Development of offline ion source for collinear laser spectroscopy at the SLOWRI facility in RIKEN

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Overview

- Introduction
  - Laser spectroscopy of RI
  - Plan for collinear laser spectroscopy at the SLOWRI
- Motivation
  - Offline Ion source for the planned spectroscopy
  - Reference ions for MRTOF-MS
- Ion source: Laser ablation in He + ion guide
- Test measurement for different ablation targets
  - m/q spectrum
- Summary

Introduction: Laser spectroscopy of RI

Powerful tool to study ground-state nuclear properties

Hyperfine structures (I≥1, J≥1)

- HFS constants A, B → Nuclear moments
- # of HFS, relative distance & intensity

→ Nuclear Spin

$$E_{\mathrm{HFS}} = A\frac{K}{2} + B\frac{3K(K+1)/4 - I(I+1)J(J+1)}{2I(2I-1)J(2J-1)}$$

$$A = \frac{\mu_I B_e(0)}{IJ}, \quad B = eQ_s\left\langle\frac{\partial^2 V}{\partial z^2}\right\rangle \longrightarrow \langle\beta_2\rangle$$

deformation

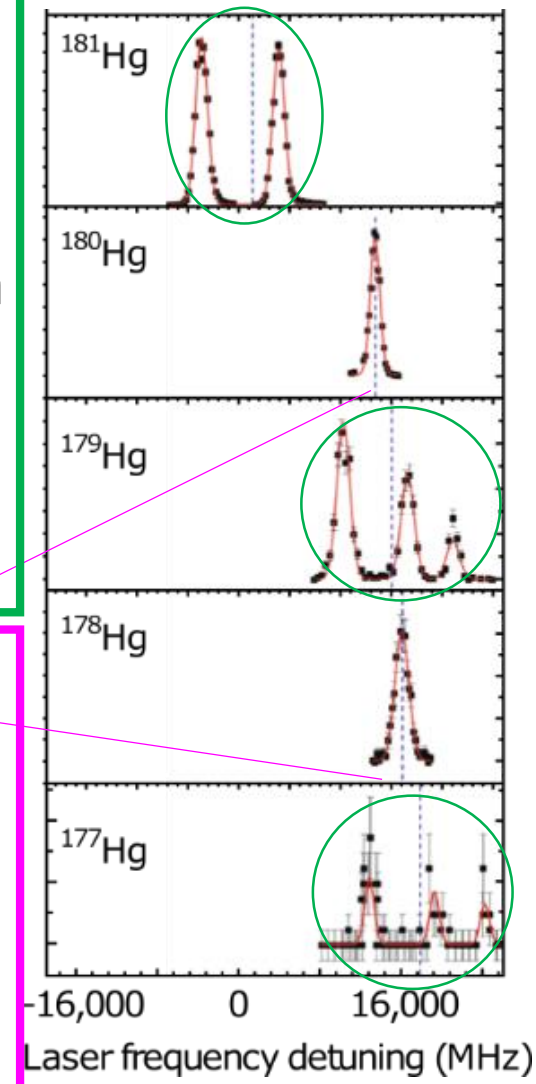
Isotope shift (for any I including I=0)

- Isotope shift $\delta\nu_{\mathrm{IS}}^{AA'} = \nu^{A'} - \nu^{A}$

→ Difference of charge radii

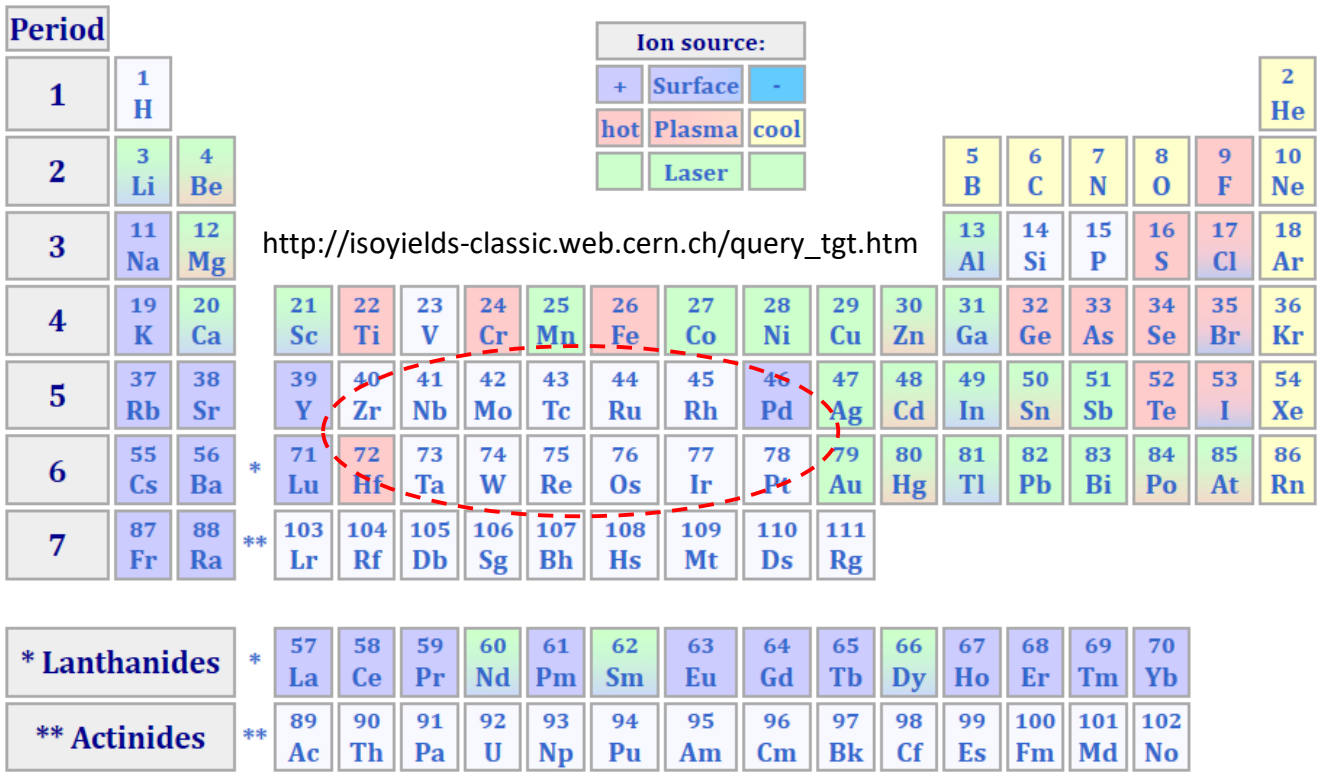
$$\delta\left\langle r_c^2\right\rangle^{AA'} = \frac{\delta\nu_{\mathrm{IS}}^{AA'} - K_{\mathrm{MS}}(1/M_A - 1/M_{A'})}{F(Z)} \longrightarrow \sqrt{\langle\beta_2^2\rangle}$$

B. Marsh et al., Nat. Phys. Oct (2018)



Introduction: Plan for collinear laser spectroscopy experiment at the SLOWRI

Laser spectroscopy has been performed elaborately at ISOL facilities except for short-lived, and/or refractory elements.



