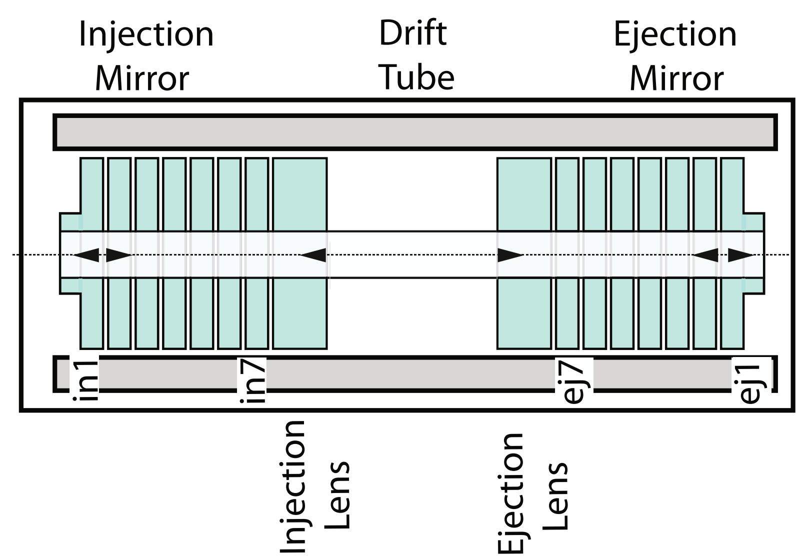
Present status and future plans for MRTOF-MS at RIBF

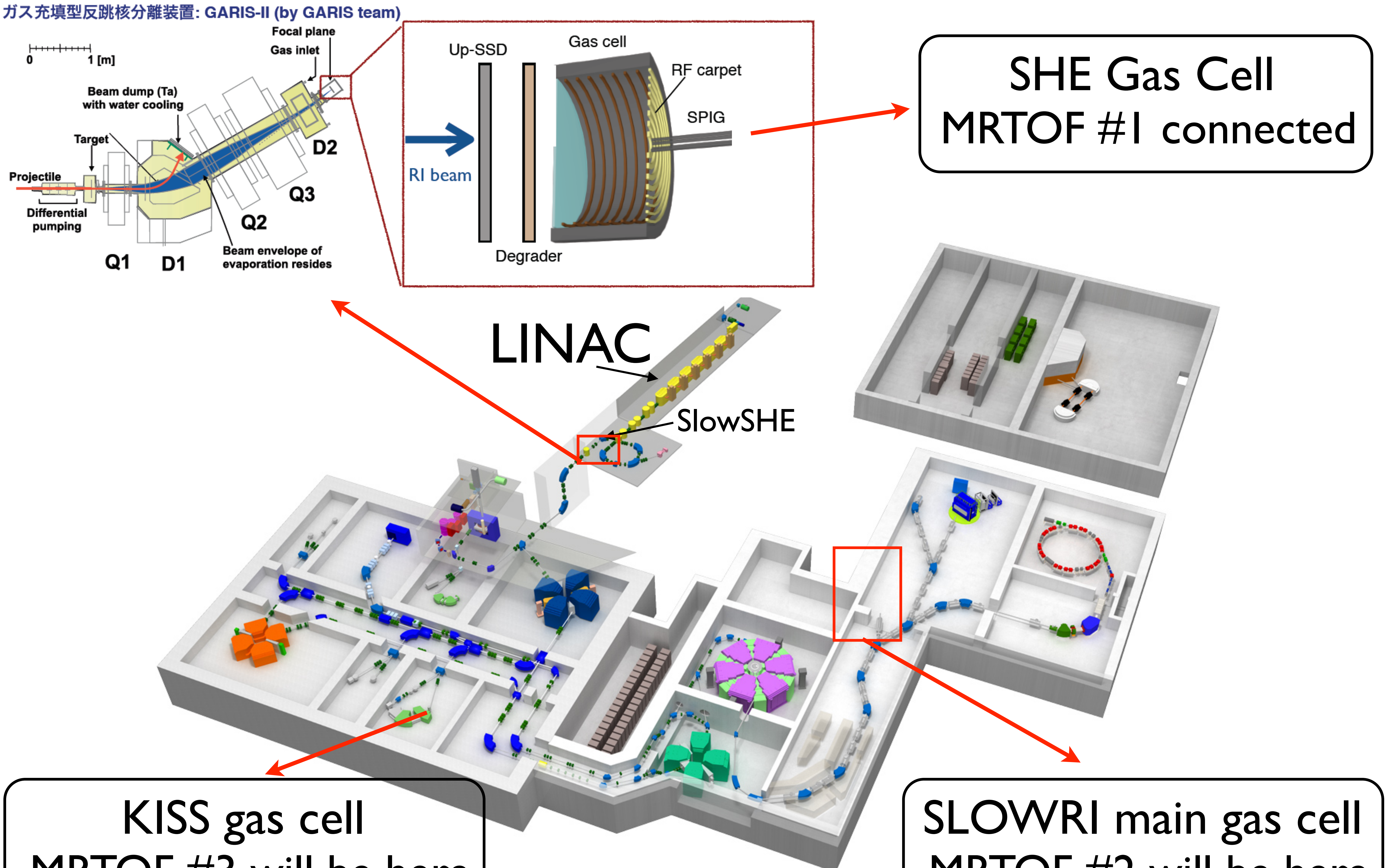


シューリ
Peter SCHURY
高エネルギー加速器研究機構、素粒子原子核研究所、
和光原子核科学センター / 短寿命核グループ

Multi-Reflection Time of Flight Mass Spectrographs

- Originally proposed by H. Wollnik before 1990
- Implementation required technological advances
  - Stable voltages
  - Fast switches
  - Computation improvements
- Initially limited interest
  - ORNL
  - Giessen
  - ESA
  - RIKEN
- Suddenly becoming popular
  - Nearly every facility now developing

MRTOF-MS at RIBF



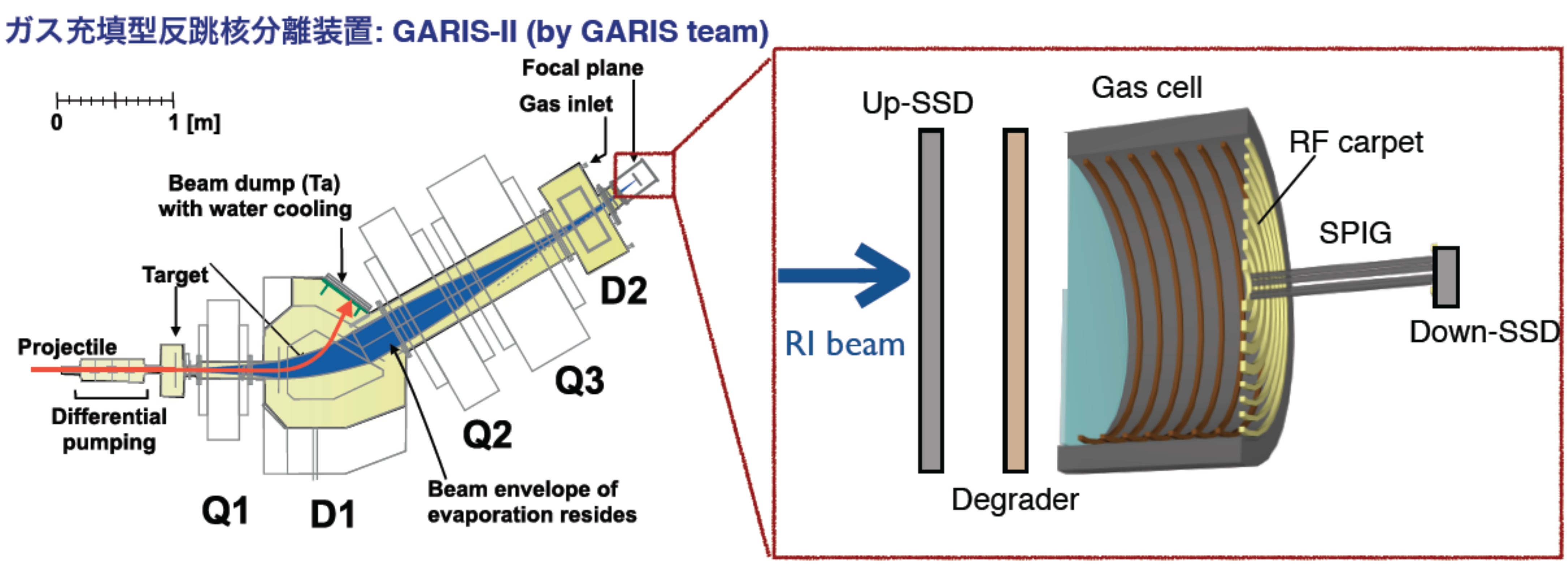
SHE Gas Cell
MRTOF #1 connected

KISS gas cell
MRTOF #3 will be here

SLOWRI main gas cell
MRTOF #2 will be here

Beam preparation

- RIB created at high-energy
  - 10 MeV ~ 200 MeV/A
- Need to thermalize for ion trapping
  - Gas cells!



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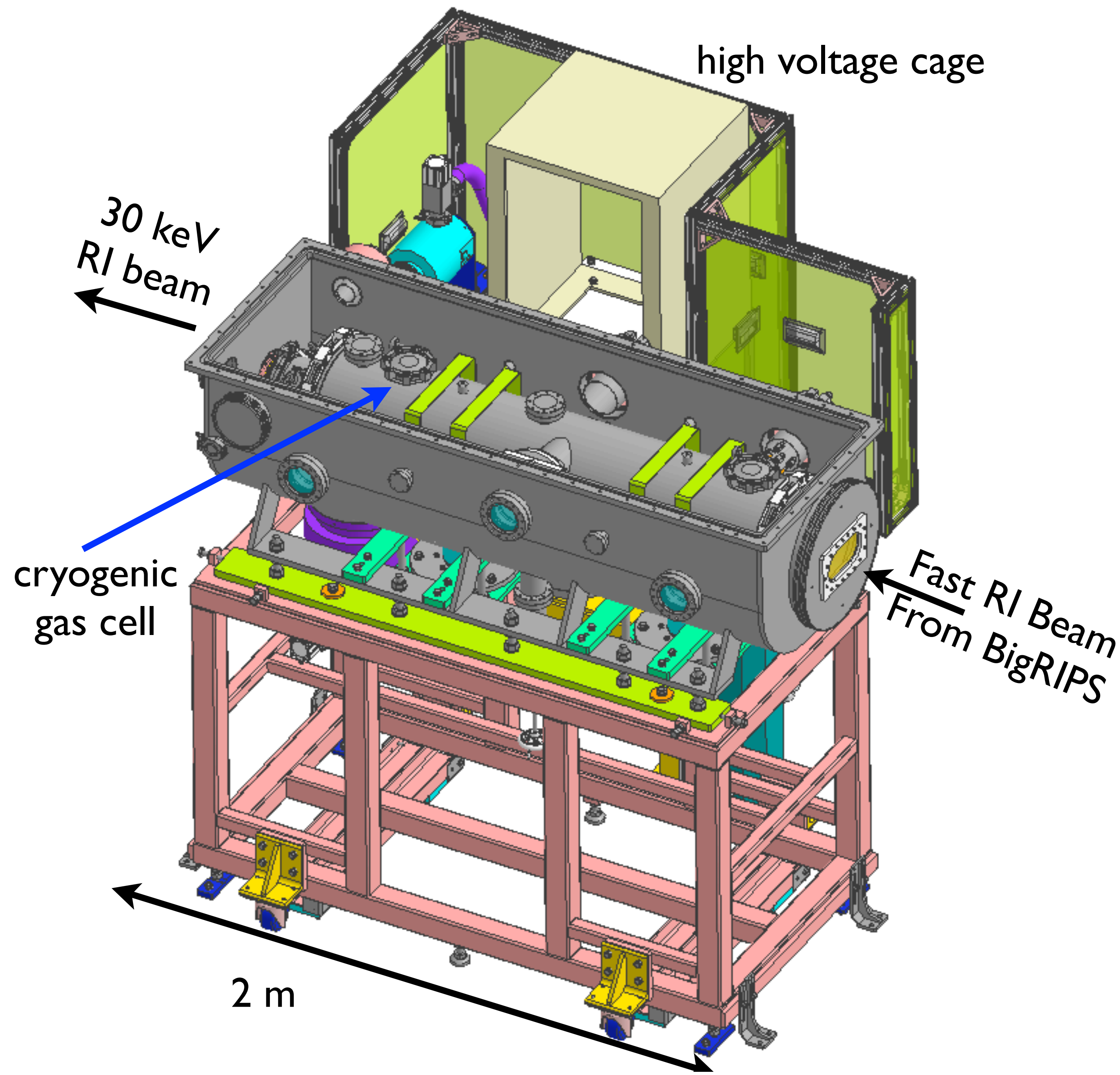

Beam preparation

- RIB created at high-energy
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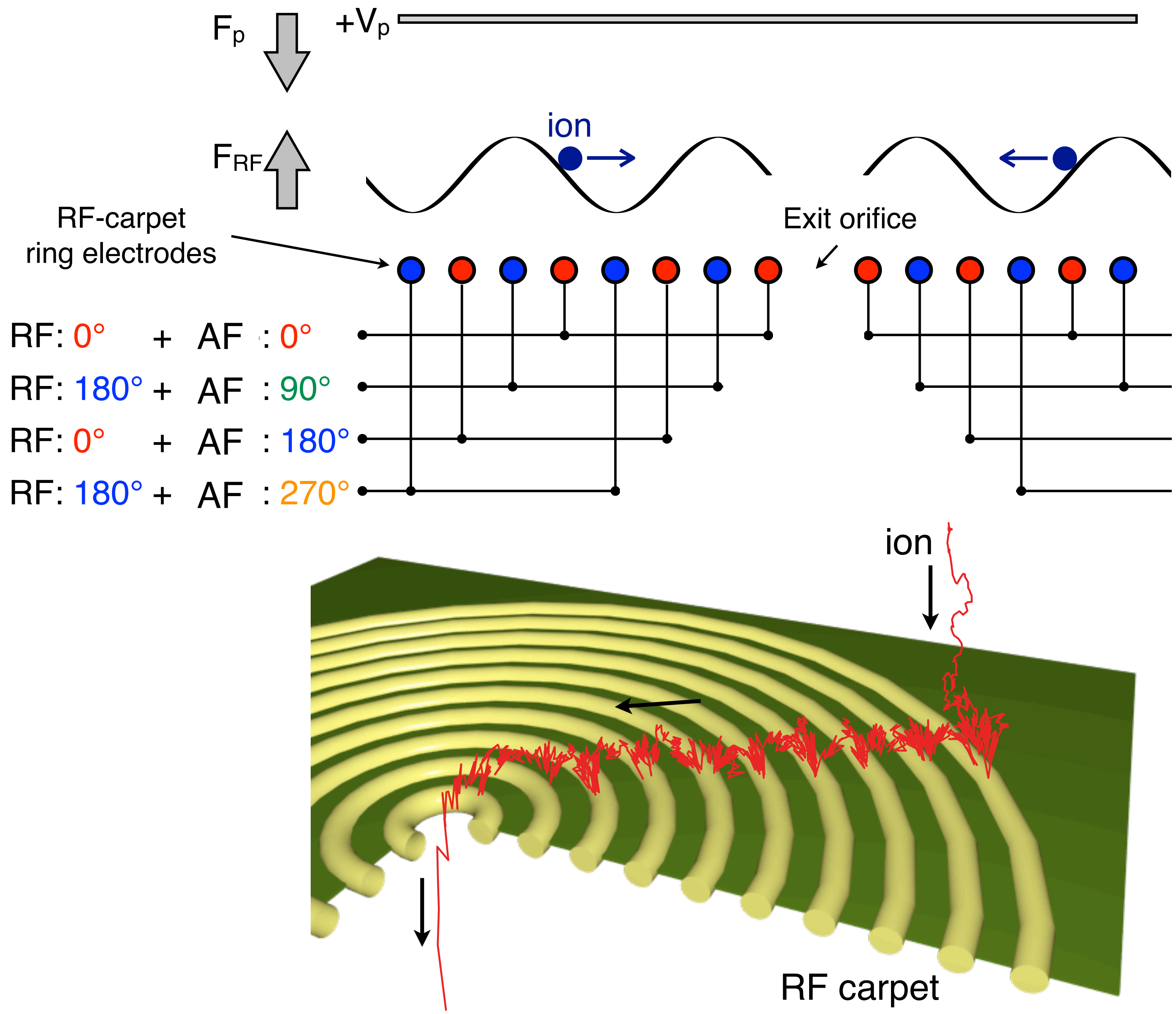
- Need to thermalize for ion trapping
  - Gas cells!

Beam preparation

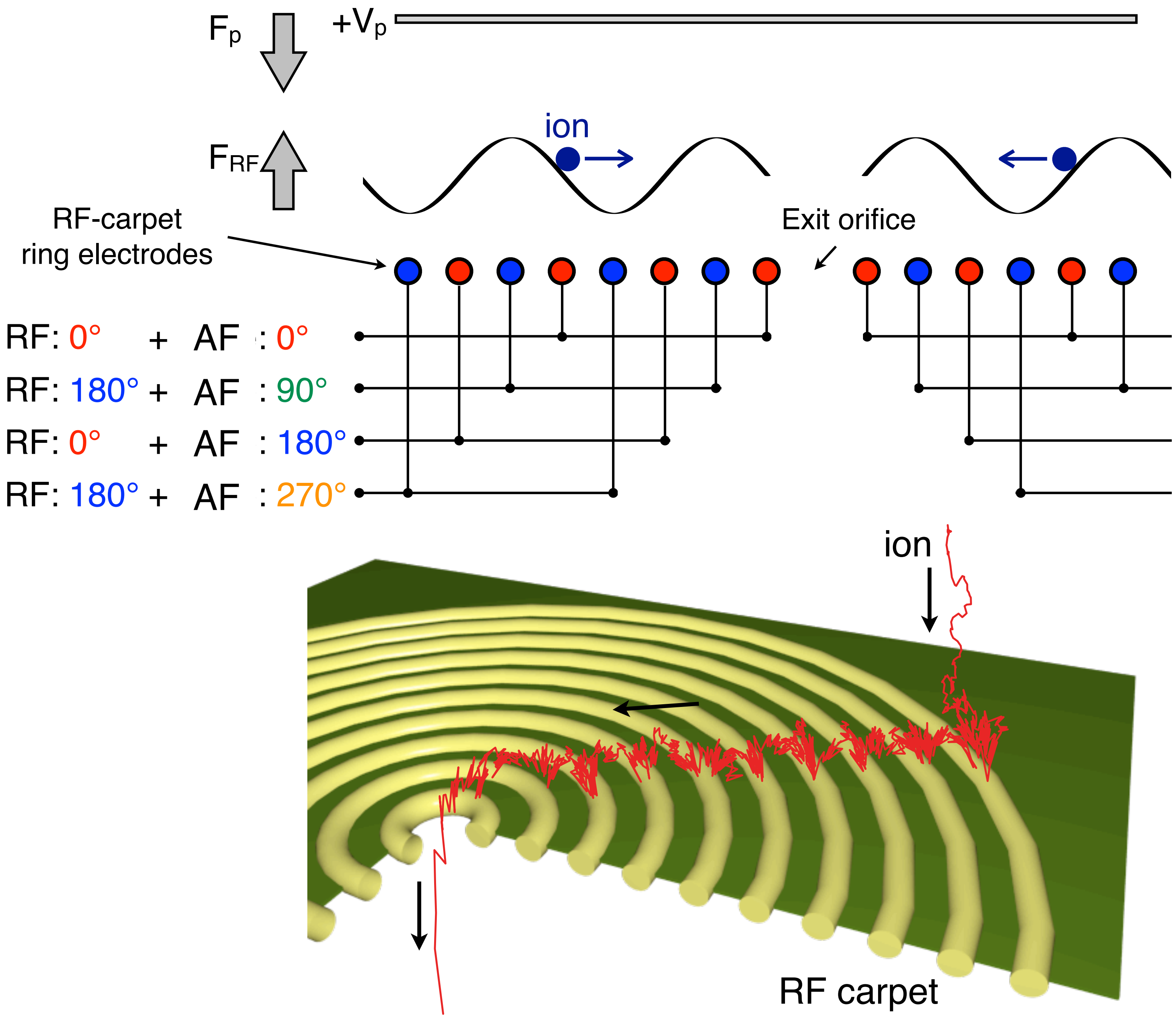
- Ions are stopped in helium
- Pushed to carpet
- Extracted by traveling wave



Beam preparation

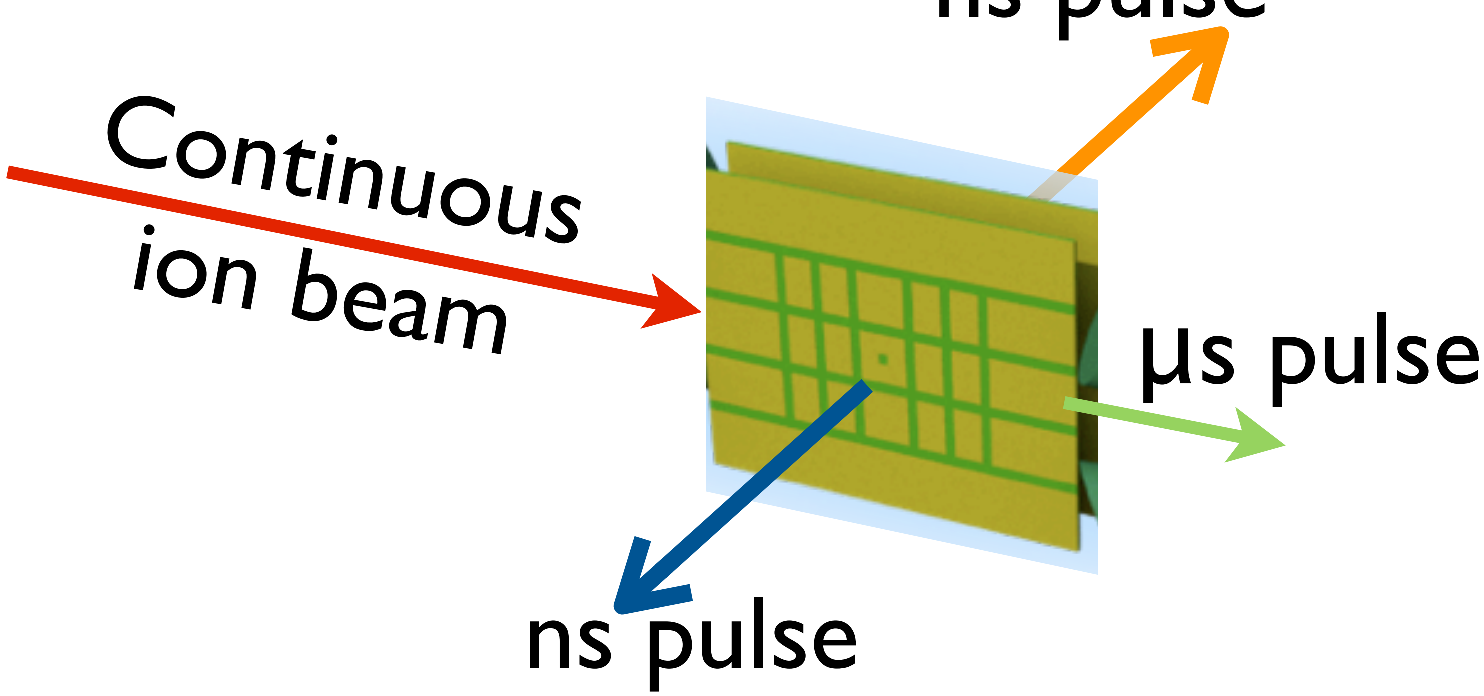
- Ions are stopped in helium
- Pushed to carpet
- Extracted by traveling wave

Not KISS or PALIS

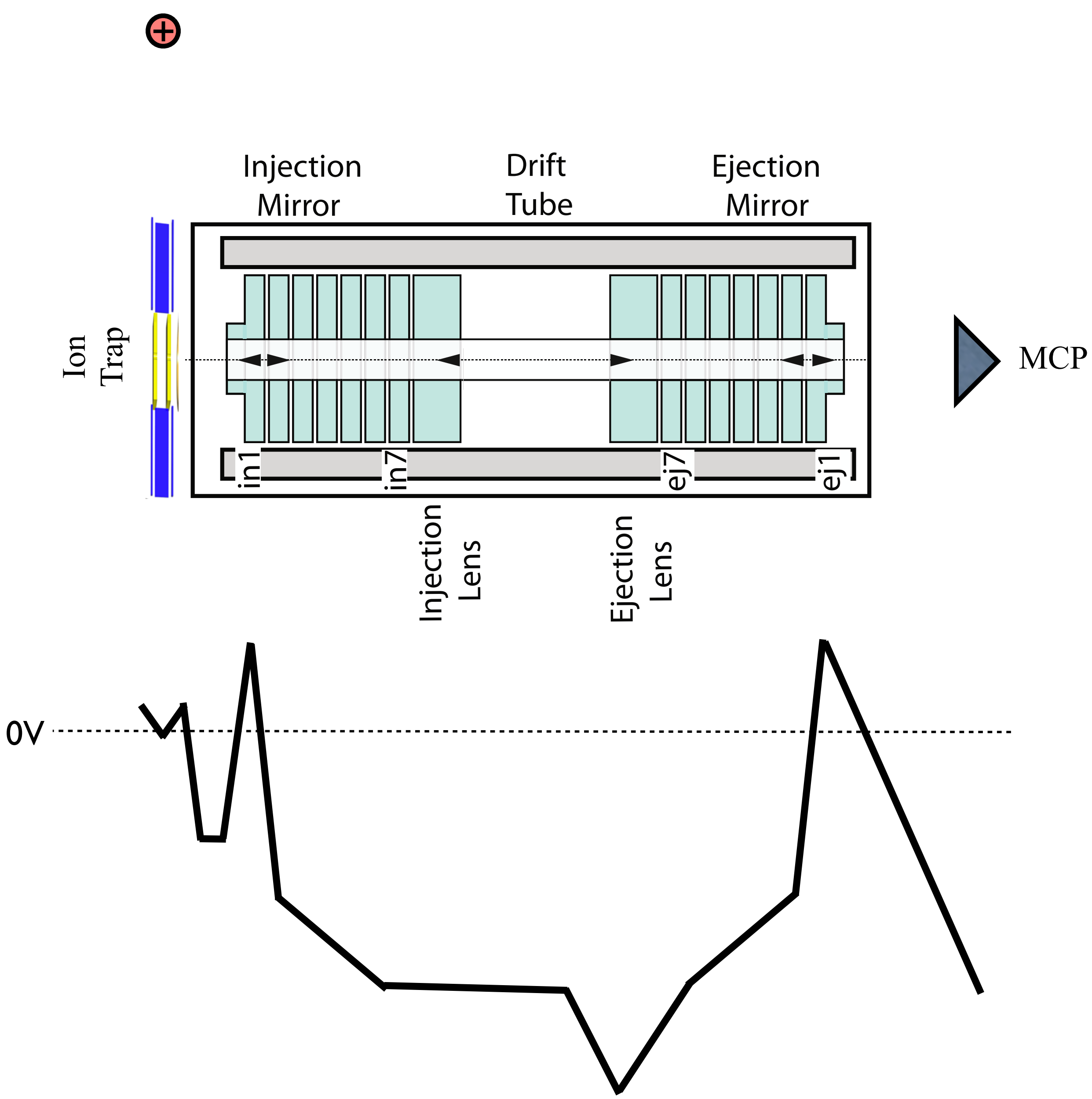


Beam preparation

- Multi-directional flat trap converts continuous beam into beam pulses
- Ejection provides start signal for TDC
- Allows simplified referencing
- Will allow simple beam splitting



