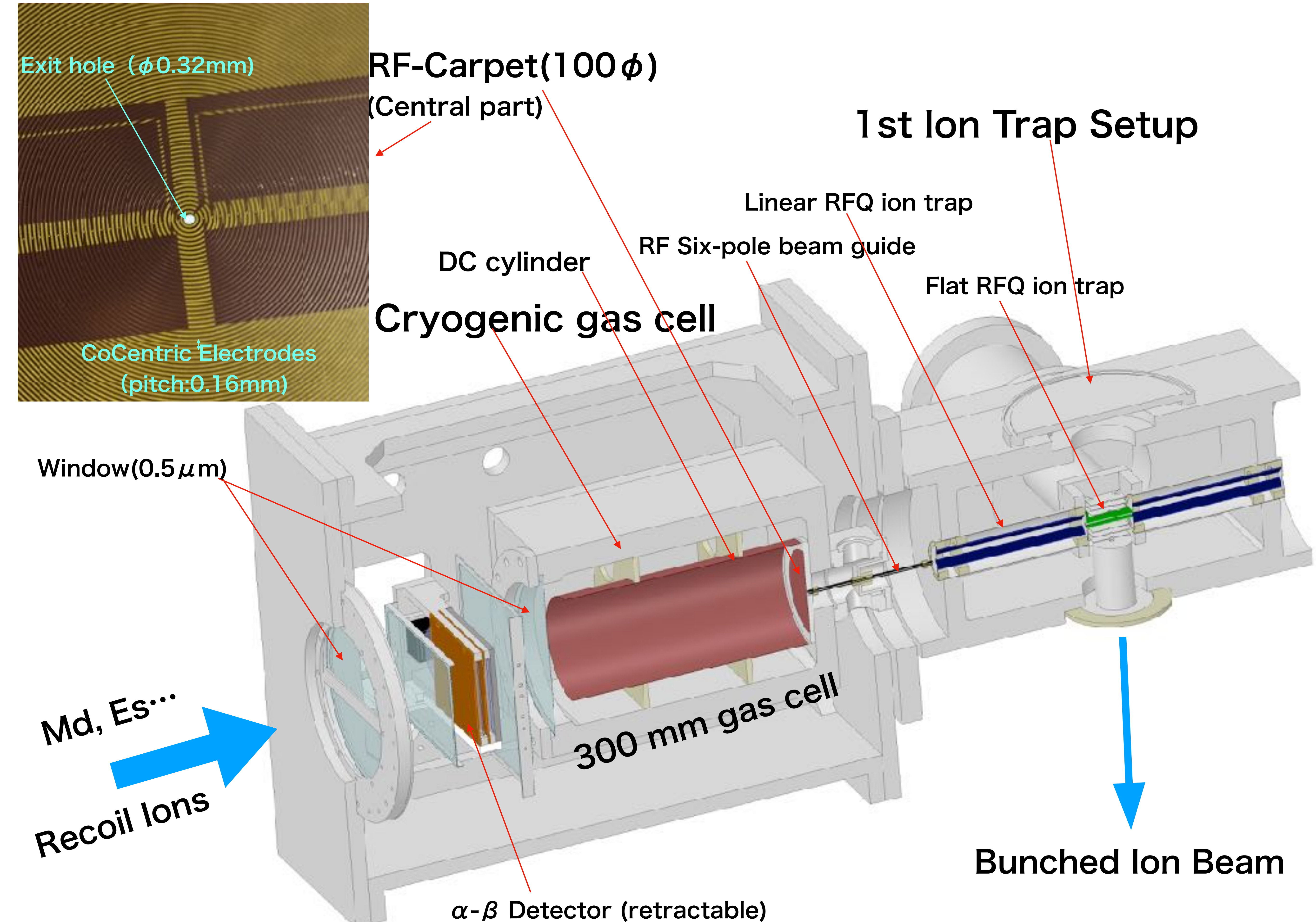


M.Wada et al, NIM B204 (2003) 570.