Z	40	41	42	44	73	74	75	76	77	78
	Zr	Nb	Mo	Ru	Ta	W	Re	Os	Ir	Pt
T_{melt}[K]	2128	2750	2896	2607	3290	3695	3459	3306	2719	2041

Introduction: Plan for collinear laser spectroscopy experiment at the SLOWRI

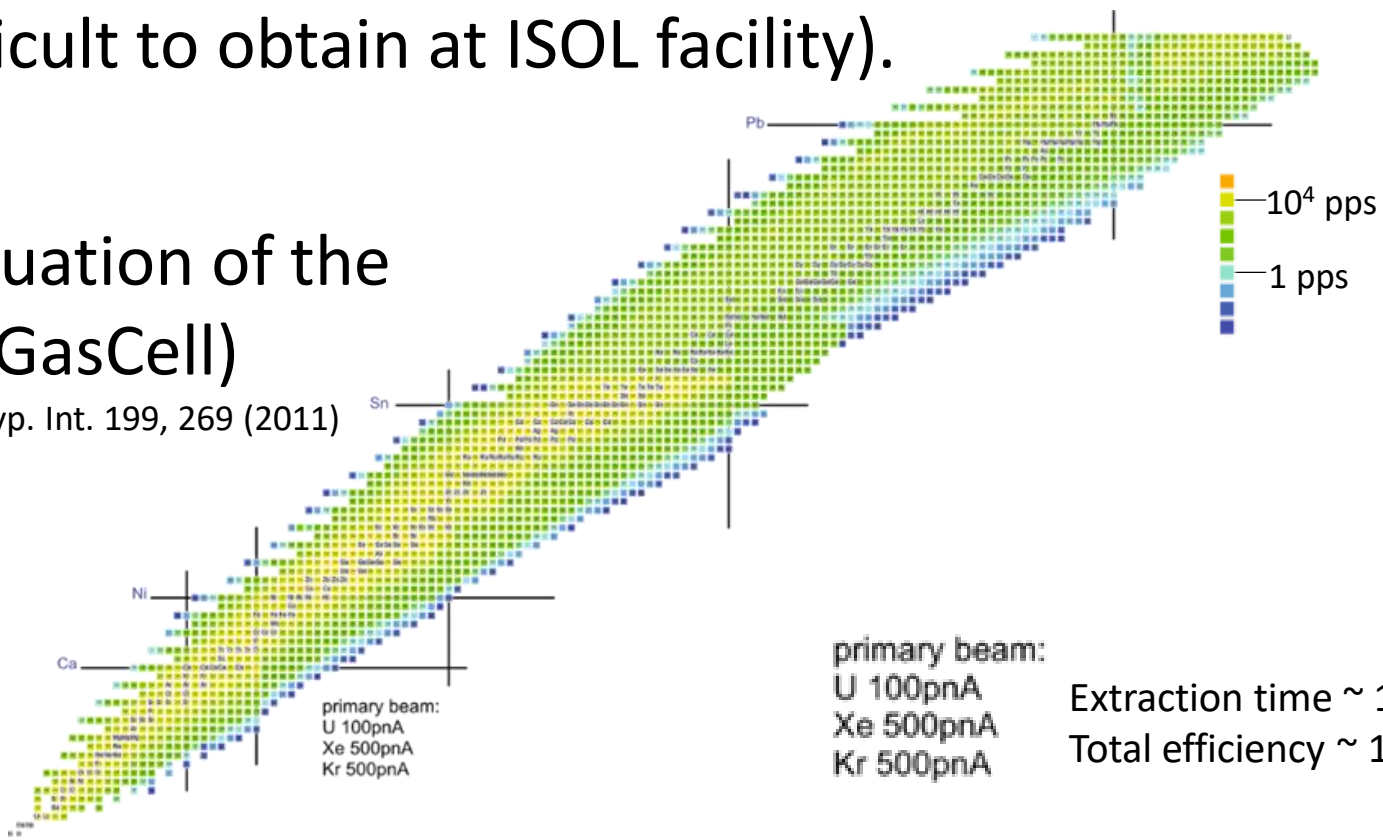
Universal slow, low-emittance RI ion beams will be available at BigRIPS (in-flight separator) + SLOWRI facility (gas cell)

↓

Laser spectroscopy at the SLOWRI is planned (for elements being difficult to obtain at ISOL facility).

Yield evaluation of the SLOWRI (GasCell)

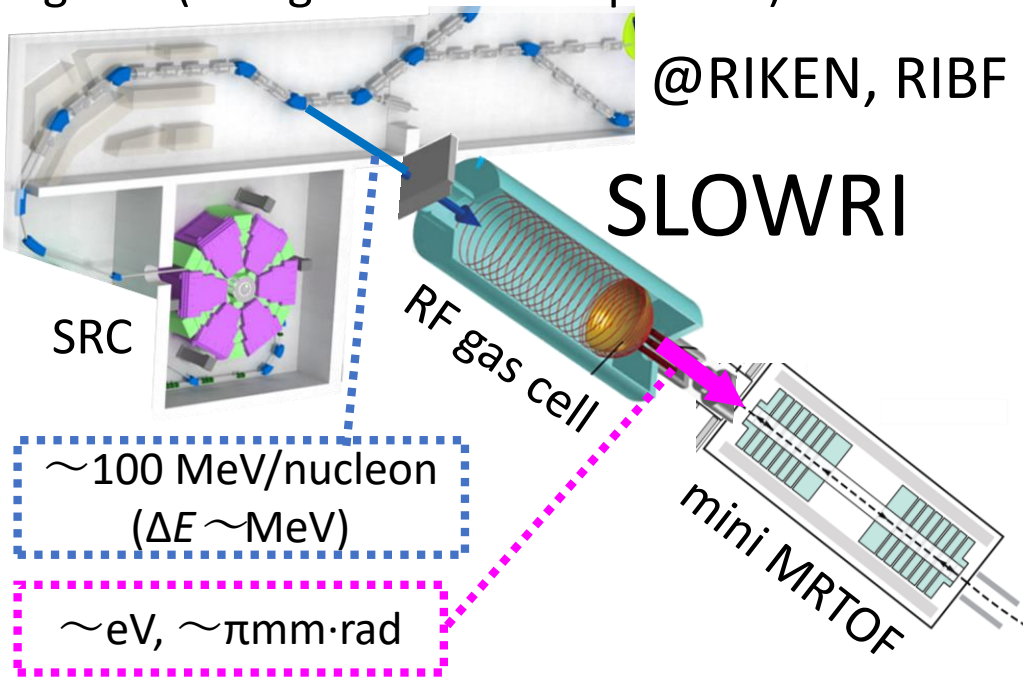
M. Wada et al., Hyp. Int. 199, 269 (2011)



