58^{th} Meeting of the INTC

High-precision measurement of the ^{18}Ne superallowed β-decay Q-value

INTC-P-545

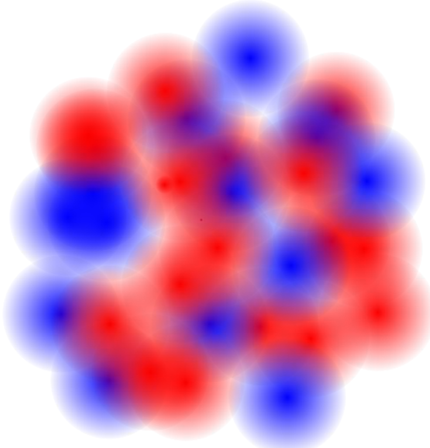
Spokepersons: Martin Eibach and Maxime Mougeot

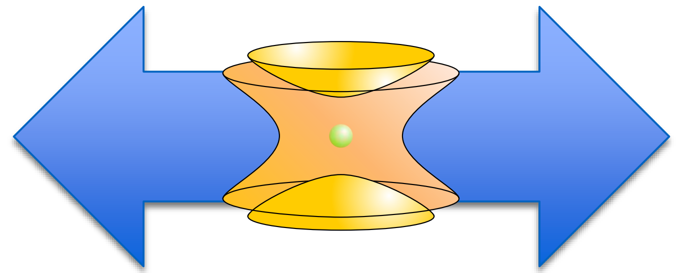
Local contact: Maxime Mougeot

7th February 2018

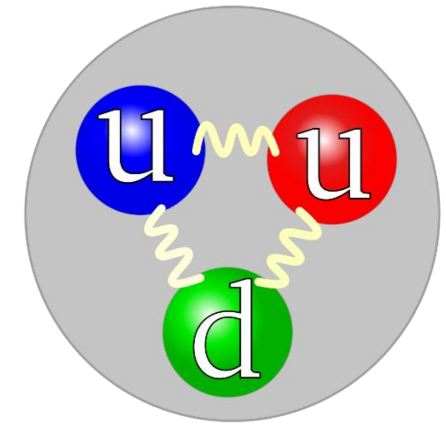
General Motivation

Nuclear physics





Particle physics



Properties of superallowed 0^+->0^+ β-decay between *T*=1 analog states :

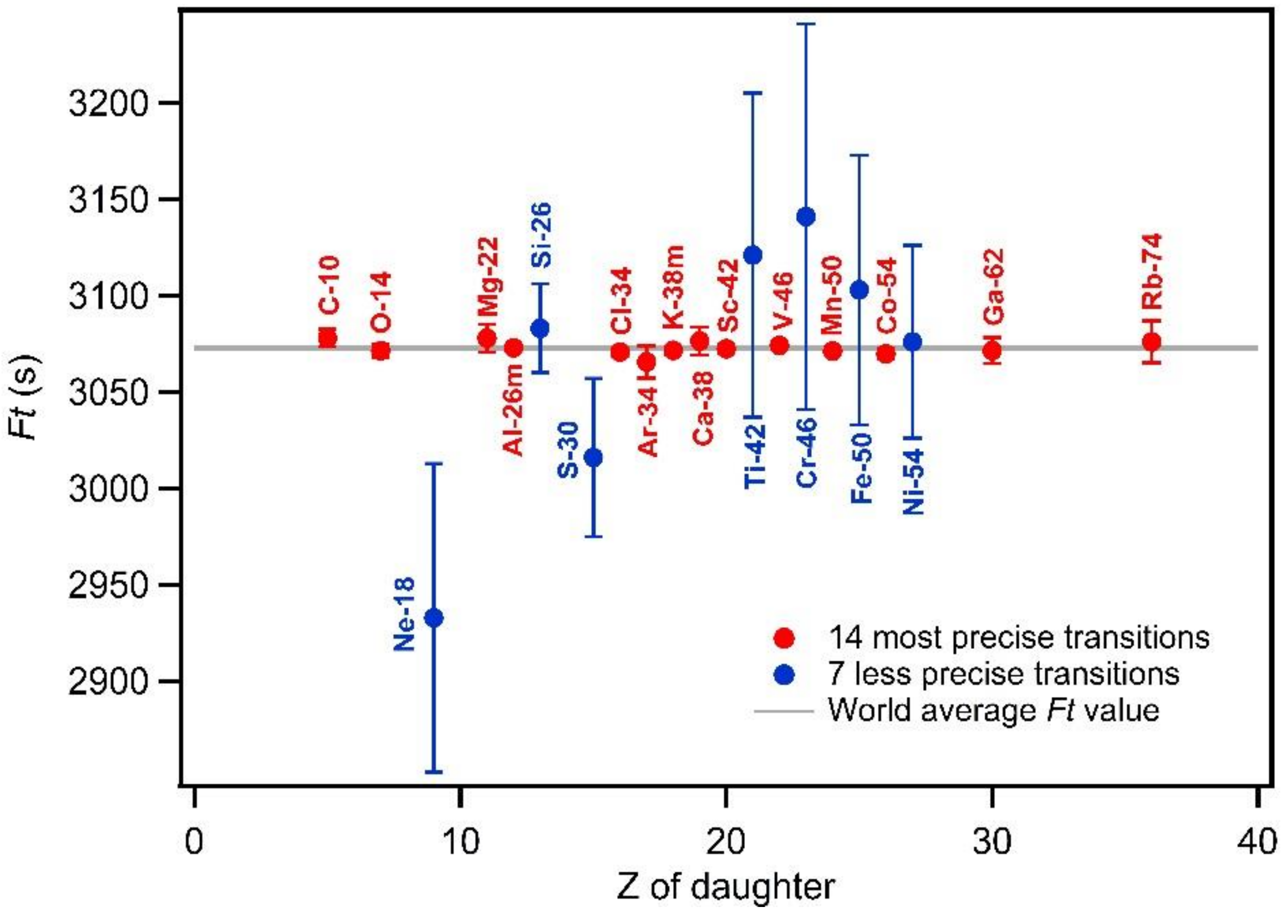
- Depend only on the vector part of the weak interaction
- CVC hypothesis → experimental ft-values directly related to G_V (same for **ALL** such transitions)
- Define corrected $\mathcal{F}t$-value:

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

- Contribute to unitary tests of **Cabibbo-Kobayashi-Maskawa Matrix (CKM-Matrix)**

$V_{ud} = \frac{G_V}{G_F}$, G_F weak interaction constant → $|V_{ud}|^2 \propto \frac{1}{\overline{\mathcal{F}t}}$

β-decay of ^{18}Ne



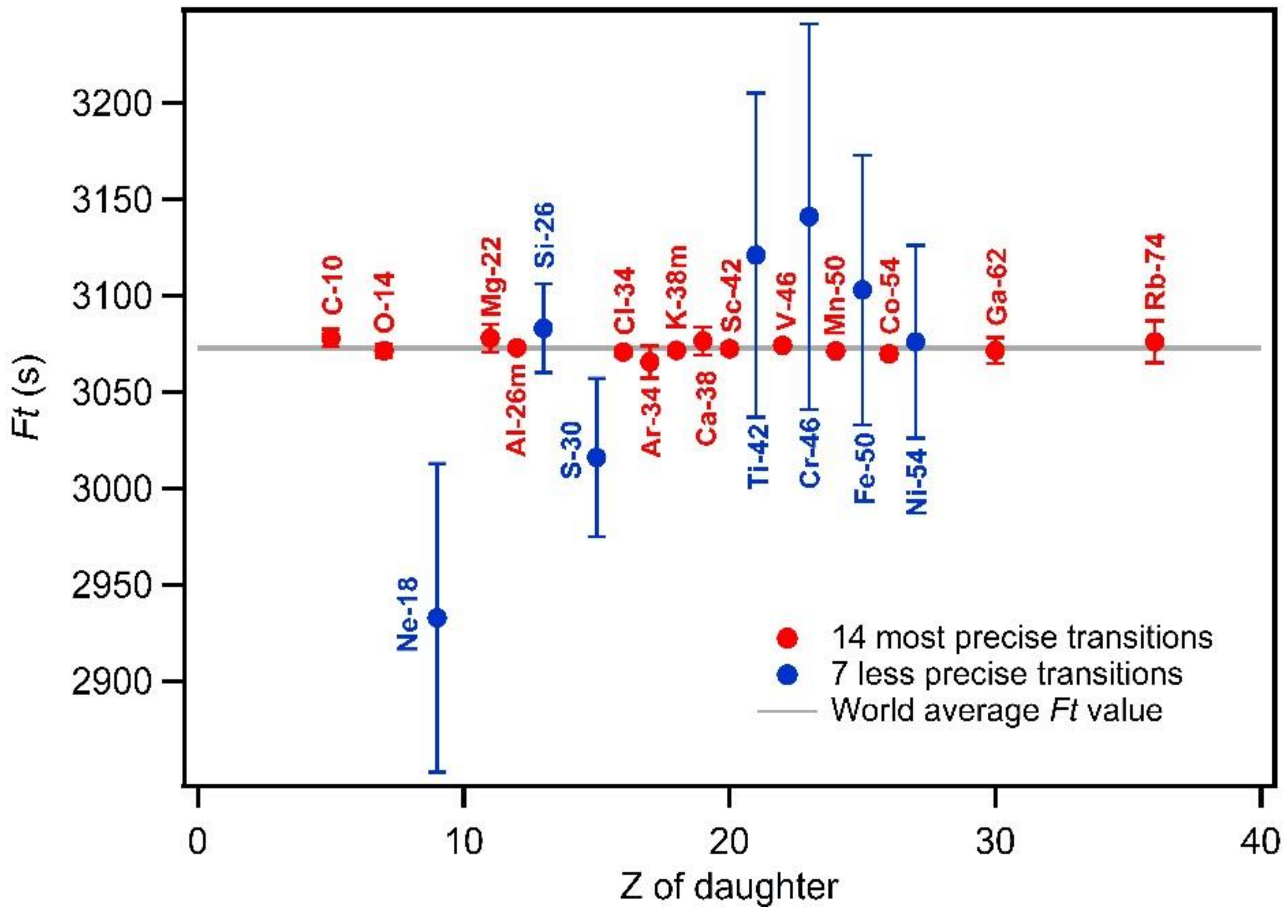
$$\mathcal{F}t = ft(1+\delta_R')(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

- ft depends on 3 experimental quantities
- $t = \frac{t_{1/2}}{R}(1+P_{EC})$
- f statistical rate function $\propto Q_{EC}{}^5$

