56th Meeting of the INTC

Q_{EC} value determination of the superallowed β-decay of ^{70}Br

INTC-P-514

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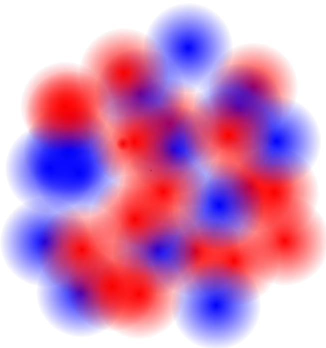
Local contact: Frank Wienholtz

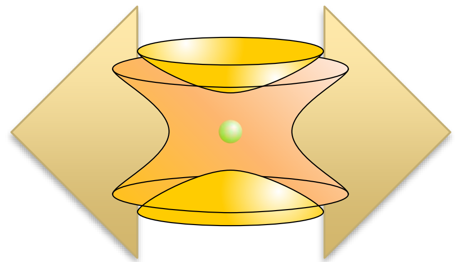
28 June 2017

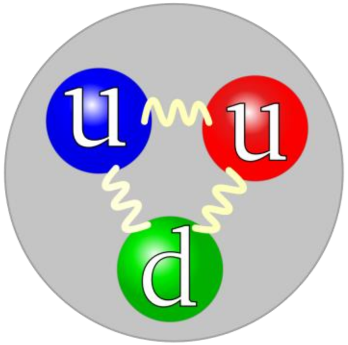
Motivation for the experiment

Nuclear physics

Particle physics







With superallowed (0+ → 0+) β-decay between *T*=1 analog states

→ Depend uniquely on the vector part of the weak interaction

→ According to **Conserved Vector Current (CVC) hypothesis**, the experimental *ft* value is related to vector coupling constant G_V → the same for all such transitions

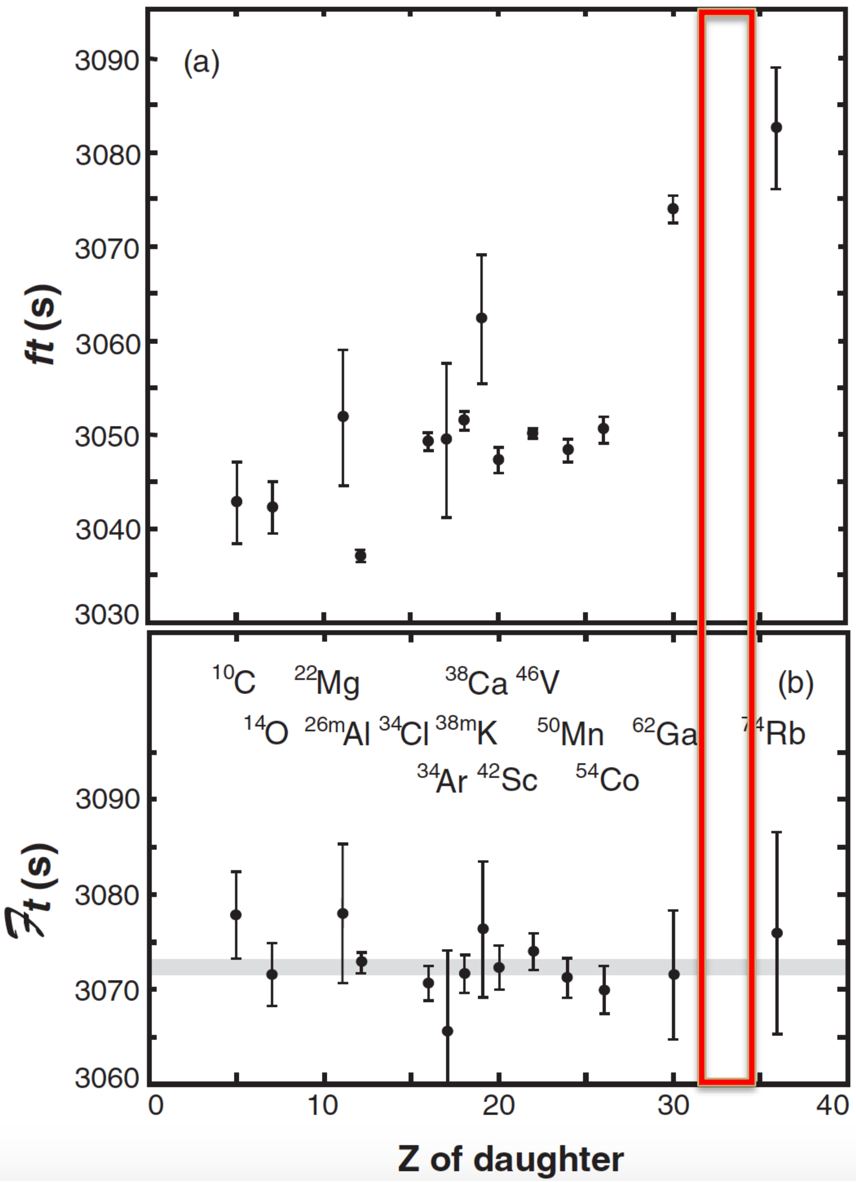
→ Allows to contribute to unitarity tests of **Cabibbo-Kobayashi-Maskawa-Matrix (CKM-Matrix)**

$$Ft = ft(1+\delta'_R)(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

$$V_{ud} = \frac{G_V}{G_F} \Rightarrow |V_{ud}|^2 = ?$$

G_F - weak interaction constant

β-decay of ^{70}Br



$$\mathcal{F}t \equiv ft(1+\delta_R')(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

$$t = \frac{t_{1/2}}{R}(1+P_{EC})$$

f - statistical rate function

^{70}Br → ^{70}Se not yet included

Need to improve experimentally:

- half-life determination of the decay, clarification of the isomer 9+ production/contamination

A. I. Morales, A. Algora, B. Rubio et al., arXiv:1704.07610, accepted at PRC.

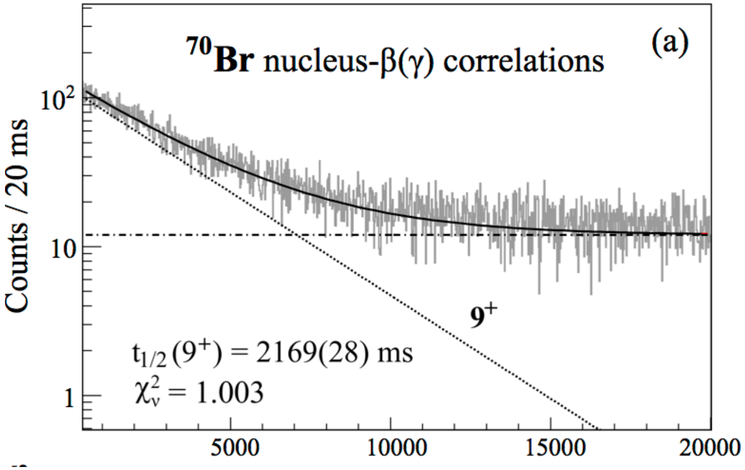
- determination of weak GT branches that compete with 0+->0+ decay if possible

- **better Q-value**

$$\overline{\mathcal{F}t} = 3072.27 \pm 0.72 \text{ s}$$

Taken from Hardy and Towner, PRC 91 (2015) 025501

β-decay of ^{70}Br (half-life values)



- 9+ isomer decay half-life determined from implant-beta(gamma) correlations (very clean).

$T_{1/2}$ (9+, present) = 2169 (28) ms

$T_{1/2}$ (9+, literature) =2200 (200) ms

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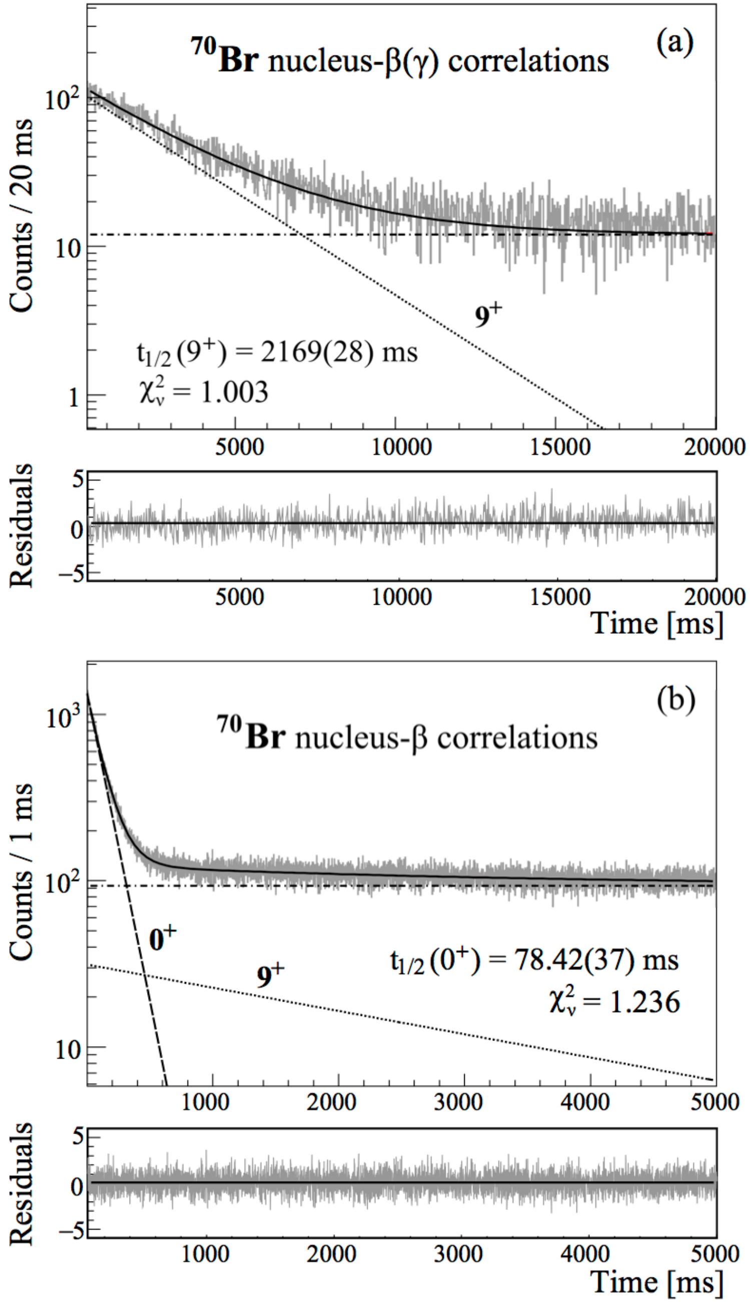
β-decay of ^{70}Br (half-life values)