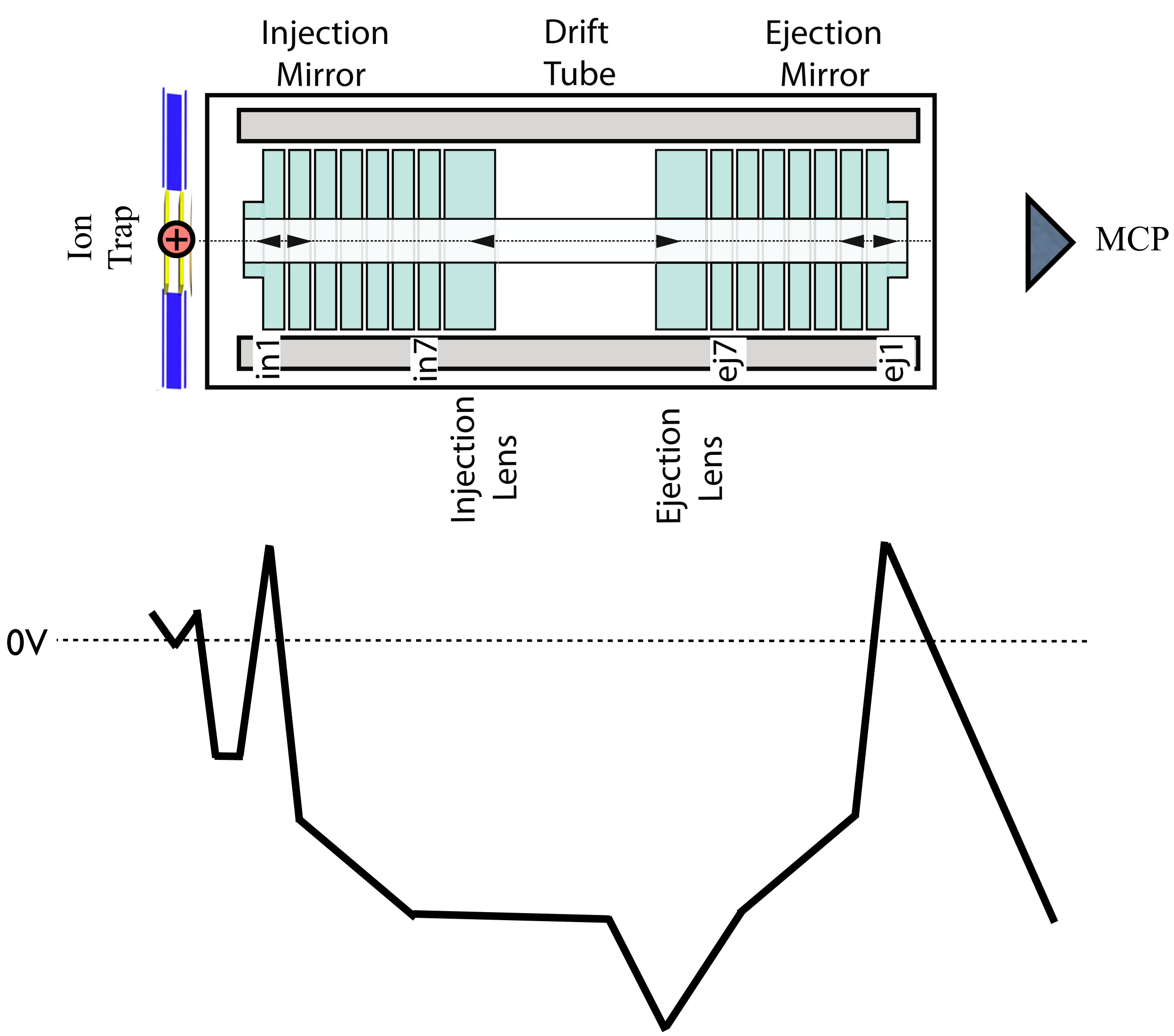
How the RIKEN MRTOF-MS works



Approx. Potential

How the RIKEN MRTOF-MS works

1. Accumulate and cool Ions in trap



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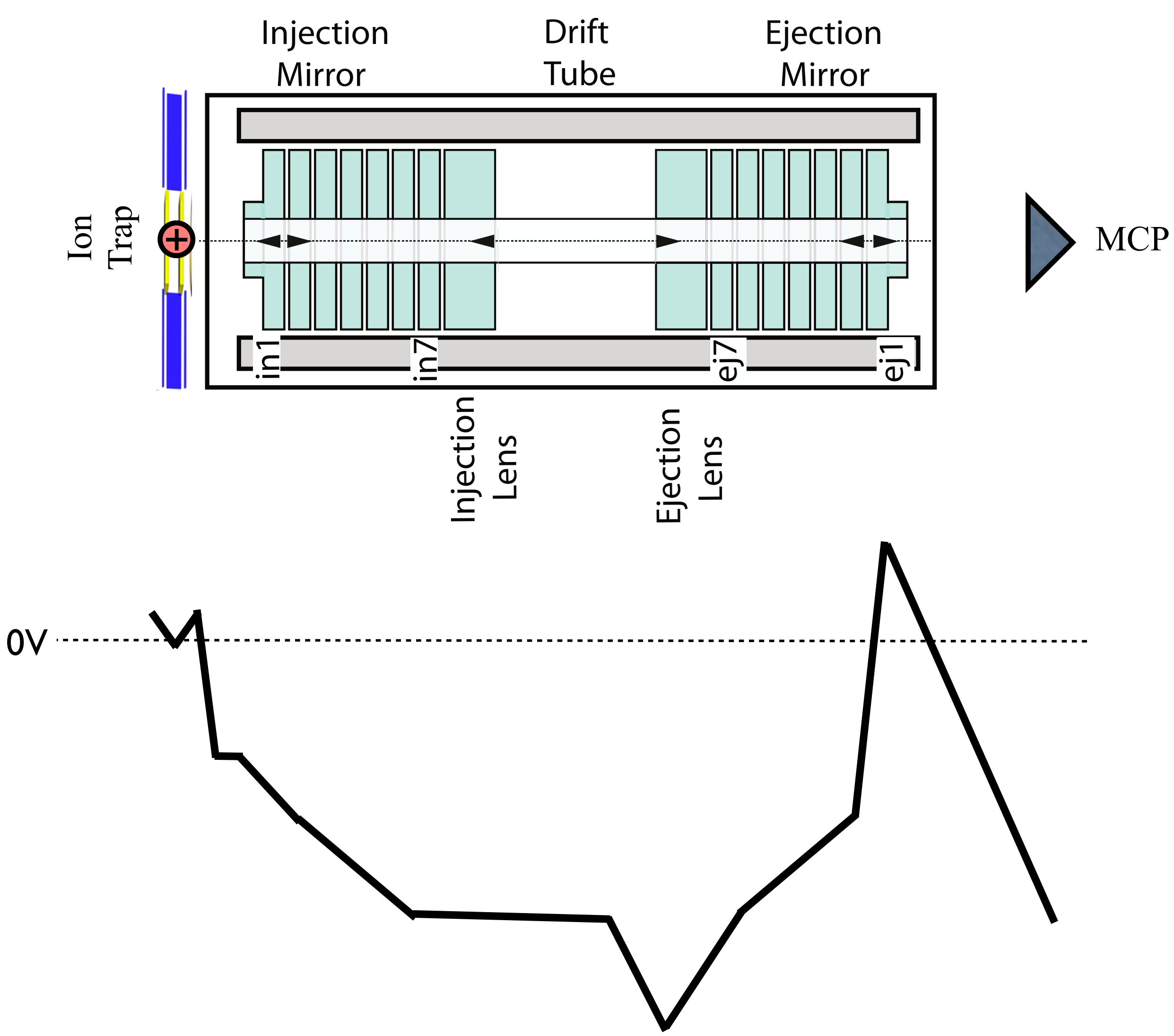
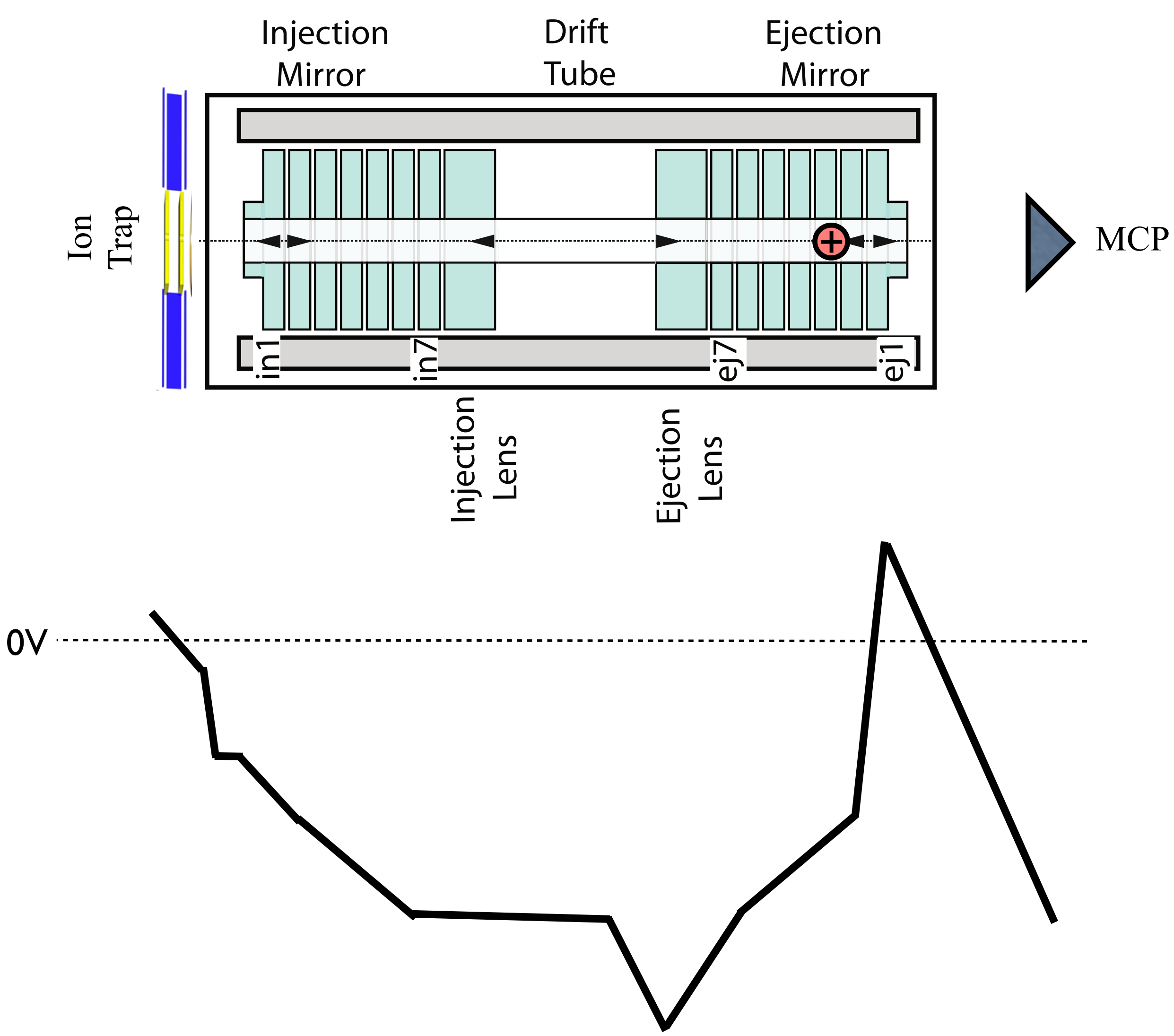


Approx. Potential

1. Accumulate and cool Ions in trap
2. Lower voltage on injection mirror

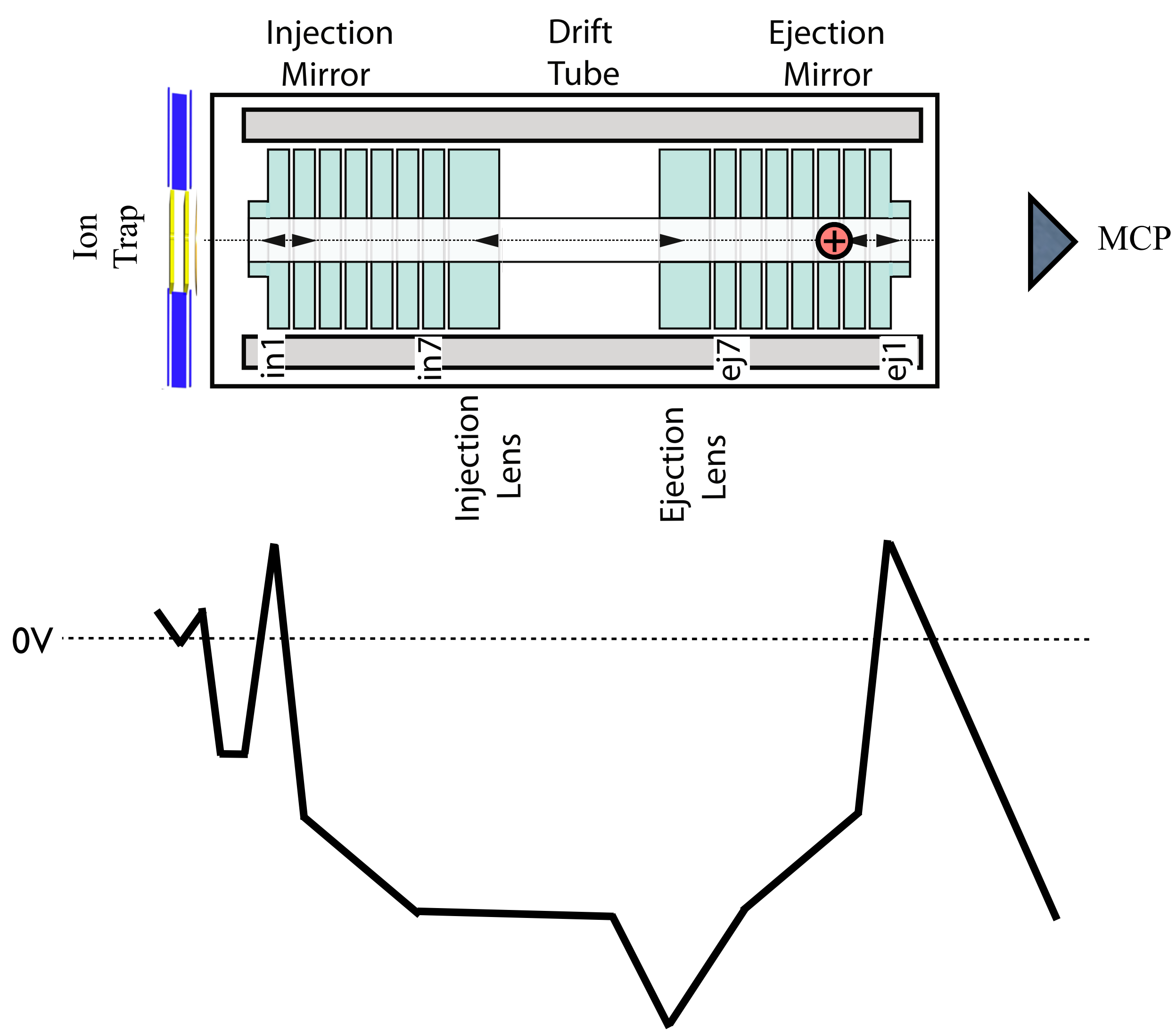
How the RIKEN MRTOF-MS works



Approx. Potential

1. Accumulate and cool Ions in trap
2. Lower voltage on injection mirror
3. Eject ions from trap

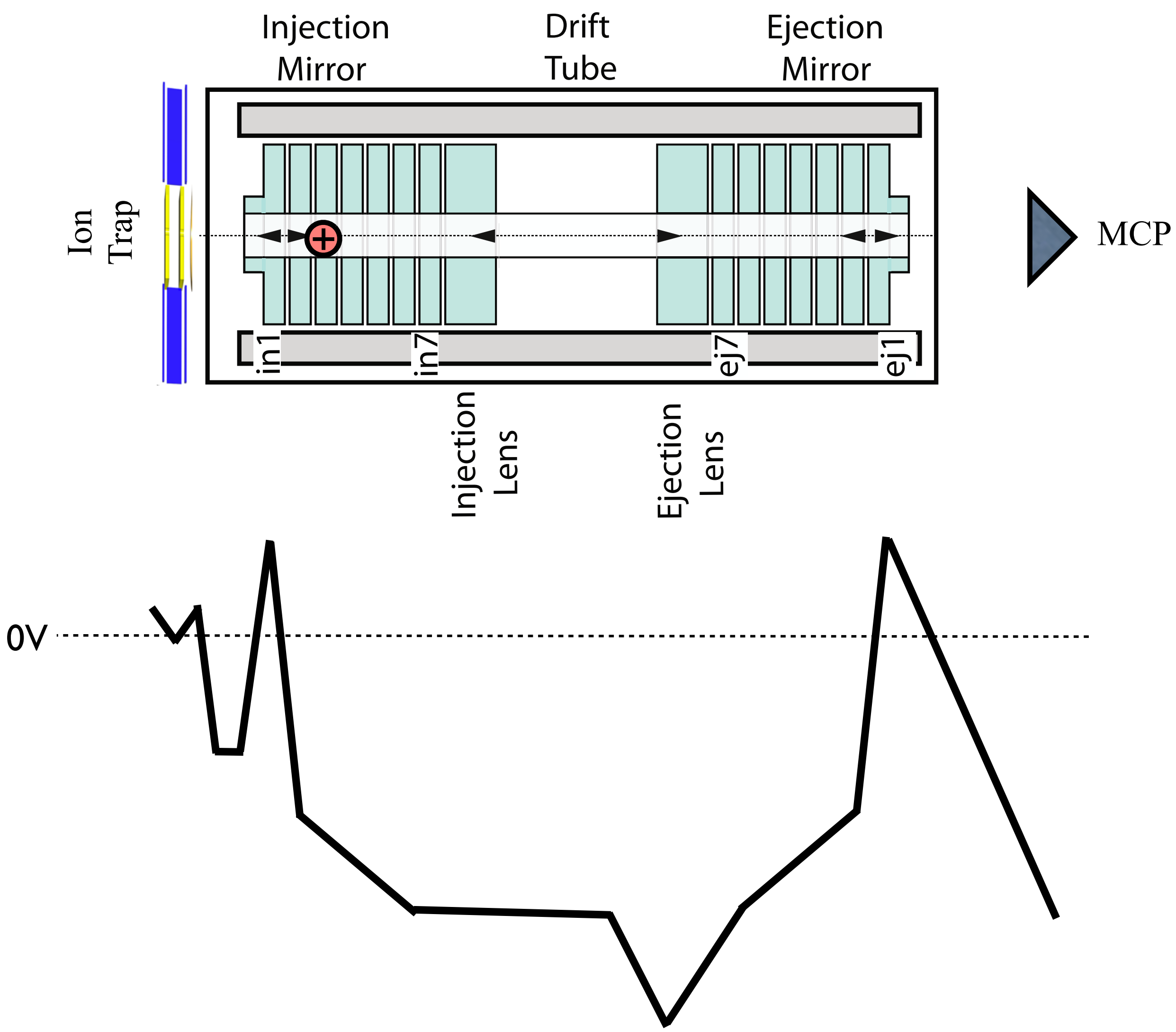
How the RIKEN MRTOF-MS works



Approx. Potential

1. Accumulate and cool Ions in trap
2. Lower voltage on injection mirror
3. Eject ions from trap
4. Raise voltage on injection mirror

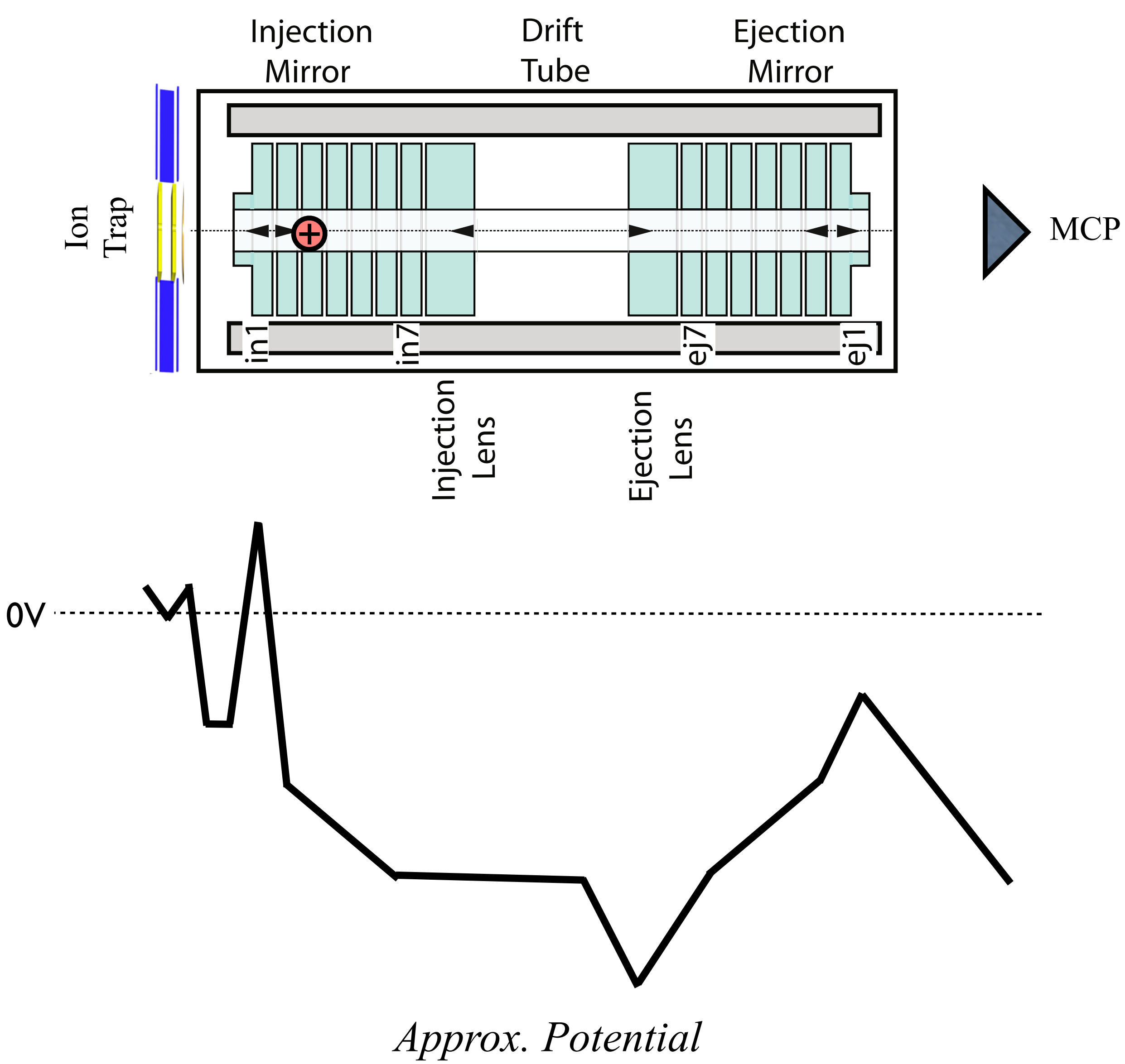
How the RIKEN MRTOF-MS works



Approx. Potential

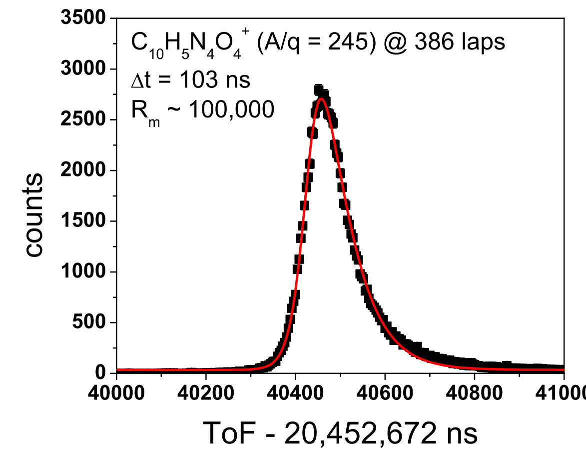
1. Accumulate and cool Ions in trap
2. Lower voltage on injection mirror
3. Eject ions from trap
4. Raise voltage on injection mirror
5. Wait for N reflections

