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Standard Model Tests – Accurate Mass Measurements, Experimental Aspects

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Experimental Access to Ft value

$$Ft = Ft\,(Q^5, T_{1/2}, b, P_{EC}, \delta_R, \delta_C)$$

- Q – Decay energy ⇔ mass *m*
- $T_{1/2}$ – Half-life
- b – Branching ratio
- P_{EC} – Electron capture fraction
- δ_R – Radiative correction
- δ_C – Isospin symmetry breaking correction

Weak Interaction
symmetry tests, CVC hypothesis

$\delta m/m < 3 \cdot 10^{-8}$

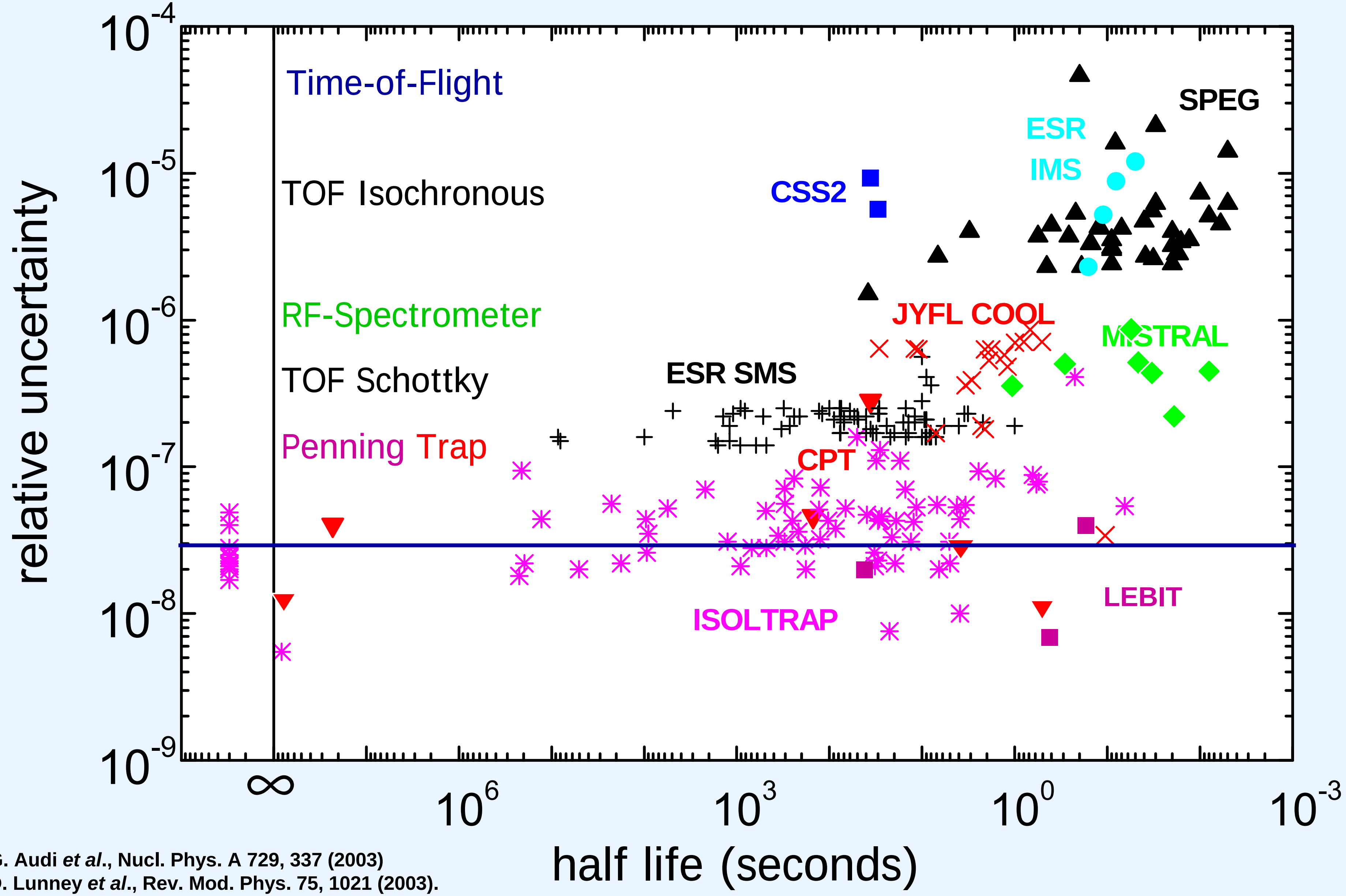
Unitarity of the CKM matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$V_{ud}^2 = \frac{G_V^2}{G_\mu^2}$$

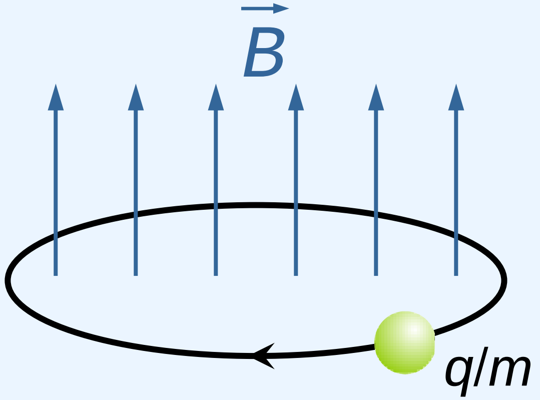
- Mean *Ft* value of all decay pairs contributes to V_{ud} via G_V
- Can check unitarity via sum of squares of elements of the first row

