Superallowed β Decay and the Standard Model

"true challenge for precision measurements"

Thanks to: T. Eronen, A. Jokinen, K. Blaum, B. Blank, J. Hardy

For a review up to 2005, see:

J. Hardy and I. Towner, Superallowed 0+ → 0+ nuclear β decays: A critical survey with tests of the conserved vector current hypothesis and the standard model
Physical Review C 71(2005) 055501

Superallowed β Decay

Conserved-vector-current hypothesis:

- Vector part of weak interaction is constant
- Decay rate only a function of the vector coupling constant G_V and the matrix element
- For 0+ → 0+ (T=1) decays

$$Ft \equiv ft(1+\delta_R)(1-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

K = product of fundamental constants

Corrections:

δ_C – isospin symmetry breaking correction
δ_R – radiative correction
Δ_R – nucleus independent radiative correction

$$ft = ft(Q^5, T_{1/2}, b, P_{EC})$$

Q – Decay energy $\Leftrightarrow$ mass m – $\delta m/m < 10^{-9}$

$T_{1/2}$ – Half-life - $\delta T_{1/2}/T_{1/2} < 10^{-4}$

b – Branching ratio - $\delta b/b < 10^{-4}$

P_{EC} – Electron capture fraction

Cabibbo-Kobayashi-Maskawa matrix

Relates the mass eigenstates and weak force eigenstates of quarks

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

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

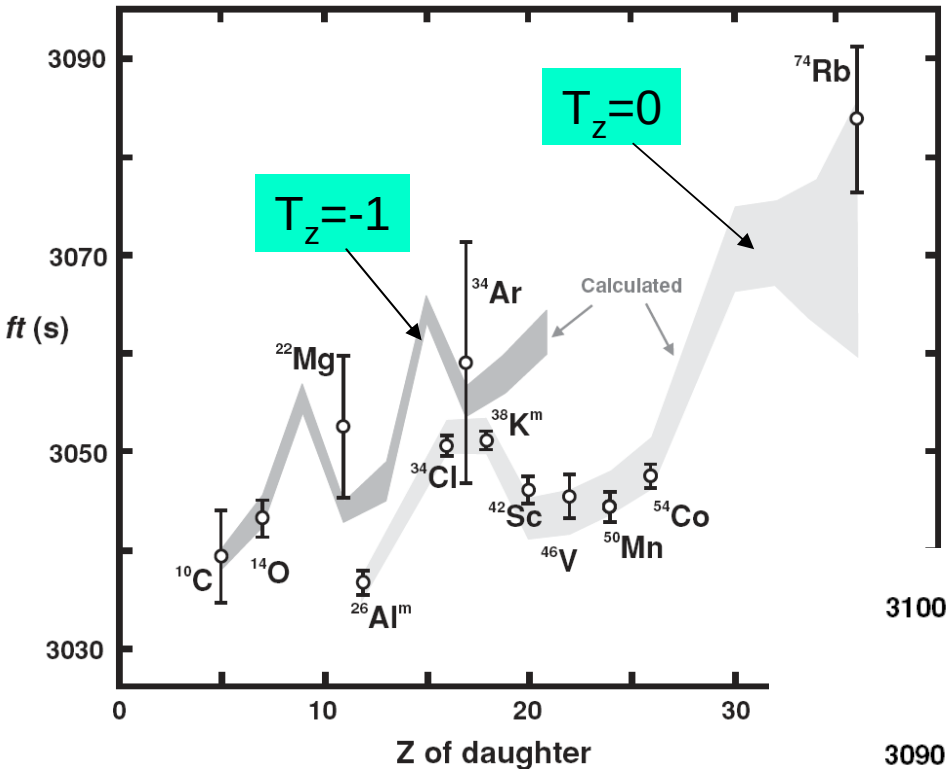
V_{us} and V_{ub} from particle physics data (K and B meson decays)