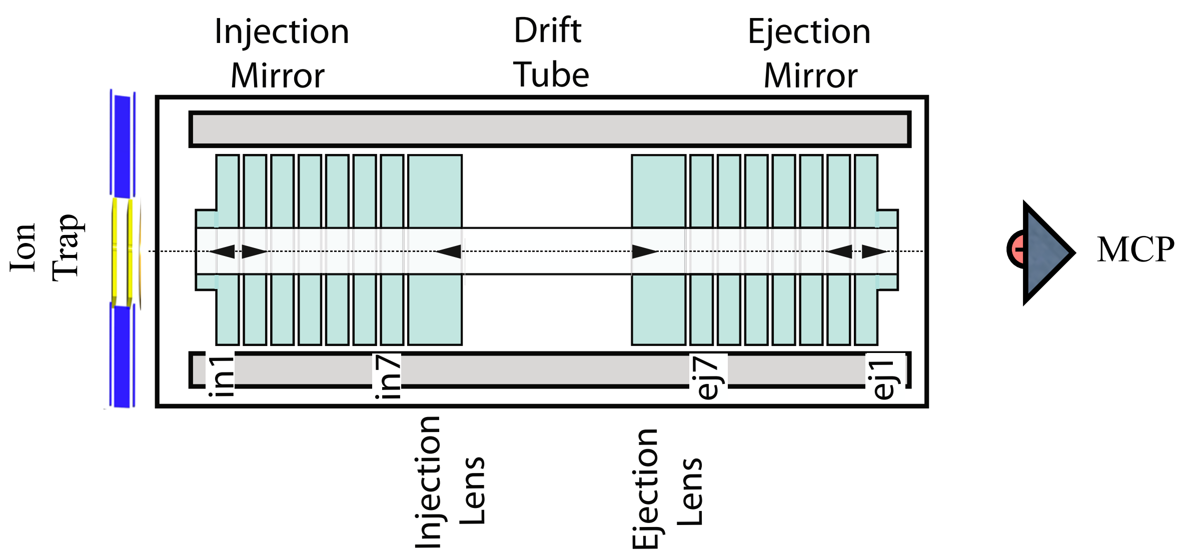
How the RIKEN MRTOF-MS works

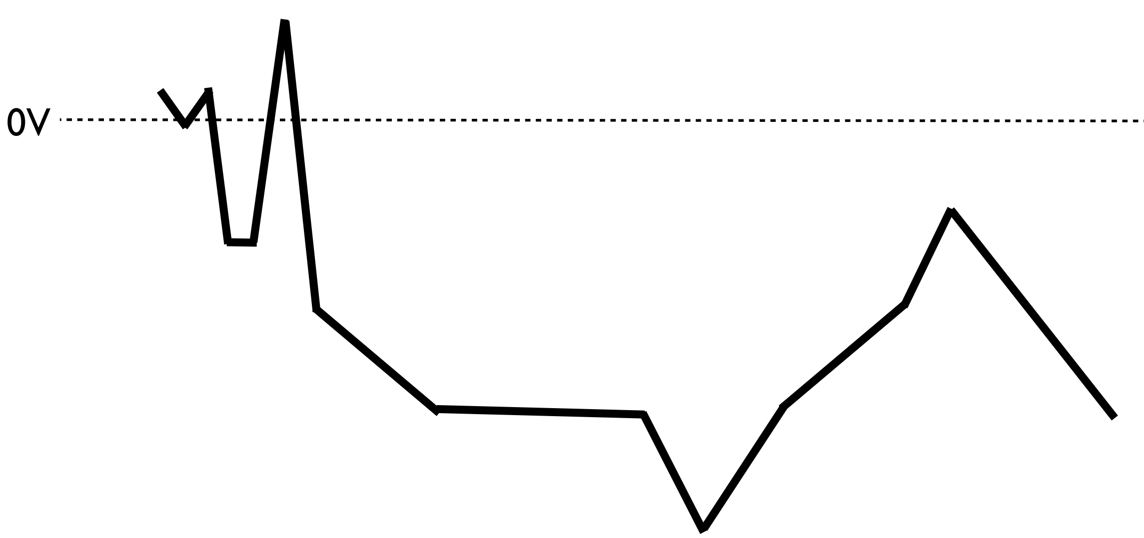


1. Accumulate and cool Ions in trap
2. Lower voltage on injection mirror
3. Eject ions from trap
4. Raise voltage on injection mirror
5. Wait for N reflections
6. Lower voltage on ejection mirror

How the RIKEN MRTOF-MS works





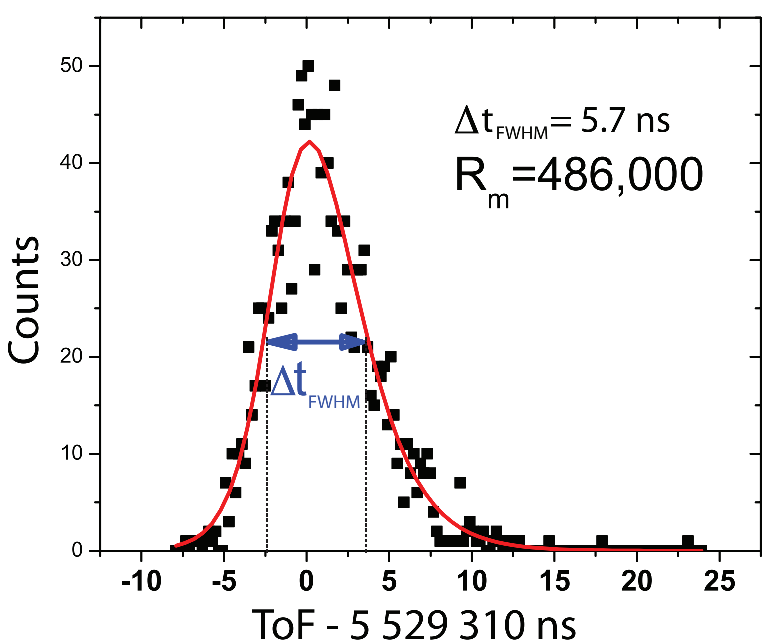


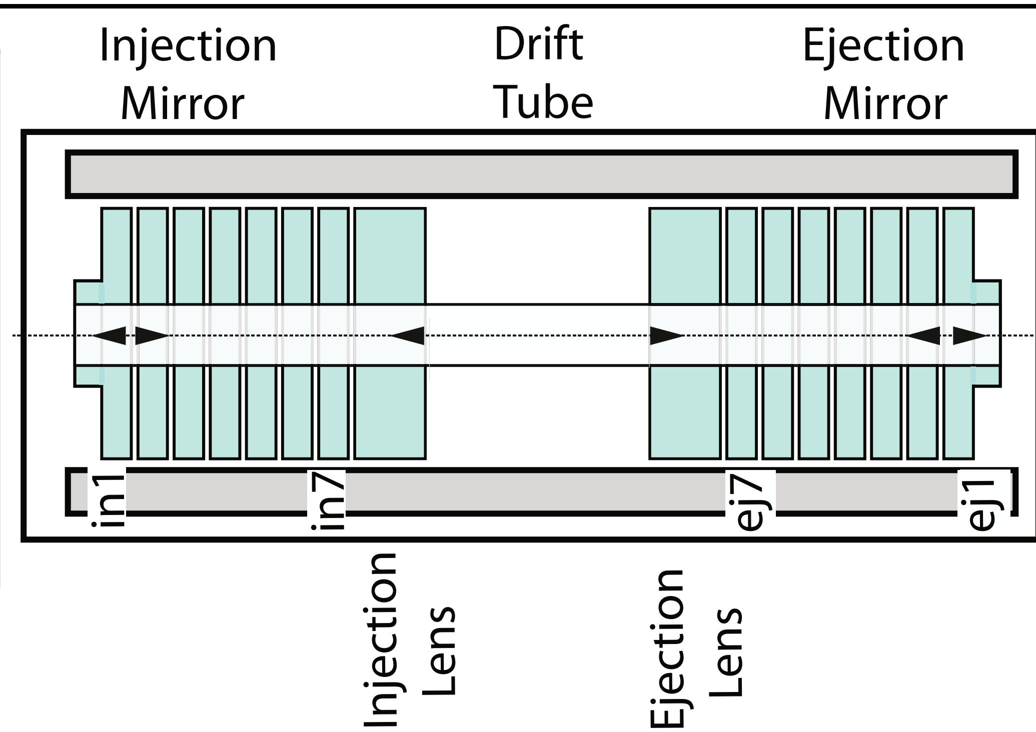
Approx. Potential

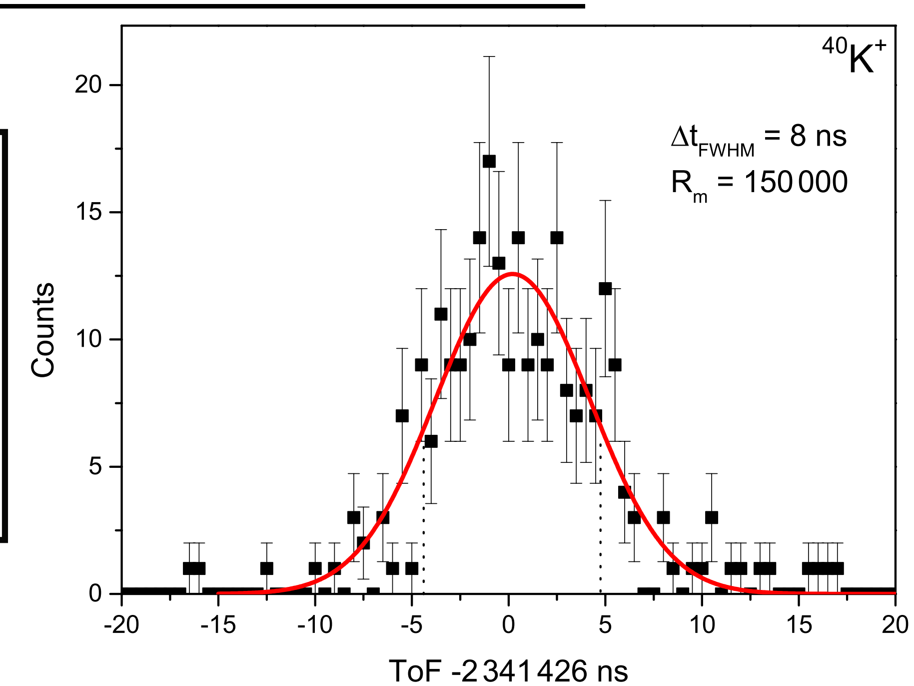
1. Accumulate and cool Ions in trap
2. Lower voltage on injection mirror
3. Eject ions from trap
4. Raise voltage on injection mirror
5. Wait for N reflections
6. Lower voltage on ejection mirror
7. Detect ions at MCP

Performance limited by voltage stability

Electrode	$\frac{\Delta t}{t} / \frac{\Delta V}{V}$	Electrode	$\frac{\Delta t}{t} / \frac{\Delta V}{V}$
ejL	−0.032	Drift	−0.265
ej1C	−0.163	in1C	−0.216
ej1O	0.002	in1O	<0.001
ej2	−0.076	in2	0.030
ej3	−0.052	in3	0.004
ej4	0.021		
ej5	0.077		
ej6	0.019		
ej7	0.012		
Mirror	0.035		







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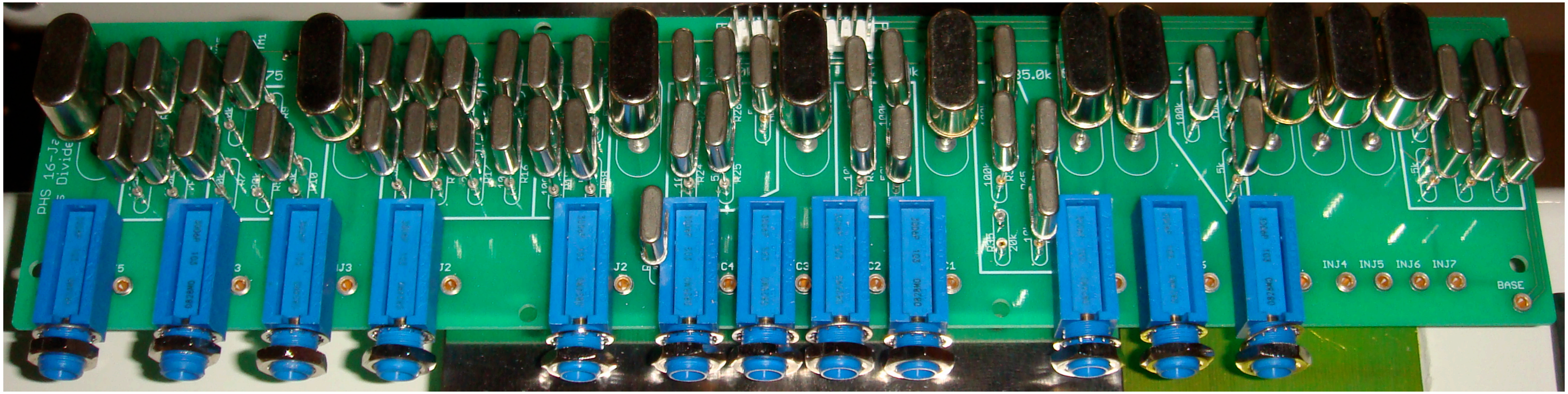
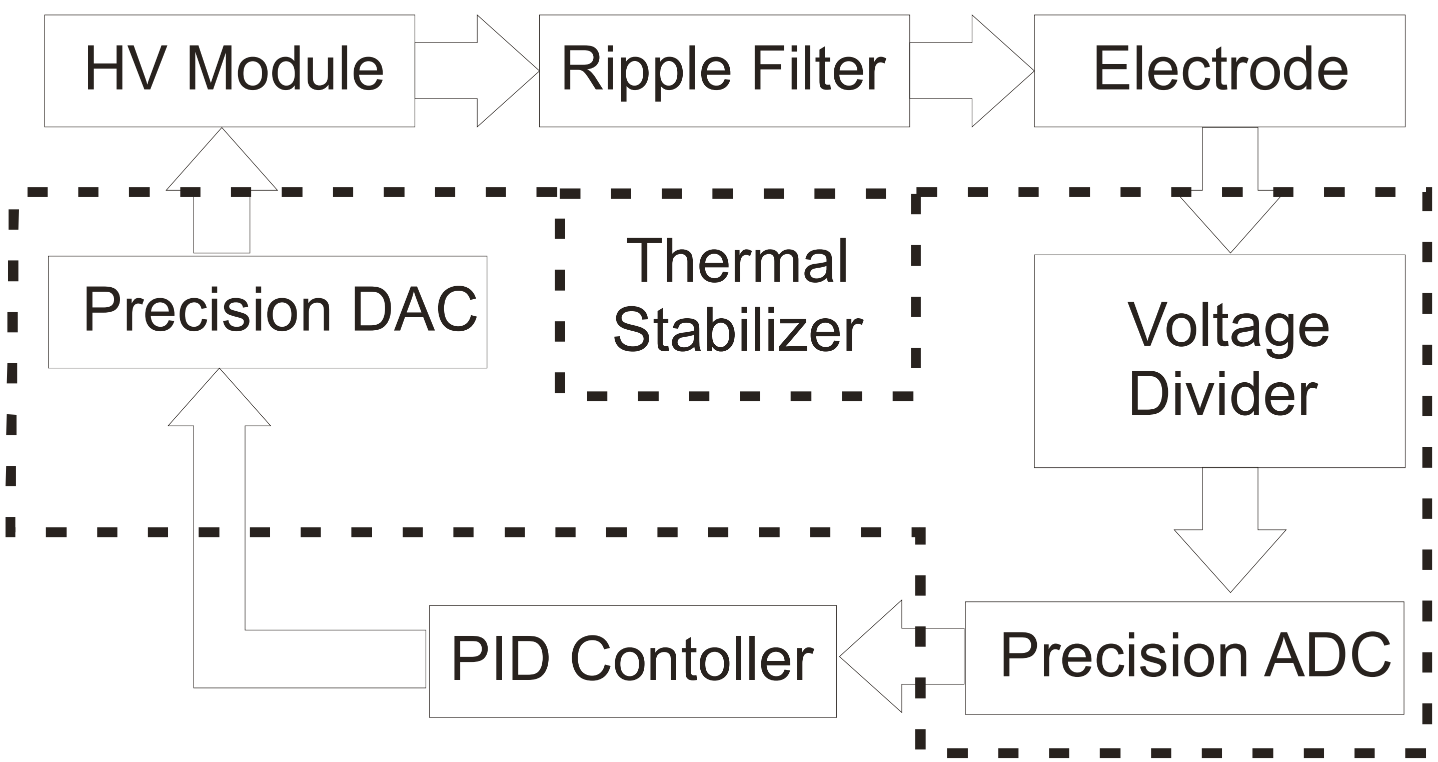
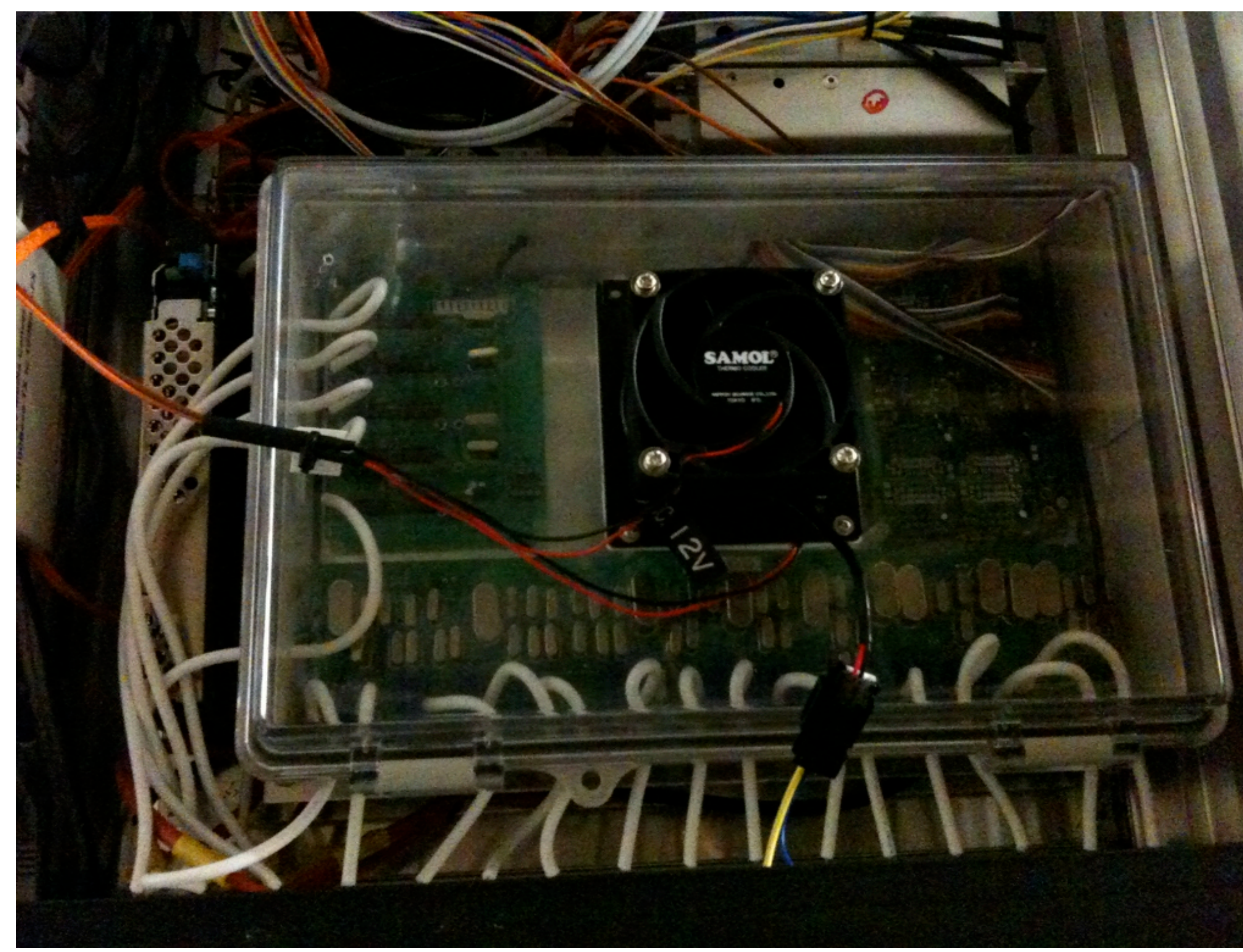






Performance limited by voltage stability

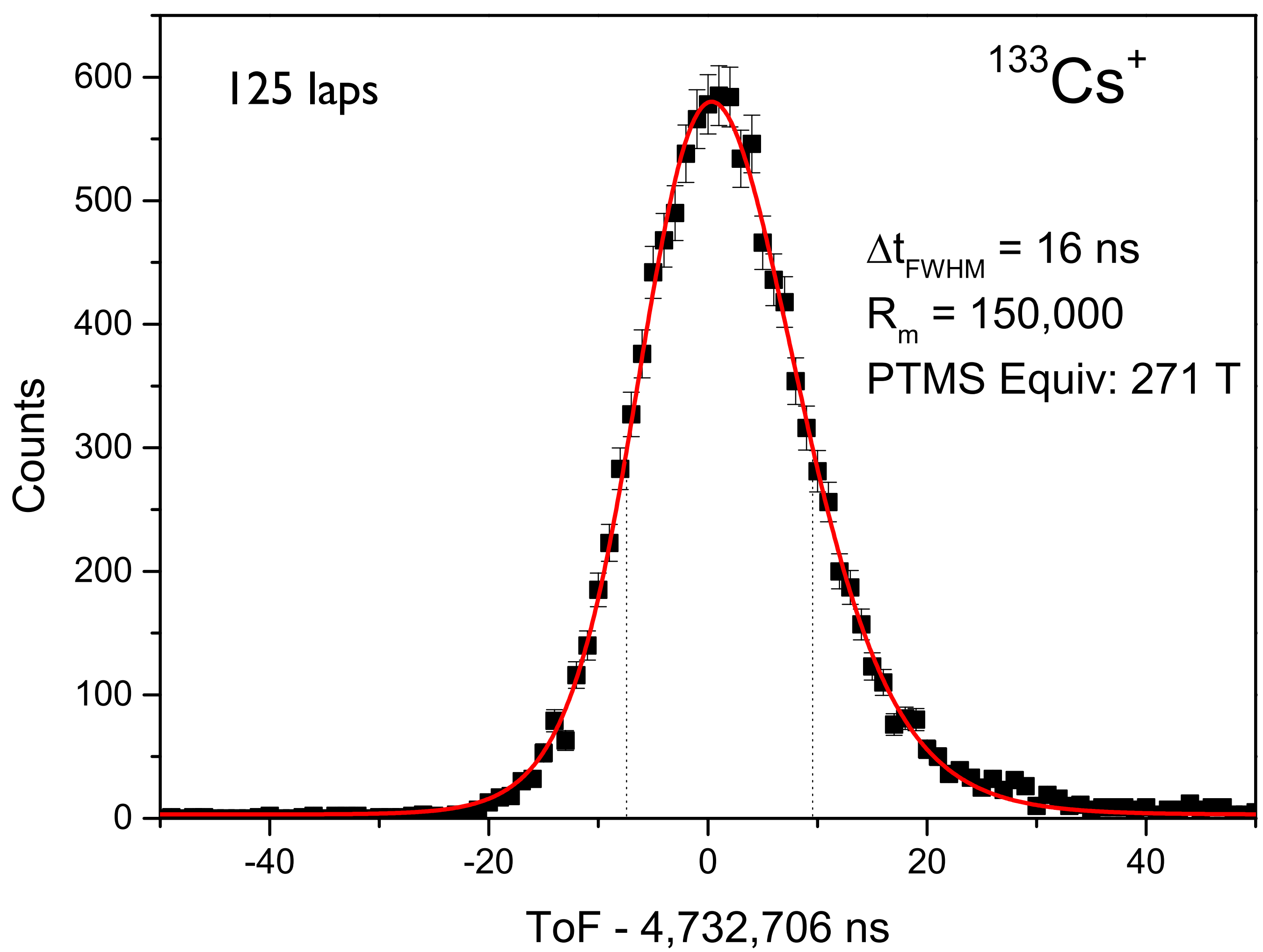
REDACTED

Analysis method

- Typically, time of flight systems require two calibration references
    - Two unknowns need to be determined
        - $t = t_0 + \sqrt{m} \cdot \kappa$
- We can measure t_0, have long time-of-flight
    - Only need one nearby reference

Analysis method

- The peak shape is not Gaussian
- Has exponential(ish) tail
- Reproduced well be exponential-Gaussian hybrid



Analysis method

$$t = t_0 + \oint \sqrt{\frac{m}{2E}} dl$$

Measured time-of-flight

t_0 is a delay between TDC and ion start

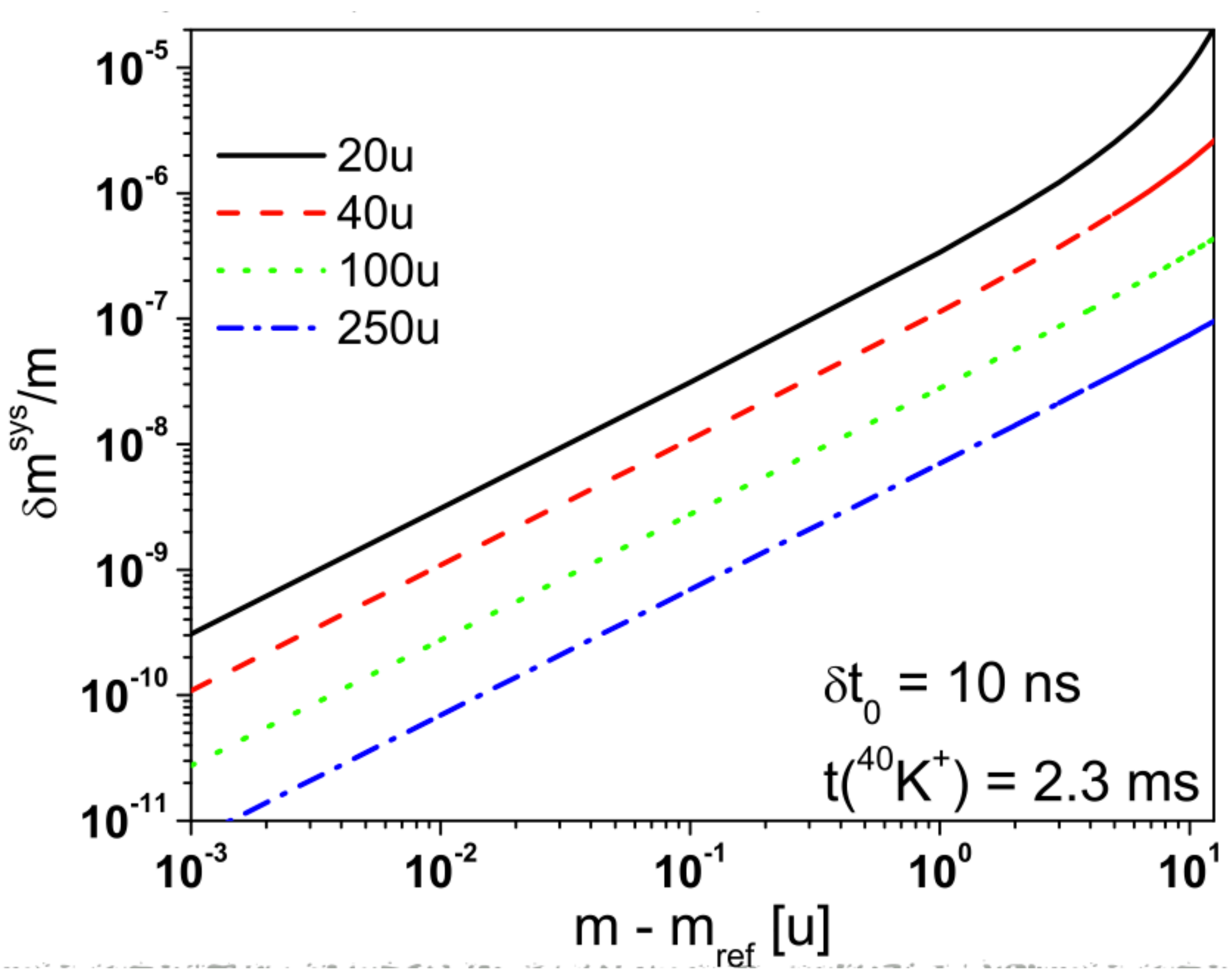
$$\frac{m}{m_{\text{ref}}} = \left(\frac{t - t_0}{t_{\text{ref}} - t_0} \right)^2$$

$$\frac{\delta m^{\text{stat}}}{m} = \sqrt{4\left[\frac{\delta t}{t} + \frac{\delta t_{\text{ref}}}{t_{\text{ref}}}\right]^2 + \left[\frac{\delta m_{\text{ref}}}{m_{\text{ref}}}^2\right]}$$