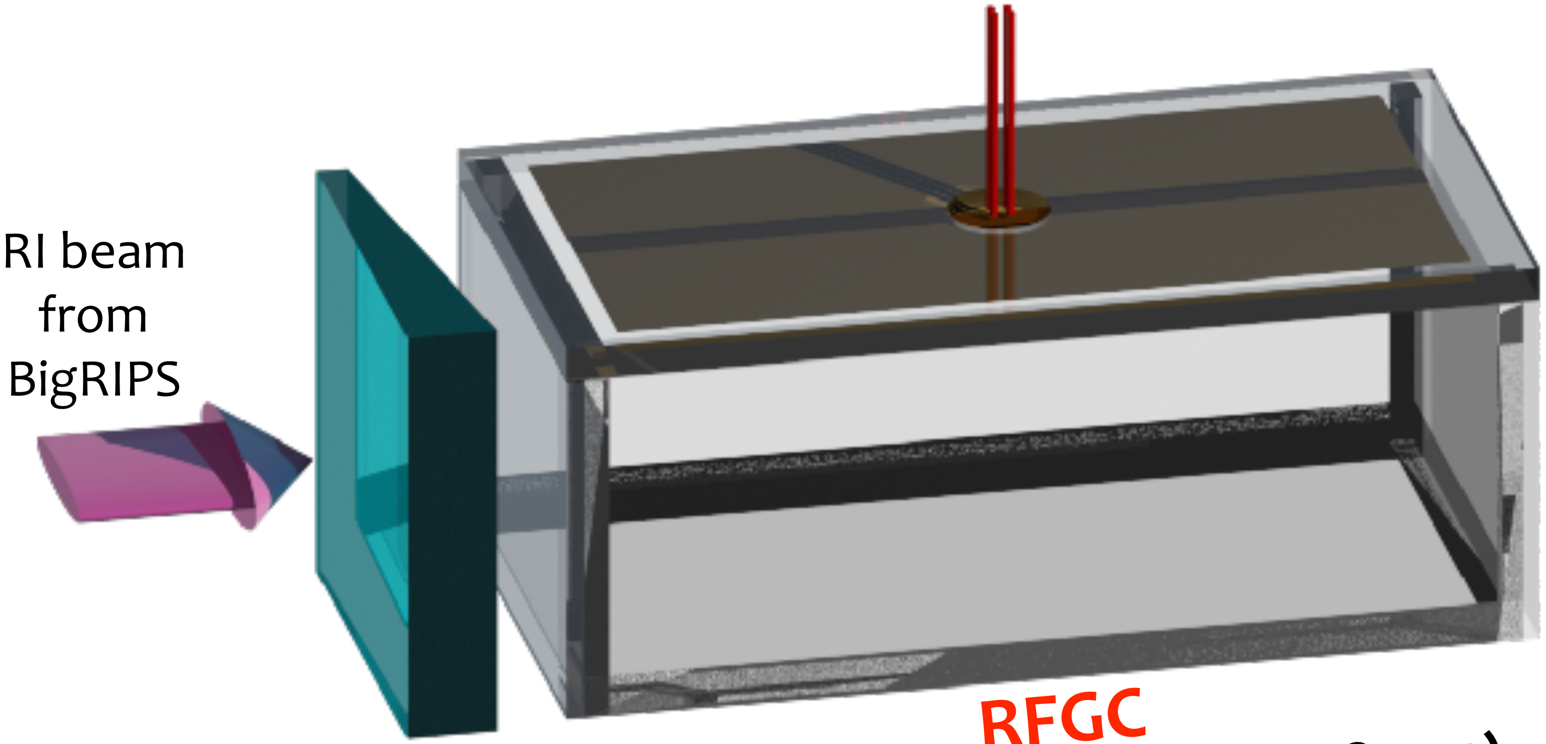
Ion Barrier at Cathode by RF carpet

SLOWRI prototype ver 2 @GARIS-II

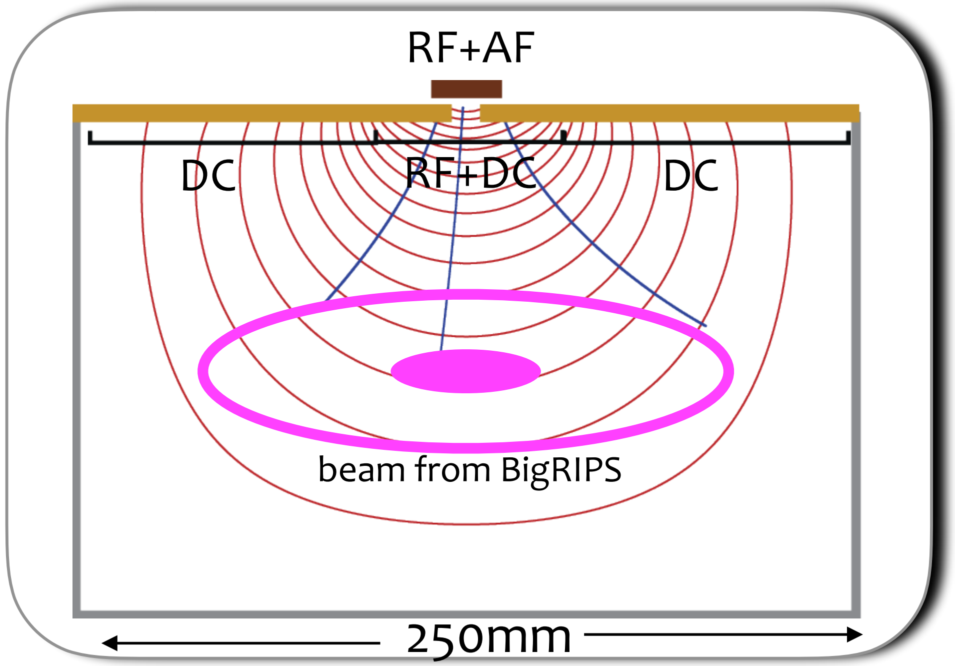
MRTOF Mass Measurements for many short-lived nuclides



SLOWRI prototype ver 3 @BigRIPS F11

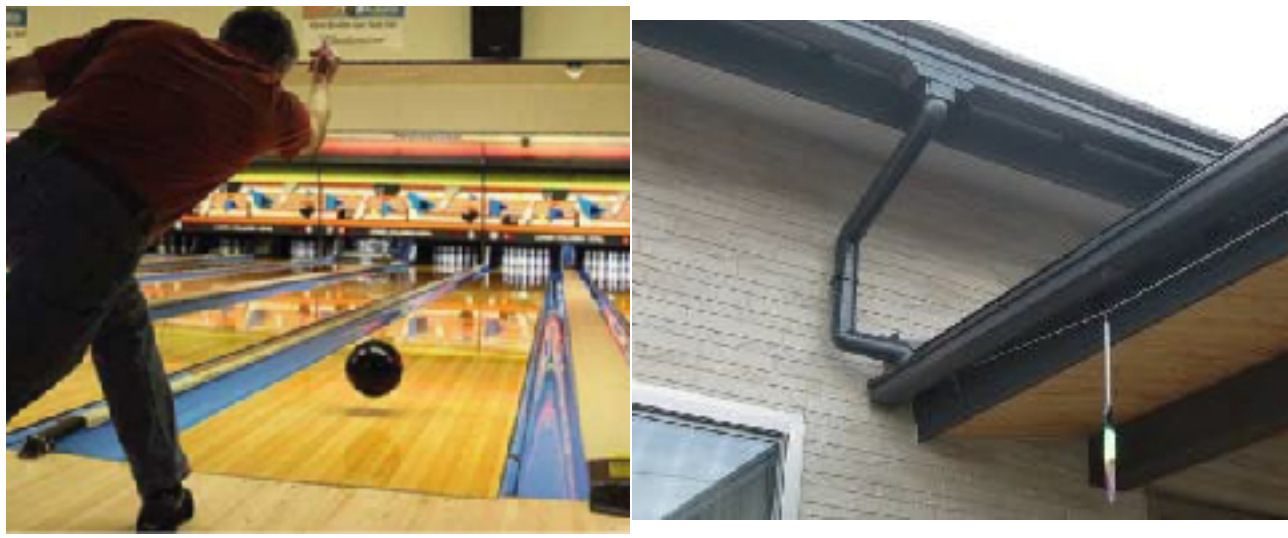


sectional view



Two stage RFcarpet: “Gutter Structure”

- scalable RFC
- accept 10^7 cps beam
- no charge up



“Gutter structure”
“雨樋構造”