Unitarity condition on the diagonal terms: $\sum_k |V_{ik}|^2 = 1 = U$

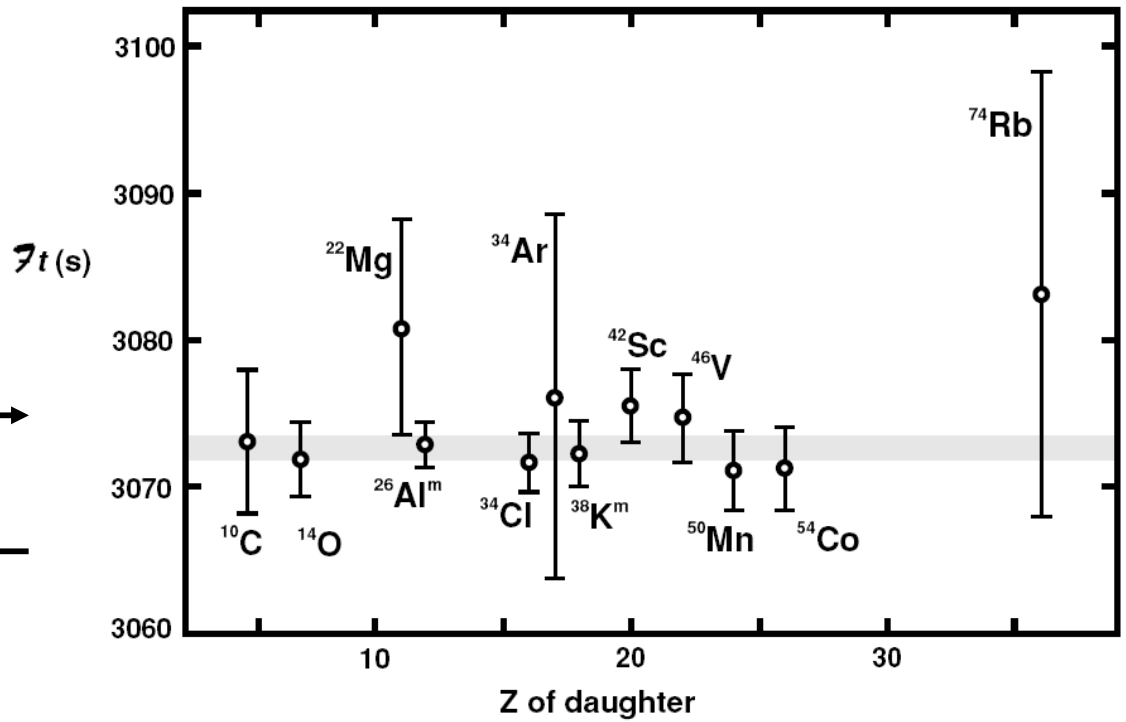
Studies of neutron and nuclear lifetimes and decay correlations can yield important information about the charged current structure of the SM while probing new physics symmetries

Recent theoretical progress has reduced the hadronic physics uncertainty in the extraction of V_{ud} from the β-decay half-lives, thereby sharpening this unitarity test

From Hardy and Towner (2005):



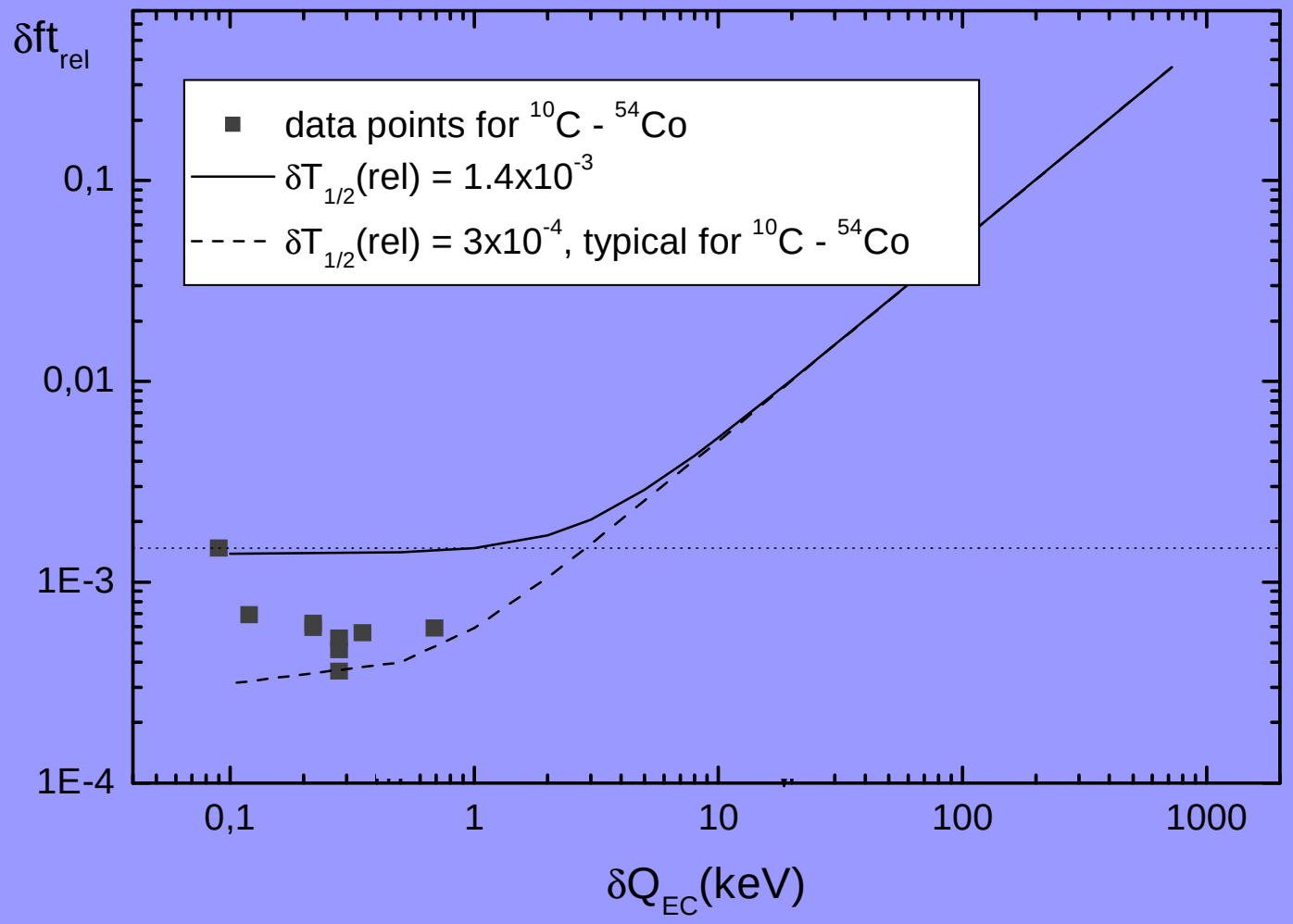
”Uncorrected ft-values”