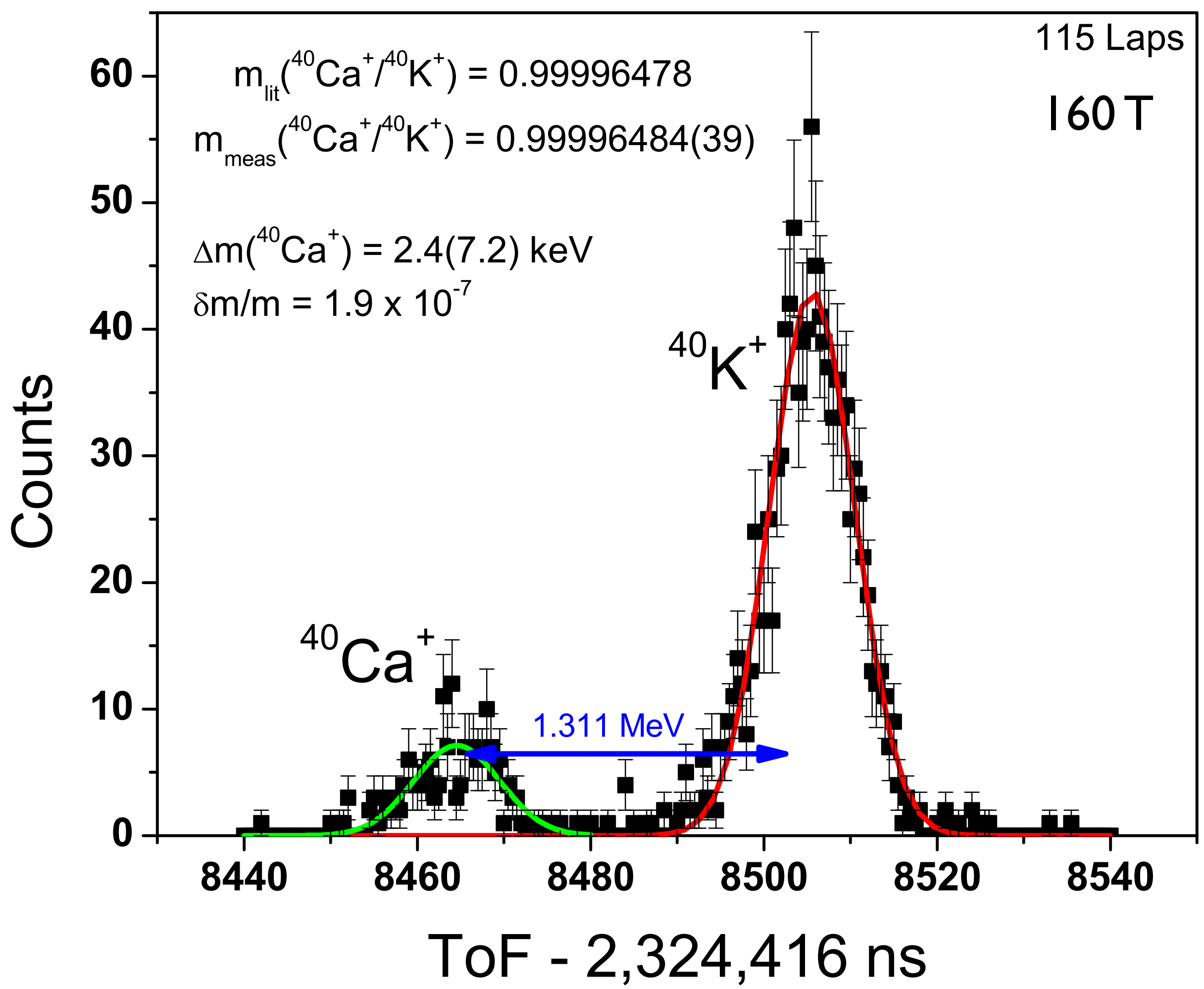
Standard statistical treatment

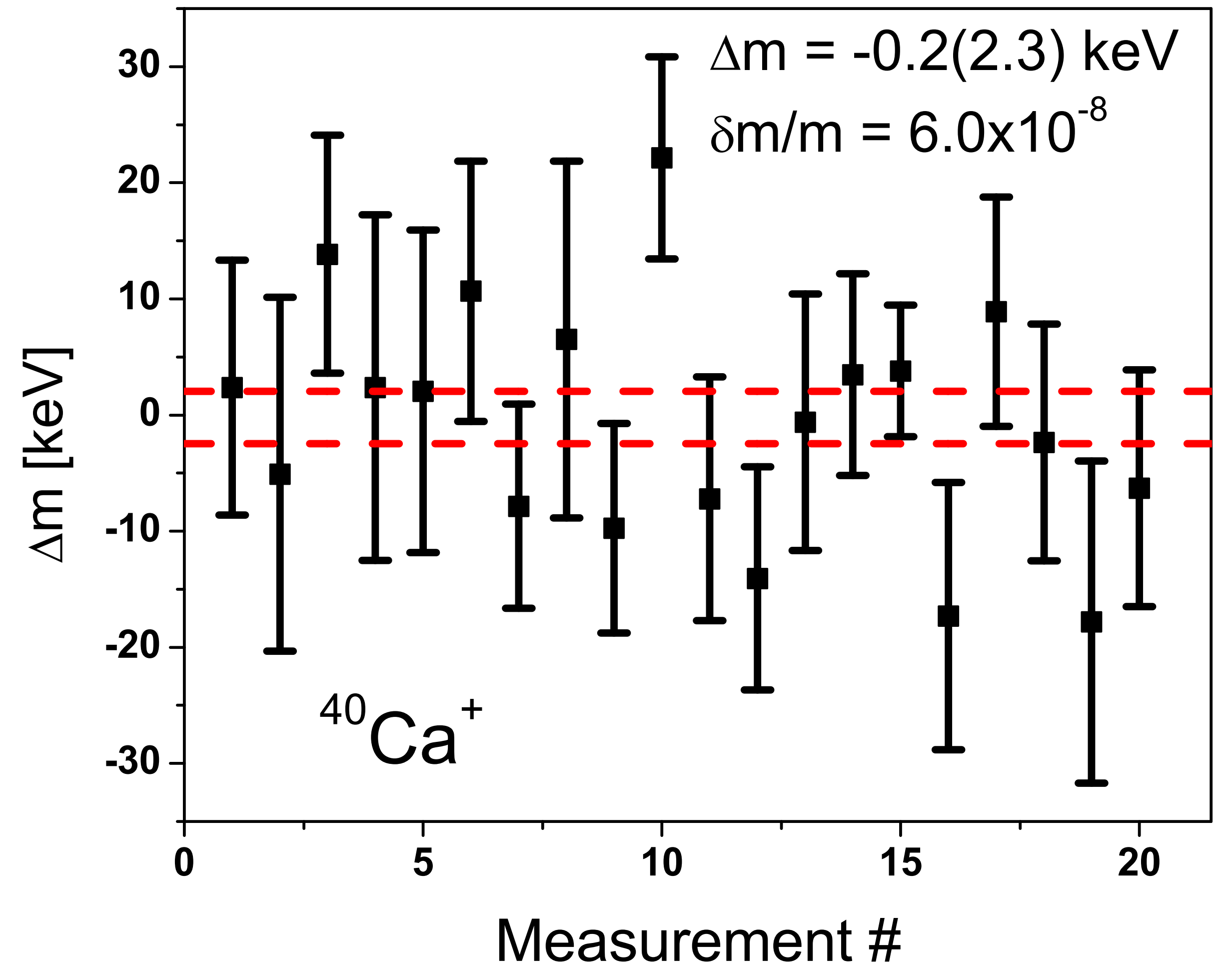
$$\delta m^{\text{sys}} = 2 m_{\text{ref}} \frac{t(t - t_{\text{ref}})}{t_{\text{ref}}^3} \delta t_0$$

The t_0-term introduces systematic error



Early offline results

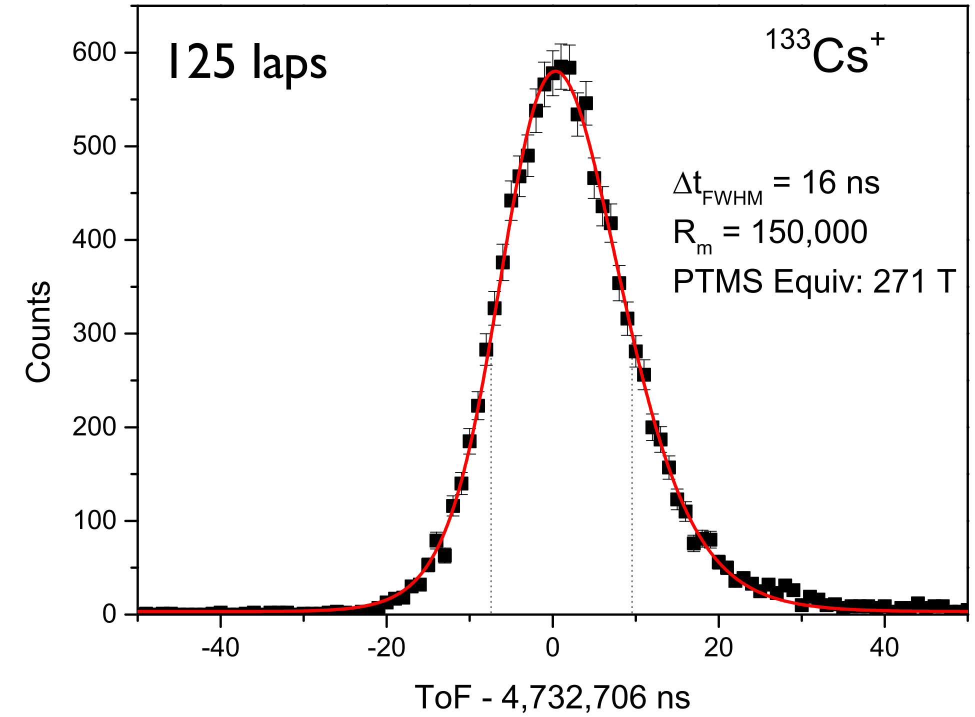




MRTOF-MS retune with faster analyzing time

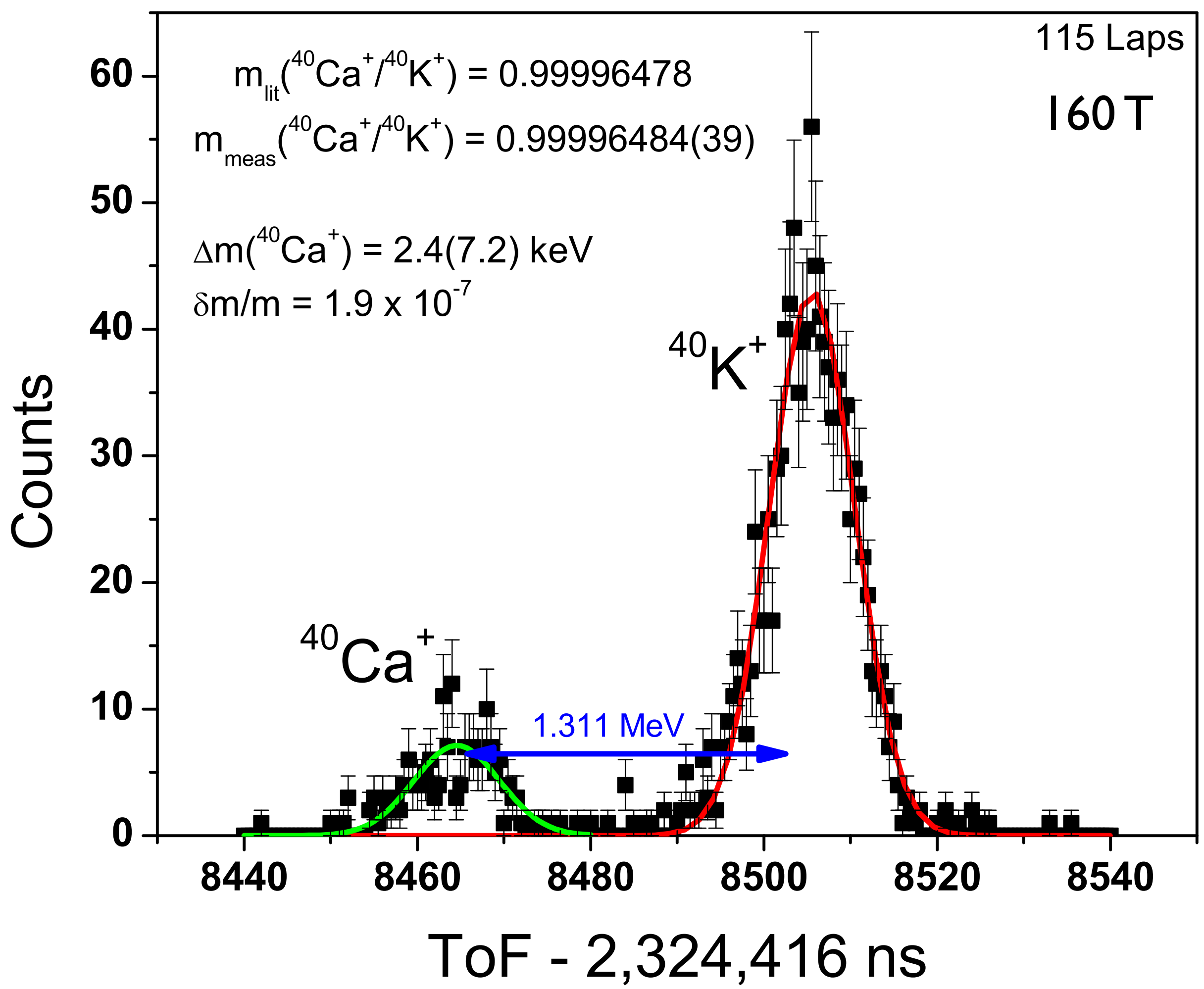
Accuracy limit is <<10^{-7}

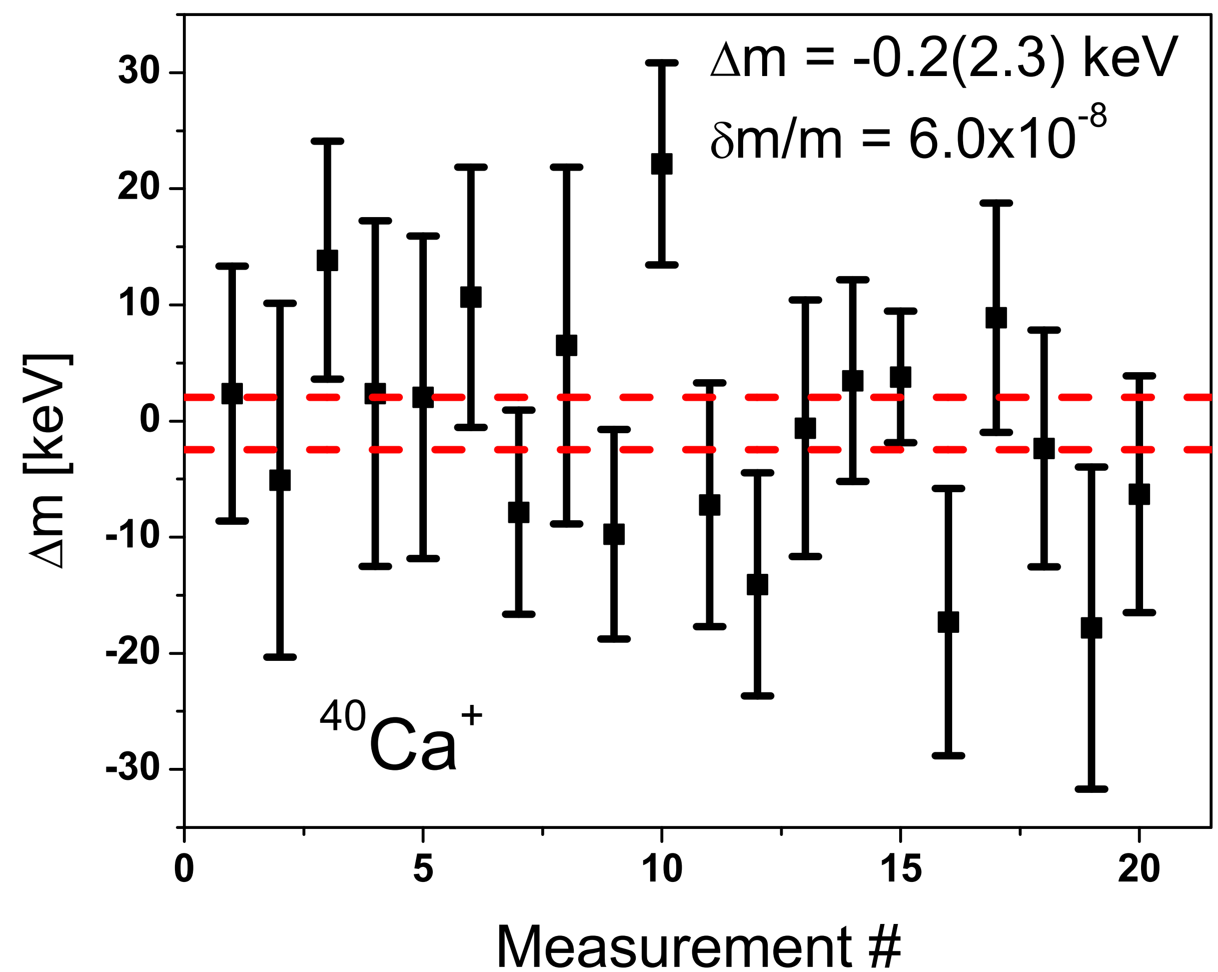
Highly competitive with PTMS



P. Schury et al., NIM **B** 335 (2014) 39–53

Early offline results





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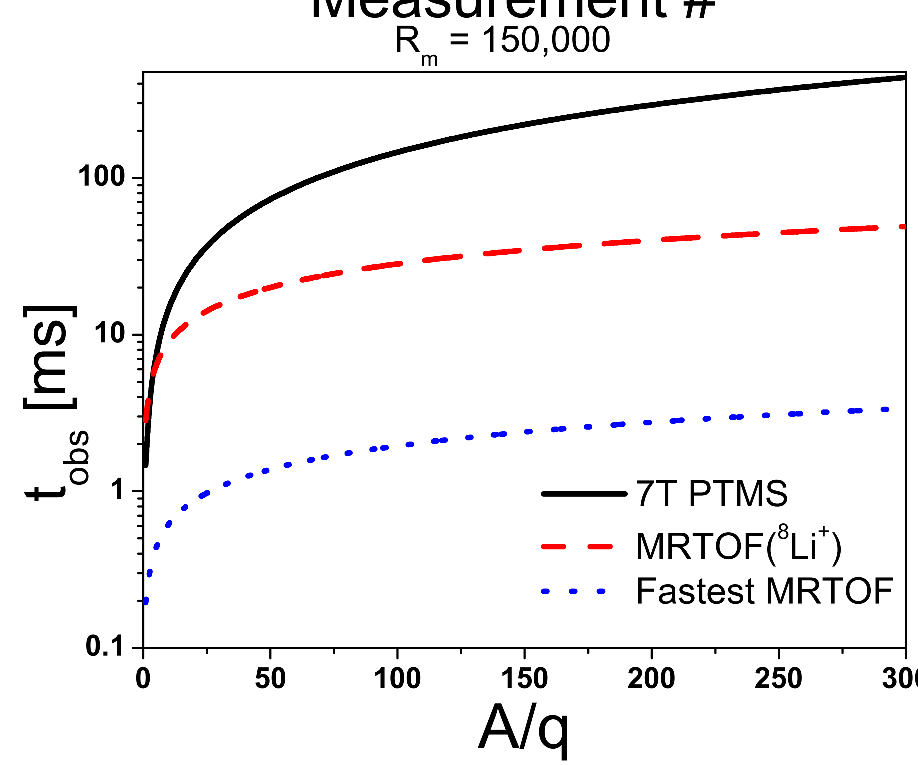

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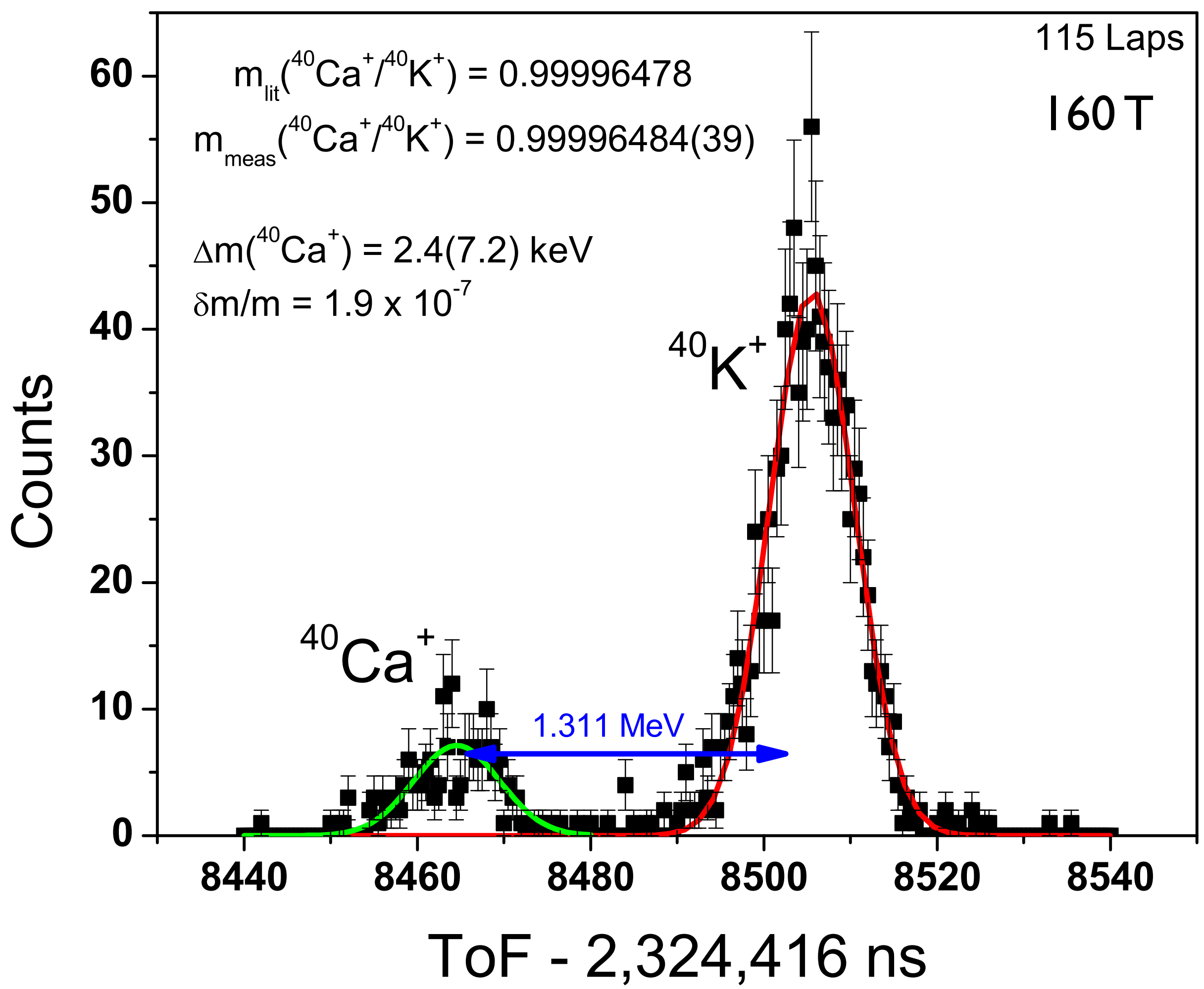