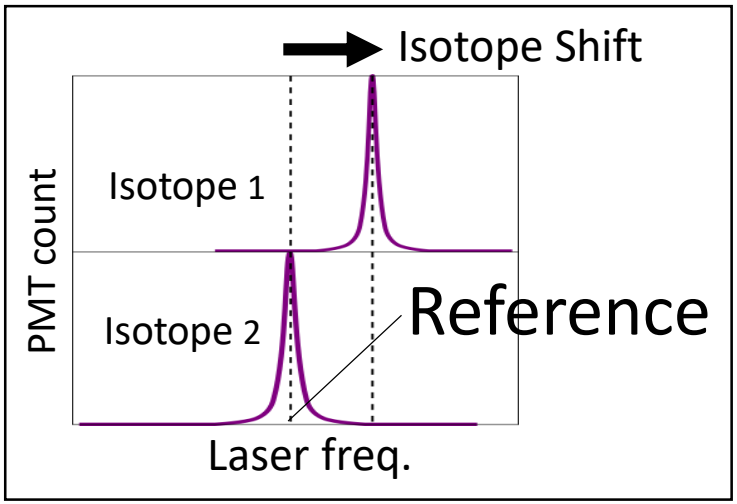
Extraction time ~ 10 ms
Total efficiency ~ 10 %

Motivation: Offline ion source for the planned spectroscopy

BigRIPS (in-flight RI beam separator)

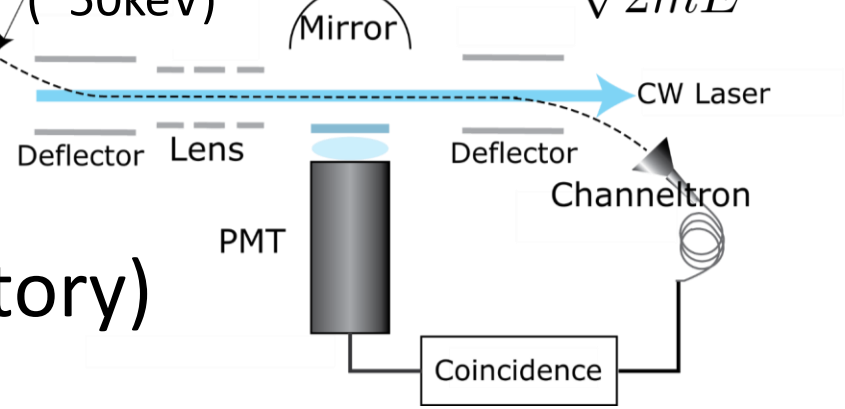


RI ion beam (first goal: ~100pps)



Re-acceleration
(~50keV)

$$\delta v = \frac{1}{\sqrt{2mE}}\delta E$$



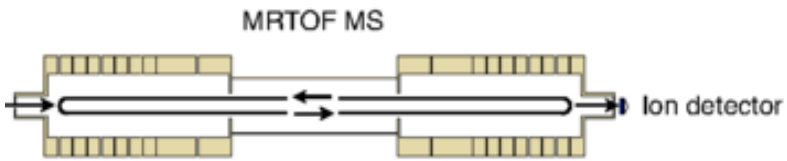
Ion detection at downstream to reduce BG by stray light of laser

Offline ion source (incl. refractory)

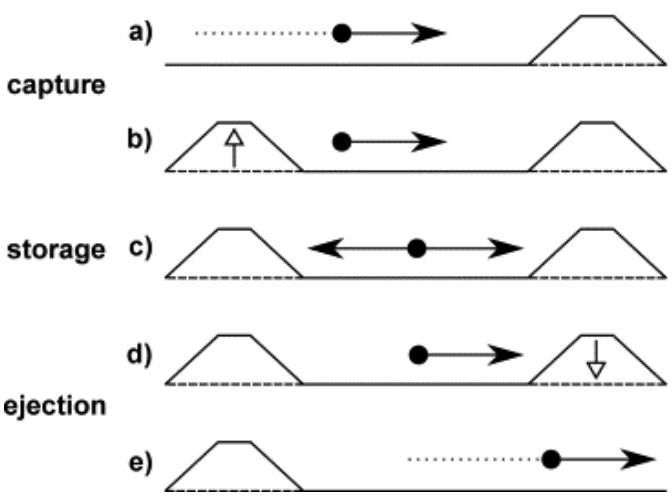
- Evaluation of the scheme
- Reference for isotope shift

Motivation: Reference ions for MRTOF-MS

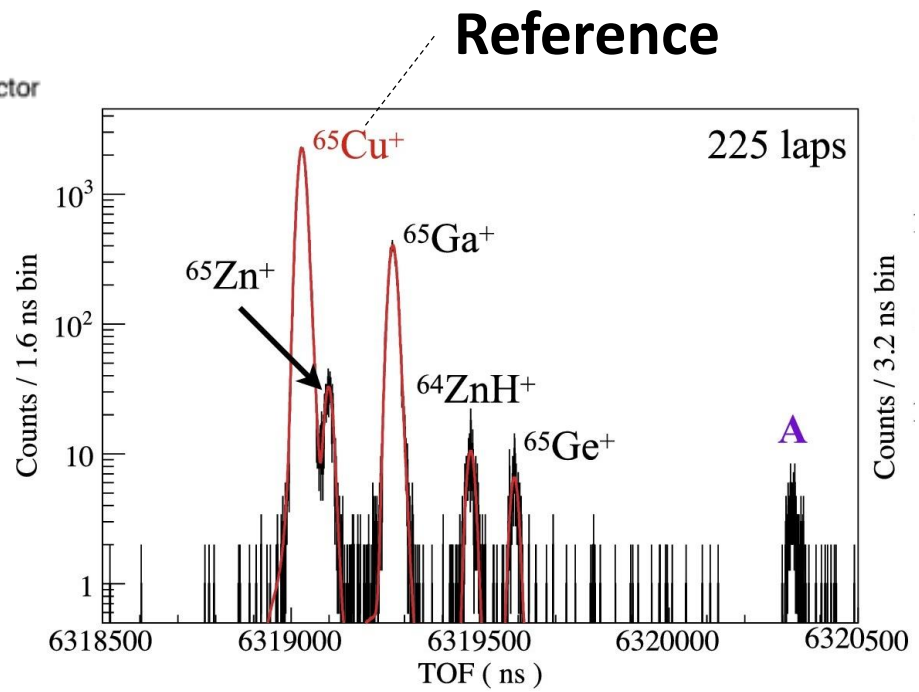
- Multireflection time-of-flight mass spectrograph (MRTOF-MS) is a powerful tool with a relative precision of 10^{-7}
- Offline ion source of many elements would be also useful as a reference