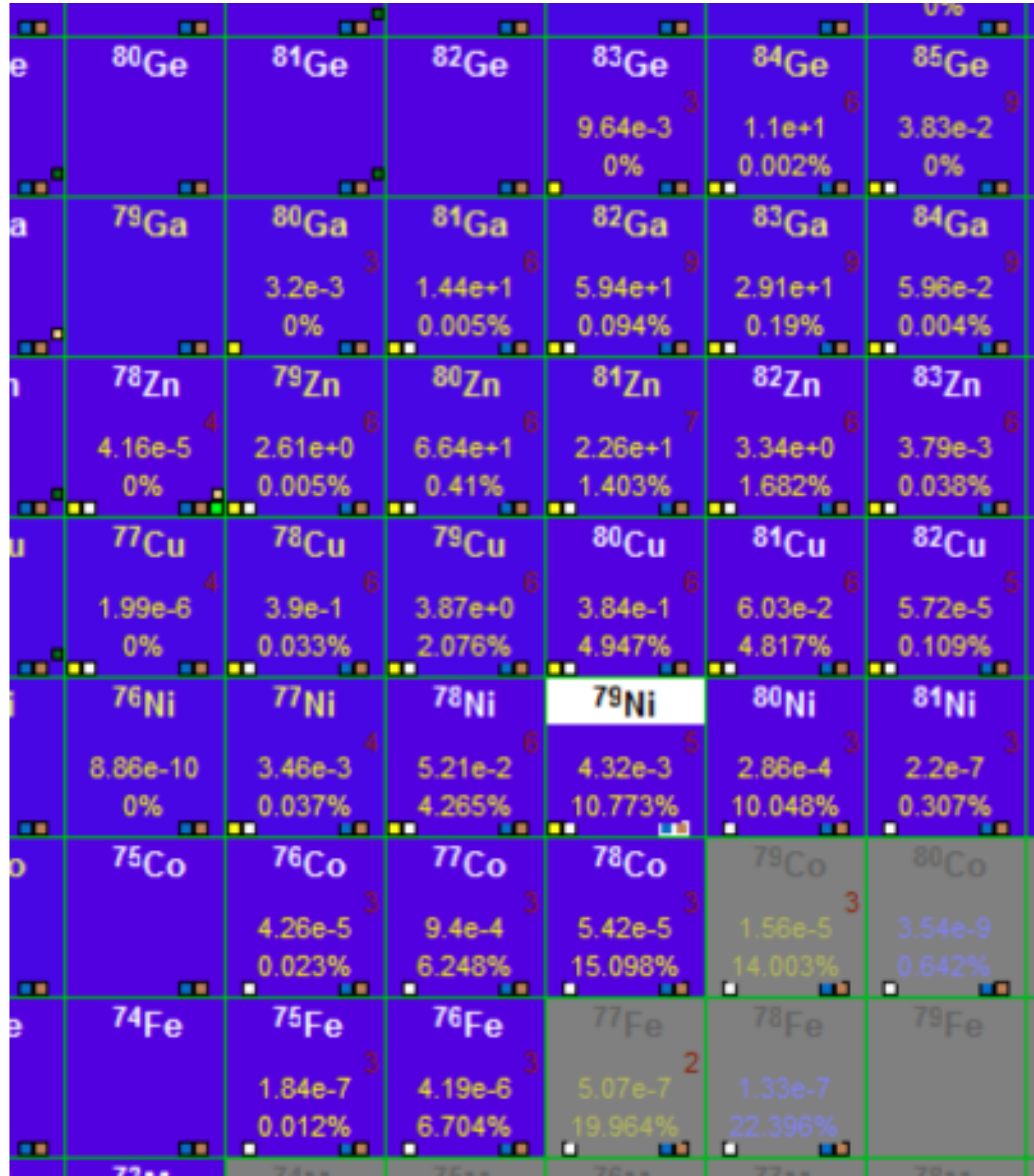
@F11 Symbiotic Experiment will be run

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

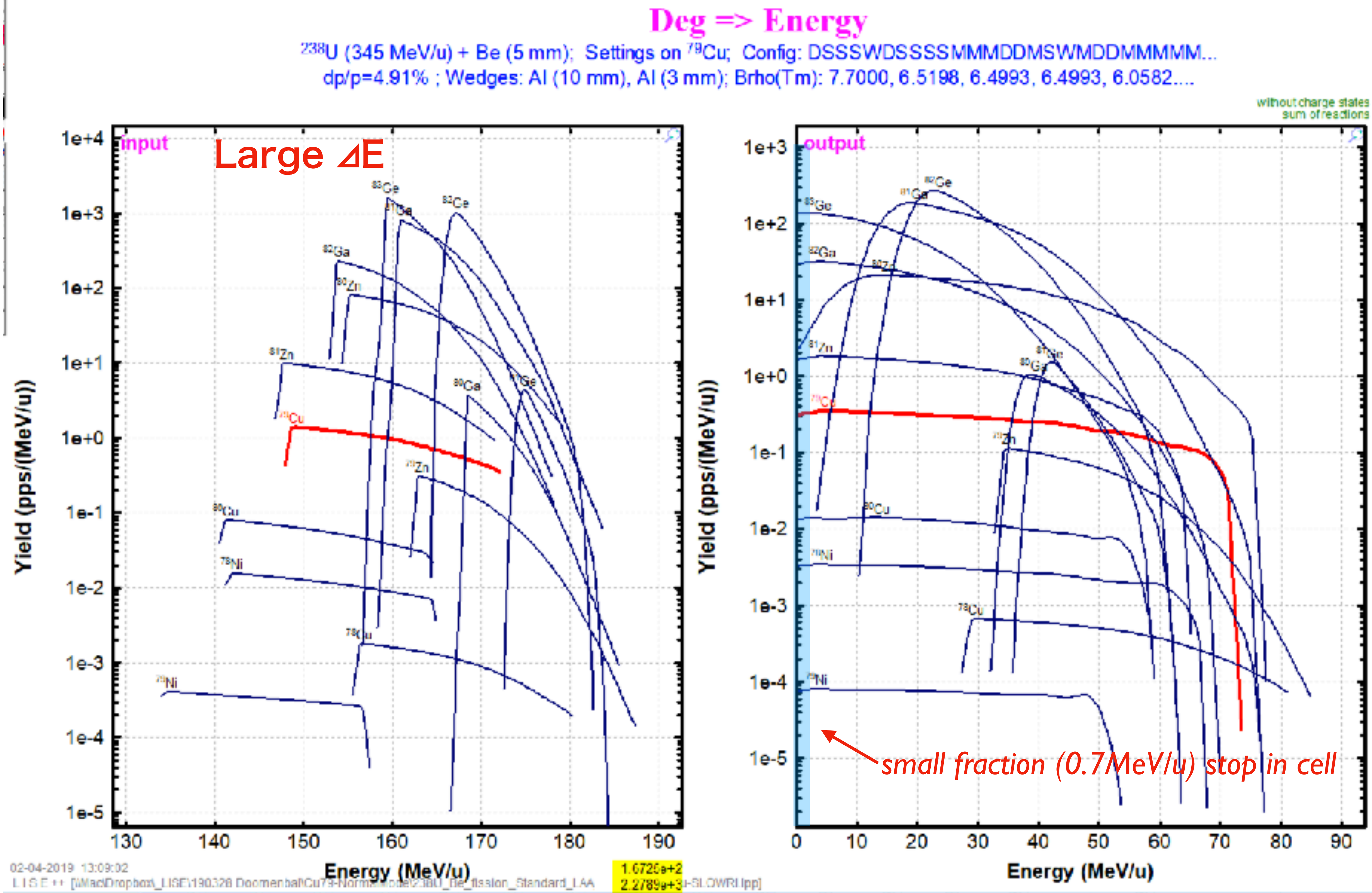
80 pnA U beam

A week of run

1% our total efficiency

What is expected?