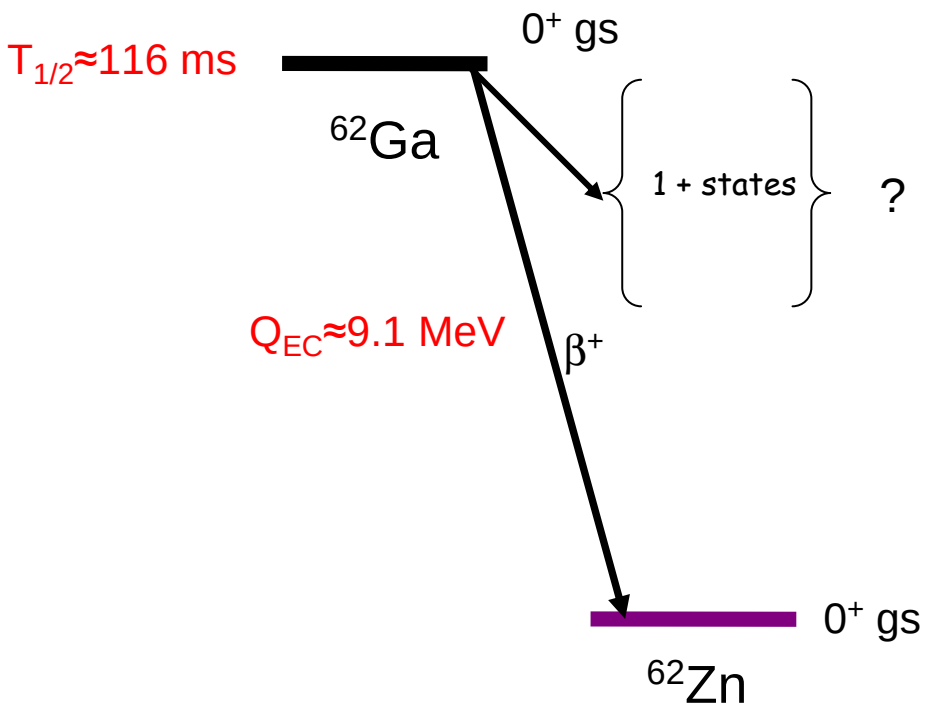
”Corrected *Ft* values”

V_{ud} = 0.97380 (40)
U = 0.9966 (14) (?!)

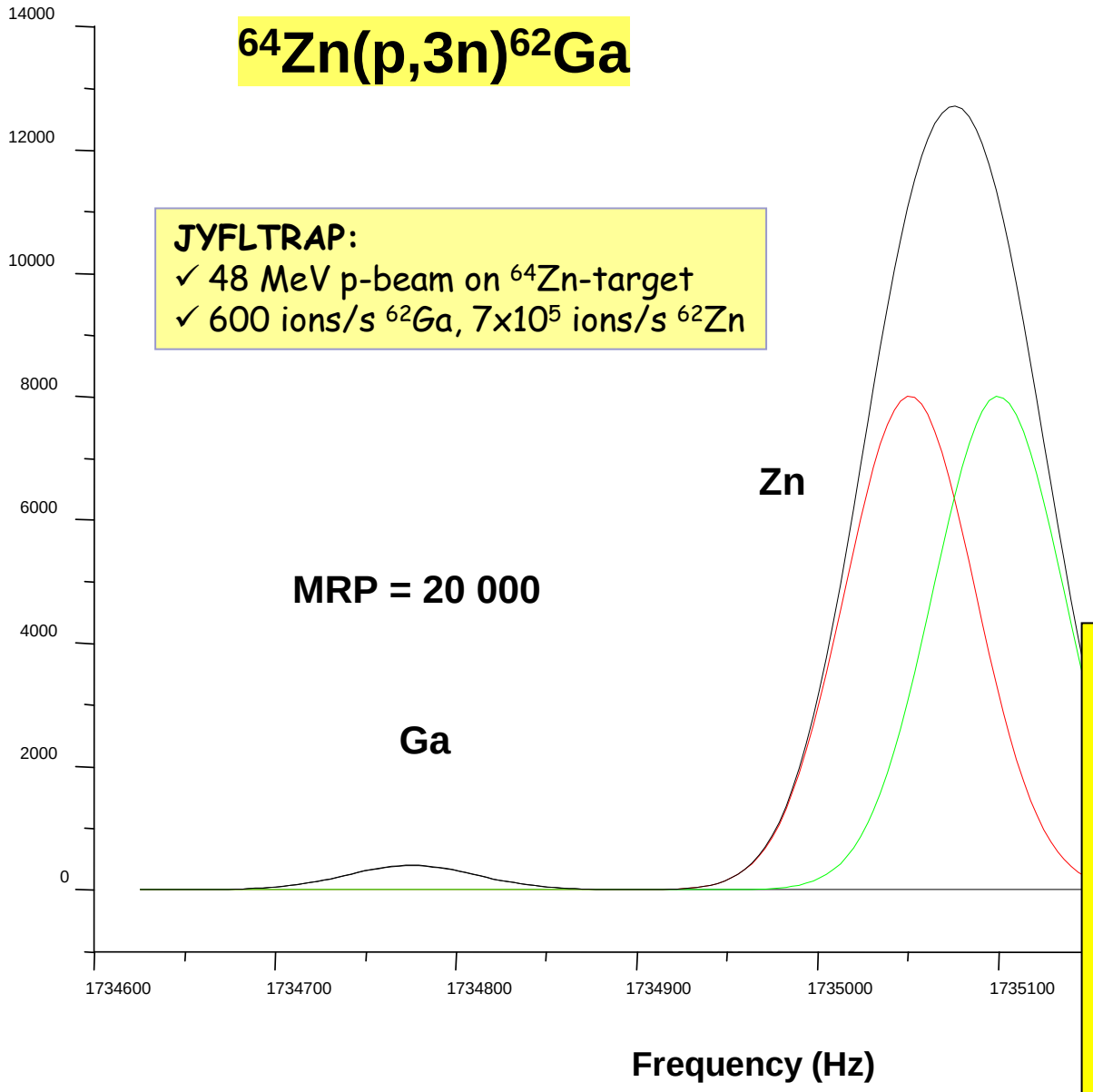
What accuracy is needed, for example, in Q_{EC} ?