Performance of the Various Methods



G. Audi *et al*., Nucl. Phys. A 729, 337 (2003)
D. Lunney *et al*., Rev. Mod. Phys. 75, 1021 (2003).

Principle of Penning Traps

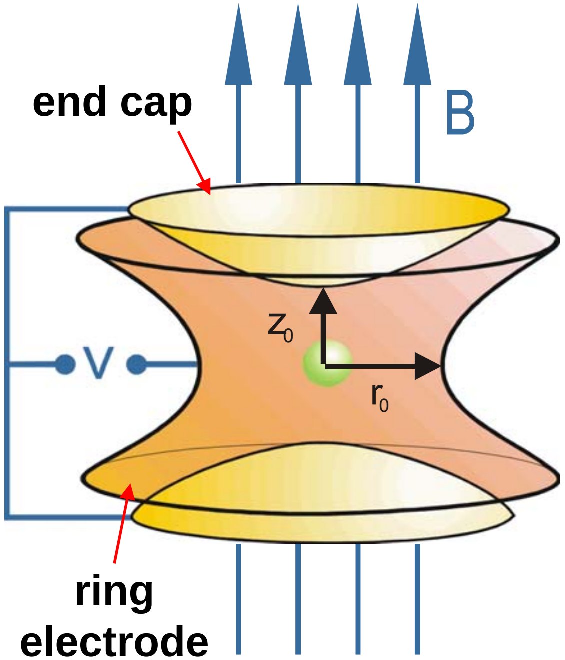


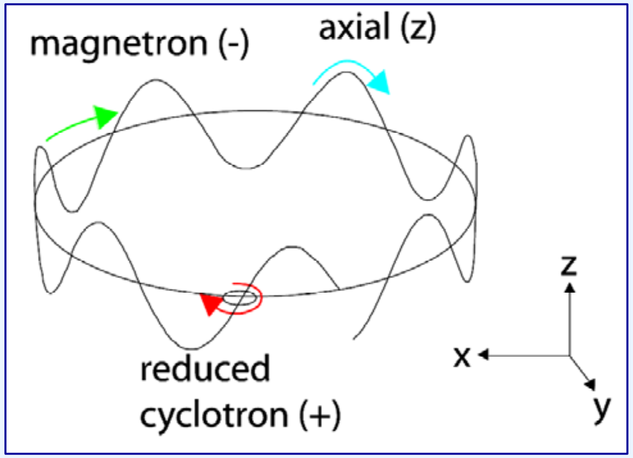
Cyclotron frequency:

$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

PENNING trap

- Strong homogeneous magnetic field
- Weak electric 3D quadrupole field



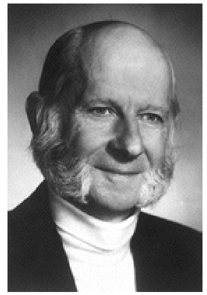


Typical frequencies
q = e, m = 100 u,
B = 6 T

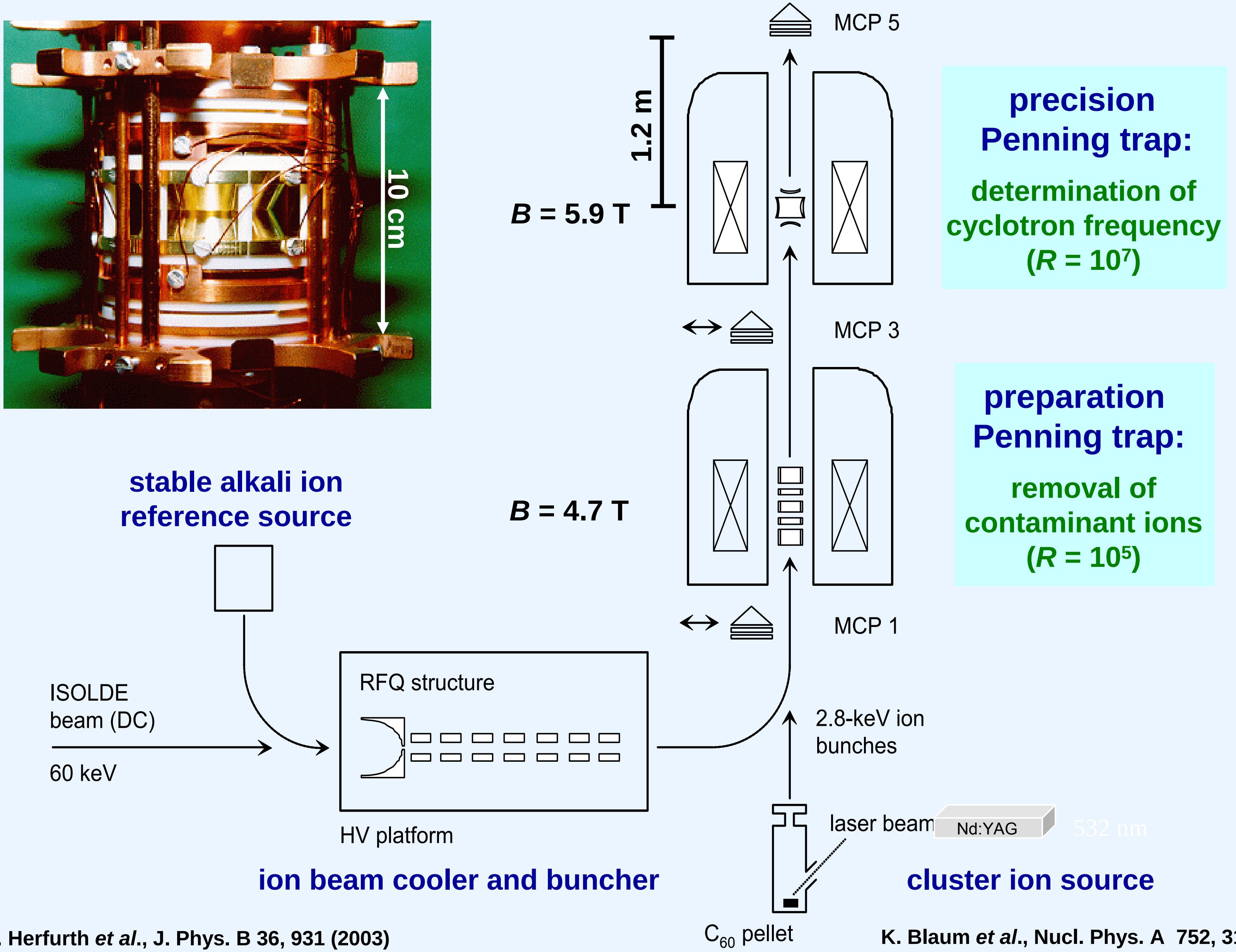
$\Rightarrow$ $f_- \approx$ 1 kHz
$f_+ \approx$ 1 MHz