Y. Ito et al. Phys. Rev. Lett. 120 152501 (2018)



R. N. Wolf et al. Int. J. Mass Spectrom. 313 (2012) 8-14

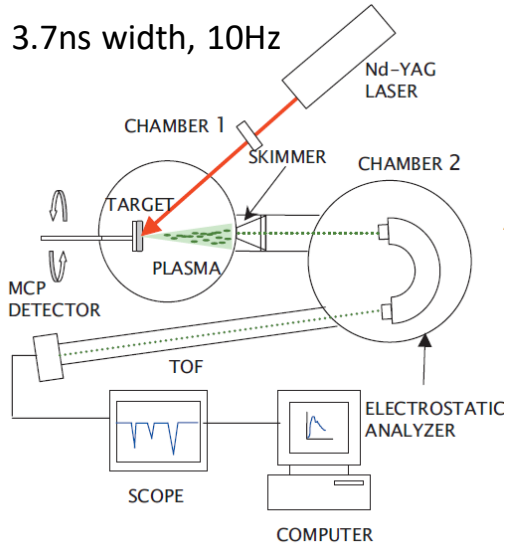


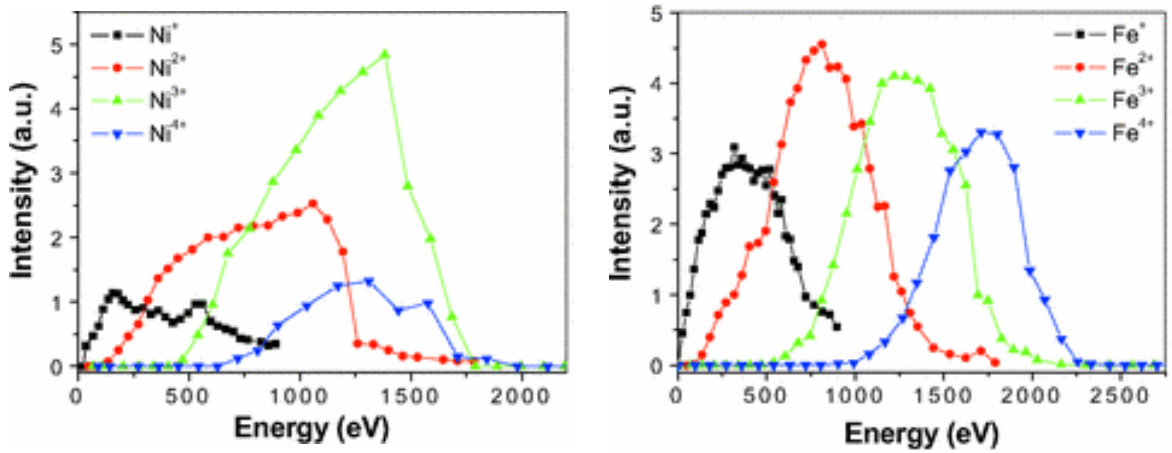
S. Kimura et al. Int. J. Mass Spectrom. 430 (2018) 134–142

Concept of ion source system

Refractory metal --- Surface ionization is difficult

→ Laser ablation in vacuum --- Large energy spread is not good for spectroscopy…



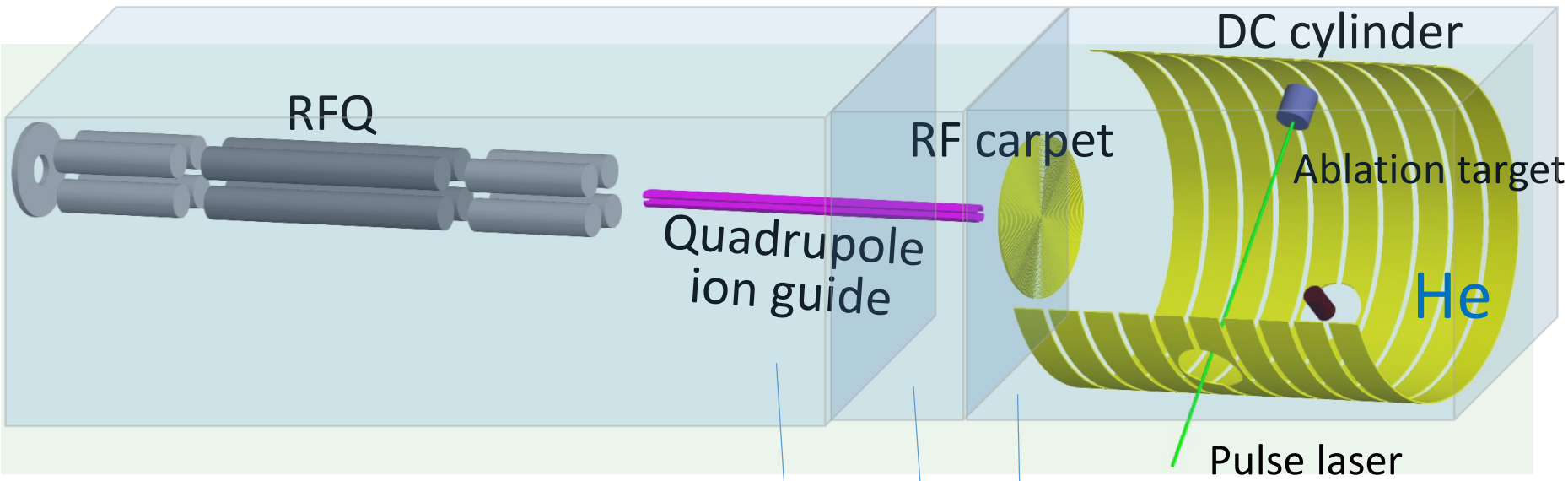


P. Écija et al. Phys. Rev. A 77, 032904(2008)

→ Laser ablation in He gas + RF ion guide system

Low-emittance ion source of many elements whichever solid target is available (incl. refractory elements)

Ion source system

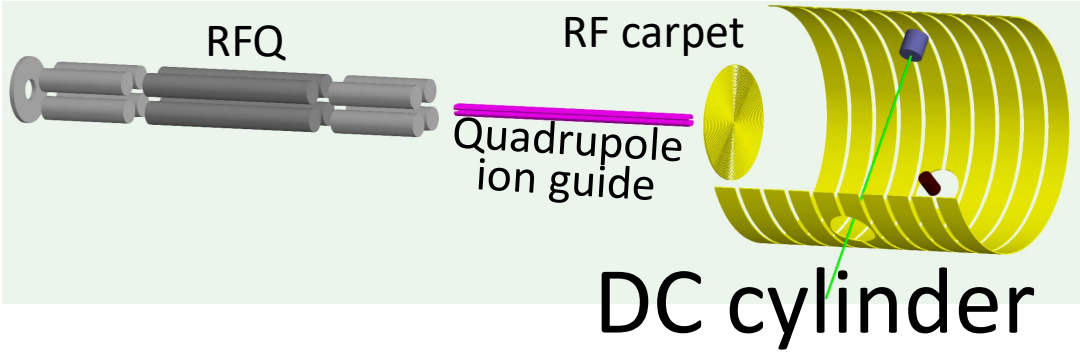


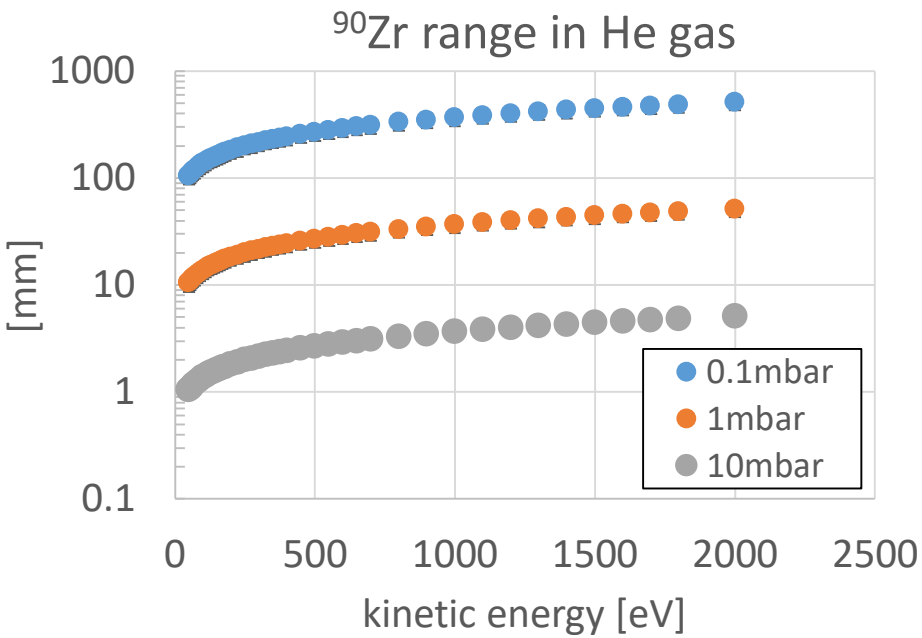
- DC cylinder (Laser ablation)
- RF carpet
- Quadrupole ion guide
- RFQ