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

J. C. Hardy and I. S. Towner, Phys. Rev. C **91**, 025501 (2015)

β-decay of ^{18}Ne



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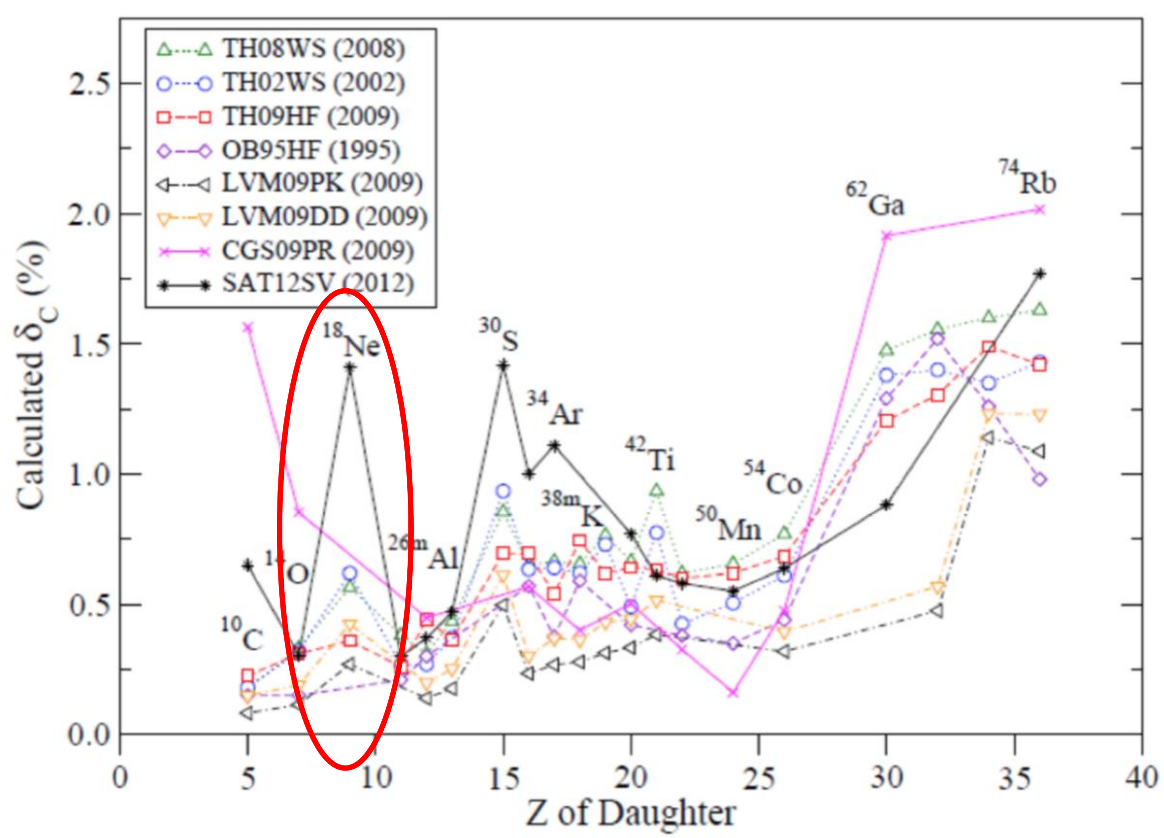
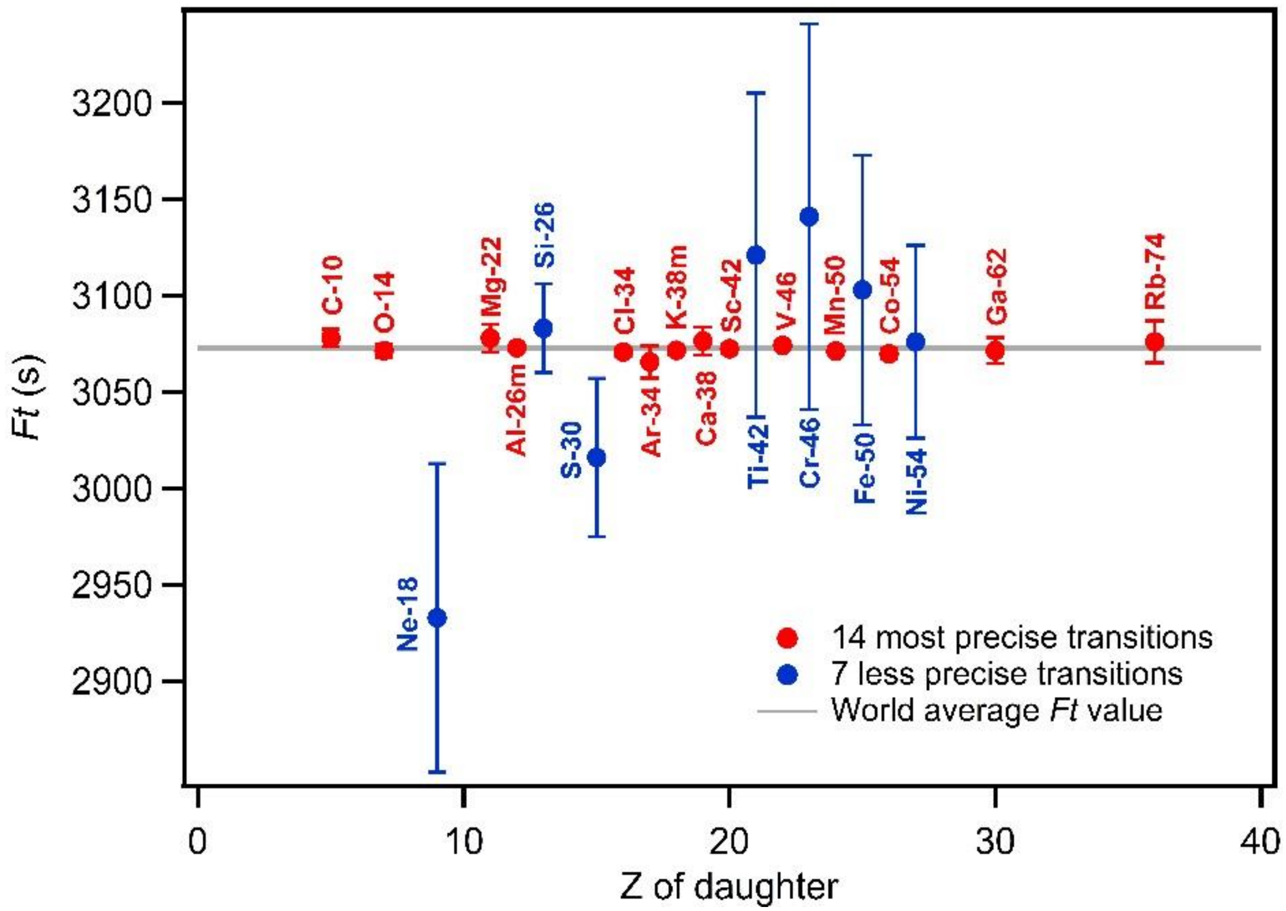


J. C. Hardy and I. S. Towner, Phys. Rev. C **91**, 025501 (2015)
Taken from A. Laffoley et al., CERN-INTC-2016-051 / INTC-P-481

β-decay of ^{18}Ne



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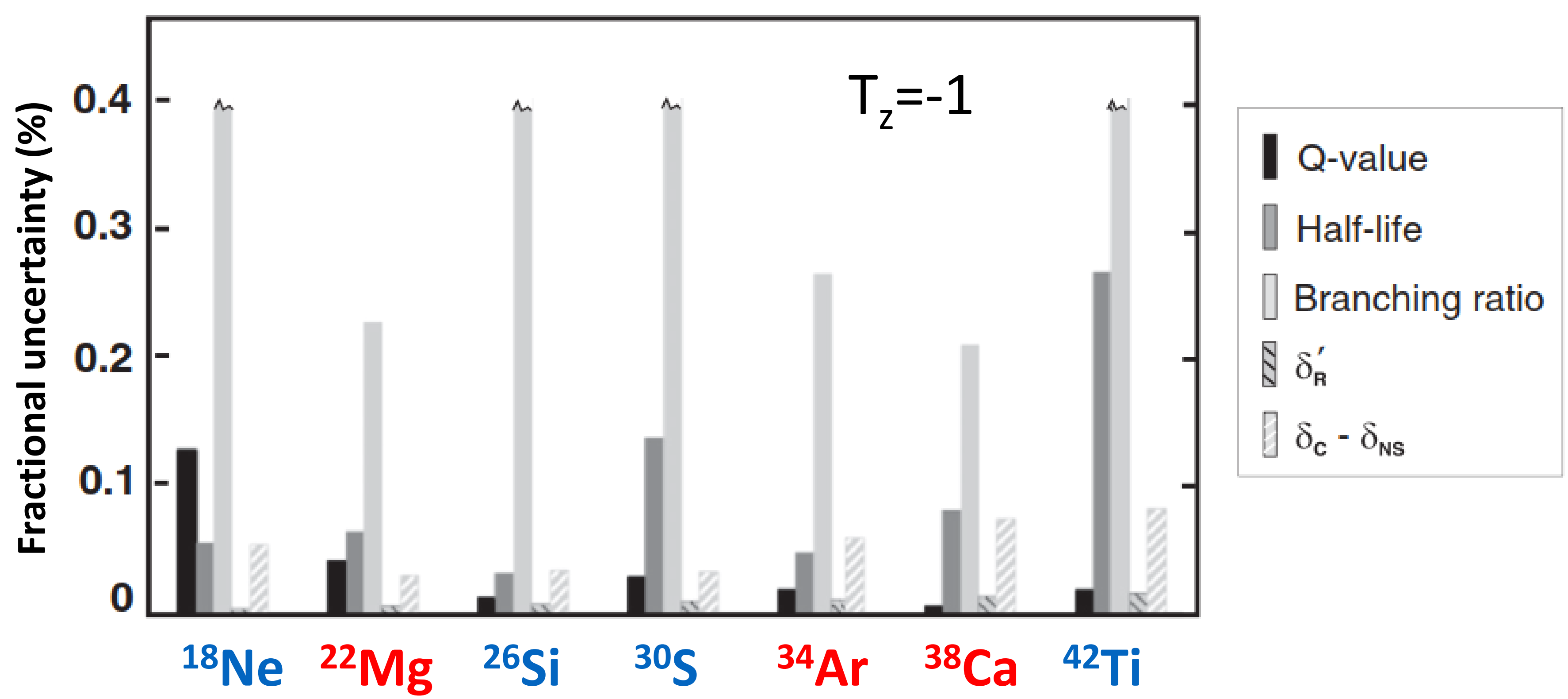


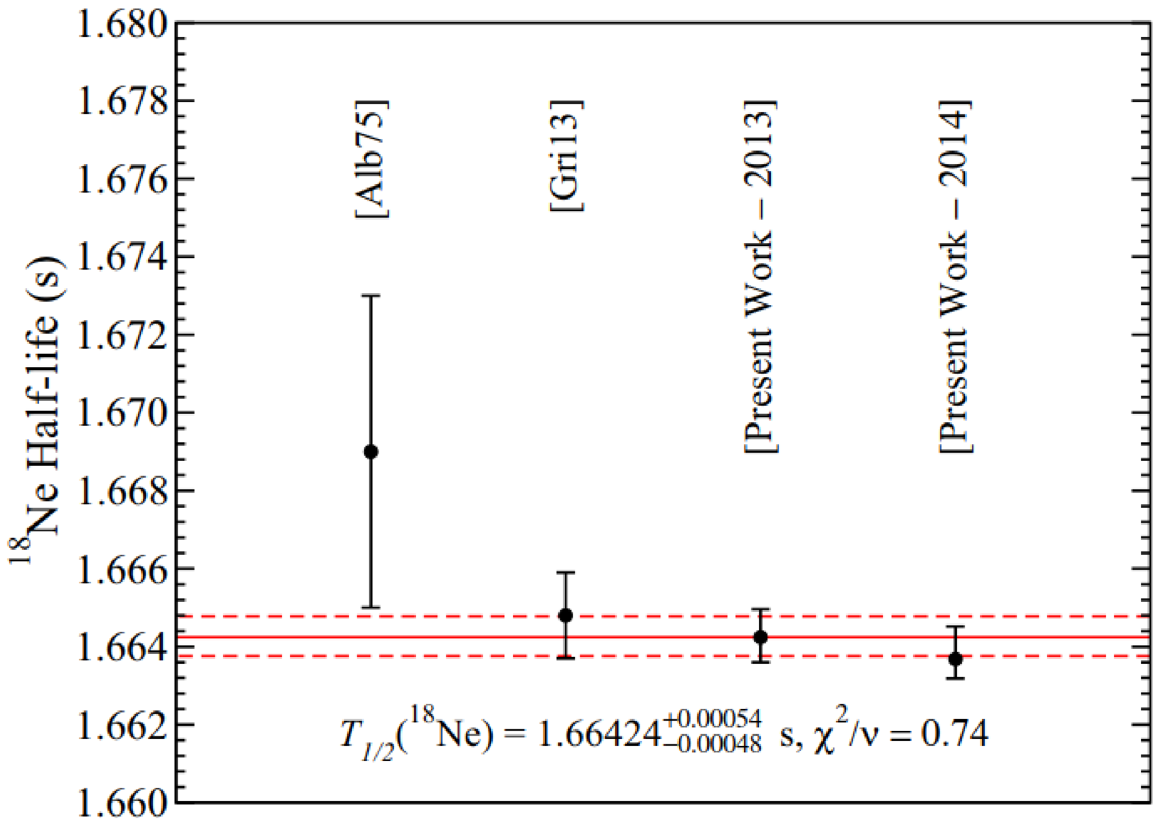
Taken from J. C. Hardy and I. S. Towner, Phys. Rev. C **91**, 025501 (2015)

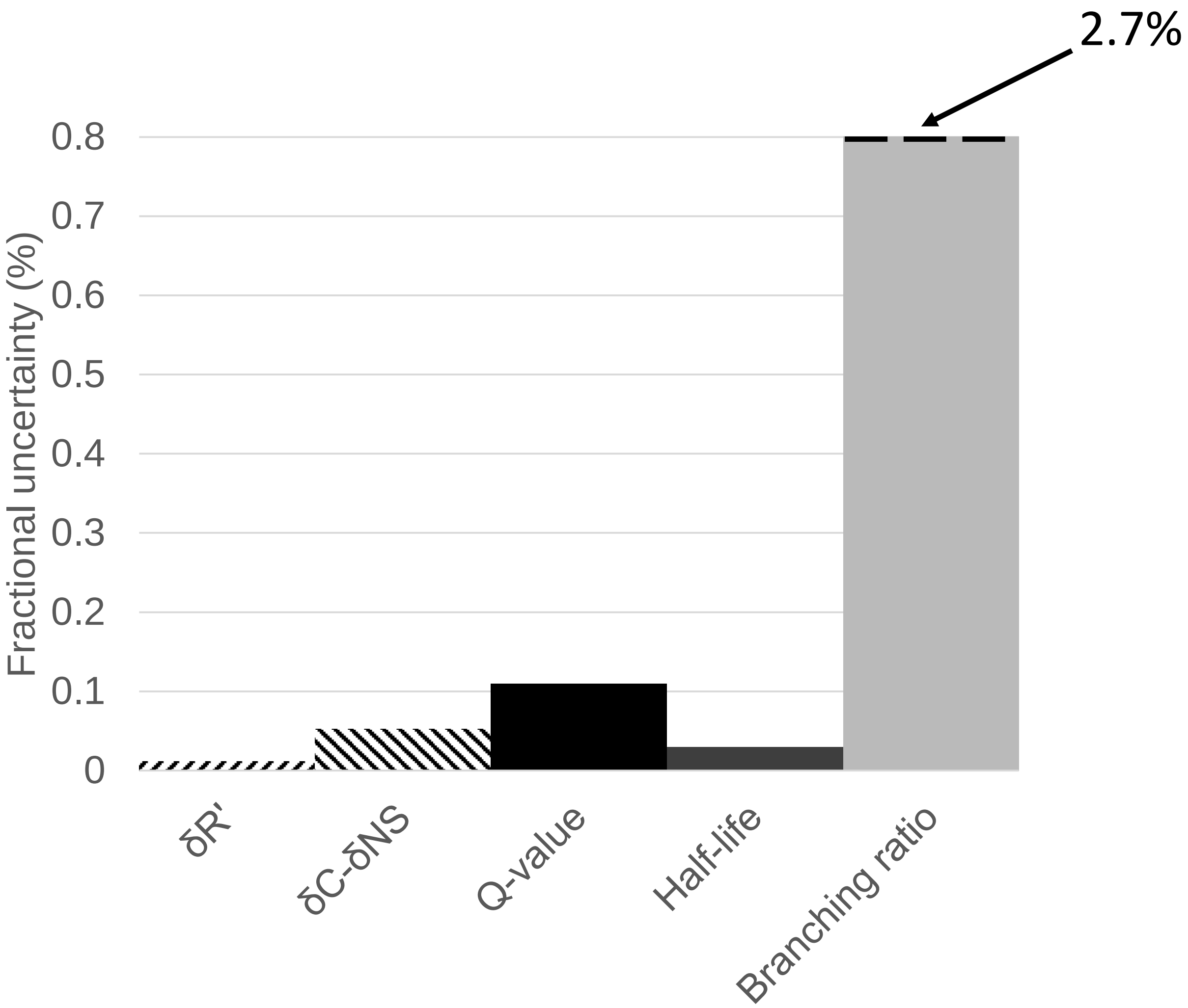
Improvement of $t_{1/2}$

- High-precision half-life measurement performed in two experiments at ISAC/TRIUMF
- Leads to new $t_{1/2}$ world average:

$$t_{1/2}=1.66400^{+0.00054}_{-0.00048}\ \mathrm{s}$$

- Fractional uncertainty reduced from 0.07% to 0.03%

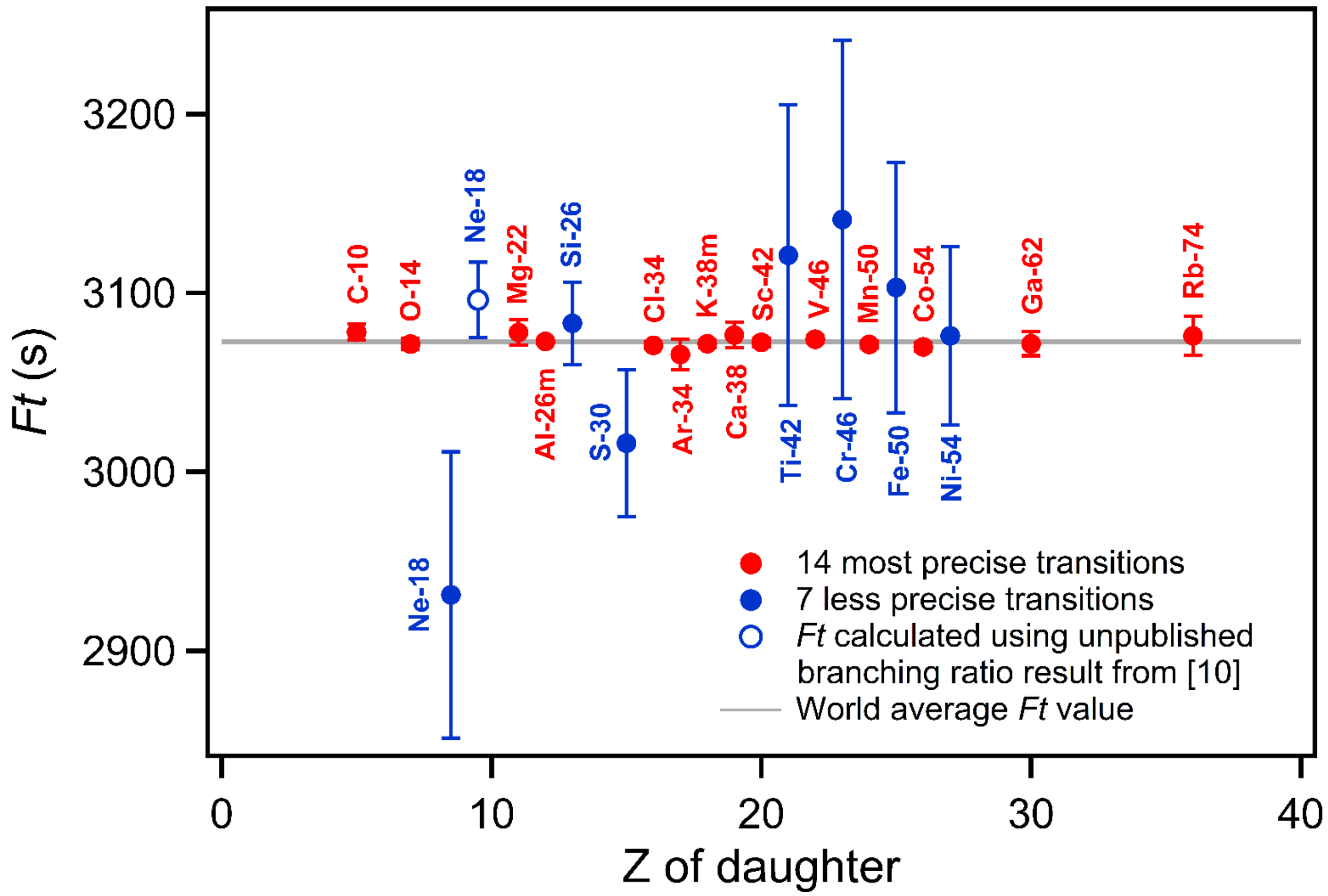


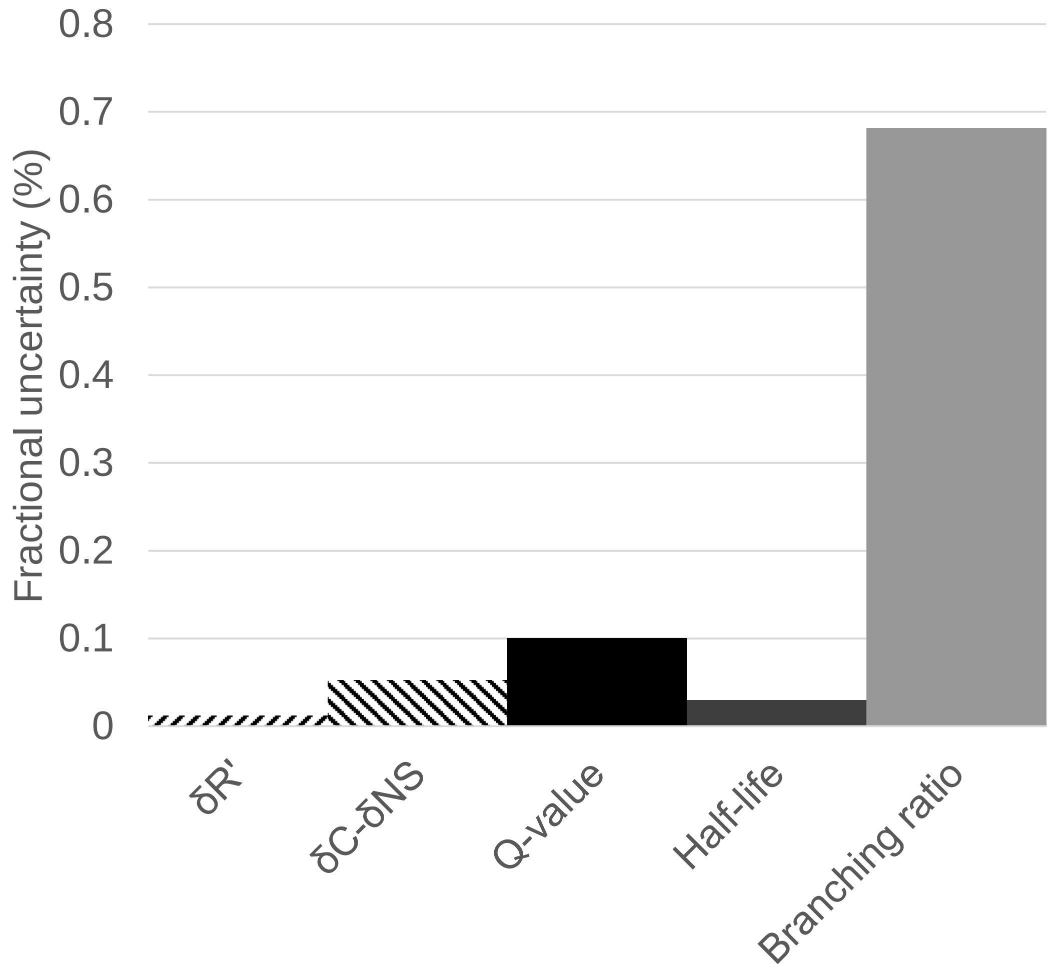


Taken from A. T. Laffoley *et al.*, Phys. Rev. C **92**, 025502 (2015)

Branching ratio measurement

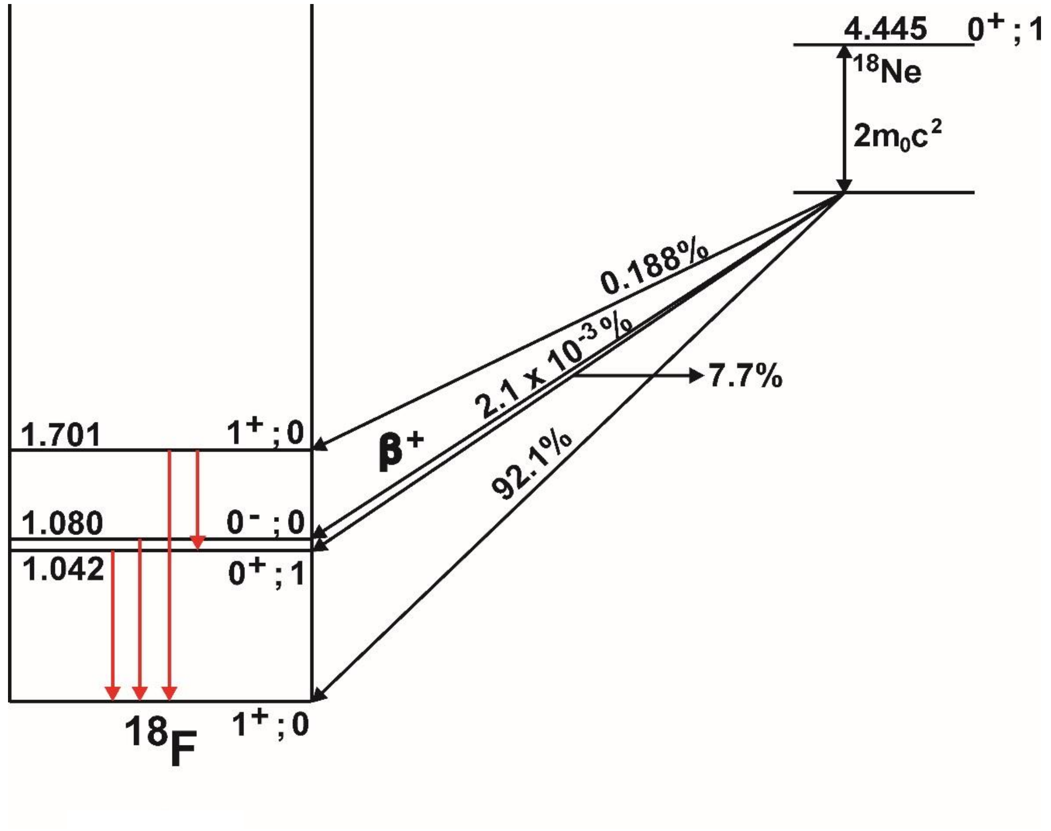
- Dominating the uncertainty of $\mathcal{F}t$ with a 2.7% fractional uncertainty
- Unpublished measurement performed at GANIL claims 0.7% fractional uncertainty
- Improvement of at least a factor 2 in reach





[10] H.Bouzomita-Zran, Ph. D. Thesis, Universite de Caen Normandie (2015)

What about the Q_{EC}-value?