Frans Michel Penning

Hans G. Dehmelt



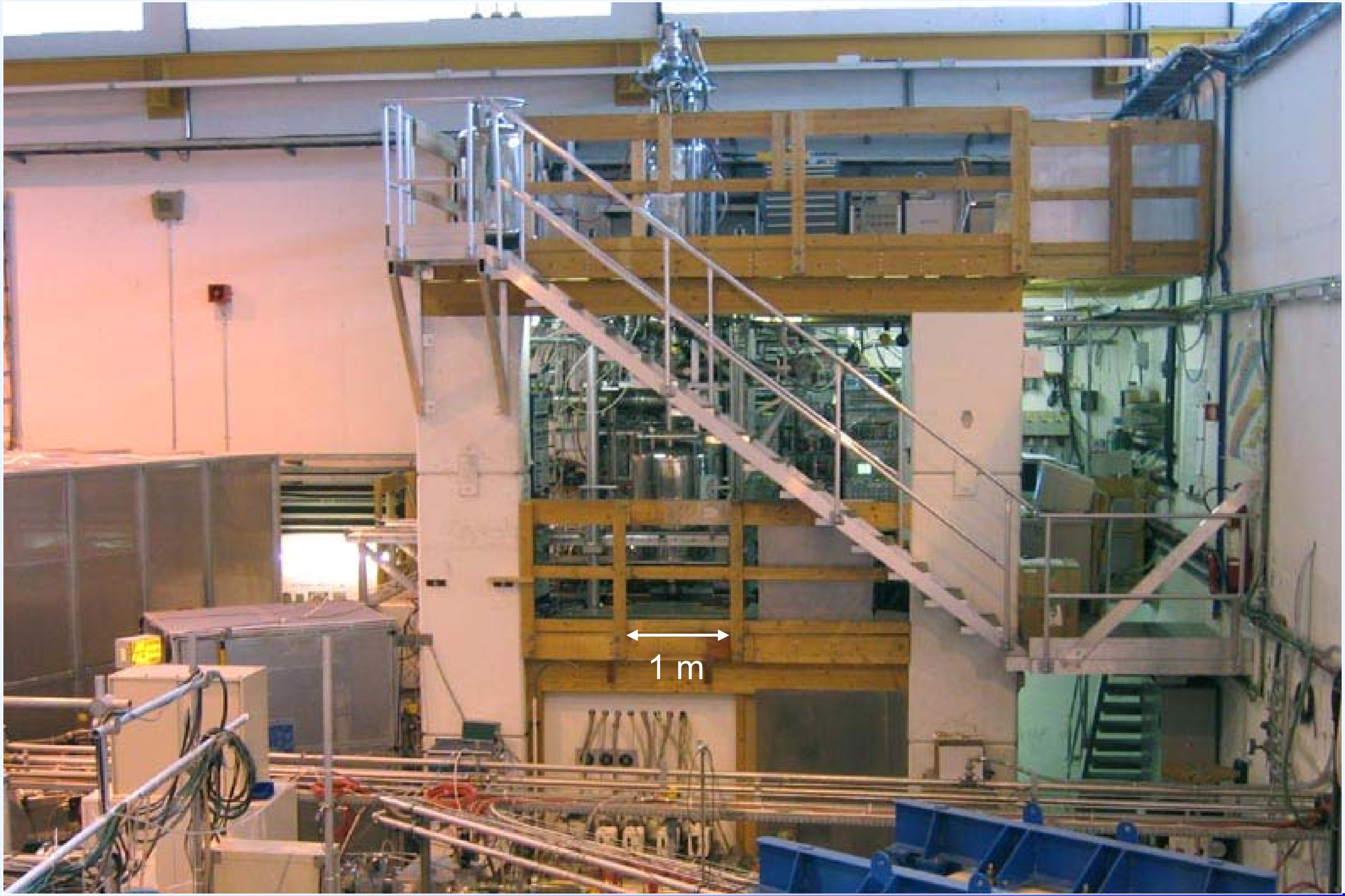
Prototype: Triple-Trap Mass Spectrometer ISOLTRAP