A.Standard ZeroDegree Optics (Achromatic focus @F11)

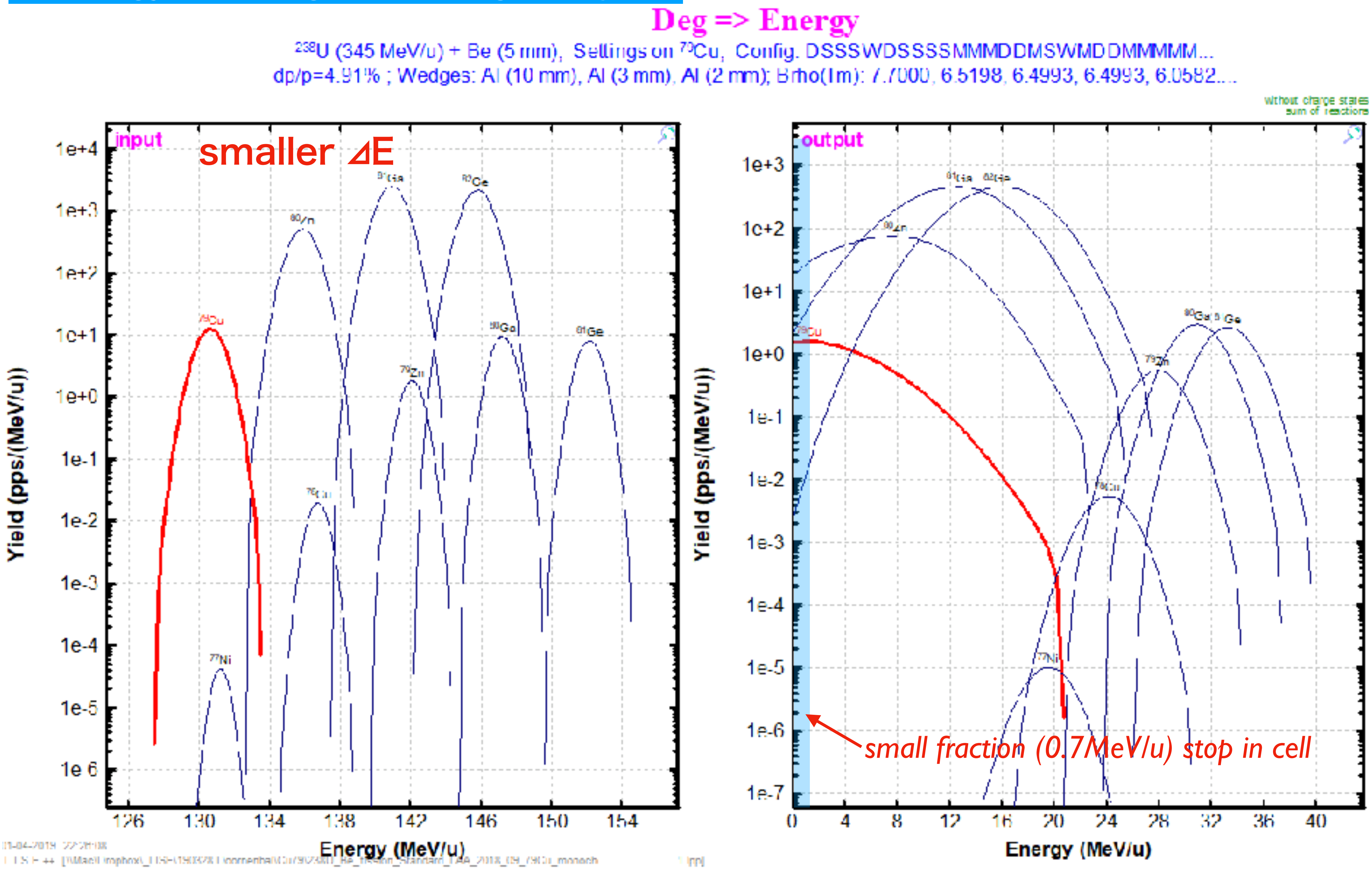


Very low efficiency, but multiple species at once

0.76% for ^{79}Cu

	^{83}Ge, ^{82}Ge, ^{80}Zn, ^{81}Zn, ^{79}Cu	^{80}Cu	^{78}Ni	^{79}Ni
stop in cell:	100 cps	700 cph	180 cpd	5 cpd
MRTOF:	30 cps	200 cph	50 cpd	0.1 cpd