Example 1: Superallowed beta decay of ^{62}Ga



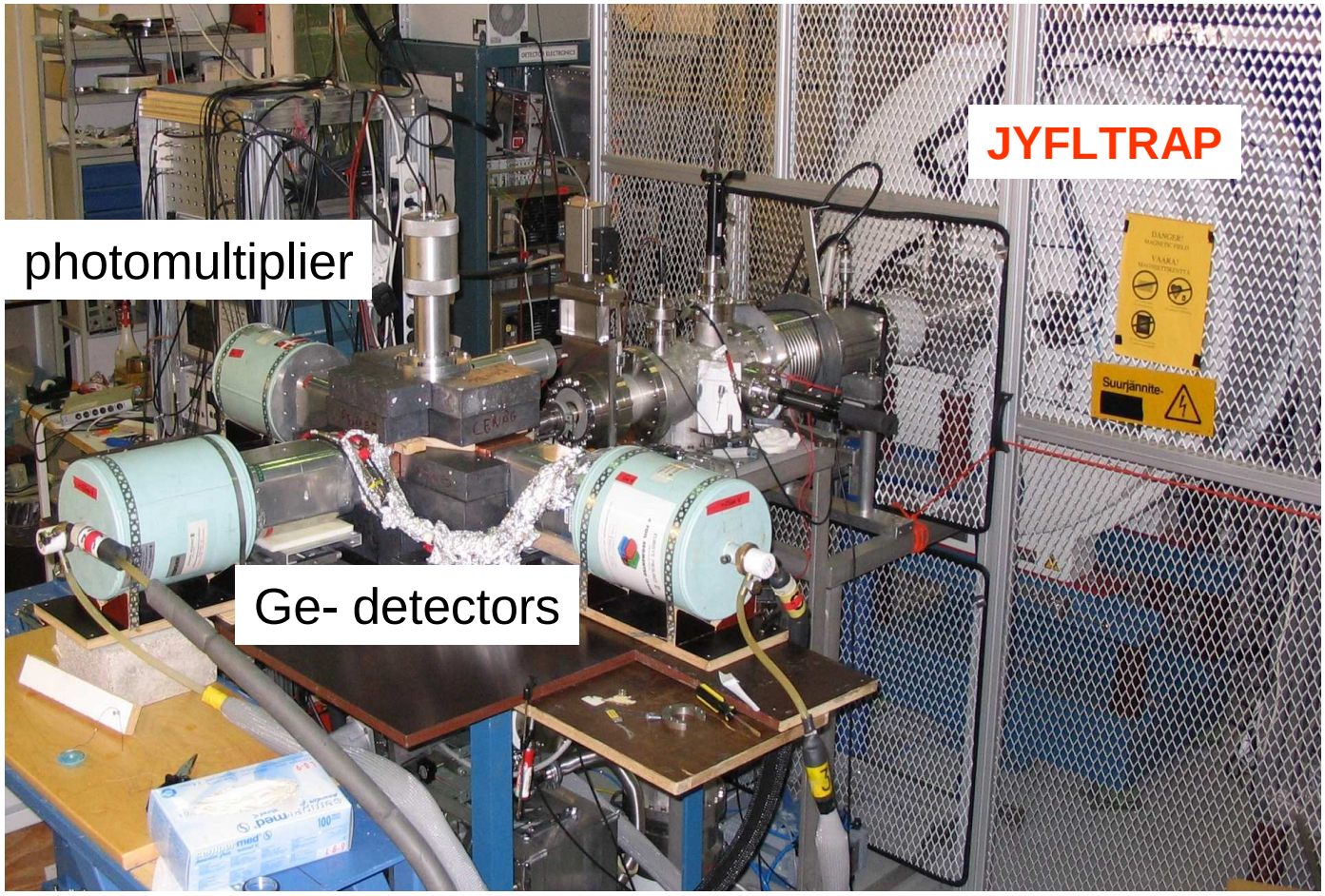
Isobar selection in the purification trap