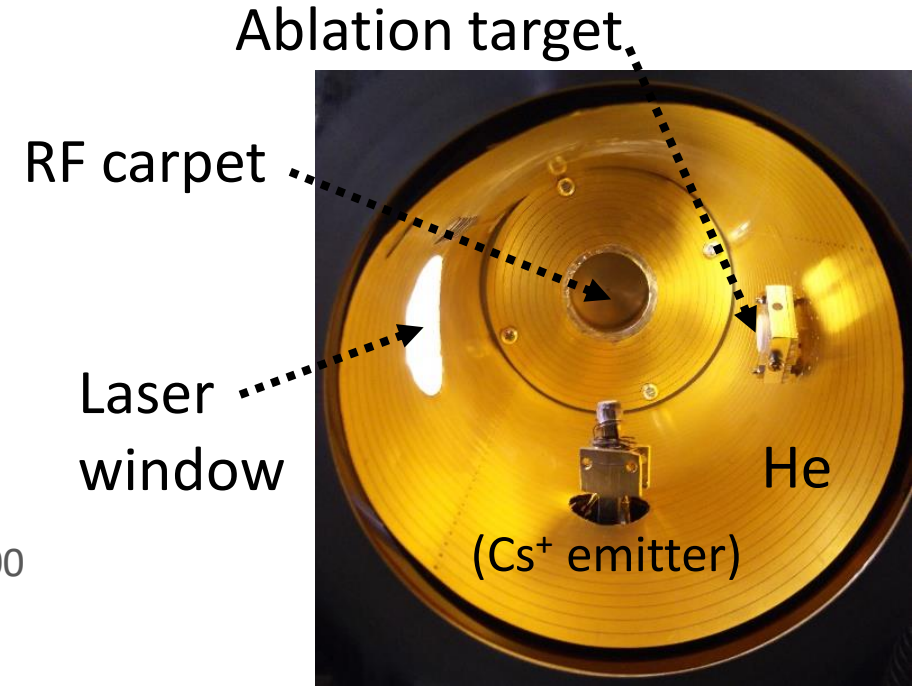
Chamber	Relative pressure
1	1
2	~ 1×10^{-2}
3	~ 5×10^{-5}

Differential pumping

Ion source system (DC cylinder)

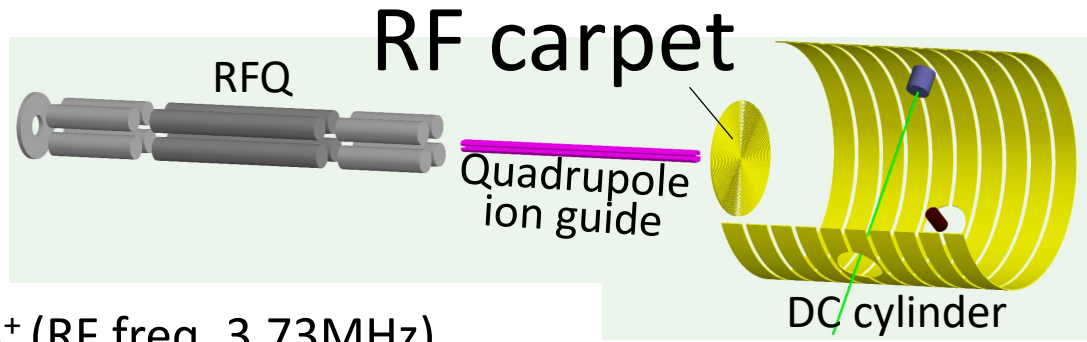


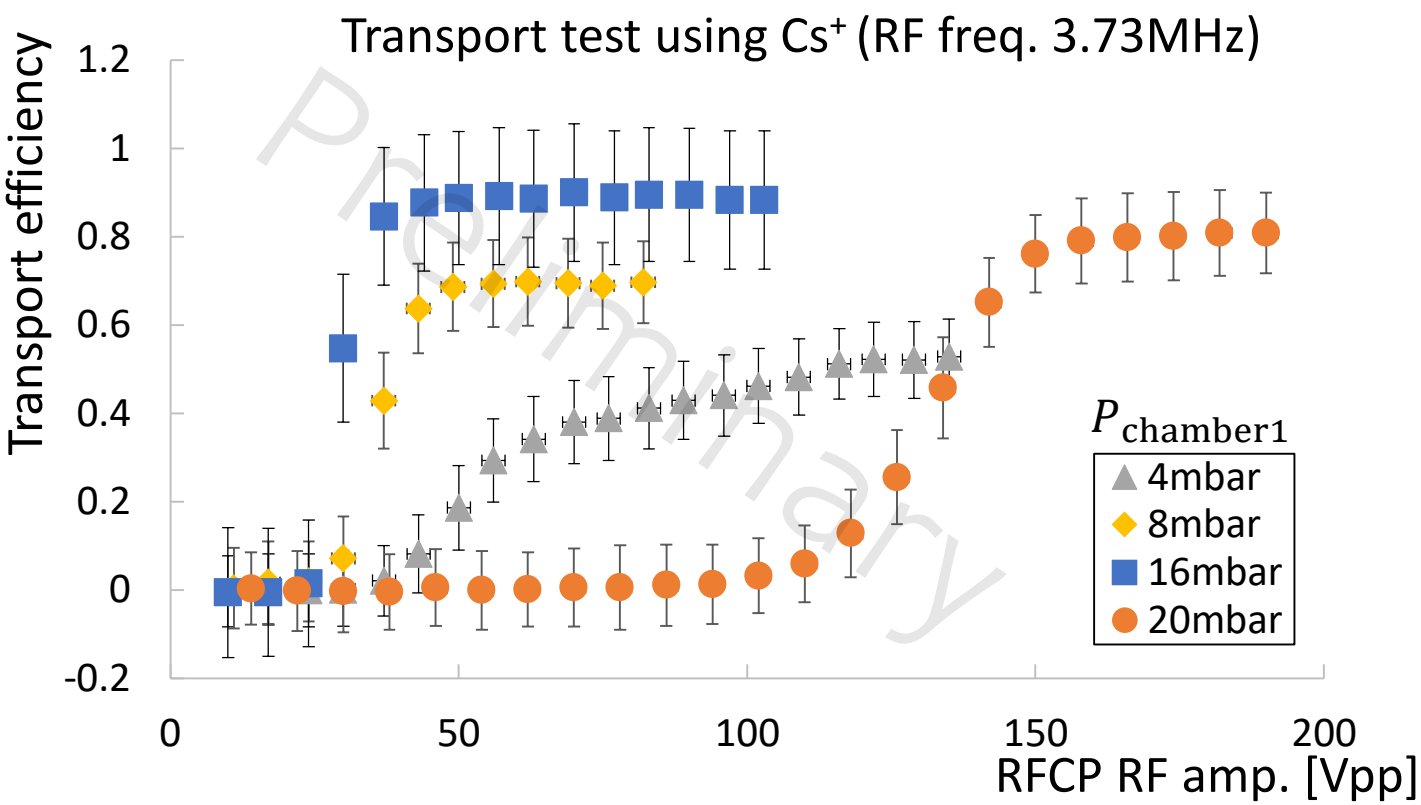




- He pressure is kept constant (feedback to piezo valve)
- Ions are stopped in He, guided down to RF carpet by DC electric field (~8V/cm).