- 9+ isomer decay half-life determined from implant-beta(gamma) correlations (very clean).
- Using this value the 0+ decay half-life can be determined from implant-beta correlations which contains both components

$T_{1/2}$ (9+, present) = 2169 (28) ms

$T_{1/2}$ (9+, literature) =2200 (200) ms

$T_{1/2}$ (0+, present) = 78.42 (37) ms

$T_{1/2}$ (0+, literature) = 79.1 (8) ms

A. I. Morales, A. Algora, B. Rubio et al., arXiv:1704.07610, accepted at PRC.

β-decay of ^{70}Br

World average $\overline{\mathcal{F}t} = 3072.27 \pm 0.72$ s

Determination of the corrected *Ft* value with the new half-life value using:

- Q_{EC} value determined from an earlier end point measurement (9970 ± 170 keV) [3].
-

Q_{EC} (keV)	f	P_{EC} (%)	ft (s)	*Ft*(s)
9970 ± 170[3]	38600 ± 3600	0,173	3096 ± 293	3086 ± 293

[1] J. Savory, et al., Phys. Rev. Lett. 102, 132501 (2009).
[2] D.G. Jenkins et al., Phys. Rev. C 65. 064307 (2002)
[3] C. N. Davids, Atomic Masses and Fundamental Constants 6, edited by J. A. Nolen and W. Benenson (Plenum, New York) p. 419 (1980).

β-decay of ^{70}Br

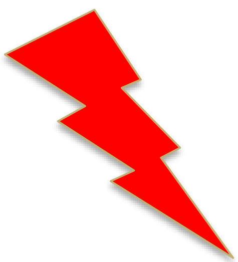
World average $\overline{\mathcal{F}t} = 3072.27 \pm 0.72$ s

Determination of the corrected *Ft* value with the new half-life value using:

- Q_{EC} value determined from an earlier end point measurement (9970 ± 170 keV) [3].
- accepted Q_{EC} value (10504 ± 15 keV) from ^{70m}Br Penning trap measurement [1] assuming excitation energy of the 9+ state of 2293keV (from linked γ-transmissions) [2]

Q_{EC} (keV)	f	P_{EC} (%)	ft (s)	*Ft*(s)
9970 ± 170[3]	38600 ± 3600	0,173	3096 ± 293	**3086 ± 293**
10504 ± 15[1]	50979 ± 385	0,133	4087 ± 83	**4078 ± 83**

12σ deviation



This clearly calls for a new measurement of the Q_{EC} value

→ Redetermination of ^{70g}Br, ^{70m}Br and ^{70}Se

[1] J. Savory, et al., Phys. Rev. Lett. 102, 132501 (2009).
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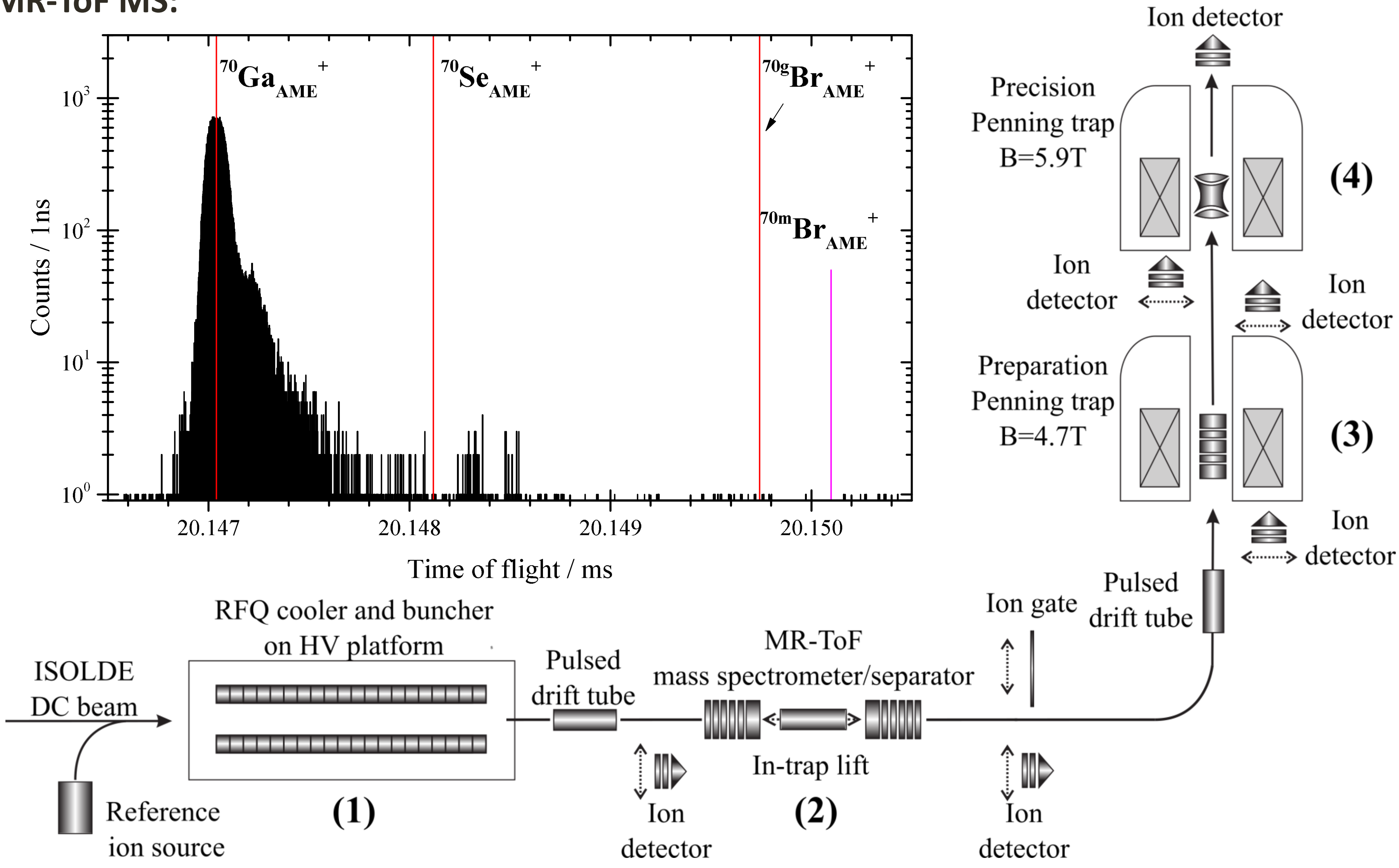
The ISOLTRAP mass spectrometer for short-lived nuclides