- Trap cycle time 71 ms
- 25 ms cooling
- 5 ms magnetron excitation
- 40 ms cyclotron excitation
- 40% cooler & trap transmission
- 150 ions/s detected after trap

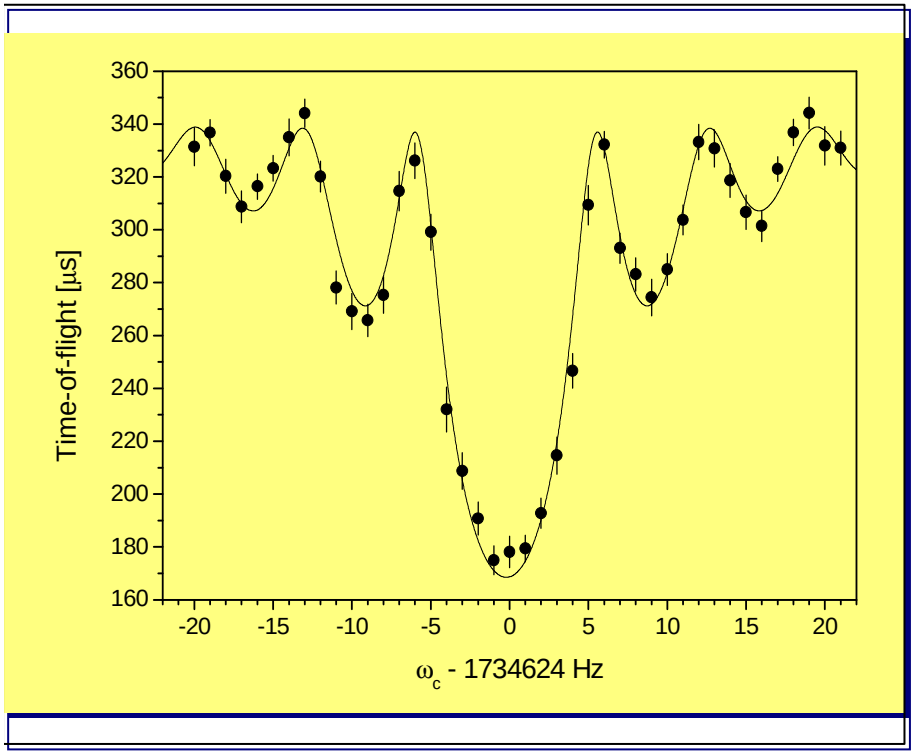
BR & $T_{1/2}$ of 0^+-0^+ decay

4π β detector and three clover germanium detectors.



G. Canchel, B. Blank, et al, Precision measurement of the half-life and the decay branches of 62Ga
Eur. Phys. J. A 23, 409 - 415 (2005).

Precision trap frequency scan (JYFLTRAP)



$$Q_{EC} = M_p - M_d = \underbrace{\left(\frac{f_d}{f_p} - 1\right)}_{\leq 10^{-3}} M_d$$

→ ΔM_d negligible !

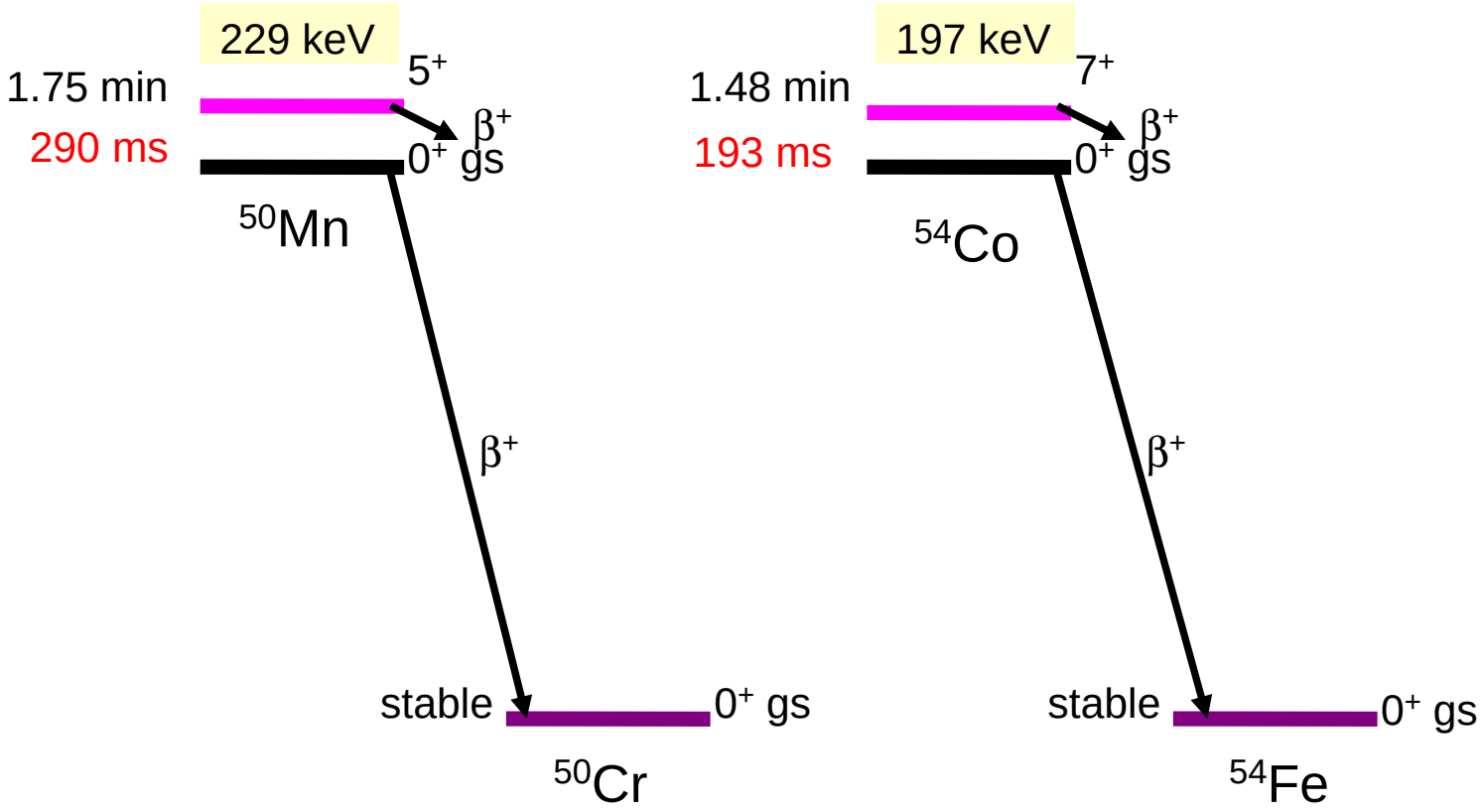
T. Eronen et al., Phys. Lett. B 636 (2006) 191