Ion source system (RF carpet)



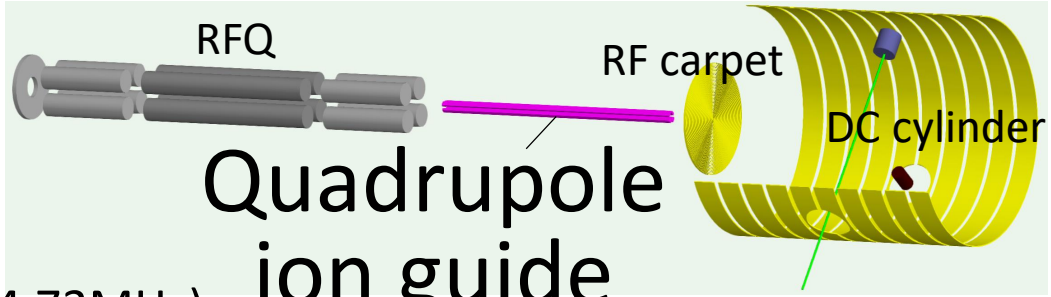


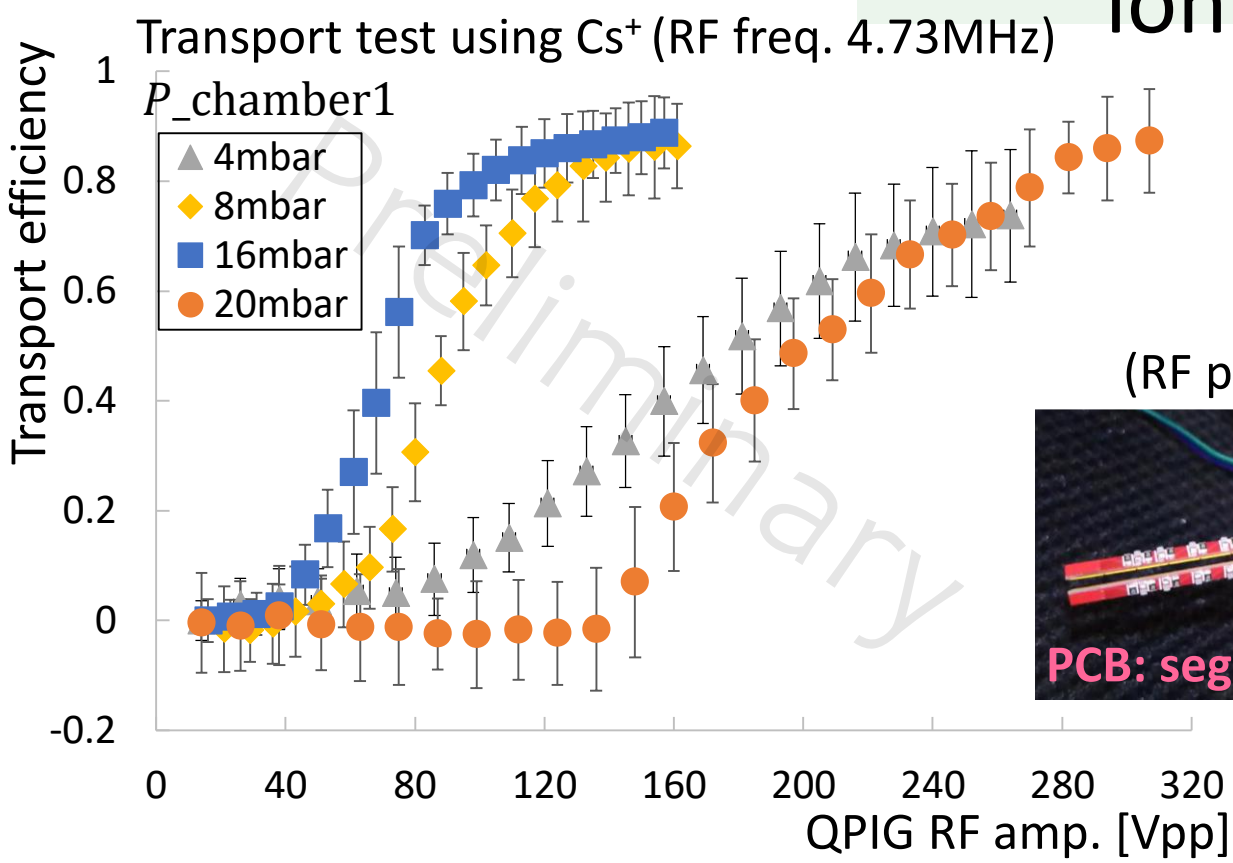
DC voltage divider, filters

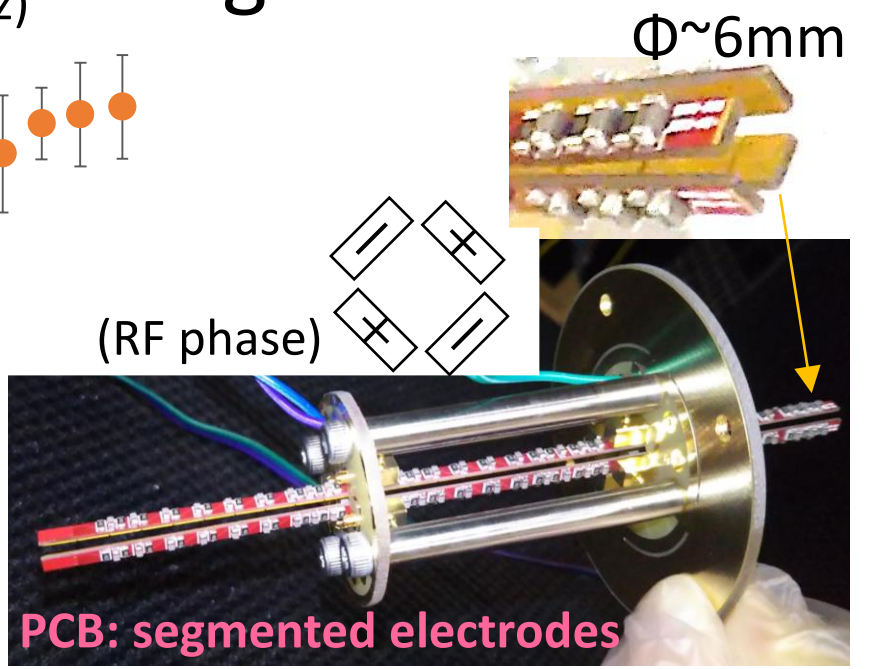
0.15mm width,
0.3mm pitch,
0.5mm hole at the center

- Ions are transported by DC (8V/cm) + RF
- Transport efficiency of ~80% was achieved.