MR-ToF MS:



Mukherjee *et al.*, Eur. Phys. J. A 35, 1 (2008); Wolf *et al.*, IJMS 349-350, 123 (2013); NIM A 686, 82 (2012)

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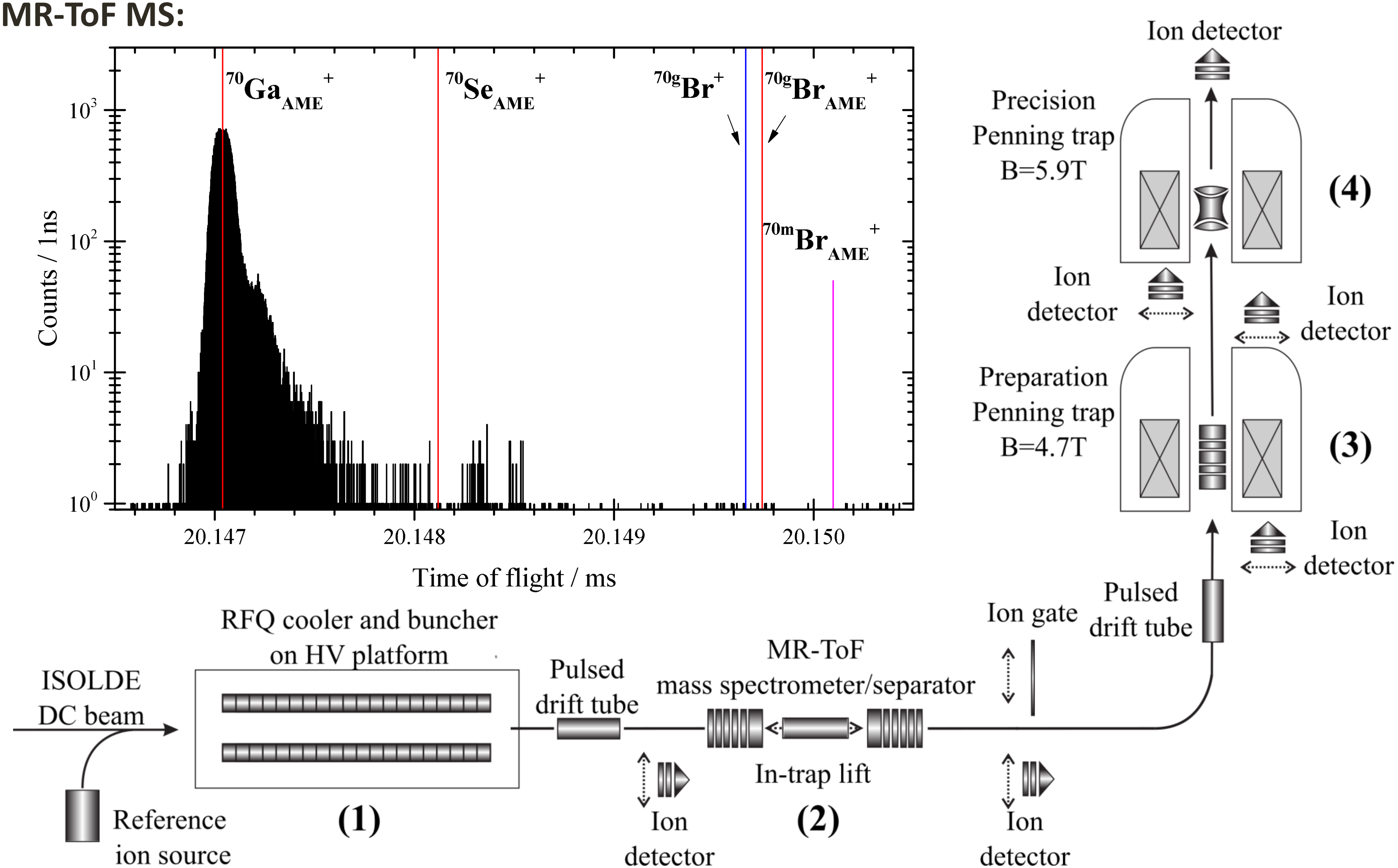