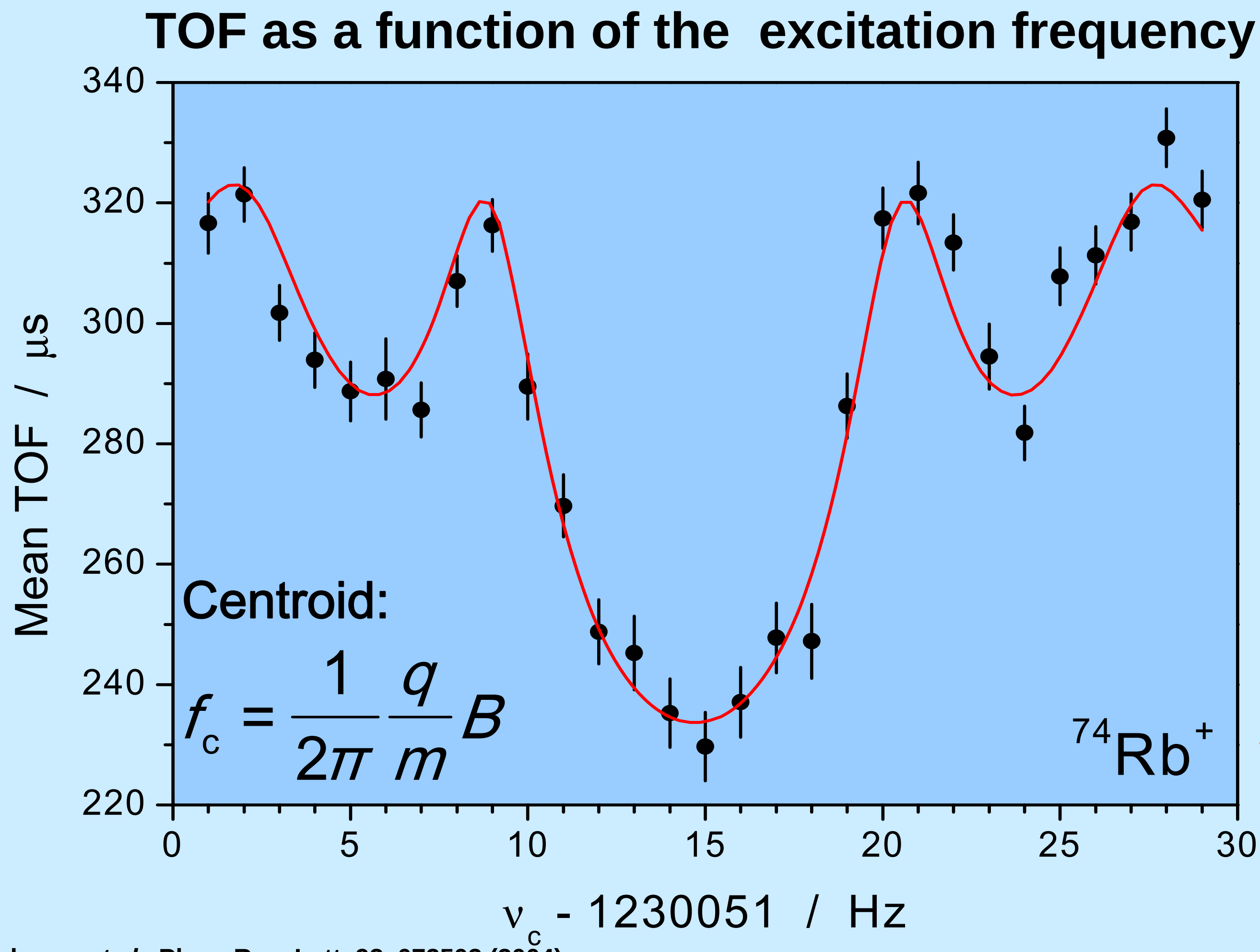
F. Herfurth *et al.*, J. Phys. B 36, 931 (2003)

K. Blaum *et al.*, Nucl. Phys. A 752, 317c (2005)

The ISOLTRAP Setup



TOF Cyclotron Resonance Curve



$T_{1/2}$ **= 65 ms**

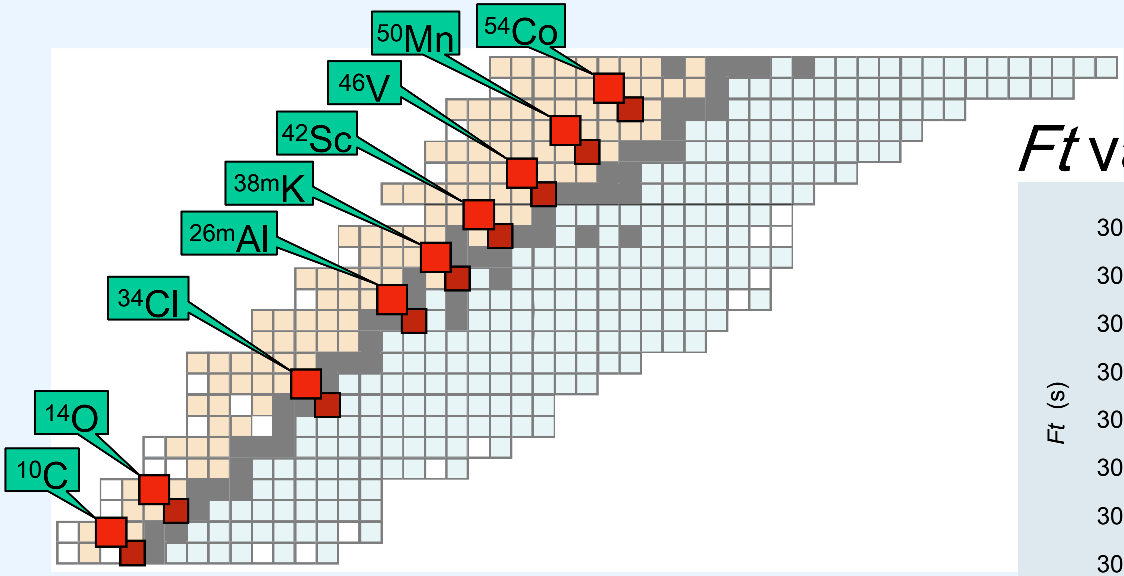
A. Kellerbauer *et al.*, Phys. Rev. Lett. 93, 072502 (2004).