Ion source system (Quadrupole ion guide)

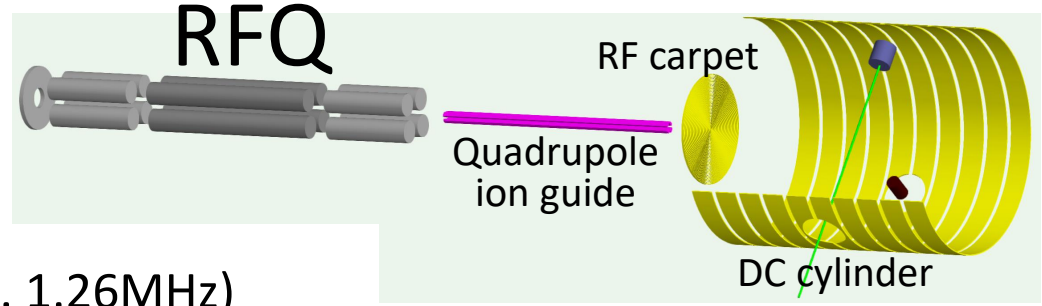




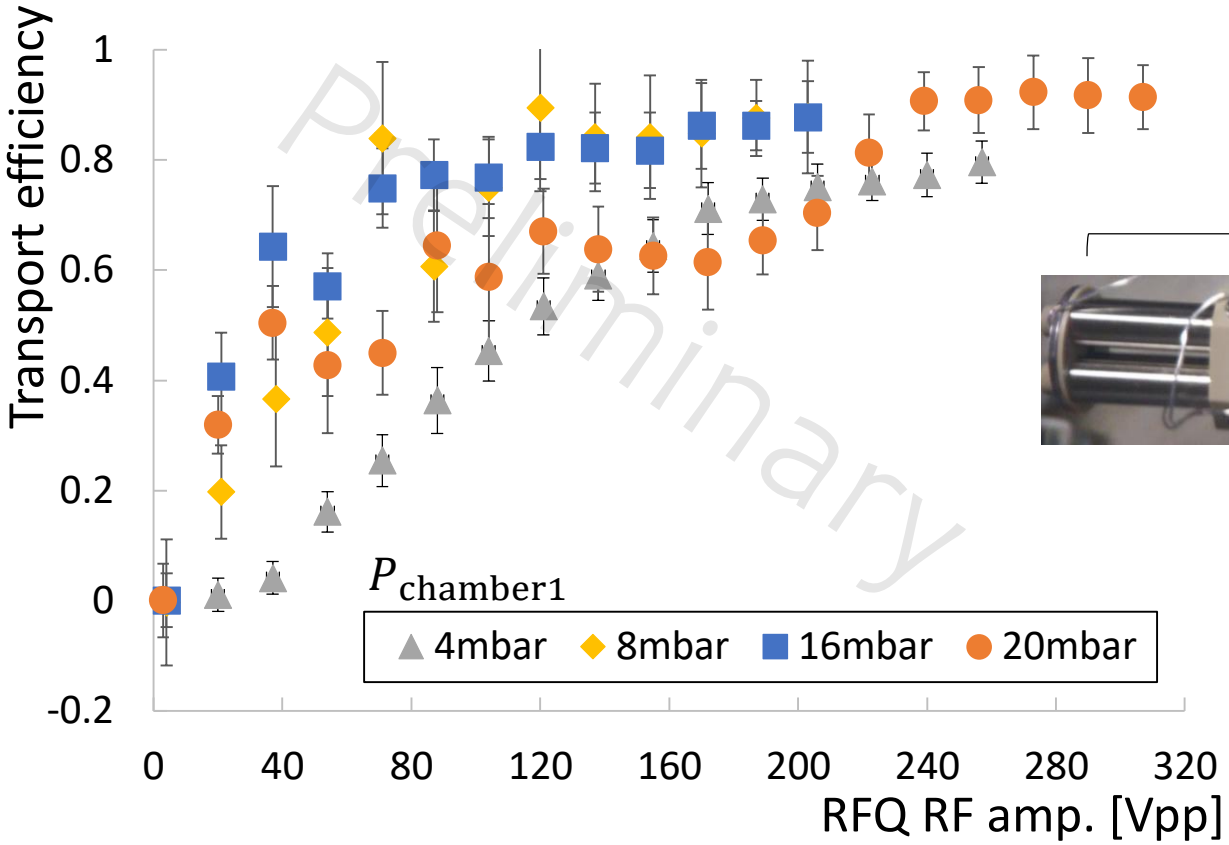


- 4 thin plates (PCB), each as a segmented electrode.
- Ions are transported by DC (~0.2V/cm) + RF
- Transport efficiency of ~90% was achieved.

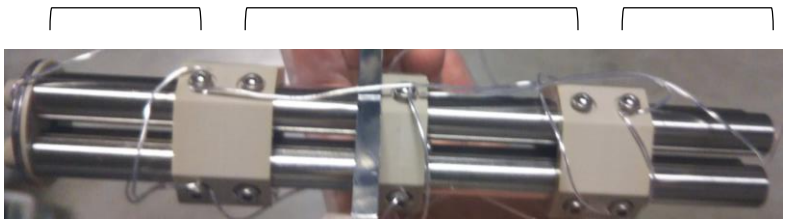
Ion source system (RFQ)



Transport test using Cs^+ (RF freq. 1.26MHz)



4 SUS rods, 3 parts

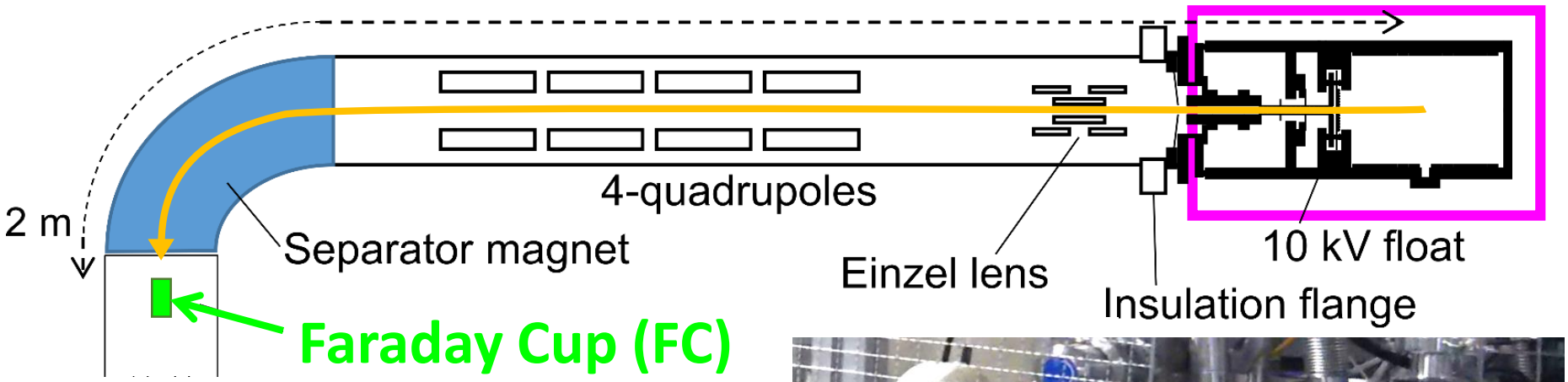


- Ions are transported by RF electric field.
- Transport efficiency of ~90% was observed.