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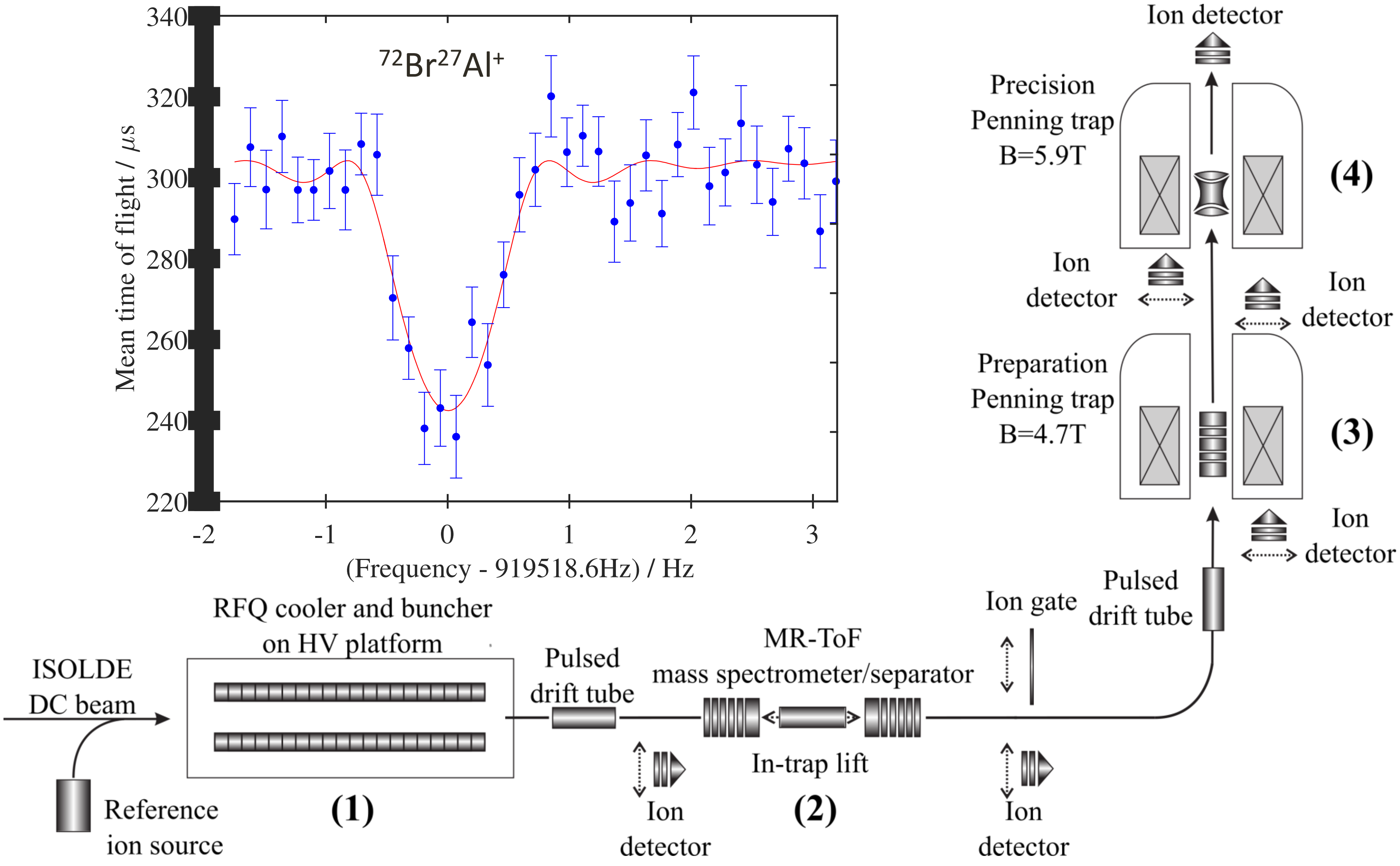
Penning trap TOF-ICR:



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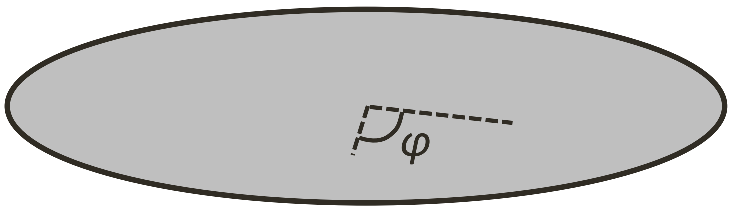
The Penning trap / Phase-imaging ion-cyclotron-resonance technique