B. Energy bunching in ZeroDegree Optics



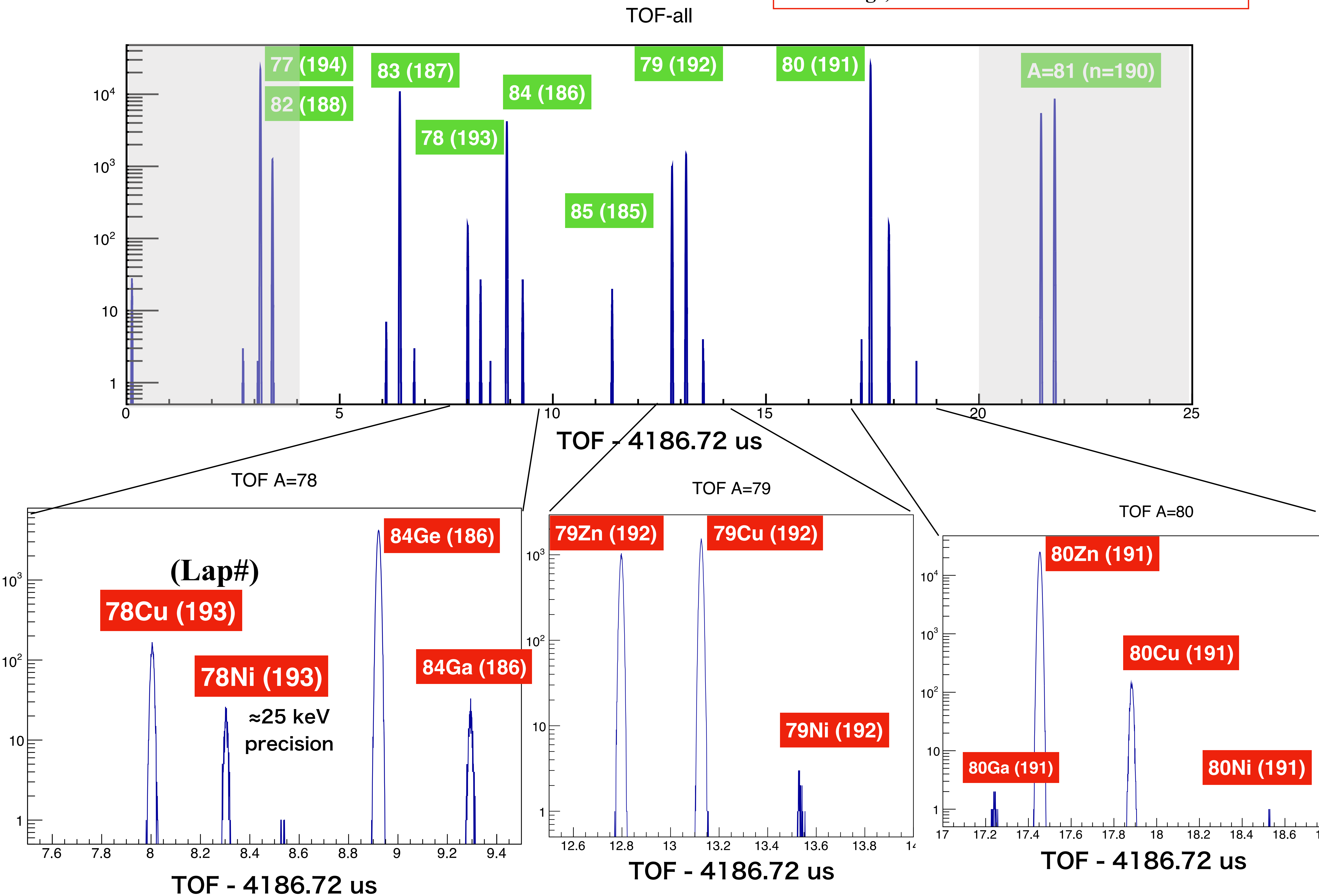
5x improved efficiency, but few species at once

3.4% for ^{79}Cu

	^{80}Zn, ^{81}Ga, ^{79}Cu, ^{82}Ge
stop in cell:	3500 cph
MRTOF:	1000 cph

Expected TOF Spectrum (simulation)

By changing the degrader angle in a few different settings, various nuclides can be measured



A.Standard ZeroDegree Optics

Very low efficiency, but multiple spices at once

B. Energy bunching in ZeroDegree Optics

Cf. P. Doornenbal

5x improved efficiency, but few spices at once

C. Dispersive focus at F11 in ZeroDegree Optics

Fukuda, Takeda under calculation

Higher efficiency would be expected

N=126?

Test of Energy bunching and dispersive focusing will be carried out in fall 2019, by a BigRIPS Machine Study

Possible Collaboration

Different degree of cooperation

Parasitic	Permission to use garbage at F11
Symbiotic	Permission to use garbage at F11 Share the Data Mention in Proposal
Collaboration	Co-authoring Proposal

Human resource contributions in any cases

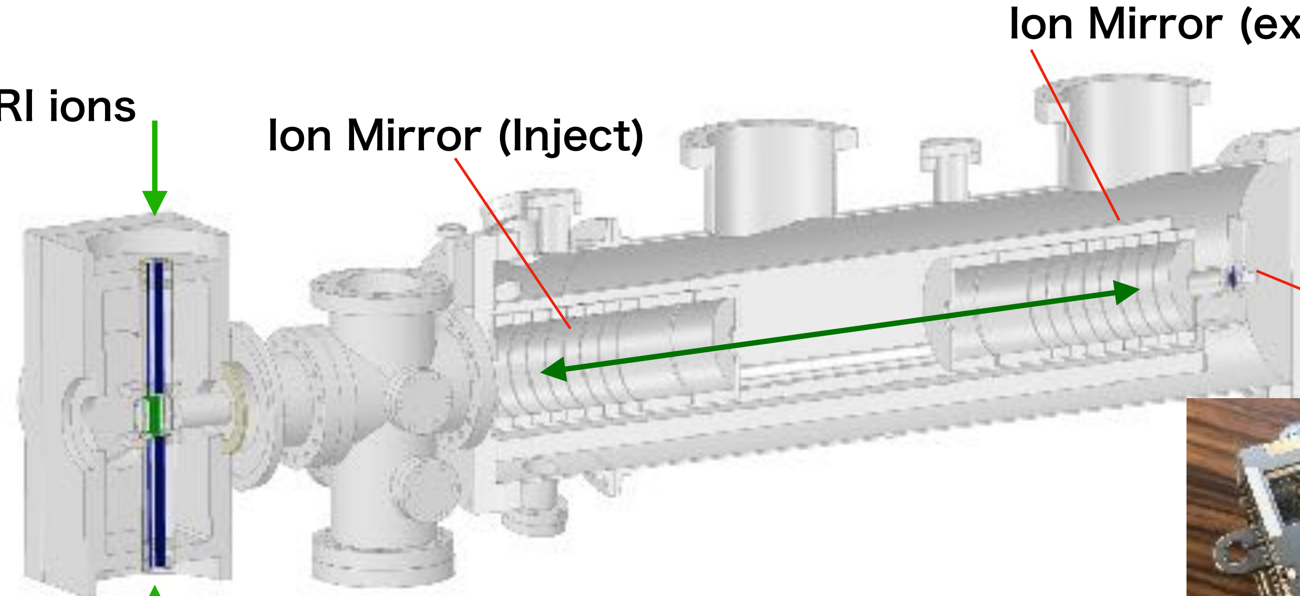
Rough Schedule:

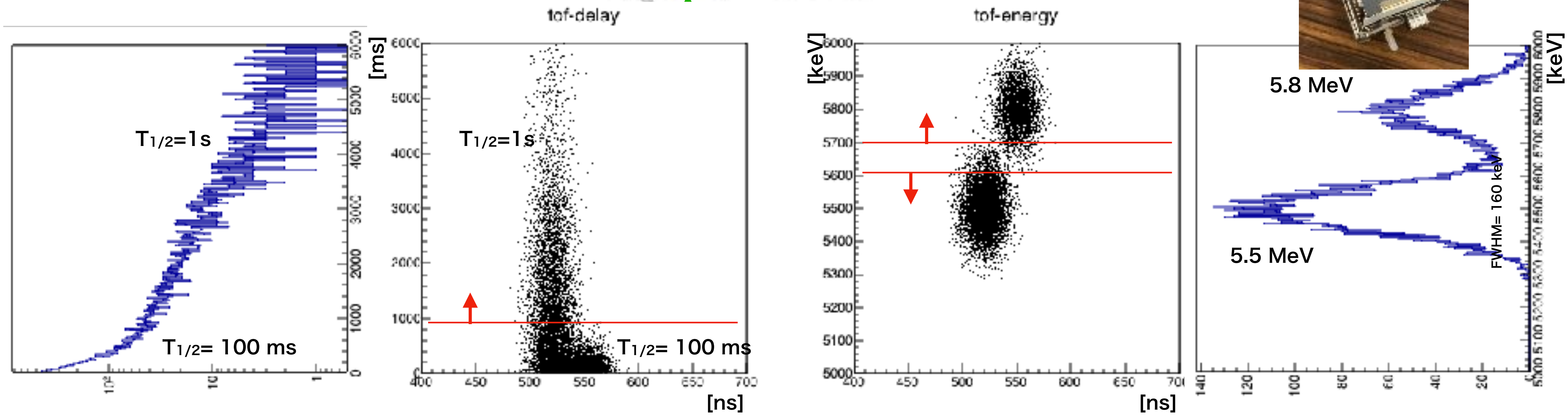
Summer 2019: Assembly of ZD-MRTOF
Fall 2019: Off-line commissioning
Winter 2019-Spring 2020: On-line commissioning with parasitic beam

Combination of Decay and Mass

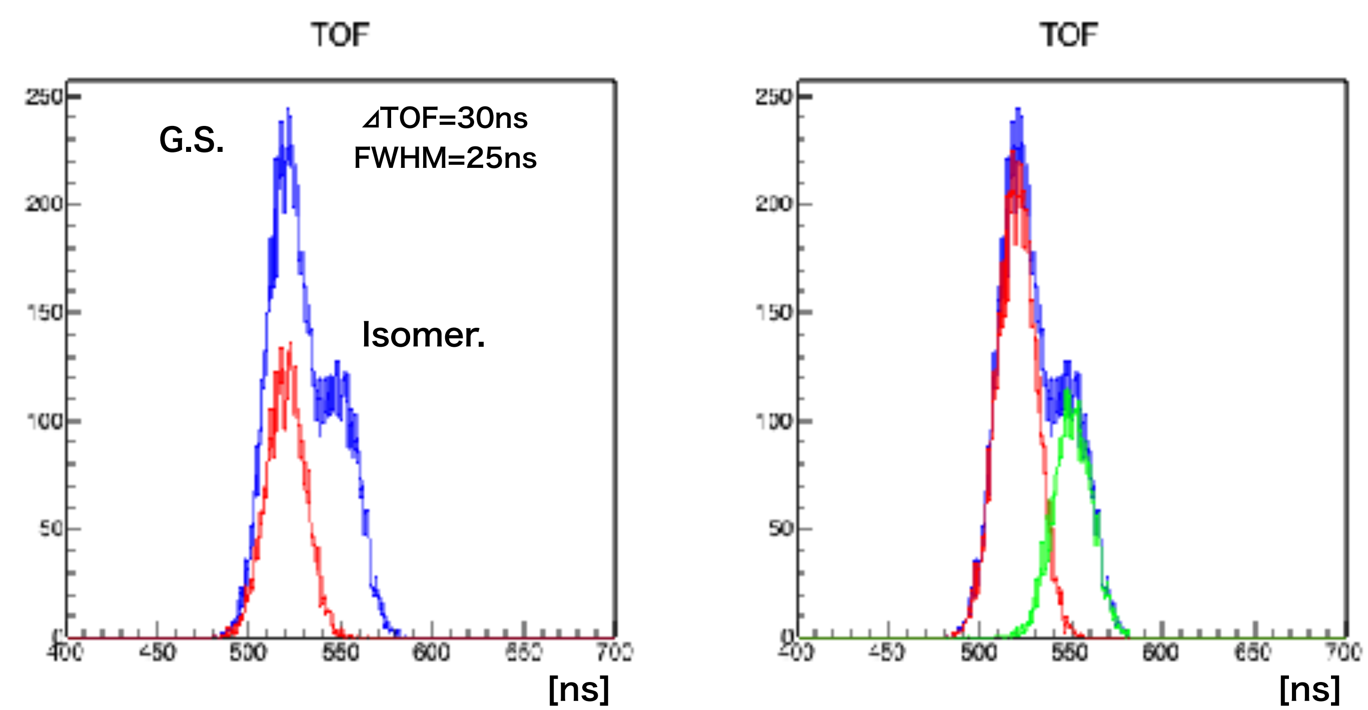
A. Confirm rare TOF events by α-Energy & Decay time