http://www.tunl.duke.edu/nucldata/GroundStatedecays/18Ne.shtml
[1] M. Wang *et al.*, Chinese Phys. C **41**, 030003 (2017)
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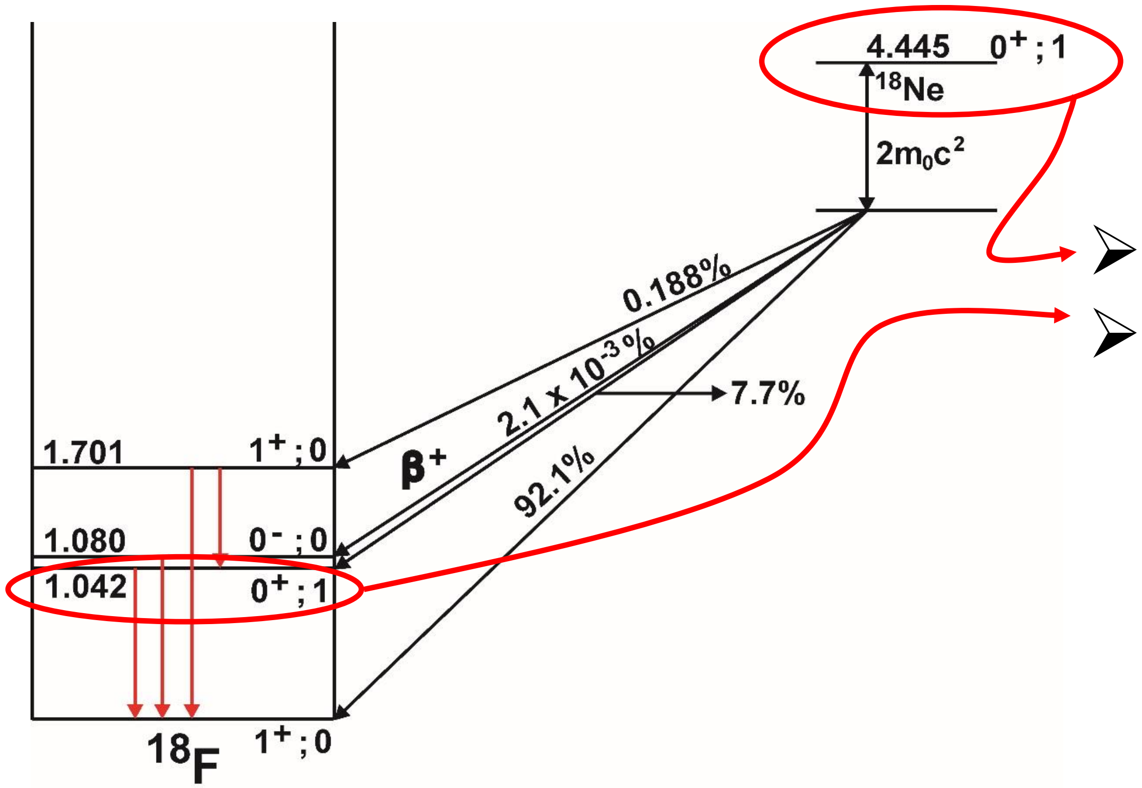
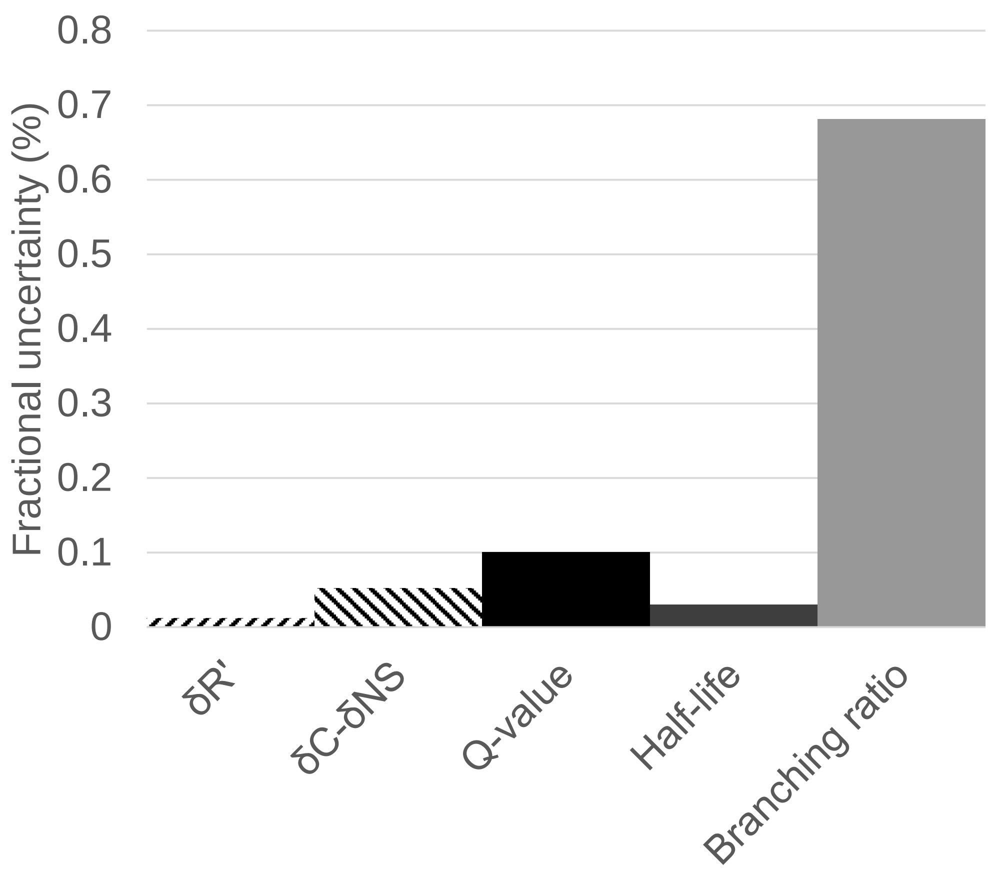


- $Q_{EC}{}^{gs} = (M_p\text{-}M_d)c^2 = 4444.5$ +/- 0.6 keV [1]
- Excitation energy known to 0.08 keV [2]



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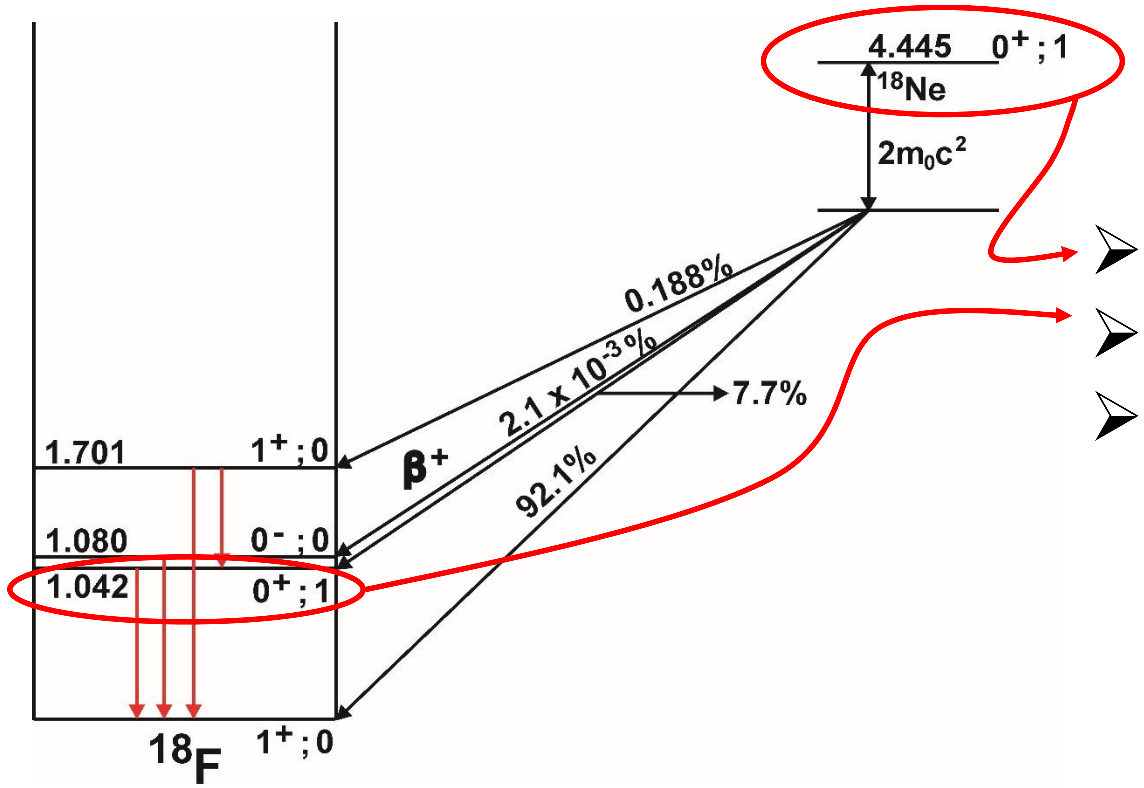

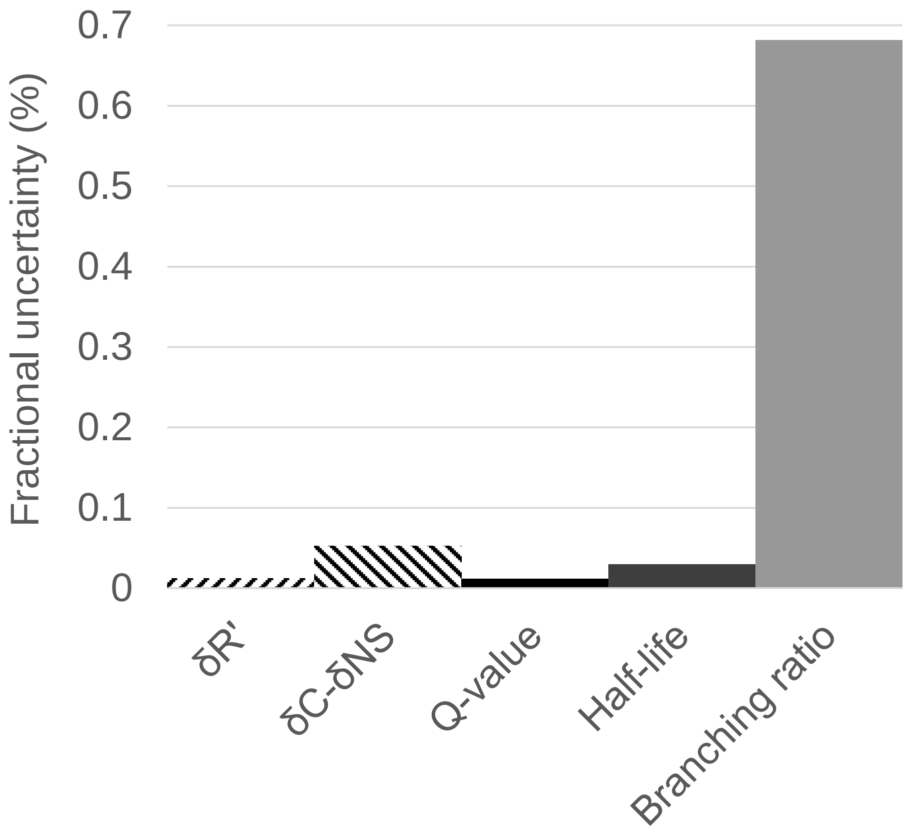

- $Q_{EC}^{\,gs} = (M_p - M_d)c^2 = 4444.5 \pm 0.6$ keV [1]
- Excitation energy known to 0.08 keV [2]
- Measure $Q_{EC}^{\,gs}$ to a precision of about 0.02 keV

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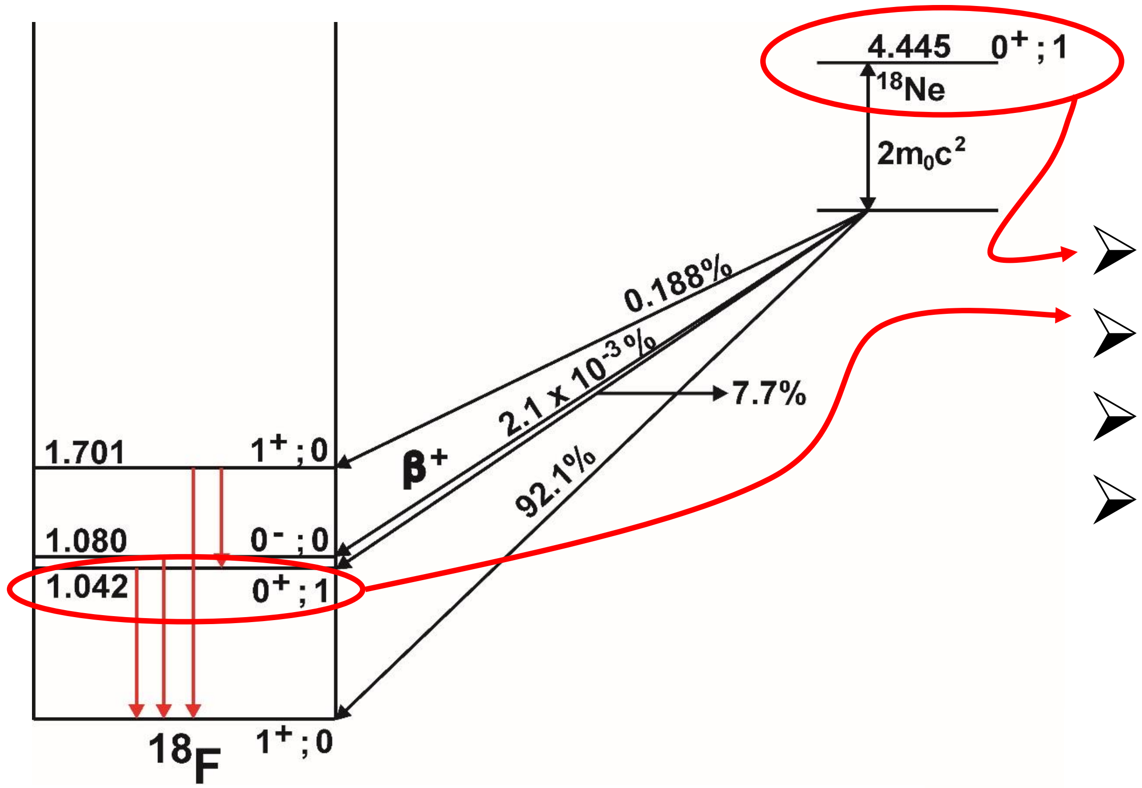