Position-sensitive detector



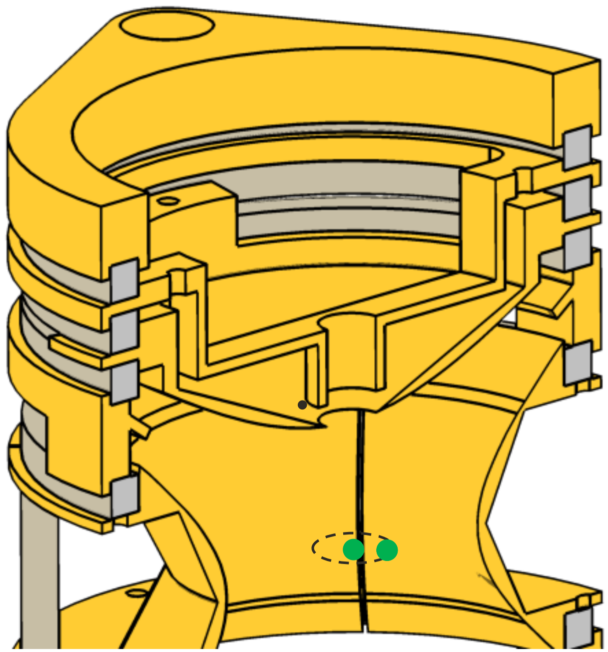
- ✓ No excitation (center position)
- ✓ On radial motion, wait for time *t*
- ✓ On radial motion, wait for time *t* + *Δt*

$$\omega = \frac{2\pi n + \varphi}{\Delta t}$$

✓ Has higher resolving power and precision than TOF-ICR (depending on spot size and position)

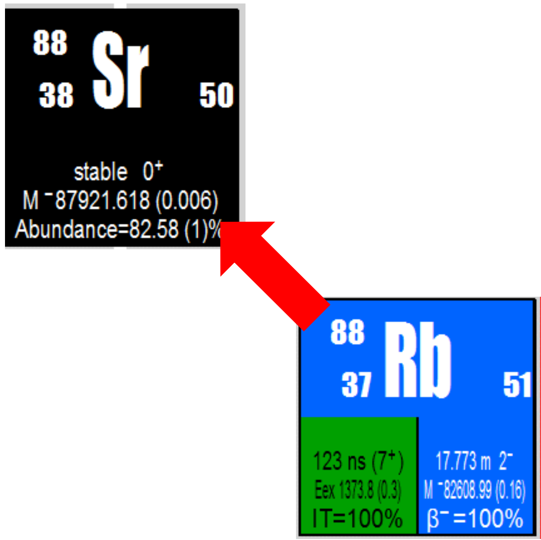
✓ Requires some prior knowledge of the frequency