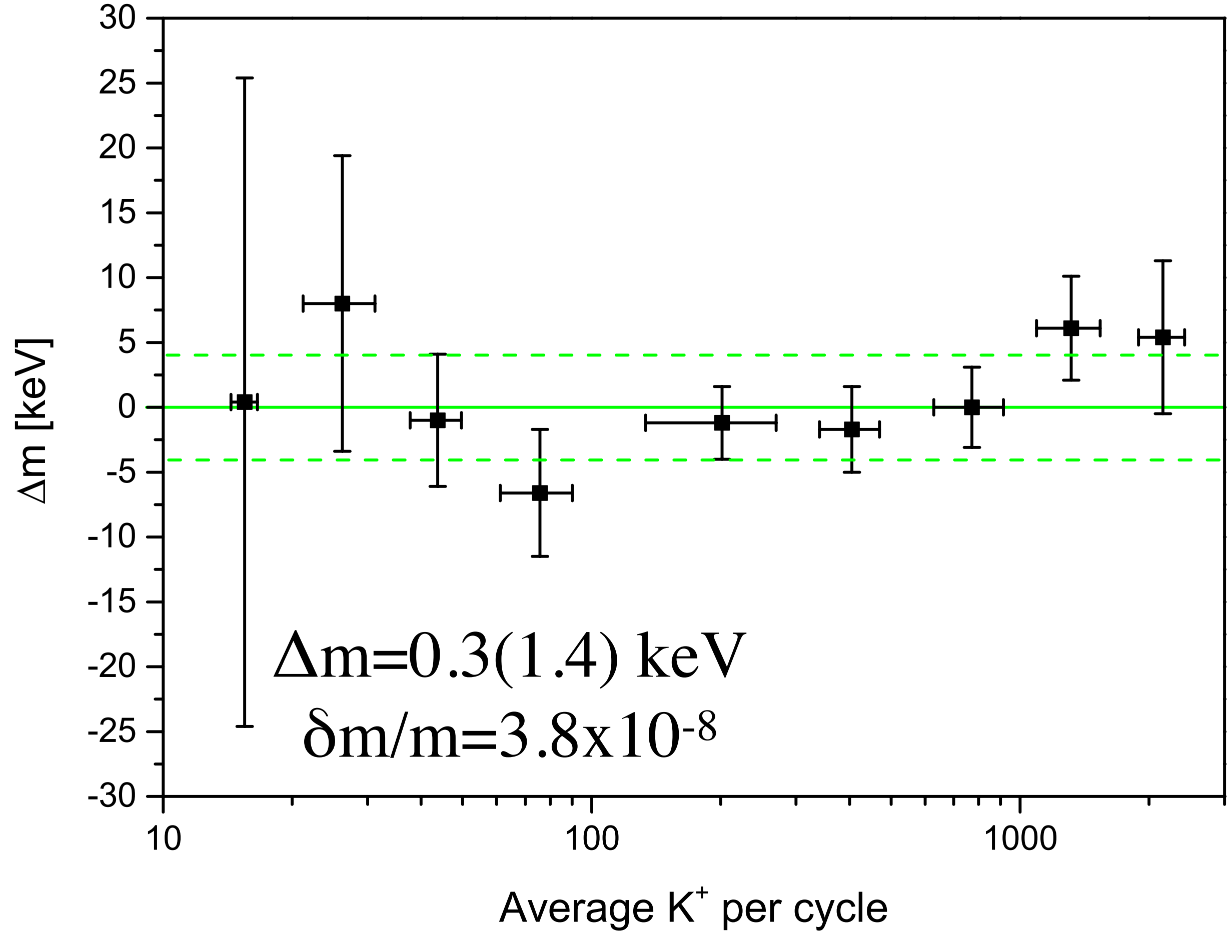

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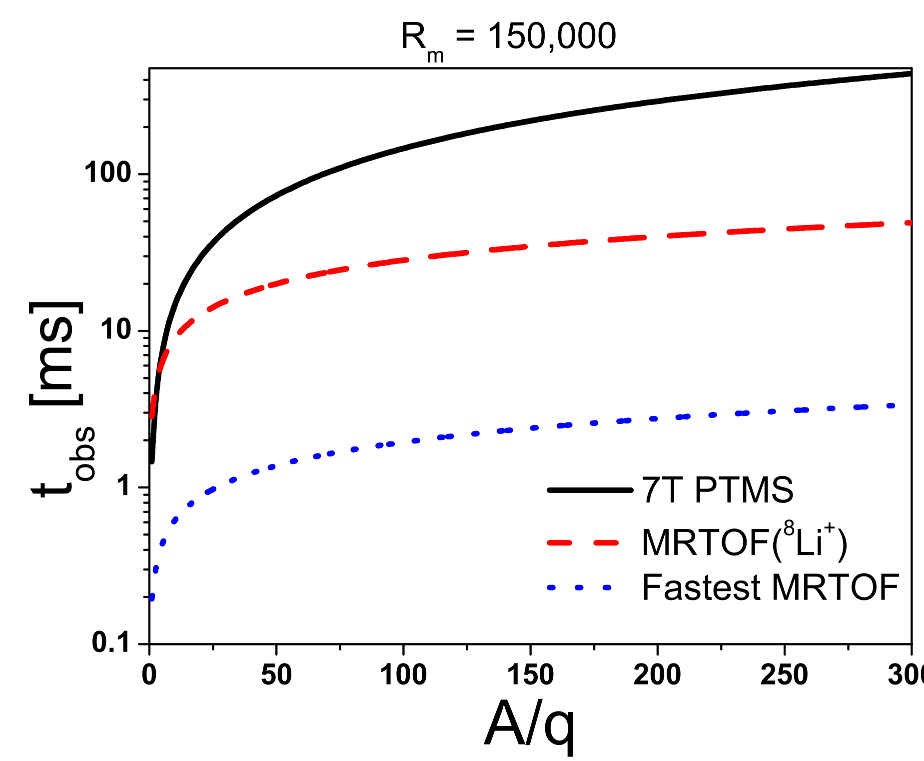
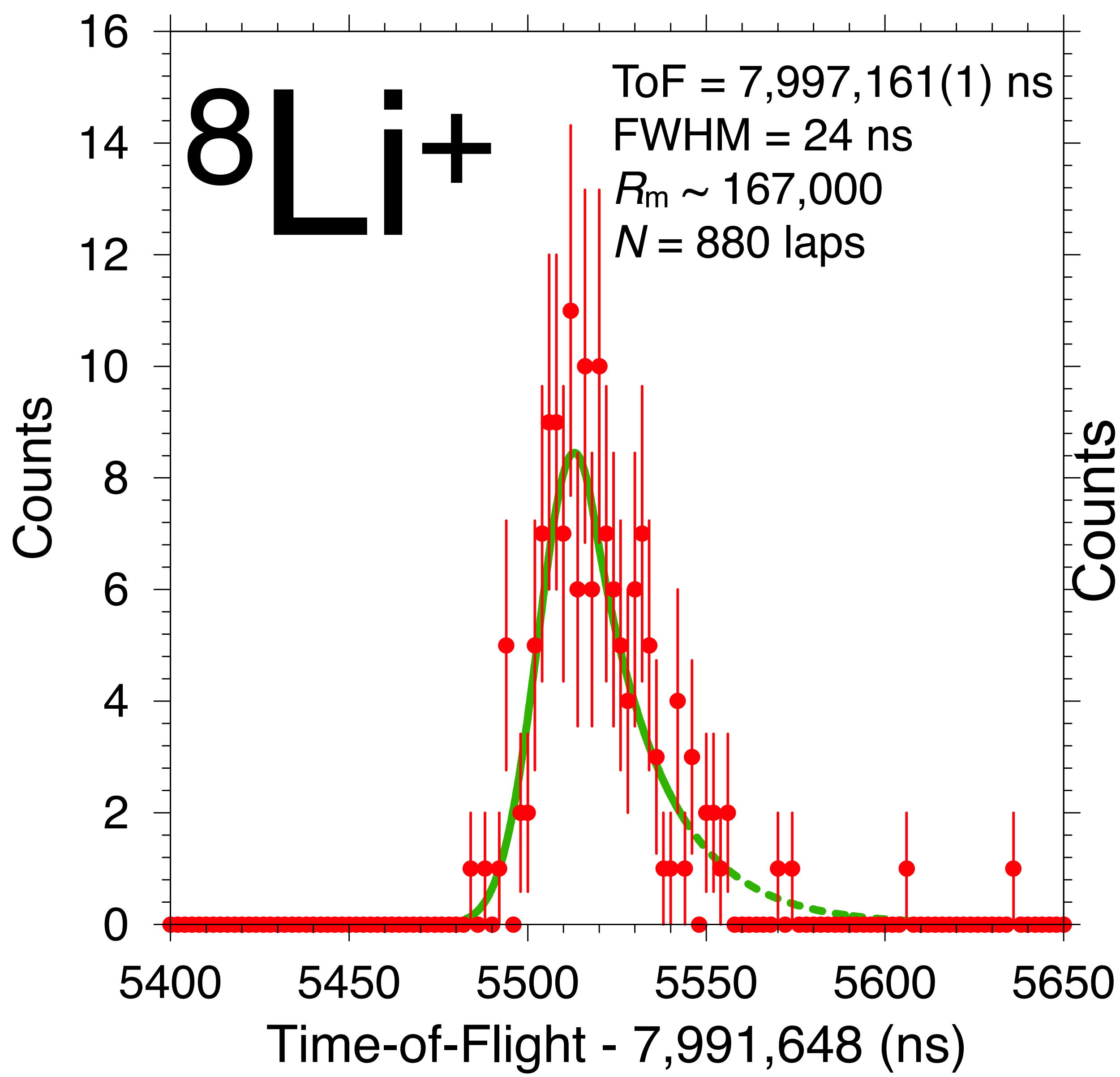
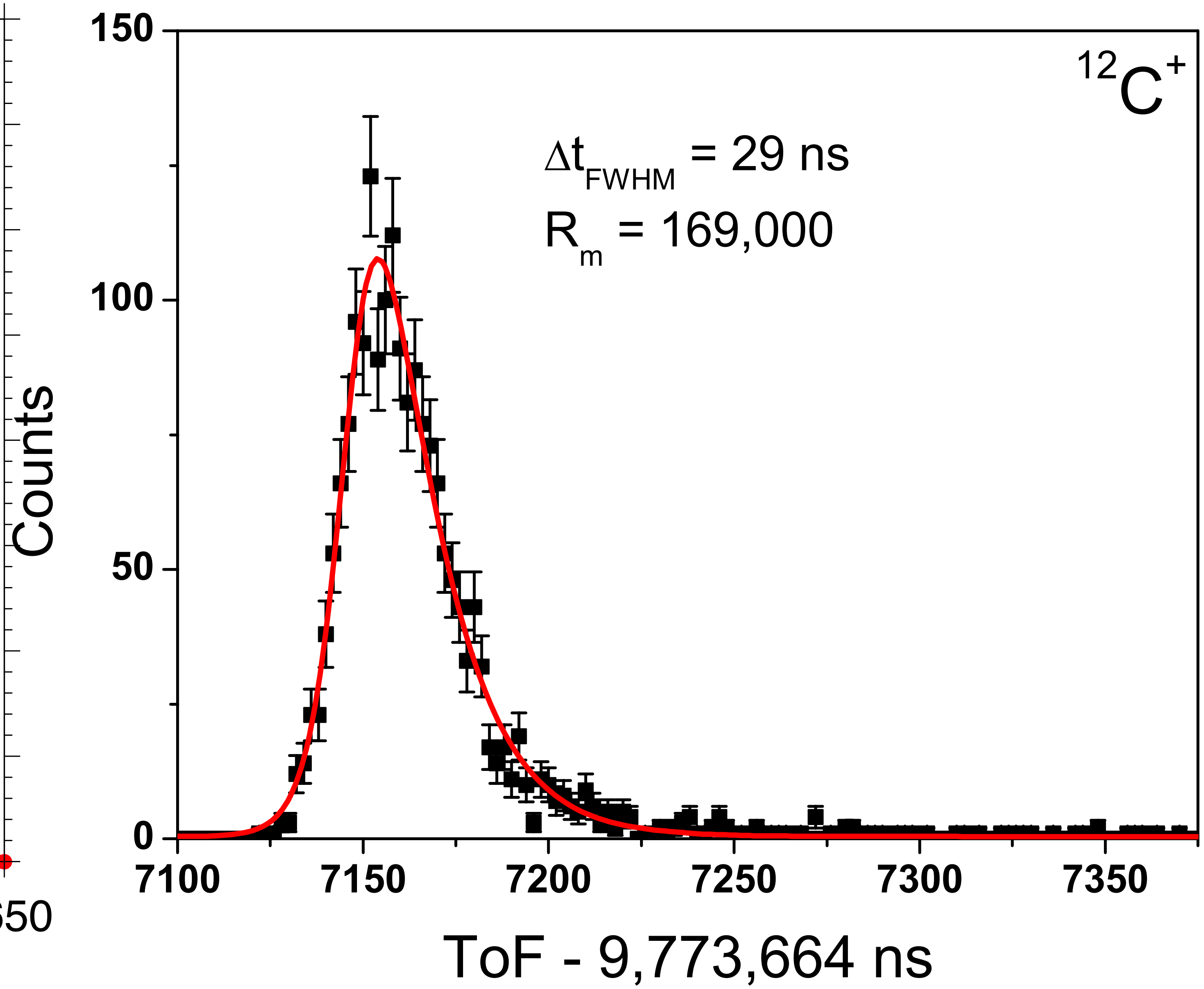


First online results

- Performed at prototype SLOWRI Facility at RIPS
- Gas cell was optimized for light ions
- Stable references were limited





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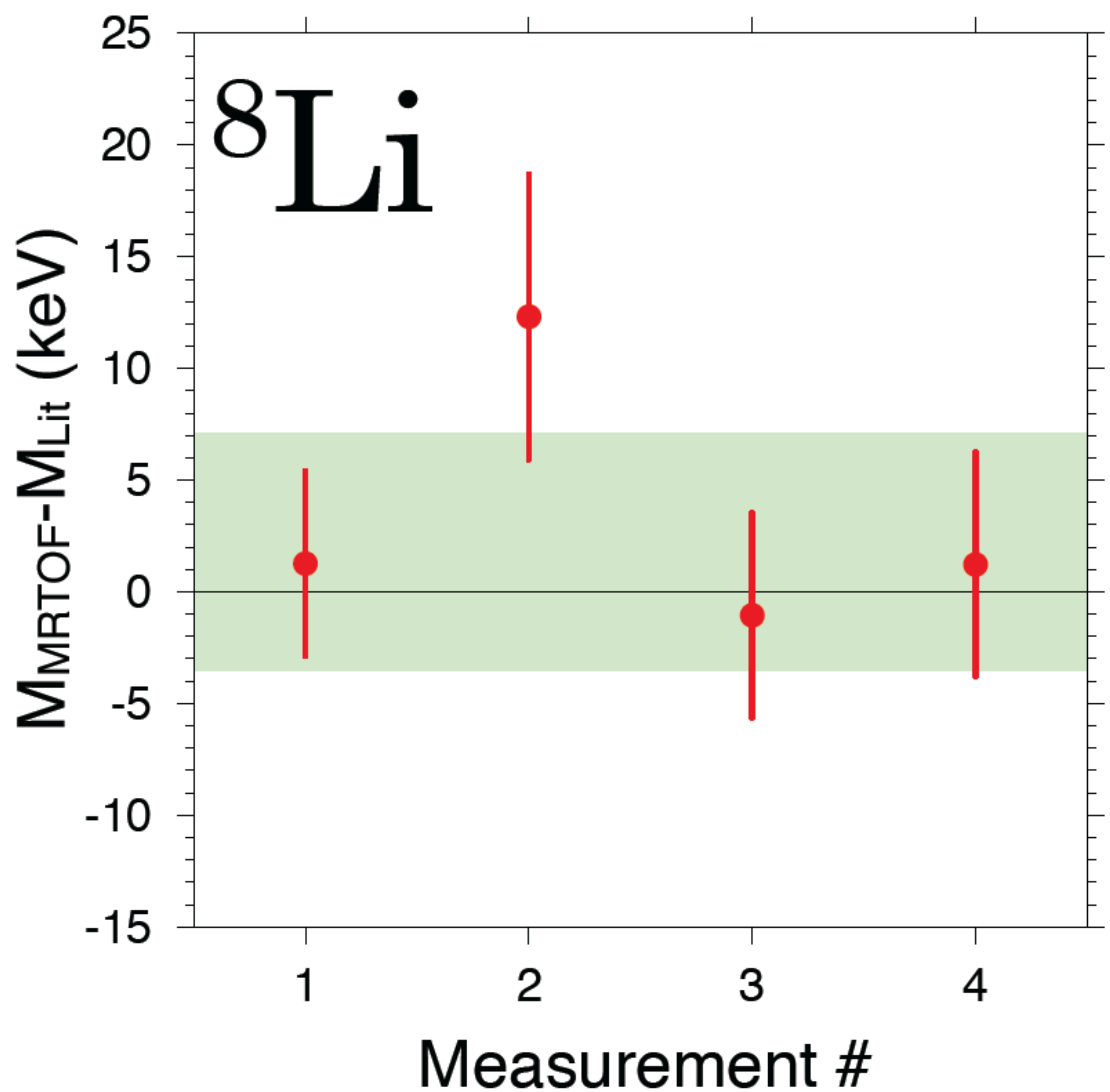
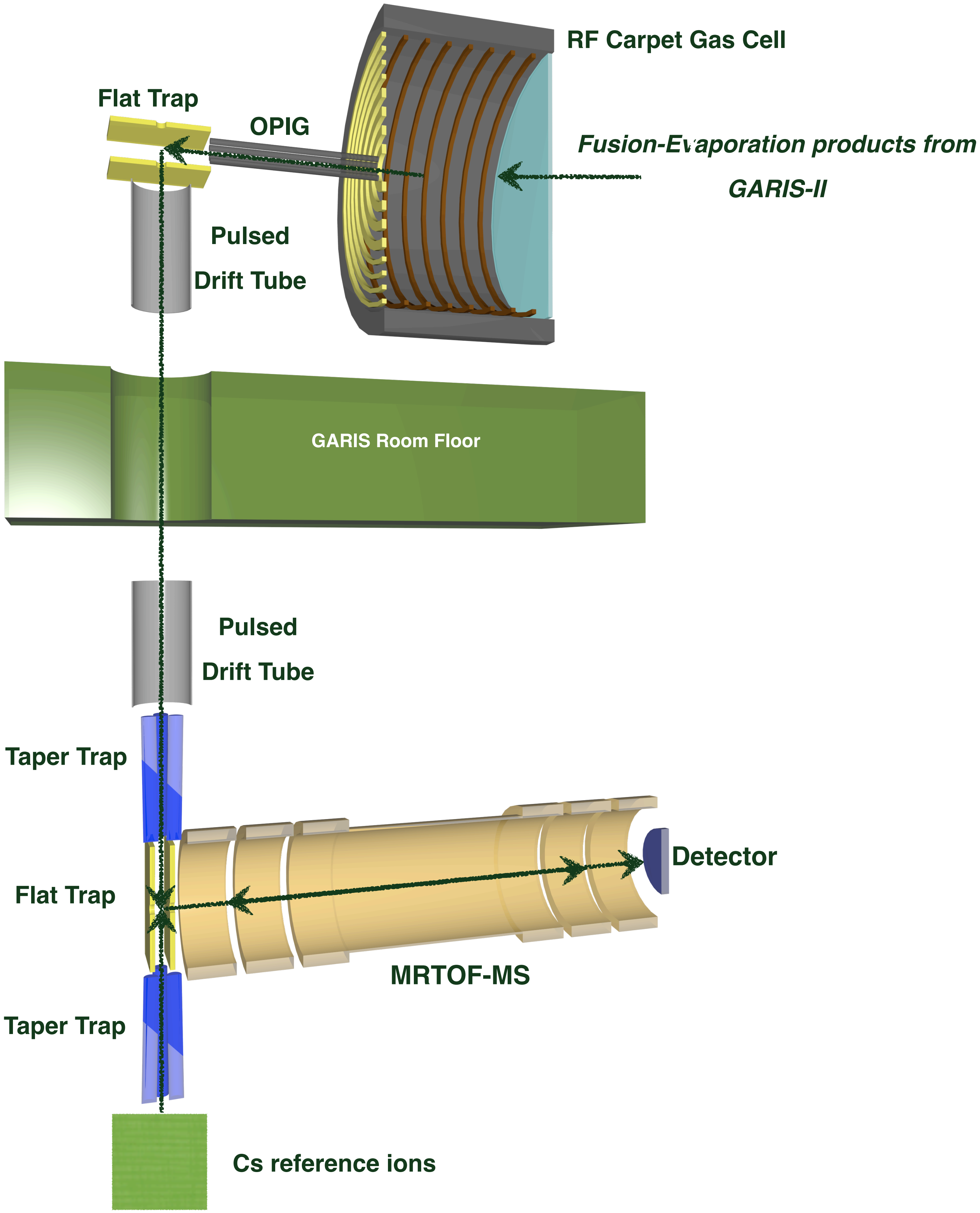
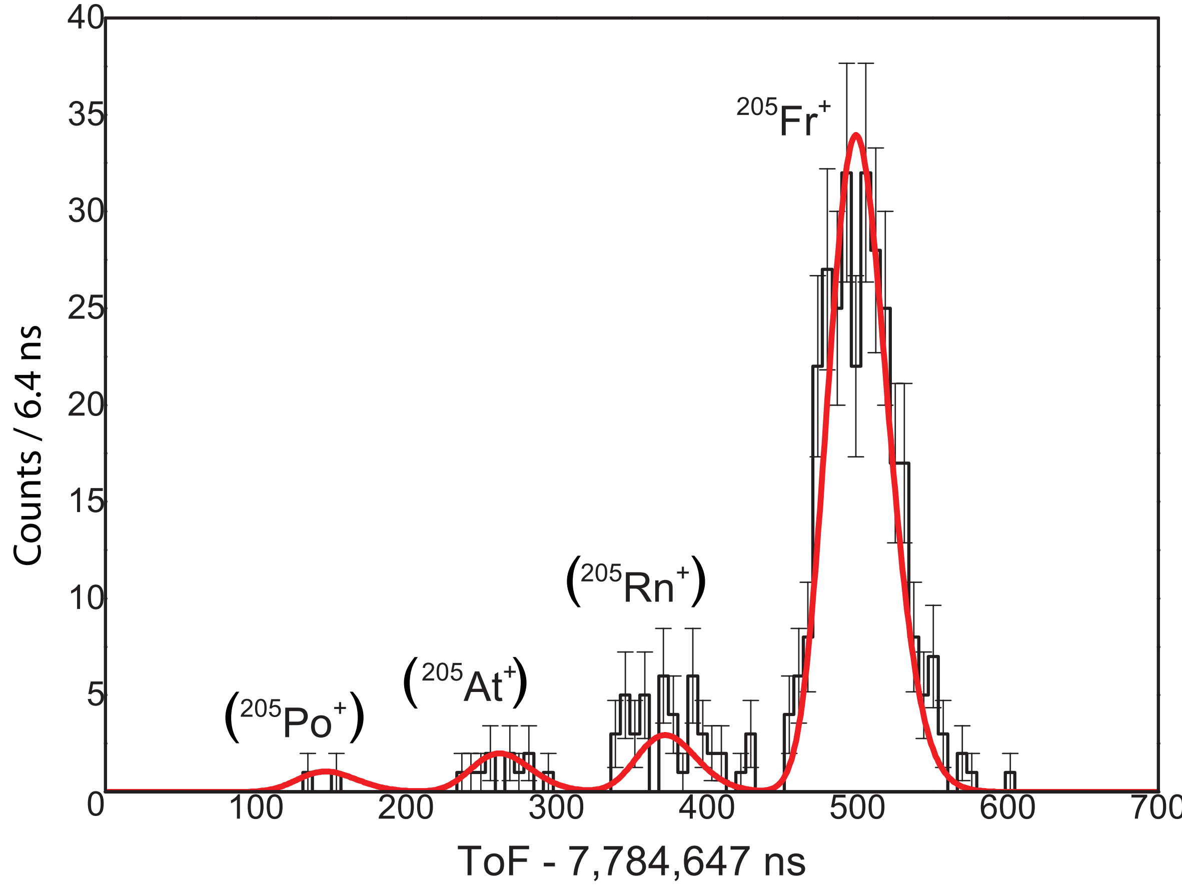