B. Hyland et al., Phys. Rev. Lett. 97(2006) 102501
(ISAC exp.on branching ratio)

Q_{EC}	= 9181.07(54) keV
$T_{1/2}$	= 116.173(38) ms
I_b	= 99.861(11) %

Uncertainty of $(\delta_{NS}-\delta_c)$ dominates !!!

Latest news: Ramsey cleaning applied in Q_{EC} value measurements of ^{54}Co and ^{50}Mn



T. Eronen et al., arXiv:0712.3463v1 [nucl-exp] 20 Dec 2007

Ramsey method

Theory:

Martin Kretzschmar, IJMS 264 (2007) 122-145

Experimental:

Sebastian George et al., IJMS 264 (2007) 110-121

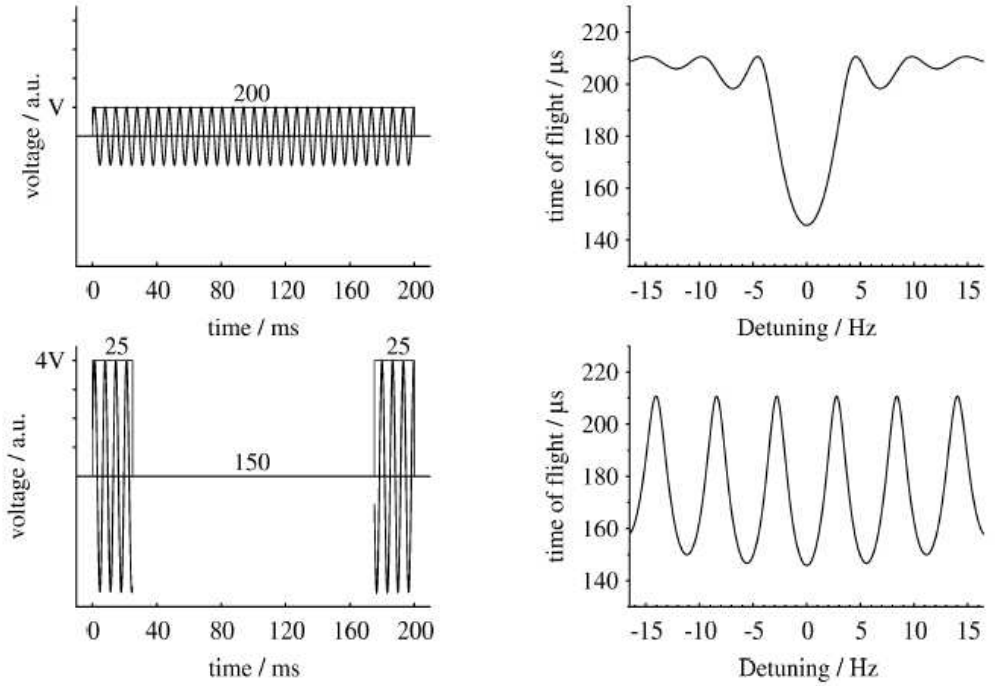
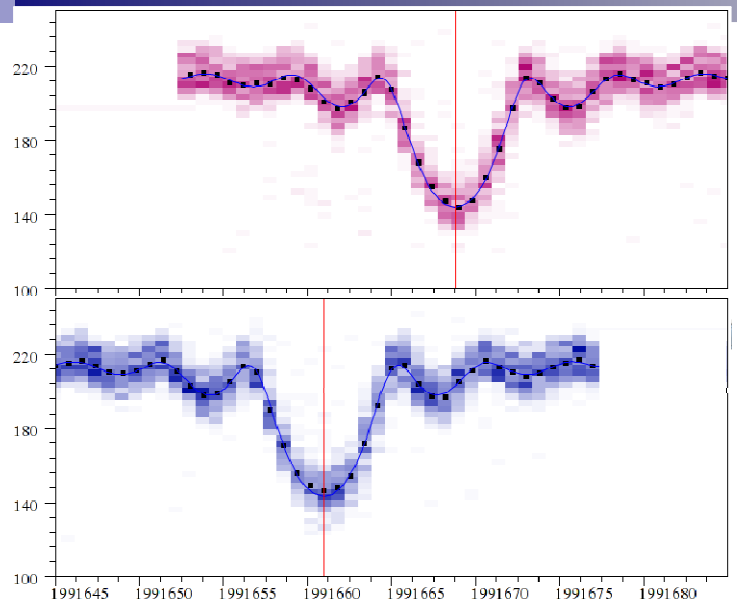