✓ Requires timing stability on ~100 ps level

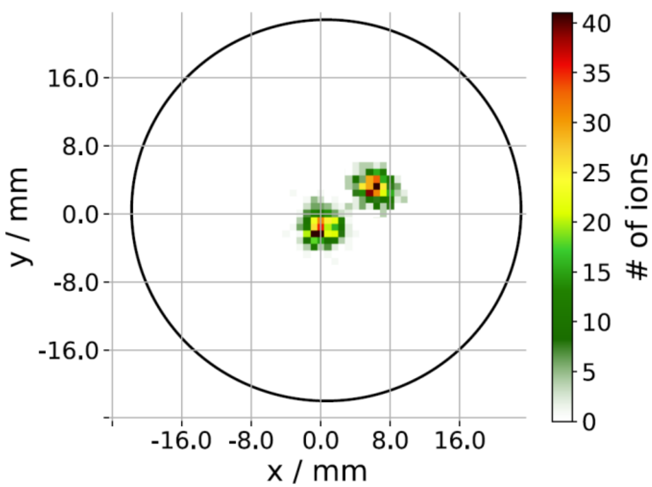


S. Eliseev et al.., PRL 110, 082501 (2013)

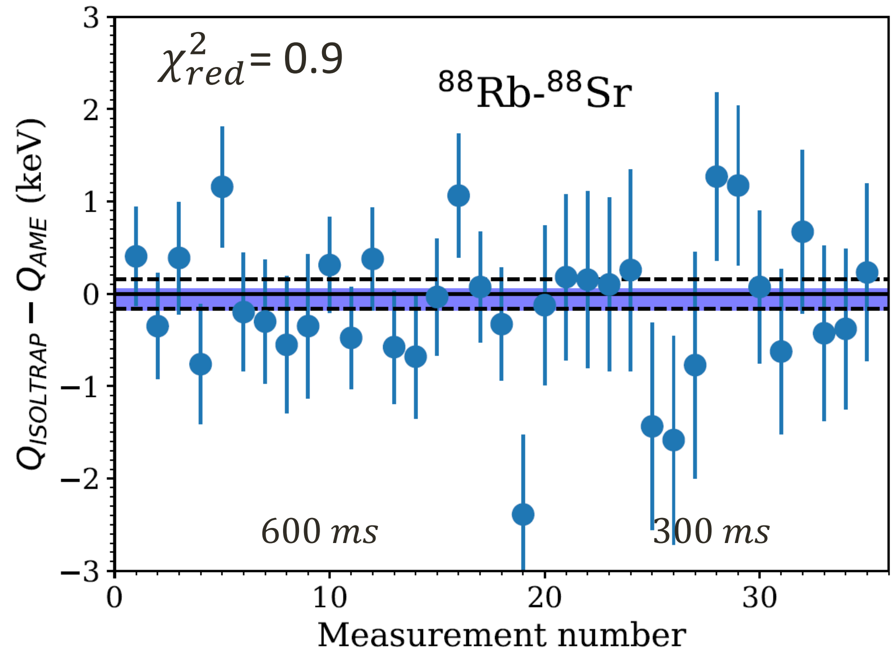
Current status of PI-ICR



Event position on MCP-PS



≈ 120 eV precision

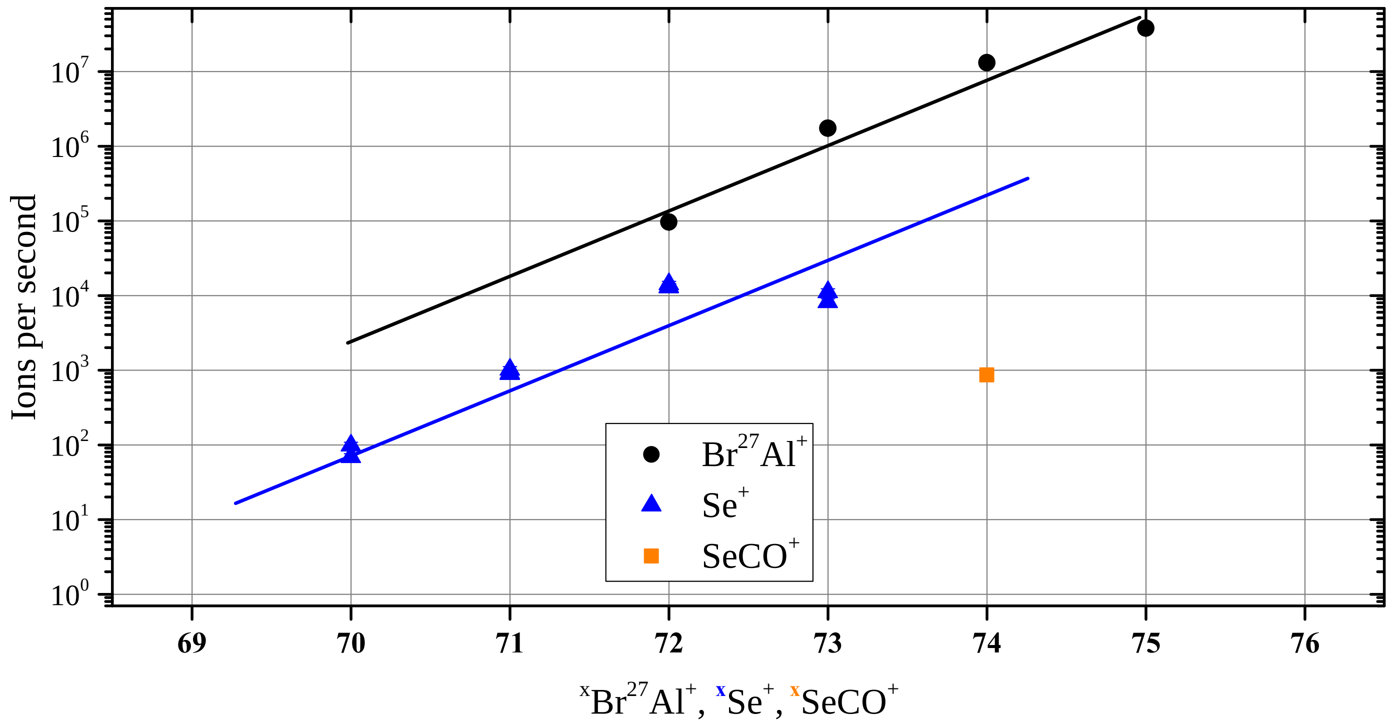


- Extensive program of tests is ongoing, in order to understand the systematic errors.
- First on-line application to a Q-value measurement shows that the systematic error is under control.

Master project of J. Karthein.

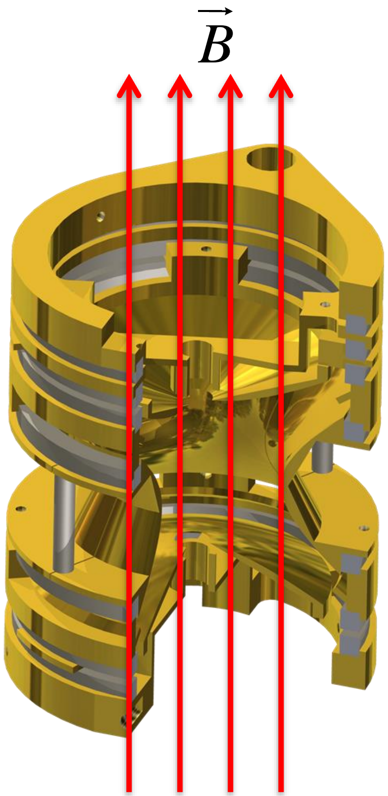
Q_{EC} value determination of the superallowed β-decay of ^{70}Br