Determine atomic mass from frequency ratio with a well-known "reference mass".

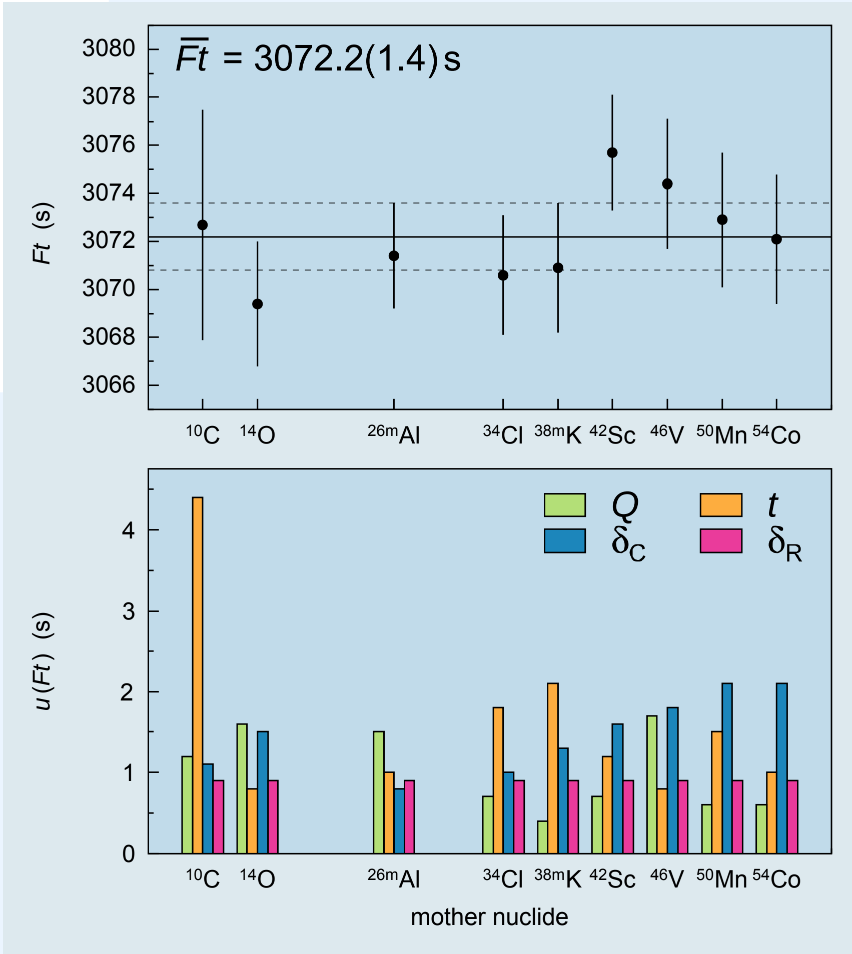
$$\frac{f_{c,ref}}{f_c} = \frac{m - m_e}{m_{ref} - m_e}$$

Previous Status Ft Values

Existing data for 9 light nuclides from ^{10}C to ^{54}Co



Ft value:



⇒ CVC hypothesis confirmed in this mass region

– Measurements in heavier nuclides required to substantiate results

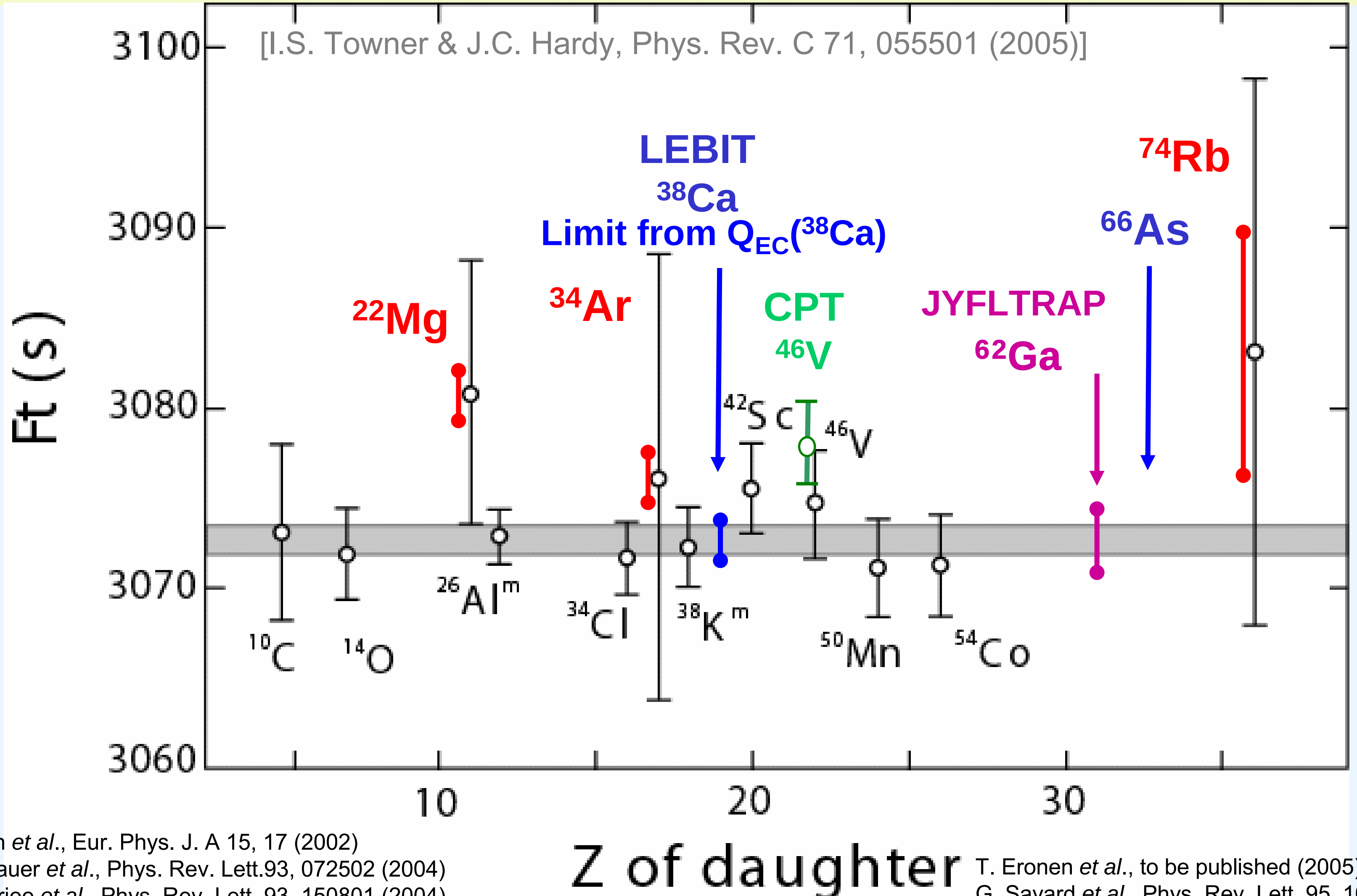
– Proposed decay: **^{74}Rb(β^+)^{74}Kr**