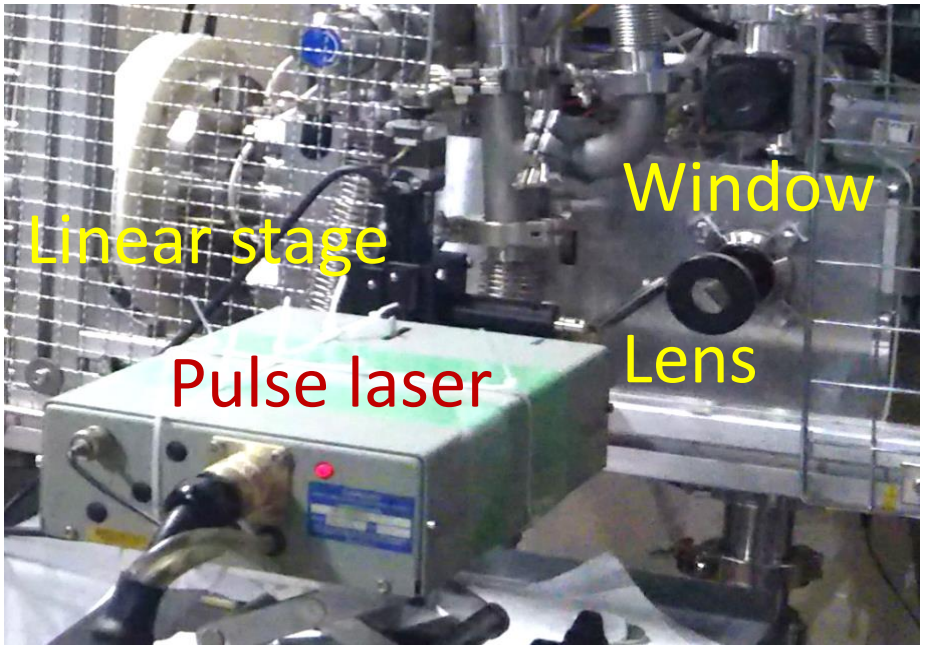
Total eff. ~70%

Test measurement for different ablation targets

- Ion source was connected to a test beamline



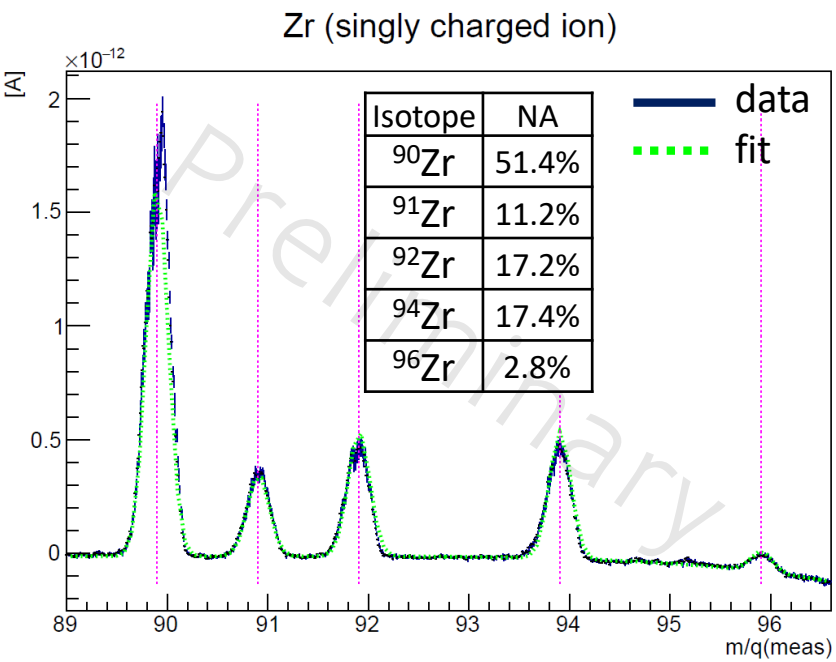
- Laser ablation of several solid targets.
- Resulted ion beams are collected at FC, sweeping the magnetic field.

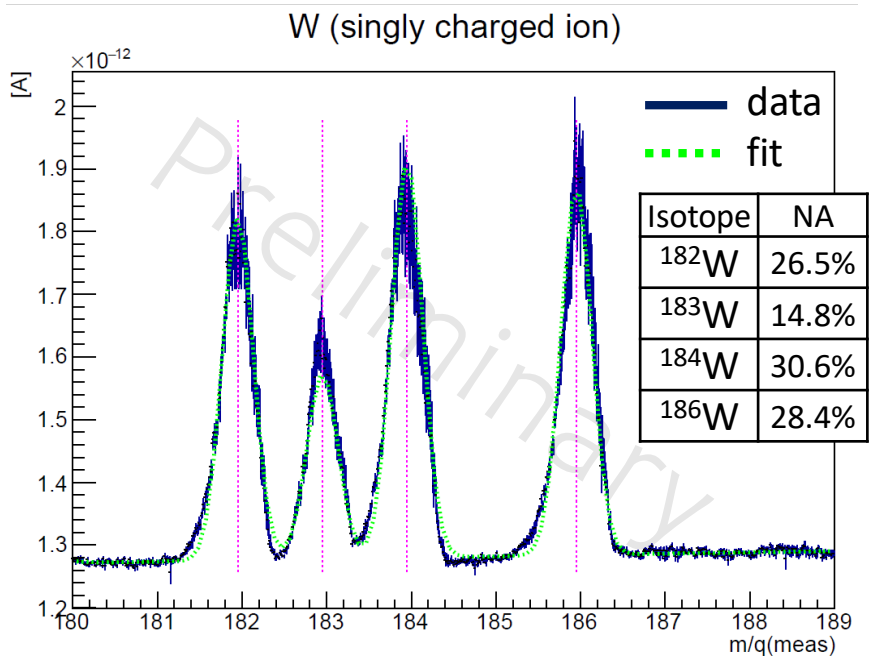


(Horizontal slits before and after the separator magnet: 0.5mm width)

m/q spectrum for different ablation targets

- Target: Ni, Ag, Zr, Ta, W, BaF_2 in He 4mbar
- Laser: 532nm, ~5ns width, 10Hz, ~10mJ/pulse (Minilite I)
- Singly charged ions of refractory elements (Zr, Ta, W), compound ($BaF_2 \rightarrow Ba^+$) with ~10^7/pulse





Summary

- Offline ion source was developed, mainly for the planned laser spectroscopy experiment at the SLOWRI facility in RIKEN.
- By combining laser ablation of a solid target in He and RF ion guide system, singly charged ions of several elements (incl. refractory) were successfully obtained.

Outlook

- Demonstration of the collinear laser spectroscopy of Ba^{+}.