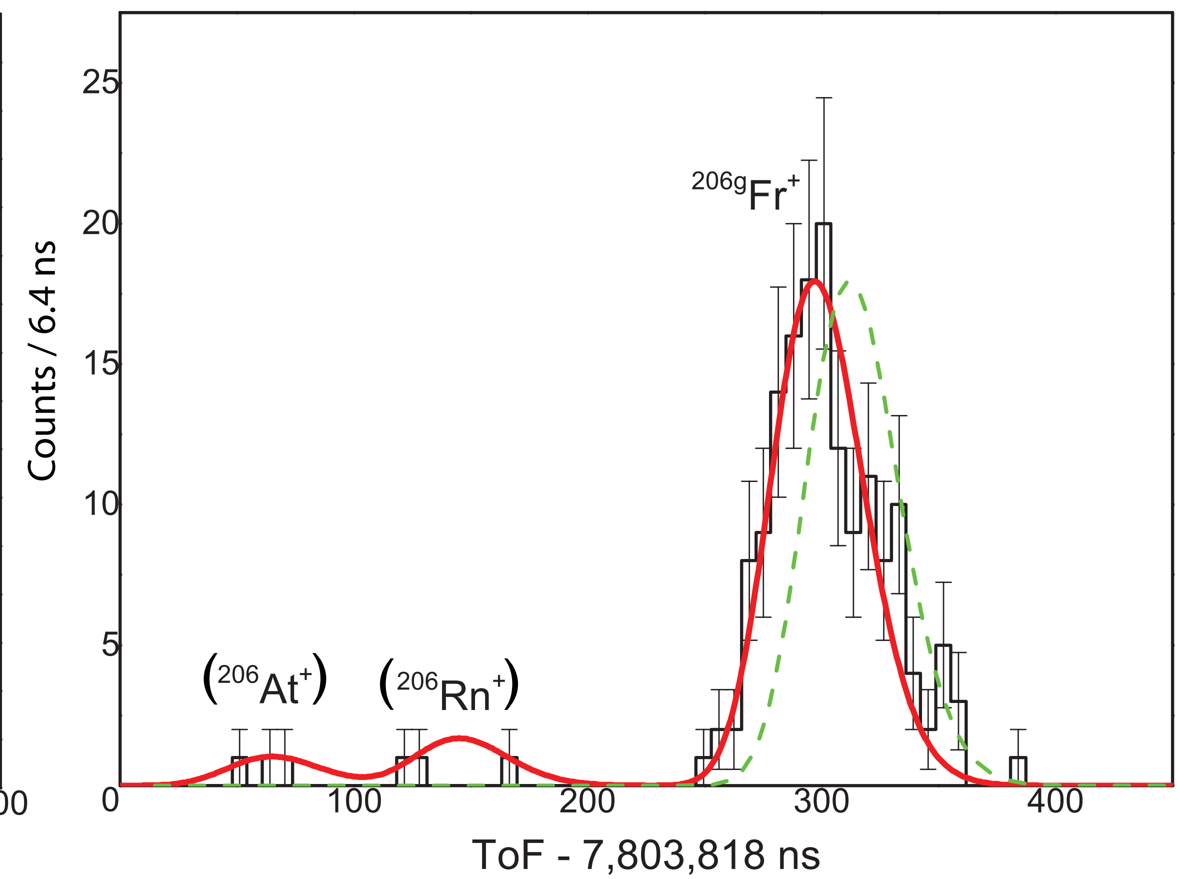
First online results with heavy ions

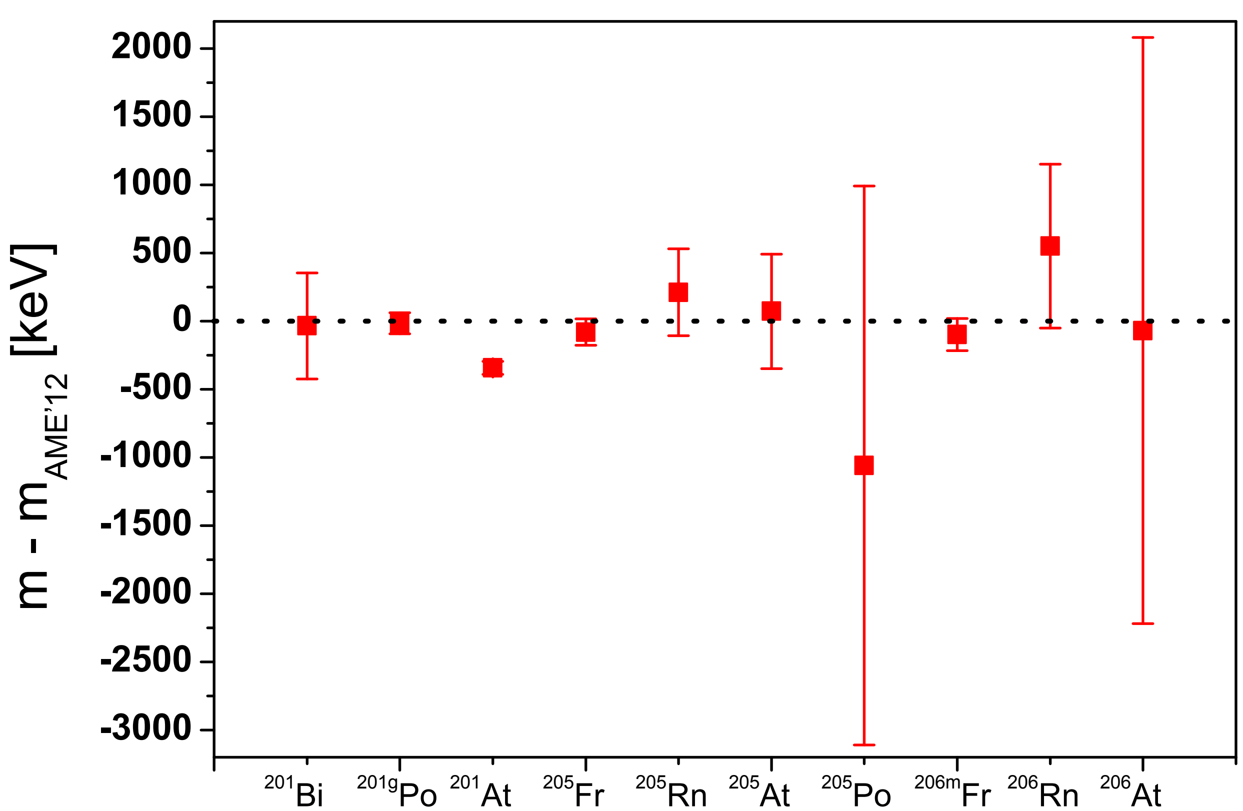


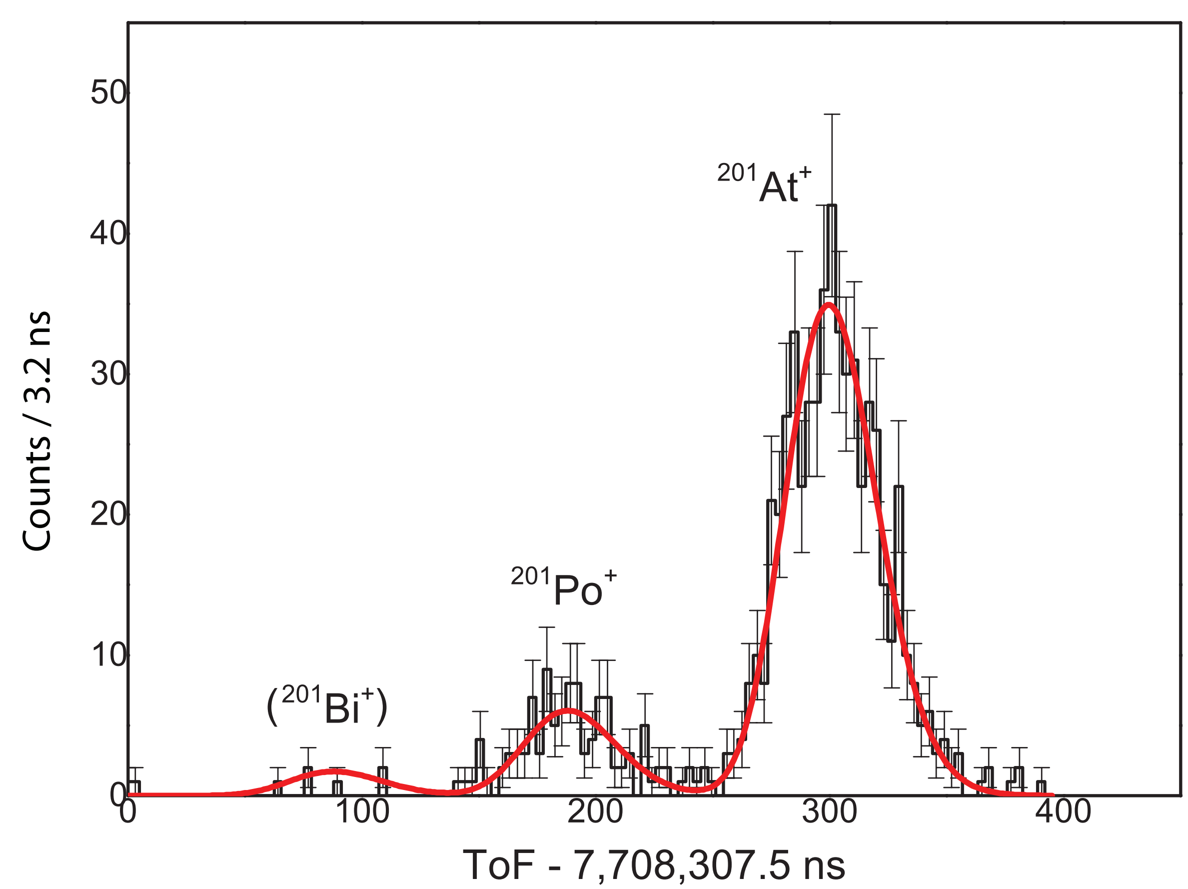
- Fusion-evaporation
- $^{165}Ho(^{40}Ar,4n)^{201}At$
- $^{169}Tm(^{40}Ar, xn)^{209\text{-}x}Fr$
- $^{133}Cs^{+}$ used as reference

First online results with heavy ions









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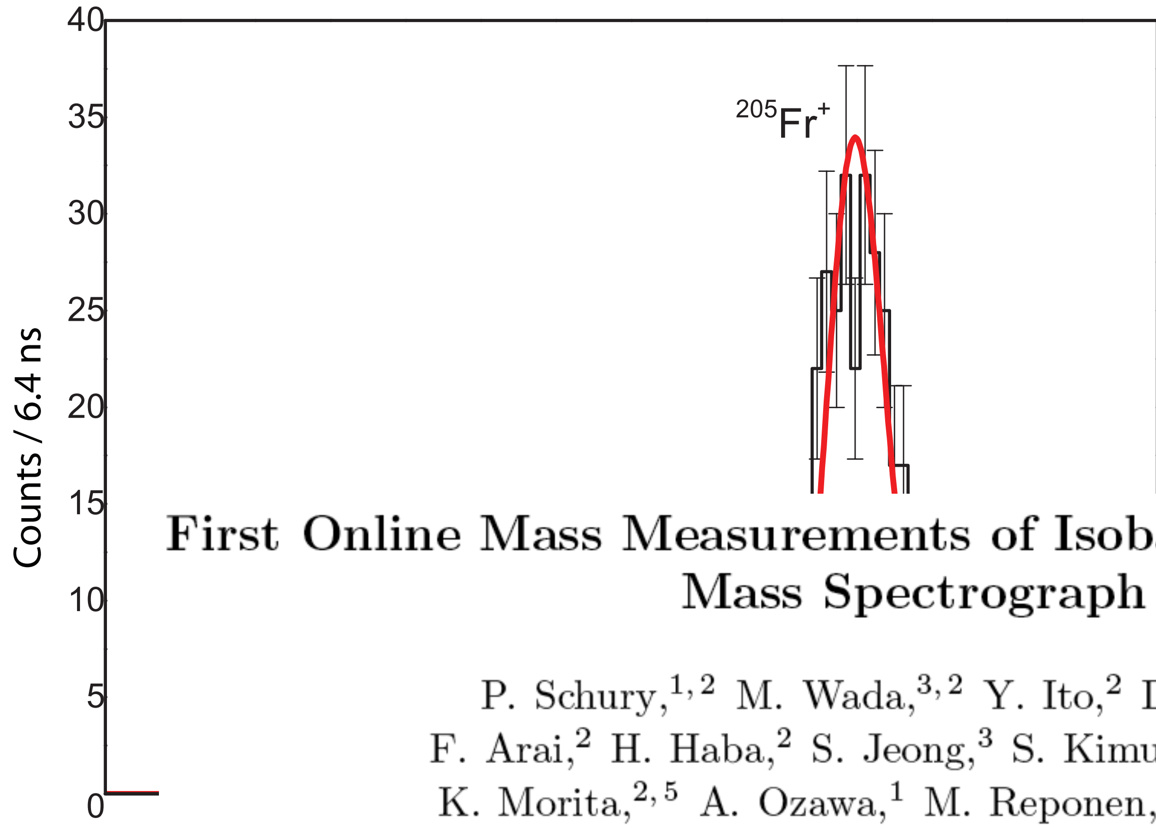
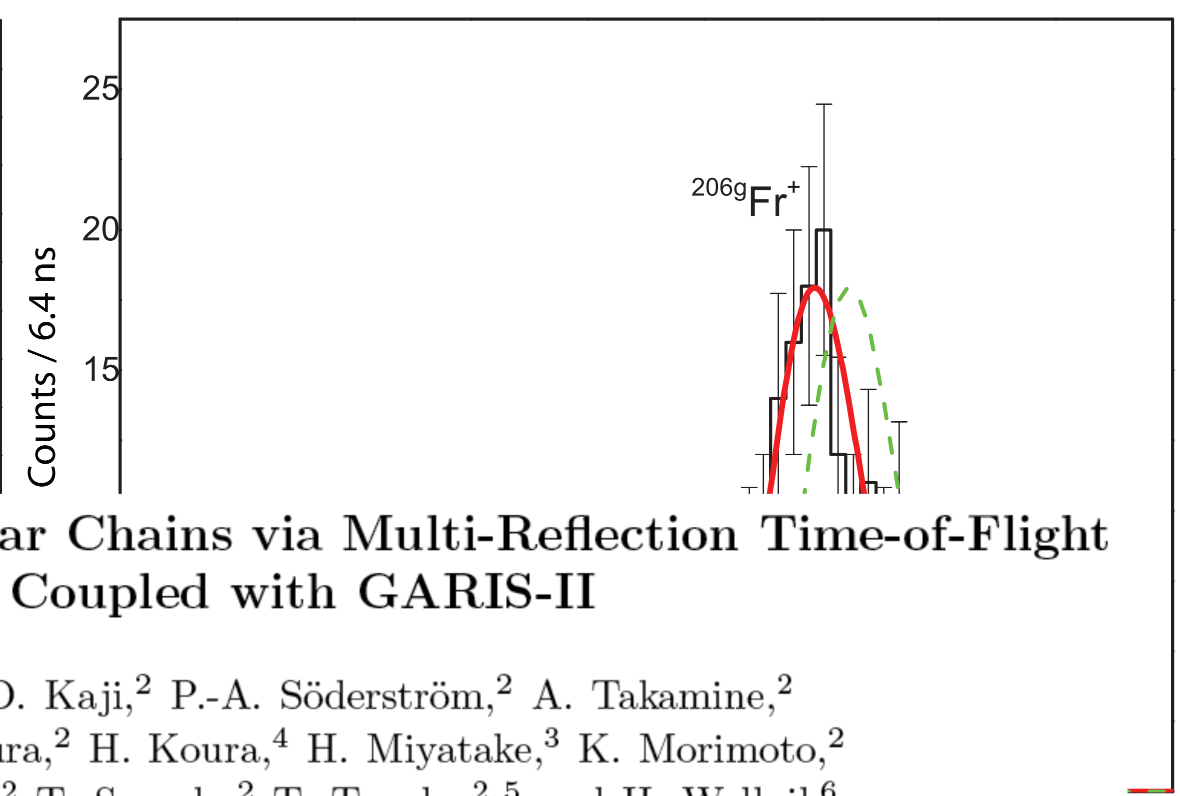


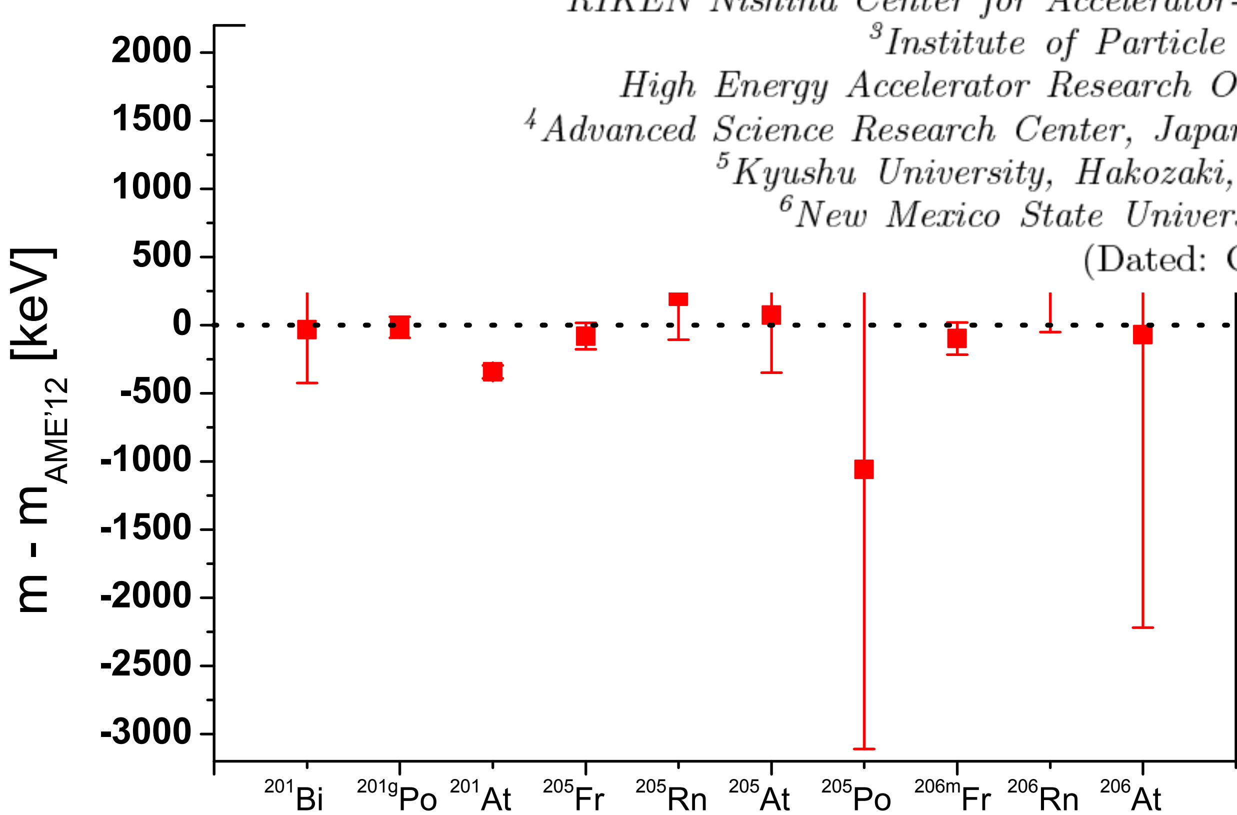


First Online Mass Measurements of Isobar Chains via Multi-Reflection Time-of-Flight Mass Spectrograph Coupled with GARIS-II

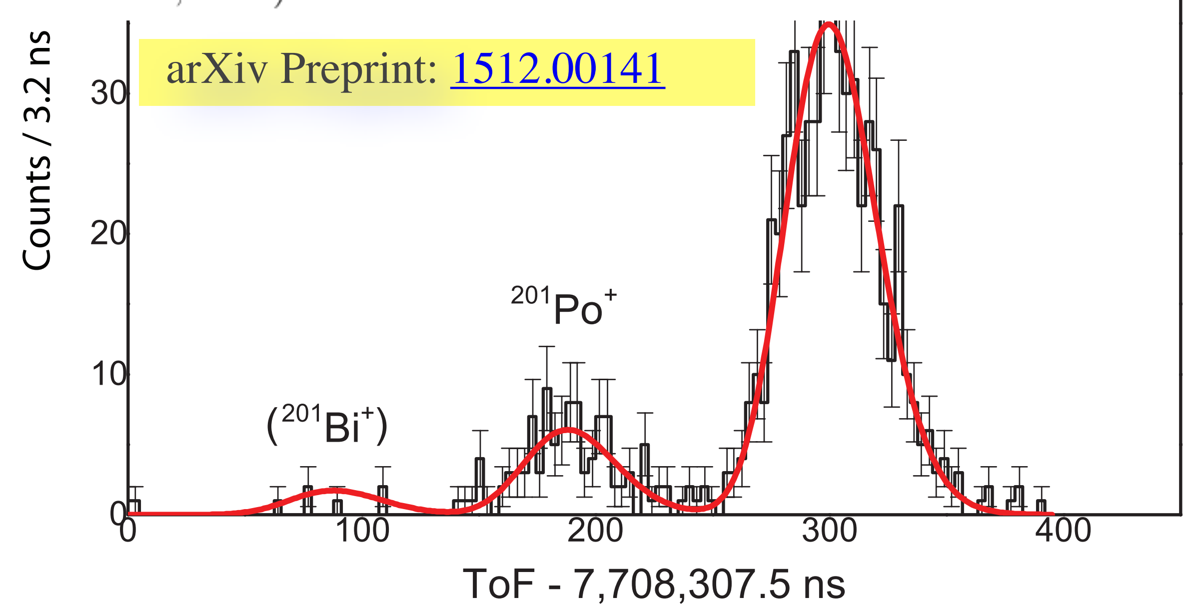
P. Schury,[1,2] M. Wada,[3,2] Y. Ito,[2] D. Kaji,[2] P.-A. Söderström,[2] A. Takamine,[2]
F. Arai,[2] H. Haba,[2] S. Jeong,[3] S. Kimura,[2] H. Koura,[4] H. Miyatake,[3] K. Morimoto,[2]
K. Morita,[2,5] A. Ozawa,[1] M. Reponen,[2] T. Sonoda,[2] T. Tanaka,[2,5] and H. Wollnik[6]

[1]*Institute of Physics, University of Tsukuba, Ibaraki 305-8571, Japan*
[2]*RIKEN Nishina Center for Accelerator-Based Science, Wako, Saitama 351-0198, Japan*
[3]*Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK), Ibaraki 305-0801, Japan*
[4]*Advanced Science Research Center, Japan Atomic Energy Agency, Ibaraki 319-1195, Japan*
[5]*Kyushu University, Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan*
[6]*New Mexico State University, Las Cruces, NM 88001, USA*

(Dated: October 27, 2015)



arXiv Preprint: 1512.00141



Concomitant referencing

REDACTED

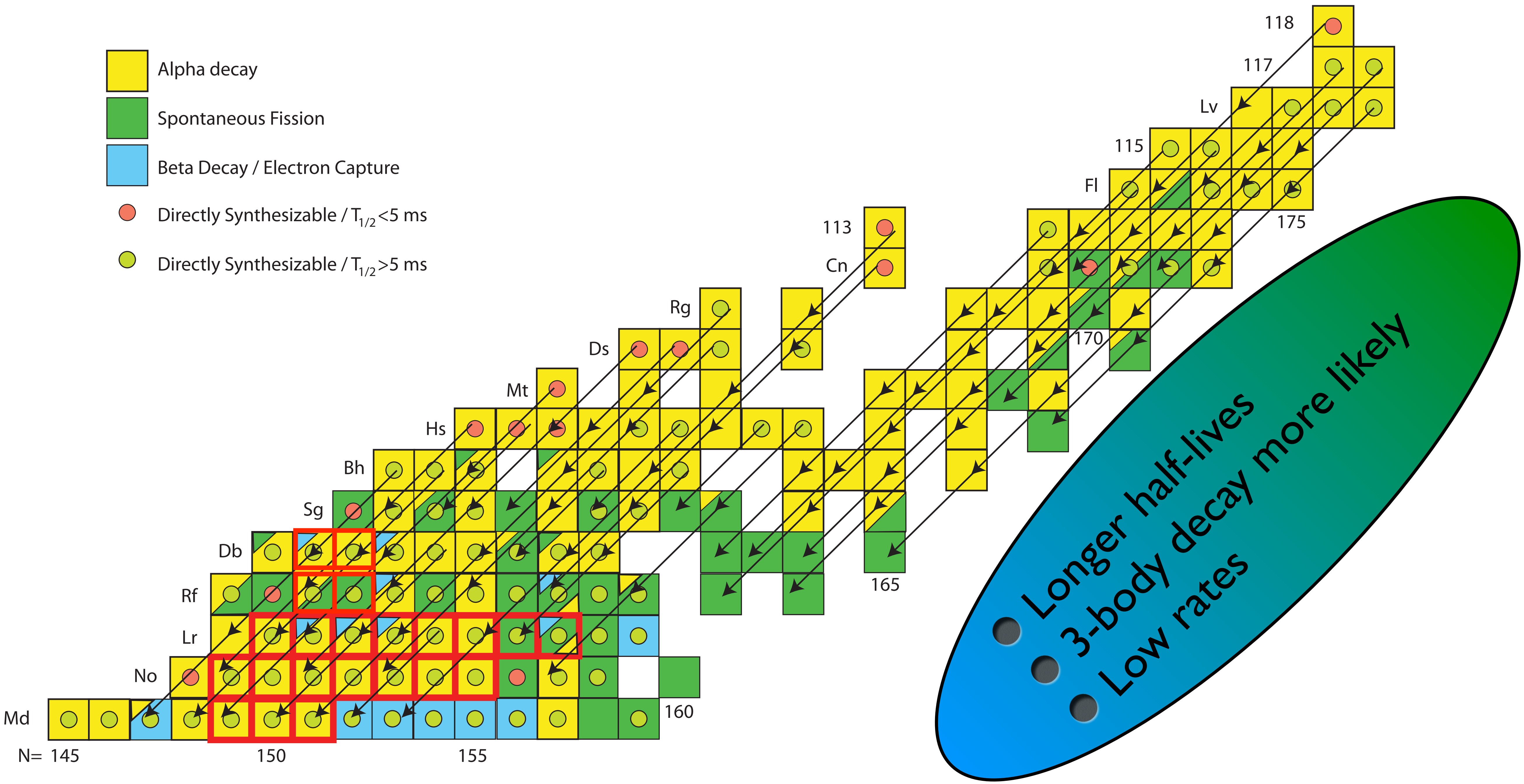
Concomitant referencing

REDACTED

Future Plans

- GARIS-II
  - Push into SHE region
  - Change the paradigm of identification
- SLOWRI
  - Study light r-process nuclei
- KISS
  - Study heavier r-process nuclei