Fig. 4. Excitation time pattern (left) and expected time-of-flight cyclotron resonance spectrum (right). The excitation with time-separated oscillatory fields (bottom) enhances the sidebands and reduces the linewidth of the resonance. The expected resonance shape with a conventional 200 ms excitation (top right) [32] and with a (25-150-25) ms (On-Off-On) pattern (bottom right) [30] is shown.

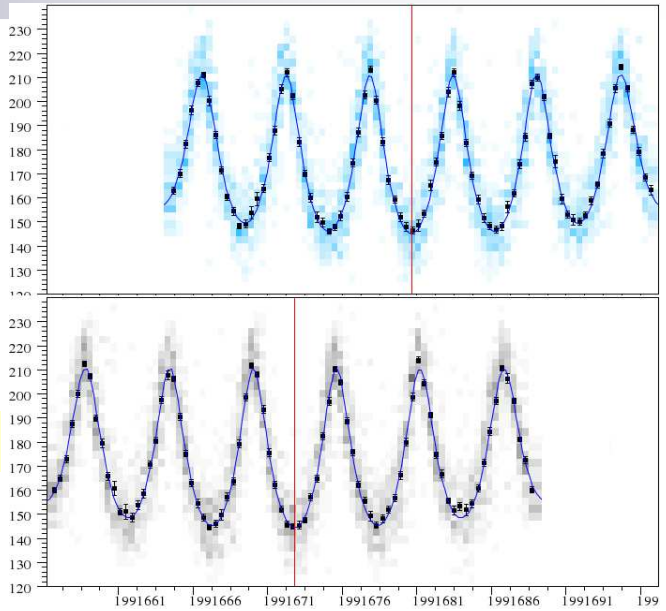
”Normal method”



”Ramsey method”

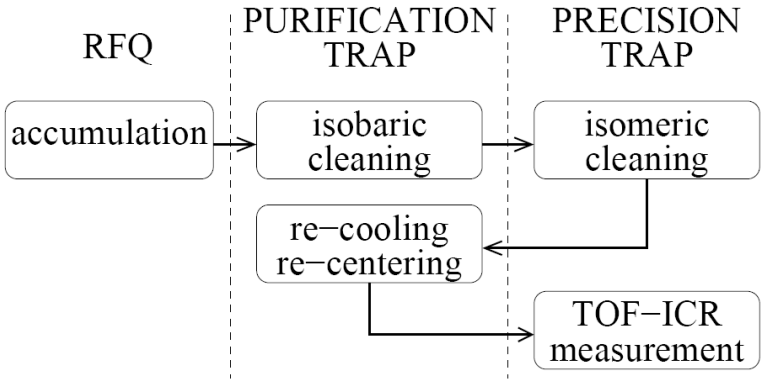
^{54m}Co

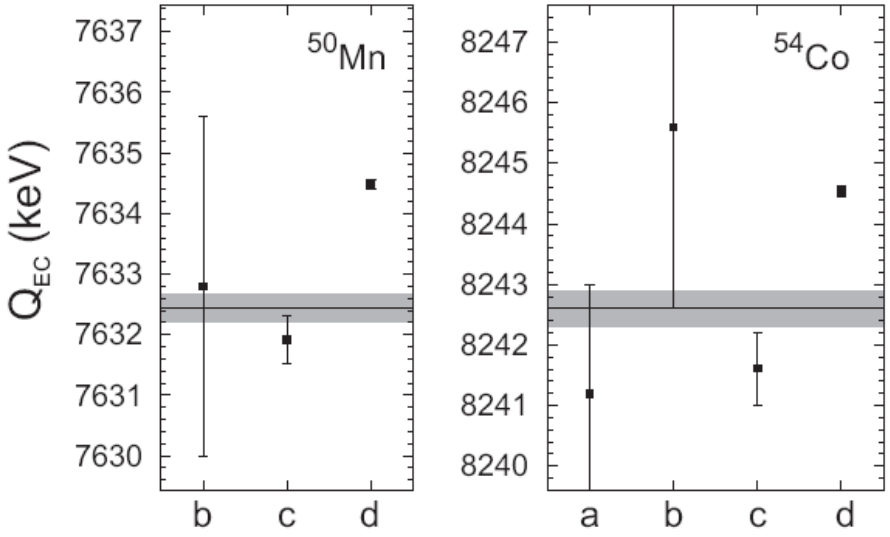
^{54}Co (gs)