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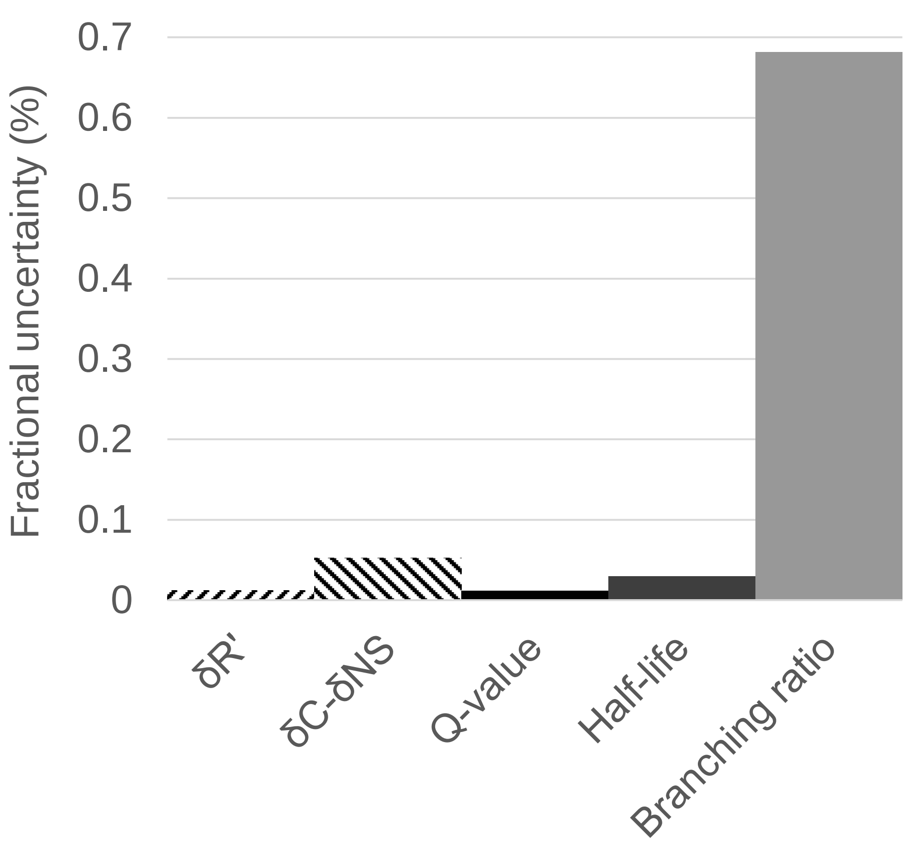
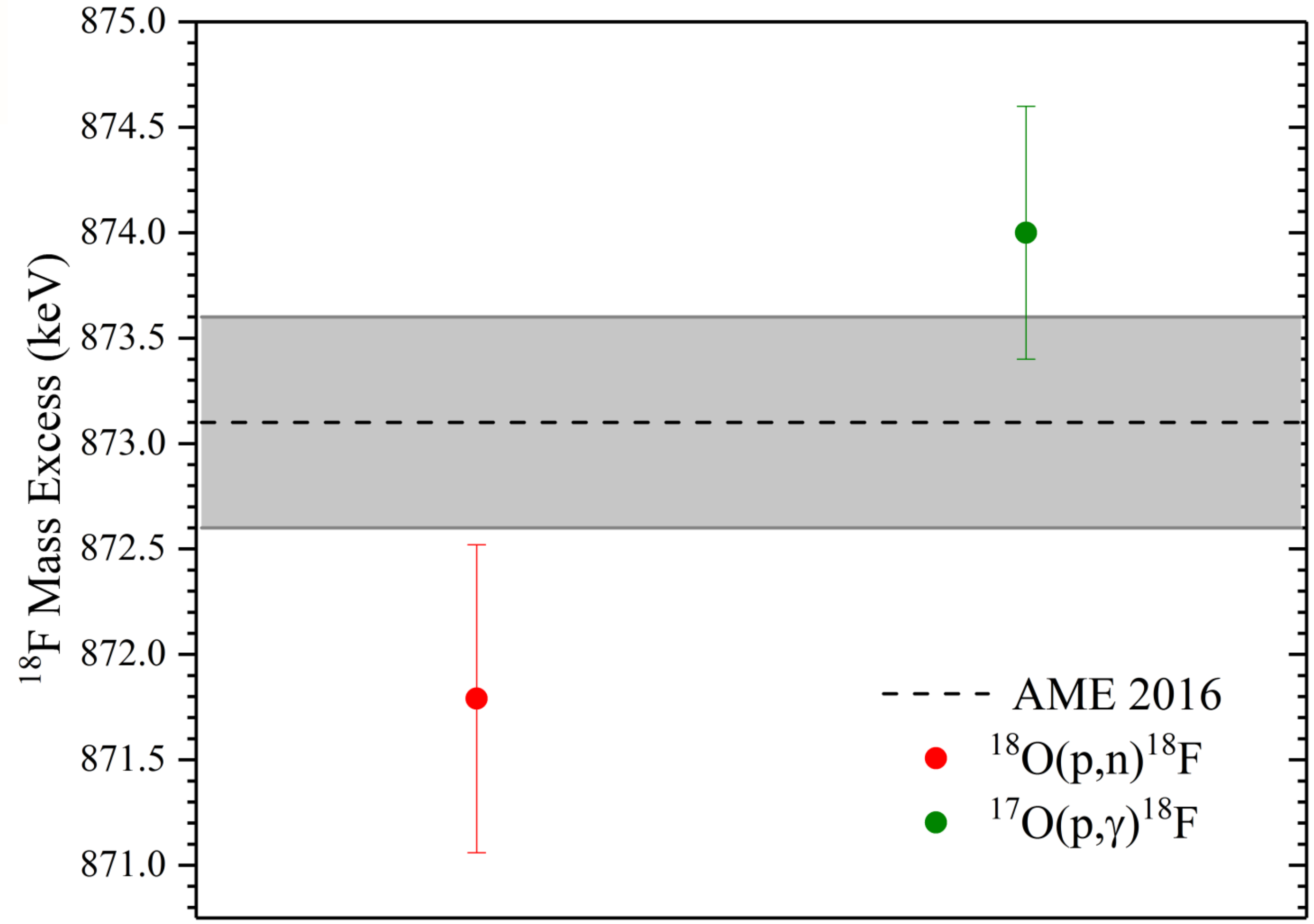
- Excitation energy known to 0.08 keV [2]
- Measure $Q_{EC}{}^{gs}$ to a precision of about 0.02 keV
- Check accuracy of ^{18}F mass





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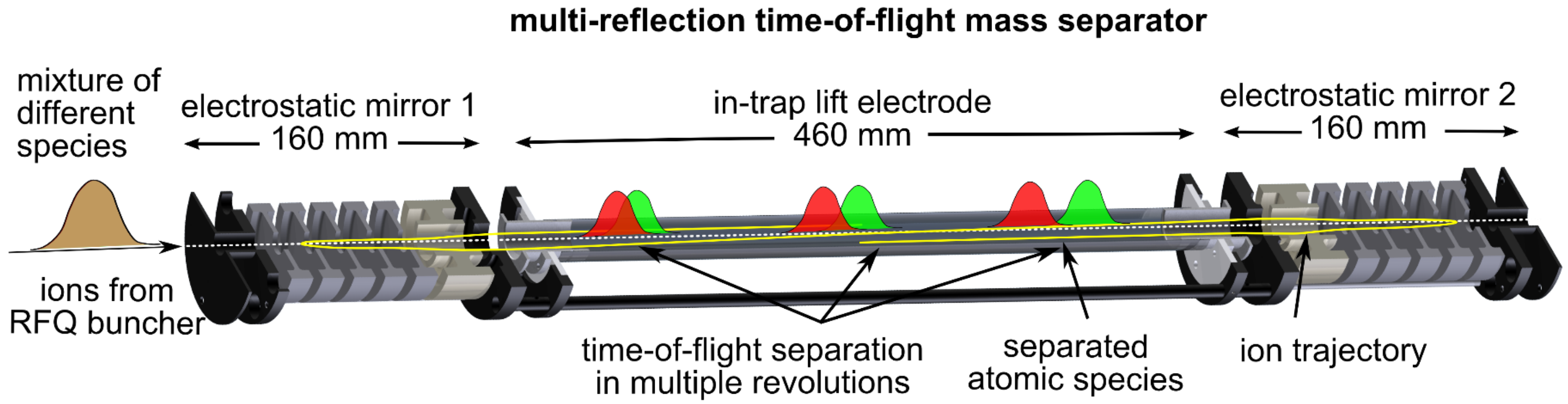
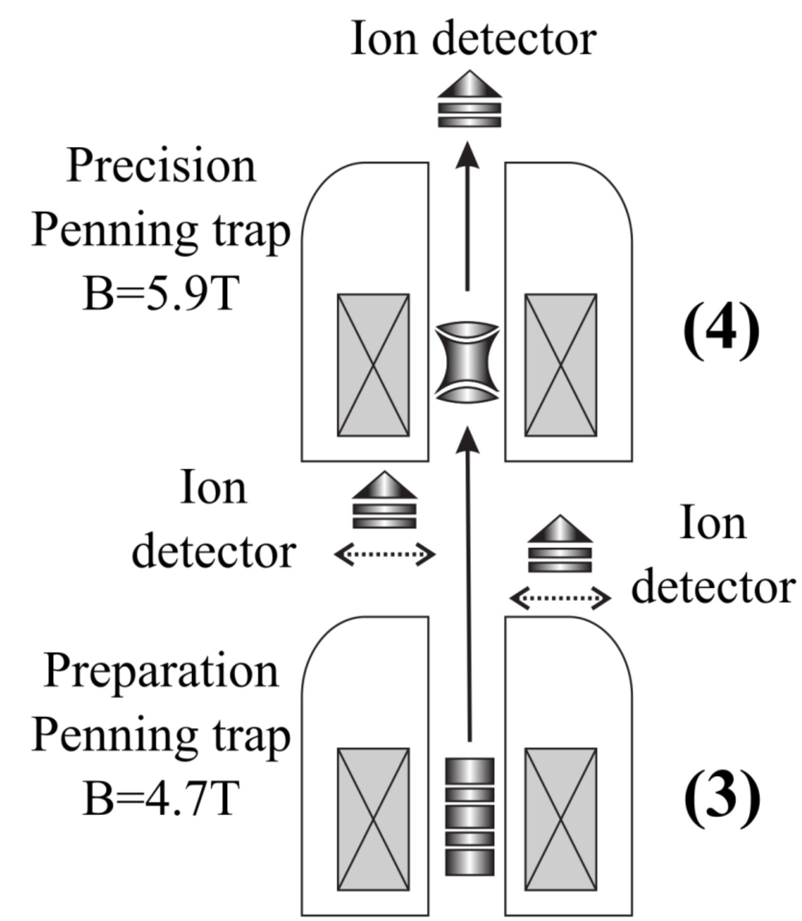
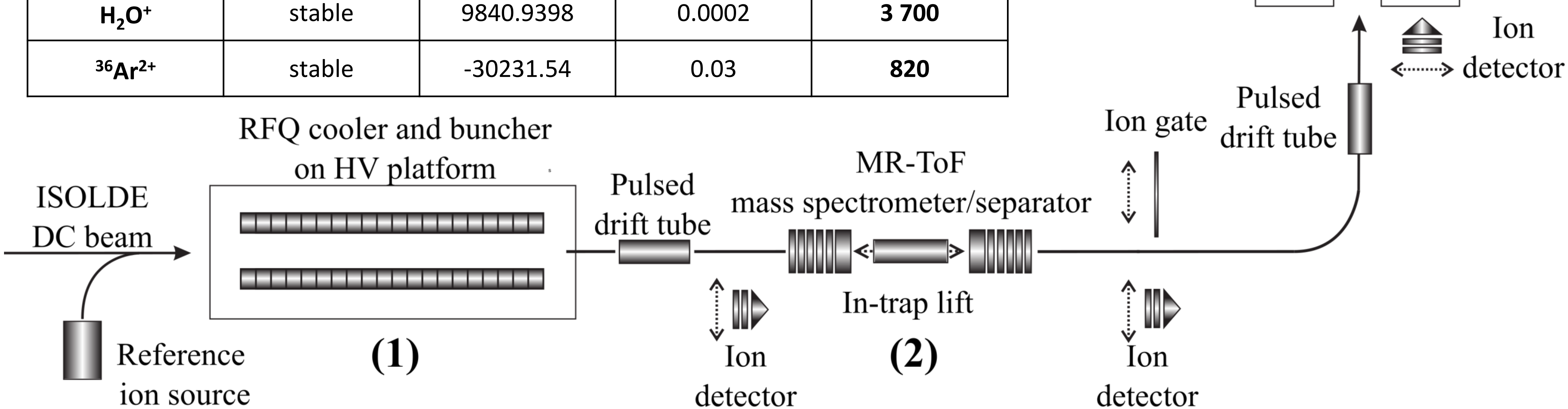
[2] J. C. Hardy and I. S. Towner, Phys. Rev. C **91**, 025501 (2015)