Future at GARIS-II

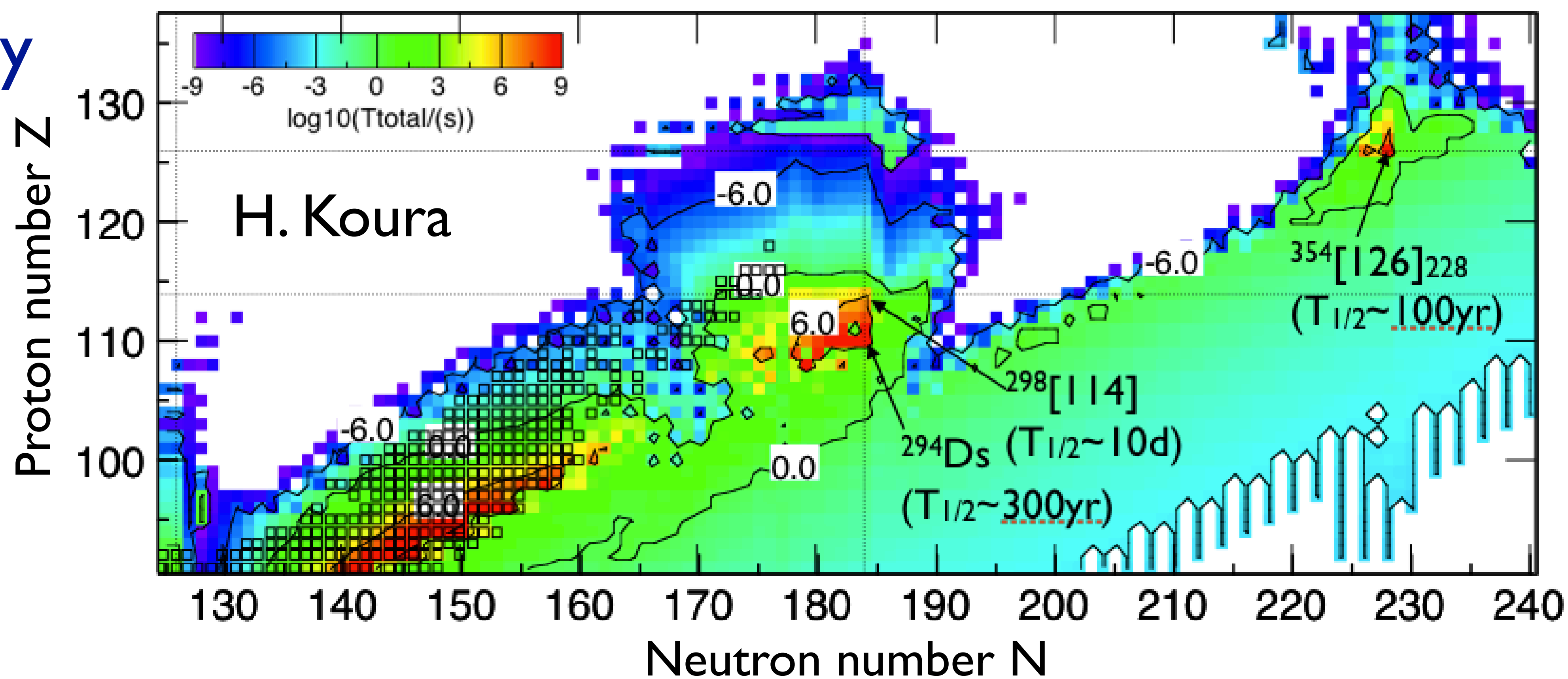


- Already start to see increase in SF
- Eventually longer $T_{1/2}$ will become bottleneck, too

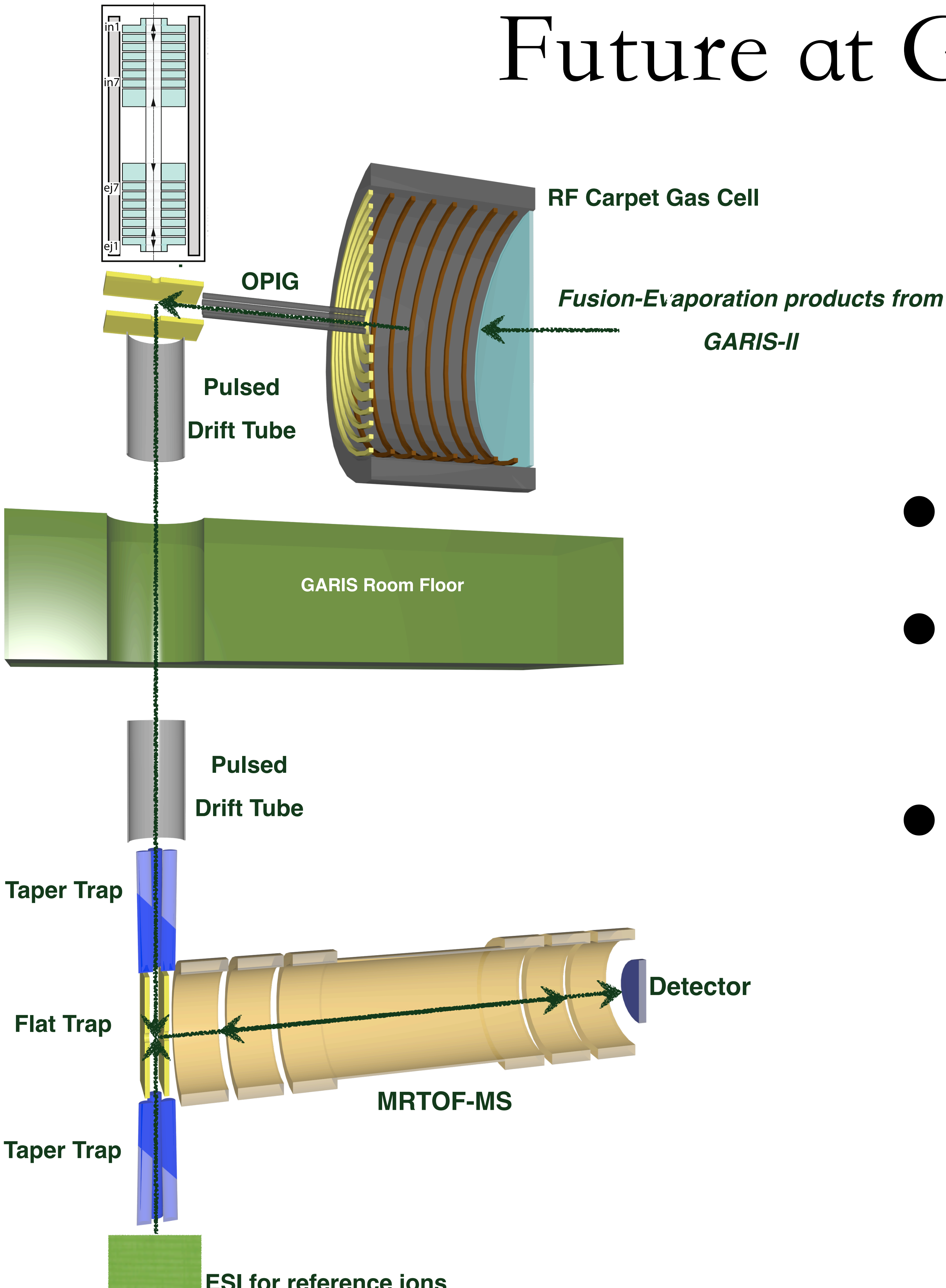
Future at GARIS-II

- As we approach island of stability, half-lives can be days to years
- Implantation-decay correlation becomes nearly impossible
- But mass spectroscopy becomes more reasonable!

Island of stability (SHE)



Future at GARIS-II



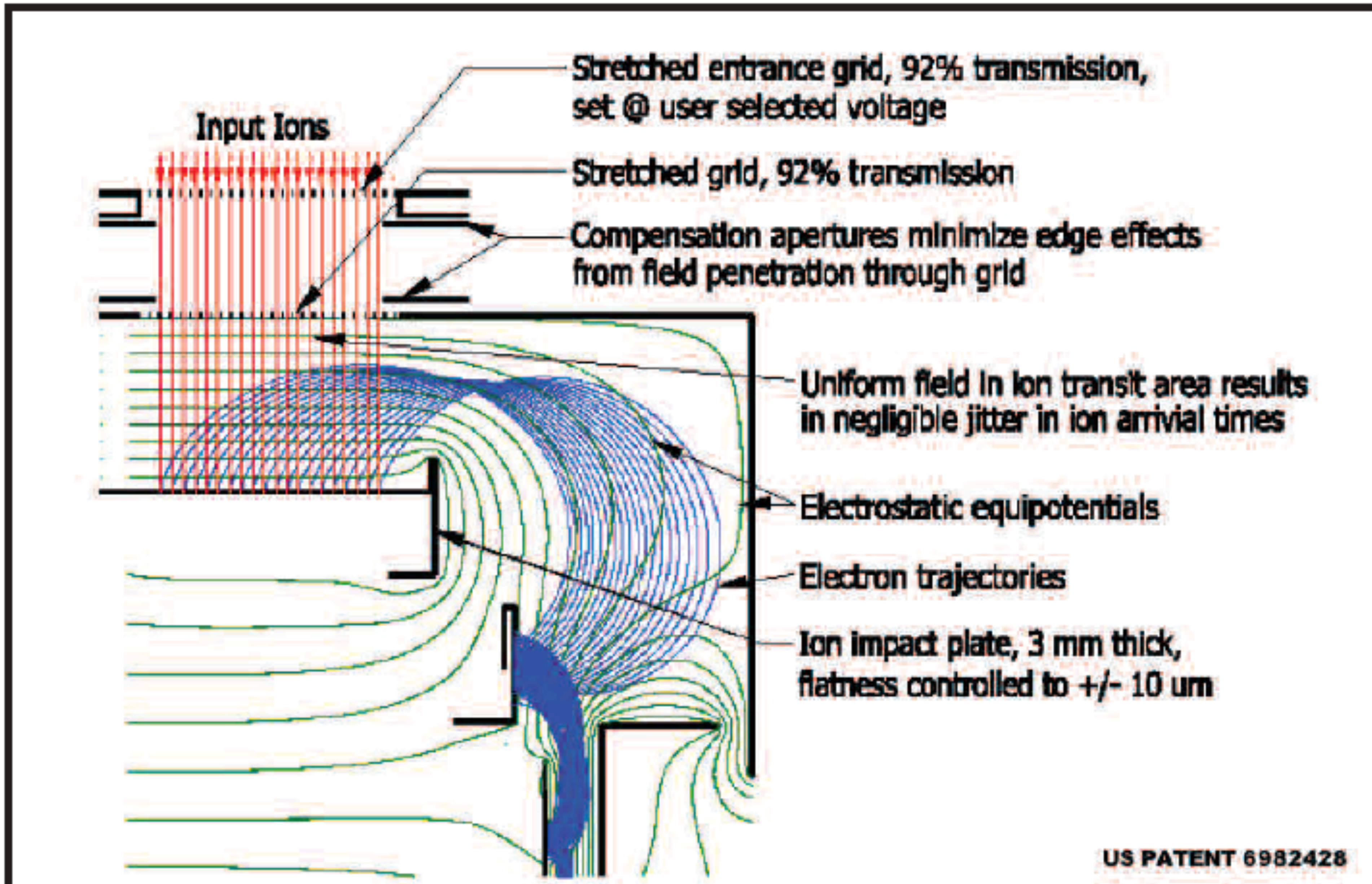
Int. Journ. Mass. Spec. 337 (2013) 24

- Add half-size MRTOF
- Implement ESI reference source
- Develop new α-ToF detector

Future at GARIS-II

For very low yield (<1/hr?) we need to be certain we are not seeing spurious events -- e.g. noise or cosmic rays

- Let's modify a commercial ToF detector!
- MagneToF uses secondary electrons
- Replace emission surface with Si detector!
- After ToF signal, we can wait for α- or β-decay signal
- Mass and half-life simultaneously?
- α-energy gates can resolve isomers



www.sge.com/root/pdfs_local/technical_articles/TA-0129-A.pdf

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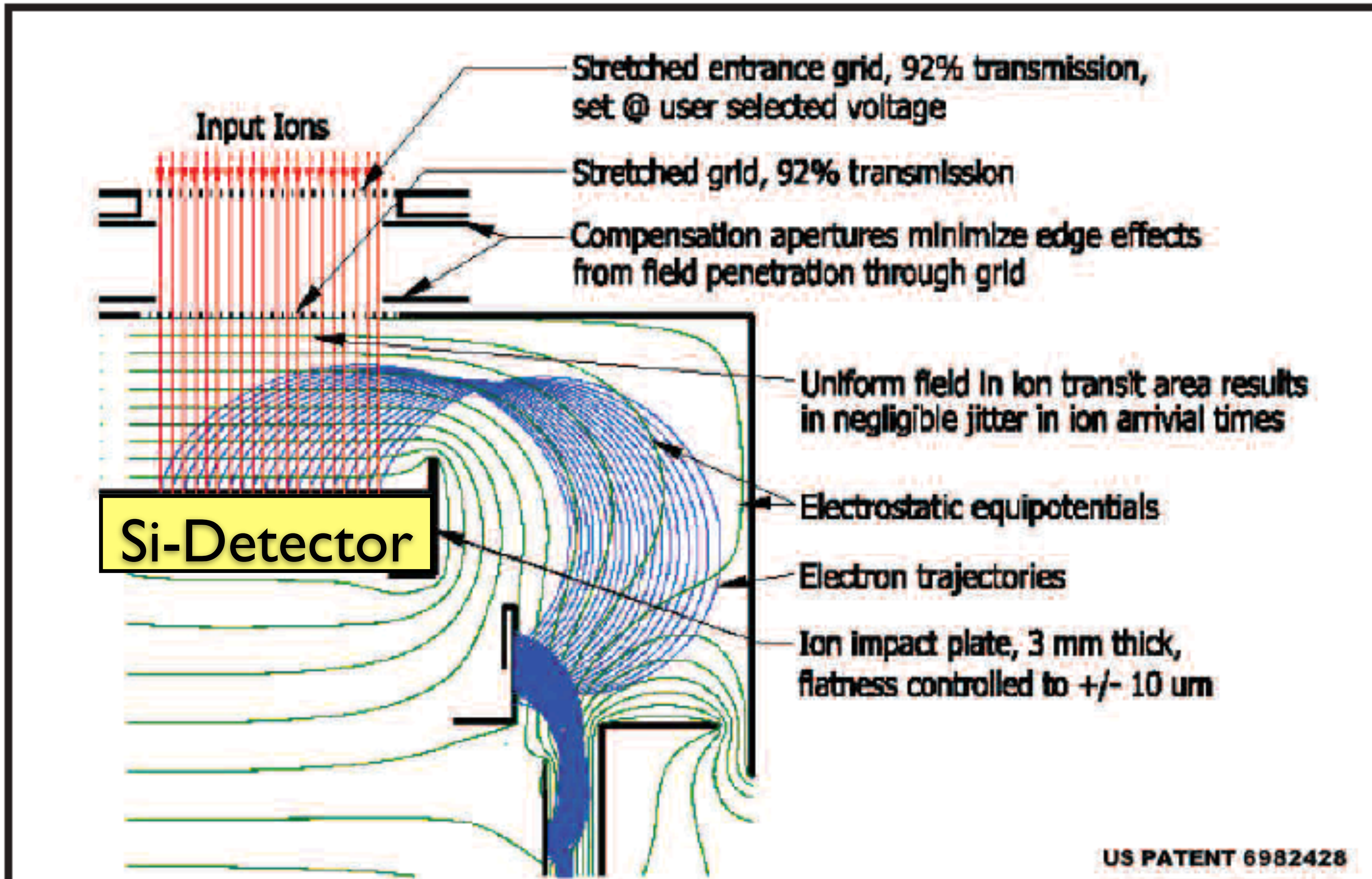

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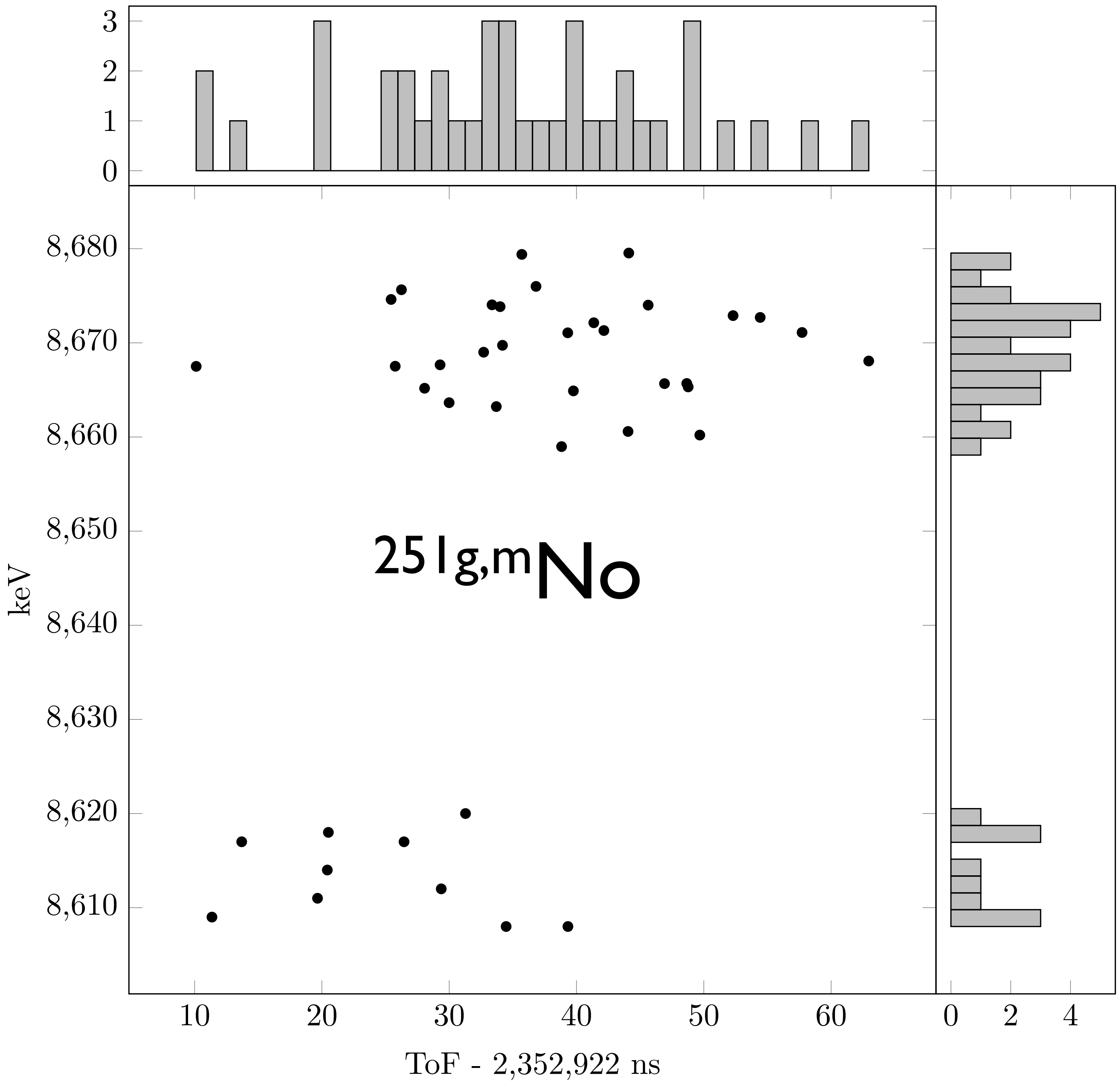
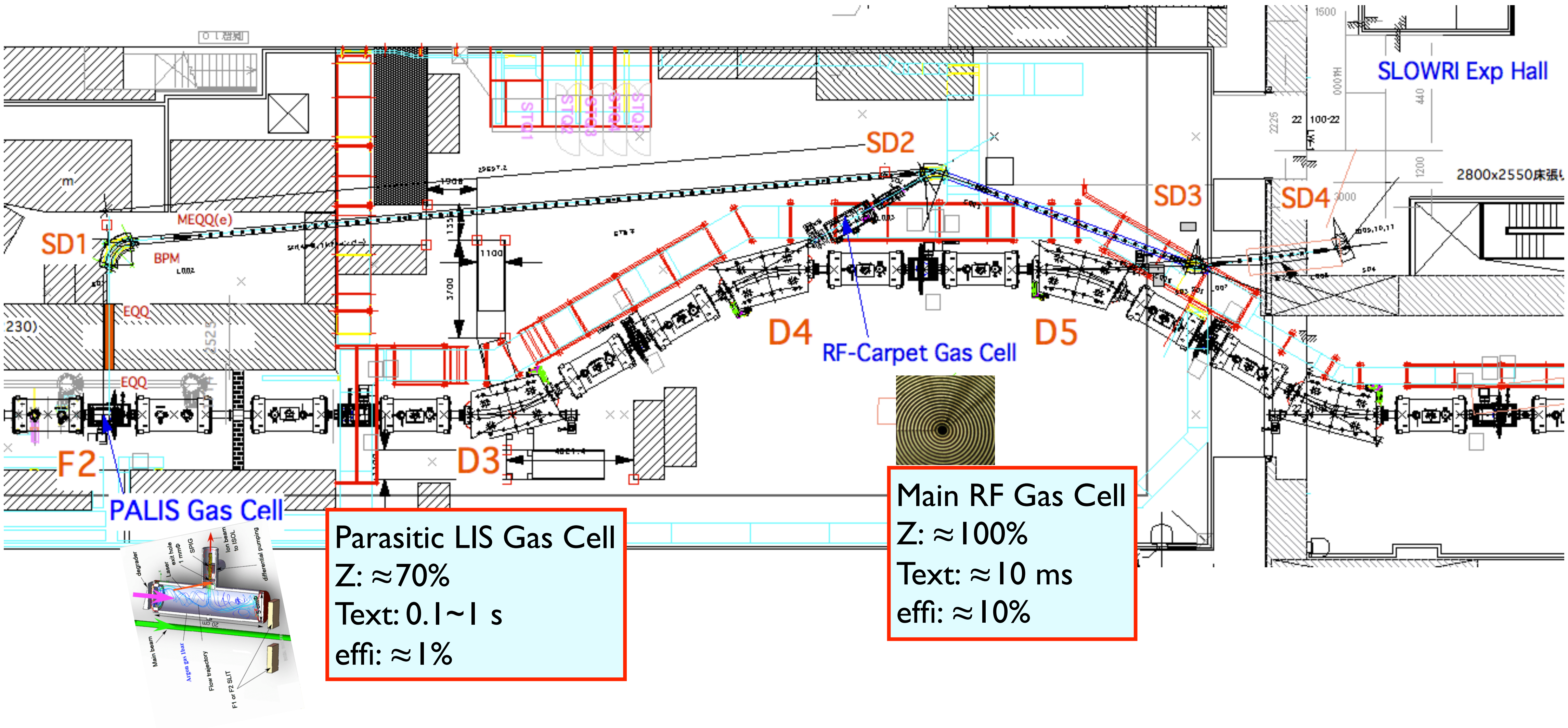
Future at GARIS-II



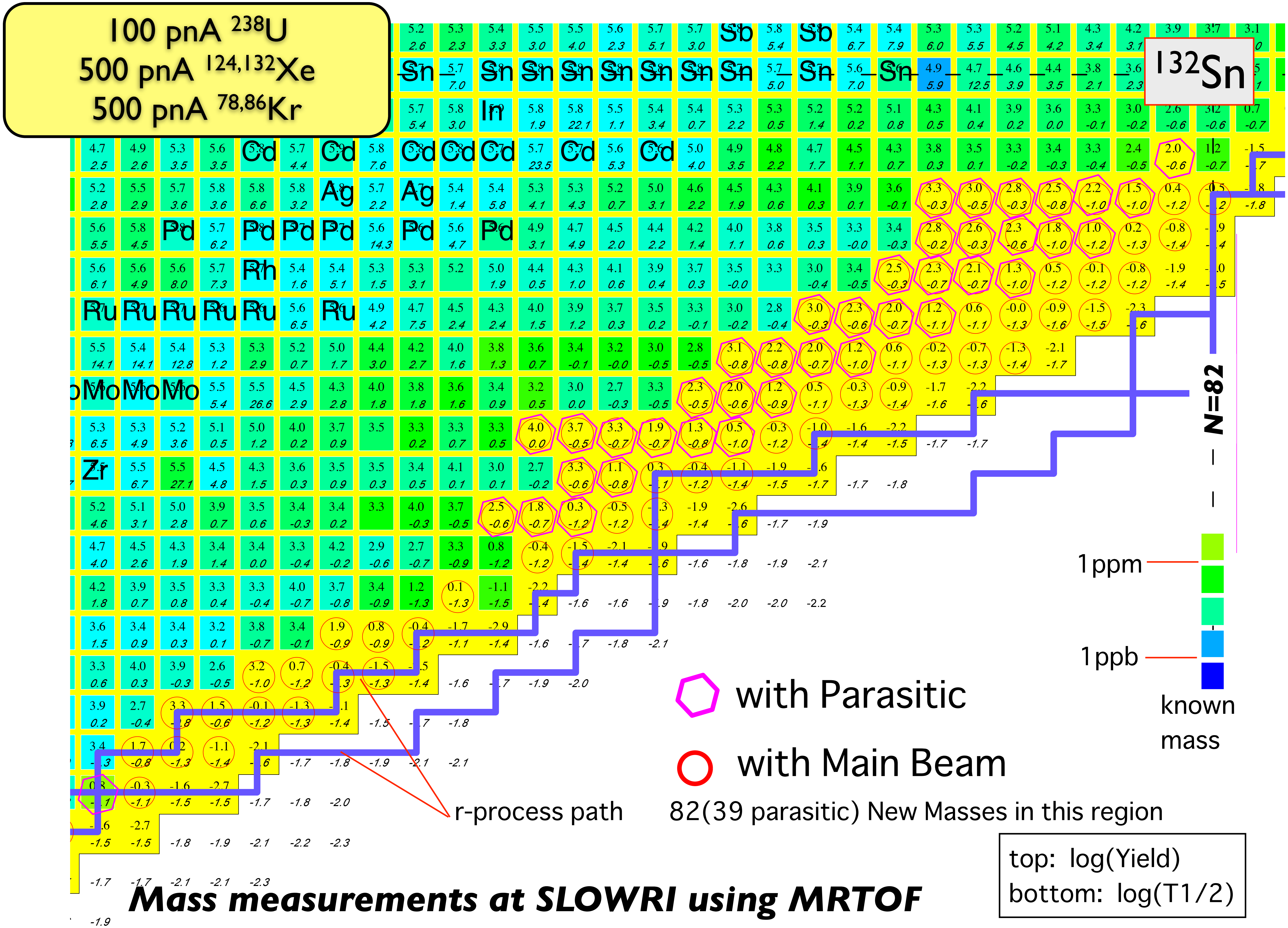
- Allow gating on α energy
- Will be able to exclude stable molecules
- Will be able to separate low-lying isomers