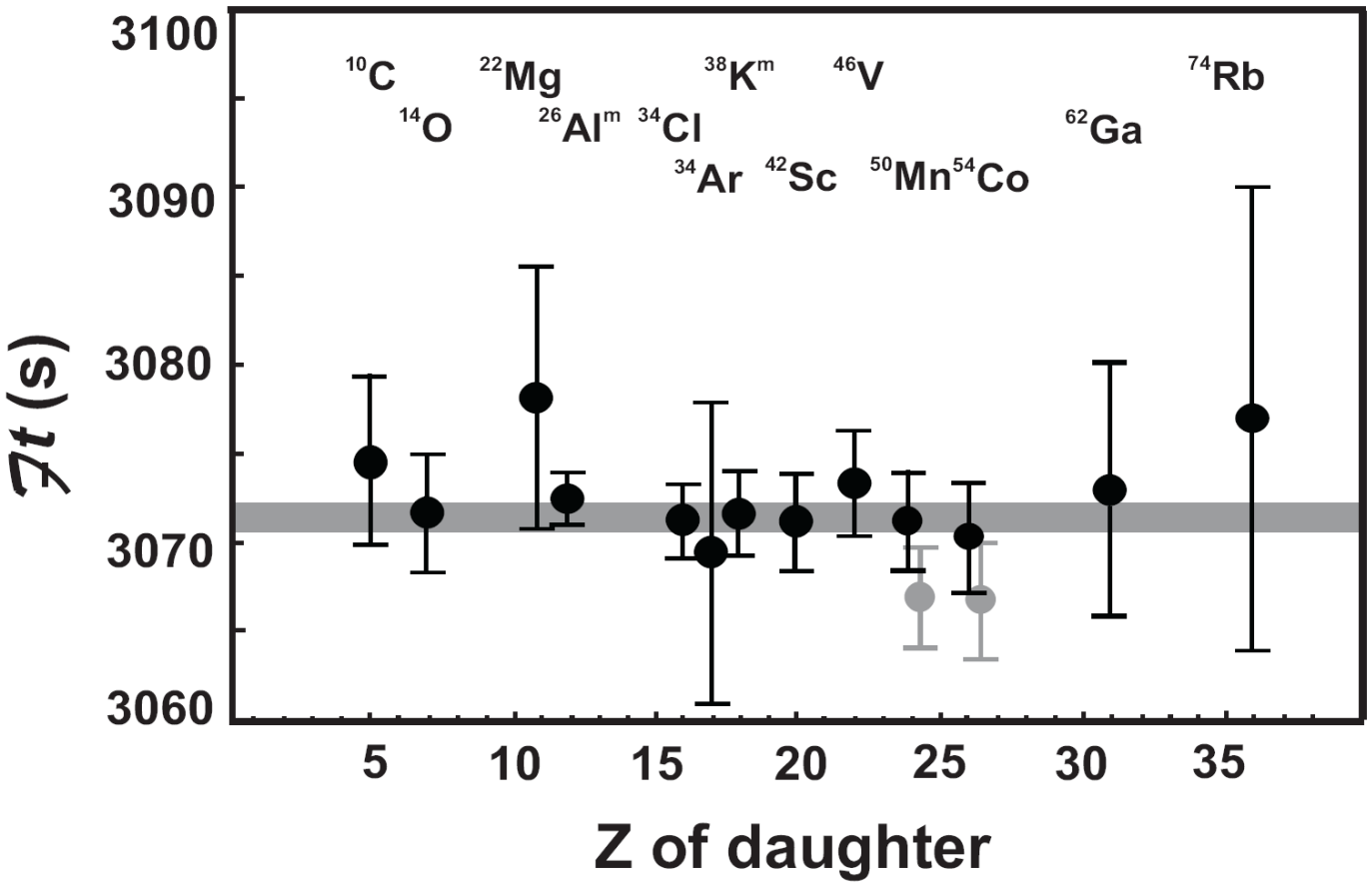
$Q_{EC}(^{50}Mn)=7634.48(7)$ keV

$Q_{EC}(^{54}Co)=8244.54(10)$ keV





All nuclei shown have been remeasured for at least on of the three quantities required for the ft-value, e.g. Q_{EC}, $T_{1/2}$ or branching since Hardy and Towner review 2005



ISOLTRAP
CPT-Argonne
LEBIT
JYFLTRAP
Texas A&M

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9998(10)$$

Evolution of precision of V_{ud}

V_{ud} = 0.97400 100	J. C. Hardy et al., NP A509 (1990)429
V_{ud} = 0.97380 (40)	J. Hardy, I. Towner, PRC 71 (2005) 055501
V_{ud} = 0.97370 (30)	T. Eronen et al., PRL 97 (2006) 232501
V_{ud} = 0.97408 (26)	T. Eronen et al., arxiv:0712.3463v1 [nucl-ex] Dec 2007

Most precise value for V_{ud} comes from nuclear beta decay !!!
Its^2 contribution > 95 %

Current results—in agreement with the SM—place important constraints on candidates for the New Standard Model, including supersymmetry,

The next step is to work on theoretical corrections

- more experiments on heavier nuclei for δ_c
- more theory on radiative corrections