The ISOLTRAP mass spectrometer : The MRToF-MS



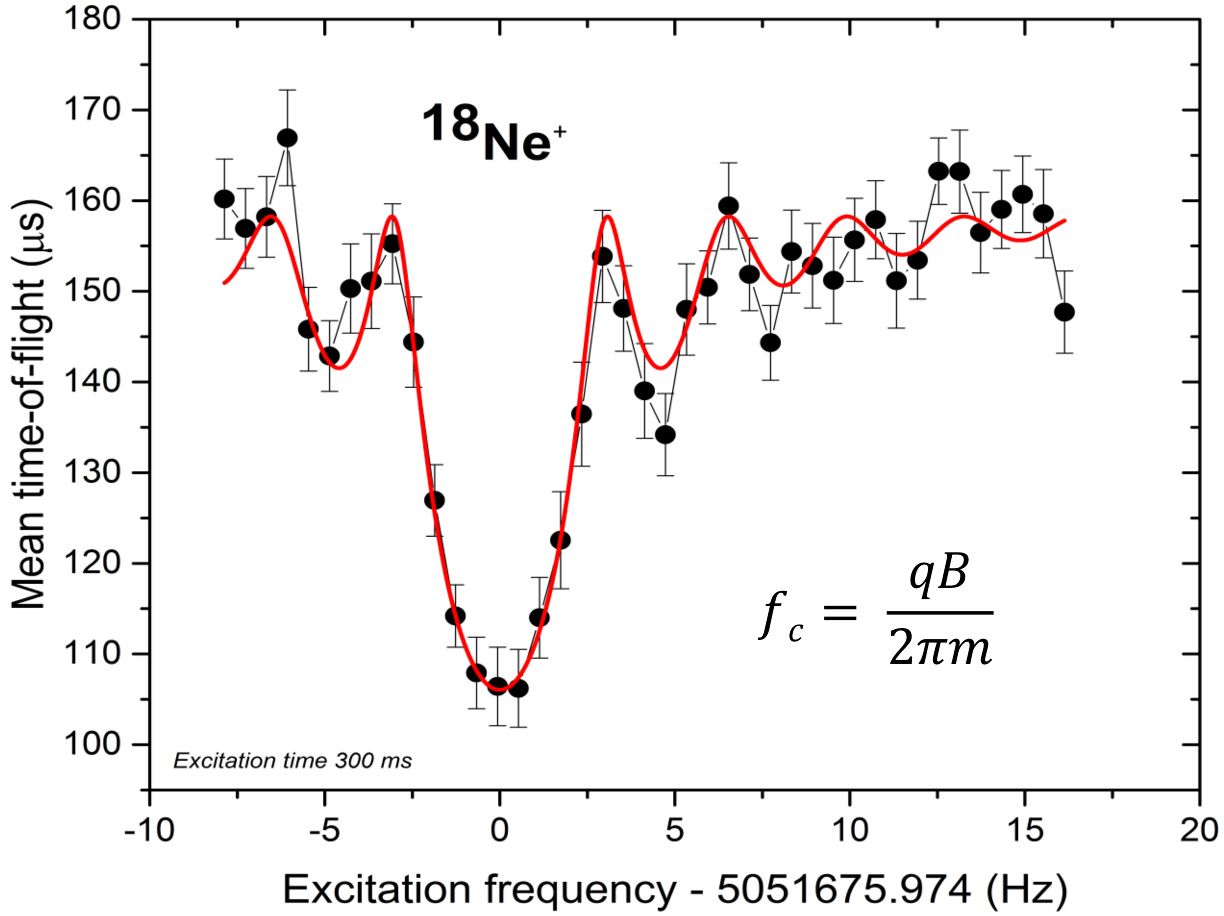
Element	Half-life	Mass Excess [keV]	unc. [keV]	Resolving Power to ^{18}Ne
$^{18}Ne^{+}$	1.6 s	5317.6	0.4	-
$^{18}F^{+}$	109.7 min	873.1	0.5	**3 800**
$^{18}O^{+}$	stable	-782.8156	0.0007	**2 800**
H_2O^{+}	stable	9840.9398	0.0002	**3 700**
$^{36}Ar^{2+}$	stable	-30231.54	0.03	**820**

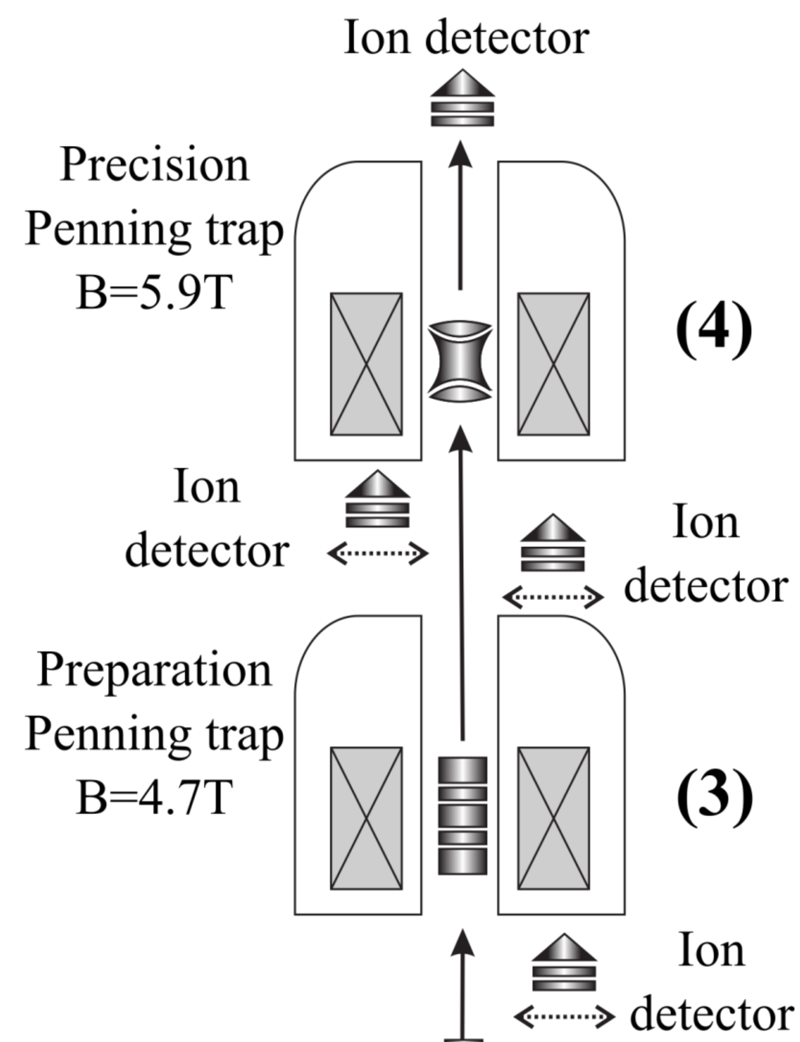




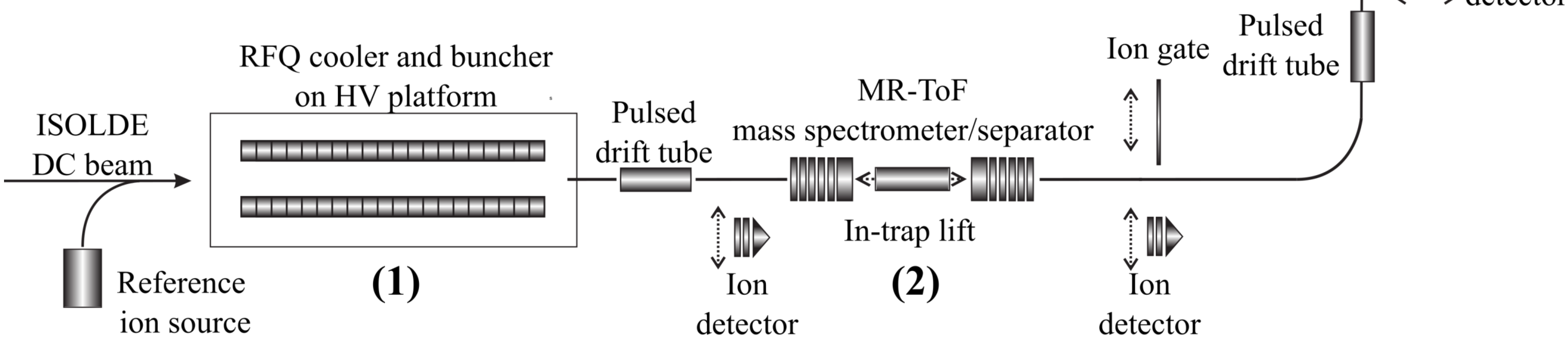
Mukherjee *et al.*, Eur. Phys. J. A 35, 1 (2008)
Wolf *et al.*, IJMS 349-350, 123 (2013); NIM A 686, 82 (2012)

The ISOLTRAP mass spectrometer : Penning trap TOF-ICR





$$Q_{EC} = (M_p - M_d)c^2 = \left(\frac{f_c^d}{f_c^p} - 1\right)(M_d - M_e)c^2 = (R - 1)(M_d - M_e)c^2$$



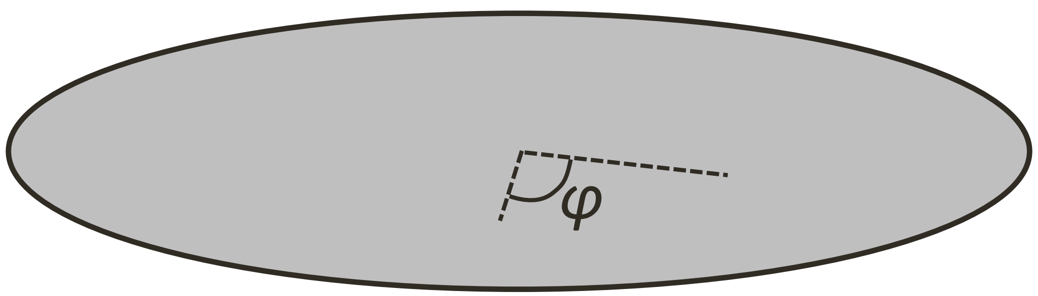
Mukherjee *et al.*, Eur. Phys. J. A **35**, 1 (2008)
K. Blaum *et al.*, Nuc. Phys. A **764**, 305c (2004)
Wolf *et al.*, IJMS 349-350, 123 (2013); NIM A **686**, 82 (2012)

- $\frac{\delta f_c}{f_c} = \frac{1}{f_c T_{rf} \sqrt{N}}$
- 1 measurement of R with N~1000 and $T_{rf} = 600\text{ms}$
  →reach Q_{EC}-value precision of 250eV
- Ramsey TOF-ICR is 3 times more precise
  → need 20 measurements of R
- At least 6 shifts are required to perform the measurement

Isotope	Half-life	Target	Yield (ions/µC)	Method	Ion source	Shifts
^{18}Ne	1.6 s	SiC	2.10^5	Penning Trap	VD5	**6**
^{18}F	109.7 min	SiC	10^6	Penning Trap		
					Transport optimization/Charge exchange studies	**1**
					Study of the systematics	**1**
					Total shifts	**8**

R.F Garcia Ruiz *et al.*, CERN-INTC-2016-037 / INTC-I-171 (2016)

Position-sensitive detector

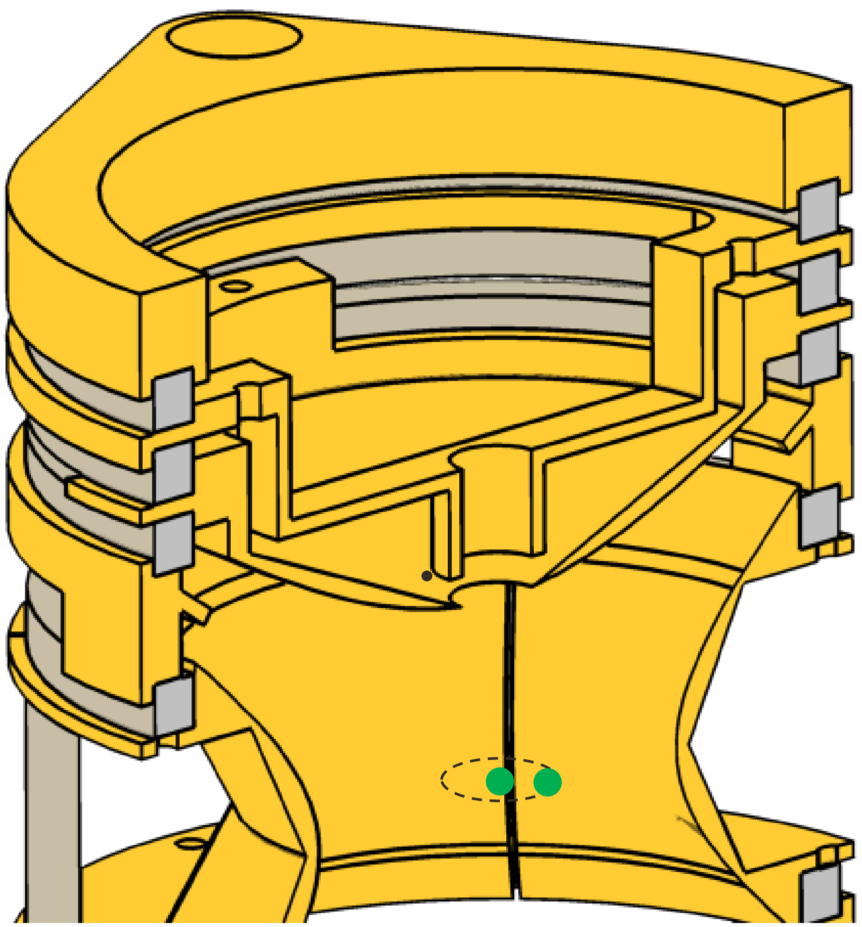


✓ No excitation (center position)

✓ On radial motion, wait for time *t*

✓ On radial motion, wait for time *t* + *Δt*

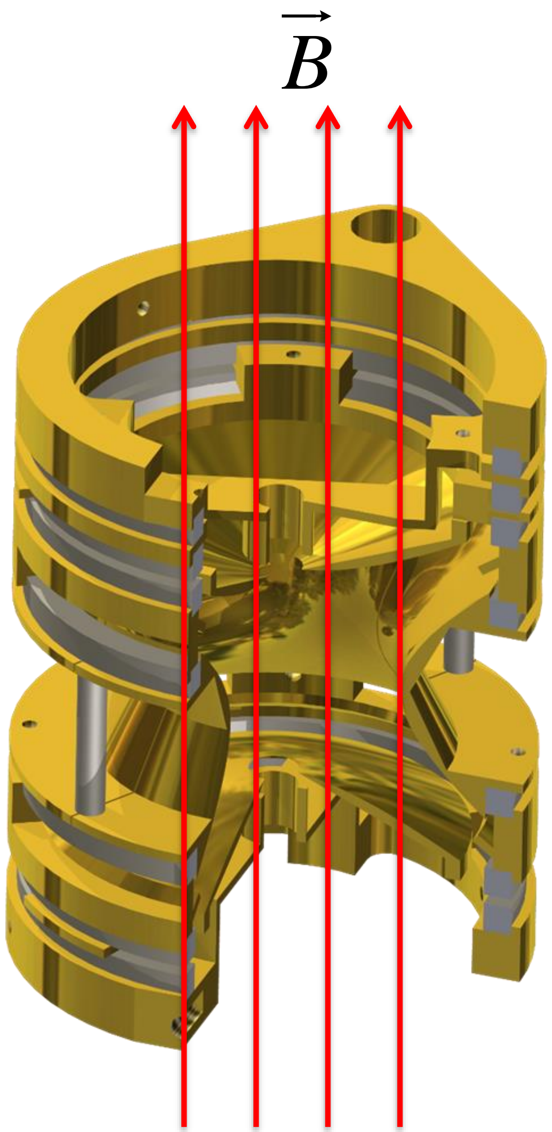
$$\omega = \frac{2\pi n + \varphi}{\Delta t}$$