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





Decay Gate

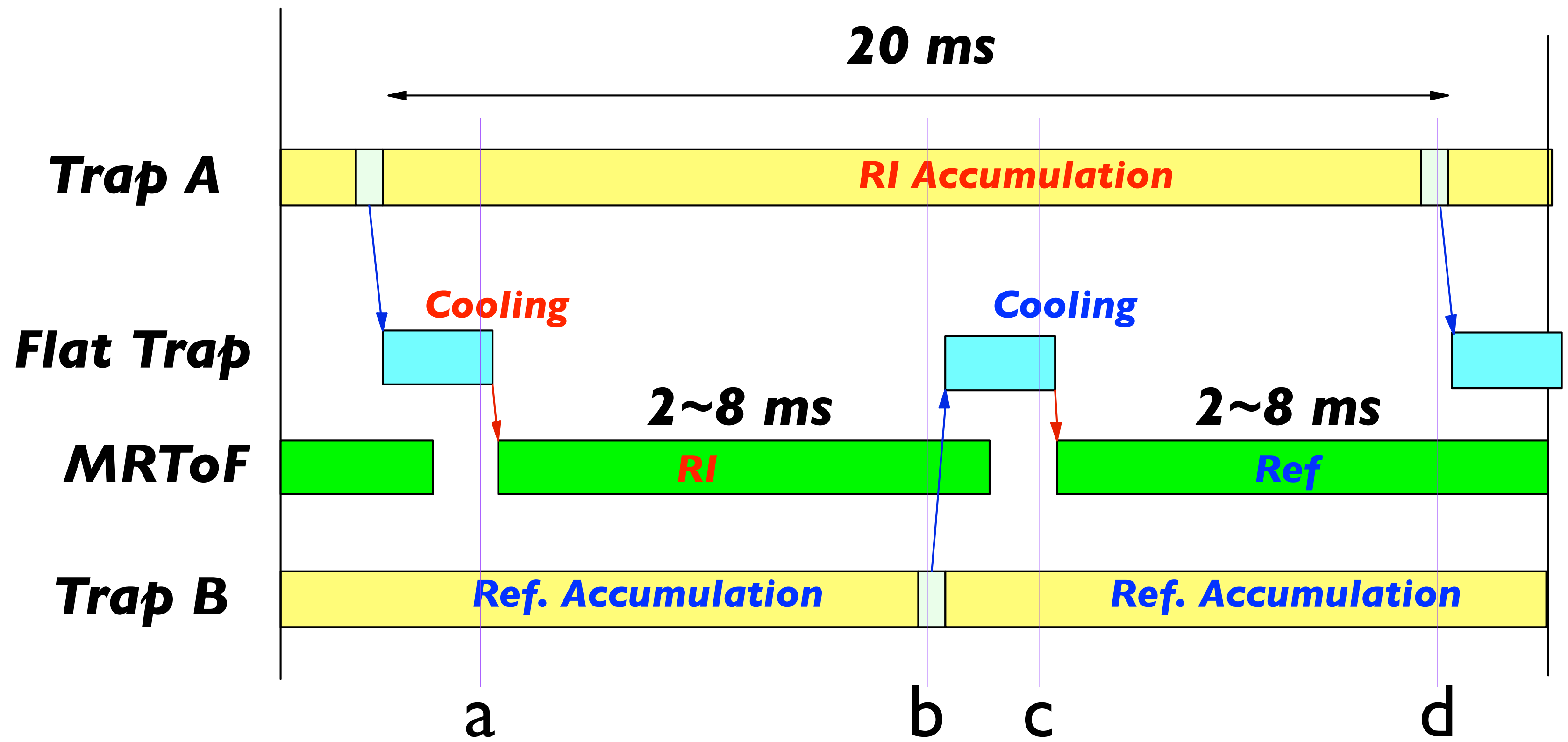


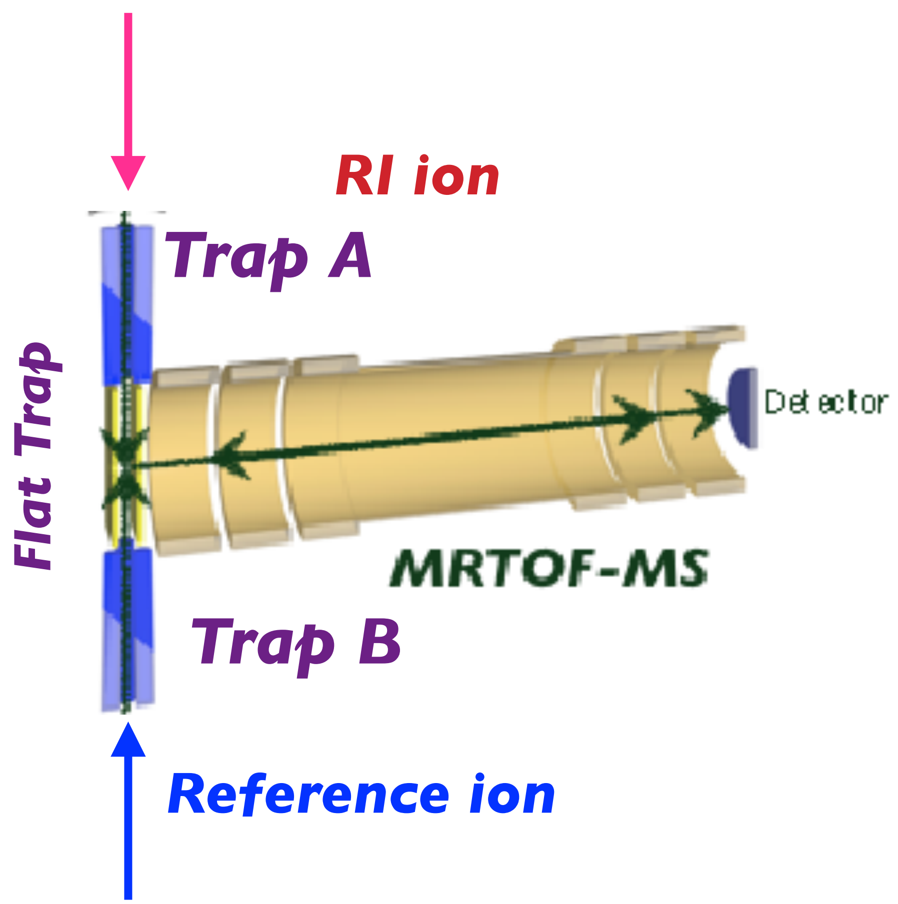
Energy Gate

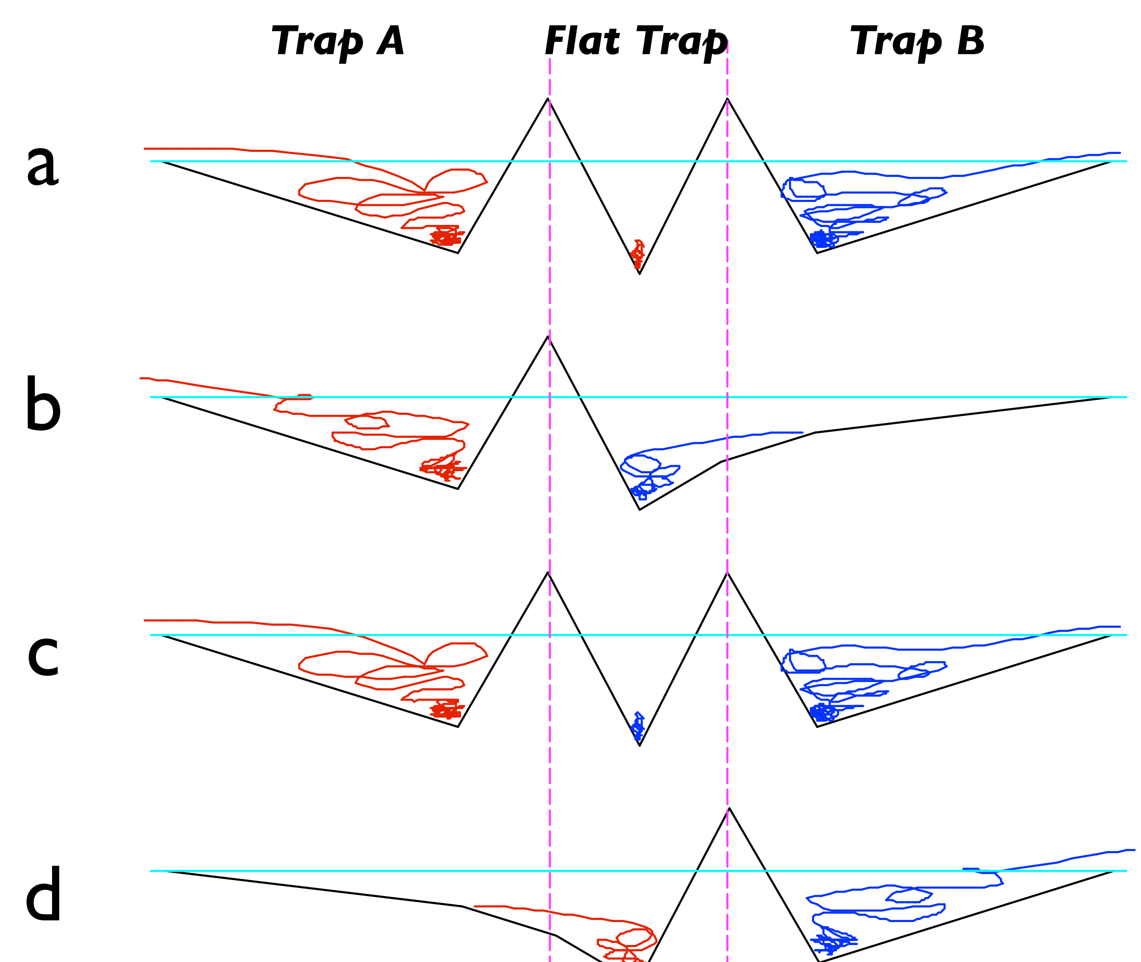
βTOF detector is under development

Concomitant Referencing Method

to Preserve Accuracy and Precision in long measurement







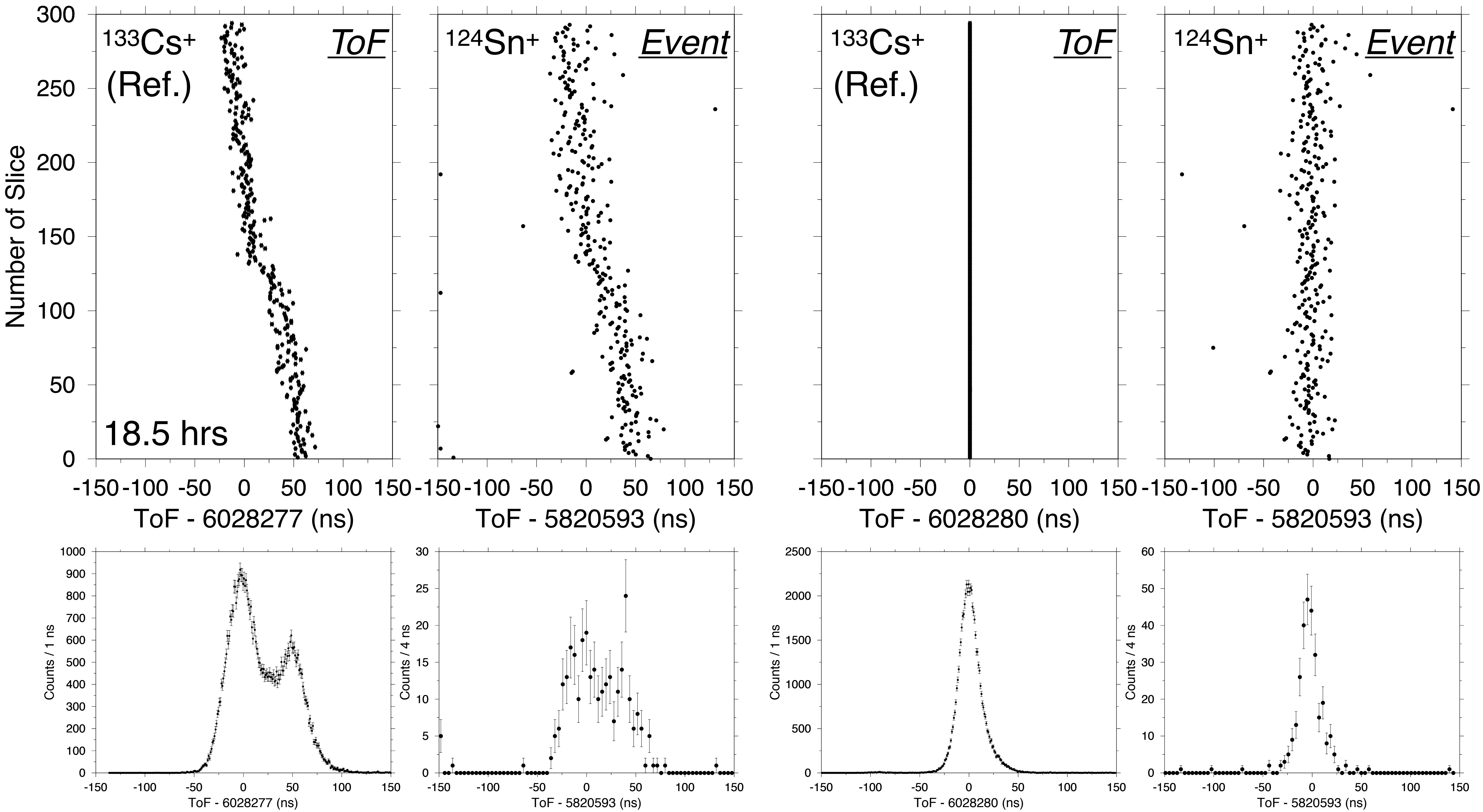
- ✸ RI and Ref ions sequentially in each cycle
- ✸ Independent Ion Traps to preserve 100% duty

concomitant reference method

Patent Pending 2016-037629 (2016年2月29日)

Drift Compensation by concomitant method

Original Data | Compensated Data



$ME_{ame}(^{124}Sn) = -88234.2(1.0)$ keV

$ME_{exp}(^{124}Sn) = -87843(926)$ keV

$\Delta m(^{124}Sn) = +391(926)$ keV

$ME_{exp'}(^{124}Sn) = -87226(28)$ keV

$\Delta m(^{124}Sn) = +8(28)$ keV

$\delta m/m = 2.4 \times 10^{-7}$

$R_m = 144{,}000$, $N(^{124}Sn^+) = 244$