MRTOF-MS at SLOWRI



- Parasitic testing using PALIS
- Wideband operation with main gas cell

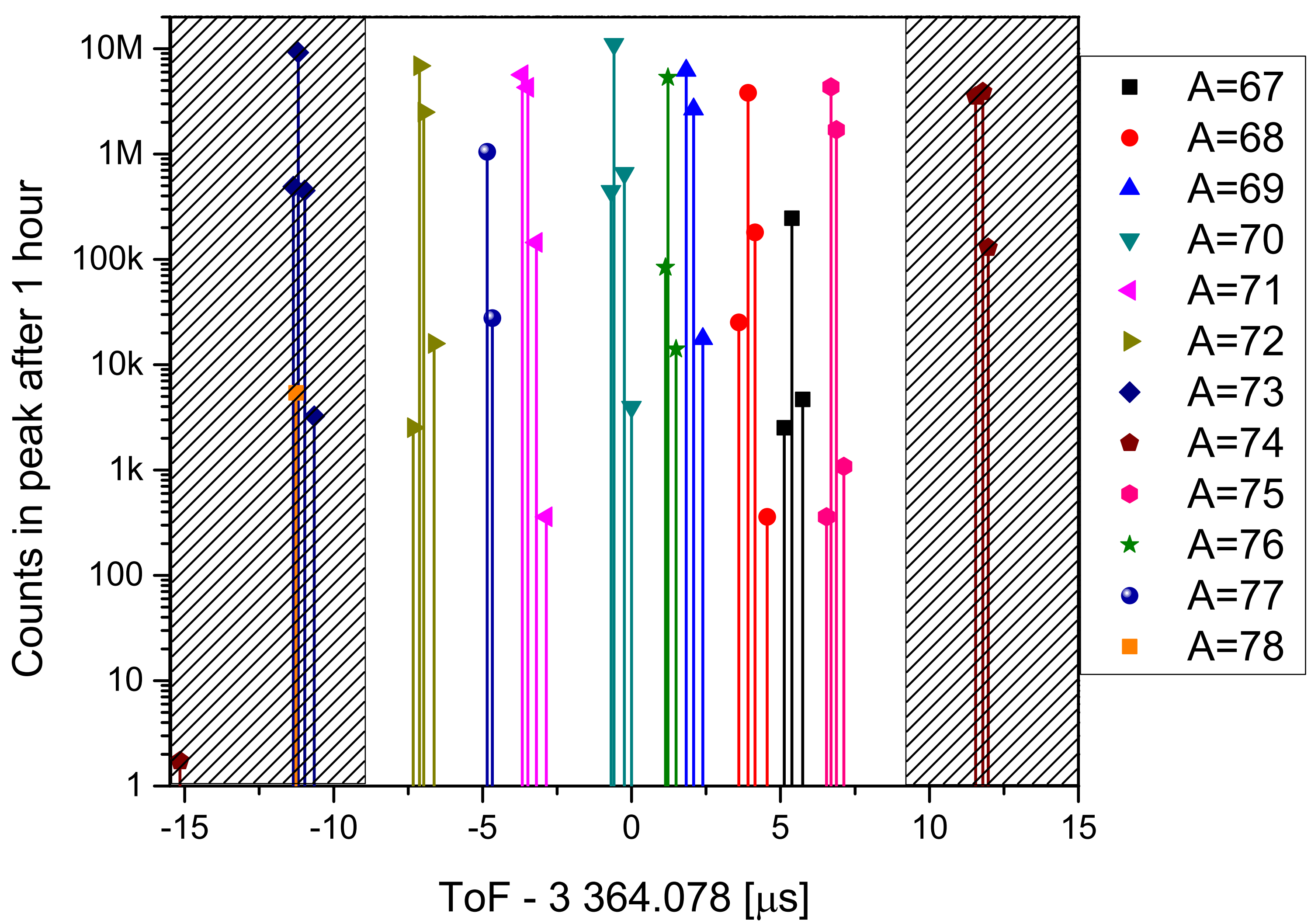
MRTOF-MS at SLOWRI

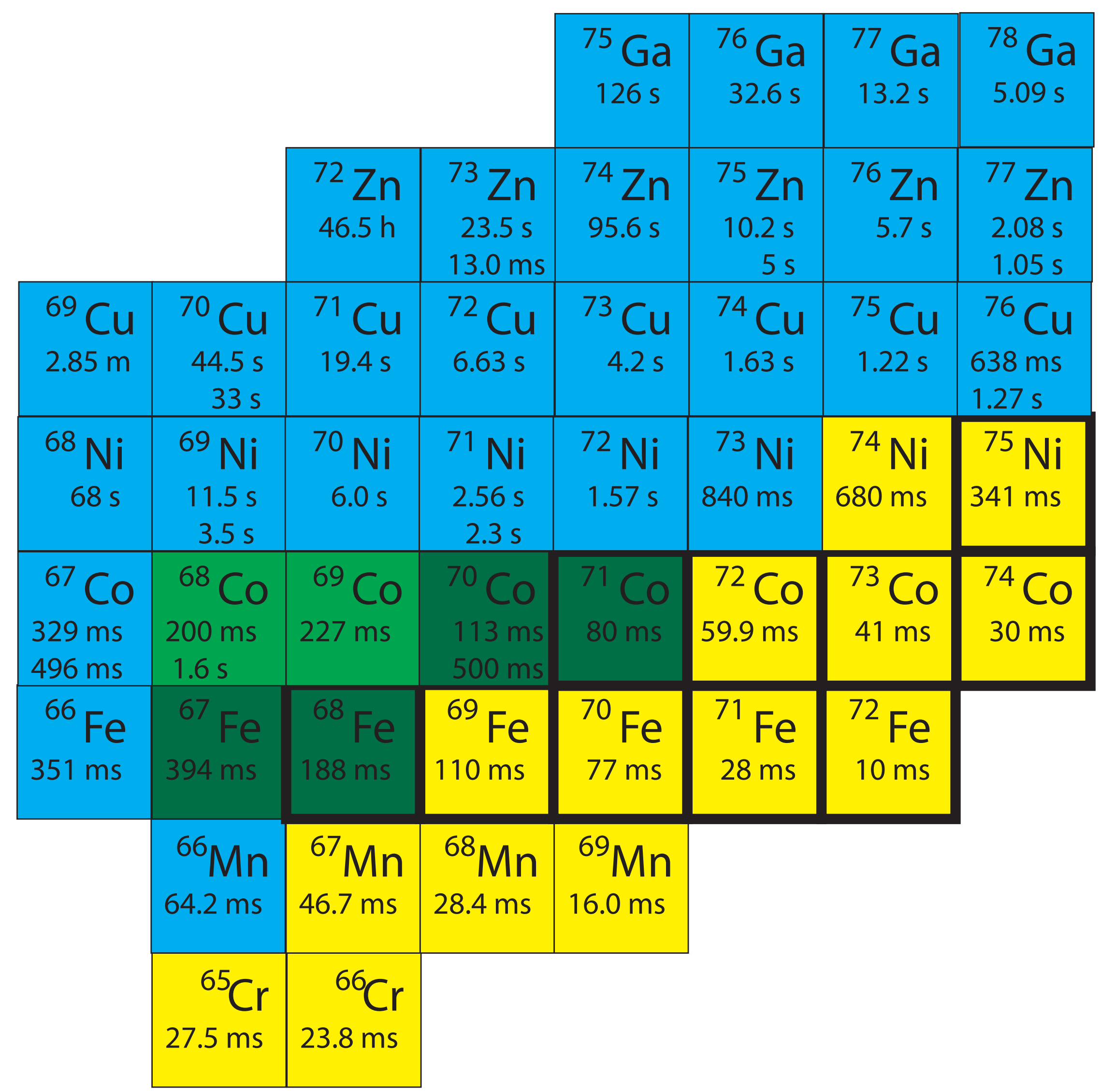


MRTOF-MS at SLOWRI

By accepting a wide-range cocktail beam, masses of many species of ions can be simultaneously measured.

In principle, the entire region from ^{78}Ni to ^{132}Sn could be analyzed with 6 tunes of BigRIPS.

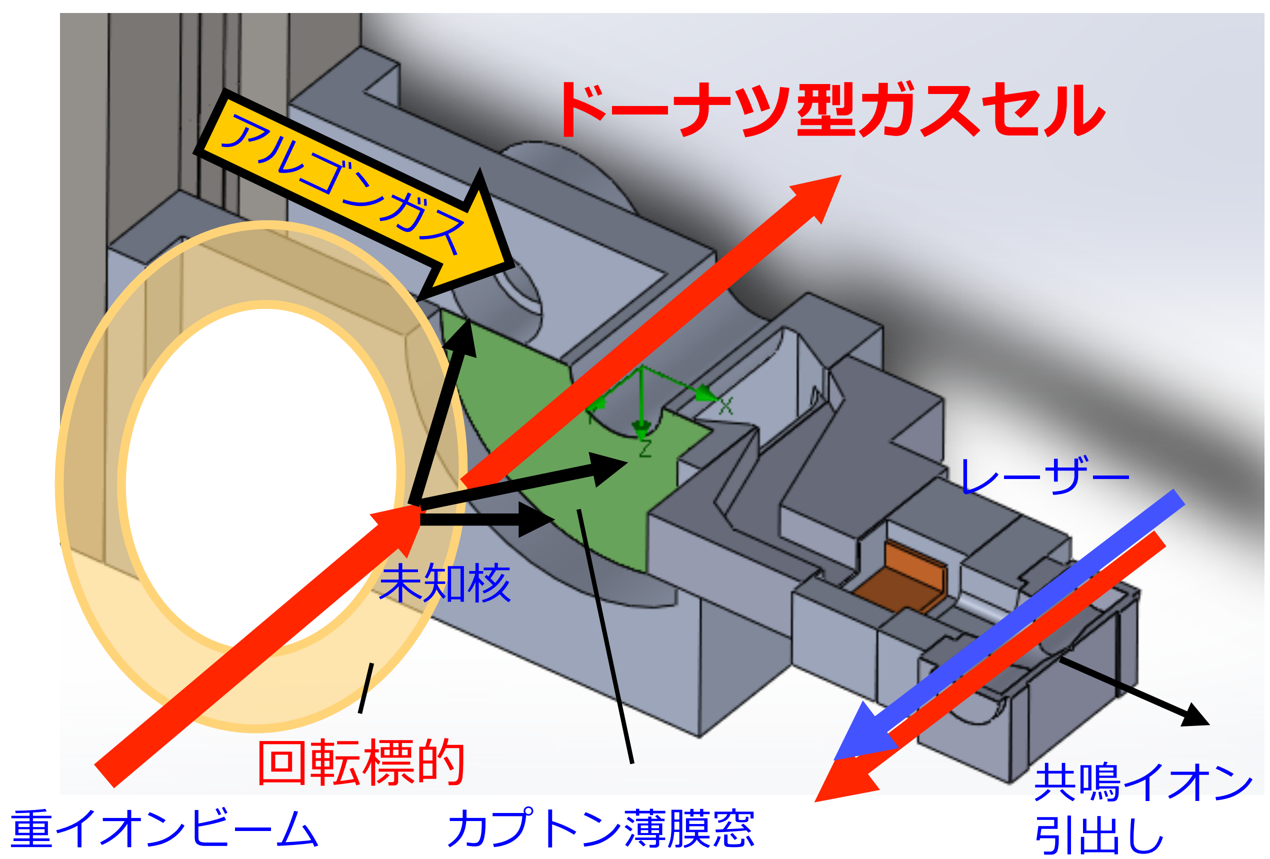




Future at KISS

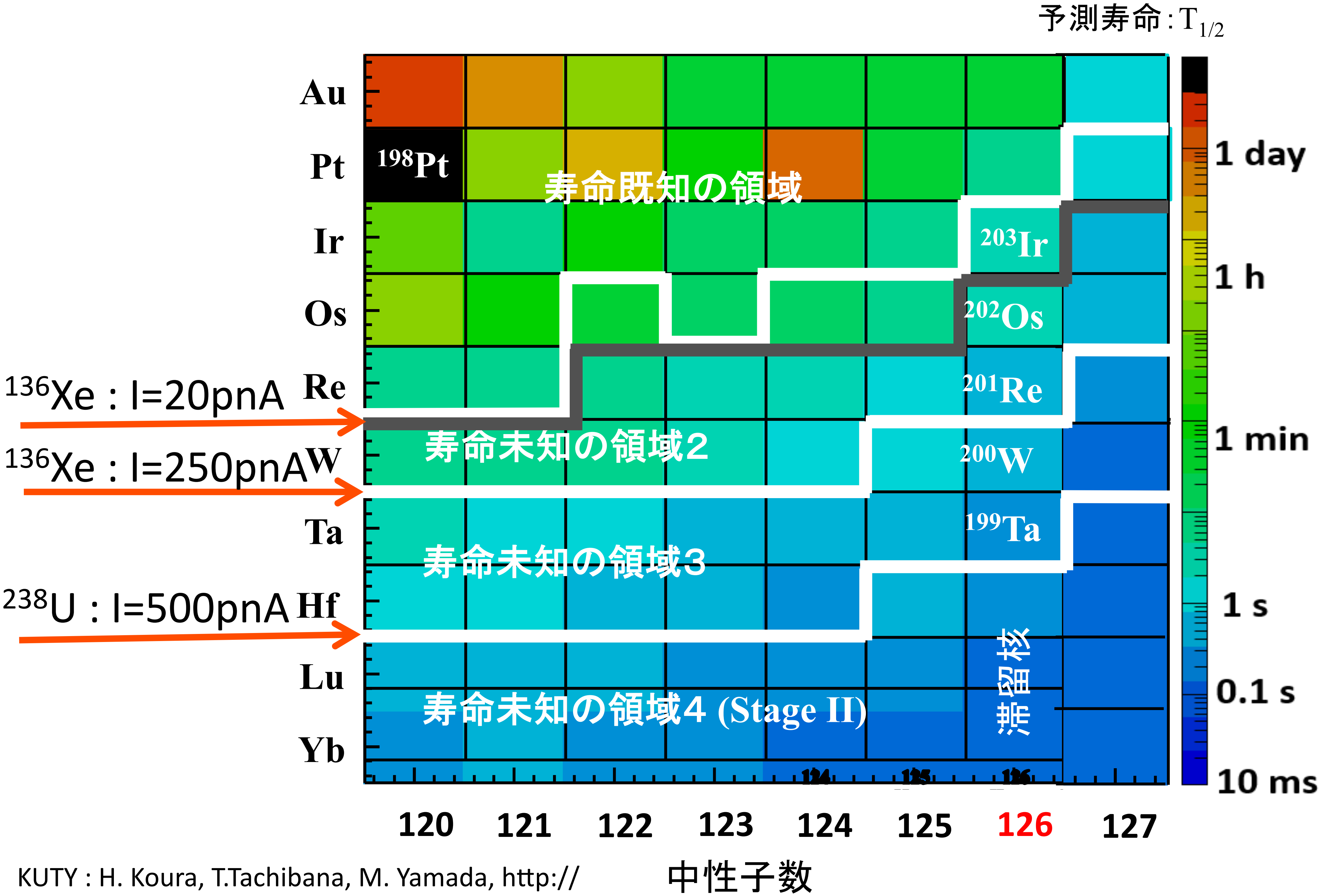
- KEK Isotope Separator System
- Use MNT to produce RI for 3rd peak of r-process
  - Need T1/2 and mass
- Neutralize in Ar and laser ionize

ビーム強度増強 : **10 pnA ^{136}Xe→ 250 pnA**

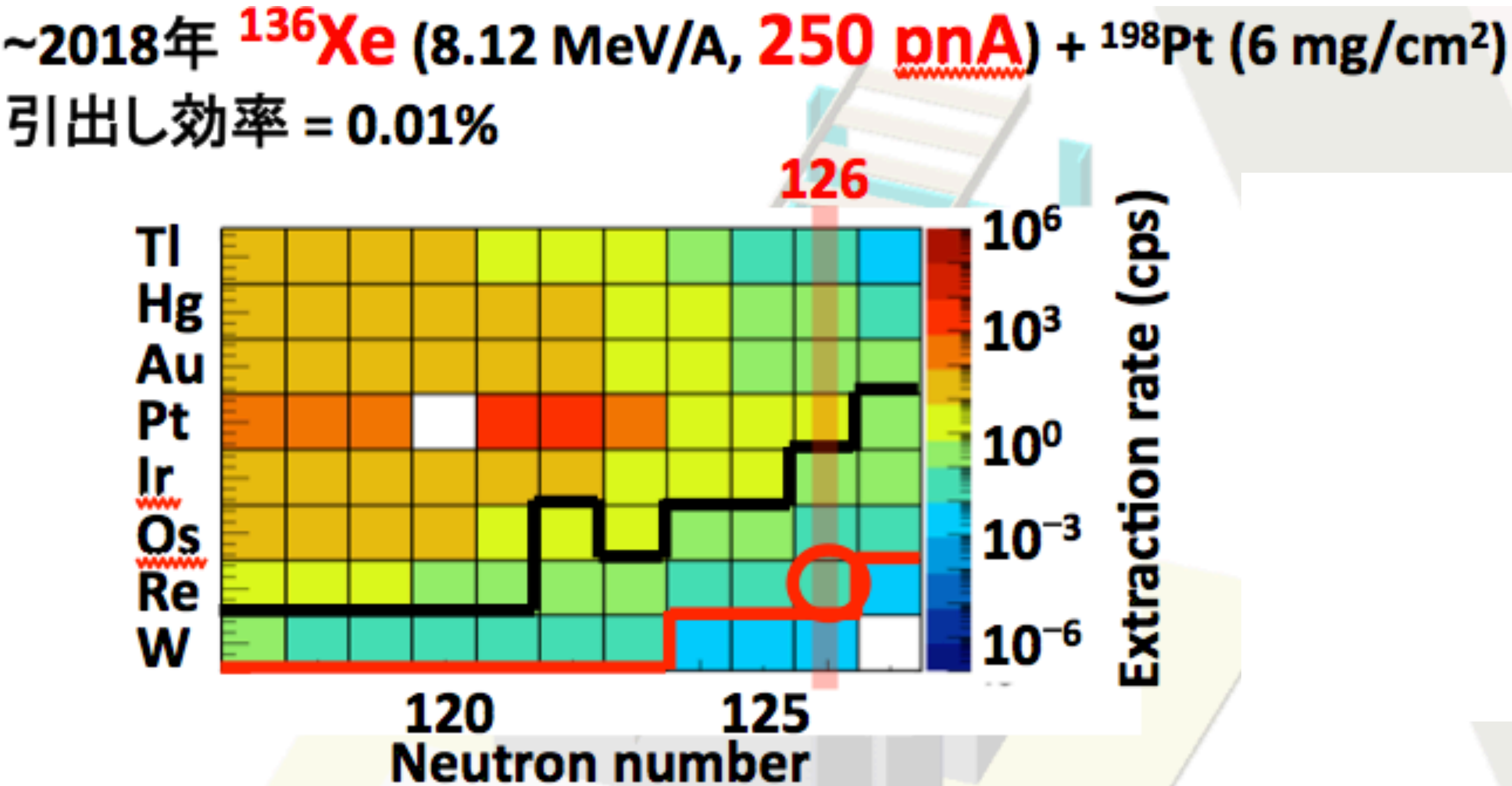


Future at KISS

1. 寿命測定 Pt,　Ir, Os 同位体 (NP-PAC2015)
2. 寿命測定 Os, Re, W, Ta 同位体 (NP-PAC2017)

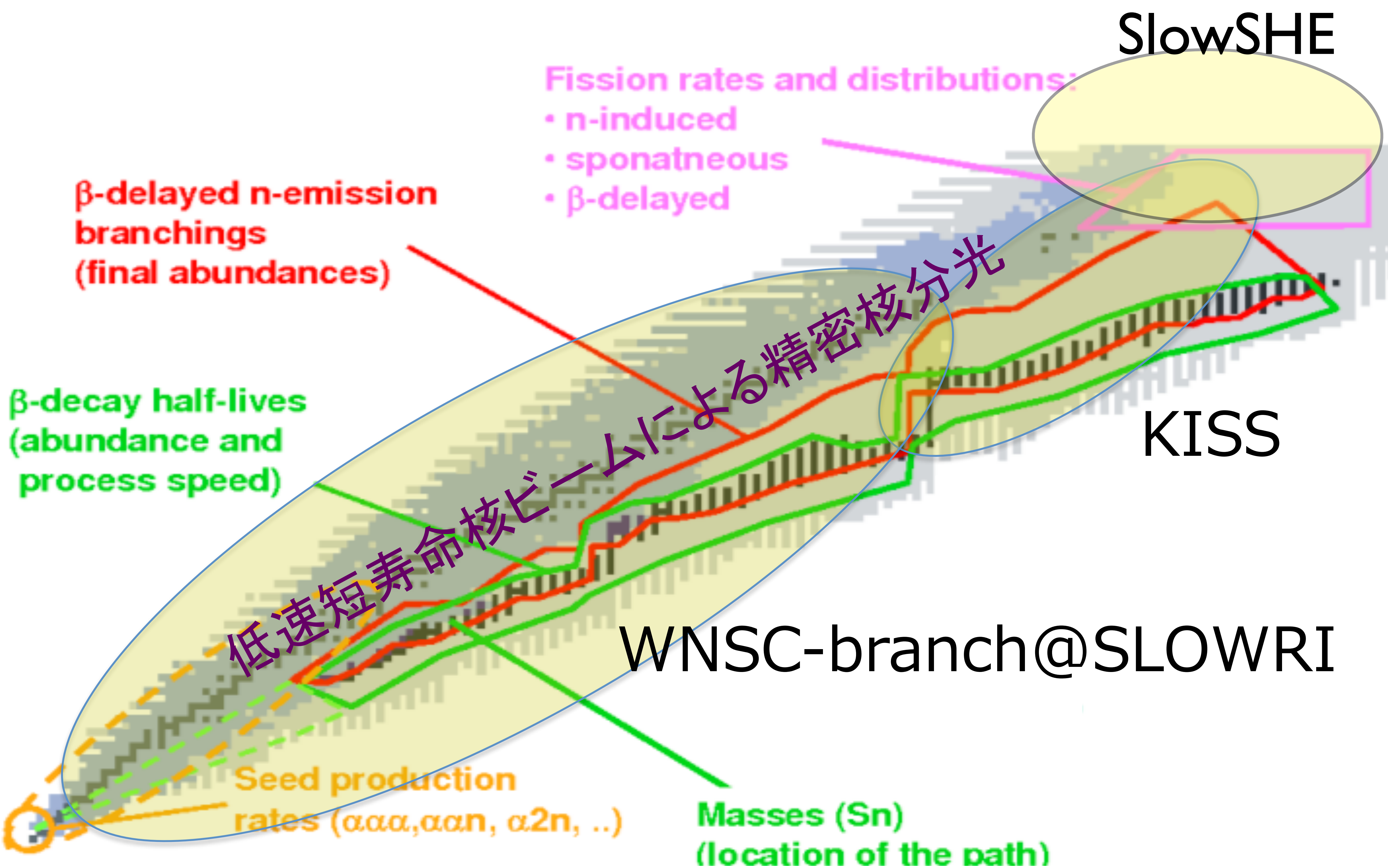


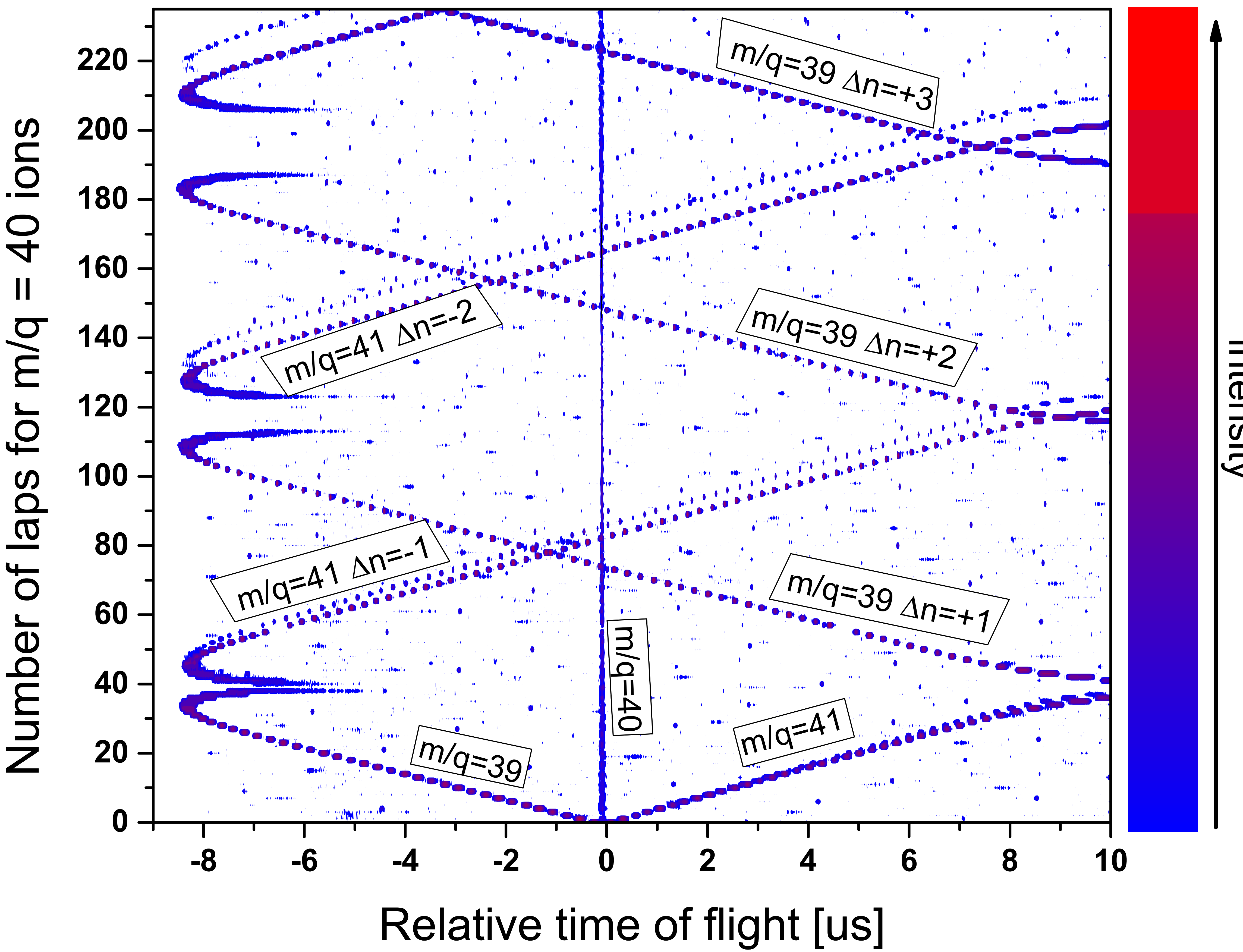
KUTY : H. Koura, T.Tachibana, M. Yamada, http://wwwndc.jaea.go.jp/CN14/index.html



- Using MRTOF we can measure masses and $T_{1/2}$?

MRTOF-MS will cover the entire range at RIBF





Number of laps for m/q = 40 ions
Relative time of flight [us]
Intensity
m/q=39 Δn=+3
m/q=41 Δn=-2
m/q=39 Δn=+2
m/q=41 Δn=-1
m/q=39 Δn=+1
m/q=40
m/q=39
m/q=41