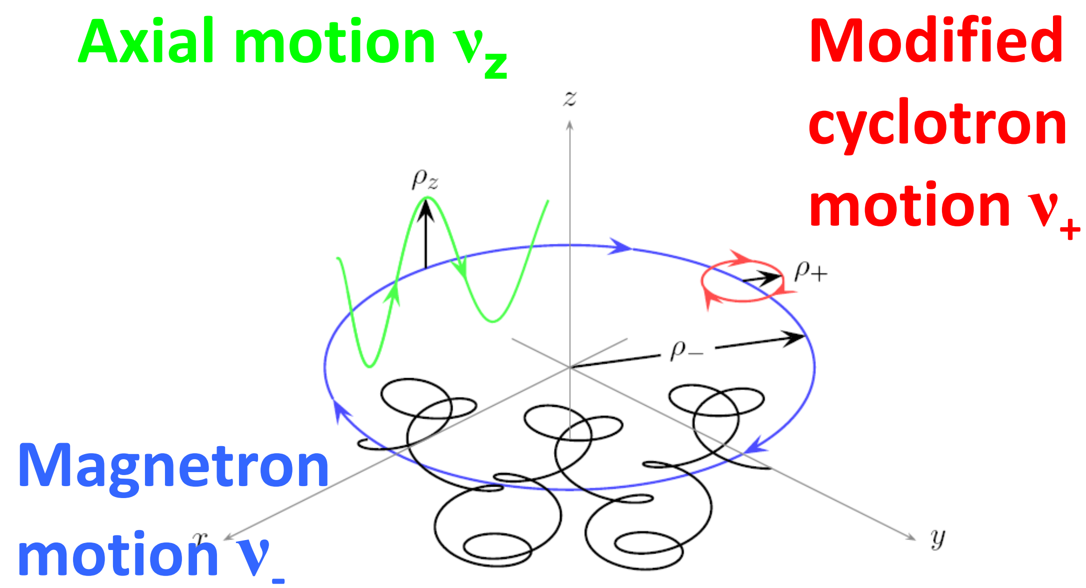
✓ Has higher resolving power and precision than TOF-ICR (depending on spot size and position)

✓ Requires some prior knowledge of the frequency
✓ Requires timing stability on ~100 ps level

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

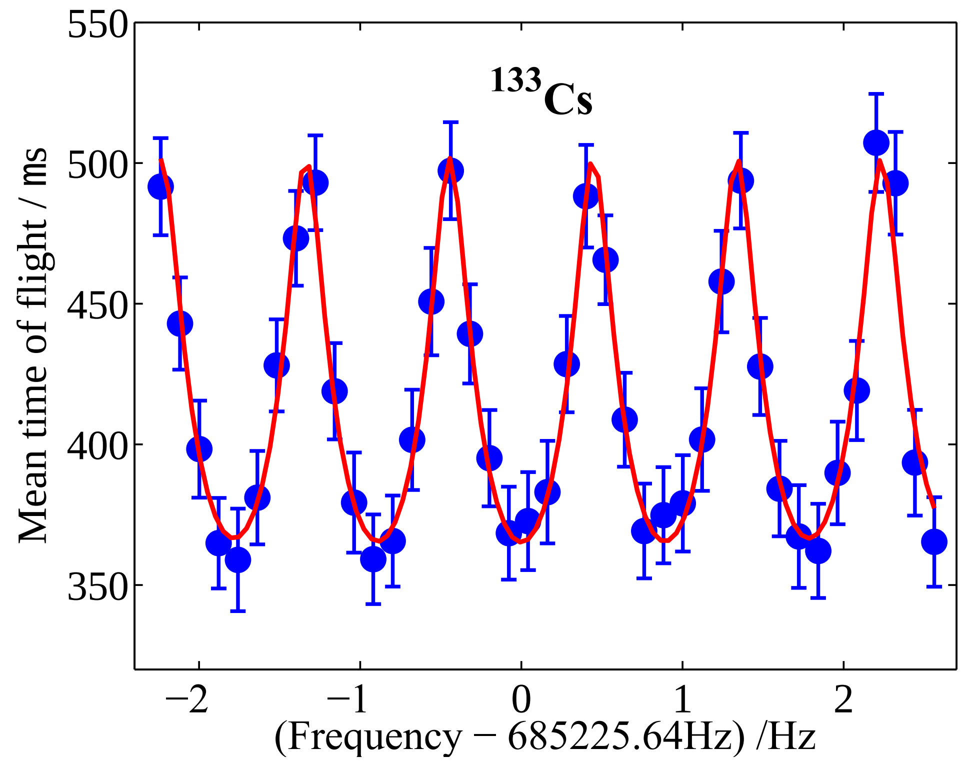


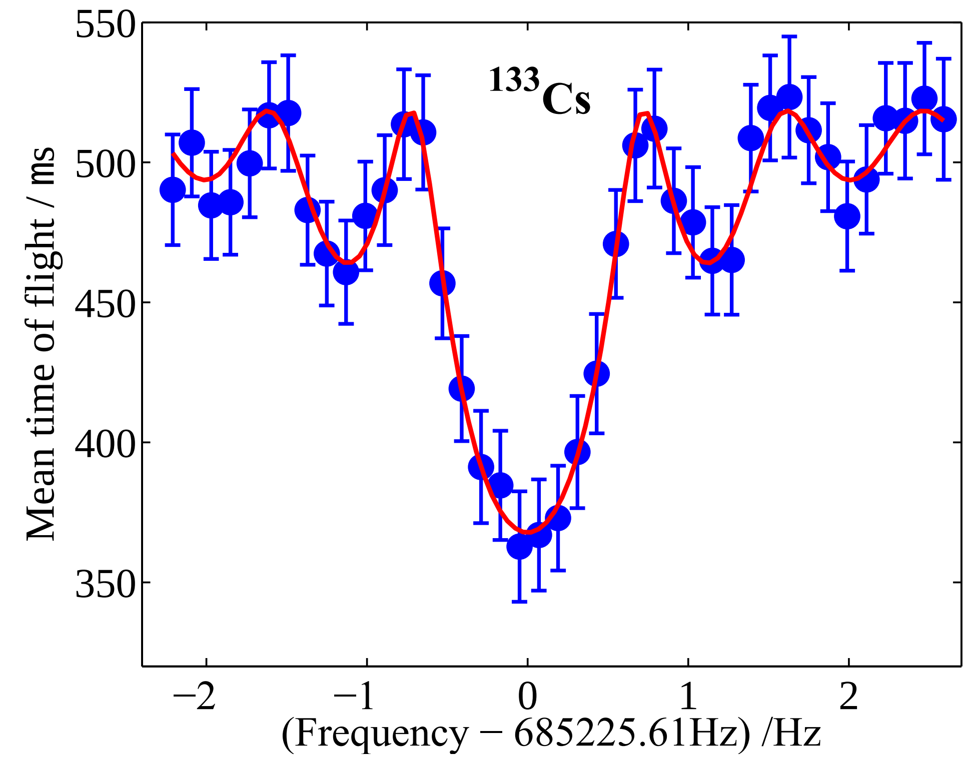
$$\omega_c = \frac{qB}{m_{ion}}$$



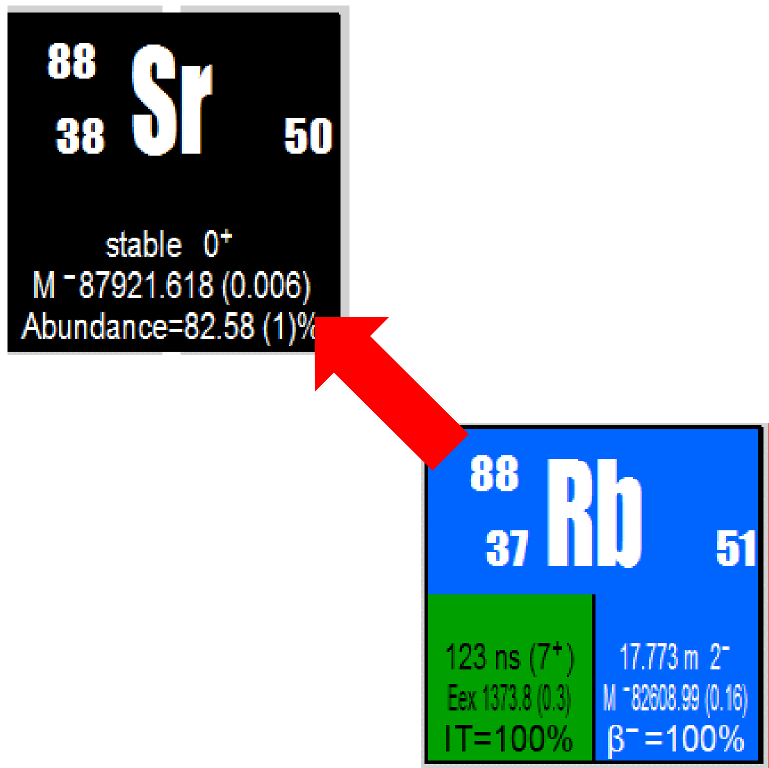
Using the TOF-ICR technique:

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

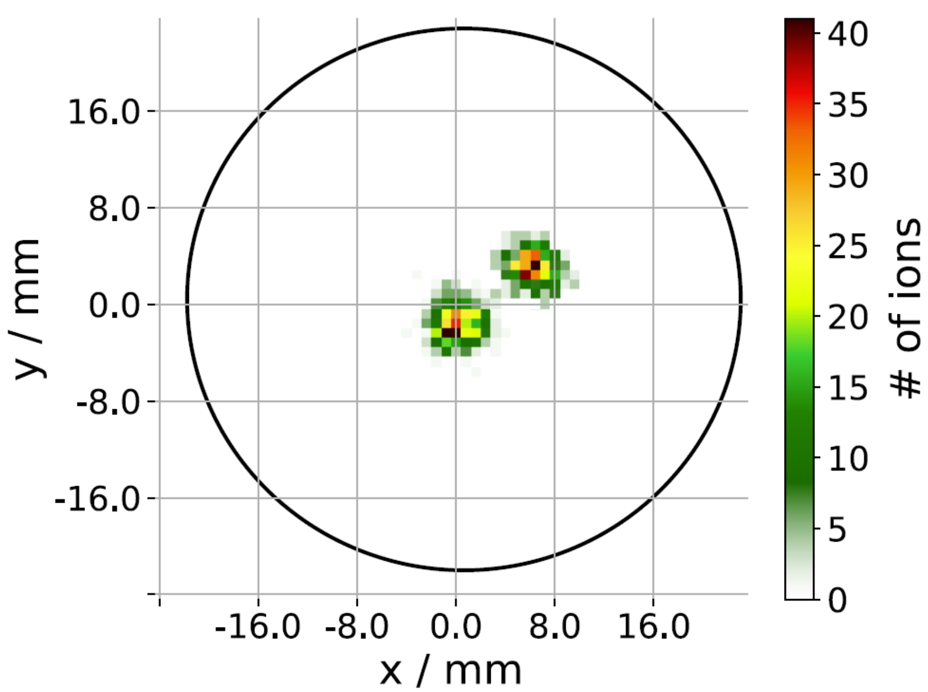




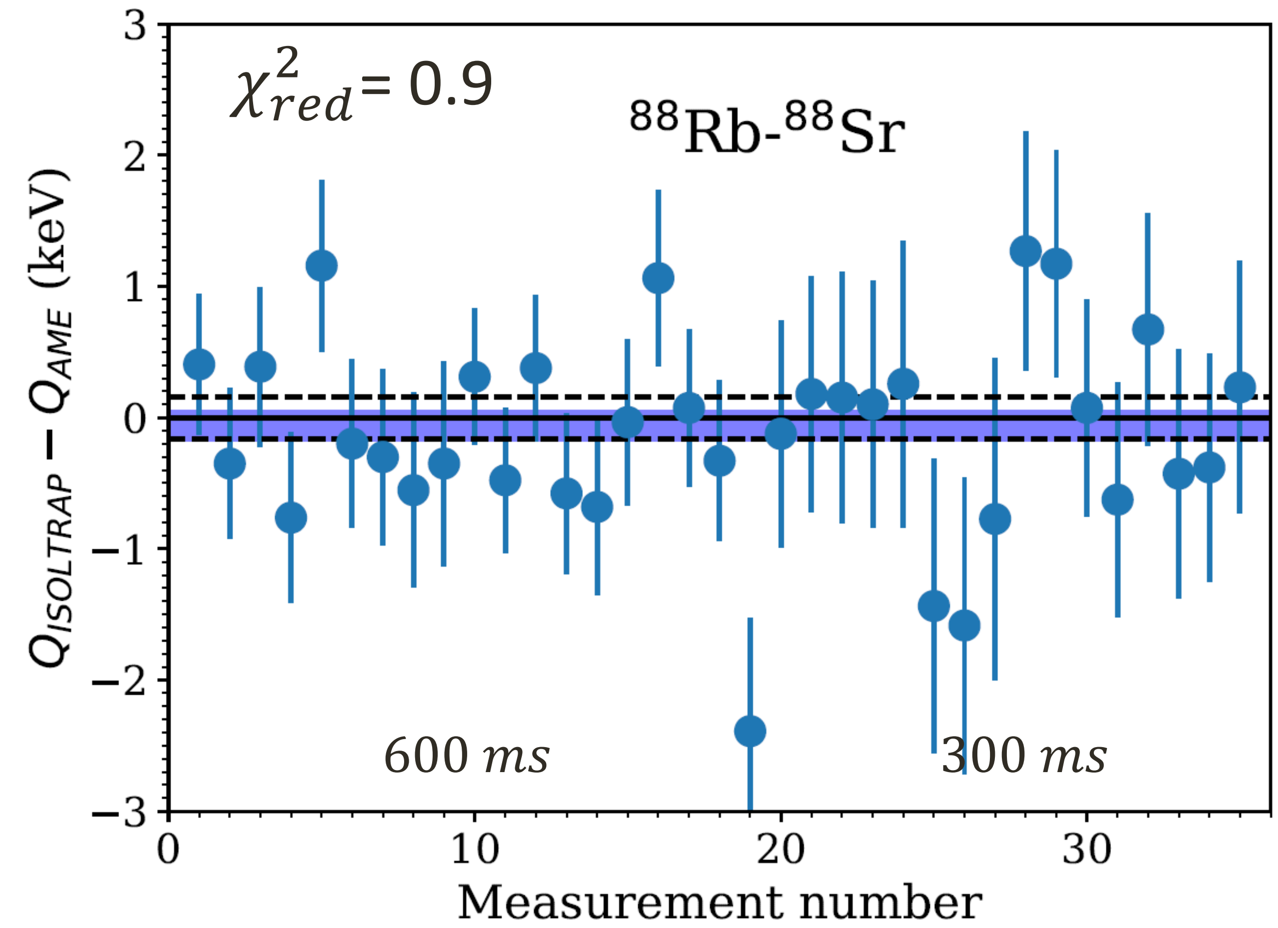
Brown & Gabrielse, Rev. Mod. Phys. 58, 233 (1986)
Gräff *et al.*, Z. Physik A -- Atoms and Nuclei 297, 35 (1980)
S. George et al., Phys. Rev. Lett. 98, 162501 (2007)



Event position on MCP-PS



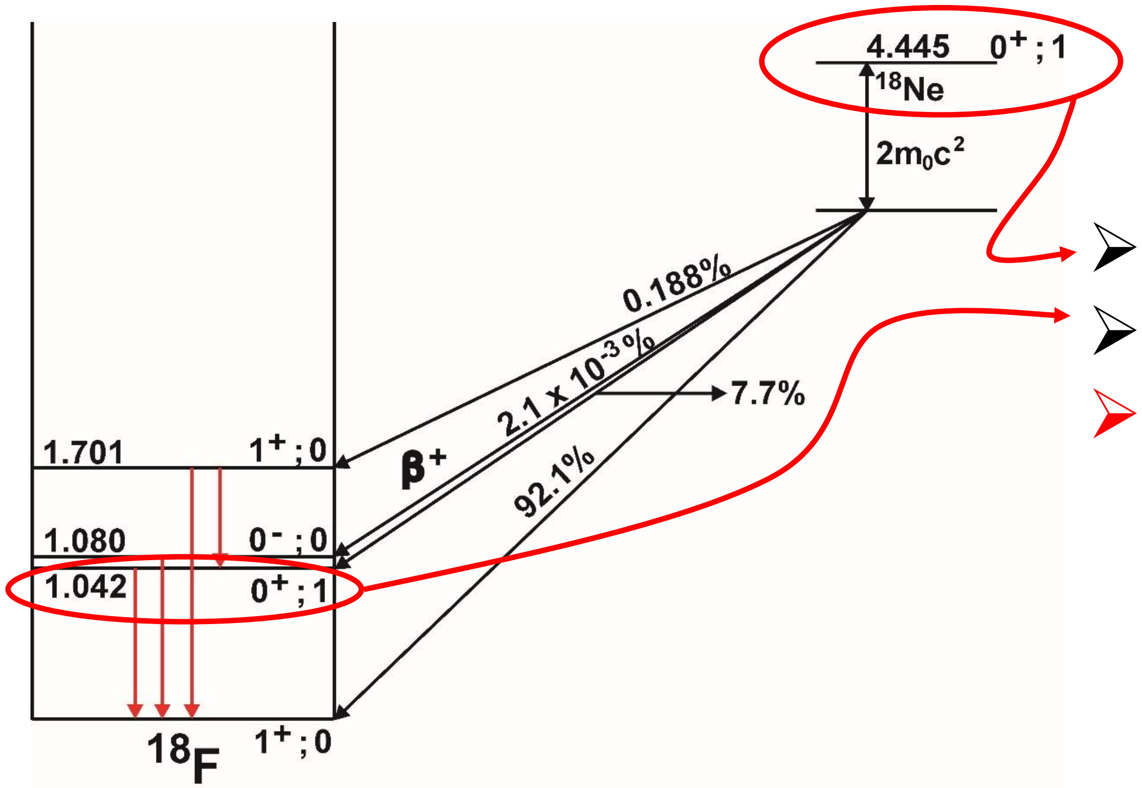
≈ 120 eV precision



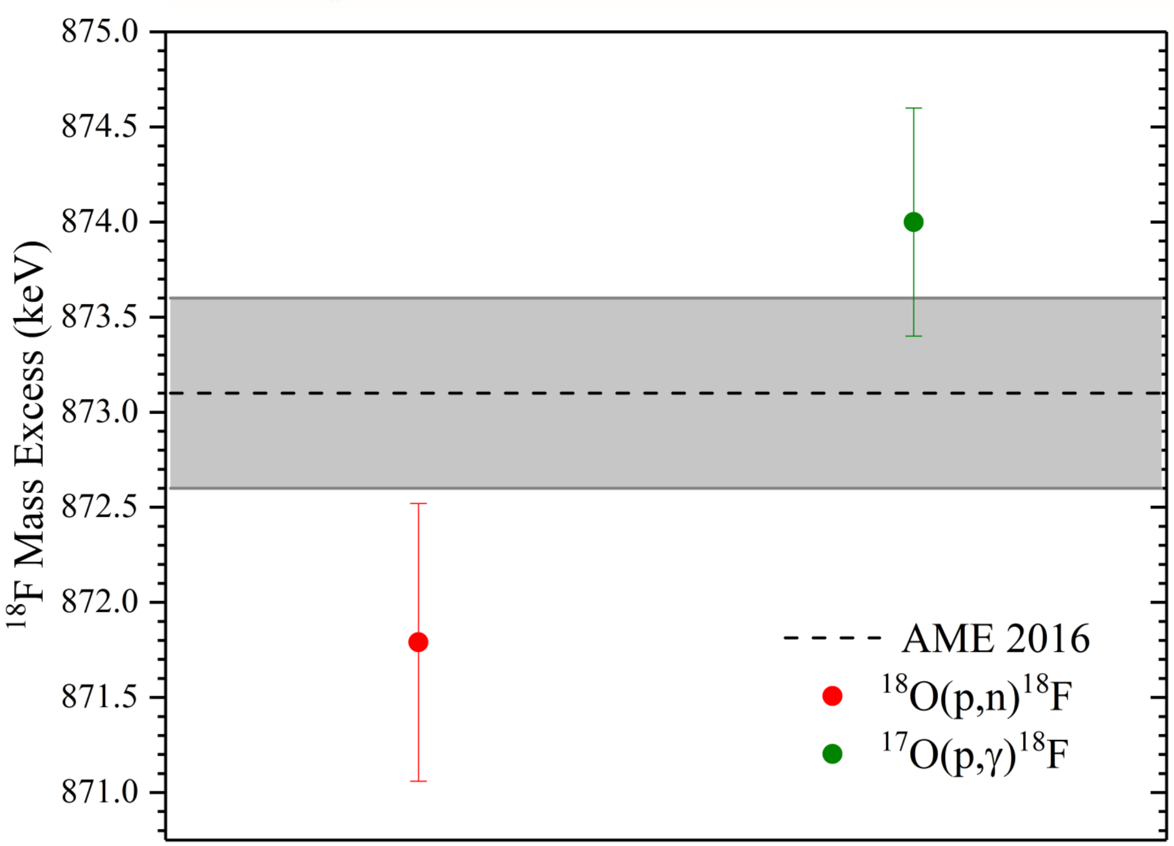
- Extensive program of tests is ongoing, in order to understand the systematic errors.
- First on-line application to a Q-value measurement shows that the systematic error is under control.

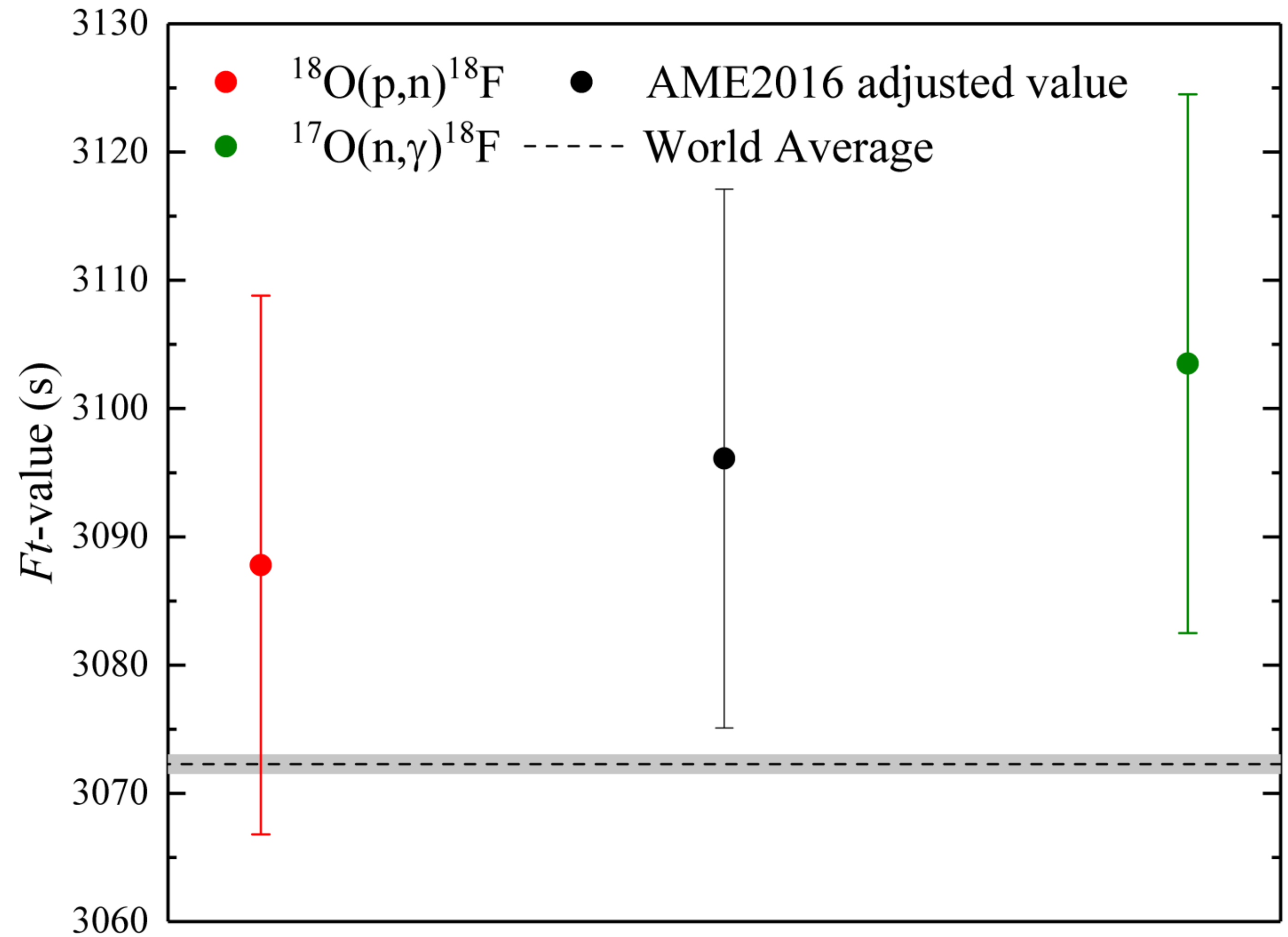
Master project of J. Karthein.

Influence of the ^{18}F mass excess :



- $Q_{EC}^{gs} = (M_p\text{-}M_d)c^2 = 4444.5 +/- 0.6$ keV [1]
- Excitation energy known to 0.08 keV [2]
- Check accuracy of ^{18}F mass(considering results from [3] and [4])





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[2] J. C. Hardy and I. S. Towner, Phys. Rev. C **91**, 025501 (2015)
[3] A. T. Laffoley *et al.*, Phys. Rev. C **92**, 025502 (2015)
[4] H.Bouzomita-Zran, Ph. D. Thesis, Universite de Caen Normandie (2015)

Measurement procedure using $^{27}Al^{18}F$

- If it is not possible to measure atomic ^{18}F

  → Measure $^{27}Al^{18}F$ instead
- Reported yields are 2e-7 ions/μc
- Mass dependent shift and 50eV uncertainty on ^{27}Al mass excess

  → Ground-state Q_{EC}-value determined to ∝ 200eV

  → factor 3.5 improvement over AME2016 value
- Would bring Q_{EC}-value contribution to the same level as the half-life
- Still be able to check the accuracy of the ^{18}F mass excess
- Doesn't affect the amount of shifts required

  →Evaluate mass dependent shift needs at least 3 species

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