Very Recent Results – Ft Values (IS413)

ISOLTRAP mass measurements

CVC hypothesis confirmed in this mass region

^{22}Mg → ^{22}Na : δ*Q*=**0.28 keV**, ^{34}Ar → ^{34}Cl : δ*Q*=**0.41 keV**, ^{74}Rb → ^{74}Kr : δ*Q*=**4.5 keV**



F. Herfurth *et al.*, Eur. Phys. J. A 15, 17 (2002)
A. Kellerbauer *et al.*, Phys. Rev. Lett.93, 072502 (2004)
M. Mukherjee *et al.*, Phys. Rev. Lett. 93, 150801 (2004)

T. Eronen *et al.*, to be published (2005)
G. Savard *et al.*, Phys. Rev. Lett. 95, 102501 (2005)

Examples of Superallowed β Decaying Nuclides

Experiment factor of 2 more precise than theory, then:

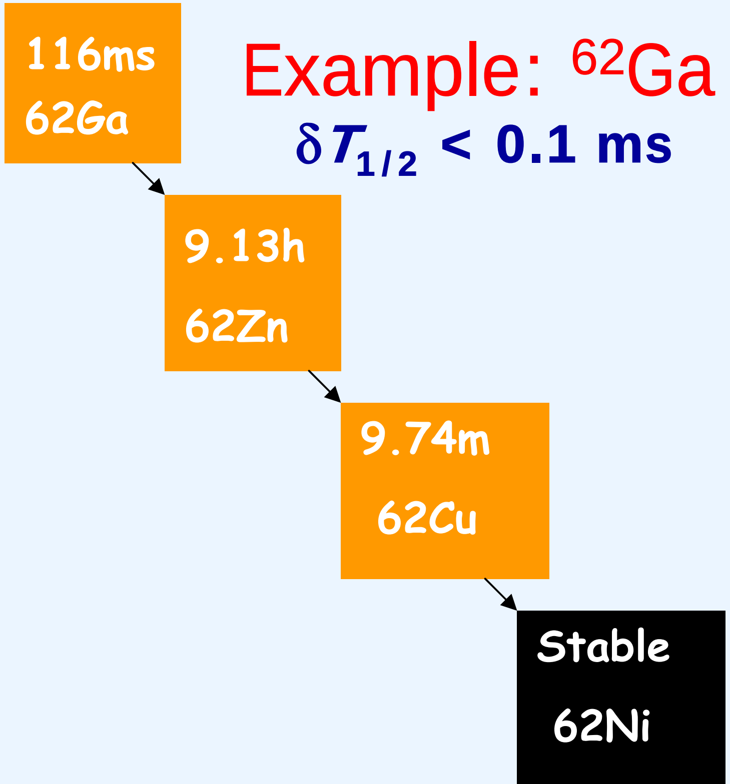
Nuclide	Q	$T_{1/2}$	BR
^{10}C	✗ (red)	✗ (red)	✗ (red)
^{14}O	✗ (dark green)	✓	✗ (dark green)
^{22}Mg	✓	✗ (red)	✗ (red)
$^{26}Al^m$	✗ (red)	✗ (red)	✓
^{34}Cl	✓	✓	✓
$^{38}K^m$	✓	✓	✓
^{42}Sc	✗ (dark green)	✗ (dark green)	✓
^{46}V	✗ (green)	✓	✓
^{50}Mn	✗ (red)	✗ (red)	✓
^{54}Co	✓	✓	✓
^{62}Ga	✓	✓	✗ (red)
^{66}As	✗ (green)	✗ (green)	✗ (green)
^{74}Rb	✗ (dark green)	✓	✓