Isotope	Half-life	Target	Yield (ions/s)	Method	Ion source	Shifts
^{70}Br	78.42(51)ms	ZrO, Nb-foil	100-1000	Penning trap and MR-TOF MS	VADIS	**5**
^{70}Se	41.1(0.3)m	ZrO, Nb-foil	100	Penning trap and MR-TOF MS		**5**
					Target/ion-source optimization	**2**
					Total shifts	**12**

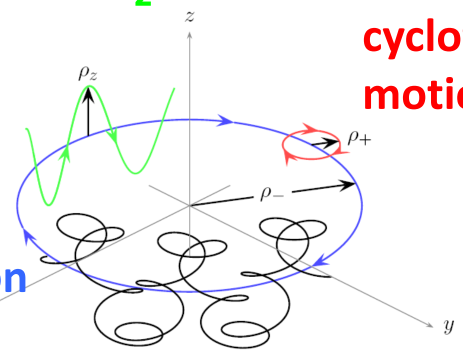


Yields: T. Stora, private communication (2017) and Herfurt et al., Eur.Phys. J. A47, 75 (2011)

The Penning trap / ToF ICR

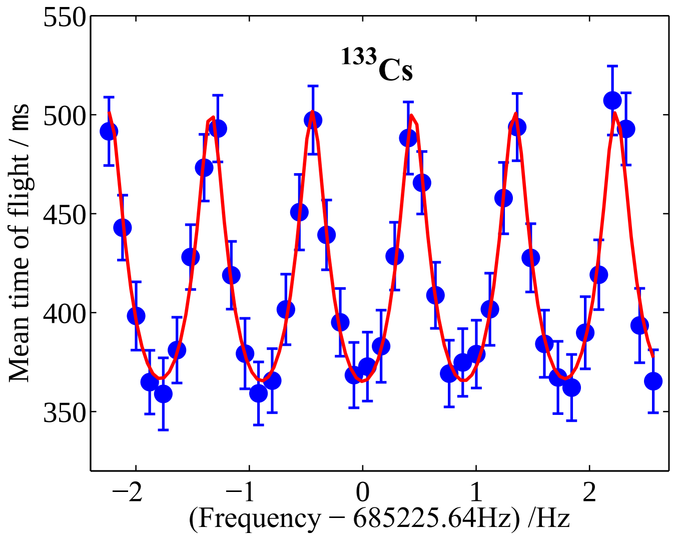


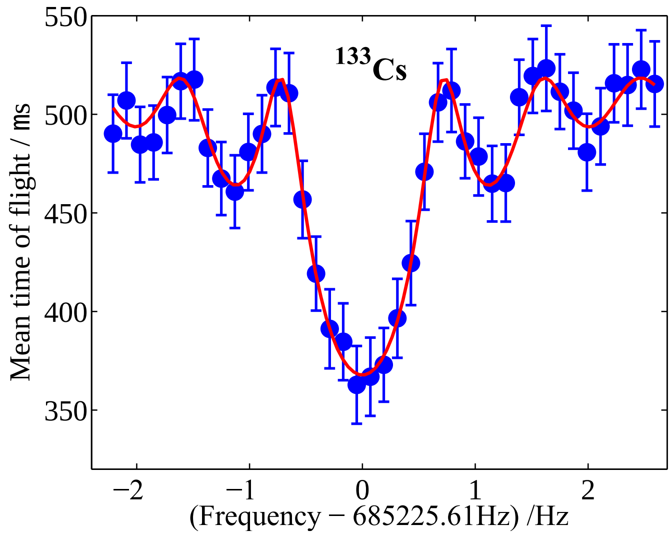
$$\omega_c = \frac{qB}{m_{ion}}$$



Using the TOF-ICR technique:

$$m = \frac{\omega_{C,\,\mathrm{ref}}}{\omega_C}\left(m_{\mathrm{ref}} - m_e\right) + m_e$$





Brown & Gabrielse, Rev. Mod. Phys. 58, 233 (1986); Gräff *et al.*, Z. Physik A -- Atoms and Nuclei 297, 35 (1980); S. George et al., Phys. Rev. Lett. 98, 162501 (2007)

Comparison of the available techniques in terms of *R*:

Penning trap ToF-ICR:

$$R = \frac{m}{\Delta m} \approx \nu_c t_{obs} \qquad \nu_c = \frac{q}{m}\frac{B}{2\pi} \rightarrow 10^6\text{Hz}$$

MR-ToF MS:

$$R = \frac{m}{\Delta m} = \frac{t_{obs}}{2\Delta t}$$

$$\cong \frac{t_{\text{transfer}} + nT}{2\sqrt{\Delta t_{th}^2 + (n\Delta T_A)^2 + \left(\Delta t_E - nT\left(\frac{\partial \delta_T}{\partial \delta_E}\right)\Delta\delta_E\right)^2}}$$

Penning trap PI-ICR:

$$R = \frac{m}{\Delta m} \approx \frac{\nu_+}{\Delta \nu_{+<}} \approx \pi\frac{\nu_+ t_{obs} r_+}{\Delta r_+}$$

relative mass uncertainty: $\frac{\delta m}{m} = \frac{k}{R\sqrt{N}}$