✓ = **Okay, criterion met**

✗ = further experiment useful

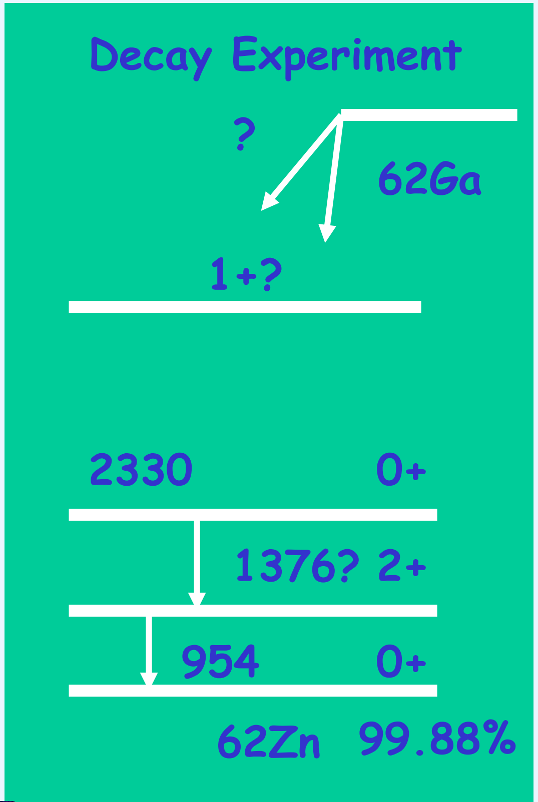
ISOLDE relevant
now / **future**

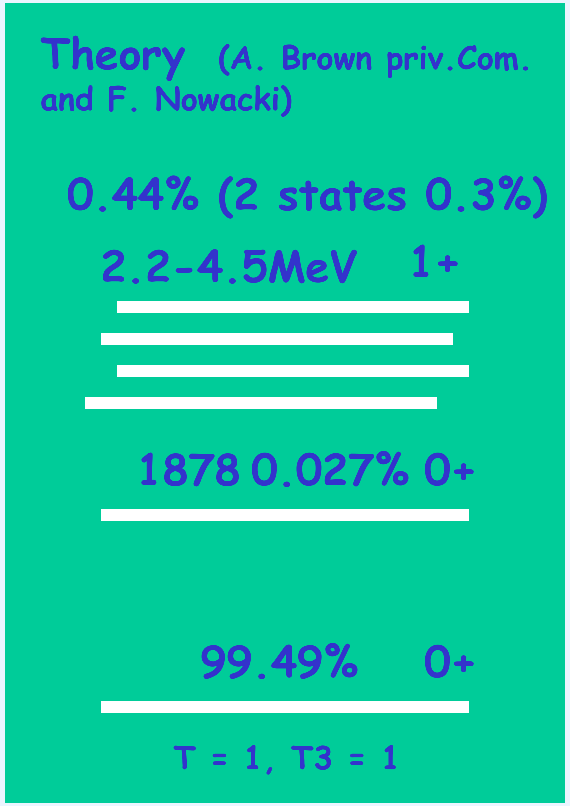
Half-Life and BR Measurements at ISOLDE (IS406)



Example: ^{62}Ga

$\delta T_{1/2}$ < 0.1 ms



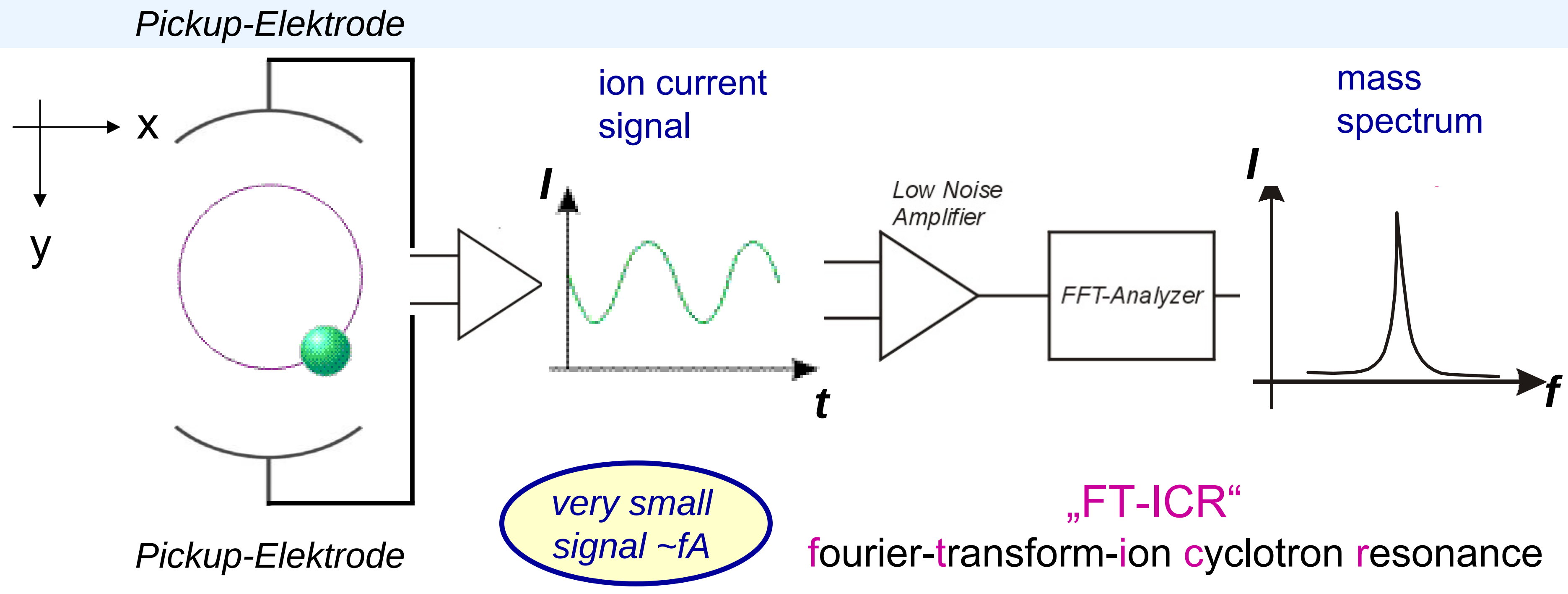


Lucrecia spectrometer:

Total Absorption Gamma-ray (TAG) spectrometer

- Neutron and gamma shielding
- NaI crystal (St. Gobain crystals)
- Ancillary β, X, and γ counters

Non-Destructive Ion Detection



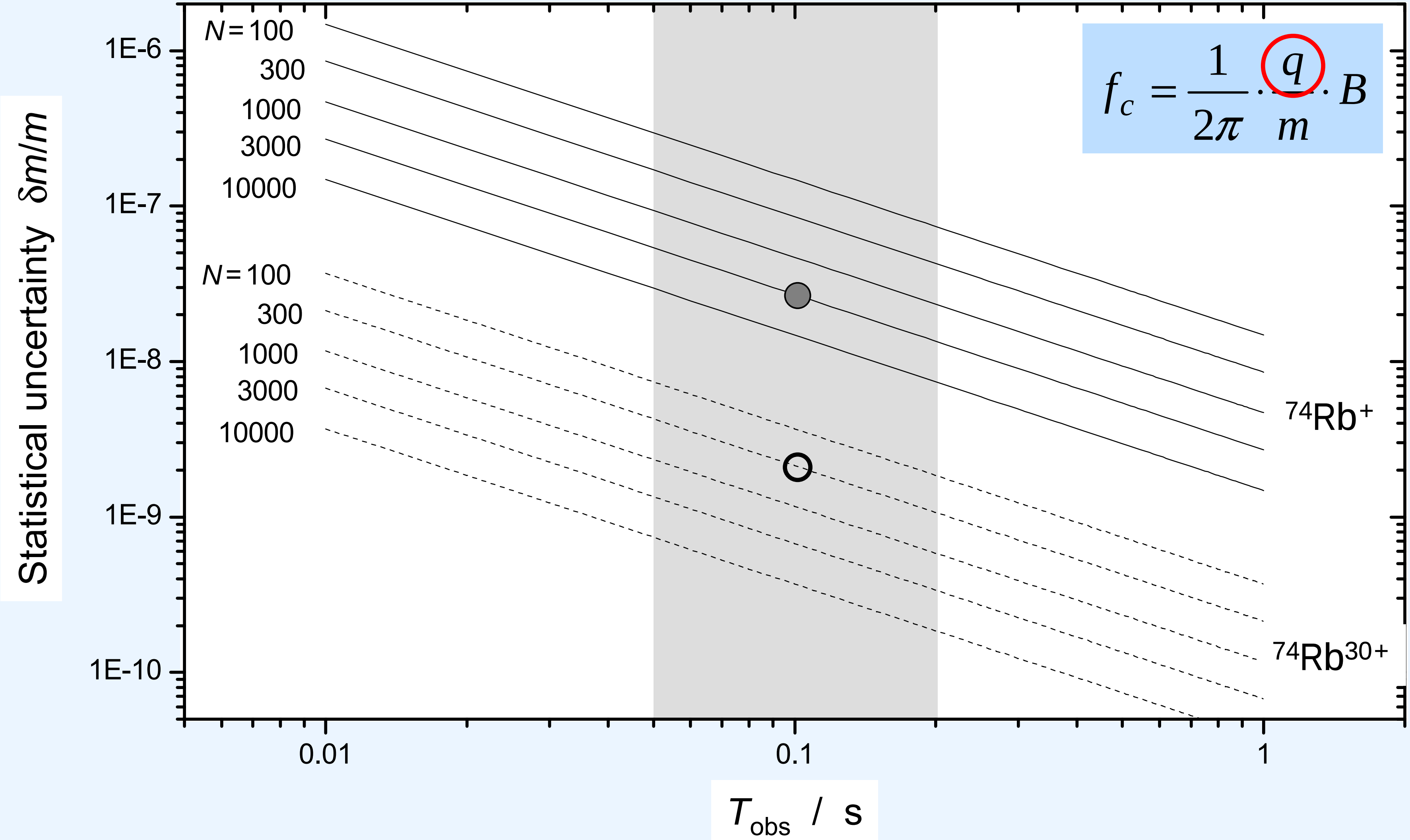
Development of **cryogenic** traps for resonant detection.

Applications

- Mass measurements on superheavy rare elements
- High-precision mass measurements on longer-lived and stable ions
- Fast identification and effective use of stored ions

C. Weber *et al.*, Eur. Phys. J A 25, 65 (2005)

The Advantage of Highly-Charged Ions



$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

- much higher resoving power and accuracy
- saving in beam time requirement

Summary and Conclusions

Traps are an ideal tool to perform atomic and nuclear physics precision experiments!

- ISOLTRAP at ISOLDE can perform high-accuracy mass measurements ($<10^{-8}$) on very short-lived nuclides (<100 ms) that are produced with very low yields (<100 ions/s)
- Such high-accuracy mass measurements can provide valuable input to nuclear structure and fundamental studies
- ISOLDE is an ideal facility for high-accuracy experiments (Q, $T_{1/2}$, BR) on superallowed β decaying nuclides for a Standard Model test
- Great potential for further measurements with even increasing sensitivity and accuracy and yet shorter half-lives!